# Impacts of Storm Hercules in Southwestern Europe

Angela Santos[1], Susana Mendes[2,3], Joao Corte-Real[4,5]

[1]Centre for Geographical Studies,
Institute of Geography and Spatial Planning, Universidade de Lisboa,
Edifício da Faculdade de Letras, Alameda da Universidade, 1600-214 Lisboa, Portugal.
angela.santos@campus.ul.pt

[2]Geophysical Institute, University of Bergen, Allegaten 70, 5007 Bergen, Norway

[3]Bjerknes Centre for Climate Research, Bergen, Norway.
Susana.Mendes@gfi.uib.no

[4]Institute of Mediterranean Agrarian and Environmental Sciences (ICAAM), University of Évora, Évora, Portugal.
jmcr@uevora.pt

[5]Department of Aeronautics and Transports, University Lusófona of Humanities and Technologies, Research Unit DREAMS, Lisbon, Portugal.
joao.cortereal@ulusofona.pt

**Abstract.** The aim of this study is to analyze the impacts of the Hercules storm in southwestern Europe. The storm occurred from January 5 -7, 2014. A brief characterization of the storm was conducted and the witnesses' accounts were compiled, complemented with field survey before and after the storm. The results show that this event had origin in an intense low pressure system that hit Portugal, Spain, France and the UK. The system triggered strong sea waves with long periods, run-ups between 6 to 9 m, and inundation depths of less than 1 m. The effects on the European coastlines showed some weaknesses in the spatial planning management: (i) the fact that a wave train restricted to the beaches, front streets, ports and marinas caused significant damage; (ii) some people ignored the emergency management authorities, putting themselves in a risk situation.

**Keywords.** Hercules storm, long waves disturbances, meteotsunami, preparedness

## 1 Introduction

Between January 5–7, 2014 a low pressure system approached south Western Europe from the Atlantic Ocean. It was called "*Hercules*" by the Weather Channel [1]. Its passage left significant damage in the south Western Europe countries due to strong winds, long period waves and intense precipitation. The most significant impacts occurred on the evening of Monday, January 6 and in the early morning of Tuesday, January 7, 2014.

Atmospheric disturbances caused by atmospheric gravity waves, storm activity, pressure jumps, frontal passages and squalls can generate long sea waves [2], [3]. These waves are similar to ordinary tsunami waves and can affect coasts in a similar way. They are usually called meteotsunamis or meteorological tsunamis [4], [5]. These events were observed all around the world: 1978 in Croatia at the Adriatic Sea [6]; 1981 in South Africa [7]; 1984, 2003, 2007 and 2008 at Adriatic Sea [3]; 2005, 2007 and 2008 in the British Colombia [8]; and more recently on June 13, 2013 in the US east coast (http://www.extremestorms.com/meteo_tsunami.htm) and on March 29, 2014 in Florida, USA (http://www.app.com/article/20130613/NJNEWS/306130114/ Ambulance

-heading-hospital-hit-by-car-Surf-City). Thus, the features of *Hercules* storm fits well in this type of natural hazards.

In this research three methodologies were applied: the storm characterization was conducted by analysing satellite images, Global Forecast System re-analysis, and tide gauge data. The eyewitnesses' accounts were compiled from the Portuguese media, mostly from TV stations, that posted the information online. The study was also complemented by field survey that was conducted on two places in Portugal.

## 2 Storm characterization

The storm Hercules was registered by the Portuguese Meteorological Office radars regarding the rain rate generated by this system (www.ipma.pt). Real time images showed that, over time, especially close to the 18:40 (UTC) on January 6, when the 1$^{st}$ big ocean wave hit the coast, the precipitation was crossing Portugal on the direction SW/NE, with nucleous of intense precipitation over the areas/regions affected.

Furthermore, the Global Forecast System re-analysis [1] showed that the storm was defined by a deep tropospheric low pressure system with a frontal system associated to it, propagating from west Atlantic to the UK, which can be clearly seen in the 500 hPa maps [1] and in the satellite images of the January 6 and January 7 (Figure 1). The most important part of this frontal system was its cold front characterized by a rather long horizontal extension, since north of UK until south of the Iberian Peninsula. This cold front had also very strong winds associated to it, especially over the Iberian Peninsula. Another important feature of the atmospheric conditions that generated the ocean waves responsible for the destruction was that Portugal, and in the subsequent days Spain, France and UK, was also under the influence of a high pressure system advecting warm air into the region. As a consequence of these two pressure systems combined, over time, the resulting winds are particularly strong, at surface and in altitude.

