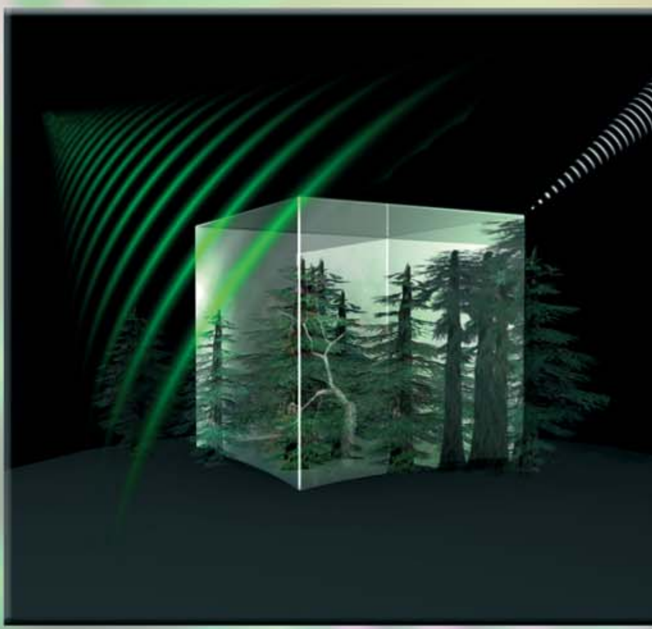
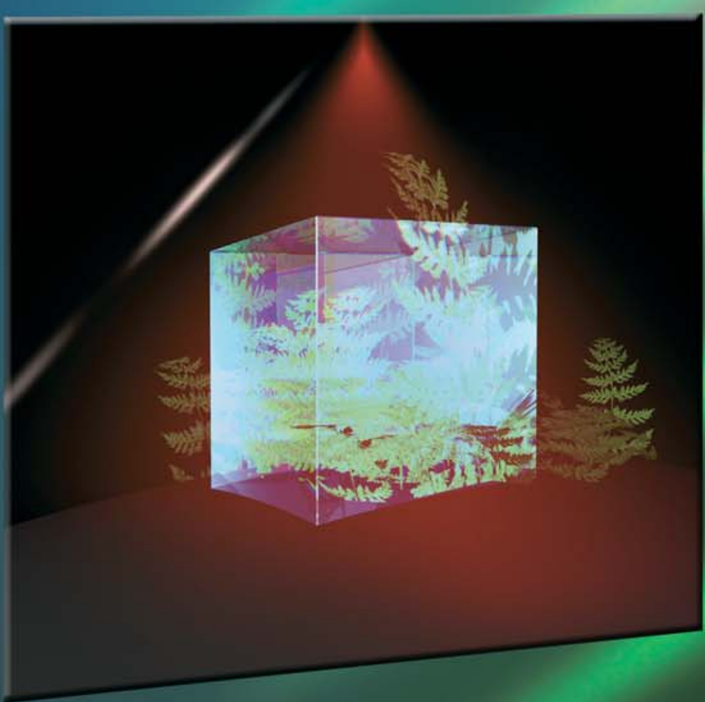
A New Earth Explorer

The Third Cycle of Core Earth Explorers





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ESA's family of Earth Explorer satellites is designed in response to specific critical issues raised by Earth-scientists, while demonstrating new observation technologies. The first six Explorer missions are being prepared for launch and, in March 2005, the Agency released a new Call-for-Ideas focused on processes that are fundamental for understanding the changing 'Earth System'. Six candidates were selected in May 2006 for assessment. The final selection is expected in 2010, for launch in 2014/2015.

Introduction

The Earth Explorer missions, as part of ESA's Living Planet Programme, seek to advance our understanding of the different 'Earth System' processes and to demonstrate new observing techniques. There are six missions already under development:

GOCE (Gravity Field and Steady-State Ocean Circulation Explorer), due for launch in early 2008, will provide high-resolution gravity data to improve the global and regional models of Earth's gravity and 'geoid' (the shape of a global ocean at rest used as a reference).

