Ice Cores and the Temporalities of the Global Environment

ALESSANDRO ANTONELLO
School of Historical and Philosophical Studies, University of Melbourne, Australia

MARK CAREY
Robert D. Clark Honors College, University of Oregon, USA

Abstract Ice cores from Antarctica, Greenland, and the high-mountain cryosphere have become essential sources of evidence on the climate dating back nearly 800,000 years. Earth scientists use ice cores to understand the chemical composition of the atmosphere, which has been trapped in the air bubbles between the ice crystals as they form annually; this knowledge also feeds into modeling the climate's future. Ice cores are not simply important sources of environmental knowledge, but have become important elements of global environmental representations and politics since the 1980s. Ice cores do a lot of work. This article is specifically concerned with examining how the practices involved in drilling, analyzing, discussing, and using ice cores for both science and broader climate or environmental policies and cultures take part in constituting the temporalities of the global environment. We suggest that ice core discourses have constituted and advanced specific textures and sensibilities of time in relation to Earth's past, the history of humans as both species and civilization, and certain apocalyptic and determined futures. While the evidence from ice cores is meant to point toward obvious choices to control our global future, the temporalities of ice cores might not lead the same way. This article joins an increasing concern in the environmental humanities with temporalities, and encourages greater attention to temporalities in environmental history.

Keywords ice cores, ice, cryosphere, temporalities, deep time, polar regions

In June 2004, the European Project for Ice Coring in Antarctica (EPICA) announced that it had retrieved an ice core from Dome C in Antarctica covering the past 740,000 years. The *Nature* article reporting the successful coring was headlined "Frozen Time."[1] While the article conveyed the important geochemical results, its title emphasized time as one of the central elements of ice cores as significant scientific objects. Pennsylvania State University glaciologist Richard Alley, after all, called a Greenland ice core a

1. Walker, "Frozen Time" 596.

Environmental Humanities 9:2 (November 2017)
DOI 10.1215/22011919-4215202

"two-mile time machine," because the two-mile-long core contained annual layers of ice laid down over more than 200,000 years.[2] Ice cores provide some of the most detailed and extensive climate records, recorded in air bubbles trapped in annual ice layers going back nearly 800,000 years in the oldest deep core. Their long temporal coverage and geochemical contents make ice cores significant for understanding the past and future of Earth's climate.

Since early efforts in the 1950s, and especially since the 1980s, drilling into the Antarctic and Greenland ice sheets, as well as mountain glaciers, to retrieve ice cores has become a critical practice in constituting knowledge, understandings, representations, and politics of the contemporary global environmental. Geoscientists drill ice cores because glaciers and ice sheets form through an annual accumulation of snow that does not fully melt and that, subjected to gravity and pressure from new snow above, transforms eventually into ice. Each year of snowfall forms a separate layer of ice in the glacier, making it possible to reconstruct chronological layers, like tree rings. The ice and trapped gases hold information about the glacier's or ice sheet's structure, physical mechanics, rate of growth or decline, mean surface temperature, contents of the atmosphere at the time of formation, and air temperature when the snow originally fell (fig. 1).

Data from ice cores therefore speaks both to the body of ice itself as well as the atmosphere and climate in which the ice formed.[3] Scientific research on ice cores has demonstrated the links between global average temperature and the chemical contents of the atmosphere, especially carbon dioxide concentrations, for the past 800,000 years. Climate historian Spencer Weart argues that the results from Antarctica's Vostok ice core in 1987 "were definite, unexpected, and momentous"—the Vostok core "tipped the balance in the greenhouse-effect controversy, nailing down an emerging scientific consensus: the gas [CO_2] did indeed play a central role in climate change" (fig. 2).[4] As such, ice cores from a small number of polar and high-mountain cryosphere sites have supported calls for comprehensive actions to reduce global carbon emissions by placing humans into longer Earth histories and by speculating about catastrophic future climate change.

But ice cores, we argue, do a lot more than record past atmospheric conditions over long time spans. Deep core drilling has generated significant concepts, ideas, and discourses relating, on the one hand, to the polar and alpine environments from which the cores are taken and, on the other, to the "global" environment that they are made to speak to by scientists, environmentalists, journalists, and policy makers. This article offers a critique and categorization of the ice core talk engaged in by these actors in

2. Alley, *Two-Mile Time Machine*.

3. For popular accounts of ice core science by some of its leading scientists, see Alley, *Two-Mile Time Machine*; Mayewski and White, *Ice Chronicles*; Jouzel, Lorius, and Raynaud, *White Planet*.

4. Weart, *Discovery of Global Warming*, 126.

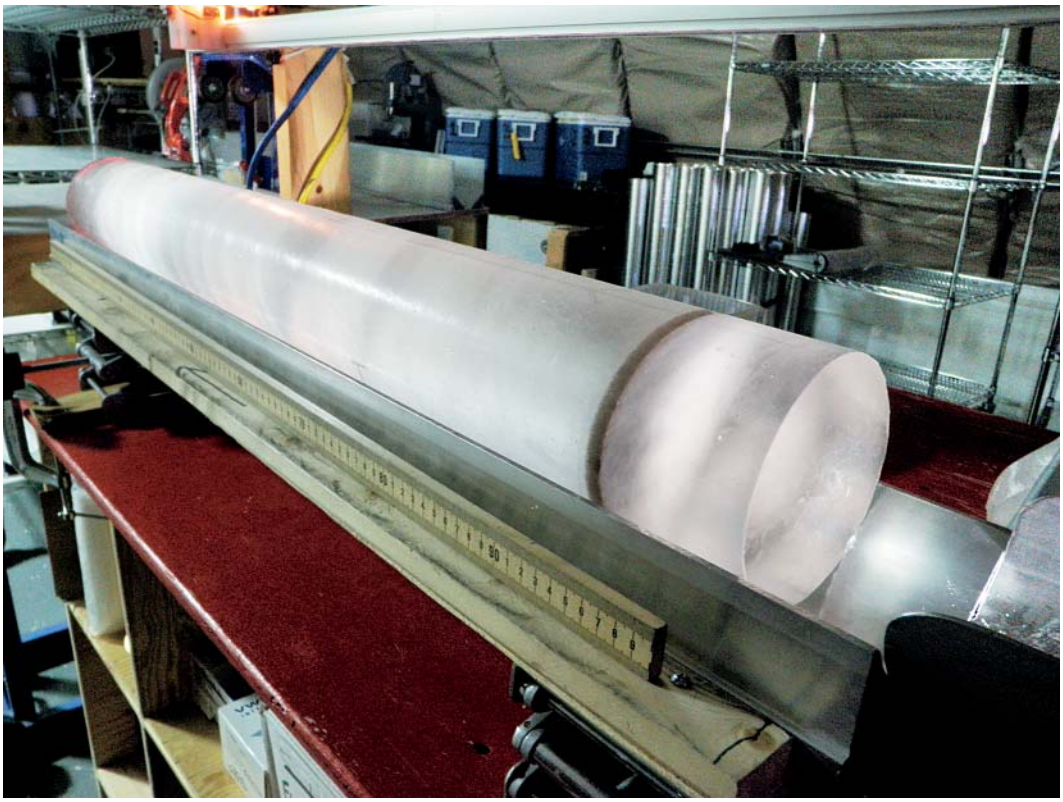

Figure 1. This section of ice core was drilled in December 2010 from the West Antarctic Ice Sheet. The layers of ice are visible, but also notable is a layer of volcanic ash deposited approximately 21,000 years ago. Photographer: Heide Roop. Source: United States Antarctic Program Photo Library, photolibrary.usap.gov/.

scientific and popular publications. A global rhetoric has been central to establishing ice core science as meaningful, necessary, and reliable. Ice cores do a lot of other work, too. Ice core discourses, discussions, reporting, representations, and narratives have also shaped temporalities, the senses of time, in the contemporary world. The glaciologist and climatologist Paul Mayewski—who was chief scientist of the US Greenland Ice Sheet Project 2 (GISP2) between 1989 and 1993—has suggested that ice cores "have the power to transform our understanding of time." Just as the space age had made humans and Earth seem spatially small, ice cores transform our "temporal consciousness" as "we locate ourselves within natural cycles that endure for thousands of years, and witness the random events that punctuate these patterns."[5]

