EUCLIPSE

EU Cloud Intercomparison, Process Study & Evaluation Project

Grant agreement no. 244067

VERSION 2

Deliverable D4.7 Revised estimates, with uncertainty bounds, of climate sensitivity from EUCLIPSE ESM ensemble.

.

Responsible Partner: MPG

Delivery date: 48 months

Deliverable 4.7: Revised Estimate of Equilibrium Climate Sensitivity

Bjorn Stevens on behalf of the EUCLIPSE science team

Aim: *Revised estimate, with uncertainty bounds, of climate sensitivity from EUCLIPSE ensemble*

A great deal of work during EUCLIPSE has contributed to this deliverable ranging from a broader analysis of the multi-model CMIP5 ensemble, to idealized studies, to conceptual studies that bound the observed records. All of the studies which are cited below were developed within the EUCLIPSE project, or with the support of investigators supported by EUCLIPSE. In a couple of the publications the EUCLIPSE funding is not acknowledged due to constraints from the publisher, or due to an authors oversight on a multi-author paper on which a EUCLIPSE author was not the lead author.

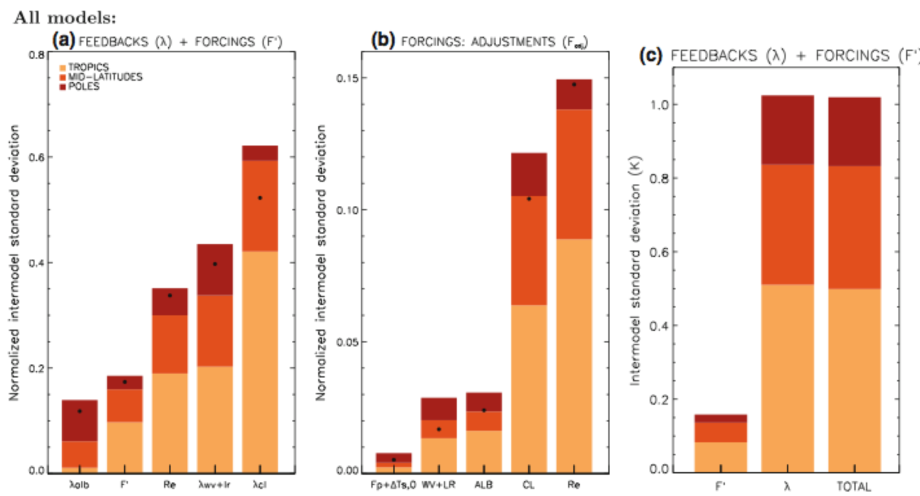

Figure 1: Contributions of different processes and regions to inter model spread in climate sensitivity. Taken from Fig. 6 of Vial et al. (2013)

The seminal study of the climate sensitivity of the EUCLIPSE model ensemble and the CMIP5 models more broadly was that by Vial et al. (2013). This paper played an important role in the AR5 and is a definitive milestone in model based estimates of climate sensitivity. The study goes beyond previous work by understanding and quantifying the contributions of adjustments to inter model spread in climate sensitivity. It is shown that cloud adjustments are generally positive and can be associated with a reduce strength of the cloud feedback. Nonetheless feedback differences, primarily from clouds in weakly subsiding regions of the tropics, account for most 70 %) of the inter model spread. The study also showed that when water vapor and lapse rate feedbacks are considered together, changes in the upper troposphere play a relatively more minor role in determining the climate sensitivity. Instead, the water vapor and lapse-rate feedback response is sensitive to a broad slab (from 900 to 400 hPa) of the tropical troposphere, with maximum sensitivities nearer 700 hPa. This finding mitigates against the inference that climate sensitivities are unduly sensitive to the structure of the upper troposphere, for which the degree of correspondence between changes over the instrumental record and what is simulated over that same period remains disputed.

Brient and Bony (2012) analyzed the processes underlying the strong low-cloud feedbacks in the IPSL model. They found that the feedback processes were exaggerated by an overly strong low-cloud radiative effect, something termed the beta-effect. By constraining this amplification of the low-cloud feedback against they showed that the low-cloud feedback of the IPSL is over-estimated by about 50% owing to its over-estimate of cloud-radiative effects. Accounting for a smaller cloud feedback would reduce the IPSL model climate sensitivity from a value of about 3.9 K as cited in Vial et al., to a value nearer to 3 K.

Mauritsen and Stevens (2014) introduced a crude representation of the effects of convective organization on the precipitation efficiency of convection under the presumption, based on process models, that convection organizes more readily in a warmer climate. This reduced the climate sensitivity of the MPI-ESM from about 2.8 to about 2.2 K, although the coupled version of the same model has a higher base sensitivity (3.7 K in Vial et al. (2013) and between 2.9 and 3.7 K in Stevens et al. (2013)) In this revised version of the ECHAM model the changes in tropical upper tropospheric temperatures were more readily reconciled with observations, and the hydrological sensitivity increased, also more in line with (admittedly disputed) inferences from observations. The study suggests however that convective processes that are currently not included in models could lead to a substantial (20%) reduction in the climate sensitivity. Much larger reductions in the climate sensitivity from such processes have been hypothesized in the literature, and were initially targeted with the introduction of a temperature dependent precipitation efficiency, but because of compensating long and shortwave cloud effects these end up being very difficult to realize in the climate system.

