



HAL
open science

West African Monsoon Dynamics and Eastern Equatorial Atlantic and Pacific SST Anomalies (1970–88)

Serge Janicot, Ali Harzallah, Bernard Fontaine, Vincent Moron

► **To cite this version:**

Serge Janicot, Ali Harzallah, Bernard Fontaine, Vincent Moron. West African Monsoon Dynamics and Eastern Equatorial Atlantic and Pacific SST Anomalies (1970–88). *Journal of Climate*, 1998, 10.1175/1520-0442(1998)0112.0.CO;2 . hal-02894846

HAL Id: hal-02894846

<https://hal.science/hal-02894846>

Submitted on 9 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

SST average over the eastern equatorial Atlantic (5°N–5°S, 20°–5°W). It is well correlated with the leading mode of variability of the tropical Atlantic SSTs (Houghton and Tourre 1992; Zebiak 1993) and describes a large part of SST variability in the Gulf of Guinea, a region above which the monsoon flows before it reaches West Africa. The second one (EPAC) is the SST average over the eastern equatorial Pacific (5°N–5°S, 180°–80°W). It is a good indicator of occurrences of ENSO episodes (Deser and Wallace 1990). Each of these indexes is averaged for July–August and standardized anomalies are computed during the period 1970–88.

c. Model description and experimental design

The model used in this study is version 5.0 of the LMD atmospheric general circulation model described in Sadourny and Laval (1984). Its major characteristics are outlined here. The LMD model is a gridpoint model with a standard resolution of 64 points equally spaced in longitude and 50 points equally spaced in the sine of latitude. The vertical coordinate is sigma, the ratio of local pressure to surface pressure. This version has eleven levels: four in the boundary layer, four in the troposphere, and three in the stratosphere. The dynamical processes make use of a lateral diffusion scheme modeled by a mixed bi-Laplacian operator in which the inner part acts on the sigma coordinate and outer parts on the pressure coordinate. The model uses an improved formulation of the solar radiation algorithm of Fouquart and Bonnel (1980), the longwave radiation algorithm of Morcrette (1990), and the interactive cloud-radiation scheme developed by Le Treut and Li (1991). There is no diurnal variation. Moist processes are represented by three condensation schemes: a supersaturation scheme for nonconvective condensation, a moist adiabatic adjustment scheme, and a Kuo scheme for penetrative cumulus convection. Cloud generation is statistically parameterized (Le Treut and Li 1991) and a prognostic scheme has been introduced for the cloud condensed water. In the parameterization of the land surface processes (Laval et al. 1981), the ground surface and the soil moisture are defined for a single layer. Surface albedo is prescribed according to the climatology of Dorman and Sellers (1989). Roughness length z_o is a combination of the climatology of Dorman and Sellers (1989) and of the roughness length used at the European Centre for Medium-Range Weather Forecasts.

A set of seven independent integrations with different initial conditions have been performed on the period 1970–88 using observed global SSTs and sea ice cover. The SST field is a combination of the dataset of Reynolds and Gemmill (1984) for the period 1970–78 and of the Center for Ocean–Land–Atmosphere Studies/Climate Analysis Center AMIP (Atmospheric Model Intercomparison Project) SST and sea-ice dataset for the period 1979–1988 (Gates 1992). More details can be found in Harzallah and Sadourny (1995).

In this paper, computations are based on the seven-member ensemble average of model outputs, to reduce the effect of internal variability of the model. The statistical significance of correlation coefficients and two-tailed Student's *t*-tests performed in this paper are estimated with regard to the space and time autocorrelations. Detailed explanations of the method followed can be found in Fontaine and Janicot (1992). In addition, Student's *t*-test statistical significance takes into account internal variability by using the between runs variability to estimate the variance in the *t*-test statistic.

3. Results

a. Equatorial SST anomalies and rainfall anomaly types

Figure 1 shows the relationships between EATL and EPAC along with the four West African rainfall anomaly types defined for July–August during the period 1970–88. Rainfall anomaly types are displayed in Fig. 1 only when EATL or EPAC is greater than two-thirds in absolute value. This threshold is a compromise between obtaining sufficiently strong SST anomalies and retaining enough cases out of the 19 available.

