ICESAT 2 SCIENCE DEFINITION TEAM
Abstracts of selected proposals.
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This synopsis describes the proposals selected in response to NASA Research Announcement *ICESat 2 Science Definition Team*, subelement A.14 of NASA ROSES 2014. ICESat 2 (http://icesat.gsfc.nasa.gov/icesat2/), expected to launch in 2017, will be critical to understanding the changes occurring in the world's major ice sheets, especially for characterizing the thinning of the Arctic sea ice cover, and for understanding the current and future contributions to sea level rise from the continental ice sheets in Greenland and Antarctica. This solicitation called for proposals for membership on the ICESat 2 Science Definition Team (SDT) to continue the science definition and planning activities for the mission from 2014-2017. This period will likely be followed by an execution phase, for which a successor Science Team will be selected.

This solicitation was open to all interested and qualified scientists, independent of their membership on the current ICESat or ICESat 2 teams. NASA selected 12 proposers, out of 26 submissions. The expertise spans the disciplines of laser altimetry; geodesy; glaciology; sea ice science; ecosystem structure science; atmospheric sciences; and relevant aspects of land, ocean, hydrologic, and applied sciences. The total funding is $850,000 per year. The Principal Investigator, institution, and investigation title are listed below.

James Morison/University of Washington, Seattle
Proposal for Membership of James Morison in the ICESat 2 Science Definition Team

To study the sub-Arctic seas and the connection of the Arctic to the world ocean, we must develop methods to process ICESat-2 data taken over open water. This is a departure from the analysis over sea ice because due to surface waves, the non-Gaussian character of the open ocean surface and scattering processes distort the distribution of photon ranges, resulting in sea state bias (SSB) in estimates of DOT. Therefore, much of the investigator's effort on the present ICESat-2 SDT has focused on characterizing the wind wave covered open ocean surface and it's effect on ICESat-2 data. He, with W. Plant, has analyzed data relating small-scale surface slope to energetic long waves and their effect on surface reflectance. In completing Intermediate Draft 2 of the Ocean Algorithm Technical Basis Document (ATBD), he has developed an algorithm that deconvolves the ICESat-2 instrument impulse response from the surface height distribution and characterizes the surface distribution as a mix of two Gaussian distributions from which four moments can Motivation for being on the ICESat 2 Science Definition Team (SDT) is rooted in a career-long effort to gather sufficient observations to understand seasonal and longer-term changes in the Arctic Ocean that have become especially significant in the last 20 years. In spite of the development of new observing programs, the ocean changes continue to be difficult to measure continuously and widely. Thankfully, ICESat observations of dynamic ocean topography (DOT = sea surface height - geoid) from 2002 to 2009 opened a new basin-wide window

on ocean surface circulation. In combination with ocean bottom pressure (OBP) measurements from the Gravity Recovery and Climate Experiment (GRACE), ICESat reveals changes in ocean freshwater content (FWC) as well. Using ICESat and GRACE, Morison et al. [2012] find trends in ICESat DOT from 2005 to 2008 that show a strengthening of both the anticyclonic Beaufort Gyre and a cyclonic DOT trough aligned with the Russian shelf break. Subtracting ICESat DOT trends from GRACE OBP trends yields basin-wide steric pressure anomaly trends and related FWC changes. These show increasing FWC in the Canada Basin balanced by decreasing FWC along the Russian side of the ocean. The trough in DOT, observed only with satellite altimetry, produces eastward velocity along the Russian coast that moves Eurasian runoff eastward into the Beaufort Gyre, supporting chemistry results showing most of the Beaufort Sea freshwater increase, 2003, 2008, was derived from Eurasian runoff.

In the future, ICESat-2 must continue tracking Arctic Ocean circulation. Further, we also must extend the approaches of Morison et al. [2012] to the sub-Arctic seas, because these are key links between the Arctic Ocean and global climate. ICESat-2 will be especially important in the sub-Arctic seas and North Atlantic and Pacific because these regions do not have TOPEX/Poseidon/Jason satellite coverage above 62Â°-64Â° N. be derived.

The investigator's future work on the SDT will include scientific feedback on mission planning and development of higher-level products, algorithms, and cal/val plans. Currently, he is completing the Ocean ATBD including methods of deriving the gridded sea surface height and wave properties, dealiasing methods, and definition of cal/val procedures. In the future he will work with the project programmers, addressing questions, and testing software. Refinement and validation of the surface finding method requires testing the scheme on MABEL, MATLAS, and ATLAS simulator data. He will further refine accounting for waves and subsurface reflection of photons, and arranging for open ocean cal/val. The model of the surface-waves and their effect on ICESat2 retrievals will be refined to include more wind speeds and directions relative to ICESat-2 tracks.

