New satellites for monitoring the polar environment

Stein Sandven
Nansen Environmental and Remote Sensing Center.
N-5006 Bergen, NORWAY

Two types of satellite earth observation sensors are particularly interesting for monitoring the polar environment: Synthetic Aperture Radar and Radar Altimetry. Sea ice and glacier observation has been significantly improved during the last 15 years through the ERS programme which operated both types of sensors. Use of Synthetic Aperture Radar (SAR) images have continued with RADARSAT from 1996 and ENVISAST from 2003, both providing wideswath images with operational monitoring capability. Use of Radar Altimetry to observed accurate surface height of sea ice and glaciers will be significantly improved with the launch of CryoSat in 2005. Laser altimetry, which is a complementary method to radar altimetry, is already operated by IceSat.

ENVISAT

ENVISAT offers a unique capability to map simultaneously the earths surface by SAR, infrared radiometer and optical imager. This capability can be used in many scientific applications, but for the cryosphere it is the ASAR sensor which is most important.

ASAR offers several modes of operation, and for ice monitoring the possibility to map large ice areas using the Wideswath mode and the Global Monitoring (GM) mode is used. The GM mode provides near real time strip-line images with a swath width of 400 km and a resolution of approximately 1 km. This mode is operated as a default mode over sea ice areas in both polar regions. These data offers an opportunity for regular mapping of most sea ice areas by SAR in the polar regions.

For smaller areas where higher resolution is required Precision Images can be used. These images can also be obtained in alternating polarisation which is useful for better discrimination of ice types and open water. An overview of the three modes is given in Table 1.

An example of an ASAR mosaics of the sea ice in the Kara Sea produced from wideswath images with 600 m pixels is shown in Figure 1. The mosaic shows detailed ice edge, leads, polynyas, ice floes, fastice, rough ice versus level ice, and ice drift can be retrieved from time series of such mosaics. These mosaics are used to support ice navigation in the Northern Sea Route as well as for ice research and climate change studies.

