Vol. 78: 41–50, 2019
https://doi.org/10.3354/cr01557

CLIMATE RESEARCH
Clim Res

Published online May 16

Reconstruction and analysis of 1900–2017 snowfall events on the southeast coast of Spain

Emilio Martínez-Ibarra[1], José Luis Serrano-Montes[2], Jonatan Arias-García[1]

[1]Departamento de Análisis Geográfico Regional y Geografía Física, and
[2]Departamento de Geogafía Humana, Universidad de Granada, 1807 Granada, Spain

ABSTRACT: In this paper, we have reconstructed and analysed snowfall events on the coast of the natural region of south-eastern Iberia (Spain) over the period 1900 to 2017. Due to the lack of continuous reliable meteorological information, we supplemented our analysis of official sources by consulting the daily newspapers for the days when snow was most likely. We selected 3 cities which are spatially representative for the study area as a whole and for which there is press coverage throughout this period. In north-south order, these cities were Alicante, Cartagena and Almería. Our analysis of official meteorological information and of press reports enabled us to broaden and improve 3 series of snowfall events in the study area. We then used these series to characterize the temporal and spatial distribution of the snowfalls and the synoptic pattern associated with them.

KEY WORDS: Mediterranean · Natural region of SE Iberian Peninsula · Reconstruction of snowfall events · Climate analysis

1. INTRODUCTION

Global warming has been affecting the climate since the mid-19th century (Stocker et al. 2013). Within this scenario, the Mediterranean region has a very low degree of resilience or adaptability to climate change (Giorgi et al. 2001). The meteorological data for this area show notable increases in temperature and falling precipitation levels (Stocker et al. 2013, Seager et al. 2014), which means that in the near future the Mediterranean region seems likely to become one of the planet's main 'hot-spots' (Giorgi 2006).

In the particular case of Spain, global warming in recent decades has been very striking, with increases in temperature that are 50% above the average for the Northern Hemisphere (Vicente-Serrano et al. 2017). Since the mid-20th century, this change has been especially notable in the spring and summer months (del Río et al. 2012), above all in southern Spain (González-Hidalgo et al. 2015), and has manifested itself in an increase in the number of hot spells and heatwaves (El Kenawy et al. 2011, Gómez-Martín et al. 2014). At the same time, for the Iberian Peninsula as a whole, the number of cold nights (10^{th} percentile of daily minimum temperature) fell by ~1.3% per decade over the period 1950 to 2006 (Rodríguez-Puebla et al. 2010). Between 1929 and 2005, there was also a downward trend in the number of days of frost in the Peninsula as a whole of ~0.6 d per decade, a dynamic that has accentuated since 1965 (Fernández-Montes & Rodrigo 2012).

Negative precipitation trends have also been detected since the mid-20th century (González-Hidalgo et al. 2011, del Río et al. 2011): a significant decrease of ~18.7 mm per decade was observed between 1961 and 2011 (Vicente-Serrano et al. 2014). There has also been an increase in the temporal concentration of rainfall during the rainy season over the period 1946 to 2005 (de Luis et al. 2011).

Within the field of climate change research, the analysis of trends has attracted a great deal of inter-

*Corresponding author: emibarra@ugr.es

est in the last 2 decades, focusing above all on temperature and precipitation (Pons et al. 2010). However, little research has been done on snowfall (Pons et al. 2010, Vicente-Serrano et al. 2017). This is normally attributed to a lack of data (Enzi et al. 2014) or to the unreliability of the available information (Pons et al. 2010).

In Spain, for example, the few research papers on snowfall trends are focused on mountain regions. In a study of northern Spain, Pons et al. (2010) noted a drop of ~50% in the number of days with snowfall from the mid-1970s to 2001. There was also a significant decrease in the number of snowy days recorded at observatories in the Meseta Norte from 1960 to 2011 (Merino et al. 2014), while in the southern mountain range of Sierra Nevada, the number of days with snowfall fell by 0.2837 d yr^{-1} over the period 1961 to 2000 (Pérez-Palazón et al. 2018). No noteworthy changes were observed in the Central and Western Pyrenees over the period 1961 to 2013, although in this case the trends were influenced by the time period chosen by the authors (Buisan et al. 2015).

There have been even fewer studies of snowfall on the Mediterranean coast, and we have found only 3 publications on this topic in peer-reviewed scientific journals: Dauphiné (1972), Houssos et al. (2007) and Enzi et al. (2014).

Dauphiné (1972) analysed snowfall on the coast of south-east France, including findings from coastal observatories for the period 1951 to 1970. The author noted the high variability of this phenomenon in terms of both space and time. In fact, >50% of the episodes of snowfall recorded in this paper were concentrated in just 4 winters (1951–1952, 1955–1956, 1962–1963 and 1969–1970). The most important event in this area was the cold spell of 1956, when snowfalls of ~50 cm were recorded on the Côte d'Azur.

In research on snowfall in the Eastern Mediterranean, Houssos et al. (2007) discovered apparently contradictory results in Athens (Greece) over the period 1958 to 2001. Until 1982, snow was an annual event in the Greek capital. Since then, although snow did not fall every year, the frequency and duration of the events increased. However, the authors associated these changes with 3 particularly severe winters: 1982–1983, 1986–1987 and 1991–1992.

Enzi et al. (2014) reconstructed and analysed series of unusually strong snowfalls (which affected large areas including the coast) on the Italian Peninsula since 1709. Although they were unable to detect clear trends, they discovered the existence of 100 and 60 yr cycles. The latter were linked to natural phenomena such as the Atlantic Multidecadal Oscillation and the winter North Atlantic Oscillation.

In the specific case of Spain's Mediterranean coast, no studies of snowfall have been published in international journals, although a few articles and reports have been published as technical reports or in non-peer-reviewed journals.

For example, research on the city of Barcelona highlighted the number of episodes of snowfall per year, their monthly distribution and a description (covering the ground or not and thickness) over the period 1867 to 1966 (Tomás-Quevedo 1976). The author observed an upward trend in the number of annual snowfall events, although this finding was influenced by the concentration of these events in a relatively small number of winters at the end of the studied period.

