COMPARATIVE ANALYSIS OF THE SWAN NUMERICAL MODEL PREDICTIONS AND OF THE PRESSURE SENSOR MEASUREMENTS AT THE ILHA SOLTEIRA LAKE

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Abstract

The Ilha Solteira dam reservoir, which has an extension of 100 km, is located in the northwest of São Paulo state, Brazil. Due to its huge dimension, wind generated waves can cause problems to the navigation security, to the stability of the river banks, to the infrastructures around the reservoir or even to public safety. In 2010/2011, a field data campaign was undertaken in order to measure the wave height and wind velocity. The bottom profile and wind velocity were used on the SWAN (Simulating Waves Nearshore) to predict the wave height. From the obtained results it can be said that the prediction from the numerical model presents similarities with the experimental ones.

1. Introduction

The Ilha Solteira dam reservoir, which has an extension of 100 km, is located in the northwest of São Paulo state, Brazil, Figure 1. As most reservoirs in the São Paulo state, it has multiple uses and it is part of the country waterways where important commercial navigation routes are established.

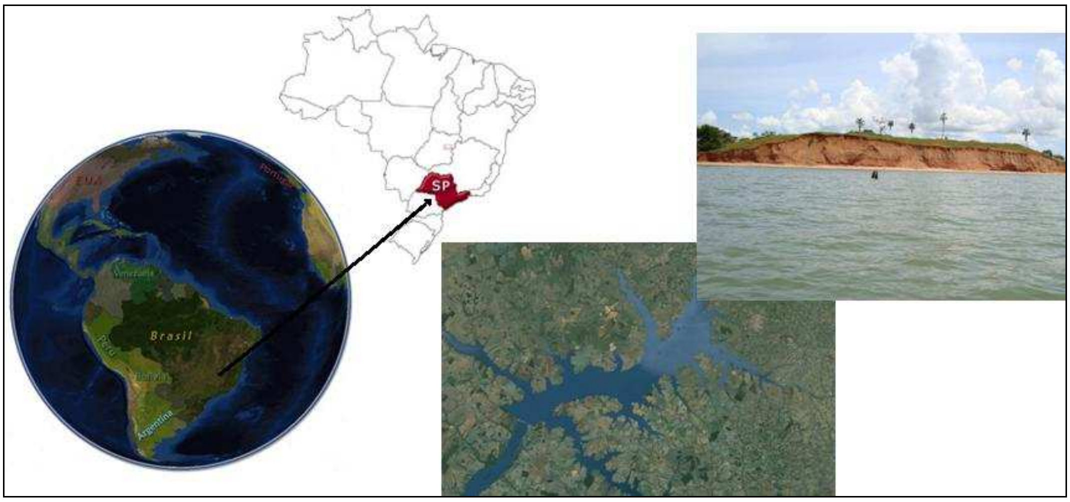

Figure 1. Geographical position of Ilha Solteira lake dam.

Due to the huge dimension of Ilha Solteira dam reservoir, wind generated waves can cause problems to the navigation security, to the stability of the river banks, to the infrastructures around the reservoir or even to public safety. Within this framework, a project code-named ONDISA (*Ondas no lago de Ilha Solteira*), UNESP (1997, 2008), is under way. This project aims to improve the understanding of hydrodynamics and morphodynamics inside Ilha Solteira dam reservoir. For that, an important aspect is the evaluation of the effects of wind generated waves on the lake margins and/or on the navigation security. So, field-data acquisition, processing and numerical

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modeling of wind-generated waves have being used to characterize the local wave climate.

An extensive field data campaign has been undertaken since January, 2010. Several instruments were deployed at different locations on the Ilha Solteira reservoir and on its margins to measure waves, currents and winds. In spite of being very useful to describe local wave and current characteristics, these measurements are of too short duration to characterize the long-term wave climate. Besides, the spatial representation of the wave conditions provided by such measurements is very restricted, in addition to the high cost of equipment deployment, maintenance and monitoring.

The use of numerical modeling for wind wave generation, propagation and attenuation can be an alternative since it can characterize spatially all the study region and it can be used to long term studies. Particularly, the use of spectral nonlinear model SWAN (Simulating Waves Nearshore, Booij et al. 1999), a numerical model that takes into account the wave generation, propagation, attenuation phenomena and non linear interactions between waves and currents, is a good choice. Anyway, the application of SWAN involves the establishment of a set of parameters, which must be calibrated for each case study. Therefore, it is interesting to apply the model to situations where data exists and to evaluate its performance.

