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Using Multiple Probability Distributions for Climate Sensitivity in Climate Policy Analysis

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Abstract

Climate policy targets consistent with the goal of preventing dangerous climate change must confront the wide uncertainty in the climate sensitivity. For example, keeping global mean temperature increase below 2ºC would require stabilization of GHG concentrations below about 700 ppm CO2 equivalent if the climate sensitivity is 1.5ºC, vs. below about 380 ppm CO2-eq if it is 4.5ºC. Given this uncertainty, it is reasonable to ask, for a given concentration stabilization target, what is the probability that the equilibrium temperature will exceed some threshold? Such a calculation can be done straightforwardly using a probability density function (PDF) for the climate sensitivity. However, there is no consensus on what is an appropriate PDF to use in such a calculation, and many different PDFs are now appearing in the literature. In this paper, we discuss the fundamental nature of the uncertainty described by the "probability" for a natural parameter such as the climate sensitivity, and the problem of drawing policy conclusions in the face of such uncertainty. We note that judgments about probabilities in this context are not value free, as they involve the distribution of risk. We conclude with an exploration of published climate sensitivity PDFs and their implications for risk management of climate change and climate impacts.

1. Introduction

It is widely recognized that the concentration stabilization level associated with any impact-based or temperature-based precautionary level of climate change is extremely dependent on the assumed value of the climate sensitivity. Given the continuing large uncertainty in the climate sensitivity, a variety of analysts have begun modeling stabilization targets using probability distributions for the climate sensitivity. However, as we discuss below, there are many plausible probability distributions that can be used for the climate sensitivity; indeed analysts have used anywhere from one [i] to three [ii] to as many as eight [iii,iv] different probability density functions (PDFs) in a single study.

The use of implicit probability distributions is quite common in everyday life, as we will demonstrate, and the formal use of mathematical PDFs is a standard tool in risk analysis. However, the availability of multiple credible PDFs for a parameter such as the climate sensitivity raises a number of very difficult problems at the interface of science and policy. In particular, when different but believable PDFs have substantially different implications for precautionary policy, it is not at all obvious how the policy process should handle this information.

Indeed, a related discussion has already taken place about the utility of providing decision-makers with information such as multiple emissions scenarios without attaching probabilities to those scenarios. One strongly held position [v] is that experts should assign probabilities even to difficult-to-judge parameters and projections such as long-term emissions trends. However, what if the items whose likelihood is uncertain are themselves probability distributions? Who is to judge the likelihood that a given PDF is "correct," when it's not even clear what it means for a PDF to be correct?

This issue has in fact been discussed in both the general literature on uncertainty analysis [vi] and in the climate literature in particular [vii,viii]. Arguments have been made for aggregating multiple PDFs into a single PDF, as well as for leaving them separate. The IPCC's non-provision of a PDF for climate sensitivity represents another response to this problem. However, as the debate intensifies over a stabilization target consistent with the UNFCCC's objective of preventing "dangerous anthropogenic interference with the climate system", a further examination of this problem with specific reference to the climate sensitivity seems timely.

2. Overview

There are not less than ten PDFs for the climate sensitivity that have either been published in the scientific literature, or can be "inferred" from the IPCC's range of 1.5 to 4.5ºC. As we discuss below, these PDFs vary quite widely. If there were a "policy mandate" that (for example) a stabilization target be set such that there were to be a 90% chance that the equilibrium temperature increase would be held below 2ºC, the necessary target would vary with the choice of the "official" PDF used in the stabilization calculation.

As has been widely noted, the IPCC has until now declined to say anything further in a quantified, probabilistic, way about the climate sensitivity, beyond the fact that it is "estimated to be between 1.5 and 4.5ºC". In spite of the fact that 2 of the 21 GCMs reported in the TAR calculated the climate sensitivity to be over 4.5ºC (up to 5.1ºC) (TAR WGI Chap 9, Table 1), there was no discussion of the probability that it might be outside the cited range. Moreover, in a subjective expert assessment done in 1995, 12 of 16 climate experts estimated at least a 5% possibility that the climate sensitivity is over 4.5ºC, and 7 of those 16 estimated a 5% possibility it was over 6[illegible][ix]. Furthermore, since the TAR several PDFs have been published, based on a variety of methods, that put as much as 18-48% of the PDF over [illegible]. The IPCC has not yet undertaken a review of the relative merits of these many probability distributions for climate sensitivity.

