PARCA 2013
Tuesday, January 29
8:30 AM - 5:00 PM
GSFC Building 33, Room H114

08:30 **Welcome: Logistics**
Tom Neumann, Goddard Space Flight Center

08:45 **View from Headquarters**
Jack Kaye/Thomas Wagner, NASA Headquarters

09:15 **Transforming PARCA**
Charles Webb, NASA Headquarters

09:30 **A Retrospective Report for the Ice-sheet Mass Balance Inter-comparison Exercise (IMBIE) of 2011-2012**
Erik Ivins, Jet Propulsion Laboratory

The Ice sheet Mass Balance Inter-comparison Exercise IMBIE was formed as a collaborative effort among 23 different academic and government research institutions with the goal of reassessing the mass balance of the Greenland and Antarctic ice sheets during the period of space observations (1991-2011). This work was prompted by the need for clarity on the issue of ice sheet mass balance. This is particularly important for preparation of the AR5 Report for the IPCC. Disparities in the contrasting reports of what space observations have revealed about ice sheet contribution to sea-level change leaves both the glaciological and sea level change communities vulnerable to unnecessary attack. The plan, jointly set by ESA and NASA, was to ensure that the primary researchers that have produced and published ice mass balance results step forward to conduct a series of formal experiments in a short period of time (about 6-7 months). The project was broken down into 6 main areas: radar altimetry (RA), input-output method (IOM), space gravimetry (SG) (exclusively from the Gravity Recovery and Climate Experiment mission data), laser altimetry (LA) (exclusively from the Ice, Cloud and Land Elevation Satellite mission data), and from new data and models of glacial isostatic adjustment (GIA). The IOM technique required retrospective experiments to be conducted in two areas: input (accumulation) and output (net melting, calving and outlet glacier flux).

The main theme that emerged was that the method of conducting the careful and community-wide experiments was overwhelmingly valuable and illuminating. This is true even when the end result continued to show disparities in either the intra- of inter-comparisons. In this talk I will try to summarize the main quantitative results that are now reported in the recent Shepherd et al. Science 338 Nov 30 2012 article. A discussion of how these results may form a baseline for future studies of ice sheets, glaciers and ice caps and se level rise will also be discussed.

09:45 **Glacier Contributions to Sea Level Rise: 2003-2009**
Alex Gardner, Clark University

Mass wasting of glaciers outside of the ice sheets contributes greatly to present rates of sea level rise. There is however a large disagreement between recent global estimates derived from satellite gravimetry (Jacob et al., 2012) and those derived from the interpolation of local-scale mass balance and geodetic measurements (Cogley et al, 2009). Adding to this uncertainty are poorly constrained estimates of mass changes of the peripheral glaciers surrounding the Greenland and Antarctic Ice Sheets. Here we compare alternative estimates of regional glacier mass changes for 19 glacierized regions and derive a new global estimate from GRACE and estimates for the peripheral glaciers of Greenland and Antarctica using ICESat. We identify uncertainties and potential biases in existing global assessments and show how the large gap between them can be narrowed by combining results from the best available techniques in each glacier region.

10:00 **Results from the Greenland Ice Mapping Project**
Ian Joughin, University of Washington

Ice sheets were once thought to evolve slowly over centuries in response to climate change. Recent results by many authors, however, have shown that glaciers in both Greenland and Antarctica can alter their flow abruptly over periods of months or less. To better understand this variability we have begun a series of regular mappings of the Greenland Ice Sheet using data from a variety of sensors, including RADARSAT, ALOS, TerraSAR-X, ASTER, and LANDSAT ETM. With a more than decade long record of variability, we are beginning to analyze the changes in more than 200 outlet glaciers. Across the population of Greenland's outlet glaciers, there is a trend toward increasing speed and discharge, but with a remarkable degree of variability. In some cases where two glacier drain through the same fjord, presumably undergoing similar environmental forcing, one glacier may speed up markedly, whereas its neighboring glacier may remain unchanged, or even slow down. While researchers using satellite data are making huge strides in characterizing glacier variability, much work is still is needed analyze these data in an effort to understand the processes controlling such change. Because of poor knowledge of the processes controlling fast glacier flow, the 4th IPCC to concluded they could place no reasonable upper bound on the contribution to sea level from unstable ice dynamics in Greenland an Antarctica. Considerable uncertainly likely will remain in the upcoming IPCC assessment.

Jakobshavn Isbrae, the largest glacier on Greenland's west coast, has undergone some of the largest changes of any glacier in the world, more than doubling it speed since the late 1990s. It continues to flow at accelerated rates, but with a marked degree of seasonal variability in flow speed. In addition to spaceborne measurements, NASA has surveyed this glacier nearly annually with airborne LIDAR and ice-penetrating radar. We have been using these data to better constrain models in an effort to understand the processes controlling fast flow. Our results suggest that the bed is relatively weak in the fast flowing areas, with much of the driving stress resisted by the margins. Much of the seasonal variability near the terminus can be explained by seasonal changes in the terminus position, which in turn appear to be largely governed by the seasonal variation of the sikkusak (mélange of icebergs bonded by sea ice) in the fjord. The speedup was likely initiated by the loss of buttressing from the retreat of grounded and floating ice, but cannot account for the full magnitude of the speedup. Instead the early, at first moderate, speedup likely triggered positive feedbacks that account for much of the subsequent speedup.

10:15 PSTG Coordinated SAR Data Collection in Polar Regions: An Update
Bernd Scheuchl, University of California Irvine

The Polar Space Task Group (PSTG) is succeeding the IPY coordinating body of international Space Agencies, Space Task Group (STG). The PSTG SAR Coordination Working Group was created to address the issue of SAR data acquisitions of the cryosphere in response to user requirements from the science community. Ice sheets is the application area selected for focused discussion during a meeting in November. We will present science and data requirements, give sensor specific recommendations and provide an update on ongoing efforts to collect SAR data in Greenland and Antarctica.

10:30 BREAK

10:50 The SUrface Mass balance and snow on sea ice working groUP (SUMup)
Lora Koenig, Goddard Space Flight Center

The Surface Mass Balance and Snow on Sea Ice Working Group (SUMup) is leading NASA's effort to improve spatial and temporal estimates of surface mass balance on ice sheets and snow accumulation on sea ice. SUMup was convened at the direction of the NASA Cryospheric Sciences Program to assess current satellite algorithms, regional models, and measurements to recommend future directions for improving calculations of surface mass balance over the ice sheets and snow accumulation on sea ice. Improving our measurement and modeling of surface processes such as accumulation, redistribution of snow and melt are required to accurately determine future changes in both land ice and sea ice.

