EVREST Project Report:
Analysis of Wave Climate

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1. Introduction

This report covers the activities performed in the framework of the following tasks: 'Task 1: Data collection and GIS integration', subtask 1.1. Compilation of existing datasets and data acquisition; and 'Task 2 – Quantification of hydrodynamic and morphologic variables', subtask 2.2. Analysis of wave records. The objectives of these tasks were the analysis of existing hydrodynamic datasets (both measured and hindcasted) of a two-decade time-series from a wave buoy deployed just offshore the barrier system, which is complemented with a 60-year wave hindcast dataset.

These tasks were programmed for a duration of 12 months (T1) and 12 months (T2), and subtasks T1.1. and T2.1., to which this report refers, were coordinated by Theocharis Plomaritis.

Activities and results are described in detail in sections 2 to 3, including references to publications and websites.

2. Wave data

2.1 Insitu data

Measured wave data time-series is about 20 years (spanning from 1993 to 2014 with variable time resolution) collected by Faro directional wave-rider buoy located about 10 km offshore of Cabo Santa Maria, in an area with approximately 93 m water depth. This data is obtained and owned by IH - Instituto Hidrográfico de Portugal (http://www.hidrografico.pt/). According to Oliveira *et al.* (2018), along the 28 years of record analysis, unregistered data episodes occurred due to occasional failure of Faro buoy, corresponding to a 19% mean percentage of unregistered data.

Following the procedure description given by Oliveira *et al.* (2018), IH buoys are equipped with sensors that measure the vertical and horizontal acceleration of sea surface, water temperature at the sea surface and the position of the buoy. Data is transmitted, by modem, to IH offices, where it is subsequently subjected to an elaborate quality control, processed and stored in a database. Presently, IH buoys acquire periodically 30 min time-series at 1.28 Hz. Under normal sea conditions, the interval between acquired time-series is 3 h. However, this interval decreases to 30 min under storm conditions. Once received and validated (quality control), time-series are subject to standard treatment by IH, which aims at estimating the characteristic wave parameters, both in time and frequency domain. For each observation period, the parameters obtained by IH are significant wave height (H_s), maximum wave height (H_{max}), mean wave period (Tz; zero-upcrossing), mean wave direction corresponding to the peak period (θ_m), and directional dispersion (σ_θ, the directional width in the peak period).

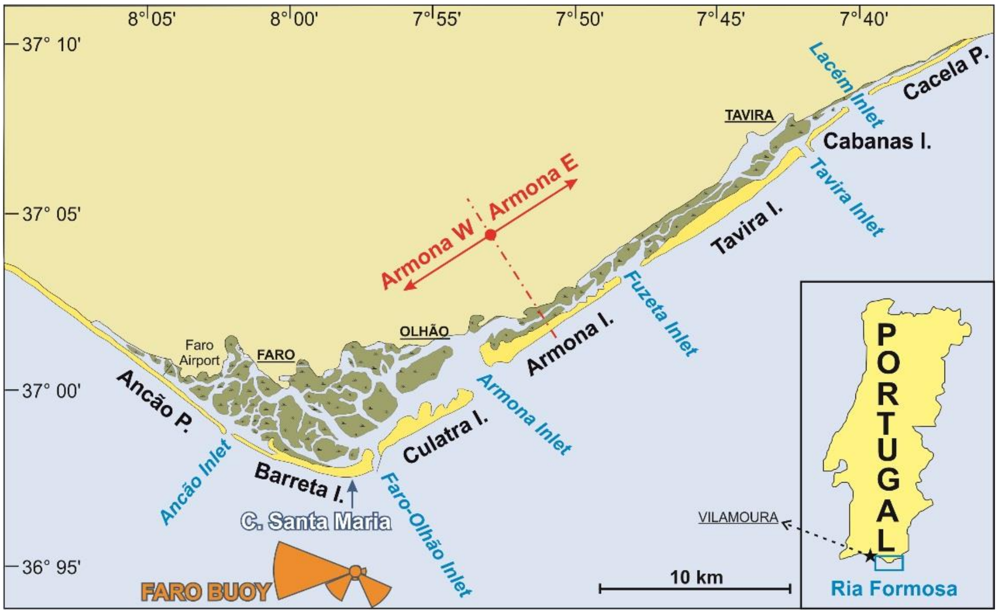

Figure 1: Location of Faro buoy, offshore the Ria Formosa barrier system.