What are policy-makers to make of this confusion? Once again, there is a fundamental problem, because it is very hard to make sense of the statement that "the probability is between 2% and 48% that the climate sensitivity is over 4.5ºC." At the same time, if there is amything near a 50/50 chance that the climate sensitivity is over 4.5°C, indicating a sizeable potential for significant and detrimental impacts from climate change in the not-too-distant future, policy-makers might want to develop policy responses that account for this outcome (this statement itself makes implicit assumptions regarding other “Bayesian” probability distributions such as the severity of climate impacts for a given temperature increase).

This may seem to be an intractable problem, and in some ways it is. Scientists will never be able to predict the climate sensitivity with full certainty—there is only one planet Earth on which we “experiment.” However, climate policy decisions can still be made under uncertainty, as we make decisions under uncertainty in our daily lives and for policy decisions in other sectors. The bottom line is the level of “acceptable risk,” a value judgment which is not a wholly scientific question. Science can provide essential information from which to make decisions about risk, but there is no “objective” definition of “acceptable risk.” Furthermore, as we explore in our paper, the way in which scientists themselves choose to report probability distributions for the climate senstivity will affect the way in which risk decisions are made, and thus the way actual risks will be distirbuted, posing deep problems for the supposed separation of facts and values.

3. Climate sensitivity PDFs

As we discussed above, there are very difficult issues that arise from the general problem of the availability of multiple PDFs for an uncertain parameter like the climate sensitivity. In what follows, we briefly survey some of the climate sensitivity PDFs that have been published and used for policy-related modeling. We show that the differences are substantial and have significant policy implications.

3.1: Fat-tailed PDFs

There are several published PDFs for the climate sensitivity which have relatively large right-hand tails - that is to say, a substantial (~20% or more) fraction of the distribution is above the oft-cited IPCC upper bound of 4.5ºC. Four of these are shown in Figure 1 below [x,xi,xii,xiii].

These four PDFs are generated from Bayesian methods; that is, by the use of simple climate models, historical estimates of radiative forcing, and Monte Carlo analysis to generate a simulated historical temperature time-series, which is then compared with one or more components of the actual historical temperature record to estimate the likelihood that a given value of the climate sensitvity (or other parameter) is the "true" value. These methods are considered "objective" in that they use a straightforwardly replicable methodology with various empirical data sets to produce the output distribution. However, as we discuss further in the paper, there is inescapable subjectivity in the choice of the data that are considered, the model that is used, the structure of the model itself, and many other aspects.