11:05 Operation IceBridge Arctic Activities and Data Products
Michael Studinger, Goddard Space Flight Center

NASA's Operation IceBridge images Earth's polar ice in unprecedented detail to better understand processes that connect the polar regions with the global climate system. Operation IceBridge utilizes a highly specialized fleet of research aircraft and the most sophisticated suite of innovative science instruments ever assembled to characterize annual changes in thickness of sea ice, glaciers, and ice sheets. In addition, Operation IceBridge collects critical data used 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. The presentation will summarize the data collected in previous campaigns over the Greenland Ice Sheet, the Canadian Arctic and the Arctic Ocean and will also give an overview of available IceBridge data products at NSIDC.

11:15 Integrated Elevation Change Estimates for the Greenland Ice Sheet
Ben Smith, University of Washington

Laser-altimetry elevations have been measured since the early nineties across Greenland, sometimes on lines that have been sampled regularly, sometimes on lines that have been measured once. More recently, photogrammetric and radar DEMs have become available that give elevations over areas tens of km wide. The altimetry data offer high precision, but irregular spatial coverage, while the DEMs offer good spatial coverage, but with substantial per-pixel and per-DEM errors that must be corrected before the DEMs can be used to calculate elevation changes. In this talk, I present a technique for combining these types of data into self-consistent maps of elevation change, and discuss the best practices that this technique suggests for collecting altimetry and photogrammetric data.

11:30 10 Years of GRACE Data: What Have We Learned?
Isabella Velicogna, University of California Irvine

The GRACE gravity mission has provided more than 10 years of monthly time variable gravity data from Apr 2012 to Sep 2012. During this time we have significantly improved our understanding the various error sources affecting the GRACE signal and their impact on uncertainties in ice sheet mass balance. These errors include spherical harmonic truncation, spatial averaging, temporal averaging, and leakage from other time-dependent gravity signals. We quantify the impact of these errors on ice sheet mass balance. As a result of this improvement, we have higher confidence in the GRACE estimates. Among the unique contributions from GRACE are the detection of an increase in mass loss in the northwest of Greenland after 2006 and the spreading of the mass loss in the northeast in more recent years. In 2012, Greenland experienced a record melt year and using GRACE we determine a 700 Gt mass loss from January 2012 to September 2012, which is more than twice larger than on a "normal" year. Combination of

GRACE time series with time series of elevation change from ICESat and Operation IceBridge (OIB) altimetry and time series of surface mass balance from RACMO unable improved characterization of the physical processes that are driving the observations. For instance based on the comparison between these three datasets, we quantify the impact of surface mass balance on the GRACE signal and identify the relative importance of surface mass balance on the total mass change, we evaluate the performance of different GIA models to reduce uncertainties in GIA correction and we identify shortcomings in surface mass balance reconstruction in some sectors of Greenland.

11:45 Land Ice Evolution from a GRACE Global Mascon Solution
Scott Luthcke, Goddard Space Flight Center

Land ice mass evolution is determined from a new GRACE global mascon solution. The solution is estimated directly from the reduction of the inter-satellite K-band range rate observations taking into account the full noise covariance, and formally iterating the solution. The new solution increases signal recovery while reducing the GRACE KBRR observation residuals. The mascons are estimated with 10-day and 1-arc-degree equal area sampling, applying anisotropic constraints for enhanced temporal and spatial resolution of the recovered land ice signal. The details of the solution are presented including error and resolution analysis.

12:00 Moderated Group Discussion: Synthesizing Knowledge about the Arctic

- Do we, as scientists, need any synthesis efforts? Is there a role for PARCA?
- Who are our audiences?
- What should be the focus: sea-level rise, ice-sheet dynamics and mass balance, ice-ocean-atmosphere interactions, or climate impacts?
- How do we consolidate, represent and store the information we have about the Arctic?
- What is needed to make this information useful and accessible to other scientific communities, government agencies and policymakers?

12:20 LUNCH

01:20 The Rapid Ice Sheet Change Observatory (RISCO): Bringing You to Useable Data Faster
Ian Howat, Ohio State University

The Rapid Ice Sheet Change Observatory (RISCO) compiles, processes, analyzes, and distributes diverse datasets, including submeter satellite imagery and m Operation IceBridge data, in a uniform format and spatial reference, with the purpose of maximizing data accessibility. The RapidIce Viewer provides a web portal to RISCO's data inventory, allowing for immediate viewing and download of over a decade of data from a growing number of sensors for rapidly-changing areas of Greenland and Antarctica. I will provide an overview of RISCO's operations and the RapidIce Viewer's functionality, as well as plans for continued development.

01:35 The Sub-meter Resolution Arctic
Paul Morin, University of Minnesota

Near full sub-meter optical imagery coverage of the arctic is now available to U.S. federally-funded researchers in a number of ways including raw NTF format, a web-based mapping application/viewer, OGC-compliant web services, as well as orthorectified scenes and mosaics. Approximately 50% of the entire Arctic has been imaged in stereo including Greenland's ablation zone and coastal Alaska. Future imagery tasking will concentrate on completing stereo, repeat coverage for areas of high scientific interest, and imaging areas at different times of the year. Tasking requirements are requested from the research community.

01:50 Ice-Ocean Interactions in Greenland
Eric Rignot, University of California Irvine

Unlike Antarctica, Greenland is not surrounded by ice shelves and floating ice tongues, except in the north, yet ice-ocean interactions are important to Greenland glaciers, perhaps as much as in Antarctica. Recent studies have revealed that melt rates along the calving faces of Greenland tidewater glaciers are orders of magnitude greater than on ice shelves and are comparable to iceberg calving as a process of mass release to the ocean. Moreover, many studies have converged to suggest that ocean warming plays a central role in the evolution of Greenland glaciers. Here we review progress in estimating melt rates both in situ and using models, their sensitivity to forcings (subglacial runoff and thermal forcing from the ocean), and the current challenges of understanding these interactions, including uncertainties in climate forcings at the fjord scale, uncertainties in the shape of fjord cavities, glacier ice thickness, and local ocean conditions. We also present new data revealing the geometry of the glacier face below the water line and how it relates to ice-ocean interactions and ice melting in seawater. We will conclude with a perspective on ongoing work in Greenland in Uummannaq and other sectors based on field surveys and numerical ocean modeling.

