The influence of tropical pacific and atlantic SST on northeast Brazil monthly precipitation

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Abstract

The monthly pattern of Northeast Brazil precipitation is analyzed in relation to sea surface temperature (SST) in the tropical Pacific and Atlantic oceans, using singular value decomposition. It is found that Pacific and Atlantic SST relate to distinct patterns of monthly precipitation throughout the rainy season. Warming in the El Niño region (equatorial east Pacific) is generally associated with a decrease in precipitation during the rainy season. However, the strongest relationships are found with tropical Atlantic SST, and are associated with modulations in the length of the rainy season. Positive SST anomalies in the equatorial Atlantic during February tend to coincide with an early southward migration of the ITCZ, and hence an earlier start of the rainy season. The presence of an Atlantic SST anomaly dipole (opposite signed anomalies to the north and south of the mean ITCZ position at about 4^{o}N) in April and May is especially well related to the overall regional precipitation during these months (warm south and cold north coincides with increased precipitation). For March, equatorial Pacific SST shows the strongest relationship to precipitation, in the sense that positive SST anomalies are associated with decreased rainfall. Extreme wet (dry) years occur when Atlantic and Pacific SST patterns associated with above(below) normal precipitation occur simultaneously.

Time-lagged analyses are utilized to assess statistical forecast potential. SST fields from several individual months prior to February (the beginning of the rainy season) show relationship to the seasonal precipitation, with January SST producing the best "forecasts". Within the rainy season, Atlantic SST anomalies are better related to subsequent monthly precipitation than are Pacific anomalies; this is true in particular for April and May, the most variable months within the rainy season.

1.Introduction

The northern part of NEB (hereafter referred to as Nordeste) is known for its semi-arid climate with its rainy season concentrated between February and May, and very large iterannual variability that can reach values as high as 40% of the mean (Strang, 1972; Kousky, 1979; Moura and Shukla, 1981).

The Nordeste not only exhibits a high variability in the total amount of precipitation from year to year (Kousky, 1979) but also, a high spatial and temporal variability in the precipitation within its rainy season (Nobre et al., 1991). This monthly variability is related to the different rainfall systems that cause precipitation over the region in the different months of the rainy season. During January and February, the precipitation over the Nordeste is highly affected by cold fronts or their remnants that can reach latitudes north to 20^{o}S (Kousky, 1979; Oliveira, 1989, Alves and Kayano, 1991). Also important is the presence of High Level Tropical Vortices, associated with the cold fronts (Kousky and Gan, 1981).

Later February/March is the period when the ITCZ over Tropical Atlantic Ocean reaches its southernmost position, initializing what is called the 'principal' rainy season over Nordeste. The presence of High Level Tropical Vortices can be also observed during this period. The return of the ITCZ to its more northern position is what determines the end of the Nordeste principal rainy season (Uvo, 1989).

Different methodologies have been developed to forecast the Nordeste's rainy season and used during the last several years for operational proposes at National Institute of Spatial Research-INPE in São José dos Campos - SP- Brazil and at the Fundação Cearense de Meteorologia e Recursos Hídricos-FUNCEME in Fortaleza - CE - Brazil. Those methodologies are based on empirical atmospheric and oceanic parameters, on results from coupled models (Cane et al., 1986), and on statistical models developed specifically for forecasting Nordeste rainy season including Ward and Folland (1991); Hastenrath (1990); Brito et al. (1991); and Sansigolo(1991).

These methodologies have been formulated in terms of the precipitation of the entire rainy season, without consideration of the variations within the rainy season. The constancy of the rainfall during the rainy season is, however, important for the development of local crops, particularly in regard to the so-called "Veranico" - the suppression of the precipitation during a period greater than 10 days - which can be disastrous for local crops. Improving the understanding of intraseasonal variability in the Nordeste precipitation, and assessing the potential of monthly precipitation forecast were the primary motivations for this work.

2. Data sources

For this study we have utilized monthly precipitation anomalies normalized by standard deviation for a network of 105 rain gage stations well distributed over NEB, and Sea Surface Temperature (SST) for the Tropical Pacific and Atlantic for the period between 1946-85.

