Meteorological and hydrodynamical analysis of the coastal region of Bahia State, Brazil

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Abstract

This study aims to analyze the meteorology and hydrodynamics of the Southern coastal region of Bahia State, Brazil, for the purpose of implementing future engineering projects and constructions in the area. To achieve this goal, an investigation on the environmental conditions in the region of interest was conducted considering several analyses: surface climatology, sea level data, satellite altimetry data, oceanic numerical modeling and wave climate. Results of the meteorological and oceanographic data processing allowed to estimate the energy associated with the dynamics in the area, as well as the long term trends. This information is very valuable for the correct dimensioning of the engineering enterprises – port building and real estate development, in order to assure their long term maintenance.

I – Introduction

This study aims to analyze the meteorology and hydrodynamics of the Southern coastal region of Bahia State, Brazil (Figure 1), for the purpose of implementing future engineering projects and constructions in the area. To achieve this goal, an investigation on the environmental conditions in the region of interest was conducted considering several analyses:-1)-Analysis of surface climatology, with an emphasis on the monthly variations over 30 years (1980-2009) of air temperature, together with the East-West and North-South wind components and wind intensity, estimated via a global atmospheric model. -2)-Analysis of sea level data of the region, in order to estimate seasonal variations and long-term trends of the mean sea level.-3)-Analysis of satellite altimetry data, from 1992 to the present, to estimate the variations and trends of the mean sea level off the area of interest.-4)-Results of an oceanic numerical model, in order to determine patterns of variation in sea level and currents according to several weather conditions and seasons of the year and -5)-Analysis of the wave climate for the region, based on data extracted from a global wave generation model.

Fig. 1 – Study region, in the Southern coast of Bahia State (Brazil) (Google Earth) .

II – Methods and Results

II.1 - Monthly Climatology (1980-2009)

Meteorological data produced by re-analysis of the global atmospheric model of the National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR) were used to determine the climatology of the coastal region of interest (Kalnay et al, 1996). Data at the surface level in the period 1980-2009 were considered (30 complete years), every 6 hours, in the point at 13.75°S 37.5°W. The series studied were ai r temperature, East-West and North-South wind components, and the composition of the latter two, in the form of wind intensity - a total of four series, with 43,833 sample points for each variable.

All series were subjected to statistical analysis to obtain the parameters mean, standard deviation, minimum, maximum, skewness and kurtosis for each month of the year and for the complete records, thus, the statistical parameters were determined for all January, February, etc ... and also for the entire series. An example of the monthly statistical analysis is shown on Figures 2 and 3, for the air temperature and wind series; the statistics clearly demonstrates the contrast winter - summer, according to which the months of October - November to April - May (summer) have the highest temperatures and the months of April - May to October - November (winter) have the lowest temperatures; on the other hand, the winds have little variation in intensity throughout the year, being the EW component always negative (east quadrant), but the NS component varying from negative values in summer (NE winds) to positive in winter (SE winds); the wind has an average of 5.73 m/s, with standard deviation of 1.85 m/s.

