



## Comparative study between modeled (SWAN) and measured (waverider buoy) wave data in Patos Lagoon – RS, Brazil

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**Abstract.** This work presents the results of a statistical comparison between wave data measured with *Datawell Mark III* waverider buoy — moored in Patos Lagoon — and data predicted by the SWAN model for the same location during March 2015. The wave records were obtained for a point, with local depth of 6 meters, located at approximately 14 km from the *São Lourenço do Sul Yacht Club* pier. Using bathymetric data from the lagoon and wind data measured at the *Praticagem da Barra de Rio Grande* weather station, the generation and propagation of waves were simulated with the SWAN model. Through the statistical analysis of significant wave heights ( $H_s$ ), peak wave periods ( $T_p$ ) and peak wave directions ( $D_p$ ), it was verified that the model presents a good correlation with the *in situ* wave measurements, even though it has presented a general tendency of underestimating the measured data. Therefore, adjustment factors were determined for each variable in order to eliminate the model bias. It was concluded that the SWAN model is an integrated tool that is extremely valuable to this region as it yielded satisfactory results and, therefore, it can be used to make wave predictions in Patos Lagoon and provide important information to mariners. Furthermore, it can serve as a basis for several coastal engineering works.

**Keywords:** waves in Patos Lagoon, directional measurement of waves in Patos Lagoon, SWAN.

**Resumo.** Estudo comparativo entre dados de ondas modelados (SWAN) e dados de ondas medidos (waverider) na Lagoa dos Patos – RS, Brasil. Este trabalho apresenta os resultados de uma comparação estatística realizada entre dados de ondas medidos pelo ondógrafo *Waverider Datawell Mark III*, fundeado na Lagoa dos Patos, e dados preditos pelo modelo SWAN, para o mesmo local, durante o mês de março de 2015. Os registros de ondas foram obtidos para um ponto localizado a aproximadamente 14 km do cais do Iate Clube de São Lourenço do Sul, onde a profundidade local é de 6 metros. Utilizando dados batimétricos da laguna, extraídos de cartas náuticas, e dados de ventos medidos pela estação meteorológica da *Praticagem da Barra do Rio Grande*, simulou-se a geração e a propagação de ondas com o modelo SWAN. Através da análise estatística dos parâmetros de altura significativa ( $H_s$ ), período de pico ( $T_p$ ) e direção de pico ( $D_p$ ) das ondas verificou-se que o modelo apresenta boa correlação com as medições de ondas realizadas *in situ*, embora tenha apresentado uma tendência geral em subestimar os dados observados. Desta forma, foram determinados fatores de ajuste para cada variável com a finalidade de eliminar a tendenciosidade do modelo. Concluiu-se que o modelo SWAN é uma ferramenta integradora de extrema valia para esta região, pois proporcionou resultados satisfatórios e, desta forma, pode ser utilizado para realizar previsões de ondas na Lagoa dos Patos, fornecendo importantes informações aos navegantes e, ainda, servindo de subsídio a diversas obras de engenharia costeira.

**Palavras-chave:** ondas na Lagoa dos Patos, medição direcional de ondas na Lagoa dos Patos, SWAN.

## Introduction

The characterization of the wave climate in coastal environments, either oceanic or lagoon, is an extremely valuable tool for several oceanography and coastal engineering professionals as its knowledge is essential to the execution of projects for coastal works. According to Alfredini & Arasaki (2009), coastal protection works form a sheltered area against wind waves and/or counter currents, protect the coast from erosion and stabilize navigation channels in coastal river mouths.

Patos Lagoon (Figure 1) is the main water body of the MERCOSUL Waterway, and until this moment, studies about its wave regime are still scarce (Fontoura *et al.* 2015). Toldo *et al.* (2006) made the first wave predictions along the Patos Lagoon's west and east margins based on records of hourly wind intensity and direction data during 1988. Fischer & Calliari (2011) made wave height measurements on the *Saco do Laranjal* beaches (northwest coast of the lagoon) during March 2004 using a graduated ruler located at 0.50 meters deep. For the specific region of *Lago Guaíba*, Nicolodi (2013) validated a wave-generating model through the correlation with data obtained from a wave and current measurer (model *FSI3D* from *Falmouth Scientific*) that was moored next to *Jangadeiros* club in the southern zone of *Porto Alegre*, from June 16 until August 2, 2005, at approximately 3 meters depth. Lemke (2015) analyzed the first time series of wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) recorded in the lagoon water body (at about 14 km from *São Lourenço do Sul* coast) using a directional waverider buoy moored during the period from January 22 to July 1, 2015.

Numerous rivers and streams outflow in Patos Lagoon where navigational activities (either fishing or recreational) are performed. Thus, it is understood that knowing the wave regime in the region is necessary so wave predictions can be made (through computational modeling) when the active winds are known, and also for the execution of various coastal works projects, such as groins, jetties, marines and breakwaters.

Given the above, this work aims to evaluate the wave-generating SWAN model applied to Patos Lagoon by comparing its  $H_s$ ,  $T_p$  and  $D_p$  predictions with values measured by a waverider buoy. The SWAN model has been widely used in sheltered coastal regions. Moeini and Shahidi (2009) worked with wave parameters measured by three waverider buoys in Lake Erie (in the Canada-United States border) to validate a wave-generating model in the

region. Lin *et al.* (2002) applied the SWAN model to the Chesapeake Bay (United States). Van Gruijthuisen (1996) validated the SWAN model in Lake George (Australia) using wave parameters measured by waverider buoys.