Morison, J. et al., (2012), Changing Arctic Ocean freshwater pathways, Nature, 481(7379), 66-70.

Alex Gardner/Jet Propulsion Laboratory
Improved Interpretation of ICESat-2 Data Through Characterization of Multiple Scattering of the Laser Micropulse

To ensure the maximum societal and scientific benefit from the ICESat-2 mission, the next Science Definition Team (SDT) will need to give thoughtful consideration to the prioritization of limited resources (both monetary and human), the finalization of measurement requirements, the development of higher level data products, algorithms and assessment of measurement and product uncertainties. As an SDT member PI Gardner will provide guidance in preparation for the launch of ICESat-2 in 2017 and its subsequent transition into an operation and data dissemination phase. He will contribute to all aspects of the SDT and his technical contributions will leverage his background in snow optics to improve knowledge of the interaction of ICESat-2's Advanced

Topographic Laser Altimeter System laser with glacier, terrestrial snow and sea ice surfaces. Such knowledge is critical to understanding ICESat-2 data. Initial results indicate that volume scattering of the 532 nm wavelength laser micropulse may lead to centimeter to decimeter temporally and spatially coherent biases in elevations derived from ICESat-2 data.

Ronald Kwok/Jet Propulsion Laboratory
Sea Ice Science in ICESat-2

This is a proposal to continue my participation as a member of the ICESat-2 Science Definition Team (SDT). My interests pertain to issues related to the definition of science requirements, instrument performance, geophysical retrievals and the validations of these retrievals over the Arctic and Southern Ocean sea ice cover. My expertise with using lidars for sea ice science has been informed by my work on freeboard and thickness retrievals using ICESat data and prior participation in the ICESat-2 SDT, IceBridge Science and CryoSat-2 Cal/Val teams.
Over the past three years, I have provided input on ICESat-2 sea ice science requirements, supported the analysis of MABEL data, and, served as the lead for the development of the Algorithm Theoretical Basis Document (ATBD) for sea ice products. A significant issue with sea ice thickness estimation stems from the need to understand how the uncertainties in freeboard from ICESat-2 propagate into estimates of thickness and volume. An important objective is to characterize and better understand the capability of the end-to-end process (measurement system and retrieval algorithms) that will in place for producing estimates of freeboard and thickness during the timeframe of ICESat-2. I propose to continue my current participation in the SDT in terms of providing science inputs. Further, I propose to define an estimation process for an ICESat-2 sea ice thickness product.

Benjamin Smith/University of Washington, Seattle
Land-Ice Algorithm Development for the ICESat-2 Science Definition Team

This proposal will fund the PI's participation in the Science Definition Team for NASA's ICESat-2 mission. As part of this project, the PI will advise the ICESat-2 project about how data need to be collected to provide data needed for glaciological studies. He will also help with development of science algorithms designed to produce data products that allow accurate estimates of glacier surface height and height change. This work will require twice-annual trips to meetings, participation in telephone conferences, the generation of documents describing the science algorithms, and interaction with a coding team at NASA who will generate the software required to produce these products.

Helen Fricker/University of California, San Diego
Optimizing Retrieval of Height Changes Over Dynamic Land-Ice Features and Calibration/Validation Over Flat Land Surfaces

This proposal is for Helen Amanda Fricker (HAF), Professor at Scripps Institution of Oceanography (SIO), to remain a member of the ICESat-2 Science Definition Team. HAF's primary experience relevant to being on this team is concerned with glaciology (land ice), in particular satellite radar and laser altimeter data over the Antarctic ice sheet, especially the ice shelves and active subglacial lakes. She also has experience with calibration and validation of satellite altimeter missions.

