CLIMATE PROJECTION

Testing climate assumptions

Studies often assume that climate is equally sensitive to emissions of warming greenhouse gases and cooling sulphate aerosols. Now, research illustrates that this is not true in models and that without this assumption recent assessments would have produced higher estimates of future temperatures.

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How bad can it be? When discussing anthropogenic climate change this question stimulates heated debate — in the scientific literature as much as anywhere else. It is an important question for climate policy and climate economics, but at its heart it is a question of climate physics. Partly as an attempt to provide a generic answer, substantial research efforts are directed towards quantifying the sensitivity of the earth's climate to increasing greenhouse gases. Yet recent studies have painted conflicting pictures. Some conclude that the climate is unlikely to be highly sensitive[1,2] whereas others conclude that it is unlikely to have a low sensitivity[3,4]. Which are right? Writing in *Nature Climate Change,* Drew Shindell reports[5] that removing a key simplifying assumption would have led some recent studies to conclude that climate is more sensitive than they did.

We are all familiar with the vast and beautiful complexity of climate. To facilitate the quantitative study of climate change, however, simplifications must be made. One such simplification uses the increase in average global temperature in response to doubling atmospheric carbon dioxide as a representation of the sensitivity of the whole system. The temperature change may be considered after the system has come to a new equilibrium — equilibrium climate sensitivity (ECS) — or at the point of CO_2 doubling, following a 1% per year increase in CO_2 concentrations — transient climate response (TCR). These sensitivities are useful as representations of the average global response resulting from some forcing (for example, increasing atmospheric CO_2 concentrations) and its related feedbacks (for example, changes in clouds or in land surface characteristics). They provide valuable, if somewhat blunt, instruments for considering the consequences of increasing atmospheric greenhouse gas concentrations. They are widely used in evaluations of climate economics, policy and impacts.

For more than a decade researchers have been producing probability distributions for climate sensitivity, often using observations to provide constraints on a variety of models. A plethora now exist. The credibility of complicated global climate models (GCMs) is often discussed in terms of where their sensitivities lie within such distributions. This is also important for policy evaluations because such models are central to many assessments of climate change — not least the IPCC, whose latest report includes an atlas of projections formed from GCM output.

Recent studies of physical processes in GCMs have concluded that the GCMs that are more realistic in some significant features relating to clouds and atmospheric convection are also those that tend to show higher sensitivities[3,4]. In contrast, recent studies based on statistical assessments of observations and simple models have concluded that the most sensitive GCMs are the least consistent with observations[1,2]. Shindell's analysis demonstrates that the conclusions of the latter studies are a consequence of their assumption that the sensitivity of climate to sulphate aerosols is the same as that to well-mixed greenhouse gases (WMGHGs) such as CO_2 — something that he shows not to be the case in the latest GCMs. Removing this assumption, he derives a value of 1.7 °C (95% confidence interval of 1.3–3.2 °C) for TCR, which is considerably higher than the 1.3 °C (90% confidence interval of 0.9–2.0 °C) reported in one recent study[1]. Of particular relevance for economic assessments and risk-centred perspectives of climate change is that the upper temperature bound has increased more than the central value.

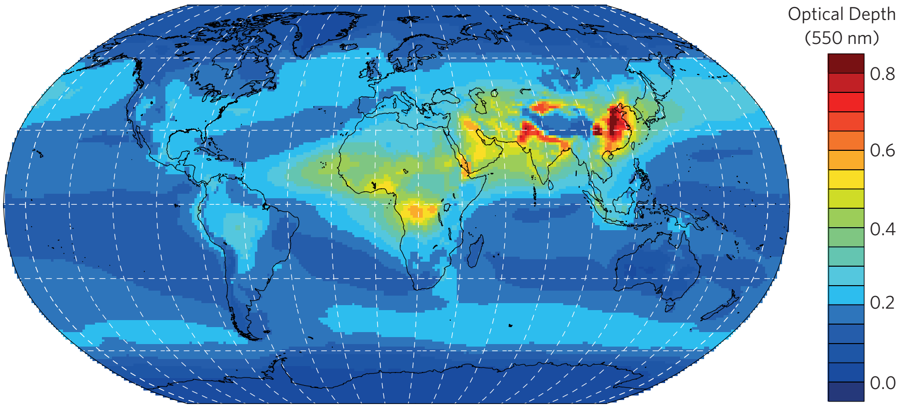

Figure 1 | The geographical distribution of aerosols. Unlike carbon dioxide, aerosols are far from uniformly distributed around the world. The figure shows the distinct spatial distribution of the 550 nm aerosol optical depth, averaged over the period 2003–2010[8,9]. The pattern varies substantially between seasons and from year to year. The figure is adapted from Figure 7.14 of the IPCC Working Group I contribution to the Fifth Assessment Report of the IPCC and only panel (a) has been used[10].

