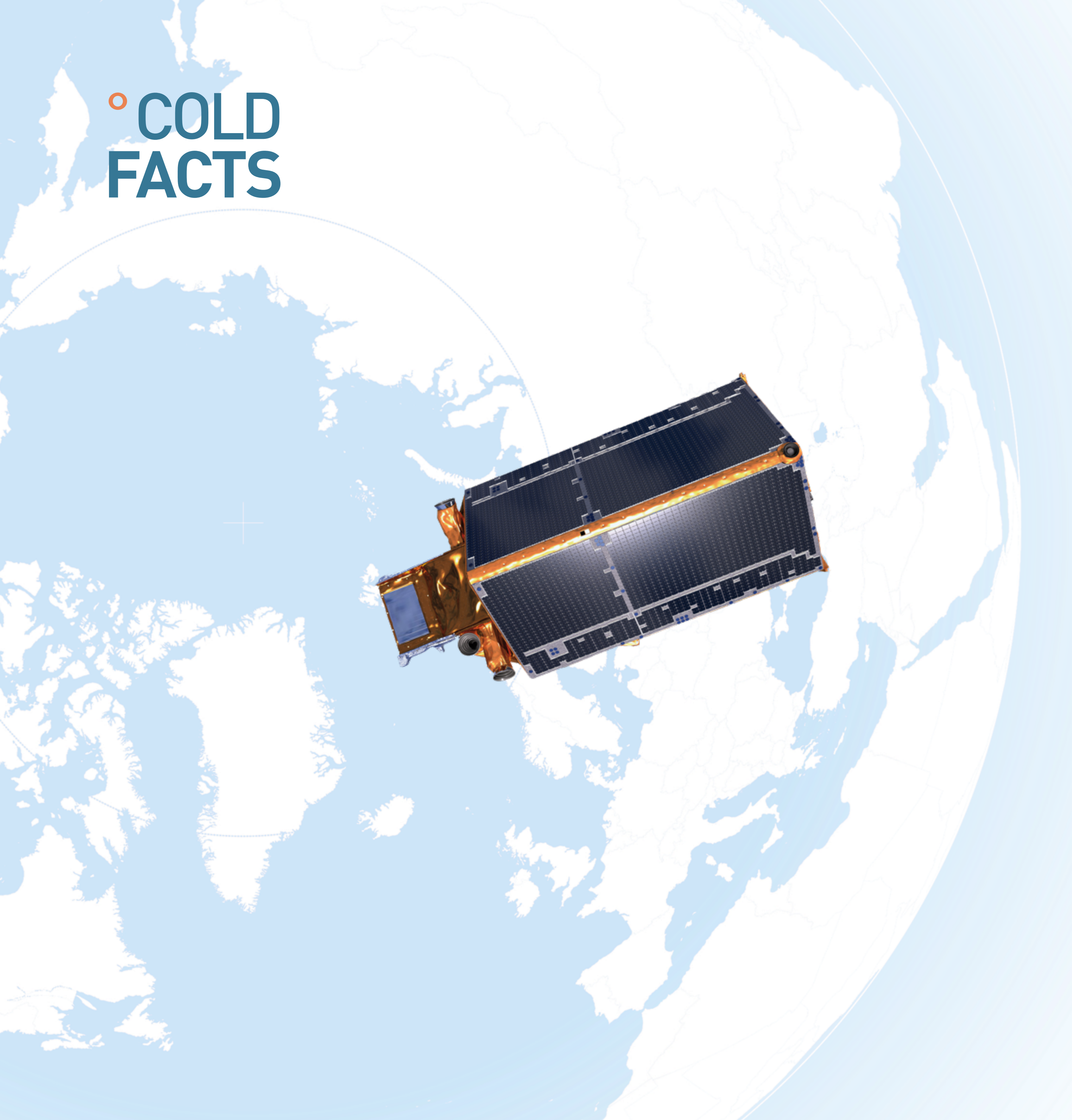
°COLD FACTS



ESA's CryoSat 2 programme

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Based on CryoSat2 - ESA's Ice Mission, ESA, 2010

ESA's CryoSat2 programme

Cryosat, ESA's ice mission

ESA's Earth Explorer CryoSat mission is dedicated to precise monitoring of the changes in the thickness of marine ice floating in the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica.