One of the Baseline Science Requirements for the ICESat-2 mission over land ice states: ICESat-2 shall produce an ice surface elevation product that enables determination of surface elevation change rates for dynamic ice features that are intersected by its set of repeated ground-tracks to an accuracy of better than or equal to 0.4 m/yr along 1-km track segments. This was written as a consequence of ICESat's observations of dynamic features on the Antarctic Ice Sheet, i.e. rapidly-changing, variable, large elevation-change regions such as grounding zones (GZs; Fricker and Padman, 2006) and subglacial lakes (Fricker et al., 2007; Smith and others, 2009), and underlines the importance of this area of inquiry for ICESat-2. These are key features that can provide information about the dynamics of the ice sheet, a recent example of which is the retreat of the GZ of Pine Island from observations acquired between 1992 and 2011 (Rignot et al., 2014). This result has led to the conclusion that this sector of WAIS is undergoing irreversible collapse; ICESat-2 might be able to provide a dataset that can extend the monitoring that is possible from InSAR data. ICESat-2 will also increase the time series of lake activity over the ice sheet, which is resolvable by CryoSat-2 in its SARIn mode (Siegfried et al., 2014) but not in the LRM mode that operates over most of the ice sheet. One of HAF's roles on the ICESat-2 SDT will be to investigate along- and across-track slope estimation over such dynamic features.
A secondary area of expertise for HAF is geodesy, which is essential for the calibration and validation (cal/val) of the ATLAS instrument. Given her current cal/val role on the ICESat-2 SDT, if this proposal is successful, HAF would be likely to lead the SDT's involvement in cal/val planning for the next several years. Given the field and cal/val expertise represented by the entire SIO team, the analytical and experimental work proposed in support of ICESat-2 cal/val would be well placed at SIO.

Sorin Popescu/Texas A&M AgriLife Research
ICESat 2 Science Definition Team: Improving Estimates of Forest Biophysical Parameters with an Integrated Multi-Scale Approach

Overall goal of this proposal is to further advance the knowledge of the vegetation science products related to the ICESat 2 mission through improved algorithms of estimating ecosystem structure and development of new algorithmic approaches to derive higher level products, such as biomass and carbon, with uncertainty estimates at multiple scales. Specific objectives include: (1) continued improvement of vegetation algorithms developed by the PI and other current members on the SDT and provide guidance on algorithm theoretical basis documents (ATBD); (2) implement calibration and validation methods for MABEL and MATLAS data and vegetation products through a suit of lidar data on multiple platforms, such as UAS, terrestrial, airborne, and ground measurements; and (3) develop approaches for deriving higher level vegetation products, such as

biomass and carbon with uncertainty estimates, by using an integrated multi-scale approach with remote sensing data and ground vegetation inventories.

This proposal has a single investigator, the PI - Dr. Sorin Popescu, and it includes support for a research scientist, Ryan Sheridan, PhD Candidate. The proposing team is highly qualified to contribute to the SDT with respect to advancing the science of vegetation products, having an extensive expertise and publication record in algorithmic development for estimating forest biophysical parameters with terrestrial, airborne, and satellite (ICESat/GLAS) lidar data. The proposing team has participated in ICESat 2 SDT meetings, as Co-I with PI Ross Nelson, and the algorithms comparison contest for photon classification into top of canopy, ground, and vegetation categories. The proposed approach is innovative by integrating lidar data on multiple platforms and multiple scales to reduce products uncertainties and advance the science of understanding interactions of photon-counting lidar and vegetation at footprint/plot level, local, regional, and continental scales.

Yuekui Yang/Universities Space Research Association, Columbia
A Holistic Approach to Improve ICESAT-2 Daytime Cloud Retrievals and Reduce Uncertainty in Surface Elevation Measurements

Clouds affect the ICESat-2 surface elevation retrieval in two ways. First, scattering from cloud particles increases the photon path length and makes the surface appear further away from the satellite. Second, cloud attenuation lowers the average number of arriving surface photons, which directly affects the first photon bias. Compared to the clear-sky surface elevation retrieval, a cloudy-sky retrieval with cloud optical depth 1.0 is 4.0 cm to 6.0 cm lower. Hence accurate cloud information is not only important to climate studies, but also to reducing the uncertainty in the ICESat-2 altimetry.

Half of the ICESat-2 measurements will be in daytime, yet the solar background noise will make the atmosphere data unsuitable for cloud analysis with conventional methods, which relies on lidar backscattering profiles for cloud information retrieval. This poses a serious problem, which not only degrades the science value of the daytime cloud products for climate studies, but also introduces uncertainty to the surface altimetry. Building on my long-term experience with ICESat and ICESat-2 and as a continuation of my current work, I propose a holistic approach that integrates the ATLAS measured solar background, surface apparent reflectance and backscattering profile to perform daytime cloud detection and to retrieve cloud optical depth and cloud height with greatly improved accuracy. With the derived cloud information, I will develop a range delay correction product for surface elevation measurements.

