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SST anomaly variability in Southwestern Atlantic and El Niño/Southern oscillation

D.N. Severov [a,*], E. Mordecki [b], V.A. Pshennikov [c]

[a] Sección Oceanología, Facultad de Ciencias, Universidad de la República, Iguá 4225, 11400 Montevideo, Uruguay
[b] Centro de Matemática, Facultad de Ciencias, Universidad de la República, Iguá 4225, 11400 Montevideo, Uruguay
[c] Instituto de Física, Facultad de Ciencias, Universidad de la República, Iguá 4225, 11400 Montevideo, Uruguay

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Abstract

The purpose of this paper is to study the relation between Sea Surface Temperature anomalies in the Southwestern Atlantic Ocean and the presence of El Niño and La Niña events, in the period 1868–2000. SST anomalies were taken from 1856–2000 Kaplan data set, and El Niño and La Niña events from different authors. Significative differences were found in the SST anomalies in the winter period (from April to October) taken at 8 points in the Southwestern Atlantic, depending on the presence of El Niño or La Niña. On an average, the El Niño events (registered in December of each year) are characterized by negative SST anomalies at the Malvinas current and positive SST anomalies at the Brazil current in the winter of the corresponding year. On the contrary, La Niña events are characterized by anomalous cold Brazil current and warm Malvinas current. Decrease of SST anomalies in Malvinas current and for preservation of its trend until October is suggested as the precursor of El Niño. Using the monthly SST anomalies in Southwestern Atlantic, statistical indicators for ENSO events were computed. These indicators are used for reconstruction of the weak, moderate strength, and strong La Niña episodes for the 1868–2000 period. El Niño (except the strongest events), could be predicted three to six months in advance from of time-space SST anomaly variability in Southwestern Atlantic.
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Keywords: Southwestern Atlantic; SST anomalies (1868–2000) variability; ENSO events

1. Introduction

Southwestern Atlantic (SWA) and, first of all, Brazil-Malvinas Confluence (BMC) zone is the world ocean western currents extension zone. It is marked by a complex array of strongly contrasting water types (Gordon, 1989). According to Gordon (1994), the South Atlantic stands out as having numerous exceptional features. Knowledge of spatial and temporal variability of current, water dynamics, thermohaline characteristics of water masses, and fronts represents a fundamental contribution to the circulation of the world oceans. Legeckis and Gordon (1982) studied processes in time-space changes of waters, transport of heat in the Confluence region using satellite data. Olson et al. (1988), Podesta et al. (1991), Provost et al. (1992), and Severov et al. (2000) analyzed the variability of sea surface temperature (SST) fields, and White and Peterson (1996), and Moore et al. (1997) analyzed the variability and transport of the SST anomalies (SSTa). In the SWA cold water enters through Drake Passage (cold water path), flows northward along the cost of South America as the Falkland or Malvinas Current and is deflected eastward. At about 35–40° S, the BMC region, it encounters the warm southward flowing Brazil Current (warm water path).

In this geographical area two main connections between Southern Oscillation (SO) and climatic variability were found: Ropelewski and Halpert (1987, 1989) and Aceituno (1988) established a relationship between extremes in SO and rainfall anomalies; Mechoso and Perez (1992) connections between SO and streamflow anomalies. The primary goal of the present article is to

* Corresponding author. Tel.: +598-2-5258618; fax: +598-2-5258617.
E-mail address: dima@fcien.edu.uy (D.N. Severov).

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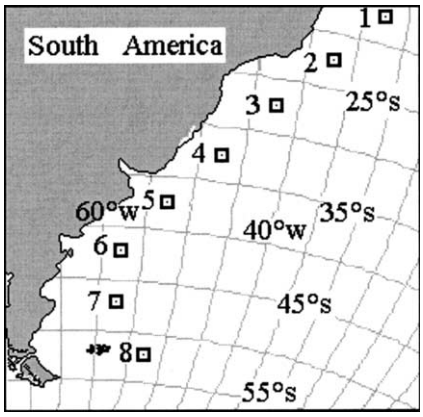


Fig. 1. Area of study in the SWA (points 1–8).

analyze the existing links between warm and cold episodes of the El Niño Southern Oscillation (ENSO) and the variability of the SSTa in the SWA (17.5–52.5° S × 32.5–57.5° W, see Fig. 1).