2.2 HINDCASTING DATA

Field data is complemented with hindcast results (SIMAR; Spanish State Port Authority; http://www.puertos.es), available for the period 1958-2014. The wave hindcast was produced by the WAM model in its nested form, run in the deep-water mode, therefore the results are appropriate for the locations around the coasts where the bottom effects do not yet start to modify the wave conditions (Rusu et al., 2008). The grid point selected is the one closest to the Faro buoy position (SIMAR point 5019020). Wave parameters obtained from this dataset (H_s, T, and θ) are given in regular intervals of 3 h.

3. METHODS

3.1 WAVE RECORD ANALYSIS

Simulated significant wave heights were compared to and corrected against the buoy data for the period that the two datasets overlap (1993-2014). After correction, the two datasets were merged and analysed as a whole. The model and measured data were separated in bins of significant wave height, to evaluate model performance within these bins. In addition, due to the cuspate shape of the barrier system (Figure 1), the storms impacting the two flanks needed to be analysed separately. Thus, only waves directly incident to the coast were accounted for in each flank, i.e., for the west flank only waves from the SW sector: W to S; and for the east flank only waves from the SE sector: E to S. The results are given in Figure 2 and Figure 3 for the west and east flanks, respectively. It can be noted that there is an underestimation of significant wave heights, which is higher for more intense storms. Especially for the case of the east flank, the underestimation is more pronounced.

Table **1** includes the correlation values for all wave parameters (significant wave height, peak period and mean direction).

