Studies with ICESat and CryoSat-2
Abstracts of selected proposals
NNH16ZDA001N-ICESAT2

This synopsis describes the proposals selected in response to the NASA Research Announcement Studies with ICESat and CryoSat-2 which is sub-element A.16 of NASA ROSES 2016.

NASA solicited investigations to derive geophysical information from NASA's Ice, Cloud, and land Elevation Satellite (ICESat) and the European Space Agency's CryoSat-2, and link these records with the initial data stream from ICESat-2, scheduled for launch in 2018. These altimetry missions were optimized to characterize changes in the Greenland and Antarctic ice sheets, and the sea ice of the Arctic and Southern Oceans. The missions' primary goals are to understand the contributions of polar land ice to current and future sea level rise, and the coupling of changes in polar sea ice cover to the Earth system. Investigations are encouraged that:

- create long-term, integrated records of change in the polar ice sheets;
- characterize processes of change in polar ice, especially couplings to climate forcings and insight into physical processes that improves predictive models; and
- any other innovative investigations using ICESat and CryoSat-2 observations for Earth science research.

The NASA Ice, Cloud, and land Elevation Satellite (ICESat) was launched in January 2003 and ceased operations in 2009. With an orbital inclination of 94 degrees, ICESat observations provided critical insight into the thinning of the Arctic sea ice cover, the ice loss from the Greenland and Antarctic ice sheets, and the global distribution of above-ground biomass. Details of the mission are at http://icesat.gsfc.nasa.gov/ and the data can be accessed from the NASA Distributed Active Archive Center (DAAC) at http://nsidc.org/data/icesat/.

ICESat's planned successor is ICESat-2 (http://icesat-2.gsfc.nasa.gov/), which is currently under development and expected to launch in 2018. ICESat-2 will be in a near-polar orbit and have a multibeam, photon-counting instrument, enabling measurements at higher resolution and over broader swaths, that enable direct measurement of both surface elevation and slope. The gap in observations between the two missions is being bridged by NASA's IceBridge Mission (http://www.nasa.gov/mission_pages/icebridge/index.html), a series of aircraft campaigns over land and sea ice in both polar regions. Data and instrument descriptions can be accessed from the NASA DAAC at http://nsidc.org/data/ icebridge/.

Launched in April 2010, CryoSat-2 is a radar altimetry mission of the European Space Agency (ESA). It is designed primarily to measure sea ice thickness with sophisticated radar processing techniques. CryoSat-2 also has the potential to measure ice sheet elevation and make other geophysical measurements. Details on the Cryosat-2 mission are at http://www.esa.int/esaMI/ Operations/SEM36Z8L6VE_0.html.

Selected proposals include a variety of studies using ICESat, IceBridge, CryoSat-2, and planned ICESat-2 altimetry data to examine the mass balance and evolution of the Greenland and Antarctic ice sheets, decadal trends in Arctic sea ice thickness and volume, and the structure of

above-ground vegetation and conversion to biomass. Out of 28 submitted proposals, 11 will be recommended for awards. The total funding is approximately $2 million per year for three years. The Principal Investigator, institution, and investigation title are listed below.

Andy Aschwanden/University of Alaska, Fairbanks
Using ICESat/OIB Elevation and Satellite-Derived Velocity Changes to Constrain Time-Varying Basal Motion
16-ICESAT2-16-0026

Motivation: The stability of the Greenland Ice Sheet in a warming climate is a critical societal concern. Predicting Greenland's contribution to sea level remains a challenge, in part due to our limited practical understanding of ice sheet basal motion, particularly the way in which that basal motion changes through time. This is critical at the transition between inland and tidewater glacier environments, where rate limiting processes may determine future discharge. The basal physics of this transitional zone, and outlet glaciers in general, is currently poorly represented in ice sheet models.

