THE WEST ANTARCTIC ICE SHEET INITIATIVE

A Multidisciplinary Study of Rapid Climate Change and Future Sea Level

2011 WAIS Workshop Agenda

Tuesday, September 20

Time	Topic	Speaker
4:00	WAIS Steering Group Meeting	
6:30	Dinner (pizza party)	

Wednesday, September 21

Wednesday, September 21

Time	Topic	Speaker
7:15 to 8:30	Breakfast	
7:30	Registration	
8:45	Welcome	Ted Scambos
Session 1	**Quadrophenia: Multi-discipline system science in WAIS (PIG, LARISSA, WISSARD, Ice2Sea)**	
9:00	Sensitivity studies of ice flow acceleration in response to increased ice shelf melting in the region of Pine Island Glacier [Abstract] [Presentation]	Eric Larour

9:15	Bedforms and melt beneath Pine Island Glacier, results from the 2011 ground radar survey [Abstract] [Presentation]	Ed King
9:30	Balancing the water budget of the Whillans Ice Plain: Implications for the nature of the subglacial hydrologic system [Abstract] [Presentation]	Sasha Carter
9:45	LARISSA: Using integrated system science to understand the impact of climate change on an ice shelf system [Abstract] [Presentation]	Scott Ishman
10:00	LARISSA Glaciology – The Bruce Plateau Ice Cap: Ice Dynamics across the Antarctic Peninsula [Abstract] [Presentation]	Erin Pettit
10:15	LARISSA Glaciology: Ongoing studies of borehole-derived surface temperature history, and continuing AMIGOS results and plans [Abstract] [Presentation]	Ted Scambos
10:30	Panel and open discussion	
10:45	Break	
Session 2	**Both Sides Now: Modern Climate and WAIS**	
11:00	The Atmospheric Control Knobs of WAIS Climate [Abstract] [Presentation]	Ryan Fogt, keynote speaker
11:30	Antarctic sea ice variability and the West Antarctic ice sheet [Abstract] [Presentation]	Marilyn Raphael, invited speaker

11:45	Modeling the surface mass balance of the Antarctic ice sheet using RACMO2: recent progress and remaining uncertainties [Abstract]	Michiel van den Broeke
12:00	Temperature changes in West Antarctica since the IGY: Perspective from the reconstructed Byrd record [Abstract] [Presentation]	Julien Nicolas
12:15	Using In-situ Firn Temperatures to Track Melt Water Retention and Firn Densification in Greenland's Accumulation Area [Abstract] [Presentation]	Neil Humphrey
12:30	Lunch (90 min) and poster set-up	
Session 3	**Back in Time: Climate, Ice Cores and WAIS**	
2:00	Tropical forcing of Circumpolar Deep Water inflow and outlet glacier thinning in the Amundsen Sea Embayment, West Antarctica, and its relationship to "global warming" [Abstract]	Eric Steig
2:15	Is West Antarctica running a tropical fever? [Abstract] [Presentation]	David Schneider
2:30	Interdecadal Climate Variability over Antarctica and Linkages to the Tropics: Analysis of Ice Core, Instrumental, and Tropical Proxy Data for the 19-20th Centuries [Abstract] [Presentation]	Yuko Okumura
2:45	West Antarctic Ice Sheet temporal and spatial accumulation variability from five new snowpits and firn cores [Abstract] [Presentation]	Landon Burgener

3:00	Histories of ice dynamics and climate inferred from ice cores and radar-detected layers [Abstract] [Presentation]	Howard Conway, invited speaker
3:15	Panel and open discussion	
Poster Session	**Signs**	
3:30	Poster session introductions	
	Break (15 min)	
3:30 to 5:30	Poster session (2 hrs) [Abstracts]	Allard, Bauer, Bridgers, Das, Fudge, Fyke, Horgan, Koffman, Larour, Leonard, Lloyd, MacAyeal, Martin, McGrath, Morin, Moussavi, Muto, Porter, Siegfried, Spector, Urasky, Walter, Williams, Zoet
5:30	Free time	
7:00	Dinner	

Thursday, September 22

Time	Topic	Speaker
7:15 to 8:30	Breakfast	
8:30	Day Two beginnings	Ted Scambos
Session 4	**Space Oddity: New Results from Satellite and Airborne Measurements, Satellites**	

8:45	Initial Assessment of CryoSat-2 Performance [Abstract]	Andrew Shepherd, keynote speaker
9:15	Antarctic Ice Velocity Mapped from Space: A Game Changing New Product [Abstract] [Presentation]	Bernd Scheuchl
9:30	Mass Balance of the West Antarctic Ice-Sheet from ICESat Measurements [Abstract] [Presentation]	Jay Zwally
9:45	Ongoing Changes in Glacier Elevation and Mass, Larsen A and B Embayments, Antarctic Peninsula [Abstract] [Presentation]	Christopher Shuman
10:00	Viewing a PIG Under a Spaceborne Microscope [Abstract]	Robert Bindschadler
10:15	Integrating and Combining Ice Sheet Mass Balance Estimates through GRACE and ICESat datasets [Abstract] [Presentation]	MacFerrin/Colgan
10:30	Panel and open discussion	
10:45	Break	
Session 5	**Fly Like an Eagle: New Results from Satellite and Airborne Measurements, Airborne**	
11:00	Under the Antarctic ice: New data in the East, new approaches in the West [Abstract] [Presentation]	Duncan Young, invited speaker
11:30	Subglacial Rivers and Thermal Structure in Dome A, East Antarctica [Abstract] [Presentation]	Michael Wolovick

11:45	Basal topography of the Institute and Möller ice streams, West Antarctica: assessing the risk of grounding-line retreat [Abstract]	Neil Ross
12:00	NASA's Operation IceBridge: using instrumented aircraft to bridge the observational gap between ICESat and ICESat-2 laser altimeter measurements [Abstract] [Presentation]	Michael Studinger
12:15	Panel	
12:30	Lunch (90 min)	
2:00	"In The Year 2525" Future of WAIS Science and WAIS Workshop (open discussion)	
Session 6	**The Logical Song: Hi Tech: Radar, Seismic, and Cosmogenic Results**	
2:30	Radar Results from the Geophysics Site Characterization of Subglacial Lake Whillans, West Antarctica [Abstract]	Robert Jacobel
2:45	Dynamics of Subglacial Lake Whillans from WISSARD Radar, Seismic and GPS Surveys and Satellite Laser Altimetry [Abstract]	Knut Christiansen
3:00	The Micro Subglacial Lake Exploration Device (MSLED) [Abstract] [Presentation]	Alberto Behar
3:15	Seismic Analysis of the Subglacial Environment of Thwaites lacier, West Antarctica [Abstract] [Presentation]	Leo Peters

3:30	Rapid early- to mid-Holocene thinning of Pine Island Glacier detected using cosmogenic exposure dating [Abstract]	Joanne Johnson
3:45	Geophysical evidence of Ice-Magma interactions beneath the West Antarctic Ice Sheet in the West Antarctic Rift System [Abstract] [Presentation]	John Behrendt
4:00	Panel	
4:15	Free time	
7:00	Dinner - BBQ	

Friday, September 23

Time	**Topic**	**Speaker**
7:15 to 8:30 am	Breakfast	
8:45am	Welcome	Ted Scambos
Session 7	**New Ideas in Ice Dynamics: Pushing the Boundaries - Honoring Barclay Kamb and Keith Echelmeyer**	
9:00	Emergence of tidewater and ice shelf calving dynamics using a granular model of ice [Abstract] [Presentation]	Jeremy Bassis
9:15	Variability in the mass flux of the Ross Sea ice streams, Antarctica, over the last millennium [Abstract] [Presentation]	Ginny Catania, invited speaker

9:30	Englacial Seismic Reflectivity – Imaging Crystal Orientation Fabric in West Antarctica [Abstract] [Presentation]	Huw Horgan
9:45	Spatial variations in ice-crystal alignments deduced from englacial radar polarimetry, central West Antarctica [Abstract] [Presentation]	Kenichi Matsuoka
10:00	Sea ice and West Antarctic ice-shelf stability [Abstract] [Presentation]	Kelly Brunt
10:15	Flow variability and propagation behavior in the Ross Ice Shelf [Abstract] [Presentation]	Christine LeDoux
10:30	Panel	
10:45	Break	
Session 8	**Somebody to Love: Ice Sheet and WAIS System Models**	
11:00	Bumpy beds, what to do about them [Abstract] [Presentation]	Olga Sergienko, invited speaker
11:15	Using radar layers to infer migration of WAIS Divide [Abstract] [Presentation]	Michelle Koutnik
11:30	Control of the width of West Antarctic ice streams by internal melting in the ice sheet near the margins [Abstract] [Presentation]	Thibaut Perol
11:45	A viscoelastic flowline model applied to tidal forcing of Bindschadler Ice Stream, Antarctica [Abstract] [Presentation]	Ryan Walker
12:00	Basal Crevasses on the Larsen C ice shelf: Implications for ice shelf stability [Abstract] [Presentation]	Dan McGrath

12:15	Panel	
12:30	Lunch /closing remarks	
2:00	Adjourn	

Poster Session (Wednesday, September 21)

	Topic	Lead Author
	History of the Ross Sea ice sheet based on glacial and lake records from Marshall Valley, Antarctica [Abstract]	Stephanie Allard
	Long-term Glacial History of the Southern Ross Sea Embayment [Abstract]	Ann Bauer
	Temporal Reduction of the ECSU Ice Shelf in Pine Island Bay Antarctica: 1972 - 2003 [Abstract]	Ya'Shonti Bridgers
	Surface Morphology Variations over Dome A due to Ice Sheet Bed-Surface-Atmosphere Interaction [Abstract]	Indrani Das
	Annual Layers and Irregular Stratigraphy: Electrical Measurements of the WAIS Divide Ice Core [Abstract]	T.J. Fudge
	How might the ocean react to loss of the WAIS? [Abstract]	Jeremy Fyke
	Subglacial Lake Whillans: A Shallow Active Reservoir Beneath a West Antarctic Ice Stream [Abstract]	Huw Horgan

	New radiocarbon dates from glacial deposits in Miers Valley constrain the past behavior of the Antarctic Ice Sheet [Abstract]	Tobias Koffman
	JPL/UCI Symposium on ISSM (Ice Sheet System Model) Public domain release [Abstract]	Eric Larour
	Snowfall, Redistribution, and Accumulation over Antarctic Sea Ice [Abstract]	Katherine Leonard
	Upper Mantle Structure Beneath the Whitmore Mountains, West Antarctic Rift System, and Marie Byrd Land from Body-Wave Tomography [Abstract]	Andrew Lloyd
	Viscous buckling on the grounding line [Abstract]	Douglas MacAyeal
	The SeaRISE-Antarctica Experiments with PISM [Abstract]	Maria Martin
	Basal Crevasses on the Larsen C ice shelf: Implications for ice shelf stability [Abstract]	Daniel McGrath
	The State of Sub-meter Commercial Satellite Imagery for the Antarctic, the Arctic and the West Antarctic Ice Sheet [Abstract]	Paul Morin
	Characterizing ICESat-2's response to snow and ice surfaces; theory and experiment [Abstract]	Mahsa Sadat Moussavi
	Subglacial bathymetry beneath the Pine Island Glacier ice shelf from airborne gravity, constrained by autonomous underwater vehicle data [Abstract]	Atsuhiro Muto

	Using High-Resolution Commercial Satellite Imagery to Advance West Antarctic Ice Sheet Research Goals [Abstract]	Claire Porter
	Continuing the Whillans Ice Stream subglacial lake record with GPS [Abstract]	Matthew Siegfried
	Glacial-Interglacial History of the Transantarctic Mountains and the Southern Ross Sea Embayment [Abstract]	Perry Spector
	Hosting a PolarTREC Teacher: A Method to Facilitate Antarctic Outreach and Dissemination of Research [Abstract]	Lesley Urasky
	Starting and stopping basal sliding on ice streams: New insights from Whillans Ice Plain, West Antarctica [Abstract]	Jacob Walter
	Spatial and temporal isotopic patterns across the West Antarctic Ice Sheet Divide from five new snowpits and firn cores [Abstract]	Jessica Williams
	Repeating Ruptures at David Glacier Modified by Tidal Influences [Abstract]	Lucas Zoet

2023 WAIS Workshop

2022 WAIS Workshop

2022 Agenda

2021 WAIS Workshop

2021 Agenda

2020 WAIS Workshop

2020 Agenda

2019 WAIS Workshop

History of the Ross Sea ice sheet based on glacial and lake records from Marshall Valley, Antarctica

Stephanie Allard, Brenda Hall, George Denton

Department of Earth Sciences and Climate Change Institute, University of Maine Orono, Maine

During the last glacial maximum (LGM), an extensive grounded ice sheet occupied the Ross Sea Embayment, Antarctica. The ice was fed by both the East and West Antarctic ice sheets and dammed large, proglacial lakes in several of the dry valleys adjacent to McMurdo Sound, including Marshall Valley (78°4'S, 164°15'E). Reconstructions of the glacial and lake deposits can afford information on past ice-sheet history. During January, we mapped the surficial deposits in Marshall Valley and logged thirteen sections of glacial and lake sediments. We also collected carbonate, gypsum, and algae samples for radiocarbon and/or U/Th dating. This work is in its very early stages, but initial radiocarbon dates of algae from ice-marginal deposits suggest that the ice reached its maximum position at ~18 ka. Preliminary U/Th dates of carbonate deposited in the former ice-dammed lakes fall into two groups – the LGM and marine oxygen isotope stage 6. Additional dates will help to constrain further the duration and timing of the LGM and the Penultimate glaciation in the Ross Sea region and thus allow us to address questions concerning the driving mechanisms behind ice-sheet change.

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Emergence of tidewater and ice shelf calving dynamics using a granular model of ice

Jeremy N. Bassis

Department of Atmospheric, Oceanic and Space Sciences, University of Michigan

Ice sheets and glaciers have traditionally been modeled as thin films of non-Newtonian fluids. This approximation is, however, incompatible with the extensive fracturing of ice that precedes and is occasionally part of the iceberg calving process. In this study, the explosive disintegration of ice shelves and rapid retreat and even advance of tidewater glaciers is explained by instead assuming that glacier ice is heavily fractured to the extent that it behaves in a manner that is more akin to a granular material than a continuous fluid. The conceptual granular ice model thus approximates the ice as a large number of discrete spheres or blocks of ice that interact through friction, damped elastic collisions and elastic bonds. The spectrum of intact to completely disarticulated ice is accommodated by allow bonds connecting adjacent blocks of ice to break. This model is shown to reproduce many of the observed features of calving including (i) the detachment of tabular bergs from ice tongues, (i) explosive disintegration of ice shelves and; (iii) smaller more frequent ice thickness sized bergs that detach from tidewater glaciers. The distinction between modes of calving is controlled by the fraction of bonds broken, ice thickness and near terminus water depth. However, it is shown that if the ice is already heavily fractured, the factor limiting retreat is the transport and export of ice away from the terminus rather than fracturing of the ice. It is possible that analogous continuum granular models can also formulated based on plasticity theory. This would return ice dynamics full circle to a version of the discarded plastic rheology glaciologists once favored.

