Climate Sensitivity and Transient Climate Response

Introduction

This dialogue focuses on the Equilibrium Climate Sensitivity (ECS) and the Transient Climate Response (TCR). Both summarize the global climate system's temperature response to an externally imposed radiative forcing (RF), expressed in W/m^2. ECS is defined as the equilibrium change in annual mean global surface temperature following a doubling of the atmospheric CO_2 concentration, while TCR is defined as the annual mean global surface temperature change at the time of CO_2 doubling following a linear increase in CO2 forcing over a period of 70 years. Both metrics have a broader application than these definitions imply: ECS determines the eventual warming in response to stabilization of atmospheric composition on multi-century time scales, while TCR determines the warming expected at a given time following any steady (and linear) increase in forcing over a 50- to 100-year time scale. TCR is a useful metric next to ECS because it can be estimated more easily than ECS, and is more relevant to projections of warming over the rest of this century.

Note that although ECS and TCR are defined in terms of a doubling of the CO_2 content, it can be applied to whatever forcing agents, such as changes in solar radiation and volcanic dust injections (bearing in mind that different types of forcings can have a slightly different temperature response per W/m2). As such, ECS is a measure for the global average temperature response to a change in the Earth's radiative balance, as characterized by the so-called radiative forcing expressed in W/m^2 (e.g. the radiative forcing due to a doubling of CO_2 is 3.7 W/m^2).

Lines of evidence for ECS

Figure 1 below shows the ranges and best estimates of ECS in AR5 (IPCC, 2013) based on studies that support different lines of evidence, which are: 1) the observed or instrumental surface, ocean and/or atmospheric temperature trends since pre-industrial time, 2) observed and modelled short-term perturbations of the energy balance such as those caused by volcanic eruptions, included under instrumental in figure 1, 3) climatological constraints by comparing patterns of mean climate and variability in models to observations, 4) climate models, and 5) temperature fluctuations as reconstructed from palaeoclimate archives and 6) studies that combine two or more lines of evidence into one 5-95% (very likely) uncertainty range for ECS.

Likely range of ECS in AR5

In AR5 the different and partly independent lines of evidence are combined to conclude that ECS is likely in the range 1.5°C to 4.5°C (grey area in figure 1) with high confidence.
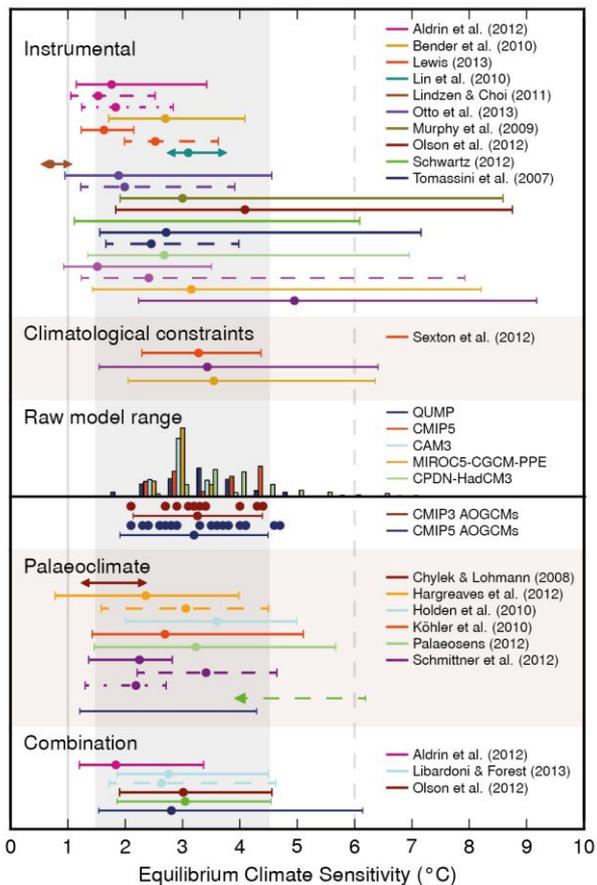
Figure 1 Ranges and best estimates of ECS based on different lines of evidence, replicated from figure 1 of Box 12.2 in AR5. Unlabeled ranges refer to studies cited in AR4. Bars show 5-95% uncertainty ranges with the best estimates marked by dots. Dashed lines give alternative estimates within one study. The grey shaded range marks the likely 1.5°C to 4.5°C range as reported in AR5, and the grey solid line the extremely unlikely less than 1°C, the grey dashed line the very unlikely greater than 6°C.

In AR4 the range was adjusted slightly upwards to 2–4.5°C, but AR5 reduced the lower bound down to 1.5°C, returning to the earlier range of 1.5–4.5°C for ECS. In Box 12.2 in AR5 it was written that: '…this change reflects the evidence from new studies of observed temperature change, using the extended records in atmosphere and ocean. These studies suggest a best fit to the observed surface and ocean warming for ECS values in the lower part of the likely range. Note that these studies are not purely observational, because they require an estimate of the response to radiative forcing from models. In addition, the uncertainty in ocean heat uptake remains substantial. Accounting for short term variability in simple models remains challenging, and it is important not to give undue weight to any short time period that might be strongly affected by internal variability.' So it is stated that estimates based on (constraints from extended records in) the instrumental period point to lower ECS values but at the same time one should be careful with overvaluing the instrumental evidence.

