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INTERANNUAL VARIABILITY VERSUS SEASONAL VARIABILITY IN THE TROPICAL ATLANTIC

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Abstract. Monthly fields of sea surface temperature and wind stress for the tropical Atlantic are constructed for January 1964 to December 1979. Inside the Gulf of Guinea the amplitude of the seasonal variability of SST ranges between 2.5 and 4 times greater than the interannual variability. In the remainder of the equatorial Atlantic this measure is less than 2. Standard deviations of wind stress anomalies indicate that, except near the Intertropical Convergence Zone, the magnitude of interannual fluctuations are greater than seasonal ones. The joint analyses of these SST and wind stress fields indicate the largest positive SST anomaly in the Gulf of Guinea (July, 1968) was immediately preceded by the only reversal of the trade winds west along the equator.

Introduction

It is now commonly accepted that the interannual variability in the tropical oceans can have devastating effects on the fisheries and climate of the surrounding countries. Such variability could be defined as a phase shift or an enhancement of the normal seasonal cycle or as an event disassociated from this cycle. The tropical Atlantic Ocean is considered as a prime region to study seasonal low-latitude oceanic variations because of the dominance of the annual frequency. This assertion is primarily based on the analyses of sea surface temperature (SST) observations in the Gulf of Guinea by Merle et al. (1980) and theoretical studies of the adjustment time scale of the basin (Philander, 1979 ; Cane and Sarachik, 1981). Sixteen years of tropical Atlantic SST and wind stress fields have been compiled, gridded and statistically analysed to provide a more thorough estimate of the interannual variability relative to the seasonal variability.

Data Processing

In preparation for the FOCAL experiment all the individual ship observations for the tropical Atlantic Ocean archived at the National Climatic Center have been obtained through December 1979. The low number of observations in the Southern Hemisphere led us to choose a study area extending from 20°S to 30°N. The present work covers the period 1964-1979 and is based on nearly 2 million observations.

The first processing step was to compute monthly averages of SST and wind stress for each 2° latitude by 5° longitude grid box. The wind stress component τ^x (τ^y) was formed by the product of the zonal (meridional) wind component and the magnitude of the wind velocity. To obtain a dimensionally correct value of the wind stress τ^x and τ^y would be multiplied by an air density and drag coefficient. Next the data within each grid box were subjected to a stringent series of quality control tests. Finally, an objective analysis method based on Cressman (1959) was used to obtain a data base of monthly averaged SST and wind stress components on a 2° x 2° grid.

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Variability of SST and Wind Stress

The 16 years of gridded SST and wind stress resulting from the objective analysis provide an opportunity to jointly analyze the seasonal and interannual variability of each field throughout the basin. The standard deviation of the 12 months for the mean seasonal cycle is used as a measure of the seasonal variability and the standard deviation of the 192 monthly departures from that seasonal cycle is used as a measure of the interannual variability. To determine what portion of the seasonal cycle has the largest interannual variability, the standard deviation about the mean of a particular month over 16 years is calculated.

Seasonal Variability

The standard deviations of the mean year for SST and zonal wind stress are presented in Figures 1a and 2a. Regions of maximum amplitude (1.5-3.5°C) correspond to the seasonal upwelling zones along the coasts of Mauritania and Senegal (NW Africa), the northern and southern coasts of the Gulf of Guinea and along the equator near 10°W. The location of the minimum SST variability, coincident with the thermal equator, is obvious between 0° and 7°N. Poleward of 25°N mid-latitude seasonal changes begin to appear.

The regions of maximum zonal (Figure 2a) and meridional (not shown) wind stress variability are contained within an envelope defined by the seasonal excursion of the Intertropical Convergence Zone (ITCZ). The maxima of the zonal wind stress fluctuations (10-15 $m^2 s^{-2}$) straddle the mean position of the ITCZ whereas the largest deviations of the meridional wind stress (15-20 $m^2 s^{-2}$) occur along this line.

