

## Review on the Roles of Renewable Energy Technologies in Climate Change Adaptation and Mitigation Among Rural Communities of Nepal

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**Abstract:** Debates on addressing climate change focus on the need to replacing fossil fuels with renewable energy. This paper reviews roles of different renewable energy technologies in adaptation and mitigation of climate change in Nepal. The potential and capacity of different energies are high in Nepal, but it has not been able to harness. However, use of fossil fuels and conventional energy are still prevalent other renewable energies have been generated that has positively impacted social, economic, and environmental sectors in Nepal.

**Renewable Energy in Nepal:** The use of renewable energy technologies (RETs) has enhanced climate change adaptation and mitigation in Nepal, a nation quite vulnerable to climate change. Solar energy, hydroelectricity plants, biogas, improved cooking stoves (ICS), and wind energy systems are being popular every year. However, the consumption of fossil fuels and conventional biomass energy is widely practiced in Nepal with adverse impacts on socio-economic, health, and environmental sectors.

Biomass and petroleum fuel account for 80% and 12% of the total energy while 3% energy is generated from grid electricity and RETs (Fig. 1). Households consume the highest energy (43%) followed by industrial sector (38%).

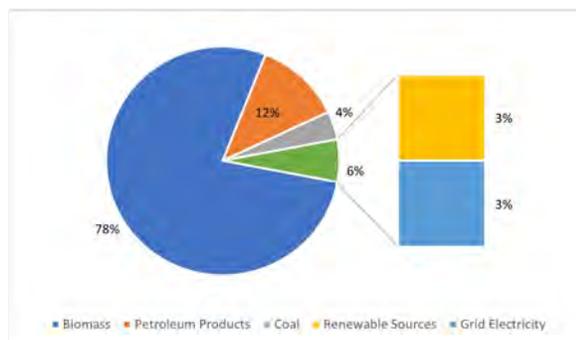


Fig. 1. Generation by different sources (GoN, 2015)

Indoor air pollution causing eye and respiratory diseases resulting mortality of more than 7500 women and children is the impact of using conventional biomass (fuelwood, cattle dung, agricultural residue), and kerosene for cooking at household level. Traditional biomass and

imported non-renewable energy are responsible for Greenhouse Gas (GHG) emissions in Nepal.

Hydro power is popular in Nepal due to perpetual flowing rivers (approx. 6000) having current capacity of 967.85 Mw. Nepal has 300 days of sun a year, receiving 3.6-6.2 kWh of solar radiation with potential of 2100 Mw (Table. 1). Wind energy accounts for 113.6 kW capacity.

Table 1. Potential of RETs (Paudyal et al., 2019).

S.N.	RETs	Potentiality
1	Mini/Micro hydro	>100 MW
2	Solar energy	2100 MW
3	Improved water mill	25-30,000 MW
4	Wind energy	3000 MW

Construction of RETs at local level has reduced dependency on forest products reducing emissions and enhancing carbon sequestration. RETs have been shown to promote health services, support quality education and social networks, create jobs, and earn revenue from clean development mechanisms.

**Acknowledgements:** Dr. Katherine Glover, Dr. Cindy Isenhour, and Dr. Suraj Upadhaya

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## Virtual Reality and the Archaeological Record: Reconstruction of the Ostra Collecting Station

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**Abstract:** This research explores using excavation data to develop a 3D immersive and interactive simulated environment representative of an archaeological site using virtual reality (VR) as a platform. VR is a tool that can be used to enhance visualizations and analyses of archaeological data. Incorporating VR in site analyses provides an interface where data can be used to test various hypotheses and can be continuously updated and modified as new or additional data become available. The implementation of VR can allow archaeologists to visualize site data with geographic context, site development, and the transition to abandonment much more effectively than when using traditional 2D representations alone. The Ostra Collecting Station, a mid-Holocene site located in northern Peru, has been an excellent example for this type of technological exploration.

### Background:

In archaeological research, context is crucial towards understanding and interpreting the lifestyles of former (sometimes ancient) inhabitants of a site or area. The Ostra Collecting Station exemplifies this.

The site and its adjacent shoreline have been radiocarbon dated to ~6,500 calibrated years B.P. It sits on top of a sea-cliff with the ancient shoreline adjacent to the site. During the time of occupation, this limited access to the site from three directions (from the north, east, or south). However, the present-day shoreline is located 5km to the west, leaving the site with the appearance of being surrounded by desert and accessible from all four directions.

The Ostra Collecting Station is also hypothesized to be the oldest site in the America's with evidence of defensive strategies. Artifacts, in the form of slingstones (round, fist-sized rocks), are found in two lines of ~50 piles with ~100 stones per pile.

### Methodology:

Unity 3D game engine is being used to create the simulated environment. A drone was flown to create a 3D model of the site and its surrounding landscape to serve as the base layer of the virtual reconstruction. Building from this base layer, a water layer (Figure 1) was added to represent the presence of the Pacific Ocean and to create the contextual visualization required to grasp the accessibility restrictions of this site.

Excavation data from a 1x1 meter unit located in the northeastern corner of a stone structure is being processed and will be accurately added to the base layer through the use of geotags and GPS coordinates. Modeling of slingstone piles found on the surface of the site is planned as well as incorporating the ability of the user to experience "slinging" the slingstones themselves.

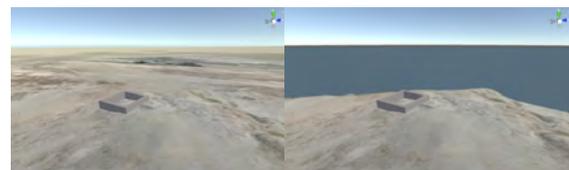


Fig. 1. Simulated environment of the Ostra Collecting Station with view looking towards the west. Left: Ostra Collecting Station in present day. Right: Ostra Collecting Station during occupation.

### Acknowledgements:

*Field Team Members:* Cecilia Mauricio, Dan Sandweiss, Paul "Jim" Roscoe, Alice Kelley, Gloria Lopez, and James Munch.

*Funding:* Churchill Exploration Fund

*Graduate Assistantship:* Dr. Nicholas Giudice, Chief Research Scientist at VEMI.

## Mechanisms for Glacier Acceleration of the Southern Patagonian Icefield, Chile

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**Abstract:** This project focuses on the impact of warm ocean water and lake drainages on glacier behavior for two tidewater glaciers of the Southern Patagonian Icefield, Chile. Ice-ocean results at Témpanos Glacier show a clear boundary between fresh glacial runoff and warm ocean water in contact with the glacier terminus. Observations of lake drainages at Bernardo Glacier show a drastic change in the timing of glacial lake outburst floods (GLOF), with the 2019 event being the earliest-known GLOF on record. Understanding how these drivers fluctuate over time and their relationships with terminus melt and glacier acceleration is critical for accurate predictions of the contribution of mid-latitude glaciers to global sea level rise. The change in timing and observed variability of this system also necessitates the establishment of a bi-monthly, long-term site monitoring initiative.

The Southern Patagonian Icefield (SPI) has retreated at an accelerated rate coincident with rising atmospheric and ocean temperatures<sup>1</sup>. However, determining how quickly the SPI will respond to continued warming remains an important question to be addressed.

For this study, we aim to quantify the impact of warm ocean water and lake drainages on glacier behavior for tidewater glaciers of the SPI (Fig 1) and to establish a protocol for bi-monthly, long-term site monitoring. *We hypothesize that warm ocean water is the dominant driving force behind accelerated retreat of tidewater glaciers of the SPI.*

We measured water temperature and salinity with depths, surface reflectance, and suspended sediment and plankton concentrations in front of Bernardo and Témpano Glaciers. Results show a clear boundary between fresh glacial runoff and warm ocean water around 6 m depth close to the terminus of Témpano Glacier. Additionally, we witnessed one of the earliest-known glacial lake outburst floods (GLOF) in a summer season at Bernardo Glacier. It is clear that to fully understand this dynamic ice-ocean system, we need longer duration measurements to capture both episodic events (GLOFs) and persistent forcing (ocean warming).

To aid in long-term monitoring of ice-ocean interactions and GLOF events, we will work with and train local partners to conduct surveys throughout the year. With the SPI contributing a disproportionate amount of ice loss relative to the size of the icefield, better understanding of the mechanisms for SPI tidewater glacier retreat are critical for projections of future ice loss.

**Acknowledgements:** Support for this research was provided by the Churchill Exploration Fund, American Alpine Club, and Geological Society of America

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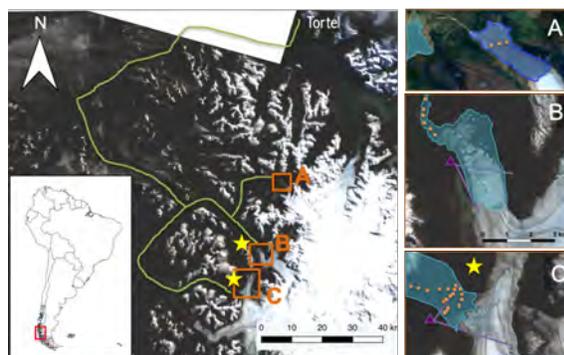


Fig. 1. Location map of the Southern Patagonian Icefield (inset) with water sampling (orange dots) and camera installations (purple triangles) sites for Olfidro Glacier (A), Bernardo Glacier (B) and Témpano Glacier (C) noted.

## Beyond the Holarctic Comfort Zone: Thermoregulation in a Sundaland Rodent

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Tropical endotherms may already be living close to their upper thermal limits, facing unexpectedly dire consequences even with minor climate perturbations. In the tropics, few physiological studies of mammals have been conducted and only a handful in the Indomalaya region. We measured the body temperature and metabolic rate (via O<sub>2</sub> consumption) of Mueller's giant Sunda rat (*Sundamys muelleri*) across a range of ambient temperatures to understand their ability to fluctuate their body temperature to better survive in changing temperatures. We found a lower limit of thermoneutrality of 31.0-31.4°C, beneath which energy consumption increased. Using measured rates of evaporative water loss, we found the upper critical limit to be 35.6 - 36.4°C. Our study is the first to report metabolic measurements for any Sundaland rodent and has implications for future climatic predictions and further evidence on the evolution of endothermy.

Endothermy, the ability to regulate body temperature through internal heat production, evolved in mammals in the tropics under warm and humid conditions (Crompton et al. 1978; Lovegrove 2017). Yet, most thermophysiological research has been done in temperate zones and despite the immense biodiversity of the Indo-Malayan region, relatively few physiological have been published (21 to our knowledge; Lovegrove 2000, Thonis et al. 2020). This biased imbalance contributes to the already-skewed representation in physiological data, where the bias towards taxa with a Holarctic distribution can lead to incorrect conclusions.

