Ice Core Working Group Update to Scientific Advisory Board

T.J. Fudge

Bess Koffman

Happening in the past year

- Field delays
- COLDEX is funded and planning begins
- Herc Dome site selection continues
- Pacific alpine coring advances

Using arrays of cores

Article

Hemispheric black carbon increase after the 13th-century Māori arrival in New Zealand

https://doi.org/10.1038/s41586-021-03858-9

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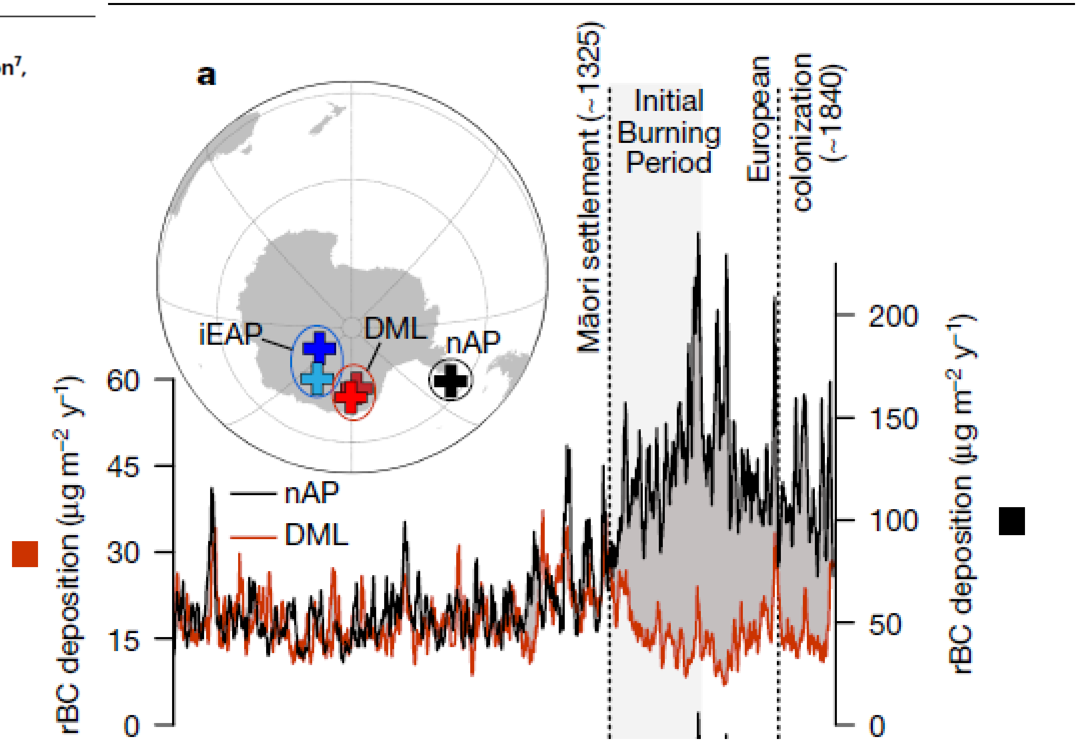
Joseph R. McConnell[1]✉, Nathan J. Chellman[1], Robert Mulvaney[2], Sabine Eckhardt[3], Andreas Stohl[4], Gill Plunkett[5], Sepp Kipfstuhl[6], Johannes Freitag[6], Elisabeth Isaksson[7], Kelly E. Gleason[8], Sandra O. Brugger[1], David B. McWethy[9], Nerilie J. Abram[10,11,12], Pengfei Liu[13,14] & Alberto J. Aristarain[15]



Coastal coring

Abrupt Common Era hydroclimate shifts drive west Greenland ice cap change

Matthew B. Osman[1,2], Benjamin E. Smith[3], Luke D. Trusel[4], Sarah B. Das[5], Joseph R. McConnell[6], Nathan Chellman[6], Monica Arienzo[6] and Harald Sodemann[7]

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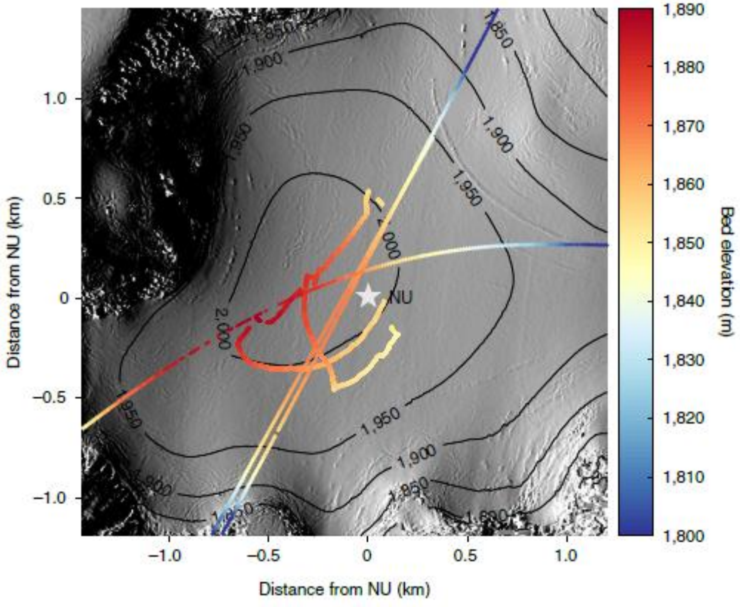
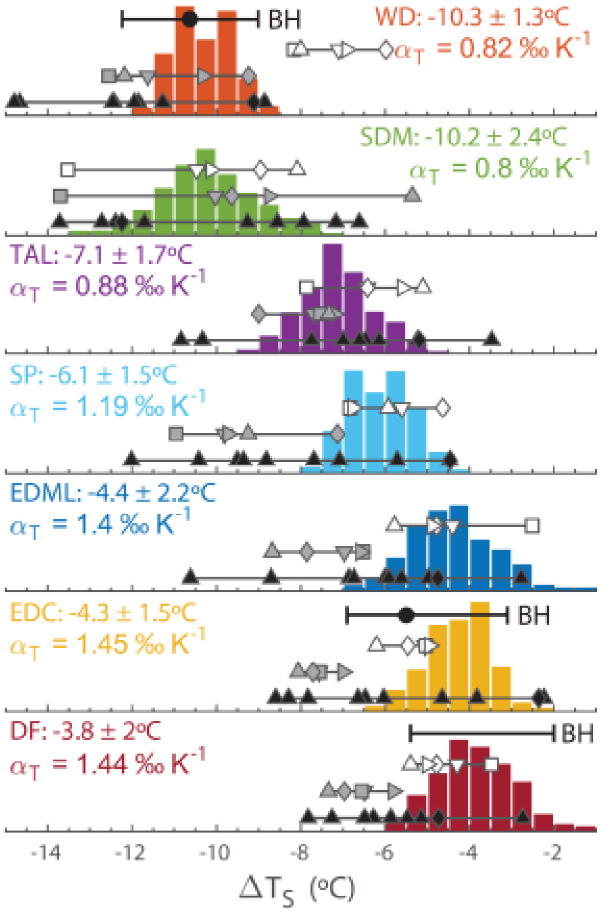