*Description of the study area:* Patos Lagoon (Figure 1) is one of the largest lagoons in the South American coast, covering an area close to 10,000 km<sup>2</sup>, about 240 km in length and approximately 40 km of average width (Toldo *et al.* 2003). The amplitude of the astronomical tide is 0.45 meters (Martins *et al.* 1989). The major northern and central tributaries of Patos Lagoon are, respectively, Guaíba River and Camaquã River, with an average discharge of 2,000 m<sup>3</sup>.s<sup>-1</sup> (Möller *et al.* 2001). In the estuarine region, the *São Gonçalo* channel has an average discharge of 700 m<sup>3</sup>.s<sup>-1</sup> (Vaz 2006). In the Rio Grande channel, an access to the Atlantic Ocean, the average outflow is 4,800 m<sup>3</sup>.s<sup>-1</sup> (Toldo *et al.* 2006). The Patos Lagoon's hydrodynamics mainly depends on the relationship between wind and river discharge. The predominant wind directions correspond to the lagoon longitudinal axis direction (NE-SW). Prevailing NE winds result in a water level decrease in the north of the lagoon and an increase in the south. However, when SW winds prevail, a water level increase occurs in the north of the lagoon and a decrease occurs in the south (Möller *et al.* 2001). The wind regime can cause differences of up to 2 meters in the water level between the northern and southern extremities of the lagoon, creating currents that maintain the fine sedimentary material from rivers in suspension. Prevailing NE winds generate waves and currents responsible for the formation of bays and sand spits on the lagoon margins (Villwock & Tomazelli 2007). According to Zenkovitch (1959), the occurrence of bidirectional winds (NE and SW) parallel to the Patos Lagoon's longitudinal axis, the microtidal regime, and the sedimentary transport resultant from the refraction of obliquely incident waves are the major factors responsible for the formation of sand spits.

Patos Lagoon presents two distinct morphological and sedimentological regions, which are: the sandy margins of the lagoon and its muddy nearly flat interior. The isobath of 5 meters separates those two parts of the lagoon (Toldo 1991). On the west margin of the lagoon, the sediments are classified as poorly sorted and ranging in size from fine sand to gravel, while on the east margin the sediments are well sorted with predominance of fine sand. The west margin usually has slopes of

approximately 1/500, while on the east margin there are higher gradients of about 1/200 (Martins *et al.* 1989). The rivers that form the *Guaíba* Complex (*Jacuí*, *Taquari*, *Caí*, *Sinos* and *Gravataí*) are responsible for carrying fine sediments to the lagoon (Martins *et al.* 1989). In the Patos Lagoon's northern region, sands from granulometric classes of very coarse, coarse and medium are found, while on the west and east margins, fine sands are found. The predominance in the lagoon bottom is of silt, while clay is mostly found in the southern region (Toldo 1994 *apud* Calliari *et al.* 2008).

Patos Lagoon is located between the 30° S and 32° 15' S parallels and the 50° 30' W and 52° 15' W meridians (Figure 1), being connected to the Atlantic Ocean through the *Rio Grande* channel (Vinzon *et al.*, 2009). It develops parallel to the Rio Grande do Sul coastline (NE-SW general orientation) and is mostly protected from the Atlantic Ocean waters by a sandy-barrier system (Toldo 1991). Due to having

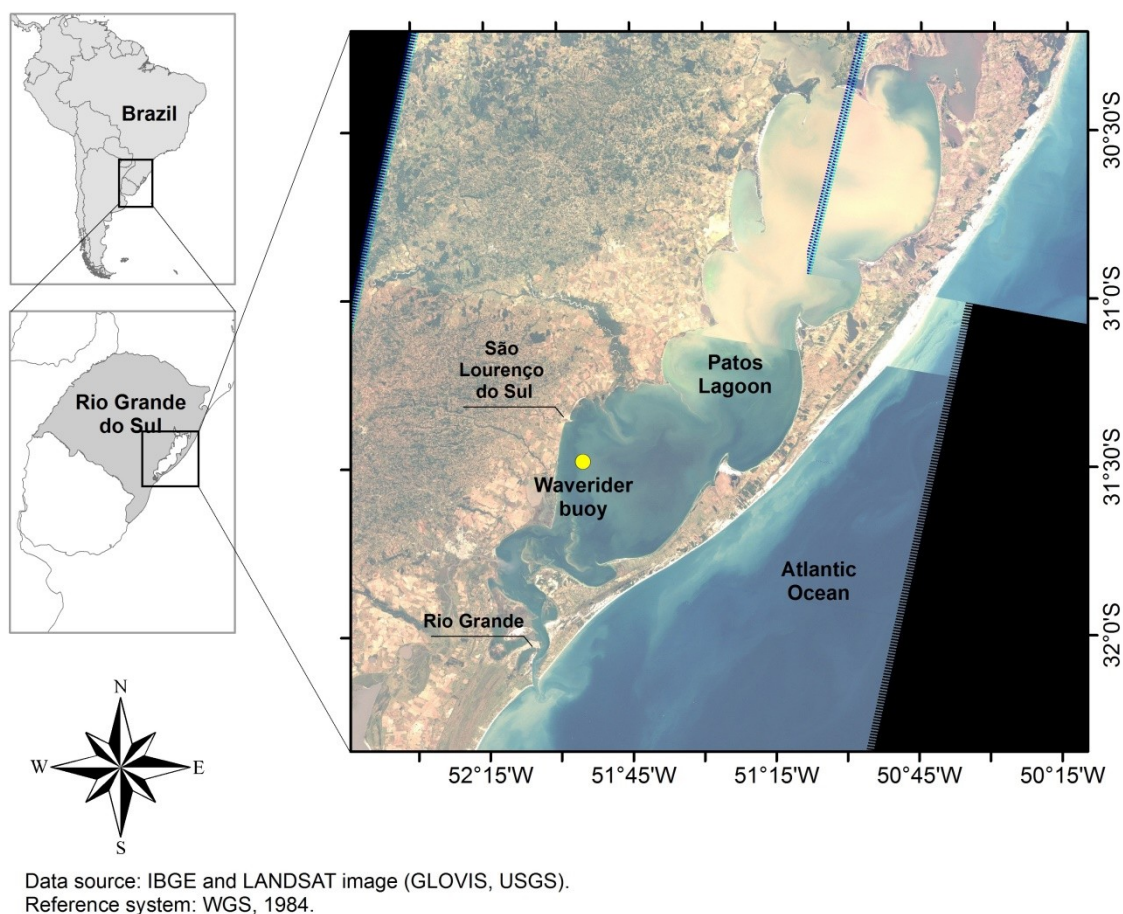
an average depth of 5 meters, it is classified as a shallow-water lagoon (Möller *et al.* 1996).