Approach: We propose to invert satellite-derived estimates of surface velocity and surface elevation histories to improve characterization of hydrology-determined patterns of basal motion. To do this, we will derive a simplified but representative model of subglacial hydrology which can be solved efficiently. In conjunction with a basal motion parameterization (i.e. a sliding law), we will find the spatially and temporally constant parameter values that minimize the misfit between modeled and observed surface velocities, subject to surface geometry evolution from Operation IceBridge and ICESat. We will validate the suitability of the derived basal state model by hindcasting the period 1979-2015 with an ice sheet model using climate forcing from a regional climate model.

Deliverables: (1) A new approach to integrating surface elevation histories and ice velocity changes to constrain basal processes. (2) A basal state model derived from this approach that is compatible with observations, ready to be implemented into ice sheet models to improve their usefulness for sea level predictions. (3) Flux divergence maps from measured and modeled velocity fields that can be compared with laser altimetry to aid in dh/dt partitioning.

Uniqueness: This will be the first time that inverse methods have been applied to a spatially-variable coupled ice flow/basal hydrology model to constrain basal motion in a generalizable and time evolvable way.

Relevance to NASA Cryospheric Science: This proposal directly responds to this call's request to use observations from ICESat, OIB, and other satellite resources to better "characterize the dynamic processes controlling ice flow and related changes in ice sheet elevation and mass balance, especially to improve ice sheet models useful for prediction of sea level rise". This work will also directly enhance the value of NASA's laser altimetry missions by providing better estimates of flux divergence needed to partition the surface elevation change signal between surface mass balance and changes in ice dynamics.

Sinead Farrell/University of Maryland, College Park
Decadal-Scale Variability and Trends in Arctic Sea Ice Thickness and Volume
16-ICESAT2-16-0020

Satellite laser and radar altimeters observing the polar and subpolar seas now provide an extensive and routine monitoring of the sea ice cover, spanning two decades. We are motivated to use these novel data to provide new insight into the dynamic and thermodynamic changes occurring in the Arctic sea ice cover today. We seek to determine the decadal trends, and inter-annual variability, in sea ice thickness and volume so as to improve knowledge of the complex relationship between the ice cover and the polar climate system, and to enhance modeling capabilities for the prediction of future change.

The key aim of this proposal is to create a synthesized time series of Arctic sea ice thickness and volume change, using measurements collected by ICESat, CryoSat-2 and ICESat-2. We will augment this time series with complementary measurements collected by the radar altimeter on-board the European Sentinel-3A mission. The proposed investigation is unique in its systematic approach to mapping the polar sea ice thickness distribution, utilizing a wide range of multi-mission altimeter data, and linking to other remote sensing including airborne altimetry from Operation IceBridge (OIB), scatterometer data from QuikScat and ASCAT, and expansive in situ measurements including from Ice Mass Balance Buoys (IMBs). We will use the independent OIB aircraft observations and IMB field measurements to validate the capabilities of the satellite altimeter systems, and understand potential inter-satellite biases between satellite sensor technologies. The major focus of this project is the state of the northern hemisphere ice pack, due to its influence on the climate, eco-system, and human infrastructure of the region.

We expect our key analyses to include: (i) An integrated time-series of Arctic sea ice thickness and volume change spanning two decades and an improved tracking of the trends and variability in the first-year and multi-year sea ice thickness distributions. (ii) Basin-scale mapping of Arctic sea ice freeboard, thickness and volume, released on monthly, seasonal and annual time scales. (iii) Near-real-time monitoring of ICESat-2 sea ice freeboard and thickness, specifically directed towards operational activities, situational awareness, short-term forecasting, and model assimilation. (iv) Data products that will be made publicly accessible via a dedicated project website and disseminated through a national data center, such as the National Snow and Ice Data Center (NSIDC). As part of the proposed research we will also create a modified snow depth climatology, utilizing novel measurements of snow depth from OIB radar systems, combined with direct measurements from IMBs. This snow climatology will be used to derive ice thickness, but will also provide a novel product of interest to the community in its own right.

The research plan responds directly to many of the key program goals associated with the NASA Research Announcement of Opportunity: A.16 Studies with ICESat and CryoSat-2 in that the proposed research seeks to exploit ICESat, CryoSat-2, ICESat-2 altimeter data to produce an "long term, integrated record of change" focusing on the northern hemisphere ice pack of the Arctic Ocean. This study will provide new metrics and data products aimed at understanding the factors driving change in the Arctic climate system, and improving predictive model capabilities.

