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Climate of the Past Discussions

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Interactive Comment

Interactive comment on "Cold tongue/Warm pool and ENSO dynamics in the Pliocene" *by* A. S. von der Heydt et al.

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We thank the Amy Clement for her thorough reading of the manuscript and the constructive and positive comments. In the revised manuscript we have included all suggested changes. Please find below our detailed answers to the comments.

- Main points:

  1. *Review: The thesis of my graduate student, Pedro DiNezio, has shown that the equilibrated response of the equatorial Pacific thermocline to increased zonal wind stress has very little signal in the eastern Pacific. The figure*

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Interactive Discussion

Discussion Paper

below shows the regression of thermocline depth on zonal mean wind, filtered at a decadal timescale. You get similar results with a shallow water model forced with strengthened zonal winds. The result goes back to the Cane and Sarachik papers, and has also recently been shown in Clarke et al. (JPO, 2010). Von der Heydt et al argue that coupled feedbacks can give you a thermocline response in the east in their model and hence move the cold tongue, but I don't understand how one can get around the equilibrated thermocline response. Perhaps calculating the heat budget, or even showing Ts may help. Could it be that the upwelling is actually the cause of the stronger cold tongue with stronger winds? This would be consistent with what is in Pedro's first and last Chapter of his thesis.

Answer: In our simulations we observe, that the background climate changes with increasing external wind stress and T_0. Under stronger wind, the mean thermocline becomes deeper in the west and shallower in the east equatorial Pacific (see figure 1a below) consistent with Chapter 2.7 of the thesis by Pedro di Nezio, who suggests a reduced thermocline tilt of the background climate state. We do not observe decadal variations in our model, which may be due to the simplicity of the model.

The stronger cold tongue with increasing wind is also due to stronger upwelling. While the backround thermocline depth in the east changes less than in the west with increasing external wind stress, the vertical velocities below the mixed layer increase most strongly in the eastern Pacific (see figure 1b below). At the same time, the minimum in the thermocline depth anomaly and the maximum of the vertical velocity shift eastward with increasing wind strength. We will add this figure to the revised manuscript and discuss the results.

2. *Review: I don't understand why the cold tongue contracts eastward with warmer To. It seems intuitive, but some additional analysis of the simulations might help show the mechanism.*

Answer: The cold tongue moves to the west under warmer T_0 (see Fig.3b in the manuscript). This works in a similar way as for the wind stress: Increasing T_0 has only a weak effect on the mean thermocline depth, though the tilt becomes somewhat stronger for warmer T_0 (see figure 1c below). The upwelling velocity in the eastern Pacific, however, increases strongly with T_0 and its maximum moves to the west, which explains the westward shift of the cold tongue under higher T_0 (figure 1d below).

- Minor points:

  1. *Review: Two papers have come out just in the last 2 months with proxies showing little change in ENSO variability in the Pliocene (Watanabe et al., Nature 2011, and a paper that is about to come out in Paleoceanography, 2011-?? I don't have it handy, but it on the journal website as about to appear).*
     Answer: We cite these two papers in the revised manuscript and add discussion on them.

  2. *Review: In the model description, it would help the reader if the authors provided more discussion about the fact that their model actually simulates the mean SST – I got all the way through the model description before I realized this distinction from the ZC model. It would be nice to just add a few sentences about what To means, and how the model can simulate temperatures that deviate from this.*
     Answer: The fully-coupled model, where both mean state and variability are computed, was extensively discussed (including the interpretation of τ_{ext}) in Dijkstra and Neelin (1995), but we will add additional description so the distinction with the ZC (anomaly) model is more clear.

  3. *Review: The authors suggest that weaker equatorial trade winds could result from a weakened equator to pole gradient. However, there is another*

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mechanism which can produce weaker surface winds in a warmer climate: that of Held and Soden (2006). Because atmospheric humidity goes up according to the Clausius –Clapeyron scaling, but precipitation is constrained by radiation budget, the overturning circulation must weaken in a warmer climate. Held and Soden (2006) and Vecchi and Soden (2007) show that this takes place in the zonally asymmetric component of the circulation.

Answer: Thank you, we include this mechanism (and references) in the revised manuscript.