Long-term Glacial History of the Southern Ross Sea Embayment

Ann Bauer, Marcus Gladden, Danielle Lemmon, Seth Cowdery and John Stone.

Department of Earth and Space Sciences, University of Washington

We measured cosmogenic Al-26 (half-life = 0.7 Myr) and Be-10 (half-life = 1.4 Myr) concentrations in bedrock samples from elevation transects on mountains alongside the outlets of Scott and Reedy Glaciers. Concentrations of these nuclides build up during interglacial periods and decrease via different decay rates during periods of ice cover. Therefore, high nuclide concentrations and high Al-26/Be-10 ratios indicate prolonged exposure throughout the past few million years, whereas low concentrations and ratios indicate longer periods of ice cover. Erosive removal of surface rock by warm-based glaciers can also reduce nuclide concentrations.

At Scott Glacier, Mt Rigby summit bedrock has high nuclide concentrations, corresponding to a minimum cumulative exposure history of ~ 2 Myr. Although this peak was overrun during the LGM, this minimum exposure age demonstrates that prior ice cover has been limited. On Reedy Glacier, comparable mountain summits have shorter cumulative exposure histories and lower Al-26/Be-10 ratios, indicating that they may have been ice-covered for as much as half of the Pleistocene. Bedrock samples from 500-800 m elevations on both transects show similar contrasts—limited Pleistocene ice cover at Scott Glacier and prolonged ice cover at Reedy Glacier. We conclude that the Siple Coast grounding line, which currently lies between these two glaciers, has returned to this interglacial position throughout much of the Pleistocene, maintaining thick ice in Reedy Glacier and thin ice in Scott Glacier.

A strong increase in nuclide concentrations with altitude over the full elevation transect at Mt Rigby is due to small but significant differences in subglacial erosion. We are investigating this by measuring the ratio of neutron capture-produced Cl-36 to spallogenic Cl-36, using biotite and K-feldspar, respectively. The production ratio by these processes is strongly depth-dependent, hence their ratio in surface samples will provide information about long-term erosion.

Supported by NSF awards OPP-0229314, OPP 0636818 and OPP-0838818.

The Micro Subglacial Lake Exploration Device (MSLED)

Alberto Behar

Arizona State University, School of Earth and Space Exploration

Antarctic subglacial lakes are believed to significantly impact glacial ice flow and therefore the Earth system due to rising sea levels and are furthermore scientifically interesting with respect to biogenic activity within these encapsulated ecosystems. In order to contribute to the Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) expedition that will explore these subglacial Antarctic environments and their impact on the cryo system, a highly miniaturized remotely operated vehicle, the Micro-Submersible Lake Exploration Device (MSLED) has been designed. Unique features are the slim form factor for the deployment through small ice boreholes as well as the extensive use of commercial-off-the-shelf components. The MSLED shall investigate Subglacial Lake Whillans with focus on the visual characterization of the lake's water and the ice-water interface, the distribution of physical and chemical parameters within the lake and the visual evidence for biogenic activity.

MSLED will perform the following functions at the Whillans Subglacial Lake and possibly the grounding-line sites of the WISSARD project:

* record the borehole ice properties, investigate the marine ice interface, examine distribution of entrained debris in basal ice, observe geometry of ice-water interface;
* inspect the water column for suspended particles as well as possible aquatic organisms, search for visual evidence of water stratification and/or horizontal/vertical motion;
* investigate the sea/lake floor for evidence of erosional and sedimentary processes (glacial flutings, subaqueous sediment failures, debris flows, deltas, drainage channels, etc.), record signs of possible bioturbation and/or evidence of benthic organisms.

The vehicle is ruggedized for the operation in depths of up to 1.5 km and within a range of one kilometer around the borehole. Video from a high-resolution camera for low light applications as well as salinity, temperature and depth measurements will be transmitted to the surface in real-time. The final design is being manufactured and will be deployed in an upcoming field test in near McMurdo Station scheduled for 2011 and an upcoming field deployment in 2013. This talk outlines the scientific background that inspired the mission, the deployment method as well as detailed information on the MSLED's subsystems, first implementations and tests.

Illustration of the Micro-Submersible Lake Exploration Device (MSLED).

Geophysical evidence of Ice-Magma interactions beneath the West Antarctic Ice Sheet in the West Antarctic Rift System

John C. Behrendt
INSTAAR University of Colorado, Boulder
And USGS, Denver

Radar Ice Sounding and Aeromagnetic Surveys reported over the West Antarctic Ice Sheet WAIS have been interpreted as evidence of subglacial eruptions. Several active volcanoes have shown evidence of eruption through the WAIS and several other active volcanoes are present beneath the WAIS (e.g. Corr et al., 2009; Blankenship et al., 1993) reported from radar ice sounding and aeromagnetic data (Behrendt et al., 1995; 2004). Aeromagnetic profiles (>10,000 km) acquired in the early 1960s over the West Antarctic Ice Sheet (WAIS) combined with coincident aeromagnetic and radar ice sounding in 1978-79 indicated numerous high-amplitude, shallow-source, magnetic anomalies over a very extensive area of the volcanically active West Antarctic rift system interpreted as caused by subglacial volcanic rocks. These early aerogeophysical surveys defined this area as >500,000 km^2. Five-kilometer spaced coincident aeromagnetic and radar ice sounding surveys since 1990 provide three dimensional characterization of the magnetic field and bed topography beneath the ice sheet. These 5-50-km width, semicircular magnetic anomalies range from 100->1000 nT as observed ~1 km over the 2-3 km thick ice have been interpreted as evidence of subglacial eruptions. Behrendt et al, (2005, 2008) interpreted these anomalies as indicating >1000 "volcanic centers." requiring high remanent normal (and at least 10% reversed) magnetizations in the present field direction. These data have shown that >80% of the anomaly sources at the bed of the WAIS, have been modified by the moving ice into which they were injected, requiring a younger age than the WAIS (about 25 Ma). Although exposed volcanoes surrounding the WAIS extend in age to ~34 m.y., Mt Erebus, (<1 Ma) Mt. Melbourne, (<0.26 Ma), and Mt. Takahae (<0.1 Ma) are examples of exposed active volcanoes in the WAIS area. However, the great volume of volcanic centers is buried beneath the WAIS. If only a very small percentage of these >1000 volcanic, magnetic-anomaly sources are active today, or in the recent past, in the drainage area of the WAIS, subglacial volcanism may still have a significant effect on the dynamics of the WAIS. Interpreted active subglacial volcanism is revealed by aerogeophysical data reported by Blankenship et al., (1993, Mt. Casertz), and Corr and Vaughan, (2008, near Hudson Mts.), who raised the question of possible volcanic effects on the regime of the WAIS. Wingham et al. (2009) reported an average rate of volume loss from 2.6 to 10.1 km^3 /yr from 1995 to 2006 for the Pine Island Glacier in the vicinity of the active subglacial volcano near the Hudson Mts. Probably wet-based areas of the WAIS would be the most likely to be impacted. Here I discuss these geophysical data over the WAIS, and conclude that even if there is a very low probability, future effects on the stability of the WAIS and associated sea-level rise should not be ignored, as changes observed in the past 20 years resulting from global warming, could be accelerated by subglacial volcanism.

Viewing a PIG Under a Spaceborne Microscope

Robert Bindschadler[1], Patricia Vornberger[2], Claire Porter[3] and Paul Morin[3]

[1] NASA (Emeritus) and Morgan State University
[2] SAIC
[3] Polar Geospatial Center

(for the session “New Results from Satellite and Airborne Measurements” or “New Ideas in Ice Dynamics: pushing the boundaries - Honoring B. Kamb and K. Echelmeyer”)

The Pine Island Glacier (PIG) has been in the scientific spotlight for more than a decade. Inferred from various lines of evidence, the dynamic changes of this glacier are caused by the interaction of the ocean and the ice shelf and the ice shelf’s influence on the glacier. Despite the keen interest in the ice shelf, *in situ* measurements are sparse due to the logistic challenges of getting to and operating in this coastal region. While that may change shortly, most of what we know is derived from satellite and airborne data sets and the resourceful exploitation of these data.

The character of the ice shelf expresses many aspects of this dynamic ocean-ice environment. Recent collections of sub-meter satellite imagery capture exciting details of the surface and provide additional insight into the nature of the ongoing dynamic processes. Most of the ice shelf surface is heavily crevassed, but the detailed view of individual crevasses afforded by this new imagery allows distinct crevasse patterns to be separated so that the likely formation mechanisms for each can be more clearly identified. Detection of crevasses, as well as confidently delineating uncrevassed areas, is a critical precursor to surface field work and a task that is superbly served with this new imagery. The agility of these imaging sensors expands their utility by collecting stereo images that can be used to generate digital elevation models and opening up the third dimension to scientific scrutiny. The examples shown illustrate that surface features of the few-meter scale, such as sastrugi, can be mapped in three-dimensions, giving a more complete description of the surface roughness. Even more promising is the potential for producing sufficiently orthorectified images so that the surface strain field can be mapped at a scale that further reveals the response of the ice shelf to highly variable melt rates at the ice shelf base.

Temporal Reduction of the ECSU Ice Shelf in Pine Island Bay Antarctica: 1972 - 2003

Ya' Shonti Bridgers (ECSU), Jessica Brownlow (MVSU), Kirsten Hawk (Spelman)
Mentor: Dr. Malcolm LeCompte, Assistant Mentor: Mr. Kaiem Frink
Principal Investigator: Dr. Linda B. Hayden
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Abstract—In an effort to determine whether the Antarctic ice sheet is growing or diminishing over long time intervals, Dr. Robert Bindschadler led an international team of glaciologists and computer scientists, including Elizabeth City State University (ECSU) students, to obtain an accurate measure of the area of the Antarctic ice sheet. Before the ice sheet's area was determined, the grounding line (GL), or boundary dividing the ice sheet resting on land from floating ice, was located by combining 2003 Landsat imagery and satellite-based laser altimetry.

Landsat image data contemporary with that used to create the grounding line was compared to earlier Landsat imagery of the same area. A small ice shelf—now known as the *ECSU Ice Shelf*—near the eastern entrance to Pine Island Bay was previously identified as having diminished over an approximate 31-year span and the progressive reduction of its area qualitatively characterized. Here, the area loss of the *ECSU Ice Shelf* is quantified over time from 1972 to its disappearance in 2003.

Departures from perfect geographic pixel registration in Landsat imagery of the *ECSU Ice Shelf* collected before 2003 was corrected with ITT's Visualization Information Solutions' ENVI image processing software using a 2003 Landsat 7 Enhanced Thematic Mapper (ETM) image as a reference. Older images from Landsat 4,5 Thematic Mapper (TM) and Landsat 7 (ETM) were registered to conform to the common fixed geographic control points visible on both images. By overlaying the GL on the registered (warped) images, the area changes in the ice shelf were computed. An average ice shelf area was determined from four independent measurement trials for each of the pre-2003 Landsat image.

Landsat Images from 2003 used in creating the GL were obtained from the United States Geological Survey (USGS) archive. The older, cloud free Landsat 4, 5 TM and 7 ETM images of the Pine Island Glacier region were obtained from another USGS archive.

Results provided: 1. A quantitative description of the disappearance of the ECSU Ice Shelf from 1972 through 2003; 2. Validation of the grounding line's actual location; 3. A survey of Antarctic coastal features that may have experienced climate related change.

Figure 1. Grounding Line bordering ECSU Ice Shelf in 1986.

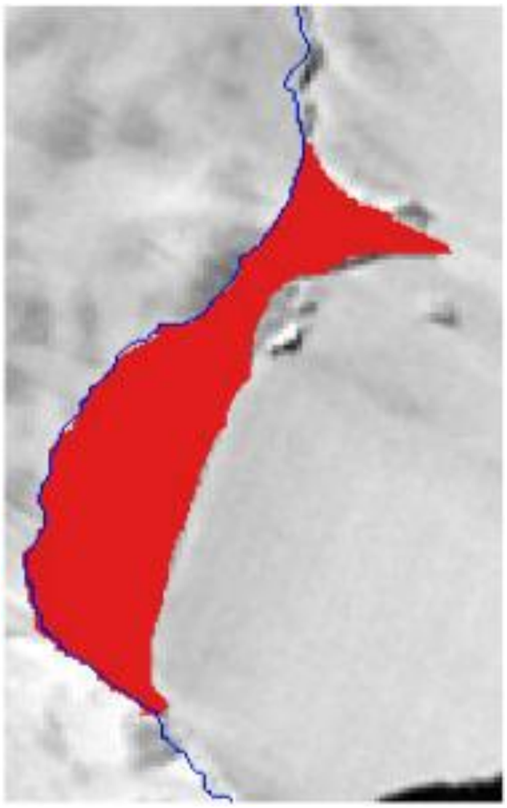
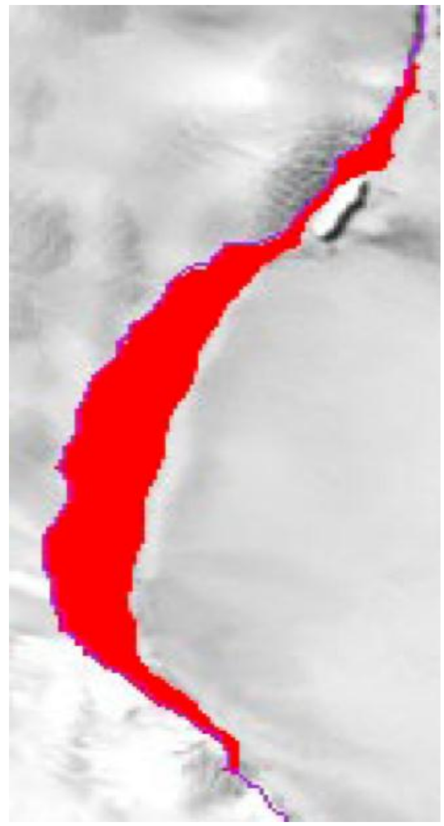


Figure 2. Grounding line bordering the ECSU Ice Shelf in 2001 (not to scale).



Sea ice and West Antarctic ice-shelf stability

Kelly M. Brunt, Emile A. Okal, and Douglas R. MacAyeal

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Department of Geophysical Sciences, University of Chicago

Sea ice plays a critical role in ice-shelf stability. It does so in two ways: 1) sea ice dampens sea swell incident on ice-shelf calving fronts and 2) fast ice can act to buttress an ice shelf, similar to the way an ice shelf buttresses an ice sheet. We examine the sea-ice conditions during two March 2011 calving events, from two different West Antarctic ice shelves. In particular, we examine a calving event on the McMurdo Ice Shelf and a tsunami-triggered calving event on Sulzberger Ice Shelf. We use satellite imagery and aerial photography to assess sea-ice conditions, and long-term ice-shelf stability, prior to these calving events.

