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Biogeosciences
Discussions

Interactive comment on “Impact of an extremely large magnitude volcanic eruption on the global climate and carbon cycle estimated from ensemble Earth System Model simulations” *by* J. Segschneider et al.

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First we wish to thank Chris Jones for his constructive remarks.

The minor points of the review were all addressed (see ‘reply to further comments’ below). The more complex issues are:

1. response to volcanic forcing as a function of eruption strength
2. the plot of delta C as function of delta T,

3. the discussion of carbon cycle-climate feedback.

(1) While we agree that it would be interesting to show a plot of the response of the carbon cycle as function of eruption strength, this cannot be done by analysis of existing model experiments. Only a few experiments with different eruption strength have been performed with the MPI-ESM, and the 1258 A.D. eruption is already one of the strongest of those. Note also that the 1258 A.D. eruption was simulated as part of the Millennium integration, and thus within a history of several volcanic eruptions, where previous eruptions still have an impact on the model state (see Fig. 3 in Brovkin et al., 2011). The 1258 A.D case thus is not directly comparable to the Yellowstone cases described here which are single eruptions started from volcano-unperturbed control states, and even with different forcing approach (Crowley et al. 2008 for 1258 A.D. vs. Timmreck et al 2011 for Yellowstone). The ensemble of simulations presented in this ms. and the preparation of forcing fields of AOD is rather demanding in terms of computing time, in fact so demanding that a special project at MPI-M was needed to allow the Yellowstone experiments being performed. A similar set of experiments with different eruption strengths simply cannot be performed in reasonable time and it would be a different study entirely. As stated in the ms. the focus of the Yellowstone study and the new aspect is to provide adequate forcing for AOD, to provide an ensemble of simulations, to relate results to internal variability, and to investigate the long term response of the carbon cycle. We, therefore, argue that our study provides original research also without the suggested analysis. Indeed Ref#1 states that “the additional analysis is not vital”. If it were only an additional analysis of existing model runs we would perform it, but with the available experiments it is not possible. A setup as in Froelicher et al. 2011 seems to be more suitable for the suggested analysis. Even then one would need to think on how to perform the analysis – show maximum perturbations, or integrated fluxes over a certain time window?

(2) The suggested plot is a useful addition to the ms We add this plot as Figure 10 and some additional text (see below) to the ms. Nevertheless one needs to keep in

mind that changes in the various carbon pools are not only a function of temperature anomalies but also anomalies of SWR, changes in ocean circulation and the inherent processes of the model (e.g. respiration time scale of soil) and it is currently not possible to disentangle the individual contributions (as stated on p8711 ln. 11). The new Fig. 10, however, reveals some interesting features of the model response not so easy to obtain from the original figures (Fig. 3 and Fig. 8).

New text (insert at the end of section 3.2.1) Fig. 10(new) shows plots of the global mean carbon pool anomalies against SAT anomalies for the different compartments of the carbon cycle for the ensemble mean. To read the figures, one should follow the line from START using the time information as navigation aid. Fig. 10a shows that, unexpectedly, at the time of maximum temperature anomaly, the atmospheric carbon content anomaly is close to zero due to compensating effects on the land and ocean carbon pools. Only from year 3 on the atmospheric CO2 anomaly becomes larger, at which time the SAT anomalies already become smaller. In year 6 the SAT anomaly is close to -1K and the atmospheric carbon content anomaly has grown to -11GtC. After year 6 both SAT and atmospheric carbon content anomalies become smaller as can also be seen in Figs. 3, and Fig. 8a. The oceanic carbon pool (Fig. 10b) initially increases in concert with decreasing SAT and then further grows as SAT anomalies remain in the range of -3 to -4 K. After year 4, the ocean looses carbon even though SAT anomalies are still negative until at year 35 the negative anomaly is close to -7GtC. After year 35 the oceanic carbon content increases again, but remains below pre-eruption level as discussed above. The soil carbon pool (Fig. 10c) initially gains up to 3 GtC carbon as SAT decreases by -4K, but towards the end of year 2 begins to loose carbon even though SAT anomalies are still in the range of -3 to -4 K. This interesting behaviour can be explained by the anomalies of the vegetation pool (Fig. 10d), which shows a loss of carbon with decreasing SAT and a gain of carbon with increasing SAT, as both temperature and photosynthesis anomalies are mainly driven by the SWR anomalies. The negative vegetation anomaly results in less litter input to the soil pool, and this temporarily overrides the inherent response of the soil pool to

temperature. Only after year 3, when the negative SAT anomalies already become less strong, does the soil pool gain up to 10 GtC of carbon even until SAT anomalies are back to zero. Also the final state of the soil pool differs from the initial state by almost 4GtC

(3) With regard to the carbon cycle-climate feedback, we apparently made not clear enough that there is a principal difference compared to the C4MIP feedback analysis of Friedlingstein et al (2006). In the volcano experiment, anomalies of temperature are not caused by atmospheric pCO2 changes. Therefore, the concept of climate-carbon cycle feedback as in Friedlingstein et al., 2006, and Roy et al., 2011 does not apply! Only the volcano induced changes of atmospheric pCO2 are then potentially driving a feedback, and these are much smaller than those caused by anthropogenic emissions, i.e., max 8ppm vs several hundreds of ppm. It is therefore that the carbon cycle-climate feedback provides only a negligible fraction of the climate response to a volcanic eruption. For clarification we now state this explicitly when discussing feedback:

Add new text on p8713 ln 12 after ….'for the MPI-ESM).' With regard to the linear carbon cycle-climate feedback analysis that has been performed in the C4MIP framework (Friedlingstein et al., 2006; Roy et al., 2011) one needs to keep in mind that the temperature anomalies in the volcano experiments are not caused by CO2, but by the volcanic aerosols. In our experiment only the volcano induced changes of atmospheric pCO2 are potentially driving a carbon cycle-climate feedback. These are much smaller than those caused by anthropogenic emissions, i.e., max 8ppm vs several hundreds of ppm. It is therefore that the carbon cycle-climate feedback provides only a negligible fraction of the climate response to a volcanic eruption:

New references

Friedlingstein, P. et al. 2006. Climate-carbon cycle feedback analysis: Results from the C4MIP model intercomparison. J. Climate, 19(14), 3337-3353.