Using benchmark records

PALEOCLIMATE

Antarctic surface temperature and elevation during the Last Glacial Maximum

Christo Buizert[1]*, T. J. Fudge[2], William H. G. Roberts[3], Eric J. Steig[2], Sam Sherriff-Tadano[4], Catherine Ritz[5], Eric Lefebvre[5], Jon Edwards[1], Kenji Kawamura[6,7,8], Ikumi Oyabu[6], Hideaki Motoyama[6], Emma C. Kahle[2], Tyler R. Jones[9], Ayako Abe-Ouchi[4], Takashi Obase[4], Carlos Martin[10], Hugh Corr[10], Jeffrey P. Severinghaus[11], Ross Beaudette[11], Jenna A. Epifanio[1], Edward J. Brook[1], Kaden Martin[1], Jérôme Chappellaz[5], Shuji Aoki[12], Takakiyo Nakazawa[12], Todd A. Sowers[13], Richard B. Alley[13], Jinho Ahn[14], Michael Sigl[15], Mirko Severi[16,17], Nelia W. Dunbar[18], Anders Svensson[19], John M. Fegyveresi[20], Chengfei He[21], Zhengyu Liu[21], Jiang Zhu[22], Bette L. Otto-Bliesner[22], Vladimir Y. Lipenkov[23], Masa Kageyama[24], Jakob Schwander[15]



White Papers

- TJ Fudge, Brent C Christner, Juliana D'Andrilli, John Fegyveresi, Andrei Kurbatov, Mark S Twickler, Community Recommendations for the NSF Ice Core Facility

- Paolo Gabrielli, Seth Campbell, Zoe Courville, Karl Kreutz, Andrei Kurbatov, Peter D Neff, Erich Osterberg, Erin Pettit, Summer Rupper, Alpine Glaciers and Ice Caps.

- Tyler R Jones, Sarah Aarons, Edward Brook, Christo Buizert, Jihong Cole-Dai, TJ Fudge, John Higgins, Kaitlin Keegan, Andrei Kurbatov, Peter D Neff, Erich Osterberg, Vasilii Petrenko, Jeffrey P Severinghaus, Eric J Steig, Paleoclimate Ice Core Research Priorities in Antarctica.

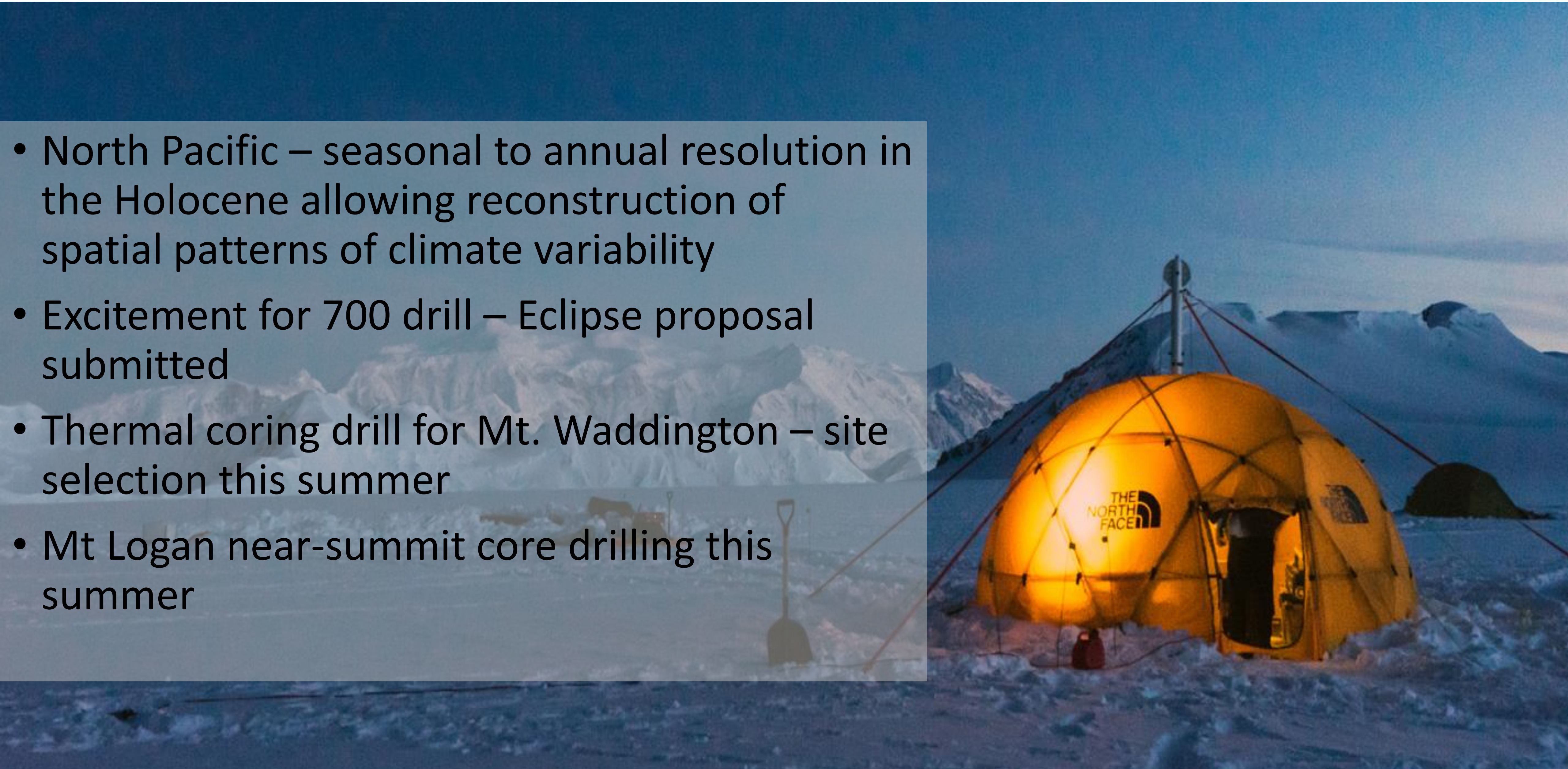
- Erich Osterberg, Jessica Badgeley, Christo Buizert, Juliana D'Andrilli, TJ Fudge, Tyler R Jones, Karl Kreutz, Vasilii Petrenko, Erin Pettit, Dominic Winski, Ice Core Research Priorities in Greenland.

Excitement for new NSF Ice Core Facility

- Hyperspectral camera arriving soon (COLDEX funding)
- Blue ice storage

Alpine Glaciers and Ice Caps

- North Pacific – seasonal to annual resolution in the Holocene allowing reconstruction of spatial patterns of climate variability
- Excitement for 700 drill – Eclipse proposal submitted
- Thermal coring drill for Mt. Waddington – site selection this summer
- Mt Logan near-summit core drilling this summer

