Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1601-1606.

RELATIONS OF ANOMALOUS SST PATTERNS IN THE PACIFIC AND RAINFALL OVER NORTHERN-NORTHEAST BRAZIL DURING THE TWO PHASES OF THE PACIFIC DECADAL OSCILLATION

Ludimila F. da Silva*, Mary T. Kayano**
Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil

ABSTRACT

In this work, monthly sea surface temperature (SST) data and rainfall time series in Fortaleza (representative of the northern Northeast Brazil - NNEB) for the 1910-2000 period are used. Differences among the SST anomaly patterns in the Pacific and Atlantic Oceans for years with El Niño/Southern Oscillation (ENSO) extremes in the two phases of the Pacific Decadal Oscillation (PDO) are analyzed. The El Niño and La Niña years used here are those with occurrence of below and above normal rainfall, respectively, over NNEB during its rainy season. Classifications of dry and wet years in the NNEB are based on the terciles of the NNEB rainy season. The onset years of ENSO extremes are identified in the SST Niño-3 index. SST anomaly evolutions for bi-months are obtained for the period from February (0)/March (0) to April (+)/May (+), where the symbols '(0)' and '(+)' refer to the onset years of ENSO extremes and the following year, respectively. The evolving aspects of the SST anomalies for El Niño and La Niña years show differences between the two PDO phases. Strong ENSO-coherent SST anomalies remain in a large area of the eastern tropical Pacific and in the tropical North Atlantic during almost all bi-months of the period from June (0)/July (0) to April (+)/May (+) for the cases when ENSO and PDO are in phase. The cases when ENSO and PDO are out of phase show different evolving features. For La Niña (El Niño) years of the positive (negative) PDO phase, negative (positive) SST anomalies remain in the central equatorial (equatorial eastern) Pacific during the period from October (0)/November (0) to April (+)/May (+) (from April (0)/May (0) to February (+)/March (+)). These differences in the evolutions of the SST anomalies might have important implications for the NNEB climate variations.

1. INTRODUCTION

El Niño-Southern Oscillation (ENSO) is the main remote influence for climate variations over northern Northeast Brazil (NNEB) (e.g., Kayano et al., 1988). Another important lower frequency mode in the Pacific is the Pacific Decadal Oscillation (PDO), which features sea surface temperature (SST) anomaly pattern nearly symmetric relative to the equator with larger amplitudes in the middle than in the low latitudes and is less equatorially confined in the eastern Pacific than ENSO (Mantua et al., 1997). This mode includes two extremes phases, one with positive SST anomalies (SSTAs) in the eastern tropical Pacific and opposite sign anomalies in the subtropics, and the other with reversed sign pattern (Mantua et al., 1997). These extremes are referred here to as PDO(+) and PDO(-), respectively. So, the PDO and ENSO extremes might act constructively or destructively.

However, the SST variability in the tropical Atlantic (TA) might also influence the NEB climate (e.g., Hastenrath and Heller, 1977; Moura and Shukla, 1981; Andreoli and Kayano, 2004). Moura and Shukla (1981) showed that the drought in this region for some years might be associated with a meridional SSTA dipole in the TA. This mode affects the position and intensity of the Intertropical Convergence Zone (ITCZ), which in turn modulates the NEB rainfall variability.

In the present paper, the SSTA patterns in the tropical Pacific and Atlantic are revised for ENSO extremes and NNEB dry and wet conditions, considering the two phases of the PDO.

2. DATA AND METODOLOGY

Corresponding authors address: Instituto Nacional de Pesquisas Espaciais, Centro de Previsão de Tempo e Estudos Climáticos, São José dos Campos, SP, Brasil.
E-mails: *ludimila@cptec.inpe.br,
**mary@cptec.inpe.br

Table 1 – Classification of the NNEB rainy season according to ENSO and PDO extremes

PDO phase	ENSO phase	NNEB rainy season	
		Dry	**Wet**
Positive	**El Niño**	1940, 1941, 1979, 1982, 1986, 1991, 1997	1925, 1993, 1994
	La Niña	1942, 1988	1933, 1938, 1944, 1984
Negative	**El Niño**	1914, 1953, 1957	1911, 1951, 1963, 1968, 1972
	La Niña	1954, 1955, 1961, 1971	1915, 1916, 1920, 1922, 1948, 1949, 1973, 1975

