

## Differences in Cyclogenesis and Extratropical Cyclone Tracks During Warm and Cool Analogs

Jeffrey D. Auger<sup>1</sup>, Kirk Allen Maasch<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.

**Abstract:** With the use of reanalysis datasets, warm and cool years will be found through variances in meteorological variables to find differences in cyclogenesis and extratropical cyclone tracks with the objective to find how warmer versus cooler years differ. This will be used to better understand the Medieval Climate Anomaly and Little Ice Age climates as well as the future environments.

Proxy data has been used to show natural variability in the atmosphere for the past one thousand years and beyond (Meeker and Mayewski 2002). With the increase of anthropogenic forcing, the natural climate is increasingly becoming unpredictable. With the Medieval Climate Anomaly (MCA) and Little Ice Age (LIA) being the most recent warm and cool analogs, respectively, more questions must be answered about these times to understand what may happen to the atmosphere and, furthermore, to the environment of the future.

With the use of reanalysis datasets, recent warm and cool years will be used to build analogs to simulate the MCA and LIA. The warm and cool years will be found by analyzing daily meteorological variables during the summer and winter months but more important the shoulder months during the spring and fall. An example of a cool year will most likely have an anomalously cool March to extend winter into the spring. A warmer March may mean that winter was “cut short”. Different regions will be analyzed taking into consideration the Great Lakes, Northeast and northern Atlantic as well as North America as a whole. The variables that will be used are temperature and wind speed at the surface, 850, 500 and 250 hPa; the location of the jet stream; melting and freezing degrees; ice out on the Great Lakes; sun spots; and the climatological Aleutian and Icelandic Lows. Figure 1 shows the difference between possible warm and cool years from 2 m temperature anomalies in March 2011 (warm) and 1990 (cool). When the majority of these variables point to a warm (cool) year, the year is binned into the MCA (LIA) analog.

The objective of this study is to further understand how cyclogenesis and extratropical cyclone (ETC) tracks changed from the MCA to

the LIA. It has been found that storminess decreased during the MCA and increased during the LIA (Meeker and Mayewski 2002). It should follow that cool years will have an increase in storminess where warm years will show a decrease. If this is the case, the future outlook of an increase in warmer years may lead to a decrease in storminess.

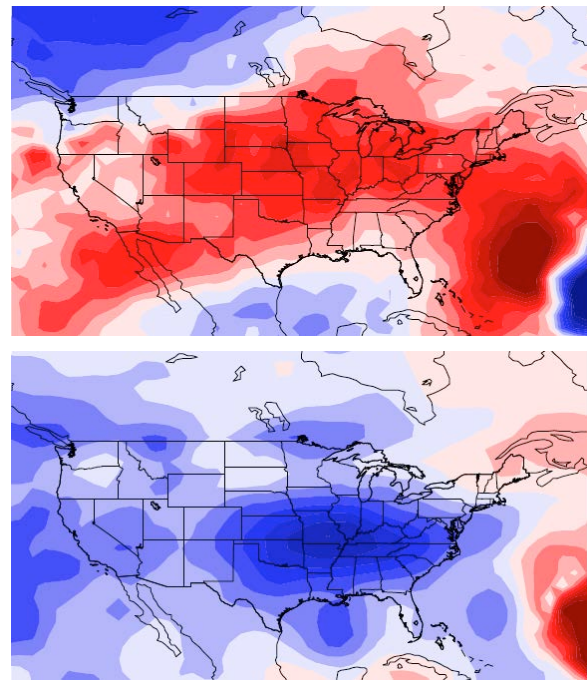


Fig. 1. Warm March 2011 (top) versus a cool March 1990 (bottom). Plots are 2 m temperature anomalies.

### Bibliography:

Meeker L.D. and Mayewski P.A. A 1400-year high-resolution record of atmospheric circulation over the North Atlantic and Asia, The Holocene, 12 (3).

## Ancient Maya Obsidian of the Three Rivers Region, Belize: A Provenance Study

Walter Isles Beckwith<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. Department of Anthropology, University of Maine.

**Abstract: A collection of 1,734 obsidian artifacts recovered from ancient Maya archaeological sites located within the Maya Three Rivers region was geochemically analyzed using portable X-ray fluorescence spectrometry (pXRF). This study evaluates the applicability of pXRF technology in Maya Lowland obsidian studies and the conclusions contribute to the broader discussions concerning ancient Maya economy.**

This paper presents the results of a portable X-ray fluorescence (pXRF) provenance analysis of obsidian artifacts recovered from ancient Maya archaeological sites located within the Three Rivers Region of northwestern Belize. Obsidian was a widely used material throughout the ancient Maya Lowlands. Its widespread distribution is strikingly offset by the fact that, as a raw material, it occurs naturally in very discrete and specific locations within a landscape. The geochemical analysis of obsidian has contributed to discussions concerning the organization of ancient Maya political and economic structures by revealing the movement of the material between source locations and Maya Lowland sites. This study is significant in that it represents the first use of pXRF in the Three Rivers region and is the first concerted obsidian provenance study conducted under the auspices of the Programme for Belize Archaeological Project (PFBAP) in northwestern Belize.

Two general points of interest are addressed in this study. First it is an inquiry into the applicability of pXRF technology in Maya Lowland obsidian research, particularly in a field environment. Second, it seeks to describe the nature of obsidian distribution in the Three Rivers region and evaluate its significance for the regions ancient economy.

In sum, 1734 obsidian artifacts from ten archaeological sites were analyzed for geochemical composition to determine their raw material source. The study was conducted at the PFBAP's field laboratory in northwestern Belize. This analysis identified at least nine known major and minor obsidian sources that are located in the highlands of Guatemala and central Mexico.

The ability of pXRF to provide precise measurements of elements useful in discriminating Mesoamerican obsidian sources and the ability to identify these sources within an archaeological sample of unknown provenance demonstrates its appropriateness for Maya Lowland obsidian research in field contexts. The obsidian source distributions provided by pXRF offer insight into the region's integration into greater Maya Lowland political and economic systems. The Three Rivers region expresses a greater similarity to distributional patterns found at other sites in the Central Petén suggesting an affiliation with overland trade routes that served these areas. Furthermore, complex patterns of obsidian source use suggest that many contemporaneous systems of obsidian exchange may have existed at any one time and operated independently of one another.

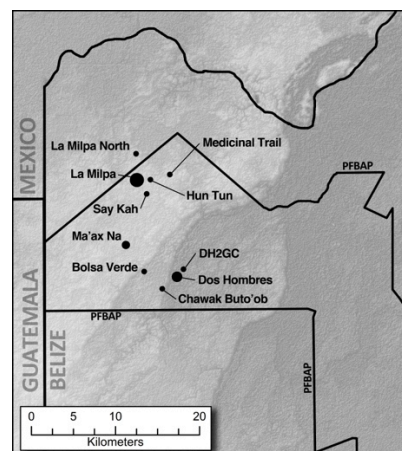


Figure 1: Representative archaeological sites in the sample.

**Acknowledgments:** Dr. Bruce, Bruker-AXS, The Dan & Betty Churchill Exploration Fund, Programme for Belize Archaeological Project, Graduate Student Government. Dr. Gregory Zaro, University of Maine.

## A Ross Sea Polynya Proxy Produced From the RICE Ice Core Record, Roosevelt Island, Antarctica

Thomas M. Beers<sup>1,2</sup>, Paul Andrew Mayewski<sup>1,2</sup>, Stefan Kern<sup>3</sup>, Andrei Kurbatov<sup>1,2</sup>, Sean Birkel<sup>1</sup>, Daniel Dixon<sup>1</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. Institute of Oceanography, University of Hamburg.

**Abstract:** The RICE deep ice core contains a ~30 kyr record of atmospheric circulation over the Ross Sea region, and the sodium time series therein is strongly correlated with the Ross Sea polynya throughout the period of overlap with the ERA-Interim climate reanalysis (1979-2011). The correlation reflects the relationship between frost flower formation, sea spray and the atmospheric conditions that develop prior to polynya expansion, (1) a synoptic low north of Roosevelt Island, and (2) a strengthening of katabatic winds flowing northwestward off the Ross Ice Shelf.

The Roosevelt Island Climate Evolution (RICE) deep ice core is situated ideally to capture sea ice fluctuations, which are largely driven by polynya surge events, as well as atmospheric and oceanographic circulation in the Ross Sea region of Antarctica. The sodium time series recorded in RICE correlates strongly with sea ice concentration over the reanalysis period (Figure 1).

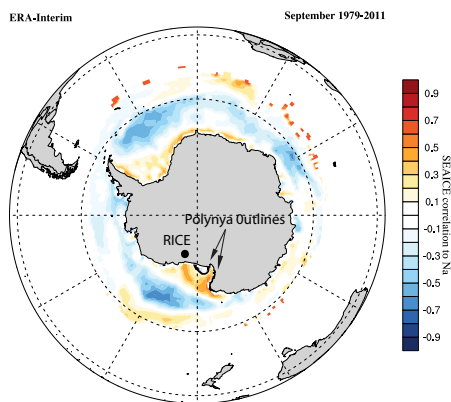


Fig. 1. Correlation between annual maximum sodium and September sea ice concentration over the reanalysis ERA-Interim period (1979-2011). The highest positive correlations are areas of new sea ice formation. Polynya outlines denoted by bold black lines. Modified from *Climate Reanalyzer*.

This strong (up to 0.60) positive correlation reflects the relationship between new sea ice formation and deposition of sodium at RICE. New sea ice is formed in the area of highest correlation by, (1) the positioning of a synoptic low north of Roosevelt Island, and (2) the coincident strengthening of katabatic winds flowing northwestward off the Ross Ice Shelf, resulting in a polynya surge event

(Figure 2, Bromwich et al., 1998). During this surge event, new sea ice is continually pushed offshore by katabatic wind forcing. As new sea ice forms brines are expelled from the ice pack, which precipitate when the eutectic is reached,  $-8^{\circ}\text{C}$  for Mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ). This produces frost flowers that are easily transported by winds. The local synoptic low north of Roosevelt Island entrains these frost flowers and sea spray, some of which are deposited at RICE.

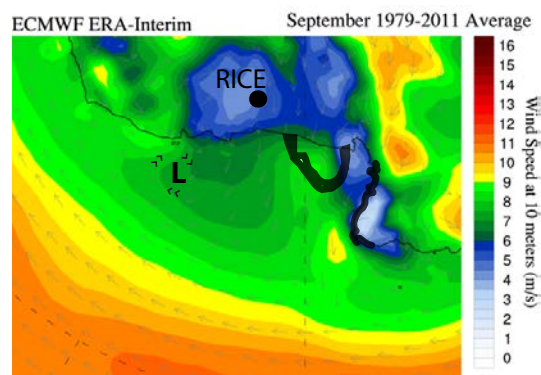


Fig. 2. ERA Interim September wind speed average for 1979-2011. Polynya outlines denoted by bold black lines. "L" stands for low-pressure system. Modified from *Climate Reanalyzer*.

Although this proxy is still being refined (sodium excess should be a stronger correlation), it will be extremely valuable for assessing sea ice production, as a result of polynya surges, over the last ~30 kyr in the Ross Sea region.

**Acknowledgements:** National Science Foundation

**Bibliography:** Bromwich, D., Liu, Z., Rogers, A. N., & Van Woert, M. L. (1998). Winter atmospheric forcing of the Ross Sea Polynya. *Antarctic Research Series*, 75, 101–133.

## Oral Research Update: Sea-Level Change Indicators From Bantry Bay, Southwestern Ireland

Daniel F. Belknap<sup>1,2</sup> and Joseph T. Kelley<sup>1,2</sup>

1. School of Earth and Climate Sciences, University of Maine.
2. Climate Change Institute, University of Maine.

In a major research project funded by the UK Natural Environment Research Council (NERC), we are collaborating with 10 other marine geologists from the UK to find and date the deglacial sea-level lowstand in Ireland, to better understand isostatic uplift and timing of relative sea-level changes. We collected high-resolution seismic and multibeam in 2011, and 148 vibracores in 2012 on research cruises around the southern and eastern shelf of Ireland and Northern Ireland, and off Wales and the Isle of Man. Bantry Bay (Plets et al., 2013) is the southwesternmost location, and should be the most distal site with respect to LGM ice cover. In the outer bay a scarp near 80 m depth forms the western edge of a lobe of sediment protruding from Bantry Bay. Southwest of this scarp are ridges up to 22 km long in water depths of 96 to 131 m, interpreted as moraine or deltaic sediments reworked by stronger-than-present tidal currents. These show evidence of iceberg scour on the outer margins. The sediment lobe is interpreted as a lowstand delta ca. -80 m prior to 14.6 cal ka. The scarp may be an erosional shoreline created at lowstand.

Seismic data and 25 vibracores reveal a lower unit of alternating sand and clay with estuarine foraminifera at the base, giving way to more marine foraminifera at the top, in depths from -75 to -30 m. This is interpreted as a transgressive bay to marine unit. Preliminary dates are prior to 11 ka cal. The data suggest a continued transgression at times and depths where existing numerical models of local sea level look for a stillstand. These data and similar work from Belfast Lough and six other major sites will help refine the isostatically influenced sea-level curve around Ireland. This work will then be compared to similar studies in the Gulf of Maine.

**Bibliography:** Plets, R., Callard, L., Cooper, G.A.G., Long, A., Belknap, D.F., Edwards, R., Jackson, D.T., Kelley, J.T., Milne, G., Monteys, X. and Quinn, R., 2013, Post-glacial sea-level history for SW Ireland (Bantry Bay) based on offshore evidence. American Geophysical Union, Paleoceanography and Paleoclimatology PP53B-199, San Francisco, 9-13 December, 2013.

## Planning For A Changing Climate: A Participatory Approach To Fishing Community Adaptation

Samuel L Belknap III<sup>1,2</sup>, Thomas Webler<sup>3</sup>, Seth Tuler<sup>3</sup>, Esperanza Stancioff<sup>4</sup>, Jess Whitehead<sup>5</sup>

1. Climate Change Institute, University of Maine.
2. Department of Anthropology, University of Maine.
3. Social and Environmental Institute.
4. UMaine Extension & Maine Sea Grant.
5. North & South Carolina Sea Grant.

**Abstract:** This project represents an interdisciplinary attempt involving three states to address issues of climate change vulnerability and adaptive planning using dialogue based participatory vulnerability analysis, mapping, and collaborative systems dynamic modeling. The project focuses on three coastal communities (S. Thomaston, Maine, New Bedford, Massachusetts, Beaufort County S. Carolina). This paper presents the results of the S. Thomaston Maine project.

### Project Goals

The goals for the project are first, to improve understandings of how a changing climate will affect fishing communities' abilities to maintain marine fisheries and the local economies historically dependent upon them. Secondly, it will investigate the role of a structured dialogue and participatory modeling process to support decision makers in fishing communities addressing consequences, vulnerabilities, and adaptive strategies in a context of climate stressors. To realize these goals, this project uses a structured dialogue and participatory modeling process known as Vulnerability and Consequences Adaptation Scenarios (VCAPS) and Systems Dynamics (SD) (Figure 1).

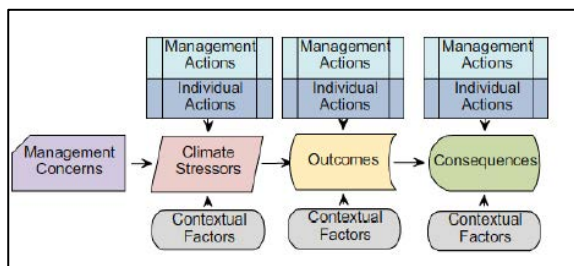


Fig. 1. Basic structure of the VCAPS causal model.

The VCAPS + SD process offers potential applications that meet the needs of coastal communities to identify the potential local impacts, vulnerabilities, consequences, and associated management options for confronting sea level rise (SLR) and associated coastal hazards that affect the marine fisheries sector. The benefits of this research will be usable knowledge for local decision makers and stakeholders on how fisheries and fisheries-

dependent communities) are vulnerable to climate change and what can be done to make them more resilient to climate change-related stressors.

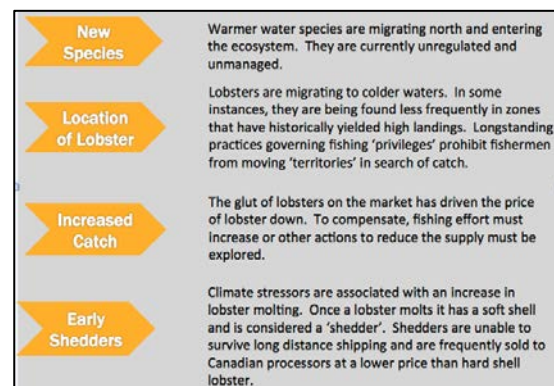


Fig. 2. Initial outcomes for lobster fishery.

### Initial Results

Both the participatory modeling process and 18 in depth follow up interviews show clear concern among fishermen regarding both climate change impacts and the potential for adaptation in coastal Maine. The primary areas of concern for the community as a whole were: warmer air temperatures, increased precipitation, increased storm surge and increased storm frequency. Fisheries centered concerns included: warmer water temperatures, ocean acidification and increased precipitation

**Acknowledgements:** NSF Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423, Coastal and Ocean Climate Program (COCA) NOAA Climate Program Office (#NA120AR4310106), Anne Baker, Robe Gobel, Yue Sun, Kristin Grant, Sherman Hoyt.

## **Modeling Erosion and Shifting Activities at the Holmes Point West Archaeological Site, Machiasport, Maine**

Kendra D. Bird<sup>1,2</sup>, Brian S. Robinson<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. Department of Anthropology, University of Maine.

**Abstract: Erosion and sea level change require people to relocate their living areas inland. Shifting cultural activities will be investigated through spatial analysis and erosional studies on Native American shell middens of Machias Bay, part of a larger study examining the relationship of cultural activities and Wabanaki petroglyphs (rock art) that are highly concentrated on the bay.**

Living areas are typically organized. In the case of Native American sites on the Gulf of Maine, it has been observed that shell middens (refuse disposal areas with exceptional organic preservation due to the addition of calcium carbonate) generally occur in front of house floors with a variety of other associated activities (Sanger and Chase 1983). Progressive loss of land surface due to erosion or sea level change would have necessitated the shifting of activity patterns inland for the original inhabitants, as well as caused systematic loss of shoreside activities as part of the archaeological record (Kellogg 1991). This research is intended to sort out and identify shifting activity patterns based on detailed spatial analysis of artifacts, stratigraphy, and erosion.

The University of Maine's archaeological field school is working with the Passamaquoddy Tribal Historic Preservation Office to better understand relationships between the occupation sites and the abundant petroglyphs (rock art) of Machias Bay. The Holmes Point West site in Machiasport is situated on a well-drained Pleistocene wave-cut bench on a glaciofluvially-deposited landform. The site itself is not bedrock-defended and hence eroding, but is located near bedrock outcrops containing petroglyphs that provide cultural context for the site, and direct evidence of how much erosion has occurred (Hedden 1996).

Site excavations have produced an extensive catalog of artifacts and associated floor plans and wall profiles. Through the use of mapping software such as ArcGIS, artifact coordinates from the catalog will be used to generate point shapefiles, which will be combined with horizontal and vertical mapping data. The goal is to identify significant correlations of artifacts,

features, and stratigraphy associated with progressive erosion.

Erosion will be investigated at different scales within the bay, utilizing the artifact patterns themselves, evidence of sea-level rise and petroglyph production, ongoing erosional activity, and historic aerial photography.

This research will contribute to problem orientation of ongoing excavations that will take place at Holmes Point West during the summer of 2014, and in turn to a more thorough understanding of the impact of erosion on Maine's coastal shell middens.

### **Acknowledgements:**

Maine Academic Prominence Initiative, Passamaquoddy Tribal Historic Preservation Office, Climate Change Institute and Department of Anthropology, University of Maine.

### **Bibliography:**

Hedden, Mark, 1996 3,500 Years of Shamanism in Maine Rock Art, in *Rock Art of the Eastern Woodlands*. pp. 7-24, American Rock Art Research Association. Occasional Paper 2.

Kellogg, Douglas 1991 Prehistoric Landscapes, Paleoenvironments, and Archaeology of Western Muscongus Bay, Maine. University of Maine dissertation.

Sanger, David and Thomas Chase 1983 An Introduction to the Roque Island Group, Maine. Paper presented to the Canadian Archaeological Association, April 1983.

## Pressing Forward with Climate Reanalyzer

Sean D. Birkel<sup>1</sup>, Paul A. Mayewski<sup>1,2</sup>, Kirk A. Maasch<sup>1,2</sup>, and Peter O. Koons<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.

**Abstract:** Climate Reanalyzer has seen initial success and a growing stream of users. In response, we are pressing forward with implementing new datasets and features, including IPCC ensemble simulations and all recent reanalysis models. Climate Reanalyzer is also being further developed to serve as the key software platform for CCI's upcoming Climate Adaptation and Sustainability (CLAS) conference for Maine community planners.

Last year, we introduced CCI's Climate Reanalyzer as a new web-based program for exploring climate models and station data. Climate Reanalyzer is getting noticed, with site visitation having increased from ~20 unique IPs visits per day last year to over 300 per day on average in recent months. The site has served 34,000 page visits spanning 126 countries and all 50 U.S. states. Notable usage spikes (1,000-2,300) occurred in January during and after the so-called "Polar Vortex" cold wave across eastern half of the U.S., when news and social media discovered Climate Reanalyzer's daily-updated temperature anomaly maps (Figure 2). Climate Reanalyzer is also becoming a go-to-source for climate reanalysis maps and timeseries – our original intention – with the site now listed on reanalysis.org as one of four comprehensive reanalysis plotting utilities.

Given Climate Reanalyzer's initial success, we are pressing forward with enhancements that will further increase the value of the site as a research and education utility. First, available datasets are being expanded to include GCM ensembles from IPCC AR5 (IPCC 2013), and latest reanalysis models. In both cases, daily and 6-hourly outputs will be made available for common meteorological fields (temperature, precipitation, wind, moisture, pressure). Second, we are integrating Google Earth, OpenLayers, and GIS frameworks with many aspects of the site. Third, we are developing and integrating the UMaine/CCI Environmental Change Model to provide a means for users to conduct inquiry-based climate experiments.

Finally, with site additions and improvements in place, Climate Reanalyzer will provide a platform for CCI's Climate Adaptation and Sustainability (CLAS) conference in the Fall of

2014, an initiative to provide Maine Communities with resources necessary for future climate and environmental planning.

**Acknowledgements:** Funding provided by CCI, Heinz Endowments, Comer Science and Education Foundation, and NSF.

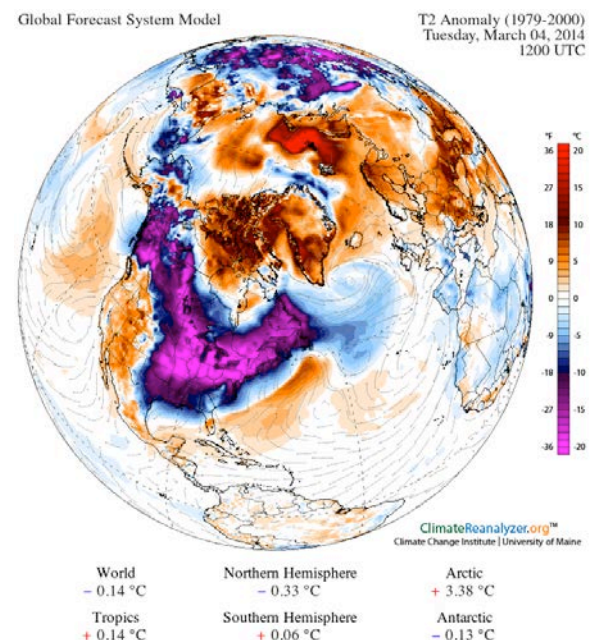


Fig.1. Temperature anomaly (departure from 1979-2000 climatology) for Tuesday, March 4<sup>th</sup>, 2014 at 1200 UTC. The 2013-2014 winter has seen a strong negative-phase Arctic Oscillation with temperatures well above normal across the Arctic, and well below normal across the middle latitudes, particularly over Canada and the central and eastern U.S.

