Journal of Coastal Research	21	4	770–783	West Palm Beach, Florida	July 2005

Surface Wind Variability on Seasonal and Interannual Scales Over Río de la Plata Area

Claudia G. Simionato†, Carolina S. Vera† and Frank Siegismund‡

†Centro de Investigaciones del Mar y la Atmósfera (CIMA/CONICET-UBA) and
Departamento de Ciencias de la Atmósfera y los Océanos FCEN
University of Buenos Aires
Argentina
claudias@at1.fcen.uba.ar

‡Zentrum für Meeres—und Klimaforschung (ZMK)
Hamburg University
Germany

ABSTRACT

SIMIONATO, C.G.; VERA, C.S., and SIEGISMUND, F., 2005. Surface wind variability on seasonal and interannual scales over Rio de la Plata area. *Journal of Coastal Research,* 21(4), 770–783. West Palm Beach (Florida), ISSN 0749-0208.

Previous works show that wind forcing is the main source of circulation seasonal variability in the Río de la Plata estuary, located on the southeastern coast of South America. Wind forcing exceeds by far the role of fresh water discharges. However, due to a lack of enough observations, the features and causes of surface wind variability are not well understood yet. Therefore this paper presents a comprehensive study of surface wind variability over the Río de la Plata estuary using the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP/NCAR) reanalysis data between 1948 and 1997. It is expected that this study contributes to better understand, model and thus predict the estuary circulation.

An onshore to offshore rotation characterizes the seasonal variations of the surface winds from summer to winter. A linear trend analysis shows a displacement of the summer–winter seasonal features to earlier months. On interannual time-scales, the first leading pattern describes east–west changes of surface winds that seems to be forced by the quasibiennial tropospheric oscillation excited in the western tropical Pacific and previously identified by many authors. The conditions over the South Atlantic and in particular the Río de la Plata are influenced by such oscillation through an atmospheric Rossby wave train propagating out of the tropics. This result is very important for its implication on the predictability levels in the region. The second leading mode is associated with anticyclonic/cyclonic wind rotations off the estuary on interannual times scales which are related with changes in both atmospheric and oceanic surface conditions at Southern Hemispher high-latitudes.

ADDITIONAL INDEX WORDS: *Estuaries, Wind variability, Seasonality, Interannual variability, Río de la Plata, Northern Argentine Continental Shelf, 41–30° S; 58–47° W.*

INTRODUCTION

The Río de la Plata, located on the southeastern coast of South America at approximately 35° S, is one of the most important estuarine systems of the world. It drains to the Atlantic Ocean an average of 22000 $m^3\ s^{-1}$ (NAGY *et al.,* 1997) coming from the second largest fluvial system of this continent, the Paraná and Uruguay rivers system. The estuary, that covers an extension of around 35000 km^2, is very broad (320 km long and 230 km wide at the open mouth) and shallow, with an average depth of 20 m. It constitutes the most developed basin in South America. The population living in the hinterlands is estimated on 30 million people and two of the most important South American cities and harbors, Buenos Aires and Montevideo, lie on its shores. When the river reaches the open ocean, it forms an intense and active salinity and turbidity front whose features and position exhibit a high variability. The outer region, where fresh water rich in nutrients interacts with coastal waters, is the spawning and nursery area for many coastal species (COUSSEAU, 1985; BOSCHI, 1988). Variability in the frontal position has been related to changes in the biota (MIANZAN *et al.,* 2001). The estuary dynamics impacts the shelf up to a distance of 400 km (CAMPOS *et al.,* 1999; PIOLA *et al.,* 2000).

Even though the estuary has been object of several investigations (FRAMIÑAN *et al.,* 1999 and references therein), not much is known about its circulation pattern and variability. Unfortunately, the lack of long time series of currents and physical properties in the Río de la Plata has limited a complete understanding of the exchange processes taking place there. Except for the tides and the storm surges related to frequent floods, that have deserved several modeling attempts (SIMIONATO *et al.,* 2004; O'CONNOR, 1991; RODRIGUES VIEIRA and LANFREDI, 1996), most of the circulation features have been historically inferred from the salinity distribution which is the parameter that basically controls

DOI: 10.2112/008-NIS.1 received and accepted in revision 8 March 2004.

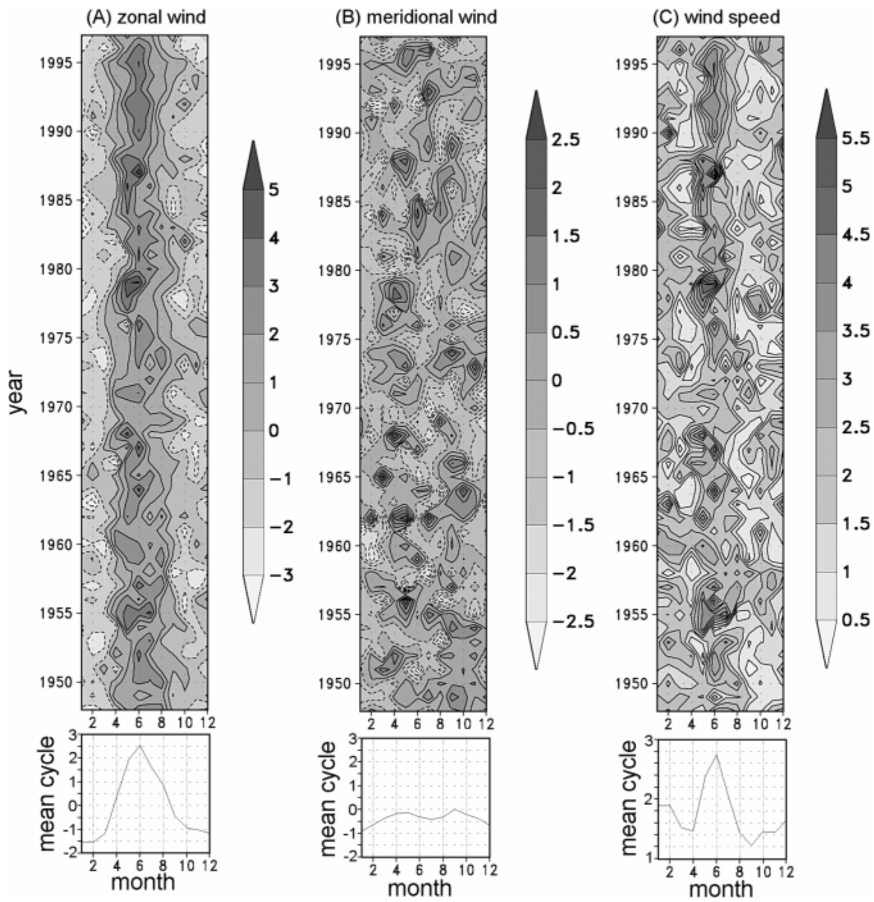

Figure 1. Month vs. year plots of monthly means an climatological seasonal cycles of (A) zonal wind component, (B) meridional wind component and (C) wind speed, for the 1948–1997 period.

the density of the estuary (OTTMANN and URIEN, 1965; URIEN, 1967, 1972) and from other physical and chemical properties (BRANDHORST and CASTELLO, 1971; BRANDHORST *et al.,* 1971). Several papers evaluating the time evolution of these properties have shown that the estuary circulation and its fresh water buoyant plume exhibit large variability at long time scales, ranging from seasonal to interannual (GUERRERO *et al.,* 1997; FRAMIÑAN *et al.,* 1999; SIMIONATO *et al.,* 2001; LUCAS *et al.,* 2001; FRAMIÑAN *et al.,* 2001; CAMPOS *et al.,* 1999; PIOLA *et al.,* 2000; MIANZAN *et al.,* 2001). This variability has important impact not only in the hydrographic characteristics, ocean circulation and mixing and convection conditions of the adjacent shelf in long distances (CAMPOS *et al.,* 1999; PIOLA *et al.,* 2000) but also in local biodiversity and fisheries (MIANZAN *et al.,* 2001).

Estuarine circulation and interaction processes generally respond to runoff, tides, buoyancy and atmospheric conditions, and the relative significance of these forcings varies in time and space (BEARDLEY and BOINCOURT, 1981; WISEMAN, 1986; SIMPSON, 1997). Thus, the understanding of the different forcings is crucial for a full description of the Río de la Plata variability. Tides and fresh water discharge have been well measured at the estuary. Several observational and modeling studies have provided an adequate view of tidal amplitudes and propagation (see for example FRAMIÑAN *et al.,* 1999 and SIMIONATO *et al.,* 2004 and references therein). The fresh water discharge variability in long time scales have been recently well studied by JAIME *et al.* (2002). Even though the wind has been proved to be the main source of seasonal variability in the Río de la Plata (GUERRERO *et al.,* 1997; FRAMIÑAN *et al.,* 1999; SIMIONATO *et al.,* 2001), exceeding by far the role of the fresh water discharge at this time scale (SIMIONATO *et al.,* 2001), the features and causes of interannual variability remain unclear in a large extent. Moreover, it is not well known yet either the seasonal cycle or the interannual variability of surface winds flowing along the estuary and surrounding area, mainly due to the lack of direct local observations. GUERRERO *et al.* (1997) performed the only data analysis based on surface wind observations at the estuary available up to this moment. In an attempt to characterize wind variability at seasonal timescales, they made a 10 year climatology based on monthly data from one station (Pontón Recalada) located at the lower portion of the estuary. They showed that mean winds have a preponderant onshore direction during summer while they are offshore during winter, but they were obviously not able to evaluate the

