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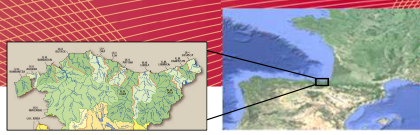

Meteorological characterization of events that generate floods impact in north part of Basque Country

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Abstract

In this work we analyzed the most important precipitation events during 21st century that generates floods impact in north part of Basque Country (Cantabric basin). To select the relevant events we have considered information coming from different sources, including information from damages, precipitation thresholds and internal Euskalmet severe weather reports.

A meteorological analysis of the selected events is performed using synoptic classification, and other weather types classifications (type of precipitation, cloud systems and severe weather categorization). Meteorological parameters are analyzed based on data coming from numerical models, the Automatic Weather Station network and other data acquisition system available in the area (Radar, Meteosat, etc..).

Here we present the main meteorological characteristics during 21st century floods episodes and the key factors involved in such events.

Introduction

The Basque Country has two hydrographic watersheds, the Atlantic and the Mediterranean side. In the first one, the steep slopes generate floods with certain regularity, because the slopes have around 1000 meters or even more in only few tens of kilometers, together with episodes of very heavy rainfall. However, rivers from the Mediterranean side have less risk of flooding, due to the fewer amount of precipitation and the lower slope of their basins (see Introduction and figure 2 in Gaztelumendi et al 2016-POSTERXX)

. These situations, when more rainfall is accumulated in the study area, occur in the **cold season**, between October and April. The zonal circulation descends from latitude and the areas of low pressure are deeper, with very active fronts associated. Sometimes rainfall, together with fallen melting snow, can cause significant floods. During the **warm season**, storms can also leave significant precipitation or in singular situations, mesoscale convective systems could leave higher amounts than the ones produced in cold periods, with higher intensities of precipitation, but these situations are unusual. One such situation was that caused one of the major floods that have hit the Basque Country in August 1983.

From the historical point of view, the August 1983 floods are the most serious in recent years with loss of life and damage which reaches more than 800 million euros. We cannot forget the July 1988 event where again loss of life and 52 million euros in damages occur. Another nearest event that leaves extensive damage is occurred on June 1, 1997 with 110 million euros, but this time no deaths occur. Already in the 21st century the two most important events are the 1 June 2008 and 4-7 November 2011.

Name	Type of structures and cloud system description.
Active fronts	It is the situation in which one or more fronts pass through the Basque Country, leaving persistent rainfall. They can be very active fronts or a succession of fronts that pass through the Basque Country leaving lots of rain, even a succession of fronts and instability lines. Most of the precipitation is stratiform, although occasionally can leave convective precipitation.
Instability line	Leave storm rainfall. Its shape and displacement mode can make the amount of accumulated rainfall is higher or lower. In any case, precipitation is associated with storms and precipitation is largely convective. In the worst situations in which an instability line moved slowly, convective cells can pass through the same point generating heavy rainfall.
Quasi-stationary warm front	Northwest flow situation at all levels with a warm front it moves from west to east, with a north-south elongation and having a slow-moving. Rainfall is stratiform. These situations can be accompanied by the passage of more fronts
Convective cells	Convective cells are small-scale storm systems. They have different shapes, but do not bind in a line, and generally each cell is independent and has its own movement, sometimes when the flow is strong in height the different cells are moved in the same direction. Rainfall is heavy in a short time.
Mesoscale Convective systems	They are mesoscale systems dimensions, but of significant size (usually the major axis exceeds 100 km), where more or less active areas are grouped, with a mixture of convective precipitation in the most active and stratiform rainfall in less active zones. They can make very heavy rainfall since in many cases they are systems that do not follow the synoptic scale flow, and present self-propagation, sometimes very slow.

Table 2. Structures and cloud system.