### Bibliography:

IPCC members, 2013. Intergovernmental Panel on Climate Change Assessment Report 5. See <http://www.ipcc.ch>.

## Evaluating The Effect of Changing Wind Strength on Thermocline Depth in Maine's Great Ponds

Kelsey Boeff<sup>1</sup>, Jasmine Saros<sup>1</sup>

1. Climate Change Institute and School of Biology & Ecology, University of Maine

**Abstract:** In response to declining wind speeds over terrestrial habitats in the northeast, we explored the impact of this climatic change on the thermal structure of lakes using diatoms as a proxy. Two species of diatoms preserved in the sediment record were used to infer magnitude of lake mixing, indicating a shift from deeper to shallower mixing conditions.

Declining wind strength has been observed during the last few decades across terrestrial habitats in North America, with the strongest declines observed in the midwestern and eastern United States (Pryor *et al.* 2009). Additionally, the yearly spring ice-out date, which strongly correlates with air temperature, has become progressively earlier since the mid-19<sup>th</sup> century in New England (Hodgkins *et al.* 2002). We examine how these climatic changes may affect the thermocline depth (location in the water column where the temperature change is most drastic) of lakes.

The depth of the thermocline can vary throughout the season due to a variety of factors including wind speed and spring ice-out date. Specifically, decreased wind mixing of the lake can result in a shallower mixed layer; additionally, warmer waters due to earlier ice-out can cause earlier stratification of the water column. Understanding how these climate changes impact thermocline depth is important due to its influence on diatom assemblages.

The objective of this study was to evaluate how thermocline depths have changed over time in large Maine lakes and the extent to which declining wind strength and earlier ice-out dates correlate with these changes. To do this, we examined the changing relative abundances of *Discostella stelligera* and *Aulacoseira* species in the sediment cores of each lake. These species are of primary interest because of differences in their preferred lake conditions—*Discostella* species prefer shallower mixing while the *Aulacoseira* species prefer deeper mixing. Results suggest that the changing climate may have influenced the diatom communities; we found declines in the relative abundance of *Aulacoseira* species and increases in *Discostella stelligera* (Fig. 1). However, these trends did not

hold true for a shallower lake, suggesting environmental factors other than wind speed and ice-out date may influence the diatom communities of shallower lakes.

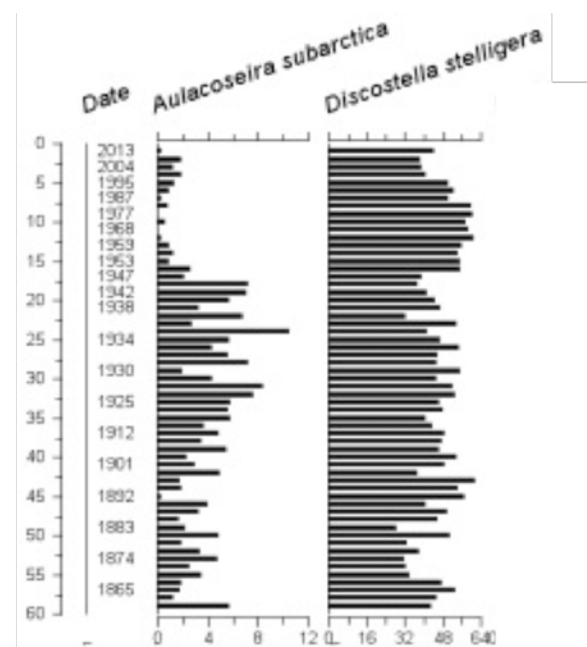


Figure 1: Relative abundance of *A. subarctica* and *D. stelligera* for one study lake.

### Bibliography:

Hodgkins G, James II IC, and Huntington TG. 2002. Historical changes in lake ice-out dates as indicators of climate change in New England, 1850-2000. *International Journal of Climatology* 22:1819-1827.

Pryor, S. C., R. J. Barthelmie, D. T. Young, E. S. Takle, R. W. Arritt, D. Flory, W. J. Gutowski Jr., A. Nunes, and J. Roads. 2009. Wind speed trends over the contiguous United States. *J. of Geophys. Res.* 114.



## Human-Climate Interactions During the Terminal Pleistocene Near Chivay, Peru

Scott Braddock<sup>1,2</sup>, Paul Pluta<sup>2</sup>, Gordon Bromley<sup>1,2</sup>, Kurt Rademaker<sup>2</sup>

1. School of Earth and Climate Sciences, University of Maine.
2. Climate Change Institute, University of Maine.

**Abstract: Surface exposure dating of samples collected from glacial erratics will be used to determine the relative timing of deglaciation in the Chivay region of Peru. Results from this analysis will help to answer the question as to whether the glacial history of this region influenced the timing that the Chivay obsidian source became available to early populations, a hypothesis first proposed by Sandweiss et al. (1998).**

The tropical Andes are an ideal location to study past abrupt climate change and the impacts such events imposed on Paleoindian populations. Using high-resolution paleoclimate archives, such as glacial deposits, we can begin to understand the interaction between humans and environmental changes over the last 13000 years. Previous work by Sandweiss et al. (1998) hypothesized that access to the Chivay obsidian source by early populations may have been influenced by the timing of glacial coverage of the area. In beginning to piece together the pattern of southern Peru's late Pleistocene climate, we can also help answer questions about resource availability during the Paleoindian period.

To determine when the obsidian source became ice free we have begun developing a record of glacier fluctuations during the late Pleistocene by mapping glacial features such as moraines, drift, and erratics in the field. Then, we collected rock samples from moraines and drift that were located near the main obsidian source to use for surface exposure age dating. Results from this analysis will provide a relative age for when obsidian outcrops were no longer covered by ice and, therefore, available for use by local populations. Additionally, nine rockshelters were discovered during archaeological survey (Fig. 1). These may have been used for shelter by the earliest people to access the source. Two of these sites contained obsidian fragments. While bearing no clear evidence of human alteration, their presence may indicate human activity because the rockshelters are outside the area of naturally occurring obsidian.

If it is found that ice occupied the obsidian-source site during the late Pleistocene/early Holocene then it affords strong evidence that the glacial history of the region played a major role in the timing of resource availability. Alternatively, if the ice had receded from this area before that time period it may suggest that older archaeological sites containing Chivay obsidian have not been discovered, or that the source was unused for other reasons. This may encourage future field investigations in the region to search for these older Paleoindian sites.



Figure 1. Example of rock shelter examined by Paul Pluta for evidence of human occupation. Shelter is ~4m tall by ~10m wide.

### Acknowledgements:

We would like to thank Dan and Betty Churchill as well as anonymous donors for their support to make this project a possibility.

### References:

Sandweiss, D.H., McInnis, H., Burger, R.L., Cano, A., Ojeda, B., Paredes, R., Sandweiss, M.C., Glascock, M.D. 1998 Quebrada Jaguay: Early South American maritime adaptations. *Science*, 281: 1830-1832.

## Holocene Sea-Surface Temperatures in the McMurdo Sound Region, Antarctica, Reconstructed From Isotope Records of *Adamussium Colbecki*

Scott Braddock<sup>1,2</sup>, Brenda Hall<sup>1,2</sup>

1. School of Earth and Climate Sciences, University of Maine.
2. Climate Change Institute, University of Maine.

**Abstract:** A suite of the marine bivalve, *Adamussium colbecki*, ranging in age from 6500 – 2000 years before present, was collected along the western McMurdo Sound coast, Antarctica, and their isotope chemistry analyzed to determine Holocene sea-surface temperatures (SST). Results suggest that this region experienced relatively constant SST's throughout the Holocene relative to modern conditions.

The marine-based West Antarctic Ice Sheet (WAIS) has been hypothesized to be inherently unstable (Mercer, 1978), and if it were to melt, would contribute between 3.3 – 4.8 m of global eustatic sea-level rise (Bamber et al., 2009). With the recent collapse of the Larsen B ice shelf attributed to continuous Holocene thinning, amplified by recent warming (Domack et al., 2005), the future stability of other ice shelves remains a critical question. In particular, predicting the future stability of the Ross Ice Shelf (RIS) is essential because of its role in buttressing ice from the WAIS. One way to assess the sensitivity of the RIS, and hence the WAIS, to rising temperatures is to determine if the ice shelf has survived past periods of warmer-than-present temperatures.



Figure 1. Adult *Adamussium colbecki* shell. Dotted red line outlines an example of the shell portion sampled for bulk isotope analysis.

The aim of this project is to develop a record of Holocene ocean temperatures for the McMurdo Sound region of Antarctica and to use these data to address questions of Holocene climate change and RIS sensitivity to ocean temperature

change. Sub-fossil *Adamussium colbecki* (*A. colbecki*), a marine bivalve mollusk (Fig. 1), were dated with radiocarbon and their oxygen and carbon isotope ratios measured. A record of ocean paleotemperatures was constructed using several equations which convert oxygen ratios ( $\delta^{18}\text{O}$ ) of the shells to paleotemperatures. In addition, Mg/Ca ratios of bulk shells are being measured to obtain an independent relative-temperature record to compare with  $\delta^{18}\text{O}$ -reconstructed temperatures.

Results show that shells dating to 6500-2000 years before present (yr BP) afford similar  $\delta^{18}\text{O}$  values compared with modern *A. colbecki*. The largest variability occurs during the interval between 5000-4000 yr BP, which may be caused by an environmental disturbance during this period (e.g. glacial meltwater input) or a diagenetic effect on  $\delta^{18}\text{O}$  values (analysis in progress). The overall similarity between  $\delta^{18}\text{O}$  values throughout the entire record suggests that during much of the Holocene, the McMurdo Sound region experienced relatively constant sea-surface temperatures and that significantly warmer water, such as Circum-Polar Deepwater which today is eroding ice in the Amundsen Sea region, has not made it to the front of the RIS in the last 6500 years.

### Acknowledgements:

Supported by a grant from the National Science Foundation.

### References:

- Mercer, J.H. 1978. West Antarctic ice sheet and CO<sub>2</sub> greenhouse effect: a threat of disaster. *Nature*, 271: 321-325.
- Domack, E., et al. 2005. Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch. *Nature* 436: 681-685.

## Algal Community Response to Increases in Dissolved Organic Carbon Over Recent Decades

Robert E. Brown<sup>1</sup>, Jasmine E. Saros<sup>1</sup>, and Sarah J. Nelson<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. George J. Mitchell Center and School of Forest Resources, University of Maine.

**Abstract:** Since the early 1990's, there has been a documented increase in dissolved organic carbon (DOC) in many Maine lakes. A shift in diatom communities from heavily silicified species to smaller species in lakes with increasing DOC trends suggests a shift to shallower mixing depths. However, this response was absent in low DOC concentration lakes, suggesting the diatom response might depend on DOC concentrations.

Dissolved organic carbon (DOC) concentrations have increased in many lakes situated in the northern forests of North America and Europe (Monteith et al. 2007). DOC is a mixture of molecules resulting from the partial decomposition of plants, animals, and microbes. An increased DOC concentration leads to brownification, an increase in the tea-stained brown color of waters. This makes DOC an important regulator in aquatic systems, affecting light attenuation and, in small lakes, the thermal structure (Fee et al. 1996). This influence on the vertical habitats has implications for the algal communities living within these systems.

To investigate how diatom communities have responded to these changes, we compared fossilized diatom remains to over 20 years of water chemistry data from the US EPA Long Term Monitoring Network. Three pairs of small (<50 ha), morphologically similar lakes were selected for this study, with each pair containing one lake with a significant increase in DOC and the other experiencing no change in DOC since 1993, when sampling began for most lakes. Furthermore, lake pairs were selected to represent both low (< 3 mg/L) and moderate (3-6 mg/L) DOC concentrations.

For the lakes in the moderate DOC concentration pair, a shift from heavily silicified *Aulacoseira* species to smaller *Discostella* species is evident in the lake with increasing DOC concentration (Fig. 1) and absent in the lakes with no DOC change. This may indicate a shift to shallow mixing depths in lakes with increasing DOC concentrations. However, this shift was not observed in either of the lakes in the low DOC concentration pair, which may

indicate the diatom community response varies depending on the concentration of DOC.

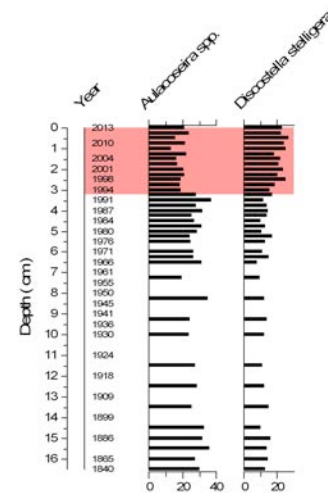


Fig. 1. Relative abundance of *Aulacoseira* species and *Discostella stelligera* in Bracey Pond, ME. Red shading indicates period of observed DOC increase.

**Acknowledgements:** This project is funded by the Maine USGS Water Resources Research Institute. The long-term databases used in this project have been collected by numerous dedicated people over the past three decades, funded by US EPA-ORD and EPA-CAMD.

### Bibliography:

- Monteith, D.T. et al. (2007) Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry. *Nature*, 450: 537-540.
- Fee, E.J. et al. (1996) Effects of lake size, water clarity, and climatic variability on mixing depths in Canadian Shield lakes. *Limnology & Oceanography*, 41: 912-920.

## What Can Bacterial Enzyme Activities Tell us About Nutrient Limitation in Southwest Greenland Lakes?

Benjamin Burpee<sup>1</sup>, Jasmine Saros<sup>2</sup>, Robert Northington<sup>2</sup>

1. Ecology and Environmental Sciences, University of Maine
2. Climate Change Institute, University of Maine.

**Abstract:** Aquatic bacteria release enzymes into their surroundings to break down organic material into simple molecules that can then be assimilated. By measuring the activity of these enzymes in aquatic environments, we are able to infer nutrient dynamics within the ecosystem in question. High activities of phosphorus-acquiring enzymes, for instance, can indicate phosphorus limitation within that system. Enzyme activities in a suite of 26 lakes surrounding Kangerlussuaq, Greenland indicate high variability in regard to nutrient limitation patterns, suggesting local controls may be affecting the microbial ecology of these lakes.

Southwest Greenland contains over 20,000 lakes<sup>1</sup>. Like many Arctic lakes, they are particularly sensitive to climate change. While changes in temperature may influence lakes in this region, recent evidence suggests that the availability of nutrients is an important interactive factor that may influence primary production and algal community structure<sup>2</sup>. Heterotrophic bacteria are important to nutrient availability, as they comprise the trophic level where many nutrients enter the food web as complex molecular structures. These complex molecules are broken down into smaller compounds by extracellular enzymes and are then taken up by bacteria. Though enzyme activity patterns of these lakes are providing us with information regarding their nutrient statuses and functional bacterial ecologies, the activities we have observed so far are highly variable across the region. It will be important to tease out factors that could determine the variability of these responses among lakes.

This study is assessing the activity of four bacterial enzymes in 26 Greenland lakes:  $\beta$ -glucosidase (BG) is involved in carbon acquisition; N-acetylglucosaminidase (NAG) and leucine aminopeptidase (LAP) are both involved in nitrogen acquisition; alkaline phosphatase (AP) is responsible for cleaving phosphate groups from molecules. For these assays, water samples from the shallow, deep, and near-shore areas were collected in June and July 2013. Biofilm and surface sediment samples were also collected to compare activities of within-lake compartments.

To date, AP activity has been assayed from the water samples. While one cluster of our sample lakes shows a consistent increase in activity from spring to summer across lake

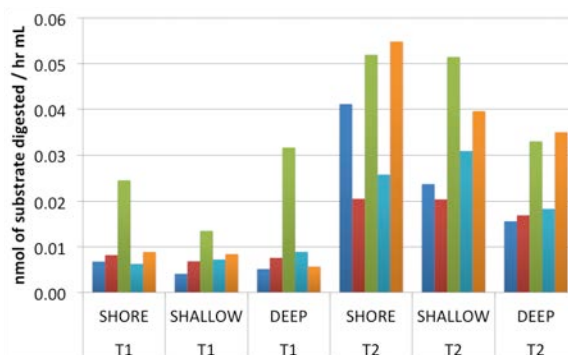


Fig. 1. Kellyville lake cluster AP activity for June (T1) and July (T2) 2013. Individual lakes are represented by different colors.

compartments (Fig. 1), the other lake clusters within our suite do not exhibit this pattern. Some display inconsistent variation between lakes, while others do not vary at all. Interestingly, two directly adjacent lakes located within the Greenland ice sheet exhibit opposite seasonal trends.

Our data so far suggest that different clusters of sample lakes exhibit distinct nutrient dynamics between spring and summer. When used in conjunction with other physicochemical data, enzyme activity may help explain the types of local controls that exist for determining nutrient patterns in lakes of southwestern Greenland.

**Acknowledgements:** The authors thank the NSF and Dan and Betty Churchill Exploration Fund for support.

### Bibliography:

Anderson et al. 2001. "Dominant factors controlling variability in the ionic composition of West Greenland lakes," 418-425.

Saros et al. 2012. "Climate-induced changes in lake ecosystem structure inferred from coupled neo- and paleo-ecological approaches," 2155-2164.

## Improving Ice Core-Based Hydro-Climate Reconstructions in the Northeast Pacific Through Geophysics and Modeling

Seth Campbell<sup>1</sup>, Samuel Roy<sup>1</sup>, Karl Kreutz<sup>1</sup>, Peter Koons<sup>1</sup>, Erich Osterberg<sup>2</sup>, Dominic Winski<sup>2</sup>

1. CCI and School of Earth and Climate Sciences, University of Maine, Orono.
2. Dartmouth College, Hanover, New Hampshire.

**Abstract:** Estimating regional precipitation variability from ice core records requires that accumulated strain of annual layers and spatial accumulation variability be removed. We are pursuing a new approach to modeling these variables with supporting geophysical data.

To determine precipitation variability at an ice core site on Mount Hunter, Alaska, we are using geophysical data to constrain glacier geometry, velocity, boundary conditions, and rheological properties of a 3-D finite element numerical model. The combined datasets will allow us to remove influences of ice flow (which causes layer thinning) and spatial variability in snow accumulation to reconstruct precipitation variability from the ice cores. Englacial stratigraphy represents years of accumulated strain and spatial variation in accumulation of each annual layer. We are using a grid of ice cores and GPR profiles collected across the site to constrain spatial accumulation variability and scale accumulation in the model. Annual accumulation rates will then be iteratively adjusted within the model and model results will be compared to GPR-imaged englacial isochrones from surface to bedrock, to estimate possible accumulation scenarios.

We propose collecting a similar geophysical dataset from the St. Elias Range ice core sites (PR Col, NW Col, King Col on Mt Logan; and the Eclipse Icefield) and completing a comparable modeling effort. These sites reside in a different precipitation zone to Hunter, and were drilled in 2002, prior to current geophysical and numerical modeling capabilities. Without this future effort, direct comparison between coastal and continental ice core precipitation records is less robust. Our future objectives for each site are to: 1) develop bedrock topography maps; 2) determine surface velocities; 3) map near-surface spatial accumulation rate patterns and deeper internal isochrones; 5) estimate ice deformation effects on layer thinning; 6) and compare corrected records from the Mt. Hunter and St. Elias sites to evaluate spatial precipitation patterns over the past millennium.

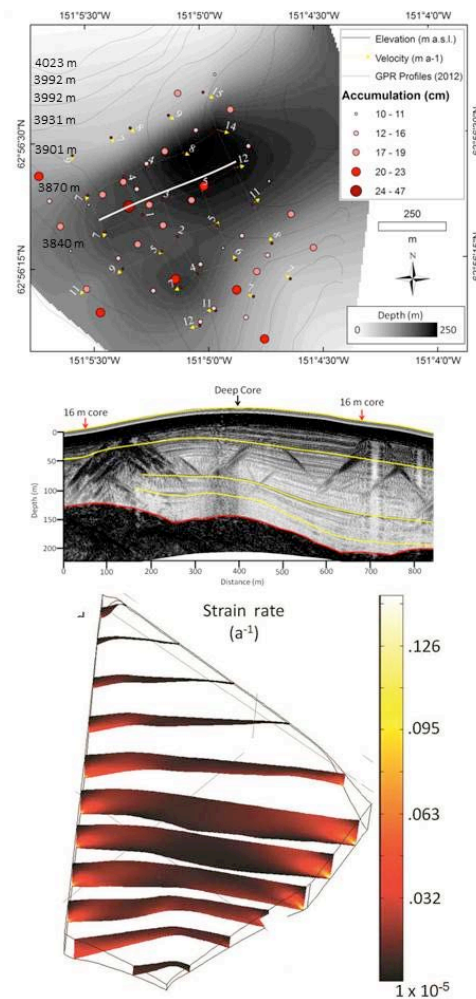


Figure 1 (a) map of Mount Hunter Ice divide showing depth (color), velocities, and accumulation rate. (b) 40 MHz GPR profile showing englacial isochrones. (c) Mount Hunter Ice divide numerical model showing modeled strain rates.

**Acknowledgments:** Funding for this work is from the Churchill Exploration Fund and NSF.

## Satellite Bio-Optical and Altimeter Comparisons of Phytoplankton Blooms induced by Natural and Artificial iron Addition in the Gulf of Alaska

Fei Chai<sup>1,2</sup>, Peng Xiu<sup>1</sup>, Andrew C. Thomas<sup>1</sup>

1. School of Marine Sciences, University of Maine
2. Climate Change Institute, University of Maine

### Abstract

An iron fertilization experiment conducted during the summer of 2012 dumped over 100 tons of an iron-containing substance into surface waters of a Haida eddy in the eastern North Pacific to stimulate a large phytoplankton bloom. Announced as a privately funded ocean fertilization effort to increase salmon returns, it attracted considerable press coverage, caused much public controversy and has been widely denounced by the science community. Here, we use available satellite bio-optical measurements from the MODIS/Aqua instrument and AVISO altimeter dynamic height data to examine the timing, magnitude and extent of this artificial iron fertilization experiment, comparing it with natural fertilization events such as volcanic ash deposition and mesoscale eddy transport in the Gulf of Alaska. With respect to the local area of the fertilization, this experiment induced the most intensive phytoplankton bloom of the past 10 years, ~2x stronger than that caused by Kasatochi volcano in 2008 and ~5x that typically produced by passing eddies of previous years. Due to its limited spatial and temporal scale, however, estimated total annual carbon drawdown over the Gulf of Alaska by this experiment is one order of magnitude smaller than the Kasatochi volcano and mesoscale Haida eddies. The target eddy followed a path typical of previous Haida eddies, but with relatively weak dynamic height and rotational circulation. Satellite-based calculations also suggest that only a small fraction of the dumped iron might have been taken up by phytoplankton. The extent to which this localized experiment may impact higher trophic levels such as salmon remains uncertain.

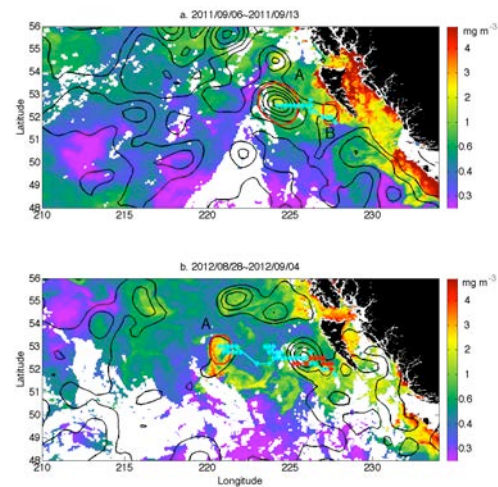


Fig. 1. The MODIS/Aqua derived surface chlorophyll concentrations over the Gulf of Alaska target area for two 8-day composite periods, (a) September 06-13 2011 and (b) August 28-September 04 2012. Black contours show merged SLA data (only positive values). For the same periods, red contours outline the eddy core. Blue dotted lines denote the track of eddy A and red dotted lines denote the track of eddy B.