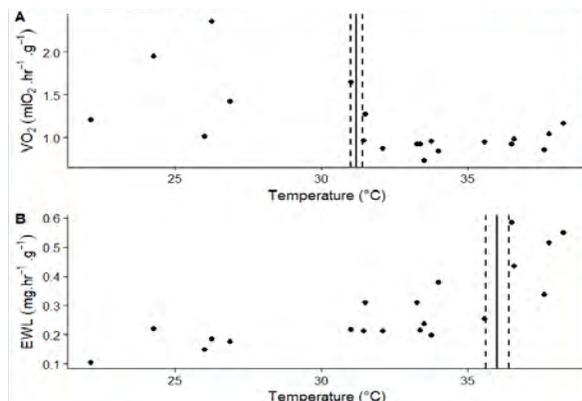


Figure 1. VO<sub>2</sub> (A) and EWL (B) of *S. muelleri* across a range of ambient temperatures. Dotted lines delineate the range of breakpoints and solid lines delineate the mean breakpoint.

Using flow-through respirometry, we measured rates of O<sub>2</sub> consumption, CO<sub>2</sub> production, and evaporative water loss (EWL) at a range of set

ambient temperatures in a wild-caught murid rodent *Sundamys muelleri* on the equatorial island of Borneo. These data were then used to determine the lower and upper critical temperatures of the thermoneutral zone, beyond which energy expenditure increases to maintain a stable body temperature. We found that the small and nocturnal *S. muelleri* has similar metabolic rates as other small mammals and maintains lower body temperatures than diurnal tropical mammals. We found the *Sundamys* rats to be more thermally flexible than small mammals found at higher latitudes, providing insight to how nocturnal tropical mammals may adapt to a warming climate.

**Acknowledgements:** This research was supported by the Maine Space Grant Consortium graduate summer fellowship to AMB and UMaine start-up funding to DLL.

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## Decoupled Acid Reactive and Biologically Relevant Fe Concentrations During Termination 1 in the South Pole Ice Core

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**The Southern Hemisphere westerlies have a significant role in modulating Southern Ocean carbon dynamics through variability in Fe delivery to phytoplankton. We provide the first high-resolution multifractional trace element analyses to hypothesize a decoupling of fractional Fe during Termination 1 (~18-12ka), possibly related to changes in dust property, atmospheric processing, or dust source.**

Atmospheric delivery of biologically-relevant trace metals (e.g., Fe, Mn, Co, Cu, and Cd) to the Southern ocean plays a role in modulating atmospheric CO<sub>2</sub> drawdown via changes in the biological pump. Antarctic ice core dust records can provide insight into the role of dust-borne metals by providing end-member estimates of fluxes and geochemistry. Previous studies have estimated changes in the trace metal fraction available to phytoplankton with low temporal resolution and/or under the assumption that total concentrations represent the bioavailable fraction. We present a new high-resolution, continuous record of three different fractions (acid reactive, dissolved and labile) of Fe for the past 54,000 years from the South Pole Ice Core (SPICEcore; 1751m).

Samples were collected from a continuous flow analysis (CFA) melt stream at 2m resolution (every ~25 years in the Holocene and ~120 years in the Last Glacial Period; 866 total samples). Each sample was split into three fractions for analysis via sector field ICPMS: 1) acid reactive (acidified with nitric acid to pH<1), 2) labile (buffered using ammonia and acetic acid to pH 5), and 3) dissolved (filtered then acidified with nitric acid to pH<1). We interpret the labile fraction as the most robust estimate of bioavailable concentration.

During Termination 1 (T1; 18-11.5 ±0.5ka; Fig. 1), we observe varied decreases between all Fe fractions. The dissolved fraction has the largest decrease (739%) followed by bioavailable (324%) and acid reactive (270%), suggesting these concentrations may be decoupled during T1. Possible explanations include changes in dust properties, atmospheric processing, and/or dust sources. These results imply that the assumption that total concentrations are accurate estimates of bioavailability is incorrect during large climate transitions.

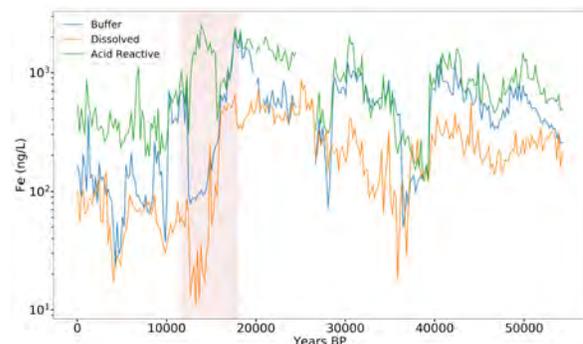


Fig. 1. Stacked record of 200-year resampled raw Fe geochemistry (green; acid reactive, blue; bioavailable, orange; dissolved).

**Acknowledgements:** Support provided by the NSF award PLR-1443397.

## Natural and Human Contributions to Pre-Monsoon Snow and Stream Chemistry from the Khumbu Region, Nepal

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**Abstract:** Here we present the most comprehensive study thus far of the chemical composition of surface snow, streams, and ice in the Khumbu region, Nepal. This research is a part of the National Geographic and Rolex's Perpetual Planet Everest Expedition and currently in review at One Earth.

Glaciers and snow cover in high mountain regions play a major role in regional hydrology and ecology. As snow and glaciers melt, entrapped chemicals are released that are both essential to ecosystems and agriculture (Immerzeel et al. 2020) and in some cases detrimental to ecosystems and human health when they contain toxic substances, such as those derived from distant activities (e.g., fossil fuel combustion, metal production) and local activities (e.g., agriculture, biomass burning).

We analyzed the chemical composition with measurements of major/trace elements, major ions, black carbon, and stable isotopes of 18 pre-monsoon stream water (4,300-5,250m) and 94 snow (5,200-6,665m) samples collected from the Khumbu region, Nepal to generate the most comprehensive record of high elevation snow chemistry (Figure 1). Principal component analyses and crustal enrichment factors are used to investigate differences in chemistry spatially and temporally. To examine changes in the chemical concentrations of the region in the past, we also sampled and analyzed chemistry from a 3.5m ice core drilled from the Khumbu glacier (28.003889°N, 86.858333°E, 5300m), directly below the Khumbu Icefall.

The pre-monsoon season is dominated by western air mass sources containing crustal elements, and less frequent southerly air mass sources, that contribute to high concentrations of pollutant chemistry from long-range transport. Significant levels of Bi and Pb, known anthropogenic tracers, were found in snow samples throughout the Khumbu region. We note that increased tourism and land usage could be a contributor to the higher values of anthropogenic source chemistry (e.g. Bi, Pb, black carbon) in the snow samples collected

from Mt. Lobuche and Everest Base Camp, in addition to the concerning concentrations of Pb in stream samples. Rising tourism in the Khumbu Valley and surrounding regions will likely contribute to pollutant loading. This preliminary study reveals the need for more spatially extensive monitoring over longer time periods to determine human impacts on the water system in the region and for adaptation and mitigation planning.

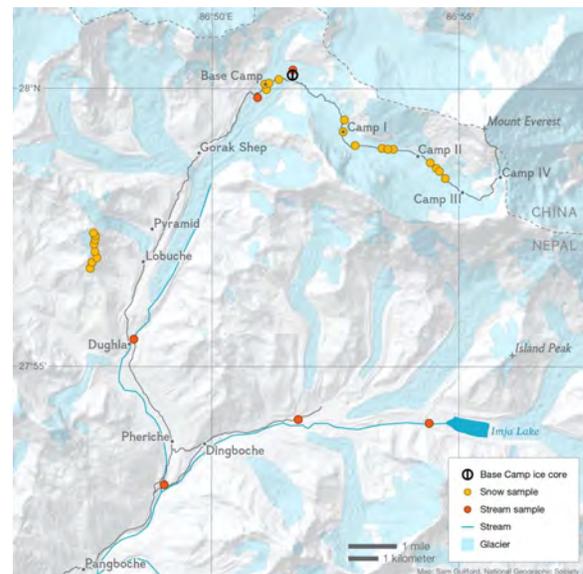


Fig. 1. Sample map from the Khumbu region, Nepal. Shaded map of the regional area with location of snow (yellow), stream (red), and ice core samples (black), as well as the current glacial extent (aqua).

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## Vertical Phytoplankton Gradients from Under-Ice to Open Water in Lakes of Acadia National Park

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**Abstract:** Dissolved organic carbon (DOC) impacts habitat availability for phytoplankton in lakes. In this study we tracked the vertical distribution of phytoplankton in high- and low-DOC lakes from winter under-ice through the summer open water season. Low-DOC Jordan Pond had higher vertical homogeneity of chlorophyll *a*, as well as greater stability between seasons compared to the high-DOC lakes.

Dissolved organic carbon (DOC) impacts many of the variables that influence phytoplankton habitat availability. High-DOC lakes are darker, with warmer surface temperatures and increased light attenuation, which can lead to oxygen depletion (Knoll et al., 2018). After two decades of widespread increases in DOC concentration and subsequent reduction of water clarity across the northeastern US (Strock et al., 2017), DOC trends in Acadia National Park lakes are now diverging.

We hypothesized that clear, low-DOC lakes would have more vertical homogeneity than high-DOC lakes, due to the greater habitat availability in low-DOC lakes. As a proxy for phytoplankton biomass, we used a submersible fluorometer to measure the relative fluorescence (RFU) of chlorophyll *a*. We found that low-DOC Jordan Pond had greater homogeneity in vertical profiles of chlorophyll *a*, as well as greater stability of chlorophyll *a* concentration from under-ice in February to peak stratification in late-July (Fig. 1). A slight decrease was observed in overall chlorophyll *a* over the season, suggesting quick uptake of limited nutrients after ice-off and low productivity overall. Meanwhile, high-DOC Witch Hole Pond and Seal Cove Pond both had greater vertical heterogeneity, with chlorophyll maxima between 3 and 5 m depths. These lakes sustained higher overall biomass through the summer compared to under-ice profiles.

As DOC concentrations diverge, the resulting impacts on vertical phytoplankton distribution can have ecosystem-scale consequences, including changes in metabolism, nutrient cycling, and food-web dynamics.

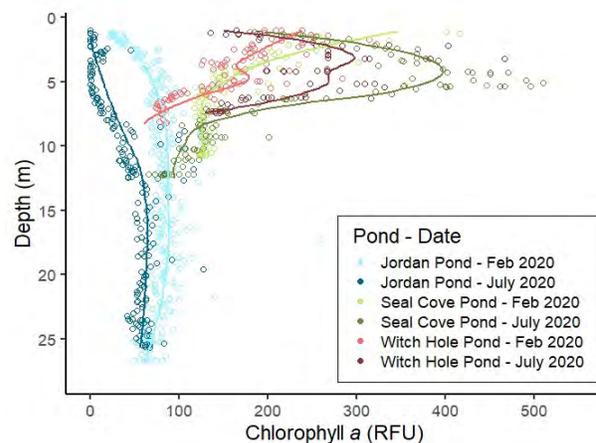


Fig. 1. Comparison of February under-ice and July open water chlorophyll *a* profiles, measured in relative fluorescence units (RFU) between two high-DOC lakes (Seal Cove Pond, Witch Hole Pond) and one low-DOC lake (Jordan Pond).

