Meteorological characterization of exceptional snowfall events

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Abstract: This paper analyses the most important snowfall events that have affected Catalonia between 1981 and 2015. After looking for all the cases in the press, the most important cases have been selected and analysed from a statistical and synoptic point of view. The specific case of February 4th, 2015 has been analysed in deep and the wet-wind snow index (WWSI) has been calculated.

I. INTRODUCTION

From 1981 to 2010, 242 snowfall events affecting Catalonia have been recorded in the press. Some of them have produced wet snow, that is particularly dangerous on power outages and highways, and society suffers its consequences. Wet snow occurs when surface temperatures are around 0°C or above, humidity is high and its density usually ranges from 0.3 to 0.8 kg/dm^3 [1].

Although meteorological bibliography about snowfalls is less than those about episodes related to floods, we must highlight the work done for the snow storm taken place in Catalonia in March, 2010 [1]. There are also other works dealing with different points of view for this snowfall event: article [3] focuses on synoptic and mesoscale atmospheric analysis; article [4] presents the synoptic framework characterised by the presence of a deep low by using ECMWF reanalyses and Meteosat images; article [5] focuses on the social impact of the snowfall; and article [6] deals with operational warnings issued by the SMC.

Likewise, up to now any study about a synthesis of meteorological situation favourable to snowfall in Catalonia at low altitudes has been made. This is the goal of this study and will be completed with an specific analysis of the meteorological situation on February 4th, 2015. In order to accomplish this objective, PressGAMA database [2] and the synoptic weather maps source [9] [10] will be presented in the first part of this paper. The next sections will be focused on the methodology including the criteria followed and the Snow Wet Wind Index, and results. Finally, a discussion of snowfall event of February 4th, 2015 will be presented along with conclusions.

II. INFORMATION SOURCES AND DATA

To make this paper, we have used data from PressGAMA [2], which is a database covering the 1981-2010 period. It contains all the press news appeared in La Vanguardia for all the natural risks that have produced any socio-economic and/or ecological impact. Then, it has been completed until 2015 for snow events by researching in La Vanguardia's archives. Thanks to the previous database and a personal selection of those events having snowfall as main feature, we can cover these 34 years. Synoptic weather maps were created from 20th Century Reanalysis [9][10]. Finally, meteorological hourly data have been obtained from the network of the *Servei Meteorològic de Catalunya (SMC)* [11].

III. METHODOLOGY

A. Data collection and classification

Just to give a bit of background information, we are going to talk briefly about the press. Meteorologists tend to use press as an indicator to show the impact of a meteorological event into society. Floods, landslides, sea storms, cold waves, droughts and snowfalls, among many other events, are interesting phenomena not only from a meteorological point of view but also from social point of view. In our case, snowfall events affect traffic, schools, high-voltage power-transmission and, consequently, power outages, forests, roads and highways, agriculture and so on. It's no wonder the government has to pay large amounts of money to palliate these consequences. That's why press is such a good indicator.

Once press data has been obtained, a series of filters to discern in which events we are truly interested have been applied. These filters are: first, to rule out all snow events having one single new; second, to save those snow events having snow as main feature; third, to rule out those snow events in the Pyrenees having two, three or four news; and finally, to do a personal selection by searching day by day so we can discern the really important ones.

Thus, it was possible to classify snowfall events into two types: Pyrenees and low altitudes. A study of how coverage in the press has evolved over this 34 years has been also done by counting the whole number of news, the whole number of snow events and the ratio between them. This will be useful to understand why snow events at low altitudes have a major impact rather than in the Pyrenees as it can be seen in next section.

B. Selection of snowfall events

After having selected the previous snow events, we must focus on those which have had a great social impact owing to the cause we just mentioned before. Snow events selected are: February 8th, 1983; January 5th, 1985; January 30th, 1986; January 22nd, 1992; March 1st, 1993; December 12th, 2001; February 26th, 2004; March 8th, 2010; and February 4th, 2015.

The main goal of this analysis is to understand what happened in each and every day by making a data sheet which includes a little introduction to the event; general aspects (such as name of the episode, starting and ending dates, regions and municipalities affected and references); hydro-meteorological and extreme values (temperature and snow depth) and impacts (damages, casualties, injuries, estimation of total damages, emergency management and basic services affection).