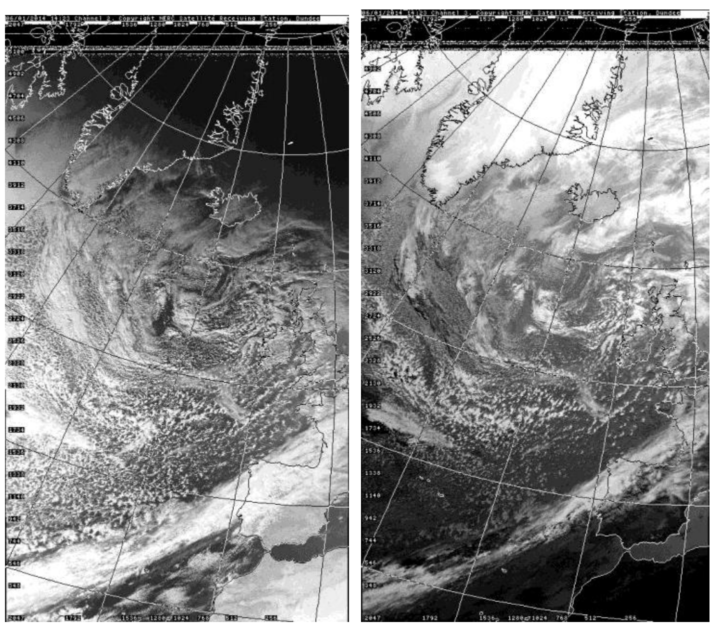

**Fig.1.** Satellite image over southwestern Europe (www.sat.dundee.ac.uk). Left: January 6, 2014, 14:23 UTC, AVHRR channel 2; right: January 7, 2014, 14:12 UTC, AVHRR channel 2

The most significant impacts occurred on the shoreline occurred in the evening of January 6 and in the early morning of January 7 during the high tides. Figure 2 shows data from tide gauge stations that recorded the *Hercules* storm (www.ioc-sealevelmonitoring.org) in Portugal and France. Data also show clearly long period waveforms of about 10 minutes, a feature also observed in meteotsunami events. All these effects combined resulted in a situation of rather intense consequences in the coastal cities exposed to the system, not only in Portugal, but also Spain, France and the UK.

