Universitat Politécnica de Catalunya

Laboratori d' Enginyeria Marítima

# Coastal Vulnerability to Storms in the Catalan Coast

Memoria presentada por

**Ernesto Tonatiuh Mendoza Ponce**

para optar al grado de Doctor por la
Universitat Politécnica de Catalunya.

Director:

**José Antonio Jiménez Quintana**

Barcelona, Enero del 2008

# Appendix A

# Long term storm characterization

This appendix describes the followed methodology to apply the storm scale already obtained in section 3.2.1 in order not only to obtain a long term but also a spatial storm characterization in the Catalan coast. This was done through a series of steps which have been defined as follows: (1) Develop a technique to transform the HIPOCAS node 2056046 wave data and make it equivalent to the Cap Tortosa buoy (Figure A.1). (2) Identify storm events and categorize them according to the five class storm classification given in section 3.2.1. (3) Obtain a long term storm characterization using the HIPOCAS node. (4) Acquire a long term spatial storm characterization of each of the 8 designated areas along the Catalan coast derived from the different HIPOCAS nodes (Figure A.1).

## HIPOCAS

The SIMAR-44 data base contains atmospheric and oceanographic parameters throughout the entire Iberian Peninsula from 1958 to 2001 was done by Puertos del Estado within the European project called HIPOCAS. From this point on the SIMAR-44 wave data will be referred as HIPOCAS. The HIPOCAS wave data was generated with the WAM spectral wave model with a grid resolution of approximately 12.5 by 12.5 Km (Guedes Soares *et al.*, 2002). According to the source, the data must be interpreted as open water at an indefinite depth. The

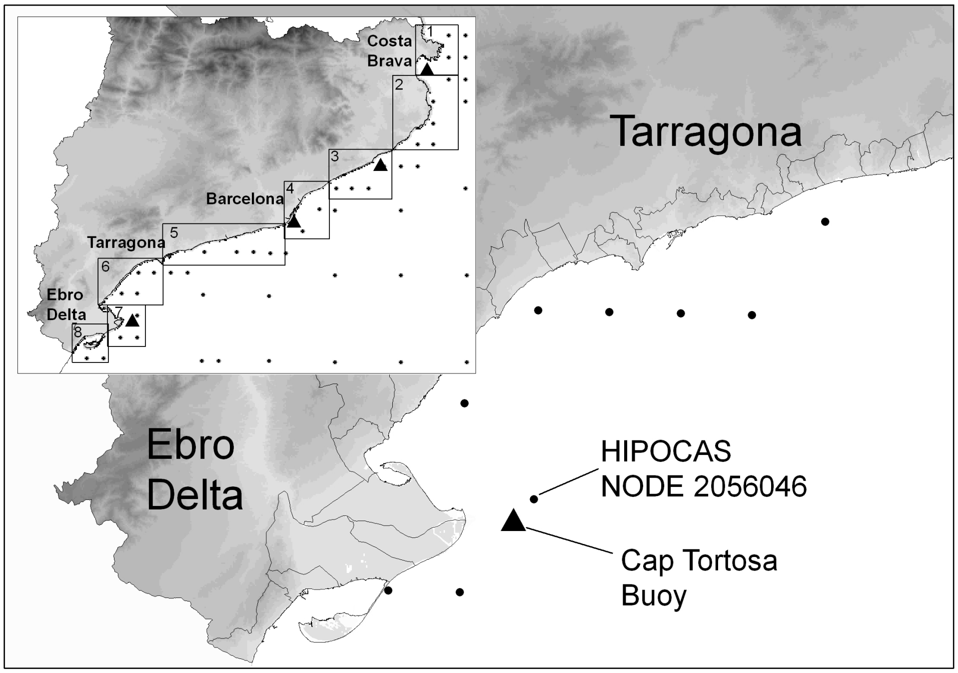


Figure A.1: Localization of the HIPOCAS node 2056046 and the Cap Tortosa buoy and the designated zonation of the coast.