The results of this research include: (1) significantly improved daytime atmosphere products, including cloud mask, cloud height, and cloud optical depth; (2) an atmosphere path delay correction product and a fast analytical model to be provided to the ICESat-2 community for related studies. The proposed effort will contribute significantly to the success of the ICESat-2 mission by greatly increasing the science value and applicability of the ICESat-2 cloud products and reducing the uncertainty in surface altimetry.

Sinead Farrell/University of Maryland, College Park
Preparing for Launch: Optimizing the Performance of ICESat-2 for Sea Ice

Understanding the nature and variability of the thickness and volume of the sea ice pack is critical in order to advance our ability to predict the future state of the Arctic, on seasonal to decadal time-scales. Recent assessments of altimetry data indicate an overall decline in the thickness of the ice pack over the last decade, but also significant interannual variability at a regional level. ICESat-2 will continue to collect critical measurements of the polar regions through the end of this decade at least, contributing to and extending the multi-decadal record of sea ice thickness and volume change.

This proposal is for the principal investigator (PI), Sinead L. Farrell, to remain a member of the ICESat-2 Science Definition Team (SDT), in order to continue providing multidisciplinary advice on aspects of the ICESat-2 mission related to the polar oceans, focusing on sea ice. She will continue to provide expert scientific advice so that the primary goals of the ICESat-2 mission may be realized, particularly with respect to the characterization of sea ice thickness and volume change, over seasonal and interannual time scales.

As NASA prepares to launch ICESat-2 in 2017, this proposal spans the final pre-launch preparation period and the initial post-launch check-out phase of the mission. During this period Dr. Farrell will advise on (i) the use of ICESat-2 altimetric observations for sea ice and polar ocean studies, (ii) optimizing algorithmic approaches for the derivation of key sea ice data products, and (iii) post-launch calibration and validation (cal/val) of these data products. The investigating team will continue to utilize existing airborne photon-counting data to simulate ICESat-2-like data prior to launch and characterize the novel measurement approach on the rough, topographically complex, sea ice surface. Through complimentary research activities they will continue to assess the time-series of Arctic sea ice thickness derived from satellite (ICESat, Envisat, and CryoSat-2) and airborne (IceBridge) measurements, spanning 2003 to present, in order to place ICESat-2 measurements in the context of decadal change. They will continue to evaluate contemporary estimates of snow depth on sea ice derived from the IceBridge snow radar system, measured in situ, and predicted by global climate models. Snow depth is a critical auxiliary input for converting ICESat-2 measurements of sea ice freeboard to basin-scale estimates of sea ice thickness.

The PI is an expert in laser altimetry, sea ice science, geodesy, altimetric theory and the application of appropriate geophysical corrections for accurate range measurements. To successfully carry out her role as an SDT member, Dr. Farrell will draw upon her experience working with altimetric measurements from other NASA missions (e.g. ICESat, IceBridge and MABEL) and interpretation of the results in the context of other remote sensing datasets. As a member of the previous SDT team, Dr. Farrell is actively involved in the development of algorithms to process ICESat-2 data and generate higher-level products. She will provide guidance on the cal/val activities most appropriate for the assessment of the accuracy and precision of ICESat-2 measurements of the sea ice

pack. The PI's expertise is based on her recent experiences conducting cal/val activities for the IceBridge, MABEL, ESA CryoVex (CryoSat-2) and NRL DISTANCE programs. The PI also currently serves as a member of the NASA Operation IceBridge science team and will facilitate coordination between the two missions.

Stephen Palm/Science Systems And Applications, Incorporated
The Atmospheric Measurements of ICESat-2: Opportunities for Atmospheric Science and an Aid to Mission Success

The ICESat-2 mission is primarily an altimetry mission to study the changes in ice, snow and biomass. It will, however, also obtain profiles of atmospheric backscatter from 14 km to the ground. The main purpose of these data will be to characterize the atmosphere to support the analysis and interpretation of altimetry data. While it is recognized that various attributes of the main instrument aboard ICESat-2 (ATLAS) produce certain limitations on the atmospheric data, it will still provide useful in a number of atmospheric research areas. This proposal seeks to identify those areas and demonstrate that even though ICESat-2 is not an atmospheric mission, it will still provide important and meaningful data that will benefit atmospheric science research in areas such as: 1) Polar clouds and aerosol, 2)Global cloud frequency, 3) Aerosol and thin cloud optical depth, 4) Blowing snow studies. In addition to the value of ICESat-2 data for atmospheric science, this proposal will show the various areas where the atmospheric data can complement and aid the main objective of the mission: accurate measurement of surface elevation. We will also demonstrate the unique qualifications of our team to provide the ICESat-2 project with scientific feedback on overall mission planning and development of higher level products, ATBD and algorithm development/testing, and calibration and validation plans as the mission transitions to its operational phase.

