COASTAL WAVE MODELLING VALIDATION USING NEW FIELD TECHNIQUES

C. Ventura Soares[(1)], E. Rusu[(1)], L. Q. Santos[(1)], A. Pires Silva[(2)] and O. Makarynskyy[(2)]

(1) Marinha, Instituto Hidrográfico, Lisbon, Portugal.
(2) Instituto Superior Técnico, Lisbon, Portugal.

1. INTRODUCTION

Traditionally wave measurements in coastal areas are made using either wave buoys or pressure sensors deployed at the bottom. In general these equipments work included in monitoring networks in order to support wave climatologic programs. They are also frequently deployed for harbor management purposes. However the collected and saved data are limited for scientific purposes especially in order to make comparisons with wave model outputs. The recent Acoustic Doppler Profilers (ADCP's) opened, in the last two years, new capabilities in this field, allowing deeper approaches namely in terms of spectral analysis procedures.

In order to compare output data from the different wave measurement techniques a set of equipments was deployed in the Portuguese West Coast during winter of 2002. This set includes a Pressure Sensor, a Directional Wave Buoy and finally an ADCP.

On the scope of the research project PAMMELA 2 developed at Instituto Hidrográfico of the Portuguese Navy (IH) and Instituto Superior Técnico (IST) SWAN model was implemented for the area. The wave climatology in the area is characterized by W/NW regular pattern swell almost all the year.

The collection of data had two main objectives:

- Make an inter-comparison of the different data output allowing comparisons between traditional and new wave measurement sensors
- To assess the quality of the wave parameters estimated by SWAN model

2. FIELD EXPERIMENT

The experiment was held in the Portuguese West Coast, off Lagoa de Óbidos inlet (north of Lisbon). The bathymetric configuration of the considered area can be seen in Figure 1. In this place were deployed three equipments for measuring waves: an AANDERAA WTR-9 Pressure Sensor, a DATAWELL Directional Wave Buoy, and a RDI Workhorse 600 KHz ADCP.

The location of the 'in situ' sensors followed roughly the isobathymetry of 20 meters and they were equally distanced with a spatial step of about 400 meters (co-located in practice). The position of these data sources is also assigned in Figure 1.

The AANDERAA WTR-9 (PS) is a Pressure Sensor (quartz) mounted on the electronic board which is casted in polyurethane foam housed in a cylindrical pressure case. The instrument operates in cycles triggered by the internal clock. When the system is turned on it remains at rest until there is 15 minutes left of the selected sample interval (in this case 30 minutes). Then the measurement starts, calculation of the parameters are performed and data are recorded. The wave measurement comprises the Significant and Maximum Wave Heights and the Mean Zero Crossing Wave Period based on a pressure time series over 8.5 minutes, sampled at 2 Hz. The PS was placed on the seabed. The recommended deployment depth is up to 15 meters. However 20 meters isobathymetric was selected for security reasons in order to avoid breaking zone. In this site storm conditions during winter are often associated with 10-meter maximum wave heights.

The RDI Workhorse 600 KHz ADCP (ADCP) is a 600 KHz acoustic Doppler device equipped with a pressure sensor that performs three independent calculations of the spectrum of surface elevation (wave spectra) using orbital velocity, surface detection ("surface track") and pressure data (2Hz sampling rate). Signal processing techniques are used (Iterative Maximum Likelihood Method) to estimate wave direction, Terray et al (1990). The computations were made from 9-minute bursts, starting each hour. The ADCP is installed in a convenient bottom mount and it collects water surface time series calculating Significant Wave Height, Peak Period, Mean Wave Direction and Directional Wave Spectra for each burst. The operation principles by which wave information can be obtained from upward-looking ADCPs are deeply discussed in Terray et al. (1997, 1999).

The DATAWELL Directional Wave Buoy (WB) is a spherical buoy which measures wave height and wave direction. The buoy follows the movements of the water surface and it estimates the waves by measuring the vertical acceleration of the buoy, pitch and roll angles, and the three components of the Earth magnetic field. From these measurements (20-minute record starting each 3 hours), the elevation and the slope of the water surface, in north-south and east-west directions, are calculated (acceleration signal is integrated twice). The sampling rate is 1.28 Hz and data are grouped in blocks of 200 seconds. Then, each 20 minutes register contains 6 blocks of 200 seconds.

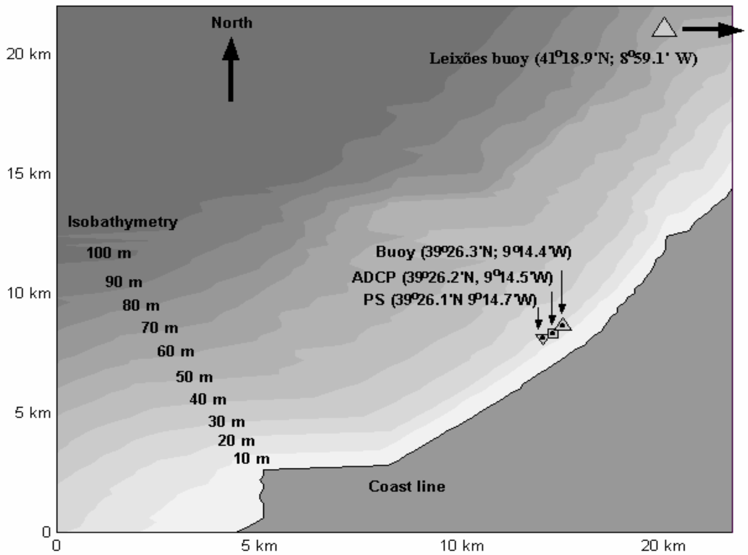

Figure 1
Location of the 'in situ' instrumentation in Óbidos

Three categories of wave parameters were compared: the Significant Wave Height (Hs), the Wave Period (both Peak and Mean, Tp and Tm) and the Peak Wave Direction (DIR). The performed analysis took also into account the fact that the data from WB is post-processed using both spectral and statistical methods. On the other side ADCP uses spectral methods and PS statistically treatment of the collected data. The instruments were deployed from 5th March to 10th May 2002. The analysis is focused on the period from 7 to 31 March 2002, the most energetic period, every 3 hours. This time step corresponds to the WB sample interval, which is the largest time step of all three considered sensors. The ADCP records every hour, while PS measures the wave parameters every 30 minutes.