HIPOCAS nodes presented wave height data derived from the model and corrected wave height data, this correction was obtained through a probability distribution using a buoy not specified by Puertos del Estado and the modelled data via equation A.1:

$$H_{corrected} = 1.703 H_{original}^{0.79} \tag{A.1}$$

Due to the fact that there was no information about how the corrections were done (usually through a validation process using real data obtained by a buoy) the first step was to compare the original and the corrected values by means of a linear regression which is presented in Figure A.2, as all the data was corrected via equation A.1 we can say that it was done in a scalar manner and applied to all directions. Figure A.2 shows that all the values are above the 1:1 linear regression (line across the figure) which means that all calibrated values will be higher than the original modelled value. Another feature of the plot is the quasi-linear behaviour

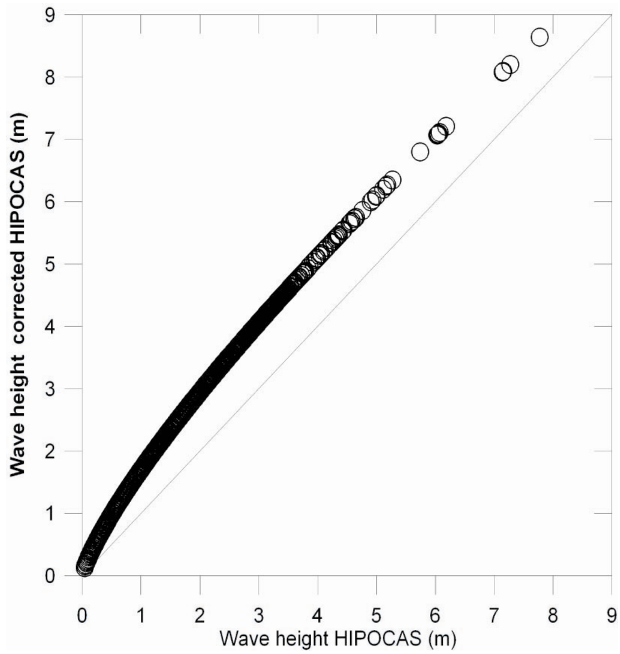


Figure A.2: Corrected versus original HIPOCAS data corresponding to the whole data set.

between the two data sets; consequently if we plot either the original or corrected HIPOCAS values against the wave height data form Cap Tortosa, the same dispersion will be obtained. In other words we will have an almost uniform displacement of the wave height using either data set. In view of the fact that the corrected values present higher wave values and that there is no information available to check the correction parameters, it was decided to use the original wave data series for this study.

## Modelled vs. real data through a linear correlation

The initial step was to find a methodology to transform the HIPOCAS wave height values and make it equivalent to the Cap Tortosa buoy. It was first assumed that the wave data from the two sources must present similar or related values since both are from the same area (Figure A.1). For this purpose it was mandatory to have simultaneous wave data which was restricted to the time period from June 1990 to November 2001 from which the Cap Tortosa Buoy presented some gaps (Figure A.3above) and were reproduced in the HIPOCAS data series (Figure A.3).