In providing this critique and categorization of ice core talk, this article builds upon existing work tracing the history of ice core science and cultures of ice more generally and brings it into conversation with work on temporalities across the humanities. Our contention is that the practices involved in drilling, analyzing, discussing, and

5. Mayewski and White, *Ice Chronicles*, 15–16.

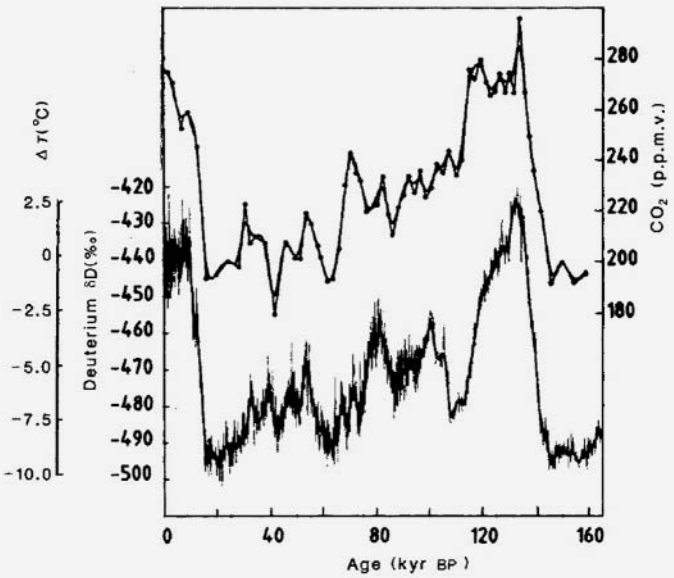

Fig. 2 CO_2 concentrations ('best estimates') and smoothed values (spline function) in p.p.m.v. plotted against age in the Vostok record (upper curves) and atmospheric temperature change derived[14] from the isotopic profile (lower curve). The deuterium scale corresponds to values after correction for deuterium changes of oceanic water[14].

Figure 2. In 1987, the results from the Antarctic Vostok ice core clearly demonstrated the close links between atmospheric CO_2 concentrations and temperature. From Barnola et al., "Vostok Ice Core," 410. Reprinted by permission from Macmillan Publishers Ltd.

using ice cores for both science and broader climate or environmental studies and policies take part in constituting the temporalities of the global environment. Ice core discussions have helped transform the understanding of what we refer to as *Earth time, human time*, and *future time*. First, ice cores have recast the history of Earth, revealing a much more turbulent and unpredictable past even as Earth has gone through fairly consistent cycles over the last 800,000 years. In this way, ice cores have made fundamental contributions to atmospheric sciences and the reconstruction of Earth's past climates. Second, human time appears in ice cores not only because of the traces of greenhouse-gas emissions, but also because scientists and journalists frequently interpolate human events into the ice core records. This particular register of human time reinforces Western views of history, while at the same time treating people both as a species and as human societies. Third, future time refers to the ways in which ice core commentaries try to predict or predetermine the future, often in apocalyptic terms in which humans are largely static or monolithically affected by climate alone. Ice cores, in short, have been at the heart of late twentieth- and early twenty-first-century developments relating to environmental perceptions and perspectives—and the way people see themselves in this world, not only spatially but temporally.

Perspectives on Ice and Time

While contemporary anthropogenic climate change has forced a focus on changing (indeed disappearing) ice, glaciers and ice sheets were historical and cultural before our

present moment. That humans are now causing the global retreat of the cryosphere—what Sverker Sörlin has labeled our "cryo-historical moment"—requires continued attention to the communities living with ice and the narratives associated with ice.[6] Existing humanities and social science research on ice cores has concentrated on several aspects. In their studies of Greenland and Antarctic cores, Janet Martin-Nielsen and Aant Elzinga have each illuminated a diverse range of questions in the history of science and environmental history, including the imaginings of the polar regions, drilling in the context of the Cold War, the formation of, or breakdowns in, scientific collaboration both within nations and internationally, and technical and engineering aspects of drilling.[7] Other researchers, including Martin Skrydstrup, Heather Frazar, and Jessica O'Reilly have conducted ethnographic work on glaciology, exploring how relationships with snow and ice, within specific scientific and political structures, have shaped ice core drilling and the development of glaciological sciences.[8] Kathryn Yusoff and Katrina Dean have each problematized the idea of ice cores as "archive," perhaps the dominant metaphor applied to them. Yusoff sees that there is an "archival impulse" in contemporary engagements with the environment, an "impetus to order this abrupt changing world," and argues that the archival metaphor is used to haunt current generations.[9]

On the whole, however, this existing scholarship on ice cores, while sometimes glancing at the issue of temporalities, has not given it sustained attention. Time is a central element in human cultures, carrying many elements and associations. Past, present, and future are widely constituted divisions to begin with, but hardly exhaust temporal registers that span from clock time and the seven-day work week of industrial modernity to cyclical time constructions in the Maya calendar. The sociologist Norbert Elias suggested that people use time, especially time devices like clocks, "as means of orienting themselves within the succession of social, biological and physical processes," as well as "regulating their behavior in relation to each other and themselves."[10] The sociologist Barbara Adam argues that temporalities emerge, at both individual and collective scales, from a human reckoning with mortality. Additionally, Adam specifically notes how environmental temporalities are different from the "clock" time of industrial modernity and "Newtonian science," and in that tension of temporalities are the failures to address contemporary environmental hazards.[11] And anthropologist Carol Greenhouse has advanced the argument that "time articulates people's understandings of agency: literally, what makes things happen and what makes acts relevant in relation to social experience, however conceived."[12] While social time has been a

6. Sörlin, "Cryo-History"; Carey, "The History of Ice"; Carey et al., "Glaciers, Gender, and Science."

7. Elzinga, "Some Aspects in the History of Ice Core Drilling and Science from IGY to EPICA"; Martin-Nielsen, *Eismitte*; Martin-Nielsen, "Deepest and Most Rewarding Hole Ever Drilled."

8. O'Reilly, "Sensing the Ice"; Frazar, "Core Matters"; Skrydstrup, "Modelling Ice"; Bowen, *Thin Ice*.

9. Yusoff, "Ice Archives," 118; Clark, "Life on Spike," 42–43; Dean, "Archives and Metaphors," 8–9.

10. Elias, *Essay on Time*, 4.

11. Adam, *Time*; Adam, *Timescapes of Modernity*.

12. Greenhouse, *Moment's Notice*.

long-standing concern within some social sciences, there has been a renewed interest in time and temporalities in recent years—especially in anthropology, philosophy, and sociology, but less so in history.[13] Given scholars' increasing emphasis on the divergent constructions of time across diverse societies and throughout history, the research within the temporal turn also questions using limited information from a few sites (such as the poles and some high-mountain sites) or a few people (scientists and journalists primarily) to draw out larger temporalities applied to groups across space and time. The critique of grand narratives in the temporal turn decenters the West and recognizes that all societies do not advance mechanistically and uniformly through stages of civilization; nor do they move homogenously and simplistically through modernization or capitalism or boom-and-bust cycles. Despite efforts to show that time is much more than an objective "technological measure of duration," as Robert Hassan puts it, critical studies on the construction of temporalities have not become as ubiquitous as analyses of the construction of space.[14]

Investigating temporalities with the specific case of ice cores thus injects new perspectives into global environmental history and the environmental humanities.[15] Scientists, environmentalists, journalists, and policy makers make ice cores speak to long periods of time, a long history of both Earth and *Homo sapiens*. There is a tension here with the spatial emphasis of what Benjamin Lazier has called the "Earthrise era."[16] One of the totemic elements of contemporary history—not simply environmental but scientific, cultural, political, economic, and social—has been a sense of global unity. This has been articulated particularly in the famous 1968 "Earthrise" and 1972 "Blue Marble" photographs of Earth, both taken by NASA astronauts.[17] These photographs were made to speak to the unity, fragility, and vitality of Earth within the great void of outer space—that is, a spatial conception of Earth. But these iconic photographs and their emphasis on one whole Earth suggests timelessness. We are interested here in critically analyzing the cultural and scientific construction of Earth's time and temporalities while, at the same time, demonstrating how ice cores have tended to universalize and create a single timeline or temporality for Earth. Environmental historians broadly have engaged with the spatial and material elements of the past, but neither they nor even big history or evolutionary history have fully engaged with how societies construct time or constitute human temporalities—which is what scientists, journalists, environmentalists, and policy makers have been doing through ice core studies and representations

13. Hassan, "Globalization and the 'Temporal Turn'"; Bear, "Time as Technique"; Corfield, "Time and the Historians"; Rosenberg and Grafton, *Cartographies of Time*.

