WAVE PREDICTION ALONG LAGOA DO PATOS COASTLINE, SOUTHERN BRAZIL

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RESUMO

As informações sobre ventos e ondas próximos da costa são dados críticos para os pesquisadores e técnicos que trabalham em projetos ligados às áreas de engenharia, geologia e oceanografia costeira, navegação e recreação. Este artigo provê as primeiras medidas de ventos e predição de ondas ao longo do litoral da Lagoa dos Patos com base em um ano de dados de velocidade de vento e direção, registrados a cada hora, durante todo o ano de 1988. Devido aos ventos nordestes prevalecerem no verão e primavera, a direção das ondas dominantes no lado ocidental da laguna é NE e ENE com média das alturas de ondas significativas entre 0,5-0,7 m e períodos entre 2,7-3,3 s. No lado oriental da laguna os ventos prevalecentes são de WNW e WSW. Durante o inverno e outono, os ventos produzem as maiores alturas máximas na laguna com valores de 1,6 m e período de 4,8 s, e alturas de ondas significativas entre 0,4-0,8 m e períodos entre 2,4-3,4 s. A alta freqüência dos ventos com velocidades entre 0-2 m/s, e sua pequena duração, constituem-se nos principais mecanismos de controle que limitam o crescimento das ondas na laguna, sendo a pequena profundidade da ordem de 6 m um fator secundário.

PALAVRAS CHAVE: Lagoa dos Patos; Sul do Brasil; Previsão de ondas.

ABSTRACT

Information on winds and waves near the coast is critical to scientists and coastal engineers working with coastal structure design, erosion rate estimates, navigation safety, and recreational purposes. This paper presents the first wind measurements and wave predictions along the coastline of Lagoa dos Patos based on one year's wind velocity and direction data recorded every hour during 1988. Due to the prevailing northeastern wind during the summer and spring, the dominant wave direction on the west margin of the lagoon is NE and ENE, with significant wave height between 0.5-0.7 m and periods between 2.7-3.3 s. On the east side, during winter and autumn, WNW and WSW winds cause a maximum wave height of 1.6 m and period of 4.8 s, and significant wave heights between 0.4-0.8 m and periods between 2.4-3.4 s, respectively. The high frequency and short duration of winds with velocity between 0-2 m/s is the main factor controlling wave height in the lagoon. The average 6-m depth in this shallow and elongated lagoon acts as a secondary factor reducing wave height.

KEY WORDS: Lagoa dos Patos; Southern Brazil; Wave prediction.

1 – INTRODUCTION

This study provides wave predictions based on accurate wind measurements along the shoreline of Lagoa dos Patos, a 240-km-plus-long lagoon. This information addresses the needs of coastal research groups working on problems affected by wind and wave conditions in the lagoon, thus helping the design of coastal engineering structures, beach restoration and maintenance projects, prediction of the fate of dredging material, and estimation of longshore transport rates and coastal erosion patterns (Toldo *et al*. 2003).

The lagoon has average length and width of 240 km and 40 km, respectively. It covers a surface of 10,000 km^2, nearly one third the area of the Coastal Plain of the state of Rio Grande do Sul (Fig. 1). The lagoon roughly runs NE-SW, with an average depth of almost 6 m, and mean tidal amplitude of 0.45 m. At its southern end, near Rio Grande city (Fig. 1), the only inlet of Lagoa dos Patos has a mean discharge of 4,800 m^3/s. Sea water penetrates northwards into the lagoon up to 200 km during exceptional conditions favored by southern winds, low water levels in the lagoon, and spring tides (Martins *et al*. 1989, Toldo 1989). The lagoon receives freshwater from about 170,000 km^2, mostly from the catchment basin of the Guaíba River system, whose mouth is located in Porto Alegre - the Jacuí Delta - at the northwestern end of the lagoon (Fig. 1).

The coastal plain bordering the lagoon typically has elevations that reach up to 6 m, mostly consisting of sandy deposits interrupted by small inlets (Delaney 1965). Such sandy marginal deposits from the lagoon are all related to four Quaternary transgressive events, which developed four depositional systems, mostly consisting of barriers and lagoons (Villwock *et al*. 1986).