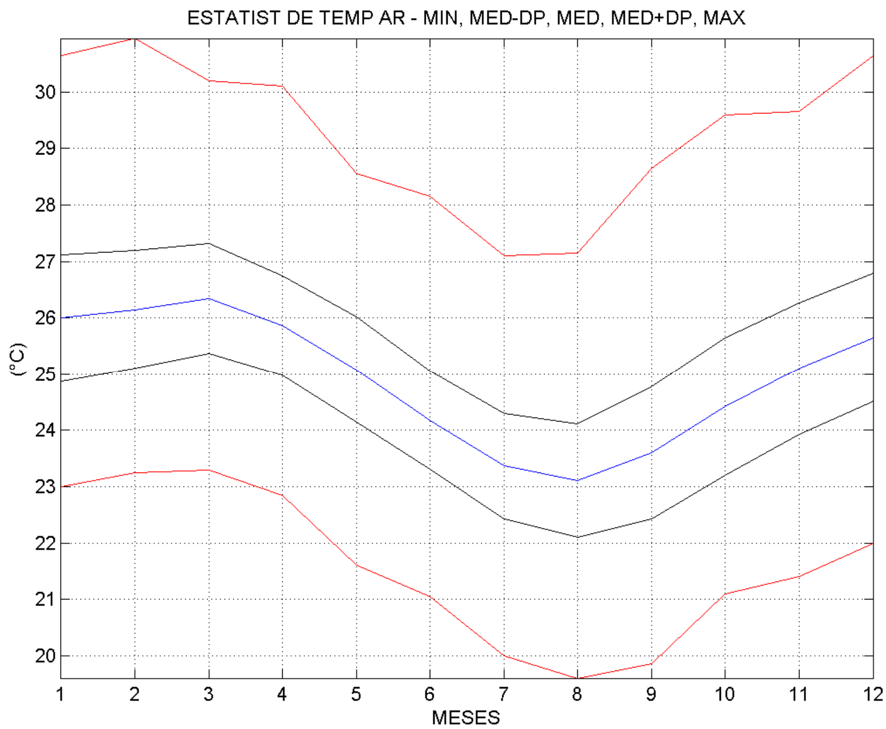

Fig. 2 – Monthly statistical parameters of surface air temperature (minimum, mean - standard deviation, mean, mean + standard deviation and maximum), in 13,75°S 37,5° W, in the period fro m 1980 to 2009. From the National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR), USA.

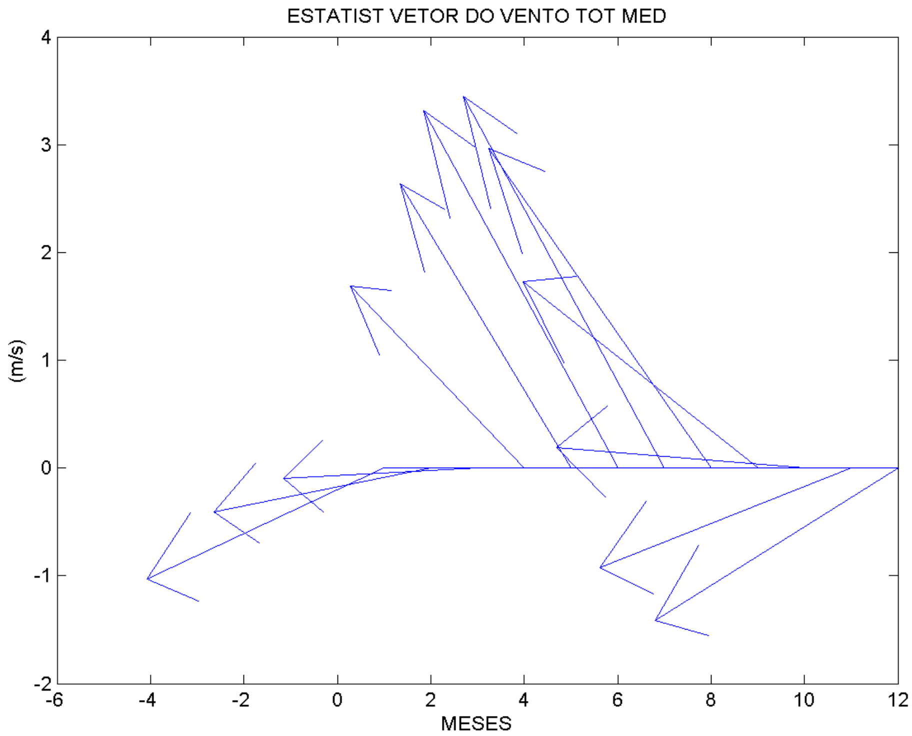

Fig. 3 – Vectors of mean monthly winds, in 13.75°S 37.5° W, in the period from 1980 to 2009. From the National Center for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR), USA.

The wind data were also represented according to the rose and compass for the entire period of analysis, in Figure 4, showing that the wind blows more often from approximately ESE.

In relation to climate variability in the study area, the analysis of the 30 years series allows us to estimate the long-term trends, which resulted in: temperature increase at a rate of +0.0038°C/year - probably related to global warming; decrease of the EW component of wind in the ratio -0.0129 m/s/year; increase of the NS component of wind at a rate of +0.0107 m/s/year; and increase of the intensity of the wind, 0.0161 m/s/year. Consequently, it the long term, occurs an intensification of the winds from SE and weakening of the NE winds.