02:05 Physical Controls on Ocean-Terminating Glacier Variability in Central West Greenland
Ginny Catania, University of Texas at Austin

Greenland's mass balance is largely modulated by the changing dynamics of marine-terminating glaciers; however, there is currently no consensus as to what factors control this variability due to the lack of coincident ice-ocean-atmosphere data. In order to refine sea-level rise projections, a process-based understanding of the interactions between outlet glacier, atmosphere and ocean dynamics is necessary. In central west Greenland, adjacent marine-terminating glaciers exhibit contrasting temporal changes in ice speed, terminus position, melange properties and mass flux. We propose a detailed investigation of these interconnected processes using a variety of datasets: detailed in-situ ice, ocean and atmospheric measurements; ongoing airborne data collected through NASA's Operation IceBridge campaign; and archival and current remote sensing and climate reconstructions. With the help of coupled numerical models to refine interpretation, these data will be used to identify the processes that control individual glacier variability. We anticipate our findings to be scalable - that is, they will help to understand, interpret, and predict mass balance and associated coupled dynamics for other ocean-terminating glaciers using historical and modern remote-sensing observations.

02:20 **The Evolution of the Retreat of Jakobshavns Isbrae: Factors Maintaining an Unstable Tidewater Terminus and Eventual Impact on Ice Sheet Flow**
Mark Fahnestock, University of Alaska Fairbanks

Since it's initial acceleration and retreat in the late 1990s, Jakobshavns has continued to thin and accelerate. Its seasonal patterns of flow have changed markedly in the last two years as its terminus has retreated to new minimum positions and calving behavior has changed. Recent observations show a tight connection between calving and changing ice flow in the lower glacier, as well as large changes in ice flow outside the main channel as the drawdown continues. Changes at the ice front have propagated inland relatively quickly, and we now have measurements of a significant increase in ice flow at 1800 m elevation, well into the ice sheet interior. These changes are accompanied by changing basal conditions as indicated by model inversions, suggesting that a stable terminus configuration will not be reached in the near future. The complete package of available measurements has allowed the character of the retreat to be captured to date, but understanding future evolution depends on our ability to anticipate changing ice flow into the stream.

02:35 **Investigation of Inland Propagation of the Greenland Marginal Thinning**
Weili Wang, Goddard Space Flight Center

Recent studies have shown that the dynamic propagation penetrates deep into the interior ice sheet on decadal timescales and that the strong mass loss since the early 2000s at the margins has had a dynamic impact on the entire Greenland ice sheet. This research project will aim at the investigation to the upstream migration trend of ice thinning along a flow line from terminus to divide in Greenland ice sheet. The ice flow model (AIF model) is applied with the combination of various observed data, e.g. thickness change from ICESat and ERS, Radio-Echo Sounding internal layers, velocities. The study will provide the suggestions for OIB to make the next set of observations.

02:50 **Submarine Melt Rates for Outlet Glaciers in Greenland**
Ellyn Enderlin, Ohio State University

The rate of mass loss from the Greenland Ice Sheet has increased over the past decade due, in large part, to changes in the dynamics of marine-terminating outlet glaciers. These changes are attributed to increased submarine melt rates of floating ice tongues and submerged calving faces resulting from increased coastal ocean heat transport. We use remotely-sensed data to calculate submarine melt rates for 13 marine-terminating outlet glaciers in Greenland on a semi-annual basis between 2000 and 2010. Over the period of study, average melt rates ranged from 0.03 to 2.98 m d-1 and account for 5 to 85% of the total volume loss from the floating ice tongue, with no clear spatial pattern. Only four glaciers show substantial inter-annual variability in melt rate during the decade. Melt rates were uncorrelated with front retreat, speed, and changes in ocean temperature. Although the small sample size limits our analysis of the relationship between oceanographic forcing and glacier response, these data suggest that changes in ice discharge vary with the calving rate, but are independent of submarine melt rates. This dataset provides first-order estimates of an important but otherwise un-quantified component of the glacier mass balance, which must be further constrained with a combination of glacier and ocean observations.

03:05 **Moderated Group Discussion: Expanding Our Collaborations**

• What other scientific communities are key to expanding our understanding of the changes taking place in the Arctic?
• What communities can most benefit from the information that we develop?
• How do we reach out to those communities?
• What are the most effective vehicles for encouraging and sustaining cross-disciplinary collaborations?
• With regard to modeling, are we as well integrated as we need to be? Do modelers have the information that they need from us? Are models helping us design observational strategies and hypotheses to test?

03:25 **BREAK**

03:45 **Climate and Sea Ice Interactions in the Record Sea Ice Decline of 2012**
Ted Scambos, National Snow and Ice Data Center

Arctic sea ice extent and volume set new record lows in September of 2012. Analysis of passive microwave data, MODIS images, ocean surface temperatures and weather patterns show several important links to the pattern of the ice decline. Even at the winter maximum, sea ice extent was very low in the northern North Atlantic. Early in the melt season, northern hemisphere snow cover set a satellite-era record low extent. Surface melt onset on the sea ice was 9 to 12 days earlier, reducing the albedo of most of the western Arctic well before solstice. While several air circulation patterns came and went, on average a pattern similar to the 'Arctic Dipole' of recent summers dominated 2012. A strong summer cyclone in early August contributed significantly to ice loss, but was not the cause of the record low extents seen by late August and early September. On September 16, NSIDC reported a minimum ice extent of 3.41 million square km, far surpassing the previous record of 2007 (4.17 M square km). Emerging, somewhat repetitive climate patterns associated with the very low ice extents since 2002 suggest that fundamental changes are underway in the Arctic ice-ocean-atmosphere system.

04:00 Arctic Sea Ice Drift Speed and Ice Thickness
Ron Kwok, Jet Prpulsion Laboratory

We highlight the trends in Arctic sea ice circulation and drift speed between 1982-2009 in connection to local winds, multiyear sea ice coverage, and the thinning of the ice cover. The 28-year circulation trend shows a strengthening of the Beaufort Gyre and the Transpolar Drift that is more significant during the summer. Positive trends in drift speed between 2001 and 2009 are found in regions where multiyear sea ice has been replaced by a thinner seasonal ice cover. In a linear model, the multiplier that relates ice motion to wind shows distinct seasonal, decadal, and geographic variability consistent with a thinner, weaker ice cover. This suggests a change in the relationship between wind and ice motion, and changes in air-ice momentum exchanges on a broad scale.

04:15 Using Combined Records of IceBridge and Satellite-Derived Thickness and Extent Data to Constrain Future Projections of Arctic Sea Ice
Julienne Stroeve, University of Colorado at Boulder

Confidence in climate models to provide reliable projections of future climate is largely built on how well they can reproduce observed features of recent climate. Although all models participating in the 5th Phase of the Coupled Model Intercomparison Project (CMIP5) show declining Arctic sea ice over the period of observations, trends from most models remain smaller than observed. The ability of climate models to capture the observed variability in the sea ice extent depends in part on how well they are able to simulate the observed sea ice thickness distribution, since models with an overly thick initial ice cover tend to lose their summer ice cover later than models with initially thinner ice given the same climatic forcing. While long-term, basin-wide sea ice thickness data are not available for the Arctic Ocean, a combination of satellite data from ERS1/2, ICESat, and Cryosat, together with sea ice thicknesses derived from data from NASA's Operation IceBridge, provide a record of the evolution of ice thickness across the Arctic from the early 1990s to present. Submarine sonar data are used to extend the record further back in time but coverage is more limited. This data illustrates that the thickest ice is found north of the Canadian Archipelago, with thinner ice along the Eurasian side of the Arctic.