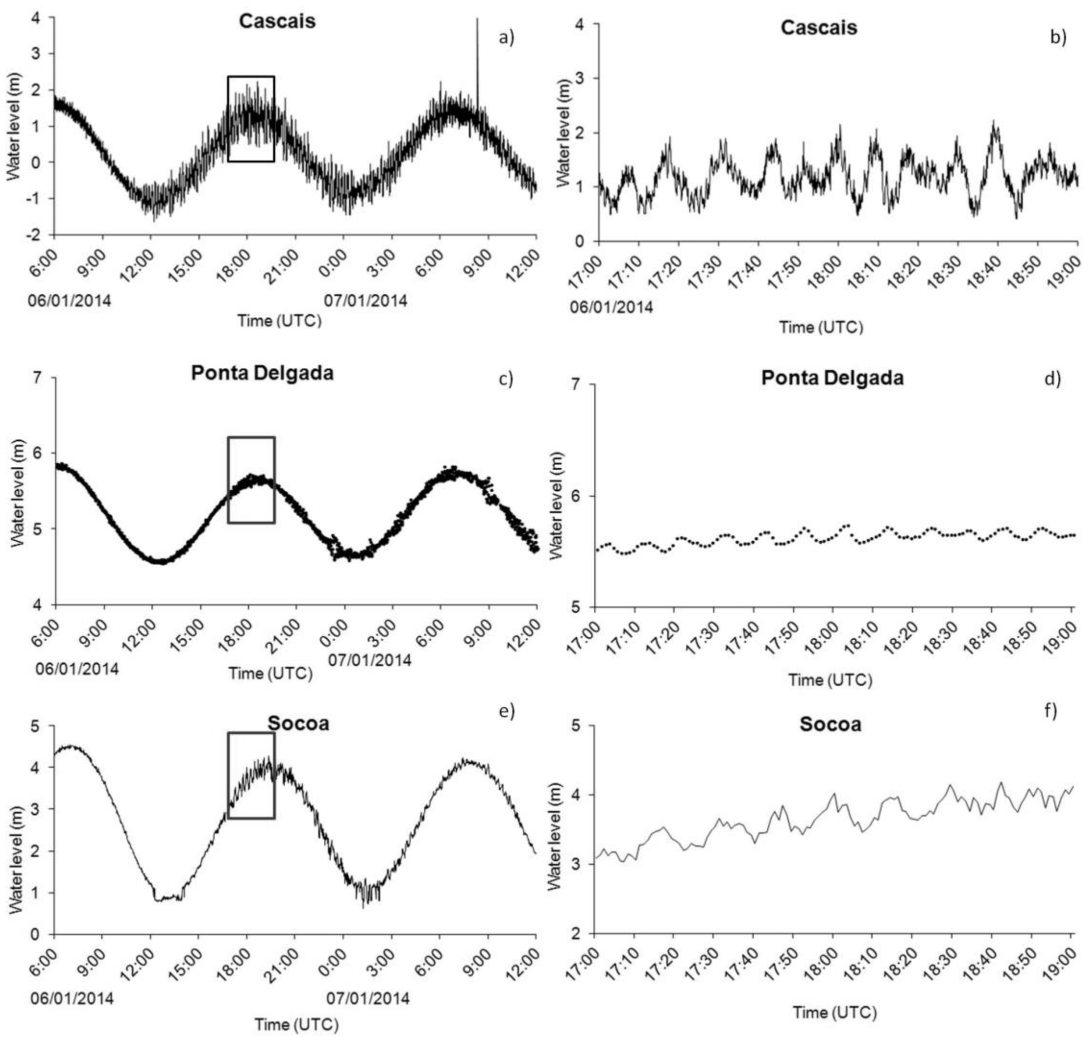


**Fig. 2.** Tide gauge recordings during the *Hercules* storm: a) Cascais, Portugal; b) zoom of Cascais data; c) Ponta Delgada, Azores Islands, Portugal; d) zoom of Ponta Delgada data; e) Socoa, France; f) zoom of Socoa data

## 3 Eyewitnesses' accounts

The storm was very well documented by live reports on the Portuguese media, mostly by TV stations, and later posted on permanent online archives. In addition, many witnesses took photos and videos and later posted online. Thus, the witnesses' accounts in Portugal were compiled [1] on 29 places on Portugal mainland, as well as in Azores and Madeira Islands (Fig.3). The authors [1] divided the storm impacts into the storm's physical parameters, damages (natural features and structures and property) and fatalities. In general, there were several waves, but two being the largest with 6 -9 m high. The low coastal areas were flooded, with sand deposition on most of the streets, while on the other areas with natural landscape, the sand dunes were destroyed. There was almost completely destruction of all beach infrastructures like bars, restaurants, sidewalks and walls. Furthermore, on the fishing ports several small boats and warehouses were also destroyed. At Oporto about 20 cars were dragged inland. It was estimated that the storm caused more than 16 million Euros in damages [9]. Official Government Administrations were able to forecast the storm and issue warnings to coastal populations to avoid going to close to the shoreline. However, people did not respect the warnings and went to the coast to watch the storm, taking photos and filming the waves. Although nobody died, many people were caught by the waves, and about 20 people needed assistance and there were at least six injured. Disaster prevention measures were also taken by stakeholders [1], either by evacuating families and elementary school children, building sand bars, and closing parking lots and roads to traffic. Thus, stakeholders' response was commendable, not only in the days before the storm by taking disaster prevention measures, but also in the emergency response, and later in assessing damages and in the cleaning operations.

