Analysis of coastal-maritime adverse events in Basque Country

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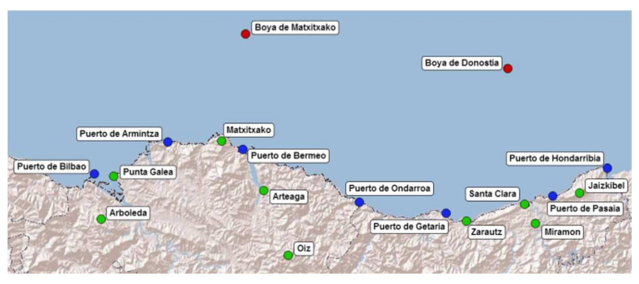


Introduction

Here we present a study of coastal-maritime adverse events in the Basque Country, taking into account different meteorological and oceanographic aspects. We include the study of parameters available in the area from local observation networks, information from oceano-meteorological models and data about damages in the Basque coastal areas caused by coastal maritime adverse events. The ultimate goal of this study is to provide some background and inputs for the update of the Basque Meteorology Agency (Euskalmet) coastal-maritime warning system. A pre-selection of events based on general criteria of adversity, considering simple significant wave height threshold, is made. From the set of episodes, a second selection is made based on representativeness and data availability. Then, the last sub-set is used for an in deep study, considering the following particular aspects:

- The available oceanographic and meteorological registered parameters, mainly those from the Basque Country Network .
- Model data available for the area, from waves and meso-meteorological models, provided from Euskalmet.
- Information on impacts, including damages in seaside areas, harbours, marinas, and others effects in sensible areas.

Selection methodology

The selection of events is done taking into account three main aspects: (i) severity potential (based on significant wave height threshold criteria), (ii) data availability (we need to guaranty enough data information for the analysis) and (iii) effects (using damages data when available).

(i) We check for wave height data, and we look for episodes where the 5 meters and 7 meters thresholds are registered in any place and time from 1990 until today (checking available data on buoys and coastal stations). The number of days with waves bigger than 5 metres are 490 and 119 are bigger than 7 metres (according with Bilbao buoy data). In both cases, the 80% of events occurred in between November and march (see figure 1).

(ii) We consider the availability of data. The Matxitxako and Donostia buoys began to operate on 19/09/2007, the first year percentage of data available is under 50%, the months 1-4-5-6-7/2008, 9-10/2011, 2-11/2012 and 3/2014, there is no data (see figure xx). The structures begin recording data in 2003 and since 2012 Getaria and Pasaia structures are available. The biggest data gap is from 02/2008 to 06/2009 (see figure 2))

(iii) Different sources for coastal damages are considered (Basque Government emergencies, regional authorities, municipalities, assurance consortium, press, experience, etc) in order to introduce information of effects of the events in the selection. Particularly, we consider data from damage reports (2004 to 2014) presented to insurance companies as a consequence of sea effects (See fig 3 & 4).

As a result of these steps and other considerations (related with model data availability, expert consideration, representativeness, potential severity, etc.) we select 28 episodes within the period 2004 to 2014. 19 of these events cover 99,9% of economic loses declared and 9 more events have no-losses reported damages (see table 1).

Analysis

In table 1 we include a summary of the main characteristics of the selected events: meteorological and oceano-meteorological features, warnings levels, wave data (Hs max, Tp, energy, tidal level) and effects and economic losses data.

Considering meteorological aspect, the events can be classified into 2 main groups. (1) The events related to deep lows travelling through the Atlantic from southwest to northeast with a marked zonal component in higher latitudes. They are mostly explosive cyclogenesis that do not affect directly the Basque Country. (2) The intense northwest flows with an extended trajectory over the sea, between the Azores anticyclone and the low pressure systems in the Britannic Islands. 90% of the events correspond to zonal circulations while 75% of events correspond with Britannic lows configurations on surface (see table 1)

The wave climate along the Cantabrian coast is related directly to its geographical setting within the Bay of Biscay and the NE Atlantic. Due to its orientation and location, in relation to the low-pressure systems, which develop in the transitional area between the high-pressure region of Azores and the sub-arctic low pressures, the Basque coast is exposed to large fetches. Such fetches extend to distances of more than 1,500 km, from the centre of the low-pressure areas; as such, they are located frequently to the northwest of the British Isles and Iceland. The low pressures generate strong winds over the North Atlantic and large waves from the fourth quadrant (270º to 360ºN). Such waves, formed as swell from the northwest, occur most frequently over the study area; they persist during periods of complete calm and, moreover, can exist in association with strong and relatively persistent winds from different directions. In fact, with strong southerly winds opposing the NW swell (typically in autumn) mixed sea estates are generated two miles far away from coast, nearest this effect are not relevant even with intense southerly winds. 82% of adverse events are related to episodes of strong maritime winds with high fetch and 14% with offshore wind with swell. At the end, 99% of losses are related with high swell.

