BEHAVIOR OF THE BEACHES ON THE NORTH OF SPAIN IS GLOBAL WARMING INVOLVED?

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This study is an analysis about morphological problems, due to anthropic or other causes. We carried out the behavior and evolution of ten beaches on the North Coast of Spain, in order to see if climate change was involved. To do this, it was necessary to consider data from Cantabrian sea buoys during fifteen years. Besides we made use of, maps, nautical charts and bathymetric records. We applied a kind of parameters to measure the energy including on each beach, so to be able to compare therm.

Keywords: beach erosion, climate change

INTRODUCTION

Many beaches on the Northern Coast of Spain are undergoing erosion. For that, The Spanish Coast Directorate of the Environment Ministry asked to CEDEX to carry out a general study of Cantabrian Coast beaches in order to determine if the erosive situation of these last years must be due to own natural evolution, human activities or, in the other hand, there are extrinsic causes such as climate change, as it has been in other coasts (Allan and Komar, 2001).

Taking into account the erosive situation of many Northern Coast Spanish beaches, the main items to study are the following:

1. Beaches that are going to be analyzed must have, at least, the following characteristics: Historical data, as bathymetries and/or profiles; and with erosive problems.
2. Evolutionary study of each one of the beaches and analysis of its problems.
3. General marine climate of the Cantabrian Coast, with special consideration in determining if there are changes in it.
4. Study of the causes that have brought about the recent evolution of the problem at issue, and probable improvement of them.

DESCRIPTION OF THE STUDY ZONE AND CHOICE OF BEACHES

Description study zone

The study area extends from the estuary of the river Bidasoa in Guipúzcoa to cape Estaca de Bares between the cities of A Coruña and Lugo. Therefore covers the coast of Galicia, Asturias, Cantabria and the Basque Country.

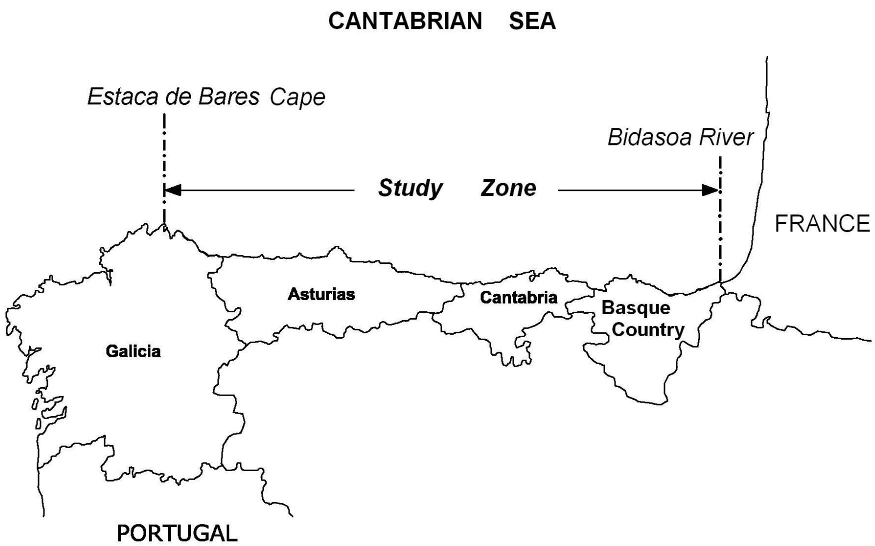

Figure 1. Main study zone, north shore Spain.

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Before going to give an overview of the physical environment that forms the coastal front, it is interesting to do an overview of its morphological structure.

Most of the north coast would be formed by a cliffy coast, with a percentage for total coast between 45% and 62%, however beach areas were in a percentage ranging from 11.3% in Asturias and 16.5% in Cantabria. In addition, there are a few beaches of certain length.

The north coast of Spain, except the final stretch west, has a nearly east-west alignment. It´s structure is influenced by the proximity of the Cantabrian mountain range that reaches to the sea forming large cliffs and rocky headlands that enter into the sea. But this proximity also makes the river system is constituted by short rivers and flowing with erosive power and mighty with its mouth forming in many estuaries, whose have been created under spits and beaches, these being the most important and numerous of this front. This circumstance makes the backshore not too high or with slope, and sensitivity to agents than their own marine climate of estuaries.

Sediments therefore are primarily on the estuaries, being these physiographic units independent.

Continental shelf

The continental coastal shelf can be subdivided into three sections, well differentiated: inner shelf, middle and outer. The basic characteristics of each of these three parts of the continental shelf are:

- The inner shelf is the seabed next to the shoreline, and is where most developed coastal events and coastal dynamics. It extends generally up to 30 or 60 feet deep and condition especially phenomena of refraction and wave propagation.
- The middle shelf extending from the outer edge of the inner platform, 30-60 meters, to a depth not defined, extending as a platform reduced slope.
- The outer platform is between the outer edge of the platform average and the continental slope, which leads to short large depths. The onset of the continental slope is located generally between 100 and 200 feet deep, depending on the coastline involved.