Interannual Variability

The standard deviation of interannual changes in SST is depicted in Figure 1b. The interannual variability is maximum in regions where the amplitude of the seasonal signal is large, e.g. the seasonal upwelling zones. In order to illustrate the time history within these zones monthly SST anomalies are presented for an

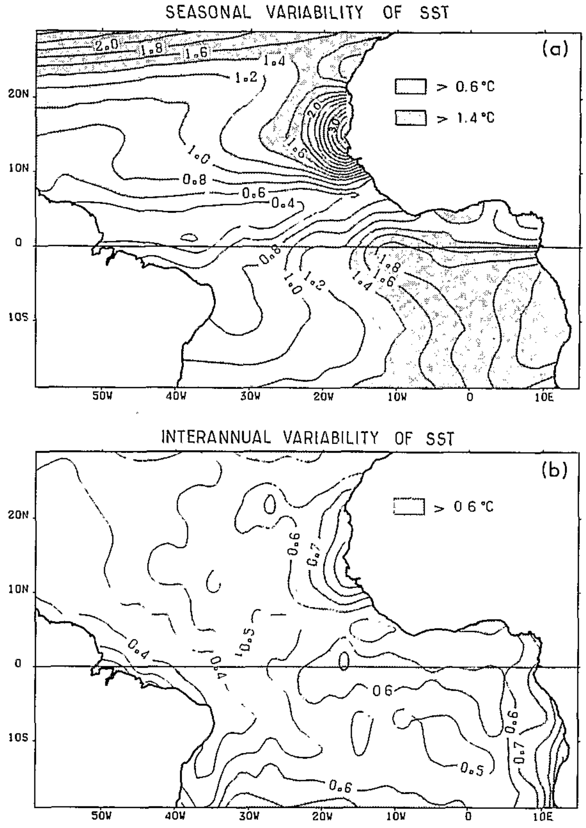

Fig. 1. (a) Standard deviations of the mean seasonal cycle of SST. (b) Standard deviations of the anomalies about the mean seasonal cycle of SST.

upwelling region off the coast of northwest Africa and another on the equator.

Along the coasts of Mauritania and Senegal the mean seasonal signal is predominantly annual with an amplitude of 3°C. The departures from this seasonal cycle are given in Figure 3a. The range of the monthly SST anomalies is ± 2°C. The 12 standard deviations of the anomalies about each monthly mean indicate there is very little year to year change in the maximum temperature of the warm season that occurs in July-November. Most of the interannual variability is associated with changes in the amplitude, timing and duration of the cold season. The period of most persistent anomalies was 1968-1970 when SST was lower than normal in 1968 and the cold seasons of the following two years had SST higher than usual.

Monthly SST anomalies for a 12° longitude strip along the equator are presented in Figure 3b. The extreme temperature anomalies occurred in 1967 (-1.5°C) and 1968 (+2°C). A brief discussion of the 1968 event is provided in the last section. The standard deviation of the anomalies in Figure 3b calculated about each month of the mean seasonal cycle indicates the largest interannual fluctuations happen during June and July. In relation to the seasonal cycle these are the two months preceding the SST minimum of August. Throughout this 16-year record there are several examples of periods in which the SST anomalies persist for greater than 12 months. Hence such anomalies cannot be the result of a simple shift in phase of the mean seasonal cycle.

The interannual variability of the zonal wind stress is presented in Figure 2b. Unlike SST, regions of significant interannual wind stress fluctuations do not necessarily coincide with the regions of maximum seasonal variability. The largest year to year changes in the zonal wind stress (12-18 m^2s^{-2}) are at the poleward extremes of the study area. This interannual signal is associated with multiple low pressure patterns propagating in each winter hemisphere. At lower latitudes the standard deviation of the interannual variability is less than 4 m^2s^{-2} in the Gulf of Guinea and between 4 and 8 m^2s^{-2} in the remainder of the equatorial Atlantic.