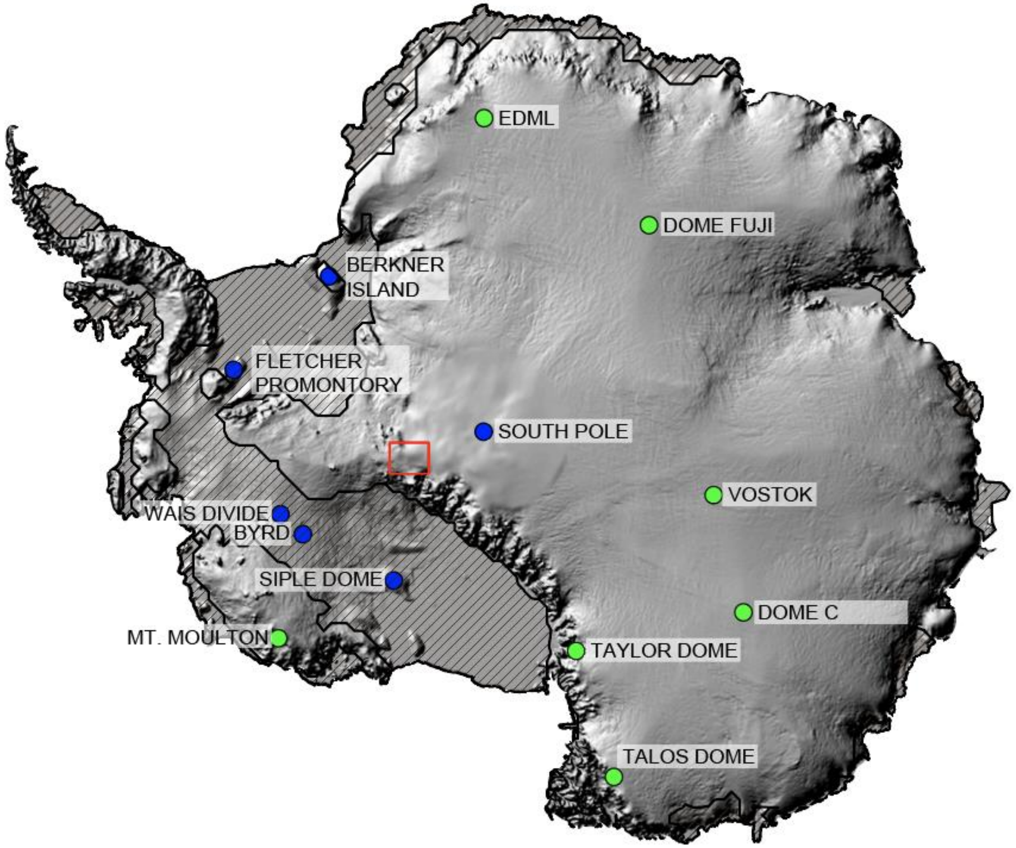


Greenland

TUNU coring will happen this summer

GreenTracs2 will be proposed, which includes site selection for Qaanaaq and South Dome intermediate cores

Antarctica


EDML
DOME FUJI
BERKNER ISLAND
FLETCHER PROMONTORY
SOUTH POLE
VOSTOK
WAIS DIVIDE
BYRD
SIPLE DOME
DOME C
MT. MOULTON
TAYLOR DOME
TALOS DOME

COLDEX

Center for Oldest Ice Exploration

Director: Ed Brook, College of Earth, Ocean, and Atmospheric Sciences (CEOAS), Oregon State University

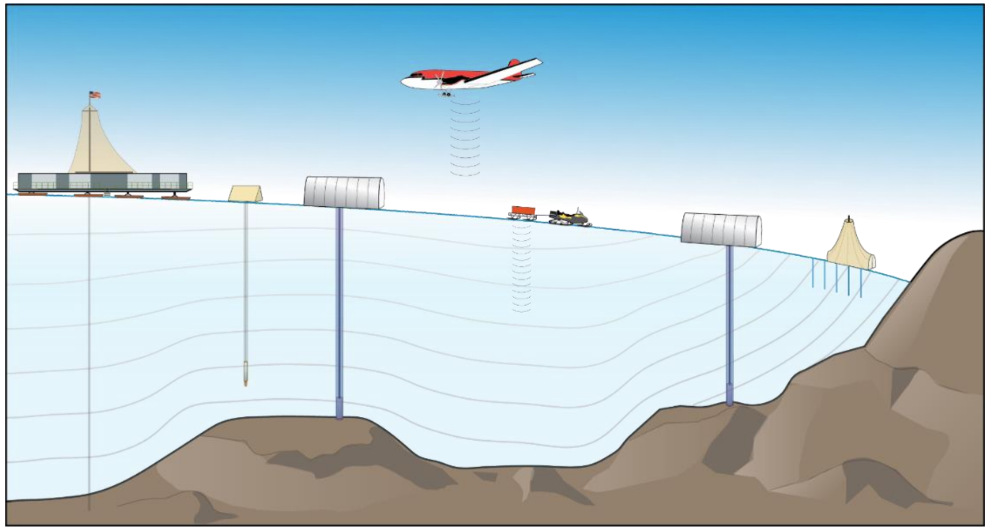
Funded by the NSF Science and Technology Center Program September 2021

www.coldex.org

COLDEX Institutions

Oregon State University	University of Kansas
University of Washington	University of Texas
Princeton University	University of California-Irvine
University of California-Berkeley	University of Maine
Dartmouth College-Ice Drilling Program	University of California-San Diego
University of Minnesota Twin Cities	University of Minnesota Duluth
Amherst College	Brown University
American Meteorological Society	*Inspiring Girls Expeditions*
Earth Science Women's Network	*Alaska Native Science and Engineering Program*

