PROGRAM & ABSTRACTS

46TH INTERNATIONAL

Arctic Workshop 2016

2-3 APRIL

BOULDER, COLORADO

Division of Polar Programs
National Science Foundation

Institute of Arctic & Alpine Research
University of Colorado at Boulder

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Cover photo:

“Ice sheet response to decadal-scale cold snaps?”. Simon Pendleton (top) and Sarah Crump sampling a moraine boulder in eastern Baffin Island for cosmogenic 10Be dating. Their research team is helping determine the sensitivity of the Laurentide Ice Sheet to abrupt climate change. August 2014. Photo: Jason Briner.

PROGRAM AND ABSTRACTS

46th ANNUAL INTERNATIONAL ARCTIC WORKSHOP

April 02 - 03, 2016

Boulder, Colorado

INSTAAR
Institute of Arctic and Alpine Research
University of Colorado, Boulder

Organizing Committee:

Gifford Milller
Wendy Roth
David Lubinski
Anne Jennings

Introduction

Overview and history
The 46th Annual International Arctic Workshop will be held April 02 - 03, 2016, on the campus of the University of Colorado, Boulder. The meeting is sponsored and hosted by the Institute of Arctic and Alpine Research (INSTAAR). This workshop has grown out of a series of informal annual meetings started by John T. Andrews and sponsored by INSTAAR and other academic institutions worldwide.

2016 Theme
"ARCTIC'S NEW NORMAL - shifting environmental baselines over decades to millennia and comparisons with the Antarctic".

Web site
http://instaar.colorado.edu/meetings/AW2016

Check-In / Registration
Please check in or register on (1) Friday evening at the Icebreaker/Reception between 4:30 – 7:30 pm in the MacAllister/SEEC building (4001 Discovery Drive) room S228, or (2) Saturday morning between 8:30 – 8:55 am in the lobby of the MacAllister/SEEC building (4001 Discovery Drive). At registration those who've ordered a print version will also receive their printed high-resolution volume.

MacAllister Building
This building is INSTAAR's new home in SEEC (Sustainability, Energy, and Environment Complex).

Wi-Fi
Wireless internet access is available.

Posters
At registration you will receive information on where to set up your poster. Please put it up as early as possible, and leave it up as late as possible during the workshop.

Presentation Files (i.e., PowerPoint)
Please load your presentation onto our computer during the Icebreaker/Reception on Friday 4:30 – 7:30 pm or the Check-In/Registration on Saturday 8:30 – 8:55 am. Time during breaks is limited.

NSF
The National Science Foundation's Division of Polar Programs has a long tradition of being a supporter of the Arctic Workshop. *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.*

Arctic Workshop 2016
Program Summary

FRIDAY 01 APRIL		
4:30 – 7:30	**Evening Reception, Check-In, Registration** Load presentations onto our computer Put up posters	*MacAllister/SEEC Room s228*

SATURDAY 02 APRIL		
8:30 – 8:55	**Check-in & Registration** Load presentations onto our computer Put up posters	*MacAllister/SEEC lobby*
8:55	**Welcome & Introduction**	*Auditorium*
9:10	**1. Glacial History**	"
10:50	20 min morning break	"
11:10	**2. Paleoceanography & Glacial History**	"
12:50 pm	Lunch buffet provided (tacos)	*Cafeteria*
2:00	**POSTER SESSION** (2 hours)	*Adjacent to Auditorium*
4:00	**Film: *Tony, Back from the Brink***	*Auditorium*
5:00	Pizza and drinks (all attendees)	*Cafeteria*
7:00	End of Day	

SUNDAY 03 APRIL		
8:50	**Announcements**	*Auditorium*
9:00	**3. A Warming Arctic**	"
10:40	20 min morning break	"
11:00	**4. Holocene paleoclimate**	"
12:40 pm	Closing comments	"
1:00	Lunch buffet provided (sandwiches)	*Cafeteria*
2:00	End of Meeting	

Program Details

PM - FRIDAY 01 APRIL 2016

4:30 to 7:30 **Evening Reception, Check in, & Registration** (*MacAllister/SEEC s228)*
Snacks and drinks will be served, including wine;
Load presentations onto our computer, put up posters.

AM – SATURDAY 02 APRIL 2016

8:30 **Check-in & Registration** (*MacAllister/SEEC Lobby*)
Load presentations onto our computer, put up posters

8:55 **Announcements** (*MacAllister/SEEC Auditorium*)

9:00 **Workshop Welcome & Introduction** (*MacAllister/SEEC Auditorium*)
James White, Director of INSTAAR

1. GLACIAL HISTORY

Chair: Martin Miles

9:10 **THE DEEP ACCUMULATION OF 10BE IN DISTAL ICE SHEET LANDSCAPES: A CASE STUDY AT UTSIRA, SOUTHWESTERN NORWAY**
Briner, Jason P.; Goehring, Brent; Svendsen, John Inge; Mangerud, Jan [pg 13]

9:30 **LAKE DENSITY AS A MEASURE OF GLACIAL EROSIONAL IMPACT ON LOWLAND BEDROCK TERRAIN (OR NOT)**
Ebert, Karin; Hamré, Moa; Principato, Sarah [pg 22]

9:50 **DIACHRONOUS RETREAT OF THE GREENLAND ICE SHEET: INSIGHTS FROM A NEW 10BE COSMOGENIC EXPOSURE DATABASE**
Sinclair, Gaylen; Carlson, Anders E.; Mix, Alan C.; Lecavalier, Benoit S.; Milne, Glenn; Mathias, Aspen; Buizert, Christo; Deconto, Robert [pg 64]

10:10 **IN SITU 10BE MEASUREMENTS IN BEDROCK CONSTRAIN EROSION BENEATH THE GREENLAND ICE SHEET**
Young, Nicolas; Briner, Jason; Schaefer, Joerg [pg 71]

10:30 **CURRENT STATE OF RENLAND (EAST GREENLAND) ICE CORE ANALYSIS**
Thayer, Abigail G; White, James W [pg 66]

10:50 ☕ 20-Minute Morning Break

AM – SATURDAY 02 APRIL 2016

2. PALEOCEANOGRAPHY AND GLACIAL HISTORY

Chair: Gifford Miller

11:10 **MULTI-PROXY EVIDENCE FOR ENHANCED DISCHARGE OF ARCTIC SEA ICE AT THE ABRUPT ONSET OF THE LITTLE ICE AGE**

Miles, Martin W.; Dylmer, Christian V [pg 46]

11:30 **DENMARK STRAIT---THE CONTACT AREA BETWEEN THE GREENLAND AND ICELAND ICE SHEETS DURING MIS3 AND MIS2---SEDIMENT SOURCES AND ABRUPT EVENTS**

Andrews, John T; Dunhill , Gita; Vogt, Christoph; Voelker, Antje [pg 9]

11:50 **WAS THERE A BAFFIN BAY ICE SHELF IN THE INTERVAL OF LGM AND HS1?**

Jennings, Anne E.; Andrews, John T.; Ó Cofaigh, Colm; St-Onge, Guillaume; Belt, Simon; Cabedo Sanz, Patricia [pg 33]

12:10 **IT TAKES TWO: USING 10BE AND RADIOCARBON DATING TO DECIPHER THE GLACIAL HISTORY OF SOUTHEASTERN ALASKA DURING THE LAST GLACIAL MAXIMUM**

Lesnek, Alia J; Briner, Jason P [pg 38]

12:30 **USING SHELL-BASED PROXY RECORDS FROM NORTHERN NORWAY TO EVALUATE HIGH LATITUDE IMPACTS OF THE ATLANTIC MULTIDECADAL OSCILLATION**

Mette, Madelyn; Wanamaker Jr., Alan D.; Carroll, Michael L.; Ambrose Jr., William G.; Retelle, Michael J. [pg 45]

12:50 **LUNCH BUFFET PROVIDED** (Cafeteria, Tacos)

PM – SATURDAY 02 APRIL 2016

POSTER SESSION 2:00 – 4:00 pm

HELIUM ISOTOPE BASED RECORD OF CONTINENTAL ACCUMULATION RATES AND PROVENANCE PROVIDES EVIDENCE OF REORGANIZATION OF NORTH ATLANTIC CIRCULATION PATTERNS OVER THE LAST 6 MA

Bhattacharya, Atreyee; Mukhopadhyay, Sujoy; Higgins, Sean; Ackert, Robert [pg 12]

A HIGH-RESOLUTION LABRADOR SEA SURFACE AND SUBSURFACE WATER FORAMINIFERAL DELTA-O-18 RECORD AND ITS RELATION TO HEINRICH EVENTS

Brown, Zoe E; Hoffman, Jeremy S; Clark, Peter U [pg 14]

INCREASES IN GROWING SEASON LENGTH AND CHANGES IN PRECIPITATION IN SIX DIFFERENT ARCTIC AND SUBARCTIC ECOSYSTEMS

Culler, Lauren; **Finger**, Rebecca; Plane, Ellen; Ayres, Matthew; Virginia, Ross [pg 18]

A MULTI-PROXY RECORD OF EARLY PLEISTOCENE SEA-ICE AND CIRCULATION CONDITIONS IN THE WESTERN ARCTIC OCEAN

Dipre, Geoffrey; Polyak, Leonid; Ortiz, Joseph; Cook, Ann; Oti, Emma [pg 19]

WIND VENTILATION OF HOMOGENOUS SEASONAL SNOW LAYERS

Drake, Stephen A; Higgins, Chad W [pg 20]

HOLOCENE FORAMINIFERA AND OSTRACODA FROM THE HERALD CANYON, CHUKCHI SEA, SWERUS-C3 EXPEDITION 2014

Gemery, Laura; Cronin, Thomas M.; Jakobsson, Martin; Barrientos, Natalia; O'Regan, Matt; Muschitiello, Francesco; Pearce, Christof; Koshurnikov, Andrey [pg 25]

SOIL RESPONSE TO AEOLIAN DISTURBANCE IN WEST GREENLAND

Heindel, Ruth C; Culler, Lauren E; Chipman, Jonathan W; Virginia, Ross A [pg 31]

UNPRECEDENTED RETREAT OF THE COLUMBIA GLACIER IN THE LAST MILLENNIUM

Kilmer, Zoe S; Carlson, Anders E; Stoner, Joseph S; Walczak, Maureen H; Leydet, David J [pg 34]

THE INFLUENCE OF SPRING AND EARLY SUMMER CLOUD RADIATIVE FORCING ON INTER-ANNUAL ARCTIC SEA ICE VARIABILITY

King, Michalea D; Veron, Dana [pg 35]

OXYGEN ISOTOPES OF PRESERVED AQUATIC ORGANIC MATERIAL RECORD PAST LAKE WATER AND CLIMATE CHANGE IN NW GREENLAND

Lasher, G Everett; Axford, Yarrow; McFarlin, Jamie M; Meredith, Kelly A; Osterberg, Erich C; Farnsworth, Lauren [pg 36]

PM – SATURDAY 02 APRIL 2016

POSTER SESSION 2:00 – 4:00 pm

EFFECTS OF SEA ICE ON THE HABITAT PREFERENCE OF ANTARCTIC MINKE WHALES (BALAENOPTERA BONAERENSIS) ALONG THE WEST ANTARCTIC PENINSULA

Lee, Jessica F; DeLiberty, Tracy L; Oliver, Matthew J; Friedlaender, Ari S [pg 37]

MID-HOLOCENE MARINE PALEOCLIMATE FROM ROLVSOYA AND INGOYA: NORTHERN FINNMARK, NORWAY

Mark, Samuel; Mette, Madelyn; Retelle, Michael; Savage, Julia; Wanamaker, Alan [pg 40]

HIGH RESOLUTION XRF SEDIMENT MINERALOGICAL ANALYSIS OF LATE SEASON PRECIPITATION EVENTS IN A HIGH ARCTIC GLACIATED WATERSHED

McCabe, Christiane; Retelle, Mike; Werner, Al [pg 42]

SATELLITE RECORD OF NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) REVEALS CONTRASTING TRENDS IN NORTHERN WEST SIBERIA

Miles, Victoria; Esau, Igor [pg 47]

RETREAT OF THE SMITH SOUND ICE STREAM IN THE EARLY HOLOCENE

Oliver, Brett; Jennings, Anne E; Andrews, John T [pg 53]

HOLOCENE SHORELINES AND RELATIVE SEA LEVEL HISTORY ON INGØYA NORTHERN FINNMARK, NORWAY

Retelle, Mike; Mark, Samuel; Savage, Julia [pg 58]

A LATE-HOLOCENE PALEOCLIMATE RECONSTRUCTION USING THE BIVALVE ARCTICA ISLANDICA FROM NORTHERN NORWAY

Savage, Julia M.; Retelle, Michael J.; Wanamaker Jr., Alan D.; Mette, Madelyn J.; Mark, Samuel Z. [pg 59]

RESPONSE OF LOCAL SEA ICE EXTENT TO PASSAGE OF THREE EXTREME CYCLONES IN THE ARCTIC

Schreiber, Erika A.P.; Serreze, Mark C. [pg 62]

SHARING INDIGENOUS WAYS OF KNOWING IN PARTNERSHIP WITH ARCTIC COMMUNITIES

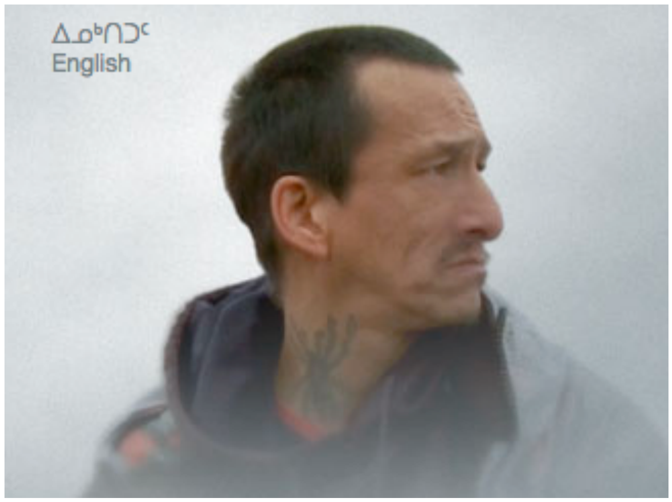
Sheffield, Betsy; McCann, Heidi; Pulsifer, Peter L.; Strawhacker, Colleen A.; McNeave, Chris [pg 63]

HOLOCENE DEGLACIATION IN TWO FIORDS ON NORTHERN CUMBERLAND PENINSULA, BAFFIN ISLAND, ARCTIC CANADA

Tulenko, Joseph P; Briner, Jason P; Miller, Gifford H; Young, Nicolas E [pg 70]

PM – SATURDAY 02 APRIL 2016

FILM 4:00 – 5:00 pm



Tony, Back from the Brink

A film produced by Joelie Sanguya and directed by Mike Jaypoody

A victim of childhood violence and neglect, Tony Kalluk spent half of his first forty years in jail or on probation. He was angry, violent; he attempted “suicide by police” but was only shot in the leg. Later something changed; he returned home to Clyde River, became a counselor to others in distress, and started a family. The film follows Tony as he tries to stay on track, while battling his demons from a past that will not leave him alone.

Runtime: 46 minutes.

PIZZA & DRINKS 5:00 – 7:00 Cafeteria

For all workshop participants

AM – SUNDAY 03 APRIL 2016

8:50 Announcements (*SEEC Auditorium*)

3. A WARMING ARCTIC

Chair: Jason Briner

9:00 **HOW UNUSUAL IS THE BARNES ICE CAP'S LIKELY DISAPPEARANCE IN THE NEAR FUTURE**

Miller, Gifford; Gilbert, Adrien; Flowers, Gwenn; Refsnider, Kurt; Pendleton, Simon [pg 49]

9:20 **ENVISIONING A WARMER ARCTIC: EXPLORING THE USE OF ANCIENT DNA PRESERVED IN INTERGLACIAL LAKE SEDIMENTS ON BAFFIN ISLAND**

Crump, Sarah E; Miller, Gifford H; Bunce , Michael [pg 17]

9:40 **ARCTIC CLIMATE PREDICTIONS: PATHWAYS TO RESILIENT, SUSTAINABLE SOCIETIES (ARCPATH)**

Ogilvie, Astrid E.J.; Einarsson, Niels; Gao, Yongqi; Keenlyside, Noel; Rasmussen, Marianne H. [pg 50]

10:00 **400 PREDICTIONS: THE SEARCH SEA ICE OUTLOOK 2008–2015**

Hamilton, Lawrence C; Stroeve, Julienne [pg 28]

10:20 **TRACKING ICE PARCELS AND CO-LOCATED DATA PRODUCTS IN THE ARCTIC USING THE SEA ICE MOTION AND AGE DATA PRODUCTS AT THE UNIVERSITY OF COLORADO AT BOULDER WITH APPLICATIONS TO STUDYING CHANGES IN THE ARCTIC ICE PACK**

Tooth, Matthew N; Tschudi, Mark [pg 69]

10:40 ☕ 20-Minute Morning Break

AM/PM – SUNDAY 03 APRIL 2016

4. HOLOCENE PALEOCLIMATE

Chair: Anne Jennings

11:00 **LATEST HOLOCENE GLACIER ACTIVITY ON CUMBERLAND PENINSULA, BAFFIN ISLAND**

Pendleton, Simon; Miller, Gifford; Anderson, Robert; Crump, Sarah [pg 55]

11:20 **DECADALLY-RESOLVED EARLY HOLOCENE TEMPERATURE AND PRECIPITATION RECONSTRUCTIONS FROM WESTERN GREENLAND**

Thomas, Elizabeth K.; Castañeda, Isla S.; Briner, Jason P.; Nguyen, Kevin; Salacup, Jeff; Schweinsberg, Avriel [pg 67]

11:40 **A 12 KA RECORD OF AQUATIC PRODUCTIVITY AND LANDSCAPE STABILITY FROM TORFDALSVATN, NORTH ICELAND**

Florian, Christopher R; Miller, Gifford H; Geirsdóttir, Áslaug [pg 24]

12:00 **STEPWISE NEOGLACIAL LANDSCAPE DESTABILIZATION IN THE CENTRAL HIGHLANDS, WEST ICELAND**

Gunnarson, Sydney R.; Geirsdóttir, Áslaug; Miller, Gifford H. [pg 26]

12:20 **A 3 KA MULTI-PROXY GLACIAL AND ENVIRONMENTAL RECORD FROM DRANGAJÖKULL, VESTFIRÐIR, ICELAND: TERRESTRIAL AND MARINE COEVOLUTION.**

Harning, David; Geirsdóttir, Áslaug; Miller, Gifford; Belart, Joaquín M.C.; Anderson, Leif [pg 30]

12:40 Closing Comments

1:00 **LUNCH BUFFET PROVIDED** (Cafeteria, Sandwiches)

2:00 **END OF MEETING** – THANKS FOR ATTENDING!

Notes

DENMARK STRAIT---THE CONTACT AREA BETWEEN THE GREENLAND AND ICELAND ICE SHEETS DURING MIS3 AND MIS2---SEDIMENT SOURCES AND ABRUPT EVENTS

Andrews, John T [1]; **Dunhill** , Gita [2]; **Vogt**, Christoph [3]; **Voelker**, Antje [4]

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[2] California State University, East Bay,; gitadunhill@gmail.com
[3] University of Bremen; cvogt@uni-bremen.de
[4] Instituto Português do Mar e da Atmosfera (IPMA);; antje.voelker@ipma.pt

Denmark Strait was the zone of intense interaction between the Greenland and Iceland ice sheets during the Last Glaciation (Andrews, 2008; Andrews and Cartee-Schoofield, 2003). We focus on changes in the provenance and delivery of sediments to the north, within, and south of the strait during MIS2 and MIS3. Specifically we focus on the records from PS2644 north of the strait in Blosseville Basin (van Kreveld et al., 2000; Voelker, 1999; Voelker and Haflidason, 2015; Voelker et al., 1998), and MD99-2323 and -2260 south of the strait from the Snorri Drift (Dunhill, 2005; Labeyrie et al., 2003) and on the Kangerlussuaq Trough Mouth Fan respectively (Andrews et al., 1998) (Fig. 1). Issues of temporal correlation are complex because of differences in the 14C Ocean Reservoir correction (? R) in space and time, but the presence of the Vedde and North Atlantic Ash Zone II (NAAZII) tephras at very similar depths in PS2644 and MD99-2323 indicates that these sites had nearly identical average rates of sediment accumulation between ~12 and 55 cal ka BP at ~13 cm/ky or ~760 yr/10 cm sampling. ?18O values on the cold water near surface planktonic species N. pachyderma s (Np s)between 0 and 700 cm from PS2644 and MD99-2323 are similar, with an abrupt transition from heavy to lighter values occurring at 96 and 120 cm depth respectively (Fig. 2). For this presentation we developed a matrix of sediment data for both cores at 10-cm intervals including: 1) counts of IRD > 2 mm, 2) coarse sand % > 153 μm, 3) total sand % > 63μm, 4) magnetic susceptibility, 5) wt% quartz, 6) wt% pyroxene, 7) wt% illite, and 8) ?18O. In order to compare the records north and south of Denmark Strait we standardized the variables (=0 ± 1) and used the program Fuzme (Minasny and McBratney, 2002) to compute cluster memberships, Principal Component loadings and scores, and Discriminant Functions. The analysis determined that for both cores a 3-fold cluster solution was the most efficient with end members associated with a broad mafic to felsic gradient in sediment composition, reflecting an alternation of glacially derived sediments from the basalts across the Greenland/Iceland Ridge (Larsen, 1983) versus a variety of quartz-rich bedrock from E/NE Greenland. Statistically, there are significantly more runs in the PS2644 data (n = 23) than on the Snorri Drift (n = 17) indicating that there is no simple correlation in the sediment archives north and south of Denmark Strait.

Andrews, J.T., 2008. The role of the Iceland Ice Sheet in sediment delivery to the North Atlantic during the late Quaternary: how important was it? Evidence from the area of Denmark Strait. Journal of Quaternary Science 23, 3-20.

Andrews, J.T., Cartee-Schoofield, S., 2003. Late Quaternary lithofacies, provenance, and depositional environments (~12 to 30 cal ka), north and south of the Denmark Strait. Marine Geology 199, 65-82.

Dunhill, G., 2005. Iceland and Greenland margins: A comparison of depositional processes under differnt glaciological and oceanographic settings, Geological Sciences. University of Colorado, Boulder, p. 242.

Minasny, B., McBratney, A.B., 2002. FuzMe version 3.0. Australian Center for Precision Agriculture, Universityof Sydney, Australia.

van Kreveld, S., Sarthein, M., Erlenkeuser, H., Grootes, P., Jung, S., Nadeau, M.J., Pflaumann, U., Voelker, A., 2000. Potential links between surging ice sheets, circulation changes, and the Dansgaard-Oeschger cycles in the Irminger Sea, 60-18 ka. Paleoceanography 15, 425-442.

