CEOS
Committee on Earth Observation Satellites

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Climate Change Special Edition 2008

THE EARTH OBSERVATION HANDBOOK

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THE EARTH OBSERVATION HANDBOOK

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Foreword

It gives me great pleasure, on behalf of the Committee on Earth Observation Satellites (CEOS), to present the 2008 edition of the CEOS Earth Observation Handbook, prepared under the auspices of the European Space Agency (ESA).

The report presents the main capabilities of satellite Earth observations, their applications, and a systematic overview of present and planned CEOS agency Earth observation satellite missions and their instruments. It also explores society's increasing need for information on our planet.

This edition has a particular focus on climate change, on the information we need to detect, monitor and adapt to it, and on the role for satellite Earth observations – which are emerging as the single most important contribution to global climate observations, potentially contributing to 25 of the 45 Essential Climate Variables recognised by the United Nations Framework Convention on Climate Change (UNFCCC).

The nature of climate change issues presents special challenges in terms of the need for global information and data on key planetary indicators which can provide the information required for governments and policy makers to make well-informed decisions. Recognising that no single country can satisfy all of the observational requirements which are necessary for monitoring of the Earth System, governments are taking steps to harmonise and integrate their observing networks and satellite observing systems to be able to address common problems of global concern.

The major aims of CEOS are to achieve international coordination in the planning of these Earth observing satellite programmes and to maximise utilisation of their data, in order to effectively address the most critical requirements.

I hope that the CEOS Earth Observation Handbook will continue to serve as a valuable reference source for a variety of readers, including those with needs in climate studies, and decision-makers in political and socio-economic sectors. I further hope that it can help improve optimisation of the overall Earth observation strategy, which is central to our future success.

Volker Liebig
Director of Earth Observation Programmes
European Space Agency

Preface

The 2008 CEOS Handbook explores society's increasing need for information on our planet, the essential foundation for sustainable development policies that are aimed at ensuring our continued health and prosperity in the face of human-made climate change, population growth, and degradation of our natural environment.

It explains the important role of Earth observation satellite programmes in fulfilling these information needs. It presents the current status and plans for future Earth observation satellite programmes of governments worldwide, through their national and regional space agencies, and describes how the data and information which they supply relate to some of society's most pressing needs for information on Earth System processes and our interaction with them.

The role of the Committee on Earth Observation Satellites (CEOS), the body with responsibility for coordination of government-funded satellite programmes worldwide, is explained, including its relation to the various global observing systems, in particular the Global Earth Observation System of Systems (GEOSS).

It is hoped that this report will prove to be a valuable source of information concerning the possible application and value of the data and information from Earth observation satellites. It should be of interest to a wide range of groups: those with responsibility for national/international development policy; those responsible for programmes with requirements for observations to enable understanding of our environment and its processes; and those needing information for decision-making in many socio-economic sectors. The information required to detect, predict, adapt to and mitigate climate change is a particular focus in this edition.

It is further hoped that this report will be of educational value, helping to explain some of the techniques and technologies underlying satellite Earth observation and making the subject as accessible as possible to the lay person who would like to investigate further.

As an up-to-date and comprehensive compilation of CEOS Agency plans, the report provides a handy reference source on current and future civil Earth observation programmes. It also provides details of points of contact within CEOS and lists relevant internet sources for those requiring more information.

Part I of the Handbook discusses Earth's changing climate, its causes, trends, impacts and economics (section 1). It explains the important role of satellite Earth observations (section 2) and CEOS (section 3). Future challenges are discussed in section 4.

Part II presents a number of case studies (section 5) to illustrate the use of Earth observation satellites supporting the provision of information for our understanding of climate change in key areas.

Part III of the handbook summarises Earth observation satellite capabilities and plans, including a description of the various types of satellite missions and instruments and their applications (section 6). For those interested in particular measurements (e.g. of 'ozone' or 'ocean temperature'), section 7 provides details of 27 different parameters and the plans for their observation during the coming decades. Sections 8 and 9 contain catalogues of satellite missions and instruments respectively.

The annexes include:

A. Further information on CEOS

B. The GCOS Climate Monitoring Principles

C. Abbreviations

PART I

→ Our Changing Climate

Larsen B ice shelf, Antarctic, ASAR.

1 Our Changing Climate

1.1 Introduction

Until very recently, humans and their activities have been an insignificant force in the dynamics of the Earth System. However, since the start of the Industrial Revolution, more than 200 years ago, developed nations have achieved ever greater prosperity and higher living standards. Combined with a six-fold increase in the global human population during that period, these factors have resulted in significantly increased consumption of resources – evident in agriculture and food production, industrial development, energy use and urbanisation.

The Earth's climate does vary naturally, mainly as a result of interactions between the ocean and the atmosphere, changes in the Earth's orbit, fluctuations in energy received from the Sun and volcanic eruptions. However, the best scientific evidence available suggests that the Earth System has recently moved well outside the range of natural variability exhibited in available paleoclimate records covering at least the last half million years. The nature of changes now occurring simultaneously in the global environment, their magnitudes and rates, are unprecedented in human history, and probably in the planet's history:

- in a few generations humankind is likely to exhaust fossil fuel reserves that were formed over several hundred million years;
- as a consequence, humankind has caused the atmospheric greenhouse gas concentrations on Earth to rise far beyond the maxima reached during at least the last 1 million years;
- human action has transformed almost half of the Earth's land surface, with significant consequences for biodiversity and climate;
- tropical forest areas have been reduced by 50%;
- more than half of all accessible freshwater is used directly or indirectly by humankind;
- coastal and marine habitats are being dramatically altered; 50% of mangroves have been removed and wetlands have shrunk by one half;
- extinction rates are increasing sharply in marine and terrestrial ecosystems around the world;
- humankind is responsible for 70% of the nitrogen cycle and 95% of the phosphorus cycle on Earth.

Some facts are slow to be absorbed and accepted by a generation unaccustomed to associating environmental factors with lifestyle and consumer choices. But today it is a reality that humankind has begun to match and even exceed Nature in terms of changes to the atmosphere and biosphere and impacts on other facets of Earth System functioning.

In spite of the many severe environmental impacts that occurred during recent centuries of industrialisation and accelerating urbanisation, these impacts, often severe, were usually seen as being of only local importance. Widespread public awareness of the 'environment' dates back to the 1960s and 1970s, born from concerns such as air and water pollution; pesticide use; nuclear testing; and disasters such as the first catastrophic supertanker oil spill. Many governments established environment ministries and environmental protection agencies in the 1970s, leading to new consideration of environmental issues and growing demands for environmental information. Industry, too, became more environmentally aware, with the realisation of new trends in consumer behaviour, and the introduction of new legislation and environmental regulations.

After the first World Climate Conference in 1979 expressed its concern about the possibility of human-induced climate change, there was almost a decade of accumulating evidence until the Intergovernmental Panel on Climate Change (IPCC) was established in 1988. Its tasks were to assess the available scientific information about climate change and formulate realistic response strategies for national and global action. The first IPCC Assessment Report in 1990 was instrumental in paving the way for the adoption of the UN Framework Convention on Climate Change (UNFCCC) in 1994. The second IPCC Assessment Report in 1995 provided key inputs to the process that led to the adoption of the Kyoto protocol in 1997 – with the aim of reducing greenhouse gases that contribute to climate change. The Third IPCC Assessment Report in 2001 concluded, "There is new and stronger evidence that most of the observed warming observed over the last 50 years is attributable to human activities."

The main message of the IPCC's Fourth Assessment Report in 2007 was that climate change is no longer a matter for debate. It is 'unequivocal', and 'very likely' that human activities are responsible. In the IPCC context 'very likely' means an assessed likelihood of at least 90%, while 'likely' (as stated in 2001) means at least 66%. Throughout its reports the IPCC has stressed the importance of systematic observations and emphasised many variables that are observed by satellite.

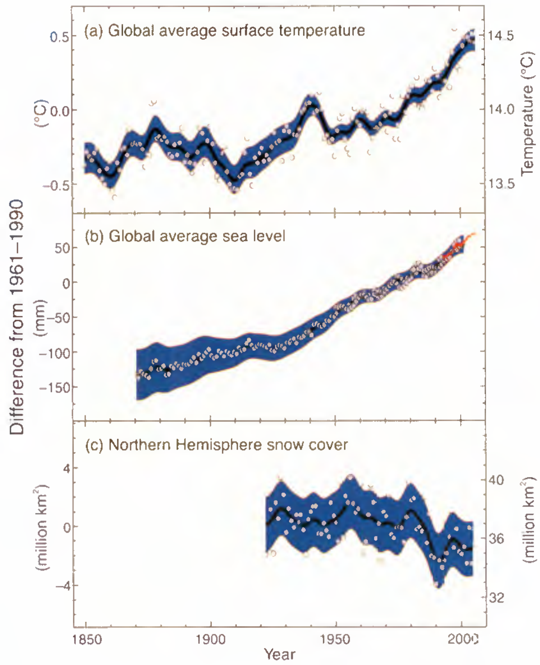
1.2 Signs of Climate Change

The IPCC was established by the United Nations to bring together the world's leading scientists to conduct rigorous surveys of the latest technical and scientific literature on climate change.

The main activity of the IPCC is to provide regular Assessment Reports of the state of knowledge on climate change. The latest of these is "Climate Change 2007", the Fourth IPCC Assessment Report, whose key conclusions are summarised below. This report has been described as a historical landmark in the debate about whether humans are affecting the state of the atmosphere.

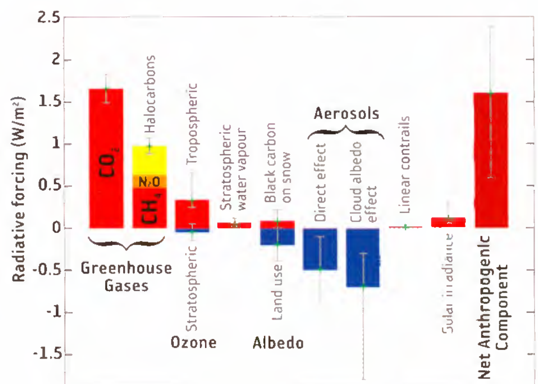
1. **Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.**
   Eleven of the last twelve years (1995–2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906–2005) is 0.74°C; temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed faster than the oceans.
2. **Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (over 90% probability) due to the observed increase in anthropogenic (man-made) greenhouse gas concentrations.**
3. **Rising sea level is consistent with warming. Global average sea level has risen since 1961 at an average rate of 1.8 mm/yr and since 1993 at 3.1 mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear.**
4. **Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7% per decade, with larger decreases in summer of 7.4% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres.**
5. **There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere.**

Source: Fourth IPCC Assessment Report, "Climate Change 2007"



Observed changes in (a) global average surface temperature, (b) global average sea level from tide gauge (blue) and satellite (red) data, and (c) Northern Hemisphere snow cover for March–April. All changes are relative to corresponding averages for the period 1961–1990. Smoothed curves represent decadal average values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).

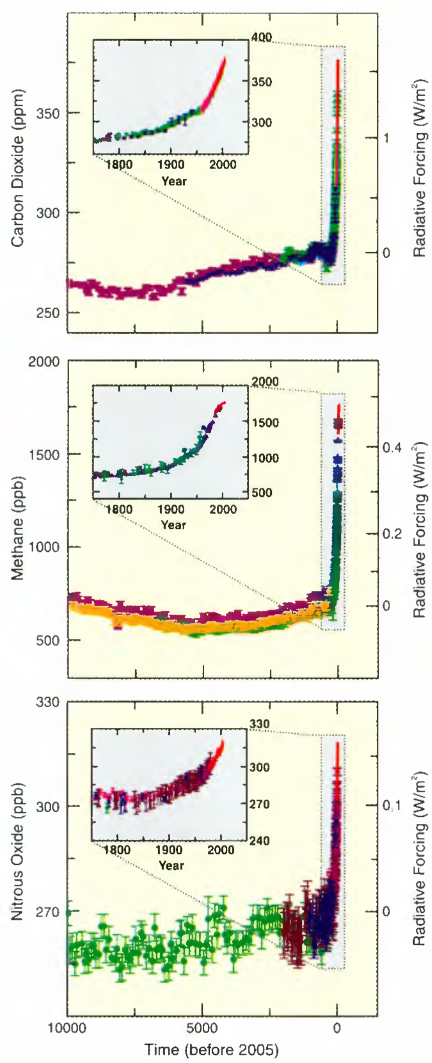
The IPCC describes warming and cooling effects on the planet in terms of radiative forcing — the rate of change of energy in the system, measured as power per unit area (in SI units, W/m²). Its AR4 report shows in detail the individual warming contributions (positive forcing) of carbon dioxide, methane, nitrous oxide, halocarbons, other human warming factors, and the warming effects of changes in solar activity.



Radiative Forcing Components.

Also shown are the cooling effects (negative forcing) of aerosols, land-use changes, and other human activities. All values are shown as a change from pre-industrial conditions.

- Total radiative forcing from the sum of all human activities is a warming force of about +1.6 watts/m².
- Radiative forcing from an increase of solar intensity since 1750 is about +0.12 watts/m².
- Radiative forcing from carbon dioxide, methane, and nitrous oxide combined is very likely (>90%) increasing more quickly during the current era (1750–present) than at any other time in the last 10,000 years.



Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines).
The corresponding radiative forcings are shown on the right hand axes of the large panels.

1.3 Causes of Climate Change

The IPCC noted in 2007 that:

- changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system;
- global greenhouse gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004;
- carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. Its annual emissions grew by about 80% between 1970 and 2004.

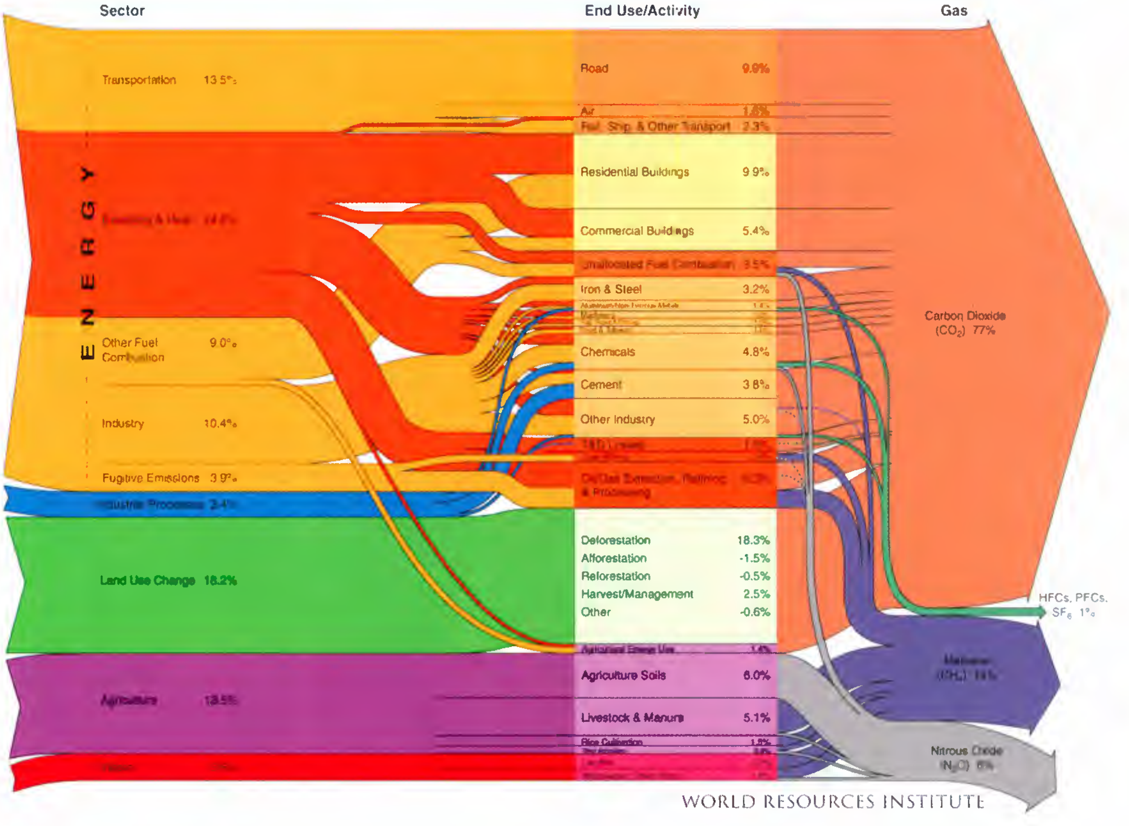
The IPCC concluded that "**most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (over 90% probability) due to the observed increase in anthropogenic (human-made) greenhouse gas concentrations**".

The IPCC noted that global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land use change providing another significant, but smaller, contribution. It is very likely that the observed increase in CH_4 concentration is due predominantly to agriculture and fossil fuel use. Methane growth rates have declined since the early 1990s, consistent with the total emission (the sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N_2O concentration is primarily due to agriculture.

The natural greenhouse effect which has maintained global temperatures within the paleo-climatologically observed range is mainly due to water vapour, with other influences coming from a wide range of variables, such as surface albedo and clouds, that can change according to circumstances. The natural greenhouse effect is much larger than that due to CO_2 and the other greenhouse gases whose concentration has a direct anthropogenic influence. Much of the uncertainty in global climate change is due to how these two components of the potential greenhouse effect interact. Climate models all show positive feedback from the water vapour, which is mainly due to a warmer climate increasing water vapour content in the atmosphere.

Assessments by the IPCC indicate that human influences extend beyond increases in global average temperature to other aspects of climate.

World GHG Emissions Flow Chart



They have:

- very probably contributed to sea level rise during the latter half of the 20th century;
- probably contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns;
- probably increased temperatures of extreme hot nights, cold nights and cold days;
- more likely than not increased risk of heat waves, areas affected by drought since the 1970s and frequency of heavy precipitation events.

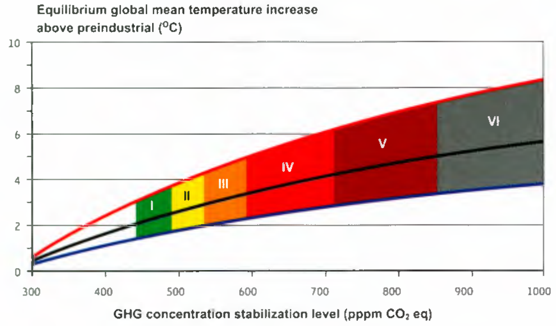
1.4 Future Climate Trends and Impacts

The IPCC's Fourth Assessment Report notes that the scientific evidence on the causes and future trends of climate change is strengthening all the time and that scientists are able to attach probabilities to the temperature outcomes and impacts on the natural environment associated with different levels of stabilisation of greenhouse gases in the atmosphere.

The current stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO_2, compared with only 280 ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades, because of the inertia in the climate system.

Even if the annual flow of emissions did not increase beyond today's rate, the stock of greenhouse gases in the atmosphere would reach double pre-industrial levels by 2050 – that is 550 ppm CO_2e (CO_2 equivalent) – and would continue growing thereafter. But the annual flow of emissions is accelerating, as fast-growing economies invest in high carbon infrastructure and as demand for energy and transport increases around the world. The level of 550 ppm CO_2e could be reached as early as 2035. At this level there is at least a 77% chance – and perhaps up to a 99% chance, depending on the climate model used – of a global average temperature rise exceeding 2°C.

Under a 'business as usual' scenario, the stock of greenhouse gases could more than treble by the end of the century, giving at least a 50% risk of exceeding 5°C global average temperature change during the following decades. This would take humans into unknown territory. An illustration of the scale of such an increase is that the global average temperature is now only around 5°C warmer than in the last ice age.



Predicted global temperature increase under different scenarios of CO_2 equivalent stabilisation levels.
(From IPCC 2007 WG III report)

Such changes would transform the Earth's physical geography, with dramatic implications for the human geography – where people live, and how they live their lives. The figure above (based on IPCC data) summarises the scientific evidence of the links between concentrations of greenhouse gases in the atmosphere, the probability of different levels of global average temperature change, and the physical impacts expected for each level. The risks of serious, irreversible impacts of climate change increase strongly as concentrations of greenhouse gases in the atmosphere rise.

Warming will have many severe impacts, often mediated through water:

- melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually threatening one-sixth of the world's population, predominantly in the Indian sub-continent, parts of China, and the Andes in South America;
- declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food. At mid to high latitudes, crop yields may increase for moderate temperature rises (2 – 3°C), but then decline with greater warming. At 4°C and above, global food production is likely to be seriously affected;
- in higher latitudes, cold-related deaths will decrease. But climate change will increase worldwide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place;
- with warming of 3 or 4°C, rising sea levels will result in tens to hundreds of millions more people being flooded each year. There will be serious risks and increasing pressures for coastal protection in South East Asia (Bangladesh and Vietnam), small islands in the

Global meltdown. A tipping point is the place of no return. This map shows the risk of different tipping points being passed this century if global warming continues at 3-5°C.

Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. According to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, greater floods, and more intense droughts;

- ecosystems will be particularly vulnerable to climate change, with around 15 – 40% of species potentially facing extinction after only 2°C of warming. Ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks.

In other words, climate change threatens the basic elements of life for people around the world – access to water, food production, health, and use of land and the environment. Significantly, the damage from climate change will accelerate as the world gets warmer, with higher temperatures increasing the chance of triggering abrupt and large-scale changes.

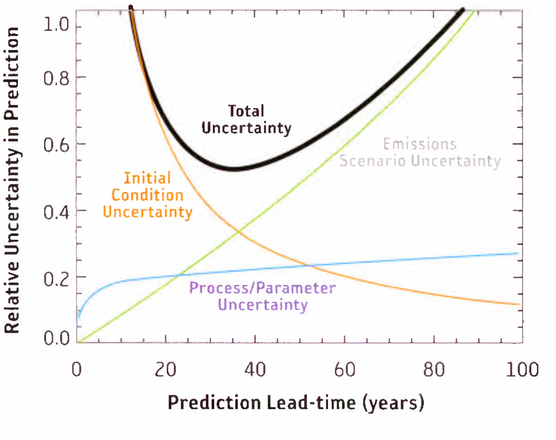
Climate scientists[1] have identified areas that they consider to be in gravest danger of passing critical thresholds or 'tipping points', beyond which they will not recover. Their assessment concluded:

- Arctic sea ice will go into irreversible decline once temperatures rise between 0.5°C and 2°C above those at the beginning of the century, a threshold that may already have been crossed;
- there is already a 50% chance that the Greenland ice sheet will soon begin melting unstoppably, although it could take hundreds of years to melt completely. The meltwater would raise global sea levels by seven metres;
- a temperature rise of 3°C could see more intense El Niños, with possible profound effects on the weather from Africa to North America;
- warming of 3°C to 5°C could reduce rainfall in the Amazon by 30%, lengthening the dry season and threatening to kill large areas of trees that will not re-establish themselves;
- the Boreal forests could also pass their tipping point, with large swaths dying off over the next 50 years;
- in Africa, more rainfall may re-green the Sahel region, but the west African monsoon could collapse, leading to twice as many unusually dry years by the end of the century;
- the Indian summer monsoon is predicted to become erratic and, in the worst case scenario, begin to flip chaotically, unleashing flash floods one year and droughts the next;
- measurements of the western Antarctic ice sheet show the balance of snowfall and melting has shifted and it is now shrinking. Local warming of more than 5°C could trigger uncontrollable melting, adding 5 metres to sea levels within 300 years;
- under the same warming, Atlantic currents that power the Gulf Stream could be severely disrupted.

While there is much to learn about these risks, the temperatures that may result from unabated climate change could take the world outside the range of human experience.

Uncertainty in climate predictions is the critical element in IPCC considerations of mitigation and adaptation strategies to cope with changing climate. This problem is easily seen in the first diagram below, taken from the IPCC 2007 report, where the predicted increase in global temperatures is shown for a range of greenhouse gas concentration stabilisation levels (I–VI). Within each of the scenarios it is clear that there is considerable uncertainty, of the same order as the predicted change in mean temperature. Reducing this uncertainty is the key challenge in climate modelling today, and the aspect of prediction which will have the greatest impact on policy.

It has been shown (Cox and Stephenson, Science, July 2007 – summarised in the figure below) that the major element of uncertainty in climate predictions up to 30 years into the future is the lack of adequate information on initial conditions – i.e. lack of quality observations. If, therefore, we wish to reduce the uncertainty in climate predictions over this period, the primary need is for more and better observations, of which many are derived from satellites.



[1] Lenton *et al.*, Feb 2008.

1.5 The Economics of Climate Change

In 2006, the British Government commissioned a report by the economist Sir Nicholas Stern on the effects of climate change and global warming on the world economy. Known as the 'Stern Review on the Economics of Climate Change', this is not the first economic report on global warming, but it is significant as the largest, most widely known and most discussed report of its kind.

The Stern Review states, "Our actions over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th Century".

The report gives prescriptions for how to minimise this economic and social disruption. Its main conclusions are that 1% of global gross domestic product (GDP) per annum is required to be invested in order to avoid the worst effects of climate change, and that failure to do so could risk global GDP being up to 20% lower than it otherwise might be – with the prospects being worst for Africa and developing countries.

The Stern Review proposes that it is practical to aim for a stabilisation of greenhouse gas levels in the atmosphere of 500–550 ppm of 'carbon dioxide equivalent' by 2050 – which is double pre-industrial levels and compares with 430 ppm today. Even stabilising at that level will probably mean significant climate change. But to stabilise at that level, emissions per unit of GDP would need to be cut by an average of three-quarters by 2050 – a very significant challenge to most of humankind's lifestyles and consumption patterns.

To meet the Stern Review's proposed targets, the power sector would need to be decarbonised by 60%–70%, deforestation will also need to be stopped, since emissions from deforestation are estimated at more than 18% of global emissions – more than transport. Deep cuts in greenhouse gas emissions from transport are also needed. The costs of all these changes are estimated by Stern to be around 1% of global GDP by 2050 – so the world would be 1% poorer than it would otherwise have been, which would be significant but far from prohibitive. This does not mean everyone would be 1% poorer than they are today, but that global growth will be slower.

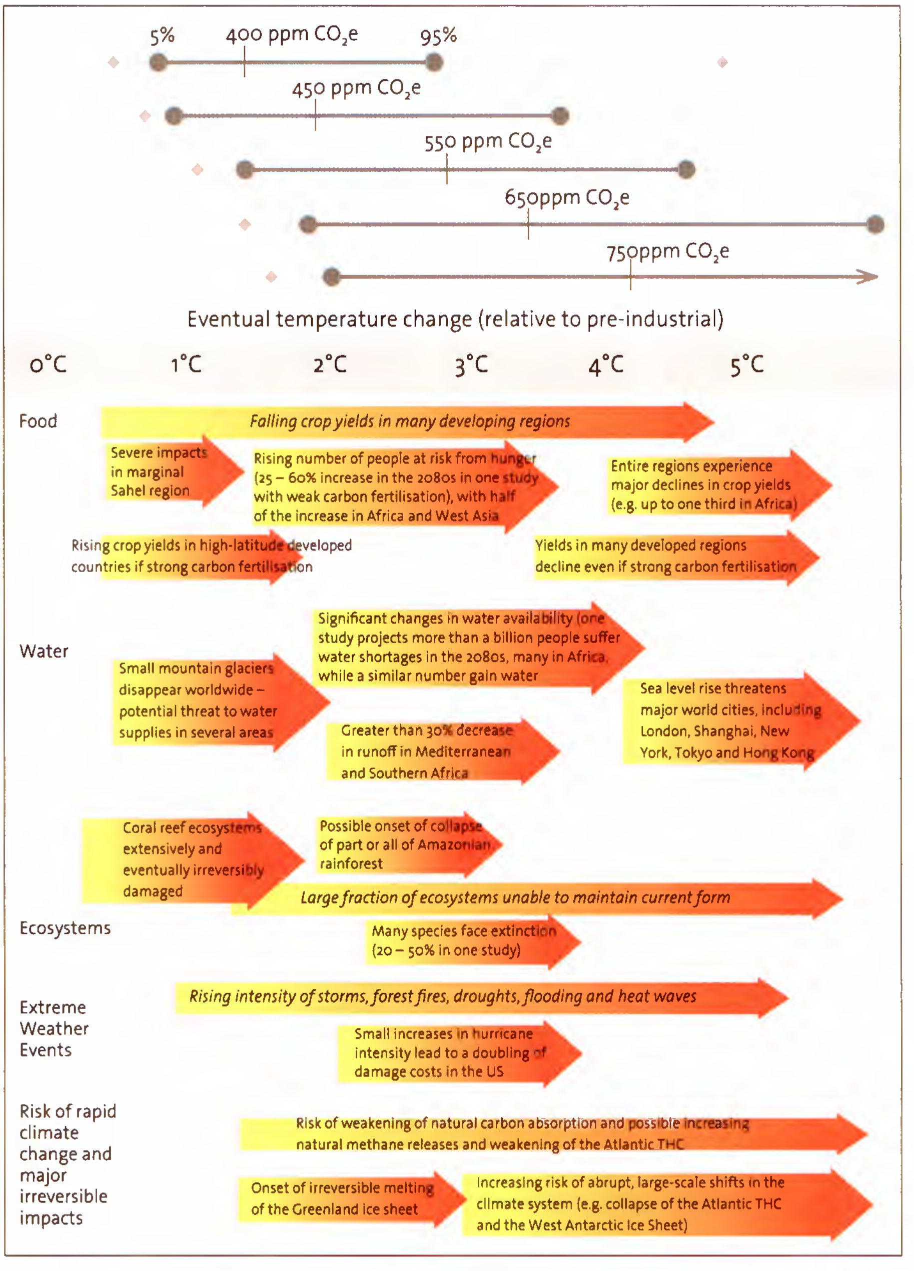
Using economic modelling to consider reductions in global output resulting from climate change, financial costs of the direct impact on human health and the environment, as well as the feedback mechanisms (which may mean that as the stock of greenhouse gases increases there is a disproportionate rise in warming with each new increment in emissions), the Stern Review reaches the stark conclusion that if we do nothing to stem climate change, there could be a permanent reduction in consumption per head of as much as 20% by 2050. These costs will not be shared evenly – there will be a disproportionate burden placed on the world's poorest countries.

Investing 1% of world GDP to be 20% richer than we will otherwise be sounds like a very attractive proposition. But there are significant hurdles, perhaps the largest of which is that it requires collective, coordinated action by most of the world's governments, and securing the requisite consensus on the way forward will not be simple. (In the interests of fairness, Stern argues that the richer countries should take responsibility for between 60% and 80% of reductions in emissions from 1990 levels by 2050.)

Assuming that an international consensus can be reached, what is the best way to correct the market failure that is currently threatening to take us on a path to poverty? How do we start to pay a price for carbon that reflects its true economic and social costs, or a price that includes the present value of future climate change? The Stern Review proposes a number of measures:

- establish a carbon price, through tax, trading or regulation, as an essential foundation for climate-change policy;
- urgently implement policies to support the development of a range of low-carbon, high-efficiency technologies;
- remove barriers to behavioural change, and encourage the take-up of opportunities for energy efficiency, such as imposing tighter standards on the energy efficiency of buildings, as well as educating the public about the true costs of wasting energy.

STERN REVIEW: The Economics of Climate Change



Stabilisation levels and probability ranges for temperature increases. The figure illustrates the types of impacts that could be experienced as the world comes into equilibrium with more greenhouse gases. The top panel shows the range of temperatures projected at stabilisation levels between 400 ppm and 750 ppm CO_2e at equilibrium.
The solid horizontal lines indicate the 5 – 95% range based on climate sensitivity estimates from the IPCC 2001 [2] and a recent Hadley Centre ensemble study [3].
The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5 – 95% range based on eleven recent studies [4]. The bottom panel illustrates the range of impacts expected at different levels of warming.
The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation.
This figure shows potential changes based on current scientific literature.

[2] Wigley, T.M.L. and Raper, S.C.B. (2001): 'Interpretation of high projections for global-mean warming', Science 293: 451–454 based on Intergovernmental Panel on Climate Change (2001): 'Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change' [Houghton, J.T., Ding, Y., Griggs, D.J., et al. (eds.)], Cambridge: Cambridge University Press.
[3] Murphy, J.M., Sexton, D.M.H., Barnett, D.N., *et al.* (2004): 'Quantification of modelling uncertainties in a large ensemble of climate change simulations', Nature 430: 768–772
[4] Meinshausen, M. (2006): 'What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates', Avoiding dangerous climate change, in Schellnhuber, H.J., *et al.* (eds.), Cambridge: Cambridge University Press, pp.265–280.

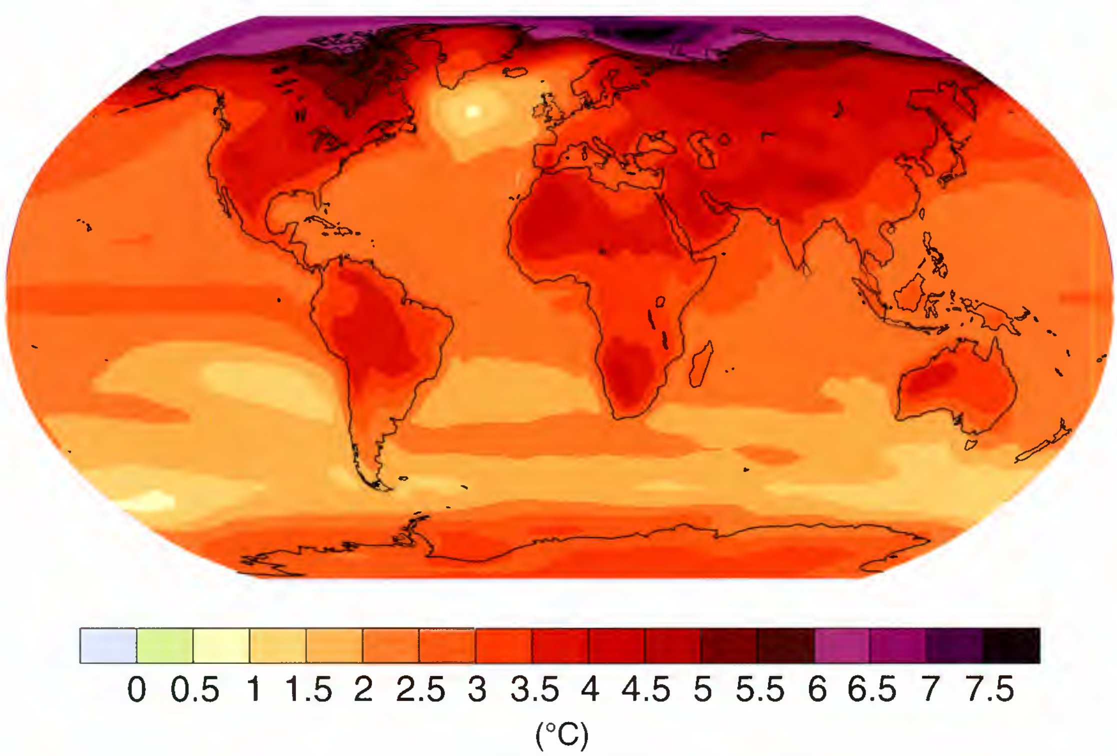
1.6 Global Environmental Decision-making

There are several examples of far-sightedness by governments as nations have struggled to assemble a coherent system of global environmental decision-making in response to increasing environmental awareness: e.g. the Montreal Protocol (on protection of the ozone layer) and the Convention on International Trade in Endangered Species (CITES). There are, in fact, 500 or so international environmental agreements now in effect, of which about 150 are global treaties. But environmental trend indicators suggest that our prodigious efforts at environmental diplomacy have so far largely failed to make serious headway against the world's most pressing environmental challenges.

Basic principles of good global environmental decision-making were pioneered at the Rio Earth Summit in 1992. 172 nations endorsed environmental governance principles when they signed the 'Rio Declaration on Environment and Development', a charter of 27 principles meant to guide the world community toward sustainable development. The problem in applying these good governance practices is not their novelty, but the fact that they profoundly challenge traditional government institutions and economic practices.

The challenge is further complicated politically by the mismatch in timing between the environmental and political/electoral impact, and by the fact that only through international action – commonly agreed and commonly implemented – can the problem of climate change be addressed, since profound structural and economic re-engineering will be involved for participating nations. Disparities between developed and developing countries will emerge and nations may seek competitive advantage in the process. Such teething problems have all been apparent in the definition and implementation of treaties such as the Kyoto Protocol to the UNFCCC, which imposes binding limits on greenhouse gas emissions by developed countries relative to their 1990 levels.

At the international level, there is rhetorical commitment to the goals of sustainable development and participatory decision-making. However, there is far less commitment to localising these goals in national policies and decision-making practices. There is a fundamental reluctance in our societies to shoulder the domestic political and financial costs to make global environmental treaties enforceable.



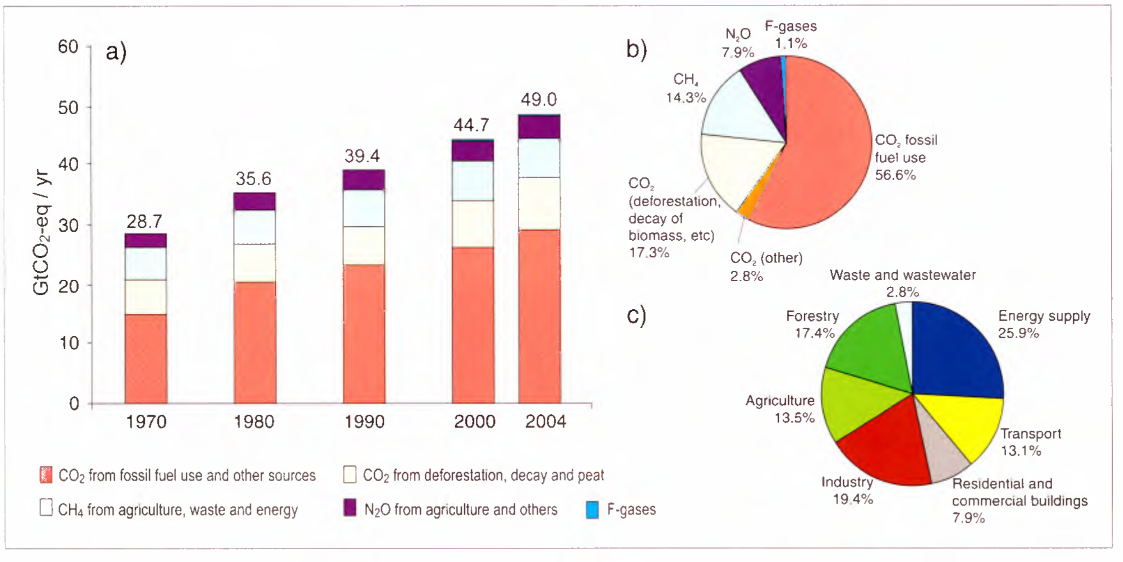
Geographical Pattern of Surface Warming. Projected surface temperature changes for the late 21st century (2090–2099). The map shows the average projection for one of the IPCC emissions scenarios. All temperatures are relative to the period 1980–1999.

1.7 Observations and Science Informing Policy

Just as science and technology have given us the evidence to measure the danger of climate change, so they can help us find safety from it. Earth System science is the key to implementing any approach towards good planetary management – providing us with the necessary insights into the feasibility, risks, trade-offs and timeliness of any strategy considered.

The nature of climate change issues presents special challenges in terms of the need for global information and data on key planetary indicators which can provide the information required for governments and policy makers to make well-informed decisions. Recognising that no single country can satisfy all of the observational requirements that are necessary for monitoring the Earth System, governments are taking steps to harmonise and integrate their observing networks and satellite observing systems to be able to address common problems of global concern.

This document discusses the need for observations of planet Earth and its climate, and highlights the opportunities presented by Earth observation satellite systems to produce information for decision-making. If the best current scientific expertise is correct in predicting the future impacts of human-induced climate change – with the apparent certainty that such changes will accelerate with an expanding human population and economic activity in the coming decades – then such information will become increasingly vital. This will provide an essential foundation for the development of the ethics of global decision-making and strategies for sustainable Earth System management which will define how mankind adapts to the expected global change.



(a) Global annual emissions of anthropogenic greenhouse gases (GHGs) from 1970 to 2004.
(b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-equivalent.
(c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-equivalent. (Forestry includes deforestation).
(Credit: IPCC AR4)

Further Information

IPCC: www.ipcc.ch

Stern Review: www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

UNFCCC: unfccc.int/2860.php

World Resources Institute: www.wri.org

UNEP: www.unep.org

2 The Important Role of Earth Observations

2.1 Why Observe the Earth?

An improved understanding of the Earth System – its weather, climate, oceans, land, geology, natural resources, ecosystems, and natural and human-induced hazards – is essential if we are to better predict, adapt and mitigate the expected global changes and their impacts on human civilisation.

Earth observation data and derived information are essential inputs in the development of this understanding. Earth observations provide the evidence necessary for informed decision-making – supporting the science which underpins strategies for global environmental decision-making – and for monitoring our progress on all geographical scales as we explore new development paths aimed at sustainable management of the planet.

The significance of Earth observations in our future decision-making processes is apparent in both the short term and long term.

- **The long term**: information extracted from long time series (several decades) of high quality observations is used in support of vital climate studies to observe and characterise the current climate, to detect climate change and to determine the rate of change. Furthermore, this information is analysed to assist in attributing the causes of change; identify any anthropogenic contribution to climate change; validate and calibrate climate models and assist in prediction of the future climate.
- **The short term**: information extracted from short time series (days or hours) of high quality observations is typically used to improve weather prediction by numerical forecast models, or to support operational applications (e.g. air quality, oceanography, land management, meteorology, disaster management). They also support land use and fresh water management and provide information for process studies to better understand physical processes in the Earth/atmosphere system.

Better information on everyday activities that support human existence will be a vital component of the global strategy for day-to-day adaptation to a world with a rapidly growing population, depleting natural resources, and short-term consequences of human-induced climate change. Regions, countries and industries can all be expected to strive for improved efficiency and international competitiveness in agricultural production, freshwater management, land use management, atmospheric emissions control, natural resources exploration and management – including forests and fossil fuels. They will also need to improve the prediction and mitigation of frequent extreme weather events and natural disasters.

Earth observation information will be required on all scales – from local to global. We can anticipate that it might be used by national and international authorities for decision-making to ensure sustainability, and also more locally as regions and industries compete for larger shares of smaller reserves of natural resources in order to support their growing populations and economic ambitions. Such information takes many forms, spanning data on population, demographics, economics and environmental indicators. Observations of planet Earth itself, and of human societies' impact upon it, might be regarded as the most important context for societal decision-making.

Earth observing systems help to provide data in support of a wide range of information needs, including parameters which are central to:

- **improved understanding**: a multitude of global-scale observations contributing to research into Earth System processes;
- **improved predictions, especially on a regional scale**: global and regional observations over recent decades are essential to identify climate changes and to test and validate climate predictions in order to increase confidence in future climate projections that are fundamental to supporting adaptation planning;
- **evidence**: Earth observations support the formulation of authoritative scientific advice. This is vital for governments when deciding whether to fund mitigation measures in response to climate change, how to react to impending crises in resource shortages, or whether to participate in agreements or Conventions which require costly changes in national consumption patterns;
- **monitoring and compliance**: we might expect to see increasing emphasis on international

policy measures and treaties such as the Kyoto Protocol emerge in future. Earth observations will form an essential role in supporting such agreements, by verifying countries' fulfilment of their treaty obligations vis-à-vis fossil fuel emissions or pollution dumping. The economic implications of such agreements can be enormous for countries, so highly visible and public measures to deter 'cheating' will be an important part of their success;

– **management and mitigation**: to support increased efficiency in basic resource provision for future generations while predicting and countering the worst effects of severe weather and natural disasters.

The beneficiaries of Earth observations are a broad range of users including: national, regional and local decision-makers; organisations responsible for the implementation of international Conventions and treaties; business, industry and service sectors; scientists and educators; and, ultimately, every inhabitant of planet Earth.

2.2 Earth Observing Systems

Current Earth observing systems include networks of satellite-borne and ground-based sensors – including ocean buoys, weather stations and atmospheric radiosondes – that provide important parameters relating to land, ocean, and atmospheric processes. It has long been recognised that a single programme, agency, or country cannot satisfy the range of observations (many of which are global), needed to understand and monitor climate and other Earth System processes , and to assess the impact of human activities. The main Earth observing networks are, therefore, typically international collaborative programmes. They include:

World Weather Watch (WWW) of the World Meteorological Organisation (WMO) a unique achievement in international cooperation, providing a truly worldwide operational system to which virtually every country in the world contributes, every day of every year, for the common benefit of humankind.

The **Global Observing System** (GOS) of the WWW ensures that every country has all the information available to generate weather analyses, forecasts and warnings on a day-to-day basis. It includes around 10,000 stations on land, providing observations at least every three hours near the Earth's surface. These include meteorological parameters such as atmospheric pressure, wind speed and direction, air temperature and relative humidity. The most obvious benefits of the GOS are the safeguarding of life and property through the forecasting, detection and warning of severe weather phenomena such as local storms, tornadoes and tropical cyclones. GOS provides observational data for agricultural management, aviation safety, meteorology and climatology, including basic information on the key atmospheric surface variables – temperature and precipitation – that are central to global change.

The GOS also provides an international database of upper air observations which provide a record of vertical climate variations and are often combined with satellite data in analyses or 're-analysis' to form a more comprehensive view of the atmosphere.

Global Atmosphere Watch (GAW) stations around the world supplement these observations with information on ozone, other greenhouse gases, solar radiation, ultraviolet radiation and other atmospheric/meteorological parameters.

The Global Observing Systems

Within the last decade, the Global Observing System of the World Weather Watch has been complemented by the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS). These produce a set of Global Observing Systems integrating *in situ* and remotely sensed data from a range of international, regional and national observing systems and networks, with each focusing on a major component of the Earth System. The Global Climate Observing System (GCOS) has also been initiated to integrate the observing needs for climate purposes.

GOOS: a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions of the sea; and the basis for forecasts of climate change.

GOOS is capitalising on existing ocean observing systems, such as:

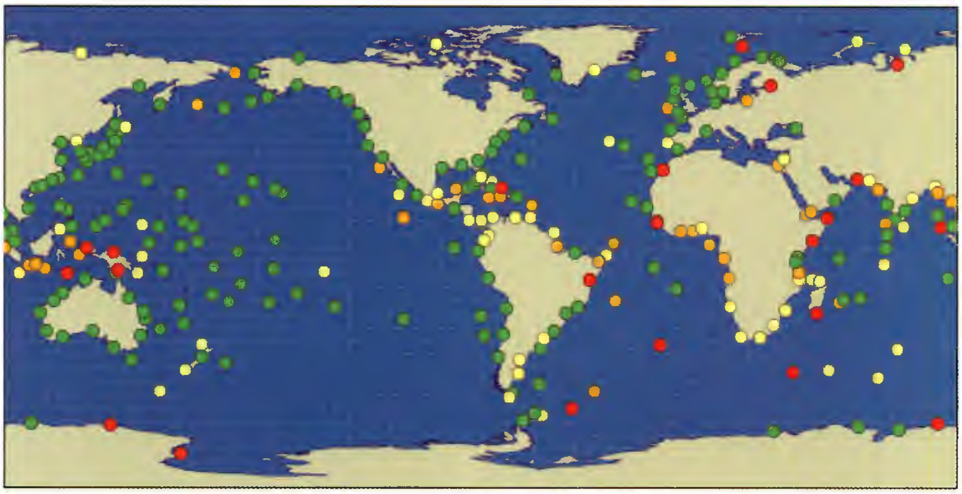
- The TAO/TRITON array: comprises 70 moored buoys in the tropical Pacific Ocean. Since its completion in 1994, it has enabled real-time collection of high quality oceanographic and surface meteorological data for monitoring, forecasting, and understanding of climate swings associated with El Niño and La Niña. Data and graphic displays from the TAO/TRITON array are updated every day, and the data are freely available to the research community, the operational forecasting community and the general public.
- The Global Sea Level Observing System (GLOSS): an international programme coordinated by the Intergovernmental Oceanographic Commission (IOC) for the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations located around the world for monitoring long-term trends and accelerations in global sea level.

There are numerous other contributors to GOOS, including voluntary observing ships that provide measurements of upper ocean and meteorological parameters, the Global Temperature and Salinity Profile Programme and the Global Coral Reef Monitoring Network.

The Joint WMO/IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM) was established by these two UN bodies in 1999 in order to ensure that all the elements necessary for GOOS are put in place and adequately funded. The system will be end-to-end, from maintaining observing systems of *in situ*, air- and space-based instrumentation to data collection and archiving, standards and quality control, and the real-time delivery of data and services to all users. The goals of JCOMM are to identify and coordinate all of the necessary subsystems as a coherent whole and to ensure that nations are aware of, and commit to, the necessary funding for the full system.

GTOS: a programme for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. The Global Terrestrial Observing System (GTOS) facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change.

GLOSS status – October 2006



- **Category 1:** *"Operational" stations for which the latest data is 2001 or later.*
- **Category 2:** *"Probably operational" stations for which the latest data is within the period 1991-2000.*
- **Category 3:** *"Historical" stations for which the latest data is earlier than 1991.*
- **Category 4:** *"Stations for which no PSMSL data exist.*

To achieve this GTOS is working towards the establishment of a 'system of networks' formed by linking existing terrestrial monitoring sites and networks, as well as planned satellite remote sensing systems. Thematic networks have been established for ecology, glaciers and permafrost. A hydrology network is in progress.

Since the sustainable development of forest resources is regarded as one of the most pressing environmental issues of our time, GTOS has established a panel on Global Observations of Forest Cover and Land Cover Dynamics (GOFC-GOLD). This panel aims to improve the quality and availability of observations of forests at regional and global scales and to produce useful, timely and validated information products from these data for a wide variety of users.

The Global Terrestrial Network (GT-Net) links the world's terrestrial research networks together. It serves as a framework for network managers to explore areas of common interest, harmonise research efforts and share data, information and experience.

GCOS: The Global Climate Observing System (GCOS) Steering Committee was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored by WMO, the Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). The GCOS Secretariat and the Steering Committee play an advisory role and work in partnership with the domain-based observing systems to advise on the climate components of those observing systems.

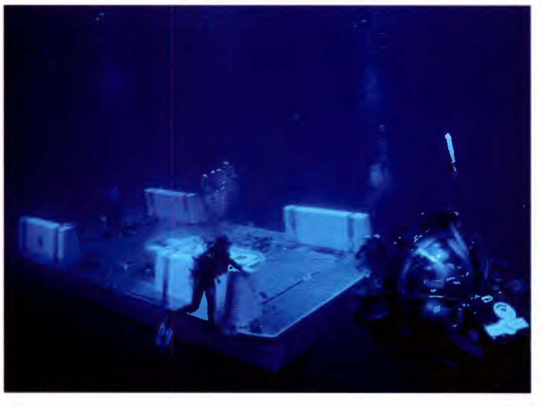
These climate components form a Global Climate Observing System that is intended to be a long-term, user-driven operational system that will be capable of providing the comprehensive observations required for monitoring the climate system, for detecting and attributing climate change, and for assessing the impacts of climate variability and climatology, including the study of global change. More details on this important role for GCOS may be found below.

GEOSS: The intergovernmental Group on Earth Observations (GEO) is coordinating efforts to develop a Global Earth Observation System of Systems (GEOSS). GEO was launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialised countries. These high-level meetings recognised that international collaboration is essential for exploiting the growing potential of Earth observations to support decision-making in an increasingly complex and environmentally stressed world.

GEO is an intergovernmental body of member governments and participating organisations. It provides a framework within which these partners can develop new projects and coordinate their strategies and investments. As of February 2008, GEO's members included 72 governments and the European Commission. In addition, 52 intergovernmental, international, and regional organisations with a mandate in Earth observation or related issues have been recognised as Participating Organisations.

GEO is coordinating GEOSS on the basis of a 10-year Implementation Plan for the period 2005 to 2015. The Plan defines a vision statement for GEOSS, its purpose and scope, expected benefits, and nine 'Societal Benefit Areas': disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity.

Its 2005–2009 programme addresses more than 70 tasks to advance work under way in these societal benefit areas and to implement an interoperable architecture that links existing and planned systems around the world, as well as improving and standardising access to Earth observations.



CEOS has begun to receive and coordinate commitments from its members to address the high priority space-related actions in these tasks.

Ministers and officials from over 100 governments and international organisations assembled at the 4th Earth Observation Summit, 28–30 November 2007, and noted with satisfaction the numerous contributions and early achievements made toward the development of GEOSS as described in the 'GEO Report on Progress 2007'.

2.3 The Global Climate Observing System (GCOS)

The Global Climate Observing System (GCOS) provides vital and continuous support to the United Nations Framework Convention on Climate Change (UNFCCC) in the definition and specification of requirements for observations relevant to climate change.

In 1998, and again in 2001, GCOS prepared reports on the adequacy of global observing systems for climate in providing the systematic climate observations required by the UNFCCC. The goals of the Second Adequacy Report were: to determine what progress has been made in implementing climate observing networks and systems since the first report; to determine the degree to which these networks meet with scientific requirements and conform with associated observing principles; and to assess how well these current systems, together with new and emerging methods of observation, will meet the needs of the UNFCCC (and IPCC).

These GCOS reports made considerable progress in defining what information was required in support of climate studies, how well current and planned systems met these needs, and what further actions were required by countries to better meet some of those needs.

In 2004, in response to the request from UNFCCC, GCOS prepared an Implementation Plan for the global observing system for climate. From the outset, the UNFCCC requested GCOS and GEO to coordinate their respective implementation plans. The GCOS Implementation Plan represents a commonly-agreed basis for GEO actions in the Climate area. The GCOS Plan, if fully implemented by the Parties to the UNFCCC, both individually and collectively, will provide those global observations of the Essential Climate Variables and their associated products, to assist the Parties in meeting their responsibilities under the UNFCCC. In addition, it will provide many of the essential observations required by the World Climate Research Programme (WCRP) and IPCC.

The proposed system would provide information to:

- characterise the state of the global climate system and its variability;
- monitor the forcing of the climate system, including both natural and anthropogenic contributions;

- support the attribution of the causes of climate change;
- support the prediction of global climate change;
- enable projection of global climate change information down to regional and local scales;
- enable characterisation of extreme events important in impact assessment and adaptation, as well as the assessment of risk and vulnerability.

The GCOS Implementation Plan (GCOS IP) remains the consensus document of the international community regarding the global observing system for climate.

2.4 The Essential Climate Variables

GCOS has defined a list of the Essential Climate Variables (ECVs) that are both currently feasible for global implementation and have a high impact on the requirements of the UNFCCC and IPCC. There are additional climate variables that are important to a full understanding of the climate system and many of these are the subjects of current on-going research, although they are not currently ready for global implementation on a systematic basis.

As our knowledge and capabilities develop, it is expected that some of these variables will be added to the list of ECVs.

The Global Climate Observing System requires observations from land-based and airborne *in situ* and remote sensing platforms, in addition to satellites. Since no single technology or source can provide all the necessary data, there will be instruments at ground stations, as well as on ships, buoys, floats, ocean profilers, balloons, samplers, aircraft and satellites. This information is then transformed into products through analysis and integration in both time and space.

Information on where and how the observations are taken (meta-data) is absolutely essential, as are historical and palaeoclimatic records that set the context for the interpretation of trends and variability. GCOS stresses that its Plan is both technically feasible and cost-effective. While its implementation is fully dependent on national efforts, success will be achieved only through internationally-coordinated action.

2.5 Observations of Climate by Earth Orbiting Satellites

Space-based remote sensing observations of the atmosphere-ocean-land system have evolved substantially since the first weather satellite systems were launched almost 50 years ago. Earth observation satellites have proved their capabilities to accurately monitor multiple aspects of the total Earth System on a global basis, unlike ground-based systems that are limited to land areas and cover only about 30% of the planet's surface.

Currently, satellite systems monitor the evolution and impact of the El Niño, weather phenomena, natural droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal

The Essential Climate Variables

Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	Surface:	Air temperature, **precipitation**, air pressure, surface radiation budget, wind speed and direction, water vapour.
	Upper air:	**Earth radiation budget (including solar irradiance), upper air temperature (including MSU radiances), wind speed and direction, water vapour, cloud properties.**
	Composition:	**Carbon dioxide**, methane, **ozone**, other long-lived greenhouse gases, **aerosol properties**.
Oceanic	Surface:	**Sea surface temperature**, sea surface salinity, **sea level, sea state, sea ice**, currents, **ocean colour (for biological activity)**, carbon dioxide partial pressure.
	Sub-surface:	Temperature, **salinity**, currents, nutrients, carbon, ocean tracers, phytoplankton.
Terrestrial	River discharge, water use, ground water, **lake levels, snow cover, glaciers and ice caps**, permafrost and seasonally-frozen ground, **albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (fAPAR), leaf area index (LAI), biomass, fire disturbance, soil moisture**.	

Measurements of variables in **bold type** are largely dependent on satellite observations.

zones and algal blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and more.

These various observations are used extensively in real-time decision making and in the strategic planning and management of industrial, economic, and natural resources. The proliferation of Earth observation satellites reflects their unique abilities and benefits, such as:

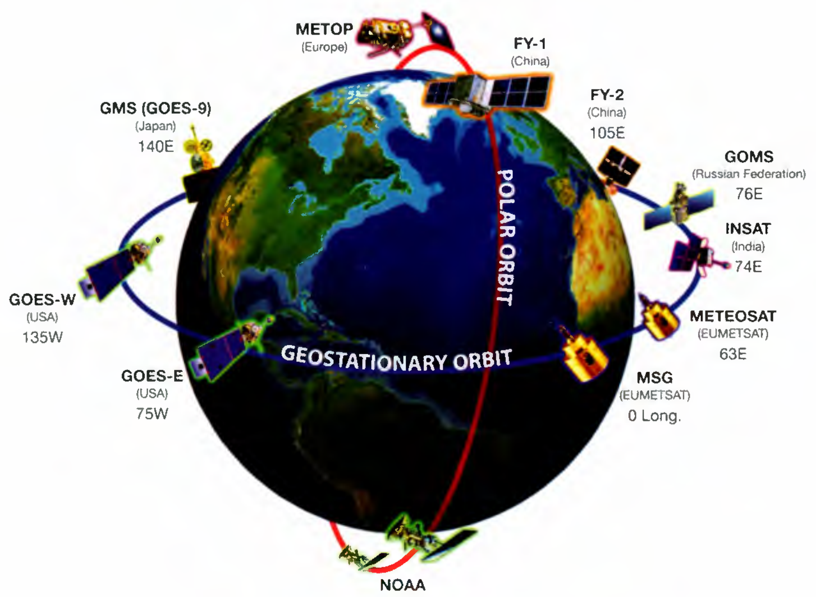
- wide area observation capability;
- non-intrusive observations allowing collection of data to take place without compromising national sovereignty;
- uniformity that enables the same sensor to be used at many different places in the world;
- rapid measurement capability, allowing sensors to be targeted at any point on Earth, including remote and inhospitable areas;
- continuity, with single sensors or series of sensors providing long time series of data suitable for climate studies.

Just one significant example – highlighted by the IPCC 4AR – is the global coverage of satellite ocean altimetry, provided over the last 15 years by the Topex/Poseidon and Jason satellites. These data have provided unambiguous evidence of non-uniform sea level rise in open oceans and have proven to be the most accurate and objective way to detect this rise in sea level.

The GCOS Implementation Plan notes that satellites provide a vital means of obtaining observations of the climate system from a global perspective, and that "a detailed global climate record for the future will not be possible without a major, sustained, satellite component". Although almost all Earth observing satellite systems were not specifically designed for climate monitoring, space agency efforts have initiated a remarkably comprehensive climate data record that is forming the basis for a better understanding of the Earth's climate system. Much has been accomplished, but more remains to be done. Significant gaps remain in measurement capabilities and their continuity.

Noting GCOS advice on the significance of the satellite contribution to climate data records, the UNFCCC invited countries that support space agencies which operate Earth observing satellite programmes to provide a response to the needs expressed in the GCOS Implementation Plan.

These countries agreed that the Committee on Earth Observation Satellites (CEOS), as the primary international forum for coordination of space-based Earth observations, was the appropriate international body to respond. CEOS prepared and delivered to the UNFCCC an assessment of the adequacy of past, present, and future satellite measurements in support of GCOS. CEOS noted that responding to these needs represents a unique opportunity for space agencies to review the way in which multi-agency cooperation on climate-related observations is prioritised, agreed, funded, implemented, and monitored. The UNFCCC has welcomed the CEOS initial report, commended space agencies for actions taken thus far, and requested CEOS to report on progress at future meetings.



Operational weather satellites.

Space agencies provide the basic satellite observations – Fundamental Climate Data Records (FCDRs) – needed to monitor global climate change. In turn, the end-user products for the Essential Climate Variables (ECVs) are generated by a range of interested communities through a variety of approaches that link satellite observation data with *in situ* data and other information through assimilation into models and other products.

The various ECVs and the status of satellite data provision in support of them are identified at the Satellite Data Stewardship website of the U.S. National Climatic Data Center (NCDC) (www.ncdc.noaa.gov/sds). The site also identifies the linkage between individual ECVs and key IPCC questions and societal benefits.

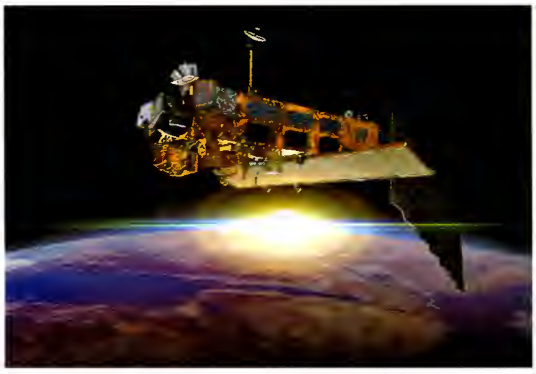
2.6 Framework for Provision of Satellite Observations

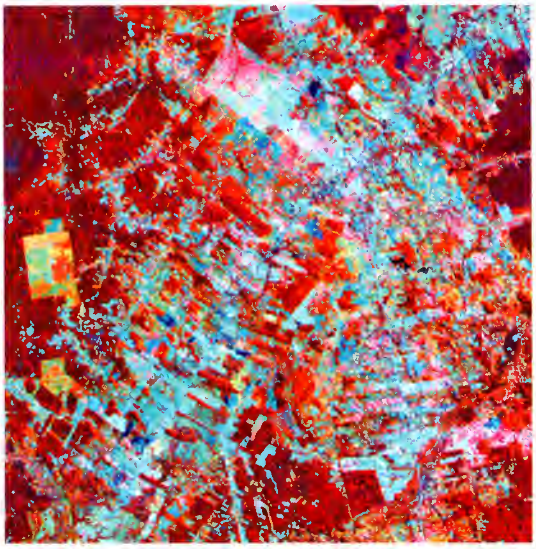
The development and operation of space vehicles, launchers and instruments are highly technical endeavours that are generally delegated by national governments to specialised space agencies. A typical space agency has responsibility for overseeing all aspects of the space activities of its host national or regional government. Applications of Earth observation satellite programmes are typically numerous and diverse, including, but not limited to, studies of climate, environmental issues, agriculture, meteorology, and natural disasters.

More information on the important role of CEOS in this framework is provided in section 3. In broad terms, CEOS membership comprises two kinds of space agencies:

- research agencies, which typically undertake cutting edge R&D activities, often involving 'one-off' Earth observation missions that are intended to demonstrate a technical concept of measurement capability in support of well-identified science objectives; and
- operational agencies, which are funded by governments to make continuous and time-critical observations, ensuring that there are no temporal or spatial gaps in coverage. A limited number of space agencies fall into this operational category.

Clearly a climate data record requires a commitment to stable and continuous measurements over long time periods, but, to date, issues such as data and mission continuity, overlap, and cross-calibration have been





undertaken by research agencies on a 'best efforts' basis. While a typical mission involves considerable effort dedicated to these activities, there remains a need to ensure that this happens systematically. In recent years, agencies have endeavoured to ensure continuity of some key measurements (e.g. ocean surface altimetry) that have become established as near-operational within some user communities. This remains, however, the exception rather than the rule for research-oriented space agencies, which are neither mandated nor funded to provide operational services.

In contrast to research-focused satellite programmes, the satellite programmes of operational agencies have many of the characteristics required by GCOS for climate applications, such as constant interaction with operational user communities and adaptation to their needs, as well as sustained, overlapping and coordinated coverage. Although recognition is growing of the need to transition research satellites that provide observations required by the GCOS IP into operational systems, constructing such a migration path in the planning for current and future systems remains difficult. To support this aim, and with the objective of creating an operational system that monitors and evaluates the calibration of the global meteorological satellite observing system in a coherent and systematic manner, the Coordination Group for Meteorological Satellites (CGMS) has recently started the Global Space-based Intercalibration System (GSICS) initiative.

Despite the utility of satellite Earth observations for climate, it also should be understood that there is presently no overall strategy across nations for a comprehensive design of these systems.

Most contributing missions were neither intended nor optimised for climate purposes. Therefore, gaps and needed improvements have been identified to realise the ambitions expressed in the GCOS IP.

The role of CEOS in helping to provide the coordination necessary to address such issues is explained in section 3. Section 4 highlights the challenges which lie ahead if we are to successfully implement the system specified by GCOS.

Some examples of the vital contribution of Earth observation satellites to the development of our climate data records are explored in the Case Studies in Part II of this document.

Part III explores in considerably more detail the adequacy of planned and existing satellite systems to meet the needs for a particular measurement or Essential Climate Variable.

Further Information

World Weather Watch: www.wmo.int/pages/prog/www/index_en.html

The Global Observing Systems: www.gosic.org

GCOS: www.wmo.int/pages/prog/gcos/index.php

GOOS: www.ioc-goos.org

GTOS: www.fao.org/gtos

GEO & GEOSS: earthobservations.org

The IGOS Partnership: www.igospartners.org

Earth observation: www.esa.int/export/esaEO & earthobservatory.nasa.gov

The science of remote sensing: rst.gsfc.nasa.gov/start.html

3 CEOS

What is CEOS?

CEOS is the Committee on Earth Observation Satellites, created in 1984 in response to a recommendation from a Panel of Experts on Remote Sensing from Space, under the aegis of the G-7 Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment.

CEOS was established to provide coordination of the Earth observations being provided by satellite missions, recognising that no single programme, agency, or nation can hope to satisfy all of the observational requirements which are necessary for improved understanding of the Earth System. Since its establishment, CEOS has provided a broad framework for international coordination on spaceborne Earth observation missions.

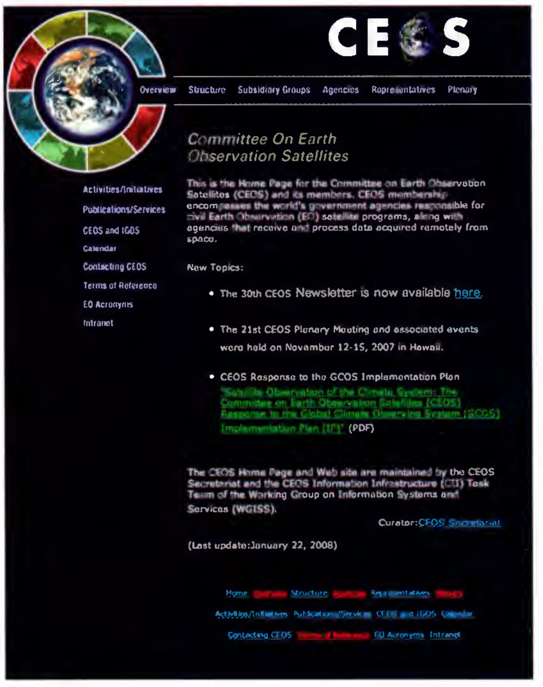
What Does CEOS Contribute?

CEOS strives to facilitate the necessary harmonisation and achieve maximum cost-effectiveness for the overall set of space-based observation programmes of member countries and agencies.

CEOS has established three primary objectives in pursuing this goal:

- to optimise benefits of spaceborne Earth observations through cooperation of its members in mission planning and in development of compatible data products, formats, services, applications and policies;
- to serve as a focal point for international coordination of space-related Earth observation activities;
- to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

The work of CEOS spans the full range of activities required for proper international coordination of Earth observation programmes and maximum utilisation of their data. It ranges from the development of detailed technical standards for data product exchange, through to the establishment of high level inter-agency agreements on common data principles for



CEOS web site.

different application areas, such as global climate change and environmental monitoring.

Who Participates in CEOS?

CEOS membership comprises most of the world's civil agencies responsible for Earth observation satellite programmes – 29 Members in 2008. CEOS also has 20 Associates, comprising:

- international or national governmental organisations that are developing Earth observing satellite programmes or significant supporting ground facility programmes;
- other satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.
- The full list of Members and Associates is shown in the tables below.

How Does CEOS Operate?

CEOS Principals meet annually in a Plenary session to determine policy, review progress on the projects and activities being undertaken, and set the agenda of activities for the upcoming year. The Chair of CEOS rotates at the annual Plenary.

The work of CEOS is conducted within its various working groups and the Strategic Implementation Team (SIT).

CEOS Membership

Organisation		Country/Countries
ASI	Agenzia Spaziale Italiana	Italy
BNSC	British National Space Centre	United Kingdom
CAST	Chinese Academy of Space Technology	China
CDTI	Centre for the Development of Industrial Technology	Spain
CNES	Centre National d'Etudes Spatiales	France
CONAE	Comisión Nacional de Actividades Espaciales	Argentina
CRESDA	China Centre for Resources Satellite Data and Application	China
CSA	Canadian Space Agency	Canada
CSIRO	Commonwealth Scientific and Industrial Research Organisation	Australia
DLR	Deutsches Zentrum für Luft- und Raumfahrt	Germany
EC	European Commission	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom
ESA	European Space Agency	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom (Czech Republic is likely to be a member by the end of 2008; Canada, Hungary, Poland & Romania are Cooperating States)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites	Austria, Belgium, Croatia, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom (plus 9 Cooperating States: Czech Republic, Iceland, Hungary, Latvia, Lithuania, Poland, Bulgaria, Romania, Estonia)
GISTDA	Geo-Informatics and Space Technology Development Agency	Thailand
INPE	Instituto Nacional de Pesquisas Espaciais	Brazil
ISRO	Indian Space Research Organsation	India
KARI	Korea Aerospace Research Institute	Korea
MEXT/JAXA	Ministry of Education, Culture, Sports, Science and Technology / Japan Aerospace Exploration Agency	Japan
NASA	National Aeronautics and Space Administration	United States of America
NASRDA	National Space Research and Development Agency	Nigeria
NOAA	National Oceanic and Atmospheric Administration	United States of America
NRSCC	National Remote Sensing Center of China	China
NSAU	National Space Agency of Ukraine	Ukraine
ROSHYDROMET	Russian Federal Service for Hydro-meteorology and Environment Monitoring	Russia
ROSKOSMOS	Russian Federal Space Agency	Russia
SNSB	Swedish National Space Board	Sweden
Tubitak-Uzay	Space Technology Research Institute of Turkey	Turkey
USGS	United States Geological Survey	United States of America

CEOS Associates

Organisation		Country/Countries
CCRS	Canada Centre For Remote Sensing	Canada
CRI	Crown Research Institute	New Zealand
ESCAP	Economic and Social Commission of Asia and the Pacific	UN
FAO	Food and Agriculture Organization	UN
GCOS	Global Climate Observing System	International Programme
GOOS	Global Ocean Observing System	International Programme
GTOS	Global Terrestrial Observing System	International Programme
ICSU	International Council for Science	International Programme
IGBP	International Geosphere-Biosphere Programme	International Programme
IOC	Inter-governmental Oceanographic Commission	UNESCO
IOCCG	International Ocean Colour Coordinating Group	International Programme
ISPRS	International Society for Photogrammetry and Remote Sensing	International Programme
NSC	Norwegian Space Centre	Norway
OSTC	Federal Office for Scientific, Technical and Cultural Affairs	Belgium
SAC/CSIR	Satellite Applications Centre/Council for Scientific and Industrial Research	South Africa
UNEP	United Nations Environment Programme	UN
UNESCO	United Nations Educational, Scientific and Cultural Organization	UN
UNOOSA	United Nations Office of Outer Space Affairs	UN
WCRP	World Climate Research Programme	UN
WMO	World Meteorological Organization	UN

Coordination throughout the year is maintained through a permanent Secretariat maintained by the European Space Agency (ESA) jointly with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the USA, and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) jointly with the Japan Aerospace Exploration Agency (JAXA).

CEOS Activities and Achievements

The establishment of the Group on Earth Observations (GEO) via a series of three ministerial-level summits from 2003 to 2005 provided a new focus and impetus for CEOS efforts. GEO includes 73 member countries, the European Commission, and 51 participating organisations – including CEOS – working together to establish a Global Earth Observation System of Systems over the next 10 years. The

Earth observation heads of 29 space agencies from around the globe meet annually at the CEOS Plenary.

GCOS plans are recognised as the climate component of GEOSS and they are addressed in this document in both contexts.

The GEO vision for GEOSS is to realise a future in which decisions and actions for the benefit of humankind are informed via coordinated, comprehensive and sustained Earth observations and information. The 20+ years invested by CEOS agencies towards these objectives has resulted in recognition of CEOS as the primary worldwide forum for coordination of space-based Earth observations. As such, CEOS is tasked to lead coordination of the space observations required by the GEOSS.

The main mechanisms which CEOS employs to implement this role are:

— the CEOS Virtual Constellations for GEOSS;

— the CEOS Working Groups;

— the CEOS Implementation Plan and teams to address the various tasks therein.

Each of these is discussed in turn below.

CEOS Virtual Constellations for GEOSS

The CEOS Virtual Constellations for GEOSS provide a new mechanism for better coordination of Earth observing satellite programmes across borders, allowing valuable contributions from a wide range of parties to build and sustain truly global observing systems in support of one or more key information needs of society. The Virtual Constellations concept involves multiple satellites working in harmony as part of the GEOSS to augment coverage, enhance system compatibility and increase data availability. Such an arrangement encourages international cooperation among space agencies while stimulating them to develop a coordinated response to space-based observation needs. It also fosters improved data management and distribution worldwide.

Four prototype virtual constellations are currently in progress by CEOS space agencies, in consultation with their respective user communities – each with a major outcome in support of climate and other applications:

— The Precipitation Constellation, which aims to strengthen international cooperation of space-based observations of precipitation, including realisation of the Global Precipitation Measurement (GPM) mission;

— The Land Surface Imaging Constellation, designed to ensure continuity and compatibility of planned land remote sensing systems;

— The Atmospheric Composition Constellation, which will address many of the climate community's needs for atmospheric observations;

— The Ocean Surface Topography Constellation, designed to ensure continuity of sea level measurement in accordance with GCOS requirements.

Each of these is designed to make key observations for the GEOSS and maintain continuity of observations, identifying and addressing potential gaps and overlaps. Part of the process is to clearly identify organisational responsibilities for ensuring the necessary continuity. Further details of the CEOS Constellations are provided in the Case Studies in Part II of this document.

CEOS SIT

The Strategic Implementation Team (SIT) of CEOS is where heads of space agencies or Earth observation programmes meet to make the decisions required to harmonise their observing programme plans. SIT plays a central role in coordination of existing and future missions of CEOS agencies to support GEO in its realisation of the GEOSS space segment.

The Chair of SIT has a two year term, with an already-nominated deputy ready to take over. This provides a level of continuity which has

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Committee on Earth Observation Satellites
http://www.ceos.org

Report from the 21st CEOS Plenary

Ms. Barbara Ryan, U.S. Geological Survey, 2007 CEOS Chair

On November 13 and 14, 2007, the 21st CEOS Plenary was hosted by the U.S. Geological Survey on the Big Island of Hawai'i. The lovely tropical setting contributed to a sense of "relaxed focus" on recent CEOS accomplishments – but more importantly, the setting allowed us to focus on our upcoming work in 2008. Hawai'i also provided a unique opportunity for CEOS members to learn more about USGS's role in volcano science and related land surface monitoring, and the use of satellite remote sensing in accomplishing the USGS mission.

The Big Island is part of a geographically remote chain of islands which many equate to "Paradise on Earth". Yet even this beautiful, remote territory is experiencing rapid land surface, ecosystem, and climate change. It was therefore fitting for the Plenary to meet in Hawai'i, since the data from CEOS members' systems are essential to life and prosperity on this island - and indeed everywhere on fragile planet.

The Plenary was attended by representatives from 29 national and international organizations. Among the many highlights of the meeting were the following:

- Welcoming two new CEOS Members: Spain's Center for the Development of Industrial Technology, and the China Center for Resources Satellite Data and Application;
- Committing to a series of detailed and comprehensive actions to support development of the Global Earth Observation System of Systems (GEOSS) space segment;
- Continuing a dialogue with the GEO Secretariat on next steps in GEO Work Plan implementation and its support by CEOS Members, Associates, and Working Groups;
- Reviewing reports from the pilot phases of the four CEOS Virtual Constellations (Atmospheric Composition, Land Surface Imaging, Ocean Surface Topography, and Precipitation) and deciding upon next steps in their development;
- Previewing a new CEOS Virtual Constellations video (courtesy of the NASA Langley Research Center production staff) which describes the societal benefits which may be realized through better coordination of remote sensing satellite systems;
- Deciding upon final steps in IGOS-P coordination and this highly successful initiative's transition into GEO;
- Thanking outgoing Working Group Chairs - Ms Yolanda Berenguer of the Working Group on Education, Training and Capacity Building and Mr Ivan Petiteville of the Working Group on Information Systems and Services, and endorsing these Groups' incoming Chairs – Mr Gordon Bridge and Ms Martha Maiden, respectively;
- Taking steps in expanded consultation and coordination with the World Meteorological Organization Space Program and with the Coordination Group for Meteorological Satellites;
- Reviewing the many accomplishments of outgoing CEOS Executive Officer, Jean-Louis Fellous, and welcoming incoming Executive Officer Ivan Petiteville; and
- Welcoming South Africa's Council for Scientific and Industrial Research (CSIR) as new CEOS Chair and the U.S. National Oceanic and Atmospheric Administration as the new CEOS Strategic Implementation Team (SIT) Chair. We look forward to supporting their leadership in 2008.

I was particularly pleased that Deputy Secretary of the Interior, the Honorable P Lynn Scarlett, and USGS Director Mark

21st CEOS Plenary 12-15 November 2007 Kohala Coast, Hawaii USA

CEOS newsletter.

resulted in the Chair of SIT being appointed as the primary interface between CEOS and GEO.

SIT has never had a formal membership. Meetings are open to any CEOS agency which is willing and ready to contribute to one or more of the activities being discussed by SIT, such as the Virtual Constellations projects or particular GEOSS space segment implementation tasks.

CEOS Working Groups

CEOS also uses three Working Groups to implement its activities:

- **Working Group on Calibration and Validation (WGCV)**: with activities on calibration and validation of Earth observations for the benefit of CEOS members and the international user community;

- **Working Group on Information Systems and Services (WGISS)**: focused on interoperability and interconnectivity of information systems and services related to the capture, archiving and exploitation of EO data;

- **Working Group on Education, Training and Capacity Building (WGEDU)**: facilitating activities that substantially enhance international education and training in Earth System Science as well as the observation techniques, data analysis and interpretation required for its use and application to societal needs.

More information is provided in Annex A.

The CEOS Implementation Plan

The first version of the CEOS Implementation Plan, prepared by the Strategic Implementation Team, was published and endorsed in 2007. It is the mechanism by which CEOS now prioritises, manages and monitors its various tasks in support of the development of the space-based observations for the GEOSS, of which the Global Climate Observing System is a significant part. The CEOS Implementation Plan represents a move to a business-like and target-oriented agenda for CEOS as it responds to its responsibilities in support of the GEOSS.

As part of the adoption of the Implementation Plan in 2007, the 29 member space agencies of CEOS agreed to establish expert teams for each of the 9 'Societal Benefit Areas' of the GEOSS, each with the responsibility of progressing and reporting on activities in support of the various GEOSS targets. Oversight of the entire activity is undertaken by the Chair of the CEOS Strategic Implementation Team (SIT), with support from the CEOS Executive Officer (CEO). In 2008, the CEO and SIT Chair have been working closely with the GEO Secretariat in order to prioritise the many actions required for CEOS in support of the GEOSS space segment.

The CEOS IP will be updated annually to demonstrate how well the coordination processes are working to achieve the required outcomes.

More Information

Further information on the structure, activities, and achievements of CEOS is provided in Annex A of this document.

Further Information

CEOS: www.ceos.org

Earth Observation Handbook: www.eohandbook.com

CEOS Newsletter: www.ceos.org/pages/newsletter.html

CEOS Response to GCOS IP: www.ceos.org/pages/CEOSResponse_1010A.pdf

4 Future Challenges

Without the capabilities offered by satellite Earth observations, there would be insufficient information for future climate change studies and insufficient evidence with which to inform our decision-making on policies aimed at mitigation and adaptation to climate change. We would also have no way of checking the effectiveness of our mitigation strategies in terms of the trends of key Essential Climate Variables. Earth-based measurement systems alone cannot provide the synoptic global picture which is required.

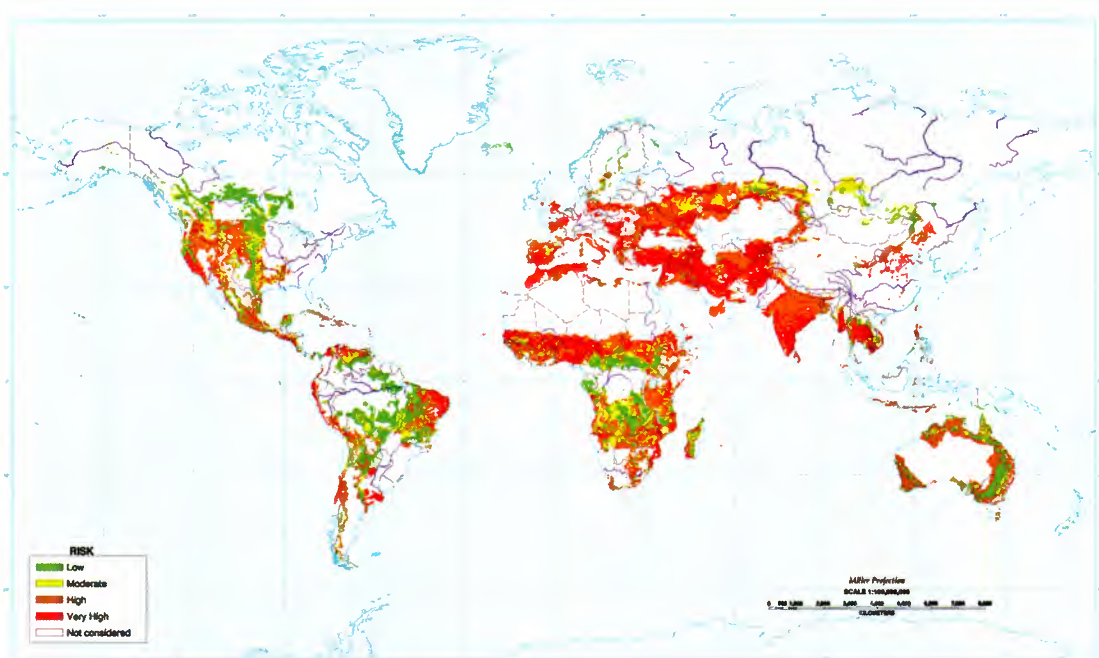
Thanks to the work of GCOS, with its sponsors and partners in support of the UNFCCC, we have established a clear community consensus on the observations that are required to deliver 45 Essential Climate Variables needed to detect, monitor, predict, adapt to and mitigate climate change in the Earth System. CEOS and GCOS together have identified 25 of the Essential Climate Variables which are largely dependent on satellite observations and have specified a number of actions required to ensure the necessary continuity or technical characteristics required for climate studies.

The vision of a global observing system for climate will only be realised through a well planned and sustained international coordination effort, involving a number of challenges:

Ensuring satellite Earth observing systems are designed, constructed and operated in a way that enables more effective climate observations. For the most part, satellite observations of climate are not sufficiently accurate at present to establish a climate record that is indisputable, and hence capable of determining whether, and at what rate, the climate is changing, or of testing the long term trend predictions of climate models. Space-based observations do provide a clear picture of the relatively large signals associated with inter-annual climate variations such as El Niño, and they have also been used to diagnose gross inadequacies of climate models, such as their cloud generation scenarios. However, satellite contributions to measuring long term change have been limited, and, at times, controversial, as in the case of differing atmospheric temperature trends derived from microwave radiometers.

Measuring long-term global climate change from space is a daunting task. The climate signals we are trying to detect are extremely small: e.g. temperature trends of only a few tenths of a degree C per decade, ozone changes as little as 1% per decade and variations in the Sun's output as tiny as 0.1% per decade or less. Current satellite systems are not up to the task. Sensors and onboard calibration sources degrade in orbit, measurements are not made to international standards, long term data sets must be stitched together from a series of overlapping satellite observations, orbital drift introduces artefacts into long-term time series, and insufficient attention is paid to meeting the high accuracy, high stability instrument requirements for monitoring global climate change.

To assist space agencies in this challenge, GCOS has defined a series of GCOS Climate Monitoring



Risk of human-induced desertification.

Principles (GCMPs – see Annex B). GCOS notes that for satellite data to contribute fully and effectively to the determination of long-term records, they must be implemented and operated in an appropriate manner to ensure adequate stability and accuracy, and with steps to ensure homogeneous products. The GCMPs require:

- continuity and overlap of satellite observations;
- enhanced orbit control;
- calibration and instrument characterisation;
- sampling strategy;
- sustained generation of products, data analysis, and archiving.

Since most existing Earth-observing satellite systems were not specifically designed for climate monitoring, there is, as yet, no systematic process for the application of the GCMPs. As part of the response to the GCOS IP, CEOS space agencies have undertaken to address this challenge and to assemble the resources and political will required to better coordinate, design, operate, process, store and distribute satellite measurements that satisfy the GCMPs.

Achieving satellite instrument calibration for measuring global climate change.

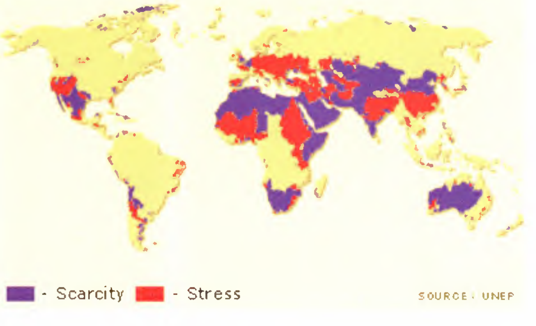
A powerful new paradigm for achieving satellite instrument calibration suitable for measuring long term global climate change has recently emerged. The basic concept is to place in space a series of highly accurate benchmark instruments in order to measure with high spectral resolution the energy reflected and emitted by the Earth. These instruments would provide reliable long term records of climate forcings, response and feedbacks to monitor climate change. Their records would also serve as the validation data needed to test and evaluate climate model predictions. The benchmark instruments would also constitute a reference standard, or calibration observatory, in space that can be applied to other environmental satellite sensors that are not as well calibrated, e.g. the sensors on operational weather satellites. Such calibrations can be performed by comparing coincident observations of the benchmark instruments with the other sensors. These spectral instruments would be joined in space by several other critical benchmark measurements.

The Global Space-based Inter-Calibration System (GSICS) is a new international programme to assure the comparability of satellite measurements provided at different times by different instruments that are the responsibility of different satellite operators. Sponsored by the World Meteorological Organisation and the Coordination Group for Meteorological Satellites, GSICS will inter-calibrate the instruments of the international constellation of operational low Earth orbiting (LEO) and geostationary (GEO) environmental satellites and tie these to common reference standards. The inter-comparability of the observations will result in more accurate measurements for assimilation into numerical weather prediction models, construction of more reliable climate data records and achieving the societal goals of the Global Earth Observation System of Systems (GEOSS). GSICS includes globally coordinated activities for pre-launch instrument characterisation, on-board routine calibration, sensor inter-comparison by collocation of individual scenes or overlap between time series, and use of Earth-based or celestial references, as well as field campaigns. An initial strategy uses highly accurate research satellite instruments as space-based reference standards for inter-calibrating the operational satellite sensors.

Transitioning from science-focused missions to operational services.

If space agencies are to supply the sustained and coordinated observations of the 25 Essential Climate Variables required by the UNFCCC and IPCC, challenges related to the way in which the Earth observation sector is structured must first be addressed. Research space agencies tend to do new things once; operational agencies, whilst adopting new technologies and useful advances as they become available, do more or less the same things over and over. If continuity is to be ensured, more climate variables must be classified and recognised as operational, and made the responsibility of an operational agency or supported as operational in other ways. Wherever possible, operational measurements should be specified so that they satisfy the stated needs of the climate community.

