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Assessment of the first consensus prediction on climate change

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In 1990, climate scientists from around the world wrote the First Assessment Report of the Intergovernmental Panel on Climate Change. It contained a prediction of the global mean temperature trend over the 1990–2030 period that, halfway through that period, seems accurate. This is all the more remarkable in hindsight, considering that a number of important external forcings were not included. So how did this success arise? In the end, the greenhouse-gas-induced warming is largely overwhelming the other forcings, which are only of secondary importance on the 20-year timescale.

One of the main problems faced by predictions of long-term climate change is that they are difficult to evaluate. Weather forecasters are able to evaluate the performance of their forecasts by computing statistics based on comparisons between predictions and observed realizations over days and years, but this is not available to climate scientists because the prediction and response timescales are so much longer than in weather forecasting. Trying to use present predictions of past climate change across historical periods as a verification tool is open to the allegation of tuning, because those predictions have been made with the benefit of hindsight and are not demonstrably independent of the data that they are trying to predict. However, the passage of time helps with this problem: the scientific community has now been working on the climate change topic for a period comparable to the prediction and the timescales over which the climate is expected to respond to these types of external forcing (from now on simply referred to as the response). This provides the opportunity to start evaluating past predictions of long-term climate change: even though we are only halfway through the period explicitly referred to in some predictions, we think it is reasonable to start evaluating their performance, because the predictions were more frequently expressed as rates of change expressed over decadal timescales (degrees Celsius per decade) than in terms of end points such as 2025 or 2030. Any interpretation of the performance of the predictions is contingent, though, in view of the fact that the additional information provided by selection of particular dates (2025, 2030, 2050 and 2100 are all mentioned) makes it clear that the bulk of climate change predictions refer to multi-decadal timescales.

In 1990 the Intergovernmental Panel on Climate Change (IPCC) published its First Assessment Report, which included an estimate of climate change as a predicted rise from 1990 (to 2030) of 0.7–1.5 °C with a best estimate of 1.1 °C (refs 1,2). As this was the first report by the international body charged with synthesizing the understanding of climate change by the scientific community, we can consider this to be the first consensus prediction of climate change[3,4]. Over the 1990–2010 period this corresponds to a best estimate of 0.55 °C warming, following the linear trends in the figures[2]. Subsequent IPCC Assessment Reports preferred the language of projection and focused increasingly on longer timescales. Reports from the 1990s explicitly estimated the multi-decadal response to greenhouse gas (GHG)-alone forcing to be 0.3 °C per decade[5,6], consistent with the GHG-alone trend (see below). Later reports[7,8] were implicitly consistent with IPCC 1990, although the context around predictions changed. The IPCC's Fourth Assessment Report qualitatively evaluated the 1990 prediction as having showed that the evolution of the actual climate system fell midway between the First and the Second Assessment Report best estimate projections[3].

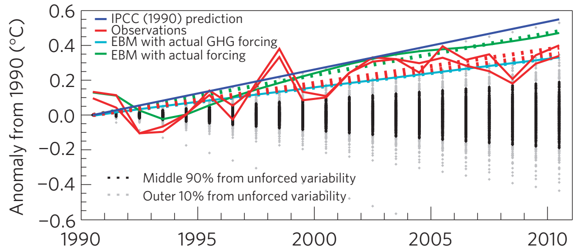

Figure 1 | Changes in global mean temperature over the 1990–2010 period. The solid and dashed lines show the annual variations; the dotted lines show best-fit linear trends. Trend and annual variations are plotted as anomalies from the 1990 value of the trend fit.

As with IPCC reports since, the 1990 report did not define the terms of application of the prediction in an observable context[4]. Here we take it to refer to the least-squares linear trend of annual mean temperatures projected over the 1990–2010 period, with estimates of the actual global mean trend experienced obtained from measurements of limited global coverage. During this period global mean temperature has risen by 0.35 °C according to the HadCRUT3 data set of land and ocean temperatures[9] or 0.39 °C if we use the GISTEMP data set constructed using different methods[10] (Fig. 1).

Are these predicted and realized trends significantly different from zero trend? Assumptions that the data are normally distributed around a central tendency underestimate natural variability because climate time series generally resemble red noise processes, yet quantifying the degree of autocorrelation in the

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complex and nonlinear climate signal is not straightforward[11–13]. One way of accessing such autocorrelation information, consistent with other studies[11,14–16], is to compare the trends against those from the ensemble of 587 21-year-long segments of control simulations (with constant external forcings) from the 24 atmosphere–ocean climate models that contributed to the recent CMIP3 exercise[17]. These give a 90% range of about ±0.19 °C if we suppose the same data coverage as in HadCRUT3 (Fig. 1). According to this estimate, the trend calculated from HadCRUT3 is significantly different from an unchanging climate. In fact, the HadCRUT3 trend is exceeded only once in these 587 control simulation segments. The HadCRUT3 trend would remain outside the 90% range even if the control simulations were underestimating the variance by a factor of 85%. This result arises despite an unexpected stability in global mean temperatures over the second half of this period[18,19] and the fact that many of these models' control simulations exhibit a secular drift because they have yet to reach a stable equilibrium.

The range of the 1990 prediction represents uncertainty in the sensitivity of the climate to CO_2 increases, and not the noise from year-to-year variability in the realized weather. As natural variability was not a part of the 1990 prediction, it is debatable whether and how this noise should be incorporated into the 1990 prediction for the purposes of this study; we choose to add it by convolving the CMIP3 noise estimate with a uniform distribution over the 0.35–0.75 °C range (the fraction of the 1990 report's 0.7–1.5 °C prediction due by 2010) to get a total 90% range of 0.28–0.81 °C. Alternatively, we could have chosen to interpret the ±0.20 °C range to be ±1s.d., in which case the total 90% range becomes 0.15–0.95 °C, or to be a 90% range on uncertainty in the climate sensitivity, in which case the total convolved range becomes 0.27–0.83 °C. Either way, the 1990 prediction was still clearly different from zero change.

