ICEBRIDGE
Abstracts of selected proposals
NNH15ZDA001N-ICEB

This synopsis describes the proposals selected in response to the NASA Research Announcement *ICEBRIDGE OBSERVATIONS* which is sub-element A.15 of NASA ROSES 2015.

IceBridge (http://www.nasa.gov/mission_pages/icebridge/index.html) is a NASA airborne mission making altimetry, radar, and other geophysical measurements to monitor and characterize the Earth's cryosphere. **The IceBridge mission began operation in 2009 and will continue through the launch of ICESat-2, currently estimated for 2018.** The Earth's cryosphere is in a period of rapid change. Understanding these changes, their causes, and impacts are critically important to understanding the Earth as a global system. Data collected under the IceBridge mission improves our knowledge of the contribution of the world's major ice sheets in Greenland and Antarctica to sea level rise. It also makes fundamental contributions to understanding changes occurring in the extent and thickness of the Arctic sea ice cap and its connection to the global system. Data collected under the IceBridge mission is available at the National Snow and Ice Data Center (http://nsidc.org/data/icebridge/).

This solicitation supports the third and final phase of IceBridge from latter half of FY 2016 through to the first half of FY 2019. During this period, IceBridge will consist of two major airborne data collection campaigns per year; with one in the Antarctic and another in the Arctic in their respective spring seasons; and one smaller campaign over the Arctic in the early fall near the end of the melt season. Studies of Alaskan glaciers contributing to sea level rise are also continued.

The specific measurements and science goals are summarized as follows:

- Make airborne altimetry measurements over the ice sheets and sea ice to extend the record of observations begun by ICESat.

- Link the measurements made by ICESat, ICESat-2, and CryoSat-2 to allow accurate comparison and production of a long-term, ice altimetry record.

- Using airborne altimetry to monitor key, rapidly changing areas of ice in the Arctic and Antarctic to maintain a long term observation record, improve understanding of glacial dynamics, and improve predictive models of sea level rise and sea ice cover.

- In conjunction with altimetry measurements, collect other remotely sensed data to improve predictive models of sea level rise and changes in sea ice cover

To support these goals, this solicitation supports proposals to supply and operate the instrument array on the NASA aircraft flying the major Arctic and Antarctic campaigns and to independently operate the Alaskan campaign.

Scientific research utilizing IceBridge data and membership on the IceBridge Science Team is not specifically supported under this solicitation, but is solicited separately via NASA ROSES. Research using IceBridge data is also supported by other NASA programs and other federal agencies.

Out of 8 submitted proposals, 5 will be recommended for awards. The total funding for the program is approximately $7 million per year for three years. The Principal Investigator, institution, and investigation title are listed below.

Christopher Larsen/University of Alaska, Fairbanks
Operation IceBridge Alaska
15-ICEB15-0008

Under this proposal, the University of Alaska Fairbanks (UAF) will fly airborne missions in Alaska to perform laser altimetry and surface mapping with LiDAR along with bed mapping radar measurements. UAF has flown these missions for Operation IceBridge (OIB) since 2009, and has a long-standing and extensive light aircraft laser altimetry program dating to 1992 in Alaska. The proposed work will continue to provide a record to link the measurements of ICESat to ICESat-2 and CryoSat-2, as well as to historical UAF airborne altimetry. The proposed work encompasses complete campaigns through data delivery to the NASA DAAC at NSIDC.

The glaciers and icefield systems targeted herein are specified in the Baseline Glaciers and Ice Caps Requirements of the IceBridge Science Requirements Summary. Furthermore, our proposed work is designed to cover a broad geographical area and is of consequence to understanding systemic impacts of global climate change on sea level rise. This work will help quantify fundamental processes that control glacier dynamics and the contribution to sea level rise. A fundamental unknown in process studies is the poorly constrained distribution of ice thickness. We will take advantage of the broad coverage of LiDAR altimetry measurements to simultaneously measure ice thickness using airborne radar.

