BR-199
April 2003

ESA's ICE MISSION

CRYOSAT

European Space Agency
Agence spatiale européenne

ESA's EARTH OBSERVATION MISSIONS

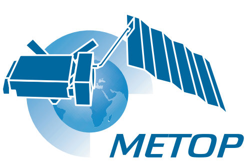
METEOSAT - In 1977 the first of seven Meteosat meteorological satellites was launched to monitor the weather over Europe and Africa from a vantage point high above the Equator. The success of the first satellites led to the formation of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) in 1986. Meteosat-7, the last in the series, was launched in 1997.

ERS-1 and 2 - ERS-1, launched in 1991, was ESA's first remote sensing satellite; it carried a comprehensive payload including an imaging Synthetic Aperture Radar (SAR), a radar altimeter and other powerful instruments to measure ocean surface temperature and winds at sea. ERS-2, which overlapped with ERS-1, was launched in 1995 and added the Global Ozone Monitoring Experiment (GOME) for atmospheric ozone level research.

ENVISAT - Launched in 2002, is the largest Earth observation satellite ever built. It carries 10 sophisticated optical and radar instruments to provide continuous observation and measurement of the Earth's oceans, land, ice caps and atmosphere for the study of various natural and man-made contributors to climate change. It also provides a wealth of information needed for the management of natural resources.

MSG (Meteosat Second Generation) - MSG is a joint project between ESA and EUMETSAT and follows up the success of the first generation Meteosat with satellites of higher performance. Four satellites are planned at present, the first of which was launched in 2002.

CRYOSAT - An Earth Explorer Opportunity mission, due for launch in 2004, will determine variations in the thickness of the Earth's continental ice sheets and marine ice cover. Its primary objective is to test and quantify the prediction of thinning polar ice due to global warming.



METOP (Meteorological Operational) - Europe's first polar orbiting satellite system dedicated to operational meteorology. MetOp is a series of three satellites to be launched sequentially over 14 years, starting in 2005, and forms the space segment of EUMETSAT's Polar System (EPS).

GOCE (Gravity Field and Steady-State Ocean Circulation Mission) - An Earth Explorer Core mission, due for launch in 2006, will provide the data set required to accurately determine global and regional models of the Earth's gravity field and the geoid. It will also advance research in the fields of steady-state ocean circulation, physics of the Earth's interior, geodesy and surveying, and sea-level change.

ADM-AEOLUS (Atmospheric Dynamics Mission) - An Earth Explorer Core Mission, due for launch in 2007, will make novel advances in global wind profile observation. It is intended to provide much needed information to improve weather forecasting and climate research.

SMOS (Soil Moisture and Ocean Salinity) - An Earth Explorer Opportunity Mission, due for launch in 2007, will provide global observations of soil moisture and ocean salinity to improve modelling of the weather and climate. It will also monitor vegetation water content, snow cover and ice structure.

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ESA's ICE MISSION

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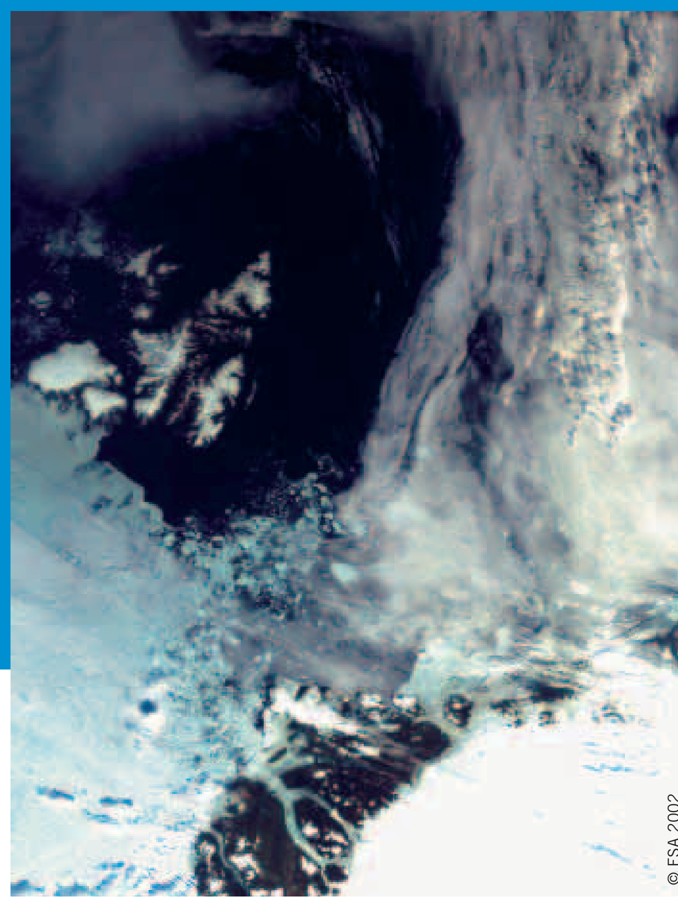
CryoSat: ESA's ice mission



CryoSat's icy mission is dedicated to monitoring precise changes in the thickness of polar ice sheets and floating sea ice over a 3-year period. The observations made over the lifetime of this mission aim to determine whether or not the Earth's ice masses are actually thinning due to a changing climate.

It is the first Earth Explorer satellite to be launched as part of ESA's Living Planet Programme and is scheduled to lift off from Russia in 2004. CryoSat has been developed as an Earth Explorer Opportunity mission, which means that it is a small research mission designed to provide some fast answers about a specific aspect of the Earth's environment. This mission, the concept of which was only approved in 1999, is a response to the current debate on climate change and the effect that this may be having on the Earth's large polar ice masses.

Although there now seems to be little doubt that the Earth's atmosphere is warming, it is extremely difficult to predict what effect this will have on the polar ice cover. And since ice plays a major role in climate regulation and the height of the sea level, it is important to determine any change in the thickness of the marine and continental ice cover.

By measuring ice thicknesses very precisely over three years, CryoSat aims to provide conclusive evidence as to whether there is a trend towards diminishing polar ice cover and consequently improve our understanding of the relationship between ice and global climate.