3. DATA ANALYSIS

In Figure 2 are presented the time series of the Hs obtained for all three instruments. This was spectral deduced for WB and ADCP and statistical processed for PS. It can be seen a reasonable agreement between ADCP and WB data while PS data is consistently lower. Besides measurement noise this discrepancy may be related with different data acquisition and processing techniques (spectral versus statistical analysis), different positions of the sensors in relation to the bottom (ADCP vs PS), tide and current influences over the pressure-based wave height spectra (ADCP vs WB) (Strong et al., 2000). Figure 3 describes the time series of the Tp (WB and ADCP). In general the values agree but with several unexpected dramatic changes in ADCP Tp values spread along the 25-day period. Figure 4 shows the time series of the Tm (WB and PS), both statistically derived. Lower Tm show more important differences than higher Tm. Figure 5 represents DIR from WB and ADCP. The differences are generally lower than 20º.

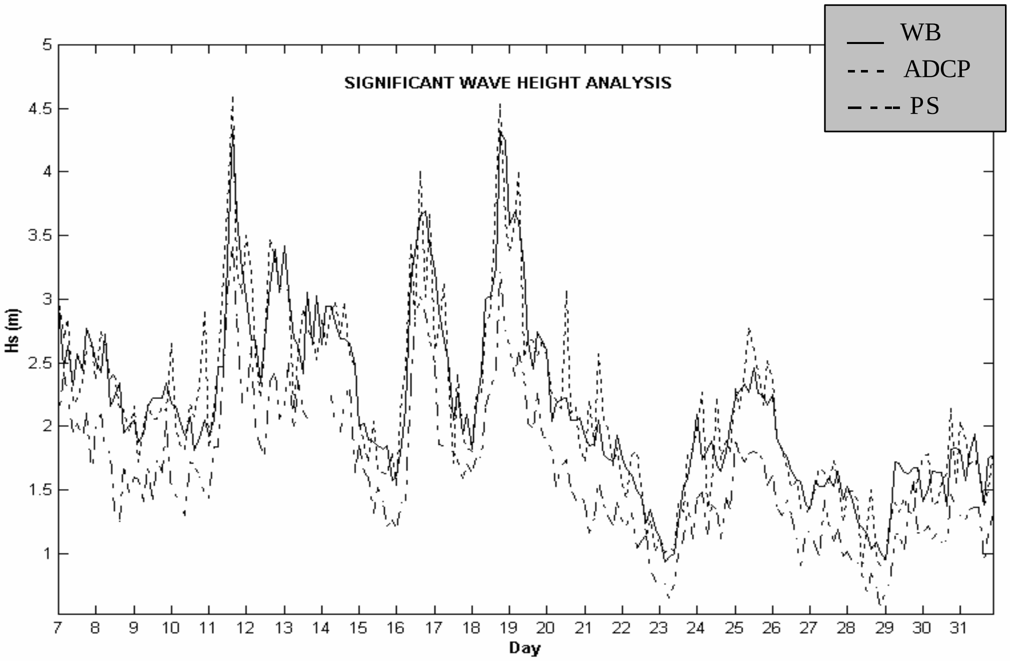

Figure 2
Significant wave height analysis, comparison WB-ADCP-PS
7-31 March 2002, 3 hours time step

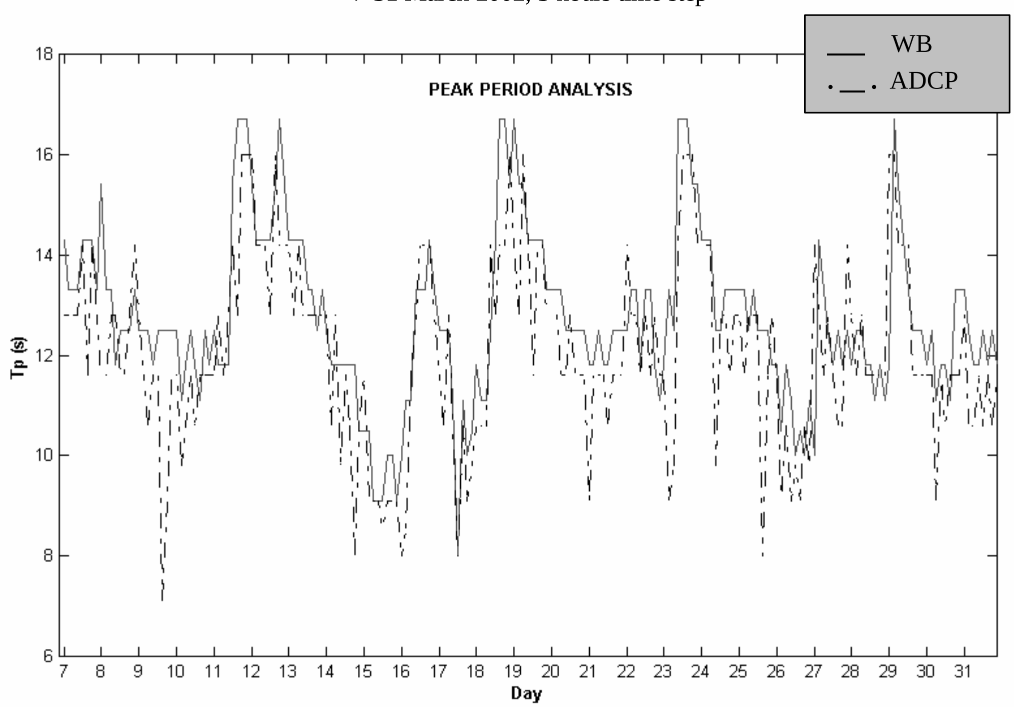

Figure 3
Peak period analysis, comparison WB-ADCP
7-31 March 2002, 3 hours time step