Voelker, A.H.L., 1999. Zur Deutung der Dansgaard-Oeschger Ereignisse in ulta-hochauflosenden Sedimentprofilen aus dem Europaischen Nordmeer, Dansgaard-Oeschger events in ultra-high resolution sediment records from the Nordic Seas. Universitat Kiel, Kiel, p. 271.

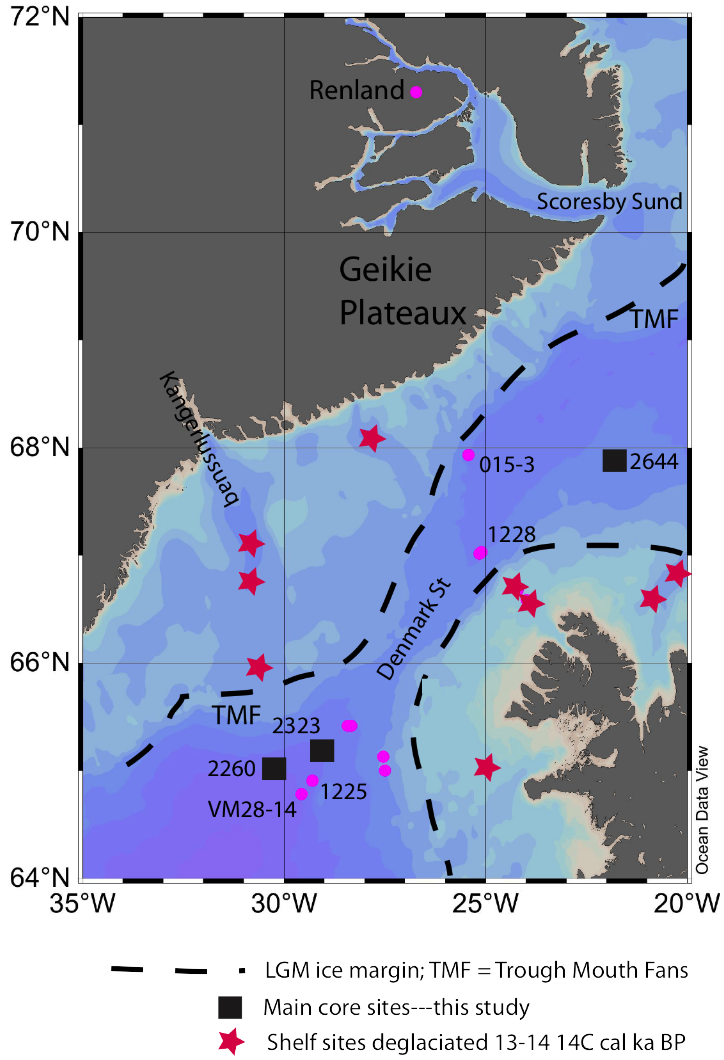

Fig 1. Map of the area of Denmark Strait showing the location of MD99-2323 and -2260, and PS2644 plus other cores from the region. The LGM extent of the Iceland and Greenland ice sheets are also shown. The star symbols represent sites that often have a basal diamicton with dates in overlying sediments of uncorrected radiocarbon dates of 13-14 ka BP.

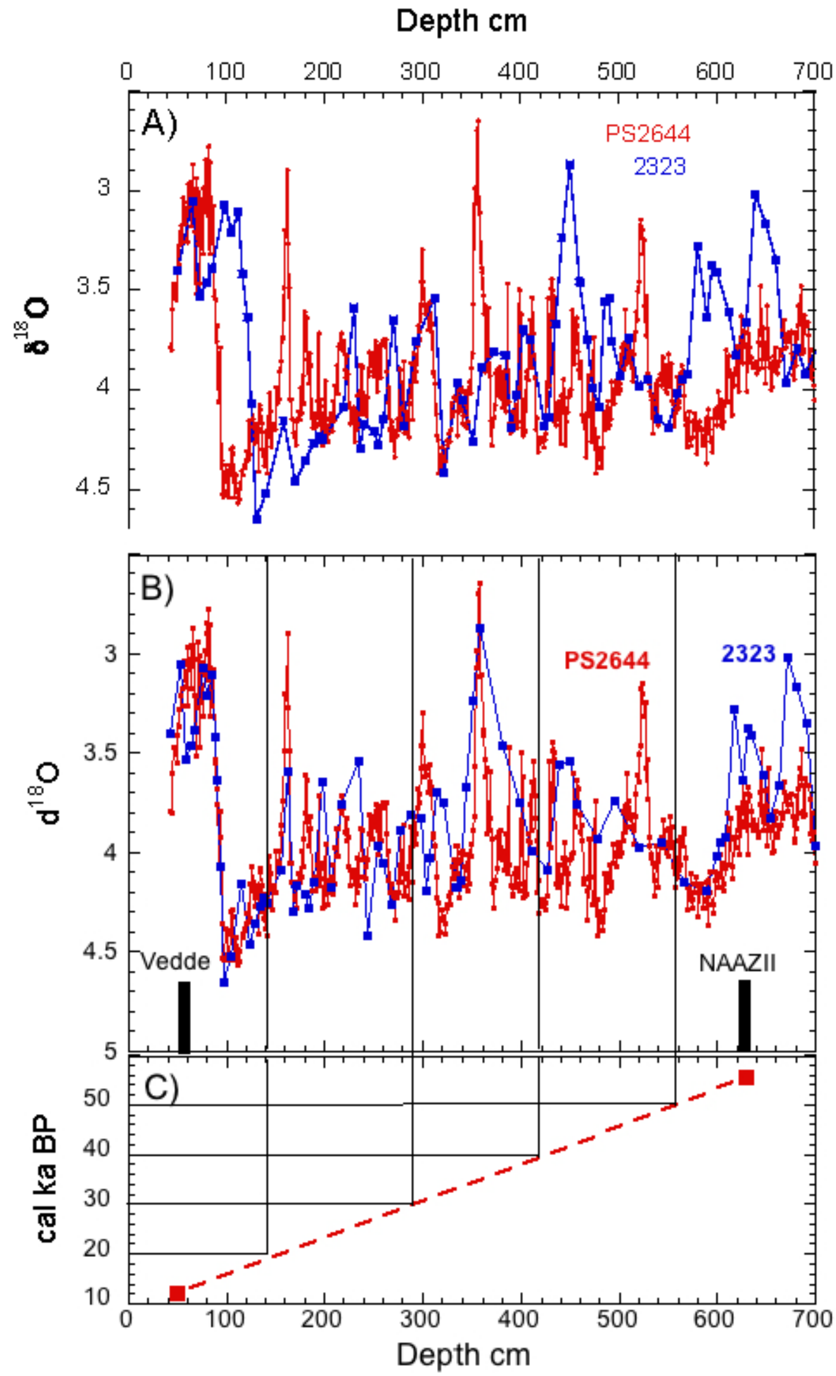

Fig 2. Figure showing A) the 18O variations of the near surface planktonic foraminifera N. pachyderma s in PS2644 and MD99-2323 versus depth; B) MD99-2323 record adjusted on depth so that the abrupt ? 18O transition lines up with that in PS2644; C) Linear depth/age plot based on the occurence pf the Vedde and North Atlantic Ash Zone II (NAAZII) tephras

HELIUM ISOTOPE BASED RECORD OF CONTINENTAL ACCUMULATION RATES AND PROVENANCE PROVIDES EVIDENCE OF REORGANIZATION OF NORTH ATLANTIC CIRCULATION PATTERNS OVER THE LAST 6 MA

Bhattacharya, Atreyee [1]; **Mukhopadhyay**, Sujoy [2]; **Higgins**, Sean [3]; **Ackert**, Robert [4]

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[2] University of California-Davis;
[3] Columbia University;
[4] Harvard University;

The Miocene to Pleistocene marks a period of transition from a warm, humid, low orbital frequency driven climate state to a cooler, more arid, northern glaciation driven climate state, with the majority of the change taking place between the late Pliocene through the early Pleistocene. In this study, we use Helium isotopes at site U1313 in the subpolar North Atlantic Ocean (reoccupation site of DSDP site 607) to reconstruct a record of input, accumulation and provenance of aeolian material over the last 6 Ma. Our record indicates a gradual increase in terrigenous flux was concomitant with climate cooling from the late Pliocene through the Marine Isotope Stage (MIS) 8 in the late Pleistocene. There appears to be an abrupt increase in terrigenous flux around 2.4 Ma followed by at least four such instances of elevated terrigenous through the late Pleistocene. We also find that the increased accumulation of terrestrial material resulted in a switch from carbonate controlled to a more clay controlled sedimentation pattern at site 1313 ~ 1 Ma. We interpret our 4He based record of terrigenous accumulation a result of reorganization of oceanic circulation in response to advance and retreat of ice sheets associated with onset and intensification of northern hemispheric glaciation. We will discuss possible offsets (and causes) with Antarctic glaciation and implication for global oceanic circulation patterns

THE DEEP ACCUMULATION OF 10BE IN DISTAL ICE SHEET LANDSCAPES: A CASE STUDY AT UTSIRA, SOUTHWESTERN NORWAY

Briner, Jason P. [1]; **Goehring**, Brent [2]; **Svendsen**, John Inge [3]; **Mangerud**, Jan [4]

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[2] Tulane University; bgoehrin@tulane.edu
[3] University of Bergen; John.Svendsen@uib.no
[4] University of Bergen; Jan.Mangerud@uib.no

Knowing the age of the Last Glacial Maximum (LGM) extent of ice sheets is fundamental to ice age theory, but methods available for constraining maximum ice extent during the LGM are limited. Cosmogenic-nuclide exposure dating (e.g., 10Be dating) has emerged in the past two decades as a useful tool for dating LGM terminal moraine boulders. Although not without limitations, cosmogenic-nuclide exposure dating has allowed many additional chronologies of LGM terminal moraines to arise from locations otherwise difficult to date. In some cases, however, cosmogenic-nuclide exposure ages might be skewed towards being too old due to the deep accumulation of 10Be from muon production.

Svendsen et al. (2015, QSR v. 107, 231-242) used 10Be dating of erratic boulders on the island of Utsira to constrain the initial retreat of the Norwegian Channel Ice Stream (a major artery of the southern Scandinavian Ice Sheet) from its maximum LGM extent. The 10Be chronology, indicating retreat of the outer ice stream ~20.2 ka, is at odds with radiocarbon constraints indicating that ice sheet recession initiated ~18.5 ka. Commonly discussed factors such as uncertainty in the 10Be production rate, isotopic inheritance from neutron-produced 10Be, or problematic radiocarbon ages do not satisfactorily explain the disagreement. Although inheritance affects the 10Be age of some erratics, and one bedrock sample from the island has obvious inheritance, the strong cluster of 10Be ages from Utsira, which are identical in age to erratics from a nearby island, is not the typical age pattern reflecting inheritance.

Here, we attempt to reconcile the age offset by suggesting that all of the 10Be ages are influenced by the deep accumulation of muon-produced 10Be, making them too old. Using the latest knowledge in production of 10Be from muons in the Earth's crust, we show that muogenic 10Be is significant at depths of 5-10 m. In ice sheet distal landscapes, where there is commonly >100,000 years of exposure between glacial overriding events (like the outer Norwegian Channel Ice Stream), this deep 10Be production can yield inventories well above current uncertainty levels. The implications of our result is that in ice sheet distal settings that are exposed for much longer than they are covered by ice sheets during Quaternary glaciation cycles, ice sheets need to erode upwards of 10 meters to reduce 10Be concentrations to within detection limits based on current analytical capabilities. This is work in progress and further sampling is planned.

A HIGH-RESOLUTION LABRADOR SEA SURFACE AND SUBSURFACE WATER FORAMINIFERAL DELTA-O-18 RECORD AND ITS RELATION TO HEINRICH EVENTS

Brown, Zoe E [1]; **Hoffman**, Jeremy S [2]; **Clark**, Peter U [3]

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Heinrich events are characterized by episodic iceberg discharge events from the Laurentide ice sheet via the Hudson Strait Ice Stream (HSIS) and into the North Atlantic. Although their occurrence throughout late Pleistocene glaciations has been well documented in the oceanic sediment record, the triggering mechanism for Heinrich events is still poorly understood. Recent work (Marcott et al., 2011) has shown that subsurface ocean (~1200 m) warming in response to a shutdown of the Atlantic Meridional Overturning Circulation (AMOC) could lead to accelerated melting and destabilization of an ice shelf fronting the Laurentide Ice Sheet and subsequently trigger Heinrich events. However, evidence for this subsurface warming remains restricted to one core site. Here we use Labrador Sea core HU2006040-006pc from the Hamilton Spur to assess spatial and depth coverage of this signal. We infer surface and subsurface temperature variability using δ18O in planktonic and benthic foraminifera, respectively. We also develop a corresponding suite of other sediment proxies, including XRF and XRD, in order to identify Heinrich layers, so as to pinpoint source regions for the Heinrich layers. This research will allow further evaluation of changes in the temperature structure of the Labrador Sea due to changes in the strength of the AMOC and their relation to Heinrich events. Results will be used to substantiate existing research and coupled ocean-atmospheric models that suggest a reduced AMOC and associated subsurface warming as the trigger for Heinrich events.

Alvarez-Solas, J., & Ramstein, G. (2011). On the triggering mechanism of Heinrich events. Proceedings of the National Academy of Sciences, 108(50), E1359–E1360. http://doi.org/10.1073/pnas.1116575108

Liu, Z., B. Otto-Bliesner, F. He, E. Brady, P. Clark, J. Lynch-Steiglitz, A. Carlson, W. Curry, E. Brook, et al. (2009). Transient Simulation of Last Deglaciation with a New Mechanism for Bolling-Allerod Warming. Science, 325, 310-314.

Marcott, S. A., Clark, P. U., Padman, L., Klinkhammer, G. P., Springer, S. R., Liu, Z., et al. (2011). Ice-shelf collapse from subsurface warming as a trigger for Heinrich events. Proceedings of the National Academy of Sciences, 108(33), 13415–13419. http://doi.org/10.1073/pnas.1104772108

Fig 1. Adapted from Google Maps, 2016; location of core HU2006040-006pc, pos. 54.65'N, -53.12'W (736 meters).

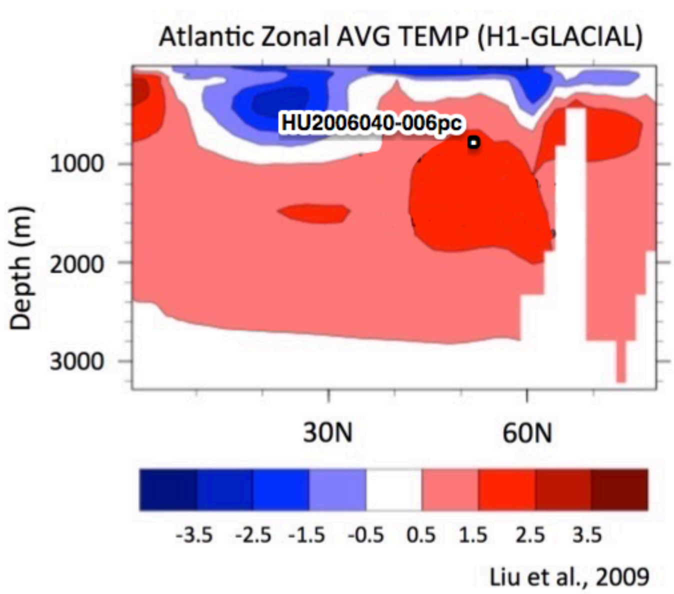

Fig 2. Adapted from Liu et al., 2009, ocean circulation model showing that core HU2006040-006pc (736 meters) is within the zone of maximum subsurface warming (400-800m) during times of reduced Atlantic meridional overturning circulation (AMOC).

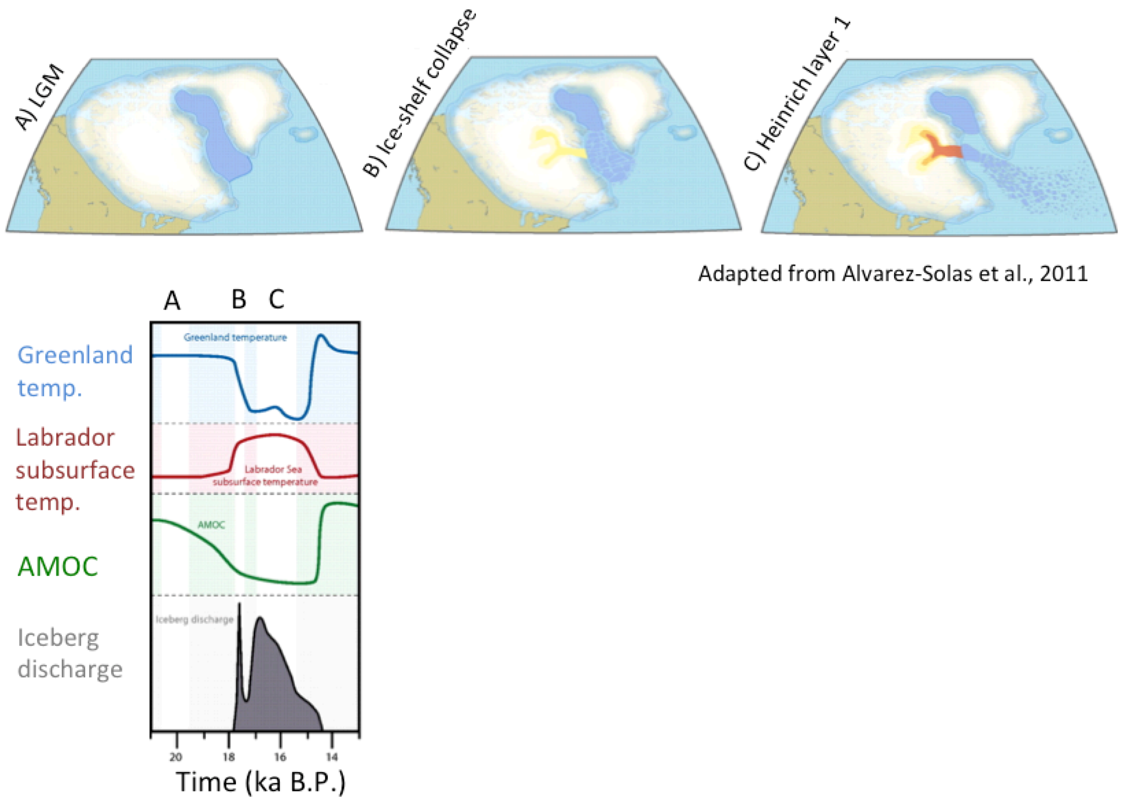

Fig 3. Adapted from Alvarez-Solas et al., 2011; diagram shows the progression of a Heinrich Event via a reduction of Atlantic meridional overturning circulation (AMOC) and the resultant warming of subsurface waters in the Northern latitudes acting as a mechanism for ice-shelf destabilization. During a Heinrich event we would expect to see: colder Greenland surface temperatures, warmer subsurface temperatures in the Labrador Basin, a shutdown of the AMOC, and evidence of iceberg discharge in the sediment record.

ENVISIONING A WARMER ARCTIC: EXPLORING THE USE OF ANCIENT DNA PRESERVED IN INTERGLACIAL LAKE SEDIMENTS ON BAFFIN ISLAND

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Rapidly rising Arctic temperatures and increasing growing-season length are expected to result in a poleward expansion of high-latitude plants. In turn, this vegetation shift is expected to both reduce surface albedo and increase atmospheric water vapor, further amplifying warming. In order to accurately capture this important positive feedback in future climate projections, it is necessary to constrain the expected ecological response to a warming Arctic. Past interglacial periods serve as useful analogues for future warmth; as such, interglacial paleoecological reconstructions can provide valuable insights into the ecological response to temperature changes and the mode of plant colonization following ice retreat.

Past studies have successfully used pollen preserved in Arctic lake sediments to characterize vegetation and climate histories over the Last Interglacial (LIG; ~130-115 ka; Miller et al., 1999; Fréchette et al., 2006; Velichko et al., 2008) and determined that the range and abundance of shrubs and trees indeed increased during LIG warmth. However, pollen-derived records only provide information about seed-bearing plants and are likely to be biased by the long-distance transport of pollen grains. On the other hand, recent methodological advances in the analysis of sedimentary ancient DNA (sedaDNA) allow for the highly sensitive detection of the presence of all plant and animal types, even in the absence of micro- or macrofossils. Taxonomic identification of sedaDNA is possible to the species or even subspecies level, compared to pollen identification to the genera or family level. Arctic soils and sediments are ideal archives for ancient DNA preservation as cold temperatures help to preserve DNA over long time periods.

Initial DNA results from Baffin Island pilot samples indicate long-term preservation and robust representation of local flora. We found ancient DNA preserved in soil emerging beneath receding Baffin Island ice caps that are beyond the range of 14C dating (>50 ka) and are likely LIG in age. These results confirm DNA preservation for >100 ka in optimal conditions. Additionally, a lake sediment sample that is ~4.8 ka yielded DNA from taxa currently growing on Baffin Island, including Betula (dwarf birch), which is currently at its northern limit in the region and is thus a useful indicator of climate change. This presentation will explore the opportunities and challenges associated with reconstructing more complete ecological records than previously possible with sedimentary ancient DNA for multiple interglacials in order to better understand climate-vegetation interactions.

Miller, G.H., Mode, W.N., Wolfe, A.P., Sauer, P.E., Bennike, O., Forman, S.L., Short, S.K., and Stafford, T.W., 1999, Stratified interglacial lacustrine sediments from Baffin Island, Arctic Canada: chronology and paleoenvironmental implications: Quaternary Science Reviews, v. 18, no. 6, p. 789–810, doi: 10.1016/S0277-3791(98)00075-4.

Fréchette, B., Wolfe, A.P., Miller, G.H., Richard, P.J.H., and de Vernal, A., 2006, Vegetation and climate of the last interglacial on Baffin Island, Arctic Canada: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 236, no. 1–2, p. 91–106, doi: http://dx.doi.org/10.1016/j.palaeo.2005.11.034.

Velichko, A.A., Borisova, O.K., and Zelikson, E.M., 2008, Paradoxes of the Last Interglacial climate: reconstruction of the northern Eurasia climate based on palaeofloristic data: Boreas, v. 37, no. 1, p. 1–19, doi: 10.1111/j.1502-3885.2007.00001.x.

