

Envisat Mission



**Opportunities for
Science and Applications**

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Preface

Nearly every week public attention is drawn to events which concern the state of planet Earth, its climate and environment. Scientist and non-scientist alike are presented with intensive media coverage, bringing into open discussion topics such as ozone depletion, global warming and the need to take international action to reduce the impact of human activities. Events such as the 1997 Kyoto meeting of the UN Framework Convention on Climate Change and the impact of the El Niño phenomenon have further heightened the level of concern.

At a more local level, but perhaps also related to global climate change, natural disasters such as flooding, landslides and extreme weather conditions continue to feature in the headlines because of the threats to human life and sustainability.

Pressure is mounting to answer an increasing number of questions about the Earth's environment posed by the scientific community, government, industry and ordinary people in the street.

Europe has a impressive track record of contributing to environmental science and since the launch of METEOSAT-1 in 1977, has demonstrated its ability to design, build and operate Earth observation satellite systems to provide a new source of information from space. The ERS programme has built on this success, introducing new sensors and increasing the scope of available information.

The Envisat satellite is the latest and most capable so far. Funded through the European Space Agency, Envisat will provide information to virtually all research domains involved in the environment and global climate change. Whilst providing continuity with the ERS satellites and building on the capability of the radar and radiometer components of those systems, Envisat will provide information from new sensors supporting atmospheric chemistry and marine biology.

Envisat will encourage the routine use of its data by organisations which provide information for the benefit of the general public, such as environmental institutions, meteorological offices and the media. Whilst this remains as yet an immature market, it is critical to the funding of future missions. The flexibility offered by the Envisat payload provides an ideal training ground for assessing new technologies and for developing innovative processing techniques and new information services.

The success of the Envisat exploitation programme will rely on continuous interaction between the European Space Agency and the science and applications communities.

This document presents an overview of the opportunities for exploitation of Envisat data products and it is hoped that it will serve the purpose of encouraging scientists and application developers to plan for the use of Envisat data in their work. Publications will follow, presenting results from the mission as they become available.

Numerous contributions to this document are gratefully acknowledged, from experts external to ESA, from the Mission Management Office in ESA Headquarters, the Envisat System and Payload Division in ESTEC, the Earth Observation Projects and Engineering Division in ESRIN and the Earth Sciences Division in ESTEC.

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Abbreviations

AATSR	Advanced Along Track Scanning Radiometer
ASAR	Advanced Synthetic Aperture Radar
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BMRC	Bureau of Meteorology Research Centre
CAP	Common Agriculture Policy
CCRS	Canada Center for Remote Sensing
CFCs	Chlorofluorocarbons
CLIVAR	Climate Variability and Predictability Study
CZCS	Coastal Zone Colour Scanner
DEM	Digital Elevation Model
DINSAR	Differential INTERferometric SAR
DNMI	Det norske meteorologiske institutt
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECMWF	European Centre for Medium-Range Weather Forecasts
ERS	European Remote Sensing Satellite
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water Experiment
GFO	Geosat Follow-On
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of the Stars
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
HH	Horizontal transmit - Horizontal receive polarisation
HR	High resolution (MERIS)
HV	Horizontal transmit - Vertical receive polarisation
IGAC	International Global Atmosphere Chemistry
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme
IPCC	Intergovernmental Panel on Climate Change

1. The Envisat Mission

Envisat is an advanced Earth observing satellite designed to provide measurements of the atmosphere, ocean, land and ice over a five year period. As the successor to the highly successful ERS-1 and ERS-2 satellites it will provide direct continuity of measurement with most ERS instruments, thereby extending to more than 10 years the long term data sets critical for global environmental monitoring, and furthering many operational and commercial applications.

As a total package the capabilities of Envisat exceed those of any previous or planned Earth observation satellite. The payload includes three new atmospheric sounding instruments designed primarily for atmospheric chemistry, including measurement of ozone in the stratosphere. There is an advanced Synthetic Aperture Radar (SAR) which can collect high resolution images with a variable viewing geometry, together with new wide swath and selectable dual polarisation capabilities. A new imaging spectrometer is included for ocean colour and vegetation monitoring, and there are improved versions of the ERS radar altimeter, microwave radiometer and visible/near infra-red radiometers, together with a new very precise orbit measurement system.

1.1 Environmental Science

Over the last decade, large scale environmental change, and particularly the degree of human influence upon it, has become the subject of intense scientific investigation, public concern and inter-governmental action. The survival of mankind depends on learning to live in harmony with the environment. Man's activities are not only causing damage to the environment, but are also capable of influencing the system of the planet itself. It is important to understand the processes of change, where changes might be predicted and where appropriate, prevented, contained or reversed.

Priority issues in global environment research identified by the Inter-Governmental Panel on Climate Change (IPCC) are:

- sources, sinks and concentrations of greenhouse gases
- the Earth's radiation balance (and in particular the effect of clouds upon it)
- the effect of ocean circulation on the timing and pattern of climate change
- availability of land surface water for human development and within the hydrological cycle
- the proportion of global water locked up in polar ice sheets and the consequences for changing sea-level and climate
- ecosystem dynamics (e.g. desertification, biomass burning, habitats and bio-diversity, carbon cycling) as affected by, or affecting, climate change
- large-scale insertion of aerosols into the atmosphere (e.g. from volcanic eruption) and their short-term effects on climate.

Identifying global environmental changes and explaining their causes requires highly coordinated large scale research which views the Earth as a complete system (Figure 1.1). Information requirements are complex and several major international research and development programmes (IGBP, IHDP, UNEP, WCRP) are addressing them in specific projects (e.g. GEWEX, IGAC, LUCC, WOCE) and observing systems (e.g. GCOS, GOOS, GTOS). These programmes assist in the formulation and monitoring of international environmental agreements (such as the

Montreal Protocol for worldwide reduction in the production of CFCs, or setting national targets for CO₂ emissions) which affect everyone on the planet. Research in many of these areas requires long term (10 years and more) data sets, which allow meaningful trends in geophysical parameters to be observed. Measurements must be synoptic, precise and consistent, both in space and time, in order to differentiate any long-term trends from more transient effects.

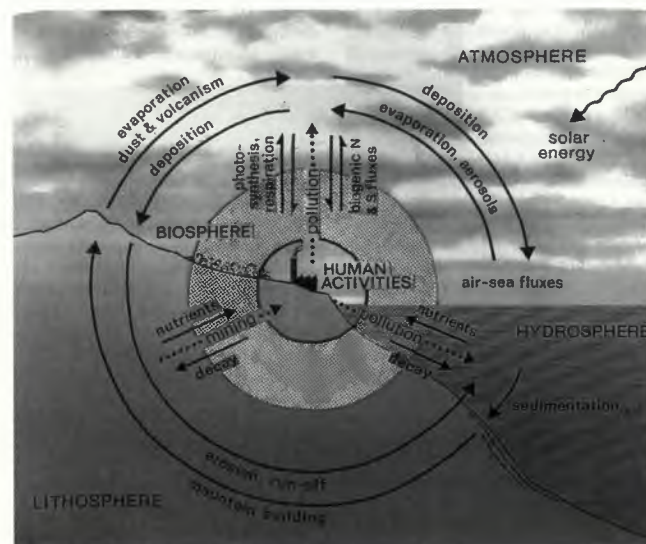


Figure 1.1 Earth system cycles

Earth observation plays a key role in many aspects of environmental science, and in many cases satellites are the only way to obtain suitable data for global environment monitoring. The ERS programme has demonstrated how satellites can provide a unique data source for synoptic measurements of the atmosphere, oceans, land and ice covering the whole Earth (ESA SP-1176/I, 1996). The main objective of Envisat is to improve the range and accuracy of such measurements.

For atmospheric science, instruments such as GOME on ERS-2 have demonstrated clearly the importance of satellite systems for global monitoring of ozone in the

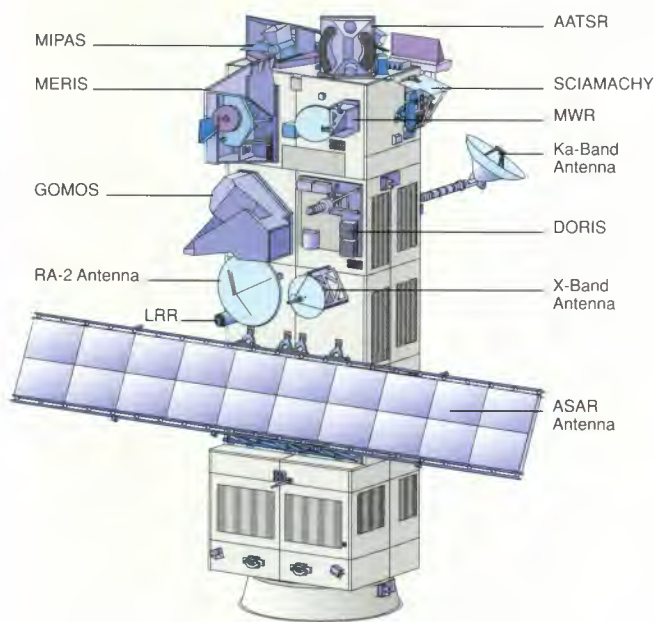


Figure 1.2 The Envisat scientific payload

thousands of atmospheric profiles will be collected each day.

The requirement for global data acquisition will be satisfied by the use of on-board data storage. Envisat has 3 tape recorders, each with a capacity in excess of 30 Gbit. For most instruments, complete orbits of data will be stored on-board for downloading to the main ESA ground stations. An additional solid state device will provide on-board storage of ASAR and MERIS HR data for later transmission to these same ground stations. Together with the Artemis data relay satellite, this will enable direct reception in Europe, of HR data from any point on the

Earth's surface. Direct downloading to other ground stations will remain important for the provision of near real time services.

Envisat can acquire 22 GBytes of instrument data every orbit which could contribute to an archive of 1 PetaByte (10^{15}) of data accumulated over the nominal 5 year mission. This is equivalent in volume to 500 million scenes from the multi-spectral scanner on board Landsat-1, the first Earth resources satellite.

1.4 Instruments

ASAR (Advanced Synthetic Aperture Radar): is a C-band SAR which continues the all-weather microwave imaging capability of the ERS SARs. Figure 1.3 shows imaging configurations for the five different modes of operation. Image Mode provides up to 100 km swath coverage at 30 m resolution, similar to the ERS SARs, but the new beam steering capability enables acquisition to take place in any one of 7 different image swath positions (IS1 to IS7 with incidence angles $15^\circ - 45^\circ$) spanning 500 km, in VV or HH polarisation. Alternating Polarisation Mode is similar, but will provide simultaneous dual-polarised images; either both VV & HH polarisation images, or one of two combinations of plane polarised and cross polarised images (VV&VH or HH & HV). Wide Swath Mode (150 m resolution) and Global Monitoring Mode (1000 m resolution) provide images covering a 400 km swath, in either HH or VV polarisation. Finally, in Wave Mode, imagettes of 5 km by (5 to 10 km) will be acquired, spaced 100 km along track and alternating between 2 of 7 across track positions, in either VV or HH polarisation. ASAR will be able to operate continuously in Global Monitoring Mode, or for up to 30 minutes per orbit in the higher resolution modes (n.b. ERS SAR operates for 12 minutes per orbit).

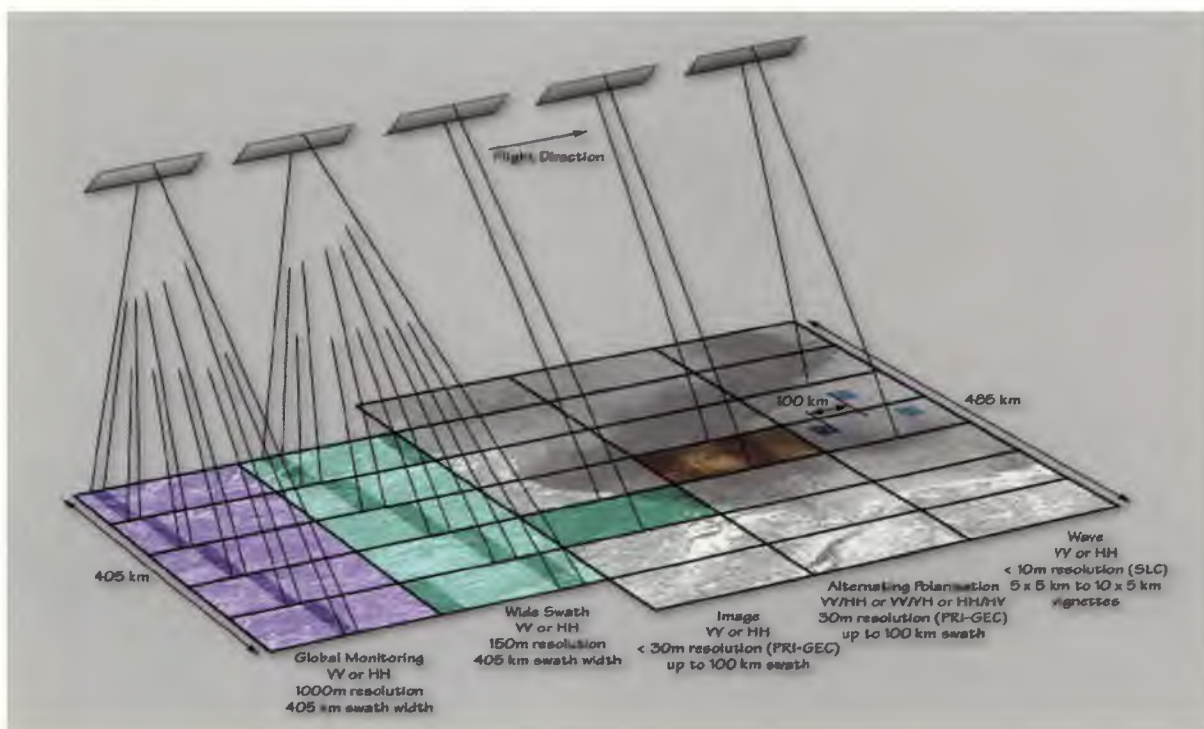


Figure 1.3 ASAR operating modes

GOMOS (Global Ozone Monitoring by Occultation of Stars): is a UV-visible and near-infrared spectrometer which measures star light as seen through the atmosphere (Figure 1.6). GOMOS is a novel instrument measuring ozone and other trace gases in the altitude range between 20 km and 100 km, with a vertical resolution of 1.7 km. The occultation technique is very stable and inherently self-calibrating. This is due to the fact that the integrated quantity of trace gases along the line of sight is obtained from the ratio of two measurements taken by the same instrument within a short time interval. Therefore, even if

the instrument characteristics change slowly over time, the ratios will still produce valid results. This long term reliability is highly relevant in the context of long term studies of ozone variability. Daytime occultations are planned in order to determine diurnal variations in the concentration of gas species, but the instrument performs best at night. The two high speed photometers are able to gather information on the scintillation of starlight and thereby provide information on the fine structure of the atmospheric vertical temperature profile and transport processes.

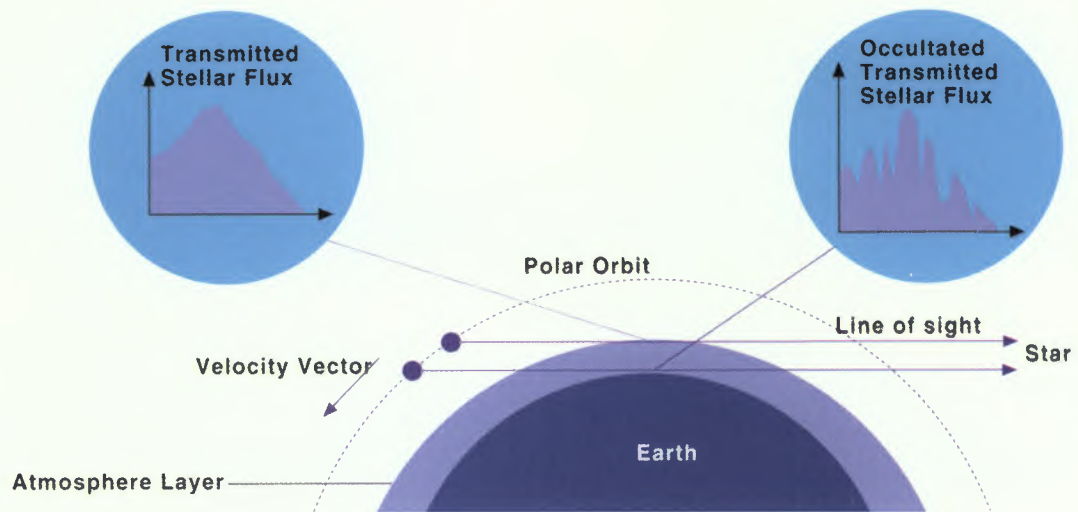


Figure 1.6 GOMOS stellar occultation

MWR (Microwave Radiometer): is a K-band passive radiometer which measures the total atmospheric water vapour and cloud liquid water content within a cone having a 20 km diameter footprint (Figure 1.9). The main purpose of the MWR is to provide atmospheric correction for RA-2 timings. To achieve this the contribution of the Earth's

surface is eliminated by taking differential measurements at two frequencies. The MWR can also be applied to low resolution measurements of surface emissivity and soil moisture, as well as supporting energy budget and ice characterisation research.