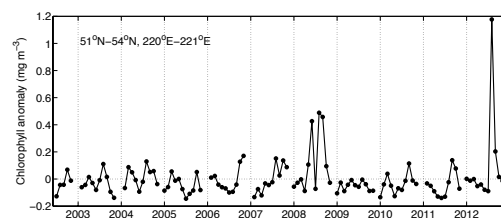


Fig. 2. Monthly surface chlorophyll anomalies (calculated by subtracting climatological monthly mean) averaged over the fertilization experiment region (51°N-54°N, 220°E-221°E) for the period July 2002 to November 2012.

## Predicting Tidal Marsh Communities Via Remote Sensing: A Potential Tool For Adaptive Coastal Conservation

Maureen Correll<sup>1,2,4</sup>, Brian J. Olsen<sup>1,2,4</sup>, Thomas P. Hodgman<sup>3</sup>, Whitney Wiest<sup>5</sup>, Steven A. Sader<sup>1</sup>

1. Climate Change Institute, University of Maine.
2. School of Biology and Ecology, University of Maine.
3. Maine Department of Inland Fisheries and Wildlife.
4. Adaptation to Abrupt Climate Change (A2C2) IGERT Program
5. University of Delaware.

**Abstract:** Tidal marshes of the northeastern United States are vulnerable to habitat loss due to impacts of both gradual and abrupt climate change. Here we attempt to quantify vegetation communities within tidal marshes from Maine to Virginia using remote sensing methods in an effort to develop a conservation tool for these areas in light of a rapidly changing climate.

Tidal marshes of the northeast are of particular importance and interest to human settlements along the coast due to the significant ecosystem services they provide. Among these services is the maintenance of biodiversity through support of several vertebrate species obligate to tidal marsh, including the Saltmarsh Sparrow (*Ammodramus caudacutus*). This bird's global breeding range falls entirely within marshes between Maine and Virginia, and is of significant concern at multiple conservation levels.

Although multiple conservation efforts are at work to conserve this sparrow's high-marsh breeding habitat, to date there has been no regional effort to locate and quantify large patches of high marsh within the north-eastern coastal complex. We present a series of scaled analyses to quantify high-marsh areas through use of Landsat Thematic Mapper (TM) imagery using established remote sensing methods (Ozesmi and Bauer 2002), and validate our analyses against a regional vegetation database collected by the Saltmarsh Habitat and Avian Research Program (SHARP). We found that while previous efforts have been fruitful in classifying high-marsh and low-marsh areas on smaller scales, our regional efforts to do the same classifications were largely unsuccessful. Our highest performing models resulting in a 71% overall accuracy. We found similar accuracies when we explored classification schemes at smaller scales (Fig. 1, purple boxes), and also used elevation data as a supplement to spectral data along a portion of our study area (Fig. 1, blue box). We found increased accuracy using LiDAR inputs, and

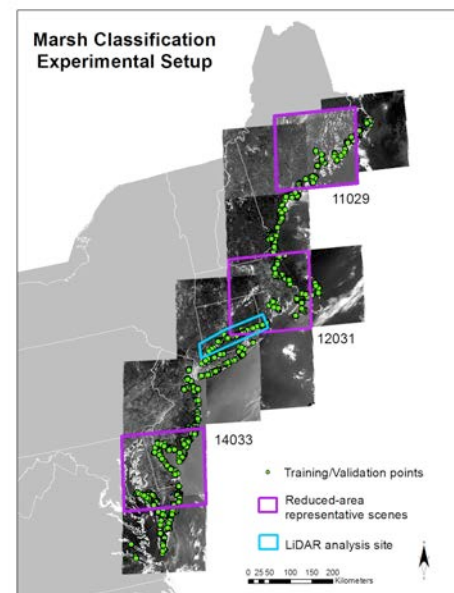


Figure 1. Analysis setup: Landsat TM scenes shown as black and white imagery.

recommend the use of a regional elevation dataset in future adaptive management planning for the Saltmarsh Sparrow.

**Acknowledgements:** Thank you to SWG, MDIFW, USFWS, NSF, MAWS, and GSG.

### **Bibliography:**

Ozesmi, S and Bauer, M. 2002. Satellite remotesensing of wetlands. *Wetlands Ecology and Management* 10:381-402.

## Remotely-Sensed Iceberg Melt Rate Estimates from Sermilik Fjord, Southeast Greenland

Ellyn M. Enderlin<sup>1</sup>, Gordon S. Hamilton<sup>1,2</sup>, Fiamma Straneo<sup>3</sup>

1. Climate Change Institute, University of Maine.
2. Department of Earth Sciences, University of Maine.
3. Department of Physical Oceanography, Woods Hole Oceanographic Institution.

**Abstract:** Little is known about submarine melting of glacier ice and icebergs in Greenland's glacial fjords, yet these sources of freshwater are likely to play an important role in ocean circulation across a range of spatial scales and to the ecological structure of Greenland's fjords. Here we describe a new technique for estimating submarine melt rates of icebergs by differencing repeat digital elevation models (DEMs) extracted from very high-resolution satellite images.

The contemporaneous onset of subsurface ocean warming on Greenland's eastern and western continental shelves [Seale et al., 2011; Holland et al., 2008], and observations of warm subsurface waters within glacial fjords [Straneo et al., 2012] supports the hypothesis that recent changes in Greenland glacier dynamics were triggered by changing oceanographic conditions. Warm subsurface water masses in Greenland's fjords are a potential heat source to drive submarine melting at the calving margins of outlet glaciers and icebergs floating in adjacent fjords. Spatial and temporal variations in the freshwater flux from submarine melting may influence fjord stratification and circulation, thus providing a potential feedback mechanism that can enhance or dampen the initial change in fjord water properties. Freshwater from submarine melting also affects the salt budget of the ocean, with potential impacts on marine ecosystems [Greene et al., 2008].

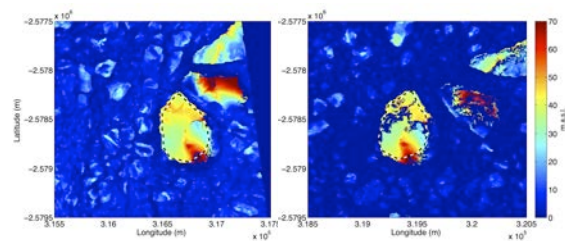


Fig. 1. DEMs from 24-06-2012 (left) and 29-06-2012 (right). The iceberg of interest is delineated with a black and white dashed line in both DEMs.

Submarine melt rates are poorly constrained, however, due to logistical difficulties in obtaining hydrographic observations near actively calving glacier margins. Here we show that submarine melt rates can be obtained by differencing repeat digital elevation models (DEMs) extracted from ~0.5 m-resolution WorldView-1 and -2 satellite images. We test our technique by

examining changes in freeboard (height above sea level) of icebergs in Sermilik Fjord, Southeast Greenland using images collected ~3-45 days apart. Assuming hydrostatic equilibrium, and correcting for ocean tides, any change in freeboard must be due to melting at the surface and below the waterline. Surface melt-rates are estimated from a positive degree-day model, leaving the residual term in the freeboard height change as being due to submarine melting.

Estimates derived using our DEM-differencing technique show that melt rates are on the order of ~0.3 m/d and that the freshwater flux due to iceberg melting is largely a function of the submerged surface area of each iceberg.

**Acknowledgements:** Work was funded by NASA award NNX13AK88G

### Bibliography:

Greene C.H., et al. (2008), Arctic climate change and its impacts on the ecology of the North Atlantic, *Ecology* **89**, 524-538.

Holland, D. M., et al. (2008), Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters, *Nature Geosci.* **1**, 659-664.

Seale, A., et al. (2011), Ocean forcing of the Greenland Ice Sheet: Calving fronts and patterns of retreat identified by automatic satellite monitoring of eastern outlet glaciers, *J. Geophys. Res.* **116**, F03013, doi:10.1029/2010JF001847.

Straneo, F., et al. (2012), Characteristics of ocean waters reaching Greenland's glaciers, *A. Glaciol.* **53**, 60, doi:10.3189/2012AoG60A059.



## Prevalent Known and Cryptic Extinctions in the Pleistocene Have Conservation Lessons for the Next Century

Jacquelyn L. Gill<sup>1</sup>, Dov Sax<sup>2</sup>

1. Climate Change Institute & School of Biology and Ecology, University of Maine.
2. Ecology and Evolutionary Biology, Brown University.

**Abstract:** Climate change in the next century is predicted to drive widespread species range reductions, endangerments and extinctions. Recently, the magnitude of these effects has been called into question by the Quaternary fossil record and accompanying interpretations that non-anthropogenic extinction was rare, in spite of rapid and repeated climate change. This has resulted in the emerging paradigm in paleoecology that species may be more resilient than predicted in the face of forecast climate change. In contrast, in our re-examination of the Quaternary fossil record we found that extinction was much more prevalent than has been previously appreciated, with respect to both documented extinctions and unidentified, or 'cryptic,' extinctions.

### Background

The Quaternary fossil record documents widespread shifts in species' ranges and abundances in response to glacial-interglacial cycles, but it is typically thought that extinction and diversification were not important processes. While there is extensive evidence for a global fingerprint of anthropogenic climate change on modern biota, the magnitude of projected climate-driven extinction has been recently called into question by the fossil record of the last 2.58 million years. Specifically, investigators have noted that despite repeated glacial cycles and often rapid fluctuations in climate, there were apparently few non-anthropogenic extinctions during the Quaternary. This so-called "conundrum" (2) has led some investigators to conclude that species may be more resilient in the face of forecast climate change than previously predicted, and that estimates of future extinction risk due to climate change may be overstated (3).

### Results

We find that extinction was much more prevalent than has been previously appreciated, with respect to both documented extinctions and unidentified, or 'cryptic,' extinctions. Documented extinctions are more common than commonly thought due to previous temporal, regional and taxonomic biases. The recent reclassification of the start of the Quaternary from <2 ma to 2.588 ma BP, means that many extinctions previously identified as end-Pliocene actually occurred in the Pleistocene, during the

onset of glacial-interglacial cycles and rapid climate change. Further, predominate attention paid to the last deglaciation misses a pulse of extinction in the mid-Pleistocene, at the onset of shifts in the periodicity and amplitude of glacial-interglacial cycles. Clade-based approaches tend to integrate taxa from different regions or habitat types, down-playing the mechanisms that drive extinction risk. Over the Pleistocene, cases of rapid speciation within habitats that are ephemeral relative to glacial-interglacial cycles provide evidence that a broader set of 'cryptic' extinctions have also occurred. Together, these data suggest that climate-associated extinctions have been much more common than previously appreciated. Consequently, the fossil record has yet to be fully marshaled to document extinction risk associated with climate change or to draw lessons from these extinctions for conservation challenges going forward.

**Acknowledgements:** Support for this research was provided by the Environmental Research Initiative's Voss Postdoctoral Fellowship at Brown University. Thanks to Jens Christian-Svenning for valuable comments on this research.

### Bibliography:

- 1) C. Parmesan, *Annu. Rev. Ecol. Evol. S.* 37, 637 (2006).
- 2) D. B. Botkin *et al.*, *BioSci.* **57**, 227 (2007).
- 3) C. Hof, I. Levinsky, M. B. Araújo, C. Rahbek, *Glob. Change Biol.* **17**, 2987 (2011).

## Examining the Relationship between Surface Albedo and Glacier Mass Balance in the Central Alaska Range

Timothy P. Godaie<sup>1</sup>, Elizabeth A. Burakowski<sup>2</sup>, Karl J. Kreutz<sup>1,3</sup>, Gordon S. Hamilton<sup>1,3</sup>, Seth W. Campbell<sup>3,4</sup>, Dominic Winski<sup>5</sup>, Sean D. Birkel<sup>1</sup>, Cameron P. Wake<sup>6</sup>, Erich C. Osterberg<sup>5</sup>, Bradley R. Markle<sup>7</sup>

1. Climate Change Institute, University of Maine.
2. National Center for Atmospheric Research, Boulder, CO.
3. Department of Earth Sciences, University of Maine.
4. Cold Regions Research & Engineering Lab, Hanover, NH.
5. Department of Earth Science, Dartmouth College.
6. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire.
7. Department of Earth & Space Sciences, University of Washington.

**Abstract:** In-situ albedo measurements from our 2013 field season on the Kahiltna Glacier (Denali National Park, AK) validate the use of satellite-derived albedo values. We examine the relationships between surface albedo and glacier mass balance.

Surfaces with high reflectance values within the cryosphere such as seasonal snowpack, glacial snow and ice, and sea ice play a vital role in the global climate system and in the energy budgets of the world's glaciers. Changes in reflectance may induce feedbacks resulting in fluctuations of glacier mass balance. My objective is to understand glacier response to climate forcing by using surface albedo as a proxy for mass balance.

To understand the relationship between surface albedo and mass balance, we used an ASD, Inc. FieldSpec4 spectroradiometer to measure incoming radiation, outgoing surface reflectance and optical grain size on the Kahiltna Glacier for seven days during our 2013 field season in Denali National Park. While on site, we deployed two Campbell Scientific automatic weather stations at Base Camp and on Mount Hunter, recovered over 450 meters of ice cores, and collected kilometers of radar profiles.

We derive surface albedo using the Moderate Resolution Imaging Spectroradiometer (MODIS) MCD43A3 data product, a 16-day composite with 500 meter resolution. Comparison of the MCD43A3 albedo to the ASD FieldSpec4 data shows a strong correlation. This means the satellite-derived albedo accurately describes what we measured in the field. The MODIS validation allows us to further examine the relationship between surface albedo and mass balance. A time series of albedo will be compared to the National Park Service and USGS mass balance data dating back to 1991.

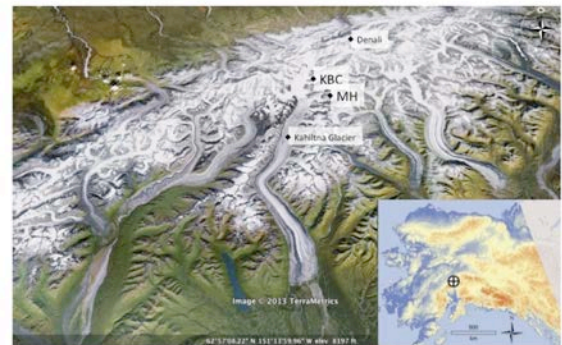


Fig. 1. Google Earth image of study locations: Kahiltna Base Camp (KBC- 2105 masl), and Mount Hunter (MH- 3910 masl). Kahiltna Glacier and Mount McKinley (Denali) also noted. Insert map (from Campbell et al., 2012) shows the Central Alaska Range (circle-plus symbol) on a DEM of Alaska (red is high elevation).

**Acknowledgements:** Funding from US National Science Foundation- Office of Polar Programs award 1203838 to K. Kreutz. Logistical support provided by: Denali National Park, Talkeetna Air Taxi, and CPS Polar Services.

### Bibliography:

Campbell, Seth, et al. "Flow dynamics of an accumulation basin: a case study of upper Kahiltna Glacier, Mount McKinley, Alaska." *Journal of Glaciology* 58, no. 207 (2012): 185-195. Doi: 10.3189/2012JoG10J33.

## 20<sup>th</sup> Century Atmospheric Dust Lows and the Weakening of the Westerly Winds over the Tibetan Plateau

Bjorn Grigholm<sup>1,2</sup>, Paul A. Mayewski<sup>1,2</sup>, Shichang Kang<sup>3</sup>, Kirk Maasch<sup>1,2</sup>, Sean Birkel<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. Department of Earth Sciences, University of Maine.
3. Institute of Tibetan Plateau Research, Chinese Academy of Sciences.

### Abstract:

Dust aerosols play an integral role in the climate system influencing the Earth's radiative balance directly<sup>1</sup>. Central Asia is one of the Northern Hemisphere's largest emitters of dust, estimated to produce 10-30% of global emissions<sup>2</sup>. Understanding past atmospheric dust variability of major dust sources is necessary to put modern atmospheric dust concentrations into historical context and assess the impacts of dust on the climate system. Unfortunately, meteorological data of atmospheric dust is temporally limited in Asia, beginning only in the 1950s.

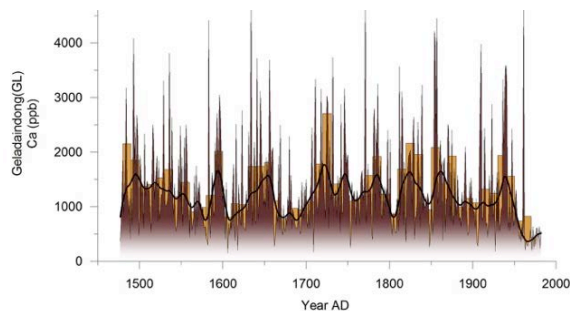


Fig. 1. Ca time-series 1477-1982AD. Brown gradient fill represents annual concentrations. Yellow columns represent 10-year means. Black-line represents a robust spline (tension 0.01).

Thus, high-resolution ice cores provide the ideal archive for reconstructing pre-instrumental atmospheric dust concentrations. Using a ~500-year (1477-1982AD) annually resolved calcium (Ca) dust proxy from a Tibetan Plateau (TP) ice core, we demonstrate that atmospheric dusts during the latter 20<sup>th</sup> century are at their lowest concentrations in

GL logCa:DM Zonal Wind Correlation

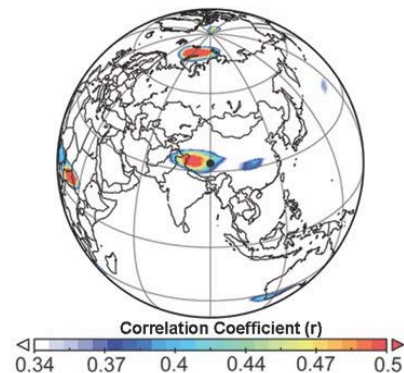


Fig. 2. NCEP/NCAR 1 spatial correlations of logCa and Dust Months (DM) zonal wind ( $U_{500}$ )

the past ~500 years. Declines in late 19<sup>th</sup>-20<sup>th</sup> century Ca concentrations significantly correspond with regional trends of zonal wind strength from two reanalysis models, suggesting that the Ca record provides a proxy for the westerlies. 20<sup>th</sup> century warming and attendant atmospheric pressure reductions over northern Asia have potentially reduced temperature/pressure gradients leading to the lower zonal wind velocities and associated dust entrainment and/or transport in the past ~500 years over the TP.

### Bibliography:

- [1] Tegen et al., *Nature*, **380**, 419-422 (1996).
- [2] Tanaka, T.Y., and Chiba, M. *Global and Planet. Change*, 52 (1-4), 88-104 (2006).

## How Does Abrupt Climate Change Influence Marine-Terrestrial Linkages?

Dulcinea V. Groff<sup>1,2</sup>, Jacquelyn L. Gill<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Biology and Ecology, University of Maine.

**Abstract: Paleoecological reconstructions using sediment analyses provide valuable associations between past ecosystem dynamics and past climate changes. Specifically, how past abrupt climate changes altered the equilibrium of seabird populations and subsequent fluctuation of nutrient inputs into coastal grasslands of the Falkland Islands will be reconstructed. In addition, the strength of the westerlies through time will be characterized using long-distance transported pollen, sediment geochemistry, and grain size analysis.**

Nutrient transport from the marine ecosystem to island ecosystems is a basic supporting service to a system that receives very little nutrient input otherwise. Marine nutrient subsidies are essential to maintain biodiversity of isolated terrestrial environments. Endemic seabirds and some of the world's most important seabird rookeries in the Falkland Islands face the threat of extinction from the impacts of a rapidly changing climate. The Falkland Islands are an ideal location to study how past global climate changes influence critical habitat of nesting seabirds.

Multiple proxy records indicate southern hemisphere westerly winds gradually strengthened over the last 3,000-5,000 years and are currently as intense as they were during the last glacial maximum (~26 – 16 kya) and the Little Ice Age (1400-1850 A.D.) (Schulmeister et al. 2004). Latitudinal shifting and wind strength of the westerlies influence both marine and terrestrial ecosystems. In the Southern Oceans, the biological responses of seabirds vary naturally based on climatic fluctuations with sea ice cover and atmospheric temperature (Sun et al. 2013). The natural range of vulnerability in seabird populations in response to interactions of the climate system and the resulting impact on the marine-terrestrial linkage is unknown.

The long history of guano deposition in terrestrial seabird habitats directly influences soil characteristics and vegetation, which in turn provides critical habitat for seabirds (Polis et al. 1997). Seabird nutrient inputs sustain terrestrial vegetation and vital seabird breeding habitats. Modern coastal grasslands are also valuable as grazing pastures for ranchers of the Falkland Islands. Native grasslands have been degraded

to 20% of their original area from livestock overgrazing and intense fires.

Analyses of sediment cores from lacustrine and peat bogs will be used to reconstruct the past. Sediments contain proxies for vegetation communities and abundance (pollen records), seabird populations (avian bioelements), as well as fire frequency and intensity (charcoal) Thus, evaluating how seabird colonies and grasslands responded to past abrupt climate changes is important for understanding biological responses of biota and the ecosystem services they provide today.

**Acknowledgements:** I gratefully thank the Churchill Exploration Fund for funding upcoming research travel.

### **Bibliography:**

Polis, G. A., W. B. Anderson, and R. D. Holt. 1997. "Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs." *Annual Review of Ecology and Systematics* 28:289-316.

Schulmeister, J., I. Goodwin, J. Renwick, K. Harle, L. Armand, M. S. McGlone, E. Cook, J. Dodson, P. P. Hesse, P. Mayewski, and M. Curran. 2004. "The southern hemisphere westerlies in the Australasian sector over the last glacial cycle: a synthesis." *Quaternary International* 118-119:23-53.

Sun, L. G., S. D. Emslie, T. Huang, J. M. Blais, Z. Q. Xie, X. D. Liu, X. B. Yin, Y. H. Wang, W. Huang, D. A. Hodgson, and J. P. Smol. 2013. "Vertebrate records in polar sediments: Biological responses to past climate change and human activities." *Earth-Science Reviews*. 126:147-55.

## The Cost of Migration Distance and Predation Risk for Migratory Songbirds

David P. Grunzel<sup>1,2</sup>, Brian J. Olsen<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. Department of Ecology and Environmental Science, University of Maine.

**Abstract:** Climate change will alter the communities and predatory-prey interactions among species at stopover sites and change the costs and benefits for current migration strategies. We observed both behavioral responses and changes in mass among birds of different migratory strategies under variation in predation risk. Because longer distance migrants did not change their behavior and were in poorer condition on average, they may pay a larger cost in areas of higher risk.

Climate change will alter the migratory phenology and routes of many migratory species. The effect of change thus far has been on species that travel greater distances in the fall to reach their non-breeding grounds. In North America, the timing of migration for longer distance migrants has shifted earlier whereas shorter distance migrants move later (Van Buskirk, Mulvihill, and Leberman 2009). The divergence of migratory timing between the two groups will result in a different community of birds at stopover sites, where birds stage to rest and forage along their migratory route. Altering community composition and predator-prey interactions among species at stopover sites will change the costs and benefits of current migratory strategies, thus disrupting the evolutionary trajectory of species. As the frequency of predator-prey interactions may change, we want to understand the cost effectiveness of certain migration strategies in the presence of variable amounts of avian predators. We conducted an aviary experiment observing the tradeoff between vigilance and foraging (cost and benefit) behavior of longer and shorter distance migrating birds in response to increased predation risk via a predator vocalization playback. As mass loss can be a consequence of reduced foraging behavior, we also examined the mass of longer and shorter distance migrants at banding locations with variation in raptor abundance during fall migration. We found shorter distance migrants increased activity (Fig. 1) and carry more mass under high predation risk. Longer distance migrants did not change their activity in response to a predator but carried less mass than shorter distance migrants at high risk locations.

