Coincident Multiscale Estimates of Arctic Sea Ice Thickness

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Recent dramatic changes in the characteristics of the Arctic sea ice cover have sparked interest and concern from a wide range of disciplines including socioeconomics, maritime safety and security, and resource management, as well as basic research science. Though driven by different priorities, common to all is the demand for an improved ability to monitor and forecast changes in the sea ice cover. Key to meeting this demand is further improvement in the quality of observations collected from remote platforms.

Satellites provide an important platform for instruments designed to monitor basin-wide changes in the volume of the ice cover, a function of ice extent and thickness. Remote techniques to monitor sea ice extent in all seasons are well developed—these observations reveal a dramatic decline in summer sea ice extent since 1979, when satellite records became available. Further, they indicate that the decline has been facilitated by a dramatic decrease in the extent of perennial (i.e., multiyear) ice. Combined estimates of ice thickness derived from submarine records between 1958 and 2000, and Ice, Cloud, and land Elevation Satellite (ICESat) laser altimetry from 2003 to 2008, provide the longest-term record of sea ice thickness observations. These data suggest a decrease in the mean overall thickness of the sea ice over a region covering about 38% of the Arctic Ocean.

The cessation of ICESat measurements in 2009 and the scheduled launch of ICESat-2 in 2016 left a gap in the ability to continuously monitor changing ice thicknesses in polar regions. To help bridge this gap, NASA launched the airborne-based IceBridge program in 2009 [Koenig et al., 2010]. Primary sensors being used over the Arctic sea ice by IceBridge are the Airborne Topographic Mapper laser altimeter, the Digital Mapping System digital camera, a Ku-band radar altimeter, and a frequency-modulated continuous-wave (FMCW) snow radar (see Table 1). In addition, the U.S. Naval Research Laboratory (NRL), in coordination with NASA IceBridge and the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (USACE CRREL), has begun a 5-year study of the changing Arctic, focusing on ice thickness and distribution variability with the intent of optimizing state-of-the-art sea ice forecasting models. NRL’s data collection began in March 2011 with an airborne suite of sensors that included a radar altimeter, lidar (light detection and ranging), and a photogrammetric camera (Table 1). Another important complementary data source is available from the European Space Agency’s CryoSat-2 satellite, launched in 2010, along with an extensive airborne and in situ calibration and validation effort involving many European Union countries, which provides observations of current ice thickness in the Arctic at variable resolutions (http://www.esa.int/CryoSat).

Together, these satellite, airborne, and in situ studies provide a rare chance to accurately pinpoint instrumental and surveying errors.

Coordinated Sea Ice Thickness Measurement Campaign

For the March 2011 data collection campaign, NRL, CRREL, and NASA IceBridge teamed to coordinate a multiscale approach to mapping snow depth and ice thickness distribution in the Arctic. In situ information for

Table 1. Instruments and Equipment Used to Map Ice Thickness and Snow Depth as Part of a Coordinated Field Project Conducted in March 2011 out of the U.S. Navy ICEX 2011 Ice Camp and Barrow, Alaska

<table>
<thead>
<tr>
<th>Measured or Estimated Quantity</th>
<th>Combined Snow and Ice Thickness</th>
<th>Sea Ice Freeboard (Portion of Sea Ice Floating Above Sea Level)</th>
<th>Snow Thickness Overlying Sea Ice</th>
<th>Open Water Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cold Regions Research and Engineering Laboratory (in situ)</strong></td>
<td>EM31 (electromagnetic conductivity) mechanical drill</td>
<td>snow magnaprobe</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NASA IceBridge (airborne)</strong></td>
<td>Airborne Topographic Mapper (ATM) (total freeboard) Ku-band radar altimeter (13–17 GHz) frequency-modulated continuous-wave snow radar (2–8 gigahertz) Digital Mapping System (DMS) (photogrammetry)</td>
<td>Riegl Q560 lidar (total freeboard) radar altimeter (10 GHz) lidar freeboard measurement minus radar altimeter freeboard measurement Applanix DSS-439 (photogrammetry)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>European Space Agency CryoSat-2 (satellite)</strong></td>
<td>Synthetic Aperture Radar (SAR)/ Interferometric Radar Altimeter (SIRAL)</td>
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calibration and validation of airborne and CryoSat-2 satellite data was collected near a manned camp established in support of the U.S. Navy’s Ice Expedition 2011 (ICEX 2011). The ice camp was located approximately 350 kilometers north of Prudhoe Bay, Alaska, at the edge of the perennial ice zone.

The suite of measurements was strategically organized around a 9-kilometer-long survey line that covered a wide range of ice types, including newly formed thin ice, deformed and undeformed first-year ice, and multiyear ice. The data set consists of coincident in situ field measurements of snow depth and ice thickness and airborne laser altimetry measurements of surface elevation and radar altimetry measurements of the snow-ice interface (Table 1). The in situ ice thickness measurements were collected using an electromagnetic induction device (Geonics® EM31) and mechanical drilling. Snow thickness data were collected using an automated snow probe. These measurements were complemented by a series of NRL and NASA aircraft flights along CryoSat-2 ground tracks and U.S. Navy submarine underpasses of the 9-kilometer-long survey line to collect ice draft measurements. This suite of data provides the full spectrum of sampling resolutions from satellite, to airborne, to ground-based, and to submarine and will allow for a careful determination of snow depth on sea ice and sea ice thickness distributions.

Anticipated Results

The analysis of these coincident measurements, combined with insights gained during previous field efforts [e.g., Hutchings et al., 2008], will enable an assessment of the true uncertainty in the estimates of snow depth and sea ice thickness derived from remote platforms as a function of ice type. Because this data set addresses the fundamental issue of data quality, its impact is far reaching and has broad scientific implications. For instance, the results will allow a reassessment of historic data sets from satellites used to estimate the decadal trends in ice thickness. The results will also influence future sensor and sensor-suite development and provide a metric for combining and contrasting future airborne and satellite data sets. Incorporating knowledge of these measurements and their accuracy into new algorithms will support improvements in regional sea ice models used to understand and predict the complex interactions among the atmosphere, ocean, and sea ice in the Arctic environment.

The in situ and airborne data collected during the March 2011 campaign will be fully documented and archived on the NASA IceBridge Web site at the National Snow and Ice Data Center, allowing for their free access by the broad research community.

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References


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