iFADO Case Study:

Combining numerical modelling, remote sensing, emerging and traditional *in situ* observations for a better characterisation of a coastal area

Introduction

This case study aims to illustrate a cost-effective monitoring looking for different sources of data and the capacity of numerical models to explain and validate the observations and to extend the observations temporally and spatially.

During the months of April and June 2015, a Wave Glider SV2, an autonomous vehicle equipped with several environmental sensors, was deployed in Nazaré (Portugal) in the context of the INTERREG Atlantic Area Turnkey project (Project number: 2013-1/279).

The glider was equipped with sensors to measure currents, wave and atmospheric data in areas of interest for the exploration of marine renewable energies. As part of this mission, the vehicle followed twice the Saral/AltiKa satellite path 160 that passes along the coast of Nazaré (Figure 1).

In order to evaluate the accuracy of the observations, wave data collected by the satellite and the autonomous vehicle were compared with observations from a moored buoy and operational wave and circulation numerical models. Though comparisons were performed for several meteorological and water parameters in this Case Study only significant wave height and water temperature are shown.

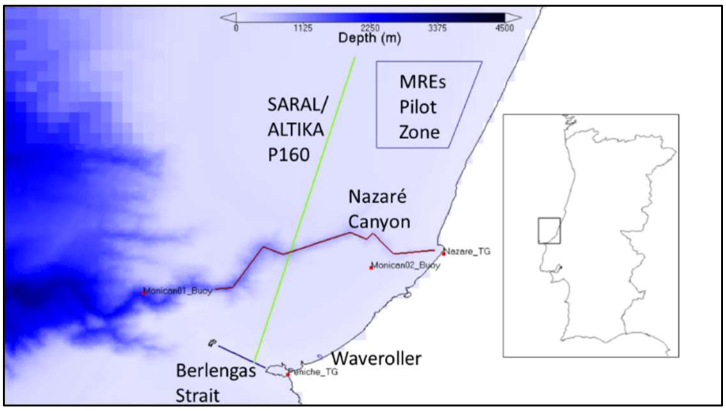

Figure 1 : Bathymetry and location of the main objectives covered by the WaveGlider mission in Portugal

Study area

The western coast of Portugal is considered a suitable area for the implementation of marine renewable energies (MREs) (Campuzano *et al.*, 2015a). For this reason, a WaveGlider mission was planned to monitor these waters. The mission was limited in the North by the MREs Pilot Zone, in the South by the Berlengas Strait and in the West by the longitude 9.50º W to avoid interferences with intense marine traffic routes (Figure 1). A major feature in this coastal area is the Nazaré canyon, which is an undersea canyon about 230 km long that crosses the continental platform in east-west direction reaching maximum depths of 4500 m and playing a major role in local hydrodynamics.

Material and methods

The WaveGlider "Hermes" SV2 was deployed the 28th of March and performed different trajectories until its recovery on the 7th of June 2015 (Figure 2). In order to evaluate the quality of the data collected by the WaveGlider, the obtained data were compared with *in situ* observations, remote altimetry data and operational numerical models implemented in the study area. Each source of information is described below.

- **The Monican02 Buoy** (9.21° E, 39.56° N; Figure 1), maintained by the Instituto Hidrográfico (IH, Portugal), collects operationally meteorological, wave and water parameters and served to compare the observations collected by the WaveGlider. For that purpose, the vehicle was "parked" in close vicinity to the buoy during part of the mission.

- **SARAL/ALTIKA satellite** passes: During the mission, the satellite completed twice the Pass 160, which crossed the study area on the 28th of April and the 2nd of June of 2015 with different trajectories due to an orbital drift.

- **Meteorological Model**: Hourly atmospheric pressure, air temperature and wind intensities and directions were obtained from an operational application of the MM5 meteorological numerical model (Grell *et al.*, 1994) that consisted of two nested grids with horizontal resolutions of 27 and 9 km implemented by the IST meteorological group (http://meteo.tecnico.ulisboa.pt; Trancoso, 2012).

- **Waves model**: propagation and dynamics of the waves reaching the Portuguese continental coast were obtained using the NOAA WAVEWATCH III (R) Model V4.18. To simulate the waves reaching the Portuguese coast, three nested levels with increasing horizontal resolution -0.5, 0.25 and 0.05 degrees- covering the North Atlantic Ocean (NAt), the southwest part of Europe (SWE) and the Portuguese Continental Coast (PCC) (Campuzano *et al.*, 2015a). The models were forced with NCEP operational Global Forecast System (GFS) with horizonal resolution of 0.25 degrees (NCEP/NWS/NOAA/U.S. Department of Commerce, 2015).