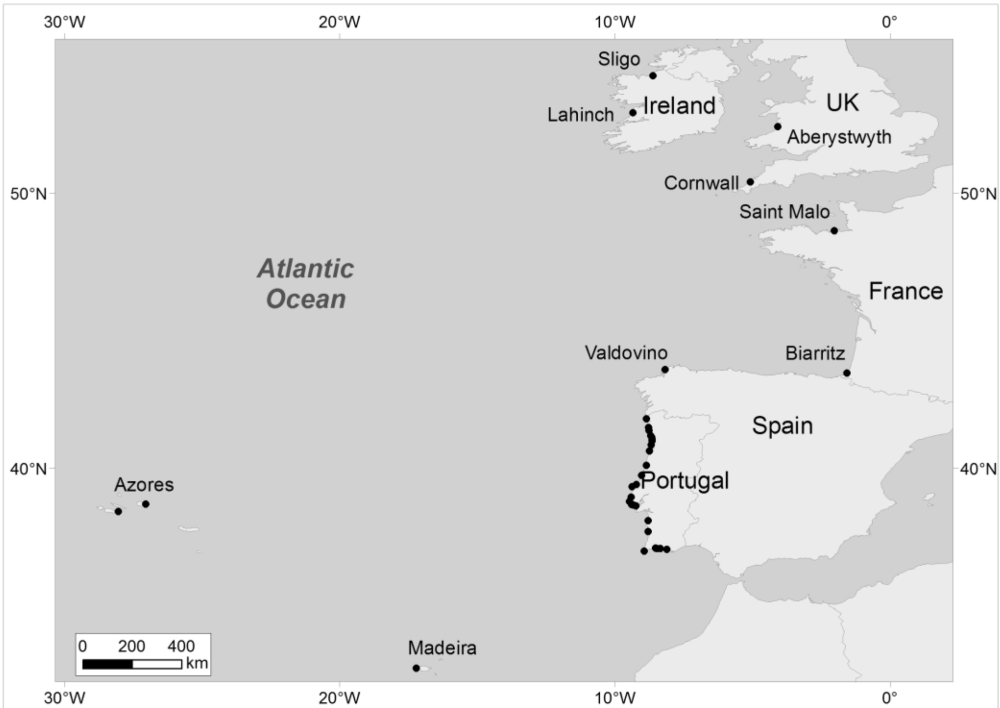


**Fig. 3.** Location of the places where the witnesses reported the storm impact

The Hercules storm also affected other European countries (Table 1). In Silgo and Lahinch, Ireland (see location in Figure 1) the waves flooded the promenades, and several witnesses were taking photos and videos too close to the coastline [10]. The UK has been hit by several storm surges, causing severe floods during December 2013 and January 2014 [11], [12]. The reports are somehow confusing, being difficult to separate the impact of the Hercules storm itself from the impact caused before and after the January 6 storm. Still, an "unexpected" wave swell was forecasted by the Natural Resources Wales to the afternoon of January 6 to Aberystwyth, and therefore all buildings along the promenade were evacuated [13]. Several videos show the storm hitting the area, flooding the promenade [10], with local populations taking photos and videos too close to the coastline, putting themselves into a danger situation. The storm deposited debris and stones on the roads [14]. In Cornwall, the waves were 8 m high [13].

In Saint-Malo, France although no damage was reported, the waves overtopped the levees and inundated the front streets [10]. Like in Portugal and in the UK, videos also show local populations taking photos and videos too close to the coastline, putting themselves in a danger situation. In Biarritz, France a video shows one wave amplifying at the cliffs, hitting three people. One person is still missing and another was seriously injured [15]. Also in Biarritz, some buildings were damaged including the local casino. Three children were injured by broken glass of a window that was hit by the waves [10]. In Valdovino, Spain three people were missing after being washed away by the waves on Monday, January 6 at about 18:40 UTC [16]. Later one body was found. A fourth person was also caught by the waves, but managed to escape without injuries [17]. The waves were 12 m high.