COLDEX is Designed to Find and Analyze the Oldest Possible Ice Cores



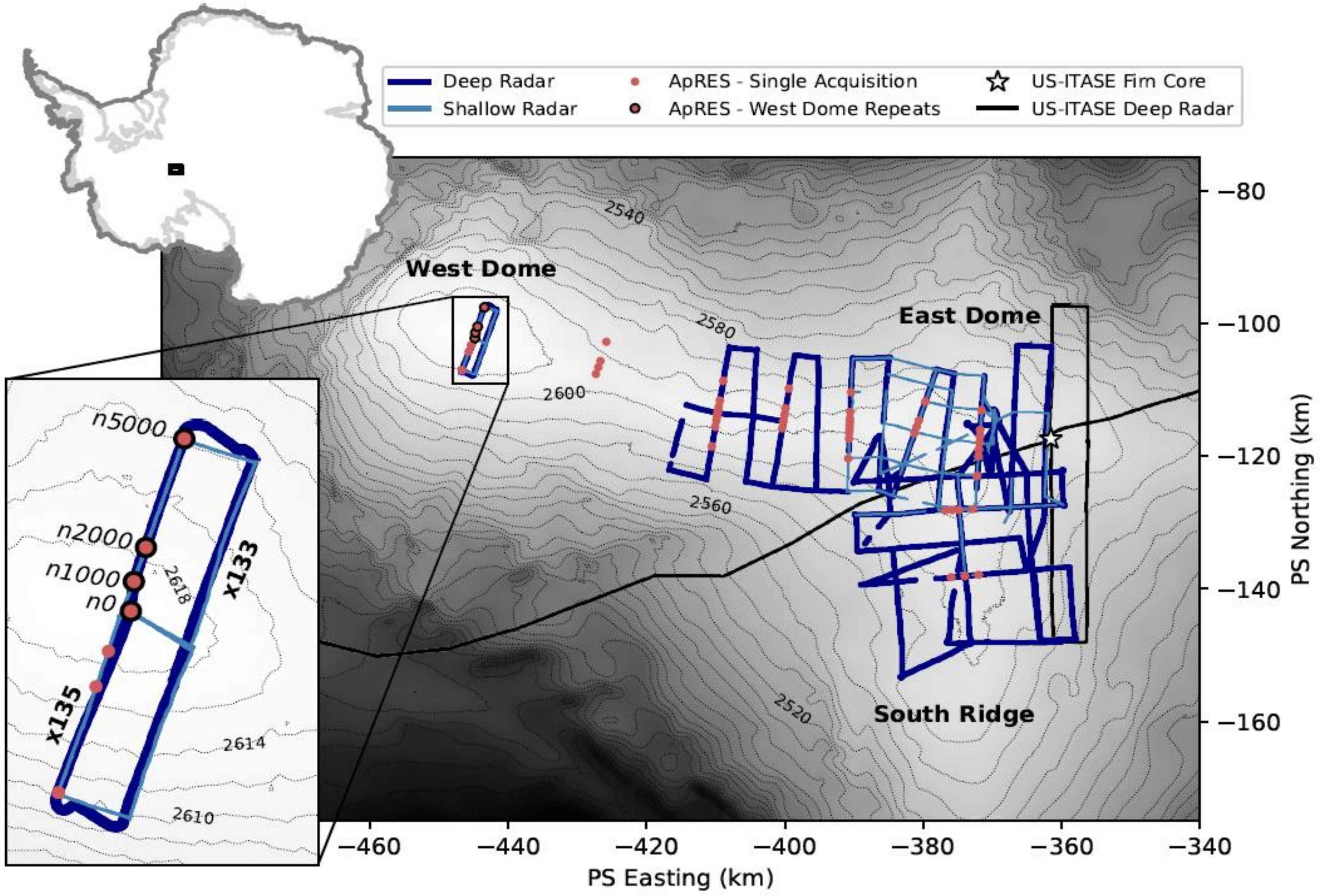
Goals

- Modelling ice flow and history to understand old ice
- Advanced radar imaging of ice sheet structure and dynamics
- Novel thermal probes for ice sheet age vs. depth relationship
- Ice coring on margin and interior
- Ice core analysis including dating old ice with advanced methods and new centralized facility
- New efforts in broadening participation, diversity and knowledge transfer

Status

- Funded by NSF Office of Integrative Activities 2021-2026, renewal proposal to 2031 expected
- Programs and staff gearing up now
- First airborne geophysics and possible ground based work in 2022/2023 season (S. Pole→Dome A region)
- First ice coring at Allan Hills in 23/24 (I-165 [Higgins] drilling there in 22/23)
- Workshops, annual meetings, seminars, REU program, scholarship funds in progress – many programs will be open to all ice coring community in US

Herc Dome – promising drill location at West Dome



Manuscript to be submitted this month

Traverse no earlier than 23/24
Drilling no earlier than 24/25

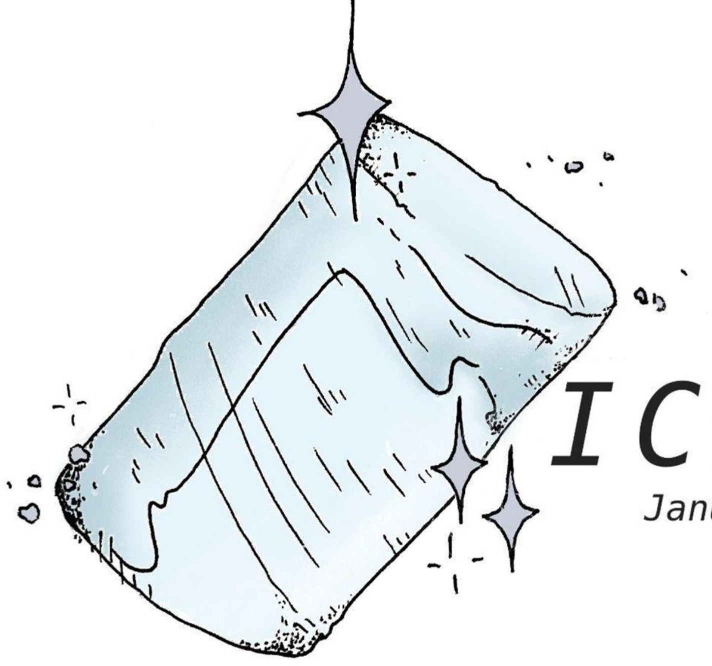
ICECReW

January 5–8th 2022

Organizing Team

Jessica Badgeley, Asmita Bannerjee, T.J. Fudge, Bess Koffman, Summer Rupper, Katie Wendt

NSF support through IDP



ICECReW

January 5–8th 2022

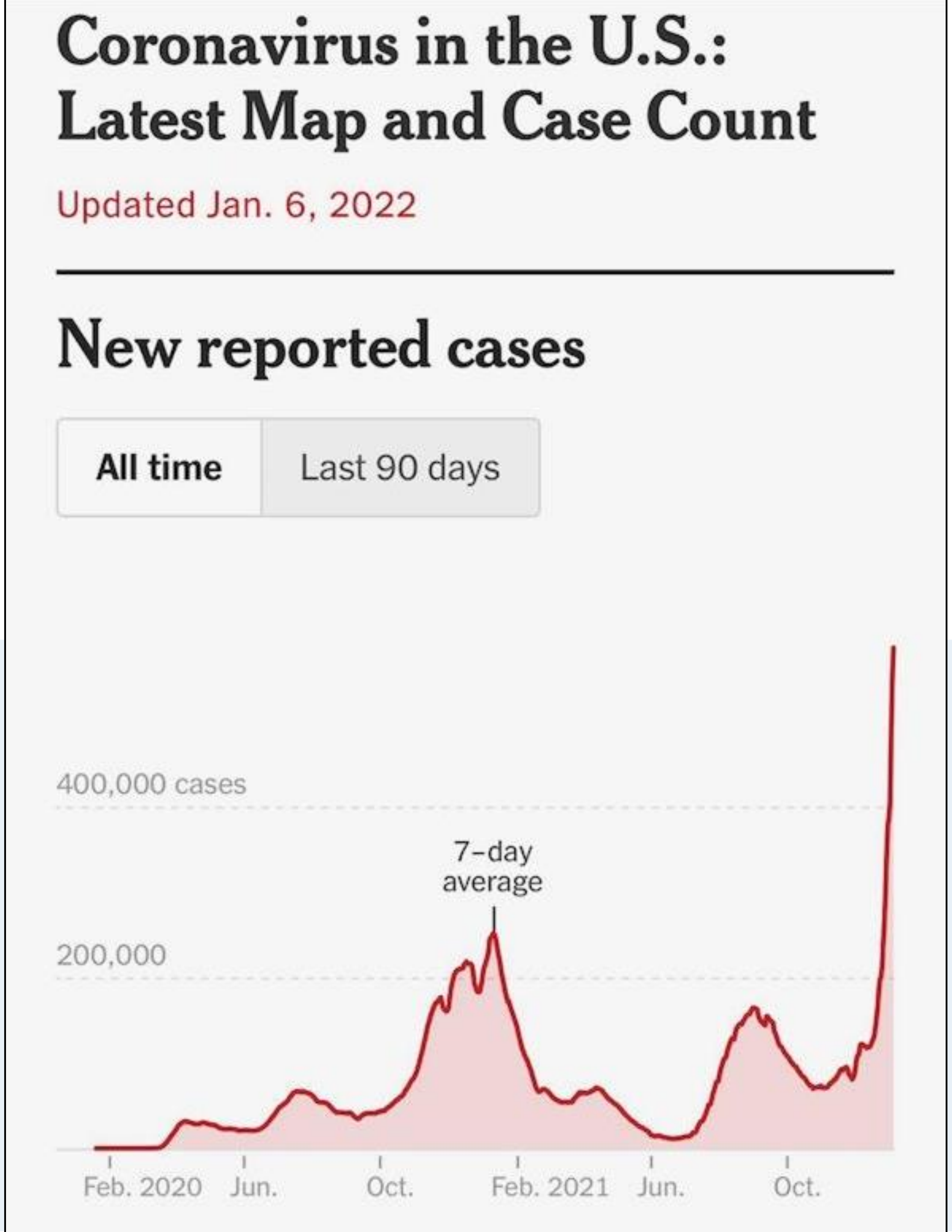
A professional development workshop for ECRs with the goals to:

- Better understand outcomes of and resources available from past ice core projects
- Learn about opportunities to engage with future efforts
- Connect with potential collaborators
- Develop synthesis papers on ice core science

The workshop generated a lot of interest from within the US ice core community and beyond!