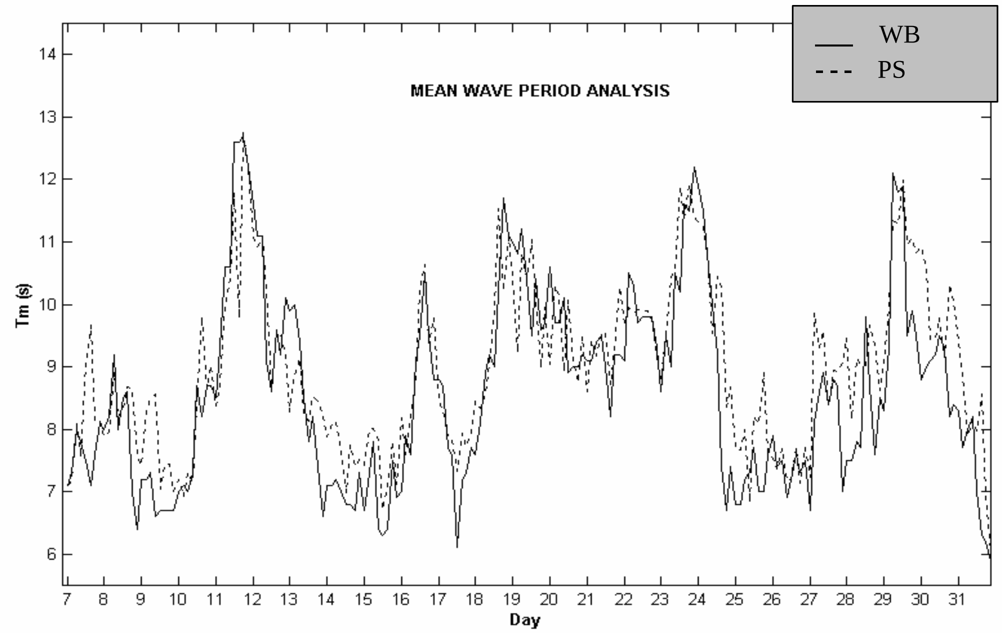

Figure 4
Mean wave period analysis, comparison WB-PS
7-31 March 2002, 3 hours time step

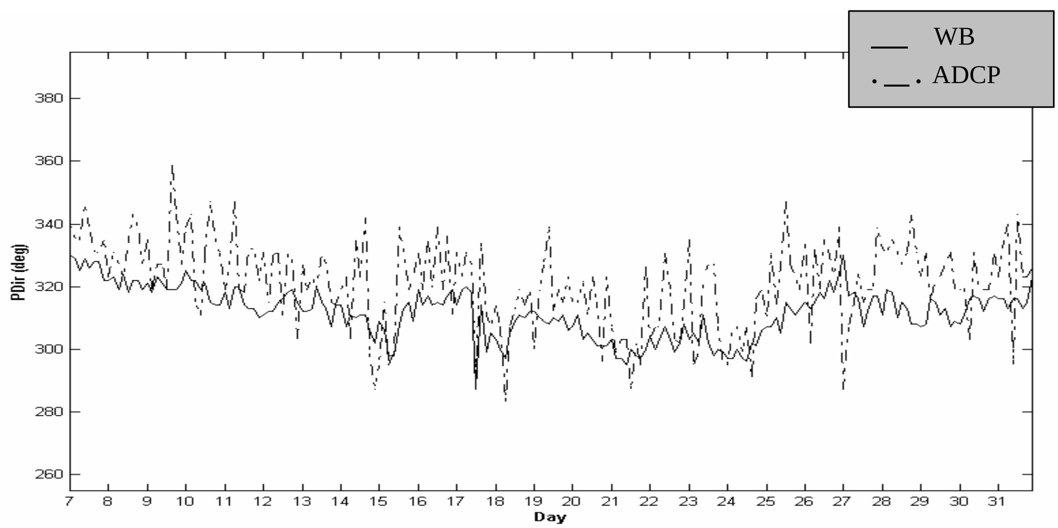

Figure 5
Peak wave direction analysis, comparison WB-ADCP
7-31 March 2002, 3 hours time step

Generally speaking and awaiting for future and detailed work analyzing this data, the ADCP and WB show reasonable agreements comparing the main wave parameters not only in calm conditions but also in storm ones (four situations with Hs above 3 meters). PS data differences from the other data are more important. In spite of this the PS output seems to be pretty reasonable.

4. WAVE MODEL SIMULATIONS AND ASSESSMENT

For describing the wave propagation in the nearshore were performed several simulations with the SWAN (acronym for Simulation WAves Nearshore), a spectral phase averaging wave model designed to obtain realistic estimates of wave parameters in coastal areas from given wind, bottom, and current conditions, Holthuijsen et al. (2001). In general SWAN was designed to implement the following wave propagation processes: propagation through geographic space, refraction due to bottom and current variations, shoaling due to bottom and current variations, blocking and reflections by opposing currents, transmission through or blockage by obstacles. The model also accounts for the dissipation effects due to whitecapping, bottom friction and wave breaking.

The domain selected for these simulations was a 22 kilometers square as can be seen in Figure 1. Since the simulations were performed using a Cartesian system of co-ordinates, it was generated a regular computational grid in the geographic space. The grid steps are of 100 meters in the east-west direction and 200 meters north-south direction. For the directional space it was used a sector between 250º and 350º with a step of 4 degrees. This directional range corresponds to the incoming swell patterns for the period analyzed. The frequency space generated has 40 frequencies between 0.05 and 0.6 Hz. A seafloor DTM (Digital Terrain Model) with 100-meter resolution in both directions was used as bottom boundary condition. Local wind and currents were not accounted for.

According to the swell propagation patterns the active boundaries were the ones from west and north. The zero boundary conditions on the sides from east and south do not induce any errors in the area of interest because most part of these boundaries are land and in this case SWAN absorbs all incoming wave energy. Moreover, for the parts with water it is assumed that no waves can enter the area but they can leave the area freely, which obviously does not affect the computations for this specific configuration of the area considered.

