Summary of the Climate Dialogue

on

Climate Sensitivity and Transient Climate Response

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This summary is based on the contributions of Nic Lewis, John Fasullo and James Annan who participated in this Climate Dialogue that took place from May until August 2014

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Introduction

Equilibrium Climate Sensitivity (ECS) is a central theme in climate science, as it characterizes the degree of temperature change that would be expected from a given radiative forcing, e.g. from a change in solar output or from a change in atmospheric greenhouse gas (GHG) concentrations. It is usually defined in terms of a doubling of atmospheric CO_2 concentrations as a common reference point, i.e. ECS is the *equilibrium* change in annual mean global surface temperature following a doubling of the atmospheric CO_2 concentration, excluding the very slow feedbacks from ice sheets and the biosphere, which are expected to further amplify what is then termed the Earth System Sensitivity (ESS). Transient Climate Response (TCR) is the expected *transient* change in temperature over a period of 70 years assuming a linear doubling of the atmospheric CO_2 concentration in this period, i.e. before equilibrium has been reached. It should be noted that the subject of climate sensitivity is very broad as it covers many aspects of climate science through the influence of feedbacks. The anthropogenic warming we may expect in the future is thus dependent on the climate's sensitivity and on the - cumulative in the case of CO_2 - emissions of GHGs and aerosols. TCR, ECS, and ESS cannot be directly measured, but rather has to be evaluated indirectly. There are different methods to do so, and the range of values found has been relatively large and similar in range for decades.

In the fifth assessment report of the IPCC (AR5) it is indicated that the peer-reviewed literature provides no consensus on a formal statistical method to combine different lines of evidence, i.e. different methods to estimate ECS. Therefore, in AR5 the range of ECS (and TCR) is expert-assessed and they conclude that ECS is likely in the range from 1.5°C to 4.5°C. The pros and cons of this expert judgement have been a frequent topic of discussion, not only in the scientific literature but also in the blogosphere and in reports and is still going on.

Participants

We invited three experts: John Fasullo, James Annan and Nic Lewis. Fasullo is a project scientist at the National Centre for Atmospheric Research (NCAR) in Boulder, Colorado, studying processes involved in climate variability and change using both observations and models. He has published extensively on the topic and was co-author of the assessment reports of the IPCC. James Annan has worked as senior scientist at the Japanese Research Institute for Global Change, JAMSTEC- perhaps better known as the home of the Earth Simulator – for the past 13 years. He published many papers and his work has been heavily cited in the recent IPCC AR5. Nic Lewis is an independent climate scientist, who studied mathematics and physics at Cambridge University. He published two key papers on ECS and TCR, one of them together with prominent IPCC lead authors[2,4]. Both are cited and discussed in AR5.

The Climate Dialogue

The experts' guest blogs dealt with all questions raised in our introduction, but due to the broadness of the subject and time limitations of the participating experts, we managed to cover the questions on ECS only and not those on TCR. In the discussion six main topics were discussed in more detail as described below. The key question in this Climate Dialogue was: *"What do you consider as a range and best estimate of ECS?"* Table 1 summarizes the answers of the three experts and their key argument(s) which will be described in more detail in the remainder of this summary.

	Nic Lewis	James Annan	John Fasullo
ECS	1.2 – 3.0 (1.7)	2.0 – 3.0 (2.5)	2.7 – 4.5 (3.4)
Key argument	All studies based on the instrumental period that have no evident serious flaws(1,..,4) arrive at best estimates for ECS in the 1.5–2.0°C range. Climate models and paleoclimate estimates are unreliable.	Paleo studies can only be reconciled with n ECS around 2 - 4.5 °C(7). Climate models give an ECS in the range of 2-5 °C. Instrumental period based studies point at the *lower* end of the IPCC range.	There is no credible climate model with an ECS of less than 2.7 °C. Key processes that drive ECS are better represented in high sensitivity climate models.(8,9) Forcings of aerosols are more effective than forcings of CO_2 (efficacy)(6).

