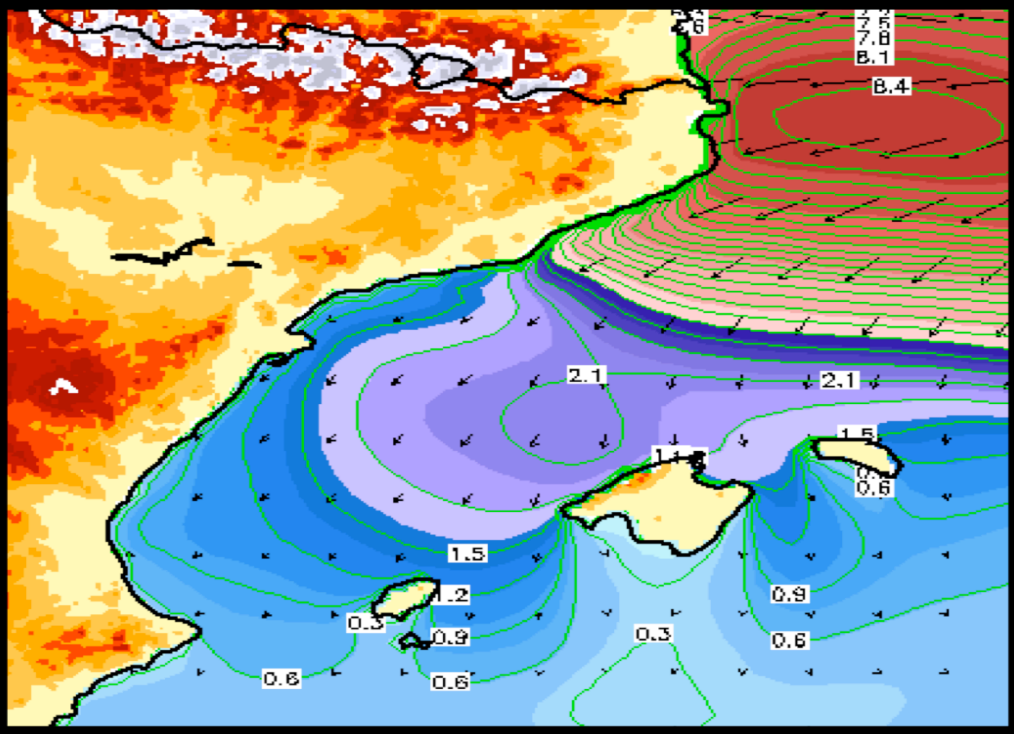

Sant Esteve's Storm (2008)

José Antonio Jiménez

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Abstract

The presence of a shallow depression over the Balearic Sea with a minimum pressure of 1012 hPa and a high pressure centre over northern Europe (1047hPa) around the 26 December 2008 (Sant Esteve's Day), originated an extreme storm with maximum wave heights of 14.4 m coming from the east. This event, is the largest ever recorded (in terms of wave height) at the locations of Roses and Palamós (Costa Brava, Spain). Using the linear theory for the wave power per unit length of wave crest in deep water condition, the analysis of the storm identified three different areas: (i) the northernmost part of the Catalan coast (Costa Brava), with the greatest wave power and heights; (ii) the central coast (north Barcelona), where the wave power decreased down to about half of that in the northern area; and (iii) the southernmost area (Barcelona and south Barcelona), where the wave power was only one third of that of the Costa Brava.

Image: Wave forecasting model by Servei Meteorològic de Catalunya

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Characterising Sant Esteve's extreme storm (26th December 2008) along the Catalan coast (NW Mediterranean)

By

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Resumen

Una depresión superficial sobre el Mar Balear (1012 hPa) junto con altas presiones en el norte de Europa (1047 hPa) en torno al 26 de Diciembre de 2008 (Día de Sant Esteve), dio lugar a una tormenta extrema con alturas máximas de ola de 14.4 m procedentes del este. Se trata del evento más extremo registrado por las boyas de Rosas y Palamós (Costa Brava, España). Aplicando la teoría lineal para la potencia de ola por unidad de longitud de cresta de ola en condiciones de aguas profundas, el análisis de la tormenta ha identificado tres áreas diferentes: (i) el norte de la Costa Brava, con máximas potencia y altura de ola; (ii) la costa central (norte de Barcelona), con potencias y alturas la mitad que en la Costa Brava; (iii) un área más al sur (Barcelona y sur de Barcelona) donde se registraron potencias y alturas un tercio de las registradas en la Costa Brava.

Abstract

The presence of a shallow depression over the Balearic Sea with a minimum pressure of 1012 hPa and a high pressure centre over northern Europe (1047hPa) around the 26 December 2008 (Sant Esteve's Day), originated an extreme storm with maximum wave heights of 14.4 m comming from the east. This event, is the largest ever recorded (interms of wave height) at the locations of Roses and Palamós (Costa Brava, Spain). Using the linear theory for the wave power per unit length of wave crest in deep water condition, the analysis of the storm identified three different areas: (i) the northernmost part of the Catalan coast (Costa Brava), with the greatest wave power and heights; (ii) the central coast (north Barcelona), where the wave power decreased down to about half of that in the northern area; and (iii) the southernmost area (Barcelona and south Barcelona), where the wave power was only one third of that of the Costa Brava.