### Materials and Methods

This section presents the study area general characteristics and describes the methodology steps. This study methodology comprises the wave parameters' acquisition, wave modeling and statistical analysis.

*Wave parameters' acquisition:* Unprecedented records of the characterization of waves in Patos Lagoon were acquired using a *Datawell Mark III* waverider buoy moored at a distance of approximately 14 km from the São Lourenço do Sul coast, at 31° 29' S and 51° 55' W (Figure 1). The directional waverider buoy used in this study belongs to FURG via the "Rede Ondas (Rede de Monitoramento de Ondas em Águas Rasas)" project of the *Interministerial Commission for the Sea Resources*.

### WAVERIDER LOCATION



**Figure 1.** Study area, Patos Lagoon, Rio Grande do Sul, Brazil. Waverider buoy mooring location (yellow dot) at approximately 14 km from São Lourenço do Sul, where the local depth is 6 meters.

The equipment was moored in the lagoon during the period January 22 to July 1, 2015, recording wave height, period and direction, water temperature and geographic position. The raw and spectral data transmission was through a radio antenna positioned at the top of the waverider buoy to a receiving station at *FURG – Campus São Lourenço do Sul*, and then via Internet to *FURG – Rio Grande*. Wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) were released in real time at <http://www.redeondas.furg.br>. More detailed information about the waverider buoy acquisition, installation and operation can be found in Fontoura *et al.* (2015) and Lemke (2015).

**Wave modeling:** To simulate the wave generation and propagation in Patos Lagoon, the SWAN (*Simulating Waves Nearshore*) model was used, developed at TUDelft (Delft University of Technology), Netherlands. A rectangular grid was created with a spatial resolution of 500 meters, with 108,741 nodes in total. The bathymetric data provided to SWAN were extracted through the digitization of the nautical charts available at the *Directorate of Hydrography and Navigation of the Brazilian Navy (DHN)* website, but also through a bathymetric survey performed in the São Lourenço do Sul bay using a *Lowrance®* echosounder (LCX-19C model). It had double frequency (200/50 kHz) and a vertical precision of the order of centimeters.

To perform the wave modeling, in addition to knowing the detailed bathymetry from the study area, it is also necessary to determine the prevailing winds' regime. Lemke (2015) conducted a detailed study on the active winds in Patos Lagoon and concluded that there is no significant spatial variations in the wind intensity and direction in the region covered by the lagoon. It was verified through the linear correlation among the *European Centre for Medium-Range Weather Forecasts (ECMWF)* reanalysis wind data from different points over Patos Lagoon. Thus, to perform the wave modeling in Patos Lagoon through SWAN, hourly wind time series from March 2015 were used. They were measured at the *Praticagem da Barra do Rio Grande* weather station at 25 meters high and converted to 10 meters high according to Equation 1 (U. S. Army Corps of Engineers 1984),  $z$  equals the height where the measurements were made (25 m) and  $u_z$  equals the wind speed intensity at this height 'z'.

$$u_{(10)} = u_z \left( \frac{10}{z} \right)^{1/7} \quad (1)$$

Through computational modeling, the wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) were simulated for the location of the waverider buoy mooring (31° 29' S and 51° 55' W) in order to carry out a statistical comparison between the measured and modeled data.

The following physical processes were activated in the SWAN model: depth-induced breaking, non-linear triad, bottom friction, wind growth whitecapping, refraction and frequency shift. Parameter default values were used to represent such processes in the model. On the other hand, the wind shear coefficient ( $C_D$ ) over the water surface was determined through the parametrization according to Wu (1982), where  $W_{10}$  is the wind speed at 10 meters high (Equation 2):

$$C_D = (0.80 + 0.065 W_{10}) \times 10^{-3} \quad (2)$$

**Statistical analysis:** The significant wave height, peak period and peak direction time series, not only measured but also modeled during March 2015, were analyzed based on statistical calculations available in the literature (Melo *et al.* 2008, Lalbeharry 2001, Aguiar 2014). Due to some technical failures that occurred in the reception of the data emitted by the waverider buoy during January and February, and also due to wind data unavailability as from April, it was decided to perform the statistical analysis between measured and modeled wave data only for March 2015. The parameters indicated in Table I were evaluated with their respective equations, where  $m$  indicates the model results,  $o$  the measurements (or observations) and  $N$  the data number.

According to Melo *et al.* (2008), the bias ( $V$ ) measures the average deviation between the model results and measurements; if it is positive, the model tends to overvalue the measurements; if it is negative, the model tends to undervalue the measurements. On the other hand, the relative bias ( $V_{rel}$ ) presents the bias as a fraction of the observed mean value. The scatter index ( $SI$ ) measures the degree of confidence that the model can present (in the literature, it is recommended that this variable is placed within the 30% range at maximum). The symmetric slope ( $SS$ ) considers that none of the data sets (modeled and measured) is "perfect", but equally contribute to the error. The ideal situation occurs when  $SS = 1$ ; otherwise, the model will be underestimating or overestimating the observed values.

**Table I.** Analyzed statistical parameters and equations.

| Parameter                                 | Mathematical Expression                                     |
|-------------------------------------------|-------------------------------------------------------------|
| Averaged measured data ( $\bar{o}$ )      | $\bar{o} = \frac{\sum_{i=1}^N o_i}{N}$                      |
| Measurements standard deviation ( $S_o$ ) | $S_o = \sqrt{\frac{\sum_{i=1}^N (o_i - \bar{o})^2}{N}}$     |
| Averaged modeled data ( $\bar{m}$ )       | $\bar{m} = \frac{\sum_{i=1}^N m_i}{N}$                      |
| Modeled data standard deviation ( $S_m$ ) | $S_m = \sqrt{\frac{\sum_{i=1}^N (m_i - \bar{m})^2}{N}}$     |
| Bias ( $V$ )                              | $V = \bar{m} - \bar{o}$                                     |
| Relative bias ( $V_{rel}$ )               | $V_{rel} = \frac{V}{\bar{o}}$                               |
| Root Mean Square Error ( $RMSE$ )         | $RMSE = \sqrt{\frac{\sum_{i=1}^N (m_i - o_i)^2}{N}}$        |
| Scatter Index ( $SI$ )                    | $SI = \frac{RMSE}{\bar{o}}$                                 |
| Symmetric Slope ( $SS$ )                  | $SS = \sqrt{\frac{\sum_{i=1}^N m_i^2}{\sum_{i=1}^N o_i^2}}$ |