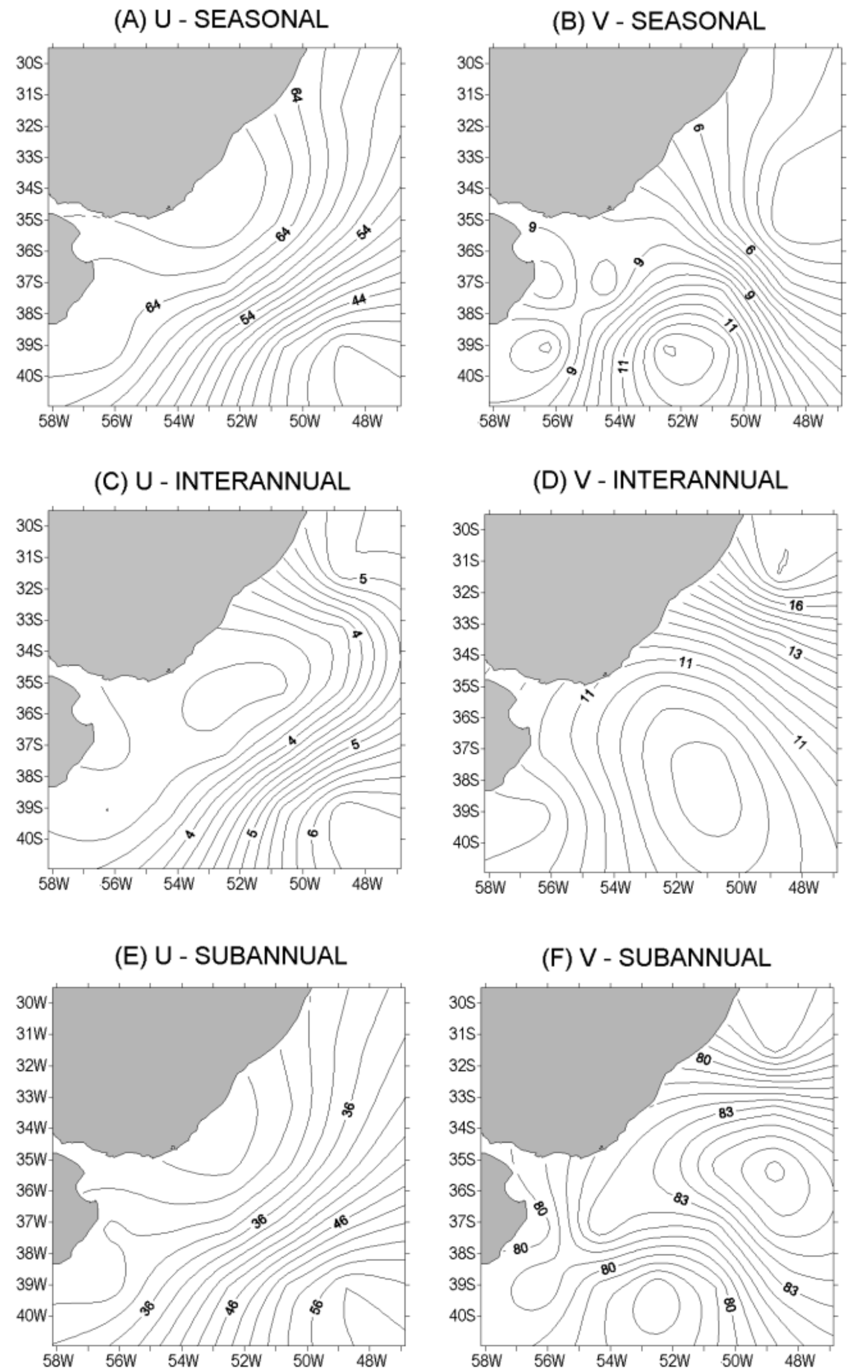

Figure 2. Surface zonal and meridional wind total variance accounted by the (A,B) seasonal, (C,D) interannual and (E,F) sub-annual variability, expressed as percentages of the total variance.

spatial pattern of the forcing neither its variability. This lack of knowledge, so as the uncertainties in wind variability at longer time scales, are clearly handicapping our capability of understanding, modeling and predicting Río de la Plata estuary's processes.

Recently, new global datasets of atmospheric variables like the reanalyses of NCEP-NCAR and European Center for Medium Range Prediction (ECMWF) provide an excellent opportunity to explore climate, and particularly surface wind, variability over any region of the globe. In that sense, the aim of this work is to make a comprehensive climatology of surface winds and to analyze their variability on seasonal to interannual scales at the Río de la Plata influence area based on four-daily fields of wind components at 10 m from NCEP-

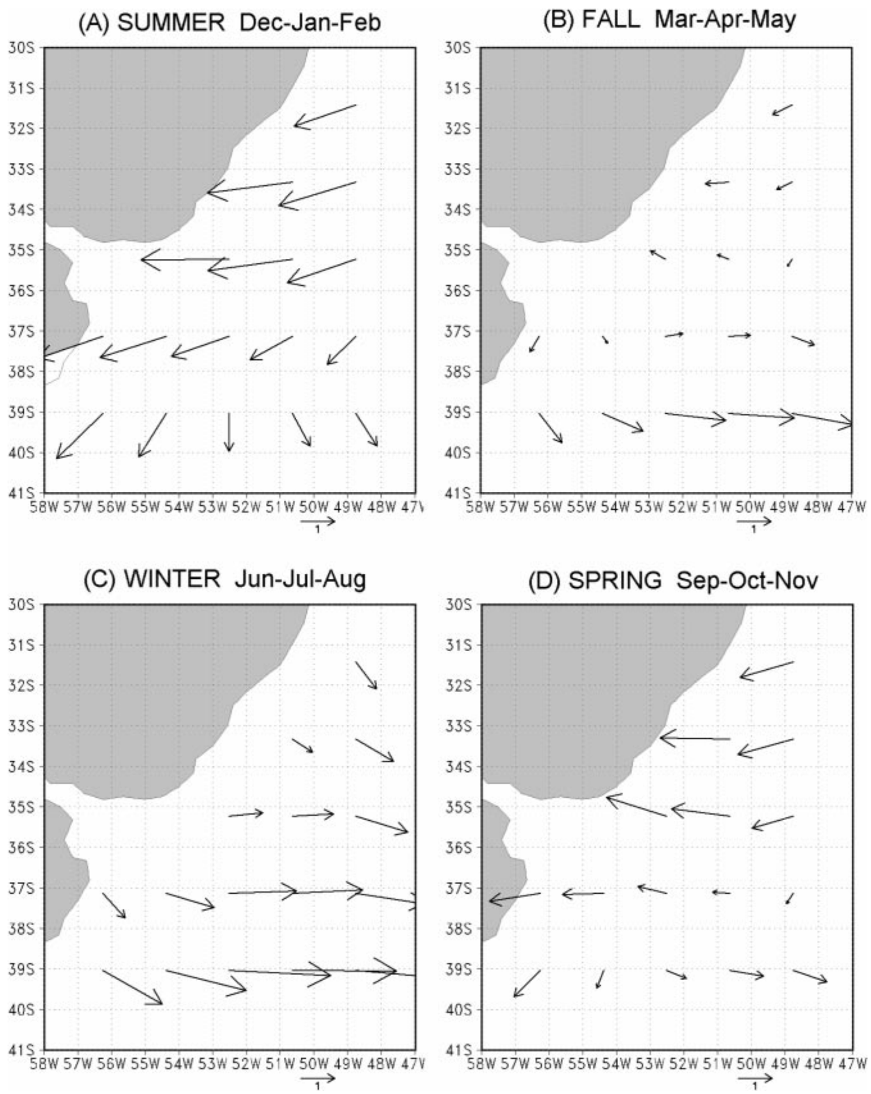

Figure 3. 50-year mean vectors of wind velocity for every season: (A) summer, (B) autumn, (C) winter and (D) spring.

NCAR reanalysis of the period 1948–1997. The paper is organized as follows: in section 2 data are described and their basic statistics are analyzed; the mean seasonal cycle and its long term variation is explored in section 3; in section 4 interannual variability and its relation to large scales are studied, and finally results are summarized and main conclusions are drawn in section 5.

DATA DESCRIPTION AND BASIC STATISTICS

The primary data used in this study are four daily fields of wind components at 10 m from NCEP-NCAR reanalysis of the period 1948–1997 on a 2.5° × 2.5° latitude–longitude grid. Additional data such as geopotential height and sea-level pressure fields were also used in the regression analyses described in section 4 as well as the monthly analysis of Reynolds sea-surface temperatures (SST) (Reynolds and Smith, 1994). Full details of the NCEP-NCAR project and the data-set are given in Kalnay *et al.* (1996) and discussions about its quality over the Southern Hemisphere can be found in Simmonds and Keay (2000), among others. Although, the analysis resolution might be relatively low for such a small area, it is a consistent long period data set and is the one of the few available for oceanic model forcing.

The sixteen gridpoints available from the dataset, located on the oceanic region around the Río de la Plata and between 31.5° S and 39° S have been selected for the analysis (Fig. 3, for example, illustrates the location of those gridpoints). The southern limit was chosen north enough to keep the westerlies out of the analysis. They flow further poleward of that limit and based on the few information available about the river circulation at the seasonal time scale (Guerrero *et al.,* 1997; Simionato *et al.,* 2001), our hypothesis is that they do not influence directly the estuary dynamics. The easternmost point of the domain is located at 48.75° W.