Predicted water scarcity and stress in 2025



In recent years, CEOS agencies have endeavoured to ensure continuity of some key measurements. For example, in ocean surface altimetry, the key agencies (CNES, EUMETSAT, NASA and NOAA) have cooperated to attempt to ensure continuity of measurements so that they may become established as near-operational within some user communities. This remains, however, the exception rather than the rule for research-oriented space agencies, which are neither mandated nor funded to provide operational services. Europe's Global Monitoring for Environment and Security (GMES) programme is a promising example of how this transition might occur, with the emergence of operational services in support of European environmental policy that are being provided through a partnership of the European Commission (EC) and the European Space Agency (ESA). Without such initiatives, the resources and mandates of space agencies as they currently stand will be insufficient to meet UNFCCC needs.

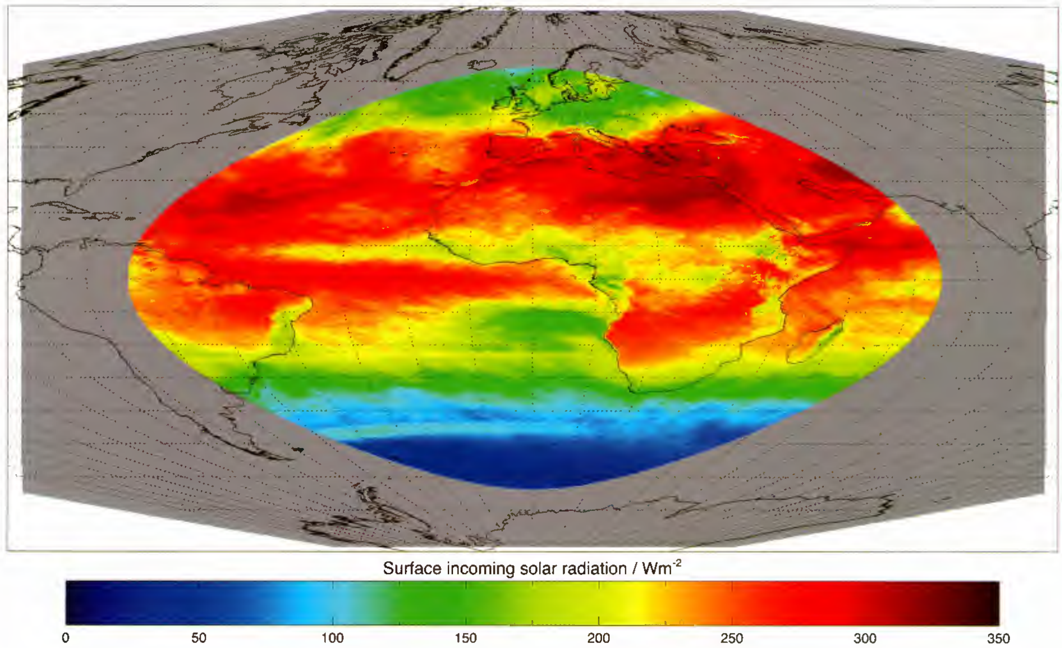
Improving access to existing climate data records generated by satellites.

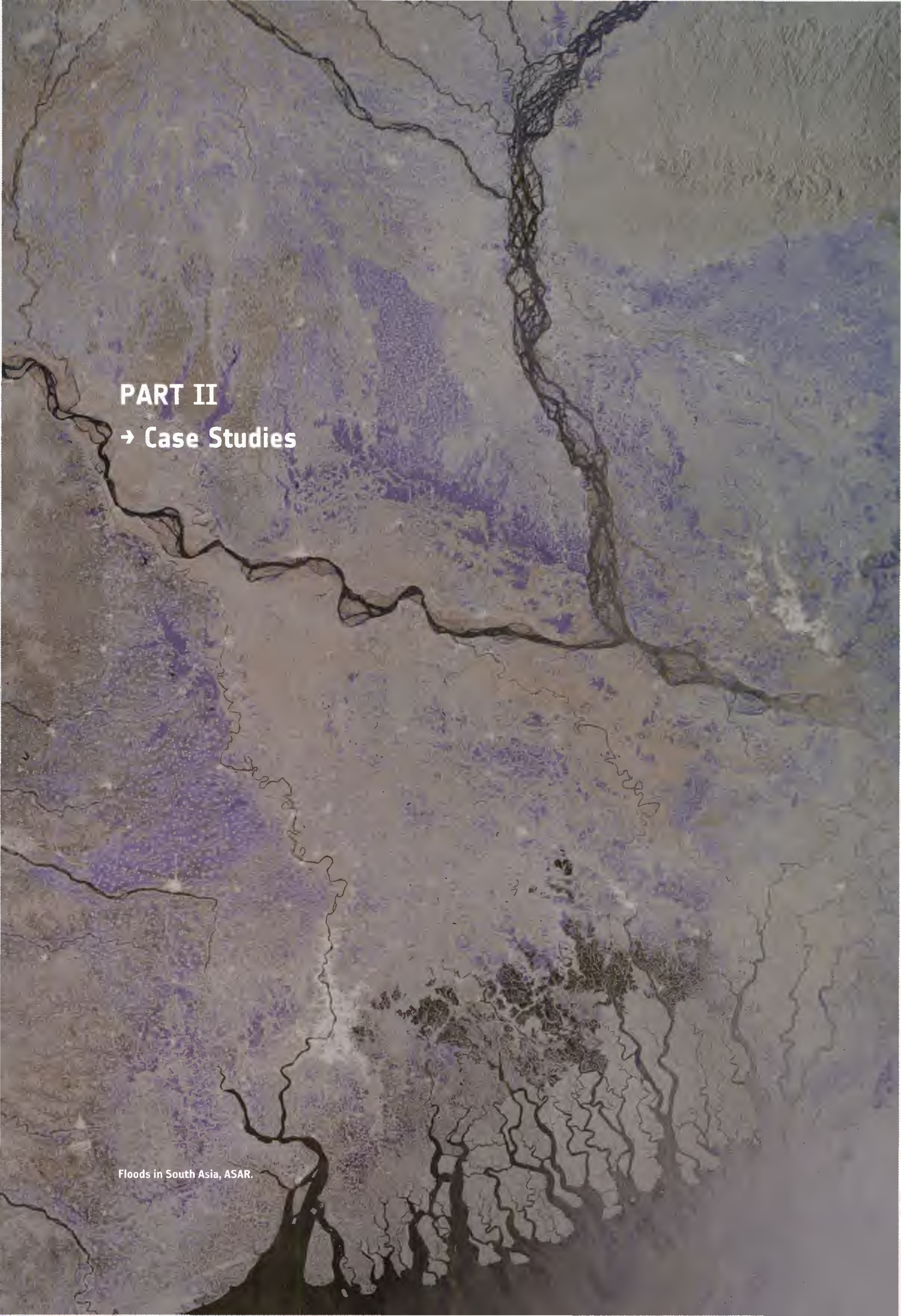
All countries must be able to benefit from the use of climate data records. This is an important issue in relation to products that depend primarily upon satellite observations. While Earth observation from satellites is a costly activity to which only a small number of countries are currently able to contribute, the derived information is generally of global utility. To meet the needs of the UNFCCC, action needs to be taken to allow global access to these products and to ensure their global utility.

Strengthened and rationalised coordination mechanisms.

CEOS is recognised as the primary international forum for coordination of the Earth observation programmes of space agencies worldwide. If space agencies are to mobilise the substantial response demanded by the challenge of both the GCOS Implementation Plan and the GEOSS Implementation Plan, then such a coordination role will be increasingly important. CEOS recognises the need to improve its coordination role and activities above the current 'best efforts' arrangements.

As climate change gains political importance and governments support the GCOS and UNFCCC assessment of the importance of Earth observations in its study and adaptation, we might expect changes in space agency policy, so that their terms of reference recognise improved coordination and climate needs and, not quite so strictly, the current emphasis on defined operational roles or advances in industrial technology. We also might expect a significantly higher priority and resources assigned to the kind of role which CEOS is providing, or has the potential to provide. Further, we should expect political direction for a clear assignment of the roles and responsibilities of the various coordination groups which exist – including CEOS, CGMS (Coordination Group on Meteorological Satellites) and others – to find new levels of efficiency through improved focus and larger critical mass. This is essential if we are to see the improved optimisation of the overall observation strategy required to meet the needs determined by GCOS and GEO.





Floods in South Asia, ASAR.

5 Case Studies – Satellite Observations in Support of Climate Challenges

5.1 Introduction

Part I highlighted the evidence of climate change facing humankind and explained the 'associated risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century' *(The Stern Review)*.

This section explores how Earth observation satellite programmes provide information in support of the 45 Essential Climate Variables needed to detect, monitor, predict, and mitigate climate change in the Earth system.

5.2 Contents

Six different case studies are presented, each focusing on different dimensions of the Earth's climate and showcasing the diverse contributions of satellite Earth observations. The case studies are:

- **Counting carbon**: monitoring the global carbon cycle to help predict, mitigate and adapt to the related climate changes.
- **The big thaw**: measuring the loss of our disappearing glaciers and polar ice caps.
- **Sea level rise**: as the oceans warm and the ice melts, the ocean rises. Satellites are already an indispensable tool in charting the changes.
- **Water security**: with water becoming an increasingly valuable resource and with its supply anticipated to become more erratic, improved management is becoming an important capability. Satellites can help governments in multiple ways.
- **Land surface change**: human action has transformed almost half of the Earth's land surface with significant consequences for biodiversity and climate. Satellites offer unique insights into activities such as deforestation of remote areas.
- **Energy resource management**: in future, energy generation will be more efficient and more sustainable. Satellites can help demand forecasting and planning of renewable energy facilities.

In each case, the issues affecting society and the anticipated future consequences are discussed. The need for information and the role of Earth observation satellites are explained, including an indication of future plans and challenges.

5.3 Counting Carbon

Earth's lights by night.

As explained in Part I, the IPCC noted in 2007 that changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system. Global greenhouse gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. The IPCC concluded that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (over 90% probability) due to the observed increase in anthropogenic (man-made) greenhouse gas concentrations".

The most important of the greenhouse gases associated with global warming is carbon dioxide (CO_2). Other important greenhouse gases include methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs). Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed the pre-industrial values determined from ice cores that span many thousands of years.

Global increases in CO_2 concentrations are due primarily to the burning of fossil fuels such as oil, gasoline, natural gas and coal, with land use change providing another significant but smaller contribution. It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. Methane growth rates have declined since the early 1990s, consistent with total emission (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N_2O concentration is primarily due to agriculture.

Future projections regarding the changing composition of the Earth's atmosphere and the impact this will likely have on its climate, have been briefly outlined in Part I of this document.

The International Response

The adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 was a major step forward in tackling the problem of global warming. Yet, as greenhouse gas emission levels continued to rise around the world, it became increasingly evident that a firm and binding commitment by developed countries to reduce emissions could send a signal strong enough to convince businesses, communities and individuals to act on climate change. As a result, UNFCCC member countries began negotiations on a Protocol, an international agreement linked to the existing Treaty, but standing on its own.

After two and a half years of intense negotiations, the Kyoto Protocol was adopted at the third Conference of the Parties to the UNFCCC (COP 3) in Kyoto, Japan, on 11 December 1997. The Protocol shares the objectives and institutions of the Convention. The major distinction between the two, however, is that while the Convention encouraged developed countries to stabilise greenhouse gas emissions, the Protocol commits them to do so.

Fossil fuel emissions and deforestation play major roles in climate change.

Because it will affect virtually all major sectors of the economy, the Kyoto Protocol is considered to be the most far-reaching agreement on environment and sustainable development ever adopted. However, any treaty not only has to be effective in tackling a complicated worldwide problem, it must also be politically acceptable. Most of the world's countries eventually agreed to the Protocol, but some nations chose not to ratify it. The Kyoto Protocol entered into force on 16 February 2005 and by early 2008 it had been ratified by 174 states.

The Protocol requires developed countries to reduce their greenhouse gas emissions below levels specified for each of them in the UN Treaty. These targets must be met within a five-year time frame between 2008 and 2012, and add up to a cut in greenhouse gas emissions of at least 5% against the baseline of 1990. Review and enforcement of these commitments are carried out by United Nations-based bodies. The Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities". This has two main reasons. Firstly, those countries can more easily pay the cost of cutting emissions. Secondly, developed countries have historically contributed more to the problem by emitting larger amounts of greenhouse gases per person than developing countries.

The Kyoto Protocol sets limits on the emission of six main greenhouse gases:

— carbon dioxide (CO_2);

— methane (CH_4);

— nitrous oxide (N_2O);

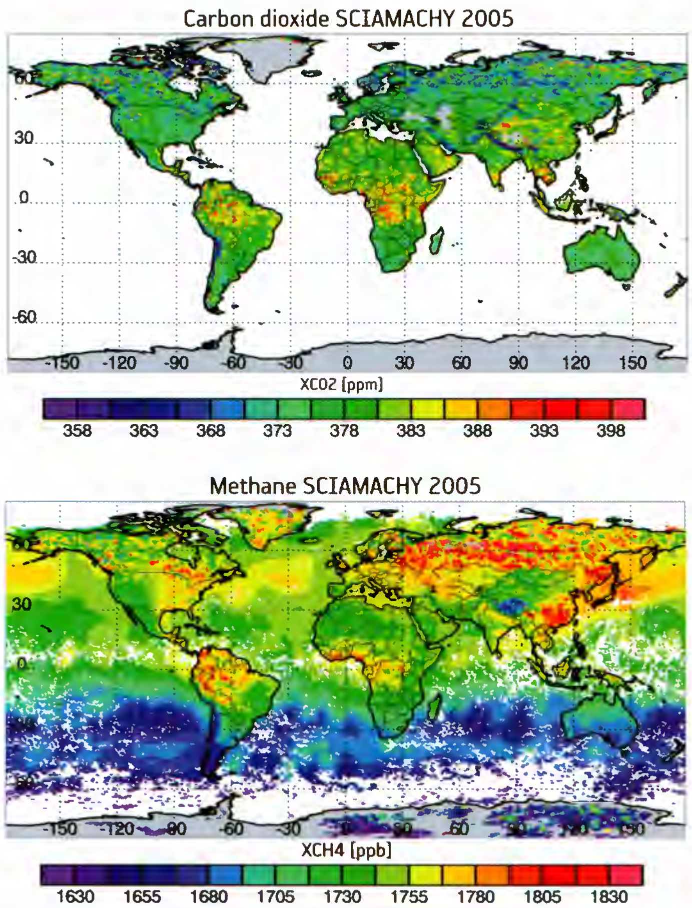
— hydrofluorocarbons (HFCs);

— perfluorocarbons (PFCs);

— sulphur hexafluoride (SF_6).

Some specified activities that emit or remove carbon dioxide from the atmosphere are also covered in the land use change and forestry sector (namely, afforestation, deforestation and reforestation). All changes in emissions and in removals by so-called 'sinks' (absorbers) are considered equivalent for accounting purposes.

The Protocol also establishes three innovative mechanisms, known as 'joint implementation', 'emissions trading' and the 'clean development mechanism'. These are designed to help Parties reduce the costs of meeting their emissions targets by achieving or acquiring emission reductions more cheaply in other countries than at home. The clean development mechanism also aims to assist developing countries to achieve



Satellites already deliver global estimates of greenhouse gas concentrations in our atmosphere.

sustainable development by promoting environmentally-friendly investment in their economies by governments and businesses from industrialised countries.

The Role of Satellite Earth Observations

For mitigation and adaptation to be effective, governments and the private sector need information about past and current climate conditions, including their variability and extremes, as well as sound projections of future conditions – not only on an annual basis but for many decades into the future. Such climate projections depend on the same information for their development and testing. The World Climate Research Programme (WCRP) was established in 1980 to coordinate international research in this domain, in order to determine the extent to which climate can be predicted and the extent of human influence on climate.

The climate system responds to both external forcings and to perturbations of internal processes. This means that it is important to be able to track climate change and variability in such a way that causes can be determined, trends and variability predicted, and appropriate adaptation and mitigation strategies defined for implementation.

As noted in Part I, the Global Climate Observing System (GCOS) prepared an Implementation Plan for the global observing system for climate in 2004, in response to a request from UNFCCC. This Plan, if fully implemented by the Parties to the UNFCCC, both individually and collectively, will provide the global observations of the Essential Climate Variables and their associated products that will assist the Parties to meet their responsibilities under the UNFCCC. In addition, it will provide many of the essential observations required by the World Climate Research Programme (WCRP) and IPCC.

CEOS, as the primary international forum for coordination of space-based Earth observations, responded by submitting to the UNFCCC its plan (comprising over 50 different actions) to help satellites deliver up to 25 of the 45 Essential Climate Variables defined by GCOS. Of the many and varied global observing systems contributing to climate data collection (including instruments at ground stations, on ships, buoys, floats, ocean profilers,

Japan's GOSAT will provide new greenhouse gas monitoring capabilities. (Credit: JAXA) balloons and aircraft), Earth observation satellites providing global coverage and well calibrated measurements will become "the single most important contribution to global observations for climate".

Since the dominant influence on future greenhouse gas trends is widely agreed to be the emission of CO_2 from fossil fuel burning, improved observation and understanding of the global carbon cycle is one of priorities for the forthcoming decades.

Observing the Carbon Cycle

The global carbon cycle spans the three major components of the Earth System: the atmosphere, oceans and land. In each domain, large pools of readily exchangeable carbon are stored in various ways ('pools') in the ocean and on the land surface. Large amounts of carbon (in source or sink 'fluxes') are transferred between the pools over various time periods, from daily to annual and much longer. Although some of the fluxes are very large, the net change over a given time period need not be. For many centuries prior to the Industrial Revolution, the carbon pools were more or less in equilibrium, and the net transfer was close to zero for the planet as a whole.

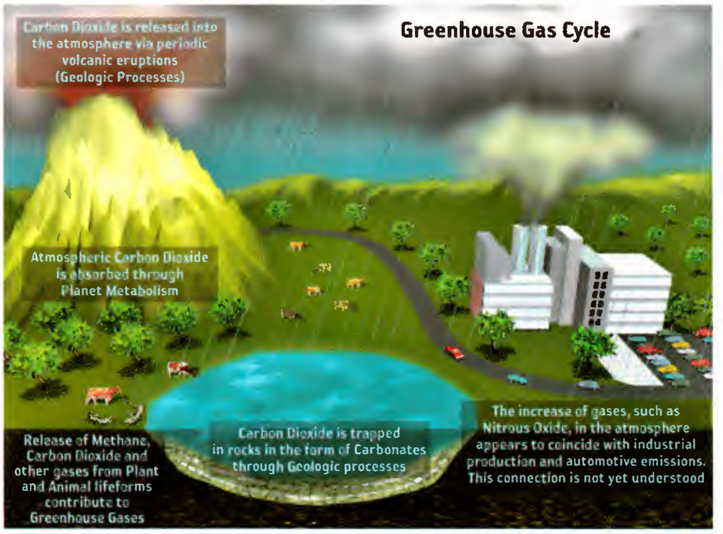
The major changes have occurred following the development of agriculture and industry, with accelerated transfer from the geological (fossil fuels) and terrestrial pools to the atmosphere. Because of the connections between pools, the increased atmospheric carbon concentration affects the oceans and land. The UNFCCC and the Kyoto Protocol represent the first global collaborative attempts by humankind to manage, at least partly, a global element of the Earth System – the carbon cycle. The Kyoto Protocol recognises the role of terrestrial systems as carbon sinks and sources, and it provides a basis for developing future 'emission trading arrangements' that involve forests and, potentially, other ecosystems. Understanding of the pathways through which the anthropogenic CO_2 is absorbed from the atmosphere and transferred to ecosystems (thus offsetting a portion of the anthropogenic emissions) is fragmentary and incomplete. These factors and dependencies make the quantification and study of the carbon cycle very challenging to model, observe, and predict.

This challenge requires the support of a coordinated set of international activities – scientific research (including modelling), observation and assessment. Assessment is perhaps the most advanced, with the pioneering work of the IPCC providing the scientific assessment required for policy action. In terms of scientific research, the International Geosphere-Biosphere Programme (IGBP) has recently joined forces with the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP) to build an international framework for integrated research on the carbon cycle (called the Global Carbon Project).

Coordinated observations of the global carbon cycle, including the land, oceans and atmospheric compartments of the cycle, are being promoted within the IGOS Partnership by the Integrated Global Carbon Observations (IGCO) Theme, now operating within the GEO framework.

The IGCO Theme builds on a number of carbon cycle observation initiatives at the Earth's surface that are underway or planned, including:

- global networks of greenhouse gas measurement stations (such as GLOBALVIEW CO_2) and the WMO World Data Centre for Greenhouse Gases (Tokyo);
- global networks of measurement tower sites that monitor the exchanges of CO_2, water vapour and energy between terrestrial ecosystems and the atmosphere; e.g. the FLUXNET system has over 260 tower sites operating on a long-term, continuous basis;
- measurement ships and arrays of buoys, including the TAO array in the equatorial Pacific;



Greenhouse gas cycle.

— the GEOMON project which aims to sustain and analyse European ground-based observations of atmospheric composition that complement satellite measurements, in order to quantify and understand the ongoing changes. GEOMON is a first step toward building a future integrated pan-European Atmospheric Observing System that will deal with systematic observations of long-lived greenhouse gases, reactive gases, aerosols and stratospheric ozone.

Data from Earth observation satellites provide the only global, synoptic view of key measures of the carbon cycle, forming an essential part of the envisaged integrated observation strategy planned within IGCO.

The major satellite applications include:

— global mapping of land cover use, land cover change and vegetation cover characteristics that are important to full carbon accounting, using sensors such as AATSR, AVHRR, Landsat TM/ETM/ETM+ and MODIS and carried out through the Global Observation of Forest Cover and Land Cover (GOFC-GOLD) project initiated by CEOS;

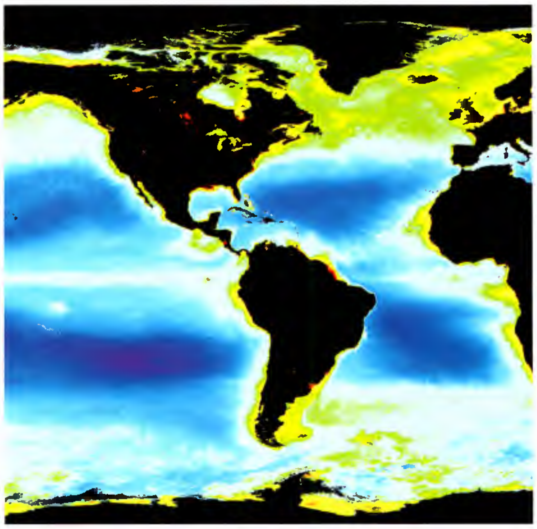
— seasonal growth characteristics, including important parameters such as fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and Leaf Area Index (LAI), are generated on a global scale (e.g. by AVHRR, MODIS, MERIS, and SPOT VEGETATION sensors);

— fire detection and burn scar mapping. In many regions of the world, fires are the most significant destroyer of vegetation, driving large inter-annual variations in carbon emissions from ecosystems. Large fires in forests and grasslands are detected and mapped from space, using thermal and optical sensors. (Radar sensors also show promise for burned area mapping);

— helping to map ocean primary productivity as a major sink of carbon dioxide is a key goal. The global annual cycle of phytoplankton bloom is a vital part of the carbon cycle and is measured by satellites indirectly through measurements of ocean colour. These measurements are calibrated using *in situ* data to give more quantitative assessments, while other colour and pigment measurements add further indications of the ocean ecosystem changes;

Flux towers monitor exchanges of CO_2, water vapour and energy between land and atmosphere.

Fire detection and mapping.



Satellite ocean colour sensors provide important information on the ocean's role in the carbon cycle.

— uncertainty in the land and ocean uptake of carbon and its possible change is of great importance and satellites are set to play a major part in monitoring these changes via CO_2 fluxes. The air/land and air/ocean CO_2 flux is key but it can only be measured directly at a few research class, *in situ* measurement locations. Satellites contribute in many ways to estimating these fluxes indirectly. First a great range of satellite data now provide, especially over the ocean, a major input to atmospheric data analysis and reanalysis that gives the best possible description of the atmosphere. This analysis process, especially the reanalysis of delayed mode data, is now including satellite measurements of both column CO_2 and vertical profiles of CO_2. This work is still in a research phase at centres like The European Centre for Medium-Range Weather Forecasts (ECMWF) and it is expected that, in the future, the regional sources of CO_2 will be able to be monitored this way over both land and sea.

Another key role for satellites relates to monitoring of the Kyoto Protocol's 'carbon trading' mechanisms, especially the Clean Development Mechanism (CDM). Existing archives of moderate resolution satellite land imagery (e.g. from Landsat and SPOT) provide the capacity for determining eligibility of CDM reforestation projects by confirming compliance with the Kyoto Protocol's rule that any proposed forestry project must be able to prove that the site "did not contain forest on 31st December 1989". The same technologies can also provide geographically explicit land use data for national inventory reports concerning carbon sinks. In addition, they provide important information in trade-offs and conflicts between mitigation/adaptation carbon initiatives involving present land use (including forestry), changes in land use over time, and long-term sustainable development strategies.

Future Challenges

Within the next few years, scientists are hopeful of an extraordinary and unique revolution in global monitoring of atmospheric CO_2 concentrations, sources, and sinks, taking advantage of space-based, high-precision measurements of column-integrated CO_2 molecular density with global, frequent coverage.

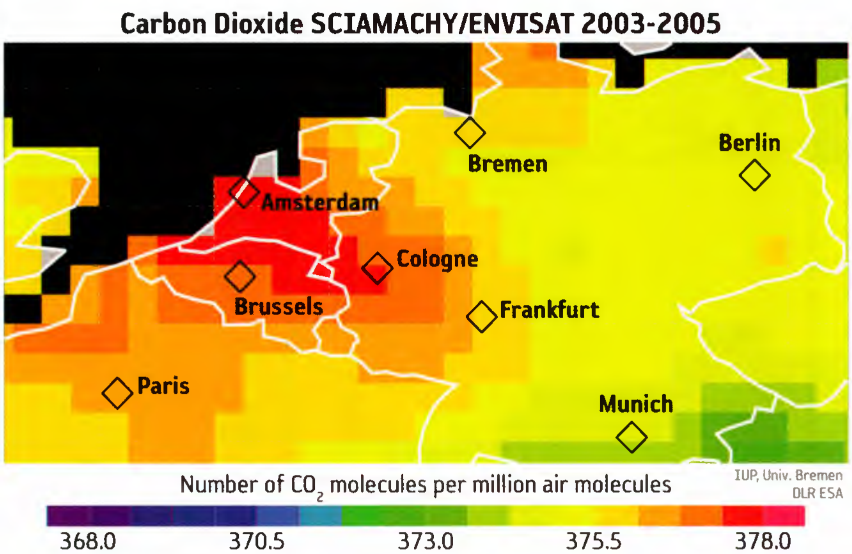
The precision requirements for such measurements are extremely taxing, requiring concentrations as low as 0.3% (1 ppm) to be achieved in order to accurately characterise carbon sources and sinks. A number of new missions, specifically dedicated to this challenge, are being planned to provide the first such data. NASA will launch the Orbiting Carbon Observatory (OCO) in 2008. This two-year mission is seen as a pathfinder for future, long-term CO_2 monitoring missions, using measurements of reflected sunlight in the short-wave infrared to provide global, high-precision measurements of the column-integrated CO_2 mixing ratio. A second satellite, provided by JAXA, also aims to provide information on CO_2. GOSAT (Greenhouse gas Observing Satellite) will also be launched in 2009.

In the interim, scientists continue to make advances in the retrieval of CO_2 information from atmospheric sounding instruments. Examples are the interpretation of hyperspectral observations by AIRS on NOAA polar orbiting satellites, IASI on EUMETSAT's MetOp satellite, and data from atmospheric chemistry instruments such as SCIAMACHY on Envisat.

Part of the future challenge will be to support a monitoring system that is suitably accurate, robust and sustained. This would effectively support the implementation process by assisting the national reporting of agreed information related to protocols and of independent, policy neutral, information that ensures that the effectiveness of the measures can be established. It will also support the monitoring of treaties such as the Kyoto Protocol. For Earth observation satellites this will require a move from research to operational status to support international policy frameworks.

The necessary coordination of the satellite missions will be undertaken by CEOS. Recognising the importance of continuity of observations of the atmosphere and its composition, CEOS has established an Atmospheric Chemistry Constellation team. Its objective is to collect and deliver data to improve predictive capabilities for coupled changes in the ozone layer, air quality and climate forcing associated with changes in the environment.

Part III of this document summarises the plans of the world's space agencies for the necessary observations.



Using data from the SCIAMACHY instrument on Envisat, scientists have for the first time detected regionally elevated atmospheric carbon dioxide.

Further Information

Global Carbon Cycle (Woods Hole Research Center): www.whrc.org/carbon/index.htm

UNFCCC and Kyoto Protocol: www.unfccc.int

Global Carbon Project: www.globalcarbonproject.org

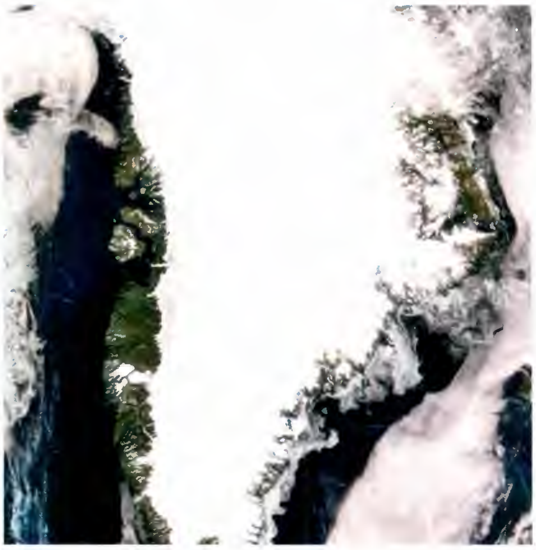
IGCO Theme: www.igospartners.org/Carbon.htm

OCO: oco.jpl.nasa.gov

GOSAT: www.jaxa.jp/projects/sat/gosat/index_e.html

UNFCCC REDD: unfccc.int/methods_and_science/lulucf/items/3896.php

5.4 The Big Thaw



Greenland.

Ice plays an important role in the regulation of the Earth's climate in a number of ways:

- a certain percentage of the solar radiation reaching the Earth's atmosphere and surface is reflected back out to space. The percentage of sunlight that is reflected depends on the albedo (reflectivity) of the surface. Ice and snow have a high albedo and hence reflect about 80% of incident sunlight. Once formed, ice tends to be maintained. However, if ice cover decreases, less solar radiation is reflected from the surface of the Earth and, as a result, the atmosphere absorbs more heat;
- each year, the Arctic and the Antarctic Oceans experience the formation and then melting of vast amounts of floating sea ice. At the North Pole, an area of ice the size of Europe melts away every summer and then freezes again the following winter. The thickness of this sea ice plays a central role in polar climate as it moderates ocean-atmosphere heat exchange by insulating the ocean from the cold polar atmosphere;
- the distribution and duration of seasonal growth and melt of polar sea ice have a significant effect on the global ocean circulation pattern – known as thermohaline circulation. As the ice melts, causing an influx of fresh water into the surrounding ocean, the salinity and density of the water decrease. Conversely, as ice is formed, the salinity and density of the surface water increase. This causes the surface waters to sink, effectively driving deep ocean currents from the polar regions towards the equator. This outflow is balanced by a surface inflow of warmer, less dense water masses from low to high latitudes. The Gulf Stream, which carries warm surface water northwards from the Gulf of Mexico to the sub-polar latitudes east of Greenland, is extremely important in moderating the climate in Europe; the coastal waters of Europe are 4°C warmer than waters at the equivalent latitude in the North Pacific. However, the warm waters of the Gulf Stream cool and sink as they reach the Arctic. If this circulation pattern is disturbed in future by a dramatically reduced cover of seasonal Arctic sea ice, this may have a profound effect on the strength or direction of the Gulf Stream. It is, therefore, apparent that an improved knowledge of the fluxes of sea ice in the Arctic and their consequences for the thermohaline circulation is important for the prediction of Europe's climate, and would have global implications.
- continental ice has an impact on sea level. The ice sheets covering Antarctica and Greenland amount to about 28 million km^3, which means that the sea level is about 65 m lower than it would be if all this ice melted. There are indications that changes are occurring at the margins of the ice sheets and it is these apparent changes that need to be quantified.

On a smaller but no less important scale, glaciers play a significant role in regional hydrology and climate, since evidence suggests the majority of the world's glaciers are currently undergoing melting. Almost 80% of the Earth's fresh water is locked up in the cryosphere (snow, ice and permafrost). The IPCC's recent 4th assessment (discussed in Part I of this document) indicates that melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually affecting one-sixth of the world's population – predominantly in the Indian sub-continent, parts of China, and the Andes of South America.

Given the important influence of the cryosphere on the climate system, and its predicted impacts on sea level, global warming, ocean circulation and freshwater availability, a thorough understanding of the state of the cryosphere is central to our ability to predict and adapt to climate change.

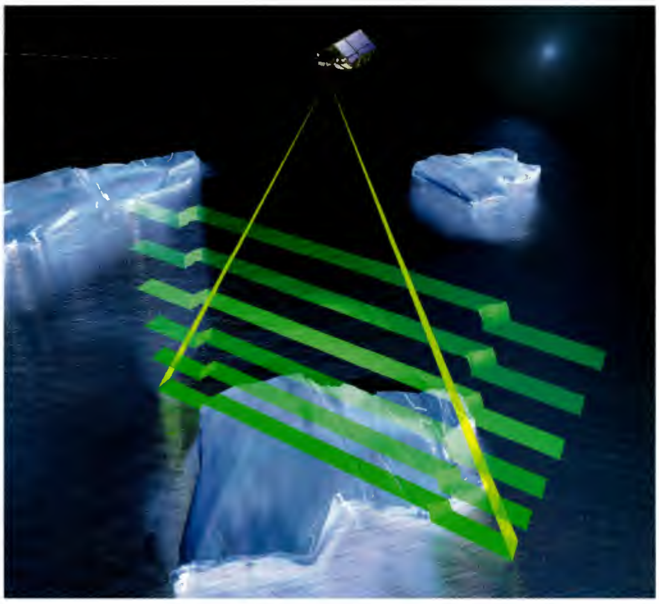
The Role of Satellites

The long-term, wide-area observations carried out by Earth observation satellites provide authoritative evidence of trends in the cryosphere – including glaciers and the polar ice caps – and enable estimation of the consequences should melting continue into the future. The poles are amongst the Earth's most inaccessible areas, so obtaining measurements of sea ice was difficult before the advent of satellites.

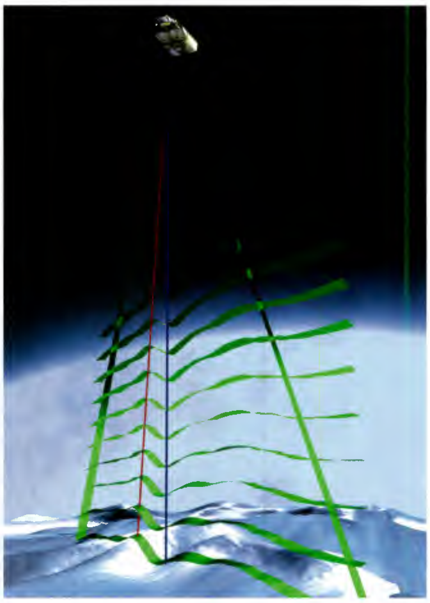
Since the 1970s, routine, all-weather, day-and-night, (passive microwave) observations, supported by available visible imagery and estimates of air temperature from weather forecasting models, have contributed to climate data records. They have revealed a dramatic decline of about 3% per decade in Northern Hemisphere sea ice cover. More recently, scatterometer instruments on European, American and Japanese satellites have augmented the passive microwave records. Together with buoy data, they have been used to monitor ice drift, and to understand seasonal to interannual variations in sea ice growth and melt processes.

For the ice sheets and glaciers, key sensors have been synthetic aperture radar (SAR) and satellite altimeters, with major contributions from the 14-year record provided by the ERS-1, ERS-2 and Envisat satellites. SAR has been used to map the ice sheets with unprecedented detail and has demonstrated the impact of streaming ice flow for the regional ice sheet mass balance, as well as the critical importance of the rate of ice stream flow and ice shelf decay to the overall stability of the large ice sheets.

In conjunction with SAR observations, altimeter time series have characterised seasonal to inter-annual changes in ice sheet elevation and topography over moderately sloping regions from basin to continental scale. These data indicate that, although the central parts of the large ice sheets appear stable and in balance, dramatic



CryoSat is able to measure the freeboard (height by which the ice rises above the water surface) of floating sea ice with its sensitive altimeter. From the freeboard, the ice thickness can be estimated if the density of the sea ice is known.



Over topographic surfaces, the first radar echo comes from the nearest point to the satellite. CryoSat can measure the angle from which this echo originates, so that the source point can be located on the ground. This, in turn, allows the height of that point to be determined.

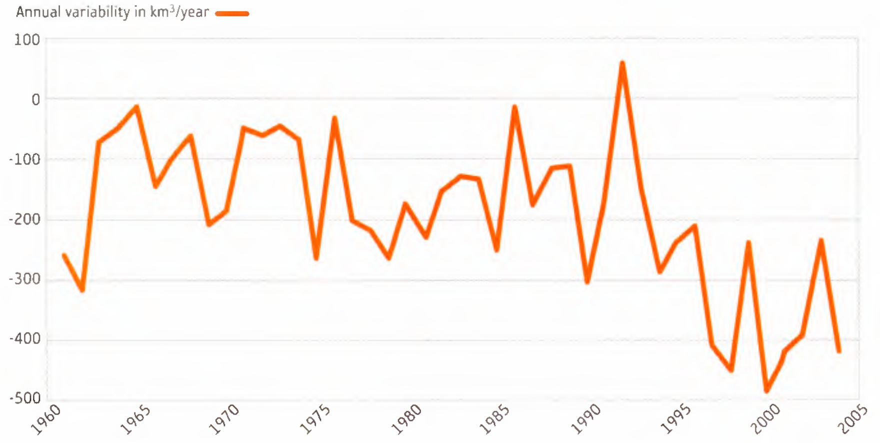
changes are taking place around their more dynamic margins, in particular around the West Antarctic ice sheet and Greenland. The dramatic disintegration of ice shelves, such as the Larsen shelf in Antarctica, indicate that the ice sheet and ice shelf dynamics may be considerably more sensitive to short-term climate fluctuations than formerly believed.

The combination of SAR and satellite altimetry is helping to determine the mass balance of ice sheets, although not yet to the level required to be confident about their overall stability. New insights are also being provided by the satellite gravity surveys of the Gravity Recovery and Climate Experiment (GRACE) mission, which provides separate estimates of ice mass. Additional information, such as ice thickness, is needed to advance the knowledge of ice flow dynamics.

Satellites observe the rapid decrease in glacier area worldwide, but better data on mass balance and volume changes are needed to fully understand the climate response and their impact on hydrology and water resources.

The long-term passive microwave records, and the more recent scatterometer and SAR data, indicate that snow seasonally covers up to 30% of the land surface. Snow cover changes therefore exert a large influence on both the radiation and freshwater balances. As global warming proceeds, it is predicted that regions currently experiencing snowfall will increasingly receive precipitation in the form of rain, and for every 1°C increase in temperature the snowline will rise by about 150 metres. Perennially frozen ground (i.e. permafrost) is estimated to underlie 24% of the exposed Northern Hemisphere land area. Permafrost has an important regulative function on the exchange of carbon and other gases between the land and the atmosphere. Fluxes of gases from northern ecosystems represent a highly uncertain contributor to future global change, and *in situ* observations suggest that global warming will strongly modify these fluxes. The wet lowlands of the Arctic permafrost landscapes, for example, are important natural sources of the greenhouse gas methane. Recent satellite observations have detected accelerated melting of Siberian bogs, which may unleash significant amounts of methane, thereby amplifying global warming. Continuous observations of permafrost extent and characteristics are needed to assess the role of the permafrost regions in climate change. Scatterometers and SAR have been used to observe the characteristics of permafrost areas, but more systematic observations at high spatial resolution are needed.

Given the significance of the cryosphere in our study of the Earth's climate, both ESA and NASA have sought to provide specialised cryosphere satellite missions in recent years. The ICESat (Ice, Cloud, and Land Elevation Satellite) mission, part of NASA's Earth Observing System, measures ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics. ICESat was launched in January 2003 and designed to operate for three to five years. Problems with the laser sensor mean that the satellite now provides observations for one month out of every 3–6 months in order to extend the time series of measurements, particularly for the ice sheets. The European CryoSat mission was lost as a result of a launch failure in October 2005. Due to the importance of the scientific goals of this satellite, there was enormous support for re-flying the mission and CryoSat-2 was approved by ESA in 2006.



Source: adapted from Dyurgerov and Meier 2005

Global glacier mass: annual variability and cumulative values.

Future Challenges

The overriding objectives are to quantify the impacts of climatic variability and change on the cryosphere, and to assess the consequences of these changes for the climate system and the environment as a whole. Although satellite observations have revealed significant changes taking place to the cryosphere, the attribution of these changes to either anthropogenic or natural causes remains unclear. Key measurements are not yet available, which limits our ability to characterise the overall behaviour of major elements of the cryosphere and to assess the nature of its interaction with the oceans, atmosphere and terrestrial systems.

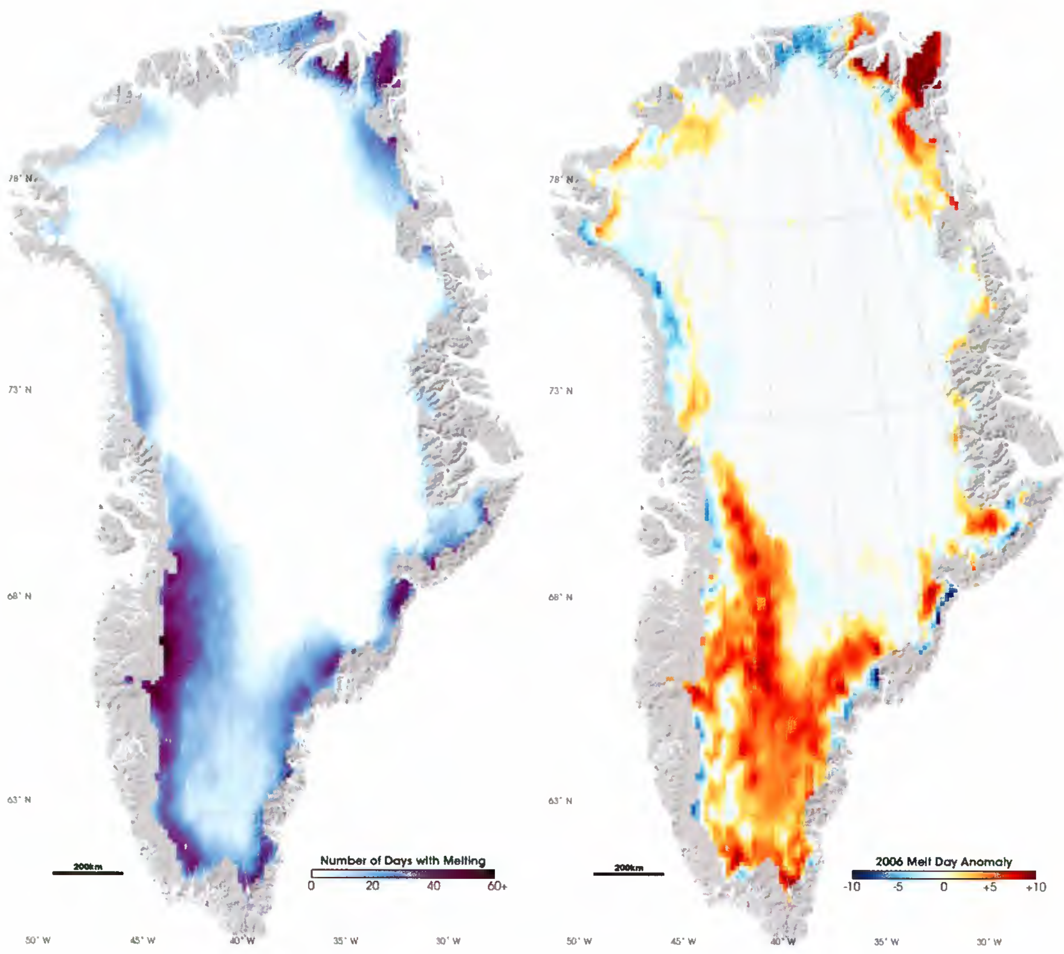
Particular observational challenges include:

— the mass, freshwater balance and distribution of sea ice, as well as current and possible future feedbacks to the ocean and atmosphere;

— the mass balance of ice sheets, ice caps and glaciers, to assess their contribution to sea level, and to evaluate their sensitivity to forcing;

— changes in snow water equivalent and solid precipitation, and their impacts on the global hydrological cycle and regional water resources.

Continuous, uniform, long-term monitoring observations are the key to assessing the response of the global cryosphere to climatic variations. Due to large year-to-year variations in seasonal signals, the

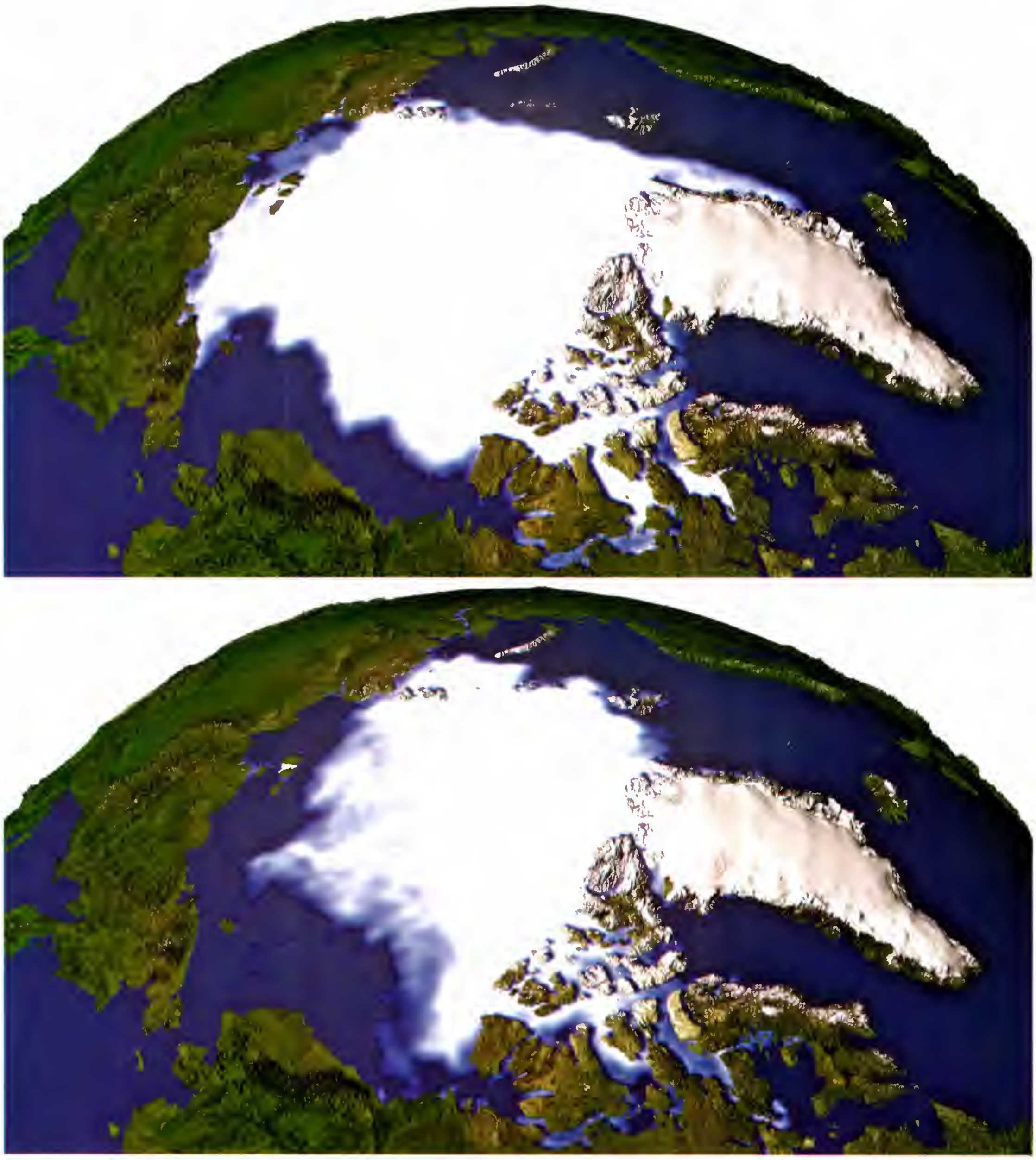


Maps based on satellite imagery showing the number of days in 2006 when melting occurred.
The dark blue areas had the most days of melting.
The number of days when melting took place in 2006 was more than the average between 1988 and 2005.
The dark red areas indicate the number of days above the average.
(Credit: NASA/Robert Simmon and Marit Jentoft-Nilsen)

duration of monitoring records has a critical impact on the certainty with which trends can be assessed. Meanwhile, high resolution temporal and spatial observations are needed to characterise rapid variations in snow and ice in response to surface processes.

To address these observational requirements effectively, a combination of routine, broad swath, low resolution, global monitoring instruments (microwave and optical) and specialised, high resolution, narrow swath data are required. New findings from current and forthcoming satellite observations, combined with more routine observations from present and future SAR, scatterometer and passive microwave missions, will advance our ability to sustain the optimum satellite observing system for the cryosphere.

The IGOS Cryosphere Theme is a combined initiative of the World Climate Research Programme (WCRP) Climate and Cryosphere (CliC) Project and the Scientific Committee on Antarctic Research (SCAR). The Theme creates a framework for improved international coordination of cryospheric observations that will result in a more comprehensive, coordinated, and integrated cryosphere observing system. It will facilitate the flow of data and information in



Comparison of sea ice from 1979 and 2003.

cryospheric research, long-term scientific monitoring, and operational applications. Many recommendations of the Cryosphere Theme will be implemented as part of the Group on Earth Observations (GEO) work plan. The 15 th WMO Congress in May 2007 approved the proposal to initiate the establishment of a Global Cryosphere Watch, based on IGOS Cryosphere recommendations.

The International Polar Year is a large scientific programme focused on the Arctic and Antarctic from March 2007 to March 2009. IPY, organised through the International Council for Science (ICSU) and the World Meteorological Organisation (WMO), is actually the fourth Polar Year, following those in 1882–3, 1932–3, and 1957–8. In order to have full and equal coverage of both the Arctic and the Antarctic, IPY 2007–8 actually covers two full annual cycles from March 2007 to March 2009 and involves over 200 projects, with thousands of scientists from over 60 nations examining a wide range of physical, biological and social research topics.

CryoSat-2

CryoSat-2's planned three-year mission is to survey natural and human-driven changes in Earth's cryosphere. It is designed to provide much more accurate data on the rate of change of the surface elevation of the polar ice sheets and sea ice thickness. From a near-polar orbit of just over 700 km altitude that reaches latitudes of 88°, CryoSat-2 will monitor precise changes in the thickness of the polar ice sheets and floating sea ice, hopefully providing conclusive evidence of the rates at which ice cover is diminishing.

Fundamentally, there are two types of polar ice – marine ice that grows and floats in the oceans and the ice that lies on land. Not only does the melting of these forms of ice have different consequences for our planet and its climate, they also pose different challenges when trying to measure them from space.

Floating sea ice is relatively thin – up to a few metres thick – but it influences regional temperature and the circulation of ocean currents, and consequently the Earth's climate. CryoSat-2 will acquire precise measurements of the thickness of floating sea ice so that annual variations can be detected.

In contrast, the ice sheets that blanket Antarctica and Greenland are several kilometres thick. It is the growth and shrinkage of these ice masses that have a direct influence on sea level. The chosen approach to measuring these vast thicknesses is to determine the height of the surface accurately enough to detect small changes. The current constraints will be overcome with the altimeter designed for CryoSat-2, which exploits sophisticated radar techniques to improve resolution and observing capabilities.

The primary instrument is the SIRAL (SAR / Interferometric Radar Altimeter). SIRAL operates in one of three modes, depending on the type of surface over which the satellite is flying. Over the oceans and ice sheet interiors, CryoSat operates like a traditional radar altimeter. Over sea ice, transmitted echoes are combined (using synthetic aperture processing) to reduce the surface footprint so that smaller ice floes can be mapped. The most advanced mode is for the ice sheet margins and mountain glaciers, when the altimeter performs synthetic aperture processing and uses a second antenna to determine the across-track angle to the earliest radar return. This provides the precise location of the area being measured when the surface is sloping.

The current target launch date for CryoSat-2 is late 2009.

Further Information

CryoSat & CryoSat-2: www.esa.int/SPECIALS/Cryosat/

IGOS Cryosphere Theme: cryos.ssec.wisc.edu

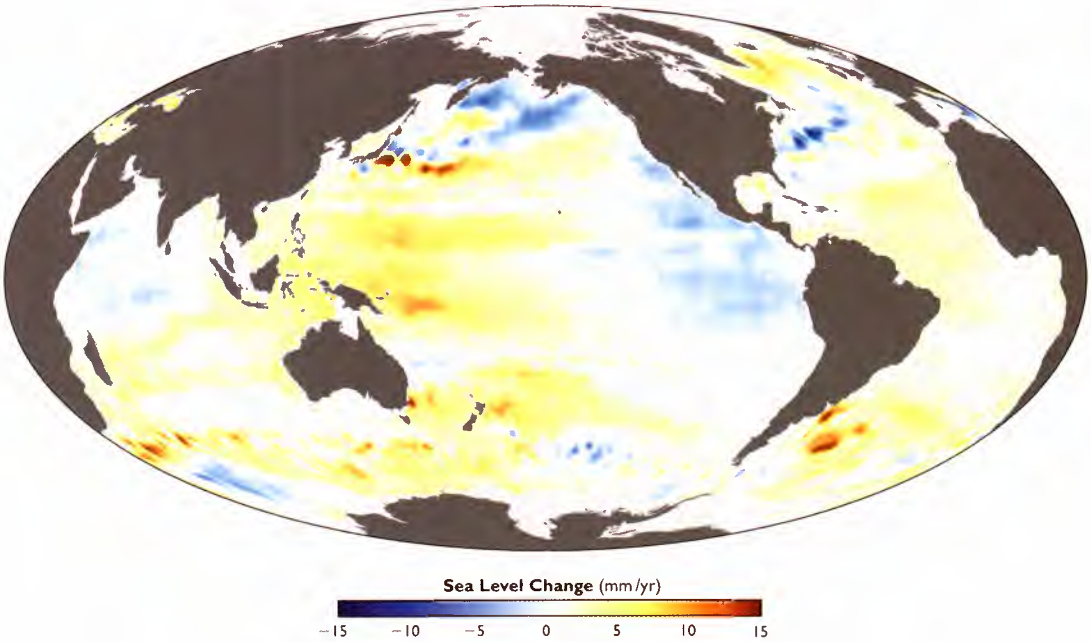
International Polar Year: www.ipy.org

NASA ice studies: www.nasa.gov/centers/goddard/news/topstory/2003/1023esuice.html

5.5 Sea Level Rise

Since the beginning of high-accuracy satellite altimetry in the early 1990s, global mean sea level has been shown by both tide gauges and altimeters to be rising at a rate of just above 3 mm/year, compared to a rate of less than 2 mm/year from tide gauges over the previous century. The exact source of the accelerated rise is uncertain, but, with regard to future uncertainty, attention is being given to understanding the rate of loss of ice caps in Greenland and Antarctica. About half of the sea level rise during the first decade of the altimeter record can be attributed to thermal expansion due to a warming of the oceans; the other major contributions include the combined effects of melting glaciers and ice sheets. Changes in the storage of water on land (such as the depletion of aquifers and increases in dams and reservoirs) remain very uncertain.

The coastal zone changed profoundly during the 20th century, primarily due to growing populations and increasing urbanisation. In 1990, 23% of the world's population (or 1.2 billion people) lived within 100 km of the coast and no more than 100 m above sea level,with population densities about three times higher than the global average. By 2010, 20 out of 30 mega-cities will be on the coast, with many low-lying locations threatened by sea level rise. With coastal development continuing at a rapid pace, society is becoming increasingly vulnerable to sea level rise and variability – as Hurricane Katrina recently demonstrated in New Orleans. (The storm surge and high precipitation associated with hurricanes mean that they are likely to be early indicators of the effects of future sea level rise). Rising sea levels will contribute to increased storm surges and flooding, even if hurricane intensities do not increase in response to the warming of the oceans. Rising sea levels will also contribute to the erosion of the world's sandy beaches, 70% of which have been retreating over the past century. Low-lying islands, such as coral atolls, are also vulnerable to sea level rise.



Sea level change 1993-2006 from satellite altimeters. (Credit: Edmisten, Univ. S. Florida)

An improved understanding of sea level rise and variability will help reduce the uncertainties associated with future sea level projections, thus contributing to more effective coastal planning and management. Adaptation measures, including enhanced building codes, restrictions on where to build, and developing infrastructures better able to cope with flooding, should help to minimise the potential losses.

The Third and Fourth IPCC Assessments

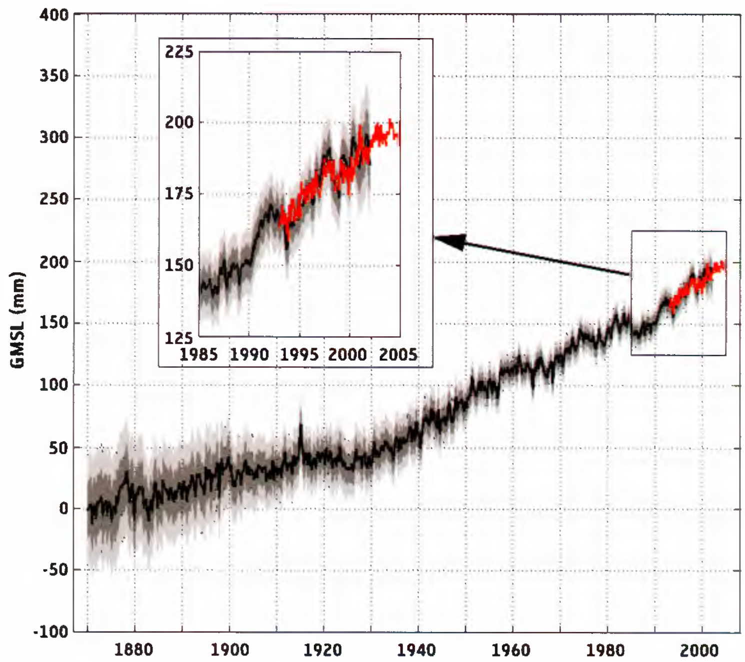
The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), published in 2001, estimated that sea level would rise between 9 and 88 cm by the end of the 21st century. The Fourth Assessment Report (AR4) released in 2007 refined this projection, with projected values between 18 and 59 cm. But this latest projection is thought to be very conservative, as it assumes a constant rate of ice flow into the oceans from Greenland and Antarctica, while there is now evidence that this rate may well be increasing.

Participants in a dedicated Workshop, held at IOC/UNESCO in Paris 6–9 June 2006, reached a consensus that the increase in the rate of global mean sea level rise towards the end of the 20th century, from less than 2 mm per year to just above 3 mm per year over the previous century, is a robust finding. However, a thorough review of current knowledge concerning all aspects of sea level rise still shows deficiencies. Sustained series of space-based and *in situ* observations and associated research are needed to determine uncertainties in knowledge of the contributing factors and subsequently reduce those uncertainties.

Historical and Present Sea Level Change

Beginning in 1992, global mean sea level has been observed by both tide gauges and satellite altimeters to be rising at a rate of 3.2 ± 0.4 mm/year, compared to a rate of 1.7 ± 0.3 mm/year from tide gauges over the previous century. The question is now raised as to what extent this increase in the global mean represents an actual acceleration.

Solving this question requires extending the Jason series of satellite altimeters for a second decade in order to resolve the spatial and temporal variability, as well as acceleration, in the rate of global sea level rise. These data will need to be completed by a corresponding enhancement of the Global Sea Level Observing System (GLOSS) network of approximately 300 gauges, each with high frequency sampling and real-time data availability. Gauges should be linked to absolute positioning wherever possible to enable an assessment of the coastal signatures of the open ocean patterns of sea level variability and the incidence of extreme events, as well as the calibration of satellite altimeters.



Monthly averages of global mean sea level reconstructed from tide gauges (black, 1870-2001) and altimeters (red, 1993-2004) show an increase in the rate of sea level rise; the seasonal cycle has been removed.

Thermal Expansion

Current estimates of thermal expansion account for approximately half of the change observed in global mean sea level rise over the first decade of the satellite altimeter record, but only about a quarter of the change during the previous half century. However, it is still necessary to ascertain the extent to which this reflects under-sampling of ocean temperature data versus a manifestation of enhanced climate change in the last decade.

The recent completion of the Argo array of 3,000 profiling floats will help obtain broad-scale, upper ocean (from surface to 2000 m depth) observations of the temperature and salinity fields. The Argo system is still in need of being sustained in the long term, and of having its capability extended in order to enable the collection of similar observations under the sea ice.

Cryosphere

As noted in the previous case study, terrestrial glaciers and the Greenland and Antarctic ice sheets have the potential to raise global sea level many metres. Most of the world's terrestrial glaciers are shrinking. During the last decade, they have been melting at about twice the rate of the past several decades. On the polar ice sheets, there is observational evidence of accelerating flow from outlet glaciers, both in southern Greenland and in critical locations in Antarctica. Once launched, the CryoSat-2 radar altimeter satellite – complemented by aircraft altimetry – and appropriate follow-on missions will be very useful to survey changes in the surface topography of the ice sheets. The Gravity Recovery and Climate Experiment (GRACE) satellites and appropriate follow-on missions will also help infer changes in the mass of the glaciers and ice sheets. Continued access to satellite Interferometric Synthetic Aperture Radar (InSAR) data will assist in the measurement of flow rates in glaciers and ice sheets, particularly over near-coastal regions of Greenland and Antarctica.

Terrestrial Water Storage

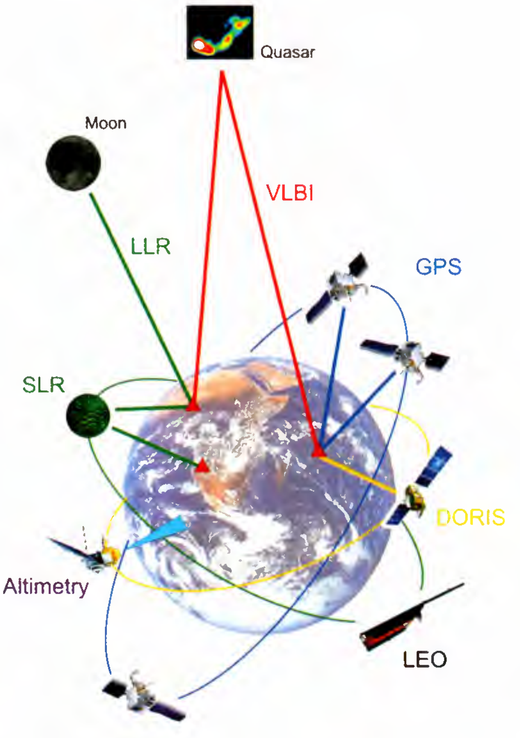
The IPCC Assessment Reports noted that the largest uncertainties in contributions to sea level rise are associated with terrestrial water storage. To significantly reduce these uncertainties requires a combination of satellite observations, which provide finer resolution, broader coverage and longer duration, and appropriate *in situ* data.

GRACE data can be utilised to observe changes in land water storage. After its launch in 2009, ESA's Soil Moisture and Ocean Salinity (SMOS) spacecraft will help observe changes in soil moisture. Current (Jason and Jason-2, Envisat, and GFO) and future (SARAL/Altika, HY-2, Jason-3, Sentinel-3) satellite altimeters will help observe river, lake and reservoir levels along the satellite ground tracks. An advanced wide-swath altimeter is needed to observe the two-dimensional surface water levels on land and their changes in space and time.

Geodetic Observing Systems

The development and implementation of geodetic techniques has enabled a revolution in the Earth sciences, providing the fundamental reference frame critical for the collection of all satellite observations and many others made *in situ* that address sea level rise and variability. However, to take advantage of those capabilities, they must be reliable and consistent over the long term (i.e. decades). While these techniques collectively define the International Terrestrial Reference Frame (ITRF) being brought together through the efforts of the Global Geodetic

Increases in dam and reservoir storage can reduce the rate of sea level rise.



Integrating existing geodetic capabilities can provide an improved reference frame.

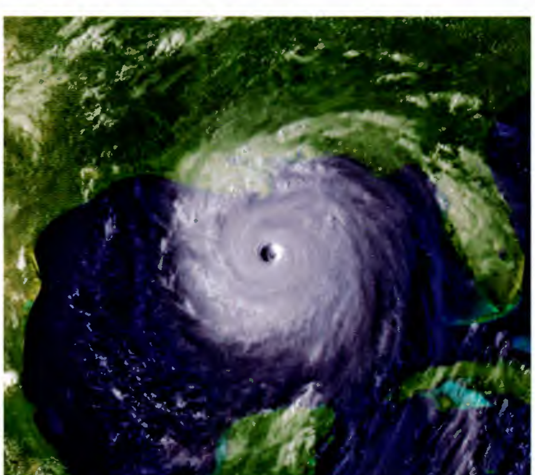
Observing System (GGOS), they are at the same time losing support and degrading in capability.

Updating and integrating complementary geodetic capabilities (SLR, VLBI, DORIS and GPS) into a reliable and consistent global geodetic ground and space network (co-locating them where possible) is now needed. This has to be complemented by installing GPS positioning at all appropriate GLOSS tide gauge stations to determine changes in global and regional sea level, as well as developing an integrated geodetic modelling capability that can be combined with Earth science models.

Once launched, the observations of Earth's time-invariant gravity field from ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) will be utilised to determine the precise geoid, thereby enabling an estimation of the absolute ocean circulation for constraining climate models, as well as an improvement in understanding geophysical processes related to sea level.

Surface Mass Loading

The main mass loads considered here are the great ice sheets, which covered large areas during the last glacial maximum. The Earth is still responding to the removal of those loads through subsequent melting. In addition, changes in the present ice sheets, glaciers, ice caps and terrestrial storage result in ongoing changes in surface loading. Uncertainties in models of Glacial Isostatic Adjustment (GIA) caused by uncertainties in modelled vertical land movements affect sea level measurements by tide gauges. These uncertainties also impact satellite altimeter measurements of sea level and measurements of changes in surface loads



A warmer ocean may contribute to more intense hurricanes.

(including sea level and ice sheet mass balance) made by temporal gravity missions such as GRACE. Other changes in mass loads include those associated with tectonic activity, such as earthquakes, as well as local extraction of water and hydrocarbons.

Measurements from tide gauges equipped with a capability for absolute positioning, together with observations from satellite altimetry, gravity, GPS, and other datasets, can improve models of past ice sheet loading and glacial isostatic adjustment that are used to estimate sea level change.

Extreme Events and Impacts on Society

Global sea level rise will have a pervasive impact by raising the mean water level, on top of which must be added the combined effect of high tides, surface waves, storm surge, and flooding rivers. This will make the incidence of flooding to a given level more frequent, i.e. a 100-year coastal flooding event may become a 10-year event at some locations. Unless such change is taken into account, design criteria for existing coastal structures can become out of date and lead to catastrophic flooding such as that experienced in New Orleans with Hurricane Katrina. Moreover, the possibility that severe weather events may become more frequent and/or intense with our changing climate will only make matters worse. There is a need to convert current knowledge of sea level rise into easily understood information that can be used by coastal planners and engineers, emergency managers, insurers and the public at large.

Requirements for a Space-based Observing System for Sea Level Rise

Improving our understanding of sea level rise and variability, as well as reducing the associated uncertainties, depends critically on the availability of adequate observations. The WCRP workshop (http://wcrp.ipsl.jussieu.fr/Workshops/SeaLevel/) helped develop international scientific consensus for those observational requirements needed to address rising sea level and its variability. These requirements include sustaining existing systematic observations, as well as the development of new and improved observing systems.

An overarching observational requirement is the need for an open data policy, together with timely, unrestricted access for all. This access would include real-time, high-frequency sea level data from the GLOSS tide gauges and co-located GPS stations, as well as data from satellite missions and *in situ* observing systems. Further requirements include the need for access to data archives — retrieving and making accessible historical, paper-based sea level records, especially those extending over long periods and in the Southern Hemisphere. Moreover, comparable satellite observations need to be as continuous as possible, with overlap between successive missions. There also needs to be a corresponding collection of appropriate *in situ* observations for calibration and validation.

The existing systems that should be sustained include those observing sea level. This includes the Jason series of satellite altimeters, as well as completion of the GLOSS network of approximately 300 gauges (each with high-frequency sampling, real-time reporting, and geodetic positioning). In order to estimate the change in sea level due to steric effects (thermal expansion and salinity-density compensation of sea water), the Argo array – which achieved global coverage of the ice-free oceans with 3,000 profiling floats in November 2007 – needs to be sustained. In order to estimate the change in sea level due to changes in ocean mass due to melting ice caps and glaciers and changes in terrestrial water storage, observations of the time-varying gravity field from GRACE need to be sustained.

Other existing and future systems to be sustained are those required to observe changes in ice sheet and glacier topography and thickness – satellites utilising radar (e.g. Envisat, GFO CryoSat-2 and Sentinel-3) and laser (ICESat) altimeters, complemented by aircraft and *in situ* observations. All of these measurements require that the International Terrestrial Reference Frame (ITRF), which integrates the geodetic components – SLR, VLBI, DORIS – and GNSS (GPS, together with GLONASS and Galileo), must be made more robust and stable than is currently the case. Finally, observations of the time-invariant gravity field from GOCE and other stand-alone missions are needed to determine the precise geoid.

The Jason-2 satellite, a critical element of the CEOS Ocean Surface Topography Constellation, was launched in June 2008.

New and improved observing systems which need to be developed include those directed at changes in the ocean volume. Based on experience gained with radar and laser satellite altimeters, the development of a suitable follow-on capability is needed to improve observations of ice sheet and glacier topography. Access to InSAR data and ongoing InSAR missions is needed to observe flow rates in glaciers and ice sheets. Finally, the development of an advanced wide-swath altimeter is needed to observe sea level changes associated with the oceanic mesoscale field, coastal variability, and marine geoid/bathymetry; surface water levels on land and their changes in space and time; and surface topography of glaciers and ice sheets.

In order to provide the necessary resources and coordination and ensure that the required continuity of observations will be available, CEOS has established an Ocean Surface Topography Virtual Constellation team, comprising those countries and agencies engaged in the provision and planning of the necessary instruments and spacecraft.

Further Information

Sea Level Rise: en.wikipedia.org/wiki/Sea_level_rise

Jason-2: www.aviso.oceanobs.com/en/missions/future-missions/jason-2/index.html

GLOSS: www.gloss-sealevel.org

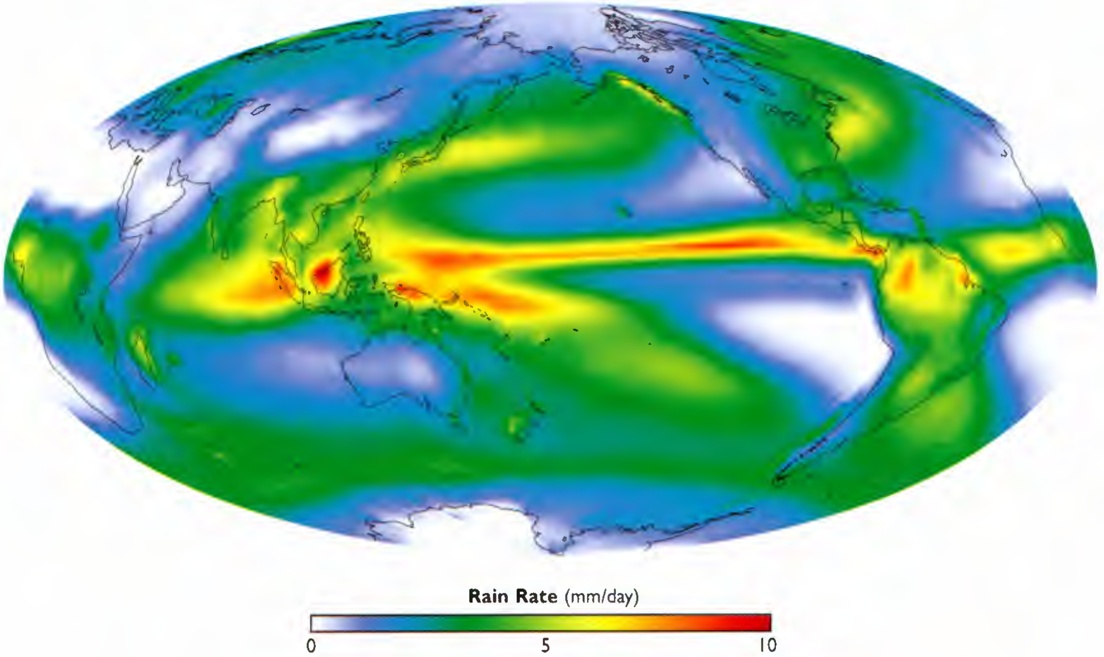
5.6 Water Security

Water is essential for of all life on Earth. It is the only known substance that can exist naturally as a gas, liquid and solid within the relatively small range of air temperatures and pressures found on the Earth's surface. Furthermore, the chemical properties of water make it the best natural solvent and a widely used medium for waste disposal and waste dilution.

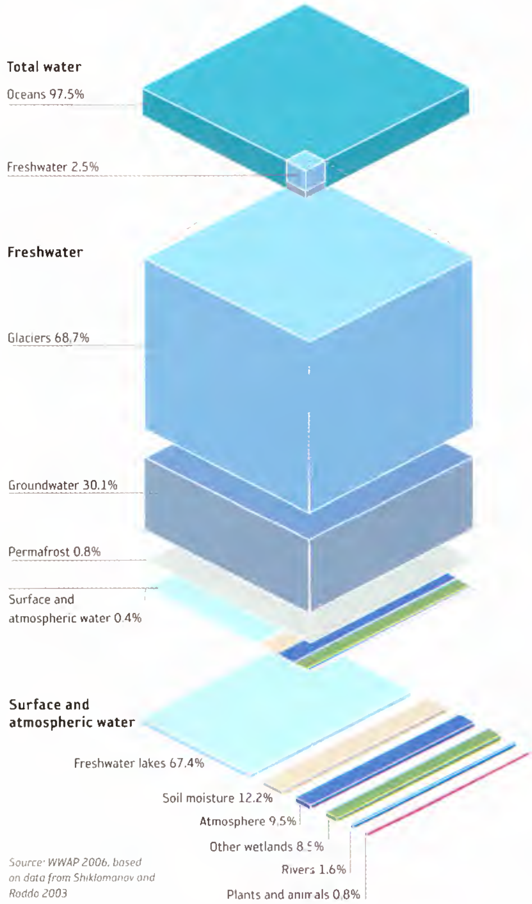
In all, the Earth's water content is about 1.39 billion cubic kilometres and the vast bulk of it, about 96.5%, is in the global oceans. Approximately 1.7% is stored in the polar ice caps, glaciers, and permanent snow, and another 1.7% is stored in groundwater, lakes, rivers, streams, and soil. Finally, a thousandth of 1% exists as water vapour in the Earth's atmosphere. Of all this water present on our planet, only 2.5% is fresh, and only 0.007% is readily available to people via rivers, lakes, and reservoirs. Fresh water is a finite and vulnerable resource, essential to sustain life, economic development and the environment, and management of this resource is expected to emerge as one of the greatest challenges facing mankind during the 21st century.

Fresh water availability and use, as well as the conservation of aquatic resources, are key to human well-being. The quantity and quality of surface and groundwater resources, and life-supporting ecosystem services are being jeopardised by the impacts of population growth, rural to urban migration, increasing wealth and resource consumption, and climate change. If present trends continue, 1.8 billion people will be living in countries or regions with absolute water scarcity by 2025, and two thirds of the world population could be subject to water stress.

Humans currently appropriate more than half of accessible freshwater run-off, and this amount is expected to increase significantly in the coming decades. 70% of the water currently withdrawn from all freshwater resources is used for agriculture. With the world's population set to increase significantly by 2050, the additional food



Global precipitation 1979–2006. (Credit: GPCP)



Global distribution of the world's water.

required to feed future generations will put further pressure on fresh water resources. Future management of freshwater resources will be complicated by the uncertainties in rainfall patterns introduced by climate change, with observations and models suggesting increased frequency and intensity of both extreme precipitation and drought events – depending on the region.

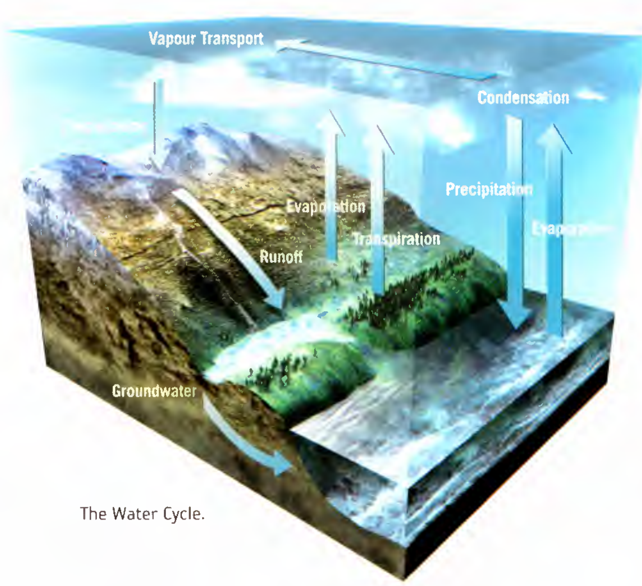
The Stern Review on the Economics of Climate Change warned that global warming will have severe impacts often mediated through water:

- melting glaciers will initially increase flood risk and then significantly reduce water supplies in some areas;
- declining crop yields due to a lack of water, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food;
- rising sea levels will result in tens to hundreds of millions more people flooded each year with warming of 3 or 4°C. By the middle of the century, 200 million people may become permanently displaced due to rising sea levels, increased flooding, and more intense droughts.

The Water Cycle

The combination of increased scarcity of global water resources and increased uncertainties in the Earth's water cycle has added urgency to the need to improve predictions of rainfall and water resources. This requires development of an integrated water cycle observing system and extension of our understanding of the physical basis of the climate system driven by the water cycle.

Because water continually evaporates, condenses, and precipitates, with average global evaporation essentially equalling global precipitation, the total amount of water vapour in the atmosphere remains approximately the same over time. This movement of water, in a continuous circulation from the ocean to the atmosphere to the land and back again to the ocean is termed the global water cycle. It is at the heart of the Earth's climate system, affecting every physical, chemical, and ecological component. Amongst the highest priorities in Earth science and environmental policy issues confronting society are the potential changes in global water cycle due to climate change. Climate changes may profoundly affect atmospheric water vapour concentrations, clouds and precipitation patterns, as well as the atmosphere's energy budget which drives the winds and the storm patterns. Many uncertainties



The Water Cycle.

remain, however, as illustrated by the inconsistent results given by current climate models regarding the future distribution of precipitation.

Better predictions of water cycle behaviour are needed for:

- monitoring climate variability and change;
- effective water management;
- sustainable development of the world's water resources, requiring knowledge of trends and long-term projections of the intensity of the global water cycle;
- improved weather forecasts and monthly to seasonal climate predictions, including mitigation against drought and flood.

As the global water cycle is relatively complex, long-term observational datasets are needed to characterise its behaviour as a function of several key parameters. These parameters include:

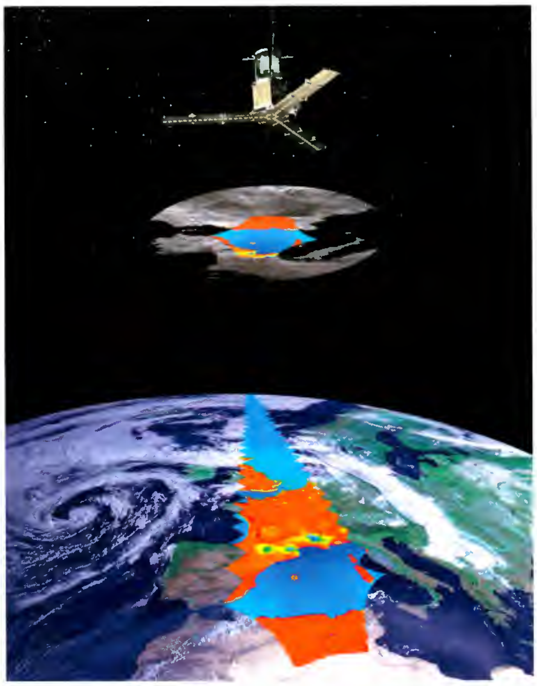
- global precipitation;
- surface temperature and salinity of continental water resources;
- atmospheric water vapour and temperature;
- sea surface temperature (as a significant factor that often markedly influences rainfall patterns, as in the El Niño). Coupled with wind and air temperatures it also provides a measure of air-sea fluxes;
- ocean salinity. If measured with sufficient spatial and temporal resolution, this would aid estimate of precipitation over the ocean and be important in helping to support climate model development;
- soil moisture;
- the amount of water stored in snow, glaciers and ice sheets.

In large parts of the world, the collection and dissemination of water-related information has been in decline in recent years. In order to strengthen cooperation amongst countries in gathering the necessary information, the WMO, in association with the World Bank, established the World Hydrological Cycle Observing System (WHYCOS) in 1993. WHYCOS is based on a global network of reference stations which transmit hydrological and meteorological data in near real-time, via satellites, to national and regional centres. A number of international scientific research programmes have been developed to address the key challenges relating to the global water cycle – most notably under the auspices of the World Climate Research Programme and its Global Energy and Water Cycle Experiment (GEWEX).

The main forum for coordination of the supporting observation programmes, including those of the satellite and *in situ* measurement communities, is the Integrated Global Water Cycle Observations Theme (IGWCO) – formerly of the IGOS Partnership and now within the GEO framework. IGWCO provides a framework for guiding international decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations so that they will support the most important applications and science goals, including the provision of systematic observations of trends in key hydrologic variables.

The Role of Earth Observation Satellites

Earth observation satellites play a major role in the provision of information for the study and monitoring of the water cycle and represent an important element of the observation strategy defined within IGWCO. The first element of this is the CEOP project (now known as the Coordinated Energy and water cycle Observation Project),



SMOS will provide new capabilities to measure soil moisture and ocean salinity.

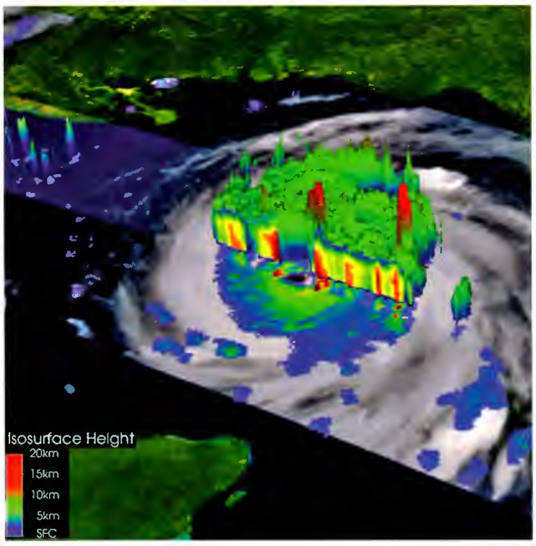
which is taking advantage of the simultaneous, long-term operation of European, Japanese and U.S. satellites to generate new integrated data sets of the water cycle.

Atmospheric temperature and water vapour data have been provided by polar orbiting meteorological satellites for decades – provided by USA (NOAA series) and more recently Europe (EUMETSAT's MetOp series), as well as China and Russia. Recent advances using high resolution infrared soundings (IASI) or radio occultation techniques (which look at the interaction of radio signals with the atmosphere to derive characteristics of the atmosphere) and the Global Positioning Satellite signal (e.g. by the COSMIC satellite constellations and GRAS on MetOp) have further augmented the contribution from space.

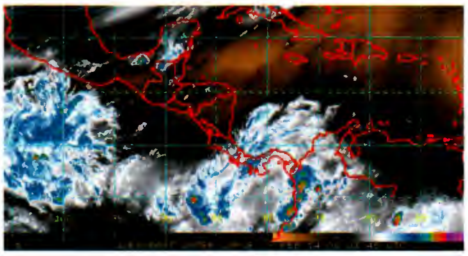
Sea surface temperature measurements are also provided by the operational meteorological satellites, by ERS and Envisat (ATSR and AATSR), and by the Terra and Aqua missions (MODIS). Ocean wind measurements are also provided by these missions, as well as by NASA's QuikSCAT and EUMETSAT's ASCAT (on MetOp) which acquires all-weather, high resolution measurements of near-surface winds over most of the global oceans on a daily basis.

Precipitation is clearly a key parameter in the water cycle. Traditionally visible/infrared images from geostationary meteorological satellites, such as GOES, GMS and Meteosat, provided the best source of information from spacecraft, with indirect, but frequent, estimates of rainfall derived from measurements of cloud top temperature. These data are used in the WCRP's GEWEX Global Precipitation Climatology Project (GPCP), which has provided monthly mean precipitation data from 1979 up to the present. Precipitation systems tend to be somewhat random in character and also evolve very rapidly, especially during the summer in convection regimes. Within a single storm, it is not uncommon for precipitation amounts to vary widely over a very small area. Also, in any given area, the amount of precipitation can vary significantly over a short time span. All of these factors make precipitation difficult to quantify. Reliable ground-based precipitation measurements are difficult to obtain over regional and global scales because more than 70% of the Earth's surface is covered by water; and many countries are not equipped with precision rain-measuring sensors (i.e. rain gauges and/or radars). The only practical way to obtain useful regional and global precipitation measurements is from the vantage point of a space-based remote sensing instrument.

The advent of the Tropical Rainfall Mapping Mission (TRMM of NASA/JAXA) in 1997 provided a breakthrough in the provision of 3D information on rainfall structure and characteristics. TRMM was the first satellite dedicated to rainfall measurement, and carries a weather radar. Now in its 11th year, the TRMM mission has provided a wealth of knowledge on severe tropical storms such as hurricanes and short-duration climate



TRMM Image of Hurricane Katrina before it hit New Orleans. The satellite's 3D look inside the storm provided unique information on the rainfall structure as it approached land.



Water vapour observations from a geostationary satellite.

shifts such as El Niño. Such active sensors have proved themselves to be an essential tool for the measurement of precipitation.

Microwave-based techniques (utilising either passive remote sensors or weather radars) provide the most accurate measurement of rainfall, especially when integrated with surface observations. An all-microwave constellation of sensors, anchored by a 'mother ship' with a weather radar to provide accurate calibration, is necessary for reliable, global coverage of precipitation in all of its liquid and solid forms. This is the measurement philosophy embodied by the Global Precipitation Measurement (GPM) suite of sensors.

GPM aims to provide precipitation measurements on a global basis with sufficient quality, Earth coverage and sampling to improve prediction of the weather, climate and specific components of the global water cycle. GPM aims to ensure a repeat observation cycle of approximately 3 hours.

Recognising the central role of the water cycle to our understanding of the Earth System and climate change, selected space agencies are operating or developing a number of new missions aimed at addressing key water cycle issues. These include Aqua (NASA), CloudSat (NASA), EarthCARE (ESA/JAXA), CryoSat-2 (ESA) and Megha-Tropiques (CNES/ISRO), which will study water cycle and energy exchanges in the tropical belt.

Revolutionary new measurement capabilities – such as the provision of information on soil moisture and ocean salinity – will be provided in future by missions such as SMOS (ESA, from 2009) and Aquarius (CONAE/NASA, from 2010). Both soil moisture and ocean salinity are key variables that link the water cycle and climate.

Other areas where satellite data are being used to explore the water cycle include: the GRACE mission and its gravimetric measurements, which are providing information that is being used to quantify groundwater; the use of optical wavelengths to assess plankton and other water-borne materials; and the exploration of radar altimetry to measure water levels in lakes and rivers.

In the context of the CEOS follow-up to the 2002 Johannesburg World Summit on Sustainable Development, the European Space Agency launched the TIGER initiative – focusing on the use of space technology for water resource management in Africa and providing concrete actions to match the Summit Resolutions.

Future Challenges

New technologies for measuring, modelling and organising data on the Earth's water cycle offer the promise of deeper understanding of water cycle processes and of how management decisions may affect them. Earth observation satellites will provide synoptic, high resolution coverage that is unprecedented in the geophysical sciences. The challenges to be faced in utilisation of these new capabilities include:

- development of new methodologies to exploit existing, long time series of satellite measurements;
- investigating novel approaches to convert satellite measurements into useful parameters that can be applied in scientific models, and that can be inter-compared and inter-calibrated among the different satellite missions;
- development of assimilation methodologies to integrate satellite and *in situ* observations;
- capacity building, particularly in developing countries, so that those countries in most direct need of water information have the means of access, analysis, and understanding required to derive maximum benefit from the data;

— continuing to collect consistent and accurate data over many years in order to detect the trends necessary for climate change studies;

— succeeding in the technology developments aimed at accurately measuring key parameters from space – including precipitation, soil moisture and ocean salinity.