INCREASES IN GROWING SEASON LENGTH AND CHANGES IN PRECIPITATION IN SIX DIFFERENT ARCTIC AND SUBARCTIC ECOSYSTEMS

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Ecological dynamics across the Arctic are responding to rapid changes in climate. As a whole, the Arctic has warmed at approximately twice the rate of the rest of the world, but changes in temperature and precipitation experienced at regional and local scales are most important for coupled human-natural systems. In addition, biologically-relevant climate indices are necessary for quantifying ecological responses of terrestrial and aquatic systems to varying climate. We compared climatic changes at six different Arctic and sub-Arctic locations, including two in Greenland (Kangerlussuaq, Sisimiut), one in Sweden (Abisko), and three in Alaska (Barrow, Nome, Fairbanks). We amassed weather data (daily temperature and precipitation), dating as far back as 1906, from public-access databases and used these data to calculate indices such as length of growing season, growing season degree days (GDD), and growing season precipitation. Annual GDD increased at all locations (average of 13% increase in GDD since 1980), but especially in western Greenland (16 and 37% in Kangerlussuaq and Sisimiut, respectively). Changes in growing season precipitation were more variable, with only Barrow, AK and Abisko, Sweden experiencing increased precipitation. All other sites experienced stable or slightly declining precipitation. Increasing temperatures and relatively stable precipitation translates to increased evapotranspiration potential, which influences soil moisture, lake depth, vegetation, carbon emissions, and fire susceptibility. Understanding local and regional trends in temperature and precipitation can help explain observed phenological changes and other processes at population, community, and ecosystem levels. In addition, identification of locations most susceptible to future change will allow scientists to closely monitor their ecological dynamics, anticipate changes in coupled human-natural systems, and consider adaptation plans for the most rapidly changing systems.

A MULTI-PROXY RECORD OF EARLY PLEISTOCENE SEA-ICE AND CIRCULATION CONDITIONS IN THE WESTERN ARCTIC OCEAN

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The early Pleistocene may represent one of the closest paleo-analogs for projected near-future Arctic environments with predominantly seasonal sea-ice cover. Major Northern Hemisphere glaciations did not fully develop until the middle Pleistocene (~0.7-0.8 Ma); therefore, investigating pre-glacial Pleistocene deposits may help to elucidate the role of sea ice and circulation in the Arctic Ocean system. However, sedimentary records that presumably represent this time period appear to be lithologically monotonous and are distinctly lacking in biogenic content due to the widespread dissolution of both calcareous and siliceous material. Difficulties in developing a stratigraphy for these sediments have led to most Arctic paleoceanographic studies focusing on middle to late Quaternary deposits that exhibit explicit glacial/interglacial cyclicity and relatively good preservation of calcareous microfossils. This lack of stratigraphic constraints results in a gap of knowledge surrounding pre-glacial Pleistocene paleoenvironments in the Arctic. This study aims to reconstruct early Pleistocene circulation and sea-ice conditions by investigating a sedimentary record from the Northwind Ridge, Western Arctic Ocean, containing unusually abundant calcareous microfauna.

Polyak et al. (2013) developed a provisional stratigraphy and characterization of paleoceanographic conditions for the western Arctic Ocean based on a neighboring sediment record that extends to estimated ~1.5 Ma. An investigation of foraminifers and ostracodes in the record implies that the early Pleistocene in this region was characterized by mostly seasonal sea ice, and that the transition to extensive perennial sea ice was stepwise, with a pronounced shift near the early-middle Pleistocene boundary. We aim to further these results by utilizing another core with a similar stratigraphy from a different water depth (top of the Northwind Ridge) and a more recent collection, which provides more complete sediment material for use. We present results from a multi-proxy investigation focused on the seasonally ice-free early Pleistocene. Physical (sediment density, grain size) and chemical (elemental composition) proxies are interpreted in terms of ocean circulation patterns, while biological (bioturbation, foraminiferal abundances and assemblages) proxies are interpreted as indicators of sea-ice conditions. Additionally, our results reveal two cyclicities: one expressed notably in manganese content and attributed to sea-level fluctuations, and a longer cyclicity expressed in grain size and foraminiferal abundances. Understanding the duration and nature of these cycles may provide insights into northern high-latitude climate during the Mid-Pleistocene Transition.

L. Polyak, K.M. Best, K.A. Crawford,E.A.Council & G. St-Onge, 2013, Quaternary history of sea ice in the western Arctic Ocean based on foraminifera: Quaternary Science Reviews, v. 79, p. 145-156.

WIND VENTILATION OF HOMOGENOUS SEASONAL SNOW LAYERS

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Atmospheric pressure changes do not stop at a permeable snow surface but rather propagate into it. These pressure changes range from high amplitude, low frequency events caused by synoptic weather systems to small amplitude, high frequency events caused by turbulence. Processes that drive interstitial and near-surface air movement depend on the amplitude and frequency of atmospheric pressure changes. These processes are locally weak but geographically pervasive and temporally persistent so the cumulative impact may be significant over seasonal timescales. In this study we performed a set of field experiments to investigate the amplitude and frequency of mid-to-high frequencies pressure changes as they vary with depth and snow permeability. We used four high-precision absolute pressure sensors to avoid bandwidth limitations previously encountered with relative pressure sensors. We deployed the instruments within homogenous snow layers under windy conditions and captured the monotonic decay of perturbation pressure energy with depth, thereby enabling calculation of spectral attenuation with depth. For a given wind forcing, surface perturbation pressure had greater amplitude than previously reported (Colbeck, 1989). We found enhanced perturbation pressure attenuation at high frequencies that was larger than theoretical predictions (Colbeck, 1989; Waddington et al., 1996) but in agreement with previous field measurements (Drake et al., 2016). Mid frequency attenuation was lacking suggesting perturbation pressure at these frequencies can propagate deep into the snowpack. Low permeability snow had depressed high frequency attenuation with depth because high frequencies are extinguished at the snow surface. Finally, we propose a simple model to diagnose the range of frequencies most likely to enhance water vapor flux by pressure-driven displacement of water vapor molecules.

Colbeck, S. C., 1989, Air movement in snow due to windpumping. J. Glaciol., 35, 209–213.
Drake, S. A., Huwald, H., Parlange, M. B., Selker, J. S., Nolin, A. W., and Higgins, C. W., In Press, Attenuation of wind-induced pressure perturbations in alpine snow. J. Glaciol.
Waddington E. D., Cunningham J. and Harder S. L., 1996, The effects of snow ventilation on chemical concentrations. Chemical Exchange Between the Atmosphere and Polar Snow, NATO ASI Series Volume 43, pp 403-451.

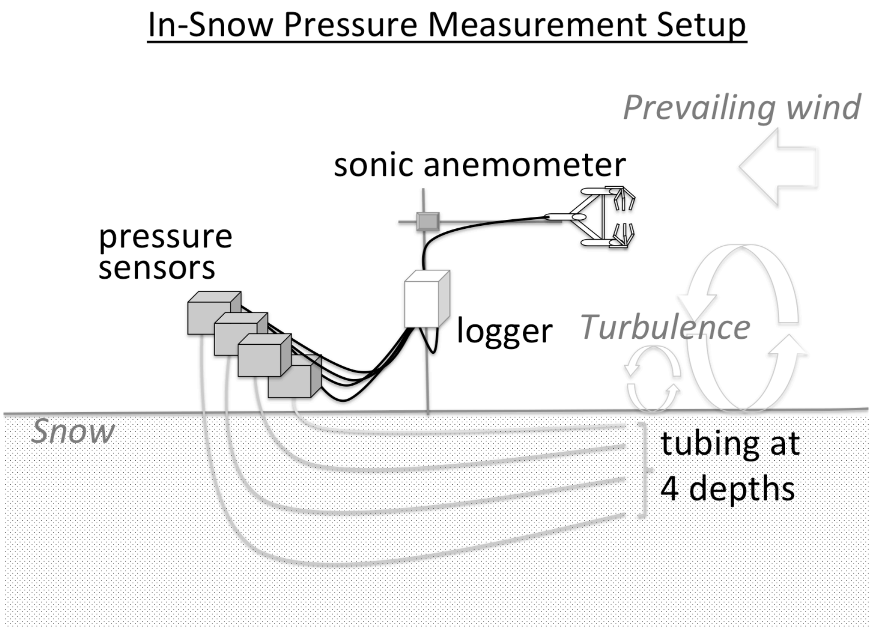

Fig 1. Schematic of experiment setup showing a sonic anemometer pointing into the prevailing wind and tubing for pressure sensors positioned in the snow below the sonic transducers.

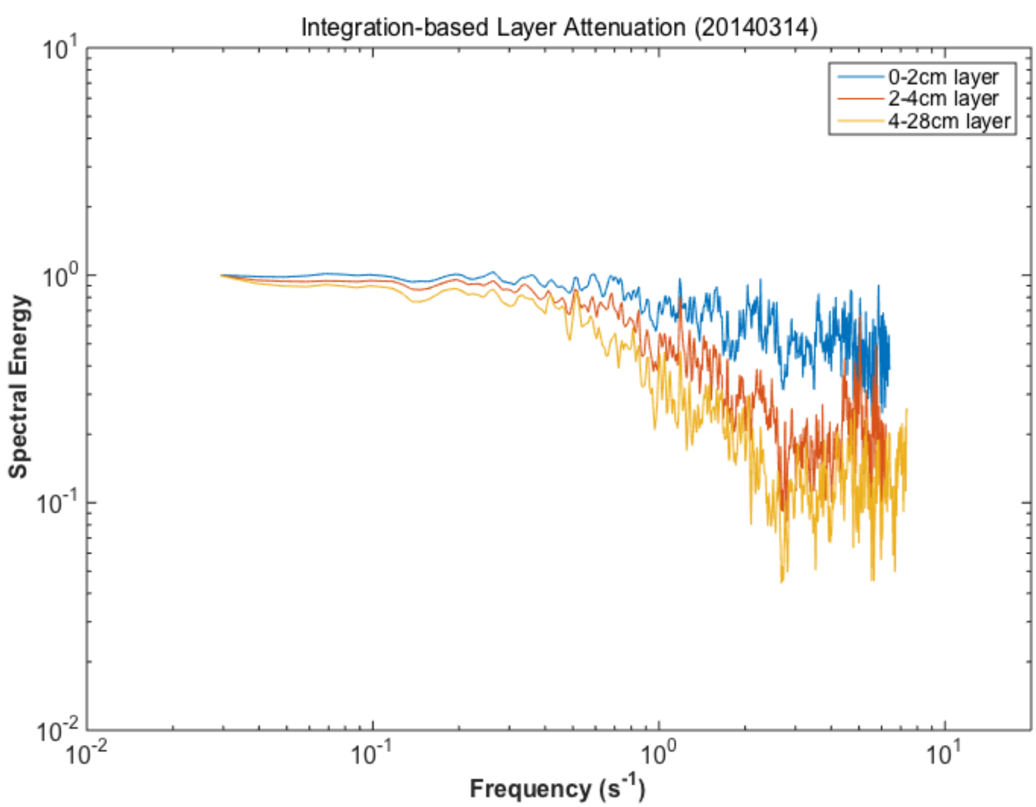

Fig 2. Spectral attenuation for snow layers defined in the legend for March 14, 2014.

LAKE DENSITY AS A MEASURE OF GLACIAL EROSIONAL IMPACT ON LOWLAND BEDROCK TERRAIN (OR NOT)

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The purpose of this study is to compile and analyze a dataset of ice scour lakes for parts of the Northern Hemisphere in order to better understand factors influencing lake formation. Lake density has been used in different geological settings as a measure of the impact of glacial erosion on bedrock (Andrews et al. 1985; Sugden, 1978; Principato and Johnson, 2009; Briner et al., 2008; Ebert, 2015). An increasing density of ice-scoured lakes in bedrock is commonly used to indicate increased impact of late-Cenozoic glacial erosion on the bedrock terrain (resulting in a greater volume of bedrock erosion).

Density of lakes formed in bedrock terrain has been used both to give glacial erosional impact on large regions such as the entire Candian shield (Sugden, 1978) or Baffin Island (Andrews et al., 1985, Ebert, 2015) but also for smaller detail areas such as a Baffin fjord onset zone (Briner, 2008), NW Iceland (Principato and Johnson, 2009) and other areas. The landform expression and the absolute number of lakes vary greatly for different regions. Lake density has been analyzed and illustrated with methods ranging from point density analyses to lake area per grid cell. Grid cells of variable size have been used in previous studies, primarily due to the contrasting resolution of available imagery and DEMs, and the varying number of lakes.

We investigate the areas of the Canadian and Fennoscandian shields, as well as the volcanic lowland areas of Iceland, to assess the reliability of lake density as a measure of glacial erosional impact in different areas. We use available hydrological, elevation and geological datasets in a GIS to assess lake density and the relationship to topography, geology, and glacial histories of these areas. Even though most of the regions studied are comprised of non-mountainous lowland terrain, they show a great variability of (pre-glacial) topographic characteristics. The topography ranges from hilly terrain across inselberg plains to river cut plains and entirely flat bedrock surfaces, as well as combinations of and transitions between these terrain types. Our preliminary results show that lake density is generally a good measure of the impact of glacial erosion. However, at least 3 exceptions to this general rule are possible

• The pre-glacial topography is a crucial factor for the development of lakes. At least 10 m of relief is required to develop an ice-scoured terrain with lakes. Areas with pre-glacial relative relief below 10 m are not likely to demonstrate high lake densities even when previous studies and other factors indicate that the region experienced high glacial erosion (Figure 1). A minimum pre-glacial topography is required to develop lakes, and low relief regions commonly experience low volumes of effective bedrock erosion.

• Ice-dammed lakes like Conn and Bieler lakes on the northeastern margin of Barnes ice cap on Baffin Iceland are not the result of glacial scouring and falsify the glacial impact pattern, especially if lakes are displayed as lake area per grid cell. Lakes dammed for hydropower or drinking water reservoirs would also bias the results.

• Lake density as an indicator of glacial scouring is most reliable in areas with exposed bedrock or thin till over bedrock Areas with thicker till or other sediments may hold a large abundance of lakes, e.g. at the west coast of southern Baffin Island. These lakes are not the result of glacial scouring but of glacial meltout and thermokarst, resulting in kettle ponds.

Andrews, J.T., Clark, P., Stravers, J.A., 1985: The patterns of glacial erosion across the Canadian Arctic. In Andrews, J.T. (ed.), Quaternary environments: Eastern Canadian Arctic, Baffin Bay, and West Greenland. Allen and Unwin, London, 69-92.

Briner, J.P., Miller, G.H., Finkel, R., Hess, D.P., 2008. Glacial erosion at the fjord onset zone and implications for the organization of ice flow on Baffin Island, Arctic Canada. Geomorphology 97, 126-134.

Ebert, K., 2015: GIS analyses of ice-sheet erosional impacts on the exposed shield of Baffin Island, eastern Canadian Arctic. Canadian Journal of Earth Sciences 52: 966-979.

Principato, S. M. & Johnson, J. S. 2009: Using a GIS to quantify patterns of glacial erosion on northwest Iceland: Implications for independent ice sheets. Arctic, Antarctic, and Alpine Research 41, 128-137.

Sugden, D.E., 1978: Glacial erosion by the Laurentide Ice Sheet. Journal of Glaciology, 20: 367-391.

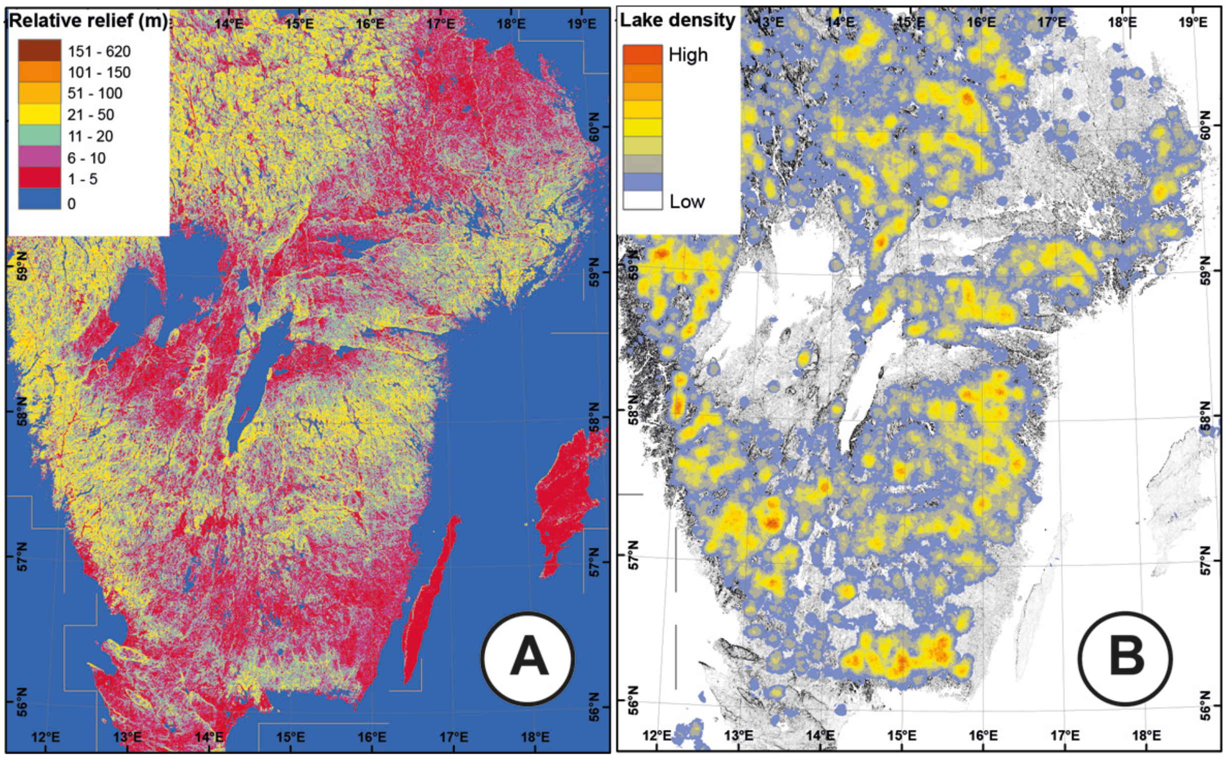

Fig 1. The relation of relative relief and lake density in southern Sweden. A) Relative relief of Southern Sweden. Note that red and purple areas have an extremely low relative relief of 0-10 m. These areas correspond to a pre-Cambrian, extremely flat bedrock surface that cuts across a great number of different bedrock types. B) Lakes in Southern Sweden expressed as point density. In this region, with a well-known ice-sheet cover and deglaciation history, a continuous high lake density would be expected. However, bedrock surfaces with a relief below 10 m are nearly lake-free, pointing to the need of an initial minimum topography to form lakes in bedrock by glacial scouring.

A 12 KA RECORD OF AQUATIC PRODUCTIVITY AND LANDSCAPE STABILITY FROM TORFDALSVATN, NORTH ICELAND

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Icelandic climate is controlled by processes that are globally significant. Biological communities are directly affected by changes in climate; therefore the regional climate history can be inferred by examining evidence of past biogeochemical change preserved in lake sediment. Building on past studies at the site, we develop a high-resolution, multiproxy lake record of Torfdalsvatn, North Iceland. The proxies used in this study provide a history of landscape stability along with the magnitude and characteristics of past aquatic productivity. This study is the first to generate a complete Holocene record of sedimentary algal pigments from an Icelandic lake. Prior to the Saksunarvatn tephra, most proxies reflect the establishment of a Holocene-like environment. The Holocene Thermal Maximum is evident after 8 ka, characterized by increased cyanobacterial abundance and denitrification, which occur as a result of longer ice-free season, lower wind stress, and greater aquatic productivity. Soil stability lags regional peak warmth, with proxies for erosion reaching the lowest Holocene values after 6ka. C:N reflects increasing input of terrestrial organic matter after 4.5 ka with the onset of late Holocene cooling. A transition to increased erosion after 1.8 ka indicates landscape destabilization as a result of cooling temperatures, which occurs in two steps. An increase in minerogenic material, likely due to increased Aeolian transport, precedes an abrupt increase in terrestrial organic matter derived from the destabilization of soils. Aquatic productivity also declines at this time, with peak erosion and lowest productivity occurring during Little Ice Age (ca. 1250-1850 AD/CE). Diatom and green algal pigments do not track regional climate events, therefore other factors such as nutrient availability may control the relative abundance of these groups. The cyanobacterial pigment record, however, corresponds well to sea surface temperatures from MD99-2275 and nearby lake sediment records, suggesting temperature sensitivity of cyanobacterial populations. Because of this, algal pigments may become an important part of Icelandic paleoclimate studies. Additionally, this study suggests that future warming may lead to an increase in cyanobacterial populations in Icelandic lakes.

HOLOCENE FORAMINIFERA AND OSTRACODA FROM THE HERALD CANYON, CHUKCHI SEA, SWERUS-C3 EXPEDITION 2014

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We analyzed Holocene Arctic benthic foraminifera and ostracode assemblages from a piston core (PC) and its complementary shorter multi- (MC) and kastenlot (KL) cores from Herald Canyon in the Chukchi Sea. The cores (SWERUS-L2-2PC1 [8.28 m], 2MC4 [24 cm], 2KL1 [18 cm], in 71.7 m water depth, were collected during Leg 2 of the 2014 SWERUS-C3 Expedition. Radiocarbon dates on mollusks show a nearly linear sedimentation rate over the last 4,600 yrs BP. Foraminifera and ostracode faunal changes downcore in 2PC1 allowed us to reconstruct the paleoenvironment during the mid to late Holocene. Dominant foraminiferal species include: Elphidium excavatum clavata, Cassidulina reniforme, Buccella frigida, and Islandiella teretis. Dominant ostracode species include: Acanthocythereis dunelmensis, Kotoracythere arctoborealis, Elofsonella concinna, Normanicythere leioderma, Cytheropteron elaeni, and Semicytherura complanata. These assemblages suggest the influence of nutrient-rich Pacific water flowing in through the Bering Strait during the last ~ 4,600 yrs BP. Ostracode and foraminiferal species have distinct habitat preferences and variability in proportions of dominant species suggesting centennial-scale events that may represent changes in Pacific water inflow and/or temperature, salinity and sea-ice conditions. One example is an ostracode faunal change from ~1,000 yrs BP when A. dunelmensis became dominant and K. arctoborealis and N. leioderma declined in abundance. This SWERUS record will be compared to other western Arctic Holocene marine records.

STEPWISE NEOGLACIAL LANDSCAPE DESTABILIZATION IN THE CENTRAL HIGHLANDS, WEST ICELAND

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Terrestrial records from lake cores are essential for linking the influence of the oceanic, atmospheric, and land processes that trigger abrupt climate changes that are observed throughout the late Holocene in Iceland (Geirsdóttir et al., 2013). However, catchment dynamics can overprint the climate signal contained within these records in some situations. In an effort to isolate the contributions of catchment-specific from the regional climate signals, we compare two characteristically different lakes from the Central Highlands of West Iceland: (1) from a shallow, oligotrophic, non-glacial lake with a low-relief catchment: Arnarvatn Stóra (ARN), (2) with the record from Hvítárvatn (HVT), a deep lake fed directly by Langjökull glacier with a steep catchment (Larsen et al., 2012).

