Methodology for the historical and synoptic analysis of snows: its application to the region of Castilla y León (Spain)

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Abstract

A methodology is proposed for the study of snowfall, applied to the region and autonomous community of Castilla y León (Spain). It is based on two major pillars: the elaboration of a Snowfall Catalogue from the consultation of documentary sources (press) between 1979 and 2021, which allows cataloging all the episodes that occurred from October to May, and the synoptic study of the atmospheric dynamics in those 43 years, identifying the different types of weather as a means of validating the cataloged episodes. The database created provides information on its intensity, duration, and frequency, as well as its genesis, distribution, typology, and climatic hazard. All this has been analyzed and has allowed to recognize different stages in its way of occurring and to estimate trends and behaviors in both the number of episodes and the number of snow days and their assessment in the current situation of climate change.

1 Introduction

Traditionally considered a "minor" risk (Calvo 2000), snowfall has been the subject of an increasing number of studies at different spatial scales and approaches in recent years. In Spain, there are precedents that deal with this phenomenon in its evolutionary behavior (Arranz 1995; Ruiz 1998; Moltó 2000) or focus on relevant episodes for their extraordinary character (Olcina and Moltó 1999; García et al. 2014, 2018; Hernández 2003). There is also no shortage of more descriptive characterizations (Gonzalo 2003; Puente 2009), which highlight its morphological importance in mountain areas (Miotke 1968), its current morphodynamics (Castañón and Frochoso 1998; González and Serrano 2010), or studies that relate snowfall events to the synoptic causes that originate them (Esteban et al. 2005; Nuñez et al. 2016; Buisan et al. 2016; Pablo et al. 2021), although these studies do not usually cover extended periods.

At the international level, there are more publications that analyze in detail the synoptic reasons and the socioeconomic effects of large snowstorms (Marwitz and Toth 1993;

Schwartz and Schmidlin 2002; Wang et al. 2011; Michaelis and Lackmann 2013; Dafis et al. 2016; Porhemmat et al. 2021; Croce et al. 2021). In general, the analysis of situations of an extraordinary nature (*blizzards*) or of intense snowfalls at specific moments prevails over the study of the evolutionary behavior of episodes of all kinds over an extended period.

This study does not focus its attention primarily on the statistical treatment of the meteorological variables that characterize such episodes. The problems in the area of study in this regard are numerous, from the scarcity of observatories that compute this meteor (especially in mountain areas) and the difficulty of obtaining daily precipitation data (due to its high cost) to the deficiencies in the data series quality (inhomogeneities, robustness). On top, the non-discrimination between liquid and solid precipitation in their records is another problem. Few observatories compute this information accurately over long series. At most, the dates of the snow days are known for a small number of them.

These questions have led us to develop an alternative methodology, from indirect sources, which is somewhat less usual, but equally valid as we intend to show by the conclusions obtained. Ours is a study on climate supported by two basic elements:

- The consultation of documentary sources which are not specifically meteorological or climatic, but these include information obtained from the press (regional

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and national) to identify the different episodes of snow-fall produced in the region, and

- The synoptic analysis of the atmospheric situations that produce them to characterize their genesis on the one side, and checking and validating the previously identified episodes on the other.

In this way, the *Castilla y León Snowfall Catalogue* (hereinafter called CNCyL) has been compiled. It allows us to appreciate in which territories it snows at the same time, from which height, and sometimes also the snowfall thicknesses; relates snowfall to the types of weather it produces; and considers its socioeconomic consequences (mountain passes closed, roads with chains, isolated towns, etc.). These aspects contribute to better understand the traits that define snowfalls, their evolution, and typology, as well as to measure their degree of hazardousness from the point of view of risk. In addition, it is a database that can continue to be fed, allowing future researches.

The analysis of journalistic information is one of the most interesting lines of climate research that exist, with important precedents in our country. Together with the use of documentary sources whether ecclesiastical, municipal, or private (Barriendos 1995; Martín and Barriendos 2000; Enzi et al. 2014), the press has revealed to be an important way of transforming qualitative information into quantitative (Ruiz 1998; Prieto 2000; Pérez 2001; Martínez-Ibarra et al. 2019). As Olcina (2000) points out, "it brings the researcher closer to the knowledge of the perception of atmospheric facts and climatic variations actually experienced by a society, oblivious to calculations of means, deviations, trends or probabilities that nature often dismantles."

Perhaps for this reason, this practice is common among weather and climate researchers, mainly as supporting documentation in the study of relevant atmospheric episodes; it has, nevertheless, not been used so much as a database over several decades. In the newspapers, one can find confirmation—in text, maps, or photographs—of meteorological events happened in a territory, and therefore, climate news become an important documentary source on which to inquire into the scientific knowledge of happened and lived times in each era.

2 Material and methods

2.1 The choice of the territory of analysis

This research focuses on the region of Castilla y León, where snowfalls are especially relevant. They are not only an important resource, but also often their effects generate situations of significant risk that determine the social and economic activity of the population.

It does not, nevertheless, happen homogeneously in its nine provinces. There are several reasons that explain this circumstance: firstly, its large area (94,147 km^2, equivalent to the surface of Portugal or three times that of Belgium) and its high average altitude (98% at 600 m above sea level, hereinafter just "m"). Secondly, the important contrast that occurs between its central sector and its periphery, due to its morphological configuration in which two large morphostructural assemblages stand out: the wide plains of its interior (700–1100 m), which occupy more than 2/3 parts of its surface, and the mountainous border that surrounds them which frequently exceeds 2000 m (Fig. 1). Plains are a large sedimentary basin extending for about 200 km in the meridian direction, between the Cantabrian and Central mountain ranges (hereinafter MR), and about 250 km in the zonal direction, between the Galician-Leonese Mountains and the Iberian MR. This configuration is a decisive factor in the characterization of the climate of the region in general, but also in the production of snowfalls in particular.

Hence, relief plays a more important role than that of its latitudinal location in the northwestern quadrant of Spain (Morales and Ortega 2002) in the genesis of snowfall. It could be considered as the main factor responsible for the quantity and spatial distribution of this meteor, with uneven behavior in all its provinces. Its annual presence conceals important differences in intensity, duration, frequency, and distribution, as well as in its effects, showing a wide range of manifestations according to years, according to periods.

Because of its location, Castilla y León is at the mercy of the seasonal swaying experienced by the circumpolar vortex. This means that in winters and springs, it is frequently affected by polar and arctic air masses (very cold and humid), inserted in circulations of low zonal index (meridians N–S and inverse NE–SW) capable of generating heavy snowfall. Therefore, dynamic factors define their time period, but their intensity and even their probability of occurrence depend on more geographical factors, such as the energy of relief and its different exposures. The influence of relief is even more evident at the equinoxes, when general atmospheric situations for wide peninsular territories only produce snowfalls in the area of these mountain ranges. Thus, we can conclude that the geomorphological configuration is ultimately responsible for its spatial distribution, intensity, and frequency.

Nor is the way it snows always the same. On the peripheral mountainous fringe, the number of snowfalls is always greater and the effects are more dramatic than on the inland plains. In spite of everything and due to their enclosure and high altitude, they foster the stagnation of cold air, keeping temperatures very low, which also encourages their production. There is a whole sample of them, because sometimes, they are sparse snowfalls that only affect the peaks, and in
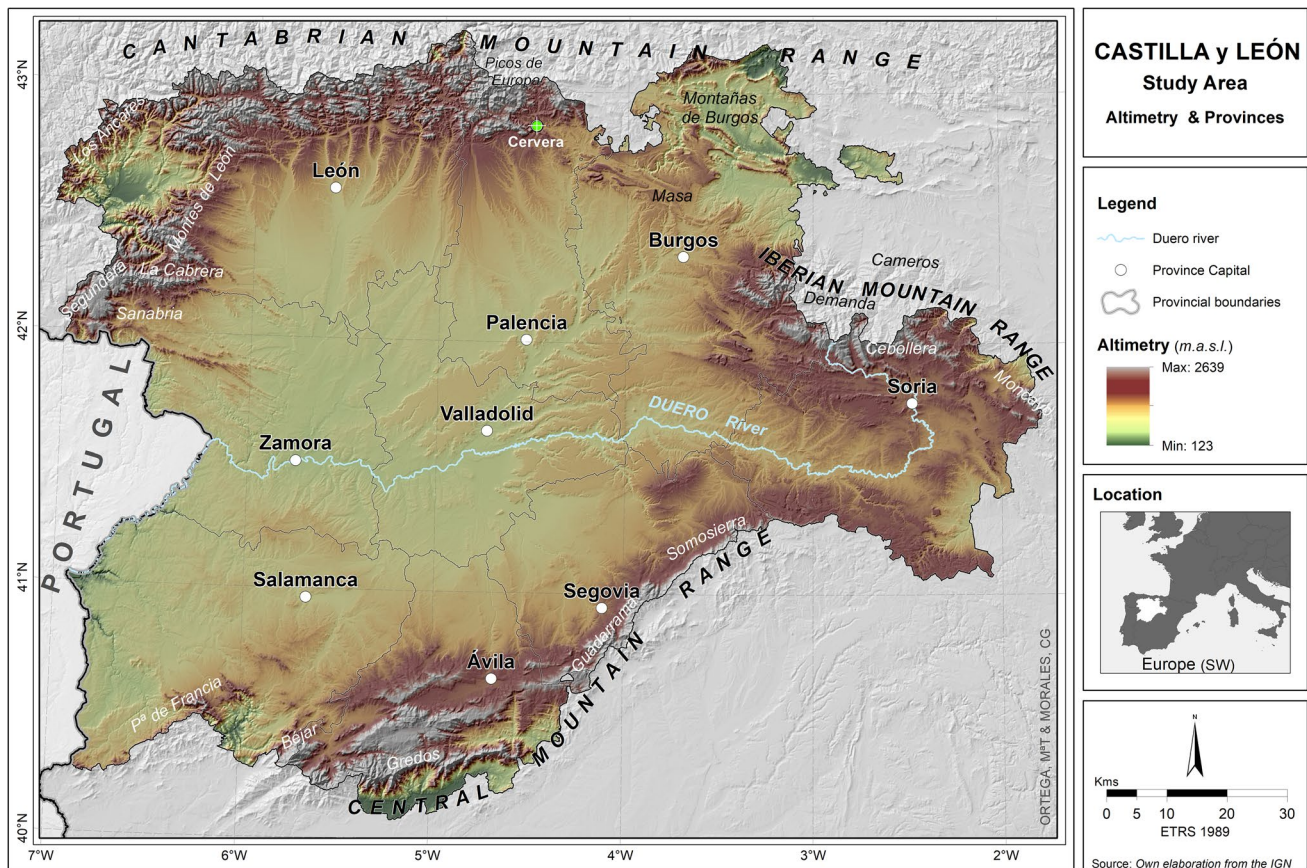
Fig. 1 Study area

other times, they are spectacular storms that spread throughout the region, creating serious issues.

Therefore, they are not uniform at all and thus the potential risk of their occurrence varies greatly from area to area. Their spatial and temporal limits change as a function of altitude, topoclimatic conditions, atmospheric circulation, as well as interannual meteorological evolution and variability. The diversity of the study area makes it possible to assess all these factors.

It is not always possible to have adequate meteorological information to learn more about the irregular distribution and frequency of snowfalls. Although this region has a large number of observatories, they are not always located at high altitudes, or with the desired spatial distribution, which has made it necessary to resort to other quality documentary sources covering long observation periods that may allow the data to be completed and compared and that may help validate the conclusions. All of these reasons have led to the development of the proposed method.

2.2 Remarks on the method

The devised methodology has focused on the creation of a database from climate information published in the daily press and its subsequent validation with the synoptic information, to which we must add the thermopluviometric data from the *Daily Meteorological Bulletins* of the several provincial capitals of the region,[1] and those shown in the newspapers of other observatories. This information has served to narrow the temperature and precipitation thresholds in snowfall situations down and to clarify the entity of each episode.

2.2.1 The construction of the Snowfall Catalogue

The basis of the historical study resides in the CNCyL, made from the consultation of the regional newspaper *El Norte de Castilla*.[2] All the daily information from 1979 to 2021 has been collected and processed, from October to May (both inclusive),

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[1] Both from the meteorological bulletins of the archive of the Department of Geography and T.P. of the University of Valladolid (Spain) as well as the Institutional Climatological and Meteorological Archive of AEMET (Arcimís) (AEMET 2020).

[2] For this, the resources available in the newspaper library of the Reina Sofía Library of University of Valladolid have been used.

Table 1 Structure of the Snowfall Catalogue in Castilla y León (1979–2021)

Fields	Definition
Case number	Order number of snowfall episodes
Date	Start and end of each episode
Duration	Deducted from the previous field 4 categories: *Short*, *Medium*, *Long*, and *Very Long* (S, M, L, and VL, respectively)
Provinces	Number of affected provinces (designated by their initials)
Affected area	Spatial location of each event by provinces (counties, mountains, etc.)
Genesis	Synoptic cause that motivates each episode
Precipitation	Daily, from the meteorological bulletins and press
Temperature	Daily maximums and minimums, from the meteorological bulletins and press
Snow cover	From press information
Thickness	From press information
Cold waves	Concurrence with cold waves according to Rodríguez (2021)
Consequences	Effects of each episode; specific places
Intensity	Deducted from the number of days involved, the affected provinces, the snow level and thickness, and the effects produced. The episodes are classified and coded: • *Occasional* snowfall (refers to very weak ephemerals and very localized) • *Weak* snowfall • *Moderate* snowfall • *Intense* snowfall • *Very intense* snowfall

Source: own elaboration.

during those 43 years. Either through microfilms (until 1999), in digital format (CDs until 2005; Internet from 2006), or in original paper format, a total of 10,460 newspaper copies have been analyzed, to which the consultation of other national newspapers for specific events (*El País* and *ABC*) should be added.