SMOS (Soil Moisture and Ocean Salinity), due for launch in 2008, will globally map soil moisture and ocean salinity to improve the representation of land in global atmospheric circulation models and to characterise the role of the ocean in the climate system.

ADM-Aeolus (Atmospheric Dynamics Mission), due for launch in 2009, will make novel advances in global wind-profile observations and provide global wind information that is crucial to climate research and numerical weather prediction.

CryoSat-2, due for launch in 2009, will determine the rate of change of variations in the thickness and mass of polar marine ice and continental ice-sheets in response to climate changes. CryoSat-2 replaces CryoSat, the first Explorer mission, which was lost at launch in 2005.

Swarm, due for launch in 2010, is a constellation of three satellites to survey the geomagnetic field and its evolution. It will provide new insights into the Earth System by improving our understanding of the Sun's influence and Earth's interior.

EarthCARE (Earth Clouds and Radiation Explorer), due for launch in 2012, is a joint European-Japanese mission to measure cloud and aerosol properties to help understand their interactions with Earth's radiative processes and climate-change predictions.

In March 2005, ESA released a new Call-for-Ideas to scientists from ESA Member States and Canada to solicit proposals for the next Earth Explorer. The scientific priorities focused on the global carbon and water cycles, atmospheric chemistry, climate and the human element as a cross-cutting issue. Twenty-four proposals were received and evaluated as 'Core' missions (these address specific areas of great scientific interest; 'Opportunity' missions are faster, cheaper and not necessarily led by ESA). Six candidates were short-listed in May 2006 for dedicated assessments, with industrial activities beginning in May/June 2007:

- BIOMASS (to monitor Earth's biomass for carbon assessment);
- TRAQ (TRopospheric composition and Air Quality);
- PREMIER (PRocess Exploration through Measurement of Infrared and millimeter-wave Emitted Radiation);
- FLEX (FLuorescence Explorer);
- A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth);
- $CoReH_2O$ (Cold Regions Hydrology High-resolution Observatory).

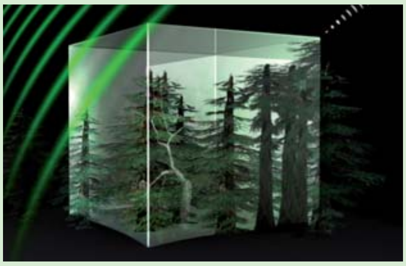
BIOMASS

The greatest uncertainties in the global carbon cycle involve estimating how carbon dioxide is taken up by land. The mission aims to improve the present assessment and future projection of the terrestrial carbon cycle by providing consistent global maps of forest biomass and forest area, forest disturbances and recovery with time, and the extent and evolution of forest flooding. Forest biomass is a key factor in the carbon cycle but it falls in a critical gap in existing measurement techniques. When coupled with biophysical models, above-ground biomass provides information on carbon dioxide stocks and fluxes and is a sensitive indicator of changes in land use and natural biophysical processes.

