STATISTICAL STUDY OF EXTREME SEA LEVELS ON THE NORTH SPANISH COAST FROM 1943 TO 2001.

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Extremely high levels on the Northern Spanish coast are studied from 1943-2001 at Vigo, La Coruña and Santander tide gauges. A increase of extreme values and their impact on coast along the period is due to the sea level trend over this area. The influence of meteorological disturbances (pressure changes and related winds) is shown by good correlation between extreme event frequencies and NAO-winter, the most important teleconnection pattern over the North Hemisphere.

1. INTRODUCTION

Tides are mainly composed of an astronomical part and a meteorological one. Their joined action is, in specific cases, the responsible of extreme behaviours in the sea level.

On the north-western coast is remarkable the inlets presence, old valleys that today are filled by the sea, forming a very scrapped coastline with long and large cliffs, promontories and sheltered areas. The Cantabric coastline is steeply, long cliffs, small inlets and not too many beaches.

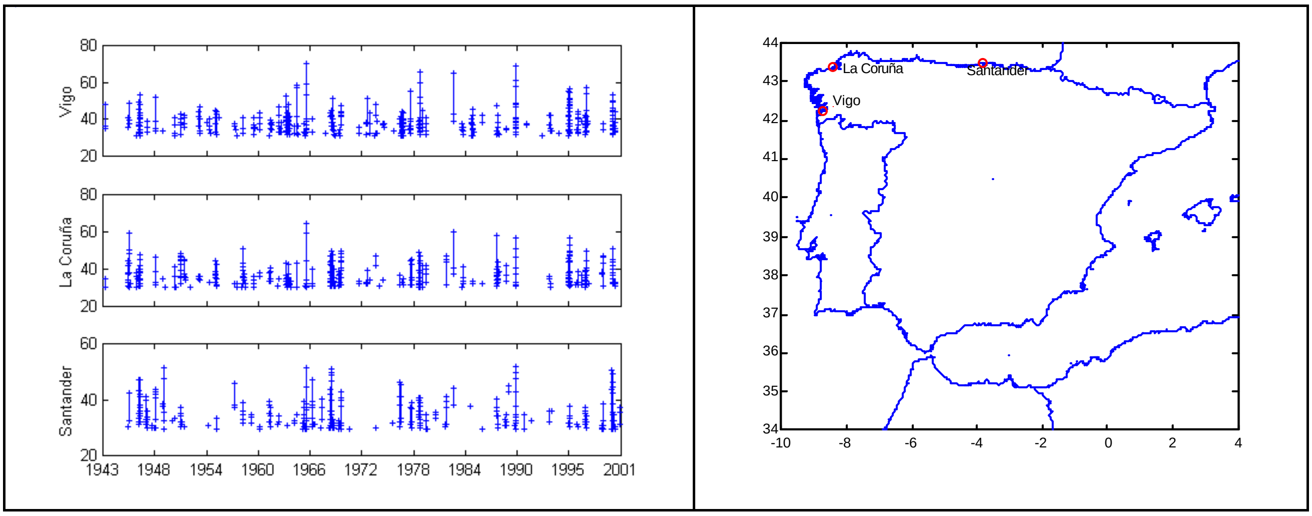

Fig. 1: Detrended MSLe at stations along the whole period and their location.

The low pressures acts along this coast causing frequent rains. Influence of pressure differences, as well as related winds, is important in the behaviour of sea level to analyse. On this coast the pressure annual variation shows an absolute maximum in summer -mainly in July-, a spring absolute minimum -around March and related to low pressure systems across the Iberian Peninsula- and an important secondary maximum in January associated with anticyclonic conditions. General atmospheric circulation forces NW and N winds during all the year, and their intensity grow while their direction change when they pass along high promontories like Finisterre. "Galernas" are winds at superficies with strong and sudden change from SW to NW related with rough weather presented on the Bay of Biscay and Cantabric coast. There are more common from May to October originated by low pressures on the Atlantic. (Font, 2000)

In the Adriatic semi-enclosed basin, specially at Venice where the owns characteristics makes the extreme events conditioned the social activities, the studies has determined the importance of the planetary meteorological disturbances contributions to the long-lasting-floods (Pasaric and Orlic, 2001) and significant increase of "acqua alta" events is documented during the last century (Battistin and Canestrelli, 2001). Analyses of sea level increase effects show that higher mean sea levels are responsible of not only an increase in floods frequency, but duration of events. An increase on these has been noted during the 90's decade (Pasaric and Orlic, 2001)

