Assessing the Sensitivity of Alaska’s Coastal Rainforest Ecosystem to Changes in Glacier Runoff

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1. Background and Need
Coastal temperate rainforests watersheds along the Gulf of Alaska (GOA) are experiencing some of the highest rates of glacier volume loss on earth (Arendt et al., 2002; Berthier et al., 2010). Glaciers currently cover 18% of the land area that drains to the GOA and runoff from glaciers accounts for about half of the land-to-ocean flux of freshwater into the GOA (Neal et al., 2010). Understanding the climate-induced vulnerability of this freshwater flux is critical considering that the changes expected from glacier runoff are much larger than those projected for other components of the water cycle (IPCC, 2007). Moreover, the North Pacific Landscape Conservation Cooperative (NPLCC) has recognized the importance of understanding changes in terrestrial snow and ice cover, its effects on freshwater discharge, and ways in which this drives highly productive nearshore marine ecosystems. These research priorities are aligned with those of the North Pacific Research Board (NPRB), which has focused on improving understanding of the coupling between nearshore waters of the Alaska Coastal Current and the influx freshwater from terrestrial sources.

At a landscape level, changes in glacier runoff shift the timing and volume of freshwater and nutrients delivered from coastal temperate rainforests to the eastern North Pacific Ocean, thereby altering both aquatic and terrestrial habitats. For example, runoff from glaciers has pronounced impacts on the physical properties of aquatic habitats such as water temperature and clarity (Hood and Berner, 2008), which are both critical parameters in salmon spawning (Lorenz and Eiler, 1989; Milner and Bailey, 1989; Dorava and Milner, 2000). Runoff from glaciers is also biogeochemically distinct compared to runoff from other terrestrial ecosystems and can strongly influence fluxes of limiting nutrients (Phosphorus), micronutrients (Iron), and bioavailable organic carbon delivered to near-shore marine ecosystems (Hood and Scott, 2008; Hood et al., 2009; Crusius et al., 2011). Recent studies suggest that micro- and macro-nutrients in glacier runoff play an important role in marine productivity along the GOA (Schroth et al., 2009; Fellman et al., 2010). This project will introduce a comprehensive framework for modeling changes in glacier runoff and associated changes in biogeochemical fluxes on a regional scale.

The results of our efforts will have broad societal impacts along the Gulf of Alaska. Runoff from glaciers along the GOA, which exceeds the annual discharge of the Mississippi River, is an important control of the structure of the freshwater-driven Alaska Coastal Current (ACC). The ACC, in turn, sustains multi-million dollar commercial fisheries, subsistence fisheries, and
millions of coastal marine birds and mammals. In this context, our findings will directly improve management of near-shore marine ecosystems along the GOA by providing information about future changes in glacier runoff. Glacier-related flooding and erosion also affect many Alaska Native villages, and Alaska has significant data gaps in this area making it difficult to assess the severity of the problem or make informed management decisions (GAO, 2003). Our findings will begin to fill that gap, providing information to reduce uncertainty geomorphic hazards such as glacial mudflow and outburst flood events in coastal watersheds. Changes in Alaska’s glacier runoff also have the potential to significantly impact the availability of hydropower resources in southcentral and southeast Alaska (Cherry et al., 2010), particularly in light of the increased generation potential associated with glacier mass loss. Thus improving future predictions of glacier discharge will inform present and future efforts to sustain and develop hydropower resources in the North Pacific region. Finally, the changes volume of Alaska glaciers and their contribution to rising sea level is similar to losses from the great ice sheets of Antarctica and Greenland (Meier et al, 2007; Bamber et al, 2010; Wu et al., 2010). While these losses do not have a direct effect on the Gulf of Alaska region due to isostatic and tectonic adjustments, other coastal communities will be affected. Therefore a robust understanding of Alaska glacier mass budget is of paramount importance to Earth’s coastal population.

2. Objectives
The overall objective of our work is to quantify the regional effects of climate changes on the timing, quantity and distribution of glacier runoff to the Gulf of Alaska. Our study will provide a framework for mapping present and projecting future effects of changes in glacier runoff on Gulf of Alaska ecosystems. The project will be structured around a detailed conceptual system model that will provide managers with a wide range of decision support tools to inform resource conservation efforts. In particular, we will identify key areas that are particularly sensitive to future changes in glacier volume loss and increased freshwater discharge. Within this framework we will address the following science objectives from the call:

1. Identify and quantify the major sources of freshwater runoff to the GOA;
2. Develop methods to upscale point measurements to be regionally representative;
3. Determine what proportion of glacier runoff is derived from a loss of glacier volume versus a melting of the seasonal snowpack;
4. Determine what proportion of glacier changes are driven by climatic versus dynamic physical processes;
5. Identify key sensitivities in physical and biogeochemical processes to the stability of the freshwater cycle;
6. Assess what parameters are likely to control the future evolution of glacier discharge to the GOA.
This science framework will fill important information gaps about the links between climate change and hydrology along the North Pacific coast and will ultimately provide valuable information for subsistence and commercial fisheries management, hydropower development, and glacier hazard mitigation.

