ENSO-Related Precipitation Changes in New Caledonia, Southwestern Tropical Pacific: 1969–98

JEAN BENOIT NICET AND THIERRY DELCROIX

Groupe ECOP, Centre IRD de Nouméa, Noumea, New Caledonia

18 August 1999 and 3 January 2000

ABSTRACT

An analysis of El Niño–Southern Oscillation (ENSO) related precipitation changes in New Caledonia, southwestern tropical Pacific, based on 21 selected stations covering the 1969–98 period is performed. The analysis at the ENSO timescale is complemented by an investigation of basin-scale precipitation changes in order to set the context, by an examination of changes in the flow rates of two major rivers of the island, and by a comparison between actual precipitation (P) records and the output of a simple linear regression model. The results indicate that a 20%–50% decrease in precipitation generally occurs during El Niño events, and vice versa during La Niña events. In accord with these P changes, the flow rates of the two rivers can almost double during La Niña years, and decrease by more that 50% during El Niño years. The magnitudes of the precipitation anomalies are however not strictly proportional to the strength of ENSO. Hence, it is found that the simple linear regression model based on the Southern Oscillation index can be used to infer the timing, but not the magnitude, of P changes.

1. Introduction

Many aspects of New Caledonia (22°S, 166°E) climatology can be found in atlases (e.g., Pesin et al. 1995). Although New Caledonia is located relatively far (~2200 km) from the equator in the southwestern tropical Pacific, its climatic environment is affected by El Niño–Southern Oscillation (ENSO) events (Morlière and Rébert 1986; Ropelewski and Halpert 1987, 1996; Delcroix and Lenormand 1997). During an El Niño event, there is a tendency for local colder than average sea surface temperature (SST), for saltier than average sea surface salinity and consistent rainfall shortage, and for southerly wind anomalies. Opposite anomalies generally occur during La Niña events.

The ENSO-related precipitation changes near New Caledonia, and in the southwestern tropical Pacific, in general, reflect the combined effects of various processes. During El Niño (La Niña) events, the eastward (westward) displacements of the equatorial Pacific warm pool modify the location of the ascending branch of the Hadley circulation and thus the location of atmospheric subsidence. The regional precipitation (P) anomalies are also linked to the location of the South Pacific convergence zone and its accompanying cloud band, which generally lies north and east of its average position during El Niño events, and south and west during La Niña events (Vincent 1994). The displacements of the warm pool further alter the location of cyclone formation. The cyclone incidence shifts northward and eastward during El Niño events, with a tendency to ignore (but not to exclude) the New Caledonia sector; conversely, during La Niña events, cyclones are more frequently observed in the vicinity of New Caledonia (Basher and Zheng 1995; Maitrepierre 1998). The occurrence of flooding associated with cyclones reinforces the P anomalies associated with ENSO.

Following the work of Morlière and Rébert (1986) covering the pre-1983 period only, this note aims at complementing their analysis of the ENSO-related P changes in New Caledonia, based on 21 selected stations covering the 1969–98 period. The analysis at the ENSO timescale is further supplemented by an investigation of basin-scale P changes in order to set the context, by an examination of changes in the flow rates of two major rivers of the island, and by a comparison between actual P records and the output of a simple linear regression model involving the Southern Oscillation index (SOI).

2. Data and data processing

The basin-scale P data are derived from the analysis of Xie and Arkin (1996). It was assembled by merging

Corresponding author address: Dr. Thierry Delcroix, Groupe ECOP, Centre IRD de Nouméa, B.P. A5, 98848 Nouméa, New Caledonia.
E-mail: delcroix@noumea.ird.nc

TABLE 1. Characteristics of the 21 selected precipitation stations in New Caledonia. The stations on the main island (1–18) are numbered clockwise from Noumea (the southeasternmost station), with stations 19–21 located in the Loyalty Islands.

