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Collaborative Research: Byrd Glacier Flow Dynamics

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Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0944087
Project Title:	Collaborative Research: Byrd Glacier Flow Dynamics
PD/PI Name:	Gordon S Hamilton, Principal Investigator
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Project/Grant Period:	08/15/2010 - 07/31/2014
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Submitting Official (if other than PD\PI):	Gordon S Hamilton Principal Investigator
Submission Date:	02/06/2015
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Gordon S Hamilton

Accomplishments

* What are the major goals of the project?

The overall aim of our proposed work is to improve our understanding of outlet glacier dynamics in East Antarctica through an in-depth field study of Byrd Glacier. We seek to test several hypotheses:

Byrd Glacier experiences variability in flow speed at a variety of timescales (daily to seasonal to annual) as a

response to tidal and hydrological forcings;

2. the configuration of Byrd Glacier's grounding line makes it susceptible to rapid retreat up the fjord;

3. subglacial lakes in the catchment fill and drain on a regular basis and provide periodic forcing of a glacier flow response.

These hypotheses are being tested using data collected by a dense network of GPS receivers deployed on the grounded glacier and floating ice shelf. We expect our work to provide new insights into the basal boundary conditions of "isbræ"-type outlet glaciers, and the effect of transient perturbations (e.g., ocean tides, subglacial floods) on their flow regime.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: Our major research activities were to (i) conduct collaborative fieldwork to understand the variability in flow on Byrd Glacier, one of Antarctica's largest outlet glaciers; (ii) carry out remote sensing studies of Byrd Glacier to extend the temporal context of our field observations; and (iii) perform a series of numerical experiments to investigate the response of Byrd Glacier to perturbations in its basal hydrology.

Our major educational activities were the advising of a PhD-level graduate student and training of several other graduate students in polar field work.

Specific Objectives: The specific objectives of the UMaine contribution to this project were to;

1. observe and understand variability in the flow dynamics of Byrd Glacier
2. use GPS methods to determine the grounding line position
3. use numerical modeling to investigate the response of Byrd Glacier to changes in basal hydrology.

Significant Results: An extensive network consisting of 29 GPS receivers was deployed on Byrd Glacier during the 2010-2011 and 2011-2012 austral summer seasons. A smaller austral summer network (10 receivers) was deployed in the 2012-2013 season. A reduced network density (8 GPS receivers) operated during the winter periods. The network was dismantled and all receivers were recovered in February 2013. The network extended from the interior catchment to the Ross Ice Shelf. Data were collected at 5 s intervals. Deployments were very successful, with 92% complete data acquisition (one summer station had an equipment failure shortly after deployment in 2010; all other summer stations have 100% complete records). Winter data acquisition is 100% complete (28 months) for one station on the main trunk of Byrd Glacier, and 69-82% complete for other stations; gaps in the time series are due to insufficient power during periods of polar darkness, mostly because of the failure of wind generators.

We have carried out an initial processing of all data (November 2010 through February 2013) for the purposes of assuring data quality. Data were post-processed using the GIPSY software package which yields precise point positions (PPP) at 30 s epochs. We plan to re-process the entire time series at the full high-rate sampling interval of 5 s.

Of particular interest is the 2-yr time series of GPS observations obtained at two sites overlying the locations of subglacial lakes. We previously hypothesized that the filling/draining cycle of the subglacial lakes must exceed seven years, based on the temporal resolution of our remote sensing record of ice speeds and the lack of previously observed speed-up events. If this were the case, we would expect our GPS receivers to show continuous uplift at both sites as they continue to fill from their last known flood in 2005-2007. Instead, our GPS observations appear to show there is an active regime of lake filling and draining, with a periodicity of about one year (Figure 1, attached). We tested alternative explanations for the observed vertical height changes. For markers installed in polar snow, some of the vertical GPS signal is due to compaction of firn beneath the depth at which the marker is anchored. We discount this explanation because it does not account for the sinusoidal pattern of vertical motion (upwards as well as downwards). Second, for markers installed on an inclined slope, some of the vertical motion can be explained by motion down- (or up-)slope. We know the speed of these markers (approximately 48 m/yr from our GPS observations), so we can estimate the slopes necessary to account for the observed vertical height change. These turn out to be two orders of magnitude steeper than measured surface slopes in the study area. Based on this analysis, we conclude that the sinusoidal vertical motions shown in Figure 1 are due to the filling and draining of the subglacial lakes. This result is the first observation of a rapidly-evolving subglacial drainage regime in East Antarctica.

