




# Climatology of waterspouts in the Balearic Islands (1989–2020)

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## Abstract

The article analyses the waterspouts recorded in the Balearic Islands (Spain) between 1989 and 2020. The extensive database used includes 234 waterspout events, which we analysed to establish their annual, monthly, seasonal and weekly spatial, temporal and hourly distribution. The autumn months account for 65% of all the waterspout events, with the highest frequency seen in September. They occur most frequently between 8:00 and 10:00 in the morning. We carried out a synoptic classification of the days on which waterspouts were recorded, observing that a synoptic trough pattern at 500 hPa over the Iberian Peninsula, which generates a south-westerly flow over the area under study, was the most conducive waterspout-creating condition (present in 25.3% of the events). Their relationship with the sea surface temperature was also analysed, revealing a higher frequency of waterspouts with higher temperature values, particularly between 23 and 26 °C. Finally, we examined the frequency of waterspouts in relation to the daily Western Mediterranean Oscillation regional teleconnection pattern index values, finding that waterspouts were more common on days when the indices were closer to 0.

**Keywords** Waterspouts · Temporal distribution · Synoptic classification · Sea surface temperature (SST) · Teleconnection pattern in the Western Mediterranean (WeMO)

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## 1 Introduction

Waterspouts (WS) are a common meteorological phenomenon in Mediterranean Sea regions (Keul et al. 2009), predominantly occurring during the summer and autumn (Sioutas and Keul 2007). Specifically, the Balearic Islands, along with Malta and Cyprus, is the region with the highest density of tornadoes and waterspouts in southern Europe (Antonescu et al. 2017), in addition to being the Spanish region with the highest incidence of these phenomena (Riesco et al. 2015). WS are defined as an intense columnar vortex that emerges from a funnel cloud of limited horizontal extension and reaches a water surface, the lower portion of which is made visible by sea spray (Golden 1971). Generally speaking, the vast majority of those occurring in Spain are weak and short-lived (Gayà 2015), categorised as being non-supercell WS (Wakimoto and Wilson 1989), which are also referred to as ‘fair-weather’ WS (Sioutas and Keul 2007), with an F0 scale (Fujita 1981). However, they should not be underestimated as they can pose a significant threat to shipping and other activities in the coastal environment (Keul et al. 2009; Devanas and Stefanova 2018). Occasionally, they make landfall and can intensify into damaging and even deadly tornadoes (Sioutas 2011), the strongest being related to the activity of some mesocyclones (Renko et al. 2016). In fact, a large proportion of the tornadoes that have occurred in the Balearic Islands were initially WS that moved inland (Gayà et al. 2001); therefore, the threat is real (Fig. 1).

For this reason, the climatic analysis of the WS phenomenon is of considerable interest, being essential for planning and developing policies around the issue of public weather warnings by the different civil protection organisations (Gayà 2005), and constructing a systematic and solid database that can be used to study their variations, among other reasons.

In recent decades, interest in monitoring and analysing tornadoes and WS has been growing among both the general population and scientific researchers. This is due, in part, to new mobile technologies that have enabled the reporting of many cases that would have previously gone unnoticed (Gayà et al. 2011), and the increasing population density in coastal areas, which also facilitates the observation of these phenomena. Also, in recent years, researchers in some Mediterranean areas have been focussing on building a solid

**Fig. 1** Fallen trees on the Menorca coast caused by two WS on 1 April 2017 (Source: [www.sinobas.aemet.es](http://www.sinobas.aemet.es))



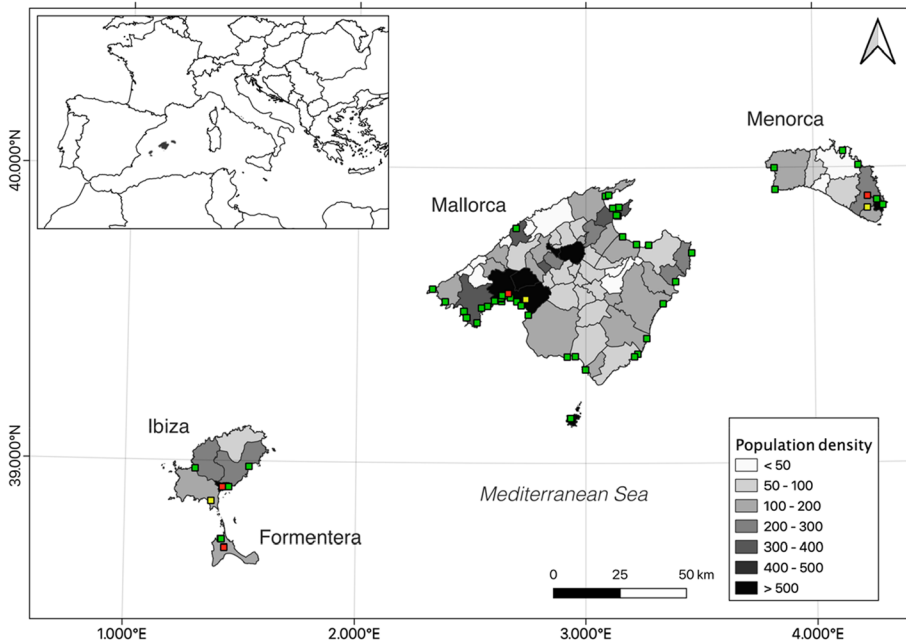
and homogeneous climate database for each of the regions (see Nastos and Matsangouras 2014; Renko et al. 2016; Miglietta and Matsangouras 2018; Rodríguez et al. 2021) and for Europe as a whole (see Antonescu et al. 2017). In all of the studies, the apparent increase observed is tempered by changing socioeconomic factors and the population's increased interest.

