"Optimizing Observations of Sea Ice Thickness and Snow Depth in the Arctic"

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LONG-TERM GOALS

This work is motivated by the desire to improve the quality of airborne and satellite-based measurements of sea ice thickness and snow depth in the Arctic; to achieve a resolution that is adequate for monitoring decadal variability and to minimize the degree of uncertainty in predictive models.

OBJECTIVES

The specific objectives of our proposed work are:

- To carefully assess remotely-based observations of Arctic sea ice thickness and snow depth using a rare set of coordinated in situ, airborne, satellite and submarine measurements collected by US Army Corps of Engineering Cold Region Research and Engineering Laboratory (CRREL), Naval Research Laboratory (NRL) and National Aeronautics and Space Administration (NASA) in conjunction with the US Navy at the ICEX2011 sea ice field camp in March 2011 in the Alaskan Beaufort Sea;
- To leverage and integrate the measurements and results from this focused effort with data collected during other related national and international activities (e.g. other NASA IceBridge sea ice missions, NRL under flights of CryoSat-2, European Space Agency (ESA) CryoVEx, submarine ice draft measurements, Alfred Wagner Institute (AWI) POLAR5 and historic ICESat records
- To use these data to revise error estimates of remotely-derived snow depth and thickness data products from, for example, ICESat, IceBridge and CryoSat-2. These error estimates (a) are critical for understanding the variability and trends in the long-term time series of observations, (b) will help tie the various satellite and airborne records together, and (c) provide important input for predictive sea ice models.

APPROACH

The paramount transformative aspect of this work will be the combined application of coincident ice thickness and snow depth measurements collected in March 2011 (Table 1). The suite of measurements was strategically organized around a 9-km-long survey line that covered a wide range of ice types, including refrozen leads, deformed and undeformed first year ice, and multiyear ice. The

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data set consists of coincident in situ field measurements of snow depth and ice thickness taken by the CRREL/NRL field team; airborne laser altimetry measurements of the surface elevation of the snow or ice/air interface, and radar altimetry measurements of the snow/ice interface, taken by NASA IceBridge and NRL airborne teams (Figure 1); and ice draft measurements taken from a submarine. This suite of data provides the full spectrum of spatial sampling resolution from satellite, to airborne, to ground-based, and will allow for a careful determination of snow depth on sea ice and sea ice thickness distributions.

Table 1. Equipment used to map the ice thickness and snow depth as part of the CRREL, NASA IceBridge, and NRL coordinated field project conducted in March 2011 out of the US Navy ICEX2011 ice camp in the Alaskan Beaufort Sea.

CRREL	NASA IceBridge	NRL
EM 31 (snow and ice thickness)	Airborne Topographic Mapper (ATM) (snow/ice surface elevation)	Riegl Q560 LiDAR (snow/ice surface elevation)
Snow magnaprobe (snow depth)	Ku band radar altimeter (13 to 17 GHz) & UKansas FMCW snow radar (2 to 8 GHz) (snow/ice interface elev. & snow depth)	10 GHz Radar Altimeter (snow/ice interface elev.)
Mechanical drill (snow, ice thickness and freeboard)	Digital Mapping System (DMS) (lead identification & ice morphology)	Applanix Photogrammetry (lead identification)

The initial focus of our work will be to process the CRREL, NASA and NRL data collected during the March 2011 field campaign. Once all discriminators and calibrations are in place, we will extend our data analysis process to an intercomparison between NASA and NRL airborne datasets to the CRREL/NRL in situ data collected along the ICEX survey line and the submarine ice draft data. Further, NRL airborne data collected during the NRL underflights of CryoSat-2 satellite tracks will be compared to SIRAL radar altimetry from CryoSat-2. We expect that this analysis will provide a characterization and error models for the various airborne sensors and the CryoSat-2 data, as well as snow and ice thickness estimates for the flight data.

We will further leverage and integrate these data with other related activities and archives. During March/April 2011 this includes airborne measurements gathered at a variety of locations around the Arctic Basin during the PAMARCMiP POLAR5 campaign; the satellite, airborne and in situ observations made during CryoVEx, north of Alert to validate sea ice observations from the CryoSat-2 satellite; and the other NASA IceBridge sea ice surveys. We will also tap into relevant historical data sets. For instance, we will compare data collected in the Southern Beaufort and Lincoln Seas gathered during the IceBridge and PAMARCMiP 2009 to 2011 experiments, focusing on analysis of flight lines with near-spatial coincidence. This comparison will allow a detailed assessment of IceBridge and PAMARCMiP ice thickness estimates over seasonal sea ice (Southern Beaufort Sea) and heavily deformed multi-year ice (Lincoln Sea).

Our culminating objective is to use the results of this work to revise error estimates of remote snow depth and thickness data products, as a function of ice type. This advancement will reduce the level of uncertainty in the observational records of sea ice trends and variability and, hence, increase our understanding of the complex interaction between the atmosphere, ice and ocean in the Arctic region. It will also help us to tie the ICESat, ICESat-2 and CryoSat-2 records together to provide a long-term time series, improving a critical resource for predictive sea ice models.