3. Methods

Our proposed work will be divided into two Phases. During Phase I we will build a conceptual framework that will provide a basis for quantifying changes in glacier runoff within watersheds along the GOA. Our first step will be to assemble any and all available direct field observations, remote sensing datasets, stream gauging and meteorological data, and glacier inventory data to determine the appropriate spatial and temporal scales over which to conduct a detailed regional analysis during phase II (Fig. 1). Detailed methodologies will be developed to allow partitioning between glacier runoff components derived from changes in glacier storage (volume change) versus seasonal runoff, as well as climate and internal dynamics as modulating forces of glacier mass balance. Understanding the sensitivity of these processes to small changes is extremely important, and we will delineate methods to evaluate sensitivities and effects of runoff changes on aquatic habitat and riverine biogeochemical fluxes in the North Pacific coastal rainforest ecoregion. During Phase I we will also work to stabilize and maintain glacier freshwater discharge monitoring networks in the Gulf of Alaska that are key resources for our ongoing research activities and identify the largest gaps in process constraints to address in Phase II.

Several processes and systems are known to present large-scale knowledge and data gaps. Our conceptual model will combine data across disciplines, giving us greater opportunities to assess factors including but not limited to: 1) methods for upscaling point measurements to regional estimates; 2) uncertainty in runoff from ungauged streams; 3) oceanic controls on glacier health; 4) strong feedbacks between physical, geochemical and biological systems; 5) the sensitivity of glacier surface mass balance to radiative and thermal forcings; and 6) the routing of glacial meltwater and the lag time for its delivery to river systems.

Phase II activities will involve expansion of research activities, model development and monitoring networks. Although Phase II goals will not be supported under the current proposal, they will guide Phase I activities so that at the end of the project, a foundation will be in place upon which broader resource management and research activities can be supported.
4. Leveraging
An extensive leveraging network will be utilized to complete the proposed work. Our group and collaborators have access to rich datasets that can be used to support the model development and extrapolation efforts, including satellite gravimetry data (Arendt, UAF), altimetry data collected as part of NASA’s Operation Ice Bridge Alaska (PI Larsen, UAF), glacier surface velocity maps determined from SAR interferometry (PI Braun, UAF), regional glacier mass balance simulations using degree-day modeling (PI Hock, UAF), detailed information about glacial biogeochemical (Carbon, Nitrogen, and Phosphorus) fluxes (Hood), estimates of GOA watershed discharge using statistical extrapolation tools (PI Hill, OSU), a quantified evolution of Columbia Glacier’s Retreat (Pfeffer, O’Neel), 4 high altitude weather stations in the coastal mountains (CRREL), the USGS benchmark glacier data set and mass balance data collected at Mendenhall Glacier (Hood) since the mid-1990s. UAF is also developing strong ties to Alaska state hazard assessment programs and will be co-sponsoring a graduate student thesis project aimed at modeling glacier runoff for a specific GOA watershed.

5. Geographic Extent
The spatial extent of our proposed research covers the northern portion of the NPLCC, however our findings will provide a framework for evaluating future changes in the hydrology and biogeochemistry of glacier-dominated ecosystems throughout the full range of the NPLCC. Development of our conceptual model will specifically target the coastal mountain ranges extending from southeast Alaska to Anchorage. This includes the Kenai Mountains, Chugach Range, St. Elias Mountains, and the Coast ranges, which include the Stikine and Juneau Icefields. Our data integration and modeling framework will incorporate field measurements from Columbia, Wolverine and Mendenhall Glaciers, including accumulation and melt rates as well as meteorological parameters.