14. We appreciate arguments that space and time need to be treated together, such as in May and Thrift, eds., *Timespace: Geographies of Temporality*. Yet, given the preponderance of spatial work, we believe that time and temporalities are underexamined in comparison, and thus deserve focused treatment on their own terms.

15. Bastian, "Inventing Nature"; Nixon, *Slow Violence*.

16. Lazier, "Earthrise."

17. Poole, *Earthrise*; Jasanoff, "Image and Imagination"; Lekan, "Fractal Eaarth."

since the 1950s.[18] As historian Penelope Corfield explains, "the need to understand the long-term workings of Time, as evidenced in human and Earth history, cannot be gainsaid." Analysis of ice core temporalities carries out her call for this kind of intertwined analysis of human and Earth history.[19]

Earth Time

From the earliest ice-drilling developments in the 1950s, a major impulse has been to understand the past—the past of the ice sheets and, by extension, of Earth. As a body of records, ice cores speak to the history of Earth from the present back 800,000 years, with most of the records covering the past 200,000 years. Ice cores are not simply formless records that give a brute quantitative age or duration of years. Rather, ice cores help generate particular temporal textures for Earth for the middle and late Pleistocene, identifying rhythms and cycles, continuity and discontinuity, synchrony and asynchrony.

Data from ice cores up to the mid-1980s demonstrated high resolution for the Holocene, and the immediately foregoing Ice Age, with only hints about the Eemian period (the warmer era between the last two ice ages, ending about 115,000 years ago). The Antarctic Vostok core results published in 1987 overcame those limitations, offering data from the second-to-last ice age, and linking cycles of atmospheric carbon dioxide with average atmospheric temperature. The 1999 Vostok results went much further, and the 2005 Antarctic EPICA core contained high-resolution details through the past eight glacial-interglacial cycles. The 100,000-year glacial-interglacial cycles were predictable and measurable against the Milankovitch cycles of Earth's orbit—except that the current Holocene epoch was now experiencing higher levels of carbon dioxide than at any point in the last 800,000 years.

While ice cores have, on the one hand, shown regular glacial-interglacial cycles over nearly a million years, some cores—particularly the GISP2 and the Greenland Ice Core Project (GRIP) drilled by a European consortium—have also uncovered a turbulent record of abrupt climate change that punctured previous theories. Analyzing the Eemian Interglacial (130,000 to 115,000 years ago) and the Younger Dryas (a 1,300-year return to near ice-age conditions ending about 11,640 years ago), researchers studying these Greenland ice cores extracted between 1989 and 1993 found that ice ages could turn on and off in the span of a few years, not necessarily on decadal or century scales.[20] University of Colorado GISP2 scientist James White captured the new insights about rapid climate-change events when he said that "I used to tell my students climate could change in their lifetime. Well, now I can tell them that it can change in less time than it takes them to graduate."[21]

18. Christian, *Maps of Time*; Russell, *Evolutionary History*.
19. Corfield, "Time and the Historians," 90.
20. Mayewski and White, *Ice Chronicles*, 84–95.
21. Monastersky, "Ice Core."

Because their data reveal similar rhythms and cycles of the atmosphere and climate, ice cores from Greenland and Antarctica synchronize Earth's two hemispheres. This has been the case since the first results from both the 1966 Camp Century core and the 1968 Byrd Station core. Ice core results have also been used by Quaternary scientists, especially those interested in stratigraphy, to date and sequence the geological history of Earth. As the quaternary scientists P. Gibbard and T. Van Kolfschoten note, one of the developments in stratigraphic sequencing over the second half of the twentieth century was a move away from local sequencing to global sequencing. Before the 1980s and 1990s, the glacial and interglacial periods had different names relating to the European and North American stages. Deep-sea sediment cores began to change this naming practice by moving to "marine isotope stages" in the 1970s. In the most recent dating efforts of the Quaternary and Pleistocene, ice cores have taken center stage as scientists began to see terrestrial strata as too local, "fragmentary and highly variable." Yet the ice cores, as Gibbard and Van Kolfschoten put it, "have provided spectacularly unrivalled sequences which allow annual resolution of climatic events."[22] Though ice cores are not long enough to date the beginning of the Quaternary or Pleistocene, they can date the onset of the Holocene, and certain ice core strata have been suggested for the proposed Anthropocene epoch. In 2008, following several years of committee work, scientists identified the Pleistocene-Holocene boundary precisely at 11,700 years before the year 2000—which was found, perhaps not surprisingly, in an ice core, the GRIP core at exactly 1,492.45 meters down, where it could be visibly spotted.[23]

If the polar cores suggested a synchronized experience of the ice ages and climatic change in the Pleistocene, ice from tropical and temperate high mountains posed a scientific problem—referred to specifically as the Mercer Problem because it was the Ohio State University geoscientist John Mercer who found that the Younger Dryas did not occur in the southern hemisphere. Mercer pointed out a "tropical asynchrony," given the contrast with the North Atlantic. Glaciologist Lonnie Thompson began tackling the Mercer Problem—among other riddles—in the 1970s, when he started ice core drilling on Peru's Quelccaya ice cap. Thompson and his colleagues' results have challenged the story from the polar ice cores, and for a time annoyed other earth scientists in what the science journalist Mark Bowen has described as the "North Atlantic School"—named for their concentration on Greenland, North America, and Europe. Thompson's "asynchrony theory" derives from the counterintuitive experience of tropical glaciers to polar ice sheets during orbital changes.[24] In the process, those working on tropical and temperate cores have challenged the synchronicity of Earth events in the Pleistocene, and the unity of the contemporary climate story.

Despite the asynchrony emerging from tropical and temperate high-mountain ice cores, the cumulative record and interpretation of the Greenland and Antarctic ice

22. Gibbard and Van Kolfschoten, "Pleistocene and Holocene Epochs," 448–49.

23. Walker et al., "Formal Definition and Dating of the GSSP."

24. Bowen, *Thin Ice*.

cores have established a strong temporality of Earth. The ice cores have embedded the seemingly permanent and stable cycles of the ice ages and the rhythms of warm and cold. Yet the transition between the cold and warm periods has been abrupt, a discontinuity within the cycles. The present is also often folded into this temporality of Earth's past. For example, Vostok ice core analyses have underscored the very recent "unprecedented" "atmospheric burdens" (that is, the very high levels of greenhouse gases) compared with any other time in the last four glacial-interglacial cycles over 420,000 years.[25] By synchronizing the records of the northern and southern hemispheres, the ice cores have stood as pillars of contemporary visions of a truly global environment, and a global environment not simply of scientific description, but one for political action.

The idea that Earth had an almost imperceptibly long history had already been achieved in the young discipline of geology in the late eighteenth and early nineteenth centuries. Since that time, Earth's age has been progressively extended, with the current four-billion year age established after World War II.[26] While scholarship on the temporal sensibilities of geology in its earliest period is well established, scholarship on the time-sense of the earth sciences in the second half of the twentieth century is less developed. In this recent period, various scientific techniques—including radiocarbon dating, deep-sea sediment coring, and ice coring, among others—all contributed, in the argument of Matthias Dörries, to a "more concrete," "more textured and discrete," view of Earth's history, filled with "specific events." Indeed, this earth science research gave Earth a "new past."[27] Ice cores, unlike fossils in earlier periods, did not demand great expansions in the age of Earth. Most ice cores deal with Earth during the existence of the human species rather than a distant and quite different one—there is no "dark abyss of time," to use James Hutton's famous statement from the late eighteenth century, but rather a contiguous, discrete stretch of time with particular temperatures and atmospheric composition.