Other interesting research was conducted by Salamanca-Salamanca (2012a). This author analysed snowfall events using the data obtained by the network of observatories on the island of Mallorca between 1980 and 2010. While the tendencies observed at the Porto Pi observatory in Palma de Mallorca were not conclusive, an upward trend was observed at the airport meteorological observatory.

The study of snowfall on the coast of the natural region of south-eastern Iberia, which runs from Benidorm (Alicante) to Adra (Almería) (Gil-Olcina 2004), is of interest for various reasons: (1) no research on this subject in this region or indeed other parts of the Spanish coast has ever been published in peer-reviewed journals; (2) snowfall is highly exceptional in the study area (Capel-Molina 2000), which is hardly surprising given that it is one of the hottest and driest parts of Europe (Steinhauser 1970); (3) there is no reliable database for studying the phenomenon in this region, a gap that this paper aspires to fill; and (4) the study of extraordinary climate events of this kind over long periods is valuable in terms of the contribution it makes to the analysis of climate trends and climate change.

2. DATA AND METHODS

We started to assemble the database of snowfall events along the SE Coast of Iberia using the digital database produced by the Spanish National Meteorological Agency (AEMET) on the hydrometeor snow (Fig. 1). To broaden and improve the official database for the study area, we requested information for a larger area around on the natural region of SE Iberia (Fig. 2).

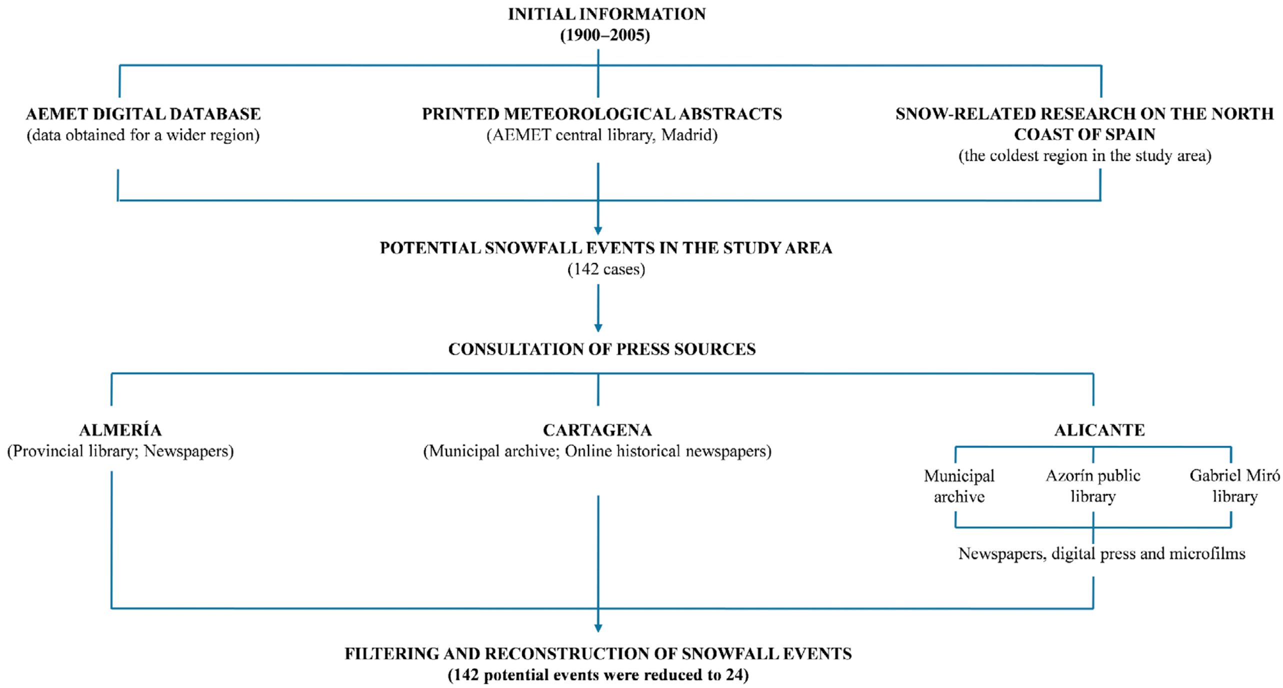

Fig. 1. Procedure followed in the detection of snowfall events

This information was completed with the analysis of meteorological summaries from books stored at the AEMET Central Library in Madrid. The following sources were consulted: (1) *Resumen de las observaciones meteorológicas* (Summary of Meteorological Observations) published annually from 1900 to 1950; (2) *Boletín Mensual Climatológico* (Monthly Climatological Bulletin) published from 1950 to 1980, which replaced the first source; and (3) *Anuario Meteorológico* (Meteorological Yearbook) which replaced the Monthly Bulletin in 1980 and which we consulted for the period up to 2005. We also collected information from articles on snowfall in coastal cities of northern Spain, namely Tomás-Quevedo (1976), García-de-Pedraza & Gozalo-de-Andrés (1988), Gozalo (2004) and Puente-Fernández (2006a,b).

On the basis of all this meteorological information (in both digital and document format), we obtained the most likely dates on which snow might have fallen in the study area over the period 1900 to 2005. From this search, we obtained a list of 142 events. We then consulted the press to try to identify on which of these days it actually snowed. After discarding all the possible episodes in which there were no references in the press to snow, we identified a total of 24 occasions of snowfall over this period. From 2005 onwards, snowfall events were recorded in the online press at the time they happened.

For our consultation of press reports, we selected the cities of Almería, Cartagena and Alicante (Fig. 2), as these were the only cities in the region with press coverage for the whole study period (1900–2017).

