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Climate of the Past Discussions

Interactive comment on "The effect of low ancient greenhouse climate temperature gradients on the ocean's overturning circulation" *by* W. P. Sijp and M. H. England

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Review of the manuscript "The effect of low ancient greenhouse climate temperature gradients on the ocean's overturning circulation", by W. P. Sijp and M. H. England

General comments

In this paper, Sijp and England investigate changes in ocean overturning circulation as consequence of a reduction in: i) pole to equator temperature difference; and

ii) wind strength. In order to do so, the authors use a coupled climate model (UVic model) with an altered radiative balance in the atmosphere. Unexpectedly, the authors find that meridional overturning circulation remains relatively stable when the pole-equator temperature gradient and wind strength are reduced. I think that the authors present some very interesting results. Because the conditions investigated in this paper are typical of a greenhouse-type of climate, the authors choose to run their simulation using a Cretaceous geography. Considering that the Cretaceous is a time period characterized by a greenhouse climate and by a geography similar to the Paleocene-Eocene one, the results of this study can be applied to explain overturning changes during a wider geological timeframe than the one discussed in this paper. In addition, understanding changes in ocean circulation as consequence of a low pole-to-equator temperature gradient is a really important step to gain insight on how ocean overturning might change as consequence of modern and future climate changes. I recommend the publication of this paper in "Climate of the Past" after few minor revisions.

Specific comments: I agree with the comments already provided by Reviewer 1. Below are few additional suggestions.

Model and experimental design. Figure 4 is cited before Figures 1, 2 and 3.

We change the part "is shown in Fig. 4a" of line 7 on page 4793 to "is described below".

Discussion. Because this paper will be read by many paleoceanographers, I think that the discussion would greatly benefit by the comparison among the results obtained by the authors and previously published data based on paleoceanographic proxies.

We add the following paragraphs to the Discussion Section:

Subpolar Atlantic summer temperatures around 60° S are between 20° and 24° C in LOWGRAD (Fig. 1a). This is in agreement with similar estimates by (*Bice et al.*, 2003) based on oxygen isotope data for the Falkland Plateau, around 60° S paleolatitude, for the mid Turionian, and lower than the 30-32° C they reported for a warm excursion during the late Turonian. The good deep ocean temperature agreement with proxies (see below) indicates that our modification of the atmospheric radiative balance yields a good simulation of polar surface temperatures at the southern source regions. Equatorial temperatures are around 32-33° C for LOWGRAD and LOWGRADWIND in the zonal mean (Figure 4d). A localised warm pool in the Thethys, were temperatures reach 36° C (Figure 1b), constitutes a significant departure from the zonal mean. This is in agreement with the high tropical temperatures of 33-34° C found by *Norris et al.* (2002); *Schouten et al.* (2003); *Wilson et al.* (2002).

We intend to illustrate a wider timeframe of greenhouse climates, and will therefore briefly discuss the Eocene. Southwest Pacific SSTs increased to ∼32°C during the early Eocene (∼53 Ma ago), and decreased to ∼21°C by the late Eocene (∼36 Ma ago *Bijl et al.*, 2009). This later cooler Eocene temperature is close to our Cretaceous simulation LOWGRAD in the Southwest Pacific. Tropical conditions (around 25 to 30°C SSTs) may have prevailed at the Canterbury Basin (55°S paleolatitude) from the late-early to early-middle Eocene (50.7-46.5 Ma) according to *Hollis et al.* (2009), although uncertainties related to TEX_{86} suggest peak temperatures at site 1172 may have been 28° C (*Hollis et al.*, 2012). *Douglas et al.* (2014) present paleotemperature records that indicate that the Seymour Island middle and late Eocene SSTs ranged between 10 to 17° C. This is significantly cooler than the temperatures found elsewhere for similar sub-polar latitudes. These findings point to a significantly reduced meridional temperature gradient during the Cretaceous and Eocene.