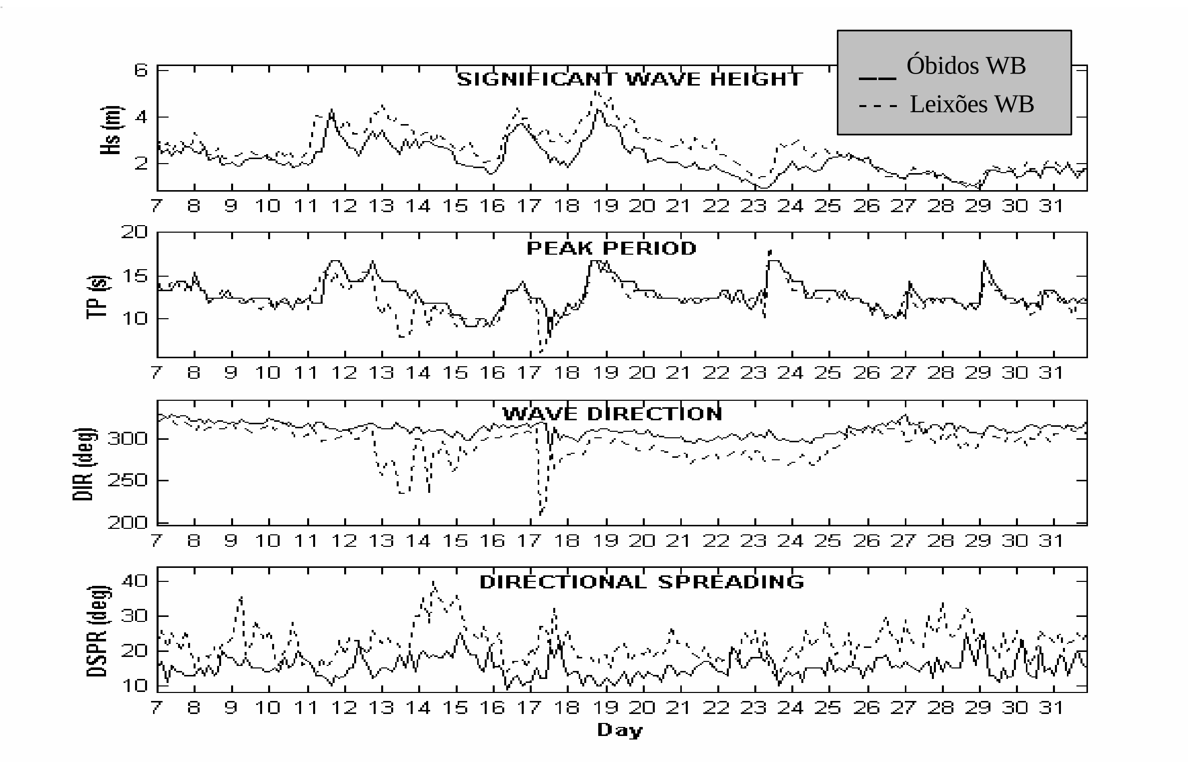

Figure 6
Comparison diagram, WB Leixões- WB Óbidos
(Significant wave height, peak period, wave direction and directional spreading)
7-31 March 2002, 3 hours time step

A parametric spectral input (offshore boundary condition) was generated using a JONSWAP spectrum with the standard value for the peak enhancement factor (3.3). Besides this factor the wave parameters that governs the spectral shape are Hs, Tp (or alternatively Tm), DIR and the Directional Spreading of waves (DSPR). In this way offshore boundary condition was defined by using deep-water wave parameters obtained from Leixões DATAWELL directional wave buoy, located in deep-water conditions (at 100 meters depth), about 110 nautical miles northward. It was assumed the offshore conditions at Óbidos site are very similar with those registered in Leixões since the comparison diagram presented in Figure 6 for the period analyzed (7-31 March 2002) shows the Óbidos 20-meter depth wave buoy with a very good concordance in phase, in all the four parameters mentioned, with the Leixões deep-water wave buoy.

The physical processes activated when making the simulations were: whitecapping, depth induced wave breaking, bottom friction and triad wave-wave interactions. The process of whitecapping in the SWAN model is represented by the pulse-based model of Hasselmann (1974), reformulated in terms of wave number as to be applicable in finite water depth, Komen et al. (1984). As regards the depth induced wave breaking was used the default SWAN parameterization with a 0.73 constant breaking factor, Eldeberky et al. (1996b). For the bottom friction was activated the Madsen model, Madsen et al. (1988). This formulation is similar to that of Hasselmann et al. (1968), but in this case the bottom friction factor is a function of the bottom roughness height and the wave conditions. For modeling the triad wave-wave interaction SWAN uses the Lumped Triad Approximation Eldeberky (1996a), in each spectral direction. Since the wind conditions were not taken into account the quadruplet wave-wave interaction was set off.

A non-stationary SWAN simulation was performed on a UNIX workstation (as a sequence of stationary simulations with the time step of 3 hours), covering the period from 7 to 31 March 2002. Under the described parameterization the computer time requested for one simulation was about 30 minutes. The convergence was good, being necessary usually from 5 to 7 iterations to reach the default numerical accuracy imposed (98%). As concerns the outputs, were requested the wave data in the points of the computational grid, which were post processed, in real-time, with the interface 'TOTAL WAVE', Rusu et al. (2002). This brought the advantage of visualization the field distribution of the parameters (either scalars or vectors). Moreover, any location could be considered in the phase of post processing without being imposed 'a priori' as an output request. Since it was used the same interpolation procedure as in SWAN (namely bilinear interpolation between the points of the computational grid) the results provided by the interface are rigorously the same with those delivered directly by the model in the correspondent locations (points, lines or isolines).

The results of the model simulations concerning the fourth parameters analyzed (Hs, Tp, DIR and DSPR) are presented in the Figure 7, being compared with the corresponding data registered at the 20-meter depth Óbidos wave buoy. The relative errors are given in Figure 8 as standard computed:

$$E_R(\%) = \frac{|V_M - V_C|}{V_M} \cdot 100 \qquad (1)$$

where V_M is the measured value and V_C the computed value of the parameter. With few exceptions (when actually the data from the two buoys differs substantially), the results presented show a good concordance (in terms of all parameters analyzed), for a wave regime characterized by Hs less or equal 3 meters. As can be seen in Figure 8 the smallest relative errors (most of the cases about 4% or less) are concerning the wave direction.

From Figure 7 can be also noticed the fact that in the cases of extreme wave conditions, at Óbidos buoy, Hs computed by SWAN are systematically greater than the corresponding measured values.