If we consider Euskalmet severe weather classification, 46% corresponds to NW Gales, 28% Wind storms and 28% to high swell. If we consider damages, 82% of the events are related to high swell episodes, while 18% is related to NW Gales (see figure 5).

Regarding waves characteristics, for most part of events significant wave heights surpass 7 m, and peak periods surpass 14 seconds (see table 1). Additionally, since we are especially interested on the effect of these adverse events on the littoral, we should also take into account the effect of tides. In fact, the most problematic events are not related to the highest wave heights but to situations of high long period waves coinciding with high tides and, specially, during spring tides. Indeed, the most harmful events occur with tide levels over 4,5 m. The two most relevant events (responsible for 70% of the reported damages for this last ten years) are those of 10-11/03/2008 and 01-02/02/2014. They correspond to a combination of tide levels over 4,7, significant wave height over 8 m and peak periods over 15 s, being the damages generated by a combination of waves and flooding. 19-20/03/2007 event occurs during an exceptional maximum tide level (5 m), conversely, the peak period and maximum wave height during the high tide are weak. The importance of the damages generated by this concrete event, illustrate the fact that the mean sea level is a key factor. During the 23-24/01/2009 (Klaus) event, the significant wave height registered beats the record of the time series (13,7 m), the significant height is 12 m and the peak period 16 s. However, the high tide level is only 3,4 m and the damages generated are not so relevant compared to other events. During the event of the 6-7/01/2014 the highest peak period of the series is registered (23 s). Maximum tide level is 4 m and significant height is 9.5 m. Damages reported are average and there is punctual flooding.

The distribution of damages along the littoral is variable, although it corresponds mostly to damage within harbours (Bermeo 30%, Orio 12% y Ondarroa 5%) and damages to shops, stores, houses and offices (Donostia 37%, Zarautz 6%) (see fig 6). The correlation between the different oceano-meteorological parameters and the registered damages is not straightforward. Some of the factors that need to be considered are: the small scale variations of the coastline, the distribution of human population and goods, the orientation of seawalls and harbours, the exposure of some areas to the incident wave field, the configuration of beaches and the effect of the preventive measures applied, the previous situation (the economic losses on previously damaged areas tend to be less significant), However, if we correlate Hs, Tp, tides and economical losses we can observe the distribution of the different events relative to their importance in terms of damages (see figures 7 and 8).

Summary and conclusion

In this work a study of coastal-maritime adverse events in Basque Country and its effects are made in order to provide some background and inputs for the update of the Basque Meteorology Agency (Euskalmet) coastal-maritime warning system.

Although the Basque coast is properly equipped with oceano-meteorological measurement systems, the data availability from buoys and structures can be unsatisfactory due to data loss and damages on the devices during storms and the difficult maintenance operations at sea.

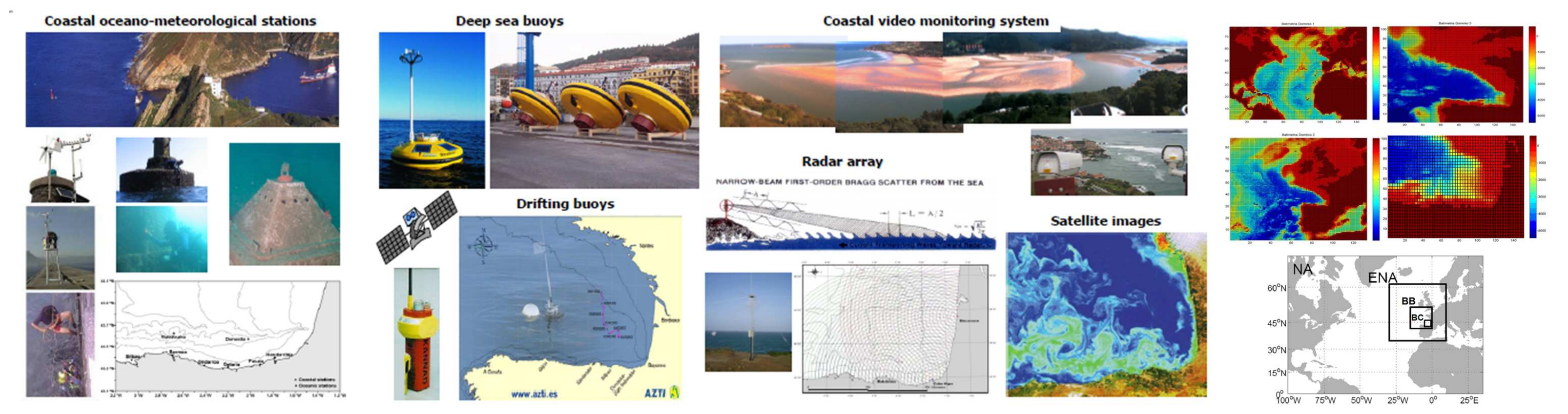
Basically, the adverse events are characterized by swell situations generated by remote deep lows and NW gales, since these configurations favour high fetch and high wave heights.