Table 1 *Likely ranges (i.e. 66% probability) and Best Estimates (between brackets) of the Equilibrium Climate Sensitivity (ECS)* as estimated by the discussants of this dialogue.

Instrumental versus model-based approach

In his guest blog, Nic Lewis suggested four studies based on the warming in the instrumental period(1,..,4) are superior to the two main other methods that are available, based on climate models and paleoclimate data.. These "preferred" studies arrive at best estimates for ECS "*in the 1.5–2.0°C range*". James Annan discussed both the pros and cons of the instrumental period based estimates, calling them "*more trustworthy than other approaches […]as they are more-or-less directly based on the long-term (albeit transient) response of the climate system to anthropogenic forcing*" and "*They point at the low end of the IPCC range due to better quality and quantity of data and better understanding of aerosol effects.*", while also mentioning that "*These estimates rely on models of the climate system, which are so simple and linear (and thus certainly imperfect)*". John Fasullo agreed with the latter remark and added that the model used in these studies captures little of the climate system's physical complexity, since it is exclusively statistical and they only make use of "*a limited subset of surface observations, questioning their relevance*". John Fasullo indicated that "*All approaches are faced with the challenges of attribution and uncertainty estimation, for which the validity of observations, underlying model, and base assumptions are key issues. It therefore is inappropriate to place high confidence in any single approach.*" Nevertheless, his best estimate and likely range (see Table 1), were mainly based on climate models or so-called General Circulation Models (GCMs). His reasoning was that the models in CMIP3[1] with "*difficulty in simulating even the basic features of observed variability in both clouds and radiation*" were with ECSs below 2.7. Furthermore, "*key processes that drive sensitivity are actually better represented in many of the high sensitivity models(8,9) […] in CMIP5*".

Cloud feedbacks

Doubling of CO_2 in the atmosphere would give about 1.2°C of warming, assuming that everything else remains the same. However, this warming is amplified by so called positive feedbacks or damped by negative feedbacks. The most important positive feedbacks are an increase in atmospheric water vapor, which is a strong GHG, and the reduction in the extent of ice- and snow surfaces. Additionally, in chapter 7 of AR5 it is concluded that changes in cloud cover "likely" represent a positive feedback although the uncertainty is large. According to John Fasullo, ECS-values below 2 ^{0}C are possible only if a strong negative cloud feedback exists, which he believes is very unlikely given the conclusion of AR5. Lewis replied that he considers the conclusion of AR5 to be wrong because it is based on models

[1] CMIP = Coupled Model Intercomparison Project, 3 or 5 stands for phase 3 vs phase 5.

which “*are known to be very far from perfect.*”, In the public commentary, Steven Sherwood, who was a co-author of chapter 7 in AR5, strongly disagreed with Lewis, when he stated that the positive cloud feedback is supported by both “*observations and explicit models of the relevant processes”*. Andrew Dessler, a leading cloud expert, also contributing to the public commentary, likewise argued that for ECS to be as low as 1.5 degrees, cloud feedback needs to be strongly negative, whereas observations point to it being positive. Lewis argued that whereas individual cloud contributions have been observed to constitute a positive feedback, there may be other, unknown contributions which still render the total cloud feedback negative.

Aerosols
An aerosol is a colloid of fine solid particles or liquid droplets, in air or another gas, like haze or dust. On a global scale aerosols are thought to have a net cooling effect on the climate. Aerosols thus partly compensate for the warming effect of greenhouse gases. This effect though is highly uncertain and has a big influence on the uncertainty in climate sensitivity.There was agreement that better constraining aerosol forcing is the key to narrowing uncertainty in ECS and TCR estimates. Lewis argued that all GCMs have larger negative forcing (i.e. cooling) for aerosols than the best estimate in AR5 (-0.9 W/m^2), and as a result the models reproduce the warming of the 20th century with a sensitivity which is (much) too high. Fasullo replied that the aerosol forcing values in models fall well within the uncertainty range of AR5, which is -0.1 to -1.9 W/m^2 and therefore the conclusion of Lewis is, according to him, unjustified.

