CHANGING WEATHER

Estimates of the regional impacts of global warming are perhaps the most sought-after outcomes of climate-change research, and the prognostications provide a stark reminder of what is at stake in the greenhouse debate.

Climate scientists around the world are making progress in removing the large uncertainties involved in predicting the regional and local effects of global warming, but in the process have found the effects more complex and challenging than previously thought.

In 1991, researchers in CSIRO's climate impact group at the Division of Atmospheric Research presented estimates of climate change for the Australian region. In summary, they calculated for 2030 a rise in average air temperatures over the continent by 1–2°C in northern coastal areas, 1–3°C in southern coastal areas and 2–4°C inland. They also predicted increases in rainfall in areas dominated by summer rainfall (roughly speaking, the northern two-thirds of the continent), and less certain decreases in areas dominated by winter rainfall (southern Western Australia and South Australia, Victoria and Tasmania).

A recent revision by the group has produced somewhat lower temperature-change estimates — rises by 2030 of 0–1·5°C on Australia's north coast, 0·5–2°C on the south coast and 0·5–2·5°C inland. The rainfall picture for 2030 has become more complex. The most important estimate is for a 0–20% increase in the November to April half-year for locations throughout Australia. Estimates for the winter half-year show a decrease in much of the southern interior of the continent, a 0–10% rise in Tasmania, and a mixed result (–10% to +10% change) in south-western Western Australia, coastal New South Wales and Victoria.

While the predictions of change in average climatic conditions are clear cause for concern, climate scientists are becoming increasingly aware that the biggest impact of global warming promises to be felt in the changed frequency and severity of extreme events such as floods and droughts.

Results of recent model-based studies for the Australian region show:

- a dramatic rise in the intensity of storms in New South Wales and Victoria
- a marked decline in the duration of snow cover in the Australian Alps
- a significant shortening of the average time between periods of heavy rainfall over the entire continent

A numerical simulation of 'cut-off lows' by the Division and the Bureau of Meteorology Research Centre indicates big increases in rainfall and gale-force winds along the south-east coast of Australia. A cut-off low is a type of low-pressure system (resembling a tropical cyclone but, unlike the cyclone, with a core of cold air) that is sometimes responsible for large-scale flooding, strong winds and sea surges in eastern Victoria and south-eastern New South Wales. Characteristically, it has a band of rain to the south and east of the core, and a curved band of gale-force winds to the south. Meteorologists call it a 'cut-off low' because the circulation of air within the system at an altitude of about 5 km is closed or isolated from the general westerly air flow.

South-eastern Australia averages about nine cut-off lows a year. These appear in two forms: coastal lows, which develop straddling the coast and then move southward along the coastline; and blocking lows, which develop inland or out to sea and then drift east or westward. The coastal lows tend to form in Spring.

With a high-speed computer, the Division's Dr Kathleen McInnes and the Bureau's Dr Lance Leslie and Dr John McBride have successfully simulated the dynamics of four east-coast lows that occurred between February and July 1990. Two of these (on 19 April and 31 July) were major events, resulting in very heavy rainfall over the Sydney region and widespread flooding in April and heavy rain and gale-force winds along the coast in July. The other two (in February and May) were relatively minor, but the February low still caused isolated flash flooding in two States.

Using a limited-area model, nested within a larger-scale model of the Australian region, the researchers satisfactorily reproduced, in a control run, the wind, pressure and rainfall patterns of the lows as each evolved over a 24-hour period. Then, in an experimental 'enhanced' run, they again simulated the progress of the lows, but this time with modified initial conditions. In place of mean observed sea surface temperatures (SSTs) in the Pacific Ocean, they used SSTs derived from a CSIRO model's predictions for a doubling of atmospheric CO_2. The model-derived SSTs were between 2·5 and 3·5°C higher than the observed ones used in the control run.

A comparison of the control and 'enhanced' runs showed similar patterns of rainfall (see the maps above), but greatly increased rainfall values in the 'enhanced' run. For example, for the cut-off low in April 1990, the highest

Storm warning

Flood warning: a computer simulation of a storm event off the south-eastern coast of Australia indicates a possible big rise in rainfall due to greenhouse-induced climate change. Under current climatic conditions (top) the simulated storm produced three 'pockets' where rainfall over a 24-hour period was 50 mm or greater. Under enhanced greenhouse conditions, the same pockets were evident, but they were larger and more intense.

24-hour rainfall value rose from 170 mm in the control run (the highest observed total was 126 mm at Perisher Valley) to 286 mm in the 'enhanced' run. The average rainfall over a 300-km by 300-km area around the peak value also rose — from 64 mm to 134 mm in a 24-hour period. Similarly, the number of points in the region that experienced wind velocities above 15 m per second (that is, strong to gale-force) rose from 63 to 93.