Station	S Lat	E Long	Name	Period of record (years)
1	22°16′	166°27′	Nouméa	1860–1998
2	22°13′	166°20′	Pointe Marie	1951–98
3	22°10′	166°24′	Païta	1936–98
4	22°01′	166°13′	Tontouta	1951–98
5	21°52′	165°52′	La Foa	1951–98
6	21°40′	165°31′	Bourail	1947–98
7	21°30′	165°08′	Poya	1952–98
8	21°03′	164°45′	Koné	1921–98
9	20°40′	164°24′	Gomen	1951–98
10	20°34′	164°17′	Koumac	1951–98
11	20°15′	164°03′	Poum	1952–98
12	20°24′	164°37′	Pouébo	1956–98
13	20°49′	164°59′	Hienghéne	1951–98
14	20°48′	165°13′	Touho	1952–98
15	20°55′	165°22′	Poindimié	1964–98
16	21°20′	165°39′	Houaïlou	1951–98
17	21°36′	166°14′	Thio	1952–98
18	22°12′	166°58′	Yaté	1936–98
19	20°53′	167°13′	Ouanaham	1969–98
20	20°48′	167°11′	Chepenehé	1951–98
21	20°38′	166°33′	Ouloup	1966–98

rain gauge measurements, satellite estimates, and numerical model predictions. The data are available monthly, on a 2.5° longitude by 2.5° latitude spatial grid, for the 1979–98 time period. Based on atoll gauge observations in the tropical Pacific, Xie and Arkin (1996, their Fig. 4) estimated the rms error of their P data as about 50%. The monthly P data in New Caledonia were obtained from Météo-France in Nouméa. We looked for evenly distributed stations, near the coastline, and with long times series, in order to capture a maximum of El Niño/La Niña events. A total of 21 stations covering the 30-yr period 1969–98 was selected. Details about the stations are given in Table 1. Data gaps at stations 11 (16 months in 1990–91) and 13 (21 months in 1991–92) have been filled by extrapolation of data from neighboring stations (10 and 14, respectively) using linear regression coefficients from overlapping time series. Two river flow time series were also selected. The data, obtained from the Institut de Recherche pour le Développement's (IRD) Hydrological Laboratory in Nouméa, concern the Tontouta (1969–81) and Ouenghi (1973–89) Rivers, which were not used for major irrigation purposes during the selected periods. These two major rivers, flowing toward the west coast, are located in the southwestern part of the main island, between stations 4 and 5; there flow rates reflect rainfall variations over a significant area.

Additional data were used for defining ENSO indexes. They include SST data from Reynolds and Smith (1994), used for computing monthly mean SST in the Niño-3 (5°N–5°S, 150°–90°W) and Niño-3.4 (5°N–5°S, 170°–120°W) regions, as well as the 5°N–5°S averaged position of the eastern edge of the warm pool defined

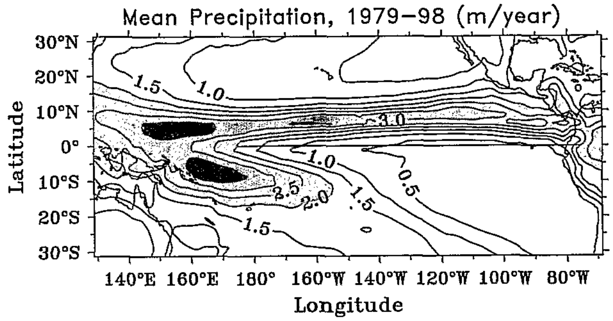

FIG. 1. The 1979–98 mean precipitation. Units are m yr^{-1}, and contour intervals are 0.5 m yr^{-1}. Values in excess of 2 m yr^{-1} are shaded. New Caledonia is located near 22°S, 166°E.

as the 28°C isotherm (see Picaut and Delcroix 1995). The SOI is similar to the one in Trenberth (1984), with an additional normalization resulting in a time series having a 1951–80 mean of 0 and a variance of 1 (Department of Commerce 1986).

The interannual variations were computed for all time series using a 25-month Hanning filter (Blackman and Tukey 1958). This filter passes almost no signal at periods of 1 yr and shorter and passes about 90% at periods of 4 yr, which is the mean El Niño return interval (Enfield and Cid 1991). The variations at periods equal or shorter that 1 yr were calculated as the differences between the original time series and the 25-month filtered time series. The variations at periods of 1 yr were calculated by least squares fit to an annual harmonic. An EOF analysis (e.g., Emery and Thompson 1997) was performed on the "high" and "low" frequency time series in order to extract the seasonal and ENSO-related variations.