**Table 1.** Summary of the Hercules storm impact in Ireland, UK, France and Spain.

| Place | Storm parameters | Damage | Fatalities |
|---|---|---|---|
| Ireland | Waves were 11.8m high at to Mullaghmore Head in Sligo, Ireland | Flooded the promenades of Sligo and Lahinch | --- |
| Aberystwyth, UK | --- | Waves overtopped the levees and deposited debris and stones on the roads | --- |
| Cornwall, UK | Waves were 8m high at Land's End | Waves overtopped the levees and deposited debris and stones on the roads | --- |
| Saint-Malo, France | Waves hit the area on Jan 1 – 5, 2014 | No damage reported, but waves overtopped the levees, inundated some streets | --- |
| Biarritz, France | 1 wave amplified at the cliffs, on sunday (Jan 5) at about 17:30 (16:30 UTC) | Damage on several buildings, including broken windows | 1 person was seriously injured, 3 children were injured by broken glass and 1 person was missing |
| Valdovino, Spain | - Waves were 12 m high | --- | 1 person was dead and 2 people were missing |

## 4 Field Survey

Previous field survey conducted in Portugal at Figueira da Foz, Ericeira, Estoril and Carcavelos [1] allowed analyzing the storm's impact, as a complement to data and the eyewitnesses' accounts. The results showed that: (i) the waves were about 6 - 9 m high, with inundation depths up to 2.7m, validating the witnesses' reports; (ii) sand dunes are natural barriers to ocean waves, even in an extreme event. However, the constant coastal erosion that has not been addressed properly puts in danger the coastal communities; (iii) damages were restricted to the coastline (beaches, fishing ports and promenades), while further inland areas were safe mainly because the Portuguese coast has high ground. This feature allows tourists and local residents to escape safely and in time to higher ground.

In addition, several photos taken by a witness from different angles [18] showed people standing nearby the Sagres Fortess (Fig 4), where the waves' amplification was recorded. By scaling an average person high as 1.6 m, it can be roughly estimated that the waves at Sagres were 15 - 33 m above the local ground. The first author conducted a field survey on the area, on different occasions (Fig 5). The survey results show that Sagres fortress is located on high ground about 36 m high, with steep cliffs. Therefore the Hercules storm run-up nearby the Sagres Fortress would be 51 - 70 m high, showing that on the cliffs the waves break and amplify significantly.

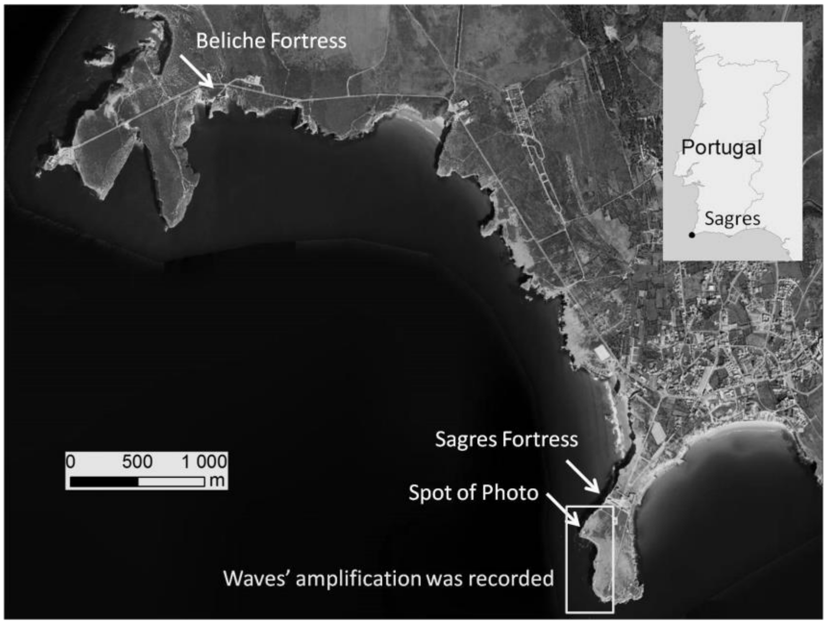


**Fig 4**. Framework at Sagres, Portugal. The field survey was conducted on the area, on both Beliche and Sagres Fortresses


**Fig .5** Field survey at Sagres: upper photo shows the view from the Sagres Fortress. Photo taken on November 1, 2011; lower: photo shows the view from the Beliche Fortress. Photo taken on August 20, 2014

Furthermore, the first author conducted a field survey at Oporto river mouth, Portugal (fig 6). The area was chosen after the detailed investigation of two videos available online [19], [20]. The two videos were filmed on approximately the same spot, on the grass between the north and the south breakwaters.