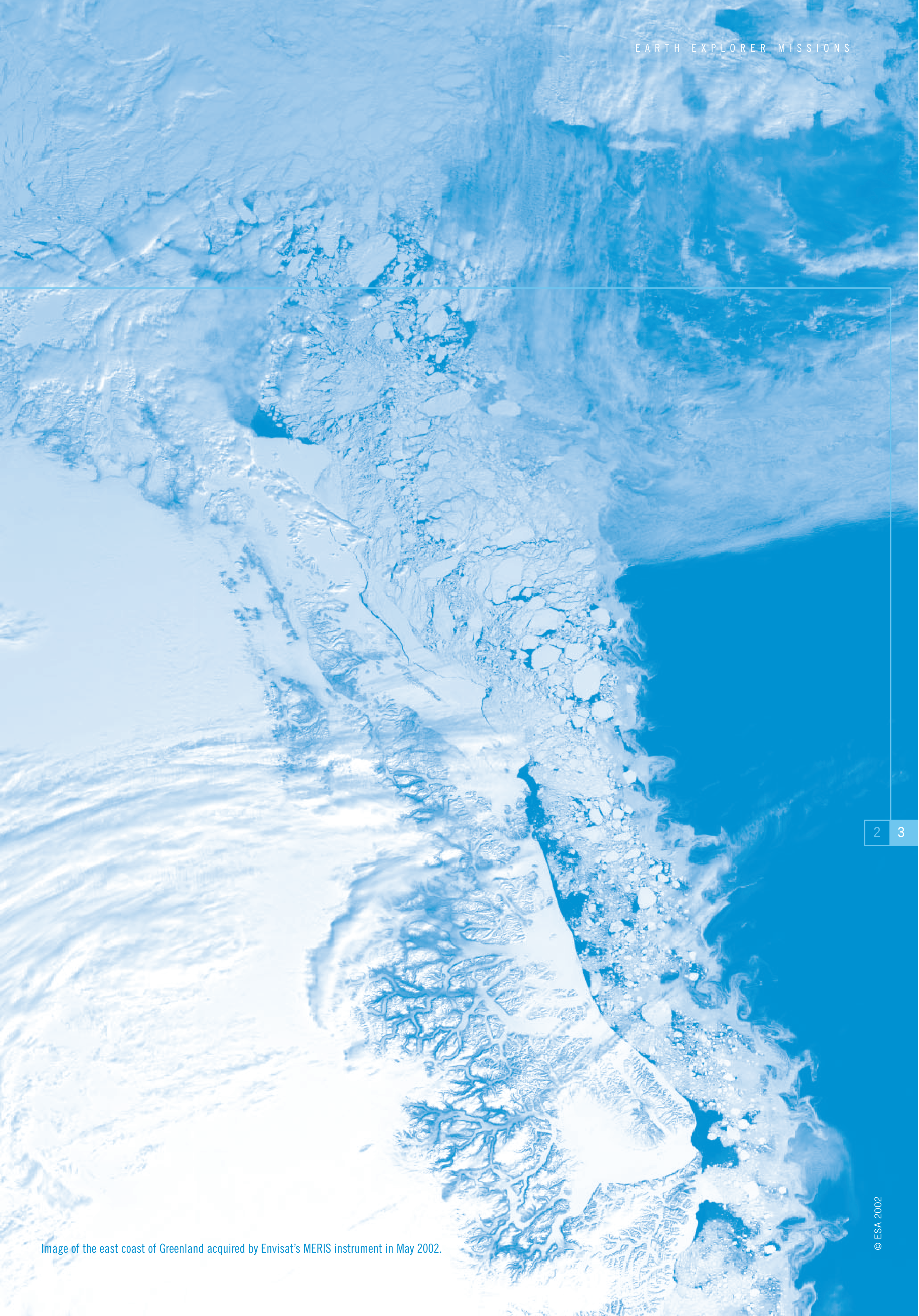


Image of the east coast of Greenland acquired by Envisat's MERIS instrument in May 2002.

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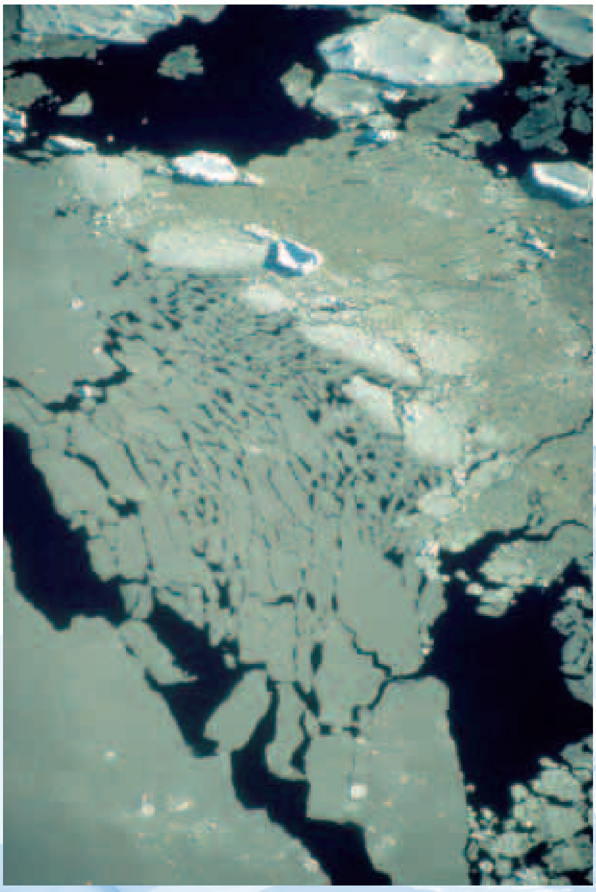
The impact of ice on climate and sea level

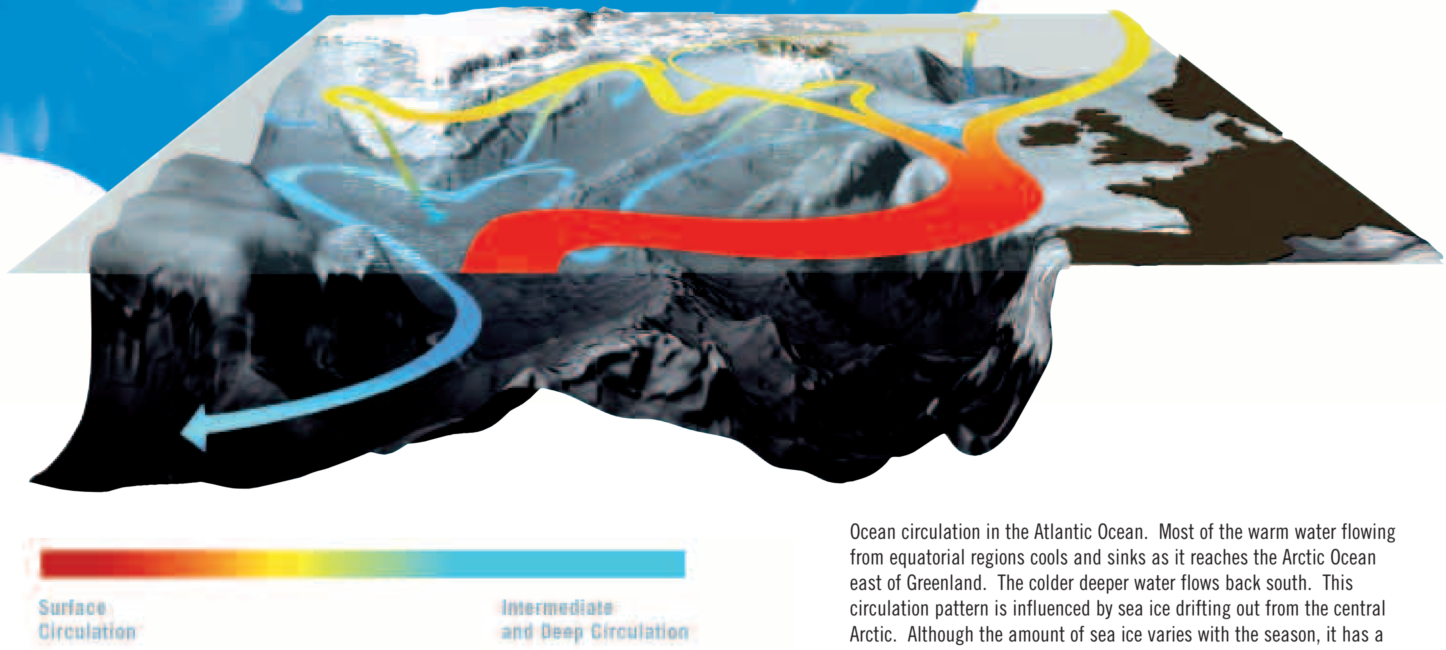


Ice plays an important role in the regulation of the Earth's climate in a number of ways:

- As solar radiation reaches the Earth's atmosphere and surface, a certain percentage is reflected back out to space. The percentage of sunlight that is reflected, however, depends on the albedo (reflectivity or whiteness) of the surface. Ice and snow have a high albedo and hence reflect about 80% of incident sunlight. Thus, once formed, ice tends to be maintained. However, if ice cover were to decrease, less solar radiation would be reflected away from the surface of the Earth and as a result the atmosphere would absorb more heat.