As a first step toward a tentative statistical prediction of ENSO-related P changes in New Caledonia, a cross-validation technique (Mosteller and Tukey 1977) was used in order to hindcast interannual P changes from a given ENSO index (say the SOI). In this technique, the 336 months (30 yr minus 2 yr given time filtering) of interannual P and SOI changes were divided into N segments of L-month duration. A linear model was run with the data of $N - 1$ segments in P and SOI shifted in time by various lags. The model was then used to compute P changes in the remaining segment using the SOI of the corresponding segment. The excluded segment was changed successively to yield 336 independent values of hindcast P changes to be compared to the observed P changes. Sensitivity tests were performed with segments of $L = 3$–24 months in duration, and with lags from 0 to 6 months.

3. Basin-scale precipitation

The 1979–98 mean distribution of basin-scale P (Fig. 1) exhibits the well-know maxima (>2.5 m yr^{-1}) in the intertropical and South Pacific convergence zones (ITCZ and SPCZ) and in the western Pacific warm pool,

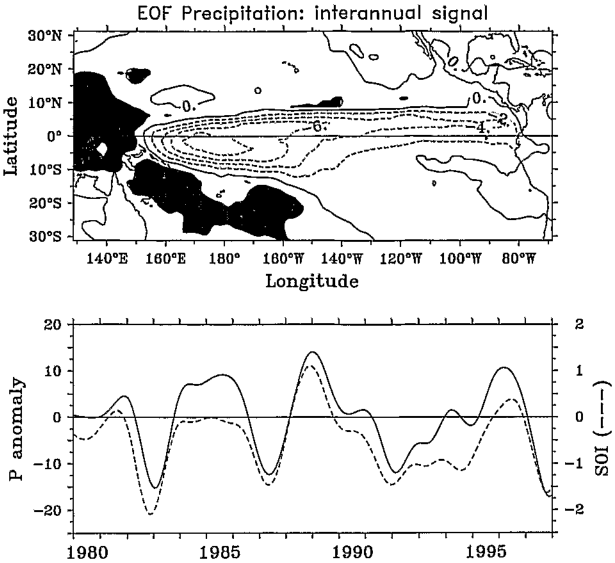

FIG. 2. (Top) precipitation spatial pattern and (bottom, full line, left scale) time function of the interannual EOF. The units are defined so that the product between the EOF spatial pattern and temporal function denotes mm month^{-1}. The dashed line in the bottom panel denotes the SOI scaled on the right axis.

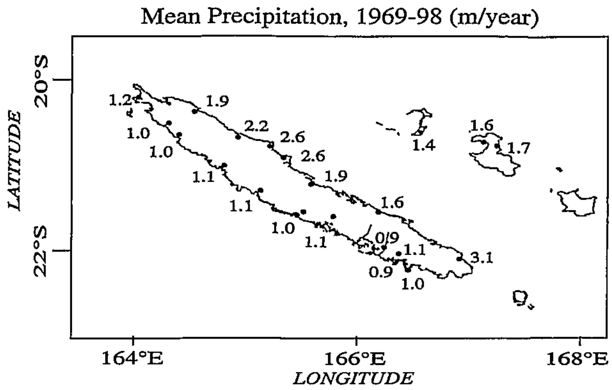

FIG. 3. The 1969–98 mean precipitation at 21 stations in New Caledonia. Units are m yr^{-1}. The courses of the two selected rivers appear near 22°S, 166°E.

and the well-known minima (<0.5 m yr^{-1}) in the NE and SE parts of the basin. These features are qualitatively consistent with previously published results (e.g., Taylor 1973); the quantitative differences are not discussed here. The mean P calculated for 2.5° latitude by 2.5° longitude boxes including New Caledonia is 1.2 ± 0.4 m yr^{-1} (the second number is one standard deviation), which is close to the mean in situ values computed for the west coast of the main island (see below).

The seasonal EOF time and space functions (not shown here; 34% of the variance) portray maximum P during the summers in the ITCZ and SPCZ mean areas (see Delcroix 1998, Plate 2). The interannual EOF time and space functions (Fig. 2) explain 45% of the variance. They are qualitatively consistent with earlier studies covering different time periods (Ropelewski and Halpert 1987, 1996; Delcroix et al. 1996). During the 1982–83, 1986–87, 1991–92, 1993, and 1997 El Niño events, we observe below average P mainly in the far western equatorial Pacific and in the SPCZ mean area, and above average P in the equatorial band near the date line and at the southern edge of the ITCZ mean area. The opposite situation occurred during the 1988–89 and 1995–96 La Niña periods. This basin-scale study suggests that ENSO did affect the P regime in New Caledonia, at least during 1980–97.