We use the combined records of satellite- and air-borne sea ice thickness data from the early 1990s to present to evaluate how well CMIP5 models capture the spatial distribution of the mean winter ice thickness fields and how this relates to the observed summer trends in sea ice extent. Performance metrics are developed for models representations of observed sea ice extent and thickness. Metrics are used as a basis for conditioning probabalistic predictions of sea ice cover in the Arctic. Three approaches are used for conditioning predictions; 1) a selection of a subset of best performing models based on thickness and extent metrics; 2) a weighting of all models, both good and bad performers, based on performance metrics; and 3) a baseline case in which all models are selected and given an equal weighting.

04:30 Towards an Improved System for Seasonal Arctic Sea Ice Forecasting
Nathan Kurtz, NASA Goddard Space Flight Center

Seasonal forecasting of Arctic sea ice extent is increasingly being seen as an area of critical importance for a wide variety of communities. Despite advances in observing systems and networks for communicating information on sea ice properties, no single forecasting system or method has shown sufficient skill to consistently forecast Arctic sea ice coverage, in particular the record low minimum seen in 2012. Reasons for the current lack of predictive capabilities are complex and manifold, but exploration of known deficiencies in the forecast system can give insight to where improvements can be made. Here we summarize known deficiencies in data observations and numerical modeling methods with an eye towards determining where identification and mitigation of the major deficiencies is possible using available resources. We focus mainly on our experience on the Operation IceBridge project and use of the 'quick look' sea ice data products for seasonal sea ice forecasting. Lastly, we discuss the challenges for cooperation between observational and modeling communities with a goal to move towards a forecasting system which synthesizes observational and model data to produce the next generation of sea ice forecasts.

04:45 In Memoriam: Seymour Laxon
H. Jay Zwally, Goddard Space Flight Center

05:30 POSTER SESSION & COCKTAIL HOUR (GSFC RECREATIONAL CENTER)

06:30 DINNER (GSFC RECREATIONAL CENTER)

POSTER SESSION
Tuesday, January 29
5:30 - 6:30 PM
GSFC Recreational Center

Greenland ice sheet snowline from MODIS and PROMICE observations
Jason Box, Ohio State University

We produce a Greenland ice sheet snowline product based on NASA Moderate Resolution Imaging Spectroradiometer (MODIS) optical retrievals calibrated and validated using Geologic Survey of Denmark and Greenland (GEUS) ground observations from The Programme for Monitoring of the Greenland Ice Sheet (PROMICE) automatic weather station data (http://promice.dk/about_us_uk/main.html). A test version of the data product is available at http://bprc.osu.edu/wiki/Greenland_Ice_Sheet_Snowline.

Sensitivity of a dynamical ice sheet model to the spatial resolution of boundary conditions
Richard Cullather, Goddard Space Flight Center

Dynamical ice sheet models (ISMs) have been developed in recent years to address well-known limitations in eustatic change prediction capabilities. Two primary inputs to ISMs are surface mass balance (SMB) and surface heat flux or temperature fields. Grids used in finite element ISMs may be highly refined for resolving complex ice flow features. In given locations, element edge lengths may be a few km or less, while input fields from assimilated observations and atmospheric general circulation models (AGCMs) typically have grid spacings on the order of 10s to 100s of km. Statistical and dynamical downscaling methods have been and continue to be developed to address this spatial disparity. For this study we seek to understand the spatial resolutions required for ISM simulations.

In a set of experiments, a transient solution is obtained from an ISM for a contemporary Greenland Ice Sheet (GIS) domain that has been forced with SeaRISE 5km grid-spaced boundary conditions. The model is then run using SMB and temperature fields that have been coarsened using a spatial filter at successive length scales. The ISM used is the Ice Sheet System Model (ISSM) from NASA Jet Propulsion Laboratory and Univ. California at Irvine. ISSM is integrated for 100 years on a GIS domain. The SMB and temperature fields are coarsened at 20km length scale increments, up to 205km. The separate and combined effects of SMB and temperature resolution are assessed. In preliminary results using the MacAyeal ice flow approximation, the coarsening of both input fields to 205km resolution results in a GIS volume discrepancy that is equivalent to 5 times the standard deviation of the ice volume over the length of the integration. Simulated total volume is more sensitive to the resolution of SMB than surface temperature. At higher spatial scales, differences in ice thickness and velocity vary over the ice sheet. Additional results are evaluated with dynamically-scaled input fields obtained from the Goddard Earth Observing System model, version 5 (GEOS-5) run at two spatial resolutions.

Some questions of interest to be addressed by this study are as follows.
- What is the influence of SMB and temperature spatial resolution on GIS volume and ice velocity?
- Which ice flow approximation is more sensitive to boundary condition spatial resolution?

Spatial and temporal variability of the percolation zone of the Greenland Ice Sheet during the period of 2004-2012: Implications for radar altimetry observations.
Santiago de la Pena, Ohio State University

Launched in April 2010, CryoSat-2 is the first satellite mission of the European Space Agency's (ESA) Earth Opportunity Programme. CryoSat-2 main payload SIRAL, is a Ku-Band radar altimeter system. The mission primary objective is to measure ice sheet elevation and sea ice thickness with unprecedented accuracy with the aim of improving our understanding of the dynamics of the cryosphere. For that purpose, an extensive validation experiment was launched over the Arctic during the spring of 2011, which included a field and airborne campaign over the western slope of the Greenland Ice Sheet (GrIS) to study the current state of the percolation zone, and to assess Ku-band radar response to percolation facies. The processing of radar altimetry data over the margins of the GrIS is particularly challenging since the heterogeneous composition of the snowpack in these regions, caused by melting and refreezing patterns and a high snow accumulation rate, makes retracking of the ice sheet surface from radar altimetry signals difficult.

Here we present results from the 2011 CryoSat Validation Experiment (CryoVEx) campaign over the Greenland interior. The objective of the campaign was to characterize near-surface snow structure and microwave radar signatures across a wide elevation range along the EGIG line in the western slope of the Greenland Ice Sheet. For the first time, it was possible to obtain ground-based radar measurements and near-simultaneous airborne and satellite radar altimetry observations. The area of study includes a wide variety of snow facies covering the transition from the percolation zone into the dry snow zone. Additionally, it was possible to assess the current state of this region, obtain surface elevation estimates derived from SIRAL, and identify changes that have occurred in the percolation zone over the last decade by comparing with previous studies made in the CryoVEx campaigns of the years of 2004 and 2006.