Ute Herzfeld/University of Colorado, Boulder
Integration of Altimeter Data from ICESat, IceBridge, CyroSat-2 and IceSat-2 --- Mathematical Approaches and Applications to Glacial Change
16-ICESAT2-16-0025

The idea of the proposed project is to create an integrated time series of altimetry-based elevation models, starting with derivation of high-quality and high-resolution elevation fields from expected ICESat-2 data and looking backwards from experience gained with ICESat-2 algorithm development and lidar data analysis at the problem of integrating the existing data and future data from ICESat GLAS, IceBridge ATM and CryoSat-2 SIRAL. The motivation for centering the proposed work around ICESat-2 is two-fold: (1) With more than 100 times better spatial resolution than GLAS data, data from the ICESat-2 Advance Topographic Laser Altimeter System (ATLAS) will set the new standard in satellite altimetry and allow to approach many of the problems in glaciology and energy balance that could not be fully addressed using lower-resolution data from ICESat and CryoSat-2, and (2) through development of algorithms for ICESat-2 data and analysis of data from airborne ATLAS simulator instruments, the proposal team has gained new perspectives in laser altimetry leading to new approaches to analysis of existing GLAS data and altimeter data in general, which are aimed at facilitating integration in time series of elevation and elevation change. The density-dimension algorithm for ice-surface analysis (DDA-ice) developed in our group allows to accurately retrieve ICESat-2 surface heights even in regions of heavy crevassing or firn cover and under intermittent clouds and will be applied to derive along-track and gridded ice-surface height fields. Elevation, elevation change and volume change products will be derived for the Greenland and Antarctic Ice Sheets, the Bering-Bagley Glacier System and Icelandic Ice Caps. As one of the IMBIE science teams, our group will participate in assessment of mass change of the Greenland and Antarctic ice sheets and their contribution to sea-level rise. To contribute to our communal improved understanding of mass balance, surface melting and energy fluxes in the climate system, surface roughness data sets from ICESat-2 data for the Greenland and Antarctic Ice Sheets will be derived and applied as new controls for the Regional Atmospheric Climate Model (RACMO). Estimations of melt energy in models have been limited to date, because energy balance calculations are influenced by surface roughness, which so far has been estimated rather than measured. It is expected that the ice-sheet wide surface roughness data sets will yield a so-far missing ingredient in improved, more realistic estimations of surface mass balance and ultimately mass loss from the ice sheets and contributions to sea-level rise. A sensitivity study of results from a dynamic ice sheet model (ISSM) to changes in present-day surface elevation (using several different years of the time series derived here) will be carried out to investigate how much the results of dynamic ice sheet modeling change when controlled by the actual, observed changes in ice-surface heights during the last years (since 2003 and through 2019). The proposed research is directly relevant to ROSES call A.16 in all its components. Research goals are also shared with the Program for Assessment of Regional Climate Change in the Arctic (PARCA), the Surface Mass Balance and Snow on Sea Ice Working Group (SUMup), to whom resultant data sets will also be contributed, the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Programme (WCRP), especially Climate and Cryosphere (CliC), with the Interagency Arctic Policy Committee (IARPC) and US CLIVAR.

Ian Joughin/University of Washington, Seattle
West Antarctic Elevation History Leading up to ICESat 2: Multi-Sensor Observation and Model-Based Analysis
16-ICESAT2-16-0003

The majority of ice loss from Antarctica emanates from the West Antarctic Ice Sheet, which model simulations suggest is in the early stages of collapse. The ICESat-2 mission will measure the change in elevation associated with these losses with unprecedented detail. West Antarctic ice loss, however, has been occurring for multiple decades with patterns of thinning that can evolve rapidly. This means that the nominal 5-year duration of the mission provides a relatively narrow temporal window with which to understand longer-term evolution. This limited interval means that extending the observational record over a long a period as possible is of paramount importance for understanding current and future ice loss from West Antarctica. Toward this goal, we will combine data from numerous missions (ICESat, Cryosat-2, IceBridge, and WorldView) to produce an ~15-year baseline data set for West Antarctica that captures the spatio-temporal patterns of elevation change from 2003 through the launch of ICESat-2. We will make these ~annually resolved maps of thinning available to the scientific community for studying numerous aspects of ice-sheet elevation change.