In addition to the actual global sea level increase that influences in the extremes, changes in the storm climate, storm intensity and frequency, are a conditioning factor to the extreme behaviour: as changes in intensity as in frequency can contribute to change the return periods for a given level (Flather, 2001). At this area, mean sea level has risen 2.4 mm/y in average along the 1943-2001 period (2.8 mm/y at Vigo, 1.5 mm/y at La Coruña and 2.2 mm/y at Santander), and considering that these values are related to relative mean sea level after correct glacial isostacy but not other land movements. Their joint annual and semi-annual ranges vary from 102 to 112 mm along the year, showing maximums in November (Tel and Garcia, 2002).

2. DATA

In this study, data from the Instituto Español de Oceanografia (IEO) tide gauge stations that are working since 1943 at Vigo (42º14'N, 8º44'W), La Coruña (43º22'N, 8º24'W) and Santander (43º28'N, 3º48'W).

Daily mean sea levels (MSL) are calculated from the hourly values. All value over 2.5 standard deviation (σ) is considered as extreme event (Fig. 1): MSLe (extreme mean sea level). In the purchase to characterise really extreme values than could be masked during the average process, another series has been considered from the highest of the high water of any specified day (HHW, higher high water); in this case the extreme value (HHWe, extreme higher high water) is taken from the 2σ calculated over the monthly mean higher high water (MHHW). Both cases, with and without trend, have been considered to evaluate the importance of sea level rise over the impacts.

It is important to be noted that HHW taking for the hourly values are a good approximation to real values, although could be a little smaller, because the difference between the high water level at high water time and the recorded level at time o'clock nearest high water is not considered.

The teleconnection index, NAO winter (North Atlantic Oscillation) has been provided by the Climate Analysis Section at National Center for Atmospheric Research, and the monthly SOI (Southern Oscillation Index) by National Center for Environmental Prediction, through their webs.

3.DISCUSION

The study of the number of events along each year does not show a significant trend nor at the MSLe series either HHWe series. Considering the study by decades, a significant increase in the number of events is not found yet, although in the 90's decade the number of events is little greater than in the 80's, these values are smaller than in the 60's or 70's (Fig.2a.). More over, in the HHWe there are no event found in the 80's at Santander (Fig 2c.). In the same way it is easy to see that the mainly of extremes has been found at the period October-March (Fig. 3a.), associated with the seasonality and bad meteorological conditions. In fact, for example, in February 1979 important floodings at Galicia were documented by Font (2000). Carefully observation of the MSLe series shows than an extreme event in sea level occurred at same time: 11 days duration at Vigo, 7 at La Coruña and Santander. It was associated with a storm weather related with a circumpolar vortex expansion, then a high pressures was situated south Azores and another one at higher latitudes; between them a sequence of low pressures and associated front crossed the Iberian Peninsula. It was a clear winter weather that gives NW winds over the Peninsula.