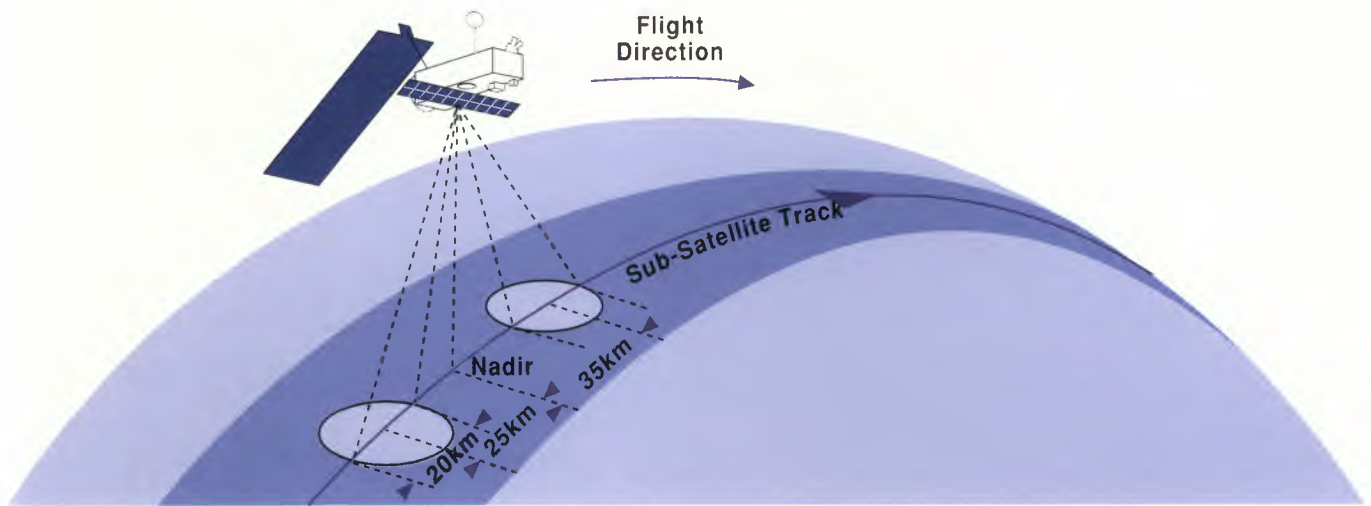


Figure 1.9 MWR operation

AATSR (Advanced Along-Track Scanning Radiometer): provides continuity with the ATSR instruments on ERS, ensuring the production of a near-continuous 10-year data set of sea surface temperature at an accuracy level of 0.3 K or better. AATSR will have the four

well established mid/thermal infrared channels, together with three visible/NIR channels. The two-angle viewing method already established with ATSR will be used to achieve accurate atmospheric corrections (Figure 1.10). Spatial resolution is 1 km at nadir in a 500 km swath.

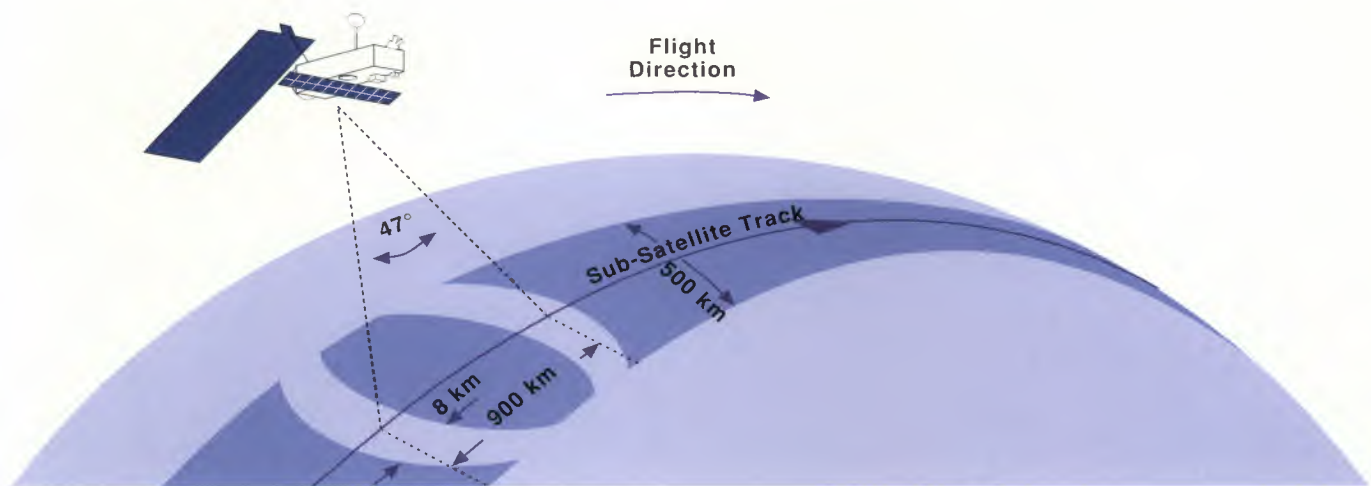


Figure 1.10 AATSR operating configuration

1.5 Instrument Synergies

Envisat carries a remarkably diverse range of instruments. Some have been designed to work closely together, thus for example, the RA-2 requires input from both the MWR and DORIS even for some of its basic geophysical products, whereas other Envisat instruments provide synergetic opportunities simply because several different types of observation are available for the same place and time. Table 1.1 shows the measurement capabilities of each of the instruments and the possibilities for combining

instrument data within different applications.

There is clearly great scope for synergy and intercomparison of results with data from SCIAMACHY, GOMOS and MIPAS which are functionally quite different instruments, but measure similar atmospheric properties in partially overlapping profiles. Data from these instruments may also be integrated with surface measurements from MERIS and AATSR to examine atmosphere/biosphere interactions and improve atmospheric corrections.

	MWR	RA-2	ASAR	MERIS	AATSR	SCIAMA CHY	MIPAS	GOMOS
ATMOSPHERE								
Temperature/Pressure				Principal contribution		Principal contribution	Principal contribution	Principal contribution
Trace Gases						Principal contribution	Principal contribution	Principal contribution
Cloud Type/Height				Principal contribution	Principal contribution	Principal contribution	Principal contribution	
Water Vapour	Principal contribution			Principal contribution	Principal contribution		Principal contribution	Principal contribution
Aerosols	Principal contribution			Principal contribution	Principal contribution	Principal contribution	Principal contribution	Principal contribution
Radiation Budget	Principal contribution			Principal contribution	Principal contribution	Secondary or experimental contribution	Secondary or experimental contribution	Secondary or experimental contribution
Turbulence								Principal contribution
OCEAN								
Marine Geoid		Principal contribution						
Global Circulation		Principal contribution			Principal contribution			
Wave Characteristics		Principal contribution	Principal contribution					
Ocean Fronts			Principal contribution	Principal contribution	Secondary or experimental contribution			
Ocean Colour and Turbidity				Principal contribution				
Sea Surface Temperature					Principal contribution			
Coastal Dynamics			Principal contribution	Principal contribution				
Oil Slicks			Principal contribution					
Ship Traffic			Principal contribution					
LAND								
Global Vegetation Monitoring			Principal contribution	Principal contribution	Principal contribution			
Surface Temperature	Secondary or experimental contribution				Secondary or experimental contribution			
Agriculture and Forestry			Principal contribution	Secondary or experimental contribution	Secondary or experimental contribution			
Geology and Topography		Secondary or experimental contribution	Principal contribution					
Hydrology Parameters	Secondary or experimental contribution	Secondary or experimental contribution	Principal contribution	Principal contribution	Principal contribution			
Flooding			Principal contribution					
Fire					Principal contribution			
ICE								
Temperature					Principal contribution			
Ice Sheet Dynamics	Secondary or experimental contribution	Principal contribution	Principal contribution	Principal contribution				
Snow Cover			Principal contribution	Principal contribution	Principal contribution			
Sea Ice Mapping	Secondary or experimental contribution	Principal contribution	Principal contribution	Principal contribution				
Ship Routing			Principal contribution					
<div> <div>Principal contribution</div> <div>Secondary or experimental contribution</div> </div>								

Table 1.1 Measurement capabilities of the Envisat instruments

1.6 Retrieving Geophysical Parameters

Satellite sensors, such as those on Envisat, provide the only currently available means for making truly global and repetitive observations, but it must be emphasised that the only observations that can be made by these instruments are electromagnetic radiation measurements, precisely fixed in space and time. Quantitative and accurate models, preferably physically based, are essential to transform these radiation measurements into useful geophysical parameters such as the concentration of ozone, annual changes in water storage of an ice cap, extent of flooding, land surface deformation or net primary productivity of the ocean.

Figure 1.13 shows some of the major processes involved in algorithm development and testing, to transfer the measurements made into calibrated geophysical parameters. Good calibration of the instrument and the data coming from it, is needed to provide a satisfactory basis for establishing the stable retrieval of geophysical parameters. As part of the process of proving and refining an algorithm, the derived geophysical values need to be validated by

comparison with in-situ measurements of these same parameters. Comparison of the results provides an accuracy or quality assessment, and feedback to the calibration for use in refining the models.

Much of the scientific work on the data sets generated by Envisat is concerned with applying, validating and improving such models. All Envisat instruments will provide well calibrated data and co-ordinated scientific activities will be organised to validate all Envisat geophysical products. Further exploitation of the geophysical products derived from Envisat involves setting up efficient information re-distribution channels which put the derived information to practical use with other environmental data for science and commercial applications.

Information on the algorithms used to produce ESA products is available on the Envisat Web site (<http://envisat.estec.esa.nl/>).

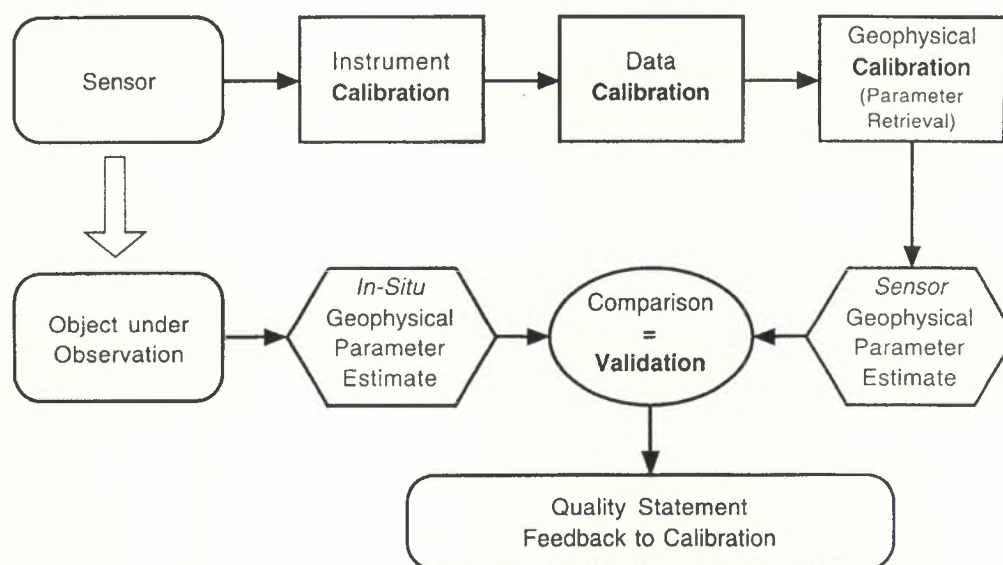


Figure 1.13 Processes involved in geophysical calibration and validation.

2. Atmosphere

Satellite remote sensing provides a unique way of monitoring the complex and dynamic processes that occur in the atmosphere. Since the future of the human race is critically dependent on the long term variability of the atmosphere, great efforts are being made to understand the many processes involved. In response to this, researchers develop models of the atmosphere as a mechanism whereby chemical reactions and physical changes in the atmosphere can be placed in context within the overall Earth system.

Such models require large amounts of data describing the spatial and temporal variability of the Earth's atmosphere at different locations and altitudes around the globe, taking account of diurnal, seasonal and longer term cycles. Sources, reservoirs and sinks of critical trace gases all need to be described. Satellite remote sensing provides a powerful set of techniques for acquiring these data to sustain models of the atmosphere, especially where information is required on a global scale and within a short time span.

2.1 Atmosphere Constituents

Many of the factors affecting the global environment are related to changes in the chemical composition of the atmosphere. The results of these changes include: the enhanced greenhouse effect, increase in the levels of ultraviolet-B radiation reaching the Earth's surface, acidification and reduced transparency. The atmosphere is very dynamic, both in terms of chemical composition and associated radiative properties and also in the way it transports materials around the globe, providing a link between land and ocean. The key role of the atmosphere in the maintenance of the Earth's environment emphasises the need to conduct research, to understand properly the processes involved and to monitor long term changes.

As a result of man's activities, which have become progressively more significant over the last century, large quantities of carbon, chlorine, nitrogen and sulphur compounds have been injected into the atmosphere and are disrupting the natural equilibrium which had become established. Whilst long term change has always been a feature of the atmosphere, it has become apparent that it is the increased rate of change, brought about by man's activities, which is having such a potentially detrimental effect on the Earth's system.

The reduction in stratospheric ozone concentrations over Europe since 1960 is the direct result of the use of ozone depleting chemicals such as refrigerants, industrial cleaners, foaming agents and those in fire extinguishers. Conversely, pollution at the Earth's surface has led to increased levels of tropospheric ozone, particularly over industrial areas, with consequent threats to human health. No other chemical in the troposphere has a concentration which is so close to being toxic.

The greenhouse effect, shown in Figure 2.1, concerns the warming of the troposphere by increasing concentrations of the so-called greenhouse gases (carbon dioxide, methane, nitrous oxide, ozone and others). This warming occurs because the greenhouse gases are transparent to incoming solar radiation, but absorb infrared radiation from the Earth that would otherwise escape from the atmosphere into space. The greenhouse gases then re-radiate some of this heat back towards the surface of the Earth. The rise in carbon dioxide as a result of industrialisation, is primarily responsible for the enhanced greenhouse gas effect. Current carbon dioxide levels are more than double pre-industrial levels and are the focus of international efforts to reduce emissions and offset the consequences of changed climate patterns, sea level rise, effects on hydrology, threats to ecosystems and land degradation.