In Almería we analysed the newspapers stored in the archives at the Almeria Provincial Library (Biblioteca Provincial de Almería Francisco Villaespesa). We consulted the following newspapers for the different periods: *La Crónica Meridional: diario liberal independiente y de los intereses generales* (1902–1935); *El Popular: diario republicano* (1910–1914); *La Independencia: diario de noticias* (1910–1935); *Diario de Almería: periódico independiente de la mañana* (1926–1933); *Heraldo de Almería: diario político* (1934–1935); *Yugo* (1945–1967) and *La Voz de Almería* (1980–2005).

In the case of Cartagena we examined the digitalized copies of the newspapers held at the city's Municipal Archives. We consulted: *El Eco de Cartagena* (1902–1935); *El Porvenir* (1902–1933); *El Baluarte* (1910); *La Razón* (1926); *La República* (1933); *Cartagena Nueva: diario defensor de los intereses generales de Cartagena* (1926–1935); *La Tierra* (1920–1935); *El Noticiero: diario independiente de la tarde* (1935–1971) and *La Verdad de Murcia* (1954–2005). For the last event, in 2017, we consulted the online edition of *La Opinión de Murcia*.

In Alicante we visited the Municipal Archives and two libraries: Biblioteca Pública Azorín and Biblioteca Gabriel Miró. There we consulted the following newspapers, either in the original paper format or on microfilm: *La Correspondencia: diario de noticias*

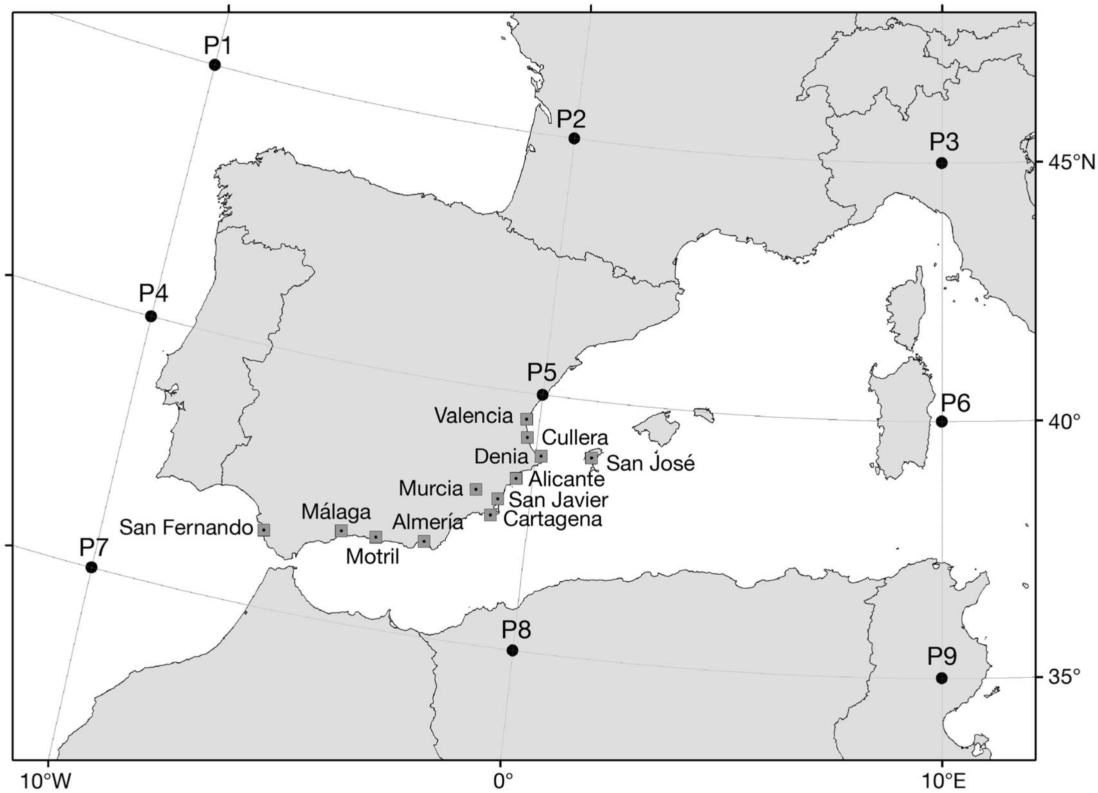

Fig. 2. Selected meteorological observatories (▪) and pressure grip points (P1 to P9)

(1901); *La Correspondencia: diario noticiero* (1902–1910); *La Voz de Alicante* (1906–1917); *Heraldo de Alicante* (1910); *El periódico para todos* (1914); La *Unión Democrática* (1914–1917); *El correo: diario de la tarde* (1917); *Diario de Alicante* (1917–1935); *El luchador: diario republicano* (1917–1938); *Nuestra Bandera* (1938) and *La Gaceta de Alicante* (1940–1941). For the period 1942–2005 we consulted the *Diario Información*, which is available in digital format. For the last instance of snowfall, in 2017, we analysed this newspaper's online edition.

In order to reconstruct the different series of snowfall events, we compared the data obtained by meteorological instruments with those obtained from documentary sources, as did Enzi et al (2014) in their study, which included data from coastal observatories. As in other research in which the press is used as a source of information for climate studies, we used the contents analysis technique (e.g. Tänzler et al. 2008, Martínez-Ibarra 2015). We applied both the intensive and extensive research model (Barriendos et al. 2002), in that some specific events were well-known from the meteorological information while others for which we had no meteorological references were uncovered by searching in press reports, which often compare the event they are reporting with a similar previous episode (an example is the snowfall of 1939 about which we had no other references).

We also considered the approaches used by previous authors to construct significant climate series from documentary sources. We focused particularly on the quality criteria and the advice offered by Alexandre (1987), and the selection criteria proposed by Le Roy (1967), in order to determine information capable of generating climate data series and analysing them. Given the simple nature of the information obtained, we decided to apply equally simple quantitative methods.

