Tropical Atlantic oceanic variability in CCSM4

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Mean and Seasonal Cycle

Wind stress mean and biases (Fig. 1)

The mean differences of the wind stress are greater in the central Tropical Atlantic. The Tropical South Atlantic (TSA) has weaker wind stress magnitude and less standard deviation than in observations. The wind stress in the Tropical North Atlantic (TNA) has greater magnitude, due to easterlies stronger than in observations. These wind stress biases are related to the seasonal biases in sea surface temperature (SST) and warm pool (WP) volume.

Tropical Atlantic warm pools (Fig. 2)

The warm pool (WP) has been defined as the volume with temperatures greater than 28.5°C. The timing of the WP in POP-CORE simulation is similar to that of the observations, although the vertical structure indicates that the Tropical South Atlantic (TSA) warm pool is deeper in CCSM4 than in observations. This deeper TSA-WP is related to the weaker wind stress and to the warm bias in the TSA region, a common challenge to many coupled models.

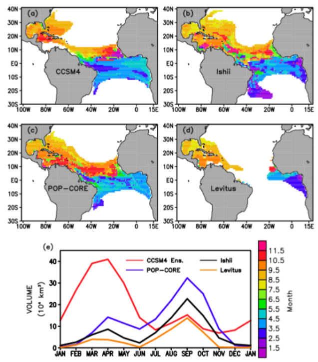


Figure 2. (a-d) Horizontal distribution of the month of deepest 28.5°C isotherm from the long-term mean from 1950 to 2005. The numbers 1 to 12 correspond to the months from January to December. The Pacific data has been masked. Panel (a) corresponds to the CCSM4 ensemble mean. Panel (c) corresponds to the POP ocean model forced with CORE surface forcing (POP-CORE). Panels (b) and (d) correspond to the observational products, Ishii and Levitus, respectively. (e) Seasonal cycle of the volume of the 28.5°C isotherm between 40°S-40°N and above 250 meters of depth.

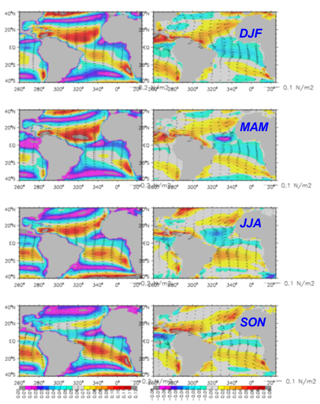
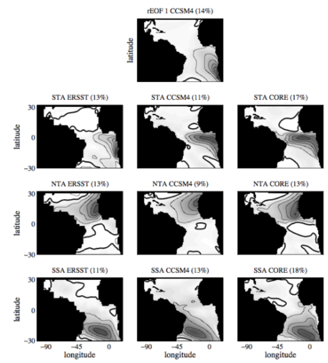


Figure 1. Tropical Atlantic wind stress (N/m^2) seasonal means (left column) and model minus observations (right column). The model mean is the ensemble mean of 20th century (20C) CCSM4 simulations.

Modes of Interannual Variability



Empirical Orthogonal Functions (Fig. 3)

Rotated EOFs (rEOFs) were applied to SST fields of the various ensemble simulations and to an observational data set (ERSST.v3b) for the period 1950-2005. The spatial patterns of the main modes of variability in the model are similar to that from the observations. The North Tropical Atlantic (NTA) and Subtropical South Atlantic (SSA) modes are found in all data sets. In CCSM4, the South Tropical Atlantic (STA) variability is represented by the STA-EQ and STA-BG modes, with SST variability in the equatorial region and the Benguela upwelling zone, respectively.

Figure 3. Dominant rotated EOFs (rEOFs) of sea surface temperature (SST) in the tropical Atlantic between 30°N and 30°S. The rEOFS are from the ERSSTv3b observational data set (left), the mean of the five 20C ensemble members of the CCSM4 (center), and the CORE-forced ocean-ice simulation (right). The rEOFs are based on a varimax rotation of the 10 dominant EOFs of detrended, area-weighted, monthly SST anomalies. The rEOFs carry the standard deviation. Negative, zero, and positive contours are thin dashed, thick solid, and thin solid, respectively, with contour interval of 0.1°C.