Thereafter, the methodology developed by Melo *et al.* (2010) was used, which aims to eliminate the model bias by considering that  $V$  is equaled to zero. To do so, the model results must be multiplied by the adjustment factor (  $\alpha$  ), according to Equation (3):

$$\alpha = \frac{\bar{o}}{\bar{m}} \quad (3)$$

In this way, the adjustment factors (  $\alpha$  ) were calculated for each variable (significant height, peak period and peak direction).

## Results

This section presents the findings obtained in this study. The following results from the measured and simulated wave parameters are presented.

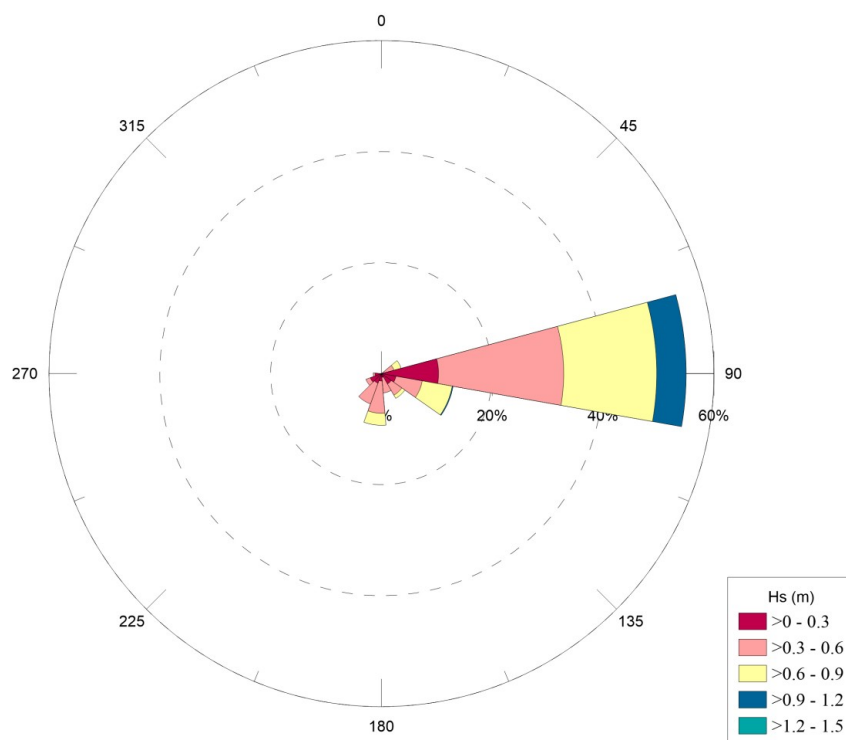
**Measured wave parameters:** Figure 2 shows the wave rose diagram for the significant wave height according to the peak wave direction (waverider buoy recorded data). Figure 3 illustrates the wave rose diagram for the peak wave period according to the peak wave direction (waverider buoy recorded data).

According to Figure 2, it can be verified that waves with  $H_s$  between 0.30 and 0.60 meters and east peak direction occurred more frequently during

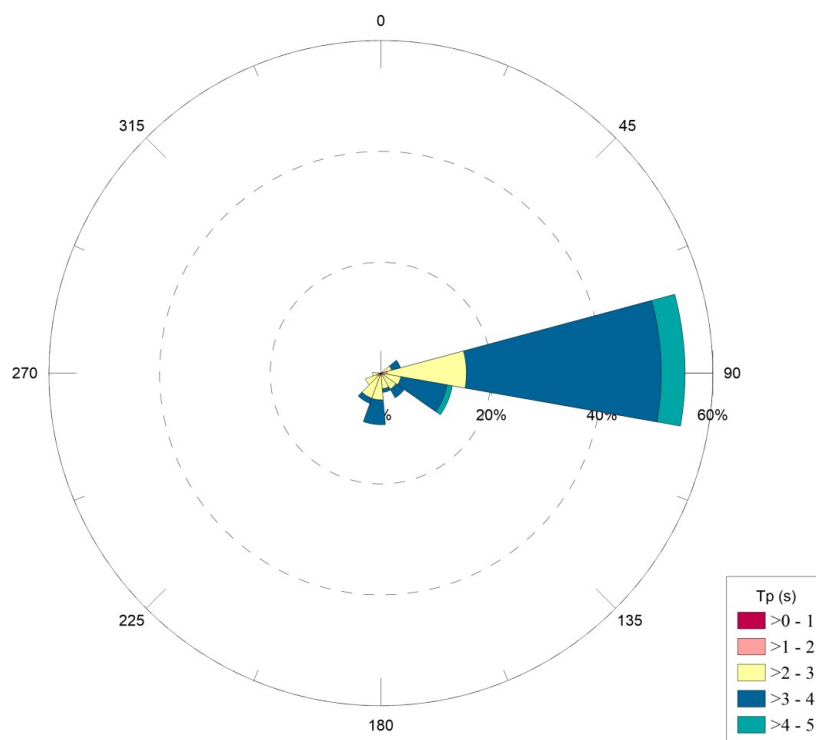
March 2015, totaling 19.9% of the cases. It can also be observed that there is a large occurrence of waves with  $H_s$  between 0.60 and 0.90 meters (17%) and up to 0.30 meters (9.55%) also with east peak direction.

According to Figure 3, it was found that waves with a peak period between 3 and 4 seconds

and an east peak direction propagated more frequently (29.4%) during March 2015. A large occurrence of waves with a peak period between 2 and 3 seconds (12.8%) and an east peak direction is also noted.