**Acknowledgements:** Funding for this project was provided by Friends of Acadia in collaboration with the Acadia National Park Service.

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## Under Ice and Early Summer Phytoplankton Dynamics in Two Arctic Lakes with Differing DOC

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**Abstract:** Seasonal dynamics were investigated in two lakes in West Greenland that differ in their dissolved organic carbon (DOC) concentrations. Seasonal distribution of phytoplankton biomass varied between lakes, with relatively high biomass in low-DOC lake under ice—underscoring the importance of including the ice-covered period in studies of lake productivity and metabolism.

We studied seasonal succession of two lakes in West Greenland that are representative of lakes across arid, low-elevation Arctic. We selected lakes that vary in dissolved organic carbon concentrations (DOC)—a key variable that simultaneously affects light penetration and nutrient concentration, having an impact on primary production (Seekell et al., 2015).

The key result of our study is that the effect of high/low DOC varies over time: under ice, high DOC exacerbates light limitation imposed by the presence of ice-cover; however, during the open-water season when photolytic and microbial degradation of organic matter occur at a faster rate, phytoplankton biomass quickly increased—leading to seasonally uneven distribution of phytoplankton biomass in the high-DOC lake. On the other hand, in the low-DOC lake, phytoplankton biomass under-ice was comparable to biomass measured during open-water season—suggesting that under-ice period should not be neglected as it can be an important part of annual phytoplankton dynamics in clear lakes (Hazuková et al., in review).

Differences in the seasonal distribution of phytoplankton biomass and DOC concentration were coupled with varying oxygen conditions under-ice, with oxygen-replete conditions in low-DOC lake and anoxia in high-DOC lake. These differences have important consequences for lake metabolic balance and ultimately affect the magnitude and direction of carbon fluxes between lakes and the atmosphere. However, to what degree are these fluxes changing as a result of climate-driven alterations of lake phenology is yet unknown.

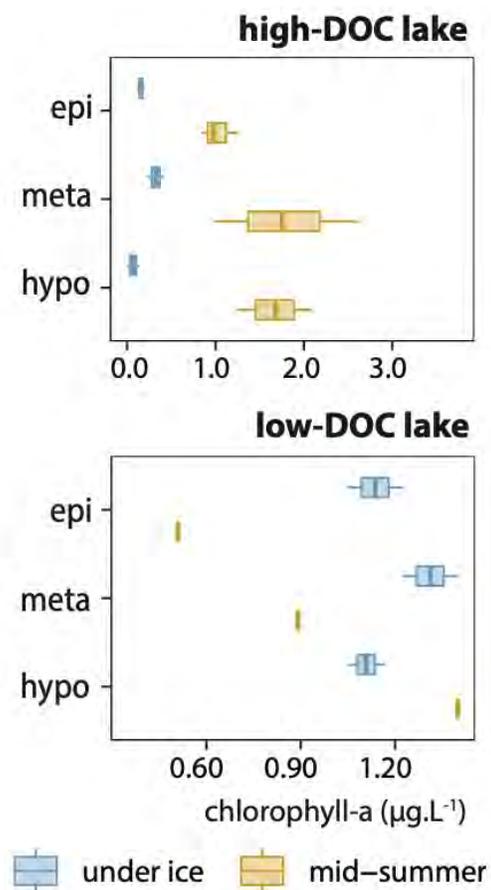


Fig. 1: Chlorophyll-a as a proxy for phytoplankton biomass is high during summer in high-DOC lake but near 0 under-ice; in contrast, chlorophyll-a is high under-ice relative to mid-summer in low-DOC lake.

**Acknowledgements:** University of Maine

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## Surface Changes Across the McMurdo Ice Shelf, Antarctica

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**Abstract: The McMurdo Ice Shelf buttresses three glaciers, and the northwest corner of Ross Ice Shelf. Through buttressing, the McMurdo Ice Shelf provides a resistant force to forward motion, making the stability of the McMurdo Ice Shelf critical for the longevity of its tributary glaciers. Here we will examine thickness changes across a region of McMurdo Ice Shelf.**

The McMurdo Ice Shelf (MMIS) spans ~1,500 km<sup>2</sup>, buttressing three tributary glaciers and the northwest corner of Ross Ice Shelf (RIS). The MMIS is particularly vulnerable to collapse due to the routing of warm ocean water directly under this region<sup>i</sup>. If MMIS collapses, a potential retreat of RIS (~500,000 km<sup>2</sup>), and the glaciers it buttresses, could follow. As ocean and atmospheric temperatures continue to rise, the positive contribution by glaciers to the MMIS mass balance is of particular importance. However, this interface and relationship between tributary glaciers and the health of the ice shelf is not well studied. Here we will focus on quantifying changes in the thickness, and therefore buttressing potential, of MMIS using remote sensing techniques.

Focusing on a small area (~7 km<sup>2</sup>) of MMIS adjacent to Hut Point, we examine the change in surface elevation between 2 Feb. 2011 and 25 Nov. 2015 (Fig. 1) using WorldView Digital Elevation Models (DEMs). After correcting for the impact of the tides<sup>ii</sup>, we find changes on the order of ± 5m, where the largest abrupt changes are to the east of Hut Point and clearly show the migration of the ice folds. Additional features include the distinct blue and red boundary cutting diagonally across the top portion of the map, marking the ice shelf-ocean boundary and the red line curving through the bottom of the map marking Pegasus Road. The MMIS also shows areas of elevation increase and decrease from 2011 to 2015, predominantly within ±2.5 m. The measured change in the broader ice shelf region agrees with prior preliminary work<sup>iii</sup> and will be the focus of our future work.

Further research will address changes in tributary glacier velocity and the response from the MMIS. Specific objectives will include constructing similar surface elevation change

products across additional areas of MMIS, quantifying changes in surface melt over time, calculating surface velocity of both tributary glaciers and the MMIS, and measuring the migration of the tributary glacier's grounding lines and the front of MMIS.

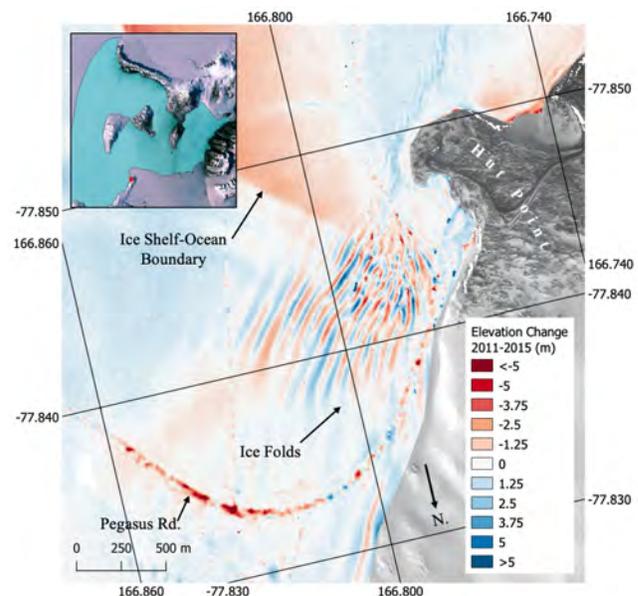


Fig. 1. Elevation change between 2 Feb. 2011 and 25 Nov. 2015 for the eastern edge of the MMIS (inset map). WorldView DEMs were corrected for tides and atmosphere, then differenced. The differenced map shows most elevation changes within ± 2.5m.

**Acknowledgments:** This work was funded by the NSF/OPP Award #1842021

<sup>i</sup> Tinto, K. J., et al., (2019) Ross Ice Shelf Response to Climate Driven by the Tectonic Imprint on Seafloor Bathymetry, *Nat. Geosci.*

<sup>ii</sup> Erofeeva, S. et al., (2020) Tide Model Driver (TMD) Version 2.5, Toolbox for Matlab, *GitHub*,

<sup>iii</sup> Campbell, S., (2018) Structure and Stability of the McMurdo Ice Shelf Transition Zone and Glaciated Hillside near Scott Base, Antarctica, *CRREL*

## Modeling Ross Ice Shelf Sensitivity to Changes Along its Western Lateral Margin using the Ice Sheet System Model (ISSM)

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**Abstract:** We utilize the Ice Sheet System Model to investigate Ross Ice Shelf response to thinning under different initial thickness scenarios to determine model sensitivity to a large discrepancy between thickness estimations between the Bedmap2 and BedMachine datasets.

Understanding controls on ice shelf stability is critical to predicting the future evolution of the Antarctic Ice sheet and subsequent sea level rise. For the Ross Ice Shelf (RIS), a particular area of vulnerability is its western lateral margin (Fig. 1, white box).

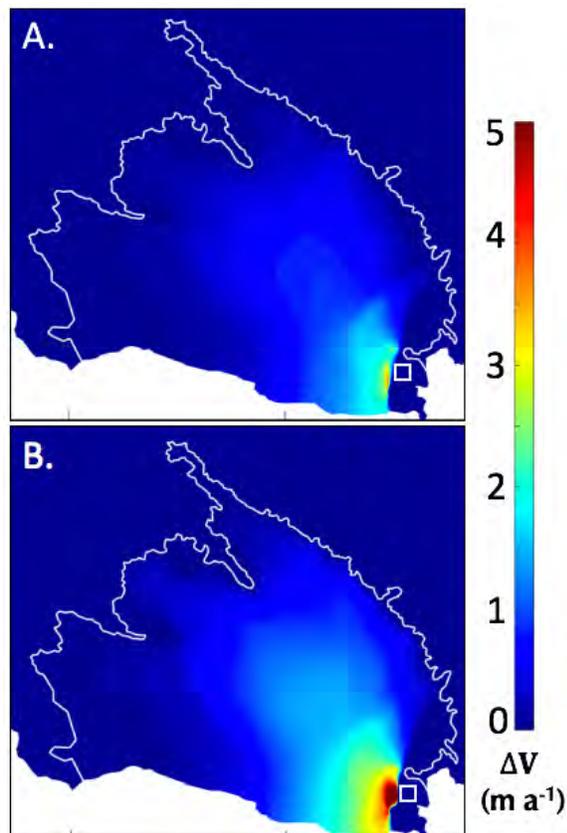


Figure 1. Magnitude of velocity change due to 2m thinning along a 20 x 20km grid cell for the BedMachine scenario (A) and Bedmap2 scenario (B). White box indicates area of applied thinning, and white line indicates the RIS grounding line.

A modeling study by Reese et al., 2018<sup>1</sup> found a thinning of ~1m in this region accelerated ice flow in regions up to 900km away. However, this study initialized its model geometry using ice thickness measurements initialized from Bedmap2. We compared thickness estimates between the Bedmap2 and newer BedMachine datasets and found the latter to be up to ~200m thicker along the RIS western lateral margin.