Its construction has taken a long time due to the large volume of information handled, apart from being tedious and meticulous work. However, this phase is essential if one wants to obtain solid results and has a truthful and specific idea of all the episodes that actually occurred. It is not only a question of drawing up a mere list of exact dates of occurrence, but also of locating each episode in each of the provinces of the region, identifying the most affected areas, assessing their effect, and then establishing a comparison and evaluating the behavior as a whole.

All the climate news analyzed ("Weather", "Cover", "Regional" and "Provinces" sections) have been organized and digitized for analysis with the appropriate software, classifying the information in several fields[3] and different identifiers, so that the possibilities of use are wide (Table 1) and facilitate different searches and filtering according to the information of interest. The database allows, for example,

learning on the number of very intense snowfalls in the region, the number of days each of them lasted, what types of weather they were due to, or what effects they caused. Another option may be to quantify how many of these situations have only been generated in the mountains, or only in some mountain range, etc. All of these practical applications have been systematized in this paper.

A detailed construction of the CNCyL is necessary for several reasons:

- It makes it possible to have real and sustained information over time (43 years).
- It accurately specifies the number of days it snows, as it contains daily weather information, as well as its forecast for several days, which helps to define the series of snow days or their possible rectification (wrongly forecasted).
- All the episodes that have occurred, whether of greater or lesser importance (real number of cases) are collected.
- It allows us to assess the intensity and magnitude of each event and its duration, frequency, and recurrence (analysis of its hazardousness).
- The importance of the event is inferred by the number of references in the press (one or several days), where appears (front page or inside, odd or even page), and the consequences in many other parts of the region in addition to the provincial capitals.
- Shows the spatial distribution of each episode (peaks, certain mountain ranges, northern or southern half of the region, generalized, etc.).

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[3] This structure has already been used by the authors in other investigations such as the Catalogue of Historical Floods included in Pilot Study 3, Carrión River: Villoldo section for the National System of Flooding Zones Cartography (Morales and Ortega 2009), although well adapted this time to this meteor.

- Relate each episode with the dynamic situations that produce them, appreciating the synoptic behavior according to years and its evolution/changes throughout those 43 years.
- Evaluate the consequences according to episodes: material, social, or human damage (from mobility restrictions, closure of roads, mountain passes, airports, railways, isolated towns, etc., to even deaths).

However, it is worth pointing out certain deficiencies and difficulties experienced during the data collection phase. Sometimes, it has been due to the way the weather information is expressed because the statement on forecast weather has changed throughout the years. Over the years, it has gained in profoundness and detail, especially regarding the distribution of snowfall.[4] Likewise, the meteor's location mapping has also improved. Its query is important because sometimes, the maps reflect snow presence of and then it is not mentioned in the text. The symbol maps help complete the information.

Another deficiency is the absence of references for some days (January 1, unedited for many years) or the lack of some copies of newspapers as they were not bound (less than 1%). In any case, the reliability of the information collected is always subjective and its veracity depends on the rigor of the reporting meteorologist, whom we assume acts seriously and professionally.

To minimize these deficiencies, it has been necessary to validate the cataloged episodes with the dynamic causes that produce them.

2.2.2 The synoptic analysis of snows

It is very interesting to know why and when snowfall occurs. It is essential to understand what atmospheric conditions are due to and to limit their production period. Therefore, the synoptic analysis is necessary. It is also a good validation method of the situations described in the press, since on occasions, forecasts of snowfall have been incongruous (they have concurred with anticyclonic situations, for example). Ultimately, it is about finding out what types of weather really generate them. Several sources have been used for this analysis:

- Most of the information has been obtained from *Wetterzentrale*, via a CFSR file (*Climate Forecast System Reanalysis* archive) for the entire period under analysis. This global climate forecasting model shows 500 hPa

geopotential topographies along with surface level isobar mapping from data at 0, 6, 12, and 18 UTC, with a grid resolution of about 28 km, which makes checking the evolution of atmospheric dynamics easy.
- The "Daily Meteorological Bulletins" of the former *Spanish National Meteorological Institute* (INM), valid until December 31, 2007. Their advantage is to include atmospheric topographies at different altitude levels, which allows for a more complete analysis.
- As of 2008, the digital consultation through Spanish AEMET (*Meteorology State Agency*) that used the images of the regional numerical prediction model HIRLAM (*High Resolution Limited Area Model*), being replaced as of June 1, 2017, by another of limited area, the HARMONIE-AROME, belonging to CEPPM (*European Center for Medium-Range Prediction*), for the North Atlantic region.

The identification of the snowfall episodes rests on the recognition of the atmospheric situations that motivate them from the different types of weather, since the change in the dynamics marks a differentiation in the genesis of snowfall, which substantiates an independent treatment.

Many snowfalls last for several days, sometimes more than a week. But, if its dynamic cause varies throughout its process, it cannot be considered as a single episode, but it is necessary to distinguish between the different types of existing weather. For example, a 5-day period of snowfall is not a single episode if it was due first to a centered mA trough (3 days) in the Iberian Peninsula and then to a centered mA cold drop (2 days).[5] These would be two different successive episodes. In the same way, a "cold wave" is not one single episode, but the computation of all weather types during its development. For this reason, the total sum of identified episodes is 814. A number that a priori may seem high, but that, in reality, includes all episodes that have occurred, regardless of their duration.

These reasons have led to the establishment of a typology of "types of weather" generating snowfall (Table 2). It may seem profuse, but it has been proven that the dynamics capable of motivating them is really very diverse. Although there is a more or less established pattern of more favorable circulations, we have proceeded in detail, identifying 30 weather types.

The key is to distinguish all the synoptic configurations capable of producing snowfall regardless of their location with respect to the region. There are snowfalls that only affect its northern half, or simply the

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[4] Until the 1990s, spatial references were less detailed, especially in the surroundings of the Iberian mountain range, with greater detail being observed from 1991, and particularly since 1999.

[5] Cold drop or DANA in Spain is cutoff lows or "Isolated Depression in High Levels".

Table 2 Types of weather generating snowfall (1979–2021)

Circulation	Air mass	Location[a]
Shear line[b]	**cP**	• Centered
		• North
		• Shocking with mP
		• Trough in the West
Troughs	**mA**	• Centered
		• East
		• Northeast
		• West
		• North
	mP	• Centered
		• East
		• West
		• North
Zonal	**mP**	• From the NW
		• From the West
Cutoff lows or cold drops	**cP**	• Centered
		• North
		• West
		• Southwest
		• East
		• Northeast
	mA	• Centered
		• Northwest
		• West
		• Southwest
		• East
	mP	• Centered
		• Northwest
		• West
		• Southwest
		• Northeast

Source: authors' own creation.

Air mass: *c* continental, *m* maritime, *P* polar, *A* arctic.

[a]Locations referenced by their position with respect to the Iberian Peninsula.

[b]Retrogression troughs or retrograde motion.

Cantabrian MR, others instead only the Central MR, or the northwestern or eastern sector of it.

3 Results

3.1 The characterization of snows from the CNCyL

The CNCyL study allows us to verify the differences in the degree of development, distribution, and effects of snowfall in this region. These parameters characterize its features and make it possible to establish a typology in the way it is produced. In the mountains, it snows about 30–60 days a year, although as from an altitude of 2000–2500 m (Picos de Europa, Sierra de Guadarrama), with some years reaching a hundred days of snow

(Ortega and Morales 2015),[6] keeping the snowy mantle in the shadiest places from October to June (sometimes more). At present, above 1800 m, the high mountain is characterized by a nivoperiglacial environment, being a key geoecological factor in Picos de Europa (González and Serrano 2010). Of all the mountain ranges, it is in the Cantabrian one where snow is most important, especially between Pajares and San Glorio mountain passes (50–65 days), precisely where the most important ski resorts are located.[7] However, along it, there is a clear zonal differentiation, since the snowfalls of its western half double or triple those of its eastern half, from the Cervera de Pisuerga meridian to the East (green dot in Fig. 1 at 04° 30′ W).

In general, the most significant snowfalls occur from November to April, with monthly averages above 4 days when above 1200 m and reaching 7–10 days in the central winter months. In the plains area, these thresholds are much lower (1–3 days a month) and more common to occur from December to March. The annual averages are always less than 20 days, and even in many of them, they do not reach 5 days.

To assess the hazard of this risk, the following parameters must be analyzed.

3.1.1 The snowfall intensity

Snowfall intensity is an intrinsic quality of each event that responds to the physical characteristics of the processes that generate them in its geographical context. Snowfall conditions the degree of severity with which an episode manifests itself, which is why it is one of the factors that determines the hazardousness of these events. Not all snowfalls have the same intensity, with the most severe being the least frequent (Table 3).

This parameter is deduced from the fulfillment of a series of premises, in which the extension of the affected territory (number of provinces), duration, snow level, thickness reached, and associated effects come into play. Therefore, snowfall will be more intense the greater number of these variables defines it in its highest value ranges. The aim is to limit the types of possible snowfalls according to their degree of intensity and what they represent in the total count.

It should be clarified that the marked thresholds are generic, that is, they attempt at synthesizing the behavior of most of the

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[6] Quote regarding the Cantabrian MR: "Above 1,200 m there are years with more than 70–80 snowfalls, which favors significant periods of snowfall. Some even exceed a hundred, but it is not usual. It has only happened in Leitariegos in 1963, Degaña in 1979 and San Isidro in 1984.".

[7] Valgrande-Pajares, Fuentes de Invierno, San Isidro, Alto Campóo, Lunada Esquí, and Tres Provincias/San Glorio.

Table 3 Snowfall intensity levels

Level	Description
Occasional	• Only mountain areas above 1200–1300 m • Snow thickness up to 5 cm
Weak	• 1–3 provinces • Altitude > 1000–1100 m • Thickness of < 5–10 cm in mountains • Do not normally close mountain passes or roads • They are not recorded in many of the inland plains
Moderate	• 3–7 provinces • Altitude > 750–900 m • 10–20 cm thickness in mountains • Closure of some mountain passes and roads (2nd and 3rd orders mainly) • Use of chains • Some incommunicado towns
Intense	• 7–9 provinces • Altitude > 600–700 m • 20–40 cm thickness in mountains • Closure of mountain passes and roads (1st, 2nd, and 3rd orders) • Chains even on the plains • Some isolated towns • Strong winds • Very low temperatures • Adverse situations
Very intense	• The whole region • Altitude > 450 m • 40–60 cm thickness in mountains • Closure of mountain passes and roads (1st, 2nd, and 3rd orders) • Chains even on the plains • Many isolated villages • Railway network disruptions • Closure of airports • Slope processes • Possibility of concurrence with cold wave • Very strong winds • Catastrophic situations • Historical

Source: own elaboration from the CNCyL

cases analyzed in each category, which does not prevent certain doubts on how some cases should be classified. This is the case of intense episodes with little copious snowfall, or episodes that affect a few provinces (less than 3) which are classified as moderate snowfall given the scope of their effects. It is also normal that depending on the type of weather (air mass, location), different snow thicknesses are counted according to mountain ranges. Thus, the mA troughs located to the East of the Peninsula (air inlet branch affecting the Cantabrian MR) usually produce a thickness of 20 cm in the most eastern Cantabrian MR, 10 cm in the Iberian MR, and 5 cm in the Central MR. In these cases, the event is considered as a whole (number of affected provinces, duration, consequences).

As an example, the "Very Intense snowfalls" events are shown from the CNCyL (Table 4). The episodes are individualized according to the type of weather, although they can be simplified in longer periods of snowfall. Of these 44 individualized episodes (5.4% of the total), the most severe ones, those with catastrophic effects, correspond to periods 9, 12, 14, 5, and 4, in this order. In their course, snowfalls affected the entire region, causing the isolation of hundreds of localities, numerous accidents, and the crash of many economic activities.

It has been found that the more intense the snowfall, the greater its spatial distribution. Regardless of the cause that originates them, when their dynamics are very deep and highly unstable, they strongly affect a large territory, often not only the regional one, but a large part of the Iberian Peninsula, as well as other European territories. In contrast, when snowfalls are of limited amount, with just a few millimeters, they occur in fewer provinces and do not affect the interior area of the region but in their mountainous periphery, forming part of the category of occasional and/or weak snowfalls (CNCyL). This type of snowfall, albeit not significant due to its discharges, is a good indicator of the number of snow events that can affect the region. It is with them that the orographic factor is best revealed.

The number of provinces affected by snowfall is not homogeneous. Its distribution shows several interesting aspects (Table 5).

