Recent Climate Observations Compared to Projections

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Observations of the climate system are crucial to establish actual climatic trends, whereas climate models are used to project how quantities like global mean air temperature and sea level may be expected to respond to anthropogenic perturbations of the Earth's radiation budget. We compiled the most recent observed climate trends for carbon dioxide concentration, global mean air temperature, and global sea level, and we compare these trends to previous model projections as summarized in the 2001 assessment report of the Intergovernmental Panel on Climate Change (IPCC) (*1*). The IPCC scenarios and projections start in the year 1990, which is also the base year of the Kyoto protocol, in which almost all industrialized nations accepted a binding commitment to reduce their greenhouse gas emissions. Although published in 2001, these model projections are essentially independent from the observed climate data since 1990: Climate models are physics-based models developed over many years that are not "tuned" to reproduce the most recent temperatures, and global sea-level data were not yet available at the time. The data now available raise concerns that the climate system, in particular sea level, may be responding more quickly than climate models indicate.

Carbon dioxide concentration follows the projections almost exactly (Fig. 1), bearing in mind that the measurements shown from Mauna Loa (Hawaii) have a slight positive offset due to the slightly higher CO_2 concentration in the Northern Hemisphere compared with the global mean. The level of agreement is partly coincidental, a result of compensating errors in industrial emissions [based on the IS92a scenario (*1*)] and carbon sinks in the projections.

The global mean surface temperature increase (land and ocean combined) in both the NASA GISS data set and the Hadley Centre/Climatic Research Unit data set is 0.33°C for the 16 years since 1990, which is in the upper part of the range projected by the IPCC. Given the relatively short 16-year time period considered, it will be difficult to establish the reasons for this relatively rapid warming, although there are only a few likely possibilities. The first candidate reason is intrinsic variability within the climate system. A second candidate is climate forcings other than CO_2: Although the concentration of other greenhouse gases has risen more slowly than assumed in the IPCC scenarios, an aerosol cooling smaller than expected is a possible cause of the extra warming. A third candidate is an underestimation of the climate sensitivity to CO_2 (i.e., model error). The dashed scenarios shown are for a medium climate sensitivity of 3°C for a doubling of CO_2 concentration, whereas the gray band surrounding the scenarios shows the effect of uncertainty in climate sensitivity spanning a range from 1.7° to 4.2°C.

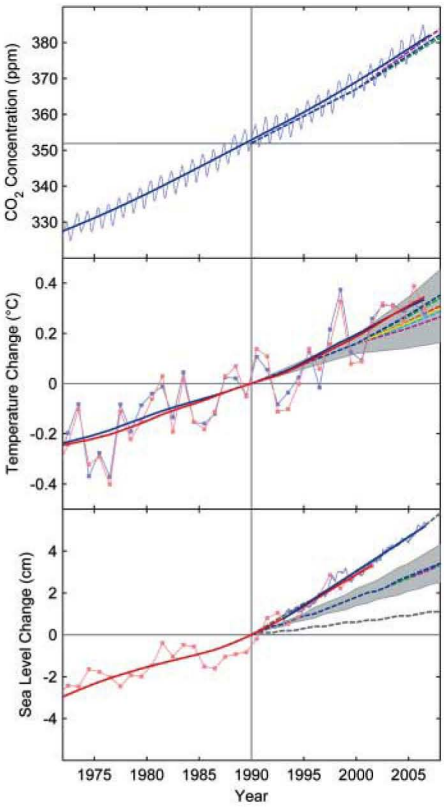

Fig. 1. Changes in key global climate parameters since 1973, compared with the scenarios of the IPCC (shown as dashed lines and gray ranges). (**Top**) Monthly carbon dioxide concentration and its trend line at Mauna Loa, Hawaii (blue), up to January 2007, from Scripps in collaboration with NOAA. ppm, parts per million. (**Middle**) Annual global-mean land and ocean combined surface temperature from GISS (red) and the Hadley Centre/Climatic Research Unit (blue) up to 2006, with their trends. (**Bottom**) Sea-level data based primarily on tide gauges (annual, red) and from satellite altimeter (3-month data spacing, blue, up to mid-2006) and their trends. All trends are nonlinear trend lines and are computed with an embedding period of 11 years and a minimum roughness criterion at the end (*6*), except for the satellite altimeter where a linear trend was used because of the shortness of the series. For temperature and sea level, data are shown as deviations from the trend line value in 1990, the base year of the IPCC scenarios.

Since 1990 the observed sea level has been rising faster than the rise projected by models, as shown both by a reconstruction using primarily tide gauge data (*2*) and, since 1993, by satellite altimeter data (*3*) (both series are corrected for glacial isostatic adjustment). The satellite data show a linear trend of 3.3 ± 0.4 mm/year (1993–2006) and the tide gauge reconstruction trend is slightly less, whereas the IPCC projected a best-estimate rise of less than 2 mm/year. Sea level closely follows the upper gray dashed line, the upper limit referred to by IPCC as "including land-ice uncertainty." The rate of rise for the past 20 years of the reconstructed sea level is 25% faster than the rate of rise in any 20-year period in the preceding 115 years. Again, we caution that the time interval of overlap is short, so that internal decadal climate variability could cause much of the discrepancy; it would be premature to conclude that sea level will continue to follow this "upper limit" line in future. The largest contributions to the rapid rise come from ocean thermal expansion (*4*) and the melting from nonpolar glaciers as a result of the warming mentioned above. Although the ice sheet contribution has been small, observations are indicating that it is rapidly increasing, with contributions both from Greenland and Antarctica [e.g., (*5*)].

Overall, these observational data underscore the concerns about global climate change. Previous projections, as summarized by IPCC, have not exaggerated but may in some respects even have underestimated the change, in particular for sea level.

References and Notes

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