Introduction

Storms generated by easterly winds tend to affect the Catalan coast with a clear seasonality, and can therefore be considered a recurrent and relatively predictable phenomenon. They occur due to very specific weather conditions: the emergence of a cyclone in the Gulf of Cadiz, which enters the Mediterranean through the Strait of

Gibraltar moving towards Italy and stopping on the NW Mediterranean, while the anticyclone occurs over the Nordic countries or central Europe. The atmospheric pressure drops remarkably and the wind blows from the E or ENE over the Mediterranean Sea, causing significant wind waves. These storms are usually associated with heavy rainfall caused by the subsidence inversion that builds up heat and moisture (Llasat & Puigcerver, 1994). The easterly storms usually occur during late autumn and early winter and less regularly in spring. According to the study by Mendoza & Jiménez (2008), two statistically distinct seasons can be defined in the year: the storm season, from October to April, and the calm period from May to September. This seasonality has been so constant over the years that locally the storms have been given names associated with other things that occur at the same time, the spring storm is called the *temporal de les faves* (storm of the beans) and the autumn storm is called the *renta-botes* (the barrel cleaning storm).

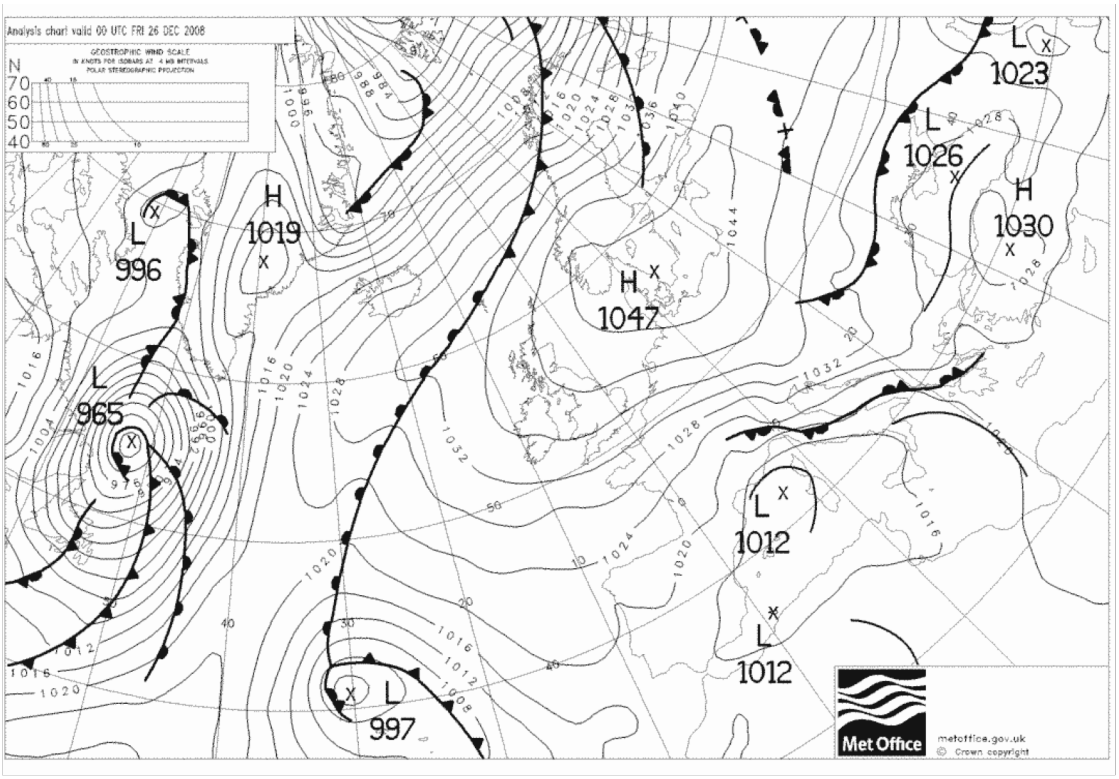

Figure 1. Sea-level atmospheric pressure during the Sant Esteve's storm of 2008.

Some of the data recorded by the Palamós buoy during the storm of December 2008 were impressive, especially for the Mediterranean Sea: the storm lasted 73 h (Hs> 2m), the Hs reached 7.5 m and there was a maximum wave height (Hm) of 14.4