**Figure 2.** Wave rose diagram for the significant wave height (waverider buoy recorded data). Period: March 2015.



**Figure 3.** Wave rose diagram for the peak wave period (waverider buoy recorded data). Period: March 2015.

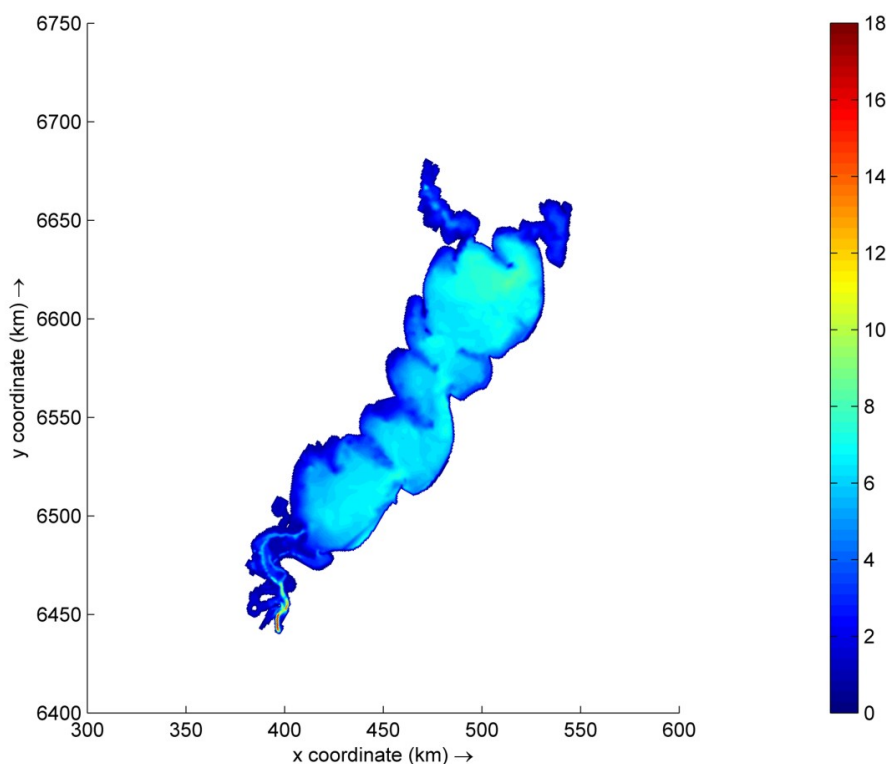
**Simulated wave parameters:** Figure 4 illustrates the bathymetric map from Patos Lagoon resulting from the triangular interpolation applied to the depth data of the region. The Delft3D software was used.

Figures 5 and 6 show the significant wave heights with peak directions and peak periods obtained from SWAN, respectively, correspondent to 2h55min p.m. on March 28, 2015. On this date and time, the waverider buoy recorded values of 0.55 m, 3.13 s and 196.9° simultaneously for  $H_s$ ,  $T_p$  and  $D_p$ . For the same time, the SWAN model provided values of 0.42 m, 2.23 s and 192.35° for the correspondent wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) at the waverider buoy location point, satisfactorily representing the measured data, but with a tendency to underestimate waverider buoy measurements. It can also be observed that prevailing ENE winds, during this time, resulted in wave refraction on the Patos Lagoon's west bank.

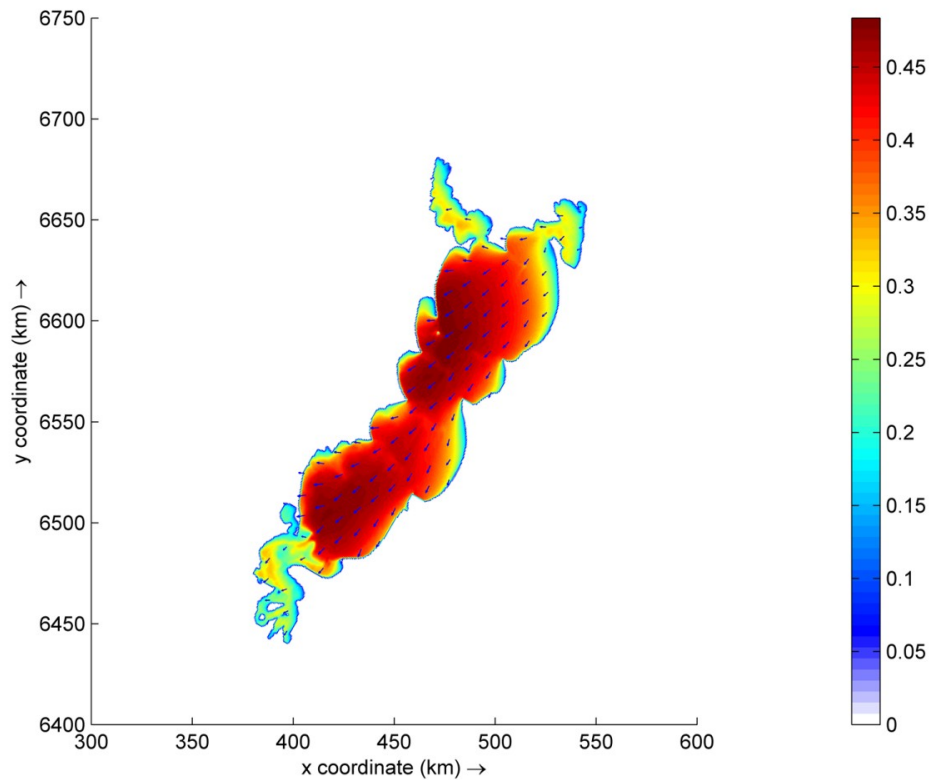
Figure 7 shows the time series of the wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) measured by the waverider buoy and generated by the SWAN model in Patos Lagoon during March, 2015. In general, it is observed that the model satisfactorily reproduced the measured parameters. The statistical analysis results between the measured values by the waverider buoy

( $\hat{m}$ ) and the generated data by the SWAN model ( $\hat{m}$ ) are shown in Table II, where it is noted that the model presented a satisfactory performance for the three analyzed wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ). The mean values of significant wave height, peak period and peak direction were, respectively, 0.50 m, 2.45 s and 75.83° for the model, and 0.57 m, 3.33 s and 105.75° for the waverider buoy measured data. It is also observed that the scatter index ( $SI$ ) is close to the 30% range, indicating the model reliability. However, the values found for the bias ( $V$ ) and the symmetric slope ( $SS$ ) indicate a tendency of the model to underestimate the data measured by the waverider buoy not only for  $H_s$ , but also for  $T_p$  and  $D_p$ .