The correlation between EPAC and EATL indexes is weak (-0.12) during the period 1970–88. This is also true for other periods (Pan and Oort 1990). The combination of these two statistically independent indexes can therefore be considered when analyzing occurrences of different rainfall anomaly types. From Fig. 1 one sees that the rainfall anomaly types $--$ (1972, 1976, 1982, 1983) are associated with positive EPAC index and with negative EATL index. The types $-+$ (1973, 1979, 1984, 1987) are characterized by positive EATL index, whatever the sign of EPAC is. Notice, for example, that the summer 1987 is characterized by high positive EATL and EPAC indexes. The remaining rainfall types, $++$ and $+ -$ (1970, 1974, 1975, 1977, 1978, and 1988), are associated mainly with negative EPAC index, whatever the sign of EATL. Also, large positive values of EPAC are accompanied by rainfall types $--$ except for 1987, and negative EATL index values are associated with above average rainfall in the Sahel when EPAC is negative, and with rainfall type $--$ when EPAC is positive.

This diagram illustrates the complexity of the relationships between SST anomalies and Sahel rainfall variability for the period 1970–88. In the Gulf of Guinea, for instance, negative SST anomalies occur during abnormally dry as well as during abnormally wet Sahelian rainy seasons. Positive and negative SST anomalies in the Gulf of Guinea can also be associated with the two types of Sahel drought ($-+$ and $--$, respectively). The period studied contains two interesting contrasting years, 1987 and 1988. During those two particular years, the Gulf of Guinea was characterized by positive SST anomalies, but 1987 was an ENSO warm event, whereas 1988 was an ENSO cold event. The West

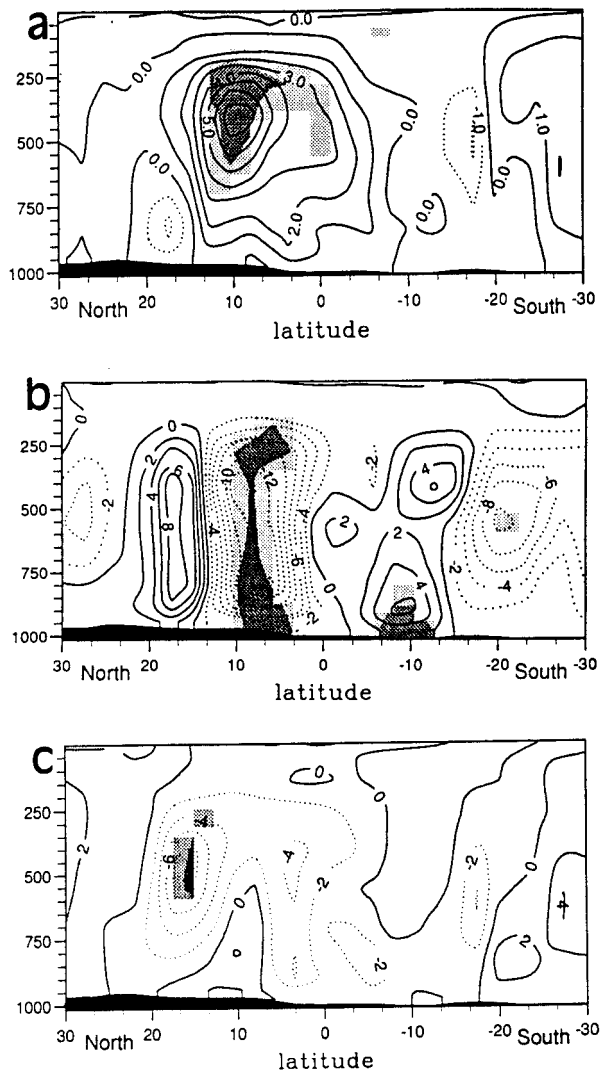


FIG. 3. (a) Latitude–pressure diagram of July–August vertical velocity (dp dt^{-1}) averaged from 15°W to 15°E for the composite anomaly of 1972, 1976, 1982, and 1983 related to the 1970–88 mean. Units: hPa day^{-1} . (b) Same as in (a) but for 1987. (c) Same as in (a) but for 1988. Values for the seven-member ensemble runs are presented. Light/dark gray area indicates Student's *t*-tests significant at the 10%/5% levels, respectively.

