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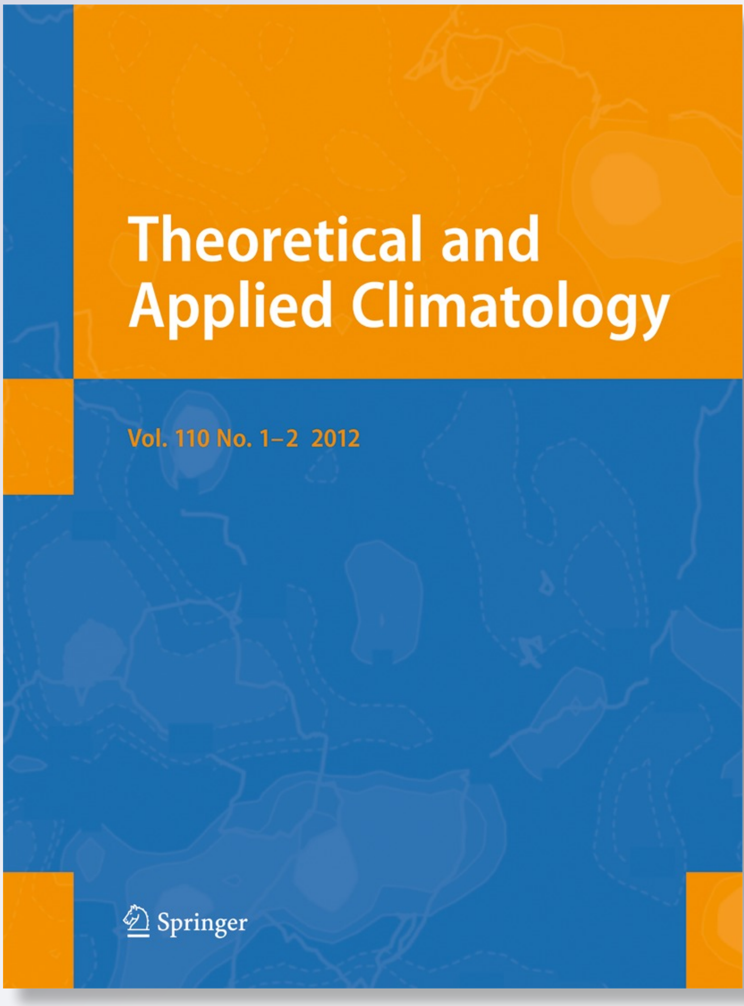

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ORIGINAL PAPER

A seasonal study of the atmospheric dynamics over the Iberian Peninsula based on circulation types

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Abstract A seasonal analysis of the atmospheric circulation over the Iberian Peninsula (IP) based on circulation types (CTs) obtained from sea level pressure and 500-hPa geopotential height is presented. The study covers the period of 1958–2008, when a high variability and important changes in winter and spring precipitation and temperature have been reported. Frequency, persistence, and the most probable transitions of the circulation types are analyzed. Among the clustering methods available in the literature, two of the most reliable classification methods have been tested, K-means and simulated annealing and diversified randomization. A comparison of both methods over the IP is presented for winter (DJF). The quality of the circulation types obtained through both methods as well as the better stability achieved by K-means suggest this method as more appropriated for our target area. Twelve CTs were obtained for each season and were analyzed. The patterns obtained were regrouped in five general situations: anticyclonic, cyclonic, zonal, summertime, and hybrid-mixed. The analysis of frequencies of these situations offers a similar characterization of the atmospheric circulation that others previously obtained by subjective methods. The analysis of the trends in frequency and persistence for each CT shows few significant trends, mainly in winter and spring with a general decrease of the cyclonic patterns and an increase of the anticyclonic situations. This can be related to the negative precipitation trends reported by other authors. Regarding the persistence, an interesting result is that there is a high interannual variability of the persistence in autumn and spring, when patterns can persist longer than in other seasons. An analysis of the most probable transitions between the CTs has been performed, revealing the existence of cyclic sequences in all seasons. These sequences are related to the high frequency of certain patterns such as the anticyclonic situations in winter. Finally, a clear seasonal dependence of the transitions between cyclonic situations associated with extratropical disturbances was found. This dependence suggests that the transitions of low-pressure systems towards the south of the IP are more likely in spring and autumn than in winter.