The precipitation data set was obtained from the Superintendência do Desenvolvimento do Nordeste (SUDENE) and Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME) (Brito et al, 1991); a total of 116 stations are included, but following Lau and Sheu (1988), we retained only stations containing less than 10% missing data between 1946 and 1985, and 105 stations remained in the data set.

The SST data set was obtained from an analysis of the Comprehensive Ocean Atmosphere Data Set (COADS) (Pan and Oort, 1990). The data were analyzed on a 1 x 1 degree Latitude x Longitude grid, and approximately 4.5^{o} latitude x 7.5^{o} longitude (Lau and Nath, 1990).

3. Methodology

The techniques employed for this study are based on a multivariate analysis procedure known as Singular Value Decomposition (SVD), that utilizes the cross-covariance matrix between two data sets (Bretherton et al., 1992). The use of SVD allows one to isolate pairs of spatial pattern that explain the maximum squared temporal covariance between two physical variable fields.

The theory of SVD is very well discussed and compared with other multivariate techniques in Bretherton et al (1992) and Wallace et al (1992). The SVD of the cross-covariance matrix of two fields gives two matrices of singular vectors and one set of singular values.

Wallace et al (1993) suggest the calculation of the normalized squared covariance (NSC) to compare the relative significance of each mode. It ranges from 0, when two fields are non related, to 1 if the variations at each grid point in the first field are perfectly correlated with the variations at all grid points in the second field (Wallace et al. 1993).

The so-called heterogeneous correlation maps of the left and right fields represent the correlation coefficients between the values of each grid point of the field and the expansion coefficients of the other field. In our application, the patterns shown by the heterogeneous correlation maps indicate how well the pattern of the precipitation (SST) anomalies relates to the expansion coefficient of SST (precipitation).

The SVD technique was applied to the covariance matrix between monthly normalized precipitation anomalies over Northeast Brazil and tropical SST, for the month between December and June. Results for individual months, as well as the combined February-May period were obtained.

4. Results

SVD analyses between monthly SST and precipitation over northeast Brazil region were computed for diagnostic and prognostic purposes; thus the analyses were done with both simultaneous and time lagged precipitation vs. SST data. Also, SVD analyses were done for Pacific SST and Atlantic SST separately, for the purpose of understanding the individual impact of SST anomalies in each ocean.

SVD was done for SST for Tropical Pacific and Atlantic (24.75^{o}N to 24.75^{o}S) separately. The fact that SVD analyses were calculated considering the precipitation over NEB allowed us to identify not only the influence of the oceans over Nordeste precipitation as a whole, but also the regional patterns of precipitation that relate to Pacific and Atlantic SST during the studied period. It was evident from the results that only the first mode of the SVD was significant for the cases studied.

a. Simultaneous analyses

The following results are based on SVD analyses for the monthly precipitation over the Nordeste from January to May, and the simultaneous SST fields over Tropical Pacific and Atlantic Oceans.

During January the rainy season is not established yet over the Nordeste and the precipitation that can occur over the region is mostly due to cold fronts or their remnants. The relationship found between Pacific SST and the precipitation for January was as follows: SST in the El Niño region over Pacific relates positively to precipitation over some areas in the southern part of NEB (nearly at the end of its rainy season in this month) and negatively to precipitation over small areas in the Nordeste (mostly in Piauí State).

During February, when the rainy season starts in the Nordeste, some interesting correlations begin to emerge. The Pacific Ocean SST influence on NEB precipitation appears to be somewhat weaker than in January. The correlations over the El Niño region are generally lower, except for a small region along the equator between 160^{o}W and the date line. On the other hand, the Atlantic Ocean shows a strong relationship with the precipitation over Nordeste in February (Fig. 1). The central region of the Atlantic, between 5^{o}N and 10^{o}S, is related positively to the precipitation over north-Nordeste; that is, warm SST anomalies in central Tropical Atlantic are related to an earlier start of the rainy season in Nordeste, mostly in the region that includes north and west of Ceará State, west of Piauí, and part of Rio Grande do Norte State, where the presence of the ITCZ is one of the most important causes of precipitation.