- 57 applicants (49 from US)
- 22 selected for in-person participation
- 45 attended virtually (no in-person)
- 50% women, 55% self-identified as member of underrepresented group including 15% non-white and 1% from URM not related to race or gender (e.g, sexual orientation, disability)
- 4 faculty mentors:
  - Ali Cristiciello
  - Laurence Yeung
  - Kaitlin Keegan
  - Brad Markle

Unfortunately, the timing was not promising for an in-person meeting…



Mental Health, Science Communication, & Anti-Racism

Mental health in academia

Dr. Desiree Dickerson

Science communication

Dr. Julia Rosen

Anti-racism in academia

Dr. Asmeret Asefaw Berhe

NSF & Community Resources

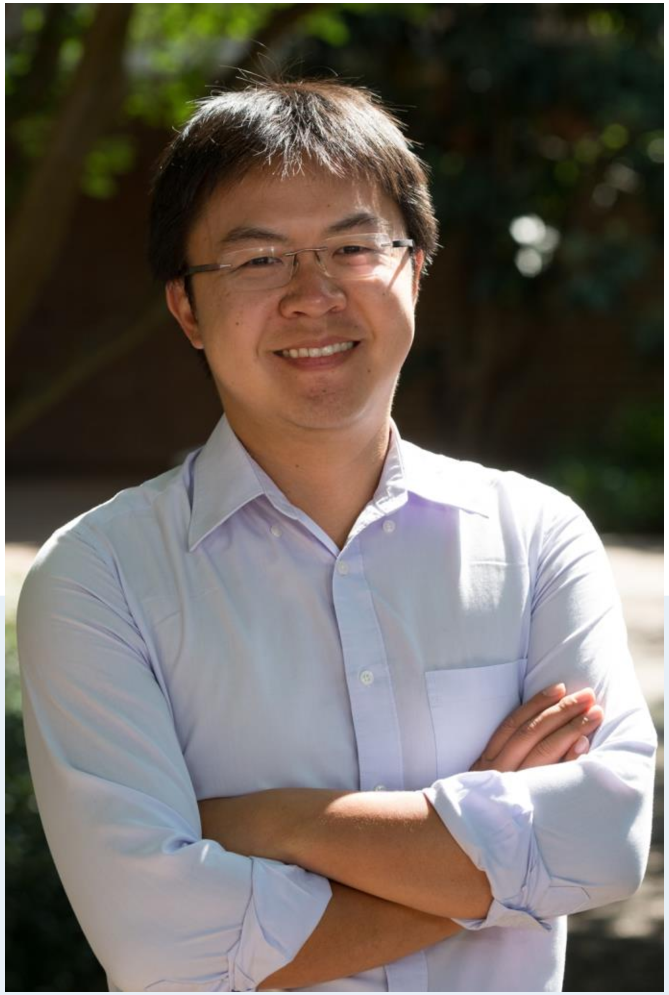
Dr. Paul Cutler

Dr. David Sutherland

Joe Souney

Proposal Writing

Dr. Greg Balco

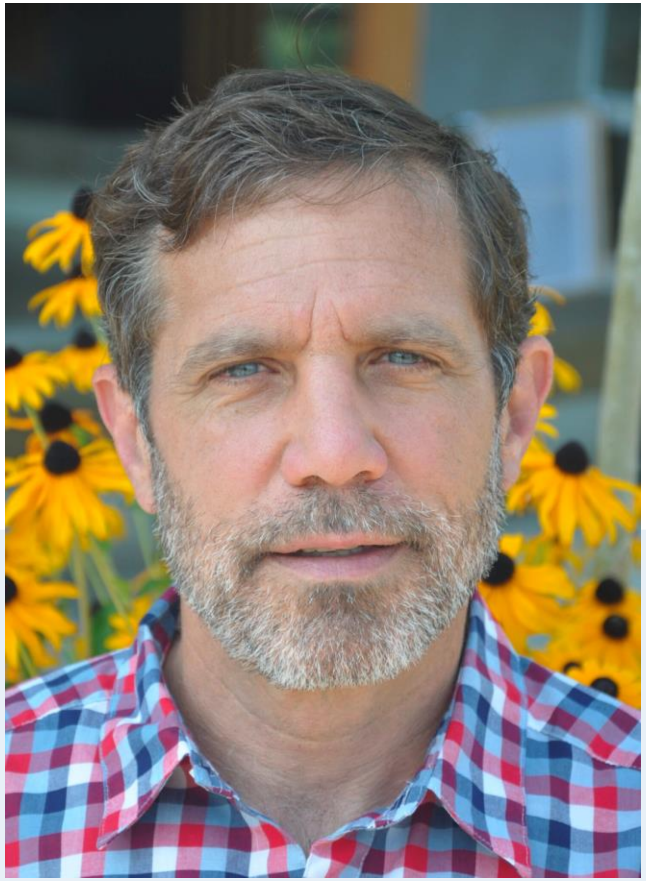


Dr. Laurence Y. Yeung

Past Ice Core Successes

Dr. Richard B. Alley   Dr. Anaïs Orsi

Upcoming Ice Core Projects



COLDEX

Dr. Edward Brook

Hercules Dome

Dr. Eric Steig

Mt Logan

Dr. Ali Cristiciello

Upcoming Ice Core Projects

Various

Dr. Joe Mcconnell

Himalaya

Dr. Summer Rupper

Mt Waddington

Dr. Peter Neff

Upcoming Ice Core Projects

Greenland

Dr. Erich Osterberg

Eclipse

Dr. Dom Winski

Ice Core-Related Projects

Microbiology

Dr. Jill Mikucki

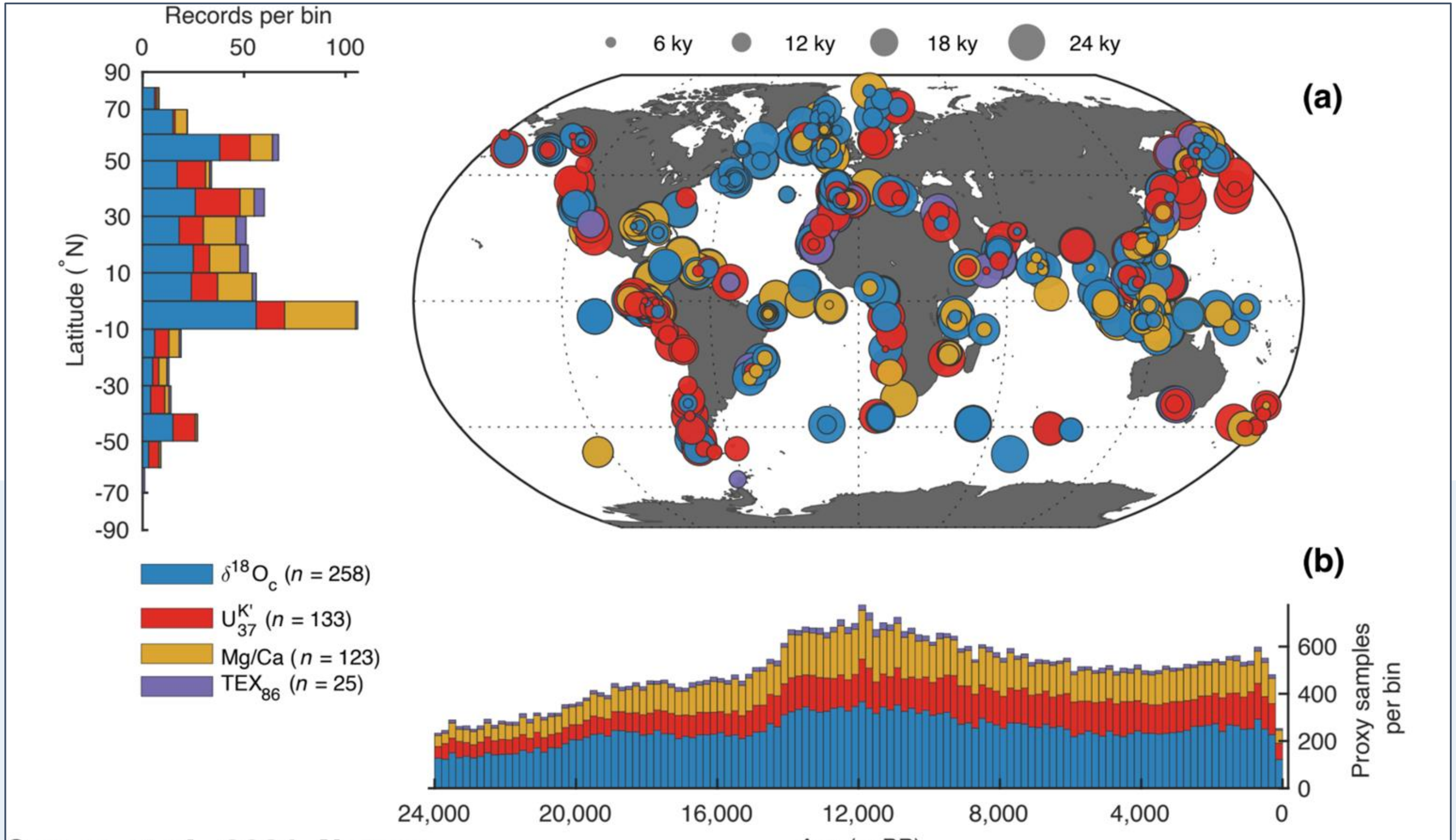
Sub-glacial geology

Dr. Brent Goehring

Ice fabric & logging

Dr. Erin Pettit

Synthesis Project Example



Osman et al., 2021, Nature

Dr. Jessica E. Tierney

Overwhelmingly positive response to workshop!

"This was one of the most **well-organized and open/welcoming** workshops I have ever been a part of."