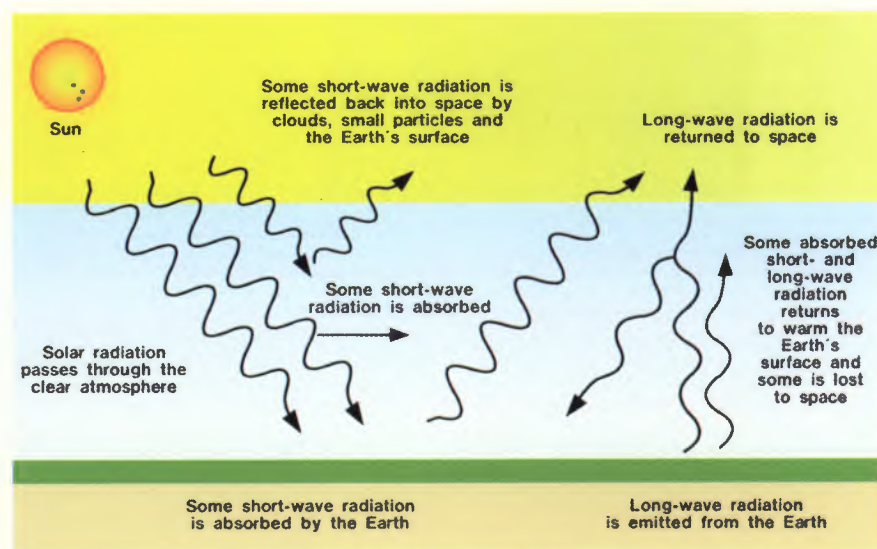


Figure 2.1 The greenhouse effect

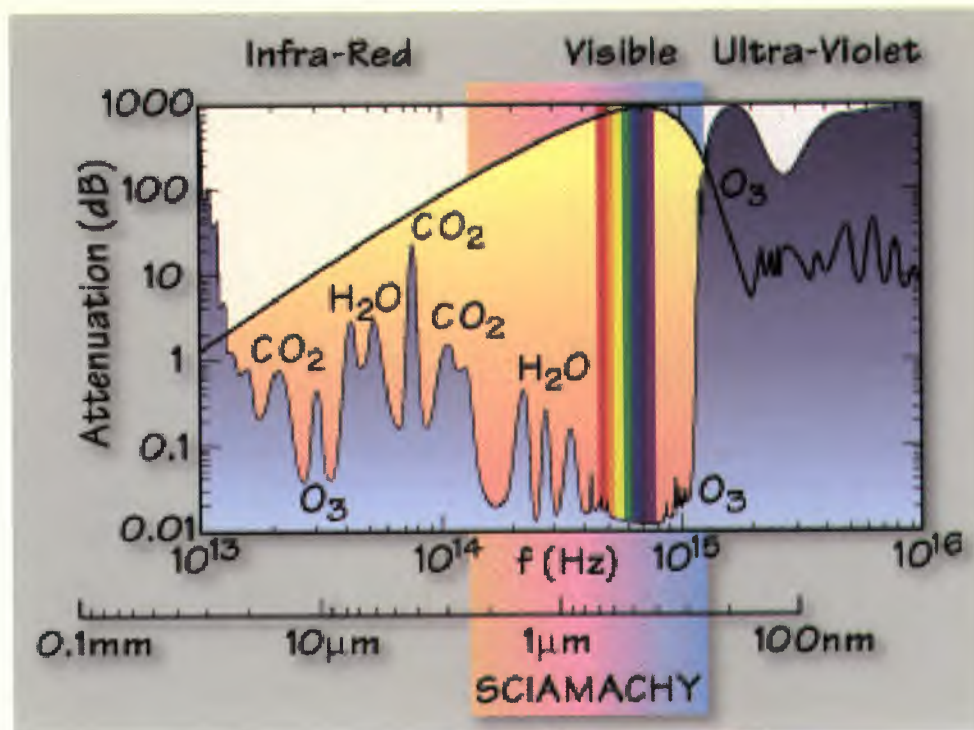


Figure 2.4 Absorption spectra for selected gas molecules and spectral region sensed by SCIAMACHY
(Acknowledgment: IFE Bremen, Germany)

Sensor	Product Type
GOMOS	Vertical concentration profiles of O ₃ , NO ₂ , NO ₃ , O ₂ , H ₂ O, (OCIO and BrO during ozone hole conditions), aerosol extinction coefficients, temperature, atmospheric turbulence, polar stratospheric clouds, (noctilucent clouds).
MIPAS	Vertical concentration profiles of around 20 relevant trace gases including primary species: O ₃ , H ₂ O, CH ₄ , N ₂ O and HNO ₃ , also temperature, distribution of aerosols, tropospheric cirrus and stratospheric ice clouds (including polar stratospheric clouds).
SCIAMACHY	Vertical concentration profiles of - in the troposphere: O ₃ , O ₄ , N ₂ O, NO ₂ , CO, CO ₂ , H ₂ O, CH ₄ , (HCHO, SO ₂ , in polluted conditions) in the stratosphere: O ₃ , O ₂ , O ₄ , NO, NO ₂ , CO, CO ₂ , H ₂ O, CH ₄ , volcanic eruption: SO ₂ and Ozone hole conditions: OCIO, ClO. Aerosol parameters, cloud measurements, pressure and temperature measurements.
MERIS	Aerosol optical thickness and type, cloud reflectance, cloud top height, water vapour column abundance.
AATSR	Cloud parameters: cloud type, water/ice discrimination and particle size distribution, aerosol distribution.
MWR	Water vapour and liquid water content of atmosphere.

Table 2.1 Atmosphere constituents measured by Envisat

Figure 2.6 shows a global map from GOME and provides an indication of the type and quality of data which will be acquired from SCIAMACHY. GOME is a precursor to SCIAMACHY; observing the atmosphere in nadir sounding only and having four spectral channels, as opposed to the eight channels of SCIAMACHY (Figure 2.7). The complex scenario associated with ozone depletion necessitates the study of a wide range of stratospheric phenomena. Understanding the role of Polar Stratospheric Clouds (PSC), their relationship with water vapour content and the crucial role they play in the chemistry of chlorine, is just one such area.

In order to model the ozone destruction processes it is important to relate the measurements to altitude. Total column measurements have value with regard to the amount of harmful ultraviolet radiation reaching the ground surface. However, vertical profiles of ozone concentration are needed to derive information about the creative and destructive processes involved. The main atmospheric sensors on Envisat will routinely provide data on constituents, resolved by height with vertical resolutions between 1.7 km and 3 km.

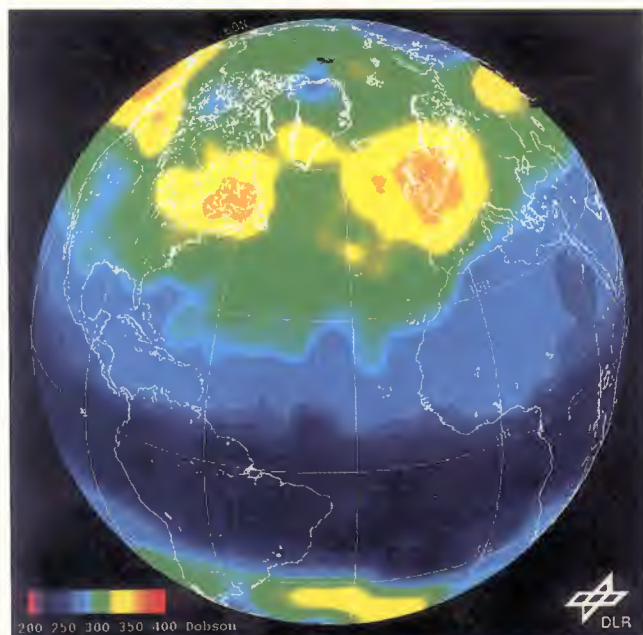


Figure 2.6 First operational GOME total column ozone map 5 - 7 July 1996.
(Acknowledgment: DLR, Oberpfaffenhofen, Germany)

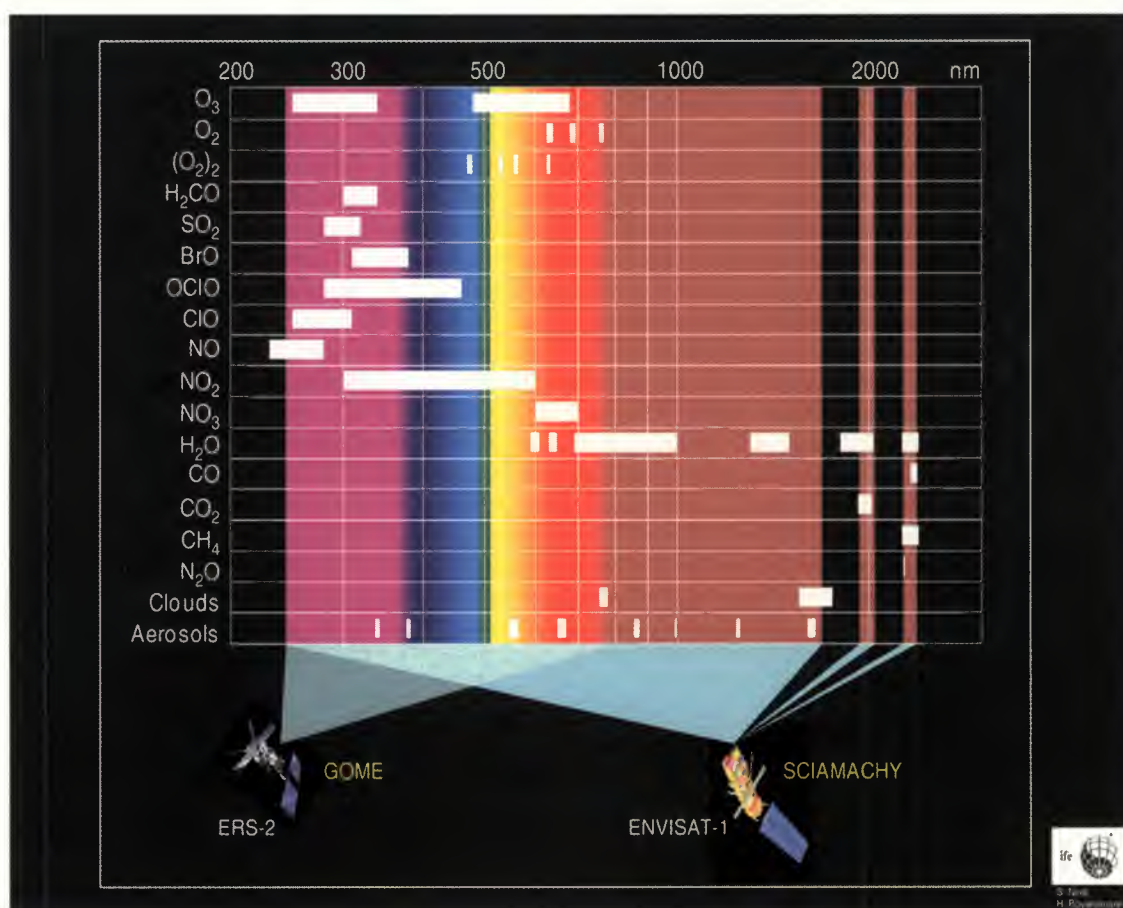


Figure 2.7 A comparison of the wavelength coverage of GOME and SCIAMACHY
(Acknowledgment: IFE, Bremen, Germany)

2.3 Troposphere

Monitoring the troposphere provides further insights into the nature of human interaction with the atmosphere. Critical issues within the troposphere include the description of cloud types, temperature profiles, water vapour profiles, amounts of methane and other man-made pollutants released.

In the lower troposphere, increase in ozone is a major concern, brought about by increased levels of nitrogen oxides and hydrocarbons. Whilst mostly associated with industrial activities in the northern hemisphere, elevated tropospheric ozone levels also occur in the southern hemisphere as a consequence of biomass burning. Although it is clear that the levels of carbon and nitrogen in the atmosphere are increasing as a result of man's activities, more information is needed to help model the processes involved. Such information will provide support for a variety of studies including, for example, the effect of higher levels of carbon and nitrogen in the atmosphere on plant growth, due to increased atmospheric fertilisation. Figure 2.9 shows global NO_2 levels derived from GOME measurements.

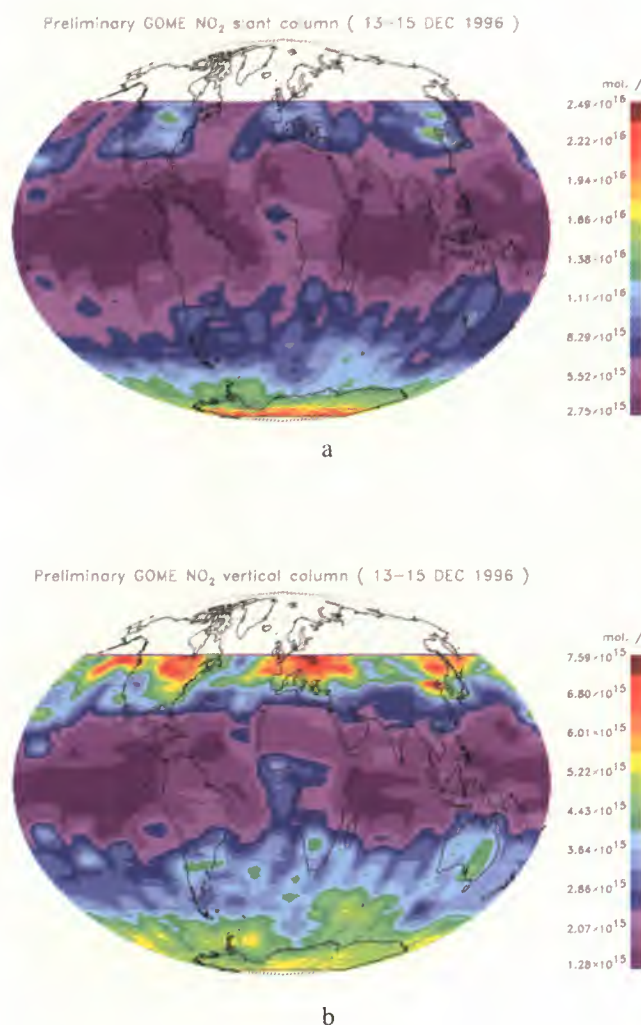


Figure 2.9 NO_2 Levels Derived from GOME
(Acknowledg^{mt}: Ricarda Hoogen, IFE, Bremen, Germany)

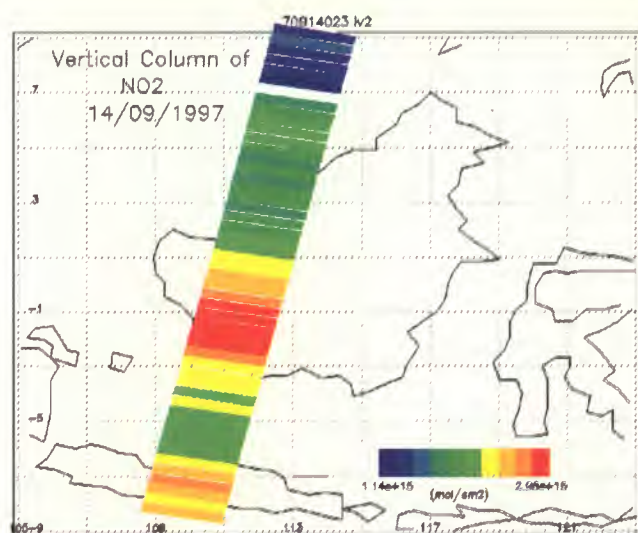


Figure 2.10 Total column NO_2 measured by GOME over Indonesia, showing high values over the forest fires in south west Kalimantan, 14 September 1997.
(Acknowledgment: S. del Corso, ESRIN)

Figure 2.10 demonstrates the ability of GOME to identify anthropogenic pollutants at a regional scale, in this case caused by forest fires in Kalimantan.

Sensors onboard Envisat will provide information about clouds, temperature and pressure, in support of data produced by operational meteorological satellites. The provision of near real time data is especially relevant in this context. Data from Envisat sensors will contribute to medium term forecasts through the incorporation of these data into operational models.

The impact of air traffic on the atmosphere, and specifically the effect of NO exhaust emissions on the production of ozone in the upper troposphere, is a significant scientific issue which also receives both media and political interest. The distribution of NO in the upper troposphere depends on a number of sources: lightning, anthropogenic pollution, downward movement from the stratosphere and aircraft exhaust. Given that NO production by aircraft is concentrated along air traffic corridors, this may provide the opportunity to acquire more data about the associated chemical and dispersion processes.

MIPAS will provide data relevant to upper tropospheric chemistry and will support the analysis of NO emissions from aircraft exhaust in air corridors. SCIAMACHY is a particularly capable instrument for acquiring data from the lower part of the troposphere and has the potential to detect biomass burning, biogenic emissions, pollution incidents over populated regions, production of oxides of nitrogen by lightning, Arctic haze, forest fires, dust storms and industrial plumes. In nadir viewing, O_2 , O_4 , and CO_2 absorption will provide estimates of cloud top height.

2.5 Earth Radiation Budget

Processes in the atmosphere which alter the Earth's radiation budget need to be better understood. To achieve this it is necessary to monitor certain trace gases and other constituents such as aerosols, whose temporal changes affect the Earth's climate by modifying radiative transfer. Long term global measurements will improve current assessments of changes in the abundance of ClO_x , HO_x , and NO_x which are associated with decreases in stratospheric temperatures through their impact on radiative transfer in the atmosphere. Observations on the extent of radiative cooling of the atmosphere can be obtained from measurements of CO_2 and NO in the middle atmosphere.