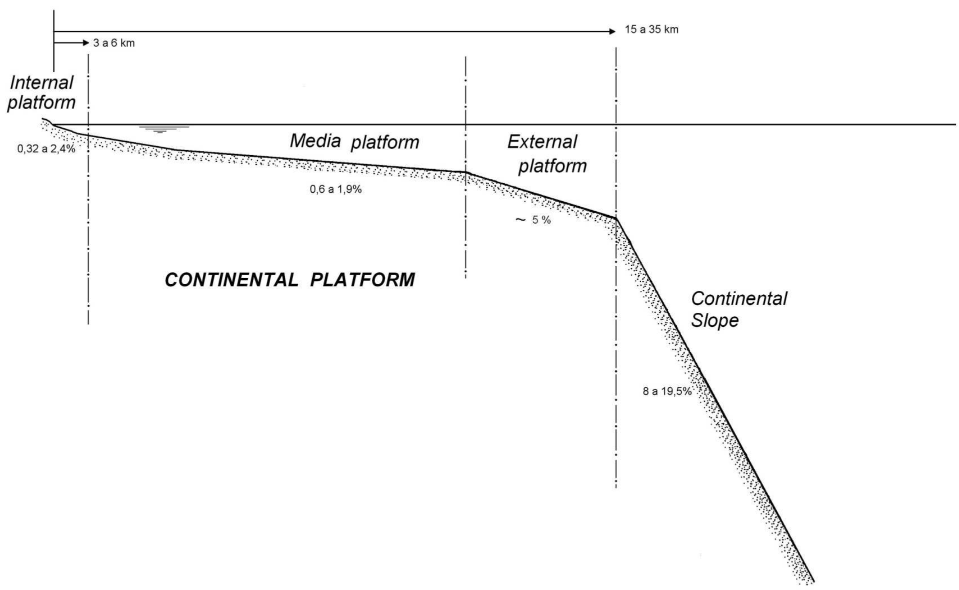

Figure 2. Coastal continental profile in the northern coast.

Types of coastal forms: beaches

From the point of view sedimentary origin are two types of beaches in northern coast of Spain:

- Associated with cliffs: usually narrow disappearing at high tide as in Celorio, near Llanes. Access to them is often difficult, so it is common to find them unaltered.
- Associated with river mouths: can be longer, are commonly found in the urban coastal, and in many cases associated with port activity for both reasons are often strongly influenced by human activity.

These two types of beaches from sedimentary origin can subdivided into more types. Having been studied beaches in the northern coast and analyzing their morphological form, there are six types:

1. Formed by a river: it generates, at its mouth, a spit that tends to close the estuary. Appears in most river mouths forming estuaries. Inside the estuary are generated and maintained sandy beaches on its banks that formed in an initial state prior. Sometimes, when the estuary is too deep cannot be generated by the spit, but beaches are created in the margins of the river facing the waves that allowed into the open, a typical example is the Bilbao estuary, although today their coastal forms are very affected by human activity.
2. Formed by the mouth of a river in a bay: sometimes rivers, flow into bays or concavities of the coast. His sedimentary activity generates beaches that form the front concavity. In many times these rivers tend to lead in the extremes.
3. Formed by the confluence of a mouth with a bay on one side and an island between the two: they are rare cases, but there are beaches as emblematic as San Sebastián or Gijón. It happens when a river flows next to a bay and there is a small island, then sediment fills and forms an isthmus with the island. Also a spit can appear in a range of the mouth.
4. Formed by a bay near an estuary: when a bay is near the mouth of a river but is not inside and besides depths benefit the longitudinal transport of sediments. Then sediments are trapped by the concavity.
5. Formed by a bay next to an estuary: when a bay is very close to the mouth then sediments fill the concavity and it can appear a spit.
6. Formed by the cliffs: sediments come mostly from erosion the coast, itself sometimes tends to isthmus forms when there are islets or cliffs nearby.