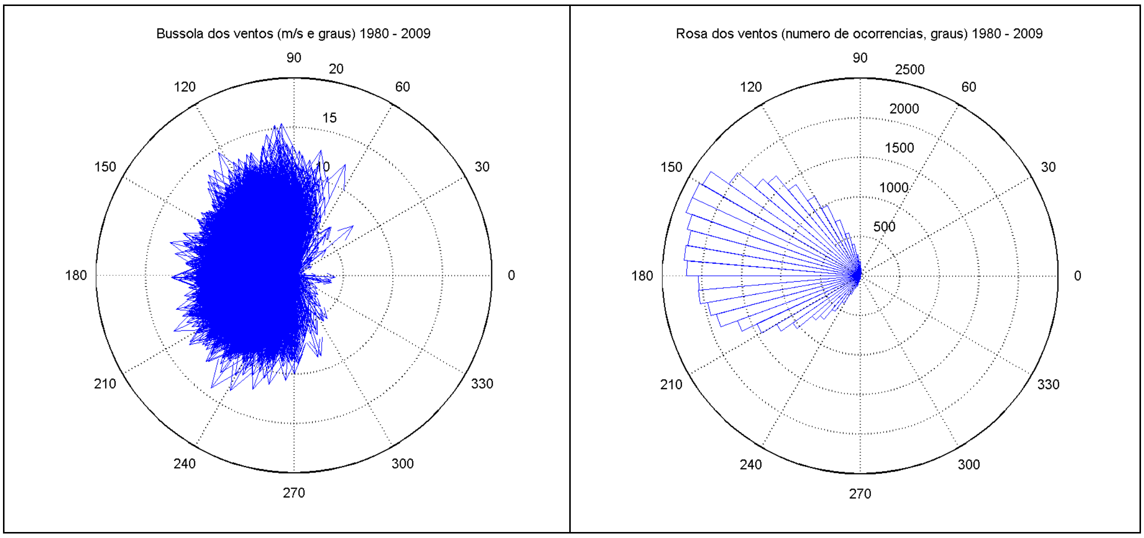

Fig. 4 - Compass and rose of the winds (m/s and number of occurrences) calculated by the model of NCEP / NCAR, at 13.75°S 37.5°W, from 1980 to 2009.

II.2 - Survey of sea level data

Sea level data were obtained from the National Oceanographic Data Bank (NODB) of Brazil Navy, from 14 points along the coast of Bahia State. These data were subjected to statistical, spectral and tidal analysis, to determine basic statistical parameters and predominant frequencies (Jenkins & Watts, 1968; Franco, 1988).

Among the series examined, the longest is of the Port of Salvador - 12° 57.9'S 038° 31.0' W, covering the period from 02 January to 22 December 1960. The processing shows that the tide is the main factor of variations in sea level in the region, with variability around 60 cm, while weather effects have much less influence, causing a variation in sea level of about 6 cm; the values of tides and sea level range from -135 cm to +135 cm, while the mean sea level values are between -15 cm and +15 cm, approximately (Figure 5).

In the data set of sea level of the region, two other series, besides the Port of Salvador, have reasonably long records, the Capitania de Salvador - 12° 58.4' S 038° 31.0' W, with data from 22/04/1988 to 13/09/1988, and the Base Naval de Aratu - 12° 47.8' S 038° 29.5' W, with data from 03 /09/2003 to 03/12/2003. These series show similar characteristics to that of the Port of Salvador, but the mean sea level reached larger extremes, +20 cm and -20 cm.

