Presidential Faculty/Student Collaboration and Publication Grant
Deadline Monday, February 20, 2017

Please use this checklist and budget. Include with your completed application. For more information about Presidential Faculty/Student Collaboration and Publication grants, please see https://gustavus.edu/kendallcenter/grant-opportunities/presidential-grant.php.

FACULTY INFORMATION

Name: Jeff La Frenierre   Email: jlafreni@gustavus.edu

Department: Geography   Rank: Assistant Professor

STUDENT INFORMATION

Name: Casey Decker   Email:cdecker@gustavus.edu

Major(s): Geography and Geology   Graduation Year: 2018

CHECKLIST

Project Details

☒ Brief description of the proposed project including its collaborative nature

☒ Clear statement of anticipated outcomes

☒ Likely placement for publication or performances

☒ Anticipated research completion date

x

Participant Details

☒ Names and brief biographies of all participants

☒ Explanation of how this project fits into the career of the faculty member
Note: Applications from faculty at all career stages are encouraged

☒ Explanation of how this project fits into the educational trajectory of the student
Note: Statement should be written by the student; include year of graduation; student eligibility is limited to full-time returning students

☒ **Presidential Budget Proposal Form**

☒ If successful, my proposal can be used as an example to assist future applications. Check to give permission. This decision will not influence the application evaluation.

Submit electronically as a PDF to cblaukat@gustavus.edu at the John S. Kendall Center for Engaged Learning.

Presidential Faculty/Student Collaboration Grant

Budget Information

Faculty Stipend ($300 per week, up to $3,000 for a maximum of 10 weeks)
Student Summer Stipend ($400 per week, up to $4,000 for a maximum of 10 weeks)
Student Summer Campus Housing ($60 per week, for a maximum of 10 weeks)
Budget Maximum ($8,100 for all categories)

Item		**Amount**
Equipment (e.g., transcription machine, camera, cassette recorder – but not to include computer hardware)		**$ 700**
1: Misc. hardware	Cost:	$700
2:	Cost:	
3:	Cost:	
Materials (e.g., books, printing, software, lab supplies)		**$**
1:	Cost:	
2:	Cost:	
3:	Cost:	
Travel Costs (cannot include conference travel, see http://gustavus.edu/finance/travel.php for allowable travel expenses)		**$ 5,090**
Airfare:		$2,100
Transportation (4WD Rental + gasoline)		$1,675
Lodging:		$840
Meals:		$475
Stipends & Housing		**$ 5,140**
Faculty Stipend	$300 per week, up to $3,000 for a maximum of 10 weeks	**$2,100**
Student Summer Stipend	$400 per week, up to $4,000 for a maximum of 10 weeks	**$2,800**
Student Summer Campus Housing	$60 per week, up to 10 weeks	**$240**
Total Expenses		**$ 10,930**
Amount Requested (Total Expenses + Requested Stipends + Housing)		**$ 8,100**

Have you applied for, or received funding from, another source to help support this project? (If no, skip a, b, and c below.)

☒ Yes ☐ No

a. Funding Source: **A: Sigma Xi Student Grant; B: Environmental Studies Collaboration Grant**
b. Amount: **A: $500; B: $2,330**
c. Please explain how the Presidential grant will be used in addition to the other funding, and (if relevant), how the Presidential grant project would be impacted if external funding is not approved.

If one or more of these requests is not approved, La Frenierre will convert his full stipend request to cover travel expenses while Decker will reduce his stipend and summer housing by 1 week.

Geodetic Mass Balance Monitoring of Tropical Glaciers Using an Unmanned Aerial Vehicle

Jeff La Frenierre, Department of Geography
Casey Decker, Geography and Geology '18

Description of Proposed Project

Background

Tropical mountain glaciers are both highly sensitive indicators of climate change (Kaser and Osmaston 2002) and critical water sources for millions of people who live downstream (Immerzeel, Van Beek et al. 2010, Mark, Bury et al. 2010). High altitude tropical regions such as the Andes of Columbia, Ecuador, Peru, and Bolivia have been identified as places where atmospheric warming over the next century may be most pronounced (Bradley, Vuille et al. 2006), and over the past several decades glacier retreat has been nearly ubiquitous in this area (Rabatel, Francou et al. 2013). The degree of anticipated warming is so significant that widespread deglaciation in the tropical Andes over the next few centuries is not out of the question (Bradley, Keimig et al. 2009).