- Each year, the Arctic and the Antarctic Oceans experience the formation and then melting of vast amounts of sea ice floating on the sea surface. At the North Pole, an area of ice the size of Europe melts away every summer and then freezes again the following winter. The thickness of this sea ice plays a central role in polar climate as it moderates heat transport by insulating the ocean from the cold polar atmosphere.

- The seasonal changes of polar sea ice have a significant effect on certain global ocean circulation patterns - known as thermohaline circulation. As ice melts there is an influx of fresh water into the surrounding ocean; this decreases the salinity and consequently the density of the water. Conversely, as ice is formed, salinity and therefore the density of the water increase. The density increase causes the surface waters to sink and effectively act as a pump, driving deep ocean currents from the polar regions towards the equator, while at the surface warmer, less dense water masses flow from low to high latitudes.

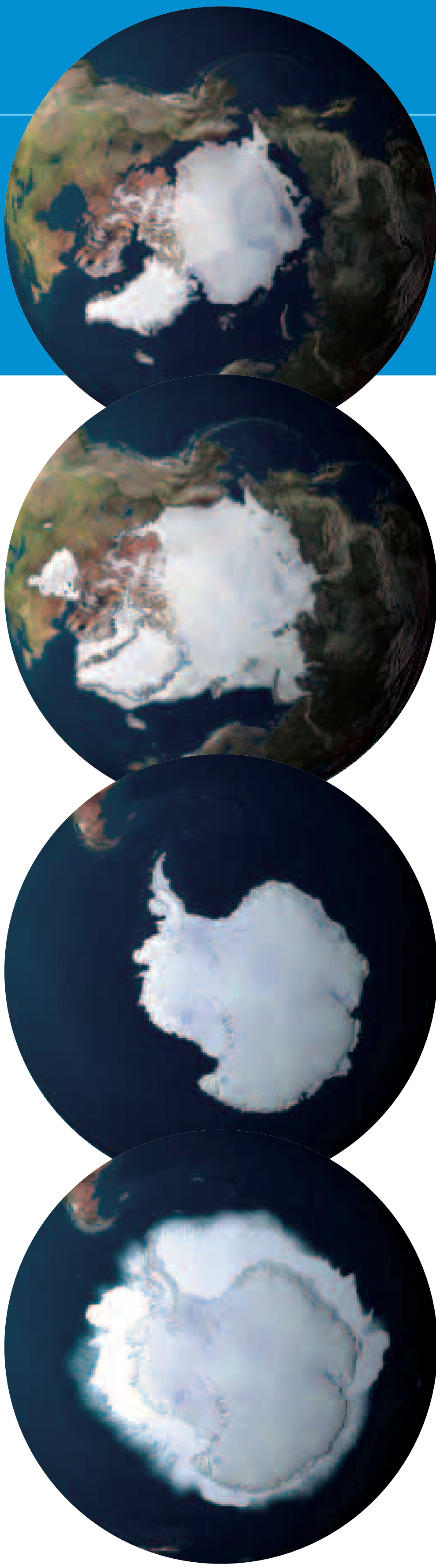


Ocean circulation in the Atlantic Ocean. Most of the warm water flowing from equatorial regions cools and sinks as it reaches the Arctic Ocean east of Greenland. The colder deeper water flows back south. This circulation pattern is influenced by sea ice drifting out from the central Arctic. Although the amount of sea ice varies with the season, it has a stabilising effect on the ocean currents. A major decrease in sea ice could have a significant impact on this balance.

The Gulf Stream, which carries warm surface waters northwards from the Gulf of Mexico to the sub-polar waters east of Greenland, is extremely important in moderating the climate in Europe; the coastal waters of Europe are 4°C warmer than waters at equivalent latitude in the North Pacific. However, the warm waters of the Gulf Stream cool and sink as they reach the Arctic. If this circulation pattern were disturbed by reduced Arctic sea ice, there would be a profound effect on the strength or direction of the Gulf Stream. It is therefore apparent that an improved knowledge of the fluxes of sea ice in the Arctic is important for the prediction of Europe's climate.

- Continental ice has an impact on sea level. The ice sheets covering Antarctica and Greenland amount to about 28 million km^3, which means that the sea level is about 65 m lower than it would be otherwise. Although observations from ERS indicate that the great central plateaus of Antarctica and Greenland are relatively stable, there are indications that changes are occurring at the margins of the ice sheets and it is these apparent changes that need to be quantified.

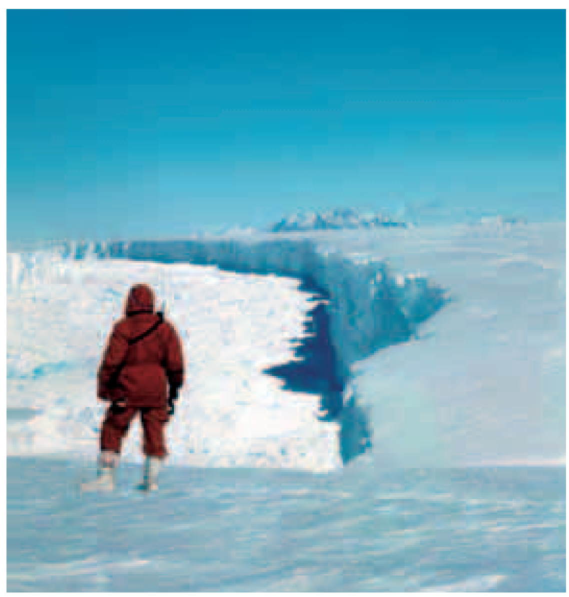
Is the Earth's ice melting?



The central areas of an ice sheet overlay solid ground but the outer edges flow into the open ocean and finally break off as icebergs.

The general consensus is that the temperature of the Earth's atmosphere is rising. During the course of the last century, the average global surface temperature rose by about 0.6°C. 1998 proved to be the warmest year since systematic meteorological measurements began in 1861, and scientists are now predicting that average global temperatures will rise by between 1 and 6°C over the next 100 years. How rising temperatures will affect the ice around the poles is difficult to estimate and this issue often appears to be surrounded by conflicting stories. For example, in the spring of 2002 news of a giant iceberg more than 200 km long breaking off the Ross Ice Shelf and drifting into the Southern Ocean hit the headlines. This event would seem to fit with the unusual high temperatures experienced in Antarctica over the last decade, but on the other hand a few weeks later there were reports of ships being trapped for weeks in unprecedented Antarctic sea ice.

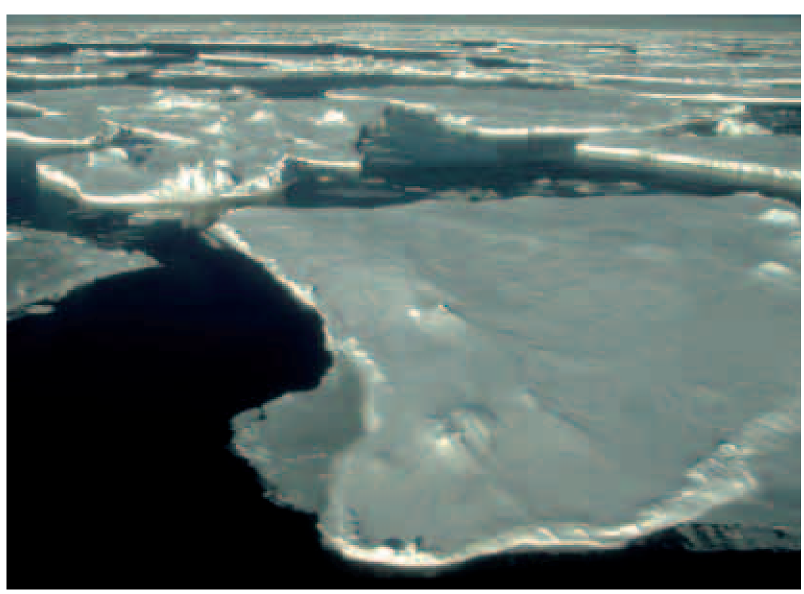
In July 2002, the Advanced SAR instrument onboard Envisat observed a giant Antarctic iceberg more than 200 km long which had broken off the Ross Ice Shelf.