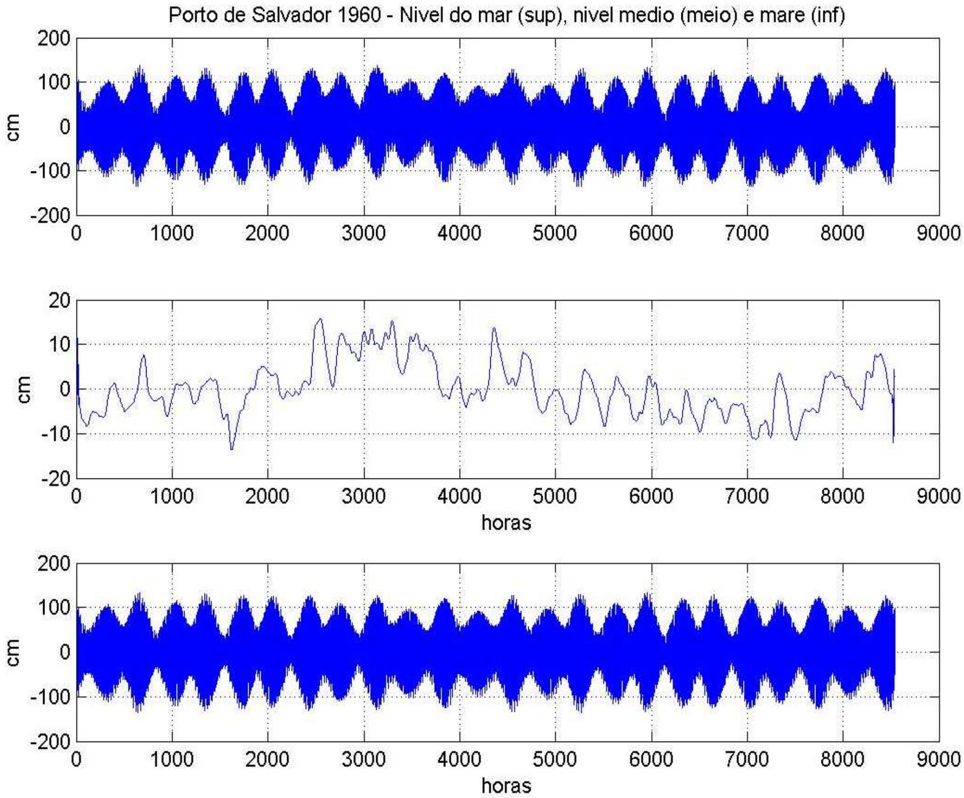

Fig. 5 - Time series of sea level at the Port of Salvador, in the period of 02/01/1960 to 22/12/1960 (above), and components of mean sea level and astronomical tide (below).

II.3 - Processing of altimeter data

The processed data of sea level were obtained by satellite altimeters TOPEX / Poseidon, Jason I and Jason II (Aviso / Altimetry, 1996). The entire series of satellite data shows a global sea level rising of +0.325 ± 0.06 cm/year, with 95% confidence interval (Figure 6), but with large spatial variability (Figure 7).

For the present study, altimetry data off the region of interest were selected, covering the period 2002 to 2009. For this region, the trends in sea level anomaly were calculated (Figure 8) and, for a selected point of the study area, 39°W 13.6273°S, the plotting of the time series of sea level anomaly is presented, whose linear regression shows a rise in mean sea level at a rate of 0.54 cm/year (Figure 8); but, again, even in a small scale, the spatial variability of the sea level trend is remarkable.