Roy, T. et al. 2011. Regional impacts of climate change and atmospheric CO2 on

future ocean carbon uptake: A multi-model linear feedback analysis. J. Climate, 24, 2300-2318.

Reply to further comments

Ref#1 -1

p.8700, lines 15-20. You mention diffuse light later, but could discuss it here as a potentially large driver of post-volcanic response. Angert et al and Mercado et al are both relevant references. Also include on figure 1?

We now refer in the ms. to Angert, A., S. Biraud, C. Bonfils, W. Buermann, and I. Fung, 2004. CO2 seasonality indicates origins of post-Pinatubo sink. GRL (31), L11103, doi:10.1029/2004/GL019760

Mercado, L.A.. et al., 2009. Impact of changes in diffuse radiation on the global land carbon sink. Nature, 458, 1014-1019,doi:10.1038/nature07949

We will add a sentence at the end of section 2.2 (p8709, ln 20) as follows: For a discussion of potential drivers of the anomalies by volcano related processes not included in the model, such as fertilization of the ocean by volcanic ashes or the impact of diffuse radiation on the terrestrial vegetation, we refer to the discussion section (Sec. 4).

In the discussion (section 4) we will change the text to:

p8714 ln 21 Limitations of the employed terrestrial vegetation model are that it does not take into account higher photosynthesis rates due to more diffuse radiation that may occur due to higher aerosol loadings after volcanic eruptions (Gu et al., 2003) or caused by anthropogenic emissions of aerosols (Mercado et al., 2009). Using evidence from tree rings, however, Krakauer and Randerson (2003) did not find enhanced Net Primary Production following volcanic eruptions, and also Angert et al. (2004) rejected the hypothesis that Net Primary Production due to more diffuse radiation could have increased after the Mt. Pinatubo eruption. For the much larger eruption that we investigate it seems likely that the reduction in short wave radiation by more than 50 Wm-2

dominates over any gain by more diffuse radiation. This implies that the neglection of diffuse radiation impact on plant growth does not severely limit our study.

Ref#1 -2

- p.8710. line 3. you say the land flux doesn't depend directly on the atmos CO2 conc. This is not strictly true - you could say that it doesn't depend "as strongly as the ocean".

We changed "not directly" to "not as strongly"

Ref#1 -3

- p.8710, line 12. Units of NPP here should be GtC PER YEAR.

- done

Ref#1 -4

- p.8713. discussion on strength of climate-carbon cycle feedback. In the linear C4MIPframework the size of perturbation shouldn't matter, the feedback gain would be the same and simply provides a scaling for the response. e.g. for a gain, "g" of 0.2, one gets a feedback factor of 1/(1-g)=1.25. So the signal should be scaled by +25% compared with a simulation without the feedback. So I don't understand why you get a much smaller response (you claim a delta T of only 1% due to carbon cycle feedback). Is your carbon cycle sensitivity smaller for small perturbations? or is this a feature of the timescale of the perturbation? what is the MPI-ESM gain?

– see (3) above

Ref#1 -5

- p.8713. can you define "tephra" for the non-volcano experts

= volcanic ash layer - done

Ref#1 -6

- figure 8. When discussing reversibility of the carbon cycle state and that this lags the SAT response, it might be illustrative to plot the carbon pools against SAT itself. A completely reversible signal would simply follow the same path down and up, whereas the lags in the system would show up as a loop on this figure (not strictly a hysteresis, but looking similar).

– see (2) above, now provided and discussed in text

Interactive comment on Biogeosciences Discuss., 9, 8693, 2012.

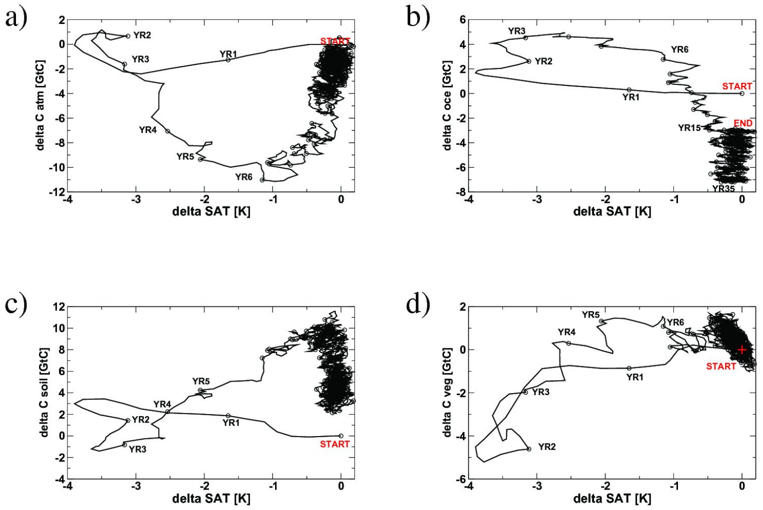

Figure 10: Plots of ensemble mean SAT anomaly vs. ensemble mean anomaly of the carbon contents of (a) the atmosphere, (b) the ocean, (c) the soil, and (d) the terrestrial vegetation for 200 yr. Time information is given by circles at the end of each year and annotaed for selected years. Note the different scales in the panels.

Fig. 1. New Fig. 10