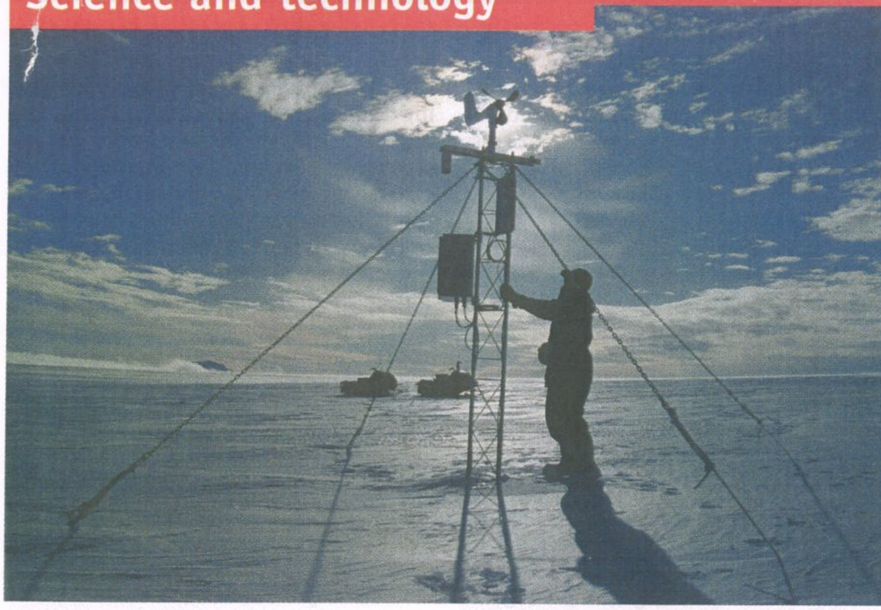


Also in this section

Climatology

Changing science

As delegates from around the world meet in Montreal to discuss climate change, what science should inform their deliberations?

THE climate changes. It always has done and it always will. In the past 2m years the temperature has gone up and down like a yo-yo as ice ages have alternated with warmer interglacial periods. Reflecting this on a smaller scale, the 10,000 years or so since the glaciers last went into full-scale retreat have seen periods of relative cooling and warmth lasting from decades to centuries. Against such a noisy background, it is hard to detect the signal from any changes caused by humanity's increased economic activity, and consequent release of atmosphere-warming greenhouse gases such as carbon dioxide.

Detection is, nevertheless, important, because the climate seems particularly changeable at the moment. Moreover, forming sensible policies towards climate change, as the United Nations Climate Change Conference in Montreal aspires to do, depends on knowing what is going on. Fortunately, the past year has seen the publication of a series of results that help to disentangle signal and noise.

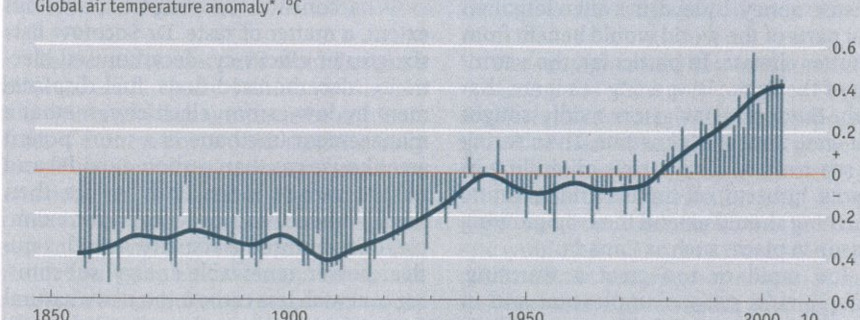
The first, and most basic, is the continuation of the warming trend at the Earth's surface that has been happening since the early 20th century. The chart on this page, assembled by Britain's Hadley Centre and the University of East Anglia, shows that the ten years to 2004 were the warmest decade since reliable measurements began in the mid-19th century. Estimates of earlier temperatures suggest it may have been the warmest in the past millennium.