West Antarctic Ice Sheet temporal and spatial accumulation variability from five new snowpits and firn cores

Landon Burgener[1], Summer Rupper[1], Jessica Williams[1], Rachel Marker[2], William Christensen[2], Lora Koenig[4], Clement Miege[3], Michelle Koutnik[5], Richard Forster[3]

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2. Department of Statistics, Brigham Young University, Provo, UT, USA
3. Department of Geography, University of Utah, Salt Lake City, UT, USA
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5. Centre for Ice and Climate, The University of Copenhagen, Copenhagen, Denmark

Five snowpits and shallow (less than 20 m) firn cores were collected along a transect across the West Antarctic Ice Sheet (WAIS) divide. Sub-annually resolved accumulation-rate records were developed by combining density, isotope and electrical conductivity datasets from each location. These new records overlap with and extend previous records in the area. The isotope record of the new core recovered from the ITASE-00-1 site (10 km from the WAIS divide deep-core site) correlates significantly with the original ITASE core, adding confidence to the utility of the new records. These new records are used to quantify the spatial and temporal patterns in accumulation, with a focus on the last decade. These results are used to re-evaluate the proposed relationship (Kaspari et al., 2004) between accumulation at WAIS and cyclonic activity in the region over the past three decades, including an evaluation of the influence of the Southern Oscillation Index and storm activity in the region.

Balancing the water budget of the Whillans Ice Plain: Implications for the nature of the subglacial hydrologic system

Sasha P. Carter[1], Helen A. Fricker[1], Matt Sigfried[1], Donald D. Blankenship[2], William Lispcomb[3]

[1]*Scripps Institution of Oceanography, UC San Diego,* [2]*UTIG, University of Texas at Austin,* [3]*Los Alamos National Laboratory*

The subglacial water system of the Whillans Ice Plain (WIP) contains numerous connected subglacial lakes contained in three distinct hydrological regimes: a north basin containing Subglacial Lake Engelhardt (SLE), a central basin containing Subglacial lake Whillans (SLW), and southern one containing Subglacial Lake Conway (SLC) and Subglacial Lake Mercer (SLM). We use surface elevation data from the ICESat mission combined with a subglacial water model to investigate how water produced in the upper Whillans and Kamb ice stream catchments is distributed among these regimes. We show that for a brief period in 2006 when at least one subglacial lake in each of the three regimes is observed to be filling that the combined filling rates are approximately equal to the sum of the predicted basal melt water production and subglacial lake discharge from upper Kamb, Whillans and Mercer Ice streams. This suggests that previous methods used to estimate basal meltwater production are reasonably accurate on basin-wide scale, and that "seal" mechanism prevents water from escaping downstream when a lake is filling. The systems by which water is distributed and seals are breached however may be more complicated than first thought. i) During the course of several simultaneous floods from lakes further upstream in 2005-06, ~85% of the water previously directed toward the southern regime became rerouted towards the central basin, resulting from a small increase in ice thickness that changed the hydropotential, indicating that subglacial waterways in a deltaic system can change course over time frames of less than a year. ii) Balancing the water budget of the Southern Basin required that water overflow SLC into SLM while its volume was still increasing, suggesting that the growth of the flow mechanism breaching the seal was limited by some factor of which our current understanding is incomplete. These initial results demonstrate that even within the relatively small area surrounding the WIP contains a myriad of dynamic subglacial environments, that could possibly serve as a microcosm for the greater ice sheet.

Variability in the mass flux of the Ross Sea ice streams, Antarctica, over the last millennium

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Various field and model data are synthesized to obtain a ~1000 year ice flow history for the Ross Sea ice stream system in West Antarctica to address the magnitude and timing of changes in mass flux for this region. The observed history shows a dominance of short-term (decade- to century-scale) variability in ice stream shear margins and the grounding line position due to internal variability of the coupled system. Our observations highlight the interplay between adjacent ice streams, which suggests that the behavior of any individual ice stream cannot be examined in isolation. In addition, individual events cannot be well understood without a more long-term and spatially extensive survey of ice sheet changes. In the context of this millennium-scale history, the relatively recent stagnation of Kamb Ice Stream is seen as just one stage in the thermodynamic cycles of ice streams in this region. The changes in mass balance that result from the KIS stagnation may thus be viewed as century-scale "noise" relative to the longer-term trend. Understanding and characterizing this is a necessary step before model-based predictions of ice sheet mass balance for the next century can be made.

Dynamics of Subglacial Lake Whillans from WISSARD Radar, Seismic and GPS Surveys and Satellite Laser Altimetry

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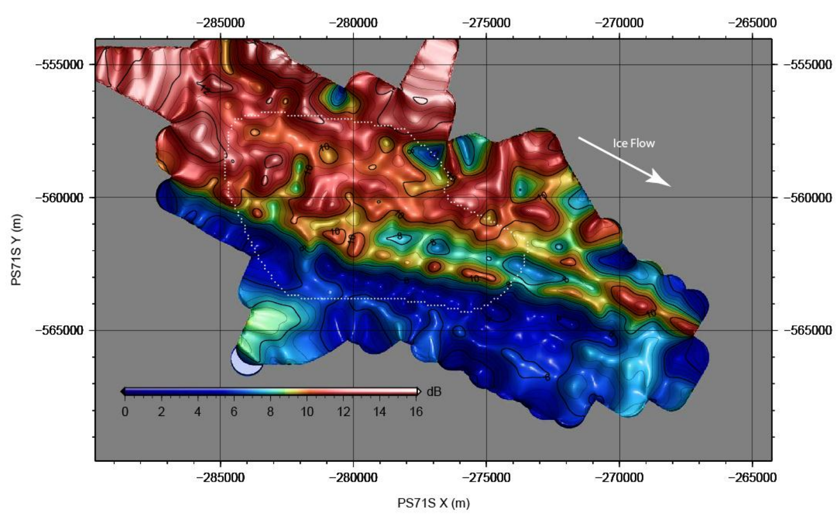
We discuss the dynamic filling/draining cycle of Subglacial Lake Whillans using ice-penetrating radar, kinematic GPS, satellite laser altimetry, and active source seismics. High spatial density kinematic GPS and ice-penetrating radar surveys, 3 m along-track spacing and 500 m or 1 km line spacing, were interpolated to 100x100 m2 grids of surface elevation, basal topography, subglacial hydropotential pressure, and relative basal reflectivity. A bed lineation along the north side of the lake coincides with the area of strongest basal reflectivity gradient (high on the lake side), showing that water is likely confined by, and flows adjacent to, this ridge. Active source seismic profiles in the lake basin show high reflection amplitudes and portions of the survey depict a phase reversal that is consistent with the presence of several meters of water. We also seismically image a shallow water column (~6 m) in area of lowest hydropotential pressure indicating that lake drainage is likely primarily controlled by changes in surface topography such that a shallow water column remains at low stand. We use GLAS ICESat laser altimetry combined with measurements of basal topography to construct a time series of changes in hydropotential gradient. Ridges in basal topography along the edges of the lake act as barriers to changes in hydropotential pressure. Changes in hydropotential are greatest in the southwest corner of the lake, corresponding to the largest elevation anomaly, and may be partially confined here by a low amplitude central ridge in basal topography. Although the exact drainage mechanism remains unclear, troughs that run parallel to and merge with basal topography suggest confinement of water and sediment flow by subtle ridges in basal topography in the filling stage of the lake cycle.



Subglacial Lake Whillans relative basal reflectivity (South Polar Stereographic). The sharp bed lineation corresponds to the marked change in reflectivity along the north margin of the lake basin indicated by the color change from blue to warmer colors at about 8 dB. Areas to the south are wet.

Histories of ice dynamics and climate inferred from ice cores and radar-detected layers

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Changes in activity of fast-flowing outlet glaciers and ice streams in Greenland and Antarctica exert strong control on the mass balance of ice sheets through discharge of inland ice to the ocean (e.g. Rignot et al., 2008; Pritchard et al., 2009). Furthermore, recent rapid changes in discharge of these fast-flowing outlets show that dynamical responses to warming play a much larger role in the future mass balance of ice sheets than previously considered (Alley et al., 2005; Truffer and Fahnestock, 2007). In West Antarctica, mass balance today is dominated by the recent slowdown of the Ross Ice Streams (Joughin and Tulaczyk, 2002), and the remarkable speedup and thinning of relatively few outlet glaciers on the Antarctic Peninsula and the Amundsen Sea sector of West Antarctica (Rignot et al., 2008). A remaining unanswered question is whether the recent changes in speed are unusual or whether they reflect ongoing adjustments to changes in climate and sea level since the last glacial maximum.

One way to give longer term perspective to these recent and possible future changes is to examine past conditions using ice-flow models constrained by radar-detected layers. Radar layers are flushed through fast-flowing outlets over short timescales; the history recorded in these outlets is typically limited to a century scale. Observations and model results show that changes in buttressing or sub-shelf melting near grounding lines affect glacier speed and force balance far inland; dynamical changes at the margins affect slow moving inland ice. The shape of radar-detected layer within inland ice contains information about past flow and climate and the layer shapes can be used to infer these histories. If the age of the radar layers can be determined from an ice core then we can infer the timing of the ice-flow and climate changes.

Here we present histories of climate and ice dynamics inferred from Roosevelt Island, Siple Dome and WAIS Divide. We also discuss these results in context with histories of deglaciation calculated directly from dated moraine limits (Stone et al., 2003; Todd et al., 2008) and glacial marine deposits (Anderson et al., 2002).

Surface Morphology Variations over Dome A due to Ice Sheet Bed-Surface-Atmosphere Interaction

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This paper uses high resolution lidar data with ice-penetrating radar profiles and other regional data sets to study surface morphology variations over Dome A. The ice surface over Dome A is influenced by both basal processes and atmosphere-surface interactions associated with variations in accumulation and ablation. Previous studies of this region with airborne ground penetrating radar have revealed interesting basal processes such as freeze-on plumes at the base of the ice sheet. The same radar images also revealed the presence of an unconformity in internal layers of ice, likely owing to a sharp change in surface accumulation pattern at the time of deposition. Using a surface roughness map derived from airborne lidar, we determine (by inference) the accumulation and ablation sites over this region, and compare those with RADARSAT backscatter data. Horizontal velocities of the internal layers are modeled to study the deformation of the internal layers and the ice surface over the freeze-on and unconformity. Surface roughness and traced isochrones are then used to study how these processes influence the surface morphology of the ice sheet. The study suggests that an interesting chain of processes may link both surface and basal features in this region.

The Atmospheric Control Knobs of WAIS Climate

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Recent studies have demonstrated a significant warming extending from the Antarctic Peninsula into West Antarctica over the last 50 years. While the state of the Southern Ocean and local cryosphere play an important role, the large-scale atmospheric controls on this warming are quite complex. The region is influenced by hemispheric wide pressure and wind variations manifested in the Southern Annular Mode (SAM). Further, remote influences from the tropics, often related to the El Niño – Southern Oscillation, are another important player in WAIS climate. However, multiple factors must be in place in order for WAIS to be influenced from the tropics, including the position of anomalous sea surface temperatures (and hence, resultant convection) in the tropics, and the atmospheric circulation pattern determined by the phase of the SAM. Both ENSO and the SAM influence a semi-permanent pressure center, the Amundsen-Bellingshausen Seas low, whose interannual and intraseasonal variations are not well known. While there are noted changes in the ABSL over the last 30 years, it is apparent that a driving mechanism in WAIS climate variations stems not only from this climatological low pressure, but also from strong influences in the underlying synoptic-scale activity.

The presentation will conclude with highlights from the last 3 years of the 'State of the Climate' reports published in the *Bulletin of the American Meteorological Society*. These yearly climate snapshots frame the changes in WAIS climate within the broader picture of ongoing Antarctic climate change and variability.

Annual Layers and Irregular Stratigraphy: Electrical Measurements of the WAIS Divide Ice Core

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We present an annually resolved timescale (WDC06A-5) of the WAIS Divide Ice Core to ~3100 m depth using measurements of the electrical properties of the ice. Below ~3100 m, the annual signal fades out due to what appears to be irregular layering and/or mixing from ice flow. We use "multi-track" images of the electrical conductivity across the core to examine the stratigraphy. We use the timescale and associated annual layer thicknesses in an ice flow model to extract preliminary estimates of past accumulation rates, past ice thickness changes, and the geothermal flux.

- Ice Sheet and WAIS system models

How might the ocean react to loss of the WAIS?

Jeremy Fyke

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The West Antarctic Ice Sheet (WAIS) has apparently retreated drastically in the past, arguably in response to changing climatic conditions (Naish et al., 2009). It may do so again under anthropogenic forcing. To explore the effect of WAIS retreat on the sea ice/ocean system, I carried out a preliminary set of simulations using the coupled ice sheet/climate model 'UVic ESCM-PSUI' (Fyke et al., 2011). When forced with prescribed increases to sub-ice-shelf melting in an otherwise preindustrial steady-state climate, the simulated AIS retreated due to both direct melting and increased ice discharge, and newly exposed ocean in the Ross and Ronne-Filchener embayments was colonized by sea ice. Subsequent sea ice export from these regions effectively transported the freshwater anomaly signal (and then some) into the open Southern Ocean, such that salinity actually increased in Ross and Ronne-Filchener basins. Because these regions contributed significantly to simulated AABW formation, a long-lived salty AABW anomaly developed synchronously with the main surface-intensified freshwater signal. The experiment described here is necessarily idealized in certain respects. Nonetheless, it demonstrates some potential effects of WAIS retreat, and highlights model development efforts that could be undertaken to better resolve AIS-ocean interactions. Hopefully, more work based on this initial effort will further illuminate AIS influence on regional and global oceanography.

Subglacial Lake Whillans: A Shallow Active Reservoir Beneath a West Antarctic Ice Stream

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Seismic and surface observations from Subglacial Lake Whillans (SLW), West Antarctica, reveal that this active lake forms a persistent, albeit fluctuating, reservoir beneath Whillans Ice Stream. Imaging and phase observations using active-source seismic data show that SLW, which was in a low-stand state when surveyed, is a perpetually shallow feature with a water column of less than 8 m depth imaged along 5 km of the 45 km profiled. This water column presents a suitable drill site at S 84.240°, W 153.694°. The water column is located within the lake's hydropotential low and is within the region of maximum observed ICESat elevation range. Elsewhere, the majority of the bed appears wet with water thicknesses below the imaging resolution of our data (< 5 m). The surface expression of the active lake, previously revealed by ICESat elevation data and image differencing, generally corresponds to the seismic estimate of water extent, with notable exceptions occurring at the upstream and downstream ends of the lake. These exceptions indicate that SLW: (1) grounds, or has negligible water, in places at low-stands (2) has disconnected or transient active and inactive portions, or, (3) is a system in transition.

Englacial Seismic Reflectivity – Imaging Crystal Orientation Fabric in West Antarctica

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Active-source seismic observations from West Antarctica offer insight into the evolution of Crystal Orientation Fabric (COF) within ice-sheets. We observe abrupt changes in COF in seismic data acquired at WAIS Divide, mid-stream and down-stream on Thwaites Glacier, and the onset region of Bindschadler Ice Stream. These data reveal a prevalence of englacial seismic-reflectivity in the bottom quarter of the ice sheet. We determine the origin of the reflectivity to be abrupt changes in the COF of ice. We base this on the following: i) seismic character is in keeping with current knowledge of COF within ice sheets, ii) COF requires the simplest genesis, especially at ice divides, and iii) amplitude analysis shows that all the reflectivity can be explained by contrasts in seismic velocity due to COF changes. The observed englacial seismic-reflectivity is complex but largely bed-conformable. Where prominent bed features are observed, distinctive englacial structures are also observed. We note that the increase in the quantity and complexity of COF observations downstream indicates that direct observations of COF at ice divides likely underestimates the role that fabric plays in ice sheet dynamics.