In our analysis we distinguished between snowfall in which the snow did not settle and other episodes in which it settled on some kind of surface such as roofs, cars, trees, gardens and in the best cases, on the ground itself. The reconstruction of the climate series for these two types of snowfall enabled us to make a spatial and temporal characterization of the episodes of snowfall in the study area. Following Dauphiné (1972), Houssos et al. (2007) and Salamanca-Salamanca (2012a), we first analysed the monthly and interannual distribution of snowfall events in a similar way to previous researchers of snowfall along the Mediterranean coast, then we studied the relationship between snowfall events and atmospheric conditions. The study was based on the Jenkinson–Collison objective classification of weather types as proposed for the Iberian Peninsula by Spellman (2000). Following Llop-Garau & Alomar-Garau (2012) we decided to take into consideration a 9-grid point, displaced 5° towards the east relatively to the location considered by Spellman (2000), because the area we were studying was the southeastern quadrant of the Iberian Peninsula. The domain considered is 35°–45° N and 10° W–10° E (Fig. 2). The mathematical formula and criteria used to define the type of weather are reported in Box 1. Atmospheric pressure and temperature fields at 850 hPa come from the NOAA-CIRES 20th Century Reanalysis and NCEP/ NCAR reanalysis (https://www.esrl.noaa.gov/psd/data/gridded/).

3. RESULTS

3.1. Spatial and temporal description of the snowfall events

Snow is an exceptional phenomenon on the coast of the region we studied and has always been a widely commented and considered memorable event for local people. In fact, in the study area as a whole, it has only snowed 25 times in the 118 yr we studied (1900 to 2017) (see the Supplement at www.int-res.com/articles/suppl/c078p041_supp.pdf). The frequency of snowfall for the natural region of south-east Iberia is 0.21 d yr^{-1}, approximately 1 episode every 5 yr. If we are more restrictive and only consider the most important events, i.e. those in which the snow settled on a surface in any of the areas we were considering (15 episodes), the frequency falls to 0.13 yr^{-1} or about once every 8 yr.

In spatial terms, the frequency was similar throughout the region, with 14 cases on the coast of Alicante and 13 on the coast of Murcia and Almeria. Clearer differences can be observed if we only consider the most important episodes, in which the snow settled on a surface of some kind. In this case, there was a much higher frequency of episodes in Alicante and Cartagena with 9 in both areas, compared to just 5 events on the coast of Almería. Latitude appears to be the crucial factor in these differences.

Regarding the seasonal distribution, the 25 events occurred between 17 December and 1 April. Most of them occurred in winter (20 out of 25 took place in December, January or February). The monthly ranking order was topped by January with 12 episodes, followed by February with 5. Only 5 events occurred in the spring: 3 in March, and 2 on 1 April.

Considering the 15 most important episodes, they show a similar monthly distribution, although January was slightly less dominant (January 6 cases, February 3 and December 3).

Box 1. Analytical expressions and algorithms for determining the weather types proposed by Jenkinson and Collison (Llop-Garau & Alomar-Garau 2012, Grimalt et al. 2013). *P*: Average pressure on the surface (hPa); *W*: zonal component of the geostrophic surface wind, calculated as a gradient of pressure between 35° and 45° N; *S*: meridional component of the geostrophic surface wind, calculated as a gradient of pressure between 10° W and 10° E; D: wind direction (°azimuth); *F*: velocity of the wind in m s^{-1}; ZW: zonal component of vorticity; ZS: meridional component of vorticity; *Z*: total vorticity. Source: Llop-Garau & Alomar-Garau (2012), Grimalt et al. (2013)

Analytical expressions

$$p = 0.0625[(P1 + P3 + P7 + P9) + 2(P2 + P4 + P6 + P8) + 4P5]$$
$$W = 0.25[(P7 + 2P8 + P9) - (P1 + 2P2 + P3)]$$
$$S = 0.653[0.25(P3 + 2P6 + P9) - 0.25(P1 + 2P4 + P7)]$$
$$D = \text{arctg}\ (W/S)$$
$$F = (W^2 + S^2)^{1/2}$$
$$ZW = 1.056[(P7 + 2P8 + P9) - (P4 + 2P5 + P6)] - 0.951[(P4 + 2P5 + P6) - (P1 + 2P2 + P3)]$$
$$ZS = 1.305[0.25(P3 + 2P6 + P9) - 0.25(P2 + 2P5 + P8)\ 0.25(P2 + 2P5 + P8) + 0.25(P1 + 2P4 + P7)]$$
$$Z = ZW + ZS$$

Algorithms

1. The direction of flow is given by D (8-direction wind rose), taking into account the signs of W and of S
2. If $|Z| < F$: An advective or *pure directional* type, defined according to D (N, NE, E, SE, S SW, W and NW)
3. If $|Z| > 2F$: Cyclonic type (C) if $|Z| > 0$, or anticyclonic (A) if $|Z| < 0$
4. If $F < |Z| < 2F$: Hybrid type, according to the sign of *Z* (algorithm 3) and the direction of flow (algorithm 1) (CN, CNE, CE, CSE, CS, CSW, CW, CNW, AN, ANE, AE, ASE, AS, ASW, AW and ANW)
5. If $F < 6$ and $|Z| < 6$: Indeterminate type (U)