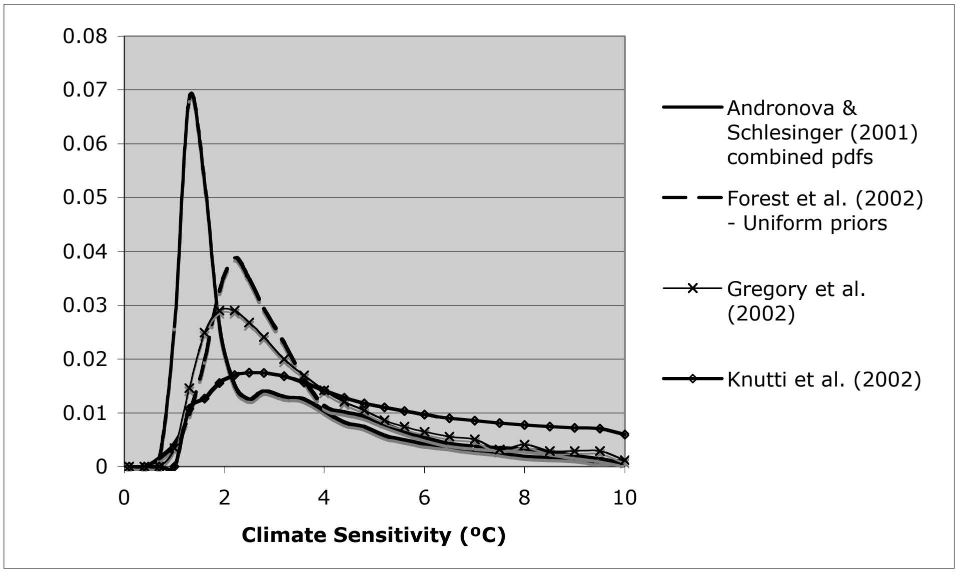


Figure 1. Climate sensitivity PDFs with long right-hand tails.

As shown in rows 1-4 of Table 1, these "objective" PDFs have between 18% and 48% of the distribution over 4.5ºC. If one were to base policy on these PDFs, the concentration targets associated with a high probability of staying under (say) a 2º threshold would be very stringent. It's worth noting also that a description of the fraction of a climate sensitivity PDF that exceeds a given threshold is by definition the likelihood that an increase of forcing equivalent to a doubling of CO_2 above pre-industrial - that is, about 550 ppm CO2-equivalent - would exceed that temperature increase at equilibrium.

PDF Description		Pct <2	Pct <2.5	Pct >3	Pct >4	Pct >4.5	pct >5
1	Andronova & Schlesinger (2001) combined pdfs	52%	59%	34%	22%	18%	14%
2	Forest et al. (2002) - Expert priors	30%	58%	23%	6%	3%	2%
3	Forest et al. (2002) - Uniform priors	21%	39%	46%	29%	24%	19%
4	Gregory et al. (2002)	22%	36%	52%	35%	29%	23%
5	Knutti et al. (2002)	13%	21%	70%	54%	48%	42%
6	Murphy et al. (2004) weighted PDF	0%	8%	72%	26%	14%	8%
7	Wigley and Raper (2001) (based on IPCC)	22%	45%	34%	10%	5%	3%
8	Normal (based on IPCCC) Mean 3 SD0 .75	9%	25%	50%	9%	2%	1%
9	Normal (based on IPCCC) Mean 3 SD 0.5	2%	16%	50%	2%	1%	0%
10	IPCC Uniform	17%	33%	50%	17%	0%	0%

Table 1: Summary descriptions of 10 climate sensitivity PDFs, showing the fraction of the distriibutions that are below or above particular threshold values of interest.

Although these four PDFs were generated using similar methods, the long right-hand tails are not a consequence of the method itself. For example, when Forest et al. [xi] used an "expert prior" based on the IPCC's assessment that the climate sensitivity is between 1.5 and 4.5ºC, the same method and data comparison produced a PDF with a much lower median and shorter tail (See Figure 2 and Row 5 of Table 1). Indeed, the fact that the result of an "objective" method depends on the Bayesian "prior" is an indication of the irreducible subjectivity of PDFs.

3.2: IPCC-based PDFs

In spite of the reluctance of the IPCC to report a consensus probability distribution of the climate sensitivity, various researchers have used interpretations of the IPCC's range to perform uncertainty analyses. There are several different parametric interpretations of the IPCC range that are readily available - in particular the uniform, normal and lognormal, as shown in Figure 2 and rows 7-10 of Table 1, and [1, 2, xiv]. Of course, a normal or lognormal distribution can be set to have any arbitrary percentage of the distribution above a threshold like 4.5ºC. For comparison, we use two different normal curves, both of which have the mean at 3ºC, and which have 0% and 2% of the distribution above 4.5ºC respectively. (The former matches the estimate used by Hansen [xv], which is consistent with but not based on the IPCC range.)