For this study, we will use the products that we produce to study how patterns of dynamic thinning evolve through time and what processes govern this evolution. Such understanding is important to provide a context in which to interpret the observations that ICESat-2 will provide. As a first step, we will analyze the elevation-change history to characterize how the spatial patterns of thinning evolve through time, following events such glacier speedup in response to grounding-line retreat. Already our past work has shown that these patterns can evolve rapidly (relative to the scale of a 5-year mission) and that the patterns of modeled change are sensitive to the form of the assumed model. For example, the exponent of the sliding law can lead to significantly different patterns of thinning. Thus, once we have a good characterization of the patterns of change, we will use our new time series to constrain ice-flow models to understand what the dominant processes are that control the observed patterns of thinning (in some cases thickening). This work will involve several case studies of glaciers in the most rapidly thinning areas. In particular, we will focus on how rapidly changes near the grounding line of Pine Island and Thwaites diffuse inland. Although thinning predominates in West Antarctica, we also will examine Kamb and Whillans ice streams where thickening due to slowdown or full stagnation has mitigated some of losses along the Amundsen coast. In addition, we will use the observations and models to better understand the relative roles of dynamic thinning and surface mass balance in producing the recent observations of increased thinning along the Bellingshausen coast. Through these case studies we will gain a much a better understanding of what collection of processes is driving ice loss in West Antarctica. Moreover, by rigorously constraining the models to reproduces change over a decade in half, we will improve our ability to project ice sheet loss in the coming decades and centuries.

Ala Khazendar/Jet Propulsion Laboratory
Constraining Mass Balance Uncertainties in East Antarctica from 2003 to the Present with Laser and Radar Altimetry Observations
16-ICESAT2-16-0011

There is broad scientific agreement that glaciers and ice sheets will contribute substantial volumes of water to the world's oceans in the coming decades as they adjust to enhanced melting caused by warming of the atmosphere and oceans. Despite this broad agreement, large uncertainties remain in estimates of the expected magnitude and rate of sea level change. One reason for this is our limited understanding of how precipitation changes in response to changing atmosphere and ocean conditions and of how ice flow responds to changes in ice-shelf buttressing and basal friction. Improved understanding of these processes will lead to reduced uncertainties in projections of sea level change. One key step towards accomplishing this is to assemble and analyze long records of glacier change that characterize grounded ice response to changes in ocean and atmosphere conditions. Here, we choose to focus on quantifying spatially detailed changes in surface elevation and mass of the East Antarctic Ice Sheet (EAIS), with the goals of constraining its recent contribution to sea level change and characterizing/separating its basin-scale response to changes in atmosphere and ocean forcing.

To do this we will dedicate considerable effort to improving the estimation estimates of glacier elevation and elevation change, with use of NASA lasers altimetry (ICESat-1, ATM, ICESat-2) and ESA radar altimetry (CryoSat-2), which we will synthesize into a spatially detailed record of EAIS volume change. We will also conduct an exhaustive analysis of the temporal evolution of the firn air content (FAC) and its respective uncertainties, allowing us to convert surface elevation changes to local changes in ice mass. We will then analyze the dataset with the goal of identifying the processes responsible for the changes we observe. In particular we hope to separate changes in glacier mass resulting from interannual changes in precipitation minus sublimation (P-S), decadal scale changes in glacier and ice stream dynamics, and century-scale imbalance between P-S and discharge.