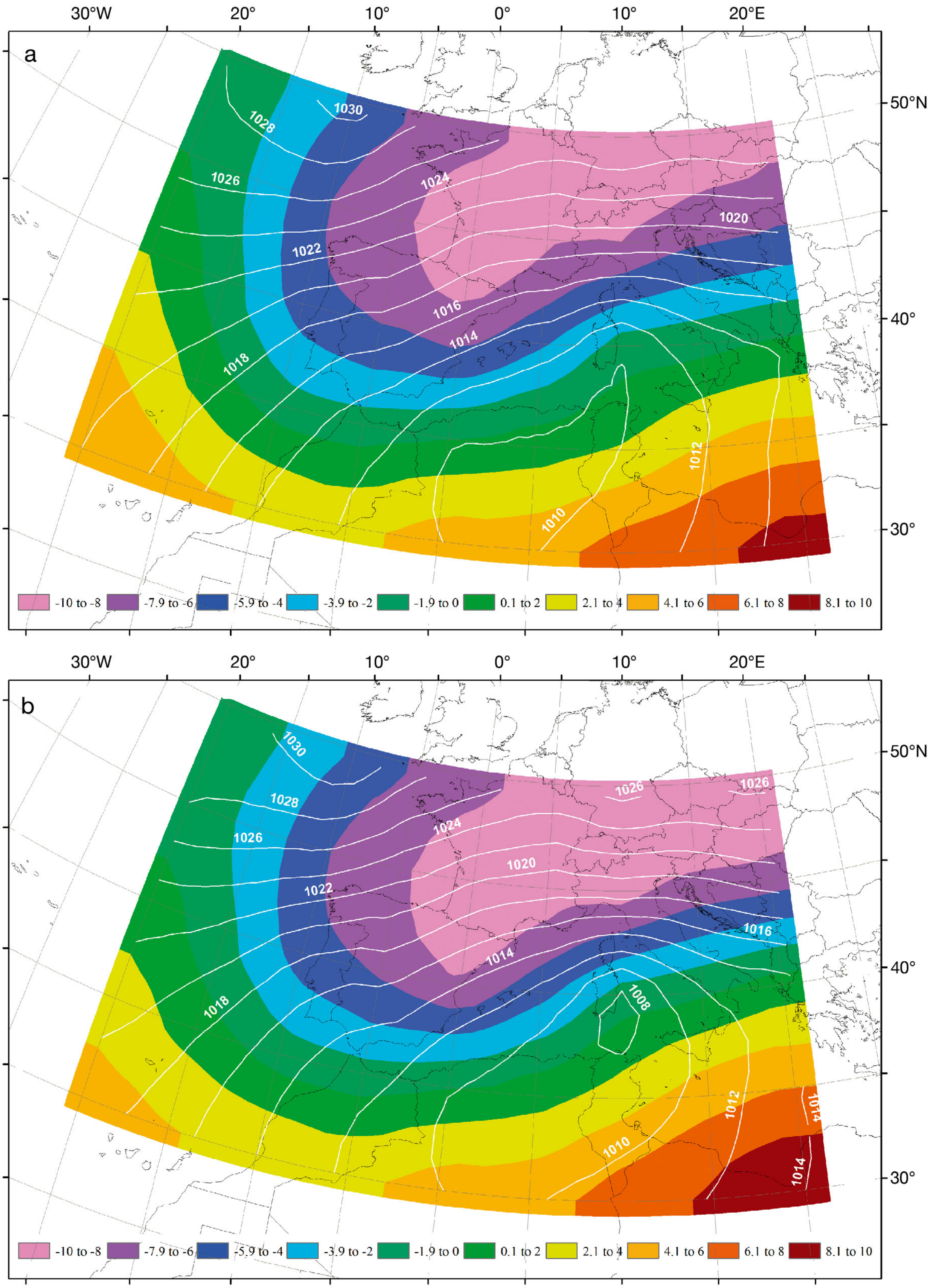

Fig. 3. Mean values of surface pressure and temperature at 850 hPa level (°C) for the entire study area for (a) all snowfall events and (b) events in which the snow settled. Source: NOAA-CIRES 20th Century Reanalysis and NCEP/NCAR reanalysis (https://www.esrl.noaa.gov/psd/data/gridded/)

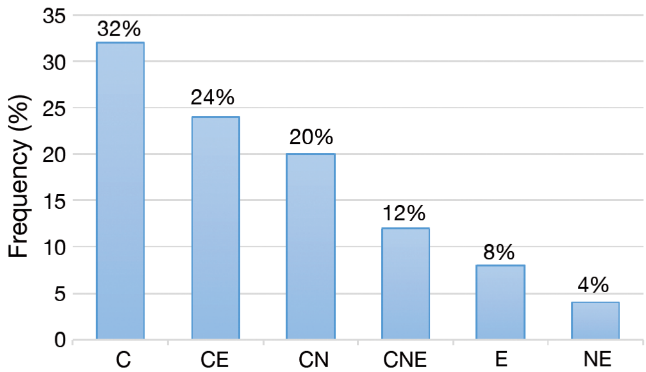

Fig. 4. Relative frequencies of the weather types associated with snowfall events on the coast of the natural region of SE Iberia (1900–2017)

There was a similar monthly distribution in all 3 areas, with the maximum in January (6 cases in all 3), followed by February and March. The only difference was in Almería in which no events occurred in March.

If we look at the whole period between 1900 and 2017, it is clear that snow is a rare phenomenon on the SE coast of the Iberian Peninsula, and therefore occurs very irregularly. The period with most cases was between 1910 and 1940, during which there were 10 cases of snowfall, 40 % of the 25 recorded episodes. The 1930s was the most important decade when the snow settled in 4 occasions out of 5 events, i.e. 27 % of the total of 15 detected.

As regards the most intense episodes (in which the snow settled), it is important to highlight that there were none between 1980 and 2004. There were no episodes of this kind in the first decade of the 20th century either. All the other decades had at least one snowfall of this kind, occurring most frequently in the 1930s (4 events) and in the 1910s, 1950s and 1960s with 2 events each. Since then, there have been no decades with 2 such episodes. This coincides with the more pronounced warming trend detected in the Northern Hemisphere, according to data about annual temperature anomalies (base period 1981–2010), offered by the NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series (https://www.ncdc.noaa.gov/cag/global/time-series/nhem/land_ocean/ytd/12/1900-2018).

As regards the interannual distribution by areas, in Almeria, we observed a concentration of these events between the 1930s and 1960s, after which there were none until 2005. This can also be observed on the coast of Alicante, although the long period with no events with settled snow began a decade later in the 1970s and continued until 2005. On the coast of Murcia, rather than a change in the trend in the 1980s and 1990s, there is a gap, given that the phenomenon reappears in the first decades of the 21st century.