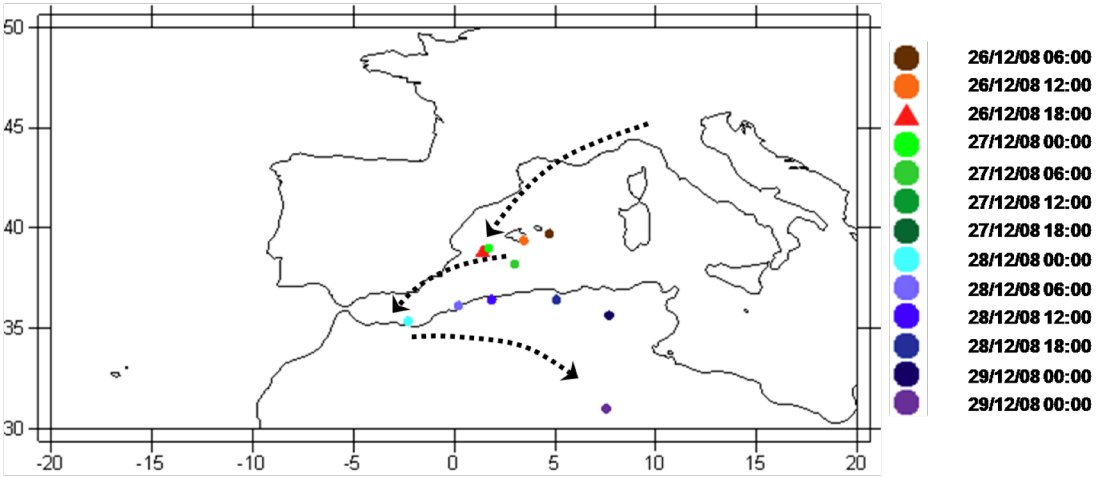

Figure 2. Evolution of the cyclone centre during the Sant Esteve's storm (from 26/12/2008 to 29/12/2008). The red triangle indicates the centre's position at the moment of the largest recorded *Hs*. Arrows indicate the approximate displacement of the centre (from Mateo, 2010).

meters. The storm progressively lost strength as it moved south: Tordera buoy (Hs= 4.65m; Hm= 7.99m; T= 66h), Llobregat buoy (Hs= 4.65m; Hm= 7.31m; T= 55h), and Tortosa (Hs = 3.24 m, Hm = 7.99 m, T = 56h). The most affected areas were the central and northern Costa Brava, and the storm became less violent north of the Roses buoy (Hs = 6.37 m, Hm = 9m, T = 64h).

Synoptic conditions

The synoptic conditions during the Sant Esteve storm were characterised by the presence of a shallow depression over the Balearic Sea (Fig. 1) with a minimum pressure of 1012 hPa and a high pressure centre over northern Europe (1047hPa). This is one of the typical mechanisms of cyclogenesis in the Mediterranean (e.g. Trigo et al. 1999, 2002). The initial position of the low pressure centre was located in the Gulf of Genoa which is one of the main areas of cyclogenesis in the Mediterranean (see e.g. Trigo et al. 1999). During the storm, the low pressure centre behaved as a "travelling low" slowly moving along the Catalan coast (Fig. 2).

Under these conditions, the action of strong NE winds in the Gulf of Lyons generated an extreme wave storm which affected the Catalan coast. Figure 3 shows the wave height forecasting calculated for storm conditions by the Servei Meteorologic de Catalunya. As it can be seen, large wave heights were only predicted for the top northern part of the Catalan coast, whereas the rest remained fairly protected.

Methods

To characterise wave conditions along the coast during the storm, we used the records obtained by the different wave buoys in Catalan

waters (Fig. 4). Annexes 1 to 5 show the wave conditions recorded in each of the buoys from N to S. Table 1 summarises the main storm characteristics at each site. The wave height values recorded on the northern part of the coast (Roses and Palamós) indicate that the storm can be classified as extreme according to the storm classification of Mendoza and Jiménez (2008) and Mendoza et al (2011). In fact, this storm is the largest recorded event (in terms of wave height) at these two locations.

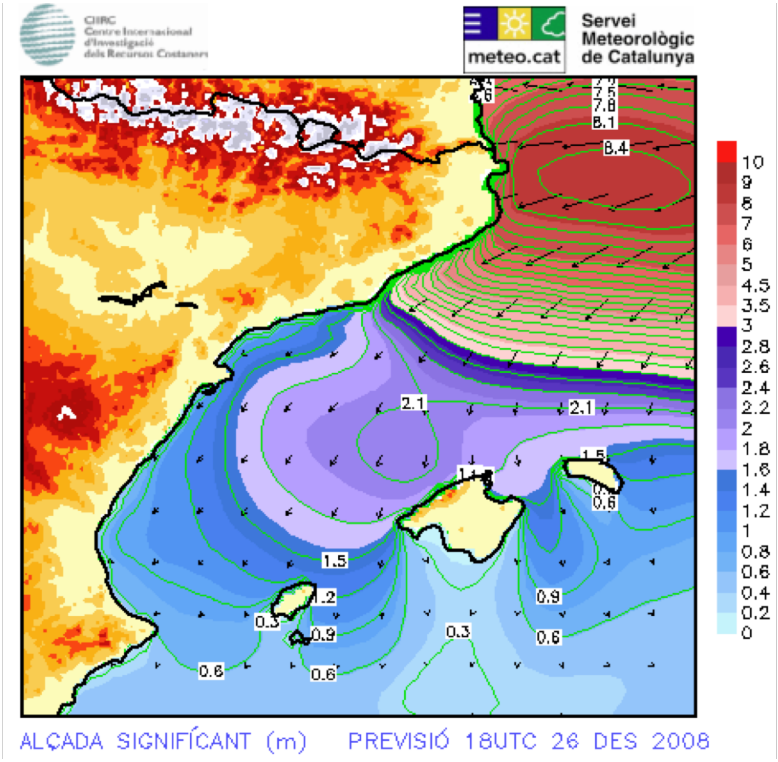

Figure 3. Wave forecasting using the *WAM* wave forecasting model for the Sant Esteve's storm conditions (Servei Meteorologic de Catalunya, 2008).

However, the storm characteristics on the southern Catalan coast were not exceptional and the storm could be classified as moderate.

