

The icebreaker RRS James Clark Ross is the research platform used in the 2010 ICEBell expedition to study Antarctic sea ice in the Southern Ocean.

# Seeing Sea Ice

*SwRI scientists analyze satellite radar data to gain insight into annual changes in the volume of sea ice near Antarctica.*



By Michael Lewis, Ph.D., and Marius Necsoiu, Ph.D.

In the frozen worlds of the Arctic and Antarctic, climate influences a seasonal cycle of growth and melt of vast amounts of sea ice. On average, sea ice covers an area comprising about 7 percent of the Earth's surface. The extent of the sea ice in low and high seasons and its concentration and thickness are important in understanding the overall mass-balance. These factors also pose questions whose answers scientists increasingly have found are not simple, nor are they consistent between the northern and southern polar regions. While the Arctic ice cap, which lies atop an ocean, has been shrinking dramatically in recent years, the extent of sea ice surrounding the Antarctic land mass has not experienced the same dramatic decline. In global terms, the amount of sea ice is important to the climate system because of its role in "ice-albedo feedback," a mechanism that enhances warming due to decreased reflectivity from loss of sea

ice and increased solar absorption in the ocean. In addition, sea ice acts as a blanket covering the polar oceans, regulating the transfer of heat, gases and wind/wave energy with the atmosphere. When sea ice forms, it loses salt to the ocean, which in turn creates locally dense saline waters that sink and drive ocean currents. When sea ice melts, the fresh water input also affects ocean circulation.

Because of its remote location and the difficulty of performing scientific research in extreme environments, the Antarctic sea-ice zone remains one of the least-known regions of the Earth. The importance of sea ice was highlighted by emphasis on cryospheric research during the International Polar Year (IPY), 2007-2008, and the recent publication of studies related to IPY sea ice research in a special issue of *Deep Sea Research II* (Vol. 58, Issues 9-10) released during 2011.

## Determining sea ice thickness

Sea ice in the Southern Ocean, which surrounds the frozen continent of Antarctica, greatly influences regional and global heat-energy balances due to its vast expansion in winter, nearing 19 million square kilometers in area, and its retreat in summer to about 3 million square kilometers. At maximum extent, Antarctic sea ice covers a greater area than the continent itself. Restrictions imposed by the Antarctic Treaty of 1959 do not allow submarines to traverse the

Antarctic sea-ice zone with upward-looking sonar instruments, so only ship-based visual estimates exist of circumpolar mean sea-ice thickness. Using satellite data from laser and radar altimeters, it has been shown that snow and ice surface elevations can be determined with enough accuracy in the Arctic to derive



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sea-ice thickness using isostatic (buoyancy) relationships. However, in the Antarctic, the buoyancy of sea ice is greatly influenced by the accumulation and redistribution of snow cover. Thick snow cover on Antarctic sea ice produces a heavy overburden that depresses the ice floe and induces seawater flooding at the snow/ice interface (also known as negative freeboard). This phenomenon complicates the use of simple isostasy to compute Antarctic sea-ice thickness from satellite altimetry measurements and requires a more complex approach.

Although point-by-point coring provides the most direct, reliable data available, it is impractical to survey the vast expanses of Antarctic ice using this painstaking method. Furthermore, attempts to study this seasonal icy advance and retreat directly are complicated by a combination of remote geography and hostile weather that literally threatens human survival. Shipboard investigations are thwarted by thick pack-ice with opening and closing leads, bitter winds and blowing snow. Studies from the relative safety of the air — or even from space — are complicated by persistent, terrain-obscuring cloudiness and the long, dark polar winter. To date, observational and analytical tools have limited our ability to accurately detect and measure sea-ice creation using satellite-borne instruments. However, new analyses of satellite imagery show promise for providing new ways to detect and evaluate sea-ice cover.