An 8 m long core was obtained from ARN (2.5 m max water depth, 540 m. a.sl.) in March of 2015 as a comparison with the existing HVT (83 m max water depth, 544 m a.sl.) record (Figure 1). Physical proxies (Magnetic Susceptibility (MS), Sediment Accumulation Rate (SAR)) and biological proxies (Total Organic Carbon flux (TOCq), Carbon-Nitrogen ratio (C:N)) from the HVT and ARN records reveal a similar Holocene pattern: after deglaciation, relative stability between ~7-5 ka (Holocene Thermal Maximum- HTM), followed by Neoglacial landscape destabilization beginning just after the deposition of the Hekla 4 tephra (~4.2 ka) and intensifying in a stepwise manner subsequent to the major Hekla 3 (~3.1 ka) and Hekla 1104 AD eruptions. These late-Holocene (4.2-0 ka) changes in physical and biological proxies, although subdued in ARN compared to HVT, suggest increased terrestrial organic matter (OM) input in both lakes. The HVT record indicates increased glacial activity during this time interval, suggesting that wind erosion triggered by Neoglacial cooling may be responsible for the contemporaneous increase in terrestrial OM in non-glacial ARN. In particular, during the last ~1000 yr BP, both ARN and HVT show unprecedented increases in SAR and TOCq since deglaciation. Evidence of intense aeolian soil erosion beginning ~1000 yr BP in the Central Highlands supports the interpretation that the proxies are reflecting increased wind erosion due to cooling and possibly human activity during this time period (Arnalds, 1999). However, disturbances in historical-aged tephra layers in the top ~2 m of the ARN core have hindered age model development, highlighting a potential limitation of using shallow lakes for latest-Holocene reconstructions. Furthermore, caution should be used when interpreting shallow lakes records like ARN as solely reflecting climate history, as trends in proxies indicating Neoglacial "cooling" could also be explained by basin shallowing. Regional, multi-proxy record comparisons from lakes with extremely different catchment characteristics, such as ARN and HVT, may be useful in isolating catchment-specific factors, which in turn can be used to identify the proxy signal(s) directly recording past climate variability.

Arnalds, Ó., 1999, Icelandic 'Rofabarð' soil erosion features: Earth Surface Processes and Landforms 25, p. 17-28.

Geirsdóttir, Á., Miller, G.H., Larsen, D.J., Ólafsdóttir, S., 2013, Abrupt Holocene climate transitions in the northern North Atlantic region recorded by synchronized lacustrine records in Iceland: Quaternary Science Reviews 70, p. 48-62.

Larsen, D.J., Miller, G.H., Geirsdóttir, Á., Ólafsdóttir, S., 2012, Non-linear Holocene climate evolution in the North Atlantic: a high-resolution, multi-proxy record of glacier activity and environmental change from Hvítárvatn, central Iceland: Quaternary Science Reviews 39, p. 14-25.

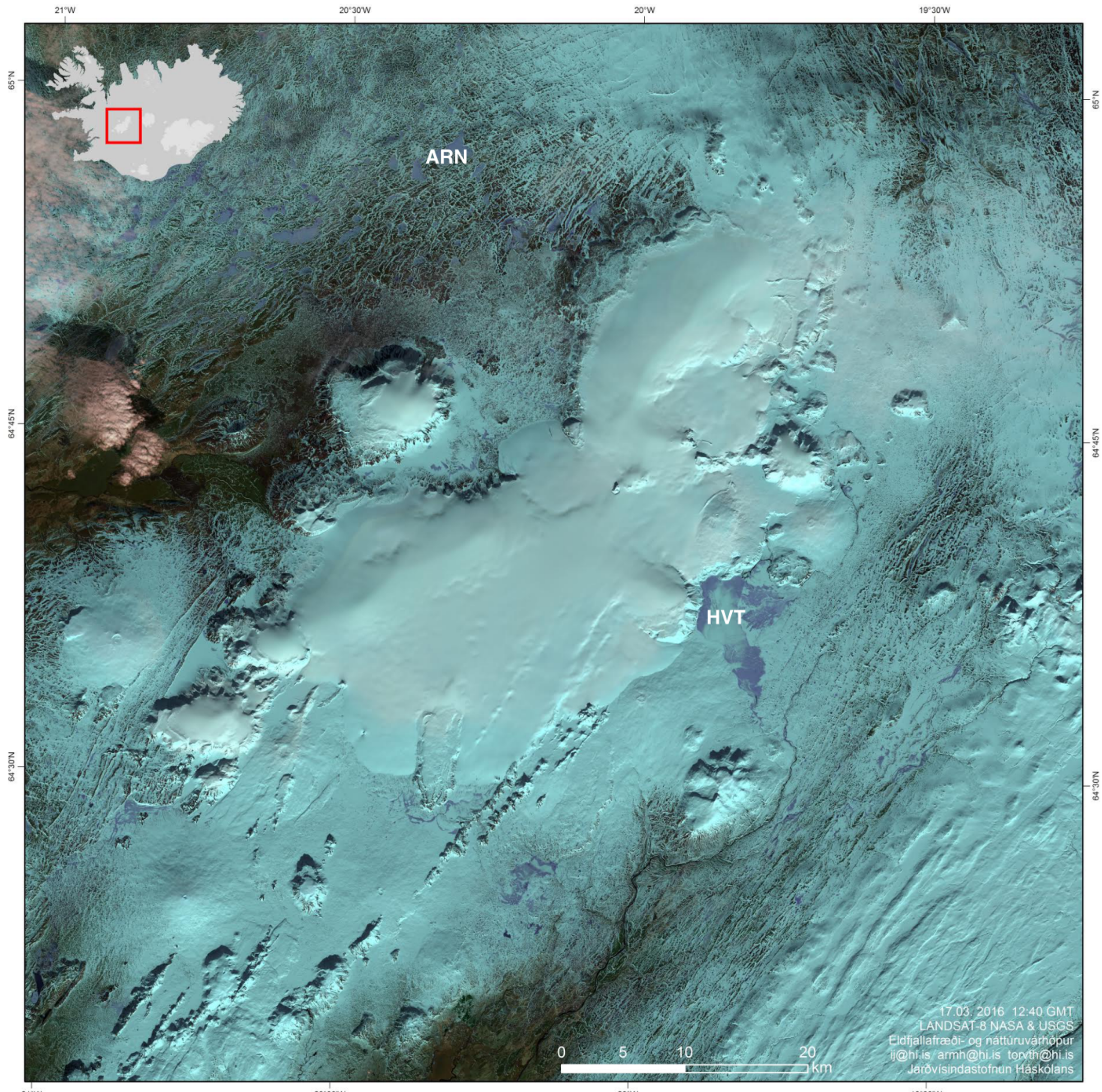

Fig 1. Study area. The Central Highlands, West Iceland, with lakes Arnarvatn Stóra (ARN) and Hvítárvatn (HVT) indicated.

400 PREDICTIONS: THE SEARCH SEA ICE OUTLOOK 2008–2015

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Each Arctic summer since 2008, the Sea Ice Outlook (SIO) has invited researchers and members of the public to contribute their predictions regarding the September mean extent of Arctic sea ice. The SIO collects and publishes these contributions online in three cycles having deadlines at the start of June, July and August each year. Post-season reports summarize how predictions compared with the observed September extent, aiming to provide feedback and insights for improvement. The unique public character of the SIO, with its focus on predicting a single number whose true value soon becomes known, brings an element of constructive gamification to the science process as well. Here we analyze the performance of more than 400 individual predictions from the SIO's first eight years, testing for differences in ensemble skill across different years, different months, and five general types of method: heuristic, statistical, mixed, and ice-ocean or ice-ocean-atmosphere modeling. In general, prediction accuracy reveals a strong pattern of easy and difficult years. Difficult years, in which most predictions are far from the observed September extent, tend to be those with large positive or negative excursions from the overall downward trend. In contrast to these large interannual effects, ensemble improvement from June to July and August, and differences among general method types, appear comparatively small.

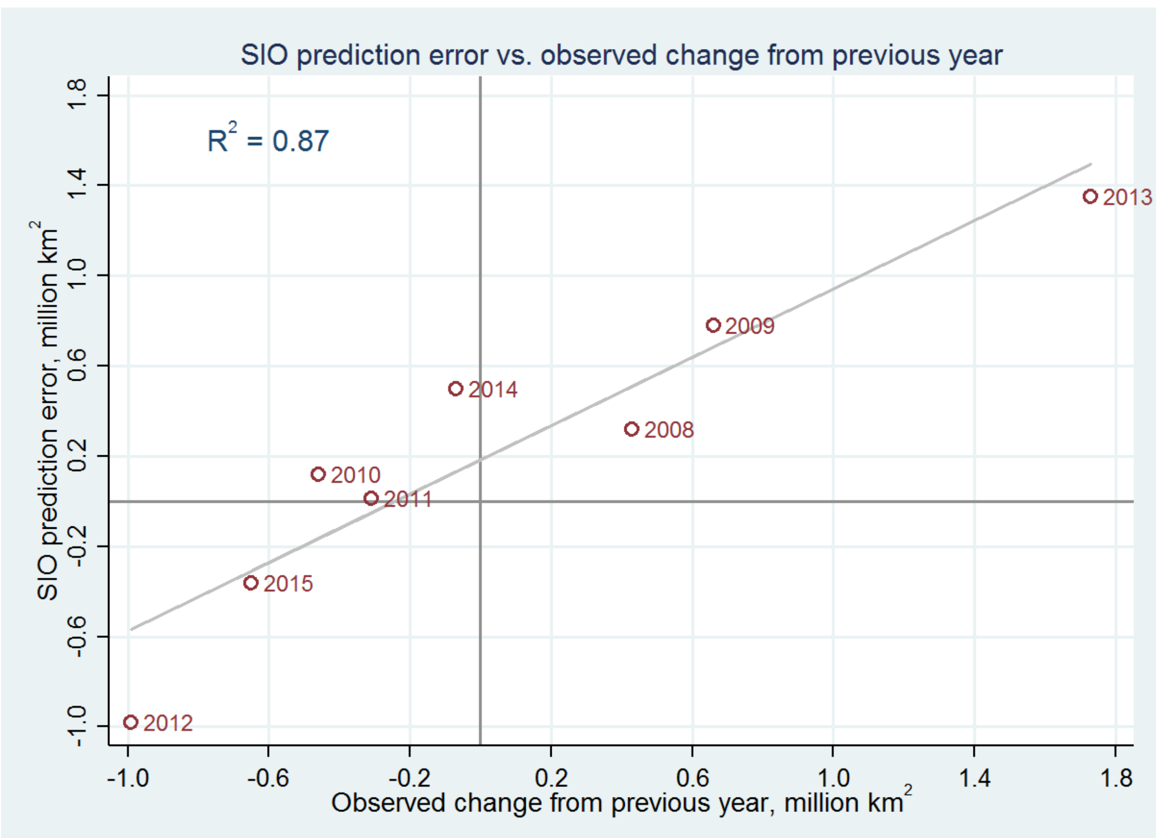

Fig 1. SIO prediction error (median July SIO minus observed) versus observed change from previous year, 2008–2015.

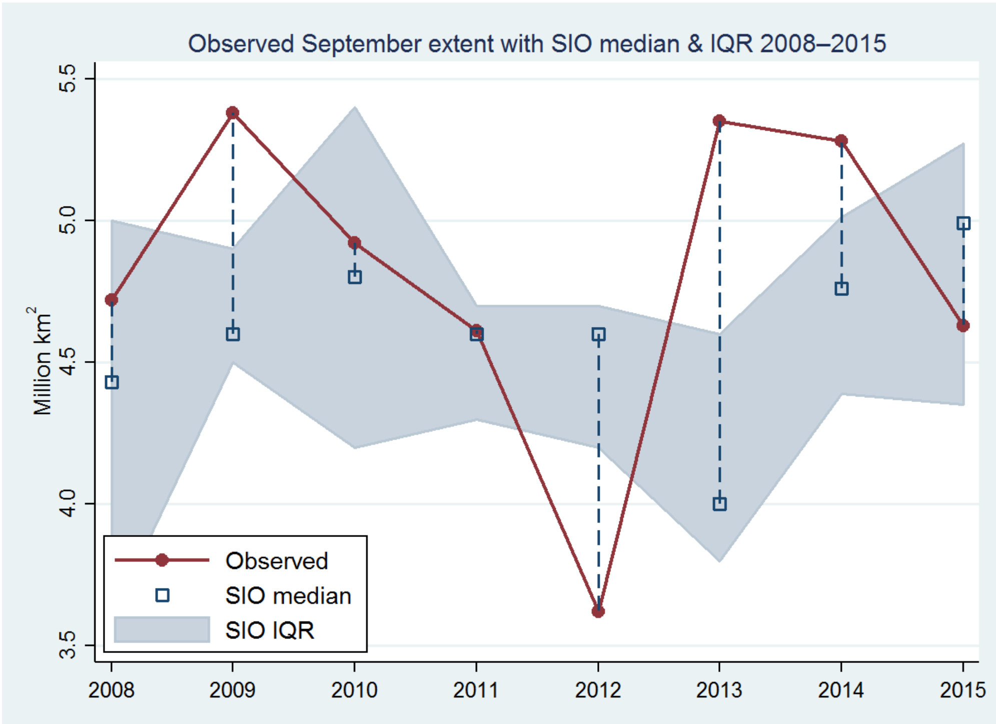

Fig 2. Observed September extent compared with median and interquartile range of July SIO predictions, 2008–2015.

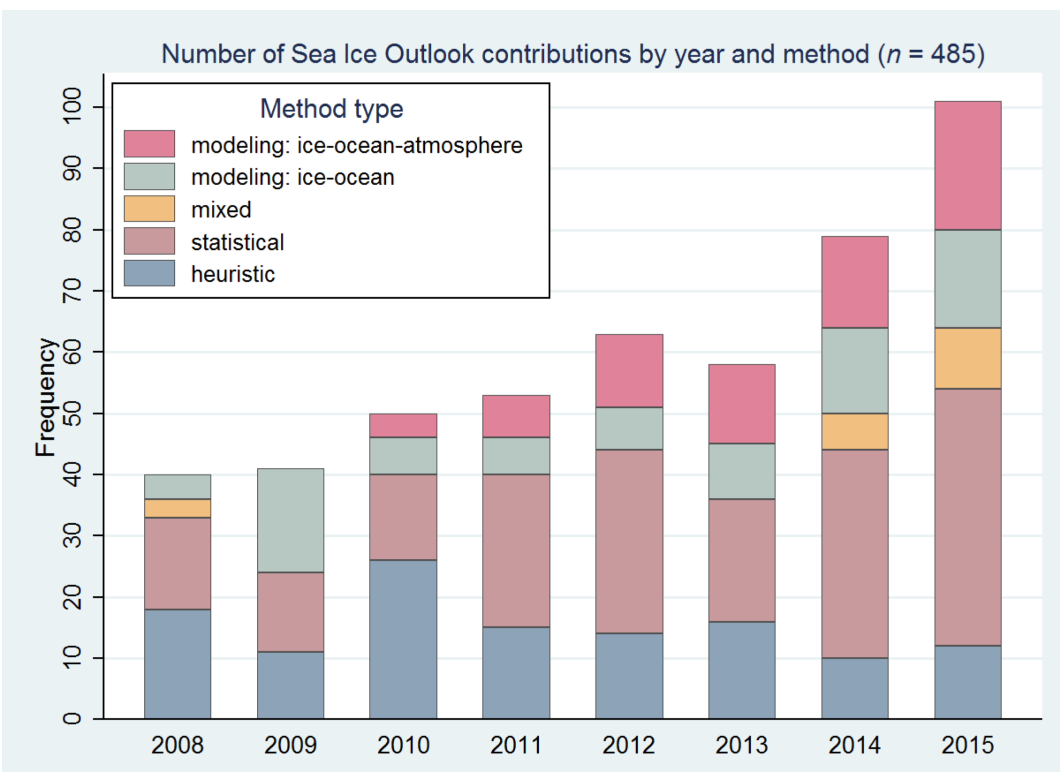

Fig 3. Number and method type of SIO contributions, 2008–2015.

A 3 KA MULTI-PROXY GLACIAL AND ENVIRONMENTAL RECORD FROM DRANGAJÖKULL, VESTFIRÐIR, ICELAND: TERRESTRIAL AND MARINE COEVOLUTION

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In light of the Arctic's sensitivity to recent warming, understanding the mechanisms behind natural and abrupt climate change remains a concern for future modeling projections. Holocene climate reconstructions from marine and terrestrial sites around Iceland demonstrate its sensitivity to both internal and external modes of climate variability yet exact forcings remain debated. By expanding our network of climate records, we can better address the mechanisms behind natural climate change and help constrain their spatio-temporal continuity. Focusing on NW Iceland and the region's largest ice cap, Drangajökull, we employ multiple and independent proxies to elucidate the ice cap´s activity alongside local environmental change over the last 3 ka. Our site's coastal proximity and location between competing Atlantic and Arctic ocean masses also make it an ideal target to investigate the role of dynamic ocean currents and sea ice export on terrestrial environments. We illustrate Drangajökull's ice marginal history through 1) geomorphology revealed in a new DEM of the southern margin, 2) 14C-dated dead vegetation exposed along the receding ice margin and 3) sediment fill of proglacial threshold lakes. Holocene lake cores were measured for magnetic susceptibility (MS), density and organic proxies (TOC, d13C, C/N). Increased MS is matched by shifts from organic sediment to glacial silt, which we interpret to signify the emergence of the ice cap into lake catchments forced under a cooling climate. Lake records in combination with remotely sensed moraines identified in our new DEM also provide a refined delineation of peak areal extent (~262 km2) during the LIA. Temporal constraint is derived from 1) tephrochronology and 14C-dated macrofossils in lake cores and 2) emergent dead vegetation whose 14C dates define past episodes of ice cap expansion and persistent cover until modern warmth forced marginal recession. Our glacial record suggests that Drangajökull was in active states of advance around 410 BC, 180 AD, 450 AD, 940 AD and 1410 AD (LIA). Differing from other Icelandic lake records which illustrate progressive landscape instability, our environmental reconstructions suggest landscape was relatively stable up to the LIA, whereupon all lake records become dominated by glacier erosional product. Moderate to significant correlations between Drangajökull's growth and increased sea ice on the North Iceland Shelf suggest sea ice export from shifting ocean currents played a role in the development of Vestfirðir's Late Holocene climate.

SOIL RESPONSE TO AEOLIAN DISTURBANCE IN WEST GREENLAND

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Arctic soils are a critical ecological resource, yet are increasingly vulnerable to global change. In the Kangerlussuaq region of West Greenland, aeolian disturbance is the greatest threat to soil stability, with strong katabatic winds off the Greenland Ice Sheet (GrIS) eroding vegetation and soil down to the underlying glacial till or bedrock (Figure 1). Distinct unvegetated patches, ranging in size from tens to hundreds of square meters, are ubiquitous throughout the region and are initially colonized by biological soil crusts (biocrusts). Little is known about the spatial distribution, rate, or history of soil deflation in Kangerlussuaq. Here we use remote sensing, lichenometry, and soil analysis of the biocrusts to characterize past and current deflation dynamics.

Our analysis of high-resolution satellite imagery shows that across the entire study region, deflated ground covers 22% of the terrestrial landscape (Heindel et al., 2015). Soil deflation occurs more frequently closer to the GrIS, but becomes restricted to south-facing slopes farther away from the ice sheet margin. The eroded areas are more vegetated farther from the GrIS, providing habitat for graminoid and herbaceous species in an otherwise shrub-dominated ecosystem.

Using lichenometry, we estimate that over the past few hundred years, erosional fronts have moved across the landscape at an average rate of 2.5 cm yr-1. Rates of soil deflation are similar across the study region and do not correlate with local topographical factors such as aspect, slope, or elevation. The initiation of widespread soil deflation occurred during the Little Ice Age, with the mean timing of onset 609 ± 87 years ago. Our results agree well with lake sediment records, which show an increase in silt influx at this time (Anderson et al., 2012; Perren et al., 2012).

Preliminary results from biocrust samples suggest that they play an important role in nutrient cycling in the disturbed soils. Stereocaulon alpinum, a N-fixing lichen, is a common member of the biocrust communities, especially at locations closer to the GrIS. Where S. alpinum occurs, soils directly under the biocrusts have higher %C, %N, lower C:N ratios, and a ?^{15}N suggesting that the cyanobacteria lichen symbionts is improving soil quality through N-fixation. However, the nutrient content of the disturbed soils is still very low, potentially keeping these areas unvegetated far into the future.

Continued soil deflation in the Kangerlussuaq region of West Greenland has the potential to reduce ecosystem productivity and alter nutrient storage and cycling. With warming temperatures potentially outpacing increases in precipitation, Kangerlussuaq may become even more arid. Understanding past and current soil deflation processes will enable us to predict future landscape trajectories in a changing climate.

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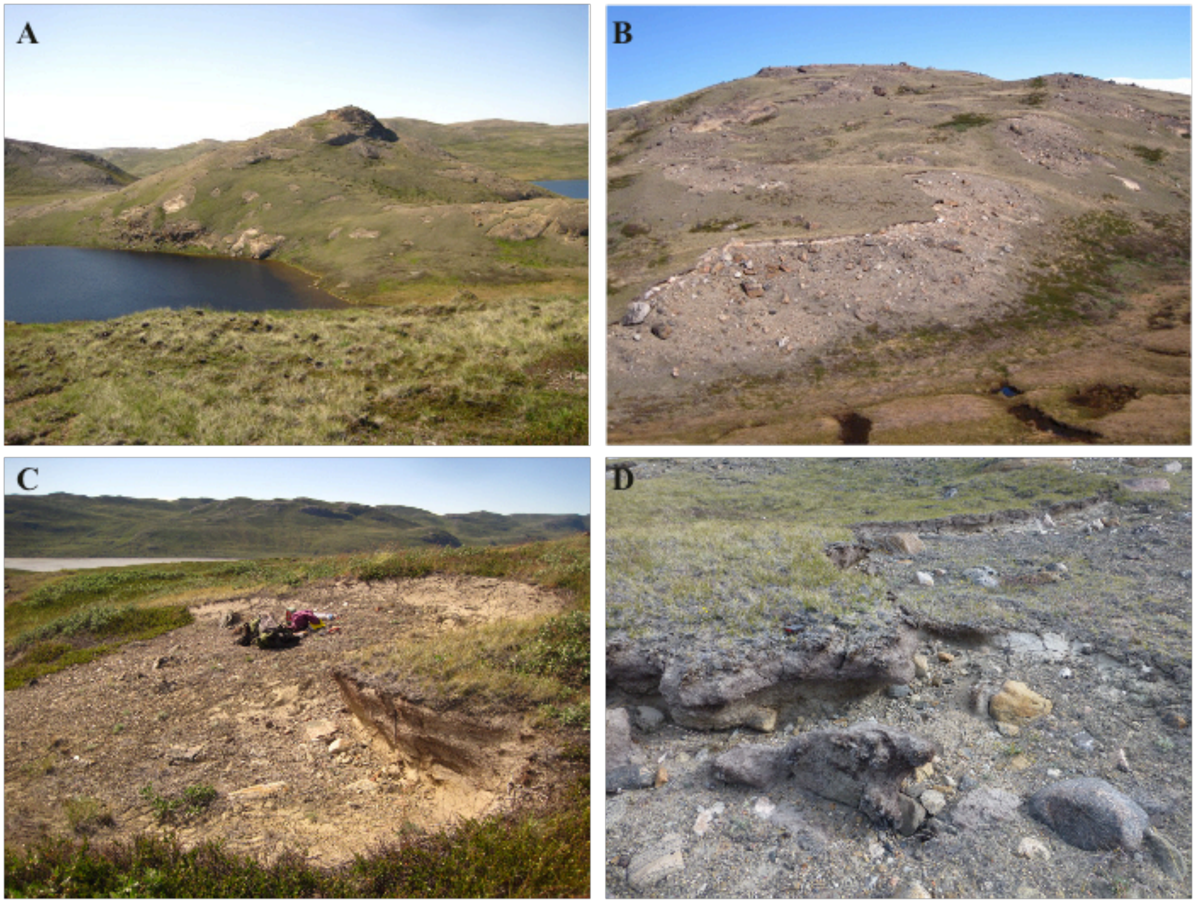

Fig 1. Deflation patches dot the tundra landscape around Kangerlussuaq (A). These bare areas can range in size from hundreds of square meters (B) to just a few square meters (C) in size. Deflation patches expand when units of vegetation and soil fall from the active edge, or scarp (D).