Previous theoretical ideas, analyses of historical data, and modelling calculations (Moore et al., 1978 ; Servain et al., 1982 ; Busalacchi and Picaut, 1983) suggest the zonal wind stress west of the Gulf of Guinea may have an important impact on the variability in the equatorial Atlantic Ocean. Figure 4 depicts the monthly anomalies of the zonal wind stress along the equator west of 20°W. This time series is characterized by equatorial easterlies weaker than normal for 1964-1968 and stronger than normal for 1976-1979. In 1966 and 1968 the equatorial easterlies were at least 10 m^2s^{-2} weaker than the seasonal mean. For a short period in 1976 the zonal wind stress was 18 m^2s^{-2} stronger than normal. Analysis of this time series

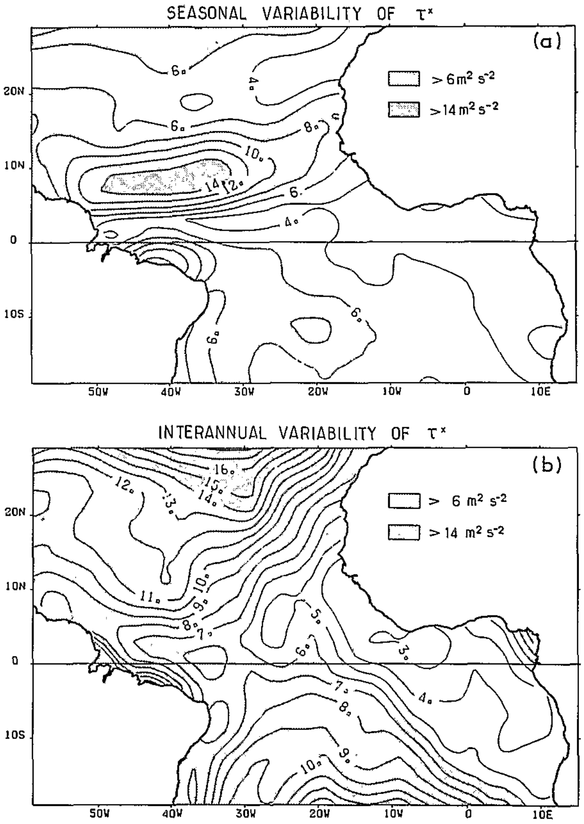

Fig. 2. (a) Standard deviations of the mean seasonal cycle of τ^x. (b) Standard deviations of the anomalies about the mean seasonal cycle of τ^x.

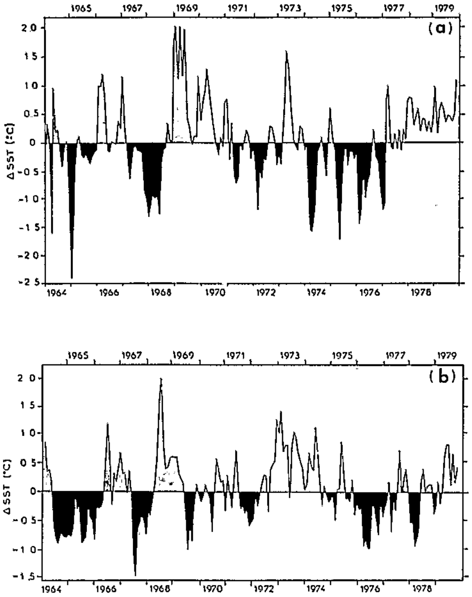

Fig. 3. (a) Monthly SST anomalies (°C) averaged from the coast of northwest Africa to 20°W and between 20°N and 8°N. (b) Monthly SST anomalies (°C) averaged for an equatorial strip bounded by 2°N, 2°S, 20°W, and 8°W.

month by month indicates the largest interannual fluctuations are in June. With reference to the seasonal cycle, June represents the mid-point of the seasonal intensification of the zonal wind stress.