Using In-situ Firn Temperatures to Track Melt Water Retention and Firn Densification in Greenland's Accumulation Area

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Geology and Geophysics, Univ. of Wyoming

ABSTRACT Poorly understood processes controlling retention of melt water in snow and firn have strong implications for the Greenland Ice Sheet's mass balance and flow dynamics. Here we present results from a three-year field campaign focused on an 85 km transect of the percolation zone of West Greenland. We installed one-to-two thermistor strings at 14 study sites, with each string having 32 sensors spaced between 0-10 m depth. Data from our network of over 500 sensors were collected at 15-60 minute intervals for 1-2 yr, thereby recording the thermal signature of melt water infiltration and refreezing across the percolation zone over one-to-two annual melt cycles. We document three types of heating of firn related to different mechanisms of melt water motion and freezing, including heterogeneous breakthrough events, wetting front advance, and year-round heating from freezing of residual deep pore water. Vertically infiltrating melt water commonly penetrates through cold firn accumulated over decades, even where ice layers are present at the previous summer surface and where ice layer thickness exceeds several decimeters. The offset between the mean annual air temperature and the 10 m firn temperature reveals the elevation dependency of melt water retention along our transect. The firn is >10 ˚C warmer than the mean annual air temperature at the region where meltwater runoff initiates. During 2007-2009, runoff was limited to elevations lower than ~1500 m with no sharp "runoff limit"; rather, the ratio of retention-to-runoff transitioned from all retention to all runoff across a ~20 km wide zone. The techniques developed should be applicable to both firn densification and studies of climatic variation and climate change on WAIS.

LARISSA: Using integrated system science to understand the impact of climate change on an ice shelf system.

Scott Ishman[1], Eugene Domack[2], Amy Leventer[3], Stefanie Brachfeld[4], Bruce Huber[5], Julia Wellner[6], Craig Smith[7], Maria Vernet[8], Michael McCormick[2], Ellen Mosley-Thompson[9], Ted Scambos[10], Erin Petit[11], Greg Balco[12], Martin Truffer[11], Ky Chuel Yoo[13] and the LARISSA Science Team.

[1]Southern Illinois University Carbondale, [2]Hamilton College, [3]Colgate University, [4]Montclair State University, [5]Lamont-Doherty Earth Observatory, [6]University of Houston, [7]University of Hawaii, [8]Scripps Institution of Oceanography, [9]The Ohio State University, [10]National Snow and Ice Data Center, [11]University of Alaska Fairbanks, [12]Berkeley Geochronology Center, [13]Korea Polar Research Institute

LARISSA (LARsen Ice Shelf System, Antarctica) is an international research program that brings together an interdisciplinary team that transcends the boundaries of Marine and Quaternary Geology, Cryospheric Studies, Oceanography and Marine Ecology. Using the Larsen Ice Shelf System as a microcosm, LARISSA is focused on the impact of climate change on an ice shelf system from its source to its terminus, and the oceanographic and ecosystem responses to ice shelf retreat and collapse.

During the 2009-2010 Antarctic field season a coordinated logistical effort was supported by the RVIB NB Palmer, two ship-based helicopters, and fixed wing aircraft based out of Rothera. The ice core team deployed to the Bruce Plateau, Antarctic Peninsula and collected an ice core to bedrock, while glaciologists installed AMIGOS stations, which continue to monitor the ice. Concurrently a team of marine geologists and Quaternary geologists, physical oceanographers and marine ecologists conducted field studies along the margins of the Antarctic Peninsula, in the reaches of the Bruce Plateau ice drainage.

Initial analyses of the ice core indicate very high accumulation rates with very few melt layers. The core is currently being continuously analyzed for stable isotopic ratios, insoluble dust flux, anions, cations, MSA, and net mass accumulation rates. Heat flow measurements are being used to determine ice divide behavior and basal ice conditions on the Bruce Plateau. AMIGOS and automated GPS stations deployed are monitoring surface atmospheric and ice conditions. High resolution bottom photography and sediment-community samples indicate substantially higher benthic abundance and biodiversity in fjords versus the open shelf. Oceanographic and primary productivity gradients vary in the Larsen (LIS) and western Antarctic Peninsula (WAP) regions with sediment proxies indicating significant temporal variability. Holocene sediments recovered show temporal and spatial variability within the LIS, from Larsen-A (LIS-A) and Larsen-B (LIS-B) embayments, and variability along an east-west transect across the Antarctic Peninsula. Deglaciation of the WAP and LIS regions is consistent, occurring at approximately 11-11.5 ka, and both regions show mid-Holocene primary productivity highs. However, behavior of the WAP and LIS shows significant lag in ice shelf retreat coupled with atmospheric and oceanographic differences. Forthcoming data from ice cores, glaciological modeling and planktonic and benthic ecosystems will provide the information necessary to better understand atmosphere/ice/ocean/ecosystem dynamics in order to help predict future changes in the larger ice shelf systems of the Antarctic. To date, our results

indicate similarities and differences between WAP and LIS that highlight the importance of regional vs local forcing in deglaciation.

Radar Results from the Geophysics Site Characterization of Subglacial Lake Whillans, West Antarctica

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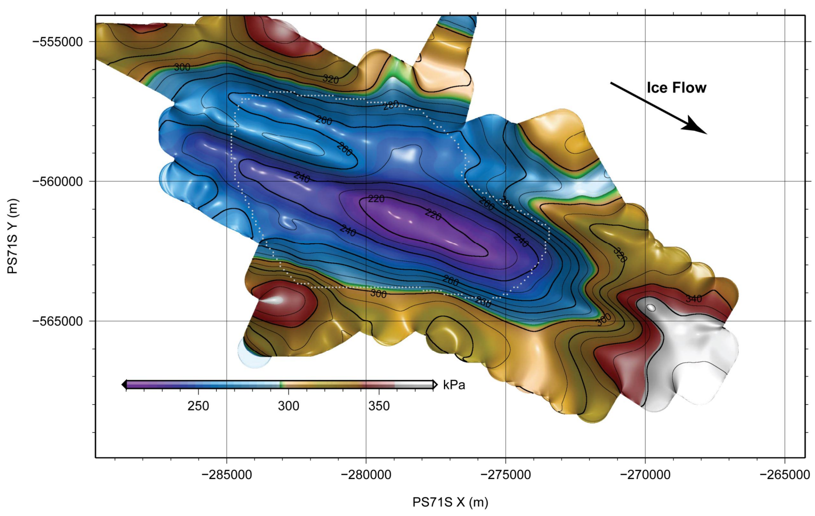
We present results from radar and GPS measurements over subglacial Lake Whillans undertaken as part of the WISSARD surface geophysics site characterization completed during the 2010-2011 field season. Over 400 km of radar data at 5 MHz were acquired on a 20 x 6 km grid of profiles spaced at either 500 m or 1 km. Waveforms were stacked 800 fold and recorded every ~3 m of surface travel together with GPS measurements of the surface position and elevation. This high-density gridded data set reveals details of bed and surface topography which define the lake basin as well as reflection characteristics of the bed. Because of the generally low surface slopes on the Whillans Ice Plain, the lake area is controlled by a combination of steep bed and broad surface features. For example, a bed lineation approximately 10 m in height provides a confining boundary for the lake to the north, sharply separating areas of high and low basal reflectivity. The lineation merges with a system of shallow troughs in the downflow direction, with no evident exit channel. While the lake was near-empty during the time of the survey, sharp differences in bed reflectivity indicate areas that are wet as well as dry margins. Based on the hydropotential map, water appears to both enter and exit primarily at the upstream end of the lake, with some influx over a ridge from the south. The radar also displays details of ice internal stratigraphy showing patterns of deformation that depict details of the ice strain history. A strong contrast from south to north across the lake reveals much larger strains on the south side, though their relation to the lake is unclear.



Subglacial Lake Whillans hydropotential (South Polar Stereographic) showing the pre-survey lake outline from Fricker et al. based on ICESat elevation changes and surface slopes. Hydropotential barriers in the downflow direction and limits based on the measured surface uplift restrict the primary water inflow and outflow path to the up-glacier direction where contours are low.

Rapid early- to mid-Holocene thinning of Pine Island Glacier detected using cosmogenic exposure dating

Joanne Johnson[1], Mike Bentley[2], Joerg Schaefer[3], Chris Fogwill[4], James Smith[1], Irene Schimmelpfennig[3], Karsten Gohl[5]

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Recent years have seen dramatic rates of thinning of major ice streams flowing into the Amundsen Sea, and in particular Pine Island Glacier. Onshore measurements of these changes are restricted to decadal timescales and in particular the satellite era, which makes it difficult to judge their significance and whether such changes are unprecedented. One way to place these events in a longer-term context is to study the geological record of past ice sheet change.

We report new cosmogenic exposure ages on erratic cobbles from nunataks in the Hudson Mountains, which are situated immediately north of Pine Island Glacier, and close to its present-day grounding line. We found erratics at all altitudes, from just at the modern ice surface, up to ~600 m above the ice. Here we use these as a vertical 'dipstick' for tracing past fluctuations in thickness of the WAIS.

A lateral moraine was observed at 500 m above present ice. ^{10}Be exposure ages from samples collected below this show that the ice sheet thinned progressively in the early- to mid-Holocene, reaching close to present elevation by ~6 ka. Exposure ages from the lowermost 100 m of two nunataks (Mt Moses and Maish Nunatak) suggest that rapid thinning was sustained there over a few hundred years. We also report exposure ages from within 40 m of the modern ice surface at Meyers Nunatak.

In summary, we have detected a rapid thinning event of Pine Island Glacier in the early to mid-Holocene, which appears to have brought the ice sheet surface close to present elevation by ~6 ka, and is recorded by erratic cobbles from several nunataks in the Hudson Mountains.

Bedforms and melt beneath Pine Island Glacier, results from the 2011 ground radar survey

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A detailed ground radar survey of the bed of Pine Island Glacier was conducted in the 2010/11 field season at the downstream limit of safe surface travel. The instrument used was a 4 MHz impulse radar and the data were collected on a 18 x 25 km grid with 500 m line spacing. The bed has three distinct zones: an area of relatively smooth topography with low amplitude (2 – 10 m) flutings, many of which are continuous for 18 km downstream; an area of higher amplitude (5-40 m) bedforms, many of which have an elongate drumlinoid form; and two narrow zones of low relief and very high reflection amplitude. With reference to near-by seismic data, we interpret these three domains as stiff till with the ice sliding over the bed; deforming till with ice motion taken up by shear deformation within the sediment; and narrow zones with high basal melt water content which underlie areas where the internal reflecting layers (isochrones) within the ice column are strongly drawn down towards the bed. The radar grid sits downstream of the convergence of one of the principal tributaries with the main trunk of Pine Island Glacier and modelling suggests different conditions at the bed in the two feeder zones. The relationship between these upstream conditions and the type and distribution of bedforms will be critically examined.

New radiocarbon dates from glacial deposits in Miers Valley constrain the past behavior of the Antarctic Ice Sheet.

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The Antarctic Ice Sheet (AIS) is by far the largest remaining ice sheet on Earth today. There is concern that ice sheet instability could result in accelerated sea-level rise, but predicting the future behavior of the AIS is an immense challenge. One approach to understanding the sensitivity of this ice sheet to climate change is to investigate the timing of its retreat after the last glacial maximum (LGM). Geophysical models driven by far-field sea-level-rise data have suggested that Antarctica contributed 15-25 meters of sea-level rise to meltwater pulse 1a (MWP1a), a rapid sea-level rise event ~14,500 cal yr BP during the last glacial termination. In contrast, geological evidence from glacial deposits across Antarctica seem to indicate that the entire LGM excess ice volume was less than 15 meters sea-level equivalent, and likely less than 10 meters. Furthermore, previous studies of grounding line retreat and ice-sheet surface lowering indicate that ice loss was delayed until after the occurrence of MWP1a. We present preliminary radiocarbon dates which constrain the history of ice in the Ross Sea sector of Antarctica. During the LGM, the Ross Sea was filled with a grounded ice sheet which extended nearly to the edge of the continental shelf. This Ross Sea Ice Sheet (RSIS) left distinctive glacial and glacial-lacustrine deposits in the foothills and valleys of the Royal Society Range on the west side of McMurdo Sound. Although our work is in its early phases, initial dates indicate that grounded ice was present in the mouth of Miers Valley between 22,000 and 11,500 calendar years BP. These dates are consistent with existing evidence for a delayed post-LGM retreat of Ross Sea ice and reduce the likelihood of a significant Antarctic contribution to MWP1a. This delay of ice retreat until well after the bulk of post-LGM sea-level rise suggests that sea-level change was not the predominant driver of retreat. In addition, the timing of ice-sheet retreat is not consistent with direct forcing by Southern Hemisphere insolation. Instead, our results point to the importance of processes such as internal ice-sheet dynamics or basal melting caused by advection of relatively warm circumpolar deep water beneath ice shelves.

Using radar layers to infer migration of WAIS Divide

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Transients in accumulation and in ice flow can drive ice-divide migration. However, it is likely that dynamical changes initiated near the ice-sheet margin control ice-divide position. Margin changes can rapidly affect interior ice, and in Central West Antarctica this has been observed upstream of outlet-glacier systems draining to the Amundsen Sea and to the Ross Sea (e.g. Rignot et al., 2008; Pritchard et al., 2009). In addition to rapid and recent changes in ice flow, the interior ice-sheet geometry may still be adjusting to changes in sea level and accumulation from the end of the last glacial.

Conway and Rasmussen (2009) report that the Western Divide, Central West Antarctic Ice Sheet (WAIS) is thinning by ~8 cm/yr and is migrating toward the Ross Sea at 10 m/yr. While this is a significant modern signal, it is unknown whether these changes are a response to centennial-scale or to millennial-scale forcing. How long has the WAIS Divide been migrating? If this magnitude of change is sustained for 100-1000 years, the interior ice may thin by 8-80 meters and the divide may migrate by 1-10 km. It is likely that changes of this magnitude have occurred in the past, which would have also affected the shape and depth of internal layers. Therefore, internal layers inform about and ice-flow changes and ice-sheet response.

We use radar layers, accumulation-rate estimates, ice-surface velocities, and modern ice thickness to infer *histories* of accumulation rate, ice thickness, and ice-divide position. The layers used in this study span 9-2 ka, and have been dated using a preliminary depth-age scale for the WAIS Divide ice core (WDC06A-4). Using our ice-flow model we assess how the signal we want to recover is represented in realizations of the available data. Using the available data we solve a suite of inverse problems to bracket the most likely history of the WAIS Divide. Understanding the history of the ice divide is necessary to interpret ice-core records and to estimate future behavior of the WAIS.

JPL/UCI Symposium on ISSM (Ice Sheet System Model)
Public domain release.