Table 1 shows the main characteristics of the storm as recorded from N to S along the Catalan coast. One of the common ways of characterising storm-induced processes is by evaluating its energy content (see e.g. Bromirsky and Kossin, 2008). Here we have used the expression given by the linear theory for the wave power per unit length of wave crest, P, in deep water conditions, which is given by:

$$P = \frac{\rho g^2}{32\,\pi} \int_{t1}^{t2} H_s^2 T_p dt$$

Conclusions

Using the integrated wave power during the storm duration, three different areas can be identified: (i) the northernmost part of the Catalan

coast (Costa Brava) – characterised by the Roses and Palamós buoys – where the greatest wave power, the largest wave heights, and the longest storm duration were recorded, and where the storm first began; (ii) the central coast – characterised by the Tordera and Llobregat buoys – where the wave power decreased down to about half of that in the northern area, with smaller wave heights (although still large), a slightly shorter duration and slightly later impact; and (iii) the southernmost area, where the wave power was only one third of that of the northern area, with relatively small wave heights.

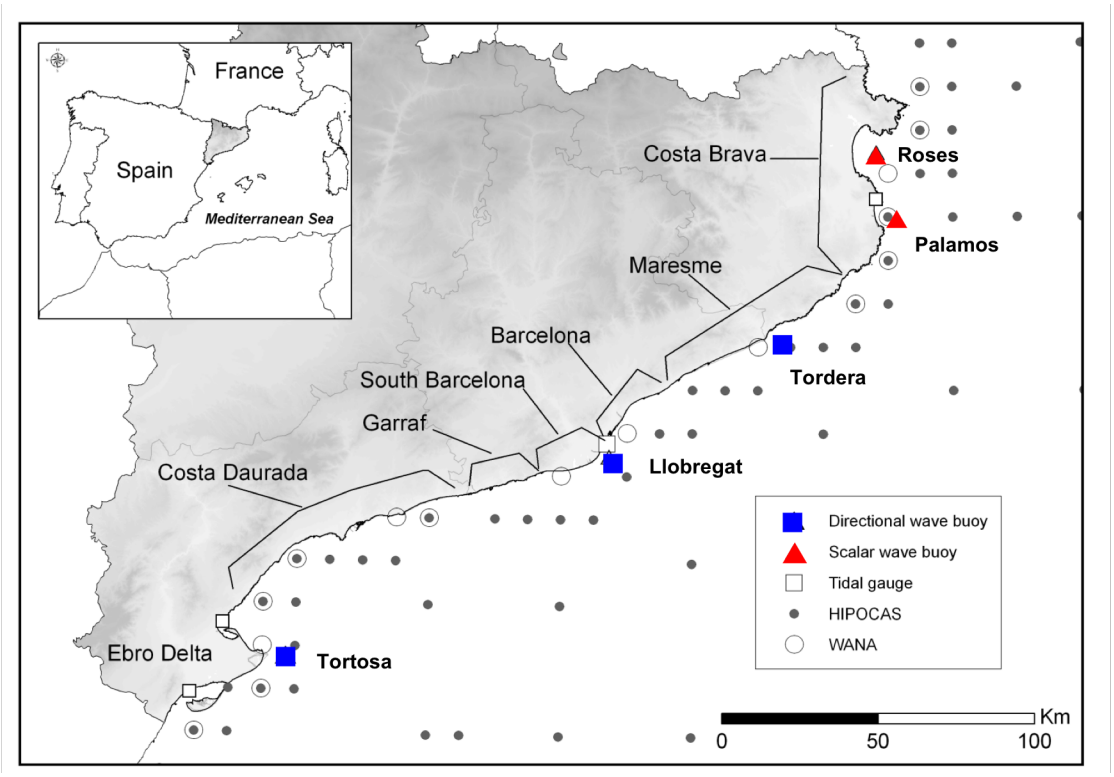

Figure 4. Location of wave buoys along the Catalan coast.

Acknowledgments

Thanks are due to the Department of Public Works of the Generalitat de Catalunya and Puertos del Estado of the Spanish Ministry of Public Works for supplying wave data. JAJ collaborated within the context of the VuCoMa research project funded by the Spanish Ministry of Research and Innovation (CTM2008-05597/MAR).

The author thanks Toni Garcia for contributing with enriching comments to this manuscript and to CSIC for funding the general framework project "Assessment of the ecological impact of the extreme storm of Sant Esteve (26 December 2008) on the littoral ecosystems of the north Mediterranean Spanish coasts" (PIEC 200430E599).

Table 1. Storm main characteristics as recorded from N to S of the Catalan coast. *Hs*: significant wave height at the peak of the storm, *Hmax*: maximum individual wave height at the peak of the storm; *Tp*: wave peak period at the moment of the largest *Hs*, *Tz*: mean wave period at the moment of the largest *Hs*; *Dur*: storm duration defined as the period of time during which *Hs* > 2 m; *Direc*: mean wave direction during the peak of the storm (- : no recorded value because the buoy was scalar); *P*: wave power integrated over the storm duration; *Day, hour*: moment of the peak of the storm at each location).