Comparison of Seasonal to Interannual Variability

A measure of the amplitude of the seasonal signal with respect to interannual changes can be obtained by forming the ratio of the standard deviation of the seasonal variability (Figures 1a and 2a) to the standard deviation of the interannual variability (Figures 1b and 2b). High values of the ratio of the seasonal to interannual SST changes are obviously found in the regions where the annual signal is important, i.e. north of 20°N, in the vicinity of seasonal coastal upwelling regions and inside the Gulf of Guinea. For this last area the SST ratio is greater than 2.5 and less than 4. These results complete those of Merle et al. (1980) who have used the Dakar-Cape Town transect across the Gulf of Guinea and studied the interannual variability only for the months of February and August. The ratio of the seasonal to interannual SST variability in their work was reported to be between 4 and 5. However it should be noted that February and August are two months in which interannual SST changes in this area are small. For the other parts of the equatorial Atlantic Ocean the results of the present study indicate the SST ratio is less than 2. The ratios of the seasonal to interannual variabilities for both wind stress components are consistently greater than 1 only in the vicinity of the ITCZ. For large regions of the basin, including the equatorial zone, this ratio is less than 1, implying a significant interannual forcing of the tropical Atlantic Ocean.

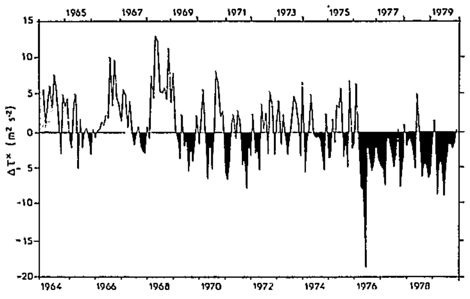

Fig. 4. Monthly τ^x anomalies (m^2s^{-2}) for an equatorial strip averaged from the coast of Brazil to 20°W and between 2°N and 2°S.

The Warm Event of 1968

The 1968 warm event within the Gulf of Guinea is one of the most spectacular episodes to occur in the tropical Atlantic Ocean during the last few decades (Bakun, 1978 ; Lamb, 1978 ; Hisard, 1980 ; Merle, 1980). Large positive SST deviations from the mean year appeared in the entire Gulf of Guinea in May-July, prior to the normal cold season. The maximum anomaly was in July, greater than 2.5°C, centered along the equator near 10°W (Figure 5a). As cited by the above authors the appearance of the high SST was coincident with an excessive southward displacement of the ITCZ. Servain (1984) shows a reversal of the trade winds along the equator near 30°W approximately one month before the appearance of maximum positive SST anomalies in the Gulf of Guinea.

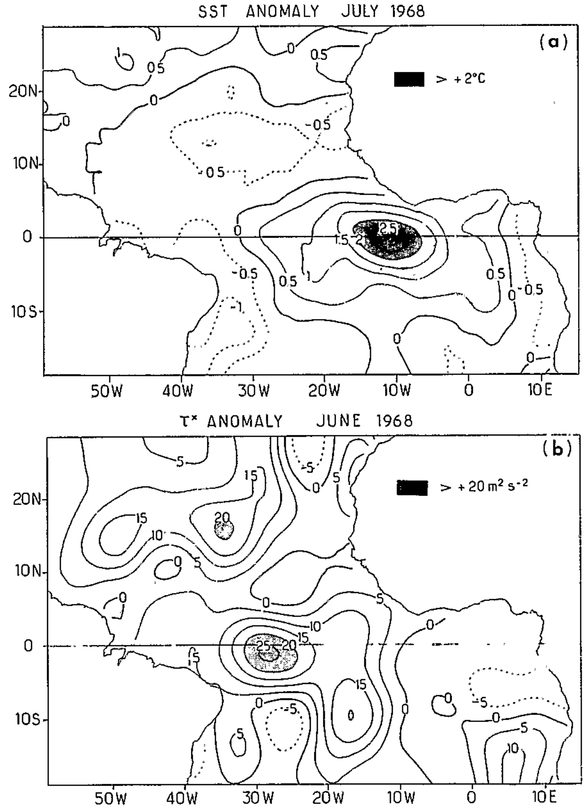

Fig. 5. (a) SST anomalies (°C) for July 1968. (b) τ^x anomalies (m^2s^{-2}) for June 1968.