Table 4 Very intense snowfall in Castilla y León

Period No.	Date	Duration	Episodes		
			Type of weather	Date	No. of days
1	15–20/1/1980	6	mA trough centered	15–16/1/1980	2
			cP shear line	17–18/1/1980	2
			mP northwest zonal circulation	19–20/1/1980	2
2	5–17/2/1983	13	mA trough to the East	5–6/2/1983	2
			cP shear line	7–14/2/1983	8
			cP shear line shocking mP trough in the West	15–17/2/1983	3
3	5–18/1/1985	14	mA trough centered	5–9/1/1985	5
			cP shear line	10–15/1/1985	6
			mA trough centered	16–18/1/1985	3
4	19–27/1/1996	9	mA trough centered	19–20/1/1996	2
			Cold drop mA centered	21–23/1/1996	3
			mA trough centered	24–27/1/1996	4
5	4–7/12/1996	4	mA trough centered	4–6/12/1996	3
			Cold drop mA centered	7/12/1996	1
6	29/12/1996 to 9/1/1997	12	cP shear line	29/12/1996 to 3/1/1997	6
			mP trough centered	4–9/1/1997	6
7	9–12/1/1999	4	mA trough centered	9–10/1/1999	2
			cP shear line	11–12/1/1999	2
8	25–27/12/2004	3	mA trough centered	25–27/12/2004	3
9	17/2 to 1/3/2006	13	mP trough centered	17–19/2/2006	3
			cP shear line	20–23/2/2006	4
			Cold drop cP centered	24/2/2006	1
			cP shear line	25–27/2/2006	3
			mA trough to the East	28/2 to 1/3/2006	2
10	19–24/3/2007	6	mA trough to the East	19–21/3/2007	3
			Cold drop mA to the East	22–24/3/2007	3
11	5–10/1/2009	6	cP shear line	5–7/1/2009	3
			Cold drop cP centered	8–10/1/2009	3
12	13–26/12/2009	14	cP shear line	13–16/12/2009	4
			mA trough to the East	17–18/12/2009	2
			cP shear line	19–20/12/2009	2
			mP trough to the West	21–26/12/2009	6
13	1–13/2/2018	13	mA trough centered	1–3/2/2018	3
			cP shear line	4–6/2/2018	3
			cP shear line	7–8/2/2018	2
			mA trough to the East	9–11/2/2018	3
			mP northwest zonal circulation	12–13/2/2018	2
14	27/12/2020 to 11/1/2021	16	mA trough centered	27–29/12/2020	3
			mA trough to the East	30–31/12/2020	2
			mA trough centered	1–3/1/2021	3
			cP shear line	4–6/1/2021	3
			cP shear line	7–9/1/2021	3
			Cold drop cP centered	10/1/2021	1
			cP shear line to the East & mT ridge to the West	11/1/2021	1

Source: own elaboration from the CNCyL

Aside from the fact that snowfalls are more important from December to February (above 17% of total), which can be considered normal, what is more interesting is that episodes that affect 6 provinces at the same time are highest in percentage (21.5%) out of total snowfall events. These tend to be León, Palencia, Burgos, Soria, Segovia, and Ávila, the most mountainous, and where the number of cases is even significant from November to April (Table 6). It is followed in importance by the episodes that affect the entire region (16.1%). It should be understood that not all snowfalls of this type are of a very intense nature, as they can also be intense. It is striking that those that occur at the same time in three provinces or less represent 21.1% of the total, compared to those that affect more than six that account for 54.4%. In other words, when it snows, the more or less generalized episodes in the region are more important than those localized ones.

There are provinces where it snows more frequently than in others. This is the case of León, Palencia, and Burgos, precisely the ones on the northern half of the region, those of the Cantabrian Mountains. Few differences exist between León and Burgos. León, due to its more northwestern location, receives snowfalls more promptly. Burgos, on the other hand, receives in addition to the snowfalls that occur in the Cantabrian Range, those that occur in the Iberian MR. Few differences can be identified with Palencia, though there is a certain decrease towards the East due to its better protected position compared to the great Leonese peaks. Also important are those of the Central MR and its surroundings, between Segovia and Ávila, in the Gredos, Guadarrama, and Somosierra mountains (Fig. 2).

It is logical to think that snowfalls affect the mountainous provinces more than those in the interior. In Salamanca and Valladolid, located in the peneplain and the sedimentary basin, snow appears much less times, especially in the second province (18.2%). However, they are also important in the ranges of Sierra de Sanabria (Zamora) and in that of Béjar and Peña de Francia (Salamanca).

Normally, the more intense the snowfall, the worse its effects, although sometimes occasional or weak snowfalls have equally damaging results. In other words, the negative repercussions do not have a one-to-one correlation with the degree of intensity of the snowfall (Fig. 3). Sometimes, these occur even though the snowfall has not been very high in its amounts (in the Masa moor, Burgos, drivers get trapped on the road all night).

In addition, almost every year, there are episodes of low intensity in which the snow causes difficulties in road traffic. Even capitals such as Ávila (1132 m), Soria (1065 m), or Segovia (1005 m) may be isolated for a few hours (Fig. 4).

3.1.2 The duration of snow

In general terms, the longer the event lasts, the greater the intensity degree and the worse the consequences. The systematized information allows establishing firstly different thresholds according to the number of days of development (Table 7) and, later, according to different degrees of intensity (Table 8).

The duration is first treated day by day,[8] and then, it is synthesized into four categories according to the CNCyL: shorts (≤1 day), medium (2–3 days), long (4–5 days), and very long (≥6 days) snowfalls. The degrees of intensity are limited to four levels (instead of five) when dealing with intense and very intense snowfalls together.

The duration of each episode depends on the duration of each type of weather, hence the domination of medium situations, 2–3 days (62.9%), although episodes of 2 days are somewhat more frequent than those of 3 days. In general, these are quite common from December to April. Another different aspect is to compute the periods of snowfall, that is, the concatenation of various types of very cold weather prone to its production. That is when they can last for a week, a dozen days, or even more.

It is not very frequent that the same type of weather produces snowfall for 6 days or more. It has only happened rarely (3.1%). They are almost always due to very deep and fairly stagnant dynamics over the peninsular territory, mainly during January and February. For the most part, they coincide with inverse zonal circulations (shear line cP) and with polar troughs (mP) centered on the Iberian Peninsula, which generate intense cold and copious snowfalls, especially the latter.

The occasional snowfalls (circumscribed to the mountains) and the weaker ones are usually brief, happening along 1 day or 2 days. They still maintain their importance in November and April where the instability and cooling of the air masses becomes more effective above 1200 m. Many times, these have been identified with early or late snowfalls, associated with troughs or pouching of cold air where only the orographic factor forces its cooling even more, causing what is water in the plains to transform into snow on the mountain ranges. The snowfalls lasting 1 day do not cease to have an important representation (18.9%), representing a much higher percentage than that of the longest ones.

Despite everything, there is a certain relationship between the intensity of the event and its duration, mainly in the shortest and longest episodes (Fig. 5). Around 42% of heavy/very intense snowfalls have lasted 6 days or more, while weak snowfall usually lasts less than 4 days in 40% of cases.

Prolonged snowfalls are usually more intense, while brief snowfalls are usually less intense. But because heavy snowfalls can occur in a few hours, especially in mountain areas, this statement may not always true.

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[8] From 1 to 8 days, as this is the maximum computed for the same episode in the series of years analyzed.

Table 5 Number of episodes by affected provinces (1979–2021)

No. of provinces	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	%
9	0	9	20	37	39	16	10	0	131	16.1
8	1	8	16	17	16	7	6	0	71	8.7
7	0	12	11	16	13	9	5	0	66	8.1
6	3	19	33	36	25	19	35	5	175	21.5
5	1	12	15	12	16	30	16	3	105	12.9
4	1	16	18	20	15	12	9	3	94	11.5
3	3	16	17	11	14	14	18	4	97	11.9
2	3	5	6	5	6	11	5	1	42	5.2
1	4	8	4	4	2	3	5	3	33	4.1
Total	16	105	140	158	146	121	109	19	814	100
%	2.0	12.9	17.2	19.4	17.9	14.9	13.4	2.3		

Source: own elaboration from the CNCyL

Table 6 Monthly number of episodes by province

Province	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	%
León	9	96	131	142	135	112	89	13	727	89.3
Palencia	7	88	119	129	129	105	85	13	675	82.9
Burgos	7	81	128	148	136	110	98	12	720	88.5
Soria	7	64	95	127	105	77	74	9	558	68.6
Segovia	12	78	113	143	118	97	85	14	660	81.1
Ávila	8	70	109	135	116	83	76	11	608	74.7
Salamanca	3	28	48	66	68	29	23	1	266	32.7
Zamora	1	38	64	87	80	43	28	1	342	42.0
Valladolid	0	9	24	45	42	18	10	0	148	18.2

Source: own elaboration from the CNCyL

Una máquina quitanieve en el casco urbano del municipio segoviano de La Granja. / ANTONIO DE TORRE

Fig. 2 Snowfall in La Granja de S. Ildefonso (source: El Norte de Castilla, Jan. 26, 2007)

3.1.3 Snowfall frequency

Frequency refers to the number of episodes that occur per unit of time. A simple way to calculate frequency is by averaging the number of cases cataloged among the total years analyzed, which gives 18.9 episodes/year. As any average value, it does not indicate much because there may be many years that it is not reached and many others that it is exceeded. In fact, the interannual irregularity is a characteristic of this meteor in the region, closely linked to the form of atmospheric dynamics (Fig. 6).

The average value is exceeded in 44.2% of the years. These were very snowy years, with more than 24 episodes (20.9%) occurring. The highest thresholds correspond to the 30 episodes occurred in 1986 and in 2018 and to the 31 episodes of 2019, followed by 29 in 1984, 28 in 1989, and 26 in 1985. Therefore, the period record has been reached recently. At first glance, the 1980s was the snowiest phase, while the 1990s was the least. In fact, it is during the latter decade that the year with the least snowfall is recorded (1993, 7 episodes). Thus, every 12 years or so, several series or stages in its evolution are recognized (Fig. 6, Table 9).

- 1979–1990, the snowiest series, where 9 of its 12 years count snowfalls above the average, with very snowy years.

Más de dos mil camiones, retenidos en carreteras de la región por la nieve

Fig. 3 Problems on the Road N-I (Burgos) (source: El Norte de Castilla, Jan. 27, 2005)

La nieve obliga a circular con cadenas en las calles de Ávila y Segovia

Fig. 4 Heavy snowfall in Segovia (source: El Norte de Castilla, Feb. 24, 2005)

- 1991–2002, there is a drastic reduction, being every year (except one) below the average. Little snowy in the intervals 1992/1994 and 1997/1998.
- 2003–2014, when the trend is reversed as its production increased, but not as much as in the first series. Again, 9 out of 12 are the above average years.
- 2015–2021, the behavior is very uneven. Although this period is not as long as the previous stages, there is a significant decrease in its first 3 years, and a large increase in the following 3 years, to register again few snowfalls in the last year (15 episodes).

When analyzing the anomalies in the number of snow episodes, a clear decrease in the trend line is observed (Fig. 7A). This can be confirmed by the negative coefficients of Kendall and Spearman ($t_K = -0.015$; $r_S = -0.094$), with which it can be considered that in the last 43 years, snow episodes have been decreasing. However, this trend is not significant ($\alpha_K = 0.892$; $\alpha_S = 0.551$). If they are analyzed from 1993 to 2021 (last 29 years), the trend is reversed, being markedly upward ($t_K = 0.587$; $r_S = 0.733$) and with an important level of confidence of 100% in both cases.

The significant reduction in snowfall in the 1990s determines the behavior of the trend. However, if we consider by series of years, trend lines are always ascending, although sometimes above and others below the mean, thus showing a clear example of metastable equilibrium.[9] Of all of them, series 3 (Fig. 7D) is the one that best fits the mean value and the only one with high significance in the Kendall and Spearman tests ($\alpha_K = 0.039$; $\alpha_S = 0.049$).

On the other hand, snowfalls are more frequent from December to February, with averages of 5 episodes or more per month. There are also years when April is very snowy (Fig. 8). The 9 events of January 1984 and the 8 events of April 1989 and March 2018 clearly stand out among the rest.

Table 7 Monthly number of episodes according to duration

Months	Short (1 day)	Medium (2–3 days)	Long (4–5 days)	Very long (6 or more days)	Total
October	6	7	1	0	14
November	30	59	16	3	108
December	24	105	16	4	149
January	33	97	21	8	159
February	22	88	30	7	147
March	20	83	21	2	126
April	15	76	17	1	109
May	6	11	2	0	19
Total	154	512	123	25	814
%	18.9	62.9	15.1	3.1	100.0

Source: own elaboration from the CNCyL

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[9] There are variations in the mean value, but with tendency to maintain a sustained direction, although with discontinuities or jumps.

Table 8 Number of episodes according to the degree of intensity

Intensity	1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days	Total
Occasional	51	65	28	11	4	0	0	0	159
Weak	60	113	89	39	10	5	1	0	317
Moderate	26	67	62	22	16	2	3	1	199
Intense/very intense	17	43	45	14	7	10	2	1	139
Total	154	288	224	86	37	17	6	2	814
%	18.9	35.4	27.5	10.6	4.5	2.1	0.7	0.2	100.0

Source: own elaboration from the CNCyL

By contrast, there are months in which it does not snow at all, although this has only happened in series 2.[10]

From a monthly analysis, we can appreciate winter snowfalls are more important than equinoctial ones. However, in the evolution of the number of episodes it has each month with respect to the annual total, a slight increase in the relative weight of snowfall from January to March can be appreciated, a decrease in the months of April and December, and a significant increase in the November ones.

It is not possible to maintain the idea that in the less snowy years, snowfalls are necessarily insignificant, and conversely, that in very snowy years, these have to be particularly intense. In fact, during the 1990s, there were years that very intense episodes were experienced. In 1993, with just only 7 events, heavy snowfalls were registered from February 26 to March 6, allowing the development of a cold wave (Fig. 9).[11] In contrast, between 1988 and 1990, which were very snowy years, no intense or very intense episodes were registered, highlighting 1989 which registered 28 episodes of which only two were of a moderate type. It is demonstrated that the irregularity in the way it originates and evolves is a characteristic of this meteor.