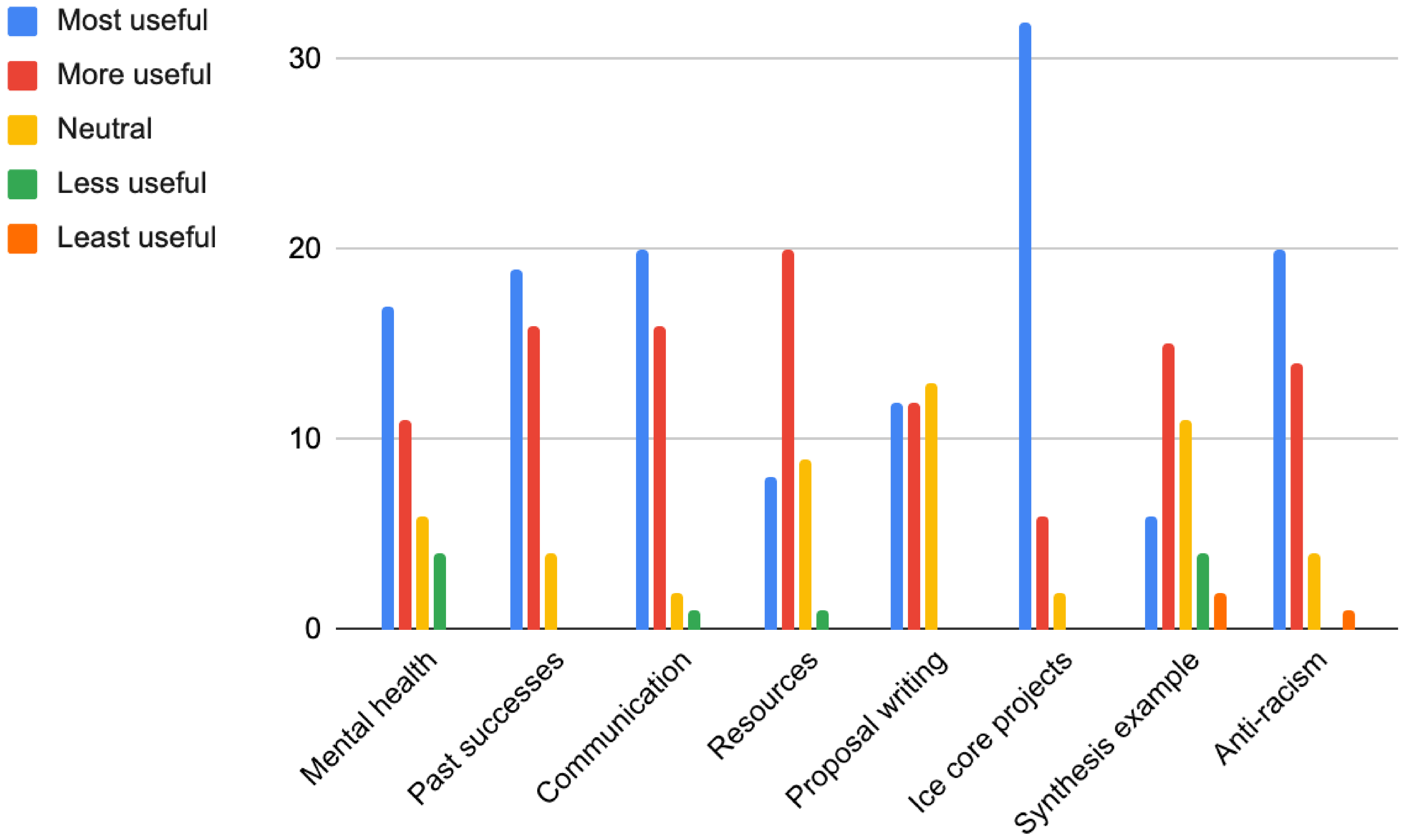
"For the first time since starting my program, **I feel like part of the ice core community.**"

"The talks and sessions really got into nuts and bolts moreso than I often see, which is **something I wish I**

"It provided a great way for me to interact with many people in my field that I haven't met before. I felt **really excited and hopeful about the future of ice core science!** I'm specifically looking forward to contributing to the synthesis publication."

"I think the conversation topics (and the speakers who spoke to them) were very well chosen. From synthesis papers to proposal writing, I was exposed to a lot of topics I've always had vague questions about. It was **really useful to be walked through these processes in a clear and accessible way.**"

“What sessions did you find most useful to you?”



Synthesis Papers

- Target a broad audience, including undergraduates, early graduate students, and science-literate public
- ECR author teams, so full scientific review article(s) seemed like a big 'ask'
- Range of topics related to ice core science emerged from the workshop breakout sessions, ideal for short synthesis papers
- Open access format a priority

Editorial team: Jessica Badgeley, T.J. Fudge, Bess Koffman, and Summer Rupper

Evidence that local dust sources supply low-elevation Antarctic regions

Bess G. Koffman[1,2] and Karl J. Kreutz[1]

Dust flux and size distribution measurements from the West Antarctic Ice Sheet (WAIS) Divide and other non-East Antarctic plateau ice core sites suggest that local dust sources supply a significant amount of dust to the high-latitude atmosphere and ocean.