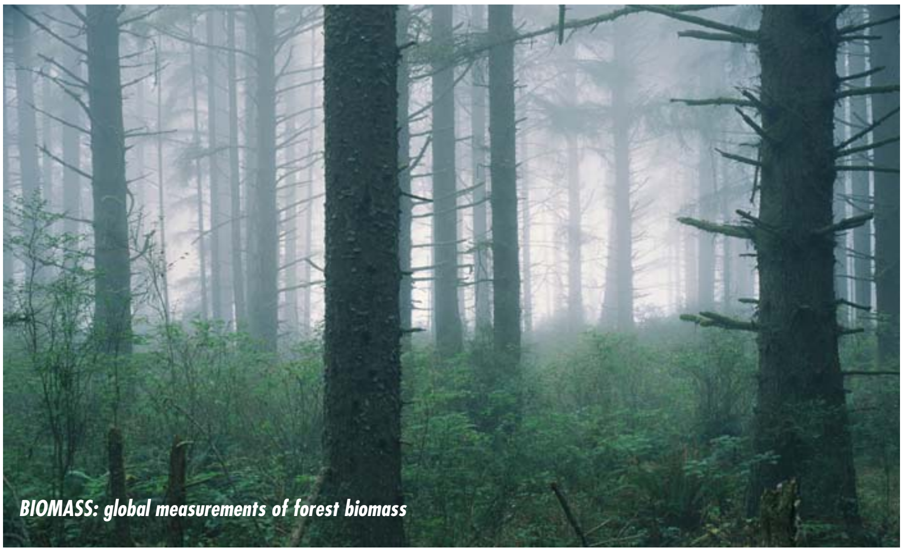
The BIOMASS primary objectives would be achieved through a P-band (435 MHz) synthetic aperture radar (SAR). Finding the above-ground biomass from calibrated SAR images will take advantage of the high sensitivity of P-band reflection to biomass.

Complementary classification techniques would exploit the polarisation of the radar signatures from different types of forest to label surface features by comparison with known reference cases.

BIOMASS Characteristics



Mission duration: 5 years
Orbit: Sun-synchronous, local time ~06:00
Coverage: global, vegetated areas
Revisit time: 25 days
Instrument: P-band (435 MHz) synthetic aperture radar
Polarisation: full polarimetry and/or circular/dual polarisation
Data acquisition: single-pass/repeat-pass polarimetric interferometry
Resolution: ≤50 x 50 m (≥4 looks)
Swath width: ≥100 km



BIOMASS: global measurements of forest biomass

Analysing the reflected radar beam would provide information on the forest vertical structure and height, with the potential to extend the observation range and/or to increase the estimation accuracy of biomass products.

The secondary objectives arise from the opportunity to explore Earth's surface with a longwave SAR for the first time. New information on ice structure, ice thickness and subsurface geomorphology in arid areas would be expected.

The satellite would carry the side-looking radar in a Sun-synchronous orbit optimised to reduce ionospheric effects on signal propagation. The orbit would cover all forested areas every 25 days globally to satisfy the major mission objectives.

BIOMASS would be the first mission dedicated to estimating biomass globally using low-frequency SAR observations.

TRAQ

Changes in the composition of Earth's troposphere (altitude 0–7/17 km) are a serious and growing problem in many regions of the world. The composition affects air quality regionally and globally as well as the climate via radiatively active trace gases and aerosols. TRAQ would assess the air quality changes at global and regional scales, determine the strength and distribution of the sources and sinks of trace gases and aerosols influencing air quality, and help in the understanding of the role of tropospheric composition in the global change.

TRAQ: air quality and long-range transport of air pollution

A new synergistic sensor concept is proposed: a high spectral resolution pushbroom shortwave spectrometer (SWS) in the range from ultraviolet to near-infrared; a high spectral resolution across-track scanning longwave spectrometer (LWS) in the thermal-infrared with an embedded cloud imager and a multi-view polarisation-resolving pushbroom radiometer. A shortwave-infrared band is also required; it would be included either in the LWS or SWS.

The cloud imager is a dual-band infrared instrument that would optimise in real time the pointing direction of the thermal-infrared spectrometer towards areas clear of clouds. The mission will offer a pixel size of 15–40 km, depending on the spectral bands.

TRAQ's orbit is selected to offer near-global coverage and unique diurnal time sampling with up to five daytime observations over Europe and other mid-latitude regions. This can be achieved by using a non-Sun-synchronous low drifting orbit with an inclination around 57º.

TRAQ would provide the following parameters: ozone, nitrogen dioxide, sulphur dioxide, HCHO (formaldehyde), water vapour and HCOOCH (1,2-ethanedione) tropospheric columns from the ultraviolet/visible/near-infrared spectral region; carbon monoxide and methane tropospheric columns from the shortwave infrared spectral region; height-resolved tropospheric profiles of ozone and carbon monoxide from the thermal-infrared channels; detailed tropospheric aerosol characterisation from the multi-view polarisation-resolving radiometer and in combination with the ultraviolet/visible/near-infrared spectrometer.