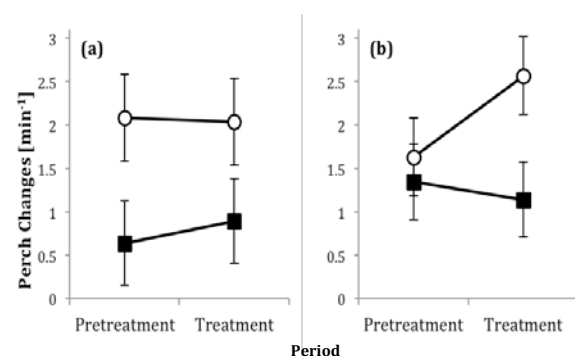


Figure 1 Movement rates of birds in response to (a) a control call and an avian predator call. The open circles are shorter distance and the solid squares are longer distance migrants.

Migration distance appears more costly in the face of increased predation. As migration timing and routes shift with climate change, we predict that longer distance migrants will pay a larger cost in areas that overlap raptor migration more heavily.

**Acknowledgements:** Thanks to the National Park Service, the University of Maine, Maine Coastal Islands National Wildlife Refuge, and Schoodic Education and Research Center. Also, many thanks to the Olsen Lab.

### Bibliography:

Van Buskirk, Josh, Robert S Mulvihill, and Robert C Leberman. 2009. "Variable Shifts in Spring and Autumn Migration Phenology in North American Songbirds Associated with Climate Change." *Global Change Biology* 15 (3) (March): 760–771.

## Ecosystem Responses to a Unique Whole-Watershed Isotopic Tracer Experiment: Where did the $^{15}\text{N}$ go?

Marie-Cécile Gruselle<sup>1</sup>, Ivan J. Fernandez<sup>1,2,3</sup>

1. School of Forest Resources, University of Maine.
2. School of Forest Resources
3. Climate Change Institute, University of Maine.

**Abstract:** At the Bear Brook Watershed in Maine, a watershed-scale  $^{15}\text{N}$  tracer pulse-chase experiment began in June 2012 to study the redistribution of  $^{15}\text{N}$  from forest canopy through soils to streams within the N-enriched and reference watersheds.

### Background:

Elevated atmospheric nitrogen (N) deposition is likely to persist into the future, as is the acceleration of N cycling in some areas by a changing physical climate. Long-term studies are rare but crucial to better understand the complex biogeochemical processes governing shifts in N dynamics that develop on decadal time scales.

Our study site is the Bear Brook Watershed in Maine (BBWM), a long-term paired forested watershed experiment comprising the West Bear watershed (WB, 10.3 ha) undergoing N addition and acidification manipulations since November 1989 and the adjacent East Bear reference watershed (EB, 11.0 ha). In the third decade of this study, ecosystem responses are emerging that were unknown when the experiment began. In order to further investigate shifts in N dynamics at the BBWM, a unique  $^{15}\text{N}$  tracer experiment was initiated on June 5, 2012 using the pulse-chase approach to study the fate of the tracer (98 atom-%  $(^{15}\text{NH}_4)_2\text{SO}_4$ ) added at the rate of  $0.4 \text{ kg ha}^{-1}$  by backpack sprayers across both watersheds.

### Results and Discussion:

By August 2012, two months after the  $^{15}\text{N}$  tracer addition, understory vegetation and the uppermost layer of the forest floor showed the strongest  $^{15}\text{N}$  enrichment in both watersheds, reflecting initial surface exposures as well as a strong physiological demand by understory vegetation for N (Fig. 1). No  $^{15}\text{N}$  had reached the mineral soil at that time, indicating nearly complete abiotic and biotic N retention above the mineral sub-soils. Understory vegetation in EB took up more  $^{15}\text{N}$  than in WB, reflecting greater N deficiencies under ambient conditions. For components repeatedly sampled over time, such as the coarse organic fraction (COF) of the

forest floor,  $^{15}\text{N}$  enrichment persisted into 2013 (day 468, Fig. 2), attributed to high microbial N demand in these C-rich substrates. Ongoing study of these  $^{15}\text{N}$  enrichments will improve our understanding of shifting N dynamics in these ecosystems.

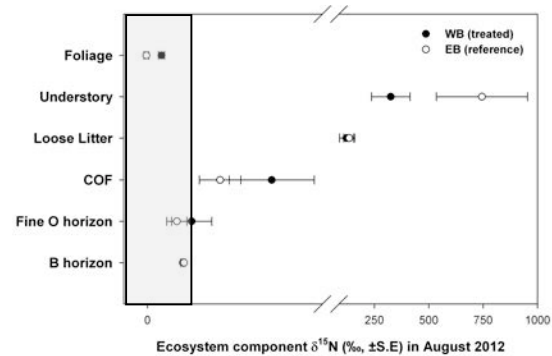


Fig. 1.  $^{15}\text{N}$  enrichment of components from both watersheds two months after  $^{15}\text{N}$  application. The gray shading indicates the range of pre- $^{15}\text{N}$  application natural abundances.

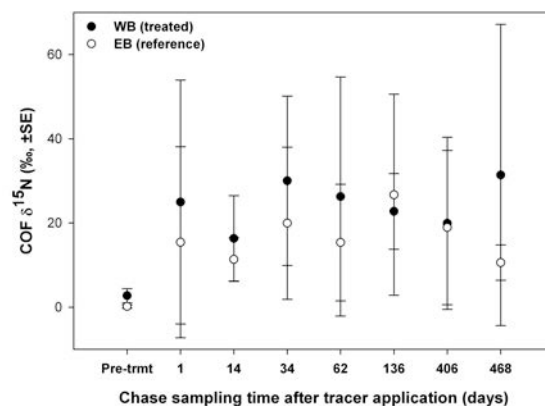


Fig. 2.  $^{15}\text{N}$  enrichment in the coarse organic fraction in both watersheds during the period 2012-2013.

**Acknowledgements:** This research was funded by the National Science Foundation (DEB 1056692 and DEB 1119708) and the University of Maine.

## Investigation of Greenland and Antarctic Ice Core Recorded Abrupt Climate Change Using Ultra-High Resolution Laser Sampling

Skylar A. Haines<sup>1</sup>, Paul A. Mayewski<sup>1,2</sup>, Andrei V. Kurbatov<sup>1,2</sup>, Kirk A. Maasch<sup>1,2</sup>, Sharon B. Sneed<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.

**We are refining interpretations of select Abrupt Climate Change (ACC) events recorded in polar ice cores using the W.M. Keck Laser Ice Facility thus allowing ultra-high resolution sampling (20  $\mu\text{m}$  compared to 1 cm resolution obtained by previous sampling methods). Glaciochemical measurements made with our inductively coupled plasma mass spectrometer (LA-ICP-MS) allow detection of annual layers potentially down to storm-scale events, yielding a detailed characterization of the timing and magnitude of atmospheric circulation, seasonality and precipitation associated with past ACC events.**

Abrupt Climate Change (ACC) is one of the greatest threats to global sustainability that the world faces today. ACC is defined as a major reorganization of atmospheric circulation where climate feedback forcing is large enough to result in substantial state changes (temperature, wind strength, precipitation, etc.) to the climate system in a short amount of time. The most recent was a  $5^{\circ}\text{C}$  increase in mean annual temperature in  $<5$  years over portions of the Arctic<sup>1</sup>. The risks of ACC are globally pervasive, having the potential to disrupt various aspects of society with large social and economic consequences. Ice cores provide evidence that ACC events occurred in the past.<sup>2,3</sup>

We refine interpretations of select ACC events recorded in polar ice cores through the use of a new ultra-high resolution (20  $\mu\text{m}$ ) non-destructive sampling method that yields a temporal resolution of hundreds of samples per year, depending on annual layer thickness. We measure concentrations of select glaciochemical species (calcium, potassium, sodium and iron), proxies for atmospheric circulation,<sup>1,3</sup> from an Arctic (GISP2: Greenland Ice Sheet Project 2) and Antarctic (Siple Dome) ice core archive.

The GISP2 ice core archive sampled in this study ranges from 2674 to 2680 meters depth, and features the abrupt climate transition from stadial to interstadial (Dansgaard-Oeschger event 21;  $\sim 83\text{-}85$  kya), as recorded by original IC concentrations.<sup>3</sup> The Siple Dome ice core archive to be investigated ranges from 713 to 725 meters depth ( $\sim 19\text{-}22$  kya), during the last glacial maximum (LGM).

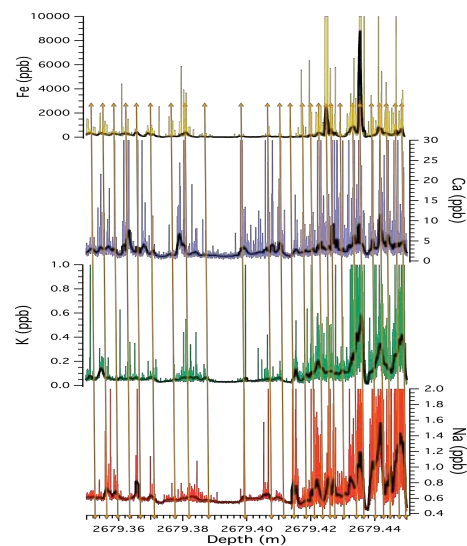


Figure 1. Concentrations, in parts per billion (ppb), of a 10 cm section of select glaciochemistry from the GISP2 ice core as measured by the W.M. Keck Laser Ice Facility LA-ICP-MS. Approximately 5000 samples shown. A 50-point box model smooth is used over the raw data. Vertical arrows delineate winter seasonality, yielding an estimated 26 years. Depth scale is in meters below the ice sheet at Summit, Greenland.

**Acknowledgements:** NSF grant ARC-1203640

### References:

- [1] Mayewski, P.A. et al. (2013), *J. Quaternary Science*, 9999, 1-7
- [2] Johnsen, S.J et al. (1992), *Nature*, 359, 311-313
- [3] Mayewski, P.A. et al. (1997), *J. Geophysical Research*, 102, 26345-26366

## Repeat Terrestrial LiDAR Scanning of a Major Outlet Glacier–Fjord System in East Greenland

Gordon S. Hamilton<sup>1,2</sup>, David C. Finnegan<sup>3</sup>, Adam L. LeWinter<sup>3</sup>, Leigh Stearns<sup>4</sup>, Ananda Fowler<sup>5</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. US Army Cold Regions Research and Engineering Laboratory.
4. University of Kansas.
5. Riegl Measurement Systems GmbH.

**Abstract:** Tidewater glaciers exhibit dynamic behaviors across a range of spatial and temporal scales, posing a challenge to both in situ and remote sensing observations. Here we describe the development of a novel near-situ measurement technique which combines the strengths of the in situ and remote sensing approaches, yet avoids most of their disadvantages. First results are presented for Helheim Glacier and Sermilik Fjord.

Tidewater glaciers exhibit dynamic behaviors across a range of spatial and temporal scales, posing a challenge to both in situ and remote sensing observations. In situ measurements capture variability over very short time intervals, but with limited spatial coverage and significant cost and risk to deploy. Conversely, airborne and satellite remote sensing is capable of measuring changes over large spatial extents but at limited temporal sampling. Terrestrial LiDAR Scanning (TLS) combines rapid acquisition capabilities of in situ measurements with the broad spatial coverage of traditional remote sensing. This paper describes a new long-range (6-10 km) terrestrial full-waveform LiDAR scanner that is optimized for glacierized environments. Our work seeks to gain insights into the processes of glacier flow and terminus dynamics at Helheim Glacier, a large East Greenland outlet glacier which moves at speeds > 25 m/d near its terminus. Rapid readjustments in speed are also known to occur following terminus retreat. Our understanding of these processes is limited by incomplete observational datasets.

Most TLS instruments operate in the near-infrared spectrum (1550 nm), which greatly limits measurement range (< 150 m) over snow and ice surfaces. Our new TLS instrument incorporates a green laser (1064 nm) which, while not eye-safe, gives significantly stronger returns over snow and ice, and thus longer range (6-10 km).

High spatial and temporal resolution surveys were conducted over a 5-day period in August 2013 at Helheim Glacier. Complete scans of the

glacier terminus and adjacent fjord were acquired every 30 minutes.

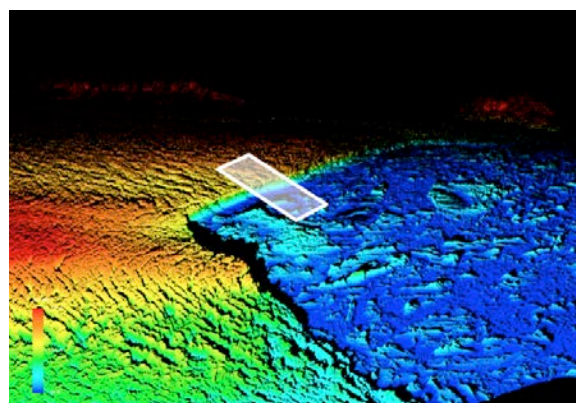


Fig. 1. Example of single LiDAR scan collected over the terminus region of Helheim Glacier, August 2013. The white box is approximately 2 km long.

Preliminary results from these surveys allow us to quantify short-term horizontal displacement rates and terminus behavior at unprecedented temporal and spatial resolutions.

**Acknowledgements:** Work was funded by NSF award ANS-0909274.



## Zooplankton Community Composition in Arctic Lakes of Southwest Greenland

Erin M. Hayes-Pontius<sup>1,2</sup>, Robert M. Northington<sup>1</sup>, Jasmine E. Saros<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Biology and Ecology, University of Maine.

**Abrupt climate change in the Arctic has the potential to alter lake ecosystem function. To examine the current state of some biological communities, we surveyed 26 lakes in southwest Greenland for zooplankton and identified water quality variables most important in structuring communities.**

Studying the biological dynamics of arctic lakes is imperative as they are more sensitive to climate change than their lower latitude counterparts. In the Arctic, the combined effects of a short growing season and rapid warming may exert a strong ecological response on lake ecosystems in the region (Smol et al. 2005).

To better understand summertime zooplankton community dynamics, a set of 26 lakes in southwest Greenland were sampled for zooplankton, a type of invertebrate, and a suite of water quality parameters twice during the summer of 2013, after ice-off in June and mid-summer in July. Lakes were situated along an east-west transect from the ice sheet out towards the coast.

Early season zooplankton communities were dominated by rotifers, while mid-summer communities were dominated by crustacean (cladoceran and copepod) zooplankton. Dominant crustacean taxa included the *Daphnia pulex*-complex, *Leptodiatomus minutus*, and *Cyclops scutifer*.

Zooplankton communities were primarily structured by chlorophyll, conductivity, dissolved organic carbon, and light. Early season copepods were most abundant in lakes with the highest chlorophyll concentration closest to the lake bottom (Fig. 1), but this trend did not persist mid-season. Temperature was only important when both sampling dates were combined, but not within months. Lakes had less chlorophyll when crustacean zooplankton dominated, possibly reflecting an increase in grazing pressure. Both within and across months, cladocerans were more abundant in lakes with higher conductivity and a lower proportion of dissolved organic matter.

A warmer Arctic may reflect conditions typically seen in the later part of the growing season,

potentially altering primary productivity and grazing dynamics in lakes.

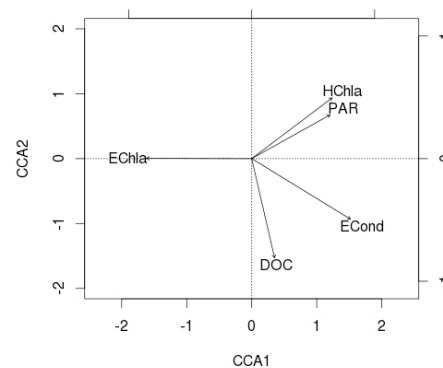


Fig. 1. CCA of zooplankton community in June.

**Acknowledgements:** This project was funded by NSF Arctic Grant 1203434. The authors would like to acknowledge Kathryn Warner, Benjamin Burpee, and Steve Juggins for their assistance in the field. Chris Osburn also helped in the field and analyzed dissolved organic carbon samples.

### Literature Cited

Smol, John P., Alexander P. Wolfe, H John B. Birks, Marianne SV Douglas, Vivienne J. Jones, Atte Korhola, Reinhard Pienitz et al. "Climate-driven regime shifts in the biological communities of arctic lakes." *Proceedings of the National Academy of Sciences of the United States of America* 102, no. 12 (2005): 4397-4402.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

## Currents of the Past: Archaeological Evidence for Past Changes in Fish Ecology in the Gulf of Maine

A. Sky Heller<sup>1,2</sup>, Brian S. Robinson<sup>1,2</sup>

1. Department of Anthropology, University of Maine.
2. Climate Change Institute, University of Maine.

**Abstract:** This project will focus on previously unexplored small fish remains from a series of rare Archaic-period shell midden archaeological sites along the Gulf of Maine. We will be investigating a possible abrupt change in Gulf of Maine currents – and associated changes in fish populations – at approximately 3,800 B.P. corresponding with the disappearance of swordfish (*Xiphias gladius*) remains archaeologically.

One of the most pronounced changes in Gulf of Maine fisheries ecology occurred in the Late Archaic period approx. 3800 B. P. when swordfish abruptly disappear from the archaeological record. The presence of swordfish is assumed to signal a period of warmer sea surface temperatures within the Gulf of Maine, possibly due to a shift in the Gulf Stream and an interruption of the cold-water Labrador current (Sanger 1988). Five coastal archaeology sites along the Gulf of Maine preserve evidence from this critical period, providing us with the opportunity to investigate this possibility, including the degree to which the change was expressed and its broader effects on fisheries and fish ecology. All of these sites are currently endangered due to sea level rise and global warming, making a detailed analysis imperative if we are to preserve this important record.

The present study will examine extant faunal assemblages and newly excavated and archived archaeological samples from at least four of the five sites, stretching from Frenchman Bay in Maine to the Hampton Estuary in New Hampshire. Fine mesh screened samples, virtually unexplored for the Late Archaic period, will be processed to maximize identification of fish species, including those not now native to the Gulf of Maine, to explore how fish communities changed through time. This study draws upon endangered archaeological evidence of a change from warm to cold water marine fish communities *that may be the reverse of future trends back to warmer environmental conditions*, and associated cultural reactions to that change.

The 2013 field season found that critical archaeological strata documented in the late 1930's are still preserved in the surviving portions of the Waterside archaeological site in Sorrento, ME. Furthermore, samples gathered during excavation demonstrate excellent bone and shell preservation for the critical period. Further excavations will take place during the coming 2014 field season at one or more additional sites to gather samples for investigation. While this research is in its earliest stages, results so far have proven encouraging.

**Acknowledgements:** We would like to thank the Archaeological Conservancy for their permission and support of our investigations at the Waterside Shellheap. We would also like to acknowledge Joseph Goodin for his invaluable help with initial processing of Waterside samples. This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

### Bibliography:

Sanger, David. 1988. "Maritime Adaptations in the Gulf of Maine." *Archaeology of Eastern North America* 16: 81–99.

## Exploring Limits of Evolutionary Rescue in Vernal Pool Amphibians Facing Abrupt Climate Change

Jared J. Homola<sup>1,2</sup>, Michael T. Kinnison<sup>1</sup>, Cynthia S. Loftin<sup>1,2</sup>

1. School of Biology and Ecology, University of Maine
2. U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, University of Maine.

**Abstract:** Evolutionary rescue is the capacity for ongoing adaptive evolution to slow or avert abundance declines in wild populations. Various forms and degrees of abrupt climate change will present different challenges for evolutionary rescue and existing theory in this area has not considered complex population structure and eco-evolutionary dynamics across realistic landscapes. We are building agent-based models to assess the capacity for metapopulations of wood frogs and spotted salamanders to adapt to abrupt climate change through phenotypically plastic and evolutionary responses. Our models will represent a critical step in understanding interactions between climate change and other human changes to natural landscapes.

Animal populations subjected to climate change are often portrayed as facing three options: maladaptation and localized population declines, *in situ* adaptation to new conditions (i.e., evolutionary rescue), or range changes into suitable habitat. However, the distinction of these options is likely artificial, as many species are expected to experience all three responses to some degree. Moreover, the magnitude and interactions of these different responses are expected to depend on patterns of climate change at varying scales and interactions with other human changes to landscapes.

The need to consider evolutionary potential and limits is emphasized by a consideration of scope for range change alone. Temperature changes of 1°C equate to an average range shift of about 160 km; therefore, under the predicted 4°C increase over the next century, many species may require a range shift of over 500 km (Thuiller 2007). Some highly mobile species may be able to accomplish such large scale range shifts, but the vast majority of the world's biodiversity likely faces dispersal limits on such short time frames. For those species persistence may depend on some capacity for evolutionary rescue facilitated by localized dispersal and gene flow across complex landscapes

Research has indicated that many populations are capable of evolving at rates fast enough to avoid extirpation under typical scenarios of environmental change (Kinnison and Hairston 2007). However, there are limits to the capacity for evolutionary rescue. Knowing those limits is important for identifying abrupt climate change risks, but existing theory has not studied realistic

spatial dynamics such as complex population structure and landscape heterogeneity.

We are developing agent-based models to examine the relationship between phenotypic plasticity, genetic evolution, and climate change in spatially structured species. Our models will be based on Maine's vernal pool-dependent amphibians, which are likely very susceptible to climate change given the vulnerability of vernal pools to environmental perturbation. We will focus on scenarios of temperature and precipitation changes that include varying rates and patterns of linear versus abrupt climate change, as well as changes in climatic variances. As part of our modeling we will collect empirical data on spatial scales of adaptation, dispersal and gene flow in our two focal species. By applying these real-world parameters to our models we will assess potential tipping point responses for vernal pool amphibians. This model could subsequently be modified to identify similar thresholds for other species.

**Acknowledgements:** This research is supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423, US National Science Foundation project grant 1313627, the US Geological Survey, and the University of Maine.

**Bibliography:** Kinnison, Michael T. and Nelson G. Hairston, Jr. "Eco-evolutionary conservation biology: Contemporary evolution and the dynamics of persistence." *Funct. Ecol.* 21(2007): 444-5.

Thuiller, W. "Climate change and the ecologist." *Nature* 448(2007):550-2.

## Visible Tephra Layers in the First 500 Meters of the R.I.C.E. Ice Core

Donna A. Kalteyer<sup>1</sup>, Andrei V. Kurbatov<sup>1</sup>, Martin Yates<sup>2</sup>, Christopher Gerbi<sup>2</sup>, Nelia W. Dunbar<sup>3</sup>, Thomas Beers<sup>1</sup>, Paul A. Mayewski<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. New Mexico Institute of Mining and Technology.

**Abstract:** Geochemical composition of five visible tephra layers from Roosevelt Island Climate Evolution (RICE) project ice core were measured using Tescan Vega XMU SEM. The geochemical fingerprint of the tephra layer from the depth of 165 meters allows us to make a preliminary correlation between this volcanic ash and a similar layer found in four other Antarctic ice cores: Siple Dome, WAIS Divide, Taylor Dome, and Talos Dome.

Preserved within the Antarctic ice cores we find evidence of volcanic products (tephra particles and aerosols) that reveals information about how global volcanism interacts with the climate system (Lamb 1971, Hammer 1980). Matching the tephra and geochemical data from a known eruption with tephra found within an ice core, we could potentially identify the unknown layer (De Angelis et al. 1985). In the RICE ice core, five visible tephra layers were sampled between 165-500 m in depth, and processed on the SEM.

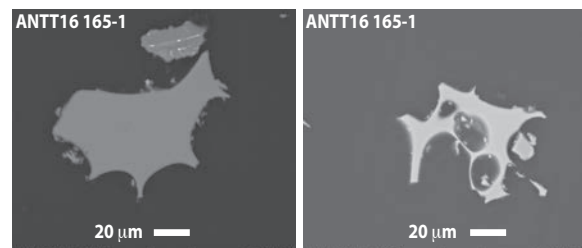


Figure 2. RICE tephra BSE images from SEM.

Potential refinement of this correlation may be accomplished by running on the LA-ICPMS.