Sand spits are the most important byproducts of the reworking process occurred during the Holocene. Those spits rise in average 1 m above the mean water level and on the west margin of the lagoon their submerged part extends about 15 km into the water body.

The lagoon has two distinct morphological and sedimentological bottom types. The first region is constituted by sandy and narrow margins, whereas the second, larger part is a muddy, nearly flat bottom, both separated by depths of five to six meters, which typically separate those two parts of the lagoon. On the west side of the lagoon the sandy margin has slopes of about 1/1500, whereas on its east side the slopes are much steeper, reaching 1/200. The evolution of four barrier-lagoon systems is believed to have formed the different slopes and general coastal plain morphology (Tomazelli *et al.* 2000, Toldo *et al.* 2000).

Early work by Instituto de Pesquisas Hidráulicas at Universidade Federal do Rio Grande do Sul – IPH / UFRGS on wind information from Project Lagoa dos Patos was summarized by Almeida *et al.* (1992). Wave prediction work based on such wind data was carried out by Centro de Estudos de Geologia Costeira e Oceânica (CECO) and was summarized by Toldo (1994).

2 – PREVIOUS STUDIES

Prior to 1988, wave data measurements on Lagoa dos Patos were generally associated with site-specific studies, and many of these were visual wave observations provided by commercial ships (Hertz 1977, Toldo 1989). In 1986, the IPH extended their wind and water level measurement program to the lagoon, obtaining continuous records through four stations fitted with anemometers and water level-gauges. The purpose of this program was to provide a comprehensive set of wind data from fixed locations. The first two stations were set up along the west side of the lagoon near the mainland, both 14 m above the ground. The two other stations were set up by the east side of the lagoon, close to its eastern edge, both 6 m above the ground (Fig. 1). Both anemographs were Will Lambrecht's type.

Wind measurements around the lagoon were done in a continuous mode from 1986 on, and the data acquired in 1988 have been selected for representing the best continuous data series, with wind data presented as the time-average velocity at a 1-hour interval. Records include station number, date, wind velocity and direction.

3 – HINDCAST PROCEDURE

Results from any hindcast numerical wave study rely heavily on the quality of the wind records used in the model. In addition to wind data quality, the length of the historical wind record is also an important consideration (Hubertz *et al.* 1991). The only data sources with sufficient recorded time for the present hindcasts are the wind measurements carried out by IPH / UFRGS at those four locations along the lagoon.

All wind data were first corrected to a 10-m elevation, by applying the standard 1/7th power law on the wind velocity profile, according to the Shore Protection Manual (1984):

$$U_{(10)} = U_{(Z)}\left(\frac{10}{Z}\right)^{\frac{1}{7}} \qquad (1)$$

where $\boldsymbol{U_{10}}$ estimates wind velocity at 10 m from the observed $\boldsymbol{U}$ at elevation $\boldsymbol{Z}$. The wind velocity measurement used in this calculation is the time-average velocity at 1-hour intervals, obtained from the anemogram.

A correction for differences in air-water temperature (R_T, equation 2) and corrections for the difference in frictional effects between land and water were applied to obtain the corrected wind velocity ($\boldsymbol{U}$). The correction for surface roughness employed was an approximation to a set of curves, developed by Resio & Vincent (1977), which relate the overland-overlake wind velocity ratio to air-water temperature differences and to the overland wind velocity.

$$U = R_T U_{(10)} \qquad (2)$$

Local topography effects (location effect) play no role in this calculation, as the wind velocity data come from the water side. Wave growth formulas are expressed in terms of a wind-stress factor, $\boldsymbol{U_A}$, and after the appropriate wind velocity conversions are made, wind velocity is converted to a wind-stress factor through the following formula, from the Shore Protection Manual (1984):