Last winter (2013-2014) has been especially extreme and severe, not just because of the significant height values, but mainly because of the continue occurrence of adverse events and the exceptional peak periods, which generated strong energies waves responsible of severe damages on the coastal infrastructures. Added to this, the coincidence with high spring tides of some events increased the damages, as it occurred on the event of February 2nd, the most harmful of the studied events and one of the most destructive of the history.

It is crucial, indeed, to take into account the sea level to correctly forecast the impact of a wave storm on the littoral and coastal infrastructures (harbours, seawalls, seafronts, etc.). The combination of high significant wave heights, without being exceptional, with high wave peak periods and spring high tides can be much more destructive than an event of extreme waves coinciding with neap tides. For this reason, the analysis of the wave characteristics during high tide is critical.

Preventive actions commonly taken after the activation of Basque Government alert levels, allow to lessen the economic losses, at least to a certain extent, and to minimize human injuries. Damages in harbours and high repair costs associated to civil works occur mostly during a few extreme events. During not so extreme events (with low impact on the mass media) damages on vehicles are possible due to lack of prevention actions from population.

Finally, it can be difficult to evaluate the damages of a second event affecting the littoral after a previous one, namely if the time between them is short as it happened during this winter. This is especially what happened on the deeply affected littoral after February 2nd event, that was affected by consecutive events (without time to repair damages) whose impacts are difficult to evaluate.



Data availability

OBSERVATIONS

In the Basque Country area, data from different acquisition systems are available in real time:

- Six coastal stations (water depths <30 m) that provide, since 2004, 10-minute data of temperature, currents, tides and waves at six strategic points of the Basque coast .
- Two buoys located over the slope in front of DonoStia-San Sebastián (Donostia Buoy) and Cape Matxitxako (Matxitxako Buoy), over 550 and 450 m isobaths, respectively, which provide, since 2007, hourly data of meteorological and oceanographic variables (air temperature, air pressure, wind intensity and direction, solar and net radiation, waves -directional sensor, sea surface temperature and sea surface currents) at the sea surface. In addition to the surface sensors, a downward looking ADCP and a CTs chain measure currents and provide temperature and conductivity data, respectively.
- Deep water Bilbao Buoy (BBB) from Puertos del Estado network (www.puertos.es)
- A high frequency (HF) radar array with two stations located at the Basque coast providing hourly surface current fields. This system is working operationally since January 2009 (Solabarrieta et al. 2014, Rubio et al. 2011). The antennae (emitting at 40 kHz broadband and 4.5 MHz frequency) cover a 150 km range with 5 km radial and 5º angular resolutions.
- An Automatic Weather Stations (AWS) network owned by Basque Government that consist on more than 100 AWS distributed all along the Basque Country territory, those AWS register different meteorological variables in real time with a temporal cadence of ten minutes.

MODELS

Different wave operational and research models are available in the area:

- The Euskalmet wave forecast system is based on WAVEWATCH (WW3) model, System runs, once daily, with three nested grids (0.9, 0.4 and 0.1 degree resolution), using previous execution fields and last available winds from GFS global model and operational Euskalmet mesoscale prediction systems. System is based in version 2.22 of the full-spectral third-generation wind-wave model. The required input data for bathymetry is derived from data of 2-minute resolution obtained from the NGDC. Input surface wind fields, are obtained from NCEP´s Global Forecast System and from Euskalmet operational mesoscale system based on PSU/NCAR model MM5 and WRF. System is executed automatically on a real time daily basis and produces maps and data files for different purposes.
- WAM wave model with a 1.6 km horizontal resolution are also available, forced by the WRF model wind fields. The conditions applied to the open boundary of the WAM grid are provided by the NOAA WAVEWATCH III model using products of NCEP as input.

