The climate sensitivity to changes in oceanic heat transport

Marcelo Barreiro[1] (barreiro@fisica.edu.uy), Annalisa Cherchi[2] (annalisa.cherchi@bo.ingv.it), Simona Masina[2] (simona.masina@bo.ingv.it)

[1] Facultad de Ciencias, Universidad de la República, Uruguay

[2]Centro Euro-Mediterraneo per i Cambiamenti Climatici, Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy

Objective

We use an atmospheric general circulation model coupled to a slab ocean to study the effects of ocean heat transport on climate prescribing the transport (OHT) from 0 to 2 times present day values.

Background

- The circulation of the oceans likely changed over the course of Earth's history, due to changes in external forcings (e.g., insolation) and changes in continental configuration. Thus, a change in ocean heat transport is a common explanation in studies of past climates.

- Increased ocean heat transport warms the climate by reducing sea ice extent and low oceanic cloud cover in the tropics and midlatitudes thus reducing the albedo of the planet (Winton 2003), and by increasing the clear-sky greenhouse trapping due to moistened subtropics (Herweijer et al 2005).

- Previous studies imply that further increasing the ocean heat transport from today's conditions will further warm the climate. Here we extend the range of imposed ocean heat transport to two times present-day values to address this issue and study the sensitivity of results to cloud parameterizations.

Methodology

- We use ECHAM5 coupled to a slab ocean, where SST evolves according to the following equation

$$C_o \frac{dSST}{dt} = Q_A + c * Q_O$$

Q_A is the net atmospheric heat flux and Q_O is a ocean heat flux divergence term that assures the correct simulation of the present seasonal cycle of SST (*c*=1). In this model ocean and atmosphere only interact thermodynamically and there is no dynamic adjustment to wind changes.

- Varying c allows imposing different ocean heat transports to the atmosphere. In this study we imposed the following values of *c*

$$c = (0 ; 0.5 ; 0.75 ; 1 ; 1.05 ; 1.10 ; 1.15 ; 1.20 ; 1.25 ; 1.5 ; 2.0)$$

Thus, we maintain the present-day spatial structure of the regions where the oceans gain and lose heat, but multiply it by a factor *c* at each grid point in order to simulate a decreased/increased oceanic heat transport.

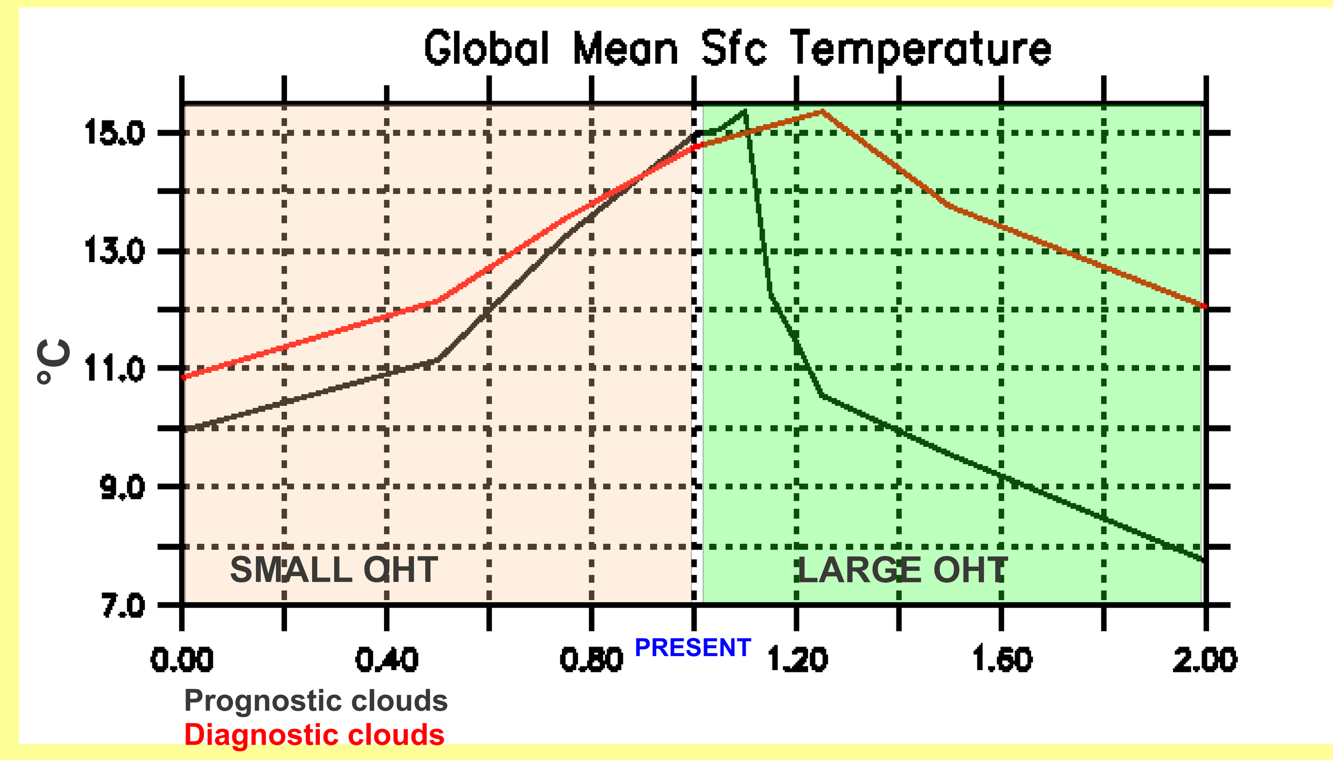
- We test the sensitivity of the results to cloud parameterization using two schemes for cloud cover (both have same microphysics):
  - a statistical scheme based on prognostic equations for the moments (skewness and width) of the probability distribution function for the total mixing ratio (Tompkins 2002)
  - a diagnostic scheme for cloud cover based on relative humidity (Sundqvist et al. 1989).