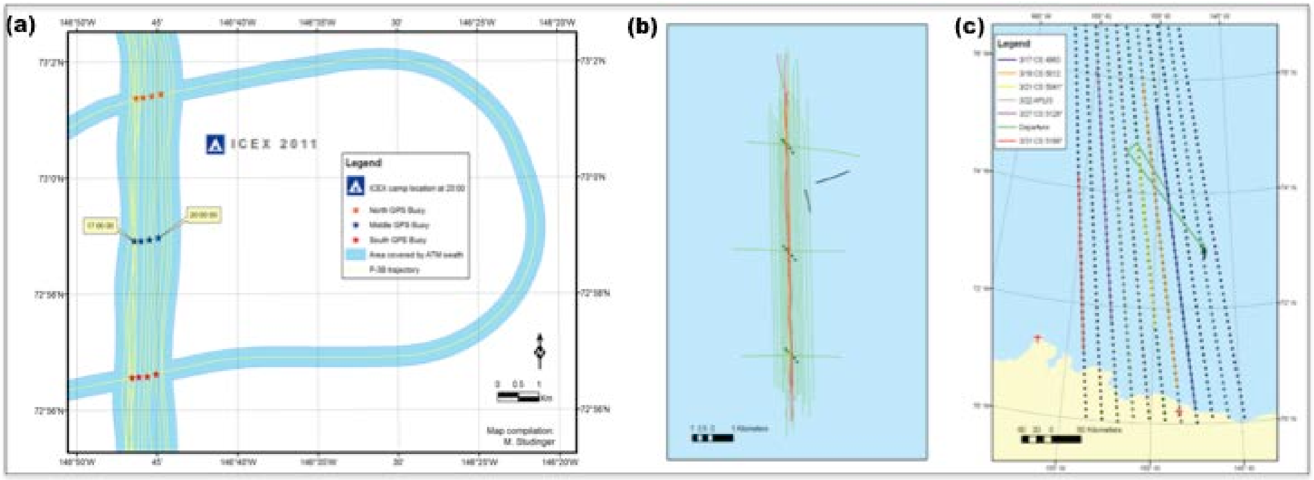

Figure 1. (a) NASA IceBridge flight lines (yellow) with ATM swath coverage (blue) over the ICEX2011 survey line showing widespread coverage of the in situ survey line. Stars mark location (center, north, and south ends) of survey line as it drifted east-ward over the duration of the IceBridge flight survey. (b) NRL flight lines (red) directly over the ICEX2011 survey line, conducted at different altitudes with additiional parallel flight lines (green), spaced at 100 m. Black lines are calibration lines flown over the runways at the ICEX ice camp. (c) NRL CryoSat-2 under flights (solid lines are NRL track lines and dotted lines are satellite tracklines).

WORK COMPLETED

A comparative analysis of the data collected during the March 2011 field campaign in conjunction with ICEX2011 is the focus of Year 1, following the proposed milestones and timeline (referenced to March 2012):

- 12 months (March 2011): Sea ice field experiment at the ICEX 2011 Beaufort Sea ice camp. Acquisition of in situ, airborne and satellite data over Beaufort Sea ice pack (Contributing parties: CRREL, NRL, NASA)

+ 0 months (March 2012): Initial assessment of data collected during field deployment (CRREL, NOAA, NRL)

+ 6 months (Sept 2012): Synthesis of in situ and IceBridge and NRL airborne data sets collected during ice camp with preliminary data analysis. Generate maps of ice thickness and snow depth for ice camp survey region. (CRREL, NOAA, NRL)

+ 9 months (Dec 2012): Development of algorithms to exploit CryoSat-2 data and initial assessment of the accuracy of CryoSat-2 elevation retrievals in the Beaufort Sea region. (NRL)

+12 months (March 2013): Complete initial report on ice camp activities to include a full description of in situ data collected and success of field campaign. Details reported to ONR Arctic and Global Prediction Program Office. (CRREL, NOAA, NRL)

CRREL progress to date:

- A preliminary analysis of the in situ snow and ice thickness data has been completed.
- Critical to the intercomparison of the in situ and NASA and NRL airborne data is the need to account for the drift and rotation of the sea ice cover during the period of observation. The locations of the in situ data have now been translated to a single date and time, selected by the team.
- The synthesis of the in situ and NASA IceBridge and NRL airborne data sets has been initiated. An example of this data synthesis is illustrated in Figure 2.