$$U_A = 0{,}71U^{1.23} \qquad (3)$$

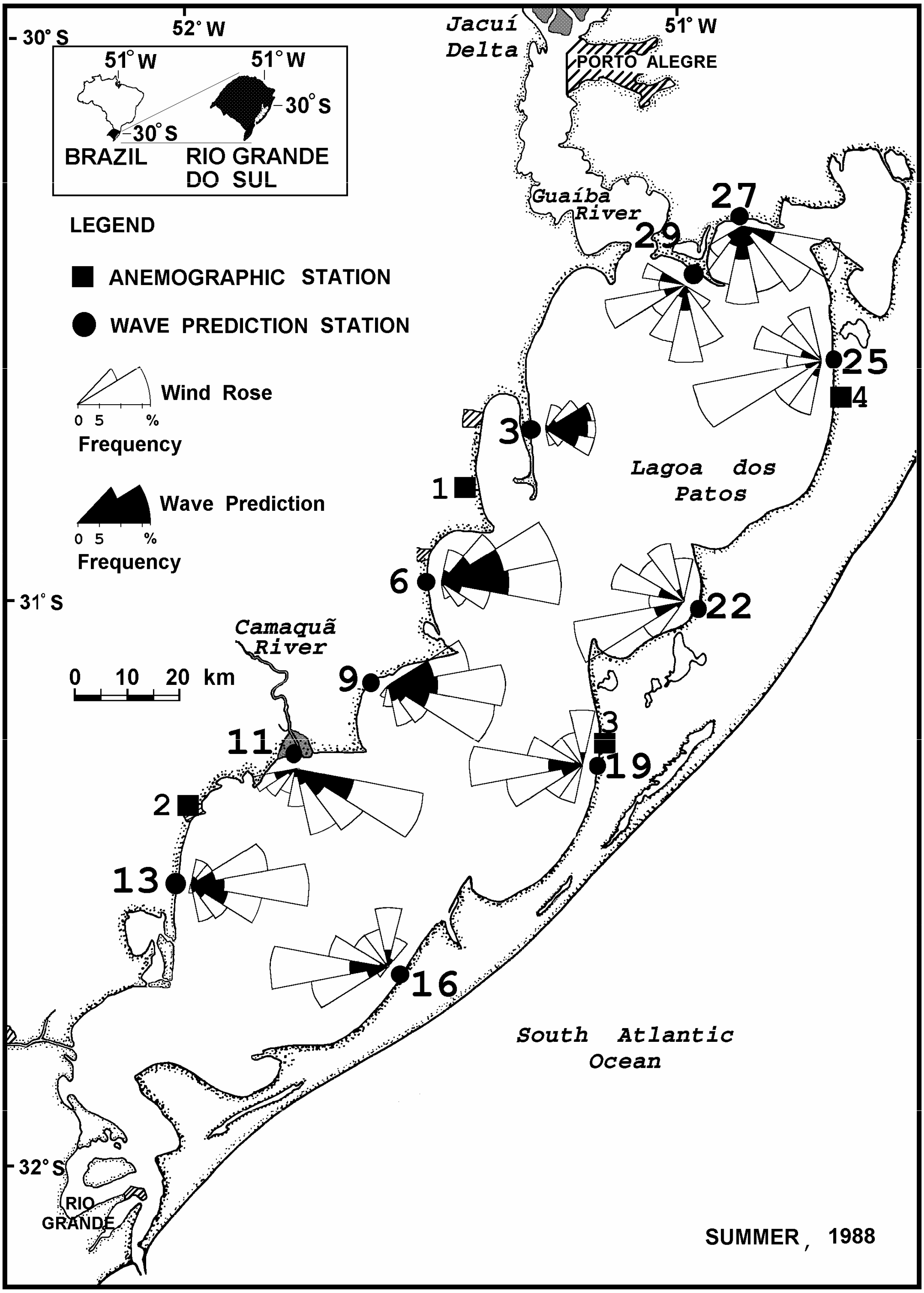

FIGURE 1 – Directional wind and wave frequency distribution, during the summer of 1988.

The wave model used in this study is described in the Shore Protection Manual (1984). All sea wave parameters, such as significant wave height, spectral peak frequency, and mean wave direction, were computed for each wave prediction station, at 1-hour intervals during 1988. The mean wave direction was assumed to be the same as the wind direction, for the waves under wind influence in the generating area. This decision is based on the proximity among the anemographic station and the wave prediction station, which reduces the difference between wind direction and wave direction. Also, for the same wind direction, situations presenting wind velocity variations up to 3 m/s were separately treated, in order to calculate wave growth.