4. Regional scale

The 1969–98 mean P in New Caledonia is shown in Fig. 3. In the main island, it evidences the contrast between the west (mean P = 1 m yr^{-1}) and east (mean P = 2.2 m yr^{-1}) coasts reflecting the effect of topographic relief. The mean P in the Loyalty Islands is of the order of 1.6 m yr^{-1}. These values are within 5% of the averages presented by Morlière and Rébert (1986) and Pesin et al. (1995) for different time periods.

The standard deviation of P (not shown here) generally increases from the southeast to the northwest: on the west coast from about 0.2 to 0.4 m yr^{-1}, and on the east coast from about 0.45 to 0.7 m yr^{-1}. Least squares fit to an annual harmonic of each time series indicates that this northwestward increase mostly reflects the concurrent rise in the annual amplitude. The annual harmonic accounts for 15%–30% of the total variance of the original P signal, with maximum values for the stations located in the northeastern part of the main island; maximum P occurs in March for the four southern stations (1 and 2 and 17 and 18) and in February for the other stations.

The percent of total variance explained by the interannual P changes ranges within 10%–20% of the original P signal (maximum in the central part of the main island), which is the same order of magnitude as the annual P changes. To illustrate the overall link between interannual P changes in New Caledonia and ENSO, Fig. 4 presents the regression diagram between interannual P changes and the SOI. The correlation coefficient is $R_0 = 0.54$ at 0-month lag, and it is maximum at $R_{max} = 0.56$ when the P changes lag behind the SOI by 2–3 months. Similar values are obtained when the SOI is replaced by the sea surface temperature anomaly (SSTA) in the Niño-3 ($R_0 = -0.46$; $R_{max} = -0.49$ for 3-month lag) or Niño-3.4 ($R_0 = -0.53$; $R_{max} = -0.55$ for 2-month lag) regions, or by the zonal displacement of the eastern edge of the warm pool ($R_0 = -0.48$; $R_{max} = -0.49$ at 2-month lag). If only one value per year can be regarded as independent, these correlations are significant at the 95% confidence level (R in excess of 0.36). In agreement with the large-scale investigation, the positive slope of the regression line (c = 23.4 mm month^{-1}) indicates that the El Niño (La Niña) events induce below (above) average precipitation in New Cal-

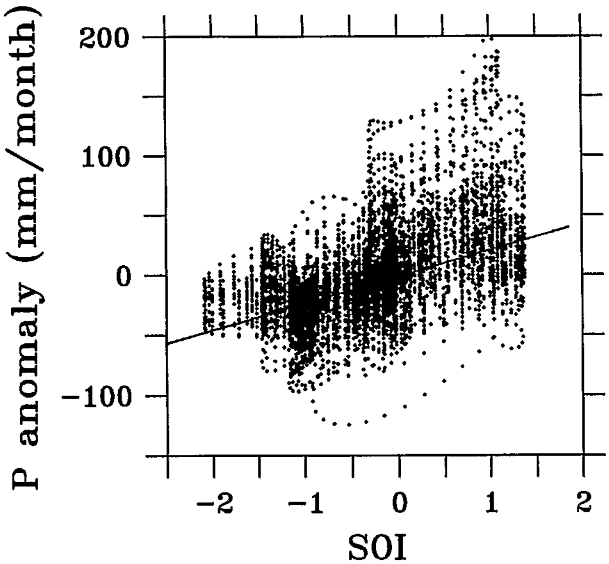

FIG. 4. Relation between monthly anomalies of precipitation (mm month^{-1}) for 21 stations in New Caledonia and the SOI.

edonia. It is however noteworthy that the relatively high value (24.3 mm month^{-1}) of the standard deviation around the regression line prohibits deriving a simple relation between interannual P changes and ENSO.