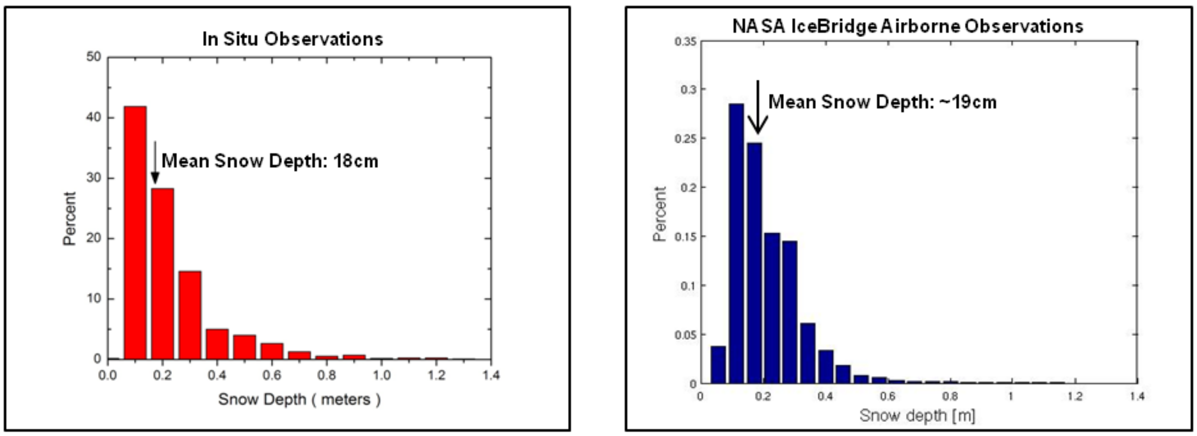

Figure 2. Intercomparison of two independent datasets over the ICEX2011 survey line showing a histogram of snow depth derived from (left) in situ and (right) NASA IceBridge airborne observations, which indicates good agreement with respect to the mean snow depth.

RESULTS

This is a new project, which began mid-way through the reporting year (March 2013). There are no significant results to report, as of yet.

IMPACT/APPLICATIONS

The revised error estimates of remotely-sensed snow depth and ice thickness observations generated by this investigation are critical for (1) understanding variability and trends in the long-term time series of NASA IceBridge observations, (2) tying the ICESat, ICESat-2 and CryoSat-2 records together, and (3) providing important input for predictive ice models. More specifically, the comparative study between the in situ data sets and coincident airborne and satellite data acquisitions will improve the understanding of new sensors. These include the Kansas snow radar, the NRL radar altimeter, and CryoSat-2's SIRAL radar altimeter. Additionally, data collected over the ICEX 2011 ice camp and several CryoSat-2 satellite tracks encompass first and multiyear ice. Based on the work of Farrell et al. (2012) we expect to see some differences, especially in accuracy, from several of the instruments both at the transition zone between these ice types and in the multiyear ice where interpretation of radar data over heavily deformed ice is more challenging. This will allow us to better assess each sensor's capabilities as a function of ice type. This knowledge will be applied to aid in the interpretation of the entire NASA IceBridge data set. The results will also influence future sensor, and sensor suite, development and provide a metric for combining/contrasting future dataset collections. Incorporating knowledge of these measurements and their accuracy into new algorithms will support improvements in regional sea ice models.

RELATED PROJECTS

- University of Maryland: "Optimizing Observations of Sea Ice Thickness and Snow Depth in the Arctic", Offcie of Naval Research Arctic Grant # N000141210512, duration: 04/01/2012 - 03/31/2015, PI: Sinead L. Farrell. This project is directly related. It provides support for a key element of our collaborative team, repsonsible for processing and analyzing the airborne data collected by NASA IceBridge during the March 2011 field campaign.
- NRL: " Determining the Impact of Sea Ice Thickness on the Arctic's Naturally Changing Environment (DISTANCE)". The DISTANCE project is directly related. DISTANCE is providing support for a key element of our collaborative team, responsible for processing and analyzing the airborne data collected by NRL during the March 2011 field campaign. The objective of DISTANCE is to understand the changing Arctic environment, characterized by reduced ice volume and increased open water, using new techniques for deriving accurate multi-sensor snow and ice thickness information and coupled ice-ocean models to explore the new Arctic dynamics. The goal of DISTANCE is to provide the Navy with an improved forecast capability that accurately describes these changing conditions in the Arctic and provide new global fields of snow and ice thickness for data assimilation.
- NASA IceBridge (http://www.nasa.gov/mission_pages/icebridge/index.html). The NASA IceBridge project is closely related, having participated in the March 2011 field campaign with airborne survey flights over the 9-km ground line used to collect in situ snow and ice thickness data. NASA's Operation IceBridge mission is to utilizes a highly specialized fleet of instrumented research aircraft to characterize annual changes in thickness of sea ice, glaciers, and ice sheets. These observations are being applied to predict the response of earth's polar ice to climate change and resulting sea-level rise. IceBridge also helps bridge the gap in polar observations between NASA's ICESat satellite missions.

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HONORS/AWARDS/PRIZES

Jacqueline Richter-Menge (PI) and Sinead Farrell (Co-I) were acknowledged for "exceptional achievement in support of NASA's IceBridge campaign" when the IceBridge Team received the NASA Agency Honor Award for Group Achievement in August 2011. IceBridge, a six-year NASA mission, is the largest airborne survey of Earth's polar ice ever flown. It will yield an unprecedented three-dimensional view of Arctic and Antarctic ice sheets, ice shelves and sea ice.