Fortunately, an extensive database already exists for the Balearic Islands thanks to work carried out by Gayà and other researchers, who conducted the first climatological study of tornadoes and WS in Spain, initially focussing on the islands (Gayà et al. 2001) and subsequently extending the study to the whole of Spain (Gayà 2005, 2015). In 2001, Gayà et al. analysed the climatology and environment in which thunderstorms produce tornadoes and waterspouts and the main thermodynamic stability indices. Their results showed that no specific conditions are required for tornado and waterspout genesis in the area. They also found that tornadoes and waterspouts form in air masses that are cooler than would typically be expected, given the region's climatology. For this work, we have opted to begin the time series in 1989, the year from which the information collected is considered to be more reliable by the aforementioned authors. Despite this, WS events can go unnoticed and unseen due to geographical and population-related reasons (occurrences in inaccessible or steep and sparsely populated areas), or for technical reasons (a lack of observers and instruments to detect them, for example, at night); therefore, it is highly probable that not all WS events are documented.

This project has two main objectives. The first is to review the climatology (spatial and temporal distribution) of WS in the Balearic Islands using a more extensive database of WS events than in previous research projects, given that it has a broader time series spanning between 1989 and 2020 (32 years). The second objective of the research is to study the relationships between WS and environmental variables. Accordingly, this publication covers three lines of work. It identifies the synoptic situations that favour the formation of WS, as well as barometric patterns such as the regional teleconnection pattern in the Western Mediterranean (WeMO; Martín-Vide & López-Bustins 2006), and it analyses the influence of the sea surface temperature (SST) in WS events.

## 2 Study area

The Balearic Islands are an autonomous community of Spain located in the Western Mediterranean with a total area of 4,992 km<sup>2</sup> and a population of 1.1 million inhabitants, mainly concentrated in the coastal municipalities (Fig. 2). The region comprises a group of islands and islets, including, from largest to smallest: Mallorca, Menorca, Ibiza and Formentera. It has 1,428 km of coastline and one of the most extensive ports and airport networks in Spain, with five main ports, more than thirty marinas and three airports. This fact is highly relevant to the study, given that WS observations are more common in regions with large marinas and busy recreational and commercial shipping lanes (Devanas and Stefanova 2018). The very insularity of the archipelago increases the population's exposure to WS, and that exposure has been further augmented in recent years due to socioeconomic changes and the growing number of inhabitants settling in coastal areas. Furthermore, many tourists visit the coast during the summer period. This is highly relevant because the resident population is substantially enlarged by the numerous visitors to the area in the months with the highest incidence of WS.



**Fig. 2** Map of the population density ( $hab * km^{-2}$ ) in the Balearic Islands (INE 2020). The island capitals (red squares), airports (yellow squares) and commercial ports and marinas (in green squares) are also indicated

### 3 Database and methodology

The incidences of WS have been extracted from available databases that have been subjected to a careful prior validation procedure. From 1989 to 2012, we used the information from Gayà's robust database (2015) that runs to 2012. This source has also been used by other studies (see Antonescu et al. 2017) and accounts for 65.4% of our database. For the years 2012–2020, we extracted information from the highly reliable Singular Atmospheric Observations Notification System database (SINOBAS; [www.sinobas.aemet.es](http://www.sinobas.aemet.es)) maintained by the State Meteorological Agency (AEMET) and climate reports from the same agency. It should be noted that SINOBAS has been operating since 2013, although it includes cases from previous years, with the first case of a waterspout in the Balearic archipelago being recorded in 2012. Data from SINOBAS and other climate reports represent 20.1% and 6.8% of our database, respectively; cases of WS reported in the media (4.3%) and social networks (3.4%) have also been considered. The latter was subjected to an in-house validation process using photographs or videos to verify the reports and discarding those for which an image or exact date could not be found. Subsequently, we conducted an exhaustive review to avoid duplicating any cases described in multiple sources, especially in 2012 when there was a temporal overlap of the two primary sources of information. It should be noted that our review found cases that were identified in SINOBAS but not in Gayà (2015). Since WS can appear in groups due to similar humidity rates at the point of formation and the same convergence of low-level winds (Grotjahn 2000) we recorded two or more vortices produced at the same time and place as a single occurrence. The database,

therefore, includes 234 events (256 vortices) occurring on 197 days. For all the WS, we have information on their latitude and longitude, the closest municipality to their location and the approximate time that they were produced (the latter not in all cases).

To determine the synoptic situations at the time of occurrence, we used the surface synoptic charts and the 500-hPa upper-air charts ([www.wetterzentrale.de/es/reanalysis.php](http://www.wetterzentrale.de/es/reanalysis.php)) as did Sioutas and Keul (2007) for their study on Greece, and Miglietta and Matsangouras (2018), for their study on Italy. In this study, we followed the manual classification proposed by Martín-Vide (2005) for the Iberian Peninsula and the Balearic Islands, which includes up to 16 synoptic situations: westerly advection, north-easterly advection, north-westerly advection, northerly advection, easterly advection, easterly advection with cold air pool, southerly advection, south-westerly advection, south-easterly advection, trough, cold air pool to the south-west, low, thermal low, flat low, anticyclone and thermal anticyclone.

Waterspouts are formed by warm water temperatures and high humidity over the sea (Huschke 1959). For this reason, we also analysed the sea surface temperature (SST) values at the time each WS was observed. This point has acquired new significance given the noticeable increase of the Mediterranean SST in the context of the current context of global climate change (Pastor et al. 2018, 2020). The National Centers for Environmental Information (NCEI) collected the SST data for the Balearic region that was previously processed by the Mediterranean Center for Environmental Studies (CEAM) and provided as a time series in the form of a mesh of geo-referenced points in the Western Mediterranean. We used this mesh to obtain the SST closest to the location of the WS for every day there was a notified event. This spatial classification was carried out using the QGIS cartography programme.