Video [19] showed the wave hitting the lighthouse, amplifying till about 3 m above it, at 29 seconds, and at 51 seconds was reaching the end of the north breakwater. The field survey results show the lighthouse is about 7 m high (fig 7), and the north breakwater is 4.7 m high. Therefore, the run-up at the lighthouse was about 14.7 m. In addition, the north breakwater is about 240 m long, allowing calculating the velocity of the wave as 11 m/s (39.3 km/h).

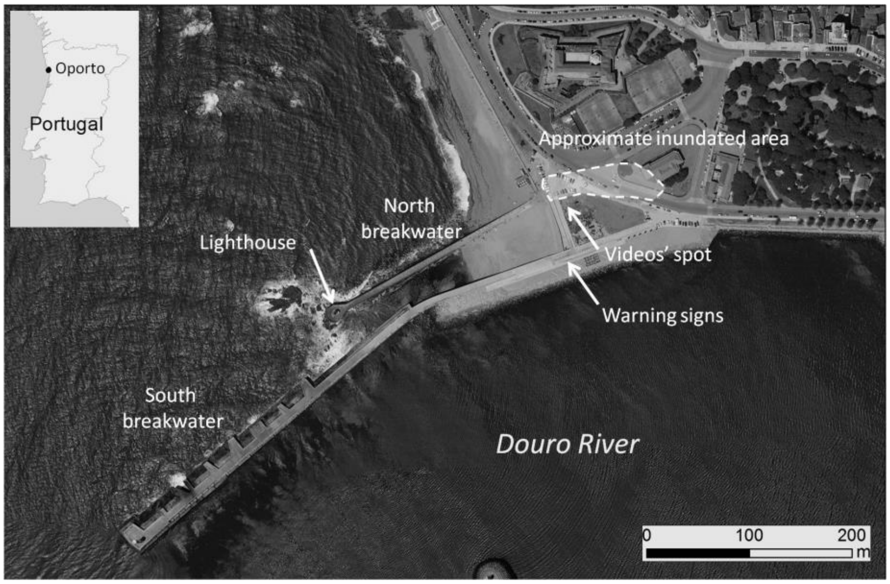


**Fig. 6** Framework of the field survey conducted on November 7, 2014 at Oporto, Portugal. There are two breakwaters, and the witnesses were nearby the parking lot.


**Fig. 7** Left photo: The south breakwater. There are two warning signs about the danger of waves overtopping the breakwater, in Portuguese and English. Right photo: the north breakwater is 4.7 m high and about 240 m in length. The lighthouse is about 7 m high. A video [19] showed the wave hitting the lighthouse about 3 m above the lighthouse, at 29 seconds, and at 51 seconds was reaching the end of the breakwater

Video [20] showed the wave inundating the area (fig 6), and one person was dragged under a car, almost drowned. The video shows very clearly that even a 0.20 m tsunami wave inundating a parking lot is very danger. The field survey results show the area is 5.2 m high, but high ground is available nearby, and those who escaped to those areas were not caught by the wave.

## Discussion

Hercules storm occurred on January 5-7, 2014. Satellite images and tide gauge data shows the Hercules storm was characterized by long period waves, causing its behavior on the coastline as “tsunami like”. Thus the Hercules storm is characterized as a meteotsunami.

The storm was also very well documented by the media and the witnesses provided important data by posting online videos and photos. The witnesses’ accounts show the maximum water level occurred around 18:40 (UTC), which was also validated by the tide gauge data, corresponding to the high tide.