The intensity of snowfall has also been related to its degree of periodicity. Those of a very intense nature (Table 4), which generate catastrophic storms, are the least frequent (5.5%; average frequency 1 case/year). They have only occurred in 12 specific years (1980, 1983, 1985, 1996, 1997, 1999, 2004, 2006, 2007, 2009, 2018, and 2020), given the circumstance that several episodes of this type can develop in the same year or that they do occur even in the least snowy stage. Its frequency is really irregular.

Fig. 5 Duration of snowfalls (%) (source: own elaboration from the CNCyL)

A significant example happened from December 29, 1996 to January 3, 1997.[12] Along with the 24 closed mountain passes, the use of snow chains was generalized in all the provinces, except in Valladolid. The thickness of snow that had accumulated in some places and the difficulty of accessing the snowplows resulted in the isolation of more than 132 localities (more than 4000 people) as well as intermittent power and telephone outages. However, the most serious was the death of seven people in two separate road accidents in Soria and Salamanca (Fig. 10), the death of another three people in a traffic accident in Treviño, and the death by freezing of an individual in Soria.

Much more frequent are intense snowfalls (10.6%), with minor consequences that are not so catastrophic but that occur practically every year (2 cases/year). Only 6 years (1988, 1989, 1990, 1991, 1995, and 2002) have not registered intense snowfalls (nor very intense for that matter). Eight years (1982, 1984, 1987, 1994, 1998, 2008, 2010, and 2014) have registered only one episode, while other years (1986, 2004, 2005, and 2013) have been especially virulent with more than five episodes of intense snowfalls a year. The great variability of its temporal distribution continues to be evident. On the other hand, moderate snowfalls (24.4%; 4.6 cases/year) and weak ones (39.4%; 7.5 cases/year) together

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[10] As in December 1991, January 1993, March 1994, February and March 1997, February 2000, January and February 2001, and March 2003.

[11] The snow made an appearance in all the provinces of the region, causing the closure of many mountain passes and requiring the use of snow chains on many roads. The worst situation was experienced by the more than 400 towns of León, Palencia, Burgos, Soria, and Ávila provinces, which were isolated for several days, some even suffering telephone service interruptions.
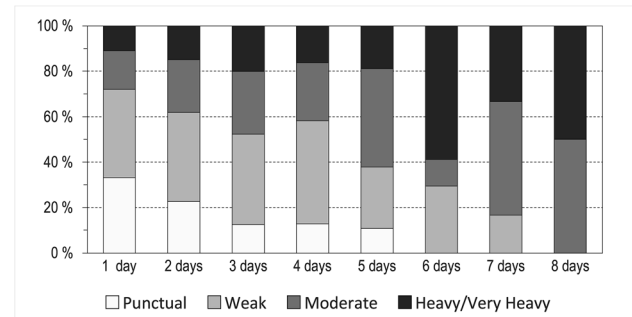
[12] It was due to a Pc retrograde that was followed on January 4/9 by a Pm trough centered on the Iberian Peninsula, which meant that the snowfalls were copious for 12 days.
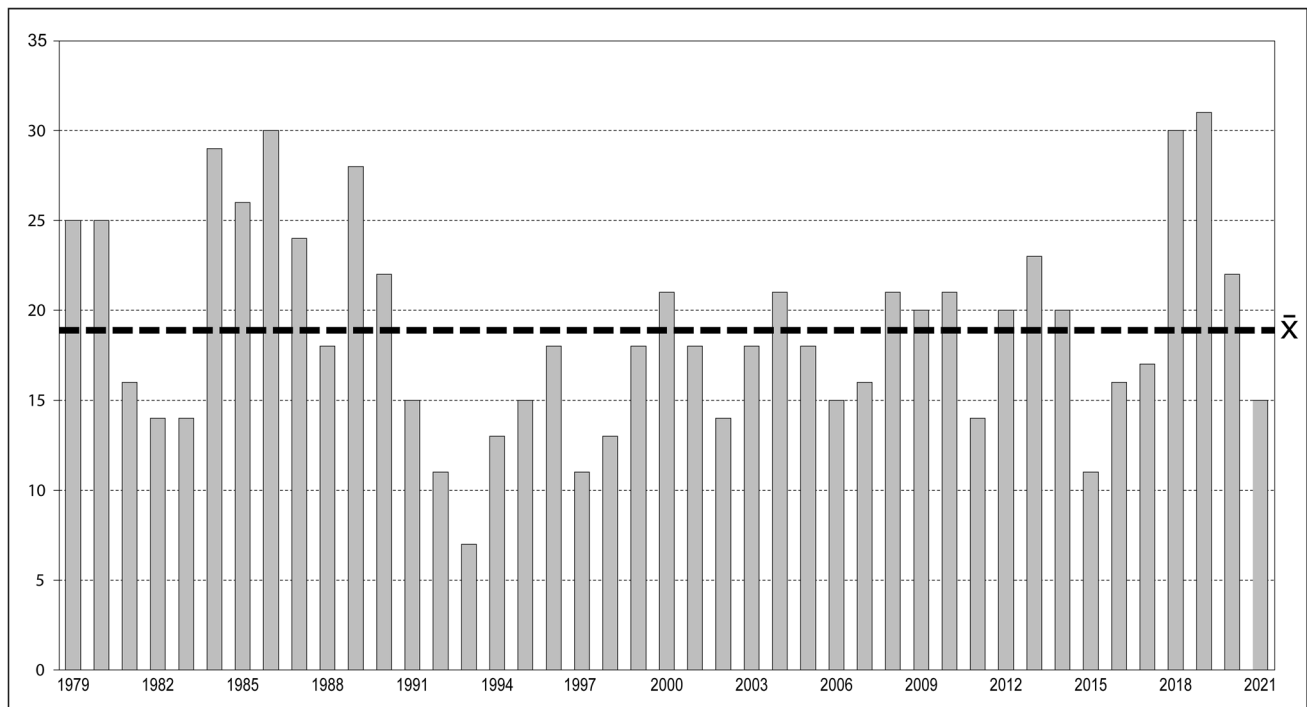
Fig. 6 Number of snow episodes in Castilla y León (1979–2021) (source: own elaboration from the CNCyL)

Table 9 Number of snowfall episodes by series in Castilla y León

Series	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1979–1990	3	28	52	58	45	42	41	2	271
1991–2002	1	26	35	36	25	19	27	5	174
2003–2014	8	30	41	39	46	31	25	7	227
2015–2021	4	20	21	30	26	25	12	4	142

Source: own elaboration from the CNCyL.

represent a not inconsiderable percentage, while the occasional ones reduce their presence (20%; 3.8 cases/year).

Now then, as important as knowing the number of episodes of snowfalls and their type is knowing the number of days of snow that this translates into (Fig. 11 and Table 10). A total of 2171 days has been computed, which represents an average of 50.5 days/year, 20.8% of the days from October to May. It should not be forgotten that this figure represents the average number of days of snow likely to occur throughout the region. The percentage of years that exceed this average is equal to that of the number of episodes (44.2%), with 80 days from 1984 to 1986 and in 2018 having exceeded this average amount.

Normally, the years with more episodes are expected to have a greater number of snow days. In general terms, generic thresholds that respond to the following guidelines can be established: years with less than 13 episodes record 20–40 days of snow, years with 14–18 episodes record

about 40–50 days, those with 19–23 episodes record about 50–60 days, and if 24 episodes are exceeded, the days of snow rise to 70–80 days or even more. Also, in the annual evolution of snow days, the previously individualized stages are distinguished (Fig. 7), with a higher proportion of snow days happening during the first series.

In the evolution of the anomalies of the snow days, there is a marked downward trend than what happens with the snowfall episodes (Fig. 12A), as shown by the negative Kendall and Spearman coefficients ($t_K = -0.043$; $r_S = -0.168$), but without being significant ($\alpha_K = 0.683$; $\alpha_S = 0.281$). Similarly, in the last 29 years, the trend is upward ($t_K = 0.657$; $r_S = 0.785$) and with a confidence level of 100%. By series, the trend is not always the same, since it increases in all except in series 2 (Fig. 12C), with series 3 (Fig. 12D) being the only one with high significance in the Kendall and Spearman tests ($\alpha_K = 0.009$; $\alpha_S = 0.003$).
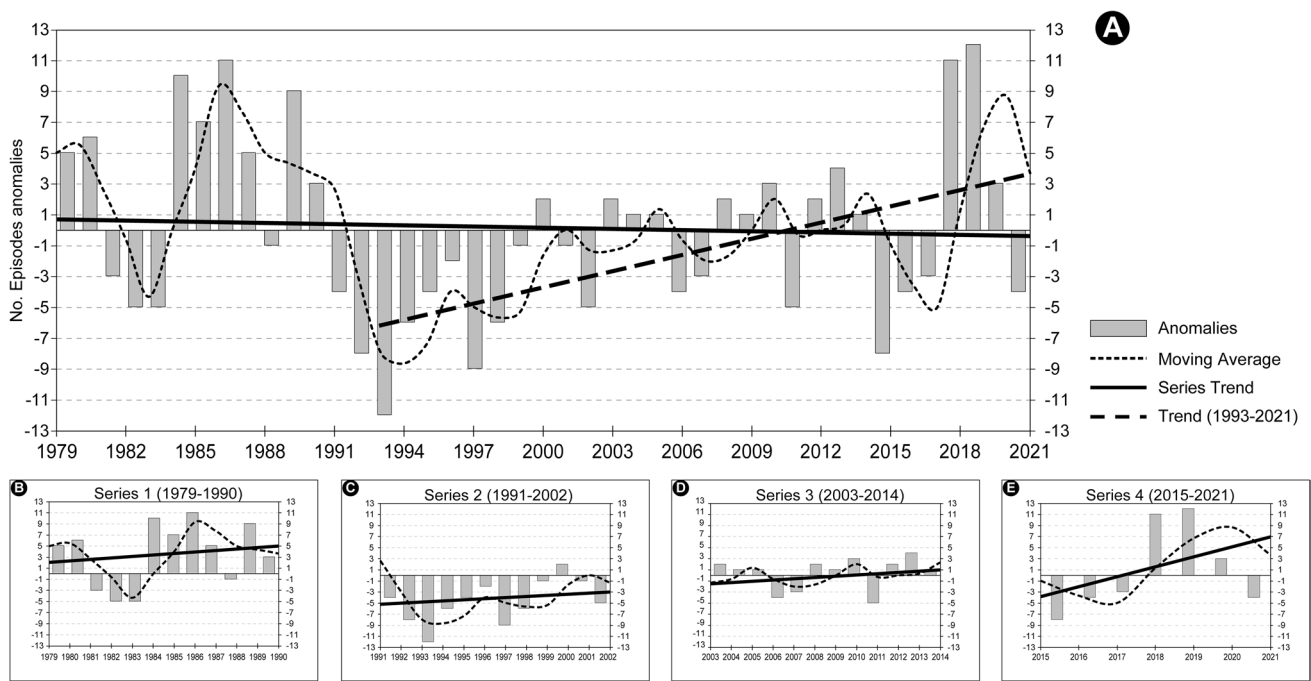
Fig. 7 Anomalies in the number of snowfall episodes. A Complete series: 1979–2021. B Series 1: 1979–1990. C Series 2: 1991–2002. D Series 3: 2003–2014. E Series 4: 2015–2021. Source: own elaboration from the CNCyL

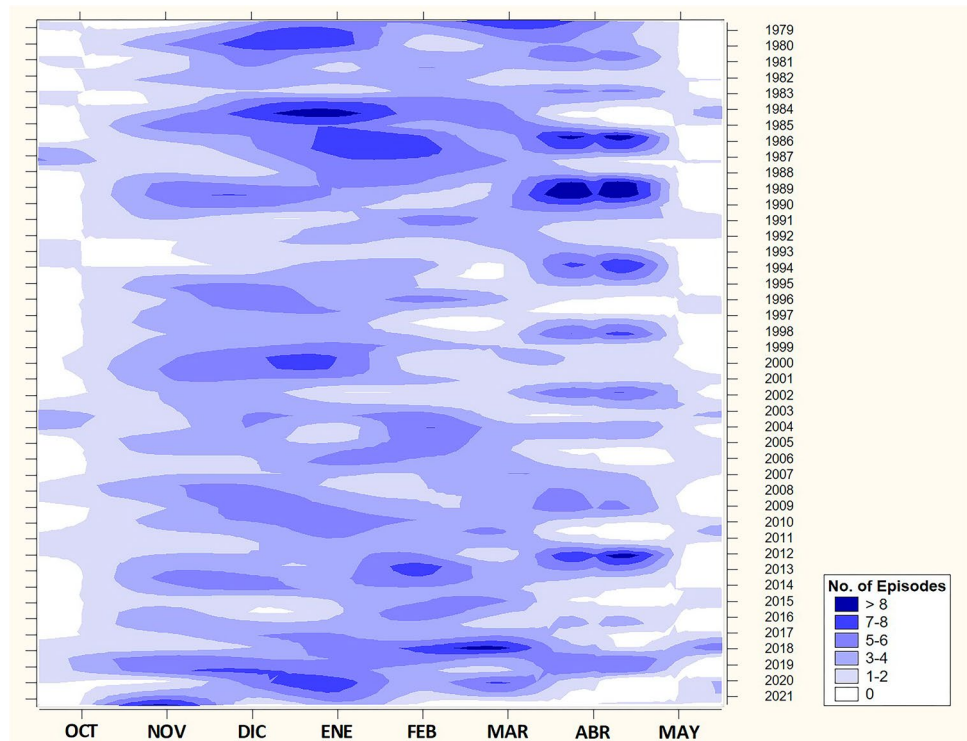**Fig. 8** Time sequence of snow episodes (source: own elaboration from the CNCyL)

Fig. 9 Snow storm in the region (source: El Norte de Castilla, Mar. 1, 1993)

The foregoing shows that the same correlation between the number of episodes and the number of snow days is not always maintained. The former is more in line with the mean values over these four decades, while the latter shows a more evident reduction in their evolution.