The patterns of vertical deflection are not quite in phase for the two lakes. As the upstream lake is draining, the downstream lake begins to fill (Figure 1). The upstream lake begins to refill prior to the complete drainage of the downstream lake, although gaps in the data coverage prevent a more detailed assessment. Interestingly, the vertical deflections are different for both lakes. The upstream lake experiences almost 4 m peak-to-peak height change over its filling/draining cycle, while the downstream lake has a more modest ~1 m deflection peak-to-peak (Figure 1). These differences are probably a reflection of different lake basin geometries. While a 4 m peak-to-peak difference seems like a large change, it is only ~50% of the observed vertical change during the 2005-2007 event. We do not currently have an explanation for this difference.

In order to evaluate the influence of subglacial hydrology on the flow dynamics of Byrd Glacier, we coupled a subglacial water-flow model to the University of Maine Ice Sheet Model (UMISM). UMISM is a map-plane model which simulates ice dynamics using the shallow ice approximation. We implement the basal water model through coupling to the vertical temperature profile of the ice and a sliding law. A flux relationship is used to model the movement of subglacial water, similar to modeling the flow of ice.

The water model provides the equilibrium basal water depth and

enables us to investigate the impact of sliding processes on ice dynamics in the Byrd Glacier catchment region. We also tested to what extent the model can reproduce the observed acceleration of Byrd Glacier. Input geometry comes from the bedmap2 dataset and a new CReSIS (Center for Remote Sensing of Ice Sheets) ice surface elevation and bedrock elevation dataset collected at the same time as this project. Bedmap2 has a gridded resolution of 1km whereas the CReSIS data were provided as a grid with 0.5km resolution.

Model simulations showed that basal melting occurs extensively throughout the Byrd Glacier catchment, with water layer thicknesses on the order of 1-3 mm (thickest near the head of glacier where converging flow enters the fjord) (Figure 2). We simulated the effect of 2005-2007 subglacial lake flood and showed that the inferred volume of water discharged in the flood is able to explain the observed change in glacier speed (Figure 3). Moreover, the simulation helped refine the timing and magnitude of the peak velocity changes. Previous analysis of the remote sensing time series showed that peak speeds approached 900 m/yr and were reached approximately 12 months after the onset of the flood. In our model, we find that the peak speeds were slightly faster (~980 m/yr) and occurred three months after the onset of lake drainage. In this regard, numerical models are able to give new insights where the sparse remote sensing data can not.

In other numerical experiments, we tested the response of Byrd Glacier to smaller drainage events (~10-20% of the flood volumes in 2005-2007). In general, floods of this magnitude lead to an increase in flow velocities of about 2-10% for the trunk of Byrd Glacier, indicating that even small floods can cause a measurable acceleration of the ice.

Key outcomes or Other achievements: See products in next section.

*** What opportunities for training and professional development has the project provided?**

This project has provided research and training opportunities for two female PhD students at the University of Maine. Jessica Scheick focused on the processing and analysis of the GPS time series. Nora Weitz focused on numerical modeling of the interaction between subglacial hydrology and the flow of Byrd Glacier. Both students have received training in research methods, field experimentation, responsible conduct of research, and communication skills.

*** How have the results been disseminated to communities of interest?**

We have communicated results from this project to our peers at professional meetings (Fall AGU 2012, US CLIVAR Workshop on Ice-Ocean Interactions 2013) and in manuscript submitted to peer-reviewed journals. Project activities have also been incorporated into outreach presentations to school and non-community groups, and results have been used in the PIs university courses.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
ODD 0044087 final	Figures to accompany Significant Results	Gordon Hamilton	02/06/2015

Products

Books

Book Chapters

Conference Papers and Presentations

Weitz, N.A., G.S. Hamilton, J.L. Fastook (2012). *Simulating rapid changes of outlet glaciers using an embedded numerical model*. American Geophysical Union, 2012 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions

Journals

Weitz, N.A., G.S. Hamilton and J.L. Fastook (2015). The subglacial water system of the Byrd Glacier catchment region and its impact on flow dynamics. *Earth and Planetary Science Letters*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Weitz, N.A.. *Modeling glaciers and ice sheets in Greenland and Antarctica with an emphasis on embedded modeling and subglacial hydrology*. (2014). University of Maine. Acknowledgement of Federal Support = Yes

Websites

Byrd Glacier data

http://gcmd.nasa.gov/getdif.htm?Byrd_flow_dynamics

Repository for data collected during this project (GPS observations) and derived products (ice velocities).

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Hamilton, Gordon	PD/PI	4
Scheick, Jessica	Graduate Student (research assistant)	12
Schild, Kristin	Graduate Student (research assistant)	1
Weitz, Nora	Graduate Student (research assistant)	12

Full details of individuals who have worked on the project:

Gordon S Hamilton**Email:** gordon.hamilton@maine.edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 4

Contribution to the Project: Dr Hamilton directed the UMaine component of the project. He prepared the logistics worksheets for the project prior to each field campaign. As UMaine PI, he participated in all field work, carried out data analysis and interpretation, and advised students working on the project.

