Journal of Coastal Research | SI 48 | 124-128 | III SCCG (Proccedings) | Spain | ISSN 0749-0208

Characterization of sea storms along the coast of Tenerife, the Canary Islands

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ABSTRACT

YANES, A., MARZOL, Mª V. and ROMERO, C., 2006. Characterization of sea storms along the coast of Tenerife, the Canary Islands. *Journal of Coastal Research,* SI 48 (Proccedings of the 3rd Spanish Conference on Coastal Geomorphology), 124-128. Las Palmas de Gran Canaria – Spain, ISSN 0749-0208

The aim of this paper is to state the impact of two sea storm patterns along the coast of Tenerife. They are both linked to two specific atmospheric conditions – one to *swell* events such as the one that took place between 26 and 30 December 1998, and the other one to *sea waves* such as those from 7 to 8 January 1999. Buoys and Wana models provided by Puertos del Estado (General Direction of Coasts) were used to obtain scale and directional swell data from 1985 to 2003. Analysis of average annual Hm, Hmax, Tp, wave length, wave direction and wind speed and direction values were used to characterise storm conditions. A first approach refers 98 possible storm events. Then, two storms are chosen and the sharp hourly variations of swell parameters are studied during their lifespan. The interest of such study lies in the fact that over half the perimeter of the island is densely populated and the urban planning system should consider the risk from storms.

ADITIONAL INDEX WORDS: *Storm, swell, sea*

INTRODUCTION

Understanding of storm types in Tenerife is of great interest, since recent economic development in the island – mainly based on tourism and export agriculture – has led to over half of its perimeter becoming densely populated. Mass tourism has grown spectacularly since 1960, leading to marked changes in the use of the coastline and to an important geographical redistribution of the population. New activities have indeed made others disappear – such as shellfish gathering, salt extraction, and the exploitation of carbonate concretions in lime furnaces – all of them practised along a wide stretch of coastline between the surf zone and about 50 metres a.s.l. (SABATÉ, 1993). The introduction of new activities has also involved a decline in traditional farming and a decrease in population in the central part of the island, a 400 to 1000 metres high bioclimatic band which, due to higher humidity, used to be the core of all farming activities and population. The displacement of people towards coastal areas has led to Tenerife Island now having 50% of its total 800,000 inhabitants living at elevations below 200 metres a.s.l. The result is an unplanned urban continuum. The increased vulnerability of which is clearly shown by the socioeconomic effects of many sea storms.

AIM, SOURCES AND METHODOLOGY

Various sea storms have been recorded in Tenerife Island between 1985 and 2003. Their geographical characterization and the assessment of the damage caused to people and land let us distinguish at least two types of sea storm whose features are analysed in this paper. The first type is storm linked to *swell* events, such as the one that took place between 26 and 30 December 1998 in the northern and western coasts of the island. The second pattern is linked to *sea waves*, such as those affecting nearly the whole island – though at a variable scale – between 7 and 8 January 1999, which resulted in port infrastructure losses amounting to more than 175 million euros (MARZOL *et al.*, 2005).

Adirectional swell data obtained from buoys located in Tenerife-Santa Cruz (1985-2003) and Tenerife-Sur-Granadilla (1999-2002), which belong to the Spanish network of swell recording and measurement (REMRO and RAYO), were used in this study. Also, directional swell data were gathered from seven

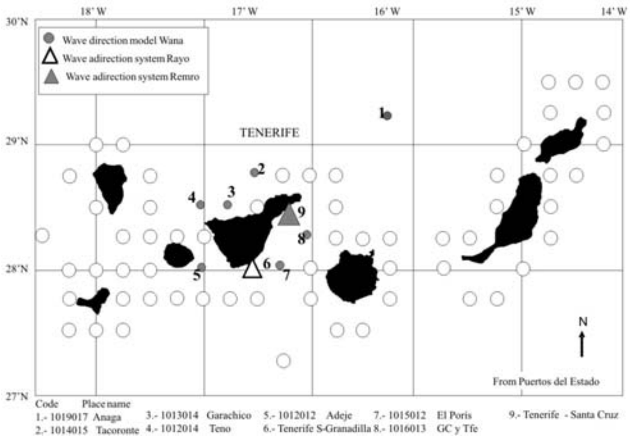

Figure 1. Location and source of swell data used in the study

Wana models (1995-2003) provided by Puertos del Estado (General Direction of Coasts) (Banco de datos. Conjunto Wana http://www.puertos.es/index2.jsp?langId=1&catId=1014806377970&pageId=1037009598954), each of them identified by the name of a mainland location used as a reference (Figure 1). Both data sources provide Hm and Tp values, but wave and wind direction and wind speed values are only provided by the Wana models. On the other hand, Hmax values are only recorded by the buoys. Still, due to their importance as indicators of low frequency and high intensity situations frequently occurring in coastal areas, Hmax parameters have also been estimated for the Wana models.