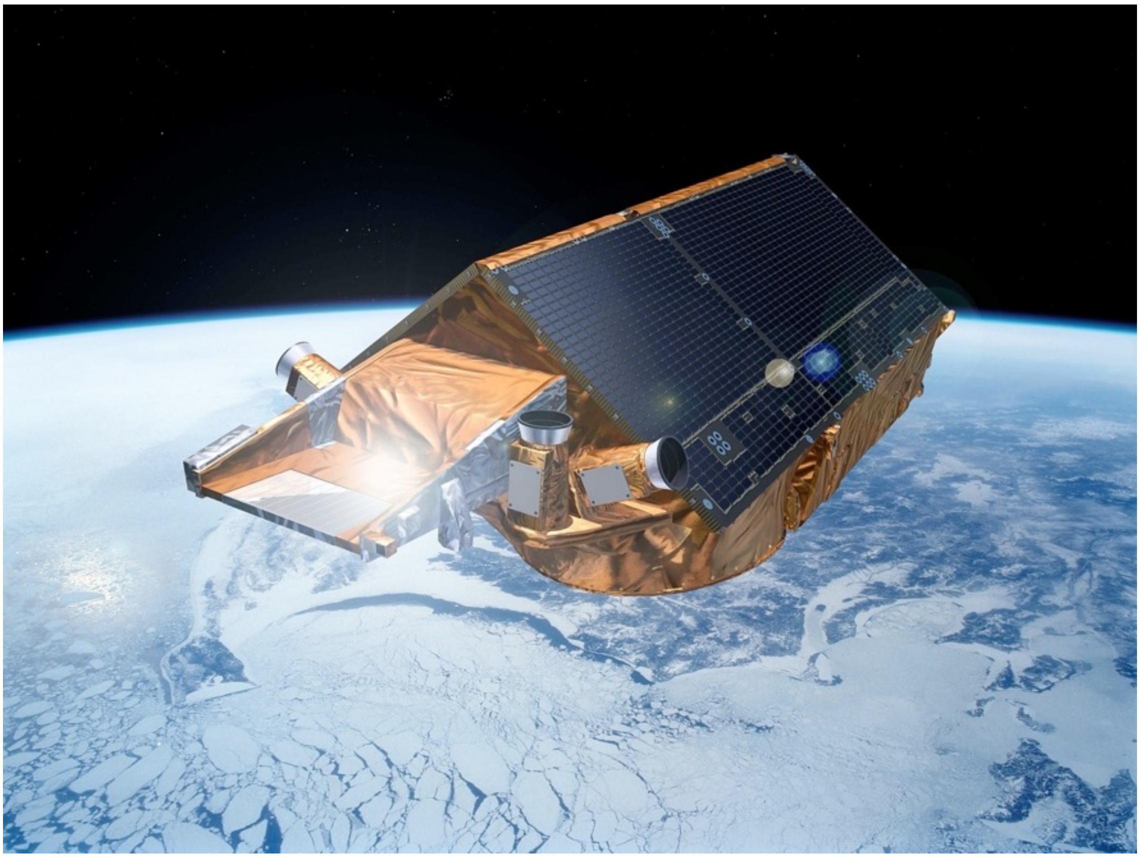
With the effects of a changing climate fast becoming apparent, particularly in the polar regions, it is increasingly important to understand exactly how Earth's ice fields are responding. Diminishing ice cover is frequently cited as an early casualty of global warming and since ice, in turn, plays an important role regulating climate and sea level, the consequences of change are far reaching.

For some years now, satellites such as ESA's Envisat have been mapping the extent of ice cover. As stated in the Climate Change 2007 Synthesis Report by the Intergovernmental Panel on Climate Change, "Satellite data since 1978 show that annual average Arctic sea-ice extent has shrunk by 2.7% per decade." However, this is only part of the picture.

In order to understand fully how climate change is affecting these remote but sensitive regions, there remains an urgent need to determine exactly how the thickness of the ice, both on land and floating in the sea, is changing. By addressing this challenge, the data delivered by the CryoSat mission will complete the picture and lead to a better understanding of the role that ice plays in the Earth system.

The CryoSat-2 satellite replaces the original CryoSat, which was lost owing to a launch failure in October 2005. Following the loss, the mission was judged to be even more important than when it was first selected for development, and the decision to rebuild was taken. Almost exactly four years to the day after that decision, the new CryoSat-2, with a number of improvements, was ready for launch.

CryoSat's original objective was to determine if there was a trend towards diminishing ice cover. There now seems little doubt that there are indeed trends – the challenge now is to characterise them.