Since 2009, Jeff La Frenierre has been investigating the impacts of climate change in Ecuador, focusing specifically on the hydrologic response to glacier change – and its implications for downstream water users – at Volcán Chimborazo, a 6279-meter (~20,700 feet) ice-capped volcano that is the country's tallest mountain. La Frenierre's dissertation research, completed in 2014, identified a considerable degree of climate change vulnerability on the part of agrarian communities near the mountain, but was only able to partly resolve the importance of glacier melt for local water users (La Frenierre 2014). In 2015, La Frenierre began a long-term collaboration with two early-career hydrologists at the University of Minnesota Department of Earth Sciences, Gene-Hua Crystal Ng and Andrew Wickert, to better understand the role of glacier meltwater in recharging local groundwater supplies, which are heavily exploited by local communities for domestic usage and irrigation. Over the past two years, the three principle investigators have invested in field instrumentation and data collection to develop a hydrological model that can help to describe these complex systems (here and elsewhere in the tropical Andes) and predict their response to future climate change. Important initial fieldwork for this new phase of research was supported by a 2015 Presidential Faculty/Student Collaboration Grant awarded to La Frenierre and geography student Helen Thompson ('17).

One key challenge to answering these questions has been to quantify the rate at which glaciers in the tropical Andes are losing ice volume. Such data is greatly limited in this region due to the complexity of glacier melt processes, the remote locations of most tropical glaciers, and an overall lack of institutional capacity to monitor multiple glaciers in these developing countries. While there has been success in measuring ice surface area loss, including at Chimborazo (La Frenierre and Mark in press; see Figure 1), such two-dimensional glacier change measurements cannot be directly converted into a water-equivalent, something necessary to assess the proportional contribution of glacier melt in a watershed. This is especially important given the high dynamism of glacier response to climate change, where even adjacent glaciers may behave quite differently from one another. While our research group is able to estimate glacier meltwater contributions by analyzing the different chemical characteristics in various surface waters, our research into the groundwater component of glacier meltwater runoff requires us to measure exactly how ice volume changes on specific glaciers over defined periods of time.

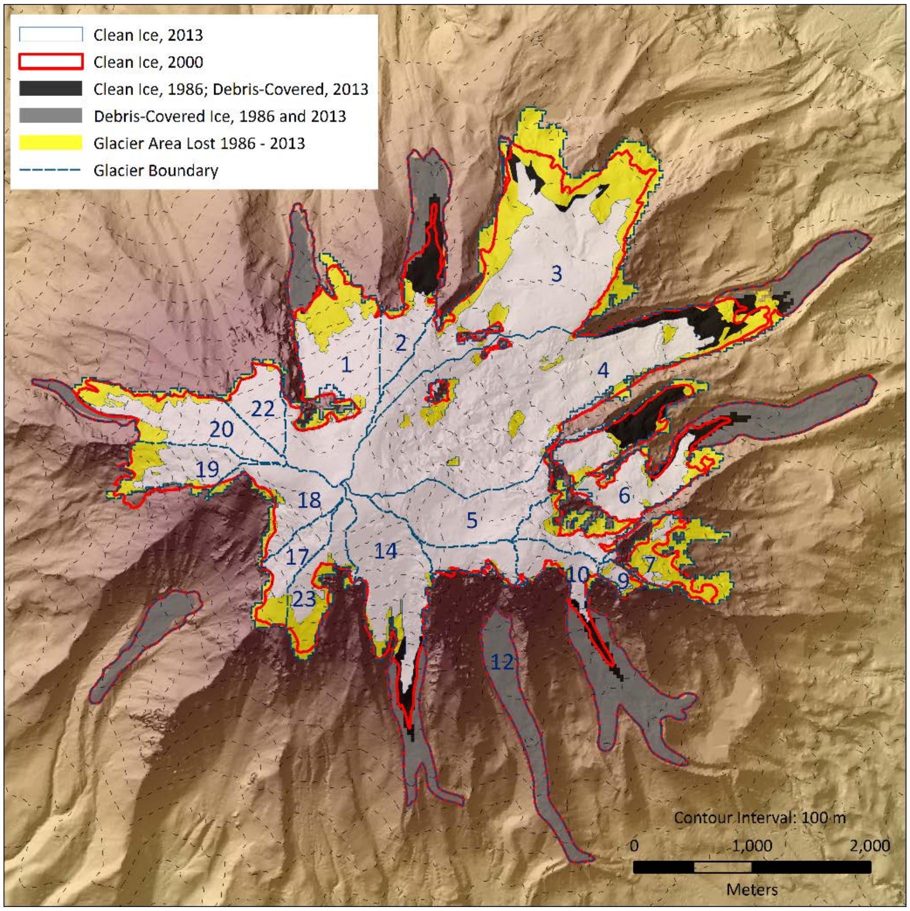

Figure 1: Glacier surface area loss at Volcán Chimborazo, 1986-2013. Numbers refer to individual glaciers.