**Acknowledgements:** We would like to thank Nancy A.N. Bertler and Peter Neff for providing access to tephra samples. Funding was provided from a grant through the U.S. NSF Polar Program grant numbers ANT-1142007 and ANT-1042883.

### Bibliography:

Dunbar, N. W. et al., (2003). Tephra in the Siple and Taylor Ice Cores. *Journal of Geophysical Research* 108, 2384. <http://dx.doi.org/10.1029/2002JB002056>.

Hammer, C, Clausen, H et al., (1980). Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature* 288, 230–235.

Lamb, H., (1971). *Volcanic Activity and Climate*. *Paleogeography, Paleoclimatology, Paleoecology* 10, 203-233.

De Angelis, M, Fehrenbach, L et al. (1985) Micrometer-sized volcanic glasses in polar ices and snows. *Nature* 317:52–54.

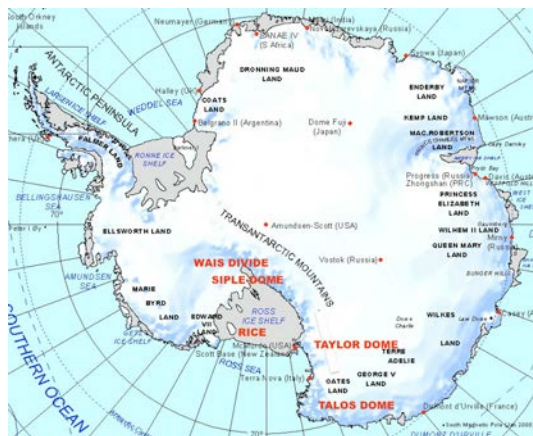


Fig. 1. Pertinent Antarctic drill site locations.

Tephra bearing ice samples were rapidly melted under clean room conditions, filtered through 0.4µm Whatman Millipore polycarbonate isopore™ membrane filter, secondary electron imaging (SE) and backscatter electron imaging (BSE) scanned on SEM then processed for geochemistry.

We found a potential correlation between Siple, Taylor, WAIS, Talos, and RICE ice core (AntT 16).

## Radiocarbon Chronology of Ice Extent in the Transantarctic Mountains From the Hatherton Glacier Region

Courtney King<sup>1,2</sup>, Brenda Hall<sup>1,2</sup>

1. Climate Change Institute, University of Maine
2. School of Earth and Climate Sciences, University of Maine

**Abstract:** Hatherton Glacier is a tributary of Darwin Glacier, a large outlet glacier that drains through the Transantarctic Mountains into the Ross Sea Embayment. Nearly 200 algae samples were collected in the Lake Wellman area at sites well above present glacier margin. Because these algae come from former ponds that must have been dammed by a thicker Hatherton Glacier, their ages help us to understand better the timing and extent of ice within the Transantarctic Mountains from the last glacial maximum to present.

There is concern regarding the future stability of the West Antarctic Ice Sheet (WAIS). If the entire WAIS melted, the sea level would rise between 3-5m. We hope to gain insight into the factors that control ice-sheet behavior by assessing how the ice sheet has responded in the past to large changes in climate and sea level. In particular, we wish to know the timing and rates of the transitions between glacial and interglacial ice configurations in the past.

Ice flows into the Ross Sea Embayment through ice streams from the WAIS and through outlet glaciers in the Transantarctic Mountains (TAM) from the East Antarctic Ice Sheet (EAIS). It is hypothesized that during the last glacial maximum (LGM) the Ross Sea contained grounded ice that caused thickening of the outlet glaciers (e.g. Denton et al 1989). The traditional model is that the maximum was reached along the coast ~18 ka and farther inland beginning around ~10 ka (Hall et al 2013). However, another hypothesis, based on far-field sea-level records and isostatic modeling, is that the continent underwent rapid deglaciation at ~14ka and contributed significantly to a ~15m rise in sea level during an event called Meltwater Pulse 1A (Deschamps et al 2012). Our study consists of collecting algae samples within the TAM in order to understand better the timing of deglaciation in Antarctica and discriminate between these hypotheses.

Previous work has produced two different interpretations of deposits alongside Hatherton Glacier. Bockheim et al (1989) separated four drift deposits at Hatherton Glacier. Based on a limited number of algae from relict lake deposits associated with one of the younger drifts, they inferred that ice remained at its maximum of the last glaciation until ~10ka. Storey et al (2010) obtained cosmogenic exposure ages of rocks in the same region and proposed instead that the last maximum was reached at ~35ka; there was no expansion of ice during the LGM.



Figure 1. View into the valleys from Lake Wellman.

We mapped glacial deposits and collected algae that grew in former ice-marginal ponds dammed by Hatherton Glacier. Radiocarbon dating of these algal samples collected within the drift deposits is in progress and will help provide chronological ages to the drift deposits.

**Acknowledgements:** This project is funded by the NSF grant #1246170.

### Bibliography:

Bockheim JG, Wilson SC, Denton GH, Andersen BG, and Stuiver M. "Late Quaternary Ice-Surface Fluctuations of Hatherton Glacier, Transantarctic Mountains," *Quaternary Research* 31 (2010): 229-254.

Denton GH, Bockheim JG, Wilson SC, and Stuiver M. "Late Wisconsin and early Holocene glacial history, inner Ross Embayment, Antarctica," *Quaternary Research* 31 (1989): 151-182.

Deschamps P, Durand N, Bard E, Hamelin B, Camoin G, Thomas AL, Henderson GM, Okuno J, and Yokoyama Y. "Ice-sheet collapse and sea-level rise at the Bolling warming 14,600 years ago," *Nature* 483 (2012): 559-564.

Hall BL, Denton GH, Stone JO, and Conway H. "History of the grounded ice sheet in the Ross Sea sector of Antarctica during the Last Glacial Maximum and the last termination," *Geological Society, London, Special Publications* 381 (2013).

Storey BC, Fink D, Hood D, Joy K, Shulmeister J, Riger-Kusk M and Stevens MI. "Cosmogenic nuclide exposure age constraints on the glacial history of the Lake Wellman area, Darwin Mountains, Antarctica," *Antarctic Science* 22 (2010): 603-618.

## Effects of Abrupt Warming on Diatom Communities in the Laurentian Great Lakes

Amy Kireta<sup>1,2</sup>, Jasmine Saros<sup>1</sup>

1. Climate Change Institute, University of Maine.
2. School of Ecology and Environmental Sciences, University of Maine.

**Abstract:** We are looking at a period of past climate change, the Medieval Climate Anomaly (MCA), to understand how modern diatom community changes are related to warming over the past century. We will look at diatom algae fossils from sediment cores from lakes Erie and Superior to compare with diatom community changes observed in recent monitoring programs.

Surface temperatures in Lake Superior have increased over the last century [1], but the effects of this warming on Great Lake ecosystems remain unclear. Diatoms, microscopic algae with glass-like cell walls, are ideal organisms for studying biological responses to climate change. Diatom remains provide a temporal record of community changes and have documented responses to climate in other lakes around the world [2]. We will investigate whether diatom shifts relating to climate change occurred throughout the Great Lakes during the MCA warming (950-1250 CE) by comparing sedimentary records from lakes Superior and Erie before, during, and after this period. We will look at modern diatom records in context to past diatom community shifts to understand the role of climate change in modern community changes.

Information gathered from this study will provide insight to the health and resilience of the Great Lakes ecosystem to a shifting climate. Our hypotheses are that diatom communities have changed in the past with warming temperatures and recent community shifts are related to modern climate change.

We will use sediment from previously collected cores from lakes Erie and Superior. Diatom remains will be mounted on permanent microscope slides and identified to species level with at least 1000x magnification. Various statistical techniques will be used to analyze community changes and for comparison with modern monitoring data. A schematic diagram of potential results is presented in Fig. 1.

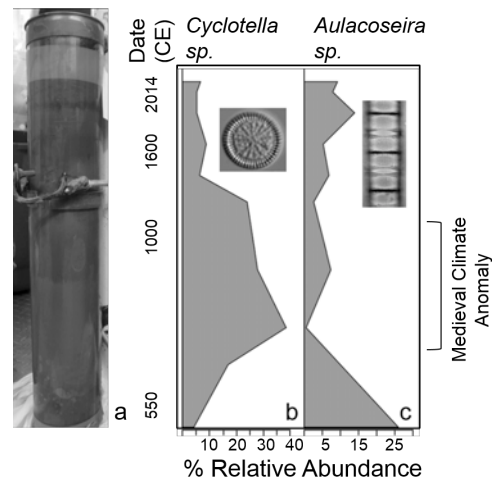


Figure 1. A lake sediment core showing dated intervals, deposited from present day to the oldest sediment at the bottom (a). A hypothetical proportion of two diatom genera (% relative abundance) at various sediment (thus time) intervals (b, c). *Cyclotella* respond to warming temperatures with increased abundance (b), while *Aulacoseira* have decreased abundance (c).

**Acknowledgements:** This project is funded by the National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

### Bibliography:

Austin, Jay A., and Steven M. Colman. "Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback." *Geophysical Research Letters* 34 no. 6 (2007).

Rühland, Kathleen, Andrew M. Paterson, and John P. Smol "Hemispheric-scale patterns of climate-related shifts in planktonic diatoms from North American and European lakes." *Global Change Biology* 14 no. 11 (2008): 2740-2754.

## Chronology of Classen Glacier Moraines Supports a Cooler-Than-Present Middle Holocene in New Zealand

Tobias N.B. Koffman<sup>1, 2</sup>, George H. Denton<sup>1, 2</sup>, Aaron E. Putnam<sup>1, 4</sup>, Joerg M. Schaefer<sup>3, 4</sup> David Barrell<sup>5</sup>, Roseanne Schwartz<sup>3</sup>, Robert Finkel<sup>6</sup>, Dylan Rood<sup>6</sup>, Trevor Chinn<sup>7</sup>

1. *Climate Change Institute, University of Maine.*
2. *School of Earth and Climate Sciences, University of Maine.*
3. *Department of Earth and Environmental Sciences, Columbia University.*
4. *Lamont-Doherty Earth Observatory, Columbia University.*
5. *GNS Science, Dunedin, New Zealand*
6. *Department of Earth and Planetary Sciences, University of California, Berkeley.*
7. *Alpine and Polar Processes, 20 Muir Rd. Lake Hawea, RD 2 Wanaka, 9382 New Zealand*

**Abstract:** Beryllium-10 surface exposure dates of moraine boulders in the forefield of New Zealand's Classen Glacier show that ice extent was greater at 5,200 years ago than during any subsequent interval. This is consistent with gradual warming in New Zealand during the Holocene.

Globally distributed temperature records can help to reveal the responses of Earth's climate to orbitally-driven changes in seasonal sunshine that are antiphased between the northern and southern hemispheres. Early and middle Holocene warmth is well documented in Europe. In contrast, glacier-inferred temperatures in New Zealand remained cooler than present-day values from around 11,000-6,900 years ago, and also between ~4,000 and 400 years ago (Putnam et al., 2012). The lack of glacial deposits formed between 6,900 and 4,000 years ago left open the possibility of reduced ice extent in New Zealand that coincided with mid-Holocene warmth in Europe. Here we present a chronology for mid- to late-Holocene episodes of greater-than-present Classen Glacier extent based on 28 <sup>10</sup>Be surface-exposure dates.

Six moraines date to 5,260 ± 130 (N=6), 5160 ± 80 (N=2), 462 ± 25 (N=1), 334 ± 35 (N=3), 287 ± 30 (N=4), and 222 ± 13 (N=6) years before 2011 when calculated with the production rate calibration of Putnam et al., 2010 using Lm scaling (Balco et al., 2008). An additional six dates on boulders from a meltwater channel overlap within error with the age of the innermost moraine, indicating little or no excess age due to inherited <sup>10</sup>Be. The moraines of the Classen Glacier show successively less extensive ice from the middle Holocene through the present day. The maximum ice extent during the past millennium occurred roughly 300-500 years ago. Gradual ice recession occurred between 300 and 100 years ago. Rapid ice retreat during the past 60 years has left a lake in place of the glacier.

Greater extent of the Classen Glacier at around 5,200 years ago than during the past millennium supports a pattern of asynchronous temperatures change with warming in New Zealand and cooling in Europe during much of the Holocene.

**Acknowledgements:** This work was supported by the National Science Foundation, the Comer Science and Education Foundation, and the Quesada Family Foundation. We thank the Department of Conservation, Te Papa Atawhai and Te Rūnanga o Ngāi Tahu for permission to access and to sample the moraines of the Classen Glacier.

**References:** Balco, G., et al., 2008. "A complete and easily accessible means of calculating surface exposure ages or erosion rates from <sup>10</sup>Be and <sup>26</sup>Al measurements." *Quaternary Geochronology* 3: 174-195.

Putnam, A.E., et al., 2010. "In situ cosmogenic <sup>10</sup>Be production-rate calibration from the Southern Alps, New Zealand." *Quaternary Geochronology* 5: 392-409.

Putnam, A.E., et al., 2012. "Regional climate control of glaciers in New Zealand and Europe during the pre-industrial Holocene." *Nature Geoscience* 5:627-630.

## A 1000-Year High Resolution Record of Climate Variability Developed From a South Pole ice Core

Elena Korotkikh<sup>1,2</sup>, Paul A. Mayewski<sup>1,2</sup>, Michael Handley<sup>1</sup>, Douglas Introne<sup>1</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.

**Abstract: Stable water isotopes ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ), deuterium excess ( $d$ ), Na, nssCa concentrations and accumulation rate were measured in a South Pole ice core for the period 1000 to 1999 A.D. We observed changes in climatic condition between ~1500-1900 A.D. and during the last century, associated with the Little Ice Age and the modern era, respectively.**

Here we present a new, 1000 year-long record of water stable water isotopes ( $\delta^{18}\text{O}$  and  $\delta\text{D}$ ), deuterium excess ( $d$ ), accumulation rate, Na and nssCa concentrations as recorded in a South Pole ice core (Fig. 1). The ice core was collected during the US International Trans-Antarctic Expedition traverse in 2002 at 89.93°S, 144.39°W at an elevation of 2808 m a.s.l. Samples collected from the top 108 meters of the core were analyzed for major and trace element content using inductively-coupled plasma sector field mass spectrometry, and for their  $\delta^{18}\text{O}$  and  $\delta\text{D}$  by cavity-ring down laser adsorption spectroscopy.

The oxygen and hydrogen isotopic composition of polar ice is commonly used to obtain paleoclimate information, such as past local surface temperature changes at the precipitation site<sup>1</sup>. Deuterium excess ( $d = \delta\text{D} - 8 \times \delta^{18}\text{O}$ )<sup>2,3</sup> is a second-order isotopic parameter and has also been used for temperature reconstructions of oceanic moisture sources<sup>4</sup> and for identifying different vapor source regions. We use Na concentrations as an indicator of marine airmass input, and nssCa concentrations as a proxy for crustal source dust airmass input in South Pole region<sup>5</sup>.

Our results show significant changes in isotopic values and elemental concentrations during the period ~1500-1900 A.D., which corresponds to the Little Ice Age. We observed major decrease in deuterium excess values, which could indicate different precipitation source regions or colder conditions at the source. Concentrations of Na and accumulation rate increase during this period, indicating increased precipitation and cyclonic activity. In contrast, nssCa concentrations are decreasing, most likely attributed to changes in position and strength of the Southern Hemisphere Westerlies.

For the 20<sup>th</sup> century, our records show increases in nssCa concentrations,  $\delta^{18}\text{O}$  values and accumulation rates, and a decrease in Na concentrations. This is most likely indicates warmer conditions, intensification of the zonal wind strength and blocking the penetration of marine air masses into the interior of Antarctica during this time.

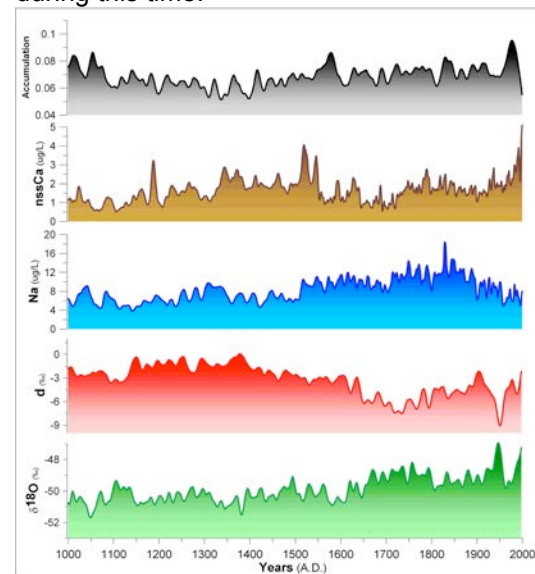


Fig. 1. Records of  $\delta^{18}\text{O}$  (‰), deuterium excess (‰), Na (ug/L), nssCa (ug/L) and accumulation rate for the period from 1000 to 1999 A.D.

**Acknowledgements:** NSF OPP

### Bibliography:

- [1] Petit, J.R. et al., (1999), *Nature*, 399, 429-436.
- [2] Dansgaard, W. (1964), *Tellus*, 16, 436-468
- [3] Craig, H. (1961), *Science*, 133, 1702-1703.
- [4] Vimeux., F. et al. (2001), *Journal of Geoph. Research*, 106, 31,863-31,873.
- [5] Dixon, D. et al. (2012), *Int. J. Climatology*, 32, 10, 1455-1465



## Hydroclimate Variability in the Northeast Pacific Over the Past Millennium

Karl Kreutz<sup>1,2</sup>, Seth Campbell<sup>1,2</sup>, Sean Birkel<sup>1,2</sup>, Erich Osterberg<sup>3</sup>, Dominic Winski<sup>3</sup>, Cameron Wake<sup>4</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. Department of Earth Sciences, Dartmouth College.
4. Complex Systems Research Center, University of New Hampshire.

**Abstract:** Paleoclimate data from the Pacific basin show significant hydroclimate changes over the past millennium, possibly in response to changes in the mean state of the El Niño Southern Oscillation (ENSO). To address this issue, we have been developing an ice core array in the NE Pacific that targets the two nodes a precipitation dipole in Northeast (St. Elias Range and Central Alaska), most recently (2013) with the recovery of two surface-to-bedrock 210-meter ice cores from Mt. Hunter (Denali National Park).

The Pacific basin presents a challenging reconstruction goal, given the large geographic area and the strong influence of ENSO dynamics on regional and larger-scale climate. Currently, there are no continuous annually resolved ENSO reconstructions that cover the last millennium. Discontinuous coral records imply a persistent La Niña-like state (cool eastern tropical Pacific sea surface temperature [SST]) during the Medieval Climate Anomaly, and a persistent El Niño-like state (warm eastern tropical Pacific SST) during the Little Ice Age. This hypothesis has been supported by modeling studies, several Pacific marine, hydroclimate, and glacier records, and most recently Antarctic ice core data. However, tropical Pacific precipitation reconstructions and certain South American marine and lake records imply the opposite evolution (i.e., a El Niño-like state during the MCA and La Niña-like state during the LIA). Resolution of this issue has implications for predicting the future evolution of the ENSO system under a warming climate, and the resulting broader-scale hydroclimate conditions.

Reconstructing spatial precipitation patterns in the Northeast Pacific will provide useful insight into this problem, because ENSO teleconnections setup characteristic spatial precipitation patterns (Figure 1). The development of millennial-length ice core records of accumulation from an array of North Pacific ice cores has been underway for the past decade, specifically focused on nodes of the precipitation dipole. The array of ice core accumulation records must be integrated with

detailed analyses of precipitation and atmospheric circulation variability in the Pacific based on reanalysis data and regional climate model output. Most recently, we recovered two surface-to-bedrock ice cores from the Mt. Hunter plateau, Alaska in 2013. Based on our initial estimates of snow accumulation and ice flow at the site, we estimate that the age of the ice at the bottom of the ice cores is ~1000 AD. We will discuss new insights from the ice core site array, including data from automatic weather stations deployed in the region.

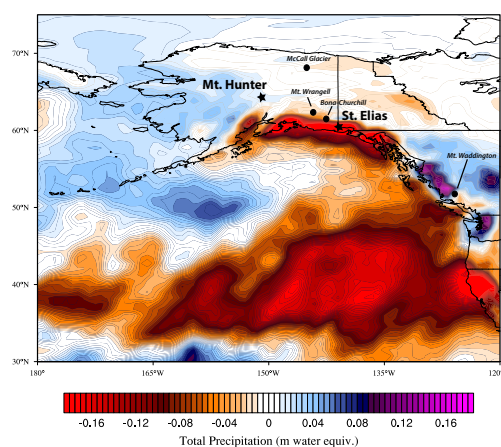


Figure 1. Winter (DJF) precipitation anomalies during the 1979-2012 period, defined as years with high N. Pacific SLP (i.e., La Niña conditions) minus years with low N. Pacific SLP (i.e., El Niño conditions). Produced using a mini ensemble of ECMWF ERA-Interim and NASA MERRA reanalysis, using the CCI Climate Reanalyzer. Ice core sites are labeled.

## The Functional Diversity of Acadia National Park's Plant Community Over 100 Years of Climate Change

Christine A. Lamanna<sup>1</sup>, Alexandra Perry<sup>2</sup>, Caitlin McDonough MacKenzie<sup>3,4</sup>, Abraham Miller-Rushing<sup>4,5</sup>

1. Sustainability Solutions Initiative, University of Maine.
2. School of Biology & Ecology, University of Maine.
3. Department of Biology, Boston College.
4. National Park Service, Acadia National Park.
5. The Schoodic Institute, Winter Harbor, ME.

**Abstract:** Over the last 100 years, Acadia National Park has lost approximately 20% of its plant species, but the mechanisms causing this loss of diversity and the ecological consequences remain unknown. We are measuring functional traits of the persistent, extirpated and introduced species to understand how this loss of taxonomic diversity affects functional diversity within the park, and to identify new species of conservation concern.

While Acadia National Park (ANP) today is home to over 800 vascular plant species, the park has lost nearly 20% of its flora since the first surveys were conducted in the late 1800s. Although these surveys can tell us which species are no longer found in the park, the cause of these extirpations remains unknown. Over the last century, land-use change, invasive species, acid rain, fire, and climate change have all impacted ANP. Functional traits, or measurable characteristics that reflect a species' life history strategy and ecological niche, can shed light on the mechanism(s) responsible for plant species persistence or extirpation from ANP. During summer 2013, we collected data on 12 functional traits of more than 50 herbaceous species currently growing within ANP. These functional traits represent major axes of plant life history variation, including leaf economics, pollination syndrome, phenology, and seed dispersal (Fig 1a). In summer 2014, we will begin a more extensive campaign to collect trait data from more persistent species, and to utilize a network of citizen scientists to locate and measure traits on extirpated species elsewhere in the state of Maine.

Functional trait data will be used to represent the functional diversity of ANP as a multi-dimensional hypervolume (Blonder et al. 2014, Fig 1b). Using this approach, we can determine what aspects of functional diversity have been lost, maintained, or gained over the last 100 years (Fig 1c), and hopefully identify mechanisms behind the extirpation of so many species from Acadia National Park.

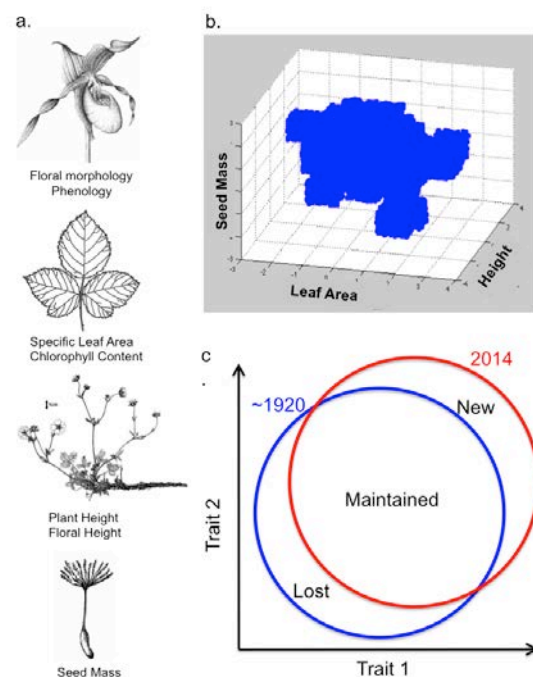


Fig. 1. Example functional traits sampled (a), an example trait hypervolume for a plant community constructed from three functional traits (b), diagram of one possible outcome from comparing the functional diversity of ANP's past and current floras (c).