Bellingshausen and Amundsen seas in the Antarctic region. Previous results from analysis of C-band backscatter radar data suggested that the unique, coherent dual-polarimetric X-band capability of TSX imagery is more sensitive to properties such as the presence of wet snow, as well as the age and temperature of summer snow pack. The SwRI team is continuing to examine the relationships between different ice types and snow or ice-surface properties, and their radar backscatter response. Their methods have potential to improve satellite applications to sea-ice characterization. As backscatter technologies evolve, sea-ice characteristics can be correlated with temperatures and changing surface conditions through the summer and into the autumnal freeze-up.

Satellite data were paired with surface characteristics derived from ship-based observations and measurement stations that had been established during two expeditions during the austral summer between

A team of scientists from Southwest Research Institute (SwRI) turned to satellite-based radar data to penetrate clouds and produce high-resolution images around the clock and in all kinds of weather. The team analyzed TerraSAR-X (TSX) dual-polarimetric, or “dual-pol,” observations to determine sea-ice characteristics in the

late October 2010 and January 2011. Data from ice mass-balance (IMB) buoys employed during those two cruises continued to be collected through the summer melt and bridged the transition into fall freeze-up conditions with the increased ice cover and snow pack.

### Field campaigns and data acquisitions

Two field campaigns in the austral summer of 2010-11 focused on characterizing sea-ice conditions and properties to gain a better understanding of satellite remote-sensing data. In the Bellingshausen Sea, the ICEBell campaign was sponsored by the British Antarctic Survey in collaboration with an international contingent of participating organizations, including SwRI. It was conducted during November 2010 on sea-ice floes in the northwest Weddell Sea and western Bellingshausen Sea near the Antarctic Peninsula. The campaign examined surface and under-ice topography, sea-ice thickness and snow and sea-ice characteristics

using a variety of techniques. ICEBell's objectives included using digital photographic imagery and ASPeCt (Antarctic Sea ice Processes and Climate, a technique for making ship-based observations of Antarctic sea-ice thickness and characteristics) to estimate sea-ice type, concentration, floe size, surface topography, and snow and ice thickness. ICEBell also sought to characterize sea-ice topography using a gridded survey plus



*A research team sets up surveying equipment on an Antarctic ice floe.*

Photo by Pete Bucktrout



GPS tracks of two ice mass-balance (IMB) buoys from ICEBell 2010 and their associated dual-pole HHV TSX acquired satellite data are shown on the large map, with IMB 8 in orange and IMB 16 in yellow, with a red arrow locating the TSX image. An inset shows the general location of the study area relative to Antarctica, with the South Pole at its center.

on the targeted sea ice floes. The images were successfully acquired through close interaction between project personnel in the field and in San Antonio, and the German Aerospace Center staff. The SwRI team obtained imagery at a low incidence angle to reduce interpretation problems associated with high winds and other surface effects. In addition, other satellite data were acquired over the Bellingshausen/Amundsen region to coincide as closely as possible with the images.

surface and airborne LIDAR (a radar-like tool that uses infrared lasers instead of radio signals). The objectives were to characterize under-ice topography using an autonomous underwater vehicle; characterize ice floes in three dimensions using ice cores, electromagnetic induction and ground-penetrating radar; and use field and ship-borne measurements of radar backscatter and passive microwave emissions.

In the Amundsen Sea, the Oden cruise between December 2010 and January 2011 was sponsored by the U.S. Antarctic Program under the National Science Foundation. It involved an international group of scientists, who sought to obtain physical data documenting the summer evolution of sea-ice cover. Its objectives included conducting ASPeCt observations of sea-ice conditions; performing automated digital imagery to estimate sea-ice concentration, floe size and surface topography; taking ice cores at 10 sampling stations for physical and structural characterization; measuring ice thickness by drilling and using multi-frequency electromagnetic induction (EMI) profiling; and using surface LIDAR to survey snow/ice surface topography. Additionally, four more ice mass-balance buoys were emplaced on ice floes, and the SwRI team acquired TSX images

relative to the buoys' position reports.

