more from studying intermediate stages of brood parasitism than from investigating the advanced cases where coevolution has already mutually adapted the parasite's and the host's life history and behaviour. Obligate parasitic cuckoos have long been a favourite of students of evolution and behavioural ecology, and I doubt that the flow of papers concerning these birds will slacken. However, we may well see an increase in studies of the intermediate — facultative — brood parasites, and they should be especially illuminating. ■

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Climate change

The 20-year forecast

Francis W. Zwiers

Policy-makers need short-term climate predictions to develop strategies for coping with climate change over the typical two-decade planning horizon. Two new studies increase our confidence in these predictions.

Earth's climate has changed during the past century[1,2]. The global mean temperature has risen by 0.6 ± 0.2 K; there have been reductions in snow cover, glacier mass and sea-ice extent; and sea level and the heat held by the oceans have increased. This observational evidence, and sophisticated detection studies that have identified the global signature of an anthropogenic effect in the twentieth-century record, have led the Intergovernmental Panel on Climate Change (IPCC) to conclude[1] that "most of the warming observed over the past 50 years is attributable to human activities". All projections of future change indicate that the warming is likely to continue. This conclusion holds regardless of the computer model used or the 'emission scenario' — the particular set of data describing the future emissions of greenhouse gases and aerosols — applied in the model.

Climate projections have often looked to the year 2100. This is scientifically valuable because it highlights differences between projections obtained using different models. It may also reveal gaps in our understanding of processes that critically affect how the climate responds to external influences such as the anthropogenic emission of greenhouse gases. However, 2100 is well beyond the typical two- to three-decade horizon for developing policy, and for planning and implementing strategies to mitigate or adapt to climate change. The attention paid to estimates for 2100 has also obscured the message that there is considerable agreement on projections for the next two to three decades — and that the agreement is independent of the particular model or emission scenario applied, especially when the projections take into account changes observed in the past century.

New papers by Knutti *et al.*[3] and Stott and Kettleborough[4] (pages 719 and 723 of this issue) consider climate change throughout the twenty-first century. But their particular value is to add considerably to the developing consensus on the projected global mean change two to three decades from now. Moreover, like several other recent analyses[1,5,6], uncertainty in the projections is presented in probabilistic terms by including estimates of the likely range of future warming that are consistent with observed twentieth-century change. Putting information in this format is helpful for planning and policy development: users can begin to assess the expected losses, costs and benefits that might occur in the absence or presence of measures to mitigate or adapt to change over a range of likely outcomes.

Knutti *et al.* and Stott and Kettleborough take very different approaches. Stott and Kettleborough[4] use a comprehensive, coupled atmosphere–ocean global climate model. This type of model simulates the circulation of the atmosphere and ocean as a whole. It produces natural variability in weather and climate, on timescales from hours to centuries, similar to that observed; and it incorporates the main feedback mechanisms that are thought to have determined the climatic response to natural influences (such as variations in solar output and the occurrence of explosive volcanic activity), as well as to anthropogenic greenhouse-gas and aerosol emissions during the twentieth century[1]. These models are expensive to run, and so only comparatively few simulations of past and future climate can be performed.

Stott and Kettleborough apply the regression methodology used in studies[7,8] to detect climate change, and attribute cause to that change. This allows them to scale up signals estimated from small ensembles of simulations of twentieth-century conditions so that they best match the observed historical change. The scaling factors are then used to adjust the model's projections of future change. An uncertainty range is estimated by accounting for uncertainty in the scaling factors and the effects of natural variability.

Stott and Kettleborough estimate that the global mean temperature in the decade 2020–30 will be 0.3–1.3 K greater than in 1990–2000 (5–95% likelihood range). This

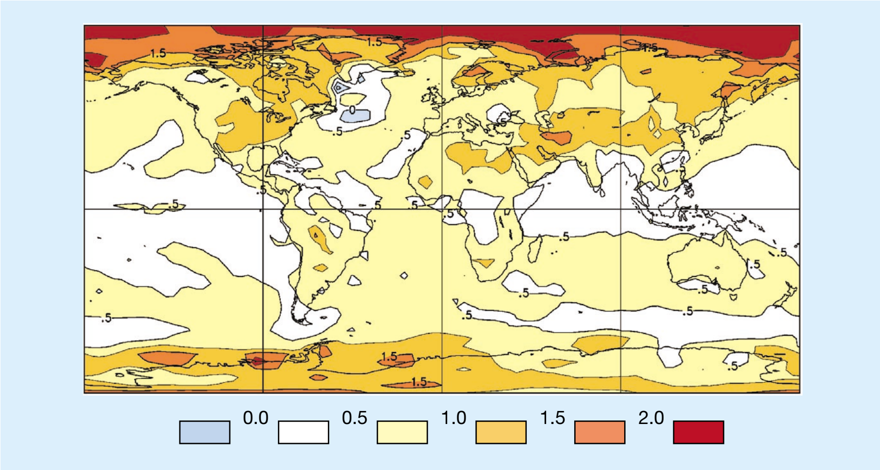

Figure 1 **A warmer world. Shown here are projected changes in surface air temperature, relative to 1990–2000, for the decade 2020–30. The global change in mean temperature estimated by this model[15], the Canadian Centre for Climate Modelling and Analysis CGCM2, is 0.68 K. This result is similar to that obtained by other atmosphere–ocean global climate models, such as that used by Stott and Kettleborough[4]. It is also similar to the conclusions drawn by Knutti *et al.*[3] from a model of intermediate complexity. The change projected by CGCM2 falls well within the approximate 5–95% uncertainty ranges estimated by Stott and Kettleborough (0.3–1.3 K) and by Knutti *et al.* (0.5–1.1 K). The global change in mean temperature is expected to have an uneven distribution geographically, with generally greater warming over land and at high latitudes than elsewhere. So local effects of climate change may be greater than one might infer from global mean projections.**