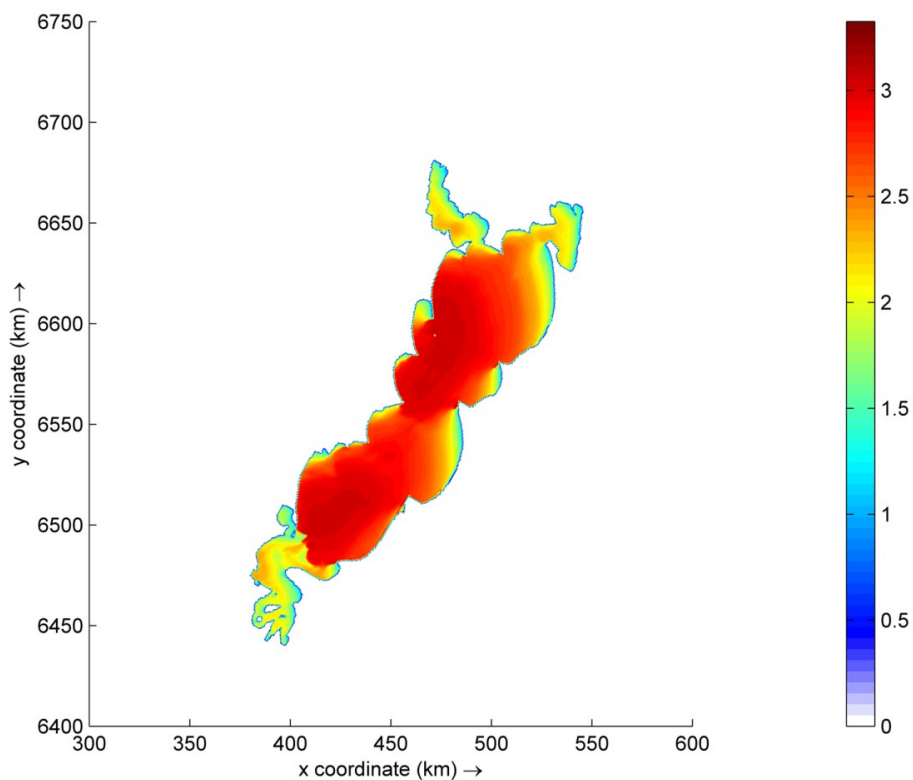
The graphs presented in Figure 8 correspond to the scatter plots between the data generated through SWAN ('x' axis) and the data measured by the waverider buoy ('y' axis) respectively for significant wave height, peak period and peak direction. The 45° dashed line defines the "perfect" adjustment. The continuous line represents the symmetric slope ( $SS$ ) passing through the origin. It can be noted that the  $SS$  values are close to one for the three analyzed parameters ( $H_s$ ,  $T_p$  and  $D_p$ ), indicating a satisfactory correlation between modeled and measured data.



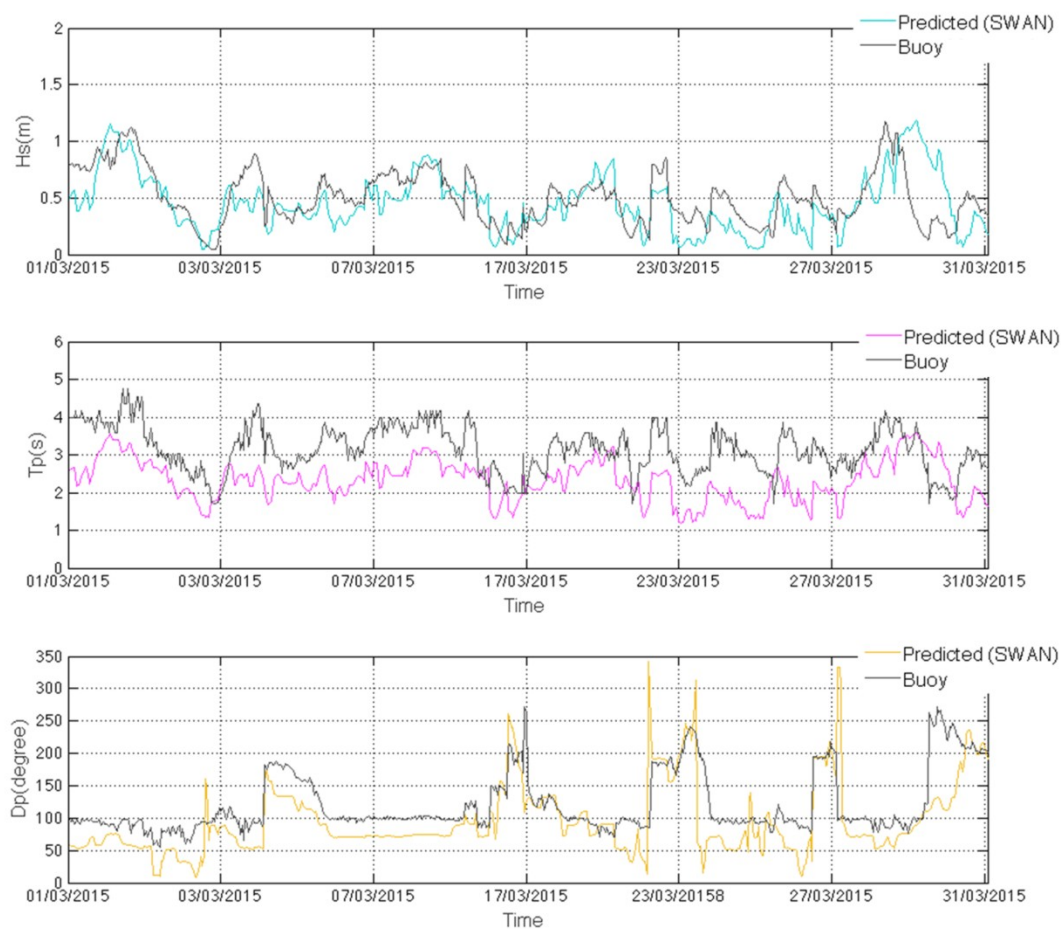
**Figure 4.** Patos Lagoon's bathymetry map. Legend in meters. UTM metric coordinates. Red dots represent the greatest depths, while dark blue dots represent the shallowest depths.