We performed a comparison study utilizing the Ice Sheet System Model (ISSM) to investigate RIS response to thinning under different initial thickness scenarios to determine model sensitivity to the large discrepancy between thickness estimations between the Bedmap2 and BedMachine datasets. We applied 2m of thinning to a 20 x 20 km grid cell along the RIS western lateral margin and completed a stress balance solution to solve for instantaneous changes in velocity.

We found the Bedmap2 model (Fig. 1B) to exhibit a greater change in velocity magnitude due thinning. This is due to the fact that the Bedmap2 model is thinner than the BedMachine model along the margin, and therefore experiences a greater reduction in loadbearing surface area to resist ice flow. These results indicate that care is needed in parameterizing the geometry of shear margins and that errors in ice thickness along the western lateral margin of the RIS could contribute to considerable uncertainties of its future contribution to sea level rise.

**Acknowledgements:** Gratitude for the support of Dr. Peter Koons, Dr. Zoe Courville, and Dr. Seth Campbell, with funding from the National Science Foundation grant ANT-1842021.

<sup>1</sup> Reese, R 2018. The far reach of ice-shelf thinning in Antarctica, *Nature Climate Change* 8.1:53.

## Causes of a Cold Bias in MODIS Land Surface Temperatures in the St. Elias Range

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**Abstract:** Remote sensing data are crucial for monitoring alpine warming. Here, we evaluate potential sources of a cold bias in MODIS LSTs in the St. Elias Range. We find the bias cannot be adequately explained by the MODIS instrument's large footprint or by poorly constrained emissivity values. We suggest in situ air temperature, surface temperature, and emissivity measurements to test for a near-surface temperature inversion and better constrain surface emissivity evolution.

### Project Goals:

The goal of this project is to identify the cause of a cold bias in NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperatures (LSTs) in the St. Elias Range. The North Pacific cordillera (St. Elias and other ranges in Alaska and northwest Canada) contains  $43.3 \pm 11.2$  mm of global sea level rise in its alpine glaciers, which are sensitive to summer temperature changes.<sup>1</sup> Because the rugged region is difficult to access for in situ measurements, reliable remote sensing data are crucial for monitoring glacier response to warming. This project focuses on a cold bias in MODIS LSTs from the St. Elias, which we hypothesize results from either MODIS' large footprint in heterogeneous alpine terrain or poorly constrained emissivity values used to calculate LSTs. To test these hypotheses, we compared LST datasets with different spatial resolutions, and brightness temperatures from which they were calculated, at study sites Eclipse and Divide.

### Initial Results:

Differences between MODIS and in situ temperatures were largest and most variable in the fall and winter (Fig. 1). ASTER temperatures were also lower than in situ, the bias persisting despite ASTER's smaller footprint (Fig. 1). MODIS brightness temperatures showed a

similar pattern to the final LST product of more dramatic cold bias in fall and winter (Fig. 1).

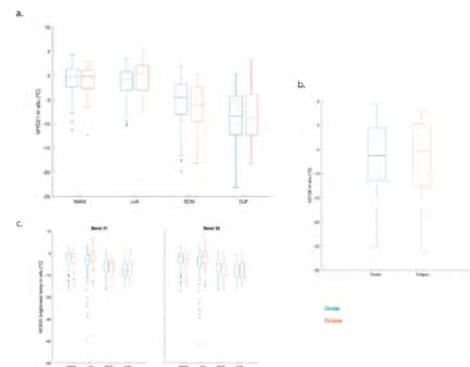


Fig. 1. Surface temperatures from (a) MODIS and (b) ASTER, as well as (c) MODIS brightness temperatures all show cold bias relative to in situ measurements.

Poorly constrained emissivity values do not fully explain the bias, but they cannot be ruled out as an exacerbating factor without further study. We suggest paired in situ measurements of emissivity and surface characteristics at sub-daily resolution to better constrain emissivity change on short timescales. We also recommend paired in situ surface and 2 m air temperature measurements to check for a near-surface temperature inversion.

**Acknowledgements:** University of Maine Climate Change Institute, Maine Space Grant Consortium

<sup>1</sup> Daniel Farinotti et al., "A Consensus Estimate for the Ice Thickness Distribution of All Glaciers on Earth," *Nature Geoscience* 12, no. 3 (March 2019):

## New Kid on the Block: El Niño Modoki- Past, Present, Future

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**Abstract:** Paleoclimatological and archaeological research has focused on canonical El Niño along the Peruvian coast, however, almost no attention has been paid to El Niño Modoki in this region even though the associated reduction in water flow must have a major, recurring effect on the irrigation-based societies that inhabit the area. Considering the societal and environmental gravity of ENSO phenomena, improving our understanding of all flavors of previous events is essential not only to anticipating them, but also to mitigating their effects on human populations. Here, we present the paleoclimatological research potential of El Niño Modoki on the northern coast of Peru with specific focus on archaeological proxy sources, prehistoric adaptive strategies, and modern applications.

El Niño Southern Oscillation (ENSO) is a coupled oceanic and atmospheric climate phenomenon that occurs on interannual and decadal timescales. Most commonly, ENSO fluctuates between warm and cool modalities on an average timescale of 2-7 years. The canonical El Niño (EP) is characterized by warm sea surface temperature (SST) anomalies that develop in the central and eastern tropical Pacific Ocean.<sup>1,2</sup> Conversely, the recently recognized El Niño Modoki (CP) generates warm SSTs in the central Pacific that are flanked on the east and west by cooler SSTs.

In locations like Peru, where common proxy records (e.g., sediment, corals, ice cores) are rare, absent, or unreliable, archaeological sites serve crucial roles as palaeoclimatological archives; often containing climate signals in well-defined and datable contexts that are directly associated with past human behavior.<sup>3</sup> Moreover, these proxies often prove useful in environmental reconstructions and climate modeling. Although research in this arena has increased over the years, the full potential of anthropological investigation into ENSO has yet to be reached. Below, we outline several potential archaeological indications of CP-like conditions.

**Past:** We know a lot about the prehistoric impacts of EP on coastal Andean communities, but the other modes of ENSO are under examined. Looking at past instances of drought could provide some insight into how coastal Andeans might have reacted to the drought-like conditions brought on by CP. Studying human

(bioarchaeology) and animal (zooarchaeology) remains are two useful methods of investigating this connection.

**Present:** CP events have been shown to reduce streamflow to the Chicama River to levels below normal resulting in water shortages.<sup>4</sup> Like EP events, the effects of CP must trickle down to other social sectors such as agriculture and public health. Few studies examining alternative environmental or societal impacts of CP events exist, leaving ample room for expanded research in this area.

**Future:** Modoki events have sparked much debate and research surrounding their causes, and there seems to be a general sense of concern among climate scientists that events will increase in frequency as global warming intensifies. Historic records and ethnographies have contributed important insight into peoples' lived experiences and responses during these (and other) climatological hazards. Tapping into these resources to identify early methods of predicting or adapting to ENSO conditions could assist in modern mitigation planning.

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## Modelling Paleohydrology in the Coastal Andes to Improve Archaeological Conceptions of Water Availability

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**Abstract:** Although archaeologists have long recognized the importance of water resources to societies living in the desert regions of the Andean coast, they have often over-looked or oversimplified the effects of upstream hydrologic variability on coastal water flows. This project analyzes paleoclimatological, hydrological, and archaeological data to generate likely scenarios of water availability in the Supe Valley of Perú during a period of settlement expansion and agricultural intensification. The research will evaluate how well current hypotheses for these cultural trends agree with likely hydrological conditions. The project will also produce a conceptual framework and methodological approach for delineating past hydrological dynamics in the north-central coast of Perú.

### Research Background and Objectives:

During the period from ca. 5000 to 3800 years before present (BP), inhabitants of the Supe Valley and the surrounding north-central region established new population centers and expanded agricultural production to the middle valley regions, requiring the adoption of widespread irrigation (Solís et al. 2001). Although these trends centered around the use and management of coastal water resources, current hypotheses for these phenomena do not explicitly consider hydrological conditions of this period, which remain poorly defined.

The primary goal of this project is to develop a conceptual model describing the paleohydrology of the Supe Valley from 6000 to 2000 BP. I use the model to evaluate current hypotheses explaining the expansion of agriculture and settlement patterns of this period and, where supported, develop new hypotheses explaining these trends. Through this case study I demonstrate the need for more nuanced spatial and temporal perspectives regarding water flows in coastal archaeology and develop a conceptual framework and methodological approach for future work.

### Methods:

The project relies primarily on a synthesis of existing hydrological, paleoclimatological, and archaeological data combined with geospatial and hydrological analyses. Circumstances permitting, results of geospatial modeling will be verified in the field. These analyses will be used

to develop a conceptual model that describes relationships between components of the hydrological system.

### Preliminary Results:

I have defined six hydrological zones in the Supe Valley based primarily on elevation, geomorphology, and predominant climate mechanisms. For most of the zones, these characteristics were largely stable through the Holocene. The upper-most and lowest zones were more dynamic on account of glaciation, sea level change, and shoreline progradation.

A synthesis of 21 highland and coastal paleoclimate records relevant to the study area indicates major climate transitions affecting the coast and/or the highlands around 6000 BP, 4000 BP, and 3200 BP. These transitions would have altered precipitation, evapotranspiration, glacial melt, and runoff production in the coastal and highlands regions with implications for coastal water availability. Next steps in the research program involve refining the geospatial analysis and applying the paleoclimate synthesis and archaeological data to the model.

**Acknowledgements:** This research is funded by the National Science Foundation Graduate Research Fellowship Program and the Dan and Betty Churchill Exploration Fund.

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## Food for Thought: Insights into Pre-colonial Canine Diets from the Maine Maritime Peninsula

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**Abstract:** The Canine Surrogacy Approach (CSA) has been proposed as a method to infer human diet based on dietary information derived from dogs<sup>1,2,3</sup>. This research utilizes stable isotope analysis (SIA) of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from *Canis familiaris* remains at the Holmes Point West archaeological site (62-8) in Machias Bay, Maine in an effort to understand canine diet and human agency during the Ceramic period (ca. 3,050-400 BP). These data, combined with recent  $^{14}\text{C}$  dates, suggest a shift away from consumption of marine resources among dogs ca. 650-450 BP.