rath 1984; Folland et al. 1986; Janicot 1992; Fontaine et al. 1995) and is also in agreement with the occurrences of rainfall anomaly type $-+$ in Fig. 1.

The correlation pattern calculated between the EPAC index and the simulated vertical velocity (Fig. 2c) is quite different. The figure shows indeed significant positive correlations at the equator and at 15°N (up to $+0.60$). The simulated ascents are therefore weaker over West Africa during ENSO warm episodes. This is consistent with the occurrence of rainfall type $--$ in Fig. 1.

An additional way to investigate the association between the vertical velocity and SST indexes is to perform composites. Figure 3a presents the meridional

cross section over West Africa of the July–August vertical velocity departures corresponding to the composite ENSO warm event of 1972, 1976, 1982, and 1983. Simulated ascents inside the ITCZ are weaker than average above 700 hPa, and this abnormal subsidence extends toward the equator. No meridional shift of the ITCZ is depicted (not shown). This is consistent with the observed occurrences of rainfall type $--$ (Fig. 1) and with the simulated rainfall anomalies shown in Janicot (1994). Our composite map agrees with the correlation pattern associated with EPAC (Fig. 2c). We therefore suggest that ENSO warm events had an impact on West African rainfall fields during these summers.

The simulated vertical velocity anomalies for 1987 are shown in Fig. 3b. The ITCZ is enhanced and shifted southward over West Africa. This corresponds to the observed rainfall type $-+$ (Fig. 1) and is consistent with the simulated rainfall anomalies shown in Janicot (1994). This is also consistent with the correlation pattern associated with EATL (Fig. 2b). Thus we can suggest that in 1987 the impact on West African rainfall field of SST anomalies in eastern equatorial Atlantic was stronger than the possible influence of the ENSO warm episode.

In 1988 the simulated vertical velocity anomaly field over West Africa (Fig. 3c) depicts enhanced ascents above 600 hPa at 15°N , consistent with observed (Fig. 1) and simulated (Janicot 1994) rainfall anomaly fields. This vertical velocity pattern bears some resemblance, with the opposite sign, to the correlation pattern associated with EPAC (Fig. 2c). Thus, it appears that in 1988 the atmospheric circulation over West Africa could be dominated by ENSO cold conditions.

2) EAST–WEST DIVERGENT CIRCULATION OVER THE TROPICAL ATLANTIC

In this section the relationship between the SST anomalies in the eastern equatorial Pacific and the West African monsoon dynamics is analyzed through the east–west divergent circulation. Following Rowell et al. (1992), we computed contours of the vertical integral of July–August simulated zonal divergent mass flux averaged between 5°S and 20°N :

$$\text{MF}(\sigma) = -\frac{a}{g} \int_{-\pi/36}^{\pi/9} \int_1^{\sigma} p_s u_{\text{div}} d\sigma d\lambda,$$

where a is the earth's radius (m), g the gravity acceleration (m s^{-2}), σ the model vertical level, p_s the surface pressure (Pa), u_{div} the zonal divergent wind (m s^{-1}), and λ the latitude (rd).

These contours can be interpreted as streamlines of the zonal divergent flow. For all the results presented here we have verified that the contribution of the zonal divergent mass flux to the vertical velocities is large and that these two quantities can be closely associated. The flow is turning clockwise (counterclockwise) around positive (negative) extrema and its value is proportional

to the mass flux gradient. The mean flow is shown in Fig. 4a. The ascending branch located at 150°E and the subsiding one located over the eastern Pacific point out the Pacific Walker cell. An east–west Atlantic circulation is depicted by its ascending branch located over continental America and its subsiding one located over the longitude band 30°W–0°. It is therefore expected that West African rainfall may be influenced by a displacement and/or a variation of the intensity of this Atlantic zonal circulation, as suggested in Janicot (1992).