Eric Larour[1], Helene Seroussi[3,1], Mathieu Morlighem[3,1], Eric Rignot[2,1], Ala Khazendar[1]

[1]Jet Propulsion Laboratory
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ISSM (Ice Sheet System Model) is the JPL (Jet Propulsion Laboratory) / UCI (University of California Irvine) developed ice sheet flow model. Capabilities of this integrated system model include:

- lower-order, higher-order (including full-Stokes), 2D-3D thermo-mechanical ice flow
- diagnostic, prognostic, transient
- anisotropic meshes, finite elements
- parallel capabilities, iterative solvers.

JPL/UCI is in the process of releasing ISSM into the public domain, under an open source license. The software will be hosted at JPL/UCI, under a versioning system, which will allow users/developers to develop a community around ISSM, geared towards improved cryosphere science.
The software will be released in conjunction with a symposium at JPL (Pasadena, CA USA) centered around the new science enabled by ISSM. The symposium will be held in mid-November (still to be determined), and will include science presentations as well as classes and tutorials on ISSM.
We will present a poster with all the details relating to ISSM and the Symposium. We would like to be part of the “Multi-discipline system science in WAIS: PIG—LARISSA—WISSARD—Ice2Sea” session.

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 Cryosphere Science Program.

Sensitivity studies of ice flow acceleration in response to increased ice shelf melting in the region of Pine Island Glacier

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[2]University of California at Irvine
[3]JPL/UCLA, Joint Institute For Regional Earth Science and Engineering
[4]Ecole Centrale Paris

The acceleration of Pine Island Glacier in the last decade correlates significantly with an increase in ocean temperatures in the Amundsen Sea during the same period. Although studies have been carried out to try and link both phenomenon, the demonstration of a significant link between sub-cavity ice shelf melting and ice flow acceleration remains an open question. Here, we present a new offline coupling of an ocean circulation/ice flow model, based on the MITgcm and ISSM models, that includes significant forcing between the sub-ice shelf cavity ocean circulation and the glacier ice flow. Computed melting rates are used to constrain ice flow, which in turn is used to constrain geometry of the sub-ice shelf cavity. The model is applied to the Amundsen Sea/Pine Island Glacier, to try and assess the sensitivity of ice flow acceleration to a scenario of increased melting under the ice shelf. The results show significant ice flow acceleration on a short term basis (10 to 100 years), as well as modification of the ocean circulation under the ice shelf, in response to a changing sub-ice shelf cavity geometry. These results demonstrate that there are significant links between changing ocean circulation patterns in the Amundsen Sea and sudden ice flow acceleration of Pine Island Glacier in the last decade.

Session: Multi-discipline system science in WAIS: PIG—LARISSA—WISSARD—Ice2Sea

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 Cryosphere Science Program.

Flow variability and propagation behavior in the Ross Ice Shelf

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Fracture geometries in the Ross Ice Shelf, observable using visible band satellite imagery from the MODIS Mosaic of Antarctica (MOA) and the Landsat Image Mosaic of Antarctica (LIMA) provide a unique opportunity to study fracture propagation behavior and discharge variability in the ice streams and outlet glaciers feeding the shelf. Propagation is driven by changes in fracture length, near-field stress conditions, and the material properties of the ice. Changes in ice stream discharge and the development of "sticky spots," in both ice streams and within the shelf, lead to redirection of flow, changes in lateral gradients of ice velocity, and the propagation of fractures in response to changes in near-field stresses. The propagation behaviors most commonly observed are the growth in the transverse direction of a fracture that formed within a shear zone and mechanical interactions between adjacent fracture tips. A fracture type that forms at lateral corners of the shelf within a zone of both shearing and compression is also highlighted.

We use fracture mechanics theory and remote-sensed imagery to categorize fracture patterns and longitudinal zones of fractured ice in the Ross Ice Shelf. Near current sites of formation, simple fracture geometries and principal stresses are used to illustrate physical processes related to the formation and propagation of fractures. To compute flow lines and principal stresses, we derive a velocity map of the Ross Ice Shelf by merging two velocity datasets using a combination of statistical methods. A structural map of the Ross Ice Shelf is constructed, with fracture geometries, relict shear margins, and structural boundaries, observable in the imagery. Using the ice shelf features, present-day flow lines, and principal stresses, we investigate the manner in which principal stresses affect propagation behavior and the variability of ice stream discharge into the shelf.

Snowfall, Redistribution, and Accumulation over Antarctic Sea Ice

Katherine Leonard (1,2), Ted Maksym (3,4)

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2. *CIRES, University of Colorado Boulder*
3. *British Antarctic Survey*
4. *Woods Hole Oceanographic Institute*

Snow cover plays a crucial role in Antarctic sea ice mass balance, sea ice surface properties and sea ice ecosystem dynamics, but the governing mechanisms controlling patterns of snow distribution are poorly constrained. Precipitation over the Southern Ocean is expected to increase as a consequence of atmospheric warming, and several studies have suggested a direct link between precipitation and sea ice extent in the Antarctic. However, the role such a precipitation increase might play in sea ice mass balance is complicated by many factors. Deep snow cover may inhibit thermodynamic growth by insulating the underlying sea ice, or it may promote ice growth through the formation of snow ice. Using the results of a field study of snow redistribution to inform a preliminary study using a blowing snow model, we show that over the entire Southern Ocean roughly half of the precipitation over sea ice can be lost to leads.

Modeled wind-borne snow erosion was greatest in the outer pack, particularly in the Ross Sea and between 90 ºE and 120 ºE. In these regions, high wind speeds outweighed the higher drift threshold and reduced transport rates caused by the warmer air temperatures. There are also substantial losses in the western Bellingshausen Sea, consistent with field observations. Snow redistribution may be even more important in the interior pack due to low temperatures and diminished precipitation rates close to the Antarctic continent. Our results suggest that in regions near the continent, most precipitation could be lost to leads due to wind redistribution. Large-scale model predictions of future Antarctic sea ice and ice-ocean-atmosphere response to climate warming that do not take aeolian processes into account may thus misrepresent the response of these processes to climate change.

Upper Mantle Structure Beneath the Whitmore Mountains, West Antarctic Rift System, and Marie Byrd Land from Body-Wave Tomography

Andrew Lloyd[1], Doug Wiens[1], Patrick Shore[1], Andrew Nyblade[2], Sridhar Anandakrishnan[2], Richard Aster[3], Audrey Huerta[4], Terry Wilson[5], Dapeng Zhao[6]

Washington University in St. Louis[1], Penn State[2], New Mexico Technical University[3], Central Washington University[4], The Ohio State University[5], Tohoku University[6]

As part of the International Polar Year in Antarctica, 37 seismic stations have been installed across West Antarctica as part of the Polar Earth Observing Network (POLENET). 23 stations form a sparse backbone network of which 21 are co-located on rock sites with a network of continuously recording GPS stations. The remaining 14 stations, in conjunction with 5 backbone stations, form a seismic transect extending from the Ellsworth Mountains across the West Antarctic Rift System (WARS) and into Marie Byrd Land. Here we present preliminary P and S wave velocity models of the upper mantle from regional body wave tomography using P and S travel times from teleseismic events recorded by the seismic transect during the first year (2009-2010) of deployment. Preliminary P and S wave velocity models indicate that the upper mantle beneath the Whitmore Mountains are seismically faster than the resolved regions beneath the WARS and Marie Byrd Land. A significant slow velocity anomaly is observed beneath Marie Byrd Land centered on Mt. Sidley and slightly slow velocity anomalies near the mean of the model are pervasive beneath the WARS.

Viscous buckling on the grounding line

Claire LaBarbera[1] *and Douglas MacAyeal*[2,*]

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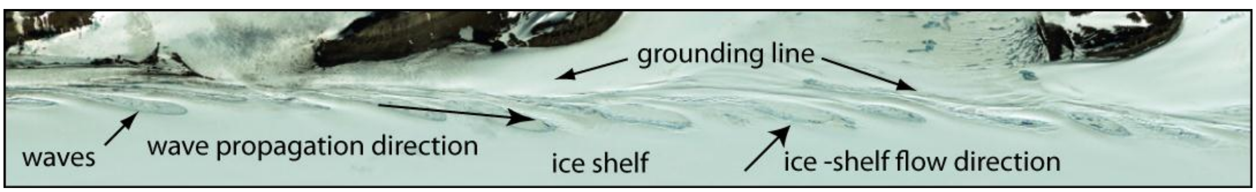
**presenting author*

There is nothing *a priori* wrong with the idea that ice can flow from sea onto land. We have, in fact, found such a circumstance on the boundary between George VI Ice Shelf and Alexander Island. Satellite imagery of this grounding line reveals propagating waves in the surface topography – a phenomena that defies efforts to explain with simple notions of grounding line dynamics. We speculate that viscous buckling, like what happens when a sheet of honey is poured onto a stack of pancakes, is what twists and warps the ice shelf at this grounding line. Oblique incidence of the ice flow onto the grounding line leads to phase propagation of the buckles. Furthermore, viscous buckling (both sinuous and varicose) appears to organize the location and morphology of surface meltwater ponds both within the grounding zone and elsewhere on the ice shelf. Troughs in the buckles contain exquisite, petal shaped meltwater ponds, the existence of which reinforces the notion that surface-hydrology on ice shelves remains largely unexplored.



Propagating waves on the grounding line of George IV Ice Shelf (DigitalGlobe browse imagery).

Integrating and Combining Ice Sheet Mass Balance Estimates through GRACE and ICESat datasets

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University of Colorado CIRES

A wide range of estimates has been made of current Antarctic and Greenland ice sheet mass balance using different methods. Large discrepancies in these estimates arise in part as a result of the various instruments and approaches used, each of which has its strengths and limitations.

The overarching objective of our project is to understand and quantify key differences among various ice sheet mass balance estimates, and use that information to improve ice sheet mass balance assessments now and in the future. Our primary focus will be on improving the analyses and interpretation of observations from the Gravity Recovery and Climate Experiment (GRACE) and the Ice Cloud and Land Elevation Satellite (ICESat) missions, which unlike most other approaches, together observe the total integrated effects of different mass balance components.

The first method of combining these datasets will reanalyze and combine ICESat dH/dt data with improved GRACE dM/dt solutions and Surface Mass Balance models into an integrated dataset, providing volume, mass and density changes into a single raster grid at greater spatial resolution than GRACE has traditionally provided, with better interpretation and spatial mapping of mass balance components than ICESat, GRACE, or other methods could ascertain alone.

The second method, Monte Carlo optimization, will eventually difference mass changes due to (i) surface mass balance and (ii) ice dynamics (inferred by correcting ICESat dH/dt observations for surface processes) at each downscaling node within from total mass change at the larger GRACE mass-con node. This approach acknowledges that a number of parameterizations are invoked in this process (i.e. retention fraction, firn density, etc.). Monte Carlo simulations are executed to vary parameters within their respective uncertainty ranges and explore the infinite combination of surface mass balance and ice dynamic changes at the downscaling nodes within a given GRACE mass-con node that can sum to the observed GRACE mass-con value. An optimal solution is selected by minimizing spatial gradients in all parameters. As a demonstration of the utility of Monte Carlo simulations in providing a robust treatment of numerous uncertain parameters, we execute the downscaling using only surface mass balance output. The methods will be compared for the observed accuracies and robustness of results, as well as cross-validated against each other as independent attempts at the combination of ICESat and GRACE datasets.

When properly exploited these assessments can provide a more robust estimate of ice sheet contributions to sea level rise than has been provided before, along with important new information on their likely (or unlikely) future behavior. They will also provide a baseline set of algorithms for combining datasets upon the launch of NASA's upcoming ICESat-2 (2016) and GRACE-II (20??) missions, invoking a keen opportunity for future data integration.

The SeaRISE-Antarctica Experiments with PISM

Maria A. Martin, Ricarda Winkelmann, Torsten Albrecht, Anders Levermann

Potsdam Institute for Climate Impact Research, Germany

We perform the SeaRISE-Antarctica experiments with up to 6.7 km resolution using the publicly available model PISM (http://www.pism-docs.org/wiki/doku.php), with the shelf specific developments from PISM-PIK now merged into pism-stable0.4. The Parallel Ice Sheet Model PISM is one of the models taking part in the SeaRISE project; the UAF group performs the experiments for Greenland.

Spatial variations in ice-crystal alignments deduced from englacial radar polarimetry, central West Antarctica

Kenichi Matsuoka[1,2], Donovan Power[2], Shuji Fujita[3], and Charles F. Raymond[2]

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3: National Institute of Polar Research, Japan

We present results of polarimetric ground-based radar surveys at 19 sites in a 100 km by 300 km area near the WAIS Divide that separates ice flow toward Ross and Amundsen Embayments. The measurements were made using 60-MHz and 179-MHz co-polarized, pulse-modulated radar. At each site, the orientation of the radar polarization plane is changed by 15-degree increments, so that depth variations of the radar returned power is collected at 12 polarization planes. We found alternations of 200~400m-thick ice bands with different degrees of the anisotropy. In strongly anisotropic band, the magnitude of the anisotropy is more than 20 dB. The most distinct polarimetric feature is uniaxial (180^o periodic), while a weaker 90^o-periodic feature is also found. These two patterns are predicted as effects of anisotropic reflectivity and birefringence caused by alignments of ice crystals (ice fabrics). Thus, we interpreted these polarimetric signatures in terms of ice fabrics. At almost all sites (regardless of the distance from the current ice-flow divide), ice fabrics are developed significantly to make anisotropic reflections as shallow as 200-500 m depths. A principal axis of the ice fabrics near the surface is consistent with the local fall line, which is consistent with GPS-measured flow direction or stretching axis at most sites. The principal axes of the ice fabrics vary with depth, suggesting a complicated flow history in the past or depth-variable flow patterns which are presumably caused by rough bed topography.

Basal Crevasses on the Larsen C ice shelf: Implications for ice shelf stability

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We identify a population (n = 27) of basal crevasses along a 31 km transect on the northern sector of the Larsen C Ice Shelf using ground penetrating radar. In total, approximately 100 basal crevasses are identified by their surface expression in visible satellite imagery. The basal crevasses form in the vicinity of Churchill Peninsula and initially extend from a region of shallow but highly fractured basal ice to form widely spaced (0.5 to 2.0 km) and deeply incised (70 to 134 m) features. Hydrostatically equilibrated surface depressions opposite in phase and smaller in amplitude than the basal crevasses are preferential locations for meltwater ponding. Surface crevasses are found at the topographic crests between the subsequent troughs. We assess these features using in situ kinematic GPS, airborne altimetry and high-resolution visible imagery. A linear elastic fracture mechanics (LEFM) model, dependent on ice shelf thickness, ice temperature and strain rate, accurately predicts observed basal crevasse height. Model results show that basal crevasse penetration height can also be expected to increase in response to the observed trends of ice shelf thinning and acceleration. We examine the possibility that a combination of basal crevassing, and enhanced surface crevassing due to meltwater hydrofracture, can explain recent ice shelf disintegration events on the Antarctic Peninsula.