**Figure 5.** Significant wave height and peak direction (vectors) in Patos Lagoon resulting from the SWAN model. Correspondent to 2h55min p.m. on March 28, 2015. Legend in meters. UTM metric coordinates.



**Figure 6.** Peak wave period in Patos Lagoon resulting from the SWAN model. Correspondent to 2h55min p.m. on March 28, 2015. Legend in seconds. UTM metric coordinates.



**Figure 7.** Time series: significant wave height, peak period and peak direction. Period: March 2015.

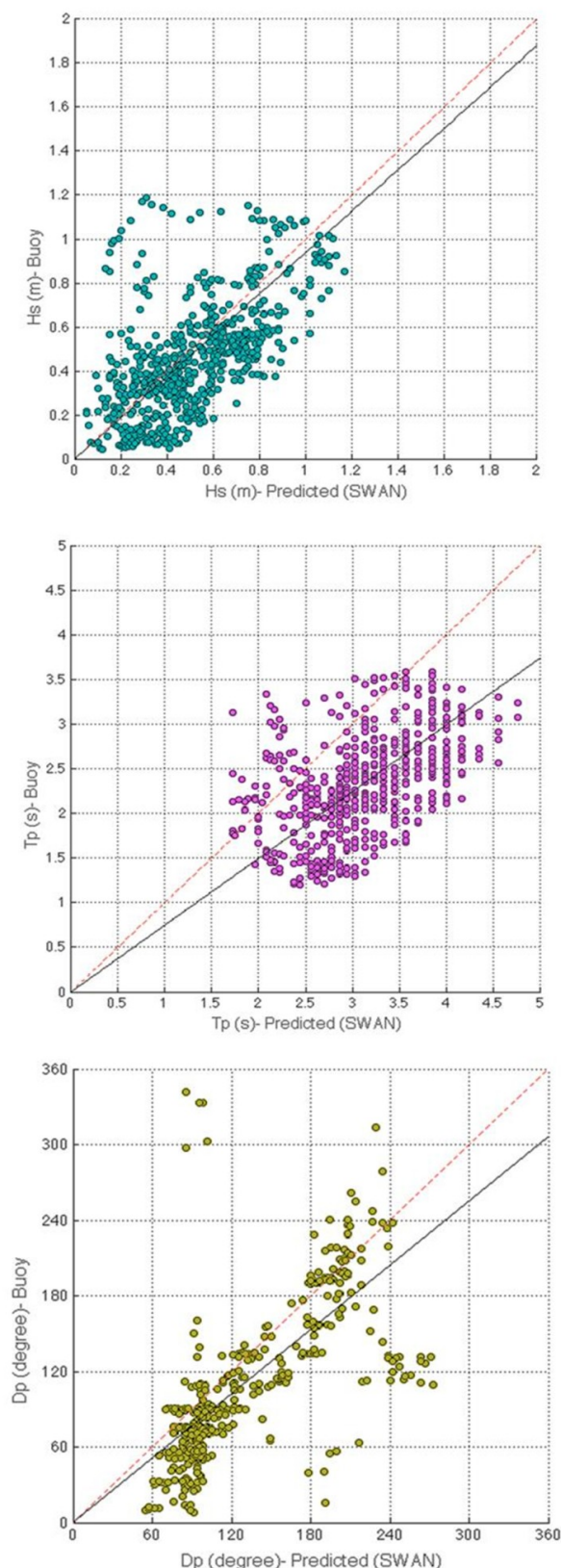
**Table II.** Statistical analysis' results for the wave parameters.

| Parameter | $\hat{o}$ | $\hat{m}$ | V       | RMSE   | SI   | SS   | $\alpha$ |
|-----------|-----------|-----------|---------|--------|------|------|----------|
|           | Measured  | modeled   |         |        |      |      |          |
| $H_s$     | 0.57m     | 0.50 m    | -0.07m  | 0.18 m | 0.31 | 0.89 | 1.14     |
| $T_p$     | 3.33 s    | 2.45 s    | -0.79 s | 1.01 s | 0.30 | 0.78 | 1.36     |
| $D_p$     | 105.75°   | 75.83°    | -21.46° | 36.79° | 0.34 | 0.83 | 1.39     |

In order to eliminate the  $V$  or model bias from the parameters' ( $H_s$ ,  $T_p$  and  $D_p$ ) prediction, the adjustment factors ( $\alpha$ ) for each variable were determined, which are 1.14 for significant wave height, 1.36 for peak period and 1.39 for peak direction. Thus, when multiplying the variables generated by SWAN by their respective adjustment factors, the symmetric slope (SS) values will be equaled to one, which indicates that, on average, the model reproduces the measurements.

## Discussion

This study holds great importance for scientific research aimed at characterizing the wave regime in Patos Lagoon because the findings obtained by the SWAN model were assessed with wave data measured by the first directional waverider buoy moored in the lagoon water body. Until the present date, no other studies have been carried out concerning the application of wave generation and propagation models in the Patos Lagoon main water body that have been adjusted with wave data measured by specific equipment. The discussions are still very limited regarding the



**Figure 8.** Scatter plots for significant wave heights, peak period and peak direction. Period: March 2015. Continuous line: symmetric slope (SS). Dashed line: drawn at 45° (only for reference).