References

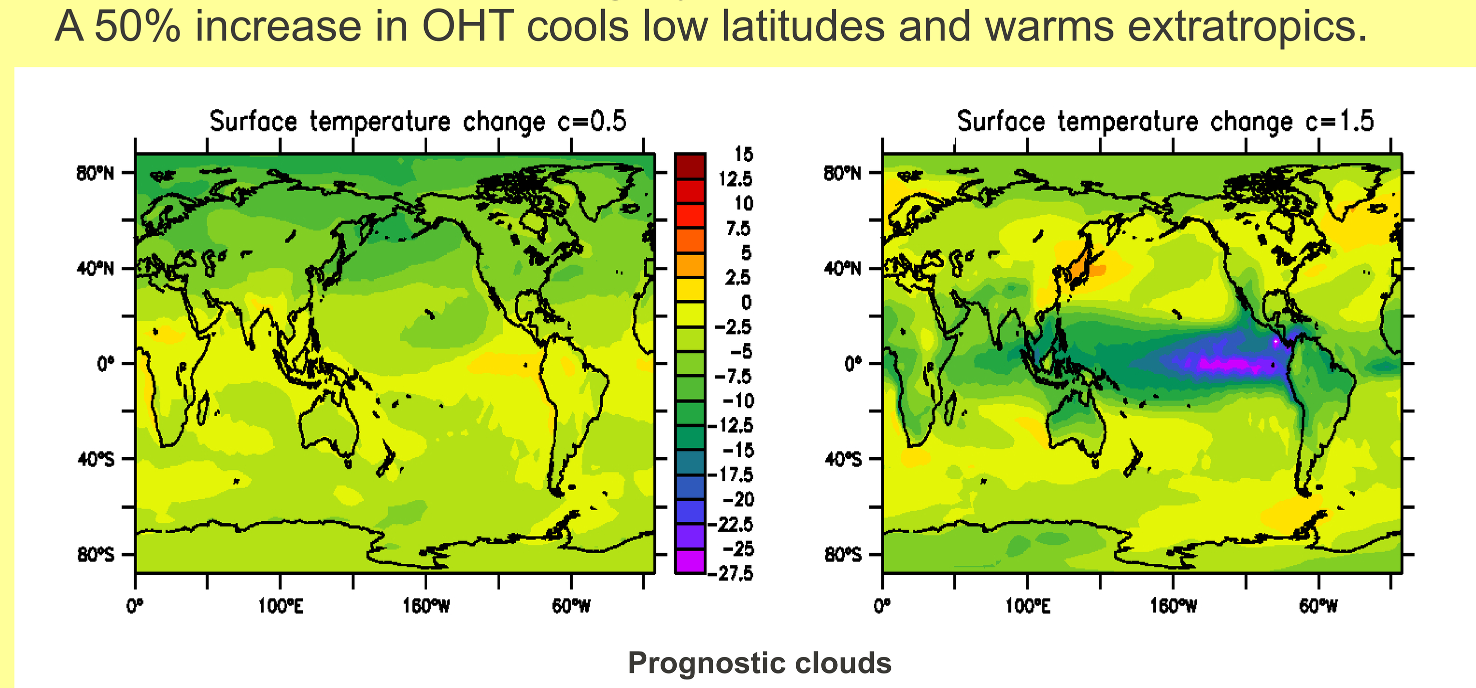
- Brierley, C., A. V. Fedorov, Z. Liu, T. Herbert, K. Lawrence, and J. LaRiviere, 2009: Greatly expanded tropical warm pool and weaker Hadley circulation in the early Pliocene. Science, 323, 1714–1718.
- Herweijer, C., R. Seager, M. Winton, and A. Clement, 2005: Why ocean heat transport warms the global mean climate. Tellus, 57A, 662–675.
- Sundqvist, H., E. Berge, and J. E. Kristjansson, 1989: Condensation and cloud parameterization studies with a mesoscale numerical weather prediction model. Mon. Wea. Rev., 117, 1641–1657.
- Tompkins, A., 2002: A prognostic parameterization for the subgridscale variability of water vapor and clouds in large scale models and its use to diagnose cloud cover. J. Atmos. Sci., 59, 1917–1942.
- Winton, M., 2003: On the climatic impact of ocean circulation. J. Climate, 16, 2875–2889.