Of particular interest, in the context of the "greenhouse effect", is the transportation of water vapour from the surface of the Earth into the free troposphere. Whilst climate models have suggested that this is a phenomenon associated with global warming, there is no firm evidence suggesting that the free troposphere is becoming more moist and therefore providing the positive feedback necessary to stimulate global warming to the levels being suggested. In terms of radiation budget, water vapour is the most important atmospheric gas in the context of cloud amount, precipitation and evaporation rates. Even small changes in global measurements of cloud albedo will have a significant effect on the Earth's radiation budget.

MERIS contributes to this work by providing information on cloud amount, cloud top height, cloud optical thickness, water vapour and cloud albedo, as well as the aerosol information discussed above. Cloud coverage and other parameters, including water/ice discrimination and particle size distribution, will also be available from the visible channels on AATSR. The MWR also produces total column measurements of water vapour and liquid water.

2.6 Dynamics and Stratospheric/Tropospheric Exchange

The distribution of the various trace gases, the thermal structure and the circulation in the atmosphere evolve as a result of complex interactions between radiative, chemical and dynamic processes. Insights into the dynamic nature of the atmosphere can be deduced from measurements of temperature and trace constituent species such as H_2O , CH_4 , N_2O and O_3 in the lower stratosphere. Understanding the processes controlling the exchange of gases between the troposphere and stratosphere demands reliable information on variations in the concentration and distribution of long lived species. Specifically, measurements of the concentrations of a number of trace gases, whose mixing ratios change significantly near the tropopause, provide the means of studying processes which are at present poorly understood. In this context ozone is a particularly useful tracer for measurements of exchange between the stratosphere and troposphere.

MIPAS and SCIAMACHY will provide complementary information on the indicator trace gases at (or near) the tropopause. These will be the best data routinely available from satellites for this area of research.

3. Oceans

The ocean exerts a major influence on the Earth's meteorology and climate through its interaction with the atmosphere. Understanding the transfer of moisture and energy between ocean and atmosphere is therefore a scientific priority. Better observations are needed, to improve the accuracy of forecasts for weather, marine conditions and climatic change.

Earth observation satellites have revolutionised the study of the ocean. They now provide detailed repetitive measurements over remote areas of the world, where previously there were only a limited number of (isolated) observations from ships and buoys. Microwave instruments, including SARs and radar altimeters, have a remarkable sensitivity to the roughness and height of the ocean surface, enabling the detection of ocean currents, fronts and internal waves, oil slicks and ships, as well as accurate measurement of sea level changes, wave height and wind speed. Optical instruments provide measurements of ocean colour and temperature, which are important indicators of phytoplankton, yellow substance (Gelbstoff) and suspended sediments.

Envisat, by including advanced SAR, radar altimeter, ocean colour and ocean temperature instruments together on the same platform, offers particularly exciting opportunities for synergetic measurements over the oceans. It will provide an improvement in measurement capability compared with ERS, together with possibilities for many new geophysical measurements. The simultaneous combination of MERIS ocean colour measurements with both AATSR sea surface temperature, and ASAR sea surface roughness is particularly exciting.

3.1 Ocean Topography and Circulation

Our knowledge of the ocean's central role in modifying climate, through its large heat capacity and transport mechanisms and the complexity of its interactions with the atmosphere and cryosphere, is insufficient for the accurate prediction of climate change (as a result of fluctuations in natural or anthropogenic forcings). For example, it is known that at least half of the excess energy input (i.e. the incoming solar radiation minus the infrared radiation to space) in tropical areas is carried towards the poles by the oceans, the other half being transported by the atmosphere. Quantitative estimates are coarse however and predictions of how such fluxes would be modified by 'enhanced

greenhouse forcings' are even coarser. The World Climate Research Programme (WCRP) includes very large oceanographic research programmes, such as WOCE and CLIVAR, focusing on this issue.

These programmes rely heavily on the availability of satellite altimetry data such as provided by the Geosat, Topex/Poseidon and ERS-1/2 missions. For example, Figure 3.1 shows data from ERS-1. Several satellites, operating in unison, allow the very precise, regular and quasi-global measurement of dynamic sea surface heights.

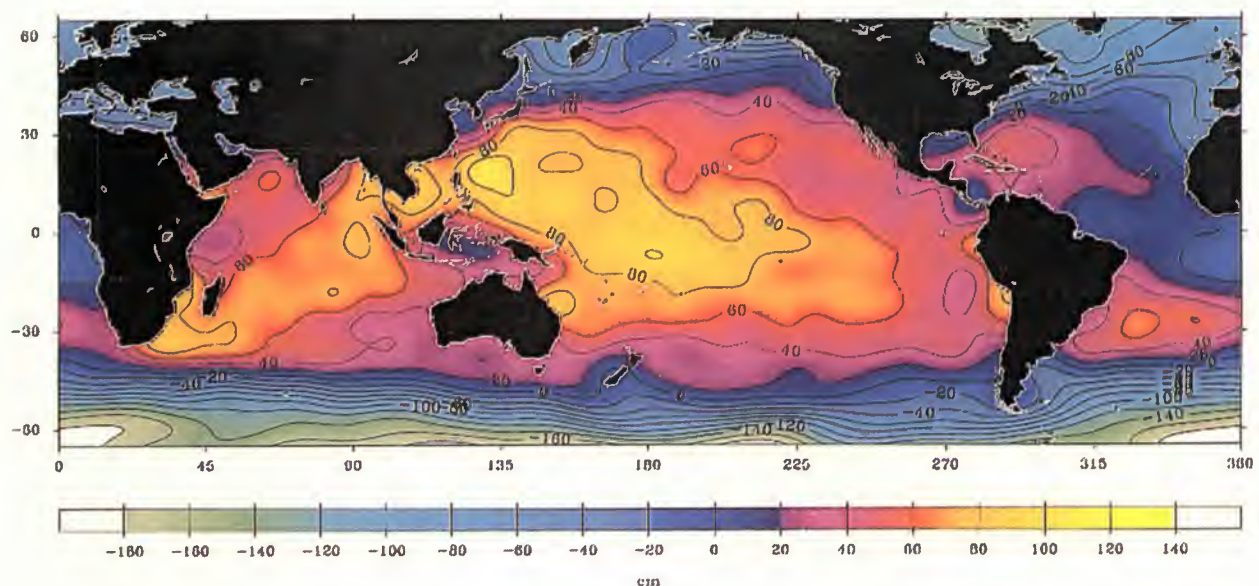


Figure 3.1 Global Ocean Topography: averaged topographic map as observed by the ERS-1 radar altimeter during a 35-day repeat orbit phase (Acknowledgment: B.Tapley, C.Shum, University of Texas at Austin, USA)

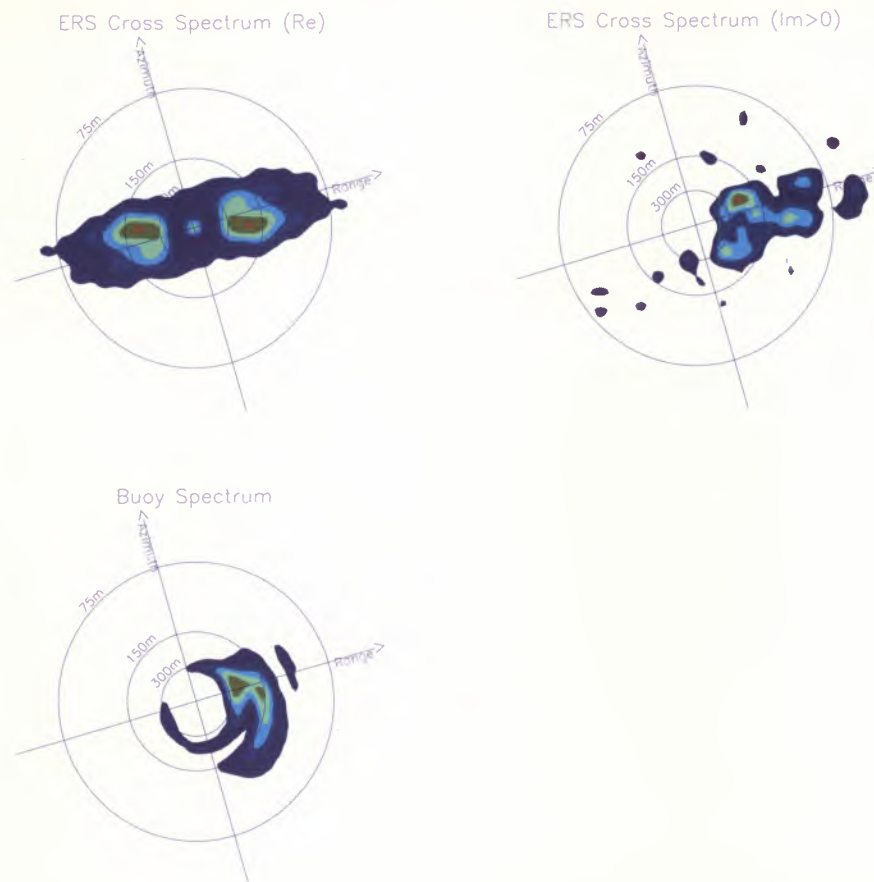


Figure 3.3 SAR ocean image cross spectra (real and imaginary part) processed from ERS-1 data using the Envisat ASAR Wave Mode Inter-Look Cross Spectra algorithm. The corresponding directional buoy spectrum is also shown (Acknowledgment: NORUT IT, Norway)

will continue to be vital for the study of mid-latitude mesoscale eddies and the impacts of high-latitude ocean and ice on seasonal and inter-annual climate predictability.

The RA-2 instrument offers improved measurement accuracy in comparison with the ERS RA, particularly with the improved tracker and through the use of DORIS data for more precise orbit determination. The second frequency channel at 3.2 GHz will enable height measurement corrections of the ionospheric effects on the signal. The near real-time products will include both this ionospheric correction and the tropospheric path correction using measurements from the MWR. Measurement accuracy after all geophysical corrections will be better than 3 cm in ocean mode.

3.2 Winds and Waves

Major features of the interaction between the ocean and the atmosphere are the creation of waves and ocean currents by surface winds. Wind and wave data are needed for climatological research, as inputs to meteorological models and for sea state forecasting in support of marine operations.

Envisat has two instruments, ASAR and RA-2, which will provide observations of surface waves and winds over the ocean. The ASAR Wave Mode will collect imagettes of minimum size 5 km x 5 km, similar to the ERS AMI Wave Mode, spaced 100 km along-track in either HH or VV

polarisation. The position of the imagette across track can be selected to be either constant or alternating between two across-track positions over the full swath width.

ERS Wave Mode products are based on image spectra (frequency and direction) estimated from SAR intensity imagettes using standard Fourier transform techniques. These products are therefore symmetric, with a 180° propagation direction ambiguity. Techniques have been developed involving the use of wave model predictions to solve the ambiguity problem, though this can be subject to error when opposite or near opposite wave components exist.

For ASAR, this problem will be solved by using a new wave product preserving the phase and a new algorithm called "inter-look cross spectral processing", whereby information on the wave propagation direction is computed from pairs of single-look images separated in time by typically a fraction of the dominant wave period. Figure 3.3 shows a simulated ASAR Wave Mode Spectrum, with the top left plot being the cross spectrum real part (symmetric and equivalent to an ERS product), and the top right plot the new imaginary part (asymmetric giving wave propagation direction). In this example, the output from the new algorithm is seen to correspond with the wave direction provided by buoy measurements, as shown in the lower plot.

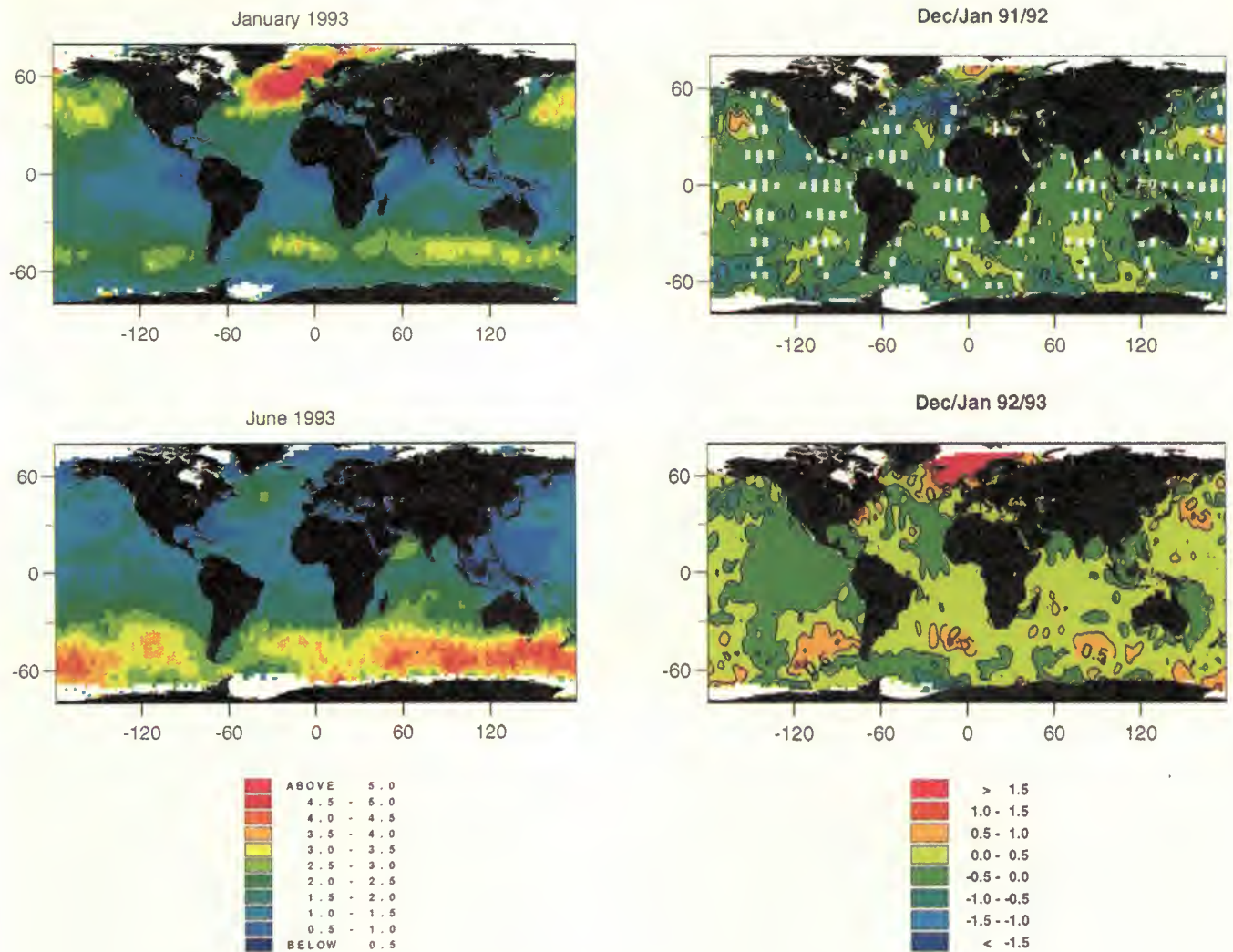


Figure 3.5 Measurement of global ocean wave height using the ERS Radar Altimeter.

- a) Seasonal variations in wave height between January and June 1993. The high values shown in the North Atlantic at the start of the year are seen in the Southern Ocean in the middle of the year.
- b) The difference in wave climate is shown for two years referenced against an average wave climate retrieved from Geosat data for 1987-88. In 1991-92, for example the lower than average values in the North Atlantic were replaced by higher than average values during the following year.