6. Timeline
Start date: July 1, 2011
Duration: 1 year

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<tr>
<th>July-Sept., 2011</th>
<th>Data stabilization efforts (Mendenhall, Columbia Glaciers, weather stations)</th>
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<tr>
<td>Summer, Fall 2011</td>
<td>Data assembly, student training</td>
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<tr>
<td>Oct. - Nov. 2011</td>
<td>PI meeting in Juneau (1 week), Development of modeling framework</td>
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<tr>
<td>Spring 2012</td>
<td>Finalize report, Prepare phase 2 proposal.</td>
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7. Outreach and Education
Each of us has extensive outreach experience, having appeared in television documentaries, designed visitor center interpretive displays and dealt with popular media. Model products and
project findings will be made available to agencies and the public through the southeast Alaska GIS library (http://seakgis.alaska.edu/), which is run by Pyare, and the Geographic Information Network of Alaska (http://www.gina.alaska.edu/). The project will include training and education opportunities for undergraduate research assistants working with Hood and Pyare at UAS. We will also conduct outreach about our project through the newly formed Alaska Coastal Rainforest Center, which is housed at UAS and was co-founded by Pyare. Finally, we will design an interpretive display highlighting key project findings for the Mendenhall Glacier Visitor Center in Juneau, which is visited by more than 300,000 people each year.

8. Qualifications and Scope of Work

Dr. Eran Hood is an Associate Professor in the Environmental Science Program at the University of Alaska Southeast and a member of the Pacific Northwest and North & West Alaska CESUs. Dr. Hood has extensive experience in the use of field measurements and models to quantify hydrological and biogeochemical fluxes in glacial watersheds along the Gulf of Alaska. He has worked collaboratively on interdisciplinary research teams involving academic institutions and federal research agencies and has previously received funding from the US Geological Survey and the National Science Foundation for his research in Alaska. Sanjay Pyare is an Associate Professor in Environmental Science & Geography at the University of Alaska Southeast. His focus is geospatial analysis and modeling across a wide variety of systems and disciplines, with specialties in ecosystem change, biogeography, and increasingly, climate science. He also coordinates the UAS Spatial Ecosystem Analysis Lab (SEALAB), a node of the UA-GINA program, facilitates a multiagency partnership to steward regional geospatial data through the Southeast Alaska Geospatial Library, and provides instructional and research-mentoring support to undergraduates in the geospatial sciences at UAS.

Hood and Pyare will both contribute to the design of a regional modeling framework for estimating current and future glacier discharge along the Gulf of Alaska. Hood will be responsible for integrating glaciological and hydrological data and for designing an approach to use existing hydrologic datasets to validate estimates of glacier runoff. In addition, he will be responsible for developing a framework for modeling riverine biogeochemical (C, N, and P) fluxes associated with estimates of glacial runoff. Pyare will be responsible geospatial aspects of the project and model development including: a) Working with the group to identify the geospatial data requirements for quantifying and modeling glacier runoff contributions, b) Investigating, collating, standardizing, and addressing uncertainties in physiographical, hydrographical, and climatological geospatial-data sources, c) Developing an analytical geospatial template for regional up-scaling and quantification of potential future investigations of glacier runoff contributions, streamflow, and hydrological parameters, and d) Developing preliminary spatial data infrastructure to steward, disseminate and exchange geospatial data and related modeling products.
9. Deliverables
The primary product of Phase I of this project is to take inventory of available data relevant to the GOA freshwater budget and prepare a detailed conceptual framework for quantifying glacier-related processes and terms in this budget. Our efforts will not only assess the available inputs to a large scale modeling effort, but will also delineate in detail the appropriate methods for performing such a task. The results of this interdisciplinary effort will be disseminated in three primary fashions including: 1) a co-written USGS report and/or academic publication by all four PIs; 2) presentations at USGS and academic meetings; and 3) outreach activities including but not limited to the Mendenhall Glacier Visitor Center.

10. References
General Accounting Office, 2003: Alaska Native Villages: most are affected by flooding and erosion, but few qualify for federal assistance. GAO-04-142 report to the Senate and House Committees on Appropriations.
11. Biographical Sketches

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Education:

Ph.D. 2001  University of Colorado, Boulder  Geography (Hydrology and Biogeochemistry)
M.A. 1997  University of Colorado, Boulder  Geography (Snow Hydrology and Climatology)
B.A. 1991  Harvard University (Biology)

Professional Background:

2010-present  Department Chair  
University of Alaska Southeast, Natural Science Department

2008-present  Associate Professor of Environmental Science  
University of Alaska Southeast, Natural Science Department

2004-present  Affiliate Professor of Environmental Science  
University of Alaska Fairbanks, Civil and Environ. Engineering Dept.