Type	Circulation	Shape
Maritime	Zone	Undefined
		Azores High
		Britannic Low
		Low latitudes circulation
	Meridian	Undefined
		Azores High
		Atlantic High
		Britannic Low
		Bay of Biscay Low
		Euro-Mediterranean Low
	Detached	Undefined
		Bay of Biscay Low
		Mediterranean Low
		Euro-Mediterranean Low
Iberic	Zone	Undefined
		Low latitudes circulation
		Britannic Low
		Euro-Mediterranean High
	Meridian	Undefined
		Centre-European High
		Britannic Low
		Bay of Biscay Low
	Detached	Undefined
		Atlantic Low
		Bay of Biscay Low
Continental	Meridian	Undefined
		Britannic-European High
		Euro-Mediterranean Low
	Detached	Undefined
		Euro-Mediterranean Low
		Continental High
		Britannic-European High
Local	Zone	Undefined
		Barometric swamp
		Iberian Thermal Low
		Iberian High
	Meridian	Undefined
		Barometric swamp
		Iberian Thermal Low
	Detached	Undefined
		Barometric swamp
		Iberian Low
		Iberian Thermal Low
		Britannic High

Table 1. Synoptic classification.

Severe weather	Description
Storms	These are the situations that occur in the summer, with heavy showers (> 10 mm in 10 minutes or > 15 mm in 1 hour) or very strong wind gusts (> 100 km / h) or large hail (above 2 cm diameter).
Hurricane winds	Situations that generate high wind gusts (> 100-120 km / h) generated by deep depressions (could be explosive cyclogenesis, or remnants of hurricanes or ordinary cyclogenesis).
CTD-s (Coastal Trapped Disturbance)	Sharp turn to the west-northwest, with sudden drop in temperatures (> 5-10 °C in 20 minutes), and maximum gusts above 60 km / h . This disturbance is spreading from west to east along the Basque coast.
Northwest gale	Intense northwest winds situation, also it is accompanied by persistent precipitation (> 60 mm in 24 hours) and wave (significant wave height exceeding 3.5 meters).
Persistent and heavy rainfall (cut-off low)	Situations cold pool in middle and upper levels, attached to efficient frontal systems or formation of mesoscale convective systems.
Swell arrival from distant deep depressions	Waves generated in remote areas that reaches the coast and sea background with heights exceeding 4 meters.
Heatwaves	Three days or more with overcoming the maximum-minimum thresholds. Arrival of a very warm air mass (temperature in the level of 850 hPa above 20-22 ° C) of North Africa or southern Iberian Peninsula with great persistence.
Heatstroke	A day with extreme high temperatures, usually in combination with the arrival of a very warm air mass from North Africa or southern Iberian Peninsula (temperature in the level of 850 hPa above 20-22 ° C) with south flows.
Severe frost	Continental very cold air advection combined with radiation cooling due to clear skies.
Snow storm	Cold and moisture air that can leave snow at low levels. Precipitation should exceed 5 mm in 24 hours.
Active frontal systems	Situations that often leave persistent rainfall, with northerly winds and quasi-stationary frontal systems, or active fronts.
Others	Events that cannot be classified in one of the previous options.

Table 3. Categories of severe weather events.

Methodology

In order to **select impact flood episodes**, different data for the 21st century are considered. On the one hand we have analyzed information available from automatic weather stations network of Basque Country. Firstly we focus on days when adverse thresholds are exceeded for heavy rainfall and persistent rainfall, determining the number of stations that exceed different thresholds. Secondly we analyzed the information on river levels at gauging stations available, checking whether the level is close to the maximum of the series. Finally impact data are considered based on Spanish insurance compensation consortium claims concerning floods risk, adequately treated and segmented for Cantabric basins data extraction. Based on those information .49 relevant events are selected

The selected events are **characterized from the meteorological point of view**, including analysis of all available meteorological parameters. These events are classified on different circulation patterns and weather types (see Table 1). It takes into account the type of structure or cloud system prevailing in each event (see Table 2), as well as the characterization of adverse weather (see Table 3) and other factors of interest.

Synoptic classification is based on three aspects: **type**, **circulation** and **shape**. Type refers to the flow of wind in lower layers, circulation to the ratio of the component u and v wind up describing the movements that occur in middle and high levels. The shape describes the situation of different pressure systems in surface (see Table 1).