Thanks to the efforts of the IGOS Global Water Cycle Theme and of GCOS in defining which Essential Climate Variables are required, the observations required to characterise and predict the water cycle are well defined, but remain challenging in some cases. To complement the satellite data, existing ground-based measurement networks and systems must continue operating to obtain current data that can be compared meaningfully with past records.

CEOS Virtual Constellation for Precipitation

CEOS recognises the vital importance of timely and accurate precipitation measurements in support of a broad range of societal needs, including climate studies, weather forecasting (including flood predictions for extreme events), water resource management and agriculture. As a result, CEOS selected a Virtual Constellation for Precipitation as one of four pioneering projects intended to improve international coordination of Earth observation satellite planning in support of common needs. The goals of this Precipitation Constellation are to:

— provide a framework to advocate and facilitate the timely implementation of the Global Precipitation Measurement (GPM) mission and encourage more nations to contribute to the GPM constellation. Although GPM offers impressive new measurement capabilities, the mission period is only 3 years;

— sustain and enhance an accurate global precipitation data record, including a Fundamental Climate Data Record essential for understanding the integrated weather/climate/ecological system, managing freshwater resources, and monitoring and predicting high-impact natural hazard events. This data record should be fit for the purpose specified by GCOS for the monitoring of precipitation as an essential climate variable.

NASA and JAXA are co-leading the development of the GPM mission which is the cornerstone of the Constellation. The Constellation team is in discussion to add further satellite missions developed by France (CNES) and India (ISRO).

Further Information

Water cycle: ga.water.usgs.gov/edu/watercycle.html

IGWCO: www.igospartners.org/Water.htm

CEOP: www.ceop.net

Global Precipitation Measurement (GPM) mission: gpm.gsfc.nasa.gov

TRMM: www.eorc.jaxa.jp/TRMM/index_e.htm

World Water Forum: www.worldwaterforum5.org

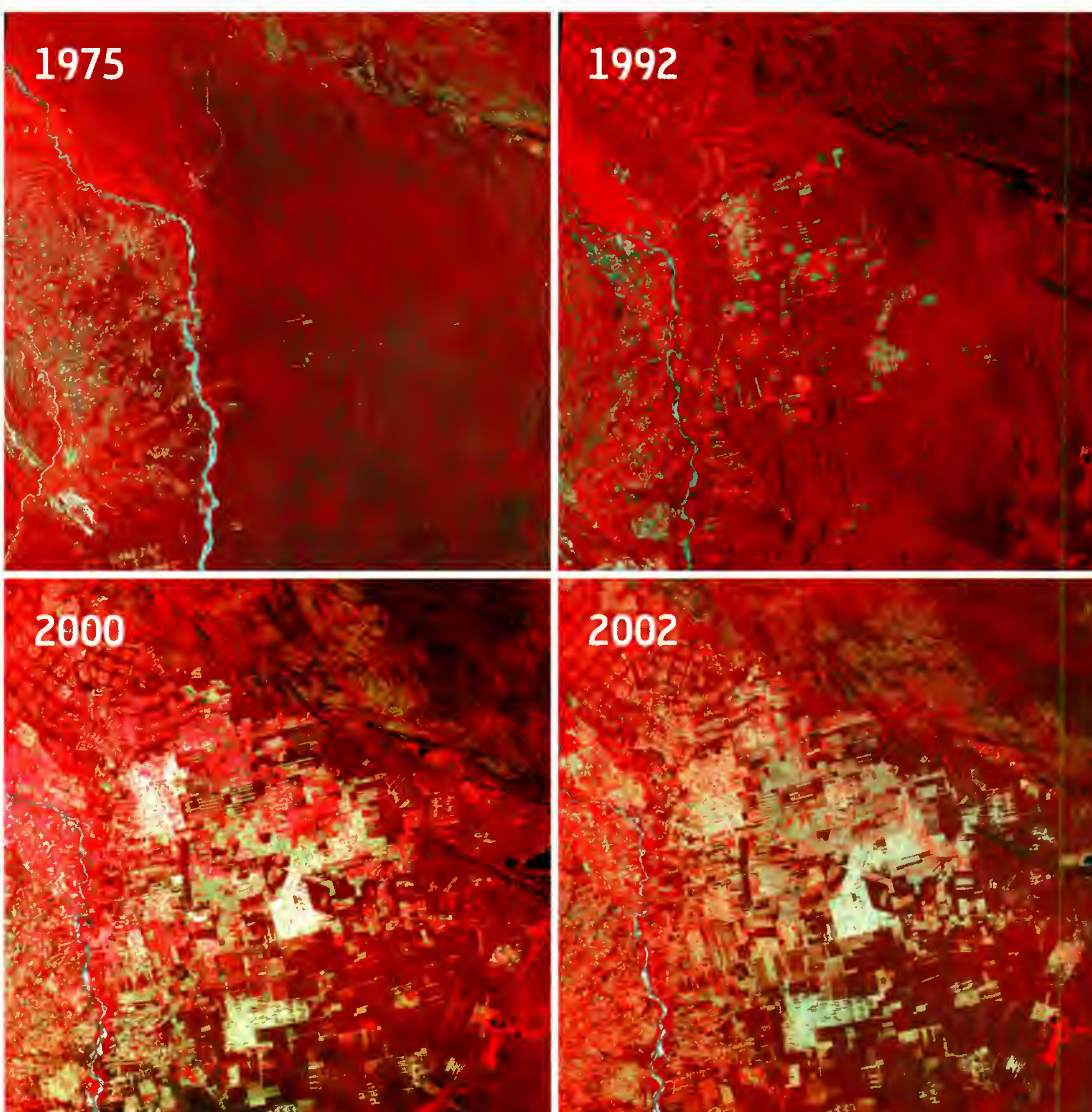
5.7 Land Surface Change

The extent and rate of land use change are directly related to human population growth. The impact of such change on the landscape has far reaching effects on our environment, including climate. The conversion of forest to agriculture, for example, contributes significantly to changes in atmospheric CO_2 concentrations and in other greenhouse gases. It can also modify land surface/atmosphere interactions (e.g. surface roughness, albedo and humidity) that affect other important environmental processes, including temperature and precipitation patterns.

A large number of regional, national and global research efforts are dependent on improved understanding of the land surface which, in turn, supports decision makers who are concerned with societal vulnerability and the environment. This information often stands alone as evidence of environmental change or is used to help parameterise ecological and climate models.

Furthermore, land use intensity has steadily increased with the Earth's population growth since the Industrial Revolution. Advances in technology, especially in the agriculture and forestry sectors, have accelerated the changing face of the land surface. Human action has transformed almost half of the Earth's land surface, with a 50% reduction in the area of tropical forests that will have significant consequences for global biodiversity and climate.

The degradation of environmental quality has far-reaching effects, including a reduction in



Landsat time series of large scale deforestation in the Amazon.

coastal fisheries production, poorer water quality, and reduced biodiversity. Regular updates of global land cover and land cover condition are required to improve our understanding of nearly every aspect of the changing environment, including fluxes of water, carbon dioxide and other trace gases; changing coastlines and their influence on marine resources; biodiversity; and biosphere/atmosphere interactions.

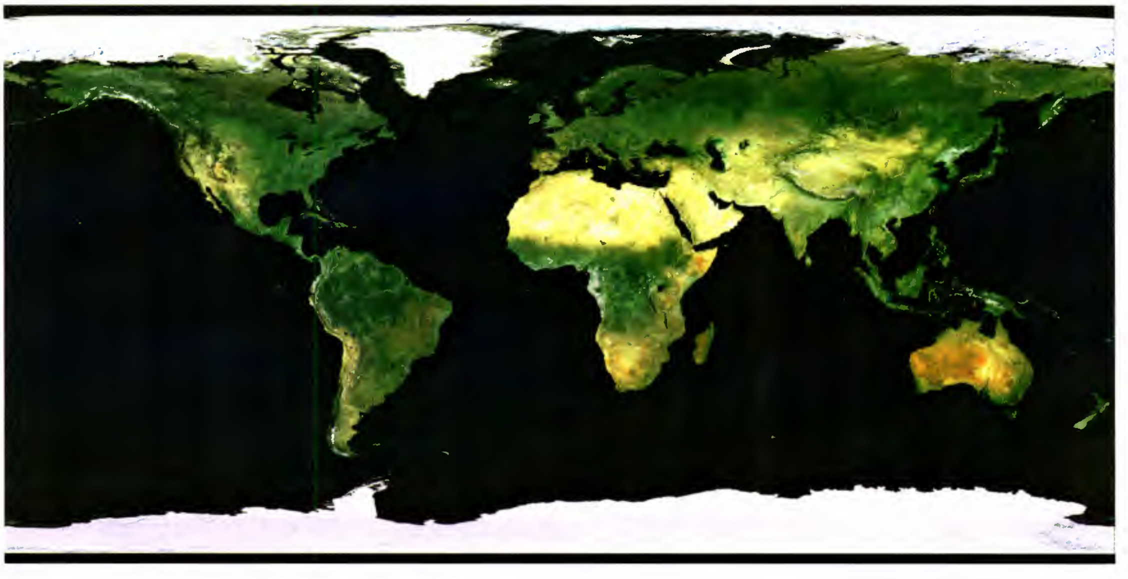
Sustainable Forestry

Sustainable forestry is one of the most challenging land use practices that humans are facing. The changing shape and condition of the Earth's forests affect biodiversity, atmospheric composition and climate. Satellite observations provide a consistent set of information about forests over large areas that are otherwise difficult to inventory and monitor. Such observations provide forest managers with the information needed to evaluate the potential impact of different uses and manage forests with sustainable practices. Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort that is working to provide ongoing space-based and *in situ* observations of forests and other vegetation cover. It is intended to support the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. Originally developed as a pilot project by CEOS, as part of its Integrated Global Observing Strategy, GOFC-GOLD is now a panel of the Global Terrestrial Observing System (GTOS).

Other major forest-related efforts that rely on Earth observation data are under way around the globe. The UN Food and Agriculture Organisation's Forest Resource Assessment 2010 is a decadal update of the world's forest resources that is dependent upon satellite-based data. The Brazilian Instituto Nacional de Pesquisas Espaciais (INPE) is utilising Landsat data for annual monitoring of forest resources in Amazonia under their Programme for Deforestation Assessment (PRODES) project in the Brazilian Legal Amazonia. The United Nations Framework Convention on Climate Change (UNFCCC) identified Reduction in Emissions from Deforestation and forest Degradation (REDD) as a key element of the UN Bali Action Plan and it may well lead to increased emphasis on utilising satellite resources for sustainable forestry practices.

Agricultural Monitoring

Assessing the need for enhanced agricultural observations (satellite and *in situ*) is a responsibility of the Integrated Global Observations of Land (IGOL) programme. IGOL advises the Group on Earth Observations (GEO) on the requirements for improved observation of the land surface. GEO recognises sustainable agriculture as one of the critical Societal Benefit Areas (SBAs) for international cooperation and collaboration. The agricultural SBA calls for an operational system for monitoring global agriculture that includes the following three main functional components:



ESA's GLOBCOVER project created the most detailed land cover map ever.
For this mosaic a total of 1561 orbits taking place over the period May, July, October and November 2004 were used to filter out the clouds.

— global mapping and monitoring of changes in distribution of cropland area and associated cropping systems;

— global monitoring of agricultural production leading to accurate and timely reporting of national agricultural statistics, and accurate forecasting of shortfalls in crop production and food supply that facilitate reduction of risk and increased productivity at a range of scales;

— effective early warning of famine, enabling the timely mobilisation of an international response in food aid.

Examples of current global crop estimation systems include those of the United States Department of Agriculture Foreign Agricultural Service (FAS-USDA) and European Commission – Monitoring Agriculture with Remote Sensing (EC-MARS), which combine weather data, *in situ* information and satellite data to estimate production and yield. Food supply assessments inform risk and damage assessments, as well as farming practice monitoring and drought assessment.

Land Cover

A number of global and regional land cover mapping efforts using Earth observation data from satellites have been undertaken over the past decade by utilizing sensors such as AVHRR, MODIS and SPOT Vegetation. A new, 300 m resolution global land cover map has been released by the POSTEL Service Center that uses the MERIS sensor aboard the Envisat satellite.

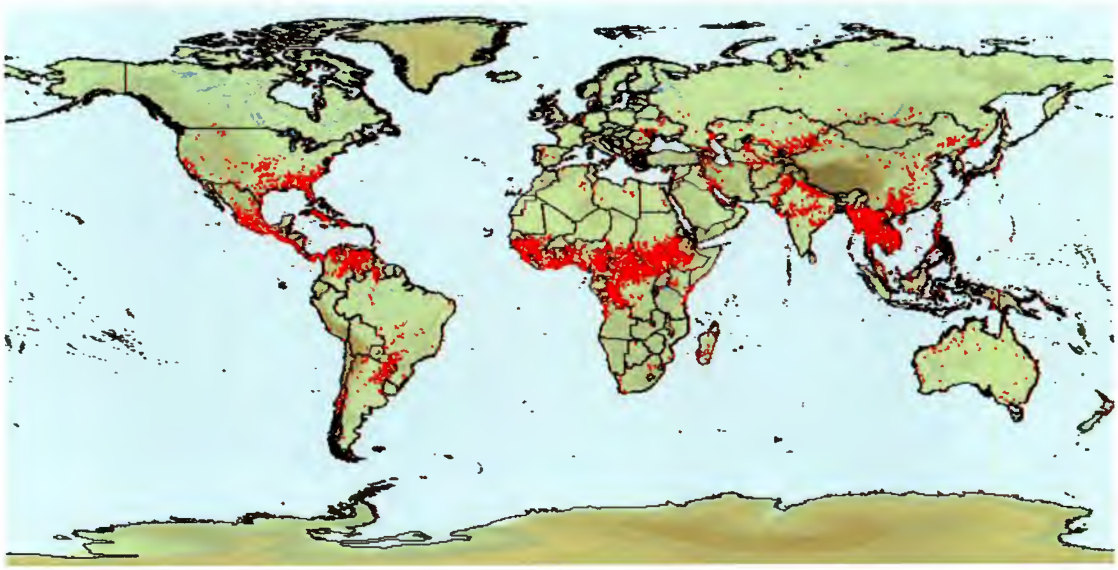
A number of national and regional land cover data sets, including the National Land Cover Database (NLCD) for the USA, CORINE for Europe, and Africover for eastern Africa, have been developed at 30 m resolution. This level of detail is necessary for detecting and characterising land cover change. For instance, the NLCD products support other land cover research projects around the United States, such as the Fire Danger Monitoring and Forecasting Project.

The Role of Satellite Earth Observations for GCOS Terrestrial Requirements

A number of CEOS agencies' assets are currently being used to meet the terrestrial requirements that are outlined in the Global Climate Observing System's Implementation Plan. These include altimetry missions to help estimate lake area, characterisation of snow and ice sheets from optical and microwave sensors, global land cover characterisation and albedo estimates. Other Essential Climate Variables required by GCOS, such a fAPAR, biomass and soil moisture, are current areas of research and development when considered at the threshold levels required by GCOS.

CEOS Virtual Constellation for Land Surface Imaging

Data acquired by land remote sensing satellite systems are fundamental tools for studying the Earth System, including the land surface and the processes that operate on or near it. These data are sources of information from which meaningful interpretations can be made about



Global web fire mapping service using MODIS.

the Earth's biological conditions and resources, geologic and hydrologic processes and resources, and human dynamics.

Since the launch of Landsat-1 in 1972, there has emerged a large and diverse international community of users who apply remotely sensed data collected by the same land surface imaging satellites, now operated by many nations, to a wide range of different scientific and practical endeavours. These include environmental monitoring, natural hazard assessment, vegetation analysis, geologic investigations, infectious disease control, natural disaster mitigation, wetlands assessment, cartography, land use and land cover classifications, glaciology, coastal and sea floor mapping, global change studies, forestry, wildlife studies, hydrology, agriculture, and many more. These endeavours have had positive effects on Earth's natural habitats and environments, the economic state of society and the well-being of mankind. Yet, many more benefits to society remain to be realised from the application of such data.

The design, construction, launch, and operation of satellite systems are complex and very expensive endeavours. Ideally, nations would not develop duplicative satellite systems, but rather would collaborate fully in the development, launch, operation and sharing of data from a constellation of satellite systems that optimally meets their full range of land surface observational requirements. That day likely will come, but it is not here yet.

Until then, CEOS has initiated the Virtual Constellations Concept by establishing four original prototype virtual constellations, including the Land Surface Imaging (LSI) Constellation. A primary objective of the LSI Constellation is to define a broad range of rather detailed characteristics (or standards) that describe the optimal, end-to-end capabilities (and policies) needed to acquire, receive, process, archive and distribute space-acquired land surface image data to the global user community. Ideally, users will find such data optimally applicable to the broadest possible range of scientific and practical endeavours important in meeting the needs of society. The beneficial outcomes from defining such standards will be the guidance they provide for the internationally coordinated development of future systems, as well as the foundation they provide for establishing criteria against which future proposed Earth observing systems can be assessed.

Another important objective of LSI Constellation studies and activities is to address current and shorter-term problems and issues facing the land remote sensing community today. One way the LSI Constellation is addressing these problems and issues is by promoting greater cooperation among CEOS space agencies that currently operate land surface imaging satellite systems. The important outcomes from accomplishing this objective lie in the early benefits that will be derived by many segments of the land remote sensing user community, and by society in general, as well as the opportunity to demonstrate the value that CEOS Constellations can contribute to the Group on Earth Observations (GEO) and its member organisations.

Currently, the LSI Constellation is working with CEOS agencies that operate mid-resolution optical LSI satellite systems, contributing data to the Forest Resource Assessment 2010 Project to

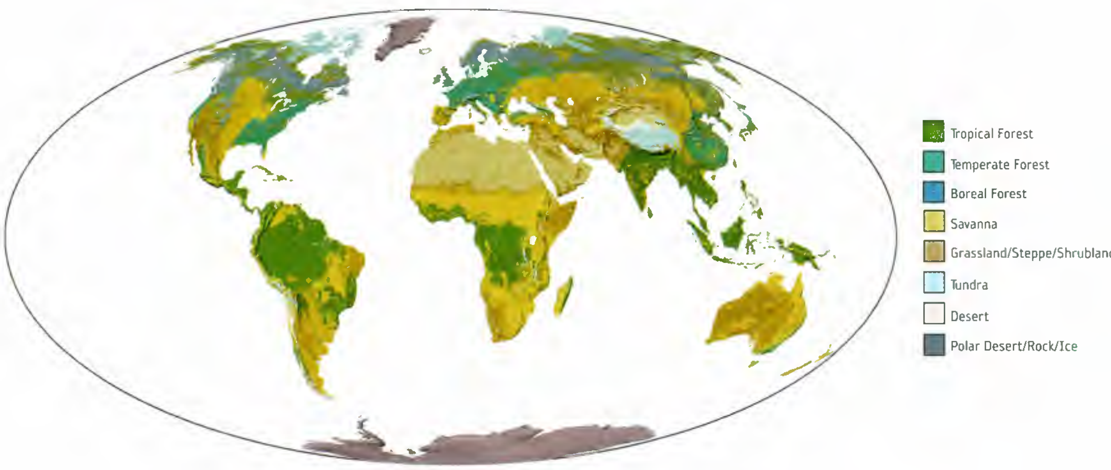
1992 Reflectance

2001 Reflectance

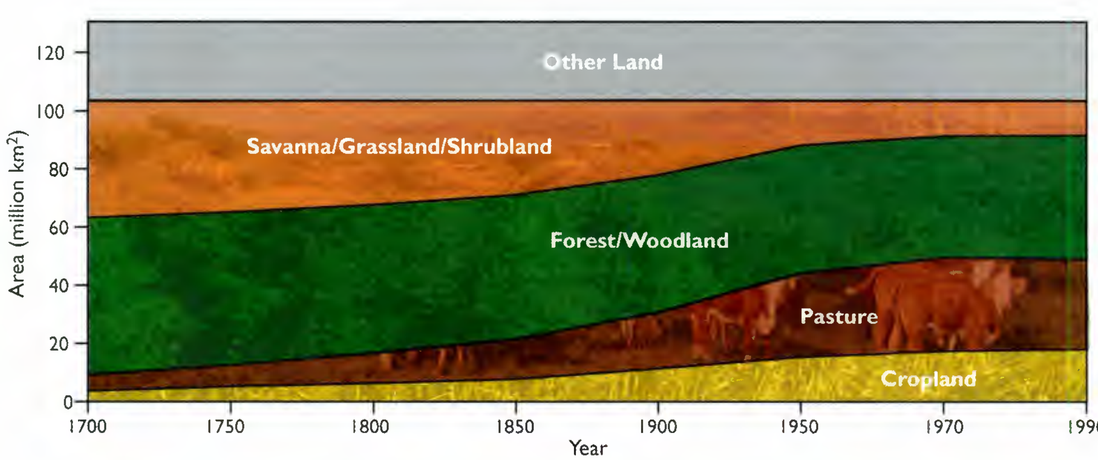
1992/2001 Change Map

Erosion and accretion along barrier islands near Beach Heaven, New Jersey, USA.
This area on the New Jersey shoreline contains small but notable changes in the barrier island complex due to wave action.
Although only 1.67% of all pixels in this area were identified as changed, there are economic consequences when high value urban real estate from Beach Haven, NJ, is transported down the coast.

fill gaps in its base data set. It is also responding to a GOFC-GOLD proposal to compile a global, mid-resolution optical data set centred on 2010 by initially creating regional data sets contributed by CEOS agencies. Other cooperative activities among CEOS agencies that are being initiated by the LSI Constellation Study Team include those designed to improve user access to existing LSI data sets, to coordinate acquisition of data, and to increase compatibility in ongoing ground segment operations.



Map of natural vegetation types that likely would exist if there were no human agricultural utilisation.
The expansion of croplands and pastures came at the expense of natural ecosystems, including forests, grasslands and savannas.



Changes in land cover during the last 300 years due to agricultural expansion.
During the last 300 years there has been a large increase in the amount of land devoted to agriculture (croplands and pastures) coming at the expense of natural ecosystems. As human population and material consumption continue to increase, the pressure on our finite land base will also continue to increase.
(Data from the Center for Sustainability and the Global Environment, University of Wisconsin)

Further Information

GOFC-GOLD: www.fao.org/gtos/gofc-gold/

CORINE: reports.eea.europa.eu/CORØ-landcover/en

FRA 2010: www.fao.org/forestry/1191/en/

5.8 Energy Resource Management

Energy underpins all aspects of countries' economic and social development policy. It is an input required by every segment of economy and society, whether in developed or developing countries.

The energy sector covers a wide range of activities, such as oil and gas exploration, extraction and production, transportation, electricity generation, transport and distribution. The optimal management of this diverse, global, trillion dollar industry – which includes the non-renewable resources of oil and gas as well as renewable resources such as solar, wind, biomass and hydropower generation – is a critical concern to all nations.

Energy resource management decisions are the basis for economic growth, ecologically responsible use of resources and human health and security. According to the International Energy Agency, worldwide energy demand over the next thirty years is expected to double, with the bulk of this increase occurring in large, rapidly developing countries, such as India and China. By 2030, global energy demand is expected to exceed supply by 20%. At the same time, existing reserves of traditional fuels from fossil sources will diminish and new reserves will be more difficult to find and exploit commercially. Alongside increased environmental awareness of the global warming effects of use of fossil fuels, renewable energy sources – which are themselves sensitive to weather and climate phenomena – are increasingly being deployed.

Major issues for the energy industry include fuel supply, type, and sustainability, as well as power efficiency, reliability, security, safety and cost effectiveness. Nations need reliable and timely information in order to manage the risks associated with uncertainty in supply, demand, and market dynamics. This requires sound management practices and strategies by industry and government.

The Role of Earth Observation Satellites

The energy industry is already an important user of information from Earth observation satellites:

- weather data are useful in estimations of both the supply and demand for electricity;
- satellites play an important role in support of exploration, extraction and safe transportation of the world's oil and gas reserves, particularly since they are now being sought in increasingly remote and hostile areas of the planet;
- satellites are playing an increasing role in providing global resource maps for renewable energy project planning and sustainable building design;
- potential disruption of the power grid by solar storms can be predicted using satellites that monitor the near-Earth environment in conjunction with atmospheric models.

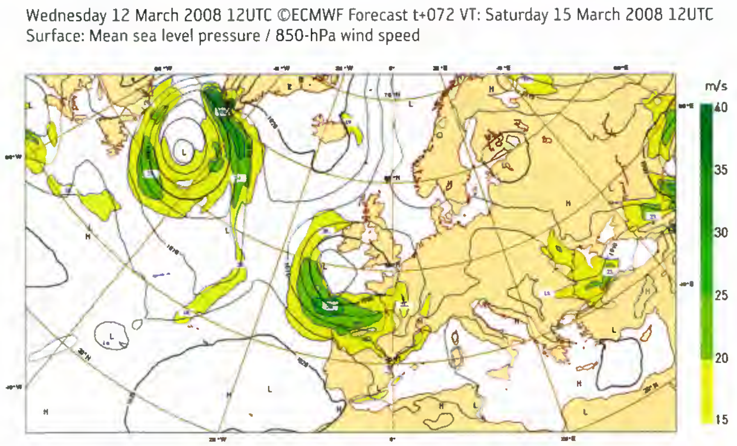
Some examples of the roles for satellite Earth observations in the global energy sector are outlined below.

Forecasting the Demand for Electricity

The electrical grid 'blackouts' in the northern USA and Canada in August 2003 were an extreme example of the effects of miscalculating the demand for electricity. The outage affected some 50 million people and losses were estimated at between $5.8bn and $11.8bn. It occurred during summer peak energy use periods when air conditioning demand was in full force, demonstrating the important influence of environmental conditions on society's daily demand for electricity.

The power industry relies heavily on projected demand requirements for the buying, selling and trading of electricity. Weather information is a necessary component of the industry's supply forecasting process. Companies make or purchase forecasts of electricity demand, ranging from a few hours ahead to many days ahead. Energy managers base operational decisions upon them.

Operational meteorological satellites play an important role in the generation of the



Weather forecasts are vital for forecasting electricity demand.

short-term and seasonal weather forecast products that are employed in the power industry. Everyday forecasts of temperature, humidity, precipitation and wind speed, and warnings of severe weather events such as hurricanes, droughts and heat waves, all have value in the prediction of how many electrical appliances each of us will use in the course of a typical day. Getting the forecast wrong means generating either too much or too little energy, and profits are lost in either case. Energy sector meteorologists have suggested that, in the USA, imperfect forecasts can have an impact on the electricity generation industry by as much as US$1 million per degree fahrenheit per day.

Weather forecasting improvements resulting from the introduction of new, advanced satellites are, therefore, of significant value to that industry. It has been estimated that the economic benefit to the U.S. supply industry resulting from improvements included in the GOES-R mission alone would amount to US$451 million in 2015. This benefit would be realised in the form of savings, primarily from improved load forecasts and better real-time weather information.

Direct observation of environmental conditions can also play an important role in ensuring electricity supply. Utilities and energy trading companies often use satellite imagery data on snow accumulation to predict snow melt and the resultant energy potential of hydroelectric dams. Longer term supply and infrastructure planning also depend on predictions of urban growth. Wide field-of-view sensors such as those on Landsat, MODIS and SPOT, have been used specifically for this purpose. Potential regional impacts of climate change are an increasing concern to the industry and 'extreme' weather forecasts are being used as a guide for planning purposes.

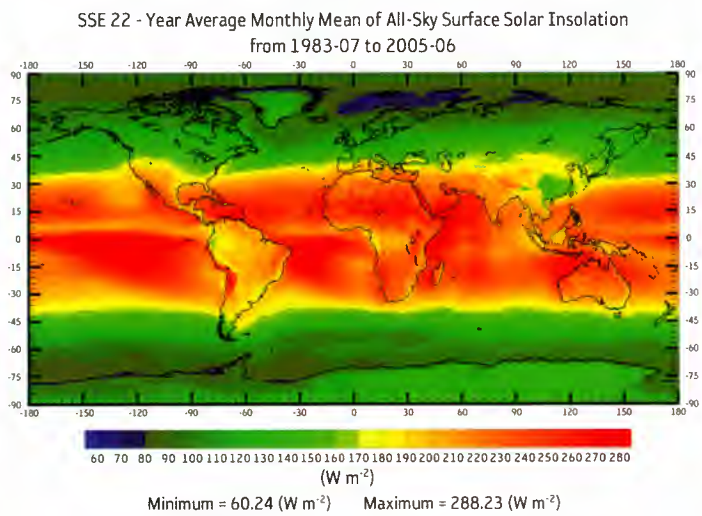
Alternative Energy Sources

In recent years, Earth observations have contributed to the optimisation of renewable energy systems for power production, and to the provision of information for optimal integration of traditional and renewable energy supply systems into electric power grids.

Renewable energy sources, such as solar, wind and wave power, offer environmentally-friendly alternatives to fossil fuels, but are particularly sensitive to environmental conditions. Since these energy sources are intermittent, their availability depends largely on local climate and weather.

Local climate data on cloud cover, solar irradiance, and wind/wave speed and direction – combined with other environmental parameters such as land elevation and land cover models – are vital elements in developing a strategy for the location and operation of renewable energy facilities.

The NASA-funded Surface meteorology and Solar Energy



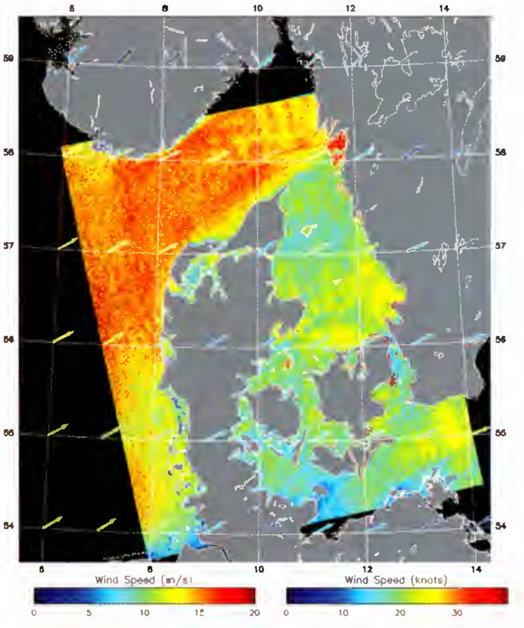
Surface solar energy map.

(SSE) dataset, a 23-year dataset of temperatures, wind, and solar radiation derived from satellite observations and model analyses, supports the preliminary design of buildings, renewable energy technologies, and agrotechnology. These historical data sets provide estimates of variability on seasonal and inter-annual timescales, as well as long-term (decadal) trends.

Geostationary satellites have been used experimentally as a tool in resource assessment for solar energy for a number of years. The Envisolar project, financed by the European Space Agency, aims to exploit Meteosat data to support the solar energy community in its efforts to increase the efficiency and cost-effectiveness of its systems and thereby improve their viability. The project aims to provide high spatial and temporal solar irradiance data as well as information on the distributions of sunlight by angle of incidence and spectral band.

EUMETSAT's Satellite Application Facility on Climate Monitoring (CM-SAF) is serving the solar energy community in providing the monthly mean solar radiation conditions at the surface on an operational basis.

A joint NASA-Ecole des Mines de Paris project to provide a compound, web-based solar energy data service suitable for use in developing



Coastal wind mapping using radar satellites.

countries was made available in 2007 as a GEO early demonstration project. The 'SoDA' project integrates the European Helioclim database and the NASA Surface meteorology and Solar Energy (SSE) dataset, based on location of interest.

SAR, scatterometer, and altimeter data from satellites are also used to support the mapping of wind energy in offshore and near-coastal regions to identify potential wind turbine sites. An 8-year climatology of ocean winds derived from measurements made by the NASA QuikSCAT scatterometer has recently been made available. This climatology is currently being expanded using observations by EUMETSAT's ASCAT. ESA's ERS-2 SAR high resolution ocean surface wave observations have been used by researchers in Denmark to provide offshore wind resource assessments. EUMETSAT's Ocean and Sea Ice Satellite Application Facility (OSI-SAF) generates surface wind products in near real-time, using measurements from the scatterometers QuikSCAT and ASCAT.

Renewable Energy Resource Management

Effective uptake of satellite measurements of quantities relevant to the energy sector requires understanding the needs of end-user policy makers and management decision makers. This includes supplying the data in readily usable formats and units. In the case of NASA's SSE dataset, partnerships with Natural Resources Canada's RETScreen clean energy project analysis tool and the US National Renewable Energy

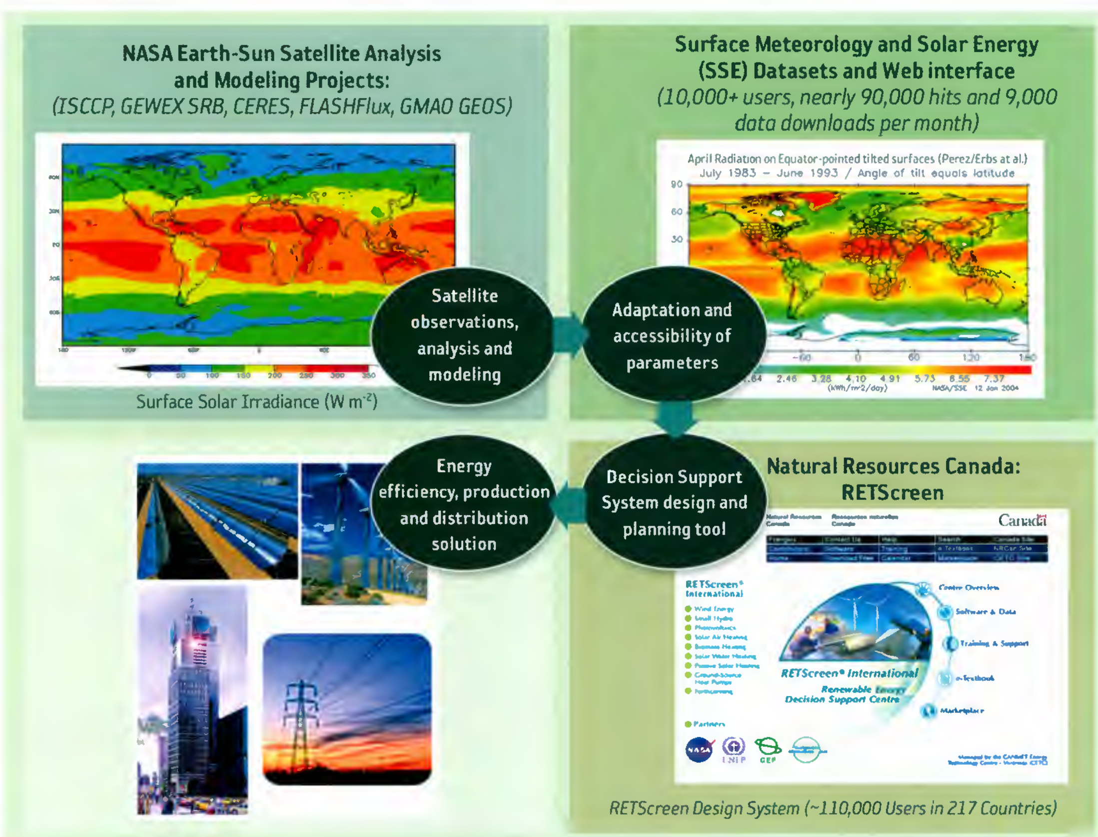
Laboratory's (NREL) HOMER micropower optimisation tool have led to their enhanced ability to inform decision making. RETScreen, used for renewable energy and energy efficiency project feasibility studies by over 140,000 users worldwide, has been translated into 26 languages. It gives users the choice of using surface measurements or, where unavailable, the NASA satellite-derived climatological data inputs. HOMER, a tool used for both stand-alone and distributed generation applications, makes similar use of NASA spaceborne-derived datasets. HOMER is used extensively worldwide for determining the optimal mix of power technologies for meeting specified load conditions at specified locations. In both instances, SSE data have been tailored to the needs of the decision support system, enabling the data to be ingested by the tool and made available in a transparent manner to the end user.

An International Energy Agency (IEA) Solar Heating and Cooling Programme task, entitled 'Solar Resource Knowledge Management', will provide the solar energy industry, the electric utility sector, governments, and renewable energy organisations with the most suitable and accurate information of the solar radiation field at the Earth's surface. This ranges from historic data sets to precise current products, and towards forecasts and scenarios as well as future availability of solar resources in a changing climate. Led by the NREL, with participation from ESA, DLR, NASA and other entities, this 5-year task contributes to current GEO energy work plan goals.

Industry and professional societies define standards for energy efficient building design. NASA SSE products are currently being evaluated by the American Institute of Architects and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). These sample datasets address unmet needs for clear-sky solar flux information for the building design community. In the case of ASHRAE, these data are provided in a specialised format employing US Department of Energy climate zones, which are in general use by these professionals for defining building energy codes.

Oil and Gas

Earth observation imagery is used extensively by exploration companies in support of their search for new oil and gas reserves – both on land and at sea. Instruments such as ASTER on NASA's Terra



RETScreen.

Satellite imagery is routinely used in exploration of offshore oil basins – including through oil 'seep' detection.

satellite are specifically designed to support geologists gathering information on remote and poorly mapped regions of the world and to supply information on the geological and tectonic features – which the trained interpreter can exploit, in association with seismic data, to optimise exploration efforts.

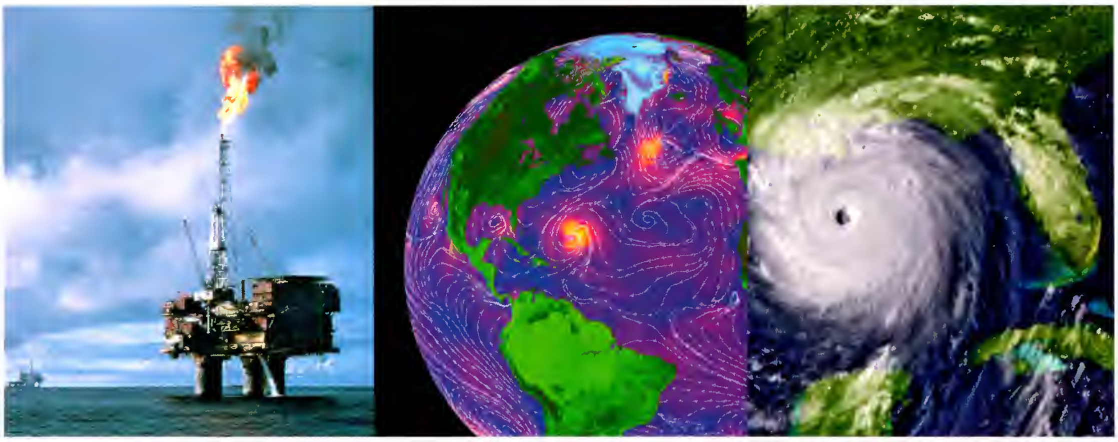
Energy Resource Management

Satellite data are used for prospecting for undersea hydrocarbon deposits. Research by oil companies in the 1990s demonstrated that over 75% of the world's oil-bearing basins contain surface seeps – which form a thin slick on the sea surface above, visibly changing the water's reflective qualities. Searches for these naturally occurring oil slicks can be undertaken using boats and aircraft, but these are time-consuming and costly, they may require access rights, and alert competitors to potential resources.

Synthetic Aperture Radar satellites offer the oil industry an effective, low-cost technique for reducing source risk in high-cost exploration environments such as the new deep frontier basins. This is due to their ability to image surface oil seeps remotely with wide swath coverage (typically 100–200 km wide scenes) and at low cost. Moreover, satellite data do not compromise national sovereignty and can provide multi-temporal coverage data over any area of the globe. Time-series data can provide the location for follow-up surface sampling from which key geochemical information on the oil reservoirs can be obtained ahead of drilling.

Oil and gas drilling increasingly takes place on the open seas – operations which are particularly vulnerable to severe storms. This vulnerability was apparent in the 2004 hurricane season when oil output from platforms in the Gulf of Mexico, the largest domestic source of oil for the USA, was reduced by about 25–30% of its usual daily rate. Oil prices increased sharply as a result of fears of supply security. Marine forecasts are essential in the offshore drilling business and for oil pipeline management, providing information on sea-state conditions, winds, waves, surface temperature and extreme events, such as severe storms and hurricanes. Satellite observations are often the only source of such information out at sea, so they are invaluable in managing offshore operations and, therefore, in ensuring security of oil supply.

The same benefits are enjoyed by ocean-going supertankers that transport much of the world's oil and gas supplies. Active microwave sensors on satellites such as MetOp and QuikSCAT provide homogeneous, global measurements of sea surface winds and wave height which are used by



Satellite observations of weather formations, sea surface winds and wave heights are essential for safe offshore operations.

meteorologists in their marine forecast models. These models are used in support of offshore operations and for ship route optimisation. The same instruments have helped improve forecasts of the landfall time and location of hurricanes. These can now typically be predicted to within 400 km, and up to 2–3 days in advance. The goals of NASA's Earth Science Enterprise call for improving this capability to within 100 km by 2010.

Environmental and climate impacts of global fossil fuel use can be expected to come under increasing scrutiny in the 21st century, as nations explore more sustainable energy policies and try to limit greenhouse gas emissions. The role of Earth observation satellites in this domain is the subject of other case studies in this document.

Future Advances

Increasing fuel prices and sensitivity to national fossil fuel emissions will ensure ever-increasing importance of the efficiency of our power generation industries. In the medium term, progress and improvement of energy resource management activities using satellite Earth observations will be largely related to the improvement of short- to medium-term (up to 8–10 days) weather predictions, as well as progress in seasonal to inter-annual climate forecasts. Application of current Earth observations to alternative energy resource assessment will continue to be exploited as deployment of these technologies increases.

The new generation of satellites is extending the range of deterministic forecasts to 15 days. Predictions of high-impact weather will also see improvement – up to 5 days ahead for flash floods, storms and blizzards, 10 days for 'plain' floods, and 15 days or beyond for droughts, heat waves and severe cold spells. The forthcoming GOSAT (JAXA) and Orbiting Carbon Observatory (NASA) missions will contribute to scientific studies related to the global carbon cycle. Future operational weather satellite systems will be extended to provide daily global analyses of greenhouse gases, and monthly estimates of the sources and sinks of CO_2

Further Information

International Energy Agency: www.iea.org

The Kyoto Protocol: unfccc.int/kyoto_protocol/items/2830.php

European Centre for Medium-Range Weather Forecasts: www.ecmwf.int

ARGOSS: www.argoss.nl

Wind and wave forecasts for offshore operations and ship routing: earth.esa.int/applications/data_util/hrisk/ssf/ssf.htm

Satellites for oil and mineral exploration: www.npagroup.co.uk/oilandmineral/index.htm

ESA Envisolar project: www.envisolar.com

EUMETSAT Satellite Application Facility on Climate Monitoring: www.cmsaf.eu

EUMETSAT Satellite Application Facility on Ocean and Sea Ice: www.osi-saf.org

NASA Surface Meteorology & Solar Energy (SSE) dataset: eosweb.larc.nasa.gov/sse

Solar Data (SoDa) web service: www.soda-is.com

Group on Earth Observations (GEO) Energy Community of Practice: www.geoss-ecp.org

Scatterometer Climatology of Ocean Winds: numbat.coas.oregonstate.edu/scow

Renewable Energy project analysis tools: www.retscreen.net

HOMER: www.nrel.gov/homer

PART III

→ Earth Observation Satellite Capabilities and Plans

Blowing in the wind, Senegal, MERIS.

6 Capabilities of Earth Observation Satellites

Many different types of instruments are flown on space missions, employing various measurement technologies and techniques – both active and passive – that utilise a wide range of the electromagnetic spectrum.

CEOS agencies are operating or planning around 240 satellites with an Earth observation mission over the next 15 years. These satellites will carry over 385 different instruments.

This sustained investment by the space agencies will ensure the provision of information of unique value in both public and commercial spheres, derived from the measurements of a diverse range of geophysical parameters and phenomena.

Public awareness of the applications of Earth observation satellites tends to focus on imagery (through internet applications such as Google Earth and Microsoft Live Local) and on meteorology, combined with the knowledge that data from meteorological satellites are used on a daily basis for the Numerical Weather Prediction models which drive our weather forecasting capabilities.

Meteorology is certainly one of the most established disciplines for application of Earth observation satellite data, with satellite-derived information being used operationally by weather services worldwide. Dedicated meteorological satellites have been in operation for several decades, providing continuous coverage of much of the globe.

In practice, only 80 missions, or around a third of those planned for the next 15 years, could be described as having meteorology as a primary objective. The other 160 missions will be applied to a diverse range of research, operational and commercial activities.

Given the significance of the issues, and the unique role of satellite Earth observations, many will be dedicated to different aspects of climate or environmental studies. Others will be employed to assist decision-making in strategic planning and management of industrial, economic and natural resources, including the provision of information required for sustainable development strategies. New missions serving operational needs related to land, ocean and atmospheric composition have recently been launched or will be in the near future.

Increased frequency of satellite measurements, improved satellite and sensor technology, and easier access and interpretation of Earth observation data have all contributed to increased demand for satellite data, and to the reality of new operational services being established in the near future for several domains, including monitoring of key oceanic and atmospheric parameters.

Information on the various missions and instruments, their capabilities and their applications is given in sections 8 (missions) and 9 (instruments).

For ease of discussion, the different instruments listed in section 9 may be considered under the following categories:

Instrument categories

- Atmospheric chemistry instruments
- Atmospheric temperature and humidity sounders
- Cloud profile and rain radars
- Earth radiation budget radiometers
- High resolution optical imagers
- Imaging multi-spectral radiometers (vis/IR)
- Imaging multi-spectral radiometers (passive microwave)
- Imaging microwave radars
- Lidars
- Multiple direction/polarisation instruments
- Ocean colour instruments
- Radar altimeters
- Scatterometers
- Gravity, magnetic field and geodynamic instruments

Plans for future missions and instruments include entirely new types of measurement technology, such as hyper-spectral sensors, cloud radars, lidars and polarimetric sensors that will provide new insights into key parameters of atmospheric temperature and moisture, soil moisture and ocean salinity. Several new gravity field missions aimed at more precise determination of the marine geoid are also planned. Importantly, every effort is being made to assure continuity of existing key measurements for the generation of long-term datasets. Agency plans also reveal that future priorities will include disaster management and studies of key Earth System processes – the water cycle, carbon cycle, cryosphere, the role of clouds and aerosols in global climate change, and sea level rise.

The following section gives a brief discussion of the different types of instruments flown on Earth observation satellite missions, including a list of the relevant instruments for each type from the full catalogue in section 9, a description of the operational characteristics, and pointers to the key applications. Information on specific measurement parameters is given in section 7.

6.1 Atmospheric Chemistry Instruments

Description

'Atmospheric chemistry instruments' is used here to describe a range of different types of instruments that use various techniques and different parts of the electromagnetic spectrum to undertake measurements of the atmosphere's composition. Each atmospheric gas is characterised by its 'absorption' and 'emission' spectra, which describe how the molecules respond to different frequencies of radiation. Remote sensing instruments exploit these 'signatures' to provide information on atmospheric composition, using measurements over a range of wavelengths, between UV and microwave.

Atmospheric absorption tends to be dominated by water vapour, carbon dioxide, and ozone, with smaller contributions from methane and other trace gases. Relatively broadband instruments can be used for measurements of the dominant gases, but high spectral resolution sensors are needed to make measurements of other species, since they produce weaker signals, and these must be discriminated from the signals from more abundant gases.

The instruments are typically operated in either:

- nadir-viewing mode: looking directly down to measure the radiation emitted or scattered in a small solid angle centred around a measurement point on the Earth, with resulting high spatial resolution in the horizontal direction, but limited vertical resolution; or

- limb-viewing mode: scanning of positions beyond the horizon to observe paths through the atmosphere at a range of altitudes – providing high vertical resolution (a few km) but limited horizontal resolution (tens of km at best) and particularly useful for studying the middle atmosphere.

Emission or absorption spectra can be studied in limb-viewing mode. One approach – known as occultation – uses known astronomical bodies (such as the Sun and stars) as well characterised target sources, and measures the effect of the Earth's atmosphere on the radiation reaching the satellite to determine atmospheric composition.

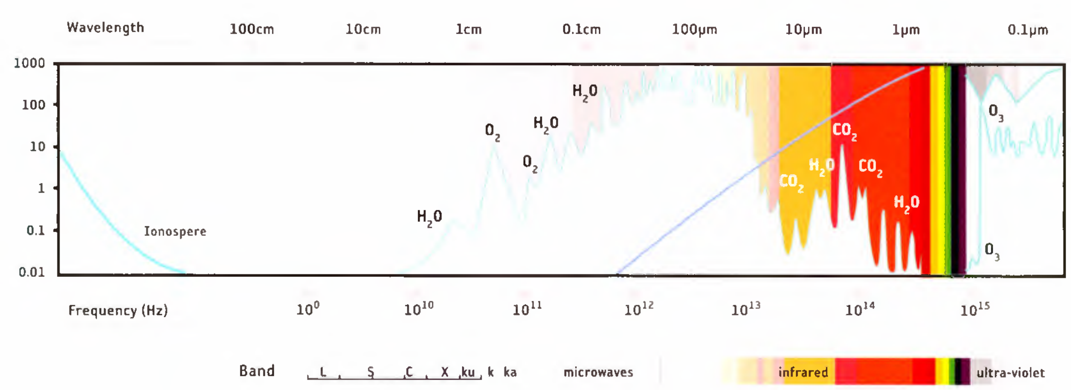
Applications

The earliest atmospheric chemistry instruments were deployed to help understanding of stratospheric ozone depletion. They succeeded in producing startling and convincing evidence of the growth of the Antarctic ozone hole. Many of the current and planned instruments continue to provide more sophisticated and accurate information on ozone chemistry in the atmosphere, including data related to gases and radicals which impact on the ozone cycle.

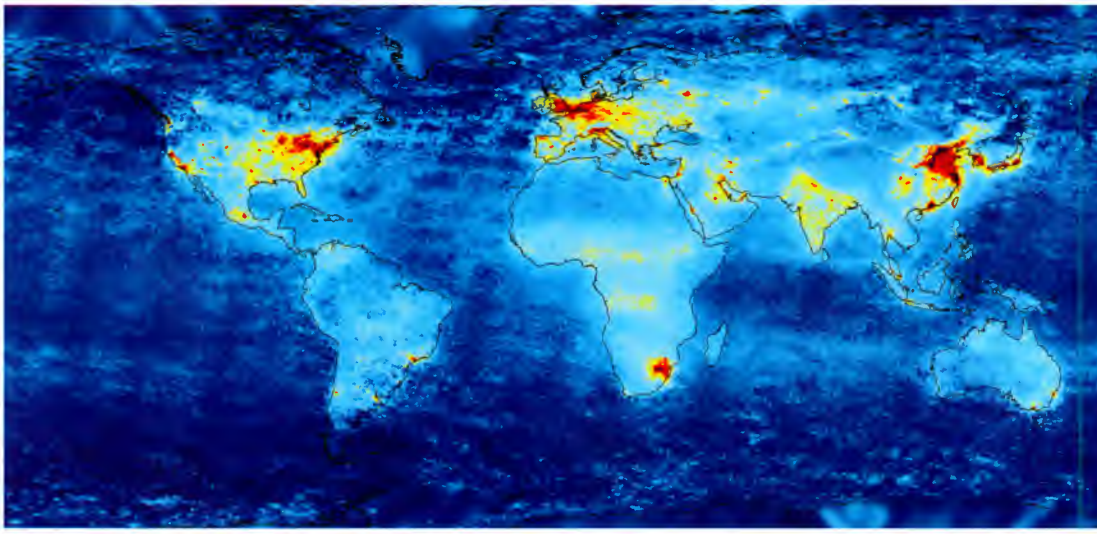
Agencies are addressing the need for sustained measurements of other key atmospheric constituents including CO_2, CO and CH_4. Research missions are also planned periodically to allow detailed examination of the complex details of atmospheric chemistry and the possibility that such details might be changing. The capability to provide a global picture of the atmosphere, and how it is changing on a daily, seasonal and geographical basis, is ensuring demand for these instruments in a wide range of applications. These include: pollution monitoring; climatology, including studies of the carbon cycle and support to policy-making processes such as the Kyoto Protocol; volcanic eruption monitoring; and operational meteorology.

Current & planned instruments

- ACE-FTS
- GOME
- GOME-2
- GOMOS
- HiRDLS
- IASI
- MAESTRO
- MAGIS
- MAVELI
- MIPAS
- MOPITT
- OMI
- OMPS
- OSIRIS
- SABER
- SBUV/2
- SCIAMACHY
- SMR
- Spectrometer (OCO)
- TANSO-FTS
- TES
- UVN (Sentinel-4)
- UVNS (post-EPS)
- UVNS (Sentinel-5 precursor)



Atmospheric transmittance and radiance for UV to IR regions.



A global air pollution (nitrogen dioxide) map produced by SCIAMACHY on Envisat.

The trend towards improved measurement resolutions and accuracies, profiling measurements (rather than total column measurements), and extended capability in the Upper Troposphere/Lower Stratosphere (UTLS) will further extend the value of these instruments in the coming years for monitoring air quality and modelling atmospheric processes.

Further Information

ACE-FTS: www.ace.uwaterloo.ca

GOMOS/MIPAS/SCIAMACHY: envisat.esa.int/instruments/index.html

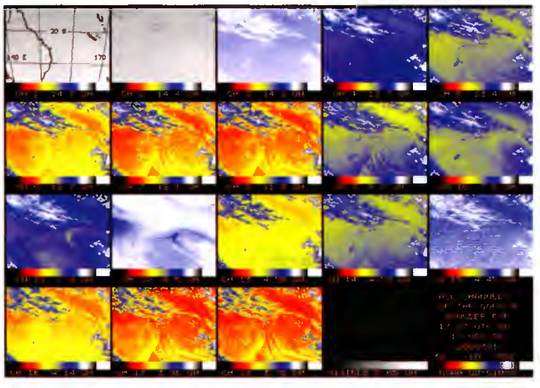
IASI: smsc.cnes.fr/IASI/

HIRDLS/MLS/OMI/TES: eos-aura.gsfc.nasa.gov/instruments/

6.2 Atmospheric Temperature and Humidity Sounders

Description

Atmospheric sounders generally make passive measurements of the distribution of IR or microwave radiation emitted by the atmosphere, from which vertical profiles of temperature and humidity through the atmosphere may be obtained. Oxygen or carbon dioxide is usually used as a 'tracer' for the estimation of temperature profiles, since they are relatively uniformly distributed throughout the atmosphere, so atmospheric temperature sounders often measure radiation at wavelengths emitted by these gases. For humidity profiling, either IR or microwave wavelengths specific to water vapour are used. Most measurements are conducted in nadir-viewing mode.



Atmospheric sounders provide crucial inputs to weather forecasting systems.

Sounders are able to estimate profiles of temperature and humidity by identifying radiation coming from different levels in the atmosphere. This is achieved by observations of the spectral broadening of an emission line, a phenomenon which is primarily caused by intermolecular collisions with other species, and which decreases with atmospheric pressure (a function of altitude).

Microwave sounders have the ability to sound through cloud and hence offer nearly all-weather capability. However, their spatial resolution (both vertical and horizontal) is generally lower than that of the IR instruments. IR sounders are routinely used to provide temperature profiles from a few km altitude to the top of the atmosphere with a temperature accuracy of 2–3K, a vertical resolution of around 10 km, and a horizontal resolution of between 10 and 100 km.

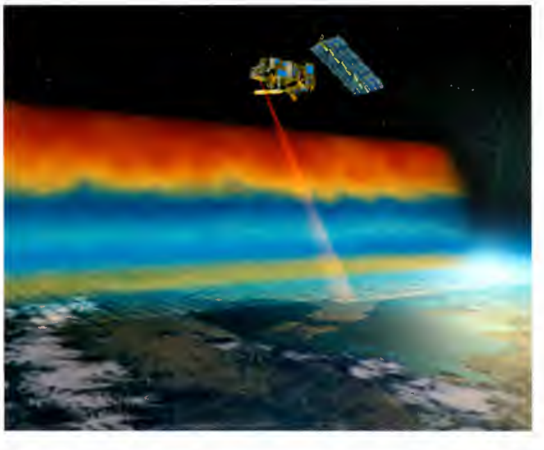
The latest generation of sounders, combining IR (AIRS, IASI, CrIS) and microwave (MHS, MIS, ATMS) capabilities feature improved accuracy of humidity and temperature measurements (of order 10% accuracy for humidity and below 1K for temperature); better spatial resolution (to 1 km); and improved capabilities in the upper atmosphere.

Observations of how the signals from Global Positioning Satellites (GPS) are affected as they travel through the atmosphere will be increasingly exploited, using a technique known as GPS occultation. This technique is used to determine profiles of the pressure, temperature and humidity, and will provide complementary information.

Applications

Since the launches of the first weather satellites in the 1960s, atmospheric sounders have provided valuable global observations of the atmosphere, even in the remotest areas. In 1969, the first temperature profile information estimated from satellite measurements was introduced into the Numerical Weather Prediction (NWP) models which are at the heart of daily weather forecasts. Even in those early days the new satellite measurements improved forecasts significantly for many areas once the challenges of data assimilation were addressed – initially in the Southern Hemisphere and later in the Northern Hemisphere.

Today, atmospheric sounders are used to infer a wide range of key atmospheric parameters on an operational basis (mostly on polar orbiting satellites), and their data are used by NWP models to such an extent that the satellite measurements are a vital and integral part of the global observing systems for operational meteorology. They also provide measurements of sea surface temperature, albedo, aerosols, trace gases,



Current & planned instruments

- AIRS
- AMSU-A
- AMSU-B
- ATMS
- ATOVS (HIRS/3 + AMSU + AVHRR/3)
- CHAMP GPS Sounder
- CMIS
- CrIS
- GOLPE
- GOX
- GRAS
- HIRS/3
- HIRS/4
- HSB
- IASI
- IKFS-2
- IMWAS
- IRAS
- IRS
- Lagrange
- MHS
- MIPAS
- MIS
- MLS (EOS-Aura)
- MTVZA-OK
- MWAS
- MWHS
- MWR
- MWTS
- Radiomet
- ROSA
- ROSA
- SABER
- SAPHIR
- SMR
- Sounder
- Sounder (INSAT)
- SSM/IS
- SSM/T-1
- SSM/T-2
- TANSO-FTS
- TOU/SBUS
- TRSR

precipitation, snow, ice, major fires and more, with frequent global coverage. Whilst these measurements do not usually have the highest spatial resolution or accuracy, they are important sources of information and can be combined with the accurate, but more limited coverage, provided by specialist instruments. These measurements of other variables are also important in allowing the generation of records of some variables extending back some 30 years. The same data are used for studies of extended weather and climate forecasting, and detection of climate change, including man-made change.

Further Information

AMSU-A: www.eumetsat.int/Home/Main/What_We_Do/Satellites/EUMETSAT_Polar_System

HIRS: www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-2.htm

Numerical Weather Prediction: en.wikipedia.org/wiki/Numerical_weather_prediction

Weather forecasting: en.wikipedia.org/wiki/Weather_forecasting

GPS radio occultation: en.wikipedia.org/wiki/GPS_meteorology

6.3 Cloud Profile and Rain Radars

Description

Cloud profile radars use very short wavelength (mm) radar (typically 94 GHz) to detect scattering from non-precipitating cloud droplets or ice particles, thereby yielding information on cloud characteristics such as moisture content and base height.

A 94 GHz cloud profiling radar has the unique property of being able to penetrate ice clouds with negligible attenuation and providing a range-gated profile of cloud characteristics.

Rain radars use microwave radiation (centimetre wavelengths) to detect backscatter from water drops and ice particles in precipitating clouds, and to measure the vertical profile of such particles. One of the key challenges with such radars is suppressing the return from the Earth's surface (ground clutter), which is inevitably much stronger than the rain echo. Recent instruments however, can map the 3D distribution of precipitating water and ice in a relatively narrow swath (around 200 km) along the track of a low altitude satellite, making it possible to infer more precise estimates of instantaneous rainfall.

The Precipitation Radar (PR) on the Tropical Rainfall Measuring Mission (TRMM), launched in 1997, was the first radar in space with the capability to measure rainfall. PR provided three-dimensional maps of storm structure and invaluable information on the intensity and distribution of rain, rain type and storm depth.

NASA's CloudSat uses an advanced 94 GHz radar to 'slice' through clouds to see their vertical structure, providing a completely new observational capability from space. These instruments are the first to study cloud profiles on a global basis, and to look at their structure, composition and effects. From 2013, the Global Precipitation Measurement (GPM) mission – an international cooperative programme – will provide more frequent and complete sampling of the Earth's precipitation using a constellation of satellites. As of 2013, the Japanese instrument onboard the ESA-JAXA EarthCARE mission, the 94 GHz CPR, will continue providing cloud profile observations, with increased sensitivity and additional Doppler capability to observe vertical motion.

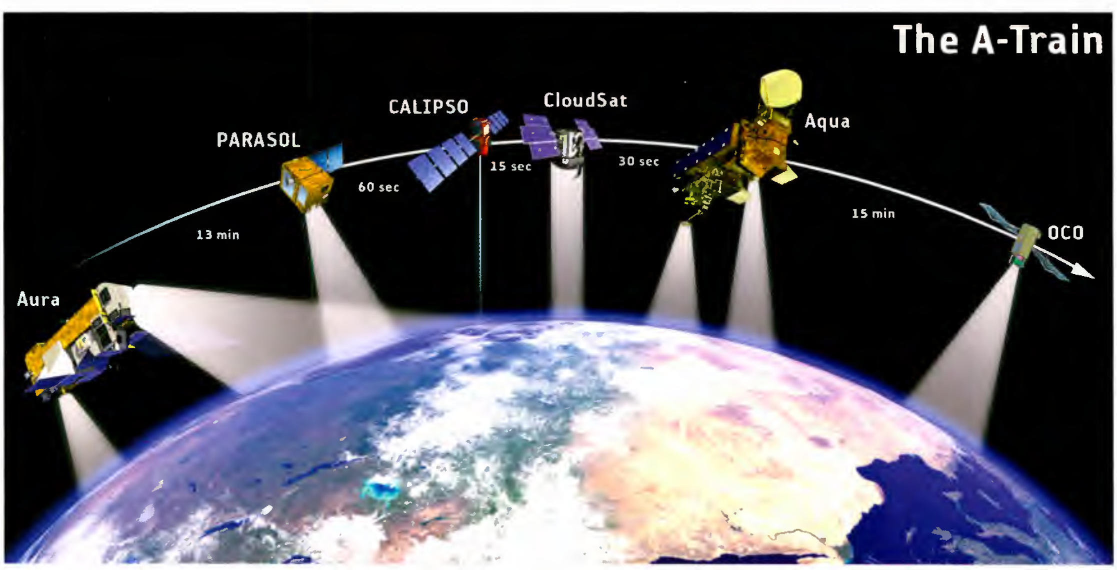
Current & planned instruments

- CPR (Cloudsat)
- CPR (EarthCARE)
- DPR
- PR

Applications

Measurements from cloud radar give information on cloud type and amount, and, more importantly, on cloud profile (currently not measured). This information is required both for improving numerical weather prediction and for climate studies. Scientists believe that some of the main uncertainties in climate model simulations are due to the difficulties in adequately representing clouds and their radiative properties. Satellite observations have now started to address this issue.

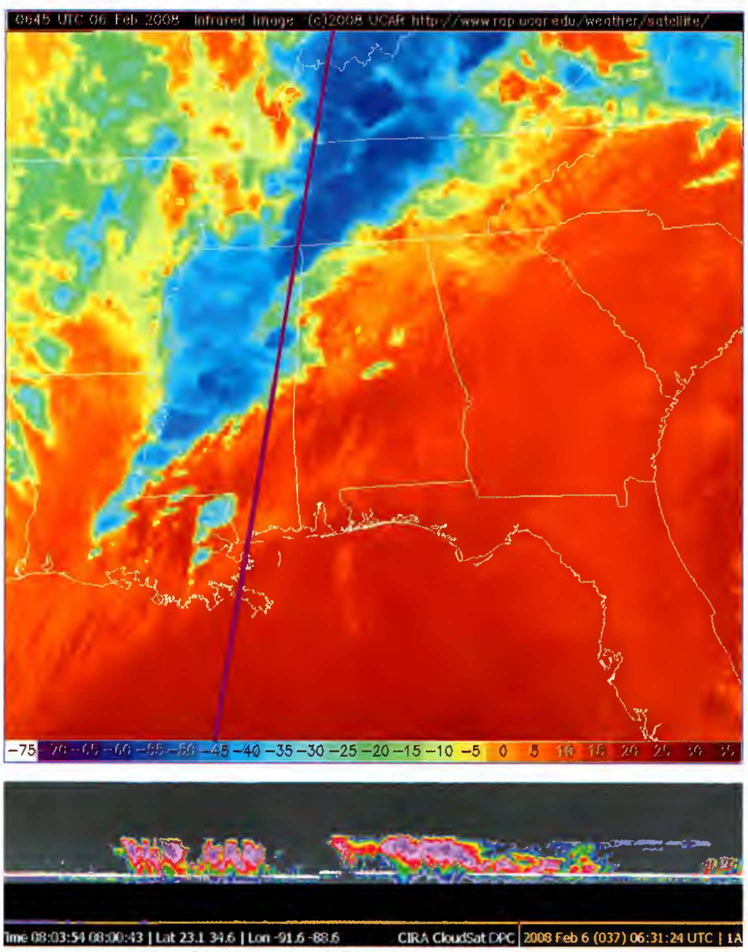
TRMM has demonstrated that spaceborne rain radars can provide a unique source of information on liquid water and precipitation rate, since the ground-based rain radars used at present have limited coverage over the oceans. The global precipitation datasets derived from TRMM have



CloudSat will fly in orbital formation as part of a constellation of satellites including Aqua, Aura (multi-sensor platforms that are a part of NASA's Earth Observing System), CALIPSO (a NASA-CNES lidar satellite), PARASOL (a CNES satellite carrying a polarimeter), and OCO (NASA's CO_2 measurement mission).

proved to be valuable tools for climatologists. Information on tropical rainfall and extreme events such as hurricanes is of particular importance, since more than two thirds of global rainfall is in the Tropics, acting as a primary driver of global atmospheric circulation.

The gap between termination of the TRMM mission (2009) and availability of the new information anticipated from GPM (no earlier than 2013) is of concern to scientists studying the Earth's global water cycle. CEOS has initiated a virtual precipitation constellation study team to address this and related coordination issues.



CloudSat profiles a tornado outbreak in February 2008.
Upper image is a night-time colour infrared view from GOES with overlay of the CloudSat track.
Lower image shows cloud profile data from CloudSat.

Further Information

CPR (Cloudsat): cloudsat.atmos.colostate.edu/instrument

Precipitation radar: trmm.gsfc.nasa.gov/overview_dir/pr.html

Global Precipitation Measurement (GPM) mission: gpm.gsfc.nasa.gov/index.html

6.4 Earth Radiation Budget Radiometers

Description

The Earth's radiation budget is the balance between the incoming radiation from the Sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space. A number of instruments contribute to measurements of these parameters. The discussion here focuses on those instruments specifically designed to study radiation budget as their sole or primary mission.

In general, different instruments are used to measure the different components of the radiation budget:

- to cover the full range of incoming solar radiation (0.2 – 4.0 µm);
- to monitor the long-wave emitted Earth radiation (3 – 100 µm);
- to measure the reflected short-wave radiation from the Earth.

The instruments offer high radiometric accuracy to provide accurate absolute measurements (~ 1 W/m² is needed). Most radiometers have a narrow field of view and are used to measure the radiance in a particular direction. Using this, together with information on the angular properties of the radiation, the flux may be obtained. Advanced instruments have a directional capability and channels which allow study of the anisotropy and polarisation characteristics of the radiation fluxes.

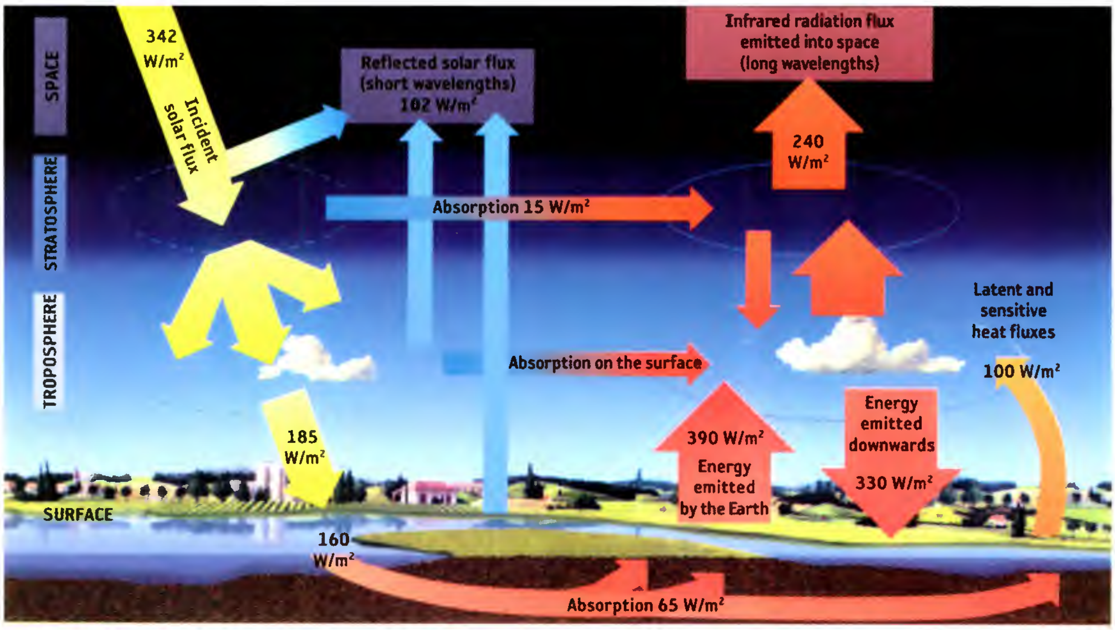
To provide the much needed improvement of temporal sampling of the Earth radiation budget (ERB), observations by the Geostationary Earth Radiation Budget (GERB) instrument on EUMETSAT's Meteosat 8 and 9 are being used. This instrument provides measurements of the ERB every 15 minutes, providing a unique view of the diurnal cycle.

Applications

Solar radiant energy is a major driver of the Earth's climate. The reflection, absorption and re-emission of that energy occurs through a complex system of clouds, aerosols, atmospheric constituents, oceans, ice and land surfaces. Variations in this complex system are the source of changes in the Earth's radiation balance. The input of energy from the Sun is not constant and its small variations with sunspots and other factors cause some small, but significant, modification of the Earth's climate. Seemingly small (0.5%) changes in the total solar irradiance (TSI) over a century or more may cause significant climatological changes, and models suggest that as much as 25% of the recent global warming of the Earth may be solar in origin. Measurements of radiation leaving the Earth suggest some changes in the components of this radiation in recent decades, so sustained measurements are critical to allowing future improved knowledge and understanding.

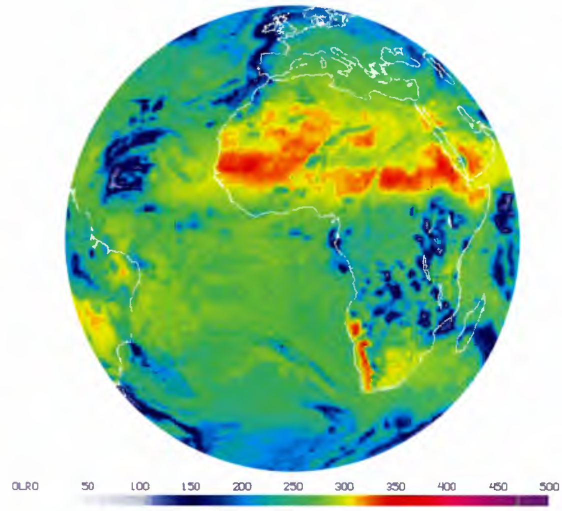
Current & planned instruments

- ACRIM III
- BBR (EarthCARE)
- CERES
- ERM
- GERB
- PREMOS
- ScaRaB
- SIM
- SIM
- SODISM
- SOLSTICE
- SOVAP
- SXI
- TIM
- TSIS



The Earth's energy budget. The numbers indicate the average energy fluxes over one year, at a global scale.

Especially when coupled with other information on clouds, aerosol and land cover, radiometers offer a unique contribution to understanding of the Earth's radiation budget, together with its relationship to global warming – such as that resulting from the greenhouse effect. Cloud and aerosol feedbacks related to global warming caused by greenhouse gases have long remained the most uncertain aspect of understanding and predicting future climate change, and improved climate projections depend on gaining the information to detail these feedbacks. Planned measurements will have unprecedented accuracy (0.1%) and precision (relative changes of 0.03%). This is necessary for detecting the small changes in Earth's radiances that correspond to the incremental changes in our climate system and which could be of major importance for humankind far into the future.



Outgoing Longwave Radiation (OLR) as measured by GERB.

Further Information

Earth radiation budget: www.atmosphere.mpg.de/enid/252.html

PICARD: smsc.cnes.fr/PICARD

TIM/SIM/SOLTICE: lasp.colorado.edu/sorce/index.htm

GERB: www.sstd.rl.ac.uk/gerb

ACRIMSAT: acrim.jpl.nasa.gov

6.5 High Resolution Optical Imagers

Description

High resolution optical imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100 m and swath widths of order 100 km. In the past few years, high resolution sensors have emerged with spatial resolution in the range 1 to 5 m. An increasing number of government-funded and private sector-funded sensors with sub 5 m resolution are planned for the coming years.

High resolution imagers are, in general, panchromatic (a single waveband) and multi-spectral (multiple waveband) sensors, with spectral bands in the visible and IR range which are simultaneously recorded. This increases the information content that may be derived from the imagery (including the ability for land cover classification) and allows corrections to be made, for example, for the effects of atmospheric water vapour on the measured surface parameters. In order to reduce atmospheric absorption and to increase image quality, the operating wavelengths of these instruments are selected to coincide with atmospheric windows.

Use of these sensors can be limited by weather conditions, since they are unable to penetrate thick cloud, rain or fog and are typically restricted to fair weather, daytime-only operation. Some have pointing capability which enables imagery of specified areas to be acquired more frequently.

Many countries, including developing countries, have and/or are planning high resolution optical imaging missions. Future trends will include a greater number of sampling channels, as well as improved spectral and spatial resolution. More instruments will also become available that are capable of producing stereo images from data collected on a single orbit, i.e. along track, as opposed to across track, so that stereo images can be acquired from different passes.

Applications

High resolution optical imagers are amongst the most common Earth observation satellite instruments, finding application in, for example:

- agriculture, including definition of crop type and area, crop inventory, yield prediction and crop stress identification;
- damage assessment associated with natural hazards;
- geological mapping;
- urban planning, including land cover mapping, topographic mapping and urban development monitoring;
- cartography, including map generation and updating, generation of digital elevation models;
- environmental planning and monitoring.

SPOT 5, launched in May 2002, features imaging sensors with 2.5 m resolution. This image is of Rome.

Current & planned instruments

ALI
ASTER
AVNIR-2
AWiFS
CCD
CCD (HJ, HY)
DMC Imager
DMC-2 Imager
Geoton-L1
High Resolution Panchromatic Camera
HiRI
HRG
HRMS
HRS
HRTC
HRV
HRVIR
IR-MSS
IRS
KMSS
LISS-III (IRS)
LISS-III (RESOURCESAT)
LISS-IV
MBEI
MIREI
MSC
MSI
MSS (Roscosmos)
MSU-200
NigeriaSat Medium and High Resolution
PAN
PAN (BJ-1)
PAN (Cartosat-1)
PAN (Cartosat-2)
PAN (Cartosat-3)
PAN (GISTDA)
PAN (IRS-1C/1D)
PAN CAMERA
PAN+MS (RGB+NIR)
PRISM
TES PAN
TOPSAT telescope
WFI
WiFS

A town in Thailand imaged by the LISS-IV sensor on ISRO's Resourcesat-1.

Further Information

ALOS (AVNIR-2 & PRISM): www.jaxa.jp/missions/projects/sat/eos/alos/index_e.htm

SPOT: www.spotimage.fr

Landsat: landsat.usgs.gov

CBERS: www.cbers.inpe.br/en/index_en.htm

TOPSAT: www.qinetiq.com/home/defence/defence_solutions/space/topsat.html

6.6 Imaging Multi-spectral Radiometers (vis/IR)

Description

Visible/IR imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at spatial resolutions of order 100 m up to several km, with a swath width generally in the range several hundred to a few thousand km.

In addition, these observations can be used to study critical components of the water cycle, such as cloud macro- and micro-physical properties, from which information on atmospheric dynamics and pollutants can be determined.

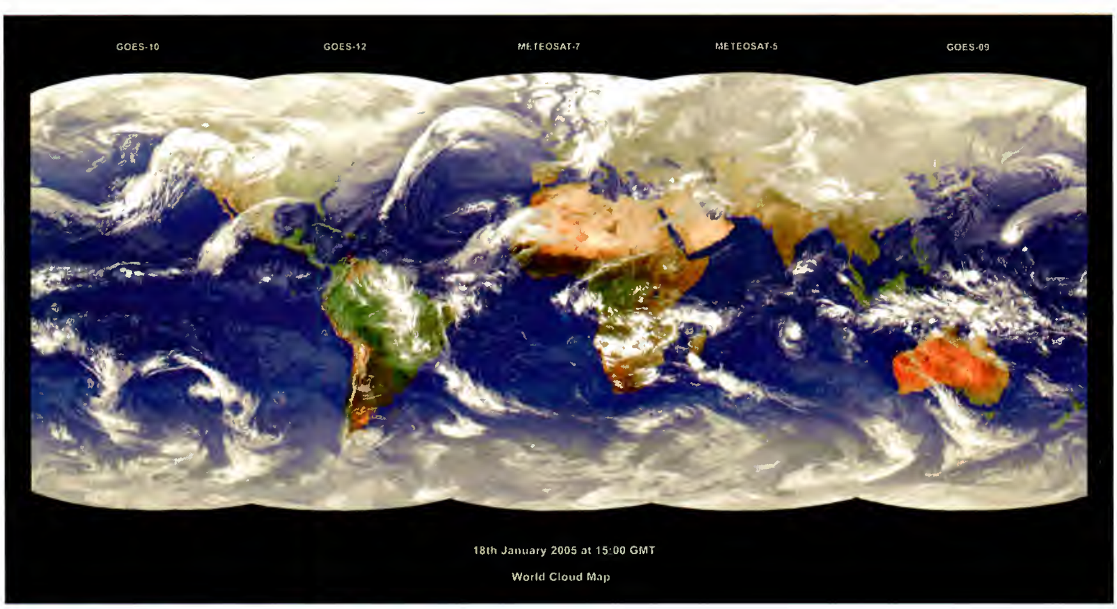
The information obtained from these instruments is often complemented by that from atmospheric sounders, since atmospheric effects such as absorption must be taken into account in deriving parameters such as surface temperatures.

Recent developments include improvements in spatial resolution (which, in some cases, is equivalent to those of high resolution imagers), spectral resolution, radiometric accuracy and multi-angle capability. Planned hyperspectral instruments that will be able to simultaneously acquire imagery in many tens of wavebands should significantly improve the quality of land cover and land use information derived from satellite imagery.

Applications

Measurements from these multi-spectral radiometers operating in IR and visible bands may be used to infer a wide range of parameters, including sea and land surface temperatures, snow and sea ice cover, and Earth's surface albedo. These instruments may also make measurements of cloud cover and cloud top temperatures. Measurements of the motion vectors of clouds made by radiometers on geostationary satellites may be used in order to derive tropospheric wind estimates. Accurate information on atmospheric dynamics, derived from the instruments mounted on geostationary meteorological satellites like GMS, GOES or Meteosat, is essential for precise short- and medium-term weather forecasts provided by NWP centres in Japan, the U.S. and Europe.

Visible/IR radiometers are an important source of data on processes in the biosphere, providing information on global vegetation and its variations on subseasonal scales. This allows monitoring of natural, anthropogenic, and climate-induced effects on land ecosystems. Observations by AVHRR on NOAA and MetOp are traditionally used to provide classification and seasonal monitoring of global vegetation types, allowing estimation of primary production (the growth of vegetation that is the base of the food chain) and terrestrial carbon balances. Such information is of great value in supporting the identification of drought areas and provides early warning of food shortages.



A geostationary satellite composite cloud map. Data from these satellites are an essential input to today's weather forecasting systems.

Current & planned instruments

- AATSR
- ABI
- ATSR-2
- AVHRR/3
- CCD camera
- CHRIS
- CZI
- ETM+
- FCI
- HRMX-TIR
- HRMX-VNIR
- HSI
- HSI (HJ-1A)
- HSMS
- HSS
- HYC
- Hyperion
- HySI (IMS-1)
- HySI (TES-HYS)
- HyS-SWIR
- HyS-VNIR
- IIR
- Imager
- Imager (INSAT)
- IMAGER/MTSAT-2
- IR (HJ-1B)
- IVISSR (FY-2)
- JAMI/MTSAT-1R
- LEISA AC
- MCSI
- MERIS
- MMRS
- MOC
- MODIS
- MS (GISTDA)
- MSI (BJ-1)
- MSI (EarthCARE)
- MSS
- MSU-GS
- MSU-MR
- MUX
- MVIRI
- MVIRS
- MVISR (10 channels)
- MxT
- NigeriaSat Medium Resolution
- OBA
- OLI
- OLS
- Panchromatic High Sensitivity Camera
- PSA
- PSS
- RASAT VIS Multi-spectral

List continues on the next page

RASAT VIS Panchromatic
RDSA
SEVIRI
SGLI
SumbandilaSat Imager
TANSO-CAI
TIR (OCEANSAT-3)
TM
VEGETATION
VHRR
VIIRS
VIRR
VIRS
VSC
WFC
WFI-2
WS LISS-III

This spectacular 'blue marble' image, produced in early 2002 using data from MODIS, is the most detailed true-colour image of the entire Earth to date.

Further Information

AVHRR: eros.usgs.gov/products/satellite/avhrr.html

SEVIRI (Meteosat):
www.eumetsat.int/Home/Main/What_We_Do/Satellites/Meteosat_Second_Generation/index.htm?l=en

IMAGER (GOES): noaasis.noaa.gov/NOAASIS/ml/imager.html

MODIS: modis.gsfc.nasa.gov

VEGETATION: vegetation.cnes.fr

6.7 Imaging Multi-spectral Radiometers (Passive Microwave)

Description

Operating at microwave wavelengths, these instruments have the advantage of cloud penetration and all-weather capability. Channels within 1 to 40 GHz and 80 to 100 GHz are used to get day/night information on the Earth's surface. They have the advantage over visible/IR radiometers of being able to probe the dielectric properties of a surface or penetrate certain surfaces, a capability that is especially useful with vegetation, soil, sea ice and snow. Observations by instruments like AMSU-A, with channels between 50 and 60 GHz, are used for deriving atmospheric parameters, especially atmospheric temperature.

Like other microwave instruments, these passive instruments offer accurate spectral information but their spatial resolution is poor. At 90 GHz, their spatial resolution is typically 5 km, and for the lower frequencies it is of order tens of kilometres – poorer than that of their visible or infrared counterparts. As a consequence, they are most used for global analysis rather than regional or local, although some instruments are used to correct measurements from other sensors, rather than for imaging applications. These include the microwave radiometers on the ERS/Envisat and Topex/Poseidon/Jason series satellites, which are used to estimate and correct for atmospheric water vapour content in the column through which altimetric readings are being taken.

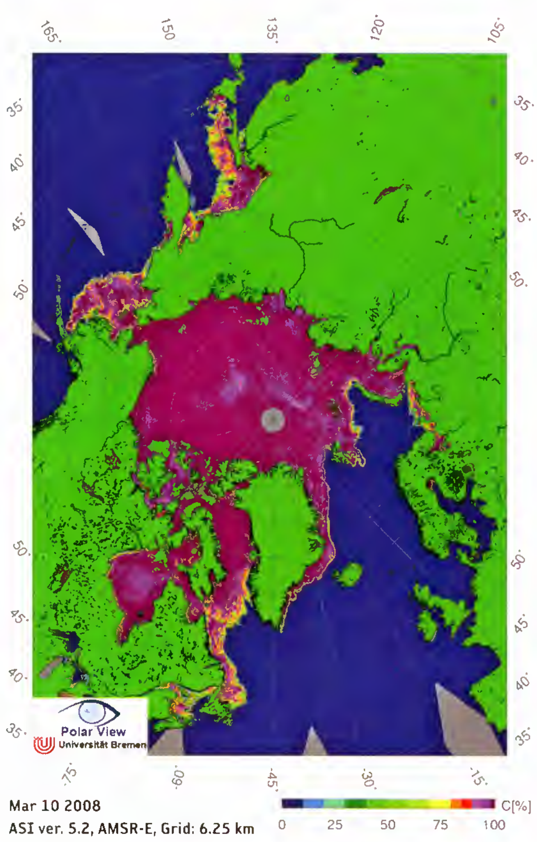
Applications

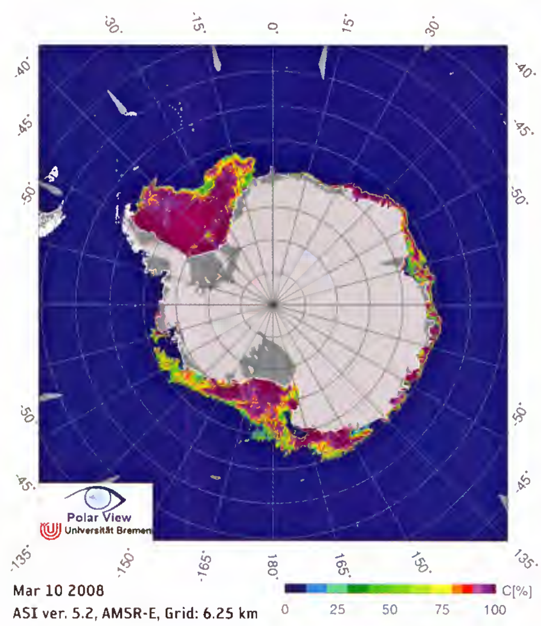
Measurements from these instruments may be used to infer a range of atmospheric and Earth surface parameters. One of their primary uses (often in conjunction with other instruments) is snow and ice mapping, due in part to their capability for cloud penetration. Current applications of passive microwave radiometer data include operational forecasting and climate analysis, and the prediction of sea ice concentration, extent and ice type. Passive microwave radiometers are also used to provide information on the liquid water content of clouds (e.g. the GPM mission).

These instruments can also supply some information on soil moisture content, which is a key surface parameter in agriculture, hydrology and climatology, and provides a measure of vegetation health. Furthermore, they are capable of contributing some information on ocean salinity, which is important to our understanding of ocean circulation. Developing these capabilities is a current research task.