Much the same picture emerged in the other three simulated lows: peak rainfall in the 'enhanced' run increased by 45–80%, average rainfall rose between 14 and 100%, and the incidence of gale-force winds increased by 50 to 70%.

The simulation results must be viewed with caution — it is not a certain thing that, given a doubling of CO_2, SSTs in the mid latitudes of the Pacific would rise by up to 3·5°C. Nor is it clear whether more or fewer cut-off lows would form under enhanced greenhouse conditions; a limited analysis of 3 years of simulated daily weather over eastern Australia suggests that fewer might. Nonetheless, the indications that such lows might be much more intense contain a dire warning for town and city planners, water and drainage boards, road and dam authorities and emergency and rescue services.

According to the models, the expected upward trend in extreme events is not likely to be limited to any one region of the continent.

The climate-impact group analysed numerical simulations of global and regional climate change (produced by the CSIRO 4-level and 9-level atmosphere models); results indicate a

What should we do, and when?

The public debate on the enhanced greenhouse effect has undergone a sea change: many governments no longer ask if the predictions of global warming warrant action, but whether they should act now or later, and how tough any policy should be at the outset.

In 1990, the Intergovernmental Panel on Climate Change (IPCC) argued that some greenhouse-abatement measures deserve immediate attention. In effect, nations should consider a 'no regrets' strategy of identifying those ways of reducing greenhouse-gas emissions that would cost little to implement and have other benefits as well. Among the early, easy options put forward were the phasing-out of CFCs (which would also protect the ozone layer), more efficient energy use by consumers (saving on new power stations), methane recovery at coal mines (providing an extra energy source) and tree-planting (which also reduces soil erosion and salinity).

Many countries have since officially or unofficially adopted such policies and elected to 'wait and see' on the tougher issues as science continues to gain a better understanding of climate change.

In the last 18 months, several researchers have published assessments of the probable impact of delaying global action to abate greenhouse-gas emissions. Atmospheric scientists at the University of Illinois have analysed the likely consequences of a 10-year delay before the implementation of a 20-year transition from a 'business-as-usual' scenario to any of the 'emission-abated' options examined by the IPCC. Their conclusion? A delay would only have a small effect on projected global warming 100 years hence.

The University's Dr Michael Schlesinger and Dr Xingjian Jiang estimated that a 10-year delay would add less than 5% to average global air temperatures by 2100. In effect, they argue that the world can safely wait and see what happens and then, if necessary, shorten the transition period to the lower emission levels envisaged for 2020 (although only with more severe restrictions on emissions in future years).

Big business is also looking at the consequences of 'wait and see'. Scientists at the Rand Corporation in California compared the costs of immediately adopting 'aggressive' abatement policies (such as switching to cleaner fuel sources) with those of adopting 'moderate' policies (such as energy conservation only) followed by a review of policy in 2000, when climate change is better understood.

Their analysis suggests that — for an expected rise of 2·5°C due to a doubling of CO_2 — it would be cheaper to begin with aggressive policies now, provided the aim is to limit the rise to less than 2°C. A higher limit, such as a 2·5 or 3°C rise by 2100, would make the use of 'moderate' policies now less expensive.

However, Dr Barrie Pittock and Dr Ian Enting, at CSIRO's Division of Atmospheric Research, say both analyses are flawed because they consider just one environmental consequence — the expected rise in global air temperatures. What has been forgotten, they say, is the impact on sea level.

The atmosphere can respond quickly to sudden changes in greenhouse-gas emission rates, but the ocean reacts much more sluggishly. 'It is thus more difficult to reduce the effect of a delay in emission reductions on sea level than on air temperatures by later more severe reductions', Dr Pittock argues.

The scientists point to an often-overlooked section of the IPCC's 1990 report, which assesses the impact of a 20-year delay in implementing a 2% a year cut in emissions. Assuming that a doubling in the concentration of CO_2 (or its equivalent among all greenhouse gases) would boost temperatures by 2·5°C, a 20-year delay would add a modest 0·7°C to average air temperatures by about 2050 and then nothing after that. However, the delay would add another 15 cm (or an extra 60%) to the expected sea-level rise by 2100. And that difference would continue to grow into the 22nd century.

The explanation, Dr Pittock says, is that the ocean acts as the world's 'long-term memory', with sea level reflecting not just the instantaneous heat balance at the surface but that over hundreds of years past.

Perhaps an extra 15 cm in sea-level rise is an acceptable environmental penalty? Estimating the cost of a higher sea level is not an easy task, but it is obvious the burden would fall unevenly on different nations — the worst-affected would be low-lying coastal and island states such as Bangladesh and the Pacific Island countries.

Expect this debate to continue for some time yet.

Revised projections of future greenhouse warming. M. E. Schlesinger and X. Jiang. *Nature*, 1991, **350**, 219–21.

A sequential-decision strategy for abating climate change. J. K. Hammitt, R. J. Lempert and M. E. Schlesinger. *Nature*, 1992, **357**, 315–8.