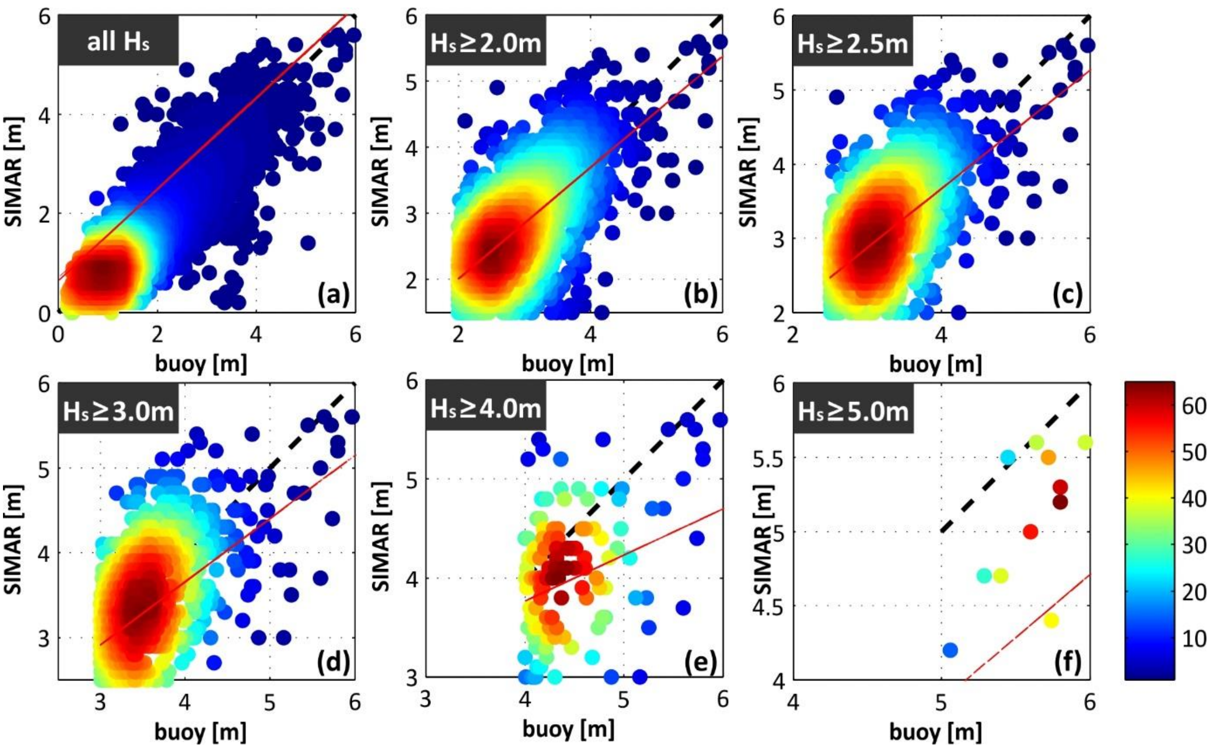

Figure 2: Comparison of observed (x: buoy data) and modelled (y: SIMAR data) significant wave heights [in m] for the West Flank: all data (a) and in five bins of increasing wave heights (b to f): Hs≥2 m, Hs≥2.5 m, Hs≥3 m, Hs≥3.5 m, Hs≥4 m ^ Hs≥5 m. The colour scale denotes the density of points, the red line the linear correlation between the two (see Table 1 for equation) and the dashed black line the perfect agreement (1:1).