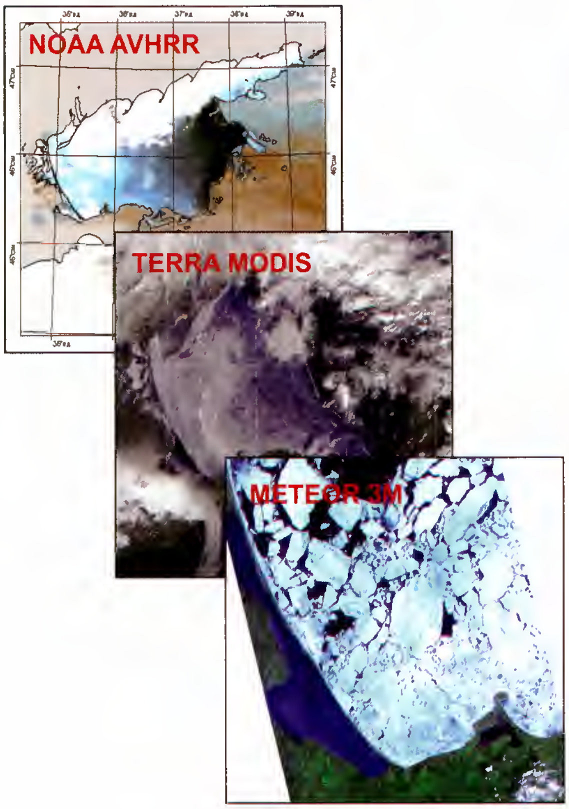
Current & planned instruments

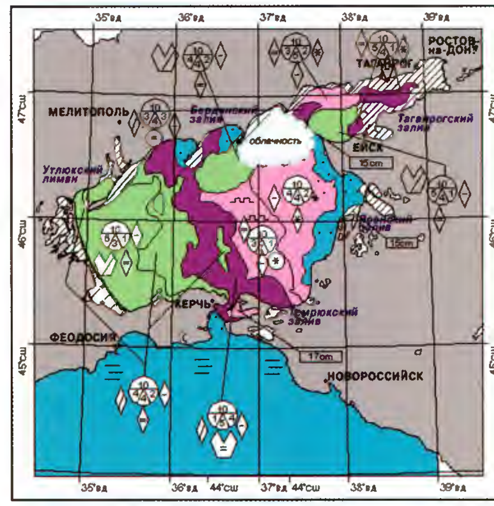
- AMR
- AMSR-2
- AMSR-E
- ATSR/M
- CMIS
- GMI
- GMI
- JMR
- L-band Radiometer
- MADRAS
- MERSI
- MI
- MIRAS
- MIRAS (SMOS)
- MIS
- MSI (Sentinel-2)
- MSMR
- MTVZA
- MWR
- MWRI
- OLCI
- PMR
- RAD
- SAR L
- SLSTR
- SSM/I
- TMI
- Water Vapour Radiometer



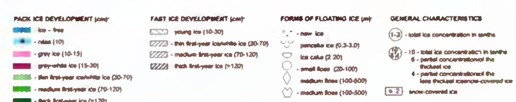


JAXA's AMSR-E instrument is used to produce daily maps of sea ice and to monitor changes in polar sea ice extent. (Credit: Univ Bremen/JAXA)





Sea ice chart of the Azov Sea for 02 March 2005



Sea ice condition chart of the Azov Sea derived from NOAA/AVHRR, TERRA/MODIS, METEOR-3M/MSU-E. Various satellites are used operationally to generate vital sea ice map products by Russian authorities.

Further Information

AMSR-E: sharaku.eorc.nasda.go.jp/AMSR/index_e.htm

CMIS: www.ipo.noaa.gov/Technology/cmis_summary.html

MWR: envisat.esa.int/instruments/mwr/

SSM/I: nsidc.org/data/docs/daac/ssmi_instrument.gd.html

EUMETSAT ocean and sea ice: www.osi-saf.org

6.8 Imaging Microwave Radars

Description

These instruments transmit at frequencies of around 1 to 10 GHz and measure the backscattered signals to generate microwave images of the Earth's surface at high spatial resolutions (between 10 m and 100 m),with a swath width of 100–500 km. Both synthetic aperture radars (SARs) and some real aperture side-looking imaging radar systems fall into this category. The images produced have a similar resolution to those from high resolution optical imagers, but radars have the capability to 'see' through clouds, providing data on an all-weather, day/night basis.

SARs also have the ability to penetrate vegetation and to sample surface roughness and surface dielectric properties. They may also be used to obtain polarisation information. Although the operating wavelength is generally fixed for a given radar, radars operating at a variety of wavelengths (typically L-, C- and X-band) will be increasingly available during the next decade.

The beam shape and direction of new generation SARs enable imagery to be acquired more frequently from many points on the Earth. Multipolarised SARs (such as ASAR on Envisat and PALSAR on ALOS) enable land cover to be classified more accurately and will soon provide improved data on biophysical parameters such as soil moisture and biomass.

A number of bistatic radar system concepts (such as BISSAT) are under study. A bistatic radar is a system that operates with separated transmitting and receiving antennae. A number of large active radar missions are foreseen for the coming decade, providing an opportunity to fly relatively small satellite missions with passive payloads in formation with one of these missions in order to gather the backscatter information.

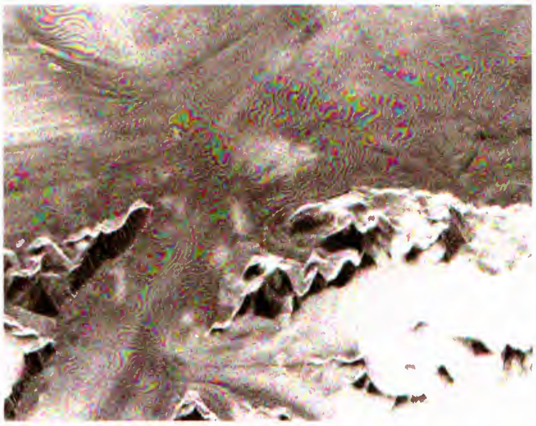
Applications

Although a variety of backscatter measurements may be taken by imaging radars, interpretation of these measurements is a complex science that, in some respects, is still developing. However, significant advances have been made in a number of areas and some SAR applications are now fully operational.

Backscatter from the ocean can be used to deduce surface waves, to detect and analyse surface features such as ocean fronts, eddies and oil slicks, and to detect and track ships from their wakes. Operational wave and sea ice forecasting is also an important near real-time application of SAR data.

Since land images may be used to infer information on vegetation type and cover, they are of use in forestry and agriculture. The ability of SARs to penetrate cloud cover makes them particularly valuable in rainforest studies and resource monitoring applications. The information obtained from such images depends upon the characteristics (e.g. wavelength) of the probing radiation. Under certain conditions, for example, some penetration of vegetation may be feasible. Such imagery is often used in order to complement visible/IR multi-spectral imagery by, in effect, providing an additional microwave channel. One of the most important current applications of imaging radars, however, is in all-weather measurements of snow and ice sheets, from which information on topography and texture may be inferred. Flood detection is another proven capability of SAR.

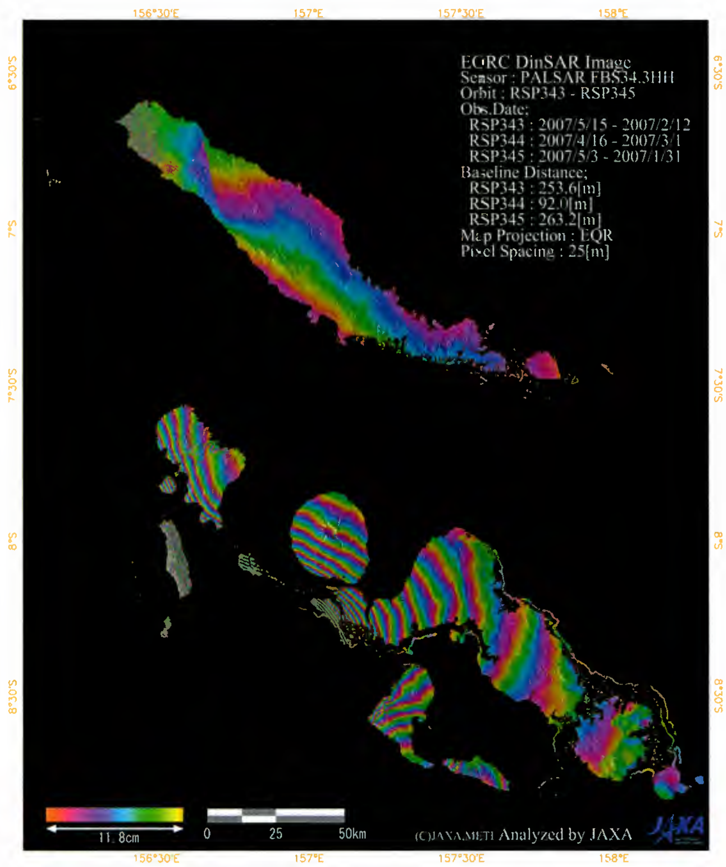
A technique known as interferometry is used to record the phase shift between two SAR images recorded at slightly different times and viewing angles. This provides accurate information on the motion of surfaces and targets such as sea ice and ice sheets, and allows large scale 3D topographical images to be produced. Similar stereo images may be produced using conventional SAR images taken on adjacent orbits. Since differential SAR interferometry can detect ground movements at millimetre/sub-millimetre level, it is of interest in the context of tectonic and volcanic hazard studies, and in studies of subsidence in urban areas.



ERS-2/Envisat interferogram of a fast-moving (>1 m/h) glacier in Greenland.

Current & planned instruments

- AMI/SAR/Image
- AMI/SAR/Wave
- ASAR
- ASAR (image mode)
- ASAR (wave mode)
- BRLK
- C/X SAR
- C-band SAR
- PALSAR
- SAR (MAPSAR)
- SAR (RADARSAT)
- SAR (RADARSAT-2)
- SAR (RCM)
- SAR (RISAT)
- SAR (Roshydromet)
- SAR (SABRINA)
- SAR 2000
- SAR-L (SAOCOM)
- S-band SAR
- WSAR
- X-band SAR



PALSAR interferogram of deformation caused by an April 2008 earthquake in the Solomon Islands.

Further Information

ASAR: envisat.esa.int/instruments/asar/index.html

PALSAR: www.palsar.ersdac.or.jp/e/index.shtml

RADARSAT:gs.mdacorporation.com/products/sensor/radarsat/radarsat1.asp

Terrasarr-X: www.dlr.de/tsx/start_en.htm

6.9 Lidars

Description

Lidars (LIght Detection And Ranging instruments) measure the radiation that is returned either from molecules and particles in the atmosphere or from the Earth's surface when illuminated by a laser source. Compared with radar, the shorter wavelengths used in a lidar allow greater detail to be observed. On the other hand, the light cannot penetrate optically thick layers such as clouds.

There are different types of lidar instrument:

- the backscatter lidar, in which the laser beam is backscattered, reflected or re-radiated by the target, gives information on the scattering and extinction coefficients of the various atmospheric layers being probed;
- the differential absorption lidar analyses the returns from a tuneable laser at different wavelengths to determine densities of specific atmospheric constituents, as well as water vapour and temperature profiles;
- Doppler lidar measures the Doppler shift of the light backscattered from particles or molecules moving with the wind, thereby allowing the determination of wind velocity;
- the ranging and altimeter lidar provides accurate measurements of the distance from a reference height to precise locations on the Earth's surface.

The first satellite-borne ranging and altimeter lidar, GLAS, is flying on the NASA ICESat mission which was launched in January 2003 to study the variations of ice topography, as well as cloud and atmospheric properties. In April 2006, the CALIOP backscatter lidar, flying on the NASA CALIPSO platform, was launched to measure cloud and aerosol properties. ESA is currently implementing two laser missions, ADM-Aeolus and EarthCARE. The ALADIN high spectral resolution Doppler wind lidar on board ADM-Aeolus will measure profiles of line-of-sight winds globally. The ATLID high spectral resolution lidar on board EarthCARE will measure cloud and aerosol optical properties.

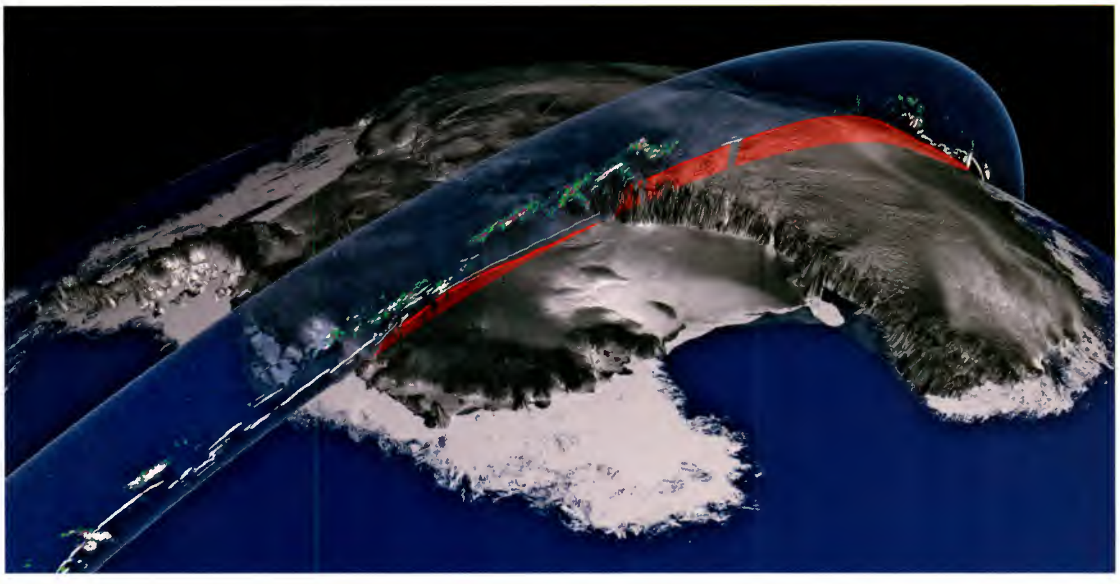
Current & planned instruments

ALADIN
ATLID
CALIOP
GLAS
GLAS Follow-on

Applications

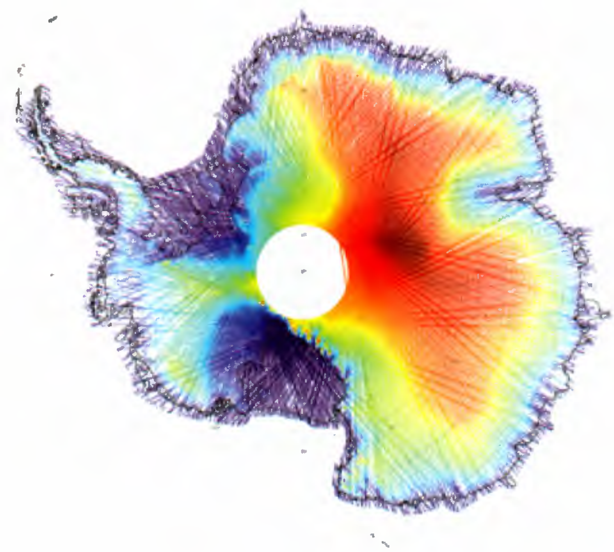
The different types of lidars may be used to measure a diverse range of parameters. Ranging and altimeter lidars may be used to provide surface topography information, for example on ice sheet height and land altitude. Missions planned within the next few years will undertake to determine the mass balance of the polar ice sheets and their contributions to global sea level change; others will focus on study of the vegetation canopy structure and provide unique data sets, including estimations of global biomass and carbon stocks, and fractional forest cover.

Multifrequency and high spectral resolution ranging lidars with probe wavelengths in the UV, visible and near IR will be used to measure aerosol height distributions, heights of clouds and their vertical profiles. Differential absorption and backscatter lidar may be used to measure aerosol and cloud properties as well as atmospheric composition. Doppler lidars may be used to measure wind profiles in clear air (i.e. in the absence of clouds or winds above clouds) and within optically thin layers. The capability of



ICESat swath over Antarctica.

measuring clear air winds is of particular importance since it will correct a major deficiency in wind-profiling of the current global meteorological observing systems. Instruments such as ESA's ALADIN on ADM-Aeolus will provide wind profile measurements to establish significant advances in atmospheric prediction and analysis.



ICESat's measurements of Antarctica's topography, using data collected from 3 October to 8 November 2004.

Further Information

ALADIN: www.esa.int/esaLP/LPadmaeolus.html

ATLID: www.esa.int/esaLP/LPearthcare.html

GLAS: icesat.gsfc.nasa.gov

CALIOP: www.nasa.gov/mission_pages/calipso/main/

6.10 Multiple Direction/Polarisation Instruments

Description

Advances in satellite instrumentation have resulted in a general trend towards multi-functional capabilities in many types of sensors, resulting in instruments with the capability to operate using different viewing modes and angles, as well as multiple polarisations. The latest SAR instruments demonstrate this trend. The category of 'multiple direction/polarisation instruments' is used here, however, to describe instruments which are custom built for observing the directional or polarisational characteristics of the target's signature (either visible/IR or microwave), as a means of deriving geophysical information.

Multi-directional radiometers can make observations from more than one incidence angle of the diffused or emitted radiation emitted by a particular element of the Earth's surface or clouds. In this way, information on anisotropies in the radiation may be identified. The emphasis in these instruments is on spectral (rather than spatial) information, with the result that the detection channels, which typically span the visible to the IR, are precisely calibrated and the spatial resolution is usually about 1 km.

Polarimetric radiometers are used for applications in which radiative information is embedded in the polarisation state of the transmitted, reflected or scattered wave. Some polarimetric radiometers also have a multi-directional capability, so that directional information can be determined or used during retrievals of geophysical parameters.

Applications

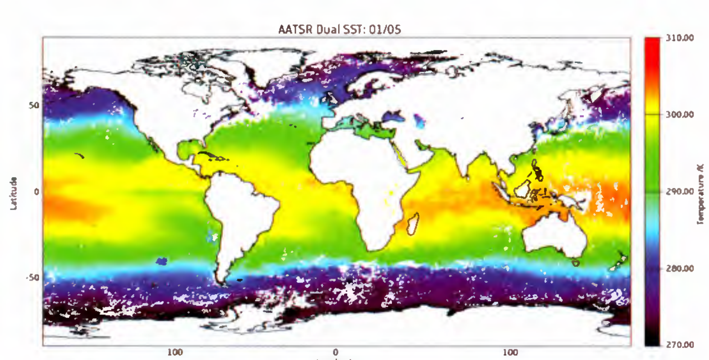
Using IR channels, multiple-angle viewing capabilities are used to achieve accurate corrections for the effects of (variable) atmospheric absorption, making it possible to infer precise temperature values, for example, of sea and land surfaces. Multi-directional radiometers are also capable of measuring cloud cover and cloud top temperatures, together with atmospheric water vapour and liquid water content.

In the visible and near IR spectrum, these instruments allow for improved measurements of the scattering properties of particles such as aerosols, as well as measurement of the angular characteristics of the various contributions to the Earth's radiation budget, including surface albedo. They also enable accurate measurement of parameters such as Normalised Difference Vegetation Indices (NDVI), which are used to assess vegetation state and crop yield at regional and global scales. MISR, currently flying on NASA's Terra mission, is providing new types of information for scientists studying Earth's climate, such as the partitioning of energy and carbon between the land surface and the atmosphere, and the regional and global impacts of different types of atmospheric particles and clouds.

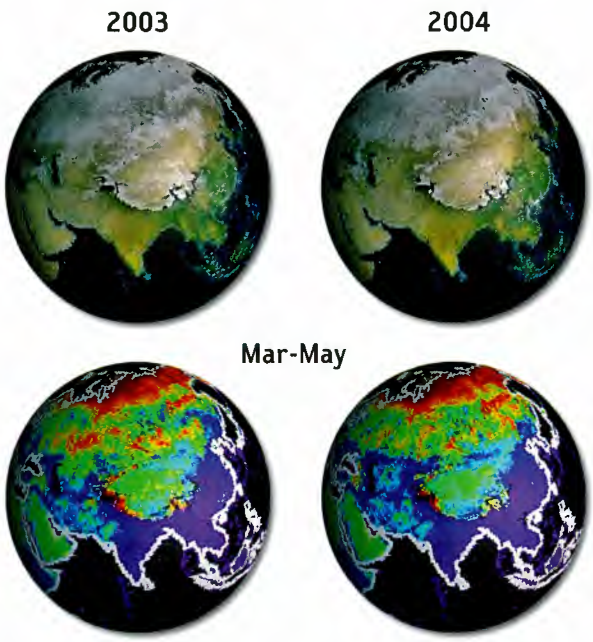
Polarisation information is used to infer a variety of parameters, including the size and scattering properties of liquid water, cloud particles and aerosols, while providing additional information on the optical thickness and phase of clouds. Polarimetric radiometers also provide information on the polarisation state of the radiation backscattered from the Earth's surface, supplementing measurements obtained from other land and sea imaging instruments. Such measurements are of interest in a range of applications from investigations of albedo and reflectance to agriculture and the classification of vegetation. ESA's SMOS mission, planned for launch in 2009, will use an L-band (1.4 GHz) microwave interferometer to measure estimates of soil moisture (a key variable for numerical weather and climate models) and ocean surface salinity (important for ocean circulation models).

Current & planned instruments

- AATSR
- APS
- ATSR-2
- MAPI
- Microwave Radiometer (CONAE)
- MIRAS (SMOS)
- MISR
- POLDER-P
- WindSat



AATSR and its predecessors ATSR-1 and ATSR-2 have obtained over 13 years of sea surface temperature measurements with the accuracy required for climate research.



Seasonal changes in Earth's surface albedo as measured by the MISR instrument on the Terra mission.

Further Information

MISR: www-misr.jpl.nasa.gov

AATSR: envisat.esa.int/instruments/aatsr

SMOS: www.esa.int/esaLP/LPsmos.html

POLDER-P: directory.eoportal.org/presentations/501/9317.html

6.11 Ocean Colour Instruments

Description

Ocean colour radiometers and imaging spectrometers measure the radiance leaving marine waters in the visible and near IR spectrum in the range 400–800 nm, where the colour is characterised by the constituents of the water – typically phytoplankton, suspended particulate material and dissolved compounds. Differences in the intensity of light received in the different bands give information on the concentration of a variety of substances present in the ocean.

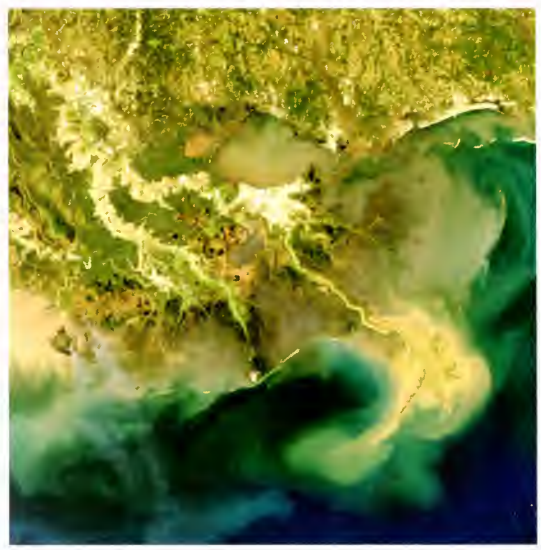
These instruments have very narrow detection channels, around 10 nm wide, to measure fine spectral details. The spatial resolution of these instruments is typically 0.3 to 1 km. The more recent ocean colour instruments have improved spatial, spectral and radiometric resolution. The trend towards multi-channel, multi-purpose sensors, such as MODIS and MERIS, is resulting in more instruments with an 'ocean colour' capability.

Significant calibration and validation activities, together with algorithm development for ocean colour instruments, continues – particularly with respect to measuring ocean productivity.

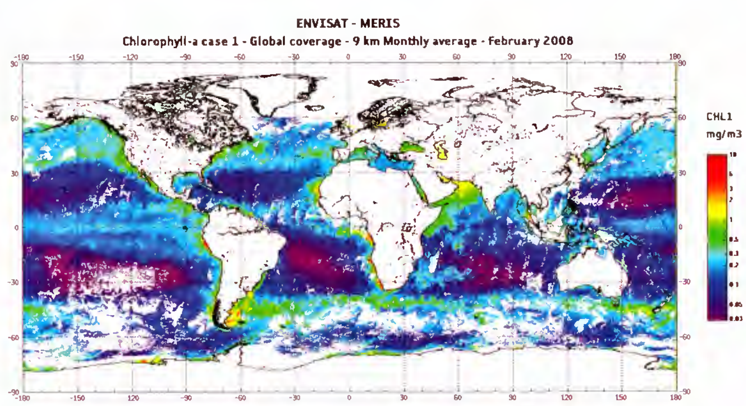
Applications

The colour of the oceans as seen from space reveals phytoplankton pigment concentration (chlorophyll), which is used as an indirect measurement of ocean biomass and its associated productivity.
These parameters are of considerable oceanographic and climatological significance, since oceanic productivity 'drives' the air-to-sea exchange of biogenic greenhouse gases (e.g. CO_2).

Ocean colour imagery can also be used in support of fisheries management or protection, for example through identification of biologically-rich areas. Other data that may be inferred from ocean colour measurements include information about suspended matter (useful in coastal studies), biological productivity, marine pollution and water dynamics (eddies, currents, etc.) in coastal zones.



MODIS view of Mississippi river delta in February 2008 showing flows of sediments and nutrients.



Global ocean chlorophyll measurements derived from MERIS.

Current & planned instruments

- COCTS
- GOCI
- MERIS
- MODIS
- MSS-BIO
- OCM
- OCM (OCEANSAT-3)
- SGLI
- VIIRS

Further Information

MERIS: envisat.esa.int/instruments/meris

MODIS: modis.gsfc.nasa.gov

Ocean colour sensors: www.ioccg.org/sensors_ioccg.html

VIIRS:www.ipo.noaa.gov/Technology/viirs_summary.html

Current & planned instruments

ALT
AltiKa
Altimeter (OCEANSAT-3)
FJP
POSEIDON-2 (SSALT-2)
POSEIDON-3
RA
RA-2
Radar Altimeter
SIRAL
SRAL

6.12 Radar Altimeters

Description

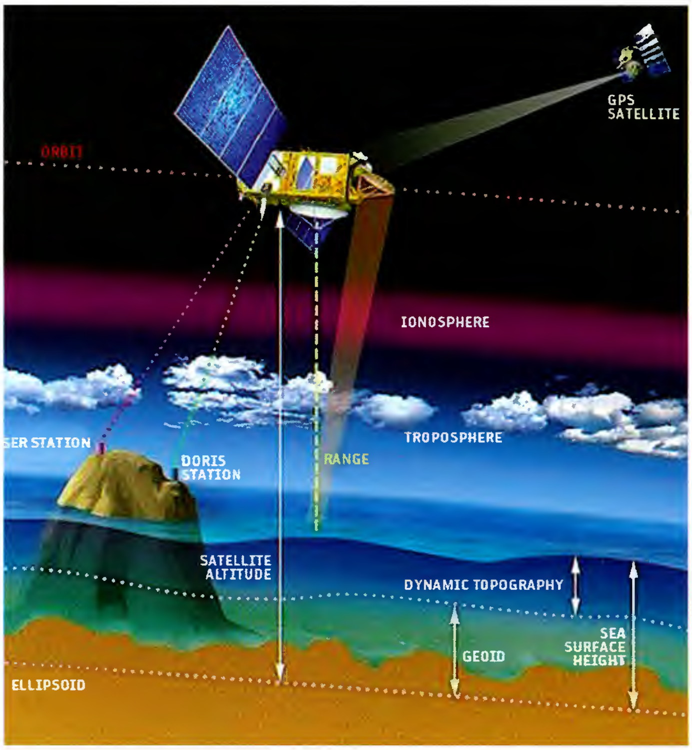
Radar altimeters are active sensors which use the ranging capability of radar to measure the surface topography profile along the satellite track. They provide precise measurements of a satellite's height above the ocean and, if appropriately designed, over land/ice surfaces by measuring the time interval between the transmission and reception of very short electromagnetic pulses.

To date, most spaceborne radar altimeters have been non-imaging, wide-beam (pulse-limited) systems operating from low Earth orbits. Such altimeters are useful for relatively smooth surfaces such as oceans and low relief land surfaces, but are less effective over high relief continental terrain as a result of their large radar footprint (of the order of 25 km).

The Ocean Surface Topography Mission (OSTM) is built around the series of Jason satellites that will collect global ocean surface data on a continuous basis for several decades. Its aims are to measure the global sea surface height to an accuracy of a few centimetres every 10 days, and to determine ocean circulation and the mean sea level trend in support of weather forecasting, climate monitoring and operational oceanography. Launched in June 2008, Jason-2 is intended to overlap with the Jason-1 mission in order to secure the continuity of high accuracy satellite altimetry observations.

Successful exploitation of the height data is dependent upon precise determination of the satellite's orbit. A number of precision radar altimetry 'packages' are available which contain:

- a high precision radar altimeter (with basic measurement accuracy in the range 2 cm to 4 cm);
- a means of correcting errors induced in the height measurements by variations in the amount of water vapour along the path (for example, by means of a microwave atmospheric sounder or radiometer);
- a high precision orbit determination system (typically based on the GPS, the DORIS beacon/satellite receiver system and/or a lidar tracking system).



Radar altimeters measure the distance between the satellite and the sea surface. The distance between the satellite and the reference ellipsoid is derived by using the Doppler effect associated with signals emitted from marker points on the Earth's surface as the satellite orbits overhead. Variations in sea surface height are caused by the combined effect of the geoid and ocean circulation (dynamic topography).

Radar altimeters have been flown on a number of satellites. Seasat was the first ocean-oriented mission carrying an altimeter package (including a precise orbit determination system) for the measurement of ocean circulation. A satellite altimetry revolution happened with the launch in 1992 of the US-French Topex/Poseidon mission. Carrying two high-precision altimeters, a multichannel microwave radiometer, and several precise orbit determination devices on a dedicated, high-altitude (1,336 km), low inclination (66°), non-Sun-synchronous orbit, it enabled the large-scale ocean circulation to be accurately measured. The European ERS-1 (from 1991) and ERS-2 (from 1995) also provided long time-series of complementary altimetric observations from a Sun-synchronous polar orbit. These observations were continued with Jason-1 (launched in 2001), Envisat (launched in 2002), and Jason-2 (launched June 2008).

Applications

A variety of parameters may be inferred using the information from radar altimeter measurements. These include: time-varying sea surface height (ocean topography), the lateral extent of sea ice and the altitude of large icebergs above sea level, as well as the topography of land and ice sheets, and even that of the sea floor. Topographical maps of the structure of the Arctic sea floor have not only revealed new mineral deposits, but they also provide new insights into how a large part of the ocean basin was formed about 100 million years ago.

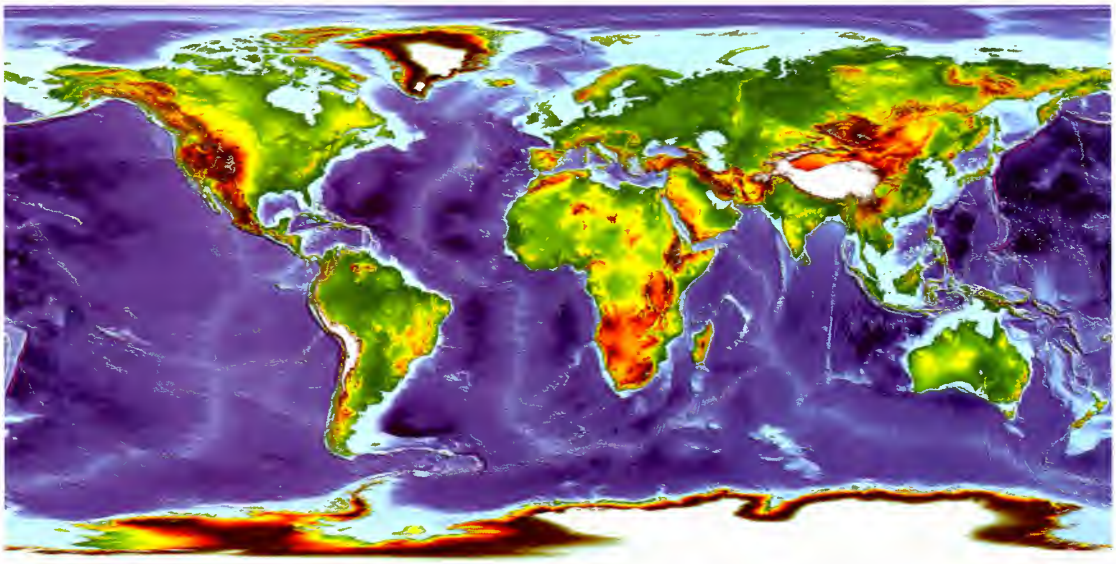
Observations by current and future radar altimeters of trends in the ice masses of the Earth are of principal importance in testing the predicted thinning of Arctic sea ice due to global warming. They also help to quantify the extent to which the Antarctic and Greenland ice sheets have contributed to the global rise in sea level. New generation radar altimeters, such as RA-2 on Envisat, are also providing useful information for the monitoring of inland waters (river and lake levels).

Satellite altimetry also provides information which is used in mapping sea surface wind speeds and significant wave heights. Precision ocean altimetry applications for sea level monitoring and ocean circulation studies require more accurate, independent measurements of the geoid – derived from the instruments described in the 'gravity field' category.

ESA's CryoSat-2 mission will provide an instrument for studying the topography of areas such as ice sheet interiors and margins, and sea ice with three-mode operation:

- conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);
- synthetic aperture operation for sea ice;
- dual-channel interferometric synthetic aperture operation for ice sheet margins.

The new generation of instruments will provide more frequent data coverage and faster access to observations for incorporation into ocean circulation and wave forecast models that are used to generate marine information products. New concepts of altimeter packages for flight on small satellites are being developed – such as AltiKA, which uses a compact Ka-band altimeter. Even more promising are the concepts of wide-swath altimeters, such as those proposed by the WATER HM and SWOT projects, which are capable of providing an imaging capability.



The world as seen by radar altimeters.

Further Information

Jason-1: sealevel.jpl.nasa.gov/mission/jason-1.html

Jason-2/OSTM: www.nasa.gov/ostm

Topex/Poseidon: topex-www.jpl.nasa.gov/

RA-2: envisat.esa.int/instruments/ra2

SIRAL: www.esa.int/esaLP/LPcryosat.html

Current & planned instruments

- AMI/scatterometer
- Aquarius
- ASCAT
- L-band Scatterometer (Aquarius)
- SCAT
- Scatterometer (ISRO)
- SeaWinds

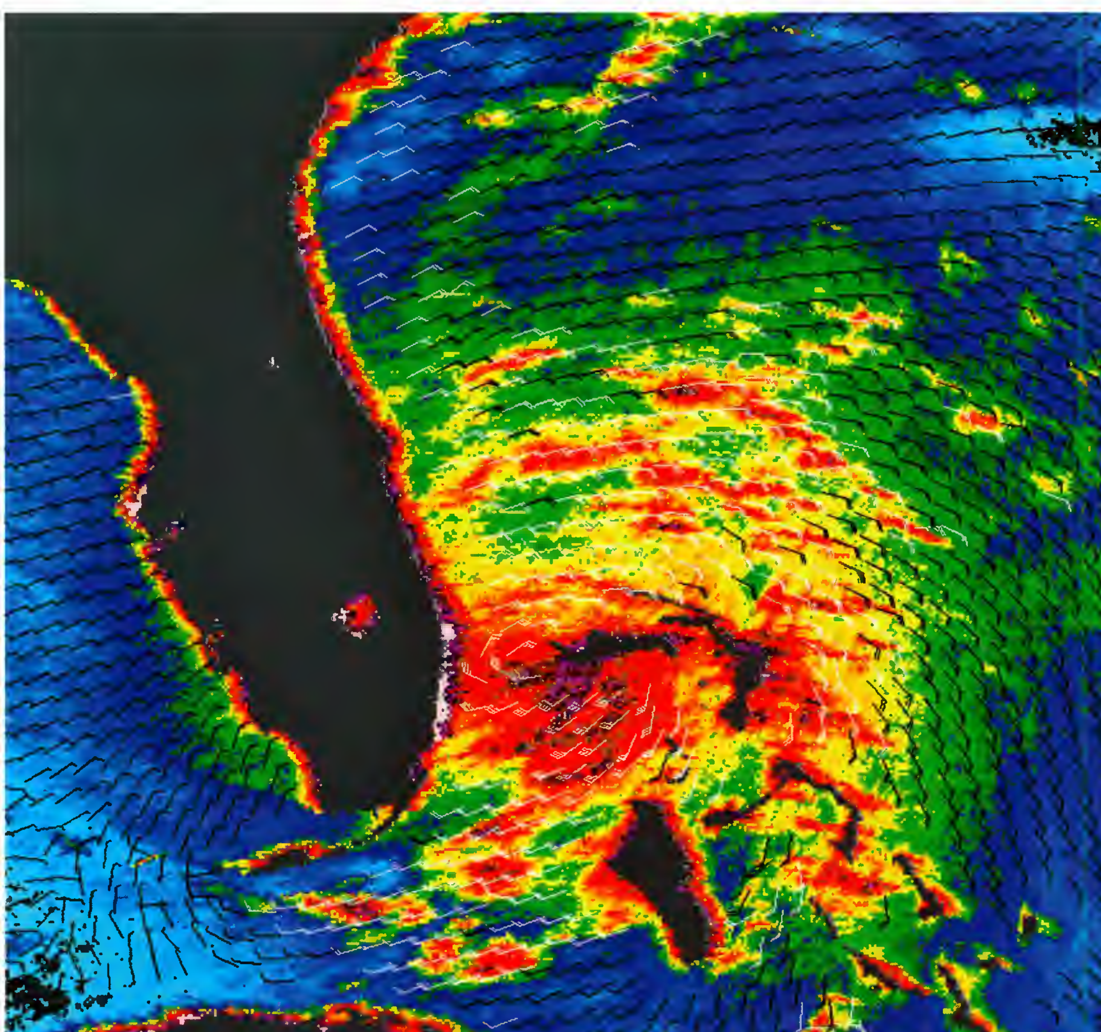
6.13 Scatterometers

Description

A scatterometer transmits radar pulses and receives backscattered energy, the intensity of which depends on the roughness and dielectric properties of a particular target. Scatterometers were originally designed to measure oceanic surface winds, where the amount of backscatter depends on two factors – the size of the surface ripples on the ocean, and their orientation with respect to the propagation direction of the pulse of radiation transmitted by the scatterometer. The first is dependent on wind stress, and hence wind speed at the surface, while the second is related to wind direction. As a result, measurements by scatterometers may be used to derive both wind speed and direction.

The main aim of these instruments is to achieve high accuracy measurements of wind vectors (speed and direction), so resolution is of secondary importance. (They generally produce wind maps with a resolution of order 25–50 km). Because scatterometers operate at microwave wavelengths, the measurements are available irrespective of weather conditions.

Spaceborne scatterometers have provided continuous synoptic microwave coverage of the Earth for nearly two decades, starting with the ERS series in 1991, NSCAT on ADEOS, SeaWinds on QuikSCAT, and more recently ASCAT on MetOp. The ERS and NSCAT instruments employed a fan-beam (multi-incidence) wind retrieval technique, whereas QuikSCAT employs a conically scanning (fixed incidence) technique. Increases in swath width capability now mean that a single instrument can provide around 90% coverage of global oceans on a daily basis.

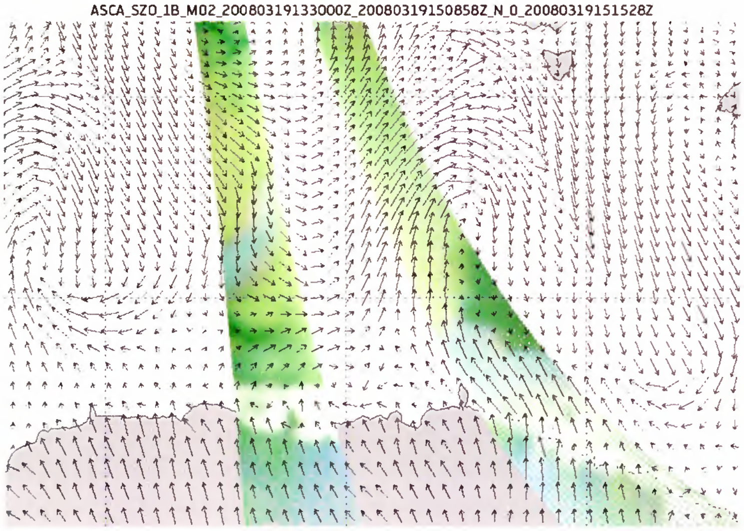


Tropical storm Katrina observed on 25 August 2005 off the Florida coast before it had reached hurricane status.

Applications

Information from scatterometers provides a unique source of data on sea surface wind speed and direction. This has important applications in weather and wave forecasting, the investigation of climate models and elaboration of marine wind climate. The assimilation of scatterometer data into atmospheric forecasting models greatly improves the description of cyclonic features which are so important in predicting future weather patterns.

A large number of new, unforeseen, terrestrial and sea ice applications has emerged beyond the original ocean winds mission of scatterometers. These include: the measurement of sea ice extent and concentration; soil moisture; snow accumulation; and regional monitoring of ice shelves, rainforests and deserts. The daily global coverage of scatterometers in the polar regions and their ability to discriminate sea ice, ice sheets and icebergs, despite poor solar illumination and frequent cloud cover, make them excellent instruments for large-scale systematic observations of polar ice.



ASCAT wind measurements south of Australia on 19 March 2008. Superimposed is an ECMWF forecast 10 m wind field.
Darker colours correspond to areas of low surface wind speeds. Colour tone changes correspond to changes in the surface wind direction, as the sensitivity of the measurement from the different antenna beams varies with the relative direction of the surface wind vector with respect to the viewing direction of each beam.

Further Information

ASCAT: www.esa.int/esaLP/SEMBWEG23IE_LPMetop_0.html

Aquarius: aquarius.gsfc.nasa.gov

SeaWinds: winds.jpl.nasa.gov/missions/quikscat/index.cfm

6.14 Gravity, Magnetic Field and Geodynamic instruments

Description

This category of instruments is used here to describe a variety of sensors and supporting systems used to derive information on the Earth's gravity field, magnetic field or geodynamic activity.

Gravity field measurements from space rely on one of three techniques:

- use of single or multiple accelerometers on one or more satellites to derive gravity or gravity gradient information;
- precise satellite orbit determination (using satellite to ground navigation systems such as GPS and satellite laser ranging systems), and separation of satellite motion, induced by the Earth's gravitational force alone, from other forces (such as solar radiation and aerodynamic drag);
- satellite to satellite tracking (e.g. by GPS or microwave link) to measure relative speed variations of two satellites induced by gravitational forces.

Satellite-borne magnetometers provide information on the strength and direction of the Earth's internal and external magnetic field and its time variations.

Applications

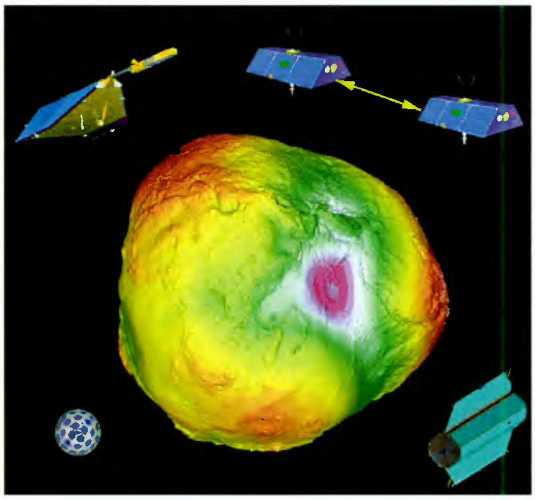
Gravity field measurements from space provide the most promising advances for improved measurement of the 'geoid' and its time variations. The geoid (the surface of equal gravitational potential at mean sea level) reflects the irregularities in the Earth's gravity field at the surface due to the inhomogeneous mass and density distribution in the planet's interior.

More accurate models of the static mean geoid and its temporal variability are vital for:

- a precise marine geoid, needed for the quantitative determination, in combination with satellite altimetry, of absolute ocean currents, their transport of heat and other properties;
- a unified global height reference system for the study of topographic processes, including the evolution of ice sheets and land surface topography;
- new understanding of the physics of the Earth's interior;
- estimates of the thickness of the polar ice sheets and their variations through a combination of bedrock topography derived from gravity measurements and ice sheet surface topography from altimetry;
- estimates of the mass/volume redistribution of fresh water in order to further understand the hydrological cycle;
- improved understanding of post-glacial rebound processes on a global scale.

Magnetic field measurements are also valuable in a range of applications, including navigation systems, resource exploration drilling, spacecraft attitude control systems, assessments of the impact of 'space weather' caused by cosmic particles and earthquake prediction studies (e.g. by the DEMETER mission).

The precision location capabilities of satellite laser ranging and other systems (such as DORIS and GPS), sometimes in combination with interferometric SAR (INSAR), are applied in support of studies of crustal deformation, tectonic movements and Earth's spin rate.



LAGEOS, CHAMP, GRACE and GOCE all provide new insights into Earth's gravity field.

Further Information

CHAMP: www.gfz-potsdam.de/pb1/op/champ/index_CHAMP.html

GRACE: www.csr.utexas.edu/grace

GOCE: www.esa.int/esaLP/LPgoce.html

Current & planned instruments

Gravity

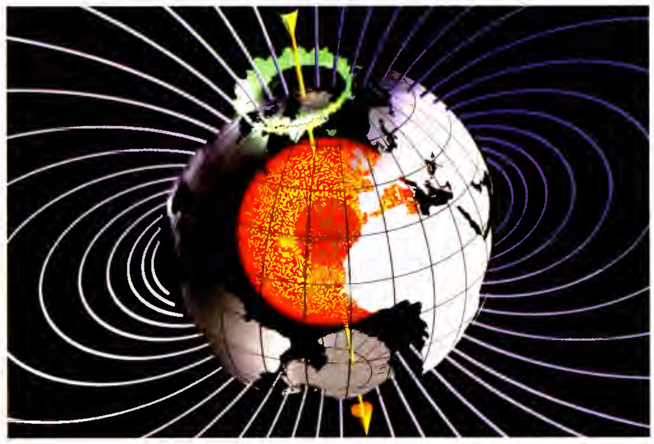
- CHAMP Gravity Package (Accelerometer+GPS)
- EFI
- EGG
- HAIRS (aka KBR)

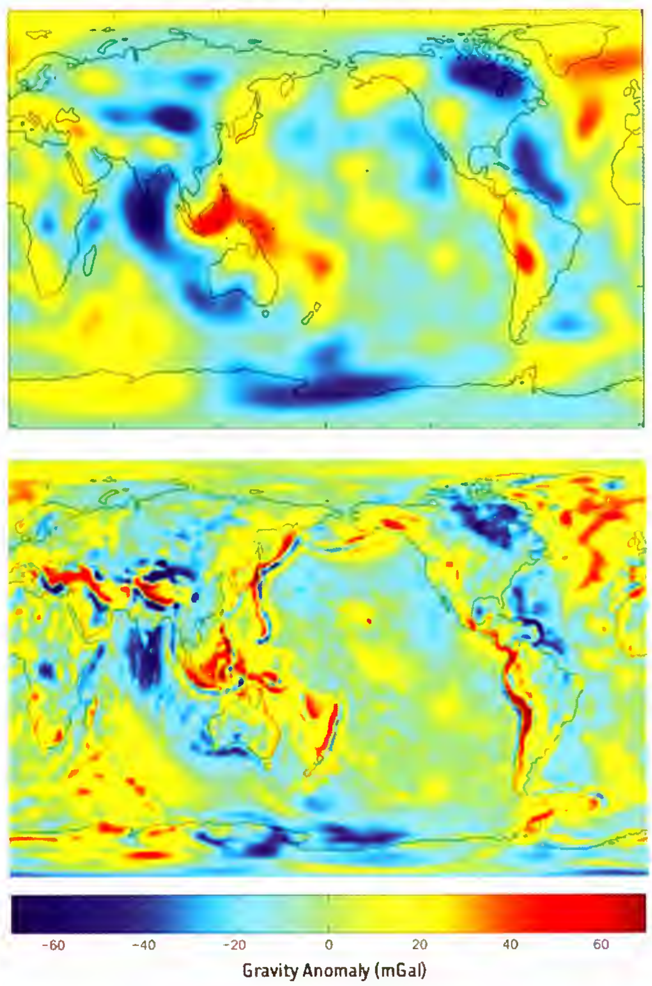
Magnetic field

- ASM
- CHAMP Magnetometry Package (1 Scalar + 2 Vector Magnetometer)
- GGAK-E
- GGAK-M
- GID-12T
- IMSC
- Magnetometer (NOAA)
- MMP
- Overhauser Magnetometer
- RBE
- SSJ/4
- SSJ/5
- SSM
- VFM

Precision orbit

- ACC
- BlackJack GPS (TRSR)
- CHAMP GPS Sounder
- DORIS (SPOT)
- DORIS-NG
- DORIS-NG (SPOT)
- EGG
- GOLPE
- GPS (ESA)
- GPS Receiver (Swarm)
- GPS ROS
- GPSP
- GRAS
- INES
- IST
- Laser Reflectors
- Laser Reflectors (ESA)
- LCCRA
- LRA
- LRA (LAGEOS)
- ROSA
- ROSA
- RRA
- SI
- STR
- TDP
- TRSR





Prior to GRACE, the long-wavelength part of the Earth's gravity field from space was determined from various tracking measurements of Earth orbiting satellites. Only the broad geophysical features of the Earth's structure could be detected. The lower image shows the final detail available after just 1 year of GRACE data.

7 Earth Observation Plans: by Measurement

7.1 Introduction

In mid-2008, there were approximately 100 satellites operating and providing important data about the Earth and its environment, helping us to develop our understanding of the basic Earth System and human influences on it. These data cover measurements of a very wide range of geophysical parameters, spanning the whole spectrum of the environment – atmosphere, land, oceans, ice and snow. This section considers some of the key observations contributed by EO satellites, as indicated in the table.

This list is not exhaustive, but it does include many key measurements of interest to the main user groups of Earth observation satellite data, and describes a significant part of the capability of current and planned instruments – including those related to the Essential Climate Variables which are largely measured by satellite.

This section identifies the satellite instruments which primarily contribute data for any particular measurement from the list shown and indicates the plans for future provision of that measurement over the next 15 years. Measurement continuity is a key requirement, particularly for climate applications, in order to detect and quantify long term trends. This section identifies the prospects for achieving that continuity, given the programmes and plans that exist in 2008 – whether it may be provided by a single series of satellites dedicated to a particular measurement, or whether users of that measurement must look to various satellite missions planned by different agencies worldwide to satisfy their information requirements.

The need for this continuity and the necessity to ensure that the measurements obtained by different agencies from different countries can be inter-compared and calibrated to meet the most demanding requirements (typically for climate applications), requires a significant degree of coordination in mission planning and data provision. Harmonisation and maximum cost-effectiveness for the total set of space-based observation programmes is the objective of CEOS.

Measurement categories

ATMOSPHERE	
	Aerosol properties
	Atmospheric temperature fields
	Water vapour
	Atmospheric winds
	Cloud type, amount and cloud top temperature
	Cloud particle properties and profile
	Liquid water and precipitation rate
	Ozone
	Radiation budget
	Trace gases (excluding ozone)
LAND	
	Albedo and reflectance
	Land topography
	Soil moisture
	Vegetation
	Surface temperature (land)
	Multi-purpose imagery (land)
OCEAN	
	Ocean colour/biology
	Ocean topography/currents
	Ocean salinity
	Ocean surface winds
	Surface temperature (ocean)
	Ocean wave height and spectrum
	Multi-purpose imagery (ocean)
SNOW AND ICE	
	Ice sheet topography
	Snow cover, edge and depth
	Sea ice cover, edge and thickness
GRAVITY AND MAGNETIC FIELDS	
	Gravity, magnetic and geodynamic measurements

7.2 Overview

Current areas of strength of the Earth observation satellites providing data today include:

- atmospheric chemistry measurements, including ozone, provided by instruments on NASA's Aura and Terra missions, ESA's Envisat, and GOME-2 on MetOp;
- aerosol properties, provided by dedicated instruments like CALIPSO and MISR, but also by instruments on ESA's Envisat and EUMETSAT's MetOp, and by traditional imagers like MERIS and AVHRR in LEO and SEVIRI in GEO;
- atmospheric humidity and temperature profiles routinely provided for operational meteorology by the NOAA, DMSP and MetOp series polar orbiting satellites and by a number of meteorological geostationary satellites;
- atmospheric winds (through cloud tracking), cloud amount and tropical precipitation estimates provided for most of the globe by the traditional imagers mounted on geostationary meteorological satellite series like MSG (EUMETSAT), GOES (NOAA), MTSAT (JMA), FY-2 (CMA), and INSAT/Kalpana (IMD);
- multi-purpose imagery for both land and sea collected by high resolution optical and synthetic aperture radar (SAR) instruments for use in environmental, public, and commercial applications. Optical sensors include AVHRR on the NOAA and EUMETSAT polar orbiters and those on ALOS, Terra, and the SPOT, Landsat and IRS series. SAR sensors include those on the ERS/Envisat and RADARSAT series and on ALOS. Future missions and increasing spatial resolution will ensure improved data collection and application opportunities;

- sea surface temperature (SST) information generated by data from existing operational meteorological satellites, such as AVHRR on low Earth orbit platforms, and by sensors in geostationary orbit, like INSAT and SEVIRI. Besides operational meteorological instruments, SST is the target of dedicated instruments like AATSR and instruments on the Aqua/Terra and ERS/Envisat series. Future plans should provide continuity. Satellites such as QuikSCAT, Jason-1, and Envisat are now also making consistent and continuous measurements of other important oceanographic parameters, such as ocean topography, ocean currents and sea surface winds;
- sea ice and ice sheet extent, currently measured by a range of missions (including ALOS, DMSP, ICESat, MetOp, TerraSAR-X and RADARSAT), with future continuity provided by missions such as CryoSat-2 and RADARSAT-2.

Future missions will feature a new generation of technology and techniques to enable Earth observation satellites to extend their contribution, including:

- a significant increase in information about the chemistry and dynamics of the atmosphere. This includes long term global measurements of concentrations of ozone and many other trace and greenhouse gases; information on the role of clouds in climate change; the ability to better map cloud cover and precipitation (including over the oceans); measurements of 3D atmospheric winds without the need for cloud tracking, either from active sensors or passive hyperspectral infrared sounders in geostationary orbit; global aerosol distributions; and extended coverage of atmospheric measurements into the troposphere to allow improved pollution monitoring. Just as significantly, existing measurement capabilities for many key parameters, such as atmospheric humidity and temperature, will have greatly improved accuracy and spatial resolution. For future missions, several novel, active instruments, such as cloud and rain radars, and lidar instruments, have been proposed. In addition to these developments, progress in developing passive hyperspectral infrared sounders has been such that the urgently needed deployment of these instruments in geostationary orbit is realistic;
- improved repeat coverage, resolution and accuracy of many oceanographic measurements, including ocean surface winds, ocean colour and biology;
- new capabilities for determination of the Essential Climate Variables soil moisture and ocean salinity, starting with ESA's SMOS mission;
- new information on global land surface processes, through use of an increased number of spectral bands, as well as multi-directional and polarisational capabilities of future imaging sensors;
- estimates from innovative new lidar systems of global biomass and carbon stocks, as well as the mass balance of the polar ice sheets and their contributions to global sea level change;
- improved measurements of global ocean currents, based on data from altimeters and gravity field instruments, such as GRACE and GOCE.

We can expect the exact plans to change as space agency programmes evolve to keep pace with accepted scientific and political priorities regarding information about the Earth System and its climate – including the influence of the processes initiated by the Group on Earth Observations (GEO), the UN Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

7.3 Measurement Timelines

For each measurement category listed in section 7.1, a brief discussion is given below of the significance of that measurement (including its relation to the recognised Essential Climate Variables), together with an indication of the present and future measurement capabilities of satellite observations. In each case, specific actions identified by CEOS to better meet the needs of GCOS for the Essential Climate Variables are described. This description is supported by two timeline diagrams spanning the period 2008–2023, indicating the instruments contributing to that measurement and the missions on which they are expected to fly.

The first timeline shows missions that are either:

- current, where the prototype has been launched and financing is approved for the whole series; or
- approved, where financing is available for the whole series, the prototype is fully defined and development is ongoing.

The second timeline shows missions which are not yet approved. They are divided into two categories:

- planned, where financing of the full series is being considered or is available up to the end of detailed definition phase; or
- considered, where conceptual studies and feasibility studies have been completed, and definition of financing is in preparation.

Of course, all missions have a degree of uncertainty. This description of mission status reflects information available from the relevant agencies at the time of compilation. If the launch month of a planned mission has not been specified, the timeline is shown to commence at the beginning of the planned year of launch. Note also that missions currently operating beyond their planned lifetime are shown as operational until the end of 2008 unless an alternative date has been proposed.

The timelines in this section represent a qualitative analysis of the provision of data from Earth observation satellites in terms of a number of key geophysical measurements and the requirement for those measurements in different disciplines.

Atmosphere

Aerosol Properties

Essential Climate Variables: Aerosol Properties

Aerosols are tiny particles suspended in the air. The majority are derived from natural phenomena such as volcanic eruptions, but it is estimated that some 10–20% are generated by human activities such as burning of fossil fuels. The majority of aerosols form a thin haze in the lower atmosphere and are regularly washed out by precipitation. The remainder are found in the stratosphere where they can remain for many months or years. Scientists have yet to quantify accurately the relative impacts on climate of natural aerosols and those of human origin, so there is still uncertainty whether aerosols are warming or cooling the Earth. Predicting the rate and nature of future climate change requires this clarification of the processes involved.

As a consequence, the IPCC identifies further information on aerosols as a priority, highlighting a particular need for additional systematic, integrated and sustained observations which include the spatial distribution of greenhouse gases and aerosols. The Integrated Global Atmospheric Chemistry Observations (IGACO) Theme of the IGOS Partnership aims to provide a framework ensuring continuity and spatial comprehensiveness of the full spectrum of atmospheric chemistry observations, including the monitoring of atmospheric composition parameters related to climate change and environmental conditions. The IGACO Theme Report (available from www.igospartners.org) was finalised in May 2004 and provides a comprehensive overview of current and future satellite measurements for tropospheric and stratospheric aerosols. The report states, in particular, that "satellite observations of aerosol optical properties have progressed to a point where they range from pre-operational to operational, although there are demonstration-mode instruments on a number of research satellites".

Reliable information on aerosols is also required by applications outside the study of the climate system. For example, accurate and timely warnings of the presence of airborne dust and ash – such as that arising from desert dust clouds and volcanic eruptions – are important to the safety of airline operations. A worldwide volcanic ash monitoring system, which is dependent on satellite observations, is in place to provide real-time advice to pilots.

Measuring the distribution of aerosols through the depth of the atmosphere is technically difficult, particularly in the troposphere. Previously, techniques using instruments such as AVHRR and ATSR were limited to producing estimates of vertically-integrated total amounts, mainly over oceanic regions.

Measurements over land are difficult (due to persistent cloud cover and the high value, and variability, of land surface reflectance), but the new generation of multi-directional or polarimetric instruments – such as AATSR, MISR and APS (planned for NPOESS but recently demanifested) – can provide detailed information. Today, MODIS, MERIS, MISR, and POLDER-P offer better optical depth at different frequencies, enabling aerosol particle sizes, particularly over oceans, to be inferred. The development of active instruments such as ATLID and ALADIN, and laser altimeter sensors, including GLAS on ICESat, should yield much improved measurement capability. Since April 2006, CALIPSO has flown a 3-channel lidar (designed specifically to provide vertical profiles) and passive instruments, orbiting in formation with Aqua, Aura, PARASOL and CloudSat to obtain coincident observations of radiative fluxes and atmospheric state. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects.

Limb-sounding instruments such as ACE-FTS, SCIAMACHY, GOMOS, and HIRDLS principally provide data on the upper troposphere and stratosphere with high vertical resolution, but horizontal resolution is relatively poor (typically of the order of a few hundred km).

Current, long-term climatologies are based upon AVHRR/3 on the NOAA and MetOp series of low Earth orbit satellites. These observations will continue to provide estimates of total column aerosol amounts over the ocean. AVHRR/3 will be replaced by a more capable visible and infrared imager, called VIIRS, on the NPOESS series of satellites, starting with the preparatory NPP mission in 2010. VIIRS will acquire high resolution atmospheric imagery and generate a variety of applied products, including some that give information on atmospheric aerosols.

The CEOS response to the GCOS Implementation Plan recognised that no operational aerosol instruments measuring particle composition and size/shape have been yet been flown and efforts should be made to rectify this. It encouraged re-planning of the aerosol measurements envisaged by APS/NPOESS and consideration of operational active sensing lidar (such as CALIPSO). CEOS committed to pursue the following action: "CEOS agencies will participate in re-planning the APS instrument removed from the planned payload of NPOESS".

Aerosols


2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
current/approved
ERS series (ATSR-2, GOME: 2)
POES series (AVHRR/3: 15-N')
OCEANSAT series (OCM: 1, 2)
TERRA (MISR, MODIS)
GOES series (ABI: R,S)(Sounder: 11-P)
SAC series (MMRS: C)
Odin (OSIRIS)
PROBA (CHRIS)
ENVISAT (AATSR, GOMOS, MERIS, MIPAS, SCIAMACHY)
Aqua (MODIS)
FY-1 series (MVISR (10 channels): 1D)
ICESat (GLAS)
SCISAT-1 (ACE-FTS, MAESTRO)
Aura (HiRDLS, OMI)
PARASOL (POLDER-P)
CALIPSO (CALIOP)
EPS series (AVHRR/3, GOME-2: 1-3)
Meteor series (MSU-MR: N1, N2)
SumbandilaSat (SumbandilaSat Imager)
Glory (APS)
ADM-Aeolus (ALADIN)
NPP (VIIRS)
PRISMA (HYC)
Sentinel-3 series (OLCI: A)
NPOESS series (APS: 1)(VIIRS: 1-4)
EarthCARE (ATLID, MSI (EarthCARE))
MTG-I (METEOSAT 3G) series (FCI: 1-4)
planned/considered
OCEANSAT series (OCM (OCEANSAT-3): 3)
ISTAG (MAGIS)
EnMAP (HSI)
Sentinel-5 precursor (UVNS (Sentinel-5 precursor))
GCOM series (SGLI: C1-C3)
ICESat-II (GLAS Follow-on)
Sentinel-3 series (OLCI: B, C)
MTG S/Sentinel-4 series (UVN (Sentinel-4): 4A, 4B)
post-EPS/Sentinel-5 series (UVNS (post-EPS): 1)

Atmosphere

Atmospheric Temperature Fields

Essential Climate Variables: Upper Air Temperature

With humidity, atmospheric temperature profile data are a core requirement for weather forecasting and are coordinated within the framework of CGMS (The Coordination Group for Meteorological Satellites). The data are used for numerical weather prediction (NWP), for monitoring inter-annual global temperature changes, for identifying correlations between atmospheric parameters and climatic behaviour, and for validating global models of the atmosphere.

Upper air temperatures are a key dataset for detection and attribution of tropospheric and stratospheric climate change, measured both by radiosondes and satellite instruments. Temperatures measured by high-quality radiosondes are an important reference against which satellite-based measurements can be calibrated. Upper air temperatures are important for separating the various possible causes of global change, and are vital for the validation of climate models.

Infrared (HIRS) and microwave sounders (MSU and AMSU) have been providing atmospheric profiles for almost thirty years. The microwave data in particular have become key elements of the historical climate record and equivalent measurements need to be continued into the future to sustain a long-term record. The MSU radiance record is a primary resource for this, providing essential coverage over the oceans and data for comparison and combination with radiosonde data over land.

For global NWP, polar satellites provide information on temperature with global coverage, good horizontal resolution and acceptable accuracy, but improvements in vertical resolution are needed. Performance in cloudy areas has been poor, but the microwave measurements such as AMSU have provided substantial improvements. As in the case of humidity profiles, the Aqua, MetOp, NOAA and NPOESS missions offer comparable improvements in vertical resolution for measuring atmospheric temperature (using AIRS+, AMSU-A, CrIS, HIRS, IASI, MSU).

For regional NWP, polar orbiting satellites provide information on temperature with acceptable accuracy and good horizontal resolution, but with marginal temporal frequency and vertical resolution for mesoscale prediction. Advanced radiometers or interferometers planned for future satellites should improve on the vertical resolution and accuracy of current radiometers.

Geostationary satellites provide frequent radiance data, but their use over land is hindered because of the difficulty in estimating surface emissivity. In nowcasting, the temperature and humidity fields are particularly useful for determining atmospheric stability for predicting precipitation type, the amount of frozen precipitation, and convective storms. As with humidity profiles, nowcasting predictions using atmospheric temperature data benefit from hourly geostationary infrared soundings (such as from the GOES and MSG series – with these missions now capable of providing such data at 15 minute intervals).

The combination of the HIRS/3 and AMSU instruments on the NOAA and MetOp series allows improved information, sufficient to infer temperature within several thick layers in the vertical. On the MetOp series, IASI is used with other instruments to deliver very precise sounding capacity. IASI data assimilation has significantly improved NWP forecasts. CrIS on the NPOESS series, which will replace HIRS, is designed to enable retrievals of atmospheric temperature profiles at 1K accuracy for 1 km layers in the troposphere. The GRAS instrument on MetOp provides temperature information of high accuracy and vertical resolution in the stratosphere and upper troposphere (helping to improve analyses around the tropopause) using a GPS radio occultation (RO) technique. Its information will thus be complementary to that provided by the passive sounding instruments on MetOp. China's FY-2 series of satellites (FY-2C, D & E), features improved measurements from October 2004 with the addition of new spectral channels to their IVISSR instrument.

GPS radio occultation (RO) measurements provide high vertical resolution profiles of atmospheric refractive index that relate directly to upper air temperatures. They provide independent observations that can be utilised to calibrate all other data. Instruments are being flown on multiple low Earth orbiting satellites (such as CHAMP and SAC-C and the COSMIC constellation). Systems need to be developed for real-time data exchange and use, implemented into operational meteorological data streams. Plans also need to be made to ensure future RO instruments and platforms, including on operational meteorological satellites.

In response to the GCOS IP, CEOS undertook to ensure continuity of GPS RO measurements with, at a minimum, the spatial and temporal coverage established by COSMIC by 2011. CEOS will also continue efforts to exploit the complementary aspects of radiometric and geometric upper air determinations of temperature and moisture.

Atmospheric Temperature Fields

Atmosphere

Water Vapour

Essential Climate Variables: Water Vapour

The observations for water vapour (atmospheric humidity) are a core requirement for weather forecasting and are largely dealt with in the framework of the Coordinating Group for Meteorological Satellites (CGMS).

A wide range of sensors is available to measure column water vapour – microwave imagers like SSM/I and traditional imagers like AVHRR or MERIS on LEO platforms, and GOES and SEVIRI on GEO platforms. Vertical profiles are provided by microwave sounders like SSM/T2, AMSU-B, HIRS/4 and MHS, by hyperspectral infrared sounders like IASI and AIRS, or by radio-occultation observations provided by GPSMET or GRASS on MetOp. These data are supplemented by instruments on Aqua (AIRS+, AMSR-E, AMSU-A), Aura (HiRDLS, MLS, TES), and the FY-3 series (MWHS), amongst others.

All of these are being improved as technology allows. In broad terms the challenges are to improve vertical resolution of observations and temporal sampling, to overcome cloud problems and improve the ability to process sounding data over land. For instance, NPOESS will feature the combination of the CrIS interferometer and ATMS sounder to derive accurate water vapour profiles.

The 3-dimensional field of humidity is a key variable for global and regional weather prediction (NWP) models that are used to produce short- and medium-range forecasts of the state of the troposphere and lower stratosphere. Polar satellites provide information on tropospheric humidity with global coverage, good horizontal resolution and acceptable accuracy, but with poor vertical resolution.

In the case of observations for regional NWP models, polar and (mainly) geostationary satellites provide estimates of total column water vapour accurate to within 10–20%. Enough information is collected to infer moisture concentration within several thick layers vertically, with good horizontal resolution. Vertical resolution is marginal for mesoscale prediction, and the infrared information is available only for cloud-free fields of view. Despite this coarse vertical resolution, the high temporal resolution of the geostationary satellite observations allows derivation of products like the instability index for convective initiation, which is used for nowcasting applications.

Until recently, performance in cloudy areas was poor, but the new microwave measurements from AMSU offer substantial improvements. Geostationary infrared soundings (e.g. by the GOES sounders and SEVIRI on MSG) are also helping to expand coverage in some regions by making measurements on repeat timescales of fifteen minutes to one hour, thus creating more cloud-free observations. Over oceans, coverage is currently supplemented by information on total column water vapour from microwave imagers.

Satellite sounding data are difficult to use over land, but progress in data interpretation is expected in the near future. Recent research has shown that the GPS-based radio occultation (RO) technique also has the potential to provide, in the middle to lower troposphere, high resolution profiles of atmospheric refractivity, combining the effects of temperature and water vapour in this region of the atmosphere.

In response to the GCOS IP, CEOS undertook to ensure continuity by 2011 of GPS RO measurements with, at a minimum, the spatial and temporal coverage established by COSMIC. CEOS will also continue efforts to exploit the complementary aspects of radiometric and geometric determinations of temperature and moisture in the upper air.

Water Vapour

Atmosphere

Atmospheric Winds

Essential Climate Variables: Upper Air Winds

Measurements of atmospheric winds are of primary importance to weather forecasting, and as a variable in the study of global climate change. Upper air wind speed and direction is a basic element of the climate system that influences many other variables.

Horizontal wind may be inferred by motion vectors or by humidity and ozone tracers in geostationary imagery. Substantial information can be derived by these methods but quality control is difficult and vertical resolution is poor. Planned instruments for geostationary satellites promise improved information, but the limited vertical resolution and the problems of accurate height assignment of winds will remain areas to be improved.

For global NWP models, wind profile information – mostly over land – is available mainly from radiosondes. Satellite Doppler wind lidar technology is being developed to provide line-of-sight wind profiles of acceptable coverage and vertical resolution, but thick cloud is a limitation. Geostationary imagers offer wind profile information by cloud tracking, or through tracking of highly-resolved features in the water vapour channels in cloud-free areas. Coverage may be supplemented in future by tracking ozone features in satellite imagery. Regional NWP models also rely heavily on radiosondes (over land) and aircraft (over ocean and over the poles) for atmospheric wind profile measurements, but they would benefit from improved satellite data.

At present, geostationary multi-channel visible and infrared imagers, such as INSAT, SEVIRI and VISSR, are used to measure cloud and water vapour motion vectors from which tropospheric wind estimates may be derived. Atmospheric motion vectors generated from the global ring of geostationary imagers provide improved data in terms of coverage, spatial and temporal resolution, and accuracy of both wind vectors and height assignment. Though valuable, because they offer wind information in areas of the world where otherwise there would be none, atmospheric wind vectors are single level observations which are only available where there are suitable image features to be tracked. Geostationary satellite measurements have been recently supplemented by the addition of water vapour wind motions from polar orbiters (MODIS). Plans need to be made to continue the polar orbiting wind measurements.

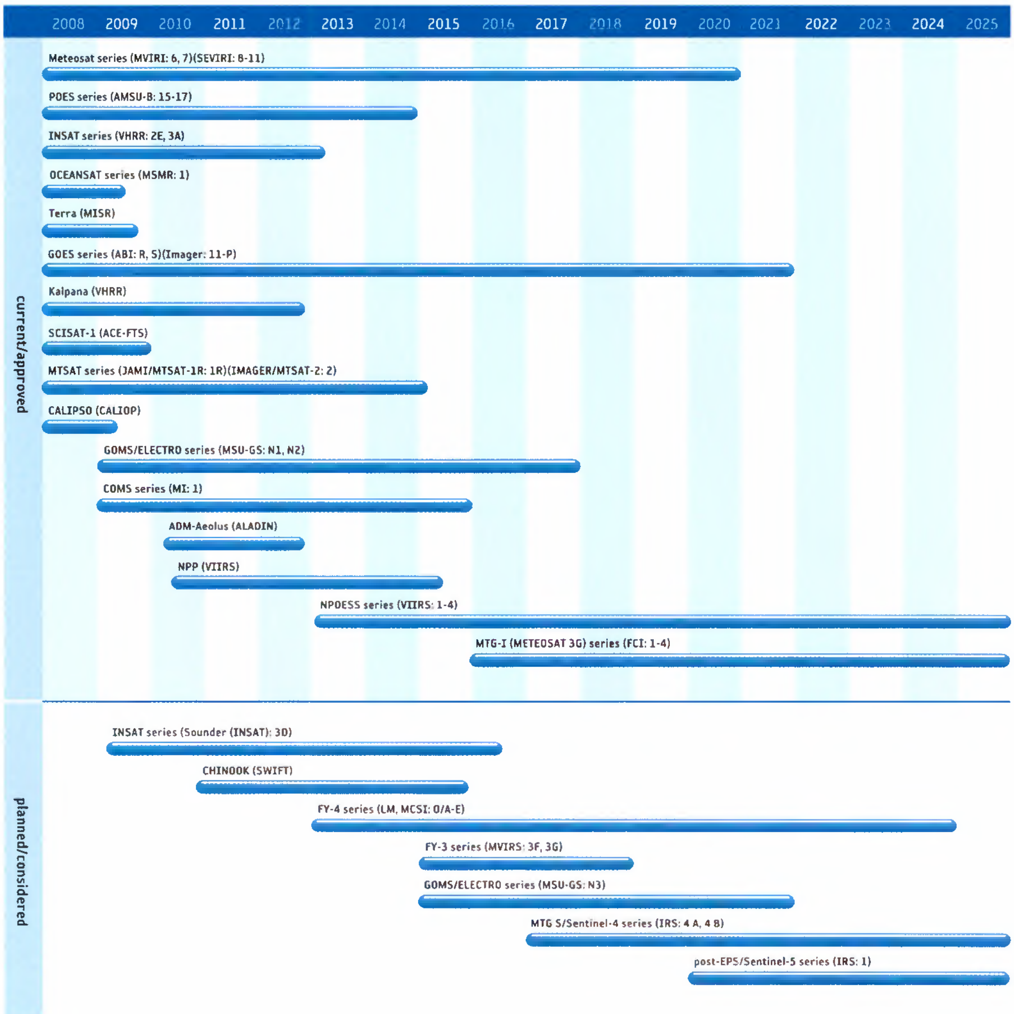
In the longer term, laser instruments such as Doppler lidars offer the promise of directly measuring clear air winds and winds within optically thin aerosol and cloud layers. Although such active instruments will provide a global coverage of vertically resolved, highly accurate measurements, the coverage offered by polar missions, such as that planned for the research-oriented ALADIN, is limited to measurements twice a day along the satellite line of sight.

Hyperspectral observations are needed to improve the vertical resolution of atmospheric motion vectors derived from geostationary satellite observations – especially in clear areas. The first opportunity for these observations may be the IRS payload on EUMETSAT's MTG-S-1 mission.

CEOS identified two actions in response to the GCOS requirements:

- to commit to reprocessing the geostationary satellite data for use in reanalysis projects before the end of the decade;
- to identify options for continuing improvements to wind determinations demonstrated by MODIS and to be demonstrated with ALADIN on the ADM-Aeolus mission.

Atmospheric Winds



Atmosphere

Cloud Type, Amount and Cloud Top Temperature

Essential Climate Variables: Cloud Properties

The study of clouds, their location and characteristics, plays a key role in the understanding of climate change. Low, thick clouds primarily reflect solar radiation and cool the surface of the Earth. High, thin clouds primarily transmit incoming solar radiation, but at the same time they trap some of the outgoing infrared radiation emitted by the Earth and radiate it back downward, thereby warming the surface. The Earth's climate system constantly adjusts in a way that tends toward maintaining a balance between the energy that reaches the Earth from the Sun and the energy that is reradiated from Earth into space. This process is known as Earth's 'radiation budget'. The components of the Earth System that are important to the radiation budget are the planet's surface, atmosphere and clouds.

The IPCC points out that even the most advanced climate models cannot yet simulate all aspects of climate, and that there are particular uncertainties associated with clouds and their interaction with radiation and aerosols.

Weather forecasters are able to draw on a range of satellite data on clouds in improving models and in making forecasts. For both global and regional NWP models, satellite instruments offer detailed information on cloud coverage, type, growth and motion. The coverage is global from polar orbiting satellites and (with the exception of high latitudes) geostationary satellites. Infrared imagers and sounders can provide information on cloud cover and cloud top height with good horizontal and temporal resolution. Hyperspectral observations in the 14 mm band are ideal to derive accurate cloud top height information. For example, observations in the oxygen A band by SCIAMACHY, MERIS (Envisat) and GOME-2 (MetOp) are used to derive cloud top pressure in an independent way. By using observations in the NIR part of the spectrum, for example from AVHRR observations, bulk cloud properties such as liquid water content can be derived.

Passive microwave imagers and sounders (SSM/I, AMSU/B, MHS) give information on cloud liquid water, cloud ice and precipitation. Microwave information is valuable for regional mesoscale models which have sophisticated parameterisation of cloud physics. In the context of nowcasting and very short range forecasting, meteorological satellite data are well suited to monitoring the rapid development of precipitation-generating systems in space and time.

In the field of climate research, the MODIS and MISR spectroradiometers on the Terra mission are enabling viewing of cloud features at higher resolutions than were previously available. MODIS measurements allow more precise determination of the contribution which clouds make to the greenhouse warming of the Earth. MISR is observing angles at which sunlight is reflected from clouds. These observations are critical in support of new research on the radiative properties of clouds. Also on the Terra mission, the ASTER radiometer, which measures visible and infrared wavelengths, complements the other instruments by providing high resolution views of specific targets of interest.

For weather forecasting, satellite instruments will continue to offer a wealth of useful information on clouds. On polar orbiting missions, HIRS, AMSU-A, MHS and IASI offer improved information on clouds. Geostationary imagers and sounders (on MSG, GOES, Elektro-L, INSAT, MTSAT and FY-3 series) will contribute to retrieval of information about cloud cover, cloud top temperature, cloud top pressure and cloud type, and will be close to meeting regional NWP modelling needs for these variables. Retrievals will not only comprise the temperature and moisture profiles, but also fractional cloud cover, cloud top height, cloud top pressure, surface temperature and surface emissivity from both infrared and microwave soundings.

The increased use of imagery data to determine cloud amount will improve the performance and the number of retrieved profiles. In general, IASI will increase sounding performance to a level very significant for global and regional NWP. On the NPOESS series of satellites, parameters that may be derived from VIIRS will include cloud cover.

The WCRP International Satellite Cloud Climatology Project (ISCCP) has developed a continuous data record of infrared and visible radiances since 1983, utilising both geostationary and low Earth orbiting meteorological satellite data. A range of products have been derived, but unfortunately the record suffers from inhomogeneities. Reprocessing the data to account for orbital drift and other issues has helped reduce uncertainties in the observations.

The active satellite instruments on board CloudSat, CALIPSO and EarthCARE will be crucial for the validation of cloud parameters observed by passive instruments, in particular cloud top height and type. EarthCARE will provide new insights by observing with lidar, radar, multi-spectral imager and a broad-band radiometer in synergy.

Cloud Type, Amount and Cloud Top Temperature

Atmosphere

Cloud Particle Properties and Profile

Essential Climate Variables: Cloud Properties

A key to predicting climate change is to observe and understand the global distribution of clouds, their physical properties – such as thickness and droplet size – and their relationship to regional and global climate. Whether a particular cloud will heat or cool the Earth's surface depends on the cloud's radiating temperature – and thus its height – and on its albedo for both visible and infrared radiation, which depends on the number and details of the cloud properties. As clouds interact with radiation at all wavelengths, a multitude of observations can be used to infer cloud properties.

Because clouds change rapidly over short time and space intervals, they are difficult to quantify from low Earth orbits. High temporal sampling provided by geostationary satellites is better suited to monitor rapidly changing conditions, albeit on a regional scale. Full 3D observations of cloud structure is a new capability that has been provided by CloudSat and CALIPSO since 2006 and will eventually be offered by ESA's planned EarthCARE mission. Together, these missions are capable of measuring the vertical structure of a large fraction of clouds and precipitation, from very thin cirrus clouds to thunderstorms producing heavy precipitation. However, the CALIPSO lidar is unable to penetrate thick clouds and the radar on CloudSat cannot penetrate heavier rain.

Traditionally basic macro- and micro-physical information on the structure of clouds (i.e. determination of whether water or ice particles are present) is being obtained from VIS and IR multi-spectral imagery, such as that provided by MODIS and MISR on Terra in LEO, and GOES and SEVIRI in GEO. These measurements are important for climate purposes as the structure of clouds (particle size and phase) greatly affects their optical properties, and hence their albedo. This has been demonstrated by the WCRP International Satellite Cloud Climatology Project which, since 1983, has provided a record of cloud properties derived from multi-spectral VIS/IR imagery observations that were initially collected for operational meteorological applications.

Together with cloud top temperatures, information on the 3D structure of clouds can be used as a basic tool for the real time surveillance of features such as thunderstorms. Microwave observations provided by instruments such as AMSR-E on Aqua, SSM/I on DMSP and AMSU-A, and MHS on NOAA and EUMETSAT polar platforms, have enhanced capabilities over the VIS and IR multi-spectral observations through their ability to probe the entire cloud and not only the cloud top. However, one limitation of these sensors is their coarse spatial resolution.

Additional phase and cloud particle information is available from polarimetric radiometers such as POLDER and from the polarisation measurement devices of SCIAMACHY on Envisat and GOME-2 on MetOp. As these instruments observe the UV-VIS-NIR part of the spectrum at moderate spectral resolution, very accurate information on macro-physical cloud properties can be obtained. However, for detailed process studies, the users' requirements for cloud data are unlikely to be met until data from instruments such as ATLID or the cloud profiling radar on EarthCARE become available.

A good example of international cooperation is the multiple satellite constellation comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL, which has flown in orbital formation since April 2006. Its objectives are to gather data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback. CloudSat maintains a tight formation with CALIPSO, with a goal of overlapping measurement footprints at least 50% of the time. CALIPSO carries a dual-wavelength, polarisation-sensitive lidar that provides high resolution vertical profiles of aerosols and clouds. CloudSat and CALIPSO maintain a somewhat looser formation behind Aqua, which carries a variety of passive microwave, infrared, and optical instruments.

EarthCARE (launch 2013) will fly a cloud/aerosol lidar, cloud radar, multi-channel imager and broad-band radiometer for measuring clouds and aerosols simultaneously with TOA radiances.

In responding to the GCOS IP, CEOS recognised that accurate measurement of cloud properties has proved to be exceedingly difficult. CEOS agreed to support investigations of cloud properties and cloud trends from combined satellite imager and sounder measurements (with horizontal as well as vertical information) using Cloudsat/CALIPSO for validation.

Cloud Particle Properties and Profile

Atmosphere

Liquid Water and Precipitation Rate

Essential Climate Variables: Precipitation and Cloud Properties

Water forms one of the most important constituents of the Earth's atmosphere and is essential for human existence. The global water cycle is at the heart of the Earth's climate system, and better predictions of its behaviour are needed for monitoring climate variability and change, weather forecasting and sustainable development of the world's water resources. A better understanding of the current distribution of precipitation, and of how it might be affected by climate change, is vital in support of accurate predictions of regional drought or flooding.

Information on liquid water and precipitation rate is used for initialising NWP models. A variety of satellites provide complete global NWP coverage, but they present two major challenges. Firstly, the satellite sensors (such as visible/IR imagers on geostationary weather satellites) typically observe quantities (such as cloud height and cloud top temperature) related to precipitation, so algorithms must be developed to get the best estimates from each particular sensor. Secondly, the mix of available data is constantly changing in space and time.

The new generation of geostationary imagers, available since the start of EUMETSAT's Meteosat Second Generation, also allows for the observation of cloud liquid water path and particle size at high temporal resolution (15 min).

Microwave imagers and sounders (e.g. AMSR-E) offer information on precipitation of marginal horizontal and temporal resolution, acceptable to marginal accuracy (though validation is difficult). Satellite-borne rain radars (e.g. on TRMM and CloudSat), together with plans for constellations of microwave imagers, offer most potential for improved observations. For regional NWP, no satisfactory precipitation estimates are available from satellites at present, although they are the only potential source of information over the oceans. Geostationary satellites do provide vital information on the location of tropical cyclones.

Increasing amounts of useful microwave data – such as those from the TRMM mission – are becoming available. TRMM was dedicated to studying tropical and sub-tropical rainfall and carried the first spaceborne precipitation radar, JAXA's PR instrument, and NASA's TMI microwave imager. Data from PR and TMI have provided new insights into the internal composition of tropical thunderstorms associated with hurricanes. NASA, JAXA and partner agencies plan to continue this collaboration in future to develop the Global Precipitation Measurement (GPM) constellation of satellites that will launch from 2013 onwards. The GPM series will provide global observations of precipitation every three hours to help develop the understanding of the global structure of rainfall and its impact on climate. The CNES-ISRO Megha-Tropiques mission will provide further measurements of tropical rainfall; MADRAS, a passive multi-frequency radiometer, will collect data on rain over the oceans.

The 94 GHz cloud radars on CloudSat and (from 2013) EarthCARE provide complimentary information on light precipitation. EarthCARE's Doppler capability will provide additional detail on sedimentation velocities.

The CMIS microwave imager/sounder on NOAA's NPOESS missions will be sensitive to various forms of water and moisture in the atmosphere and clouds, and will provide an all weather measurement capability.

Future coordination of these satellite programmes, as well as the efforts of the *in situ* measurement community, was addressed by the Integrated Global Water Cycle Observations Theme (IGWCO) of the IGOS Partnership. The first element of IGWCO is a 'Coordinated Enhanced Observing Period (CEOP)' which is taking the opportunity of the simultaneous operation of key satellites of Europe, Japan and USA to generate new data sets of the water cycle.

The IGWCO Theme report is available from www.igospartners.org. This document represents a comprehensive overview of the state-of-the-art in water cycle observations and formulates recommendations for an international work programme to better understand, monitor and predict water processes.

To meet GCOS IP needs, CEOS agencies will ensure continued improvements to precipitation determinations demonstrated by TRMM and planned by GPM from 2013. JAXA and NASA are leading a CEOS study team to establish the basis for a future Global Precipitation Constellation – building on GPM to incorporate measurements from more countries over an extended period.

Liquid Water and Precipitation Rate

Atmosphere

Ozone

Essential Climate Variables: Ozone

Ozone (O_3) is a relatively unstable molecule, and although it represents only a tiny fraction of the atmosphere, it is crucial for life on Earth. Depending on its location, ozone can protect or harm life on Earth. Most ozone resides in the stratosphere, where it acts as a shield to protect the surface from the Sun's harmful ultraviolet radiation. In the troposphere, ozone is a harmful pollutant which causes damage to lung tissue and plants. Man-made chemicals and weather conditions over Antarctica combine to deplete stratospheric ozone concentrations during the southern hemisphere's winter.

The total amount of O_3 in the troposphere is estimated to have increased by 36% since 1750, due primarily to anthropogenic emissions of several O_3-forming gases.

Satellite instruments have for many years provided data measuring interactions within the atmosphere that affect ozone, and more advanced sensors will soon be in orbit to collect more detailed measurements, increasing knowledge of how human activities are affecting the protective ozone layer.

Total column measurements of ozone have been provided over long periods by NASA's TOMS and NOAA's SBUV instruments. Stratospheric ozone profiles have also been measured by instruments such as HALOE and MLS (UARS mission), GOME (ERS-2), and SAGE III (part of the International Space Station payload).

Since launch in March 2002, GOMOS, MIPAS and SCIAMACHY on ESA's Envisat mission have provided improved observations of the concentration of ozone and trace gases in the stratosphere. Operation of GOME-2 on EUMETSAT's MetOp satellites guarantees the continuity of these observations for another decade.

A wide range of instruments dedicated to, or capable of, ozone measurements are planned for the next decade. On the recently launched Aura mission, HIRDLS, OMI and MLS study and monitor atmospheric processes which govern stratospheric and mesopheric ozone, and continue the TOMS record of total ozone measurements. TES on Aura is used to create three-dimensional maps of ozone concentrations in the troposphere. AIRS on Aqua (and, in future, CrIS on NPP/NPOESS) also supplies an ozone product that has some application in the lower stratosphere and also can be used to identify regions of stratospheric/tropospheric mixing.

IASI and GOME-2 on the MetOp series have provided information since early 2007 on both total column ozone and vertical profile. The Ozone Profiler on China's FY-3 series will contribute further data continuously from 2008. Though the infrared imagers on the GOES and Meteosat geostationary platforms have limited capabilities to provide vertical information on ozone, they provide total stratospheric ozone amount with a high temporal resolution. This information can be used to depict stratospheric dynamical processes, relevant for NWP applications.

The IGOS theme on Atmospheric Chemistry Observations (IGACO) has developed a strategy for the integrated provision of chemistry observations (and associated meteorological parameters) required to realise the theme's objectives, including the monitoring of atmospheric composition parameters related to climate change.

The CEOS response to the GCOS IP acknowledged that profiles of ozone were to be addressed by the NPOESS OMPS, but that instrument has been removed from the payload manifest. Furthermore, the discontinuation of solar occultation measurements will profoundly impact one of the climate data record pillars of ozone assessments.

CEOS agencies will participate in re-planning the OMPS limb instrument removed from the planned payload of NPOESS.