Perhaps, this highly irregular behavior can relate to the evolution followed by temperatures in the region in recent decades (Ortega et al. 2006). Between 1961 and 2003, it was revealed that the trend of the annual frequency of the highest extreme values of the maximum temperature anomalies was increasing and that of the lowest extreme values decreasing, in both cases at a confidence level above the 95%. On the other hand, the minimum temperatures showed similar results; the lowest values have a decreasing annual frequency and the highest increasing ones, at a very similar level of confidence (94%). Likewise, it can be linked to evolution that the atmospheric pressure values have experienced during the same interval (Labajo et al. 2004), where a reinforcement and/or increase of the anticyclonic situations can be observed, which may partially justify this reduction in the days of snow.

These, although being more frequent in the central winter months, are actually likely to appear during any season of the year; what varies is their monthly frequency. Their period of appearance is long: from November to April, the days of snow are usually present every year, and in some, even from October to May (Fig. 13).

The irregularity in the monthly distribution is manifest. February is the snowiest month (19.3% of snow days),[13] followed by January and December. There are years when it is highest in spring[14] (1983, 1986, 1989, 2007, 2012, and

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[13] In February, there have been 15 years with more than 13 days of snow, reaching 20 in 1986 and 21 in 2018.

[14] More than 10 days a month for 12 years in March (maximum 26 days in 2018) and 13 in April (maximum 23 days in 1986).

Fig. 10 Effects of very intense snowfall (source: El Norte de Castilla, Jan. 4, 1997)

2018), or even snows equally in both seasons (1989, 1991, 1992, 2004, 2008, 2010, and 2019). There are also years with very limited days of snow recorded.[15]

The monthly evolution of the number of snow days with respect to the annual total in the analyzed period shows a similar behavior as in the case of the number of episodes.

On the other hand, early autumn and late spring snowfalls do not show exactly the same pattern. Snow in October has only happened in 9 years, and snow in November has happened every year except for 7. Conversely, the month of April has not witnessed snow in only 8 years and May in 28 years. The behavior of the months of November and April is very similar, not so much those of October and May. There is a greater presence of snowfall during this last month, from which it can be inferred that the arrival of the first snows costs more than the dismissal of the last.

From December to March, 70.8% of snow days occur, although by astronomical seasons, the distribution of 55.2%

occurred in winter, 30.4% in spring, 14.1% in autumn, and 0.2% to the possible, but very infrequent, in the summer. Although not analyzed in this piece of work, it is not at all anomalous that it could snow in the summer season, especially in June and August, since in July for the series of years considered, it has never done so. It is a very rare phenomenon which may be due to the eruption of arctic air troughs (mA) that penetrate the Peninsula ragingly, or to its cold strangled drops that, in a short space of time, trigger snowy precipitations in the highest areas of the region.[16] However, it must be taken into account that the energy and heat absorbed by the ground complicate the formation of a snow cover, which is why they usually only leave a thin layer of ephemeral snow as a trace.

It can be concluded that the results obtained from the information in the Catalog on the evolutionary behavior of

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[15] With less than 3 days/month, there have been 3 years in January, 6 years in February, 8 years in December, 9 years in March, and up to 16 years in April.

[16] This happened at the beginning of the summer of 1997 (June 28) in the province of Segovia. Although the episode only lasted a few hours, the snow and low temperatures took La Granja de San Ildefonso and Puerto de Navacerrada by surprise, who had not remembered seeing snow at those heights for more than 50 years. A cold arctic drop in the North of Spain was responsible. Also in mid-June of 2016, a 5-cm snowfall fell in Picos de Europa (León).
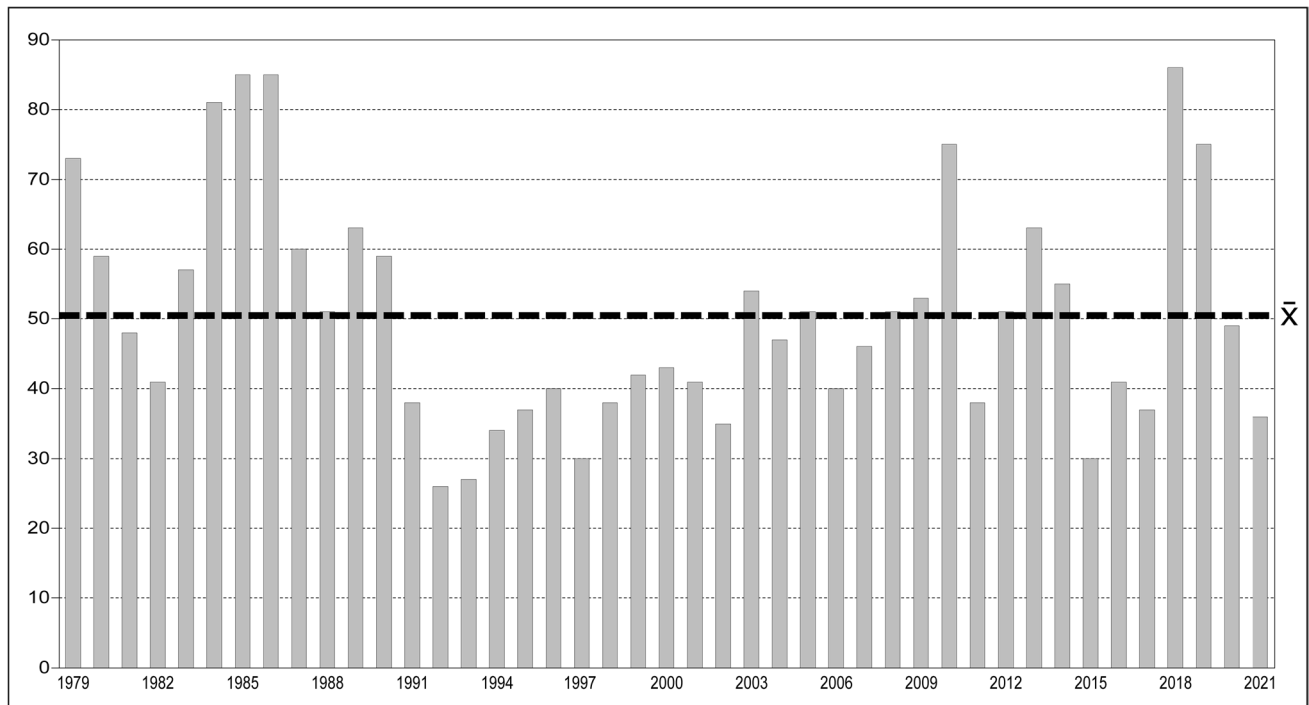
Fig. 11 Snow days frequency in Castilla y León (1979–2021) (source: own elaboration from the CNCyL)

Table 10 Number of days of snow by series in Castilla y León

Series	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1979–1990	9	83	148	150	136	122	109	5	762
1991–2002	1	57	78	85	75	50	74	10	431
2003–2014	16	76	95	108	145	100	66	18	624
2015–2021	11	54	48	70	64	66	30	11	354

Source: own elaboration from the CNCyL.

snowfall (snow days) are analogous to those achieved by other authors from the analysis of meteorological information (Pons et al. 2010). This helps to give more consistency and validity to the CNCyL and the methodology followed.

3.2 Synoptic study of the snows in Castilla y León

As a second part of the applied method, a synoptic analysis of the atmospheric situations on the cataloged dates has been carried out. This has served to validate the data handled and to fine-tune the information, and to establish a relationship between the intensity and duration of the episodes with the types of weather that produce them. It has made possible to establish a typology of snowfall according to dynamic causes, adding value to this work from the point of view of preventive diagnosis for risk situations.

3.2.1 Genesis of the snows: main responsibility

The number of situations cataloged according to atmospheric circulations and what they represent in the total count and their distribution by months is expressed in Table 11, where the importance of each of the previously identified types of weather in their production is noted (Table 2).

The *arctic troughs* stand out among all representing 29% of the total. They penetrate in raging way over Spain, which has earned them the qualification of "coladas árticas" (arctic air inrushes), of special incidence in this region. In their forays, they take advantage of the slower circulation of the western flows, channeling very cold air masses soaring in the meridian direction N–S. Coming from the North Pole (polar vortex), they can reach up to 30°–35° N, although along their prolonged displacement, they become denatured. However, the speed with which they enter allows them to keep
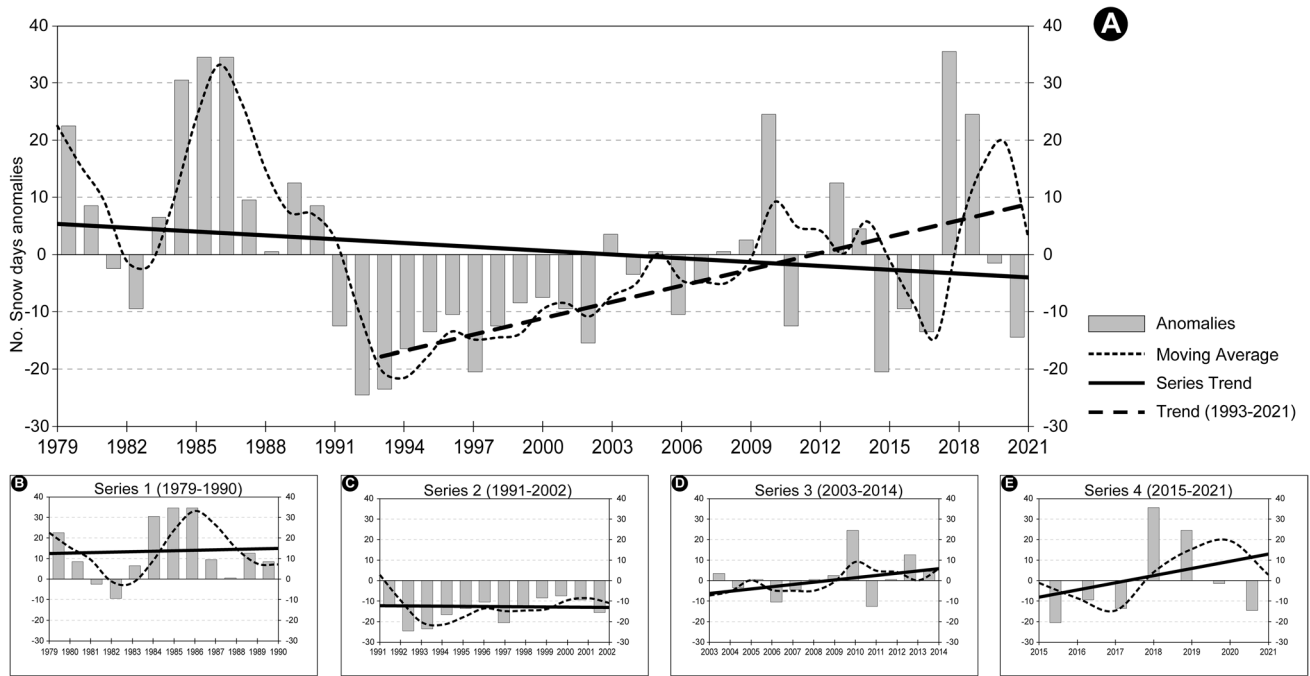
Fig. 12 Anomalies in the number of snow days. A Complete series, 1979–2021. B Series 1, 1979–1990. C Series 2, 1991–2002. D Series 3, 2003–2014. E Series 4, 2015–2021. Source: own elaboration from the CNCyL

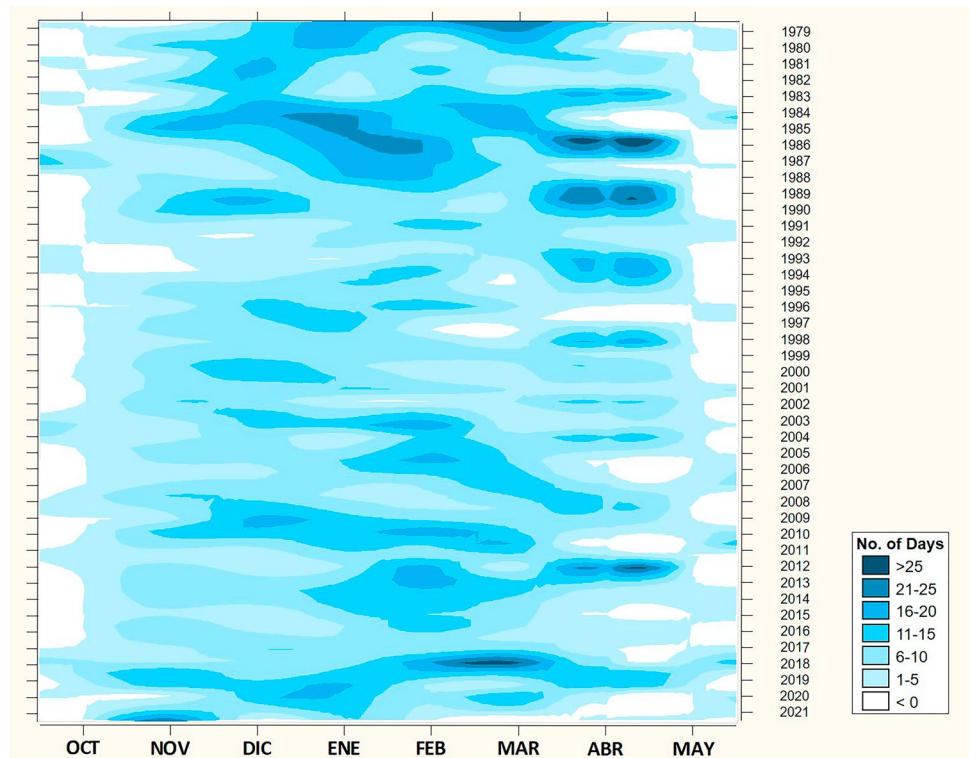**Fig. 13** Time sequence of snow days (source: own elaboration from the CNCyL)

Table 11 Number of situations according to atmospheric circulations

Atmospheric circ	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	%
Shear line cP	1	11	25	35	33	24	15	0	144	17.7
Arctic troughs	10	43	46	33	36	28	34	6	236	29.0
Polar troughs	2	14	41	53	41	30	20	0	201	24.7
Zonal circulation (W & NW)	0	6	14	12	10	11	5	0	58	7.1
Cold drop cP	0	4	6	12	9	10	8	0	49	6.0
Cold drop mA	3	20	7	8	8	7	15	9	77	9.5
Cold drop mP	0	6	10	10	5	7	8	3	49	6.0
Total	16	104	149	163	142	117	105	18	814	100.0

Source: own elaboration from the CNCyL.

their thermal characteristics practically unchanged despite their long transoceanic journey. With them, the minimum temperatures in Castilla y León are always below 0 °C, oscillating between −3 and −8 °C, observing a progressive decrease as the type of weather passes as a consequence of the accumulated cooling throughout the days. Regarding the maximums, it is not surprising that they maintain negative values, although they are normally between 5 and 7 °C.

