Revisiting the CMIP5 Thermocline in the Tropical Pacific

Antonio Castaño-Tierno[1], Elsa Mohino[1], Belén Rodríguez-Fonseca[1,2] and Teresa Losada[1]

[1]Departamento de Fisica de la Tierra y Astrofísica, Universidad Complutense de Madrid, Madrid, Spain.
[2]IGEO, Madrid, Spain.

Motivation

Important!

The thermocline is the ocean layer which separates the mixed layer (the part of the ocean that interacts with the atmosphere) and the deep ocean (which doesn't interact with the atmosphere). It is defined as the layer of maximum vertical gradient of temperature.

Its location is very important for tropical ocean-atmosphere dynamics, such as the El Niño-Southern Oscillation phenomenon. The ENSO constitutes the main mode of interannual variability in the tropics, and depends on the interaction of the thermocline, the sea surface temperatures and the dominant easterly winds.

The depth of the thermocline in the tropical Pacific ocean is usually taken to be that of the 20 degree isotherm (z20). In this work, we compare both measurements (z20 and the depth of the maximum gradient of temperature, maxgrad), both for the SODA reanalysis and for an ensemble of 18 coupled models.

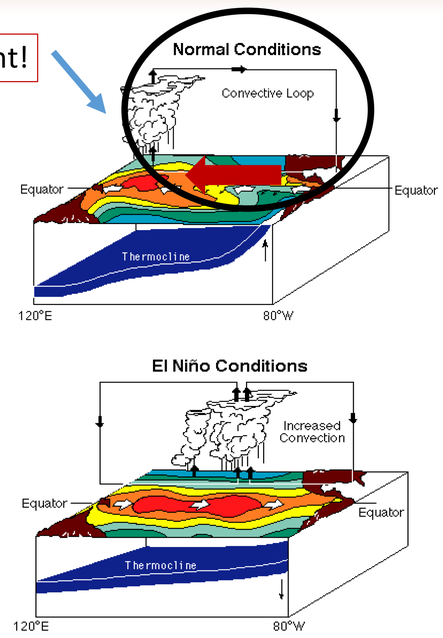

Figure 1: scheme of El Niño. Figure taken from http://www.pmel.noaa.gov/toga-tao/pmel-graphics/web-graphics.html

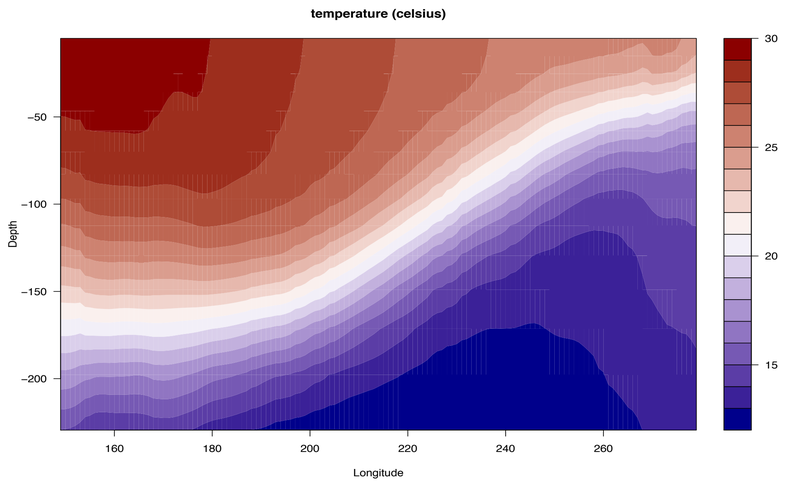

Figure 2: SODA climatology (1981-2010) of the tropical Pacific temperature (first 250 meters)

Methodology

The ocean temperature (thetao) has been used, both from the SODA reanalysis (1981-2010) and from the whole preindustrial (piControl) runs of 18 models included in the Coupled Model Intercomparison Project Phase 5 (CMIP5). The models used are shown on the right, and the length of the runs vary from 240 to 1000 years depending on the model. Observed sea surface temperature (SST) climatologies have been computed for the same period as the SODA reanalysis (1981-2010) from the ERSST database.

Annual climatologies are computed and regridded to a regular 1x1 degree grid, while keeping the vertical resolution of each dataset intact. The depth of the thermocline is computed as that of the level in which the maximum vertical temperature gradient is located. The depth of the 20 degree isotherm is computed by linearly interpolating the temperature curve between the levels above and below the isotherm. Significance is assessed in all cases with a Student t-test at the 95% confidence level.