Ozone


2008
2009
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2018
2019
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2021
2022
2023
2024
2025
current/approved
ERS series (ATSR-2, GOME: 2)
POES series (ATOVS (HIRS/3 + AMSU + AVHRR/3): 15, 16)(HIRS/3: 15-17)(HIRS/4: 18, N')(SBUV/2: 16-N')
Terra (MODIS)
GOES series (Sounder: 11-P)
Odin (OSIRIS, SMR)
TIMED (SABER)
Envisat (GOMOS, MIPAS, SCIAMACHY)
Aqua (AIRS, MODIS)
Meteosat series (SEVIRI: 8 -11)
SCISAT-1 (ACE-FTS, MAESTRO)
Aura (HiRDLS, MLS (EOS-Aura), OMI, TES)
CALIPSO (IIR)
EPS series (GOME-2, HIRS/4, IASI: 1-3)
FY-3 series (IRAS, TOU/SBUS: 3A-3D)
GOMS/ELECTRO series (MSU-GS: N1, N2)
Meteor series (IKFS-2: N2)
NPP (OMPS)
MTG-I (METEOSAT 3G) series (FCI: 1-4)
NPOESS series (OMPS: 3, 4)
planned/considered
CHINOOK (SWIFT)
FY-3 series (IRAS, TOU/SBUS: 3E-G)
Sentinel-5 precursor (UVNS (Sentinel-5 precursor))
GOMS/ELECTRO series (MSU-GS: N3)
MTG S/Sentinel-4 series (UVN (Sentinel-4): 4A, 4B)
post-EPS/Sentinel-5 series (UVNS (post-EPS): 1)

Atmosphere

Radiation Budget

Essential Climate Variables: Earth Radiation Budget (Including Solar Irradiance)

The Earth's radiation budget is the balance within the climate system between the energy that reaches the Earth from the Sun and the energy that returns from Earth to space. Satellite measurements offer a unique means of assessing the Earth's radiation budget. The goal of such measurements is to determine the amount of energy emitted and reflected by the Earth. This is necessary to understand the processes by which the atmosphere, land and oceans transfer energy to achieve global radiative equilibrium, which in turn is necessary to simulate and predict climate.

Systematic observations of the Earth System energy balance components are noted by the IPCC as being of key importance in narrowing the uncertainties associated with the climate system. In addition to these continuous global measurements of the radiation budget, which are necessary both to estimate any long term climatic trends and shorter term variations overlying these trends, measurements on a regional scale are useful to understand better the dynamics of certain events or phenomena and to assess the effect of climate change, for example on agriculture and urban areas.

In general, three types of measurements are currently possible:

- the shortwave and longwave radiation budget at the top of the atmosphere;
- the shortwave radiation budget at the Earth's surface;
- the total incoming broadband radiation flux.

Since the mid-1960s, NASA has been measuring the net radiation with the ERBE, ACRIM, and CERES sensors. The MISR spectroradiometer (also on Terra with CERES) provides data on the top of the atmosphere, cloud and surface hemispheric albedos, and aerosol opacity. Continuity of Total Solar Irradiance (TSI) measurements was assured by the launch of the SORCE mission at the beginning of 2003, carrying 4 instruments (TIM, SOLSTICE, SIM, XPS) that operate over the 1 nm–2000 nm waveband and measure over 95% of the spectral contribution to TSI. ESA's EarthCARE will embark a broadband radiometer (BBR) together with instruments providing profile information (ATLID, CPR).

The French-Indian mission Megha-Tropiques (2009) will carry the broadband ScaRaB radiometer, similar to the instrument flown in the mid-1990s on the Russian Meteor satellites, for ERB measurements over the tropical and equatorial regions.

An increasing number of radiation budget measurements are featuring on operational meteorology missions. These include: GERB (operating since September 2002 on Meteosat and measuring shortwave and longwave radiation every 15 minutes from a geostationary orbit); TSIS on NPOESS; and continued narrowband information from the HIRS, AVHRR, SEVIRI (top of atmosphere and surface radiative fluxes) and VIIRS instruments.

An important component of the Earth Radiation Budget is the Outgoing Longwave Radiation (OLR). This is calculated from multi-spectral infrared imager observations, such as those from AVHRR or imagers on geostationary platforms.

The past multi-satellite record of measurements suffers from an absence of absolute calibration. It is recognised that development of absolute, spectrally resolved measurements is needed to provide information on variations in climate forcings and responses, and to calibrate the operational meteorological satellite sensors. In addition, there is the likelihood of a measurements gap after 2020; the recent change in NPOESS plans for climate-relevant measurements calls for coordinated re-planning efforts.

In support of the GCOS IP, CEOS aims by 2011 to make absolute, spectrally resolved measurements of radiance emitted and reflected to space by the Earth for information on variations in both climate forcings and responses. CEOS agencies will also participate in re-planning ERBS removed from the planned payload of NPOESS.

Radiation Budget

Atmosphere

Trace Gases (Excluding Ozone)

Essential Climate Variables: Carbon Dioxide, Methane and Other Greenhouse Gases

Trace gases other than ozone may be divided into three categories:

- greenhouse gases affecting climate change;
- chemically aggressive gases affecting the environment (including the biosphere);
- gases and radicals impacting on the ozone cycle, thereby affecting both climate and environment.

The presence of trace gases in the atmosphere can have a significant effect on global change as well as potentially harmful local effects through increased levels of pollution. The chemical composition of the troposphere, in particular, is changing at an unprecedented rate. Meanwhile, the rate at which pollutants from human activities are being emitted into the troposphere is now thought to exceed that from natural sources (such as volcanic eruptions).

As explained in Part I of this document, the IPCC noted in 2007 that:

- changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system;
- global greenhouse gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004;
- carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas. Its annual emissions grew by about 80% between 1970 and 2004.

The IPCC concluded that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely (over 90% probability) due to the observed increase in anthropogenic (man-made) greenhouse gas concentrations". They consider that reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilise radiative forcing.

Measurements from satellite sensors have already made an important contribution to the recognition that human activities are modifying the chemical composition of both the stratosphere and the troposphere, even in remote regions.

A variety of instruments provide measurements on the concentration of trace gases. In general, high spectral resolution is required to detect absorption, emission and scattering from individual species. Some instruments offer measurements of column totals, i.e. integrated column measurements, whilst others provide profiles of gas concentration through the atmosphere (usually limited to the upper troposphere and stratosphere, using limb measurements).

To date, the instruments on UARS (operated 1991–2005) have provided the most significant source of data on trace gases and have been vital for studies of stratospheric chlorine chemistry, stratospheric tracer-tracer correlation, tropospheric water vapour, the chemistry of the Arctic lower stratosphere in winter, and tropospheric aircraft exhaust studies.

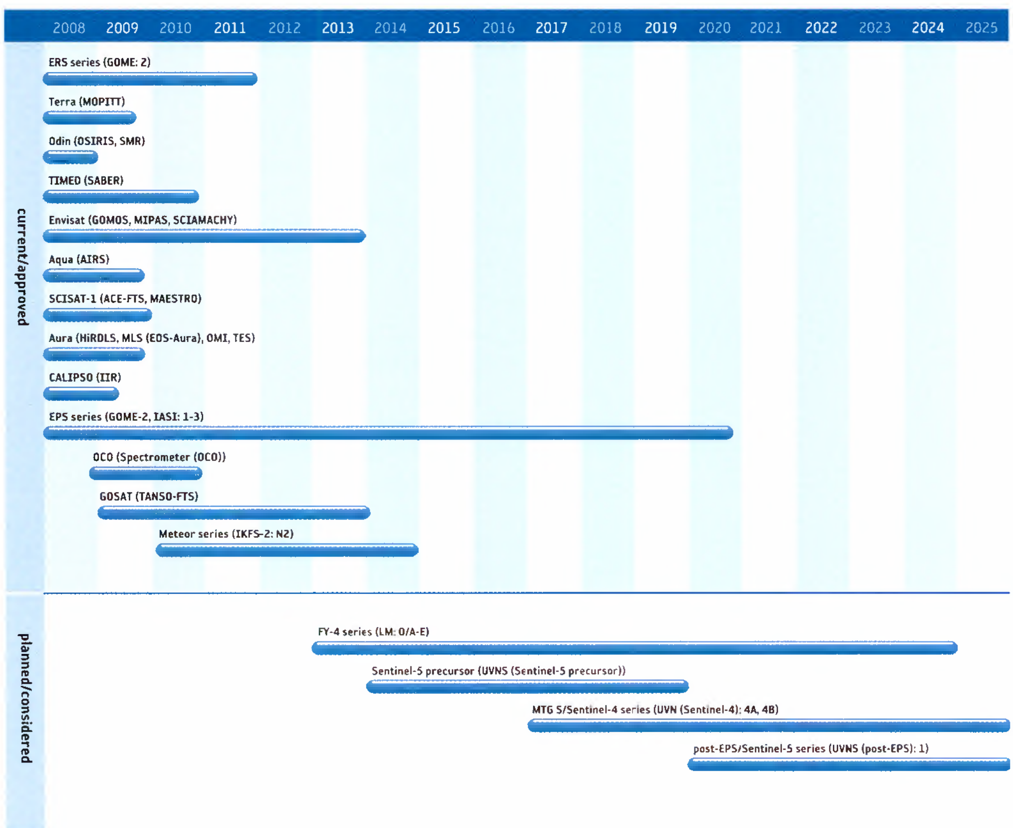
The last few years have seen the arrival of new and significant capabilities, with advanced instruments on Terra (MOPITT, providing global measurements of carbon monoxide and methane in the troposphere), and Envisat (GOMOS, MIPAS and SCIAMACHY, providing profiles of trace gases through the stratosphere and troposphere). AIRS (on Aqua) and IASI (on MetOp) also contribute to such information and their sounder products can help quantify atmospheric mixing and help determine sources and sinks.

On NASA's Aura mission, HiRDLS, an infrared limb-scanning radiometer, carries out soundings of the upper troposphere, stratosphere and mesosphere to determine concentrations of trace gases, with horizontal and vertical resolutions superior to those previously obtained. On the same mission, MLS measures concentrations of trace gases for their effects on ozone depletion, TES provides a primary input to a database of 3D distribution on global, regional and local scales of gases important to tropospheric chemistry, and OMI continues the TOMS record for atmospheric parameters related to ozone chemistry and climate. JAXA's GOSAT mission (from 2008) and NASA's OCO mission (also from 2008) are expected to make significant contributions to observations of trace gases, particularly carbon dioxide and methane.

The IGOS IGACO Theme for observations of atmospheric chemistry has considered all relevant chemical species to interpret properly the observations and intends to monitor the research required to improve understanding of Earth processes so that air quality evolution can be predicted. ESA is considering atmospheric composition missions (such as TRAQ, PREMIER and A-SCOPE) to meet these needs.

The CEOS Response to the GCOS IP cautions that demonstrations of potential future operational measurements are neither complemented by plans for operational implementation nor any R&D follow-on. CEOS agencies will participate in planning, by 2011, the current chemistry missions and those planned for the next 5 to 7 years.

Trace Gases (Excluding Ozone)



Land

Albedo and Reflectance

Essential Climate Variables: Albedo

Albedo is the fraction of solar energy that is diffusely reflected back from Earth to space. Measurements of albedo are essential for climate research studies and investigations of the Earth's energy budget.

Different parts of the Earth have different albedos. For example, ocean surfaces and rain forests have low albedos, which means that they reflect only a small portion of the Sun's energy. Deserts, ice and clouds, however, have high albedos; they reflect a large portion of the incoming solar energy. The high albedo of ice helps to insulate the polar oceans from solar radiation. Over the whole surface of the Earth, about 30% of incoming solar energy is reflected back to space. Because a cloud usually has a higher albedo than the surface beneath it, clouds reflect more shortwave radiation back to space than the surface would in the absence of the cloud, thus leaving less solar energy available to heat the surface and atmosphere. Hence, this 'cloud albedo forcing', taken by itself, tends to cause a cooling or 'negative forcing' of the Earth's climate.

Surface albedo can be estimated from shortwave, broadband or multi-spectral radiometer measurements with good horizontal resolution. Current measurements of albedo and reflectance are obtained primarily using multi-spectral imagers such as AATSR, AVHRR, MODIS, MERIS, Vegetation and instruments on some geostationary satellites (such as MSG).

Clouds, aerosols and atmospheric gases affect the achievable accuracy, which is currently marginal to acceptable, but should improve as progress is made in interpreting data from high resolution, multi-spectral instruments. Surface conditions (moisture, surface vegetation, snow cover etc.) strongly affect albedo and high quality ground truth data is necessary in support of satellite measurements. Better understanding of the reflectance properties of different surfaces and more accurate aerosol data (to correct atmospheric effects) are needed to improve surface reflectance measurements.

As aerosol concentration increases within a cloud, more cloud droplets form. Since the total amount of condensed water in a cloud does not change much, the average droplet becomes smaller. This has two consequences: clouds with smaller droplets reflect more sunlight and such clouds last longer. Both effects increase the amount of sunlight that is reflected to space without reaching the surface.

The Terra spacecraft is yielding greater knowledge of such cloud/aerosol effects, with MODIS and MISR providing data on cloud features, and ASTER providing complementary, high spatial resolution measurements. Terra's data provide new insights into how clouds modulate the atmosphere and surface temperature. Further multi-directional and polarimetric instruments (e.g. POLDER) also provide measurements leading to better estimates of albedo.

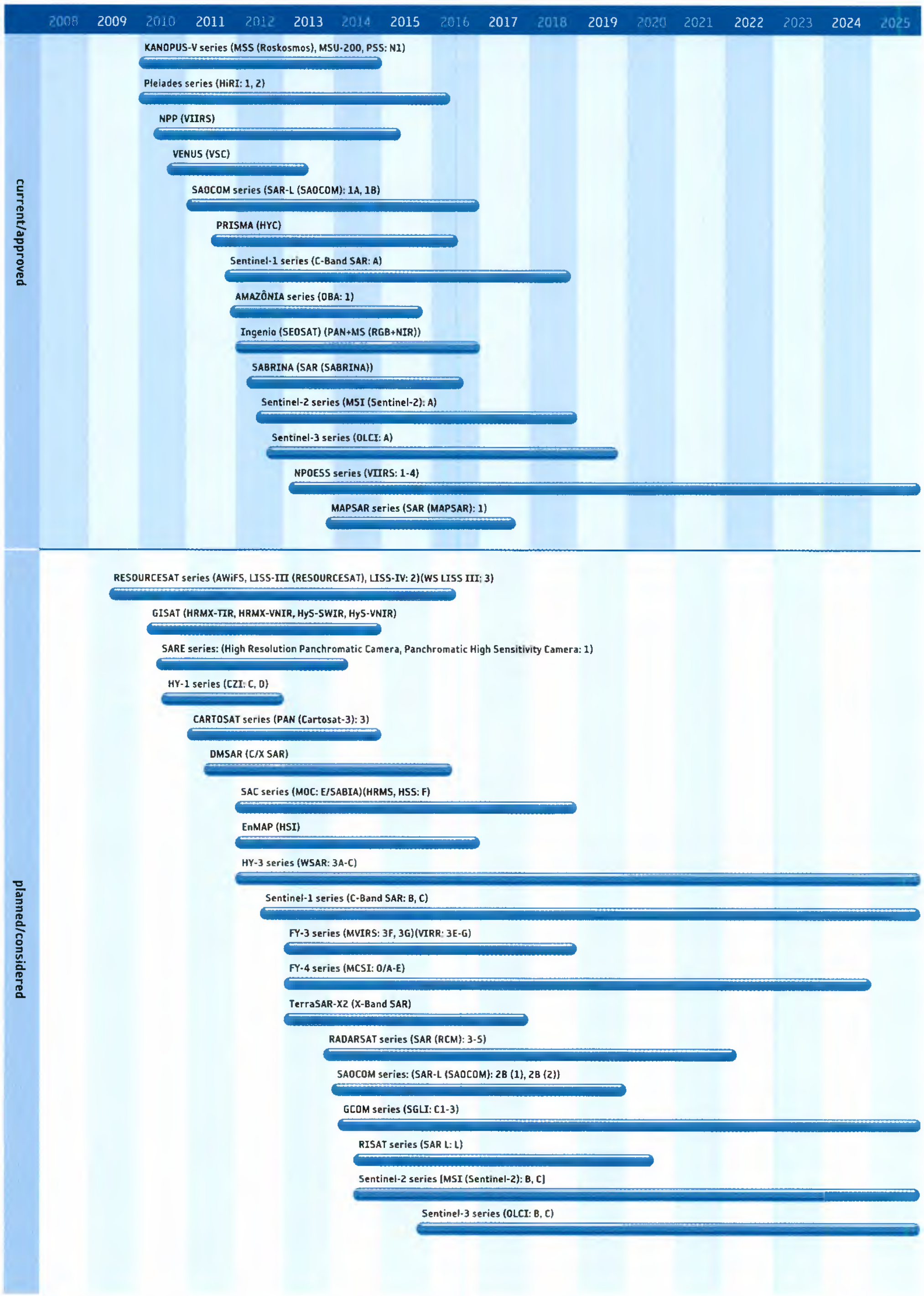
New sensors, such as GERB and SEVIRI on board the MSG missions (starting with Meteosat-8) are providing improved capabilities for measuring surface albedo. Improved sounder performance will yield more information on the infrared surface emissivity spectrum. Multi-spectral imaging sensors such as AVHRR/3, IVISSR and AWIFS will provide global visible, near-infrared and infrared imagery of clouds, ocean and land surfaces.

CEOS has undertaken to improve the continuity of terrestrial climate monitoring through enhancements to the moderate-resolution historical record. AVHRR data reprocessing will be undertaken to ensure a consistent data set to contribute to historical albedo. CEOS will also work to enhance the quality of the Fundamental Climate Data Records generated from the AVHRR record.

Albedo and Reflectance

Land

Albedo and Reflectance



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Land

Landscape Topography

Essential Climate Variables: Lake Areas and Levels

Many modelling activities in Earth and environmental sciences, telecommunications and civil engineering increasingly require accurate, high resolution and comprehensive topographical databases with, indication of changes over time, where relevant. The information is also used by, amongst others, land use planners for civil planning and development, and by hydrologists to predict the drainage of water and likelihood of floods, especially in coastal areas. In its Fourth Assessment Report in 2007, the IPCC predicts that (by conservative estimation techniques) global mean sea level may rise as much as 28–43 cm by the end of the 21st century. Potentially, sea level rise will cause severe flooding, with disastrous impacts on large, densely populated, low-lying coastal cities and deltaic areas, such as Bangladesh.

Satellite techniques offer a unique, cost-effective and comprehensive source of landscape topography data. At present, most information is obtained primarily from multi-band optical imagers and synthetic aperture radar (SAR) instruments with stereo image capabilities. The pointing capability of some optical instruments allows the production of stereo images from data gathered on a single orbit (e.g. by ASTER) or multiple orbits (e.g. by SPOT series).These are then used to create digital elevation maps, which give a more accurate depiction of terrain.

Since SARs can also be used in interferometric mode to detect very small changes in topography, they have important applications in monitoring of volcanoes, landslides, earthquake displacements and urban subsidence. Current missions include Envisat, RADARSAT-2, TerraSAR-X and ALOS (which carries both high precision optical and SAR topographic mapping instruments). In future, ESA's Sentinel-1 mission will also contribute to such information.

Radar altimeters can also provide coarse topographic mapping over land. They have been supplemented by a new generation of laser altimeters, such as GLAS (on ICESat) which can provide landscape topography products with height accuracies of order 50–100 cm, depending on slope.

The role of these satellites and their importance in mitigating geo-hazards, such as earthquakes, landslides, and volcanic eruptions, is the focus of the IGOS Geo-hazards Theme. The Geo-hazards Theme report is available from www.igospartners.org.

GCOS notes that measurements of lake area and lake level give an indication of the volume of the lake, an integrator variable that reflects both atmospheric (precipitation, evaporation-energy) and hydrological (surface water recharge, discharge and ground water tables) conditions. GCOS threshold requirements for these variables are currently met by existing missions.

Landscape Topography

Soil Moisture

Essential Climate Variables: Soil Moisture

Soil moisture plays a key role in the hydrological cycle. Evaporation rates, surface runoff, infiltration and percolation are all affected by the level of moisture in the soil. Changes in soil moisture have a serious impact on agricultural productivity, forestry and ecosystem health. Monitoring soil moisture is critical for managing these resources and understanding long-term changes, such as desertification, and should be developed in proper coordination with other land surface variables. There is a pressing need for measurements of soil moisture for applications such as crop yield predictions, identification of potential famine areas, irrigation management, and monitoring of areas subject to erosion and desertification, as well as for the initialisation of NWP models.

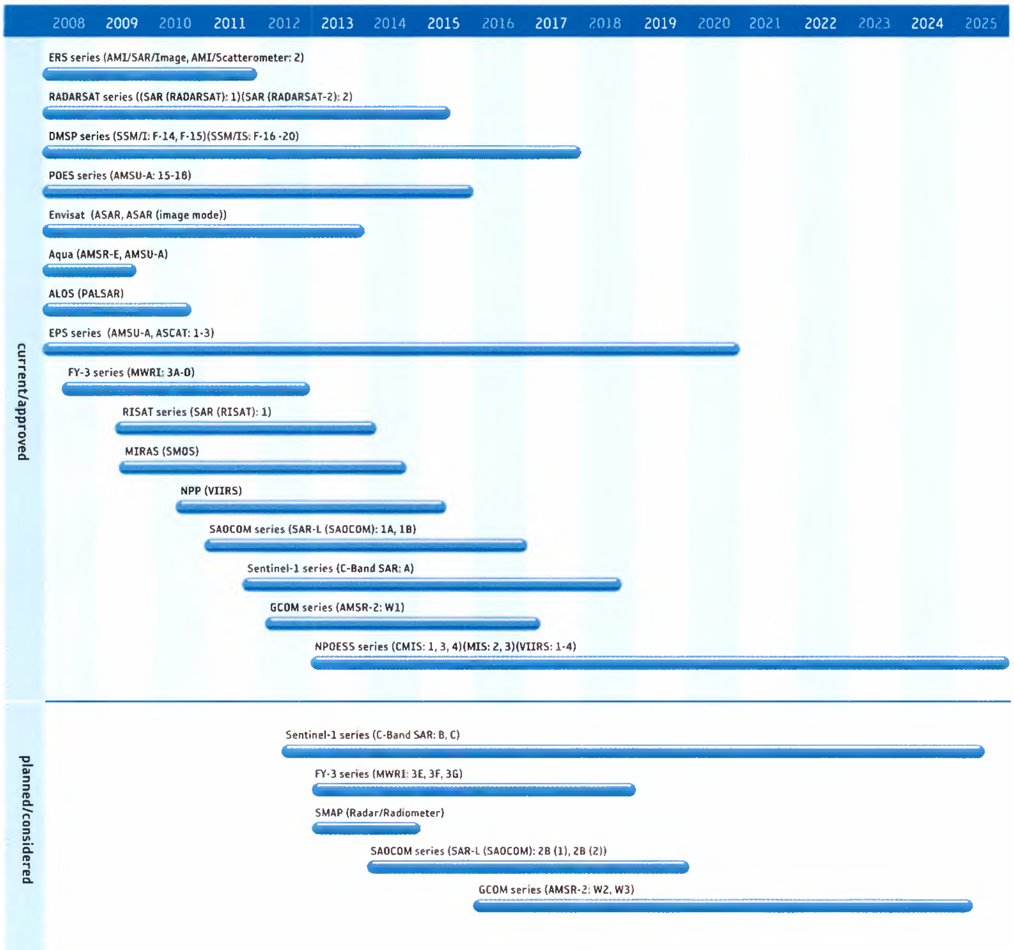
Direct measurement of soil moisture from space is difficult. Most of the active and passive microwave instruments provide some soil moisture information for regions of limited vegetation cover. However, under many conditions remote sensing data are inadequate and information regarding moisture depth remains elusive. While recent studies have successfully demonstrated the use of infrared, passive microwave, and non-SAR sensors to obtain soil moisture information, the potential of active microwave remote sensing based on SAR instruments remains largely unrealised. The main advantage of radar is that it provides observations at a high spatial resolution of tens of metres compared to tens of kilometres for passive satellite instruments, such as radiometers, or non-SAR active instruments, such as scatterometers (e.g. QuikSCAT and ERS). The main difficulty with SAR imagery is that soil moisture, surface roughness and vegetation cover all have an important and nearly equal effect on radar backscatter. These interactions make retrieval of soil moisture possible only under particular conditions, such as bare soil or surfaces with low vegetation, or through complex modelling to 'subtract' the contributions/effects of vegetation.

An appropriate instrument for measurements of soil moisture would appear to be the passive microwave radiometer, although some success has been achieved by radar – despite the complications of analysing the signals reflected from the ground. Microwave radiation emitted at the ground can be monitored to infer estimates of soil moisture. Passive microwave sensors can be used to do this, based on detection of surface microwave emissions, although the signal is very small. Reliable data (high signal to noise ratio) need to be taken over a large area – which introduces the problem of understanding how to interpret the satellite signal, since it consists of radiation from many different soil types.

SAR data currently provide the main source of information on near-surface (10–15 cm) soil moisture, for example, ASAR on Envisat. ASCAT (an improvement of the ERS-1/2 scatterometer) on EUMETSAT's MetOp series also provides data from which soil moisture information can be inferred.

AMSR-E on Aqua provides a variety of information on water content by measuring weak radiation from the Earth's surface. NOAA's conical microwave imager/sounder (CMIS) will provide environmental data including indications of soil moisture.

With launch likely in 2009, the first mission likely to satisfy requirements for observing soil moisture from space for the primary applications of hydrologic and meteorological modelling will be ESA's SMOS (Soil Moisture and Ocean Salinity Mission), carrying the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) passive L-band 2D interferometer. The new capabilities provided by SMOS will help reduce process uncertainties and improve climate models.


2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
current/approved
ERS series (AMI/SAR/Image, AMI/Scatterometer: 2)
RADARSAT series ((SAR (RADARSAT): 1)(SAR (RADARSAT-2): 2)
DMSP series (SSM/I: F-14, F-15)(SSM/IS: F-16 -20)
POES series (AMSU-A: 15-18)
Envisat (ASAR, ASAR (image mode))
Aqua (AMSR-E, AMSU-A)
ALOS (PALSAR)
EPS series (AMSU-A, ASCAT: 1-3)
FY-3 series (MWRI: 3A-D)
RISAT series (SAR (RISAT): 1)
MIRAS (SMOS)
NPP (VIIRS)
SAOCOM series (SAR-L (SAOCOM): 1A, 1B)
Sentinel-1 series (C-Band SAR: A)
GCOM series (AMSR-2: W1)
NPOESS series (CMIS: 1, 3, 4)(MIS: 2, 3)(VIIRS: 1-4)
planned/considered
Sentinel-1 series (C-Band SAR: B, C)
FY-3 series (MWRI: 3E, 3F, 3G)
SMAP (Radar/Radiometer)
SAOCOM series (SAR-L (SAOCOM): 2B (1), 2B (2))
GCOM series (AMSR-2: W2, W3)

Land

Vegetation

Essential Climate Variables: Land Cover, Fire Disturbance (Burnt Area), Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and Biomass

Changes in land cover are important aspects of global environmental change, with implications for ecosystems, biogeochemical fluxes and global climate. Land cover change affects climate through a range of factors from albedo to emissions of greenhouse gases from the burning of biomass.

Deforestation inter alia increases the amount of carbon dioxide (CO_2) and other trace gases in the atmosphere. When a forest is cut and burned to establish cropland and pastures, the stored carbon joins with oxygen and is released into the atmosphere as CO_2. The IPCC notes that about three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years were due to fossil fuel burning. The rest was predominantly due to land use change, especially deforestation.

In 2005, a number of developing countries proposed to incorporate deforestation prevention into the Kyoto Protocol, in part through an emissions trading system. The initiative, known as REDD, (Reducing Emissions from Deforestation in Developing countries) would allow developing countries to sell emissions savings from forest conservation. Developed countries would buy the savings to credit against their own emissions targets.

IGOS has set up an Integrated Global Carbon Observation (IGCO) Theme (report available from www.igospartners.org) to develop a flexible, robust strategy for international global carbon observations over the next decade. A key component of IGCO is terrestrial carbon observations aimed at the determination of terrestrial carbon sources and sinks with increasing accuracy and spatial resolution. The IPCC has highlighted an improved understanding of carbon dynamics as vital in tackling one of the biggest environmental problems facing humanity. The IGCO work will be an essential input to the implementation of the United Nations Framework Convention on Climate Change (UNFCCC), particularly on the role of natural sinks in meeting targets under the UNFCCC Kyoto Protocol.

Satellite observations allow scientists to map land cover and the dynamics of fire disturbance, and track two key elements of Earth's vegetation – the 'Leaf Area Index' (LAI) and the 'Fraction of absorbed Photo-synthetically Active Radiation' (fAPAR). LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies, or as the projected needle leaf area per ground unit in needle canopies. fAPAR is the fraction of photosynthetically active radiation absorbed by vegetation canopies. Both LAI and fAPAR are data necessary for understanding how Sunlight interacts with the Earth's vegetated surfaces.

Multiple types of satellite observations are used in agricultural applications. Space imagery provides information which can be used to monitor quotas and to examine and assess crop characteristics and planting practice. Information on crop condition, for example, may also be used for irrigation management. In addition, data may be used to generate yield forecasts, which in turn may be used to optimise the planning of storage, transport and processing facilities. Classification and seasonal monitoring of vegetation types on a global basis allow the modelling of primary production – the growth of vegetation that is the base of the food chain – which is of great value in monitoring global food security.

A number of radiometers provide measurements of vegetation cover, including the ATSR series, AVHRR/3, MODIS, MERIS, SEVIRI and Vegetation. These instruments are helping production of global maps of surface vegetation for modelling of the exchange of trace gases, water and energy between vegetation and the atmosphere. Multi-directional and polarimetric instruments (such as MISR and POLDER) will provide more insights into corrections of land surface images for atmospheric scattering and absorption, as well as Sun-sensor geometry, allowing better calculation of vegetation properties.

Synthetic aperture radars (SARs) are used extensively to monitor deforestation and surface hydrological states and processes. The ability of SARs to penetrate cloud cover and dense plant canopies makes them particularly valuable in rainforest and high-latitude boreal forest studies.

Instruments such as ASAR, SAR (RADARSAT), and PALSAR provide data for such applications as agriculture, forestry, land cover classification, hydrology and cartography.

CEOS and GCOS have concluded that many of the Essential Climate Variables related to vegetation and supported from space will require reprocessing of the moderate resolution historical record (in particular AVHRR) to be of greater value for climate purposes, and appropriate actions have been defined, including the development of enhanced calibration and validation schemes which guarantee long-term stability and consistency over different temporal and spatial scales. Research topics like scaling, and the development of 'community radiative transfer models' integrated into sophisticated assimilation schemes, are of paramount importance for an integrated approach.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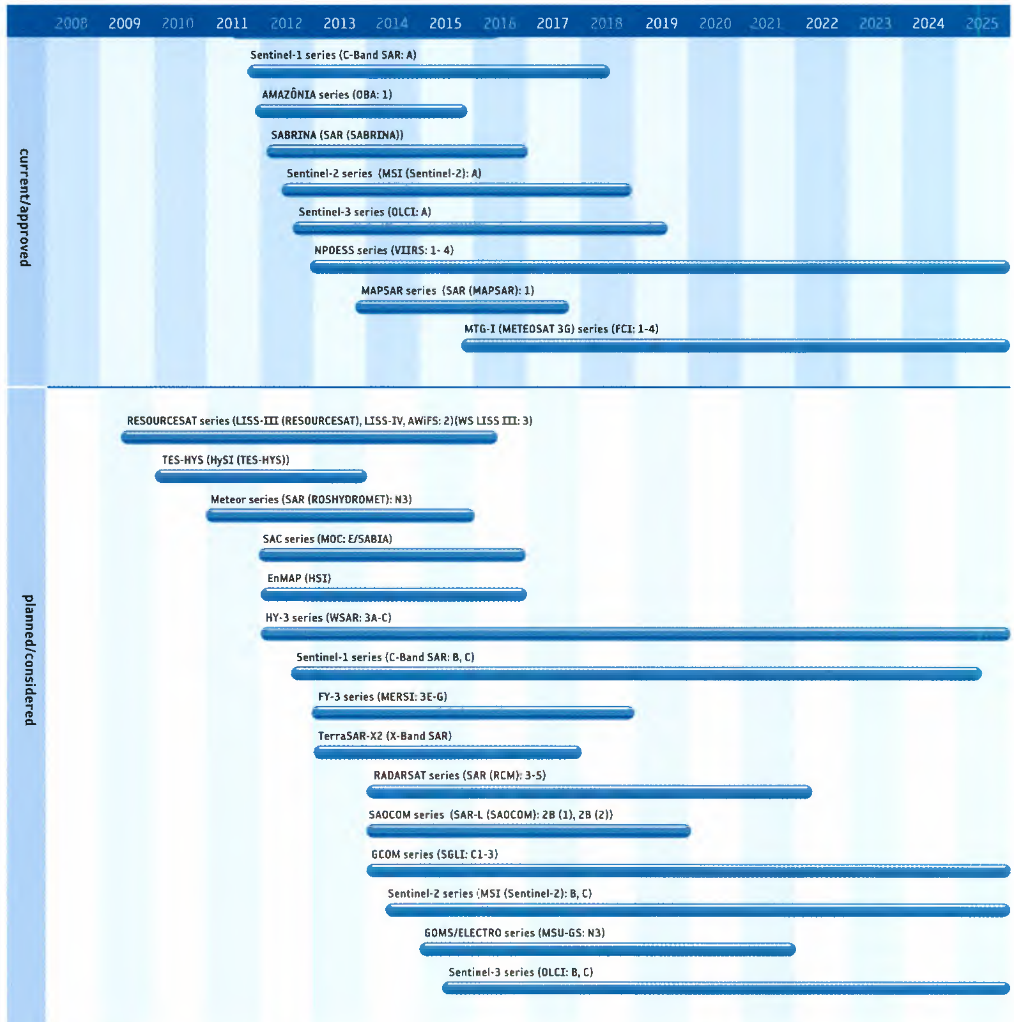
Landsat series (TM: 5)(ETM+: 7)(OLI: 8)
SPOT series (HRV: 2)(HRVIR: 4)(VEGETATION: 4, 5)(HRG, HRS: 5)
ERS series (AMI/SAR/Image, AMI/Scatterometer, ATSR-2: 2)
RADARSAT series (SAR (RADARSAT): 1)(SAR (RADARSAT-2): 2)
IRS series (LISS-III (IRS), WiFS: 1D)
POES series (AVHRR/3: 15-N')
Terra (ASTER, MISR, MODIS)
NMP series (ALI, Hyperion: 1)
SAC series (HRTC, MMRS: C)
PROBA (CHRIS)
Envisat (AATSR, ASAR, ASAR (image mode), MERIS)
Aqua (MODIS)
FY-1 series (MVISR (10 channels): 1D)
Meteosat series (SEVIRI: 8-11)
UK-DMC (DMC Imager)
RESOURCESAT series (AWiFS, LISS-III (RESOURCESAT), LISS-IV: 1)
CBERS series (CCD, WFI: 2, 2B)(PAN, WFI-2: 3, 4)
FY-2 series (IVISSR (FY-2): 2C-F)
PARASOL (POLDER-P)
TopSat (TOPSAT Telescope)
ALOS (AVNIR-2, PALSAR)
KOMPSAT series (MSC: 2)
EPS series (AVHRR/3: 1-3)
COSMO Skymed series (SAR 2000: 1-4)
TerraSAR-X (X-Band SAR)
IMS-1 (HySI (IMS-1))
FY-3 series (MERSI: 3A-D)
THEOS (MS (GISTDA))
RapidEye (MSI)
HJ series (HSI (HJ-1A): 1A)
UK-DMC2 (DMC-2 Imager)
Meteor series (BRLK, MSU-MR: N1, N2)
GOMS/ELECTRO series (MSU-GS: N1, N2)
Sich series (MBEI, MIREI: 2)
SumbandilaSat (SumbandilaSat Imager)
RISAT series (SAR (RISAT): 1)
TanDEM-X (X-Band SAR)
KANOPUS-V series (PSS: N1)
Pleiades series (HiRI: 1, 2)
NPP (VIIRS)
VENUS (VSC)
SAOCOM series (SAR-L (SAOCOM): 1A, 1B)
PRISMA (HYC, PAN CAMERA)

Land

Vegetation



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Surface Temperature (Land)

Essential Climate Variables: Fire Disturbance (Active Fires)

Land surface temperature varies widely with solar radiation. It is of help in interpreting vegetation and its water stress when the range of temperatures between day and night and from clear sky to cloud cover are compared.

Estimates of greenhouse gas emissions due to fire are essential for realistic modelling of climate and its critical component, the global carbon cycle. Fires caused deliberately for land clearance (agriculture and ranching) or accidentally (lightning strikes, human error) are a major factor in land cover changes, affecting fluxes of energy and water to the atmosphere. On a local scale, surface temperature imagery may be used to refine techniques for predicting ground frost and to determine the warming effect of urban areas (urban heat islands) on night-time temperatures. In agriculture, temperature information may be used, together with models, to optimise planting times and provide timely warnings of frost.

Measurements of surface temperature patterns may also be used in studies of volcanic and geothermal areas and resource exploration.

Land surface temperature measurements are made using the thermal infrared channel of medium/high resolution multi-spectral imagers in low Earth orbit. In addition, visible/infrared imagers on geostationary satellites also provide useful information, with the advantage of very high temporal resolution. However, difficulties remain in converting the apparent temperatures as measured by these instruments into actual surface temperatures – variations due to atmospheric effects and vegetation cover, for example, require compensation using additional imagery/information.

A number of capable sensors designed to provide land surface temperature data are currently operating or planned. These include advanced sounders (IASI, HIRS/4) on operational meteorological platforms. On the NPOESS missions, VIIRS will combine the radiometric accuracy of AVHRR with the high spatial resolution of the DMSP's OLS instrument, and the CMIS imager/sounder will measure thermal microwave emissions from land surfaces.

The Hot Spot Recognition Sensor (HSRS) on BIRD (launched 2001) has already demonstrated its value as a purpose-built fire detection instrument while MODIS provides regular sampling of active fires, SEVIRI observes the diurnal cycle of fire occurrence in Africa and the ATSR series, despite not being designed for active fire observations, has produced the longest record of hot spot detection (at night). ESA offers a monthly world fire atlas product available online at dup.esrin.esa.it/ionia/wfa.

Surface Temperature (Land)

Land

Multi-purpose Imagery (Land)

Essential Climate Variables: Land Cover

The spatial information that can be derived from satellite imagery is of value in a wide range of applications, particularly when combined with spectral information from multiple wavebands of a sensor. Satellite Earth observation is of particular value where conventional data collection techniques are difficult, such as in areas of inaccessible terrain, providing cost and time savings in data acquisition – particularly over large areas.

At regional and global scales, low resolution instruments with wide coverage capability and imaging sensors on geostationary satellites are routinely exploited for their ability to provide global data on land cover and vegetation. Land cover change detection is important for understanding global environmental change and has profound implications for ecosystems, biochemical fluxes and climate. Instruments on satellites with wide and frequent coverage provide data useful for spin-off applications. AVHRR on NOAA's polar orbiting satellite series was originally intended only as a meteorological satellite system, but it has subsequently been used in a multitude of diverse applications, while the Envisat MERIS instrument is being used to generate global land cover imagery at 300 m resolution.

On national and local scales, the spatial resolution requirements for information mean that moderate resolution imaging sensors, such as those on SPOT, Landsat and IRS, and imaging radars (such as those on ERS, Envisat and RADARSAT) are most useful. Such sensors are routinely used as practical sources of information for:

- agriculture monitoring, farming and production forecasting;
- resource exploration and management, e.g. forestry;
- geological surveying for mineral exploration and identification;
- hydrological applications such as flood monitoring;
- civil mapping and planning, involving cartography, infrastructure and urban management;
- coastal zone monitoring, including oil spill detection and monitoring;
- topographic mapping, generation of DEMs.

SAR data are particularly useful in monitoring and mapping floods because they are available even in the presence of thick cloud cover. Instruments on RADARSAT, Envisat, ALOS and TerraSAR-X continue to provide improved capabilities in this field. Such multi-incidence, high resolution SAR systems will also be useful for landslide inventory maps and earthquake prediction. Moreover InSAR techniques can be used to document deformation and topographic changes preceding, and caused by, volcanic eruptions. Volcanic features also have distinctive thermal characteristics which can be detected by thermal imagery, such as that provided by the ASTER radiometer flying on Terra. The IGOS Geo-hazards Theme report provides a comprehensive guide as to the value of satellite Earth observations for such applications. Future SAR instruments will continue to be important for land imagery because of their all-weather, day and night observing capability and high spatial resolution (1–3 metres), as provided by RADARSAT-2 and COSMO-SkyMed.

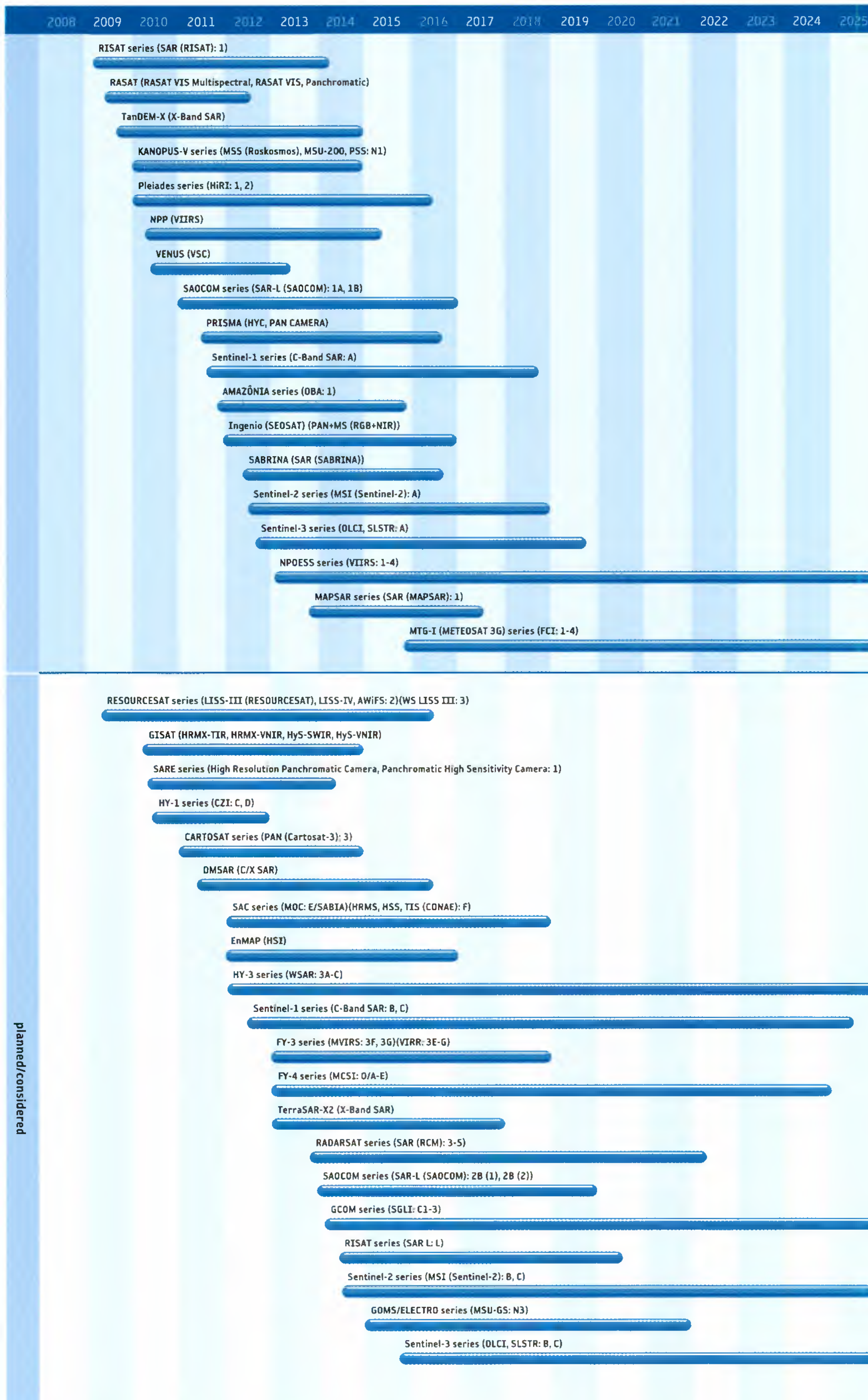
New instruments, such as AVNIR-2 and PRISM on ALOS, have provided enhanced land observing technology and improved data products. In general, future sensors will benefit from a greater number of sampling channels. NOAA's VIIRS instrument, for instance, will have multi-channel imaging capabilities and will combine the radiometric accuracy of AVHRR with the high spatial resolution of the OLS flown on DMSP missions.

CEOS has initiated a virtual constellation study team for land surface imaging to provide the coordination framework necessary to secure continuity of moderate resolution imagery used for many land surface applications, including their relation to climate.

Multi-purpose Imagery (Land)

Land

Multi-purpose Imagery (Land)



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Ocean

Ocean Colour/Biology

Essential Climate Variables: Ocean Colour (for Biological Activity)

Remote sensing measurements of ocean colour (i.e. the detection of phytoplankton pigments) provide the only global-scale focus on the biology and productivity of the ocean's surface layer. Phytoplankton are microscopic plants that live in the ocean, and like terrestrial plants, they contain the pigment chlorophyll, which gives them their greenish colour. Different shades of ocean colour reveal the presence of differing concentrations of sediments, organic materials and phytoplankton. The ocean over regions with high concentrations of phytoplankton is shaded from blue-green to green, depending on the type and density of the phytoplankton population. From space, satellite sensors can distinguish even slight variations in colour which cannot be detected by the human eye.

Ocean biology is important not only for understanding ocean productivity and biogeochemical cycling, but also because of its impact on oceanic CO_2 and the flux of carbon from the surface to the deep ocean. Over time, organic carbon settles in the deep ocean, a process referred to as the 'biological pump'. CO_2 system measurements, integrated with routine ocean colour and ecological/biogeochemical observations, are critical for understanding the interactions between oceanic physics, biology, chemistry and climate. CO_2 measurements are also important for making climate forecasts and for satisfying the needs of climate conventions.

At a local scale, satellite observations of ocean colour, usually in conjunction with sea surface temperature measurements, may be used as an indication of the presence of fish stocks. Measurements may also be used to monitor water quality and to give an indication of the presence of pollution by identifying algal blooms. Measurements of ocean colour are particularly important in coastal regions where they can be used to identify features indicative of coastal erosion and sediment transfer.

An Ocean Theme was set up within the former IGOS framework in 1999 to develop a strategy for an observing system serving research and operational oceanographic communities and other users.

Building on the CEOS Ocean Biology and GODAE Projects, the Ocean Theme Team published its final report in January 2001. This brought together information on:

- the variety of needs for global ocean observations;
- the existing and planned observing systems;
- the planning commitments required to ensure long term continuity of the observations.

Ocean colour measurements from space are the focus of the International Ocean Colour Coordinating Group (www.ioccg.org/).

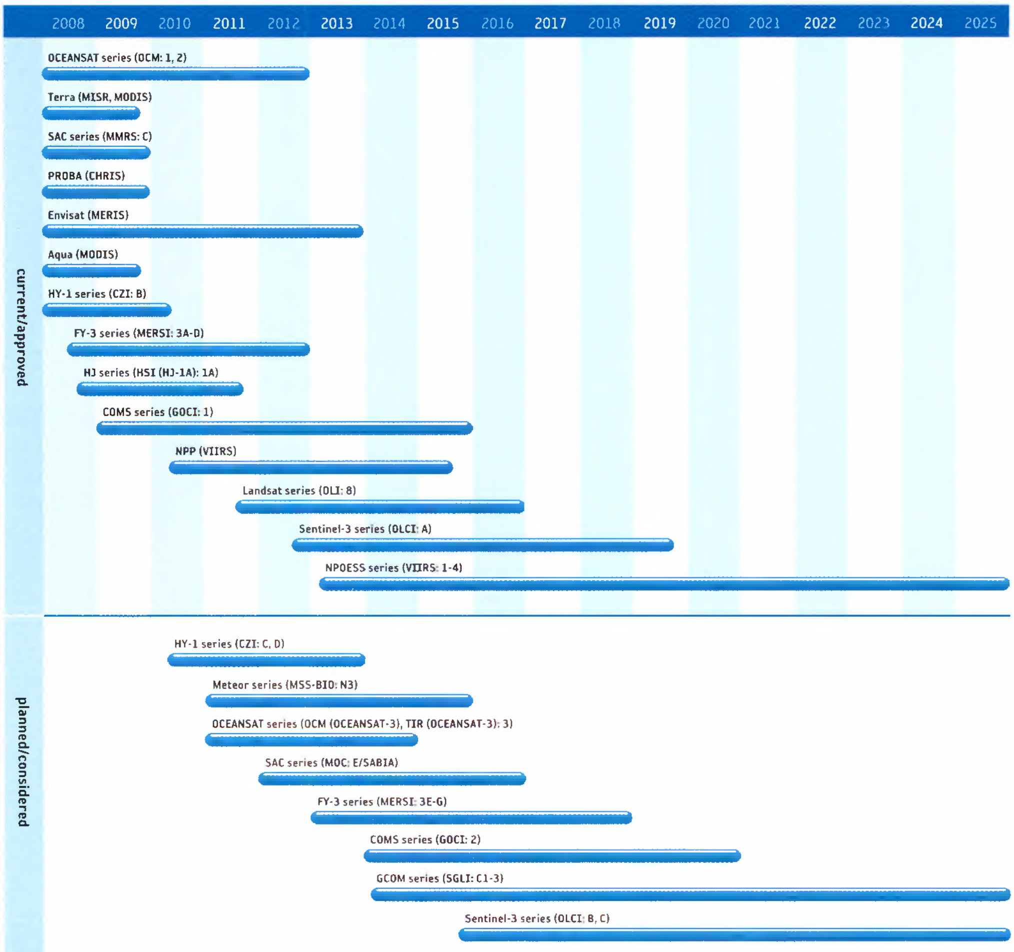
In recent years there has been a steady flow of ocean colour data at various scales from instruments such as OCTS (on ADEOS), SeaWiFs, OCM (on IRS), MODIS (on Terra and Aqua), and MERIS (on Envisat), as well as POLDER and PARASOL. As the timeline shows, a number of current missions will end in the near future. Information available on agency plans indicates that future continuity will be provided by OCM-2 on Oceansat-2 (India), the HY-2 series (China), Sentinel-3 (Europe) and others.

Beyond these research or pre-operational missions, NOAA is developing VIIRS for its NPOESS missions – with an operational capability for ocean colour.

Four actions were identified in the CEOS response to GCOS requirements:

- ISRO will lead planning of Oceansat-2, ESA and the EC of Sentinel-3, and JAXA of GCOM-C, which are all new missions planned to carry an ocean colour sensor;
- relevant CEOS agencies will examine their respective plans to maintain continuity of the 25-km-resolution ocean colour global product;
- CEOS agencies will cooperate to support the combination of all existing ocean colour data sets into a global FCDR;
- in consultation with GCOS and the relevant user communities, CEOS agencies will explore the means to secure, by 2011, continuity of the 1-km-resolution global ocean colour product needed to fulfil the target GCOS requirements

Ocean Colour/Biology



Ocean

Ocean Topography/Currents

Essential Climate Variables: Sea Level, Current

Ocean surface topography data contain information that has significant practical applications in such fields as the study of worldwide weather and climate patterns, the monitoring of shoreline evolution and the protection of ocean fisheries. Ocean circulation is of critical importance to the Earth's climate system. Ocean currents transport a significant amount of energy from the tropics towards the poles, leading to a moderation of the climate at high latitudes. Thus knowledge of ocean circulation is central to understanding the global climate. Circulation can be deduced from ocean surface topography, which may be readily measured using satellite altimetry. However, altimeters can only provide this geostrophic part of ocean currents to optimal accuracy when the geoid is known more accurately.

Using satellite altimetry, large scale changes in ocean topography, such as those in the tropical Pacific, may be observed. During an El Niño event, the westward trade winds weaken, allowing warm, nutrient-poor water to occupy the entire tropical Pacific Ocean. During the following La Niña the trade winds are stronger, so that cold, nutrient-rich water occupies much of the tropical Pacific Ocean.

On a local scale, topographic information from satellites may be used to support off-shore exploration for resources, detection of oil spills and optimisation of pipeline routing on the sea floor.

The Topex/Poseidon (1992–2005), ERS-1 (1991–2000) and ERS-2 (since 1995) missions have demonstrated that satellite altimetry may be utilised in a wide range of ocean research, such as planetary waves, tides, global sea level change, seasonal-to-inter-annual climate prediction, defence, environmental prediction and commercial applications. Thanks to its high altitude and non Sun-synchronous, dedicated orbit, Topex/Poseidon could measure the height of the ocean surface directly under the satellite with an accuracy of 2–3 cm. The follow-on Jason-1 mission, launched in late 2001, aims to:

- provide a 5-year view of global ocean topography;
- increase understanding of ocean circulation and seasonal changes;
- improve forecasting of climate events like El Niño;
- measure global sea-level change;
- improve open ocean tide models;
- provide estimates of significant wave height and wind speeds over the ocean.

Information on ocean circulation may also be obtained indirectly from features such as current and frontal boundaries in SAR imagery, and by using differences in ocean surface temperature or ocean colour as observed by visible and infrared imagers.

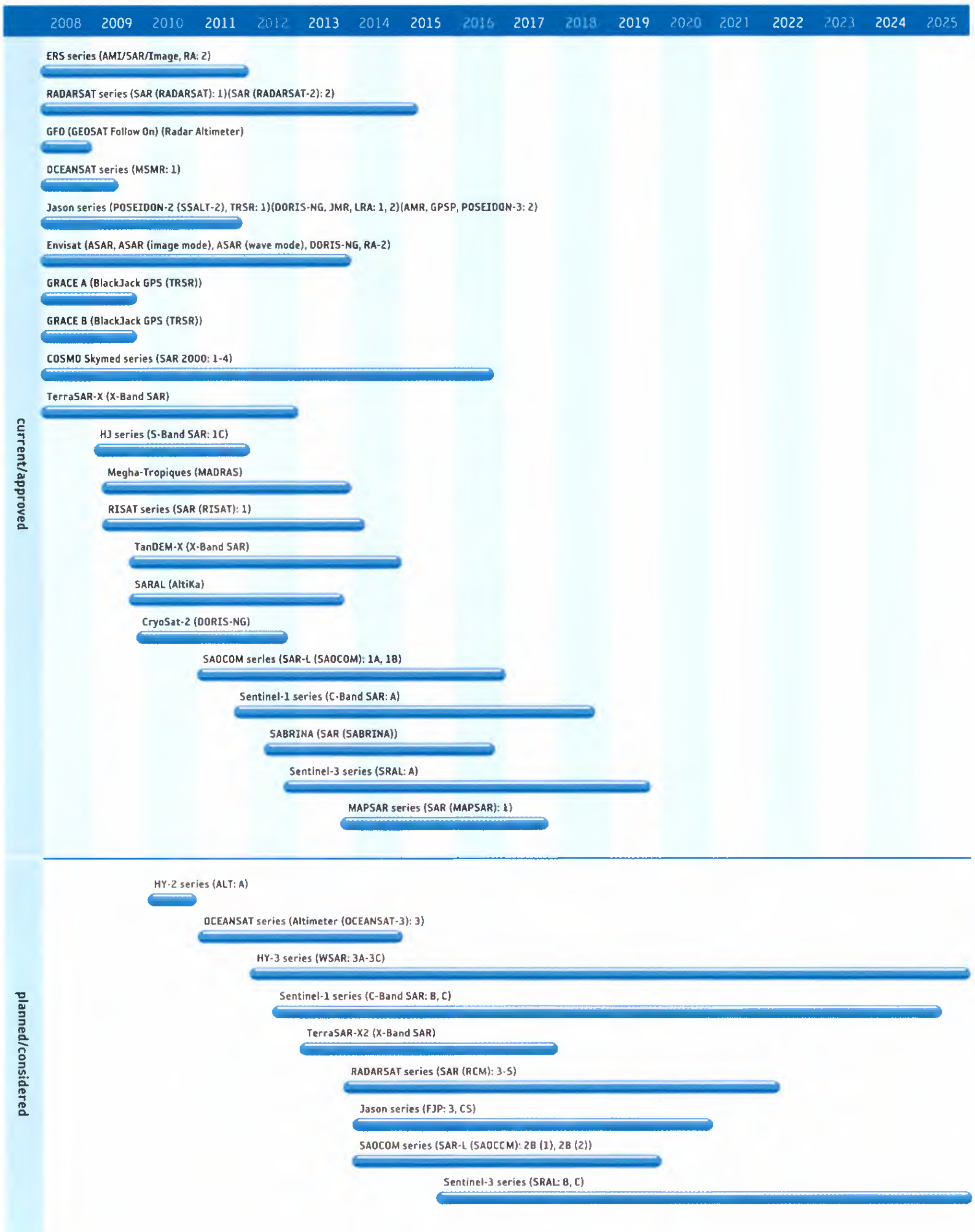
In their Final Report, in early 2001, the IGOS Ocean Theme Team identified a long-term need for continuity of a high-precision mission (e.g. the Jason series) and at least one polar-orbiting altimeter (e.g. the ERS and Envisat series) to enhance temporal/spatial coverage of the global ocean. The launches of Jason-2, a mission jointly funded by CNES and EUMETSAT in Europe, NASA and NOAA in the US, and of an altimeter on the forthcoming ESA Sentinel-3 mission, will contribute to this objective. Additional satellite missions that are planned will ensure continuity of ocean currents measurements. They include the Indian-French SARAL that will carry an innovative Ka-band altimeter on a polar orbit, and the Chinese HY-2 mission.

Ocean altimetry, which is a unique and powerful tool that can determine ocean currents, accurately measure sea level and detect sea level rise – a critical indicator of global warming as well as a crucial parameter for ecosystems, coastal cities and other human assets – has been recognised as a priority for futuresustained observations. This is the goal of the Ocean Surface Topography Constellation established by CEOS for GEO.

Two actions were identified in the CEOS response to GCOS requirements:

- NOAA and EUMETSAT will lead a CEOS study team to establish the basis for a future Ocean Surface Topography Constellation that satisfies the threshold requirements for the sea level ECV (and those of the sea state ECV). This will include consideration of a future Jason-3 mission and requirements for new altimeter technologies to improve spatial resolution and extend observations in coastal regions (and over lakes and rivers for the lakes ECV);
- CNES and ISRO will cooperate on a new polar-orbiting altimeter aimed at filling a potential data gap beyond 2008. ESA and the EU will lead planning for Sentinel-3 to carry an altimeter that will complement spatial/temporal coverage of the sea level (and sea state) ECVs – and possibly sea ice extent and thickness, river and lake level with the altimeter operating in synthetic aperture radar (SAR) mode beyond 2012.

Ocean Topography/Currents



Ocean

Ocean Salinity

Essential Climate Variables: Ocean Salinity

Ocean salinity measurements are important because surface salinity and temperature control the density and stability of the surface water. Thus, ocean mixing (of heat and gases) and water-mass formation processes are intimately related to variations of surface salinity. Ocean modelling and analysis of water mass mixing should be enabled by new knowledge of surface-density fields derived from surface salinity measurements. The importance of the ocean in the global hydrological cycle also cannot be overstated. Some ocean models show that sufficient surface freshening results in slowing down the meridional overturning circulation, thereby affecting the oceanic transport of heat.

Sea surface salinity is emerging as a new research product from satellite measurements of ocean brightness temperature at L-band (microwave) frequencies. The monitoring of surface salinity from space, combined with the provision of regular surface and sub-surface salinity profiles from *in situ* observing systems, such as surface ships, buoys, and the Argo array, will provide a key constraint on the balance of freshwater input over the ocean. This will allow for better determination of the marine aspects of the planetary hydrological cycle and the possibility of important ocean circulation changes. New research missions must demonstrate capabilities and pave the way to future continuous, climate-quality data records.

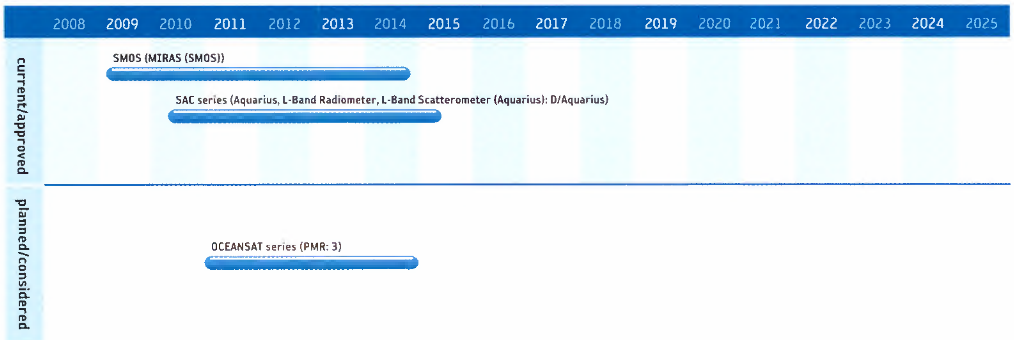
To date, there has been no contribution from space-based observations to this variable. ESA and NASA/CONAE (Comisión Nacional de Actividades Espaciales of Argentina) plan to fly demonstrator missions (SMOS and Aquarius/SAC-D) for salinity measurements.

CEOS identified two actions in response to the GCOS IP in relation to this measurement:

— ESA will fly SMOS in 2009 to demonstrate measurement of the sea surface salinity (and soil moisture) ECV; NASA/CONAE will fly Aquarius/SAC-D in 2010 to demonstrate measurement of the sea surface salinity ECV.

— CEOS agencies will cooperate in developing future plans for an Ocean Salinity Constellation.

Ocean Salinity



Ocean

Ocean Surface Winds

Essential Climate Variables: Atmospheric Surface Wind Speed and Direction

High resolution vector wind measurements at the sea surface are required in models of the atmosphere, ocean surface waves and ocean circulation. They are proving useful in enhancing marine weather forecasting through assimilation into NWP models and in improving understanding of the large-scale air-sea fluxes which are vital for climate prediction purposes. Accurate wind vector data affect a broad range of marine operations, including offshore oil operations, ship movement and routing. Such data also aid short-term weather forecasting and the issue of timely weather warnings.

Polar-orbiting satellites provide information on surface wind with global coverage, good horizontal resolution and acceptable accuracy, though temporal frequency is marginal for regional mesoscale forecasts. They provide useful information in two ways:

- scatterometers provide dense observations of wind direction and speed along a narrow swath, although the most recent and planned scatterometers provide better coverage via broader swaths (90% global coverage daily); scatterometers have made a positive impact in predicting marine forecasting, operational global NWP and climate forecasting;
- passive microwave imagers and altimeters provide information on wind speed only.

The single swath scatterometer on ERS-1/2 and the broad swath scatterometer on QuikSCAT have long provided adequate coverage. QuikSCAT, launched in 1999, carries the SeaWinds scatterometer that measures near-surface wind speed and direction in all weather and cloud conditions. Global coverage by a broad swath scatterometer is now provided by ASCAT on the European MetOp-A mission. Developed by ESA as a follow-on from the 'wind mode' of the AMI on the ERS series, ASCAT is used primarily for global measurement of sea surface wind vectors and provides quasi-global coverage within 24 hours. The SSM/I (Special Sensor Microwave/ Imager) on board the US DMSP satellites is currently providing operational surface wind data. The cooperative NASA/JAXA AMSR-E on Aqua (launched in 2002) also provides data on sea surface wind speed.

Starting with the second satellite, C-2, the operational NPOESS missions will use the CMIS instrument, which employs a passive microwave approach for collecting data on sea surface winds.

In recent years, the ability to detect and track severe storms has been dramatically enhanced by the advent of weather satellites. Data from SeaWinds is augmenting traditional satellite images of clouds by providing direct measurements of surface winds enabling better determination of a storm's location, direction, structure and strength.

In its response to the GCOS IP, CEOS agreed to review the capability of passive microwave sensors to make scatterometer-quality measurements and will work to ensure AM and PM satellite coverage of surface wind speed and direction by 2015.

Ocean Surface Winds

Ocean

Surface Temperature (Ocean)

Essential Climate Variables: Sea Surface Temperature

Ocean surface temperature (often known as 'sea surface temperature' or SST) is one of the most important boundary conditions for the general circulation of the atmosphere. The ocean exchanges vast amounts of heat and energy with the atmosphere and these air/sea interactions have a profound influence on the Earth's weather and climate patterns. SST is linked closely with the ocean circulation, as demonstrated time and again by the El Niño-Southern Oscillation (ENSO) cycle. A major research goal is to enable seasonal and longer time scale forecasting by development of coupled atmosphere and ocean models that correctly link the many processes. Progress towards this goal depends on a more precise and comprehensive set of SST measurements for use in initialising and verifying such models.

Satellite remote sensing provides the only practical means of developing such a dataset. In situ data, predominantly from ships of opportunity and from networks of moored and drifting buoys, are limited in coverage, whereas satellites offer the potential for surveying the complete ocean surface in just a few days. The *in situ* data have a key role to play in calibrating the satellite data and in providing information needed for deriving bulk temperatures.

Instruments on polar satellites provide information for short to medium-range NWP with global coverage, good horizontal and temporal resolution and accuracy, except in areas that are persistently cloud-covered. Accurate SST determinations, especially in the tropics, are important for seasonal to inter-annual forecasts. The advent of high spectral resolution infrared sounders will enable separation of surface emissivity and temperature, and the accuracy of the SST product is expected to improve to an acceptable level.

Geostationary imagers with split window measurements are also helping to expand the temporal coverage by making hourly measurements, thus creating more opportunities for finding cloud-free areas and characterising any diurnal variations (known to be up to 4K in cloud-free regions with relatively calm seas). For regional NWP, sea-surface temperature is inferred with acceptable horizontal resolution from polar satellites, while geostationary satellites complement information with better temporal resolution.

A range of instruments with thermal bands are being used for SST measurements. Visible/infrared imagers such as AVHRR, AATSR, and MODIS currently provide the main source of SST data, with AATSR and MODIS providing better accuracy (0.25–0.3K). AVHRR, however, gives greater coverage, enabling it to track ocean currents and monitor ENSO phenomena through its larger swath width. The Aqua mission, which includes MODIS along with AIRS+ and AMSR, provides oceanographers with further precise information and the ability to remove atmospheric effects. NOAA's VIIRS and CMIS instrument on the planned NPOESS missions will provide capabilities to produce higher resolution and more accurate measurements of SST than currently available from AVHRR. Other sources of SST data include: AMSR-E on Aqua; the SEVIRI and IASI instruments on the Meteosat-8/9 (MSG-1/2) and MetOp missions respectively.

The GHRSST Pilot Project provides a new generation of global, high resolution (<10 km) SST products, combining complementary satellite and *in situ* data (www.ghrsst-pp.org/).

GCOS is concerned that the continuity of the 4 km resolution global data be maintained through adequate instruments onboard operational weather satellites and its quality must be enhanced through high-precision sensors on board other Earth observation missions. CEOS has defined four actions in support:

- an ATSR-like instrument is planned on ESA's Sentinel-3, presently scheduled for launch in 2012. JAXA will lead planning for the Global Change Observation Mission to maintain continuity of the sea surface temperature ECV;
- CEOS agencies will examine their respective plans to maintain provision of microwave brightness temperatures for the sea surface temperature ECV;
- relevant CEOS agencies will examine their respective plans to maintain continuity of a 10 km resolution sea surface temperature data sets global product;
- CEOS agencies will cooperate to support the combination of all existing sea surface temperature data sets into a global FCDR.

Surface Temperature (Ocean)

Ocean

Wave Height and Spectrum

Essential Climate Variables: Sea State

Sea state and wind speed govern air-sea fluxes of momentum, heat, water vapour and gas transfer. The state of the sea and surface pressure are two features of the weather that are important to commercial use of the sea (e.g. ship routing, warnings of hazards to shipping, marine construction, off-shore drilling installations and fisheries). Information on surge height at the coast is key to the protection of life and property in coastal habitats.

These data are also important for climate purposes as they are needed for the correct representation of turbulent air-sea fluxes.

Wave height is influenced by wind speed and direction, the wind 'fetch' and its rate of change. In the nowcasting context, ocean wave models are driven by NWP predictions of surface wind. However, errors in waves generated at large distances can accumulate. Improvements in forecasts, especially of long wavelength swell, can be achieved by assimilating observations from different sources. These are currently available from isolated buoys, satellite altimeter and scatterometer data. In the absence of direct observations, initial wave state is deduced from the wind history. This is currently available over the sea from isolated buoys and from low-Earth-orbiting satellite scatterometer and microwave instruments.

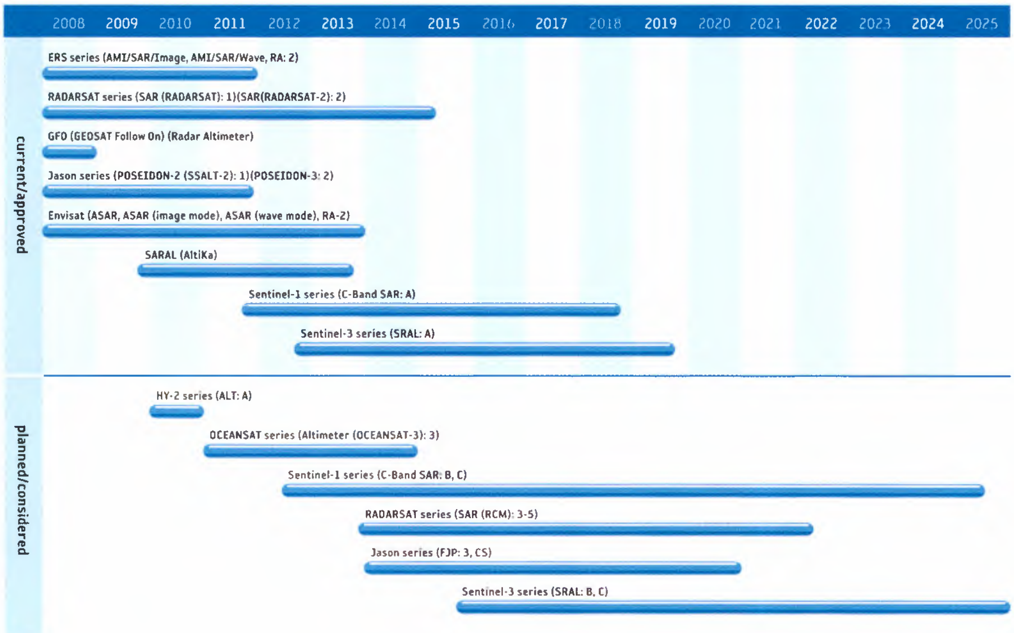
For global NWP, ships and buoys provide observations of acceptable frequency that are acceptable to marginal accuracy, but coverage is marginal or absent over large areas of the ocean. Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy, but horizontal/temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy, but marginal horizontal/temporal resolution.

SAR instruments can accurately measure changes in ocean waves and winds, including wavelength and the direction of wave fronts, regardless of cloud, fog or darkness. The AMI SAR on ERS-2 has been operating in both wave and image mode, and the ASAR on Envisat continues to provide the ERS wave mode products, but with improved quality. PALSAR on JAXA's ALOS mission provides data on sea surface wind and wave spectrum required for oil spill analysis and for studies of coastal topography-air-sea interaction. The ScanSAR wave data supplied by RADARSAT will continue to be provided by RADARSAT-2. Europe's Sentinel-1 mission will also ensure future provision of SAR data supply.

Information from radar altimeters, such as that on the Jason-1 mission, is limited to data on significant wave height.

The GCOS IP recognises that altimetry and SAR measurements useful for sea state measures (wave height, direction, wavelength and time period) have been continuously available since 1991 and will be maintained in the future, but no consolidated data product has ever been produced. GCOS proposes that new altimeter (wide-swath) and SAR technologies are needed to advance retrieval of near-shore sea state parameters. CEOS agencies propose to cooperate with the user community to support efforts aimed at building on the decade-long satellite sea state records and making a comprehensive use of future altimeter- and SAR-bearing missions.

Wave Height and Spectrum



Ocean

Multi-purpose Imagery (Ocean)

In addition to the specific ocean measurement observations discussed in previous sections, a number of sensors are capable of providing a range of ocean imagery from which useful secondary applications can be derived.

High resolution radiometers, such as AVHRR, AATSR, and VIIRS, have multi-channel imaging capabilities to support the acquisition and generation of a variety of applied products, including visible and infrared imaging of hurricanes. They provide observations of large-scale ocean features, using variations in water colour and temperature to derive information about circulation, currents, river outflow and water quality. Such observations are relevant to activities such as ship routing, coastal zone monitoring, toxic algal bloom detection, management of fishing fleets and sea pollution monitoring.

High to medium resolution imaging sensors, such as MERIS, are better suited to observations of coastal zone areas and can provide information on sedimentation, bathymetry, erosion phenomena and aquaculture activity.

In addition, SAR instruments, such as RADARSAT, ASAR and PALSAR, provide a valuable all-weather, day and night source of information on oceanographic features, including fronts, eddies and internal waves. SAR imagery is also useful for:

- pollution monitoring – notably oil spill detection;
- ship detection – useful to rescue services, port authorities, custom and immigration services;
- coastal change detection – topography mapping;
- bottom topography mapping, valuable for resource exploration and pipeline routing.

Multi-purpose Imagery (Ocean)

Snow and Ice

Ice Sheet Topography

Essential Climate Variables: Glaciers and Ice Caps

The state of the polar ice sheets and their volumes are both indicators and important parts of climate change processes and feedbacks. Consequently, it is important to monitor and study them in order to investigate the impact of global warming and to forecast future trends. The IPCC expects that, globally, ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after the global climate has been stabilised. They note that:

- contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m if global average warming in excess of 1.9 to 4.6°C relative to pre-industrial values was sustained for millennia;
- ice dynamic models suggest that melting of the West Antarctic ice sheet could contribute up to 3 m of sea level rise over the next 1000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors.

Satellite remote sensing allows observations of the changes in the shape of ice sheets, and identification of the shape and size of large icebergs that have detached from the ice sheet.

SAR instruments are one source of data on the polar ice sheets. RADARSAT provides routine surveillance of polar regions and has created the first high resolution radar images of Antarctica, enabling detection of changes in the polar ice sheet and improved understanding of the behaviour of the Antarctic glaciers. ASAR on the Envisat mission is continuing the observations of polar ice topography started by the ERS-1 and ERS-2 satellites.

Interferometric measurements by PALSAR, together with observations by the AVNIR-2 instrument on JAXA's ALOS mission, are contributing to understanding the ice sheet mass balance and glacier variation near the South Pole and in Greenland.

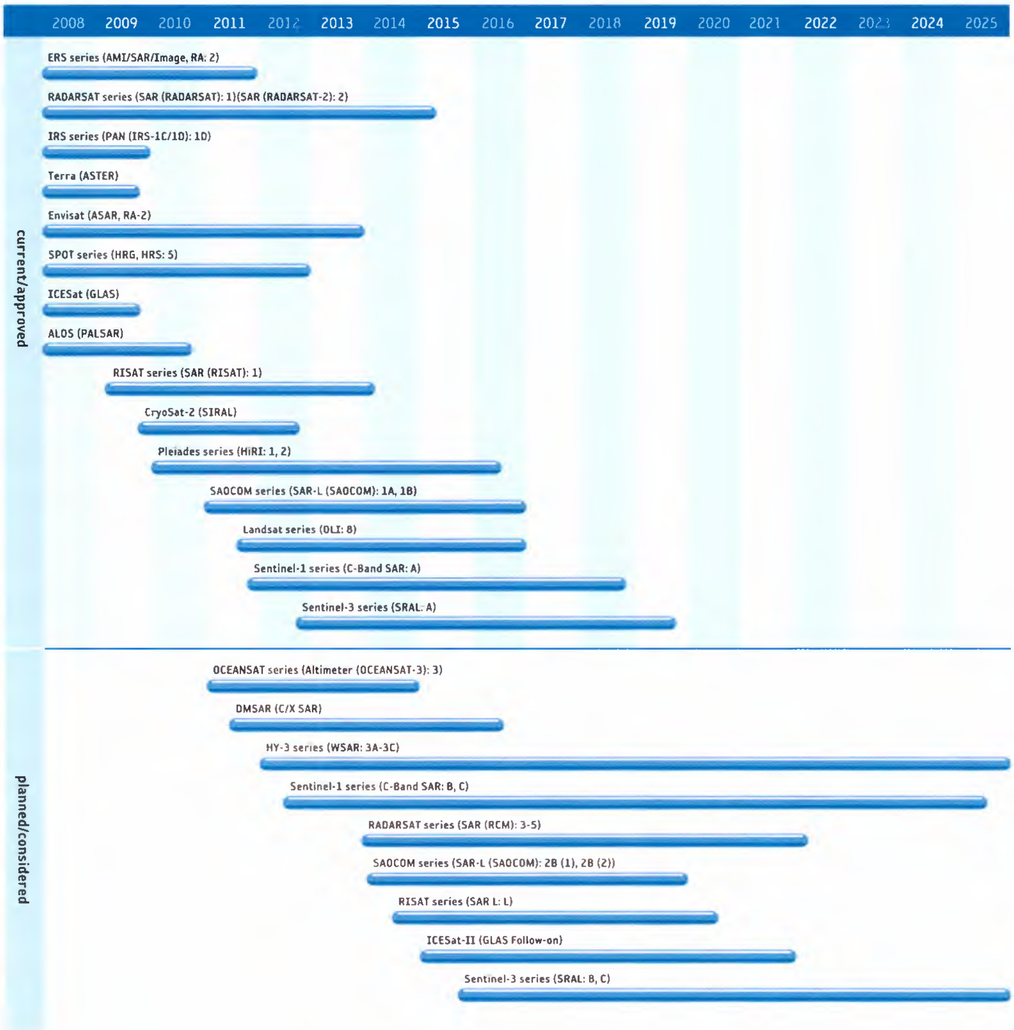
Altimeters provide useful data on ice sheet topography. While many have high vertical resolution, their limited horizontal resolution means that their observations over smoother, near-horizontal portions of ice sheets are of greatest value. The RA-2 instrument on Envisat is providing improved mapping of ice caps.

Given the significance of information on changes in the continental ice sheets, two missions dedicated to their study have been developed: NASA's ICESat (launched Jan 2003 but with reduced acquisition capabilities due to technical issues) and ESA's CryoSat-2 (from 2009, following the loss on launch of CryoSat in 2005). CryoSat-2 will provide an instrument for the ice sheet interiors and margins, for sea ice and other topography, with three-mode operation:

- conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);
- synthetic aperture operation for sea ice;
- dual-channel synthetic aperture/interferometric operation for ice sheet margins.

ICESat-II is scheduled for launch in 2015.

Ice Sheet Topography



Snow and Ice

Snow Cover, Edge and Depth

Essential Climate Variables: Snow Cover

Regular measurements of terrestrial snow cover are important because snow dramatically influences surface albedo, thereby making a significant impact on the global climate, as well as influencing hydrological properties and the regulation of ecosystem biological activity. The IPCC has found that – on the evidence of satellite data – there is likely to have been a decrease of about 10% in the extent of snow cover since the late 1960's.

Snow forms a vital component of the water cycle. In order to make efficient use of meltwater runoff, resource agencies must be able to make early predictions of the amount of water stored in the form of snow. Coverage area, snow water equivalent and snow pack wetness are the key parameters to be determined in this process.

Snow cover information has a range of additional applications such as detecting areas of winterkill in agriculture that result from lack of snow cover to insulate plants from freezing temperatures. Locally, monitoring of snow parameters is important for meteorology and for enabling warnings of when melting is about to occur – which is crucial for hydrological research and for forecasting the risk of flooding.

A range of different instrument types can contribute to measurements of snow. Visible/near-infrared satellite imagery provides information of good horizontal and temporal resolution and accuracy on snow cover in the day-time in cloud-free areas. AVHRR provides snow cover information and this will be continued in the future by VIIRS. MODIS data are being used to monitor the dynamics of snow and ice cover over large areas (greater than 10 km^2) and, on a weekly basis, to report the maximum area covered by both. The resulting snow maps should be available within 48 hours of MODIS data collection.

Passive microwave instruments such as SSM/I, AMSR and CMIS have all-weather and day/night monitoring capability, and are able to estimate the thickness of dry snow up to about 80 cm deep.

Data from RADARSAT and ERS-2 have shown the usefulness of SAR remote sensing techniques to determine snow area extent and to monitor the physical conditions of snow. Envisat, ALOS and RADARSAT-2 are providing continuity of such snow information.

Snow Cover, Edge and Depth

Sea Ice Cover, Edge and Thickness

Essential Climate Variables: Sea Ice

Sea ice variability is a key indicator of climate variability and change which is characterised by a number of parameters. Systematic global observation of sea ice extent and concentration, inferred from passive microwave radiometry, has produced a 30 year record. The length and consistency of this record has made it the most often cited data source for sea ice climate research. Sea ice observations from newer instruments have relatively short records, but offer complementary characteristics such as greater accuracy for determining ice concentration and improved resolution.

In addition to monitoring ice extent (the total area covered by ice at any concentration) and concentration (the area covered by ice per unit area of ocean), it is necessary to know ice thickness in order to estimate sea ice volume or mass balance. In the past, only scarce *in situ* data from boreholes, or upward-looking sonar from moored instruments or submarines, were available for this purpose. Now, satellite borne altimeters are emerging as an important new data source. Early work with radar altimeters demonstrated the utility of altimetry for ice thickness. The Geoscience Laser Altimeter System (GLAS) on board ICESat, launched in 2003, has provided high resolution ice thickness maps. CryoSat-2, due for launch in 2009, has a radar altimeter that will provide precise ice thickness maps.

All-weather, day and night active radar, including the low resolution QuikSCAT scatterometer and high resolution RADARSAT synthetic aperture radar, is sensitive to the unique electromagnetic signature of multiyear ice. This ice has survived a summer's melt and is generally thicker than younger ice. Active radar and other new sensors played an important part in attributing the surprisingly low Arctic ice extent of September 2007 to various causes. Summer ice extent has had a downwards trend since the 1990s, as determined by the passive microwave record. The active microwave sensors provided data that showed that the Arctic Ocean had lost a considerable amount of multiyear sea ice over the past few years as a result of the prevailing circulation pattern, suggesting that the ice cover was unusually thin as summer began and predisposed to melting back further. Wide area sea ice motion and deformation products from visible band sensors, as well as higher resolution AMSR data, provided corroborating evidence. Finally, investigators using ICESat confirmed that the ice thickness at the beginning of summer was well below its typical average value.

Operational ice services place a higher priority on timeliness and accuracy than on consistency over a long data record, and accordingly use a wide variety of near-real-time remote sensing data to construct ice charts. These charts are used by shipping to avoid damage and delay, and to reduce fuel costs; offshore drilling companies; maritime insurance companies; and government environmental regulatory bodies.

High resolution synthetic aperture radars, such as those on Envisat and RADARSAT, offer the best source of data for operational services. Data from these instruments provide information on the nature, extent and drift of ice cover and are used not only for status reports, but also for ice forecasting and as an input for meteorological and ice drift models. JAXA's PALSAR radar provides polarimetric data, which will improve the accuracy of sea ice classification. Low resolution scatterometer observations, such as those from ASCAT on MetOp, can also be used to retrieve information on sea ice extent and concentration in all weather conditions, day or night.

Looking to the future, continuation of RADARSAT/Envisat class radar-equipped missions is important in providing complementary high resolution data to further elucidate sea ice processes. JAXA's AMSR-E radiometer on Aqua and operational sensors such as the DMSP SSM/I will ensure continuity of the passive microwave global sea ice concentration data source in the near term. The MIS sensor, currently planned for the second NPOESS flight, will be the follow-on sensor for SSM/I. It will offer improved capabilities, including a baseline aperture size of 1.8 m compared to SSMIS' 0.6 m. The baseline channel selection for MIS includes the SSM/I channel set with minor modifications, with channels at 6 and 10 GHz as well.

In 2006, CEOS defined a series of actions to better meet the GCOS-defined needs for the sea ice Essential Climate Variable:

- CEOS agencies will examine their respective plans to maintain provision of microwave brightness temperatures and visible/infrared radiances for the sea ice ECV;
- CEOS space agencies will consult with the science community on appropriate retrieval algorithms of passive microwave observation for reprocessing sea ice products;
- New space-based measurements and products, including ice thickness and ice drift, will be considered by CEOS agencies as part of their future research missions.

Sea Ice Cover, Edge and Thickness

Sea Ice Cover, Edge and Thickness

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Gravity and Magnetic Fields

Gravity, Magnetic and Geodynamic Measurements

Essential Climate Variables: Groundwater, Sea Level

Not all near-Earth measurements undertaken by satellite observations are discussed in this document, since the focus here is on land, sea, and air parameters. Many others are observed on a routine basis, including measurements of the space environment and solar activity. Of particular note are measurements of the Earth's gravity field, magnetic field and geodynamic activity.

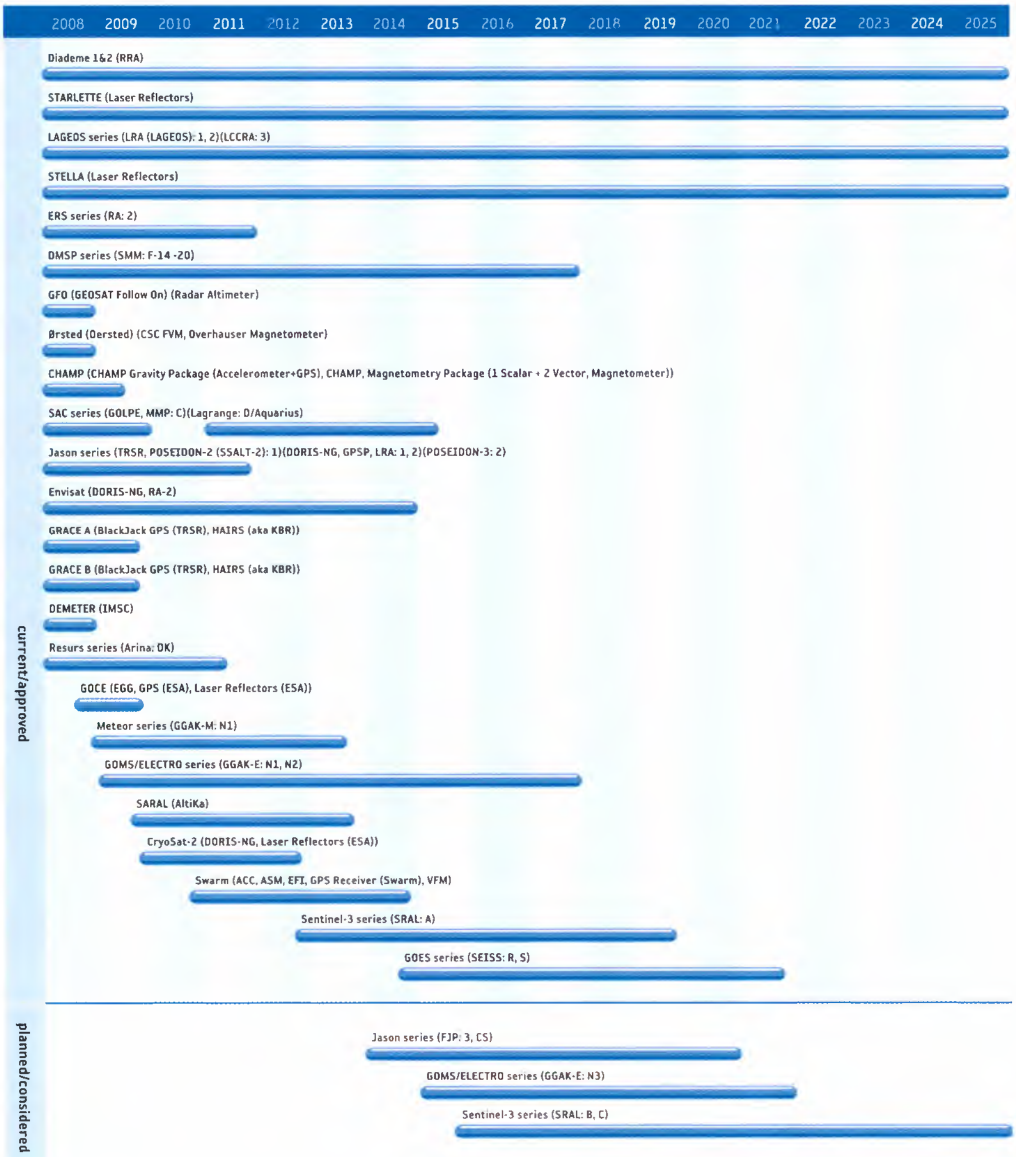
Gravity field measurements from space provide the most promising advances for improved measurement of the 'geoid' and its time variations. The geoid is the surface of equal gravitational potential at mean sea level, and reflects the irregularities in the Earth's gravity field at the planet's surface caused by the inhomogeneous mass and density distribution in the interior. Such measurements are vital for quantitative determination – in combination with satellite altimetry – of ocean currents, improved global height references, estimates of the thickness of the polar ice sheets and its variations, and estimates of the mass/volume redistribution of fresh water in order to better understand the hydrological cycle.

Gravity field measurement packages on satellites often utilise combinations of different instrument types in order to derive the necessary information: single or multiple accelerometers; precise satellite orbit determination systems; and satellite to satellite tracking systems.