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1 Introduction

The classification of the atmospheric circulation over a region in a discrete set of atmospheric patterns may result an unrealistic task if we take into account the chaotic nature of the atmospheric dynamics (Lorenz 1956). Nevertheless, from a synoptic point of view, the atmospheric patterns defined by large-scale variables (generally sea level pressure or geopotential at a given level) present recurrent spatial configurations that could be considered as the attractors of the system. They are usually named circulation types (CTs). Traditionally, the CTs have been used for the analysis of the regional climatic variability of elements such as precipitation (Gallego 1995; Romero et al. 1999), temperature (Bermejo and Ancell 2009; Philipp et al. 2006; Cassou et al. 2005; Yiou et al. 2008), and wind (Jiménez et al. 2008), so that their influence in these variables has been used to develop conceptual models or empirical–statistical relations useful for prediction. Nowadays, its use has been extended to other interesting climatological applications like the validation of climate models (Crane and Barry 1988; Hulme et al. 1993; Huth 2000) or the possible changes in the circulation under different climate change scenarios (Kyselý and Huth 2006; Huth 1997).

The first classifications started to be developed in the second half of the twentieth century (Hess and Brezowsky 1952; Lamb 1950). The synoptic patterns were grouped according to a number of subjective rules adopted by experts. The limitation of these classifications lay on the assignation of the states in the different groups when the databases were very large; so, they were usually developed for relatively short periods (10–15 years). The availability of gridded atmospheric databases (e.g., NCAR, ERA40) carried out the development of objective techniques on assignation. The most frequently used among them are as follows: (1) correlation method (Lund 1963), (2) sums of squares (Kirchhofer 1974), (3) cluster analysis (Key and Crane 1986), and (4) principal component analysis (PCA) (Richman 1981). Huth (1996) shows a comparative study of the aforementioned methods, concluding that those using PCA get the best results. Specifically, the T-mode rotated PCA is the method reproducing more realistically the underlying physical structure of the data, providing the most stable clusters in time and space. Furthermore, the nonhierarchical grouping method K-means obtains a larger separation among clusters, albeit requires a set of seeds for its initialization. With the aim of joining the quality of two methods, Huth (2000) and Kyselý and Huth (2006) proposed a clustering methodology in two stages. The first stage provides a set of seeds as a result of applying the T-mode rotated PCA, whereas the second stage consists on a K-means grouping initialized from the seeds obtained in the previous stage. In the last years, new classifications have been added considering other non-hierarchical clustering methods like simulated annealing and diversified randomization (SANDRA, Philipp et al. (2006)) and self-organizing maps (Bermejo and Ancell (2009); Hewitson and Crane (2002)). The main attribute of SANDRA is its capability to obtain clusters with a high quality and stability (Philipp et al. 2006). The quality of a clustering is defined as the proportion of the original variance explained by the groups (Eq. 1), while the stability is defined as the probability to obtain the same clusters when they are achieved using shorter or different temporal periods. Clusters with high quality and stability allow making more realistic studies of the frequencies, persistences, and transitions of the different CTs (Beck and Philipp 2010; Huth 1996). The trend analysis of the annual or seasonal frequency series of the CTs is an interesting exercise that helps understanding, under a climate change context, some of the regional changes observed (Bárdossy and Caspary 1990; Philipp et al. 2006) or projected in precipitation, temperature, or other variables if we previously know the influence on them of the CTs. Despite the number of methods existing, none of them presents a clearly superior behavior (Philipp et al. 2010, COST733) so that its selection depends on the criteria of the researchers based on their experience and the objectives of the classification (Casado et al. 2008).