TRAQ would be the first mission fully dedicated to air quality and the science issues around tropospheric composition and global change.

TRAQ Characteristics

Mission duration: 3–5 years
Orbit: drifting low orbit, inclination ~57°
Coverage: latitudes 40°S–60°N
Revisit time: 3 months
Temporal sampling: up to 5 times/day over continental areas within 40–55°N
Instruments: UV/visible/near-infrared spectrometer (SWS); thermal-infrared spectrometer (LWS); shortwave infrared (either SWS or LWS); infrared Cloud Imager; multi-view polarisation resolving radiometer
Resolution: 15–40 km (UV/shortwave infrared), 15 km (thermal-infrared); 1 km (Cloud Imager); 1–4 km (multi-view polarisation resolving radiometer)

PREMIER

The primary aim of PREMIER is to explore the processes that control the composition of the mid/upper troposphere and lower stratosphere (altitude 3/10–51/58 km). It would be the first mission to explore from space the links between atmospheric composition and climate globally in unprecedented detail and, for the first time, with sufficient resolution.

PREMIER would observe the distributions of trace gases, particulates and temperature in this region down to finer scales than any previous satellite mission. It would also facilitate integration with measurements made at higher resolution at particular locations and times by ground and airborne instruments.

The secondary aim is to the explore processes that control the composition of the lower troposphere/boundary layer and the links to higher layers.

Through synergy with Europe's

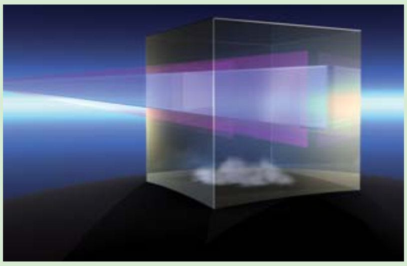
PREMIER: atmospheric processes linking trace gases, radiation, chemistry and climate

MetOp satellite, flying in tandem, the composition of the lower troposphere will be clearly discriminated from that of higher layers. The mission objectives call for 3-D sounding of the mid/upper troposphere and stratosphere by two complementary limb-sounders at infrared and mm/sub-mm wavelengths. The limb would be imaged at high resolution to account for the effects of clouds and to derive cloud/aerosol properties.

The infrared sounder is an imaging Fourier transform spectrometer either in a high spectral resolution mode, optimised for observation of minor trace gases or in a high spatial resolution mode, optimised to resolve atmospheric structure.

The mm/sub-mm sounder is a limb-sounding heterodyne receiver with a channel in the 320–360 GHz range for measurements of the main target species of water, ozone and carbon monoxide (or with a slight spectral shift to observe hydrogen cyanide, HDO water isotope, nitrous oxide, chlorine monoxide, nitric acid) in the upper troposphere/lower stratosphere altitude range, and a channel in the 488–504 GHz range with improved sensitivity to stratospheric target species (such as chlorine monoxide, nitrous oxide, water and its isotopes). The instrument would be developed as a Swedish national contribution to the mission.

