With the ab initio potential energy surface, one can calculate the trajectories of the interacting molecules using classical equations of motion. This approach provides the first point of comparison with the experiment. However, because classical mechanics does not contain the wave nature of particles, it is inherently unable to reproduce the interference phenomena that are the hallmark of quantum mechanics. Classical trajectories that carry products to the same angle through different paths (see the figure) simply add at the detector, whereas quantum mechanical trajectories interfere, reinforcing at some angles and canceling at others depending on the difference in the path lengths. Only a highly resolved experiment and a comparably detailed quantum mechanical calculation can observe and predict such behavior.

Lorenz *et al.* use all these tools to study the scattering of Ar by NO. They cross a beam of cold NO molecules in their lowest rotational state with a beam of Ar and detect the angle and speed distribution of the scattered NO in different rotational states by ionizing the NO and imaging it onto a detector. The use of circularly polarized light is the crucial addition to their imaging experiment. The interaction of this light with NO depends on the sense of molecular rotation, and the experiment is therefore sensitive to the direction, not just the amount, of rotation.

It seems surprising at first that the experiment should produce a preferred sense of rotation; after all, the impact parameter—the "miss distance" labeled *b* in the figure—and orientation of the molecules are randomly distributed in the crossed molecular beams. Indeed, there can be no preferred sense of rotation for the entire distribution of molecules, but a preferred rotation direction for particular scattering angles and product states is possible. Lorenz *et al.* observe this effect. They find that NO rotates in one direction on one side of the angular distribution and in the other on the opposite side, in agreement with a classical prediction.

The most telling observation, however, is that the sense of rotation oscillates with scattering angle. The observation agrees quantitatively with quantum mechanical calculations using an ab initio potential that includes the attraction between the molecules (*8*, *9*). In contrast, a classical calculation using solely repulsions between the molecules recovers only some features of the scattering.

The study illustrates a new and powerful application of highly resolved experimental techniques and sophisticated theoretical calculations. Similar approaches are possible for reactive collisions, where reactant and product orientation is likely to play an important role. Such studies promise an intimate view of chemistry at the level of individual collisions.

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PERSPECTIVES: PALEOCLIMATE

No Two Latitudes Alike

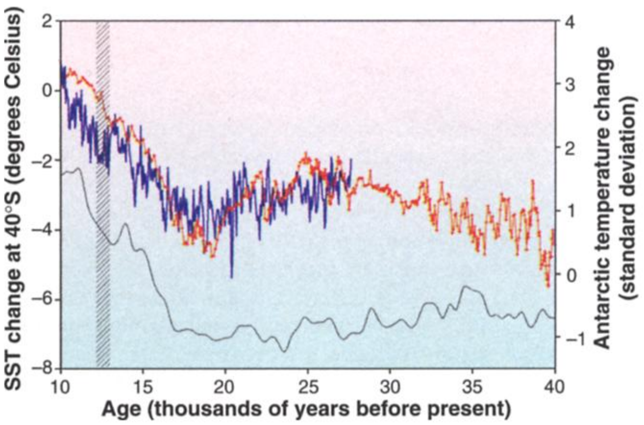
Eric J. Steig

Ice and ocean sediment cores provide a detailed picture of the temporal characteristics of climate over the past 100,000 years. We now know that the slow variations of the ice-age cycles were regularly interrupted by more rapid events, during which mean annual temperature changed by as much as 10° or 20°C in just a few decades (*1*). However, except for the past 600 years (*2*), the spatial pattern of climate change remains virtually unknown because most data come from just a few locations: the Greenland Ice Sheet, the Antarctic Ice Sheet, and the North Atlantic Ocean.

Two reports in this issue help to address this problem by providing records of sea surface temperatures (SSTs) in the mid-latitude oceans of the Southern Hemisphere, a particularly data-poor area. Both studies show that the timing of temperature change in this area is substantially different than in either the North Atlantic or Antarctic. This result will please those that argue that the tropics and mid-latitudes have a larger role to play in climate change than has generally been believed.

The first set of data comes from an ice core from Dome C in East Antarctica. This may seem a surprising location for a record of mid-latitude SSTs. The idea is that deuterium excess—the small difference between oxygen and deuterium isotope ratios—should provide a measure of evaporative conditions at the ocean source of polar moisture. However, researchers have been reluctant to interpret deuterium excess data in terms of SST because other variables, particularly relative humidity, also affect deuterium excess (*3*). On page 2074, Stenni *et al.* (*4*) address this problem in three ways.

First, they note that the modern distributions of humidity and temperature are highly correlated with latitude. This correlation seems to hold through major climate transitions, allowing them to use the isotope data to define a unique set of relations between ice sheet surface temperature and humidity and temperature at the ocean surface. Second, they allow both humidity and SST to vary independently in a simple atmospheric model to place statistical error distributions on the temperature estimates. Third, they show that the sodium concentrations in the ice core record—a proxy for ocean surface wind speed and meridional air mass transport—vary exponentially with the magnitude of the temperature difference between the ocean moisture source and ice sheet. This is the expected relation, indicating that the latitudinal temperature gradient is correctly quantified by the isotopic data.



Temperature change in the Southern Hemisphere. Temperatures are given relative to the average early Holocene temperature. Red line: SSTs from South Atlantic core TN057-21-PC2 at 41°S (*5*). Blue continuous line: Indian Ocean SSTs from Dome C, Antarctica (*4*). Black continuous line: Antarctic surface temperature change at Vostok after correction for moisture-source changes (*8*). Shaded area: Younger Dryas cold period as defined in European and Greenland climate records.

