Viewpoint

How to ask the right questions about climate change

The weather of 2003 was exceptional. After temperatures of 27 °C were reached in the UK as early as 16 April (13 degC higher than average for the time of year), the national record was broken on 10 August when temperatures exceeded 38 °C in south-east England. The year was the seventh warmest in the Central England Temperature data series, which extends back to 1659 (with the period from March to August being the hottest on record), and globally it was the third warmest year since records began in 1861 (Met Office 2003, updated by Hardwick, personal communication, 2004). Periods of 2003 were also characterised by exceptionally low rainfall, England and Wales as a whole having experienced the driest year since 1975 (Met Office 2004; correction by Alexander, personal communication, 2004), with only 761 mm of rain (compared with a 1961–90 average of 915 mm). Indeed, the occurrence of weather extremes appears to be increasingly common (see also Folland and Brown 2004), with extensive flooding events following very high rainfall in the UK in 2000; (the third wettest year since 1766 with 1233 mm of rainfall) and 2001, and all of the ten hottest years worldwide since 1861 having been recorded since 1990.

Whenever extreme events occur, the question which is inevitably asked is “Is this climate change?” Certainly, the observed weather of today is different from that of the world, say, 100 years ago, with a global mean temperature at the end of the 1900s around 0.6 degC higher than that of a century earlier. The questions “Is this increase part of a significant trend?” and “Is this increase due to the effects of human influence?” are perhaps more meaningful.

Throughout the earth’s history, there have been climatic fluctuations over all time-scales, from runs of hot, cold, wet or dry days, weeks, years or decades, through centennial variations (such as the ‘Little Ice Age’ – a run of years between about 1400 and 1850 when the mean global temperature was 1–2 degC below that of today), up to millennial cycles, such as the alternation between glacial and interglacial periods which is controlled by variations in the geometry of the earth’s orbit. Changes even occur over longer, geological time-scales, being brought about by the arrangement of the continents and the circulation patterns of the oceans in any particular epoch; the earth’s average temperature in the late Cretaceous period, for example, approximately 90 million years ago, was around 10 degC higher than that of today, and the planet was completely ice-free. Those variations which occur over centennial, or shorter, time-scales may be caused by natural factors (such as changes in solar output, cosmic rays, or variations in the amount of global volcanic activity), man-made processes (such as the emission into the atmosphere of greenhouse gases (*e.g.* CO_2, which has increased from around 280 ppmv prior to 1860 to 373 ppmv in 2002) or aerosols (*e.g.* sulphate)), or may simply be due to random fluctuations.

The process of forecasting requires a computer model which, in its most basic sense, represents the physical processes occurring in the atmosphere. However, modelling the climate is a fundamentally different problem to that of forecasting the weather. In the latter case, the model must be set up (‘initialised’) such that it represents the current state of the atmosphere, as constrained by weather observations, and then run forwards in time to generate a forecast. However, the weather only has predictability in this sense out to a time-scale of perhaps two weeks, due to its inherently chaotic nature. Beyond this, the effects of initial observational errors become important, and dominate the model results.

If we are to model the climate, therefore, for a particular time in the past, present or future, the best we can hope to achieve is a prediction of the time-averaged characteristics of the weather, based on estimates of the climate forcings, or ‘boundary conditions’ (*e.g.* the amount of CO_2 in the atmosphere, the value of the solar output, and so on), for that particular time. Setting up the model in this way and running it for a long time (say, several hundred years of model time) will tell us, for example, how often (*i.e.* the ‘return period’) we can expect a storm of a particular size, or a summer which is warmer than some threshold, given those boundary conditions.

Numerous extensive research programmes, including the running of large numbers of such experiments (using complex models which include many of the components of the real climate system), have been carried out in institutions such as the Met Office, Hadley Centre. This research very strongly suggests, given our knowledge of the amounts of anthropogenic emissions, records of solar output, volcanic activity, etc., that the observed warming over the twentieth century can be explained only if man-made, as well as natural, factors are included (see *e.g.* Mitchell *et al.* 2001). In other words, it seems almost certain that at least part of the observed global warming since the Industrial Revolution is attributable to human influence.