Buoy	Hs (m)	Hmax (m)	Tp (s)	Tz (s)	Dur (h)	Direc (º)	P (MW)	Day	Hour
Roses	6.4	9	14.6	9	64	-	50,564	26	16:00
Palamós	7.5	14.4	12.8	9.6	73	-	49,100	26	17:00
Tordera	4.65	8.0	14.3	8.2	66	88	25,161	26	18:00
Llobregat	4.65	7.3	13.3	8.3	55	86	21,748	26	20:00
Tarragona *	1.9	-	6.4	-	-	-		26	13:00
Tortosa	3.2	5.8	13.3	7.3	56	75	15,155	27	6:00

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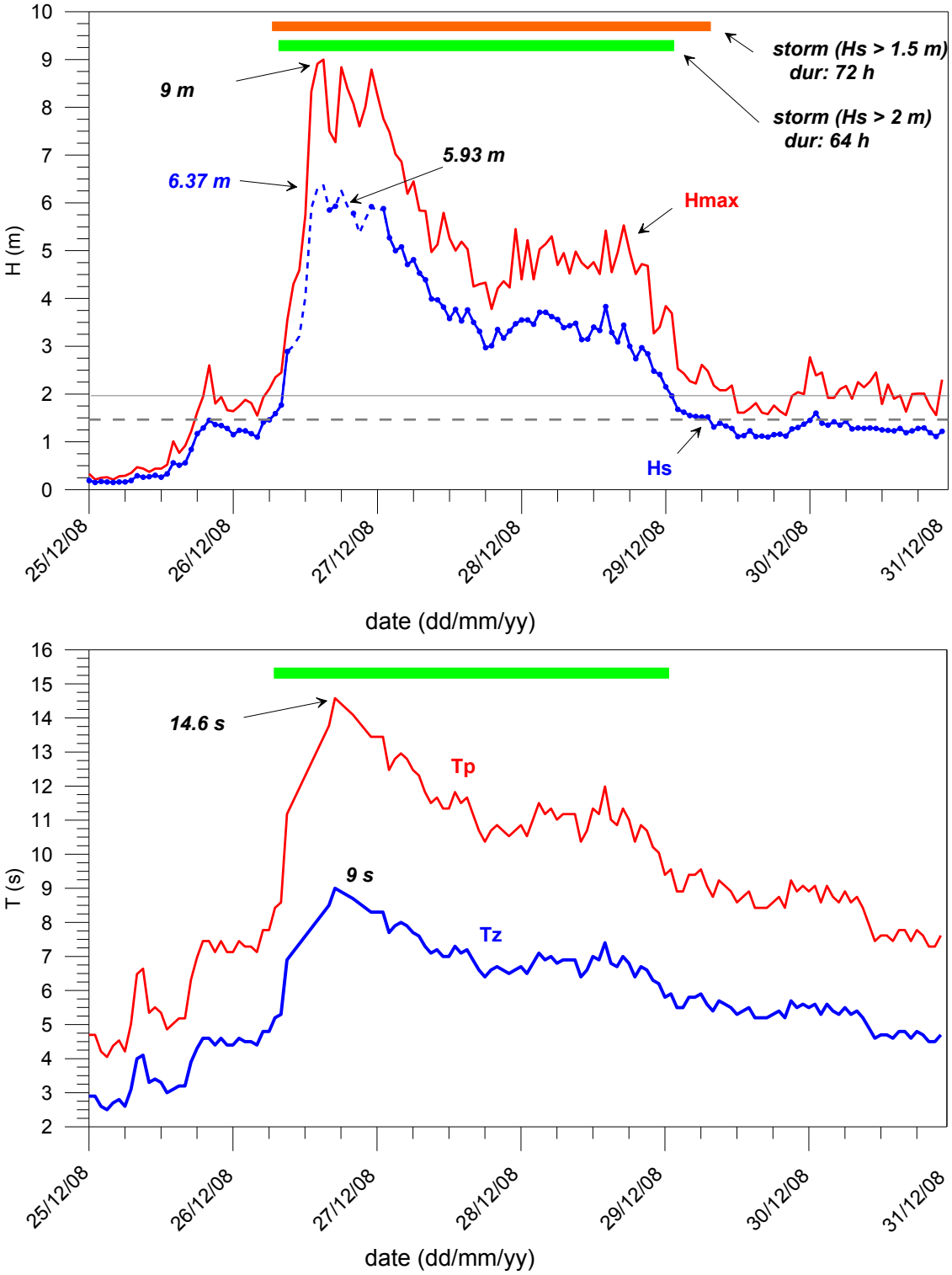
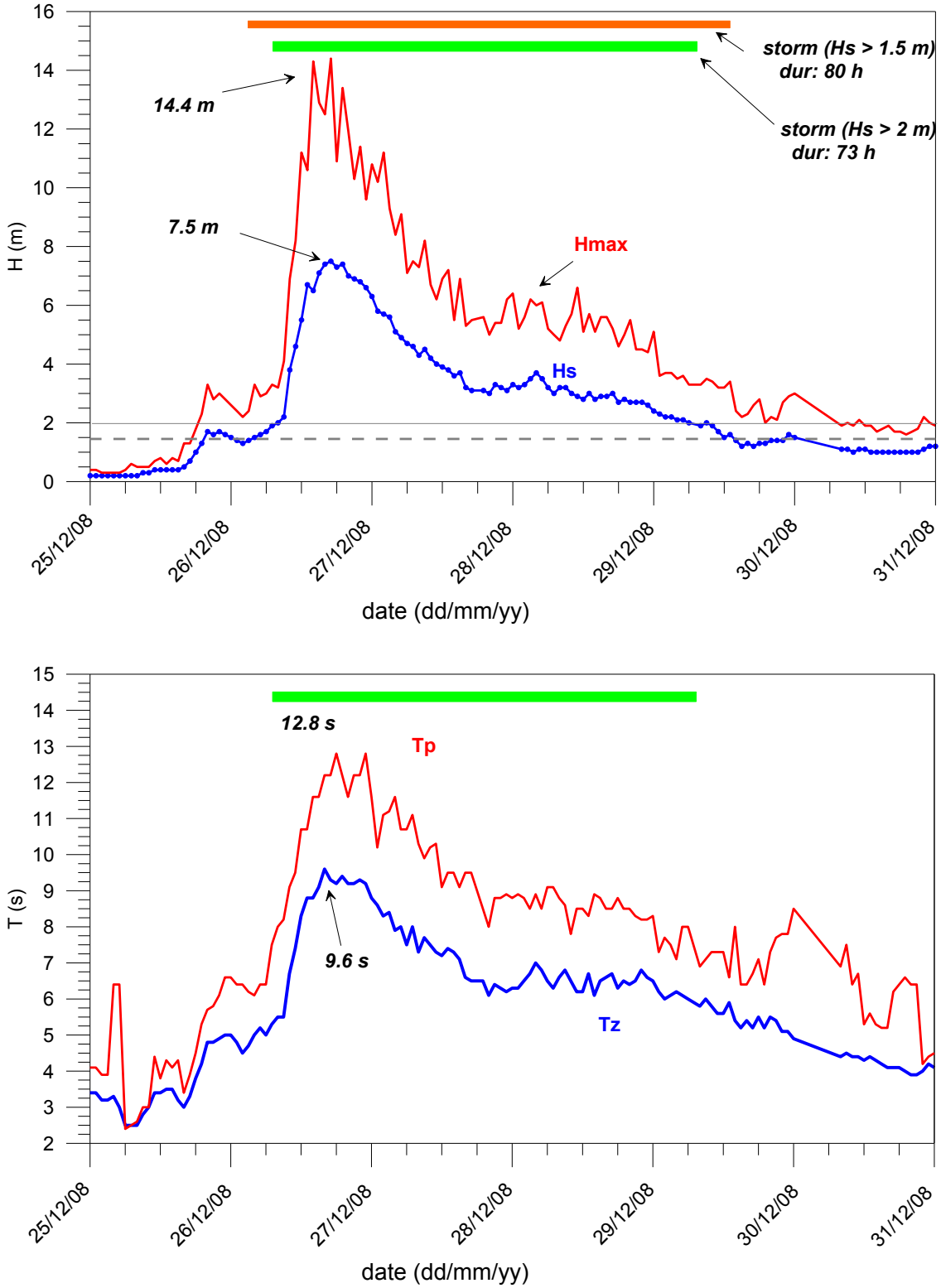
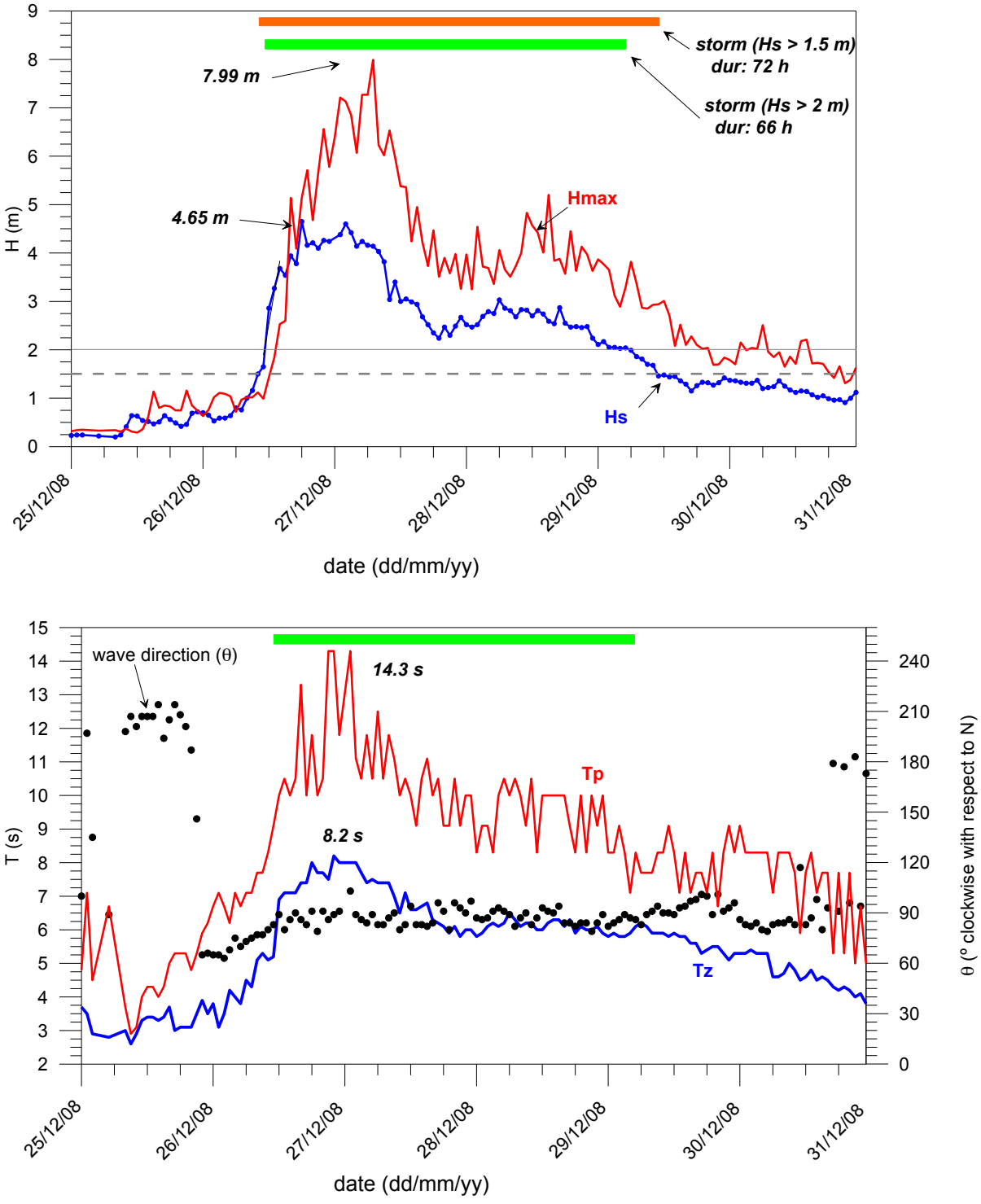