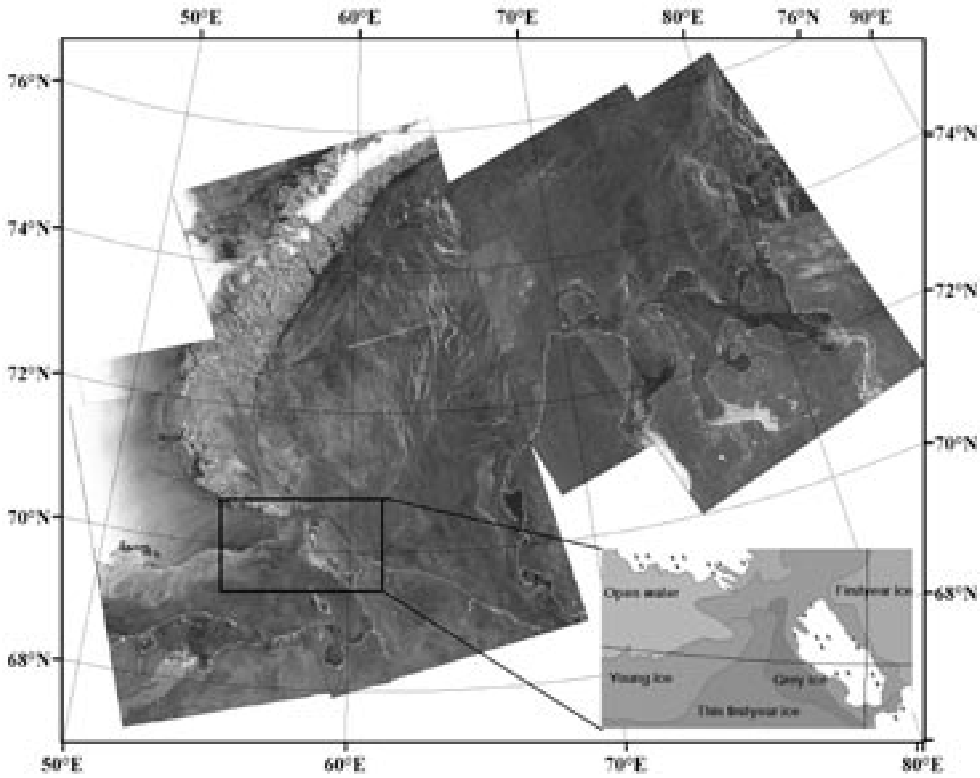


Figure 1. Mosaic of ENVISAT ASAR Wideswath images obtained on 27 – 28 February 2005, showing the ice extent, ice types, leads and polynyas which are important for ice navigation. The inserted ice chart is based on analysis of a part of the mosaic covering the Kara Gate area.

	Global Monitoring	Precision Image	Wide Swath
Geometric resolution	1 km x 1 km	12.5m x 12.5m	150m x 150m
Pixel spacing	500m x 500m	30m x 30m	75m x 75m
Swath width	400 km	100 km	400 km
Continuous coverage	up to 40,000 km (1 orbit)		4,000 km
Radiometric resolution (effective number of looks)	~ 8 at near range ~ 6.5 at far range	~3	~11.5
Data volume	~ 1.3 Mbytes per 400 km	130 Mbytes per 100 km	59 Mbytes per 400 km

Table 1. ASAR Global Monitoring, Precision Image and Wide Swath product specifications.

CRYOSAT

The CryoSat mission was selected, in June 1999, as the first mission in ESA's Earth Explorer Opportunity Mission series. The goals of CryoSat are to measure variations in the thickness of perennial sea and land ice fields based on data over three years, which is the estimated operation time for CryoSat. The primary instrument on CryoSat is a radar altimeter (SIRAL) which has three modes of operation:

- Conventional pulse limited operation for the ice sheet interiors and open ocean.
- Synthetic aperture (SAR) operation for sea ice.
- Dual-channel synthetic aperture/interferometric (SARIn) operation for ice sheet margins with more topography than the relatively flat ice sheet interiors

Over sea ice the new *Synthetic Aperture* mode will use the entire (beam-limited) along-track signal history to retrieve height measurements. The height profiles will be used to estimate the ice freeboard which furthermore will be used to retrieve ice thickness (Fig. 2). An important property of the synthetic aperture processing is to obtain enhanced resolution along track, about 250 m, as shown in Fig. 3a. This will improve the capability to observe freeboard of sea ice significantly compared with the ERS altimeter with about 7 km footprint. The enhanced along-track resolution will be important for improved ice thickness estimates.

