Nonlin. Processes Geophys., 17, 1–3, 2010
www.nonlin-processes-geophys.net/17/1/2010/
doi:10.5194/npg-17-1-2010

Nonlinear Processes in Geophysics

Comment on "Another look at climate sensitivity" by Zaliapin and Ghil (2010)

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Received: 17 April 2010 – Revised: 27 July 2010 – Accepted: 2 August 2010 – Published:

Abstract. Zaliapin and Ghil (hereafter, ZG) claim that the linearity of the climate feedback model in Roe and Baker (2007) (hereafter, RB) invalidates our derivation of the well-known skewed shapes of published probability distributions (pdfs) of climate sensitivity. We show here that linearity is fully justified. Nonlinearity could be of some importance only if the focus is on exotic and improbable events, which appear to be the focus of ZG, instead of the sensitivity pdfs, which were the focus of RB.

Equation (9) of ZG relates the equilibrium temperature rise, or climate sensitivity, ΔT, to the equilibrium radiative response, $\Delta R \sim -4[\mathrm{W/m^2}]$, produced by step-function radiative forcing:

$$\Delta R \equiv \frac{(f-1)}{\lambda_0}\Delta T - a\Delta T^2, \qquad (1)$$

where f is the total feedback factor, $\lambda_0 \approx 0.3$ is a reference sensitivity, $a \equiv -f'/(2\lambda_0)$. ZG show that if the coefficient a is sufficiently large, the relationship between ΔT and f tends to linear, and in that case the pdf of T derived from that of f would not have the characteristic high T tail that is the focus of intense interest in climate science (see refs. below, and note some sign confusion in ZG).

While the ZG statement is trivially correct as an algebraic exercise, we are interested in the application of Eq. (1) to climate simulations, where we are not free to pick arbitrary values of the parameters. We now show that in order to significantly decrease the skewness in the $\Delta T - f$ relationship a would have to take on values outside the range derived from published climate studies. The fact that the climate simulations do not yield such large values of a and do yield skewed climate sensitivity pdfs therefore renders the ZG exercise irrelevant for the study of these simulations.

Since ΔR and λ_0 are known, the importance of the nonlinear term in Eq. (1) depends only on the ratio $a/(f-1)$. Thus to examine the effect of linearizing the equation on computing sensitivity pdfs, we have analyzed the ranges of values of f and a relevant for this problem. We first consider the conceptually possible limiting case that $f \to 1$. RB explicitly cut off the feedback distribution at $f = 0.85$, and in our supplemetary online material (SOM) we showed that the resulting linear model still gives excellent reproduction of the many climate sensitivity distributions found in the literature. Thus extreme feedback behaviors, though interesting in principle, do not contribute significantly to climate sensitivity distributions produced by a range of climate models.

Table 1 shows values of the relevant parameters in Eq. (1), derived from a number of studies using a range of models and covering a range of simulations. These, as well as the sample calculation in the SOM of RB, show that typically $-0.06 \le a \le 0.06$ (See Table 1, and contrast with ZG, Fig. 2). However, if $a > 0$ its magnitude must be almost an order of magnitude greater than this in order to significantly impact the relationship between f and ΔT, and, hence, diminish the skewness of the sensitivity pdf. Note that in several of the reported cases $a < 0$; the nonlinearity actually increases the skewness of the distribution.

In order to compare the ZG nonlinear relationships (Eq. 1 and the derived sensitivity pdf) with those of RB (for which $a = 0$) and with the results of previous published climate simulations, we must at least ensure that pairs of $\overline{f}$, ΔT cross ($\sim 0.65, \sim 3.5\,°\mathrm{C}$) for all values of a, since this is the combination that is typically calculated from pairs of control and perturbation GCM experiments (with all their internal nonlinearities of course). ZG's curve does not even meet this requirement. Figure 1a shows the functional relationship between f and ΔT, adjusted in this way for the linear model

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Published by Copernicus Publications on behalf of the European Geosciences Union and the American Geophysical Union.