The data used is monthly global gridded SST at 2° by 2° latitude-longitude resolution grid and monthly precipitation of Fortaleza (representative of NNEB). The SST data consists of the extended reconstructed SST for 1854-2000 (Smith and Reynolds, 2003). Roberto L. Guedes kindly provided Fortaleza data for 1849-2000. Analyses are done for 1910-2000. So, monthly anomalies of SST at each gridpoint and of precipitation are based on 1910-2000 means. The anomalies series are standardized by the corresponding standard deviations and linearly detrended. For the period of analysis, PDO(+) occurred during 1925-1946 and 1977-2000, and PDO(-), during 1910-1924 and 1947-1976 (Mantua et al., 1997).

Linearly detrended Niño-3 SST index, define as the 5-month running mean of the averaged SSTAs in the area bounded at 4°N, 4°S, 150°W and 90°W, is used. An El Niño (a La Niña) event is identified when this index exceeds (is less than) 0.5°C (-0.5°C) for at least six consecutive months (Trenberth, 1997).

The seasonal (February to May - FMAM) rainfall values for 1910-2000 ranked from 1 for the smallest value to 91 for the largest one divided by 91 give percentile ranks (R) varying from zero to 1 (Meisner, 1976). Years with $R \leq 0.33$, with $0.33 < R < 0.66$ and with $R \geq 0.66$ are classified as dry, normal and wet years, respectively. Table 1 lists the onset years of ENSO extremes followed by dry or wet conditions in the NNEB during FMAM of the following year.

Composite technique is used to get the SSTA patterns for El Niño (La Niña) years with dry (wet) NNEB during FMAM. The other cases listed in Table 1 are not analyzed here. In order to assess the statistical significance of the composites the Student t-test is applied for the confidence level of 95%.

To simplify discussion, positive (negative) SST dipole in the TA refers to the pattern with positive SSTAs in the TNA (TSA) and opposite sign SSTAs in the TSA (TNA).

3. RESULTS

3.1 *Composites for El Niño (La Niña) years with dry (wet) conditions over NNEB*

El Niño composite for PDO(+) shows significant positive SSTAs in the eastern tropical Pacific and along the west coast of Americas flanked to the north, the south and the west by opposite sign significant SSTAs (Fig.1a). This pattern is similar to that noted for PDO(+). This composite also shows significant positive SSTAs in an extensive area of the TNA, typical of a canonical El Niño (Enfield and Mayer, 1977). El Niño might remotely induce the TNA warming (Wang, 2002). The TNA anomalies create a northward SSTA gradient in the TA. The combined actions of the SSTA gradient in the TA and of El Niño justify dry conditions over NNEB.

The SSTA pattern for El Niño years of the PDO(-) is shown in Figure 1c. Significant positive SSTAs are found in small areas of the central Pacific and weak negative SSTAs are found elsewhere in this Basin (Fig. 1c). A positive dipole in the TA favors the location of the ITCZ to the north of its climatological position justifying the dry condition over NNEB. Dynamical explanations are found in previous work. Moura and Shukla (1981) suggested that this dipole mode creates an anomalous direct thermal circulation in the meridional direction with upward (downward) motions over the region with positive (negative) SSTAs. This meridional circulation explains dry conditions over NNEB.

La Niña composite for PDO(+) features significant negative SSTAs in the central equatorial Pacific and weak SSTAs in the TA which are negative in the TNA and positive in the TSA (Fig. 1b). The TA SSTA patterns are consistent with enhanced rainfall over NNEB.

For the PDO(-) the pattern with significant negative SSTAs in the eastern tropical Pacific and in the TNA resembles that one for a canonical La Niña (Fig. 1d). The negative SSTAs in the eastern Pacific extend meridionally along the west coast of the Americas, due to the constructive actions of the PDO(-) and La Nina events. Another PDO(-) feature noted is the occurrence of significant positive SSTAs in the subtropical Pacific in both hemispheres. On the other hand, the negative SSTAs in the TNA create a southward SSTA gradient, which favors the southern than normal position of the ITCZ, which in turn enhances rainfall over NNEB.