### Introduction and Background

Past research shows that dog diets can help to infer past human dietary choices, based on the assumption that the two shared resources<sup>4,5</sup>. In this study, the Canine Surrogacy Approach (CSA) is applied to dog remains recovered from the Holmes Point West site (62-8) in order to understand their diet and the relationship between Wabanaki people and their canine companions. 62-8 is a shell-bearing site located on Machias Bay in eastern Maine. Multiple lines of evidence indicate that Wabanaki people used the site throughout the Ceramic and contact periods (~3,050-200 BP).<sup>6</sup> The remains of four dogs excavated in 1973 are the focus of this analysis. Two of the dogs were buried whole and unmodified, suggesting ritual interment.<sup>7</sup>

### Methods

Stable isotope analysis (SIA) was completed for five canine samples from 62-8. Delta values of  $^{13}\text{C}$  and  $^{15}\text{N}$  are used to identify relative contributions of marine vs. terrestrially derived proteins<sup>8</sup> and their trophic levels<sup>9</sup>. Ten additional dog samples are included from Ceramic period coastal sites in eastern Maine.<sup>10</sup> Eight  $^{14}\text{C}$  dates are available for comparison, six from the *C. fam.* remains and two from associated charcoal.

### Results and Significance

The five canine samples taken from 62-8 canines range from a diet heavily influenced by marine protein to one which is primarily terrestrial (Figure 1). When combined with  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotope data from other regional Ceramic period dogs and available  $^{14}\text{C}$  dates, these data suggest a trend away from a marine-based diet in the past 700 years. This period in

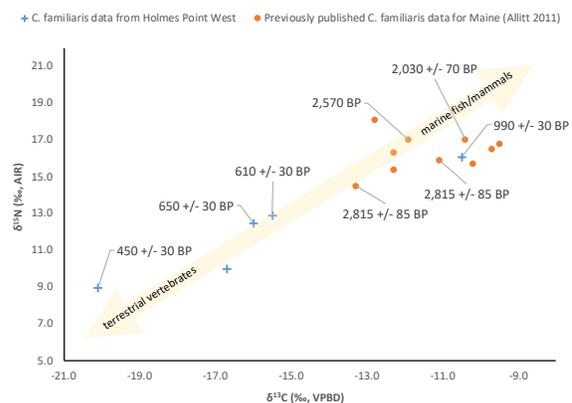


Fig. 1. SIA results with available  $^{14}\text{C}$  dates labeled. Generalized marine vs. terrestrial ratios are indicated.

history is one of extreme social change for northeastern North America, when Europeans and Indigenous people began to interact and trade. Additional archaeological and ethnohistoric data are necessary to further understand these findings and confirm interpretations presented here.

**Acknowledgements:** Funded by Maine Academic Prominence Initiative (MAPI). Thanks to B. Newsom, E. Guiry, D. Sandweiss, A. Spiess, D. Soctomah, the Passamaquoddy Tribe, Maine Coast Heritage Trust, and the Brack Family. Grad. Assist: TRIO SSS.

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## Exploring Past and Present Beringia to Understand the Mammoth Steppe

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**Abstract:** During the Summer 2019, the University of Maine’s Climate Change Institute organized an expedition to the Republic of Sakha (Yakutia, Russia) with two main goals: to uncover clues about the lost mammoth steppe ecosystem, the expansive grassland that during glacial periods covered most of the Northern Hemisphere, and to investigate the role of large herbivores in shaping Arctic landscapes today. During the expedition, we worked with collaborators from Sakha’s Academy of Science to sample specimens from their collection. We visited an encampment of mammoth tusk hunters on the Indigirka river, where permafrost tunnels are uncovering well-preserved fossils from the Pleistocene, including animals with preserved soft tissue. Finally, we visited the Northeastern Scientific Station on the Kolyma river, which is home to a rewilding experiment called “Pleistocene Park”, to prepare for future studies on the effect of reintroduced large herbivores on modern high-latitude vegetation.

### Description:

For most of the Late Pleistocene, the Arctic was dominated by biome known as the “mammoth steppe”, a mosaic of grassland, tundra and steppe vegetation (Zimov et al. 2012). Fossil findings indicate that this environment was able to sustain large numbers of cold-adapted megafauna. Between ~16,000 and ~9,000 years ago the mammoth steppe disappeared, and most of its dwellers experienced the same fate. Some researchers think that the mammoth steppe was maintained by the action of large herbivores on the landscape, and that their extinction caused the biome’s disappearance. According to this view, reintroducing these animals could kickstart the lost ecosystem processes once again. This has been proposed as a tool to promote the formation, instead of the loss, of permafrost. The current rate of anthropogenic climate change leaves us a very short window to understand the feasibility of such ideas. For this reason, the University of Maine’s Climate Change Institute organized an expedition to the Republic of Sakha (Yakutia, Russia). With the logistic support and collaboration of scientists from Sakha’s Academy of science, we visited an encampment of mammoth tusk hunters near Belaya Gora, on the Indigirka river. There, the extreme cold conditions over the last millennia allowed for the preservation of an incredible number of fossils, including animals with perfectly preserved soft tissue (fur, skin,

muscles, intestines). We collected a large number of new samples, that will be studied together with samples from the archives of the Academy of Science to reconstruct the interactions between the dwellers of the mammoth steppe and their environment. The final destination of our expedition was Cherskiy’s Northeastern Scientific Station, on the Kolyma river, and the nearby “Pleistocene Park”. The Park was established to test the effect of large herbivores as a tool to fight permafrost melting, in an attempt to recreate the ecological processes thought to have shaped the mammoth steppe. To reach this goal, local researchers reintroduced animals living in the area during the Pleistocene and used heavy vehicles to simulate the action of larger, extinct ones. To plan how to understand on how herbivore-plants interactions (and their cessation) affects high latitude landscapes, we explored this unique site and identified locations suitable for studying the effect of modern large herbivores on vegetation.

**Acknowledgement:** The expedition was founded through NSF CAREER grant awarded to Jacquelyn Gill.

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## Differences Between Land-Terminating Glaciers and Marine-Terminating Glaciers Since the Last Glacial Maximum in the Royal Society Range, Antarctica

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**Abstract:** The behavior of the Antarctic Ice Sheet (AIS) since the Last Glacial Maximum (LGM) is still under debate. The purpose of this study is to examine the past interactions of the land-terminating Walcott and Howchin Glaciers with the marine Ross Sea ice sheet in the Royal Society Range of the Transantarctic Mountains. Here, we combine radiocarbon ages and surface exposure ages with a glacial-geomorphic map to reconstruct a chronology of the past extent of ice. By reconstructing its past behavior, we hope to predict how this system will respond to future warming.

The future contribution of the Antarctic Ice Sheet (AIS) to global sea-level rise is a high-priority question. Insight into its future contribution can be sought from its past behavior. We examine the history of the AIS since the LGM in the Royal Society Range of the Ross Sea sector. Grounding of ice in the Ross Sea at the LGM led to expansion of an ice sheet to the continental shelf edge, fed by both East and West Antarctic ice<sup>1</sup>. This ice sheet deposited a distinct drift along the headlands of the Royal Society Range adjacent to the western Ross Sea.



Fig. 1. Map of the field area with location inset

There are at least two competing hypotheses on the driving mechanisms of this ice sheet. The first is that increased accumulation caused thickening of East Antarctic Ice Sheet outlet glaciers which caused the expansion of the grounded ice sheet. The second hypothesis is that the initial advance was caused by lower sea level and reduced melting along the grounding line.

Our preliminary <sup>10</sup>Be and radiocarbon ages show that Ross Sea ice was depositing the headland moraine and nearing its maximum extent by 18,400 years before present, which corresponds well with other dates along the coast,<sup>2</sup> while the land-terminating Walcott and Howchin glaciers did not surpass their current extent, and perhaps shrunk. Cross-cutting relationships between Ross Sea drift and alpine moraines indicate that local glaciers did not advance and contribute to the Ross Sea ice sheet during the LGM. This suggests that the Ross Sea ice was controlled by a different mechanism than the land-terminating glaciers. The extent of Walcott and Howchin glaciers appears to be controlled by accumulation, while the Ross Sea grounding was driven by marine mechanisms.

### Acknowledgements:

National Science Foundation  
Tess Walther, Laura Mattas, Tyler Pollock, and Allie Balter.

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## Defining the Anthropocene: Consideration of the Sedimentary Archive in Herd Lake Idaho, USA for the GSSP 'Golden Spike' of the Human Epoch

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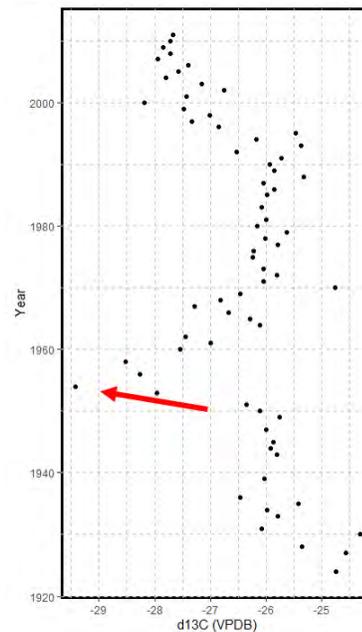
**Abstract:** The Anthropocene has been proposed as a new geological epoch. Herein we examine a candidate stratigraphic sequence for placing the 'golden spike that will define the Anthropocene.

### The Anthropocene:

The newly recognized, current epoch is being defined by changes in human activities that have severely impacted the ecological world and is preserved in sediment records worldwide. In 2019 the Anthropocene Working Group decided that the best defining moment for the new epoch happened in the mid-20<sup>th</sup> century, being radionuclides spread worldwide by thermonuclear bomb testing. This moment cooccurs with many human-made ecological and geological impacts to the natural world (Colin et al. 2020).

Herd Lake Idaho, USA holds a sedimentary archive that exhibits characteristics that make it a strong candidate for the 'golden spike' marker bed. The sediment is marked by light and dark banding (varves) that is deposited every summer and winter much like tree rings. The varve bands in Herd Lake's sediment are remarkably thick (~1cm per year) and persistent, having been continuously varves for ~1300 years. This sediment characteristic is found in nearby lakes as well making correlation across this region easily identifiable. The sediment has been analyzed for the concentration of d13C that is contained in it. Here we report that the Seuss effect is clearly preserved in the year 1952 according to varve count and Pb 210 dating (Shapley, Finney, and Krueger 2019). These characters make Herd a strong candidate section for the 'golden spike' for the Anthropocene.

**Acknowledgements:** We thank Dr. Mark Shapley, Dr. Bruce Finney, Dr. Jeffery Stone, and Bethany Kile for recovering and processing the core.



**Figure 1:** the amount of d13C buried in sediment in Herd Lake from 2011-1924. Note the major decline of d13C in 1952 (red arrow) which marks the Seuss effect caused by thermonuclear bomb testing.

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## Post-Glacial Sedimentary Architecture and Accumulation Rate of an Oligotrophic Lake in Central Maine, USA

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**Abstract: Radar surveys and core analysis of Kingsbury Pond in Central Maine reveal spatial changes in sedimentation as well as an anomalously low post-glacial sedimentation rate.**

Freshwater lakes in the northern United States and Canada retain stratigraphic information that can illuminate watershed history since Laurentide Ice Sheet (LIS) retreat. The LIS eroded or mobilized tens to hundreds of meters of bedrock in some areas of Maine, and additionally removed nearly all surficial sediment deposited prior to the glaciation (Bell and Laine, 1985). Deglaciation, the process of converting an ice-covered landscape to an ice-free one, triggers a sequence of drastic landscape and biophysical changes whose signatures appear as characteristic layers in downstream sediment records. Sediment on the bottom of perennial lakes record this geologic history and landscape evolution since deglaciation.