They can appear centered on the Iberian Peninsula, accessing through a narrow corridor between the British Islands and the Scandinavian Peninsula (Fig. 14), or they can be located slightly East of it (Fig. 15), with their axis over Central Europe. Three aspects help to reinforce snowfall: the marine trajectory it follows which increases its degree of instability, the effect of the relief that causes abrupt rise in the air masses, and the states of frontogenesis that are created when breaking into a space where mild or warmer air masses dominate, generating a strong hydrostatic imbalance that represents the most constant and strongest engine in the genesis of atmospheric instability (Trzpit 1978).

With arctic troughs, it is very normal for them to have a single day when accumulation of most of the precipitated volume occurred, during which it exceeds 10 mm, or even 15 mm or more on the mountainous cingulum of the region. Inside precipitations are more restrained. In the final days, the skies become more transparent, which brings on intense irradiation frosts, while snowfall is considerably reduced due to the progressive displacement experienced by these troughs towards the East.

Many of them end up strangling in deep cold drops that, depending on the way they detach, focus on the Peninsula (frequently) or around it. In fact, they represent the highest percentage within this type of circulation (9.5%), having special representation in November and April. The important thing is that they contribute to prolong the bad weather for 2 or 3 additional days in instability reactivation. As a consequence, for at least a week, a very cold period is triggered, with important snowfalls.

With a somewhat lower frequency (24.7%) are those caused by *mP troughs*, coming from the Lower North Atlantic (Fig. 16 and Fig. 17), in the space between Greenland, Iceland, and the British islands. Although their air masses affect the region throughout the year, they show their most extreme features during winter, at which time they erupt deeply, quickly, and markedly unstable, bringing very cold air, but much more humid than in the previous case. Its arrival allows the passage of storms with associated fronts that discharge abundant rainfall, especially in its western half. If they are very deep, its consequences are felt throughout it and snowfalls are inevitable. Many times, they are responsible for very damaging situations due to the intense snow precipitations recorded (closure of mountain passes and communication routes, isolated towns, etc.). As in the previous case, they show different ways of penetrating (centered, West, North, etc.), hence generating snowfall with different amounts and spatial distributions.

Surrounding or located in the center of the Peninsula, these troughs can also strangle into cold air cores in height. Although their presence is usual from November to April, together they represent a percentage similar to those of cP origin (6.0%).

On another side, *retrograde cP* troughs account for 17.7% of the snowfall. Some are so deep that they descend to 30° N and beyond 20° W, reaching temperatures of −32 °C/−36 °C at 500 hPa. This air is very cold and drier because its source area is in the vast Siberian basin (Fig. 18), but in its reverse movement towards the West, it collides with warmer and more humid air masses, triggering snow precipitations together with a drastic thermal drop. With these advections, cold weather is very intense for several days. The maximum temperatures do not usually

Fig. 14 mA trough centered (source: Wetterzentrale; CFSR; 500 hPa geopotential height)
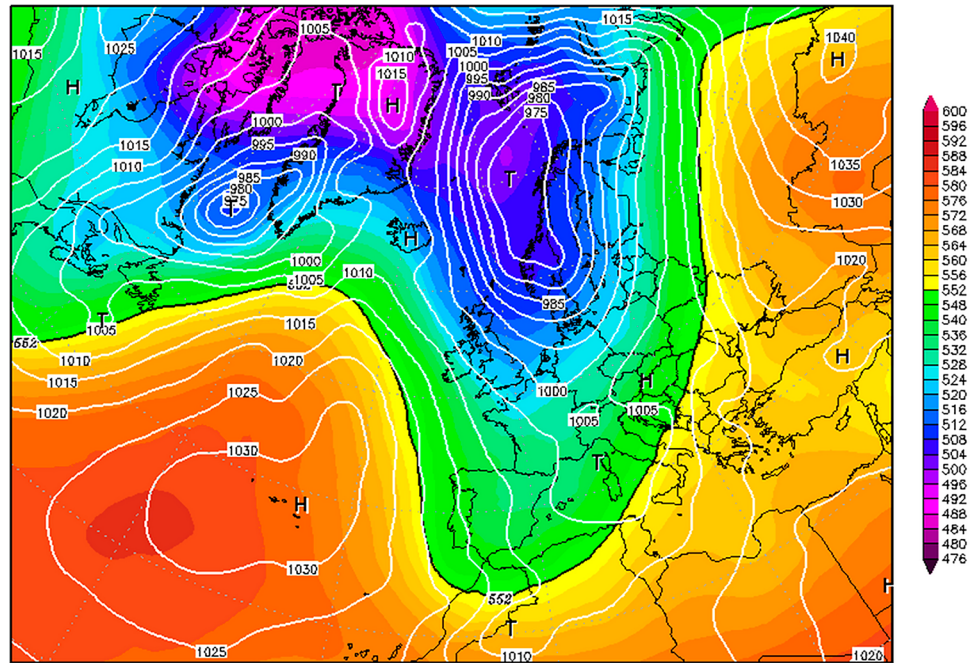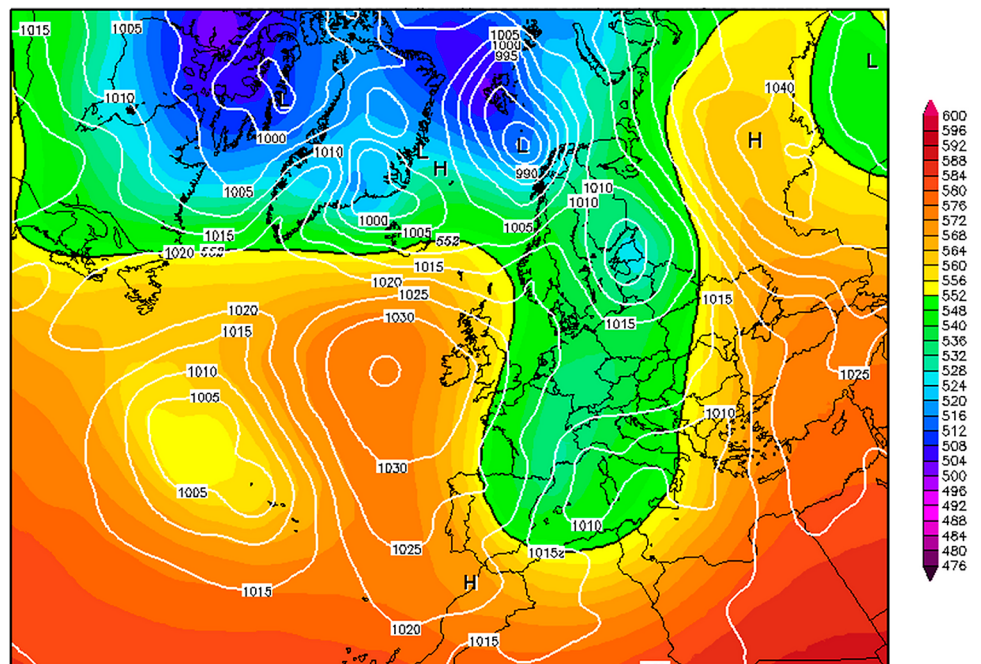

**Fig. 15** mA trough to the East (source: Wetterzentrale; CFSR; 500 hPa geopotential height)

exceed 3 °C, while the minimum temperatures, always negative, are between − 5 °C/ − 10 °C or even less. They are associated sometimes with absolute minimums (in the order of − 20 °C).

Snowfalls under this frame are typical during the first day of the incursion, and can continue the following day, although not always, with the eruption of sudden pulses of even colder air. They are very abundant in the peripheral mountains due to the orographic effect, while in the plains, their amounts differ greatly from one locality to another. Snowfalls, whether they occur continuously (more than 1 day of snowing) or are due to isolated cloudbursts, can even occur throughout the Duero basin. Its way of manifesting itself spatially is uneven, since sometimes, it causes very weak snowfalls, even nonexistent in the interior (Valladolid, Salamanca), and in other

Fig. 16 mP trough centered (source: Wetterzentrale; CFSR; 500 hPa geopotential height)
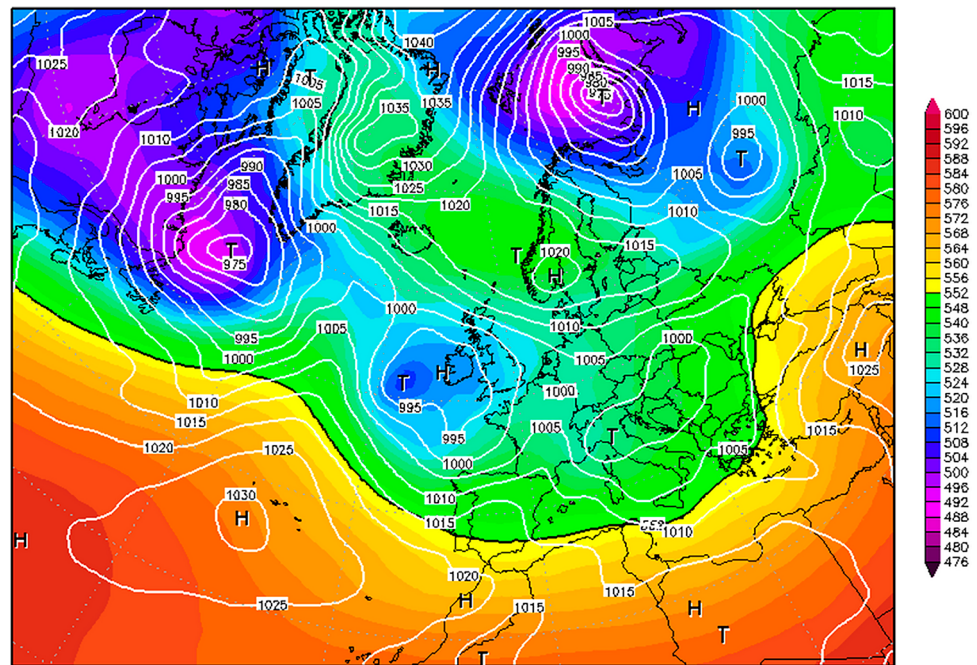
times, it allows significant thicknesses. It all depends on the degree of deepening of the trough, the air pulsations it receives, how it evolves, and the position it maintains over each area.

Although not very frequent, it is worth highlighting those situations in which these advections meet a mP trough to the West of the Iberian Peninsula due to the heavy snowfall they give rise to, affecting the entire region (snow level above 600/700 m).[17] In other times, they strangle themselves into DANAS in different locations (6.0%), highlighting for their frequency those that occur from January to April centered on the Peninsula (Fig. 19). On average, they are kept for 2 days/3 days, which, together with those of the trough of origin, result in very cold and unpleasant weather during 5 days/6 days.[18]

Finally, circulations with a marked *zonal index* are produced to a lesser extent (7.1%) and are mainly linked to penetrations from the NW (6.7%). This is not strange because the air masses which entered from the West (0.4%), although they are very humid, are also milder, so it is hence in the mountains where their presence is more guaranteed.

In summary, it can be said that most of the snowfall in Castilla y León is linked to N–S circulations of arctic and polar troughs, since, together, they represent 53.7% of the total. However,

considering the relationship of types of weather identified (Table 2), individually, it is the cP retrograde that mostly causes them (16.1%), followed by the centered mA troughs (15.5%), both very common from November to April. It is followed by the centered mP troughs (10.7%), the mA troughs to the East (8.1%), and the mP troughs to the West (7.5%), both of which are more common from December to February. Among the cold drops, those centered on the Iberian Peninsula always stand out with arctic air in first place (5.3%) especially between November and April; the cP (3.4%) from January to April; and mP (2.2%) more frequent in the central winter months. The rest of the individualized types of weather always represent percentages inferior to 1.5%, which speaks of their lesser importance as dynamics that generate snowfall. However, having identified up to 30 types of weather is an indication of the great diversity of atmospheric situations that are capable of producing it.