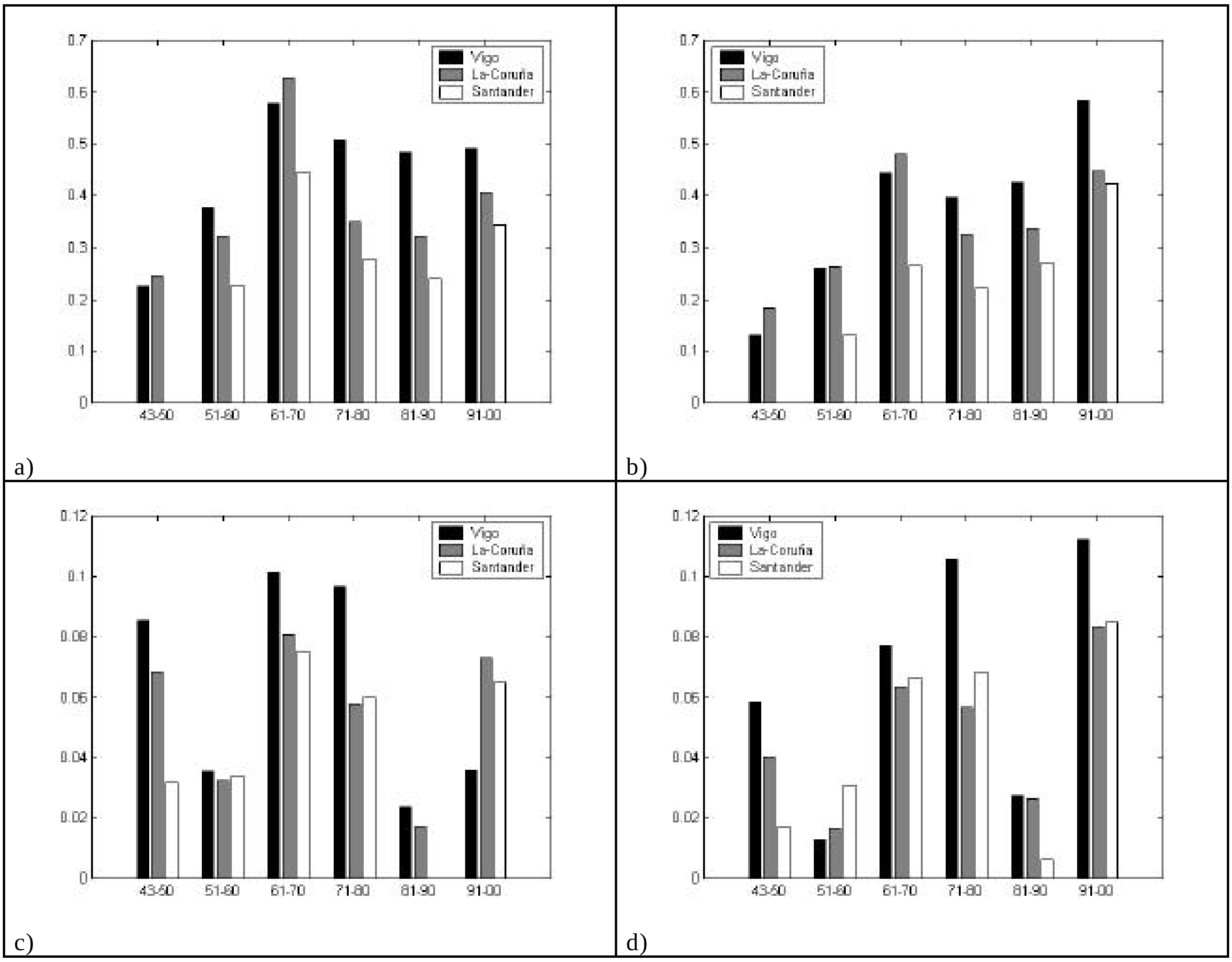

Fig 2. Relative frequency by decades: a) Detrended MSLe b) MSLe , c) Detrended HHWe, d) HHWe. By comparison between them the impact due to the linear increasing trend can be seen.