Wave growth related to the fetch within the lagoon was also incorporated in the calculations (Shore Protection Manual, 1977). The fetch width effect in limiting wave growth was also applied in the wave generation routine, as the generated area is limited by the surrounding landforms.

The correlation between hindcast and measured wave parameters was verified during field work with the help of a measuring rod in a 1-m water depth near station 06 (Fig. 1). Readings were made during 5 minutes and repeated at a 1-hour interval during 10 hours, on 25th November, 1993. At this day, wind velocity direction and duration for wave generation remained steady for 4 hours. Winds blew from ESE, with mean velocity of 5 m/s in the first two hours and 7 m/s in the last two hours. Measures from the first two-hour interval indicated a significant wave height (H_s) of 0.43 m and period (T) of 2.9 s, whereas in the second interval, the measures were 0.55 m and 3.0 s, at a 1.09-m depth. Based on the wave-prediction method (Shore Protection Manual, 1984), respective values of 0.4 and 0.6 m (H_s), and 2.6 and 3.1 s (T) were calculated, being equivalent for the same depth. In sum, the numbers of wave height and period occurrences show good agreement between measured and calculated values, with low standard deviation, or ± 0.03, for wave height, and between 0.21-0.07 for the period. In his critical analysis of the wave prediction method proposed by the Shore Protection Manual, Bishop *et al.* (1992) observed similar wave results, with wave height values of less than 2 m and periods lower than 6 s.

4 – SUMMARY STATISTICS

The results of all wave studies produced by the above hindcasting method are summarized below. Five figures and one table were prepared in order to indicate the wave climate at each station for each season in 1988. Wave rose diagrams in Figures 1, 2, 3, and 4 qualitatively indicate the wind and wave direction frequency distribution for each wave prediction station around the lagoon. For a more specific analysis, the hindcasting wave parameters are presented in Table 1.

TABLE 1 – Seasonal mean significant wave parameters, along the coastline of Lagoa dos Patos, during 1988, where H_s = significant height (m), T = period (s).

Station		Summer		Autumn		Winter		Spring	
West side	East side	H_s	T	H_s	T	H_s	T	H_s	T
03		0.7	3.3	0.5	2.7	0.5	2.6	0.7	3.3
06		0.5	2.8	0.4	2.3	0.4	2.5	0.5	2.8
09		0.6	2.9	0.4	2.5	0.4	2.5	0.6	2.9
11		0.5	2.7	0.4	2.4	0.3	1.9	0.5	2.7
13		0.6	3.1	0.5	2.8	0.5	2.7	0.6	3.0
	16	0.4	2.5	0.5	2.9	0.5	2.9	0.5	2.8
	19	0.4	2.6	0.5	2.9	0.5	3.0	0.5	2.8
	22	0.3	2.2	0.6	3.1	0.5	2.6	0.6	2.8
	25	0.2	2.0	0.8	3.4	0.7	3.1	0.6	2.9
	27	0.4	2.3	0.4	2.4	0.4	2.3	0.5	2.6
	29	0.4	2.3	0.5	2.7	0.5	2.8	0.5	2.8

The weather of Rio Grande do Sul state in southern Brazil is highly seasonal and strongly related to the large scale pressure systems of the Polar Anticyclone in autumn and winter, and the Atlantic Anticyclone in summer and spring (Hasenack & Ferraro, 1989).

Spring and summer cover the period from October to March, with strong and consistent winds on the west side of the lagoon, and the surface wind blowing mainly