The State of Sub-meter Commercial Satellite Imagery for the Antarctic, the Arctic and the West Antarctic Ice Sheet

Paul J. Morin and the staff of the Polar Geospatial Center

Polar Geospatial Center, Dept of Earth Sciences, University of Minnesota

Characterizing ICESat-2's response to snow and ice surfaces; theory and experiment

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NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2), programmed to be launched late in this decade, is expected to extend the time series of ICESat observations to characterize the trend of change in the Greenland and Antarctic ice sheets, and the thickness characteristics of Arctic and Antarctic sea ice. Adopted by the current mission design, the instrument will be a high repetition rate (10 KHz), low energy (25-100 μJ), photon-counting multi-beam laser altimeter system. In order to assess the capability of the ICESat-2 to achieve its science objectives, several studies have been designed to model the expected performance of the ATLAS[1] instrument on-board ICESat-2. In this poster, a research plan is proposed to evaluate the ICESat-2's response to different terrestrial surfaces, most importantly those in Polar Regions. The objectives are to investigate the impacts of surface characteristics such as small to medium scale roughness and slope on laser echo pulses under different realistic measurement scenarios and to assess how optical properties of ice/snow including reflectivity and angular scattering distribution, affect the statistics of photon return from the surface. This is of great significance since one of the issues the original ICESat mission experienced was detector saturation due to the assumption of Lambertian scattering on the ice/snow surface. This resulted in many echo pulses exceeding the linear dynamic range of the GLAS[2] instrument and consequently saturation of the detector electronics. If not corrected, this could cause a significant bias in the elevation measurements. The study will encompass both theoretical simulations using radiative transfer models and laboratory measurements on laser light scattering off of the ice/snow covered surfaces. Simulations aid in exploring the relationship between the instrument configuration, the expected performance and the terrain characteristics. As a complimentary approach, Bidirectional Reflectance Distribution Function (BRDF) measurements of the ice surface will be conducted by simulating the photon-counting laser altimeter concept in the laboratory. Furthermore, the analysis of ATLAS-like data provided by the MABEL[3] instrument will be another component of this study to develop algorithms for surface tracking over the ice sheets. The results of this work will aid in developing data processing and analysis methods for future ICESat-2 measurements in order to maximize its application to its science objectives.

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[1] Advanced Topographic Laser Altimeter System
[2] Geoscience Laser Altimeter System
[3] Multiple Altimeter Beam Experimental Lidar

Subglacial bathymetry beneath the Pine Island Glacier ice shelf from airborne gravity, constrained by autonomous underwater vehicle data

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Nearly two decades of satellite observations have revealed that Pine Island Glacier (PIG) is experiencing acceleration in its flow speed and rapidly losing mass. Oceanic influence has been identified to play a key role in the mass loss of PIG; warm Circumpolar Deep Water (CDW) penetrates in to Pine Island Bay and under the ice shelf, causing several tens of meters per year of melting under the ice shelf which leads to its thinning and speed-up of the flow. The delivery of the heat to the bottom of the ice shelf from the ocean is controlled by the bathymetry and the configuration of the cavity beneath the ice shelf that allows the access of the CDW. However, the subglacial cavity configuration is poorly known except along a few survey lines of an autonomous underwater vehicle (AUV) that was conducted in 2009 (Jenkins et al., 2010).

Here we present models of the subglacial bathymetery underneath the ice shelf of PIG inverted from the airborne gravity data acquired by the Operation IceBridge. Our aim is to improve the existing bathymetry model by constraining the inversion with several profiles of the seabed depth beneath the ice shelf gathered by an AUV. Gravity inversion is an inherently non-unique problem and interpretation of the result needs caution. Therefore, we attempt to quantify the uncertainty of the model by examining statistical measures of large number of models obtained by a method based on Simulated Annealing, as well as comparing the model given by a different approach (Parker-Oldenberg's algorithm).

Changes in the Antarctic surface mass balance since 1979: Perspective from five global reanalyses

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An intercomparison of the surface mass balance (precipitation minus evaporation/sublimation (P-E)) simulated by five global reanalyses (NCEP-2, JRA-25, ERA-Interim, MERRA and CFSR) was recently published. The primary purpose of the study was to report on some spurious trends in the reanalysis fields that could be related to changes in the observing system. The study concluded on the unsuitability of the some of the datasets for climate change assessment in high southern latitudes. This initial investigation focused on the 20-year period of overlap between the reanalyses (1989-2009), a relatively short period by Antarctic standards. The ERA-Interim dataset was recently extended back to 1979. The talk provides an updated overview of the changes in Antarctic P-E depicted by the different datasets during 1979-2010, with some emphasis on the West Antarctic Ice Sheet.

Interdecadal Climate Variability over Antarctica and Linkages to the Tropics: Analysis of Ice Core, Instrumental, and Tropical Proxy Data for the 19-20th Centuries

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The Antarctic continent holds most of the global ice and plays an important role in a changing climate. The nature and cause of Antarctic climate variability is, however, poorly understood beyond interannual time scales due to the paucity of long, reliable meteorological observations. The present study analyzes low-frequency climate variability over Antarctica using a network of annually-resolved ice core records and various instrumental and proxy data for the 19-20th centuries. During the 20th century, Antarctic ice core records indicate strong linkages to sea surface temperature (SST) variations in the tropical Pacific and Atlantic on decadal-interdecadal time scales. Antarctic surface temperature anomalies inferred from the ice cores are consistent with the associated changes in atmospheric circulation and thermal advection. A set of atmospheric general circulation model experiments supports the idea that the low-frequency SST variations in the tropics force atmospheric teleconnections that affect Antarctic surface temperatures. When coral records are used as proxies of tropical SSTs, similar Antarctic-tropical linkages are identified for the past two centuries. Over the past 50 years, a change in the phase of Pacific and Atlantic interdecadal variations may have contributed to the rapid warming of the Antarctic Peninsula and West Antarctica.

Control of the width of West Antarctic ice streams by internal melting in the ice sheet near the margins

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Could the 40 to 80 km widths of West Antarctic (Ross Shelf) ice streams be controlled by onset of melting within the ice sheet at the stream margins?

The streams are driven by gravity which is resisted by basal drag, inferred to be small, and by shear stress at the lateral margins, assuming longitudinal stress gradients are unimportant [Whilans & van der Veen, JG'93]. Lateral shear stress in the sheet scales with the difference between gravitational stress and basal drag, and increases linearly with the lateral distance X from the center of a stream. With increasing X, that lateral shear stress times the creep strain rate it induces becomes a significant heat source within the ice sheet (proportional to X^4 using Glen's law), and must induce internal melting.

We study this possibility using data for a set of 5 ice stream profiles (A, WNar, C, D, E) of Joughin et al. [JGR'02]. They used measured lateral shear strain rates at the margins, and a depth-averaged values of the Glen's law creep parameter, based on a 1-D conduction-advection heat transfer analysis, without internal heating, to estimate the lateral drag. We find that when we incorporate the product of their drag stress and strain rate as a source in a conductive heat transfer model, the predicted margin temperatures are in excess of melting over some depth range for all five profiles.

Next, we reformulated the 1-D vertical heat flux problem allowing some lower depth range of the of ice sheet to be partially melted ice at the melting temperature, with the rest of the sheet frozen and undergoing conductive heat transfer. The sheet was subjected to a uniform lateral shear rate, allowing the Glen's law parameter and local shear stress to be different for the two zones. The predicted fraction of the thickness that is molten, if any, depends on the lateral shear strain rate. For the profiles (A, WNar, C, D, E), the observed strain rates are respectively (1.2, 2.4, 0.6, 0.9, 1.9) times the levels at which internal melting should begin; with the exception of profile C, the results are compatible with the hypothesis that the margin is undergoing internal melting. Also, the model predicts that a 5% increase in lateral stress, and hence in ice stream width, is enough to go from onset of internal melting to melting half the thickness of the ice sheet.

The liquid production rate in the melting zone is also predicted. Using the permeability model of Nye and Franck [JG'73], melt rains downward via a vein system and reaches a Darcy flux of ~5 m/yr at the bed. We expect that the massive drainage associated with melting causes low fluid pressurized R-channel development; making effective normal stress on the bed adjacent to the channel notably larger than in the central regions of the stream. That is conjectured to lock the ice sheet to the bed outboard of the R-channel and hence create the limit to width of the stream of fast-flowing ice.

Seismic Analysis of the Subglacial Environment of Thwaites Glacier, West Antarctica

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[5]Center for the Remote Sensing of Ice Sheets (CReSIS)

Thwaites Glacier, one of the fastest and largest glaciers draining the West Antarctic Ice Sheet, is a prime candidate for inducing the potential catastrophic collapse of this marine ice sheet, given that this glacier is situated in an overdeepened basin that extends well into the interior of the ice sheet. While much attention has been given to the retreat, thinning, and acceleration near the grounding line, little is known on the subglacial environment of Thwaites Glacier far inland of the grounding line and how it may evolve in relation to these recent coastal fluctuations. Here we present the results of an active seismic survey performed along Thwaites Glacier to characterize the subglacial environment and determine its influence on the present and potential future ice dynamics in this sector of the ice sheet.

During the 2008-2009 Antarctic field season, 60 km of reflection seismic data were collected ~200 km inland of the current grounding line of Thwaites Glacier, West Antarctica, consisting of one 40-km profile along flow and two 10-km transverse profiles. Our seismic results highlight considerable variability in the shallow subglacial regime of the glacier, particularly in the spatial coverage of subglacial water and deformable sediment at the ice-bed interface. These detailed observations will allow modelers to more accurately conceptualize the subglacial environment, and to better predict how the interior of Thwaites Glacier will respond to the current perturbations near the grounding line.

LARISSA Glaciology – The Bruce Plateau Ice Cap: Ice Dynamics across the Antarctic Peninsula

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The Bruce Plateau is a broad, gently undulating ice plateau at 2000m elevation spanning the divide of the Antarctic Peninsula near 66^{o} S. The western side is the catchment area for the glaciers of inlet fjords such as Beascochea and Barilari Bays. The eastern side is the catchment area for the glaciers of the southern Larsen B Embayment and the northern Larsen C Ice Shelf. The LARISSA Project, an NSF-funded multi-disciplinary investigation of the region, has a series of observation sites located from the ice divide to the ice shelf: an ice core was drilled to bedrock in 2010 (447m of ice), instruments were installed on the Leppard and Flask Glaciers, and the Scar Inlet Ice Shelf of the southern Larsen B Embayment. We present the preliminary results of an observational and modeling analysis of the dynamics of the Bruce Plateau with respect to its role as the source region for the glaciers and ice shelves of the Larsen B Embayment and the western outlet fjords.

We use a suite of data from site installations and remote sensing efforts. Surface topography data are from NASA (including IceBridge Data) augmented with surface-based GPS profiles. We mapped bedrock and internal structure with a RES survey. We installed geophysical weather stations (AMIGOS) on Flask Glacier and the Scar Inlet Ice Shelf. On upper Leppard and Flask Glaciers we installed continuous GPS stations. We combined these surface velocity observations with InSAR-derived surface velocities.

Bedrock topography of the central Bruce Plateau near the ice core site consists of several hills with relief of several hundred meters. Ice thickness ranges from 200m above the hills to more than 700m deep in the troughs. The ice divide is up to 2 km to the west of the local bedrock divide. Accumulation at the ice core site ~1km east of the divide averaged ~2 m/yr between 1963 and 2010 (from beta radioactivity). Accumulation rates decrease by at least an order of magnitude towards the Larsen B Embayment. At the ice core site, mean annual temperature is -15.1^{o} C and the basal ice temperature is -11.2^{o} C.

Due to high accumulation rates, the Bruce Plateau ice slopes steeply from the divide and initiates channelized valley glacier flow within less than 5 km of the ice divide. The strong orographic precipitation pattern leads to steep, short glaciers ending in fjords on the warmer, wetter, western side of the Peninsula and more gently sloping, longer glaciers which end in ice shelves on the colder, drier, eastern side of the Peninsula. Recent warming and western-side sea ice loss has likely led to increased accumulation rates on the western side of the Antarctic Peninsula. Our radar data suggest a recent (within the top 150 m of internal layering) westward migration of the crest of the ridge. We confirmed this with finite element modeling of divide migration in response to change in accumulation. The timescale for the response of the divide to changes in accumulation rate is 25 years.

Using High-Resolution Commercial Satellite Imagery to Advance West Antarctic Ice Sheet Research Goals

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The Rapid Ice Sheet Change Observatory (RISCO) and the Polar Geospatial Center (PGC) acquired and processed 0.5 to 4 meter resolution commercial satellite imagery with a repeat frequency of 2 to 4 weeks during the austral summers from 2009 to 2011 over West Antarctic glaciers and mountain ranges. Specific areas of interest include the Fosdick Mountains, Pine Island Glacier, and Thwaites Glacier. RISCO and PGC also derived 4 meter digital elevation models (DEMs) using stereoscopic image pairs of high-interest WAIS research areas which had previously been modeled at only 200 meter to 5 kilometer resolution. Accurate DEMs are critical in correcting imagery, measuring glacier thickness changes, and modeling ice flow and surface melt water drainage. With a combination of the stereoscopically derived DEMs and frequent monoscopic imagery, researchers can observe glacial dynamics with an unprecedented synoptic view.

Logistical constraints severely limit the opportunities for field research in West Antarctica. And yet, because of its topography and glacial history, studying the West Antarctic Ice Sheet is crucial for our understanding of glacial processes, oceanography, and climate, both past and future. This high-resolution imagery can compensate for the difficulty of traditional field methods by providing temporal frequency, detailed spatial resolution, and accurate elevation models simultaneously.

Antarctic sea ice variability and the West Antarctic ice sheet

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Antarctica's remoteness, the difficulty of conducting research there and the paucity of observations, are some reasons why the Antarctic climate and sea ice variability are not as well understood as in the Arctic. However, research has shown that the climate of Antarctica including its sea ice is dictated by numerous influences with origins ranging from the Tropics to local atmosphere/surface interactions. Over the period of record indications are that much of Antarctica is warming, led by the Antarctic Peninsula. Regional changes in atmospheric circulation, sea surface temperatures and sea ice may explain this warming. Overall, sea ice extent is increasing, contrary to climate model predictions for the 21^{st} century, and this increase has strong regional and seasonal signatures. Sea ice variability is strongly influenced by ENSO, the Southern Hemisphere Annular Mode (SAM) and by zonal wave three (ZW3) among other large scale atmospheric circulation mechanisms. Using observations and global climate models, the Antarctic climate and sea ice variability are examined with respect to the atmospheric and modes that influence them. Potential influences on the West Antarctic ice sheet are discussed.

Basal topography of the Institute and Möller ice streams, West Antarctica: assessing the risk of grounding-line retreat.

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Grounding-line retreat into deep subglacial basins over reversed bed slopes is seen as a fundamental process by which marine-based ice sheets, such as the West Antarctic Ice Sheet (WAIS), undergo retreat and dynamic thinning. The potential risk posed by marine-ice-sheet instability has been assessed for the Ross and Amundsen Sea sectors of WAIS, where airborne radio-echo sounding (RES) datasets provide a comprehensive definition of basal topography. Since a reconnaissance aerogeophysical survey undertaken in the late 1970s, however, little new data have been acquired over large parts of the Weddell Sea sector of WAIS, significantly precluding evaluation of the risk posed by marine-ice-sheet instability within the third major drainage basin of WAIS.