Polar ice is an important high-latitude archive of past environmental and atmospheric changes. The physical measurement of dust particles trapped in well-dated ice cores provides independent information, in the form of dust flux and particle size distribution (PSD) parameters, about past environmental changes in dust source regions, the proximity of dust sources, and variability in atmospheric circulation intensity. Much effort has gone into understanding the sources and transport of dust to the high-elevation sites (~3200-3500 m a.s.l.) Vostok and Dome C on the East Antarctic Ice Sheet (EAIS) plateau (Fig. 1). These records together provide a climatic history spanning the past eight glacial cycles (Lambert et al. 2008; Petit et al, 1999; Wolff et al. 2006). The East Antarctic plateau predominantly receives far-traveled dust, as evidenced by its lognormal distribution, small size (mode of 2 μm) and geochemical signature (e.g. Basile et al. 1997; Delmonte et al. 2004). The ice cores from this region provide invaluable information about hemispheric-scale changes in dust emissions and transport, but due to their high altitude, they do not capture dust carried in the lower-to-middle troposphere, and thus do not represent dust delivery to about half the Antarctic continent.

In order to assess changes in dust supply and transport to the lower-elevation regions of Antarctica, we must look to ice core records from West Antarctica and around the margins of the EAIS. Dust flux and particle size distribution measurements from WAIS Divide and other low-er-elevation and coastal cores show that these sites receive both higher dust fluxes and coarser PSDs than the East Antarctic plateau cores. Accordingly, we infer that local dust sources supply a significant amount of dust to the atmosphere and ocean around Antarctica.

Higher dust fluxes near the Antarctic coast

Dust flux is measured in units of mass per area and time. It takes into account the possible dilution effects of the snow accumulation rate on aerosol deposition, and thus can be compared readily among sites and across time intervals. Changes in dust flux are considered to represent changes in atmospheric dust concentrations (Fischer et al. 2007; Wolff et al. 2006); therefore, flux measurements offer insight into the atmospheric dust burden and its potential impacts on climate.

During the late Holocene, dust fluxes measured at sites near the margins of the Antarctic ice sheet and at elevations below ~2500 m a.s.l. range from about 1-12 mg m^{-2} yr^{-1} (Fig. 2). This contrasts with the significantly lower fluxes well below 1 mg m^{-2} yr^{-1} measured at high-elevation East Antarctic sites. At WAIS Divide a background dust flux of ~3-5 mg m^{-2} yr^{-1} is punctuated by several particularly dusty intervals during the last two millennia, reaching peak fluxes of ~15-25 mg m^{-2} yr^{-1} (Koffman et al. 2014). At James Ross Island near the tip of the Antarctic Peninsula (1540 m a.s.l.), dust flux (calculated using aluminum concentrations) was found to be 12 mg m^{-2} yr^{-1} ca. 150 years ago, prior to the effects of land-use changes in Patagonia (McConnell et al. 2007). Near the Transantarctic Mountains at 2315 m a.s.l., the Talos Dome ice core yields a late Holocene dust flux of about 1 mg m^{-2} yr^{-1} (Albani et al. 2012). While these records come from different sectors of the Antarctic continent and are almost undoubtedly influenced by different dust sources, they consistently show dust fluxes substantially higher than those seen on the East Antarctic plateau, where the interglacial dust flux is 0.2-0.6 mg m^{-2} yr^{-1} (Lambert et al. 2012). Corroborating these observations, Bory et al. (2010) report that the dust flux measured in modern snow at Berkner Island (899 m a.s.l.) in the Weddell Sea is about three times higher than at Kohnen Station in Dronning Maud Land (DML; 2890 m a.s.l.) for particles in the 5-10 μm range. Similarly, *nss*Ca^{2+} fluxes (a common proxy for mineral dust in ice cores) measured in the EPICA (European Project for Ice Coring in Antarctica) DML ice core at Kohnen Station were found to be three times higher than those measured at Dome C, which is about 300 m higher and several thousand km further from Patagonian dust sources (Fischer et al. 2007). In short, during the late Holocene, sites from Antarctica show an inverse relationship between elevation and dust flux (Fig. 2).

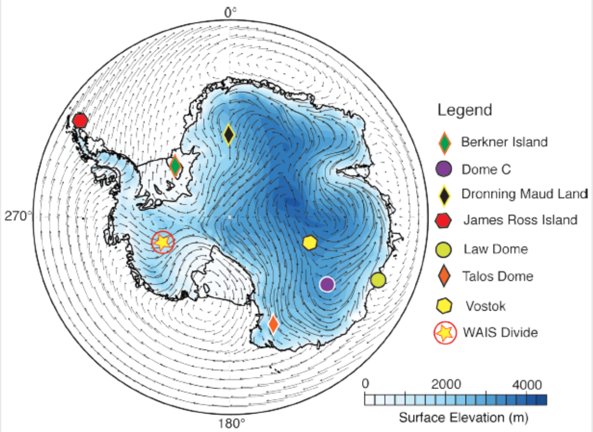


Figure 1: Surface elevation map of Antarctica showing sites discussed in the text and annual average winds at 700 hPa (ERA-Interim climate reanalysis). Image obtained using Climate Reanalyzer (http://cci-reanalyzer.org).

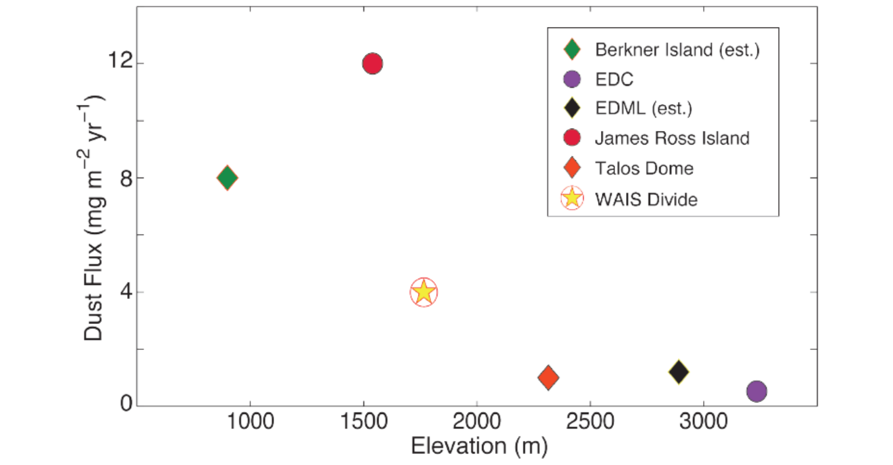


Figure 2: Dust flux versus elevation for: Berkner Island (Bory et al. 2010), EPICA Dome C (EDC; Lambert et al. 2012), EPICA Dronning Maud Land (EDML; Fischer et al. 2007), James Ross Island (McConnell et al. 2007), Talos Dome (Albani et al. 2012) and WAIS Divide (Koffman et al. 2014). Flux values for EDML and Berkner Island are estimated based on published flux ratios to other sites and available particle size information.

These observations imply an elevational gradient in the atmospheric dust burden over Antarctica, with the ice sheet margins receiving about 1-2 orders of magnitude more dust than the East Antarctic plateau. Further supporting evidence comes from high and low iron flux measurements from coastal Law Dome and high-elevation Dome C in East Antarctica, respectively (Edwards et al. 2006). Observation of an elevational dust flux gradient within the EAIS confirms that observed flux differences across Antarctica do not relate to regional (e.g. WAIS vs. EAIS) differences. Instead, it seems likely that the higher fluxes at coastal sites and below ~2500 m elevation reflect greater proximal dust emissions activity, and possibly also higher deposition of far-traveled dust (e.g. from Patagonia and Australia). Today, about 2% of Antarctica is ice-free, comprising an area roughly the size of New Zealand (Campbell and Claridge 1987). Although much of this area consists of exposed bedrock, several regions with available fine-grained material could serve as dust sources.