result is unaffected by the choice of emission scenario used to make the projection. Indeed, temperature projections produced using high- and low-emission scenarios do not diverge significantly until mid-century. That is partly because the large thermal inertia of the oceans means that a good proportion of the change in the next two decades will result from the climate's adjustment to changes in the greenhouse-gas content of the atmosphere that have already occurred. It is also partly because the effects of greenhouse-gas and sulphur-dioxide emissions offset each other in a similar way in the various scenarios. Sulphate aerosols produced from sulphur-dioxide emissions partially counteract the warming effect of greenhouse-gas emissions — both directly, by reflecting some solar radiation back into space, and indirectly, by increasing the reflectivity and longevity of clouds.

Knutti *et al.*[3] use a climate model of intermediate complexity[9]. It has an atmospheric component that represents north–south variations in the distribution of heat and moisture, and an oceanic component that accounts for north–south and vertical motion of water, and variations in salinity and heat content. Because of its simplicity, this model, and others like it, runs very quickly, allowing a thorough analysis of variations in the model's parameters.

Knutti *et al.* pursue this approach on a grand scale. Beginning with a broad distribution of settings that are consistent with previous studies using the method[5,10,11], they screen thousands of randomly selected parameter combinations to identify settings that produce changes in surface warming and ocean heat content that are consistent with those observed in the past century. They then extend these simulations forward in time using particular emission scenarios — the SRES A2 and B1 scenarios[12]. What they obtain are probability distributions of future temperature change that are consistent with past changes in surface temperature and ocean heat content.

Overall, their conclusions agree with those of Stott and Kettleborough. Knutti *et al.* find that the projected distribution of likely surface warming is independent of the choice of emission scenario for the next several decades; that the probable warming for 2020–30 relative to 1990–2000 is about 0.5–1.1 K (5–95% likelihood range); that the upper range of the warming uncertainty is probably greater than the IPCC range[1]; and that 'scenario uncertainty' (differences resulting from the particular choice of emission scenario) and 'model uncertainty' (as embodied in the range of parameter settings that are consistent with observed climate change) contribute about equally to the range of uncertainty in projected change at the end of the twenty-first century.

These results, obtained using very different methods, present a consistent picture of future climate, both within the two- to three-decade planning horizon (Fig. 1) and for the end of the twenty-first century. For the near term, projections made by different models with different emission scenarios produce remarkably similar results on the global scale. Furthermore, presenting results probabilistically gives policy-planners the information they need to assess expected costs, losses and benefits over a range of probable outcomes. In the longer term, these and other studies[1,5] show that model and scenario uncertainty are roughly equal contributors to the total uncertainty about warming by 2100.

Neither Knutti *et al.* nor Stott and Kettleborough take into account factors such as 'structural uncertainty'[5] (uncertainty that arises because models may not accurately represent all climatically important processes), carbon-cycle feedbacks[13] or rapid, nonlinear climate change[14]. Uncertainties therefore remain that are beyond the statistical uncertainties described in the two papers. But both sets of authors point out that the upper bound on the potential warming for 2100 may well be above the IPCC figure[1] of 5.8 K under 'heavy emissions' scenarios. So policy-makers should not discount the possibility of a very warm climate when considering long-range policy options. ■

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DNA repair

Breaking the seal

Sebastian D. Fugmann

The diversity of the receptors on our immune cells that recognize 'foreign' material is ensured by combining a set of gene segments to form the final receptor genes. A crucial player in that process has now been found.

One hallmark of our immune system is its ability to recognize and react efficiently to a nearly infinite variety of infectious microorganisms. Such remarkable versatility stems from a cut-and-paste process that rearranges the genome of immune cells as they develop. These cells — B and T lymphocytes — detect pathogen molecules through 'antigen-receptor' proteins and, by assembling the genes encoding these receptors from different DNA segments, the cells ensure that the receptors themselves come in a huge variety of forms.

During the assembly process, a pair of lymphocyte-specific scissors accurately excises the regions between such receptor-encoding gene segments, and a general DNA-repair machinery joins the resulting 'loose' DNA ends together. But it has long been unclear how these two processes are connected. Two years ago[1] it was discovered that the gene encoding a protein named Artemis is mutated in people who, because of a lack of T and B cells, suffer severe immunodeficiency. Writing in *Cell*, Ma *et al.*[2] now provide convincing evidence that the Artemis protein is the catalytic subunit of an enzyme that might be the long-sought missing link between DNA cutting and pasting.

The assembly of antigen-receptor genes from individual gene segments — '*V*(*D*)*J* recombination' — is one of four known processes in which a mammalian cell, in this case a developing B or T cell, actively modifies its own genome. (The three others are targeted to the recombined antigen-receptor genes in B cells, and are responsible for fine-tuning pathogen recognition and subsequent cellular responses.) *V*(*D*)*J* recombination is, of course, advantageous in that it ensures maximal diversity of antigen receptors. But it also poses a risk for the cell. If the process runs out of control — if the loose DNA ends are not joined, for example — it can lead to genomic aberrations and, eventually, to cancer. So the lymphocyte-specific scissors have to communicate efficiently with the ubiquitous DNA-repair machinery to ensure a tightly regulated transfer of the intermediate DNA ends. Studies in numerous labs have yielded an elaborate model for the DNA-cutting step[3]. But the joining phase