SOUTH AMERICAN SUMMER SEASON CLIMATE PREDICTABILITY: A FULLY COUPLED OCEAN-ATMOSPHERE STUDY.

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ABSTRACT

This work investigates the use of coupled ocean atmosphere-ocean and atmospheric global circulation models to predict summer rainfall variability over South America and South Atlantic regions. It is shown that while the coupled model presents severe climate drift during the first months of integration, summer rainfall anomalies over the area of study can be better predicted using the coupled model than the atmospheric global model.

Key words: Seasonal climate predictability; coupled ocean-atmosphere model; tropical Atlantic.

INTRODUCTION

Global tropics sea surface temperature (SST) anomalies are considered as the main element controlling seasonal climate variability in the tropics. The occurrence of recurrent El Niño – Southern Oscillation (ENSO) events over the equatorial Pacific, with worldwide climate variations associated with, is one of the most notable examples of tropical SST influences on climate. However, there are other SST-induced seasonal climate variations, which are subtler than the Pacific ENSO, but nonetheless are of significant impact on regional climates. One such case is the modulation of the Atlantic's intertropical convergence zone (ITCZ) north-south displacements by the interhemispheric gradients of SST anomalies locally (Moura and Shukla 1981; Hastenrath and Greischar 1993; Nobre and Shukla 1996). The point here is that while the signal-to-noise ratio between ENSO-related SST variability and SST background "noise" over the eastern equatorial Pacific is of the order of a few degrees centigrade, i.e., SST anomalies of two to three degrees over very large areas of the equatorial east Pacific are often observed during the mature phases of and El Niño or La Niña (the cold phase of ENSO) events, interannual SST variability over the tropical Atlantic seldom reach one degree over significant areas (Servain, Picaut et al. 1985). Such differences, alone, put both kinds of climate predictability problems in completely different baskets. Among the reasons for such differences are the main mechanisms that generate SST anomalies over both tropical oceans: ENSO can be explained in large part by equatorial ocean wave dynamics (Suarez and Schopf 1988), while SST anomaly variability over the off-equatorial tropical Atlantic is by-en-large dictated by one-dimensional heat fluxes across the ocean surface (Foltz, Grodsky et al. 2003).

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SSTA variability over the tropical Atlantic is crucial to understand and predict seasonal climate variability over portions of South America, like Nordeste Brazil (Ward and Folland 1991; Hastenrath and Greischar 1993) and southern Brazil – northern Argentina (Diaz, Studzinski et al. 1998). Yet, there are indications that the cloudiness variability associated with the South Atlantic Convergence Zone (SACZ) is not modulated by SSTA over the SE Atlantic, but contributes to modulating SSTA variability there (Chaves and Nobre 2004).

Therefore, predicting SSTA over the tropical oceans, in particular over the tropical Atlantic, is critically important to improve seasonal climate predictability over South America. This work exploits the use of a coupled ocean-atmosphere global model to forecast SST globally, also comparing the use of a coupled model's one tier approach to predict rainfall anomalies over South America with the more traditional atmospheric global circulation model's (AGCM) two tier approach.

MODEL AND EXPERIMENT DESCRIPTION

The coupled ocean-atmosphere model used is CPTEC AGCM at resolution T062L28 (triangular truncation at wave number 62 and 28 sigma levels in the vertical) using relaxed Arakawa-Schubert (RAS) deep cumulus convection scheme fully coupled to GFDL's MOM_3 at resolution 0.25 degree lat lon in the deep tropics of the Atlantic (between 10S and 10N), decreasing monotonically to 2 degree resolution in the mid-latitudes of both hemispheres and other ocean basins. The coupling region is the global tropics between 40S and 40N. Poleward of these latitudes, SSTA from the initial condition are persisted throughout the forecast period. Coupling interval is one day, through the following variables: AGCM's wind stress, total heat flux, precipitation minus evaporation, and OGCM's SST. Atmospheric initial conditions (IC) are individual NCEP analysis from NCAR-NCEP reanalyzes project; ocean IC are obtained by running MOM_3 forced by atmospheric wind forcing and parameterized surface heat fluxes (Rosati and Miyakoda 1988). There is no ocean data assimilation to generate the ocean IC fields.

The forecast experiment (hereafter referred to as DERF) consisted of generating ten member ensembles, each member starting from a distinct pair of atmospheric and oceanic IC field for ten consecutive days of each calendar month of the year. The coupled model (CGCM) runs then extended for a period of eight months. This procedure was repeated for each month of the 20 years period from October 1982 to December 2001.

In order to evaluate the coupled model rainfall forecast skill, a twin forecast experiment was conducted with the AGCM component of the coupled model. The AGCM forecast runs were forced with SST fields composed by persisted SSTA of the month of the initial condition added to the monthly varying global SSTs climatology during the forecast period of integration.