(Acknowledgment: D.Cotton, James Rennell Centre for Ocean Circulation, Southampton, UK)

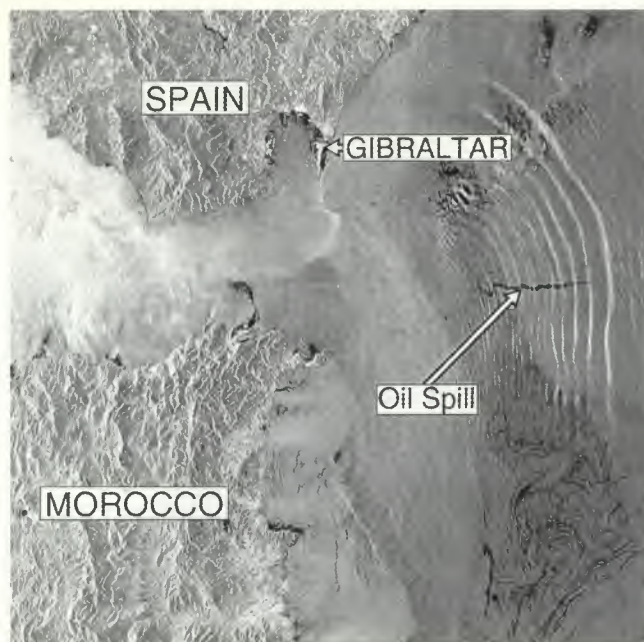


Figure 3.8 An ERS-1 image showing surface roughness patterns associated with an internal wave packet propagating eastwards in the Strait of Gibraltar (Acknowledgment: W.Alpers, C.Bruening, University of Hamburg, Germany)

Internal waves are undulations in the interface between layers of water of different density. They are caused by mechanisms such as the flow of water over sills in the Strait of Gibraltar, or tidal currents meeting coastal shelves. Their significance relates to the fact that internal waves can break at the ocean margin. This is an important cause of vertical mixing in the ocean and thus contributes to global water circulation. Observations of the spatial structure and propagation characteristics of internal waves is only possible by using SAR, as it is able to detect the surface roughness signature created by internal waves (Figure 3.8).

3.4 Atmospheric Effects on the Sea Surface

The local variability of sea surface winds can produce distinctive patterns in sea surface roughness patterns which are more readily revealed by SARs such as the ASAR than by optical instruments. ASAR will provide similar images to the ERS-1/2 SAR. The type of atmospheric features seen on images include:

- Tropical cyclones and monsoons
- Storm structures
- Katabatic winds and convective cells
- Atmospheric gravity waves
- Atmospheric boundary layer rolls

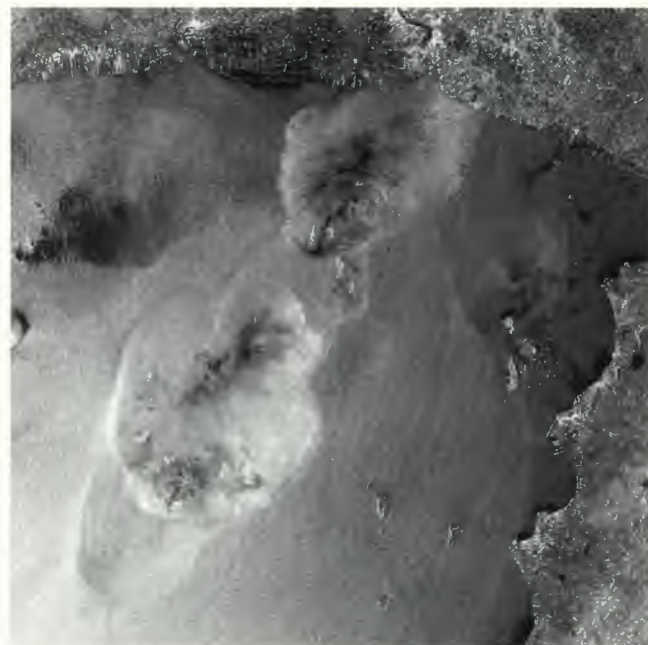


Figure 3.9 ERS-1 SAR image of the Gulf of Thailand showing footprints of thunderstorm clouds (Acknowledgment: Lichtenegger, 1996)

Figure 3.9 shows an example from the Gulf of Thailand in which the footprints of thunderstorm clouds are clearly seen (Lichtenegger, 1996). SAR is highly sensitive to changes in surface roughness of the sea caused by the wind (both wind strength and direction). Higher intensity brightnesses are seen where wind downdrafts impact on the sea surface. Zones of sudden change of wind speed and direction, so-called 'wind fronts' outline the presence of single thundercloud cells in the image. By analysing these wind fronts one can identify up to six cloud cells in this particular example.

There are limitations, of course, in the use of SAR for analysing weather phenomena. Such phenomena are only present under certain atmospheric/oceanic conditions, but when identified they allow detailed studies of the atmospheric boundary layer process to be carried out. This is not possible using in-situ measurements, because of lack of sufficient coverage.

3.5 Ocean Bio-Physical Properties

Open Ocean

There remain major uncertainties about the amount of carbon stored in the ocean and the biosphere, and about the fluxes between these reservoirs and the atmosphere. In particular there is an important need for better information on the spatial distribution of biological activity in the upper ocean and its temporal variability, especially in the case of oceanic phytoplankton biomass, which has an important role in fixing CO₂ through photosynthesis. In the upper layers of the open ocean, chlorophyll concentration is the most convenient index for phytoplankton abundance and this can be measured using the visible part of the spectrum.

“The remote measurement which has caused the greatest interest within the JGOFS (Joint Global Ocean Flux Study) is the estimation of basin and global-scale variability in the concentration of chlorophyll in the upper ocean. The images of the global distribution of these pigments, derived from data taken by the coastal zone scanner (CZCS) on board the United States’ Nimbus-7 spacecraft, have revolutionised the way biological oceanographers view the oceans. For the first time, the blooming of the ocean basins in spring has been observed, as has the extent of the enriched areas associated with the coastal ocean.” (International Geosphere-Biosphere Programme (IGBP) *A study of Global Change*, Report No. 12, 1990).

Although CZCS, launched in 1978, was intended as a one year proof of concept mission, the sensor continued to transmit data over selected oceanic test sites until early 1986. Figure 3.11 shows examples of CZCS chlorophyll maps of the Earth and the Mediterranean Sea.

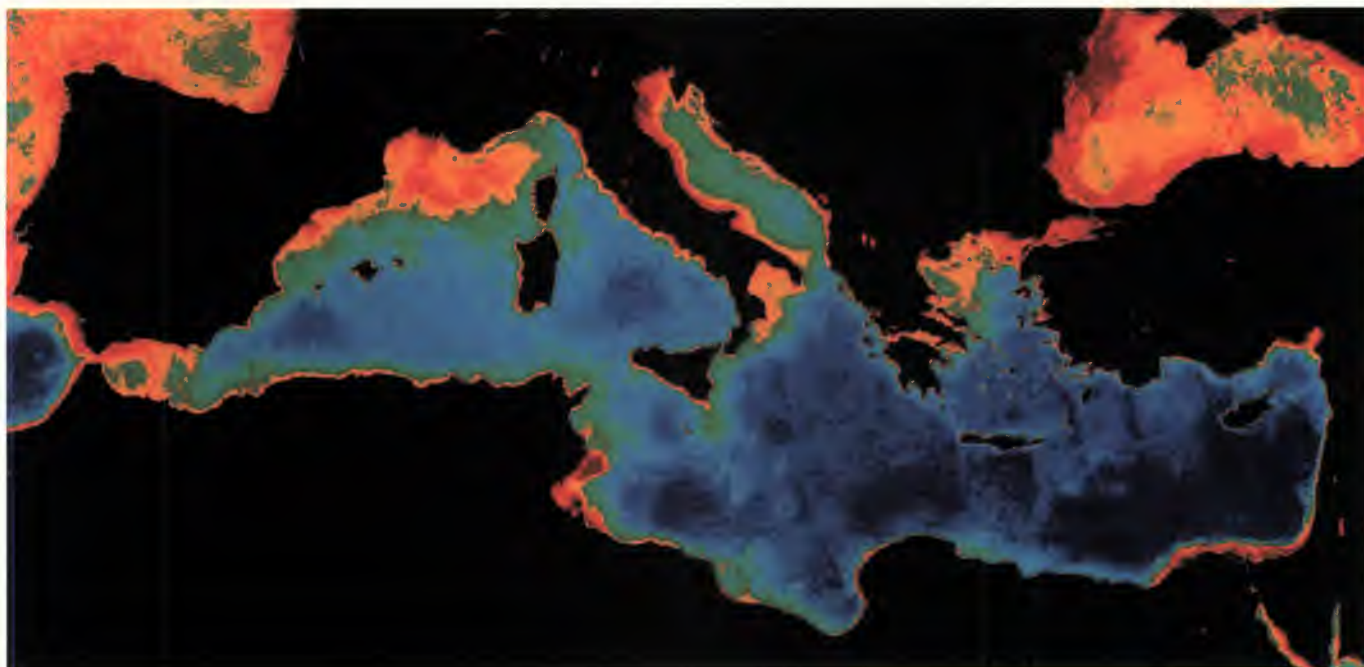
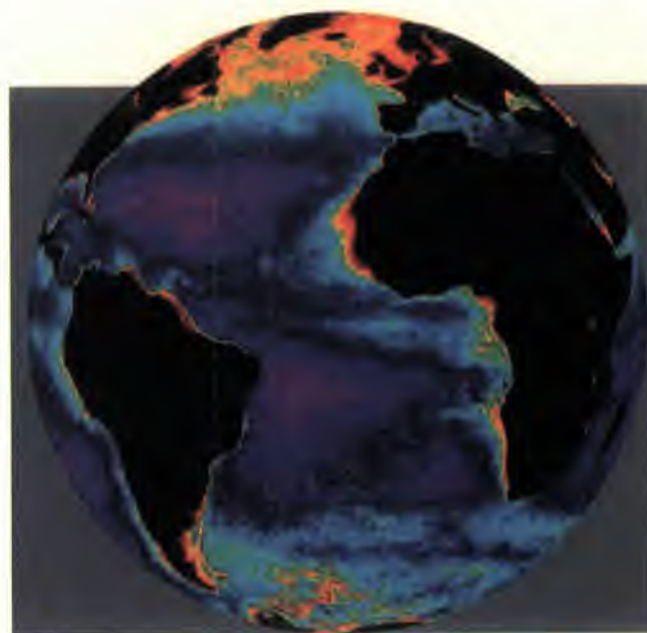


Figure 3.11 CZCS Chlorophyll Maps of the World and the Mediterranean produced by the ESA/JRC Ocean Project.

No.	Band centre (nm)	Bandwidth (nm)	Application
1	412.5	10	Yellow substance and turbidity
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll and other pigments
4	510	10	Turbidity, suspended sediment and red tides
5	560	10	Chlorophyll, suspended sediment
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence, red edge
9	705	10	Aerosol, red edge transition
10	753.75	7.5	Oxygen absorption reference band, vegetation
11	760	2.5	O ₂ absorption R-branch
12	775	15	Aerosol, vegetation
13	865	20	Aerosol
14	890	10	Water vapour, vegetation
15	900	10	Water vapour

Table 3.1 Nominal MERIS Spectral Bands

MERIS is a flexible programmable imaging spectrometer with the capability to observe the Earth over the entire spectral range from 390 to 1040 nm, at a resolution of 2.5 nm. The 15 band configuration with which MERIS will be flown will be finalised during the course of the algorithm development phase though this configuration may be modified further during the commissioning phase. Table 3.1 shows the current nominal set of spectral bands, together with the width of each spectral band, and its main application.

Coastal Waters

The coastal regions are the most populated areas in the world and coastal waters are highly affected by human activities. These marine ecosystems are subject to biogeochemical forcing, due to the influx into the coastal seas of pollutants from rivers and the atmosphere, which inhibit or stimulate marine productivity. In addition, large amounts of agricultural and industrial pollutants and sewage are discharged into these waters.

Continuous long term observations of coastal waters, which cover more than three million square kilometres, is most important for climate impact studies and for environmental monitoring. Remote sensing measurements from satellite are the only available means for providing us with a synoptic view of such large areas of water.

The major water constituents, which determine the marine and estuarine ecology and the bio-geochemical budget and whose concentration and distribution can be determined by optical remote sensing, are suspended matter, phytoplankton and Gelbstoff.

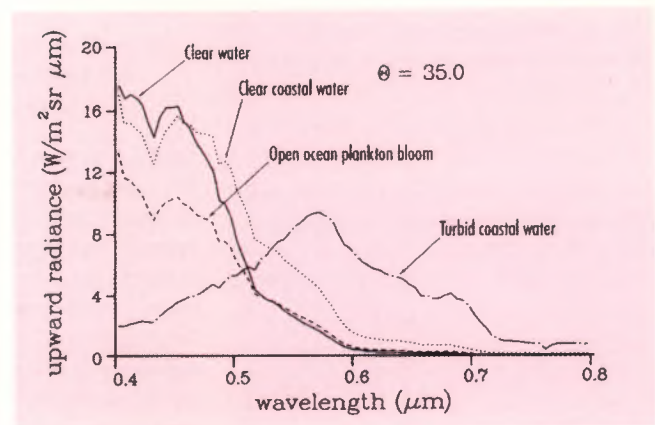


Figure 3.14 Simulated multispectral radiances for a spectral resolution of 5 nm just above the water surface.

Suspended matter is defined as a combination of:

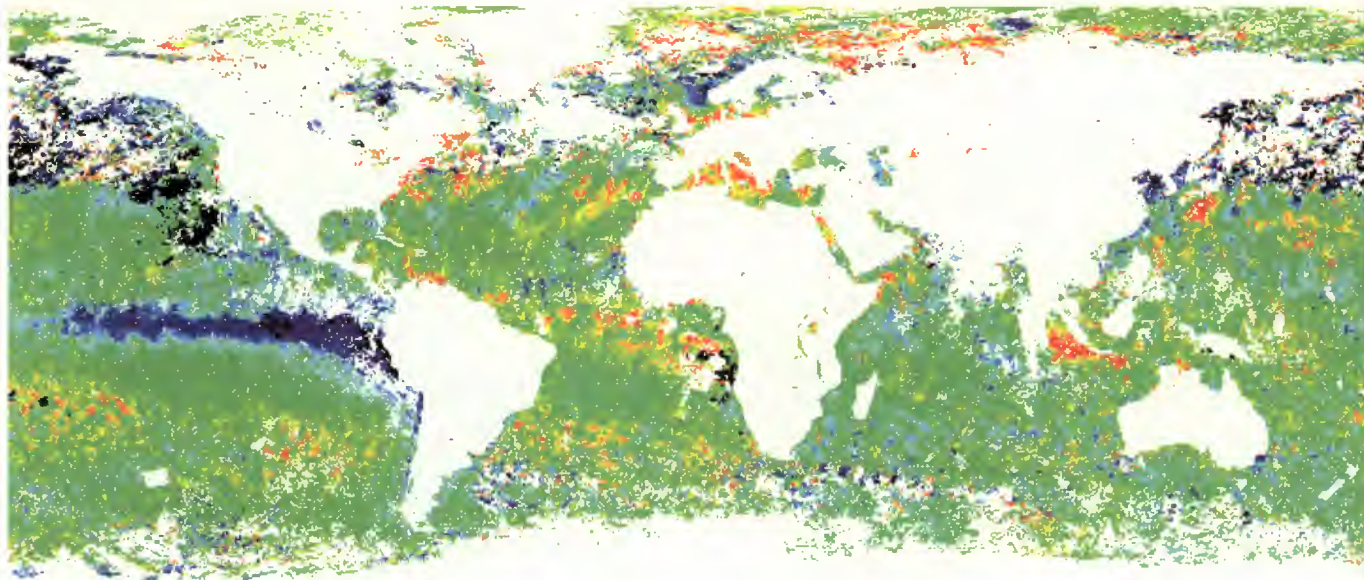
- inorganic particles and detritus, present due to re-sedimentation and advection processes
- atmospheric inputs
- dead material of plankton

Gelbstoff consists of various polymerised dissolved organic molecules which are formed by the degradation products of organisms. These originate in brackish and underground water as well as in extraordinary plankton blooms. All these constituents have different optical properties, but there are similarities in their spectral scattering and absorption coefficients.

The upward radiance at any visible wavelength is composed of contributions from all these substances. Figure 3.14 shows simulated multispectral radiances for different ocean waters. Suspended matter usually enhances the upward radiances through reflection within the visible spectrum, while Gelbstoff reduces these radiances mainly in the blue.

To convert from the optical properties of the water constituents, used in the radiative transfer model, to pigment or suspended matter concentration units, robust algorithms have been developed with global applicability. The accuracy of derived oceanic properties depends strongly on the precision of the atmospheric correction procedure.

The development of inverse modelling techniques for the interpretation of MERIS measurements is an ongoing process. For monitoring coastal regions world wide, precise multispectral radiances, with contemporary optical and concentration measurements of the water constituents, are needed. As well as the chlorophyll concentration and several atmospheric parameters, planned geophysical products include total suspended matter and yellow substance concentration.



