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Preparing Kibo's New Home

Sea Ice Thickness: Hidden Key To Understanding Arctic Change

By Christian Haas, posted on March 27th, 2008 in Articles, Climate, Earth Observation, Water

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In the summer of 2007, satellite observations showed that the sea ice coverage of the Arctic Ocean declined to a record low areal extent of only 4.14 km^2, 23% less than during the previous summer minimum observed in 2005. The shrinkage of the Arctic sea ice cover is generally considered as one of the most striking expressions of the ongoing global climate warming, and if the trend continues, the Arctic Ocean will be ice free by the summer of 2030.

However, the retreat of Arctic sea ice is much more rapid than predicted by most climate models, pointing to a general lack of understanding of the processes determining the coverage of sea ice. The difficulty lies in the variety of different environmental factors influencing the presence of sea ice, as this depends not only on air temperature, but also on the heat flux from the ocean, and the direction and speed of the winds.

The EM-bird, a helicopter-towed electromagnetic sensor used for regional surveys of sea ice thickness (Photo: S. Goebell, Alfred Wegener Institute, Germany).

For nearly 30 years, the drift of sea ice has been observed by the International Arctic Buoy Program by means of buoys deployed on individual ice floes, transmitting their positions via satellites to global data centers. These measurements showed that the age of Arctic sea ice is between 2 and 6 years on average, and that most ice floes have left the Arctic Ocean after that time to eventually melt in the North Atlantic Ocean. However, more recently, the drift speed has increased, and the average age of the ice has significantly decreased. This change in ice drift and ice age is closely related to the decrease of the ice covered area, and provides an important mechanism for the rapid sea ice decline independent of changes in air temperature.

More importantly, the drift of the ice is closely related to its thickness, and is responsible for the overall thickness distribution in the Arctic Ocean. The thickest ice is found off the coasts of Canada and Greenland, against which ice floes are pushed by the predominant drift systems, the Transpolar Drift and Beaufort Gyre. The compression of the ice against the coasts results in strong thickening by deformation, when ice floes break under compressional forces and are rafted above each other to form pressure ridges and rubble fields of several tens of meter thickness. In turn, ice drift speed decreases with increasing mean ice thickness, because thicker ice does not deform as easily as thin ice. However, this delicate interplay of ice thickness, deformation, and speed is not well understood and is poorly represented in sea ice and climate models. One reason for this is the lack of systematic, large scale ice thickness measurements.

Because sea ice is only a thin layer a few meters thick, it is very difficult to measure its thickness either from satellites or from in-situ measurements. Most measurements so far have been performed by means of upward-looking, ice profiling sonars, which can measure the draft of the ice below the water level. This can be converted into ice thickness reasonably well if isostatic equilibrium is assumed and the density of the ice is accounted for. Most of these measurements were performed during US and UK military nuclear submarine missions during the cold war. Results showed a strong dependence of Arctic sea ice volume on the predominant drift patterns, with certain ice drift patterns leading to the removal of thick ice from the Arctic Ocean. Other upward-looking sonars have been moored to the sea floor and provide time series of the thickness of ice passing over them. These measurements have provided invaluable information on the seasonal cycles of ice growth and deformation, and on the export of ice from the Arctic Ocean to the subpolar seas.

The lack of systematic, large-scale ice thickness information has led the European and American Space Agencies to the launch of the ICESat and CryoSat satellite missions. These satellites carry laser and radar altimeters, respectively, with which the height of the ice surface above the water level can be retrieved. This freeboard height can then be converted into ice thickness using the same density assumptions as with upward-looking sonar profiling. However, uncertainties due to the generally unknown snow thickness can lead to large errors of the estimated ice thickness, although the accuracy of the freeboard measurement can be as good as a few centimeters. ICESat was successfully launched in 2003. CryoSat was first launched in 2005, but failed just minutes later. A replacement satellite is scheduled to be launched in 2009.

These novel altimetric satellite missions require careful validation of their results. An ideal technique for the validation of satellite thickness measurements is airborne electromagnetic (EM) sounding. With this classical geophysical method it is possible to determine the electrical conductivity structure of the underlying surface. In the case of sea ice, the method is sensitive to the distance to the ice underside, which is the boundary between the resistive ice and the conductive sea water. EM sounding can be performed from helicopters while flying over the ice, and thus provides regional-scale ice thickness measurements within the range of helicopters, which can be extended by means of fuel caches on the ice. EM sounding will be extensively used for the validation of CryoSat thickness retrievals, by means of coincident underflights of the satellite. In addition, a systematic ice mass balance monitoring program has been initiated by Canadian, American and German scientists in the region between the coasts of Canada, Alaska, and the North Pole. This will provide accurate biannual thickness observations to better understand seasonal and interannual ice variability as a result of changes in the atmosphere-ocean system.

Since the successful introduction of regional EM thickness surveys, there are numerous efforts to extend the areal coverage of those measurements. In fact, EM sounding can be performed by any low-flying airborne platform. Therefore, a French-German-Canadian project is investigating the possibility of using a manned, long-range airship to cross the Arctic Ocean and to obtain the most comprehensive Arctic-wide thickness data set gathered so far. Unfortunately, operational problems have prevented a long survey so far. Similarly, plans are being made to operate an EM instrument from a long-range Basler BT67 aircraft of the German Alfred Wegener Institute for regular surveys of large regions of the Arctic Ocean beginning in 2009. Finally, a hovercraft will be used in waters around Svalbard as a complementary platform to provide more regular measurements on spatial scales comparable to those of helicopters.

The near-term goal is to observe routinely ice thickness on Arctic-wide scales by a combination of satellite measurements, sonar profiling, and airborne EM measurements. These measurements will complement the existing Arctic observing network to provide a better understanding and prediction of the rapid changes that are occurring in the Arctic.

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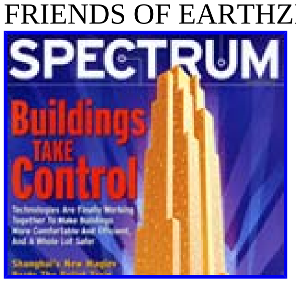

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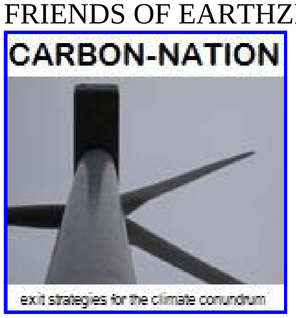

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