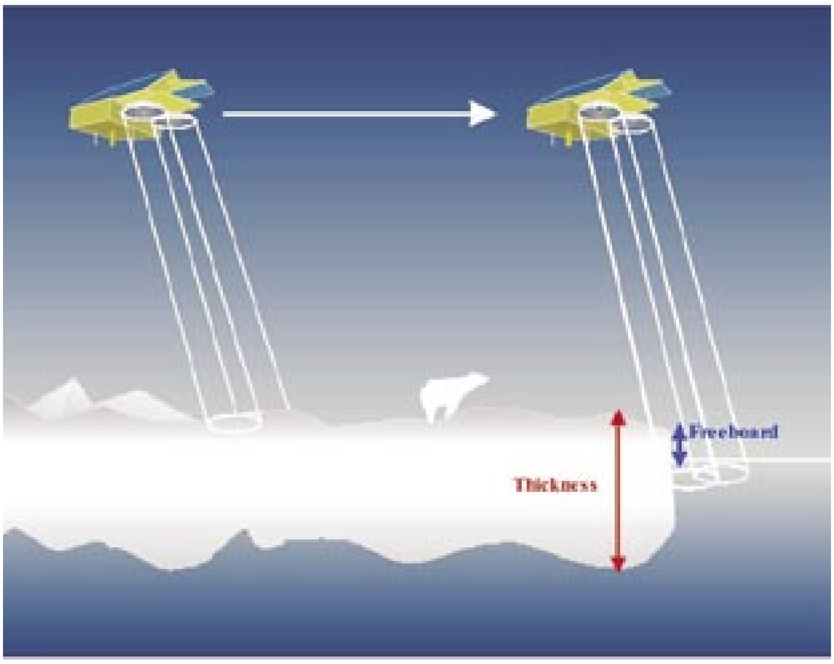
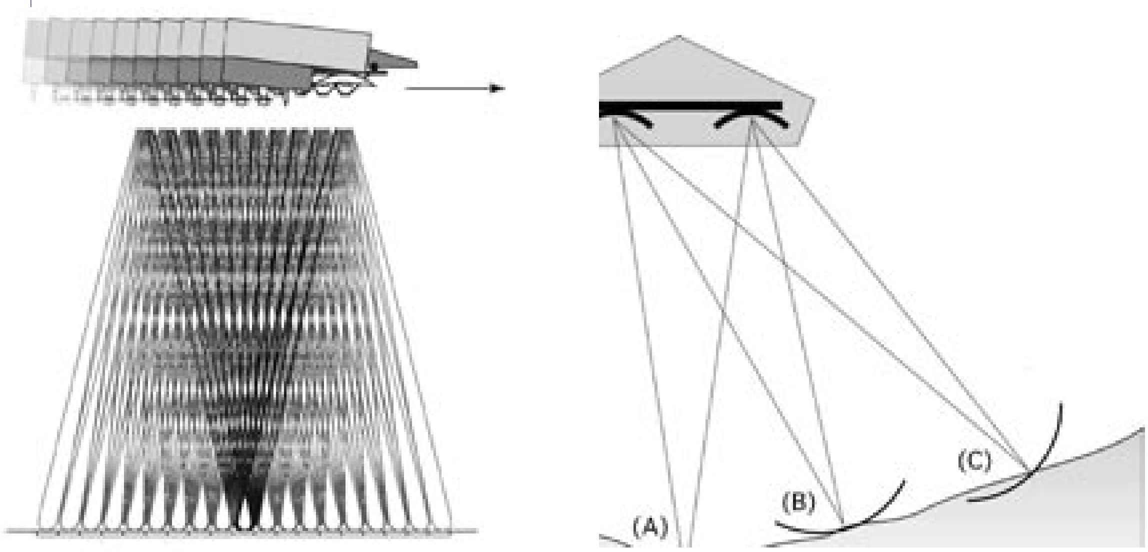


Figure 2. Illustration of CryoSat measurements over sea ice. The freeboard height will be retrieved by estimating the height difference between ice floes and open water.

Stein Sandven, is research director at NERSC. He is leader and participant in several national and international marine research and polar projects, with focus on remote sensing application and operational ice/ocean monitoring. He is currently member of ESA's CryoSat Science Advisory Group. Published about 50 papers in international refereed journal and books.

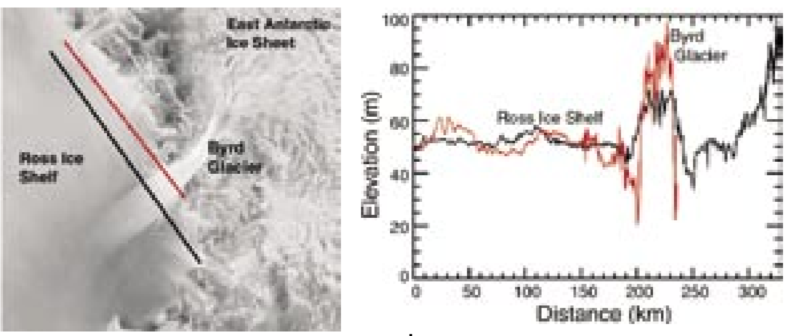


a b

Fig. 3. Principle Operation Modes of the SIRAL altimeter. a): SAR-Mode over sea ice, where the arrow shows the flight direction. b): SARIn-Mode over steep ice sheet terrain, showing the capability to measure across track slope of the terrain.