*Figure 3.17 Global SST differences between July 1995 and July 1997, showing temperature increase of 3° - 6°C in the eastern Pacific (in blue)
(Acknowledgment: P. Goryl, ESRIN)*

Interactions between the atmosphere and the circulation of currents around the globe involve the transfer of vast amounts of energy which can only be effectively monitored by remote sensing from space. AATSR will continue to increase knowledge of the processes reflecting the way in which the oceans, as reservoirs of heat, dominate the weather systems which are critical to life on the planet. A good example is the El Niño anomaly in the tropical east Pacific, where a change in atmospheric circulation is reflected in the pattern of SST distribution in this area (Figure 3.17). In addition to changes in the local and global climate, there are more specific impacts of El Niño, for example, the way the economic life style of populations in adjacent countries is affected through the wholesale displacement of fishing grounds. The accuracy of AATSR data makes it a unique source of information for this type of research.

Sea surface temperature information helps resolve many phenomena associated with the ocean circulation, such as mesoscale eddies, meanders, coastal currents and upwelling.

AATSR data are applicable to research into fishing as a global source of nutrition for an ever expanding human population. The propensity of fish to be found at fronts between warm water and cold upwelling water containing food sources, demonstrates the value of SST measurements derived from AATSR. Moreover, the analysis of SST trends can be of assistance in deriving information on the migration of marine species. Pre-operational fishery support systems have been developed, for example ESA SeaSHARK for processing SeaWiFS and AVHRR data.

3.7 Coastal Bathymetry and Sediment Movements

Knowing the shape of the sea floor is vital for shipping, fisheries and off-shore activities. It is also needed for the calibration and validation of morphodynamic models which are being developed to forecast changes in sea-bed topography linked with sediment transport, river deposition and coastal erosion. Traditional bathymetric surveys conducted by ship are time consuming and expensive. Assessments have shown that the efficiency of bathymetric surveys can be improved by combining traditional measurements and models with SAR data. SAR images of the water surface can be used to estimate the shape of the sea bed in shallow waters, typically less than 30 m deep. Interactions between tidal flows and the sea floor cause modulations in the surface current velocity. These modulations lead to local variations in the spectrum of short gravity waves at the ocean surface or the surface roughness, which show up as intensity variations in SAR images.

ASAR will have a much improved capability for oil slick monitoring, because of its higher sensitivity in the far range. Wide Swath Mode is of particular interest, because of its potential for more frequent large area coverage than Image Mode. It has been difficult to justify the development of operational surveillance systems based on the 35 day repeat cycle of ERS. The 3 day repeat possible using the Wide Swath Mode is much more appropriate. Some of the operational systems currently used for ERS data employ techniques to reduce the spatial resolution from 25 m to around 100 m, so the 150 m resolution in Wide Swath Mode is expected to be appropriate for this application. The optimum polarisation will be VV, because there is less contrast between slicks and the ocean with HH polarisation.

3.9 Ship Traffic

The ERS programme has demonstrated the potential of SAR data for ship detection and prototype systems have been developed, not just to identify ships automatically, but also to distinguish between different types of vessel and to determine the speed and direction of motion. However, ship detection with ERS data was limited because of the low incidence angles.

ASAR will have improved capability because of the higher incidence angles and dual polarisation. As illustrated in Figure 3.20, ERS roll-tilt mode images, obtained at high incidence angles are better for the detection of large ships and fishing vessels. Outer ASAR standard beams, therefore, will be best for ship detection, although this is countered somewhat by the fact that imaged swaths become narrower at higher incidence angles. Also, cross polarised images in the Alternating Polarisation Mode should further improve detection capability at steeper incidence angles.



Figure 3.20 ERS roll-tilt image (i.e. incidence angle range 33° to 37°) showing ships in the North Sea close to Rotterdam harbour. This image, produced by the ASAR generic processor, shows the expected ASAR performance at higher incidence angles. (Acknowledgment: P. Lim, P. Meisl, MDA)

4. Land

The Earth's land surface is a critical component of the Earth system as it carries over 99% of the biosphere. It is the location of most human activity and it is therefore on land that human impacts on the Earth are most visible. Within the biosphere, vegetation is critical as it supports the bulk of human and animal life and largely controls the exchanges of water and carbon between the land and the atmosphere.

Observations of the land surface by Envisat will allow the characterisation and measurement of vegetation parameters, surface water and soil moisture, surface temperature, elevation and topography. Global scale measurements (1 km resolution) will provide critical data sets for improved climate models, in particular estimates of albedo, vegetation productivity and land surface fluxes.

Envisat also provides managers of local natural resources with a capability to monitor their land with detailed (selective) observations on a monthly basis. In particular, ASAR provides 30 m spatial resolution multi-look images for monitoring economically important land units, such as agricultural fields and forest compartments. Natural resources can also be monitored at global and regional scales every few days using the low resolution imaging of MERIS, AATSR and the ASAR Global Mode.

The relatively high frequency of global coverage provided by Envisat is also of great value for hazard monitoring, in which locally infrequent events such as earthquakes, volcanic eruptions, floods and fires, require intensive observation over short periods. The beam steering mode of ASAR (in conjunction with its independence from cloud and illumination conditions) will also permit (at least) 3-day repeat observation of certain localised events at high spatial resolution. Whilst locally rare, certain natural hazards are frequent events on a global scale, thus they can have substantial effects on climate, especially large vegetation fires and volcanic dust clouds. Hazard monitoring is therefore an important component of the Envisat mission.

4.1 Global Land Cover

A major scientific uncertainty in global change research is the cycling of carbon in the Earth system. It is well known that CO₂ contributes to the greenhouse effect and that over the last few centuries increased human activity, especially the burning of fossil fuels and deforestation, have resulted in an increase in the release of CO₂ into the upper atmosphere. Much of the estimated anthropogenic CO₂ emission cannot currently be accounted for, indeed there is an order of magnitude uncertainty in the global carbon budget.

Critical to this carbon accounting activity is global vegetation monitoring. Figure 4.1 shows a global land cover product, and Figure 4.2 a forest map of S.E Asia, both derived from 1 km AVHRR data. The narrow bands of MERIS will make it possible to derive more accurate global maps and more effective vegetation indices than have previously been available. From physically based vegetation indices it is then possible to retrieve key variables in modelling plant productivity (and thus carbon sequestration), surface-atmosphere gas exchanges and energy transfers at the land surface.

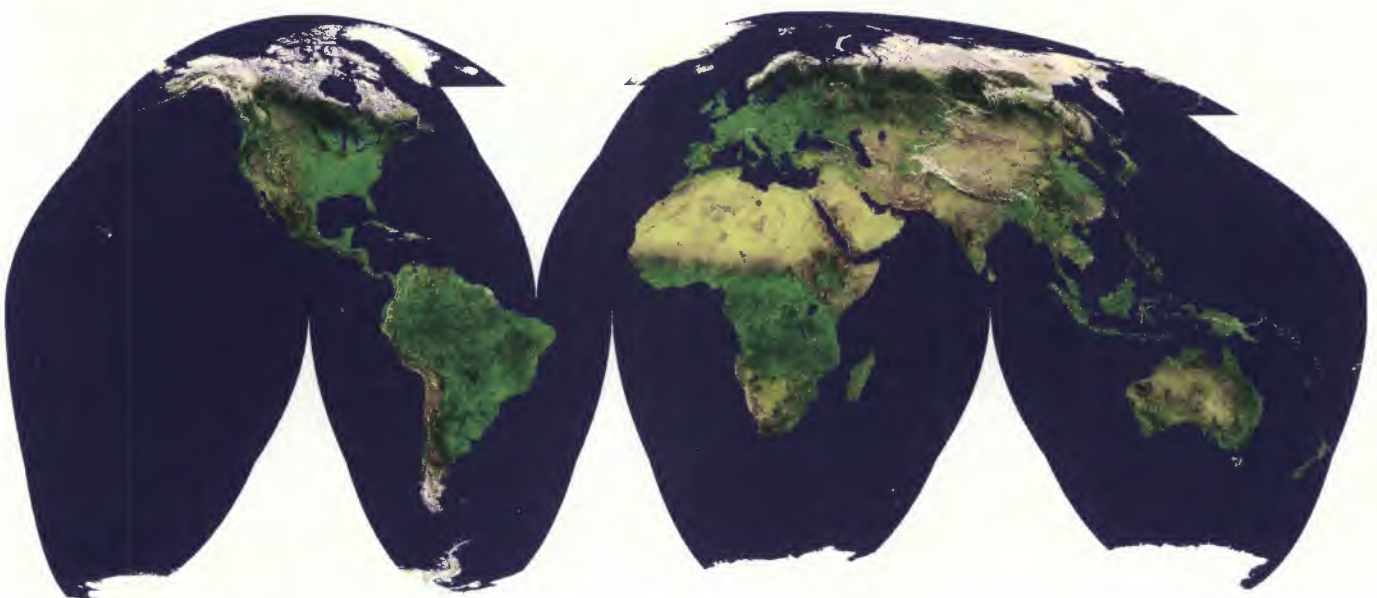


Figure 4.1 Global land cover map (Acknowledgment: IGBP Global Landcover Project)

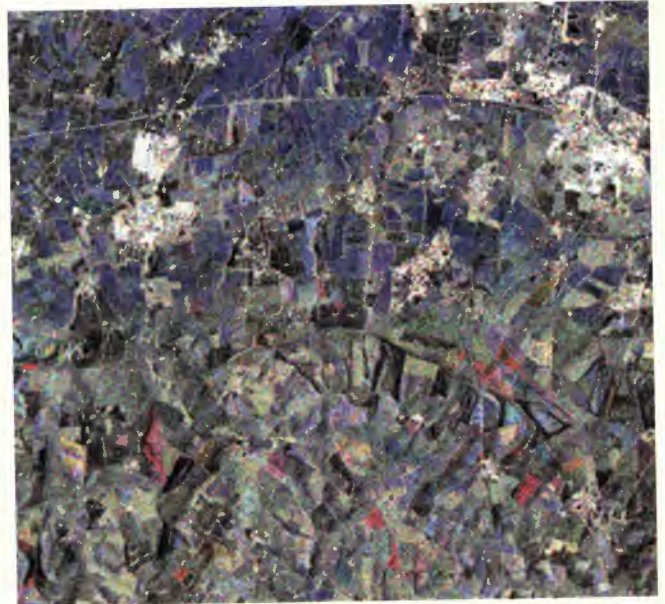
Besides the scatterometer image, the so-called Hovmoeller diagram shows a slice through Africa from 35°N to 35°S extending longitudinally from 20° to 26°E. Monthly averages of the radar intensity are plotted for 1991 to 1997. The predominant signal in the Hovmoeller diagram is the annual variation in radar backscatter in the savanna regions north and south of the rain forest and it can be seen how the seasonal backscatter patterns are repeated every year. The much better resolution of the ASAR Global Monitoring Mode will provide a significantly better capability for such continental or regional scale measurements.

4.2 Local Land Cover

For local land-cover mapping, ASAR high resolution products will continue the role already established for ERS SAR in complementing conventional optical images from other satellites, particularly under poor solar illumination conditions or in cloudy areas.

The new features of ASAR include image acquisitions at multiple incidence angles and with dual polarisation, which will open up new possibilities in land-cover classification from SAR.

Figure 4.5 provides an illustration of the use of multiple incidence angles to improve land cover discrimination for an area (18 x 17 km) near Oxford, UK. In this case 3 Radarsat images, taken within a period of 10 days have been combined (Blue - 23° - 23 March 97, Green - 37° - 13 March 97, Red - 43° - 3 March 97). Most of the coloured areas on the image, indicative of backscatter differences related to incidence angle, are bare soil fields, while grassland, woodland and urban areas tend to have grey tones, showing a similar backscatter at the different incidence angles. In the northern half of the area, which has clay soils, practically all bare soil fields have a blue colour indicating higher backscatter at the lowest incidence angle, as one would expect. In the southern half of the area which has chalk soils, some of the bare soil fields also have blue colours, but some of the fields coloured red are also bare soil fields and this seems somewhat of an anomaly. Possible explanations are that these fields have marked differences in soil roughness, or possibly that cultivation changes took place during the period over which the 3 images have been acquired.



*Figure 4.5 Multi-incidence angle composite for Thames, UK, produced from 3 Radarsat images
(Blue: 23° 23 March 97, Green: 37° 13 March 97, Red: 43° 3 March 97)
(Acknowledgment: Remote Sensing Applications Consultants, Alton, UK & Radarsat Data Copyright Canadian Space Agency/Agence spatiale canadienne 1997).*

4.3 Soil and Land Surface Properties

Information on the state of soil and land surface is critical for many purposes: global climate modelling, monitoring ecosystem dynamics, hydrological forecasting, water resources management, agriculture and forestry. Important instruments for measuring land surface properties at a global or regional level are the ASAR (in Wide Swath and Global Monitoring Modes), MERIS, AATSR and MWR.

Hydrology

Hydrology in particular will benefit from Envisat, as detailed spatial and temporal information on a wide range of land surface parameters is required in order to run physically based models and management scenarios. Major variables which can be derived from Envisat observations include land surface temperature, vegetation state, soil moisture, surface roughness and terrain. Much hydrological modelling is based on gridded data at around 1 km. Because of its narrower bands and improved radiometry, MERIS may be better suited for providing vegetation parameters for hydrology than other instruments such as AVHRR. Some hydrological applications require information on snow cover distribution and snow-water equivalent (see Section 5.4). Research is required on how to derive these variables from ASAR data at high incidence angles, particularly in mountainous terrain.

Land Surface Temperature.

Physical relationships link the land surface temperature (LST) to the evapotranspiration of vegetation canopies. Earth observation provides a unique source for global LST measurement.

It is expected that AATSR will make a significant contribution to the measurement of LST to the required accuracy of, typically, 1 K. The AATSR LST algorithm will rely only on nadir AATSR split window radiances.

Further research is required before the forward view AATSR data can be reliably incorporated into the algorithm.

Soil Moisture and Roughness

Previous research has demonstrated the relationship between soil moisture and SAR backscatter across a range of soil conditions (Le Toan et al, 1993). The use of multi-polarised and multi-incidence angle data available from ASAR should increase the accuracy of soil moisture retrievals at high resolution by reducing the effect of surface roughness and vegetation. There is however a constraint that the multi-angle images must be acquired within a short time period.

For regional/global soil moisture monitoring, the much improved revisit capability of the ASAR Wide Swath and Global Monitoring Modes (in comparison with what is possible with ERS in a standard 35 day orbit) is of particular interest. Figure 4.7 shows simulated Image, Wide Swath and Global Monitoring Mode images for an area of 20 x 17 km near Oxford, UK. This illustrates how land cover discrimination becomes progressively more difficult with decreasing resolution. Although the field pattern disappears from the Global Monitoring Mode image it is still possible to identify land cover units which might provide the basis for monitoring soil moisture changes (Zmuda et. al. 1997).

Lake Levels

Closed lakes provide a potential indicator of regional climate change. The enhancements in range gating provided with RA-2 will allow more effective monitoring of lake levels around the world, because this will eliminate the 'loss of lock' over small lakes which was experienced with the simpler ERS Altimeters.

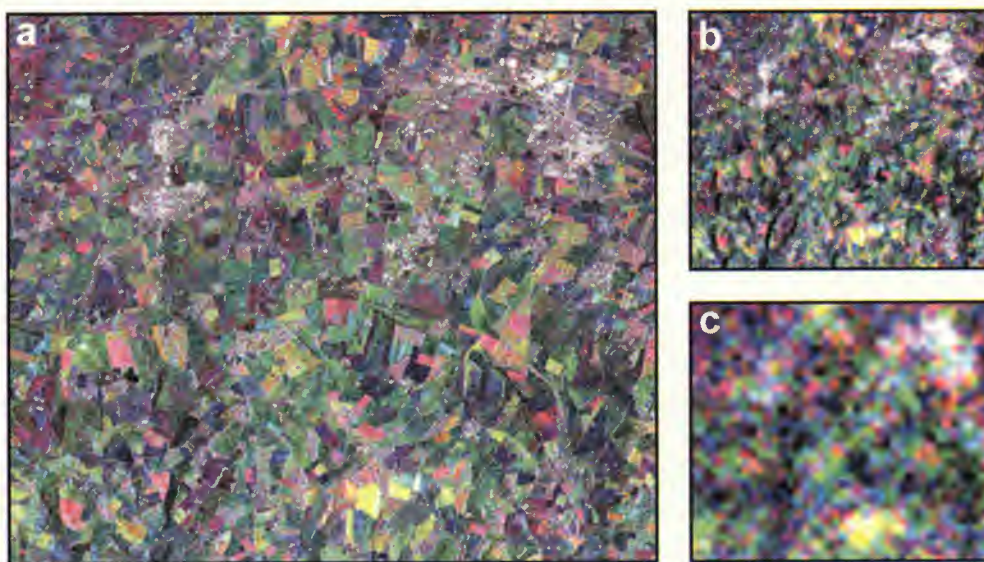


Figure 4.7 Simulated multi-temporal ASAR images:
a. Image Mode, b. Wide Swath Mode, c. Global Monitoring Mode
(Acknowledgment: Remote Sensing Applications Consultants, Alton, UK).