The constructive (destructive) actions of the PDO and ENSO extremes are evident in Figure 1. The El Niño (La Niña) related positive (negative) SSTAs in the tropical Pacific are relatively weak for years of the PDO(-) (PDO(+)) phase. In these cases the TA SST variability might play more important role in determining the NNEB rainfall anomalies.

3.2 *SSTA evolution*

The symbols (0) and (+) in the next Figures refer to onset year of ENSO extremes and the following year, respectively.

El Niño composite for PDO(+) shows significant positive SSTAs in the central tropical Pacific in Feb (0)/Mar (0) (Fig. 2a). Gradually, these anomalies enhance and expand eastward, yielding the El Niño pattern in Oct (0)/Nov (0) (Fig. 2e). This pattern remains quite strong up to Apr (+)/May (+) (Fig. 2h). The SSTA Pacific pattern resembles that one of the PDO(+). Hints of positive SSTAs, noted in the TNA during the first two bi-months, persist and enhance during the last two bi-months. Previous work suggested that the El Niño, through the associated anomalous Walker and Hadley circulations, might remotely induce warming in the TNA during the austral autumn of the year after the El Niño onset (Wang, 2002). The positive SSTAs in the TNA create a northward gradient of the SSTAs and induce a southward sea level pressure anomalous gradient, which causes the northward migration of the ITCZ (Carton et al., 1996). Under this situation, the descending Walker cell branch intensifies causing strong subsidence over NEB, which inhibits convection and rainfall in this region.

El Niño composites for PDO(-) are shown in Figure 3. Although weak, positive SSTAs are noted in the eastern tropical Pacific in most bi-months, the significant ones are found only in small areas of this oceanic Basin. An El Niño pattern with significant positive SSTAs equatorially confined in the central Pacific is noted during Oct (0)/Nov (0) and Dec (0)/Jan (+) (Figs. 3e and 3f). The equatorial confinement of positive SSTAs might be due to the fact that ENSO and PDO are out of phase. The El Niño pattern weakens during the last two bi-monthly periods. Weak SSTAs prevail in the TA for the first five bi-months, while a weak positive dipole is established during Feb (+)/Mar (+) and Apr (+)/May (+) periods (Figs. 3g and 3h). This dipole seems to explain the dry conditions in NNEB.

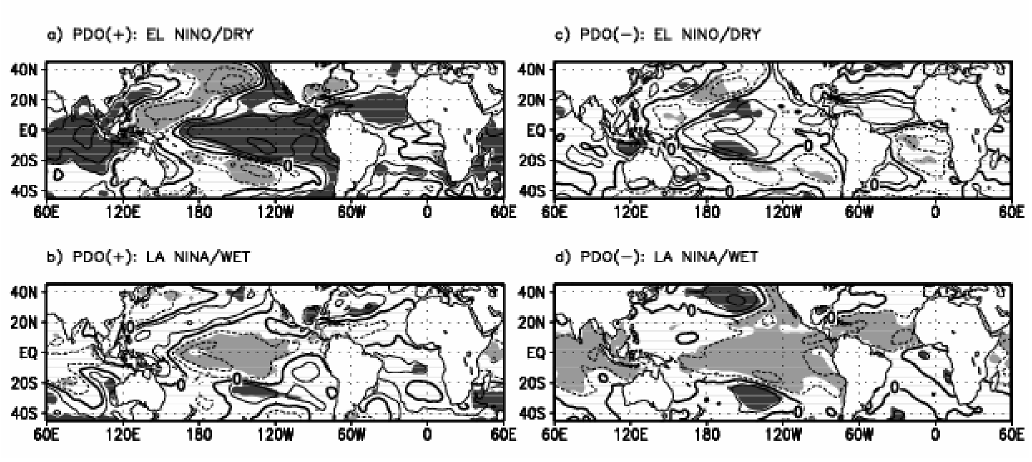

Fig. 1 – SSTA composites for El Niño (La Niña) years with wet (dry) conditions in the NNEB for the two PDO phases. Contour interval is 0.5 standard deviations, with negative (positive) contours being dashed (continuous) and the zero contour being the thicker one. Shading area encompasses significant values at the 95% confidence level.