Airborne altimetry has been used to show that Alaska's regional mass balance is -75+11/-16 Gt yr-1 (1994-2013) (Larsen et al., in review). The rate of surface mass loss observed on non-tidewater glaciers is extremely high. Presently, Alaska contributes ~1 mm to global sea level rise every 5 years. Sea level rise driven by the transfer of water from glacier melt to the oceans will have severe societal impact over the next century (Meier et al., 2007).

This proposed work targets several key elements and goals of OIB as identified in the IceBridge Science Requirements Summary. By performing the proposed work, we will directly contribute to OIB's four strategic measurement objectives: 1) Make airborne altimetry measurements over glaciers to extend and improve the record of observations begun by ICESat, 2) Link the measurements made by historical airborne laser altimeters, ICESat, ICESat-2, and CryoSat-2 to allow accurate comparison and production of a long-term, ice altimetry record, 2) Monitor key, rapidly changing areas of ice to maintain a long term observation record, and 4) Provide key observational data to improve our understanding of ice dynamics, and better constrain predictive models of sea level rise.

Our proposed use of a DHC-3T Otter contract aircraft is based on several critical factors: 1) Weather systems in Alaska tend to shut down all targeted glaciers and icefields across the state simultaneously for periods of several days. Over the past 7 years of OIB-Alaska, we flew roughly one out of every 4-5 days on average. Over a campaign, the cumulative amount of downtime for a NASA aircraft, with attendant ground and flight crews, would be very inefficient and expensive. 2) We have flown these surveys since 2003 exclusively with the same pilot, who now has over 1500 hours of experience on these exact flightlines and surveys, in addition to his 30,000+ hours of flight time in Alaska's mountains. 3) The turbine converted DHC-3T Otter with wheelskis has proven to be the perfect platform for these surveys, having excellent maneuverability and performance required for safe flight in Alaska's high mountains, while remaining cost effective for this mission.

Carlton Leuschen/University of Kansas
Airborne Radar Surveys of Land and Sea Ice and Data Processing Using CReSIS Instrumentation to Support IceBridge Observations
15-ICEB15-0006

To support the third phase of NASA's Operation IceBridge mission, we propose to perform airborne radar measurements on five OIB deployments, generate data products that provide detailed information on the three-dimensional structure of land and sea ice, and submit data products to the National Snow and Ice Data Center (NSIDC). The Center for Remote Sensing of Ice Sheets (CReSIS) has contributed to the IceBridge mission since 2009 by performing radar measurements on fixed wing aircraft and generating data products. The proposed instrumentation and resulting data products directly address critical and desirable measurements identified in the NASA ROSES 2015 IceBridge Observations research announcement. We will perform radar mapping of the following elements: (1) the beds of land-based ice sheets (critical & desirable); (2) snow on sea ice (critical) and land ice (desirable); and (3) ice structures (desirable). The CReSIS radars also support altimetry (critical) by providing very high-resolution measurements of snow cover at Ku-band frequencies, which is important to the interpretation of measurements from the SAR Interferometric Radar Altimeter (SIRAL) on-board CryoSAT-2. As an addition, we propose the application of tomographic and other three-dimensional processing algorithms to radar depth-sounder/imager data for the production of high-resolution bed topography maps.

CReSIS developed a suite of radar instrumentation and antenna structures for measurements over land and sea ice, and we have operated them on NASA platforms (including the DC-8, P-3, and C-130) as a part of the OIB mission. The instrumentation includes four radars operating over the frequency spectrum extending from 180 MHz to 18 GHz. These radars have been used to sound ice as thick as 4.7 km, image the ice-bed interface, and map internal structure from the surface to the bed. The Multi-Channel Coherent Radar Depth Sounder and Imager (MCoRDS/I) uses a large cross-track array [Byers et al., 2012] to sound ice and image ice-bed interfaces covered with more than 4 km-thick ice. The snow radar and Ku-band radar are ultra-wideband (UWB) microwave systems capable of measuring near-surface accumulation layering and snow cover over sea ice with fine centimeter-scale range resolution [Panzer et al., 2013; Kurtz et al., 2013; Kwok et al., 2014; Patel et al., 2015]. Lastly, the accumulation radar has measured internal layers to depths of a few hundred meters (with sub-meter range resolution), sounded shallow ice caps, estimated the bottom melt rates of ice shelves, and demonstrated a potential capacity to measure

sea-ice thickness [Medley et al., 2014; Lewis, 2015; Koenig et al., 2014; Meige et al., 2013; Foster et al., 2014].