The present work, which is a contribution to the ONDISA project, deals with the application of SWAN model to Ilha Solteira dam reservoir, in order to simulate the wind waves generation and propagation inside the dam. Moreover, it presents a comparative analysis of the SWAN numerical model predictions with data measured by one of the equipment (sensor pressure) installed in the Ilha Solteira reservoir, in order to evaluate the model performance and to calibrate some of its parameters for this region. The analysis was made for the data measured on March 1, 2011.

This paper begins with a short description of the data acquisition (section 2). Then the description (section 3) of the numerical model used and its application to the study area is presented. A discussion of the results obtained with the model is presented in section 4. Finally, the conclusions are drawn in section 5.

2. Data collection

2.1 General description and methodology

An extensive monitoring plan in this region is being carried out as well the definition of an alert system within the framework of the research project FINESP - ONDISA5. The objective is to develop predictive models for wind wave generation to be included in a warning system for navigation. Several wind and wave measuring campaigns have been undertaken.

Several equipments (pressure sensors, anemometers and others) were installed at the Ilha Solteira reservoir to continuously measure wind and wave characteristics (Dall'Aglio Sobrinho et al., 2011).

One group of those instruments was installed at a tree inside the lake, located at 20020'49.07" latitude, longitude 51018'17.63", Figure 2, to measure wind and wave characteristics. In detail, the equipment deployed inside the lake and near the tree consist on (Figure 2 and Figure 3a): (1) an ADCP-WAVES, which was deployed at 8 m depth, 20 m away from the tree basis and connected via cable to the radio located in the instrumentation box; (2) a pressure transducer (Druck), which was deployed at 1 m depth and connected to the data-logger set / radio located in the box instrumentation; (3 and 4). Conventional shell-type anemometers, which are located at 0.3 and 0.6m high on the structure tied to the tree; (5) a 2D Ultrasonic Anemometer, which was located at 1.2m high; (6) Box instrumentation, which contains radio, data loggers, batteries, etc; (7) Antennas for data transmission; (8) a solar panel power system, 80w; (9) a camera camcorder with high resolution and low power, for real time wave visualization.

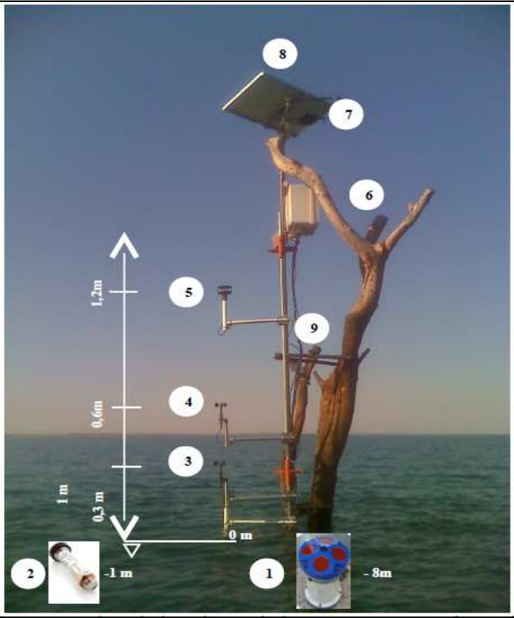

Figure 2. Instrumentation and telemetry.

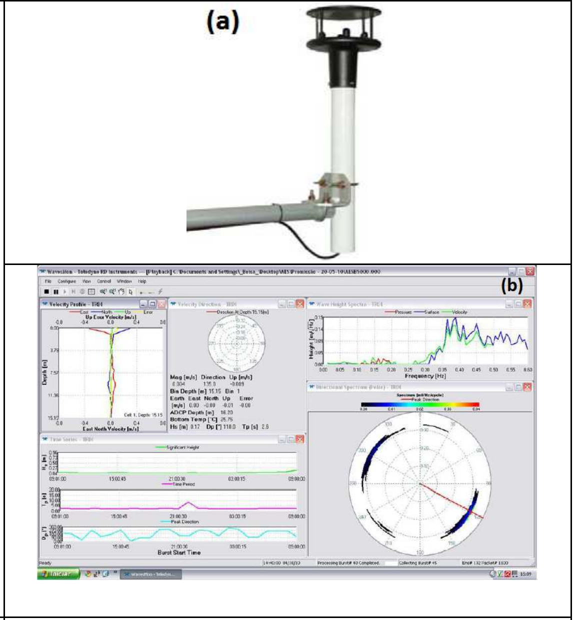

Figure 3. (a) 2D sonic anemometer, (b) Wave processing software WAVESMON.