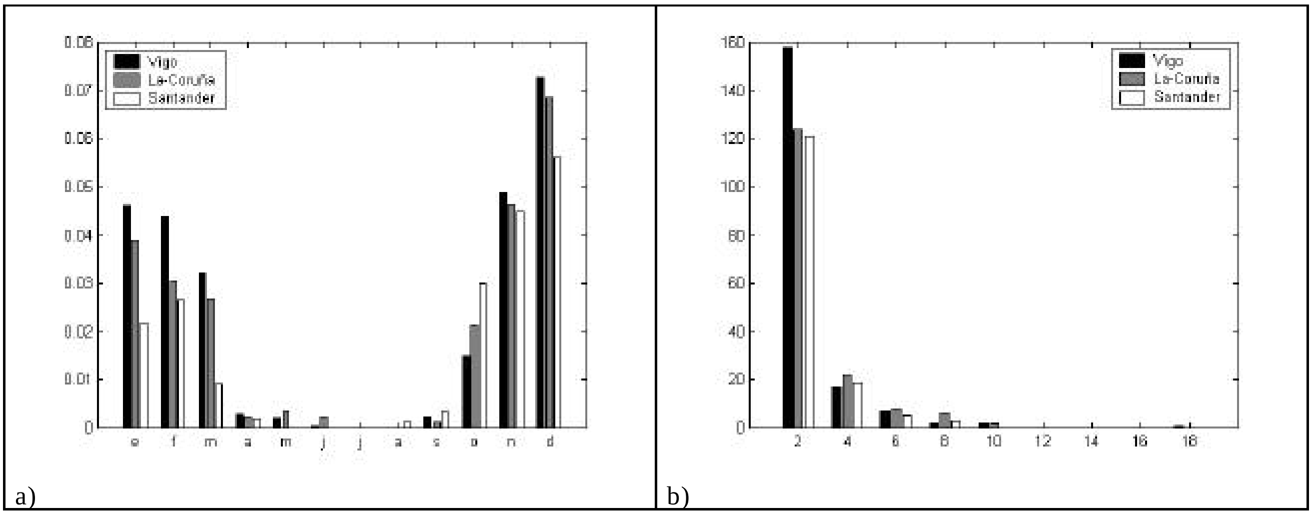

Fig 3. a) MSLe relative frequency by months. The main number of events appears from October to March coinciding with the annual and semi-annual, S_a+S_{sa}, cycle maximum and the bad meteorological conditions associated to Autumn-Winter climate. b) Duration of MSLe events in days.

Obviously if the series without remove their trends are considered to evaluate the possible impact of this events at coast, an progressive increase can be seen, due to the influence of the increasing sea level trend (fig 2b,d). The comparison between the MSLe and HHWe series after remove trends lets to distinguish the importance of impacts. In this study, statistics do not consider coincidences between extreme events and neap tides. Then, an extreme event occurred during a neap tide could not appear at HHWe series, but instead the daily mean sea level could rise quite enough, although the incidence over population could be none because it is not over the high tide level (for example 24-29 Dec 1989 event at Vigo, fig 4). On the other hand, high values during spring tides could have a great impact on coast.

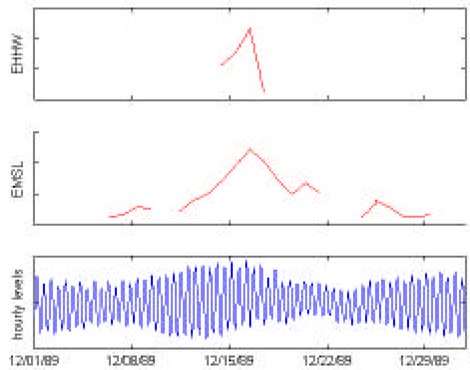

Fig 4. Extreme event occurred during neap tides (sea level (cm) vs date)

The main part of these extreme events takes from 2 to 5 days (fig 3b), related with low pressures and associated to fronts crossing the Iberian Peninsula in typical winter weather situations: high pressures in the subtropical Atlantic (south Azores) or low pressures in the Bay of Biscay, mainly. Strong winds or their large duration can produce pile up effects that tide gauges record too.

The correlations between the frequencies at the different stations are high and more important if the stations are nearer. Then, Pearson's correlation coefficients (significant at 0.01) are 0.739 between Vigo and La Coruña, 0.694 between, La Coruña and Santander, and 0.555 between Vigo and Santander for the MSLe series and slightly greater for the HHWe series. (tables 1, 2)

Table 1: Corr. Coef. MSLe relative frequencies			
	Vigo	La Coruña	Santander
Vigo	1.000		
La Coruña	0.739	1.000	
Santander	0.550	0.694	1.000

Table 2: Corr. Coef. HHWe relative frequencies			
	Vigo	La Coruña	Santander
Vigo	1.000		
La Coruña	0.622	1.000	
Santander	0.579	0.390	1.000