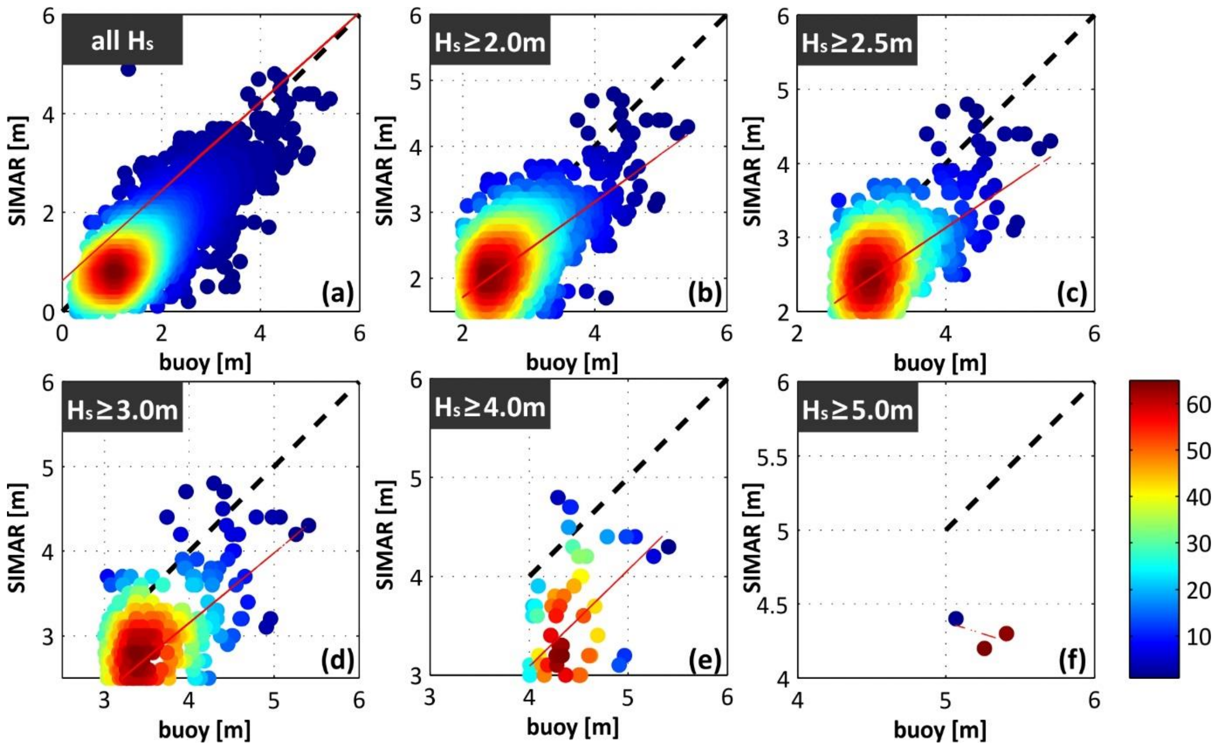

Figure 3: Comparison of observed (x: buoy data) and modelled (y: SIMAR data) significant wave heights [in m] for the East Flank: all data (a) and in five bins of increasing wave heights (b to f): Hs≥2 m, Hs≥2.5 m, Hs≥3 m, Hs≥3.5 m, Hs≥4 m ^ Hs≥5 m. The colour scale denotes the density of points, the red line the linear correlation between the two (see Table 1 for equation) and the dashed black line the perfect agreement (1:1).

Table 1: Correlations between observed and modelled wave parameters for the west and the east flank, considering all waves and five bins of increasing wave heights: Hs≥2 m, Hs≥2.5 m, Hs≥3 m, Hs≥3.5 m, Hs≥4 m ^ Hs≥5 m. (y is the linear fit between observation and simulated significant height - see Figures 2 and 3 – and R(Hs), R(Tp) and R(θ) are the correlation coefficients for significant wave height, peak period and direction).

		Significant wave height, Hs					
		all	≥2.0 m	≥2.5 m	≥3.0 m	≥4.0 m	≥5.0 m
West fl.	y=	0.92x+0.63	0.84x+0.32	0.80x+0.48	0.74x+0.68	0.46x+1.91	0.85x-0.38
	$R(H_s)$	0.91	0.68	0.56	0.45	0.35	0.37
	$R(T_p)$	0.56	0.63	0.62	0.67	0.36	0.59
	$R(\theta)$	0.29	0.56	0.56	0.57	0.63	0.80
East fl.	y=	0.91x+0.61	0.72x+0.27	0.68x+0.43	0.82x-0.14	0.98x-0.83	-0.33x+6.02
	$R(H_s)$	0.87	0.63	0.55	0.56	0.47	-0.56
	$R(T_p)$	-0.03	0.28	0.21	0.31	0.09	-0.76
	$R(\theta)$	0.29	0.43	0.47	0.56	0.07	0.88

The above results reviled relatively good correlations of the measured and simulated time-series when the full data set is used. The linear correlation parameters for the different bins are similar and correlation coefficients are dropping as the bin cut off is increasing.

Given the bimodal nature of the wave direction (storms with east and west components associated with different fetch distances), applied a correction was performed to improve the underestimation of storm wave heights, noted especially for the waves of the east sector (generated in the Gulf of Cadiz). It consisted in fitting the model wave height to observations, focusing mainly on the case of storm conditions, and evaluating the differences between model and measured wave directions using a vector correlation approach (Plomaritis *et al.*, 2015). The comparison of the initial, non-processed

data and the data after correction are given in Figure 4 and Figure 5, respectively. The wave height validation was evaluated by calculating the bias and the brier skill score (BSS). The latter parameter relates the variance of the difference between data and model with the variance of the data. BSS = 1 means perfect skill, BSS = 0 means no skill. Both wind waves and swell were analysed together since they coexist during storm events and no spectral information was available. The wave height validation and correction were evaluated through the model bias (corrected: -0.06; initial: -0.1) and the Brier Skill Score (corrected: 0.77; initial: 0.71) values.