2.2 Wind and wave measurements

As referred, the wind speed are measured by several shell-type anemometers positioned at 0.3 and 0.6m as well as with a 2D sonic anemometer positioned at 1.2 m above water level, which can also measure wind direction. The objective is to profile the wind data at this site. For the present work only the data of the 2D sonic anemometer is considered. That data have been recorded in a CR1000 data-logger from Campbell Scientific. These data are transmitted, by telemetry, to a data bank in LH^2 - Laboratory of Hydrology and Hydrometric UNESP – Campus of Ilha Solteira, Cunha et al. (2009).

In relation to wave measurements and for the present work, wave data (wave heights and periods) are determined from the data measured with a Druck PDCR 1830 pressure sensor (for up to 50 psig, nonlinearity of 0.06% of full scale, equipped with cable feeding 150 m) positioned at 1.5 m below water level (a ventilation tube that provides the reference atmospheric pressure). These data are also transmitted, by telemetry, to a data bank in LH^2, and an example of wave processing is shown on Figure 3b.

It is important to notice that the main guidelines of the acquisition system are the data acquisition frequency and its transmission by radio waves. Since wave height and period from the studied reservoir were not known, it was decided to use an almost continuous sampling considering the greater frequency as possible. The data logger has an internal program which verifies the available memory and the necessary transmission time so that it will not be full. Besides, it was considered an additional time as a safety factor in order to prevent eventual loss of data because of communication problems. Therefore, based on a primary test, it was assumed a frequency of 8 Hz for the pressure sensor and 0.2 Hz for the wind speed (Dall'Aglio Sobrinho et al., 2011).

The data logger available memory also depends on the frequency in which the data is transmitted. At first, the transmission is made at every hour. But, due to eventual failure it is necessary to decrease this transmission time. In case of system failure, the time is reduced by half. Then, if the failure persist the transmission time becomes at every 10 minutes. And finally, a last resource is the transmission at every minute.

3. SWAN application

3.1 SWAN description

SWAN is a numerical model developed at the Delft University of Technology (TUDelft), Netherlands. It is used to obtain wave spectrum evaluation in coastal areas, such as estuaries and extended to closed areas, as lakes. It uses wind speed, bottom profile, current velocity to simulate the wave height and it is based on the spectral action balance equation (Booji et al., 1999). The 2D model is available to anyone since it is public domain.

The equations solved on SWAN deal with wave generation, dissipation and nonlinear interaction in deep waters. It also solves dissipation due to bottom friction, nonlinear interaction and wave breaking in shallow water. Beji and Battjes (1994) show which processes are important as the wave travels from deep to shallow waters on Table 1.

Table 1. Processes that are important as the wave travels from deep to shallow waters. Adapted from Beji e Battjes (1994)

Processes	Deep water	Intermediate water	Shallow water
Wind generation	xxx	xxx	x
Quadruplet interactions	xxx	xxx	x
Triad interactions	o	o	xx
Partial breaking	o	xxx	x
Bottom friction	o	xx	xx
Refraction	x	x	xx
Shoaling	o	xx	xxx
Breaking	o	x	xxx
Reflection	o	o	x/xx
Diffraction	o	o	x

Symbol	Effect
xxx	Dominant
xx	Significant
x	Little relevance
o	Irrelevant

The spectrum action balance equation is a function of the action density, $N(\sigma, \theta) = E(\sigma, \theta)/\sigma$, where σ is the relative frequency, θ is the wave direction and E is the energy density. Written in Eulerian coordinates, the spectrum action balance equation is given by Equation 1:

$$\frac{\partial N}{\partial t} + \frac{\partial c_{g,x} N}{\partial x} + \frac{\partial c_{g,y} N}{\partial y} + \frac{\partial c_{\theta} N}{\partial \theta} + \frac{\partial c_{\sigma} N}{\partial \sigma} = \frac{S(\sigma,\theta)}{\sigma} . \qquad (1)$$

The first term on the left hand side of Equation 1 represents the local rate of change of action density in time, the second and third term represent propagation of action in the x-y plane, with propagation velocities $c_{g,x}$ and $c_{g,y}$ in x and y space, respectively. The fourth term represents shifting of the relative frequency due to variations in depths and currents and, finally, the fifth term represents the depth-induced and current-induced refraction. In summary, the left hand side of Equation 1 represents the kinematic part of the equation while the right hand side represents the source term.

The required data to run the SWAN model are the bathymetry of the study region, wind, wave and currents fields as boundary conditions, in addition to a set of computation parameters. Among the several results produced by SWAN it is worth mentioning the significant wave height, the average and the peak periods, directional spreading, the bandwidth parameter and the mean water level at any point of the defined computational domain.