The **categories of adverse weather** events that can promote floods are limited to 4 options: cut-off lows, active frontal systems, northwest gale and storms. The most relevant situations occur with a cut-off low or due to frontal systems (table 2)

Moreover it has taken into account the type of structure or prevailing cloud system (tables 3) and the predominant **type of precipitation.** Being stratiform when the intensity of rainfall is weak or moderate; convective if the precipitation dominated by strong or very strong rainfall.

Considering precipitation data registers each 10 minutes, it has been established a threshold of 1.9 mm to determine the type of precipitation, being stratiform when it is less and convective when exceeds this threshold, based on the relationship between precipitation and reflectivity (Marshall-Palmer) since the consideration of a convective cell is usually produced for a reflectivity over 40 dBz.

Table 4. Selected events.

Event	Synoptic classification.			Severe weather	Type prec	Systems and structures
	type	circulation	shape			
4-5 May 2001	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform	Quasi-stationary warm front
8-9 May 2002	Maritime	Detached	Mediterranean low	Cut-off low	Stratiform	Quasi-stationary front
24-28 August 2002	Maiítime	Detached	Euro-mediterranean low	Cut-off low	Convective	Convective cells
9-10 October 2002	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Active fronts
30 October 2002	Maritime	Detached	Bay of Biscay low	Cut-off low	Convective	Instability line
1-4 December 2002	Maritime	Zone-meridian	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
4 February 2003	Maritime	Meridian	Euro-mediterranean low	Northwest gale	Stratiform	Active fronts
6-7 May 2003	Maritime	Detached	Mediterranean low	Cut-off low	Stratiform	Quasi-stationary front
7 June 2003	Local	Meridian	Thermal low	Storms	Convective	Convective cells
24 January 2004	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
19 July 2004	Maritime	Zone	Undefined	Storms	Convective	Active fronts
16-17 May 2005	Maritime	Detached	Mediterranean low	Cut-off low	Convective	Convective cells
29-30 December 2005	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Active fronts
10-11 March 2006	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
4 July 2006	Local	Meridian	Thermal low	Storms	Convective	Convective cells
21-22 November 2006	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
19-22 March 2007	Maritime	Meridian	Azores high	Northwest gale	Stratiform-Convectiva	Instability line
21-24 August 2007	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Active fronts
25-may-08	Local	Detached	Iberian low	Storms	Convective	Instability line
31May-1June 2008	Maritime	Detached	Undefined	Cut-off low	Convective	Mesoscale Convective systems
9-11 June 2008	Maritime	Detached	Mediterranean low	Cut-off low	Convective	Instability line
2-3 November 2008	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform	Quasi-stationary front
23-26 November 2008	Maritime	Meridian	Euro-mediterranean low	Northwest gale	Stratiform-Convectiva	Active fronts
26-27 January 2009	Maritime	Meridian	Euro-mediterranean low	Active frontal systems	Stratiform	Quasi-stationary warm front
11-12 February 2009	Maritime	Meridian	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
18 September 2009	Maritime	Detached	Undefined	Cut-off low	Convective	Mesoscale Convective systems
10 November 2009	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Active fronts
30 January 2010	Maritime	Meridian	Atlantic high	Active frontal systems	Stratiform	Active fronts
16 June 2010	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Quasi-stationary front
21-23 February 2011	Maritime	Zone	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
16 March 2011	Maritime	Detached	Mediterranean low	Cut-off low	Stratiform-Convectiva	Quasi-stationary front
24 April 2011	Maritime	Detached	Mediterranean low	Cut-off low	Stratiform-Convectiva	Active fronts
6-7 June 2011	Maritime	Meridian	Undefined	Storms	Convective	Instability line
3 September 2011	Maritime	Detached	Undefined	Cut-off low	Stratiform-Convectiva	Mesoscale Convective systems
4-7 November 2011	Maritime	Detached	Mediterranean low	Cut-off low	Stratiform	Quasi-stationary front
18-21 October 2012	Maritime	Detached	Undefined	Cut-off low	Stratiform-Convectiva	Active fronts
14-16 January 2013	Maritime	Zone	Azores high	Northwest gale	Stratiform	Active fronts
18 January 2013	Maritime	Zone	Low latitudes circulation	Active frontal systems	Stratiform	Active fronts
24 January 2013	Maritime	Meridian	Bay of Biscay low	Active frontal systems	Stratiform	Active fronts
8-9 February2013	Maritime	Meridian	Atlantic high	Active frontal systems	Stratiform	Active fronts
11-12 February 2013	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform	Quasi-stationary front
17-18 May 2013	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Quasi-stationary front
13 November 2013	Maritime	Meridian	Azores high	Active frontal systems	Stratiform	Quasi-stationary front
25 January 2014	Maritime	Meridian	Azores high	Active frontal systems	Stratiform	Active fronts
1 February 2014	Maritime	Zone	Britannic low	Active frontal systems	Stratiform	Active fronts
3-4 July 2014	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Instability line
29-31 January2015	Maritime	Zone-meridian	Azores high	Active frontal systems	Stratiform	Active fronts
25-26 February 2015	Maritime	Zone-meridian	Azores high	Active frontal systems	Stratiform	Quasi-stationary warm front
26-27 April 2015	Maritime	Detached	Euro-mediterranean low	Cut-off low	Stratiform-Convectiva	Active fronts