- **Circulation models:** Tides, currents and water properties for the Nazaré region were obtained from operational model applications (http://forecast.maretec.org) using the MOHID Water numerical model (http://www.mohid.com; Neves, 2013). The Nazaré Canyon operational model (Campuzano *et al.*, 2015b) is adapted from previous work by Pando *et al.* (2013) and Ballent *et al.* (2013). The application consists of two nested domains Nazaré L1 and Nazaré L2 with horizontal resolutions of 0.02 and 0.004 degrees that receive offline boundary conditions from the Portuguese Coast Operational Modelling System (PCOMS; Mateus *et al.*, 2012).

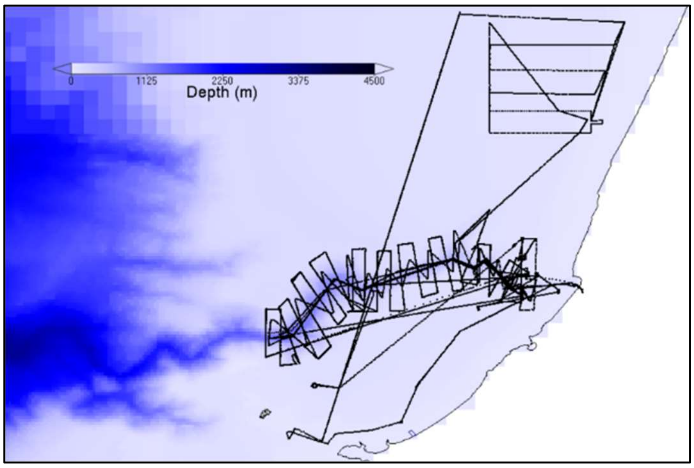

Figure 2 : Top = The WaveGlider SV2 "Hermes" during its deployment in the coast of Nazaré the 28th of March 2015. (Credits: Vítor Estrelinha/Câmara Municipal de Nazaré). **Down** = Monitored tracks during the WaveGlider mission in Portugal.

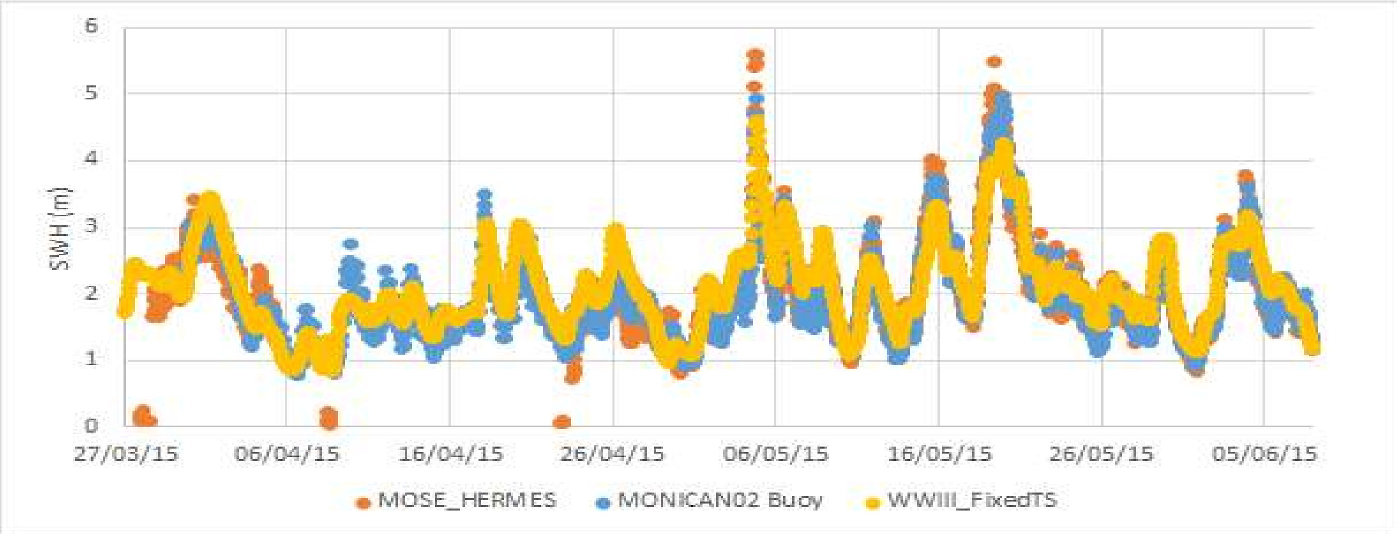

Figure 3 : Significant wave height (m) for the complete period of the mission observed by the WaveGlider Hermes, the Monican02 buoy and the WaveWatch III model.