March presents a completely different picture. No significant relationship was observed between Atlantic SST and the precipitation over the Nordeste (Ne). This can be explained by the fact that, during March, the Atlantic ITCZ cloud band is near the Equator regardless of other factors; thus precipitation is likely in all years at this time. The Ne precipitation does seem to be correlated weakly with SST anomalies in the El Niño region, especially north of 7^{o}S (Fig. 2).

In April, the Pacific equatorial band between 120°W and the date line displays the highest negative correlation with the precipitation over Nordeste (mostly north of 10°S and west of 39°W) (Fig. 3). Over the Atlantic, for the first time, the so-called dipole feature (Moura and Shukla, 1981) is observed, and is highly correlated to the precipitation in most parts of Nordeste, north of 10°S (Fig. 4). This map presents the highest normalized squared covariance value observed for the heterogeneous maps (19.6%).

For May, the region with highest correlation over the Pacific is displaced to the east, from 150°W to the South American coast, along the equator . This region is mostly related to the Nordeste precipitation north to 6°S. The dipole pattern appears again over the Atlantic, related also to the precipitation over Nordeste, mostly north of 6°S, and also to a small area in the northeastern part of Bahia State.

The heterogeneous fields for the average February-May SST and precipitation show clearly the different influence of Pacific and Atlantic SST over the Nordeste rainy season. For the Pacific, the highest correlations were observed in the equatorial band from 170°E to the South American coast, correlated negatively with the precipitation over the northern and western part of Nordeste (Fig. 5). The NSC was 7.8%. For the Atlantic, the dipole pattern in SST is evident. The north basin of the Atlantic ocean is negatively correlated with Nordeste precipitation (mostly north of 10°S) while the south basin showed a positive correlation with the precipitation over the same area (Fig.6). The normalized squared covariance associated to this field is 11.2%. Features over the Atlantic Ocean appear to explain more of the precipitation variance than the Pacific patterns.

In summary, the influence of Pacific ocean over the Nordeste rainy season is more evident from March on (before that it affects southern NEB only). Atlantic SST show a relatively strong relationship to Nordeste precipitation, explaining a higher part of the covariance. SST anomalies over the Atlantic seem well related to the start of the rainy season and also to its duration. It is worth emphasizing that the quality of the rainy season is primarily related to how long the ITCZ remains over its southernmost position.

b. Time-lagged analyses

Analyses were made relating monthly SST during December-May to the precipitation averaged over the whole Northeast rainy season (February to May), as well as the precipitation in each of the rainy season months. The objective was to isolate patterns in the SST field that systematically preceded patterns in the Nordeste precipitation during the rainy season.

Overall, the results showed that January SST presents modest forecast potential for the total rainy season (February-May) precipitation. Over the Pacific, two bands along the equator, between 170°E and 160°W, and between 140°W and the South American coast gave significant negative correlations (over -0.5) with precipitation over a small region in north-Nordeste, north of 5°S (Fig. 7). The normalized squared covariance (NSC) for this heterogeneous correlation map was 7.5%. Inspection of the heterogeneous correlation maps between Tropical Atlantic SST in January and Northeast February-May average precipitation (Fig. 8) shows that the Atlantic dipole is highly correlated with the precipitation over almost the whole Nordeste region, north to 10°S. Actually, the south tropical Atlantic showed the highest positive correlations, reaching values greater than 0.6, while north tropical Atlantic presented negative correlations of magnitude exceeding 0.4 relating to a smaller area of precipitation anomaly. This heterogeneous correlation map had a NSC equal to 10.5%.

Comparing Figs. 7 and 8, it seems that the Atlantic Ocean SST anomalies have the greater influence over the Nordeste rainy season, so that the Atlantic anomalies cannot be neglected when forecasting the precipitation for the Nordeste. This is true despite the fact that Atlantic SST during December to March is less persistent than Pacific SST.