**Acknowledgements:** This work is supported by SSI and the Senator George J. Mitchell Center.

**Bibliography:** Blonder B, Lamanna C, Violle C and B Enquist. 2014. The n-dimensional hypervolume. *Global Ecology & Biogeography*.

## <sup>10</sup>Be Surface-Exposure Chronology Of The Tres Hermanos And Rosa Irene Moraines Near Bahía Inútil, Chilean Patagonia

Jennifer Lennon<sup>1</sup>, Brenda Hall<sup>1,2</sup>, George Denton<sup>1,2</sup>, Aaron Putnam<sup>3</sup>, Tom Lowell<sup>4</sup>, Mike Kaplan<sup>3</sup>, Alex Introne<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. Lamont-Doherty Earth Observatory, Columbia University.
4. Department of Geology, University of Cincinnati.

**Abstract: Thirty-three surface-exposure dates were obtained from boulders on the south side of Bahía Inútil, Tierra del Fuego, in southernmost South America. The results have refined the LGM chronology in southernmost South America and firmly date the formation of the innermost LGM moraine on the eastern side of the Strait of Magellan to  $18,200 \pm 753$  years BP.**

Milankovitch's orbital theory of ice ages predicts that glacial cycles should differ between the northern and southern mid-latitudes, because insolation forcing is out of phase between the hemispheres. However, the termination following the last glacial maximum (LGM) appears to have occurred in both hemispheres at nearly the same time (Mercer, 1978). Detailed glacial reconstructions from around the world allow for the testing of hypotheses which attempt to explain this apparent hemispheric synchrony.

The research goal of this project was to reconstruct the glacial history of Bahía Inútil, Chilean Patagonia, in order to constrain the timing of the Last Glacial Maximum (LGM) in the Southern Hemisphere, as well as the timing of the onset of the termination. In March 2013, our field team mapped the glacial geomorphology of Estancia Tres Hermanos (ETH) and Estancia Rosa Irene (ERI) moraine belts, sampling thirty-three erratic boulders for cosmogenic surface-exposure age dating on the south side of Bahía Inútil (Fig. 1).

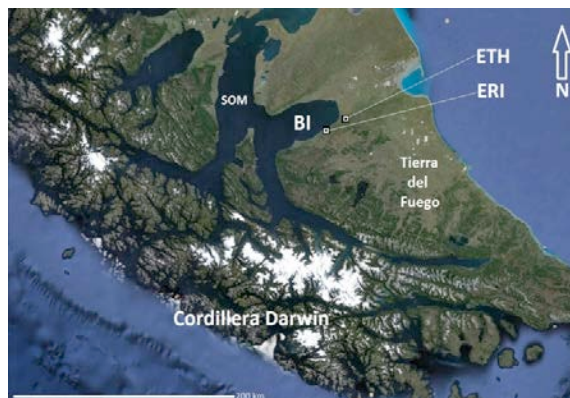


Figure 1. Map of southernmost South America showing ETH and ERI field sites. SOM denotes the Strait of Magellan, and BI labels Bahía Inútil. Scale bar at the bottom left is 200 km.

The moraine belt mapped at Rosa Irene was the last terrestrial expression of the Bahía Inútil lobe before it began its recession back to Cordillera Darwin, 135 km to the southwest. The innermost moraine was dated to  $18,200 \pm 753$  years BP based on twenty exposure dates. Outboard of ERI, the moraine system at ETH

was dated to  $27,752 \pm 8,448$  years BP based on four exposure dates. However, interpretation of these latter dates proves difficult, as the boulders here give exposure ages between  $21,185 \pm 622$  to  $72,751 \pm 2,114$  years BP. This range of ages may be the result of previous exposure by the boulders, exhumation of boulders from the moraine, or multiple overriding glaciations.

These data indicate that the culmination of the LGM and the start of deglaciation in Tierra del Fuego began just after  $\sim 18,200$  years BP when ice receded from the ERI moraines. Ice had retreated to the heart of Cordillera Darwin by  $\sim 17,000$  years BP, implying an average rate of retreat of  $\sim 55$  km/yr. This rapid collapse marks the onset of the Southern Hemisphere termination and is similar in timing and speed to that found farther north in Chile and in New Zealand (Putnam et al., 2013).

The termination in the southern mid-latitudes occurred at the same time as Heinrich Stadial 1 in the North Atlantic region, which was a time of cold temperatures, ice-rafted debris, and diminished ocean deepwater circulation. It is possible that the different climate signatures in the two hemispheres can be explained either as a result the oceanic bipolar seesaw (Broecker, et al., 1998) and/or the southward shift of westerlies in the Southern Hemisphere, two phenomena which can be linked to northern stadials (Denton et al., 2010).

### Acknowledgements:

The Churchill Exploration Fund and the NSF provided the funding for this project.

### References:

- Broecker, W., 1998. *Paleoceanography* 13, 119-121.
- Denton, G.H., et al., 2010. *Science* 328, 1652-1656.
- Mercer, J., 1978. *Nature* 271, 321-325.
- Putnam, A.E., et al., 2013. *Quaternary Science Reviews* 62, 114-141.

## Deciphering the Mechanisms Behind Climate-Driven Changes in the Relative Abundances of the Diatom *Cyclotella*

Heera I. Malik<sup>1</sup>, Jasmine E. Saros<sup>1</sup>

1. Climate Change Institute and School of Biology and Ecology, University of Maine.

**Abstract:** Multiple climate-mediated mechanisms have been associated with the increase in relative abundance of *Cyclotella* across many lakes in the northern hemisphere. However, the actual mechanisms responsible for these changes are still not evident. The primary goal of this study is to decipher those mechanisms behind the climate-driven changes in the relative abundance of *Cyclotella*.

Increasing air temperatures are of great concern for freshwater lakes because of their influence on the thermal structure of lakes, which in turn can affect the distribution of phytoplankton species<sup>3</sup>. Diatoms are a group of phytoplankton commonly observed in almost every aquatic ecosystem. Recent surveys across many lakes have reported a sudden increase in the relative abundance of the small size diatom, *Cyclotella*, which is thought to be a key indicator species of warming across lakes in arctic, alpine, and boreal regions<sup>1, 2, 3</sup>. The potential mechanisms for this expansion have been associated with **direct climate** impacts through temperature<sup>1</sup> or **indirect climate** impacts through interactive effects of water column stability, i.e. mixing depth (light), and nutrients<sup>2</sup>.

A difference in response of *Cyclotella* species to both mixing depths (light) and nutrients has been observed in arctic and alpine lakes suggesting spatial-temporal variability. To study the interactive effects of temperature, light and nutrients, we conducted factorial design experiments in-lake and in growth chambers for Greenland lakes and high-frequency sampling of *Cyclotella* populations over the course of ice-free periods in a Maine lake (as a model boreal lake) to determine potential drivers and mechanisms behind the climate-driven changes in the relative abundance of this key diatom species. In recent experiments, we found complex interactions among the tested variables. There were significant interactive effects of light, temperature & nutrients on cell densities of *Cyclotella stelligera* and positive effects of light on *Cyclotella radiosa*. These preliminary results suggest the importance of indirect effects of temperature mediated through light and nutrient availability. However, further experimentation is needed to explore these interactions and relationships further.

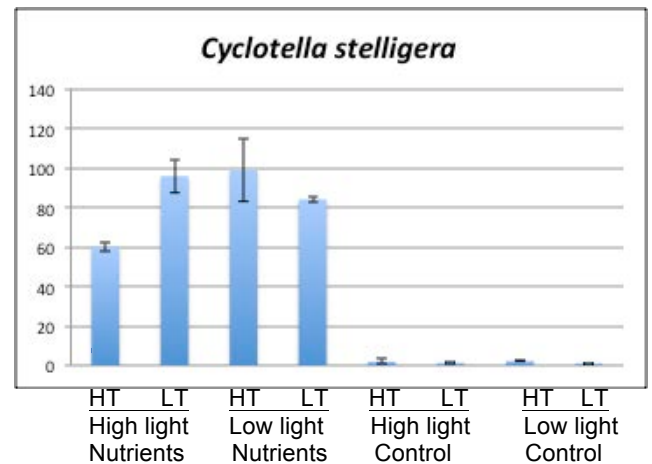


Fig1. Final cell densities of *Cyclotella stelligera* under manipulated temperature (HT-high temperature, LT-low temperature), light, nutrients and control.

### Bibliography:

- (1). Ruhland, K., Paterson, A.M., Smol, J. P. (2008). Hemispheric-scale patterns of climate-related shifts in planktonic diatoms from North American and European lakes. *Global Change Biology* 14: 2740-2754.
- (2). Saros, J. E., Stone, J. R., Pederson, G. T., Slemmons, K., E., H, Spanabuer., T, Schliep, A., Cahll, D., Williamson, C. E., Engstrom, D. (2012). Climate-induced changes in lake ecosystem structure inferred from coupled neo- and paleo-ecological approaches. *Ecology* 93: 2155-2164.
- (3). Smol, J. P. et al. (2005). Climate-driven regime shifts in the biological communities of arctic lakes. *Proceedings of the National Academy of Sciences*. 102: 4397-4402.

## Using Individual-Based Particle Trajectory Models To Predict The Effects Of Climate Change On Songbird Migration Within The Gulf Of Maine

Jennifer McCabe<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Biology and Ecology, University of Maine.

**Abstract: Migration is a critical stage in many songbirds' life-cycle, and the environmental factors that influence migration will directly affect individual success and population viability across the annual cycle. One such factor is weather and its effects on flight speed, flight times, and energy expenditures, thereby affecting survival. Despite considerable research focused on atmospheric patterns as a controlling factor in birds' migratory flight costs, the influence of local and regional weather patterns along migration are still poorly understood.**

Migrant birds are influenced by environmental factors in multiple locations: breeding, wintering, and along migration. Because of the proposed effects of climate change, such as shifts in wind conditions, these birds may become more threatened with population declines. Migration routes are and will continue to be affected by climate change through alterations in the strength and direction of prevailing winds and the location and quality of stopover sites. Impacts of climate change on atmospheric and oceanic circulation patterns have been increasingly reported in recent literature, and these impacts have dramatic consequences for the patterns of regional weather systems. Understanding the current and future relationships between songbird migration and regional winds, therefore, will be invaluable for conserving North American birds in the face of climate change.

Individual-based particle trajectory models are used by fisheries and oceanic researchers to track recruitment and population viability of migratory ocean animals moving through their physical world (Fig. 1). I propose to adapt these models to investigate past and future bird migration patterns within the Gulf of Maine (GOM) region. Just like migratory fish, birds are influenced by the environment around them. Oceanic currents influence migratory speed, timing, and movement vectors of fish, as atmospheric wind patterns affect birds' migratory flight. I intend to use breeding bird abundances from across Northern Maine and Canada coupled with weather reanalysis data as input into the migration model. The model will run nightly to mimic birds' nocturnal migration. Once established, I will validate the model output by comparing it to the number of birds captured on the ground at thirteen migration monitoring stations operated during four fall migration

seasons (2009-2013) in Acadia National Park (ANP), Maine.

With projected changes in weather patterns through climate change I expect to see changes in bird migration patterns. The International Panel on Climate Change's (IPCC) 2007 synthesis report outlines six emissions scenarios. Emission scenarios will each create varying surface temperature increases and affect wind patterns differently. Using the validated migration model I hope to model future migration patterns in the GOM region under each emission scenario. This model will allow ANP and other partners to predict areas of high concentrations of migrants as well as forecast changes in timing of migrants utilizing ANP's habitats.

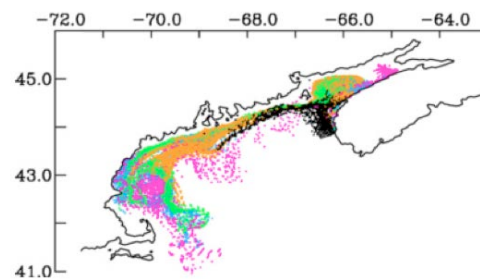


Fig 1. Trajectories of lobster larvae released west of Nova Scotia on 11 June, 2004. Colors indicate larval and post-larval stages (Xue et al 2008).

**Acknowledgements:** Thank you to Peter Koons and Sean Birkel for their continued support with this project.

### **Bibliography:**

- IPCC. 2007. An assessment of the International Panel on Climate Change: Synthesis Report.
- Xue, H., Incze, L., Xu, D., Wolff, N., and Pettigrew. 2008. Connectivity of lobster populations in the coastal Gulf of Maine. *Ecological Modeling*, 210: 193-211.

## Temporal Changes to Dissolved Organic Carbon Concentrations in Southwestern Greenland Lakes

Robert M. Northington<sup>1</sup> and Jasmine E. Saros<sup>1</sup>

1. Climate Change Institute, University of Maine.

**Abstract:** Dissolved organic carbon (DOC) export from terrestrial to aquatic systems in Arctic regions has been suggested to increase due to greater climate warming in recent decades. Changes in DOC may influence thermal structure and biogeochemical processing within lake basins. However, in-lake DOC concentrations have shown a decreasing trend in the last decade in southwestern Greenland, in contrast to other parts of the Arctic.

Dissolved organic carbon (DOC) has a great influence on the dynamics of lake ecosystems. Physically, DOC can alter light and heat attenuation in lakes, changing how lakes mix thermally. Biogeochemically, DOC can serve as a resource for microbial metabolism in the water column or in lake sediments. Recent evidence from some parts of the Arctic have suggested that with climate warming, DOC concentrations in aquatic systems have been increasing due to export from terrestrial ecosystems through permafrost melting and hydrologic pathways (Kicklighter et al. 2013).

In order to investigate patterns of DOC change in the Arctic, we sampled 26 lakes in southwestern Greenland in 2013, with 13 of them having been sampled previously from 2001-03 for DOC (Anderson and Stedmon 2007). The lakes were also surveyed for chemical, physical, and biological components.

In contrast to other parts of the Arctic, our data demonstrate that there has been a net decline in DOC concentrations in Greenland lakes from 2001 to 2013 (Fig. 1), with SS12 demonstrating no change and SS16 increasing slightly. Additionally, spectral analyses of DOC indicate no significant change in overall quality in the lakes. Variability in DOC change across the landscape suggests local controls on carbon processing in both terrestrial and aquatic ecosystems. Further studies will consider mechanisms through which DOC is processed across the Arctic landscape, and its overall impact on the carbon cycle and climate change.

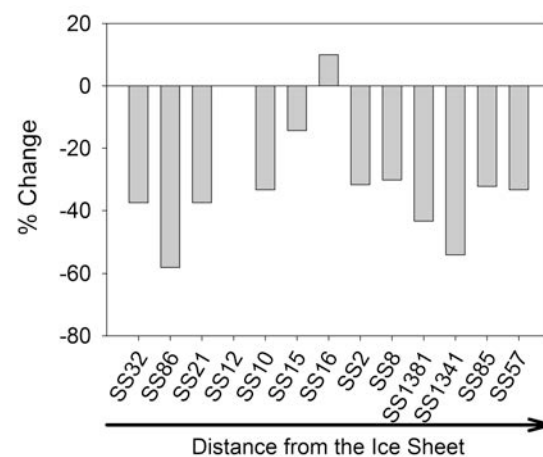


Fig. 1. Percent change in surface water DOC concentrations for 2013 compared to those taken from 2001-2003. All lakes were sampled during the summer and are arranged along a transect from the Greenland Ice Sheet towards the coast in the vicinity of Kangerlussuaq.

**Acknowledgements:** This research was supported by the National Science Foundation.

### Bibliography:

Anderson, N. J., and C. A. Stedmon (2007) Effect of evapoconcentration on dissolved organic carbon concentration and quality in lakes of SW Greenland. *Freshwater Biology*, 52: 280-289.

Kicklighter, D. W. et al. (2013) Insights and issues with simulating terrestrial DOC loading of Arctic river networks. *Ecological Applications*, 23: 1817-1836.

## Fluvial Deposition, El Niño and Landscape Construction at San José de Moro and Huaca del Sol, Peru

Paul M. Pluta<sup>1</sup>, Alice R. Kelley<sup>1,2</sup>, Daniel H. Sandweiss<sup>1,3</sup>

1. Climate Change Institute, University of Maine.
2. School of Earth and Climate Sciences, University of Maine.
3. Department of Anthropology, University of Maine.

**Abstract: We interpret the alluvial sedimentary sequences at the archaeological sites of San José de Moro and Huaca del Sol to infer patterns of past El Niño flooding and its potential significance for prehistoric human inhabitants of the region.**

San José de Moro and Huaca del Sol are archaeological sites of the Moche period (100-800 AD) located in the coastal desert of northern Peru. During the 2013 summer field season we investigated the alluvial sedimentary sequences underlying the Moche occupations at both sites in order to better understand the past chronology of El Niño flooding as well as its effect on landscape development and its relationship to the archaeological record.

San José de Moro is located along the Chamán River, just north of the city of Chépén. The limited size of the river's drainage basin and the extremely dry nature of the regional environment limit flooding to periods of El Niño rainfall. For this reason, the sedimentary sequence formed at the site is interpreted as a record of past El Niño flooding. Our detailed stratigraphic examination and textural analysis of the exposed 2.7 m section suggest changes in El Niño intensity over time. A major shift from broad, fine-grained floodplain deposits to higher energy, coarser grained, channelized deposits may indicate an increase in flood velocity at this site or a change in channel location related to increased flood discharges, both potentially resulting from significant increase in the strength of El Niño events.

Huaca del Sol is located along the Moche River near the city of Trujillo. The Moche River has a much larger drainage basin than the Chamán River and extends much higher into the Andes Mountains, meaning that floods may be caused by both El Niño and non-El Niño events. This fact complicates the interpretation of El Niño's role in floodplain aggradation along the Moche River, but El Niño must play a significant role. Our investigations revealed that the monumental adobe structure of Huaca de Sol is built above a fluvial sequence similar to that at San José de Moro. Although there is no clear shift in the sequence as at San José de Moro, there is a general trend of increasing grain size with increasing height throughout the bottom 2.8 m of

our exposed section, indicating an increase in the energy of the depositing source over time.

The general trend of vertically increasing grain size at Huaca del Sol, and the shift from finer grained to coarser grained floodplain deposits at San José de Moro, may both be caused by increasing intensity of El Niño activity during the time periods represented by these sequences. This trend has been suggested by others working in the region, and may be related to the increases in El Niño frequency that have occurred since approximately 5,800 cal yr BP (Sandweiss et al. 2007). As our research continues, dating may provide valuable insight into the relationship between these sequences and help assess this interpretation.

Our data suggest that both sites are located on surfaces created at least in part by El Niño-driven aggradation that produced broad, elevated areas with decreased risk of El Niño flooding that were attractive for both occupation and ceremonialism. Therefore, El Niño should not only be seen as a potential cause of weather variation and catastrophism, but also as a constructor of propitious landscapes that served as the setting for two of the region's important Moche sites. Reconstructing past patterns of El Niño activity is thus essential to understanding the physical setting of prehistoric human settlements.

**Acknowledgements:** This research is funded by NSF Award ARC-1152156 to Jeffrey Quilter (Harvard University).

### **Bibliography:**

Sandweiss, Daniel H., Kirk A. Maasch, C. Fred T. Andrus, Elizabeth J. Reitz, James B. Richardson III, Melanie Riedinger-Whitmore, and Harold B. Rollins. 2007. "Mid-Holocene Climate and Culture Change in Coastal Peru." In *Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions*, edited by David G. Anderson, Kirk A. Maasch, and Daniel H. Sandweiss, 25-50. San Diego: Academic Press.

## A New Ice Core From the Central Andes (Tupungatito)

Mariusz Potocki<sup>1,2</sup>, Paul A. Mayewski<sup>1,2</sup>, Andrei V. Kurbatov<sup>1</sup>, Daniel A. Dixon<sup>1,2</sup>, Bjorn Grigholm<sup>1,2</sup>, Gino Casassa<sup>3</sup>, Rodrigo Zamora<sup>4</sup>, Elena Korotkikh<sup>1,2</sup>, Michael Handley<sup>1</sup>, Douglas Introne<sup>1</sup>, Sharon B. Sneed<sup>1</sup>

1. *Climate Change Institute, University of Maine.*
2. *Department of Earth Sciences, University of Maine.*
3. *Geostudios, Puente Alto, Santiago, Chile.*
4. *Centro de Estudios Científicos, Valdivia, Chile.*

**Abstract: A 61 m ice core extracted from Tupungatito Glacier in 2012 reveals the history of environmental change in the Central Chilean Andes. The record covers the last ~100 years.**

The study of atmospheric circulation and past climate variability from ice cores has been largely focused in the polar regions. Over recent decades more ice cores have been recovered from high mountain glaciers. Despite this recent effort, a large data gap still remains in the Southern Hemisphere mid-latitudes. To help fill this spatial gap, a 61 m ice core was recovered, in February 2012, from the caldera glacier of Tupungatito (5600m, 33°24'S, 69°48'W) in the Central Chilean Andes.

Tupungatito Glacier is located near the southern extent of the Central Andes where climate is dominated by the quasi-permanent influence of the South Pacific High Pressure center and the seasonal north-south displacement of the westerlies that direct frontal depressions towards central Chile during the winter. Tupungatito receives the majority of its precipitation from frontal systems that develop in the Pacific Ocean and travel eastward. The region receives 80-90% of its annual precipitation from May through September. Tupungatito and surrounding glaciers are also a main source of water for Santiago and surrounding regions. (Vimeux et al., 2009; pers. comm. Jorge Carrasco Cerda, 2012).

Tupungatito borehole temperatures range from -10.5°C at the bottom to -15.5°C (approximate mean annual temperature) at 10 m below surface. These temperatures suggest that surface melting is not common. However, lab observations reveal distinct thin (up to 8 cm) melt features in the core.

Preliminary glaciochemical and isotopic analyses of this core indicate that the record is well preserved. Dating by annual layer counting reveals ~100 years. This record offers insights into the past displacement of atmospheric

circulation patterns in the region and the impact of human activities.

Human activities including industry, agriculture, mining, construction and large-scale land use release heavy and trace metals in concentrations greater than natural background levels (Nriagu and Davidson, 1986). South American emissions of trace metals are increasing as a result of increasing populations, agriculture, and industrial production (Fig 1). In Chile, the primary source of heavy metals and trace elements in the atmosphere is the transport of dust emitted during surface mining and milling operations (Barbante et al. 2001).

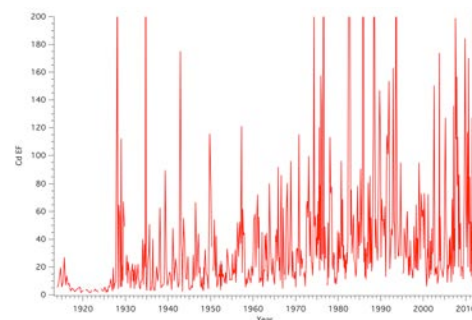


Fig 1. Cd Enrichment Factor (EF) time series developed from the Tupungatito 2012 ice core. An EF of >10 range exceeds that from natural crustal source emissions (Planchon et al. 2002).

**Acknowledgements:** The Garrand Family, Portland, Maine.

### Bibliography:

- [1] F. Vimeux, et al., *Paleoenvironmental Res* **14**, 1535–41 (2009).
- [2] J.O. Nriagu and C.I. Davidson, eds. *Book*, **17**, (1986).
- [3] C. Barbante, et al., *Environ. Sci. Technol.* **35**, 4026-4030 (2001).
- [4] F. A. M. Planchon, et al., *Earth and Planetary Science Letters* **200**, 207-222 (2002).