Human Time

Ice cores do not simply tell the story of Earth's climatic and atmospheric history, but also interweave human and natural history to constitute certain temporalities of the human species and human civilizations. On the one hand, the interpolation of events from human history and prehistory into ice cores—most often, by marking specific depths with notable human events—is a way of orienting publics to scientific meaning and significance; making ice cores meaningful is important and necessary work. Yet, on the other hand, only certain societies have been enrolled into ice core talk and the

25. Petit et al., "Climate and Atmospheric History," 429.

26. Rudwick, *Earth's Deep History*.

27. Dörries, "Politics, Geological Past, and the Future of the Earth," 23 and 25. See also Caseldine, "Conceptions of Time in (Paleo)Climate Science and Some Implications."

process of constructing "history." These practices—often unintentionally and subtly—constitute certain temporal textures, perceiving and privileging eventfulness rather than continuity, Western and modern rather than inclusively plural, and with uncertain and climate-focused causalities.

The earliest ice core studies in the 1950s demonstrated the worldwide impact of certain human actions, such as nuclear weapons testing. While glaciologists found they could analyze the tritium (the radioactive isotope of hydrogen) in ice to date snow accumulations, they quickly found that global radioactive fallout of tritium from hydrogen bomb explosions had left a clearly discernible layer in the ice. After discovery of the nuclear signature, scientists also found greenhouse gases in the ice.[28] While several scientists dating back to the late nineteenth century had established the link between carbon dioxide (including anthropogenic sources) and warming, there were increasing public statements on the matter in the 1950s and 1960s. In his popular 1962 book *The World of Ice*, the glaciologist James Dyson asked: "Are the smokestacks of our factories and the exhaust pipes of our automobiles seriously increasing the amount of carbon dioxide in the atmosphere?" Yes or no (and in 1962 he strongly suspected yes), the answers would be found in ice cores.[29]

But the human presence in ice cores exceeds the identification of these anthropogenic global impacts. An almost ubiquitous part of ice core discourse involves noting particular depths and layers of the ice as directly related to events in human history. As Dyson explained in 1962 about a Greenland core, "a depth of 165 feet represented snow that fell during the American Civil War. Somewhere down below this is an ice layer from snow that fell on Greenland when Washington's men suffered through the winter at Valley Forge."[30] In September 1966, after US scientists had drilled to bedrock at Camp Century, *Time* magazine reported how Pentagon officials used ice "formed from snow that fell around the time that Christ was born" to cool their Coca-Cola during the press conference announcing the feat.[31] Elizabeth Kolbert, a leading journalist and writer of global environmental change, has similarly invoked the American Civil War, the life of Plato, and the painters of the caves of Lascaux, to make the ice cores' contents meaningful.[32] The ice core on display at the American Museum of Natural History—the first such core on public display—has a corresponding description that refers to Roman lead smelting, the Industrial Revolution, and the 1974 US Clean Air Act.[33] The interpretation for the artificial ice core at the Melbourne Aquarium was both more nationalistic and more recent, noting alongside the ice description Australia's achievements and milestones in the Antarctic as well as important nuclear events like

28. Langway, *History of Early Polar Ice Cores*. See note 3 above.
29. Dyson, *World of Ice*, 99.
30. Ibid., 96.
31. "Geophysics," 115.
32. Kolbert, "Ice Memory."
33. Hoffman, "To Lava Woman."

Chernobyl.[34] This practice partly perpetuates an older tradition—dating from the late nineteenth century—of dating tree rings with major human events (also concentrating on Western history).[35] Generating meaning and significance, and eliciting affect, are not unproblematic tasks, and while recognizing the human presence in ice cores is crucial, the focus on events in Western cultures perpetuates grand narratives long eschewed by historians.

In addition to marking human events in the ice cores, some discussions find or generate vital connections across millennia. In a 1994 article, the geoscientists Claude Allègre and Stephen Schneider noted that "the ice-core borers determined that the air breathed by ancient Egyptians and Anasazi Indians was very similar to that which we inhale today—except for a host of air pollutants introduced over the past 100 or 200 years."[36] James Dyson asked a similar question: "Did Columbus and Erik the Red and Charlemagne breathe the same kind of air we do?"[37] The goal of ice coring is not necessarily to create human history, but these discussions clearly insert human time into the ice core equation—with nationalist, triumphalist, and environmentalist historical narratives.

The emphasis on the West often neglects the people who actually live near ice coring sites, such as the Inuit in Greenland. This Western orientation may be warranted on one level: the majority of greenhouse gases identified in ice cores were emitted from the West. Yet a simple list of dates and events like the birth of Christ or the American Civil War fails to explain how varying atmospheric conditions stemmed from capitalist development, fossil-fuel consumption, and European colonialism. The human time emerging from these simple timelines evades analysis of the political-economic-social processes and structures that have caused climate change, or that equipped Western nations with the technical capacity, global military support, and geopolitical (Cold War) drive to be drilling the cores in the precise places where local people are invisible in the ice core presentations.[38]

In two specific cases, research surrounding ice cores has made strong claims about climate and human history. Both scientists and journalists have used climate data from several Greenland cores to speculate as to why the Viking settlements established in Greenland in the tenth century collapsed four centuries later. The basic thrust of commentary starting in the 1970s has been that the climate was too harsh for the Vikings, ultimately causing the collapse of their Greenland settlements by 1400.[39]

34. Borutta 3D Services—a temporary exhibit that is no longer there. For a critique especially of Australia's nationalist discourses relating to East Antarctica, including ice coring, see Dodds, "Awkward Antarctic Nationalism."

35. Rosenberg and Grafton, *Cartographies of Time*.

36. Allègre and Schneider, "Evolution of the Earth," 74.

37. Dyson, *World of Ice*, 100.

38. Cameron, "Climate Anti-politics."

39. "Glaciology"; Dansgaard et al., "Climatic Changes, Norsemen, and Modern Man"; Diamond, *Collapse*; Bell, "Is Our Climate Unstable?"

While some studies have demonstrated successful Norse adaptation to the Greenland environment—thereby reintroducing the social sphere into discussions of collapse—the invocation of ice cores and their linear, climatic data makes Erik the Red and his descendants almost exclusively victims of climate.[40]

The so-called Maya collapse between about AD 800 and 1000 is also often considered in ice core research, with the low ammonium levels of the cores suggesting a period of significant drought. Again, the basic tendency of this research has been to ascribe civilizational collapse to climatic factors.[41] While the ice core records do provide crucial evidence about environmental factors such as drought, the human time of ice cores is one of eventful collapse, of human failure; the societal is subsumed into the climatic, thus simplifying and even mischaracterizing what archaeologists and historians have discovered about these societies—that a combination of factors including religious beliefs, persistent warfare, politics and power struggles, agricultural and land use practices, and population density, among others, all combined to lead to collapse.[42] In a different and particularly innovative approach, Thompson's ice coring team collaborated with a group of archaeologists to help understand the fate of Peru's Moche society that abruptly abandoned its large-scale urban settlements around AD 700.[43] Combing 1,500 years of precipitation data from two Quelccaya ice cores with cultural evidence collected by archaeologists, the multidisciplinary project was able to avoid the climatic determinism evident in some of the Maya and Viking conclusions.