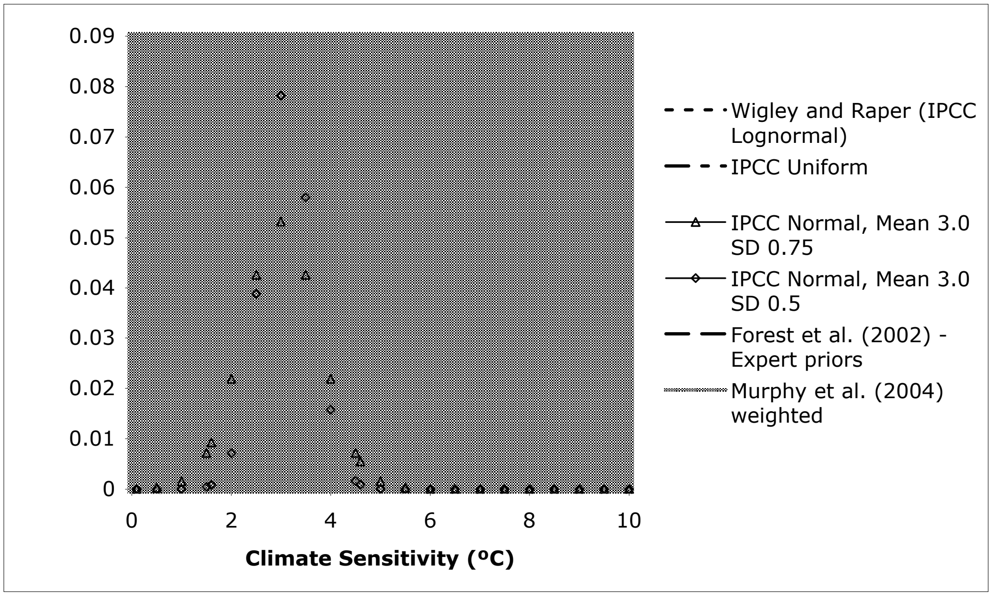


Figure 2. Six additional PDF climate sensitivity PDFs either published in the literature or based on the IPCC's range.

3.3: Other PDFs

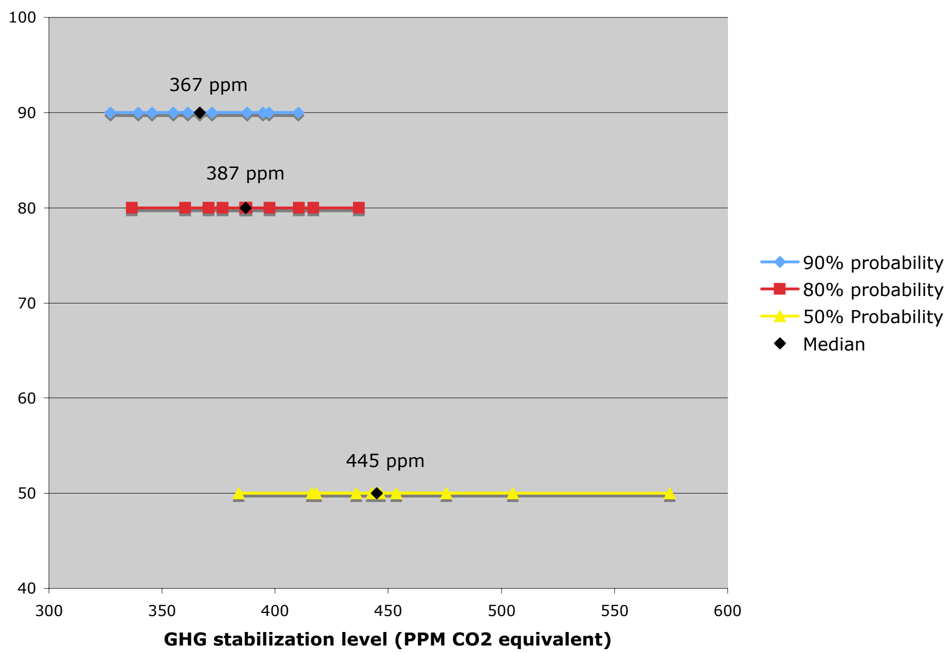
In addition to the "Expert Prior" PDF from Forest et al. [11], Figure 2 and Table 1 also include a recently published PDF from Murphy et al.'s probabilistic analysis of the Hadley Center's HadAM3 model [xvi]. The authors performed a large Monte Carlo analysis on a reduced-form version of their model, varying 18 parameters, many related to cloud feedbacks. Their "weighted" PDF had a median of 3.5ºC, with 14% of the distribution higher than 4.5ºC.