During the austral summer 2010-11 a new geophysical dataset was acquired over the catchments of the Institute and Möller ice streams. 25,000 km of survey line were flown, acquiring RES, gravity, magnetic and lidar measurements. We use the RES data to describe the underlying geomorphology of these ice streams. Inland of their present grounding lines, the Institute and Möller ice streams are underlain by deep linear troughs (>1500 m below present sea level), characterized by steep reversed slopes with gradients exceeding those determined for the ice streams of the Amundsen Sea sector of WAIS. Basal reflections suggest the Institute and Möller troughs are floored with weak unconsolidated subglacial sediments, believed to have been deposited when the WAIS was less extensive than it is today. We use these findings to assess the sensitivity of the Institute and Möller ice streams to future grounding line retreat.

LARISSA Glaciology: Ongoing studies of borehole-derived surface temperature history, and continuing AMIGOS results and plans

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The Larsen Ice Shelf System, Antarctica (LARISSA) is an International Polar Year (2007-2009) multi-disciplinary investigation of physical and environmental changes in the region of the Larsen B Ice Shelf embayment. As part of the glaciological component, a series of studies are underway investigating the past climate history and ongoing response to climate change. Future work will integrate these observations with oceanography, marine geology, geophysics, and biosciences for the region.

One near-complete study (led by V. Zagorodnov) investigates a 430 m borehole thermal profile collected at the summit of the ice divide above the southwestern Larsen B and northwestern Larsen C, at the Bruce Plateau ('Site Beta') drill site. Inversion of this profile provides a 200-year proxy record of surface temperature at the drill site. AMIGOS (Automated Meteorology-Ice-Geophysics Observation Systems) thermal monitoring to 120 m at the same site shows that the thermal record measured shortly after drilling was stable for the following several months (i.e., there is no evidence of thermal disturbance from drilling). A comparison of the surface temperature record derived from the inversion at Site Beta with other proxy temperature records from manned weather stations, ice core analysis, and other borehole thermal inversions along an 18-degree latitude transect of the Peninsula region (Orcadas to Rutford Ice Stream) shows a consistent and interesting pattern of climate change for the past ~150 years. A multi-decade cool period occurred around the years 1890 – 1950 (0.5 to 1.0 C cooler than the long-term mean), followed by rapid warming (~1.5 C) in the 1950-2010 period that may have recently slowed or stopped.

Ongoing work with AMIGOS stations and cGPS stations located on two outlet glaciers draining the Bruce Plateau into the remnant Larsen B Ice Shelf (Scar Inlet Shelf area) show that climate in the past two summer seasons has been relatively cool, with few extensive melt events. An additional AMIGOS system, with a high-resolution camera, is planned for installation in November 2011 on a rock bluff overlooking the Scar Inlet Ice Shelf front.

- Multi-discipline system science in WAIS: PIG—LARISSA—WISSARD—Ice2Sea

Is West Antarctica running a tropical fever?

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Despite sparse in-situ data and uncertain satellite measurements, evidence is mounting that West Antarctic surface climate has warmed significantly in recent decades. Previously, the spatial patterns of temperature trends in Antarctica have been interpreted as the signature of a persistent positive trend in the Southern Annular Mode (SAM), which can be forced by stratospheric ozone depletion. However, we show that there is much more going on in Antarctica. We analyze multiple datasets (including in-situ, satellite, and statistical reconstructions) of Antarctic surface temperatures and related physical variables such as sea ice and atmospheric circulation. We find that along with an annual-mean trend during the past 50 years of about 0.1°C/decade averaged over Antarctica, there is a distinct seasonality to the trends, with insignificant change (and even some cooling) in austral summer and autumn in East Antarctica, contrasting with warming in austral winter and spring concentrate din the Peninsula and West Antarctica. Second, using a variety of polar and tropical observational datasets, we examine the seasonally dependent spatial patterns of tropical climate signals over Antarctica. It is observed that the strongest teleconnection of tropical and Antarctic climate occurs in the austral spring via the Pacific South American pattern (PSA), a wave train with a center of action in the South Pacific. A secondary tropical teleconnection operates in the austral summer and projects onto the SAM. Next, we use a statistical congruency analysis, together with modeling, to illustrate the contribution of tropical sea surface temperature (SST) trends to a trend in the PSA and the warming of West Antarctica in the austral spring. Similarly, trends in the SAM more than account for East Antarctic cooling trends in austral summer and autumn, though separating the roles of SST and ozone forcing remains a challenge. This has implications for our ability to predict 21st Century Antarctic climate change, as we cannot rely on estimates of a single forcing (e.g. stratospheric ozone) to accurately predict future changes. Further modeling studies by Steig et al. (this meeting and submitted manuscript) directly link tropical SST trends with wind changes in the South Pacific that have brought warm, circumpolar deepwater in contact with several outlet glaciers of the WAIS.

Bumpy beds, what to do about them

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Basal topography is one of the key factors controlling ice flow. Therefore, it is interesting to know how different models are able to simulate ice flow over bumpy beds. Comparison of a suite of numerical models demonstrates that solutions of the flowline model are dominated by large unphysical artifacts in both surface velocity and free-surface elevation when basal topography is strictly represented by the actual centerline basal topography profile. These simulations also show how well the basal topography needs to be resolved to make sure that the models perform well enough.

Initial Assessment of CryoSat-2 Performance

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Following the launch of CryoSat-2 in April 2010, we have examined the performance of the CryoSat-2 SAR Interferometer over the continental ice sheets of Antarctica and Greenland, the Arctic Ocean, and, for the purposes of calibration, over the oceans. Our aim has been to provide confirmation of the engineering performance of the radar interferometer, and to provide an initial geophysical validation of the resulting elevation measurements. We have confirmed the engineering performance at system level of the interferometer through performing a sequence of satellite rolls over the oceans, which provide a surface of known behavior and surface gradient. The activity has identified some errors in the SARIN L1b data products presently issued by ESA. Once corrected, the ocean calibration has demonstrated that the interferometer measures across-track surface slopes with a precision of 25 micro-radians and an accuracy of 10 micro-radians, which may be compared with a pre-launch estimation of 100 micro-radians; in short, the engineering performance greatly its the specification.

The elevation measurement over the ice sheets combines the interferometer measurement of across track slope with the range measurement deduced from the SAR echoes. We have examined the performance of the range estimation, and determined the range precision to be 19 cm RMS at 20 Hz. We have examined the retrieval of the phase information over the ice sheets, and found the phase estimates to be robust and little affected by the uncertain ice sheet topography. Based on the calibration of the interferometer, the contribution of the across track slope error is, at 0.4 mm, negligible. While the quantity of data available to us that contains the corrections identified by the interferometer is limited, we have been able to confirm the range precision values from a limited cross-over analysis.

Over marine sea ice, we have verified the discrimination of sea ice and ocean lead returns using contemporaneous SAR imagery from ENVISAT. Using one month's of data, we have determined an initial dynamic topography that agrees with a high resolution region ocean model to 4 cm. We have estimated the precision of individual (20 Hz) measurements to be 2 cm. We have combined estimated the Arctic ice thickness for January and February 2011, and made a preliminary comparison with contemporaneous in-situ and air-borne estimates of thickness which agree to 20 cm.

In summary, with the corrected data products, we are able to confirm that the system performance of CryoSat-2 will meet or exceed its specification over the continental and marine ice sheets.

Ongoing Changes in Glacier Elevation and Mass, Larsen A and B Embayments, Antarctic Peninsula

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Abstract
We investigate the elevation and mass balance response of northern Antarctic Peninsula tributary glaciers over the period 2001 to the present following the loss of the Larsen A and B ice shelves (in 1995 and 2002 respectively). Our study uses MODIS imagery to track ice extent, and ASTER and SPOT5 satellite stereo-image DEMs plus ATM, LVIS, and ICESat laser altimetry to track elevation changes, spanning the period 2001-2010. The measured Larsen B tributary glaciers (Hektoria, Green, Evans, Punchbowl, Jorum and Crane) have lost up to (165 m in elevation during 2001-2010. Elevation changes were small for the more southerly Flask and Leppard glaciers, which are still constrained by a remnant of the Larsen B Ice Shelf in Scar Inlet. In the Larsen A embayment, continued thinning of >3 m a^{-1} on Drygalski Glacier, 14 years after the Larsen A Ice Shelf disintegrated, suggests that mass losses for the exposed Larsen B tributaries will occur well into the future. Grounded ice volume losses now exceed 13 km^3 for the Crane Glacier and 30 km^3 for the Hektoria-Green-Evans glaciers. The combined mean loss rate for 2001-2006 is at least 11.2 Gt a^{-1} and continues into the Operation Ice Bridge (OIB) time frame. Our values differ significantly from other published mass-budget-based estimates for these embayments, but are a reasonable fraction of GRACE-derived rates for the overall northern Peninsula mass-loss region (~40 Gt a^{-1}).

Continuing the Whillans Ice Stream subglacial lake record with GPS

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The synthesis of multiple remote sensing missions over the Antarctic ice sheet have shown patterns of localized elevation change that are attributed to the surface expression of water flux into and out of subglacial lakes. The ICESat mission provided a precise, yet discontinuous, time-series of the elevation of these dynamic features from 2003 to 2009. To continue monitoring during the gap between the ICESat and ICESat-2 missions and to learn more about the relationship between subglacial lakes and ice sheet dynamics, we deployed twelve on-ice Global Position System (GPS) units on several subglacial lakes on the Whillans Ice Stream, Siple Coast, Antarctica. Here we evaluate the efficacy of GPS observations over subglacial lakes using 22 days of high-rate GPS data from seven sites (four on subglacial lakes, two on hypothesized flow paths away from a subglacial lake, and one on a local high point). We process the data using both double differencing (DD) and precise point positioning (PPP) methods to find that, although the DD baselines approach 100 km, DD processing techniques provide a more robust solution than any PPP implementation. We also investigate how the advection of a GPS unit downstream can contribute to a spurious signal in the vertical component. Assessing how well our data collection and processing methods capture subglacial lake dynamics is critical to determining how to effectively monitor these features remotely and ultimately to establishing the role of sub-ice hydrology within ice sheet dynamics.

Glacial-Interglacial History of the Transantarctic Mountains and the Southern Ross Sea Embayment

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Research into the glacial history of the Ross Embayment has concentrated on the northern half of the Transantarctic Mountains bordering the Ross Sea. This work has identified the general character of the most recent deglaciation (e.g. [1]), however details of the deglaciation further south are unclear. Additionally, very little is known about the southern Ross Sea's long-term glacial history over the past few million years. To improve our understanding of both the recent and long-term history of the southern Ross Embayment we are currently measuring cosmogenic nuclides in glacial deposits and bedrock samples collected in 2010-11 from mountains flanking Beardmore Glacier.

During the Last Glacial Maximum, ice draining into the Ross Sea at the mouth of Beardmore Glacier reached a maximum elevation of ~1050-1100 m. Initial Be-10 exposure ages from an elevation transect of glacial erratics on Mt Hope show that during the subsequent deglaciation, substantial ice loss occurred by or during the early Holocene, and that the grounding line had retreated to or past Beardmore Glacier by 7.5 ka. Substantial research in the northern Transantarctic Mountains and Ross Sea supports a rapid grounding-line retreat and deglaciation of the northern Ross Sea during this period. The data from Beardmore Glacier also agree with unpublished exposure ages from Scott Glacier [2] in the Southern Transantarctics, which show two episodes of rapid deglaciation at ~8 ka and ~6 ka separated by a few-hundred-year hiatus at ~7 ka. The deglaciation data is similar in timing and pattern to high-resolution eustatic sea-level data [3] suggesting that the observed sea-level rise was either caused by or the result of Ross Sea deglaciation.

To investigate the earlier glacial history of the southern Ross Sea we are measuring Be-10, Al-26, and Cl-36 in bedrock samples. These cosmogenic nuclides are produced in bedrock when it is exposed above glacier level; during glacial periods, they decay at different rates. At the base of Mt Hope, striated and glacially-carved bedrock suggest that subglacial erosion has removed the record of exposure during previous interglacial periods. In contrast, weathered bedrock higher on the mountain has survived prior glaciations and we expect it to retain a record of previous exposure. Although we cannot assign dates to specific glacial or interglacial periods, at each elevation we will determine 1) lower limits on the cumulative time exposed and cumulative time ice-covered during the past ~1-2 Myr, and 2) upper limits on the proportion of time each sample has been ice-free. Subglacial erosion may complicate the interpretation of these data. To distinguish the effects of erosion vs radioactive decay, we will measure Cl-36 produced in biotite by low-energy neutron capture in short bedrock depth profiles. In biotite, the Cl-36 depth profile is very sensitive to surface erosion, and will allow determination of erosion rates in the range of 0-2 m/Myr [4,5].

References:
[1] Conway, H. et al., (1999) Science, 286, 280-283.
[2] Stone, J. O. et al., unpublished.
[3] Bird, M. I. et al., (2010) Geology, 38, 803-806.
[4] Liu, B. et al., (1994) Water Resour. Res., 30, 3115-3125.
[5] Phillips, F. M. et al., (2001) Chem. Geo., 175, 689-701.

Tropical forcing of Circumpolar Deep Water inflow and outlet glacier thinning in the Amundsen Sea Embayment, West Antarctica, and its relationship to "global warming"

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Ice shelves and glaciers along the margin of the Antarctic ice sheet are thinning rapidly. The greatest thinning rates are occurring in the Amundsen Sea and western Antarctic Peninsula sectors of West Antarctica (Rignot et al., 2008). This region has also experienced significant climate changes, including rising temperatures (Vaughan et al., 2003; Steig et al., 2009), and declines in sea ice (Parkinson et al., 2002), both a result of changing atmospheric circulation (Fogt and Bromwich, 2006; Turner et al., 2009; Ding et al., 2011). There is good evidence that the climate and ice sheet changes are linked by the wind-driven intrusion of warm Circumpolar Deep Water (CDW) onto the continental shelf, which melts the ice shelves from below (Dinniman and Klinck, 2004; Thoma et al., 2008; Jenkins et al., 2010; Bindschadler et al., 2011).

These recent changes in atmospheric circulation in West Antarctica have not happened in isolation. It is well established that the direct radiative effects of both greenhouse gas increases in the troposphere and ozone depletion in the stratosphere have contributed to decreasing pressure over the Antarctic continent and a resulting increase in the circumpolar westerlies (Kushner and Held, 2001; Thompson and Solomon, 2002; Alabaster and Meehl, 2006) and intensification of the circumpolar current (Polvani et al., 2011). These changes are limited, however to austral summer, while in the Amundsen Sea Embayment, the largest changes in the local wind stress in the have occurred in fall and early winter (Steig and others, 2011). The evidence for a significant influence on circulation from the direct effects of radiative forcing, whether ozone-related or from tropospheric greenhouse gases, is equivocal at best (*cf.* Turner et al., 2009; Sigmond and Fyfe, 2011; Blanchard-Wriggleworth et al., 2011). On the other hand, it is clear that the significant rise in temperatures in the equatorial Pacific in the last 30 years has contributed to circulation changes over the Amundsen Sea, especially in austral winter and spring, via increased poleward-propagating Rossby waves (Schneider and others; 2011; Ding and others, 2011). The local ASE wind stress is significantly correlated with surface temperatures and rainfall (a measure of atmospheric divergence) over the central tropical Pacific, and this relationship is easily reproduced in atmospheric general circulation models. To the extent that recent changes in ASE glaciers a response to wind-driven ocean circulation changes, tropical forcing has therefore played a leading role.