Efficacy
A related discussion was on the so-called ‘efficacy’, i.e. the hypothesis that the transient climate response (TCR and thus also ECS) to historical aerosols and ozone is substantially greater than the transient response to CO_2. According to Shindell[(5)] this is primarily caused by more of the short-lived aerosol and ozone forcing being limited to the places of emission, which are predominantly in the Northern Hemisphere continental regions. Since land temperatures respond stronger to a change in forcing than ocean temperatures do, this triggers a stronger temperature response, relative to the magnitude of the forcing, than the more evenly distributed CO2 does. Annan and Fasullo indicated that estimates of ECS based on 20th-century observations have assumed that a forcing by aerosols is equal to the same forcing by CO_2, i.e. that the efficacy is 1. Kummer and Dessler[(6)] show that the aerosol efficacy could be as high as 1.33 or 1.5, which increases the instrumental based ECS estimates to a value that is similar to estimates from GCM’s and from paleoclimate. Lewis disagreed: “*Shindell […]never refers to efficacy at all in his paper*.” and according to Lewis, Kummer & Dessler confuse “*forcing efficacy with transient climate sensitivity*” and therefore “*their calculations make no physical sense.”*

Priors
A prior probability distribution in Bayesian theory is intended to tell how likely different values of ECS are without considering the data on global surface temperature (or other data) and in the ‘non-informative’ case, without considering any data at all. When introducing the data, the prior probability distribution is updated and gives rise to the posterior distribution as a Probability Density Function (PDF). In his blog,, Nic Lewis indicated that the priors of many of the observational instrumental-period warming based ECS estimates cited in AR5 start from a ‘uniform prior’ in ECS, meaning that the starting position is that “*all climate sensitivities are, over a very wide range, equally likely*.” According to Lewis, this biases ECS estimates substantially upwards. Therefore, he argues, a ‘*non-informative prior*’ should always be used.

Salvador Pueyo, who published on the use of prior[(10)], wrote several long comments in the public thread. He emphasized it is not obvious that using a uniform prior overestimates ECS, but “*it is obvious that it is inappropriate”.* Pueyo argued, however, that Lewis does not actually use a non-uniform prior but rather a so-called ‘reference prior’, which in Pueyo’s opinion is meaningless. The point is that using a reference prior as if it were non-informative "*can cause serious trouble unless the amount of data makes the result quite insensitive to the prior, which is rarely the case with climate sensitivity.*" and it "*results into a vast underestimation of climate sensitivity*." . Lewis disagreed and replied that "*the distinction between 'reference priors' and 'non-informative priors' makes no sense*".

Paleoclimate
Changes in temperature have occurred in the distant past, as a result of natural forcings including e.g. changes in Earth's orbit and natural changes in greenhouse gas concentrations over hundreds of thousands and even millions of years. This allows to use paleo climatic evidence to estimate ECS. However, it should be realized that non-linearity occurs due to the fact that on such long timescales the world was very different from today with respect to ice sheet coverage, vegetation cover the location of continents, mountain ridges, opening or closing of ocean passages, etc. According to Fasullo and Annan paleo climatic knowledge can be reconciled with a sensitivity in the range 2 - 4.5 °C[(7)]. According to Lewis, on the other hand, the uncertainties are far too great to support the 2–4.5°C range. He referred to the 1–6°C range for sensitivity, as reported in AR5, but he indicated that he considers this as a *likely* range instead of the reported *very likely* range.

Relevance
An additional question was raised on the relevance of the scientific debate on Climate Sensitivity to climate policy and policy makers. All of them agreed that the political debate is largely disconnected from the scientific debate on climate sensitivity, and for Lewis and Fasullo this is a problem. While Lewis argued that policymakers should listen to a wider range of voices on climate sensitivity, including those suggesting sensitivity is low, Fasullo thinks that US-policymakers who insist climate sensitivity is low, do so out of convenience, rather than based on scientific evidence. For Annan a lack of interest from policymakers should not be a problem because of the great scientific confidence that *"human activity is significantly changing the global climate".*

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