- CanESM2
- CCSM4
- CNRM-CM5
- CSIRO-Mk3-6-0
- GFDL-ESM2G
- GFDL-ESM2M
- GISS-E2-H
- GISS-E2-R
- HadGEM2-CC
- HadGEM2-ES
- inmcm4
- IPSL-CM5A-LR
- MIROC4h
- MIROC5
- MIROC-ESM-CHEM
- MPI-ESM-LR
- MRI-CGCM3
- NorESM1-M

Results

The thermocline (maxgrad) is shallower than the 20 degree isotherm (iso20) both in SODA and in the CMIP5 ensemble. The relative differences between them are much bigger in the CMIP5 ensemble (15% in the eastern region, from 250 to 280 degrees and 2.5% in the central Pacific, from 150 to 250 degrees) than in the SODA reanalysis (7% and 1.5% differences, respectively). This means that, even if z20 were a good measurement of the thermocline in the observations, this is not true for the models.

Why does the 20 degree isotherm behave differently than the thermocline in the CMIP5 models?

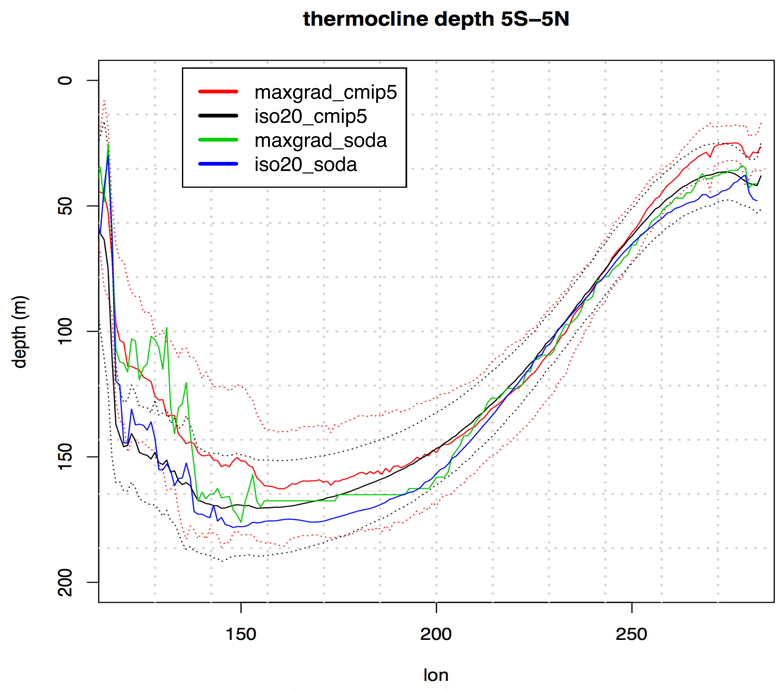

Figure 3: equatorial Pacific ocean depth of the thermocline in CMIP5 (red), z20 in CMIP5 (black), depth of the thermocline in SODA (green) and z20 in SODA (blue)

Mechanism

1) Thermocline depth (maxgrad) not related with intermodel SST variability!
2) z20 closely related with SST: the warmer the surface, the more isotherms on top of iso20.

Significant correlation between SST and z20, but not between SST and maxgrad.

1

z20 follows maxgrad closely.

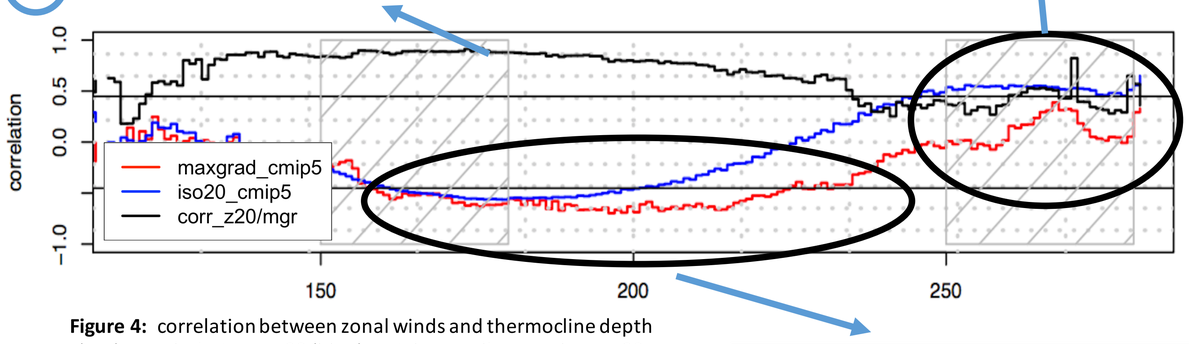

Figure 4: correlation between zonal winds and thermocline depth (red), zonal winds and z20 (blue) and thermocline depth and z20 (black) in the equatorial Pacific for CMIP5 models.

Significant correlation between SST and z20, and SST and maxgrad, stronger in the second case.

2a

Figure 5: correlation between zonal winds and thermocline depth (red), zonal winds and z20 (blue) and zonal winds and SST(black) in the equatorial Pacific for CMIP5 models. The horizontal lines show threshold for values significant at the 95% confidence level.