With a surface area of 10 million square kilometers and enough stored ice to raise sea levels by ~55 m, the EAIS has the potential to greatly influence rates of sea level change (mitigate or exacerbate). However, the observation of elevation changes in this area present a unique observational challenge as, over most of the ice sheet they are at the detectability limit of space based altimetry (+/- 1 cm/yr). Consequentially, any attempt to reduce uncertainties in ice sheet mass change derived from satellite altimetry will require a detailed technical analysis and validation of the disparate altimetry datasets. Here, we proposed to conduct such a study, with the purposes of reducing uncertainties in EAIS contributions to sea level from during the period 2003-2018 and identifying the processes that underlie the observed changes. We will make our 15 year, spatially detailed (1 km) record of EAIS elevation, mass and FAC publically available with the hope that the results will stimulate additional research into the temporal evolution of the EAIS.

Eric Larour/Jet Propulsion Laboratory
Data Assimilation of Altimetry Signals Using the Ice Sheet System Model
16-ICESAT2-16-0006

We propose to synthetize a coherent data set record of altimetry for the Greenland Ice Sheet from 2002 onwards, and to use it towards data assimilation into an ice flow model, the Ice Sheet System Model. The goal is to reconstruct the state of the snowpack and the ice from 2002 onwards, to understand the sensitivity of such a reconstruction to different processes affecting elevation within the snow pack (such as compaction, diffusion and advection, refreeze and melt, etc.) and within the incompressible ice (such as horizontal buttressing, dynamic thinning, etc.).

The approach taken here is to rely on the GEMB regional snowpack model, to integrate it into ISSM and to rely on the automatic differentiation capabilities of the latter to drive a data assimilation run over an extensive period where altimetry data is available. Our science goals are: 1) provide a new homogeneous/coherent altimetry record for Greenland, along with associated errors and uncertainties; 2) reconstruct the state of the snowpack and ice over that period and 3) assess the processes which are responsible for the evolution of surface elevation through time, and understand the spatio-temporal signatures of such processes.

Jan Lenaerts/University of Colorado, Boulder
Combining Satellite Altimetry, IceBridge and Atmospheric Reanalyses to Map Antarctic Ice Sheet Surface Mass Balance at Very High Resolution
16-ICESAT2-16-0005

The goal of the proposed work is to map the Antarctic Ice Sheet (AIS) surface mass balance (SMB) at an unprecedentedly high resolution (1 km), using a unique combination of elevation data derived from radar and laser altimetry (CryoSat-2 and ICESat-2), atmospheric reanalyses, and IceBridge radar data. The upcoming NASA ICESat-2 mission will provide high-precision insight into elevation change over the ice sheets at high spatial detail and is currently scheduled for launch in late 2017. A remaining challenge for scientists, however, is in partitioning these elevation changes into ice-dynamical and surface-induced processes, complicating the inversion from elevation (volume) to mass changes, the latter of which ultimately determine the ice sheet's contribution to sea level change. The surface mass balance, one of the major components of surface-induced elevation change, can be mapped in space and time using atmospheric reanalyses, which are models that assimilate observational data. State-of-the-art atmospheric reanalyses, currently working at grid resolutions of approximately 50 to 100 km, provide a realistic picture of large-scale Antarctic SMB. At this scale, SMB is predominantly driven by precipitation, the spatial patterns of which are mostly determined by large-scale orography that is well resolved by climate models. In contrast, unresolved fine-scale topography causes wind-driven redistribution and sublimation of snow that significantly affects SMB at length scales smaller than the model grid size (so-called sub-grid drifting snow processes), but larger than the small-scale and highly mobile drifts and sastrugi that are not considered in this study. These subtle topographic variations of a few meters can span hundreds of meters to a few kilometers and can lead to SMB variations of a factor of six. Here, we propose to map Antarctic ice sheet surface topography at sub-grid resolution (~1 km) by combining ICESat-2 laser and CryoSat-2

radar altimetry data. In conjunction with this new elevation model, surface winds and climate simulated by NASA's MERRA-2 reanalysis will provide the input for a snow redistribution model (SnowModel) that simulates SMB at the elevation model scale. The results will be evaluated and refined using Operation Ice Bridge snow radar derived SMB and ICESat-2 drifting snow frequency.

