STATISTICAL PREDICTION OF SEA SURFACE TEMPERATURE OVER THE TROPICAL ATLANTIC

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ABSTRACT

A statistical system to predict sea surface temperature anomalies (SSTA) over the tropical oceans, with emphasis on the tropical Atlantic, is described. Canonical correlation analysis (CCA) is used to identify critical sequences of predictor patterns which tend to evolve into subsequent patterns, and that can be used to form a forecast. The results indicate that SST fields over the equatorial Pacific and tropical Atlantic can be a potential predictor of the SSTA over the tropical Atlantic with three to four months in advance. The spatial structures of the SSTA over the tropical Atlantic for the period March-April-May are well captured by the predictions done with initial conditions from September to February. Model performance is better over the northern tropical Atlantic than over the southern tropical Atlantic, where persistence is hardly beaten. Results of this work can contribute to improve seasonal climate predictions of rainfall anomalies over the Northeast Brazil region.

1. INTRODUCTION

Seasonal climate predictions have become a reality during the last decade, with operational seasonal forecasts appearing even more recently [*Graham*, 1994]. However, present approaches for climate prediction, either statistical or dynamical are critically dependent on SST forecasts [*Ward & Folland*, 1991, and *Shukla*, 1984]. The dynamical models use SST fields as a forcing for the interactive processes (heat flux, for example) of the ocean-atmosphere system [*Cavalcanti et al*, 1998]. The statistical models use SSTA as a predictor parameter of the regression equations [*Hastenrath*, 1990*; Ward & Folland*, 1991]. The interhemispheric SST gradient of the tropical Atlantic, often referred to as the Atlantic SST dipole pattern, is a mode of variability apparently unique to the tropical Atlantic. Studies suggest that this mode of variability is associated with the rainfall variability over the Northern South America and the African Sahel [*Moura & Shukla*, 1981; *Servain*, 1991; *Nobre & Shukla*, 1996; *Parker et al*, 1988].

Statistical and dynamical models have been developed to forecasting SSTA fields over the equatorial Pacific [*Cane et. al*, 1986; *Chen et. al*, 1997; *Barnston & Ropelewsk*, 1992; *Penland & Magorian*, 1993; and others]. Studies about the possibility of forecasting SSTA over the tropical Atlantic through statistical methods are recent [*Penland & Matrosova*, 1998] and useful, due to the great importance of the tropical Atlantic on climate variability over some areas over the Americas and the Caribbean [*Hastenrath*, 1984].

Penland & Mastrosova [1998] developed a model to predict the tropical Atlantic SSTA index for different areas of the basin (north, equatorial, south and Caribbean) using a statistical technique known as linear inverse modeling. They used global tropical SSTA fields as predictor parameters, and concluded that on time scales of several months to a year, predictions of northern tropical Atlantic and Caribbean SSTA are much more skillful than equatorial and southern tropical Atlantic SSTA. That model did not beat persistence over the southern area.

In the present study, the use of canonical correlation analysis CCA [*Bretherton et al*, 1992, *Barnett & Presendorfer*, 1987] pre-filtered with EOF to predicting fluctuations of monthly SSTA over the tropical

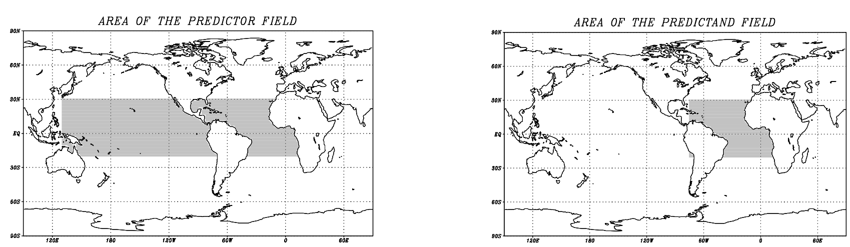
Atlantic with 1 to 12 months lead time is examined. Special emphasis is given for the season March-April-May because of its impact on interannual variability of the Northeast Brazil (Nordeste) rainy season [*Hastenrath & Heller*, 1977; *Moura & Shukla*, 1981].