We try to establish the SSTa variability along coastline of the South America before El Niño and La Niña events and use this variability as an indicator for both northward and southward flows. In order to explore this existing links, we propose to construct a statistical indicator, taking as input the year data of SSTa along the referred points, producing a numerical value related to the presence of El Niño or La Niña events (and its strong and weak versions).

2. Data and methods

El Niño (W) and La Niña (C) events in the period 1868–2000, used in the present study, are presented below in List 1 and List 2 respectively, according to different authors. W−, W, W+ designate weak, moderate strength, and strong El Niño events respectively; C−, C, C+ weak, moderate strength, and strong La Niña events. In the period 1868–1982, the weak, moderate strength, and strong El Niño episodes were taken from Quinn and Neal (1982). In 1950–2000, the weak, moderate strength, and strong warm and cold ENSO episodes are taken from Climate Prediction Center (CPC), 2001.

List 1 of 46 El Niño events according to authors ([1,2,3,4,5,6,7]):

1868(W) [1,6], 1877(W+) [1,2,3,5,6], 1880(W) [1,2,3,5,6], 1884(W+) [1,2,3,5], 1885(W−) [1], 1887(W+) [1,2,3,5], 1888(W) [1,6], 1891(W+) [1,2,3,5], 1896(W) [1,2,3,5,6], 1899(W+) [1,2,3,5,6], 1900(W) [1], 1902(W) [1,2,3,5,6], 1905(W) [1,2,3,5,6], 1911(W+) [1,2,3,4,5,6], 1912(W) [1], 1913(W) [6], 1914(W) [1,2,3,4,5], 1918(W+) [1,2,3,4,5,6], 1919(W) [1], 1923(W−) [1,2,3,4,5], 1925(W+) [1,2,3,4,5,6], 1929(W) [1,6], 1930(W) [1,2,3,4,5,6], 1932(W−) [1,2,3,4,5], 1939(W) [1,2,3,4,5], 1940(W−) [1,6], 1941(W+) [1,2,3,4,5], 1948(W−) [1], 1951(W−) [1,2,3,4,5,6,7], 1953(W) [1,2,3,4,5,7], 1957(W+) [1,2,3,4,5,6,7], 1958(W+) [1,7], 1963(W−) [1,6,7], 1965(W+) [1,2,3,4,5,6,7], 1969(W−) [1,2,3,4,5,6,7], 1972(W+) [1,2,4,5,6,7], 1976(W−) [1,2,3,4,5,6,7], 1982(W+) [1,2,3,4,5,6,7], 1986(W) [4,6,7], 1987(W) [5,6,7], 1990(W−) [7], 1991(W) [6,7], 1992(W−) [7], 1993(W−) [7], 1994(W) [7], 1997(W+) [7].

[1]Quinn and Neal (1982); [2]Rasmusson and Carpenter (1983); [3]Ropelewski and Halpert (1987); [4]Mechoso and Perez (1992); [5]O'Hare (1997); [6]ENSO Japan Meteorological Agency (JMA) (1998); [7]CPC (2001).

List 2 of 47 La Niña events according to authors ([1,2,3,4,5]):

1869 [4], 1871 [4], 1872 [4], 1873 [4], 1874 [4], 1875 [4], 1886 [1,2,3,4], 1889 [1,2,3,4], 1892 [1,2,3,4], 1893 [4], 1898 [3], 1903 [3,4], 1906 [3,4], 1908 [3,4], 1909 [1,2,4], 1910 [2,4], 1916 [2,3,4], 1917 [2], 1920 [3], 1922 [4], 1924 [2,3,4], 1928 [1,2], 1931 [3], 1938 [2,3,4], 1942 [3,4], 1944 [4], 1949 [3,4], 1950(C) [2,5], 1954(C) [3,4,5], 1955(C+) [2,4,5], 1956(C−) [2,4,5], 1964(C) [1,2,3,4,5], 1966 [3], 1967 [4], 1970(C) [2,3,4,5], 1971(C−) [2,4,5], 1973(C+) [2,3,4,5], 1974(C−) [5], 1975(C+) [2,3,4,5], 1978 [3], 1983(C−) [3,5], 1984(C−) [5], 1988(C+) [3,4,5], 1995(C−) [5], 1998(C) [4,5], 1999(C) [5], 2000(C−) [5]. [1]Ropelewski and Jones (1987); [2]Ropelewski and Halpert (1989); [3]O'Hare (1997); [4]ENSO JMA (1998); [5]CPC (2001).