Upon examination of all of the monthly wind stress fields from January 1964 to December 1979 we note that the only trade wind reversal along the equator is during May-June, 1968. Figure 5b indicates a patch of anomalous eastward wind stress along the equator near 30°W which differs from the 16-year mean by more than 20 m^2s^{-2}.

Conclusions

The availability of carefully established fields of SST and wind stress encompassing a period of 16 years has enabled us to compute a few simple measures of the interannual variability with respect to the seasonal variability for the tropical Atlantic. Interannual changes in SST are largest in regions where the seasonal SST signal is large. Analyses of the monthly SST anomalies for upwelling regions along northwest Africa and the equator indicate the majority of interannual fluctuations are related to changes in the amplitude, timing and duration of the cold season. In the Gulf of Guinea the ratio of seasonal to interannual SST fluctuations is between 2.5 and 4. In the remainder of the equatorial Atlantic this ratio is less than 2. An analogous ratio for the wind stress is less than 1 throughout the basin except near the ITCZ. Wind stress anomalies along the equator are noted to persist for more than 12 months. Anomalies of this duration cannot be the result of a simple phase shift of the seasonal cycle. The dramatic warm event in the Gulf of Guinea of 1968, possibly associated with a reversal of the trade winds further west, has a SST signature with the same magnitude as an El Niño event in the Pacific.

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References

Bakun, A., Guinea current upwelling. Nature, 271, 147-150, 1978.

Busalacchi, A.J., and J. Picaut, Seasonal variability from a model of the tropical Atlantic Ocean. J. Phys. Oceanogr., 13, 1564-1588, 1983.

Cane, M.A., and E.S. Sarachik, The response of a linear equatorial ocean to periodic forcing. J. Mar. Res., 39, 651-693, 1981.

Cressman, G.P., An operational objective analysis system. Mon. Wea. Rev., 87, 367-374, 1959.

Hellerman, S., Charts of the variability of the wind stress over the tropical Atlantic. GATE sup. II Deep-Sea Res., 26, 63-75, 1980.

Hisard, P., Observation de réponses de type "El Niño" dans l'Atlantique tropical oriental Golfe de Guinée. Ocean. Acta, 3, 69-78, 1980.

Lamb, P.J., Case studies of tropical Atlantic surface circulation pattern during recent sub-Saharan weather anomalies, 1967-1968. Mon. Wea. Rev., 106, 482-491, 1978.

Merle, J., Variabilité thermique annuelle et interannuelle de l'océan Atlantique équatorial est. L'hypothèse d'un "El Niño" Atlantique. Ocean. Acta, 3, 209-220, 1980.

Merle, J., M. Fieux, and P. Hisard, Annual signal and interannual anomalies of sea surface temperature in the eastern equatorial Atlantic Ocean. GATE sup. II Deep-Sea Res., 26, 77-101, 1980.

Moore, D.W., P. Hisard, J.P. Mc Creary, J. Merle, J.J. O'Brien, J. Picaut, J.M. Verstraete, and C. Wunsch, Equatorial adjustment in the eastern Atlantic. Geophys. Res. Letters, 5, 637-640, 1978.

Philander, S.G.H., Variability of the tropical oceans. Dyn. Atm. Ocean., 3, 191-208, 1979.

Servain, J., Réponse océanique à des actions éloignées du vent dans le Golfe de Guinée en 1967-1968. Ocean. Acta, 7, 1984.

Servain, J., J. Picaut, and J. Merle, Evidence of remote forcing in the equatorial Atlantic ocean. J. Phys. Oceanogr., 12, 457-463, 1982.

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