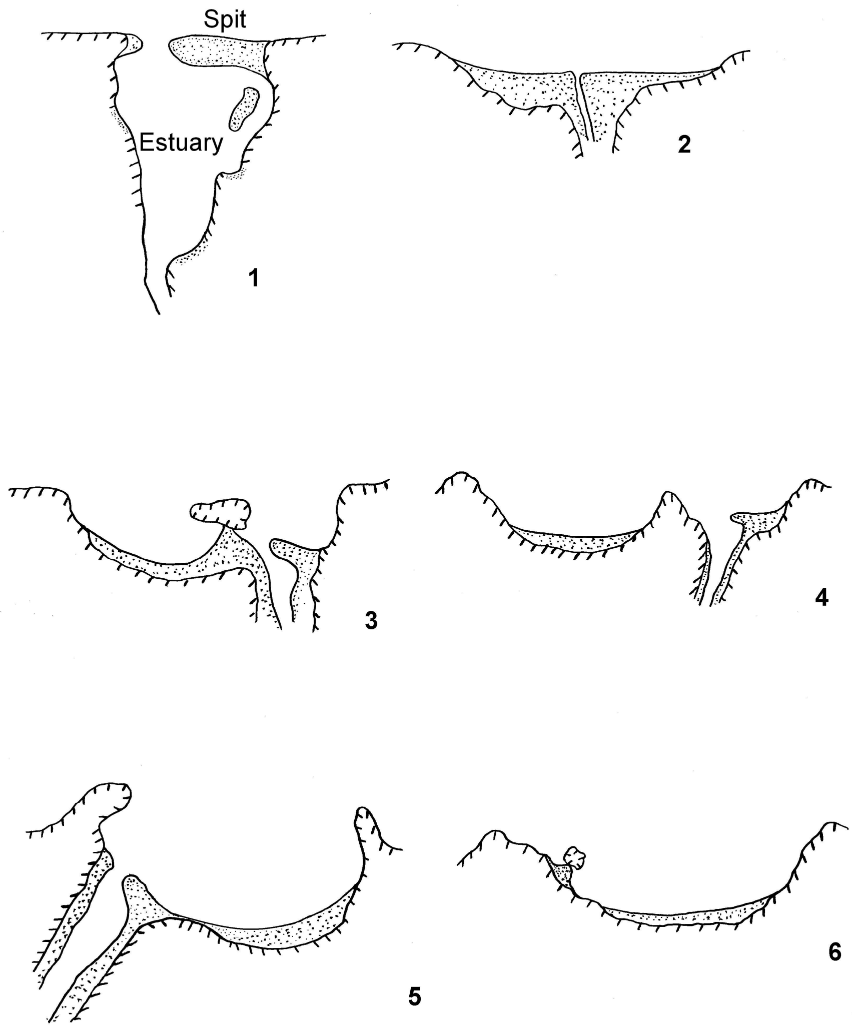

Figure 3. Types of structures beaches in the Cantabrian.

Choice of beaches

To characterize the behavior of the beaches of northern Spain have been chosen from all nine locations, ten beaches. This choice is due to various technical criteria that can be summarized in the following points:

1. Beaches must have the main characteristics: historical data, as bathymetries and/or profiles; and with erosive problems.
2. Beaches should be representatives of the Cantabrian coast, so is chosen three beaches in the Basque coast, two beaches in the Cantabrian coast, two in the Asturian coast, and three on the Galician coast.
3. If possible, should represent the maximum types of coastal forms.

The beaches chosen for this study were the follows (Figure 4):

In the Basque coast:

La Zurriola in San Sebastián (Guipúzcoa)
Deba in Deba (Guipúzcoa)
La Arena in Muskiz (Vizcaya)

In the Cantabrian coast:

Laredo in Santander
Oyambre in San Vicente de la Barquera

In the Asturian coast:

San Lorenzo in Gijón
Salinas in Castrillón

In the Galician coast:

Rapadoira and San Cosme in Foz (Lugo)
Arealonga in Vicedo (Lugo)

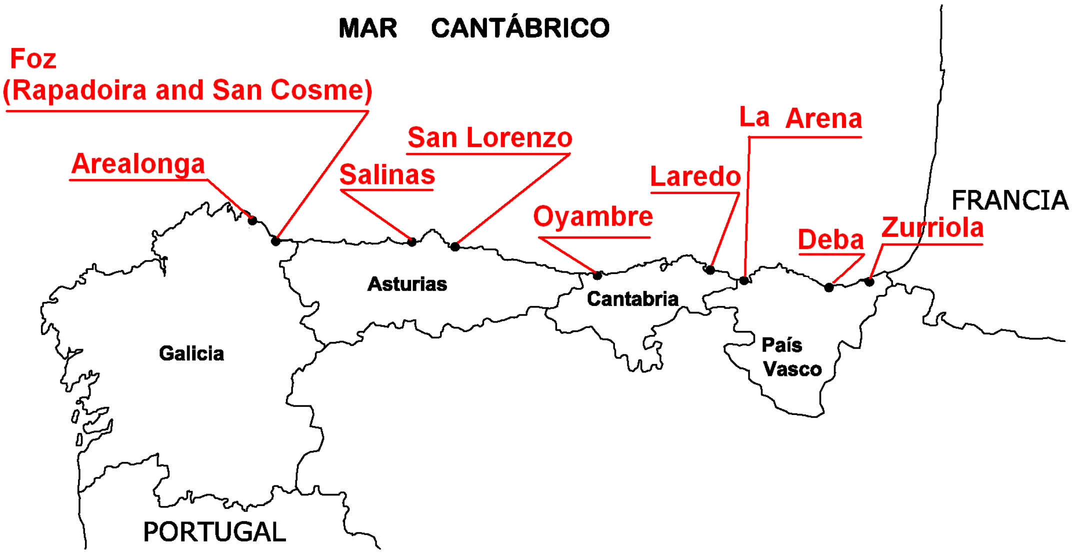

Figure 4. Beaches representatives chosen in the Cantabrian.