Data comparison

In this section, the values were observed with different methods: WaveGlider, moored buoy and satellite will be compared between them and with the numerical models for wave height and water temperature.

Waves

Similar ranges of significant wave heights were collected both by the WaveGlider and the moored buoy "Monican02" indicating that the wave conditions were similar for the entire monitored area. The same patterns were modelled by the WaveWatch III model application with 0.05 degrees in Figure 3 ; however, it underestimates slightly the maximum values. The similitude between the different sources of information is confirmed by the statistics between the different timeseries (Table 1).

The main purpose of statistical models is either the prediction of future outcomes or the testing of hypotheses. It uses statistics to provides a measure of how well observed outcomes are replicated by the model, and in this way to validate it. Three statistics are used:

- **The bias**: it assesses if predictions are precise or not, and if the model tend to overestimate or underestimate the values. More the bias is closed to 0, the better the prediction.
- **The Root Mean Square Error RMSE**: it provides an indication against dispersion or variability of the quality's prediction. Better the prediction is if RMSE is closed to 0.
- **The coefficient of determination R^2**: it shows the differences between the prediction and the reality. The closer R^2 is to 1, the better the prediction.

Data Sources	Bias	RMSE	R^2
Monican02 buoy **vs** WaveGlider	0.037	0.253	0.900
Monican02 buoy **vs** WWIII model	0.168	0.341	0.850
WaveGlider **vs** WWIII model	0.162	0.375	0.817

Table 1 : Significant wave height statistics for comparisons between the data sources for the period 26th of April and the 2nd of June of 2015.

Erro! A origem da referência não foi encontrada. shows the Significant Wave Height (SWH) obtained by the WaveGlider following the path described by the Saral/AltiKa pass 160. To replicate the satellite path, it took the WaveGlider around two days, the instant when the glider and the satellite coincided are marked with a vertical grey line. The WaveWatch III results shown in the

Figure 4 was obtained at the same time and location of the satellite data.

Erro! A origem da referência não foi encontrada. shows the Significant Wave Height (SWH) obtained by the WaveGlider following the path described by the Saral/AltiKa pass 160. To replicate the satellite path, it took the WaveGlider around two days, the instant when the glider and the satellite coincided are marked with a vertical grey line. The WaveWatch III results shown in the Figure 4 was obtained at the same time and location of the satellite data. The three sources of data show good agreement for both Saral/AltiKa passes under different wave conditions.

WaveWatch III modelling results for the same instant and location of the satellite and the observed values by the northward trajectory of the WaveGlider along the same pass starting at 03:00 28-04-2015 and ending at 16:00 29-04-2015. The vertical grey line indicates the instant when the WaveGlider coincided in time and location with the satellite pass.