Finally, we used the Western Mediterranean Oscillation Index (WeMOi), a regional teleconnection pattern that uses the barometric information from two stations (Padua, in northern Italy, and San Fernando, in south-west Spain). Negative values in the index produce episodes of torrential rain in the east of the Iberian Peninsula and the Balearic Sea (López-Bustins et al. 2016), which is why its study and application to WS are deemed to be highly relevant.

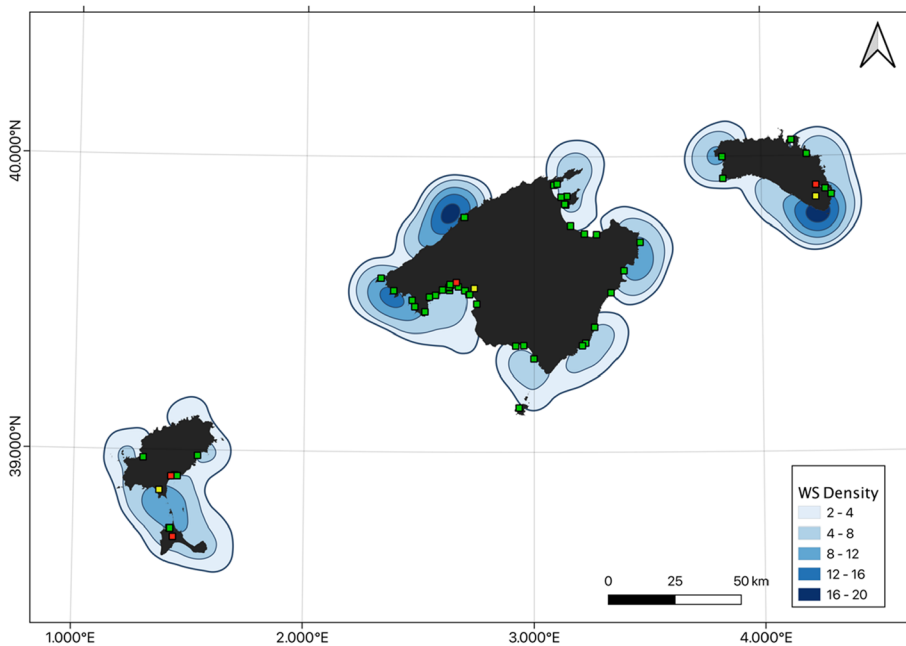
## 4 Results and discussion

### 4.1 Spatial distribution

The Kernel density estimation technique (Fig. 3) allows us to easily visualise the formation points and concentrations of WS events. In this context, there is a clear relationship between the concentration of WS occurrences and port areas with higher population densities.

The areas with the highest density of WS are the north-west and east coasts of Mallorca, around marinas and fishing ports. On Menorca, the most significant concentration occurred in the east of the island, close to the capital. However, a certain concentration was also observed in the west, where the island's main commercial port is located. In Ibiza and Formentera, there was a high concentration almost certainly linked to the influx of travellers between the islands' ports.

The northern regions of Mallorca, Menorca and Ibiza were the areas with the lowest density of WS events. This can be explained by the fact that these regions have steeper coastal geography, lower population rates and no ports.

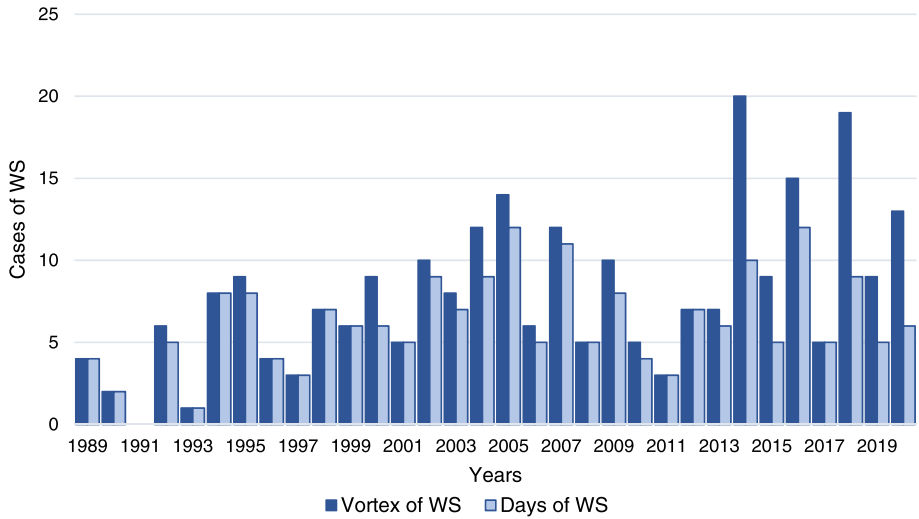


**Fig. 3** Kernel density estimation map for the location of recorded WS formations in proximity to the Balearic coast (1989–2020) for a radius of influence of 15 km. The island capitals (red squares), airports (yellow squares) and commercial ports and marinas (in green squares) are also indicated

Therefore, the distribution of observed WS events appears to have a clear relationship with areas that have ports and capitals, as already indicated by Gayà et al. (2001). In Catalonia (Spain), the highest number of WS occurrences was reported in the central coastal and pre-coastal areas, which also happen to be the areas with the highest population density (Rodríguez et al. 2021), a pattern that can also be seen in the Lazio region of Italy, where the high population in Rome is linked to it having the highest number of WS observations (Miglietta and Matsangouras 2018).