The second result is that the Arctic, a place where any warming trend would be amplified by changes in local absorption of heat as the ice melts, does indeed show signs of rapid warming. A report published this year as part of the Arctic Climate Impact Assessment showed that the amount of sea ice has fallen by 8% in the past 30 years, and also found signs that Greenland's ice cap is melting more rapidly than in the past.

The third finding is the resolution of an inconsistency that called into question whether the atmosphere was really warming. This was a disagreement between the temperature trend on the ground, which appeared to be rising, and that further up in the atmosphere, which did not. Now, both are known to be rising in parallel.

Onwards and upwards

Global air temperature anomaly*, °C



Source: The University of East Anglia

*Deviation from mean temperature between 1961 and 1990

The fourth is a study by researchers at the Scripps Institution of Oceanography, in California, into changes in the way the world's oceans have warmed up at different depths over the past 65 years. These match climate models' predictions of what happens when warming is induced by greenhouse gases better than they match predictions of the result of variations in the sun's activity, the main alternative hypothesis for what might be causing the climate to change.

The fifth is the observation in reality of a predicted link between increased sea-surface temperatures and the frequency of the most intense categories of hurricane, typhoon and tropical storm.

And the sixth, as reported in last week's *Economist*, is an observation that ocean currents in the North Atlantic are faltering in ways that computer models of the climate previously suggested would happen in response to increased temperatures.

The signal, in other words, looks strong. That said, there are still a number of uncertainties. For instance, the solar hypothesis is not yet dead. A few researchers who agree the data show a warming trend nevertheless argue that this may be caused not ▸▸

by man but by nature, in the form of minute increases in the sun's heat output. That output is known to vary during the course of the 11-year sunspot cycle, as well as over the longer term, and although such changes have not been matched to temperature changes in the way that rises in the level of greenhouse gases have been, they may still be making a contribution.

Another issue is that a second type of pollutant, aerosols such as the minute sulphate particles that form when sulphurous fuel is burned, promote the formation of clouds. These reflect sunlight away from Earth and thus oppose the effect of greenhouse gases. Some have seen this as a possible counterbalance and, indeed, such "dimming" has been noticed in several parts of the world. However, yet another study published this year suggests the dimming is going away as anti-sulphur pollution-control measures kick in.

Perhaps the most important uncertainty, though, is that caused by a lack of enough good-quality, long-term, internally consistent data. Even the industrialised parts of the world, Europe and North America and their adjacent seas, have been studied properly for only a century and a half. Too much climate science relies on drawing conclusions from patchy information. It is therefore a nice irony that only under the presidency of George Bush, the *bête-noire*-in-chief of many environmentalists, has a unified Earth Observation System of satellites, ocean buoys, terrestrial weather stations, balloons and aircraft started to take shape. Though the system involves some 60 countries, the moving spirit is America's National Oceanic and Atmospheric Administration.

Watcha gonna do about it?

That the climate is warming now seems certain. And though the magnitude of any future warming remains unclear, human activity seems the most likely cause. The question is what, if anything, can or should be done.

One option, of course, is to do nothing—or at least nothing beyond eliminating the sort of economic nonsense, such as subsidising coal mining, that not only encourages global warming (because coal is the most carbon-rich fuel around), but wastes money. Indeed, it is often forgotten that parts of the world would benefit from a hotter climate. In particular, the warming of the Arctic is opening sea lanes that early European navigators avidly sought but were unable to penetrate. The clearing of sea ice will also permit oil-drilling in places hitherto off-limits. And a gentle warming should extend the crop-growing season in places such as Canada.

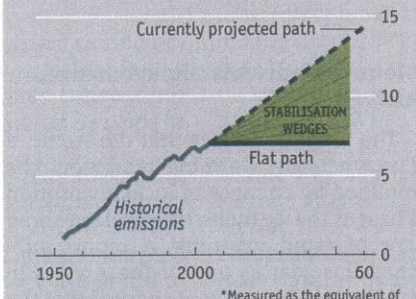
Too rapid or too great a warming, though, risks serious, unpleasant and in some cases irreversible changes, such as the melting of large parts of the Greenland and Antarctic ice caps. There is, to put it politely, a lively debate about how far the temperature can rise before things get really nasty and how much carbon dioxide would be needed to drive the process. Unfortunately, existing models of the climate are not accurate enough to resolve this dispute with the precision that policymakers would like.