The composite of zonal divergent mass flux anomalies according to ENSO warm events of 1972, 1976, 1982, and 1983 (July–August) is presented in Fig. 4b. The Atlantic east–west circulation is enhanced, in association with larger ascending motions in the whole troposphere over the eastern Pacific and stronger subsiding motions above 500 hPa over the tropical Atlantic and West Africa. This result is consistent with the previous hypothesis of a connection between these ENSO warm events and droughts over West Africa.

In 1987 (Fig. 4c), the zonal divergent mass flux anomaly field depicts weak negative departure values over the Atlantic. This confirms our suggestion that during this summer the West African rainfall anomaly field was mostly controlled by SST anomalies in the eastern equatorial Atlantic. In 1988 (Fig. 4d), large negative anomalies of zonal divergent mass flux are located over the western part of the tropical Atlantic but do not reach West Africa. We therefore cannot confirm the hypothesis of a direct connection between this ENSO cold episode and West African monsoon dynamics through east–west divergent circulation.

3) PACIFIC-ATLANTIC ZONAL ATMOSPHERIC OSCILLATION

Atmospheric connections between the tropical Pacific and the tropical Atlantic have been examined in various studies. For example, eigenvector analysis performed by Kidson (1975) shows that the equatorial Atlantic zone is part of the large region of variability centered over Indonesia and the western Pacific oscillating with opposite sign to the center located in the eastern Pacific.

An ocean–atmosphere coupling involving the tropical Atlantic and eastern Pacific during northern summer can be described by the difference between EPAC and EATL (Fig. 5a). The correlation field calculated between these values and the simulated mean sea level pressure (Fig. 5b) shows a large zonal dipole between the tropical Atlantic and the eastern part of the tropical Pacific. This zonal oscillation works well when the EPAC–EATL difference is large, as was the case during the ENSO warm events of 1972, 1976, 1982, 1983, or during the cold event of 1988 (Fig. 5a). On the other hand, during summer 1987, the difference between EPAC and EATL was weak. This is consistent with the weak anomalies of east–west divergent circulation over the tropical Atlantic (Fig. 4c).