The starting point for identifying storm conditions is the statistical characterization of the normal swell regime. Firsttly, annual average Hm, Hmax, Tp, wave length, wave provenience direction and wind speed and direction values were obtained. To avoid the interference of coastal breeze, the data obtained at 9.00 a.m. and 6.00 p.m. were used in the study. Nevertheless, values are recorded daily every three hours by the buoys and Wana models. Then, a provisional storm risk threshold was established, from which individual strong swell situations are identified and changes affecting the main wave parameters during the two storms selected were analysed. The information was recorded on an hourly basis, in order to determine its length, wave behaviour and relation to specific atmospheric dynamics. The National Institute of Meteorology (INM) daily journals were checked to determine the atmospheric conditions that led to such storms. Finally, information about affected areas and generated losses are obtained from the press.

WAVE CLIMATE

The following issues must be taken into account in studying the impact of sea storms in Tenerife Island:

A) First of all, storms must be distinguished from background wave conditions. In this respect the island is usually affected by relatively moderate energy waves. They consist of waves from a NNE direction, whose annual average Hm height is 1.4 metres, Hmax 2.1 metres and Tp 9.5 seconds. 0 to 1 metre and <10 seconds waves occur for 34% of the year followed by 1 to 2 metres and ≤10 second waves for 20% of the year (Table 1). *Sea swells* are abundant throughout the year, associated with 18 to 22 km/h NNE and NE winds (50%), which point to the impact of trade winds along the coast of Tenerife.

The wave pattern varies seansonally. *Sea waves* are more frequent from late autumn till early spring. *Swell* becomes more frequent between October and March. They originate in the Northern Atlantic and approach the island from NNW and NW directions, leading to a 2 to 3 metres increase in Hm and a Tp increase of up to 18 seconds. At the same time, Hmax stays at about 4 metres (40%) and waves over 300 metres length are recorded (20%). There are also spatial differences with average Hm of 2 metres and Hmax of 3 metres values and Tp 10 and 14 seconds, respectively along the northern and wester coastlines which are exposed to non local swells. To the east, southeast and south of the island, coastal areas are sheltered from strong swells and waves are on average lower than 0.7 metres Hm, 1.1 metres Hmax and 6 seconds Tp.

Table 1: Annual frequency of the significant wave height and the peak period (%) (YANES, MARZOL AND ROMERO, 2005).

Hm	Tp (seconds)					
Metres	2 - 6	6 - 10	10 - 14	14 - 18	18 - 22	% Total
0 - 1	21,1	13,2	5,5	1,6	0,3	41,7
1 - 2	7,3	13,2	10,6	0,9	0,2	32,2
2 - 3	1,3	5,0	9,4	1,5	0,3	17,5
3 - 4	0,1	0,8	3,8	1,6	0,2	6,5
4 - 8	0,0	0,0	0,9	1,2	0,0	2,1
∑Tp	29,8	32,2	30,2	6,8	1,0	100

B) Secondly, there is an intrinsic difficulty of isolating individual storm episodes, because it´s necessary to fix the threshold of sea storm´s situation. Since the storm risk threshold has not yet been determined, the minimum established by the Recommendations of Spanish Maritime Works (ROM 0.3-91) is adopted as starting reference to estimate the point at which of coastal infrastructure is at risk. This minimum has been established at 1.5 metres Hm height for Tenerife Island, a value that can only be applied to the eastern, south-eastern and southern coast (Tenerife-Santa Cruz and Tenerife-South-Granadilla buoys; Gran Canaria-Tenerife and El Porís Wana models), where Hm remains below 0,8 metres on average and Hmax is just 1.2 metres during the winter. The suggested threshold is not applicable in the northern coast (Wana models at Anaga, Tacoronte, Garachico and Teno), since the swell pattern of 70% of the time would correspond to a storm event. The annual average Hm height during the winter is 2.6 metres and Hmax 4 metres. Considering these values the threshold should hence be set at a height of around 5 metres. Several studies on coastal dynamics and morphology at different locations in the Canary Islands suggest a similar threshold – e.g. in the north of Gran Canaria, where many of the greatest storms have had waves above 5 and 10 metres, Hm or to Hmax, respectively (HERNÁNDEZ *et al.*, 2005). Finally, the threshold was set to 3 metres in the western coast (Wana model at Adeje), since the average Hm and Hmax values during the winter in this area are 1.8 and 2.8 metres, respectively.

