News & views

Climate change

Short-term tests for long-term estimates

Tim Palmer

Six-hour weather forecasts have been used to validate estimates of climate change hundreds of years from now. Such tests have great potential — but only if our weather-forecasting and climate-prediction systems are unified.

How sensitive is climate to atmospheric carbon dioxide levels? For a doubling of CO_2 concentration from pre-industrial levels, some models predict an alarming long-term warming of more than 5 °C. But are these estimates believable? Writing in the *Journal of Advances in Modeling Earth Systems*, Williams *et al.*[1] have tested some of the revisions that have been made to one such model by assessing its accuracy for very short-term weather forecasts. The results are not reassuring — they support the estimates.

There is little doubt, at least among those who understand the science, that climate change is one of the greatest challenges facing humans in the coming decades. However, the extent to which unchecked climate change would prove catastrophic rests on processes that are poorly understood. Perhaps the most important of these concern the way in which Earth's hydrological cycle — which includes the evaporation, condensation and movement of water — will react to our planet.

One of the key problems is how clouds adjust to warming[2]. If low-level cloud cover increases, and high-level cloud decreases, then clouds will offset the warming effect of increased atmospheric CO_2 concentrations and thereby act as a negative feedback, or damper, on climate change, buying us some breathing space. By contrast, if there is positive cloud feedback — that is, if low-level clouds decrease with warming and high-level clouds increase — then, short of rapid and complete cessation of fossil-fuel use, we might be heading for disaster.

So what have clouds been doing as global warming has slowly taken hold? Trends in global cloud cover can be estimated only from space-based observations (Fig. 1). However, cloud data sets derived from multiple satellites over several decades suffer from spurious artefacts related to changes in satellite orbit, instrument calibration and other factors[3]. These artefacts are particularly large when estimating globally averaged cloud cover, currently preventing any reliable estimation of trends in one direction or the other.

In lieu of observational evidence, we must turn to computational models of the climate system. But there is a problem. Clouds are on too small a scale to be represented using the laws of physics in current climate models. Instead, they are represented by relatively crude, computationally cheap bulk formulae known as parameterizations. These do encode some basic ideas of cloud physics — clouds' dependence on the ambient temperature, humidity and vertical air velocity, for example — but they are far from being *ab initio* estimates. Hence, the role of clouds in climate change is crucial but uncertain[4].

The cloud-feedback problem has been brought sharply into focus in recent months as results have been emerging from the dozens of climate-change models in an ensemble called the Coupled Model Intercomparison Project (CMIP6; see go.nature.com/3garyzc). Projections of future climate from this global effort have fed into the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), due next year.

Some of the latest-generation models in CMIP6 now indicate climate sensitivities exceeding 5 °C (refs 5–7). Here, climate sensitivity refers to the global warming after

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Figure 1 | Cloudy skies, viewed from space. How clouds will adjust to a warming climate is difficult to predict, but Williams *et al.*[1] have used short-term weather forecasts to assess whether recent revisions to long-term climate models are getting us nearer to the truth.

climate has equilibrated to a doubling of CO_2 concentration relative to pre-industrial levels, an equilibrium that might take a few hundred years to establish[8]. These sensitivity values are outside the range of those produced by the CMIP5 ensemble, which fed into the previous IPCC Assessment Report[8] in 2013. They seem to have arisen largely because of revisions to how cloud microphysics is represented, particularly in the parameterization of supercooled liquid water. Cloud microphysics describes the properties (such as size and relative concentration) of water and ice droplets in a cloud. On such tiny matters might our future rest.

And so, the question is this. Are we to believe these new estimates of climate sensitivity, or will they end up being reverted to earlier CMIP5 values as the models go through a further round of revisions?