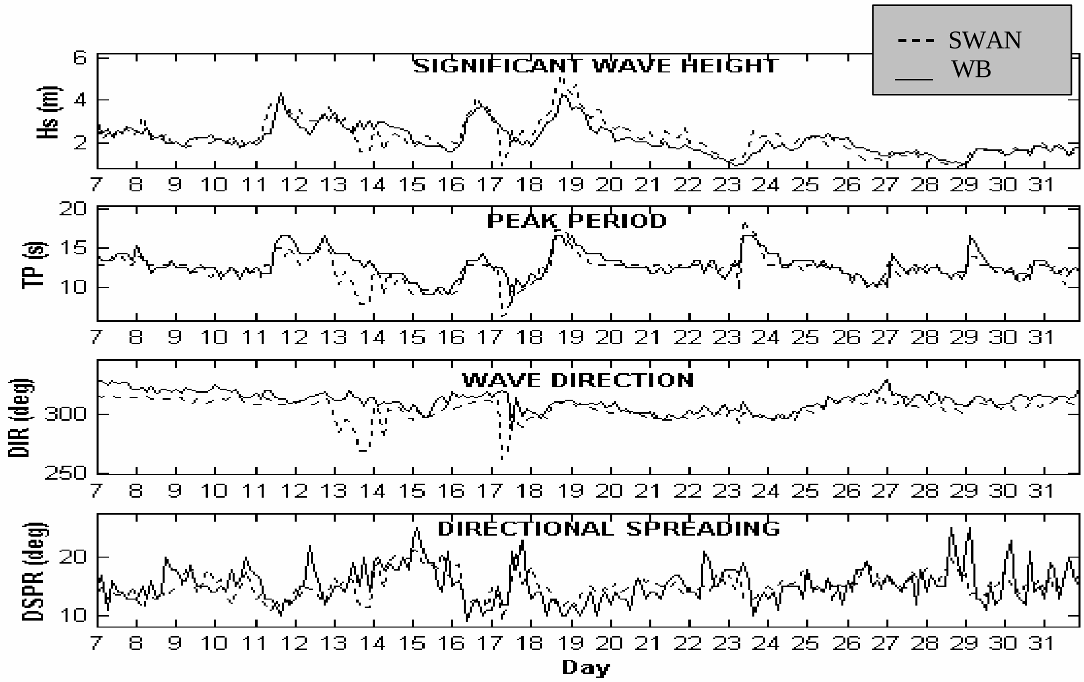

Figure 7

Simulation with SWAN: 7-31 March –2002, 3 hour time step.

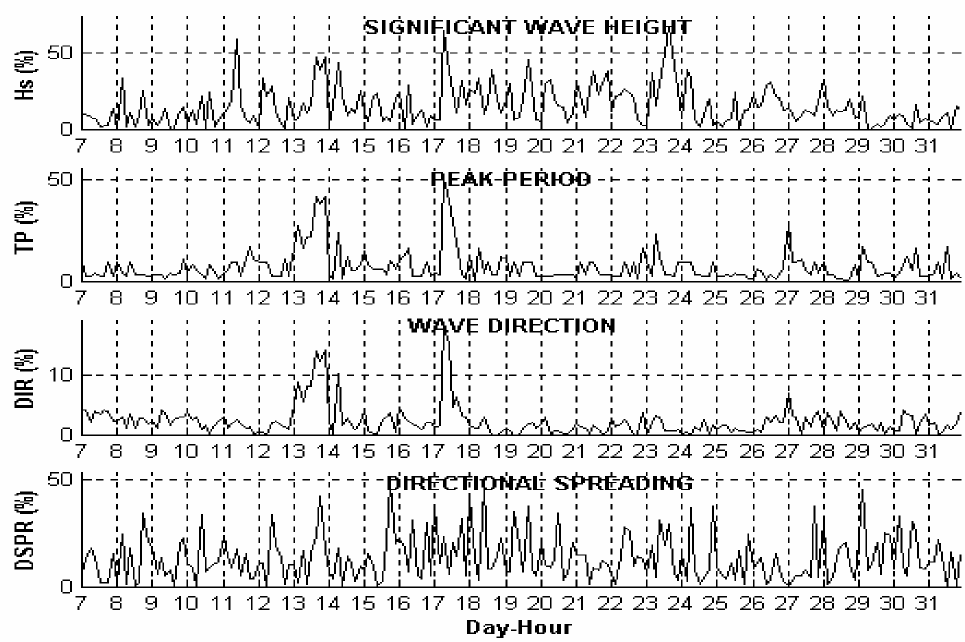

Figure 8

Relative errors (Óbidos wave buoy measured data versus SWAN computed wave data, %);
7-31 March -2002

We can compare measured data from the 3 different instruments considered with SWAN output for selected storm wave conditions. For this purpose we select two energetic peaks: one registered between 0900 16 March and 0000 17 March and other registered between 0900 18 March and 0900 19 March.

Figures 9 and 10 present an overview comparison in terms of Hs and Tp, between SWAN output and data recorded. It can be seen the output model surpasses consistently recorded data. In addition ADCP and WB are significantly close in all the considered periods.

Figures 11, 13 and 15 compare, in detail, SWAN output with all the instrumentation data, individually considered.

Figures 12, 14 and 16 express the registered differences, in terms of percentage of error (relative errors), between SWAN output and the instrumentation data, individually considered.

The analysis of data shows SWAN output, in its default parameterization, with good estimations if compared with WB and ADCP data and less reasonable estimations if compared with PS data.

They are of course several factors affecting not only the SWAN output results but also the quality of measured instrumentation data. In the first case should be referred the need for a better and more comprehensive parameterization (introducing wind and currents, for example). In the instrumentation field, as referred before, different data acquisition and processing techniques, different positions of the sensors in relation to the bottom, tide and current influences over the pressure-based wave height spectra among others can affect the raw data recorded.