One approach to quantifying ice volume change (known in glaciology as mass balance monitoring) is to perform repeated geodetic measurements of the glacier surface. In essence, this involves making high-resolution, three-dimensional surface terrain models of the glacier surface at different times, then comparing the two models to see how surface elevation has changed over that period of time. If the elevation has increased, then it can be assumed that the glacier has gained ice mass whereas elevation loss represents net ice melt. By integrating such changes over the entire glacier surface, and converting the measured change in ice mass to a water volume equivalent, it is possible to state with reasonable certainty the quantity of water that has been generated by the glacier over that time interval. Various approaches for making repeat geodetic mass balance measurements have been developed over the past 10-15 years, including the use of spaceborne radar or aerial reflected-light sensors, however the low resolution (spaceborne) and great acquisition expense (aerial) limits the utility of these approaches for site specific research. A ground-based reflected-light sensor (called a terrestrial laser scanner) provides another option, and this technique was used by La Frenierre to create surface models of one portion of one of Chimborazo's glaciers in 2012 and 2013 (Figure 2). However, this equipment is difficult to transport to remote locations and costs hundreds of thousands of dollars, putting it beyond reach for this research. A third geodetic approach that has been developed in the last five years involves the use of small, autonomous "unmanned aerial vehicles" (UAVs, aka drones) to capture hundreds of digital photographs of a surface that are then processed using photogrammetric software to create a three-dimensional, elevation-corrected surface model. To this end, La Frenierre and Charles Niederriter (Physics) have collaborated to build a research-grade UAV for less than $5,000 (Figure 3). Based on an operational UAV developed by a graduate-school colleague of La Frenierre's, the UAV is now complete and ready for field research.

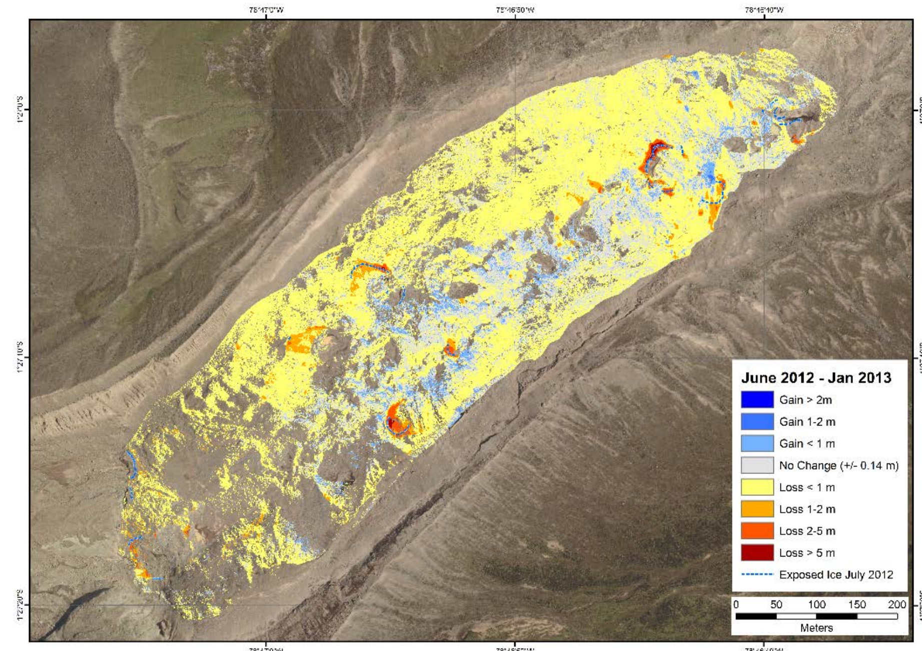

Figure 2: Mass balance changes on the lower Reschreiter Glacier derived from terrestrial laser scanning analysis in June 2012 and January 2013.