Ice cores have been made to speak of humans not only as civilizations but also as a species. A recurring question (often rhetorical) in ice core stories asks if the human species is living at the best possible time, climatically speaking. Elizabeth Kolbert reported the thoughts of J. P. Steffensen, one of the field directors of the North Greenland Ice Core Project (NGRIP), on the question of both the human species and human civilization:

> Now you're able to put human evolution into a climatic framework. You can ask, Why did human beings not make civilization fifty thousand years ago? You know that they had just as big brains as we have today. When you put it in a climatic framework, you can say, Well, it was the ice age. And also this ice age was so climatically unstable that each time you had the beginning of a culture they had to move. Then comes the present interglacial—ten thousand years of very stable climate. The perfect conditions for agriculture.[44]

40. Dugmore et al., "Cultural Adaptation, Compounding Vulnerabilities, and Conjunctures in Norse Greenland."

41. Mayewski and White, *Ice Chronicles*, 124.

42. Freidel and Shaw, "Lowland Maya Civilization."

43. Shimada et al., "Cultural Impacts of Severe Droughts in the Prehistoric Andes."

44. Kolbert, "Ice Memory."

Species and civilization bleed into each other as categories in this ice core talk. In April 1997, a *Time* article similarly noted: "The climate record shows that the whole 8,000-year span of human civilization, from the dawn of cities to space flight, has taken place during a period of extraordinary warmth and stability."[45] Attributing the flourishing of the human species (particularly rendered as agricultural, not hunter-gatherer, man) solely to climatic conditions, however, neglects other forces—such as culture and biology—that powerfully influence humanity. It also presupposed a single path of human civilization and progress: through a particular type of agriculture, which thereby excludes or marginalizes many of the indigenous groups living in cold regions where the cores are extracted. When ice core discourse neglects to mention, or downplays, these other factors in the evolution and development of the human species, it can misrepresent cause-effect dynamics and again simplify the course of the human species during the Holocene or Pleistocene, centering attention particularly on Europe and not on other sites with long human habitation and cultures, like Australia or the Arctic. Moreover, the focus on a single path of human development can still direct attention away from the more specific causes of anthropogenic climate change. As Dipesh Chakrabarty asks, "Why should one include the poor of the world—whose carbon footprint is small anyway—by use of such all-inclusive terms as *species* or *mankind* when the blame for the current crisis should be squarely laid at the door of the rich nations in the first place and of the richer classes in the poorer ones?"[46] Nevertheless, ice core discussions like Kolbert's do encourage new questions about humans, asking that we reconsider the human timeline, extending histories into the poorly named "prehistory" era, and bringing climate and ice into studies of big history and evolutionary history—all necessary developments.

Most recently, ice cores have been deployed in arguments surrounding the proposals to formalize "Anthropocene" as an epoch in the geological time scale used by earth scientists. They have been deployed for at least two significant reasons. First, they contain clear and identifiable signals of human impacts on the global environment as revealed through carbon dioxide levels, lead, and atomic fallout. Second, as physical objects within geophysical bodies, ice cores can materially be identified within the existing framework of the geological time scale. A golden spike—a GSSP—can be driven, metaphorically, into the core to signal the beginning of the Anthropocene. Paul Crutzen has identified a golden spike in 1782, the year James Watt invented the steam engine. As Crutzen explains, "This is the period when data retrieved from glacial ice cores show the beginning of a growth in the atmospheric concentrations of several 'greenhouse gases,' in particular CO_2, CH_4, and N_2O."[47] British global environmental change scientists Simon Lewis and Mark Maslin have more recently argued for two other Anthropocene

45. Linden, "Antarctica," 59.
46. Chakrabarty, "Climate of History," 216.
47. Crutzen, "'Anthropocene,'" 16.

start dates. The first in 1610, marking the invasion and colonization of the New World by European empires, the consequent massive decline of the native population, and the resulting massive carbon sequestration as forests and vegetation reclaimed lands from human use. Lewis and Maslin argue that this event can be precisely pinpointed in Antarctica's Law Dome ice core, exactly at 285.2 meters down, where the dip in atmospheric carbon correlates with Spanish colonization in the Americas.[48] Their second potential start year is 1964, the peak global record of radioactive carbon-14 owing to nuclear weapons testing—it is more broadly representative of other chemicals and elements globally distributed during the "Great Acceleration."

Ice cores are as much about humans as they are about glaciers and climates, and indeed ice ties people and climate together closely, in some ways synchronizing them. The linear representation of time, however, and the ways in which climate is represented as having a singular and potent effect on societies and species helps create a particular sensibility not only of Earth's past but also of human history. Just as individual ice cores—or even the collection of the fairly small number of global cores from specific places—make the polar regions and cryosphere speak for Earth, ice discourses about human time offer an overly narrow conceptualization of people and their past—focusing unevenly on the industrialized West, on Europeans, North Americans, and North Atlantic peoples suffering under the Little Ice Age or benefitting from the Medieval Warm Period or polluting the atmosphere during the Roman Empire. When non-Western societies are brought into the ice core discussion, such as with the Maya, it is often to show societal collapse, civilizations that could not withstand climatic changes and that offer lessons for the present day. Thompson's tropical and subtropical ice cores have gestured toward the great civilizations closer to the equator. Yet there is much more to be done with Thompson's cores and climatic implications for societies in Asia, Africa, and South America, particularly among social scientists and humanities scholars working on human societies. Ice cores can subtly manifest and perpetuate the uneven geographies and attendant frictions and injustices that come from attempts to speak of global changes in a global environment that is nonetheless populated by diverse, fragmented, and differentiated communities shaped by diverse influences.

Future Time

While ice cores provide data about past climatic conditions, they are also used—sometimes explicitly, sometimes implicitly—to reflect upon, structure, or even predict the future. On the one hand, a key motivation for drilling ice cores and compiling climate history is to understand long-term cycles and dynamics over time to predict future climatic conditions. Scientists have made significant progress understanding the past and modeling future scenarios, especially related to the correlation between temperature and greenhouse gases. On the other hand, the future projections emerging

48. Lewis and Maslin, "Defining the Anthropocene." See also Wolff, "Ice Sheets and the Anthropocene."

from climate models have limitations as researchers continue their quest to comprehend global circulation and downscale their models to better understand local and regional levels. When scientists and journalists, among others, increasingly use ice cores to project the future, there is thus more at stake with these representations than the weather. Scientists themselves may note the limitations of their models or recognize that models of the future are not predictions but rather scenarios based on certain variables that they put into the models. But discussions, representations, and news about ice cores—especially in our society that has embraced a science-to-policy paradigm in which scientific results inform policy making without the added step of understanding societal dynamics—risks turning modeled projections into certain futures.[49] In the projected future time, humans again appear, and predictions share a few key characteristics: the fragility of Earth and vulnerability of human societies; tumult and apocalypse ahead; urgency to act now to save the planet; and climate as the all-dominant force shaping humanity.

By the 1990s the steady accretion of data from sources like ice cores, increased worries that society, like the world's climate, could be on a one-way path to crisis and collapse. In the mid-1980s, Columbia University climate scientist Wallace Broecker worried that, even though "we don't know nearly enough about the operation of the Earth's climate to make reliable predictions of the consequences of the build-up of greenhouse gases, we do know enough to say that the effects are potentially quite serious."[50] As environmental historian Tom Griffiths points out, "In the final two decades of the twentieth century, ice cores from both Antarctica and Greenland delivered a sense of urgency and crisis about global warming." This corresponded, Griffiths explains, with the end of "balance" in ecology, which was replaced by disturbance as the norm. In short, "catastrophism was back."[51] This context is important for the societal lens through which ice cores were studied, discussed, debated, and evaluated. Journalists were also extracting "warnings from the ice"—especially the two major Greenland ice cores of the early 1990s—with *Time* magazine worrying in 1997 about the ways in which a "flickering climate" would unleash "a biblical disaster in today's crowded world. Droughts, heat waves, floods and plagues of pests would play havoc with crops, and rapid sea-level rise would inundate cities and destroy rich agricultural lands"—it was a temporality of persistent shock.[52] Future climate change was put into scriptural terms with the imminent end of the world. In these scenarios, there is no time for humans to adapt, only time to await their Maker. Historian Mark Levene argues that these types of "religiously subversive notions" of the apocalypse are warranted as a way to successfully combat severe anthropogenic climate change in the Anthropocene.[53]

49. On this issue generally, see Hulme, "Reducing the Future to Climate." Callaway makes a contrastive point, however, in "Space for Justice."