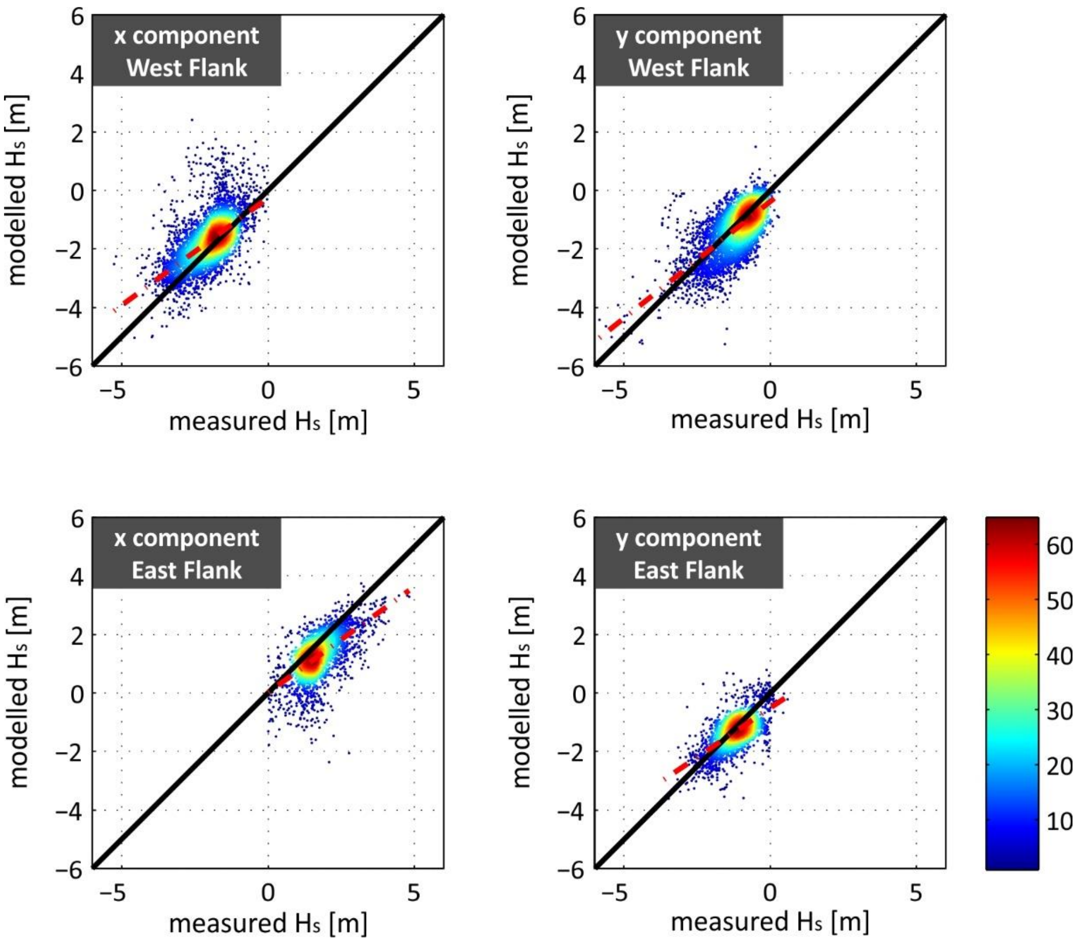

Figure 4: Comparison of observed (x: buoy data) and pre-processed, modelled (y: SIMAR data) significant wave heights [in m], analysed in longitudinal and latitudinal components (left and rights panels, respectively) for the West and East flanks (top and bottom rows, respectively). The colour scale denotes the density of points, the red dashed line shows the linear trend and the black line the perfect agreement (1:1).