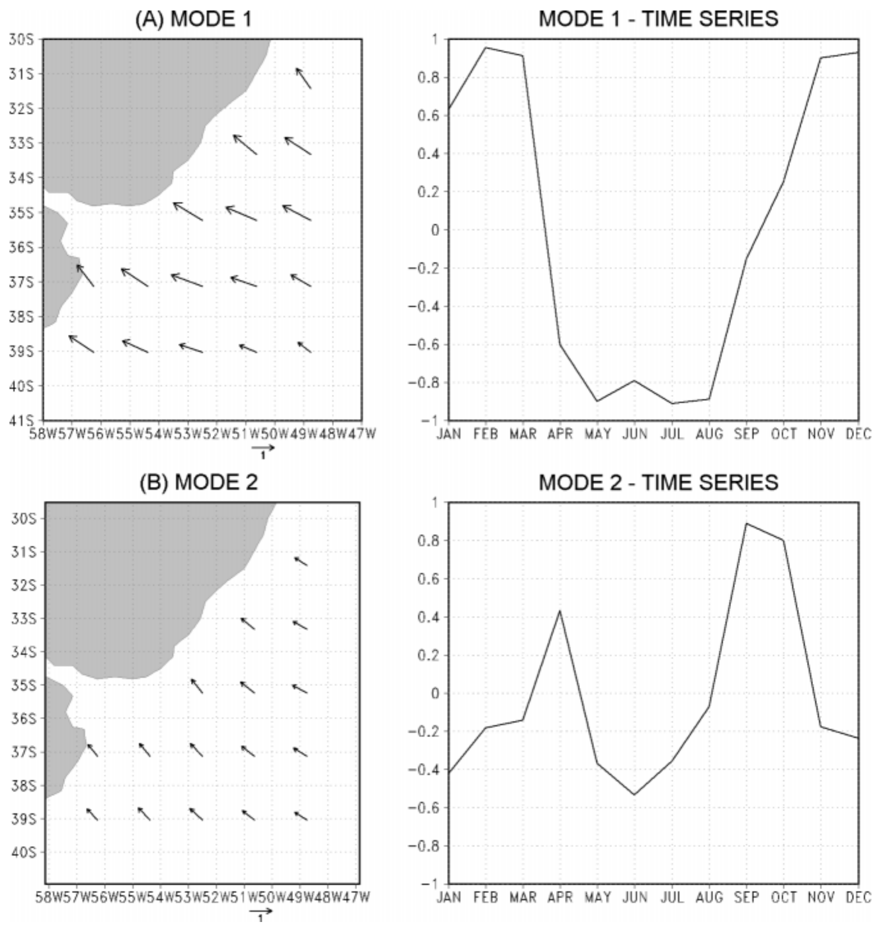

Figure 4. (A,B) Spatial patterns and (C,D) the related time patterns of the two first modes obtained by a principal component analysis on t-mode of surface wind climatological monthly means.

A general view of the data and its variability is presented in Figure 1, which shows month vs. year plots of monthly means of both zonal (Figure 1A) and meridional (Figure 1B) wind components, as well as of the wind speeds (Figure 1C) as well as the corresponding climatological seasonal cycles. Some of the known features about the seasonal wind cycle are evident, like the fact that it is mostly related to the zonal component of the wind with positive (negative) values during winter (summer). These features seem to be dominating the wind speed variability (Figure 1C) with maximum intensity during winter and minimum in spring. In addition, an important amount of variability is observed on interannual time scales, especially for the meridional component. On the other hand, trends and/or longer-period oscillations can be observed during most of the year for the zonal component and the wind speed. In particular, a positive trend seems to dominate the zonal component (and thus the wind speed) during both winter and summer seasons. This is particularly evident for June and December, months that indicate the beginning of the cold and warm seasons at the Southern Hemisphere (SH) respectively. This could be an indication of a displacement of the main features of the seasonal cycle along the year. Superimposed to this signal, long period oscillations of 5 to 15 years are also evident for every season.

In order to quantify how much of the surface-wind total variance is accounted by the seasonal, interannual and subannual variability, a variance analysis for both wind components was performed over each of the grid points considered in the region of interest. Results are displayed in Figure 2 as percentages of the total variance. The first feature that emerges is that while the spatial distribution for u-wind variability tends to have extreme values over the northwestern and southeastern portion of the region, the v-wind variability does it over the south-southwestern and northeastern areas. In addition a large amount of the variance of both components is related to sub-annual scales, especially for the v-wind (Figures 2E and F). The area between 30°S and 45°S is characterized by one of the highest cyclogenetic activity within the Southern Hemisphere (NECCO, 1982; SINCLAIR, 1994; GAN and RAO, 1991). Cyclogenesis events have over that area a mean frequency of around 120 events by year (GAN and RAO, 1991), with higher frequency during winter and spring. Thus, it is hypothesized here that they are probably respon-

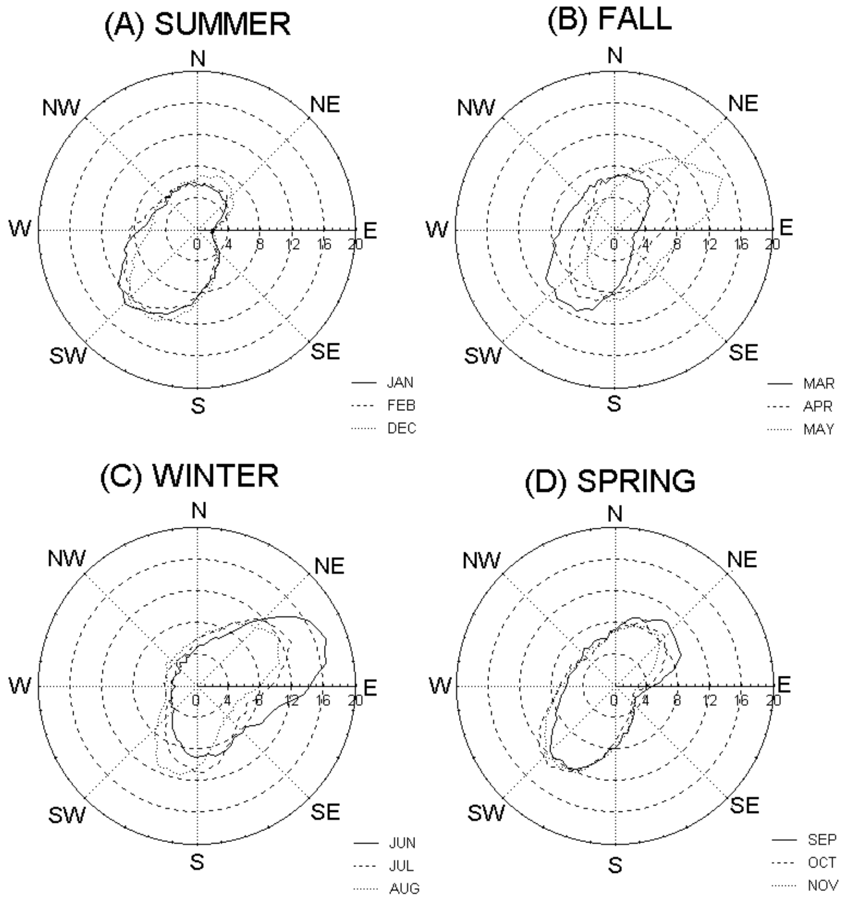

Figure 5. Frequency of occurrence of a given wind direction, computed using the four daily data, by adding the wind speed value every time that it occurs from one of the 72 given direction intervals for every of the year months, for (A) summer, (B) fall, (C) winter and (D) spring.

sible for the high variability observed on the surface winds at sub-annual scales.

Approximately 62% of the total zonal wind variance is related to seasonal and inter-annual time ranges, while only 18% is associated to these scales for the meridional component. As expected, the variability on seasonal time ranges (Figure 2A and B) is dominated by the zonal component, which is known to vary from onshore in summer to offshore in winter (GUERRERO *et al.,* 1997; FRAMIÑAN *et al.,* 1999). Almost 58% of the total variability is related to this range for the zonal component, reaching a maximum of more than 66% north of the estuary. On interannual scales (Figure 2C and D) the average percentage of variance over the region is of 4% on the zonal wind component and 10.6% on the meridional one.

THE MEAN SEASONAL CYCLE AND ITS LONG-TERM VARIATION

The 50-year mean vectors of wind velocity for every season are presented in Figure 3. Seasons are defined as Dec–Jan–Feb (austral summer), Mar–Apr–May (autumn), Jun–Jul–Aug (winter) and Sep–Oct–Nov (spring). Consistently with the analyses of GUERRERO *et al.* (1997) and FRAMIÑAN *et al.* (1999) and with the results of the previous section, it is clear that the seasonal cycle is dominated by the u-wind. During summer (Figure 3A) the mean wind direction is from the northeast over most of the area, being the responsible for the observed salinity front retraction to the west/south-west (GUERRERO *et al.,* 1997; FRAMIÑAN *et al.,* 1999; SIMIONATO *et al.,* 2001). On the other hand, during winter (Figure 3C), mean winds rotate to the west/north-west, being the main responsible for the observed frontal extension to the north (GUERRERO *et al.,* 1997; FRAMIÑAN *et al.,* 1999; SIMIONATO *et al.,* 2001). Average spring values (Figure 3D) exhibit a pattern that resembles the summer but with a reduced intensity while fall pattern (Figure 3B) has a distinctive structure with much smaller average wind speeds.