European authorities have worn the coastal populations in advance, and disaster prevention measures were taken. In some places evacuation orders were issued before the storm in Portugal and UK. However, several people put themselves in danger by going too close to the shoreline, to take photos and filming the waves. As a consequence, there was one person dead in Spain, three people were missing (one in France and two in Spain), more than 10 people were injured (four in France and more than six in Portugal), and more than 20 people needed assistance in Portugal. These results show that it is necessary to develop strategies of spatial planning that involve the implementation of safety awareness, dissemination of disaster prevention measures and mitigation strategies to the general public, as discussed by [1]. In fact, during the November 7, 2014 field survey in Oporto, the weather conditions were stormy yet people did not take any precaution and were standing on the south breakwater. Although, nobody was washed away, a large wave overtopped the breakwater (fig. 8). Later that afternoon the weather conditions deteriorated and the Portuguese Meteorological Office issued a warning to Oporto. The Maritime Authority took actions and put a stripe on the south breakwater to stop people to go there. In spite of all the precautions, two men went fishing, and in the early morning of November 9 one of them was washed away [21], [22]. The next day, on November 10 the body was still missing [23], [24]. Nevertheless, stakeholders’ response was commendable, not only in the days before the storm by taking disaster prevention measures, but also in the emergency response, and later in assessing damages and in the cleaning operations.


**Fig. 8** In spite of the warning signs, people were standing on the south breakwater, putting themselves in a danger situation. Photos were taken with two seconds interval

The flooded areas were not significantly large being restricted to the beaches, sea fronts, marinas and ports, and on some streets of the low coastal areas, including both commercial and residential buildings. Thus, the storm showed the weaknesses of the coastal areas to a maritime extreme event, showing that coastal protections need serious evaluation and urgent mitigation actions are necessary [1].

In general, the witnesses reported waves of 6 -9 m. However, field survey results show the waves amplified significantly locally. In Sagres, Portugal the run-ups were estimated has 51 – 70 m high. At Oporto, the inundation depth was about 0.20 m, with run-up of 5.2 m, however at the north breakwater the wave broke, amplified and reached about 15 m high. In addition, field survey allowed calculating the velocity of the waves as 11 m/s (39.3 km/h), which is compatible to a tsunami. This result proves that a person cannot run from a tsunami wave and therefore should evacuate to higher ground before the wave reach the coast.

Furthermore, in the north-Statland in Namdalseid in Nord- Troendelang, Norway there was a landslide on Wednesday afternoon January 30, 2014, nearby a lake. This landslide triggered 4-5 m waves that hit the local marina and up to 10 meters high (http://www.adressa.no/nyheter/nordtrondelag/article9046577.ece), causing significant damages on the boats and warehouses (http://www.adressa.no/nyheter/ nord-trondelag/article9047229.ece). Between 44 and 55 people were evacuated after the flood however nobody was injured (http://www.dagbladet.no/2014/01/30/nyheter/innenriks/flodbolge/ras/ulykke/31553784/). Therefore, these events show that European coastlines or nearby water bodies are more vulnerable to tsunamis than previous thought.

## Acknowledgments

This research was supported by the TsuRiMa Project - TSUnami RIsk MAnagement for spatial planning and civil protection (PTDC/CSGEO/118992/2010), funded by the Foundation of Science and Technology (FCT), Portugal.

## References

[01] Santos, A. Mendes, S., Corte-Real-J.: Impacts of the storm Hercules in Portugal. Finisterra, XLIX, 98 (2014) 185-203 (in press).

[02] Rabinovich, A., Vilibi, I., Tinti, S.: Meteorological tsunamis: Atmospherically induced destructive ocean waves in the tsunami frequency band. Physics and Chemistry of the Earth, 34 (2009) 891-893

[03] Vilibic, I., Sepic, J.: Destructive meteotsunamis along the eastern Adriatic coast: Overview. Physics and Chemistry of the Earth, 34 (2009) 904–917.

[04] Nomitsu, T.: A theory of tsunamis and seiches produced by wind and barometric gradient. Memoirs of the College of Science, Kyoto Imperial University, A 18 - 4 (1935) 201–214.

[05] Defant, A.: Physical Oceanography, vol. 2. Pergamon Press, Oxford, UK. 1961

[06] Vucetic, T., Vilibic, I., Tinti, S., Maramai, A.: The Great Adriatic flood of 21 June 1978 revisited: An overview of the reports, Physics and Chemistry of the Earth, 34 (2009) 894–903

[07] Rabinovich, A., and Monserrat, S.; Meteorological Tsunamis Near the Balearic and Kuril Islands: Descriptive and Statistical Analysis, NaturaI Hazards, (1996 )13: 55-90.