Figure 3: The Gustavus UAV

Proposed Research

We propose to use requested Presidential Faculty-Student Collaboration Grant funds to support a June 2017 field campaign to create surface terrain models of two Chimborazo glaciers. These terrain models will be used to quantify glacier mass balance change changes at the headwaters of the Rio Mocha watershed, the drainage basin for which our hydrologic model of Chimborazo glacier melt/groundwater processes is being built. With this grant, we will:

1. Perform all fieldwork necessary to create new surface terrain models of the stagnant, debris-covered tongue of the Reschreiter Glacier (glacier #4 in Figure 1), a rapidly-detaching but still active clean-ice section of the Reschreiter Glacier, and the active, clean-ice tongue of the adjacent Hans Meyer Glacier (glacier #3 in Figure 1). This work includes establishing Global Position System (GPS) ground control, and using the UAV to collect imagery over each ice area.
2. Process the imagery using photogrammetric software to create sub-meter resolution surface terrain models of each glacier segment.
3. Analyze the Reschreiter tongue surface terrain model in conjunction with the 2013 terrestrial laser scanner surface model to quantify ice mass loss in this section of the glacier over the 42 month interval between measurements. (Surface terrain models for the other two glacier segments will be used as baselines against which future geodetic mass balance measurements will be compared).
4. Quantify the proportional contribution of meltwater generated by the debris-covered tongue of the Reschreiter Glacier to watershed discharge over the 42-month interval by comparing calculated ice mass loss to data from continuous streamflow measurements made approximately 3 km downstream over the same time. (This information will ultimately be used to help constrain the hydrological model at the core of this research).
5. Fine-tune operational procedures for UAV data collection and processing and create a user manual for future research using this instrument.

Decker and La Frenierre will work closely through all phases of this research, with the ultimate objective of Decker assuming co-leadership of UAV operation in the field and taking a lead role in subsequent image processing. Decker has already been an active participant in the development and maintenance of the UAV, and briefly piloted it during its recent first flight tests. Before departure to Ecuador in June, he will also work to complete the training necessary to program a data-collection flight plan into the flight control software and ensure that he is capable of performing maintenance (and, if necessary, repair) of the UAV in the field. While in Ecuador, La Frenierre will be responsible for flight-planning and most manual UAV piloting (note that UAV typically flies autonomously using a pre-programmed flight plan), while working jointly with Decker to set GPS ground-control at different points adjacent to the glacier surface. Eventually, Decker will assume some flight planning and operational responsibilities. Decker and La Frenierre will also work together to download instrumental data from previously-established meteorological, hydrological, and glaciological stations, and maintain and repair these sites as necessary. La Frenierre and Decker will also work with Ng and other University of Minnesota participants on other field data collection tasks. Upon return from Ecuador, Decker will assume leadership for image processing using the Agisoft Photo Scan photogrammetric software and will assist La Frenierre in subsequent glacier change analysis using GIS software. Because this will be the first project undertaken with the UAV, Decker will also assume leadership for developing a data collection and operational procedures user manual that will support subsequent projects in Ecuador, Minnesota, and potentially elsewhere.

<u>Anticipated Project Outcomes and Publication Outlets</u>

1. *Scholarly presentations:* La Frenierre and Decker will jointly create a research poster that Decker will present at a major 2017-2018 geoscience conference (most likely the Fall Meeting of the American Geophysical Union in December 2017). Decker will also present results at on- and off-campus undergraduate research forums such as the 2018 Celebration of Creative Inquiry and the 2018 Midwest Undergraduate Geography Symposium (MUGS).
2. *Peer-reviewed publications:* La Frenierre expects to submit a manuscript describing ice mass loss on the lower Reschreiter Glacier that is based on this research for publication in a peer-reviewed journal in the 2017-2018 academic year. This manuscript will combine data obtained from this project with measurements La Frenierre previously made in 2012 and 2013, as well as with glaciological measurements from instrumentation installed by La Frenierre and collaborators (with Decker's assistance) in Summer 2016. Potential targets for submission include the *Annals of Glaciology* and the *International Journal of Remote Sensing*.
3. *A baseline glacier mass balance dataset:* This grant will support the creation of high resolution surface terrain models for portions of the Reschreiter and Hans Meyer glaciers against which future assessments of glacier mass balance change can be made. Pending future external funding (see below), La Frenierre anticipates repeating surface terrain model acquisition for these glaciers annually over the next several years.
4. *Applied research experience for Casey Decker:* Decker was previously provided with modest funding from the Department of Geology to assist with Chimborazo fieldwork in June 2016 (significantly augmented by La Frenierre's start-up fund and contributions from the UMN collaborators). While this opportunity provided Decker with a great introduction to geoscience field work (and much-needed field help to La Frenierre and collaborators!), his objective at that time was not to undertake a research project of his own. This grant will support just such an opportunity, providing Decker with material sufficient to complete a senior thesis at Gustavus, while offering him the type of research experience that can make him a very competitive graduate school applicant.
5. *Strengthened collaboration with University of Minnesota partners:* La Frenierre has invested nearly all of his start-up fund in his Chimborazo project, having been able to build the UAV, purchase other essential equipment, and support the 2016 field season with his UMN collaborators (both of whom have also invested heavily in shared instrumentation and fieldwork expenses). However, with start-up now exhausted, La Frenierre is unable to participate in further fieldwork in Ecuador until external funding can be secured (see below). This grant will cover this funding gap for one final year until such external funding can (hopefully) be realized, ensuring the ongoing work of the