Due to its importance in meteorology, maps of sea level surface, surface air temperature, geopotential height at 850 hPa and 500 hPa and air temperature at 850 hPa and 500 hPa, were chosen.

C. Analysing tools for February 4th, 2015

In addition to the meteorological analysis that has just been mentioned above, the so named Wind, Wet-Snow Index (WWSI) has been calculated for the snowfall event of February 4th, 2015. Since we could not dispose of the downscaled SAFRAN data [7] that was applied in [1], data from the meteorological network of the SMC, XEMA, has been used instead [11].

Every meteorological station on the affected areas in Catalonia must be searched manually, as well as writing down atmospheric features such as snow depth, wind velocity and temperature, which are needed to use WWSI. The higher this index is, the higher are these atmospheric features.

So, basically, what we are proposing is an indicator that summarizes wet-snow production. It must be taken into account that areas with high level of WWSI are closely related to probability of suffering damage. Therefore, we can infer that this index allows us to estimate hazards and its geographical distribution if needed. In the first instance, one might think that, if damage are related to the WWSI, then, governmental subsidies are related to damage. However, that is not true due to the complexity of the factors involved and socio-political decisions [1]. Now, Eq.(1) give us an hourly index $WWSI_h$:

$$WWSI_h = Snow \times Temperature \times Wind \qquad (1)$$

where

$$Snow = \begin{cases} 1 & \text{if} \quad S \geq 0{,}1 cm \cdot h^{-1} \\ 2 & \text{if} \quad S \geq 0{,}2 cm \cdot h^{-1} \\ 3 & \text{if} \quad S \geq 0{,}4 cm \cdot h^{-1} \\ 4 & \text{if} \quad S \geq 0{,}6 cm \cdot h^{-1} \end{cases}$$

$$Temperature = \begin{cases} 0 & \text{if} \quad (T < -4^oC) or (T > 4^oC) \\ 1 & \text{if} \quad (-4^oC \leqslant T < -1^oC) \\ & \quad\; or (2^oC < T \leqslant 4^oC) \\ 2 & \text{if} \quad -1^oC \leqslant T \leqslant 2^oC \end{cases}$$

$$Wind = \begin{cases} 1 & \text{if} \quad W < 15 km \cdot h^{-1} \\ 2 & \text{if} \quad 15 km \cdot h^{-1} \leqslant W < 30 km \cdot h^{-1} \\ 3 & \text{if} \quad W \geqslant 30 km \cdot h^{-1} \end{cases}$$

Then, a daily WWSI index is calculated following Eq.(2):

$$WWSI = 100 \cdot \sum_{i=1}^{24} \frac{WWSI_h}{576} \qquad (2)$$

where 576 is the maximum daily possible score (24×24).

Thus, the scale of the WWSI index goes from 0 to 100. This approximation is a simple application that highlights the importance of having mesoscale reanalysis fields to calculate an aggregated index that summarizes important aspects related to the atmospheric events.

IV. RESULTS

A. Results of data collection and classification

Table I summarizes the number of events and news in newspaper about snow events on the Pyrenees and at low altitudes. Ratio between both quantities has been also calculate in order to see impact on society.

	Pyrenees	Low-altitudes	Total
Number of news	322	942	1264
Number of events	25	43	68
Ratio Nn/Ne	12,88	21,91	18,59

TABLE I: *Number of news and snow events at low altitudes and Pyrenees. We show the ratio between them as well.*

Besides, Fig.(1) below shows this evolution from 1981 to 2014. Year 2015 is not included because, at the time in which this study was made, the year had not run out yet.