## 4.2 Temporal distribution

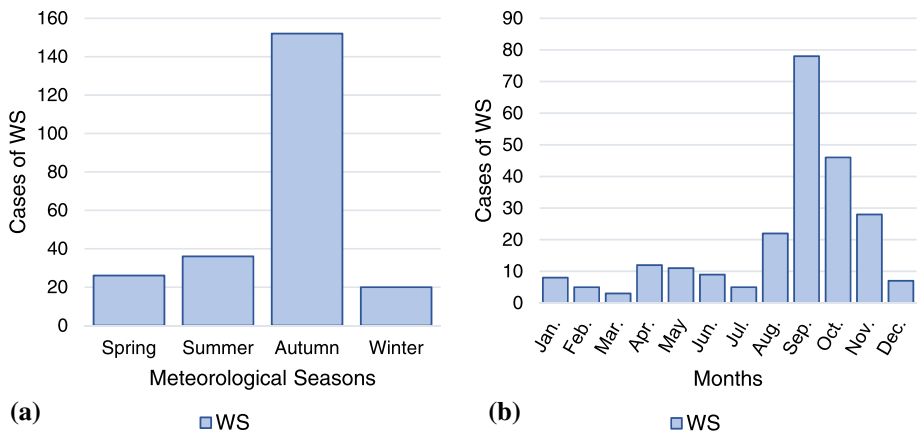
Between 1989 and 2020, there is a clear upward trend in the number of WS events (Fig. 4). However, rather than being associated with higher WS activity, this results from an increase in their recording. The most extreme values in the time series are a maximum of 21 vortices in 2014 and a minimum of 0 observed in 1991; however, that same year, an F2 tornado formed in inland Mallorca (Gayà et al. 2001). This annual maximum coincides with the data from Italy (Miglietta and Matsangouras 2018) and Greece (Sioutas and Doe 2019), which experienced unusual meteorological conditions in 2014, with frequent intrusions of cold air in the Mediterranean (Miglietta et al. 2017). With regard to the number of days with WS events, the years with the highest number of days observing the phenomenon were 2005 and 2016, the latter coinciding with the data from the nearby region of Catalonia (Rodríguez et al. 2021).



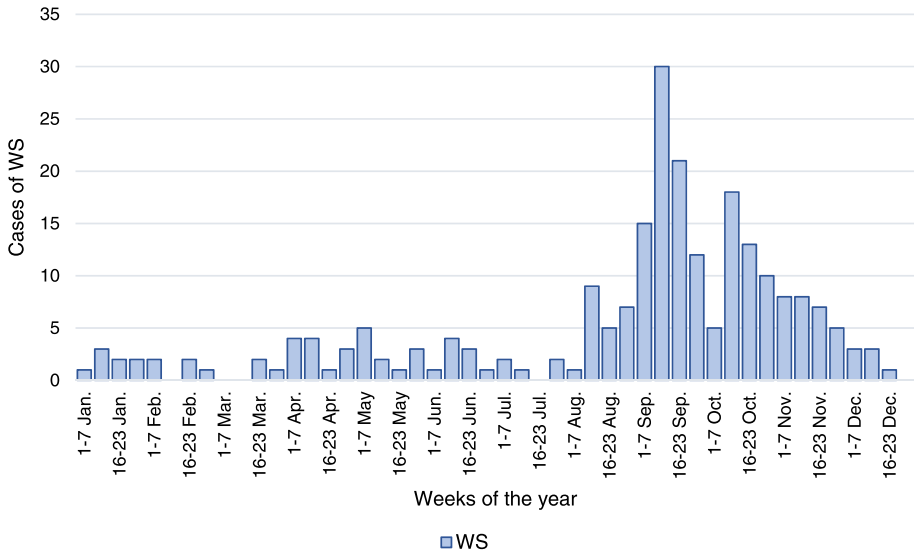
**Fig. 4** Annual distribution of WS events and observation days recorded in the Balearic Islands (1989–2020)

On average, between 6 and 8 WS are observed per year, with a frequency of 5 to 7 days. By island, the temporal distribution is proportional to the kilometres of coastline, being between 1 and 2 WS per year in Ibiza and Formentera, 2 per year in Menorca and 3 to 4 per year in Mallorca.

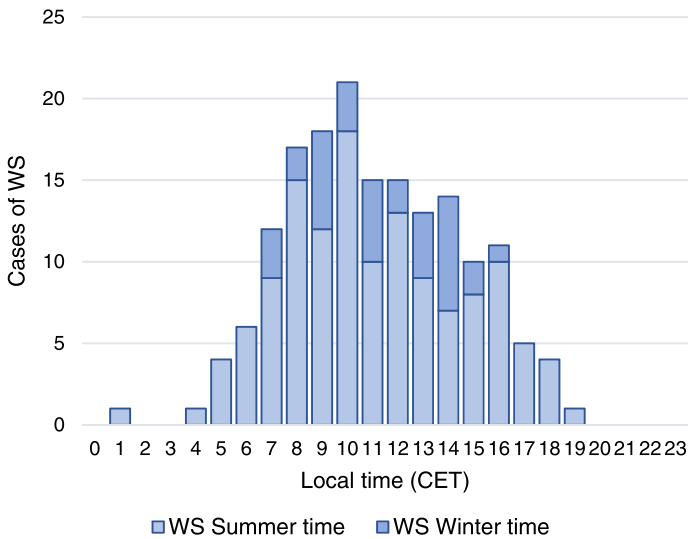
By seasons, most of the reports (152 WS) occur in the meteorological autumn (September, October and November), followed by summer, spring and winter (Fig. 5a). Specifically, 1 in 3 WS cases occurred in September (78 WS); this high concentration is followed by the months of October, November and August, determining the WS season in this area (Fig. 5b). It should be noted that this monthly distribution is similar to that observed by



**Fig. 5 a** Distribution of WS events recorded in the Balearic Islands by meteorological season (1989–2020). **b** Monthly distribution of WS events recorded in the Balearic Islands (1989–2020)



**Fig. 6** Weekly distribution of WS events recorded in the Balearic Islands (1989–2020)



**Fig. 7** Time distribution of WS events recorded in the Balearic Islands (1989–2020) classified according to summer and wintertime

other studies of storm activity in the Balearic Sea (Tomás-Burguera and Grimalt 2014). The analysis of the weekly distribution (Fig. 6) reveals a season that begins in early August, ends in late November or early December, and concentrates around 75% of annual WS events. These dates are similar to those initially identified by Gayà et al. (2001).

