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COMPOSITES OF SEA LEVEL PRESSURE AND SURFACE WINDS IN THE WESTERN SOUTH ATLANTIC RELATED TO STORM SURGE ACTIVITY IN SANTOS, BRAZIL

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1. INTRODUCTION

The southern portion of South-America Atlantic coast is frequently affected by synoptic scale systems (Climanálise, 1986), which can drive energetic disturbances on the ocean. This influence occur basically in two ways: low frequency oscillations of the mean sea level and the generation of surface gravity waves, being both responsible by serious implications to human activities along the coastline. Closed harbors due to severe weather conditions, coastal floods and beach erosion are some of the direct effects related to the passage of large-scale atmospheric transients over the ocean.

The subtidal oscillations of the mean sea level in Santos, central part of the coast of Sao Paulo State, Brazil, are the focus of the present work. These fluctuations are generated by surface winds associated with synoptic scale systems and can be detected through tidal record filtering. With simultaneous records of sea level heights, surface pressure and winds along Brazilian coastal stations between 28S and 23S, Castro & Lee (1995) analyzed the low frequency variability of the mean sea level driven by the wind, and detected disturbances with 6 to 7 day-period propagating equatorward since the southernmost station of the study region.

Stech & Lorenzzetti (1992) and Camargo & Harari (1994) are examples of numerical efforts to represent this kind of phenomena over the southeastern Brazilian platform; the first one used wind fields from a conceptual model of cold front evolution over the shelf, while the second employed winds extracted from synoptic charts supplied by the Brazilian Navy.

This work is initially based on tidal series of Port of Santos (23°56.95'S 046°18.50'W, Brazil), one of the most important Brazilian harbors. During extreme storm surge events, as the recent case of May'2005, the observed sea level reached about 80 cm above the predicted spring tide high water. A picture of the main coastal avenue in Santos during this event is shown in Figure 1, being evident the over-elevation that covered the whole beach and reached the street.

The goals of the present study are: (i) characterization of low frequency sea level variations ranging from 1 to 10 days, through the use of filtering techniques applied in time domain and basic statistics to quantify the different seasons of the year; and (ii) with the identification of events of interest, the establishment of a conceptual model for the meteorological conditions related to this kind of phenomena based on NCEP/Reanalysis data (Kalnay *et al*., 1996) of sea level pressure and surface winds over the Western South Atlantic.

Figure 1 - Bartolomeu de Gusmao Avenue in Santos, during the event occurred in early May'2005.

2. DATA AND METHODOLOGY

The hourly data set of sea level heights of Port of Santos from 1944 to 1990 was analyzed by Harari & Camargo (1995), with evaluation of the yearly variability of harmonic constants besides annual, seasonal and monthly mean sea level trends.

The proposed analysis for this work is quite simple and considers only the last 10 years (1981-1990) of the available data set of Santos. The original data were submitted to filtering procedures based on band-pass Lanczos formulation, in order to remove the astronomical constituents, besides monthly, seasonal and annual cycles. The band-pass filter was set to retain only oscillations with periods ranging from 1 to 10 days, which characterize the atmospheric synoptic scale influence over the ocean (Pugh, 1987).

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With the filtered series, monthly distributions of surge occurrences were obtained, in order to evaluate the seasonal variability of the phenomena. The limits of 2 and 3 standard deviations were used to determine the periods related to the most important events, for both positive (over-elevation) and negative (under-elevation) fluctuations. Once determined, the corresponding daily data fields of sea level pressure and surface winds over the Western South Atlantic obtained at CDC/NOAA, the NCEP Reanalysis, were employed to obtain the composites of synoptic conditions as the mean of the daily conditions for each category.

3. RESULTS AND DISCUSSION

Figure 2 shows the filtered series related to the period August 3 to December 31, 1984, enhancing the 2 standard deviation limits and some events of interest. It's important to stress that the typical astronomical range (difference between high and low water) in Santos during spring tides is about 150 cm, meaning that low frequency oscillations above 40 to 50 cm have strong relevance over the observed sea level.

