**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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The reason for writing a critical comment on the original paper AH06 was that we believe that certain assumptions made in it without the necessary supporting arguments, some of them only implicit in the text, have no real justification in the considered context but have nevertheless influenced its results significantly. We criticized (i) the use of pdfs and likelihood functions interchangeably, and (ii) the assumption of conditional

independence of the different sources of information, given only the value of the climate sensitivity x. J. D. Annan and J. C. Hargreaves submitted a Short Comment (hereinafter referred to as the Short Comment), admitting the theoretical correctness of both our main criticisms, but then questioning our view that this could have seriously influenced the result that they had derived and arguing that their result is nevertheless better than results obtained in earlier research. We argue that the shortcomings of AH06 are indeed serious, and provide our arguments in the following four points:

1. It would be very hard to follow to the request presented in the Short Comment, asking us to quantify the error caused by their approximation, as this would require performing the task of redoing the calculations of AH06 by using their background data, which are not even available to us. We note that it is in principle even possible that new data O do not give new information on the sensitivity parameter x beyond what is already provided by the old data H. This happens if $f(O|x,H)$ does not depend on x. Although such a circumstance is unlikely in the situation considered in AH06, and therefore proper accounting for the additional data utilized in AH06 would very likely reduce the uncertainty in the estimates of x when compared to results that had been derived earlier, we find it equally unlikely that the reduction would be a strong as was claimed in AH06.

2. In the example calculation of the Short Comment it is obvious that the assumption of equal aerosol forcings actually is behind the result being narrower than in the calculation using the AH06 method. The equality of the aerosol forcings is obviously a poor assumption. However, it is not clear that the forcings should be completely independent either. More realistic assumptions and including all three sources of information would be needed to defend the AH06 result. Assumptions concerning the "nuisance parameters" of the ocean heat capacity and radiative forcing should be made more explicitly, especially concerning 20th century warming and volcanic cooling (see also Knutti and Hegerl, 2008, p. 741). When in the volcanic cooling case radiative forcing uncertainty is considered, also the corresponding posterior will be broadened. We

think the last glacial maximum is likely to be a more independent constraint, but like discussed in AH06 (and treated by broadening the likelihood funtion by a subjective amount), different characteristics of climate might make climate sensitivity at the LGM and at present different from each other (the choices related to this in AH06 are based on an article that obtains a most likely value for climate sensitivity of 4.5 degrees (Annan et al, 2005)). However, it is our opinion that especially the very likely positive correlation between ocean heat capacity estimates for 20th century warming and volcanic cooling and considering radiative forcing uncertainty in the volcanic forcing case will limit uncertainty reduction (by an unknown amount).

3. AH09, the later article by Annan and Hargreaves, does not address issues related to combining information from different sources and their dependence or independence but is advocating using narrower priors, thereby narrowing the end result this way.

4. As to comparing the different approximations presented in the Short Comment, we understand that the point made in it is that it advocates using three sets of data (then making the crude assumption of their conditional independence given only the sensitivity parameter x) rather than using only a single set (when obviously no such assumptions are necessary). We have two arguments here. Firstly, estimates based on, say, 20th century warming already contain a large amount of observational information. Secondly, in the likely case that the error caused by the AH06 approximation is large, then it is better to use less information in a correct calculation than to use more in an incorrect one. Moreover, the notation used in the Short Comment for explaining these intuitions only adds to the earlier conceptual confusions. More exactly, an approximation of the form $f(O1,O2,H,\Omega|x) \sim f(H|x)$ (p. C870) can make any sense only if $f(O1,O2,H,\Omega|x)$ and $f(H|x)$ are taken to mean the corresponding likelihood functions, i.e., are considered as functions of x, which then leads to a corresponding approximation between the posterior densities $f(x|O1,O2,H,\Omega)$ and $f(x|H)$. However, and unlike the Short Comment claims, we – or "earlier research" - have not "adopted such an approximation". Clearly, a posterior of x based on O1, O2, H and Ω should be different from

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the posterior based on only H; this is so unless $f(O1,O2,\Omega|x,H) = f(O1,O2,\Omega|H)$, that is, all the relevant information in $(O1,O2,H,\Omega)$ on x is already contained in H. Instead, our point in the Comment was that the posterior $f(x|O1,O2,H)$ was derived in AH06 in a manner which does not hold under critical scrutiny. Finally, all these issues are confused even more when Annan and Hargreaves write in their Short Comment (p. C872) that "If the authors (referring to us) are really prepared to argue that $f(O1,O2,H,\Omega|x)$ is better approximated by $f(H|x)$ than by $f(O1|x) f(O2|x) f(H|x)$, then they should state . . .". We have certainly not argued $f(O1,O2,H,\Omega|x)$ is approximated by $f(H|x)$, nor that $f(x|O1,O2,H,\Omega)$ is approximated by $f(x|H)$ (see above).

We agree with the basic idea of AH06 and believe that the uncertainty in climate sensitivity estimates can indeed be reduced by using it. We also see this idea as a welcome contribution in the field of climate science. However, the Bayesian calculation in AH06 is too superficial to reliably reduce the uncertainty of climate sensitivity. The "nuisance parameters" of ocean heat capacity and radiative forcing should be treated more explicitly, and this shortcoming of AH06 may have significantly affected the result derived in it. Therefore, based solely on the result of AH06, it is impossible to make a quantitative assessment of the uncertainty reduction that would have been achieved if the Bayesian method had been used properly to combine information from the three different observationally-based sources.

Annan, J. D., Hargreaves, J. C., Ohgaito, R., Abe-Ouchi, A., and Emori, S.: Efficiently constraining climate sensitivity with paleoclimate simulations, SOLA, 1, 181-184, 2005.

Knutti, R. and Hegerl G. C., The equilibrium sensitivity of the Earth's temperature to radiation changes, Nature Geoscience, 1, 735 – 743, 2008.