Considering individual months within the rainy season (February to May), the best relationships were found between May SST and the total precipitation in the season. For the Pacific, two different regions in the equatorial band (between 160°W and the date line and from 150°W to the South American coast) appeared well related to the precipitation over parts of the Nordeste, including mostly Piauí State, Ceará, Rio Grande do Norte and west of Paraíba (NSC equal to 8.4%) . For the Atlantic, the dipole pattern appears very well related with nearly the entire Nordeste, north of 8°S (NSC equal to 12.2%). The high relationship between May SST patterns and the total precipitation in the rainy season reflects the fact that May precipitation is a critical variable in determining the quality of the rainy season (Uvo, 1989) and May precipitation is best related to simultaneous SST fields. Of course, this represents a diagnostic rather than prognostic relationship.

A simple correlation analysis between monthly precipitation indices and a seasonal precipitation index showed that the precipitation occurring in April has a correlation coefficient of 73.2% with the seasonal precipitation. The corresponding values for May is 71.9%, whereas that for each of the other months is less than 53%.

SVD analyses between individual months SST anomalies from January to April and the precipitation for each month of the Nordeste rainy season revealed first that, in general, Atlantic SST is a better parameter to forecast the Nordeste monthly precipitation from one to three months in advance. The primary exception is for March when precipitation is better related to preceding Pacific SST's (in the El Niño region) than to Atlantic anomalies.

5. Conclusions

We have used Singular Value Decomposition (SVD) to analyze the relationships between monthly normalized tropical sea surface temperature anomalies and monthly normalized precipitation anomalies over Northeast Brazil, from December to June, considering both simultaneous and time-lagged relationships.

The results showed different influences of Atlantic and Pacific SST on Nordeste precipitation during different months of the rainy season. In February, when the rainy season starts, no pattern over the Pacific was found to significantly influence the precipitation over the Nordeste. However, Atlantic ocean SST anomalies seem to play a more important role: positive anomalies over the central Atlantic in February are significantly related to the precipitation in the northern part of the Nordeste. Presumably, positive SST anomalies in the central Atlantic can influence the southward displacement of the ITCZ generating an earlier start of the rainy season.

March is the month when the ITCZ cloud band and tropical trough are normally about at their southernmost position. The proximity of the cloud band and the tropical trough to the Nordeste increases the precipitation over the region. This occurs virtually every year regardless of SST anomalies in Atlantic basin. Consequently, during this month, the Atlantic SST does not display any significant relationship with the precipitation over Nordeste. On the other hand, SST anomalies in the equatorial east Pacific do show some relationship with precipitation over parts of the Nordeste during March, indicating that the presence of an anomalous circulation cell between equatorial east Pacific and Nordeste region would be the principal influence on the Nordeste precipitation in this month.

Precipitation during April and May is very important in determining the quality of the rainy season (a good rainy season means precipitation above normal). The proximity of the ITCZ to the vicinity of Nordeste during these two months, and consequently the amount of precipitation over the region, is what results in a good rainy season. Our analyses showed that during these two months, both the SST dipole over the Atlantic ocean and the El Niño signal in the Pacific have a large influence over the ITCZ position, but the Atlantic pattern presented the stronger relationship in both months.

An investigation with time lags showed that January offers modest forecast potential for the whole rainy season precipitation (February to May). Within the rainy season, the Atlantic ocean SST anomalies seemed to be a better parameter for monthly precipitation forecasts. March precipitation; however, is better related to the El Niño region SST anomalies in January and February.

The results obtained in this work are a first step toward an intraseasonal precipitation forecast for the Brazilian semi-arid region. They show clearly the importance of both the Pacific and the Atlantic SST conditions in driving the precipitation over the region and also, that different parts of the semi-arid region are affected differently by the SST patterns.