The *SAR-Interferometric* mode of SIRAL is intended for improved elevation estimates over ice sheets with variable topography. Generally, over ice sheets the surface is not plane, and a method for determining the echo location is required. A second synthetic aperture system is added and used to form an interferometer across the satellite track (Fig. 3 b). The angle of the echo at each range may be determined, and this, together with the range, determines the elevation and across-track location of the surface.

More information can be found at http://www.esa.int/export/esaLP/cryosat.html



a b

Figure 4. a) RADARSAT image of the Byrd Glacier in Eastern Antarctica with two IceSat profiles superimposed; b) IceSat elevation measurements across the Byrd Glacier (Courtesy: NASA).

IceSat

IceSat (Ice, Cloud and Land Elevation Satellite) carrying laser altimeter was launched in December 2002 as part of the NASA EOS system. The onboard laser lidar instrument GLAS (= Geoscience Laser Altimeter System) operates in the infrared (1064 nm) and in the green (532 nm) spectral bands. The infrared signal is used for altimetry and the green signal for atmospheric profiling. The primarily objectives of IceSat are to measure glaciers and ice-sheet elevation and sea ice thickness. Over polar ice sheets instantaneous surface height measurements will have accuracy of about 15 cm. By averaging data from many orbits, changes in surface height of about 1 cm/year over the mission duration (3 –5 years) is expected to be detected.

IceSat will be a complementary satellite to CryoSat, because laser and radar altimeters measure different properties of the ice surface. The laser signal will be reflected from the snow surface while the radar signal will penetrate dry snow and be reflected from the ice surface. The spatial resolution of the laser data will be higher than the radar data, about 70 m, compared to 250 m for the radar data.

The first results of IceSat observations in the Antarctica have been published by NASA. Figure 4 shows data from Byrd Glacier, which is the largest outlet glacier draining ice from the East Antarctic Ice Sheet through the Trans-Antarctic Mountains into the Ross Ice Shelf. The ice sheet is grounded on bedrock and the ice shelf is floating on the ocean. Two IceSat profiles across the glacier show details of the troughs formed on the sides of the glacier as it plows into the ice shelf. The differences between the elevations and widths of the glacier at the inner (red) profile and the outer (black) profile show how the glacier thins and spreads as it merges with the ice shelf. With time, IceSat's measurements of small changes in the elevations of the ice sheets, outlet glaciers, and ice shelves will provide information on whether the rate of ice discharge into the ocean is increasing or decreasing and thus influencing sea level.

Further information is found on http://icesat.gsfc.nasa.gov.

Concluding remarks

Combined use of SAR and altimeters from ENVISAT, CryoSat and IceSat is expected to advance the cryospheric monitoring capability significantly in the coming years. SAR and radar altimeters can obtain useful data throughout the year independent of cloud and light conditions, while laser data will be a useful supplement during selected cloud-free periods. While imaging sensors such as SAR can provide detailed two-dimensional maps of the cryosphere, altimeters will be important to establish three-dimensional picture of the ice masses.

Figure A3
Byrd Glacier, shown in a radar image from RADARSAT (top), is the largest outlet glacier draining ice from the East Antarctic Ice Sheet through the Trans-Antarctic Mountains into the Ross Ice Shelf. The ice sheet is grounded on bedrock and the ice shelf is floating on the ocean. Two ICESat profiles across the glacier show details of the troughs formed on the sides of the glacier as it plows into the ice shelf. The differences between the elevations and widths of the glacier at the inner (red) profile and the outer (black) profile show how the glacier thins and spreads as it merges with the ice shelf. With time, ICESat's measurements of small changes in the elevations of the ice sheets, outlet glaciers, and ice shelves will provide information on whether the rate of ice discharge into the ocean is increasing or decreasing and thus influencing sea level. Credit: NASA