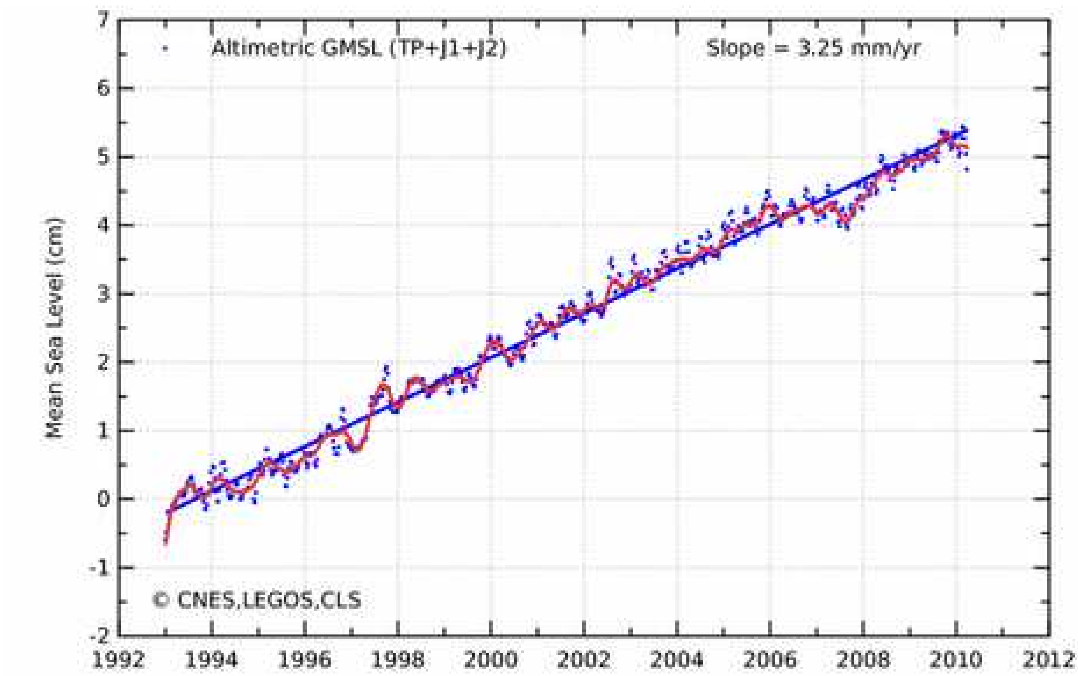

Fig. 6 - Variation of the global mean sea level after removal of the annual and semi-annual signals (2 months filter applied to the points in blue and 6 months for the red curve) (http://www.aviso.oceanobs.com/).

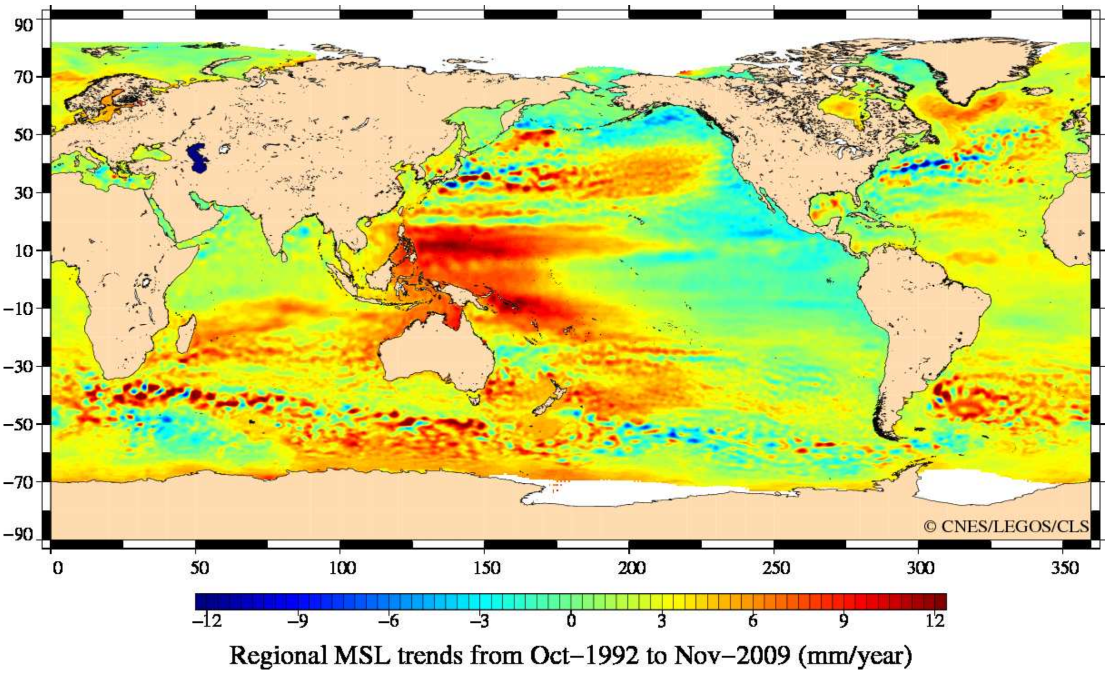

Fig. 7 – Spatial distribution of variation of mean sea level in all oceans from the satellite altimeter for the period October 1992 to November 2009, with values between -1.2 and +1.2 cm/year (resolution of 1/3° Mercator projection) (http://www.aviso.oceanobs.com/).