Weighing the evidence

In AR5 it is indicated that the peer-reviewed literature provides no consensus on a formal statistical method to combine different lines of evidence. Therefore, in AR5 the range of ECS and TCR is expert-assessed, supported by, as indicated above, several different and partly independent lines of evidence, each based on multiple studies, models and data sets. Obviously, this expert judgement in AR5 has been performed deliberately, but it is not a straightforward procedure. The discussion on how to weigh the different lines of evidence is very old, not only in the scientific literature but also in the blogosphere and in reports and is still going on. For example, Nic Lewis, who takes part in this dialogue and was author/co-author of two studies mentioned in the instrumental category in figure 1, argues that instrumental or empirical approach studies with relatively low ECS values should be weighted much higher than IPCC did in AR5 (Lewis and Crok, 2014).

Others argue that the main limit on ECS is that it has to be consistent with palaeoclimatic data which point at ranges being consistent with the IPCC-range (Palaeosens, 2012, also mentioned in figure 1) and also in line with climate models likely range of about 2 to 4.5 ^{0}C (CMIP5). Some argue that palaeoclimatic data points to values in the upper part of the IPCC range (Hansen, 2013). In this dialogue we therefore want to focus first on the following two questions:

1) What are the pros and cons of the different lines of evidence?

2) What weight should be assigned to the different lines of evidence and their underlying studies?

Best estimate

With respect to the best estimate it was reported in AR5 that: "No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence." Also, it was concluded that ECS is extremely unlikely less than 1°C (grey solid line in figure 1), and very unlikely greater than 6°C (grey dashed line). So IPCC did not choose between the different lines of evidence with respect to the best estimate, but it was not discussed in much detail why. Therefore, the third question we will address is:

3) Why would a lack of agreement between the lines of evidence not allow for a best estimate for ECS?

4) What do you consider as a range and best estimate of ECS, if any?

TCR range in AR5

AR5 concludes with high confidence that the TCR is likely in the range 1°C to 2.5°C, and extremely unlikely greater than 3°C (see figure 2).
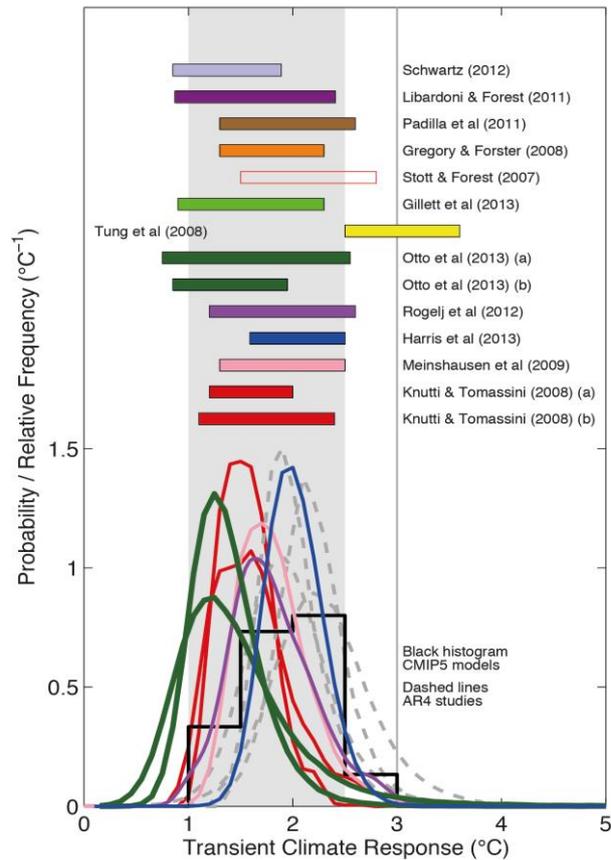
Figure 2 Probability density functions, distributions and ranges (5 to 95%) for the TCR from different studies, replicated from figure 2 of Box 12.2 in AR5. The grey shaded range marks the likely 1°C to 2.5°C range, and the grey solid line marks the extremely unlikely greater than 3°C.

TCR is estimated from the observed global changes in surface temperature, ocean heat uptake and RF, the response to the solar cycle, detection/attribution studies identifying the response patterns to increasing GHG concentrations, by matching the AR4 probability distribution for ECS and the results of the CMIP5 model inter-comparison study. Estimating TCR suffers from fewer difficulties in terms of state- or time-dependent feedbacks, and is less affected by uncertainty as to how much energy is taken up by the ocean. But still, there is a debate on the likely range. Again, Nic Lewis argues that studies showing a lower value in figure 2 (Gillett et al. (2013), Otto et al. (2013) and Schwartz (2012)) should be weighted much higher than the others resulting in substantially lower values for TCR (1.3-1.4°C) than, for example, the average of the CMIP5 models (1.8-1.9°C). Therefore, the question that will be discussed with respect to TCR is:

5) What weight should be assigned to the different studies mentioned in figure 2?

6) What is your personal range for TCR, if any?

References

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