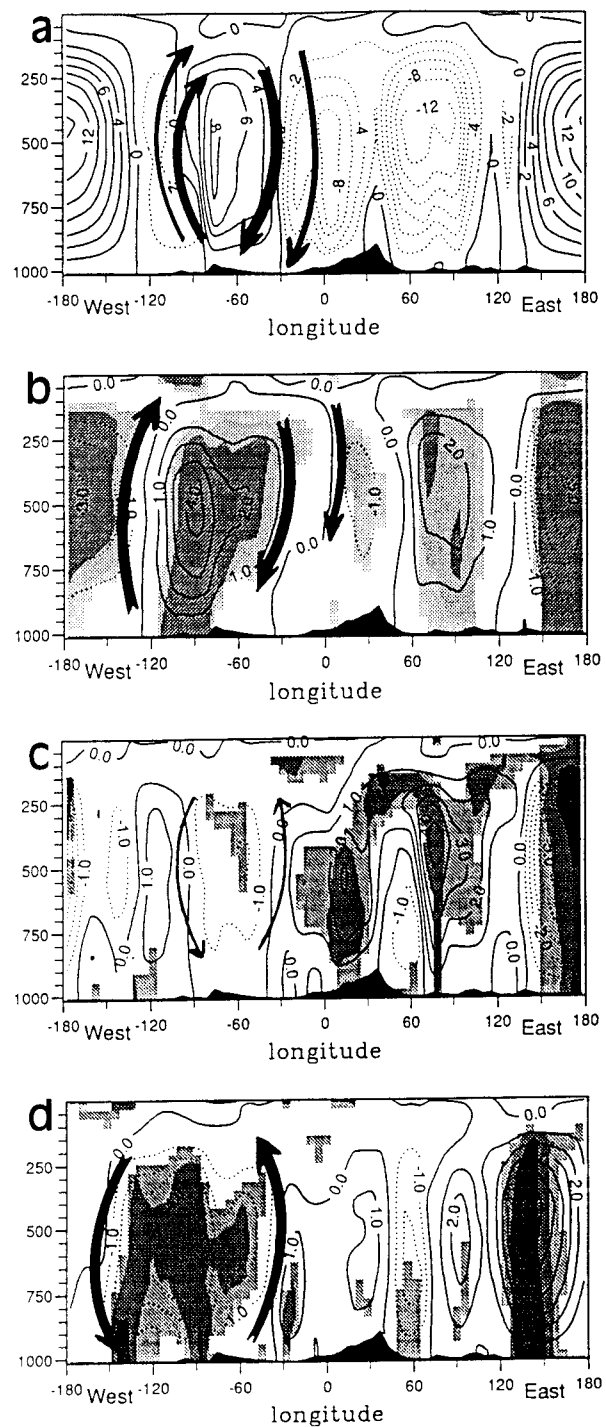


FIG. 4. (a) Longitude–pressure diagram of vertical integral of the zonal divergent component of mass flux averaged from 20°N to 5°S in July–August 1970–88. Contour interval is 10^9 kg s^{-1} . (b) Same as in (a) but for the composite anomaly of 1972, 1976, 1982, and 1983 related to the 1970–88 mean. (c) Same as in (b) but for 1987. (d) Same as in (b) but for 1988. Values for the seven-member ensemble runs are presented. Light/medium/dark gray area indicates Student's *t*-tests significant at the 10%/5%/1% levels, respectively. Arrows indicate the zonal divergent circulation over the tropical Atlantic.

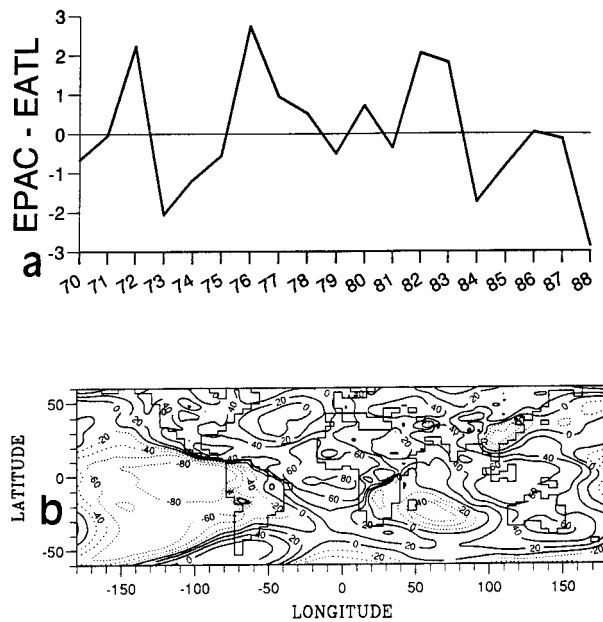


FIG. 5. (a) Time series of the mean July–August difference (EPAC – EATL) index from 1970 to 1988. (b) Correlations (multiplied by 100) between the difference (EPAC – EATL) index and mean sea level pressure for July–August on the period 1970–88. Values for the seven-member ensemble runs are presented.