Our new SMB map will aid in better constraining mass balance of Antarctic ice sheet and ice shelves, and the contribution of the AIS to contemporary sea level rise (SLR). Our new estimate of AIS SMB can be used directly to derive regional scale mass balance, improve volume-to-mass conversion for IceSat-2 and CryoSat-2 repeat altimetry, and provide the ice coring community with a tool to pick representative drilling locations for SMB reconstructions. Moreover, our results will provide uncertainty bounds on climate model SMB by quantifying the impact of neglecting sub-grid drifting snow processes and highlighting regions on the AIS for which these models are more or less reliable.

This proposal is highly relevant to at least two specific goals of the call, namely to "gain insight into the surface mass balance, especially to improve models of polar precipitation" and to "use satellite altimetry to determine any other properties of the ice sheets critical to improved models of their contributions to current and future sea level rise." The work involves a unique combination of NASA investments including IceBridge, ICESat-2, and MERRA-2, and it will be an early result of ICESat-2 since it does not require multiple crossovers for change analysis.

Amy Neuenschwander/University of Texas, Austin
Aboveground Structure and Biomass of Dynamic and Low-density Vegetation from Synergism of ICESAT-2 lidar and International Radar Observations: A Precursor to ICESat-2/NISAR Data Fusion
16-ICESAT2-16-0008

Applied Research Laboratories, The University of Texas at Austin (ARL:UT) proposes to work with the Jet Propulsion Laboratory (JPL) to develop a methodology to convert the ICESat-2 vegetation height measurements to aboveground structure and biomass along with associated uncertainty. One limitation of ICESat-2 is that the measurements are collected in a profiling manner and there is not wall-to-wall sampling of lidar data, even at higher latitudes. In this proposal, we will provide a synergistic approach to combine the ICESat-2 canopy height measurements and biomass estimates with satellite L-band radar measurements to map forest biomass density over a variety of global ecosystems with low biomass density (< 100 Mg/ha). When building a methodology to estimate biomass across a landscape, it is critical to quantify the errors and uncertainties associated with the proposed data products. Associated with this effort, we intend to characterize the uncertainty from the photon level to the ICESat-2/ATL08 data product level to the estimated biomass for the ICESat-2 data and finally the scaled up biomass estimates using radar. The proposed research will focus on several sites with existing ground and airborne lidar observations such as boreal forests (Arctic Boreal Vulnerability Experiment, or ABoVE, study domain), woodland Savanna and dry forests in Tanzania and Mexico, temperate fragmented and secondary forests in the US, and secondary and degraded forests in humid tropical forests in the Amazon basin (Brazil). By fusing ICESat-2 biomass

estimates with NASA-ISRO SAR Mission (NISAR), a complete and more accurate representation biomass is feasible for low biomass ecosystems. The NISAR radar mission is set to launch in 2020 –thus providing sufficient time to develop a methodology to fuse ICESat-2 biomass estimates with radar to provide wall-to-wall biomass estimates for low biomass ecosystems such as boreal forest and wooded savannas. Until the launch of the NISAR mission, we will use Advanced Land Observation Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) data over selected areas as a surrogate for NISAR radar data.

Laurence Padman/Earth And Space Research
Understanding the Climate Drivers of Antarctic Ice Shelf Changes Through Analyses of Multi-Mission Satellite Altimetry, Airborne Remote Sensing and Models
16-ICESAT2-16-0018

The Antarctic Ice Sheet contains enough ice to raise global sea level by ~58 m if it melted entirely. Even a 0.5 m sea-level rise contribution (~1% reduction in ice-sheet mass), which is now regarded as possible on time scales of decades to a century, would present a significant threat to coastal communities and infrastructure. This proposal addresses one significant factor influencing the projected rate of mass loss from the grounded portion of the Antarctic Ice Sheet: climate-driven changes in the thickness and mass of its ice shelves, the floating portions of the ice sheet where it comes into contact with the ocean. Contact of ice shelves with the sidewalls and local high spots on the seabed exerts a back-stress on the grounded ice streams and glaciers that carry ice into the ocean. Observations and models confirm that lowering of this back-stress caused by reduction of ice-shelf volume increases dynamic loss of grounded-ice mass and consequent sea-level rise. Our team has recently developed the longest and most highly-resolved record of space- and time-dependent height change for the 85% of total ice-shelf area that was covered by ESA's radar altimeter (RA) satellites up to 2012 [Paolo et al., 2015, Science]. This 18-year record shows that ice shelves are changing on a broad range of timescales from annual to decadal and likely longer.