WAS THERE A BAFFIN BAY ICE SHELF IN THE INTERVAL OF LGM AND HS1?

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Did an ice shelf cover Baffin Bay during the last glacial maximum (LGM)? This question arises in response to several modeling studies that grow a large ice shelf during the LGM that covers the Labrador Sea and extends from the Hudson Strait to Greenland, grounding on Davis Strait and both covering and isolating Baffin Bay. The motivation for the modeling studies was to understand the mechanics of Heinrich Events. The expansion of the modeled ice shelf in Baffin Bay is a model byproduct that allows us to test the model. We assume that the modeled ice shelf would prevent in situ primary production and advection of food from the Labrador Sea, thereby severely limiting biological activity in Baffin Bay. Core HU2008029-12PC from the northern Disko trough mouth fan on the central West Greenland continental slope is used to test the ice shelf hypothesis and to investigate LGM and HS1 environments in Baffin Bay, including the role of ocean warming in initiating retreat of the Greenland Ice Sheet from the shelf edge. We use benthic and planktic foram assemblages, stable isotope analysis of planktic forams, biomarkers, ice-rafted detritus (IRD), lithofacies defined from CT scans and quantitative mineralogy to reconstruct paleoceanographic conditions, sedimentation processes and sediment provenance. HU2008029-12PC is bioturbated to varying degrees throughout. We define three intervals in the core that are tied to 3 distinct paleoenvironmental conditions. 1. High CT# sediments between the core base at 11.3 m and 4.6 m (c. 27 to 16.2 cal ka BP) comprise thin turbidites, plumites and hemipelagic sediments with Greenlandic provenance consistent with processes active while the Greenland Ice Sheet margin was at its maximum position, grounded at or near the shelf edge. Abundance spikes of planktic forams provide the radiocarbon dates in this interval and coincide with elevated abundance of benthic forams indicative of chilled Atlantic Water, meltwater and intermittent marine productivity. IRD and IP25 are very rare in this interval, but brassicasterol, an indicator of marine productivity, reaches and sustains low levels by 21.5 cal ka BP. These biological characteristics are consistent with a sea-ice covered ocean with chilled Atlantic Water at depth, rather than full ice-shelf cover. 2. Initial Greenland ice margin retreat is manifested by a pronounced shift from high to low CT#s that corresponds to a lithofacies shift to bioturbated mud with dispersed IRD of Greenlandic origin at 460 cm (16.2 ka BP). This transition occurs within Heinrich Stadial 1. A spike in ocean warmth indicator benthic forams between 16.5 and 16 cal ka BP precedes and straddles the initial ice retreat from the shelf edge and suggests that submerged Atlantic Water shoaled at this time and likely was involved in the ice retreat. After 16.2 ka BP, IP25, brassicasterol and benthic forams indicative of sea-ice edge productivity increase, indicating warming conditions. The sediments continue to have a Greenlandic source. 3. At 286 cm, within the Bølling interstadial, c. 14.3 cal ka BP a strong rise in IP25 content and IRD spikes rich in detrital carbonate with a northern Baffin Bay provenance provide evidence for increased open water, advection of Atlantic Water in the West Greenland Current, and formation of an IRD belt along the W. Greenland margin.

UNPRECEDENTED RETREAT OF THE COLUMBIA GLACIER IN THE LAST MILLENNIUM

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The Columbia Glacier, Alaska's iconic tidewater glacier terminating into the Prince William Sound, has been the subject of an abundance of observational data collection due to its drastic retreat beginning in the 1980's. Here, we couple shifts in magnetic grain size and sediment geochemical variability analyzed in a proximal marine record to depict the chronologic variations of the glaciers terminal ice margin spanning the last 2 ka. At ~0.9 ka, magnetic grain size decreases and a change in sediment geochemistry occurs. This change records the glaciers most recent substantial advance in which it crossed a fault and began eroding both marine sedimentary and mafic bedrock: signature of the basalt protrusions in the region. According to the marine record and more recent direct observations, the terminal margin remained in this equilibrium position until the early 21st century. Today, after some 20 km of rapid mass loss by melting and calving events, the glacier lies north of the fault boundary. Thus the recent magnitude of retreat is unprecedented in the last 0.9 ka of the Columbia Glaciers history. Analyzing the mechanisms behind this retreat prove difficult due to tidewater glaciers high susceptibility to natural internal processes causing drastic retreats. However, using surface air temperatures reconstructed from tree rings, we dispute natural variability and instead interpret recent warming over the last century as the trigger of glacier destabilization resulting in the unprecedented retreat of the Columbia Glacier's ice margin in the last millennium.

THE INFLUENCE OF SPRING AND EARLY SUMMER CLOUD RADIATIVE FORCING ON INTER-ANNUAL ARCTIC SEA ICE VARIABILITY

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The recent decline in autumnal Arctic sea ice extent has been well documented by satellite instrumentation. The mechanisms responsible for a high degree of inter-annual variability, however, remain less understood. In this study, we analyze how cloud radiative forcing anomalies in April through July contribute to this variability by influencing the location and degree of ice loss during the melt season. Recent studies have supported the concept that spring and early summer atmospheric conditions are related to September sea ice extent [Choi et al., 2014; Kapsh et al., 2014]. Although variables such as sea ice concentration and extent are temporally and spatially complete, changes in sea ice thickness and total volume can provide a more holistic understanding of the magnitude of surface energy imbalances at work. This study uses modeled monthly sea ice thickness values from the Pan-Arctic Ice Ocean Modeling Assimilation System (PIOMAS) to track changes in ice thickness throughout the melt season. Comparisons between ICESat and CryoSAT observational sea ice thickness data allow for validation and bias correction when possible. Anomalies and noted trends in ice thickness, advection, melt rate, and date of melt onset are compared to anomalies in cloud and surface radiative flux data from the Cloud and Earth's Radiant Energy System (CERES) data. Anomalies in the net cloud radiative forcing during individual months (April through July), as well as the calculated cumulative anomaly during this time, are of particular emphasis in this study. Preliminary results suggest certain regions, such as the Beaufort Sea, are more sensitive to springtime cloud radiative anomalies. This is due, in part, to an earlier melt onset that accompanies enhanced downwelling radiative fluxes.

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OXYGEN ISOTOPES OF PRESERVED AQUATIC ORGANIC MATERIAL RECORD PAST LAKE WATER AND CLIMATE CHANGE IN NW GREENLAND

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Oxygen isotopes of paleo lake water archived in subfossil aquatic organic material offer new insights into Arctic Holocene climate histories. Here we present new constraints on the timing and magnitude of peak warmth in NW Greenland inferred from d18O of chironomid head capsules, Cladocera ephippia, and aquatic macrophytes. Sediment cores recovered from two small, non-glacial lakes in 2014 near Thule Air Base capture continuous 7.7 kyr and 10.4 kyr records. d18O of chironomids and macrophytes from Secret Lake decreases after 6 ka by 3 ‰ into the Neoglacial. Early Holocene values from Wax Lips Lake (informal name) are 3 to 4 ‰ higher than modern and decrease to the present. Along with the consistent trends among preserved organics in both cores, surface sediment d18O of these materials record lake water d18O and, at appropriate sites, precipitation d18O. d18O of aquatic insect remains from surface sediments show consistent enrichment relative to lake-water. Lake-water d18O collected during the summer of 2014 is comparable to modern and historical local meteoric water, and landscape position precludes anything but precipitation inputs. At both lakes, declining d18O from the early/middle to late Holocene is clearly recorded in multiple aquatic materials and is greater in magnitude than the mid to late Holocene changes in d18O of the nearest ice core records (Agassiz and Camp Century, ~2 ‰). The temperature change inferred from this new d18O approach is larger than, but within the error of, chironomid assemblage based temperatures from nearby lakes. This may indicate larger temperature changes at the ice sheet's margin than inferred from high-elevation ice core sites, some overprinting by enhanced evaporation of lake water, or reduced northern Baffin Bay sea ice extent in the warmer climate of the early Holocene.

EFFECTS OF SEA ICE ON THE HABITAT PREFERENCE OF ANTARCTIC MINKE WHALES (BALAENOPTERA BONAERENSIS) ALONG THE WEST ANTARCTIC PENINSULA

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This study aims to understand the habitat preference of Antarctic minke whales (Balaenoptera bonaerensis) with respect to sea ice extent and concentration around the West Antarctic Peninsula (WAP). Ship- and aerial-based surveys have suggested this mesopredator exhibits a pagophilic nature, and we aim to provide the first satellite tag-based habitat analysis. As a relatively small whale species, the Antarctic minke whale is well suited to life in the pack ice where larger cetacean species, such as blue and humpback whales, are unable to maneuver or hunt as successfully. In February 2013, Dr. Friedlaender and colleagues attached Argos satellite tags to three Antarctic minke whales in Wilhelmina Bay, on the western coast of the WAP. We aim to correlate the whales' movements over time with proximity to the ice edge and evaluate if there are differences in day/night behavior as well as determine if their relationship with the ice changes throughout the season. Daily ice records exhibit a relatively constant sea ice extent throughout February and March before steadily increasing as the austral winter months progressed. Preliminary results indicate periods of migration and rest for each whale, as seen by the change in tortuosity, speed, and distance travelled between timesteps. Two of the whales also seem to prefer sea ice habitats during summer and fall months, while the third whale remained in the Southern Ocean for the entire study period, suggesting a possible difference in reproductive cycles or sex-dependent migration patterns.

IT TAKES TWO: USING 10BE AND RADIOCARBON DATING TO DECIPHER THE GLACIAL HISTORY OF SOUTHEASTERN ALASKA DURING THE LAST GLACIAL MAXIMUM

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The route and timing of early human movement to the Americas has been a contentious topic for decades. Traditionally, humans were thought to have colonized the Americas via an inland ice-free corridor between the Cordilleran and Laurentide ice sheets, but recent studies suggest this migration took place before the ice-free corridor was ecologically viable (Dixon, 2013). In light of this evidence, it has been proposed that early humans used coastal ice-free areas (refugia) as “stepping stones” to the New World. Despite southeastern Alaska’s potential role in the human colonization of the Americas, well-dated records of its late Pleistocene glacial history are lacking, and there remains no direct evidence that portions of the region were ice-free during the Last Glacial Maximum (LGM; ~30-17 ka). To address this issue, 13 bedrock and boulder samples were collected from mapped refugia (Carrara et al., 2007) in the Alexander Archipelago of southeastern Alaska. Thus far, five 10Be exposure ages have been obtained. Two bedrock samples from Dall Island return an average 10Be exposure age of 17.5 ± 0.5 ka, and three samples from Suemez Island (two erratics and one ice-sculpted bedrock sample) average 17.2 ± 0.9 ka. These two sites, previously mapped as LGM refugia, appear to have been occupied and eroded by the Cordilleran Ice Sheet during the LGM, which retreated from the outer coast of the Alexander Archipelago between 18 and 17 ka.

Additional information about the glacial history of southeastern Alaska comes from a cave on northern Prince of Wales Island known as Shuká Kaa. Excavations of the cave during the 1990s unearthed hundreds of fossils, of which 122 have been reliably radiocarbon dated (Heaton and Grady, 2004). We have calibrated these radiocarbon ages for the first time, revealing a nearly continuous fossil record that spans from the limit of the radiocarbon dating method to the present. However, none of the fossils in Shuká Kaa yielded radiocarbon ages between ~19-17 cal kyr BP. The lack of radiocarbon ages in this interval could simply result from non-deposition of fossils in the cave, or alternatively, it could imply that the Cordilleran Ice Sheet covered Prince of Wales Island between ~19 and 17 ka. Interestingly, our 10Be exposure ages align with this gap in the fossil record at Shuká Kaa. Furthermore, visual identification and ancient DNA analysis (Heaton and Grady, 2004) show that fossils bracketing this interval are exclusively from animals adapted to glacial conditions, such as arctic fox (Vulpes lagopus) and ringed seal (Phoca hispida), leading us to conclude that the Cordilleran Ice Sheet occupied this region from ~19-17 ka.

Taken together, the radiocarbon and 10Be exposure ages provide two new insights into the glacial history of southeastern Alaska: (1) in contrast to previous reconstructions (Dyke, 2004; Carrara et al., 2007), this first direct chronology indicates that the western Cordilleran Ice Sheet seems to have overridden the outer islands of the Alexander Archipelago, and (2) the advance and retreat of the Cordilleran Ice Sheet in southeastern Alaska between ~19 and 17 ka was in phase with fluctuations of the broader ice sheet (Cosma et al., 2008). Although we have yet to find evidence of LGM refugia in southeastern Alaska, our results demonstrate that the outer islands of the Alexander Archipelago were ice-free ~1 kyr prior to the first pulse of human migration to the Americas at ~16 ka (Erlandson and Braje, 2011; Pitblado, 2011), and therefore the region may have indeed served as a “stepping stone” to the New World.

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MID-HOLOCENE MARINE PALEOCLIMATE FROM ROLVSOYA AND INGOYA: NORTHERN FINNMARK, NORWAY

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Adapting and responding to impending shifts in climate requires a comprehensive understanding of past climatic variability. As direct records of climate extend only as far as modern human history, more extensive reconstructions rely on proxy data to hindcast historical climatic systems and patterns. One such proxy is the marine bivalve Arctica Islandica, a long lived marine bivalve species prevalent in many high latitude ocean ecosystems. A. Islandica archive environmental records in their carbonate shell, both in the morphology of annually deposited growth increments as well as the isotopic concentration of the aragonitic shell material. Sclerochronology, the study of these concealed climatic indications, has been a valuable tool in reconstructing the history of the world's oceans (Wanamaker et al., 2011). We recovered A. Islandica specimens from the northern Norwegian islands of Rølvsoya and Ingøya, located within the Arctic Circle at 71°05 N 24°03 E and 70°98 N 24°03 E (Figure 1) respectively. A wide variety of atmospheric and oceanic systems influence the islands, making them highly sensitive to even minor shifts in the climatological trends, and making Rølvsoya and Ingøya an ideal location to catalog Arctic climate history.

Evidence from both marine and terrestrial realms suggest a general temperature decrease in the North Atlantic region over the past 6000 years (Wanner et al., 2008). Annual growth increments from two mid-Holocene A. Islandica specimens, dated at 6245 and 6011 years B.P, were subsampled in order to establish annual seasonality differentials. Mid-Holocene A. Islandica specimens from Rølvsoya and Ingøya show substantially more compressed summer to winter temperature differentials than currently exist at the island. Furthermore, the older of the two specimens shows lower overall temperatures and a greater seasonal temperature differential. This inversion of temperature and seasonal amplitude may be a result of diminished vertical water column mixing in warmer overall conditions.

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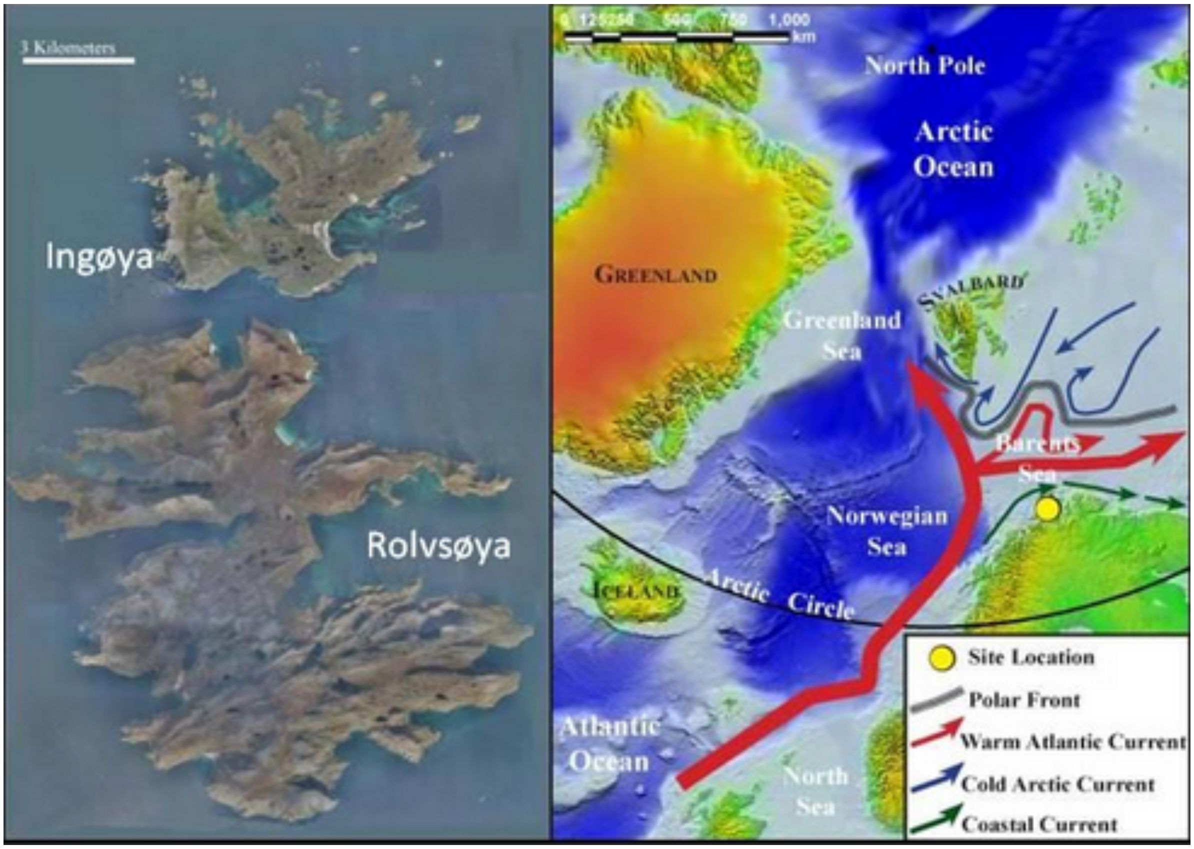

Fig 1. Aerial image of study location and oceanographic context map (From Wanamaker (unpublished) modeled after Loeng 1997, and Google Earth)

HIGH RESOLUTION XRF SEDIMENT MINERALOGICAL ANALYSIS OF LATE SEASON PRECIPITATION EVENTS IN A HIGH ARCTIC GLACIATED WATERSHED

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Sediment transport in High Arctic watersheds has historically been dominated by the melt-induced processes (Woo and McCann, 1994). However, in Svalbard, the last decade has experienced increased discharge variability and late season sedimentation events (Nowak and Hodson, 2013). This study provides a detailed description of sedimentation corresponding to these late season precipitation events in Linnevatnet, western Spitsbergen (figure 1). Annual sediment traps of three consecutive years ('12-'13, '13-'14, and '14-'15) were examined through the coupling of high-resolution x-ray fluorescence (XRF) analysis with lower resolution grain size and magnetic susceptibility measurements. Geochemical signatures were compare temporally and geographically across the basin. Zirconium counts and Fe/Ti ratios (Cuven et al., 2010) were used to delineate events (Figure 2) and seasonal boundaries.

All three years experienced large fall precipitation events, resulting in peaks of coarse sediment deposition coupled with variable Ca content. Principle Component Analysis was run on 10 elemental constituents (Al, Si, K, Ca, Ti, Mn, Fe, Rb, Sr, and Zr) in order to examine the relationship between their variation. The '13-'14 year showed a strong relationship (PC1>0.5) between all 10 elements and the first principle component (PC1), suggesting the elements varied together. The '13-'14 sediment budget was dominated (>40%) by a single late August precipitation event. Multiple late season precipitation events in '12-'13 and '14-'15 were reflected by increased variance in sediment geochemistry.

Cuven S, Francus P, Lamoureux SF., 2010, Estimation of grainsize variability with micro Xray fluorescence in laminated lacustrine sediments, Cape Bounty, Canadian High Arctic: J Paleolimnol v. 44, p. 803–817.

Nowak A & Hodson AJ., 2013, Hydrological response of a High Arctic catchment to changing climate over the past 35 years; A case study of Bayelva watershed, Svalbard: Polar Research v. 32, 19691,http://dx.doi.org/10.3402/polar.v32i0.19691.

Woo, M.K. and McCann, B.S., 1994, Climatic variability, climatic change, runoff, and suspended sediment regimes in northern Canada: Physical geography v. 15, p. 201.