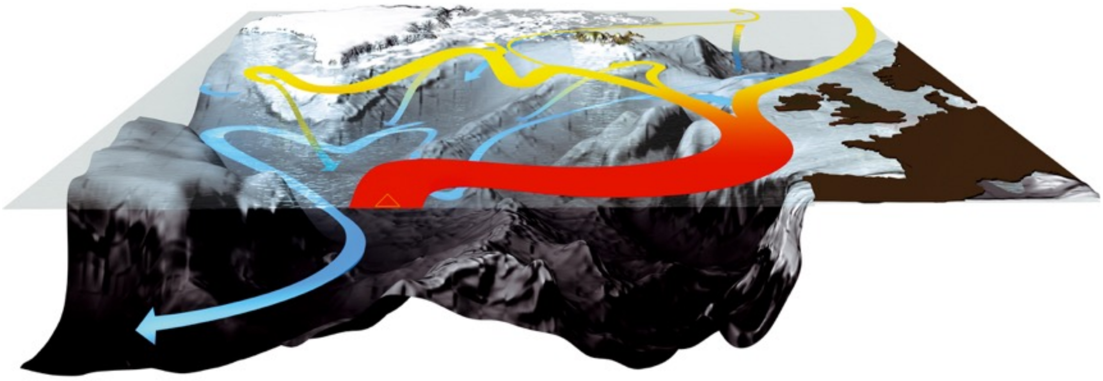
CryoSat-2 in orbit above the arctic ice cap (ESA)

Ice, climate and sea level

Ice plays an important role in regulating Earth's climate in a number of ways. As solar radiation reaches Earth's atmosphere and surface, a certain percentage is reflected back out to space, depending on the 'albedo' (the reflectivity or whiteness) of the surface. Snow-covered ice has a high albedo and reflects about 80% of sunlight. Thus, once formed, ice tends to be maintained. As ice cover begins to melt, the albedo decreases and the combined effect of diminishing ice extent results in less solar radiation being reflected from Earth's surface. The surface then absorbs more and more energy, leading to positive feedback and resulting warming.

The polar oceans each year experience the formation and then melting of vast amounts of sea ice. At the North Pole, an area the size of Europe melts every summer and then freezes again the following winter. The thickness of this sea ice plays a central role in polar climate because it moderates heat transport by insulating the relatively warm ocean from the cold polar atmosphere.

In addition, the seasonal changes of sea ice have a significant influence on the global ocean circulation pattern known as the 'thermohaline circulation'. As ice melts, there is an influx of fresh water into the surrounding ocean. This reduces the salinity and, consequently, the density of the water. Conversely, as the seawater cools and sea ice forms, the salinity and density of the surface seawater increase. This density increase causes the surface waters to sink and effectively to act as a pump, driving deep ocean currents towards the equator and away from the polar regions. To compensate for this loss, a return flow of warmer, less dense surface water is drawn northwards from low to high latitudes.



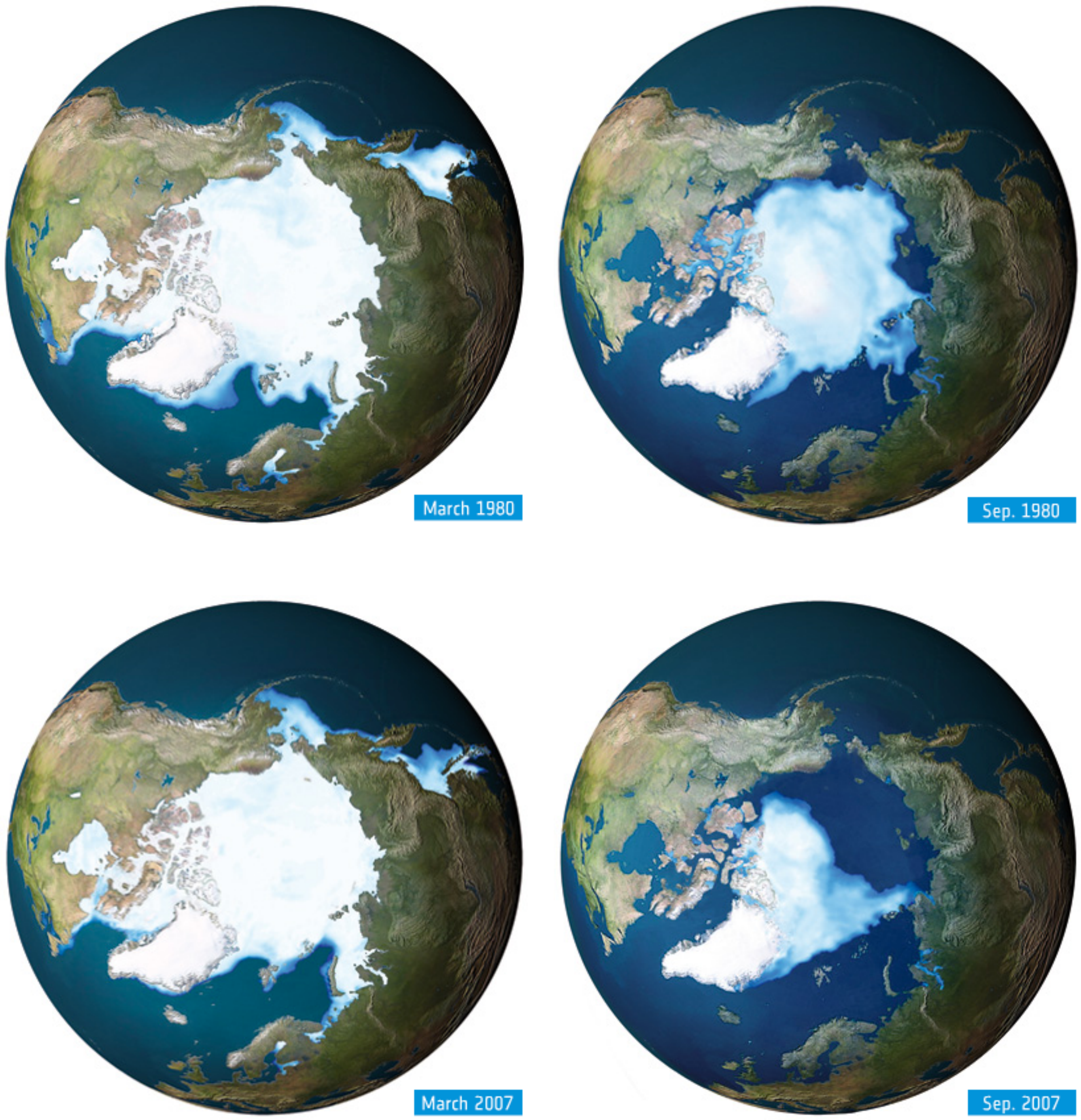
Ocean circulation in the Atlantic (ESA)