In quantitative terms, we noticed a negative trend in the number of episodes on the coast of SE Iberia (slope of the sine of −0.143), although it was not significant at 95 % (Mann-Kendall test), perhaps due to the small size of the sample group (n = 25).

3.2. Synoptic characterization

The temperatures in part of the area we analysed were around −5°C at 850 hPa (Fig. 3a,b), and in the most extreme cases in the north of the region, the values were around −10°C. The average pressure at the surface for the 25 events was characterized by a mechanism consisting of a powerful anticyclone to

Table 1. Climatology of snowfall events on the Mediterranean coast (studies ordered from NE to SW)

Study area	Period	Snow days	Frequency per year	First month	Last month	Higher frequency	Source
Atenas	1958–2001	96	2.18	November	March	February	Houssos et al. (2007)
Barcelona	1867–1966	94	0.94	December	April	February	Tomás-Quevedo (1976)
Génova	1951–2001	177	3.47	November	April	January	Del Ponte (2003a,b)
Coast of Alicante (central and southern)	1900–2017	14[a]	0.12	December	March	January	Present study
Coast of Murcia	1900–2017	13[a]	0.11	December	March	January	Present study
Coast of Almería	1900–2017	13[a]	0.11	December	April	January	Present study
Coast of Ibiza	1900–2005	32[a]	0.30	December	March	February	Authors' database
SE coast of France	1950–1970	–	–	December	March	February	Dauphiné (1972)
Coast of Mallorca	1980–2010	13 to 41	0.4 to 1.3	November	March	January (February)	Salamanca-Salamanca (2012a)

[a]Event days

the north of the Iberian Peninsula combined with a low-pressure area in the western Mediterranean to the east of the Iberian Peninsula (Fig. 3a). This creates a powerful dipole that is more pronounced in those cases when the snow settled (Fig. 3b). A flow from inland Europe develops between the 2 poles, with an elongated patch of very cold air at 850 hPa (values below −8°C), which extends from this area towards the Iberian Peninsula (Fig. 3a,b).

As regards the weather types (Jenkinson and Collison, see Box 1) associated with the 25 episodes of snowfall detected in the whole region, it is important to make clear that only 6 types were identified: pure cyclonics (C) with 8 cases; cyclonics with NE winds (CNE) with 6 cases; advective flows from the northeast (NE) with 5 cases; cyclonics with east winds (CE) with 3 cases; advective flows from the east (E) with 2 cases; and cyclonics from the north (CN) with 1 case (Fig. 4). The same weather types, except for CN, were also observed in the most important snowfall events (when the snow covered some kind of surface). The most frequent weather type was again pure cyclonics (C), although in a smaller proportion (7 out of 15).

By areas, and considering all 25 events in both Almeria and Alicante, the dominant synoptic weather type was C (38.5 and 50% of the cases respectively). In Murcia, however, the dominant type was CNE (with 30.8% of the cases). Another interesting finding was that the C weather type was proportionally more important in Alicante than in the other areas.

If we restrict the analysis to the most important episodes (those in which the snow settled), we noted that C was important in all cases (60% in Almería, 33.3% in Murcia and 55.6% in Alicante). However, a greater diversity of weather types was observed in Murcia.

4. DISCUSSION

Even though this is an important subject, there is no complete, official, reliable database about snowfall events on the coast of SE Iberia. This is why, during the course of this research, we also had to consult documentary sources, in order to obtain climate proxies from newspaper reports. As in previous research (Brazdil et al. 2005), we found that the press offers a direct, climatically relevant documentary source with high temporal resolution (Gallego et al. 2007), which enables the creation or completion of climate databases. This method has been used by various previous authors (e.g. Ruíz-Urrestarazu 1998, Olcina-Cantos & Moltó-Mantero 1999, Moltó-Mantero 2000, Barriendos et al. 2002, Brunet et al. 2006, Llasat et al. 2009). It is important to remember that the information obtained in this way is produced by people who are not experts in atmospheric sciences and is therefore more subjective (Gallego et al. 2008).

Snow has always been an exceptional phenomenon on the coast of SE Iberia. For the study area as a whole over the 118 yr period we analysed (1900–2017), it snowed only 25 times, with an annual frequency of 0.21 yr^{-1}. These are the lowest levels recorded on the northern coast of the Mediterranean basin, and are even more striking if the results are taken individually for the different areas we analysed (Table 1). This highlights the climatic differences between different parts of the northern coast of the Mediterranean basin. In general, the number of snowfall events seems to vary according to the latitude of the different coastal areas studied. Another important factor is exposure to cold air flows from the continent. This is more likely in easterly locations and in places in which the flows from the north are full of moisture. In fact, even within the small region we analysed, these differences are noticeable in the most important events. The 2 most northerly coastal areas (in the centre and south of the province of Alicante as well as the coast of Murcia) had 9 events in which the snow settled, compared to only 5 in Almería, the furthest to the south.

With regard to the seasonal distribution of the snowfall events, they occurred in a period from December to April. The highest number was in January. This seasonal pattern is very similar to that for the rest of the northern coast of the Mediterranean Sea, although in some places, February is the month with most cases. These snowfalls were a predominantly winter event in that 20 of 25 events were concentrated between December and February. The others took place in early spring (as is the case in the rest of the north coast of the Mediterranean).

Regarding a trend in the number of snowfall events grouped by decades, no conclusive pattern could be observed. It is important to emphasize again that snow is a very unusual, and therefore very irregular, phenomenon. This means that our preliminary results match those obtained in other coastal areas of the Mediterranean in which no conclusive trends were observed (e.g. Dauphiné 1972, Houssos et al. 2007, Enzi et al. 2014, Salamanca-Salamanca 2012a).

Regarding the atmospheric conditions leading to snowfall, the low troposphere often suffers very powerful invasions of cold air with temperatures at

850 hPa of around −5°C or even lower, similar to those recorded during snowfall events in Palma de Mallorca (Salamanca-Salamanca et al. 2012b), Athens (Houssos et al. 2007), the Côte d'Azur and the island of Corsica (Goulet 2017).