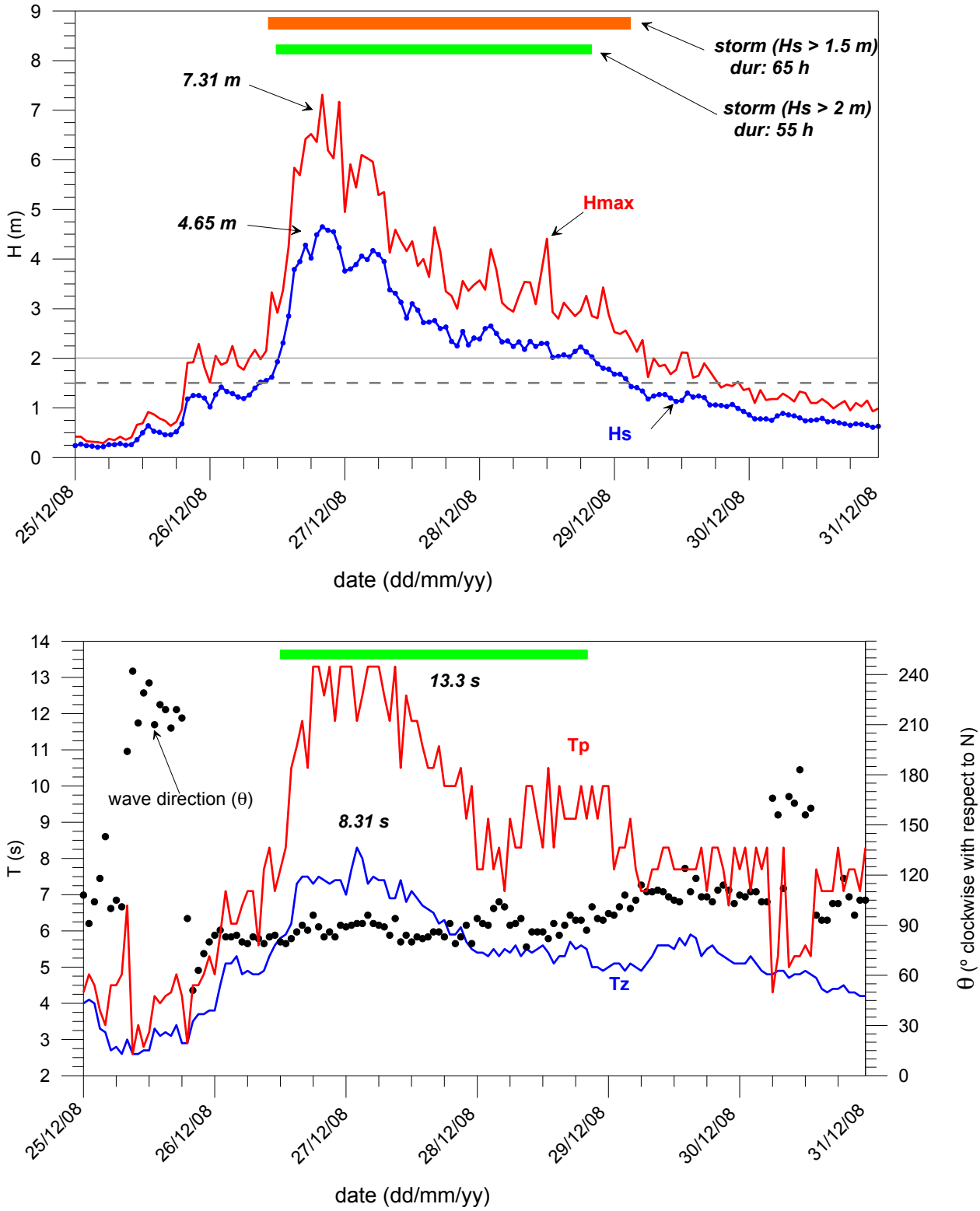
Annex 1. Wave records at the Roses buoy during the Sant Esteve's storm. *Top*: wave heights (*Hs* and *Hmax*). *Bottom*: wave periods (*Tz* and *Tp*). Direction was not recorded because it is an ominidirectional (scalar) buoy. The dashed part of the *Hs* record was derived from *Hmax*.