The Gulf Stream, which carries warm surface water northwards from the Gulf of Mexico to the sub-polar ocean east of Greenland, is extremely important for moderating the climate in Europe. The coastal waters of Europe are 4°C warmer than waters at the equivalent latitude in the North Pacific. These warm waters mix with surrounding water, and cool and sink as they reach the Arctic. If this circulation pattern were disturbed by reduced sea ice in the Arctic, there could be a profound effect on the strength and direction of this current. Clearly, an improved understanding of the fluxes of Arctic sea ice is important for predicting Europe's climate.

Lastly, the large ice sheets overlying land have an important effect on sea level. The Antarctic and Greenland ice sheets amount to about 28 million km3, which equates to sea level being 65 m lower than it would be if this ice were to melt. Until relatively recently, it was thought that these huge thick ice sheets were largely stable. However, recent observations have shown that regional changes are occurring much faster than previously expected.

How is earth's ice changing

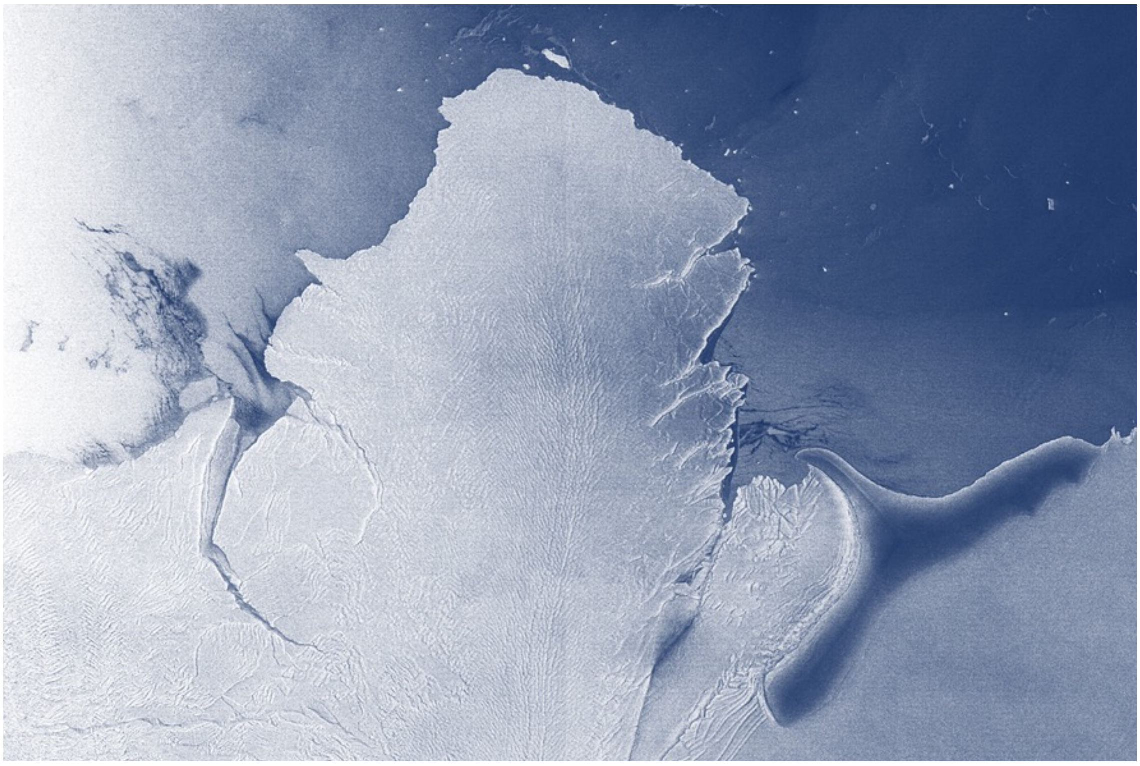
There is now little doubt that the temperature on Earth is rising due to increased concentrations of greenhouse gases in the atmosphere. During the course of the last century, the average global surface temperature rose by about 0.6°C and 10 of the warmest years on record have occurred since 1997. Scientists are predicting that average global temperatures will rise by 4°C by the end of the century. How rising temperatures will affect Earth's ice is still a hotly debated issue. However, recent evidence strongly suggests that ice cover is diminishing. One of the most dramatic signs of climate change has been seen in the extent of Arctic sea ice. Since 2000, the area of the Arctic Ocean covered by ice in the summer has reduced drastically, with the minimum occurring in September 2007. 2008 would have been a new record if it had not been for 2007, and 2009 was similar.