Field observation of ice shelf break up.

Although there are several research stations in the Arctic and Antarctica dedicated to scientific research into polar ice, the huge expanse and remoteness of these regions hampers practical experimentation and observation. Despite being able to witness events such as iceberg calving and monitor the shrinking of glaciers with modern space technology over the last 20 years, there is, so far, no conclusive evidence as to whether polar ice really is melting. Therefore, the jury is still out on whether these changes are significant and indicative of a general trend in rising temperatures.

In essence, we are currently unsure whether any reported change in ice cover is actually due to global warming, inadequate observation techniques, or simply due to natural variability. ESA's CryoSat mission will determine rates of ice thickness change and consequently improve our understanding of the relationship between the Earth's ice cover and global climate.



How CryoSat will detect ice thickness changes

The Challenge

Fundamentally, there are two types of polar ice - the ice that covers landmasses and the ice that floats in the oceans. Not only do these two forms of ice have different consequences for our planet and its climate, they also pose different challenges when trying to measure thicknesses.

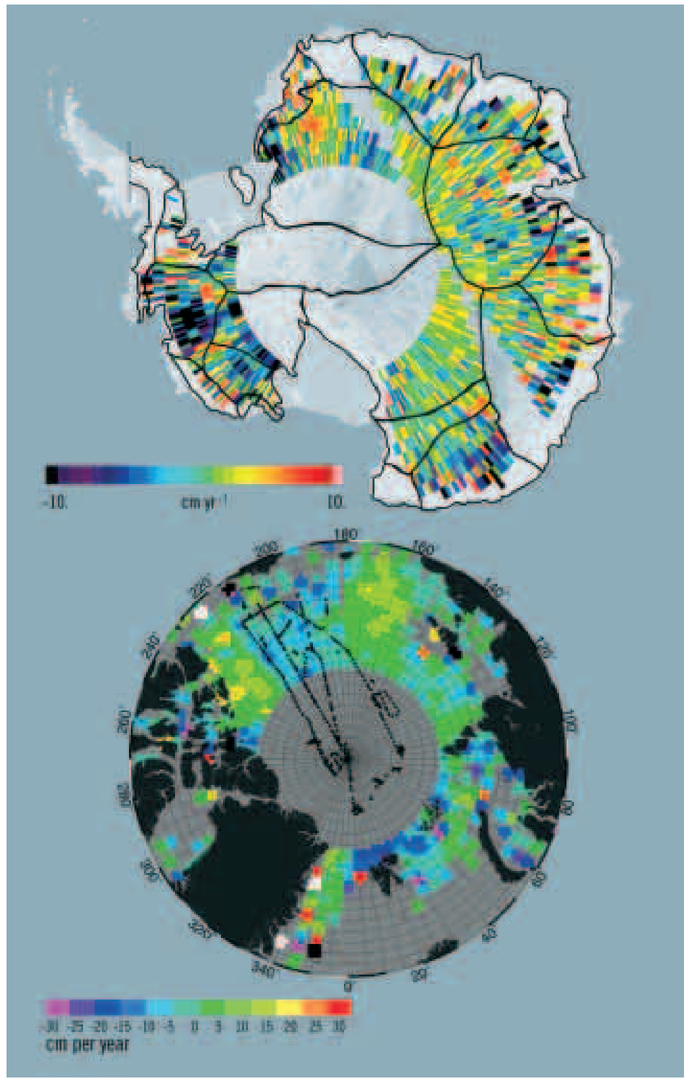
There is a strong link between Arctic sea ice and climate; it is expected that a change in ocean circulation patterns and weather would be associated with changes in sea ice cover. Since sea ice is relatively thin - just a few metres thick - its thickness can be measured directly. However, current methods (such as drilling holes through the ice) are only possible in small areas, and as such provide only localised data.

The ice sheets that blanket Antarctica and Greenland though are kilometres thick and it is the melting of these ice masses on land that have a direct influence on sea level. The best approach to measuring these vast thicknesses is to determine the height of the surface.

The challenge facing the CryoSat mission therefore falls into two areas: firstly to acquire accurate measurements of the thickness of floating sea ice so that annual variations can be detected; and secondly to survey the surface of the ice sheets accurately enough to detect small changes.

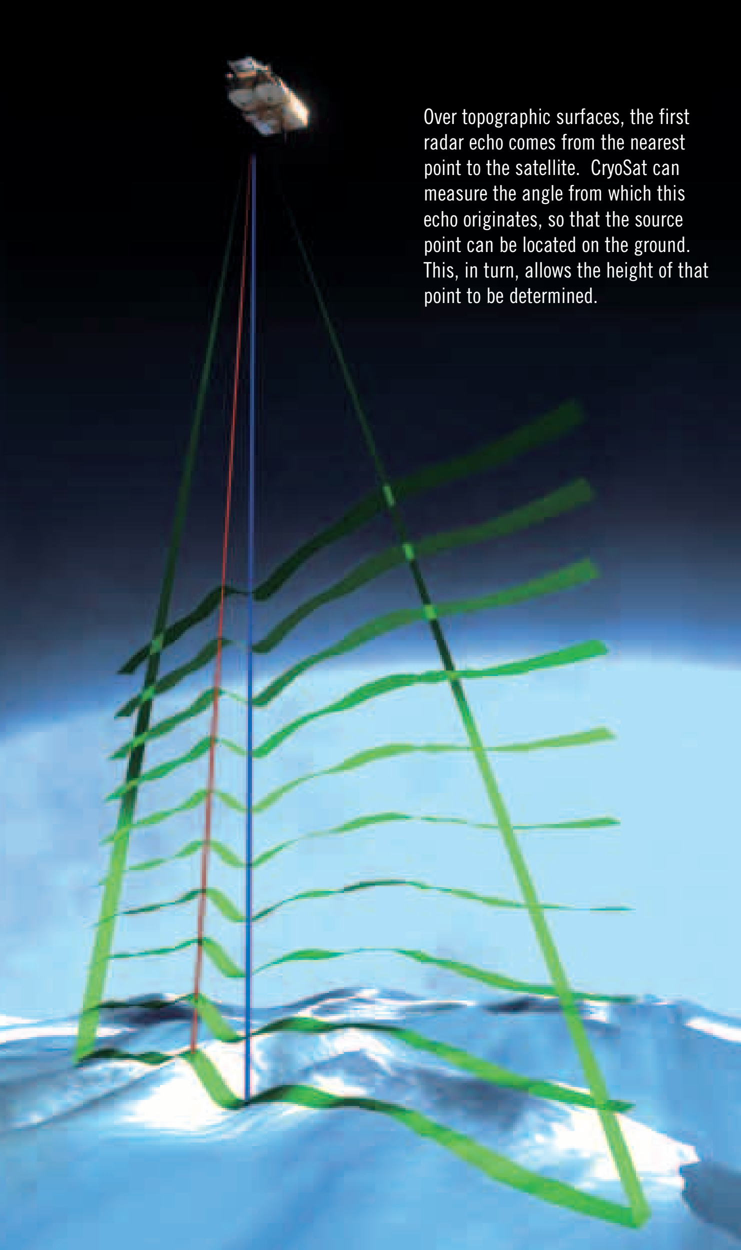
Meeting the challenge requires that CryoSat carry a precise radar altimeter. An altimeter sends out a short radar pulse and measures the time that it takes for this signal to travel from the spacecraft to the ground and back. Altimeters have become an important tool for oceanographic research. Observations with the ERS and Envisat radar altimeters, as well as those on TOPEX/Poseidon and Jason, are routinely used for estimating sea surface heights and wave heights. Today, the height of sea surfaces can be measured with an accuracy of 2-3 cm.

