Comments on "The Relationship between Land–Ocean Surface Temperature Contrast and Radiative Forcing"

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Abstract

In a recent article Dommenget [2009] (hereafter D09) discussed the role of sea surface temperature variability for continental climate variability and change. Lambert et al. [2011] comment on D09 in their article several times arguing that the sensitivity experiment in D09, in which the SST response to surface land temperature changes are discussed, is inconsistent with their and other previously published studies. In this comment the results of the D09 sensitivity experiments are discussed in more detail and the experiments are extended for longer response times. It is shown that the discussion of how the ocean responses to land forcing is time scale depending, with a very weak response to land forcing on interannual time scales as discussed in D09 and an about twice as strong near equilibrium response to land forcing on time scales longer than 100yrs. The asymmetric land-sea interaction, with the ocean forcing the land much more strongly than the land forces the oceans as discussed in D09, is confirmed by this study.

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Introduction

In a recent article Dommenget [2009] (hereafter D09) discussed the role of sea surface temperature (SST) variability for continental climate variability and change. The focus of this article is on the role of the natural SST variability in forcing interannual natural climate variability in continental surface temperatures. But some discussion in D09 is also focused on climate change scenarios and the role of the ocean in the continental response to doubling of CO_2.

Lambert et al. [2011] (here after LWJ11) comment on D09 in their article several times arguing that the sensitivity experiment in D09, in which the SST response to surface land temperature changes are discussed, is inconsistent with their and other previously published studies. In particular LWJ11 point out that the simulation is only 20yrs long and is therefore unlikely to be in equilibrium. They further point out that the weak SST response is inconsistent with Forsters et al. [2000]. Implicitly, LWJ11 argue [personal communication with Hugo Lambert] that the experiment should result in the same land-sea warming ratio of 1.7 as in the OZ-2xCO2 experiment of D09.

Indeed, it seems reasonable to assume that the 20yrs SST response simulation in D09 is not in equilibrium. In this comment the results of the D09 sensitivity experiments are discussed in more detail and it is further shown how they relate to long-time near equilibrium responses. The experiment with land forcing is extended for a longer response time and compared with a twin experiment using a slab-ocean model. Further the simple toy model of D09 is used to discuss the relative roles of ocean and land in climate change, natural variability and in different sensitivity experiments to better understand the results of D09 and how they relate to other studies and that of LWJ11.

Model Simulations

As in D09 all simulations are based on the atmospheric GCM ECHAM5 [Roeckner et al., 2003] with a horizontal resolution of T31 (3.75^ox3.75^o) and 19 vertical levels. In the OZ-TLAND experiment the atmosphere is coupled to the simple 1-dimensional ocean mixed layer model OZ [Dommenget and Latif, 2008] as in D09. As describe in D09 the ocean model OZ has 19 vertical layers that are connected through vertical diffusion only. It is further important to note that the OZ models lowest level is coupled, by Newtonian damping, to a fixed deep ocean temperature. This approach basically assumes that the deep ocean is a weak damping (infinite heat sink) to interannual to decadal timescales natural climate variability [e.g. Alexander et al., 2000 , Dommenget and Latif, 2002 or Dommenget and Latif, 2008].

However, as this deep ocean damping will reduce the equilibrium SST response of the OZ model it is instructive in the context of this comment to look at the SST response in a slab ocean model that does not include any deep ocean damping. We therefore repeat the OZ-TLAND simulation with the OZ model replaced against a 50m slab ocean model (hereafter SLAB-TLAND). Both simulations are integrated for 2x100yrs with continental surface temperatures, T_{land}, increased by 1K and decreased by 1K. The response is defined in all cases as the difference between the +1K and the -1K divided by two. As an analog for the OZ 2xCO_2 simulation in D09 we also simulate the slab ocean response to doubling of CO_2 (refereed to as SLAB 2xCO_2). The near equilibrium response in SLAB 2xCO_2 is defined as the difference between the mean of the years 21-50 in the $2xCO_2$ simulation minus the mean of a 50yrs control simulation.