C) Thirdly, the coastal and neighbouring inshore seabed features, must be considered in terms of how they are affected by the increased wave energy at breakpoint. This applies to many stretches of coastline along the island’s perimeter, particularly to geologically recent coast. Of particular importance is the existence of great water depths very close to the breakers and/or to the "engagement" of water in the lateral margins *volcanic levées* (SPARKS *et al.*, 1976; CAS and WRIGHT, 1987) which spread under the sea. In these circumstances the waves preserve much of their initial energy up to the breakpoint. There are other areas where the presence of volcanic platforms, such as Punta del Hidalgo, Bajamar, El Prix-Mesa del Mar, Puerto de la Cruz, San Juan de La Rambla, Icod de Los Vinos, Garachico, Buenavista and Teno, in the north of Tenerife Island (Figure 2), favours convergent refraction phenomena. Furthermore, we must also consider the wave reflection that occurs at the cliffed front of such platforms. The building of infrastructures and facilities to cater for the needs of urban, port, commercial and leisure areas in stretches of land reclaimed from the sea leads to similar effects. This is of particular importance in the area around the capital, as well as the main tourist resorts on the southern coast.

STORM EVENTS

Initial application of the above mentioned thresholds identifies of 98 possible sea storms. Storm events recorded by the buoy located at Tenerife-Santa Cruz between 1985 and 1995 – a total of 24 – have also been excluded, since we do not have any data

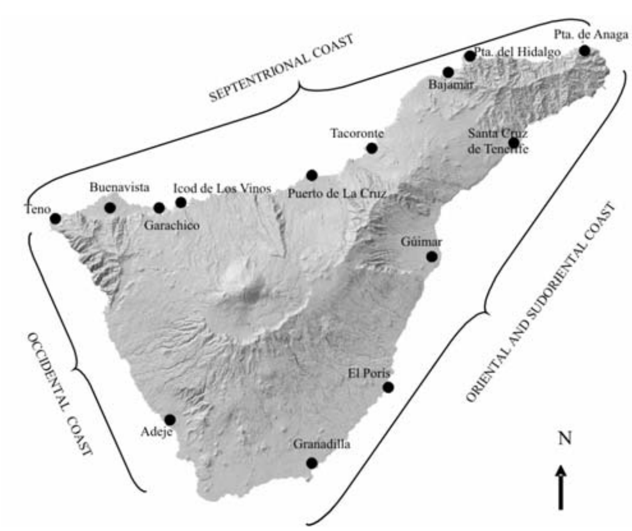

Figure 2. Differentiation of coastal sectors and locations where the risk of sea storms is higher in Tenerife Island

reflecting swell conditions in other parts of the island during that same 10-year period, neither obtained from buoys nor from the mathematical model. Although the data recorded by this buoy are used for the general characterization of the usual swell, it does not seem realistic that these are the only storm events on Tenerife Island during that period. Hence, between 1995 and 2003, 77% of high energy situations correspond to independent storms, which affect just one coastal part of the island – whether it is the north (4%), the west (17%), or the east-southeast (79%). The remaining episodes (23%) were record simultaneously in at least two of those sectors. Spatial and seasonal contrasts are obvious. Over 75% of storm episodes affect the whole E, SE, and S coastline, and they do so mainly between the winter and spring (52%), closely followed by the summer (40%). The remaining episodes affect the N and W and take place during the autumn and winter (85%), with no event recorded in the summer.

The atmospheric instability occasionally affecting the Canary Islands is of the cause of those situations where the energy affecting the waves notably changes the usual swell pattern. The sequence of strong storms that affected the northern and western coast of Tenerife Island between 26 and 30 December 1998 is a clear example of such instability (Figure 3). The episode began when the island was reached by NNW and N 500 metres length, 4.7 metres Hm height, 7.6 metres Hmax, and 18 seconds Tp waves, on 26-27 December. Such values point to a *swell* event coming from the North Atlantic, associated with winds from warm latitudes and an about 3,000 km fetch. The area around the Canaries was at that time governed by an Eastern weak circulation accompanied by dry winds from the Sahara. The move from such atmospheric stability situation towards a Northern circulation led to an intensification of the storm on 29-30 December, when N-NNW winds, at an average 35 to 45 km/h speed, arrived to the island from an area of very low pressure situated over Ireland.