During the northern summer, when the trade winds and the equatorial oceanic upwelling are well developed in the tropical Atlantic domain, the occurrence of positive SST anomalies in the very eastern part of the equatorial Pacific, similar to the canonical ENSO onset (Rasmusson and Carpenter 1982), can enhance the trade winds over the western Atlantic (Servain and Merle 1993). This would induce an eastward remote dynamical response along the equatorial guideline and the enhancement of the equatorial upwelling in the Gulf of Guinea in a time lag of 1–2 months (Servain et al. 1982; Latif and Barnett 1995). Such a situation is illustrated by the mean July–August simulated 900-hPa zonal wind and SST departures for the composite ENSO warm event of 1972, 1976, 1982, and 1983 (Figs. 6a and 6b). On the other hand, in July–August 1987 (Figs. 6c and 6d), positive SST anomalies are displaced westward in the tropical Pacific. This corresponds to a different pattern that characterizes the mature phase of the canonical ENSO evolution (Rasmusson and Carpenter 1982). No significant variation of the trade winds appears in the western Atlantic as well as no upwelling enhancement in the Gulf of Guinea. One notices that during summer

1987 the easterly component of the harmattan is enhanced over West Africa, which can be associated to the southward retreat of the ITCZ.

4. Conclusions

West African rainfall anomaly types and monsoon dynamics have been examined in connection with two equatorial SST key areas in the eastern parts of Pacific and Atlantic basins. Outputs of seven integrations of the LMD atmospheric general circulation model forced by observed global SSTs for the period 1970–88 have been investigated. This period is characterized by large ENSO warm and cold episodes. The use of ensemble average simulations enables us to extract the impact of SST anomalies on the atmosphere from internal atmospheric dynamics. The extent to which the conclusions of this experiment are model dependent is, of course, an open question although the conclusions from observations and simulations are in close agreement. Other modes of variability of the atmosphere forced by SST centers other than EATL and EPAC may also influence the western African monsoon.

The use of both rainfall indexes in the continental Sahel and Guinean region has been helpful to better differentiate the statistical associations with the EATL and EPAC indexes. SST anomalies in the eastern equatorial Atlantic are linked to the latitudinal location of the ITCZ over West Africa: positive SST anomalies are accompanied by a southward shift of the ITCZ and thus by a drought limited to the Sahel. The east–west divergent circulation over the tropical Atlantic is linked to SST anomalies in the eastern equatorial Pacific and tends to modulate the vertical motion over West Africa. ENSO warm events, when associated with negative SST anomalies in the eastern equatorial Atlantic, are linked to enhanced Atlantic east–west divergent circulation and to decreased upward motions over West Africa, leading to a drought over West Africa. The ENSO warm episode of 1987 seems to have no large impact on West African rainfall. The simulated Atlantic east–west divergent circulation is slightly weaker than average, and the drought, limited to the Sahel, appears to be associated with positive SST anomalies in the eastern equatorial Atlantic and with a southward shift of the ITCZ.

A Pacific–Atlantic zonal atmospheric oscillation is evident in the period 1970–88. It is coupled to the difference of SST anomalies in the eastern equatorial Atlantic and Pacific basins. Janicot et al. (1996) showed that the relationships between SST anomalies and West African rainfall has changed after 1970; in particular,

FIG. 6. (a) July–August zonal component of the wind (positive eastward) at 900 hPa for the composite anomaly of 1972, 1976, 1982, and 1983 related to the 1970–1988 mean. Units: 0.1 m s^{-1} . Light/medium/dark gray area indicates Student's t-tests significant at the 10%/5%/1% levels, respectively. (b) July–August SST anomaly field for the composite of 1972, 1976, 1982, and 1983 related to the 1970–88 mean. Units: 0.1°C . (c) Same as in (a) but for 1987. Light/dark gray area indicates Student's t-tests significant at the 10%/5% levels, respectively. (d) Same as in (b) but for 1987. Values for the seven-member ensemble runs are presented in (a) and (c).

the correlation between SST anomalies in the eastern equatorial Pacific and Sahel rainfall has increased to a highly significant value. The setup of the Pacific–Atlantic zonal atmospheric oscillation, depicted here for the period 1970–88, could be a possible explanation for the strong connection between Pacific SSTs and Sahel rainfall.