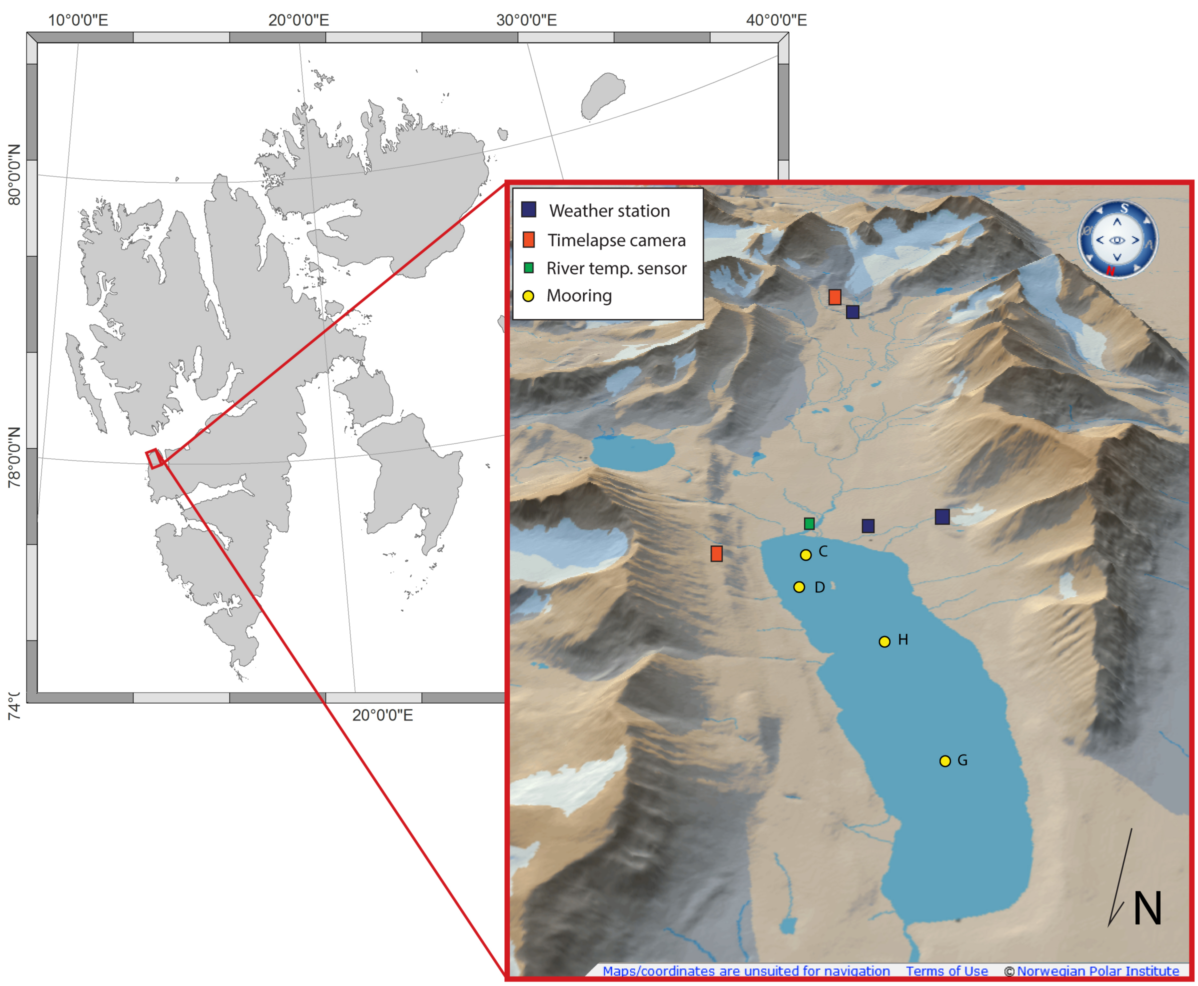

Fig 1. Study location with an inset of the Linnedalen monitoring system. Moorings containing sediment traps are arranged in a transect across the lake from proximal (C) to distal (G). The 3D rendering was produced in Toposvalbard (Norwegian Polar Institute).

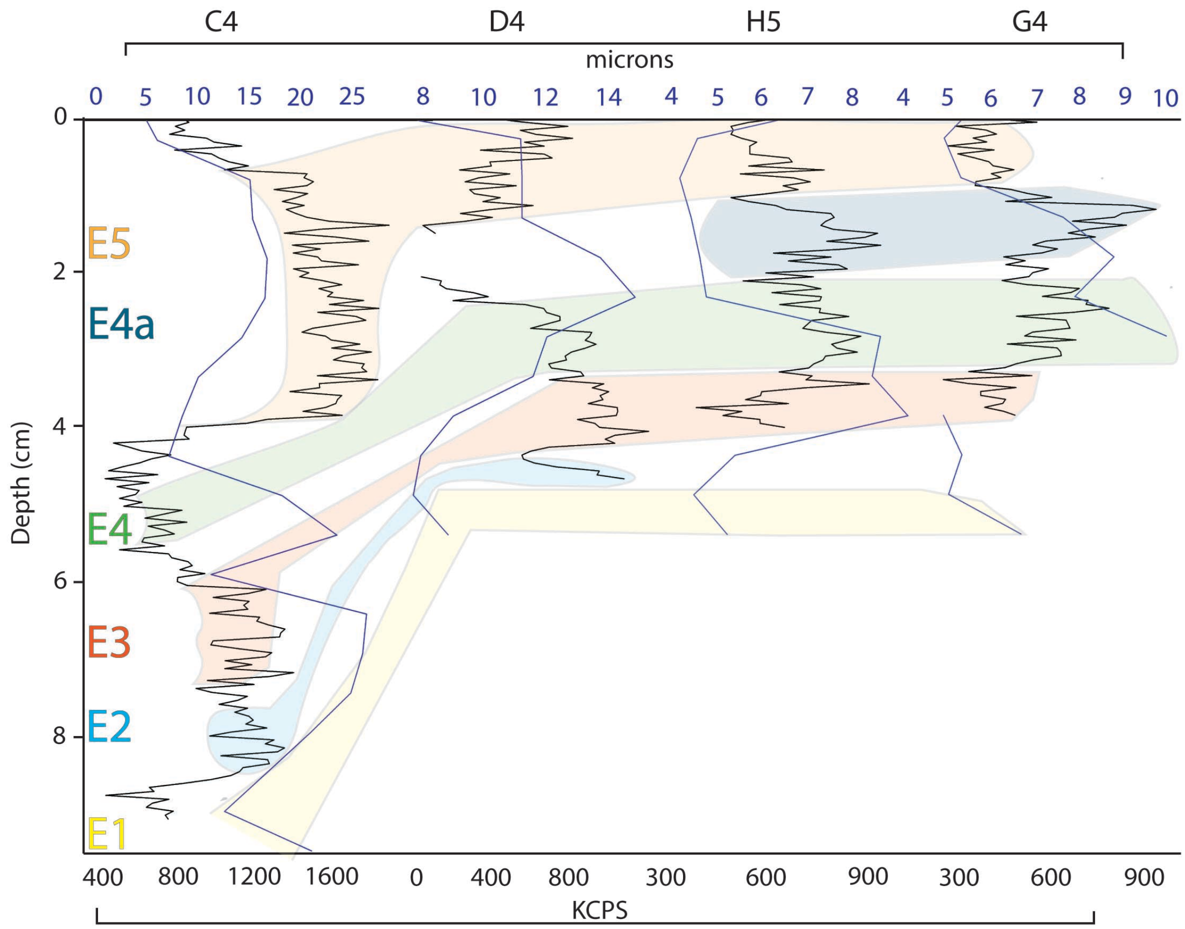

Fig 2. The cross basin event (E) chronology for the '14-'15 sediment. Kilo-counts per second (KCSP) of zirconium (black line) were used to develop the event chronology. Grainsize (blue line) is presented for comparison.

USING SHELL-BASED PROXY RECORDS FROM NORTHERN NORWAY TO EVALUATE HIGH LATITUDE IMPACTS OF THE ATLANTIC MULTIDECADAL OSCILLATION

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The Atlantic Multidecadal Oscillation (AMO) is thought to be a persistent feature of North Atlantic Ocean climate variability, switching between warm and cool periods on the order of 60-80 years. The lack of long-term, high-resolution surface ocean records, however, hinders a complete understanding of its persistence, interactions with other climate modes, and possible forcing mechanisms. Evidence for the AMO's influence and persistence at high northern latitudes is especially scarce (Drinkwater et al., 2014). Arctica islandica shell-growth and geochemical records from northern Norway show significant correlations with the AMO index over the past 112 years ($r2 = 0.39$). Running correlations with the North Atlantic Oscillation vary in sign coincidently with AMO phases, suggesting complex air-sea interactions at high latitudes. Extending the shell-growth and geochemical records for several centuries will provide insight into the AMO's influence in the Barents Sea, and help establish the long-term dynamics and persistence of the AMO.

Drinkwater, K. F., Miles, M., Medhaug, I., Otterå, O. H., Kristiansen, T., Sundby, S., and Gao, Y. 2014, The Atlantic Multidecadal Oscillation: Its manifestations and impacts with special emphasis on the Atlantic region north of 60°N: Journal of Marine Systems, v. 133, p. 117-130.

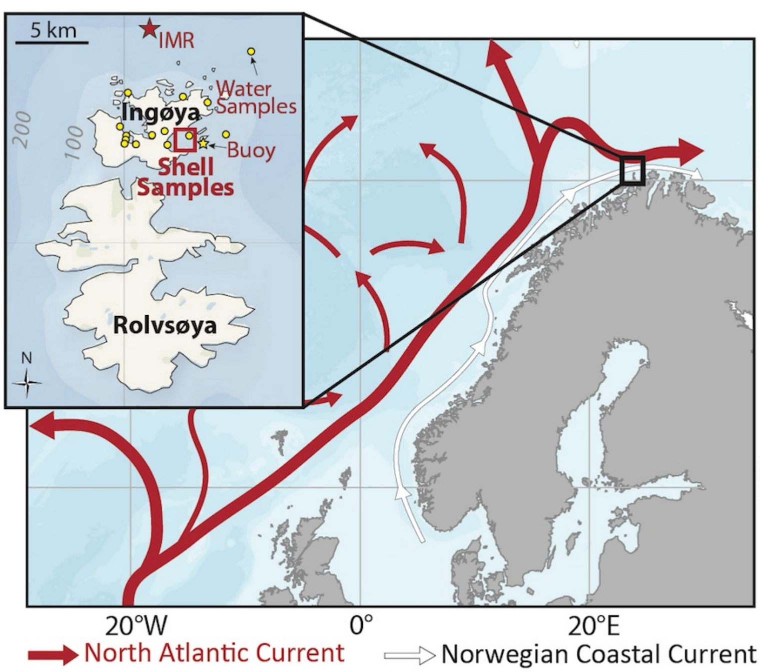

Fig 1. Map of the northeastern North Atlantic Ocean showing paths of two major surface currents in the region. Map of the study site at Ingøya and Rolvsøya (inset) showing locations of sample collection, observational mooring (buoy), and IMR Oceanographic Monitoring Station. Bathymetric contours are shown in meters.

MULTI-PROXY EVIDENCE FOR ENHANCED DISCHARGE OF ARCTIC SEA ICE AT THE ABRUPT ONSET OF THE LITTLE ICE AGE

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Sea ice is a key component of the climate system and an amplifier of climate change, e.g., expanded sea ice cover may have been a factor in the Little Ice Age (LIA)(Miller et al., 2012). An important aspect is the sea ice and freshwater exported from the Arctic Ocean through Fram Strait and transported towards the North Atlantic via the East Greenland Current (EGC). The EGC is the Earth's largest pathway of Arctic sea ice and freshwater transport, with important linkages to ocean circulation and climate-system variability, e.g. Great Salinity Anomalies (GSAs) may affect subpolar gyre dynamics and deep convection in the Labrador Sea. The long-term variability of this sea-ice stream is not well known at high-resolution beyond the historical record of observations. Previous paleo research has been fragmentary, often focused on limited data records. The increasing number of high-resolution records recently developed for sea ice and ocean proxies along the pathway of the EGC opens an opportunity to more comprehensively identify changes and linkages in this exceptionally complex regional system.

Here we present a data synthesis focused on constraining and understanding modulations in this sea-ice stream during the past millennium. During this period, we focus on changes occurring at the onset of the LIA through to the Early Twentieth Century Warming (ETCW), as well as shorter-term excursions such as GSAs. These goals are addressed through a targeted and integrated data synthesis of disparate historical and paleoceanographic data records from along EGC pathway (including the Jan Mayen Current and East Icelandic Current) and farther downstream. These are comprised of existing records indicative of sea ice and ocean conditions based on multiple proxies, including direct sea-ice proxies (IP25) and indirect indicators (mineralogical, e.g., ice-rafted debris, and biological indicators, e.g., foraminifera and diatoms). We compiled and evaluated detailed metadata on over 180 records, and based on multiple criteria have selected 12 commensurate records spanning the length of the extended EGC sea-ice pathway from the Fram Strait to Cape Farewell and around to its farthest extension along southwest Greenland – the latter being co-located with the Norse Greenland colonies.

We find reasonable coherence between the disparate records, particularly around 1300 at the abrupt onset of the LIA, when markedly enhanced discharge - i.e., a pulse of sea ice - from the Arctic Ocean can be inferred from a statistically extreme peak in sea ice apparent in records throughout the length of the EGC pathway and farther downstream. Positive anomalies in sea ice and polar waters are generally persistent through the following centuries, though with large fluctuations across a range of time scales. In the perspective of EGC sea ice, the LIA is not seen to terminate until the abrupt onset of the ETCW around 1920.

Miller, G. H. et al. 2012, Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks: Geophys. Res. Lett., v. 39, L02708.

SATELLITE RECORD OF NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) REVEALS CONTRASTING TRENDS IN NORTHERN WEST SIBERIA

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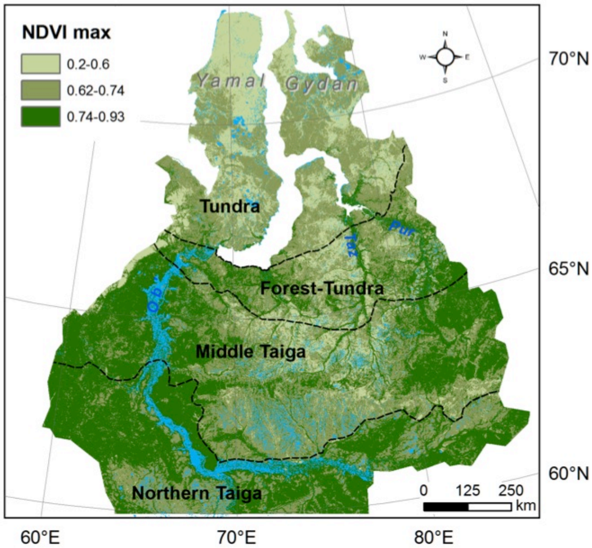
Studies of normalized difference vegetation index (NDVI) from low-resolution satellite sensors have found broad changes in vegetation productivity in high northern latitudes in the past decades, including widespread increases in NDVI ("greening") in tundra regions and decreases ("browning") in forest regions. This study updates and expands upon previous studies of high northern latitude vegetation productivity, here focused on northern West Siberia (NWS), an expansive region with a high degree of regional and landscape heterogeneity. We use high-resolution (250 m) satellite data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard of the Earth Observing System-Terra satellite. Using the MODIS NDVI data products, we generate a spatially detailed 15-year series of annual maximum NDVI (NDVImax) for the entire NWS for 2000–2014. We examine spatial–temporal variability and changes in vegetation productivity, focused on differences in vegetation productivity patterns and trends between – and within – different forest types in four bioclimatic zones: tundra, forest–tundra and the boreal zone with northern and middle taiga sub-zones. Our results show that only 18% of the total NWS area had statistically significant changes in productivity, with 8.4% increasing (greening) and 9.6% decreasing (browning) (see Fig.1). There is spatial heterogeneity (patchiness) in the trends, and there are contrasting trends both between and within bioclimatic zones. Browning of forest and non-forest vegetation has a latitudinal gradient and occurred more frequently in the warmer part of the species ranges; in particular the middle taiga sub-zone shows significant decline in both forest and non-forest vegetation. A key finding is the identification of contrasting trends for different species within the same bioclimatic zone. In particular, most negative trends in the taiga appear to be related to a decline in evergreen coniferous forest, with the dark (Picea abie, Picea obovata) or light (Pinus sylvestris) evergreen and evergreen-majority mixed forests showing highest decline in productivity (76% of all negative trends for forested areas) in every zone. In contrast, deciduous needle-leaf forest dominated by larch (Larix sibirica) shows a significant increase in productivity (54% of all positive trends for forested areas), even while neighboring different species show decreasing productivity. These results underscore the complexity of the patterns of variability and trends in vegetation productivity, and suggest the need for spatially and thematically detailed studies to better understand the response of different northern forest types and species to climate warming.



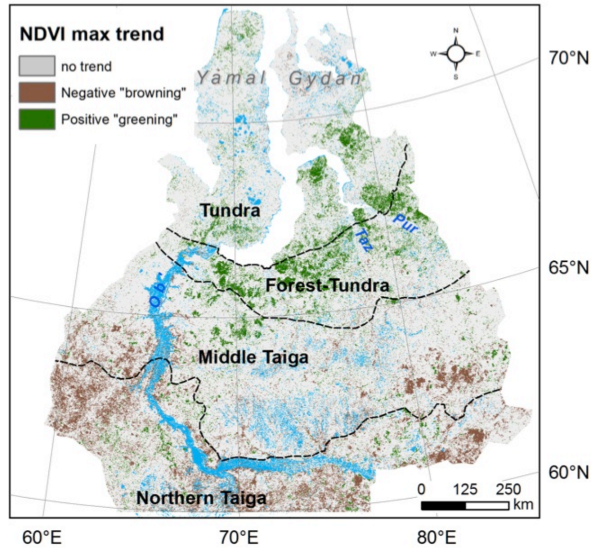


Fig 1. The 15-year mean NDVImax (left) and NDVImax trend 2000-2014 ($p<0.05$) (right)

HOW UNUSUAL IS THE BARNES ICE CAP'S LIKELY DISAPPEARANCE IN THE NEAR FUTURE

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The Barnes Ice Cap (BIC), central Baffin Island, is the only true relict of the great Laurentide Ice Sheet (LIS) that once covered much of northern North America. As the last of the LIS continued to recede during the early and middle Holocene, its final remnant was an elongate proto-BIC that resided over the central Baffin Island plateau. This ice cap reached the modern dimensions of the BIC about 2 ka, and underwent a slight expansion during the LIA. It has been known for more than 50 years that should the BIC disappear, it would not reform. In other words, it creates its one climate sufficient to sustain the ice cap. A long-unanswered question is how often does the residual LIS completely disappear during interglaciations of the Quaternary. The presence of ice-transported thick lenses of vegetation bearing evidence of warmer-than-present summers close to the current BIC margin testifies to earlier times when the BIC melted completely, but these deposits have never been accurately dated.
Recent field studies around the BIC showed that the ice cap is losing mass rapidly in recent decades, and NASA overflights document surface lowering at all elevations. We sampled bedrock and erratic clasts close to the ice cap from which cosmogenic radionuclides (CRN) provide temporal constraints on the timing and duration of Quaternary exposure at and nearby the current BIC margin. We have also modeled the current mass balance of the ice cap and derived estimates of its future state under various emissions scenarios. Ice-cap modeling indicates that BIC will disappear within a few hundred years under the most probably emissions scenarios. CRN inventories and disequilibria indicate that the BIC almost never melt completely in Quaternary interglaciations. Combined, the modeling and CRN data are consistent with the Arctic entering into a new state that has rarely, if ever, occurred over the past 2 million years.

ARCTIC CLIMATE PREDICTIONS: PATHWAYS TO RESILIENT, SUSTAINABLE SOCIETIES (ARCPATH)

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This presentation will focus on ARCPATH, a large interdisciplinary Nordic Centre of Excellence project that has recently been funded by NordForsk (http://www.nordforsk.org/en/news/nok-112-million-awarded-to-four-new-nordic-centres-of-excellence-in-arctic-research). Project team members are from institutes in the Nordic countries of Iceland, Norway, Denmark and Sweden. International members are from Canada, USA (including from INSTAAR and NSIDC), UK, Russia, China, and Germany. The project is led by Yongqi Gao at the Nansen Environmental and Remote Sensing Centre (NERSC) in Bergen, Norway, and co-led by Astrid Ogilvie via the Stefansson Arctic Institute (SAI) in Akureyri, Iceland (http://arcticiceland.is/en/?option=com_content&view=article&id=257&catid=8&Itemid=102). The project will last for 5 years beginning in January 2016. The context of the project is the fundamental importance of the Arctic in the climate system, host to key atmospheric and oceanic processes and feedbacks. Added to this, global warming has caused intense changes in Arctic climate, with a rise in temperatures during recent decades that is close to twice that of other regions (IPCC, 2013; Arctic Report Card, 2015). These rapid changes are a challenge to human welfare that is already at risk from socio-economic as well as climatic drivers (Einarsson, et al., 2004). Loss of sea ice is particularly relevant, with a direct and immediate effect on Arctic communities, through increased shipping (and attendant risks) as well as the many complex issues involved in Arctic oil and gas exploration, together with effects on fisheries and marine mammals (Bravo and Rees, 2006; Lovecraft, 2013). Anticipating climate change in the Arctic over coming decades is potentially more important from a societal and adaptation-planning perspective than simply projecting climate to 2100 – an exercise that is intrinsically uncertain, especially at a regional level (IPCC, 2013). Climate fluctuations on the timescale of a decade, and at local levels, are strongly influenced by feedbacks internal to the climate system. Above these uncertainties in climate stand the complex socio-ecological interactions between climate and global change. Together they bring manifold challenges to planning responsible development in the Arctic.

The ARCPATH project seeks to address these issues by focusing on near-term changes, with the overarching goal of fostering responsible and sustainable development. This requires the reconciliation of environmental, social, and economic demands.Thus, these three aspects are central to the project's three main goals: i) To predict regional changes in Arctic climate over the coming decades using innovative methods to capture both anthropogenic and natural factors in global and high-resolution regional models; ii) To increase understanding and reduce uncertainties regarding how changes in climate interact with multiple societal factors, including the development of local and regional adaptation measures; iii) To combine improved regional climate predictions with enhanced understanding of environmental, societal, and economic interactions in order to supply new knowledge on potential "pathways to action". These pathways will include: i) Evaluations of how potential climate-driven physical and ecosystem changes may affect interlinked economic activities, ecosystem services, and human welfare in Arctic coastal communities; with particular regard to fisheries, marine-mammals, tourism, shipping, and industrial activities; ii) Strategies regarding societal effects of reduced sea-ice cover, and related climate impacts, and local, regional and international measures to adapt to such changes, including resource management, preparedness and human security.

Previously unused historical climate and marine data will also be analysed to explore, integrate, and disentangle the multiple factors involved in climate-socio-ecological linkages (Ogilvie, 2010). Furthermore, ARCPATH will use risk analysis and assessment to gain new insights into the nature of environmental change, social impacts and resilient response pathways in marine resource-based and vulnerable Arctic communities. Research results will have clearly defined socio-economic relevance to the national interest of Nordic countries, and these will be disseminated to policy makers and stakeholder groups. ARCPATH will facilitate planning adaptation strategies, and will also take advantage of new opportunities to reduce environmental and economic risks. ARCPATH brings together a strong team, leaders in their respective fields, experienced in collaborative studies, and situated at institutions in the forefront of Arctic research. The combined multi-disciplinary expertise of team members, covering climate and social sciences, and extending from marine biology to environmental economics, will create the synergistic environment needed to address the crucial issues facing northern societies.