Ocean heat and Greenland's glaciers: Model simulations and in-situ observations
Ian Fenty, Jet Propulsion Laboratory

One factor driving Greenland ice sheet mass loss may be anomalous melting at marine terminating glaciers, glaciers whose termini are partially submerged in seawater. Enhanced melting at glacial termini may caused by an increase in the temperatures of the relatively warm, subtropical-origin waters found between 200-400 m. Here, we (1) examine the pattern of spreading of these warm waters around Greenland for the years 1992-2009 using a high resolution (4-km horizontal grid) coupled ocean and sea ice simulation and (2) report ocean and seafloor measurements taking during a 2012 cruise to several fjords with marine terminating glaciers in West Greenland. Both model and in situ observations show that detailed knowledge of the seafloor and repeat in-situ hydrographic observations of these fjords is required to understand and predict ice sheet mass loss.

Updating the locations of mass loss from the Greenland ice sheet using GRACE
Christopher Harig, Princeton University

We present an update to our Greenland mass loss estimates from GRACE, using Slepian basis functions. We continue our recently published results (Harig and Simons, PNAS 2012) up to April 2012 for Release 4 data, and compare to the Release 5 data which continues further into 2012 (currently September). The new results compare well with other observations that recent years have had record amounts of mass loss from Greenland. We will also generally discuss our new method of working with GRACE Level 1b data, in the hopes of increasing the spatial sensitivity we can extract from GRACE.

Changes in ice-surface roughness and implications for changes in glacier dynamics and morphogenesis: Applications of ICESat, MABEL and IceBridge data analysis
Ute Herzfeld, University of Colorado at Boulder

The objective of this poster is to demonstrate applications of recently collected altimeter data in understanding complex cryospheric change processes. The Multiple Altimeter Beam Experimental Lidar (MABEL) is an airborne predecessor of the photon-counting six-beam laser altimeter that will be carried on ICESat-2 (expected launch 2016). First data over ice surfaces were collected in April 2012 using NASA's high-altitude aircraft ER-2. Transects sample Jakobshavn Isbrae in Greenland and Pine Island Glacier in Antarctica. We develop and apply mathematical algorithms for surface detection and retrieval of elevation from MABEL data, then derive roughness characteristics of the ice surface. For Jakobshavn Isbrae, changes in roughness characteristics, based on ICESat, IceBridge and MABEL data analysis, allow new insights in the causes of acceleration and surface lowering in recent years.

Surge of Bering Glacier and Bagley Ice Field: Parameterization of surge characteristics based on automated analysis of crevasse image data and laser altimeter data
Ute Herzfeld, University of Colorado at Boulder

The dynamical processes that occur during the surge of a large, complex glacier system are far from being understood. The aim of this paper is to derive a parameterization of surge characteristics that captures the principles processes and can serve as the basis for a dynamic surge model. Innovative mathematical methods are introduced that facilitate derivation of such a parameterization from remote sensing observations. Methods include automated geostatistical characterization and connectionist-geostatistical classification of dynamic provinces and deformation states, using the vehicle of crevasse patterns. These methods are applied to analyze satellite and airborne image and laser altimeter data collected during the current surge of Bering Glacier and Bagley Ice Field, Alaska.

Altimetry validation at Summit, Greenland
Eric Lutz, Dartmouth College

Operation IceBridge has collected extensive remote sensing data of sea ice and terrestrial ice sheets and glaciers over the past 3 years. A primary IceBridge science objective is to acquire elevation information of these rapidly changing environments during the interim period between IceSat and IceSat-2. We characterize the accuracy of surface elevation products from IceBridge's ATM and LVIS instruments (l1b and l2 respectively) and initial data from MABEL in a field validation study along IceSat Track 412 near Summit, Greenland. We compare these data with contemporaneous along- and cross-track surface-based DGPS measurements to identify potential errors.

Evaluating airborne radar stratigraphy in Greenland: do we see annual layers?
Brooke Medley, University of Washington

Recent spatio-temporal ice-sheet accumulation rates can be calculated by tracking near-surface internal radar reflections over hundreds of kilometers. Unlike ice-core accumulation studies that provide a record at a single location and suffer from the impact of small-scale variability, the radar technique provides accumulation records over large distances. Recently, the Center for Remote Sensing of Ice Sheets (CReSIS) developed an ultra-wideband airborne radar, referred to as snow radar, with bandwidth sufficient to resolve near-surface annual layers. Typically, radar accumulation studies require the survey to intersect an ice-core site in order to date the internal horizons. However, if the reflections are annually spaced, the need for independent ice-core glaciochemical analysis is eliminated. Annual spacing was found over Thwaites Glacier, West Antarctica, and we were able to generate 30-year records of accumulation over nearly 1600 km of the flight surveys. It is likely possible that the same method can be applied in Greenland. Here we will briefly show the methods and results from our work in West Antarctica as well as an assessment of the Greenland snow radar data by applying what we learned in Antarctica.

Radar sounding of temperate ice masses in southeastern coastal Alaska
Jeremie Mouginot, University of California Irvine

We developed a low frequency (2.5 MHz) radar for the sounding of temperate ice masses that circumvents the limitations of higher-frequency radars. The Warm Ice Sounding Explorer (WISE) was flown in Alaska in October 2008 and March 2012 to yield the first comprehensive, GPS-tagged, precise measurements of ice thickness over major glaciers and icefields in the Southeastern coast of Alaska (Hubbard, Columbia, Bering, Malaspina). Application of this radar sounder to other temperate glaciers in Alaska or temperate ice masses elsewhere as Southern Greenland will yield significant change in our knowledge of ice thickness in these regions, which in turn is critical to understand glacier dynamics, its contribution to sea level change, and projections of its evolution in a warming climate.

Elevation change and mass balance estimates of Alaska glaciers from airborne LiDAR surveys
Nate Murphy, University of Alaska Fairbanks

We present recent results and updated analyses from the UAF airborne LiDAR campaign. Since 1994, the UAF campaign has measured the surface elevation changes of glaciers throughout Alaska and NW Canada. The results presented here include elevation changes of glaciers in Denali National Park and the Juneau Icefield. We also discuss recent and future developments in the analysis techniques used to derive volume changes and mass balances from the LiDAR data.