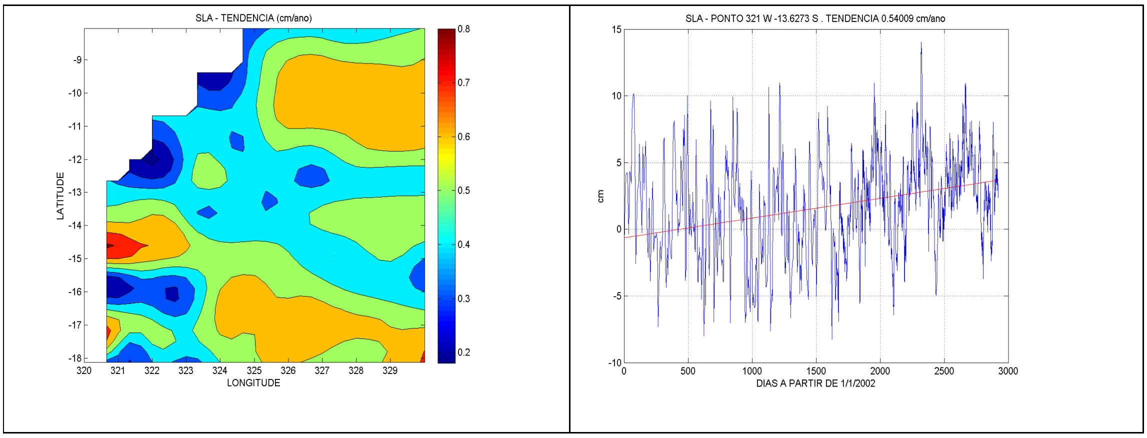

Fig. 8 - Map of the trend of the anomaly in sea level by altimetry, in cm/year, for the period 2002 to 2009 (left) and time series of anomalies in the selected point 39°W 13.6273°S, with its linear re gression (right).

II.4 – Hydrodynamical numerical modeling

Data produced by global numerical hydrodynamic model Hycom (Bleck, 2001) were analyzed, a model which uses hybrid coordinates in a grid 1/12° x 1/12°, with data assimilation. The model results are distributed online on a daily basis, having been used in this study those of the region bounded by 12.5°S - 15.0°S and 37°W - 39.5°W, for the full year of 2010.

The hydrodynamic analysis also clearly demonstrates the contrast winter - summer, according to which the months of October - November to April - May (summer) have the lowest elevations and higher temperatures and salinities, while in April - May to October - November (winter) occur the higher elevations and lower temperatures and salinities. The variability of the currents throughout the year can also be found on analysis of specific periods, as shown in Figure 9, representing the Hycom model calculations with surface current monthly averages in February and August 2010: at the shelf, in summer the currents are to the South and Southeast and in winter to the North and Northeast.

