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OCEAN SCIENCE

Hemispheric Asynchrony of Abrupt Climate Change

Jean Lynch-Stieglitz

It is now well established that the climate in the North Atlantic underwent rapid and dramatic changes during the cool periods of the past 80,000 years (Dansgaard-Oeschger events) and during the transition out of the last ice age (Younger Dryas–Bølling-Allerød Oscillation). Although these millennial-scale climate changes were first well characterized in the ice core records from Greenland, it is increasingly apparent that much of the Northern Hemisphere experienced synchronized climate swings. When Greenland warmed, the North Atlantic sea surface warmed, the trade winds strengthened, changes in North Pacific ventilation occurred, and the Asian monsoon intensified (*1*). How the Southern Hemisphere participated in these climate changes is less clear. Climate records from Antarctic ice cores show warmings and coolings that are clearly asynchronous with the rapid changes of the Northern Hemisphere (*2*). However, although some researchers suggest that the Antarctic pattern is typical of the Southern Hemisphere, others believe that the Antarctic is isolated, with the rest of the Southern Hemisphere warming and cooling in synchrony with the Northern Hemisphere. The controversy persists because the vast majority of continuous records capable of resolving these events have been collected in the Northern Hemisphere. The study by Lamy *et al.* on page 1959 of this issue (*3*) provides an important addition to the very limited set of Southern Hemisphere records and shows that sea surface temperature changes off Chile have Antarctic timing. This supports a model of asynchronous temperature changes between the Northern and Southern Hemispheres.

Establishing the spatial pattern of rapid climate changes contributes to a better understanding of the mechanisms driving them. The school of thought that favors synchronous change in the Northern and Southern Hemisphere climate on a millennial time scale cites the timing of glacial advances and vegetation changes in New Zealand and Chile (*4*–*6*). In this view, the isolated Antarctic is responding asynchronously with respect to the Northern Hemisphere but is not representative of the Southern Hemisphere as a whole. The proposal requires a global mechanism that could synchronize the timing and magnitude of warmings and coolings in the two hemispheres. This would require either a change in the greenhouse capacity of the atmosphere or the amount of sunlight absorbed by Earth. Climate changes originating or amplified in the tropical ocean-atmosphere system could be responsible for such hemispherically symmetric warmings and coolings (*7*).

However, the most well-developed paradigm for the origin of these rapid climate changes is that they represent changes in the way the ocean currents transport heat around the globe. Because the ocean currents that bring heat to one area must take it away from another, this paradigm predicts that Northern Hemisphere warming should be accompanied by Southern Hemisphere cooling. Surface waters become dense and sink in the North Atlantic. As these deep waters flow south, warm surface waters travel northward to replace them, bringing warmth to the North Atlantic. When deep-water production slackens, the North Atlantic cools. In this view, the strongest climate response will be in the Northern Hemisphere (in particular the North Atlantic), and subtle coolings in the Southern Hemisphere will accompany the warming in the Northern Hemisphere when deep-water production is strong (*8*, *9*). Recent work has suggested that these changes in North Atlantic Deep Water and the resulting asynchronous temperature changes between the hemispheres can be driven by changes in freshwater delivery to the ocean in the Southern Hemisphere as well as in the North (*10*, *11*). This mechanism, which is broadly consistent with the asynchronous Antarctic record, predicts that open-ocean records from the Southern

Sampling the sea. The scientific research vessel JOIDES Resolution leaving the harbor in Valparaiso, Chile, on an expedition to sample sea surface temperature off the coast of southern Chile.