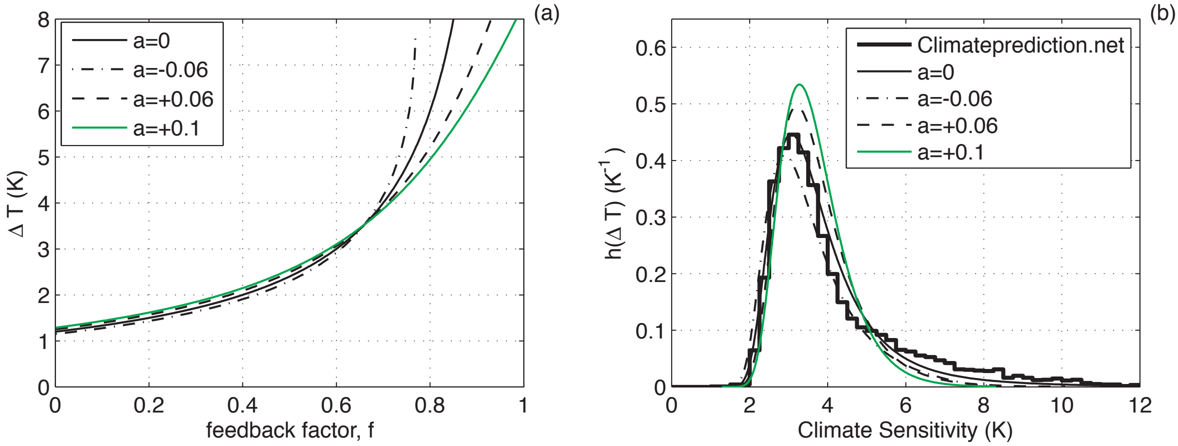

Fig. 1. **(a)** relationship between f and ΔT for extreme range of a found in models. The curves all go through $(\overline{f}, \Delta T)$ = ($\sim$ 0.65, $\sim$3.5 °C), as they must in order to match published calculations of model feedbacks which have assumed the $\Delta T - f$ relationship to be linear. That is: in cases for which $a \neq 0$ we adjust the true $\overline{f}$ so that a linear analysis would produce apparent values (0.65, 3.5 °C). **(b)** The resulting pdfs of climate sensitivity for normal distributions in feedbacks (see RB), and the *climateprediction.net* results. Also shown are results for $a = 0.1$, the smallest value countenanced by ZG, who also consider $a = 1$ and $a = 10$.

Table 1. Modelled feedback nonlinearities: (i) Boer and Yu (2003), (ii) Senior and Mitchell (2000), (iii) Colman et al. (1997), (iv) Crucifix (2007), (v) Hewitt and Mitchell (1997), (vi) Broccoli and Manabe (1987), (vii) Wetherald and Manabe (1975), (viii) Colman and McAveny (2009). These studies use various ways of estimating climate sensitivity and thus feedbacks as a function of mean state.

Study	Model	ΔT	*df/dT* [K^{-1}]	a [Wm^{-2} K^{-2}]
i	CCCma	4.0 °C	−0.0048	0.008
i	CCCma	7.0 °C	−0.0060	0.010
ii	Hadley	3.5 °C	0.038	−0.063
iii	BMRC	1 °C	−0.0025	0.0042
iv	CCSM	6 °C	−0.036	0.060
iv	HADCM3	6 °C	0.010	−0.017
iv	IPSL	6 °C	0.019	−0.032
iv	MIROC	6 °C	0.035	−0.058
v	UKMO	4.9 °C	−0.012	0.020
vi	GFDL	3.6 °C	−0.033	0.054
vii	GFDL	4.4 °C	−0.035	0.059
viii	BMRC	20 °C	−0.012	0.020

($a = 0$) and the extreme positive and negative values of a from Table 1 and the even larger value ($a = 0.1$) from ZG. Figure 1b shows the pdf of climate sensitivity distributions corresponding to each of the $\Delta T - f$ relationships in Fig. 1b. Also shown is the *climateprediction.net* distribution, whose shape is very similar to many other published sensitivity pdfs cited earlier.

These figures show that the linear approximation is fully appropriate for understanding the main features of the calculated distribution and is the best fit to the *climateprediction.net* results. The pdf calculated from ZG's curve is the worst fit. Thus in their analysis ZG use unrealistic (high) values of a and their model is inconsistent with all the climate simulations. It is both misleading and counterproductive to claim that complex models are necessary in order to understand all climate phenomena. In particular, nonlinear terms in the relationship linking equilibrium temperature rise to step-function forcing are irrelevant to climate sensitivity distributions. The trivial fact that the climate system is nonlinear does not preclude the use or value of linear analyses.

We have focussed here on ZG's discussion of Eq. (1). However, it is useful to point out several nontrivial mathematical and physical errors in ZG. Among these are the following: they misunderstand and misuse the quantity ΔR, crucial to interpretation of Eq. (1); they have modified and confused Fig. 1, RB; they present their climate model as realistic evidence for the possibility of bifurcation when according to that model the current global temperature is 300 K – at $T = 288$ K the model would put us in an unstable regime.

Finally, there is little support in the literature for "tipping points" or bistable behavior being of practical concern on a global scale, and over the range of reasonable future climates we can contemplate, as shown by a host of climate models, including the very crude early model of Wetherald and Manabe (1975), cited by ZG in support of their point (see Table 1 below). Using more complete models, Voigt and Marotzke (2009), Colman and McAveny (2009), and many others have demonstrated this.

Edited by: D. Schertzer
Reviewed by: P. Ditlevsen and another anonymous referee

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