The CReSIS team has used radar measurements to support polar research for more than two decades and is well qualified to install radars on new aircraft, as shown by the recent installation and operation of the MCoRDS/I, snow radar, and Ku-band radar on the NASA C-130 for the spring 2015 OIB deployment. A prototype Ka-band (32-38 GHz) system was also installed on the C-130 and is currently generating usable data products. We improved instrument performance by increasing power and bandwidth to enhance measurement capabilities without compromising its compatibility with data products from previous seasons. CReSIS has extensive experience processing, archiving, and distributing large datasets. We have interactive browsing capabilities to view a number of data products with a simple user interface and tools to quickly process, deliver, and document data products to NSIDC in standardized formats for use by the scientific community. This project will involve investigators from the University of Kansas (KU) and Indiana University (IU). Our proposal responds directly to the scientific goals outlined in the OIB research announcement, and the team and our radars sensors provide a proven capability to collect and generate data products for the OIB mission.

Eric Rignot/University of California, Irvine
Gravity Sounding of Southern Greenland Glaciers
15-ICEB15-0004

Measuring ice thickness is fundamental to our understanding of glacier dynamics and ice sheet mass balance. While outstanding progress has been made with modern ice sounding radars in recent decades, several sectors of Greenland are still a problem, especially in the south: the ice is highly lossy due to the presence of liquid water in the firn and existing ice sounding radars operate at a relatively high frequency, which make it impossible to alleviate strong scattering by water inclusions. Here, we propose to employ a novel approach that employs high-resolution gravity data from helicopter to map the glacier thickness of southeast Greenland glaciers at a spatial resolution of 500 m, with a precision better than 1 mgal to enable ice thickness mapping with a precision of about 50 m. In prior years, in a project funded by the Gordon and Betty Moore Foundation, we have demonstrated the usefulness of these data for sounding challenging ice in Patagonia and west Greenland, and resolve the ice-ocean boundaries at glacier fronts in a unique fashion. These gravity data will be used in coordination with seafloor bathymetry data to be collected by the EVS-2 Ocean Melting Greenland (OMG) project in 2015-2016, IceBridge thickness data using conventional radars and bed mapping products from the Bed Machine project to facilitate data inversion into bed maps. Level 1-4 products will be generated by our instrument partners and our research group for delivery at the National Snow and Ice Data Center (NSIDC) for us by the scientific community. This deployment will help resolve a major remaining uncertainty in glacier thickness in southern Greenland and complete the description of glacier geometry around the entire ice sheet once for all, thereby enabling major advances in ice sheet modeling to reduce uncertainties in future sea level rise from Greenland. This data collection will be directly serving the science objectives of Operation IceBridge, it will help understand and interpret data collected by the ICESat missions, and it will directly serve NASA's

overarching goal to study the evolution of the Earth's large ice masses and their impact on sea level rise.

Michael Studinger/Goddard Space Flight Center
Airborne Topographic Mapper (ATM) Data Collection, Data Processing, and Mission Support for Operation IceBridge
15-ICEB15-0001

The primary purpose of the proposed work is to provide NASA's Operation IceBridge with the support to operate the suite of NASA-owned airborne LiDAR sensors and ancillary instruments, collectively known as the Airborne Topographic Mapper (ATM), for the planned data collection and processing activities through 2019. The proposed work also includes providing data products, metadata and documentation in NASA's Earth Science Data and Information Systems (ESDIS) approved standard formats to the National Snow and Ice Data Center (NSIDC) for archiving and distribution. Sensor hardware and software maintenance and enhancement, as well as mission planning support and precision aircraft guidance for IceBridge are part of the proposed effort as well.