Temperature

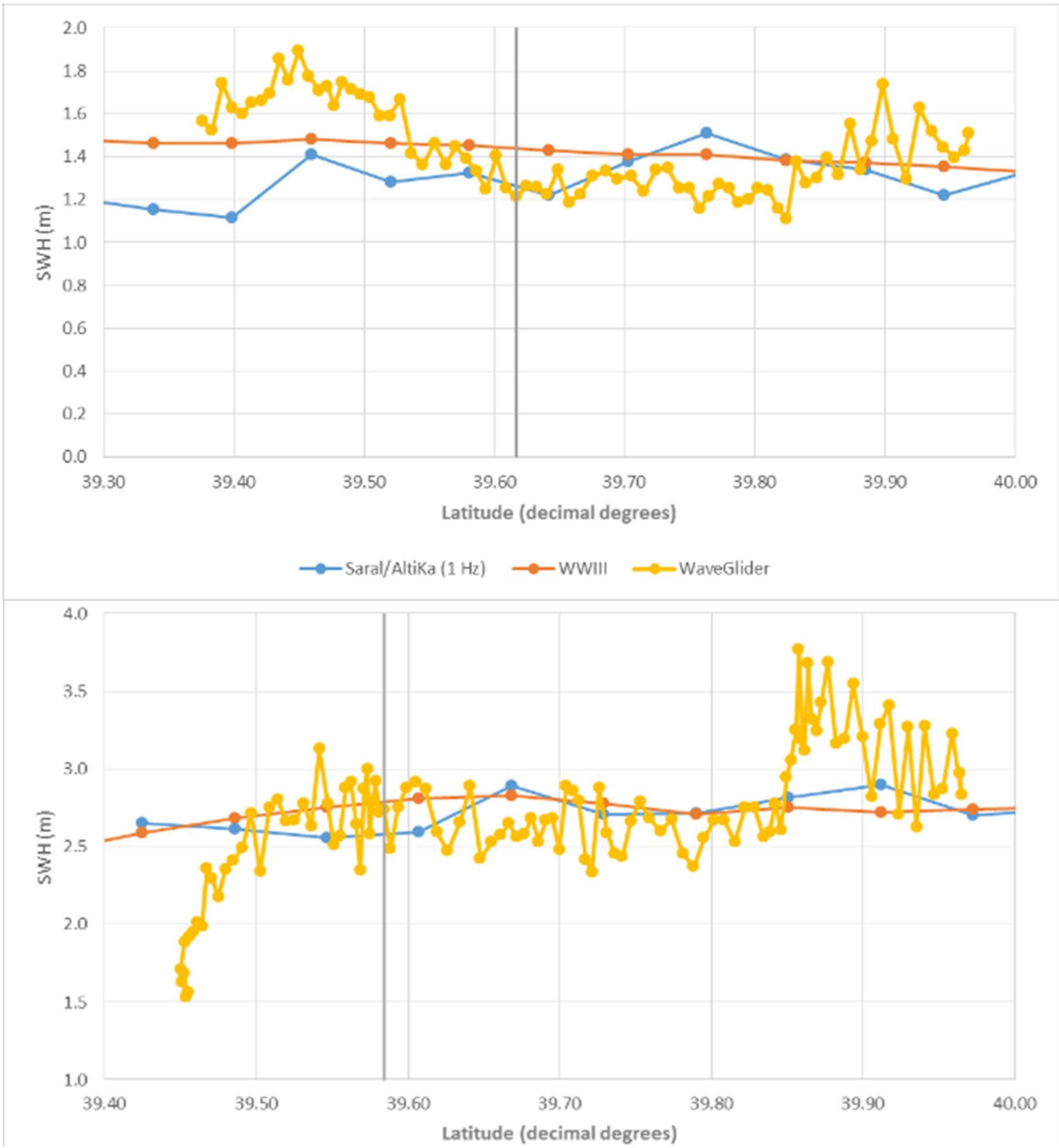

Figure 4 : Significant wave height (m) observed by the Saral/AltiKa satellite along the pass 160 on the 28th of April 2015 (up) and on the 02nd of June 2015 (down) with 1 Hz resolution (blue line).

The WaveGlider was equipped with a CTD sensor, an instrument for autonomous gliders with the high accuracy necessary for research and inter-comparison with moored observatory sensors, it measures conductivity, temperature and pressure. This sensor was attached to its propeller mechanism at around 5 m depth while the Monican02 buoy collect the temperature near the surface.

Figure 5 illustrates the temperature values registered by the CTD and the Monican02 buoy along with the modelling results from the MOHID 0.02 domain resolution at both depths. From the beginning of the mission until mid-May, temperature values rise continuously in a similar manner at the surface and at 5 meters depth. However, from mid-May upwelling events take place bringing colder water to the surface and several episodes of temperature inversion can be identified by the observations and reproduced by the numerical model.

The coefficient of determination (R^2) between the hourly-averaged temperature observed by Monican02 buoy and the WaveGlider was 0.60 for the whole observed period. Modelling results from the 0.02 degrees horizontal resolution can achieve coefficient of determination of 0.80 for each pair of datasets, Monican02 buoy vs surface model timeseries and WaveGlider vs depth dependent moving time series.

The combination of this novel monitoring methodology along with the classic observing stations such as coastal buoys allows to monitor and collect metocean information in larger areas and longer periods and during coastal conditions that would not be possible by a classic monitoring campaign. The combination of these monitoring methodologies with numerical models allow to complete spatially and temporally the information. The observations and the models allow to validate each other values as during the mission some of the sensors went out of calibration and by adding an extra source of information the suspicious information can be easily discarded.

Acknowledgements

The present work was performed within the framework of the research project "Transforming Underutilised Renewable Natural Resource into Key Energy Yields (Turnkey- Project number: 2013-1/279)". This project was co-financed by the European Regional Development Fund (ERDF) through the Interreg Atlantic Area Programme. The project is very grateful for the support of the Nazaré and Peniche local and coastal authorities and ENONDAS for help with the authorizations for the MREs Pilot Zone. The project would like to thank also to the Liquid Robotics operations centre for the successful piloting of the WaveGlider and the assistance of EMS and Atlantic Safaris for the support during its deployment, surveillance, and recovery.