WAVE DATA SOURCE

Four type of wave data have been used of climatic source: Visual data; Offshore data buoy (REDEX), Coastal data buoy (REDCOS), and the calculated wave data in the points of network WANA (program WAM) of “Puertos del Estado”.

Visual data from the National Climatic Data Center

Characterize wave climate Cantabrian general maritime front, giving the principal directions of wave. It´s the largest data based along the time therefore more reliable than characterize best wave.

Observations are taken from different sources: ships on route, weather ships, or buoys observations. And the data are differentiated by the type of waves, Sea or Swell, providing for each observation: the height, period and direction of the wave and the geographical coordinates of the observation point.

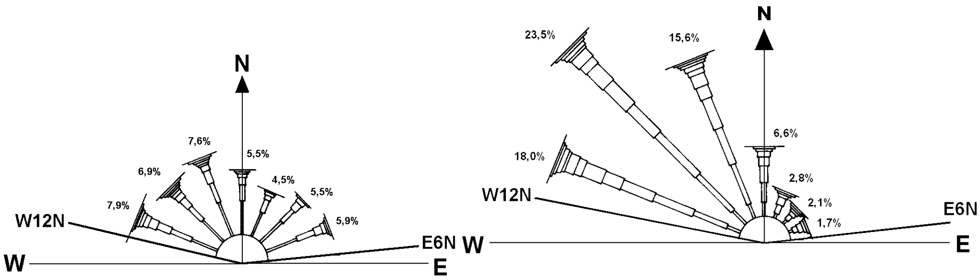

Figure 5.Joint distribution visual wave height / direction, distinguishing between types of waves Sea (left) and Swell (right).

In the wave Sea, the most important sector is the fourth, with the main directions WNW and NNW and frequency of 7,9% and 7,6%. However in the wave Swell, the main direction is NW with frequency of 23,5%.

Offshore data buoy (REDEX)

The joint of buoys known as REDEX consists in buoys located in deep water and form the called "Red Exterior". This network is formed by the old networks RAYO and EMOD, which was unified and extended.

These buoys are located far of shoreline, at depth usually over 130 meters, between 135 and 1200 meters. And provide directional wave data not affected by the coast being representative of large coastal areas. Besides provide oceanographic and meteorological parameters.

Data from this kind of buoys complement visual data. They are in some occasions more exactly but have a few numbers of years of data.

The buoys used in this study area are the buoy of Bilbao-Vizcaya, the Cape of Peñas buoy and Estaca de Bares buoy.

Coastal data buoy (REDCOS)

The joint of buoys known as REDCOS consists in buoys located near the cost and form the called "Red de Boyas Costeras". This network is formed by the old network REMRO.

Their buoys are located near the shoreline, at depth less than 100 meters, and always next to harbors. The network consists on scalar buoys and have the advantage, that due to be the first network in Spanish coast the number of years of data is the most extensive. The wave data are conditioned by the effects of the coast, especially refractive.

They are used to characterize parameters of wave unrelated expressly and directly to the direction of wave. The buoys consider in this study area are Pasajes, Bilbao and Gijón (Figure 6).

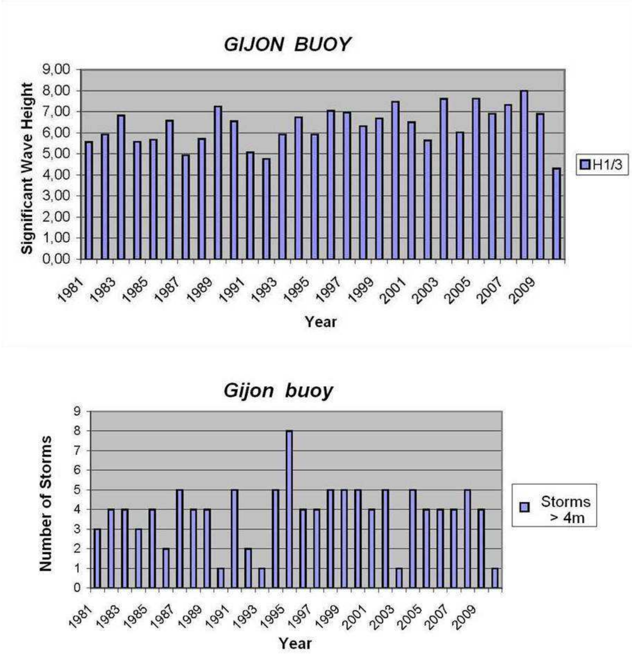

Figure 6. Coastal data buoy (REDCOS) - Gijon.