Response to land surface temperature

Fig.1 shows the SST response of the OZ-TLAND and SLAB-TLAND simulation to +1K T_{land} increase. A few points regarding the response pattern can be note here in respect to the discussions in D09 and LWJ11:

- The OZ-TLAND response pattern for the years 1-20 is not identical to that of D09, because the simulation has been started from slightly different initial condition to produce an independent estimate to that of D09.
- The OZ-TLAND SST response pattern is very similar over all time intervals, indicating that the pattern is a robust signature of the ECHAM5-OZ model. The amplitude is slightly increasing over time and is also tending towards a larger global mean SST warming (regions of negative SST response decrease).
- The response pattern has some clear structure, which even includes regions that cool in the tropical and southern hemisphere. This is indicating that atmosphere circulation changes are involved in the pattern formation. The structure to some extend resembles the hyper mode pattern of multi decadal SST variability as discussed in Dommenget and Latif [2008].
- It is also interesting to note that equatorial east Pacific region tends towards a negative response to positive T_{land} changes, which is similar to the El Nino unrelated trends as discussed in Compo and Sardeshmukh [2010]. They argued that the trend over the last decades, that is unrelated to the El Nino dynamics is a cooling in the equatorial east Pacific region. In the context of the OZ-TLAND simulation result, the cooling found in the Compo and Sardeshmukh [2010] may be interpreted as the oceans response to land warming not involving El Nino dynamics.
- The warming pattern seems also quite consistent with the Forster et al. [2000] experiment, where 3xCO2 was increase only over land. They also find a much weaker response over the oceans than over land and also have negative SST responses in the southern hemispheric subtropics to extra-tropics.
- The SLAB-TLAND experiment shows a response pattern similar to that of the OZ-TLAND, but shifted to positive values and overall with larger amplitudes. Some significant differences in the patterns reflect the different ocean dynamics of the OZ and SLAB ocean models.

The global mean response of the oceans to +1K T_{land} increase can better be discussed on the basis of the time series of global mean SST of ice free regions, T_{ocean}, see Fig. 2. The following should be noted here:

- The OZ-TLAND simulation is close to equilibrium after about 20yrs, with the equilibrium T_{ocean} response slightly below 0.3K, which is about 0.1K larger than the mean of the first 20yrs. It has to be noted here that the discussion in D09 focus on response of the ocean to the natural variability of T_{land}. Since the continental variability does not involve much variance on time scales longer than a year, the mean of the first 20yrs seems to be a good upper boundary value for the ocean response. However, if we want to consider the oceans equilibrium response to long time forcings from land, as in climate change scenarios, the mean of the first 20yrs is not a sufficient estimate of the equilibrium T_{ocean} response.

- The SLAB-TLAND simulation is essentially in equilibrium after 20yrs, with the global mean ocean heat uptake of 0.005±0.06W/m^2 in the period 51-100yrs.
- The SLAB-TLAND response is significantly larger than in the OZ-TLAND simulation, by about 60% (0.18K). The OZ model has a Newtonian damping to the deep ocean, which acts as a weak (~0.4W/m^2/K) damping to the SST, that is not present in the slab ocean model. While this damping is more realistic for interannual to decadal SST variability, it becomes unrealistic for long time (>100yrs) equilibrium.
- The land-sea warming response ratio (T_{land}/T_{ocean}) in the OZ TLAND experiment is 5.0 for the first 20yrs (as in D09) and 3.6 for the period 51-100yrs. The near equilibrium SLAB-TLAND land-sea warming response ratio is 2.2 (with a +/-0.1 95% confidence interval), which is still significantly much larger than the 1.3 land-sea warming response ratio found in the experiment SST+1K in D09. Thus clearly indicating a significant asymmetry in land-sea interaction, with the ocean forcing the land much more strongly.

Box Model Discussion

In D09 the series of different sensitivity experiments is summarized in a simple two box models. This simple conceptual model allows discussing how the climate system may response in different idealized sensitivity experiments, which are in some case highly hypothetical. In the following we will use this box model to discuss some of the characteristics that the climate models would have in idealized sensitivity experiments. In particular we will discuss how the discussion may change or not change, if we consider equilibrium responses.