The proposed study is organized around three goals: (1) develop techniques to extend the ice-shelf height record through the ESA's current CryoSat-2 RA mission and the early years of NASA's ICESat-2 laser altimeter mission (launch in late 2017); (2) identify climate mechanisms contributing to interannual variability in ice-shelf volume seen in the extended time series; and (3) estimate the contribution of freshwater flux to the Southern Ocean from ice-shelf volume changes. By comparing the time and space variability of ice-shelf height with measured and modeled changes in the atmosphere and ocean, we will identify which processes have the largest effect on ice-shelf thickness and, therefore, on the buttressing effect on the adjacent grounded ice. There are very few simultaneous observations of atmospheric and ocean state during the same period that ice-shelf height data are available, and so our climate information will come from existing models: atmospheric reanalysis products for the same period as we have ice-shelf height data (1994-present); global ocean state models such as ECCO-2; and global coupled climate models developed for the IPCC AR5 report. The daily observational record of sea-ice concentration (1979-present) provides further guidance on variability in both the atmosphere and ocean.

This study directly addresses the 2016 ROSES call for A.16: Studies with ICESat and CryoSat-2. We will carry out comparative studies of ICESat, ERS/Envisat, OIB, CryoSat-2 and early years of ICESat-2 measurements over ice shelves, and use data from other satellite sensors (including SSM/I sea ice concentrations) to augment these studies. Initial comparisons between existing laser altimeter (ICESat and OIB) and RA data will facilitate rapid integration of ICESat-2 data as it becomes available. This effort will generate long-term continuous, homogeneous records of change in the polar ice sheets, contributing to continuity of the Antarctic ice-shelf change record into the ICESat-2 era. By comparing these records with climate reanalysis and predictive models, we will also quantify the processes causing changes in polar ice, especially to identify the response of Antarctic ice shelves to climate forcing and develop our process understanding to improve predictive models. The study contributes to NASA's Strategic Plan, Objective Goal 2.2, to “Advance knowledge of Earth as a system to meet the challenges of environmental change, and to improve life on our planet”.

Michael Studinger/NASA Goddard Space Flight Center
Investigating Snow Accumulation Variability for Development of a Multi-Sensor Elevation Time Series Pole-Ward of 86°S in Support of Altimetry Validation and Ice Sheet Mass Balance Studies
16-ICESAT2-16-0012

Polar ice sheets play a critical role in Earth’s climate system. Measurements from satellites and aircraft have revealed that the vast ice sheets of Greenland and Antarctica are changing at an accelerating rate suggesting increasing rates of global sea-level rise as the ice sheets melt. In order to project future rates of sea-level rise, numerical models of an ice sheet’s response to climate forcing require input data of the surface mass balance (SMB) and its spatial variability. Observing changes in ice-surface elevation (dh/dt) from satellite and airborne platforms has long been recognized as a powerful tool for assessing and quantifying ice sheet mass balance. In order to produce a cross-calibrated long-term record of ice-surface elevation change for input into ice sheet models and mass balance studies it is necessary to link the measurements made by airborne laser altimeters, satellite measurements of ICESat, ICESat-2, and CryoSat-2 and determine the biases and the spatial variations between radar altimeters and laser altimeters using different wavelengths. To properly interpret the observed elevation change (dh/dt) as mass change, however, the various processes that control surface elevation fluctuations must be quantified. Our proposed work has two objectives:

Objective 1: Quantify the spatial variability in snow accumulation rates pole-ward of 86°S and in particular around 88°S, where all CryoSat-2 and future ICESat-2 orbits converge, in support of past, current and future altimetry measurements and SMB model evaluation.