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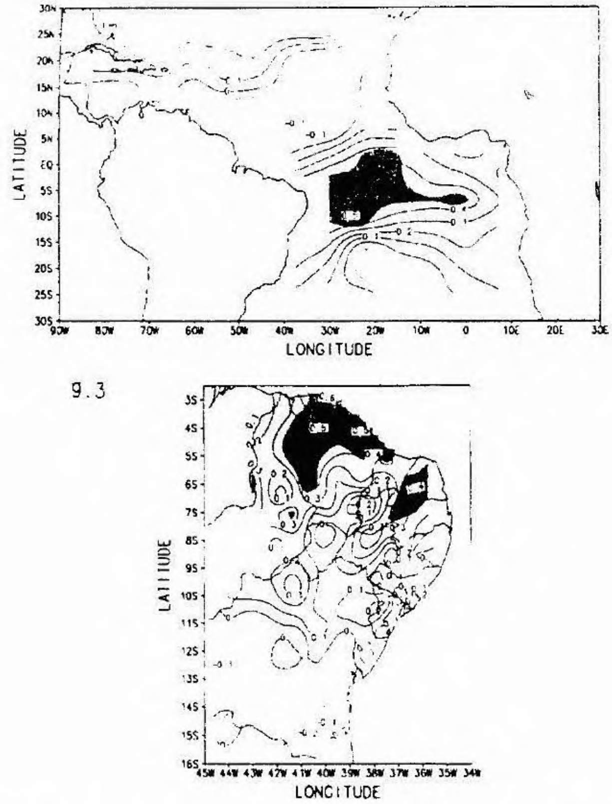

FIG. 1 - Heterogeneos correlation map for the first mode in the SVD expansion for February Atlantic SST (upper panel) and Precipitation fields (lower panel). The number printed on the left is thenormalized squared covariance (NSC) in percents. Shading indicates significance at or above the 95% level. Contour interval is 0.1, dashed contours indicate negative values.

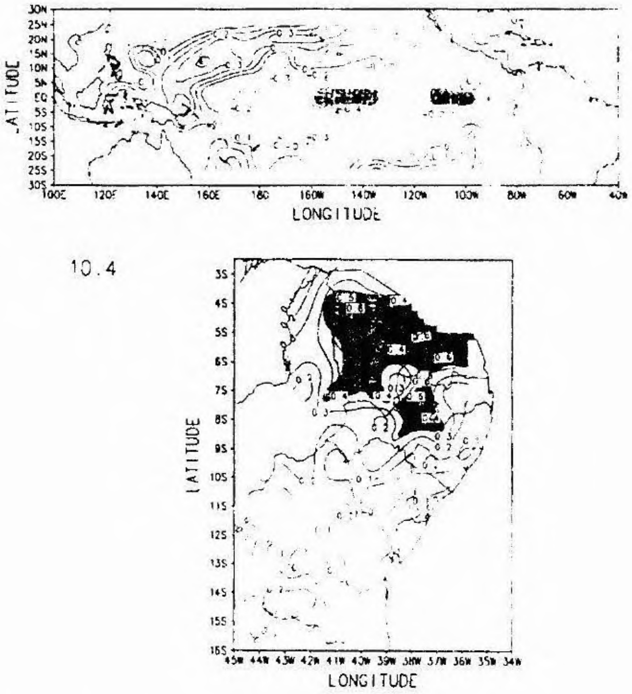

FIG. 2 - Heterogeneos correlation map for the first mode in the SVD expansion for March Pacific SST (upper panel) and Precipitation fields (lower panel). The number printed on the left is thenormalized squared covariance (NSC) in percents. Shading indicates significance at or above the 95% level. Contour interval is 0.1, dashed contours indicate negative values.

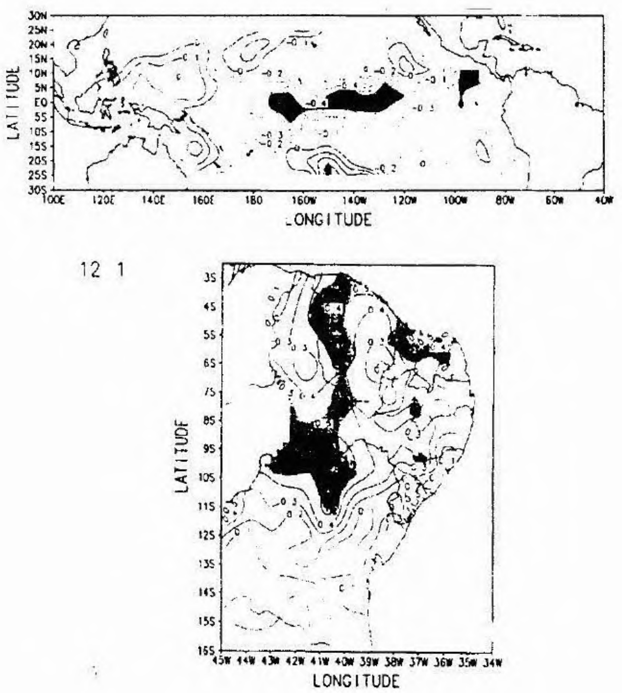

FIG. 3 - As in Fig. 2 but for April.