Stronger easterlies (wind is positive to the East, therefore stronger easterlies = negative sign) leed to cooler SSTs.

Significant correlation between SST and maxgrad, but not SST and z20!

2b

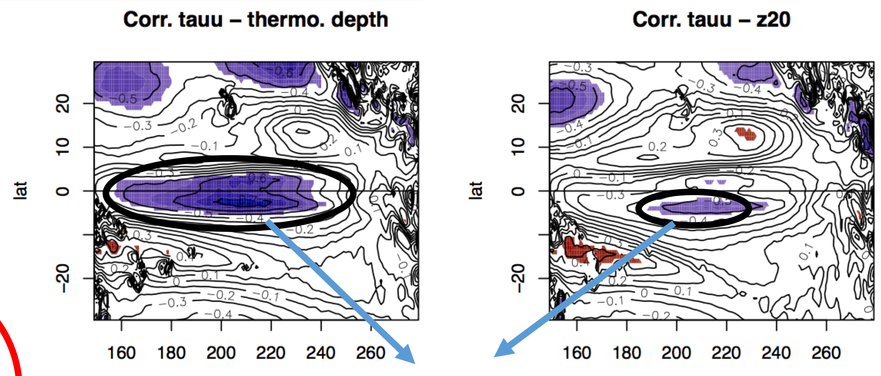

Figure 6: spatial correlation of zonal wind and thermocline depth (left) and zonal wind and z20 (right). Coloured areas show areas significant at the 95% confidence level (blue is negative, red is positive).

Sverdrup transport (meridional surface transport towards the Equator, caused by easterlies) works better for thermocline depth than for z20.

3

To sum up:

Stronger easterly winds pile up water in the West.

Easterly winds refresh the surface in the central-western Pacific, making surface water denser, and causing an imbalance in the water column.

Sverdrup transport goes from the extraequatorial region to the Equator.

3) Western thermocline deepens. z20, not so much.

Conclusions and consequences

1) There are relevant differences between z20 and the depth of the thermocline in coupled models. These differences are stronger in the eastern region of the Pacific.

2) Coupled model SST biases in the eastern Pacific are mainly not due to the ocean component of the models.

3) Using z20 as a proxy for the thermocline is not a good idea when studying SST biases, since it is strongly influenced by the model SST.

4) The dynamical mechanism that explains the behaviour of the thermocline in the central and western Pacific is much less clear for the 20 degree isotherm.

As tropical oceans get warmer, the difference between the depth of the thermocline and the depth of the 20 degree isotherm will increase, according to CMIP5 models.

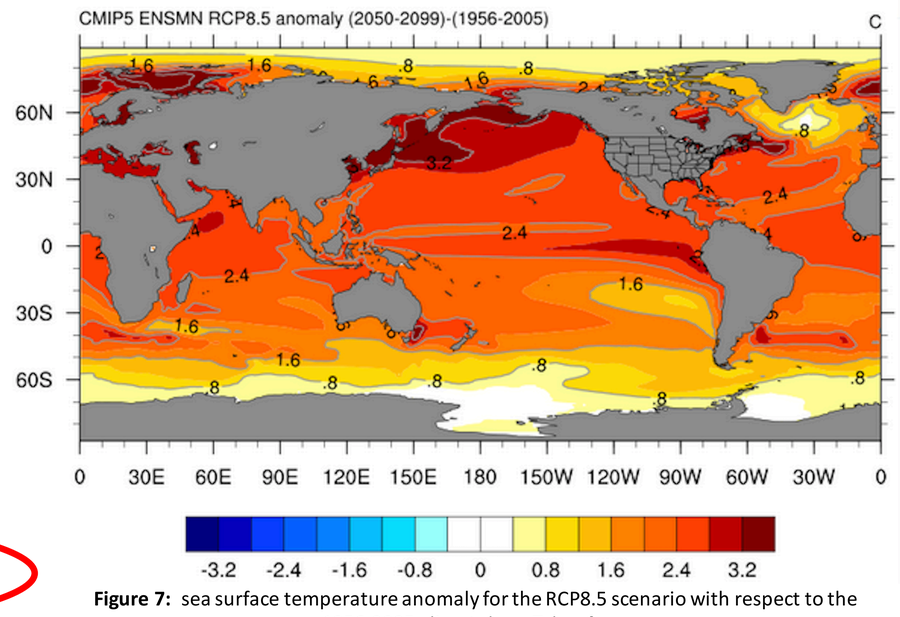

Figure 7: sea surface temperature anomaly for the RCP8.5 scenario with respect to the 1956-2005 climatology. Taken from http://research.noaa.gov/sites/oar/EasyGalleryImages/12/455/Ocean%20Climate%20Change%20Portal.png