Network WANA (program WAM) of "Puertos del Estado"

The data set WANA consists in time series of parameters of wind and waves from numerical modeling. They are therefore simulated data and not come from direct measures of nature. Network WANA comes from the prediction system which "Puertos del Estado" has develop in collaboration with the National Institute of Meteorology, today Agency National Weather. These wave data are obtained from the mathematical model WAM that begins from other variables such as wind and pressure. Obtaining data wave is made to certain points around the Spanish coast and period from data are available is from 1995. On the Cantabrian front there are 30 points since WANA point 1074075 to WANA point 1048076. To complement the general wave data in the Cantabrian front and center on the beach La Zurriola, the only data source that can provide us with a number of year maximum, are the point from forecast WANA. The wave data that have been considered are from the WANA point 1072074 near La Zurriola beach. A resume of this data is presented in table 1.

Table 1. Storms in WANA point 1072074 (Zurriola Beach)

Hs max	>8	>7	>6	>5	>4	>3	3–2'5	2'5-2	2-1'5	1'5-1	TOTAL	Max Anual	Months with data
1996	0	0	2	1	2	4	1	0	0	0	10	6,9	12
1997	0	0	0	5	2	3	0	0	1	0	11	5,5	12
1998	1	0	1	2	2	2	1	1	2	0	12	9,0	12
1999	1	0	0	1	5	1	2	0	2	0	12	10,5	12
2000	1	0	2	2	3	0	3	0	1	0	12	9,2	12
2001	0	0	0	2	4	0	3	1	2	0	12	5,5	12
2002	0	0	1	2	3	3	0	2	1	0	12	6,2	12
2003	0	0	1	4	1	2	2	1	1	0	12	6,0	12
2004	0	0	0	2	3	3	2	1	1	0	12	5,4	12
2005	0	1	0	1	0	4	1	1	2	2	12	7,2	12
2006	0	1	0	0	4	3	0	2	2	0	12	7,2	12
2007	1	1	1	1	2	4	1	1	0	0	12	8,4	12
2008	0	1	3	0	3	2	2	1	0	0	12	7,0	12
2009	2	1	1	1	2	1	2	1	1	0	12	11,9	12
2010	1	0	2	2	2	1	2	1	0	0	11	8,0	12
2011	0	0	0	1	0	1	1	0	0	0	3	5,9	3

ANALISIS OF BEHAVIOR OF THE NORTHERN BEACHES

After analyzing types of coastal forms and wave data source, the next step is to analyze the behavior of the beaches of northern coast, in Spain.

The study of the storms that have been happening in the beaches of the Cantabrian coast, and its evolutionary tendency, has been made both in intensity and number of important storms, which are considered bigger than 4m.

Storm intensity

To analyze the first aspect, storm intensity, we consider the parameter, "average annual energy value", defined as:

$$\overline{E_{mra}} = \sum\sum(N_i \cdot H_i^2)_j / j$$

Where: H_i=Significant wave height

N_i=number of storms with maximum significant wave height H_i.

J=number of years

Considering the number of storms that have occurred in each beach, included in the maritime climate study of each beach, and calculating their average annual energy value, the results are resumed in the table 2.

Table 2: Average annual energy value	
Beach	**(m^2/year)**
La Zurriola	198,58
Deba	175,15
La Arena	146,82
Laredo	5,30
Oyambre	57,48
San Lorenzo	20,40
Salinas	269,25
Rapadoira	16,37
San Cosme	129,12
Arealonga	6,85

Another indicator of the intensity of the storms is the maximum wave height recorded and their return period (PR). In the following table are included this data, where is possible discover that in none of the cases have been achieved wave heights with return periods over 100 years, and in some cases storms can be consider with normal frequency, when the return period is lower than 15 years. Therefore, on this point, it seems that hasn't been exceptional temporary regarding their frequency of occurrence in time, although they have been hard and unaccustomed to suffer them.

Table 3: Return Period for Storm Maximum (1996-2010)										
Beach	Zurriola	Deba	Arena	Laredo	Oyambre	S.Lorenzo	Salinas	Rapadoira	S.Cosme	Arealonga
$(H_{1/3})_{max}$ (m)	11,9	12	12	4,4	9,1	6,4	11,7	4,9	8,8	5,3
Year	2009	2009	2009	2007	2009	2008	2009	1997	2010	1997
R P (years)	70	70	50	40	20-25	Normal	25	15	Normal	¿?

Looking at the group of beaches, its average annual energy value and the evolutionary tendency it has been studied in the period between 1996 and 2010, and shows that the sector between N14º E and N45º W is the most energy, although, in most cases, there is a tendency to increase in the energy sector, is only in the beach of La Arena where it is more pronounced, softening in the sectors on both sides.

From the normal direction of the beach N14º E to east, beaches have experienced a decreasing tendency or remained. The energy value that will represent the value of the energy incident on them an average year, is fewer than in the last sector.