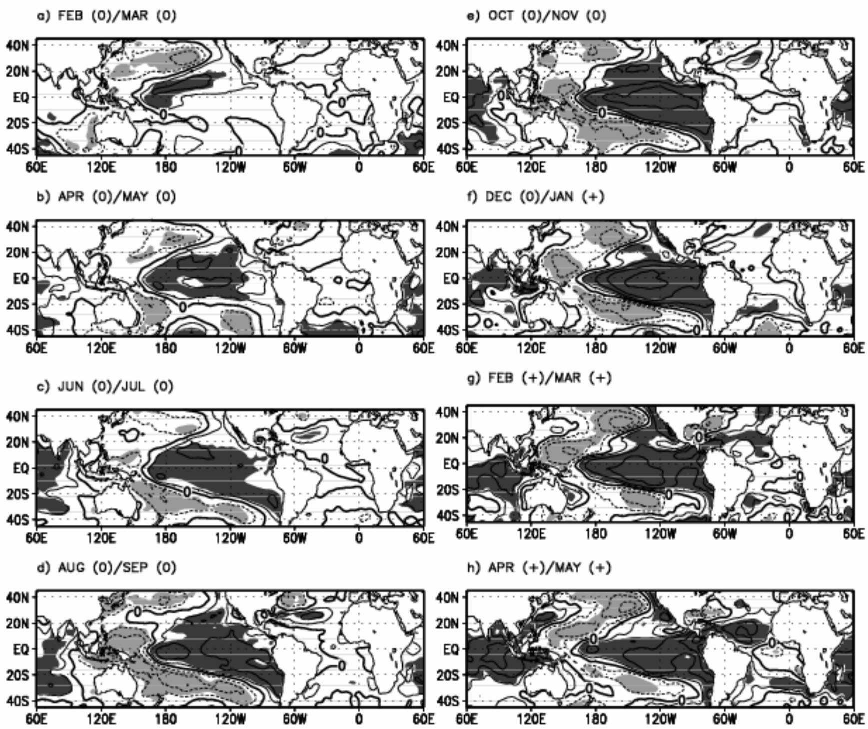

Fig. 2 – El Niño composites for dry NNEB and PDO(+). Display is the same as that in Figure 1.

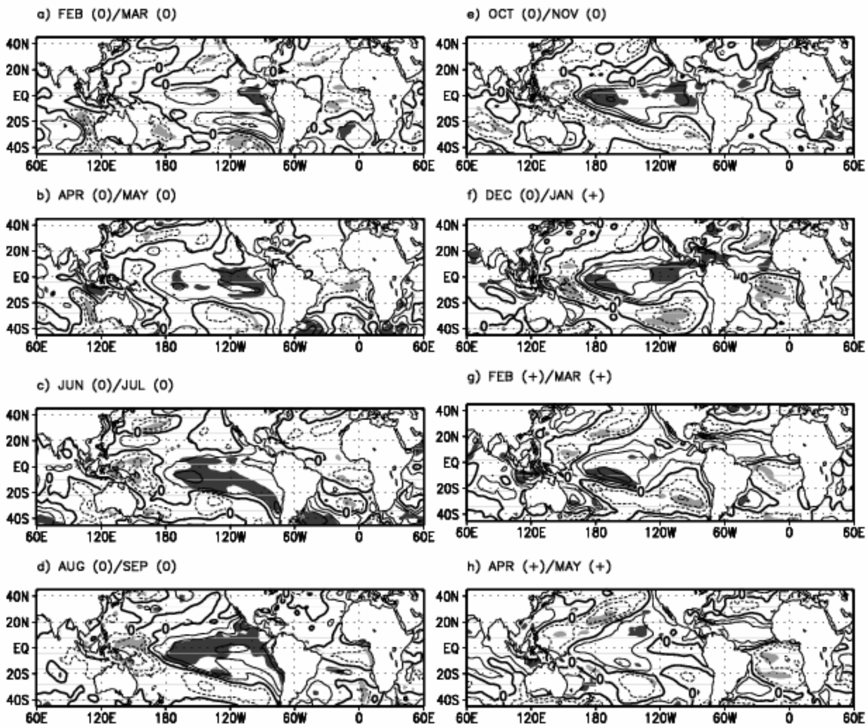

Fig. 3 – El Niño composites for dry NNEB and PDO(-). Display is the same as that in Figure 1.