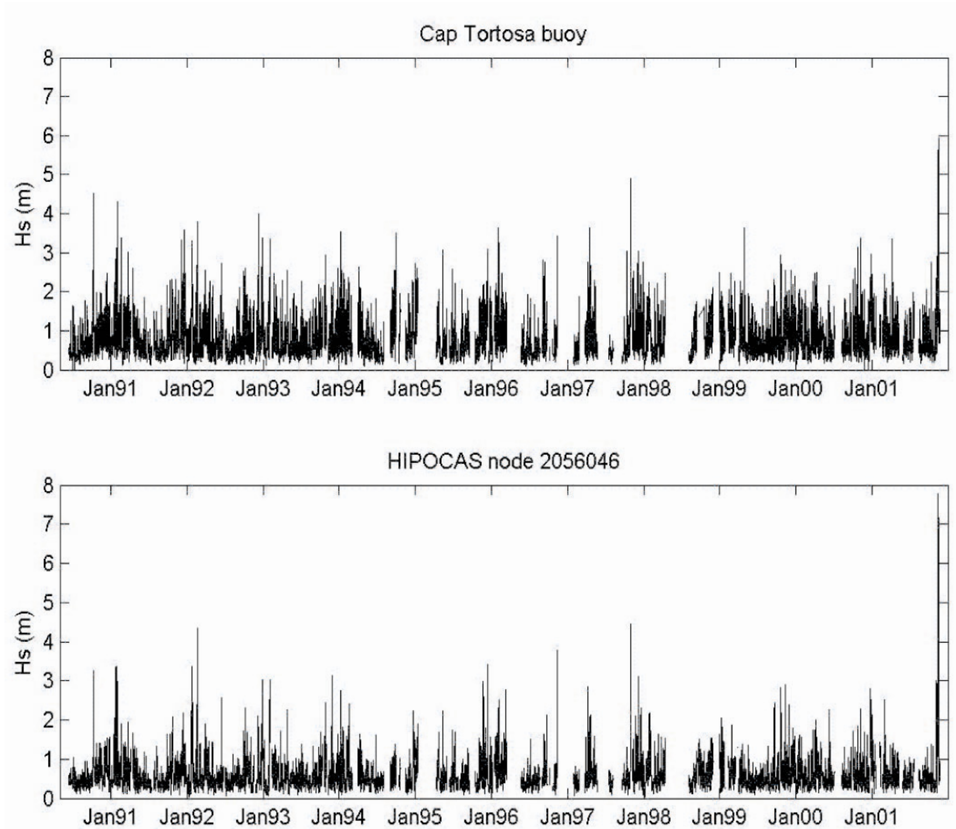


Figure A.3: Wave heights from June 1990 to November 2001 in Cap Tortosa Buoy (above) and HIPOCAS node 2056046 (below).

As a first approach it was presumed that a linear function will describe any relation between both wave data. The analysis was done by means of a linear regression by least squares in which the determination coefficient $r^2$ can be interpreted as indicative of the ability of the linear model to represent the data. From the series of linear correlations, it was first used the entire simultaneous wave heights for the entire time period (Figure A.4 left), and using only the wave data of the identified storm events (see storm definition in section 3.3) from the cap Tortosa buoy (Figure A.4 right). The next linear correlation was done only considering E and S storms (Figure A.4 right) which was done because of information given by Puertos del Estado *"the model correctly reproduces the regional winds from the E and the*

*S”* and because as mentioned before in section 3.3.2 the NW component waves propagate off shore and are non effective for coastal dynamic effects (Figure A.5 left).

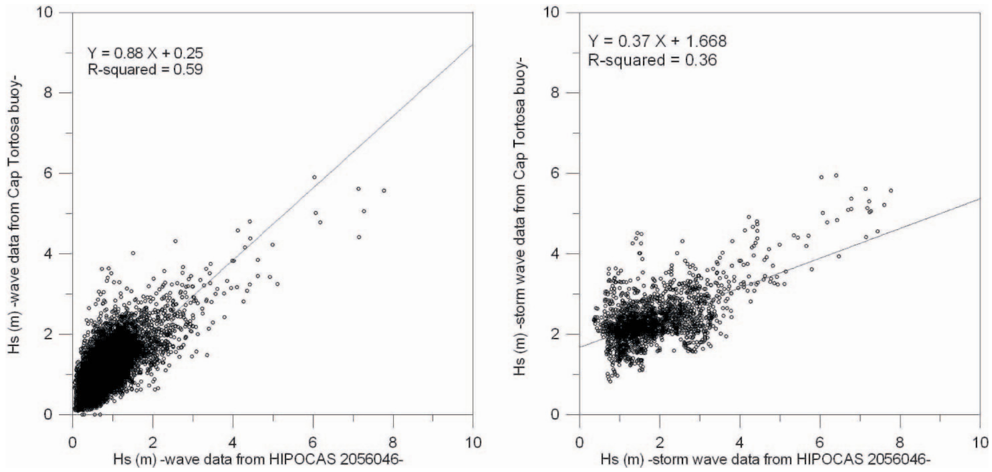


Figure A.4: Linear regression between simultaneous wave data form Cap Tortosa Buoy versus HIPOCAS wave data (left) considering only storm conditions (right) The Hs < 2m is *Hs* data within an identified storm.