PREMIER Characteristics

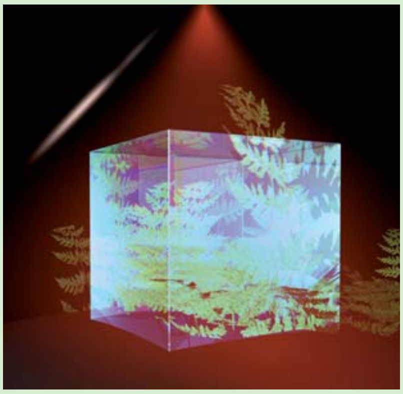


Mission duration: 4 years
Orbit: Sun-synchronous in tandem with MetOp (835 km)
Coverage: near-global, latitudes 80°S–80°N
Instruments: Infrared Limb Sounder (IRLS); Infrared Cloud Imager (IRCI); Microwave Limb Sounder (MWLS)
Vertical coverage: IRLS 48 km (3/10–51/58 km arctic/tropics); IRCI 25 km (3/10–28/35 km arctic/tropics); MWLS 23 km (5–28 km upper troposphere/lower stratosphere, 12–35 km stratospheric mode)
Vertical sampling: IRLS 0.5–2 km (depending on mode and range); IRCI 0.5 km; MWLS 1.5 km
Horizontal sampling: IRLS 25–80 km across-track, 50–100 km along-track; IRCI 4 km across-track, 8–50 km along-track; MWLS ≤ 50 km (≤ 300 km in stratospheric mode) along-track

FLEX

The mission would improve our knowledge of the carbon cycle by globally measuring the efficiency of photosynthesis of ecosystems. Photosynthesis by land vegetation is an important component of the global carbon cycle, closely linked to the hydrological cycle through transpiration. This type of information has never been available before from space observations.

FLEX Characteristics



Mission duration: 3–5 seasonal cycles in northern and southern hemispheres
Orbit: Sun-synchronous, local time descending node around 10:00
Coverage: global coverage of land surfaces (56°S–75°N)
Revisit time: 1 week
Instruments: Fluorescence Spectrometer; Visible/Near-Infrared Imaging Spectrometer (0.45–1 µm); Shortwave Infrared Imager (1.4–2.2 µm); Thermal Infrared Imaging Radiometer (8.8–12 µm); optional multi-view Visible/Shortwave Infrared Imager
Resolution: 100–300 m

Fluorescence under sunlight is a sensitive and direct probe of photosynthesis in both healthy and perturbed vegetation. It gives an early indication of plant stress before it can be observed by more conventional means. For FLEX, direct fluorescence measurements of vegetation chlorophyll are proposed, complemented by hyperspectral reflectance and canopy temperature to help interpret the fluorescence.

The core instrument is a spectrometer to measure the fluorescence in the blue, red and far-red using the 'Fraunhofer Line Discriminator' method.

The fluorescence of chlorophyll in the red and far-red is the key for monitoring photosynthesis. Blue-green fluorescence adds information about the vegetation's status and health. The complementary

FLEX: global photosynthesis

A-SCOPE: global carbon cycle and regional carbon dioxide fluxes

instruments are: a coarse resolution visible/near-infrared spectrometer and a 6-channel shortwave infrared imager for basic vegetation parameters, a thermal-infrared radiometer with four channels for estimating the temperature of the vegetation canopy. An optional off-nadir two–three band visible/ shortwave-infrared imager would help to correct for atmospheric effects.

A single satellite in a Sun-synchronous orbit is the baseline for the mission. A local time of 10:00 would provide adequate balance between maximum fluorescence emission and maximum solar illumination. A spatial resolution of the order 100–300 m is required.

A-SCOPE

A-SCOPE, like other missions to observe carbon dioxide from space, would be an innovative source of data for understanding the carbon cycle and validating inventories of greenhouse gas emissions. It would provide near-global coverage with good time resolution, mapping the sources and sinks of carbon dioxide on a scale of 500 km or better. This is a major improvement over today's observation network and forthcoming *in situ* and space systems.

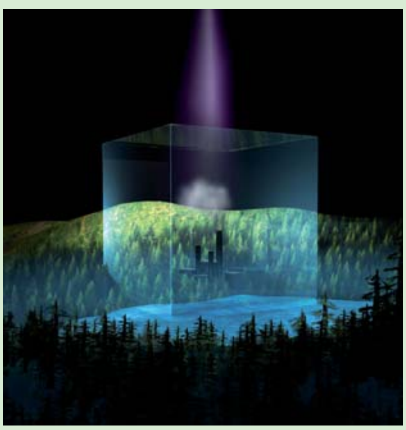
A-SCOPE would be the first mission dedicated to measuring carbon dioxide with an active 'Differential Absorption Lidar' (DIAL) sensor. It would provide better accuracy and spatial and temporal coverage than the planned satellites carrying passive sensors: OCO (Orbiting Carbon Observatory; NASA) and GOSAT (Greenhouse gases Observing Satellite; JAXA). Only active sensing would provide high-accuracy measurements and truly global, day/night coverage under both clear and broken-cloud conditions.