In order to make comprehensive measurements of the polar regions, a radar altimeter needs a more specialised design than those in orbit today, which have been optimised for measurements over the oceans or the land. It also has to be carried on a satellite in an unusually high inclination orbit, which will take it very close to the poles. Until the launch of NASA's ICESat, with its laser altimeter, no remote-sensing satellite had ever flown in such an orbit. And compared to ICESat's latitude limit of 86°, CryoSat will go even further, reaching latitudes of 88° North and South on every orbit.

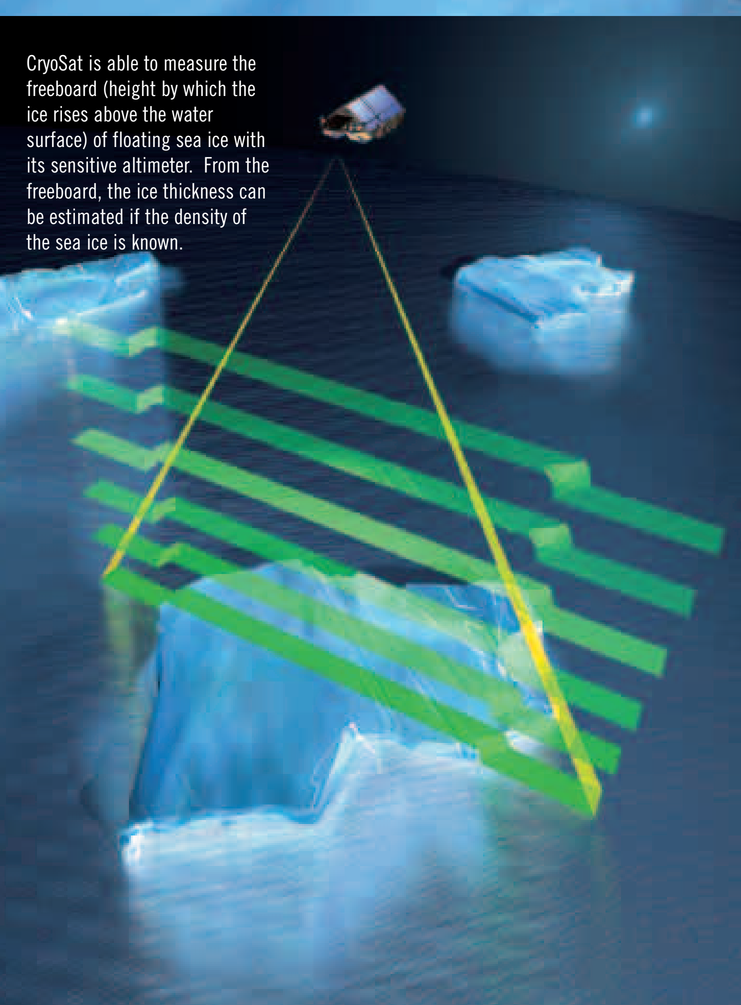


The radar altimeter on the European ERS satellites made it possible to measure the change in topography of the Antarctic ice sheets (upper image) and estimate sea-ice thickness in the Arctic (lower image). Although a remarkable scientific achievement, the maps demonstrate the shortcomings of the existing satellite systems - there is a large data gap at each pole and the most dynamic areas at the outer edges of the ice sheets are not covered.

The surface of the sea is not flat! Although invisible to the eye, the sea surface has ridges and valleys that echo the topography of the ocean floor - on a greatly reduced scale. The effect of the slight increase in gravity caused by the mass of rock in an undersea mountain is to attract a permanent mound of water several metres high over the seamount. The deep ocean trenches have a surface counterpart, which may be up to 10 m deep. However, spread over a width of 200 km these features can only be detected by radar altimetry from space. Smaller and more transient deviations from 'sea level' are caused by a range of phenomena, from tides to ocean currents.



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



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

Because of its operations in SAR and Interferometric modes, the altimeter on CryoSat is called SIRAL, short for 'SAR Interferometric Radar Altimeter'. It is complementary to the laser altimeter on the recently launched ICESat mission. ICESat will provide very accurate results over the ice sheets, but only when they are cloud-free.

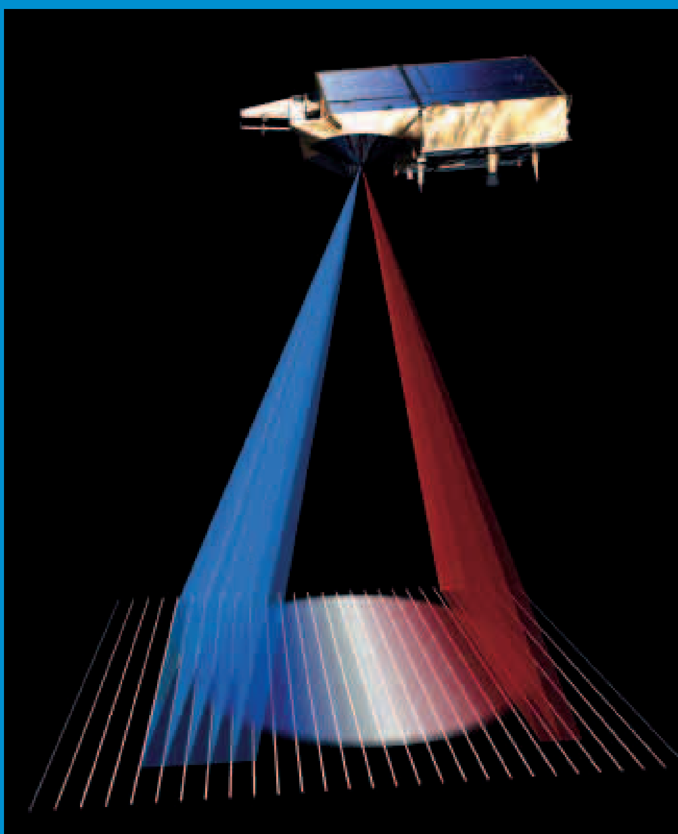
The Answer

The current constraints will be overcome with the altimeter designed for CryoSat, which exploits sophisticated radar techniques to improve resolution and observing capabilities. CryoSat will provide estimates of sea-ice thickness for the whole Arctic basin and monitor thickness changes in ice sheets, particularly around the edges where icebergs break off, as the glaciers reach the open sea. Although the satellite is only designed to have a 3-year lifetime, the accuracy of its measurements will be sufficient to detect evidence of thinning ice sheets and trends in the annual freezing and melting cycles of sea ice in the Arctic Ocean.

The radar altimeter on CryoSat is based on heritage from existing instruments, but with several major enhancements designed to overcome the special difficulties intrinsic to the precise measurement of icy surfaces. CryoSat determines the thickness of floating sea ice by measuring the *freeboard* of ice floes, that is the height by which the ice extends above the water surface. This technique has been demonstrated with the ERS-1 radar altimeter, but this instrument, as all conventional radar altimeters, is hampered by its relatively low spatial resolution of about 5 km. The key to CryoSat's ability is the measurement of sea-ice thickness all over the Arctic Ocean and its greatly improved spatial resolution in the along-track direction, achieved by the *Synthetic Aperture* technique.