Further integrations of both CGCM and AGCM models were done (hereafter referred to as LRUN), which consisted of ten members starting in December 1987 and running for 20 years. SST forcing for the LRUN AGCM experiment were monthly OI SST climatology (Reynolds and Smith 1995). A single LRUN integration of the OGCM was also done, forced by observed surface stresses and parameterized surface heat fluxes covering the period October 1982 to.December 2001.

For the DERF forecast experiment, AGCM and CGCM outputs monthly climatologies are calculated as the twenty years monthly averages for each set of monthly IC. Therefore, the models' climatologies are a function of both the calendar month of forecast and the month of the experiment's initial conditions. For the LRUN experiment (continuous integrations from one single set of Ics), the models' outputs monthly climatologies are the simple arithmetic means of the ten member ensembles for each month of the twenty years of integration.

Observations are Global Precipitation Climatology Project (GPCP) rainfall fields for the period 1982-2001 and OI SST from NCEP.

RESULTS

Systematic errors are a common feature of most atmosphere and ocean GCMs. Such kind of errors is of special interest in the case of coupled models, since positive feedbacks may result unrealistic simulations. On the other hand, both AGCM and OGCM forced runs are handicapped in the sense that the lack of ocean-atmosphere feedbacks may result unrealistic surface fluxes (e.g., the lack of SST cooling due the shadowing effect of clouds). Figure 1 shows the Niño 3.4 area averaged SST for the LRUN experiment as simulated by the CGCM. It is noteworthy the strong initialization shock during the first almost two years of integrations, with SST cooling during the first few months and the subsequent steep SST warming during the next 12 to 18 months. The warming, of the order of six degrees centigrade, overshoots the initial cooling and settles the model's SST climatology some 4.5 degrees warmer than the IC. The CGCM then stabilizes at this warmer state, with irregular SST variability, showing both periods of warming and cooling.

Figure 2 shows the time series of SST anomalies (SSTA) for the Niño 3.4 area both observed and simulated/forecast by the OGCM/CGCM runs. SST forecasts shown in Figure 2 are for each member of the January IC DERF experiment.

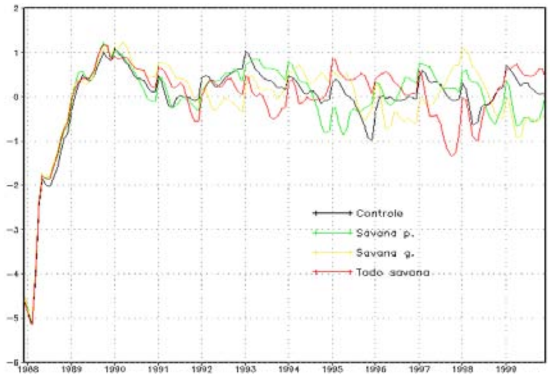

Figure 1 – Time series of Niño 3.4 SST simulated by CPTEC fully coupled CGCM.

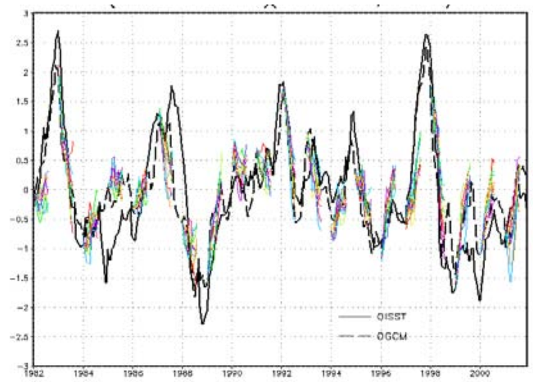

Figure 2 – Time series of Niño 3.4 SSTA: OI observations (continuous thick black line), OGCM simulation (dash thick black line), and CGCM DERF forecasts for IC of January of each year.

Two facts caught our attention in Figure 2. One is the apparent departures between observed (continuous black line) and OGCM simulated (dashed black line) SSTAs (e.g. during the years 1985 and 1999). This is a clear indication that even though OGCM SST simulations are generally good over this area (correlation coefficients between simulated and observed SSTA for the Niño 3.4 area reach values greater than 0.8), there are occasions when simulated SSTs significantly depart from observations. This may be related to the lack of ocean data assimilation in our model. The second noteworthy feature shown in Figure 2 is the good degree of agreement among the SSTA forecasts (shown by the color lines for each ensemble member) and both simulated and observed SSTAs.