Arctic sea ice cover: winter maximum (left) and summer minimum (right) in 1980 and 2007 (ESA)

There is also emerging evidence of changes to continental ice cover. Before 2000, indications were that Earth's two major ice caps, covering Antarctica and Greenland, were generally stable, at least in their interiors. However, it is now known that the ice caps are melting at their base, caused by warming oceans. It has been discovered that a large glacial basin at the coastal boundary of West Antarctica – the Pine Island Glacier – is thinning at a rate of 16 m per year, acting as a huge drainage basin. Satellites also continue to observe the break up of the Wilkins Ice Shelf on the southwest side of the Antarctic Peninsula. In April 2009, rifts that had developed on the ice shelf led to the collapse of the ice bridge that connected it to Charcot Island.

New information about changes in continental ice cover has led to a projection of sea-level rise on the order of 1.4 m by 2100. This figure, cited in the 2009 report by the Scientific Committee on Antarctic Research Antarctic Climate Change and the Environment, is significantly higher than the 28–43 cm projections by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007).



Antarctic ice shelf system (ESA)

While there seems to be clear evidence that Earth's ice is changing, the real question is by how much. Reductions in the area of sea ice are readily observable using a variety of satellite remote-sensing techniques; however, there is only one practical way of converting this knowledge of 'area' of sea ice into 'volume' of sea ice. To do this conversion, information about ice thickness is needed – which is what CryoSat will measure.

CryoSat has been developed to measure thickness change not only in sea ice but also in the ice sheets on land. In particular, CryoSat carries sophisticated technologies to measure precisely changes at the margins of these ice sheets, where other satellite altimeter technology is currently limited. By accurately measuring thickness change in both types of ice, CryoSat will provide clear information to build a more detailed picture of exactly how Earth's ice is behaving.

How Cryosat will detect change

The challenge

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

There is a strong link between Arctic sea ice and climate; changes in ocean circulation patterns and weather are associated with changes in sea-ice cover. Melting of this ice has no direct effect on sea level, because it is already floating. Since sea ice is relatively thin – just a few metres – its thickness can be measured directly. However, current methods, such as drilling holes through the ice, sample only small areas and provide localised data only.

The ice sheets that blanket Antarctica and Greenland, however, 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.

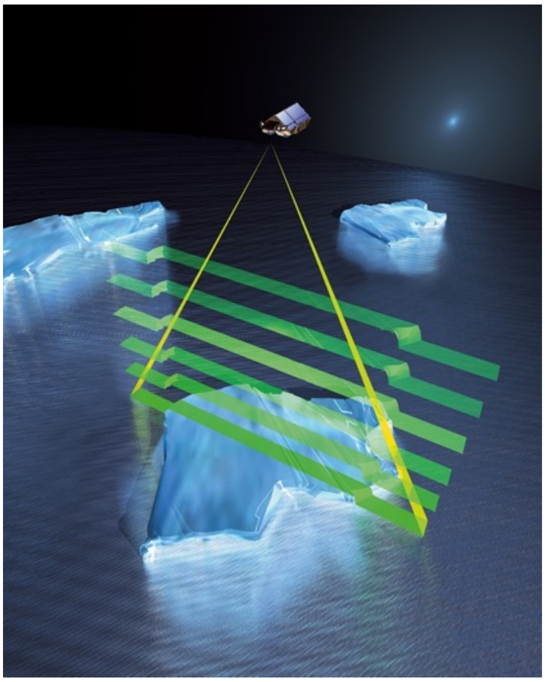
The challenge facing the CryoSat mission falls into two areas. Firstly, to acquire accurate measurements of the thickness of floating sea ice so that annual variations can be detected. Secondly, to survey the surface of the ice sheets accurately enough to detect small changes.