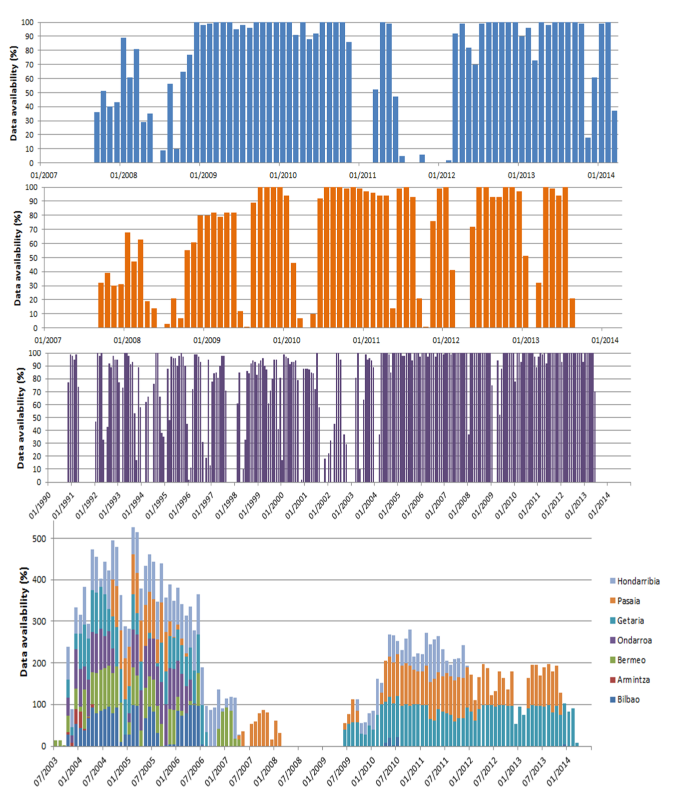


Fig.2 . Data availability for Donostia, Matxitxako , Bilbao buoys and Coastal stations

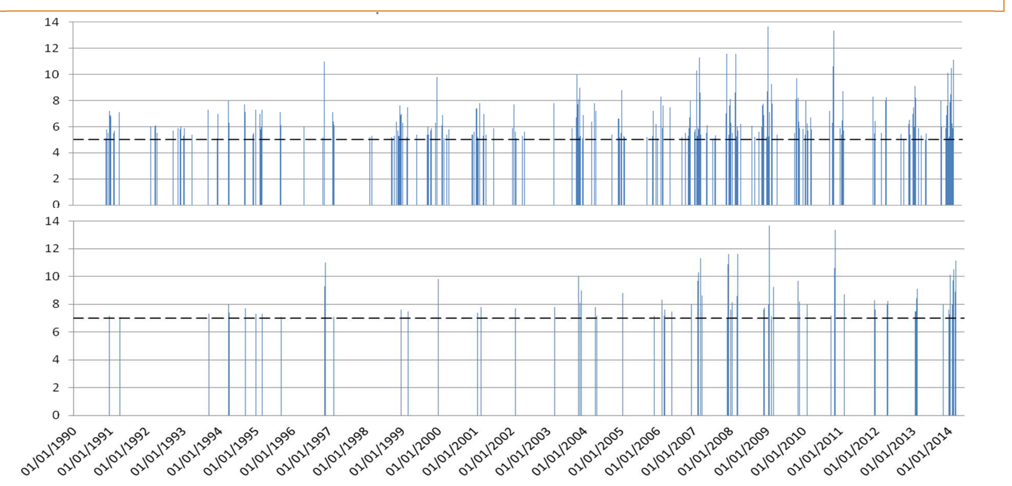


Fig.1: Observed events where Hs is over 7m and 5 m since 1990

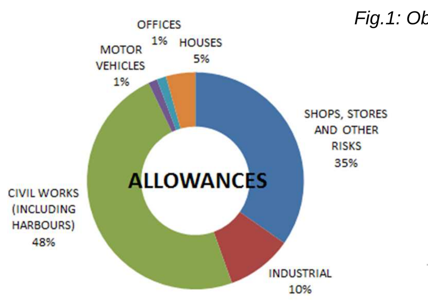


Fig.4 . Allowance type distribution (%)

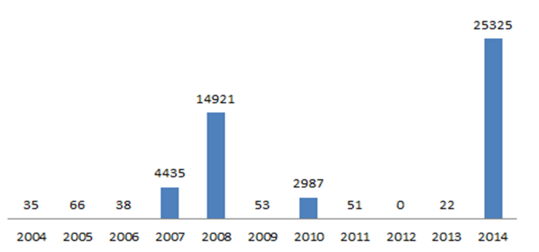


Fig.3 . Damages annual distribution (k€)

Table.1 . Data summary for selected events.