In order to characterize this seasonal cycle a principal component analysis was carried out on t-mode considering the 50-year time series of monthly means for each grid point. In this analysis, both zonal and meridional components of the wind are considered together and to avoid a first mode representing the annual mean, it was subtracted from the climatological series.

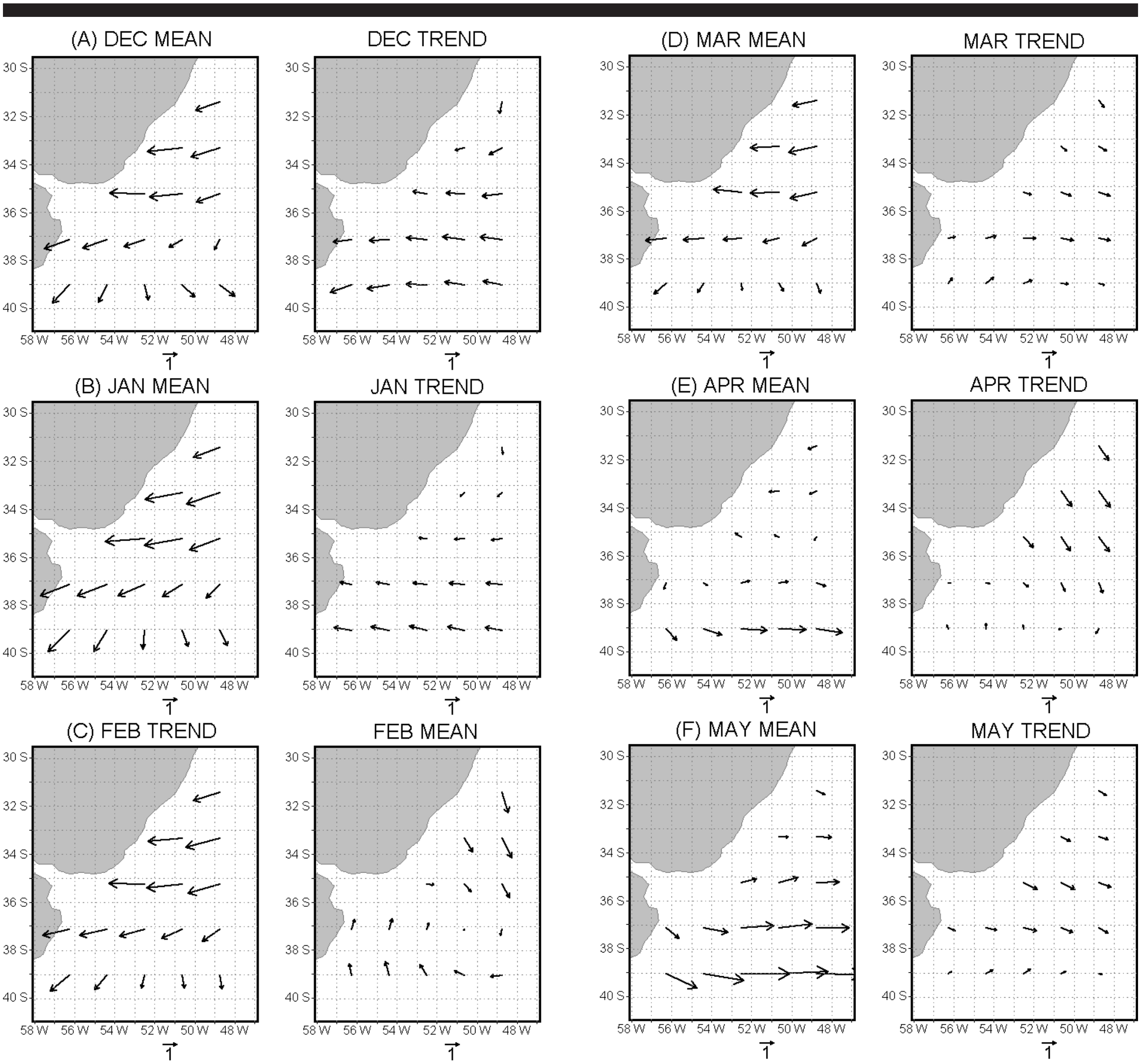

Figure 6. Surface wind climatological monthly means for each calendar month and its respective trend along the 50-year record.

Almost 82% of the variance is explained by the first two modes. The spatial patterns of those 2 modes together with the temporal series related to them are shown in Figure 4. The first mode (Figure 4A), accounting for almost 61% of the variance represents the onshore-offshore variation from summer to winter, while the second mode (Figure 4B), explaining almost 21% of the variance, is related to a semiannual signal. In particular, the second leading pattern exhibits the largest amplitudes during the intermediate seasons and reaches its maximum during spring, when the first mode is almost negligible, representing a larger incidence of southeasterly winds during that particular season. On the other hand, the second mode has negative amplitude during summer and winter, contributing when it is combined with the first mode to a more intense northwesterly wind during winter and to a northeasterly wind during summer.

A complementary analysis is presented in Figure 5 which shows the frequency of occurrence of a given wind direction. That frequency has been computed using the four daily data, by simply adding the wind speed value every time that it occurs at one of the 72 given direction intervals. So, a high value from a given direction can be related both to a higher frequency of occurrence or to more intense wind speeds at that direction. The seasonal cycle is very clear in the figure,

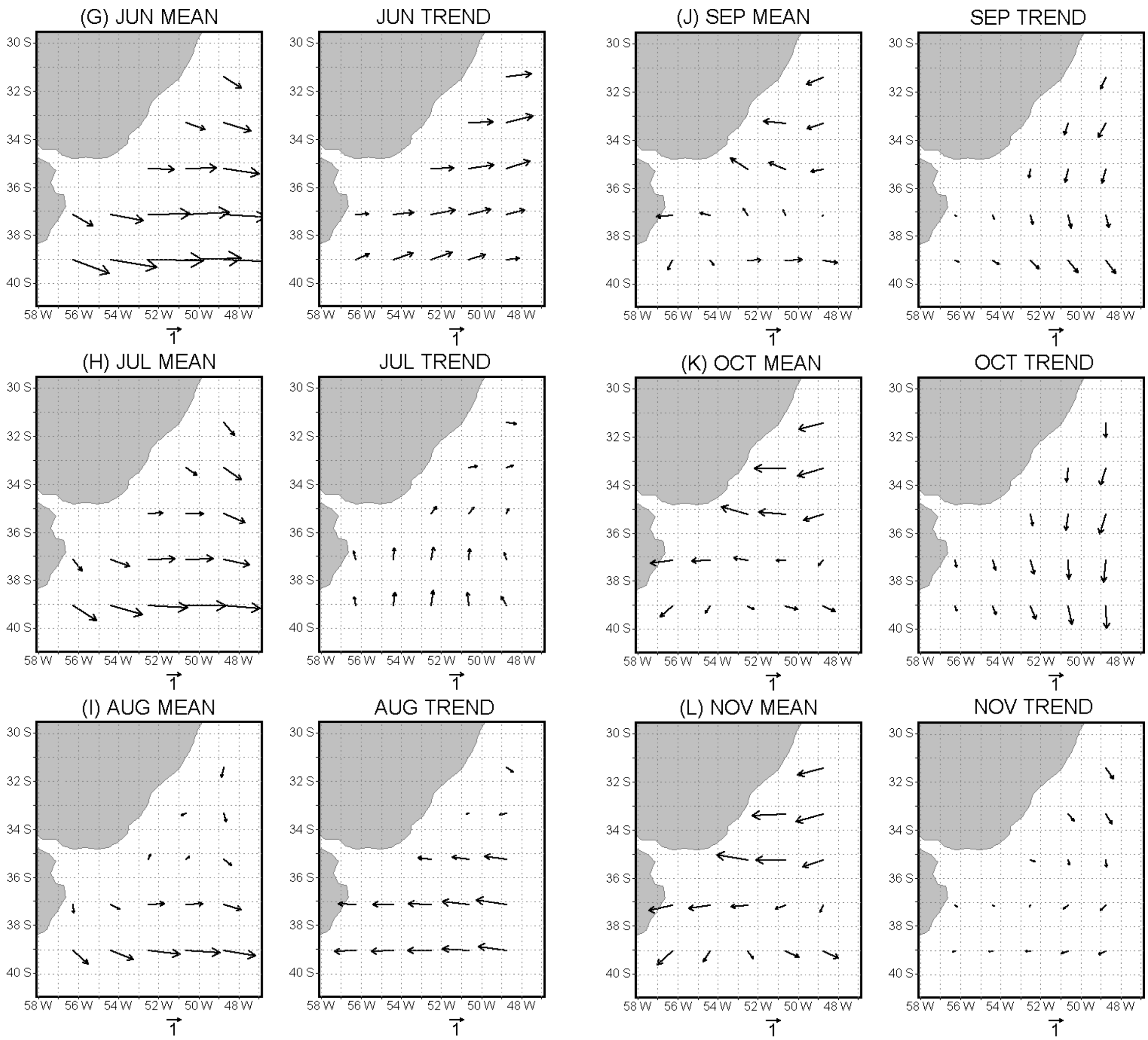

Figure 6. Continued.

with the rotation from east to west from summer to winter. During summer (Dec–Jan–Feb, Figure 5A) the wind mainly blows to the second and third quadrants with a clear north-east dominant component, meanwhile during winter (Jul–Aug, Figure 5C) it mainly comes from the west (goes to the first and fourth quadrants). By the end of fall (May–Jun, Figure 5B) there is an increase of the west/south-west events that is consistent with the second mode of the principal components analysis (Figure 4B). Except for a small intensification of the southwest winds, spring (Figure 5D) is characterized by a structure similar to that during summer. This intensification of the southwest events can explain in part the less intense mean winds that are observed during this season with respect to the summer. In agreement with the results presented in Figure 3, Figure 5 also shows that the fall pattern is rather different from the other seasons.