This conclusion is not really surprising and, arguably, does not tell us a great deal. It is certainly true that in simple models of the climate system (*e.g.* one-dimensional energy balance models) the emission of greenhouse gases into the atmosphere will make the planet hotter than it would have been otherwise (see *e.g.* Hartmann 1994), regardless of what any natural climate forcings are doing. This is a physical consequence of the spectral properties of greenhouse gases, in that they are transparent to the short-wave radiation which is emitted from the sun but absorb the longer-wave (infrared) radiation emitted by the earth. Therefore, the equilibrium state of an atmosphere which is rich in greenhouse gases will be warmer than one which is poor in greenhouse gases. Of course, in a complex, nonlinear system like the real atmosphere (plus oceans, land surface, etc.), in which feedbacks are important, we should not necessarily expect such a straightforward relationship between CO_2 content and global temperature. However, we should expect on physical grounds that an increase in greenhouse gases should lead to a warmer planet; this is indeed what is shown by the existing complex climate-system models, and the amounts of emissions are consistent with the observed warming. If we are to minimise global warming as far as is possible, it is thus absolutely true that instituting policies such as controlling greenhouse-gas emissions will be the way to achieve this.

Fundamentally, therefore, the problem of attribution of 'climate change' is, in some senses, insoluble, since, in a system which is subject to natural fluctuations even when none of the boundary conditions are changing, we can never say what would have happened if we had not (say) put a particular amount of CO_2 into the atmosphere. The truth of this statement is most obvious when the problem is phrased in the form of a question such as "Is the severe rainstorm which occurred in Cambridge on 21 October 2001 due to greenhouse-gas-induced climate change?" This is not only unanswerable, but essentially meaningless. What we can say is how often we might expect such an event to occur, given the current amounts of greenhouse gases in the atmosphere, compared with, for instance, the return period which is consistent with a pre-Industrial Revolution atmosphere. This gives us an estimate of the current proportion of the risk of such an event which is due to human influence, an idea which is key to an area of research currently being undertaken by Myles Allen at the University of Oxford (Allen 2003). We cannot ever say whether a particular event would have occurred if we had not perturbed the content of the atmosphere, whether this event be a storm on a particular day, or an unusually hot century. This inherent uncertainty is, however, irrelevant; for those types of event (*e.g.* extreme storms or hot summers) which are predicted to occur more frequently under future emissions scenarios, the strategies (such as minimising CO_2 emissions) which we are able to adopt to minimise the risks of such events in the future will be the same regardless.

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Meeting report

Meteorology and agriculture

Research at the interface of meteorology and agriculture was presented and discussed at the RMetS Wednesday meeting held on 18 February 2004. The incentive for the meeting was provided by increasing public concern about the impacts of climate change on society, and on food production in particular. The meeting opened by considering the cornerstone of agrometeorology – the establishment of relationships between weather and crops (*Mike Dennett*, University of Reading). Historically, such relationships have proved difficult to identify, for a variety of reasons. However, it was demonstrated that robust crop–weather relationships can be derived through rigorous selection of good-quality data, and careful use of appropriate parameters. The existence of such relationships enables crop predictions, which may be achieved through the development of crop simulation models.

A range of applications of crop simulation models was presented. Predictions of crop yields at regional and country scales were achieved through the development of a combined weather and crop forecasting system (*Andrew Challinor*, University of Reading). This forecasting system exploited the relationship between large-scale patterns of weather and crop productivity to develop a crop model driven directly from the output of numerical weather models. Simulation of the growth, development and yield of rice enabled the impacts of climate change in south-east Asia to be examined (*Robin Matthews*, Cranfield University). Only a small decrease of 4% in rice yields was predicted for 2050 under current management practices. However, such a small change in productivity is not going to match the 40–60% increase in demand for rice anticipated in this region. The future demand for irrigation water in the UK was estimated using a model of crop water use (*Jerry Knox* and *Keith Weatherhead,* Cranfield University). Estimates of future demand for water use in agriculture are subject to large uncertainties, but will potentially increase by up to 55% in dry years by 2050, and issues of water availability to the agricultural sector will become more important.

These country and regional studies were followed by a consideration of the global impacts of climate change, food supply and the risk of hunger (*Martin Parry*, Co-Chair, Intergovernmental Panel on Climate Change Working Group II). Globally, a reduction in agricultural production was predicted, leading to an increase in the risk of hunger. Regions in the arid and sub-humid tropics are likely to be the most adversely affected. For example, 20 million more people in Africa were predicted to be at risk of hunger by 2050. The possibility of reducing predicted yield decreases through the stabilisation of CO_2 emissions was illustrated.

The meeting closed by identifying a number of key issues and challenges for future research in agriculture and meteorology. First, there is a need to capture the effects of temporal and spatial variability in climate and weather on crop productivity. Second, attempts should be made to identify, then quantify, uncertainties in model predictions, and in projections of the impacts of climate change. Last, the wider aspects of the interactions among weather, agriculture, and social and environmental factors should be addressed. All these research issues are crucial to the problems of understanding and predicting the impacts of climatic change on food production globally. They therefore provide a major challenge for scientists working at the interface of meteorology and agriculture.

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