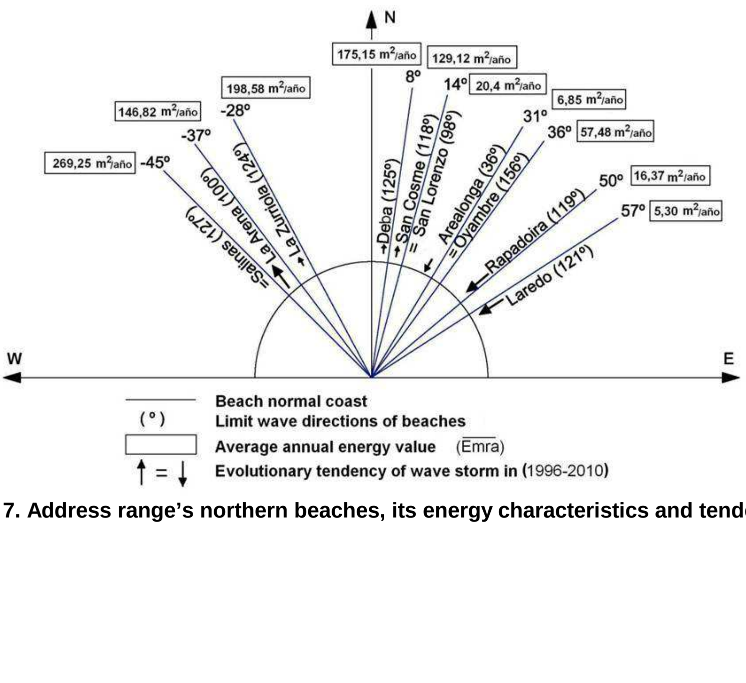

Figure 7. Address range's northern beaches, its energy characteristics and tendency.

The results of the evolution energy value from the mean in two beaches, La Zurriola and Laredo, are in the following figures. Where is represented the regression line to show the evolutionary tendency of wave energy impacted on the beach.

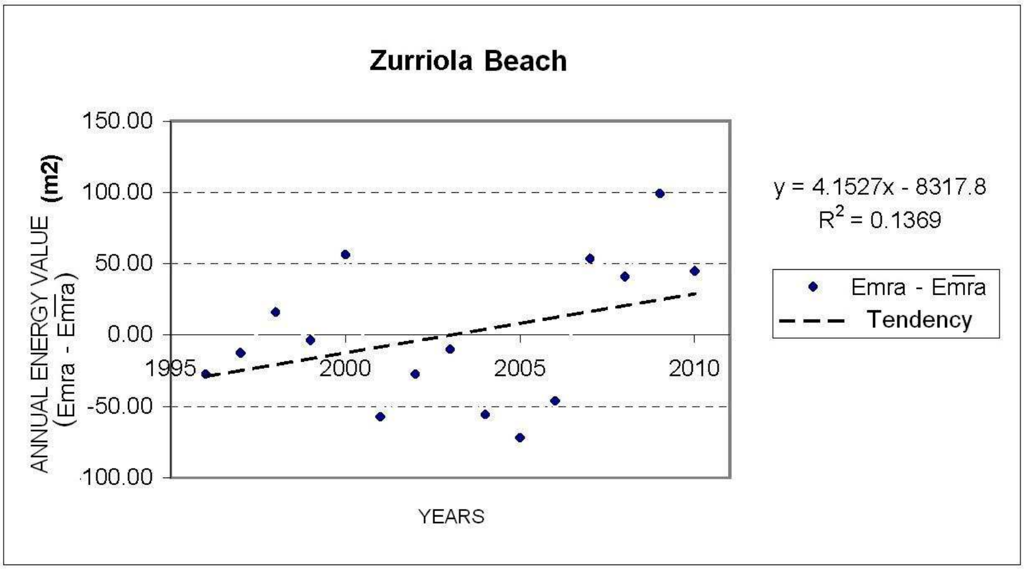

Figure 8. Evolution of the wave energy on La Zurriola beach.

La Zurriola beach has a tendency in the period 1996-2010 to increase the wave energy incident on the beach. There is a swing around half of the period, increasing in the last year about 50% and decreasing in the first year about -30%. So there are small variations in the intensity.