The box model in D09 is given by two equations for the tendencies of T'_{land} and T'_{ocean} (deviations from the climatological global mean surface temperature over land and over the ice free oceans, respectively):

$$\lambda_{land} \frac{\partial T'_{land}}{\partial t} = c_L T'_{land} + c_{LO}(T'_{ocean} - T'_{land}) + F_L \qquad [1]$$

$$\lambda_{ocean} \frac{\partial T'_{ocean}}{\partial t} = c_O T'_{ocean} + c_{OL}(T'_{land} - T'_{ocean}) + F_O \qquad [2]$$

with the feedback parameters c_L and c_O representing the net effects of all local feedbacks, the effective coupling parameters c_{LO} and c_{OL}, and the net forcings over land F_L and over the ocean F_O. The different heat capacities over land and ocean are given by λ_{land} and λ_{ocean}, respectively. The model parameters in D09 where computed by a least square fit to five sensitivity experiments with the OZ model. Taking the new results with the longer integration of the OZ-TLAND and the slab ocean model experiments into account, the following points can be made:

- Given the parameters of D09, the simple box model predicts for the SST equilibrium response over ice free regions, T'_{ocean}:

$$T'_{ocean} = \frac{c_{OL}}{c_{OL} - c_O} T'_{land} = \frac{0.5}{1.3} T'_{land} = 0.4 \cdot T'_{land} \qquad [5]$$

This is roughly what we found in the SLAB-TLAND experiment.

- The box model parameters can be estimated with the new experiment results: We can replace the OZ-TLAND and OZ-2xCO_2 values against those of the SLAB-TLAND and SLAB 2xCO_2 equilibrium response values (T'_{land} = 6.9K and T'_{ocean} = 4.3K). The FIXLAND-2xCO_2 of D09 has no slab ocean counter part, but it may be assumed, based on the SLAB-TLAND and SLAB 2xCO_2 equilibrium response values, that the equilibrium ocean response of the FIXLAND-2xCO_2 would be about 1.2K. With these response values we find the parameters are: c_L=1.6Wm^{-2}K^{-1}, c_O=-0.6Wm^{-2}K^{-1}, c_{LO}=5.1Wm^{-2}K^{-1}, c_{OL}=0.5Wm^{-2}K^{-1} and the root-mean-square error of the fit is 0.06K (0.09K in D09). The parameters have not change much compared to D09, with some exception for c_O, which was significantly stronger in D09, because the OZ model used in D09 does include an ocean damping term, which is not present in the slab ocean model used here.
- We can use the box model to compare the results of D09 with the experiments 3xCO_2, 3xCO_2(land only) and 3xCO_2(ocean only) of Forster et al. [2000]. They find that the global warming is 29% of the 3xCO_2 if only land is forced and 73% is only the ocean is forced. The box model of D09 is quite consistent with these finding, predicting 26% for land and 74% for ocean only forcing.

Summary

In summary we discussed the response of the ocean to land forcing in sensitivity experiments of D09 in some more detail. In particular we have shown that the strength of the response of the oceans is time scale dependent with a very weak response to land forcing on interannual time scales as discussed in D09 and an about twice as strong near equilibrium response to land forcing on time scales longer than 100yrs. The asymmetric land-sea interaction, with the ocean forcing the land much more strongly than the land forces the oceans as discussed in D09, is confirmed by this study.

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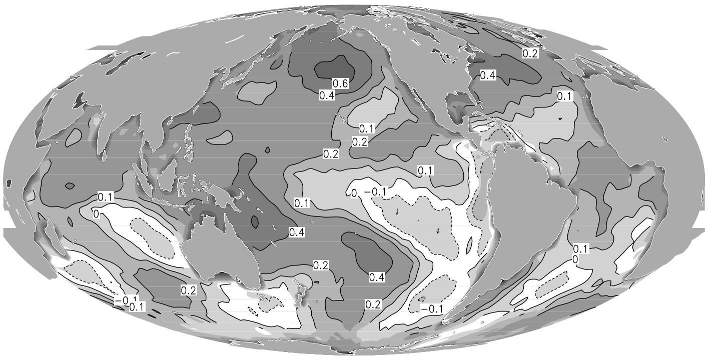
Figures

Figure 1: SST response to T_{land} +1K forcing in different experiments.

