Deconstructing LGM climate in the tropical Atlantic and Pacific with an AGCM-slab ocean model

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Recent paleoevidence have indicated significant millenial-timescale changes in the mean zonal sea surface temperature gradient in the equatorial Pacific [1], and shifts to the mean position of the Intertropical Convergence Zone (ITCZ) in the Atlantic [2]. They appear related to changes associated with the dominant mode of interannual-to-decadal variability in the respective basins, namely the meridional mode in the tropical Atlantic [e.g. 3], and ENSO for the tropical Pacific [e.g. 4]. It begs the question of to what extent the tropical responses could be understood as a response of these modes to millennial-scale forcing, and what in particular about the millennial-scale changes that forces them. I investigate this issue for the Last Glacial Maximum (LGM) situation from the perspective of an atmospheric general circulation model (the Community Climate Model version 3.10) coupled to a 50m slab ocean model (SOM). I'll focus mainly on the tropical Atlantic, for which this model configuration is more appropriate as it models the present-day tropical Atlantic variability reasonably well.

Using the present day simulation as the control, the LGM (21K bp) forcing I apply are:

1. CO_2 changed to 200ppm
2. Land ice sheet extent according to the Peltier [5] reconstruction
3. Sea ice extent according to CLIMAP [6] (sea ice is imposed, not predicted)
4. Orbital changes according to Berger [7]

The Q-flux applied to the SOM assumes that the ocean heat transport (OHT) is kept to present-day conditions. All runs are 50 years, taking the last 30 years as the equilibrated climate.

With all forcings (1-4) applied, the tropical Atlantic SST climate alters very much after the fashion of the meridional mode, but in mean sense: there is a systematic shift of the ITCZ to the south, with associated convection and cool north/warm south meridional SST gradient (figure 1). There is a notable increase in the northeasterly trades over the northern tropical and subtropical Atlantic. On top of this SST gradient is a net ~1K cooling of the entire tropical Atlantic basin. When anomalies from each individual forcing are summed, they resemble the result with all forcings, implying to first approximation a linear response to forcing 1-4. With that assumption, the CO_2 forcing accounts for the majority of the basinwide cooling but almost none of the surface circulation and precipitation changes. The ice sheet forcing takes the lion's share of the changes associated with the southward ITCZ shift, including the stronger northern subtropical trades, the meridional SST gradient, and the southward cross-equatorial flow.

The ice sheet is directly responsible for the increase in the northeasterly trades. In parallel with how the present-day meridional mode comes about [8], the increased trades drives an initial cooling of the north tropical Atlantic SST that in turn creates the conditions necessary for the southward shift in the ITCZ through creating the meridional SST gradient across the mean ITCZ latitude. The tropical thermodynamic ocean-atmosphere interaction characterizing the meridional mode appears essential to bring the ice sheet influence to the tropical regions. Additional simulations to understand the influence of the ice sheet suggests that it is the albedo component, and not the orographic component, of the ice sheet that is responsible for the increased northeasterly trades.

The neglect of ocean heat transport changes during LGM precludes a serious comparison between our model runs and records of LGM climate. We attempt initial sensitivity studies on the role of OHT change due to thermohaline or tropical Pacific SST change on the tropical and global climate. For thermohaline change, we prescribed modified OHT convergence in the North and tropical Atlantic based on the model study by Fitchefet et al. [9]. I conclude that the Atlantic ITCZ can be shifted significantly (northwards in this case) by thermohaline OHT change, in agreement with recent studies [e.g. 10]. The interesting aspect here is that the ITCZ shift comes about without change in the northeasterly trades. The situation for the tropical Pacific is more interesting. The model run with all forcings 1-4 gives an initial tendency for the equatorial Pacific zonal SST gradient to reduce in strength and the ITCZ to move equatorwards. To understand how the ENSO dynamics might react to this initial tendency, we forced an intermediate coupled ocean-atmosphere model [similar to the one used in 4] with the tendencies implied by our AGCM-slab ocean run. The intermediate model responds by warming the eastern equatorial Pacific SST even further with a spatial pattern that looks basically like the SSTA in the peak El Niño phase, reducing the mean zonal SST gradient by ~1.5-2K across the width of the basin. The reduced zonal SST gradient is in agreement with a recent observational finding [1]. This eastern Pacific warming, when inserted back into the AGCM-SOM, causes a pronounced equatorward shift of the eastern Pacific ITCZ and a significant change in the global atmospheric circulation. Over the tropical Atlantic, the eastern Pacific warming reduces the meridional SST gradient in the tropical Atlantic set up by the other 1-4 LGM forcing, though not enough to reverse the southward shift.

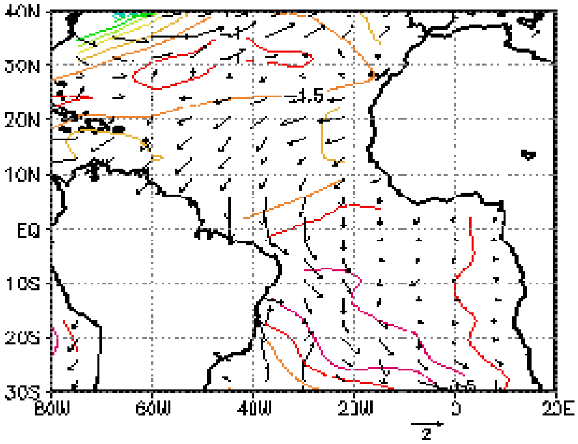

Figure 1. Annual mean differences between the ‘all forcing’ (forcings 1-4) and control runs over the tropical Atlantic. The contours are SST (contour interval 0.5K), and vectors are the lowest model level (992mb) wind change. The reference vector is 2m/s.

[1] Koutavas, A, J Lynch-Stieglitz, TM Marchitto, and JP Sachs, *Science*, **297**, 226-230 (2002).
[2] Hughen, KA, JT Overpeck, LC Peterson, and S Trumbore, *Nature*, **380**, 51-54 (1996).
[3] Chang, P., Ji, L., and Li, H., *Nature* **385**, 516-518 (1997).
[4] Cane MA, SE Zebiak, and SC Dolan, *Nature*, **321**, 827-832.
[5] Peltier, WR, *Science*, **273**, 195-201 (1994)
[6] CLIMAP Project members, Seasonal reconstruction of the earth’s surface at the Last Glacial Maximum. Map and Chart Series, **36**, Geological Society of America, 18pp (1981)
[7] Berger, AL, *J. Atmos.Sci.*, **35**, 2362-2367 (1978)
[8] Chiang, JCH, Y Kushnir, and A Giannini, *J. Geophys.Res.*, **107**, 10.1029/2000JD000307 (2002)
[9] Fichefet T, S Hovine, and J-C Duplessy, *Nature*, **372**, 252-255 (1994)
[10] Dong B-W, and RT Sutton, *Geophys. Res. Lett.*, **29**, 10.1029/2002GL015229 (2002)