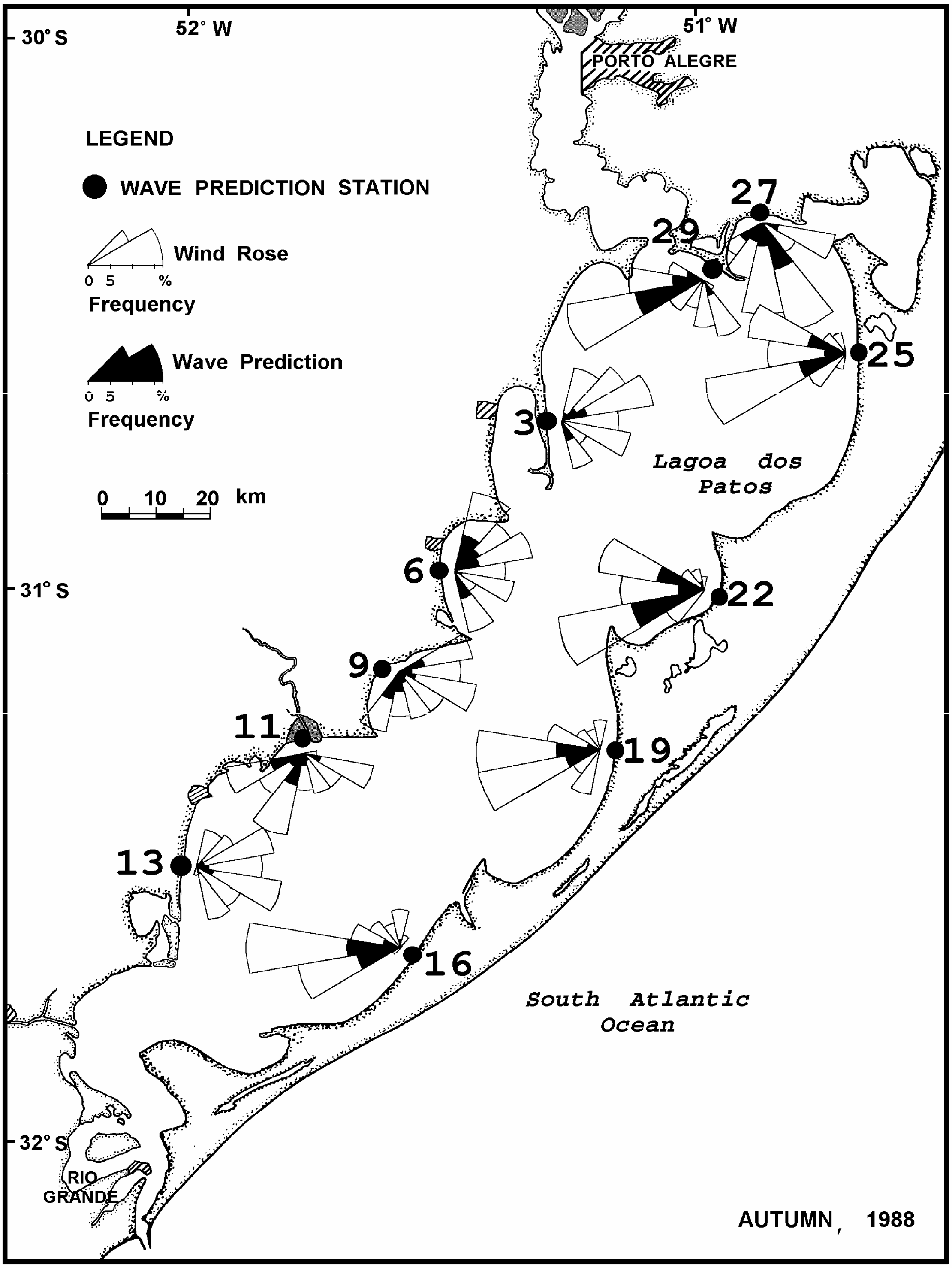

FIGURE 2 – Directional wind and wave frequency distribution, during the autumn of 1988.