Acknowledgments. The authors are very thankful to NCAR, CILSS, AGRHYMET, and the numerous African administrations for providing the rainfall data, and to UKMO for providing the MOHSST4 tape. We are grateful to Peter Lamb and the anonymous reviewers for their comments, which greatly improved the manuscript, and to Chris Landsea for his thought-provoking comments. We thank also Jean Luc Melice and Sylwia Trzaska for reading the manuscript. The simulations were performed in part on the Cray-2 of the Centre de Calcul Vectoriel pour la Recherche (C²VR) and in part on the Cray-YMP of Electricité de France.

REFERENCES

- Bottomley, M., C. K. Folland, J. Hsiung, R. E. Newell, and D. E. Parker, 1990: *Global Ocean Surface Temperature Atlas 'GOSTA'*. United Kingdom Meteorological Office/Massachusetts Institute of Technology, 20 pp. + 313 plates.
- Deser, C., and J. M. Wallace, 1990: Large-scale atmospheric circulation features of warm and cold episodes in the tropical Pacific. *J. Climate*, **3**, 1254–1281.
- Dorman, J. L., and P. J. Sellers, 1989: A global climatology of albedo, roughness length and stomatal resistance for atmospheric general circulation models as represented by the simple biosphere model (SIB). *J. Appl. Meteor.*, **28**, 833–855.
- Folland, C. K., T. N. Palmer, and D. E. Parker, 1986: Sahel rainfall and worldwide sea temperature 1901–1985. *Nature*, **320**, 602–607.
- Fontaine, B., and S. Janicot, 1992: Wind field coherence and its variations over West Africa. *J. Climate*, **5**, 512–524.
- , and —, 1996: Near-global SST variability associated with West African rainfall anomaly types. *J. Climate*, **9**, 2935–2940.
- , —, and V. Moron, 1995: Rainfall anomaly patterns and wind field signals over West Africa in August (1958–1989). *J. Climate*, **8**, 1503–1510.
- Fouquart, Y., and B. Bonnel, 1980: Computations of solar heating of the earth's atmosphere: A new parameterization. *Contrib. Atmos. Phys.*, **53**, 35–62.
- Gates, W. L., 1992: AMIP: The Atmospheric Model Intercomparison Project. *Bull. Amer. Meteor. Soc.*, **73**, 1962–1970.
- Harzallah, A., and R. Sadourny, 1995: Internal versus SST-forced atmospheric variability as simulated by an atmospheric general circulation model. *J. Climate*, **8**, 474–495.
- , J. O. Rocha De Aragao, and R. Sadourny, 1996: Interannual rainfall variability in Northern Brazil: Observations and model simulations. *Int. J. Climatol.*, **16**, 861–878.
- Hastenrath, S., 1984: Interannual variability and annual cycle: Mechanisms of circulation and climate in the tropical Atlantic sector. *Mon. Wea. Rev.*, **106**, 1280–1287.
- Houghton, R. W., and Y. M. Tourre, 1992: Characteristics of low-frequency SST fluctuations in the tropical Atlantic. *J. Climate*, **5**, 765–771.
- Janicot, S., 1992: Spatiotemporal variability of West African rainfall. Part II: Associated surface and air mass characteristics. *J. Climate*, **5**, 499–511.
- , 1994: The West African monsoons of 1987 and 1988: Pacific or Atlantic signal? *Proc. Int. Conf. on Monsoon Variability and Prediction*, Trieste, Italy, WMO, 765–772.
- , V. Moron, and B. Fontaine, 1996: Sahel droughts and ENSO dynamics. *Geophys. Res. Lett.*, **23**, 515–518.
- Kidson, J. W., 1975: Tropical eigenvector analysis and the Southern Oscillation. *Mon. Wea. Rev.*, **103**, 187–196.
- Krishnamurti, T. N., 1986: Workbook on numerical weather prediction for the tropics for the training of class I and class II meteorological personnel. WMO Tech. Note No. 669, 355 pp.
