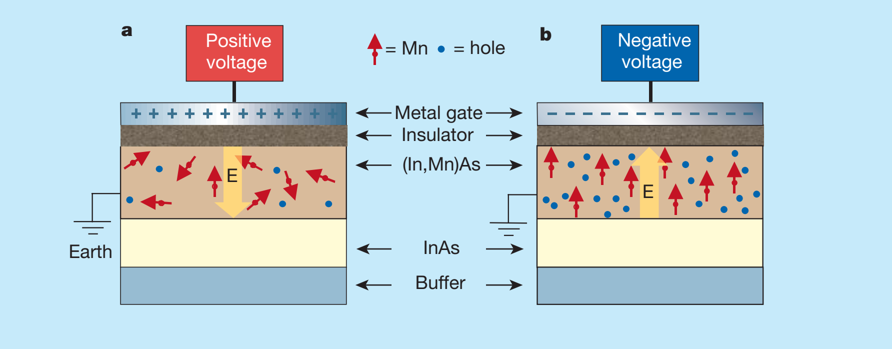

Figure 2 **An electrically controlled magnetic switch. The device designed by Ohno *et al.*[2] has a layer of indium manganese arsenide, (In,Mn)As, material sandwiched within a field-effect transistor.** a, **A positive voltage on the metallic 'gate' electrode creates electric fields (orange arrow) that repel holes (blue circles), causing the Mn magnetic moments (red arrows) to orient randomly.** b, **A negative voltage on the gate electrode creates electric fields that attract holes, causing the Mn magnetic moments to align.**

onto (In,Mn)As semiconductors and related magnetic alloys — thereby varying the concentration of charge carriers — can also produce changes in magnetization[7,8]. If it is possible to control the hole concentration in real-time using an electric field, then it should be possible to drive the system reversibly from a ferromagnetic phase (aligned Mn moments) to a paramagnetic phase (randomly oriented Mn moments) and vice versa. Crucially, for practical applications, these changes in magnetization would occur at a fixed temperature (dashed line in Fig. 1).

In their work, Ohno *et al.*[2] change the hole concentration of an (In,Mn)As thin film by placing it in the active region of a field-effect transistor (FET). The FET structure shown in Fig. 2 is created by growing a thin layer of (In,Mn)As on an InAs-terminated buffer layer, followed by subsequent deposition of an insulating layer and a metallic 'gate' electrode. Applying a positive voltage to the gate (Fig. 2a) creates electric fields that repel the positively charged holes (because like charges repel). The reduced hole concentration in the (In,Mn)As layer makes the system paramagnetic. Applying a negative voltage to the gate (Fig. 2b) creates electric fields that attract the positively charged holes (because opposite charges attract). This increases the hole concentration and makes the system ferromagnetic. So by simply applying a voltage to the gate electrode, the magnet can be reversibly turned on (ferromagnetic with a net magnetic dipole moment) and off (paramagnetic with zero magnetic moment).

The concept behind Ohno *et al.*'s device is quite elegant, and begs the question 'why didn't anyone think of this before?'. Of course, they did, and there have been many unsuccessful attempts to build such devices. For instance, it has proved very difficult to change the charge-carrier concentration in metals (and most ferromagnets are metallic). In addition, there has been no success with devices made using gallium manganese arsenide, (Ga,Mn)As — which has a T_C as high as 110 K — because of their high intrinsic carrier concentration[5]. Most semiconductor materials break down under high electric fields, which limits the extent to which one can control the carrier concentration in an FET. In an effort to reduce the hole density, the ferromagnetic semiconductor layers were made thinner, but ferromagnetism in (Ga,Mn)As disappears below a thickness of around 5 nm. To circumvent these difficulties, Ohno *et al.* used a different material, (In,Mn)As.

This newly emergent behaviour is quite promising, but do not expect to see this 'magnet switch' on your desktop tomorrow. The effects are seen at low temperatures (about 25 K) and with the application of large voltages (± 125 volts). So many challenges need to be overcome before this effect can be used in a commercially viable device. Nonetheless, this experiment is a 'proof of concept' for the idea that the magnetic properties of ferromagnetic semiconductors can be controlled using standard electronic techniques. This finding, along with the discovery of new ways to control electronic spin — for example, creating longer spin lifetimes in semiconductors[9] and spin-injection from magnetic semiconductors[10] — paves the way for practical spintronics. ■

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Meteorology

Oscillating opinion

Heike Langenberg

Why, since around 1960, have winters in northern Europe tended to become milder and wetter? The meteorological conditions responsible came under discussion at a meeting last month.