We surveyed Kingsbury Pond, a 175 ha freshwater lake in central Maine, with ground-penetrating radar (GPR), to map stratigraphy and quantify sediment volume. We find a mean thickness of 1.0 m ( $2.2 \times 10^6$  m<sup>3</sup>) of Holocene gyttja spread across the lake floor, draped atop several meters of densely-packed clay, sand, and lodgment till. Additionally, we recovered several meters of sediment in coring efforts in 2018 and 2019. Analysis of sediment revealed a graded transition between highly organic gyttja and inorganic clay which represents the basin's transition from a glaciated to forested landscape. <sup>14</sup>C analysis at the base of gyttja suggests a later ecological succession of the watershed than expected based on existing literature (Borns *et al.*, 2004), less than 9 k cal. yr BP, although this is a minimum age.

We find unusually slow sediment accumulation throughout the Holocene (mean of  $1.1 \times 10^{-1}$  m ka<sup>-1</sup> across the whole lake, maximum of  $5.5 \times 10^{-1}$  m ka<sup>-1</sup> in the deepest areas). This suggests two orders of magnitude slower sedimentation rate over the entire Holocene compared with rates elsewhere in the state.

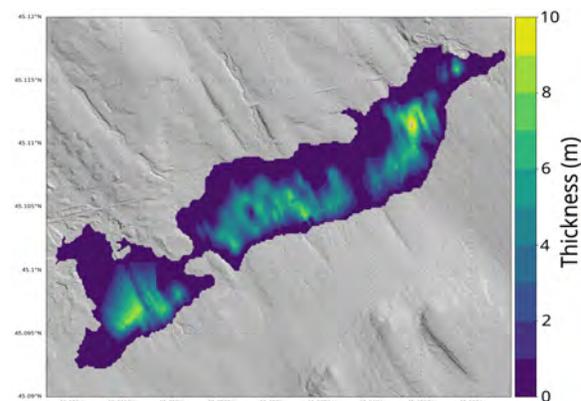


Fig. 1. Radar-delineated sediment thickness in Kingsbury Pond overlaid on 2 m LiDAR. Spatial variation in sedimentation appears to follow southeast-trending glacial streamline orientation.

GPR observations reveal highly variable spatial and temporal accumulation patterns (Fig. 1) which appear to follow glacial streamline orientation. We find that radar profiling adds significant value to stratigraphic interpretation of freshwater lake core records, can be the basis of spatially-integrated sedimentation rate estimates, and can provide necessary stratigraphic context that coring alone lacks.

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## Advances in *Aulacoseira* Ecology to Reconstruct Alpine Climate

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**Abstract: Observations of the distribution of *Aulacoseira pusilla* in alpine lakes in the central US Rocky Mountains identified that light is the main factor shaping the abundance and distribution of the taxon in lakes. Sediment analyses of different species of this genus confirmed the trend.**

Peaks in the abundance of diatoms in the genus *Aulacoseira* are attributed to mixing of the water column. This statement is used for limnological reconstructions to identify thermal changes in lakes. Taxonomic identification of this genus complicate the understanding of the ecology of the species group. Our analyses on *Aulacoseira pusilla*, suggest that changes in the abundance of this diatom are not induced by temperature, but by complex light regulations. Using this finding we wanted to know whether the species can be used to detect changes in lakes light access by shifts in snow precipitation.

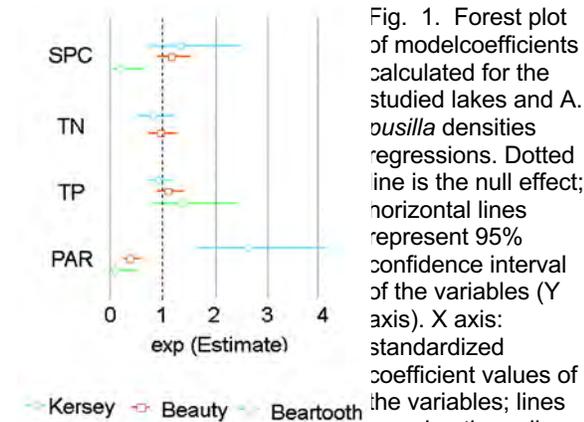


Fig. 1. Forest plot of model coefficients calculated for the studied lakes and *A. pusilla* densities regressions. Dotted line is the null effect; horizontal lines represent 95% confidence interval of the variables (Y axis). X axis: standardized coefficient values of the variables; lines crossing the null

effect line are not significant. Conductivity (SPC), average total nitrogen (TN), average total phosphorus (TP), and average light in each zone (PAR).

The postulation that turbulence stimulates *Aulacoseira* suggests that species in this genus have low light requirements and spring and/or autumn occurrences during lake turnover periods (Lund 1971). Our studies on *A. pusilla* showed that light is the factor that determines the peak of abundance of the species (Fig. 1) We found that light molds the distribution of the species in the water column, but the light requirement varied between populations according to the nutrient conditions.

We studied the sediment records of Beauty Lake (alpine lake in the Beartooth mountains) for the last 2000 years to determine if fossil *Aulacoseira* species showed a pattern associated to changes in snowpack records (represented by Snow Water Equivalent -SWE) or air temperature reconstructions available for the area (Pederson et al. 2011).

We found that SWE was the first component identified as associated to changes in *Aulacoseira* species composition. The species associated to low SWE values thus seasons with decreased snowpack were *A. pusilla*, *A. lirata* and *A. perglabra*. These species peaked in the time identified to the Medieval Climate Anomaly and after 1902 CE, which showed a decrease in SWE values. *A. subarctica* and *A. valida* peaked during low SWE, while *A. alpigena* decreased.

**Acknowledgements:** Thank you to Fulbright Program and to Churchill Exploration Funds for funding.

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## World's Highest Ice Core – Collection, Sampling and Preliminary Results

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**Abstract: The world's highest ice core extracted from Mt. Everest's South Col glacier, reveals well-preserved annual layers and potential for a several hundred-year record of past climate and environmental change.**

From April to June 2019 the National Geographic and Rolex Perpetual Planet Extreme Expedition to Mt. Everest conducted the most comprehensive single scientific expedition to the mountain in history. This international, multi-disciplinary expedition provided many new world records for science including the highest ice core ever recovered – South Col of Mt. Everest 8,020 m), in addition to other ice cores collected at lower elevation. South Col glacier is the highest glacier on Mt. Everest. Because of the extreme conditions at South Col - effective oxygen percentage (7.7%) and an average annual temperature of -22°C, working at this elevation requires supplementary oxygen and significant acclimatization. Challenges involved in the recovery of the South Col ice core included working at 8025 m for an extended period of time and using a drilling system that had never been tested at this altitude. Despite this the team recovered a 10m ice core close to the upper reaches of the glacier and a 2m ice core at 7916 m from the base of the South Col glacier.

Glaciochemical laser (Fig. 1) and oxygen isotopic analyses of the collected ice indicate that the climate record is well preserved. Standard ice core continuous melting procedures could not have detected such thin annual layers.

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has changed ice core sampling from ~1 cm (high resolution) to ~120 μm (ultra-high resolution) allowing examination of low net mass balance and highly compressed old ice core records for several elements (eg., Pb, Na, Mg, Fe, Cu, Ca, and Al). Laser ablation sampling of even highly compressed old ice such as the ice at the transition from the end of the Younger Dryas to the onset of the Holocene (~11,700 years ago), at a depth in the GISP2 Greenland

ice core of 1678m, where annual layer thickness is ~1.5 cm per year and 3cm per year, respectively, is on the order of 500 and 1500 samples per year, respectively (Mayewski et al. 2014).

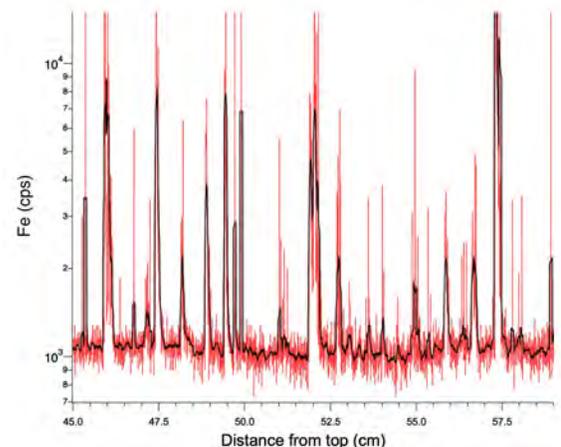


Fig. 1. Laser ablated ICP-MS Fe data (intensity; raw – red, smoothed - black) of ~2200 years <sup>14</sup>C age South Col ice with visible potential annual layers.

Preliminary results from LA-ICP-MS sampling and analysis will be presented, in addition to discussion of other core properties to be investigated such as radiocarbon dating and a full suite of chemical measurements.

**Acknowledgements:** This research was conducted in partnership with the National Geographic Society and Rolex. Funding provided by National Geographic and Rolex Perpetual Planet.

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## A Design for Loosely Coupled Scientific Applications

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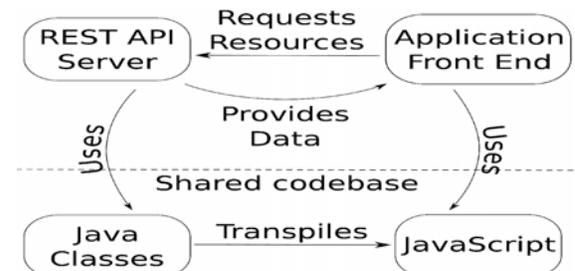
**Abstract:** We describe a technique for developing scientific applications using a loosely coupled system that supports both locally-run and remote applications. Using this approach allows flexibility in application design choices to encourage the reuse and sharing of software dependencies. Because applications run in diverse contexts (i.e., desktop, mobile, and various operating systems), software developers must often port the applications per environment, leading to code duplication and potential software bugs. To avoid these bug-prone ports, we investigate the following four-pronged design strategy: 1) embed software domain logic with necessary virtual machines (VM) or interpreters 2) use a REST API to encapsulate the software logic 3) transpile shared code as necessary and 4) write front-end code in a language that is pervasively supported (e.g., JavaScript or any language that may be straightforwardly transpiled into JavaScript). Using this approach allows fluid use of software requirements in local or remote application environments. We provide a simple core dating application to demonstrate this technique.

At the heart of any software application is the set of domain logic that governs how data is created, stored, and manipulated. Reusing application logic in various systems may be achieved using a language that executes on a VM (e.g., Java) or an interpreter (e.g., Python). Embedding a VM or interpreter with the domain logic code provides support for these languages without requiring additional software installation.