DLR's CHAMP gravity package (since 2000) and the NASA/DLR twin satellite GRACE mission (since 2002) have been providing new information that has resulted in new and unique models of the Earth's gravity field and its variability over time, and determination of the geoid to centimetre accuracy at length scales of several hundred kilometres. GRACE has demonstrated that satellites can detect groundwater variations by measuring subtle temporal variations in gravity. From 2008, this data will be supplemented by ESA's GOCE satellite, which is designed to make significant advances in our understanding of ocean circulation and the crucial role which it plays in regulating the climate, as well as sea level rise and processes occurring in the Earth's interior. GOCE data will also find a broad range of applications in the field of geodesy and surveying.

A number of Earth missions, including Australia's Fedsat, launched in 2002, have carried sensors to study the electromagnetic environment of spacecraft. Satellite-borne magnetometers provide information on the strength and direction of the Earth's internal and external magnetic field and its time variations. Such instruments are on board the Ørsted satellite, which is Denmark's first satellite dedicated to the magnetic field, launched in 1999. The CHAMP mission also provides these measurements, which are of value in a range of applications, including navigation systems, resource exploration drilling, spacecraft attitude control systems and assessments of the impact of 'space weather'.

Further missions are under way or planned for more in-depth, dedicated studies of magnetic field. They include DEMETER (launched June 2004), which is investigating links between earthquakes and magnetic field variations, and Swarm (from 2010), which aims to provide the best ever survey of the geomagnetic field and its temporal evolution, providing new insights by improving our knowledge of the Earth's interior and climate.



Gravity, Magnetic and Geodynamic Measurements

8 Catalogue of Satellite Missions

8.1 Introduction

This section gives details of the satellite missions of CEOS members and of the CEOS/WMO database from which much of the data in this handbook is derived.

Nearly all information contained in this catalogue has been gathered from and verified by CEOS agencies, but it should be noted that the launch date and duration of some planned missions is uncertain (e.g. due to changes in funding or policy, changes in requirements, etc.) hence, the accuracy of timelines relating to these missions cannot be guaranteed. If the month of the launch of a planned mission has not been specified, the timeline is shown to commence at the beginning of the planned year of launch. It should also be noted that missions currently operating beyond their planned life are shown as operational until the end of 2008 unless an alternative date has been proposed.

The catalogue of CEOS agency EO satellite missions is arranged both chronologically by launch date and alphabetically by mission name. For each of the missions, the following information is supplied:

Mission	Mission acronym Full mission name Agency acronym
Status	Current: at least the prototype has been launched, and financing is approved for the whole series Approved: financing is available for the whole series, the prototype is fully defined, the development is in phase C/D Planned: financing is available up to the end of phase B, financing of the full series is being considered Considered: conceptual studies and phase A have been completed, financing of phase B is in preparation
Key dates	Launch date Estimated end of life date
Primary applications	Of those measurements discussed in section 7
Instruments	A list of instruments on board the mission from the catalogue in section 9
Orbit details	Type of orbit Altitude Period Inclination Repeat cycle LST: Local Solar Time – the time of satellite equator overpass Longitude (for geostationary orbits) Ascending/descending: whether the satellite crosses the equator in a northbound (ascending) or southbound (descending) direction
URL	For further information via internet

8.2 Recent Events

Eleven missions were launched by CEOS agencies from the start of 2007 through to end June 2008:

Mission	Agency	Launch date
Kanopus-Vulcan	Roscosmos	Gen 2007
CARTOSAT-2 (Cartography Satellite - 2)	ISRO	Gen 2007
HY-1B (Ocean colour satellite B)	NSOAS/CAST	Apr 2007
COSMO-SkyMed 1 (COnstellation of small Satellites for Mediterranean basin Observation 1)	ASI/MiD (Italy)	Jun 2007
TerraSAR-X	DLR	Jul 2007
CBERS-2B (China Brazil Earth Resources Satellite 2B)	CRESDA/INPE	Sep 2007
COSMO-SkyMed 2 (COnstellation of small Satellites for Mediterranean basin Observation 2)	ASI/MiD (Italy)	Dec 2007
RADARSAT-2 (Radar Satellite-2)	CSA	Dec 2007
MS-1 (Indian Mini Satellite-1)	ISRO	Apr 2008
FY-3A (FY-3A Polar-orbiting Meteorological Satellite)	NRSCC / CMA	May 2008
Jason-2 (aka OSTM) (Ocean Surface Topography Mission)	NASA / CNES / EUMETSAT	Jun 2008

16 missions are planned for launch between July 2008 and the end of the year:

Mission	Agency	Launch
Meteor-M N1 (Meteor-M N1 Meteorological Satellite)	Roshydromet Roscosmos	Jul 2008
RapidEye	DLR	Aug 2008
THEOS (Thailand Earth Observation System)	GISTDA	Aug 2008
HJ-1A (Disaster and Environment Monitoring and Forecast Small Satellite Constellation A)	CAST	Sep 2008
HJ-1B (Disaster and Environment Monitoring and Forecast Small Satellite Constellation B)	CAST	Sep 2008
COSMO-SkyMed 3 (COnstellation of small Satellites for Mediterranean basin Observation 3)	ASI / MiD (Italy)	Sep 2008
GOCE (Gravity Field and Steady-State Ocean Circulation Explorer)	ESA	Sep 2008
OCEANSAT-2 (Ocean satellite-2)	ISRO	Sep 2008
DMSP F-18 (Defense Meteorological Satellite Program F-18)	NOAA	Sep 2008
UK-DMC2 (UK Disaster Monitoring Constellation 2)	BNSC	Oct 2008
GOES-O (Geostationary Operational Environmental Satellite - O)	NOAA	Dec 2008
OCO (Orbiting Carbon Observatory)	NASA	Dec 2008
Elektro-L N1 (Geostationary Operational Meteorological Satellite - 1)	Roshydromet Roscosmos	Dec 2008
FY-2E (FY-2E Geostationary Meteorological Satellite)	NRSCC	Dec 2008
FY-3B (FY-3B Polar-orbiting Meteorological Satellite)	NRSCC / CMA	Dec 2008
FY-3C (FY-3C Polar-orbiting Meteorological Satellite)	NRSCC / CMA	Dec 2008

8.3 Current Missions

100 different Earth observation satellite missions are estimated to be currently operating (June 2008). Many of these comprise series of missions planned to provide the continuity which is essential for many observations and applications. The principal satellite series are highlighted below.

Geostationary meteorological satellites:

There is a worldwide network of operational geostationary meteorological satellites which provide visible and infrared images of the Earth's surface and atmosphere. Countries/regions with current geostationary operational meteorological satellites are the USA (NOAA GOES series), Europe (EUMETSAT Meteosat series), Japan (JMA MTSAT series), India (IMD INSAT series), China (CMA FY series), Russia (Roshydromet GOMS/ Elektro-L series), and (from 2009) Korea (KMA COMS series).

Crustal motion and gravitational field series:

A number of small satellite missions designed to measure the Earth's crustal motion and the Earth's gravitational field have been launched since 1967. The space segment typically comprises corner cube laser retroreflectors and the ground segment is a global network of transportable laser sites. The design life of the space segment is many thousands of years. These missions include the Diademe and Starlette series (CNES) and the LAGEOS series (NASA and ASI). More recently, missions such as CHAMP (DLR) and GRACE (NASA/DLR) have been launched to provide high precision measurements of the Earth's gravitational field.

DMSP series:

The long-term meteorological programme of the US Department of Defense (DoD) – with the objective of collecting and disseminating worldwide atmospheric, oceanographic, solar-geophysical and cloud cover data on a daily basis.

NOAA and EUMETSAT polar orbiters:

Until 2006, operational polar orbiting meteorological satellites were provided only by NOAA – with two satellites maintained in polar orbit at any one time, one in a 'morning' orbit and one in an 'afternoon' orbit. The series provides a wide range of data of interest, including sea surface temperature, cloud cover, data for land studies (notably the AVHRR sensor), temperature and humidity profiles, and ozone concentrations (AMSU and HIRS sensor packages). Since 2006, these have been supplemented by the first of the EUMETSAT Polar System satellites, MetOp-A, offering additional measurements such as high resolution temperature and humidity profiles, wind speed over the oceans, ozone and measurements of trace gases such as carbon dioxide, nitrous oxide and methane.

Topex/Poseidon and Jason series:

These satellites form a joint NASA/CNES precision radar altimetry mission to measure ocean topography and hence, the speed and direction of ocean currents. The follow-on Jason-2, developed by NASA/CNES and operated by NOAA/EUMETSAT, was launched on 20 June 2008, and will provide a core contribution to GOOS.

ERS and Envisat series:

ERS-1 was launched by ESA in July 1991, ERS-2 in April 1995, and Envisat in March 2002. This series concentrates on global and regional environmental issues, making use of active microwave techniques that enable a range of measurements to be made of land, sea and ice surfaces, independent of cloud cover and atmospheric conditions. In addition, the ATSR/AATSR instruments on these missions provide images of the surface or cloud top and the GOME instrument on ERS-2 provides measurements of ozone levels. ERS-1 and ERS-2 operated in tandem for around 1 year in 1995 and 1996, providing data for topographic applications such as differential interferometry. Envisat features a range of new sensors for land surface and atmospheric studies.

IRS series:

The Indian IRS satellites include three thematic series addressing the areas of: land and water resources; cartography; and ocean and atmosphere (which include the RESOURCESAT, CARTOSAT and OCEANSAT missions). These are coordinated through the unique institutional framework of the National Natural Resources Management System (NNRMS). Their primary objectives are in support of agriculture, disaster management, land and water resource management, cartographic mapping, and studies of ocean and atmosphere. The latest in the series are Kalpana launched in December 2002; RESOURCESAT-1 (IRS-P6) launched in October 2003; CARTOSAT-1 launched in May 2005, CARTOSAT-2 launched in January 2007. The Indian EO segment will be augmented with the launch of OCEANSAT-2, RISAT-1, and INSAT-3D during 2008–09.

Meteor series:

Roshydromet maintains these missions, mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and Earth's radiation budget.

RADARSAT series:

Launched in November of 1995, RADARSAT-1 provides researchers and operational users with a range of SAR data products which are used for marine applications such as ship routing and ice forecasting, as well as land applications, such as resource management and geological mapping. RADARSAT-2 was launched in December 2007 to ensure data continuity.

SPOT and Landsat series:

The SPOT satellites (lead agency CNES) and the Landsat series (lead agency USGS) provide high resolution imagery in a range of visible and infrared bands. They are used extensively for medium resolution land studies. Data from these satellites are supplemented by availability of very high resolution imagery (up to 1 m) from various commercial satellites.

CBERS series:

A joint mission series of China and Brazil, aimed at environmental monitoring and Earth resources. The latest in the series (CBERS-2B) was launched in September 2007.

KOMPSAT (Arirang) series:

These South Korean missions are aimed at cartography, land use and planning, and ocean and disaster monitoring. The first satellite was launched in December 1999, with a second launch in July 2006.

NASA's EOS missions:

Carrying the latest advanced sensors, each mission is dedicated to investigation of particular Earth System issues. In addition to the Terra, Aqua and Aura missions, NASA has also launched a number of missions aimed at developing understanding of the Sun's variability and its influence on our climate, including ACRIMSAT, SORCE, and TIMED.

Cloud properties and climate links:

Since April 2006, a multiple satellite (NASA and CNES) constellation, dubbed the A-Train, has been in place (comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL) flying in orbital formation to gather data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback. The constellation will be joined by the Orbiting Carbon Observatory from late 2008.

Polar ice cap studies:

Given the significance of information on changes in the continental ice sheets, two missions have been dedicated to their study: NASA's ICESat (launched January 2003) and ESA's CryoSat (lost on launch in October 2005 but rebuilt as CryoSat-2 for launch in 2009).

Gravity and magnetic field studies:

The GRACE (from 2002) and GOCE (from 2009) missions are dedicated to providing more precise measurements of the geoid, while DEMETER (currently in orbit), Kanopus-Vulkan, and Vulkan-Kompas-2 will study links between electromagnetic fields and earthquake predictability.

8.4 Future Missions

Current plans supplied by CEOS agencies estimate that in the order of 100 new satellite missions will be launched for operation between 2008 and 2013. The next few years will mark a significant era for satellite Earth observations, with half of these new missions to be launched by June 2010. These new programmes will ensure continuity of key measurements, provide improved resolutions and accuracies, and introduce several exciting new capabilities. Some of the highlights are described below:

Operational meteorology:

The current geostationary programmes will continue operationally, supplemented by China's FY-3 from May 2008 and South Korea's COMS-1 from 2009. The NOAA series of polar orbiting satellites will evolve to become NPOESS, featuring more advanced sensors and new capabilities. EUMETSAT will launch further MetOp series satellites and is planning to expand the capabilities of its geostationary satellite programme with the proposed launch of an advanced imager and a lightning imager on the Meteosat Third Generation – Imager (MTG-I) platform, as well as a hyperspectral infrared sounder on the MTG-sounder (MTG-S) platform. The capabilities will grow further through the inclusion of the ESA Sentinel-4 UVN mission on the MTG-S platform.

Atmospheric studies:

New data on the chemistry and dynamics of the Earth's atmosphere will be gathered by missions from many countries, including future missions such as GOSAT and GCOM (JAXA), OCO (NASA) and EarthCARE (ESA/JAXA). ADM-Aeolus (ESA) will provide new information on winds.

Radiation budget:

Continuity and new capabilities are provided by NASA's SORCE (launched in 2003), the PICARD mission (2009) of CNES, and operational meteorology missions, such as the MSG and NPOESS series.

Ocean observations:

Continuity and improvements in many current measurements have been assured with the launch of missions such as Envisat and Aqua. SMOS (2009) and SAC-D/Aquarius (2010) are worthy of special note, since they will provide new capabilities for measurements of ocean salinity. Ocean surface wind and topography measurements – pioneered by the Topex/Poseidon and ERS missions – are to be continued operationally by sensors on the Jason-2 mission and on the MetOp and NPOESS series. Europe's GMES programme will also provide the Sentinel-3 mission.

Land surface observations:

Advanced SAR systems on ALOS, TerraSAR-X and RADARSAT-2 are expected to yield new information on land surface properties. ESA's SMOS will measure soil moisture from 2009. Operational meteorological satellites will supply continuous observation of land surface radiation and vegetation parameters. GMES will contribute the Sentinel-1 and 2 missions.

Hyperspectral observations:

A new generation of sensors is emerging, featuring hundreds of different spectral bands, with the capability – using spectral-libraries – to remotely sense the chemical composition of surfaces. Such sensors (including those on ASI's PRISMA and China's HJ-1A) are expected to provide new and exciting capabilities for Earth observation of land, sea and atmosphere.

8.5 CEOS/WMO Database

The information presented in the CEOS Handbook is a much condensed summary of the information provided in the CEOS/WMO Database. This database contains extensive information on the capabilities of both satellite and *in situ* observing system capabilities, and relates them in some detail to the requirements of key user programmes. The database is maintained by ESA (core mission and instrument data) and WMO (detailed performance data and requirements information).

The database was established to support planning of future observing systems, with the primary aim of improving the extent to which space system capabilities meet user requirements for observations. Although many possible uses have been identified for the database, its structure and level of detail are designed primarily to assist in the assessment of conformance between users' requirements for observations and the potential capability of the space segments of satellite systems. To this end, the following information is included in the database:

- from the user communities, a summary of their observational requirements, as available to CEOS through its partnerships with many user communities;
- from the *in situ* observing system operators and space agencies, a summary of the potential performances of their instruments, expressed in the same terms as the user requirements;
- instrument and mission descriptions sufficiently detailed to support the evaluation of their performances; programmatic information to permit assessment of service continuity aspects.

CEOS plans to develop the database capability in future to allow online access to its search capabilities, including the generation of tables and timelines of interest to various user communities. As these capabilities develop, they will be accessible via the online edition of the CEOS Handbook at:

www.eohandbook.com

List of Satellite Missions (by year and sponsoring agency)

Launch Year	EO Satellite Mission (and sponsoring agency)
1967	Diademe 1&2 (CNES)
1975	STARLETTE (CNES)
1976	LAGEOS-1 (NASA)
1978	SeaSat (NASA)
1984	Landsat-5 (USGS / NASA)
1990	SPOT-2 (CNES)
1992	LAGEOS-2 (NASA / ASI)
1993	SCD-1 (INPE) STELLA (CNES) Meteosat-6 (EUMETSAT)
1995	ERS-2 (ESA) RADARSAT-1 (CSA)
1997	DMSP F-14 (NOAA) Meteosat-7 (EUMETSAT) IRS-1D (ISRO) TRMM (NASA / JAXA)
1998	GFO (GEOSAT Follow-on) (DoD (USA) / US Naval Research Lab / CNES / NASA) SPOT-4 (CNES) NOAA-15 (NOAA) SCD-2 (INPE)
1999	INSAT-2E (ISRO) Landsat-7 (USGS / NASA) OCEANSAT-1 (ISRO) QuikSCAT (NASA) Ørsted (Oersted) (DNSC / CNES / NASA) DMSP F-15 (NOAA) Terra (NASA) ACRIMSAT (NASA)
2000	GOES-11 (NOAA) CHAMP (DLR) NOAA-16 (NOAA) NMP EO-1 (NASA) SAC-C (CONAE)
2001	Odin (SNSB / TEKES / CNES / CSA) GOES-12 (NOAA) PROBA (ESA) TES (ISRO) Jason-1 (NASA / CNES) TIMED (NASA)
2002	Envisat (ESA) GRACE A (NASA / DLR) GRACE B (NASA / DLR) Aqua (NASA) SPOT-5 (CNES) FY-1D (NRSCC / CMA) NOAA-17 (NOAA) Meteosat-8 (EUMETSAT) Kalpana (ISRO)

Launch Year	EO Satellite Mission (and sponsoring agency)
2003	CORIOLIS (DoD (USA) / NASA) ICESat (NASA) SORCE (NASA) INSAT-3A (ISRO) SCISAT-1 (CSA) UK-DMC (BNSC) NigeriaSat-1 (NASRDA) RESOURCESAT-1 (ISRO) DMSP F-16 (NOAA) CBERS-2 (CAST / INPE)
2004	DEMETER (CNES) Aura (NASA) FY-2C (NRSCC) PARASOL (CNES)
2005	MTSAT-1R (JMA / JCAB) CARTOSAT-1 (ISRO) NOAA-18 (NOAA) Monitor-E (Roscosmos) TopSat (BNSC) BJ-1 (NRSCC) Meteosat-9 (EUMETSAT)
2006	ALOS (JAXA) MTSAT-2 (JMA / JCAB) COSMIC-1/FORMOSAT-3 FM1 (NSPO / NOAA / UCAR) COSMIC-2/FORMOSAT-3 FM2 (NSPO / NOAA / UCAR) COSMIC-3/FORMOSAT-3 FM3 (NSPO / NOAA / UCAR) COSMIC-4/FORMOSAT-3 FM4 (NSPO / NOAA / UCAR) COSMIC-5/FORMOSAT-3 FM5 (NSPO / NOAA / UCAR) COSMIC-6/FORMOSAT-3 FM6 (NSPO / NOAA / UCAR) CloudSat (NASA) CALIPSO (NASA / CNES) GOES-13 (NOAA) Resurs DK 1 (Roshydromet / Roscosmos) KOMPSAT-2 (KARI) MetOp-A (EUMETSAT) DMSP F-17 (NOAA) FY-2D (NRSCC)
2007	CARTOSAT-2 (ISRO) HY-1B (NSOAS / CAST) COSMO-SkyMed 1 (ASI / MiD (Italy)) TerraSAR-X (DLR) CBERS-2B (CRESDA / INPE) COSMO-SkyMed 2 (ASI / MiD (Italy)) RADARSAT-2 (CSA)
2008	IMS-1 (ISRO) FY-3A (NRSCC / CMA) Jason-2 (aka OSTM) (NASA / CNES / EUMETSAT) RapidEye (DLR) THEOS (GISTDA) HJ-1A (CAST) HJ-1B (CAST) COSMO-SkyMed 3 (ASI / MiD (Italy)) GOCE (ESA) OCEANSAT-2 (ISRO) DMSP F-18 (NOAA) UK-DMC2 (BNSC) Meteor-M N1 (Roshydromet / Roscosmos) GOES-O (NOAA) OCO (NASA) Elektro-L N1 (Roshydromet / Roscosmos) FY-2E (NRSCC) FY-3B (NRSCC / CMA) FY-3C (NRSCC / CMA)

Launch Year	EO Satellite Mission (and sponsoring agency)
2009	GOSAT (JAXA / MOE (Japan) NIES (Japan)) Sich-2 (NSAU) PICARD (CNES) HJ-1C (CAST) COMS-1 (KARI / NIES (Japan)) SumbandilaSat (CSIR / Uni of Stellenbosh) NOAA-N' (NOAA) Megha-Tropiques (CNES / ISRO) RISAT-1 (ISRO) INSAT-3D (ISRO) LARES (ASI) SMOS (ESA / CDTI / CNES) DMSP F-19 (NOAA) Glory (NASA) RESOURCESAT-2 (ISRO) RASAT (Tubitak) NigeriaSat-2 (NASRDA) COSMO-SkyMed 4 (ASI / MiD (Italy)) TanDEM-X (DLR) SARAL (CNES / ISRO) CryoSat-2 (ESA) GOES-P (NOAA) Meteor-M N2 (Roshydromet / Roscosmos) Kanopus-V N1 (Roshydromet / Roscosmos)
2010	Pleiades 1 (CNES) TES-HYS (ISRO) HY-2A (NSOAS / CAST) GISAT (ISRO) ADM-Aeolus (ESA) SARE-1 (CONAE) SAC-D (CONAE / NASA) HY-1C (NSOAS / CAST) NPP (NASA / NOAA / DoD (USA)) VENUS (CNES / ISA) Swarm (ESA / CNES / CSA) CBERS-3 (CRESDA / INPE) CHINOOK (CSA) HY-1D (NSOAS / CAST) FY-3D (NRSCC / CMA) Elektro-L N2 (Roshydromet / Roscosmos) Meteor-M N3 (Roshydromet / Roscosmos)
2011	Meteosat-10 (EUMETSAT) SAOCOM 1A (CONAE / ASI) CARTOSAT-3 (ISRO) ISTAG (ISRO) OCEANSAT-3 (ISRO) MetOp-B (EUMETSAT) Pleiades 2 (CNES) DMSAR (ISRO) RESOURCESAT-3 (ISRO) PRISMA (ASI) LDCM (USGS / NASA) DMSP F-20 (NOAA) Sentinel-1 A (ESA / EC) AMAZÔNIA-1 (INPE) FY-2F (NRSCC)
2012	SAOCOM 1B (CONAE / ASI) SAC-E/SABIA/mar (CONAE / INPE) Ingenio (SEOSAT) (CDTI / ESA) EnMAP (DLR) HY-3A (NSOAS / CAST) GCOM-W1 (JAXA) SABRINA (ASI) Sentinel-2 A (ESA / EC) Sentinel-1 B (ESA / EC) Sentinel-3 A (ESA / EC) FY-3E (NRSCC / CMA) FY-4 O/A (NRSCC / CMA)

Launch Year	EO Satellite Mission (and sponsoring agency)
2013	Meteosat-11 (EUMETSAT) TerraSAR-X2 (DLR) SMAP (NASA) NPOESS-1 (NOAA) EarthCARE (ESA / JAXA) GPM Core (NASA / JAXA) CBERS-4 (CRESDA / INPE) MAPSAR (INPE / DLR) RADARSAT CONSTELLATION-1 (CSA) Jason-3 (NOAA / CNES / EUMETSAT / NASA)
2014	SAC-F (CONAE) SAOCOM-2A (CONAE) COMS-2 (KARI / NIES (Japan)) Sentinel-5 precursor (ESA) GCOM-C1 (JAXA) Sentinel-2 B (ESA / EC) RISAT-L (ISRO) RADARSAT CONSTELLATION-3 (CSA) GOES-S (NOAA) GPM Constellation (NASA / JAXA) GPM-Br (INPE) FY-3F (NRSCC / CMA) Elektro-L N3 (Roshydromet / Roscosmos)
2015	SAOCOM-2B (CONAE) ICESat-II (NASA) RADARSAT CONSTELLATION-2 (CSA) GOES-R (NOAA) Sentinel-3 B (ESA / EC) MetOp-C (EUMETSAT) MTG-I1 (EUMETSAT) FY-4 O/B (NRSCC / CMA) FY-4 O/C (NRSCC / CMA) FY-4 M/A (NRSCC / CMA)
2016	NPOESS-2 (NOAA) GCOM-W2 (JAXA) FY-3G (NRSCC / CMA) Jason-CS (ESA / EC)
2017	MTG S1/Sentinel-4 A (EUMETSAT / ESA / EC) HY-3B (NSOAS / CAST) MTG-I2 (EUMETSAT)
2018	NPOESS-3 (NOAA) GCOM-C2 (JAXA) Sentinel-1 C (ESA / EC) FY-4 M/B (NRSCC / CMA)
2019	Sentinel-2 C (ESA / EC) Sentinel-3 C (ESA / EC) FY-4 O/D (NRSCC / CMA) FY-4 O/E (NRSCC / CMA)
2020	post-EPS/Sentinel-5 (EUMETSAT / ESA / EC) NPOESS-4 (NOAA) GCOM-W3 (JAXA)
2022	HY-3C (NSOAS / CAST) GCOM-C3 (JAXA) FY-4 M/C (NRSCC / CMA)
2023	MTG-I3 (EUMETSAT)
2024	MTG S2/Sentinel-4 B (EUMETSAT / ESA / EC)
2025	MTG-I4 (EUMETSAT)

List of Satellite Missions (alphabetical)

A

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
ACRIMSAT Active Cavity Radiometer Irradiance Monitor **NASA**	Currently being flown	20 Dec 99	01 Oct 09	Will sustain long-term solar luminosity database by providing measurements of total solar irradiance and the solar constant.	ACRIM III	Type: Sun-synchronous Altitude: 716 km Period: 90 mins Inclination: 98.13° Repeat cycle: LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: http://acrim.jpl.nasa.gov/
ADM-Aeolus Atmospheric Dynamics Mission (Earth Explorer Core Mission) **ESA**	Approved	01 May 10	01 Dec 12	Will provide wind profile measurements for global 3D wind field products used for study of atmospheric dynamics, including global transport of energy, water, aerosols, and chemicals.	ALADIN	Type: Sun-synchronous Altitude: 408 km Period: 92.5 mins Inclination: 97.01° Repeat cycle: 7 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/export/esaLP/aeolus.html
ALOS Advanced Land Observing Satellite **JAXA**	Currently being flown	24 Jan 06	01 Sep 10	Cartography, digital terrain models, environmental monitoring, disaster monitoring, civil planning, agriculture and forestry, Earth resources, land surface.	AVNIR-2, PALSAR, PRISM	Type: Sun-synchronous Altitude: 692 km Period: 98.7 mins Inclination: 98.16° Repeat cycle: 46 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.jaxa.jp/projects/sat/alos/index_e.html
AMAZÔNIA-1 **Remote Sensing Satellite 1** **INPE**	Approved	01 Dec 11	01 Dec 15	Earth resources, environmental monitoring, land surface.	OBA	Type: Sun-synchronous Altitude: 905 km Period: 103.2 mins Inclination: 0° Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.inpe.br/programas/mecb/default.htm
Aqua Aqua (formerly EOS PM-1) **NASA**	Currently being flown	04 Jun 02	01 Oct 09	Atmospheric dynamics/water and energy cycles, cloud formation, precipitation and radiative properties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere. Option of 705 km or 438 km orbit altitude.	AMSU-A, AIRS, MODIS, CERES, HSB, AMSR-E	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2° Repeat cycle: 16 days LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.gsfc.nasa.gov
Aura Aura (formerly EOS Chemistry) **NASA**	Currently being flown	15 Jul 04	01 Oct 09	Chemistry and dynamics of Earth's atmosphere from the ground through the mesosphere.	MLS (EOS-Aura), TES, HiRDLS, OMI	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2° Repeat cycle: 16 days LST: 13:45 Longitude (if geo): Asc/desc: Ascending URL: http://aura.gsfc.nasa.gov/

B|C

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
BJ-1 **Beijing-1 Small Satellite** **NRSCC**	Currently being flown	27 Oct 05	27 Oct 10	Earth Observation.	MSI (BJ-1), PAN (BJ-1)	Type: Sun-synchronous Altitude: 686 km Period: Inclination: 98.17° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.blmit.com.cn
CALIPSO **Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations** **NASA / CNES**	Currently being flown	28 Apr 06	28 Apr 09	Measurements of aerosol & cloud properties for climate predictions, using a 3 channel lidar and passive instruments in formation with Aqua and CloudSat for coincident observations of radiative fluxes and atmospheric state.	WFC, IIR, CALIOP	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2° Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www-calipso.larc.nasa.gov/
CARTOSAT-1 **Cartography Satellite - 1 (IRS P5)** **ISRO**	Currently being flown	05 May 05	01 Jul 09	High precision large-scale cartographic mapping of 1:10000 scale and thematic applications (with merged XS data) at 1:4000 scales.	PAN (Cartosat-1)	Type: Sun-synchronous Altitude: 618 km Period: 97 mins Inclination: 97.87° Repeat cycle: 5 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
CARTOSAT-2 **Cartography Satellite - 2** **ISRO**	Currently being flown	10 Jan 07	01 Jan 11	High precision large-scale cartographic mapping of 1:10000 scale and thematic applications (with merged XS data) at 1:4000 scales.	PAN (Cartosat-2)	Type: Sun-synchronous Altitude: 635 km Period: 97.4 mins Inclination: 97.87° Repeat cycle: 5 days LST: 9:30 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
CARTOSAT-3 **Cartography Satellite - 3** **ISRO**	Planned	01 Jan 11	01 Jan 15	Suitable for cadastral and infrastructure mapping and analysis.	PAN (Cartosat-3)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
CBERS-2 **China Brazil Earth Resources Satellite - 2** **CRESDA / INPE**	Currently being flown	21 Oct 03	31 Dec 08	Earth resources, environmental monitoring, land surface (joint with INPE).	WFI, CCD, IR-MSS, DCS (CAST)	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5° Repeat cycle: 26 days LST: 10:50 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers1-2.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
CBERS-2B **China Brazil Earth Resources Satellite - 2B** **CRESDA / INPE**	Currently being flown	19 Sep 07	20 Oct 10	Earth resources, environmental monitoring, land surface (joint with INPE).	WFI, CCD, IR-MSS, DCS (CAST)	Type: Sun-synchronous Altitude: 778 km Period: Inclination: 98.5º Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers1-2.htm
CBERS-3 **China Brazil Earth Resources Satellite - 3** **CRESDA / INPE**	Approved	20 Oct 10	21 Oct 13	Earth resources, environmental monitoring, land surface (joint with INPE).	WFI-2, MUX, DCS (CAST), IRS, PAN	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5º Repeat cycle: 26 days LST: 11:50 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers3-4.htm
CBERS-4 **China Brazil Earth Resources Satellite - 4** **CRESDA / INPE**	Approved	20 Oct 13	20 Oct 16	Earth resources, environmental monitoring, land surface (joint with INPE).	WFI-2, MUX, IRS, PAN	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5º Repeat cycle: 26 days LST: 12:50 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers3-4.htm
CHAMP **Challenging Mini-Satellite Payload for Geophysical Research and Application** **DLR**	Currently being flown	15 Jul 00	01 Jul 09	Gravity field, precise geoid, magnetic field, atmospheric physics.	CHAMP Gravity Package (Accelerometer+GPS), CHAMP Magnetometry Package (1 Scalar + 2 Vector Magnetometer), CHAMP GPS Sounder	Type: Inclined, non-Sun-synchronous Altitude: 470 km Period: Inclination: 87º Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: http://op.gfz-potsdam.de/champ/index_CHAMP.html
CHINOOK **CSA**	Considered	01 Dec 10	01 Dec 15	Stratospheric wind measurements and ozone flux.	SWIFT	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL:
CloudSat **NASA**	Currently being flown	28 Apr 06	31 Dec 12	CloudSat will use advanced radar to "slice" through clouds to see their vertical structure, providing a completely new observational capability from space. One of first satellites to study clouds on global basis. Will fly in formation with Aqua and CALIPSO.	CPR (CloudSat)	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2º Repeat cycle: LST: 13:35 Longitude (if geo): Asc/desc: Ascending URL: http://cloudsat.atmos.colostate.edu/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
COMS-1 **Communication, Oceanographic, Meteorological Satellite** **KARI / NIES (Japan)**	Approved	01 Jan 09	01 Jan 16	Korea's geostationary meterological satellite series.	GOCI, MI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
COMS-2 **Communication, Oceanographic, Meteorological Satellite** **KARI / NIES (Japan)**	Planned	01 Jan 14	01 Jan 21	Korea's geostationary meterological satellite series.	GOCI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
CORIOLIS **DoD (USA) / NASA**	Currently being flown	06 Jan 03	01 Jan 09	Validating space bourne multi-channel polarametric radiometry for wind vector measurements.	WindSat	Type: Sun-synchronous Altitude: 840 km Period: 101 mins Inclination: 98.7° Repeat cycle: LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.nrl.navy.mil/WindSat/
COSMIC-1/ FORMOSAT-3 FM1 **Constellation Observing System for Meteorology, Ionosphere and Climate-1** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 800 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/
COSMIC-2/ FORMOSAT-3 FM2 **Constellation Observing System for Meteorology, Ionosphere and Climate-2** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 800 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
COSMIC-3/ FORMOSAT-3 FM3 **Constellation Observing System for Meteorology, Ionosphere and Climate-3** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 711 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/
COSMIC-4/ FORMOSAT-3 FM4 **Constellation Observing System for Meteorology, Ionosphere and Climate-4** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 800 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/
COSMIC-5/ FORMOSAT-3 FM5 **Constellation Observing System for Meteorology, Ionosphere and Climate-5** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 800 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/
COSMIC-6/ FORMOSAT-3 FM6 **Constellation Observing System for Meteorology, Ionosphere and Climate-6** **NSPO / NOAA / UCAR**	Currently being flown	14 Apr 06	15 Mar 11	Meteorology, ionosphere and climate.	GOX	Type: Inclined, non-Sun-synchronous Altitude: 800 km Period: 100 mins Inclination: 72° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cosmic.ucar.edu/
COSMO-SkyMed 1 **COnstellation of small Satellites for Mediterranean basin Observation 1** **ASI / MiD (Italy)**	Currently being flown	08 Jun 07	08 Jun14	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications.	SAR 2000	Type: Sun-synchronous Altitude: 622 km Period: 97.15 mins Inclination: 97.8° Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.asi.it/SiteEN/ContentSite.aspx?Area=Osservare+la+Terra

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
COSMO-SkyMed 2 **COnstellation of small Satellites for Mediterranean basin Observation 2** **ASI / MiD (Italy)**	Currently being flown	09 Dec 07	09 Dec 14	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications.	SAR 2000	Type: Sun-synchronous Altitude: 622 km Period: 97.15 mins Inclination: 97.8° Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.asi.it/SiteEN/ContentSite.aspx?Area=Osservare+la+Terra
COSMO-SkyMed 3 **COnstellation of small Satellites for Mediterranean basin Observation 3** **ASI / MiD (Italy)**	Approved	08 Sep 08	08 Sep 15	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications.	SAR 2000	Type: Sun-synchronous Altitude: 622 km Period: 97.15 mins Inclination: 97.8° Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.asi.it/SiteEN/ContentSite.aspx?Area=Osservare+la+Terra
COSMO-SkyMed 4 **COnstellation of small Satellites for Mediterranean basin Observation 4** **ASI / MiD (Italy)**	Approved	08 Sep 08	08 Sep 16	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications.	SAR 2000	Type: Sun-synchronous Altitude: 622 km Period: 97.15 mins Inclination: 97.8° Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.asi.it/SiteEN/ContentSite.aspx?Area=Osservare+la+Terra
CryoSat-2 **CryoSat-2 (Earth Explorer Opportunity Mission)** **ESA**	Approved	01 Nov 09	01 Nov 12	To determine fluctuations in the mass of the Earth's major land and marine ice fields.	DORIS-NG, SIRAL, Laser Reflectors (ESA)	Type: Inclined, non-Sun-synchronous Altitude: 717 km Period: 100 mins Inclination: 92° Repeat cycle: 369 days LST: 0.25° nodal regression per day Longitude (if geo): Asc/desc: N/A URL: www.esa.int/export/esaLP/cryosat.html
DEMETER **Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions** **CNES**	Currently being flown	29 Jun 04	31 Dec 08	Micro-satellite to study; ionospheric disturbances related to seismic activity, ionospheric disturbances related to human activity, pre and post-seismic effects in the ionosphere, global information on the Earth's electromagnetic environment.	ICE, IMSC, IAP, ISL, IDP	Type: Sun-synchronous Altitude: 800 km Period: Inclination: Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: URL: http://smsc.cnes.fr/DEMETER/index.htm

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Diademe 1&2 **CNES**	Currently being flown	15 Dec 67	31 Dec 50	Geodetic measurements using satellite laser ranging.	RRA	Type: Inclined, non-Sun-synchronous Altitude: 1200 km Period: 108 mins Inclination: 40º Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://galileo.crl.go.jp/ilrs/diademe.html
DMSAR **Disaster Management SAR** **ISRO**	Considered	01 Jul 11	01 Jul 16	For disaster management purpose, mainly to overcome the problems of cloud during observation, most useful for flood and cyclone.	C/X SAR	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
DMSP F-14 **Defense Meteorological Satellite Program F-14** **NOAA**	Currently being flown	04 Apr 97	01 May 10	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophyscial and cloud cover data on a daily basis.	OLS, SSM/I, SSM/T-1, SSM/T-2, SSB/X-2, SSI/ES-2, SSJ/4, SSM	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.7º Repeat cycle: LST: 20:29 Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-15 **Defense Meteorological Satellite Program F-15** **NOAA**	Currently being flown	12 Dec 99	01 May 13	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis (Primary operational satellite).	OLS, SSM/I, SSM/T-1, SSM/T-2, SSI/ES-2, SSJ/4, SSM	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.9º Repeat cycle: LST: 20:29 Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-16 **Defense Meteorological Satellite Program F-16** **NOAA**	Currently being flown	18 Oct 03	01 Jan 10	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSM/IS, SSM, SSI/ES-3, SSJ/5, SSULI, SSUSI	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.9º Repeat cycle: LST: 21:32 Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-17 **Defense Meteorological Satellite Program F-17** **NOAA**	Currently being flown	04 Nov 06	01 Jan 18	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSM/IS, SSM, SSI/ES-3, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7º Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
DMSP F-18 **Defense Meteorological Satellite Program F-18** **NOAA**	Approved	16 Sep 08	16 Sep 11	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSM/IS, SSM, SSI/ES-3, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-19 **Defense Meteorological Satellite Program F-19** **NOAA**	Approved	15 Apr 09	15 Apr 12	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSM/IS, SSM, SSI/ES-3, SSULI, SSUSI	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.7° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-20 **Defense Meteorological Satellite Program F-20** **NOAA**	Approved	15 Oct 11	15 Oct 14	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSM/IS, SSM, SSI/ES-3, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://dmsp.ngdc.noaa.gov/dmsp.html
EarthCARE **ESA / JAXA**	Approved	01 Jun 13	01 Jun 16	Clouds-aerosol-radiation interactions.	CPR (EarthCARE), ATLID, BBR (EarthCARE), MSI (EarthCARE)	Type: Sun-synchronous Altitude: 450 km Period: Inclination: 97° Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.esa.int/export/esaLP/earthcare.html
Elektro-L N1 **Geostationary Operational Meteorological Satellite - 1** **Roshydromet / Roscosmos**	Approved	31 Dec 08	31 Dec 15	Hydrometeorology, climatology, DCS.	MSU-GS, DCS (Roshydromet), GGAK-E, S&R (Roshydromet)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -76 Asc/desc: N/A URL: http://planet.iitp.ru
Elektro-L N2 **Geostationary Operational Meteorological Satellite - 2** **Roshydromet / Roscosmos**	Approved	31 Dec 08	31 Dec 17	Hydrometeorology, climatology, DCS.	MSU-GS, DCS (Roshydromet), GGAK-E, S&R (Roshydromet)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -76 Asc/desc: N/A URL: http://planet.iitp.ru

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Elektro-L N3 **Geostationary Operational Meteorological Satellite - 3** **Roshydromet / Roscosmos**	Planned	31 Dec 14	31 Dec 21	Hydrometeorology, climatology, DCS.	MSU-GS, DCS (Roshydromet), GGAK-E, S&R (Roshydromet)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -14 Asc/desc: N/A URL: http://planet.iitp.ru
EnMAP **Environmental Mapping & Analysis Program** **DLR**	Planned	01 Jan 12	01 Jan 17	Hyperspectral imaging, land surface, geological and environmental investigation.	HSI	Type: Sun-synchronous Altitude: 650 km Period: 97.5 mins Inclination: Repeat cycle: 21 days LST: 11:00 Longitude (if geo): Asc/desc: Descending URL: www.enmap.org/
Envisat **Environmental Satellite** **ESA**	Currently being flown	01 Mar 02	31 Dec 13	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles.	DORIS-NG, MWR, ASAR (image mode), ASAR (wave mode), Envisat Comms, MERIS, MIPAS, ASAR, GOMOS, SCIAMACHY, RA-2, AATSR	Type: Sun-synchronous Altitude: 782 km Period: 100.5 mins Inclination: 98.52° Repeat cycle: 35 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: http://envisat.esa.int/
ERS-2 **European Remote Sensing satellite - 2** **ESA**	Currently being flown	21 Apr 95	31 Dec 01	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring, atmospheric chemistry.	MWR, ERS Comms, GOME, RA, ATSR/M, ATSR-2, AMI/SAR/Image, AMI/SAR/Wave, AMI/Scatterometer	Type: Sun-synchronous Altitude: 782 km Period: 100.5 mins Inclination: 98.52° Repeat cycle: 35 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/ers
FY-1D **FY-1D Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Currently being flown	15 May 02	31 Dec 08	Meteorology, environmental monitoring.	MVISR (10 channels)	Type: Sun-synchronous Altitude: 863 km Period: 102.3 mins Inclination: 98.8° Repeat cycle: LST: 9:00 Longitude (if geo): Asc/desc: Descending URL:
FY-2C **FY-2C Geostationary Meteorological Satellite** **NRSCC**	Currently being flown	19 Oct 04	19 Oct 08	Meteorology and environmental monitoring. Data collection and redistribution.	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-2D **FY-2D Geostationary Meteorological Satellite** **NRSCC**	Currently being flown	08 Dec 06	08 Dec 09	Meteorology and environmental monitoring. Data collection and redistribution.	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-2E **FY-2E Geostationary Meteorological Satellite** **NRSCC**	Approved	31 Dec 08	31 Dec 11	Meteorology and environmental monitoring. Data collection and redistribution.	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-2F **FY-2F Geostationary Meteorological Satellite** **NRSCC**	Approved	31 Dec 11	31 Dec 16	Meteorology and environmental monitoring. Data collection and redistribution.	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-3A **FY-3A Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Currently being flown	27 May 08	31 May 11	Meteorology and environmental monitoring. Data collection and redistribution.	IRAS, MWAS, MWRI, VIRR, ERM, MERSI, MWTS, TOU/SBUS, SEM, SIM	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-3B **FY-3B Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Approved	31 Dec 08	31 Dec 10	Meteorology and environmental monitoring. Data collection and redistribution (Experimental pre-cursor to FY-3C).	IRAS, MWAS, MWRI, VIRR, ERM, MERSI, MWTS, TOU/SBUS, SEM, SIM	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-3C **FY-3C Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Approved	31 Dec 08	31 Dec 10	Meteorology and environmental monitoring. Data collection and redistribution (Operational follow-on to FY-3B).	IRAS, IMWAS, MWHS, MIRAS, MWRI, VIRR, MERSI, MWTS, TOU/SBUS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-3D **FY-3D Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Approved	31 Dec 10	31 Dec 12	Meteorology and environmental monitoring. Data collection and redistribution.	IRAS, IMWAS, MWHS, MIRAS, MWRI, VIRR, MERSI, MWTS, TOU/SBUS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-3E **FY-3E Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 12	31 Dec 14	Meteorology and environmental monitoring. Data collection and redistribution.	IRAS, IMWAS, MWHS, MIRAS, MWRI, VIRR, MERSI, MWTS, TOU/SBUS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-3F **FY-3F Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 14	31 Dec 16	Meteorology and environmental monitoring. Data collection and redistribution.	IRAS, IMWAS, MWHS, MIRAS, MVIRS, MWRI, VIRR, MERSI, MWTS, TOU/SBUS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-3G **FY-3G Polar-orbiting Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 16	31 Dec 18	Meteorology and environmental monitoring. Data collection and redistribution.	IRAS, IMWAS, MWHS, MIRAS, MVIRS, MWRI, VIRR, MERSI, MWTS, TOU/SBUS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FY-4 M/A **FY-4A Microwave Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 15	31 Dec 20	Meteorology and environmental monitoring. Data collection and redistribution.	TBD	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 M/B **FY-4B Microwave Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 18	31 Dec 23	Meteorology and environmental monitoring. Data collection and redistribution.	TBD	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 M/C **FY-4C Microwave Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 22	31 Dec 27	Meteorology and environmental monitoring. Data collection and redistribution.	TBD	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-4 O/A **FY-4A Optical Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 12	31 Dec 17	Meteorology and environmental monitoring. Data collection and redistribution.	LM, MCSI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 O/B **FY-4B Optical Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 15	31 Dec 20	Meteorology and environmental monitoring. Data collection and redistribution.	LM, MCSI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 O/C **FY-4C Optical Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 15	31 Dec 20	Meteorology and environmental monitoring. Data collection and redistribution.	LM, MCSI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 O/D **FY-4D Optical Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 19	31 Dec 24	Meteorology and environmental monitoring. Data collection and redistribution.	LM, MCSI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
FY-4 O/E **FY-4E Optical Geostationary Meteorological Satellite** **NRSCC / CMA**	Planned	31 Dec 19	31 Dec 24	Meteorology and environmental monitoring. Data collection and redistribution.	LM, MCSI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: N/A URL:
GCOM-C1 **Global Change Observation Mission-C1** **JAXA**	Planned	01 Feb 14	01 Feb 19	Understanding of climate change mechanism.	SGLI	Type: Sun-synchronous Altitude: 800 km Period: 98 mins Inclination: 98.6° Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.jaxa.jp/projects/sat/gcom/index_e.html

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GCOM-C2 **Global Change Observation Mission-C2** **JAXA**	Planned	01 Feb 18	01 Feb 23	Understanding of climate change mechanism.	SGLI	Type: Sun-synchronous Altitude: 800 km Period: 98 mins Inclination: 98.6º Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.jaxa.jp/projects/sat/gcom/index_e.html
GCOM-C3 **Global Change Observation Mission-C3** **JAXA**	Planned	01 Feb 22	01 Feb 27	Understanding of climate change mechanism.	SGLI	Type: Sun-synchronous Altitude: 800 km Period: 98 mins Inclination: 98.6º Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.jaxa.jp/projects/sat/gcom/index_e.html
GCOM-W1 **Global Change Observation Mission-W1** **JAXA**	Approved	01 Feb 12	01 Feb 17	Understanding of climate change mechanism.	AMSR-2	Type: Sun-synchronous Altitude: 700 km Period: 98 mins Inclination: 98.2º Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.jaxa.jp/projects/sat/gcom/index_e.html
GCOM-W2 **Global Climate Observation Mission-W2** **JAXA**	Planned	01 Feb 16	01 Feb 21	Understanding of climate change mechanism.	AMSR-2	Type: Sun-synchronous Altitude: 700 km Period: 98 mins Inclination: 98.2º Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.jaxa.jp/projects/sat/gcom/index_e.html
GCOM-W3 **Global Change Observation Mission-W3** **JAXA**	Planned	01 Feb 20	01 Feb 25	Understanding of water circulation mechanism.	AMSR-2	Type: Sun-synchronous Altitude: 700 km Period: 98 mins Inclination: 98.2º Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.jaxa.jp/projects/sat/gcom/index_e.html
GFO (GEOSAT Follow-on) **DoD (USA) / US Naval Research Lab / CNES / NASA**	Currently being flown	10 Feb 98	01 Jan 09	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology.	Radar Altimeter, Water Vapour Radiometer	Type: Inclined, non-Sun-synchronous Altitude: 1336 km Period: 122.4 mins Inclination: 66º Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: http://gfo.wff.nasa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GISAT **Geo Imaging Satellite** **ISRO**	Considered	01 Apr 10	01 Jan 15	High repetivity sensor on geo-stationary platform.	HRMX-TIR, HyS-SWIR, HRMX-VNIR, HyS-VNIR	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
Glory **NASA**	Approved	15 Jun 09	15 Jun 12	Concentration and nature of both natural and anthropogenic aerosols (BC, sulfates, etc.) with accuracy and coverage sufficient for quantification of the aerosol effect on climate, the anthropogenic component of this effect, and the long-term change of this effect caused by natural and anthropogenic factors.	APS, TIM	Type: Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: http://glory.gsfc.nasa.gov/
GOCE **Gravity Field and Steady-State Ocean Circulation Explorer** **ESA**	Approved	10 Sep 08	31 Oct 09	Research in steady-state ocean circulation, physics of Earth's interior and levelling systems (based on GPS). Will also provide unique data set required to formulate global and regional models of the Earth's gravity field and geoid.	EGG, Laser Reflectors (ESA), GPS (ESA)	Type: Sun-synchronous Altitude: 270 km Period: 90 mins Inclination: 96.7° Repeat cycle: 60 days LST: 6:00 Longitude (if geo): Asc/desc: URL: www.esa.int/export/esaLP/goce.html
GOES-11 **Geostationary Operational Environmental Satellite - 11** **NOAA**	Currently being flown	03 May 00	15 Jul 11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	DCS (NOAA), S&R (GOES), WEFAX, Sounder, Imager, GOES Comms, SEM (GOES), LRIT	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 103 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-12 **Geostationary Operational Environmental Satellite - 12** **NOAA**	Currently being flown	23 Jul 01	15 Jan 11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	DCS (NOAA), S&R (GOES), WEFAX, SXI, Sounder, Imager, GOES Comms, SEM (GOES), LRIT	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-13 **Geostationary Operational Environmental Satellite - 13** **NOAA**	Currently being flown	24 May 06	24 May 11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX. On-orbit spare.	S&R (GOES), SXI, Sounder, Imager, GOES Comms, SEM (GOES), DCS (GOES-R), LRIT	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.oso.noaa.gov/goes/

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GOES-O **Geostationary Operational Environmental Satellite - O** **NOAA**	Approved	12 Dec 08	12 Dec 13	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	S&R (GOES), Sounder, Imager, GOES Comms, SEM (GOES), DCS (GOES-R), LRIT	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-P **Geostationary Operational Environmental Satellite - P** **NOAA**	Approved	09 Dec 09	09 Dec 14	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	S&R (GOES), SXI, Sounder, Imager, GOES Comms, SEM (GOES), DCS (GOES-R), LRIT	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-R **Geostationary Operational Environmental Satellite - R** **NOAA**	Approved	15 Apr 15	31 Oct 20	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	ABI, GLM, Magnetometer (NOAA), EXIS, SEISS, SUVI, DCS (GOES-R	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: N/A URL: www.osd.noaa.gov/goes_R/index.htm
GOES-S **Geostationary Operational Environmental Satellite - S** **NOAA**	Approved	01 Sep 14	31 Oct 21	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX.	ABI, GLM, Magnetometer (NOAA), EXIS, SEISS, SUVI, DCS (GOES-R)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: N/A URL: www.osd.noaa.gov/goes_R/index.htm
GOSAT **Greenhouse gases Observing Satellite** **JAXA / MOE (Japan) / NIES (Japan)**	Approved	01 Jan 09	01-Jan-14	Observation of Greenhouse gases.	TANSO-CAI, TANSO-FTS	Type: Sun-synchronous Altitude: 666 km Period: 98 mins Inclination: 98.05° Repeat cycle: 3 days LST: 13:00 Longitude (if geo): Asc/desc: Descending URL: www.jaxa.jp/projects/sat/gosat/index_e.html
GPM Constellation **Global Precipitation Measurement Mission Constellation spacecraft** **NASA**	Planned	01 Nov 14	01 Nov 19	Study of global precipitation, evaporation, and cycling of water are changing. The mission comprises a primary spacecraft with active and passive microwave instruments, and a number of constellation spacecraft with passive microwave instruments.	GMI	Type: Inclined, non-Sun-synchronous Altitude: 600 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://gpm.gsfc.nasa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GPM Core **Global Precipitation Measurement Mission Core spacecraft** **NASA / JAXA**	Planned	21 Jul 13	21 Jul 18	Study of global precipitation, evaporation, and cycling of water are changing. The mission comprises a primary spacecraft with active and passive microwave instruments, and a number of 'constellation' spacecraft with passive microwave instruments.	GMI, DPR	Type: Inclined, non-Sun-synchronous Altitude: 400 km Period: 95 mins Inclination: 65° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://gpm.gsfc.nasa.gov
GPM-Br **Global Precipitation Measurement Satellite** **INPE**	Approved	01 Dec 14	02 Sep 18	Global precipitation measurements.	GMI, LIS, DCS	Type: Sun-synchronous Altitude: 600 km Period: Inclination: 30° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
GRACE A **Gravity Recovery and Climate Experiment A** **NASA / DLR**	Currently being flown	17 Mar 02	01 Oct 09	Extremely high precision gravity measurements for use in construction of gravity field models.	HAIRS (aka KBR), BlackJack GPS (TRSR)	Type: Inclined, non-Sun-synchronous Altitude: 400 km Period: 94 mins Inclination: 89° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.csr.utexas.edu/grace/
GRACE B **Gravity Recovery and Climate Experiment B** **NASA / DLR**	Currently being flown	17 Mar 02	01 Oct 09	Extremely high precision gravity measurements for use in construction of gravity field models.	HAIRS (aka KBR), BlackJack GPS (TRSR)	Type: Inclined, non-Sun-synchronous Altitude: 400 km Period: Inclination: 89° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.csr.utexas.edu/grace/
HJ-1A **Disaster and Environment Monitoring and Forecast Small Satellite Constellation A** **CAST**	Approved	01 Sep 08	01 Sep 11	Disaster and environment monitoring and forecasting.	CCD (HJ, HY), HSI (HJ-1A)	Type: Sun-synchronous Altitude: 649 km Period: Inclination: 97.9° Repeat cycle: 31 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HJ-1B **Disaster and Environment Monitoring and Forecast Small Satellite Constellation B** **CAST**	Approved	01 Sep 08	01 Sep 11	Disaster and environment monitoring and forecasting.	CCD (HJ, HY), IR (HJ-1B)	Type: Sun-synchronous Altitude: 649 km Period: Inclination: 97.9° Repeat cycle: 31 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
HJ-1C **Disaster and Environment Monitoring and Forecast Small Satellite Constellation C** **CAST**	Approved	01 Jan 09	01 Jan 12	Disaster and environment monitoring and forecasting.	S-band SAR	Type: Sun-synchronous Altitude: 499 km Period: Inclination: 97.3° Repeat cycle: 31 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HY-1B **Ocean colour satellite B** **NSOAS / CAST**	Currently being flown	11 Apr 07	01 May 10	Detecting ocean colour and sea surface temperature.	COCTS, CZI	Type: Sun-synchronous Altitude: 798 km Period: Inclination: 98.6° Repeat cycle: 7 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HY-1C **Ocean colour and temperature satellite C** **NSOAS / CAST**	Planned	01 Jun 10	01 Jan 13	Detecting ocean colour and sea surface temperature.	COCTS, CZI	Type: Sun-synchronous Altitude: 798 km Period: Inclination: 98.6° Repeat cycle: 7 days LST: 10:31 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HY-1D **Ocean colour and temperature satellite D** **NSOAS / CAST**	Planned	01 Dec 10	01 Jan 13	Detecting ocean colour and sea surface temperature.	COCTS, CZI	Type: Sun-synchronous Altitude: 798 km Period: Inclination: 98.6° Repeat cycle: 7 days LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.cast.cn/
HY-2A **Ocean dynamics satellite A** **NSOAS / CAST**	Planned	01 Jan 10	01 Jan 11	Detecting ocean surface temperature, wind field, wave and topography.	RAD, SCAT, ALT	Type: Sun-synchronous Altitude: 963 km Period: Inclination: 99.3° Repeat cycle: 14 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.nsoas.gov.cn/
HY-3A **NSOAS / CAST**	Planned	06 Jan 12	06 Jan 17	Ocean monitoring, environmental protection, coastal zone survey, etc.	WSAR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
HY-3B **NSOAS / CAST**	Planned	06 Jan 17	06 Jan 22	Ocean monitoring, environmental protection, coastal zone survey, etc.	WSAR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
HY-3C **NSOAS / CAST**	Planned	06 Jan 22	06 Jan 27	Ocean monitoring, environmental protection, coastal zone survey, etc.	WSAR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
ICESat **Ice, Cloud, and Land Elevation Satellite** **NASA**	Currently being flown	12 Jan 03	01 Oct 09	Monitors mass balance of polar ice sheets and their contribution to global sea level change. Secondary goals: cloud heights and vertical structure of clouds/aerosols; roughness, reflectivity, vegetation heights, snow-cover.	GLAS	Type: Inclined, non-Sun-synchronous Altitude: 600 km Period: 97 mins Inclination: 94° Repeat cycle: 183 days LST: Longitude (if geo): Asc/desc: N/A URL: http://icesat.gsfc.nasa.gov/
ICESat-II **Ice, Cloud, and Land Elevation Satellite II** **NASA**	Planned	01 Jan 15	01 Jan 21	Continue the assessment of polar ice changes and measure vegetation canopy heights, allowing estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, and allow measurements of solid earth properties.	GLAS Follow-on	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://icesat.gsfc.nasa.gov/index.php
IMS-1 **Indian Mini Satellite-1** **ISRO**	Currently being flown	28 Apr 08	01 May 12	Micro-satellite for Third World countries for natural resources monitoring & management.	MxT, HySI (IMS-1)	Type: Sun-synchronous Altitude: 632 km Period: 97 mins Inclination: 97.92° Repeat cycle: 22 days LST: 9:30 Longitude (if geo): Asc/desc: Descending URL:
Ingenio (SEOSAT) **CDTI / ESA**	Approved	01 Jan 12	01 Jan 17	Cartography, land use, urban management, water management, environmental monitoring, risk management and security.	PAN+MS (RGB+NIR)	Type: Sun-synchronous Altitude: 668 km Period: 98 mins Inclination: 98° Repeat cycle: 38 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
INSAT-2E **Indian National Satellite - 2E** **ISRO**	Currently being flown	03 Apr 99	04 Mar 11	Meteorology, data collection and communication, search and rescue.	VHRR, CCD camera	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: N/A URL: www.isro.org/
INSAT-3A **Indian National Satellite - 3A** **ISRO**	Currently being flown	04 Apr 03	10 Apr 13	Meteorology, data collection and communication, search and rescue.	VHRR, DRT-S&R, CCD camera	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -94 Asc/desc: N/A URL: www.isro.org/
INSAT-3D **Indian National Satellite - 3D** **ISRO**	Planned	01 Mar 09	01 Jul 16	Meteorology, data collection and communication, search and rescue.	Imager (INSAT), Sounder (INSAT)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -93.5 Asc/desc: N/A URL: www.isro.org/
IRS-1D **Indian Remote Sensing Satellite - 1D** **ISRO**	Currently being flown	29 Sep 97	31 Dec 09	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils.	LISS-III (IRS), PAN (IRS-1C/1D), WiFS	Type: Sun-synchronous Altitude: 817 km Period: 101 mins Inclination: 98.6° Repeat cycle: 24 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/insat2b.htm
ISTAG **Indian Satellite for Aerosol and Gases** **ISRO**	Planned	01 Jan 11	01 Jan 15	Study of changes in atmospheric aerosol and trace gases.	MAPI, MAVELI, MAGIS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
Jason-1 **Ocean surface topography** **NASA / CNES**	Currently being flown	07 Dec 01	01 Oct 09	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology.	LRA, JMR, DORIS-NG, POSEIDON-2 (SSALT-2), TRSR	Type: Inclined, non-Sun-synchronous Altitude: 1336 km Period: 112.4 mins Inclination: 66° Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: http://sealevel.jpl.nasa.gov/mission/jason-1.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Jason-2 (aka OSTM) **Ocean Surface Topography Mission** **NASA / CNES / EUMETSAT**	Currently being flown	20 Jun 08	07 Dec 11	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology.	LRA, JMR, DORIS-NG, POSEIDON-3, AMR, GPSP	Type: Inclined, non-Sun-synchronous Altitude: 1336 km Period: 112.4 mins Inclination: 66° Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: http://sealevel.jpl.nasa.gov/mission/ostm.html
Jason-3 **NOAA / CNES / EUMETSAT / NASA**	Considered	31 Dec 13	31 Dec 18	Meteorology, climatology, oceanography.	FJP	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
Jason-CS **ESA / EC**	Considered	31 Dec 16	31 Dec 20	Meteorology, climatology, oceanography.	FJP	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
Kalpana **Meteorological satellite** **ISRO**	Currently being flown	12 Sep 02	09 Dec 12	Meteorological applications.	VHRR, DRT-S&R	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: N/A URL: www.isro.org/insat2b.htm
Kanopus-V N1 **Kanopus-V N1 Environmental Satellite** **Roscosmos / Roshydromet**	Approved	31 Dec 09	31 Dec 14	Land surface, disaster monitoring.	PSS, MSS (Roscosmos), MSU-200	Type: Sun-synchronous Altitude: 650 km Period: 98 mins Inclination: 98° Repeat cycle: 35 days LST: Longitude (if geo): Asc/desc: Ascending URL: http://planet.iitp.ru
Kanopus-Vulkan **Roscosmos**	Planned	01 Jan 07	31 Dec 12	Hydrology, hydrometeorology, monitoring man-made and natural accidents, research into short-term forecasting of earthquakes.	MTVZA-OK, NVK, RCHA, RBE, GID-12T, ECHO-V	Type: Sun-synchronous Altitude: 700 km Period: Inclination: 97° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
KOMPSAT-2 **Korea Multi-Purpose Satellite 2** **KARI**	Currently being flown	27 Jul 06	27 Jun 09	Cartography, land use and planning, disaster monitoring.	MSC	Type: Sun-synchronous Altitude: 685 km Period: 98.5 mins Inclination: Repeat cycle: 28 days LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: http://kompsat.kari.re.kr/english/index.asp
LAGEOS-1 **Laser Geodynamics Satellite - 1** **NASA**	Currently being flown	04 May 76	04 May 16	Geodesy, crustal motion and gravity field measurements by laser ranging.	LRA (LAGEOS)	Type: Inclined, non-Sun-synchronous Altitude: 6000 km Period: 225 mins Inclination: 110° Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lagoes.html
LAGEOS-2 **Laser Geodynamics Satellite - 2** **NASA / ASI**	Currently being flown	22 Oct 92	22 Oct 32	Geodesy, crustal motion and gravity field measurements by laser ranging.	LRA (LAGEOS)	Type: Inclined, non-Sun-synchronous Altitude: 5900 km Period: 223 mins Inclination: 52° Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lagoes.htmlNASA\NASA_Agency_Missions1x2.doc
Landsat-5 **USGS / NASA**	Currently being flown	01 Mar 84	31 Dec 10	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover.	MSS, TM, Landsat Comms	Type: Sun-synchronous Altitude: 705 km Period: 98.9 mins Inclination: 98.2° Repeat cycle: 16 days LST: 9:45 Longitude (if geo): Asc/desc: Descending URL: http://landsat7.usgs.gov/
Landsat-7 **USGS / NASA**	Currently being flown	15 Apr 99	31 Dec 12	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover.	ETM+, Landsat Comms	Type: Sun-synchronous Altitude: 705 km Period: 98.9 mins Inclination: 98.2° Repeat cycle: 16 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: http://landsat7.usgs.gov/
LARES **Laser Geodynamics Satellite - 3** **ASI**	Approved	30 Mar 09	01 Jan 50	Lense-Thirring measument accuracy improvement, crustal motion and gravity field measurements by laser ranging.	LCCRA	Type: Inclined, non-Sun-synchronous Altitude: 1450 km Period: 115 mins Inclination: 71° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lag1_general.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
LDCM **Landsat Data Continuity Mission** **USGS / NASA**	Approved	31 Jul 11	31 Dec 16	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover.	OLI	Type: Sun-synchronous Altitude: 750 km Period: 99 mins Inclination: 98.2° Repeat cycle: 16 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: http://ldcm.nasa.gov
MAPSAR **Multi-purpose SAR** **INPE / DLR**	Approved	03 Dec 13	03 Sep 17	Multi-purpose SAR.	SAR (MAPSAR), DCS	Type: Sun-synchronous Altitude: 620 km Period: Inclination: 98° Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL:
Megha-Tropiques **CNES / ISRO**	Approved	01 Mar 09	01 Jan 14	Study of the inter-tropical zone and its convective systems (water and energy cycles).	ScaRaB, SAPHIR, MADRAS, GPS ROS	Type: Sun-synchronous Altitude: 867 km Period: 102.16 mins Inclination: 20° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.cnes.fr/espace_pro/communiques/cp2001/5_17_va.html
Meteor-M N1 **Meteor-M N1 Meteorological Satellite** **Roshydromet / Roscosmos**	Approved	01 Dec 08	01 Dec 13	Hydrometeorology, climatology, heliogeophysics, DCS.	MTVZA, MSU-MR, DCS (Roshydromet), KMSS, GGAK-M, BRLK	Type: Sun-synchronous Altitude: 835 km Period: 102 mins Inclination: 98.7° Repeat cycle: 37 days LST: Longitude (if geo): Asc/desc: Ascending URL: http://planet.iitp.ru
Meteor-M N2 **Meteor-M N2 Meteorological Satellite** **Roshydromet / Roscosmos**	Approved	31 Dec 09	31 Dec 14	Hydrometeorology, climatology, heliogeophysics, DCS.	MTVZA, IKFS-2, MSU-MR, DCS (Roshydromet), KMSS, Radiomet, BRLK	Type: Sun-synchronous Altitude: 835 km Period: Inclination: 98.7° Repeat cycle: 37 days LST: Longitude (if geo): Asc/desc: Ascending URL: http://planet.iitp.ru
Meteor-M N3 **Meteor-M N3 Meteorological Satellite** **Roshydromet / Roscosmos**	Planned	31 Dec 10	31 Dec 15	Oceanography, hydrometeorology, climatology.	SAR (Roshydromet), Radiomet, MSS-BIO	Type: Sun-synchronous Altitude: 835 km Period: 102 mins Inclination: 98.7° Repeat cycle: 37 days LST: Longitude (if geo): Asc/desc: Ascending URL: http://planet.iitp.ru

M

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Meteosat-6 **EUMETSAT**	Currently being flown	20 Nov 93	01 Dec 10	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	Meteosat Comms, MVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 9 Asc/desc: N/A URL: www.eumetsat.de/en/dps/news/spacecraft.html
Meteosat-7 **EUMETSAT**	Currently being flown	03 Sep 97	31 Dec 10	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	Meteosat Comms, MVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/mtp/index.html
Meteosat-8 **Meteosat Second Generation-1** **EUMETSAT**	Currently being flown	13 Aug 02	30 Jul 11	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	MSG Comms, SEVIRI, GERB	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
Meteosat-9 **Meteosat Second Generation-2** **EUMETSAT**	Approved	21 Dec 05	30 Jun 14	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	MSG Comms, SEVIRI, GERB	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
Meteosat-10 **Meteosat Second Generation-3** **EUMETSAT**	Approved	01 Jan 11	01 Jan 19	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	MSG Comms, SEVIRI, GERB	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
Meteosat-11 **Meteosat Second Generation-4** **EUMETSAT**	Approved	01 Jan 13	01 Jan 21	Meteorology, climatology, atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.	SEVIRI, GERB	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
MetOp-A **Meteorological Operational Polar Satellite - A** **EUMETSAT**	Currently being flown	19 Oct 06	01 Nov 11	Meteorology, climatology.	SEM (POES), ARGOS, S&R (NOAA), MCP, MHS, IASI, GRAS, GOME-2, ASCAT, AMSU-A, AVHRR/3, HIRS/4, A-DCS4, SARSAT	Type: Sun-synchronous Altitude: 840 km Period: 107.1 mins Inclination: 98.8º Repeat cycle: 29 days LST: 9:30 Longitude (if geo): Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic2.html
MetOp-B **Meteorological Operational Polar Satellite - B** **EUMETSAT**	Approved	01 Apr 11	01 May 16	Meteorology, climatology.	SEM (POES), ARGOS, S&R (NOAA), MCP, MHS, IASI, GRAS, GOME-2, ASCAT, AMSU-A, AVHRR/3, HIRS/4, A-DCS4, SARSAT	Type: Sun-synchronous Altitude: 840 km Period: 101.7 mins Inclination: 98.8º Repeat cycle: 29 days LST: 9:30 Longitude (if geo): Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic2.html
MetOp-C **Meteorological Operational Polar Satellite - C** **EUMETSAT**	Approved	01 Nov 15	01 Dec 20	Meteorology, climatology.	ARGOS, MCP, MHS, IASI, GRAS, GOME-2, ASCAT, AMSU-A, AVHRR/3, HIRS/4, A-DCS4	Type: Sun-synchronous Altitude: 840 km Period: 101.7 mins Inclination: 98.8º Repeat cycle: 29 days LST: 9:30 Longitude (if geo): Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic2.html
Monitor-E **Roscosmos**	Currently being flown	26 Aug 05	31 Dec 10	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology.	PSA, RDSA	Type: Sun-synchronous Altitude: 540 km Period: Inclination: 97.5º Repeat cycle: LST: 5:40 Longitude (if geo): Asc/desc: URL:
MTG S1/ EUMETSAT / ESA **Sentinel-4 A ESA / EC**	Planned	01 Jan 17	31 Dec 25	Supporting European atmospheric composition and air quality monitoring services.	UVN (Sentinel-4), IRS	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.esa.int/esaLP/LPgmes.html
MTG S2/ EUMETSAT / ESA **Sentinel-4 B ESA / EC**	Planned	01 Jan 24	31 Dec 32	Supporting European atmospheric composition and air quality monitoring services.	UVN (Sentinel-4), IRS	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.esa.int/esaLP/LPgmes.html

M

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
MTG-I1 **Meteosat Third Generation - Imaging Satellite 1** **EUMETSAT**	Approved	15 Dec 15	15 Sep 23	Meteorology, climatology, atmospheric dynamics/water and energy cycles.	FCI, LI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.int/Home/Main/What_We_Do/Satellites/Future_Satellites/Meteosat_Third_Generation/index.htm
MTG-I2 **Meteosat Third Generation - Imaging Satellite 2** **EUMETSAT**	Approved	15 Dec 17	15 Nov 25	Meteorology, climatology, atmospheric dynamics/water and energy cycles.	FCI, LI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.int/Home/Main/What_We_Do/Satellites/Future_Satellites/Meteosat_Third_Generation/index.htm
MTG-I3 **Meteosat Third Generation - Imaging Satellite 3** **EUMETSAT**	Approved	15 Mar 23	15 Dec 30	Meteorology, climatology, atmospheric dynamics/water and energy cycles.	FCI, LI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.int/Home/Main/What_We_Do/Satellites/Future_Satellites/Meteosat_Third_Generation/index.htm
MTG-I4 **Meteosat Third Generation - Imaging Satellite 4** **EUMETSAT**	Approved	15 Mar 25	15 Dec 32	Meteorology, climatology, atmospheric dynamics/water and energy cycles.	FCI, LI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.int/Home/Main/What_We_Do/Satellites/Future_Satellites/Meteosat_Third_Generation/index.htm
MTSAT-1R **Multi-functional Transport Satellite** **JMA / JCAB**	Currently being flown	26 Feb 05	26 Feb 10	Meteorology, aeronautical applications.	MTSAT Comms, JAMI/MTSAT-1R, MTSAT DCS	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
MTSAT-2 **Multi-functional Transport Satellite** **JMA / JCAB**	Currently being flown	18 Feb 06	26 Feb 15	Meteorology, aeronautical applications.	IMAGER/MTSAT-2, MTSAT Comms, MTSAT DCS	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL:
NigeriaSat-1 **NASRDA**	Currently being flown	27 Sep 03	27 Sep 08	Small satellite mission with technical and scientific objectives (environmental) monitoring.	NigeriaSat Medium Resolution	Type: Sun-synchronous Altitude: 686 km Period: 97 mins Inclination: 98° Repeat cycle: 3 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.nasrda.net
NigeriaSat-2 **NASRDA**	Approved	01 Sep 09	01 Sep 16	Small satellite mission with technical and scientific objectives (environmental) monitoring.	NigeriaSat Medium and High Resolution	Type: Sun-synchronous Altitude: 700 km Period: 97 mins Inclination: Repeat cycle: 4 days LST: Longitude (if geo): Asc/desc: URL: www.nasrda.net
NMP EO-1 **New Millenium Program Earth Observing-1** **NASA**	Currently being flown	21 Nov 00	30 Oct 09	Land surface, earth resources.	ALI, Hyperion, LEISA AC	Type: Sun-synchronous Altitude: 705 km Period: 99 mins Inclination: 98.2° Repeat cycle: 16 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: http://eo1.gsfc.nasa.gov/
NOAA-15 **National Oceanic and Atmospheric Administration-15** **NOAA**	Currently being flown	01 May 98	31 Dec 10	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue.	ARGOS, S&R (NOAA), ATOVS (HIRS/3 + AMSU + AVHRR/3), AMSU-A, HIRS/3, AMSU-B, AVHRR/3, NOAA Comms	Type: Sun-synchronous Altitude: 813 km Period: 101.4 mins Inclination: 98.6° Repeat cycle: LST: 7:08 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
NOAA-16 **National Oceanic and Atmospheric Administration-16** **NOAA**	Currently being flown	21 Sep 00	31 Dec 12	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue.	SEM (POES), ARGOS, S&R (NOAA), ATOVS (HIRS/3 + AMSU + AVHRR/3), AMSU-A, HIRS/3, SBUV/2, AMSU-B, AVHRR/3, NOAA Comms	Type: Sun-synchronous Altitude: 870 km Period: 102 mins Inclination: 98.8° Repeat cycle: LST: 13:54 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NOAA-17 **National Oceanic and Atmospheric Administration-M** **NOAA**	Currently being flown	24 Jun 02	31 Dec 14	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue.	SEM (POES), ARGOS, S&R (NOAA), AMSU-A, HIRS/3, SBUV/2, AMSU-B, AVHRR/3, NOAA Comms	Type: Sun-synchronous Altitude: 833 km Period: 101.4 mins Inclination: 98.75° Repeat cycle: LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
NOAA-18 **National Oceanic and Atmospheric Administration-18** **NOAA**	Currently being flown	20 May 05	31 Dec 15	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue.	SEM (POES), ARGOS, S&R (NOAA), MHS, AMSU-A, SBUV/2, AVHRR/3, NOAA Comms, HIRS/4	Type: Sun-synchronous Altitude: 870 km Period: 102.1 mins Inclination: 98.75° Repeat cycle: LST: 14:00 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-N' **National Oceanic and Atmospheric Administration-N'** **NOAA**	Approved	31 Jan 09	01 Mar 16	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	CrIS, VIIRS, ATMS, TSIS, CMIS, A-DCS4, APS, SARSAT, SEM-N	Type: Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: 98.75° Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-1 **National Polar-orbiting Operational Environmental Satellite System-1** **NOAA**	Approved	31 Jan 13	01 Jan 20	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	CrIS, VIIRS, ATMS, TSIS, CMIS, A-DCS4, APS, SARSAT, SEM-N	Type: Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: 98.75° Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-2 **National Polar-orbiting Operational Environmental Satellite System-2** **NOAA**	Approved	31 Jan 16	01 Jan 22	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	VIIRS, A-DCS4, SARSAT, MIS	Type: Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: 98.75° Repeat cycle: LST: 17:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-3 **National Polar-orbiting Operational Environmental Satellite System-3** **NOAA**	Approved	31 Jan 18	01 Jan 25	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	CrIS, VIIRS, ATMS, TSIS, CMIS, OMPS, A-DCS4, SARSAT, MIS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75° Repeat cycle: LST: 17:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NPOESS-4 **National Polar-orbiting Operational Environmental Satellite System-4** **NOAA**	Approved	31 Jan 20	01 Jan 27	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	CrIS, VIIRS, ATMS, TSIS, CMIS, OMPS, A-DCS4, SARSAT	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75° Repeat cycle: LST: 21:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPP **NPOESS (National Polar-orbiting Operational Environmental Satellite System) Preparatory Project** **NASA / NOAA / DoD (USA)**	Approved	02 Jun 10	02 Jun 15	Operational Polar weather and climate measurements.	CrIS, CERES, VIIRS, ATMS, OMPS	Type: Inclined, non-Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: http://jointmission.gsfc.nasa.gov/
OCEANSAT-1 **Ocean satellite-1** **ISRO**	Currently being flown	26 May 99	01 Jul 09	Ocean and atmosphere applications.	OCM, MSMR	Type: Sun-synchronous Altitude: 720 km Period: 99.31 mins Inclination: 98.28° Repeat cycle: 2 days LST: Longitude (if geo): Asc/desc: Descending URL:
OCEANSAT-2 **Ocean satellite-2** **ISRO**	Approved	15 Sep 08	01 Jan 13	Ocean and atmosphere applications.	OCM, Scatterometer (ISRO), ROSA	Type: Sun-synchronous Altitude: 720 km Period: 99.31 mins Inclination: 98.28° Repeat cycle: 2 days LST: 12:00 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
OCEANSAT-3 **Ocean Satellite-3** **ISRO**	Considered	01 Jan 11	01 Jan 15	Ocean and atmosphere applications.	Scatterometer (ISRO), Altimeter (OCEANSAT-3), TIR (OCEANSAT-3), PMR, OCM (OCEANSAT-3)	Type: Sun-synchronous Altitude: 720 km Period: 99.31 mins Inclination: 98.28° Repeat cycle: 2 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
OCO **Orbiting Carbon Observatory** **NASA**	Approved	15 Dec 08	15 Dec 10	High resolution carbon dioxide measurements to characterize sources and sinks on regional scales and quantify their variability over the seasonal cycle.	Spectrometer (OCO)	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2° Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://oco.jpl.nasa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Odin **SNSB / TEKES / CNES / CSA**	Currently being flown	20 Feb 01	31 Dec 08	Atmospheric research, stratospheric ozone chemistry, mesospheric ozone science, summer mesospheric science.	OSIRIS, SMR	Type: Sun-synchronous Altitude: 590 km Period: 97.6 mins Inclination: 97.8º Repeat cycle: LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.ssc.se/?id=7180
Ørsted (Oersted) **DNSC / CNES / NASA**	Currently being flown	21 Nov 99	31 Dec 08	Earth magnetic field mapping.	Overhauser Magnetometer, CSC FVM, SI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://web.dmi.dk/projects/oersted/
PARASOL **Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a LIDAR** **CNES**	Currently being flown	01 Dec 04	31 Dec 08	Micro-satellite with the aim of characterisation of the clouds and aerosols microphysical and radiative properties, needed to understand and model the radiative impact of clouds and aerosols.	POLDER-P	Type: Sun-synchronous Altitude: 700 km Period: 98.8 mins Inclination: Repeat cycle: LST: 12:00 Longitude (if geo): Asc/desc: URL: http://smsc.cnes.fr/PARASOL/index.htm
PICARD **CNES**	Approved	01 Jan 09	01 Jan 11	Simultaneous measurements of solar diameter, differential rotation, solar constant, and variability.	SODISM, SOVAP, PREMOS	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://smsc.cnes.fr/PICARD/
Pleiades 1 **CNES**	Approved	01 Jan 10	01 Jan 15	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence.	HiRI	Type: Sun-synchronous Altitude: 694 km Period: Inclination: Repeat cycle: 26 days LST: 10:15 Longitude (if geo): Asc/desc: Descending URL: http://smsc.cnes.fr/PLEIADES/Fr/index.htm
Pleiades 2 **CNES**	Approved	01 Jun 11	01 Jun 16	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence.	HiRI	Type: Sun-synchronous Altitude: 694 km Period: Inclination: Repeat cycle: LST: 10:15 Longitude (if geo): Asc/desc: Descending URL: http://smsc.cnes.fr/PLEIADES/Fr/index.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
post-EPS EUMETSAT / ESA **Sentinel-5 ESA / EC**	Planned	01 Jan 20	01 Jan 27	In early stages of mission definition. Other payloads will be added.	IRS, UVNS (post-EPS)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: www.esa.int/esaLP/LPgmes.html
PRISMA **Hyperspectral Mission** **ASI**	Approved	30 Jul 11	30 Jul 16	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils.	HYC, PAN CAMERA	Type: Sun-synchronous Altitude: 700 km Period: 98.4 mins Inclination: 98.2º Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.spazio.galileoavionica.com/C35_co.htm
PROBA **Project for On-Board Autonomy** **ESA**	Currently being flown	22 Oct 01	31 Dec 09	PROBA is a technology experiment to demonstrate the on-board autonomy of a generic platform suitable for small scientific or application missions. A number of earth observation instruments are included. CHRIS – a hyperspectral imager provides data related to Earth Resources science and applications.	CHRIS	Type: Sun-synchronous Altitude: 615 km Period: 96.97 mins Inclination: 97.9º Repeat cycle: 7 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: http://earth.esa.int/proba/
QuikSCAT **Quick Scatterometer** **NASA**	Currently being flown	19 Jun 99	31 Dec 08	Acquires accurate, high resolution, global measurements of sea-surface wind vectors in 1 to 2 day repeat cycles for studies of tropospheric dynamics and air-sea interaction processes, including air-sea momentum transfer. End of life date TBD.	SeaWinds	Type: Sun-synchronous Altitude: 803 km Period: 101 mins Inclination: 98.6º Repeat cycle: LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: http://winds.jpl.nasa.gov/missions/quikscat/index.cfm
RADARSAT CONSTELLATION-1 **CSA**	Planned	06 Dec 13	01 Apr 20	Ecosystem monitoring, maritime surveillance, disaster management.	SAR (RCM), AIS (RCM)	Type: Sun-synchronous Altitude: 600 km Period: 96.5 mins Inclination: 97.7º Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/asc/eng/satellites/radarsat/default.asp

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
RADARSAT CONSTELLATION-2 **CSA**	Planned	14 Mar 15	01 Feb 21	Ecosystem monitoring, maritime surveillance, disaster management.	SAR (RCM), AIS (RCM)	Type: Sun-synchronous Altitude: 600 km Period: 96.5 mins Inclination: 97.7° Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/asc/eng/satellites/radarsat/
RADARSAT CONSTELLATION-3 **CSA**	Planned	06 Jul 14	01 Apr 22	Ecosystem monitoring, maritime surveillance, disaster management.	SAR (RCM), AIS (RCM)	Type: Sun-synchronous Altitude: 600 km Period: 96.5 mins Inclination: 97.7° Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/asc/eng/satellites/radarsat/
RADARSAT-1 **Radar satellite-1** **CSA**	Currently being flown	04 Nov 95	31 Mar 09	Environmental monitoring, physical oceanography, ice and snow, land surface.	SAR (RADARSAT), RADARSAT DTT, RADARSAT TTC	Type: Sun-synchronous Altitude: 798 km Period: 100.7 mins Inclination: 98.594° Repeat cycle: 24 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/asc/eng/satellites/radarsat1/
RADARSAT-2 **Radar satellite-2** **CSA**	Currently being flown	14 Dec 07	17 Apr 15	Environmental monitoring, physical oceanography, ice and snow, land surface.	SAR (RADARSAT-2)	Type: Sun-synchronous Altitude: 798 km Period: 100.7 mins Inclination: 98.6° Repeat cycle: 24 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/asc/eng/satellites/radarsat2/
RapidEye **DLR**	Approved	15 Aug 08	01 Jan 15	System of 5 satellites for cartography, land surface, digital terrain models, disaster management, environmental monitoring.	MSI	Type: Sun-synchronous Altitude: 622 km Period: Inclination: 98.7° Repeat cycle: 1 days LST: 11:00 Longitude (if geo): Asc/desc: Descending URL: www.rapideye.de/
RASAT **RASAT Remote Sensing Satellite** **Tubitak**	Approved	01 Jul 09	01 Jul 12	Cartography, land cover/land use, city planning, disaster mitigation/monitoring, environmental monitoring.	RASAT VIS Panchromatic, RASAT VIS Multi-spectral	Type: Sun-synchronous Altitude: 700 km Period: 98.8 mins Inclination: 98.21° Repeat cycle: 4 days LST: 10:30 Longitude (if geo): Asc/desc: URL: www.uzay.tubitak.gov.tr/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
RESOURCESAT-1 **Resource satellite-1** **ISRO**	Currently being flown	01 Oct 03	01 Oct 08	Natural resources management; agricultural applications; forestry etc.	AWiFS, LISS-IV, LISS-III (RESOURCESAT)	Type: Sun-synchronous Altitude: 817 km Period: 102 mins Inclination: 98.72° Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
RESOURCESAT-2 **Resource satellite-2** **ISRO**	Planned	01 Jul 09	01 Jul 13	Natural resources management; agricultural applications; forestry etc.	AWiFS, LISS-IV, LISS-III (RESOURCESAT)	Type: Sun-synchronous Altitude: 817 km Period: 102 mins Inclination: 98.72° Repeat cycle: 26 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
RESOURCESAT-3 **Resource Satellite-3** **ISRO**	Considered	01 Jul 11	01 Jul 16	Natural resources management; agricultural applications; forestry etc.	WS LISS-III, ATCOR	Type: Sun-synchronous Altitude: 817 km Period: 102 mins Inclination: 98.72° Repeat cycle: 26 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
Resurs DK 1 **Resurs DK Environmental Satellite 1** **Roscosmos / Roshydromet**	Currently being flown	15 Jun 05	30 Jun 11	Land surface.	Geoton-L1, Pamela, Arina	Type: Inclined, non-Sun-synchronous Altitude: 600 km Period: 92 mins Inclination: 70° Repeat cycle: 17 days LST: Longitude (if geo): Asc/desc: Ascending URL: http://planet.iitp.ru
RISAT-1 **Radar Imaging Satellite** **ISRO**	Approved	01 Mar 09	01 Mar 14	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils – especially during cloud season.	SAR (RISAT)	Type: Sun-synchronous Altitude: 610 km Period: 96.5 mins Inclination: 97.844° Repeat cycle: 12 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
RISAT-L **Radar Imaging Satellite** **ISRO**	Considered	01 Jul 14	01 Jul 20	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils – especially during cloud season.	SAR L	Type: Sun-synchronous Altitude: Period: 96.5 mins Inclination: 97.844° Repeat cycle: 12 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SABRINA **SAr Bissat Radar for INterferometric Applications** **ASI**	Approved	20 Apr 12	08 Sep 16	Resarch and testing on interferometric and bistatics techniques.	SAR (SABRINA)	Type: Sun-synchronous Altitude: 622 km Period: 97.15 mins Inclination: 97.8º Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL:
SAC-C **CONAE**	Currently being flown	21 Nov 00	01 Jan 10	Earth Observation, studies the structure and dynamics of the Earth's surface, atmosphere, ionosphere and geomagnetic field.	MMRS, HRTC, HSTC, MMP, GOLPE, IST, INES, ICARE, WTE, DCS (SAC-C)	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2º Repeat cycle: 9 days LST: 10:25 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAC-D **Satélite de Aplicaciones Científicas-D** **CONAE / NASA**	Approved	22 May 10	22 May 15	Earth observation studies; measurement of ocean salinity; emergency management.	Lagrange, ICARE, Aquarius, Microwave Radiometer (CONAE), HSC, SODAD, NIRST, CARMEN-1, DCS (SAC-D), ROSA, TDP, L-band Radiometer, L-band Scatterometer (Aquarius)	Type: Sun-synchronous Altitude: 657 km Period: 98 mins Inclination: 98º Repeat cycle: 9 days LST: 10:15 Longitude (if geo): Asc/desc: Ascending URL: www.conae.gov.ar/
SAC-E/SABIA/mar **CONAE / INPE**	Planned	01 Jan 12	01 Jan 17	Food production; environmental monitoring; inner coastal and water quality.	MOC	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: 9 days LST: 10:15 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAC-F **CONAE**	Planned	01 Jan 14	01 Jan 19	Earth observation studies; emergency management; landscape epidemiology.	HRMS, HSMS, TIS (CONAE), HSS	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2º Repeat cycle: 9 days LST: 10:15 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM 1A **CONAE / ASI**	Approved	01 Jan 11	01 Jan 16	Earth Observation and Emergency management with an L-band SAR.	SAR-L (SAOCOM)	Type: Sun-synchronous Altitude: 620 km Period: Inclination: 98º Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.conae.gov.ar/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SAOCOM 1B **CONAE / ASI**	Approved	01 Jan 12	01 Jan 17	Earth Observation and Emergency management with an L-band SAR.	SAR-L (SAOCOM)	Type: Sun-synchronous Altitude: 620 km Period: Inclination: 98º Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM-2A **CONAE**	Planned	01 Jan 14	01 Jan 19	Earth Observation and Emergency management with an L-band SAR.	SAR-L (SAOCOM)	Type: Sun-synchronous Altitude: 620 km Period: Inclination: 98º Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM-2B **CONAE**	Planned	01 Jan 15	01 Jan 20	Earth Observation and Emergency management with an L-band SAR.	SAR-L (SAOCOM)	Type: Sun-synchronous Altitude: 620 km Period: Inclination: 98º Repeat cycle: 16 days LST: 6:00 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SARAL **Satellite with ARgos and ALtiKa** **CNES / ISRO**	Approved	01 Oct 09	01 Oct 13	This will provide precise, repetitive global measurements of sea surface height, significant wave heights and wind speed.	ARGOS, AltiKa	Type: Sun-synchronous Altitude: 799 km Period: 100.59 mins Inclination: 98.55º Repeat cycle: 35 days LST: Longitude (if geo): Asc/desc: Descending URL:
SARE-1 **CONAE**	Planned	01 May 10	01 May 14	Earth observation studies, technology testing.	High Resolution Panchromatic Camera, Panchromatic High Sensitivity Camera, SAR components testing	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
SCD-1 **Data Collecting Satellite 1** **INPE**	Currently being flown	09 Feb 93	01 Dec 12	Data collection and communication.	DCP (SCD)	Type: Inclined, non-Sun-synchronous Altitude: 750 km Period: 100 mins Inclination: 25º Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/default.htm