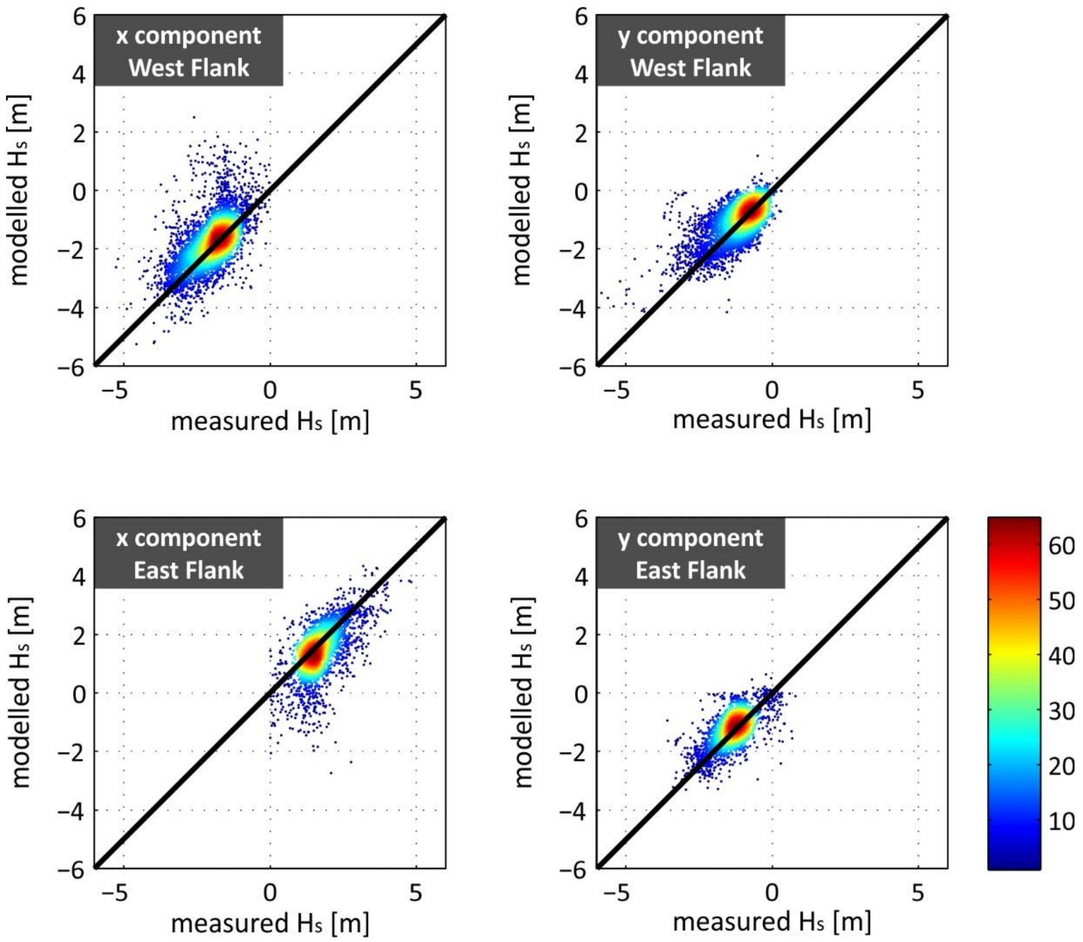

Figure 5: Comparison of observed (x: buoy data) and post-processed, modelled (y: SIMAR data) significant wave heights [in m], analysed in longitudinal and latitudinal components (left and rights panels, respectively) for the West and East flanks (top and bottom rows, respectively). The colour scale denotes the density of points and the black line the perfect agreement (1:1).

3.2 Storm identification

To identify storm events during the study period, wave records from the Faro buoy (see Figure 1 for location) and modelling results were used. In order to obtain independent events of storm conditions, a peak over threshold analysis (POT) was used (Plomaritis *et al.*, 2018). The threshold value for the POT analysis was set to 2.5 m wave height according to previous thresholds defined in the area (Almeida *et al.*, 2011) and with 0.95 quantile of the time-series as defined by Masselink *et al.* (2014). A storm (or meteorological) independence criteria (time between two consecutive independent storms) was set to 72 h (typical length of a synoptic event (Harley, 2017)). The considered storm duration threshold is 6 hours (Oliveira *et al.*, 2018), corresponding to the 95th percentile of the wave time-series (Plomaritis *et al.*, 2018). The entire time-series, obtained after correction, of storm wave characteristics, including significant wave height, peak period and direction, is given in Figure 6.