50. Gribbin, "See-Saw Climatic System."

51. Griffiths, "Commentary."

52. Linden, "Antarctica."

53. Levene, "Climate Blues."

One of the key results of the early 1990s Greenland ice cores was the notion of abrupt climate change. While the cores showed climatic cycles over tens of millennia, they also revealed clear, short-lived events that punctured these rhythms. On the one hand, Earth could "correct" itself and adhere to cycles over the very long term of hundreds of thousands of years. Yet, at the same time, the rapidity of climatic changes pointed to the planet's fragility—and thus the vulnerability of human societies to withstand such enormous temperature swings taking place over just a few years. As one journalist worried in 1994, "if the GRIP team are interpreting their data correctly, all bets are off. Scientists must now consider the possibility that the present stable climate is peculiar—and potentially fragile."[54] Others discussing ice cores more recently have also underscored Earth's fragility, such as *New York Times* columnist Thomas Friedman who reported that humans should not be emitting unprecedented quantities of greenhouse gases "because you never know—*you never know*—what will tip the balance and send us hurtling into another abrupt change . . . and into another era."[55] The strong tone of fear and anxiety, and the likelihood of a dark future ahead, presents a specific and singular view of our path forward.

When the "future time" of ice core talk portrays human history as shaped solely or primarily by climate—without regard for other social, economic, political, cultural, or technological forces—the past turns into a story of climatic determinism. Researchers have critiqued such determinism for more than a century, in particular because of the imperial and racist agendas embedded in nineteenth- and early twentieth-century climatic determinism.[56] More recently, scholars like geographer Mike Hulme have questioned the ways in which mathematical models reduce the future to a largely quantitative story of climate impacts, without the creative or unpredictable ways in which societies evolve and respond to environmental change.[57] Others note the way the public has embraced climatic explanations for events like war and human migration, which are far more complex than climatically determined explanations allow.[58]

In ice core talk, two forms of climatic determinism are often at work—one about the past and another about the future. First, as discussed above in relation to "human time," ice core discussions of the past can draw explicit and implicit conclusions about the history of past societies (especially their failures), such as Viking settlements in Greenland and the Maya in Mesoamerica. Second, ice core records are often mobilized to predict future human events based solely on climatic conditions. While many scientists are reticent to use ice cores to comprehensively predict the future, some nonetheless identify broader impacts of their research, often focusing on negative societal

54. Bell, "Is Our Climate Unstable?"

55. Friedman, "Iceman Cometh."

56. Carey, "Beyond Weather"; Fleming, *Historical Perspectives on Climate Change*; Livingstone, "Moral Discourse of Climate."

57. Hulme, "Reducing the Future to Climate."

58. Livingstone, "Climate of War"; Black et al., "Effect of Environmental Change on Human Migration."

outcomes in the future. As several scientists who have worked extensively in Greenland to understand abrupt climate change explained, "These and other possible tipping points all slant in directions that would cause harm to economies and existing ecosystems, with losers substantially outnumbering winners. . . . We have built our cities, societies, and economies for the climate we have, and our ecosystems are adapted to our present-day climate. Thus, big jumps [in the climate] tend to go in bad directions, a little like trying to adjust a watch with a hammer."[59] In this vision, societies cannot adapt and will not change in the future because, despite understandings to the contrary, they are shaped primarily by climate. A 2013 *Mother Jones* article does allow people to do something in the future to prevent catastrophe, but their only action is to control climate. The article concludes that Greenland is melting very fast, and cities like Hamburg, Shanghai, and Philadelphia will be inundated by the year 2200. That is, unless "something big changes—something big enough to start Greenland cooling."[60] The point is not about whether the projection is correct about sea-level rise, but rather about how climate alone acts to shape the future. The only thing humans can do to stop Greenland melting is to stop global warming. There are no adaptation programs, no social or political or economic forces causing some segments of the population to be more or less vulnerable, and no perceptions of risk shaping future policies, among other factors. It portrays a one-dimensional society that remains static—except for trying to reduce greenhouse-gas emissions to curb climate change—until the year 2200. The centuries ahead are eerily foreshortened.

Not all researchers involved with ice cores point in deterministic directions when discussing the future. Glaciologist Paul Mayewski and science writer Frank White have been careful about drawing future conclusions from ice core evidence. Nevertheless, they hope that "with the longer records available from the Ice Chronicles and other climate records, it may be possible to investigate past cases of extremes in climate, differentiate between natural and human-induced climate change, and improve predictability. If we can achieve this goal, it will have positive effects on society that will be immense."[61] Ice cores for them help with reconstructing the recent past, which can influence policy and management decisions for the future without turning into climatic determinism. In Australia, for example, analysis of 1,000 years of climate data from a Law Dome (Antarctica) ice core showed that drought over the last millennium has been the norm. The researchers thus concluded that drought conditions should be factored into river-catchment management plans in ways that have not yet been done.[62] In essence, the ice core analysis divulged past climatic patterns, which can help with environmental policies and water management to avoid future drought impacts—in productive rather than deterministic ways.

59. Conkling et al., *Fate of Greenland*, 192.

60. Mooney, "Why Greenland's Melting Could Be the Biggest Climate Disaster of All."

61. Mayewski and White, *Ice Chronicles*, 178.

62. Australian Antarctic Division, "Antarctic Ice Cores Tell 1,000-Year Australian Drought Story."

Continued global warming driven by unchecked greenhouse-gas emissions absolutely poses monumental obstacles for our future. Yet climate discourses, as geographer Erik Swyngedouw argues, can generate an "enemy" climate that "becomes socially disembodied, is always vague, ambiguous, unnamed and uncounted, and ultimately empty." The apocalyptic perspective about future climate change can derail more democratic discussions about climate change that both ground it in social relations and power imbalances as well as allow, in Swyngedouw's words, "the articulation of divergent, conflicting and alternative trajectories of future socio-environmental possibilities and of human-human and human-nature articulations and assemblages."[63] After all, ice core analysis can decipher the air bubbles to reveal amazingly precise climate records. But the ice and air cannot easily factor in laws, cultural values, trade policies, racism, or any other forms of human behavior or societal dynamics that all influence human resilience and adaptive capacity. The future time of ice cores is a complex perpetuation of the deterministic elements of their human time but, ironically, also turns away from a richly peopled future to weave binding catastrophic textures.

Conclusions

In the last sentence of his 1962 book *The World of Ice*, James Dyson wrote, "Unless we can level the mountains, the human race will just have to expect to be pushed around once in a while by the World of Ice."[64] Ignoring the rhythms archived in the cores seems a perilous choice. Yet while ice cores seem to offer an unmediated window onto Earth's past, they have also been enrolled in global political and scientific discourses about humanity, history, and the future. Mobilized as objective scientific objects, ice cores are used by various actors and stakeholders to construct certain narratives of the past while casting an ominous specter over an inevitable, catastrophic future based on inaction in the present. And because of the quantitative nature of their climate records, ice cores—and the scientists who have extracted them with some difficulty from remote polar and high-mountain regions—hold immense credibility.

Ice cores have thus become powerful objects and documents in climate-change discussions and thinking about our social and earthly futures. This article's critique and categorization of ice core temporalities has demonstrated how they speak to the complex textures of Earth's past, of the past of humans as species and as civilizations, and of a narrow, frightening future. By embodying these temporalities, ice cores are meant to regulate our way out of the climate crisis, though they seem to have a limited effect in the policy world, given the slight progress in reducing greenhouse-gas emissions and adapting to global change. Michelle Bastian has suggested that "a key task of the environmental humanities is transforming the temporal framework that supports

63. Swyngedouw, "Apocalypse Forever?" See also Dalby, "Framing the Anthropocene"; O'Lear, "Climate Science and Slow Violence."

64. Dyson, *World of Ice*, 274.

the radical de-coupling of what has been classed as 'nature' from that which has been classed as 'culture.'" Have ice cores, ironically, increased our sense that we can "tell the time" when, in fact, their temporalities do not contribute to the task of coordination and relations among humans and non-humans?[65] What seems to be missing from the ice core discussion is a more profound understanding and portrayal of human history—and the ways in which traditional categories of analysis like race, class, gender, and environment shape the ways in which we grapple with global environmental change.