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SCD-2 **Data Collecting Satellite 2** **INPE**	Currently being flown	22 Oct 98	01 Dec 12	Data collection and communication.	DCP (SCD)	Type: Inclined, non-Sun-synchronous Altitude: 750 km Period: 100 mins Inclination: 25º Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/default.htm
SCISAT-1 **SCISAT-I/ACE** **CSA**	Currently being flown	12 Aug 03	31 Dec 09	To improve our understanding of the depletion of the ozone layer, particularly over Canada and the Arctic.	ACE-FTS, MAESTRO	Type: Inclined, non-Sun-synchronous Altitude: 650 km Period: 97.7 mins Inclination: 74º Repeat cycle: 365 days LST: Longitude (if geo): Asc/desc: N/A URL: www.space.gc.ca/asc/eng/satellites/scisat/default.asp
Sentinel-1 A **ESA / EC**	Approved	01 Nov 11	01 Nov 18	Providing continuity of C-band SAR data for operational applications notably: Marine Core services, Land Monitoring and Emergency Services.	C-band SAR	Type: Sun-synchronous Altitude: 693 km Period: 98.74 mins Inclination: 98.19º Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-1 B **ESA / EC**	Planned	01 Jul 12	01 Jul 19	Providing continuity of C-band SAR data for operational applications notably: Marine Core services, Land Monitoring and Emergency Services.	C-band SAR	Type: Sun-synchronous Altitude: 693 km Period: 98.74 mins Inclination: 98.19º Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-1 C **ESA / EC**	Considered	01 Jul 18	01 Jul 25	Providing continuity of C-band SAR data for operational applications notably: Marine Core services, Land Monitoring and Emergency Services.	C-band SAR	Type: Sun-synchronous Altitude: 693 km Period: 98.74 mins Inclination: 98.19º Repeat cycle: 12 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-2 A **ESA / EC**	Approved	01 Jul 12	01 Jul 19	Supporting land monitoring related services.	MSI (Sentinel-2)	Type: Sun-synchronous Altitude: 786 km Period: 100.7 mins Inclination: 98.62º Repeat cycle: 10 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/esaLP/LPgmes.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Sentinel-2 B **ESA / EC**	Planned	01 Jul 14	01 Jul 21	Supporting land monitoring related services.	MSI (Sentinel-2)	Type: Sun-synchronous Altitude: 786 km Period: 100.7 mins Inclination: 98.62º Repeat cycle: 10 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-2 C **ESA / EC**	Considered	01 Jul 19	01 Jul 26	Supporting land monitoring related services.	MSI (Sentinel-2)	Type: Sun-synchronous Altitude: 786 km Period: 100.7 mins Inclination: 98.62º Repeat cycle: 10 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-3 A **ESA / EC**	Approved	01 Oct 12	01 Oct 19	Supporting land monitoring related services.	OLCI, SLSTR, SRAL	Type: Sun-synchronous Altitude: 814 km Period: 100 mins Inclination: 98.65º Repeat cycle: 27 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-3 B **ESA / EC**	Planned	01 Oct 15	01 Oct 22	Supporting land monitoring related services.	OLCI, SLSTR, SRAL	Type: Sun-synchronous Altitude: 814 km Period: 100 mins Inclination: 98.65º Repeat cycle: 27 days LST: 10:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-3 C **ESA / EC**	Considered	01 Jul 19	01 Jul 25	Supporting land monitoring related services.	OLCI, SLSTR, SRAL	Type: Sun-synchronous Altitude: 814 km Period: 100 mins Inclination: 98.65º Repeat cycle: 27 days LST: 10:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/esaLP/LPgmes.html
Sentinel-5 precursor **ESA**	Planned	01 Jan 14	01 Jan 20	Supporting global atmospheric composition and air quality monitoring services.	UVNS (Sentinel-5 precursor)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.esa.int/esaLP/LPgmes.html

S

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Sich-2 **NSAU**	Approved	01 Jan 09	01 Jan 14	Land Observation.	MBEI, MIREI	Type: Sun-synchronous Altitude: 668 km Period: 98 mins Inclination: 98° Repeat cycle: 5 days LST: 10:50 Longitude (if geo): Asc/desc: Descending URL:
SMAP **Soil Moisture Active Passive** **NASA**	Planned	15 Jan 13	15 Jan 15	Global soil moisture mapping.	Radar/Radiometer	Type: Inclined, non-Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: http://smap.jpl.nasa.gov/
SMOS **Soil Moisture and Ocean Salinity (Earth Explorer Opportunity Mission)** **ESA / CDTI / CNES**	Approved	15 Apr 09	01 Dec 14	Overall objectives are to provide global observations of two crucial variables for modelling the weather and climate, soil moisture and ocean salinity. It will also monitor the vegetation water content, snow cover and ice structure.	MIRAS (SMOS)	Type: Sun-synchronous Altitude: 780 km Period: 100.075 mins Inclination: 98.445° Repeat cycle: 149 days LST: 6:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/export/esaLP/smos.html
SORCE **Solar Radiation and Climate Experiment** **NASA**	Currently being flown	25 Jan 03	01 Oct 09	Continues the precise, long-term measurements of total solar irradiance at UV and VNIR wavelengths. Daily measurements of solar UV. Precise measurements of visible solar irradiance for climate studies.	SOLSTICE, SIM, TIM, XPS	Type: Inclined, non-Sun-synchronous Altitude: 600 km Period: Inclination: 40° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://lasp.colorado.edu/sorce/
SPOT-2 **Satellite Pour l'Observation de la Terre - 2** **CNES**	Currently being flown	22 Jan 90	31 Dec 08	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring.	HRV, DORIS (SPOT)	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7° Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL:
SPOT-4 **Satellite Pour l'Observation de la Terre - 4** **CNES**	Currently being flown	24 Mar 98	01 Jan 12	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring.	HRVIR, VEGETATION, DORIS (SPOT)	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7° Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.spot.com/home/system/introsat/welcome.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SPOT-5 **Satellite Pour l'Observation de la Terre - 5** **CNES**	Currently being flown	04 May 02	01 Jan 13	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring.	HRG, VEGETATION, HRS, DORIS-NG (SPOT)	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7° Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.spotimage.fr/home/system/future/spot5/welcome.htm
STARLETTE **CNES**	Currently being flown	06 Feb 75	31 Dec 50	Geodesy/gravity. Study of the Earth's gravitational field and its temporal variations.	Laser reflectors	Type: Inclined, non-Sun-synchronous Altitude: 812 km Period: 104 mins Inclination: 49.83° Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
STELLA **CNES**	Currently being flown	30 Sep 93	31 Dec 50	Geodesy/gravity. Study of the Earth's gravitational field and its temporal variations.	Laser reflectors	Type: Inclined, non-Sun-synchronous Altitude: 830 km Period: 101 mins Inclination: 98° Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
SumbandilaSat **Sumbandila Satellite** **CSIR / Uni of Stellenbosh**	Approved	01 Jan 09	01 Jan 14	Primary payload (imager) will be used to support decision making in natural resource management, disaster management, agriculture, urban planning and other applications.	SumbandilaSat Imager	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
Swarm **Earth's Magnetic Field and Environment Exploreres; Constellation of three satellites** **ESA / CNES / CSA**	Approved	01 Oct 10	01 Dec 14	To provide the best ever survey of the geomagnetic field and its temporal evolution, and gain new insights into improving our knowledge of the Earth's interior and climate.	ASM, VFM, STR, EFI, ACC, GPS Receiver (Swarm)	Type: Inclined, non-Sun-synchronous Altitude: 450 km Period: 90 mins Inclination: 87.4° Repeat cycle: LST: 6:00 Longitude (if geo): Asc/desc: N/A URL: www.esa.int/export/esaLP/swarm.html
TanDEM-X **TerraSAR-X Add-on for Digital Elevation Measurements** **DLR**	Approved	30 Sep 09	31 Dec 14	Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring.	X-band SAR	Type: Sun-synchronous Altitude: 514 km Period: 94.85 mins Inclination: 97.4° Repeat cycle: 11 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.dlr.de/hr/desktopdefault.aspx/tabid-2317/3669_read-5488

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Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Terra (formerly EOS AM-1) **NASA**	Currently being flown	18 Dec 99	01 Oct 09	Atmospheric dynamics/water and energy cycles, atmospheric chemistry, physical and radiative properties of clouds, airland exchanges of energy, carbon and water, vertical profiles of CO and methane vulcanology.	MOPITT, MODIS, MISR, CERES, ASTER	Type: Sun-synchronous Altitude: 705 km Period: 99 mins Inclination: 98.2° Repeat cycle: 16 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: http://terra.nasa.gov/
TerraSAR-X **DLR**	Currently being flown	15 Jul 07	01 Jan 13	Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring.	X-band SAR	Type: Sun-synchronous Altitude: 514 km Period: 94.85 mins Inclination: 97.4° Repeat cycle: 11 days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.terrasar.de/
TerraSAR-X2 **TerraSAR-X follow-on** **DLR**	Planned	01 Jan 13	01 Jan 18	Commercial follow-on mission to TerraSAR-X operated by Infoterra. Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring.	X-band SAR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL:
TES **Technology Experimental Satellite** **ISRO**	Currently being flown	22 Oct 01	01 Jul 09	For demonstrating many satellite technologies for future Cartosat satellites.	TES PAN	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
TES-HYS **Technology Experimental Satellite on Hyperspectral** **ISRO**	Considered	01 Jan 10	01 Jan 14	For demonstrating many satellite technologies for future Cartosat satellites.	HySI (TES-HYS)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
THEOS **Thailand Earth Observation System** **GISTDA**	Approved	02 Aug 08	01 Jan 13	Earth resources, land surface and disaster monitoring, civil planning.	PAN (GISTDA), MS (GISTDA)	Type: Sun-synchronous Altitude: 822 km Period: 101 mins Inclination: 98.7° Repeat cycle: 26 days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: www.gistda.or.th

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
TIMED **Thermosphere Ionosphere Mesosphere Energetics and Dynamics mission** **NASA**	Currently being flown	07 Dec 01	07 Dec 10	Investigates the influences of the sun and humans on the least explored and understood region of the Earth's atmosphere – the mesosphere and lower thermosphere/ ionosphere (MLTI).	SABER	Type: Inclined, non-Sun-synchronous Altitude: 625 km Period: Inclination: 74.1° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.timed.jhuapl.edu/WWW/index.php
TopSat **Optical Imaging Satellite** **BNSC**	Currently being flown	27 Oct 05	01 May 09	Prototype low-cost high resolution imager.	TOPSAT Telescope	Type: Sun-synchronous Altitude: 600 km Period: Inclination: 98° Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: URL: www.bnsc.gov.uk/content.aspx?nid=5907
TRMM **Tropical Rainfall Measuring Mission** **NASA / JAXA**	Currently being flown	27 Nov 97	01 Oct 09	Atmospheric dynamics/water and energy cycles.	LIS, PR, CERES, VIRS, TMI	Type: Inclined, non-Sun-synchronous Altitude: 405 km Period: 93.5 mins Inclination: 35° Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: http://trmm.gsfc.nasa.gov/
UK-DMC **UK Disaster Monitoring Constellation** **BNSC**	Currently being flown	27 Sep 03	30 Sep 08	Medium resolution visible imager for support of disaster management.	DMC Imager	Type: Sun-synchronous Altitude: 785 km Period: Inclination: 98.2° Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.sstl.co.uk/index.php?loc=113
UK-DMC2 **UK Disaster Monitoring Constellation 2** **BNSC**	Approved	01 Oct 08	01 Jan 13	Wide area, medium resolution optical imaging for mapping, environmental resource and disaster management.	DMC-2 Imager	Type: Sun-synchronous Altitude: 686 km Period: 97.7 mins Inclination: 98.2° Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Ascending URL: www.dmcii.com
VENUS **Vegetation and Environment monitoring on a New Micro-Satellite** **CNES / ISA**	Approved	01 Jul 10	01 Jul 13	Vegetation, agriculture monitoring, water management.	VSC	Type: Sun-synchronous Altitude: 720 km Period: Inclination: 98.27° Repeat cycle: 2 days LST: Longitude (if geo): Asc/desc: Descending URL: http://smsc.cnes.fr/VENUS/index.htm

9 Catalogue of Satellite Instruments

This section contains an alphabetical list of all instruments on the missions listed in section 8.
For each instrument the following information is given:

Instrument name	Instrument acronym Full instrument name
Missions	A list of missions that the instrument is expected to fly on, plus the agency and any partners
Status	Short description of the status of the instrument (eg whether being developed or currently operational)
Type	Instrument type – using the categories outlined in section 6
Measurements & applications	Primary measurements and applications of the instrument
Technical characteristics	Waveband Spatial resolution Swath width Accuracy

The descriptions of waveband adopt the following conventions for defining which parts of the spectrum are measured:

Frequency		Acronym	Wavelength range	
Region	**Sub-region**		**from**	**to**
Ultraviolet		UV	~0.01 μm	~0.40 μm
Visible		VIS	~0.40 μm	~0.75 μm
Infrared	Near Infrared	NIR	~0.75 μm	~1.3 μm
	Short Wave Infrared	SWIR	~1.3 μm	~3.0 μm
	Mid Wave Infrared	MWIR	~3.0 μm	~6.0 μm
	Thermal Infrared	TIR	~6.0 μm	~15.0 μm
	Far Infrared	FIR	~15.0 μm	~0.1 cm
Microwave		MW	~0.1 cm	~100 cm

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
AATSR Advanced Along-Track Scanning Radiometer BNSC	Envisat	Operational	Imaging multi-spectral radiometers (vis/IR) & Multiple direction/polarisation radiometers	Measurements of sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–NIR: 0.555 µm, 0.659 µm, 0.865 µm SWIR: 1.6 µm MWIR: 3.7 µm TIR: 10.85 µm, 12 µm IR ocean channels: 1 km x 1 km Visible land channels: 1 km x 1 km 500 km Sea surface temperature: <0.5K over 0.5° x 0.5° (lat/long) area with 80% cloud cover Land surface temperature: 0.1K (relative)
ABI Advanced Baseline Imager NOAA	GOES-R GOES-S	Being developed	Imaging multi-spectral radiometers (vis/IR)	Detects clouds, cloud properties, water vapour, land and sea surface temperatures, dust, aerosols, volcanic ash, fires, total ozone, snow and ice cover, vegetation index.	Waveband: Spatial resolution: Swath width: Accuracy:	16 bands in vis, NIR and IR ranging from 0.47 µm to 13.3 µm 0.5 km in 0.64 µm band 2.0 km in long wave IR and in the 1.378 µm band 1.0 km in all others Varies by product
ACC Accelerometer ESA	Swarm	Being developed	Precision orbit and space environment	Measurement of the spacecraft non-gravitational accelerations, linear accelerations range: ± 2*10–4 m/s2; angular measurement range: ± 9.6* 10–3 rad/s2; measurement bandwidth: 10–4 to 10–2 Hz; Linear resolution: 1.8*10–10 m/s2; angular resolution: 8*10–9 rad/s2	Waveband: Spatial resolution: Swath width: Accuracy:	N/A 0.1 nm/s^2 N/A overall instrument random error: <10–8 m/s^2
ACE-FTS Atmospheric Chemistry Experiment (ACE) Fourier Transform Spectrometer CSA	SCISAT-1	Operational	Atmospheric chemistry	Measure and understand the chemical processes that control the distribution of ozone in the Earth's atmosphere, especially at high altitudes.	Waveband: Spatial resolution: Swath width: Accuracy:	SWIR – TIR: 2–5.5 µm, 5.5–13 µm (0.02 cm^{-1} resolution)
ACRIM III Active Cavity Radiometer Irradiance Monitor NASA	ACRIMSAT	Operational	Earth radiation budget radiometer	Measurements of solar luminosity and solar constant. Data used as record of time variation of total solar irradiance, from extreme UV through to infrared.	Waveband: Spatial resolution: Swath width: Accuracy:	UV – MWIR: 0.15–5 µm 5° FOV 71 mins per orbit of full solar disc data 0.1% of full scale
A-DCS4 ARGOS-Data Collection System NOAA	MetOp-A, MetOp-B, MetOp-C, NOAA-N', NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4	Operational	Data collection	Data collection and communication system for receiving and retransmitting data from ocean and land-based remote observing platforms/transponders.	Waveband: Spatial resolution: Swath width: Accuracy:	UHF
AIRS Atmospheric Infrared Sounder NASA	Aqua	Operational	Atmospheric temperature and humidity sounders	High spectral resolution measurement of temperature and humdity profiles in the atmosphere. Long-wave Earth surface emissivity. Cloud diagnostics. Trace gas profiles. Surface temperatures.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-TIR: 0.4–1.7 µm, 3.4–15.4 µm, Has approximately 2382 bands from VIS to TIR 1.1° (13X13 Km at nadir) ± 48.95° Humidity: 20% Temperature: 1 K

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AIS (RCM) Automated Identification System (RADARSAT Constellation) CSA	RADARSAT Constellation-1, RADARSAT Constellation-2, RADARSAT Constellation-3	Being developed	Communications	Ship identification (name, location, heading, cargo etc.).	Waveband: Microwave: 162 MHz Spatial resolution: N/A Swath width: 800 km Accuracy:
ALADIN Atmospheric Laser Doppler Instrument ESA	ADM-Aeolus	Being developed	Lidars	Global wind profiles (single line-of-sight) for an improved weather prediction.	Waveband: UV: 355 nm Spatial resolution: One wind profile every 200 km along track, averaged over 50 km Swath width: Along line 285 km parallel to satellite ground track Accuracy: Wind speed error below 2 m/s
ALI Advanced Land Imager NASA	NMP EO-1	Operational	High resolution optical imagers	Measurement of Earth surface reflectance. Will validate new technologies contributing to cost reduction and increased capabilities for future missions. ALI comprises a wide field telescope and multi-spectral and panchromatic instrument.	Waveband: 10 bands: VIS&NIR: 0.480–0.690 μm, 0.433–0.453 μm, 0.450–0.515 μm, 0.525–0.605 μm, 0.630–0.690 μm, 0.775–0.805 μm, 0.845–0.890 μm, 1.200–1.300 μm SWIR: 1.550–1.750 μm, 2.080–2.350 μm Spatial resolution: PAN: 10 m VNIR&SWIR: 30 m Swath width: 37 km Accuracy: SNR at 5% surf refl Pan: 220 Multi 1: 215 Multi 2: 280 Multi 3: 290 Multi 4: 240 Multi 4': 190 Multi 5': 130 Multi 5: 175 Multi 7: 170 (prototype instrument exceeds ETM+ SNR by a factor of 4–8)
ALT Altimeter NOAA	HY-2A	Being developed	Radar altimeters	Global ocean topography sea level and gravity field measurements.	Waveband: 13.58 GHz and 5.25 GHz Spatial resolution: 16 km Swath width: 16 km Accuracy: < 4 cm
AltiKa Ka-band Altimeter CNES	SARAL	Being developed	Radar altimeters	Sea surface height.	Waveband: 35.5–36 GHz Spatial resolution: Swath width: Accuracy:
Altimeter (OCEANSAT-3) Ku-band Altimeter ISRO	OCEANSAT-3	Being developed	Radar altimeters	Mainly sea state applications including SWH, Geoid etc., establishment of global databases.	Waveband: 1306 GHz Spatial resolution: 1 km Swath width: 1500 m Accuracy:
AMI/SAR/Image Active Microwave Instrumentation. Image Mode ESA	ERS-2	Operational	Imaging microwave radars	All-weather images of ocean, ice and land surfaces. Monitoring of coastal zones, polar ice, sea state, geological features, vegetation (including forests), land surface processes, hydrology.	Waveband: Microwave: 5.3 GHz, C-band, VV polarisation bandwidth 15.5 ± 0.06 MHz Spatial resolution: 30 m Swath width: 100 km Accuracy: Landscape topography: 3 m Bathymetry: 0.3 m Sea ice type: 3 classes

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AMI/SAR/Wave Active Microwave Instrumentation. Wave mode ESA	ERS-2	Operational	Imaging microwave radars	Measurements of ocean wave spectra.	Waveband: Microwave: 5.3 GHz (C-band), VV polarisation Spatial resolution: 30 m Swath width: Accuracy: Sea surface wind speed: 3 m/s Significant wave height: 0.2 m
AMI/Scatterometer Active Microwave Instrumentation. Wind mode ESA	ERS-2	Operational	Scatterometers	Measurements of wind fields at the ocean surface, wind direction (range 0–360°), wind speed (range 1–30 m/s).	Waveband: Microwave: 5.3 GHz (C-band), VV polarisation Spatial resolution: Cells of 50 km x 50 km at 25 km intervals Swath width: 500 km Accuracy: Sea surface wind speed: 3 m/s Sea ice type: 2 classes
AMR Advanced Microwave Radiometer NASA	Jason-2 (aka OSTM)	Operational	Imaging multi-spectral radiometers (passive microwave)	Altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature.	Waveband: Microwave: 18.7 GHz, 23.8 GHz, 34 GHz Spatial resolution: 41.6 km at 18.7 GHz, 36.1 km at 23.8 GHz, 22.9 km at 34 GHz Swath width: 120° cone centred on nadir Accuracy: Total water vapour: 0.2 g/cm^2 Brightness temperature: 0.15 K
AMSR-2 Advanced Microwave Scanning Radiometer-2 JAXA	GCOM-W1, GCOM-W2, GCOM-W3	Approved	Imaging multi-spectral radiometers (passive microwave)	Measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover, soil moisture.	Waveband: Microwave: 6.925 GHz, 7.3 GHz, 10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89.0 GHz Spatial resolution: 5–50 km (dependent on frequency) Swath width: 1450 km Accuracy: Sea surface temparature: 0.5 K Sea ice cover: 10% Cloud liquid water: 0.05 kg/m^2 Precipitation rate: 10% Water vapour: 3.5 kg/m^2 through total column Sea surface wind speed 1.5 m/s
AMSR-E Advanced Microwave Scanning Radiometer-EOS JAXA (NASA)	Aqua	Operational	Imaging multi-spectral radiometers (passive microwave)	Measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover and soil moisture.	Waveband: Microwave: 6.925 GHz, 10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89.0 GHz Spatial resolution: 5–50 km (dependent on frequency) Swath width: 1445 km Accuracy: Sea surface temparature: 0.5K Sea ice cover: 10% Cloud liquid water: 0.05 kg/m^2 Precipitation rate: 10% Water vapour: 3.5 kg/m^2 through total column Sea surface wind speed 1.5 m/s
AMSU-A Advanced Microwave Sounding Unit-A NOAA (BNSC)	Aqua, MetOp-A, MetOp-B, MetOp-C, NOAA-15, NOAA-16, NOAA-17, NOAA-18	Operational	Atmospheric temperature and humidity sounders	All-weather night-day temperature sounding to an altitude of 45 km.	Waveband: Microwave: 15 channels, 23.8–89.0 GHz Spatial resolution: 48 km Swath width: 2054 km Accuracy: Temperature profile: 2 K Humidity: 3 kg/m^2 Ice & snow cover: 10%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
AMSU-B Advanced Microwave Sounding Unit-B NOAA (BNSC)	NOAA-15, NOAA-16, NOAA-17	Operational	Atmospheric temperature and humidity sounders	All-weather night-day humidity sounding.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 89 GHz, 150 GHz 183.3± 1.0 GHz (2 bands) 183.3± 3.0 GHz (2 bands) 183.3± 7.0 GHz (2 bands) 16 km 2200 km Humidity profile: 1 kg/m^2
APS Aerosol Polarimetry Sensor NOAA	Glory, NPOESS-1,	Proposed	Multiple direction/polarisation radiometers	Global distribution of natural and anthropogenic aerosols for quantification of the aerosol effect on climate, the anthropogenic component of this effect, and the long-term change of this effect caused by natural and anthropogenic factors.	Waveband: Spatial resolution: Swath width: Accuracy:	9 bands: VIS and SWIR: 0.412 µm, 0.488 µm, 0.555 µm, 0.672 µm, 0.910 µm, 0.865 µm, 1.378 µm, 1.610 µm, 2.250 µm 10 km 10 km AOT Ocean .02, land .04
Aquarius NASA (CONAE)	SAC-D	Being developed	Scatterometers	Understanding ocean circulation, including measurements of sea surface salinity, global water cycle and cliamte interaction, soil moisture measurements over Argentina.	Waveband: Spatial resolution: Swath width: Accuracy: .	L-band (1.413-1.260 GHz) 100 km 390 km 2 psu
ARGOS CNES (NASA)	MetOp-A, MetOp-B, MetOp-C, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-N', SARAL	Operational	Data collection	Location data by doppler measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	
Arina Roscosmos	Resurs DK 1	Operational	Space environment	Insights into electromagnetic field variations as the precursors of Earth quakes.	Waveband: Spatial resolution: Swath width: Accuracy:	
ASAR Advanced Synthetic-Aperture Radar ESA	Envisat	Operational	Imaging microwave radars	All-weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications. Has 2 stripmap modes (Image and Wave (for ocean wave spectra)) and 3 ScanSAR modes.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: C-band, with choice of 5 polarisation modes (VV, HH, VV/HH, HV/HH, or VH/VV) Image, wave and alternating polarisation modes: approx 30 m x 30 m Wide swath mode: 150 m x 150 m Global monitoring mode: 950 mm x 950 m Image and alternating polarisation modes: up to 100 km Wave mode: 5 km Wide swath and global monitoring modes: 400 km or more Radiometric resolution in range: 1.5-3.5 dB Radiometric accuracy: 0.65 dB

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ASAR (image mode) Advanced Synthetic Aperture Radar (Image mode) ESA	Envisat	Operational	Imaging microwave radars	All-weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications.	See above.
ASAR (wave mode) Advanced Synthetic Aperture Radar Wave mode) ESA	Envisat	Operational	Imaging microwave radars	Measurements of ocean wave spectra.	See above.
ASCAT Advanced Scatterometer EUMETSAT (ESA)	MetOp-A, MetOp-B, MetOp-C	Operational	Scatterometers	Sea ice cover, sea ice type and wind speed over sea surface measurements. Air pressure over ocean, polar ice contours, ice/snow imagery, soil moisture.	Waveband: Microwave: C-band, 5.256 GHz Spatial resolution: Hi-res mode: 25–37 km Nominal mode: 50 km Swath width: Continuous 2 x 500 km Accuracy: Wind speeds in range 4–24 m/s: 2 m/s and direction accuracy of 20°
ASM Absolute Scalar Magnetometer CNES	Swarm	Being developed	Magnetic field	Absolute calibration of Vector Field Magnetometer on board Swarm satellites.	Waveband: N/A Spatial resolution: 0.1 nT Swath width: N/A Accuracy: 0.1 nT
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer NASA (METI (Japan))	Terra	Operational	High resolution optical imagers	Surface and cloud imaging with high spatial resolution, stereoscopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation maps. Surface temperature and emissivity.	Waveband: VIS-NIR: 3 bands in 0.52–0.86 µm SWIR: 6 bands in 1.5–2.43 µm TIR: 5 bands in 8.125–11.65 µm Spatial resolution: VNIR: 15 m, stereo: 15 m horizontally and 25 m vertical SWIR: 30 m TIR: 90 m Swath width: 60 km Accuracy: VNIR and SWIR: 4% (absolute) TIR: 4 K Geolocation: 7 m
ATCOR Atmospheric correction ISRO	RESOURCESAT-3	Proposed	TBD	Atmospheric correction.	Waveband: Spatial resolution: Swath width: Accuracy:
ATLID ATmospheric LIDar ESA	EarthCARE	Approved	Lidars	Derivation of cloud and aerosol properties - Measurement of molecular and particle backscatter in Rayleigh, co-polar and cross-polar Mie channels.	Waveband: Laser at 355 nm Spatial resolution: 300 m horizontal (TBC) Swath width: Accuracy:
ATMS Advanced Technology Microwave Sounder NASA (NOAA)	NPOESS-1, NPOESS-3, NPOESS-4, NPP	Being developed	Atmospheric temperature and humidity sounders	Collects microwave radiance data that when combined with the CrIS data will permit calculation of atmospheric temperature and water vapour profiles.	Waveband: Microwave: 22 bands, 23–184 GHz Spatial resolution: 5.2° – 1.1° Swath width: 2300 km Accuracy: 0.75–3.60 K
ATOVS (HIRS/3 + AMSU + AVHRR/3) Advanced TIROS Operational Vertical Sounder NOAA	NOAA-15, NOAA-16	Operational	Atmospheric temperature and humidity sounders	Advanced TIROS Operational Vertical Sounder insturment suite.	Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ATSR/M CNES	ERS-2	Operational	Imaging multi-spectral radiometers (passive microwave)	Belongs to ATSR payload on board ERS1 and ERS2.	Waveband: Spatial resolution: Swath width: Accuracy:
ATSR-2 Along Track Scanning Radiometer - 2 BNSC (CSIRO)	ERS-2	Operational	Imaging multi-spectral radiometers (vis/IR) & Multiple direction/polarisation radiometers	Measurements of sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content.	Waveband: VIS-SWIR: 0.65 μm, 0.85 μm, 1.27 μm, 1.6 μm SWIR-TIR: 1.6 μm, 3.7 μm, 11 μm, 12 μm Microwave: 23.8 GHz, 36.5 GHz (bandwidth of 400 MHz) Spatial resolution: IR ocean channels: 1 km x 1 km Microwave near-nadir viewing: 20 km instantaneous field of view Swath width: 500 km Accuracy: Sea surface temperature to <0.5 K over 0.5° x 0.5° (lat/long) area with 80% cloud cover Land surface temperature: 0.1 K
AVHRR/3 Advanced Very High Resolution Radiometer/3 NOAA	MetOp-A, MetOp-B, MetOp-C, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-N'	Operational	Imaging multi-spectral radiometers (vis/IR)	Measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring.	âWaveband: VIS: 0.58-0.68 μm NIR: 0.725-1.1 μm SWIR: 1.58-1.64 μm MWIR: 3.55-3.93 μm TIR: 10.3-11.3 μm, 11.5-12.5 μm Spatial resolution: 1.1 km Swath width: 3000 km approx, Ensures full global coverage twice daily Accuracy:
AVNIR-2 Advanced Visible and Near Infrared Radiometer type 2 JAXA	ALOS	Operational	High resolution optical imagers	High resolution multi-spectral imager for land applications which include environmental monitoring, agriculture and forestry, disaster monitoring.	Waveband: VIS: 0.42-0.50 μm, 0.52-0.60 μm, 0.61-0.69 μm NIR: 0.76-0.89 μm Spatial resolution: 10 m Swath width: 70 km Accuracy: Surface Resolution:10 m (Nadir)
AWiFS Advanced Wide Field Sensor ISRO	RESOURCE-SAT-1, RESOURCE-SAT-2	Operational	High resolution optical imagers	Vegetation and crop monitoring, resource assessment (regional scale), forest mapping, land cover/ land use mapping, and change detection.	Waveband: VIS: 0.52-0.59 μm, 0.62-0.68 μm NIR: 0.77-0.86 μm SWIR: 1.55-1.7 μm Spatial resolution: 55 m Swath width: 730 km Accuracy: 10 bit data
BBR (EarthCARE) BroadBand Radiometer (EarthCARE) ESA	EarthCARE	Approved	Earth radiation budget radiometers	Top of the atmosphere radiances and radiative flux.	Waveband: Shortwave channel: 0.2-4 μm Total channel 0.2-50 μm Spatial resolution: 10 x 10 km ground pixel size for each of the three views Swath width: Accuracy: flux retrieval accuracy 10 W/m²
BlackJack GPS (TRSR) BlackJack Global Positioning System (Turbo Rogue Space Receiver) NASA	GRACE A, GRACE B	Operational	Precision orbit		Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
BRLK Synthetic Aperature Radar Roshydromet (Roscosmos)	Meteor-M N1, Meteor-M N2	Prototype	Imaging microwave radars	Microwave radar images for ice watch.	Waveband: X-band Spatial resolution: 400–700 m Swath width: 600 km Accuracy: 1 dB
C/X SAR SAR ISRO	DMSAR	Proposed	Imaging microwave radars	Disaster management, mainly to overcome problems of cloud during observation, most useful for flood and cyclone.	Waveband: C/X-band Spatial resolution: Swath width: Accuracy:
CALIOP Cloud-Aerosol Lidar with Orthogonal Polarization NASA	CALIPSO	Operational	Lidars	Two-wavelength, polarization lidar capable of providing aerosol and cloud profiles and properties.	Waveband: 532 nm (polarization-sensitive), 1064 nm, VIS - NIR Spatial resolution: Vertical sampling: 30 m, 0–40 km Swath width: 333 m along-track Accuracy: 5% (532 nm)
CARMEN-1 CNES (CONAE)	SAC-D	Being developed	Space environment	Studying space environment effects.	Waveband: Spatial resolution: Swath width: Accuracy:
C-band SAR C-band Synthetic Aperture Radar ESA	Sentinel-1 A, Sentinel-1 B, Sentinel-1 C	Being developed	Imaging microwave radars	Marine core services, land monitoring and emergency services. Monitoring sea ice zones and arctic environment. Surveillance of marine environment, monitoring land surface motion risks, mapping of land surfaces (forest, water and soil, agriculture), mapping in support of humanitarian aid in crisis situations.	Waveband: C-band: 5.405 GHz, HH, HV, VH, VV, Incidence angle: 20–45º Spatial resolution: Strip mode: 5 x 5 m Interferometric wide swath mode: 5 x 20 m extra-wide swath mode: 25 x 100 m (3 looks) wave mode: 5 x 20 m Swath width: Strip mode: 80 km Interferometric wide swath mode: 250 km extra-wide swath mode: 400 km Wave mode: sampled images of 20 x 20 km at 100 km intervals Accuracy: NESZ: -22 dB; PTAR: -25 dB; DTAR: -22 dB Radiometric accuracy 1 dB (3 sigma) Radiometric stability: 0.5 dB (3 sigma)
CCD (HJ, HY) CCD camera CAST	HJ-1A, HJ-1B	Being developed	High resolution optical imagers	Multi-spectral measurements of Earth's surface for natural enviroment and disaster applications.	Waveband: 0.43–0.90 µm (4 bands) Spatial resolution: 30 m Swath width: 360 km (per set) 720 km (two sets) Accuracy:
CCD camera **Charged Coupled Device Camera** ISRO	INSAT-2E, INSAT-3A	Operational	Imaging multi-spectral radiometers (vis/IR)	Cloud and Vegetation monitoring.	Waveband: VIS: 0.62–0.68 µm NIR: 0.77–0.86 µm SWIR: 1.55–1.69 µm Spatial resolution: 1 x 1 km Swath width: Normal: 6000 km (N-S) x 6000 km (E-W) anywhere on earth disc Programme: 6000 km (N-S) x (n x 300) km (E-W) : n and number of frames programmable Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
CCD High Resolution CCD Camera CAST (INPE)	CBERS-2, CBERS-2B	Operational	High resolution optical imagers	Measurements of cloud type and extent and land surface reflectance, and used for global land surface applications.	Waveband: VIS: 0.45–0.52 μm, 0.52–0.59 μm, 0.63–0.69 μm NIR: 0.77–0.89 μm PAN: 0.51–0.71 μm Spatial resolution: 20 m Swath width: 113 km Accuracy:
CERES Cloud and the Earth's Radiant Energy System NASA	Aqua, NPP, Terra, TRMM	Operational	Earth radiation budget radiometer	Long term measurement of the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface; provision of an accurate and self-consistent cloud and radiation database.	Waveband: 3 channels: 0.3–5 μm, 0.3–100 μm, 8–12 μm, UV-FIR Spatial resolution: 20 km Swath width: Accuracy: 0.5%, 1%, 1% (respectively for the 3 channels)
CHAMP GPS Sounder GPS TurboRogue Space Receiver (TRSR) NASA (DLR)	CHAMP	Operational	Atmospheric temperature and humidity sounders & precision orbit	Temperature and water vapour profiles.	Waveband: Spatial resolution: Swath width: Accuracy:
CHAMP Gravity Package (Accelerometer+GPS) STAR Accelerometer CNES (DLR)	CHAMP	Operational	Gravity instruments	Earth gravity field measurements.	Waveband: Spatial resolution: Swath width: Accuracy:
CHAMP Magnetometry Package (1 Scalar + 2 Vector Magnetometer) Overhauser Magnetometer and Fluxgate Magnetometer DLR	CHAMP	Operational	Magnetic field	Earth gravity field measurements.	Waveband: Spatial resolution: Swath width: Accuracy:
CHRIS Compact High Resolution Imaging Spectrometer ESA (BNSC)	PROBA	Operational	Imaging multi-spectral radiometers (vis/IR)	Supports a range of land, ocean and atmospheric applications, including agricultural science, forestry, environmental science, atmospheric science and oceanography.	Waveband: VIS – NIR: 400–1050 nm (63 spectral bands at a spatial resolution of 36 m; or 18 bands at full spatial resolution (18 m)) Spatial resolution: 36 m or 18 m depending on wavebands selected Swath width: 14 km Accuracy: S/N 200 at target albedo of 0.2. 12 bits digitisation
CMIS Conical-scanning Microwave Imager/Sounder NOAA	NPOESS-1, NPOESS-3, NPOESS-4	Being developed	Imaging multi-spectral radiometers (passive microwave) & Atmospheric temperature and humidity sounders	Collects microwave radiometry and sounding data. Data types include atmospheric temperature and moisture profiles, clouds, sea surface winds, and all-weather land/water surfaces.	Waveband: Microwave: 190 GHz Spatial resolution: 15–50 km depending on frequency Swath width: 1700 km Accuracy: Temperature Profiles to 1.6 K water vapour 20%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
COCTS China Ocean Colour & Temperature Scanner CAST	HY-1B, HY-1C, HY-1D	Operational	Ocean colour instruments	Ocean chlorophyll, ocean yellow substance absorbance, Sea-ice surface temperature.	Waveband: B1: 0.402–0.422 μm B2: 0.433–0.453 μm B3: 0.480–0.500 μm B4: 0.510–0.530 μm B5: 0.555–0.575 μm B6: 0.660–0.680 μm B7: 0.740–0.760 μm B8: 0.845–0.885 μm B9: 10.30–11.40 μm B10: 11.40–12.50 μm Spatial resolution: 1.1 km Swath width: 3083 km Accuracy:
CPR (Cloudsat) Cloud Profiling Radar NASA	CloudSat	Operational	Cloud profile and rain radars	Primary goal is to provided data needed to evaluate and improve the way clouds are represented in global climate models. Measures vertical profile of clouds.	Waveband: Microwave: 94 GHz Spatial resolution: Vertical: 500 m Cross-track: 1.4 km Along-track: 2.5 km Swath width: Instantaneous Footprint < 2 km Accuracy: Cloud liquid water content <=50% ice water content within +100%, -50% detect all single layer clouds with optical depth >=1.0
CPR (EarthCARE) Cloud Profiling Radar (EarthCARE) JAXA (NICT)	EarthCARE	Approved	Cloud profile and rain radars	Measurement of cloud properties, light precipitation, vertical motion.	Waveband: Microwave: 94 GHz Spatial resolution: 500 m horizontal Swath width: Accuracy:
CrIS Cross-track Infrared Sounder NOAA (NASA)	NPOESS-1, NPOESS-3, NPOESS-4, NPP	Prototype	Atmospheric temperature and humidity sounders	Daily measurements of vertical atmospheric distribution of temperature, moisture, and pressure.	Waveband: MWIR-TIR: 3.92–4.4 μm, 5.7–8.62 μm, 9.1–14.7 μm, 1300 spectral channels Spatial resolution: IFOV 14 km diameter, 1 km vertical layer resolution Swath width: 2200 km Accuracy: Temperature profiles: to 0.9 K Moisture profiles: 20–35% Pressure profiles: 1%
CSC FVM CSC fluxgate vector magnetometer DNSC	Ørsted (Oersted)	Operational	TBD	Measurements of the strength and direction of the Earth's magnetic field.	Waveband: Spatial resolution: Swath width: Accuracy:
CZI Coast region imager CAST	HY-1B, HY-1C, HY-1D	Operational	Imaging multi-spectral radiometers (vis/IR)	Imagery of coastal regions – estuaries, tidal regions, etc.	Waveband: B1: 0.433–0.453 m B2: 0.555–0.575 m B3: 0.655–0.675 m B4: 0.675–0.695 m Spatial resolution: 250 m Swath width: 500 km Accuracy:
DCP (SCD) Data Collecting Platform Transponder INPE (CAST)	SCD-1, SCD-2	Operational	Data collection	Data collection and communication.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS (CAST) Data Collecting System Transponder (CAST) CAST	CBERS-2, CBERS-2B, CBERS-3	Operational	Data collection	Data collection and communication.	Waveband: Spatial resolution: Swath width: Accuracy:

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
DCS (GOES-R) Data Collection System (NOAA, GOES-R) NOAA	GOES-13, GOES-O, GOES-P, GOES-R, GOES-S	Approved	Data collection	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS (NOAA) Data Collection System (NOAA) NOAA	GOES-11, GOES-12	Operational	Data collection	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS (Roshydromet) Data Collection System Roshydromet (Roscosmos)	Elektro-L N1, Elektro-L N2, Elektro-L N3, Meteor-M N1, Meteor-M N2	Operational	Data collection	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS (SAC-C) Data Collection System CONAE	SAC-C	Operational	Communications	DCS is able to receive data from 200 meteorological and environmental stations for re-transmission of all the data to Cordoba Ground Station.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS (SAC-D) Data Collection System CONAE	SAC-D	Being developed	Communications	UHF 401.55 MHz uplink.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS Data Collection System INPE	GPM-Br	Approved	Data collection	Support to Data Collection Platforms.	Waveband: Spatial resolution: Swath width: Accuracy:
DCS Data Collection System INPE (DLR)	MAPSAR	Approved	Data collection	Support to Data Collection Platforms.	Waveband: Spatial resolution: Swath width: Accuracy:
DMC Imager Disaster Management Constellation Imager BNSC	UK-DMC	Operational	High resolution optical imagers	Visible and NIR imagery in support of disaster management.	Waveband: VIS and NIR Spatial resolution: 32 m Swath width: 2 beams of 300 km Accuracy:
DMC-2 Imager Disaster Management Constellation Imager BNSC	UK-DMC2	Approved	High resolution optical imagers	Visible and NIR imagery in support of disaster management – part of the Disaster Management Constellation.	Waveband: VIS: 0.52–0.62 μm, 0.36–0.96 μm NIR: 0.76–0.9 μm Spatial resolution: 22 m Swath width: 660 km imaging swath Accuracy:
DORIS (SPOT) Doppler Orbitography and Radio-positioning Integrated by Satellite (on SPOT) CNES	SPOT-2, SPOT-4,	Operational	Precision orbit	Orbit determination.	Waveband: Spatial resolution: Swath width: Accuracy: Orbit error ~2.5 cm

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
DORIS-NG (SPOT) Doppler Orbitography and Radio-positioning Integrated by Satellite-NG (on SPOT) CNES	SPOT-5	Operational	Precision orbit	Precise orbit determination Real time onboard orbit determination (navigation).	Waveband: Spatial resolution: Swath width: Accuracy: Orbit error ~1 cm
DORIS-NG Doppler Orbitography and Radio-positioning Integrated by Satellite-NG CNES	CryoSat-2, Envisat, Jason-1, Jason-2 (aka OSTM)	Operational	Precision orbit	Precise orbit determination Real time onboard orbit determination (navigation).	Waveband: Spatial resolution: Swath width: Accuracy: Orbit error ~1 cm
DPR Dual-frequency Precipitation Radar JAXA (NASA)	GPM Core	Being developed	Cloud profile and rain radars	Measures precipitation rate classified by rain and snow, in latitudes up to 65°.	Waveband: Microwave: 3.6 GHz (Ku-band) 35.5 GHz (Ka-band) Spatial resolution: Range resolution: 4–5 km Horizontal Swath width: 245 km (Ku-band) 100 km (Ka-band) Accuracy: rainfall rate 0.2 mm/h
DRT-S&R ISRO	INSAT-3A, Kalpana	Operational	Communications	Relay of search and rescue information.	Waveband: Spatial resolution: Swath width: Accuracy:
ECHO-V Roscosmos	Kanopus-Vulkan	TBD	Space environment		Waveband: Ee 3–3 MeV, Ee 30–100 MeV Spatial resolution: Swath width: Accuracy:
EFI Electric Field Instrument ESA (CSA)	Swarm	Being developed	Gravity and space environment	Suprathermal ion imager and Langmuir probe to measure ion temp, electron temp, ion density, electron density, spacecraft potential and ion incident angle.	Waveband: N/A Spatial resolution: 0.3 mV/m Swath width: N/A Accuracy: <3 mV/m
EGG 3-Axis Electrostatic Gravity Gradiometer ESA	GOCE	Being developed	Gravity and precision orbit	The main objective of EGG is to measure the 3 components of the gravity-gradient tensor (i.e. gradiometer data).	Waveband: Spatial resolution: Swath width: Accuracy:
Envisat Comms Communications package on Envisat ESA	Envisat	Operational	Communications	Communication package onboard Envisat series satellites.	Waveband: Spatial resolution: Swath width: Accuracy:
ERM Earth Radiation Measurement NRSCC	FY-3A, FY-3B	Operational	Earth radiation budget radiometers	Measures Earth radiation gains and losses on regional, zonal and global scales.	Waveband: 0.2–3.8 μm, 0.2–50 μm Spatial resolution: 25 km Swath width: 2200 km Accuracy: DLR/DSR 10 W/m2 net solar 3 W/m2 OLR 5 W/m2
ERS Comms Communication package for ERS ESA	ERS-2	Operational	Communications	Communication package onboard ERS series satellites.	Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ETM+ Enhanced Thematic Mapper Plus USGS	Landsat-7	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications.	Waveband: VIS–TIR: 8 channels: 0.45–12.5 µm Panchromatic channel: VIS 0.5–0.9 µm Spatial resolution: Pan: 15 m Vis–SWIR: 30 m TIR: 60 m Swath width: 185 km Accuracy: 50–250 m systematically corrected geodetic accuracy
EXIS Extreme Ultraviolet and X-ray Irradiance Sensors NOAA	GOES-R, GOES-S	Prototype	Other	Monitors the whole-Sun X-ray irradiance in two bands and the whole-Sun EUV irradiance in five bands.	Waveband: Spatial resolution: N/A Swath width: Accuracy:
FCI Flexible Combined Imager EUMETSAT (ESA)	MTG-I1, MTG-I2, MTG-I3, MTG-I4	Prototype	Imaging multi-spectral radiometers (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature.	Waveband: VIS: 0.56–0.71 µm, 0.5–0.9 µm (broadband) NIR: 0.74–0.88 µm SWIR 1.5–1.78 µm SWIR: 3.48–4.36 µm TIR: 5.35–7.15 µm, 6.85–7.85 µm, 8.3–9.1 µm, 9.38–9.94 µm, 9.8–11.8 µm, 11–13 µm, 12.4–14.46 µm Spatial resolution: 1 km (at SSP) for one broadband visible channel HRV 5 km (at SSP) for all other channels Swath width: Full Earth disc Accuracy: Cloud cover: 10% Cloud top height: 1 km Cloud top temparature: 1 K Cloud type: 8 classes Surface temparature: 0.7–2.0 K Specific humidity profile: 10% Wind profile (horizontal component): 2–10 m/s Long wave Earth surface radiation: 5 W/m^2
FJP Future Jason Payload CNES	Jason-3, Jason-CS	Proposed	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data.	Waveband: Microwave Spatial resolution: Swath width: Accuracy:
Geoton-L1 Roscosmos (Roshydromet)	Resurs DK 1	Operational	High resolution optical imagers	Multi-spectral images of land surfaces.	Waveband: 0.58–0.8 µm, 0.5–0.6 µm, 0.6–0.7 µm, 0.7–0.8 µm Spatial resolution: 1–3 m Swath width: 30 km within swath band 400 km Accuracy:
GERB Geostationary Earth Radiation Budget EUMETSAT (ESA)	Meteosat-10, Meteosat-11, Meteosat-8, Meteosat-9	Operational	Earth radiation budget radiometer	Measures long and short wave radiation emitted and reflected from the Earth's surface, clouds and top of atmosphere. Full Earth disc, all channels in 5 mins.	Waveband: UV–MWIR: 0.32–40 µm UV–FIR: 0.32–30 µm Spatial resolution: 44.6 km x 39.3 km Swath width: Full Earth disc Accuracy: Emitted radiation: 0.12–1.3 W/m^2 Reflectance: 1%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
GGAK-E Module for Geophysical Measurements Roshydromet (Roscosmos)	Elektro-L N1, Elektro-L N2, Elektro-L N3	Prototype	Space environment and magnetic field	Monitoring and forecasting of solar activity, of radiation and magnetic field in the near-Earth space, monitoring of natural and modified magnetosophere, ionosphere and upper atmosphere.	Waveband: Spatial resolution: Swath width: Accuracy:
GGAK-M Module for Geophysical Measurements (SEM) Roshydromet (Roscosmos)	Meteor-M N1	Prototype	Space environment and magnetic field	Space Environmental Monitoring (SEM).	Waveband: Spatial resolution: Swath width: Accuracy
GID-12T Roscosmos	Kanopus-Vulkan	TBD	Magnetic field and space environment		Waveband: 1200 MHz, 1600 MHz Spatial resolution: Swath width: Accuracy:
GLAS Follow-on Geoscience Laser Altimeter System (Follow-on) NASA	ICESat-II	Proposed	Lidars	Provision of data on ice sheet height/thickness, land altitude, aerosol height distributions, cloud height and boundary layer height.	Waveband: VIS–NIR: Laser emits at 1064 nm (for altimetry) and 532 nm (for atmospheric measurements) Spatial resolution: 66 m spots separated by 170 m Swath width: Accuracy: Aerosol profile: 20% Ice elevation: 20 cm Cloud top height: 75 m Land elevation: 20 cm geoid: 5 m
GLAS Geoscience Laser Altimeter System NASA	ICESat	Operational	Lidars	Provision of data on ice sheet height/thickness, land altitude, aerosol height distributions, cloud height and boundary layer height.	Waveband: VIS–NIR: Laser emits at 1064 nm (for altimetry) and 532 nm (for atmospheric measurements) Spatial resolution: 66 m spots separated by 170 m Swath width: Accuracy: Aerosol profile: 20% Ice elevation: 20 cm Cloud top height: 75 m Land elevation: 20 cm geoid: 5 m
GLM GEO Lightning Mapper NOAA	GOES-R, GOES-S	Being developed	Lightning imager	Detect total lightning flash rate over near full disc.	Waveband: Spatial resolution: 10 km Swath width: Accuracy: 70%
GMI GPM Microwave Imager INPE	GPM-Br	Proposed	Imaging multi-spectral radiometers (passive microwave)	Precipitation estimation.	Waveband: 10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz, 165.5 GHz, 183.31 GHz Spatial resolution: 26 / 15 / 12 / 11 / 6 / 6 / 6 km Swath width: 904 km Accuracy:

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
GMI GPM Microwave Imager NASA	GPM Constellation, GPM Core	Being developed	Imaging multi-spectral radiometers (passive microwave)	Measures rainfall rates over oceans and land, combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce three hour, daily, and monthly total rainfall maps over oceans and land.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 10.65 GHz, 19.4 GHz, 21.3 GHz, 37 GHz and 85.5 GHz Horizontal: 36 km cross-track at 10.65 GHz (required – Primary Spacecraft, goal – Constellation Spacecraft) 10 km along-track and cross-track (goal – Primary Spacecraft) 800 km (Primary Spacecraft) 1300 km (Constellation Spacecraft) NEDT 0.5 K–1.0 K
GOCI Geostationary Ocean Colour Imager KARI (NIES (Japan))	COMS-1, COMS-2	Operational	Ocean colour instruments	Ocean colour information, coastal zone monitoring, land resources monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – NIR: 0.40–0.88 μm (8 channels) 236 m x 360 m 1440 km
GOES Comms Communications package on GOES NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:	
GOLPE GPS Occultation and Passive reflection Experiment NASA (CONAE)	SAC-C	Operational	Atmospheric temperature and humidity sounders and precision orbit	Measurements of atmospheric effects on GPS signals, and precise positioning information to assist gravitational measurements.	Waveband: Spatial resolution: Swath width: Accuracy	
GOME Global Ozone Monitoring Experiment ESA	ERS-2	Operational	Atmospheric chemistry	Measures concentration of O_3, NO, NO_2, BrO, H_2O, O_2/O_4, plus aerosols and polar stratospheric clouds, and other gases in special conditions.	Waveband: Spatial resolution: Swath width: Accuracy:	UV–NIR: 0.24–0.79 μm (resolution 0.2–0.4 nm) Vertical: 5 km (for O_3) Horizontal: 40 x 40 km to 40 x 320 km 120–960 km
GOME-2 Global Ozone Monitoring Experiment - 2 EUMETSAT (ESA)	MetOp-A, MetOp-B, MetOp-C	Operational	Atmospheric chemistry	Measurement of total column amounts and stratospheric and tropospheric profiles of ozone. Also amounts of H_2O, NO_2, OClO, BrO, SO_2 and HCHO.	Waveband: Spatial resolution: Swath width: Accuracy:	UV–NIR: 0.24–0.79 μm (resolution 0.2–0.4 nm) Horizontal: 40 x 40 km (960 km swath) to 40 x 5 km (for polarization monitoring) 120–960 km Cloud top height: 1 km (rms) Outgoing short wave radiation and solar irradiance: 5 W/m² Trace gas profile: 10–20% Specific humidity profile: 10–50 g/kg
GOMOS Global Ozone Monitoring by Occultation of Stars ESA	Envisat	Operational	Atmospheric chemistry	Stratospheric profiles of temparature and of ozone, NO_2, H_2O, aerosols and other trace species.	Waveband: Spatial resolution: Swath width: Accuracy:	Spectrometers: UV-Vis: 248–371 nm, 387–693 nm NIR: 750–776 nm, 915–956 nm Photometers: 644–705 nm & 466–528 nm 1.7 km vertical Not applicable

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
GOX Global Positioning Satellite Occultation Experiment (GOX) NASA, NSPO (JPL)	COSMIC-1/ FORMOSAT-3 FM1, COSMIC-2/ FORMOSAT-3 FM2, COSMIC-3/ FORMOSAT-3 FM3, COSMIC-4/ FORMOSAT-3 FM4, COSMIC-5/ FORM COSMIC-6/ FORMOSAT-3 FM6	Operational	Atmospheric temperature and humidity sounders	Each instrument equipped with 4 GPS antennas to receive the L1 and L2 radio wave signals transmitted from the 24 US GPS satellites. Based on the signal transmission delay caused by the electric density, temperature, pressure, and water content in the ionosphere and atmosphere, information about ionosphere and atmosphere can be derived.	Waveband: L1/L2 Spatial resolution: Vertical: 0.3–1.5 m Horizontal: 300–600 km Swath width: Accuracy:
GPS (ESA) GPS Receiver ESA	GOCE	Being developed	Precision orbit	Satellite positioning.	Waveband: Spatial resolution: Swath width: Accuracy:
GPS Receiver (Swarm) GPSR (Swarm) ESA	Swarm	Being developed	Precision orbit		Waveband: Spatial resolution: L1 C/A code range error better than 0.5 m RMS; L1/L2 P-code range error better than 0.25 m RMS; L1 carrier phase error better than 5 mm Swath width: Accuracy:
GPS ROS GPS Radio Occultation Sensor ISRO	Megha-Tropiques	Being developed	Precision orbit	Enables measurement of water vapour and temperature profiles in the tropics.	Waveband: Spatial resolution: Swath width: Accuracy:
GPSP Global Positioning System Payload NASA	Jason-2 (aka OSTM)	Operational	Precision orbit	Precision orbit determination.	Waveband: Spatial resolution: Swath width: Accuracy:
GRAS GNSS Receiver for Atmospheric Sounding EUMETSAT (ESA)	MetOp-A, MetOp-B, MetOp-C	Operational	Atmospheric temperature, humidity sounders and precision orbit	GNSS receiver for atmospheric temperature and humidty profile sounding.	Waveband: Spatial resolution: Vertical: 150 m (trophosphere) 1.5 km (stratosphere) Horizontal: 100 km approx (troposphere) 300 km approx (stratosphere) Swath width: Altitude range of 5–30 km Accuracy: Temperature sounding to 1 K rms
HAIRS (aka KBR) High Accuracy Inter-satellite Ranging System (aka K-band Ranging System) NASA (DLR)	GRACE A, GRACE B	Operational	Gravity instruments	Inter-satellilte ranging system estimestes for global models of the mean and time variable Earth gravity field.	Waveband: Microwave: 24 GHz and 32 GHz Spatial resolution: 400 km horizontal, N/A vertical Swath width: N/A Accuracy: 1 cm equivalent water

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
High Resolution Panchromatic Camera CONAE	SARE-1	TBD	High resolution optical imagers		Waveband: Spatial resolution: Swath width: Accuracy:	
HiRDLS High Resolution Dynamics Limb Sounder NASA (BNSC)	Aura	Operational	Atmospheric chemistry	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NO_x, N_2O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops.	Waveband: Spatial resolution: Swath width: Accuracy:	TIR: 6.12–17.76 µm (21 channels) Vertical: 1 km Horizontal: 10 km Trace gas: 10% Temparature: 1K Ozone: 10%
HiRI High Resolution Imager CNES	Pleiades 1, Pleiades 2	Being developed	High resolution optical imagers	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence.	Waveband: Spatial resolution: Swath width: Accuracy:	4 bands + PAN: Near IR (0.77–0.91 µm) Red (0.61–0.71 µm) Green (0.50–0.60 µm) Blue (0.44–0.54 µm) Pan (0.47–0.84 µm) 0.70 m 20 km swath at nadir Agile platform giving ±50° off-track
HIRS/3 High Resolution Infrared Sounder/3 NOAA	NOAA-15, NOAA-16, NOAA-17	Operational	Atmospheric temperature and humidity sounders	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–TIR: 0.69–14.95 µm (20 channels) 20.3 km 2240 km
HIRS/4 High Resolution Infrared Sounder/4 NOAA	MetOp-A, MetOp-B, MetOp-C, NOAA-18, NOAA-N'	Operational	Atmospheric temperature and humidity sounders	Atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures. Same as HIRS/3, with 10 km IFOV.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – TIR: 0.69–14.95 µm (20 channels) 20.3 km 2240 km
HRG CNES	SPOT-5	Operational	High resolution optical imagers	High resolution multi-spectral mapper. 2 HRG instruments on this mission can be processed to produce simulated imagery of 2.5 m. Images are 60 km x 60 km in size.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: B1: 0.50–0.59 µm B2: 0.61–0.68 µm NIR: B3: 0.79–0.89 µm SWIR: 1.50–1.75 µm Panchromatic: 0.49–0.69 µm Panchromatic: 2, 5 m Multi-spectral: 10 m 60 km (1 instrument) 117 km (2 instruments) Same as SPOT 4 with off-track steering capability (±27°)

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
HRMS High Resolution Multi-spectral Scanner CONAE	SAC-F	TBD	High resolution optical imagers	High resolution multi-spectral mapper. 2 HRG instruments on this mission can be processed to produce simulated imagery of 2.5 m. Images are 60 x 60 km in size.	Waveband: VIS: B1: 0.50–0.59 μm B2: 0.61–0.68 μm NIR: B3: 0.79–0.89 μm SWIR: 1.50–1.75 μm Panchromatic: 0.49–0.69 μm Spatial resolution: Panchromatic: 5 m Multi-spectral: 10 m Swath width: 60 km (1 instrument) 117 km (2 instruments) Same as SPOT 4 with off-track steering capability (±27°) Accuracy:
HRMX-TIR High Resolution Multi-Spectral TIR ISRO	GISAT	Proposed	Imaging multi-spectral radiometers (vis/IR)	Natural resources management purpose.	Waveband: 3 bands: Band 1: 8.2–9.2 μm Band 2: 10.3–11.3 μm Band 3: 11.5–12.5 μm Spatial resolution: 1.5 km Swath width: Accuracy:
HRMX-VNIR High Resolution Multi-Spectral VNIR ISRO	GISAT	Proposed	Imaging multi-spectral radiometers (vis/IR)	Natural resources management and disaster monitoring purpose.	Waveband: 4 bands: Band 1: 0.45–0.52 μm Band 2: 0.52–0.59 μm Band 3: 0.62–0.68 μm Band 4: 0.77–0.86 μm Spatial resolution: 50 m Swath width: Accuracy:
HRS High Resolution Stereoscopy CNES	SPOT-5	Operational	High resolution optical imagers	High resolution stereo instrument.	Waveband: Panchromatic: VIS 0.49–0.69 μm Spatial resolution: Panchromatic: 10 m Altitude: 15 m Swath width: 120 km Accuracy:
HRTC High Resolution Panchromatic Camera CONAE	SAC-C	Operational	High resolution optical imagers	High resolution eath imagery to complement MMRS on the same mission.	Waveband: VIS-NIR: 400–900 nm Spatial resolution: 35 m Swath width: 90 km Accuracy:
HRV High Resolution Visible CNES	SPOT-2	Operational	High resolution optical imagers	2 HRV instruments on this mission provide 60 km x 60 km images for a range of land and coastal applications.	Waveband: VIS: B1: 0.5–0.59 μm B2: 0.61–0.68 μm NIR: B3:0.79–0.89 μm Panchromatic: VIS 0.51–0.73 μm Spatial resolution: 10 m (panchromatic) or 20 m Swath width: 117 km (i.e. 60 km + 60 km with 3 km overlap) Steerable up to ±27° off-track Accuracy:
HRVIR High Resolution Visible and Infrared CNES (SNSB)	SPOT-4	Operational	High resolution optical imagers	2 HRVIR instruments on this mission provide 60 km x 60 km images for a range of land and coastal applications.	Waveband: VIS: B1: 0.50–0.59 μm B2: 0.61–0.68 μm NIR: 0.79–0.89 μm SWIR: 1.58–1.75 μm Panchromatic: (B2) 0.61–0.68 μm Spatial resolution: 10 m (0.64 μm) or 20 m Swath width: 117 km (i.e. 60 km + 60 km with 3 km overlap) Steerable up to ±27° off-track. Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
HSB Humidity Sounder/Brazil INPE (NASA)	Aqua	Operational	Atmospheric temperature and humidity sounders	Humidity soundings for climatological and atmospheric dynamics applications.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 5 discreet channels in the range of 150–183 MHz 13.5 km 1650 km Temperature: 1.0–1.2 K coverage of land and ocean surfaces Humidity: 20%
HSC High Sensitivity Camera CONAE	SAC-D	Being developed	Lightning imager	High Sensitivity Camera (HSC) measures top of atmosphere radiance in the VIS & NIR spectral range measured by a high sensitivity sensor detects: urban lights, electric storms, polar regions, snow cover, forest fires.	Waveband: Spatial resolution: Swath width: Accuracy:	PAN (VIR–NIR): 450–900 nm 200–300 m Min 700 km
HSI (HJ-1A) Hyper Spectrum Imager CAST	HJ-1A	Being developed	Imaging multi-spectral radiometers (vis/IR)	Hyperspectral measurements for environment and disaster management operations.	Waveband: Spatial resolution: Swath width: Accuracy:	0.45–0.95 µm 100 m 50 km
HSI Hyperspectral Imager DLR	EnMAP	Approved	Imaging multi-spectral radiometers (vis/IR)	Detailed monitoring and characterization of rock and soil targets, vegitation, inland and coastal waters on a global scale.	Waveband: Spatial resolution: Swath width: Accuracy:	420–2150 nm GSD 30 m 30 km 30 m (1 Pixel)
HSMS High Swath Multi-spectral Scanner CONAE	SAC-F	TBD	Imaging multi-spectral radiometers (vis/IR)	Detect urban lights, electric storms, polar regions, snow cover, forest fires.	Waveband: Spatial resolution: Swath width: Accuracy:	
HSS Hyper-spectral Scanner CONAE	SAC-F	TBD	Imaging multi-spectral radiometers (vis/IR)		Waveband: Spatial resolution: Swath width: Accuracy:	
HSTC High Sensitivity Technological Camera CONAE	SAC-C	Operational	Lightning imager	Monitors forest fires, electrical storms and geophysical studies of aurora borealis.	Waveband: Spatial resolution: Swath width: Accuracy:	PAN: VIS – NIR: 450–850 nm 300 m 700 km
HYC HYperspectral Camera ASI	PRISMA	Approved	Imaging multi-spectral radiometers (vis/IR)	Pancromatic and Hyperspectral data for complex land ecosystem studies.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–NIR: 400–900 nm, 400–1000 nm SWIR: 900–2500 nm Spectral resolution 10 nm for 220 bands 30 m 30 km 5%
Hyperion Hyperspectral Imager NASA	NMP EO-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Hyperspectral imaging of land surfaces.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–NIR: 400–1000 nm NIR–SWIR: 900–2500 nm Spectral resolution 10 nm for 220 bands 30 m 7.5 km SNR at 10% refl target: VIS: 10–40 SWIR: 10–20

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
HySI (IMS-1) Hyperspectral Imager (IMS-1) ISRO	IMS-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Ocean and atmosphere study of Earth surface.	Waveband: 64 bands of 8 nm seperation between 400–950 nm spectral range Spatial resolution: 505.6 m Swath width: 125.5 km Accuracy:
HySI (TES-HYS) Hyperspectral Imager (TES-HYS) ISRO	TES-HYS	Being developed	Imaging multi-spectral radiometers (vis/IR)	Ocean and atmosphere study of Earth surface.	Waveband: 200 channels of 5 nanometer width Spatial resolution: 15 m Swath width: 30 km Accuracy:
HyS-SWIR Hyperspectral SWIR ISRO	GISAT	Proposed	Imaging multi-spectral radiometers (vis/IR)	Natural resources management purpose.	Waveband: 150 bands in range 1.0 µm to 2.5 µm Spatial resolution: 192 m at nadir Swath width: Accuracy:
HyS-VNIR Hyperspectral VNIR ISRO	GISAT	Proposed	Imaging multi-spectral radiometers (vis/IR)	Natural resources management purpose.	Waveband: 60 bands in range 0.4 µm to 0.87 µm Spatial resolution: 320 m at nadir Swath width: Accuracy:
IAP Instrument for plasma analysis CNES	DEMETER	Operational	Space environment	Density, temperatures, speeds of major ions.	Waveband: Spatial resolution: Swath width: Accuracy: Ion density: +5% Temperature: +5% Speed: +5%
IASI Infrared Atmospheric Sounding Interferometer CNES (EUMETSAT)	MetOp-A, MetOp-B, MetOp-C	Operational	Atmospheric temperature and humidity sounders and atmospheric chemistry	Measures tropospheric moisture and temperature, column integrated contents of ozone, carbon monoxide, methane, dinitrogen oxide and other minor gases which affect tropospheric chemistry. Also measures sea surface and land temperature.	Waveband: MWIR-TIR: 3.4–15.5 µm with gaps at 5 µm and 9 µm Spatial resolution: Vertical: 1–30 km Horizontal: 25 km Swath width: 2052 km Accuracy: Temperature: 0.5–2 K Specific humidity: 0.1–0.3 g/kg Ozone, trace gas profile: 10%
ICARE Influence of Space Radiation on Advanced Components CNES (CONAE)	SAC-C, SAC-D	Operational	Space environment	Improvement of risk estimation models on latest generation of integrated circuits technology.	Waveband: Spatial resolution: Swath width: Accuracy:
ICE Instrument for Electric Field CNES	DEMETER	Operational	Space environment	Electric field.	Waveband: DC to 3 MHz Spatial resolution: Swath width: Accuracy: DC field +3 mV/m
IDP Instrument For Plasma Detection CNES	DEMETER	Operational	Space environment	Energy spectrum of electrons.	Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
IIR Imaging infrared radiometer CNES	CALIPSO	Operational	Imaging multi-spectral radiometers (vis/IR)	Radiometer optimized for combined IIR/lidar retrievals of cirrus particle size.	Waveband: Spatial resolution: Swath width: Accuracy:	TIR: 8.7 μm, 10.5 μm, 12.0 μm (08.μm resolution) 1 km 64 km 1 K
IKFS-2 Fourier spectrometer Roshydromet (Roscosmos)	Meteor-M N2	Prototype	Atmospheric temperature and humidity sounders	Atmospheric temperature/humidity profiles, data on cloud parameters, water vapour and ozone column amounts, water and surface temperatures.	Waveband: Spatial resolution: Swath width: Accuracy:	5–15 μm more then 2000 spectral channels 35 km 1000/2000 km 0.5 K
Imager (INSAT) Very High Resolution Radiometer ISRO	INSAT-3D	Being developed	Imaging multi-spectral radiometers (vis/IR)	Cloud cover, severe storm warnings/monitoring day and night (type, amount, storm features), atmospheric radiance winds, atmospheric stability rainfall.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.55–0.75 μm SWIR: 1.55–1.7 μm MWIR: 3.80–4.00 μm, 6.50–7.00 μm TIR: 10.2–11.3 μm, 11.5–12.5 μm 1 x 1 km (VIS and SWIR) 4 x 4 km (MWIR, TIR) 8 x 8 km (in 6.50–7.00 μm) Full Earth disc and space around, Normal Frame (50° N to 40° S and full E–W coverage) Program Frame (Programmable, E–W Full coverage)
Imager NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, atmospheric radiance, winds, atmospheric stability, rainfall estimates. Used to provide severe storm warnings/ monitoring day and night (type, amount, storm features).	Waveband: Spatial resolution: Swath width: Accuracy:	GOES 8–12 N, O, P: VIS: 1 channel (8 detectors) IR: 4 channels: 3.9 μm, 6.7 μm, 10.7 μm, 12 μm GOES 12–Q: VIS: 1 channel (8 detectors) IR: 4 channels: 3.9 μm, 6.7 μm, 10.7 μm, 13.3 μm 1 km in visible 4 km in IR (8 km for 13.3 μm band (water vapour)) Full Earth disc
IMAGER/MTSAT-2 Imager/MTSAT JMA	MTSAT-2	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temparature and Earth radiation.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–SWIR: 0.55–0.90 μm MWIR–TIR: 3.5–4 μm, 6.5–7 μm, 10.5–11.3 μm, 11.5–12.5 μm Visible: 1 km TIR: 4 km Full Earth disc every hour
IMSC Instrument Search Coil Magnetometer CNES	DEMETER	Operational	Magnetic field	Magnetic field.	Waveband: Spatial resolution: Swath width: Accuracy:	10 Hz–17.4 kHz
IMWAS Improved MicroWave Atmospheric Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Atmospheric temperature and humidity sounders	Atmospheric sounding measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 19.35–89.0 GHz (8 channels)

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
INES Italian Navigation Experiment ASI (CONAE)	SAC-C	Operational	Precision orbit	Composed of GPS Tensor and GNSS Lagrange Receiver to perform navigation experiment on precise orbit determination.	Waveband: Spatial resolution: Swath width: Accuracy:	
IR (HJ-1B) Infrared Camera CAST	HJ-1B	Being developed	Imaging multi-spectral radiometers (vis/IR)	Infrared measurements for environment and natural disaster monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	0.75–1.10 μm, 1.55–1.75 μm, 3.50–3.90 μm, 10.5–12.5 μm 300 m (10.5-12.5 m) 150 m (the other bands) 720 km
IRAS InfraRed Atmospheric Sounder NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Atmospheric temperature and humidity sounders	Atmospheric sounding for weather forecasting.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-TIR: 0.65-14.95 μm (26 channels) 14 km
IR-MSS Infrared Multi-spectral Scanner CAST (INPE)	CBERS-2, CBERS-2B	Operational	High resolution optical imagers	Used for fire detection, fire extent and temperature measurement.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-NIR: 0.5-1.1 μm NIR-SWIR: 1.55-1.75 μm, 2.08-2.35 μm TIR: 10.4-12.5 μm Visible, NIR, SWIR: 78 m TIR: 156 m 120 km
IRS CAST (INPE)	CBERS-3, CBERS-4	Being developed	High resolution optical imagers	Used for fire detection, fire extent and temperature measurement.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-NIR: 0.5-1.1 μm NIR-SWIR: 1.55-1.75 μm, 2.08-2.35 μm TIR: 10.4-12.5 μm Visible, NIR, SWIR: 78 m TIR: 156 m 120 km
IRS Infrared Sounder EUMETSAT (ESA)	MTG S1/ Sentinel-4 A, MTG S2/ Sentinel-4 B, post-EPS/ Sentinel-5	Being developed	Atmospheric temperature and humidity sounders	Measurements of vertically resolved clear sky atmospheric motion vectors, temperature and water vapour profiles.	Waveband: Spatial resolution: Swath width: Accuracy:	LWIR: 700–1210 cm^{-1} MWIR: 1600–2175 cm^{-1} Horizontal: 4 km at SSP Vertical: 1 km Full Earth disc clear sky AMVs: 2 m/s temperature profile: 1 K water vapour profile: 5%
ISL Langmuir probes CNES	DEMETER	Operational	Other	Density of the plasma and electron temperature.	Waveband: Spatial resolution: Swath width: Accuracy:	Relative ion and electron density <5% Absolute temperature <5% Potential 10 mV Ion direction +15°
IST Italian Star Tracker ASI (CONAE)	SAC-C	Operational	Precision orbit	Test of a fully autonomous system for attitude and orbit determination using a star tracker.	Waveband: Spatial resolution: Swath width: Accuracy:	

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
IVISSR (FY-2) Improved Multi-spectral Visible and Infrared Spin Radiometer (5 channels) NRSCC (CAST)	FY-2C, FY-2D, FY-2E, FY-2F	Operational	Imaging multi-spectral radiometers (vis/IR)	Meteorological.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–TIR: 0.5–12.5 μm (5 channels) 5 km Full Earth disc
JAMI/MTSAT-1R Japanese Advanced Meteorological Imager JMA	MTSAT-1R	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temparature and Earth radiation.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–SWIR: 0.55–0.90 μm MWIR–TIR: 3.5–4 μm, 6.5–7 μm, 10.5–11.3 μm, 11.5–12.5 μm Visible: 1 km TIR: 4 km Full Earth disc every hour
JMR Jason Microwave Radiometer NASA	Jason-1, Jason-2 (aka OSTM)	Operational	Imaging multi-spectral radiometers (passive microwave)	Altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 18.7 GHz, 23.8 GHz, 34 GHz 41.6 km at 18.7 GHz 36.1 km at 23.8 GHz 22.9 km at 34 GHz 120° cone centred on nadir Total water vapour: 0.2g/cm² Brightness temperature: 0.15 K
KMSS Multi-spectral Imager (VIS) Roshydromet (Roscosmos)	Meteor-M N1, Meteor-M N2	Being developed	High resolution optical imagers	Multi-spectral images of land and sea surfaces and ice cover.	Waveband: Spatial resolution: Swath width: Accuracy:	0.4–0.9 μm, 6 channels 60–100 m 900 km
Lagrange LABEN GNSS Receiver for Advanced Navigation, Geodesy and Experiments ASI	SAC-D	Being developed	Atmospheric temperature and humidity sounders	GPS Receiver including specialised version equipped with limb sounding antenna and dedicated signal tracking capability for meteorological, climate and space weather applications.	Waveband: Spatial resolution: Swath width: Accuracy:	
Landsat Comms Communications package for Landsat USGS	Landsat-5, Landsat-7	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:	
Laser Reflectors (ESA) Laser Reflectors ESA	CryoSat-2, GOCE	Being developed	Precision orbit	Measures distance between the satellite and the laser tracking stations.	Waveband: Spatial resolution: Swath width: Accuracy:	
Laser Reflectors CNES	STARLETTE, STELLA	Operational	Precision orbit	Measures distance between the satellite and the laser tracking stations.	Waveband: Spatial resolution: Swath width: Accuracy:	
L-band Radiometer Microwave radiometer NASA	SAC-D	Being developed	Imaging multi-spectral radiometers (passive microwave)	L-band passive microwave radiometer measures brightness temperature of ocean to retrieve salinity.	Waveband: Spatial resolution: Swath width: Accuracy:	L-band (1.4 GHz) 100 km 300 km 0.2 psu

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
L-band Scatterometer (Aquarius) NASA (CONAE)	SAC-D	Being developed	Scatterometers	L-band scatterometer to provide roughness corection to brightness temperature.	Waveband: Spatial resolution: Swath width: Accuracy:	L-band (1.2 GHz) 100 km 300 km 0.2 psu
LCCRA Laser Corner Cube Reflector Assembly ASI	LARES	Operational	Precision orbit	Accuracy measuments on Lense-Thirring effect and baseline tracking data for precision geodesy. Also for calibration of radar altimeter bias.	Waveband: Spatial resolution: Swath width: Accuracy:	2 cm overhead ranging
LEISA AC LEISA Atmospheric Corrector NASA	NMP EO-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Corrects high spatial resolution multi-spectral imager data for atmospheric effects.	Waveband: Spatial resolution: Swath width: Accuracy:	256 bands NIR-SWIR: 0.89-1.58 μm 250 m 185 km
LI Lightning Imager EUMETSAT (ESA)	MTG-I1, MTG-I2, MTG-I3, MTG-I4	Being developed	Lightning imager	Real time lightning detection (cloud-to-cloud and cloud-to-ground strokes, with no discrimination between the two), lightning location.	Waveband: Spatial resolution: Swath width: Accuracy:	NIR neutral oxygen ligthning emission features at 777.4 nm 2 km at SSP <10 km at 45° N 80% of visible earth disc, all EUMETSAT member states Lightning intensity: 50/10% hit rate/false alarm rate Lightning location: 50/10% HR/FAR (for isolated events 90% HR)
LIS Lightning Imager Sensor INPE	GPM-Br	Proposed	Lightning imager	Atmospheric electrical discharge imager.	Waveband: Spatial resolution: Swath width: Accuracy:	0.7774 μm 3-6 km 600 km
LIS Lightning Imager Sensor NASA	TRMM	Operational	Lightning imager	Global distribution and variability of total lightning. Data can be related to rainfall to study hydrological cycle.	Waveband: Spatial resolution: Swath width: Accuracy:	NIR: 0.7774 μm 4 km FOV: 80 x 80° 90% day and night detection probability
LISS-III (IRS) Linear Imaging Self Scanner - III (IRS) ISRO	IRS-1D	Operational	High resolution optical imagers	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, land use and land cover change.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: Band 2: 0.52-0.59 μm Band 3: 0.62-0.68 μm NIR: Band 4: 0.77-0.86 μm SWIR: Band 5: 1.55-1.75 μm Bands 2, 3, 4: 23.5 m Band 5: 70.5 m 141 km
LISS-III (RESOURCESAT) Linear Imaging Self Scanner - III (RESOURCESAT) ISRO	RESOURCESAT-1, RESOURCESAT-2	Operational	High resolution optical imagers	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, land use and land cover change.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: Band 2: 0.52-0.59 μm Band 3: 0.62-0.68 μm NIR: Band 4: 0.77-0.86 μm SWIR: Band 5: 1.55-1.75 μm 23.5 m 141 km
LISS-IV Linear Imaging Self Scanner - IV ISRO	RESOURCESAT-1, RESOURCESAT-2	Operational	High resolution optical imagers	Vegetation monitoring, improved crop discrimination, crop yield, disaster monitoring and rapid assessment of natural resources.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.52-0.59 μm, 0.62-0.68 μm NIR: 0.77-0.86 μm 5.8 m 70 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
LM Lightning Mapper NRSCC	FY-4 0/A, FY-4 0/B, FY-4 0/C, FY-4 0/D, FY-4 0/E	Approved	Lightning imager	Lightning mapping for locating thunder storms in flooding season, CCD camear operating 0.77 μm to count flashes and intensity.	Waveband: 0.77 μm Spatial resolution: 10 km Swath width: Full Earth disc Accuracy:
LRA (LAGEOS) Laser Retroreflector Array ASI	LAGEOS-1, LAGEOS-2	Operational	Precision orbit	Baseline tracking data for precision geodesy. Also for calibration of radar altimeter bias. Several types used on various missions. (ASI involved in LAGEOS 2 development).	Waveband: Spatial resolution: Swath width: Accuracy: 2 cm overhead ranging
LRA Laser Retroreflector Array NASA (ASI)	Jason-1, Jason-2 (aka OSTM)	Operational	Precision orbit	Baseline tracking data for precision orbit determination and/or geodesy. Also for calibration of radar altimeter bias. Several types used on various missions. (ASI involved in LAGEOS 2 development).	Waveband: Spatial resolution: Swath width: Accuracy: 2 cm overhead ranging
LRIT Low-Rate Information Transmission NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P, NOAA-N'	Operational	Communications	Follow-on from the Weather Facsimile (WEFAX) Processing System.	Waveband: Spatial resolution: Swath width: Accuracy:
MADRAS Microwave Analysis and Detection of Rain and Atmospheric Structures ISRO (CNES)	Megha-Tropiques	Being developed	Imaging multi-spectral radiometers (passive microwave)	To estimate rainfall, atmospheric water parameters and ocean surface winds in the equatorial belt.	Waveband: 18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz, 157 GHz Spatial resolution: 40 km Swath width: 1700 km Accuracy:
MAESTRO Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation CSA	SCISAT-1	Operational	Atmospheric chemistry	Chemical processes involved in the depletion of the ozone layer.	Waveband: UV-NIR: 0.285–1.03 μm (1–2 nm spectral resolution) Spatial resolution: Approx 1–2 km vertical Swath width: Accuracy:
MAGIS Measurement of Atmospheric Gases using Infrared Spectrometer ISRO	ISTAG	Being developed	Atmospheric chemistry	To study the regional/global distribution of carbon monoxide (CO).	Waveband: Spatial resolution: Swath width: Accuracy:
Magnetometer (NOAA) Magnetometer NOAA	GOES-R, GOES-S	Approved	Magnetic field		Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MAPI Multi-Angle Polarisation Imager ISRO	ISTAG	Being developed	Multiple direction/polarisation radiometers	Measurement of column integrated aerosol spectral optical depth.	Waveband: Spatial resolution: Swath width: Accuracy:
MAVELI Measurements of Aerosols by Viewing Earth's Limb ISRO	ISTAG	Being developed	Atmospheric chemistry	Vertical profiles of aerosols, ozone and water vapour in the free troposphere and stratosphere and cloud top height.	Waveband: Spatial resolution: Swath width: Accuracy: <1.0 K temperature 0.2 g/kg humidity
MBEI Multi-band Earth Imager NSAU	SICH-2	Being developed	High resolution optical imagers	Multi-spectral scanner images of land surface.	Waveband: VIS–NIR: 0.51–0.90 µm VIS: 0.51–0.59 µm, 0.61–0.68 µm; NIR: 0.80–0.89 µm Spatial resolution: 7.8 m Swath width: 46.6 km pointable ±35° from nadir Accuracy: 8 bits
MCP Meteorological Communications Package (MCP) EUMETSAT	MetOp-A, MetOp-B, MetOp-C	Operational	Communications	Meteorological Communications Package (MCP) onboard MetOp series satellites.	Waveband: Spatial resolution: Swath width: Accuracy:
MCSI Multiple Channel Scanning Imager NRSCC	FY-4 O/A, FY-4 O/B, FY-4 O/C, FY-4 O/D, FY-4 O/E	Approved	Imaging multi-spectral radiometers (vis/IR)	Multi-purpose visible/IR imagery and wind derivation.	Waveband: 12 channels from 0.55–13.8 µm Spatial resolution: 1 km VIS 2 km NIR 4 km TIR Swath width: Full Earth disc Accuracy:
MERIS Medium-Resolution Imaging Spectrometer ESA	Envisat	Operational	Imaging multi-spectral radiometers (vis/IR)	Main objective is monitoring marine biophysical and biochemical parameters. Secondary objectives are related to atmospheric properties such as cloud and water vapour and to vegetation conditions on land surfaces.	Waveband: VIS–NIR: 15 bands selectable across range: 0.4–1.05 µm (bandwidth programmable between 0.0025 and 0.03 µm) Spatial resolution: Ocean: 1040 m x 1200 m Land & coast: 260 m x 300 m Swath width: 1150 km global coverage every 3 days Accuracy: Ocean colour bands typical S:N = 1700
MERSI Moderate Resolution Spectral Imager NRSCC	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Imaging multi-spectral radiometers (passive microwave)	Measurement of vegetation indexes and ocean colour.	Waveband: Spatial resolution: 250 m for broadband channels 1 km for narrowband channels Swath width: 2800 km Accuracy:
Meteosat Comms Communications package for Meteosat EUMETSAT	Meteosat-6, Meteosat-7	Operational	Communications	Communication package onboard Meteosat series satellites.	Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MHS Microwave Humidity Sounder EUMETSAT	MetOp-A, MetOp-B, MetOp-C, NOAA-18, NOAA-N'	Operational	Atmospheric temperature and humidity sounders	Atmospheric humidity profiles, cloud cover, cloud liquid, water content, ice boundaries and precipitation data.	Waveband: Microwave: 89 GHz, 166 GHz and 3 channels near 183 GHz Spatial resolution: Vertical: 3–7 km Horizontal: 30–50 km Swath width: 1650 km Accuracy: Cloud water profile: 10 g/m² Specific humidity profile: 10–20%
MI Meteorological Imager NRSCC	COMS-1	Approved	Imaging multi-spectral radiometers (passive microwave)	Continuous monitoring capability for the near-realtime generation of high resolution meteorological products and long-term change analysis of sea surface temperature and cloud coverage.	Waveband: 1: VIS, 0.55–0.80 μm 2: SWIR: 3.50–4.00 μm 3: WV (Water Vapour): 6.50–7.00 μm 4: TIR1 (Thermal Infrared 1): 10.3–11.3 μm 5: TIR2 (Thermal Infrared 2): 11.5–12.5 μm Spatial resolution: VIS: 1 km IR: 4 km Swath width: Full Earth disc Accuracy:
Microwave Radiometer (CONAE) MWR Radiometer (CONAE) CONAE	SAC-D	Being developed	Multiple direction/polarisation radiometers	Precipitation rate, wind speed, sea ice concentration, water vapour, clouds.	Waveband: (K-band) 23.8 GHz V Pol and 36.5 GHz H and V Pol Eight beams per frequency Spatial resolution: < 47 km Swath width: 380 km Accuracy: 1 K
MIPAS Michelson Interferometric Passive Atmosphere Sounder ESA	Envisat	Operational	Atmospheric temperature and humidity sounders and atmospheric chemistry	Data on stratosphere chemistry (global/polar ozone), climate research (trace gases/clouds), transport dynamics, tropospheric chemistry. Primary/secondary species: O_3, NO, NO_2, HNO_3, N_2O_5, $ClONO_2$, CH_4.	Waveband: MWIR–TIR: between 4.15 and 14.6 μm Spatial resolution: Vertical resolution: 3 km Vertical scan range 5–150 km Horizontal: 3 x 30 km Spectral resolution: 0.035 lines/cm Swath width: Accuracy: Radiometric precision: 685–970 cm^{-1}: 1% 2410 cm^{-1}: 3%
MIRAS (SMOS) Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) ESA	SMOS	Being developed	Multiple direction/polarisation radiometers & Imaging multi-spectral radiometers (passive microwave)	Imaging multi-spectral radiometers (passive microwave) and multiple direction/polarisation radiometers.	Waveband: L-band 1.41 GHz Spatial resolution: 33–50 km depending on the position in the swath, resampled to 15 km grid Swath width: Hexagon shape, nominal width 1050 km allowing a 3 day revisit time at the equator Accuracy: 2.6 K absolute accuracy, RMS 1.6–4 K depending on the scene and the position within the swath
MIRAS Multichannel Infrared Atmospheric Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Prototype	Imaging multi-spectral radiometers (passive microwave)		Waveband: Spatial resolution: Swath width: Accuracy:
MIREI Middle IR Earth Imager NSAU	SICH-2	Being developed	High resolution optical imagers	Scanner images of land surface in middle Infrared range.	Waveband: NIR: 1.55–1.7 μm Spatial resolution: 46.0 m Swath width: 55.3 km pointable ±35° from nadir Accuracy: 8 bits