It has been shown that surface wind data exhibit a long-term variation on their seasonality (Figure 1). This variation was further explored by computing the mean wind pattern and its change along the 50-year record for every single month, as estimated from the respective linear trends for every grid point (Figure 6). Hereafter, the changes along the 50 years record will be called 'trend'. The first feature that comes out from this figure is that the trends (Figure 6, second

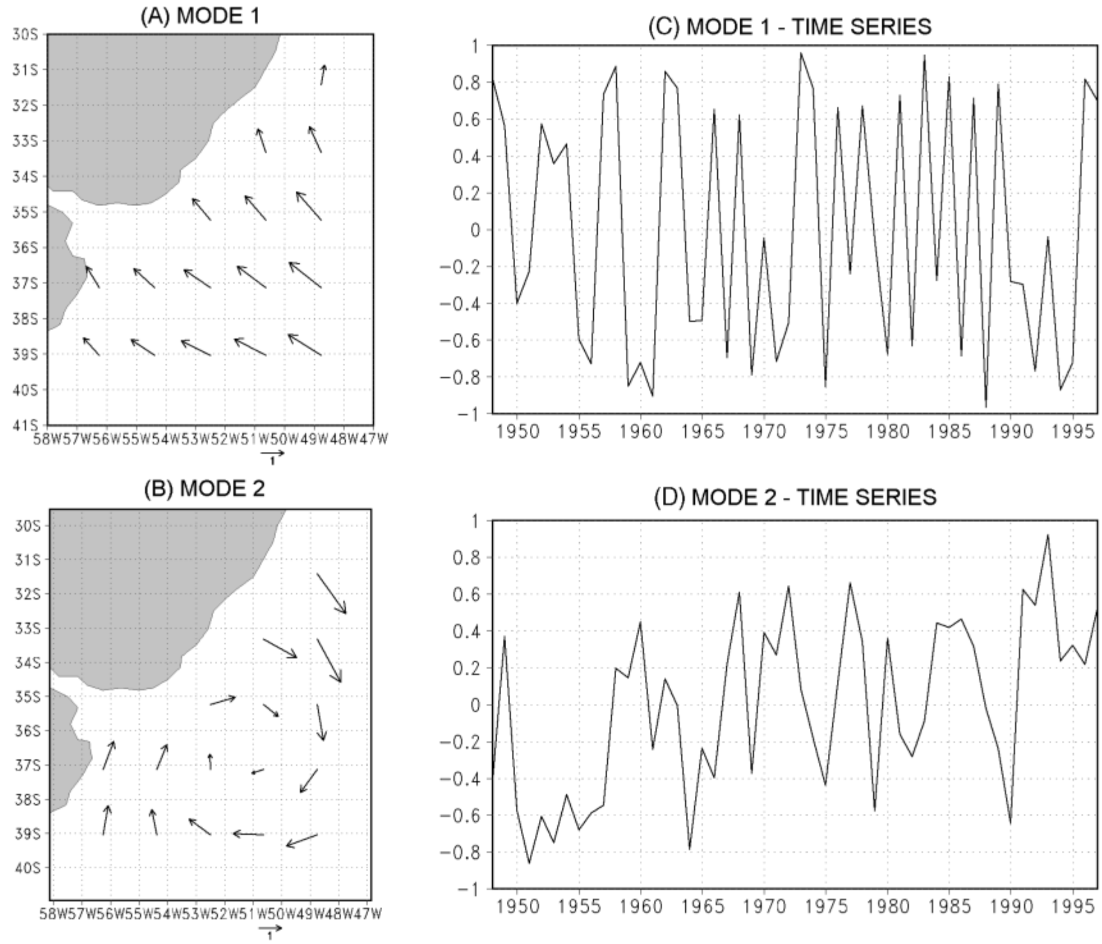

Figure 7. Leading modes of interannual variability for the surface winds obtained from a principal component analysis (t-mode) applied to the annual mean anomalies of the two wind components: (A,B) their spatial patterns and (C,D) the related temporal patterns.

and fourth columns) are very important when compared to the climatological mean values (Figure 6, first and third columns) for most of the year.

Climatological monthly mean fields show that easterly winds increase between December, January and February. This summer pattern is still observed in March, although not so strong. Consistent with that, the corresponding trends show an intensification of the easterlies at the beginning of the season while they have opposite sign during March, indicating a displacement of the summer season to an earlier period. A similar feature can be observed during winter. Winds have increased their westerly component between May and June, and are reduced during August; which is also consistent with a displacement of the season to an earlier period. During the early spring (Sep–Oct) and fall (Apr), the north component has become more important.

THE INTERANNUAL VARIABILITY

In this section, the leading modes of interannual variability in the region were identified for the surface winds in the region through a principal component analysis (t-mode) applied to the annual mean anomalies of both wind components. The first 6 modes account for 96% of the variance, with the two first modes explaining 64.3% of it. The spatial patterns of these modes are shown in Figure 7A and B, while the related temporal patterns are displayed on Figure 7C and D. In order to check the stability of these modes, additional principal component analyses were performed for the periods 1948–1970 and 1970–1997. The leading modes of both analyses showed the same spatial patterns however, differences in their temporal variations were noticed. In particular, while the leading mode for the first period showed a peak of variability at around 5 years, during the second period it exhibits variations at around 2 years. Several authors have described a climate shift during the middle seventies, noticeable in different regions of the world (VAN LOON *et al.,* 1993, among others). However, this result should be taken cautiously as NCEP reanalyses over the Southern Hemisphere included for the first period a considerable lower number of observations than the second. Not only more rawinsonde observations were available after the seventies, but also the inclusion of the satellite data produced a significant improvement on the reanalysis quality.

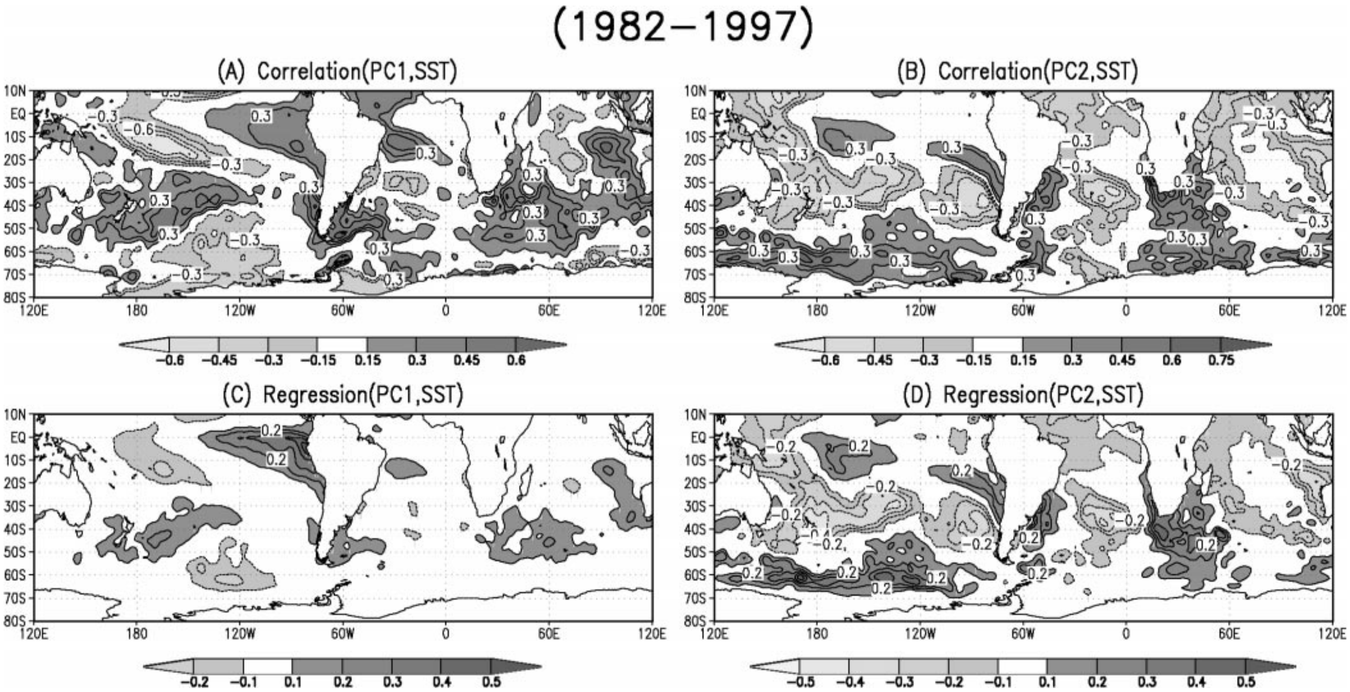

Figure 8. SST anomalies correlated upon the time series of modes (A) 1 and (B) 2. Contour interval is 0.15 and zero contour is omitted. SST anomalies regressed upon modes (C) 1 and (D) 2. Contour interval is 0.1°C and zero contour is omitted.