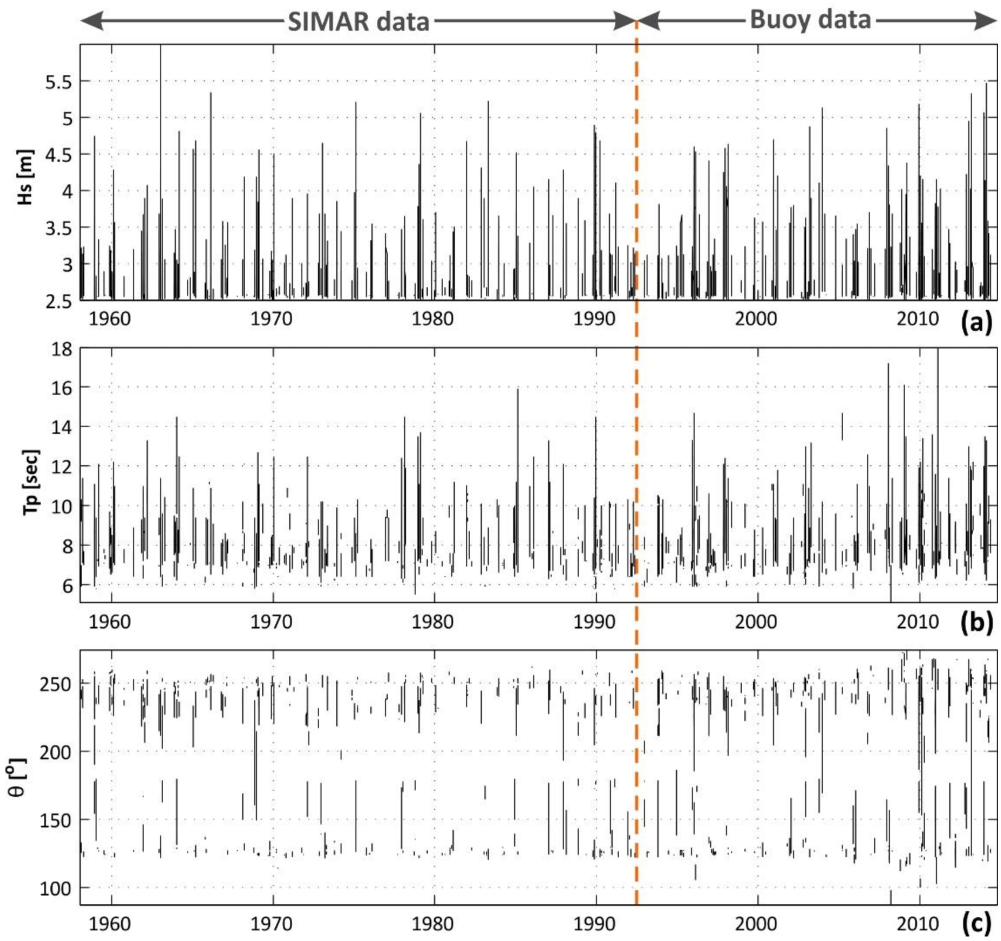

Figure 6: Composite timeseries of storm wave characteristics: significant wave height (a), peak period (b) and direction (c). The transition between SIMAR (Rusu et al., 2008) and Faro buoy (Fig. 1) datasets is noted with a dashed line.

In order to link this data to the geomorphological evolution of the barrier islands in Ria Formosa (Task 3), it was necessary to examine interannual to decadal storm incidence in the area and, thus, storm characteristics needed to be transferred to annual timescales. The yearly timeseries of average storm significant wave height and total duration for the two flanks is given in Figure 7.