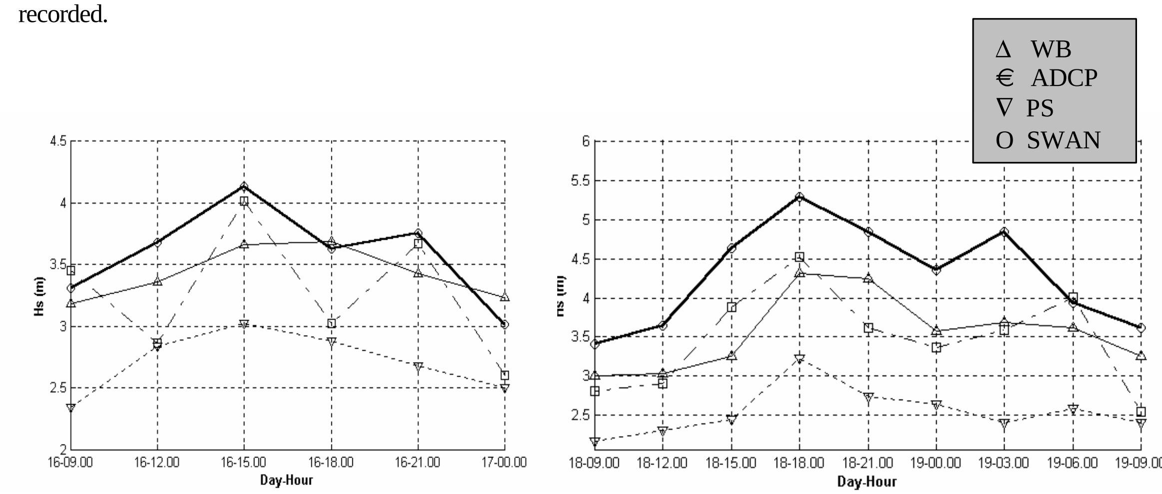

Figure 9
Significant wave height: comparison Buoy-ADCP-Pressure sensor-SWAN;
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

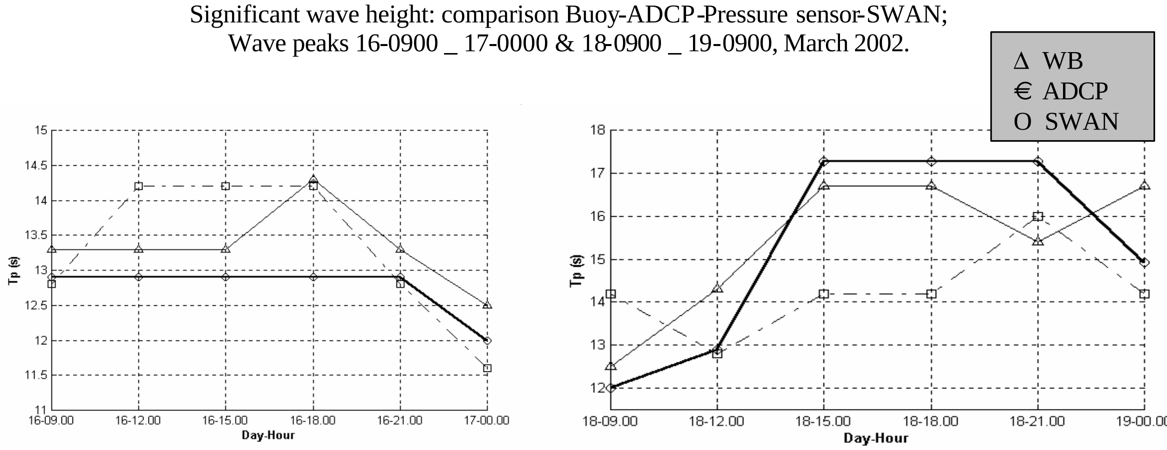

Figure 10
Peak period: comparison Buoy-ADCP-SWAN;
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

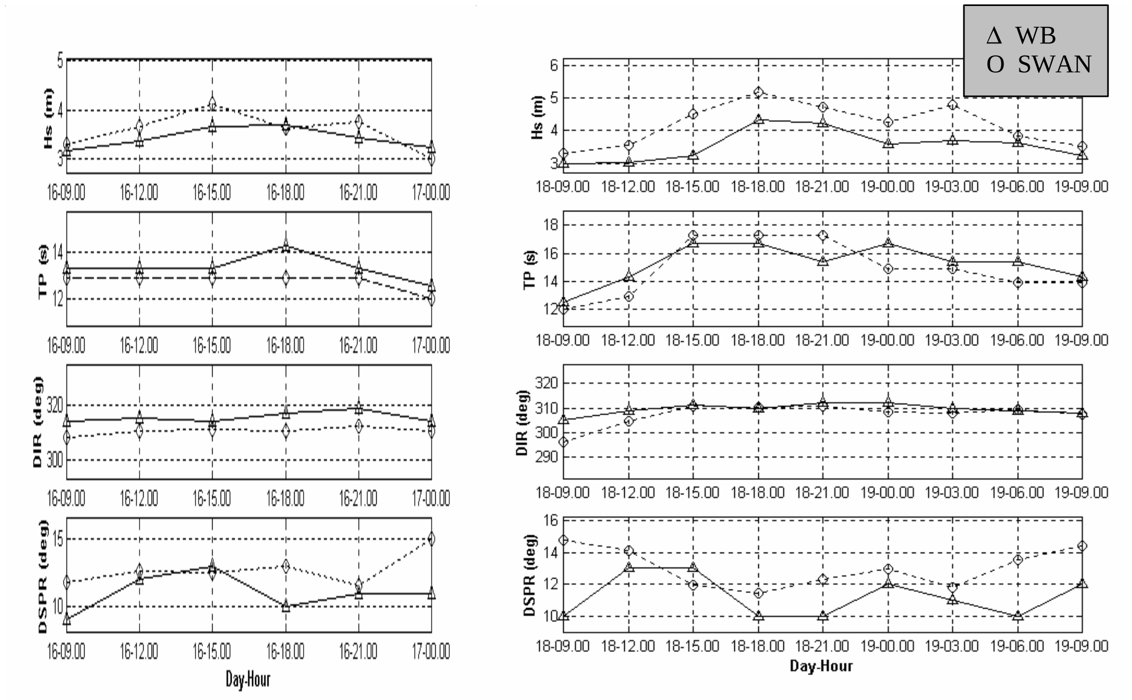

Figure 11
Comparison WB-SWAN (significant wave height, peak period, wave direction and directional spreading);
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