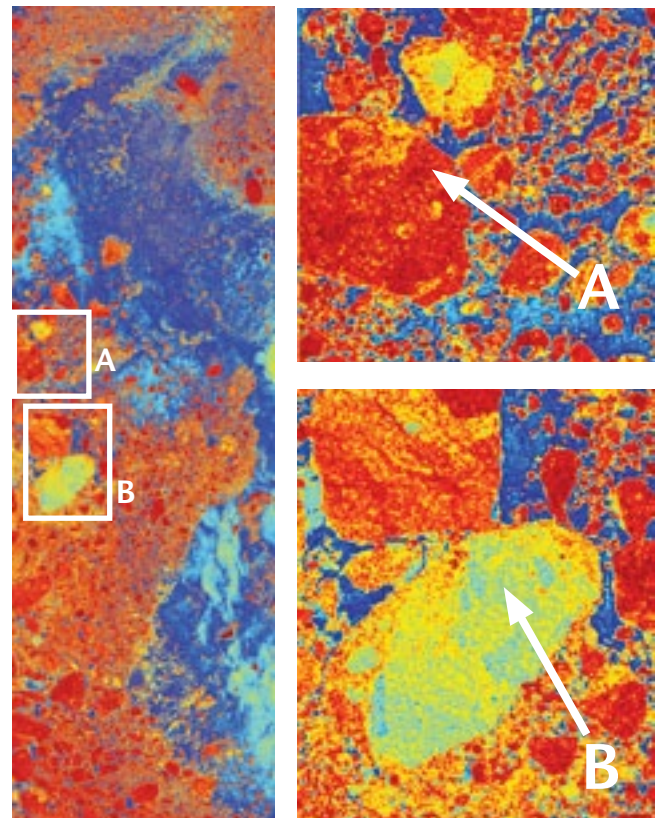
The specially designed buoys continued to track the position and measure the changing characteristics of the targeted floes after the ships departed. During ICEBell, detailed sampling was performed at 12 sites on eight sea-ice floes. The SwRI team acquired TSX images related to buoy positions for three of the floes.

During both field campaigns, airborne and satellite remote-sensing data were acquired over numerous targets. The co-location of satellite acquisitions with rapidly moving sea-ice floes containing the target sites was challenging because three to four days are needed to acquire TSX images. Despite this challenge, 14 images were successfully acquired for the Bellingshausen Sea campaign and 12 images were acquired for the Amundsen Sea by using a global positioning system (GPS) to track the locations of ice mass-balance buoys installed

### Remote sensing methods

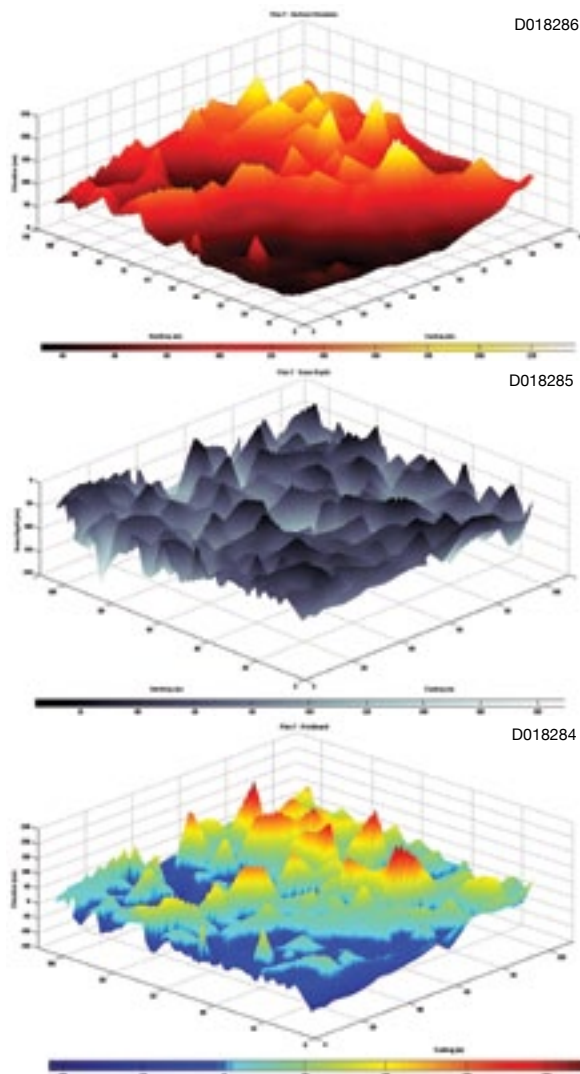
Because of differences in their structure and composition, various types of ice — with names such as “frazil,” “nilas,” “first-year” and “multi-year” — have different polarimetric scattering behaviors. Their distinct characteristics were investigated using conventional backscattering