The results of the clustering process are sensitive not only to the method considered but also to other parameters such as the large-scale variable or variables considered for the definition of the CTs, the size and the resolution of the clustering window (Jiménez et al. 2008; Demezure et al. 2008; García-Bustamante et al. 2012), the seasonalization (or not) of the classification, the number of principal components (PCs) to be retained (when adopting a classification scheme based on the PCA), and the number of clusters to consider (Michelangeli et al. 1995; Philipp et al. 2006; Fereday et al. 2008). These variables largely affect the results of the classification. The election of the synoptic variables for characterizing the CTs obeys to practical criteria (e.g., their availability and mainly the objective of the classification). Frequently, most of those obtained for Europe and other regions were developed using the sea level pressure (SLP) in order to relate the classifications to regional variables influenced directly by the state of the low levels of the atmosphere, like surface temperature (Philipp et al. 2006; Cassou et al. 2005; Yiou et al. 2008), the sea surface temperature (Fereday et al. 2008), or the wind (Jiménez et al. 2008). Other classifications used the geopotential at 500 hPa (Z500) (Kirchhofer 1974; Casado et al. 2008; Yiou and Nogaj 2004), which provides a global vision of the average state of the atmosphere. In a lesser extent, several authors used together the SLP and Z500 for characterizing the atmospheric dynamics with the aim of analyzing precipitation (Gallego 1995; Romero et al. 1999; Petisco 2003). Precipitation is specially sensitive to the moisture fluxes at low levels, governed by the distribution of the pressure field at those levels. Nonetheless, in regions where the rain regime is very irregular and most of precipitation is convective, as occurring during the warm half of the year in the mediterranean area of the Iberian Peninsula (Font-Tullot 2000), the advective component of the low levels defined by the SLP is not enough to explain its variability, and hence, it should be to consider in addition the degree of average atmospheric instability represented by Z500.

The size and resolution of the clustering window are two parameters which should be made adequate to the objectives of the classification. An indirect relation should exist between them in order to improve the quality of the clusters; that is, high resolutions should be avoided when using large windows and low resolutions when the windows are small. Generally, most of the authors that have characterized the circulation in big regions as Europe used windows that covered this entire region and a large portion of the Northern Atlantic Ocean, with resolutions between 2.5° and 5°. Here, we intend to characterize the circulation over a smaller area, and hence, it seems logical to use higher resolutions and smaller windows, covering at least the target area. Working with small windows helps in improving the quality of the clustering, specially when the clustering method uses the results of a PCA, because the variability modes whose origin responds to remote areas with small influence in the target area will not appear in the clusters. The idea of developing (or not) seasonal classifications is another aspect to consider, and it depends in a great extent on the level of detail pursued by the classification. Furthermore, the reduction of the database in more homogeneous samples may lead to an improvement in the quality of the clusters obtained. On the other hand, if the regional variable analyzed with the CTs presents an important seasonal variability, the separation by seasons will be more justified.

Probably one of the most determining factors is the number of groups to consider in the classification. Choosing a reduced number could be not enough to characterize the atmospheric variability; albeit the election of a too large number deviates from the sense of this kind of classifications, which is having a handy number of situations. For its election, different methods have been used (Milligan 1980) based upon quality (Calinski and Harabasz 1974) and stability criteria (Michelangeli et al. 1995). More sophisticated indices have been developed like Silhouette (Kaufman and Rousseeuw 1990), which indicates that the centroids of the clusters are located in regions of high object density or overlap (Gesterngarbe and Werner 1997), which assesses the overlapping ratio of object between two clusters. However, in all these indices, the researcher must take a subjective decision, because generally there is always more than a possible option that highlights the nonexistence of a genuine number of groups (Philipp et al. 2006; Fereday et al. 2008).

The Iberian Peninsula (IP) is considered as a climate change hot-spot (Giorgi 2006). The trends for temperature and precipitation along the twentieth century highlight a rising temperature specially during summer and spring (Brunet et al. 2007) and a decrease of precipitation at the end and beginning of winter and spring, respectively, mainly in the last three decades (Serrano et al. 1999). The decrease of precipitation has been related with a northern shift of the storm tracks (Paredes et al. 2006), which is compatible with the increase and/or decrease in frequency or persistence of some CTs. The trends observed together with the projections of climate change forecasting drier and warmer conditions in summer and spring make this region a place of special interest for the study of the atmospheric circulation.