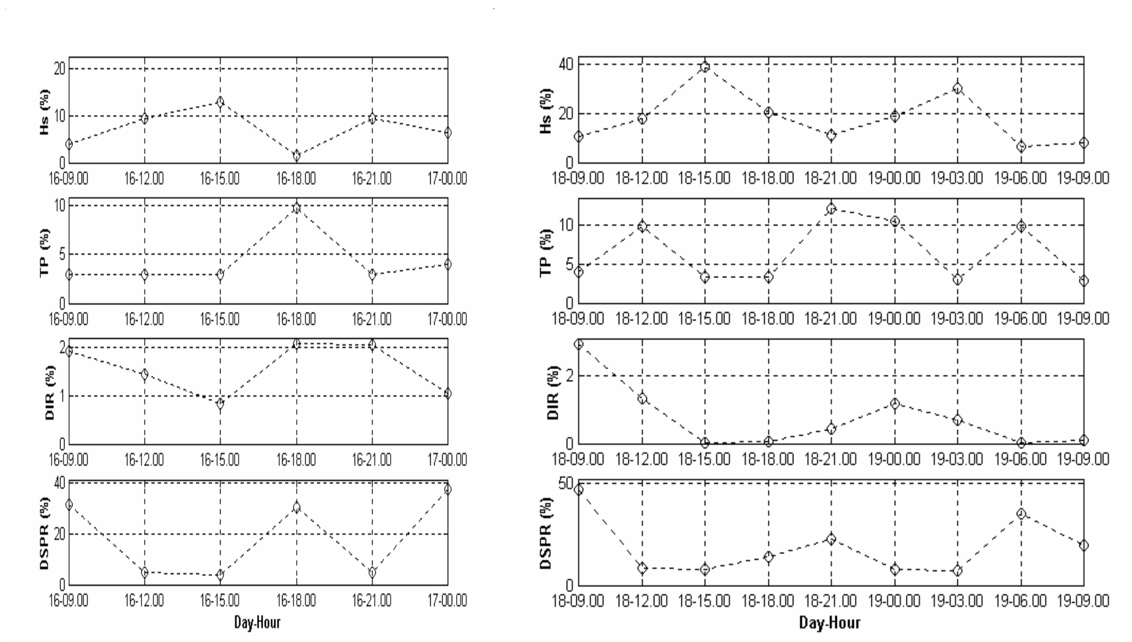

Figure 12
Errors relative to the WB data of the SWAN simulation results;
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

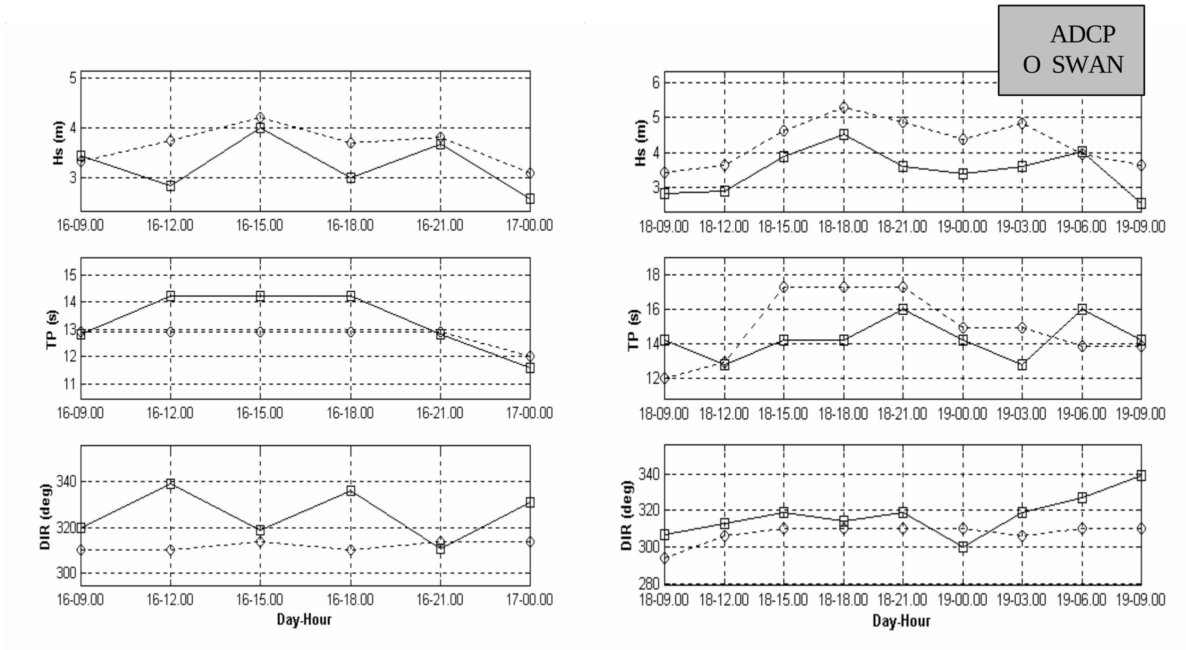

Figure 13
Comparison ADCP-SWAN (significant wave height, peak period and wave direction);
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