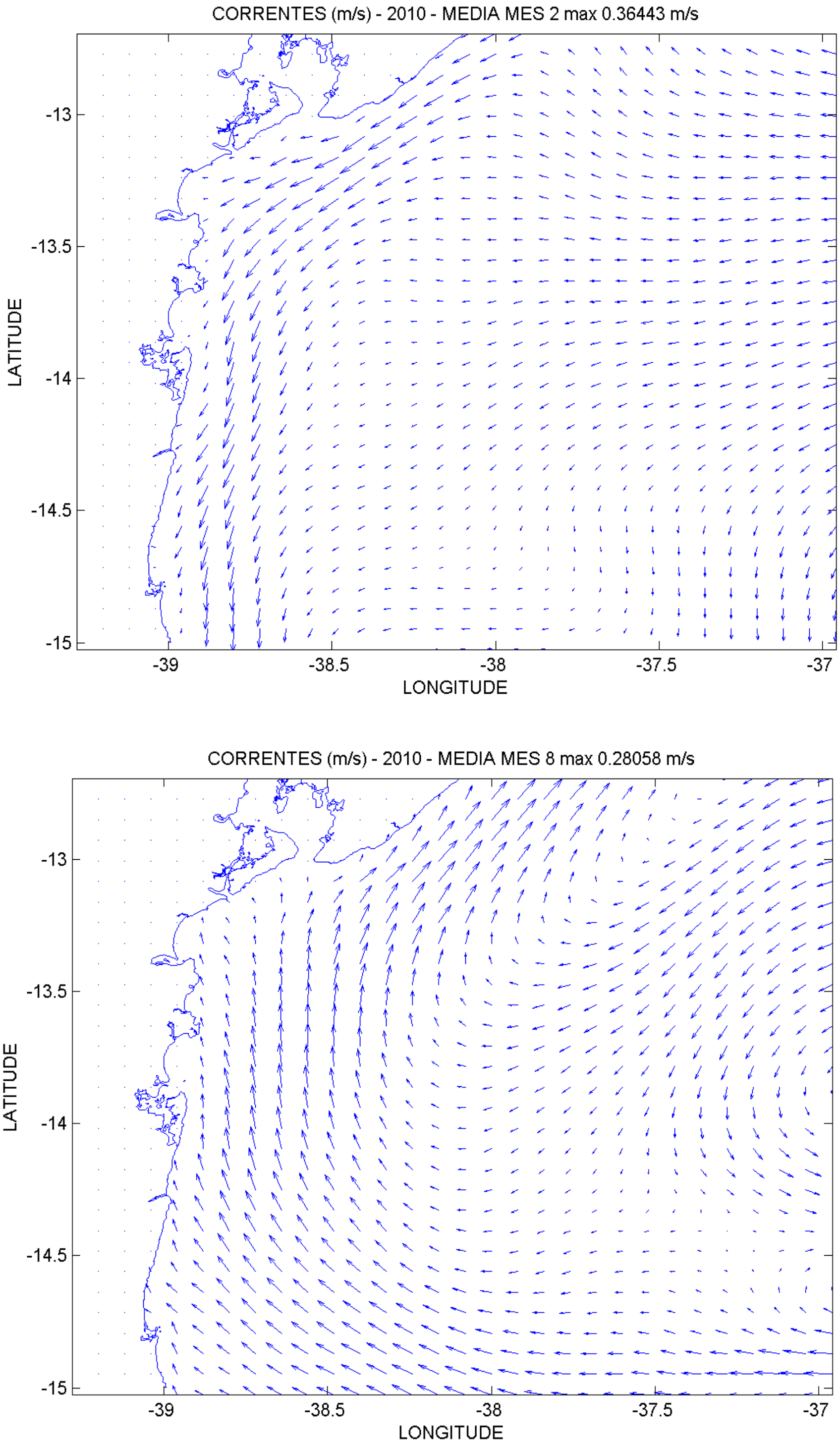

Fig. 9 – Monthly mean surface currents, computed by Hycom numerical model, in February and August 2010 (http://www.hycom.org/).

A nested coastal grid was considered for a high resolution hydrodynamical model. Due to the small depth of the region of interest (less than 15 meters), a two-dimensional (vertically integrated) hydrodynamic numerical model was used (Kowalik & Murty, 1993). The corresponding system of basic hydrodynamic equations, subject to initial and boundary conditions, allows the calculation of time evolution of the surface level and velocity components at any grid point. The computational grid used in the coastal model processing has uniform spacing in x and y directions of 333.33 m and consists of 100 points in x - EW and 100 points in y - NS; the area covered by the grid is bounded between latitudes 13.85°S and 13.55°S and between longitudes 39.02°W and 38.72°W. Figure 10 presents the modeling results with the processing of tides added to winds from Southeast and Northeast.