In order to distinguish the previous overall relation in space and time, an EOF analysis was performed on the interannual P changes. The first EOF, explaining 80% of the variance, is shown in Fig. 5. The EOF time function presents a rather good correspondence with the SOI ($R_0 = 0.65$; $R_{max} = 0.66$ at 1-month lag), with an excess of P during the 1971–72, 1974–75, 1988–89, and 1995–96 La Niña events, and a rainfall deficit during the 1972–73, 1976–77, 1982–83, 1986–87, 1991–92, 1993, 1994–95, and 1997 El Niño events. The EOF spatial pattern reflects the mean annual values (Fig. 3). An EOF analysis performed on the P time series normalized by their standard deviation (not shown here) indicates a slight relative maximum for stations located in the center of the main islands, in agreement with Morlière and Rébert (1986). The magnitude of the ENSO-related P changes, derived from the product between the time function and the spatial pattern in Fig. 5, ranges within 20%–50% of the mean annual values. This unambiguously stresses that ENSO is a major modulator of the P regime in New Caledonia. However, despite the general phase agreement between the EOF time function and the SOI, it is interesting to note that the magnitudes of the P changes are not proportional to the magnitudes of the SOI. This is clearly evidenced when noting the weak P anomalies during the very strong 1982–83 El Niño, and the huge P anomalies during the 1988–89 as compared to the 1974–75 La Niña events. (Note that the P anomalies of the present 1998–99 La Niña, not shown here, are even stronger than those observed in 1988–89.)

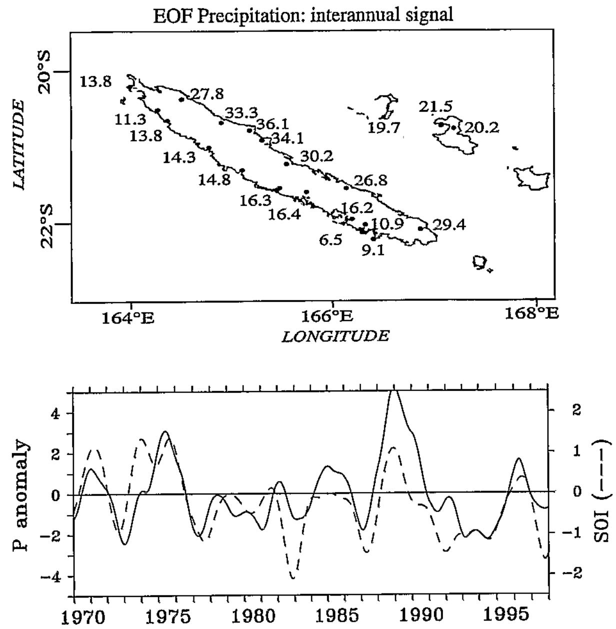

FIG. 5. (Top) precipitation spatial pattern and (bottom) time function of the interannual EOF. The units are defined so that the product between the EOF spatial pattern and temporal function denotes mm month^{-1}. The dashed line in the bottom panel denotes the SOI scaled on the right axis.

In accord with the P changes associated with ENSO, the anomalous flow rates of the two major rivers located on the southwestern part of New Caledonia have a tendency to present below average (above average) values during El Niño (La Niña) events (Fig. 6). The correlation coefficients between the anomalous flow rates and the

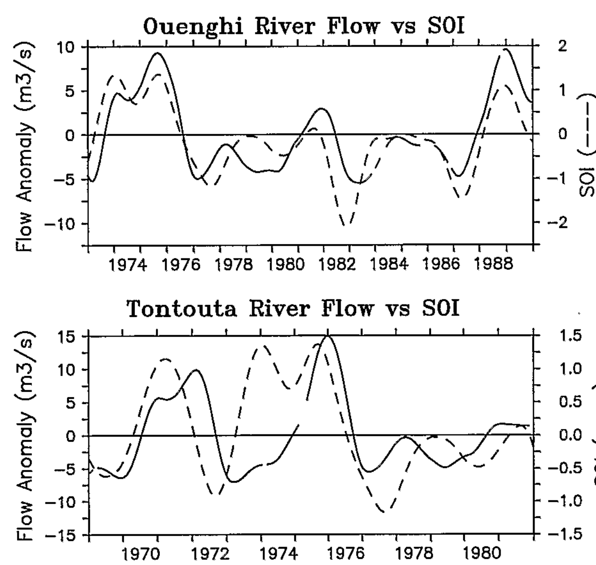

FIG. 6. Comparison between river flow anomalies (full line, left vertical axis) and the SOI (dashed line, right vertical axis) for the Tontouta and Ouenghi Rivers, located in the southwestern part of New Caledonia. Note the different horizontal and vertical axes.