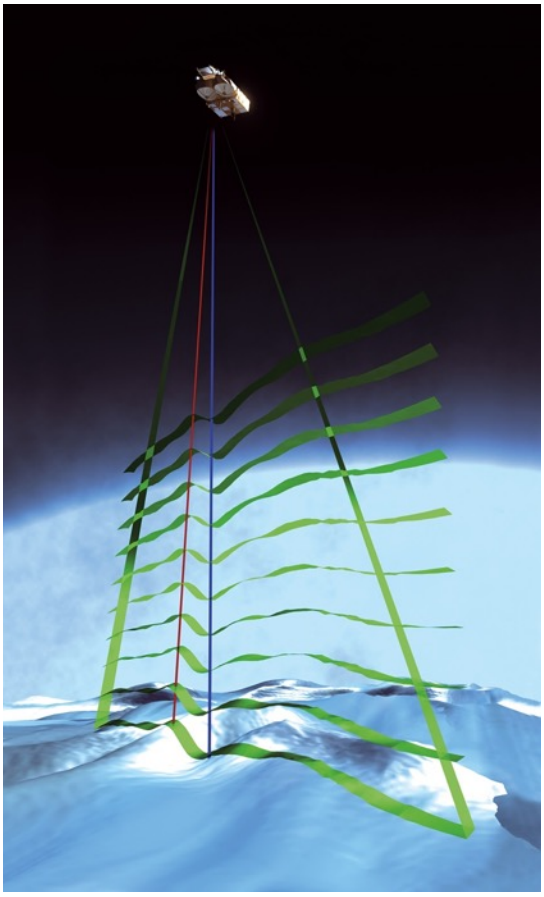
To meet these challenges, CryoSat-2 carries a precise radar altimeter. It sends out short radar pulses and measures the time it takes for the signals to travel from the satellite to the ground and back. Altimeters have become an important tool for oceanographic research. Observations from ESA's Envisat radar altimeter and those on the Jason-2 NASA/CNES Ocean Surface Topography Mission are routinely used for estimating sea-surface 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 to have a more specialised design than those currently in orbit. It also has to be carried on a satellite in an unusually high-inclination orbit, to 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. CryoSat-2 travels even further than ICESat's latitude limit of 86°, reaching 88° north and south on every orbit.

The answer

The current constraints are overcome with the altimeter designed for CryoSat-2, which exploits sophisticated radar techniques to improve resolution and observing capabilities. The mission will provide estimates of sea-ice thickness for the whole of the Arctic basin and monitor thickness changes in ice sheets, particularly around the edges, where icebergs break off as glaciers reach the open sea. Although the satellite is planned to be operational for only three years initially, 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. Together with observations of ice extent, this will lead to a better understanding of how the volume of ice is changing.





CryoSat-2 measuring the freeboard of floating sea ice (above) and the elevation of land-based ice sheets (right).

The radar altimeter on Cryosat-2 is based on heritage from existing instruments, but with several major enhancements to overcome the difficulties intrinsic to the precise measurement of icy surfaces. CryoSat-2 determines the thickness of floating sea ice by measuring the 'freeboard' of ice floes – the height protruding from the water. The key to the mission's ability to measure sea-ice thickness all over the Arctic Ocean is high spatial resolution in the along-track direction, which is achieved by the 'synthetic aperture' technique.

The first returning energy in the radar echo comes from the part of 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-2 is able to pin down the location of the echo in the fore- and aft-direction by using its Synthetic Aperture Radar (SAR) capability. To resolve left and right needs an additional feature: over these sloping surfaces the 'SAR-Interferometry' mode provides the key measurements of the angle of arrival of the echo.