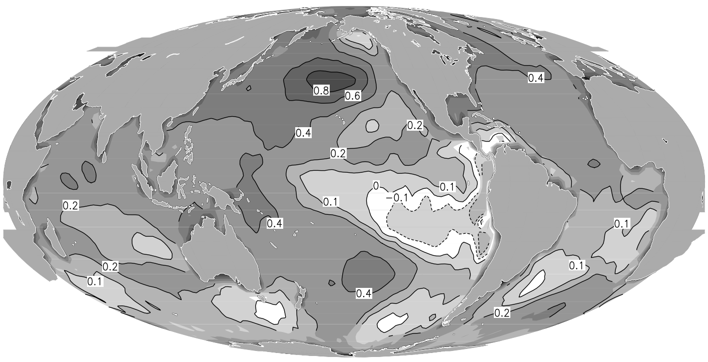
Figure 2: T_{ocean} response to T_{land} +1K forcing in different experiments.

Figure 1

a) OZ-TLAND mean response 1-20yrs



b) OZ-TLAND mean response 51-100yrs



c) SLAB-TLAND equilibrium response (mean 51-100yrs)

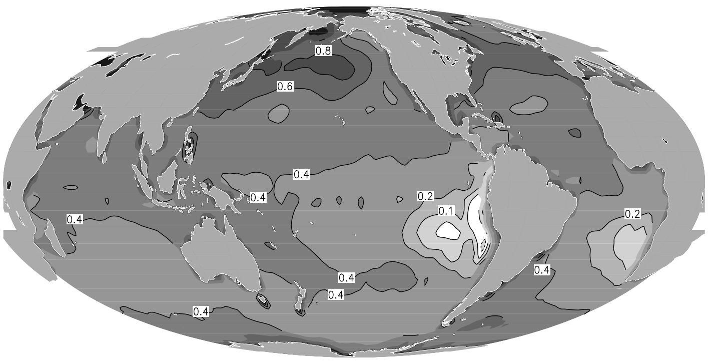


Figure 1: SST response to T_{land} +1K forcing in different experiments.

Figure 2

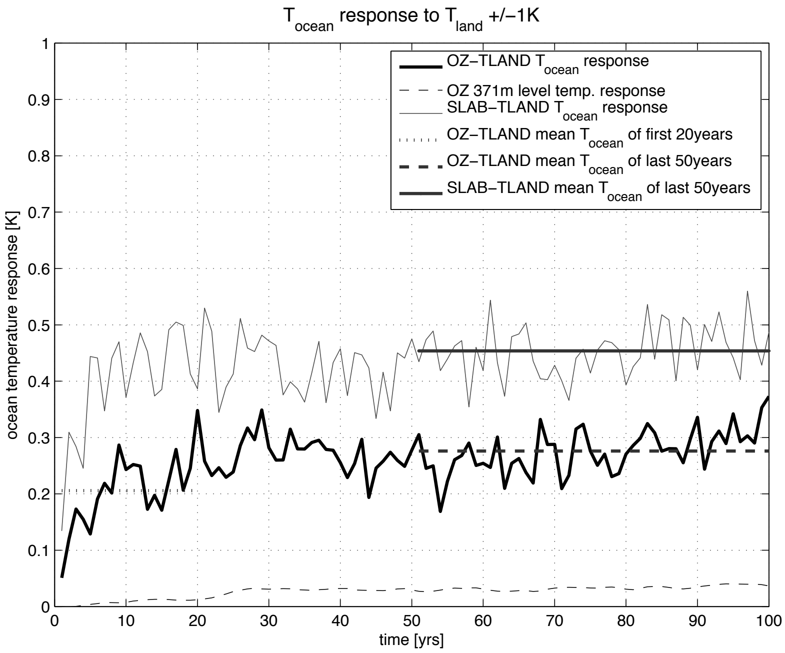


Figure 2: T_{ocean} response to T_{land} +1K forcing in different experiments.