Results

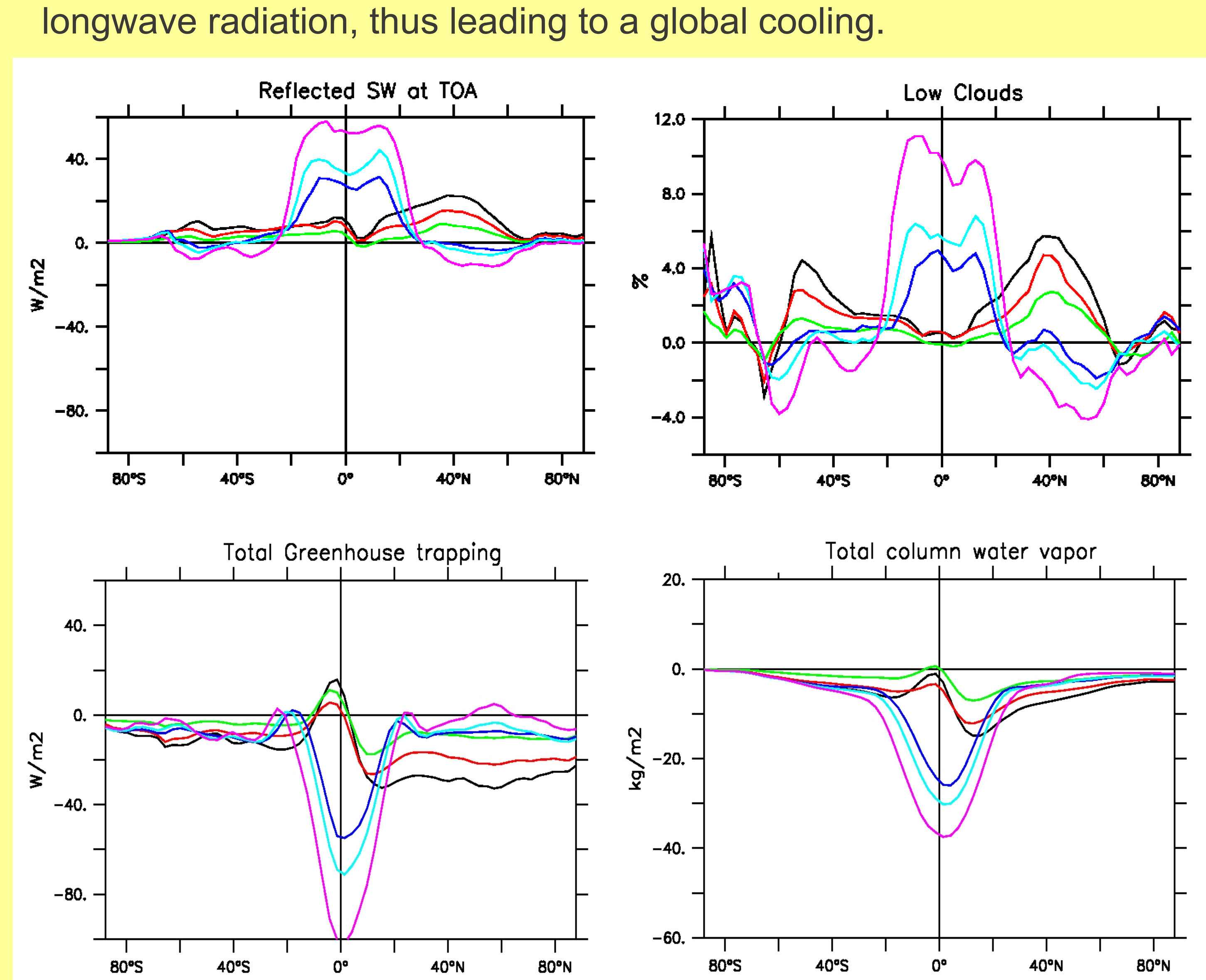
1) Changes in mean surface air temperature: The climate warms from 0 up present-day values. Further increases in OHT lead to a global cooling. The maximum warming and the climate response for large OHT largely depend on the cloud parameterization.