On the surface, the atmospheric context was dominated by powerful dipoles: very intense winter anticyclones in the north of the Iberian Peninsula, with average values in their centre of ~1030 hPa, and low pressures from the Mediterranean to the south. An altered flow of cold air from inland Europe is channelled between the 2 poles, as happened in Athens (Houssos et al. 2007). This situation was very similar to that described in the snowfall events in Barcelona (Tomás-Quevedo 1976) and in the most extreme cases of snowfall in Italy and its coastline (Enzi et al. 2014).

As regards the weather types, the predominance of pure cyclonics (C) is particularly noticeable with 8 cases, together with the cyclonics with NE winds (CNE) with 6 cases. This distribution of weather types is similar to that detected in Mallorca in Spain, for the most intense outbreaks of cold air (Salamanca-Salamanca et al. 2012b) and during the appearance of generalized snowfalls affecting the whole island (Salamanca-Salamanca 2012a), although in this case, the type C weather type was more dominant.

5. CONCLUSIONS

The results of this research show that snow is a very unusual phenomenon on the coast of the natural region of SE Iberia and occurs very irregularly. In the 118 yr period analysed, we found only 25 instances of snowfall. Of these instances, the snow settled on the ground or some other surface on only 15 occasions. The seasonal distribution shows that snow is mainly a winter event, with most of the events occurring in January, followed by spring with 5 events. We found no events during summer or autumn.

Regarding the large-scale atmospheric patterns favouring snowfall, the events are associated with the presence of an anti-cyclonic area over the British Isles and Scandinavia and a deep depression over the Western Mediterranean. The presence of these low Mediterranean pressures determined that the dominant weather types were C and CNE, with a frequency of occurrence of 32 and 24 %, respectively.

The long-term evolution of the phenomenon over the period 1900 to 2017 shows a decreasing trend, although not significant at the 95 %probability level. In the future, we intend to extend our analysis to the entire Mediterranean coast of Spain to obtain a larger number of events which, we hope, will allow us to confirm the existence or not of a significant decreasing trend.

Acknowlegement. This research was conducted with the support of the research group SEJ170 (Paisaje, Planificación Territorial y Desarrollo Local).

LITERATURE CITED

Alexandre P (1987) Le climat en Europe au moyen âge. Ecole des Hautes Etudes en Sciencies Sociales, París

Barriendos M, Martín-Vide J, Peña JC, Rodríguez R (2002) Dailymeteorological observations in Cádiz–San Fernando. Analysis of the documentary sources and the instrumental data content (1786–1996). Clim Change 53: 151–170

Brazdil R, Pfister C, Wanner H, von Storch H, Luterbacher J (2005) Historical climatology in Europe — the state of the art. Clim Change 70:363–430

Brunet M, Saladie O, Jones P, Sigro J and others (2006) The development of a new dataset of Spanish daily adjusted temperature series (sdats) (1850–2003). Int J Climatol 26: 1777–1802

Buisan ST, Saz MA, López-Moreno JI (2015) Spatial and temporal variability of winter snow and precipitation days in the western and central Spanish Pyrennes. Int J Climatol 35:259–274

Capel-Molina JJ (2000) La nieve y su distribución espacial en la Península Ibérica. Nimbus. Rev Climat Meteorol Paisaje 5-6:6–12

Dauphiné A (1972) Les chutes de neige sur le littoral méditerranéen du Sud-Est français. Méditerranée 11: 141–157

de Luis M, González-Hidalgo JC, Brunetti M, Longares LA (2011) Precipitation concentration changes in Spain 1946–2005. Nat Hazards Earth Syst Sci 11:1259–1265

Del Ponte S (2003a) Le nevicate a Genova del periodo: 1951–2001. Parte Prima 1951–1970. R L Met 8:1–5

Del Ponte S (2003b) Le nevicate a Genova del periodo: 1951–2001. Parte Seconda 1971–2001. R L Met 9:1–4

del Río S, Herrero L, Pinto-Gomes C, Penas A (2011) Spatial analysis of mean temperature trends in Spain over the period 1961–2006. Global Planet Change 78:65–75

del Río S, Cano-Ortiz A, Herrero L, Penas A (2012) Recent trends in mean maximum and minimum air temperatures over Spain (1961–2006). Theor Appl Climatol 109: 605–626

El Kenawy A, López-Moreno JI, Vicente-Serrano SM (2011) Recent trends in daily temperature extremes over northeastern Spain (1960–2006). Nat Hazards Earth Syst Sci 11:2583–2603

Enzi S, Bertolin C, Diodato N (2014) Snowfall time-series reconstruction in Italy over the last 300 years. Holocene 24:346–356

Fernández-Montes S, Rodrigo FS (2012) Trends in seasonal indices of daily temperature extremes in the Iberian Peninsula, 1929–2005. Int J Climatol 32:2320–2332

Gallego D, García-Herrera R, Calvo N, Ribera P (2007) A new meteorological record for Cadiz (Spain) 1806–1852: Implications for climatic reconstructions. Geophys Res