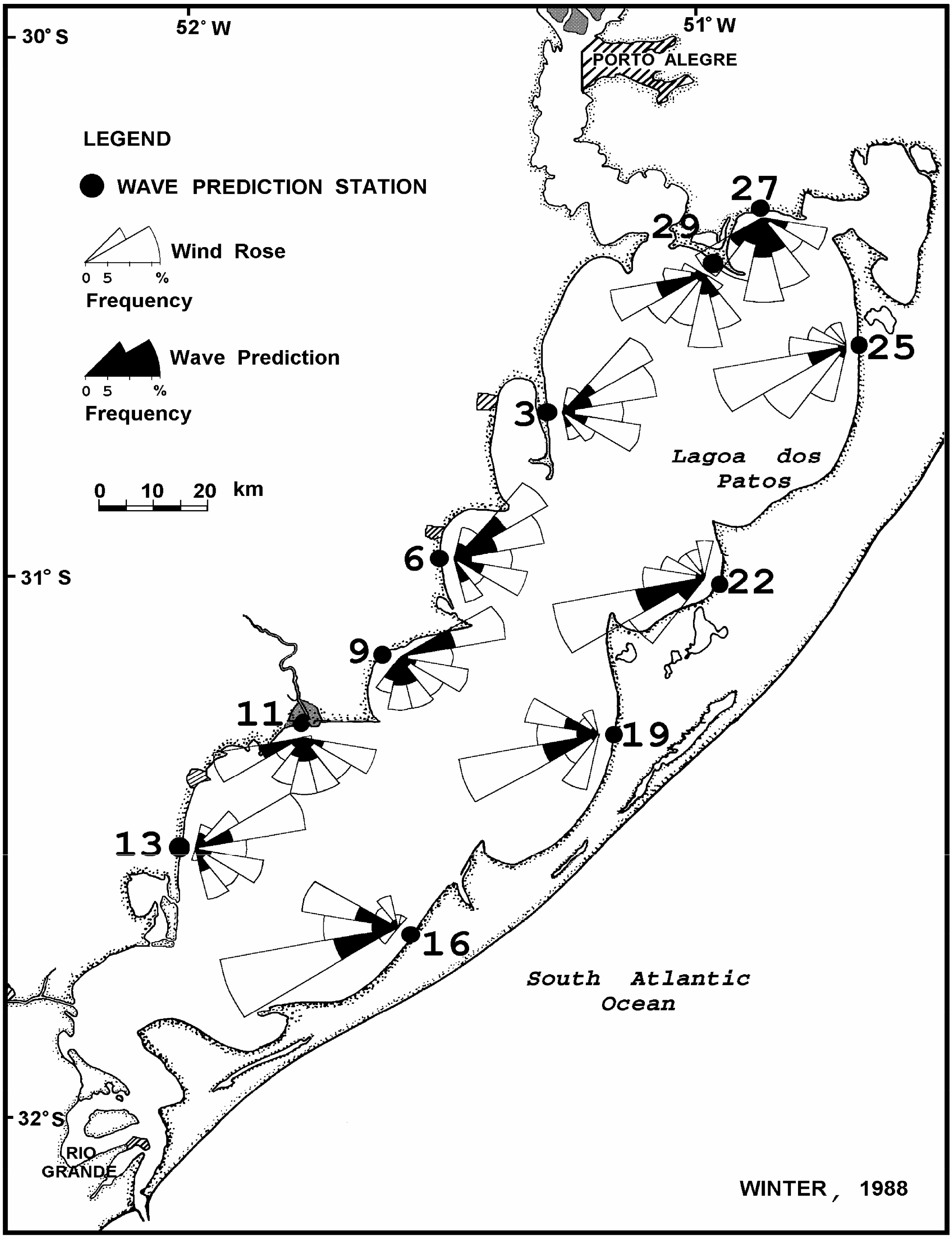

FIGURE 3 – Directional wind and wave frequency distribution, during the winter of 1988.