4. *Review: DiNezio et al (Chapter 4 in the thesis) provided an argument for why ENSO doesn't change much in response to GHG forcing in a multi-model mean sense. Weakened upwelling associated with the weaker atmospheric circulation with a warmer climate (Held and Soden 2006) tends to weaken the strength of ENSO events, while a sharper thermocline (associated with stronger radiative forcing perhaps akin to To in your paper) tends to strengthen the events. These opposing influences mean that ENSO doesn't change much, and the inter-model differences in ENSO behavior can be explained by differences in the balance between these mechanisms. I wonder to what extent something similar happens in the ZC model, which explains why there is little change in ENSO over a wide range of climates.*

   Answer: This is most likely what happens in our model as well: weaker wind leads to a reduced tilt in the thermocline and to a smaller amplitude of ENSO events (Figure 4a in the manuscript). Increasing T_0 on the other hand strengthens the thermocline tilt and enhances the amplitude of ENSO events.

5. *Review: In the figure captions, the authors note that there is no physical solution for a certain range of parameters; this should be discussed in the text. What does that mean?*

   Answer: The model does not converge for certain parameter values, particularly for strong wind forcing and high To. This is due to surfacing of the ther-

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mocline where also the linearity of the shallow-water model breaks down. We did not attempt to implement limiters on h as we are more interested in the weak wind cases than in the strong wind cases.

6. *Review: It looks to me like there are 3 'regimes' for cold tongue position. Or is this just related to the resolution?*
   Answer: This is most likely related to the resolution. However, the shift in the cold tongue is not linear. There is a relatively strong shift between the cases with and without ENSO variability (In Fig. 3a between τ_0=0.07Pa and 0.09Pa). There seems to be another shift at higher values of τ_0, but this is probably related to resolution.

7. *Review: I have not seen the PRISM data plotted in the way it is shown in Figure 7. It looks pretty strange compared to modern observations, and in fact more like the simple model results. Why? Why in the model is there an increase of SST near the eastern boundary? Absence of coastal phenomena? Perhaps this could have some bearing on the interpretation of the PRISM data.*
   Answer: The PRISM data set is based on relatively few data points along the equator. The warm temperatures in the east are actual data points (84-95°W), as well as one point around 133°W. The minimum SST along the equator is therefore not very reliable and could be warmer for example. Nevertheless, the minimum needs to be somewhere between 95°W and 133°W, which indicates a westward shift of the cold tongue as compared to present day.
   The SST increase near the eastern boundary in the model results is caused by a stronger upwelling feedback with respect to thermocline feedback and is described in detail in Dijkstra and Neelin (1995), (Fig. 2 - Fig. 4 + description on p1346-1347) which we will not repeat here; however, a short summary will be included in the revised paper.

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Caption to figure 1: Change in background climate state for different external wind stresses τ_0 and temperatures T_0: (a) Mean thermocline depth anomaly for $T_0 = 30°$C and different τ_0; (b) Mean vertical velocity below the mixed layer w_1 for $T_0 = 30°$C and different τ_0; (c) Mean thermocline depth anomaly for $\tau_0 = 0.01$ Pa and different T_0; (d) Mean vertical velocity below the mixed layer w_1 for $\tau_0 = 0.01$ Pa and different T_0.

Interactive comment on Clim. Past Discuss., 7, 997, 2011.

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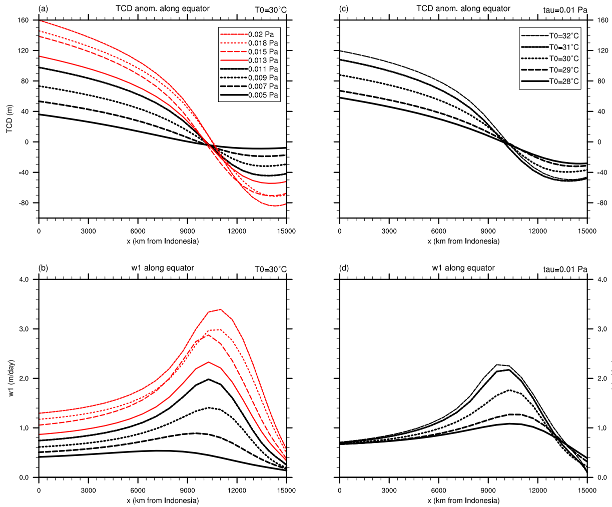

Fig. 1. Change in background climate state for different external wind stresses τ_0 and temperatures T_0.