2) A 50% decrease in OHT cools high latitudes because of increased sea ice and low level clouds, and slightly warms low latitudes.
A 50% increase in OHT cools low latitudes and warms extratropics.

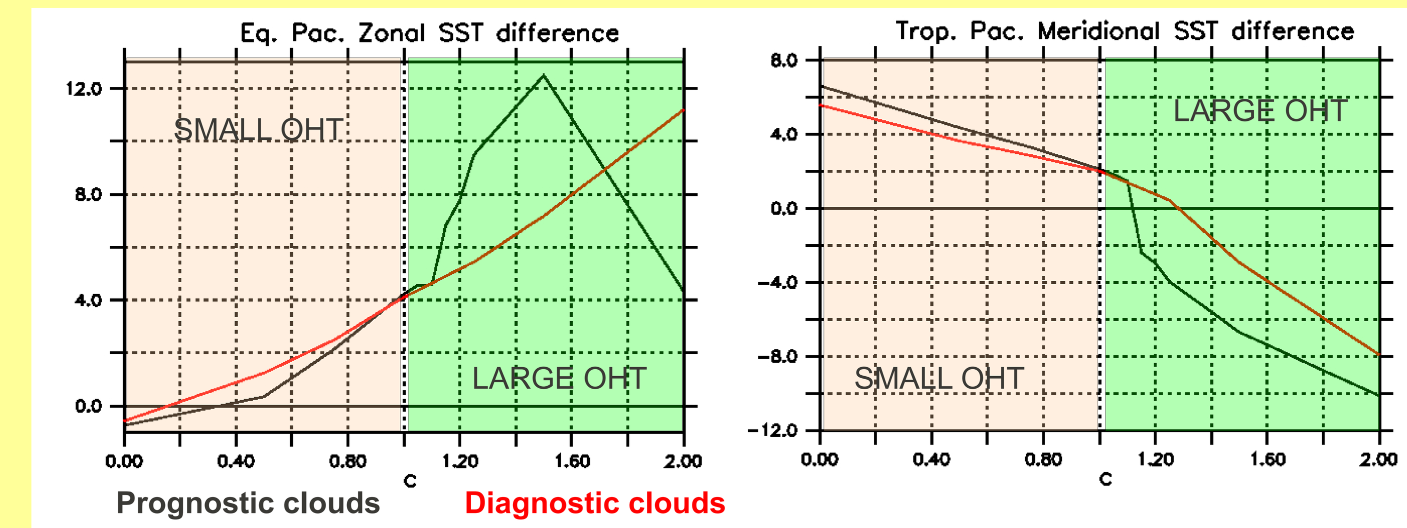


3) A decrease in OHT increases low clouds in high latitudes reflecting more short wave radiation thus decreasing the temperature.
An increase in OHT increases low clouds and reduces the total column water vapor in the tropics, thus increasing the albedo and trapping less longwave radiation, thus leading to a global cooling.

