with cooling in the North Atlantic and some parts of China and North America (N. Nicholls, Bureau of Meteorology Research Centre, Melbourne). Data on retreat of mountain glaciers from the tropics to high latitudes reinforce this evidence (M. F. Meier, Univ. Colorado). Although there is evidence that the seasonal cycle is also shifting towards earlier winters (D. J. Thomson, Bell Labs), there was considerable dispute about how certain we could be that greenhouse gas increases were accelerating the shift that is itself due to changes in the Earth's orbital elements.

Several investigators (G. C. Reid, National Oceanic and Atmospheric Administration, Colorado; D. V. Hoyt, Research and Data Systems, Maryland) reported statistical linkages between climate fluctuations and variations in solar irradiance, but the evidence that variations in the Sun's energy output can be large enough to cause the changes will be at best circumstantial until a plausible mechanism is quantified. A diagnostic model aiming to match the climate record of the past few centuries indicated that solar variations could only have had an important effect in the unlikely event that the cooling influence of sulphate aerosols is largely compensating for the warming influence of greenhouse gases. For the future, all indications are that the greenhouse gas effect will increasingly govern the behaviour of the climate (M. E. Schlesinger, Univ. Illinois).

Interestingly, the warming pattern since the mid-1970s looks rather like the footprint of El Niño events, although this does not explain the strong warming over parts of Eurasia (C. K. Folland, Hadley Centre, UK). These quasi-periodic events warm the eastern tropical Pacific Ocean, which sets off a chain of events that cool the central North Pacific, warm northwest Canada, increase precipitation in the southeastern United States and intensify the large-scale pressure pattern across the Pacific, North America and the North Atlantic Ocean that alters mid-latitude storm tracks. Does this finding mean that the recent warming is due primarily to an increased (but not understood) frequency of El Niño events, or is this the pattern by which greenhouse-gas-induced warming is becoming evident? We don't know. Climate models are only just starting to achieve the high resolution and verisimilitude needed to reproduce, although often not strongly enough, the observed El Niño signature. Some model simulations suggest that the warming pattern will be similar to a persistent El Niño, but that oscillations will continue, superimposed on the higher average temperature (G. A. Meehl, National Center for Atmospheric Research, Colorado).

A variety of model simulations for the nineteenth and twentieth centuries are being conducted. Simulations that couple ocean, atmosphere and land surface aerosols show better agreement with the historical record if they include the increasing concentrations of both greenhouse gases and sulphate aerosols than if they take into account just greenhouse gases (J. F. B. Mitchell, Hadley Centre; U. Cubasch, Max-Planck-Institut für Meteorologie, Hamburg; see J. F. B. Mitchell *et al. Nature* **376**, 501–504; 1995). This is evident both in the records of the global average temperature and in the geographical patterns of changes in surface and tropospheric temperatures (B. D. Santer and K. E. Taylor, Lawrence Livermore National Lab.). The chief discrepancy found in analyses of the vertical temperature pattern is that the simulated warming extends up into the lower stratosphere whereas the observations show cooling in this region. This discrepancy is probably a result of not including the effects of stratospheric ozone depletion, which other modelling studies indicate causes cooling due to reduced absorption of solar and terrestrial radiation.

In addition to lowering projections of overall global warming, including sulphates in the simulations has regional effects, including reversing the projected intensification of the Asian summer monsoons found in greenhouse-gas-only calculations (Mitchell). This occurs because the high (but uncertain) projections of future sulphur emissions (mainly from energy generation) for eastern Europe, India and China create a cooling pall over southern Asia. Interestingly, the change in the Earth's orbit since 6,000 years ago had a radiative influence of similar character, and the modelled and observed result of the change is a reduction of the summer monsoon and the aridification of much of the Middle East and northern Africa (suggesting that the models are responding as would nature).

Another important issue is understanding the internal variability of the atmosphere–ocean(–glacier) system. The picture slowly emerging from observations seems to fit reasonably well (at least in some cases) with mechanisms of decadal to interdecadal variability found in simulations with coupled ocean–atmosphere models, which are becoming more realistic (U. Mikolajewicz, Max-Planck-Institut für Meteorologie).

In the vernacular popular in the United States today, one could say that the DNA (here for Distinguishing Natural and Anthropogenic) evidence is becoming quite compelling. Although greenhouse gases and aerosols are not yet convicted beyond all reasonable doubt, the case is becoming steadily stronger. □

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DAEDALUS

Holes within holes

DRILLING for oil, says Daedalus, is a triumph of misguided technology. There must be a better way than sinking an outsized rasp into the Earth on the end of kilometres of revolving pipe. He recalls the destructive 'cavitation' created in a violently stirred liquid. Tiny bubbles of vacuum are formed, whose subsequent collapse creates vast local pressure and shock. Cavities can erode ships' propellers and give bite to ultrasonic drills. The problem is to create them on a large enough scale.

Daedalus's scheme is to create normal gas-filled bubbles, and then remove the gas. Chemists of a certain age may remember the venerable 'fountain experiment', in which water rushes into a flask to dissolve a soluble gas, such as ammonia or hydrogen chloride. If you could suddenly insert a tiny bubble full of hydrogen chloride into water, the same thing would happen. The gas would dissolve almost instantly in the surrounding water, which would rush in from all sides. The bubble would collapse like a cavity. The smaller the bubble, the greater its surface-to-volume ratio, and the faster and more destructively it would collapse.

To generate the bubbles in the first place, Daedalus plans to make bubbles of a mixture of hydrogen and chlorine, and expose them to an intense sudden flash. This causes the gases to combine explosively to hydrogen chloride. After the initial detonating expansion, which may have useful destructive power of its own, the hydrogen chloride will dissolve and the bubble will collapse.

DREADCO engineers are now testing a pilot 'chemical cavitation' drilling rig. It has no moving parts. It is simply a system for dispersing a mixture of hydrogen and chlorine at the bottom of a water-filled hole, and a strobe flash-lamp for firing the bubbles at rapid intervals. The gases may be piped down to the drill, or generated *in situ* by electrolysis; either way, hundreds of kilowatts of power can be efficiently channelled into destructive cavitation. Hydrogen and oxygen, exploding to water vapour, may cavitate even more violently if ultraviolet flashes can be made intense enough to set them off.

The deeper the drill goes down, the higher the hydrostatic pressure at the bottom, the more forcefully the cavities will collapse, and the better everything gets. With no revolving shaft, it can be sent round corners, backed up to drill a side-arm on its own bore, and so on. Oil and gas prospectors should welcome the chemical cavitation drill with open arms. Its lack of moving parts may even appeal to dentists. David Jones