Wetter clouds dampen global greenhouse warming

Tony Slingo

VARIATIONS in cloudiness can significantly affect the Earth's radiation budget — the absorbed solar energy and the thermal energy radiated back to space¹. This conclusion is supported by various modelling studies of the 'greenhouse' effects of increased CO₂ concentrations²⁻⁴. In these studies, the CO₂ forcing induces changes in the cloud coverage and liquid-water content, which alter the radiation budget further and thus modify the original perturbation. On page 132 of this issue⁵, Mitchell *et al.* add a new twist to the story, showing how changes in the relative amounts of ice-crystal and water-drop clouds substantially reduce the sensitivity of their model to changes in concentration of CO₂. Indeed, it is becoming apparent that uncertainties in the treatment of clouds severely undermine model prediction of climate.

Mitchell *et al.* used various versions of the UK Meteorological Office atmospheric general circulation model⁶ coupled to a 50-m ocean mixed layer⁷. Replacing the standard cloud prediction scheme based on relative humidity by a more sophisticated prescription including liquid water and ice virtually halves the average equilibrium surface warming due to doubled CO₂ — from 5.2 K to 2.7 K. They argue that this spectacular sensitivity to details of the cloud scheme is caused by the replacement of ice clouds by water clouds near the freezing level. In the new cloud scheme, the fall-speed assumed for water drops is much smaller than that for ice crystals, so that liquid-water clouds can dissipate more slowly than ice clouds. According to Mitchell *et al.*, this leads to the predicted relative increase in water clouds near the freezing level, which consequently reduces the amount of solar energy absorbed in the system (more is reflected back into space) and hence gives a smaller warming. When, in addition, cloud radiative properties are allowed to depend on the liquid-water content of clouds, the surface warming drops still further, to only 1.9 K.

The strong dependence of the magnitude of cloud feedback in this work on the details of the model parallels results presented recently⁸ by a large *ad hoc* group (including Mitchell and myself) led by Robert Cess of the State University of New York. We compared 14 general circulation models and found a three-fold variation in global climate sensitivity, caused largely by differences in the cloud feedbacks. The models disagreed not only as to the magnitude but also the sign of the net cloud feedback. For this reason, it is

clear that uncertainty in how to formulate clouds represents a formidable obstacle to reliable climate prediction.

This underlines the continuing need for physical parameterizations to be compared with results from field studies. This is particularly important now that models are becoming increasingly complex. Mitchell *et al.* argue that the assumptions in their model are 'at least qualitatively realistic', but if climate change simulations are to be believable, then all parts of a model must be validated quantitatively, and important processes that are ignored must be identified. Of particular relevance to the cloud problem is the FIRE programme (first regional experiment of the international satellite cloud climatology project), both in its stratocumulus⁹ and cirrus¹⁰ field phases. Several papers are in preparation that highlight the complexity of the meso-scale dynamical structure of cirrus, so that the fall-speed of ice crystals is only part of the story. It is also interesting that two cases of highly supercooled liquid-water altostratus clouds at temperatures around -30 °C were observed (A.J. Heymsfield *et al.*, personal communication), which suggests that the transition from water to ice clouds is more subtle than Mitchell *et al.* assumed for their model.

The substantial sensitivity of climate models to the details of their formulation,

ECOLOGY

Just proportions in food webs

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IN FOOD webs of natural communities with varying numbers of species, the number of green plants and other species that consume no prey in the web (basal species) is nearly proportional, on average, to the number of species that have both predators and prey in the web (intermediate species), according to studies reported over the past dozen years¹⁻⁴. Empirical rules^{5,6} of that type describe structural or anatomical properties of food webs. An important question in community ecology is whether parallel regularities exist in the way in which food webs function^{7,8}. On page 142 of this issue⁹, McNaughton *et al.* report remarkable regularities in measures of food web function. Their findings indicate the existence of a physiology of food webs that generalizes across natural communities. Their report opens up the distant, but highly attractive, prospect of linking the previously known structural regularities

and the fact that 14 models give 14 different answers for the cloud feedback, show that we are far from the goal of accurate predictions of future climate change. Sensitivity studies such as that reported by Mitchell *et al.* and comparisons between models as done by Cess *et al.* are now the bread and butter of climate modelling. But at the present rate of progress, it will be several years before reliable predictions of global and regional climate change are available from the models. That underlines the need for comprehensive monitoring that is capable of unravelling the climate change signal from the noise and of providing enough data on the state of the atmosphere, the Earth's radiation budget and clouds for the feedbacks to be determined by observation. Such an analysis may well yield the fifteenth answer but at least it will have come from the real world and will permit a much needed test of the models. □

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with new functional patterns.

McNaughton *et al.* show that the biomass, consumption and net secondary productivity (NSP) of herbivores are all related to the net above-ground primary productivity (NAP) of a natural habitat by simple power laws. Particularly striking is that the exponent of the power law that relates NSP to NAP is not significantly different from 1: to a first approximation, NSP and NAP are directly proportional. In effect, the energy converted into herbivores per square metre of surface area per year is, on average, about one-thousandth of the energy that is converted into plants per square metre of surface area per year. The ecological energy pyramid has a much larger base than second storey.

This proportionality would be a triviality if secondary productivity were passively controlled and limited by primary productivity. But this trickle-down view of