- Lamb, P. J., 1978a: Case studies of tropical Atlantic surface circulation patterns during recent sub-Saharan weather anomalies: 1967 and 1968. *Mon. Wea. Rev.*, **106**, 482–491.
- , 1978b: Large-scale tropical surface circulation patterns associated with Sub-Saharan weather anomalies. *Tellus*, **30**, 240–251.
- Latif, M., and T. P. Barnett, 1995: Interactions of the tropical oceans. *J. Climate*, **8**, 952–964.
- Laval, K., R. Sadourny, and Y. Serafini, 1981: Land surface processes in a simplified GCM. *Geophys. Astrophys. Fluid. Dyn.*, **17**, 129–150.
- Le Treut, H., and Z. X. Li, 1991: Sensitivity of an atmospheric general circulation model to prescribed SST changes: Feedback effects associated with the simulation of cloud optical properties. *Climate Dyn.*, **5**, 175–187.
- Morcrette, J. J., 1990: Radiation and cloud radiative properties in the European Centre for Medium-Range Weather Forecasts forecasting system. *J. Geophys. Res.*, **96**, 9121–9132.
- Moron, V., 1994: Guinean and Saharan rainfall anomaly indices at annual and monthly time scales (1933–1990). *Int. J. Climatol.*, **14**, 325–341.
- , S. Bigot, and P. Roucou, 1995: Rainfall variability in subequatorial America and Africa and relationships with the main SST modes (1951–1990). *Int. J. Climatol.*, **15**, 1297–1322.
- Motha, R. P., S. K. Leduc, L. T. Steyaert, C. M. Sakamoto, and N. D. Strommen, 1980: Precipitation patterns in West Africa. *Mon. Wea. Rev.*, **108**, 1567–1578.
- Palmer, T. N., 1986: Influence of the Atlantic, Pacific, and Indian Oceans on Sahel rainfall. *Nature*, **322**, 251–253.
- Pan, Y. H., and A. H. Oort, 1990: Correlation analyses between SST anomalies in the eastern equatorial Pacific and the World Ocean. *Climate Dyn.*, **4**, 191–205.
- Rasmusson, E. M., and T. H. Carpenter, 1982: Variations in tropical SST and surface wind fields associated with the Southern Oscillation. *Mon. Wea. Rev.*, **110**, 354–384.
- Reynolds, R. W., and W. H. Gemmil, 1984: A SST analysis based on in situ and satellite data. *Proc. Ninth Annual Climate Diagnostics Workshop*, Corvallis, OR, NOAA, 408–416.
- Rowell, D. P., C. K. Folland, K. Maskell, J. A. Owen, and M. N. Ward, 1992: Modelling the influence of global sea surface temperatures on the variability and predictability of seasonal Sahel rainfall. *Geophys. Res. Lett.*, **19**, 905–908.
- , —, —, and M. N. Ward, 1995: Variability of summer rainfall over Tropical North Africa (1906–1992): Observations and modelling. *Quart. J. Roy. Meteor. Soc.*, **121**, 669–704.
- Sadourny, R., and K. Laval, 1984: January and July performance of the LMD general circulation model. *New Perspectives in Climate Modelling*, A. Berger, Ed., Elsevier, 173–198.
- Semazzi, F. H., V. Metha, and Y. C. Sud, 1988: An investigation of the relationship between Sub-Saharan rainfall and global SSTs. *Atmos.–Ocean*, **26**, 118–138.
- , —, and —, 1989: Reply to “Comments on an investigation of the relationship between sub-Saharan rainfall and global SSTs.” *Atmos.–Ocean*, **27**, 601–605.
- Servain, J., and J. Merle, 1993: *Interannual Climate Variations over the Tropical Atlantic Ocean*. Vol. 16, NATO ASI Series, Springer-Verlag, 153–172.
- , J. Picaut, and J. Merle, 1982: Evidence of remote forcing in the equatorial Atlantic Ocean. *J. Phys. Oceanogr.*, **12**, 457–463.
- Ward, M. N., 1992: Provisionally corrected surface wind data, worldwide ocean–atmosphere surface fields, and Sahelian rainfall variability. *J. Climate*, **5**, 454–475.
- Zebiak, S. E., 1993: Air–sea interaction in the equatorial Atlantic region. *J. Climate*, **6**, 1567–1586.