3.2.2 Snow and cold waves

Without it being a primary objective of this research, some observations have been made regarding cold waves. It is not a question of delving into the definition of what is understood by such since there are many and varied. The imprecision of the term means that there is still no unanimity in its consideration. Different studies reach disparate results depending on the thresholds and the starting premises.

However, from the CNCyL, snowfall has been related to its possible concurrence or not with a cold wave. It must be borne in mind that it is not always when there is a very intense and prolonged cold event that it must necessarily coincide with the generation of intense snowfalls, and that

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[17] Similar to what happened in January 2021 with the storm "Filomena.".

[18] Like the situation experienced on January 19/23, 2020, which due to the entry position of the retrograde and strangulation of the cold drop, affected more fully the Mediterranean coast and the eastern half of the Peninsula, causing heavy snowfalls classified as historical in that sector.

Fig. 17 mP trough to the West (source: Wetterzentrale; CFSR; 500 hPa geopotential height)
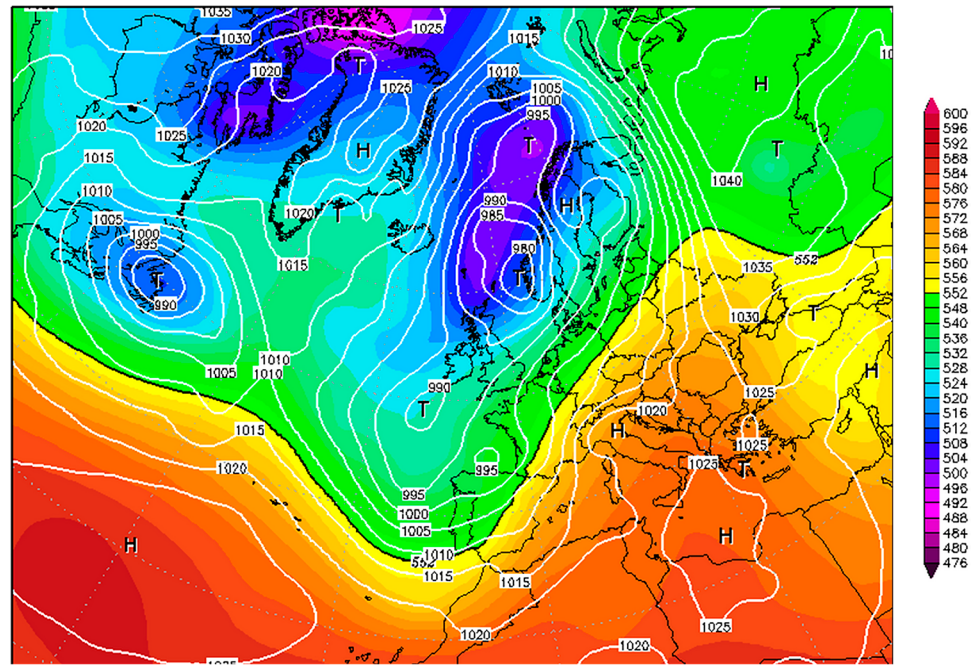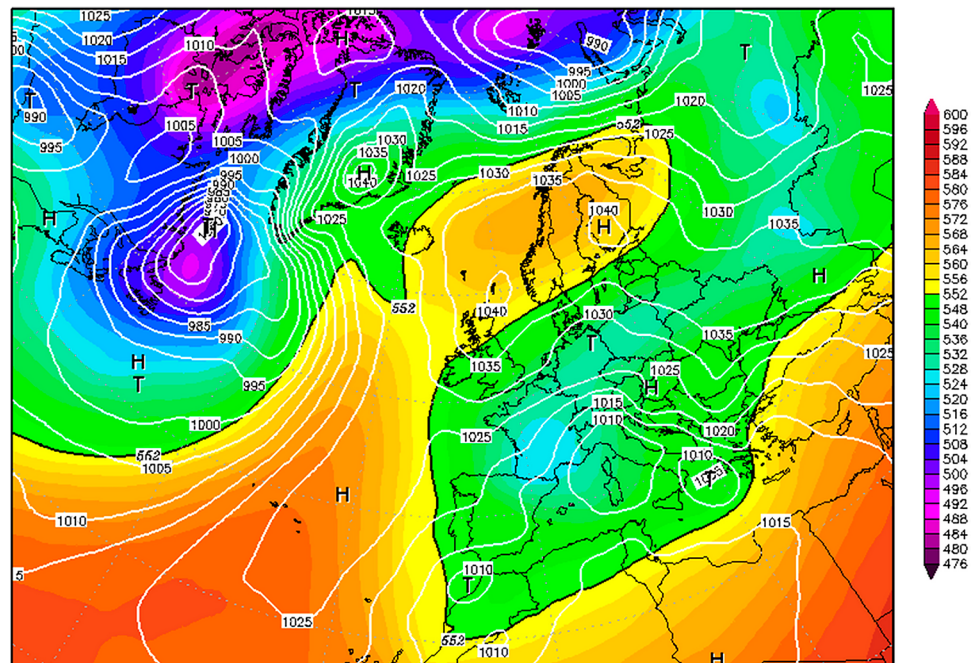

Fig. 18 cP shear line (source: Wetterzentrale; CFSR; 500 hPa geopotential height)

in doing so, these are not always generalized for the entire peninsular territory. Sometimes, long periods of intense cold coincide with blocking anticyclonic ridge situations. Therefore, the fact that it snows does not mean that we are inevitably facing a cold wave. However, it is also true that when the most intense snowfalls have occurred, at least for this region, many times they have coincided with them.

The study carried out by Rodríguez (2021) for Spain considers as such "an episode of at least 3 consecutive days in which at least 10% of the stations considered register minimum temperatures below the 5% percentile of their series of minimum of January and February daily temperatures of the period 1971–2000." For the author, the factors that define its intensity are determined by the temperatures, the duration, and the affected territory. His characterization does not

Fig. 19 cP cold drop centered (source: Wetterzentrale; CFSR; 500 hPa geopotential height)
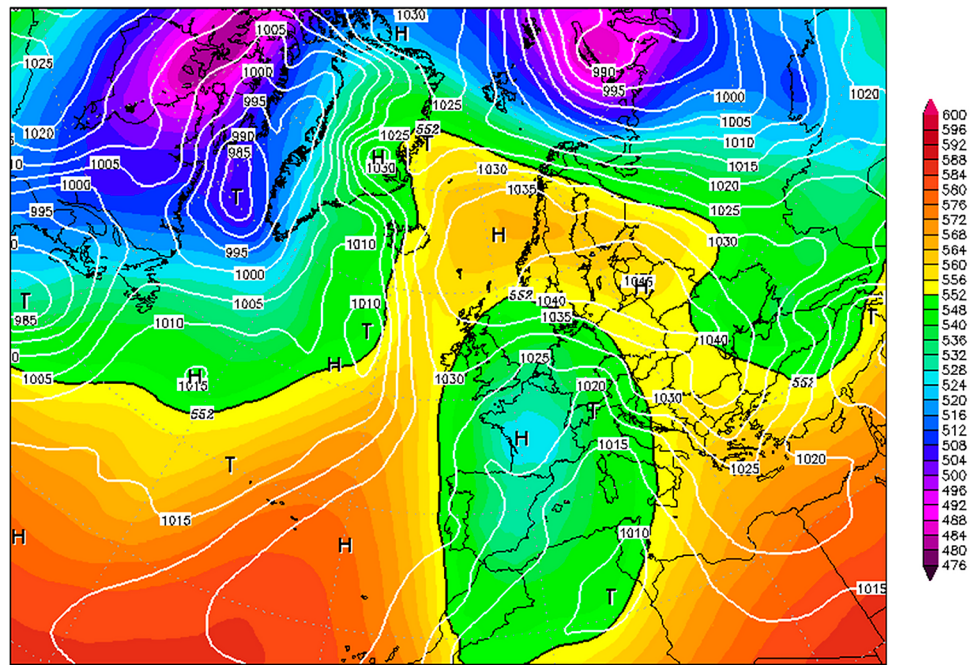
consider the snowfall that can be registered or other parameters (winds, fogs, etc.), although later, it does refer to them in the most significant episodes that he has analyzed. His analysis allows him to identify 61 different cold waves. In our opinion, this is a somewhat debatable result, considering more than cold waves, periods of intense cold.

Applying the periods identified in the aforementioned study to the CNCyL, it can be seen that there is only a coincidence of dates on 37 occasions, of which only 6 coincide with episodes of very intense snowfall and 12 with intense snowfall.[19] This is because what can generate intense cold in some part of the peninsular territory may not manifest itself in this region. It is striking that 19 cold waves are due to powerful anticyclonic ridges centered in Spain. There is no doubt that they do not produce them, but such situations in this region, although they even if they may produce very low minimums, are not always accompanied by reduced maximums, except if dense fogs are generated throughout the day that end up creating even significant freezing fogs.

Our results differ from the aforementioned study because we manage a different concept of what a *cold wave* is. In our understanding, a cold wave is a succession of types of weather that generate the most intense and long-lasting cold states that are reached in this region (and other territories of Spain and Europe), mainly during winters, with a duration of at least a week or even two. A type of weather, no matter how cold it may be, if it occurs randomly and interspersed with other warmer or less cold ones, does not generate cold waves (Ortega 1993). This happens every year and in all seasons. Cold waves do not have to happen every year.

The arrival of a cP trough from the Northeast has nothing special, except that for 2–4 days intense cold is experienced, a fact that is possible for a large number of months a year. What is distinctive is that again cP air pulsations are received, which can be strangled in DANAs, or that mA or mP air troughs follow one another almost in relay, all of which are also deeper than usual (strong descents of the circumpolar vortex). It is also normal for them to start with or end with mT ridge situations, which help prolong the cold for longer (especially at night). If the dynamics are manifested in this way, we can then consider that it is a real cold wave, at least from the climatic point of view.

Sometimes, cold waves erupt in an almost unexpected way, maintaining sudden thermal declines with unsuspected values for many days. The cold becomes more acute as it lasts over time, which allows it, in Castilla y León, to reach maximums that do not exceed 3 °C/5 °C (usually − 3 °C/2 °C) and minimums that are always lower than − 5 °C, although in their most critical days, they achieve − 10 °C, − 15 °C, or even − 20 °C. Intense snowfalls are added to this—more abundant in mountain areas—strong winds (blizzards) not being unknown. In general, snowfalls are more frequent in the northern half of the Peninsula (Castilla y León, Aragon, Northern Cataluña, Extremadura, and Castilla-La Mancha). They can also appear in Andalucía (Granada), Levante, and Spain's Southeast area, although they tend to manifest more with intense rains.

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[19] The rest of 13 episodes coincide with moderate snowfall, 5 with weak snowfall, and 1 with occasional snowfall.

If they are not a common phenomenon in winters, they are not exceptional events either, since they appear every certain number of years with a rather irregular rhythm. Normally every 7–12 years, there are cases of cold waves happening every 2–3 years (much less frequent). They show a particular trend to occur from the second half of December to the first of February. This would be due to the concatenation of advections of Siberian air that displaces NE winds throughout Europe, as what happened in the pass of the years 1970 to 1971. In other times, cold waves can be caused by the violent raid of mP air from the NW or mA that is located above the Iberian Peninsula in a "block". This happened in January 1985. At that time, temperatures were − 50 °C, − 37 °C, and − 40 °C in Finland, Germany, and France, respectively, all of them had temperatures lower than those shown in those days in Moscow or some cities in northern Siberia. At that time, it was considered as the worst winter experienced in Europe so far this century.[20] Something similar happened during the last week of January 2019 in the USA and Europe, or the most recent during the passage from 2020 to 2021 was suffered in Spain (was called "Filomena").

This cold wave was very long and intense, due to a succession of very cold types of weather concatenated from December 27, 2020 to January 16, 2021.[21] Colloquially, the name of Filomena has been used to refer to the whole period, although in reality, it is the name of a depression linked to cP shear line that entered on January 6. It is noteworthy that the AEMET will not speak of a cold wave until January 12, when high pressures were installed over the peninsular territory.

Throughout the analyzed period, there have been eight cold waves in Castilla y León according to the aforementioned terms (Table 12). Not all of them had the same effects or affected this region and our country equally. Previously, there were many others,[22] which is not an unusual process in the behavior of air dynamics. There are those who today consider that cold waves are directly related to the current climate change context,[23] but they

Table 12 Cold waves in Castilla y León (1979–2021)

Start	End	Duration (days)
5/02/1983	17/02/1983	13
5/01/1985	18/01/1985	14
29/12/1996	9/01/1997	12
14/02/2005	5/03/2005	20
17/02/2006	1/03/2006	13
13/12/2009	26/12/2009	14
1/02/2018	13/02/2018	13
27/12/2020	16/01/2021	21

Source: own elaboration from the CNCyL.

are normal climatic processes. What they all have in common is their temporal extension, over 10 days, and the appearance of copious snowfalls. This does not prevent other situations of intense cold and heavy snowfalls, shorter, or affecting more intensely other territories of the Iberian Peninsula.

For all the above, for the authors, the main features that best define them from the climatic point of view are strong drops in temperature, both maximum and minimum; the presence of snowfall, although not always with the same degree of intensity and duration; its prolongation for a large number of days, over a week, due to a succession of types of weather, all of them very cold; and its wide extension by affecting a large part of the peninsular territory and although not all its regions show the same extreme effects, do accuse them to a greater or lesser extent. There are some parameters that fortunately do not occur every year.