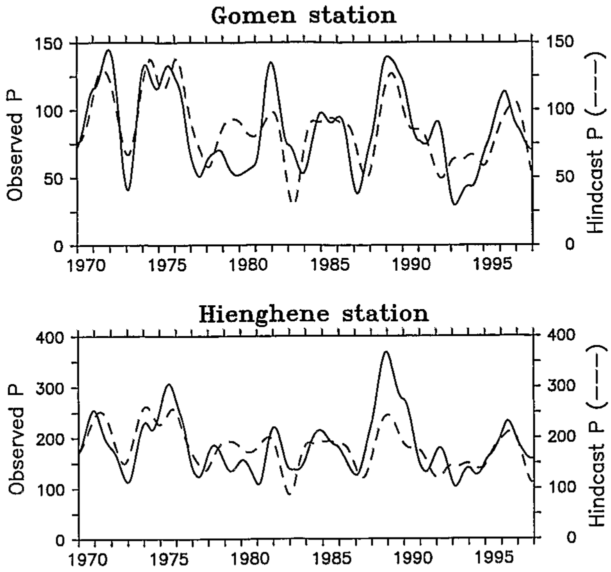

FIG. 7. Comparison between observed (full line) and hindcast (dashed line) interannual P changes for two stations located on the west (Gomen) and east (Hienghene) coasts of New Caledonia. Units are mm month^{-1}. Note the different vertical scales for the two stations.

SOI is $R_0 = 0.77$ ($R_{max} = 0.79$ at 3-month lag) for the Ouenghi River and $R_0 = 0.44$ ($R_{max} = 0.62$ at 6-month lag) for the Tontouta River. The mean flow rates of these two rivers during the periods presented here are 7.8 and 12.7 m^3 s^{-1}, respectively, indicating that their flow rates can almost double during La Niña years and can be reduced by more that 50% during El Niño years.

As a first step toward statistically predicting the impact of ENSO on P changes in New Caledonia, the cross-validation technique described in section 2 was employed in order to hindcast the ENSO-related P changes from the SOI. The best overall results were obtained using the regression between the observed P anomalies and the SOI lagged by 3 months, and with excluded segments of $L = 3$ month duration ($L = 6$ months gave quasi-identical results). With these features, the mean correlation coefficient between the observed and hindcast P changes is $R = 0.59$, and the mean rms difference is 30 mm month^{-1}, that is, the same order of magnitude as the standard deviation in P. These results are somewhat improved when considering only the stations located in the northern half of the main island (e.g., with stations 8–15, $R = 0.65$), as exemplified in Fig. 7 comparing the observed and hindcast interannual P changes at stations 9 (Gomen; $R = 0.75$) and 13 (Hienghene; $R = 0.65$). Hence, the simple linear regression model offers potential capabilities for hindcasting the timing of P anomalies, but it performs poorly in predicting their magnitude. We can expect that the use of more sophisticated statistical (He and Barnston 1996; Yu et al. 1997) and/or dynamic (Stockdale et al. 1998) models will help us to refine our results. In the meantime, it is clear that the evidenced 3–6-month time delay between the SOI and the ENSO-related P anomalies, as well as the usual 1-yr duration of these anomalies, should enable decision makers to mitigate the resulting economic impacts (agriculture, public construction, tourism, dengue fever, etc.) and to devise suitable precautionary measures.

Acknowledgments. The precipitation station data in New Caledonia were provided by L. Maitrepierre from Météo-France in Nouméa, the two river flow rates in New Caledonia by J. Danloux from the IRD Hydrological Laboratory in Nouméa, the basin-scale precipitation data by P. Xie and P. Arkin from NOAA, and the SST data by D. Reynolds from NOAA. We are very thankfull for having had the possibility to use all these data. Fruitful discussions with C. Hénin were appreciated. This work was partly supported by ZoNeCo (Programme d'Exploration et d'Évalutation des Ressources Marines de Nouvelle Calédonie), and the authors sincerely thank J. M. Auzende. For one of us (JBN), this note is part of a Mémoire de Diplôme d'Etudes Approfondies of the Paris VI University undertaken while visiting the IRD Center in Nouméa: support from this institution has been greatly appreciated.