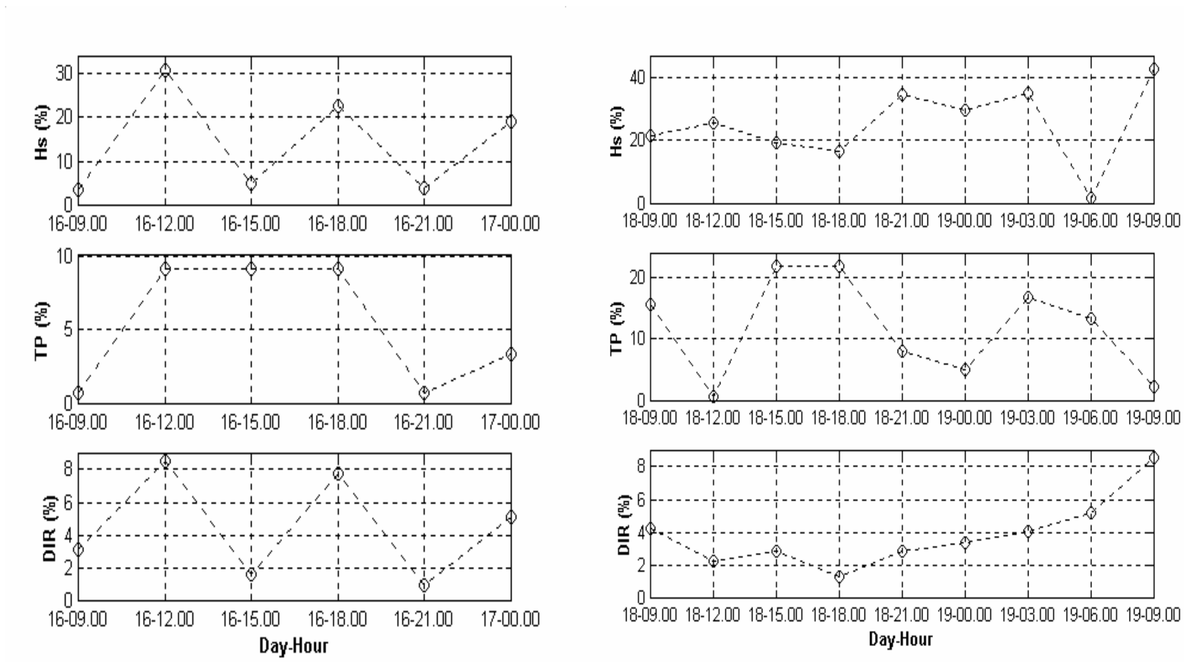

Figure 14
Errors relative to the ADCP data of the SWAN simulation results;
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

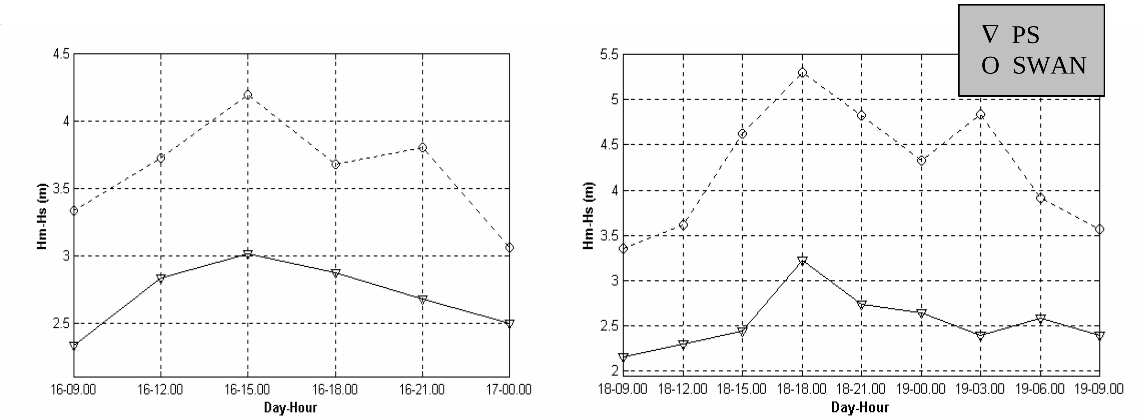

Figure 15
Comparison PS-SWAN (significant wave height);
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

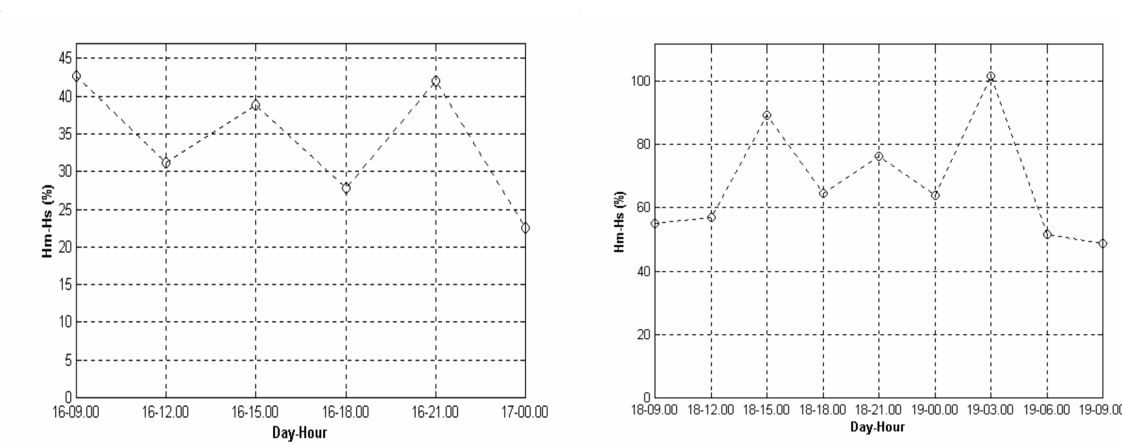

Figure 16
Errors relative to the PS data of the SWAN simulation results;
Wave peaks 16-0900 _ 17-0000 & 18-0900 _ 19-0900, March 2002.

5. CONCLUDING REMARKS AND FUTURE WORK

In order to compare output data from different wave measurement techniques and equipments a Pressure Sensor (PS), a Directional Wave Buoy (WB) and an ADCP were deployed off Lagoa de Óbidos inlet (20-meters depth), in the Portuguese West Coast, during March 2002. At same time the data obtained were used to assess the quality of the wave parameters estimated by SWAN model implemented for the area.

It can be seen a reasonable agreement between ADCP and WB Significant Wave Height (Hs) data while PS Hs data is consistently lower than the others. The discrepancies may be related with different data acquisition and processing techniques (derived spectral wave parameters vs derived statistical wave parameters), different positions of the sensors in relation to the bottom and current influences over the pressure-based wave height spectra.

The SWAN runs show Hs computed systematically greater than the corresponding measured values. The overall estimations are pretty reasonable, especially if compared with WB and ADCP data.

Preliminary data analysis was shown. All data set (5th March to 10th May 2002) will be processed in the near future. Several data corrections should be made in order to eliminate undesirable effects in wave measurement comparisons (different level sensors and current effects, for example). On the other hand SWAN output should be refined introducing wind and current effects in the area.

6. ACKNOWLEDGEMENTS

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The Instituto da Água (Portuguese Water Institute) is gratefully acknowledged for permission to use ADCP data, included on Lagoa de Óbidos environmental monitoring program and operationally ruled by IH.

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