Some years ago, the meteorologist Mark Rodwell and I proposed[9] a method for assessing predictions of climate sensitivity — one based on very short-range (6-hour) weather forecasts. We were motivated by startling results suggesting that warming could be as much as 11 °C for a doubling of CO_2 levels[10]. These high estimates arose in climate models in which a particular cloud-system parameter, known as convective entrainment, was set to unusually small values that could not readily be ruled out by studying the accuracy of the models' climate simulations. By showing that errors of 6-hour weather forecasts were made substantially worse using a model with these reduced values of convective entrainment, we were able to cast doubt on the credibility of these exceptionally large estimates of climate sensitivity.

We found that if we ran a state-of-the-art numerical weather-prediction system with a low convective entrainment parameter, it produced much less accurate 6-hour forecasts than when the forecast model had more-typical values plugged in. To everyone's relief, this suggested that the low values of the parameter used in the climate models were unrealistic, and thus we could discount the alarming 11 °C sensitivity estimates.

Williams *et al.* have now subjected the CMIP6 Met Office climate model to the same 6-hour weather-forecast test. The authors chose to test this model because it was one of those that produced a relatively large climate sensitivity of about 5.5 °C. The model has a revised scheme for cloud microphysics as mentioned above, in which there are more supercooled water droplets and fewer ice droplets.

The authors found that the 6-hour-forecast errors were smaller for the revised model than for a version of the model without the cloud-microphysics revisions. Hence, instead of being able to discount estimates of high sensitivity, as Rodwell and I had done, their result provides some of the best current evidence that climate sensitivity could indeed be 5 °C or greater.

In short, these results, published in a specialist journal, and probably read by few climate policymakers, carry a far-reaching message: we cannot afford to be complacent. It seems that cloud adjustment to climate change is not going to give us breathing space. Instead, we need to redouble our efforts to cut emissions.

There is a serious caveat to the general application of this technique. The test makes sense only if the model used to do the short-term forecast is the same as the one used to do the climate projection. The Met Office weather and climate models are reasonably similar (their model is often called the 'Unified Model'), but weather models do not generally correspond well with climate models.

On top of this, an accurate 6-hour weather forecast is possible only if one can come up with accurate initial conditions for the model from observations, a process known as data assimilation. This is a complex and computationally demanding optimization problem[11], and most climate institutes do not have such data-assimilation capability. Moreover, accurate data assimilation requires the spatial and time resolution of climate models to be increased to be comparable with those used for state-of-the-art weather forecasting. Conversely, the parameterizations in weather-forecast models must be as complex and comprehensive as the ones in corresponding climate models; few weather-forecast centres have the resources for this.

Thus, to reduce uncertainty in estimates of the crucial cloud feedbacks, climate institutes and weather-forecast centres should work together to ensure that their model systems are as seamless[12,13] as possible. I contend that weather and climate modelling must be rationalized worldwide, and that human and computational resources should be pooled to produce high-resolution, unified weather–climate models[14,15].

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Atomic physics

Quantum matter orbits Earth

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Exotic ultracold gases called Bose–Einstein condensates have been created on board the International Space Station. This feat is not only a technological landmark, but could also improve our understanding of fundamental physics. **See p.193**

States of matter known as Bose–Einstein condensates (BECs) were first observed 25 years ago[1,2]. Since then, these quantum objects have become a key tool in the study of quantum physics, and they are routinely produced in hundreds of laboratories around the world. On page 193, Aveline *et al.*[3] report the generation of rubidium BECs aboard the International Space Station, which is in orbit around Earth. The condition of perpetual free fall on the station offers new methods for probing BECs and for making a wide range of high-precision measurements.

A BEC is produced when a dense cloud of trapped bosonic atoms (atoms that have an even total number of protons and neutrons) is cooled to temperatures near absolute zero[4,5]. In these ultracold ensembles, the atoms mainly populate the lowest energy state of the trap. A central tenet of quantum mechanics is wave–particle duality, whereby every particle can be described as a wave of matter. BECs are useful objects for testing quantum mechanics because the entire cloud of atoms