Clim. Past Discuss., 5, C987–C990, 2009
www.clim-past-discuss.net/5/C987/2009/

Climate of the Past Discussions

Interactive comment on "Comment on "Using multiple observationally-based constraints to estimate climate sensitivity" by J. D. Annan and J. C. Hargreaves, Geophys. Res. Lett., 33, L06704, doi:10.1029/2005GL025259, 2006" *by* S. V. Henriksson et al.

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Received and published: 13 December 2009

General comments

In recent years the issue of inferring probabilistic estimates of climate sensitivity has attracted a lot of attention and many studies have been published on the subject, following different approaches. In their comment, Henriksson and colleagues (hereinafter referred to as HR09) question the robustness of the results from one of these recent

studies (Annan and Hargreaves, GRL 2006, referred to as AH06). In their work AH06 undertook a Bayesian analysis by accounting for multiple lines of evidence, namely observational data of last Century's warming, of temperature anomalies caused by volcanic eruptions, and of the large cooling during the glacial climate. When accounting for the combined effect of the different data sources, their approach led to a pronounced lowering of the upper bound of climate sensitivity (as compared to previous estimates focusing on individual data sets). Lowering the upper estimate of climate sensitivity has important implications and should be based on robust analyses. As such the authors of the comment address a delicate and important issue. HR09 mainly criticize two aspects of the Annan & Hargreaves study which concern their use of a Bayesian formalism. These aspects will be discussed in the following paragraph. While the basis for their criticism seems justified to me, it remains unclear to what extent the results of AH06 are affected in quantitative terms.

Specific comments

The first point of criticism of HR09 concerns the approach of how AH06 apply the Bayesian formalism to infer a posterior distribution of climate sensitivity. The authors of the comment argue that - instead of subjectively generating density and likelihood functions (as AH06 did by fitting Gamma or Gaussian distributions to estimated quantiles based on previous work) – the authors should have inferred "proper Bayesian posterior densities". While following the strict rules of Bayesian statistical inference would be an improvement to the more ad hoc approach chosen by AH06, it is not obvious how this would affect their results quantitatively. Probably the largest source of uncertainty does not result from a bias in the precise shape of the inferred density or likelihood functions but from the subjective choice of the prior in the first place. This is especially the case for studies which assume a rather broad uniform distribution to describe "ignorance" in the knowledge of the true magnitude of climate sensitivity before data were accounted for (see Annan and Hargreaves 2009 for a detailed discussion).

The second and probably more important point of criticism concerns the assumption made by AH06 that their different lines of evidence are independent from each other. HR09 belief this assumption to be seriously flawed. Undoubtedly this is an important issue and worth further exploring. For supporting their argument, HR09 discuss a simple energy-balance formula which describes how observationally constrained climate sensitivity estimates depend on the assumed magnitude of past radiative forcing, temperature change and ocean heat capacity. HR09 argue these data share common sources of uncertainty for the three different observational constraints (20th Century warming, volcanic forcing, Last Glacial Maximum (LGM) cooling). Thus a proper Bayesian approach should account for the joint probability distribution of the uncertain parameters when updating the prior. HR09 claim, that the assumption of independence seems especially violated for estimates of ocean heat uptake and radiative forcing. At least, for the constraint based on the climate state of the LGM and 20th Century warming, this might not be the case. Given that the glacial climate had enough time to adjust to the glacial boundary conditions, the LGM can be considered to be in quasi-equilibrium. Thus the uncertainty in the strength of transient heat-uptake (which affects estimates of 20th Century warming) does not contribute to the spread in climate sensitivity estimates based on LGM data. Additionally, it is questionable to which extent the data describing 20th Century forcing share common sources of uncertainty with data estimating LGM radiative forcing. While the first have their origin mainly in the unknown magnitude of sulphate cooling, the latter are mainly caused by different assumptions about the radiative effect of the large glacial ice sheets, of modified vegetation patterns and of increased dust content during glacial times. To me, the assumption of independent evidence seems at least a fair approximation for considering 20th Century warming and LGM cooling. As the latter is the most tight constraint in the study of AH06, the consideration of joint pdfs seems worthwhile exploring for getting more accurate posterior distributions, but probably is unlikely to crucially broaden the estimated sensitivity range of AH06.

Altogether, the comment by HR09 illustrates the need for improved statistical analyses when estimating uncertainty in climate sensitivity, but it leaves open the question of

how robust the results from AH06 are to a more proper Bayesian analysis. Previous studies (such as Andronova and Schlesinger, 2001, Forest et al. 2002, Knutti et al., 2002) have used only a subset of the available observational evidence to constrain climate sensitivity. So the conclusion of HR06 that these previous works provides us with the best estimates of climate sensitivity is likely to lead to a too pessimistic view as this means neglecting important sources of information about the sensitivity of the climate system.

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Forest, C. E., et al. (2002), Quantifying Uncertainties in Climate System Properties with the Use of Recent Climate Observations, Science, 295, 113-117.

Knutti, R., et al. (2002), Constraints on radiative forcing and future climate change from observations and climate model ensembles, Nature, 416, 719-723.

Annan J., Hargreaves J. (2006), Using multiple observationally-based constraints to estimate climate sensitivity, Geophysical Research Letters, 33

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Interactive comment on Clim. Past Discuss., 5, 2343, 2009.