Ice cores thus open possibilities for collaboration among the disciplines that are most involved with time: the geoscientists studying the physical world and the historians and archaeologists studying the diverse times of human life. The cross-disciplinary impulse of the environmental humanities makes these researchers particularly suited to help analyze, discuss, and produce human time and future time in ice cores. Human history is messy and complex, defying efforts to chart it neatly as a linear progression influenced by single, large-scale forces such as climate. Thus, when ice core discourses venture into human time and future time, researchers in the social sciences and environmental humanities—those sensitive to the processes driving human societies—should be working alongside the geoscientists drilling and analyzing ice cores.

ALESSANDRO ANTONELLO is a McKenzie Postdoctoral Fellow at the University of Melbourne. He works in the fields of environmental history, international history, and the history of science. His research investigates the history of Antarctica and the Southern Ocean since 1945; more broadly, he is interested in the conceptualizations, politics, and diplomacy of global and international environments in the twentieth century.

MARK CAREY is professor of history and environmental studies in the Robert D. Clark Honors College at the University of Oregon. His research focuses on glacier-society dynamics, icebergs, climate change, natural disasters, and water. He is the author of *In the Shadow of Melting Glaciers: Climate Change and Andean Society* (2010) and coeditor of *The High-Mountain Cryosphere: Environmental Changes and Human Risks* (2015).

Acknowledgments

This work is supported by the US National Science Foundation under grant #1253779. We thank Rebecca Marshall and Sadie Trush for research assistance.

References

Adam, Barbara. *Time*. Cambridge: Polity, 2004.

———. *Timescapes of Modernity: The Environment and Invisible Hazards*. London: Routledge, 1998.

Allègre, Claude J., and Stephen H. Schneider. "The Evolution of the Earth." *Scientific American* 271, no. 4 (1994): 66–75.

65. Bastian, "Fatally Confused."

Alley, Richard B. *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future*. Princeton, NJ: Princeton University Press, 2000.

Australian Antarctic Division. "Antarctic Ice Cores Tell 1000-Year Australian Drought Story." December 16, 2014. www.antarctica.gov.au/news/2014/antarctic-ice-cores-tell-1000-year-australian-drought-story.

Barnola, J. M., D. Raynaud, Y. S. Korotkevich, and C. Lorius. "Vostok Ice Core Provides 160,000-Year Record of Atmospheric CO_2." *Nature* 329, no. 6138 (1987): 408–14.

Bastian, Michelle. "Fatally Confused: Telling the Time in the Midst of Ecological Crisis." *Environmental Philosophy* 9, no. 1 (2012): 23–48.

———. "Inventing Nature: Re-writing Time and Agency in a More-Than-Human World." *Australian Humanities Review*, no. 47 (2009): 99–116.

Bear, Laura. "Time as Technique." *Annual Review of Anthropology* 45 (2016): 487–502.

Bell, Melinda. "Is Our Climate Unstable?" *Earth* 3, no. 1 (1994): 24–31.

Black, Richard, W. Neil Adger, Nigel W. Arnell, Stefan Dercon, Andrew Geddes, and David Thomas. "The Effect of Environmental Change on Human Migration." *Global Environmental Change* 21, supplement 1 (2011): 3–11.

Bowen, Mark. *Thin Ice: Unlocking the Secrets of Climate in the World's Highest Mountains*. New York: Holt, 2005.

Cameron, Emilie. "Climate Anti-politics: Scale, Locality, and Arctic Climate Change." In *Ice Blink: Navigating Northern Environmental History*, edited by Stephen Bocking and Brad Martin, 465–95. Calgary: University of Calgary Press, 2017.

Carey, Mark. "Beyond Weather: The Culture and Politics of Climate History." In *Oxford Handbook of Environmental History*, edited by Andrew Isenberg, 23–51. New York: Oxford University Press, 2014.

———. "The History of Ice: How Glaciers Became an Endangered Species." *Environmental History* 12 (2007): 497–527.

Carey, Mark, M. Jackson, Alessandro Antonello, and Jaclyn Rushing. "Glaciers, Gender, and Science: A Feminist Glaciology Framework for Global Environmental Change Research." *Progress in Human Geography* 40, no. 6 (2016): 770–93.

Caseldine, Chris. "Conceptions of Time in (Paleo)Climate Science and Some Implications." *WIREs Climate Change* 3 (2012): 329–38.

Chakrabarty, Dipesh. "The Climate of History: Four Theses." *Critical Inquiry* 35 (2009): 197–222.

Christian, David. *Maps of Time: An Introduction to Big History*. Berkeley: University of California Press, 2004.

Clark, Nigel. "Life on Spike." In *Bipolar*, edited by Kathryn Yusoff, 42–43. London: TheArtsCatalyst, 2008.

Conkling, Philip, Richard Alley, Wallace Broecker, and George Denton. *The Fate of Greenland: Lessons from Abrupt Climate Change*. Cambridge, MA: MIT Press, 2011.

Corfield, Penelope J. "Time and the Historians in the Age of Relativity." *Geschichte und Gesellschaft. Sonderheft* 25 (2015): 71–91.

Crutzen, Paul. "The 'Anthropocene.'" In *Earth System Science in the Anthropocene: Emerging Issues and Problems*, edited by Eckart Ehlers and Thomas Krafft, 13–18. New York: Springer, 2006.

Dalby, Simon. "Framing the Anthropocene: The Good, the Bad and the Ugly." *Anthropocene Review* 3, no. 1 (2016): 33–51.

Dansgaard, Willi, S. J. Johnsen, N. Reeh, N. Gundestrup, H. B. Clausen, and C. U. Hammer. "Climatic Changes, Norsemen, and Modern Man." *Nature* 255 (1975): 24–28.

Dean, Katrina. "Archives and Metaphors." In *Bipolar*, edited by Kathryn Yusoff, 8–9. London: TheArts Catalyst, 2008.

Diamond, Jared. *Collapse: How Societies Choose to Fail or Succeed*. New York: Viking, 2004.

Dodds, Klaus. "'Awkward Antarctic Nationalism': Bodies, Ice Cores and Gateways in and Beyond Australian Antarctic Territory/East Antarctica." *Polar Record* 53, no. 1 (2017): 16–30.

Dörries, Matthias. "Politics, Geological Past, and the Future of the Earth." *Historical Social Research-Historische Sozialforschung* 40, no. 2 (2015): 22–36.

Dugmore, Andrew J., Thomas H. McGovern, Orri Vésteinsson, Jette Arneborg, Richard Streeter, and Christian Keller. "Cultural Adaptation, Compounding Vulnerabilities, and Conjunctures in Norse Greenland." *Proceedings of the National Academy of Sciences* 109, no. 10 (2012): 3658–63.

Dyson, James L. *The World of Ice*. New York: Knopf, 1962.

Elias, Norbert. *An Essay on Time*. Dublin: University College Dublin Press, 2007.

Elzinga, Aant. "Some Aspects in the History of Ice Core Drilling and Science from IGY to EPICA." In *National and Trans-national Agendas in Antarctic Research from the 1950s and Beyond. Proceedings of the 3rd Workshop of the SCAR Action Group on the History of Antarctic Research*, edited by Cornelia Lüdecke, Lynn Tipton-Everett, and Lynn Lay, 86–115. Columbus, OH: Byrd Polar Research Center, 2011.

Fleming, James Rodger. *Historical Perspectives on Climate Change*. New York: Oxford University Press, 1998.

Frazar, Heather. "Core Matters: Greenland, Denver and the GISP2 Ice Core." In *High Places: Cultural Geographies of Mountains, Ice and Science*, edited by Denis Cosgrove and Veronica della Dora, 64–83. London: Tauris, 2009.

Freidel, David, and Justine M. Shaw. "The Lowland Maya Civilization: Historical Consciousness and Environment." In *The Way the Winds Blows: Climate, History, and Human Action*, edited by Roderick J. McIntosh, Joseph A. Tainter, and Susan Keech McIntosh, 271–300. New York: Columbia University Press, 2000.

Friedman, Thomas L. "The Iceman Cometh." *New York Times*, August 3, 2008.