Shannon Entropy images depict higher values, which correspond to different types of ice in red, green and yellow. Lower values corresponding to water are shown in dark blue.



coefficients, a reflectivity ratio parameter that corresponds to horizontal and vertical intensities. The TSX imagery was used to emphasize volume-scattering through the polarimetric descriptors derived from entropy/alpha decomposition. The initial part of this research involved using a high-resolution TSX StripMap mode image acquired over the Bellingshausen Sea. A polarimetric descriptor was calculated for these TSX images known as Shannon entropy, which relates to the sum of intensity, degrees of polarization and the intrinsic degrees of coherence. The Shannon Entropy measures the degree of randomness, which is inversely related to the intrinsic degrees of coherence.

Radar backscatter signature is sensitive to snow and ice properties, such as the presence of thick snow cover, snow wetness, presence of layered features such as ice lenses, age and temperature profile, as well as the presence of sea-water flooding at the interface of the sea-ice and the snow cover. During the ICEBell campaign, two sea-ice floes were characterized in the field. The area in the vicinity of these floes is predominantly small first-year floes with approximately 0.5 meter of snow cover mixed with highly broken ice, scattered among less than 10 percent of larger 1-2 kilometer sea-ice floes with thicker snow cover. Gridded survey data for surface elevation and snow depth were used to assess the differences in snow and ice characteristics of the two floes. The relatively uniform surface topographic features in the data for one floe were associated with relatively thick snow cover and a large area of negative freeboard, indicating a predominance of flooding at the snow-ice interface. In contrast, surface features of the other floe were relatively level over a small portion of the grid but showed much greater relief, thinner snow cover and positive freeboard over a larger percentage of the survey area. A much smaller area of negative freeboard for this floe indicated less flooding at the snow-ice interface. These different features



appeared to correspond with distinctly different Shannon Entropy values, with a much greater degree of randomness seen in the floe with thin snow cover.

## Conclusions

Based on preliminary results, TSX appears to be a useful tool for assessing sea ice surface properties, with the potential to derive ice type, snow thickness and surface roughness features. More study of polarimetric descriptors and detailed analysis of field measurements will be needed, but these initial results advance an integrated sea-ice algorithm based on several data sources, including TSX satellite imagery.

Continued refinement of this approach, and further application to the Amundsen Sea sites, will reveal relationships between different ice types, as well as snow or ice-surface properties, and their radar backscatter response. This

Grid-survey data for a single ice floe show surface elevation (top image), snow depth (middle image) and calculated freeboard contours (bottom image). Horizontal scale is in meters and vertical scale in centimeters.

work has the potential to improve satellite applications to sea ice, particularly as backscatter may evolve with temperature and changing surface conditions through the summer and into the fall freeze-up period. These data also may be used to better predict the isostatic conditions of sea-ice floes based on their characteristics, thereby allowing more accurate estimation of sea-ice thickness and overall ice mass-balance in the Antarctic sea-ice zone.

Crucial to these interpretations is the detailed and direct survey of ice characteristics on the sea-ice floes and the capability, provided by location of the drifting buoys, to follow sampled floes with designated high-resolution but narrow-swath satellite data acquisitions during the months following surface sampling. Additionally, IMB sensors provide the capability to track changing surface conditions using temperature and other measurements, such as snow depth and flooding, to correlate with near-simultaneous measurements of radar backscatter over those exact locations for an extended period.

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