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Early-career perspectives on ice-core science

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Ice cores have changed the way we understand the Earth. Ice cores drilled in the 1990s in Greenland showed definitively for the first time the abrupt nature of climate change events in the past (e.g. Dansgaard et al. 1993; Grootes et al. 1993). Ice cores from Antarctica have yielded a continuous climate history of the past 800,000 years, as well as snapshots of climate older than two million years (Jouzel et al. 2007; Yan et al. 2019, Bergelin et al. 2022), providing important context for climate changes underway today. The global network of ice cores drilled in remote mountainous and polar regions provides insight into topics beyond climate, including the history of wildfires and anthropogenic activities (e.g. Dahe et al. 2002; Grieman et al. 2018). Today, we continue to drill ice cores in Greenland, Antarctica, and mountain glaciers worldwide to better understand the Earth.

It takes a global community of scientists from a variety of disciplines to locate sites, drill cores, conduct analyses, and interpret the data in the broader context of the Earth system (Fig. 1). Like many countries around the world, the United States (US) recognizes both the contributions of ice-core science and the importance of a dedicated and inclusive scientific community. In 2022, the US National Science Foundation, via the Ice Drilling Program, funded a workshop for US early-career researchers to become more deeply involved in the ice-core community. This opportunity came together as the Ice Core Early Career Workshop (ICECReW; icedrill.org/meetings/ice-core-early-career-researchers-workshop-icecrew). Participants shared a collective desire to develop resources to help communicate ice-core science to undergraduate students and ice-core-adjacent researchers, inspiring this contribution to *Past Global Changes Magazine*.

The following 10 articles resulted from collaborations among the early-career scientists who attended the ICECReW workshop. The first article follows an ice core from the field to the lab. The next article addresses how to build an ice-core timescale, which is essential for placing measurements in context. The following eight articles cover key areas of ice-core science and adjacent fields: climate, atmosphere, wildfires, human activity, microbes, snow-to-ice transition, sub-ice materials, and sea-level change.

In reflecting on the important advances of the past decade, one thing is clear. Our community is stronger – and the science is better – when everyone is included. Inclusion has been particularly challenging during the COVID-19 pandemic, and one goal of ICECReW was to connect US early-career researchers of all races, genders, identities, abilities, and disciplines. Inclusion must occur at every level – for instance, the International Partnerships in Ice Core Sciences (IPICS; pastglobalchanges.org/ipics) open science meetings foster international inclusion. Through both individual and institutional actions, we can create a community where all feel welcome.

Figure 1: Photos highlight key elements of ice-core research, from geophysical surveys of potential drilling locations to laboratory analysis and timeseries data: **(A)** Glacier survey on Denali, Alaska (Photo credit: Brad Markle); **(B)** Radar echogram from West Hercules Dome, Antarctica (Image credit: T.J. Fudge); **(C)** Ice-core drilling rig on Mount Logan, Canada (Photo credit: Brad Markle); **(D)** Ice-core barrel at WAIS Divide, Antarctica (Photo credit: Brad Markle); **(E)** Ice core from the Juneau Ice Field, Alaska (Photo credit: Brad Markle); **(F)** Ice-core transport by Basler aircraft at Byrd Station, Antarctica (Photo credit: Lora Koenig); **(G)** US National Science Foundation Ice Core Facility, Colorado (Photo credit: NSF-ICF); **(H)** Processing samples in the Pico-Trace Ultraclean Lab, Lamont-Doherty Earth Observatory of Columbia University, New York, USA (Photo credit: Bess Koffman); **(I)** Ice-core thin section (Photo credit: British Library); **(J)** Ice-core CO_2 and isotope data from the EPICA Dome C ice core, Antarctica (Jouzel et al. 2007; Lüthi et al. 2008; Parkinson 2016).

In addition to building a more inclusive ice-core community, continued advances in ice-core science will be enabled through measurements of ice from new sites. Some current and future projects include multiple searches for a continuous climate record spanning 1.5 million years in East Antarctica, and projects targeting previous warm periods—such as the Last Interglacial (~130,000 years ago)—to determine the amount and rate of sea-level rise at that time. New cores from mountain regions are filling in the global network and providing important regional perspectives. In the coming decades, ice coring will not only expand on Earth but will also likely extend to the Moon and Mars. These are all significant undertakings that require international partnership and cooperation.

Analytical improvements and integration of ice-core data with other proxy records and with models will be just as important for the field as drilling new cores. Clumped isotope analysis enables insight into past atmospheric conditions, while micrometer-scale measurements push the spatial and temporal resolution of the old, highly-thinned portions of ice cores. Advances in timescale development already permit synchronization of ice cores with many paleoclimate proxy records, allowing for global assimilation with climate models. Such efforts provide benchmarks for model performance, aiding in our projections of future climate change.

As we look to the future of ice-core science, we see great promise among the current generation of early-career scientists. We are excited to showcase their perspectives on some of the important ice-core science developments in the articles that follow.

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