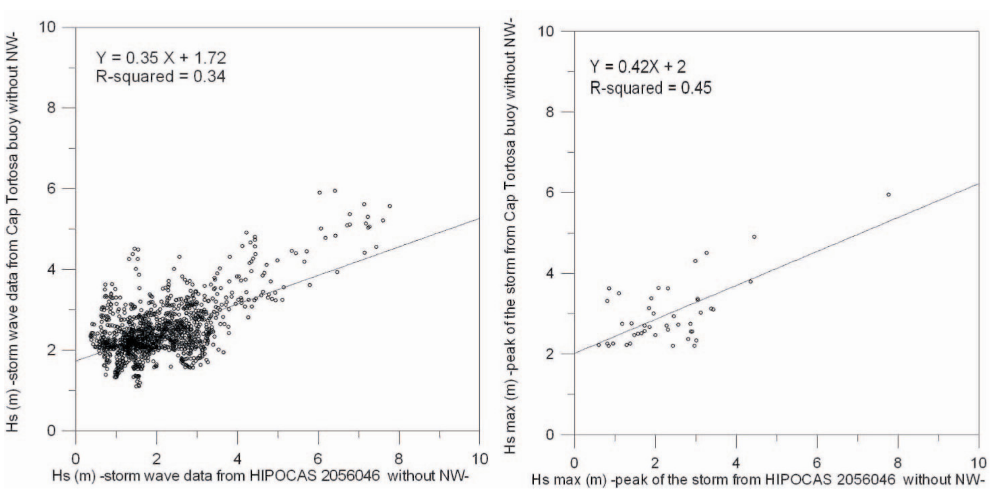


Figure A.5: Linear regression between simultaneous storm wave data without NW storms form Cap Tortosa Buoy versus HIPOCAS wave data and considering the maximum wave height for each storm.

Lastly a linear correlation was done using the maximum wave height (peak of the storm) of each storm for the purpose of reducing the number of data points (Figure A.5 right).

The first linear regression using the entire simultaneous wave heights presented an $\boldsymbol{r^2}$= 0.59 and presented some dispersion, especially with wave data under 2 meters (lower left portion of Figure A.4 right). The second linear regression which considered the wave heights during storm events (Hs > 2 m) derived in a reduction of dispersion due to the decrease of wave data but a significant reduction of the fit ($\boldsymbol{r^2}$= 0.36). The following comparison was done just considering storm wave heights with E and S component which yielded results practically identical to the previous analysis ($\boldsymbol{r^2}$ = 0.34). Finally, when considering only the maximum wave height of each storm presented a dispersion reduction (due to the large reduction in data) with and a slight increase in the $\boldsymbol{r^2}$ (0.45).

## Probability distribution

Given the previous results it was decided to carry out a probability analysis using the same wave data, based on the assumption that both are representative of the same site and therefore must have the same probability. The Weibull frequency distribution adjustment was applied into both sites. Equation A.2 is a three parameter equation derived for the Cap Tortosa buoy, and Equation A.3 is derived for the HIPOCAS node data.

$$F_T\left(H_{mo}\right) = 1 - \exp\left\{-\frac{H_T - A_T{}^{CT}}{B_T}\right\} \quad \text{(A.2)}$$

With the parameter values of $A_T$ = 0.11, $B_T$ = 0.750, $\boldsymbol{C_T}$ = 1.33 with an $r$ = 0.99.

$$F_H\left(H_{mo}\right) = 1 - \exp\left\{-\frac{H_H - A_H{}^{CH}}{B_H}\right\} \quad \text{(A.3)}$$

With values of $A_H$ = 0.05, $B_H$ = 0.548, $C_H$ = 1.08 with an $r$ = 0.99.

Both equations were equalized and reduced in order to obtain the probability distribution of the wave height in Cap Tortosa using the wave height of the HIPOCAS model and is expressed in Equation A.4 and was used to correct wave height data from HIPOCAS from June 1990 to November 2001 and making it simultaneous to the Cap Tortosa buoy data series. Both data sets were used for a linear regression by least squares analysis in which the determination coefficient ($R^2$).

$$H_T = A_T + \left\{ B_T - \left( \frac{H_H - A_H}{B_H} \right)^{\frac{C_H}{C_T}} \right\} \tag{A.4}$$

The first one was done using the complete wave data (Figure A.6 right); the second one was done using the data that was identified as a storm event in the Cap Tortosa buoy with its correspondent HIPOCAS data and lastly the correlation was done using only the maximum wave height for each storm (Figure A.6 left). We must say that all storm directions were considered this time based on earlier findings that storm direction does not influence in a significant manner the analysis (see Figures A.4 and A.5).