Michael Jasinski/Goddard Space Flight Center
Science Definition, Planning and Vision for ICESat2 Inland Hydrology

Arctic and Subarctic hydrologic processes play a critical but poorly understood role in climate change dynamics. Important unknowns are the impact of climate warming on terrestrial surface water fluxes and stores, altered snow and freshwater discharge to the Arctic, and thawing of permafrost and other ground ice. Hydrologic science can both benefit from and be a benefit to ices sheet and sea ice requirements for ICESat-2 science.

Participation on the ICESat-2 Science Definition Team (SDT) is proposed, focusing on the hydrology of the terrestrial Arctic and Subarctic (>50deg latitude), and also relevant mid latitude cold climate regions. The overall objective is to support the further planning and design of the ICESat-2 mission in its primary goal of observing ice, sea ice, and carbon stock assessment, while advocating for hydrology and its linkage to Arctic and Subarctic climate variability. The goal is to work, in close collaboration with other SDT members, and the greater external hydrologic community on prioritization of science goals, measurement requirements and accuracies, guidance for calibration and validation including recommendations for field sites, prelaunch studies, definition of data products, development and testing of algorithms and documentation. The PI will leverage off other

ongoing projects, and liaise with other members of the Arctic and Subarctic hydrology community and satellite altimetry community.

Lori Magruder/University of Texas, Austin
Calibration and Validation Strategic Planning for the ICESat-2 Mission

NASA has identified a need for a laser ranging expert in the area of calibration on the next ICESat-2 Science Definition team to develop optimal plans for the mission data product validation and perform the necessary pre-launch studies to meet the science objectives. This proposal is to support my selection as this needed individual based on my experience with cal/val efforts in the past on ICESat as well as current research associated with performance evaluation for several diverse airborne lidar systems. I have expertise in photon counting systems, laser instrumentation and data processing which will bring comprehensive solutions to the ICESat-2 project in terms of the design and development of techniques that will satisfy questions associated with the mission data product accuracies. Beyond using typical approaches, I can also facilitate access to many unique resources (e.g. data sets) for use in the cal/val effort and data uncertainty determinations through my research collaborations with government lidar programs. This proposal reviews my technical and scientific experience providing strong support for me as a member of the next SDT. In addition, based on my past leadership opportunities and current management capabilities I feel that I am also poised to be placed into the role of SDT leader.

Amy Neuenschwander/University of Texas, Austin
Assessment of ICESat-2 Data and Data Products for Terrestrial Ecosystems

The purpose of this proposal is to continue to serve on the science definition team for the ICESat- 2 mission. During the two first phases of the ICESat-2 Science Definition Team (2008 - 2014), the PI has assumed the leadership role for the terrestrial land/vegetation working group. Responsibilities in this role include the analysis and compilation of results from individual SDT members ground/canopy surface finding experiments, developed an off-nadir pointing plan for the spatial densification of ICESat-2 measurements over terrestrial ecosystems, provided guidance for MABEL acquisition targets, developed and assembled land/vegetation data product list and definitions, coordinated the writing of the algorithm theoretical basis document, interacted with the ICESat-2 applications working group to engage interest and users for the ICESat-2 data products, and coordinated with ICESat-2 project engineers/management on a variety of mission specific tasks. During this phase, the PI will continue to develop the ATBD as well as to develop uncertainty estimates for the ATL08 data products for a variety of ecosystems (i.e. tropical forest and savannas) using simulated ICESat-2 data (e.g. mATLAS or waveform derived simulated data). The uncertainty metrics from the simulated data will be calculated for fixed (i.e. 30, 50, 60, 90, and 100 m) and variable (i.e. 100, 250, 300, signal photons) segment sizes for minimizing the canopy height error yet maintaining sufficient detail to capture the heterogeneity on the landscape.