Gibbard, P., and T. Van Kolfschoten. "The Pleistocene and Holocene Epochs." In *A Geologic Time Scale 2004*, edited by Felix Gradstein, James Ogg, and Alan Smith, 441–52. Cambridge: Cambridge University Press, 2004.

"Geophysics: History on the Rocks." *Time*, September 30, 1966, 115.

"Glaciology: Secrets of the Icecap." *Time*, November 14, 1969, 94.

Greenhouse, Carol J. *A Moment's Notice: Time Politics across Cultures*. Ithaca, NY: Cornell University Press, 1996.

Gribbin, John. "A See-Saw Climatic System." *New Scientist*, July 18, 1985, 28.

Griffiths, Tom. "Commentary [on Broecker and Petit et al.]." In *The Future of Nature: Documents of Global Change*, edited by Libby Robin, Sverker Sörlin, and Paul Warde, 359–62. New Haven, CT: Yale University Press, 2013.

Hassan, Robert. "Globalization and the 'Temporal Turn': Recent Trends and Issues in Time Studies." *Korean Journal of Policy Studies* 25, no. 2 (2010): 83–102.

Hulme, Mike. "Reducing the Future to Climate: A Story of Climate Determinism and Reductionism." *Osiris* 26 (2011): 245–66.

Hoffman, Jan. "To Lava Woman, Earth Is a Molten Wonder." *New York Times*, June 4, 1999

Jasanoff, Sheila. "Image and Imagination: The Formation of Global Environmental Consciousness." In *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, edited by Clark Miller and Paul N. Edwards, 309–37. Cambridge, MA: MIT Press, 2001.

Jouzel, Jean, Claude Lorius, and Dominique Raynaud. *The White Planet: The Evolution and Future of Our Frozen World*. Translated by Teresa Lavender Fagan. Princeton, NJ: Princeton University Press, 2013.

Kolbert, Elizabeth. "Ice Memory." *New Yorker*, January 7, 2002.

Langway, C. C., Jr. *The History of Early Polar Ice Cores*. Hanover, NH: Cold Regions Research and Engineering Laboratory, US Army Engineer Research and Development Center, 2008.

Lazier, Benjamin. "Earthrise; or, the Globalization of the World Picture." *American Historical Review* 116, no. 3 (2011): 602–30.

Lekan, Thomas M. "Fractal Earth: Visualizing the Global Environment in the Anthropocene." *Environmental Humanities* 5 (2014): 171–201.

Levene, Mark. "Climate Blues: Or How Awareness of the Human End Might Re-instil Ethical Purpose to the Writing of History." *Environmental Humanities* 2 (2013): 147–67.

Lewis, Simon L., and Mark A. Maslin. "Defining the Anthropocene." *Nature* 519, no. 7542 (2015): 171.

Linden, Eugene. "Antarctica: Warnings from the Ice." *Time*, April 14, 1997, 54–59.

Livingstone, David N. "The Climate of War: Violence, Warfare, and Climatic Reductionism." *WIREs Climate Change* 6, no. 5 (2015): 437–44.

———. "The Moral Discourse of Climate: Historical Considerations on Race, Place and Virtue." *Journal of Historical Geography* 17, no. 4 (1991): 413–34.

Martin-Nielsen, Janet. "'The Deepest and Most Rewarding Hole Ever Drilled': Ice Cores and the Cold War in Greenland." *Annals of Science* 70, no. 1 (2013): 47–70.

———. *Eismitte in the Scientific Imagination: Knowledge and Politics at the Center of Greenland*. New York: Palgrave Macmillan, 2013.

May, John, and Nigel Thrift, eds. *Timespace: Geographies of Temporality*. London: Routledge, 2001.

Mayewski, Paul, and Frank White. *The Ice Chronicles: The Quest to Understand Global Climate Change*. Hanover, NH: University Press of New England, 2002.

Monastersky, Richard. "Ice Core Shows Speedy Climate Change." *Science News*, December 12, 1992, 404.

Mooney, Chris. "Why Greenland's Melting Could Be the Biggest Climate Disaster of All." *Mother Jones*, January 24, 2013. www.motherjones.com/environment/2013/01/greenland-ice-melting-climate-change/

Nixon, Rob. *Slow Violence and the Environmentalism of the Poor*. Cambridge, MA: Harvard University Press, 2011.

O'Lear, Shannon. "Climate Science and Slow Violence: A View from Political Geography and STS on Mobilizing Technoscientific Ontologies of Climate Change." *Political Geography* 52 (2016): 4–13.

O'Reilly, Jessica. "Sensing the Ice: Field Science, Models, and Expert Intimacy with Knowledge." *Journal of the Royal Anthropological Institute (N.S.)* 22, no. S1 (2016): 27–45.

Petit, J. R., J. Jouzel, D. Raynaud, N. I. Barkov, J. M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V. M. Kotlyakov, M. Legrand, V. Y. Lipenkov, C. Lorius, L. Pepin, C. Ritz, E. Saltzman, and M. Stievenard. "Climate and Atmospheric History of the Past 420,000 Years from the Vostok Ice Core, Antarctica." *Nature* 399, no. 6735 (1999): 429–36.

Poole, Robert. *Earthrise: How Man First Saw the Earth*. New Haven, CT: Yale University Press, 2008.

Rosenberg, Daniel, and Anthony Grafton. *Cartographies of Time*. New York: Princeton Architectural Press, 2010.

Rudwick, Martin J. S. *Earth's Deep History: How It Was Discovered and Why It Matters*. Chicago: University of Chicago Press, 2014.

Russell, Edmund. *Evolutionary History: Uniting History and Biology to Understand Life on Earth*. New York: Cambridge University Press, 2011.

Shimada, Izumi, Crystal Barker Schaad, Lonnie G. Thompson, and Ellen Mosley-Thompson. "Cultural Impacts of Severe Droughts in the Prehistoric Andes: Application of a 1,500-Year Ice Core Precipitation Record." *World Archaeology* 22, no. 3 (1991): 247–70.

Skrydstrup, Martin. "Modelling Ice: A Field Diary of Anticipation on the Greenland Ice Sheet." In *The Social Life of Climate Change Models: Anticipating Nature*, edited by Kirsten Hastrup, 163–82. New York: Routledge, 2013.

Sörlin, Sverker. "Cryo-History: Narratives of Ice and the Emerging Arctic Humanities." In *The New Arctic*, edited by Birgitta Evengård, Joan Nymand Larsen, and Øyvind Paasche, 327–39. Cham: Springer, 2015.

Swyngedouw, Erik. "Apocalypse Forever? Post-political Populism and the Spectre of Climate Change." *Theory, Culture, and Society* 27, nos. 2–3 (2010): 213–32.

Walker, Gabrielle. "Frozen Time." *Nature* 429, no. 6992 (2004): 596–97.

Walker, Mike, Sigfus Johnsen, Sune Olander Rasmussen, Trevor Popp, Jørgen-Peder Steffensen, Phil Gibbard, Wim Hoek, John Lowe, John Andrews, Svante Björck, Les C. Cwynar, Konrad Hughen, Peter Kershaw, Bernd Kromer, Thomas Litt, David J. Lowe, Takeshi Nakagawa, Rewi Newnham, and Jakob Schwander. "Formal Definition and Dating of the GSSP (Global Stratotype Section and Point) for the Base of the Holocene Using the Greenland NGRIP Ice Core, and Selected Auxiliary Records." *Journal of Quaternary Science* 24, no. 1 (2009): 3–17.

Weart, Spencer R. *The Discovery of Global Warming*. Cambridge, MA: Harvard University Press, 2008.

Wolff, E. W. "Ice Sheets and the Anthropocene." In *A Stratigraphical Basis for the Anthropocene*, edited by C. N. Waters, J. A. Zalasiewicz, M. Williams, M. A. Ellis, and A. M. Snelling, 255–63. London: Geological Society, 2013.

Yusoff, Kathryn. "Ice Archives." In *Bipolar*, edited by Kathryn Yusoff, 116–23. London: TheArtsCatalyst, 2008.