The first mode, accounting for 47.3% of the variance is related to a wind shift in the southeast to northwest direction (Figure 7A) with a pattern almost identical to the main seasonal mode (Figure 4A). Thus, it seems this mode could be a modulation of the main seasonal feature on interannual scales. The corresponding principal component temporal series (Figure 7C) shows significant interannual variation. A spectral analysis performed for the period 1970–1997 reveals a significant peak at around 2 years and a secondary maximum at around 5 years. On the other hand, the second mode, explaining 17% of the variance depicts a pattern of clockwise/counterclockwise rotation (Figure 7B) of the winds and it exhibits oscillating periods between 8 and 12 years (Figure 7D).

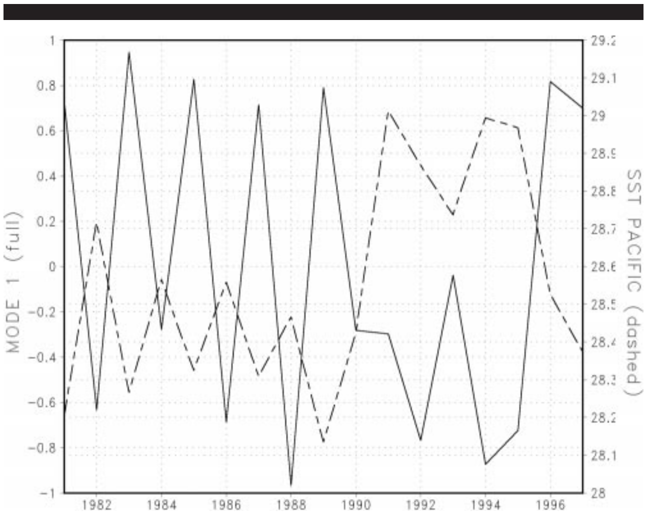

Figure 9. SST variations over the region confined by 10°S–16°S and 170°W–155°W over the western tropical Pacific (dotted line, right axis) and the times series of interannual variability mode 1 (solid line, left axis) during the satellite observational period.

The possible links of these mode variations with distinctive large-scale conditions of SST and atmospheric circulation were explored through a spatial correlation/regression analysis performed over the period 1982–1997, which is the period where the global SST are more reliable everywhere due to the incorporation of satellite information. Examples of the use of those techniques in documenting the spatial signatures associated with different modes of low frequency climate variability can be found in GARREAUD and BATTISTI (1999) and VERA (2003), among others.

The signature of the mode 1 variability on the SST fields (Figure 8A) is characterized by maximum anti-correlation values over the western tropical Pacific and also large values over the tropical regions of both the Indian and the South Atlantic oceans. This pattern resembles those associated with the quasi-biennial tropical oscillation identified by BARNETT (1991) and TRENBERTH (1975), among others.

The corresponding regressed field (Figure 8B) shows the largest SST anomalies over the tropical eastern Pacific while weaker anomalies are observed over the western portion of the basin from tropical to high latitudes. A comparison between the SST variations over the region confined between

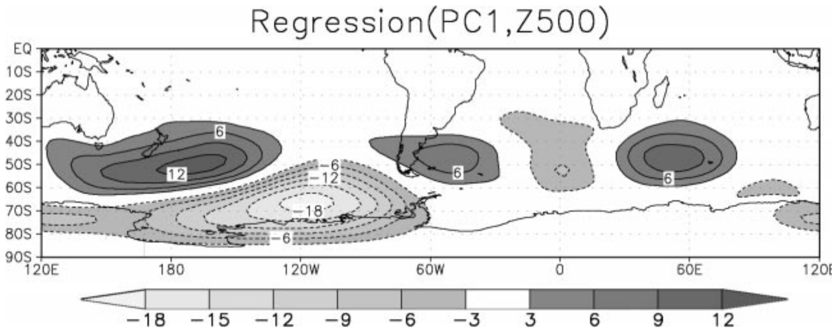

Figure 10. Geopotential heights at 500 hPa (middle troposphere) regressed upon interannual variability mode 1. Contour interval is 3 mgp and zero contour is omitted.

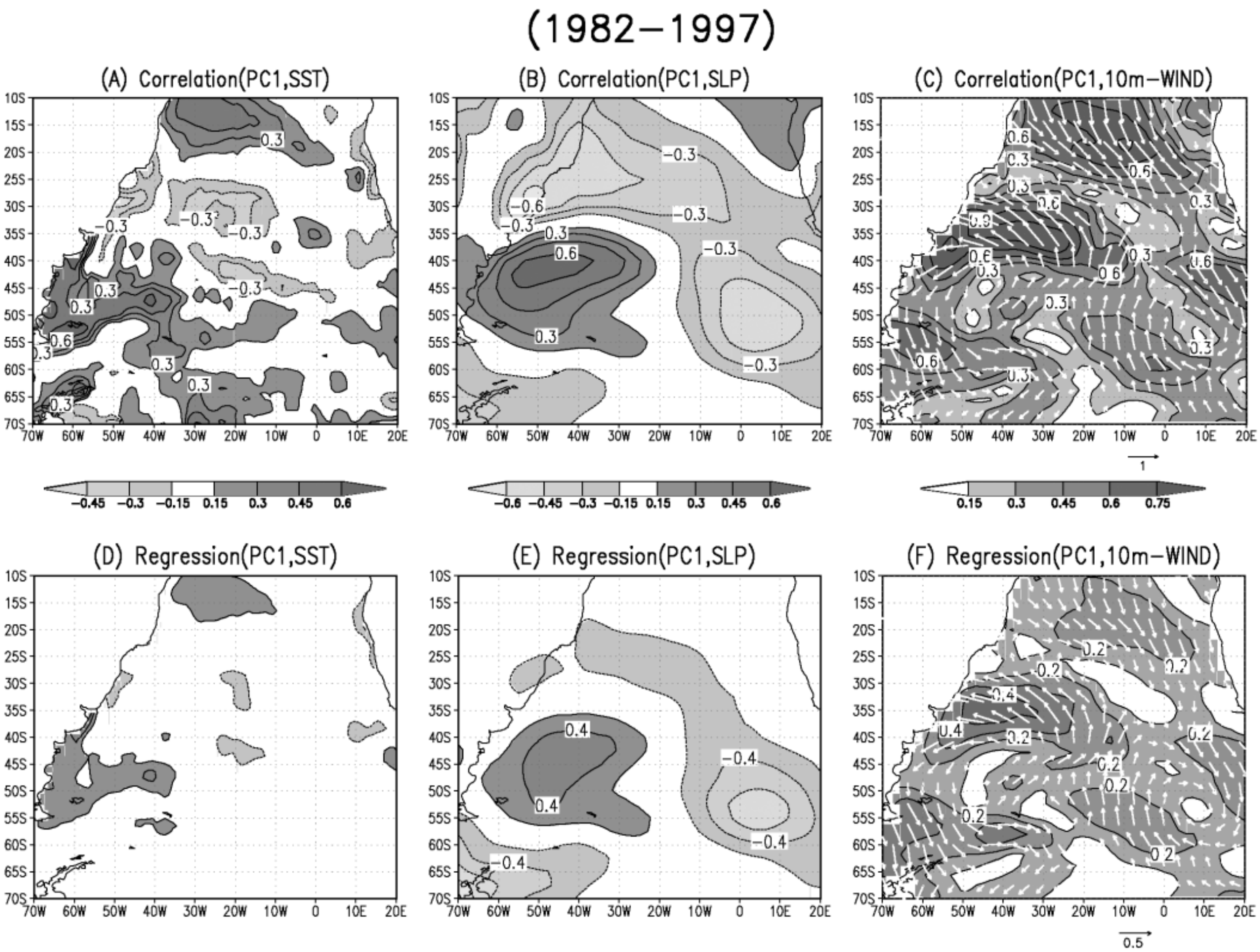

Figure 11. (A) SST, (B) SLP and (C) 10-m wind anomalies correlated upon mode 1 over the South Atlantic ocean (upper panels). Contour interval is 0.15 and zero contour is omitted. (D) SST, (E) SLP and (F) 10-m wind anomalies regressed upon mode 1 over the South Atlantic ocean (lower panels). Contour interval is 0.1°C, 0.2 hPa and 0.1 m s^{-1}, respectively. Zero contour is omitted.