Date	Synoptic features	Maritime features	Severe weather clasification	Hs max PASAIA (m)	Hs max BMA (m)	Hs max BDO (m)	Hs max BBB (m)	Hs max (m)	Peak Period (s)	Energy (Kw/m)	Wave direction	Max tide level (m)	Hs max at high tide (m)	Peak period at high tide (s)	Barometric component (cm)	Euskalmet warning level	Effects	Stimated Damages (k€)
19/04/2004	Z, BL	SMW HF	NW Gale	6,5			7,8	7,8	14-15	432	NW	4,4	7,2	12,6	9	orange	light	35
18-19/01/2006	Z, an	SMW HF	NW Gale	10,8			8,8	10,8	17-20	1057	NW	3,5	7,8	18,0	-12	orange	moderate	65
17/02/2006	Z, BL	SMW HF	High swell				8,3	8,3	15-18	557	NW	4,3	7,7	14,5	6	orange	light	29
25/01/2007	M, BBL	SMW LF	Wind storm				5,8	5,8	8-10	148	NW	4,2	5,4	9,3	5	yellow	light	238
10/02/2007	Z, BL	OW S	NW Gale		8,1	8,7	9,7	9,7	17	784	NW	3,4	9,1	17,0	0	orange	light	10
12/02/2007	Z, BL	SMW HF	Wind storm		8,8	8,9	10,3	10,3	17	884	NW	3,2	9,7	17,0	5	orange	light	4
7-8/03/2007	Z, BBL	SMW HF	Wind storm		10,3	9,6	11,3	11,3	12-14	813	NW	4,2	10,0	12,0	6	orange	moderate	
19-20/03/2007	M, AH	SMW HF	NW Gale		8,6	7,7	8,0	8,6	12-14	471	NW	5,0	7,1	13,0	4	red	strong	1 039
10/12/2007	Z, BL	SMW HF	NW Gale		11,6	11,1	11,6	11,6	17-18	1154	NW	4,1	9,9	15,0	-3	red	strong	3 125
10-11/03/2008	Z, BL	SMW HF	High swell	8,0	10,9	10,0	11,6	11,6	20	1319	NW	4,7	9,7	15,0	4	red	strong	14 917
23-24/01/2009	Z, BBL	SMW HF	Wind storm	13,1	13,4	13,5	13,7	13,7	15-17	1471	NW	3,4	12,0	16,0	23	red	moderate	2
10/02/2009	Z, BL	SMW HF	Wind storm	5,7	7,1	7,1		7,1	13-15	346	NW	4,5	6,7	13,0	-2	orange	light	27
05/03/2009	Z, BL	SMW HF	NW Gale		9,3	8,5		9,3	13-15	593	NW	3,2	8,5	14,0	8	orange	light	
08/11/2009	Z, BL	SMW HF	NW Gale		9,6	9,2	9,7	9,7	16-18	784	NW	4,0	9,1	12,5	5	red	light	11
8-9/11/2010	M, BL	SMW HF	NW Gale	9,1	10,6	9,3	9,8	10,6	17-20	1019	NW	4,2	9,2	14,5	33	red	strong	2 983
14-17/12/2011	Z, AH	SMW HF	Wind storm		8,3		7,6	8,3	15-18	557	NW	4,0	6,3	15,0	-2	red	light	45
18-19/04/2012	Z, BL	SMW HF	NW Gale	5,7		8,0	6,7	8,0	15-17	502	NW	4,4	5,7	15,0	15	orange	light	
23-24/04/2012	Z, BL	SMW HF	NW Gale	6,4		8,2	7,4	8,2	13-15	461	NW	4,2	6,2	14,0	1	orange	light	
28/01/2013	Z, BL	WW HS	High swell			7,4	7,5	7,5	15-17	441	NW	4,4	4,9	12,5	-7	orange	light	
11-12/02/2013	Z, BL	SMW HF	NW Gale			8,1	9,1	9,1	15	609	NW	4,5-4,8	6,4	14,5	0	orange	light	
3-4/01/2014	Z, BL	OW S	High swell			7,2		7,2	16-18	432	NW	4,8	6,9	16,0	8	orange	strong	5.005
6-7/01/2014	Z, BL	OW S	High swell			10,1		10,1	23	1150	NW	4,0	9,5	23,0	-2	orange	moderate	270
27-28/01/2014	Z, BL	SMW HF	NW Gale			7,9		7,9	16-17	505	NW	3,7-4	6,6	17,0	4	orange	moderate	608
1-2/02/2014	Z, AH	SMW HF	High swell			8,5		8,5	20	708	NW	4,9	8,1	19,0	-4	red	strong	18.559
05/02/2014	Z, BL	OW S	High swell			9,5		9,5	17-18	774	NW	3,9	8,0	17,5	0	orange	light	
8-9/02/2014	Z, BBL	SMW HF	High swell			10,5		10,5	20	1080	NW	3,3	10,3	18,5	2	orange	light	
28/02-01/03/2014	Z, BL	SMW HF	Wind storm			8,9		8,9	15-17	621	NW	4,4-4,8	6,1	16,5	0	orange	moderate	
3-4/03/2014	Z, BL	SMW HF	NW Gale			11,1		11,1	19	1147	NW	4,6-4,8	8,6	18,5	3	red	strong	821