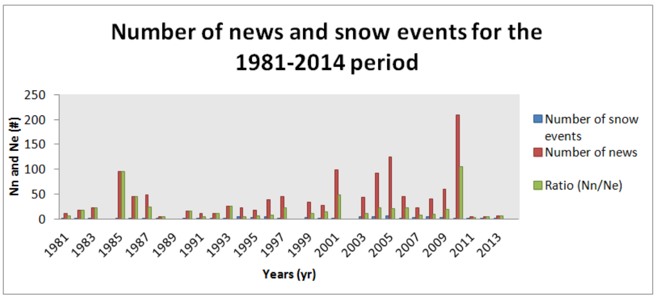

FIG 1: *Evolution of number of news and snow events from 1981 to 2014.*

According to the results, we can infer that snowfall episodes in the Pyrenees are extremely usual and, for that reason, press does not echo. Often, these episodes cause the same consequences such as use of snow chains in many roads and highways, closing of mountains ports, ski resorts save season and so on. From what we can gather, press does usually echo of extraordinaries snowfall events in the Pyrenees if affecting at low altitudes and big cities. Finally, even though these snowfall episodes at low altitudes may have a scarce presence, press usually echoes as we are a country not used to this sort of events. Consequently, there are usually many incidences and government tends to act late.

B. Results of selection of snowfall events

In Table II the most important features of the nine selected events are summarized.

Date	Number of casualties	Max Snow Depth (cm)	More Affected area
Feb 8th '83	0	50	BCN Metropol. Area
Jan 5th '85	19	33	Barcelona
Jan 30th '86	3	50	Girona
Jan 22nd '92	0	15	Costa Brava
Mar 1st '93	0	15	Barcelona
Dec 14th '01	6	40	BCN Metropol. Area
Feb 26th '04	0	65	Sant Hilari de Sacalm
Mar 8th '10	1	101,7	Gironès
Feb 4th '15	0	35	Anoia

TABLE II: *The most important features of the nine snowfall events analysed such as number of casualties, maximum snow depth and more affected area.*

In Table III, common traits among the nine episodes analysed through downloaded weather maps are presented.

C. Results of analysis for February 4th, 2015

On February 4th, 2015, a snowfall event swept over a large proportion of Catalonia, which is reflected on the amount of municipalities having snow depths above 10 cm. Mainly, road network was the most affected infrastructure, with many traffic jams on highways and roads all over Catalonia. Consequently, many school buses could not drive as usual and loads of student remained at home.

A small low formed above the Iberian Peninsula moved through from west to east to situate at the south of the Catalan coast during the morning of the February 4th. Moreover, an advection of wet air from the Mediterranean to Catalonia produced a snowfall situation at low altitudes at the center and south of Catalonia along with a cold air mass coming from the north.

Snowfall began at western regions in the night of Tuesday 3rd to Wednesday 4th and spread out to the center and south of the country in the morning of Wednesday 4th, especially on the pre-littoral coast.

Date	Synoptic analysis
Feb '83	High pressure centred over British Islands. Depression situated in Northern Italy. Generalised snowfall along the Mediterranean coast. Entrance of cold air.
Jan '85	There were two depressions: one was located on the Atlantic ocean; the other, over the Iberian Peninsula. Advection from the west and east, respectively. Anticyclone above Iceland. Entrance of cold air.
Jan '86	Depression generated over Iberian Peninsula. There were two high pressure situated above Russia and Azores. Depression could not move as anticyclones acted as a barrier. Entrance of very cold air coming from Northern latitudes.
Jan '92	Anticyclone situated on North and East of Europe. Depression just in the middle of the Iberian Peninsula. Depression above the Pyrenees and Catalonia. Cold air island above Cantabric sea and Alps. Entrance of very cold air from east.
Mar '93	Low pressure over Sardinia. Advection from the Mediterranean. We can see a low pressure over Extremadura at 850 hPa. Anticyclone located above Scandinavian countries. Entrance of cold air from the Cantabric sea.
Dec '01	Depression above Sardinia. High pressure located on British Islands. Entrance of cold air from the north-east.
Feb '04	Anticyclone situated over Atlantic ocean. There were two depressions: one was situated above Scandinavian countries; the other, which is not very pronounced in the upper troposphere, was situated above Catalonia. Entrance of polar cold air.
Mar '10	Depression of 1005 hPa situated between Greece and south of Italy. There were two high pressure: one was located above British Islands; the other, above Scandinavian countries. Warm and wet advection from the Mediterranean. Entrance of cold air coming from the north-east of Europe. Little depression above Balearic Islands. There was a trough of 500 hPa producing instability and contributed cold air from north and east of Europe.
Feb '15	Depression situated between Sardinia, Corsica and Balearic Islands. Entrance of cold air. Anticyclone situated above British Islands.