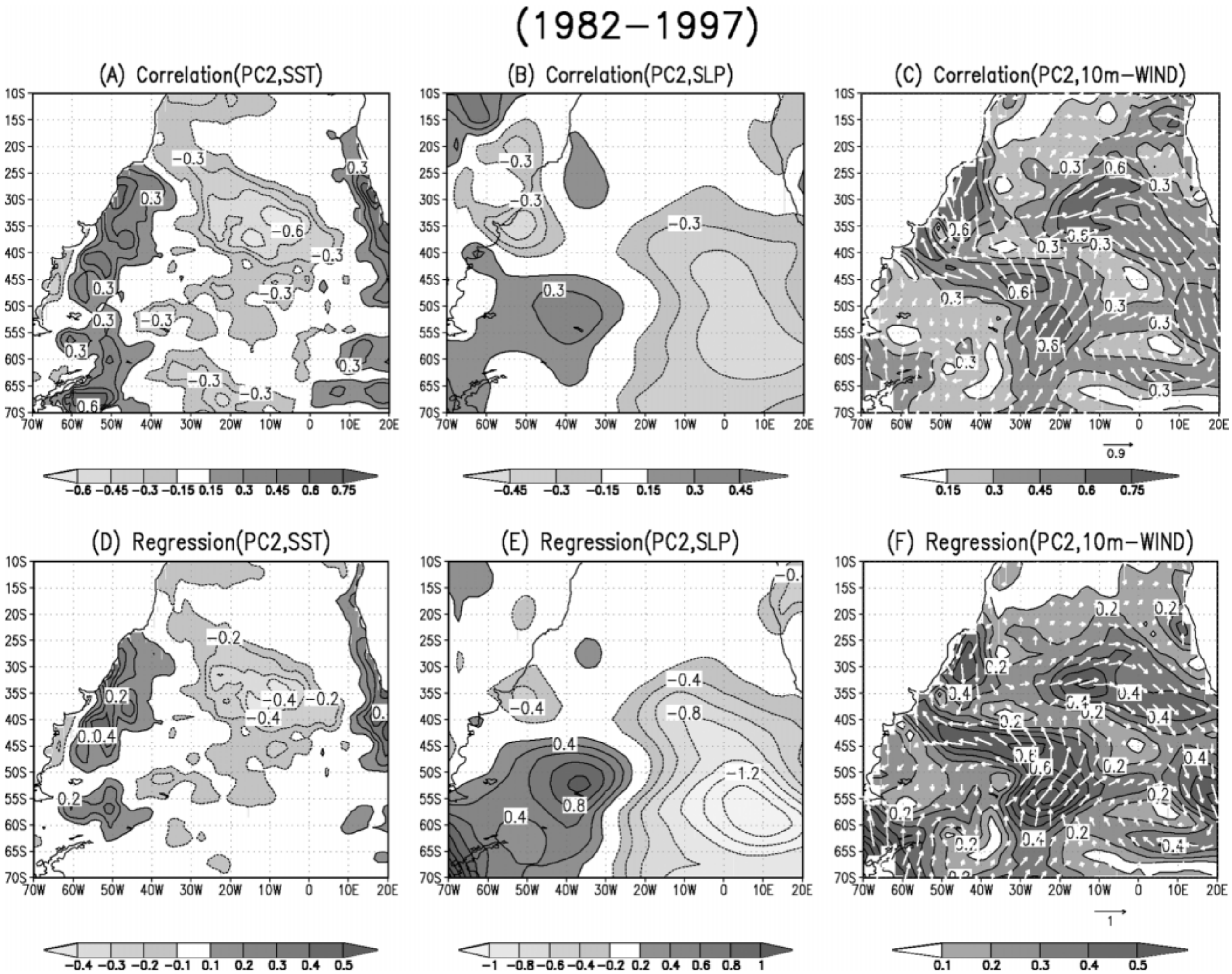

Figure 12. idem figure 11 for mode 2.

10°S–16°S and 170°W–155°W over the western tropical Pacific and the times series of mode 1 (Figure 9) shows a clear correspondence in their interannual variations although with opposite sign. Cold (warm) anomalies over that region are associated with an intensification of the southeasterlies (northwesterlies) over the Río de la Plata estuary. That particular region of the tropics is located over the well-known tropical Pacific warm pool with SST values above 28° all year around. Changes in the SST conditions over that region produce subsequent changes in the atmospheric convective system activity. The diabatic heating released by that convection excites atmospheric Rossby wave trains propagating out of source region (SARDESHMUKH and HOSKINS, 1988). In that sense, the map of geopotential height at 500 hPa (that is at the middle troposphere) regressed upon the mode 1 (Figure 10), shows a well defined wave train emanating from the tropical western Pacific poleward, reflecting equatorward west of the Antarctic Peninsula and then extended eastward over the South Atlantic and South Indian oceans. This pattern resembles the third mode of interannual variability of the Southern Hemisphere atmospheric circulation (KIDSON, 1988, among others). Furthermore, MO (2000) shows that this mode known as "Pacific-South American" pattern also exhibits a peak of interannual variation at 2-year periods.

The signal of this atmospheric wave train over the South Atlantic ocean is characterized by an anticyclonic anomaly over the western portion of the basin and a cyclonic anomaly to the east, both being features also evident at surface (Figure 11B and E). A detailed inspection of this pattern over the basin shows that the variability of mode 1 correlates above 0.6 with that of the anticyclonic anomaly as it is described by the sea-level pressure (Figure 11B) and above 0.8 with the east-southeasterly surface winds flowing along the northern portion of the anticyclone (Figure 11C). In addition, strong surface wind anomalies against the Malvinas current direction are observed and consequently, positive SST anomalies are found along the eastern coast of Argentina being correlated with mode 1 with values above 0.6 (Figure 11A and D).

The signature of the mode 2 variability onto both SST and atmospheric circulation fields exhibits a rather different pattern. Right panels of Figure 8 show that this mode has almost no relationship with SST variations at tropical latitudes while, largest correlation and regression values are observed at middle and high latitudes of the SH and especially over the South Atlantic Ocean. Over the latter, largest correlation values between mode 2 and SST are observed between 25°S and 50°S with positive values along both coasts and negative values at the inner portion (Figure 12A and D). Consistently, the spatial signature of mode 2 on sea-level pressure fields is characterized by an anticyclonic anomaly centered at 40°W and 50°S and a cyclonic anomaly at the same latitude but located further east, both features exhibiting very large regressed values (Figure 12B and E). In agreement, very intense equatorward surface wind anomalies are identified at the central portion of the basin that diverge at around 40°S, flowing to the Argentinean coast over the western portion of the basin (Figure 12C and F). Near the west coast, southeasterly winds converge with those flowing poleward along the coast of Brazil and Uruguay, producing the cyclonic circulation right out of the estuary that characterize the mode 2 positive phase. In agreement, sea-level pressure fields show a negative anomaly over that particular region (Figure 12B and E).

SUMMARY AND CONCLUSIONS

Several papers have emphasized the importance of regional winds in controlling the estuary circulation in large spatial and time scales. Particularly, in their numerical simulations SIMIONATO *et al.* (2001) showed that surface winds are the main contributor in explaining the observed seasonal cycle of Río de la Plata surface salinity front, being more important than the discharge and tides effects. Therefore, this paper describe the main characteristics of surface wind variability over the Río de la Plata estuary.

Our analysis shows that 62% and 18% of the zonal and meridional components total variance, respectively, are related to the seasonal to inter-annual scales while interannual scales account for 4% and 10.6% respectively. Nevertheless the wind variability sub-annual scales is also important over the region, dominating the meridional component behavior. The seasonal cycle is characterized by an onshore to offshore rotation of the winds from summer to winter. This cycle results by the superposition of an annual west-northwestward to east-southeastward dominating signal and a northwestward to southeastward semiannual one. The prevailing winds blow from the east-northeast during summer and from the west-northwest during winter. An important variation on both winter and summer wind speeds is observed during the last 50 years, with a displacement of the summer–winter seasonal features to earlier months. Meanwhile, transition seasons show an important change of the wind directions related to a larger influence of northern winds.

On interannual timescales, two distinctive and important modes of variability have been found. The first mode seems to be a low-frequency modulation of the main seasonal pattern with periods around 2 years and it is highly anticorrelated with SST changes over the western tropical Pacific, resembling the atmospheric quasi-biennial tropical oscillation pattern identified by other authors. Southeasterlies (northwesterlies) over Río de la Plata region are associated with negative (positive) SST anomalies over that tropical region. Consistent with that, a well defined atmospheric Rossby wave train propagating out of that tropical region and extending towards South America links both regions and it is associated with an anticyclonic (cyclonic) anomaly over the western portion of the South Atlantic and a cyclonic (anticyclonic) anomaly to the east.

The second mode is related with clockwise/counterclockwise rotations of the winds with periods between 8 and 12 years and it has almost no relationship with SST variations at tropical latitudes while it is highly correlated with SST changes at middle and high SH latitudes and particularly over the South Atlantic Ocean. Clockwise (counterclockwise) wind rotation out off the estuary are associated with positive (negative) SST anomalies along both South Atlantic basin coasts and negative (positive) values at the inner portion. In agreement, an east-west oriented dipole is the main feature in the corresponding SLP field, with an anticyclonic (cyclonic) anomaly at 40°W, 50° and cyclonic (anticyclonic) anomaly located further east.

Non-significant signal between ENSO and changes of local annual mean winds over Río de la Plata area have been found. However, results might be different if the same study were performed on monthly average winds. In addition, the quasi-biennial signal on surface wind interannual variability found here, and its possible links to changes in the tropical regions should be further explored as it may increase the predictability skills over the region. Finally, although this paper focuses on seasonal and interannual scales, results show that a large portion of the variance is concentrated on subannual timescales and thus they would deserve further attention.