Z: Zonal, M: Meridian SMW HF: Strong maritime wind with high fetch, SMW LF: Strong maritime wind with low fetch, OW S: Offshore wind with swell, WW HS: Weak wind and high fetch
BL: Britanic low, BBL: Bay of Biscay low, AH: Azores High

Fig.6 . Economical losses distribution along Basque Coast.

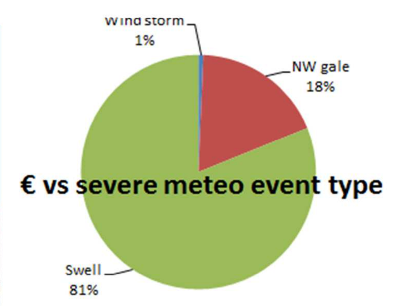
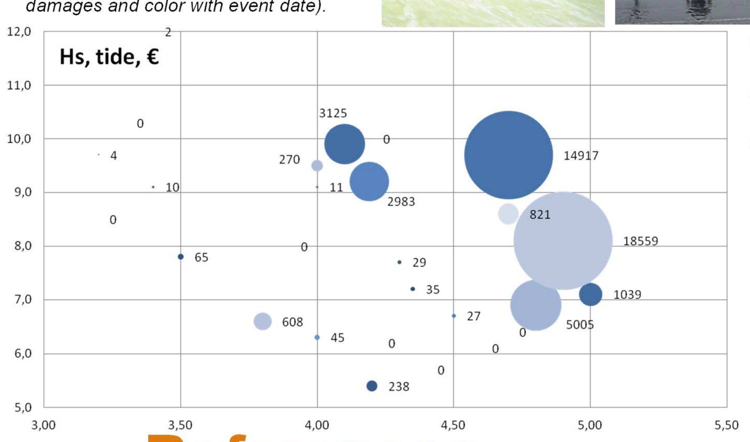


Fig.5 . Damages distribution by severe weather event type.

Fig.7 : Hs versus tide (size related with damages and color with event date).



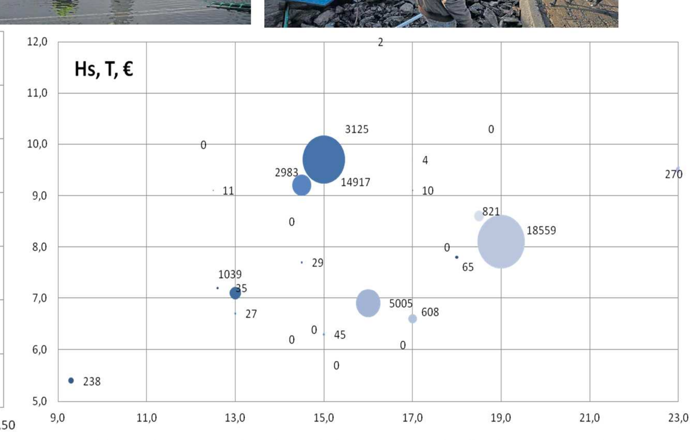


Fig.8 : Hs versus Peak period (size related with damages and color with event date).

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