The North Atlantic Oscillation has a big influence on weather and climate in the Atlantic region, and so has been termed El Niño's northern cousin. But as was clear at a conference* on the topic, the phenomenon is more complicated than its counterpart in the tropical Pacific — which itself is far from understood. Not surprisingly, then, even the question "What exactly is the North Atlantic Oscillation?" is controversial.

The North Atlantic Oscillation (NAO) has been discussed for almost 70 years[1], and is generally defined as the principal pattern of wintertime atmospheric-pressure variability at sea level over the North Atlantic. The most widely used index for the period since 1864 is the difference between normalized atmospheric pressures at Stykkisholmur, Iceland, and Lisbon, Portugal[2]. In the positive phase — that is, in years with high pressure differences (see Fig. 1) — a strong storm track reaches far north, into the Barents Sea. This results in storms, rain and mild temperatures in northern Europe, while temperatures in Greenland and Labrador are colder than average. In a winter with a negative NAO index, this pattern reverses, as there is a weaker storm track that does not reach as far north. Atmospheric pressure at sea level is almost always lower at Iceland than Lisbon; it is the magnitude of the difference between them that determines the index.

Controversy about the nature of the pattern was sparked off by the suggestion that the NAO is better described as only part of a larger pattern of variability, which spans the Northern Hemisphere and is centred around the North Pole[3]. Such a pattern has been identified for the Southern Hemisphere, where it is symmetric about the pole. But in

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**The North Atlantic Oscillation*, AGU Chapman Conference, Ourense, Spain, 28 November–1 December 2000. Abstracts are at www.ldeo.columbia.edu/NAO/conference/chapman_conf.html the north the hemispheric mode is dominated by the North Atlantic and Arctic regions, with only a weak link to the north Pacific (C. Deser, Natl Center for Atmospheric Res., Boulder, Colorado)[4]. Which of these views of the NAO is the more useful therefore depends on the research agenda. For instance, for studies of seasonal predictability in the Atlantic region it is usually better to concentrate on the NAO.

Another aspect is that the NAO may not always have shown the same behaviour. Indirect data for the past four centuries suggest that the amplitude of variability might have increased significantly after the end of the Little Ice Age, around 1850 (E. Cook, Lamont–Doherty Earth Obs., Palisades, New York). Moreover, the consequences of the pattern, for example on sea-ice extent in the Arctic (J. E. Walsh, Univ. Illinois, Urbana-Champaign), depend on the exact positions of the two pressure centres — which can differ significantly in years with the same index value.

The persistent positive trend in the index since about 1960 raises the question of whether global warming is responsible. There is no clear answer. A new index, based on surface pressures from Gibraltar, Reykjavik in Iceland and Ponte Delgada in the Azores, shows a similar trend for the early part of the twentieth century (P. Yiou, Lab. des Sciences du Climat et de L'Environnement, Gif-sur-Yvette), implying that natural variability can account for Europe's mild and wet winters since 1960. But an analysis of the Lisbon–Iceland index indicates that natural variability can be rejected as a cause for the recent trend (S. B. Feldstein, Univ. Pennsylvania). After considering these conflicting results and the processes that drive variations of the NAO, most participants, asked to give their best guess for the coming decade, expected the index to increase further, rather than decline towards the mean as would be expected in the absence of a link with climate change.