For a systematic application of SWAN model to different incident wave conditions, a software package named SOPRO-SWAN, Fortes et al. (2006), was developed. It is made of a user interface and the numerical model SWAN itself. The user interface facilitates data storage and manipulation and the execution of the SWAN model, as well as the post-processing of its output, namely their graphical visualization. The package was built using both Microsoft Access database and Visual Basic for Applications programming language.

3.2 SWAN input conditions

The application of the SWAN model to Ilha Solteira reservoir was made for the wind characteristics measured by the 2D sonic anemometer during the period between 0:00 and 24:00 h of March 1, 2011, every 10 min.

The SWAN model computational domain was discretized through three rectangular grids, with one covering the whole area of the reservoir, as shown in Figure 4. The larger mesh (global) has the dimensions 54 km x 33 km, and is composed of 1 km^2 units. The 2nd grid (nested) was defined with a resolution of 500 m, covering a rectangle of 26.6 km x 18.4 km. The 3rd grid (nested) was defined with a resolution of 250 m, covering a rectangle of 14.8 km x 14.3 km, as it can be seen in Table 2. The use of multiple grids is needed to achieve better numerical performance. One point was defined in the 3rd grid where SWAN results were extracted, which corresponds to the location of the pressure sensor instrument.

The wind field conditions, which were based upon the 2D sonic anemometer measurements, during March 1, 2011, Figure 6, were considered constant in space in all three grids.

All the SWAN version 40.72 runs were carried out in stationary mode considering wind time variation and without the presence of currents. The physical phenomena included were at the three grids: refraction, diffraction, shoaling and wave breaking due to bottom influence, whitecapping, triad and quadruple wave-wave interactions. All the relevant parameters were introduced in the SOPRO-SWAN (Fortes et al. 2009) package.

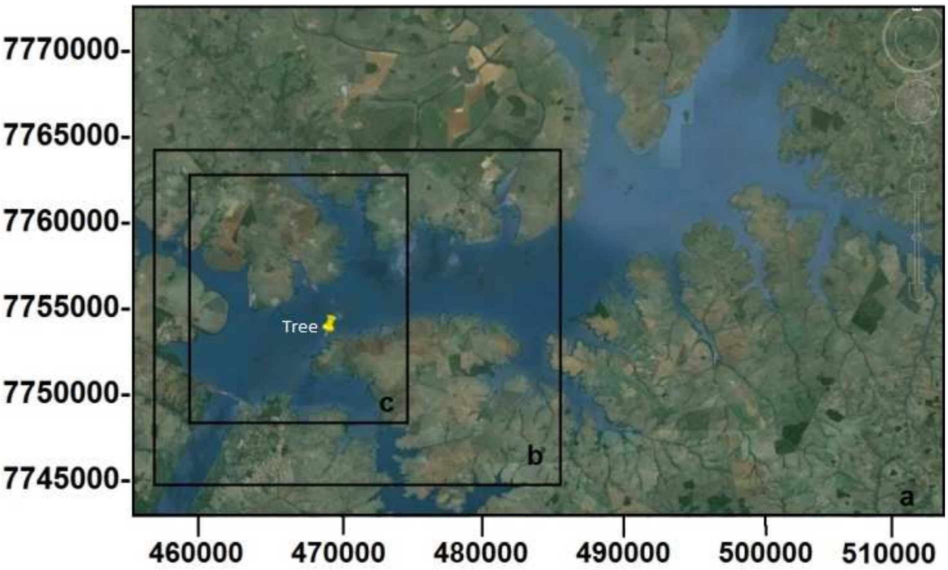

Figure 4. SWAN model: Domain and grids.

Table 2. Mesh characteristics.

Mesh	Initial X	Initial Y	Nº. DX	Nº. DY	DX (m)	DY (m)
1	456680	7741700	58	33	1000	1000
2	457220	7744520	53	34	500	500
3	459329	7745690	58	57	250	250

4. Comparison between in-situ data and numerical results

For the above conditions, numerical results along the study period, in terms of wave heights and periods, are obtained for the all domain and at the location of the pressure sensor equipment. For that position, numerical results and in situ data are compared.

Figure 5 presents in all domain the significant wave height and their respective mean wave periods for the day March 1, 2011 at 18:26 h, which yielded wind intensity 13.1m/s toward 75.9º.

