Observations and models in the IPCC's 5th Assessment

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The Energy and Climate Change Committee has requested evidence addressing apparent disagreements between "observational" and "model-based" projections of future climate in the 5th Assessment of the Intergovernmental Panel on Climate Change (IPCC AR5).

General observations:

1) **There is no such thing as a purely observational or purely model-based projection of future climate.** Much emphasis has been placed on new estimates of climate system properties based on recent observations, but some kind of climate model is always required to interpret these observations. All models are idealized to some degree. Hence all projections are based on combination of observations and models, with a substantial role for expert judgment weighing up the different lines of evidence and assessing whether a (simple or complex) model is suitable for a specific purpose.
2) **There is no irreconcilable disagreement between recent climate observations and long-term projections of current climate models.** The figure shows the response to a high emission scenario (left panel) and an aggressive mitigation scenario (right panel) based on the simple 'fast and slow response' model[2] used for metric calculations by IPCC AR5. Red lines show a high response model-version, green lines show a low response. Blue dots show observed temperatures, and the inset panel shows rates of climate system heat uptake, with a grey band showing the observed range[3] in this quantity for the 2000s. Neither high nor low response is inconsistent with these climate observations when uncertainty in forcing is taken into account. Vertical pale blue bars shows the 5-95% range of projections of the CMIP5 multi-model ensemble for average temperatures over the 20 years around 2090. Simple-model versions consistent with recent climate observations encompass the CMIP5 ranges except for the upper bound under the aggressive mitigation scenario (and simple models should be treated with caution when the balance between forcing and heat-uptake changes radically between past and future, as it does under this scenario).
3) **It is misleading to focus on "best fit" responses rather than ranges of uncertainty.** This is especially true when distributions of uncertainty are strongly asymmetric. For example, it rained by 1mm or less (a few hours' gentle drizzle) on 50% of days in Oxford over the past winter, and yet to characterize this winter's weather as the "best-estimate daily rainfall of 1mm" would be misleading, to put it mildly. In the simple climate model provided on the excel spreadsheet, the fit to climate observations over the past decade deteriorates rapidly as response parameters are reduced below their default "best fit" values, but deteriorates much more slowly as they are increased. Hence the "best fit" response is also close to the bottom of the range of uncertainty consistent with these observations. Focusing solely on the "best fit" also introduces the danger of over-fitting: if the past decade has been relatively cool because of natural variability in the Pacific, for example, then requiring a climate model to fit these temperatures would give a misleadingly low response, just as fitting to a decade that happened to be anomalously warm would give a misleadingly high response. Providing ranges of uncertainty that account for internal climate variability is essential to guard against over-interpreting these observations.

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[1] The views expressed in this note are those of the authors and not of the University of Oxford or the Oxford Martin School.

[2] Boucher, O. & Reddy, M. S. Climate trade-off between black carbon and carbon dioxide emissions. *Energy Policy* 36, 193–200 (2008).

[3] Otto, A. et al. Energy budget constraints on climate response. *Nat. Geosci.* 6 2–3 (2013).

Responses to specific questions:

4) **Why were AR5 summary projections for 2025 lower than the range of the CMIP5 multi-model ensemble, while projections for 2090 were not?** All projections are informed by multiple lines of evidence and different lines of evidence are relevant to different timescales. For example, the CMIP5 ensemble projects warming rates of up to 0.4°C per decade over the period 1985 to 2035. Given that temperatures in 2012 were only 0.15°C warmer than the 1986-2005 average (for various reasons including natural variability), temperatures would have to rise at over three quarters a degree per decade from 2012 to 2035 to 'catch up' with the top end of the CMIP5 range of projections for the 2016-2035 average, which was considered unlikely. On longer timescales, the underlying climate response is more relevant than the current state: note how the high response under the RCP8.5 scenario (red line, left figure panel) is well below the top of the CMIP5 range (purple bar) for 2025, but level with the top of the CMIP5 range (pale blue bar) by 2090.
5) **Were the AR5 models re-run with revised estimates of aerosol forcing?** Aerosol forcing is not specified in complex models. Each calculates the impact of aerosol emissions on the planetary energy budget in a different way. The models in the CMIP5 ensemble generated a range of aerosol forcing that encompassed the latest best estimate of this forcing, although not the lowest end of the latest range of uncertainty. Simple models, for which aerosol forcing is prescribed, were re-run to check the impact of revised forcing estimates. The low response (green line) in the figures corresponds to a low climate response and an anthropogenic aerosol forcing close to zero. Its projection for 2090 is below the low end of the CMIP5 range under the high emissions scenario, but coincides with the low end of the CMIP5 range for the mitigation scenario. Processes not in this simple model, such as feedbacks changing as the world warms, might give an even higher response than the red line. Note the IPCC interpreted this CMIP5 range as "likely", meaning a 1-in-3 chance that the real response might lie outside it, even though only 10% of CMIP5 models lay outside it.