On the other side, statistically homogenous concatenation of Kaplan et al. (1998) OS SST, and Reynolds and Smith (1994) NCEP OI analysis (OS × NCEP) is used to establish the variability of the monthly SSTa in the SWA. This data set has a resolution of only 5° lat/lon but covers a much longer period (1856–2000). Fig. 1 shows the 8 points, selected for study: 1, 17.5° S–32.5° W; 2, 22.5° S–37.5° W; 3, 27.5° S–42.5° W; 4, 32.5° S–47.5° W; 5, 37.5° S–52.5° W; 6, 42.5° S–57.5° W; 7, 47.5° S–57.5° W; 8, 52.5° S–52.5° W.

In order to compute the ENSO statistical indicators $I(y)$ for year y (based on the SSTa by Kaplan) we assign a numerical value $P(y)$ equal to one of the following seven values: −1.5 (strong La Niña, C+); −1 (moderate strength La Niña, C); −0.5 (weak La Niña, C−); 0 (neutral year); 0.5 (weak El Niño W−); 1 (moderate strength El Niño, W); 1.5 (strong El Niño, W+). This statistical indicators $I(y)$ are then compared with the ENSO events in Lists 1 and 2.

Fig. 2 shows El Niño and La Niña events presented as points of either a positive or negative $P(y)$ index and the SST anomalies averaged at point 7 in 1868–2000 (undoubtedly, the apparent trend deserves further investigation). The proposal is to produce a statistical indicator $I(y)$ for each year y, as similar as $P(y)$ as possible, based on the SSTa data. We then take SSTa data, corresponding to the eight points taken monthly, during the years 1868–2000. A first exploration of the data consists in drawing of contour graphics of mean values. For this, we compute mean values of SSTa, in each point and month, producing the contours for periods of El Niño, La Niña, and Neutral years as shown in Fig. 3.

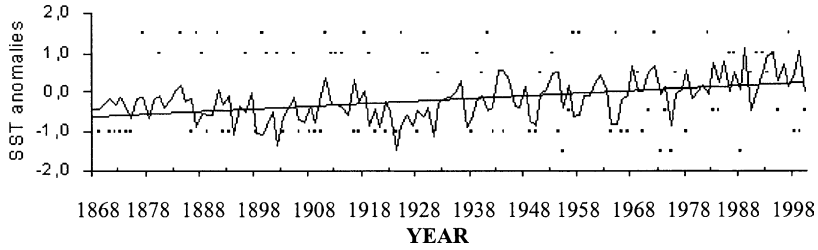


Fig. 2. Kaplan SSTa averaged at point 7 (1868–2000) and $P(y)$ index.

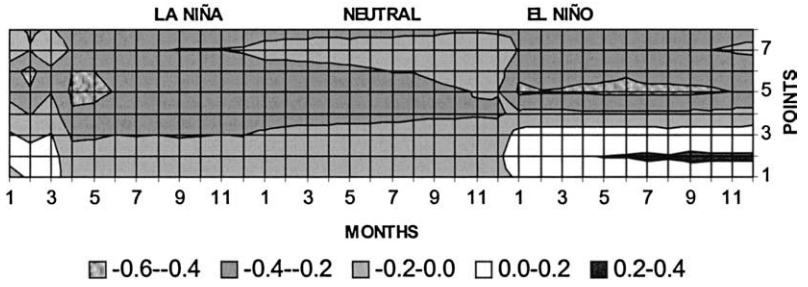


Fig. 3. The monthly averaged SSTa for La Niña, Neutral, and El Niño years at points 1–8 (1868–2000).

We now turn to the computation of indicators $I(y)$, based on the least squares method. Denote then $S(p,m,y)$ the SSTa corresponding to point $p = 1,\ldots,7$ (corresponding to geographical points 2–8 in Fig. 1), taken at month $m = 1,\ldots 12$, and year $y = 1,\ldots,133$. In order to model the relationship between the SSTa data, and the type of year, we put

$$I(y) = \sum_{p=1}^{7}\sum_{m=1}^{12} a(p,m)xS(p,m,y).$$

In other words, the indicator is a linear combination of the SSTa corresponding to that year. The statistical problem is the to find the 84 coefficients $a(p,m)$ that indicate the incidence of the information in this geographical point and month in the presence of El Niño. This is carried out by minimization of

$$\sum_{y=1}^{133}\left[\sum_{p=1}^{7}\sum_{m=1}^{12} a(p,m)xS(p,m,y) - P(y)\right]^2.$$

3. Results and discussion

At the examination of the monthly SSTa at 8 points in the SWA, several differences were found between El Niño and La Niña years in pre ENSO winter period (April through October). On an average, the El Niño events are characterized by negative SSTa at the Malvinas current and positive SSTa at the Brazil current. On the contrary, La Niña events are characterized by anomalous cold Brazil current and warm Malvinas current (see Fig. 4, left).