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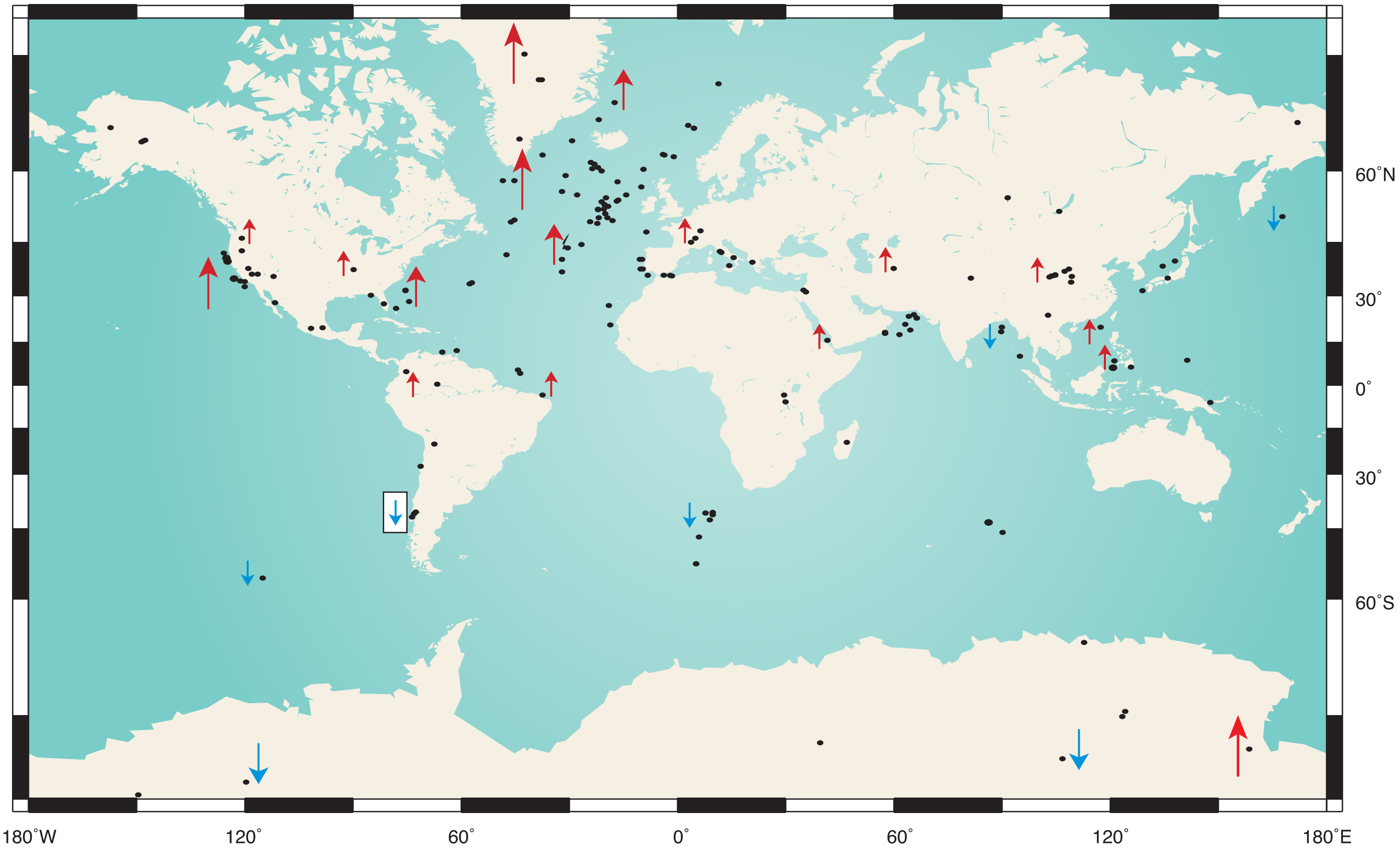

Patterns of millennial climate change. Global temperature change during the warm phase of the Dansgaard-Oeschger events taken from Voelker's (*1*) compilation of continuous high-resolution records. Dots represent locations of continuous data series capable of resolving millennial-scale climate changes. When the Northern Hemisphere warms (red arrows), the few Southern Hemisphere sites for which continuous data are available cool (blue arrows). The high-resolution oceanic records from near Chile published by Lamy *et al.* (*3*) (indicated with a box) contribute to the sparse data coverage in the Southern Hemisphere and support this picture of asynchronous climate changes between the Northern and Southern Hemispheres.

Hemisphere should show subtle warmings with the same timing as those seen in Antarctica. In this view, there can be changes in heat transport that affect regional temperatures without changes in the total amount of solar energy absorbed by Earth or the greenhouse capacity of the atmosphere.

The paradigm of hemispheric asynchrony is most clearly seen in the ice records from Greenland and the Antarctic. However, extrapolar records from the Southern Hemisphere have not presented a clear picture. Most land-based glacial and vegetation records seem to support hemispheric synchrony, whereas some oceanic records show an Antarctic timing for surface conditions (*12*, *13*), and others yield more ambiguous timing (*14*). In a valuable addition to this data, Lamy *et al.* (*3*) present a well-dated and exceptionally high-resolution history of sea surface temperature derived from biochemical markers from off the coast of Chile (see the second figure), which shows Antarctic timing (hemispheric asynchrony). They also suggest why the land-based records appear to support the hemispheric synchrony model: Because of the response time of glaciers, glacial maxima do not necessarily correspond to the coolest conditions in the atmosphere. They measured the iron content in the same sediment core that revealed the sea surface temperature history, and argued that the iron content reflects the level of glacial activity on the nearby land. The iron content does not increase immediately when the sea surface temperature drops, leading the authors to suggest that the glaciers are slow to respond and that the times of maximum glacier extent do not necessarily reflect the times of the coldest regional climate. The vegetation on land can be influenced not only by the regional climate changes, but also by the presence of large ice-sheets nearby. This can explain some of the discrepancy between the timing of the land records, which appear to support hemispheric synchrony, and that of the ocean records, which support asynchrony.

Clearly, further work is needed to better understand the nature and timing of the glacial and vegetation records representing conditions on land, as well as to expand the spatial coverage of well-resolved oceanic records, before ruling out hemispherically synchronous climate change. Such work deserves a high scientific priority, because it can lead to a better understanding of the mechanisms underlying the dramatic changes in climate that appear to characterize much of the Pleistocene.

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