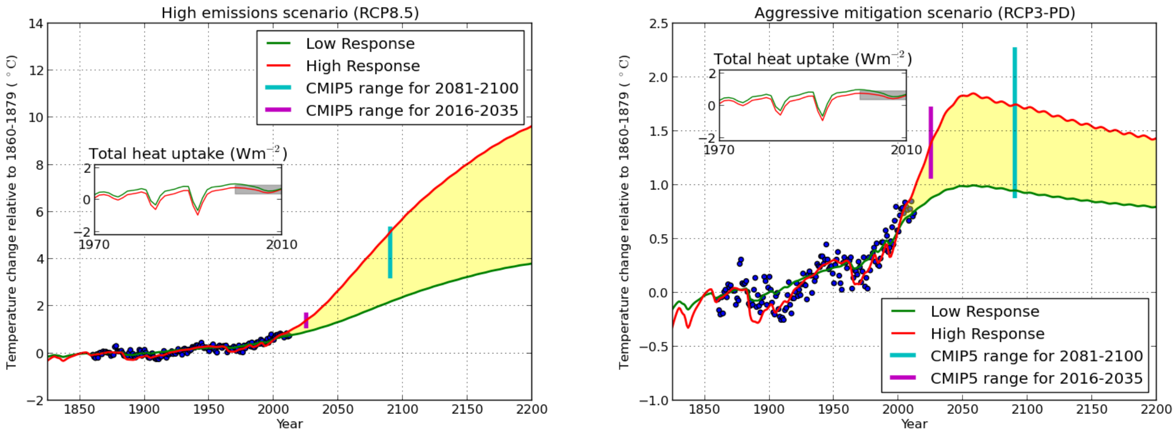

Figure 1: Observed and projected changes using a simple 'fast and slow response' model with different climate system properties consistent with past climate observations. The red lines show the response with an Equilibrium Climate Sensitivity (ECS, meaning the long-term equilibrium warming on doubling carbon dioxide) of 4.5°C and a Transient Climate Response (TCR, meaning the warming at the time of doubling carbon dioxide after a steady ramp-up, before the system re-equilibrates) of 2.5°C (the upper end of the likely ranges of these climate system properties as assessed by AR5), and an anthropogenic forcing in 2011 of 1.6 W/m^2 (the lower end of the AR5 likely range for this quantity[4]). The green lines show the same simple model with an ECS of 1.5°C and a TCR of 1.0°C (the lower end of the AR5 likely ranges), and an anthropogenic forcing in 2011 of 2.9 W/m^2 (the upper end of the likely range). The forcing series were obtained by scaling anthropogenic aerosol contribution to the standard RCP time-series[5] to match anthropogenic forcing in 2011. Inset panel shows diagnosed climate system heat uptake in both model versions, with the grey band showing 5-95% range of uncertainty in this quantity for the 2000s. Pale blue and purple bars show ranges of projections from the CMIP5 ensemble (5-95% of models) for 20-year periods centered on 2090 and 2025 respectively.

An excel spreadsheet, scm_ar5_temperature.xlsx, is provided to facilitate exploration of the impact of varying climate system properties on temperature and heat uptake.

4 Scaling down 5-95% ranges by a factor of 1.7 to give a "likely" (one-standard-error) range.
5 http://www.pik-potsdam.de/~mmalte/rcps