Since variation of the warm and cold flows at the Brazil and Malvinas currents are linked with SO, we tried to find the details of the space-time anomaly variability, corresponding to every El Niño, La Niña, and Neutral year. We try to establish these peculiarities analyzing the mean anomalies in every point in the precedent month, year, and in the cold period (April through October). The grade of manifestation of these peculiarities in the ENSO years, varies from one episode to

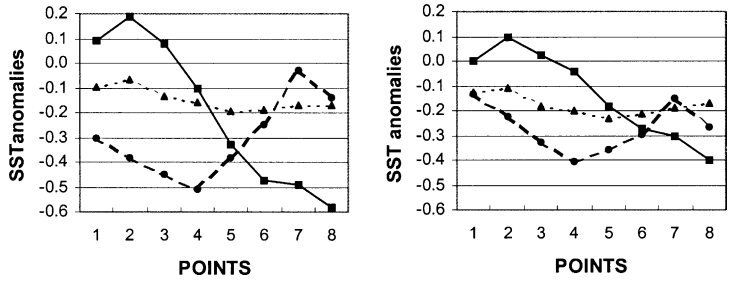


Fig. 4. The winter SSTa averaged in 1868–2000 for the 29 El Niño events (solid), 13 La Niña events (dashed), and 13 Neutral events (dotted) – left; for the 41 El Niño events, 37 La Niña events, and 40 Neutral events – right.

another. In the case of El Niño, these peculiarities (warm Brazil current and cold Malvinas current) are suggested as a precursor of El Niño events.

Similar peculiarities were also established for 41 (89%) El Niño, 37 (79%) La Niña, and 13 (33%) Neutral years. This peculiarities of ENSO events are still present on SSTa average values, with different intensities, depending on the number and selection of years (see Fig. 4, right). These peculiarities in anomaly variability in space-time follow: the period precedent to El Niño is characterized by both the high positive anomalies in the Brazil current and low negative anomalies in the Malvinas current; the rising of the positive anomalies and lowering of the negative anomalies begins in April-May and continues until October. On the contrary, the period precedent to La Niña is characterized by lower negative anomalies in the Brazil current than in the Malvinas current; the lowering of the negative anomalies in the Brazil current begining in April and ending in September; at the same time, in the Malvinas current, the rising of the negative anomalies, which is marked in many cases, gets positive values at the point 7.

In what concerns cold periods preceding neutral years, the following peculiarities were found: absence of high negative anomalies in both Brazil and Malvinas currents; variability only at BMC (points 4 and 5); negative anomalies in the first part of the period became positive from July to October in the cold water path (Malvinas current). These peculiarities of the neutral years are found in a few cases (only 13), in other years the anomaly variability, at both the warm and cold water paths, varies significantly from one month to another. Eight Neutral years have the peculiarities of La Niña events, and 18 years are similar to El Niño events. However, for all neutral years and for the neutral years preceding El Niño no high anomalies are present in any the region. The absence of the cooling in the Malvinas current from July through October is present as the common peculiarity.

The peculiarities for La Niña episodes are not common for the rest 10 years, and can be divided in two groups: (1869,1889,1898,1928,1988) and (1886,1938,1973,1984, 1995). The peculiarities of the first group correspond more to El Niño, with the positive or weak negative anomalies at points 1–3, with the low negative anomalies at points 4 and 5 of the BMC, and with the cold Malvinas current at points 6–8. This group of La Niña events differs from El Niño events, due to the earlier rising of the positive anomalies and decreasing of the negative anomalies (before April) prolonged until June-July only, the same as in the Neutral years preceding El Niño. Peculiarities of the second group do not correspond to ENSO episodes. In these years, very high positive anomalies both in the Brazil and Malvinas currents are noted.