The first returning energy in the radar echo obviously comes from the part of the Earth's surface closest to the satellite. Over sea ice (and ocean) this point is directly below the satellite, but on sloping surfaces, such as those found around the edges of ice sheets, this nearest point can be anywhere. A conventional radar altimeter can determine the range from the satellite to the nearest point very accurately, but as there is no way of knowing where the point *is*, it is impossible to ascribe a position and elevation to it. CryoSat is able to pin down the location of the echo in the fore- and aft-direction by using its SAR capability, but to resolve left and right needs an additional feature. Over these sloping surfaces CryoSat will operate in the *SAR-Interferometry* mode, which provides the key measurement of the angle of arrival of the echo.

The instruments



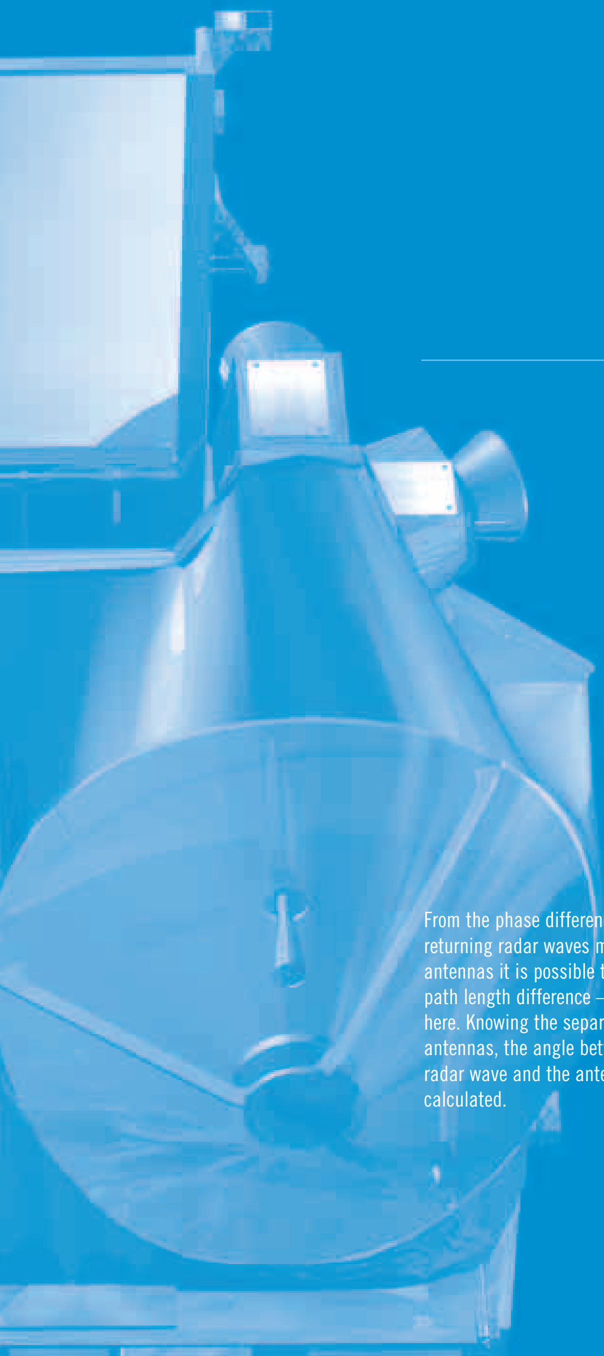
The footprint of the radar beam on the ground has parts slightly ahead of the satellite and parts behind it. The satellite moves at high speed in its orbit – towards some parts of the footprint and away from others. This relative speed induces slight frequency shifts in the returning radar energy, due to the Doppler effect, shown as a blue or red tint here. The radar echo contains the combination of all this energy but by processing a correlated burst of radar pulses it is possible to slice the returning echo up into a series of Doppler beams.

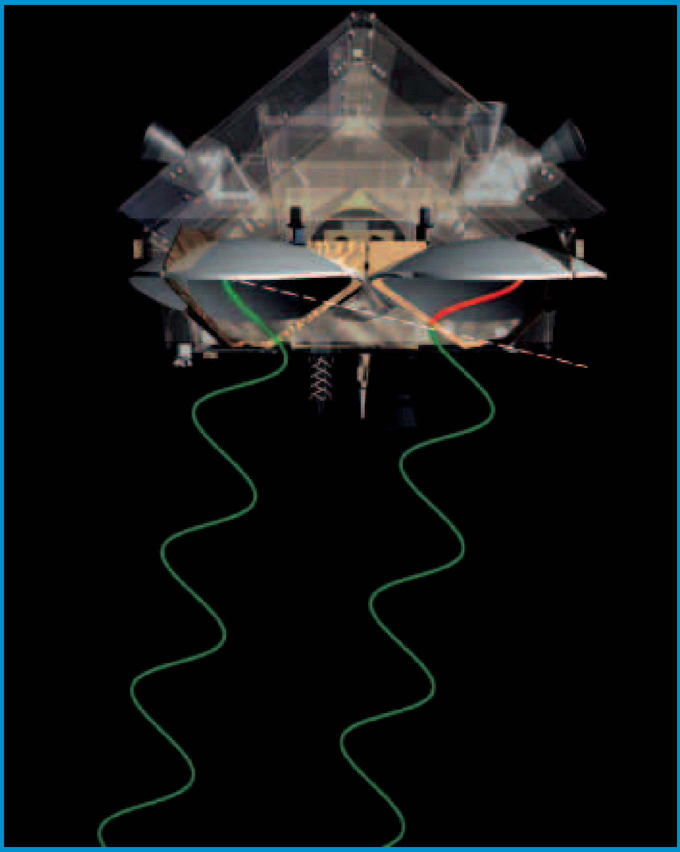
CryoSat's primary payload is the SIRAL radar altimeter with its extended capabilities to meet the measurement requirements for ice-sheet elevation and sea-ice freeboard.

Conventional radar altimeters send radar pulses with a large enough interval between them that the echoes are uncorrelated; many uncorrelated echoes can be averaged to reduce noise. At the typical satellite orbital speed of 7 km/sec, the interval between pulses is about 500 µs. The CryoSat altimeter sends a burst of pulses with an interval of only about 50 µs between them. The returning echoes are correlated, and by treating the whole burst at once, the data processor can separate the echo into strips arranged across the track by exploiting the slight frequency shifts (caused by the Doppler effect) in the forward- and aft-looking parts of the beam. Each strip is about 250 m wide and the interval between bursts is arranged so that the satellite moves forward by 250 m each time. The strips laid down by successive bursts can therefore be superimposed on each other and averaged to reduce noise. This mode of operation is called the *Synthetic Aperture Radar*, or SAR mode.

In order to measure the arrival angle, a second receive antenna is activated to receive the radar echo with two antennas simultaneously. When the echo comes from a point not directly beneath the satellite there will be a difference in the path-length of the radar wave, which is measured. Simple geometry then provides the angle between the *baseline*, joining the antennas, and the echo direction. The difference in path length is tiny - up to a wavelength of the radar wave (2.2 cm) - and has to be accurately determined in a range measurement of 720 km.

In addition to the altimeter, the knowledge of the precise orientation of the baseline of the two receiving antennas is essential for the success of the mission. CryoSat measures this baseline orientation using the oldest and most accurate of references: the positions of the stars in the sky. Three *star trackers*





From the phase difference between the returning radar waves measured by two antennas it is possible to determine the path length difference – shown in red here. Knowing the separation between the antennas, the angle between the arriving radar wave and the antennas can be calculated.

are mounted on the support structure for the antennas. Each of these devices contains an electronic camera, which takes five pictures per second. Each image is analysed by the star tracker's built-in computer and compared to a catalogue of star positions.