Relationships between fjord bathymetries and recent tidewater glacier behavior in Greenland
David Porter, Columbia University

The geometry of glacial fjords may play a large role in determining the stability of outlet glaciers. Sloping seafloors will feedback on a moving grounding line and shallow sills and deep continental shelf troughs will allow greater interaction with the surrounding ocean water. New estimates of fjord bathymetries in Greenland, using airborne gravimetry measurements from Operation IceBridge flights, are compared to several important characteristics of their outlet glaciers and ocean waters. We investigate the importance of glacier parameters such as surface velocity and elevation changes on recent changes in glacier behavior. Are faster flowing glaciers found in fjords with deep sills and a greater exchange with continental shelf water? These broad correlations are a starting point in an effort to investigate the role of bed geometry in the variability of observed recent changes in some of Greenland's largest outlet glaciers.

Iceberg coverage in the Bellingshausen-Amundsen Seas from 2010 NASA IceBridge DMS Imagery
David Prado, University of Texas San Antonio

Iceberg distribution in the Bellingshause–Amundsen Seas has not been well studied due to a limited number of ship based observations and limited temporal coverage of active microwave satellite systems. While Synthetic Aperture Radar satellite coverage has greatly increased the ability to detect medium to large icebergs in the Southern Oceans, small icebergs and bergy bits are still problematic to resolve from space. Digital Mapping System (DMS) imagery from the 2010-10-30 flight line show 0.06% of the total coverage area (1085 square km) to contain bergy bits and 0.16% of small icebergs. The small percentage of bergy bits (0.06%) has little effect on the estimation of sea ice volume in the area.

Sensitivity of the Northeast Greenland Ice Stream to errors in surface mass balance forcing using Ice Sheet System Model
Nicole-Jeanne Schlegel, Jet Propulsion Laboratory

A clear understanding of exactly how the Greenland ice sheet responds to climate change requires a high-degree of spatial resolution and the modeling of longitudinal stresses, especially within the ice sheet's large drainage basins, as they contain outlets capable of high-velocity flow. The Ice Sheet System Model (ISSM) is a finite-element model capable of simulating transient ice flow on an anisotropic mesh that can be refined to higher resolutions and considers longitudinal stresses in the areas of enhanced ice flow. These features offer a distinct advantage over previous models of the Greenland Ice Sheet, specifically in terms of modeling fast-flowing outlet glaciers. With use of established ISSM capabilities, we examine the sensitivity of ice flow within the Northeast Greenland Ice Stream to uncertainties in a historic reconstruction of yearly surface mass balance forcing. This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration's Modeling, Analysis and Prediction (MAP) Program.

Warm events at Summit, Greenland during 2012 relative to an evolving 25 year ice sheet temperature record (1987-2012)
Chris Shuman, Goddard Space Flight Center

An evolving temperature record from the Greenland Summit Station, at approximately 3216 m in elevation, has documented unusual periods of near and above freezing air temperatures in July 2012. Since August 2005, data has been collected from well-calibrated and actively-ventilated temperature sensors at a NOAA-ESRL climate observatory. Comparison of these data from a nominal 2 m height above the ice sheet surface over the past seven summers reveals several periods of unusual warmth at the highest elevations of the ice sheet in 2012. Detailed analysis of the available data indicates that temperatures rose to or above freezing for almost 6.5 hours on July 11 at Summit Station. A maximum air temperature of 1 degree C was recorded repeatedly in the 1-minute averages during this period.

Constraining ice sheet visco-elastic response to supraglacial lake drainage events
Laura Stevens, Massachusetts Institute of Technology

Hydro-fracture events establishing surface-to-bed drainage networks have been observed at supraglacial lakes on the central western margin of the Greenland Ice Sheet (GrIS). Uncertainty remains around the mechanisms of hydro-fracture crack initiation and explanations for the differing supraglacial lake drainage styles ("catastrophic" vs. "slow") observed. We are using inverse and forward numerical modeling efforts, constrained by GPS observations of ice surface motion, to investigate (1) the fracture opening and propagation geometry and (2) the stress field in the ice-sheet prior to a hydro-fracture event. Results will increase prediction accuracy of future ice-sheet contributions to sea level rise by improving scientific knowledge on the mechanics of ice-sheet hydro-fracture and the influence of surface meltwater on ice-sheet flow.

21st century projections of surface mass balance changes for major drainage systems of the Greenland ice sheet
Marco Tedesco, City College of New York

Outputs from the regional climate model Modele Atmospherique Regionale at a spatial resolution of 25 km are used to study 21st century projected surface mass balance (SMB) over six major drainage basins of the Greenland ice sheet (GrIS). The regional model is forced with the outputs of three different Earth System Models (CanESM2, NorESM1 and MIROC5) obtained when considering two greenhouse gas future scenarios with levels of CO_2 equivalent of, respectively, 850 and >1370 ppm by 2100. Results indicate that the increase in runoff due to warming will exceed the increased precipitation deriving from the increase in evaporation for all basins, with the amount of net loss of mass at the surface varying spatially. Basins along the southwest and north coast are projected to have the highest sensitivity of SMB to increasing temperatures. For these basins, the global temperature anomaly corresponding to a decrease of the SMB below the 1980–99 average (when the ice sheet was near the equilibrium) ranges between +0.60 and +2.16 degC. For the basins along the northwest and northeast, these values range between +1.50 and +3.40 degC. Our results are conservative as they do not account for ice dynamics and changes in the ice sheet topography.

Evidence and analysis of 2012 Greenland records from spaceborne observations, a regional climate model and reanalysis data
Marco Tedesco, City College of New York

A combined analysis of remote sensing observations, regional climate model (RCM) outputs and reanalysis data over the Greenland ice sheet points out to the evidence of multiple records set during summer 2012. Melt extent was the largest in the satellite era (~ 97% of the ice sheet) and melting lasted up to ~ two months longer than the 1979–2011 mean. Melting has also been starting progressively up to a month earlier during the 1979-2012 period. Surface mass balance and near-surface temperature values in 2012 were ~3 standard deviations (sigma) below the 1958–2011 mean and runoff was 3.9 sigma above the mean over the same period. Albedo, exposure of bare ice and surface mass balance also set new records, and so did the total mass balance with summer and annual mass changes of, respectively, -510 Gt and -482 Gt, 2 sigma below the 2003–2012 mean.

We identify in persistent anticyclonic conditions over Greenland associated to anomalies in the North Atlantic Oscillation (NAO), changes in surface conditions (e.g., albedo) and pre-conditioning of surface properties from recent extreme melting some of the driving mechanisms for the 2012 records. Because of the self-amplifying nature of positive feedbacks, less positive if not increasingly negative SMB will likely occur should large-scale atmospheric circulation and induced surface characteristics observed over the past decade persist. Since the general circulation models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) do not simulate the abnormal anticyclonic circulation resulting from extremely negative NAO conditions as observed over the past recent years, contribution to sea level rise projected under different warming scenarios will be underestimated should the trend in NAO summer values continue.