Coarse particles imply local sources

Coarser particle sizes near the margin of the Antarctic ice sheet and at elevations below 2500 m a.s.l. further support that proximal dust sources play an important role. At WAIS Divide, the dust flux is dominated by particles in the 5-10 μm range, and the long-term (100 year average) mode size of the volume-weighted distribution is 5-8 μm diameter (Koffman et al. 2013). From the few sites in Antarctica where mode sizes have been reported, it appears that relatively coarse PSDs are a common feature of lower-elevation regions. For example, late Holocene dust deposited at Berkner Island and at Talos Dome is dominated by particles > 5 μm diameter (Albani et al. 2012; Bory et al. 2010). The high proportion of coarse particles contrasts with observations from the East Antarctic plateau, where the volume-weighted mode size is close to 2 μm diameter for both glacial and interglacial periods (Delmonte et al. 2002). Although very coarse (> 75 μm diameter) particles have been observed to travel distances greater than 10,000 km (Betzer et al. 1988), particles larger than 5 μm diameter generally are associated with short transport distances (e.g. Mahowald et al. 2013; Tegen and Lacis 1996), implying local sources of dust.

Conclusions

The observed differences in dust fluxes and PSDs between lower- and higher-elevation sites in Antarctica (e.g. below or above ~2500 m a.s.l.) indicate that locally sourced dust is transported too low to reach the East Antarctic plateau. Climate models suggest that dust originating from southern South America and Australia is transported at altitudes greater than 4000 m (Krinner et al. 2010), i.e. well above the Vostok and Dome C ice core sites (e.g. Basile et al. 1997; Delmonte et al. 2004; Revel-Rolland et al. 2006). In contrast, based on existing particle size measurements, we infer that dust from Antarctic ice-free areas is transported below ~2500 m. Additional PSD measurements from a range of elevations are needed to confirm this interpretation.

The relatively coarse PSDs at WAIS Divide and other sites below 2500 m a.s.l. are good evidence that Antarctic ice-free areas comprise active dust sources for the high-latitude atmosphere and ocean.

While some areas, such as the McMurdo Dry Valleys, are known to be dusty (e.g. Bory et al. 2010), additional work is needed to understand the emissions activity and importance of Antarctic potential dust source areas, including the relative contributions of glacier-derived sediments and material of volcanic origin.

ACKNOWLEDGEMENTS

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DATA

The WAIS Divide ice core dust record can be obtained from the Global Change Master Directory (GCMD) public database.

AFFILIATIONS

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[2]Lamont-Doherty Earth Observatory of Columbia University, Palisades, USA

CONTACT

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REFERENCES

Full reference list under:

www.pages-igbp.org/products/magazine/ref2014_2.pdf

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Bory AJ-M et al. (2010) Earth Planet Sci Lett 291: 138-148

Delmonte B et al. (2004) Earth Sci Rev 66: 63-87

Koffman BG et al. (2014) Clim Past 10: 1-20

Lambert F et al. (2012) Clim Past 8: 609-623

Synthesis Papers

Life cycle of an ice core: Collection, transport, storage, records obtained

Lindsey Davidge, PhD Student, University of Washington (lead author)

Hanna Brooks, PhD Student, University of Maine

Merlin Mah, Postdoc, University of Minnesota

Bradley Markle, Assistant Professor, University of Colorado

Methods used to date ice cores

Kaden Martin, PhD Student, Oregon State University (lead author)

Meredith Helmick, PhD Student, University of Maine

Samantha Barnett, Masters Student, Northern Arizona University

T.J. Fudge, Research Assistant Professor, University of Washington

Synthesis Papers

Atmospheric change through time from ice cores

Asmita Banerjee, PhD Student, Rice University (lead author)

Ben Riddell-Young, PhD Student, Oregon State University

Ursula Jongebloed, PhD Student, University of Washington

Ice core insights on past climate change

Kathleen A. Wendt, Postdoc, Oregon State University (lead author)

Hayley Bennett, PhD Student, University of Colorado, Boulder

Austin Carter, PhD Student, Scripps Institute of Oceanography

Julia Marks Peterson, PhD Student, Oregon State University

Synthesis Papers

Ice core perspectives on human impacts on the environment

Sophia Wensman, Postdoc, Desert Research Institute (lead author)

Jacob Morgan, PhD Student, Scripps Institute of Oceanography

Kaitlin Keegan, Assistant Professor, University of Nevada, Reno

Wildfire records from ice cores

Sandra Brugger, Postdoc, Desert Research Institute (lead author)

Liam Kirkpatrick, Undergraduate Student, Dartmouth College

Laurence Yeung, Associate Professor, Rice University

Synthesis Papers

Ice core constraints on past sea level change

Drew Christ, Postdoc, University of Vermont (lead author)

Justin Toller, PhD Student, University of Nevada, Reno

Julia Andreasen, PhD Student, University of Minnesota

Biology in ice cores: What can we learn from studying life within and under the ice?

Madelyne Willis, PhD Student, Montana State University (lead author)

Heidi Smith, Assistant Research Professor, Montana State University

Nathan Chellman, Postdoc, Desert Research Institute

Synthesis Papers

Ice flow and ice-bed interactions: How they shape our understanding of ice cores

Caleb Walcott, PhD Student, University at Buffalo (lead author)

Ben Hills, PhD Student, University of Washington

Emma Erwin, PhD Student, University of Maine

Firn: Applications in dating, climate reconstruction, and interpreting atmospheric records

Drake McCrimmon, PhD Student, University of Nevada, Reno (lead author)

Alex Ilhe, PhD Student, University of Rochester

Summer Rupper, Professor, University of Utah

Synthesis Papers

Future directions in ice core science

Matt Osman, PhD Student, University of Arizona (lead author)

Alison Criscitiello, Director of Canadian Ice Core Lab, University of Alberta

Bess Koffman, Assistant Professor, Colby College

Timeline:

- May 1: initial submission deadline
- May 24-26: lead authors present at La Jolla meeting; opportunity for community input
- June-August: reviews and revisions
- Sept: revised articles submitted to *Past Global Changes*
- Oct/Nov: Issue published

La Jolla – Ice Core Open Science Meeting

- May 24-26
  - Paleoclimate
  - Ice physics or dynamics
  - analytical methods
  - modern or recent climate
  - ice sheet boundary conditions
  - atmospheric composition/chemistry
  - science communication and outreach
  - biology/biochemistry
  - community and diversity
- COLDEX pre-meeting on afternoon of May 23
- Ice Core Working Group or more! On afternoon of May 26

La Jolla – Ice Core Open Science Meeting

- Organized by Herc Dome, COLDEX, ICWG/IDP, and JIRP
- (Eric Steig (HD), Heidi Roop (COLDEX), T.J. Fudge (ICWG), Sarah Aarons (local), Seth Campbell (JIRP) and Murat Aydin (Herc Dome) and Joe Souney (IDP)
- Longer term goal is to have a community meeting similar to the WAIS workshop
  - With the diversity of ice coring projects, the model of WAIS Divide Ice Core annual meetings has become outdated
- Discussions – synergies with other working groups
  - Short term for afternoon meeting on May 26
  - Long term for future conferences