## Biological Interactions With Mesoscale Ocean Features

Alice Ren<sup>1,2,3</sup>, Fei Chai<sup>1,2,3</sup>

1. Climate Change Institute, University of Maine.
2. School of Marine Sciences, University of Maine.
3. Adaptation to Abrupt Climate Change (A2C2) IGERT Program

**Abstract:** The physics of ocean features such as fronts and eddies have a large influence on the dynamics of marine biology. Phytoplankton blooms have been observed in eddies and satellite-tagged organisms have been observed to circle eddies as well as appear to associate with fronts. We investigate the role of eddies in providing a habitat to higher trophic-level organisms in the oligotrophic ocean using a biophysical model of the North Pacific Ocean.

The physical features of the ocean are important to biological dynamics. Features such as eddies and fronts can work to bring nutrients into an ocean environment, providing material to support life. Organisms such as phytoplankton at the base of the marine food-web require nutrients such as iron, nitrogen and silica to grow. In many areas of the oceans, the water contains a concentration of nutrients too low to support a large phytoplankton community.

Large regions of the oceans low in nutrients and chlorophyll are termed oligotrophic. Oligotrophic regions of the oceans include the subtropical gyres in the Atlantic and Pacific Oceans. The world's oceans have warmed during the past century and some research has suggested that the ocean's oligotrophic regions are expanding due to climate change.<sup>1</sup>

Especially in oligotrophic regions, features such as fronts and mesoscale eddies may provide crucial habitat and food source for marine organisms from plankton to fish to migrating marine turtles. The physical oceanographic feature may prove to be a biological hotspot, providing a supply of prey that will attract organisms higher on the food chain such as fish.<sup>2,3</sup>

Because eddies are vortices of moving water that can travel through space, it is difficult to determine the biological dynamics of an eddy by making in-situ observations. At this point, it becomes advantageous to use a model to test some hypotheses and predictions.

The ROMS-CoSiNE model provides physical oceanography parameters, nutrients, and biological information for the Pacific Basin. We use the model output as well as modeled marine biology data and satellite data to statistically

investigate the relationships between the physical oceanography features and the marine biology.

**Acknowledgements:** This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

### Bibliography:

Polovina, Jeffrey J., Evan A. Howell, and Melanie Abecassis. "Ocean's least productive waters are expanding." *Geophysical Research Letters* 35, no. 3 (2008).

Palacios, Daniel M., Steven J. Bograd, David G. Foley, and Franklin B. Schwing. "Oceanographic characteristics of biological hot spots in the North Pacific: a remote sensing perspective." *Deep Sea Research Part II: Topical Studies in Oceanography* 53, no. 3 (2006): 250-269.

Polovina, Jeffrey, Itaru Uchida, George Balazs, Evan A. Howell, Denise Parker, and Peter Dutton. "The Kuroshio Extension Bifurcation Region: a pelagic hotspot for juvenile loggerhead sea turtles." *Deep Sea Research Part II: Topical Studies in Oceanography* 53, no. 3 (2006): 326-339.

## Paleoclimate Reconstruction in the Peruvian Andes: Reconnaissance of a New Field Site

Charles Rodda<sup>1</sup>, Paul Mayewski<sup>1</sup>, Skylar Haines<sup>1</sup>, Sharon Sneed<sup>1</sup>, Douglas Introne<sup>1</sup>, Anton Seimon<sup>1,2</sup>, Baker Perry<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. Appalachian State University.

**We present the initial analyses of snow and ice samples collected from a previously-unstudied glacier in the Cordillera Vilcanota in southern Peru. High-precision measurement of trace element concentrations in glacier ice suggests that annual and sub-annual signals are preserved in ice dating to ca. 400 years before present. Excellent exposure of ice layers from the modern surface down to the beginning of the Little Ice Age will allow future sampling to target likely eras of abrupt climate changes in the Peruvian tropics.**

The Peruvian Andes are home to the greatest concentration of tropical glaciers on Earth, and thus represents the richest potential source of information on low-latitude paleoclimate.

We collected two short ice cores (each ca. 4m long) from a previously unstudied glacier on Nevado Osjollo Anante (NOA), in the Cordillera Vilcanota in southern Peru, as well as snow samples from the last season's snowpack. Concentrations of stable isotopes of oxygen and hydrogen in the core were measured using conventional discrete sampling techniques, and trace element concentrations were measured using an ultra high resolution laser-sampling protocol (Sneed et al., near press 2014). A first-order dating of one core (R2) was performed by layer-counting in field photographs from a prominent melt layer known to date to the 1983 El Niño event down to the top of the core, which was found to date to AD1662 +/- 33yrs.

At the level in the glacier from which the R2 core was retrieved, observed layer thickness is ~2cm. High-resolution sampling of trace elements in the R2 core records Ca, Na, and Fe concentrations with a regular pattern of peaks, with a characteristic wavelength of ~2cm (fig.1), confirming that observed layers are annual. Sampling resolution with the laser system is on the order of 1000 samples/year, meaning that individual precipitation events should be resolved, at least down to the level of the R2 core.

By comparing trace-element chemistry to dated samples of the snowpack to data from a series of weather stations that collaborators and we have installed in the Cordillera Vilcanota, as well as precipitation samples collected by local

ranchers, we will establish the meteorological significance of the observed down-core chemical signals. Those analyses are on-going.

A continuous ice record exposed at the margin of NOA should span the entire Little Ice Age (locally ~AD1350-1880) and allow us to characterize the climate system immediately and during the transition into and out of that period

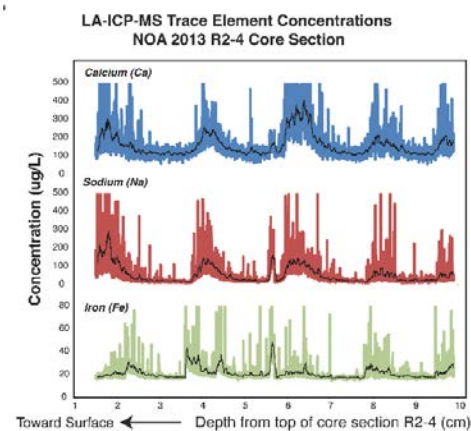


Fig.1. High-resolution measurements of trace element (Ca, Na, Fe) chemistry in a section of ice core collected from the Cordillera Vilcanota. Five annual peaks are apparent, reflecting nearly 4,000 measurements in a section approximately 8 cm thick. Black lines are running means, with an average temporal scale of 10 days.

**Acknowledgements:** This research was funded by the Dan & Betty Churchill Exploration Fund and benefits from collaboration with citizen-scientists Pedro Godofredo and Felipe Crispin.

**Bibliography:** S. B. Sneed, P. A. Mayewski, W. Sayre, M. Handley, A. V. Kurbatov, K. C. Taylor, P. Bohleber, and D. Wagenbach. Validation of micrometer resolution chemical analysis of ice cores by LA-ICP-MS. *Journal of Glaciology*, in review, 2014

## A Java Library For Dynamically Loading And Executing Remote Octave Functions

Mark Royer<sup>1</sup>, Sudarshan S. Chawathe<sup>1,2</sup>, Andrei V. Kurbatov<sup>2</sup>, Paul A. Mayewski<sup>2,3</sup>

1. School of Computing and Information Science, University of Maine.
2. Climate Change Institute, University of Maine.
3. Department of Earth Sciences, University of Maine.

**Abstract: We describe a technique for loading and executing Octave functions remotely from a Java application. There are many scientific re-sampling techniques developed for Octave, and new functions are constantly being created. Because of this, it is important that a scientific application is able to take on new functions without low level maintenance or recompiling of the system. In order to allow systems to achieve that end, we have developed a Java library that can be integrated into Java-based applications. We use the P301 system to demonstrate this technique.**

The Climate Change Institute (CCI) is an interdisciplinary research unit organized to conduct research and graduate education funded by public and private sources. It is a requirement for the CCI students and faculty to report annually about research and educational activities.

Executing Octave code from Java applications is a common requirement in scientific fields. In order to seamlessly make a connection, the application must have access to a library that forms the bridge, and the computer running the application must have Octave installed. The most common approach is to start an Octave instance from the Java application as a separate process, and then interact with the process by utilizing standard input and output streams. This is the technique used by the joPAS and javaOctave projects.

However, the approaches used by the joPAS and javaOctave projects have their limitations. Because each system directly interacts with Octave using the standard input and output streams, they are susceptible to any minor deviations in Octave output, which can occur during version changes. Secondly, they both require that an Octave program is installed on the machine that is executing the code. Lastly, in order to introduce a new function to the application, the user of the system must make Octave aware of the location of the new function. This can be achieved by placing the function where Octave has been installed on the system or by modifying environment variables to point Octave to the location of the new function. The technique that we suggest is not limited by any of these conditions.

To avoid problems with reading and writing to Octave via input and output streams, our approach simply does not use them. Instead of using Octave's interactive shell, we use a script to run the function in batch mode. The script first loads any data that is required by the function to run, and then it executes the requested function. Finally, any results are written to a data file and retrieved by the Java library.

In order to avoid the need to have Octave installed on the machine running the application, we separate the connection library into a client/server model. The client part of the library allows the application to query the server for functions and to execute those functions. The server side of the library maintains and stores information about functions, such as a function's name, description, parameters, and results.

Using a client/server model for the application library has the additional benefit of no longer requiring the end user to have intricate knowledge of the Octave installation. The server manages the details that ensure code is properly executed. A client may execute any function that has been loaded to the server, assuming that the necessary parameters to the function have been supplied. These requirements are enforced by the client-side library and then invoked on the server via Java Remote Method Invocation. For applications that want to run Octave locally, the server library can be added to the Java classpath, and the server may be specified as the localhost.

The developed library for dynamically loading and executing remote Octave functions will be demonstrated using the P301 system.

## Latitudinal Trends in Saltmarsh Sparrow (*Ammodramus caudacutus*) Nest Failure from Competing Risks

Katharine J. Ruskin<sup>1</sup>, Matthew A. Etterson<sup>2</sup>, Brian J. Olsen<sup>1</sup>, Thomas P. Hodgman<sup>3</sup>, Chris S. Elphick<sup>4</sup>, Adrienne I. Kovach<sup>5</sup>, W. Gregory Shriver<sup>6</sup>, Alyssa Borowske<sup>4</sup>, Chris R. Field<sup>4</sup>, Rebecca A. Kern<sup>6</sup>, Jennifer Walsh<sup>5</sup>

1. School of Biology & Ecology, Climate Change Institute, University of Maine.
2. U.S. Environmental Protection Agency, Mid-Continent Ecology Division.
3. Department of Ecology and Evolutionary Biology, University of Connecticut.
4. Bird Group, Maine Dept. of Inland Fisheries and Wildlife.
5. Department of Natural Resources and the Environment, University of New Hampshire.
6. Department of Entomology and Wildlife Ecology, University of Delaware.

**Abstract:** In this study, we quantify nest survival of Saltmarsh Sparrows across their global species range. We observed large-scale trends, most notably a latitudinal gradient in predation.

Saltmarsh Sparrows (*Ammodramus caudacutus*) are endemic to tidal marshes and breed exclusively in the northeastern United States (Greenlaw & Rising, 1994). They are considered globally threatened due to declining populations, habitat loss, and sea level rise (Greenlaw & Rising, 1994). Saltmarsh Sparrows are named on the National Audubon Society's current WatchList as a species of global conservation concern (National Audubon Society, 2007). Working toward an assessment of the Saltmarsh Sparrow's global population status, we estimated the fecundity of populations across the majority of the species' range. From 2011-2013, we conducted intensive demographic surveys of breeding Saltmarsh Sparrow populations in Maine, New Hampshire, Massachusetts, Connecticut, and New Jersey. We calculated average probabilities of nest failure for each population via MCEstimate, a program created by the Environmental Protection Agency to estimate failure probabilities of competing risks by using a Markov Chain framework. Probability of depredation was greatest in New Jersey, and decreased northward in Massachusetts and Maine. We also observed a weak latitudinal trend of increased flooding probability at higher latitudes. However, this trend was complicated by high degrees of interannual variability at all sites. Additionally, failure probabilities at the New Hampshire site deviated from our observed trends in depredation and flooding, likely because the site is farther inland and upriver than our other study sites.

**Acknowledgements:** Funding for my research has been provided by the U.S. Fish & Wildlife

Service and the University of Maine. Thanks to the Saltmarsh Habitat & Avian Research Program collaborators, my committee, particularly Matt Etterson, and the Olsen lab.

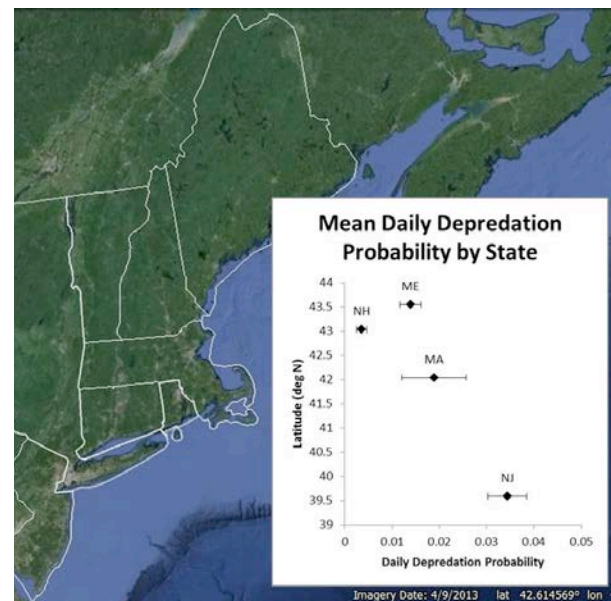


Figure 1. This study provides support for the hypothesis that predation increases with decreasing latitude. Imagery by GoogleEarth.

### Bibliography:

Greenlaw, J. S., & Rising, J. D. (1994). Saltmarsh Sparrow (*Ammodramus caudacutus*). Birds of North America.

National Audubon Society. (2007). Saltmarsh Sparrows. National Audubon Society WatchList.

## Wind-Driven Changes in Lake Thermal Structure in the Lake Superior Region

Jasmine E. Saros<sup>1</sup>, Kristin Strock<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. Environmental Science, Dickinson College.

**Abstract:** Over the 20<sup>th</sup> century, wind speeds have increased over the Lake Superior region as a result of warming. We investigated how this change has altered lake mixing depths over the past century in a lake situated on Isle Royale in Lake Superior, and discuss a new sediment record from the same system that will extend back several millennia.

Over the 20<sup>th</sup> century, water temperatures in Lake Superior, one of the largest lakes in the world, have increased more rapidly than air temperatures in the area (Austin & Colman 2008). This difference has led to increasing wind speeds in the region of Lake Superior. As wind speed is one of the primary controls on lake thermal structure, and many moderately-sized lakes are situated in this region, we investigated how changing wind speeds will alter the thermal structure of lakes in this area.

Desor Lake, situated on Isle Royale in Lake Superior, was selected for this study. Sensor data from the summer of 2012 revealed that wind speeds are correlated with the depth of the mixed layer in this lake ( $\rho=0.29$ ,  $p<0.05$ ), such that periods of stronger wind result in deeper mixing depths. Diatom-based reconstructions of lake mixing depth from a short sediment core revealed that lake mixing depth over the past century was correlated with wind speeds over Lake Superior ( $\rho=0.60$ ,  $p<0.05$ ) (Fig. 1). Both of these lines of evidence suggest that the thermal structure of Desor Lake is linked to wind speeds over Lake Superior.

As the Desor Lake record provides an archive of the wind and hence, temperature history of the Lake Superior region, we collected a longer core from the lake in 2013. The 40-cm short core captured a record back to 1870; the new, long core provides 10 m of record, which should span back to at least the mid-Holocene.

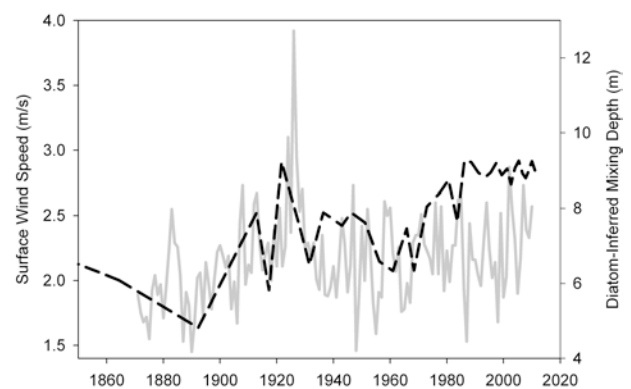


Fig. 1. Diatom-inferred lake mixing depth from Desor Lake sediment core (dashed line) compared to 20<sup>th</sup> century reanalysis of surface wind speed over Lake Superior (gray line).

**Acknowledgements:** This research is supported by a grant from the National Park Service Air Resources Division and the George Melendez Wright Climate Change Fellowship.

### Bibliography:

Austin, J. and S. Colman. 2008. A century of temperature variability in Lake Superior. *Limnology & Oceanography* 53: 2724-2730.

## Iceberg Hazards and Maritime Traffic in Disko Bay, West Greenland

Jessica Scheick<sup>1</sup>, Gordon Hamilton<sup>1</sup>, M. Brady Butler<sup>2</sup>, Eva Mätzler<sup>3</sup>, Jakob Abermann<sup>3</sup>

1. Climate Change Institute and School of Earth and Climate Sciences, University of Maine.
2. Department of Physics and Astronomy, University of Maine.
3. Asiaq, Greenland Survey, Nuuk, Greenland.

**Abstract:** Icebergs off the coast of Greenland pose a significant hazard to ships and other marine vessels operating in the region. Currently, little is documented about the distribution and occurrence frequency of icebergs in Disko Bay, West Greenland, and marine operators are limited to – at best – real time information. This project aims to develop a predictive tool of iceberg presence and distribution.

Abrupt climate changes are clearly manifest in a number of areas in the Arctic, including the rapid diminishing of summer sea ice and the recent speedup and retreat of Greenland's outlet glaciers. These changes are likely to lead to an increase in both vessel traffic and iceberg occurrence in Arctic waters. Icebergs pose a significant hazard to ships, drilling platforms, and other marine vessels. As perennial sea ice cover continues to decline in the Arctic, marine traffic is expected to increase. Operators unfamiliar with the hazards of working in poorly charted, Arctic waters increase the risk of maritime accidents, resulting in loss of life, resources, and/or economic assets and environmental degradation. Current available resources showing Arctic ice conditions are broad in scope and do not provide a detailed level of assessment at the bay or fjord scale, where ships are actually traversing the heaviest iceberg laden waters. Additionally, these charts are based on hindsight and provide no means for understanding how icebergs may be distributed in the future. Thus, a thorough understanding of past patterns of iceberg frequency and distribution is necessary to inform the development of safe and effective shipping and navigation policy.

Jakobshavn Isbræ, West Greenland, drains approximately 7% of the Greenland Ice Sheet (GIS) into Disko Bay (Figure 1; Joughin *et al.* 2004), which provides access to the important Greenland town of Ilulissat. In 1997, Jakobshavn began a period of rapid thinning and retreat (Joughin *et al.* 2004 and others), providing an ample supply of large icebergs to the fjord and bay beyond. This study aims to develop an automatic detection and tracking algorithm for delineating and tracking icebergs in Disko Bay,

ultimately compiling a dataset of iceberg frequency and distribution for the region. This dataset will then be compared to a number of climate parameters and used to develop a predictive tool that can be used by ship operators, port managers, and policymakers to enhance safety practices and develop effective policy for managing maritime traffic and iceberg hazards.

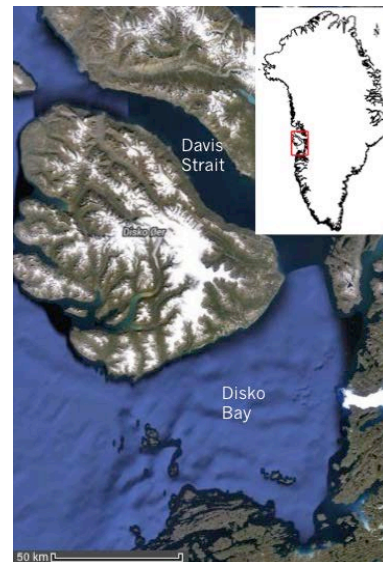


Fig. 1. Map showing the region of interest, encompassing Disko Bay and Davis Strait. Inset shows location of study area on Greenland coast. Map from maps.google.com.

**Acknowledgements:** This work has been supported by the US NSF Adaptation to Abrupt Climate Change (A2C2) IGERT program (grant DGE-1144423) and in cooperation with Asiaq, Greenland Survey.

**Bibliography:** Joughin, Ian, Waleed Abdalati, and Mark Fahnestock. 2004. "Large Fluctuations in Speed on Greenland's Jakobshavn Isbræ Glacier." *Nature* 432 (7017): 608–10.

## Can North American Trees Keep Pace With Climate Change?

Benjamin J. Seliger<sup>1,2</sup>, Jacquelyn L. Gill<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School of Biology and Ecology, University of Maine.

**Abstract:** Forecasting the effects of climate change on biodiversity demands understanding the capacity for tree distributions to migrate long distances in response to warming. We aim to distinguish if seed dispersal mechanisms determine tree species' ability to track climate. By analyzing the extent tree species utilize habitat opened up since the last ice age, we can deduce their migration capacity and identify which species may not track warming climates.

A chain is only as strong as its weakest link; likewise, an ecosystem can only adapt as fast as its slowest moving organisms. Projections show future climates moving far from where similar conditions are found today (Loarie et al. 2009), requiring many species to adjust their range by hundreds of kilometers to survive. Such travel is a slow process for trees, which need successive generations of propagules to disperse to and establish in areas far outside current ranges to migrate. Considering this challenge, can North America's tree species migrate quickly enough to keep pace with 21<sup>st</sup> century climate change?

Tree species underwent continental scale range migrations to follow millennial climate changes since the last glacial maximum (Jacobson et al. 1987), but it is not known if migration rates are fast enough to track abrupt changes in the next century. Modern studies of seed dispersal yield migration rates an order of magnitude lower than what is observed in the fossil pollen record (Clark et al. 1998). Current understanding of plant migration posits chance, long distance dispersal (LDD) events as necessary for range shifts, and that these events are too rare to be detected by observational study. European tree ranges appear limited by migration rate after postglacial warming (Svenning and Skov 2004); suggesting a poor ability of trees to migrate quickly. The focus of our investigation is to distinguish if ranges of North American trees are limited by migration rate, and whether limitations are correlated with how a species disperses its seed.

The morphological characteristics of a seed that allow for transportation are called a dispersal syndrome. Common dispersal syndromes of temperate trees are wind, bird and mammal. Whether dispersal syndromes influence the probability LDD events is unknown, but not all

dispersal syndromes are reliable. Species with fruits so large that no extant animal can properly disperse them (e.g. *Maclura*, *Gymnocladus*) were likely dispersed by extinct Pleistocene megafauna (Janzen and Martin 1982). These trees may not be dispersed at all today.

As glaciers retreated, exposed land would have been quickly realized by species that could migrate well, while poor migrators lagged behind. We will compare this postglacial range filling between species with varying dispersal syndromes to test if dispersal syndromes are correlated with migration rate. To do this, we will model the potential geographic range for individual species based on climates each is found living in now, and use the proportion of this range the species occupies today as a proxy for its migration rate. If dispersal syndromes influence migration rate, a given syndrome should show trends in range filling across species, which could highlight poorly migrating species for conservationists.

**Acknowledgements:** Thank you to the Climate Change Institute and the School of Biology and Ecology for supporting this research.