3.2.3 Spatial and dynamic distribution of snows

Snowfalls in this region are subject to two fundamental facts: first, its close relationship with the atmospheric dynamics that motivate them; that is, with the way different types of weather manifest themselves according to the origin of the air masses and their form of penetration, and second, its link to the morphological characteristics of the relief, both due to the entity of its morphostructures and its dispositions. Taking both aspects into account, the following considerations can be established:

- *Generalized snowfall*, which affects the entire region (nine provinces) often including all its capitals (above 650 m), accounts for 16.1% of the total number of cataloged episodes (Table 13). It is always identified with very unstable dynamics causing important damage mainly due to very deep cP shear lines, which reach very

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[20] In France, 126 people died and 50 in Spain (*El Norte de Castilla*, January 8 and 17, 1985).

[21] During all that time, the following occurred: Am trough centered (December 27–29, 2020), Am trough to the east (December 30–31, 2020), Am trough centered (January 1–3, 2021), cP shear line and cold drop cP (January 4–5, 2021), cP shear line (January 6–9, 2021), cold drop cP centered (January 10, 2021), cP shear line to the East (January 11, 2021), and mT ridge (January 12–16, 2021).

[22] It should be noted those of the months of January 1910, 1927, and 1935; those of February 1901, 1902, and 1907; that of December 28, 1944 to January 6, 1945; that of February 2–22, 1956; the one from January 26, 1962 to February 6, 1963, and the one from December 16, 1970 to January 7, 1971.

[23] Greater drop of advections of the circumpolar vortex for sudden stratospheric warming (SSW) episodes, greater contrasts between air masses, greater instability, etc.

Table 13 Monthly distribution of snowfall by sectors (percentages with respect to the total number of episodes)

		No	%	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total episodes		814	100	2.0	12.9	17.2	19.4	17.9	14.9	13.4	2.3
By sectors											
1. The whole region	9 provinces	131	16.1	0.0	8.6	14.3	23.4	26.7	13.2	9.2	0.0
	Except Va	71	8.7	6.3	7.6	11.4	10.8	11.0	5.8	5.5	0.0
	Except Va-Sa	66	8.1	0.0	11.4	7.9	10.1	8.9	7.4	4.6	0.0
2. North	Le-Pa-Bu	647	79.5	37.5	75.2	80.0	82.6	87.7	83.5	75.2	52.6
3. West	Le-Za-Sa	223	27.4	6.3	18.1	27.1	36.1	41.8	23.1	17.4	0.0
4. Northwest	Le-Za	337	41.4	6.3	35.2	45.0	55.1	54.8	33.9	24.8	5.3
5. South	Sa-Av-Se	243	29.9	6.3	23.8	32.1	38.6	44.5	20.7	18.3	5.3
	Av-Se	578	71.0	43.8	61.9	74.3	81.6	76.7	64.5	67.0	52.6
6. East	Bu-So-Se	508	62.4	31.3	52.4	65.0	74.7	65.8	57.9	60.6	36.8
	Bu-So	536	65.8	25.0	57.1	66.4	78.5	70.5	61.2	64.2	42.1

Source: own elaboration from the CNCyL.

Av Ávila, *Bu* Burgos, *Le* León, *Pa* Palencia, *Sa* Salamanca, *Se* Segovia, *So* Soria, *Va* Valladolid, *Za* Zamora.

southern latitudes, and to centered mA troughs. With them, it snows a lot in the Cantabrian MR and in the Montes de León, Sª de la Cabrera, and Segundera (region of Sanabria, Zamora), as well as in the section from Gredos to Somosierra in Central MR, being frequent that it snows every day of its development. Likewise, its presence is generalized with centered mP troughs, which unleash strong winds from the NW and thermal drops which, even if they are not as cold as the arctic, allow significant snow falling in the provinces of León, Palencia, and Zamora. Its appearance is even inevitable when, after accumulated cooling of several days due to stable situations (strong nighttime irradiation processes, fogs), very humid air mass mP burst from the W or NW (Morales and Ortega 2000).

- For other generalized snowfall situations, it can happen that it does not snow in the *interior of the region*. It has not done so in the province of Valladolid, 8.7% of the occasions, and 8.1% in Valladolid simultaneously with Salamanca. The types of weather remain the same as on other occasions, but their insights are less dazzling. The truth is that 32.9% of the total episodes cataloged have affected at least seven of its provinces.

- In the *North of the region*, in the Cantabrian Mountains, is where it most snows throughout the year. The North of the provinces of León, Palencia, and Burgos has registered 79.5% of the total of cataloged episodes. Snow is unavoidable if mA and mP troughs penetrate from the NW. From November to April, the number of episodes is above 75%.

- Snowfalls in the *eastern sector* are unavoidable if there are reverse circulations (cP) with little western penetration,[24] cold drops of them lowered, and arctic troughs to the East of the region. In general, they do not have the importance of the previous cases, being the Iberian MR and the easternmost section of the Cantabrian and Central MR the most affected. More characteristic are the associated strong winds, from the N and NE, due to their high baric gradient (average speeds of 60–80 km/h), which contribute to making the cold more intense. In the provinces of Burgos and Soria, snowfalls are more important in the central winter months with values above 65% of the total, obtaining a somewhat lower percentage if they are computed at the same time with those of the province of Segovia.

- Regarding the snowfalls that occur only in the *southern part of the region*, the following clarification should be made: those that are registered throughout the entire Central MR (Salamanca, Ávila, and Segovia) are not usually very frequent (29.9%). Percentages above 32% are only exceeded from December to February. Although they can be present in the rest of the months of the year, they are much less common. On the other hand, the snowfalls that affect only the provinces of Segovia and Ávila are far more numerous (71.0%) and above 74% from December to February. The higher altitudes of this section (Gredos, Guadarrama) and its capitals justify this increase with respect to the province of Salamanca.

- Finally, the snowfalls that occur only in its *western sector* are mainly associated with mP troughs located to the

[24] Unless the cP shear line is very deep, since it affects the entire region.

West of the Peninsula, as well as cold drops (mP, cP) of the same location. The SW flows that distinguish them cause temperatures not to be as low as in other types of weather, but they are equally effective in the formation of snow in the higher-altitude areas of this sector (Sª Cabrera, Culebra, Peña de Francia, etc.). However, the infrequency of those affecting the provinces of León, Zamora, and Salamanca at the same time (27.4%) is striking. The usual situation is that when it snows in Zamora (Sanabria), it also snows in León (41.4%), but they are really scarce in the most southwestern province.

The CNCyL has informed us of a precise scheme in the distribution of snowfall in Castilla y León, which is closely linked to the dynamics of each type of weather, but also to the morphological configuration of the region. Along with the atmospheric situations capable of causing generalized snowfall throughout it (or except the interior), there are others located in certain sectors of it, particularly peripheral and closely related to the presence of mountain systems, with the northwestern sector standing out above all the rest.

4 Discussion of the results

The topic developed is considered of interest within climate studies as it is not normally dealt with for such a long period of time. Its historical approach, obtained from the treatment of press information and its subsequent validation with atmospheric dynamics, has allowed a good characterization of the behavior of snowfall in the region. From the first moment, the study has not attempted to interpret the snowfalls from the information of a few observatories with long series, but to understand its behavior in the whole of Castilla y León, the number of situations and dynamics that affect it year after year, and its spatial differentiation when it occurs in each of its provinces and by sectors (mountain ranges, plains). All this has been obtained from the data collected in the press, which is shown as another valid source of information when it does not exist from a meteorological point of view or this is deficient.

In this sense, the completion of the CNCyL (first to date) has turned out to be a primary source that has revealed the importance of historical studies in climate research. It is one of the main tools when it comes to learning about the number, intensity, duration, and frequency of the events that have occurred. All of them are fundamental parameters when it comes to analyzing the hazardousness of this climate risk.

Its preparation, although tedious and long due to the large number of newspapers consulted, has generated a broad, detailed, and solid database, which will always allow for it to be completed and serve as a basis for other studies. Its daily information, aside from giving the exact dates of its production, allows knowing the snowfall intensity, having texts and real images of the events that occurred, the specific allusions to the affected spaces, as well as the associated consequences caused. Its structure organized into 13 fields and several indicators has allowed filtering according to various criteria and conditions to reach an optimal characterization of them.

The intrinsic subjectivity of the root source and the lower depth of treatment in the first years of the period analyzed were the reasons that led to relating the different episodes with their dynamic causes and their thermopluviometric values. The identification of each episode, with its date and duration, rests on the recognition of the different types of weather that produce them. This method contributes to qualify the importance and magnitude of snowfall and what they represent in the global atmospheric computation and to propose a typology according to different intensity thresholds and their spatial behavior.

On the other hand, the unequal degree of intensity with which they manifest has allowed us to relate those of a more intense nature to situations of cold waves, establishing a series of climatic assessments in this regard.

The methodology followed and the treatment of the information are likely to be applied to other territorial areas and even to other meteorological variables (storms, stability situations, winds, heavy rains, etc.) with the consequent adjustments to each one of them.

5 Conclusions

In Castilla y León, the snow is a common and remarkable meteor of its climate for at least 6 months of each year, although with a heterogeneous behavior and distribution in its different provinces. The relief conditions its presence, sometimes more than the atmospheric dynamics itself.

The CNCyL developed has made it possible to detect and analyze, in addition to the number of days of snow, how these are grouped in different episodes of snowfall. These have been identified from the synoptic analysis of the different types of weather that individualize them. This process has been able to know the behavior of snowfall from the study of both the number of episodes and snow days.

The information collected by this procedure has made it possible to discover the differences in intensity, duration, frequency, and trends shown by snowfall, as well as the contrasts in their distribution and effects. The 814 episodes identified in the 43 years of study (1979–2021) allow us to conclude the following considerations:

- The snowfall of greater severity is the least frequent, but the more intense (very deep dynamics), the greater its spatial distribution area, often affecting not only the regional territory but also a large part of the Iberian Peninsula and other European territories. Intensity is therefore a nonspecific character of the region.
- When they are of small amount (occasional and/or weak snowfalls), these affect few provinces and do not occur in the interior. In addition, they are more common in the equinoctial seasons, especially in autumn, and are usually brief situations, with duration of 1–2 days.
- Generalized snowfall episodes, affecting at least more than six provinces at the same time (54.4% of the total), are much more frequent than the more localized ones, which only occur in three provinces or less (21.1%).
- By mountains, it is in the Cantabrian MR where they are most frequent and intense, followed by those of the central-eastern sector of the Central MR (Sª de Gredos, Guadarrama, and Somosierra) and, finally, those of the Iberian MR and the easternmost Cantabrian (Burgos Mountains).
- There is also a close relationship between the intensity of the event and its duration, mainly in the shortest and longest episodes. In general, the higher the intensity and the worse the consequences, the longer the event duration.
- The duration of each episode is linked to that of each type of weather, that is why situations of 2–3 days are predominant (62.9%). It is not very frequent for the same type of weather to produce snowfalls for 6 or more days (3.1%); on the other hand, snowfalls lasting one single day (18.9%) are more important.
- Irregularity is perhaps the word that best qualifies them, and this is from different points of view. The year-on-year irregularity is responsible for the fact that the maximum in episodes (≥ 30/year) having been reached on three different occasions more than 30 years apart (1986, 2018, and 2019) and being very recent when the record of the period has been reached. Something similar happens with the maximum number of snow days (> 80/year), having now been reached on four occasions (1984, 1985, 1986, and 2018). Logically, this is linked to the way the atmospheric dynamics are produced. Irregularity also manifests itself throughout the year, since the arrival of the first snows always costs more than the dismissal of the last ones. There is irregularity in the spatial distribution, in the intensity, duration, and frequency and, above all, in the temporal evolution.
- Several individualized stages or series are identified every 12 years. From 1979 to 1990, snowfalls were very important. All years between 1991 and 2002 were below the average number of snow days (50.5 days/year), and only 1 year was above the average number of episodes (18.9 episodes/year). Again from 2003 to 2014, its production was increased, although not as much as in series 1. Since then and until today, very unequal years have alternated, with irregularity being the normal. We will have to wait to see if this trend continues or is modified.
- In the calculation of the anomalies, in both the number of episodes and the number of snow days, a downward trend is appreciated throughout the period; however, they are not significant according to the Kendall and Spearman tests. The same does not happen if the anomalies of the last 29 years are considered, with a markedly upward trend appreciated and a confidence level of 100% in both tests.
- Nevertheless in these four decades, the number of episodes is more in line with the average values than the number of snow days, which shows a more palpable reduction in its evolution. It can be said that from the dynamic point of view, the same favorable atmospheric conditions continue to exist, but these translate into a somewhat lower amount of snowfall.
- By months, there is a slight increase in the relative weight of snowfall from January to March, a decrease in December and April, and a significant rise in November.
- Regarding their origin, the great diversity of atmospheric situations capable of motivating them according to origin and form of penetration of the air masses is appreciated (30 types of weather possible). Most of them are linked to N–S circulations of arctic and polar troughs (53.7% of the total), although individually, by the type of weather, it is the retrograde cP shear line, the mA troughs, and the mP centered ones over Spain that originate them most of the times, followed, in importance, by the mA cold drops and cP torn from them.

The method applied to the study of snowfalls has made it possible to conclude how diverse and irregular the snowfalls of recent decades are, possibly associated with climate change in which we are inserted, and in which uncertainty is one of its most defining features.

acquisition, M.O. and C.M. All authors read and approved the final manuscript.

Data availability The data is publicly available in the newspaper archives of the consulted sources, also in the State Meteorological Agency of Spain (AEMET) and in https://wetterzentrale.de. The datasets generated in the CNCyL and analyzed during the current study are not publicly available, because of the constant update of a personal database and, on which, another research is based, but are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent for publication All authors consent for publication.

Conflict of interest The authors declare no competing interests.

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