REFERENCES

Basher, R., and X. Zheng, 1995: Tropical cyclones in the southwest Pacific: Spatial patterns and relationships to Southern Oscillation and sea surface temperature. *J. Climate,* **8,** 1249–1260.

Blackman, R. B., and J. W. Tukey, 1958: *The Measurement of Power Spectra.* Dover Publications, 190 pp.

Delcroix, T., 1998: Observed surface oceanic and atmospheric variability in the tropical Pacific at seasonal and ENSO time scales: A tentative overview. *J. Geophys. Res.,* **103,** 18 611–18 633.

——, and O. Lenormand, 1997: ENSO signals in the vicinity of New Caledonia, South Western Pacific. *Oceanol. Acta,* **20,** 481–491.

——, C. Hénin, V. Porte, and P. Arkin, 1996: Precipitation and sea-surface salinity in the tropical Pacific. *Deep-Sea Res.,* **43,** 1123–1141.

Department of Commerce, 1986: *Climate Diagnostic Bulletin.* No. 8614, 12 pp.

Emery, W., and R. Thomson, 1997: *Data Analysis in Physical Oceanography.* Elsevier Science, 634 pp.

Enfield, D., and L. Cid, 1991: Low-frequency changes in El Niño Southern Oscillation. *J. Climate,* **4,** 1137–1146.

He, Y., and A. Barnston, 1996: Long-lead forecasts of seasonal precipitation in the tropical Pacific islands using CCA. *J. Climate,* **9,** 2020–2035.

Maitrepierre, L., 1998: Le risque cyclonique en Nouvelle Calédonie. Météo-France, Direction Interrégionale de Nouvelle Calédonie et de Wallis et Futuna, 43 pp. [Available from Meteo-France, BP 151, 98845 Nouméa Cedex, New Caledonia.]

Morlière, A., and J. P. Rébert, 1986: Rainfall shortage and El Niño Southern Oscillation in New Caledonia, southwestern Pacific. *Mon. Wea. Rev.,* **114,** 1131–1137.

Mosteller, T., and J. Tukey, 1977: *Data Analysis and Regression.* Addison Wesley, 586 pp.

Pesin, E., S. Blaize, and D. Lacoste, 1995: Atlas climatique de la Nouvelle Calédonie. Edition Météo-France, Direction Interrégionale de Nouvelle Calédonie et de Wallis et Futuna, 103 pp. [Available from Meteo-France, BP 151, 98845 Nouméa Cedex, New Caledonia.]

Picaut, J., and T. Delcroix, 1995: Equatorial wave sequence associated with warm pool displacement during the 1986–1989 El Niño and La Niña. *J. Geophys. Res.*, **100,** 18 398–18 408.

Reynolds, D., and T. Smith, 1994: Improved global sea surface temperature analyses using optimum interpolation. *J. Climate,* **7,** 929–948.

Ropelewski, C. F., and M. S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Mon. Wea. Rev.*, **115,** 1606–1626.

——, and ——, 1996: Quantifying Southern Oscillation–precipitation relationships. *J. Climate,* **9,** 1043–1059.

Stockdale, T., D. Anderson, J. Alves, and M. Balmaseda, 1998: Global seasonal rainfall forecasts using a coupled ocean–atmosphere model. *Nature,* **392,** 370–373.

Taylor, 1973: *An Atlas of Pacific Islands Rainfall.* Department of Meteorology Publ. 25, University of Hawaii Rep. HIG 73-8, 165 pp. [Available from Dept. of Meteorology, University of Hawaii, Honolulu, HI 96822.]

Trenberth, K., 1984: Signal versus noise in the Southern Oscillation. *Mon. Wea. Rev.*, **112,** 326–332.

Vincent, D., 1994: The South Pacific convergence zone (SPCZ): A review. *Mon. Wea. Rev.*, **122,** 1949–1970.

Xie, P., and P. Arkin, 1996: Analyses of global monthly precipitation using gauge observations, satellite estimates, and numerical model predictions. *J. Climate,* **9,** 840–858.

Yu, Z.-P., P.-S. Chu, and T. Schroeder, 1997: Predictive skills of seasonal to annual rainfall variations in the U.S. affiliated Pacific islands: Canonical correlation analysis and multivariate principal component regression approaches. *J. Climate,* **10,** 2586–2599.