La Niña composites for PDO(+) show weak negative SSTAs in most of the eastern tropical Pacific and weak positive SSTAs elsewhere in this basin during the first four bi-months (Fig. 4). The negative SSTAs enhance and a La Niña pattern is established in Oct (0)/Nov (0), when significant negative SSTAs are note in the central equatorial Pacific (Fig. 4e). These anomalies intensify and are equatorially confined in the central Pacific during the following two bi-months (Figs. 4f and 4g). The equatorial confinement of negative SSTAs might be related to the PDO(+) which acts to establish opposite sign SSTA of those for La Niña. Although weak, positive SSTAs persist in the equatorial Atlantic and in the TSA for all bi-months. A weak southward SSTA gradient is noted during Feb (+)/Mar (+) and Apr (+)/May (+). Thus, this southward SSTA gradient seems to explain the excessive rainfall over NNEB.

La Niña composites for PDO(-) show a different evolution (Fig. 5). Significant negative SSTAs appear in small areas close to the west coast of South America during Jun (0)/Jul (0) (Fig. 5c). These anomalies rapidly intensify and expand to most of the eastern tropical Pacific and along the west coast of the Americas with the La Niña pattern being established in Oct (0)/Nov (0) (Fig. 5e). This pattern resembles that one for the PDO(-). Simultaneously, significant negative SSTAs intensify in the TNA, establishing a La Niña canonical pattern. These anomalies remain quite strong up to Apr (+)/ May (+). The resulting southward SSTA gradient in the TA contributes to the southward displacement of the ITCZ, which in turn favors excessive rainfall over NNEB.

Constructive (destructive) actions of the PDO(-) (PDO(+)) and La Niña are evident in Figures 4 and 5.

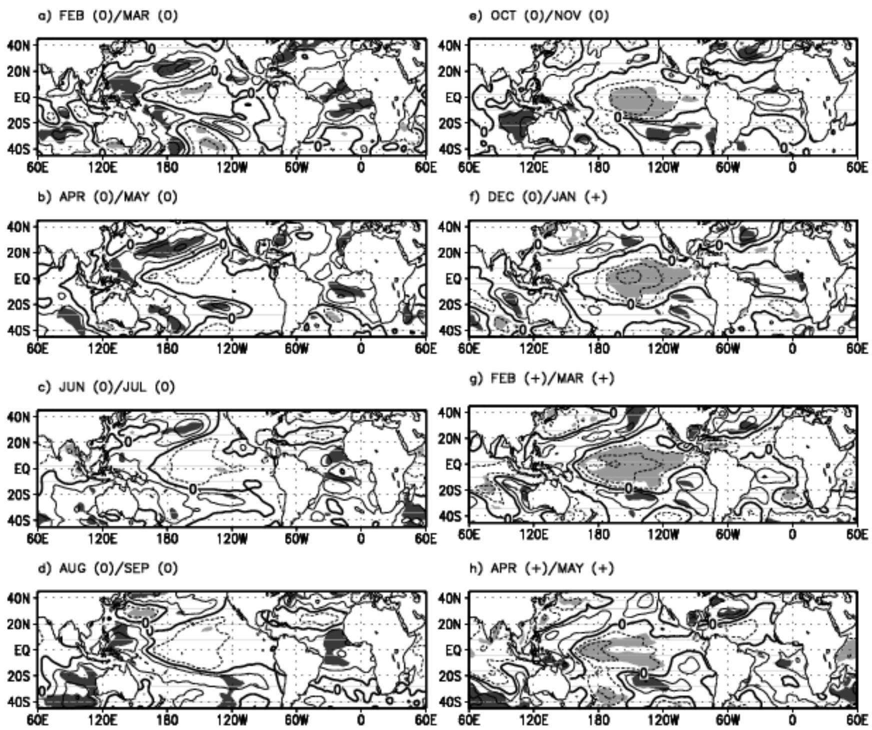

Fig. 4 – La Niña composites for wet NNEB and PDO(+). Display is the same as that in Figure 1.