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Stenni *et al.*'s calculations result in two time series of relative temperature change, one for the Antarctic plateau and the other for the moisture source for East Antarctic precipitation. General circulation models and isotopic tracer studies show that this moisture source is the area between 30° and 50°S in the Indian Ocean.

A potential problem remains. The deuterium excess proxy for SST can only tell us about the evaporation temperature of the average moisture reaching Dome C. The SST variations reported by Stenni *et al.* may thus merely reflect changes in the relative contribution of moisture from different latitudes with different mean SSTs. However, this possibility is addressed by the report by Sachs *et al.* on page 2077 (*5*), which should put to rest any remaining skepticism about the utility of deuterium excess.

Sachs *et al.* determine SSTs (*6*) from a sediment core from the southeast Atlantic, at about the same latitude (41°S) as the average moisture source for Dome C. The results are remarkably similar to those of Stenni *et al.* (see the figure). Both show a change of about 4°C across the glacial-interglacial transition and of 2°C between 30,000 and 20,000 years before present. They also generally agree on the magnitude of change (1° to 2°C) for more rapid temperature fluctuations. This provides an independent empirical calibration of deuterium excess versus SST. The effective sensitivity is about 1 per mil per degree Celsius, in excellent agreement with the relation determined from models (*7*, *8*).

What do the two data sets tell us about climate change? Above all, they both show that mid-latitude SSTs parallel neither the classic Southern Hemisphere temperature record (the Vostok ice core) nor the archetypal North Atlantic temperature records (the central Greenland ice cores). The most marked difference, highlighted by Sachs *et al.*, is that when the polar regions cooled between 40,000 and 25,000 years ago, the mid-latitudes (at least in the Southern Hemisphere) experienced warming.

Stenni *et al.*'s data do not cover this period, but published deuterium excess data from Vostok—which can now be interpreted with greater confidence in terms of SST—show the same increasing trend (*7*). This trend parallels local insolation changes that primarily reflect variations in the tilt of Earth's axis, adding support to the hypothesis (*9*) that the growth of Northern Hemisphere ice sheets owes as much to warming of the mid-latitudes (and the resulting increase in poleward moisture transport) as to the cooling of the poles. In that case, neither the polar regions nor the lower latitudes are the dominant players in the ice-age cycle: All latitudes play different but equally important roles.

Another important finding is Stenni *et al.*'s observation of a cold oscillation in Indian Ocean SSTs, about 800 years after the Antarctic Cold Reversal (~14,000 years ago) seen in Antarctic climate records. It remains to be determined whether this "Oceanic Cold Reversal" is a Southern Hemisphere expression of the Younger Dryas cold period in the North Atlantic, with which it is suspiciously comparable in timing. There is no doubt, however, that the Antarctic Cold Reversal precedes the Indian Ocean cooling: Stenni *et al.*'s study neatly avoids relative dating uncertainty (which often plagues paleoclimate studies) because both local Antarctic temperature and distant SST records are derived from a single ice core.

Sachs *et al.*'s data show no Oceanic Cold Reversal but do show a small cooling during the Antarctic Cold Reversal. Taken alone, this appears to confirm earlier work showing an antiphase relation between the Southern and the Northern Hemispheres, which has led to the concept of a temperature "seesaw" between the hemispheres (*10*). Stenni *et al.*'s results suggest otherwise. It seems that the north-south antiphase may be limited to the Atlantic and that the seesaw model is far too simple to account for the real longitudinal and latitudinal heterogeneity of millennial-scale climate change.

Just as interannual variation in modern climate cannot be captured with one or two temperature records, understanding century-scale, millennial-scale, and longer term changes of past climate requires records from across the globe. The unexpected results of the new records demonstrate that this task is still in its infancy.

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PERSPECTIVES: GEOPHYSICS

Top-Down Tectonics?

Don L. Anderson

There are two competing models for mantle convection. In the first, the mantle is stratified into two or more separate convecting regions. In the second, the whole mantle convects as a single unit. Recent progress in plate tectonics, seismology, solid-state physics, and mantle convection is providing strong support for stratified convection. The results may also help explain how plate tectonics relate to mantle convection. Upper mantle convection may be driven by plate tectonics, whereas the deep mantle may convect in a completely different style.

Enhanced online at www.sciencemag.org/cgi/content/full/293/5537/2016

Evidence for whole mantle convection comes primarily from seismology (*1*). Images of bright blue bands represent high-velocity seismic anomalies that appear to be slabs traversing the mantle. The visual evidence for occasional slab penetration below 650 km (*2*) is usually taken as sufficient evidence for whole mantle convection. Whole mantle convection is also the reigning paradigm among geodynamic modelers because of the seismic evidence cited above and the similarity between the geoid (the surface of constant gravitational potential that would represent the sea surface if the oceans were not in motion) and deep mantle seismic tomography (which works much like medical x-ray tomography except that seismic velocities are imaged). Whole mantle convection simulations are also easier to do.

Arguments for stratified convection are more complex and harder to understand (*2*, *3*). Pressure suppresses the effect of temperature on density, making it more difficult for the deep mantle to convect. It also suppresses the effect of temperature on seismic velocities, which are used by seismologists to map temperature variations. Ab initio calculations of mantle minerals (*4*, *5*) indicate that subtle differences in seismic gradients and velocities may be compositional; even small changes in chemistry can stratify mantle convection. Furthermore, computer simulations of three-dimensional (3D) mantle convection with self-consistent thermal properties and variable heating (*6*) show thermochemical convection involving deep dense layers, which help explain the spatial and spectral

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