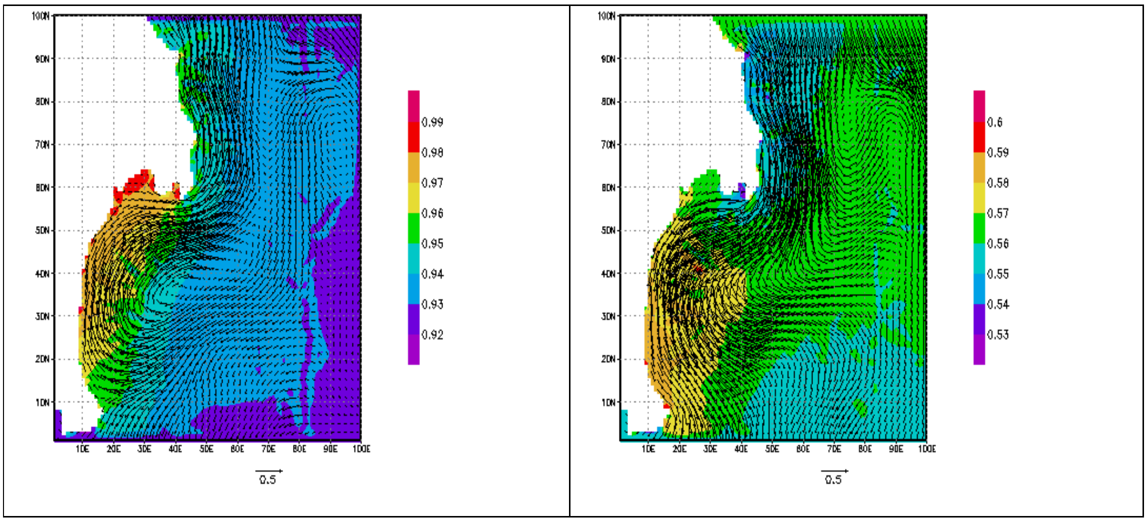

Fig. 10 - Results of the coastal model: sea level elevations (shaded, in m) and currents (vectors, in m/s), for processing of tides and winds from southeast (left) and tides and winds from northeast (right).

The most important results of the hydrodynamic model, considering processing periods of spring tides with typical winds, variations in the mean sea level and river discharges, are the following: 1) in the processing with tidal forcing alone, there is intensification of currents near the coast and their rotation counterclockwise, but the intensity of the currents does not exceed 0.05 m/s; 2) the residual effect of the tides is to the southwest, but with very low intensity; 3) typical and extreme weather effects produce currents that prevail in relation to tidal currents, following the wind direction, and producing currents with typical intensities of 0.5 m/s, being more intense near the coast; 4) the prevailing winds are from ESE and virtually vary between NE and SE, with small variations in intensity, which produce defined currents patterns, that are much stronger than the tidal currents; and 5) river discharges have small influence.

II.5 – Regional wave climate

The regional wave climate definition is based on data available through the global wave generation model NWW3 from NOAA/NCEP (Tolman, 1997, 1999). The NWW3 simulations are based on the reanalysis of wind data from NCEP / NCAR available for a 13-year period, from 1987 to 2009. Based on the model grid (1° latitude x 1°15' longitude) the data extra ction was defined for the continental shelf in front of the area of interest, for the coordinate 14°0'0.00" S; 38°45'0.00" W.

Waves approach the region with directions varying between the southeastern and eastern quadrants, with clear dominance of waves from east (approximately 50 %), but highest waves coming from the southeast, which are also associated to longer periods. Most frequent waves in the region are from east with heights of about 1.5 m (Figure 11).

Average wave heights vary between 1.0 and 1.7 m, with minimum mean values were registered between December and March, increasing from June to August. Although the months of September to November present a gradual decrease in the monthly means, during this period peaks with wave heights up to 3 m still occur. The modeled waves time series for the region shows that the average wave height is 1.25 m, with peaks that rarely exceed 3 m. Based on the results, extreme wave events occur when wave heights exceed 2 or 3 m. In average, over the analyzed period, wave heights exceeded 3 m only 0.3 times/year, and the 2 m limit was reached 9.4 times/year.

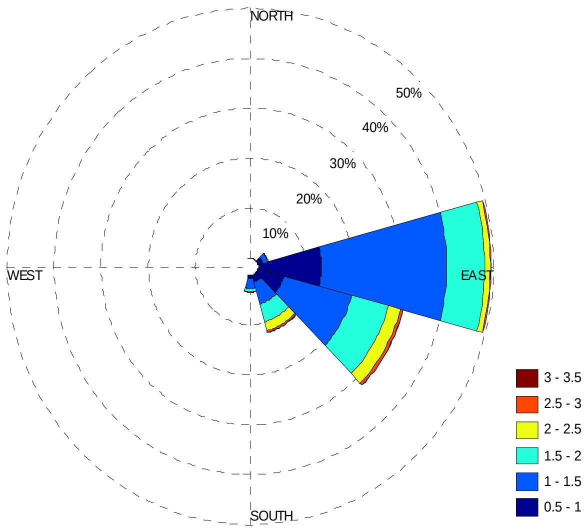

Fig. 11 – Wave height distribution rose based on the 13-year period (in meters). (http://polar.ncep.noaa.gov/).

III – Concluding Remarks

Based on the atmospheric and ocean characterization of the Southern coastal region of Bahia State (38 W; 13S) a set of recently developed met and ocean methods were devised, which can help the engineering projects presently in progress in the area. Results of the meteorological and oceanographic data processing allowed to estimate the energy associated with the dynamics in the area, as well as the long term trends. This information is very valuable for the correct dimensioning of the engineering enterprises – port building and real estate development, in order to assure their long term maintenance.

IV – Bibliography

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