The observed trend lies just on the borderline outside the range stated by the 1990 scientists. However, adding noise from natural year-to-year variability through any method widens that prediction enough to comfortably include the observed trend. The degree of consistency between the prediction and observations thus depends strongly on whether or how one incorporates natural variability into the prediction. Furthermore, there are a couple of other reasonably significant factors to be considered in the comparison between observed and modelled forcings and response. The highlighted prediction assumed a business-as-usual scenario of GHG emissions; three other scenarios were considered and in fact Scenario B (which assumed a shift to natural gas, a decrease in the deforestation rate and implementation of the Montreal Protocol, all independent of global climate negotiations[1]) was closer to the mark as of 2010, especially with respect to methane emissions[20,21]. Scenario B gives a best estimate of about 0.37 °C for 1990–2010 with a range of about 0.16–0.63 °C accounting for climate sensitivity uncertainty and interval variability using the most restrictive interpretation discussed above, which very closely matches the observed trend.

Of course, these predictions were based on idealized future scenarios that did not foresee the eruption of Mount Pinatubo, the collapse of the Soviet Bloc industry or the growth of some Asian economies, so one could argue that the prediction is right for the wrong reasons. Fortunately, we can test this using a simple one-dimensional energy balance model (EBM) comparable to the main model used to make the 1990 prediction but following a popular simpler formulation[22–24]. The values for the model parameters describing equilibrium sensitivity per doubling of CO_2 (2.5 °C) and ocean mixed layer depth (70 m) are the same as used in 1990 (refs 2); as our model treats diffusion processes in the ocean differently, the value of the vertical thermal diffusivity parameter is tuned such that our model produces the same trend as did the 1990 model when driven by identical forcings, thus providing comparability between the technology behind the 1990 prediction and the technology we are using to evaluate it. We can run the EBM with variations in radiative forcings calculated from changes in GHG concentrations, tropospheric sulphate aerosol burden, stratospheric volcanic aerosol burden, and solar luminosity through 2005 determined from observational measurements, and the Representative Concentration Pathway 4.5 (RCP4.5) scenario thereafter assuming no major volcanic eruptions[21]. With these more realistic forcing estimates, this EBM predicts a temperature trend of 0.29–0.67 °C assuming the CMIP3 variability, consistent with both the observed trend and the 1990 prediction but not with zero trend (Fig. 1).

If we restrict ourselves to GHG forcing, as the IPCC did in 1990, we get a trend of 0.27 °C, still consistent with the observations but not with zero trend (Fig. 1). If we remove natural variability in the forcings arising from the post-1989 volcanic forcing, the trend rises to 0.33 °C. Increasing and decreasing forcing changes by 75% in various combinations still fails to produce a prediction that is consistent with zero trend. Most remarkably, if anthropogenic forcings had been held at 1989 levels over the past two decades the resulting 0.10–0.48 °C trend would still have been consistent with the observed trend and not with zero trend: as climate predictability comes from the forcing, it is governed primarily by the accumulating stock of GHGs, that is, concentrations, and is relatively insensitive to short-term details associated with the flow of emissions[25].

What messages can be taken from this evaluation? First, it is important for the context of predictions to be clearly stated[4], otherwise scientists attempting to evaluate predictions after the fact are required to fill in the gaps that may actually do a lot of the work in deciding a prediction's accuracy. This invites problems associated with researchers' ability to separate the prediction from the evaluation, given that they cannot make the types of subjective methodological decision required to fully evaluate the incomplete prediction without some knowledge of the implications of their decisions for their evaluation. Notwithstanding this substantial limitation, it is clear that the analysis here shows that the timescales associated with climate system predictability are considerably longer than those associated with socioeconomic predictability, because predictability is such a strong function of the stock of atmospheric GHGs and is so insensitive to their flow. On the arguments set out here, and on the experience of the past 20 years, the climate of the 2030s is thus relatively insensitive to climate policies enacted between now and 2030; the cost and benefits of policies enacted across this period will only very gradually manifest themselves in the climate signal as the act to slow or accelerate the accumulation of long-lived GHGs in the atmosphere.

Even though the climate research community clearly has much work to do to improve regional climate predictability—the most relevant scales for most impacts—it seems highly likely that even in 1990 we understood the climate system well enough to make credible statements about how its aggregate properties would change on timescales out to a couple of decades, even in the presence of considerable uncertainty surrounding the exact forcing trajectory. Given the advances in climate science since 1990, this predictability probably now extends to some regional scales, too. Nevertheless, the 1990 prediction following their business-as-usual scenario covered a full 0.4 °C range due solely to uncertainty in the climate sensitivity that has not narrowed substantially so far[26], whereas a larger range was implied by the examination of further scenarios of emissions and a larger range still should have been considered owing to uncertainty in the evolution of natural forcings and internally generated variability.

As is always the case in science, we cannot know for certain that the 1990 prediction was accurate for the right reasons but, given the apparent absence of any credible alternative theories and the robustness of the prediction, this evaluation strongly supports the contention that the climate is responding to enhanced levels of GHGs in accordance with historical expectations.

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Author contributions

D.J.F. and D.A.S. wrote the text and D.A.S. performed the calculations.

Additional information

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Competing financial interests

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