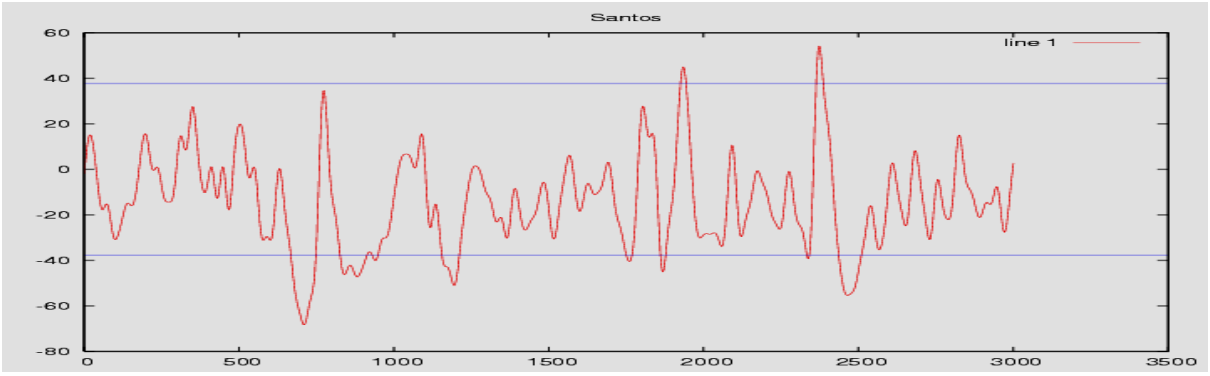

Figure 2 - Filtered series of sea level heights (in cm) observed at Port of Santos from August 3 to December 31, 1984, with emphasis to the 2 standard deviation limits.

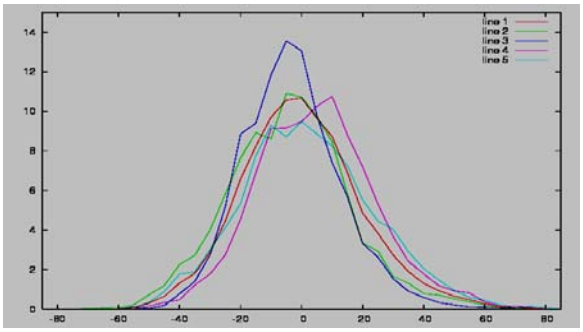

Figure 3 - Distribution of occurrence (in %) of surge levels (in cm) for the 1981-1990 series (red), and its seasonal subdivisions: spring (green), summer (dark blue), autumn (pink) and winter (blue).

The distribution of surge levels for the whole filtered series has a gaussian shape around the long term mean sea level, as well as the seasonal distributions (Fig. 3). The seasonal variability shows autumn and winter with more occurrences of positive events while spring and winter present the higher frequencies of negative events (Tab. 1).

Table 1 - Occurrence of significative surge levels by season of the year, in percentage of time with levels under/over 2 standard deviations.

Season/Level	< -30 cm	> 30 cm
Spring	0.0229	0.0121
Summer	0.0089	0.0076
Autumn	0.0079	0.0239
Winter	0.0154	0.0273

With the identification of specific periods of interest, the correspondent daily mean large-scale meteorological fields of sea level pressure and surface winds from NCEP/Reanalysis were employed to represent the synoptic conditions related to significative events under and over 2 and 3 standard deviations.

4. CONCLUDING REMARKS

Analyzing the frequency of positive and negative values of surge events in Santos, it's possible think about the importance of cyclogenetic processes and cold intrusions to the higher occurrence of positive oscillations in autumn and winter. In the latter, extra-tropical anti-cyclones with high intensity can be associated to the negative fluctuations. On the same thinking, the relevance of blocking systems over the Atlantic can be related to the higher occurrence of negative values during spring.

The distribution of extreme events revealed winter, autumn, spring and summer, in this order, as the typical seasons for the occurrences - but with small differences in amplitude of the events. Positive anomalies of mean sea level were basically associated with spatial patterns of extra-tropical cyclones over the ocean and extra-tropical anti-cyclones over the continent. The opposite pattern, related to persistence of low pressure center over land and high pressure

over the ocean, appeared associated with negative anomalies of mean sea level in Santos. These patterns were usually associated with different stages of the evolution of meteorological systems over the Western South Atlantic.