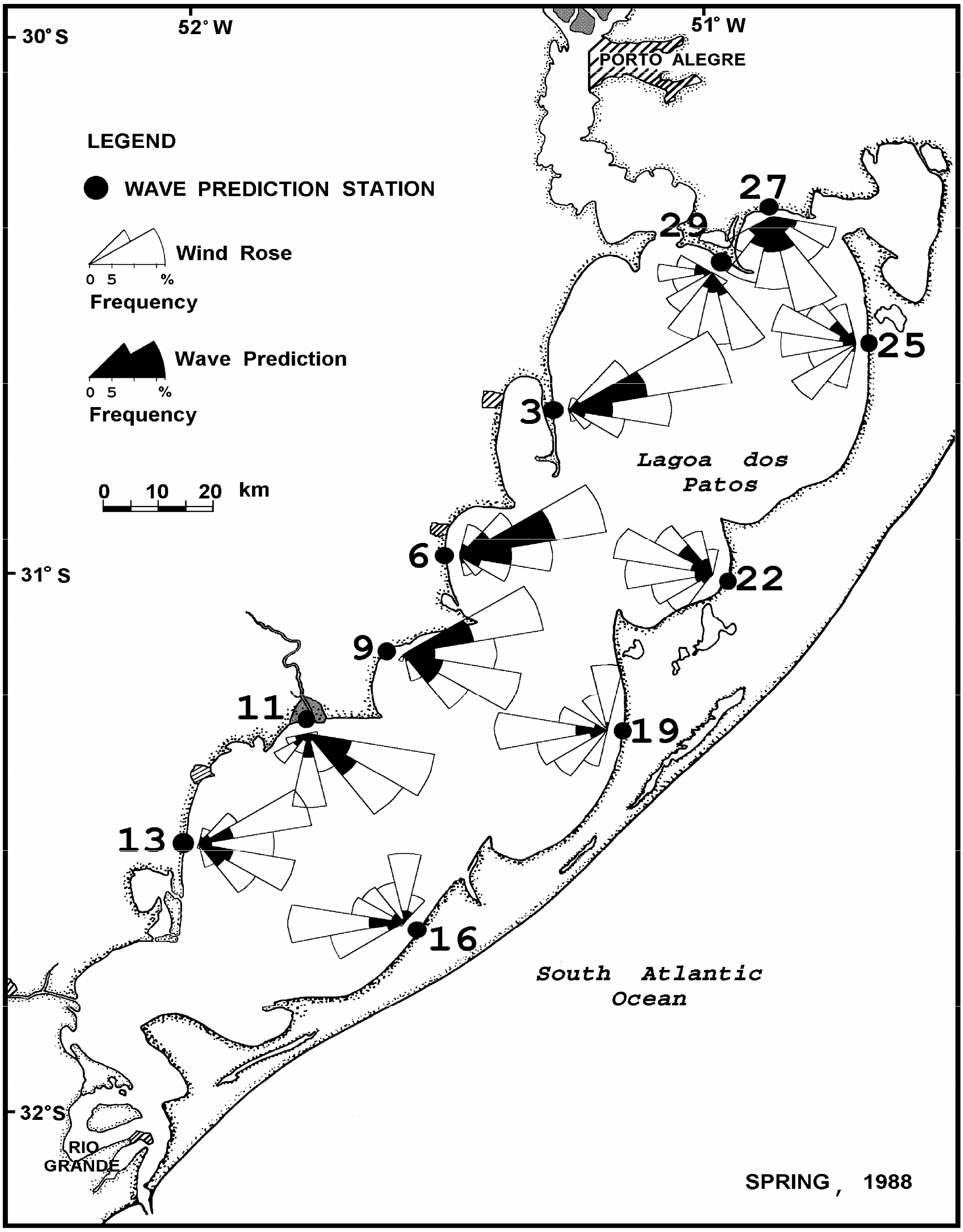

FIGURE 4 – Directional wind and wave frequency distribution, during the spring of 1988.

from the northeast and southeast (Fig. 1 and 4). The autumn and winter season extends from April to September. It is the period for the occurrence of the strong and consistent southwest and northwest winds over the east side of the lagoon, as observed by Tomazelli (1990) (Figs. 2 and 3).

Figures 1 to 4 show the frequency of wind measurement and wave prediction data. In the present study, wave data with height lower than 0.10 m has not been considered. Those figures show that most winds in the area are unable to generate waves greater than 0.10 m. On the west side of the lagoon, the sum of the hours with hindcasting waves during 1988 is lower than 91 days for each prediction station (Fig. 5). On the eastern, oceanic side, this sum is lower than 40 days. The dominance of weak winds with velocities between 0-2 m/s, and their short duration, which is lower than 2 hours, are the main controls limiting wave growth in the lagoon.