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
MIS Microwave Imager/Sounder NOAA	NPOESS-2, NPOESS-3	Being developed	Imaging multi-spectral radiometers (passive microwave)	Collects microwave radiometry and sounding data. Data types include atmospheric temperature and moisture profiles, clouds, sea surface winds, and all-weather land/water surfaces.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 190 GHz 15–50 km depending on frequency 1700 km Temperature Profiles to 1.6 K Water vapour 20%
MISR Multi-angle Imaging SpectroRadiometer NASA	Terra	Operational	Multiple direction/polarisation radiometers	Measurements of global surface albedo, aerosol and vegetation properties. Also provides multi-angle bidirectional data (1% angle-to-angle accuracy) for cloud cover and reflectances at the surface and aerosol opacities. Global and local modes.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.44 μm, 0.56 μm, 0.67 μm NIR: 0.86 μm 275 m, 550 m or 1.1 km Summation modes available on selected cameras/bands: 1 x 1, 2 x 2, 4 x 4, 1 x 4 1 pixel = 275 m x 275 m 360 km common overlap of all 9 cameras 0.03% hemispherical albedo 10% aerosol opacity 1–2% angle to angle accuracy in bidirectional reflectance
MLS (EOS-Aura) Microwave Limb Sounder (EOS-Aura) NASA	Aura	Operational	Atmospheric temperature and humidity sounders	Measures lower stratospheric temperature and concentration of H_2O, O_3, ClO, HCl, OH, HNO_3, N_2O and SO_2.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 118 GHz, 190 GHz, 240 GHz, 640 GHz and 2.5 THz 3 x 300 km horizontal 1.2 km vertical Limb scan 2.5–62.5 km Limb to limb Temparature: 4 K Ozone: 50%
MMP Magnetic Mapping Payload JPL, DNSC (CONAE)	SAC-C	Operational	Magnetic field	Measurement of the Earth's magnetic field with a vector and a scalar magnetometer.	Waveband: Spatial resolution: Swath width: Accuracy:	
MMRS Multi-spectral Medium Resolution Scanner CONAE	SAC-C	Operational	Imaging multi-spectral radiometers (vis/IR)	Applications related to agriculture, environment, forestry, hydrology, oceanography, mineralogy and geology, desertification, contamination and protection of ecosystems.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–NIR: 480–500 nm, 540–560 nm, 630–690 nm, 795–835 nm SWIR: 1550–1700 nm 175 m 360 km
MOC Multi-spectral Optical Camera CONAE	SAC-E/ SABIA/ma	Approved	Imaging multi-spectral radiometers (vis/IR)	Sea and coastal studies.	Waveband: Spatial resolution: Swath width: Accuracy:	Optical and Thermal Infrared Cameras, up to 15 bands
MODIS MODerate-Resolution Imaging Spectroradiometer NASA	Aqua, Terra	Operational	Imaging multi-spectral radiometers (vis/IR) and ocean colour instruments	Data on biological and physical processes on the surface of the Earth and in the lower atmosphere, and on global dynamics. Surface temperatures of land and ocean, chlorophyll fluorescence, land cover measurements, cloud cover (day and night).	Waveband: Spatial resolution: Swath width: Accuracy:	VIS–TIR: 36 bands in range 0.4–14.4 μm Cloud cover: 250 m (day) and 1000 m (night) Surface temperature: 1000 m 2330 km Long wave radiance: 100 nW/m^2 Short wave radiance: 5% Surface temperature of land: <1 K Surface temperature of ocean: <0.2 K Snow and ice cover: 10%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MOPITT Measurements Of Pollution In The Troposphere CSA (NASA)	Terra	Operational	Atmospheric chemistry	Measurements of CO in the troposphere.	Waveband: SWIR-MWIR: 2.3 μm, 2.4 μm, 4.7 μm Spatial resolution: CO profile: 4 km vertical, 22 x 22 km horizontal; CO, CH_4 column: 22x22 km horizontal Swath width: 616 km Accuracy: Carbon monoxide (4 km layers): 10%
MS (GISTDA) Multi spectral imager GISTDA	THEOS	Approved	Imaging multi-spectral radiometers (vis/IR)	THEOS MS consists of 4 spectral bands (R,G,B, NIR) with resolution 15 m and swath width at 90 km. The applications which are suitable for this instrument such as cartography, land use, land cover change management, agricultural and natural resources management, etc.	Waveband: 0.45-0.52 μm, 0.53-0.60 μm, 0.62-0.69 μm, 0.77-0.90 μm Spatial resolution: 15 m Swath width: 90 km Accuracy:
MSC Multi-Spectral Camera KARI	KOMPSAT-2	Operational	High resolution optical imagers	High resolution imager for land applications of cartography and disaster monitoring.	Waveband: VIS-NIR: 0.50-0.92 μm; VIS: 0.45-0.52 μm, 0.52-0.60 μm, 0.63-0.69 μm; NIR: 0.76-0.90 μm Spatial resolution: Pan: 1 m; VNIR: 4 m Swath width: 15 km Accuracy:
MSG Comms Communications package for MSG EUMETSAT	Meteosat-10, Meteosat-8, Meteosat-9	Operational	Communications	Communication package onboard MSG series satellites.	Waveband: Spatial resolution: Swath width: Accuracy:
MSI (BJ-1) Multi-spectral Imager NRSCC (CAST)	BJ-1	Operational	Imaging multi-spectral radiometers (vis/IR)	To provide multi-spectral analysis of hydrological, oceanographic, land use and meteorological parameters.	Waveband: Green 520-600 nm, Red 630-690 nm, NIR 760-900 nm Spatial resolution: 32 m Swath width: 600 km Accuracy: 800 m
MSI (EarthCARE) Multi Spectral Imager (EarthCARE) ESA	EarthCARE	Approved	Imaging multi-spectral radiometers (vis/IR)	Observation of cloud properties and aerosol (aerosols to be confirmed.	Waveband: VIS - NIR: Band1: VIS, 670 nm; Band2: NIR, 865 nm; Band3: SWIR-1, 1.67 μm; Band4: SWIR-2, 2.21 μm; Thermal Infrared: Band5: 8.8 μm; Band6: 10.8 μm; Band7: 12.0 μm Spatial resolution: 500 x 500 m Swath width: 150 km asymmetrically 35 km to 115 km versus nadir point Accuracy:
MSI (Sentinel-2) Multi-Spectral Instrument (Sentinel-2) ESA (EC)	Sentinel-2 A, Sentinel-2 B, Sentinel-2 C	Being developed	Imaging multi-spectral radiometers (passive microwave)	Monitoring of land surfaces for operational land services: land cover, land use, bio-geophysical products.	Waveband: 13 bands in the VNIR/SWIR Spatial resolution: 10 m for 4 bands in VNIR; 60 m for 3 dedicated atmospheric correction bands; 20 m for remaining bands Swath width: 290 km Accuracy: absolute radiometric accuracy for L1c data 3-5%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
MSI Multi Spectral Imager DLR	RapidEye	Approved	High resolution optical imagers	High resolution images with short observing cycle for commercial and scientific applications.	Waveband: Spatial resolution: Swath width: Accuracy:	4 VIS + 1 NIR band: 440–510 nm, 520–590 nm, 630–685 nm, 690–730 nm, 760–850 nm 6.5 m 78 km 2–3%
MSMR Multifrequency Scanning Microwave Radiometer ISRO	OCEANSAT-1	Operational	Imaging multi-spectral radiometers (passive microwave)	Sea surface temperature, ocean surface winds, cloud liquid water, precipitation over ocean.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 6.6 GHz, 10.6 GHz, 18 GHz, 21 GHz 40 m at 21 GHz to 120 m at 6.6 GHz Wind speed: 75 x 75 km Sea surface temperature: 146 x 150 km 1360 km Sea surface temperature: 1.5K Sea surface wind speed: 1.5 m/s
MSS (Roscosmos) Multi-spectral film-making system Roscosmos (Roshydromet)	Kanopus-V N1	Prototype	High resolution optical imagers	Multi-spectral images of land and sea surfaces and ice cover.	Waveband: Spatial resolution: Swath width: Accuracy:	0.5–0.6 µm, 0.6–0.7 µm, 0.7–0.8 µm, 0.8–0.9 µm 12 m 20 km
MSS Multi-spectral Scanner USGS (NASA)	Landsat-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance. Data mostly used for land applications.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – NIR: 4 bands: 0.5–1.1 µm 80 m 185 km
MSS-BIO Polyzonal scanning system of bioefficiency of sea water areas Roshydromet (Roscosmos)	Meteor-M N3	Being developed	Ocean colour instruments	Multi-spectral images sea surfaces for water areas bioefficiency.	Waveband: Spatial resolution: Swath width: Accuracy:	0.41–0.9 µm 80 m, 300 m 800 km, 3000 km
MSU-200 Multi-spectral high resolution electronic scanner (VIS) Roscosmos (Roshydromet)	Kanopus-V N1	Prototype	High resolution optical imagers	Multi-spectral images of land and sea surfaces and ice cover.	Waveband: Spatial resolution: Swath width: Accuracy:	0.54–0.86 µm 25 m 250 km
MSU-GS Multi-spectral scanning imager-radiometer Roshydromet (Roshydromet)	Elektro-L N1, Elektro-L N2, Elektro-L N3	Prototype	Imaging multi-spectral radiometers (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.5–0.65 µm, 0.65–0.8 µm (broadband) NIR: 0.9 µm MWIR: 3.5–4.01 µm TIR: 5.7–7.0 µm, 8 µm, 8.7 µm, 9.7 µm, 10.2–11.2 µm, 11.2–12.5 µm 1 km for VIS 4 km for IR channels Full Earth disc VIS: 5% IR: 0.35 K

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
MSU-MR Images of clouds, snow, ice and land cover Roshydromet (Roscosmos)	Meteor-M N1, Meteor-M N2	Prototype	Imaging multi-spectral radiometers (vis/IR)	Images of clouds, snow, ice and land cover for derivation of Earth and atmosphere geophysical parameters.	Waveband:	Visible: 0.5–0.7 µm NIR: 0.7–1.1 µm SWIR: 1.6–1.8 µm MWIR: 3.5–4.1 µm TIR: 10.5–11.5 µm, 11.5–12.5 µm
					Spatial resolution:	1 km
					Swath width:	3000 km
					Accuracy:	VIS: 0.5% IR: 0.1 K
MTSAT Comms Communications package for MTSAT JMA	MTSAT-1R, MTSAT-2	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:	
MTSAT DCS Data Collection System for MTSAT JMA	MTSAT-1R, MTSAT-2	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:	
MTVZA Scanning microwave radiometer Roshydromet (Roscosmos)	Meteor-M N1, Meteor-M N2	Operational	Imaging multi-spectral radiometers (passive microwave)	Provision of atmospheric temperature and humidity profiles, detection of precipitation etc.	Waveband:	10.6–183.3 GHz, 26 channels
					Spatial resolution:	12–75 km
					Swath width:	2600 km
					Accuracy:	0.4–2.0 K depending on spectral band
MTVZA-OK Scanning microwave radiometer Roshydromet	Kanopus-Vulkan	Approved	Atmospheric temperature and humidity sounders	Multi-Spectral Scanner Images of Earth Surface.	Waveband:	Microwave: 6.9 (V,H), 10.6 (V,H), 18.7 (V,H), 23.8 (V), 31.5 (V,H), 36.7 (V,H), 42 (V,H), 48 (V,H), 52.3–57.0 (V,H), 91 (V,H), 183.31 GHz VIS: 0.37–0.45 µm, 0.45–0.51 µm, 0.58–0.68 µm, 0.68–0.78 µm IR: 10.4–11.5 µm, 11.5–12.6 µm
					Spatial resolution:	Microwave: 12 x 200 km Visible: 1.1 or 4.0 km IR: 1.1 or 4.0 km
					Swath width:	2000 km
					Accuracy:	
MUX Multi-spectral CCD Camera CAST (INPE)	CBERS-3, CBERS-4	Being developed	Imaging multi-spectral radiometers (vis/IR)	Earth resources, environmental monitoring, land use.	Waveband:	
					Spatial resolution:	20 m
					Swath width: Accuracy:	
MVIRI Meteosat Visible and Infrared Imager EUMETSAT (ESA)	Meteosat-6, Meteosat-7	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, motion, height, upper tropospheric humidity and sea surface temperature.	Waveband:	VIS-NIR 0.5–0.9 µm TIR: 5.7–7.1 µm (water vapour), 10.5–12.5 µm
					Spatial resolution:	Visible: 2.5 km Water vapour: 5 km (after processing) TIR: 5 km
					Swath width:	Full Earth disc in all three channels, every 30 minutes
					Accuracy:	Cloud top height: 0.5 km Cloud top / sea surface temperature: 0.7 K Cloud cover: 15%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
MVIRS Moderate Resolution Visible and Infrared Imaging Spectroradiometer NRSCC (CAST)	FY-3F, FY-3G	Approved	Imaging multi-spectral radiometers (vis/IR)	Measures surface temparature and cloud and ice cover. Used for snow and flood monitoring and surface temperature.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – TIR: 0.47–12.5 µm (20 channels)
MVISR (10 channels) Multi-spectral Visible and Infrared Scan Radiometer (10 channels) NRSCC (CAST)	FY-1D	Operational	Imaging multi-spectral radiometers (vis/IR)	To provide multi-spectral analysis of hydrological, oceanographic, land use and meteorological parameters. Global imager & SST. Ocean colour.	Waveband: Spatial resolution: Swath width: Accuracy:	10 channels: VIS: 0.43–0.48 µm, 0.48–0.53 µm, 0.53–0.58 µm, 0.58–0.68 µm NIR: 0.84–0.89 µm NIR – SWIR: 0.90–0.965 µm, 1.58–1.68 µm, 3.55–3.93 µm TIR: 10.3–11.3 µm, 11.5–12.5 µm 1.1 km 3200 km
MWAS MicroWave Atmospheric Sounder NRSCC (CAST)	FY-3A, FY-3B	Operational	Atmospheric temperature and humidity sounders	Meteorological applications.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 19.35–89.0 GHz (8 channels)
MWHS MicroWave Humidity Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Atmospheric temperature and humidity sounders	Meteorological applications.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 19.35–89.0 GHz (8 channels) 15 km at media 41 x 27 km at outer edge 2700 km 0.1–0.9 km
MWR Microwave Radiometer ESA	Envisat, ERS-2	Operational	Imaging multi-spectral radiometers (passive microwave) and atmospheric temperature and humidity sounders	To provide multi-spectral analysis of hydrological, oceanographic, land use and meteorological parameters. Global imager & SST. Ocean colour.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 23.8 and 36.5 GHz 20 km 20 km Temparature: 2.6 K
MWRI MicroWave Radiation Imager NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Imaging multi-spectral radiometers (passive microwave)	All weather observations of precipitation, cloud features, vegetation, soil moinsture sea ice, etc.	Waveband: Spatial resolution: Swath width: Accuracy:	12 channels, 6 frequencies: 10.65 GHz, 18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz, 150 GHz 7.5 x 12 km at 150 GHz to 51 x 85 km at 10.65 GHz 1400 km
MWTS MicroWave Temperature Sounder NRSCC	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Atmospheric temperature and humidity sounders	Temperature sounding in nearly all weather conditions.	Waveband: Spatial resolution: Swath width: Accuracy:	50.3 GHz, 53.6 GHz, 54.94 GHz, 57.29 GHz 62 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MxT Multi-spectral CCD Camera ISRO	IMS-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Natural resources management.	Waveband: VIS: Band 1: 0.45–0.52 μm Band 2: 0.52–0.59 μm Band 3: 0.62–0.68 μm NIR: Band 4: 0.77–0.86 μm Spatial resolution: 37 m Swath width: 151 km Accuracy:
NigeriaSat Medium and High Resolution NigeriaSat Remote Sensing (Medium and High Resolution) NASRDA	NigeriaSat-2	Approved	High resolution optical imagers	High resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications.	Waveband: NIR: ~0.75 μm – ~1.3 μm VIS: ~0.40 μm – ~0.75 μm Spatial resolution: 2.5 PAN, 5 m multi-spectral (red blue green, NIR), 32 m multi-spectral (red, green, NIR) Swath width: 20 x 20 km , 300 x 300 km Accuracy: 25–35 m
NigeriaSat Medium Resolution NigeriaSat Remote Sensing (medium resolution) NASRDA	NigeriaSat-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Medium resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications.	Waveband: NIR: ~0.75 μm – ~1.3 μm VIS: ~0.40 μm – ~0.75 μm Spatial resolution: 32 m multi-spectral (red, green, NIR) Swath width: 600 x 600 km Accuracy: 150–300 m
NIRST New Infrared Sensor Technology CONAE (CSA)	SAC-D	Being developed	Other	NIRST detects hot spots and High Temperature Events (HTE), caused by biomass fires, volcanic eruptions, and other phenomena in order to measure their temperatures, and their released energy over land (fires & volcanic events). Supplementary measurements of sea surface temperatures (SST) off the coasts of South America and other targets of opportunity with 180 km swath, overlapping the Aquarius inner beams.	Waveband: Infrared push-broom scanner based on 2 linear uncooled microbolometric arrays sensitive to Mid-Wave Infrared (3.8 μm) and Long-Wave Infrared (10.85 and 11.85 μm) spectral bands respectively Spatial resolution: Space resol: 350 m Less burned area detectable: 200 m^2 Swath width: Instant: 182 km Extended: 1000 km Accuracy: 0.5°C
NOAA Comms Communications package for NOAA NOAA	NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-N'	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:
NVK Low-frequency wave complex Roscosmos	Kanopus-Vulkan	TBD	Other		Waveband: 1 Hz – 25 kHz Spatial resolution: Swath width: Accuracy:
OBA Observador Brasileiro da Amazonia INPE	AMAZÔNIA-1	Approved	Imaging multi-spectral radiometers (vis/IR)	Used for fire extent detection and temperature measurement, coastal and vegetation monitoring, land cover and land use mapping.	Waveband: VIS: 0.45–0.50 μm, 0.52–0.57 μm, 0.63–0.69 μm NIR: 0.76–0.90 μm MWIR: 3.4–4.2 μm Spatial resolution: VIS-NIR: 100 m MIR: 300 m Swath width: 2200 km (equatorial belt from latitude 5°N to 15°S) Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
OCM (OCEANSAT-3) Ocean Colour Monitor (OCEANSAT-3) ISRO	OCEANSAT-3	Proposed	Ocean colour instruments	Ocean colour data, estimation of phytoplankton concentration, identification of potential fishing zones, assessment of primary productivity.	Waveband: Spatial resolution: Swath width: Accuracy:	12 channel
OCM Ocean Colour Monitor ISRO	OCEANSAT-1 OCEANSAT-2	Operational	Ocean colour instruments	Ocean colour data, estimation of phytoplankton concentration, identification of potential fishing zones, assessment of primary productivity.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-NIR: 0.40–0.88 µm (8 channels) 236 m x 360 m 1440 km
OLCI Ocean and Land Colour Imager ESA (EC)	Sentinel-3 A, Sentinel-3 B, Sentinel-3 C	Approved	Imaging multi-spectral radiometers (passive microwave)	Marine and land services.	Waveband: Spatial resolution: Swath width: Accuracy:	21 bands in VNIR/SWIR 300 m 1270 km, across-track tilt 12.2° to the West 2% abs 0.1% rel.
OLI Operational Land Imager USGS (NASA)	LDCM	Being developed	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-SWIR: 9 bands: 0.43–2.3 µm Pan: 15 m VIS-SWIR: 30 m 185 km Absolute geodetic accuracy of 65 m Relative geodetic accuracy of 25 m (excluding terrain effects) Geometric accuracy of 12 m or better
OLS Operational Linescan System NOAA (DoD (USA))	DMSP F-14, DMSP F-15, DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Imaging multi-spectral radiometers (vis/IR)	Day and night cloud cover imagery.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-NIR: 0.4–1.1 µm TIR: 10.0–13.4 µm, 0.47–0.95 µm 0.56 km (fine) 5.4 km (stereo products) 3000 km
OMI Ozone Measuring Instrument NIVR (Netherland) (NASA)	Aura	Operational	Atmospheric chemistry	Mapping of ozone columns, key air quality components (NO_2, SO_2, BrO, OClO and aerosols), measurements of cloud pressure and coverage, global distribution and trends in UV-B radiation.	Waveband: Spatial resolution: Swath width: Accuracy:	UV: 270–314 nm & 306–380 nm VIS: 350–500 nm 13 km x 24 km or 36 km x 48 km depending on the product. Also has zoom modes (13 km x 13 km) for example for urban pollution detection 2600 km
OMPS Ozone Mapping and Profiler Suite NOAA	NPOESS-3, NPOESS-4, NPP	Being developed	Atmospheric chemistry	Measures total amount of ozone in the atmosphere and the ozone concentration variation with altitude.	Waveband: Spatial resolution: Swath width: Accuracy:	Nadir Mapper: UV 0.3–0.38 µm Nadir profiler: UV 0.25–0.31 µm Limb soundings: UV-TIR 0.29–10 µm Mapper: 50 km Profiler: 250 km Limb: 1 km vertical Mapper: 2800 km Profiler: 250 km Limb: 3 vertical slits along track ± 250 km Total Ozone: 15 Dobson units Profile Ozone: 10% between 15 and 60 km, 20% between Tropopause and 15 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
OSIRIS Optical Spectrograph and Infrared Imaging System CSA (SNSB)	Odin	Operational	Atmospheric chemistry	Detects aerosol layers and abundance of species such as O_3, NO_2, OClO, and NO. Consists of spectrograph and IR imager. Measures temperature for altitudes above 30 km.	Waveband: Spatial resolution: Swath width: Accuracy:	Spectrograph: UV-NIR: 0.28–0.80 µm IR Imager, NIR: 1.26 µm, 1.27 µm, 1.52 µm Spectrograph 1 km at limb, Imager 1 km in vertical N/A, but measures in the altitude range 5–100 km Depends on species
Overhauser Magnetometer OM CNES	Ørsted (Oersted)	Operational	Magnetic field	Measurements of the strength of the Earth's magnetic field.	Waveband: Spatial resolution: Swath width: Accuracy:	
PALSAR Phased Array type L-band Synthetic Aperture Radar JAXA (METI (Japan))	ALOS	Operational	Imaging microwave radars	High resolution microwave imaging of land and ice for use in environmental monitoring, agriculture and forestry, disaster monitoring, Earth resource management and interferometry.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: L-band 1270 MHz (depending on looks, incident angle and bandwidth) Hi-res: 7–44 m or 14–88 m ScanSAR mode: 35–77 m or 70–154 m Polarimetry: 24–88 m High resolution mode: 70 km Scan SAR mode: 250–360 km Polarimetry: 30 km Surface Resolution: 10 m (Fine Mode) Surface Resolution: 100 m (Scan Mode) Radiometric: ±1 dB
Pamela Roscosmos	Resurs DK 1	Operational	Space environment	Cosmic ray research.	Waveband: Spatial resolution: Swath width: Accuracy:	
PAN (BJ-1) Panchromatic Imager NRSCC (CAST)	BJ-1	Operational	High resolution optical imagers	To provide panchromatica analysis of hydrological, oceanographic, land use and meteorological parameters.	Waveband: Spatial resolution: Swath width: Accuracy:	500–800 nm 4 m 24 km 100 m
PAN (Cartosat-1) Panchromatic sensor ISRO	CARTOSAT-1	Operational	High resolution optical imagers	High resolution stereo images for study of topography, urban areas, development of DTM, run-off models etc. Urban sprawl, forest cover/timber volume, land use change.	Waveband: Spatial resolution: Swath width: Accuracy:	Panchromatic VIS: 0.5–0.75 µm 2.5 m 30 km
PAN (Cartosat-2) Panchromatic Camera ISRO	CARTOSAT-2	Operational	High resolution optical imagers	High resolution stereo images for large scale (better than 1:0000) mapping applications, urban applications, GIS ingest.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.5–0.75 µm 1 m 10 km
PAN (Cartosat-3) Panchromatic sensor ISRO	CARTOSAT-3	Being developed	High resolution optical imagers	High resolution images for study of topography, urban areas, development of DTM, run-off models etc. Urban sprawl, forest cover/timber volume, land use change.	Waveband: Spatial resolution: Swath width: Accuracy:	Panchromatic VIS: 0.5–0.75 µm 0.3 m 6 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
PAN (GISTDA) Panchromatic imager GISTDA	THEOS	Approved	High resolution optical imagers	THEOS PAN is an optical instrument with resolution 2 m and swath width at 22 km. It can be used in several applications such as cartography, land use planning and management, national security, etc.	Waveband: 0.45–0.90 μm Spatial resolution: 2 m Swath width: 22 km Accuracy:
PAN (IRS-1C/1D) Panchromatic sensor ISRO	IRS-1D	Operational	High resolution optical imagers	High resolution stereo images for study of topography, urban areas, development of DTM, run-off models etc. Urban sprawl, forest cover/timber volume, land use change.	Waveband: Panchromatic VIS: 0.5–0.75 μm Spatial resolution: 5.8 m Swath width: 70 km at nadir Accuracy:
PAN CAMERA Pancromatic camera ASI	PRISMA	Approved	High resolution optical imagers	Pancromatic and Hyperspectral data for complex land ecosystem studies.	Waveband: Spatial resolution: 5 m Swath width: 30 km Accuracy: 5%
PAN Panchromatic and multi-spectral imager CAST	CBERS-3, CBERS-4	Being developed	High resolution optical imagers	Measurements of cloud type and extent and land surface reflectance, and used for global land surface applications.	Waveband: VIS: 0.52–0.59 μm, 0.63–0.69 μm NIR: 0.77–0.89 μm PAN: 0.51–0.85 μm Spatial resolution: 5 m panchromatic and 10 m multi-spectral Swath width: 60 km Accuracy:
PAN+MS (RGB+NIR) Ingenio PAN+MS (RGB+NIR) CDTI (ESA)	Ingenio (SEOSAT)	Approved	High resolution optical imagers	High resolution multi-spectral and optical images for applications in cartography, land use, urban management, water management, environmental monitoring, risk management and security.	Waveband: VIS+NIR band: 450–680 nm, 450–520 nm, 520–600 nm, 630–690 nm, 760–900 nm Spatial resolution: PAN: 2.5 m MS: 10 m Swath width: 60 km Accuracy:
Panchromatic High Sensitivity Camera CONAE	SARE-1	TBD	Imaging multi-spectral radiometers (vis/IR)		Waveband: Spatial resolution: Swath width: Accuracy:
PMR Passive Microwave Radiometer ISRO	OCEANSAT-3	Being developed	Imaging multi-spectral radiometers (passive microwave)	Mainly for ocean biology and sea state applications including SWH, geoid etc., establishment of global databases, meteorological applications.	Waveband: 18 GHz, 21 GHz, 37 GHz Spatial resolution: 20 km, 17 km, 10 km Swath width: 1500 km Accuracy:
POLDER-P POLarization and Directionality of the Earth's Reflectances (PARASOL version) CNES	PARASOL	Operational	Multiple direction/polarisation radiometers	Measures polarization, and directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces.	Waveband: VIS–NIR: 0.490 μm, 0.670 μm and 0.865 μm at 3 polarisations, and 0.49 μm, 0.565 μm, 0.763 μm, 0.765 μm, 0.91 μm and 1.02 μm with no polarisation Spatial resolution: 5.5 km x 5.5 km Swath width: 1600 km Accuracy: Radiation budget, land surface, Reflectance: 2%

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
POSEIDON-2 (SSALT-2) Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter) CNES	Jason-1	Operational	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data.	Waveband: Microwave: Ku-band (13.575 GHz), C-band (5.3 GHz) Spatial resolution: Basic measurement: 1/sec (6 km along track) Raw measurement: 10/sec (600 m along track) Swath width: On baseline Topex/Poseidon orbit (10 day cycle): 300 km between tracks at equator Accuracy: Sea level: 3.9 cm Significant waveheight: 0.5 m Horizontal sea surface wind speed: 2 m/s
POSEIDON-3 Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter) CNES	Jason-2 (aka OSTM)	Operational	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data.	Waveband: Microwave: Ku-band (13.575 GHz), C-band (5.3 GHz) Spatial resolution: Basic measurement: 1/sec (6 km along track) Raw measurement: 10 /sec (600 m along track) Swath width: On baseline Topex/Poseidon orbit (10 day cycle): 300 km between tracks at equator Accuracy: Sea level: 3.9 cm Significant waveheight: 0.5 m Horizontal sea surface wind speed: 2 m/s
PR Precipitation Radar JAXA (NASA)	TRMM	Operational	Cloud profile and rain radars	Measures precipitation rate in tropical latitudes.	Waveband: Microwave: 13.796 GHz and 13.802 GHz Spatial resolution: Range resolution: 250 m Horizontal resolution: 4.3 km at nadir Swath width: 215 km (post-boost: 245 km) Observable range: from surface to approx 15 km altitude Accuracy: Rainfall rate 0.7 mm/h at storm top
PREMOS PREcision Monitoring of Solar variability CNES	PICARD	Being developed	Earth radiation budget radiometer	Solar UV and visible flux in selected wavelength bands.	Waveband: UV: 230 nm, 311 nm, 402 nm VIS: 548 nm Spatial resolution: Swath width: Accuracy:
PRISM Panchromatic Remote-sensing Instrument for Stereo Mapping JAXA	ALOS	Operational	High resolution optical imagers	High resolution panchromatic stereo imager for land applications which include cartography, digital terrain models, civil planning, agriculture and forestry.	Waveband: VIS-NIR: 0.52-0.77 μm (panchromatic) Spatial resolution: 2.5 m Swath width: 35 km (triplet stereo observations) 70 km (nadir observations) Accuracy:
PSA Panchromatic film-making equipment Roscosmos	Monitor-E	Operational	Imaging multi-spectral radiometers (vis/IR)	Earth surface monitoring.	Waveband: VIS - NIR: 0.51-0.85 μm Spatial resolution 8 m Swath width: 90/780 km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
PSS Panchromatic film-making system Roscosmos (Roshydromet)	Kanopus-V N1	Prototype	Imaging multi-spectral radiometers (vis/IR)	Panchromatic data for environmental monitoring, agriculture and forestry.	Waveband: 0.5–0.8 µm Spatial resolution: 2.5 m Swath width: 20 km Accuracy:
RA Radar Altimeter ESA	ERS-2	Operational	Radar altimeters	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries.	Waveband: Microwave: Ku-band: 13.8 GHz Spatial resolution: Footprint is 16–20 km Swath width: Accuracy: Wave height: 0.5 m or 10% (whichever is smaller) Sea surface elevation: better than 10 cm
RA-2 Radar Altimeter - 2 ESA	Envisat	Operational	Radar altimeters	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries.	Waveband: Microwave: 13.575 GHz (Ku-band) & 3.2 GHz (S-band) Spatial resolution: Swath width: Accuracy: Altitude: better than 4.5 cm, Wave height: better than 5% or 0.25 m
RAD Microwave radiometer NSOAS	HY-2A	Being developed	Imaging multi-spectral radiometers (passive microwave)	Ocean wind and temperature measurements.	Waveband: 6.6 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, 37.0 GHz Spatial resolution: 100 km, 62 km, 36 km, 30 km, 18 km Swath width: 1600 km Accuracy: 1 K
Radar Altimeter NASA	GFO (GEOSAT Follow-on)	Operational	Radar altimeters	Ocran altimetry observations.	Waveband: 13.5 GHz Spatial resolution: 3.5 cm Swath width: Accuracy:
Radar/Radiometer NASA	SMAP	Proposed	Other	Soil moisture.	Waveband: Microwave Spatial resolution: Swath width: Accuracy:
RADARSAT DTT X-band (downlink of payload) CSA	RADARSAT-1	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:
RADARSAT TTC S-band (Tracking, Telemetry and Command) CSA	RADARSAT-1	Operational	Communications		Waveband: Spatial resolution: Swath width: Accuracy:
Radiomet Roscosmos (Roscosmos)	Meteor-M N2, Meteor-M N3	Approved	Atmospheric temperature and humidity sounders	Provision of high vertical resolution atmospheric temperature and humidity profiles.	Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
RASAT VIS Multi-spectral RASAT VIS Multi-spectral camera Tubitak	RASAT	Being developed	Imaging multi-spectral radiometers (vis/IR)	High resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications.	Waveband: Spatial resolution: Swath width: Accuracy:	Band 1: 0.42–0.55 µm Band 2: 0.55–0.63 µm Band 3: 0.58–0.73 µm 15 m 30 km
RASAT VIS Panchromatic RASAR VIS Panchromatic camera Tubitak	RASAT	Being developed	Imaging multi-spectral radiometers (vis/IR)	High resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications.	Waveband: Spatial resolution: Swath width: Accuracy:	0.42–0.73 µm 7.5 m 30 km
RBE Roscosmos	Kanopus-Vulkan	TBD	Magnetic field and space environment		Waveband: Spatial resolution: Swath width: Accuracy:	150 MHz, 400 MHz
RCHA Roscosmos	Kanopus-Vulkan	TBD	Other		Waveband: Spatial resolution: Swath width: Accuracy:	50 kHz – 15 MHz
RDSA Multi-spectral Imager Roscosmos	Monitor-E	Operational	Imaging multi-spectral radiometers (vis/IR)	Multi-spectral Earth surface monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS-NIR: 0.54–0.59 µm, 0.63–0.68 µm, 0.79–0.9 µm 20/40 m 160/890 km
ROSA Radio Occultation Sounder for Atmospheric studies ISRO	OCEANSAT-2	Being developed	Atmospheric temperature and humidity sounders and precision orbit	It will provide vertical profiles of atmospheric density, refractivity, pressure, temperature and humidity upto height of 30 km.	Waveband: Spatial resolution: Swath width: Accuracy:	Frequency 1560–1590 MHz and 1212–1242 MHz <1.0 K temperature 0.2 g/kg humidity
ROSA Radio Occultation Sounder for the Atmosphere ASI (CONAE)	SAC-D	Being developed	Atmospheric temperature and humidity sounders and precision orbit	Climate change studies.	Waveband: Spatial resolution: Swath width: Accuracy:	
RRA Retroreflector Array CNES	Diademe 1&2	Operational	Precision orbit	Satellite laser ranging for geodynamic measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	
S&R (GOES) Search and Rescue NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P	Operational	Other	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress.	Waveband: Spatial resolution: Swath width: Accuracy:	

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
S&R (NOAA) Search and Rescue Satellite Aided Tracking NOAA	MetOp-A, MetOp-B, NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-N'	Operational	Other	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress.	Waveband: Spatial resolution: Swath width: Accuracy:
S&R (Roshydromet) Search and Rescue Roshydromet	Elektro-L N1, Elektro-L N2, Elektro-L N3	Being developed	Other	For emergency calls.	Waveband: Spatial resolution: Swath width: Accuracy:
SABER Sounding of the Atmosphere usingBroadband Emission Radiometry NASA	TIMED	Operational	Atmospheric temperature and humidity sounders and atmospheric chemistry	SABER provides measurements of the mesosphere and lower thermosphere globally to support investigations into the fundamental processes governing the energetics, chemistry, dynamics, and transport of the atmospheric region extending from 60 km to 180 km.	Waveband: NIR–FIR: 1.27–17 µm (10 channels) Spatial resolution: 2 km vertical resolution Swath width: Accuracy:
SAPHIR Sondeur Atmospherique du Profil'd'Humidite Intertropicale par Radiometrie CNES	Megha-Tropiques	Being developed	Atmospheric temperature and humidity sounders	Cross-track sounder with the objective of measuring water vapour profiles in the troposphere in six layers from 2–12 km altitudes.	Waveband: Microwave: 183.3 GHz (6 channels) Spatial resolution: 10 km Swath width: 2200 km Accuracy:
SAR (MAPSAR) Synthetic Aperture Radar (MAPSAR) INPE (DLR)	MAPSAR	Proposed	Imaging microwave radars	Multi-Application Purpose Radar.	Waveband: Spatial resolution: Swath width: Accuracy:
SAR (RADARSAT) Synthetic Aperture Radar (CSA) C-band CSA	RADARSAT-1	Operational	Imaging microwave radars	All-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes.	Waveband: Microwave: C-band: 5.3 GHz, HH polarisation Spatial resolution: Standard: 25 x28 m (4 looks) Wide beam (1/2): 48–30 x 28 m/ 32–25 x 28 m (4 looks) Fine resolution: 11–9x9 m (1 look) ScanSAR (N/W): 50 x 50 m/ 100 x 100 m (2–4/4–8 looks) Extended (H/L): 22–19x2 m/ 63–28 x 28 m (4 looks) Swath width: Standard: 100 km Wide: 150 km Fine: 45 km ScanSAR Narrow: 300 km ScanSAR Wide: 500 km Extended (H): 75 km Extended (L): 170 km Accuracy: Geometric distortion: < 40 m Radiometric: 1.0 dB

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
SAR (RADARSAT-2) Synthetic Aperture Radar (CSA) C-band CSA	RADARSAT-2	Operational	Imaging microwave radars	All-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: C-band 5.405 GHz: HH, VV, HV, VH polarisation – includes fully polarimetric imaging modes, and left – and right – looking capability Standard: 25 x28 m (4 looks) Wide beam (1/2): 48–30 x 28 m/ 32–25 x 28 m (4 looks) Fine resolution: 11–9 x 9 m (1 look) ScanSAR (N/W): 50 x 50 m/ 100 x 100 m (2–4/4–8 looks) Extended (H/L): 22–19 x 28 m/ 63–28 x 28 m (4 looks) Ultrafine: 3 m Standard: 100 km (20–49°) Wide beam (1/2): 165 km/ 150 km (20–31/ 31–39°) Fine resolution: 45 km (37–48°) ScanSAR (W): 510 km (20–49°) Extended (H/L): 75 km/170 km (50–60/ 10–23°) Ultrafine: 10–20 km Geometric distortion: < 40 m Radiometric: 1.0 dB
SAR (RCM) Synthetic Aperture Radar (CSA RADARSAT Constellation) CSA	RADARSAT CONSTELLATION-1, RADARSAT CONSTELLATION-2, RADARSAT CONSTELLATION-3	Being developed	Imaging microwave radars	All-weather, C-band data to support ecosystem monitoring, maritime surveillance and disaster management.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: C-band 5.405 GHz: HH, VV, HV, VH polarisation – includes fully polarimetric imaging modes. Low Resolution: 100 x 100 m (8 looks) Medium Resolution: 50 x 50 m (4 looks) Medium Resolution Land: 16 x 16 m (4 looks) Medium Resolution Land ScanSAR: 30 x 30 m (4 looks) High Resolution: 5 x 5 m (1 look) Very High Resolution: 3 x 3 m (1 look) Ice-Oil Low Noise: 100 x 100 m (8 looks) Ship Detection Mode: Variable Low Resolution: 500 km Medium Resolution: 350 km Medium Resolution Land: 30 km Medium Resolution Land ScanSAR: 125 km High Resolution: 30 km Very High Resolution: 20 km Ice-Oil Low Noise: 350 km Ship Detection Mode: 350 km Radiometric Accuracy: 1.0 dB
SAR (RISAT) Synthetic Aperature Radiometer (RISAT) ISRO	RISAT-1	Being developed	Imaging microwave radars	Radar backscatter measurements of land, water and ocean surfaces for applications in soil moisture, crop applications (under cloud cover), terrain mapping etc.	Waveband: Spatial resolution: Swath width: Accuracy:	C-band (5.350 GHz) 3–6 m (FRS-1) 9–12 m (FRS-2) 25/50 m (MRS/CRS) 30 km (HRS) 30 km (FRS-1/FRS-2) 120/240 km (MRS/CRS)

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SAR (Roshydromet) Synthetic Aperture Radar (CSA) C-band Roshydromet (Roscosmos)	Meteor-M N3	Being developed	Imaging microwave radars	High resolution microwave radar images for ice watch.	Waveband: X-band Spatial resolution: Swath width: Accuracy:
SAR (SABRINA) Synthetic Aperature Radar (SABRINA) ASI	SABRINA	Approved	Imaging microwave radars	All-weather images of ocean, land and ice for monitoring of land surface processes, ice, environmental monitoring, risk management, environmental resources, maritime management, Earth topographic mapping and DEM, moving target indication.	Waveband: Microwave: X-band, with choice of 4 polarisation modes (VV, HH, VV/HH, HV/HH) Spatial resolution: Swath width: Accuracy:
SAR 2000 Multi-Mode Synthetic Aperture Radar ASI (MiD (Italy))	COSMO-SkyMed 1, COSMO-SkyMed 2, COSMO-SkyMed 3 COSMO-SkyMed 4	Operational	Imaging microwave radars	All weather images of ocean, land and ice for monitoring of land surface processes, ice, environmental monitoring, risk management, environmental resources, maritime management, earth topographic mapping.	Waveband: Microwave: X-band, with choice of 4 polarisation modes (VV, HH, VV/HH, HV/HH) Spatial resolution: Single polarisation mode: Stripmap: few metres ScanSAR: from few tens to several tens of metres Frame: resolution: order of 1 m Two polarisation mode: PING PONG: few metres Swath width: Single polarisation mode: Stripmap (40 x 40 km) ScanSAR (100 x 100 km or 200 x 200 km) Spotlight (10 x 10 km) Two polarisation mode: PING PONG (30 x 30 km) Accuracy:
SAR components testing CONAE	SARE-1	TBD	TBD		Waveband: Spatial resolution: Swath width: Accuracy:
SAR L Synthetic Aperture Radiometer (L-band) ISRO	RISAT-L	Proposed	Imaging multi-spectral radiometers (passive microwave)	Studies related to soil moisture and ocean salinity.	Waveband: L-band Spatial resolution: Swath width: Accuracy:
SAR-L (SAOCOM) Synthetic Aperture Radar (CONAE) CONAE	SAOCOM-1A, SAOCOM-1B, SAOCOM-2A, SAOCOM-2B	Being developed	Imaging microwave radars	Land, ocean, emergencies, soil moisture, interferometry, others.	Waveband: Microwave: L-band SAR 1.275 GHz Spatial resolution: 10 x 10 m – 100 x 100 m Swath width: 40–320 km Accuracy: 5 dB
SARSAT Search and Rescue Satellite Aided Tracking NOAA	MetOp-A, MetOp-B, NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4	Operational	Data collection	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress.	Waveband: UHF 406.0 MHZ Spatial resolution: Swath width: Accuracy

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
S-band SAR S-band Synthetic Aperture Radar CAST	HJ-1C	Being developed	Imaging microwave radars	Radar measurements for natural and disaster monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	S-band SAR 20 m (4 looks) 100 km 3 dB
SBUV/2 Solar Backscattter Ultraviolet Instrument/2 NOAA	NOAA-16, NOAA-17, NOAA-18, NOAA-N'	Operational	Atmospheric chemistry	Data on trace gases including vertical profile ozone, and solar irradiance and total ozone concentration measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	UV: 0.16–0.4 μm (12 channels) 170 km Absolute accuracy: 1%
ScaRaB Scanner for Earth's Radiation Budget CNES	Megha-Tropiques	Being developed	Earth radiation budget radiometer	Measures top-of-atmosphere shortwave radiation (0.2–4.0 μm) and total radiation (0.2–50 μm). Two additional narrow-band channels (0.5–0.7 μm and 11–12 μm) allow cloud detection and scene identification.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS window channel: 0.5–0.7 μm Solar channel UV-SWIR: 0.2–4 μm Total channel UV-FIR: 0.2–50 μm Thermal window channel: 10.5–12.5 μm 40 km 2200 km Absolute: ± 2.5 $W/m^2/sr$ Relative: ± 0.7 $W/m^2/sr$
SCAT Scatterometer NSOAS	HY-2A	Being developed	Scatterometers	Monitoring global sea surface winds.	Waveband: Spatial resolution: Swath width: Accuracy:	13.2515 GHz, HH, VV 50 km 1300 km 0.5 dB
Scatterometer (ISRO) ISRO	OCEANSAT-2 OCEANSAT-3	Being developed	Scatterometers	Ocean surface wind measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	13.515 GHz 50 km 1400–1840 km
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Chartography ESA (DLR)	Envisat	Operational	Atmospheric chemistry	Measures middle atmosphere temperature. Provides tropospheric and stratospheric profiles of O_2, O_3, O_4, CO, N_2O, NO_2, CO_2, CH_4, H_2O, and tropospheric and stratospheric profiles of aerosols and cloud altitude.	Waveband: Spatial resolution: Swath width: Accuracy:	UV-SWIR: 240–314 nm, 309–3405 nm, 394–620 nm, 604–805 nm, 785–1050 nm, 1000–1750 nm, 1940–2040 nm and 2265–2380 nm Limb vertical 3 x 132 km Nadir horizontal 32 x 215 km Limb and nadir mode: 1000 km (max) Radiometric: <4%
SeaWinds NASA (JAXA)	QuikSCAT	Operational	Scatterometers	Measurement of surface wind speed and direction.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 13.402 GHz 25 km 1600 km Speed: 2–3.5 m/s Direction: 20°
SEISS Space Environment In Situ Suite NOAA	GOES-R, GOES-S	Prototype	Space environment	Monitor proton, electron, and alpha particle fluxes.	Waveband: Spatial resolution: Swath width: Accuracy:	30 eV–500 MeV 15°, 30°, 60°, 90° 25%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SEM (GOES) Space Environment Monitor NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P	Operational	Space environment	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite.	Waveband: Spatial resolution: Swath width: Accuracy:
SEM (POES) Space Environment Monitor NOAA	MetOp-A, MetOp-B, NOAA-16, NOAA-17, NOAA-18, NOAA-N'	Operational	Space environment	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite.	Waveband: Senses and quantifies intensity in the sequentially selected energy bands, with energies ranging from 0.05–20 keV. Senses protons, electrons and ions with energies from 30 keV to levels exceeding 6.9 MeV. Spatial resolution: Swath width: Accuracy:
SEM Space Environment Monitor NRSCC	FY-3A, FY-3B	Operational	Space environment	Measures space environment parameters to support space craft operations.	Waveband: Spatial resolution: Swath width: Accuracy:
SEM-N Space Environment Monitor - NPOESS NOAA	NPOESS-1	Operational	Space environment	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	Waveband: Senses and quantifies intensity in the sequentially selected energy bands, with energies ranging from 0.05–20 keV. Senses protons, electrons, and ions with energies from 30 keV to levels exceeding 6.9 MeV Spatial resolution: Swath width: Accuracy:
SEVIRI Spinning Enhanced Visible and Infrared Imager EUMETSAT (ESA)	Meteosat-10, Meteosat-11, Meteosat-8, Meteosat-9	Operational	Imaging multi-spectral radiometers (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature.	Waveband: VIS: 0.56–0.71 μm, 0.5–0.9 μm (broadband) NIR: 0.74–0.88 μm SWIR 1.5–1.78 μm SWIR: 3.48–4.36 μm IR: 5.35–7.15 μm, 6.85–7.85 μm, 8.3–9.1 μm, 9.38–9.94 μm, 9.8–11.8 μm, 11–13 μm, 12.4–14.46 μm Spatial resolution: 1 km (at SSP) for one broadband visible channel HRV, 5 km (at SSP) for all other channels Swath width: Full Earth disc Accuracy: Cloud cover: 10% Cloud top height: 1 km Cloud top temparature: 1 K Cloud type: 8 classes Surface temparature: 0.7–2.0 K Specific humidity profile: 10% Wind profile (horizontal component): 2–10 m/s Long wave Earth surface radiation: 5 W/m^2

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
SGLI Second-generation Global Imager JAXA	GCOM-C1, GCOM-C2, GCOM-C3	Approved	Imaging multi-spectral radiometers (vis/IR) and ocean colour instruments	Medium resolution multi-spectral imaging of land, ocean and atmosphere.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – NIR: 0.38–0.865 μm SW: 1.05–2.21 μm TIR: 10.8–12.0 μm 250 m, 500 m, 1000 m 1150 km (VNR) 1400 km (IRS)
SI Star Imager DNSC	Ørsted (Oersted)	Operational	Precision orbit	Measurements to determine the orientation of both the satellite and the CSC magnetometer.	Waveband: Spatial resolution: Swath width: Accuracy:	
SIM Solar Irradiation Monitor NRSCC	FY-3A, FY-3B	Operational	Earth radiation budget radiometer	Solar irradiance monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	
SIM Spectral Irradiance Monitor NASA	SORCE	Operational	Earth radiation budget radiometer	Measures solar spectral irradiance in the 200–2000 nm range.	Waveband: Spatial resolution: Swath width: Accuracy:	UV-SWIR: 200–2000 nm
SIRAL SAR Interferometer Radar Altimeter ESA	CryoSat-2	Being developed	Radar altimeters	Marine ice and terrestrial ice sheet thickness measurement.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 13.575 GHz (Ku-band) Range resolution 45 cm along-track resolution 250 m Footprint 15 km Arctic sea-ice: 1.6 cm/year for 300 km x 300 km cells Land ice (small scale): 3.3 cm/year for 100 km x 100 km cells Land ice (large scale): 0.17 cm/year for Antarctica size area
SLSTR Sea and Land Surface Temperature Radiomete ESA (EC)	Sentinel-3 A, Sentinel-3 B, Sentinel-3 C	Approved	Imaging multi-spectral radiometers (passive microwave)	Marine and land services.	Waveband: Spatial resolution: Swath width: Accuracy:	9 bands in VNIR/SWIR/TIR 500 m (VNIR/SWIR) 1 km (TIR) 1675 km (near-nadir view) 750 km (backward view) 0.2 K abs., 80 mK rel.
SMR Submillimetre Radiometer SNSB	Odin	Operational	Atmospheric temperature and humidity sounders and atmospheric chemistry	Measures global distributions of ozone and species of importance for ozone chemisty, ClO, HNO_3, H_2O, N_2O, (HO_2, H_2O_2). Measures temperature in the height range 15–100 km.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 118.7 GHz + 4 bands in the region 480–580 GHz: Tunable measures 2–3 x 1 GHz regions at a time Vertical resolution 1.5–3 km along track 600 km Altitudes of 5–100 km 2–40% depending on species and altitude
SODAD Orbital System for an Active Detection of Debris CONAE (CNES)	SAC-D	Approved	TBD		Waveband: Spatial resolution: Swath width: Accuracy:	

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
SODISM SOlar Diameter Imager and Surface Mapper CNES	PICARD	Being developed	Earth radiation budget radiometer	Measures diameter and differential rotation of the sun – a whole Sun imager.	Waveband: Spatial resolution: Swath width: Accuracy:	UV: 230 nm, VIS: 548 nm, Active regions: 160 nm plus Lyman alpha detector
SOLSTICE SOLar STellar Irradiance Comparison Experiment NASA	SORCE	Operational	Earth radiation budget radiometer	Data on UV and charged particle energy inputs, and on time variation of full-disc solar UV spectrum. Measures solar UV radiation (115–430 nm) with resolution of 0.12 nm. Compares solar UV output with UV radiation of stable bright blue stars.	Waveband: Spatial resolution: Swath width: Accuracy:	UV: 115–180 nm & 170–320 nm 1%
Sounder (INSAT) IR Sounder ISRO	INSAT-3D	Being developed	Atmospheric temperature and humidity sounders	Atmospheric soundings, atmospheric stability, thermal gradient winds.	Waveband: Spatial resolution: Swath width: Accuracy:	SWIR: 3.74–4.74 μm MWIR: 6.51–11.03 μm TIR: 12.02–14.71 μm VIS: 0.55–0.75 μm 10 x 10 km Full (Full Earth disc sounding), Program (Options provided for Sector Scans)
Sounder NOAA	GOES-11, GOES-12, GOES-13, GOES-O, GOES-P	Operational	Atmospheric temperature and humidity sounders	Atmospheric soundings and data on atmospheric stability and thermal gradient winds.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – TIR: 19 channels 10 km Horizon to horizon
SOVAP SOlar Variability Picard radiometer CNES	PICARD	Being developed	Earth radiation budget radiometer	Total solar irradiance measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	Total irradiance
Spectrometer (OCO) NASA	OCO	Being developed	Atmospheric chemistry	Global measurements of atmospheric CO_2 needed to describe the variability of CO_2 sources and sinks.	Waveband: Spatial resolution: Swath width: Accuracy	0.76 μm, 1.61 μm, 2.06 μm
SRAL SAR Radar Altimeter ESA (EC)	Sentinel-3 A, Sentinel-3 B, Sentinel-3 C	Approved	Radar altimeters	Marine and land services.	Waveband: Spatial resolution: Swath width: Accuracy:	Dual freq radar altimeter, Ku-band, C-band 300 m Profiling 3 cm in range (1 s average, 2 m SWH including atm. corrections)
SSB/X-2 Special Sensor Gamma Ray Particle Detector NOAA (DoD (USA))	DMSP F-14	Operational	Space environment	Detects the location, intensity and spectrum of X-rays emitted from the Earth's atmosphere.	Waveband: Spatial resolution: Swath width: Accuracy:	
SSI/ES-2 Special Sensor Ionospheric Plasma Drift/Scintillation Meter NOAA (DoD (USA))	DMSP F-14, DMSP F-15	Operational	Space environment	Measurement of the ambient electron density and temperatures, the ambient ion density and ion temperature and molecular weight.	Waveband: Spatial resolution: Swath width: Accuracy:	

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
SSI/ES-3 Special Sensor Ionospheric Plasma Drift/Scintillation Meter NOAA (DoD (USA))	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Space environment	Measurement of the ambient electron density and temperatures, the ambient ion density and ion temperature and molecular weight.	Waveband: Spatial resolution: Swath width: Accuracy:	
SSJ/4 Special Sensor Precipitating Plasma Monitor NOAA (DoD (USA))	DMSP F-14, DMSP F-15	Operational	Magnetic field	Measurement of transfer energy, mass and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field.	Waveband: Spatial resolution: Swath width: Accuracy:	
SSJ/5 Special Sensor Precipitating Plasma Monitor NOAA (DoD (USA))	DMSP F-16	Operational	Magnetic field	Measurement of transfer energy, mass and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field.	Waveband: Spatial resolution: Swath width: Accuracy:	
SSM Special Sensor Magnetometer NOAA (DoD (USA))	DMSP F-14, DMSP F-15, DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Magnetic field	Measures geomagnetic fluctuations associated withMeasures geomagnetic fluctuations associated with solar geophysical phenomena. With SSIES and SSJ provides heating and electron density profiles in the ionosphere.	Waveband: Spatial resolution: Swath width: Accuracy:	
SSM/I Special Sensor Microwave Imager NOAA (DoD (USA))	DMSP F-14, DMSP F-15	Operational	Imaging multi-spectral radiometers (passive microwave)	Measures atmospheric, ocean and terrain microwave brightness temperatures to provide: sea surface winds, rain rates, cloud water, precipitation, soil moisture, ice edge, ice age.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 19.35 GHz, 22.235 GHz, 37 GHz, 85 GHz 15.7 km x 13.9 km to 68.9 x 44.3 km (depends on frequency) 1400 km
SSM/IS Special Sensor Microwave Imager Sounder NOAA (DoD (USA))	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Atmospheric temperature and humidity sounders	Measures thermal microwave radiation. Global measurements of air temp profile, humidity profile, ocean surface winds, rain overland/ocean, ice concentration/age, ice/snow edge, water vapour/clouds over ocean, snow water content, land surface temperature.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 19–183 GHz (24 frequencies) Varies with frequency: 25 x 17 km to 70 x 42 km 1700 km
SSM/T-1 Special Sensor Microwave Temperature Sounder NOAA (DoD (USA))	DMSP F-14, DMSP F-15	Operational	Atmospheric temperature and humidity sounders	Measures Earth's surface and atmospheric emission in the 50–60 GHz oxygen band.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 7 channels in the 50–60 GHz range 174 km diameter beam 1500 km
SSM/T-2 Special Sensor Microwave Water Vapour Sounder NOAA (DoD (USA))	DMSP F-14, DMSP F-15	Operational	Atmospheric temperature and humidity sounders	Water Vapour profiler.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 91.6 GHz, 150 GHz, 183.31 GHz (3 channels) (Total 5 channels) approx 48 km 1500 km

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SSULI Special Sensor Ultraviolet Limb Imager NOAA	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Space environment	Measures vertical profiles of the natural airglow radiation from atoms, molecules and ions in the upper atmosphere and ionosphere.	Waveband: Spatial resolution: Swath width: Accuracy:
SSUSI Special Sensor Ultraviolet Spectrographic Imager NOAA	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Space environment	Monitors the composition and structure of the upper atmosphere and ionosphere, as well as auroral energetic particle inputs, with spectrographic imaging and photometry.	Waveband: Spatial resolution: Swath width: Accuracy:
STR Star Tracker Set (3) ESA	Swarm	Being developed	Precision orbit	Precise attitude determination from the combination of two or three star trackers.	Waveband: N/A Spatial resolution: < 1 arcsec Swath width: N/A Accuracy: < 3 arcsec pointing accuracy around all STR axes
SumbandilaSat Imager CSIR (Uni of Stellenbosh)	SumbandilaSat	Approved	Imaging multi-spectral radiometers (vis/IR)	Primary payload (imager): Support decision making in natural resource management, disaster management, agriculture, urban planning and other applications.	Waveband: Blue 440–510 nm, XAN 520–540 nm, Green 520–590 nm, Red 630–685 nm, RedEdge 690–730 nm, NIR 845–890 nm Spatial resolution: 6.25 m GSD Swath width: 45 km; Off-nadir: 530 km Accuracy:
SUVI Solar Ultraviolet Imager NOAA	GOES-R, GOES-S	Being developed	Other	The SUVI will monitor the entire dynamic range of solar x-ray features, including coronal holes and solar flares, and will provide quantitative estimates of the physical conditions in the Sun's atmosphere.	Waveband: Spatial resolution: Swath width: Accuracy:
SWIFT Stratospheric Wind Interferometer for Transport Studies CSA	CHINOOK	Being developed	Other	Objective is to measure stratospheric winds and ozone fluxes.	Waveband: An ozone rotation-vibration line near 9 mm Spatial resolution: Vertical resolution approx 1.5 km (from 15–55 km altitude) Swath width: N/A Accuracy: 3–5 m/s for wind vector, 5% for ozone density (from 15–30 km)
SXI Solar X-ray Imager NOAA (USAF)	GOES-12, GOES-13, GOES-P	Operational	Earth radiation budget radiometers	Obtains data on structure of solar corona. Full disc imagery also provides warnings of geomagnetic storms, solar flares and information on active regions of sun and filaments.	Waveband: Spatial resolution: Swath width: Accuracy:
TANSO-CAI Thermal And Near infrared Sensor for carbon Observation - Cloud and Aerosol Imager JAXA (MOE (Japan), NIES (Japan))	GOSAT	Being developed	Imaging multi-spectral radiometers (vis/IR)	Measurement of cloud and aerosol for calibration of TANSO-FTS.	Waveband: 0.380 μm, 0.678 μm, 0.870 μm, 1.62 μm Spatial resolution: 0.5 km (0.380 μm, 0.678 μm, 0.870 μm bands), 1.5 km (1.62 μm band) Swath width: 1000 km (0.380 μm, 0.678 μm, 0.870 μm bands), 750 km (1.62 μm band) Accuracy:

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Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
TANSO-FTS Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer JAXA (MOE (Japan), NIES (Japan))	GOSAT	Being developed	Atmospheric temperature and humidity sounders and atmospheric chemistry)	CO_2 and methane distribution.	Waveband: 0.758–0.775 μm, 1.56–1.72 μm, 1.92–2.08 μm, 5.56–14.3 μm Spatial resolution: 10.5 km Swath width: 160 km Accuracy:
TDP Technological Development Package CONAE	SAC-D	Being developed	Precision orbit	Develop, test, and operate the Technological Demonstration Package (TDP) for demonstrating a newly developed GPS receiver for position, velocity, and time determination and an Inertia Reference Unit (IRU) to measure inertial angular velocity.	Waveband: Spatial resolution: Swath width: Accuracy:
TES PAN Panchromatic sensor ISRO	TES	Operational	High resolution optical imagers	High resolution images for study of topography, urban areas etc.	Waveband: Panchromatic VIS: 0.5–0.75 μm Spatial resolution: 1 m Swath width: Accuracy:
TES Tropospheric Emission Spectrometer NASA	Aura	Operational	Atmospheric chemistry	3D profiles on a global scale of all infrared active species from surface to lower stratosphere. Measures greenhouse gas concentrations, tropospheric ozone, acid rain precursors, gas exchange leading to stratospheric ozone depletion.	Waveband: SWIR–TIR: 3.2–15.4 μm Spatial resolution: In limb mode: 2.3 km vertical resolution In down-looking mode: 50 km x 5 km (global) 5 km x 0.5 km (local) Swath width: Limb mode: global: 50 km x 180 km local: 5 km x 18 km Accuracy: Ozone: 20 ppb Trace gases: 3–500 ppb
TIM Total Irradiance Monitor NASA	Glory, SORCE	Operational	Earth radiation budget radiometer	Measurement of total solar irradiance directly traceable to SI units with an absolute accuracy of 0.03% abd relative accuracy of 0.001% per year.	Waveband: Spatial resolution: Swath width: Looks at the sun every orbit, providing 15 measurements per day Accuracy:
TIR (OCEANSAT-3) Thermal Infrared Radiometer (OCEANSAT-3) ISRO	OCEANSAT-3	Being developed	Imaging multi-spectral radiometers (vis/IR)	TIR and OCM combination will support joint analysis for operational potential fishing zones.	Waveband: 5 bands Spatial resolution: 1 km Swath width: 1500 km Accuracy:
TIS (CONAE) Thermal IR Scanner CONAE	SAC-F	Approved	TBD		Waveband: Thermal IR Spatial resolution: Swath width: Accuracy:
TM Thematic Mapper USGS	Landsat-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance and emittance, lands cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications.	Waveband: 0.45–12.50 μm Spatial resolution: VIS–SWIR: 30 m TIR: 120 m Swath width: 185 km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
TMI TRMM Microwave Imager NASA	TRMM	Operational	Imaging multi-spectral radiometers (passive microwave)	Measures rainfall rates over oceans (less reliable over land), combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce monthly total rainfall maps over oceans.	Waveband: Spatial resolution: Swath width: Accuracy:	Microwave: 10.7 GHz, 19.4 GHz, 21.3 GHz, 37 GHz, and 85.5 GHz Vertical: 2.5 km approx Horizontal: 18 km 790 km Liquid water: 3 mg/cm^3 Humidity: 3 mg/cm^3 Ocean wind speed: 1.5 m/s
TOPSAT Telescope BNSC	TopSat	Operational	High resolution optical imagers	Experimental medium-resolution imaging satellite supporting a range of possible land applications.	Waveband: Spatial resolution: Swath width: Accuracy:	Panchromatic imagery Resolution 2.8 m Multi-spectral imagery (RGB) Resolution 5.6 m Panchromatic imagery 17 x 17 km Multi-Spectral - Swath 12 x 18 km
TOU/SBUS Total Ozone Unit & Solar Backscatter Ultraviolet Sounder NRSCC	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Atmospheric temperature and humidity sounders	Ozone total column vertical profile measurements.	Waveband: Spatial resolution: Swath width: Accuracy:	TOU: 6 channels in the range 308–360 nm SBUS: in the range 252–340 nm TOU: 50 km total ozone SBUS: 200 km total ozone TOU: 3000 km SBUS: nadir only
TRSR Turbo-Rogue Space Receiver NASA	Jason-1	Operational	Atmospheric temperature and humidity sounders and precision orbit	Precise continuous tracking data of satellite to decimeter accuracy.	Waveband: Spatial resolution: Swath width: Accuracy:	
TSIS Total Solar Irradiance Sensor NOAA	NPOESS-1, NPOESS-3, NPOESS-4	Being developed	Earth radiation budget radiometer	0.2–2 µm solar spectral irradiance monitor.	Waveband: Spatial resolution: Swath width: Accuracy:	UV – SWIR: 0.2–2 µm 1.5 W/m^2
UVN (Sentinel-4) UV-visible-near-infrared imaging spectrometer (Sentinel-4) ESA (EC)	MTG S1/ Sentinel-4 A, MTG S2/ Sentinel-4 B	Proposed	Atmospheric chemistry	Supporting atmospheric composition and air quality monitoring services.	Waveband: Spatial resolution: Swath width: Accuracy:	UV-1: 290–308 nm UV-2: 308–400 nm VIS: 400–500 nm NIR: 750–775 nm < 5 km at SSP, possibly relaxed to 50 km for wavelengths < 308 nm FOV E-W: 30°W–45°E at 40°N, N-S: 30°N–65°N
UVNS (post-EPS) UV-visible-near infrared-shortwave infrared imaging spectrometer (post-EPS) ESA (EC)	post-EPS/ Sentinel-5	Proposed	Atmospheric chemistry	Supporting atmospheric composition and air quality monitoring services.	Waveband: Spatial resolution: Swath width: Accuracy:	UV-1: 270–300 nm UV-2: 300–400 nm VIS: 400–500 nm NIR: 710–775 nm SWIR-1: 1593–1672 nm SWIR-2: 1940–2030 nm SWIR-3: 2305–2385 nm 5–15 km at SSP, possibly relaxed to 50 km for wavelengths < 300 nm Daily global coverage

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
UVNS (Sentinel-5 precursor) UV-visible-near-infrared imaging spectrometer (Sentinel-5 precursor) ESA (EC)	Sentinel-5 precursor	Proposed	Atmospheric chemistry	Supporting atmospheric composition and air quality monitoring services.	Waveband: Spatial resolution: Swath width: Accuracy:	UV-1: 270–300 nm UV-2: 300–400 nm VIS: 400–500 nm NIR: 710–775 nm SWIR-3: 2305–2385 nm 5–15 km at SSP, possibly relaxed to 50 km for wavelengths < 300 nm Daily global coverage
VEGETATION CNES (EC)	SPOT-4, SPOT-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Data of use for crop forecast and monitoring, vegetation monitoring, and biosphere/geosphere interaction studies.	Waveband: Spatial resolution: Swath width: Accuracy:	Operational mode: VIS: 0.61–0.68 μm NIR: 0.78–0.89 μm SWIR: 1.58–1.75 μm Experimental mode: VIS: 0.43–0.47 μm 1.15 km at nadir – minimal variation for off-nadir viewing 2200 km
VFM Vector Magnetometer ESA	Swarm	Being developed	Magnetic field	Magnetic field vector measurments.	Waveband: Spatial resolution: Swath width: Accuracy: <	N/A <0.1 nT N/A 0.5 nT/15 days
VHRR Very High resolution Radiometer ISRO	INSAT-2E, INSAT-3A, Kalpana	Operational	Imaging multi-spectral radiometers (vis/IR)	Cloud cover, rainfall, wind velocity, sea surface temperature, outgoing longwave radiation, reflected solar radiation in spectral band 0.55–0.75 μm, emitted radiation in 10.5–12.5 μm range.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.55–0.75 μm NIR: 5.7–7.1 μm TIR: 10.5–12.5 μm 2 km in visible 8 km in IR Full Earth disc every 30 minutes
VIIRS Visible/Infrared Imager Radiometer Suite NOAA (NASA)	NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4, NPP	Being developed	Imaging multi-spectral radiometers (vis/IR) and ocean colour instruments	Global observations of land, ocean, and atmosphere parameters: cloud/weather imagery, sea-surface temperature, ocean colour, land surface vegetation indices.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS – TIR: 0.4–12.5 μm (22 channels) 400 m – 1.6 km 3000 km SST 0.35 K
VIRR Multi-spectral Visible and Infrared Scan Radiometer (10 channels) NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Operational	Imaging multi-spectral radiometers (vis/IR)	Multi-spectral Visible and Infrared Scan Radiometer.	Waveband: Spatial resolution: Swath width: Accuracy:	Instrument features 10 channels over 0.43–10.5 μm 1.1 km at nadir 2800 km
VIRS Visible Infrared Scanner NASA	TRMM	Operational	Imaging multi-spectral radiometers (vis/IR)	Data to be used in conjunction with data from CERES instrument to determine cloud radiation. Will enable 'calibration' of precipitation indices derived from other satellite sources.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.63 μm SWIR-MWIR: 1.6 μm and 3.75 μm TIR: 10.8 μm and 12 μm 2 km at nadir 720 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
VSC Venus Superspectral Camera CNES (ISA)	VENUS	Being developed	Imaging multi-spectral radiometers (vis/IR)	High resolution superspectral images (12 spectral bands) for vegetation and landcover applications.	Waveband: Spatial resolution: Swath width: Accuracy:	420 nm centre wavelength (width: 40 nm), 443 nm (40), 490 nm (40), 555 nm (40), 620 nm (40), 620 nm (40), 667 nm (30), 702 nm (24), 742 nm (16), 782 nm (16), 865 nm (40), 910 nm (20) 5.3 m spatial resolution with 27 km swath 27 km
Water Vapour Radiometer NASA	GFO (GEOSAT Follow-on)	Operational	Imaging multi-spectral radiometers (passive microwave)	Measurement of the water vapour content along the altimeter pulse path.	Waveband: Spatial resolution: Swath width: Accuracy:	22 GHz, 37 GHz
WEFAX Weather Facsimile NOAA	GOES-11, GOES-12	Operational	Communications	Weather Facsimile.	Waveband: Spatial resolution: Swath width: Accuracy:	
WFC Wide Field Camera NASA	CALIPSO	Operational	Imaging multi-spectral radiometers (vis/IR)	Acquires high spatial resolution imagery for meteorological context.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 620 to 670 nm 125 m 60 km
WFI Wide Field Imager CAST (INPE)	CBERS-2, CBERS-2B	Operational	High resolution optical imagers	Data used for coastal and vegetation monitoring.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.63–0.69 μm NIR: 0.77–0.89 μm 258 m 890 km 0.3 pixels
WFI-2 Wide Field Imager 2 CAST (INPE)	CBERS-3, CBERS-4	Being developed	Imaging multi-spectral radiometers (vis/IR)	Earth resources, environmental monitoring, land use.	Waveband: Spatial resolution: Swath width: Accuracy:	VIS: 0.45–0.52 μm, 0.52–0.59 μm, 0.63–0.69 μm, 0.77–0.89 μm 73 m
WiFS Wide Field Sensor ISRO	IRS-1D	Operational	High resolution optical imagers	Vegetation and crop monitoring, resource assessment (regional scale), forest mapping, land cover/land use mapping, and change detection.	Waveband: Spatial resolution: Swath width: Accuracy:	2 channels: R–IR 188 m 810 km
WindSat DoD (USA) (NASA)	CORIOLIS	Operational	Multiple direction/polarisation radiometers	Measure ocean surface wind vectors.	Waveband: Spatial resolution: Swath width: Accuracy:	6.8 GHz, 10.7 GHz, 18.7 GHz, 23.8 GHz, 37 GHz 8 x 13 km - 40 x 60 km ± 2 m/s, ± 20°
WS LISS-III Wide Scan LISS-III ISRO	RESOURCESAT-3	Proposed	Imaging multi-spectral radiometers (vis/IR)	For crops and vegetation dynamics, natural resources census, disaster management and large scale mapping of themes.	Waveband: Spatial resolution: Swath width: Accuracy	3 bands in VNIR and 1 band in SWIR 23.5 m, 10 m 700 km

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics	
WSAR NSOAS (CAST)	HY-3A, HY-3B, HY-3C	Proposed	Imaging microwave radars	High resolution radar measurements of land and ocean features.	Waveband: Spatial resolution: Swath width: Accuracy:	X-band: 8–12 GHz 3 modes: 1 m, 5 m, 10 m 3 swaths: 40 km, 80 km, 150 km
WTE Whale Tracker Experiment CONAE	SAC-C	Operational	Data collection	Tracking of Eubalean Australis and environmental data collection system.	Waveband: Spatial resolution: Swath width: Accuracy:	
X-band SAR X-band Synthetic Aperture Radar DLR	TanDEM-X, TerraSAR-X, TerraSAR-X2	Operational	Imaging microwave radars	High resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications.	Waveband: Spatial resolution: Swath width: Accuracy:	9.65 GHz, 300 MHz bandwidth, all 4 polarisation modes Spotlight: 1.2 x 1–4 m Stripmap: 3 x 3–6 m ScanSAR: 16 x 16 m Spotlight: 5–10 km x 10 km Stripmap: 30 km ScanSAR: 100 km
XPS XUV Photometer System NASA	SORCE	Operational	Other	Objective is to measure the extreme UV solar irradiance from 1–35 nm.	Waveband: Spatial resolution: Swath width: Accuracy:	UV: 1–35 nm

A Further Information on CEOS

A.1 Overview

The Committee on Earth Observation Satellites (CEOS) was created in 1984, in response to a recommendation from a panel of experts on remote sensing from space, under the aegis of the Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment. This group recognised the multidisciplinary nature of satellite Earth observation and the value of coordination across all proposed missions.

CEOS combined the previously existing groups for Coordination on Ocean Remote Sensing Satellites (CORSS) and Coordination on Land Observation Satellites (CLOS), and established a broad framework for coordinating all spaceborne Earth observation missions.

A.2 Purpose

CEOS coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and to avoid planning satellite missions which overlap each other unnecessarily.

CEOS has three primary objectives in pursuing this goal:

- to optimise benefits of spaceborne Earth observations through cooperation of its members in mission planning and in development of compatible data products, formats, services, applications and policies;
- to serve as a focal point for international coordination of space-related Earth observation activities;
- to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

A.3 Participants

Members: Governmental organisations that are international or national in nature and are responsible for a civil spaceborne Earth observation programme that is currently operating or has reached Phase B or its equivalent stage of system development, are eligible for membership in CEOS.

Associates: CEOS Associates are either:

- Governmental organisations that are international or national in nature and currently have a civil space-segment activity in Phase A/pre-Phase A, or an equivalent stage of system development, or a significant ground segment activity that supports CEOS objectives; or
- Other existing satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.

A.4 CEOS Plenary

Currently, 29 member space agencies, along with 20 other national and international organisations, participate in CEOS planning and activities. Participating agencies meet in plenary session annually, with activities and coordination occurring throughout the year. The Plenary reviews progress on the various projects and activities being undertaken within CEOS. The Chair of CEOS rotates at the annual plenary meeting. The CEOS Chair for 2008 is the Council for Scientific and Industrial Research (CSIR) of South Africa. For 2009, the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand will undertake CEOS chairmanship.

Plenary	Year	Venue	Host
1st Plenary	1984	Washington, DC, USA	NOAA
2nd Plenary	1986	Frascati, Italy	ESA
3rd Plenary	1988	Ottawa, Canada	CSA
4th Plenary	1990	São José dos Campos, Brazil	INPE
5th Plenary	1991	Washington, DC, USA	NASA/NOAA
6th Plenary	1992	London, UK	BNSC
7th Plenary	1993	Tsukuba, Japan	MEXT/NASDA
8th Plenary	1994	Berlin, Germany	DARA
9th Plenary	1995	Montreal, Canada	CSA
10th Plenary	1996	Canberra, Australia	CSIRO
11th Plenary	1997	Toulouse, France	CNES
12th Plenary	1998	Bangalore, India	ISRO
13th Plenary	1999	Stockholm, Sweden	EUMETSAT
14th Plenary	2000	Rio de Janeiro, Brazil	INPE
15th Plenary	2001	Kyoto, Japan	MEXT/NASDA
16th Plenary	2002	Frascati, Italy	ESA
17th Plenary	2003	Colorado Springs, USA	NOAA
18th Plenary	2004	Beijing, PR China	NRSCC
19th Plenary	2005	London, UK	BNSC
20th Plenary	2006	Buenos Aires, Argentina	CONAE
21st Plenary	2007	Hawaii, USA	USGS
22nd Plenary	2008	George, South Africa	CSIR
23rd Plenary	2009	Thailand	GISTDA

CEOS History.

A.5 CEOS Secretariat

A permanent Secretariat, chaired by the current CEOS host organisation, provides most of the coordination between plenary sessions and is maintained by:

- the European Space Agency (ESA) jointly with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT);
- the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the United States;
- the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) jointly with the Japan Aerospace Exploration Agency (JAXA).

The Secretariat is chaired by the current CEOS host organisation in support of the CEOS Plenary. As part of the ongoing contribution to CEOS Secretariat activities, ESA is responsible for the CEOS Handbook, NASA for the CEOS Annual Report and Web site content, and MEXT/JAXA for the CEOS Newsletter, Brochure and maintenance of the Web site.

ESA currently funds the engagement of a full-time post to increase the capacity of the CEOS Secretriat, particularly with regards to the relationship with GEO (Group for Earth Observations). This post, the CEOS Executive Officer, is funded by ESA through to the end of 2009 (see below).

A.6 CEOS Working Groups

Working Group on Calibration and Validation (WGCV): The objectives of the WGCV are to enhance coordination and complementarity, to promote international cooperation, and to focus activities in the calibration and validation of Earth observations for the benefit of CEOS members and the international user community. WGCV addresses sensor-specific calibration/validation and geophysical parameter/ derived products validation. WGCV meets approximately every nine months. The subgroups of WGCV are as follows:

- The Infrared and Visible Optical Sensors Subgroup;
- The Microwave Sensors Subgroup;
- The SAR Subgroup;
- The Terrain Mapping Subgroup;
- The Land Product Validation Subgroup;
- The Atmospheric Chemistry Subgroup.

http://wgcv.ceos.org

Working Group on Information Systems and Services (WGISS): The objective of WGISS is to facilitate data and information management and services for users and data providers in dealing with global, regional, and local issues. In particular, it addresses the capture, description, processing, access, retrieval, utilisation, maintenance and exchange of spaceborne Earth observation data and supporting ancillary and auxiliary data and information, enabling improved interoperability and interconnectivity of information systems and services. WGISS meets approximately every six months.

There are two subgroups of WGISS: 'Technology and Services', and 'Projects and Applications'. WGISS has started a new initiative called the WGISS Test Facility which offers a framework for partnership with selected international science and EO projects to test and develop information systems and services to meet their requirements. The Global Observation of Forest Cover (GOFC) international science project was the first test of this concept. More recent projects include WTF–CEOP (WGISS Test Facility for Coordinated Energy and Water Cycle Observation Project), which aims to provide assistance to the CEOP science community in the development of data services associated with satellite data integration.

http://wgiss.ceos.org

Working Group on Education, Training and Capacity Building (WGEDU): The CEOS Working Group on Earth Observation, Education, Training, and Capacity Building (WGEdu) has developed a strategy for EO education and training in order to establish an effective coordination and partnership mechanism among CEOS agencies and institutions offering education and training around the world. The key objective of the strategy is to facilitate activities that substantially enhance international education and training in Earth System Science and the observation techniques, data analysis and interpretation required for its use and application to societal needs. The Group has developed a CEOS education portal to provide easy access to data sets available for these purposes.

http://wgedu.ceos.org

A.7 Strategic Implementation Team

CEOS has established a Strategic Implementation Team (SIT) which is responsible for addressing implementation issues – notably those related to the space component of the Global Earth Observing System of Systems (GEOSS). The SIT provides a forum where the heads of space agencies can meet to develop agreements on programme commitments in order to address gaps or overlaps in mission planning. Progress towards the GEOSS space segment is monitored and managed using the CEOS Implementation Plan, which is maintained by the SIT Chair and updated annually for the CEOS Plenary.

In 2008, the SIT is chaired by NOAA. JAXA is currently Vice-Chair and will commence its 2-year chairmanship in late 2009.

A.8 CEOS Executive Officer

The post of a full-time CEOS Executive Officer (CEO) was agreed in late 2006 to bolster the resources available to CEOS. The post is funded by the European Space Agency for an initial period of 3 years. The Executive Officer is charged with ensuring the efficient conduct of the CEOS contribution to GEO – including the implementation of the response to the GCOS IP (Implementation Plan for the Global Observing System for Climate), the GEO Work Plans, and development of the CEOS 'Virtual Constellations for GEOSS'.

A.9 Further Information on CEOS Activities

Refer to **www.ceos.org**

The CEOS Newsletter supplements the latest information available on-line about CEOS and is distributed internationally on a 6-monthly basis. Subscription requests should be sent to:

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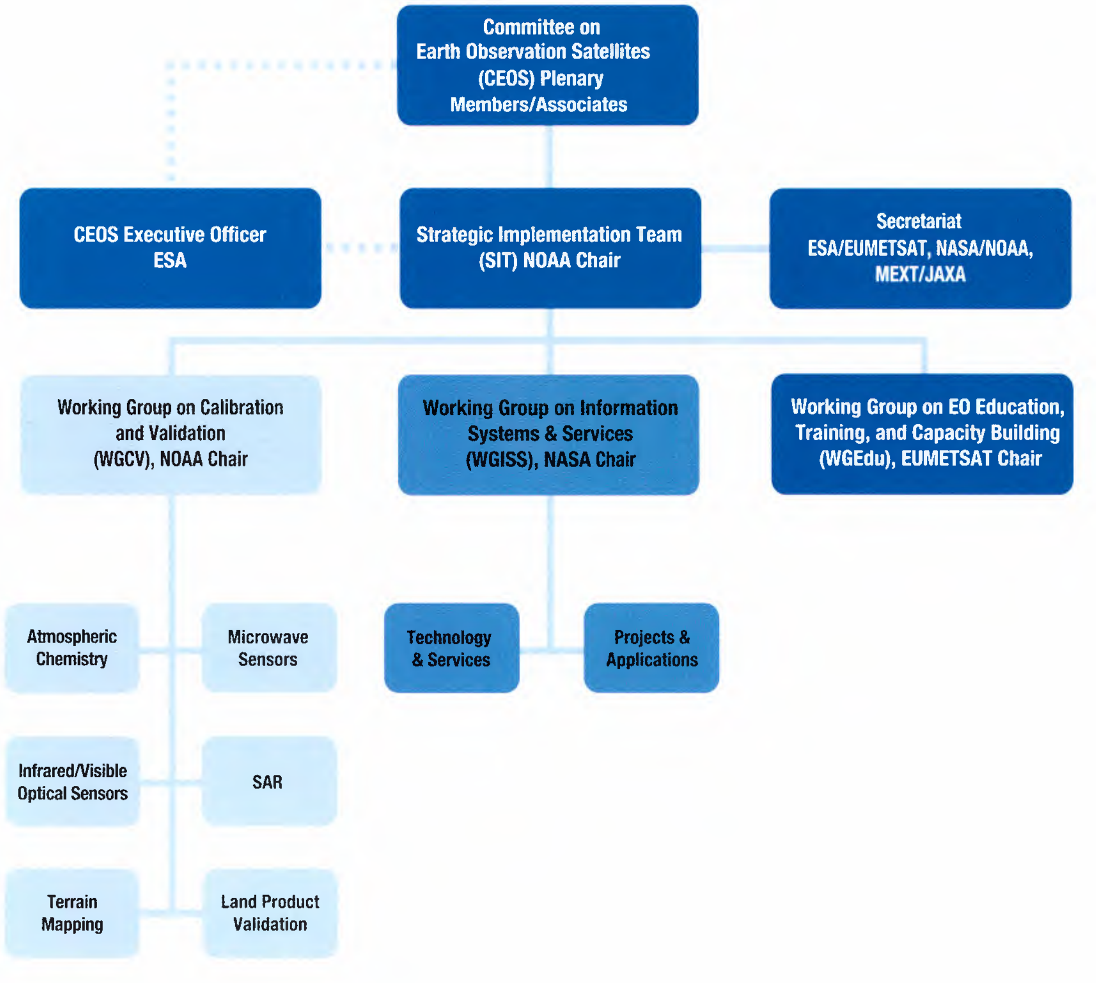


CEOS Structure.

B GCOS Climate Monitoring Principles

Effective monitoring systems for climate should adhere to the following principles:

The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and

(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term inter-annual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimising the effects of orbital decay and orbit drift) should be maintained.
12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.
13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.
14. Rigorous pre-launch instrument characterisation and calibration should be ensured, including radiance confirmation against an international radiance scale provided by a national metrology institute.
15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.
16. Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced, as appropriate.
17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained.
18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites.
19. Complementary *in situ* baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.
20. Random errors and time-dependent biases in satellite observations and derived products should be identified.

C Abbreviations

AR4	IPCC's Fourth Assessment Report
ASI	Agenzia Spaziale Italiana
BNSC	British National Space Centre
CAST	Chinese Academy of Space Technology
CCRS	Canada Centre for Remote Sensing
CDTI	Centre for the Development of Industrial Technology
CEO	CEOS Executive Officer
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CFCs	Chlorofluorcarbons
CGMS	Coordinating Group for Meteorological Satellites
CLIVAR	Climate Variability and Predictability
CNES	Centre National d'Etudes Spatiale
CONAE	Comisión de Actividates Espaciales
COP	Conference of the Parties
CRESDA	Centre for Resources Satellite Data and Applications
CRI	Crown Research Institute
CSA	Canadian Space Agency
CSD	United Nations Commission for Sustainable Development
CSIR	Satellite Applications Centre (SAC)/ Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DLR	Deutsches Zentrum für Luft-und Raumfahrt
DMSG	Ad Hoc Working Group on Disaster Management Support
DoD	US Department of Defense
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasting
ENSO	El Niño-Southern Oscillation
EO	Earth Observation
EPS	EUMETSAT Polar System
ERB	Earth Radiation Budget
ESA	European Space Agency
ESCAP	Economic and Social Commission of Asia and the Pacific
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization
FCDR	Fundamental Climate Data Record
FIR	Far Infrared
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GAW	Global Atmosphere Watch
GCMPs	GCOS Climate Monitoring Principles
GCOS	Global Climate Observing System
GEO	Ad-hoc Group on Earth Observations
GEOSS	Global Earth Observing System of Systems
GEWEX	The Global Energy and Water Cycle Experiment
GFMC	Global Fire Monitoring Center
GIS	Geographic Information Systems
GISTDA	Geo-Informatics and Space Technology Development Agency
GLOSS	Global Sea Level Observing System
GMES	Global Monitoring for Environment and Security

GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOOS	Global Ocean Observing System
GPS	Global Positioning Satellites
GSICS	Global Space-based Intercalibration System
GTOS	Global Terrestrial Observing System
ICSU	International Council for Science
IDNDR	International Decade for Natural Disaster Reduction
IGACO	The Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGCO	Integrated Global Carbon Observation
IGOL	International Global Observations of Land
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy Partnership
IGWCO	International Global Water Cycle Observations Theme
IHDP	International Human Dimensions Programme
INPE	Instituto Nacional de Pesquisas Espaciais
IOC	Inter-governmental Oceanographic Commission
IOCCG	International Ocean Colour Coordinating Group
IP	Implementation Plan
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project
ISDR	International Strategy for Disaster Reduction
ISPRS	International Society for Photogrammetry and Remote Sensing
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
KNMI	Royal Netherlands Meteorological Institute
LAI	Leaf Area Index
LIDAR	LIght Detection And Ranging instruments
LSI	Land Surface Imaging
LST	Local Solar Time
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MWIR	Medium Wave Infrared
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NASRDA	National Space Research and Development Agency of Nigeria
NDVI	Normalised Difference Vegetation Indices
NGOs	Non-governmental organisations
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NRSC	Norwegian Space Centre
NRSCC	National Remote Sensing Center of China
NSAU	National Space Agency of Ukraine
NWP	Numerical Weather Prediction
OSTC	Federal Office for Scientific, Technical and Cultural Affairs
REDD	Reducing Emissions from Deforestation in Developing Countries
RO	Radio Occultation
Roshydromet	Russian Federal Service for Hydrometeorology and Environment Monitoring

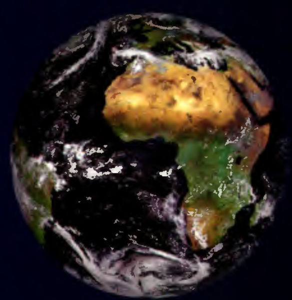
Roscosmos	Russian Aviation and Space Agency
SAR	Synthetic Aperture Radar
SBA	Societal Benefit Area
SIT	Strategic Implementation Team
SNSB	Swedish National Space Board
SST	Sea surface temperature
SWIR	Short-wave Infrared
TAR	Third Assessment Report of the IPCC
TCO	Terrestrial Carbon Observations
TIR	Thermal Infrared
TOA	Top of atmosphere
TSI	Total solar irradiance
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNOOSA	United Nations Office of Outer Space Affairs
USGS	United States Geological Survey
UV	Ultraviolet
VIS	Visible
WCRP	World Climate Research Programme
WGCV	Working Group on Calibration and Validation
WGEDU	Working Group on Earth Observation Education, Training, and Capacity Building
WGISS	Working Group on Information Systems and Services
WMO	World Meteorological Organization
WWC	World Water Council
WWW	World Weather Watch

CEOS, the Committee on Earth Observation Satellites, coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and to harmonise satellite mission planning to address gaps and overlaps.

→ **www.ceos.org**

ESA, the European Space Agency, is Europe's gateway to space. It is an international organisation with 17 Member States. ESA's mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world.

→ **www.esa.int**



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