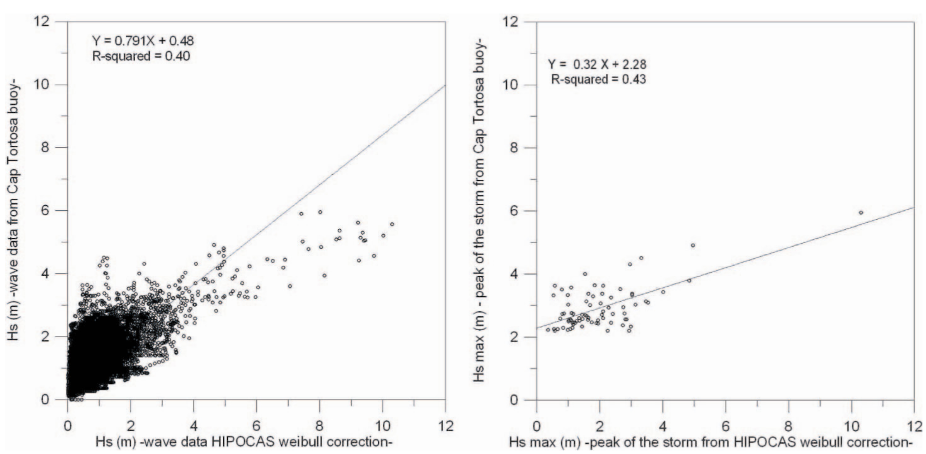


Figure A.6: Linear regression between simultaneous storm wave data without NW storms form Cap Tortosa Buoy versus HIPOCAS wave data (left) and considering the maximum wave height for each storm (right).

The overall results yielded $r^2$ values ranging between 0.43 and 0.38. (Figure A.6 right) shows large dispersion which is greatly reduced just considering the peak of the storms (Figure A.6 left). Although the best fit was found using the maximum wave height during a storm this value proves to have poor correlation.

# Data Equivalence

The highest overall obtained R-squared value was the linear correlation considering the entire simultaneous wave height data ($r^2$= 0.59), the second best linear correlations were obtained considering the peak of the storm ($r^2$ = 0.45) for both linear correlation and probability distribution. When considering wave data during storms the linear fit dropped down to an ($r^2$ = 0.36) and ($r^2$ = 0.38) respectively. It seem that the storm direction does not influence in a significant manner the previous analysis, since a very similar fit was obtained ($r^2$ = 0.34) similar to the one considering all storm directions.

Asides the best linear correlation found ($r^2$ = 0.59), all the other results show a poor relation, which makes questionable the proper representation of the HIPOCAS wave data to characterize wave height on a wave on wave basis. The results obtained using a probability distribution to correct the wave height data series yielded to some extent inferior results to the ones acquired using the linear correlation correction. Therefore when using the HIPOCAS data for storms analysis it must be kept in mind that these should only be used as an indicative of the real conditions.

According to the first objective of this analysis, It is proposed the use of Equation A.5 to use the HIPOCAS node 2056046 wave data and make it equivalent to the Cap Tortosa buoy.

$$Hs_{Tortosa} = 0.88(Hs_{Hipocas}) + 0.25 \tag{A.5}$$

Bearing in mind equation A.5, and storm classification based on Table 3.3.2, it was possible to attain long term storm characterization (1958- 2001) for the HIPOCAS node 2056046 wave data (see table A.1).

Table A.1: Five class storm categories for Hipocas node 2056046 based on the *Hs*. (n: number of storms; Duration (hours); *Hs* max: wave height in the peak of the storm; *Tp*max: peak period associated to the *Hs* max.

| *Storm Class* | *Direction* | *Number* *n* | *Duration* *(hrs)* | Hs max. *(m)* | Tp *max.* *(s)* |
|---|---|---|---|---|---|
| I | All | 123 | 16 | 2.3 | 8.1 |
| I | E | 73 | 19 | 2.4 | 8.7 |
| I | S | 24 | 13 | 2.4 | 7.7 |
| I | Other | 26 | 10 | 2.3 | 6.8 |
| II | All | 48 | 31 | 3.0 | 8.9 |
| II | E | 40 | 33 | 3.1 | 9.2 |
| II | S | 5 | 23 | 3.0 | 8.8 |
| II | Other | 3 | 17 | 3.0 | 6.1 |
| III | All | 7 | 43 | 3.9 | 10.8 |
| III | E | 6 | 45 | 3.9 | 11.1 |
| III | Other | 1 | 28 | 3.6 | 9.2 |
| IV | All E | 3 | 73 | 4.5 | 10.2 |
| V | All E | 2 | 123 | 6.3 | 15.3 |