The proposed ATM data collection effort will continue to provide the science community with state-of-the-art, geodetic quality, precision ice surface elevation measurements that are consistent with more than two decades of existing ATM measurements, as well as existing ICESat and future ICESat-2 measurements. The proposed ATM data collection will link the measurements made by airborne laser altimeters, ICESat, ICESat-2, and CryoSat-2 to allow accurate comparison and production of a long-term, cross-calibrated ice altimetry record, directly supporting core IceBridge science goals. Existing ATM laser altimetry products available from NSIDC go back to 1993 and are the only coherent data set that connects all space-borne altimeter missions from ICESat, over CryoSat-2 to the planned ICESat-2 measurements, creating an almost 3 decade-long cross-calibrated time series of elevation change.

In addition to continuing the current suite of 11 IceBridge ATM data products, we propose to include a new ATM waveform product while re-processing pre-2013 (missions prior to NASA directed data format change) ATM data to ESDIS standards, ensuring a uniform NSIDC data format for ATM products (IceBridge Mid-Term Review Team recommendation). We also propose to upgrade the existing ATM system to simultaneously transmit 532 and 1064 nm laser pulses from the same laser. This capability will aid the investigation into differential penetration into snow and ice surfaces by two different wavelengths of laser light, in preparation for ICESat-2 launch and ICESat, IceBridge and ICESat-2 data comparisons. The proposed upgrade to dual wavelength transmission is based on recommendations by the IceBridge Mid-Term Review Team.

The laser altimetry products will be augmented by several ancillary measurements and data products, including a downward pointing infrared pyrometer for measuring surface temperatures, an up- and downward looking albedo spectrometer package, and a new thermal imaging camera. These additional instruments have been added in response to direct requests from the science team and science community or have been based on recommendations by the IceBridge Mid-Term Review Team.

Kirsty Tinto/Columbia University
High Resolution Gravity and Magnetics Measurements for Operation IceBridge Antarctic Campaigns, 2016-2019
15-ICEB15-0005

This proposal is to support collection and processing of high-resolution potential field data as part of the 2016-2019 OIB Antarctic programs, including mission-critical gravity data on P-3, C-130 or DC-8 based campaigns and mission-desirable magnetics data on P-3 based campaigns. The gravity data will be used to infer the bathymetry beneath floating ice shelves and to determine ice sheet bed topography beneath fast-flowing, heavily crevassed areas where radar returns are attenuated or hard to interpret. The magnetics data will be used to constrain the tectonic framework of the underlying bedrock and in particular to identify the location of boundaries between geologic formations where the rocks may have differing densities. The magnetics data may also allow us to locate areas of sediment accumulations that will affect ice sheet dynamics and to identify sub-ice geologic structures that will affect the gravity interpretation and possibly geothermal fluxes.

Gravity measurements will be made using the Sander Geophysics Ltd AIRGrav system, the same system used on OIB campaigns since 2009. This system is based on three orthogonal accelerometers mounted on a Schuler-tuned stabilized platform. The AIRGrav system delivers better than 1 mGal accuracy when flown in the draped flight configuration required by Operation IceBridge surveys. Time-based filters applied to the data give a half-wavelength resolution of 4-5 km.

Magnetic measurements will be made with a Scintrex CS3 cesium vapor magnetometer, mounted in the tail of the P3 aircraft, which was originally designed to carry such an instrument. Magnetic surveys are repeatable to within ~2 nT with a ~1 km resolution determined by the survey elevation of 500 m above ground level.

Inversion of gravity data to model bathymetry under floating ice requires the integration of a number of different data sets including altimetry, radar, magnetics, marine bathymetry and geologic mapping results. We have developed procedures to integrate all the necessary datasets and perform inversions that result in bathymetric and geological models of key regions around the ice sheet grounding zones. We use inversion techniques that are applicable to either gridded datasets or single-line profiles according to the survey configuration over a particular target.

We will continue to provide data products to the National Snow and ice Data Center according to the procedures already established in the Operation IceBridge data management plan and data provider agreement between LDEO and NSIDC. Anomaly data will be provided as a Level 2 product within 4 months of the end of the field season. Grids of these anomalies will be provided, where appropriate, as a Level 3 product. Bathymetry models from gravity inversions are a Level 4 product, and will be provided regularly throughout the performance period.