TABLE III: *Synoptic characteristics of the nine snowfall events analysed for the 191-2015 period.*

At the beginning, snow level was about 400 and 500 m over the sea level. Nevertheless, it decreased rapidely up to about 100 and 200 m. It could be seen snow even at sea level. Early morning, snowfall was relevant at center and south regions of Catalonia, above all in littoral and pre-littoral zones, while over the course of the morning precipitation was getting feeble up to completely disappear. However, northeaster wind produced precipitation anew in some regions of the north-east of Catalonia the evening of Wednesday 4th until early morning of Thursday 5th, affecting especially the region of Maresme, the Montseny Massif and Guilleries. Snow levels were low anew, about 100 and 200 m, or even locally below.

Meteorological situation in surface was characterised by the presence of a low pressure situated on the Mediterranean sea, between Balearic Islands, Corsica and Sardinia sending northeaster wind as it can be seen in Fig.(2). Besides, the presence of a high pressure on the British Islands let a cold air mass to descend to our latitudes. Concretely, temperature Wednesday morning was about -3.9°C around 1,300 m of altitude, according to Barcelona radiosounding station, which made the snow level to descend up to 100 and 200 m over the sea level.

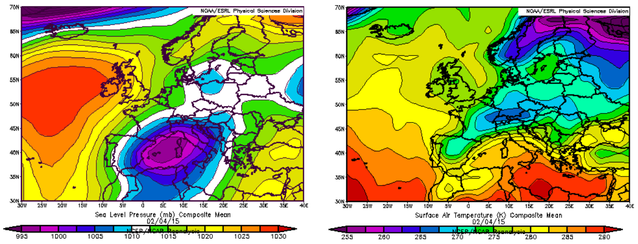

FIG 2: Surface analysis: pressure and temperature. February 4th 2015. Daily average value. 20th Century Reanalysis V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA.

A strong character of this low pressure can be seen clearly on geopotential maps at 850 hPa, Fig.(3), and 500 hPa (even though we have not included this later weather maps as they looked identical to those 850 hPa geopotential maps).

As far as temperature at high altitudes is concerned, the 267 K line encompassed whole Catalonia and the 273 K line arrived up to Cadis Gulf.

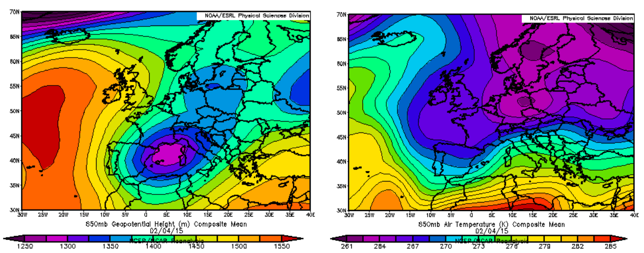

FIG 3: 850 hPa analysis: pressure and temperature. February 4th 2015. Daily average value. 20th Century Reanalysis V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA.

On the other hand, Fig.(4) shows the maximum of snow depth measured by the Meteorological Observers Network, as well as some stations of XEMA between Wednesday February 4th, 2015 and Thursday February 5th, 2015.