If greenhouse-gas emissions are to be capped, however, a mixture of political will and technological fixes will be needed. Political will is the subject of the Montreal meeting, which is seeing the opening shots about what, if anything, will replace the Kyoto climate-change protocol after 2012. But a good way to think about the technology, known as "stabilisation wedges", was recently invented by Rob Socolow, of Princeton University.

Dr Socolow observes that on current trends the amount of greenhouse gases emitted by human activity will double over the next 50 years. Kyoto, a preliminary agreement, will make but a small difference. He calls the space on the graph between the trend line and the line representing stability at current levels the stabilisation triangle. That triangle can, in turn, be divided into a number of wedges, each of which represents a way that carbon-dioxide emissions might be curbed. This way of looking at things, he observes wryly, decomposes a heroic challenge (eliminating the emissions in the stabilisation triangle) into a limited set of merely monumental tasks.

Carving up the future

Greenhouse gases released*, per year, tonnes bn



Source: Rob Socolow

*Measured as the equivalent of the carbon in carbon dioxide

What constitutes a wedge is, to a certain extent, a matter of taste. Dr Socolow lists six: greater efficiency, decarbonised electricity, decarbonised fuels, fuel displacement by low-carbon electricity, methane management (methane is a more potent greenhouse gas than carbon dioxide) and natural carbon sinks. Each wedge then breaks down into sub-wedges (for example, decarbonised electricity includes nuclear power, renewable energy, substituting coal with less carbon-intensive natural gas, and capturing and storing carbon dioxide from power stations).

As can be seen from this list, a lot of Dr Socolow's sub-wedges rely on the wider deployment and sharpening up of existing technologies, such as ways of generating electricity from renewable energy sources (see Technology Quarterly). They also rely on building what might be called "emissions awareness" into a huge range of things that either generate or consume power—a fact that some firms see as a new business opportunity.

The wedge approach also encourages conceptual shifts. The more hair-shirt sort of environmentalism emphasises the idea of moving away from fossil-fuel use (though not, heaven forfend, towards nuclear power). Wedge theory, if it may be so described, balances that with thinking about ways to continue using fossil fuels while keeping the carbon dioxide that generates out of the atmosphere.

One way to do this is to extract it at the power station and inject it into porous rocks deep underground, from which it cannot easily escape. Some oil firms do this already to carbon dioxide that forms part of raw natural gas. Statoil, Norway's national oil company, has had such a "carbon sequestration" project in the North Sea for almost a decade and BP now has a similar project in Algeria.

Power-station extraction could either use the exhaust gases or be pre-emptive, by reacting the fuel with water in a process called steam reformation. This yields hydrogen, which is then used to make the electricity, and carbon dioxide. America's Department of Energy is sponsoring a series of projects designed to see if either of these techniques can succeed without raising costs too much, and signed a deal to build a prototype coal-based reformation plant this week.

Then comes Dr Socolow's last wedge. One other carbon-sequestration technology exists, and it is a tried and tested one—photosynthesis. Plants form themselves literally out of thin air, combining carbon dioxide, water and the energy of sunlight to give themselves substance. Photosynthetic carbon sequestration is a game that anyone, rich or poor, can play.

According to David Kaimowitz, of the Centre for International Forestry Research, an intergovernmental organisation, 15-20% of the greenhouse-gas emissions caused by human activity are the result of the degradation and destruction of forests. Simply replanting the equivalent of what is being lost would thus make a useful sub-wedge. Indeed, an annexe to the Kyoto agreement allows rich countries to pay poor ones to do just that, instead of cutting their own emissions, although oddly there is no incentive not to cut the trees down in the first place. Changing that is one item that has garnered support at Montreal—and one that even the most sceptical environmentalist would surely applaud. ■