With regard to the hourly distribution (Fig. 7), the majority of cases were observed during the day, confirming the limitations affecting night observation. This limitation is also



evident in the change from summer (late March to late October) to wintertime (late October to late March), when, in addition to a fall in the number of recorded incidences, the data reveal a narrowing of the time frame in which they are observed due to the reduced daylight hours. By time (Fig. 7), most WS events occur during the morning (starting at 06:00 CET and peaking between 10:00–10:59 CET) and the middle hours of the day, which is precisely when solar radiation is at its strongest.

### 4.3 Synoptic types

Identifying the synoptic characteristics common to the formation of WS is key to improving our ability to predict their occurrence (Homar et al. 2001; Keul et al. 2009). WS can develop in a wide range of different synoptic situations (Fig. 8). A subjective analysis of the surface synoptic chart and 500-hPa upper-air chart for each of the days in which WS were observed revealed the following synoptic situations: troughs (25.3%), easterly advection with or without cut-off low (15.9%), lows (15.0%), north-westerly advection (12.0%) and north-easterly advection (11.6%). In smaller percentages, advection from the north (6.9%), cut-off low to the south-west (3.4%), anticyclonic advection from the west (3.4%), high (2.1%) and barometric swamp (1.3%) also stand out. The barometric patterns accounting for less than 1% of the sample have been categorised as ‘others’. These are south-west advection (0.9%), thermal anticyclone (0.9%), thermal low (0.4%), southern advection (0.4%) and westerly advection (0.4%).

The first five synoptic situations account for 80% of all cases. To a greater or lesser degree, they are characterised by their ability to produce atmospheric instability in the Balearic archipelago, especially during late summer and autumn when instability is at its highest due to maximum SSTs, among other reasons. While not a guarantee of instability alone, a high SST can be influential if accompanied by other conditions, such as cold air intrusions at high levels.

The trough, which was revealed to be the most frequent synoptic type associated with WS in the Balearic archipelago, is characterised by a long wave at 500 hPa that affects the

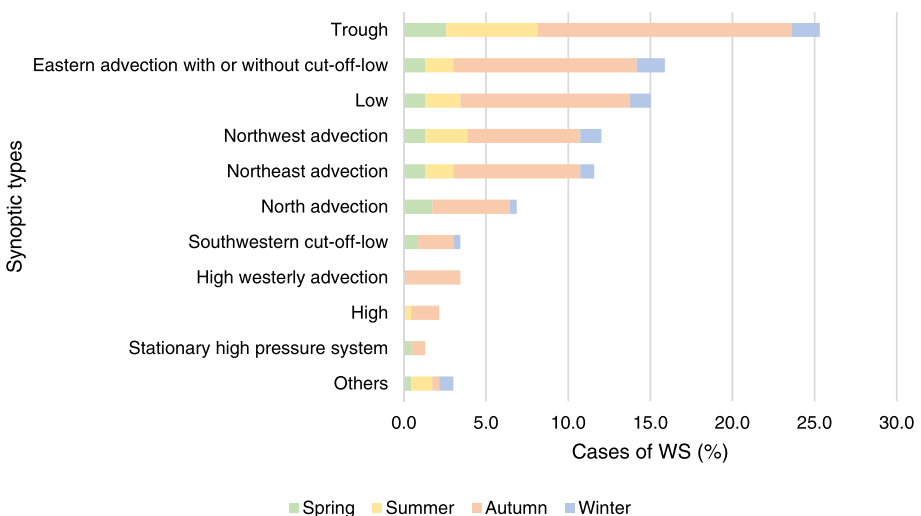
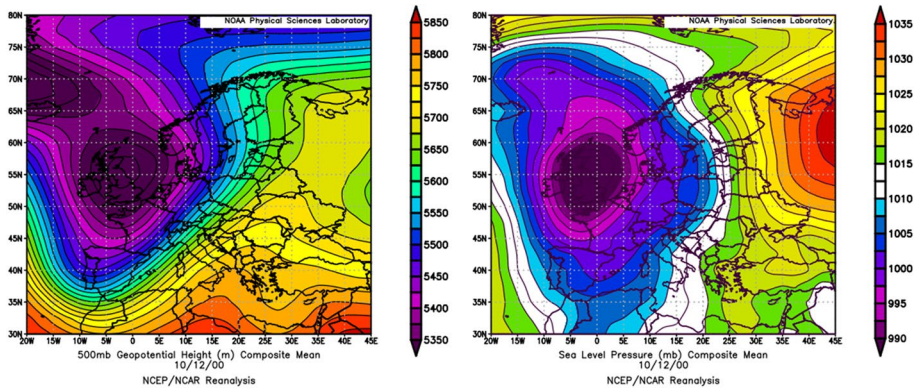
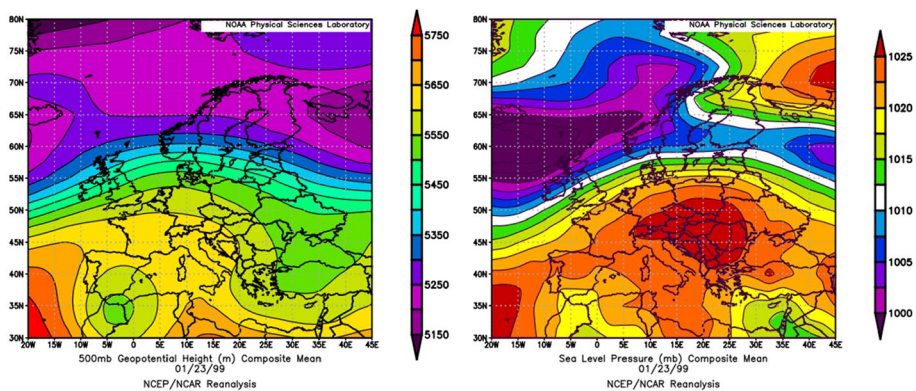