How does this change come about? Sulphate aerosols provide a characteristic geographical pattern of negative (cooling) forcing, mostly located over land in the Northern Hemisphere (Fig. 1). This pattern leads to stronger feedbacks than those resulting from the same amount of positive (warming) forcing from WMGHGs that are fairly uniformly distributed around the world. The effect is seen in all the GCMs studied — the model TCR for aerosols and ozone is on average about 50% greater than for WMGHGs. Now consider simple models. In these models sensitivity is prescribed rather than generated internally. The same value is used for all forcing types, whether cooling or warming. This means that if sensitivity were chosen to accurately reflect the twentieth century warming due to increasing WMGHGs, then the sulphate aerosol cooling would be underestimated and therefore the total warming in the model would be greater than that observed. Better agreement with observations is achieved with lower values of sensitivity, which also underestimate WMGHG warming.

Some of the most directly policy-relevant research is based on simple box models[6,7] and integrated assessment models that incorporate simple climate models. The inability to differentiate between the sensitivities to sulphate aerosols and WMGHGs makes it impossible for these models to provide accurate projections of both long-term future temperature changes (in which WMGHG forcing is expected to dominate) and shorter-term changes (where the effect of cooling aerosols is also important). For longer timescales, relatively high values of sensitivity may be appropriate but this has the effect of overestimating near-term temperature changes. Probabilistic twenty-first century projections based on these models and observational constraints suffer from the same issue highlighted above, thus under-weighting the possibility of high impacts and over-weighting low impacts on multi-decadal timescales.

The scale of the effect in the GCMs varies widely, so there is certainly a need to better understand and quantify it. Future assessments will need to take it into account and previous assessments may need to be revisited. It is worth reflecting, however, that this new estimate for TCR comes about by questioning a widely-made implicit assumption in the application of simple climate models. Climate predictions would generally benefit from increased efforts to understand, rather than reduce, their uncertainties — something that can be in conflict with the remit provided by funders. Greater emphasis on the inherent assumptions could aid both policy interpretation and the advancement of the science. The challenge is to generate cross-disciplinary reflection and debate on the conditionalities of the latest predictions. The robust physical basis for confidence in some results, such as the reality and seriousness of anthropogenic climate change, could then be separated from more speculative, cutting-edge research. This would be valuable for public discourse on the subject and help science focus on those issues most likely to increase understanding, if not necessarily reduce uncertainty. ❐

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OCEANOGRAPHY

Southern Ocean polynya

From 1974 to 1976, an unexpected large hole appeared in the Weddell Sea winter sea-ice cover, a consequence of ocean heat carried to the sea surface by convection. This may have been a window to the past, as model analysis suggests anthropogenic climate change will diminish the chances of a repeat performance.

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Along Antarctica's continental margins, cold, dense water formed above the continental shelf spills over the edge, cascading to the depths. The resultant water mass, Antarctic Bottom Water (AABW), spreads northwards along the sea floor throughout the global ocean. En route it is modified through ocean mixing and blending with the warmer, more saline North Atlantic Deep Water. It returns to the Southern Ocean as a relatively warm deep layer, closing the circulation loop (Fig. 1). Although this is widely recognized as the predominant mode of overturning circulation, it is not the only Southern Ocean ventilation process: another mode exists, that of open-ocean convective, an exchange of deep and surface water driven by density instability[1]. However, model simulations of the Southern Ocean exposed to anthropogenic climate change indicate that open-ocean convention may be a thing of the past, reports Casmir de Lavergne and colleagues in *Nature Climate Change*[2].

Soon after the era of passive microwave satellites began, a large open-water region in the midst of the winter sea-ice cover, a polynya, 250,000 km^2 in extent, was detected within the Weddell Sea for three consecutive years, 1974 to 1976 (refs 3,4). One might conclude that it was the normal condition, but although small, week-long polynyas are now commonly observed in the Weddell Sea, a persistent, winter-long polynya hasn't formed since the mid-1970s. It was a fortuitous observation, for if the satellite had been delayed by three years, we would know nothing about the 'Great Weddell Polynya'. Ship-based observations from summer 1977 in the area of the polynya found that temperature and salinity stratification was nearly absent, marking a breakdown of the normal situation of cold, fresh water sitting above a warmer, saltier deep water across a stabilized, albeit weak, density gradient — the pycnocline[1]. This suggests that the polynya had been maintained, in the face of an intense winter sea-to-air heat flux, by relatively warm deep water (~1 °C) being brought to the surface, countering descent of the cold surface water (~−1.9 °C) in convective overturning reaching to nearly 3,000 m. Although there is a suggestion that deep-reaching open-ocean convection, and by inference, a Weddell Polynya, occurred in the early twentieth century[5], it is clearly an infrequent event.

During the coldness of winter, slight changes in the surface layer salinity can trigger water column instability, leading to deep-reaching convection and an open-ocean polynya. Should cold, dry polar