The effect of a delay in limiting greenhouse gas emissions. A. B. Pittock and I. G. Enting. *Proceedings 2nd SPREP Meeting on Climate Change and Sea Level Rise, Noumea, 6–10 April 1992* (in press).

tendency towards more rainfall over Australia due to thunderstorms. According to the simulations, Australia would have — under enhanced-greenhouse conditions — more days of heavy rain and fewer days of light rain. In one simulation, an extreme rainfall event that currently occurs only once in 5 years would, under doubled-CO_2 conditions, occur every 2·5 years. In terms of soil erosion alone, such an eventuality would have national implications.

Regional warming is also expected to adversely affect snow cover in the Australian Alps. Dr Bob Galloway, formerly of the Division of Water Resources, Dr Peter Whetton of the Division of Atmospheric Research and Mr Carl Desborough, a student at Macquarie University, have devised a simple model that links possible temperature and rainfall changes with likely duration of snow cover. The model has been used to generate snow maps of the Australian Alps under present and possible future climates.

For example, the Falls Creek/Mt Bogong area — a popular ski ground in Victoria — currently has an estimated average snow-cover duration of 143 days a year. The model predicts that, with a 1°C rise in temperatures, the average duration would drop to under 120 days, even if precipitation rose by 20%. It would fall below 80 days for a 2°C rise and, for a 3°C rise, below 30 days. The model predicts similar trends for the Victorian peaks of Mt Hotham and Mt Feathertop.

Under a simulated scenario of no change in precipitation and a 2°C rise in temperatures, Mt Baw Baw in Victoria would have, on average, snow cover for fewer than 30 days a year, while Falls Creek and large sections of the Snowy Mountains in New South Wales would have snow cover for fewer than 90 days a year.

Dr Whetton warns, however, that estimates are based on a simplistic representation of climate change that does not take into account large-scale shifts in global and regional circulation that could alter levels of snow formation. Nor do they give an indication of how snow cover could vary from year to year. Even though a ski resort might on average have a snow season as short as 30 days, in wet and cold years the seasons could still be much longer.

The implications of reduced snow-cover duration extend beyond the pleasures of skiing. A marked decline in snow cover would lower mountain run-off in late spring and summer, and raise it in winter, thereby affecting the availability of water for hydro-electric power generation and irrigation.

David Whillas

A severe 'cut-off low' event in April 1990 caused flooding in Gippsland and south-eastern New South Wales. Simulations suggest such events may intensify under enhanced greenhouse conditions.

The possible impact of climate change on natural ecosystems is of grave concern to biologists. It is an area of research with wide tracts of unexplored territory — and the early evidence is gloomy.

Using CSIRO model scenarios of climatic change, zoologists at the Victorian Department of Conservation and Environment have devised 'bio-climatic range' maps of Victoria and estimated the ecological impact on 42 native animal species (about 6% of the State's vertebrate species). The bio-climatic range of a species is, in effect, the outer limit of its possible distribution. According to the estimates, a 1°C rise in average regional temperatures would see 33 species, or 78% of the total, experience a contraction in available range, six enjoy an expansion and two have their ranges fragmented. If a 3°C rise occurred across the State, nine species would experience a complete loss of bioclimatic range; these include the mountain pygmy possum, Mitchell's hopping mouse, the Murray striped skink, the western whipbird and Victoria's faunal emblem, the helmeted honeyeater.

The research results described above demand complex policy decisions from governments and industry on a wide range of issues. Dr Pittock says the common assumption that agriculture is the sector most likely to be significantly affected by climate change is not necessarily true. Because agriculture has a capacity to adapt to climatic variability, hardest-hit could, instead, be transport, water supply, dam safety, coastal planning and native flora and fauna.

'As climate changes so that extremes increase in magnitude or frequency, agriculture may indeed be seriously affected, but less adaptable systems such as natural ecosystems and the built environment may suffer more', he said.

Brett Wright

More about the topic

Numerical simulation of cut-off lows on the Australian east coast: sensitivity to sea-surface temperature. K. L. McInnes, L. M. Leslie and J. L. McBride. *International Journal of Climatology*, 1992, **12** (in press).

Developing regional climate change scenarios: their reliability and seriousness. A.B. Pittock. *Hawkesbury Centenary Conference, 25–7 November 1991, University of Western Sydney.*

Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: implications for extreme rainfall events. H.B. Gordon, P.H. Whetton, A. B. Pittock, A.M. Fowler and M. R. Haylock. *Climate Dynamics*, 1992, **7** (in press).

The potential effect of the enhanced greenhouse climate change on selected Victorian fauna. S. Bennett, R. Brereton, I. Mansergh, S. Berwick, K. Sandiford and C. Wellington. *Arthur Rylah Institute Technical Report Series* No. 123, 1991.