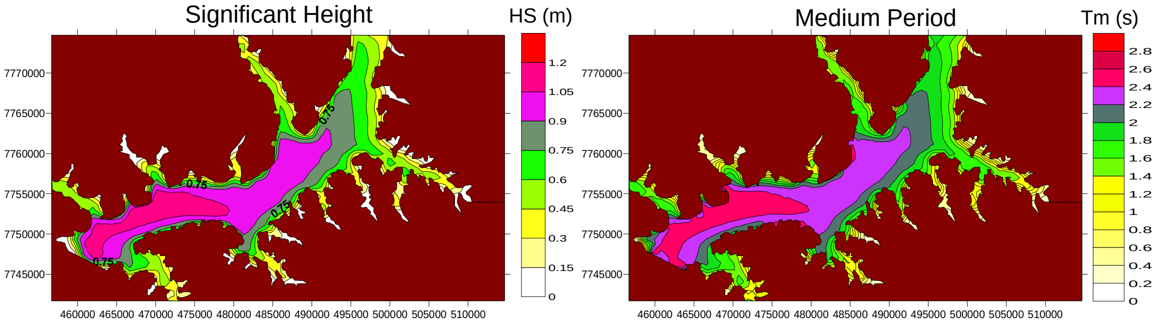

Figure 5. Graphical representation of the significant wave heights and mean wave period.

The results show that the significant wave heights and mean wave periods vary from 0 to 1.4m and 0.2 to 3s, respectively, being the largest ones observed at the southeast of Ilha Solteira reservoir. This is in agreement with the wind direction and velocity.

Figure 6 presents, along the day March 1, 2011, the numerical and in situ data of significant wave height values.

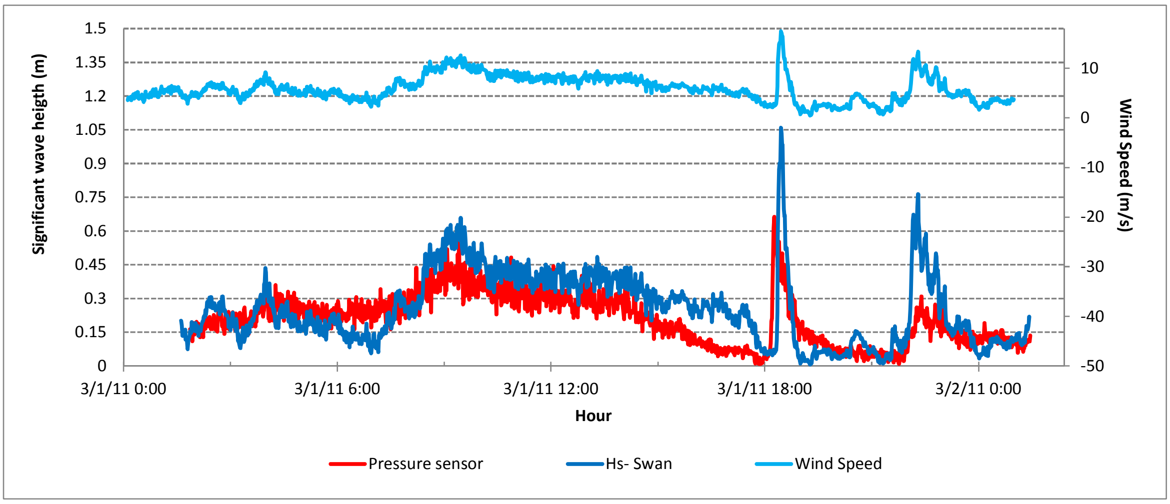

Figure 6. Graphical representation of the significant wave heights on March 1, 2011 using the SWAN and pressure sensor. The wind data are also shown in figure.

From Figure 6, one can conclude that the behavior and magnitude of the numerical and experimental values are very similar. Moreover, both numerical and in situ data follow the wind data variation. However, there are some differences: the numerical results are lower than the measured ones until 7:00 am, while after it the opposite occurs, i.e., the numerical results overestimate, in general, the observed values especially when the wind blows with high intensity (18:00 and 21:00). This can be due to the fact that the wind characteristics were considered constant in the whole domain due to the lack of information.

5. Conclusions

Waves generated in large multipurpose reservoirs can be harmful to sluice operations, navigation, etc. In this context, waves are mainly generated by wind and without current effect.

This paper analyses the wave heights and periods in Ilha Solteira dam reservoir, Brazil, obtained from field measurements and numerical modelling made for one single day: March 1, 2011. Numerical model results present great similarities with the experimental ones, which contributes to the confidence on the application of the SWAN model to restricted waters, like lakes or dam reservoirs. However, numerical modelling depends significantly on the accuracy of the wind field characterization.

Future work consists on the application of the model to longer time periods as well to other locations on the Ilha Solteira dam reservoir.

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