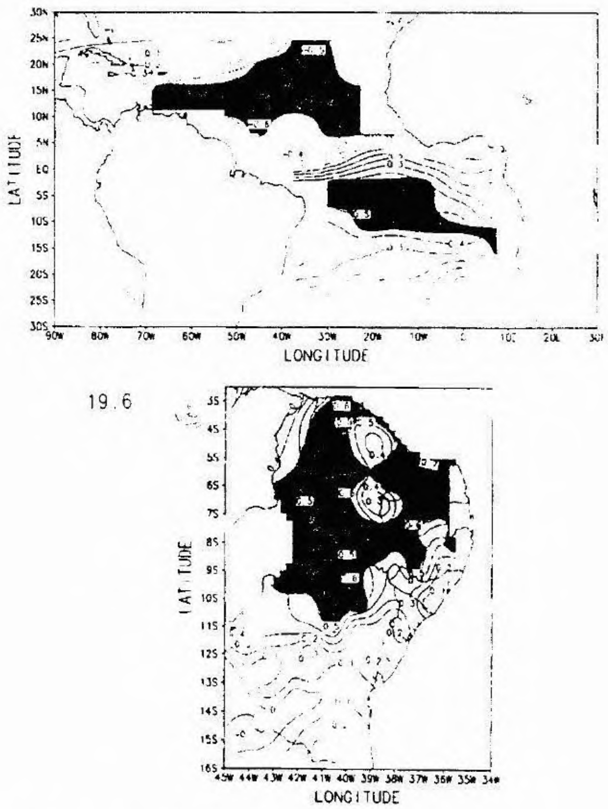

FIG. 4 - As in Fig. 1 but for April.

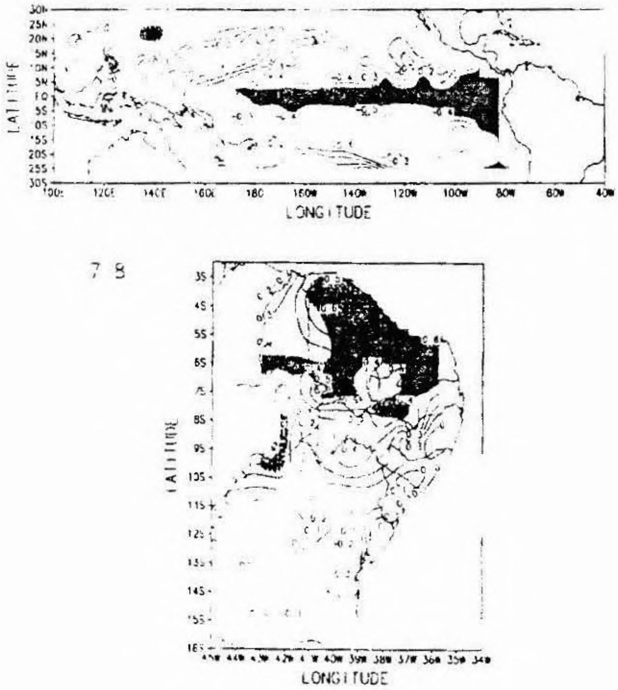

FIG. 5 - As in Fig. 2 but for the time average February-May.