larger project and maintaining the strong research collaboration that has developed between the two institutions.

6. *A competitive proposal for July 2017 submission to the National Science Foundation's Hydrological Sciences program:* Initially, La Frenierre and collaborators intended to submit a proposal for multi-year NSF funding to support their Ecuador research in late 2015. However, the need to improve instrumentation and obtain additional data sufficient to provide proof-of-concept for the hydrological model at the core of the proposal necessitated a delay until additional fieldwork could be completed in 2016 and 2017. The data we obtain from the 2017 field campaign, including the quantification of ice mass loss that would be supported by this grant proposal, should allow us to make a strong case justifying our proposal to this highly competitive funding program.

Project Participants

Jeff La Frenierre: Jeff La Frenierre is an Assistant Professor in the Department of Geography, and has been on the faculty at Gustavus Adolphus College since 2014. La Freniere earned his Ph.D. in Geography from Ohio State University. His research is focused on understanding the hydrological consequences of climate change, both from biogeophysical and socioeconomic perspectives. His work focuses particularly upon mountain glacier change and its impact on downstream water supply. La Frenierre's dissertation research was supported by a National Science Foundation Doctoral Dissertation Research Improvement Grant, a Fulbright research grant, and funding from the Geological Society of America.

Casey Decker: Casey Decker is currently a junior at Gustavus Adolphus College. He is majoring in both Geography with an emphasis in GIS (Geographic Information Systems) and Geology. Upon graduation he is planning on continuing his education to obtain his Master's degree in a field that can encompass skills from both geography and geology. Decker is mainly interested in water resources and how water and water availability is ever changing, as well as how climate change is more so than ever affecting these areas. He is also very interested in using GIS to solve problems related to water resources.

Gene-Hua Crystal Ng: Crystal Ng is an Assistant Professor in the Department of Earth Sciences at the University of Minnesota. Ng's research investigates interlinkages within hydrological systems, and the impact of environmental change on those interlinkages. Her research emphasizes the use of computer models to describe the movement of water between the land surface and underground aquifers.

Andrew Wickert: Andrew Wickert is also an Assistant Professor in the Department of Earth Sciences at the University of Minnesota. Wickert's research combines field observations, field instrumentation, and numerical modeling to understand the dynamics of ice and water in glacier systems worldwide.

Career and Educational Trajectories

Jeff La Frenierre: As a scientist, I continue to devote my energies to documenting the impacts of global environmental change, particularly climate change, on hydrological processes and to understand how these impacts manifest for people using these water supplies. This work remains attractive to me because it allows me to work at the intersection of physical and social systems while undertaking applied research that can directly influence decision-making by citizens and policy experts. While I am interested in how these issues might play out in any watershed, circumstance has led me to focus my work on the tropical Andes, and I remain deeply committed to understanding the complexity of these changes in the corner of Ecuador I have come to know so well. In my first three years as a tenure-track faculty at Gustavus, the majority of my research effort – and nearly all of my start-up funding – has been invested in further developing my research infrastructure there, and in building a strong collaborative effort with my University of Minnesota colleagues. This collaboration is important to me for several reasons. First, the synergies created by our disparate expertise (e.g. Ng's skill at developing complex hydrological models; Wickert's ability to design and build robust field instrumentation, and my understanding of tropical glacier processes and the mountain hydrology) greatly increases the likelihood that we can answer our research questions compared to our working alone. Second, it provides me access to the types of research resources such as laboratory equipment that are available at a large university but not a small liberal arts college like Gustavus. Third, this collaboration has opened a new potential pipeline through which I can connect my students with one of the premier geoscience graduate programs in the country. This grant will allow my participation in the field component of this collaboration to continue uninterrupted, and help position us to be competitive applicants for the kind of NSF grant that can have a profound impact on our academic careers.