Objective 2: Develop a cross-validated multi-sensor time series of surface elevation change pole-ward of 86°S that, in combination with measured accumulation rates, will support ICESat-2 calibration and validation and ice sheet mass balance studies.

The convergence zones of all ICESat tracks (86°S) and all ICESat-2 and CryoSat-2 tracks (88°S) are in regions of relatively low accumulation, making them ideal for satellite altimetry

calibration. In preparation for ICESat-2 validation, the IceBridge and ICESat-2 science teams have designed IceBridge data acquisitions around 86°S and 88°S. While the long-term signal in dh/dt is likely due to ice dynamics, at short timescales (such as over the satellite record), the surface component of dh/dt in the vicinity of the South Pole is almost entirely dominated by variability in snow accumulation. Therefore, in order to develop a cross-validated time series of these NASA and ESA missions, it is necessary to quantify the spatial variability in snow accumulation rates, a quantity measurable from IceBridge shallow radar data.

The goal of this proposal is to measure accumulation at high latitudes to not only determine mass balance, but also evaluate models and to better understand altimetric error sources, such as penetration. To meet the two objectives of this proposal, we will: 1) establish the spatial variability in the accumulation rates using existing airborne and ground radar data, using firn cores for control; and 2) crosscalibrate all available altimetry data from ICESat, IceBridge, and CryoSat-2, using geodetic elevation measurements along ground traverses for control. Our results will contribute to the altimetry and ice-sheet modeling communities. The proposed work is directly relevant to several aspects of the cryospheric science solicitation, including ice sheet mass balance studies, and makes use of and supports several past, current and future NASA missions as well as ESA's CryoSat-2 mission. The proposed work directly supports a 1 billion dollar investment by NASA in ICESat-2 and will be crucial for interpreting the early data products collected during ICESat-2's commissioning phase in 2017.

Marco Tedesco/Columbia University
Combining Altimetry with Electromagnetic and Regional-Climate Models for Improved Estimation of Greenland Ice Sheet Mass Balance
16-ICESAT2-16-0022

We propose to generate improved long-term estimates of Greenland mass balance between 2003 and 2019 (and beyond) based on a combination of altimetry, gravimetry, and in-situ datasets used in conjunction with electromagnetic and regional climate modeling. Among the products of this work there will be maps of specific mass balance (i.e. the mass balance per unit area of the ice sheet, expressed in water-equivalent elevation change), as partitioned between changes driven by surface mass balance and by ice dynamics, of firn-thickness change and of the bias expected for Cryosat-2 based on the firn model, and also improved GRACE estimates of total mass changes.

We propose to accomplish these tasks by using the different datasets to improve a regional climate model to better capture the timing and magnitude of snow and ice accumulation, and ablation signals. We will then use the improved climate-model output, combined with a firn model to predict elevation changes for the ice sheet, and will further adjust the firn model to match measured density profiles and to match elevation changes in dynamically stable parts of the ice sheet. Last, we will translate the adjusted firn-model output into an electromagnetic model of the surface to calculate how KU-band radar energy penetrates the surface of the ice sheet, and to predicted biases and bias changes for Cryosat-2 data under different retracking strategies. The outputs of the improved SMB model will also be used to generate improved GRACE solutions over Greenland at regional scales (e.g., mascon solutions).

The synergic approach proposed in this project offers a unique and, to our knowledge, unprecedented way to address crucial known issues concerning the estimates of mass changes from altimetry data as well as their inter-mission calibration. The combination of the different tools (e.g., regional and electromagnetic models) overcomes the limitations of the single approaches, addressing one of the largest problems in altimetry (and ice sheet remote sensing in general) on how to relate the knowledge of snow/firn parameters to the electromagnetic quantities that are driving the signal recorded by the remote sensing instruments. The final product will consist of coherent, improved, spatially distributed and long-term estimates of mass and elevation changes which will benefit from the process-oriented vision and tools of the project's team, hence supporting not only this specific project but also the growth of the altimetry community in anticipation of the ICESat-2 launch.