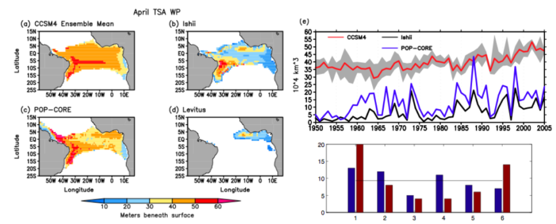
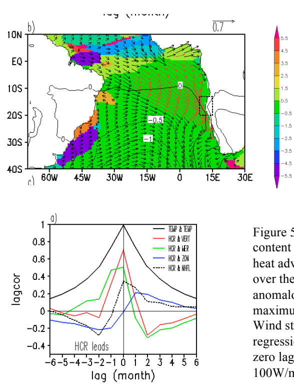


Figure 4. The tropical South Atlantic (TSA) Warm Pool in April. (a-d) Mean depth (meters) of the 28.5°C isotherm in April. The CCSM4 ensemble mean (panel a) is the mean of five different simulations. (e) Time series of the volume (10^4 km^3) encompassed by the 28.5°C isotherm in April south of 5°N. The black line is the Ishii observational product; the blue line is the ocean POP simulation forced by CORE forcing; the red line is the CCSM4 ensemble mean with the ensemble spread in gray. The bottom panel is a Rank Histogram (from detrended data) based on the 5-simulation CCSM4 ensemble with either the Ishii observations (blue) or the POP ocean-only hindcast (burgundy) forced with CORE observations. The black line in the histogram corresponds to a uniform distribution.

The Warm Pool in the Tropical South Atlantic (Fig. 4)

In CCSM4 the April WP in the TSA is much deeper than in observations, which is consistent with the SST and wind stress biases in the TSA region. As a consequence, the time series of the WP volume in April in CCSM4 are distant from those obtained from observational estimates. Furthermore, the Rank Histogram indicates that the TSA WP in CCSM4 has less variability (under-dispersed) against that from the POP simulation forced by CORE observations, or against that from the Ishii observations.

The Benguela Niño heat budget



Benguela Niño region (Fig. 5)

Analysis of the model heat budget in the Benguela region suggests that anomalous vertical advection accounts for about 50% of the anomalous heat content rate (HCR) variance while the contribution by anomalous meridional heat advection is half as strong. Local surface flux accounts for only 12% of the anomalous HCR variance. The impact of zonal advection is weak.

Figure 5. (**a**) Lagged autocorrelation of anomalous SST and lagged correlation of anomalous heat content rate of change (HCR) with anomalous vertical (VERT), meridional (MER), zonal (ZON) heat advection, and anomalous net surface heat flux (NHF). All variables are spatially averaged over the Benguela region box and vertically integrated in the upper 80m. (**b**) Lagged correlation of anomalous vertical heat advection in the Benguela region with wind stress elsewhere. Arrows show maximum correlation. Shading shows time lag (in month) corresponding to maximum correlation. Wind stress leads for positive lags. Correlations exceeding 0.3 are shown in red. Temporal regression of anomalous vertical heat advection on anomalous mean sea level pressure elsewhere at zero lag is overlain as contours. Contour values show pressure anomalies (mbar) corresponding to 100W/m^2 anomalous vertical heat advection in the Benguela region. The data used is from a 100-year control simulation.

Synopsis

In this study we analyze important aspects of the tropical Atlantic Ocean from the new simulations of the 4th version of the NSF-DOE coupled climate model, the Community Climate System Model (CCSM4). The data used in this study are from several different simulations, among them a set of five 20th-century (20C) simulations with different initial conditions, but similar radiative forcing. The analyses indicate that:

1. Some of the biases of the tropical Atlantic have been reduced in CCSM4 compared to the previous version of the CCSM. Yet, in CCSM4 the TSA continues to be warmer than observations, and with weaker wind stress; and the TNA continues to be colder than observations, and with stronger wind stress.
2. The volume of the TSA Warm Pool (WP) in CCSM4 is much greater than in observations during the last half of the 20th century. Furthermore, the TSA WP has under-variability in the ensemble.
3. The variability of SSTs in the tropical Atlantic is well represented in CCSM4 although the leading rotated EOF in CCSM4 does not have a counterpart in observations.
4. The variability of SSTs in the Benguela region is dominated by vertical advection.

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