Fig. 8 Classification of synoptic types of WS events recorded in the Balearic Islands (1989–2020)



**Fig. 9** 500 hPa geopotential height chart and sea-level pressure chart for 12 October 2000 at the time of 2 WS events in Ibiza, classified as a trough according to Martín-Vide (2005)

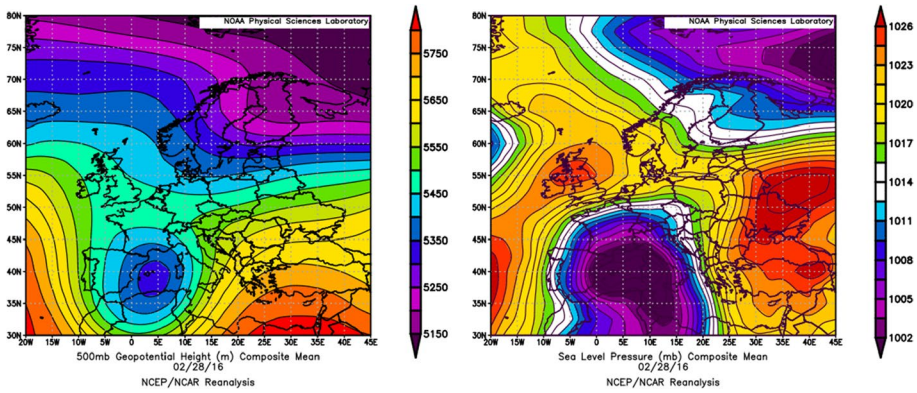


**Fig. 10** 500 hPa geopotential height chart and sea-level pressure chart for 23 January 1999 at the time of 1 WS event in Mallorca, classified as an easterly advection with cut-off low according to Martín-Vide (2005)

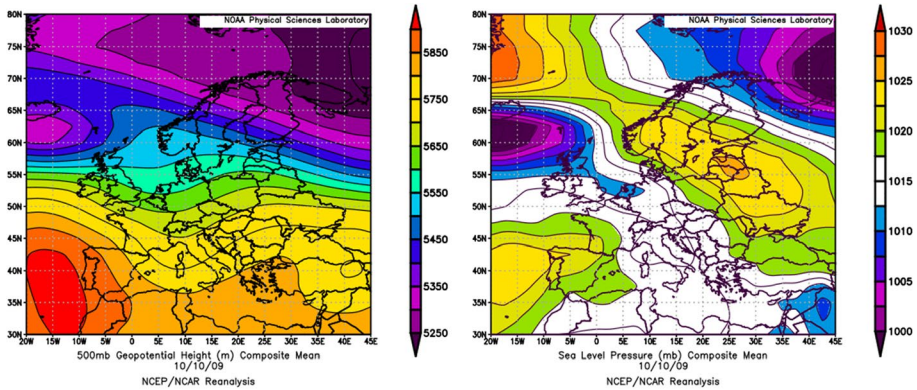
Iberian Peninsula and interferes in the Balearic region with a flow from the south-west (Fig. 9). Following general circulation patterns, troughs will move towards the east and, after the passage of a cold front through the region, the winds will roll to the north-west or north, imposing a colder air mass.

This south-westerly flow prior to a cold front is also linked to the appearance of WS in other regions. For the central and eastern Mediterranean, it was determined that a south-westerly flow, characterised by the presence of a longwave trough to the west of the area of interest, is the conditions most frequently associated with WS activity (Keul et al. 2009). In western Greece, the average daily synoptic situation associated with WS events in the autumn is a wide trough throughout central and southern Italy (Nastos and Matsangouras 2014). The same occurs in the Adriatic Sea, where a south-westerly flow is the most associated with the appearance of WS (Renko et al. 2016).

The second most dominant situation is an easterly advection with or without cut-off low. This situation is characterised by an isolated depression at high and medium levels of the atmosphere and a typically humid easterly flow over the Western Mediterranean (Fig. 10). It brings abundant rainfall to the region, often with associated storms. If there is no cold air



**Fig. 11** 500 hPa geopotential height chart and sea-level pressure chart for 28 February 2016 at the time of 1 WS event in Mallorca, classified as a low according to Martin-Vide (2005)



**Fig. 12** 500 hPa geopotential height chart and sea-level pressure chart for 10 October 2009 at the time of 2 WS events in Mallorca, classified as an advection from the north-west according to Martín-Vide (2005)

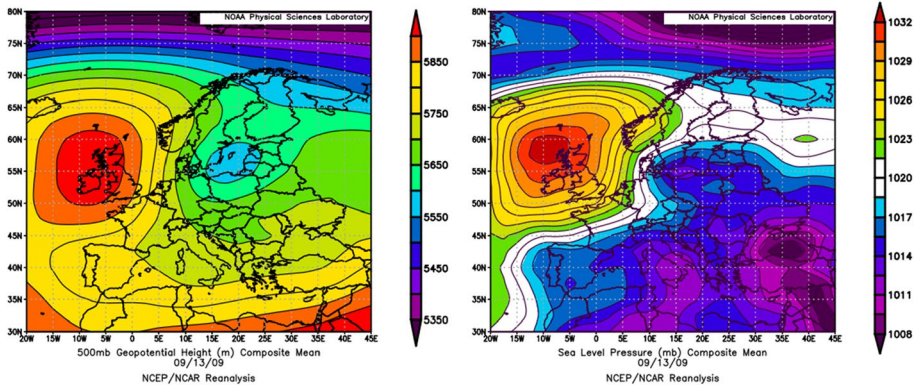
pool, the situation is also characterised by a humid easterly flow over the Western Mediterranean, resulting in rain and, occasionally, storms in the region. In the latter set of circumstances, the instability is manifest but not usually as intense as in the first.