2. DATA AND METHODOLOGY

The data sets used in this work are monthly mean global 1° x 1° latitude-longitude gridded SST fields over the ocean. Data sources are the Comprehensive Oceanic and Atmospheric Data Set (COADS) for the 1945 - 1993 period [*Da Silva et al*., 1994]; and the optimal interpolation SST (OI-SST) for the period 1994 - 1998 provided by the Climate Prediction Center of NCEP [*Reynolds & Smith*, 1994]. A routine is applied to mask out the points over the continents and calculate the long-term monthly means and standard deviations at each grid point. Then, monthly anomaly time series are calculated by subtracting the long-term monthly means from the monthly values and normalizing by the local standard deviations. This process ensures that all grid points have equal opportunity to participate in the predictive patterns, regardless of their latitude and longitude-dependent interannual variances [*Barnston & Ropelewski,* 1992].

Before applying the CCA calculations, the predictor and predictand anomaly data sets are filtered separately with the use of the Empirical Orthogonal Function (EOF). The EOFs of each data set are calculated independently. Then the filtered data are reconstructed using a number of eigenvectors and eigenvalues, retaining 80% of the original variance of each field. CCA is calculated in order to find the predictive equations that relate the predictand and predictor fields and a set of diagnostic and prognostic fields can be obtained.

The system developed to calculated the forecasts operationally (Statistical Modeling System-SIMOC) allows the selection of different predictor and predictand parameters for any area of the globe and any lead/lag time. Pacific and Atlantic Oceans between 20°S and 30°N (Fig. 1a) for the area chosen to contain the predictor field. The area of the predictand is set over the same latitude band of the predictor field, but only over the tropical Atlantic, since the major interest is to investigate the potential predictability of the tropical Atlantic SSTA (Fig. 1b). A total of 49 years in the period 1945 to 1993 are used to validate the model; 34 years for the training period (1945 to 1978) and the following 15 years for the hindcast period. Lead times from 1 to 12 months are tested starting each month of the year.



a) **b)**

Fig. 1: Areas used as (a) predictor and (b) predictand on the validation tests of SIMOC.

The average correlation coefficients for some areas of the ocean basin are analyzed for all lead/lag experiments. Also, some experiments were done in order to test the ability of the model in predicting the SSTA of the particular period March-April-May. The focus of the predictions over this period is particularly useful for climatic predictions over Brazil's Nodeste, since MAM is the period of its rainy season.

Once the hindcasts are calculated for different lead for the period 1979 to 1993 (independent period), the performance of the model is investigated through the calculation of the correlation coefficients between the predicted and the observed SSTA. Those are then compared with correlation obtained by persisting the SSTA. Also, a statistical test of null hypothesis is applied (t-student) in order to calculate the significance level of the correlation coefficients found.

3. RESULTS

Area averaged monthly correlation coefficients between observed SSTA and CCA model forecasts, and persistence, were calculated for the southern (20°S-0°S) and northern tropical Atlantic (0°N-30°N) for up to 12 months lead time for predictor sets taken from September to August. For the southern tropical Atlantic as a whole, only the CCA forecasts with initial conditions in September outperformed persistence. For all the other cases the model forecasts were essentially as skillful as persistence, or worst. Also, correlation coefficients were modest, with peak values ranging between 0.4 to 0.6. For the northern tropical Atlantic, the area average correlation coefficients are generally small for both the persisted and the forecast SSTA. However, SSTA forecasts by the CCA model with lead times ranging from one to six months have a higher skill than persistence for the period of March through June.