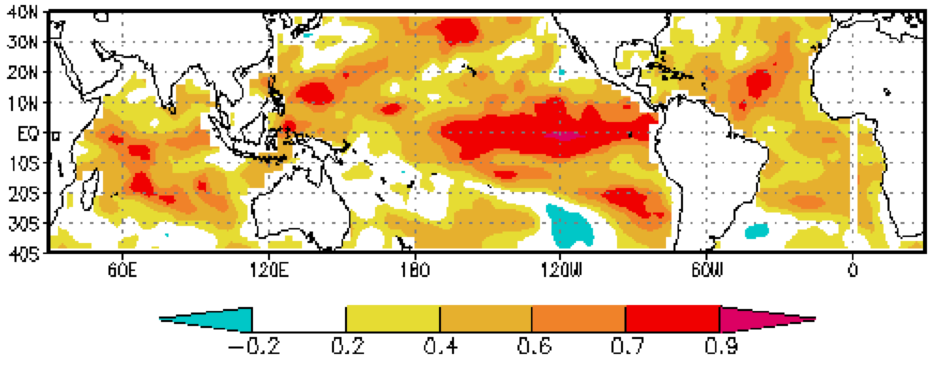

Figure 3 – CPTEC CGCM's DJF SSTA forecast anomaly correlations map for DERF experiment with November Ics.

Such agreement, or forecast skill, can be better appreciated in Figure 3, which shows SST anomaly correlation map for DJF SSTA forecasts for the DERF experiment with November IC. Note that not only anomaly correlations are as high as 0.9 over the eastern equatorial Pacific, but correlation coefficients as high as 0.7 are shown over the northern tropical Atlantic as well.

Yet, the most significant result of this investigation is show by the CGCM DJF rainfall anomaly forecast skill over the SACZ and South Atlantic areas, as shown in Figure 4. This figure depicts DJF rainfall anomaly correlations for both AGCM and CGCM of the DERF experiment, as well as the difference between them (the upper panel in Figure 4). Note that while the CGCM forecast skill is marginally larger than the AGCM forecast skill over most of the South Atlantic and parts of SE Brazil, it is less than AGCM's over the eastern equatorial Atlantic and the Nordeste. We speculate here that such results are a consequence, for the case of higher skill over the SACZ area, of missing ocean-atmosphere interactions (Chaves and Nobre 2004) of the AGCM experiments; and for the case of lower skill over the Nordeste, of erroneous feedbacks of the excessive warming of CGCM SSTs over the equatorial eastern oceans (figures not shown).

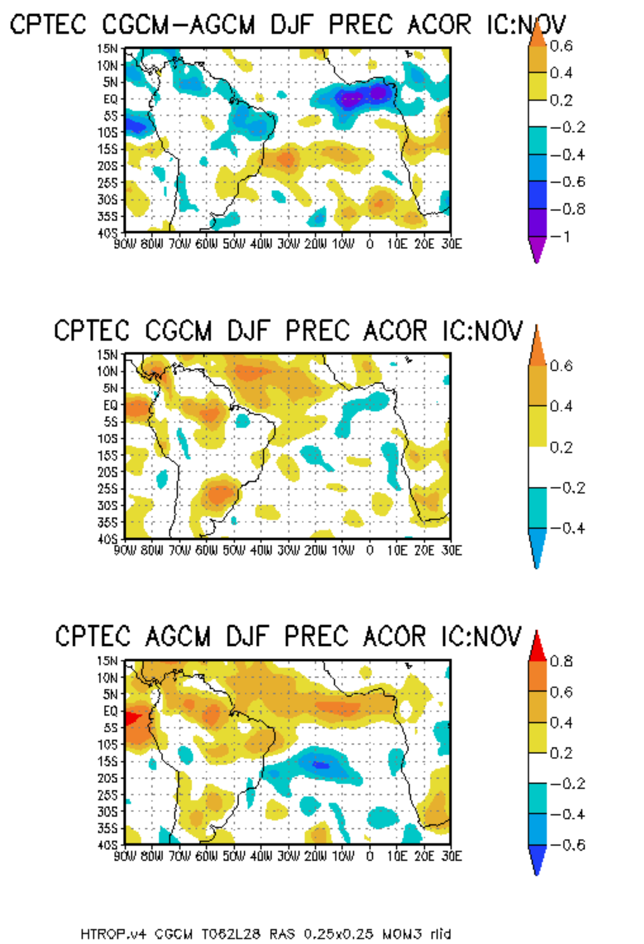

Figure 4 – DJF rainfall anomaly correlation maps for CPTEC AGCM's forecast (lower panel), CPTEC CGCM's forecast (middle panel), and the difference CGCM minus AGCM correlations (upper panel).

CONCLUDING REMARKS

This investigation has shown that coupled ocean-atmosphere GCMs are a promising venue for climate modeling and forecast. While the CGCM of this study presents steep SST systematic errors, primarily over the eastern tropical oceans, its summer rainfall seasonal forecast skill over parts of SE South America and South Atlantic is higher than AGCM forecast skill, forced by persisted SSTAs. It is speculated that such CGCM forecast skill gain is in part due to the lack of atmospheric feedback on SSTs of the AGCM's forced experiments. Nevertheless, the results shown here so far indicate that further research is needed to meliorate the strong CGCM SST warm bias over the eastern tropical oceans, which, once done, may improve the CGCM rainfall forecast skill over the equatorial regions.

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