4. Using multiple PDFs

Figure 3 shows graphically for 10 climate sensitivity PDFs the range of stabilization levels (in ppm CO_2-equivalent) associated with a variety of probabilities of staying below 2ºC increase above pre-industrial. For example, if one were to take the median PDF for a 90% probability of staying below 2º, it would require stabilization at or below 367 ppm CO_2-eq, with a range from about 340 to 410 ppm CO2-eq for the "lowest" and "highest" PDFs.

Two facts stand out. First, for any reasonable PDF, stabilizating GHG concentrations to keep equilibrium temperature increase below 2ºC (a target endorsed by the European Council among others) will be quite a challenge (see also [4,xvii]). Current CO_2 is about 380 ppm. The net forcing of other well mixed greenhouse gases adds the equivalent of about 70 to 80 ppm CO_2. It is estimated that the aggregate effect of other positive and negative forcings, particularly including a substantial negative forcing from sulfate aerosols, roughly offsets these non-CO_2 GHGs, maintaining current net forcing on the order of 360 to 400 PPM CO_2 equivalent. Thus there is little room for additional positive forcings while staying under a precautionary 2º target. Yet CO_2 concentrations are certain to continue to rise for from years to decades even under optimistic reduction scenarios. This implies that, unless forcings drop rapidly below their peak, there is a substantial risk of overshooting 2º, possibly substantially so.

The other point, to return to our basic theme, is that, given the wide range of stabilization levels from the for a given risk level, the choice of a PDF to use in the estimation of a stabilization target has real consequences for the distribution of risk. It is precisely the job of both individual experts and the collective judgment of scientists in fora like the IPCC to suggest what the "best guess" for the shape of the climate sensitivity PDF is. But it is specious to claim that any such best guess is value neutral, either in terms of the distribution of impacts or the reasons for selecting it. How to best address the necessary value choices is a significant challenge for scientists addressing climate change.



REFERENCES

i. T.L. Wigley, *Clim. Change*, In press.
ii. M.D. Mastrandrea, S.H. Schneider, *Science* **304**, 571 (2004).
iii. R.N. Jones, *Clim. Change,* In press.
iv. B. Hare, M. Meinshausen, Potsdam Inst. for Clim. Impact Res. Rept. 49 No. 23 (2004).
v. S.H. Schneider, *Nature* **411**, 17 (2001).
vi. M.G. Morgan, M. Henrion, Eds., *Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge Univ. Press, New York, NY, 1990).
vii. J.G. Titus, V. Narayan. *Clim. Change* **33,** 151 (1996).
viii. E. Pate-Cornell, *Clim. Change,* **33**, 145 (1996).
ix. M.G. Morgan and D.W. Keith, *Env. Sci. & Tech.* **29**, 468 (1995)
x. N.G. Andronova, M.E. Schlesinger, *J. Geophys. Res.* **106**, 22605 (2001).
xi. C.E. Forest et al., *Science* **295**, 113 (2001).
xii. J. M. Gregory, R. J. Stouffer, S. C. B. Raper, P. A. Stott, N. A. Rayner, *Journal of Climate* **15**, 3117 (2002).
xiii. R. Knutti, T. F. Stocker, F. Joos, G. K. Plattner, *Nature* **416**, 719 (2002).
xiv. T.L. Wigley and S. Raper, *Science* **293**, 451 (2001)
xv J. Hansen*, Scientific American* **290**, 68 (2004).
xvi. J. M. Murphy *et al.*, *Nature* **430**, 768 (2004).
xvii P. Baer, T. Athanasiou, "Honesty about Dangerous Climate Change", http://www.ecoequity.org/ceo/ceo_8_2.htm