The low or squall is the third synoptic situation associated with the appearance of WS. It is characterised by a depression centred over the Iberian Peninsula and reflected on the surface (Fig. 11). This situation affects the Balearic Islands similarly to a trough because depending on the extension and position of the low, it may cause south-westerly advection.

Advection from the north-west (Fig. 12) and north-east (Fig. 13) brings cold, or, in the summer, cool air to the Balearic region, although, at times, that can be sufficient to destabilise the atmosphere. North-easterly advection is often associated with the Ligurian depression over or near the Gulf of Genova.

Given that the synoptic situations accounting for the remaining 20% are far from negligible, this study’s wide-ranging spectrum (16 different synoptic situations) allows us to take into account some of the less statistically significant synoptic situations. In contrast,





**Fig. 13** 500 hPa geopotential height chart and sea-level pressure chart for 13 September 2009 at the time of 1 WS event in Mallorca, classified as an advection from the north-east according to Martin-Vide (2005)

others have had a more limited scope of just a few synoptic types. In regard to these less significant synoptic situations specifically, it is worth mentioning that northerly advection accounts for a similar percentage of WS in the spring as the first five synoptic types. This can be explained by the instability brought about by the colder temperatures associated with it and the increased radiative contribution seen at this time of the year. In general, these situations in the spring tend to cause a drop in temperature and greater instability in the Balearic region.

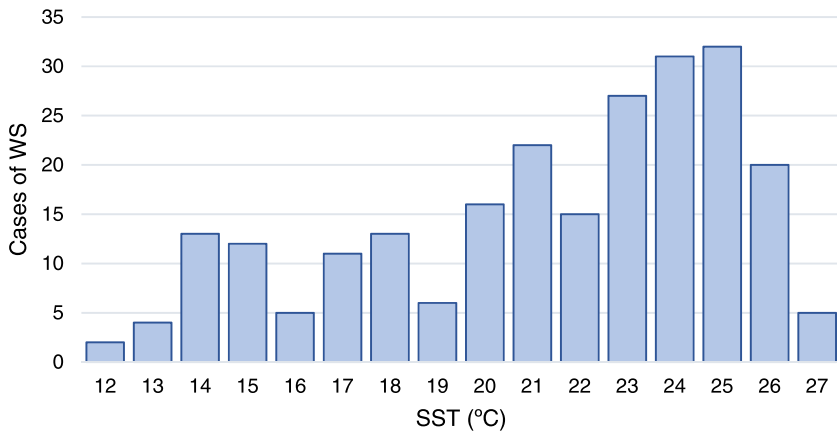
#### 4.4 Sea surface temperature

Sea surface temperature is an influential parameter in WS formation as it depends significantly on low-level atmospheric conditions (Gayà 2015). This dependence between the sea surface layer and the lowest layer of the atmosphere has already been demonstrated by the Szilagyi nomogram, an empirical WS forecasting method that considers, among other parameters, the difference between SST and 850 hPa temperature (Szilagyi 2005).

The relationship between SST and WS (Fig. 14) shows that WS occur more frequently in warm waters. This was expected given that the vast majority of WS occur in the warmest part of the year, from early spring to late autumn (Sioutas 2003). Values above 20 °C and, in particular, between 23 and 26 °C are most frequently associated with the occurrence of WS. Furthermore, the influence of peak temperatures between 14 and 15 °C or 17 and 18 °C cannot be underestimated and may be related to the spring period when the SST is relatively colder, but the solar radiation is already intense, or the conditions for convective phenomena are already favourable.

We have calculated the SST anomalies for each day in the study period with reported WS events. 65.6% had positive SST anomalies, and 34.4% had negative ones.

As noted above, WS events have increased in frequency over the decades, and this may well be linked to the fact that SST has followed a similar trend (Pastor et al. 2020; Pisano et al. 2020). However, given the limitations of the available data and the fact that SST is not the only parameter to influence their formation, we cannot currently prove that the increase in the frequency of WS is associated with the increase in SST. Nonetheless, it may play a decisive role (Sioutas et al. 2013), and we must continue to study and observe the evolution of WS in the future scenarios where the SST is expected to continue rising.



**Fig. 14** Frequency of WS recorded in the Balearic Islands (1989–2020) with respect to the SST at the mesh point closest to the WS

#### 4.5 WeMO index

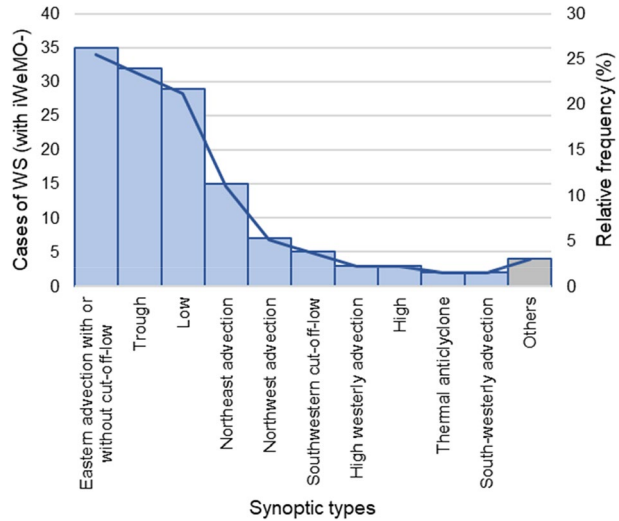
The relationship between teleconnection patterns and WS, tornadoes, and even hurricanes has been studied with the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO). In the USA, negative ENSO index values between January and April were shown to be linked to a lower frequency of tornadoes (Cook et al. 2017). In Italy, it was observed that positive NAO values in September have a statistically significant relationship with intense WS activity (Miglietta and Matsangouras 2018).