The altimeter makes a measurement of the distance between the satellite and the surface. But this measurement cannot be converted into the more useful measure of the height of the surface until the satellite position is accurately known. These days the orbital position of altimetry satellites can be determined to a few centimetres, but this requires the satellite to carry some specific equipment. CryoSat has two such devices:

- A radio receiver called DORIS (Doppler Orbit and Radio Positioning Integration by Satellite) detects and measures the Doppler shift on signals broadcast from a network of over 50 radio beacons spread around the world. Although the full accuracy of this system is only obtained after ground processing, DORIS is able to provide a real-time estimate onboard, good to about half a metre. The DORIS system has been in operation for over a decade, and is used on many satellites, including Envisat.

- A small laser retroreflector is attached to the underside of CryoSat. This little device has seven optical corner cubes, which reflect light back in exactly the direction it came from. A global network of laser tracking stations will fire short laser pulses at CryoSat and time the interval before the pulse is reflected back. These stations are relatively few, but because their position is very accurately known from their routine work of tracking geodetic satellites, they provide a set of independent reference measurements of CryoSat's position.

The essential groundwork

Like any scientific measurement, to be truly useful the CryoSat results have to be accompanied by an assessment of the extent to which they may be in error. A comprehensive assessment of the way measurements are made and interpreted as ice thickness information has been performed. This has identified all of the areas where errors may creep into the final results. For example, snow layers are unavoidable when observing ice surfaces, and the influence they have on the observing techniques used by CryoSat has to be assessed very carefully if trends towards changing ice thicknesses are to be verified. There are many other issues to be considered, such as variations in the density profiles in the ice layers and the wetness of the upper snow layer and how such parameters vary over a particular area.

In order to account for these error sources and attach numbers to the uncertainty they introduce, measurements of the phenomena involved have to be made. This means expeditions into the polar regions with suitable measurement equipment. Such expeditions are needed both before launch, as essential input to the data processing software development, and after launch in order to compare the CryoSat estimations of thickness with direct measurements on the ground.

A range of physical properties of snow and ice are earmarked for detailed measurements and appropriate measurement techniques identified. These include a mix of surface measurements by field parties, systems mounted on helicopters and aircraft, and measurements from polar research ships:

- Ice profiles are measured by airborne versions of the CryoSat altimeter in order to understand and validate the operating principles for this kind of observation. Additional profiles are obtained with laser altimeters.

- Ice-core drilling on ice sheets and sea-ice floes allows examination of the structure of the snow and ice layers, which have an impact on the altimeter measurements.

- Measurements from underwater sonar devices, buoys and special electromagnetic sensors operated from above the sea provide independent information on the thickness of sea ice.

The satellite

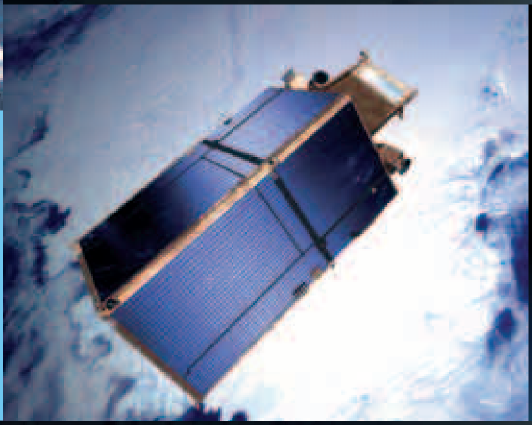
CryoSat will be launched on a Rockot vehicle from Plesetsk in Russia. Rockot is based on the SS-19 intercontinental ballistic missile, with a versatile third stage added to the 2-stage missile booster. Recently commercialised, Rockot has already launched several satellites and the SS-19 has had over 150 test firings.

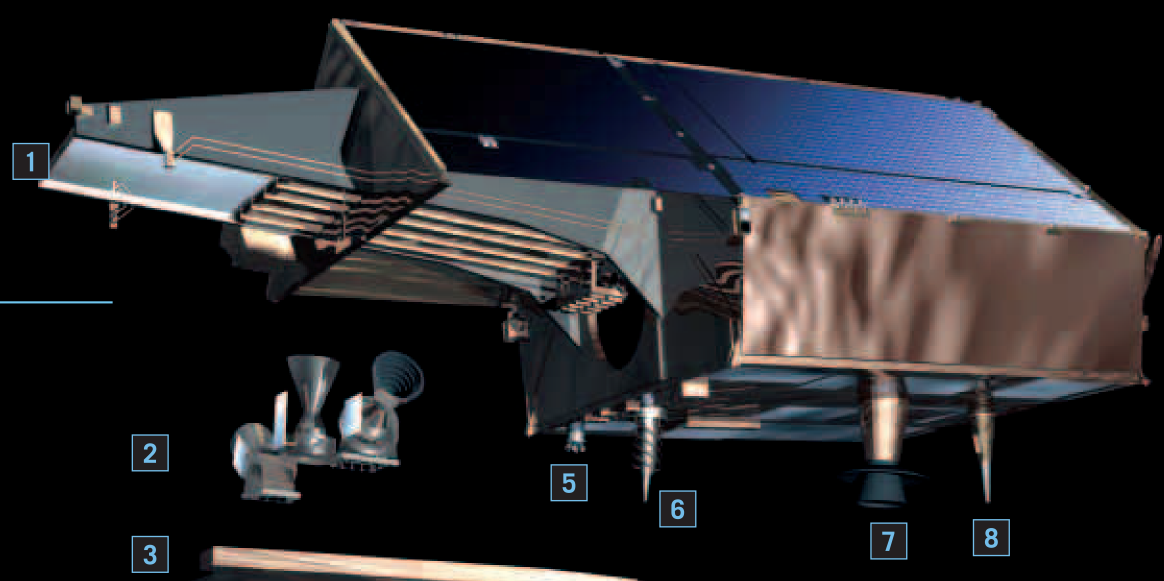
The single ground station for the CryoSat mission is located at the ESA station in Kiruna, in northern Sweden. The station is linked to the Mission Control Centre, at ESOC in Darmstadt, for the control and monitoring of the satellite. In addition, all of the considerable science data processing will be done locally at the Kiruna station by an automated system of computer workstations and a robot to handle the data tapes.

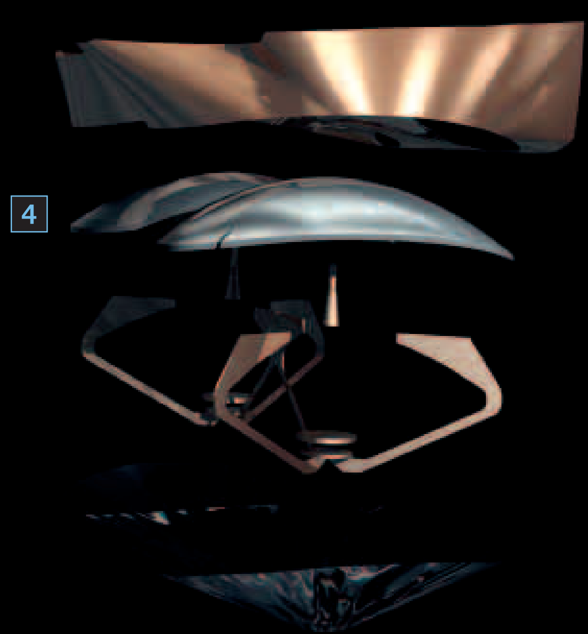
CryoSat is a satellite with a single mission objective - therefore, the selection of its orbit and basic characteristics have been entirely driven by the scientific needs. Thus, the orbit has a high inclination of 92°, which takes it almost to the poles - it will be just 2° short. This orbit is not Sun-synchronous (commonly used for remote sensing satellites) and will drift through all angles to the Sun in 8 months. This has presented some challenges in the satellite design; all parts will at some time be exposed to the full heating power of the Sun, while at other times half the satellite will be in permanent shadow for weeks on end.