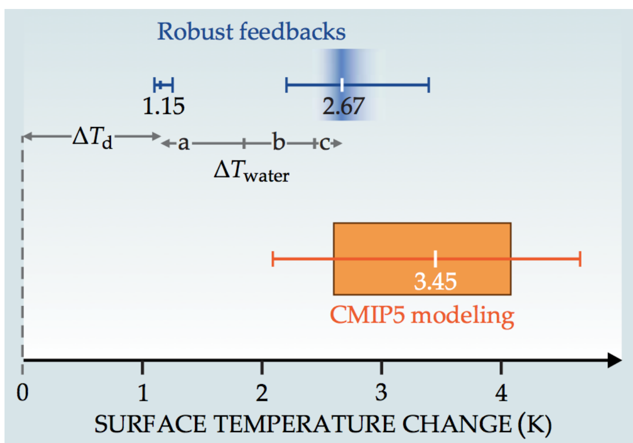

Figure 2: Different measures of the equilibrium climate sensitivity. Taken from Fig. 4 of Stevens and Bony (2013)

Stevens and Bony (2013) surveyed the existing literature on feedback parameters and separated feedbacks from what they termed robust processes from processes which are much less certain. Examples of robust feedbacks include the combined lapse-rate and water vapor feedback, the surface albedo feedback, and the feedback from changes to tropical high-clouds associated with the tendency of the tropical tropopause to maintain a fixed temperature. They showed, Fig. 2, that only accounting for robust feedbacks leads to an estimate of the equilibrium climate sensitivity of about 2.7 K. The spread in the equilibrium climate sensitivity increases partly because of a poor understanding of the basic feedbacks in climate models, and partly as a result of cloud processes other than those of the rising tops of tropical ice clouds.

By constructing a simple model of aerosol forcing which captures the main properties of much more comprehensive models Stevens (2014) explored the time history of aerosol forcing. Using the fact that the aerosol forcing established itself earlier in the industrial period than did greenhouse gas forcing he argued that an aerosol forcing more negative than -0.9 $\mathrm{W\,m^{-2}}$ is implausible and that a net aerosol forcing of about -0.5 $\mathrm{W\,m^{-2}}$ is a more plausible central estimate. A smaller magnitude for the aerosol forcing implies a climate sensitivity toward the smaller end of the accepted range, and something more consistent with what was inferred from the observational record by (Otto et al., 2013). Accepting the results from Mauritsen and Stevens (2014) which deliberately attempted to modify processes that would lower the climate sensitivity in their model, but were not able to produce a model with a climate sensitivity of less than 2 K the above results suggest that a climate sensitivity of between 2 and 3 K, smaller than the range (1.5-4.5 K) adopted by AR5. A difficulty with this developing story line of a somewhat lower climate sensitivity, is that convective aggregation processes are poorly understood, and whether or not the ansatz developed by Mauritsen and Stevens (2014) is a reasonable one is very much an open question. Likewise the use of the observational record to infer smaller sensitivities generally fails to account for studies that show feedbacks strengthening as equilibrium is approached.

Other work points, particularly work on emerging constraints, points to a climate sensitivity nearer 4 K or even higher. Among these studies perhaps the most convincing is one, which was conducted at LMD (an EUCLIPSE laboratory) with two EUCLIPSE investigators, Sherwood et al. (2014) and is based in large part on ideas developed during the EUCLIPSE project, that shows how models with a climate sensitivity larger than 4 K are more consistent with available data. Because the constraint employed in this study had to be evaluated with the help of reanalyses, and involved a process, lower tropopsheric mixing, which is not well constrained by the observations going into the reanalysis. However other work on emergent constraints which is less dependent on the reanalyses also points to higher sensitivities, and a great deal of experience shows that it is much easier to build a model with a higher, rather than a lower climate sensitivities. But because the emergent constraint literature articulates specific hypotheses it provides a basis for evaluating processes thought to be responsible for a particular model's climate sensitivity (many of which build on EUCLIPSE work) and thus a route for reconciling the apparently contradictory story line between a high and low climate sensitivity.

Work within the EUCLIPSE project has been a major advance in our understanding of climate sensitivity. But because much of it appeared concurrently with, or even after, the preparation of the AR4, these advances are not fully reflected in that report. To help communicate these advances to the broader community a special workshop is being organized at the instigation of EUCLIPSE investigators (Bony, Stevens, Webb) to revisit the assessment of climate sensitivity. This workshop is being organized through the WCRP grand challenge on clouds, circulation and climate sensitivity, and will take place after the end of the EUCLIPSE project, but is only possible as a result of the advances and collaborations developed through EUCLIPSE. At the workshop the strengths and weaknesses of story lines for a high versus low climate sensitivity will be explored in more depth.

References

Brient, F. and S. Bony, 2012: How may low-cloud radiative properties simulated in the current climate influence low-cloud feedbacks under global warming? *Geophys. Res. Lett.*, **39 (20)**, n/a–n/a.

Mauritsen, T. and B. Stevens, 2014: Climate change with an iris-effect. *Nature*, 1–11–sumbitted.

Otto, A., et al., 2013: Energy budget constraints on climate response. *Nature Geoscience*, **6**, 415–416.

Sherwood, S. C., S. Bony, and J.-L. Dufresne, 2014: Spread in model climate sensitivity traced to atmospheric convective mixing. *Nature*, **505 (7481)**, 37–42.

Stevens, B., 2014: Rethinking the lower bound on aerosol radiative forcing. *Nature*, 1–19–in review.

Stevens, B. and S. Bony, 2013: Water in the atmosphere. *Physics Today*, **66 (6)**, 29.

Stevens, B., et al., 2013: Atmospheric component of the MPI-M Earth System Model: ECHAM6. *J. Adv. Model. Earth Syst.*, **5 (2)**, 146–172.

Vial, J., J.-L. Dufresne, and S. Bony, 2013: On the interpretation of inter-model spread in CMIP5 climate sensitivity estimates. *Climate Dynamics*, **41 (11-12)**, 3339–3362.