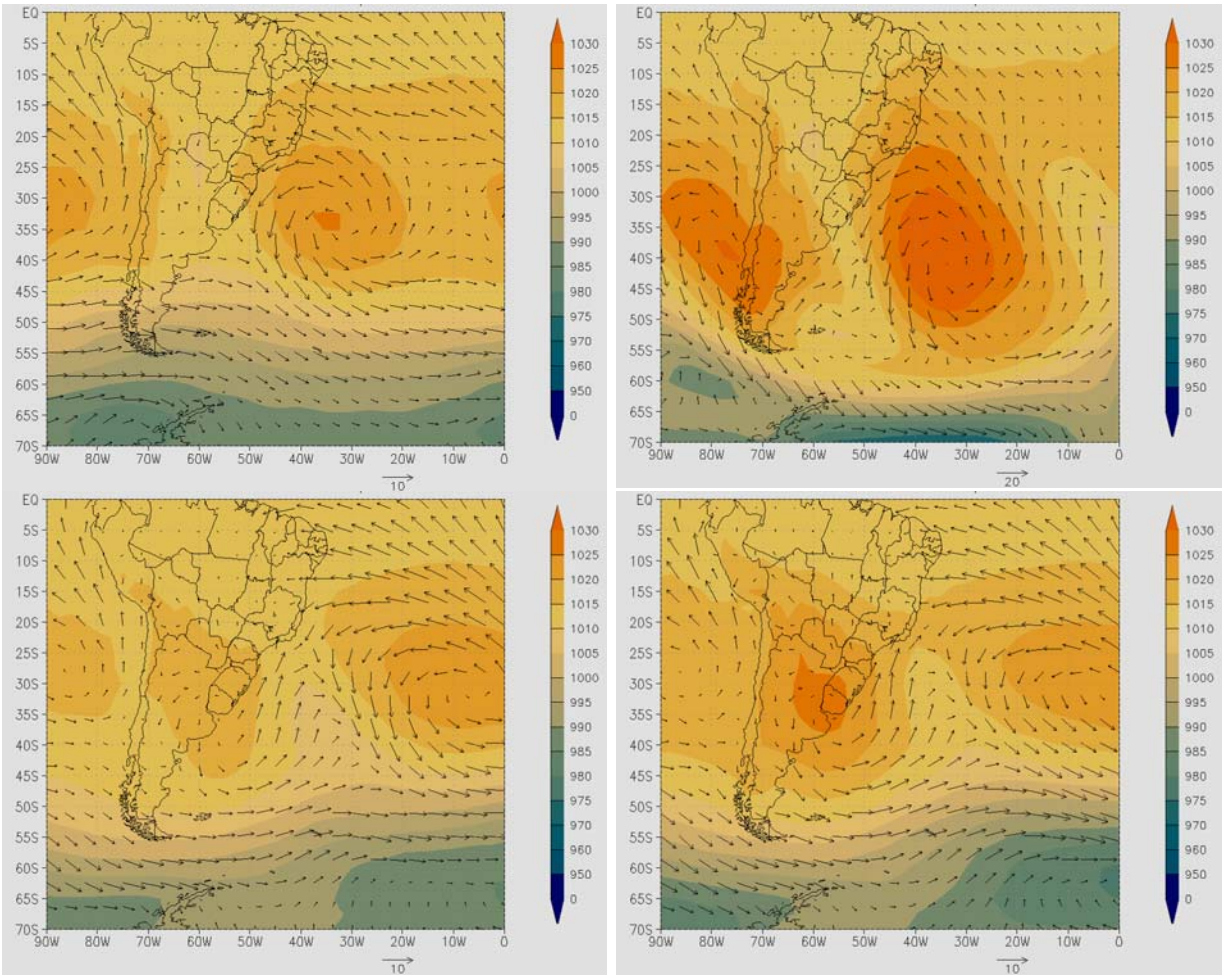

Figure 4 - Up: Composites of sea level pressure (shaded, in hPa) and surface winds (vector, in m/s) related to under-elevations above 2 and 3 standard deviations, left and right respectively. Down: the same as up, but for over-elevations.

In a general way, days of extreme storm surges in Santos are related with occurrences in southernmost stations one or two days before, due to meteorological activity of frontal systems and the correspondent cyclones and anti-cyclones persistence and propagation. On the other hand, sub-tropical cyclogenesis can play an important role for surges in Santos with small influence on southern stations.

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