Bathymetry of Greenlandic fjords from Operation IceBridge aerogravity
Kirsty Tinto, Columbia University

Operation IceBridge has flown aerogravity along the axis of fjords in Greenland since 2010 with the aim of inverting gravity anomalies for bathymetry in the fjords. Inversion for bathymetry requires a compilation of ice surface and bed elevation data over grounded ice to pin bathymetry models and an understanding of local and regional geology that is aided by magnetic anomaly measurements. Two types of survey geometry have been flown: curved lines along the fjord axes and straight lines parallel to the coast. We show the different techniques and assumptions for inverting bathymetry in these different geometries, and discuss the errors associated with each technique. We present bathymetries of fjords in Northern Greenland as the first of a series of products to be released to the community, as well as a progress report on the regional compilation.

Modeling dynamic changes of the Greenland ice sheet in the next 500 years
Weili Wang, Goddard Space Flight Center

A 3-dimensional ice flow model (AIF model) is applied to the Greenland ice sheet for SeaRISE experiments: (1) sensitivity to changes of climate at the upper surface, (2) sensitivity to changes of sliding at the subglacial interface, and (3) sensitivity to changes of ocean-induced melting at the ice sheet perimeter. The model runs for 500 years into the future. The experimental results presented here will focus on the dynamic response of the ice sheet to the changes in the boundary conditions.

Sensitivity of dynamic change to basal sliding of the Greenland Ice Sheet
Weili Wang, Goddard Space Flight Center

In order to study the sensitivity of ice sheet to the changes of sliding at the subglacial interface, one set of the SeaRISE experiments is designed to enhance the basal sliding velocity by an amplification factors as 2x, 2.5x and 3x, respectively. We perform the experiments by applying two versions of AIF (Anisotropic Ice-Flow) model to the Greenland ice sheet. Two models (AIFa and AIFb) use the different basal sliding laws, i.e. the basal sliding velocities are estimated based on the cubic (AIFa) and linear (AIFb) power relation of the basal share stress, respectively. The changes of the ice sheet volume have shown that the models predict larger ice losses when the basal sliding is an exponential function of the basal stress as compared to the linear function. Here, we compare the results from two models to show the impact of basal sliding on the dynamic change of the Greenland ice sheet.

PARCA 2013
Wednesday, January 30
8:30 AM - 12:00 PM
GSFC Building 33, Room H114

08:30 **Mobile Slippery Spots Produce Uplifted Basal Bodies in Ice Sheet Stratigraphy**
Michael Wolovick, Columbia University

Large uplifted basal reflectors have been observed in radio-echo sounding data from both Antarctica and Greenland and interpreted as the result of basal freeze-on. However, order-of-magnitude considerations of latent heat requirements suggest that these basal bodies are unlikely to be produced purely from basal freeze-on. Here, we propose a complimentary mechanism capable of building large basal bodies with a small volume fraction of freeze-on ice. Using a two-dimensional higher order thermomechanical flowline model coupled to a simple basal hydrology model, we show that temporal variability in water input can produce warm-based patches ("slippery spots") that travel with the ice sheet and produce large amounts of uplift and subsidence of the ice sheet stratigraphy through changes in the sliding velocity. The amplitude of vertical motion produced by mobile slippery spots is larger than the amplitude of vertical motion produced by stationary slippery spots (the "Weertman Effect"), and the stratigraphic structures are more intricate as well. This theory makes three observational predictions that can be tested with borehole experiments: 1. the bed underneath regions of drawn down stratigraphy should be cold, 2. the bed underneath the uplifted basal bodies should be warm, and 3. the majority of the volume fraction of the basal bodies should be composed of deformed meteoric ice.

08:45 **Influence of Basal Freeze-on Bodies on Surface Accumulation over Petermann Glacier Catchment**
Indrani Das, Columbia University

We use a comprehensive geophysical data set over Petermann Glacier Catchment to identify a large region where basal processes like compressive and extensive folds and freeze-on deform the overlying structure of the ice sheet. Close to the onset of fast flow, these deformed structures are often horizontally several times the ice thickness and they modify the basal shear stress. The larger bodies of active deformation deflect the internal layers creating undulations on the surface. Stratigraphy from shallow ice radar indicates that these undulations have a localized impact on surface accumulation. In this study, we use shallow ice radar stratigraphy and a variable snow density profile to quantify the localized impact on surface accumulation.

09:00 **Greenland's Supra and Proglacial Rivers**
Asa Rennermalm, Rutgers University

This presentation summarizes collaborative, multi-institutional research to study the production, storages and fluxes of Greenland ice sheet meltwater in supraglacial streams, rivers and lakes that form on the ice surface and emerge as proglacial braided rivers downstream at its edge. Preliminary analysis indicates that Greenland supraglacial rivers represent major, high-flux pathways for meltwater transport, with flow velocities and hydraulic characteristics quite extraordinary as compared with terrestrial rivers. Furthermore, analysis of proglacial river discharge and ice sheet runoff modeling suggest that large amount of ice sheet meltwater is retained internally and released with a delay that may last years.

09:15 **Surface Melt Induced Changes in Subglacial Drainage, West Greenland**
Winnie Chu, Columbia University

The hydraulic configuration and water availability in a subglacial drainage system has a crucial control on the sliding behavior of the Greenland Ice Sheet. In the Sarqardliup Sermia catchment, south of Jakobshavn Isbrae, supraglacial lake drainage provides a fast mechanism to inject large volumes of meltwater to the ice sheet base. Here, we use airborne ice-penetrating radar data and potential field data from the Antarctica's Gamburstev Province Project and Operation IceBridge/CReSIS to investigate changes in the structure and behavior of subglacial drainage system in this catchment. By combining a 2-D subglacial flow model with the derived hydrological potential we explore the evolution of the subglacial water network as effective pressure changes due variations in water supply.

09:30 **Integrating IceBridge and ICESat Data with a Monte-Carlo Modeling Framework to Constrain the Mechanisms of Recent Acceleration in West Greenland Outlet Glaciers**
Hari Rajaram, University of Colorado at Boulder

The objective of our research is to constrain the mechanisms contributing to the recent acceleration of outlet glaciers in Greenland using a Monte-Carlo data assimilation framework. Our approach combines IceBridge, ICESat, GRACE and InSAR measurements with Monte-Carlo simulations of coupled thermo-mechanical ice flow and hydrologic models. Our coupled models are being enhanced to incorporate several interacting processes that contribute to acceleration of ice flow, including terminus retreat, basal sliding and cryo-hydrologic warming. The spirit of our Monte-Carlo approach is illustrated with applications to the Columbia glacier in Alaska, whose retreat is well documented. The Columbia glacier offered an attractive modeling target for illustrating the Monte-Carlo model selection approach, because it is temperate, and uncertainties in ice temperature are not relevant. On the other hand, empirical parameterizations of calving and basal sliding are unavoidable for modeling the Columbia glacier, and the Monte-Carlo approach offers a useful framework for diagnosing these uncertain parameterizations. We also report on the development of models for outlet glaciers in west Greenland and improving parameterizations of cryo-hydrologic warming, a process that can potentially impact the thermo-mechanical state of these outlet glaciers.