2002-2008  Assistant Professor of Environmental Science  
University of Alaska Southeast, Natural Science Department

2002  Postdoctoral Researcher, LTER DON inter-site comparison project, University of Colorado

Publications (five most relevant):


Five Other Relevant Publications


organic matter in near-shore marine ecosystems, *Marine Chemistry*,
doi:10.1016/j.marchem.2010.03.009.

**Synergistic Activities**
Associate Editor, *Biogeochemistry*, 2007-present
Science Fair Mentor/Judge, *Juneau/Douglas High School* 2004-present
Undergraduate Student Mentor: *National Science Foundation* Research Experience for Undergraduates (REU) Program and *University of Alaska EPSCoR* Undergraduate Research Program (9 Students total, summers 2005-2009).
Member, *City and Borough of Juneau Mayor’s Panel on Climate Change*, 2006.
Advisor, *City and Borough of Juneau (CBJ) Avalanche Control Program*. Maintain and operate a remote, real-time snow/climate monitoring station at the CBJ Eaglecrest Ski Area.
Ad-hoc NSF proposal reviewer: Hydrologic Sciences, Ecosystem Science, and Arctic Biology.

**Scientific Collaborators:**

Anthony Arendt (UAF Geophysical Institute)  
David D’Amore (PNW Forestry Science Lab)  
Cory Cleveland (Univ. Montana)  
Richard Edwards (PNW Forestry Science Lab)  
Scott Gende (NPS Juneau)  
Mike Gooseff (Penn State)  
Matthew Heavner (Los Alamos National Lab)  
Peter Hernes (UC Davis)  
Regine Hock (Univ. of Alaska Fairbanks)  
Diane McKnight (Univ. Colorado Boulder)  
Amy Miller (NPS Anchorage)  
Sonia Nagorski (Univ. Alaska Southeast)  
Diana Nemergut (Univ. Colorado Boulder)  
Shad O’Neel (USGS Alaska Science Center)  
Peter Raymond (Yale)  
Durelle Scott (Virginia Tech)  
Robert Spencer (Woods Hold Research Center)  
Aron Stubbins (Skidaway Institute of Ocean.)  
Mark Williams (Univ. Colorado Boulder)  
Kevin White (AK Dept of Fish and Game)

**Graduate Advisees:**

Jason Fellman (Univ. of Alaska Fairbanks)  PhD  2005-2009
Jonathan O'Donnell (Univ. of Alaska Fairbanks)  PhD  2007-2010
Mike Nassry (Virginia Tech)  PhD  2009-present

**Postdocs:**

Andrew Vermilyea (University of Alaska Southeast)  2009-present

**Graduate and Postdoctoral Advisor:**

Mark Williams  University of Colorado Boulder
Sanjay Pyare  
11120 Glacier Hwy  
University of Alaska Southeast  
Juneau AK 99801  
907.796.6007  
sanjay.pyare@uas.alaska.edu

**Professional Preparation:**
- Hartwick College  
  Biology B.A., 1992
- University of Nevada Reno  
  Conservation Biology and Ecology Ph.D., 2000
- University of Nevada Reno  
  Endangered Species Recovery Post-Doc., 2001-2004

**Appointments:**
- 2005-present  
  Assistant Professor of Environmental Science and Geography  
  University of Alaska Southeast
- 2006-present  
  Affiliate Professor  
  Institute of Arctic Biology & School of Fisheries and Ocean Sciences  
  University of Alaska Fairbanks

**Recent and Relevant Publication Activity**
- Breck, S.W., M.I. Goldstein, S. Pyare & D. Kellet. 2010. Use of occupancy modeling to monitor occurrence of beavers in the Colorado River Ecosystem. In review in *Ecological Indicators*.


Recent and Relevant Funding

- Interdisciplinary lab for analysis of ecosystem change. Alaska EPSCoR Integrative Faculty-Development Award. $18,000. 2009-2010.
- Southeast Alaska GIS Library. U.S. Forest Service Alaska Region. $45,000. 2009-2010.
- Monitoring of boreal toads in Southeast Alaska. Alaska Department of Fish and Game Non-Game Program. $70,000. 2005-2006.

Synergistic Activities

- Alaska Coastal Rainforest Center, Affiliate Scientist and Co-founder, 2009-present
- Southeast Alaska Geospatial Library, Chair of Steering Committee, 2007-present
- Spatial Ecosystem Analysis Lab, Coordinator, University of Alaska Southeast, 2005-present
- Southeast Regional Program Leader, Alaska Gap Analysis Project, 2008-present