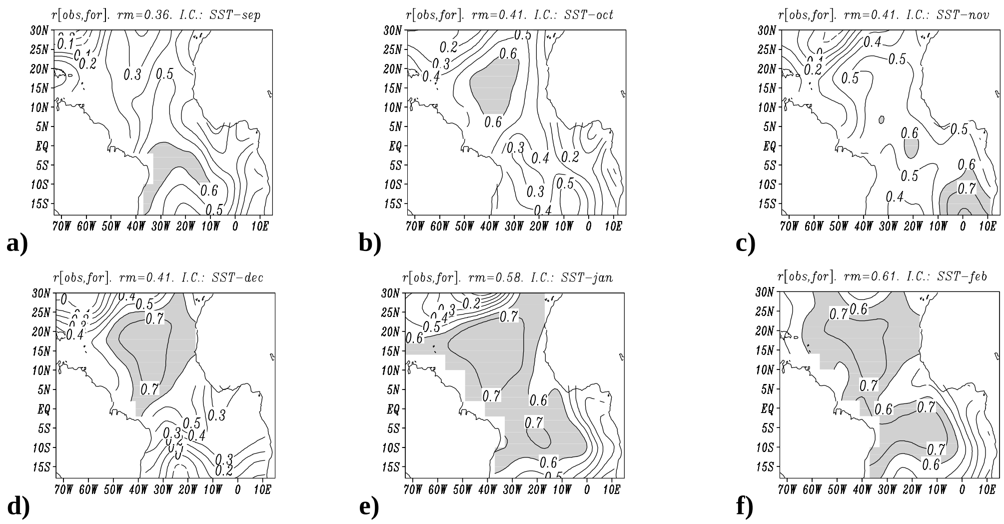


Fig. 1: Correlation coefficients maps between observed SSTA versus SSTA forecast by SIMOC for the period of March-April-May, with SSTA initial conditions of (a) September; (b) October; (c) November; (d) December; (e) January and (f) February. Regions with correlation coefficients higher than 0.6 are shaded and have significance higher than 99%.

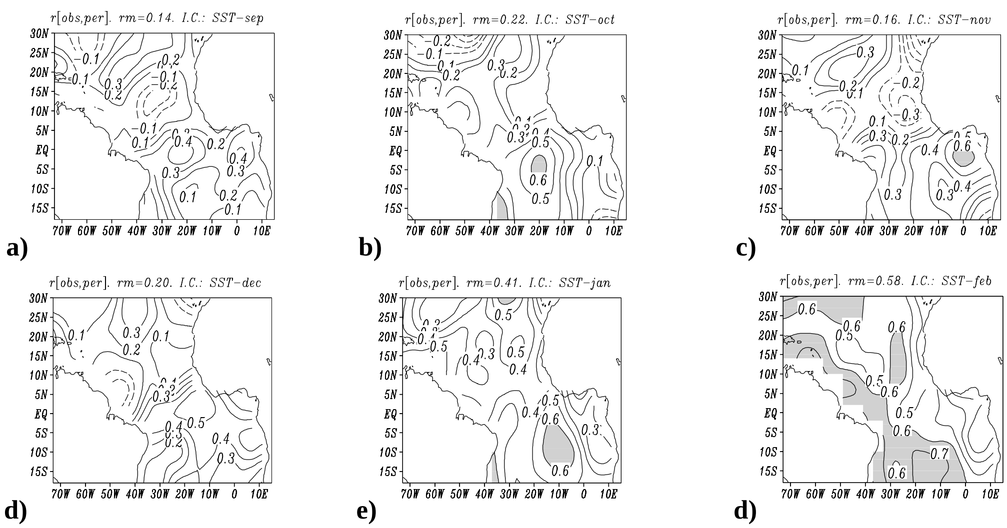


Fig. 2: The same as Fig. 1 but for SSTA forecast by persistence of SSTA initial conditions.

The correlation coefficients between area averaged SSTA over the whole basins as discussed above is a stringent test, since it encompasses areas where the models have high forecast skill with areas where the models perform poorly. Fig. 2(a-f) shows the correlation coefficients between observed and forecast MAM SSTA fields using initial conditions from September through February, respectively. It is readily noticeable in Fig. 2 that the correlation coefficients increase both in magnitude and area as the lead-time for the prediction decreases. The best predictions are those using the initial conditions of January and February. Correlation coefficients higher than 0.6 (significant at the 99% level) and 0.7 occur over both the northern and the southern parts of the basin. The correlation coefficients between the persisted SSTA from the months September through February and observed MAM SSTA are show in Fig. 3a-f. The persisted SSTA has some skill for predicting MAM SSTA only during February. Comparing the results shown in Fig. 2 to those in Fig. 3, it can be seen that the forecast skill of the CCA model outperforms persistence for all lead times. Moreover, the spatial structure of the correlation field of the forecasted SSTA (Fig. 2) resembles the spatial structure of the observed SSTA much closer than that obtained by persistence. This fact alone suggests the advantages of using CCA forecasts of MAM SSTA over the tropical Atlantic as boundary conditions for the use of atmospheric general circulation modeling for seasonal climate predictions [*Cavalcanti et al*, 1998].