Funding Support: This award, and academic year salary from UMaine

International Collaboration: Yes, Spain

International Travel: Yes, Antarctica - 0 years, 3 months, 0 days

Jessica Barbara Scheick**Email:** jessica.scheick@maine.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 12

Contribution to the Project: Ms Scheick is a PhD student working under Dr Hamilton's guidance. She was primarily responsible for the geodetic processing and analysis of GPS observations collected in the field. Ms Scheick deployed to Antarctica for fieldwork as part of her involvement.

Funding Support: This award for 1 year, and follow-on support as part of an NSF IGERT fellowship.

International Collaboration: Yes, Spain

International Travel: Yes, Antarctica - 0 years, 1 months, 0 days

Kristin Meredith Schild**Email:** Kristin.M.Schild.GR@dartmouth.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 1

Contribution to the Project: Ms Schild participated in one season of Antarctic fieldwork (she is a former MS student of Dr Hamilton, and currently a PhD student at Dartmouth College).

Funding Support: This award.

International Collaboration: No

International Travel: Yes, Antarctica - 0 years, 1 months, 0 days

Nora Amelie Weitz**Email:** nora.weitz@maine.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 12

Contribution to the Project: Ms Weitz was a PhD student working under Dr Hamilton's guidance. She was responsible for the numerical modeling contributions to this project, including model code development, data set preparation, running model simulations, and interpreting results. She also participated in fieldwork.

Funding Support: This award.

International Collaboration: No

International Travel: Yes, Antarctica - 0 years, 1 months, 0 days

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Pedro Elosegui	Other Organizations (foreign or domestic)	Barcelona, Spain
University of Kansas	Academic Institution	Lawrence, KS

Full details of organizations that have been involved as partners:

Pedro Elosegui

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Barcelona, Spain

Partner's Contribution to the Project:

In-Kind Support

Collaborative Research

More Detail on Partner and Contribution: We collaborated closely with Dr Elosegui on details of the GPS network design, and in aspects of the GPS data processing.

University of Kansas

Organization Type: Academic Institution

Organization Location: Lawrence, KS

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Dr Stearns is overall project director. We are collaborating closely on all aspects of this project, including joint field campaigns, exchange visits, and joint advising of project graduate students.

What other collaborators or contacts have been involved?

YES

Impacts

What is the impact on the development of the principal discipline(s) of the project?

This project was the first detailed examination of an outlet glacier draining through the Transantarctic Mountains (TAM). These glaciers drain a significant fraction of Earth's largest ice sheet (the East Antarctic Ice Sheet), yet their dynamics are largely unknown which makes it difficult to predict future behavior. Based on this project, we now know

that TAM outlet glaciers are sensitive to perturbations in subglacial water distribution, i.e., they are able to change speed on relatively short timescales. This behavior is essential to include in numerical models of future ice sheet changes and their contribution to sea level rise.

What is the impact on other disciplines?

The GPS data collected during this project have been used to develop improved processing schemes for geodetic analysis. These processing schemes are relevant to any application requiring precise positioning (geoscience, engineering, etc.).

What is the impact on the development of human resources?

This project provided new opportunities for collaborative research and trained several scientists on observational glaciology, geodesy, instrumentation and numerical modeling. These scientists have in turn communicated this knowledge to other researchers and students (by way of workshops and presentations at specialized conferences, and by incorporating project materials in pedagogical activities).

The project supported several female graduate students and contributed to the growing number of women in STEM-intensive disciplines. All students involved in the project have continued with glaciological research at UMaine or other institutions, and a female PhD student who graduated has moved into a postdoctoral position at another university.

What is the impact on physical resources that form infrastructure?

The project contributed to our community's ability to make observations in rugged and challenging environments. Our achievements include the development of low-power, field-transportable easily-installed GPS stations for polar environments, the development of techniques and protocols to deploy instrumentation in hazardous environments (e.g., GPS receivers on heavily-crevassed glaciers), and the successful demonstration of helicopter-intensive logistics as a tool for Antarctic glaciology.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

This project has generated unique time series of observations of ice motion for a large Antarctic outlet glacier.

What is the impact on technology transfer?

The project involved the development and testing of renewable power systems for remote instrumentation. Results are potentially transferable to commercial instrumentation used for unattended monitoring networks.

What is the impact on society beyond science and technology?

Results of this study have contributed to our understanding of the coupling between hydrology and ice sheet dynamics, and will help inform predictions of future sea level rise.

Changes/Problems

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

GPS data processing is not yet complete because the student working on this analysis took a 2-yr gap to participate in an interdisciplinary training program in climate sciences and policy, during which time she was an NSF IGERT fellow. The student has now returned to the Byrd Glacier analysis and will be completing the work as the core part of her PhD

thesis.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.