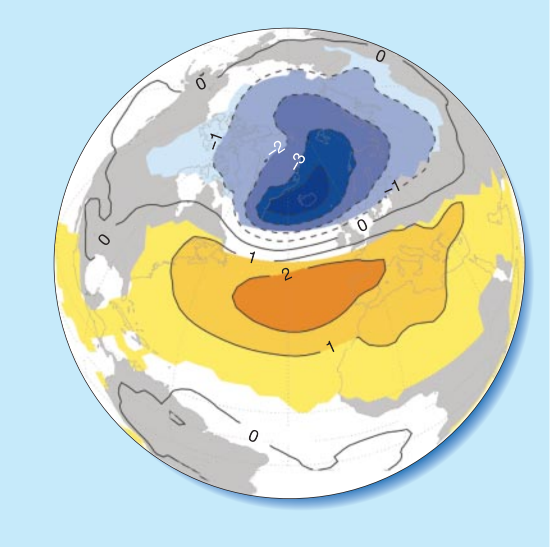

Figure 1 **Deviations from a 52-year average of sea-level atmospheric pressures over the North Atlantic region, during winters with a high North Atlantic Oscillation index (1 standard deviation above the average). Anomalously large differences between pressures over Iceland and Lisbon lead to a strong storm track in the North Atlantic, bringing mild, wet and stormy weather to northern Europe. The data are derived from measurements for the months December to March, for 1948–99. Units are hectopascals (= millibars). (Graphic courtesy of Thomas Jung and Michael Hilmer.)**

Two main candidate mechanisms emerged that might explain the long-term persistence of trends in the lower atmosphere (in which disturbances can normally be tracked for only about a week). Interactions with the ocean are one possibility. A statistical analysis of observations reveals two patterns of Atlantic sea surface temperatures that tend to precede specific phases of the NAO: positive anomalies in mid-latitude temperatures induce a positive phase with a lead time of six months, and the tropical Atlantic surface temperatures exert a weaker influence on timescales of up to two months (A. Czaja, Massachusetts Inst. Technol.).

The other candidate mechanism is atmospheric, and centres on the polar stratospheric vortex — a rotating circulation pattern in the higher levels of the atmosphere above the poles. Depending on its strength, the vortex acts as a window that allows atmospheric waves originating in the troposphere to pass into the upper atmosphere, or as a mirror reflecting the waves back down. This second phenomenon could amplify a positive NAO phase if there is interference between the reflected waves and the original waves (H.-F. Graf, MPI für Meteorologie, Hamburg)[5].

Both sea surface temperatures and the strength of the polar stratospheric vortex are thought to increase with increasing greenhouse gases in the atmosphere. So this consideration points to a causal connection between global warming and the positive trend of recent years. If this is indeed the case, there could be a beneficial effect: simulations with a general circulation model suggest that a positive NAO may temporarily mitigate one of the most worrying possible impacts of global warming, the slowing of the thermohaline circulation in the North Atlantic (T. L. Delworth, Geophys. Fluid Dynamics Lab., Princeton Univ.). This circulation is one of the main engines of heat transport around the globe — if it slowed or stopped, the climatic consequences would be severe.

The NAO has a considerable impact on natural ecology and human economies, in arenas ranging from plant and animal population dynamics to energy production in Scandinavia. So many researchers are attempting to predict its behaviour on both seasonal and decadal timescales. At the seasonal scale, the aim is to exploit the predictive value of sea surface temperatures. According to one forecast, in which observed Atlantic sea surface temperatures for May and November 2000 were fed into a model, there is a 66% chance of a positive NAO for the coming winter (M. Rodwell, Hadley Centre, Reading, Berks.). If increasing greenhouse-gas concentrations in the atmosphere are driving the current positive phase, we should expect further increases in the frequency of mild, wet winters in northern Europe. But to confirm whether global warming does indeed change the balance between the positive and negative phases, we will simply have to wait until a clear, tell-tale signal emerges from the noise of natural variability. ■

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Nanotechnology

Solid progress in ion conduction

Alan V. Chadwick

Materials that conduct ions are useful in devices involving electrochemical reactions, such as fuel cells and batteries. Low ionic conductivity was a problem for these materials until researchers built nanoscale versions.

The development of materials with dimensions in the nanoscale range is a highly active area of research because they often have very different properties from the bulk material. These properties can offer new or improved technological applications. So far, materials scientists interested in nanotechnology have mostly focused on semiconductors and ceramics. For example, semiconductors made from nanocrystals have unusual optical, electrical and magnetic properties, and ceramics made from nanoparticles have greater hardness and plasticity than normal. However, on page 946 of this issue, Maier and colleagues[1] demonstrate that restructuring simple ionic crystals at the nanoscale can also alter their electrical properties, pointing the way to potentially