[08] Thomson, R., Rabinovich, A., Fine, I., Sinnott, D., McCarthy, A., Sutherland, N., Neil, L.: Meteorological tsunamis on the coasts of British Columbia and Washington, Physics and Chemistry of the Earth, 34 (2009) 971–988.

[09] Pinto, C., Rodrigues, A., Costa, C. R., Lima, J.: Registo das ocorrências no litoral - Temporal de 3 a 7 de janeiro de 2014, Relatório Técnico, Agência Portuguesa do Ambiente (2014) 120p.

[10] EURONEWS: Mar violento mata e provoca prejuízos. Euronews Portugal online (2014) [pt.euronews.com/2014/01/07/ europa-mar-violento-mata-e-provoca prejuizos/]. Last access on January 7, 2014.

[11] Sky News: Flood Warnings As Tidal Surges Hit. Sky News online (2014) [news.sky. com/story/1189668/weather-flood-warnings-as-tidal-surges-hit]. Last access on January 7, 2014.

[12] WMN: Severe weather batters Devon and Cornwall, with more to come. Western Morning News online (2014). [www.westernmorningnews.co.uk/Severe-flood-warning-issued-Westcountry-coastline/story-20392542-detail/story.html] Last access on January 7, 2014.

[13] BBC: Giant waves hit amid fresh flooding fears. BBC online (2014a) [www.bbc.co.uk/news/uk-25618080]. Last access on January 7, 2014

[14] BBC: Wales storm: Councils counting cost and ready for high tide. BBC online (2014b) [www.bbc.com/news/uk-wales-25612744]. Last access on January 7, 2014.

[15] TVI24: Onda gigante em Biarritz: "No início, eles acharam engraçado…". TVI24 online (2014) [www.tvi24.iol.pt/503/internacional/tvi24-onda-biarritz-franca-desaparecido-mar/1525958-4073.html]. Last access on January 7, 2014.

[16] JN: Três pessoas da mesma família arrastadas por onda na Galiza. Jornal de Notícias online (2014) [www.jn.pt/PaginaInicial/Mundo/Interior.aspx?content_id=3618444]. Last access on January 7, 2014.

[17] SICN: Localizado corpo de uma das três pessoas arrastadas por onda na Galiza. SIC Notícias online (2014) [sicnoticias.sapo.pt/mundo/2014/01/07/localizado-corpo-de-uma-das-tres-pessoas-arrastadas-por-onda-na-galiza]. Last access on January 7, 2014.

[18] TVI24: Ondas em Sagres (Fotos por Vanda Rita, e enviadas pela leitora Vanda Oliveira), TVI24 online (2014) [http://www.tvi24.iol.pt/fotos/3/342773], Last access on January 7, 2014.

[19] Fonseca, R.: Foz do Douro tempestade Hércules. Vídeo available on YouTube channel (2014) [https://www.youtube.com/watch?v=W8FdkMqlzco]. Last access on January 7, 2014.

[20] PC: Quatro feridos e dezenas de carros arrastados por onda na Foz do Porto, Porto canal online (2014) [http://videos.sapo.pt/agTUaAeLr3ENbOsNP6IN], Last access on January 7, 2014.

[21] RTP noticias: Pescador encontra-se desaparecido no mar desde as 5 da manhã (2014) [http://videos.sapo.pt/aDq6Fj53KUn9QmtaFy4d]. last access on November 11, 2014.

[22] RTP noticias: Homem desapareceu arrastado por uma onda quando pescava junto à barra do Douro (2014). RTP noticías online. [http://www.rtp.pt/noticias/index.php?article=780675&tm=8&layout=121&visual=49]. Last access on last access on November 11, 2014

[23] RTP noticias: Corpo de pescador continua desaparecido (2014). RTP noticías online. [http://www.rtp.pt/noticias/index.php?article=780902&tm=8&layout=122&visual=61]. Last access on last access on November 11, 2014

[24] TVI24: Retomadas as buscas para encontrar pescador no Douro (2014) [http://www.tvi24.iol.pt/sociedade/pescador-desaparecido/retomadas-as-buscas-para-encontrar-pescador-no-douro] Last access on last access on November 11, 2014