Mapping the area of crops, for the policing of subsidies and crop area inventories, is expected to continue as a primary application to be supported by Envisat. However, yield estimation techniques will also be improved through the availability of Envisat data. Regional yield estimation has been previously accomplished by exploiting the temporal curve of vegetation response obtained from satellite borne instruments such as AVHRR which have low spatial resolution but frequent revisit capability. This information is compared with previous years and combined with meteorological data and crop growth modelling to predict year-on-year yield variations.

MERIS will greatly improve the quality of the spectral information compared to AVHRR, as its spectral bands are narrower and less sensitive to atmospheric effects. MERIS calibration and atmospheric correction is also more accurate than AVHRR, and the spatial resolution is improved whilst still providing regional revisit every 3 days. Although the VIS/NIR bands on AATSR are broad, the superior atmospheric correction capability and multi-angle view will assist in improving estimates of bi-directional reflectance distribution functions for crop growth modelling. ASAR could also contribute to improved crop yield estimates and the identification of stress and disease in crops, particularly in very cloudy areas, but considerable research still needs to be undertaken to prove the potential of ASAR data in these areas.

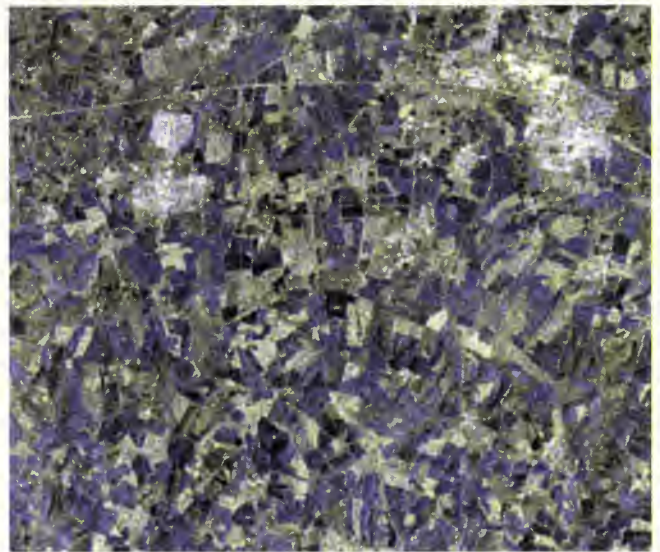


Figure 4.10 Simulated Alternating Polarisation image of an area in Oxfordshire, UK, based on the combination of ERS-2 and Radarsat images taken 1 day apart (Acknowledgment: Remote Sensing Applications Consultants, Alton, UK & Radarsat Data Copyright Canadian Space Agency/Agence spatiale canadienne 1997).

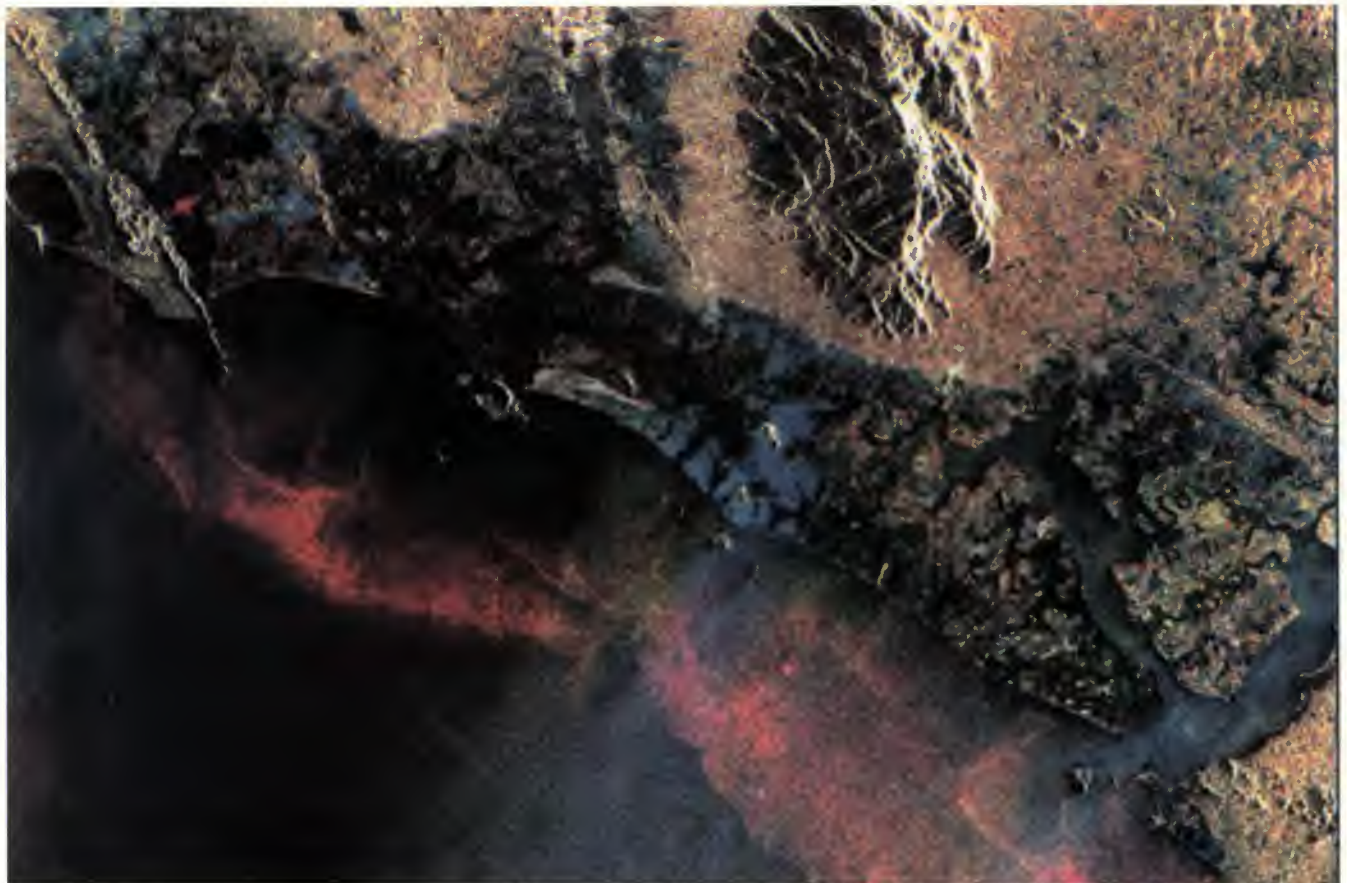
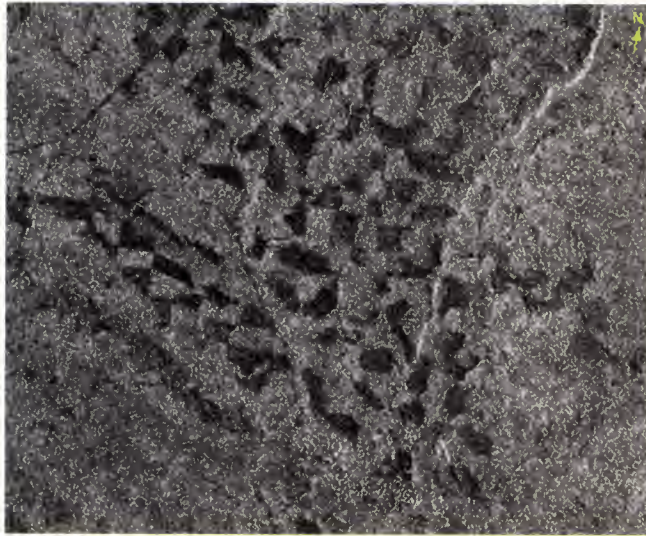


Figure 4.9 Mapping rice in Chantaburi, eastern Thailand. This composite image has been derived from 3 ERS SAR images acquired during 1993 (18 September, 23 October and 27 November). The rice growing area, shown in light blue, can be identified because, unlike the surrounding land, the backscatter from rice increases as the crop matures. (Acknowledgment: R. Schumann, ESA/AIT, Bangkok, Thailand)



*Figure 4.12 Radarsat images acquired at different incidence angles: a. 20° - 27°, b 45 °- 49°
(Acknowledgment: L.Gray, CCRS & Radarsat Data Copyright Canadian Space Agency/Agence spatiale canadienne 1997).*

Geological mapping

Geological mapping with SAR data has become well established and a number of organisations offer a commercial service to the oil and gas industry for mapping structures, but the effect of radar layover in hilly terrain prevents widespread use of the data. ASAR Image Mode with high incidence angles is therefore of particular interest as it can be used to reduce terrain distortion. Alternating Polarisation Mode may also be of value for texture analysis in arid areas. The synoptic view provided by Wide Swath Mode is of interest for looking at regional and continental geological structures.

Tectonics

The capability of ASAR for monitoring large scale tectonic motions of continental plate boundaries in unvegetated terrain could lead to new and important results. A very interesting problem to study could be the prediction of topographic changes resulting from tectonic motion.

Earthquakes

SAR can provide high resolution maps of co-seismic deformation generated by an earthquake (Figure 4.14). Geodetic networks undersample the deformation field and in any case, very frequent measurements are needed when strain accumulation is suspected. Satellite observations can help in the creation of a global data set to study the

statistics of Earth motion in connection with seismic phenomena. This could help in the prediction of the locations of future earthquakes. The temporal coverage needed is in the order of a day, and the cooperation of several wide swath satellites like ASAR and Radarsat could allow just that.

Volcanism

In addition to their important atmospheric consequences (see Section 2.4), volcanic eruptions are a serious local hazard which requires prediction. Vulcanologists will be able to use AATSR to assist ground observations and temperature measurements of volcanoes and large lava flows.

The ability to remotely sense volcano deformations would be an enormous benefit to volcano studies; SAR interferometry holds tremendous potential, but possible artefacts due to atmospheric effects have to be identified and, if possible, corrected. Volcanoes with vegetation cover cannot usually be studied using DINSAR due to loss of coherence. ASAR, in its global coverage and wide swath modes, will frequently be able to revisit volcano locations around the globe so that, if the technical problems can be overcome, a suitable data base could be available to monitor possible surface dilations on a daily basis, as an alarm for volcanic activity.

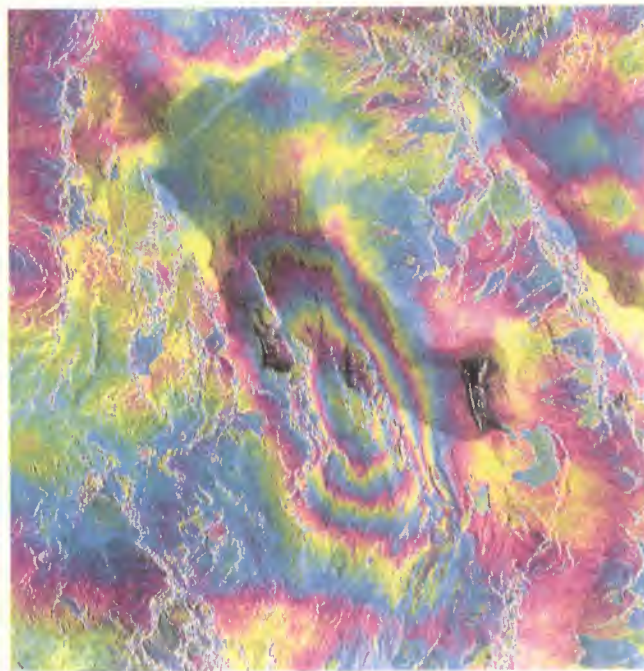


Figure 4.14 Interferogram derived from three ERS-1 images showing the results of an earthquake in Eureka Valley, California in May 1993. The interferogram clearly depicts elongated, concentric ring-shaped fringes resulting from the subsidence of the fault block overlying the inclined fault. The maximum displacement measured is 10-20 cm (Acknowledgment: G. Peltzer, JPL, Pasadena, USA)

4.8 Fires

Large vegetation fires are a major source of atmospheric pollutants and fire is a key indicator of anthropogenic activity and biomass destruction. In some ecosystems and economies, fire is a normal and locally beneficial phenomenon whereas in others it is a major hazard which needs monitoring. A number of environmental research programmes have an interest in fire monitoring at a global level (notably the IGAC core project of the IGBP) in order to monitor destruction of vegetation and assist with flux calculations of carbon and other elements which are sequestered in vegetation and released upon combustion.

The ATSR-2 instrument on ERS-2 has already demonstrated a capability for monitoring fires. ATSR-2 has a $3.7\ \mu\text{m}$ channel which corresponds to the peak radiative emission of fires. Figure 4.17 is an ATSR-2 image showing fires in Kalimantan, Indonesia, on 15 September 1997. The maps shown in Figure 4.18 have been derived from a time series of images taken over a three month period, during which the fires caused the well publicised severe smoke and haze problems across the region.

AATSR will provide continuity, and contribute with other sensors, such as MODIS and AVHRR, to improve the frequency of global fire monitoring.

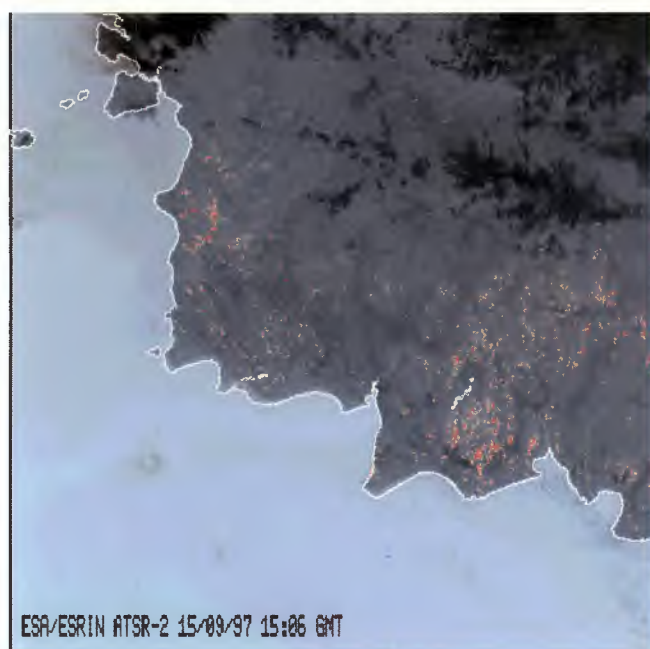


Figure 4.17 Fires in south west Kalimantan detected at night using ATSR-2 channel $3.7\ \mu\text{m}$, 15 September 1997.
(Acknowledgment: A. Bongiorno et al, ESRIN)

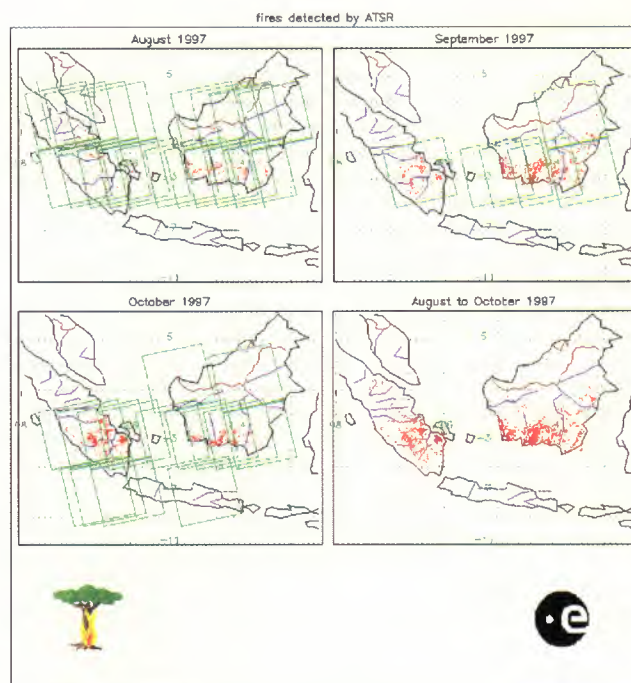


Figure 4.18 ATSR-2 mapping of fires in Kalimantan and Sumatra, August to October 1997.
(Acknowledgment: E. Antikidis and O. Arino, ESRIN)

5. Cryosphere

The hostility, remoteness, winter darkness, rough weather conditions and frequent cloud cover of the high latitude ice covered regions, make the use of earth observation data well suited for monitoring ice cover. The ERS satellites have already proved the all weather capability of SAR and radar altimetry for collecting data at high latitudes and have, for example, produced the first reliable high resolution coverage of sea ice regions.