SWAN model application specifically in the study area (Patos Lagoon); therefore, the results from the wave modeling presented in this study will be compared to similar works conducted in other shallow-water lagoons. Furthermore, specifically for the wave data acquired by the waverider buoy, discussions will be based on the results obtained by Toldo *et al.* (2006) on Patos Lagoon's wave prediction.

Toldo *et al.* (2006) obtained mean values of significant wave heights and periods for a point located on the Patos Lagoon's west margin (very close to São Lourenço do Sul), which are, respectively: 0.6 m and 3.1 s during summer; 0.5 m and 2.8 s during fall; 0.5 m and 2.7 s in the winter; and 0.6 m and 3.0 s in the spring. The comparison between wave data measured by the waverider buoy and the predictions from Toldo *et al.* (2006) are made only for the summer and fall as the equipment operation period in the lagoon (January 22 to July 1, 2015) mostly corresponds to these seasons. The mean values of significant wave height, peak period and peak direction measured by the waverider buoy were, respectively: 0.5 m, 3.2 s and 119° during the summer; and 0.36, 2.7 s and 137° during fall. From these presented data, it can be inferred that the mean values of significant wave height and period determined by Toldo *et al.* (2006) are very close to those parameters measured by the waverider buoy. It is also noted that the mean values of significant wave height (0.6 m) and period (3.1 s) obtained by Toldo *et al.* (2006) for the summer are also very similar to the wave parameters measured by the waverider buoy in March 2015 (this study period), which are 0.57 m for  $H_s$  and 3.33 s for  $T_p$ . Regarding waves direction, Toldo *et al.* (2006) established the same active wind directions in the region. However, Lemke (2015) verified the linear correlation between wind directions data measured at "Praticagem da Barra do Rio Grande" weather station and peak wave directions measured by the waverider buoy, noting the occurrence of wave refraction in Patos Lagoon. Although the location of the comparison point between the waves parameters obtained by Toldo *et al.* (2006) is not exactly the same location of the waverider buoy mooring, the  $H_s$  and  $T_p$  results found through different methodologies are very similar.

The wave parameters measured by the waverider buoy in Patos Lagoon in 2015 represent a major breakthrough for developing the characterization of wave climate in this environment. Besides consisting of unprecedented

measured data in the lagoon water body, they also constitute a real basis for calibrating numerical models of wave generation and propagation. In this study, through the statistical comparison between the wave data measured by the waverider buoy and the wave data simulated with SWAN, it was verified that the model presented a tendency of underestimating the wave parameters recorded by the waverider buoy, not only for significant wave height, but also for peak period and direction. However, as the scatter index (SI) and symmetric slope (SS) statistical results are within an acceptable margin according to the literature, it implies that SWAN presented a good performance when applied to Patos Lagoon.

Studies with the application of the SWAN model have been conducted for several sheltered environments. Nicolodi (2007) validated the SWAN model for *Lago Guaíba (Rio Grande do Sul, Brazil)* and noted that the less accurate results occurred for the peak wave period parameter and the largest discrepancies in significant wave height values appeared when the wind intensities weakened followed by a direction shift from the south to west. The referred author discusses that these divergences might have occurred due to SWAN time-delayed response to wind variations and the consequent appearance of waves in sheltered environments.

Lin *et al.* (2002) and Moeini & Shahidi (2009) applied the SWAN model to the Chesapeake Bay (United States) and the Lake Erie and observed the model tendency of overestimating significant wave height data and underestimating peak wave period, respectively. Van Gruijthuisen (1996) validated the SWAN model in Lake George (Australia) through the comparison of wave data measured at eight stations arranged along the lake. Several tests with different values for the physical processes' parameters were conducted with SWAN in order to find the best fit for significant wave heights of waves measured at stations. The averaged relative absolute error for significant wave heights was used to select the best fit. This error was 0.16 in the test with the model's default configuration, while it was 0.06 in the test with the best result.

In general, the SWAN model is a widely used tool to simulate wave regime in sheltered environments, even though it presents a bias between the model results and the measurements. In this study, the tendency presented by SWAN to underestimate the wave parameters ( $H_s$ ,  $T_p$  and  $D_p$ ) can be explained by the fact that the wind data assigned to the numerical model correspond to the

minimum intensities recorded at each hour interval. It is also important to highlight that the values assigned to the parameters of each physical process activated in the model correspond to the model defaults.

Therefore, the importance of continuing this study should be stressed, hereafter working with mean wind intensities and other coefficients for the physical processes' parameters until a result that best represents the wave regime in Patos Lagoon is obtained. By minimizing the bias, the aim is to make the symmetric slope (SS) even closer to one.

## Conclusions

The comparative analysis between the wave parameters obtained through the model and the waverider buoy measured data showed, in general, a good performance of the SWAN model. It is emphasized that the model presented a tendency of underestimating the waverider buoy measurements, not only for the significant wave height, but also for the peak period and peak direction. However, this bias is eliminated when multiplying the model results by the respective adjustment factors of each variable. Therefore, it is concluded that the SWAN model can be applied to Patos Lagoon with reliable results. Experiments that aim to find adjustments for the simulated physical processes' parameters can aid to achieve more accurate results. Therefore, further research is needed to apply the calibration in a more broadly way for the entire waverider mooring period, including investigating other coefficients for the physical processes' parameters for this area, thus improving the wave modeled results presented in this study.

Aiming at collaborating with the research on the characterization of Patos Lagoon's wave regime, this work innovates with respect to the wave modeling in the region, since the model used was adjusted with real and reliable measured data. Thus, it becomes possible to determine wave parameters (significant wave height, peak period and peak direction) that are essential for coastal engineering and naval construction projects. Furthermore, this study provides useful information on making wave predictions when the wind forecasts are known, significantly contributing to the aspects linked to navigation in the region.

## Acknowledgements

The research group "Rede Ondas" from the *Interministerial Commission for the Sea Resources*

for operating the first directional waverider buoy mooring in Patos Lagoon.

The research groups from FURG, LEC (Coastal Engineering Laboratory) and LOG (Geological Oceanography Laboratory), for the campaigns.

“Praticagem da Barra do Rio Grande” for the wind data.

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Received: November 2016

Accepted: February 2017

Published: April 2017