ARCPATH research will build on, and improve, cross-disciplinary state-of-the art research in order to provide new insights and novel approaches to responsible development in the Arctic. This requires the consideration of numerous complex elements. The Arctic has seen dramatic changes in environmental, social, and economic spheres during the last decade. The region is no longer a place of isolation, and local community livelihoods and global processes are closely interlinked. Abrupt climate change magnifies these complex linkages through biophysical changes such as the movement of fish stocks; for example, mackerel, formerly associated with more southerly waters, to northern waters off Iceland and Greenland. Such major ecosystem alterations have profound social and economic impacts on coastal communities. This calls for flexibility in resource-use practices and governance systems. The Arctic is also opening up to mass tourism, providing new sources of economic and employment opportunities. A key example of this is marine tourism, in particular the activities of whale watching and cruise tourism (Einarsson, 2009; Rasmussen, 2014). However, tourism also contains potentially negative challenges manifested in conflicts with existing harvesting practices such as indigenous and other whaling. Oil and gas seismic exploration, and its impacts on cetacean behaviour are also perceived by some coastal communities as highly problematic, and a potential threat to local livelihoods. Clearly, changes in climate will prompt widespread and, in some regions, even radical changes in biodiversity, stock sizes, migration, and distribution, and other changes in marine ecosystems. However, at present, there is not enough information to forecast these changes accurately. The Arctic Biodiversity Assessment notes: "To date, no studies have been designed or implemented that attempt to distinguish between the effects of climate change and the effects of increasing anthropogenic activity in the Arctic for marine mammals" (CAFF, 2013).

In order to most constructively propose strategies to deal with coming changes, ARCPATH will adopt a regional approach to consider how specific areas and communities in three Arctic countries are being affected by such changes. These are: Iceland (coastal and fjord communities in the northeast); Greenland (Ittoqqortoormiit, formerly Scoresbysund, in eastern Greenland, see Figure 1); and northern Norway (in particular Honningsvåg and vicinity in Finnmark, and the Lofoten region). The study areas have been chosen because they are Arctic locations where change on many levels is occurring very rapidly, but also because they lend themselves well to the emphasis on climate change in the project.

In terms of climate, the Arctic North Atlantic is one of the more variable regions of the world. This is partly because variability tends to be amplified in high latitudes relative to the global mean, but also because of naturally high atmospheric, oceanic, and sea-ice variability. Importantly, climate variations in this region are particularly pronounced on decadal timescales; for example, there have been periods, such as during the early-twentieth century warming, that appear to have been regionally stronger than the anthropogenically-driven, centennial-scale warming. Historical records indicate the persistence of decadal variations over the past few centuries (Miles et al., 2014), their links to marine ecosystem shifts in the Atlantic and Arctic sectors, impacting whales and fisheries, and consequent socio-economic impacts on Arctic residents (Ogilvie et al., 2016). There is evidence that these decadal variations are linked to ocean circulation in the Atlantic, and result from partly predictable feedbacks internal to the climate system. Thus, ARCPATH will undertake near-term or decadal climate predictions that account for natural, internal and anthropogenic, external factors. High-resolution regional models will be used to downscale these predictions to make them more relevant to understanding social processes. Accounting for natural climate variability, and focusing on centennial timescales, will make the results more useful than are currently available from climate projections that include only the effects of external forcing.

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Rasmussen, M., 2014, The whaling versus whale-watching debate, Whale-watching: Sustainable Tourism and Ecological Management, 81.

Fig 1. The photograph shows Ittoqqortoormiit in Kangertittivaq, East Greenland. Photo taken by Niels Einarsson during fieldwork in August, 2014.

RETREAT OF THE SMITH SOUND ICE STREAM IN THE EARLY HOLOCENE

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Nares Strait, which forms a main connection between the Arctic Ocean and Baffin Bay was blocked by coalescent Innuitian and Greenland ice sheets during the LGM. Nares Strait opened c. 9000 cal ka BP when the connection between the two ice sheets was severed. Our research focuses on the events and processes leading up to the opening of the strait and the response of the glacier and marine systems to establishment of the throughflow. The study involves analysis of core 2001LSSL-163PC and TC from Smith Sound, at the southern end of Nares Strait. X-radiography and core photographs were studied to establish basic lithofacies and stratigraphy. Foraminiferal faunas provide insight into changes in ice margin proximity, Atlantic Water advection, sea-ice conditions and establishment of the North Water Polynya (NOW). Foraminifera are used to develop the radiocarbon chronology. Quantitative X-ray diffraction analysis of bulk sediments aids in determining changing sediment sources and the establishment of a north to south connection. Counts of >2mm clasts from the X-radiographs are a proxy for iceberg rafting. A radiocarbon date of >50 kyr was obtained from foraminifera in an overconsolidated, gray diamicton at the base of core 163PC that is interpreted as a till. The till is overlain by a red/gray laminated, ice proximal deglacial sequence barren of foraminifera. This unit is overlain by gray pebbly mud with abundant foraminifera interpreted as a glacial marine unit deposited in a calving bay in front of the retreating Smith Sound Ice Stream. Two radiocarbon dates from near the base of the pebbly mud constrain the timing of ice retreat from Smith Sound to ?11.2 cal ka BP. We hypothesize that a distinct IRD layer marks the opening of Nares Strait. Foraminiferal assemblages indicative of marine productivity overlie the IRD layer. Two radiocarbon dates have been prepared from positions below and above the IRD layer to test whether this layer marks the timing of the opening of Nares Strait and establishment of the NOW.

NORTH PACIFIC TEMPERATURE, PRECIPITATION, ATMOSPHERIC CIRCULATION AND POLLUTION OVER THE COMMON ERA FROM THE DENALI ICE CORE

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Tree ring and lake sediment studies have revealed a great deal about North Pacific surface temperature variability over the past millennium, but we do not have an equivalent understanding of North Pacific hydroclimate variability or temperatures at high elevations. A millennial-length precipitation proxy record is needed to place late 20th century Alaskan precipitation increases into longer context, and to evaluate hydroclimate changes during the Little Ice Age (LIA) and Medieval Climate Anomaly (MCA). Previous research from the North and Tropical Pacific regions hypothesize that the LIA and MCA were associated with changes in the mean state and variability of the El Nino-Southern Oscillation and its extra-tropical teleconnections to the Aleutian Low. Additional high-resolution proxies sensitive to temperature, precipitation and storminess spanning the past 1000-2000 years are needed to further test these hypotheses. High-elevation summer temperature records are also valuable for understanding the sensitivity of Alaskan glaciers to past warm and cool periods. Finally, trans-Pacific pollution from Asia has been shown to significantly enhance toxic trace element concentrations in the North Pacific atmosphere, but additional records are needed to refine spatiotemporal variability in pollution sources and transport.

Here we present an overview of the new Denali Ice Core record collected from the summit plateau (4000 m a.s.l.) of Mt. Hunter (63° N, 151° W) in Denali National Park, Alaska. Two parallel ice cores were collected to bedrock (208 m in length) in May-June 2013, sampled using the Dartmouth continuous melter system, and analyzed for major ion, trace element, and stable isotope chemistry at Dartmouth and the Universities of Maine and New Hampshire. The cores span more than 1500 years, and are dated using robust annual oscillations in dust elements, methanesulfonate, ammonium, and stable isotopes, and validated using major volcanic eruptions recorded as sulfate, chloride and heavy metal spikes, and the 1963 nuclear weapons testing 137Cs spike.

Preliminary analyses indicate a dramatic increase in both summer temperature and annual snow accumulation over the 20th century, and significant relationships with North Pacific atmospheric pressure patterns and major ocean-atmospheric modes including the Pacific Decadal Oscillation. The new Denali records of sea-salt variability and accumulation show similar patterns of enhanced and diminished Aleutian Low intensity during the LIA and MCA, respectively, as shown in the Mt. Logan ice core. Toxic metals such as lead, cadmium, copper and zinc are significantly elevated in the Denali core over the 20th century, interpreted as a mixture of trans-Pacific and North American anthropogenic emissions.

LATEST HOLOCENE GLACIER ACTIVITY ON CUMBERLAND PENINSULA, BAFFIN ISLAND

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Precise chronological control of glacier advances through time are an important tool for reconstructing local and regional equilibrium line altitudes (ELAs) and for identifying climate trends on centennial to millennial time scales (Young et al., 2015). Glacier margin chronologies are typically built by dating the stabilization of glacial moraines or the formation of geomorphic features on the landscape using surface exposure dating methods (lichenometry, cosmogenic exposure dating, etc.). In general, on Baffin Island, glaciers reached their largest Holocene extents during the Little Ice Age, often overrunning previous advances, meaning only the Little Ice Age advance is preserved (Davis, 1985). However, the highlands of southern Baffin Island are often mantled by thin, cold-based ice that is now retreating and exposing preserved ancient landscapes complete with in situ plants (Miller et al., 2013). We take advantage of these conditions at Divide Ice Cap on Cumberland Peninsula (Figure 1) to reconstruct the spatial and temporal history of ice extent over the last ~1000 years. A transect of 10 radiocarbon ages of in situ dead plants that were killed by the advancing ice range from 910 +28/-39 CE at the 2015 ice margin to 1780 +111/-165 CE at the local trimline ~200 m away. The current ice margin lies at the bottom of a small saddle and the transect continues up the opposing south-facing hill to the trimline (Figure 1). These conditions mean that an advancing ice margin up this south-facing slope is more representative of the elevation of ice in the saddle than horizontal extent.
Four samples collected near the ice margin with dates between 900 and 1050 CE are seemingly out of order given their position with respect to the modern ice margin (Figure 2). However, it is possible that they each faithfully record smaller advances of a fluctuating ice cap early in the first millennium. Moving farther from the ice margin, radiocarbon ages become progressively younger with increasing distance (and elevation) from the 2015 ice margin (Figure 2). Overall, these data show and advancing ice margin and the expansion of the Divide Ice Cap from ~1000 CE towards its local maxima during the late 18th century. Aerial photography show the ice margin retracted to ~13 m below the trimline, but still ~40 m above the 2015 ice margin (Figure 2). It should be noted that since our data suggest the preservation of multiple advances, it is possible our chronology is incomplete, and only dating of additional in situ plants within the transect will expose additional ice margin advances.We will also employ a simple 2D finite element numerical model to simulate the steady state ELA for both the 2015 ice margin and local trimline to determine the minimum ELA change and infer the cooling required to expand the ice margin to it's local trimline between ~1000 and ~1800 CE (Kessler et al., 2006). This cooling is a minimum value, and it is likely that ELA fluctuations were of higher magnitude and frequency. Preliminary model outputs indicate a strong gradient in mass balance with respect to aspect. We hope to produce one of the first chronologies of late Holocene cryosphere expansion on Cumberland Peninsula and assign approximate ELA fluctuations and climate trends during the same time period.

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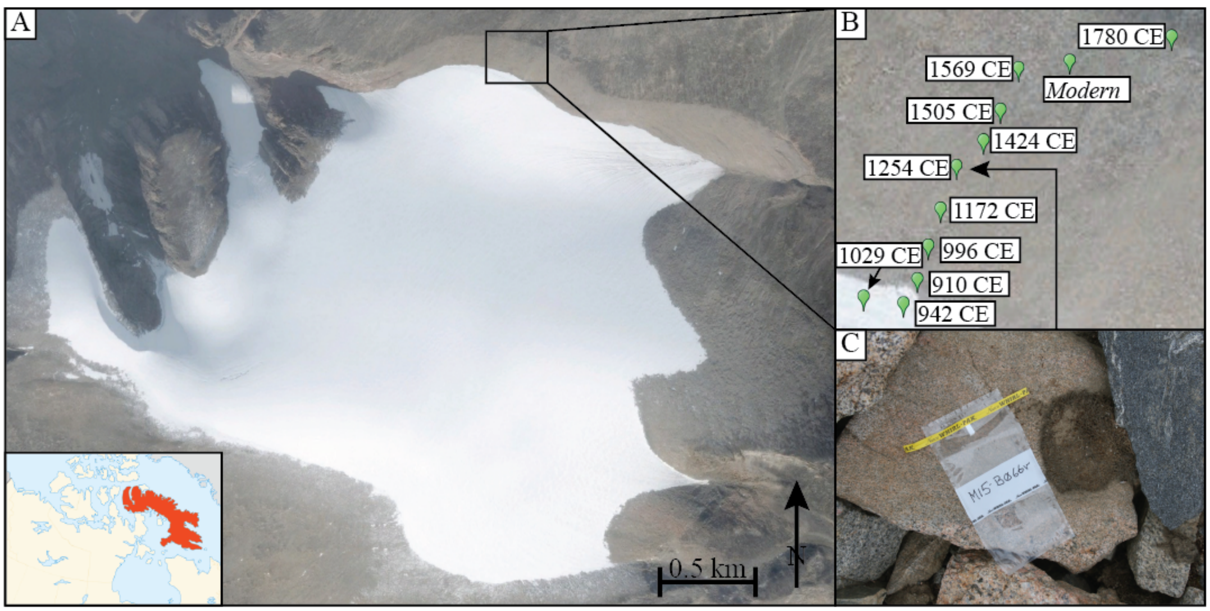

Fig 1. A) 2013 satellite photo of Divide Ice Cap, with inset map of Baffin Island with the location of the ice cap (star) and the location of the transect (black box). B) Close up of transect showing the location of each in situ plant sample and its calibrated 14C date. C) Close up of sample M15-B066v showing the dead moss head in growth position on a boulder.

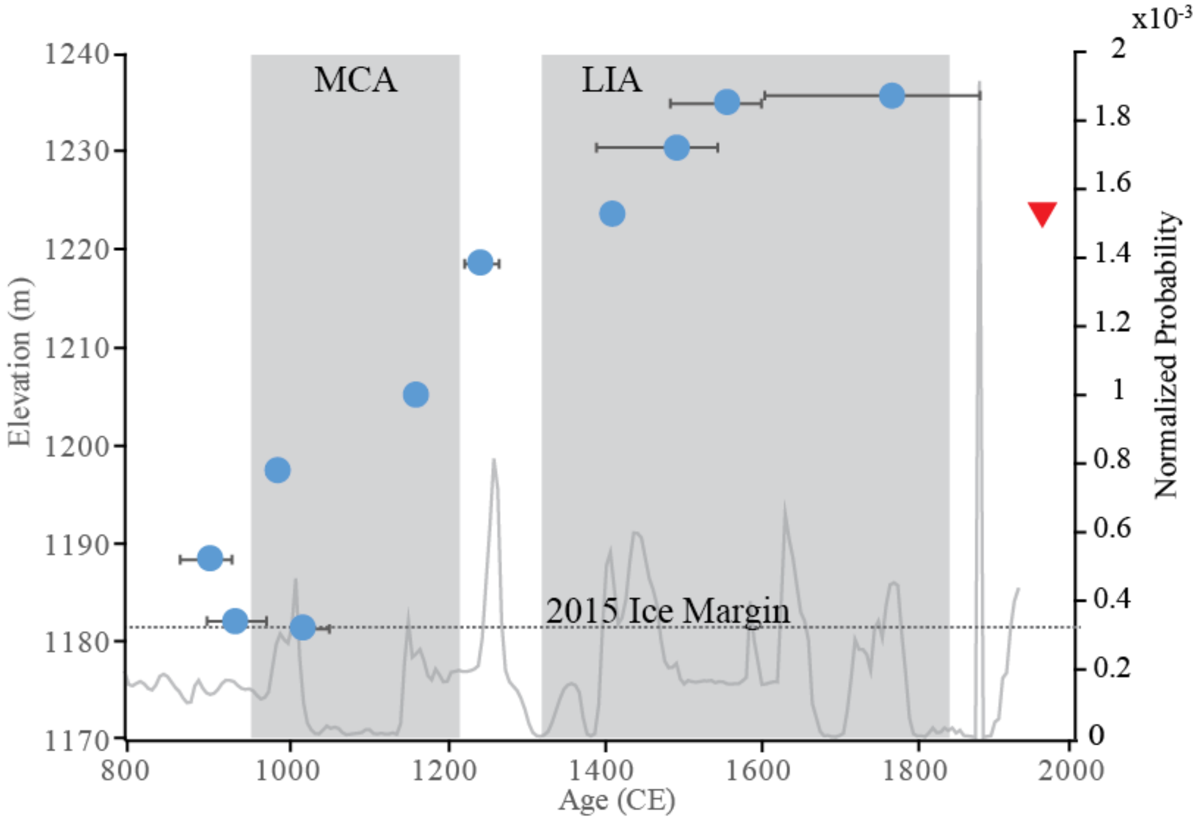

Fig 2. Plot of sample age and elevation with 1-sigma errors (blue circles), showing increasing ice elevation towards present, followed by deflation to the 1960 ice margin (red triangle). Also shown is the normalized probability distribution of in situ dead vegetation ages from Cumberland Peninsula, plotted for a regional comparison (n=37; gray line). The 2015 ice margin (dashed line) and Medieval Climate Anomaly (MCA; Lamb, 1965) and Little Ice Age (LIA; Grove, 1988) are also shown (gray shading).

HOLOCENE SHORELINES AND RELATIVE SEA LEVEL HISTORY ON INGØYA NORTHERN FINNMARK, NORWAY

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Radiocarbon-dated raised beaches and marine terraces provide the basis for reconstructing deglacial and Holocene relative sea level history in glaciated arctic regions. In northern Finnmark, detailed reconstructions have generally been hampered by a lack of dateable materials directly associated with the shoreline deposits. In part, the apparent lack of dateable materials may be due to the thick and extensive blanket of peat and vegetation that drapes the landscape. Some recent studies in the region (e.g. Romundset et al., 2011) have therefore utilized the isolation basin method for reconstructing late glacial and Holocene sea level in these northern islands. The study presented here is one facet of a schlerochonology project focused on reconstructing Holocene marine environmental conditions utilizing the long-lived marine bivalve *Arctic islandica* in northern Finnmark. Relative sea level reconstruction utilizing shell-dated beaches provides insight for targeting bivalve sampling for a range of ages in other locations on Ingøya and adjacent Rolvsøya to the south. In this study a new relative sea level curve is presented from southern coastal Ingøya where a prominent set of raised beaches extends from the modern shore to approximately 10 meters a.s.l. The beach ridges and swales between the ridges contain abundant bivalve shells, predominantly *Modiolus modiolus*, which were recovered by excavating in the peat and by utilizing rabbit burrows dug into the sandy deposits. Raised beach elevations were determined using the standard autolevel survey method. Shell ages were determined by first submitting a set of 10 samples for low precision AMS ^{14}C age analysis (Bush et al., 2013; J. Southon Lab, UCal Irvine) paired with amino acid analysis (D. Kaufman Lab, NAU). Subsequently, standard high precision AMS ^{14}C ages were determined on the same 10 shells from the raised beaches. The calibrated shell ages range from 1,319 to 6,457 years B.P. (CALIB Marine 13) increasing in elevation from 2.6 meters asl to the uppermost beach terrace at 9.3 meters asl. The upper terrace, dated at 6,457 B.P. is a broad and flat prominent terrace that likely corresponds to the maximum limit of the mid-Holocene Tapes Transgression. The Tapes Transgression is widely recognized in northern and western coastal sectors of the Fennoscandian and Barents Ice sheets where mid-Holocene eustatic sea level rise regionally outpaced glacioisostatic uplift due to increased meltwater flux from Antarctica and/or the Laurentide ice sheets (Wolfarth et al., 2008). The highest level raised beach on southern Ingøya at 29.8 meters is a broad cobble-boulder beach that likely represent the marine limit shoreline. A second lower cobble boulder beach and gravel spit occurs at 19.6 meters. At present, deposits above the 9.6 meter Tapes Shoreline have not yielded dateable materials.

Bush, S. L., Santos, G.M., Xu, X, Southon, J.R., Thiagarajan, N., Hines, S. K., Adkins, J.F., 2013, Simple, rapid, and cost effective: a screening method for 14C analysis of small carbonate samples: Radiocarbon, v. 55, no. 2-3, p. 631-640.

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A LATE-HOLOCENE PALEOCLIMATE RECONSTRUCTION USING THE BIVALVE ARCTICA ISLANDICA FROM NORTHERN NORWAY

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Samples of the marine bivalve, Arctica islandica, collected on the island of Ingøya in Finnmark, Norway, were used to produce a high-resolution annual and seasonal record of marine environmental conditions. This study site may provide unique regional insights into oceanic and atmospheric circulation patterns as it is influenced by three major currents: the North Atlantic Current, the Norwegian Coastal Current, and the Arctic Current (Figure 1). Shells utilized in this study were collected from a 3 meter high stratigraphic section, referred to as the Molo section, where several distinctive units comprised of disarticulated shells, shell hash, sand and pebbles are exposed.

The environmental reconstruction consists of three distinct parts: A 400 year floating chronology developed using growth increments of five A. islandica shells, two floating d18O records spanning periods of <30 years, and a single, six-year record of seasonal d18O changes. The first two aspects of this record are used to investigate changes in prominent oceanic and atmospheric circulation patterns, including the NAO and AMO. The seasonal record produced is compared to mid-Holocene and modern day values from the same location to determine changes in seasonality through the Holocene.

Ages were determined for 21 A. islandica shells using new low precision AMS radiocarbon ages (Bush, 2013; Roberts, 2013). Subsequently, 2 long-lived shells were also chosen for standard precision AMS radiocarbon dating. Resulting ages for the two samples that were run using both techniques were not within 1-sigma error of one another, though they did fall just outside of this range. However, this may be due to the additional uncertainty of taking samples from the margin of the shell (Butler et al., 2009). Ages from both types of dating techniques were used to construct a crossdated record. Yet because this record, which falls somewhere between 1,400-1,800 calendar years BP, is not tied to modern A. islandica reconstructions, it is classified as a “floating” chronology and as such has not been assigned calendar values (Mette et al., 2016).

The individual growth chronologies produced display a greater degree of variability over time than was expected, indicated from several standardized growth increment reconstructions, implying distinct changes in the marine environment over individual bivalves life times. Sub-annually, the records produced display seasonal cyclicity, with a mean seasonal variation of 4.68 degrees C. This seasonal variation indicates an increase in seasonal variability through the Holocene, as mid-Holocene (~6,000 calendar year BP) values indicate a smaller degree of seasonality while modern values indicate a larger degree of seasonality.