Results and discussion

In the **table 4** we present a summary with the meteorological characterization of the 49 studied events.

Considering the classification of **severe weather**, most situations are due to cut-off lows or frontal systems. In the most serious events are the only groups that are present. That is, for a severe flood situation atmospheric is determined by a cut-off low or on the other hand it can also be produced by active frontal systems (see Figure 1).

The predominant type of precipitation is **stratiform** during 53% episodes. Only in 22% of the events predominant precipitation type are convective. In the rest of events the two types of precipitation are present (see Figure 2).

Systems and structures that predominate are **frontal systems** (75%). They can be quasi-stationary fronts or different active fronts, passing through the Basque Country consecutively. Among the quasi-stationary fronts one of the groups consisting of a warm front moving from west to east by a north-south shape and with a very slow movement generate persistent low intensity precipitation. They can accumulate important precipitation amount in the Cantabrian slope and particularly in the east side, by instance the Urumea basin suffers these situations relatively frequently (see Gaztelumendi et al 2016 - POSTERXX). Rainfall are usually very widespread and occur in the cold season. In some cases melting factor is important, since the arrival of these fronts rises temperatures and if this situation occurs after an episode of snow, melting may be a relevant factor in flooding. Another important consideration is the soil water saturation factor (see Figure 3).

The synoptic surface configuration is dominated by two large groups: Situations in which dominates **Azores anticyclone** and situations influenced by the **Mediterranean depression.** In the first case, affect the Basque Country Atlantic fronts. The second one, often associated with a cut-off low, affecting us air masses of Mediterranean origin (see Figure 4).

At the end the situations that cause serious flooding problems in north part of Basque Cantabric can be grouped into 3 types:

A. Zonal-meridional circulation, with northwesterly flows at all levels and active or quasi-stationary fronts in the cold season (see Figure 5).

B. Cut-off lows in the Mediterranean, with active or quasi-stationary Mediterranean origin fronts (see Figure 6).

C. Cut-off lows in the Iberian Peninsula, with retrograde movement at high and mid-levels. In this synoptic environment can form mesoscale convective systems (see Figure 7).

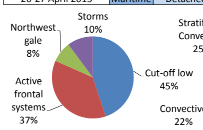

Figure 1. Adverse weather.

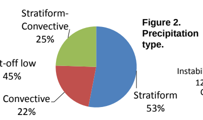

Figure 2. Precipitation type.

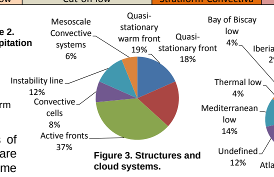

Figure 3. Structures and cloud systems.