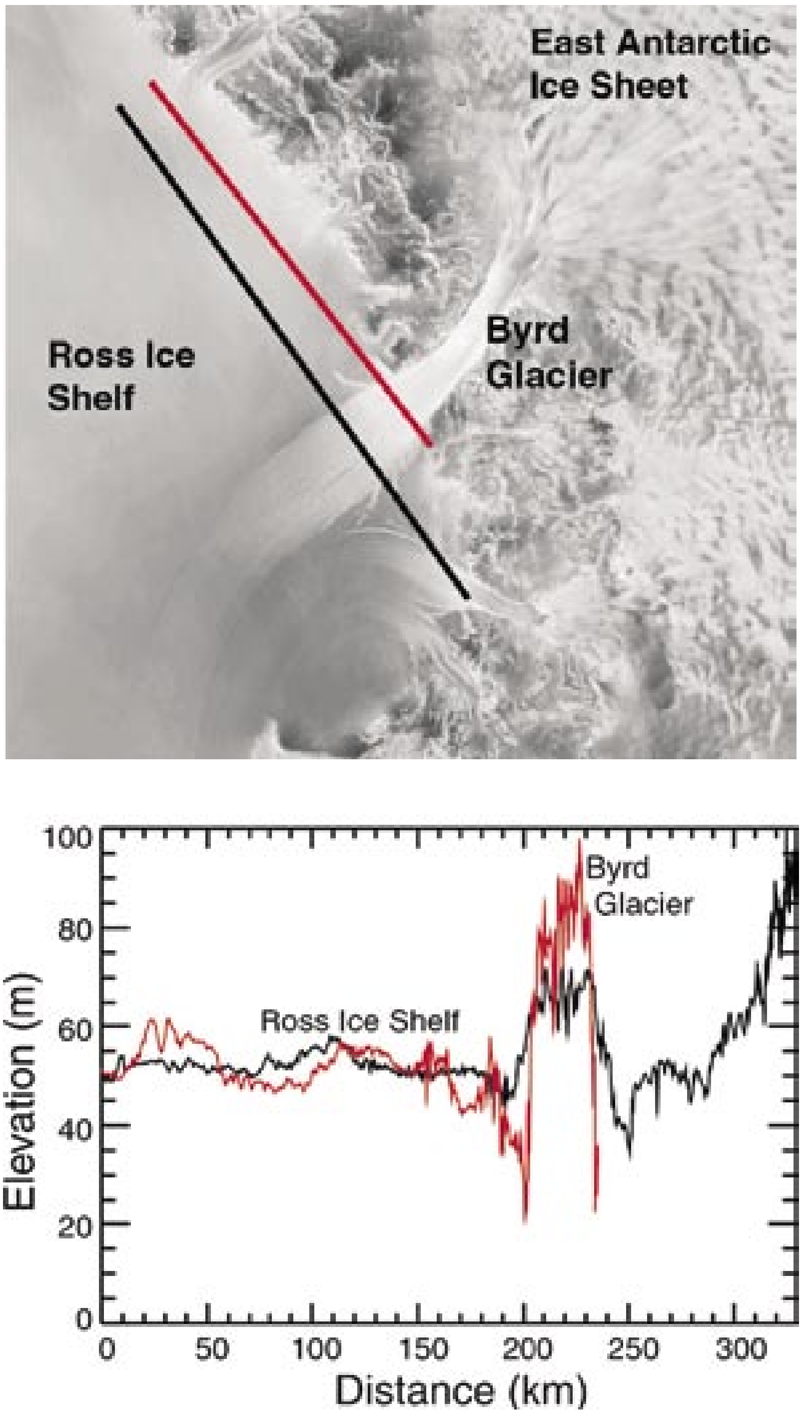


Figure A3. Laser profiles of Byrd Glacier from IceSat data