We find southern sinking in our simulations. Although it is difficult to infer meridional overturning circulation polarity for the Turonian, *Cramer et al.* (2009) argue that more homogeneous deep ocean conditions before the late Eocene arose from deep sink-

ing in both hemispheres, and that a period of enhanced heterogeneity during the late Cretaceous may have arisen from changes in the ability of winds to make water in the deep ocean circulate via a Tethyan circum-equatorial current that might have functioned in analogous fashion to the ACC (*Hotinski and Toggweiler*, 2003). For the Eocene, *Corfield and Norris* (1996); *Thomas et al.* (2003); *Thomas* (2004); *Via and Thomas* (2006); *Coxall and Pearson* (2007) find proxy evidence for deep ocean ventilation from the south. A further discussion of the warm polar conditions during the greenhouse climates, including terrestrial proxies, can be found in *Sijp et al.* (2014).

Figure 3. Should depth be in km rather than m?

Yes, we now correct this.

References

Bice, K. L., B. T. Huber, and R. D. Norris (2003), Extreme polar warmth during the Cretaceous greenhouse?: Paradox of the late Turonian d18o record at DSDP site 511, *Paleoceanography*, *18*, doi: 10.1029/2002PA000,848.

Bijl, P. K., S. S. Schouten, and A. Sluijs (2009), Early palaeogene temperature evolution of the Southwest Pacific Ocean, *Nature*, *461*, 776–779.

Corfield, R. M., and R. D. Norris (1996), Deep water circulation in the Paleocene ocean, *Geological Society, London, Special Publications.*, *101*, 443–456.

Coxall, H. K., and P. N. Pearson (2007), The Eocene-Oligocene transition, in *Deep Time Perspectives on Climate Change: Marrying the signal from computer models and biological proxies*, The Micropaleontological Society Special Publication.

Cramer, B. S., J. R. Toggweiler, J. D. Wright, M. E. Katz, and K. G. Miller (2009), Ocean overturning since the late cretaceous: Inferences from a new benthic foraminiferal isotope compilation., *Paleoceanography*, *24*, doi:10.1029/2008PA001,683.

Douglas, P. M. J., H. P. Affek, and L. C. Ivany (2014), Pronounced zonal heterogeneity in Eocene southern high-latitude sea surface temperatures, *PNAS, in review*.

Hollis, C. J., L. Handley, E. M. Crouch, and co authors (2009), Tropical sea temperatures in the high-latitude south pacifi c during the eocene, *Geology*, *37*, 99–102.

Hollis, C. J., K. W. R. Taylor, L. Handley, and co authors (2012), Early Paleogene temperature history of the Southwest Pacific Ocean: Reconciling proxies and models., *Earth and Planetary Science Letters*, *349*, 53–66.

Hotinski, R. M., and J. R. Toggweiler (2003), Impact of a Tethyan circumglobal passage on ocean heat transport and "equable" climates, *Paleoceanography*, *18*, DOI: 10.1029/2001PA000,730.

Norris, R. D., K. L. Bice, E. A. Magno, and P. A. Wilson (2002), Jiggling the tropical thermostat in the Cretaceous hothouse, *Geology*, *30*, 299–302.

Schouten, S., E. C. Hopmans, A. Forster, Y. van Breugel, M. M. Kuypers, and J. S. S. Damste (2003), Extremely high sea-surface temperatures at low latitudes during the middle Cretaceous as revealed by archaeal membrane lipids, *Geology*, *31*, 1069–1072.

Sijp, W. P., A. S. von der Heydt, H. A. Dijkstra, S. Flögel, P. Douglas, and P. K. Bijl (2014), The role of ocean gateways on cooling climate on long time scales, *Global and Planetary Change*, *119*, 1–22.

Thomas, D. (2004), Evidence for deep-water production in the north pacific ocean during the early cenozoic warm interval, *Nature*, *430*, 65–68.

Thomas, D., T. J. Bralower, and C. E. Jones (2003), Neodymium isotopic reconstruction of the late paleocene- early eocene thermohaline circulation., *Earth Planet. Sci. Lett.*, *209*, 309–322.

Via, R., and D. Thomas (2006), Evolution of atlantic thermohaline: Early oligocene circulation onset of deep-water production in the north atlantic, *Geology*, *34*, 441–444.

Wilson, P. A., R. D. Norris, and M. J. Cooper (2002), Testing the Cretaceous greenhouse hypothesis using glassy foraminiferal calcite from the core of the Turonian tropics on Demerara Rise, *Geology*, *30*, 607–610.