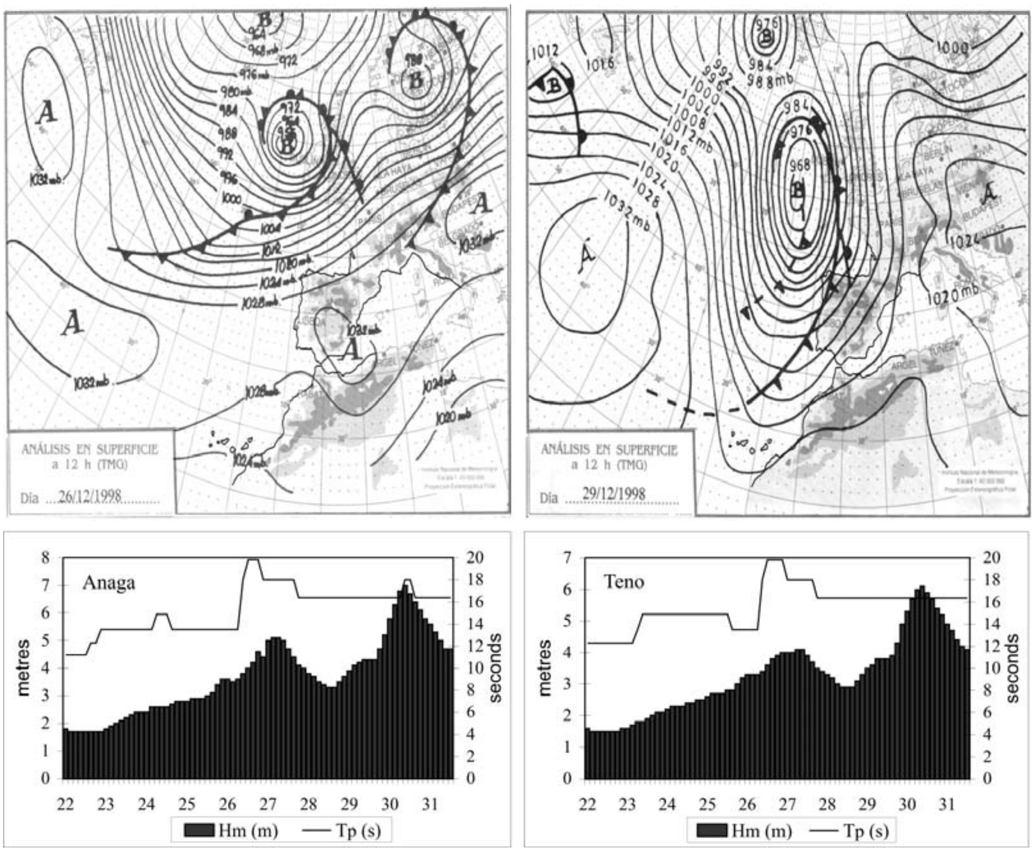

Figure 3. Atmospheric conditions and Hm and Tp evolution during the sea storm from 26 to 30 December 1998

This explains why the average Hm was 5.7 metres and the Hmax $\geq$10 metres. The decrease in wind intensity that took place in the following hours accounts for the prevailing *swell*, where long periods were maintained and, at the same time, wave height decreased gradually. The eastern, south-eastern and southern coasts were sheltered due to their leeward location.

The storm on 7 and 8 January 1999 was a different situation. It fully affected the east and south of the island (Figure 4). It originated from an initial *swell* event and then changed into a powerful *sea* through the direct action of the wind. The change was due to a decrease in latitude and deepening of a low pressure area located seaward of Lisbon between 5 and 6 January. It was associated with a depression located between the high pressure area around the Azores and one in the Mediterranean, which channelled the winds towards the Canary Islands. Those winds, originally moving in a S-SW direction, ended up veering SE. The average wind intensity increase, from 30 to 60 km/h and with gusts of 70 to 80 km/h at most (CRIADO and DORTA, 2003), determined the recording of Hm average values of 2.5 metres, Hmax values between 4 and 5 metres – up to 8 metres at times – and a drop from 12 to 6 seconds in Tp along the eastern, south-eastern and southern coastline.

A decrease in wave length accompanied these changes. In contrast to a 200 metres wave length during the hours prior to the storm, the values recorded during the episode never exceeded 50 metres. A fetch distance below 70 km also contributed to these circumstances since the core of the low pressure area was located between the east of Tenerife Island and the west of Gran Canaria. Such a strong swell caused large material damage to the port, road and city infrastructures of Santa Cruz de Tenerife, together with the sinking of vessels and breaks and holes in the dykes protecting the fishing ports and marinas at numerous sites in the south of the island – e.g. Güimar, Arico, Los Abrigos and Granadilla.