DIAL would measure the reflections from Earth's surface and clouds tops of laser pulses at slightly different wavelengths. Carbon dioxide in the atmosphere would absorb some of the laser light, varying with wavelength. The differences between the two wavelengths yields the concentration of carbon dioxide, with a target minimum accuracy of 1.5 parts per million by volume and a goal of 0.5 ppmv. Suitable absorption can be found in the near-infrared around 1.6 µm and 2.1 µm.

In both spectral regions, temperature sensitivity and interference from water vapour and other trace gases can be minimised by careful selection of the laser's exact wavelengths.

A camera operating in the visible, near-infrared and thermal-infrared with a narrow swath width of 50 km would put the measurements in context with a broader view of the clouds and Earth's surface texture.

A-SCOPE Characteristics



Mission duration: 3–5 years
Orbit: Sun-synchronous
Coverage: near-global
Instruments: nadir-viewing pulsed-laser DIAL at 2.1 µm or 1.6 µm; visible/near-infrared/thermal-infrared Imaging Camera
Vertical resolution: total column
Horizontal resolution: DIAL 50 km along-track; Imaging Camera 100 m

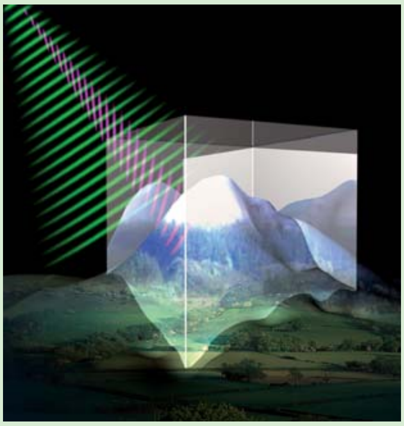
CoReH$_2$O

The mission aims at all four science priorities identified in the Call for Ideas, with emphasis on the global water cycle and significant contributions in understanding the global carbon cycle, atmospheric chemistry and climate, as well as assessing the human impact on these aspects.

The mission would focus on detailed observations of important snow, ice and water-cycle parameters. It would improve our understanding and modelling of surface processes and surface/atmosphere exchange mechanisms in regions where snow and ice play a major role in the water and energy cycles, as well as in biospheric processes.

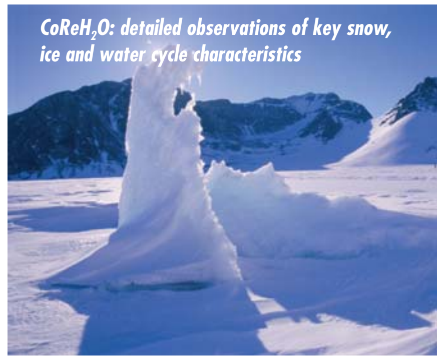
The key parameters to be found describe a snow layer: extent, thickness and water-equivalent (the amount of water from the instantaneous melting of

$CoReH_2O$ Characteristics



Mission duration: 5 years
Orbit: Sun-synchronous, local time 06:00
Coverage: test sites (phase-1); global coverage of snow and ice areas (phase-2)
Revisit time: 3 days (phase-1); ≤15 days (phase-2)
Instrument: dual-frequency (9.6/17.2 GHz) synthetic aperture radar
Polarisation: dual (vertical-vertical; vertical-horizontal)
Resolution: ≤50 x 50 m (≥5 looks)
Swath width: ≥100 km

a snow pack). These observations will help data-assimilation systems, numerical weather prediction and climate models, and the understanding and modelling of land-cryosphere-atmosphere exchange processes.