### Bibliography:

- Clark, James S., et al. "Reid's Paradox of Rapid Plant Migration Dispersal theory and interpretation of paleoecological records." *BioScience* 48, #1 (1998): 13-24.
- Jacobson Jr, George L., et al. "Patterns and rates of vegetation change during the deglaciation of eastern North America." *North American and Adjacent Oceans during the Last Deglaciation* (1987): 277-288.
- Janzen, Daniel H., and Paul S. Martin. "Neotropical anachronisms: the fruits the gomphotheres ate." *Science* 215, no. 4528 (1982): 19-27
- Loarie, Scott R., et al. "The velocity of climate change." *Nature* 462, no. 7276 (2009): 1052-1055.
- Svenning, Jens-Christian, and Flemming Skov. "Limited filling of the potential range in European tree species." *Ecology Letters* 7, no. 7 (2004): 565-573.

## Combining Novel Ice Core Analysis with Ancient Historical Records: First Results from the Colle Gnifetti Ice Core Project, European Alps

Nicole E. Spaulding<sup>1,2</sup>, Pascal Bohleber<sup>1,2,3</sup>, Sharon B. Sneed<sup>1</sup>, Dietmar Wagenbach<sup>3</sup>, Paul A. Mayewski<sup>1,4</sup>, Michael McCormick<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. Initiative for the Science of the Human Past, Harvard University
3. Institute for Environmental Physics, Heidelberg University.
4. Department of Earth Sciences, University of Maine.

**Abstract:** Ice core drilling studies performed on mountain glaciers in mid-latitudes can provide paleoclimate records closer to human settlements that are complementary to polar ice cores. Here we present an overview of the project goals for one such ice core, collected at Colle Gnifetti in the Swiss-Italian Alps, as well as first results from a new analytical technique.

Within the European Alps, the small-scale Colle Gnifetti (CG) glacier saddle (4450m asl, Monte Rosa, Swiss-Italian Alps – Fig. 1) is the only ice core drilling site with an annual net snow accumulation low enough to archive multi-millennial records in spite of ice thickness barely exceeding 100 meters. So far, however, the interpretation of climate signals within the existing CG ice core array has been hampered, among other complications, by the lack of a well-constrained age-depth relation exceeding the last couple of hundred years. Rapid layer thinning limits the use of annual layer counting, especially for the lower portion of the ice core. Here, much could be gained from ultra-high depth resolution impurity analyses using a new state-of-the-art laser-based system.



Fig. 1. The location of the new ice core complements the existing Colle Gnifetti ice core array.

Laser ablation inductively-coupled plasma mass spectrometry (LA) is capable of analyzing 50,000 samples per meter, in comparison with the ~100 typically achieved by continuous flow analysis (CFA). Mineral dust concentrations from the newest CG ice core (KCC) have been analyzed by both LA and CFA. Their comparison suggests that LA yields additional

high frequency information, potentially reflecting annual signals not resolved by CFA, while capturing similar low frequency trends (Fig. 2).

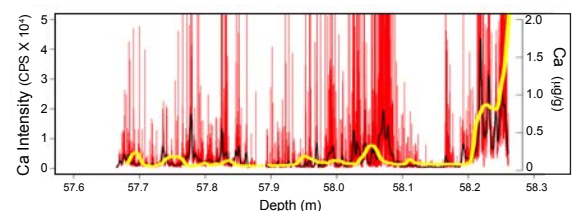


Fig. 2. The LA (red – raw; black – first component of singular spectrum analysis with 1% window) captures more variability than the CFA profile (full red-yellow), though both exhibit the same overall trend.

Using this additional information we hope to extend a chronology obtained from established dating methods to the lower sections comprising the last millennium. Doing so will allow us to examine the relationships between humans and climate in Medieval Europe through comparison of our CG ice core proxies with written historical accounts. For this portion of the project we will utilize a new geodatabase of historical climate records under way at the Digital Atlas of Roman and Medieval Civilization (DARMC), Harvard University <http://darmc.harvard.edu/>.

**Acknowledgements:** Financial support from the Arcadia Fund. Thanks also to: Physical Institute Uni Bern for drilling the 2013 CG ice core, our field team, the University of Fribourg, the staffs of the Capanna Margherita Hut, AirZermatt and Alpin Cargo, Sepp Kipfstuhl and Johannes Freitag for their assistance during processing of KCC at AWI, and Mike Handley and Andrei Kurbatov for helpful discussions about ICP-MS operation and experimental design, respectively.



## <sup>10</sup>Be Surface Exposure Chronology of the Former Pukaki Glacier, South Island, New Zealand

Peter D. Strand<sup>a</sup>, George H. Denton<sup>a</sup>, Joerg M. Schaefer<sup>b</sup>, Aaron E. Putnam<sup>b</sup>, David J.A. Barrell<sup>c</sup>, Samuel E. Kelley<sup>d</sup>, Alice M. Doughty<sup>e</sup>, Tobias N.B. Koffman<sup>a</sup>, Colin W. Dowey<sup>a</sup>, Rosanne Schwartz<sup>b</sup>

<sup>a</sup> School of Earth and Climate Sciences, University of Maine.

<sup>c</sup> GNS Science, New Zealand.

<sup>d</sup> Department of Geology, University at Buffalo.

<sup>e</sup> Department of Geology, Bates College.

A prominent version of the Milankovitch (1941) hypothesis of ice ages is that variations of Earth's ice sheets are paced by periodic changes in Earth's orbit and consequent seasonal redistribution of incoming solar radiation at 65°N latitude. Following the Milankovitch (1941) hypothesis, glacier volume variations are expected to be anti-phased between the hemispheres due to the opposite effects of orbital precession on insolation. However, problems are realized when comparing mountain-glacier fluctuations during the last glacial cycle in New Zealand's Southern Alps with variations of local summertime solar insolation. The existing chronologies of glacial landforms reveal that glaciers in the Southern Alps of New Zealand repeatedly achieved full-glacial extents throughout Marine Isotope Stages (MIS) 4, 3 and 2, during high, low, and intermediate values of local summertime insolation intensity.

I used the <sup>10</sup>Be exposure-age dating technique (as described in Putnam et al., 2013) to determine the chronology of glacial landforms northeast of Lake Pukaki. I calculated surface-exposure ages using the <sup>10</sup>Be production rate of Putnam et al., 2010.

The highest-elevation, left-lateral deposits of the former Pukaki glacier reveal glacier fluctuations correlating to Heinrich stadials during MIS 4, 3 and 2. The earliest dated moraine of this study places the maximum recognized MIS 3 extent of the former Pukaki Glacier at **42,494 ± 2,100** yrs ago. Ages of inboard moraine belts of **36,178 ± 1,257** yrs ago, **26,613 ± 2,885** yrs ago, and **19,950 ± 665** yrs ago demonstrate that the glacier edge reached its maximum areal extent multiple times during, and prior to, the classic global Last Glacial Maximum. The moraine belt dated to **17,910 ± 387** yrs ago is the final robust position of the Pukaki Glacier before its rapid retreat into the Pukaki Valley. The <sup>10</sup>Be chronology derived from the upper-left lateral moraines of the former Pukaki Glacier is consistent with other published <sup>10</sup>Be chronologies from nearby moraine sets (Kelley et al., in press, Doughty et al., in prep, Putnam et al., 2013).

The results suggest that the timing of millennial-scale maxima and minima of glaciers in the Southern Alps of New Zealand follow the pulsebeat of Heinrich stadials in the North Atlantic. The millennial-scale climate fluctuations are superimposed on long-term changes in orbitally-driven insolation. The Pukaki left lateral <sup>10</sup>Be surface-exposure glacial record supports the suggestion that shifting atmospheric circulation bands provide the mechanism for teleconnections between the Northern and Southern Hemispheres (Denton et al., 2010;

Putnam et al., 2013). The <sup>10</sup>Be surface-exposure record of this study provides further evidence that the climate of the Southern Hemisphere mid-latitudes follows the millennial pulsebeat of North Atlantic Heinrich stadials during MIS 4, 3, and 2.

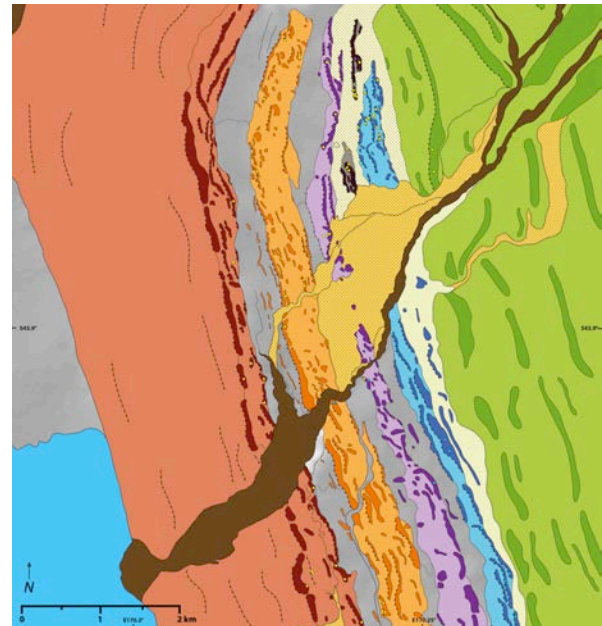


Figure 1. Geomorphic map of field area

**Acknowledgements:** We thank the Gary C. Comer Science and Education Foundation, the National Science Foundation, and the Quesada Family Foundation for support.

### References:

- Denton, G.H., et al. 2010. The last glacial termination. *Science*.
- Doughty, A.M., et al., in prep. Mismatch of Glacier Extent and Summer Insolation in Southern Hemisphere Mid- Latitudes.
- Kelley, S.E., et al., in press. New Zealand moraine record of a Southern Hemisphere cold episode 41,000 years ago. *Geology*.
- Milankovitch, M., 1941. *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeiten-problem*. Royal Serbian Academy, Belgrade.
- Putnam, A.E., et al., 2010. In situ cosmogenic <sup>10</sup>Be production-rate calibration from the Southern Alps, New Zealand. *Quaternary Geochronology*.
- Putnam, A.E., et al., 2013. The Last Glacial Maximum at 44S documented by a <sup>10</sup>Be moraine chronology at Lake Ohau, Southern Alps, New Zealand. *Quaternary Science Reviews*.

## Identifying Optimal Thermal Habitat for American Lobsters in the Coastal Waters of Massachusetts.

Kisei Tanaka<sup>1</sup> and Yong Chen<sup>2</sup>

1. Climate Change Institute, University of Maine.
2. School of Marine Sciences, University of Maine.

**Abstract: Fisheries and corresponding environmental data from 1982 to 2012 in Massachusetts's coastal water were used to develop a suitability index (SI) in the form of a linear transfer function based on lobster abundance for bottom temperature.**

Climate change will likely alter size and distribution of optimal habitats for American lobster (*Homarus americanus*) in New England (Fogarty et al. 2007). To identify the optimal thermal habitat for American lobster in Massachusetts's coastal water, suitability index (SI) in the form of a linear transfer function based on lobster abundance (Catch-Per-Unit-Effort: CPUE) was developed.

Suitability index (SI) is used to quantify the optimal environmental conditions from 0 (unsuitable habitat) to 1 (very suitable habitat) for one or more environmental variables (Franklin 2009).

To estimate abundance of lobsters in state water of Massachusetts, CPUE at each sampling station from the state lobster trawl survey was calculated as;

$$CPUE = \frac{Catch}{TowDuration}$$

This CPUE as abundance index was used to develop suitability index (SI) for bottom temperature as;

$$SI_n = \frac{CPUE_n - CPUE_{min}}{CPUE_{max} - CPUE_{min}}$$

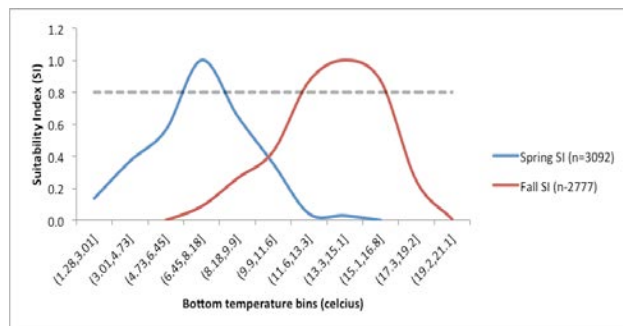


Figure 1: Suitability Index (SI) graph for bottom temperature from MA lobster survey (1982-2012).

The result shows that the optimal range of bottom temperature with the highest class of SI (i.e. 0.8 - 1.0) for MA lobster stock significantly differed between spring and fall.

Combined with SI for other key habitat variables such as depth and bottom salinity, a Habitat Suitability Index (HSI) model can be developed to quantify the spatio-temporal variability of suitable habitat for lobster stocks in the Gulf of Maine and Southern New England. This is a part of ongoing research that will contribute to the development of modeling framework to incorporate habitat information for current lobster management given the expected changes in the northeastern US marine ecosystem.

### Acknowledgements:

This research was supported by: (1) US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423 and (2) Massachusetts Division of Marine Fisheries Inshore Bottom-Trawl Survey Program

### Bibliography:

Fogarty, Michael, Lewis Incze, Richard Wahle, David Mountain, Allan Robinson, Katherine Hayhoe, Anne Richards, and James Manning. 2007. "Potential Climate Change Impacts on Marine Resources of the Northeastern United States." *Northeast Climate Impacts Assessment Technical Series: 1-33.*

Franklin, Janet. 2009. *Mapping Species Distributions: Spatial Inference and Prediction.* Cambridge University Press.

**Disclaimer:** Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

## Ecological and Economic Vulnerability of Maine Drinking Water Resources to Increased Frequency of Extreme Storm Events

Kate A. Warner<sup>1,2</sup>, Kristin E.D. Strock<sup>3</sup>, Mario F. Teisl<sup>4</sup>, Jasmine E. Saros<sup>1,2</sup>

1. Climate Change Institute, University of Maine.
2. School Biology and Ecology, University of Maine.
3. Environmental Science Department, Dickinson College.
4. School of Economics, University of Maine, Orono.

**Abstract: Increases in extreme precipitation across the Northeastern U.S. has led to increased dissolved organic carbon (DOC) in aquatic ecosystems. Increased DOC in drinking water resources has significant implications on water quality and water treatment practices. By integrating ecological and economic metrics we aim to assess the sensitivity and adaptive capacity of Maine's water resources to extreme events.**

The northeastern U.S. has experienced a 61% increase in extreme precipitation events since 1950 (Figure 1; Spierre et al. 2010). Analysis of a 30-year database of surface water geochemistry and watershed-specific landscape data throughout the Northeast suggests increased concentrations of dissolved organic carbon (DOC) in lakes during extreme wet years (Strock K.E.D. 2013).

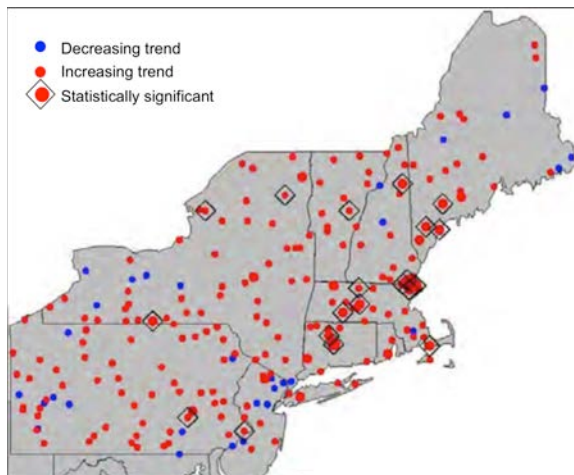


Fig. 1. Trends in the 99<sup>th</sup> percentile of daily precipitation accumulations per decade from 1948-2007. Increasing trends are shown in red, decreasing in blue. Statistically significant trends are indicated by black diamonds. (Modified from Spierre et al. 2010).

DOC, an important regulator of ecosystem structure and function, flows into lakes and streams via surface, ground and soil waters and can have profound implications on the quality of drinking water and for drinking water practices. Taste and odor problems, harmful by-products, increased levels of complexed heavy metals and absorbed organic pollutants are some of the

problems created by an increase of DOC in drinking water (Matilainen et al. 2010). Throughout the state of Maine many drinking water sources are not required to filter their water like other regions of the U.S. and increases in DOC pose high economic costs.

A better understanding of Maine's aquatic ecosystem vulnerability and the implications of extreme events on drinking water resources is needed. For this research we will be conducting a vulnerability assessment across Maine that integrates ecological and economic metrics to better understand the sensitivity and adaptive capacity of Maine's drinking water sources to extreme events. This will inform the development of adaptation strategies for Maine's drinking water resources to ensure sustained high water quality and a better understanding of the susceptibility of these sources to extreme events.

**Acknowledgements:** This research was supported by the US National Science Foundation Adaptation to Abrupt Climate Change IGERT program grant DGE-1144423.

### Bibliography:

Matilainen A. et al. 2010. Natural organic matter removal by coagulation during drinking water treatment: A review. *Advances in Colloid and Interface Science*, 159: 189-197.

Spierre S.G. et al. 2010. Trends in Extreme Precipitation Events for the Northeastern United States 1948-2007. *Carbon Solutions New England*, University of New Hampshire.

Strock K.E.D. 2013. *Deciphering Climate Mediated Changes in Boreal Lake Ecosystems*. (Dissertation). University of Maine, Orono, ME.

## Modeling Seasonal Meltwater-Activated Ice Acceleration in Southwest Greenland

Nora Weitz<sup>1,2</sup>, Gordon Hamilton<sup>1,2</sup>, James Fastook<sup>1,3</sup>

1. Climate Change Institute, University of Maine.
2. Department of Earth Sciences, University of Maine.
3. Department of Computer Science, University of Maine.

**Abstract:** Numerous observations document the existence of a widespread subglacial water system under the ablation zone of the Greenland Ice Sheet (GIS). Ice acceleration due to enhanced basal sliding is linked to the increase of surface melt water production early in the summer. Here, we simulate the land-terminated area of the southwestern Greenland Ice Sheet with a map-plane ice flow model that incorporates a subglacial water flow model. We find that the summer acceleration of the ice is strongly seasonal and does not effect following years.

Until lately, subglacial water systems beneath large ice sheets were considered to be in a steady-state (Bell, 2002), but recent observations show that this is not the case and that subglacial hydrology impacts both the spatial and the temporal evolution of ice dynamics. In Greenland, surface melt water can reach the bed of the ice sheet through cracks and moulins and by that enhance basal sliding. The influence of subglacial water on ice flow depends on the capacity of the subglacial hydrologic system (Bell, 2008). The influence of subglacial hydrology on ice dynamic processes was not included in the IPCC's 4th Assessment Report, compromising the estimated sea-level rise (Bell, 2008). A better understanding of the interactions between surface melt, subglacial drainage systems and ice dynamics is needed to determine the sensitivity and response of the GIS to future climate scenarios.

We investigate how summer acceleration of a land-terminated region of the GIS can be included in ice sheet modeling, using the University of Maine Ice Sheet Model with the incorporated basal water flow model. In the simulations the observed balance velocities can be obtained using three different parameter settings for the sliding law constant and the drainage coefficient, however, the basal water thickness differs for each combination. How much additional water is needed to simulate the observed summer acceleration of the ice sheet? Based on observations we add three different amounts of melt water to the basal water layer in the summer months, each distributed over June, July and August. To match observed ice acceleration, the basal drainage efficiency has to be increased significantly, otherwise ice

velocities exceed observed values. Our model results indicate that the maximum ice acceleration can be observed about 3 to 5 days after the season's first melt water pulse, assuming the drainage system capacity does not change in these days.

Our modeling experiments show that the subglacial drainage system adjusts every summer depending on the melt water input to the system. The relation between melt water production and ice velocity change is a seasonal process and long-term trends therefore depend on the yearly surface melt and on the development of the drainage system. For a land based region of the ice sheet, the basal drainage system will adapt to the additional amount of melt water and become more efficient in evacuating basal water, therefore this process is not expected to influence future sea level calculations significantly.

### Bibliography:

Bell, R. E. (2002), Origin and fate of Lake Vostok water refrozen to the base of the East Antarctic ice sheet. *Nature* 416, 307-310.

Bell, R. E. (2008), The role of subglacial water in ice sheet mass balance, *Nature Geo-science*, Vol. 1, p. 297.

IPCC (2007), The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

**Acknowledgements:** This project is supported by the National Science Foundation award NSF-0944087.

## Determining Late Holocene Hydrography in the Gulf of Maine Using *Arctica Islandica* Oxygen Isotopic Composition

Nina M. Whitney<sup>1</sup>, Karl J. Kreutz<sup>1</sup>, Alan D. Wanamaker<sup>2</sup>, Douglas S. Introne<sup>1</sup>

1. Climate Change Institute, University of Maine.
2. Department of Geological and Atmospheric Sciences, Iowa State University.

**Abstract:** Our research aims to establish the natural variability and climatic drivers of seawater temperature fluctuations in the Gulf of Maine over the last 250 years using oxygen isotopes measured in shells of the mollusc *Arctica islandica*.

Anomalous summer 2012 sea surface temperatures (SSTs; Fig. 1) in the Gulf of Maine (GoM) had major impacts on marine ecosystems, fisheries and the regional economy. In order to determine whether these warmer waters are a result of anthropogenic climate change or of natural fluctuations in the climate system, the natural variability of SSTs in the GoM needs to be established on centennial time-scales. Our approach is to use annually-resolved oxygen isotopes in the carbonate shells of the marine mollusc *Arctica islandica* with the goal of determining seawater temperatures in the GoM over the last 250 years. Additionally, in order to better understand the climatic influences on hydrography in the GoM, our research will compare Gulf of Maine SSTs to North Atlantic Oscillation (NAO) reconstructions (e.g. Trouet et al., 2009) in order to better understand this relationship.

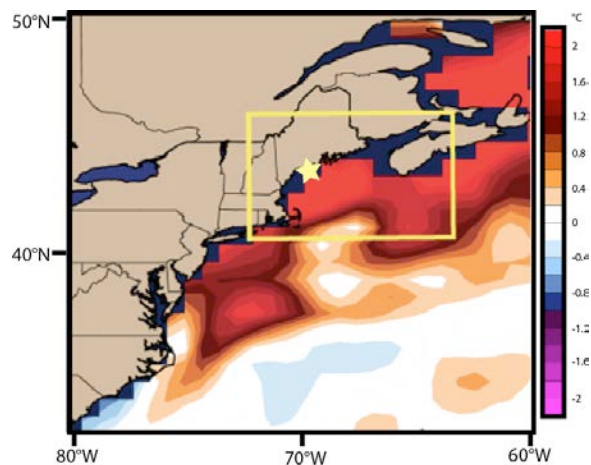


Figure 1. SST anomalies for June, July and August (JJA) 2012 compared to climatic average JJA SSTs from 1982-2011. Yellow rectangle indicates GoM region. Yellow star indicates collection site at Seguin Island. Map made using Climate Reanalyzer and ERA Interim data.

Over the last several years, over 400 live caught and fossil *A. islandica* shells have been collected off of Seguin Island in the GoM (Fi. 1). Because *A. islandica* grow their shells in annual increments, the unique pattern of these increments can be used to date the collected shells using the technique of cross-dating (Schone et al., 2013). Thirty-three shells have been dated using cross-dating and placed into a master chronology that extends from 1760-2009. Oxygen isotope data will be measured in each of these shells in order to determine seawater temperatures in the GoM over this time period. SST calculation is possible because *Arctica islandica* shells form in isotopic equilibrium with seawater (Schone et al., 2013).

*A. islandica* is currently the only absolutely dated, annually resolved, non-tropical, marine proxy in the North Atlantic. It is therefore an ideal proxy for determining natural variability and climatic forcings of seawater temperatures in the GoM. This research is crucial for understanding the current and future impacts of anthropogenic climate change on the region.

**Acknowledgements:** This research is funded by a Paleo Perspectives on Climate Change grant from the National Science Foundation.

### References:

- Schöne, Bernd R. "*Arctica Islandica* (Bivalvia): A Unique Paleoenvironmental Archive of the Northern North Atlantic Ocean." *Global and Planetary Change* 111 (2013): 199-225.
- Trouet, V., J. Esper, N. E. Graham, A. Baker, J. D. Scourse, and D. C. Frank. "Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly." *Science* 324, no. 5923 (Apr 3 2009): 78-80.