Trends from both the 400-year crossdated record and the <30 year d18O records indicate large-scale variation occurring in this marine environment. Morlet and DOG Wavelet analyses are used to investigate cyclical trends in the 400-year record. Periodicities of 50, 35, and 10-20 years were found, ranging in significance. The period of 50 years was the most significant (>90%), while the latter periods of 35 and 10-20 years were found to be less significant (40-70%). The longer periodicity is consistent with the lower end of published values for AMO variability, which are reported at between 50-80 years (Delworth and Mann, 2000; Wei and Lohmann, 2012). The periodicity of 35 years may be indicative of larger-scale changes in the NAO, which occur on time scales of 30-40 years (Fromentin and Planque, 1996; Hurrell et al., 1995), while the periodicity of 10-20 years most likely corresponds to Hale and Schwabe solar cycles (Butler et al., 2010). MTM analysis was also used to determine lower-order variability in this cycle, consistent with NAO changes.

The 14C ages determined from different shells taken from throughout the Molo in addition to a relative sea level curve constructed from raised beaches located at Kuhelleran (Figure 1c; Retelle et al., 2016) were used to reconstruct the depositional history of the exposure. The phases of deposition found correspond to three distinct periods of sea level on the island (Figure 2).

Bush, S. L., Santos, G.M., Xu, X., Southon, J.R., Thiagarajan, N., Hines, S.K., Adkins, J.F., 2013, Simple, rapid, and cost effective: A Screening method for 14C analysis of small carbonate samples: Radiocarbon, v. 55, no. 2-3, p. 631-640.

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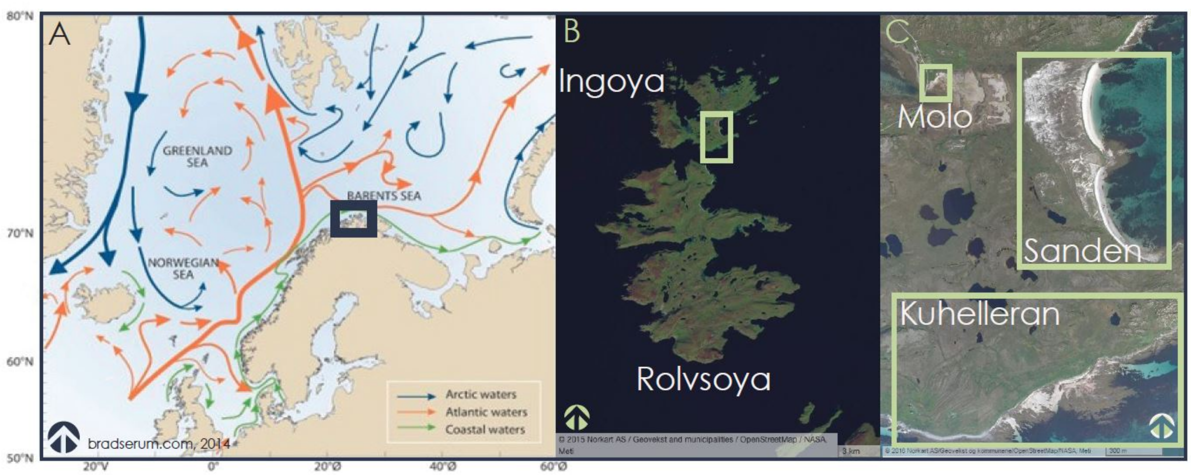

Fig 1. A) Regional oceanic currents, study area highlighted in black. B) The islands of Ingoya and Rolvsoya, study site highlighted in green. C) An aerial photo of the three sites on Ingøya discussed in this abstract: the Molo, a stratigraphic section containing mid-to late Holocene shelly deposits, Sanden Beach System, a modern beach system with distinct dune and storm features, and Kuhelleran Beach System, a south-facing beach system with a series of raised beaches.

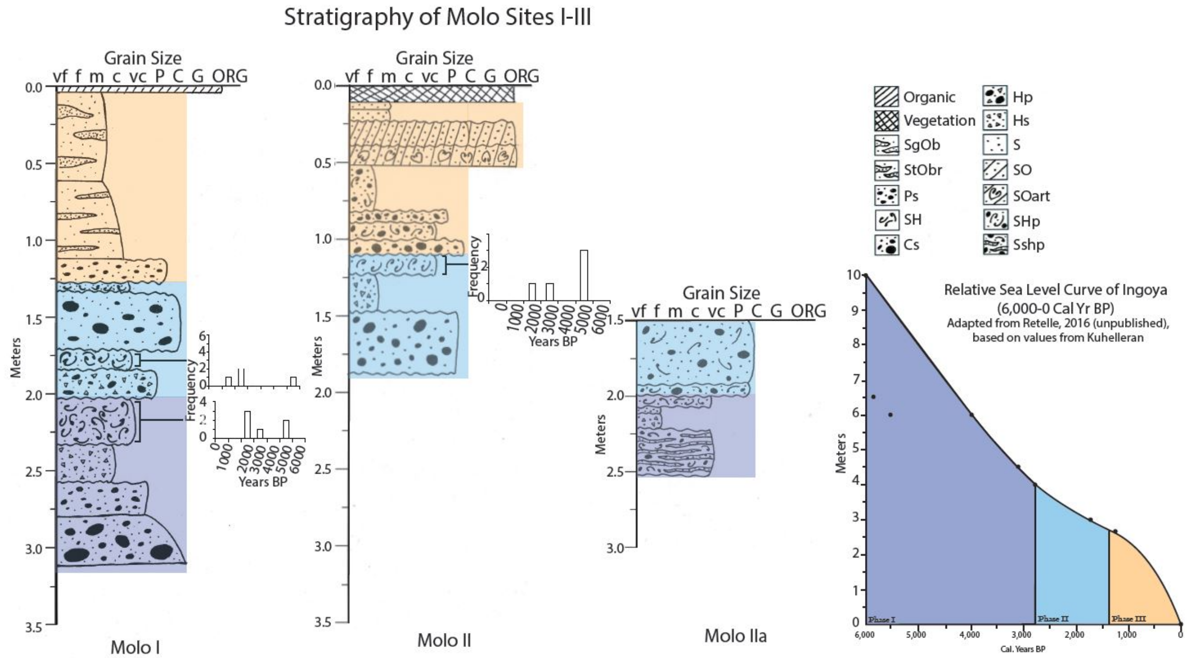

Fig 2. Left) The Stratigraphy of Molo Sites I, II, and IIa. Right) Relative sea level curve of Ingoya. Colors correspond to the three phases of deposition.

RESPONSE OF LOCAL SEA ICE EXTENT TO PASSAGE OF THREE EXTREME CYCLONES IN THE ARCTIC

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Sea ice concentration change in response to the passage of strong cyclones is investigated with AMSR-2 passive microwave data. Recent decreases in annual sea ice extent parallel observed trends in increased strength of Arctic cyclones, and thinning sea ice may be even more vulnerable to cyclone activity (Simmonds & Keay, 2009). This study is a preliminary look at three Arctic cyclones tracked in December 2015, July 2014, and August 2012, with minimum central pressures of 963.8, 991.3, and 964.7 hPa, respectively. We seek to understand the magnitude of cyclone effects on sea ice and any apparent seasonal differences. Generally the Arctic sees its strongest cyclones in winter, but it is evident that strong summer cyclones are also a meaningful part of the system (Serreze, Crawford, & Barrett, 2015). The record summer sea ice minimum in 2012 following the strongest ever observed August cyclone in the region raises questions as to the precise effects of this and other individual cyclones on the total sea ice concentration. Storm passage appears to result in an areal loss of up to 20% of sea ice extent in a 48-hour period, indicating the importance of cyclone dynamics in understanding sea ice conditions into the future.

Serreze, M. C., Crawford, A. D., & Barrett, A. P. (2015). Extreme daily precipitation events at Spitsbergen, an Arctic Island. International Journal of Climatology. http://doi.org/10.1002/joc.4308

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SHARING INDIGENOUS WAYS OF KNOWING IN PARTNERSHIP WITH ARCTIC COMMUNITIES

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Indigenous Arctic residents have a unique understanding of the environment in which they live. For millennia, Indigenous Knowledge was handed down orally from elder to youth through experiences on the land, such as traveling across sea ice, learning seasonal hunting and harvesting patterns, preparing and storing food for the community, making durable clothing, and watching the sky to read the weather. Over the last few decades, a collaboration between Indigenous Arctic populations and Arctic research scientists has developed to address shared challenges and to provide significant contributions to the understanding of a rapidly changing Arctic climate. As the digital world reached the far North, Indigenous Arctic peoples began reclaiming control of how their knowledge was presented and shared using online applications. With the advent of newer technological tools, such as interactive databases and online mapping, smart phones, and social media, community elders are embracing the benefits of the digital age, seeing that these tools can engage and connect the youth to their rich, cultural pasts in a manner that will reflect the values of their respective cultures. Used effectively, such tools provide an additional method for Indigenous people to present themselves and their views of the world around them to local and global audiences and to future generations. As cultural shifts embrace technology and as worldwide interest in the value of Local and Indigenous Knowledge increases, programs to care for such collected information must meet the demand of curating this knowledge over the long term.

Now in its 9th year, the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) addresses the critical need to manage Local and Indigenous Knowledge so that (1) the information is not lost, but rather protected and preserved; (2) the information is discoverable; and (3) the information has influence on environmental research, policy, and public awareness. ELOKA provides data management services and user support to facilitate the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. For example, ELOKA has collaborated with Alaskan, Canadian, and Siberian communities to create interactive online atlases mapping local place names and displaying important Local Knowledge. These atlases are actively used, maintained, and expanded by individuals in those communities. Web sites provide context for the Local and Indigenous Knowledge and contain interviews from several Arctic Inuit hunters. Other products include software applications to display near real-time weather conditions from stations on Baffin Island, Nunavut, Canada, and an interactive database of ongoing local observations of sea ice and weather on the Alaskan coast.

Based at the National Snow and Ice Data Center (NSIDC) and within the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder, ELOKA is part of a long-standing data management tradition and research entity. NSIDC is well known worldwide for its management and distribution of cryospheric data, creating tools for data access, supporting data users, performing scientific research, and educating the public about the cryosphere. CIRES is at the forefront of environmental research and CU Boulder is world-renowned for its reputation for excellence in research, creative work and teaching across 150 academic fields.

DIACHRONOUS RETREAT OF THE GREENLAND ICE SHEET: INSIGHTS FROM A NEW 10BE COSMOGENIC EXPOSURE DATABASE

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Since 2007, 618 10Be cosmogenic exposure ages have been published from around the Greenland Ice Sheet. These ages are located around the ice sheet, covering coastal areas to the ice margin in 14 individual regions. The dataset has great potential for elucidating deglacial patterns of ice retreat and identifying how these relate to climatic changes over the last deglaciation. However, changes in 10Be ages as published are not directly comparable with each other. Here, we will present a new database with all existing 10Be ages, recalculated consistently with the most up-to-date production rates, and analyzed using new statistical methods to objectively identify spatial-temporal patterns in ice sheet retreat.

We have compiled all existing 10Be ages, and recalculated them using the CRONUS online calculator (http://hess.ess.washington.edu) and the Arctic production rate (Young et al., 2013). Once the ages have been calculated, we will present a factor analysis of the 10Be database, building on the methods outlined by Imbrie and Van Andel (1964) and applying them to probability density functions of 10Be ages. This analysis allows us to objectively identify the main modes of variability within the data, revealing four factors which when combined explain the majority of the variability within the data. Four factors were sufficient to explain more than 70% of the variance in the Greenland 10Be ages. These factors peak at ~12 ka, 11 ka, 10 ka, and 7.5 ka. Comparing factor loadings of 10Be ages (grouped by 20km gridcells) around the ice sheet reveals significant spatial variability. The 12 ka and 11 ka factors are dominant in eastern Greenland and in isolated samples along the outer coasts of southern and western Greenland. In contrast, the 10 ka and 7.5 ka factors have their highest values in southern and western Greenland. Taken together, the four factors and their loadings show a distinct pattern, and suggest the terrestrial deglaciation of the Greenland Ice Sheet was spatially variable. East Greenland shows a higher probability of earlier deglaciation, peaking around 12 ka, followed by southern Greenland with a high probability of deglaciation at 11-10 ka. West Greenland likely deglaciated last, between 10 and 7.5 ka. These patterns are supported by regional probability density functions, which show areas in east Greenland deglaciating first, followed by south and finally west Greenland.

In addition to revealing these patterns of ice sheet retreat around the island, this 10Be database presents an excellent opportunity to independently validatae the next generation of ice sheet models. These models have traditionally been tuned and validated using relative sea level records from around the ice sheet (e.g. Huybrechts, 2002; Simpson et al., 2009; Lecavalier et al., 2014). Until recently, there were too few 10Be ages to systematically test the ice extent outputs from these models. Here, we will present a method for independently testing these models, comparing regional probability density functions with histograms of Huy3 model deglaciation ages of gridcells that contain 10Be ages (Lecavalier et al., 2014). This comparison indicates the model overlaps with 10Be ages in western and parts of southern Greenland. In contrast, 10Be ages generally lead model ages in eastern Greenland. The Huy3 model reconstruction therefore does not capture all the spatial variability in ice retreat described by the 10Be ages: instead it shows a more spatially uniform terrestrial retreat at 11-10 ka around the island.

We outline three hypotheses for this diachronous retreat and the model-data mismatch. A systematic inheritance signal in the 10Be ages from east Greenland may lead to an artificially old deglaciation signal in these ages. However, our test for outliers (the Chauvenet test) should remove any samples with significant random inheritance. In addition, comparison of bedrock and boulder ages suggests bedrock samples which have a higher likelihood of containing inherited 10Be, are statistically indistinguishable from boulder samples from the same region. Alternately, model approximations and resolution may contribute to the model-data disagreement, but this does not explain our observation of spatial variability in the 10Be ages. Our preferred explanation for these observations is that early ocean warming before and potentially during the Younger Dryas in eastern and southern Greenland drove early retreat in these areas (e.g. Winsor et al., 2012). West Greenland did not see warmer waters until significantly after the Younger Dryas, with cold glacial conditions in Disko Bugt, west Greenland, until 8-7 ka (Jennings et al., 2014), possibly corresponding with the 7.5 ka factor. The ice sheet model used here does not include a spatially-variable climate forcing, or explicitly resolve the effect of ocean temperatures on ice sheet retreat (Lecavalier et al., 2014).

In the future, we will use the 10Be database to begin to investigate the distribution of warm- and cold-based ice during the last glacial cycle, and compare this to new ice sheet modeling results. In addition, we will discuss a new 14C database, and methods for using 14C data on ice extent to quantitatively test ice sheet models in conjunction with the 10Be database.

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CURRENT STATE OF RENLAND (EAST GREENLAND) ICE CORE ANALYSIS

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The Renland peninsula is located on the eastern coast of Greenland in the Scoresbysund Fjord, and is covered by an ice cap approximately 500 m thick and 40 km wide. Steep fjords isolate Renland from the Greenland Ice Sheet and constrain the size of the ice cap, such that the elevation of the ice cannot change significantly. The peninsula accumulates approximately 0.5 m of ice equivalent precipitation per year and the ice experiences little summer melting due to its high elevation at 2340 m, making it ideal for ice core analysis. Additionally, the shallow depth of the ice means that it does not have a brittle zone, which typically occurs below 700 m. Holocene ice is typically lost in the brittle zone in cores from the Greenland Ice Sheet, but the Renland ice cap contains a continuous record of usable ice extending into the Eemian interglacial period.

A previous ice core drilled at the summit in 1988 (Johnsen et al, 1992) was of poor quality due to limitations in technology, but demonstrated that the Renland ice cap was a promising location to obtain a continuous ice record. A 584 m ice core was drilled in May-June 2015 after using radar to determine the optimal drilling location. The core was processed by continuous flow analysis at the Center for Ice and Climate in October-December 2015. Measurements included water isotopes, methane, conductivity, sodium, insoluble dust particles, black carbon, acidity, soluble iron, ammonium, calcium, and peroxide. Discrete samples were also collected for additional bulk analysis, and new data is currently being analyzed at the Institute of Arctic and Alpine Research and the Center for Ice and Climate.

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DECADALLY-RESOLVED EARLY HOLOCENE TEMPERATURE AND PRECIPITATION RECONSTRUCTIONS FROM WESTERN GREENLAND

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Quantifying ice sheet responses to climate change is critical for predicting sea level rise in a warming world. In particular, increased precipitation may play an important role in offsetting ice sheet mass balance losses caused by rising temperatures (Bintanja and Selten, 2014). Past intervals of rapid climate change occurring on human-relevant timescales provide natural experiments for quantifying ice sheet response to temperature and precipitation. Two distinct early Holocene moraine systems near Jakobshavn Isbrae on western Greenland have been identified and dated using cosmogenic ^{10}Be exposure dating (Young et al., 2011; Young et al., 2013). The deposition of these moraines coincides with abrupt, short-lived (ca. 50 to 150 years) cooling events at 9,300 and 8,200 years ago recorded at Summit, Greenland (Rasmussen et al., 2007). If these early Holocene Greenland Ice Sheet margin advances/stillstands were of similar duration as the "9.3 and 8.2 ka events," it is somewhat surprising that the ice sheet would erode enough rock to remove inherited cosmogenic nuclides. The character of early Holocene decadal-scale temperature and hydroclimatic changes near the margins of the Greenland Ice Sheet remains unknown, however, so direct comparison of climate and ice sheet margin reconstructions currently is not possible.

Here, we present decadally-resolved multiproxy records of early Holocene terrestrial temperature and hydroclimate using branched glycerol dialkyl glycerol tetraethers (brGDGTs), leaf wax hydrogen isotopes, and a suite of organic and inorganic proxies from a well-dated lake sediment sequence on Nuussuaq, western Greenland. Branched GDGT-inferred temperature shows a ca. 1°C cooling at 9,350 years ago that lasted 150 years, a ca. 2°C cooling starting 8,910 years ago that lasted 360 years, and a ca. 1.5°C cooling at 8,500 years ago that lasted 200 years. Early Holocene hydroclimate inferred from leaf wax hydrogen isotopes was driest from 8,730 to 8,220 years ago, roughly coincident with lowest temperatures. Thus, the deposition of early Holocene moraines by the western Greenland Ice Sheet was likely caused by cooler conditions, rather than by changes in hydroclimate.

The cooling at 8,910 years ago may coincide with the opening of the Nares strait, which would have allowed cold Arctic waters to flow southward into Baffin Bay (Jennings et al., 2011). The prolonged cool and dry period 8,910 to 8,200 years ago may have caused the western margin of the Greenland Ice Sheet to advance or halt retreat prior to the 8.2 ka event recorded at Summit, Greenland, and then remain in positive or neutral balance for ca. 600 years, 450 years longer than the 8.2 ka event. A longer-duration advance may explain why the ice sheet margin was able to erode enough rock to remove inherited cosmogenic nuclides. These high-resolution records of early Holocene temperature and precipitation on western Greenland highlight the importance of obtaining climate records near the sensitive margins of ice sheets in generating a complete understanding of ice sheet response to climate change.

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TRACKING ICE PARCELS AND CO-LOCATED DATA PRODUCTS IN THE ARCTIC USING THE SEA ICE MOTION AND AGE DATA PRODUCTS AT THE UNIVERSITY OF COLORADO AT BOULDER WITH APPLICATIONS TO STUDYING CHANGES IN THE ARCTIC ICE PACK

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The past several decades have seen an alarming decline in sea ice extent and a trend toward thinner, first-year ice throughout the Arctic. This younger ice has a lower probability of surviving the next melt season and features different surface properties than multi-year ice floes typically possess. Through the combination of satellite passive microwave observations and buoy data, the motion and age of the ice pack in the Arctic are tracked and analyzed using datasets produced at the University of Colorado at Boulder that are archived at the National Snow and Ice Data Center. The ice motion product is produced daily from 1978 to the present, and the weekly age data span from 1985 onward. Through tracking the trajectory and locations of ice parcels in our ice motion product, we can use other co-located data products to assess the impact of various climate components' forcing on the Arctic ice pack. In addition, the use of the motion product allows for tracking the advection of first-year and multi-year ice through several key ice "gates" throughout the Arctic on relatively short time scales.

HOLOCENE DEGLACIATION IN TWO FIORDS ON NORTHERN CUMBERLAND PENINSULA, BAFFIN ISLAND, ARCTIC CANADA

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Marine-terminating outlet glaciers greatly influence the stability of ice sheets (Briner et al., 2009). Investigating past outlet glacier change can help assess the behavior of outlet glaciers draining current ice sheets and place modern ice sheet behavior in a long-term context. Here, we present six cosmogenic 10Be exposure ages from erratic boulders in two fiords on northern Cumberland Peninsula. Since the Last Glacial Maximum (26-19 ka; Clark et al., 2009), Okoa and Maktak fiords both drained ice sourced from the Penny Ice Cap; Okoa fiord currently has a tidewater glacier at its head, whereas a ~14 km long sandur separates an outlet glacier from the head of Maktak fiord. Three 10Be ages from erratics perched on bedrock near the mouth of Okoa Fiord average 11.8±1.0 ka. Three 10Be ages from erratics perched on bedrock from middle Maktak Fiord average 10.9±0.4 ka. Both age groups have a tight cluster of two ages and one age that is ~1-2 kyr older, hinting at minor amounts of isotopic inheritance. The ages suggest that the fiords were completely glaciated during the Younger Dryas (12.9-11.7 ka; Rasmussen, et al., 2006), and that deglaciation began shortly after. The timing of middle and outer fiord deglaciation will help to constrain the chronology of local alpine glacier and ice-sheet outlet glacier changes farther up valley than our sites, which is work in progress.

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IN SITU 10BE MEASUREMENTS IN BEDROCK CONSTRAIN EROSION BENEATH THE GREENLAND ICE SHEET

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Warm-based ice sheets and glaciers erode and modify the terrain that they mantle, but precise estimates of the rate at which sub-glacial erosion occurs are rare. Estimates of sub-glacial erosion occurring beneath ice sheets, such as the Greenland Ice Sheet (GrIS), are particularly important because they can provide key insights into sediment availability at ice-sheet margins that influences ice-sheet stability. Moreover, estimates of sub-glacial erosion can help inform predictive geophysical ice-sheet models that incorporate a basal sliding parameter. Here, we combine in situ cosmogenic 10Be measurements from strategic bedrock locations, with a detailed ice margin history of the GrIS, to quantify the rate of sub-glacial erosion beneath the GrIS near Jakobshavn Isbræ. Our bedrock 10Be measurements are from 1) locations that deglaciated ~7,500 years ago and have remained ice-free through present day, and 2) locations that also deglaciated ~7,500 years ago, but were briefly re-occupied by GrIS during the ice sheet's historical maximum extent. After accounting for the slightly different exposure histories between bedrock locations, and despite the short duration in ice-cover, initial 10Be measurements reveal a detectable difference in 10Be concentrations between the two bedrock surfaces. The offset in 10Be concentrations represents the magnitude of sub-glacial abrasion beneath the GrIS, and by combining our 10Be measurements with a profile of 10Be production with depth in bedrock, we calculate that the GrIS eroded through 5.87 ± 2.20 cm of bedrock at the rate of 0.54 ± 0.20 mm yr-1.

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