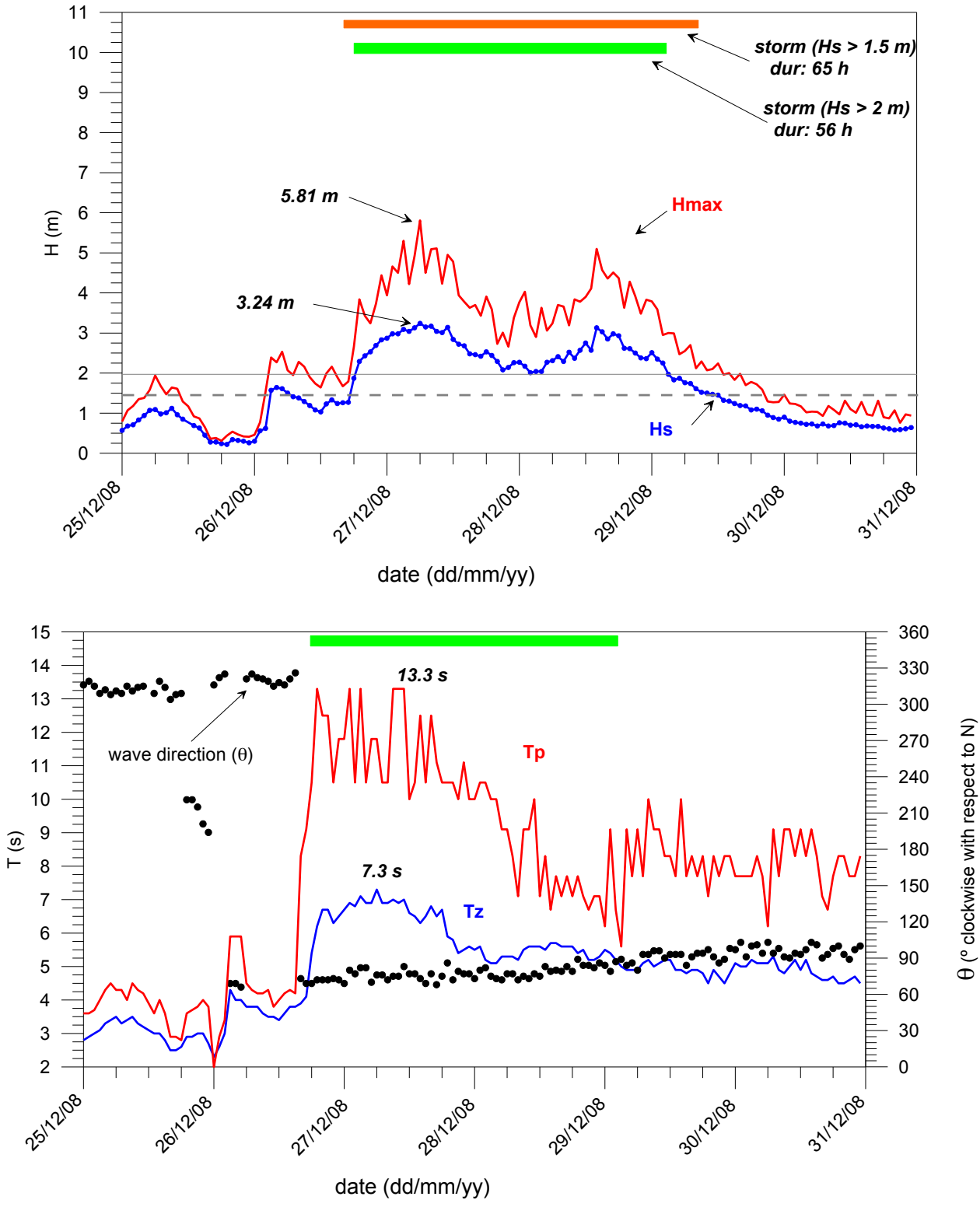
Annex 2. Wave records at the Palamós buoy during the Sant Esteve's storm. *Top*: wave heights (*Hs* and *Hmax*). *Bottom*: wave periods (*Tz* and *Tp*). Direction was not recorded because it is an ominidirectional (scalar) buoy.



Annex 3. Wave records at the Tordera buoy during the Sant Esteve's storm. *Top*: wave heights (*Hs* and *Hmax*). *Bottom*: wave periods (*Tz* and *Tp*) and direction (θ).



Annex 4. Wave records at the Llobregat buoy during the Sant Esteve's storm. *Top*: wave heights (*Hs* and *Hmax*). *Bottom*: wave periods (*Tz* and *Tp*) and direction (θ).



Annex 5. Wave records at the Cap Tortosa buoy during the Sant Esteve's storm. *Top*: wave heights (*Hs* and *Hmax*). *Bottom*: wave periods (*Tz* and *Tp*) and direction (θ).