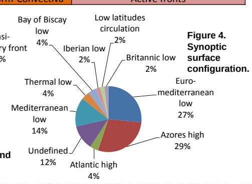

Figure 4. Synoptic surface configuration.

Conclusions and remarks

Severe events that promote floods in north part of Basque Country can be grouped in three main configurations.

A. The most common is the zonal-meridional circulations, with northwesterly flow at all levels along which different active fronts, the most frequent being quasi-stationary warm fronts, leaving stratiform rainfall, widespread and persistent. These are situations that occur in the cold season and in these situations must take into account factors such as melting and saturation. These situations have high predictability and generate widespread flooding, affecting most of the Basque Country.

B. Situations generated by cut-off lows in the Mediterranean, with quasi-stationary fronts that leave persistent and widespread rainfall, with a greater intensity of rainfall due to the origin of the air mass. This aspect makes the uncertainty in quantitative precipitation forecast increase, but remain situations with a relatively high degree of predictability. The degree of involvement of the different basins depends on the specific position of the fronts and the most active areas. The prevailing type of precipitation is stratiform, although there are areas of convective precipitation due to origin of the air mass.

C. Situations of the warm season with cut-off lows located in the Iberian Peninsula with retrograde flow in middle and high levels, with options to generate intense and persistent rainfall. Convective cells can form, which may end up being part of a mesoscale convective system. These systems generate a large area of stratiform rainfall with areas within the most active area left convective precipitation. Thus you can obtain significant accumulated precipitation in a short time. These are situations that present maximum uncertainty. They are unusual situations and compared with the other two groups are less frequent, although potentially are the most dangerous.

The two most important events in the analyzed period are the event May 31-June 1, 2008 and the event from 4 to 7 November 2011. The first affects especially west, and the second especially affects to the east, being for the Urumea basin (situated in the east) the most important event of the entire study period, comparable with the famous floods of August 1983 in that area (see POSTER XX).

The storm episodes in which the degree of organization is not high at synoptic level, can also cause damage, but are usually localized and they have an order of magnitude much lower than those generated severe flooding situations. In any case must be taken into account, as they can generate pools of water and local flooding, being more relevant in urban areas where intensities of rainfall exceeding 10 mm in 10 minutes, and often because they are accompanied by hail and strong wind gusts , especially in extreme situations when a supercells form. In any case, these situations dont promote severe flooding in the area.

Weather conditions that create flooding problems are mostly frontal situations, so the synoptic scale is the main driving factor and precipitation are therefore largely stratiform However, in the most dangerous events an interaction between the synoptic and mesoscale are produced

The most dangerous situations occur in the warm season with a small cut-off low located in the area of the north of Iberian Peninsula, leaving the Basque Country in the northeast edge of it, the most favorable area to form mesoscale convective systems. In high levels there is a retrograde motion. In surface predominate low relative pressures centered in the Pyrenees, which provide northerly flow, and therefore a relatively warm and wet air mass in lower layers. Moreover, this situation favors a slow movement of systems that can be formed. These situations can generate very heavy rainfall in a short period of time in a relatively large area. There are infrequent situations, we can estimate a return period of 10 years.

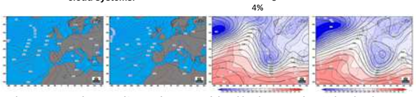

Figure 5: Example type A (SLP and geopotential and isotherms at the 500 hPa level.

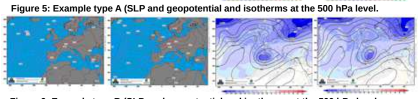

Figure 6: Example type B (SLP, and geopotential and isotherms at the 500 hPa level.

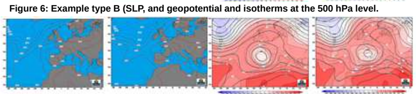

Figure 7: Example type C (SLP and geopotential and isotherms at the 500 hPa level.

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