For this study on the Balearic archipelago, we used the Western Mediterranean Oscillation (WeMO) regional teleconnection pattern proposed by Martín-Vide (2002) and Martín-Vide and López-Bustins (2006). We opted not to use the NAO because its influence in the western Mediterranean basin is weak due to the region's location downwind of the Atlantic flows (López-Bustins et al. 2016). In addition, given that WS are highly local phenomena, we believe the regional scope offered by the WeMOi (which encompasses the study area) may be better suited to our research.

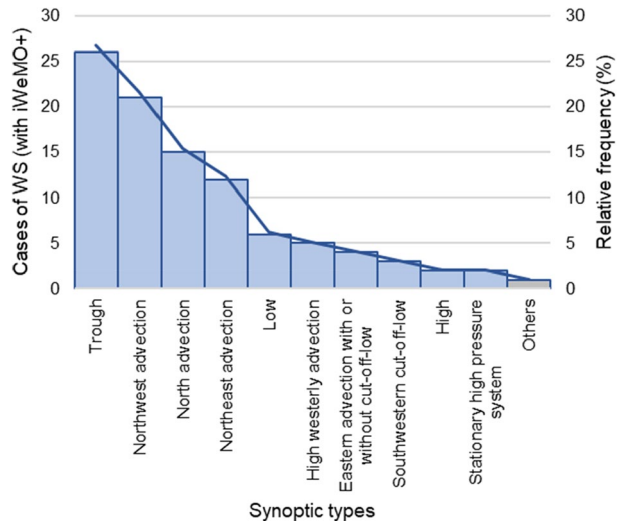
The results obtained show a high frequency of cases for index values close to 0, which is precisely when the north-westerly winds typical of a positive WeMOi and the easterly winds typical of a negative WeMOi are not pronounced in the Balearic Islands. This indeterminacy ( $\text{WeMOi} \pm 0$ ) leads us to think that a south-westerly flow is characterised by close to 0. However, there is great variability in the results obtained, making it difficult to identify a clear relationship. It should be considered that WS formation is considered to have a very local component, with the sea breeze regime playing an important role in its formation (Gayà 2015).

In order to explore the synoptic differences between WS events linked to positive and negative WeMOi, each group has been re-classified. The results show a clear difference between the synoptic types of the two groups. For the cases with negative WeMOi, three synoptic types account for 75% of the events: eastern advection with or without cut-off low, trough and low (Fig. 15). For the cases with positive WeMOi, the three northern advectations (north-west, north and north-east), in addition to the trough, account for around 75% of the events (Fig. 16).

**Fig. 15** Histogram of WS events with a negative WeMOi recorded in the Balearic Islands (1989–2020), related to the synoptic classification



**Fig. 16** Histogram of WS events with a positive WeMOi recorded in the Balearic Islands (1989–2020), related to the synoptic classification



## 5 Conclusions

The work presented has resulted in a successful update of WS climatology in the Balearic Islands, allowing us to consolidate a solid and systematic database and a synoptic characterisation that can be used to effectively predict WS based on synoptic types. In addition, we have studied their relationship with the SST and the WeMOi that affects the Balearic Islands and their spatial and temporal behaviour throughout the archipelago.

In terms of spatial distribution, we have determined that the location of recorded WS events does not correlate with physical geographical factors in the islands but, above all, with the most populated zones and port areas of the archipelago. Furthermore, we have identified a WS season that starts in early August and ends in late November or

early December. These data are especially valuable because it allows us to specify when increased effort should be concentrated on forecasting, preventing and monitoring the phenomenon. This is particularly true at night-time, given the existing bias in the database during that time slot.

The synoptic pattern of a trough at 500 hPa is associated with the highest frequency of WS in the study area (25.3%). The eastern side of this trough over the Iberian Peninsula produces a south-westerly flow over the Balearic Islands located to the east (Grimalt-Gelabert et al. 2021). Easterly advection with or without cut-off low (15.9%), low (15.0%), north-westerly advection (12.0%) and north-easterly advection (11.6%) are also relevant.

With regard to sea temperatures, WS occur more frequently under warm SST conditions. Despite this, we are still unable to determine whether an increase in SST will lead to an increase in WS events. In relation to SST anomalies, 65,6% of WS occurred with positive SST anomalies and 34,4% with negative anomalies. On the other hand, WS frequency in relation to the daily WeMOi value seems to be associated with indices close to 0, indicating no clear relationship between the two. This is logical given the diverse synoptic spectrum identified.

The conclusions obtained provide invaluable information for forecasting, preventing and monitoring the phenomenon, as well as for protecting citizens from this natural hazard, particularly those who live on the seafloor, own boats or practise coastal sports. They will also help to inform any future installation of maritime infrastructures in the Balearic Sea, such as offshore wind farms, which would increase exposure and, therefore, the risk of being affected by the phenomenon.

In the future studies, it would be interesting to apply an objective synoptic classification, such as that of Jenkinson and Collison. Furthermore, based on the available SST information, it would be interesting to apply the Szilagyi waterspout nomogram and study the relationship between WS and the areas with the highest levels of electrical activity in the archipelago.

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## Declarations

**Conflict of interest** The authors declare they have no conflicts of interest relevant to the content of this article.

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