One possible approach to creating spin currents is to exploit spin-orbit coupling, an effect in which the trajectory of an electron moving under the influence of an electric field depends on its spin state. For example, a recent proposal (*6*) suggests passing electrons through a heterostructure engineered so that spin-orbit coupling is relatively strong, generating a spin current perpendicular to the electric current. Murakami *et al*. demonstrate that spin currents produced via spin-orbit coupling can be generated more simply with holes rather than electrons, because relatively strong spin-orbit coupling naturally exists for holes in many semiconducting systems in which it is small or absent for electrons. This idea offers several practical advantages.

First, many of the materials needed are commonly available and can easily be processed. Second, because the directions of spin and electric currents are connected, the information carried by the spin currents could in principle be translated into normal electric currents. This would facilitate the integration of spintronics with traditional microelectronic devices. The use of common semiconducting materials is a further benefit in developing such integrated devices. Finally, the polarization of the current is fixed not by a magnetic field but by the direction of the currents themselves, obviating the need for magnets to fix the spin polarization. This property may prove important in miniaturized systems, where one may not wish to have magnetic fields in every part of a device.

Once spin currents can be created and manipulated in this way, quantum computers will arguably represent their most exciting possible application. Other applications may emerge much sooner, including spin diodes and transistors (which could be at the heart of high-speed, reprogrammable logic circuit elements and nonvolatile memory applications) (*7*), electro-optic light modulators (*8*), and circularly polarized light-emitting diodes (*9*).

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PALEOCLIMATE

What Drove Past Teleconnections?

Frank Sirocko

Ever since two long ice cores, GISP2 and GRIP, were recovered from the Greenland Ice Sheet about 10 years ago (*1*, *2*), the mechanisms of abrupt climate change during the past 100,000 years have been the subject of intense research. Variations on decadal and millennial time scales in North Atlantic sediment composition were soon connected with the ice core record (*3*). These variations show a pattern that is now regarded as typical for the entire Northern Hemisphere. The associated temperature anomalies are most probably caused by changes in the rate and position of North Atlantic deep-water formation, and/or by surging glaciers over North America/Fennoscandia. Both processes strongly affect the sea surface temperature (SST) of the North Atlantic surface water.

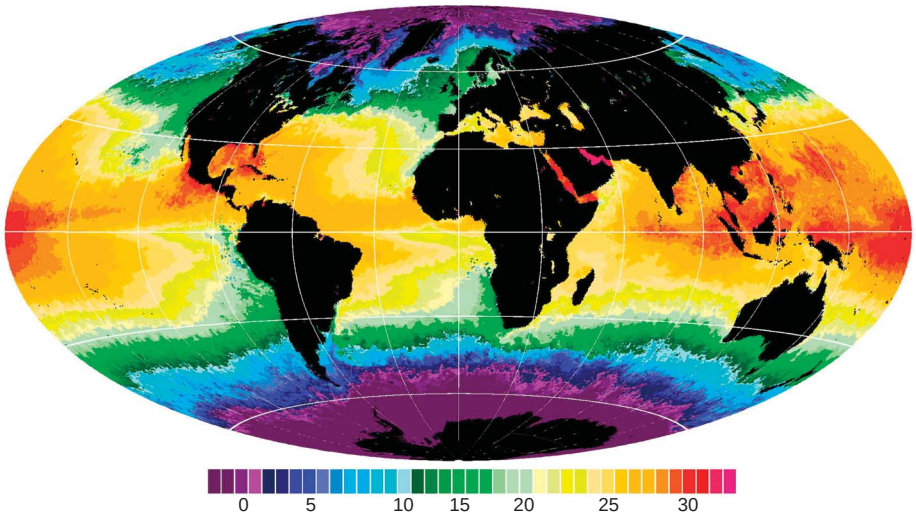
Enhanced online at www.sciencemag.org/cgi/content/full/301/5638/1336

Similar patterns of climate variability have been detected at low latitudes in the Pacific (*4*), Indian (*5*), and Atlantic oceans (*6*). The latest review on the global extent of abrupt climate variations between 30,000 and 60,000 years before present (B.P.) lists 183 sites on both hemispheres (*7*). The unsettled climate during the early phase of the last ice age was clearly a global phenomenon, although the interactions between the southern and northern high latitudes were complex (*8*).

On page 1365 of this issue, Burns *et al*. (*9*) present a new stalagmite record (from ~40,000 to 50,000 years B.P.) from the island of Socotra in the Indian Ocean, off the coast of Somalia. The record shows a succession of monsoon humid phases of century- to millennial-scale duration that is very similar to the pattern seen in the North Atlantic and Greenland. There are only two differences between the two records. First, in Greenland, interstadials 13 and 9 (warm phases at 43,000 and 53,000 years B.P.) do not reach the same upper boundary as the other interstadials [see fig. 2 of (*9*)]. Second, the temperature minimum at 50,000 years B.P. is much more severe in the monsoon precipitation record than in the North Atlantic, where surges of continental glaciers occurred.

This similarity puts the spotlight on past climatic teleconnections, which link climate forcing between distant parts of the world. In most early studies, the low latitudes were thought to simply respond to a dominating influence from the North Atlantic. But how much of this interpretation is based on the fact that the ice core records are an archive of unique quality and were published first?