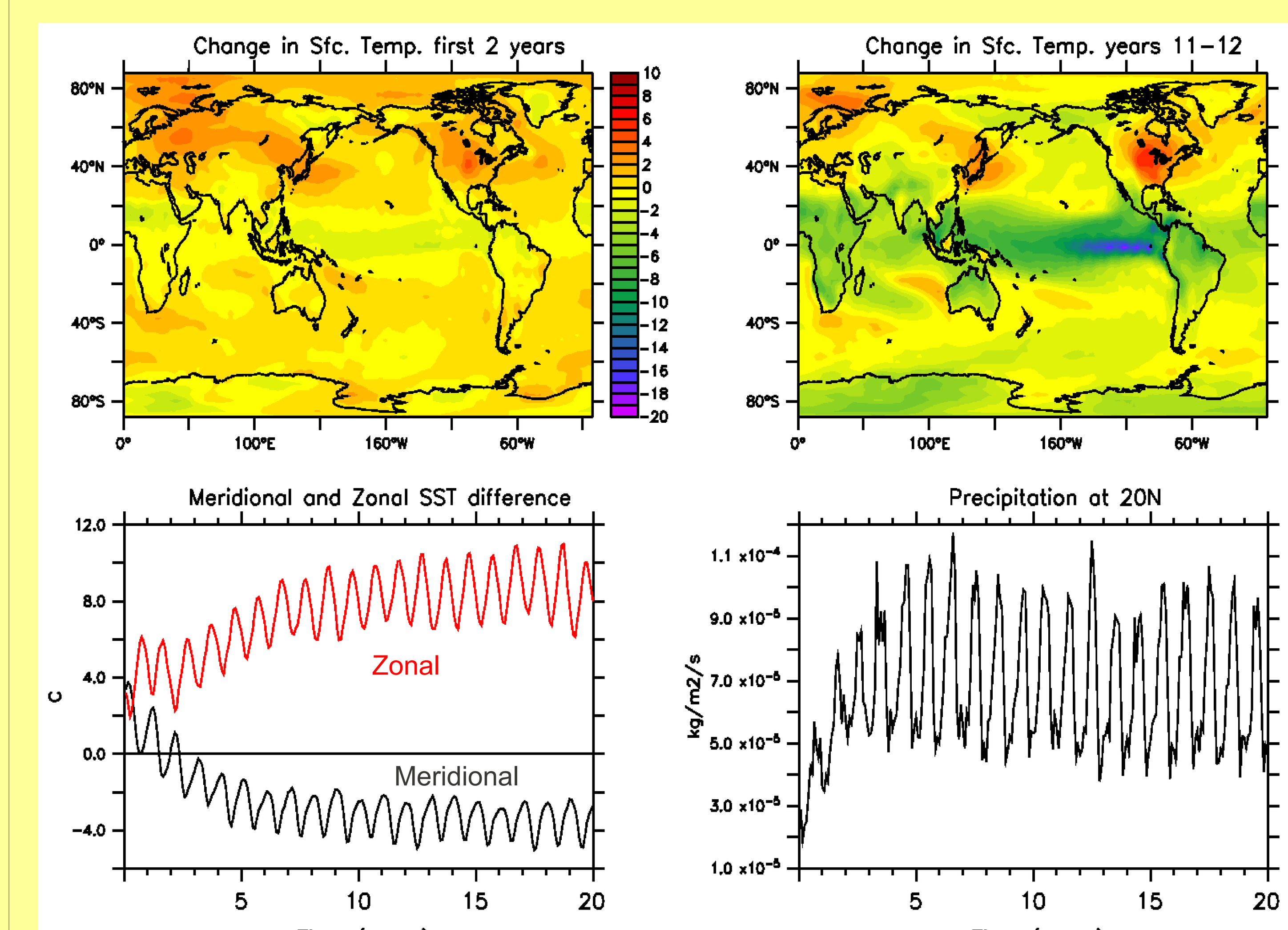


Prognostic clouds, *c*=(0; 0.5; 0.75; 1.25; 1.5; 2.0)

4) Changes in the tropical SST gradients: As the OHT increases the equatorial Pacific zonal SST gradient increases because of the increase in low clouds. At the same time the meridional SST gradient decreases. Thus, the model does not support the existence of broad and zonally uniform warm tropics, as occurred in the Pliocene (Brierley et al 2009).



5) The solutions are physically realizable as long as the meridional SST gradient is larger than zero. The transition to a cold state happens because of a positive feedback between low clouds and SST in the tropics. Initially the tropics cool uniformly but if the feedback is very strong the equatorial region becomes colder than the subtropics generating double ITCZs at ±20 that induce subsidence on the equator that favors the development of low clouds and dries the atmosphere.



Prognostic clouds for c=1.25

Summary

- For a decrease in the OHT from present-day values we have recovered previously reported results. These results are robust because they represent small deviations from today's conditions.

- The climate response is very different for an increase in OHT and depends highly on cloud parameterizations. A sensitive cloud scheme suggests that our current climate is very close to the maximum positive effect of the OHT on climate; another scheme suggest a 25% increase In OHT can further warm the climate by 0.6 °C.

- For OHT increases larger than 25% of present-day values, a strong positive radiative feedback between tropical low-level clouds and SST is established that always leads to an unrealistic cold climate. In this state low-level clouds cover the tropics.

- The results presented here do not support the hypothesis that larger ocean heat transport may have led in the past to warmer than present-day climates without changing the total poleward heat transport.