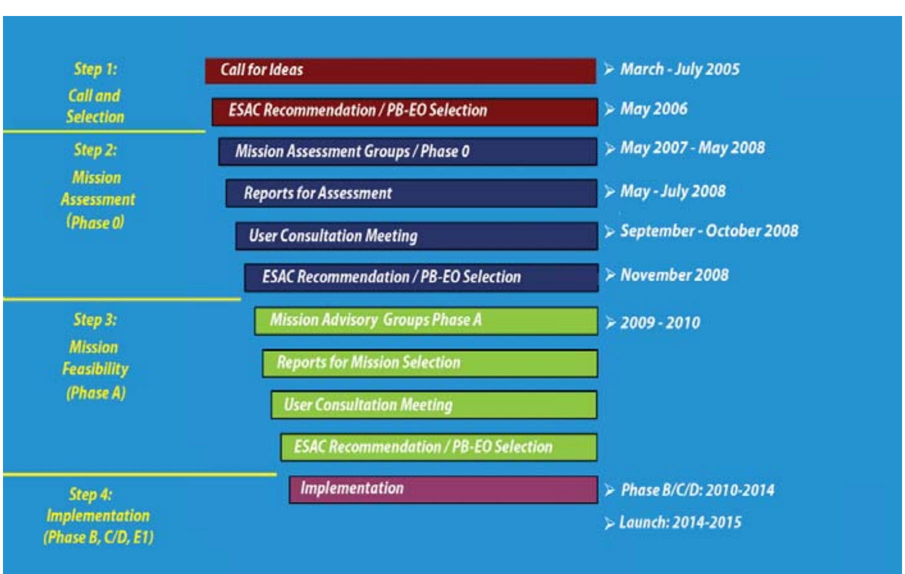


$CoReH_2O$: detailed observations of key snow, ice and water cycle characteristics

The secondary objectives aim at ice-surface parameters that would help the analyses of sea-ice dynamics in local and global climate models.

Producing this geophysical information depends on backscatter measurements from a synthetic aperture radar at X- and Ku-band at relatively high resolution. Ku-band is more sensitive to shallow dry snow, while X-band provides greater penetration of deeper snow layers. The combination of observations at two frequencies would improve the accuracy of the snow information and provide a high level of information on sea ice, ice sheets and glaciers.

Measurements of the polarisation of the reflected radar pulses are important for separating surface and volume scattering and for estimating the snow water equivalent.



The mission is based on a single satellite in a Sun-synchronous orbit with a local time early in the morning at around 06:00 to avoid the effects of daily warming and melting. The mission would be divided into two phases: the first phase (2 years) with revisits every 3 days, in order to observe the more rapid processes in selected test areas. These frequent visits are at the expense of limited coverage. The second phase (2–3 years) would revisit every 15 days, with near-global coverage of snow and ice areas.

The Selection Process

The current cycle will lead to the selection in 2010 of the seventh Earth Explorer, due for launch in 2014/2015. As in the previous cycles, the process has four steps. The first step (Phase-0: mission assessment) began in 2006 with the nomination of the Mission Assessment Groups that provide independent advice to the Agency for the definition of the detailed scientific objectives of the missions, the consolidation of the mission requirements, the definition of required scientific support and the production of the Reports for Assessment. The other major element of this step is the Phase-0 industrial studies, beginning in May/June 2007 to identify end-to-end implementation concepts for each mission as well as their preliminary feasibility in terms of required technology and compliance with programme constraints. The assessment step will conclude with a User Consultation Process that reviews the assessments and proposes a short-list of candidates to enter the next step in 2009 (Phase-A: mission feasibility).

At the end of Phase-A in 2010, a second User Consultation Process will recommend the final candidate to enter the development phases (B/C/D) and finally join the Earth Explorer family as the seventh mission of the series.

Acknowledgments

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