It remains an open question whether the anomalously warm decade of the 1990s in the tropics reflects anthropogenic climate change (e.g. Trenberth and Hoar, 1997), or is simply 'decadal variability' (e.g. Latif et al., 1997). However, it is unequivocal that the 1990s (and 2000s) were the warmest decade of the last century in the tropical Pacific, and ice core evidence shows that, for West Antarctica, the 1990s were the most anomalous decade of the last 150 years (at least). Recent, large changes in Amundsen Sea climate, oceanography and ice dynamics are thus intimately tied in with the large-scale warming of the planet.

NASA's Operation IceBridge: using instrumented aircraft to bridge the observational gap between ICESat and ICESat-2 laser altimeter measurements

Michael Studinger and the IceBridge Science and Instrument Teams

NASA Goddard Space Flight Center

In 2009, the NASA satellite laser altimeter mission ICESat (Ice, Cloud and Land Elevation Satellite), which was launched in 2003, ceased to operate. To bridge the gap in polar laser observations between ICESat and its replacement ICESat-2, scheduled for launch in 2016, Operation IceBridge was initiated in 2009. From a series of yearly polar flights, Operation IceBridge uses airborne instruments to map rapidly changing areas in the Arctic and Antarctic, building on two decades of repeat airborne and satellite measurements. Combined with previous aircraft observations, as well as ICESat, CryoSat-2 and the forthcoming ICESat-2 observations, Operation IceBridge will produce a cross-calibrated 17-year time series of ice sheet and sea-ice elevation data over Antarctica, as well as a 27-year time series over Greenland. These time series will be a critical resource for predictive models of sea ice and ice sheet behavior. In addition to laser altimetry, Operation IceBridge is using a comprehensive suite of instruments to produce a three-dimensional view of the Arctic and Antarctic ice sheets, ice shelves and the sea ice. The suite includes two NASA laser altimeters, the Airborne Topographic Mapper (ATM) and the Land, Vegetation and Ice Sensor (LVIS); four radar systems from the University of Kansas' Center for Remote Sensing of Ice Sheets (CReSIS), a Ku-band radar altimeter, accumulation radar, snow radar and the Multichannel Coherent Radar Depth Sounder (MCoRDS); a Sander Geophysics airborne gravimeter (AIRGrav), a magnetometer and a high-resolution stereographic camera (DMS). Since its start in 2009, Operation IceBridge has deployed 5 geophysical survey aircraft, 16 science instruments, and has flown 1,613 hours during 181 science missions covering over 760,000 flight kilometer. All IceBridge data is freely available from NSIDC (http://nsidc.org/data/icebridge) 6 months after completion of a campaign.

Website: http://www.nasa.gov/icebridge/

Hosting a PolarTREC Teacher: A Method to Facilitate Antarctic Outreach and Dissemination of Research

Lesley Urasky

PolarTREC teacher 2010-2011
(Accompanied John Stone's field research (I-414): Constraints on the Last Ross Sea Ice Sheet from Glacial Deposits in the Southern Transantarctic Mountains)

The NSF funded PolarTREC program aims to advance polar science education and understanding by bringing K-12 educators and polar researchers together through hands-on field experiences. Through the pairing of researchers and teachers, PolarTREC is dedicated to:

- Improving teacher instructional practices, especially the use of inquiry-based learning to translate polar science to the classroom, thereby increasing student interest in science, technology, engineering, or mathematics (STEM) careers.
- Improving polar researchers' understanding and engagement in K-12 education to strengthen and enrich outreach and dissemination of research.

As part of the "Race to the Top" initiative, there are three national priorities for STEM education: 1) increasing STEM literacy so all students can think critically in science, math, engineering and technology; 2) improving the quality of math and science teaching so American students are no longer outperformed by those in other nations; 3) expanding STEM education and career opportunities for underrepresented groups, including women and minorities.

In order to address these priorities, there were two primary issues I hoped to better understand: 1) How to better bring scientific inquiry into the classroom; 2) Which skills students need to possess upon exiting high school in order to find success in science, math, and engineering disciplines.

During the 2010-2011 Antarctic field season I accompanied John Stone's (University of Washington) research group to their series of remote camps along the Beardmore Glacier. My role with the research team was to assist with collection of samples and data in the field. My function as a PolarTREC teacher was to enable students and the general public to experience the research project through the posting of daily journals, answering questions about the project through an "Ask-the-Team" forum, maintain a photo album, and to provide real-time "Polar Connect" webinars to students and community members around the world.

As a result of my participation in John Stone's research, students and community members have demonstrated an increased interest in Antarctica along with a desire to understand the current knowledge amassed by the scientific community. This experience has greatly enriched my ability to bring relevant science into the classroom and engage my students in learning. As a result of this opportunity, I have implemented the following into my instructional practices:

- Increased the number and quality of hands-on classroom activities and introduced new laboratory activities
- Developed new or revised content for lessons and laboratories
- Introduced new technologies in class and laboratory exercises
- Increased requirements for formal written and oral reports
- Discussed polar-related science careers and related jobs with students

The PolarTREC program matches teachers and researchers with similar scientific interests and outreach goals. There are many benefits to hosting a PolarTREC teacher during your field research. These include, but are not limited to:

- Fulfilling the outreach and education goals of your team, institution, and NSF's Broader Impacts
- Connect your research to new audiences and build connections to the education community
- Inspiring the next generation of polar scientists

Modeling the surface mass balance of the Antarctic ice sheet using RACMO2: recent progress and remaining uncertainties

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We report results of recent and ongoing efforts to model the surface mass balance (SMB) of the Antarctic ice sheet, using evaluated output of the regional atmospheric climate model RACMO2. The model is forced at the lateral boundaries by ERA-Interim data, and has a horizontal resolution of 27 km. The new albedo scheme generates a realistic melt distribution, and we present the spatial and temporal melt rate distribution in Antarctica, and compare it to satellite-detected melt frequency. RACMO2 now also includes a routine to simulate blowing snow, and we show that blowing snow sublimation is the largest ablation component of the Antarctic SMB. Together with snowdrift erosion, it accounts in a realistic fashion for the distribution of blue ice areas in Antarctica. We show how blowing snow and SMB characteristics in Adélie Land and Victoria Land change when the model is run at very high (5.5 km) resolution. Using model output to drive a firn densification model, we show how accumulation variability impacts ice sheet surface elevation, and compare the calculated elevation trends to those derived from ICESat (2003-2008). We briefly show some ice2sea/IPPC AR5 related results, for which the model was forced by a climate scenario-driven GCM until the year 2200. Finally, we discuss the upgrade of RACMO2 to the latest ECMWF physics cycle, which results in a more advanced treatment of surface processes, atmospheric shortwave/longwave radiation transport and cloud physics. We present the first results of the upgraded model and discuss the improvements in the climate representation when output is compared to the current model.

A viscoelastic flowline model applied to tidal forcing of Bindschadler Ice Stream, Antarctica

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The motion of Bindschadler Ice Stream, West Antarctica, is dominated by sliding over a weakly velocity-strengthening (nearly plastic) bed, according to analysis of kinematic GPS data with a new viscoelastic flowline model. Inversions of time-averaged velocity data with viscous ice-flow models can be consistent with multiple sliding laws, but propagation of velocity perturbations in a viscoelastic model can distinguish between sliding laws with different exponents. We develop such a model and apply it to a time series of velocity for the tidally modulated flow of Bindschadler Ice Stream (formerly Ice Stream D). Observed velocity perturbations are found to be consistent with a flow-law exponent $m \geq 8$, which indicates basal motion with a relatively weak till bed; lower exponents consistent with motion dominated by deformation within the ice over a hard or frozen bed are found to be unlikely. This result suggests that Bindschadler Ice Stream would respond rapidly to any future loss of buttressing from the Ross Ice Shelf.

Starting and stopping basal sliding on ice streams: New insights from Whillans Ice Plain, West Antarctica

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The bidaily speed-up events of the Whillans Ice Plain, West Antarctica, provide a unique glimpse into glacier basal mechanics. Our results locate the slip initiation south of Ice Raft A, closer to the grounding line and the southernmost extent of the Ross Ice Shelf. The initiation may be controlled by a discontinuity in basal boundary conditions at the suture between two ice streams. A strong correlation between the amplitude of seismic waves generated at the rupture front and the total slip achieved over the duration of the slip event (~ 30 min) suggests slip-predictable behavior, i.e., the ability to forecast the eventual slip based on the first minute of seismic radiation. Successive slip events propagate with different rupture speeds (100-300 m/s) that strongly correlate with the inter-event duration, suggestive of a healing mechanism. The basal stress conditions currently promote freezing during inter-event periods and melting during the speed-up events. We update the results of Walter et al. (2011) with new insights from data collected in the 2010/11 field season, as well as examination of archived far-field seismic data from the last decade.

Walter, J. I., E. E. Brodsky, S. Tulaczyk, S. Y. Schwartz, and R. Pettersson (2011), Transient slip events from near-field seismic and geodetic data on a glacier fault, Whillans Ice Plain, West Antarctica, J. Geophys. Res., 116, F01021, doi:10.1029/2010JF001754.

Spatial and temporal isotopic patterns across the West Antarctic Ice Sheet Divide from five new snowpits and firn cores

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Sub-annually resolved shallow firn and ice cores were collected during the 2010-2011 field season across the West Antarctic Ice Sheet (WAIS) divide. A high resolution depth-age relationship was determined through a combination of electrical conductivity (ECM), density, and isotope data. These new records are used to extend the existing isotope records over the central WAIS. A new core drilled 10 km from the WAIS divide deep-core site correlates significantly with the original ITASE core recovered from the same site, giving confidence in the utility of the new records. These new isotopic records are combined with existing isotopic records in the region to quantify the spatial and temporal patterns in the isotopes. These patterns are compared to temperature records over the same time period. The results of the isotope-temperature comparisons are used to re-evaluate the warming of the West Antarctic interior over recent decades; the proposed mechanisms (Steig et al., 2009) are regional changes in atmospheric circulation, sea surface temperature, and sea ice.

Subglacial Rivers and Thermal Structure in Dome A, East Antarctica

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Subglacial water both effects and is affected by the basal shear stress, mass balance, and thermal structure of continental ice sheets. We have used two different methods to locate subglacial water in the Gamburtsev Subglacial Mountains (GSM) in central East Antarctica from radio-echo sounding (RES) measurements. Manual picks and automatic reflectivity anomalies both indicate water in subglacial valleys upstream of the source regions for previously reported "valley head" accretion ice plumes, as well as in a number of other areas within the survey domain. The water bodies tend to cluster into networks defined by pathways in hydraulic potential, suggesting a transport system better described as subglacial rivers than as subglacial lakes. Many of these water networks have a complex morphology, with characteristic widths on the order of a kilometer and portions which appear to meander. In addition, simple one-dimensional thermal models suggest that the observed distribution of bed echo power with ice thickness is best fit by a a warm-bedded model. This provides further support for the concept of basal accretion, and also implies that the geothermal flux in the GSM is higher than previously believed, although closer to the global continental average.

Under the Antarctic ice: New data in the East, new approaches in the West

Duncan Young, Dusty Schroeder, Don Blankenship, Charles Jackson, and the ICECAP team

The success of IPY and the advent of Operation Ice Bridge, coupled with new developments in technology are significantly contributing to our understanding of the Earth ice sheets. Here we review radar sounding results from the recent campaigns in West and East Antarctica, acquired with fully coherent radar sounders. In East Antarctica, the geometry of the Aurora and Wilkes Subglacial basins are being reveled by IPY and OIB airborne radar surveys; we will discuss initial results from this new dataset. A significant new finding involves a highly modified subglacial landscape, including a richly fjordized landscape, in the interior of the ice sheet with important implications both for the long-term evolution of the ice sheet and the short term structure of the underlying subglacial hydrology. We also discuss the importance of the distribution of subglacial roughness in East Antarctica, and possible implications for sediment distribution.

More mature datasets exist in West Antarctica; we report on new methodologies for analyzing these data. We compare the information content of amplitude and specularity approaches for basal analysis, and discuss the implications for survey design. We also discuss higher order interpolation methods for these data.

Repeating Ruptures at David Glacier Modified by Tidal Influences

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We report on a pattern of repeating earthquakes originating from the base of David Glacier as it flows through the Transantarctic Mountains. The seismic events (with moment magnitude Mw=1.8) recurred regularly (approximately every 20 minutes) over a period of 275 days during 2002 and 2003. Before and after this 275-day period, the interval between events was random and irregular. The events are likely caused by an asperity beneath David Glacier that regularly releases stress accumulated by the flow of the glacier. We suggest that the change in seismic behavior is due to changes over time in debris concentration of the basal ice as relatively cleaner or dirtier ice is advected over the bedrock asperity. This results in the rheology of the ice-asperity contact also changing over time, leading to the observed seismicity patterns.

The location of the asperity resulting in the observed seismicity is approximately 55 km from the grounding line. David Glacier goes afloat and becomes the prominent Drygalski Ice tongue in the Ross Sea. The ice tongue is subject to the strong diurnal ocean tide. During the times of regular recurrence of seismicity, the inter-event time is approximately 22 minutes. Both the inter-event spacing and the magnitude of the events changes slowly over time, and are related to tidal amplitudes. There is a lag between the tidal amplitude maxima and the inter-event spacing maxima, and that phase lag is also related to the dominant tidal periods.

During periods of high tide the mean inter-event time is longest, which likely results from backpressure of the tides end loading the glacier. It is theorized that the added backpressure causes a decrease in flow velocity resulting in less displacement at the asperity as well as a longer healing period at the ice-rock interface. This increased healing results in a stronger ice-bed interface at the time of slip, which leads to higher magnitude events.

Mass Balance of the West Antarctic Ice-Sheet from ICESat Measurements

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Mass balance estimates for 2003-2008 are derived from ICESat laser altimetry and compared with estimates for 1992-2002 derived from ERS radar altimetry. The net mass balance of 3 drainage systems (Pine Island, Thwaites/Smith, and the coast of Marie Bryd) for 2003-2008 is a loss of 100 Gt/yr, which increased from a loss of 70 Gt/yr for the earlier period. The DS including the Bindschadler and MacAyeal ice streams draining into the Ross Ice Shelf has a mass gain of 11 Gt/yr for 2003-2008, compared to an earlier loss of 7 Gt/yr. The DS including the Whillans and Kamb ice streams has a mass gain of 12 Gt/yr, including a significant thickening on the upper part of the Kamb DS, compared to a earlier gain of 6 Gt/yr (includes interpolation for a large portion of the DS). The other two DS discharging into the Ronne Ice Shelf and the northern Ellsworth Coast have a mass gain of 39 Gt/yr, compared to a gain of 4 Gt/yr for the earlier period. Overall, the increased losses of 30 Gt/yr in the Pine Island, Thwaites/Smith, and the coast of Marie Bryd DSs are exceeded by increased gains of 59 Gt/yr in the other 4 DS. Overall, the mass loss from the West Antarctic ice sheet has decreased to 38 Gt/yr from the earlier loss of 67 Gt/yr, reducing the contribution to sea level rise to 0.11 mm/yr from 0.19 mm/yr.