Unlike most satellites, CryoSat does not have any deployable solar panels; in fact the satellite has no moving parts at all, except for some valves in the propulsion system. This has enabled a very significant cost saving, but does pose some problems for the provision of adequate solar power in CryoSat's unusual orbit. The solar panels are rigidly fixed to the satellite body, forming a "roof" with a carefully optimised angle, which provides adequate power under all orbital conditions and still fits within the launch vehicle.

The other area that has received particular attention has been the mounting of the two SIRAL antennas. Any distortion in the support of the antennas, leading to a tilt in the baseline, is indistinguishable from an offset in the calculated angle of arrival of the echo. This would lead to errors in the assumed location of the echo and hence the elevation of the surface. To stay within the allowed error limits for the mission, such distortions have to be less than 30 arcseconds (approximately the same as the size of a football seen from 2 km away), a significant challenge given CryoSat's unusual orbit. The challenge has been met by designing the structure to be intrinsically stable and providing auxiliary attitude measurement sensors directly mounted onto this structure.







3 Antenna Bench:
stable and rigid support structure isostatically mounted to the satellite nose.

4 SIRAL Antennas:
rigidly mounted to the antenna bench immediately beneath the SIRAL electronics - they are protected in front by a layer of radar-transparent thermal isolation film.

5 Laser Retroreflector:
reflects incoming laser tracking pulses directly back to the ground-based laser station.

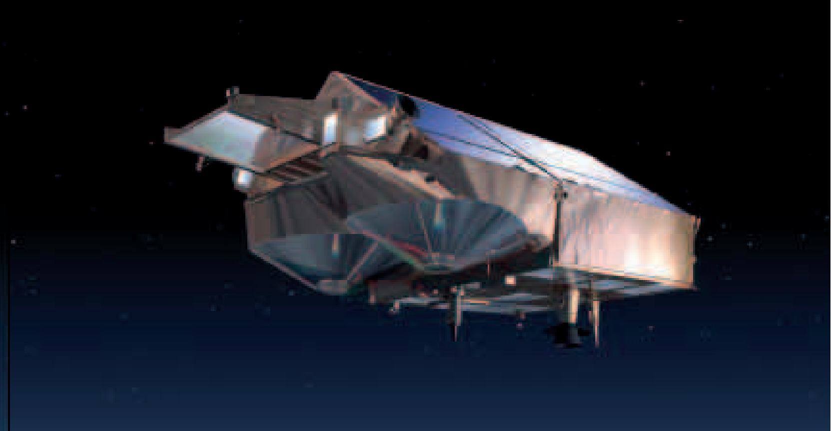
6 DORIS Antenna:
receives signals from a global network of radio beacons, for orbit determination.

7 X-band Antenna:
transmits the enormous volume of SIRAL measurement data to the ground, when the satellite is above the horizon at Kiruna - the antenna is designed to provide the same signal strength when the satellite is at the horizon as when it is overhead.

8 S-band Helix Antenna:
receives telecommands from the ground and transmits status and monitoring information.

1 Radiator:
a heat-radiating panel at the tip of the nose structure which houses the SIRAL electronics under the solar array.

2 Star Tracker:
three are mounted directly on the antenna bench.



CryoSat Overview

CryoSat Mission
To determine variations in the thickness of the Earth's continental ice sheets and marine ice cover. Its primary objective is to test the prediction that ice is thinning due to global warming. Selected in 1999 as an Earth Explorer Opportunity mission as part of ESA's Living Planet Programme.

Mission Duration
Six months of commissioning followed by a 3-year operational mission.

Mission Orbit
Type:	LEO, non Sun-synchronous
Repeat cycle:	369 days (30 day sub-cycle)
Mean altitude:	717 km
Inclination:	92°
Nodal regression:	0.25° per day

Payload
SIRAL (SAR/Interferometric Radar Altimeter)
- Low-Resolution Mode provides conventional pulse width - limited altimetry over central ice caps and oceans;
- SAR Mode improves along-track resolution (~250 m) over sea ice by significantly increased pulse repetition frequency and complex ground processing;
- SAR Interferometric Mode adds a second receive chain to measure the cross-track angle of arrival of the echo over topographic surfaces at the margins of ice caps.

Star Trackers (3) measure the interferometric baseline orientation, as well as driving satellite attitude control.

DORIS enables precise orbit determination, as well as providing in-orbit position to the AOCS.

Laser Retroreflector enables tracking by ground-based lasers.

Configuration
- Simplified rigid structure with no moving parts;
- All electronics mounted on nadir radiator;
- SIRAL electronics mounted close to antennas;
- SIRAL antennas on isostatically mounted plate with Star Trackers.

Dimensions
4.60 m x 2.34 m x 2.20 m

Mass
711 kg (including 36 kg of fuel).

Power
- 2x GaAs body-mounted solar arrays, delivering 800 W each at normal solar incidence.
- 60 Ah Li-ion battery.

Spacecraft Attitude
- 3-axis stabilised local-normal pointing, with 6° nose-down attitude.
- Star trackers, magnetometers, magnetotorquers and 10 mN cold-gas thrusters.
- <0.1° pointing error; <0.001°/s stability.

Command and Control
Integrated data handling and AOCS computer - communication by 1553 bus and serial links.

On-board Storage
- 1 Solid-State Recorder, capacity 2 ˘ 128 Gbits.
- Data generated on-board: 320 Gbits/day.
- Full mission operation with a single ground station at Kiruna.

RF Links
- X-band data downlink: 100 Mbps at 8.100 GHz.
- S-band TTC link: 2 kbps uplink, 8 kbps downlink.

Launch Vehicle
Rockot (converted SS-19), launch from Plesetsk, Russia

Flight Operations
- Mission control from ESOC *via* Kiruna ground station.
- Onboard measurements automatically planned according to a geographically defined mask.

Payload Data Processing
- Data processing facility at Kiruna ground station.
- Local archiving of data with precision processing after one month following delivery of precision orbits from DORIS ground segment.
- Possibility of quick-look data.
- User Services coordinated *via* ESRIN with dissemination of data from Kiruna.

Satellite Prime Contractor
Astrium GmbH

The CryoSat mission has been designed from the start in accordance with its scientific goals. However, programmatic realities have ensured that a limited budget and a demanding development schedule have been important drivers in the actual implementation of the design. Much of the equipment on CryoSat has been manufactured according to existing designs from various other projects. This saves much development time (and cost) but has meant that the design team has had to provide the 'glue' to make these different electronic boxes work together.

In conventional satellite development, at least two versions of the satellite would be built, as the design is tested by first building a fully representative 'Engineering Model'. This step has been avoided with CryoSat by instead creating a full set of software simulations of the equipment, which communicate via a special hardware/software interface with the satellite's computer. Eventually, the real CryoSat equipment will replace the simulations, until the entire set of avionics is running on a tabletop.

Why doesn't CryoSat fly in a 90° inclination orbit, which would take it directly over the poles to observe all of the polar regions?The choice of orbit is a compromise as a 90° orbit would be beneficial for the survey of Arctic sea-ice, but would seriously degrade the monitoring of the Greenland and Antarctic ice masses. Such measurements are made at orbit crossovers, where the north-going satellite track crosses over an earlier (or later!) south-going track. With a 90° inclination orbit, crossovers would be few, only occurring due to the Earth's rotation since the orbit tracks are otherwise directly along the lines of longitude and do not cross. The 2° offset from a true polar orbit is enough to ensure an adequate density of crossovers over the ice sheets.

European Space Agency
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