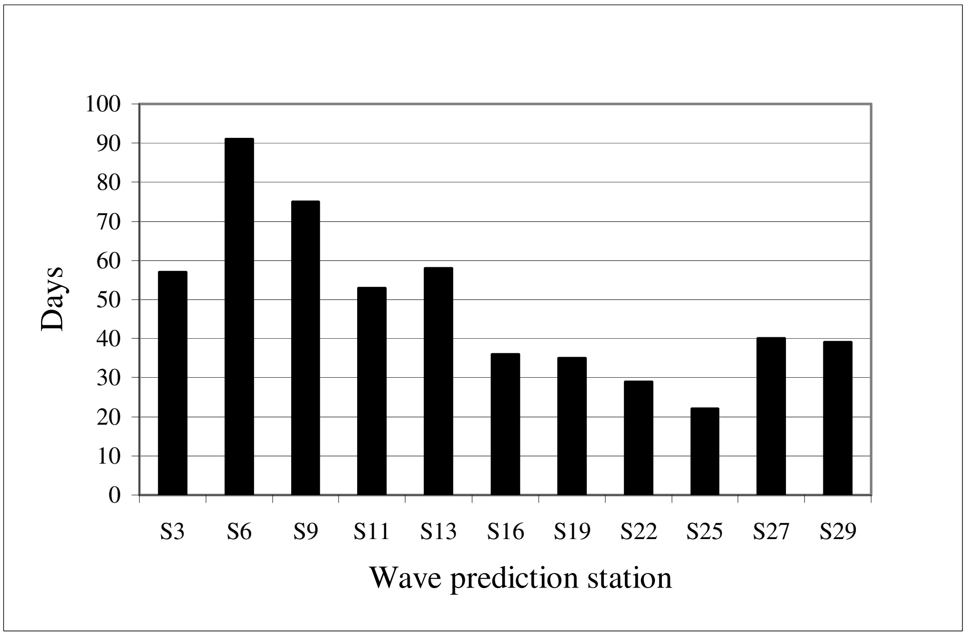

FIGURE 5 – Sum of hours with significant wave height prediction higher than 0.10 m, during 1988.

With steady winds, an energy versus frequency equilibrium is eventually reached for wave growth, but on the lagoon the wave energy growth and propagation is also limited by the shallow water and mainly by the unusual fetch characteristics of the lagoon, where the spits provide important limitations to wave growth. For example, after 1.5 hours, a 35-km fetch and wind-stress velocity of 28 m/s developed waves with height and period of 1.6 m and 4.8 s, respectively. This was the maximum wave value measured in the lagoon in 1988 and resulted from WNW windstorms over wave-prediction station 25 (Fig. 1) in autumn of that year.

Under strong wind conditions, wind-stress velocities of 14 m/s or more produce storms on the lagoon with modal significant wave height and period of 1.0 m and 4.0 s. The sum of hours with storms of such magnitude in 1988 amounts to 15 days.

Table 1 shows the period and height distribution for the seasonal prediction from 1988. On the west side of the lagoon, during summer and spring, the prediction stations showed high values, with a modal significant wave height between 0.5-0.7 m, and period between 2.7-3.3 s, respectively for stations 03 and 11. In contrast, in autumn and winter, modal significant wave height and period were lower at those stations, between 0.3-0.5 m, and 1.9-2.7 s, respectively. On the north side and east oceanic side those values are lower in summer and higher in autumn; i.e., prediction stations 25 and 27 showed modal significant wave height and period between 0.2-0.4 m and 2.0-2.3 s in summer, and between 0.4-0.8 m and 2.4-3.4 s in autumn, respectively.

5 – CONCLUSIONS

The following results were obtained from the study of the wave climate along the coastline of Lagoa dos Patos:

1) The hindcast study through wave parameter prediction yielded excellent results and was cost-effective.

2) The predominant wind direction over the landward west side of the lagoon in summer and spring is NE and SE, and on its seaward side in autumn and winter is NW and SW.

3) The largest calculated wave height was 1.6 m, with a period of 4.8 s, produced by a 28-m/s wind-stress. The number of hours with storms; i.e., wave height of 1.0 m or more within the lagoon amounts to 15 days/year.

4) For all five prediction stations on the west side of the lagoon, summer and spring show modal significant wave heights and periods of 0.5 and 0.7 m, and 2.7 and 3.3 s, respectively.

5) On the north and east side of the lagoon, typical modal significant wave heights and periods are between 0.2-0.4 m and between 2.0-2.6 s for the six prediction stations in summer, and 0.4-0.8 m and 2.4-3.4 s in autumn.

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