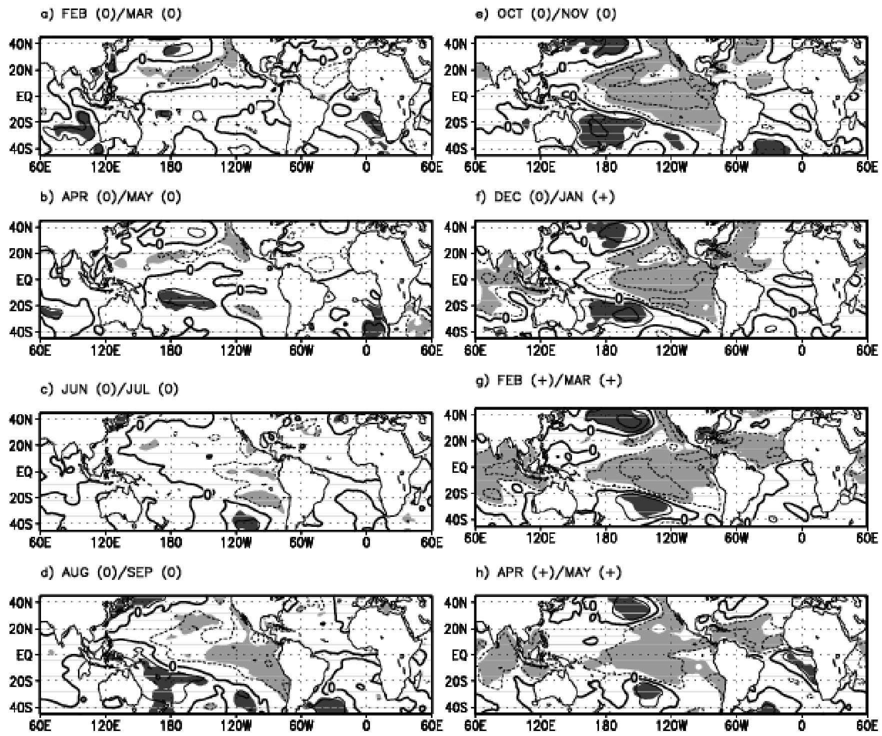

Fig. 5 – La Niña composites for wet NNEB and PDO(-). Display is the same as that in Figure 1.

4. CONCLUDING REMARKS

The above analyses showed that ENSO extremes are more (less) intense when they are in (out of) phase with PDO extremes, due to their constructive (destructive) actions. ENSO-related canonical pattern for the SSTA in the TNA occurs when PDO and ENSO are in phase. For these cases, ENSO and the resulting meridional SSTA gradient in the TA are the main factors in determining the rainfall variability over NNEB. For the situations when PDO and ENSO are out of phase, the SST variability in the TA seems to play more important role than the ENSO extremes in determining the rainfall variations over NNEB.

5. REFERENCES

Andreoli, R. V., and M. T. Kayano, 2004: Multi-scale variability of the sea surface temperature in the tropical Atlantic. *J. Geophys. Res.,* **109**.

Carton, J. A., X. Cao, B. S. Giese, and A. M. da Silva, 1996: Decadal and interannual SST variability in the tropical Atlantic Ocean. *J. Phys. Oceanog.,* **26**, 1165-1175.

Enfield, D. B., and D. A. Mayer, 1997: Tropical Atlantic SST and its relation to El Niño-Southern Oscillation. *J. Geophys. Res*., **102**, 929-945.

Hastenrath, S., and L. Heller, 1977: Dynamics of climatic hazards in Northeast Brazil. *Quart. J. Roy. Meteor. Soc.*, **103**, 77-92.

Kayano, M. T., V. B. Rao, and A. D. Moura, 1988: Tropical circulations and the associated rainfall anomalies during two contrasting years. *J. Climatol*., **8**, 477-488.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis,1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteorol. Soc.*, **78**, 1069-1079.

Meisner, B. N., 1976: *A study of Hawaiian and Line Island rainfall*. Rep. UHMET 76-4, Dept. Meteor., University of Hawaii, 82 p.

Moura, A.D., and J. Shukla, 1981: On the dynamics of droughts in Northeast Brazil: observations, theory and numerical experiments with a General Circulation Model. *J. Atmos. Sci*., **38**, 2653-2675.

Smith, T. M., and R. W. Reynolds, 2003: Extended reconstruction of global sea surface temperatures based on COADS data (1854-1997). *J. Clim*., **16**, 1495-1510.

Trenberth, K. E., 1997: The definition of El Niño. *Bull. Amer. Meteorol. Soc.*, **78**, 2771-2777.

Wang, C. 2002: ENSO and Atmospheric Circulations Cells. *CLIVAR Exchanges*, **7**, 9-11.