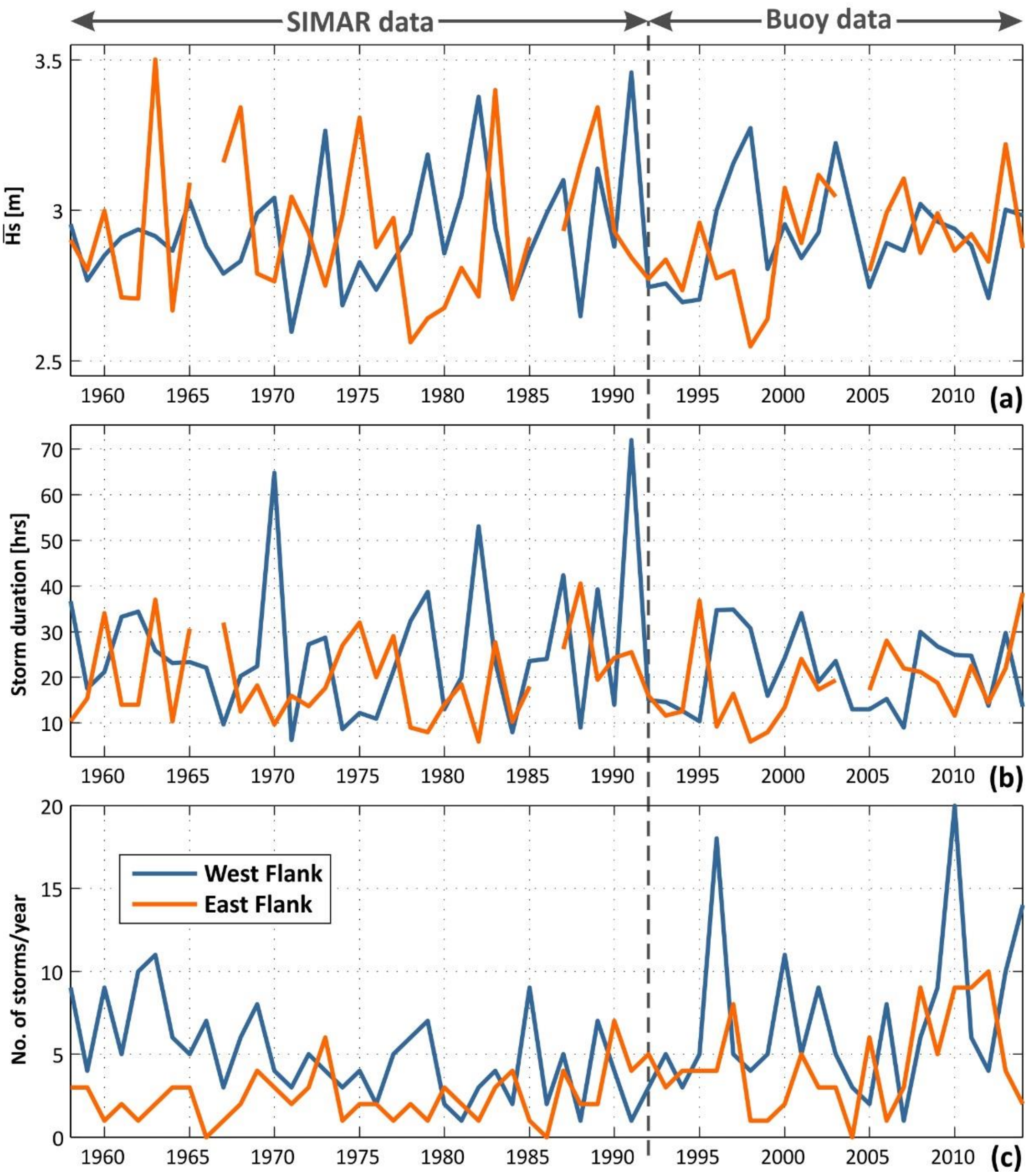

Figure 7: Storm waves in the west (blue line) and the east (orange line) flank: average storm significant wave heights (a) and total annual storm duration (b) and number of storms per year (c). The transition between SIMAR (Rusu et al., 2008) and Faro buoy (Fig. 1) datasets is noted with a dashed line.

4. Final remarks

- Measured and forecasted data were compared in order to estimate the performance of hindcasted data.
- The comparison showed that the two data set are largely in agreement with small differences mainly at the extreme storm conditions. Such differences were corrected by applying a vector correlation method.
- After correlation the two data set were combined constructing a synthetic wave time-series with a total extend of 55 years.

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