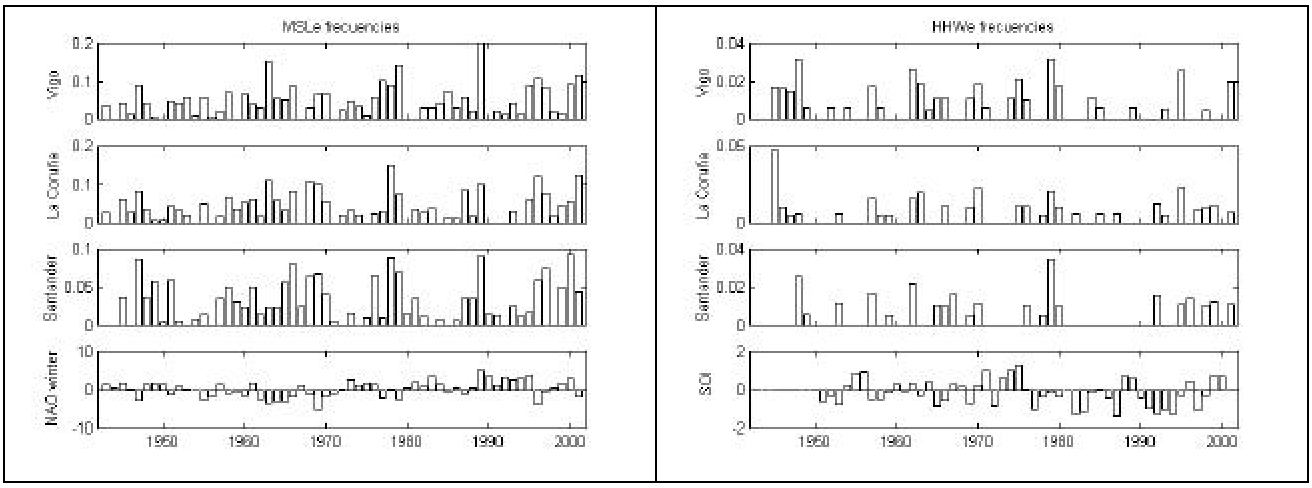

Fig 5: MSLe relative frequency of extreme events by years and teleconnection patterns

Winter (December though March) index of NAO is bases on the difference of normalised sea level pressure between Lisbon and Reykjavik. Positive values indicate stronger-than-average westerlies over Europe, high pressures over Azores and “good weather” at Spain. If the NAO winter (NAOw) is negative, high pressures over Azores are weak and fronts and cyclones cross over the Iberian Peninsula. Cross correlation between NAO winter and the extremes frequency is negative and significantly important. It is easy to see by simple visual inspection that grater number of extreme events mainly corresponds with strong negative NAO values, whereas if NAO returns to positive values, the number of extreme events decreases. It is interesting to show that in La Coruña there are significant correlations with NAO winter not only at order 0, but at order 1 too. That means amount of extremes recorded in a year depends on NAO winter value at this year and at year before (fig 6). Strong and continue negative NAOw values in the 60’s correspond with great number of MSLe relative frecuencies (Fig 5.a.) and the value –3.78 in 1996 are related with high levels in 1997-1998. In both cases the negative NAOw index and high values of MSLe are simultaneous with rainy periods documented by Font (2000).

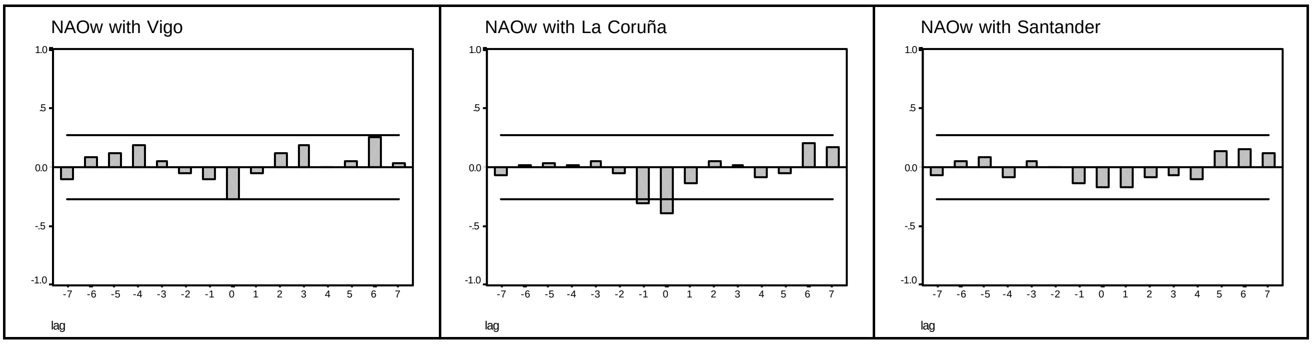

Fig 6. Cross correlation between the NAO winter and the MSLe relative frequency series.

The Southern Oscillation Index (SOI), in a similar way that NAO index, is calculated as the normalised difference between Tahiti and Darwin. Sustained negative values of SOI often indicate strong El Niño episodes, whereas positive values are associated with stronger Pacific trade winds and are known as La Niña episodes. These El Niño phenomena have repercussions throughout the world climate and have opened new research ways in the climatic variability field. In fact, strong La Niña events are clearly related with peninsular rain periods. Most rainy period in the XX century over the Iberian Peninsula, 1956-1977, coincides with most La Niña events (Font, 2000). In the same way, and although Pacific behaviour could seem not to be related with the sea level at Spain, significant correlation values are founded between the SOI and the relative frequency series of diaries maximums at as Vigo as La Coruña (fig 7). These two stations are, by its location, opened to the Atlantic meteorological force actions.