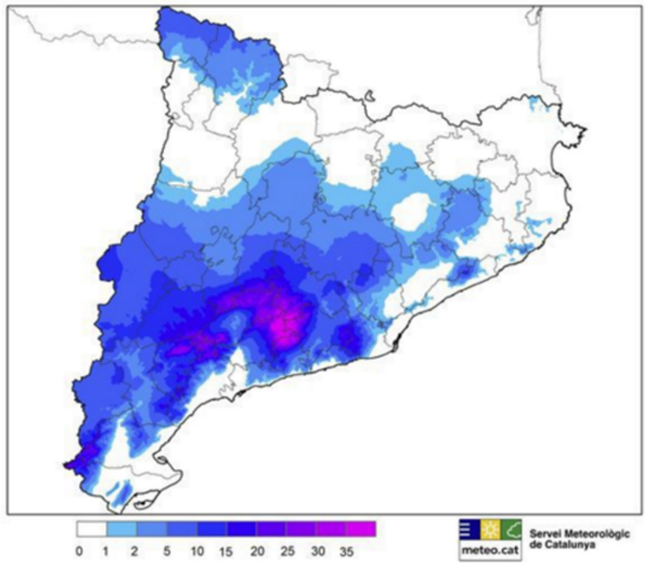

FIG 4: Maximum of snow depth measured between February 4th and February 5th until 10 o'clock. Graph obtained from XEMA stations.

Out of 42 regions in Catalonia, 32 were affected by snow. Out of the 183 operating meteorological stations in Catalonia, 130 were affected by snowfall. According to reports of SMC, the maximum values of snow depth were recorded by 21 station, 14 of which provides us full information about surface temperature, precipitation and wind velocity at 2 m above ground. For these 14 meteorological stations, Wind Wet-Snow Index was calculated. Since we could not dispose of snow depth by hours, the hypothesis that all precipitation was falling as snow throughout the hours was made, in which average temperature was below 4°C. Fig.(5) shows the WWSI evolution throughout the hours for February 4th.

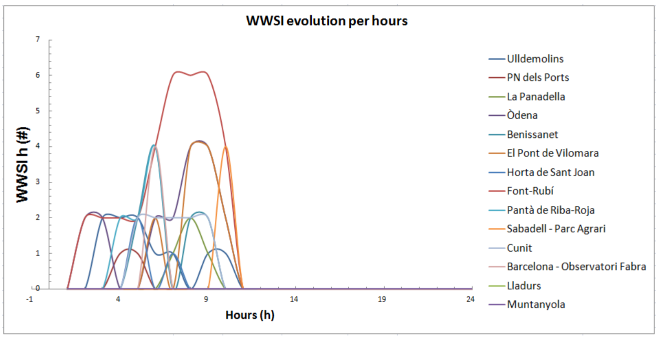

FIG 5: WWSI evolution per hours

Following Eq. (2), WWSI has been calculated for the previous 14 meteorological stations. To sum up these results, Table IV is presented. WWSI values are very low (in the 2010 event, they overpassed 10 and arrived to 100). These values agrees with the observations and corroborates that it was a fair snow event.

Meteorological station	WWSI
Ulldemolins	1,7361
PN dels Ports	0,3472
La Panadella	0,6944
Òdena	3,125
Benissanet	1,7361
El Pont de Vilomara	2,0833
Horta de Sant Joan	0,5208
Font-Rubí	5,9027
Pantà de Riba-Roja	1,388
Sabadell-Parc Agrari	0,694
Cunit	1,7361
Barcelona-Observatori Fabra	0,694
Lladurs	0
Muntanyola	0

TABLE IV: *WWSI for 14 meteorological stations.*

V. CONCLUSIONS

Throughout this paper, analysis of the impact of snowfall events mainly at low altitudes on press over these later 34 years has been made. It can be concluded that press often echoes of those snow episodes affecting large cities such as Barcelona or its metropolitan area. Even though they may not be very important from a meteorological point of view, they may produce severe consequences such as traffic jams in roads and highways, power outages, damages to agriculture and forests, among many others. This can be understood given the fact that Catalonia is not used to this sort of event and government tends to act late. After having searched and selected the most important snowfall events in Catalonia, we can conclude that they have some traits in common. There is usually a high pressure situated nearby the British Islands or in the north of Europe. Consequently, that situation allows a very cold air mass coming from the north or north-east to descend up to our latitudes. Besides, a low pressure is formed nearby the Iberian Peninsula, usually in the Mediterranean Sea, which provokes a wet advection. Finally, for the snowfall event of February 4th, 2015, the synoptic situation has been described. The WWSI for 14 meteorological stations affected by this snow episode has been also calculated, showing values between 2 and 6, that are considerably inferior to those obtained for the March 8th, 2010 event [1] and, consequently, showing that it was not a wet-snow event.

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