From the long term data series, class I storms were the most frequent (123 storms), with a rather small mean duration (16 hrs) and a mean maximum wave height of 2.3 m. Class II storms were frequent (48 storms) and a mean duration which doubles the previous class (31 hours). Significant storms (class III) had a lesser number of storms (7 storms) with a significant increase in mean storm duration (43 hours) presenting only E and S storm direction components. Class IV storms was represented by three E storms with a duration of 73 hours and a maximum wave height of 4.5 meters. Finally, class V -extreme- storm was characterized by two storms which presented a mean duration of approximately 5 days (123 hours) and a maximum wave height of 6.3 m. According to this analysis the extreme events in the last 43 years have been the storms from December 1980 and September 2001 which was ranked as the seventh highest intensity cyclone in the Mediterranean in the last 45 years (Genovés *et al*., 2006).

# Long term spatial storm characterization

Once achieved the long term storm characterization, there was doubt about using the same linear regression for all the HIPOCAS nodes along the Catalan coast, so all the buoys were compared by using a linear regression with the nearest HIPOCAS nodes (Barcelona buoy was compared with node 2062049, the Blanes buoy was compared with node 2071053 and the ROSES buoy was compared with node 2075058) in order to validate this assumption.

As presented in Figure A.7 the obtained linear regression in the Barcelona and the Blanes region presented very similar regressions. The Roses buoy did not present the same regression, due to several reasons, for example the northern wind has a significant role on the wave regime in that region, the HIPOCAS node position is seaward and it is quite far from the buoy, with this reasoning it was decided to use equation A.5 for the HIPOCAS nodes along the shoreline.

The HIPOCAS nodes were divided in a series of sectors (Figure A.7, in order to achieve spatial characterization on the long term. The eight sectors were divided based on coast orientation, HIPOCAS node coverage, and making special emphasis in wave characteristics in deep waters do not significantly vary. For each sector one HIPOCAS node was selected this choice was the previous buoy-node analysis and the distance form the coast (approximately 10 km). The final spatial long term characterization is fully described and can be seen in section 3.3.4.

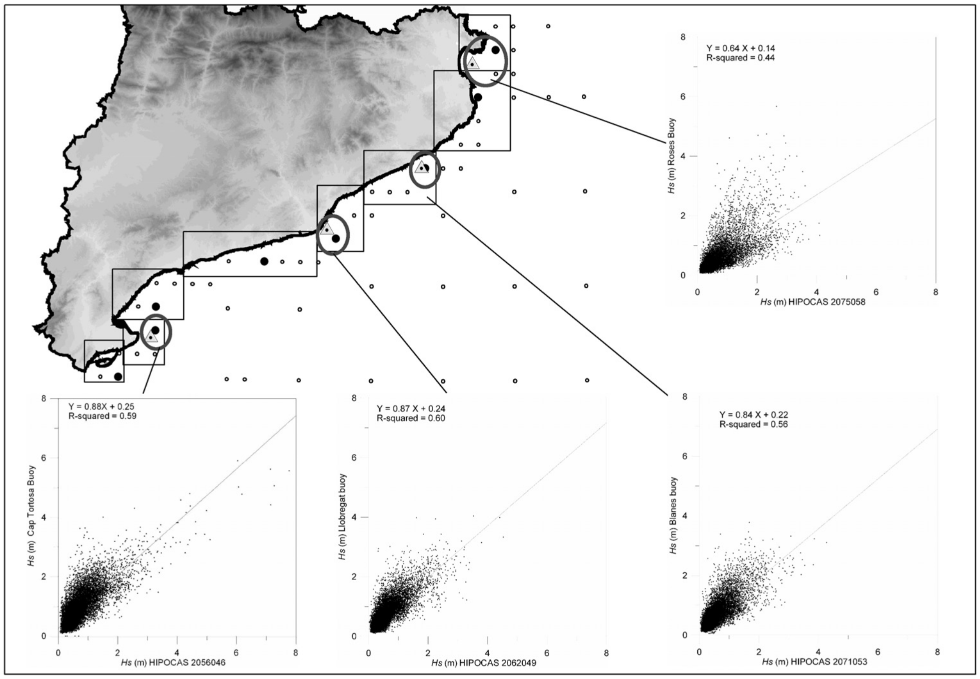


Figure A.7: Linear regressions using (from South to North) Cap Tortosa buoy vs. node 2056046, Barcelona buoy vs. 2062049, Blanes buoy vs. 2071053 and Roses buoy vs. node 2075058).