A look at today's SST patterns helps to understand how past teleconnections may have worked. The figure shows a satellite map of global night-time SSTs. The map is not the standard Mercator projection (in which Greenland appears nearly as large as



Global night-time SST in July 2002. The data acquired by satellite-borne Advanced Very High Resolution Radiometer and presented in Hammer-Aitoff equal area projection.

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South America), but an equal-area projection that helps us to understand the potential role of processes associated with area (such as albedo, clouds, snow and vegetation cover, and SST).

The two dominant features of the global SST pattern are (i) the export of cold surface water from the circum-Antarctic current to the low latitudes of the Southern Hemisphere, and (ii) the export of warm equatorial waters to the high latitudes of the Northern Hemisphere. This different behavior of the two hemispheres appears to be caused by the plate-tectonic position of the continents, which act as barriers (Europe, North America) or obstacles (Africa, South America) in the west wind zone of the mid-latitudes on both hemispheres.

The areas of homogeneous SST are largest in the cold circum-Antarctic current and in the warm-water masses of the low latitudes (see the figure). The North Atlantic is comparatively small but unique: It is the only ocean where warm surface waters are transported from the subtropics all the way up to the Norwegian Greenland Sea. Here, the water masses cool and descend to form the deep-water part of the global thermohaline conveyor belt. However, it is difficult to understand how the largest climatic zone (subtropics and tropics) should exactly follow a temperature anomaly from an area the size of the North Atlantic, if rapid decay of continental ice sheets is not also involved.

Whatever the mechanisms for the high similarity between the Socotra stalagmite (*9*) and the Greenland temperature variation have been in the past, it is obvious that both regions have been extremely tightly coupled. It is, however, also well documented that Antarctic temperature changes precede Northern Hemisphere ice surges by a few millennia (*8*). Recent studies have shed much light on the nature of the past global climate teleconnections that underlie these patterns. Additional well-synchronized records from remote parts of the globe are becoming available, and the missing connections are now mainly between the low latitudes (where the El Niño–Southern Oscillation plays a key role) and the circum-Antarctic current, and between the Atlantic SST and central Asian snow cover.

New high-resolution, well-dated records like the stalagmite from Socotra (*9*) allow us to understand the time scales, rate of change, and synchronicity of regional climatic evolution with increasing accuracy. Satellite observations and model studies are the appropriate tools needed to understand the physical and chemical processes behind the climatic changes. However, these results could be interpreted more easily if satellite data and modeling results were presented as realistic maps and projections. The large areas of the circum-Antarctic current and the low-latitude warm-water pool are then clearly visible (see the figure), highlighting their potential as global players in past temperature variations.

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ECOLOGY

Making Allelopathy Respectable

Alastair Fitter

Allelopathy—the suppression of neighboring plant growth by the release of toxic compounds—has had a checkered history among ecologists. Much of the early work on allelopathy was insufficiently rigorous, and an unusually influential review by John Harper (*1*) of a monograph on the subject (*2*) convinced most ecologists that chemical warfare between plants was not a profitable field of study, despite its undeniable importance in microbiology. On page 1377 of this issue, Bais *et al*. (*3*) now place allelopathy firmly back on center stage. Their carefully documented account of the displacement of native plant species by the Eurasian spotted knapweed (*Centaurea maculosa*) in the western United States neatly avoids the pitfalls of earlier work (see the figure). Their findings suggest that chemistry may play a large part in successful invasion by certain plant species.

Many ecologists subscribe to a key argument against the idea that plants might interfere with each other by chemical interactions as well as by resource depletion. They argue that to be effective as a toxin, a compound must be produced by a donor plant and then transported (by simple physical diffusion or convective transport) to the vicinity of the recipient plant. In the absence of a mechanism to concentrate the toxin, the amount of toxin around the donor plant would be higher than that around the receiver, suggesting that the donor plant must have evolved resistance to the toxin. In that case, however, there would be a powerful selection pressure on recipient plants to also evolve resistance to the toxin, eventually rendering the toxin ineffective within that community. A similar argument might apply to plant chemical defense against insects, except that the damage inflicted on plant tissues by a herbivore offers opportunities for compartmentation and other devices that protect the plant from its own toxin. However, the argument also leads to the hypothesis that plant species that normally coexist should evolve resistance to each others' toxins, but not to the toxins of species with which they do not coexist.



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Phytochemical weapons for a successful invader. The spotted knapweed (*Centaurea maculosa*) is an economically destructive plant invader in the western United States. It may owe part of its success to release of a phytotoxin from its roots that triggers the death of the root systems of susceptible plant neighbors.

Bais *et al*. subject this hypothesis to a powerful test. They reveal that *C. maculosa*, a major invasive weed in western North America, produces the phytotoxin (−)-catechin. This compound accumulates in soils around roots, and inhibits the germination and growth of native North American grass species that the knapweed is known to displace from natural habitats. In contrast, the germination and growth of several closely related European grasses were unaffected by the same concentrations of catechin. Curiously, the concentration of (−)-catechin in soils under *C. maculosa* was twice as high in North America as in Europe, but the European grasses (and *C. maculosa* itself) were capable of growth even at the higher (−)-catechin concentrations recorded in North American soils. This observation provides strong evidence for the differential susceptibility of target plants to a phytotoxin, and supports the discovery of an ecologically important allelopathic interaction.

Importantly, Bais *et al*. go one step further, characterizing in detail the mechanism by which (−)-catechin kills its susceptible plant neighbors. They used two target species: *Centaurea diffusa*, a close

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