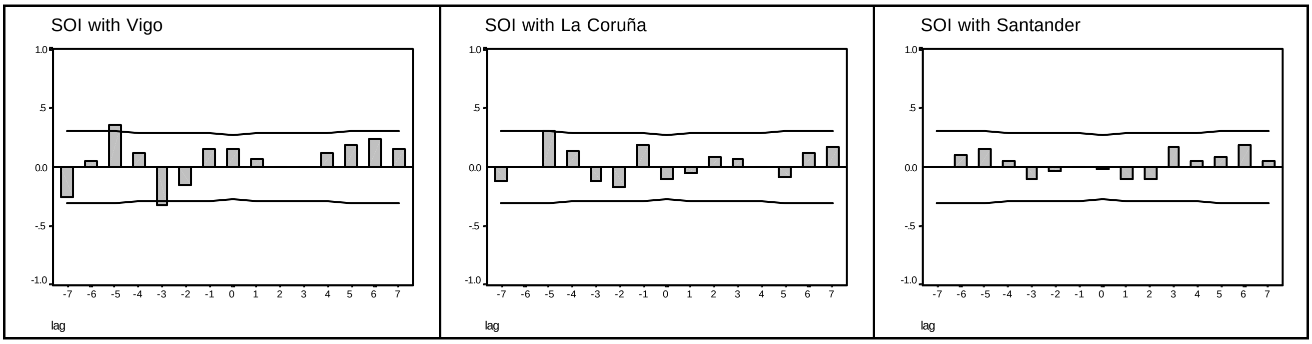

Fig 7. Cross correlation between the SOI annual and the HHWe relative frequency series.

Following the El Niño events of the 20th century facilitated by NCDC and obtained by studying the SST anomalies, La Niña events associated with strong positive SOI index, NAO index and extreme sea level events on the Northern Spanish coast, a relationship between them can be found. In fact, the combined action of strong positive SOI (5-year lag) with strong negative SOI (3-year lag) gives HHWe values as in 1962 or 1975. If NAO values are strong negative, then the MSLe rises too, which help to obtain HHWe, as in 1979 or 2001. In other cases with positive NAO values, low frecuecies values for MSLe and high HHWe values can be seen at same time as in 1948 or 1957. Actually, the joint action EL Niño/La Niña events and strong negative NAO is used to see, although sometimes phenomena are not apparently related in other times (table 3)

. These correlations show up as the atmosphere-ocean relationship importance at the sea level study as that the sea level in this area is representative of the global behaviour.

Table 3. Extreme events related with teleconection indexes.

La Niña Event	SOI anual	El Niño event	SOI annual		Extreme event	% HHWe Vigo	% HHWe Coruña	% HHWe Santander	NAO index	% MSLe Vigo	% MSLe Coruña	% MSLe Santander
1956	0,967	1958	-0,483		1962	2,6	1,6	2,2	-2,38	3,0	1,9	1,5
1964	0,425	1966	-0,542	(1965: -0,842)	1969	1,1	1,0	0,5	-4,89	6,7	10,0	6,8
1971	1,000	1972	-0,842		1975	2,1	1,1	0,0	1,63	1,0	0,0	1,1
1974	1,017	1977	-1,025	(no event)	1979	3,2	2,0	3,4	-2,25	14,5	7,4	6,9
—	—	1982	-1,317	(1983: -1,108)	1985	0,6	0,6	0,0	-0,63	7,6	1,4	0,0
1989	0,567	1992	-1,242		1995	2,6	2,4	1,1	3,96	8,9	6,1	1,8
1996	0,492	1997	-1,083	(1998: -0,300)	2001	2,0	0,7	1,1	-1,89	11,6	12,5	4,3

4. CONCLUSIONS

There is no detected a significant increase in the number of extreme events during the period 1943-2000 id the data are detrended. The impacts on the coast are due to the increasing trend of mean sea level.

The influence of meteorological conditions in the recorded extremes is important. Duration of events is related with duration of bad weather events.

The number of events is related to strong negative NAO winter, and the combined effect with negative SOI 5 years before gives a rise in the number of extremes recorded per year.

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