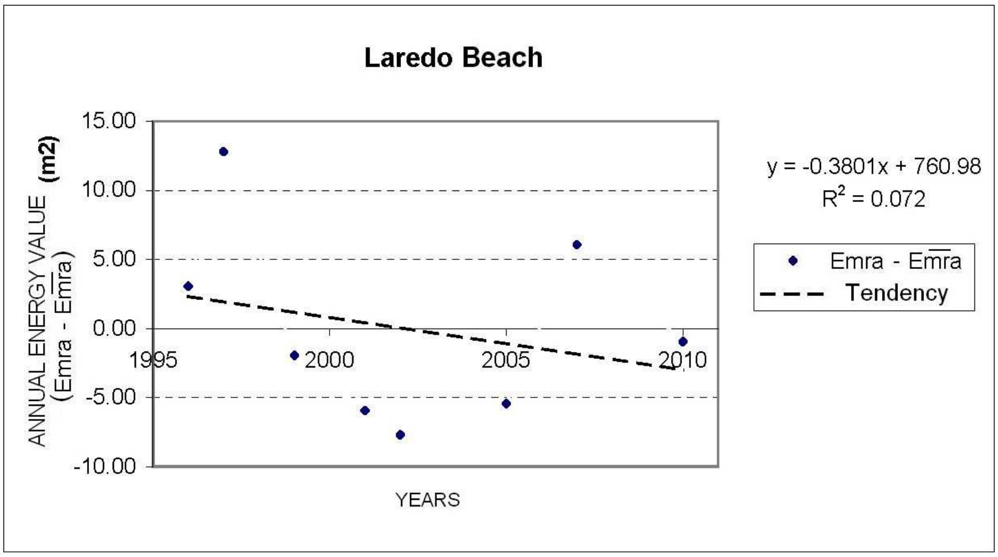

Figure 9. Evolution of the wave energy on Laredo beach.

Laredo beach is particularly protected from the main directions of waves, so the intensity and energy of the storms incident on the beach is less than the other beaches. The tendency of the energy incident on the beach in the period 1996 – 2010 is decreasing. Although the oscillations about half a year are bigger: reaching values of 140% and -70% above and below the average year, approximately.

Storm number in the coastal buoys

As the period in which it has been studied the waves and storms produced in northern coastal peninsular has been short, 1996 – 2010, and the results obtained from its analysis, both the incident wave energy annual on beaches chosen, as in the significant storm number ($H_{1/3}$ > 4m), don't show clear tendencies or behaviors, is preferred, before giving any valuation, analyze data provide scalar buoys Bilbao and Gijon (REDCOS), located near the coast and with longer period. In Bilbao buoy from 1976 – 2010 and in Gijon buoy from 1981 – 2010.

Taking data from these two buoys, applying the same methodology of analysis than in each beach, and taking into account some important factors:

- Buoys are scalars and therefore reflect data can come from all directions without distinction.
- In certain years there are fewer records months.

The first of the considerations causes the average energy value, is bigger than calculated for each beach. Thus obtained values are:

$$\overline{(E_{mra})}_{BILBAO} = 248{,}9 m^2 / año$$

$$\overline{(E_{mra})}_{GIJÓN} = 245{,}40 m^2 / año$$

The second could be modified giving a weighting in the years that have less records, but it may fall into a greater mistake than we have to consider partially register, therefore was preferred as a first approximation, leave as shown.

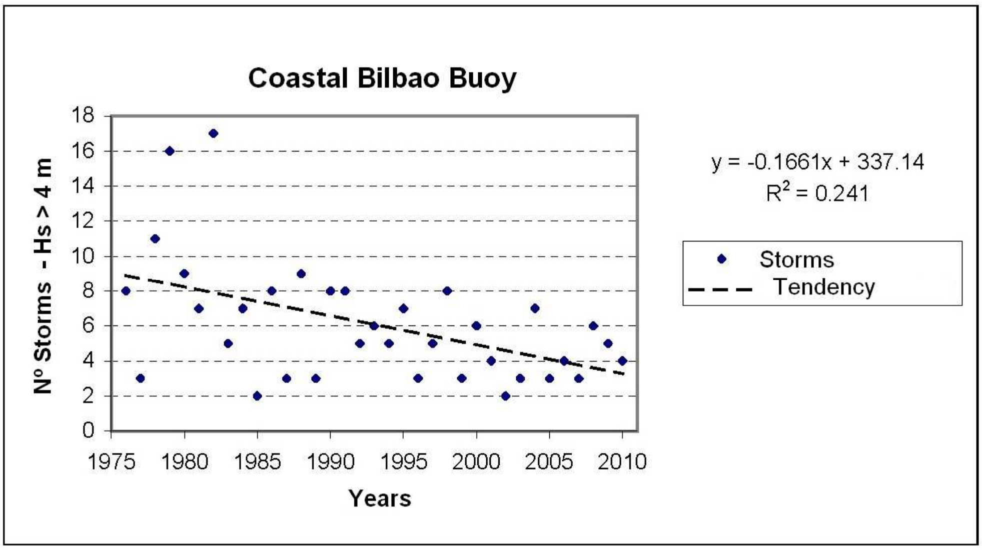

Figure 10. Evolution of wave energy buoy in Bilbao (REDCOS).

The variation, from the mean, of the energy value in Bilbao buoy (REDCOS) indicates that for the period between 1975 and 2010, there is a decreasing tendency. This tendency is due to the years 1978, 1979 and 1982 were "very hard" giving very high energy values, also taking into account that for the years 1980 and 1981, have only half time registered, with somewhat higher energy values average, could say that the period "very hard" extends to five years 1978 – 1982. In addition the number of strong storms, ($H_{1/3}$ > 4m), were very high: 11, 16 and 17 in the years 1978, 1979 and 1982, respectively.