ACKNOWLEDGMENTS

This work was partially supported by SETCIP of Argentina and BMBF of Germany through the Co-operation Project AL/A98-UVII/15. The research of C. Simionato and C. Vera is supported by UBA Grant X072, BID-PICT 99-76355 and IAI/CRN-055. Useful discussion with scientists of SHN and INIDEP have resulted of cooperative work promoted by the UNDP/GEF project "Proteccion Ambiental del Río de La Plata y su Frente Marítimo" conducted by the Consortium CARP/CTMFM.

LITERATURE CITED

BARNETT, T. P., 1991. The interaction of multiple time scales in the tropical climate system. *Journal of Climate,* 8, 1853–1873.

BEARDLEY, R.C. and BOINCOURT, W.C., 1981. On estuarine and continental shelf circulation in the middle Atlantic Bight. *In*: WARREN, B.A. and WUNSCH, C. (eds) *Evolution of Physical Oceanography.* MIT Press Cambridge pp. 198–233.

BOSCHI, E.E., 1988. El ecosistema estuarial del Río de la Plata (Argentina y Uruguay). *Anales del Instituto de Ciencias del Mar y Limnología,* Universidad Nacional Autónoma de México, 15:159–182.

BRANDHORST, W. and CASTELLO, J.P., 1971. Evaluación de los recursos de anchoíta (*Engraulis Anchoita*) frente a la Argentina y Uruguay. I. Las condiciones oceanográficas, sinopsis del conocimiento actual sobre la anchoíta y el plan para su evaluación. *Proyecto de Desarrollo Pesquero FAO Tech Rep 29* Mar del Plata, Argentina.

BRANDHORST, W.; CASTELLO, J.P.; PEREZ HABLAGA, R., and ROA, B.H., 1971. Evaluación de los recursos de anchoíta (*Engraulis Anchoita*) frente a la Argentina y Uruguay. IV. Abundancia relativa entre las latitudes 34°30′–44°10′ S en relación a las condiciones ambientales en agosto-septiembre de 1970. *Proyecto de Desarrollo Pesquero FAO Tech Rep 36* Mar del Plata, Argentina.

CAMPOS, J.D.; LENTINI, C.A.; MILLER, J.L., and PIOLA, A.R., 1999. Interannual variability of the sea surface temperature in the South Brazilian Bight. *Geophysical Research Letters,* 26(14), 2061–2064.

COUSSEAU, M.B., 1985. Los peces del Río de la Plata y su Frente Marítimo. *In*: YAÑEZ-ARANCIBIA, A. (ed). *Fish community ecology in estuaries and coastal lagoons: Towards an ecosystem integration.* UNAM Press Mexico pp. 515–534.

FRAMIÑAN, M.B.; BROWN, O.B.; VALLE-LEVINSON, A., and MÜNSCHOW, A., 2001. Turbidity Front in the Río de la Plata: Physical characteristics and variability from remote sensing and in-situ data. *Joint Assembles of the International Association for Physical Sciences of the Oceans and International Association for Biological Oceanography—XII Coloquio Argentino de Oceanografía Mar del Plata,* Argentina, October 21–28, 2001. *Symposium IB01: Regional Estuarine and Coastal Systems of the Americas.*

FRAMIÑAN, M.B.; ETALA, M.P.; ACHA, E.M.; GUERRERO, R.A.; LASTA, C.A., and BROWN, O.B., 1999. Physical characteristics and processes of the Río de la Plata Estuary. *In*: PERILLO, G.M.E.; PICCOLO, M.C., and PINO QUIVIRA, M. (eds.) *Estuaries of South America: Their morphology and dynamics.* Springer. pp 161–194.

GAN, M.A. and RAO, V.B., 1991. Surface cyclogenesis over South America. *Monthly Weather Review* 119(5), 1293–1302.

GARREAUD, R. and BATTISTI, D.S., 1999. Interannual and interdecadal (ENSO-like) variability in the Southern Hemisphere tropospheric circulation. *Journal of Climate.* 12, 2113–2123.

GUERRERO, R.A.; ACHA, E.M.; FRAMIÑAN, M.B., and LASTA, C.A., 1997. Physical oceanography of the Río de la Plata Estuary, Argentina, *Continental Shelf Research,* 17(7), 727–742.

JAIME, P.; MENÉNDEZ, A.; URIBURU QUIRNO, M., and TORCHIO, J., 2002. Análisis del régimen hidrológico de los ríos Paraná y Uruguay. *Informe LHA 05-216-02.* Instituto Nacional del Agua. Argentina.

KALNAY, E. and COAUTHORS, 1996. The NCEP/NCAR 40-Year reanalysis project. *Bulletin of the American Meteorological Society,* 77, 437–471.

KIDSON, J. W., 1988. Interannual variations in the Southern Hemisphere circulation. *Journal of Climate,* 1, 1177–1198.

LUCAS A.J.; GUERRERO, R.A.; MIANZÁN, H.W.; ACHA, E.M., and LASTA, C.A., 2001. Coastal oceanographic regimes of the Northern Argentine Continental Shelf (34–43° S). *Submitted to Continental Shelf Research.*

MIANZAN, H. W.; ACHA, E.; GUERRERO, R.; RAMÍREZ, F.; SORARRAIN, D.; SIMIONATO, C., and BORUS, R., 2001. South Brazilian marine fauna in the Río de la Plata estuary: discussing the barrier hypothesis. *Colacmar IX (Congreso Latinoamericano en Ciencias Marinas) Colombia* October 2001.

MO, K., 2000. Relationships between low-frequency variability in the Southern Hemisphere and sea surface temperature anomalies. *Journal of Climate.* 13, 3599–3610.

NAGY, G.J.; MARTINEZ, C.M.; CAFFERA, R.M.; PEDRALOZA, G.; FORBES, E.A.; PERDOMO, A.C., and LABORDE, J.L., 1997. The hydrological and climatic setting of the Río de la Plata. *In*: *The Río de la Plata, An Environmental Review, An EcoPlata Project Background Report.* Dalhausie University, Halifax, Nova Scotia. 17–68.

NECCO, G., 1982. Comportamiento de vórtices ciclónicos en el área sudamericana durante FGGE: Ciclogénesis. *Meteorológica,* 13, 7–20.

O'CONNOR, W.P., 1991. A numerical model of tides and storm surges in the Río de la Plata Estuary. *Continental Shelf Research* 11(12), 1491–1508.

OTTMANN, F. and URIEN, C.M., 1965. La melange des eaux douces et marines dans le Río de la Plata. *Cahiers Oceanographiques.* 17, 213–234.

PIOLA, A.R.; CAMPOS, E.J.; MOLLER, O.O.; CHARO, M., and MARTINEZ, C., 2000. Subtropical Shelf Front off eastern South America. *Journal of Geophysical Research,* 105(C3), 6565–6578.

REYNOLDS, R.J. and SMITH, T.M., 1994. Improved global sea surface temperature analyses using optimal interpolation, *Journal of Climate,* 7, 929–948.

RODRIGUES VIEIRA, J. and LANFREDI, N.W., 1996. A hydrodynamic model for the Río de la Plata, Argentina. *Journal of Coastal Research,* 12(2), 430–446.

SARDESHMUKH, P.D. and HOSKINS, B.J., 1988: The generation of global rotational flow by steady idealized tropical divergence. *J. Atmos. Sci.,* 45, 1228–1251.

SIMIONATO, C. G.; DRAGANI, W.; NUÑEZ, M., and ENGEL, M., 2004. A set of 3-D nested models for tidal propagation from the Argentinean Continental Shelf to the Río de la Plata Estuary—Part I M_2. *Journal of Coastal Research,* 20(3), 893–912.

SIMIONATO, C.G.; NUÑEZ, M.N., and ENGEL, M., 2001. The Salinity Front of the Río de la Plata—a numerical case study for winter and summer conditions. *Geophysical Research Letters,* 28(13), 2641–2644.

SIMMONDS, I. and KEAY, K., 2000. Mean Southern Hemisphere extratropical cyclone behavior in the 40-year NCEP-NCAR Reanalysis. *Journal of Climate,* 13, 873–885.

SIMPSON, J.H., 1997. Physical processes in the ROFI regime. *Journal of Marine Systems,* 12, 3–15.

SINCLAIR, M.R., 1994. An objective cyclone climatology for the southern hemisphere. *Monthly Weather Review,* 122, 2239–2256.

TRENBERTH, K. E., 1975. A quasi-biennial standing wave in the Southern Hemisphere and interrelations with sea surface temperature. *Quarterly Journal of the Royal Meteorological Society,* 101, 55–74.

URIEN, C.M., 1972. Río de la Plata Estuary environments. *Geol. Soc. Am. Mem.,* 133, 213–234.

URIEN, C.M., 1967. Los sedimentos modernos del Río de la Plata Exterior. *Bol. SHN* 3, 197–203.

VAN LOON, H.; KIDSON, J.W., and MULLAN, A.N., 1993. Decadal variation of the annual cycle in the Australian dataset. *Journal of Climate,* 6, 1227–1231.

VERA, C. S. 2003. Interannual and interdecadal variability of atmospheric synoptic-scale activity in the Southern Hemisphere. *Journal of Geophysical Research.* 108 (C4), 8077, doi:10.1029/2000JC000406.

WISEMAN, W.J., Jr., 1986. Estuarine-shelf interactions. *In:* MOOERS, C.N.K. (ed) *Baroclinic processes on the continental shelves.* Coastal and Estuarine Sciences 3, AGU, Washington DC, 63–93.