From a more practical standpoint, this grant will support the first field research campaign of the UAV that I have built in collaboration with Charles Niederriter. This UAV represents a gamble – one costing $5,000 and requiring some 18 months to complete – in our ability to develop a low-cost, easily transportable tool for making repeated geodetic mass balance measurements on small mountain glaciers. If the UAV proves successful at Chimborazo, additional opportunities for my collaboration in high-impact glaciological research in the tropical Andes and elsewhere are likely to develop. In addition, the UAV is a tool with potential utility for a wide range of environmental change research projects, and successful demonstration of the UAV may encourage other Gustavus faculty who can benefit from high resolution aerial imagery and surface terrain models to seek collaborative research opportunities with me and my students.

Finally, this grant provides me with the opportunity to continue my pattern of collaborating with students on research in Ecuador, something I have been able to undertake each of my first two years as a faculty member. The opportunity for this type of experience was one of the primary reasons why I chose to accept a position at Gustavus, and it remains one of the most satisfying aspects of my professional life.

Casey Decker: Being able to continue working with Jeff on this research project will be very beneficial for future careers. Not only do I plan to help Jeff with his research, but I also plan on taking on my own research and creating a thesis to use to complete my Geology major at

Gustavus. This research has given me the opportunity to use the knowledge I have gained in geography and geology in a real world application. This research is also very interesting to me as well as being very important for the people affected by the significant change in water dynamics within the Andes mountains. With this research I will gain new skills and abilities that are not necessarily gained through class work in college. As a junior, I am also looking into my future in terms of graduate programs and careers after college. I have gained a new found interest in research after my first trip to Ecuador last summer. Going back this summer will give me the experience in research that I need in order to be competitive when applying for graduate programs in the fall. After graduate school I plan on getting a job in the field of Geography or Geology and work with water resources. Many of the skills and knowledge I have learned throughout my work with Jeff will be very beneficial when applying to jobs and working in the future.

Budget Justification

Travel

Roundtrip airfare Minneapolis to Quito, Ecuador for La Frenierre and Decker (June 12-29, 2017): $2,100

4x4 truck rental in Ecuador (18 days): $1,500

Gasoline: $175

Lodging for La Frenierre and Decker in Ecuador (includes 6 nights of camping): $840 ($70/night x 12 nights)

Meals for La Frenierre and Decker in Ecuador: $475 ($25/day x 19 days)

Equipment

Miscellaneous equipment, including spare components for UAV repair as well as hardware for repair of existing instrumentation in Ecuador: $700

Materials

No additional materials will be purchased for this research.

Stipends

7 week stipend for Decker ($400/week; 3 weeks in Ecuador, 4 weeks in Minnesota): $2,800

4 weeks summer housing at Gustavus Adolphus College for Decker ($60/week): $240

7 week stipend for La Frenierre ($300/week; 3 weeks in Ecuador, 4 weeks in Minnesota): $2,100

Total Budget: $10,930

Amount Requested: $8,100

Note, additional funding support is being requested via the Sigma Xi Undergraduate Research Grant (Decker) and the Environmental Studies Faculty/Student Collaboration Grant. If one or more of these requests is not approved, La Frenierre will convert his full stipend request to cover travel expenses while Decker will reduce his stipend and summer housing by 1 week.

Anticipated Research Completion Date

The field component of this research will be complete on June 30, 2017. Image analysis and surface terrain model creation will be complete by July 21, 2017 (anticipated end of stipend support for both La Frenierre and Decker). Additional analyses and scholarly presentations will occur throughout the 2017-2018 academic year. Decker will complete his senior thesis by May 1, 2018. La Frenierre anticipates submission of a journal manuscript by December 31, 2017. The NSF grant will be submitted by La Frenierre, Ng, and Wickert no later than August 1, 2017. All work related to this proposal will be complete by May 20, 2018.

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