For years 1868, 1904 and 1976, the common peculiarities of El Niño events are not observed. In these years, anomalies in the Brazil and Malvinas currents were near or lower normal (points 1, 2, 6, 7 and 8) and only in the BMC was cold (points 3–5). The 1919 and 1951 years also differs from El Niño. In 1919, the preceding period is characterized by peculiarities of the Neutral years, and the 1951 year is characterized by peculiarities of La Niña years. However, in these years the cooling in the Malvinas current was unusually later (September or October), for the usual weak and moderate El Niño events. These later cooling of the anomalies at the cold water path are more characteristic of very strong El Niño, as was observed in the preceding period in 1982 and 1997 El Niño years.

The statistical methodology was applied in order to support the empirical evidence just described. The least squares method was used to capture the relationship between SSTa variability and the type of ENSO, (with values from −1.5 to 1.5). This method does not require any assumptions on the data, and is possible to reconstruct weak, moderate strength and strong La Niña periods (from Fig. 5).

In the method, SST anomalies at 7 points during 12 months each year were used giving 84 coefficients. The statistical error, measured as the mean of the absolute value of the indicator minus the type of ENSO (over 133 years) was 0.327. Although these 84 coefficients $a(p, m)$

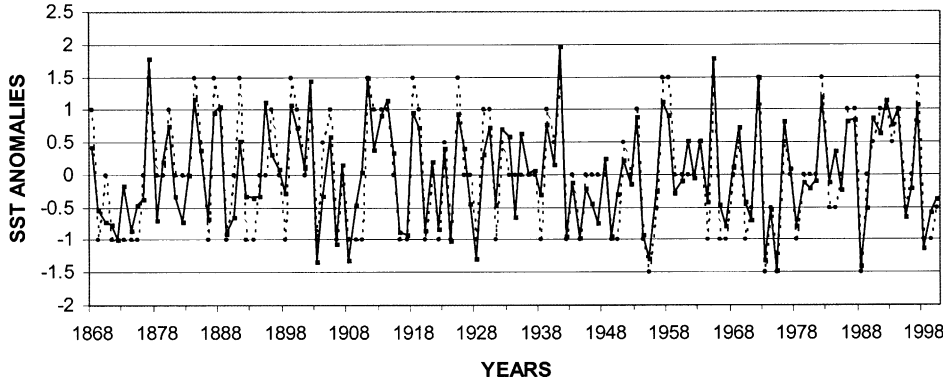


Fig. 5. Mathematical indicators based on SST data (solid), and strong, moderate and weak ENSO events (dotted).

made possible this reconstruction, it is clear that this is a preliminary statistical exploration of the data. Further work (in order, for instance, to make predictions based on this anomalies) include a more detailed use of input information (depending on the geographical point and month simultaneously) and, possible, more sophisticated statistical methods. These mathematical indicators $I(y)$ made possible to reconstruct the weak (C−), moderate strength (C), and strong (C+) La Niña episodes for the 1868–1950 period as follows: 1869 (C−), 1871 (C), 1872 (C), 1873 (C−), 1874 (C), 1875 (C−), 1886 (C−), 1889 (C), 1892 (C−), 1893 (C−), 1898 (C), 1903 (C+), 1906 (C+), 1908 (C+), 1909 (C−), 1910 (C−), 1916 (C), 1917 (C), 1920 (C), 1922 (C), 1924 (C), 1928 (C+), 1931 (C−), 1938 (C−), 1942 (C), 1944 (C), 1949 (C). Years 1966 (C−), 1967 (C), 1978 (C), were reconstucted in a similar way, for the period 1951–2000.

4. Conclusion

A link between space-time SSTa variability, in particular in the interaction of the Malvinas and Brazil currents in the SWA and the type of ENSO of the corresponding year was established.

The main observation is a decrease of the SST in cold water paths, simultaneously with an increase of the SST in warm water paths related to the presence of El Niño.

The opposite phenomena (increase of temperature in cold paths, decrease in warm paths) is observed related to La Niña. Neutral years are characterized by moderate variations of these parameters in the same region, in space and time.

These empirical observations give the possibility of predicting ENSO period with several months in advance. A statistical analysis of SSTa data corresponding to 133 years (1856–2000) supported the empirical observations, finding statistical relationship with the ENSO types. It was possible to reconstruct weak, moderate strength and strong periods for years of La Niña.

We hope that the empirical and statistical results obtained in this study will contribute in the prediction of ENSO.

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