Lett 112:D12108
Gallego D, García-Herrera R, Prieto R, Peña-Ortiz C (2008) On the quality of climate proxies derived from newspaper reports-a case study. Clim Past 4:11–18
García-de-Pedraza L, Gozalo-de-Andrés C (1988) Nieve en Santander (1924–1987). Boletín Climatológico de Cantabria 1
Gil-Olcina A (2004) La región climática del sureste ibérico. In: Gil-Olcina A, Morales Gil A, Torres-Alfosea FJ (eds) Aridez, salinización y agricultura en el Sureste Ibérico. Fundación Ramón Areces, Madrid, p 13–35
Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33:1–4
Giorgi F, Whetton PW, Jones RG, Christensen JH and others (2001) Emerging patterns of simulated regional climatic changes for the 21st century due to anthropogenic forcings. Geophys Res Lett 28:3317–3320
Gómez-Martín MB, Armesto-López XA, Martínez-Ibarra E (2014) The Spanish tourist sector facing extreme climate events: a case study of domestic tourism in the heat wave of 2003. Int J Biometeorol 58:781–797
González-Hidalgo JC, Brunetti M, de Luis M (2011) A new tool for monthly precipitation analysis in Spain: MOPREDAS database (monthly precipitation trends December 1945–November 2005). Int J Climatol 31:715–731
González-Hidalgo JC, Peña-Angulo D, Brunetti M, Cortesi N (2015) MOTEDAS: a new monthly temperature database of Spanish continental land and the temperature trend between 1951–2010. Int J Climatol 35:4444–4463
Goulet L (2017) The ingredients of snow episodes over southeastern France. Newsl WGCEF 22:22–31
Gozalo C (2004) La nieve en Santander (1924–2003). Revista del Aficionado a la Meteorología (RAM) 18
Grimalt M, Tomás M, Alomar G (2013) Determination of the Jenkinson and Collison's weather types for the western Mediterranean basin over the 1948–2009 period. Temporal analysis. Atmosfera 26:75–94
Houssos EE, Lolis CJ, Bartzokas A (2007) The atmospheric conditions over europe and the mediterranean, favoring snow events in Athens, Greece. Adv Geosci 12:127–135
Le Roy E (1967) Historie du climat depuis l'an mil. Flammarion, París
Llasat MC, Llasat-Botija M, López L (2009) A press database on natural risks and its application in the study of floods in Northeastern Spain. Nat Hazards 9:2049–2061
Llop-Garau J, Alomar-Garau G (2012) Clasificación sinóptica automática de Jenkinson y Collison para los días de precipitación mayor o igual a 200 mm en la isla de Mallorca. Territ. Rev Dep Ciènc Terr 8:143–152
Martínez-Ibarra E (2015) Climate, water and tourism: causes and effects of droughts associated with urban development and tourism in Benidorm (Spain). Int J Biometeorol 59:487–501
Merino A, Fernández S, Hermida L, López L, Sánchez JL, García-Ortega E, Gascón E (2014) Snowfall in the Northwest Iberian Peninsula: synoptic circulation patterns and their Influence on snow day trends. ScientificWorldJournal 2014:480275
Moltó-Mantero E (2000) Grandes nevadas y percepción de las mismas en Alcoy. Investig Geogr 23:101–118
Olcina-Cantos J, Moltó-Mantero E (1999) La nevada de 1926. Repercusiones en la montaña alcoyana (Alicante). Nimbus 3:105–137
Pérez-Palazón MJ, Rafael-Pimentel R, Polo MJ (2018) Climate trends impact on the snowfall regime in Mediterranean mountain areas: future scenario assessment in Sierra Nevada (Spain). Water 10:720
Pons MR, San-Martín D, Herrera S, Gutiérrez JM (2010) Snow trends in Northern Spain: analysis and simulation with statistical downscaling methods. Int J Climatol 30: 1795–1806
Puente-Fernández JM (2006a) Olas de frío y temporales de nieve en Cantabría. ¿Un síntoma de cambio climático (parte VIII y final). Meteored 38
Puente-Fernández JM (2006b) La nieve en la ciudad de San Sebastián (1880-2006). Revista del Aficionado a la Meteorología (RAM) 45
Rodríguez-Puebla C, Encinas AH, García-Casado LA, Nieto S (2010) Trends in warm days and cold nights over the Iberian Peninsula: relationships to large-scale variables. Clim Change 100:667–684
Ruíz-Urrestarazu E (dir) (1998) El clima del País Vasco a través de la prensa. Euskal Herriko Klima prentsaren bidez. Grupo de Climatología de la Universidad del País Vasco. Servicio Vasco de Meteorología del Gobierno Vasco, Vitoria
Salamanca-Salamanca M (2012a) Aproximació a la innivació a Mallorca en època contemporània. MS thesis, Universitat de les Illes Balears, Palma de Mallorca
Salamanca-Salamanca M, Tomas-Burguera M, Grimalt M (2012b) Climatología de las irrupciones de aire frío en Mallorca durante el periodo 1980–2010 a partir de la temperatura a 850 hPa. Intensidad, distribución, temporal, tipos de tiempo asociados y su correlación con los días de nieve. In: Rodríguez-Puebla Concepción, Ceballos-Barbancho A, González-Reviriego N, Morán-Tejeda E, Hernández-Encinas A (eds) VIII Congreso Internacional AEC. Cambio climático. Extremos e impactos, Salamanca, p 623–630
Seager R, Liu H, Henderson N, Simpson I, Kelley C (2014) Causes of increasing aridification of the Mediterranean region in response to rising greenhouse gases. J Clim 27: 4655–4676
Spellman G (2000) The application of an objective weather-typing system to the Iberian peninsula. Weather 55: 375–385
Steinhauser F (ed) (1970) Atlas climático de Europa. UNESCO, Geneva
Stocker TF, Qin D, Plattner GK, Tignor M and others (eds) (2013) Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
Tänzler D, Feil M, Krömker D (2008) The challenge of validating vulnerability estimates: the option of media content analysis for identifying drought-related crises. Reg Environ Change 8:187–195
Tomás-Quevedo A (1976) La nieve en la ciudad condal. Miscellanea Barcinonensia 45:45–57
Vicente-Serrano SM, Azorín-Molina C, Sánchez-Lorenzo A, Morán-Tejeda E and others (2014) Temporal evolution of surface humidity in Spain: recent trends and possible physical mechanisms. Clim Dyn 42:2655–2674
Vicente-Serrano SM, Rodríguez-Camino E, Domínguez-Castro F, El Kenawy A, Azorín-Molina C (2017) An updated review on recent trends in observational surface atmospheric variables and their extremes over Spain. Cuad Invest Geogr 43:209–232

Editorial responsibility: Filippo Giorgi, Trieste, Italy

Submitted: September 14, 2018; Accepted: February 15, 2019
Proofs received from author(s): April 29, 2019