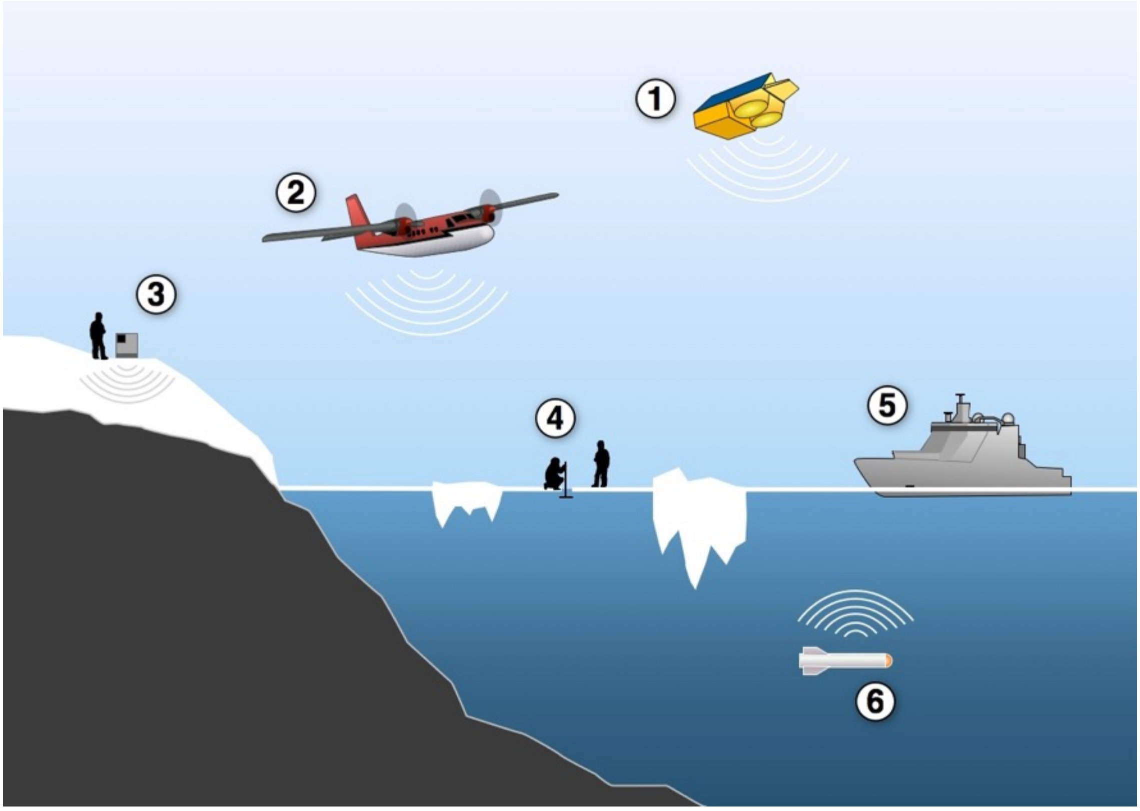
The essential ground work

Given that the aim of the CryoSat mission is to measure global changes in ice thickness down to a few centimetres per year using its sophisticated SIRAL radar altimeter, it is hardly surprising that a lot of effort goes into ensuring the data are as accurate as possible and that all possible errors are accounted for.

There are a number of ways in which errors could creep into the resulting ice-thickness maps. For example, snow layers are unavoidable when observing icy surfaces so the influence they have on the measurements taken by CryoSat-2 has to be assessed very carefully. There are many other potential error sources, including changes in snow wetness with time, the weight of snow on top of sea ice and variations in snow and ice density over a particular area.

To understand and correct for such natural sources of error means that large-scale expeditions to the polar regions have to be undertaken to collect information on snow and ice properties. These expeditions are needed both before launch, as essential input to the software that will transform CryoSat-2's measurements into ice-thickness maps, and after launch in order make a direct comparison between ground and satellite measurements.

ESA has organised a number of these Arctic and Antarctic expeditions. During April and May 2011 for example, the CryoSat Arctic campaign will gather a wealth of in-situ data using a range of instruments on the ground and radar installed on aircraft. These measurements taken on and over land and sea ice, and can then be compared with the data being received from CryoSat-2 in orbit. The one-month venture is an enormous logistical undertaking, involving teams of scientists in central Greenland, Svalbard and the Fram Strait, Devon Island and Alert in northern Canada.



Cryosat Arctic Campaign:
1. CryoSat-2
2. Radar-equipped aircraft
3. Ground based radar on land-based ice sheets
4. Local measurements of sea ice-thickness and snow cover
5. Ships conduct interdisciplinary missions
6. Automated Underwater Vehicle (UAV)