However considering Gijon buoy, with data between 1981 and 2010, the results are very different. With practically the same average annual energy value of Bilbao buoy, the tendency is not the same, having a soft increase. The dispersions are also higher in this buoy. The number of strong storm, are between 5 and 9, although there are punctual cases outside.

The energy values recorded in some years in the Bilbao buoy in 1978 of 468 m^2, didn't reached in either scalar buoys, approaching in Gijon buoy in 2007 with 431,75 m^2.

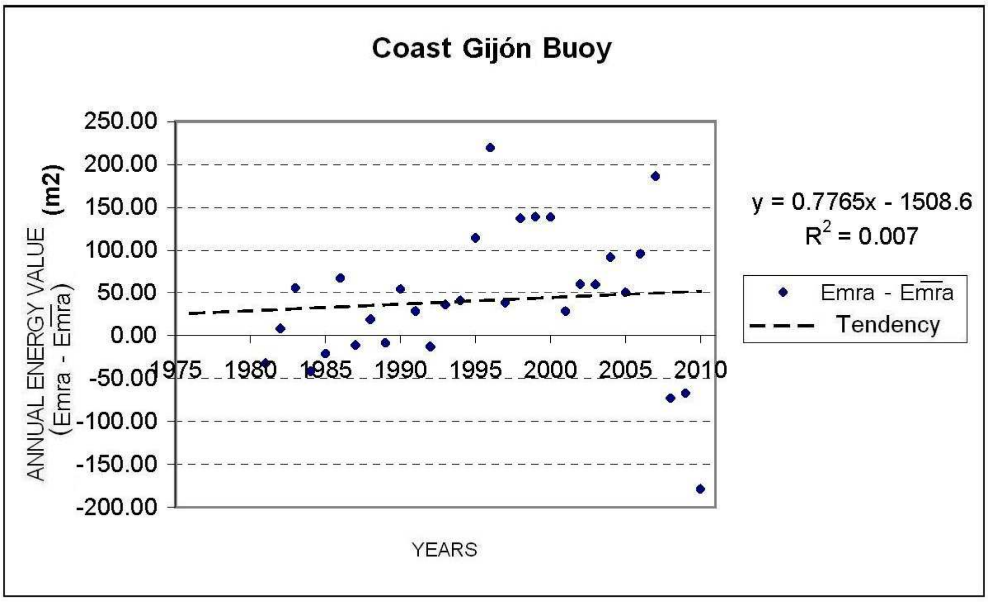

Figure 11. Evolution of wave energy buoy in Gijón (REDCOS).

CONCLUSIONS

The analysis of the evolution of storms results, seems to rid there are not enough data to be able to indicate a trend clear in the evolution of the maritime climate. Likewise it is not changing or increasing the number of storms or its intensity in the Cantabrian coast.

The number of years that have data does not include possible cycles or alternations in the climate; example of this is the difference in trends in data from the buoys of Bilbao (REDCOS) with the largest number of years, and the Gijon (REDCOS) with fewer years.

In the period from 1996 to 2010 has existed in a covered zone of addresses between N45W and N15E an intensity of important waves, with particularly "hard" years between 2006 to 2010, producing storms with return periods around 70 years.

As a result is not easy to wake meaningful conclusions with respect to climate changes. Nothing can be readily generalized.

ACKNOWLEDGES

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REFERENCES

Alonso, A., F. Lorenzo y J.L. Pagés. 2000. *Dinámica litoral y erosión en la ría de El Barquero: factores antrópicos y procesos naturales; Geogaceta, 28, 7-10.*

Allan, J.C., and Komar, P.D. 2001. *Wave climate change and coastal erosion in the US Pacific Northwest; Proceedings of 4th International Symposium on Ocean Waves Measurement and Analysis (WAVES 2001)*

Birkemeier, W.A. 1985. *Field Data on Seaward Limit of Profile Change Journal of Waterways, Port, Coastal and Ocean Engineering, American Society of Civil Engineers*, vol. 111, nº 3, 598-602.

C.U.R. 1987. *Manual on Artificial Beach Nourishment.* Center for Civil Engineering Research, Codes and Specifications, report 130.

Grupo e Ingeniería Oceanográfica y de Costas. *Atlas de Inundación del Litoral Español*; Universidad de Cantabria y Ministerio de Medio Ambiente.

Lechuga Álvaro, A. 1993. *Evaluación de la situación actual desde el punto de vista sedimentario de la ría de Foz y playa de San Cosme de Barreiros.* CEDEX (technical report for D.G.S.C.M).

Peña, J.M. and Antón, A. I. 2011. *Comportamiento reciente de diversas playas del norte.* Centro de Estudios de Puertos y Costas del CEDEX (technical report for D.G.S.C.M).