A RESTful API helps avoid software domain logic duplication by decoupling the main system logic from the end-user interface. Using a RESTful API allows legacy code to be accessed and reused. As an example, we use Climate Data Workbench data structures and the collection of resampling functions. The data, functions, and additional resources are exposed to the client interface using URL paths that return JavaScript Object Notation (JSON). The REST API is made available to the client by a locally or remotely run server.

Code shared between the domain logic and the front-end software is automatically converted into the required programming language. This is shown in the diagram to the right. In our example system, Java code is first transpiled into TypeScript code using the JSweet transpiler. The mechanisms to keep the shared code up-to-date

with domain logic code occur in the project's build script. This automatic process prevents software bugs from being introduced from human error.



The application's front-end design is dependent on the choice of the underlying system. For desktop applications, this may be a native application or a single page application (SPA) run inside a web browser similar to Jupyter Notebooks. For mobile applications, the front end is likely an app. For our system, we chose to use a SPA. The generated, shared, TypeScript code is automatically transpiled to JavaScript and executed inside a web browser.

We outline a software engineering technique for creating loosely coupled scientific applications. Application domain logic is served as a REST API using an embedded VM. Using this technique facilitates legacy software reuse and the interfacing of multiple language dependencies.

## Tracking the Southern Hemisphere Westerlies Through Paleoclimatic Reconstruction of the Falkland Islands

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**Abstract:** The Southern Hemisphere Westerly Winds (SHW) have a tremendous impact on the climate and ocean currents of the mid-latitudes in the Southern Hemisphere. Paleorecords suggest that the SHW have changed in average position and intensity since the Last Ice Age and may be a potential driver of abrupt climate change. This research reconstructs the paleoclimatic history of the Falkland Islands, situated within the modern belt of the SHW, to identify shifts in the location and/or intensity of the SHW and its effect on regional climate since the last Ice Age.

The goal of this project is to provide constraints on the meridional location and/or intensity of the Southern Hemisphere Westerlies (SHW) since the Last Ice Age. This will assess its influence on late-glacial and Holocene climate change and improve models predicting the movement and impacts of this system on future climate.

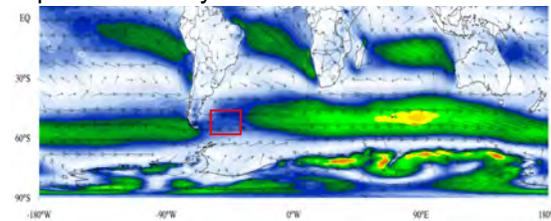


Figure 1 The modern location and intensity of the Southern Hemisphere Westerly Winds. The SHW are centered over 50°S on average, with shifts poleward (equatorially) in austral summers (winters). The map shows arrows for wind direction and warm colors for increased wind speed (Climate Reanalyzer, 2018). The Falkland Islands are boxed in red.

The Falkland Islands currently have a relatively warm, wet climate within the SHW belt. Episodes of cooler, drier climate are expected to coincide with northward shifts in the SHW. Thus, I hypothesize that changes in the position of the SHW will be expressed in the Falkland Islands through variations in temperature, precipitation, and wind intensity. My work reconstructs paleoenvironmental change reflective of the SHW in the Falkland Islands using a multiproxy approach on lake sediments from high-elevation tarns on Mt. Osborne. I utilize physical core parameters, pollen, and leaf wax isotopes ( $\delta D$  and  $\delta^{13}C$ ) to provide paleotemperature and precipitation information.

### Results

The preliminary results suggest variations in climate on both centennial and long (Holocene) timescales. Centennial-scale banding in the sediment cores suggest variations in lake

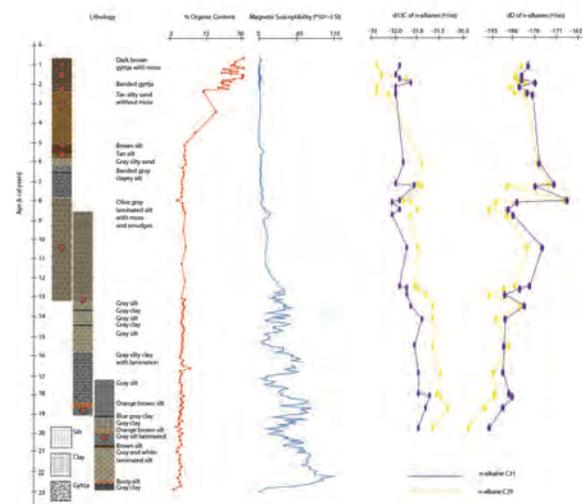


Figure 2 The core TAR4-18-1 from Tarn 4 (520 m asl) extends from the LGM through the Holocene. The stratigraphy, organic content (red), magnetic susceptibility (blue), along with the  $\delta^{13}C$  and  $\delta D$  extracted from bulk sediment leaf wax of n-alkanes C-29 (yellow) and C-31 (red), are plotted versus age. Red stars indicate the placement of radiocarbon dates used in an age model created using R Bacon.

productivity likely caused by temperature and wind-driven mixing. A sharp transition from low organic content silt to high organic content gyttja at about 5.5kya indicates a major change in lake productivity. Deuterium isotopes of leaf waxes, reflecting  $\delta D$  of precipitation, show a gradual trend to more positive values from the LGM until the mid-Holocene, as well as some shorter-term variability. A preliminary interpretation is that this trend may represent a shift to more northerly moisture sources as the SHW moved south.

**Bibliography:** Climate Reanalyzer 2018

**Acknowledgements:** Churchill Exploration Fund support, University of Maine Graduate School Grant, Falkland field crew, University of Cincinnati- especially Dr. Tom Lowell and Dr. Aaron Diefendorf

## Mollusk Bivalves as El Niño-Southern Oscillation (ENSO) Proxies

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**Abstract:** This research is an effort to assess the strength and nature of the ENSO signal recorded by oxygen isotopes in modern bivalves within and across species along the north coast of Peru. The results of this work will inform and refine sea surface temperature (SST) reconstructions of past environments created using the same information from archaeological material.

### Project Background:

ENSO is characterized by aperiodic shifts in atmospheric pressure and sea surface temperature (SST) in the east-central Equatorial Pacific Ocean. Primary impacts are felt on the north coast of Peru, the site of this research. My goal is to use mollusk bivalves as ENSO proxies to track frequency and intensity of El Niño events over time and to identify extreme events. In this study, I compare modern bivalve oxygen isotope data to instrumental records of local marine conditions to improve our understanding of the strengths and limitations of bivalve proxies. In 2019, I harvested bivalves growing in harbors with *Instituto del Mar del Perú* (IMARPE) SST monitoring buoys. I prepared these samples for analysis at Universidad Peruana Cayetano Heredia in Lima, Peru. Analyses will be performed at a collaborating lab at Iowa State University.

### Objectives:

The three primary aims of this research are: (1) Assess variation in oxygen isotope signatures in different species of bivalves by conducting a cross-species comparison to assess the strength and nature of the ENSO SST signal encoded by isotopes. I will compare isotopic-derived SST (using standard equations) from my samples (*Argopecten purpuratus*, *Trachycardium procerum*, *Anadara tuberculosa*, *Tivela hians*) to IMARPE records; (2) Determine if the oxygen isotope signature of *A. tuberculosa* shell are reliable proxies of ENSO events; and (3) Assess if *T. hians* growth increments are identifiable using oxygen isotope analysis. If so, these signatures may serve to record ENSO events through time, particularly in time-transgressive north coastal beach ridges.



Fig. 1. *T. hians* microscope photo: section of valve showing daily growth lines.

### Methods:

Daily, fortnightly, and monthly growth lines were identified in the mollusk valves, and a micromill was used to recover monthly samples from each shell. The  $\delta^{18}\text{O}$  values for each sample (the ratio of oxygen-16 and -18 isotopes), will be used to calculate SST during the shell's lifetime. These data will be compared to instrumental records. I anticipate that some of these samples experienced the 2017 Coastal El Niño and may record the signature of that event.

**Acknowledgements:** NSF Graduate Research Fellowship Program, Dan and Betty Churchill Exploration Grant, UMaine GSG grant, and a Phi Kappa Phi Love of Learning grant.

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## The Last Glaciation and Termination Documented in the Southern Alps of New Zealand and the Altai Mountains of Western Mongolia

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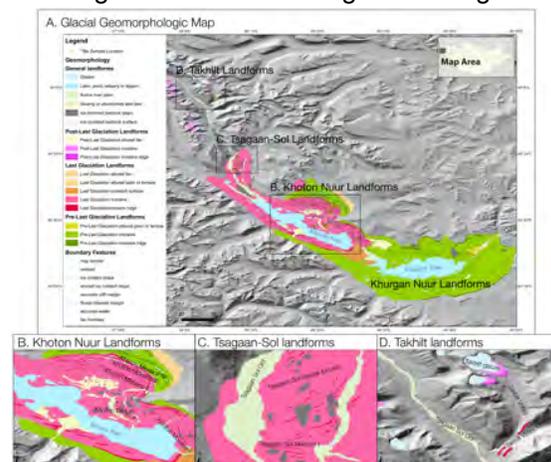
**Determining the signature of past glacier fluctuations at different latitudes and in different climatic settings can aid in solving orbital and millennial scale ice-age puzzles. A more complete understanding of the timing of glacier fluctuations in the Southern Hemisphere and interior Asia can help to evaluate the role of radiative drivers of ice-age climate changes, such as orbital forcing and greenhouse gases. Here, we test possible drivers of the last glacial termination by comparing chronologies of mountain glacier recession in the middle latitudes of both polar hemispheres. We present <sup>10</sup>Be surface-exposure chronologies and glacial geomorphologic maps of mountain glacier recession since the Last Glacial Maximum in the Southern Alps of New Zealand (44°S, 170°E) and the Altai Mountains of western Mongolia (49°N, 88°E).**

The last glacial termination (~18,000 – 11,000 yrs ago) represents the last great global warming and the last time CO<sub>2</sub> rose by a substantial amount before the industrial period. In addition, a prominent version of the Milankovitch 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.

Extra-polar mountain glaciers are highly sensitive to atmospheric temperature, and glacial landforms afford insight into past climate conditions. Here, present <sup>10</sup>Be surface-exposure chronologies and glacial geomorphologic maps of mountain glacier recession since the Last Glacial Maximum in the Southern Alps of New Zealand (44°S, 170°E) and in the Altai Mountains of western Mongolia (49°N, 88°E) (Figure 1).