09:45 Uncertainty Analysis of Ice Flow Models in Antarctica and Greenland
Eric Larour, Jet Propulsion Laboratory

Inputs such as ice thickness, ice rigidity, basal friction and surface mass balance are critical in constraining transient ice flow models. Such inputs are inherently uncertain, and can only be measured/known within a certain error range. Here, we try and quantify the impact of such errors on the modeled mass balance of ice streams such as Pine Island Glacier, Antarctica, and 79 North, Greenland. We also use our results to understand the sensitivity of ice flow models to inputs, and try and assess which ones are most critical in constraining diagnostics such as mass flux at the grounding line.

10:00 BREAK

10:20 Radiostratigraphy of the Greenland Ice Sheet
Joe Macgregor, University of Texas at Austin

We are developing a comprehensive radiostratigraphy of the Greenland Ice Sheet (GrIS) from the nearly two decades (1993-2012) of airborne radar-sounding surveys collected by the University of Kansas. This radiostratigraphy will be used to investigate the ice sheet's basal condition and millennial-scale history in conjunction with ice-flow modeling and other remote-sensing data. It will also be gridded at the same resolution as next-generation surface- and bed-elevation models, so that ice-sheet models can validate their spin-up with these isochrones. To trace this stratigraphy efficiently, we are using several new and established methods (layer-slope prediction and data flattening). The classic depth pattern of reflectors in the GrIS is observed throughout the ice sheet (many reflections in the Holocene, a reflectivity hiatus between ~15-30 ka, and a distinct reflector triplet between ~35-50 ka), along with intermittent basal freeze-on in northern Greenland. This radiostratigraphy is potentially a valuable constraint on models of the GrIS's evolution since the last interglacial period.

10:35 Bedrock and Ice Thickness Mapping in Greenland
Mathieu Morlighem, University of California Irvine

Detailed maps of bed elevation and ice thickness are essential to many glaciological applications including numerical ice flow models. We propose to give an overview of our knowledge of the Greenland ice sheet thickness, and the different existing approaches of bedrock and ice thickness mapping. Operation IceBridge conducted a detailed survey over the periphery of the Greenland Ice Sheet, which transformed our knowledge of the ice sheet morphology. In order to be readily usable by ice sheet modelers, these radar-sounding profiler data need to be interpolated onto regular grids. Most interpolation algorithms are based on geostatistical techniques, such as co-Kriging or the minimum curvature method. A different approach consists of using the mass conservation equation by combining OIB data with high-resolution ice motion data from interferometric SAR (ALOS PALSAR, RADARSAT-1 and Envisat ASAR). The results reveal overdeepening in the glacier fjords that are not apparent in current maps, and deep subglacial valleys that channelize ice flow to the coast. These features have potentially a significant impact on ice flow modeling and are mapped for the first time around Greenland using a combination of OIB and InSAR data. These results provide guidelines for future deployments and improvements in the bedmap of Greenland.

10:50 Extensive Basal Freeze-on and Deformation at Base of Greenland Ice Sheet
Robin Bell, Columbia University

Using a comprehensive geophysical data set over the Petermann Catchment, in northwest Greenland we have identified a large region where the fundamental structure of the ice sheet is modified by a combination of compression, extension and freeze-on. Large bodies of basal ice often more than half the ice thickness deflecting even the shallowest layers in the ice sheet develop in regions with low basal shear stress. Linked to subglacial water and varying basal slip, this process impacts the distribution of surface accumulation, localizes the onset of fast flow and may be linked to the formation of melt channels at the grounding line in the floating ice tongue. The combination of freeze-on and deformation impacts important ice sheet processes from the interior to the grounding line.

11:05 Coastal bathymetry of NW Greenland, from airborne gravity
Kirsty Tinto, Columbia University

Operation IceBridge has flown a coast-parallel grid of 5 km spaced survey lines both onshore and offshore across the fjords of NW Greenland. The measured gravity anomaly has been inverted as a grid to provide a self-consistent bathymetry model for the region. We show the resulting bathymetry model providing the vital link between IBCAO marine bathymetry and radar-based bed mapping in the region.

11:10 Tomographic Observation and Bedmapping of Umanaq Glaciers of Western Greenland with IceBridge Sounder
Xiaoqing Wu, Jet Propulsion Laboratory

NASA's airborne IceBridge mission started from 2010 and has collected data over Greenland and Antarctica for three years. The IceBridge sounding radar MCoRDS (Multichannel Coherent Radar Depth Sounder) is the main source for ice thickness estimation along the flight lines. Due to the unique design of MCoRDS with multiple antennas and receivers, we were able to process the MCoRDS data tomographically and produce high resolution bedmaps of the covered regions. In an attempt to evaluate the possibility to process all the IceBridge MCoRDS data into bedmap products, we started with Russell Glaciers last year and produced a 40 km x 20 km bedmap of the area with 10m average thickness accuracy and 50m ground range resolution. We moved on to bedmap the Umanaq Glaciers, which was covered with 2 flights in 2011. The coverage is over 300km long 60km wide. We also observed strong surface and sub-surface clutter in some areas of this region, which may help us to understand and to characterize the internal layers and pockets between the surface and the bottom. In the talk we are presenting the tomographic observations of the surface and sub-surface clutters, their impact on the bedmapping and the bedmap of the entire Umanaq Glaciers.

11:25 **Discussion of Some Next Steps in Ice Sheet Geophysics**
Ken Jezek, Ohio State University

This talk outlines several overarching questions in ice sheet geophysics. These will be used to try and seed discussion about where we might want to focus future research.

11:40 **Moderated Group Discussion**

- Is it time to step back and revisit some of the fundamentals of ice-sheet geophysics? How do we do that?
- Are there specific observations not currently being collected that are needed to advance our predictive capabilities?
- Are changes needed to current data acquisition strategies, either in spatial or temporal coverage?
- Is it time for an academy workshop, analogous to what the sea ice community recently did, which identified new research foci?
- What should PARCA become, as a program and as a meeting?

12:00 **ADJOURN**