CONCLUSIONS

The analysis of the normal swell parameters and their variability under specific atmospheric conditions, as shown by the two storm patterns discussed above, indicate the need to establish a risk threshold that allows a clear identification of storm episodes. Still, this cannot be a single threshold. According to the different spatial behaviour of the annual average swell, the threshold will vary in terms of height between the northern, western or eastern-southeastern coast. Three different thresholds should thus be established. Only then shall we be able to reach a detailed characterization of storm pattern, paying special attention not only to the behaviour of the main swell parameters and their origin in relation to atmospheric conditions, but also to their frequency, energy, intensity and approximate angle to the coast. Typifying the phenomenon will help mitigate and even avoid the effects of events which, are natural phenomena, within the context the Canary Islands, where volcanism and flood debris accumulation are seen as the major natural risks. Nevertheless, the socioeconomic effects of many sea storms make their dangers obvious. The analysis of sea storms has become a relevant issue in many studies, based on the way they modify the coastal morphology, particularly in beach areas whose profile is altered

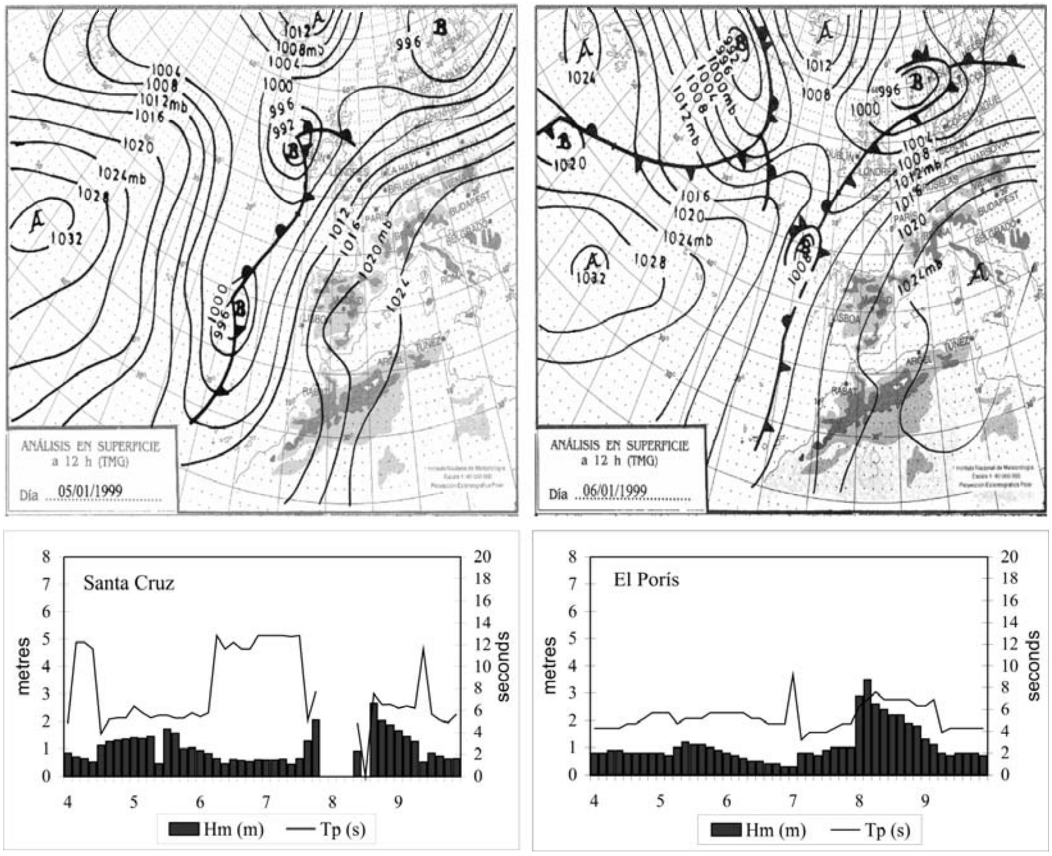

Figure 4. Atmospheric conditions and Hm and Tp evolution during the sea storm from 7 to 8 January 1999

and beaches are eroded. On the island of Tenerife, the predominance of cliffs pushes those geomorphologic effects into the background. The strong dissipation of energy produced by storms is interesting in itself, since it leads to human losses particularly considering that, under such circumstances, waves may reach between 200 and 400 metres inland during storms. This fact becomes especially relevant when it affects coastal lava platforms where there is an intense farming activity and a high concentration of population.

ACKNOWLEDGEMENTS

This study is part of the *Climatic Modelling of subtropical Mountainous Islands: Tenerife* research subproyect (INTERREG-CLIMAAT 2.3/A.3).

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