Examples of real predictions of the SSTA of MAM/1998 are shown in Fig. 4a-c. The observed SSTA for December/1997 is shown in Fig. 4a, the CCA SSTA forecast in Fig. 4b, and the observed SSTA for MAM/1998 in Fig. 4c. SSTA during December/1997 were cooler than the mean over the northern tropical Atlantic, and the southern tropical Atlantic was warmer, compared to the climatology. Hence, the SSTA meridional gradient pointed southward during December/1997. On the other hand, SSTA forecast by the model using initial conditions from December/1997 (Fig. 4b) predicted a warmer northern tropical Atlantic, thus, reversing the meridional SSTA gradient. This forecast for MAM/1998, based on the initial conditions of December/1997, was used as part of the boundary conditions for the General Circulation Model of the Center for Weather Forecast and Climatic Studies (CPTEC) to forecast the precipitation for the 1998 Nordeste rainy season [Cavalcanti et al, 1998]. *Pezzi et al* [1998] also shows SSTA forecast by the CCA model for MAM/98 using different initial condition lead months (October/1997 through January/98.

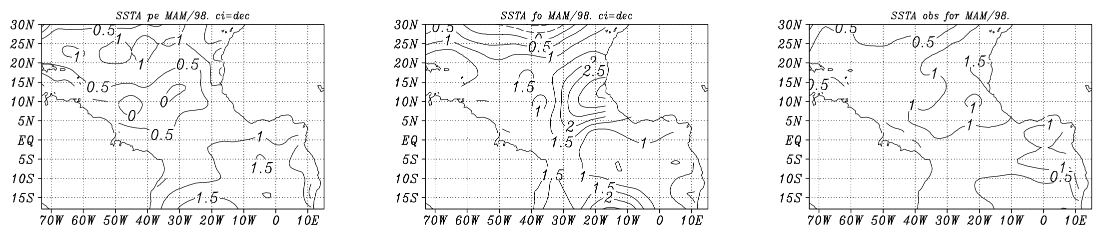


Fig. 4: SSTA anomaly a) persisted from Dec/97; b) forecasted for MAM/98 [Initial conditions: Dec/97]; and c) observed for MAM/98.

4. CONCLUSIONS

The results of this work show that skillful SSTA forecasts over the tropical Atlantic using CCA technique can be obtained. However the forecasts skill score, as measured by anomaly correlation maps over the tropical Atlantic, presented a seasonality with best performance over the northern tropical Atlantic with a few months prior to March-April-May. It is suggested that the model skill score seasonality might be related to the influence of the tropical Pacific over the northern tropical Atlantic. Other seasons are potentially less predictable using the methodology followed in this work. The results have also indicated that the SSTA field is a better predictor of the whole tropical Atlantic than surface winds or pressure alone. Further work is needed to test the prediction potential of a combination of these variables.

Persistence of SSTA over the southern tropical basin are hardly beaten by the statistical forecast scheme developed, but the spatial structure of the correlation fields between persisted and observed MAM SSTA is very noisy. Meanwhile, the CCA forecast SSTA for MAM shows an inter-hemispheric asymmetric mode of variability, which is similar to the mode found on observed data. The results show that the spatial structure of SSTA fields over the tropical Atlantic for the average period of March-April-May can be predicted with reasonably good skill from September to February. As this model forecasts the SSTA spatial structures for several lags better than persistence and because the predicted field is available for every grid point of the domain, it represents a furthering of SSTA forecasting capabilities over the tropical Atlantic, and a step forward towards numerical climate forecasting. SIMOC model has been run experimentally at CPTEC to generate SSTA forecasts over the tropical Atlantic since November 1996 [*Cavalcanti et al*, 1998].

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