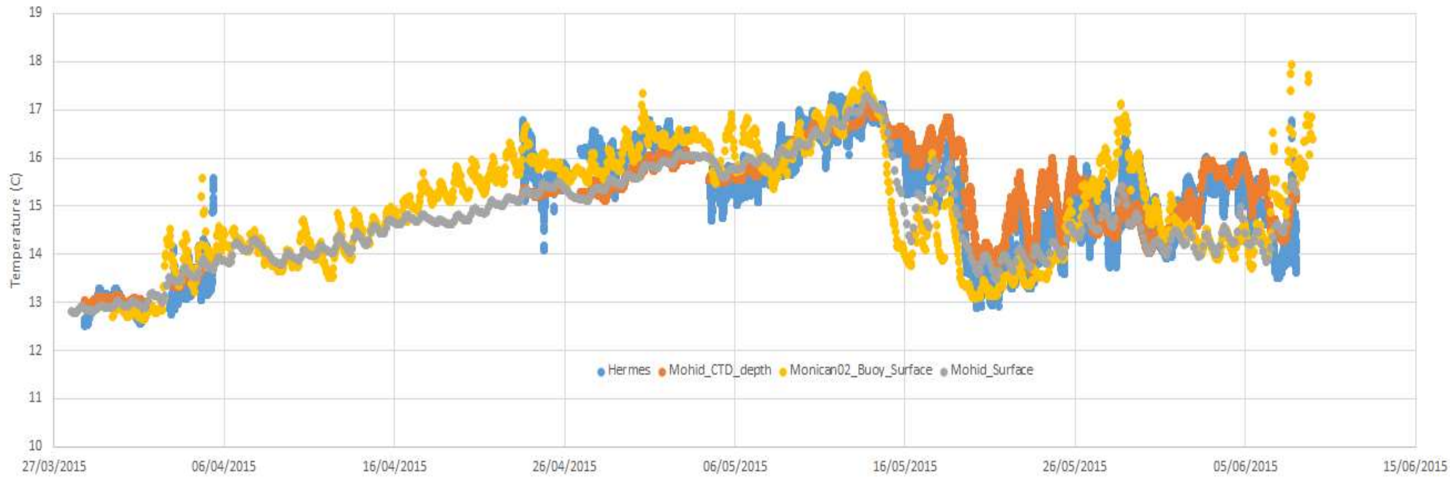

Figure 5 : Temperature for the entire WaveGlider mission period registered by the installed CTD, the Monican02 buoy and the MOHID model at surface and 5m depth.

Conclusions

References

Ballent A, Pando S, Purser A, Juliano MF, Thomsen L. **Modelled transport of benthic marine microplastic pollution in the Nazaré Canyon**. Biogeosciences. 2013; 10: 7957-7970.

Campuzano FJ, Juliano M, Fernandes R, Neves R. (2015a). **Marine Renewable Energy Resources - Atlas for Continental Portugal**. Report for the EnergyMare Project (Atlantic area Interreg project Contract Number: 2011-1/157). Link to report

Campuzano FJ, Juliano M, McIlvenny J, Goddijn-Murphy L, Fernandes R, Neves R. (2015b) The WaveGlider Mission in Portugal**. Assessment of the WaveGlider technology for sea conditions long term monitoring applied to energy resource evaluation**. Report for the Turnkey Project (Atlantic area Interreg project Contract Number: 2013-1/279). Link to report

Grell GA, Dudhia J, Stauffer D, 1994. **A description of the fifth-generation Penn State/NCAR Mesoscale Model** (MM5). NCAR Technical Note NCAR/TN-398+STR.

Mateus M, Riflet G, Chambel P, Fernandes L, Fernandes R, Juliano M, Campuzano F, de Pablo H, Neves R. **An operational model for the West Iberian coast: products and services**. Ocean Science. 2012; 8: 713-732.

NCEP/NWS/NOAA/U.S. Department of Commerce. 2015, updated daily. NCEP GFS 0.25 **Degree Global Forecast Auxiliary Grids Historical Archive. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory**. DOI: 10.5065/D6W09402.

Neves R., 2013. The MOHID concept. In: M. Mateus & R. Neves (eds.). **Ocean modelling for coastal management - Case studies with MOHID**. IST Press, Lisbon, 1-11.

Pando S, Juliano MF, García R, de Jesus Mendes PA, Thomsen L. **Application of a lagrangian transport model to organo-mineral aggregates within the Nazaré canyon**. Biogeosciences. 2013; 10: 4103-4115.

Trancoso AR, 2012. “**Operational Modelling as a Tool in Wind Power Forecasts and Meteorological Warnings**”, PhD in Environmental Engineering, Instituto Superior Técnico, Lisbon Technical University.