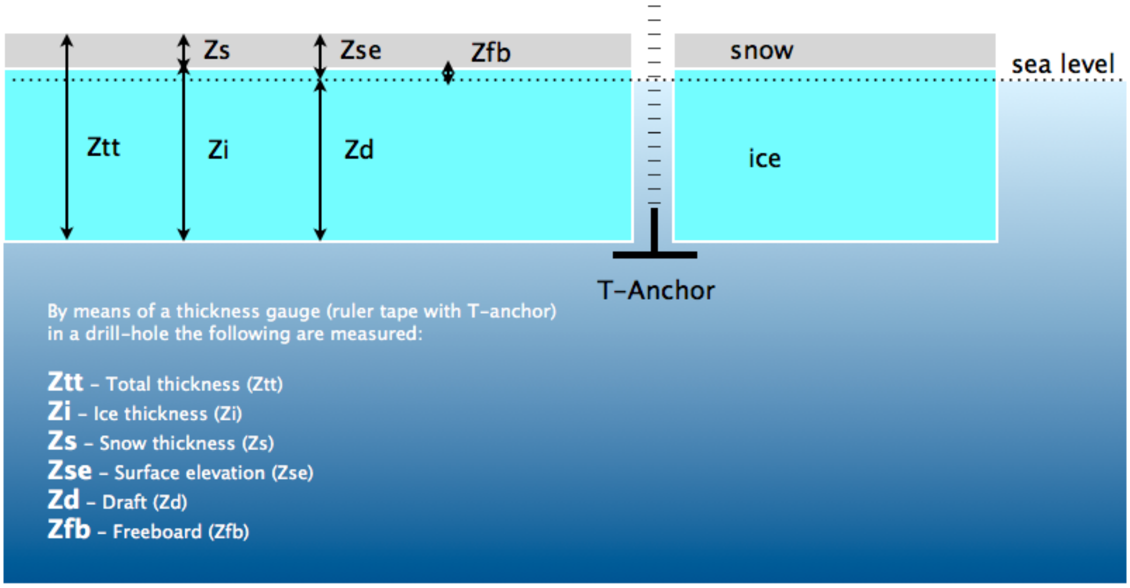
On the ground, sophisticated equipment such as ground-radar and neutron probes, as well as more traditional techniques, such as digging snow pits and drilling through the ice, are used to measure snow and ice properties.

While direct measurements of land and sea ice are taken on the ground, planes will be flying above taking measurements, and at times coincide with CryoSat's orbital path. The aircraft carry a radar instrument very similar to that on the satellite. These airborne data are then compared to the measurements taken on the ground and to the actual satellite measurements to fully understand and correct for the main error sources.

Various ships will conduct interdisciplinary missions in the Arctic, addressing sea-ice dynamics and biogeochemical studies as well as collecting field data for satellite remote sensing and model validation studies.

In addition, an automated Underwater Vehicle (AUV) can be deployed to conduct draft surveys in coordination with airborne acquisitions.

This is one of the most important validation campaigns for CryoSat, as for the first time, simultaneous measurements of ice from space, from the air and on the ground are being made. ESA is collaborating with NASA in this huge international effort. As part of their IceBridge airborne campaign to survey polar ice cover, NASA is taking part in joint flights with ESA planes, overflights of European ground sites and underflights of CryoSat.



Ice drilling procedures (Protocols and information by Christian Haas / Marc Cornelissen)

In addition to the large expeditions organised by ESA, several polar explorers, inspired by the CryoSat mission, have also volunteered to contribute by taking snow-depth and other measurements during their treks across the Arctic.

All this groundwork represents an essential part of the mission and the data collected allow scientists to interpret accurately the variations in ice thickness with time observed by CryoSat-2 so that the best possible trend in ice-thickness change over time can be derived.

Polar explorers measuring sea sea ice-thickness in the Arctic (Marc Cornelissen)

CryoSat-2 facts and figures

Launch	8 April 2010
Launcher	Russian/Ukrainian Dnepr, based on SS-18 intercontinental ballistic missile
Launch provider	International Space Company Kosmotras
Launch site	Baikonur Cosmodrome, Kazakhstan
Mission control	ESA's European Satellite Operations Centre (ESOC) in Darmstadt, Germany via ESA's ground station in Kiruna, Sweden
Data processing	Science data download to Kiruna ground station. Data is distributed directly to the users from Kiruna. Distribution is managed by ESA-ESRIN in Frascati, Italy
Orbit	Mean altitude of 717 km and 92° inclination; low-Earth, polar, non-Sun-synchronous
Nominal life	3 years (plus 6 months commissioning)
Instruments	SAR Interferometric Radar Altimeter (SIRAL), supported by Doppler Orbit and Radio Positioning Integration by Satellite (DORIS) and Laser Retro-Reflector (LRR) for precision orbit determination
Satellite mass	720 kg at launch, including 37 kg of fuel
Satellite dimensions	4.6 × 2.4 × 2.2 m
Power	2 × GaAs body-mounted solar arrays each delivering 850 W, 78 AH Li-ion battery
Satellite Prime Contractor	Astrium GmbH

References

1. **ESA.** ESA's Ice Mission (2010).
2. **ESA.** CryoSat Fact Sheet (2010).
3. **Pearson, T., M. Wooding.** CryoVEx 2011 Campaign Implementation Plan, ESA (2010).
4. **ESA.** CryoSat Ice Blog, http://blogs.esa.int/cryosat-ice-blog/arctic-campaign/, accessed April 22, 2011.