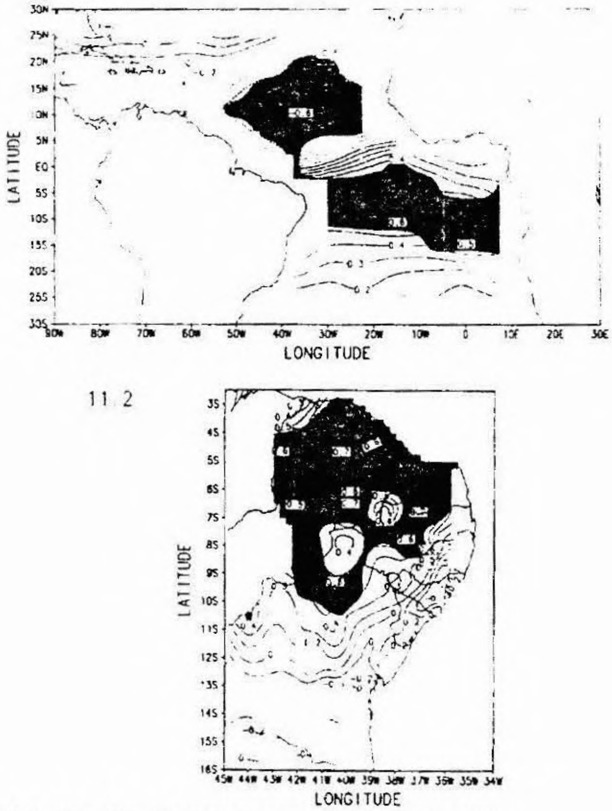

FIG. 6 - As in Fig. 1 but for the time average February-May.

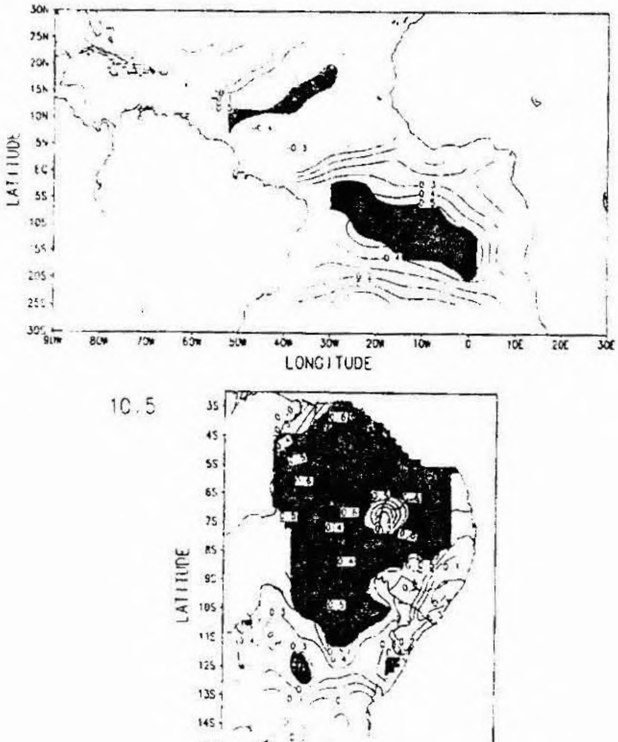

FIG. 7 - As in Fig. 2 but for SST in January and February-May Precipitation

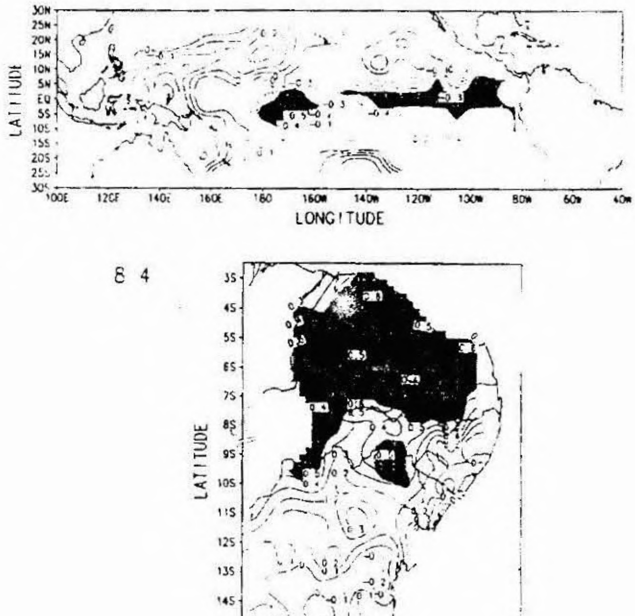

FIG. 8 - As in Fig. 1 but for SST in January and February-May Precipitation