5.1 Sea Ice

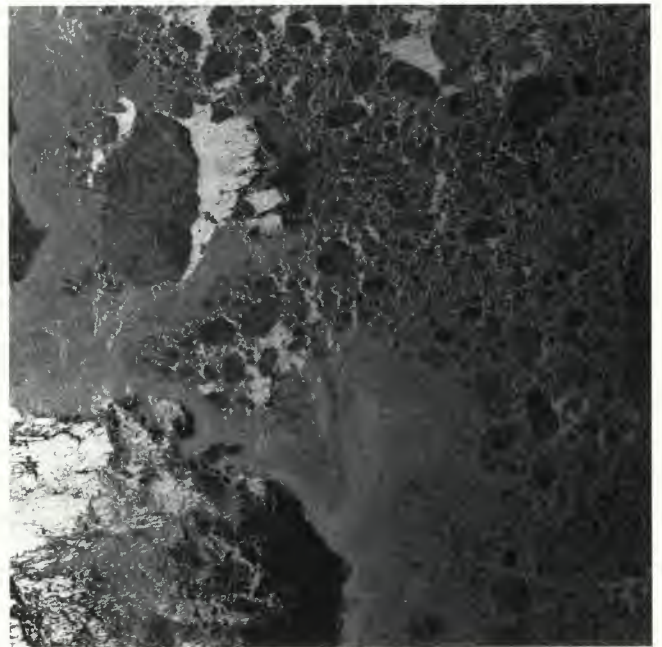
The long term monitoring of sea ice extent and thickness in Arctic and Antarctic regions, provides a sensitive indicator of climate change. In addition, the seasonal and annual sea ice changes influence the Earth's albedo and fresh water cycle in the shorter term. It is necessary to monitor sea ice at a global level for climate change studies and also, more locally, to advance understanding of the processes involved. Information about sea ice is also required to satisfy operational needs for navigation, offshore operations and weather forecasting.

The Envisat sensors will ensure the continuity of data supply following on from those onboard ERS, with the exception of the scatterometer derived sea ice field. ERS has shown how SAR images can distinguish different ice types and map leads, polynyas, shear zones, landfast ice, drifting ice and the location of the ice edge. ASAR provides certain advanced capabilities which enhance its performance for sea ice monitoring. The lower resolution modes will open up new possibilities for applications requiring large area coverage and more frequent revisits. The sea-ice edge is also better determined using higher incidence angle data which are available from the ASAR. Wide Swath Mode and Global Monitoring Mode, will both provide near daily revisit capability of wide swaths (400 km) of sea ice in polar regions.

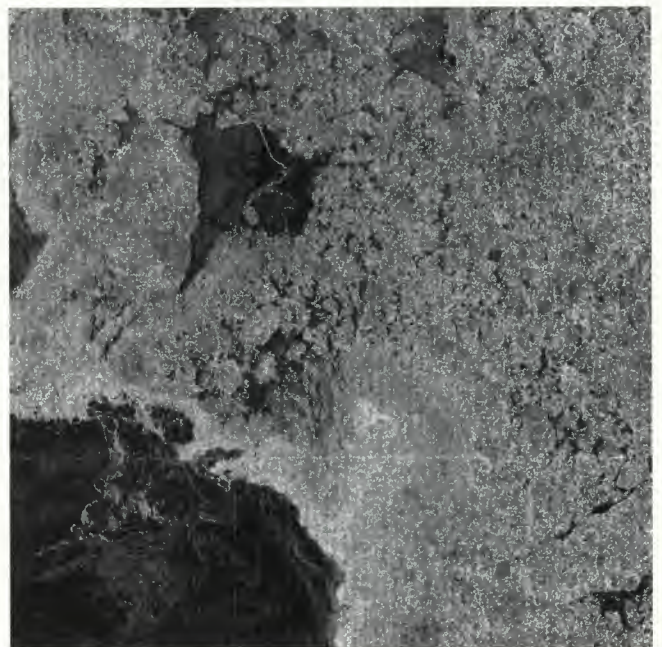
Research effort will be necessary to determine the optimum choice of polarisation for specific elements of sea ice monitoring. At present it is believed that cross polarisations (i.e. HV or VH) will be particularly useful for mapping ice topography (ridging and rafted ice) and that this mode is also likely to give improved ice type discrimination. As shown by Figure 5.1, comparisons between ERS (VV polarisation) and Radarsat (HH polarisation) have already demonstrated the different information content of the two channels which will be acquired simultaneously with ASAR.

Figure 5.1 Almost simultaneous ERS and Radarsat images covering 80 km x 80 km in the Baltic Sea. The ERS image was acquired from a descending orbit and the Radarsat image from an ascending orbit, both on 19 Sept. 1996.

(Acknowledgment: J. Askne and A. Li, Chalmers Univ. of Technology, Gothenburg, Sweden. Radarsat data copyright Canadian Space Agency/Agence spatiale canadienne, 1996)



a. ERS-2 (VV polarisation)



b. Radarsat (HH polarisation)

single frequency and single polarisation operation imply that only one channel of information is available for interpretation of the SAR images. For the tactical navigation of icebreakers, information down to the level of individual ice floes is needed for both rough and smooth ice conditions.

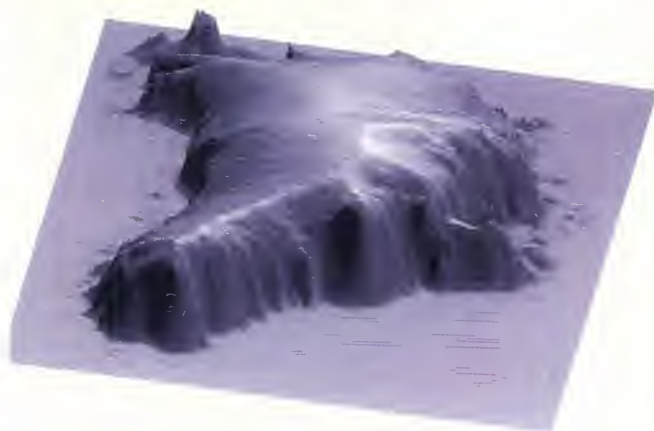
Figure 5.4, a simulation using ERS browse data, shows that the ice-edge location will probably be identifiable at 1 km resolution. It is also expected that there will be sufficient detail in the imagery to recognise areas of different ice pack concentration and, through the analysis of multi-temporal imagery, to identify large scale movement. The Global Monitoring Mode also has the advantage of being in continuous operation, thereby supporting global climate modelling through the generation of regularly updated maps of sea ice cover.

The dual frequency Radar Altimeter (RA-2) not only provides data continuity with the ERS Radar Altimeters, in terms of measuring ice sheet elevation and extent, but also has new capabilities which make possible the more precise geographical determination of sea ice margins. This is achieved principally through autonomous selection by the instrument of the tracking window. When the radar echo is about to move out of the tracking window, due to a change in land surface elevation, the window is broadened to re-capture it. This enables the uninterrupted collection of data over the boundaries between different surfaces.



Figure 5.4 ASAR Global Monitoring Mode simulation, using ERS browse image mosaic, of Svalbard (Norway).

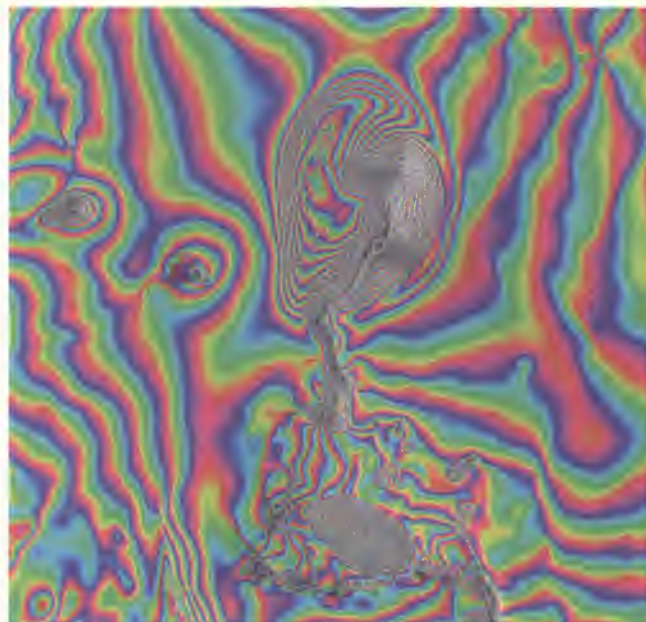
The ice-edge location is indicated by the white line. The area north of Spitsbergen (top left on the image) shows an ice-edge which is easy to distinguish from the open water, while in the area north of Nordaustlandet (top right on the image) it is possible to see two ice-edges. This is due to the ice movement within the 10 days separating the various ERS acquisitions used for the mosaic. (Acknowledgment: S. Dokken, H. Laur, ESRIN)



*Figure 5.6 Topographic Map of the Greenland Ice Sheet
Produced from ERS-1 Radar Altimeter Data
(Acknowledgment: J. Bamber, Mullard Space Science
Laboratory, University College London, UK)*

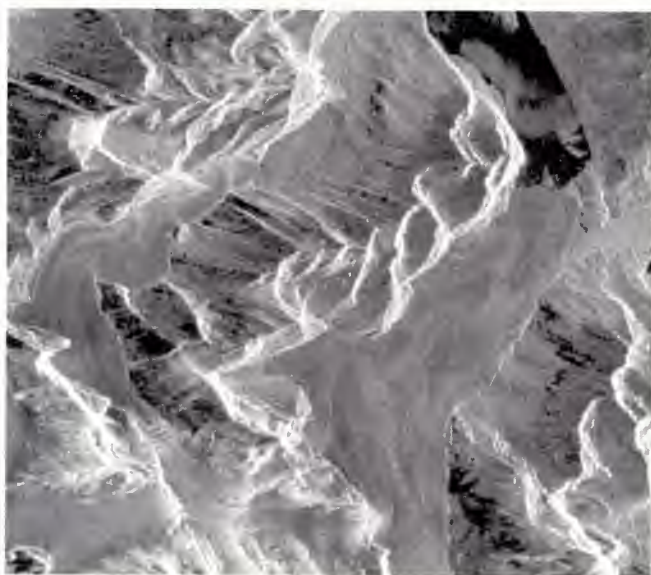
ERS SAR data have already provided significant information on the changes which take place as snow compacts and changes to ice, within an annual cycle. By analysing successive years of data it is possible to infer climate change by monitoring critical boundaries between ice and melting snow at the end of the summer melt season. Similarly, by mapping the frontal extent of glaciers on a regular basis, made feasible by using spaceborne radar sensors, long term and increasingly valuable data sets can be compiled, which represent trends in global climate change.

SAR interferometry has been used to monitor the changes which take place in a glacier and the relative velocities of the components involved. Figure 5.7 provides an excellent example of how mapping surface topography can provide information on glacial processes. In this case, the effects of sub-glacial volcanic activity could be quantified in terms of the volume of melt water.



*Figure 5.7 Interferogram from ERS Tandem data, of part
of the Vatnajökull Glacier, Iceland, May 1997. This shows
glacial topography, including a major depression (400 -
600 m deep) in the upper central part of the image, caused
by sub-glacial volcanic eruption
(Acknowledgment: H.Rott, Institut für Meteorologie und
Geophysik, Innsbruck, Austria).*

It is often difficult to use SAR images in glaciated mountainous areas because of severe terrain distortions. Figure 5.8 shows how the degree of terrain distortion relates to incidence angle, with distortion being much less at higher incidence angles. The higher incidence angles available from ASAR will provide imagery more suited to monitoring glaciers in deeply dissected terrain. The new capability for supplying dual polarisation images will provide more accurate information on the conversion process undergone by snow during the year.



*Figure 5.8 ERS and Radarsat images of the Moreno and Ameghino Glacier, Southern Patagonia, Argentina.
These show differences in terrain distortion between the top image (ERS) acquired with an incidence angle of 23°
and the bottom image (Radarsat) (incidence angle of 47°).
(Acknowledgment: H.Rott, Institut für Meteorologie und Geophysik, Innsbruck, Austria).*

References

ESA Documents:

- SP-406 ERS SAR Interferometry, Fringe 96 Workshop, Zurich, March 1997
- SP-1143 Report of the Earth Observation User Consultation Meeting, October 1991
- SP-1174 SAR Ocean Feature Catalogue, October 1994
- SP-1176/I Scientific Achievements of ERS-1, April 1995
- SP-1176/II Applications Achievements of ERS-1, February 1996
- SP-1184 MERIS The Medium Resolution Imaging Spectrometer, February 1996
- SP-1186 The Earth Observation User Consultation Meeting, ESTEC October 1994
- SP-1193 ERS-1 SAR Sea Ice Catalogue, March 1997
- SP-1212 GOME The Global Ozone Monitoring Experiment, June 1997
- Proceedings of the First ERS Thematic Working Group Meeting on Flood Monitoring June 1995, ESRIN
- Envisat-1 Mission System, Critical Design Review, Envisat-1 Payload Executive Summary,
(ESA and Daimler-Benz Aerospace)
- Envisat-1 Mission and System Summary,
(ESA, Daimler-Benz Aerospace, Matra Marconi Space and Thomson-CSF)

Others:

- International Geosphere-Biosphere Programme (IGBP), "A Study of Global Change", Report No. 12, 1990
- Johannessen J. A., Shuchman R. A., Digranes G., Lyzenga D. R., Wackermann C., Johannessen O. M. and Vachon P. M.**, "Coastal ocean fronts and eddies imaged with ERS-1 synthetic aperture radar." J. Geophys. Res., Vol 101, No C3, pp 6651-6667, 15 March 1996
- Korsbakken E., Johannessen J.A. and Johannessen, O.M.**, "Coastal wind field retrievals from ERS synthetic aperture radar", accepted paper in J. Geophys. Res., 8 September 1997
- Le Toan T, Merdas M., Smacchia P., Souyris J. C., Beaudoin A., Nagid Y. and Lichtenegger J.**, "Soil moisture monitoring using ERS-1", Second ERS-1 Symposium "Space at the Service of our Environment", Hamburg, Germany, 11-14 October 1993, pp 243 to 244
- Le Traon P.Y. et al**, "Multi-mission Altimeter Intercalibration Study", ESA Study Contract 11583/95/NL/CN, 1996
- Lichtenegger J.** "ERS-1 SAR images - mirror of thunderstorms", Earth Observation Quarterly, No. 53, p 7, September 1996
- Mitchum G.T.**, "Comparison of TOPEX sea surface heights and tide-gauge sea levels", J. Geophys. Res. , 99. C12, 24541 - 24554, 1994
- Pavakis P., Sieber A. and Alexandry S.**, "Monitoring oil-spill pollution in the Mediterranean with ERS SAR", Earth Observation Quarterly, No 52, p 9, September 1996
- Wegmüller U., Werner C. L., Nüesch, D. and Borgeaud, M.**, "Forest mapping using ERS repeat-pass SAR interferometry", Earth Observation Quarterly, No 49, p 4, September 1995
- Zmuda, A., Corr, D., Bird, P., Blyth, K. and Stuttard, M. J.**, "The potential of ASAR for soil moisture monitoring - a simulation study", Proceedings of the 23rd Annual Conference of the Remote Sensing Society, University of Reading, United Kingdom, 2-4 September 1997, pp 591 to 596