In New Zealand, the moraine ridges and glacial geomorphologic deposits of the former Tekapo Glacier reveal multiple glacier advances during MIS 4, 3 and 2. This preliminary chronology also reveals that glaciers in the Southern Alps of New Zealand responded rapidly to the onset of the Last Glacial Termination (~18,000 yrs ago). Such a glacial retreat requires a powerful and rapid global climate driver, including atmospheric CO<sub>2</sub> or major atmospheric and oceanic reorganizations. In the Mongolian Altai, <sup>10</sup>Be ages from moraines and glacial topography indicate that the warming

which ended the Last Glacial period occurred contemporary with that in New Zealand. This finding also implicates a powerful, global climate driver. On the basis of these two chronologies, we evaluate the relative roles of rising atmospheric CO<sub>2</sub>, local insolation forcing, and ocean-atmosphere reorganizations in driving the warming that ended the last global ice age.



**Figure 1.** Glacial geomorphologic map of the study area in the Mongolian Altai (49°N, 88°E).

**Acknowledgements:** We thank the Churchill Exploration Fund, Comer Family Foundation, Quesada Family Foundation, and the National Science Foundation for support.

## Coupled Model Sea Surface Temperature Biases and Their Influence on Tropical Cyclone Environmental Conditions in an Atmospheric General Circulation Model

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**Abstract:** Changes in sea surface temperature (SST) distribution can significantly alter regional climate patterns. Of particular interest are the tropics, where SST variability is closely linked to regional climate conditions, such as El Niño Southern Oscillation (ENSO) events. Most CMIP5 models are currently unable to properly simulate all observed features of the climatological SST distribution, particularly in upwelling regions. Emphasis here is on the potential impacts of model SST biases on environmental conditions that influence tropical cyclone genesis and potential intensity. Both are found to be sensitive to biases in the climatological SST distribution.

### Project Goal:

The overall goal of this research project is to determine the influence of SST biases in coupled climate models to simulations of regional climate. Emphasis here is on tropical cyclone (TC) formation development and potential intensity given the importance of TC impacts around the world.

### Methodology:

An atmospheric climate model (ECHAM5) is used in two sets of model experiments. In a control experiment, ECHAM5 is forced with observed SST. In a “bias” experiment, the model is forced with observed SSTs plus the mean climatological SST bias averaged across 31 coupled climate models. The model outputs are then analyzed, which includes calculating a genesis potential index (GPI), which is a measurement of the total number of TC genesis events per unit time, and a theoretical measure of TC potential intensity (PI;  $m\ s^{-1}$ ).

### Results:

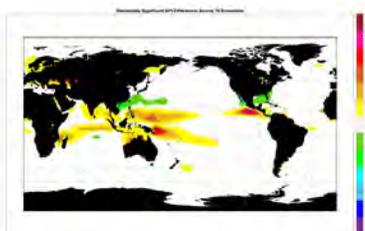


Fig. 1. Statistically significant ( $P < 0.05$ ) differences in TC genesis frequency (events/time) between

ECHAM5 SST control runs and reanalysis data for Jan. 1982 – Dec. 1990. Reds and oranges depict regions where ECHAM5 is overestimating the frequency of TC genesis whereas green indicates an underestimation.

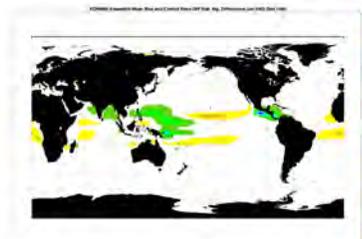


Fig. 2. Statistically significant ( $P < 0.05$ ) differences in TC genesis frequency (events/time) between ECHAM5 SST control and bias runs for Jan. 1982 – Dec. 1990. Reds and oranges depict regions where ECHAM5 bias runs are overestimating the frequency of TC genesis whereas green indicates an underestimation.

### Future Work:

Seasonality testing will be conducted to examine the impacts of SST biases during each season.

### Acknowledgements:

This work is supported by a grant from the National Science Foundation (NSF) Division of Atmospheric and Geospace Sciences Award #1650037.

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## Smoothed Particle Hydrodynamics Brings High Resolution Answers to Questions of Coast and Covid

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**Abstract:** Particle-based methods of computational fluid dynamics modeling are capable of characterizing the propagation of inertial terms and turbulent behaviors of a fluid in low-viscosity systems. This has not been possible until very recently and opens the door to study fluid dynamics within environments and habitat that are fundamentally defined by fluid-solid interaction. This paper presents two use-cases: (1) nearshore wave actions, and (2) complex airflow in confined spaces.

### Nearshore wave action:

The movement of water waves tends to be predictable until their interaction with solid obstacles. These could be the hull of a ship, sea ice, or the coastline itself. The chaotic transfer of energy to the obstacle on the arrival of a wave has long been difficult to characterize but nevertheless holds critical implications for the endurance of a structure or the erosion of the coastline. Smoothed particle hydrodynamics (SPH) provides a numerical approximation of the full Navier-Stokes equations for the impact and dynamic redirection of wave energies in the first example (Fig. 1).

Here, a model of a coastal bluff has been captured in centimeter-scale resolution by photogrammetry to provide a real-world boundary condition for the SPH model. Arbitrarily-shaped “ice blocks” have been placed as rigid-body freely-floating objects at the shoreline. Higher frequency surface waves are forced by a piston system to move through a body of fluid which is also modulated by a subtler long-period elevation change (representative of a tidal cycle or distant swell).

The jumbling of the ice blocks and the pressure waves of fluid continuing through the spaces between the blocks are some notable examples of the dynamic behavior captured by SPH.

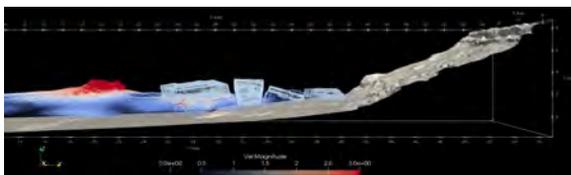


Figure 1. Breaking waves interacting with sea ice.

**Acknowledgements:** funded by NSF grant 2019299 to R. Turner, P.O. Koons, H. Xue, B. Segee. Apecial thanks to the developers of

### Airflow in confined spaces:

Very low viscosity fluids such as air are prone to turbulent behaviors but are described just as effectively as water by the same Navier-Stokes equations. The physics are the same, it is the fluids that are different. The Covid-19 pandemic brought focus to the air around us and how it may move. While vaccines for Covid-19 are becoming readily available, the study of airflow in confined spaces remains just as important for a variety of airborne illnesses (ie. Tuberculosis, MRSA) and just as many settings (ie. schools, hospitals, airplanes). SPH allows us to examine the exchange of air currents, lingering eddies, and potential carrying capacity of a draft, with implications for the people within such spaces.

In this scale model of an aircraft cabin and its passenger (Fig. 2), SPH is used to fill the cabin with air and provide the HVAC inlets and outlets that govern airflow in this space. A ‘gasper,’ the personally controlled directional jet featured above each seat, is the central focus of the model, in relation to its passenger.

3D airflow model data is noisy and can be challenging to present in a single image. SPH provides robust and high resolution data that can be sampled and filtered to unlock insights from each simulation.



Figure 2. Turbulent airflow in an airplane cabin.

DualSPPhysics (<https://dual.sphysics.org/>) for making SPH methods accessible by providing free and open source access to their solver.

## A Key to Past Ocean Temperatures: Mg/Ca of Foraminiferal Calcite in the North Atlantic (*N. incompta*)

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2. School of Earth and Climate Sciences, University of Maine.

**Abstract:** The Holocene (0 - ~11,000 Cal. yrs. BP) is a warm interglacial climate mode. Reconstructing ocean temperatures and oxygen isotopes ( $\delta^{18}\text{O}$ ) in the Gulf of Maine region could provide essential context for understanding and predicting modern climate change.

### Holocene Ocean-Climate Dynamics:

The Holocene epoch has been characterized by long-term shifts in mean conditions (e.g., SST, precipitation, and ocean circulation) punctuated by abrupt ocean-climate events<sup>1</sup>. The causes of these events are not fully understood, but the fairly stable mean annual solar insolation at 45°N suggests ulterior driving forces caused by internal feedbacks in the ocean-climate system. High-resolution paleo-reconstructions of the North Atlantic (NA) during a warm interglacial climate mode could provide essential context for understanding and predicting modern climate change.

The North Atlantic is an ideal location to understand natural ocean-atmospheric dynamics during an inter-glacial period. The Gulf of Maine (GOM) in particular has the potential to experience major temperature changes due its unique position at the confluence of the Northern Hemisphere Westerlies, the warm, salty Gulf Stream, and the colder, fresher Labrador current<sup>2</sup>. Different water sources entering the GOM are characterized by different seawater oxygen isotope ( $\delta^{18}\text{O}_{\text{sw}}$ ) signals<sup>3</sup>, and changes in North Atlantic ocean circulation are likely to be reflected in temperature and  $\delta^{18}\text{O}$  values of the GOM.

### GOM Reconstructions:

The goal of this project is to generate continuous ocean temperature and  $\delta^{18}\text{O}_{\text{sw}}$  records in the GOM for the past ~11,000 years. A principal proxy used for determining sea surface temperatures is the ratio of magnesium to calcium (Mg/Ca) in foraminifera calcite shells<sup>4</sup>. Temperature is considered the primary factor controlling foraminiferal Mg/Ca, but uncertainty still exists for secondary controls such as salinity

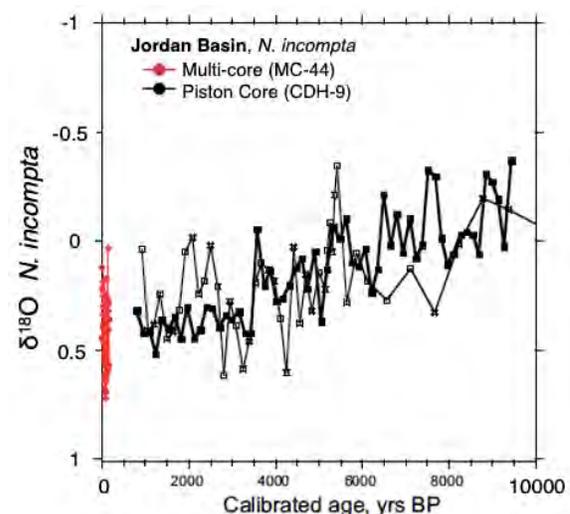


Fig. 1. The  $\delta^{18}\text{O}$  of calcite from *N. incompta* in sediments from the Jordan Basin, GOM, indicating a possible cooling during the Holocene<sup>5</sup>.

and carbonate system influences<sup>6</sup>. We will utilize prior Mg/Ca proxy calibrations and corrections obtained from the North Atlantic to complete paleotemperature reconstructions downcore in the GOM, using the planktonic foraminiferal species *Neogloboquadrina incompta*. A rigorous assessment of Mg/Ca in *N. incompta* from the GOM will improve our paleo-reconstructions and help us to better understand temperature and circulation changes during the Holocene.

**Acknowledgements:** This work is supported by an NSF CAREER Award to Katherine Allen and an NSF GRFP to Madelyn Woods.

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