Hence, this work aims to characterize the daily circulation over the IP. For that, several clusters of CTs have been obtained for each season of the year; thus, improving the up-to-date classifications for the Iberian Peninsula (Petisco 2003; Rasilla 2003; Romero et al. 1999; Goodess and Palutikof 1998; Jiménez et al. 2008), which did not take into account the seasonal separation. The characterization of the CTs has been made considering SLP and Z500. Both have been included together in the PCA previous to the clustering method considered, which involves a differentiating element from the rest of the classifications using two variables (that used the PCA separately for each of them, Romero et al. 1999). The classification period covered was 1958–2008, extending the periods considered in the previous works aforementioned. This period presents an important relevance for the analysis of frequencies, persistence, and transitions of the CTs because of the great variability depicted over the IP. So, in the first half of the period, there was a predominance of cold and wet years, meanwhile in the last years, there are some of the warmest and driest years during the instrumental period (Brunet et al. 2007). This contribution is organized as follows: Section 2 describes the database and the clustering window considered; Section 3 shows a previous comparative study of the algorithms K-means and SANDRA over the target clustering window and describes the method followed for the classifications; Section 4 indicates the CTs obtained and the analysis of their frequency and persistence together with the most significant transitions. Conclusions are summarized in Section 5.

2 Data

Daily operational analysis (2003–2008) and reanalysis (1958–2002) at 12:00 UTC data from the European Center for Medium-Range Weather Forecast (Uppala et al. 2005) have been used for the characterization of the CTs. The variables employed were sea level pressure and 500 hPa geopotential height (Z500). The maximum common resolution (1.125 degrees) was used, covering the period 1958–2008 (18,973 days). The use of analysis and reanalysis data together could be a potential problem, obtaining some inconsistencies. In order to guarantee the homogeneity of the analysis plus reanalysis data, we have analyzed the mean and variance of the time series of both variables (spatial averaged over the small window) SLP and Z500. We have detected some small changes, but anyway they pass the penalized maximal F test (Wang 2008)

The spatial window considered for the characterization of the CTs consist of 150 grid points, with coordinates ranging from 34.875°N–45°N and 10.125°W–5.625°E. Nevertheless, in order to have a view of the synoptic situation defined by each CT, a larger window has been used for their representation, formed by 1,364 grid points and centered over the IP (Fig. 1).

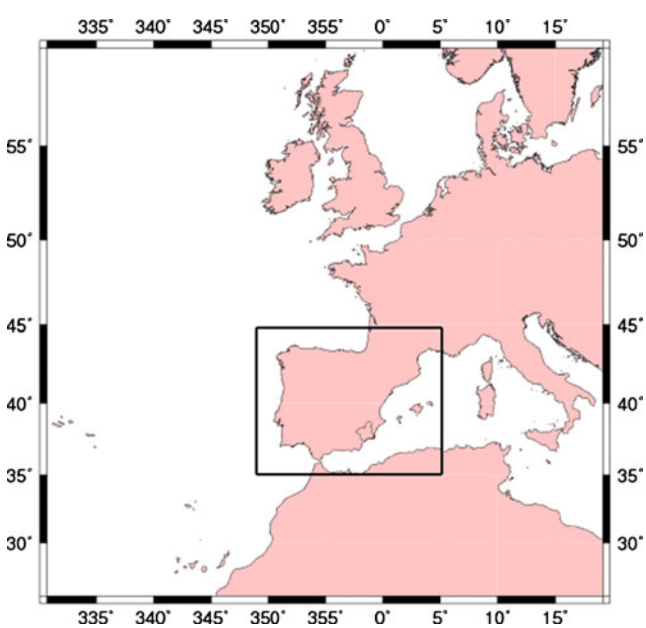

Fig. 1 Windows employed for representation (*larger*) and clustering (*inner*)

3 Clustering methodology

As commented in Section 1, there are many clustering algorithms that are frequently used for getting CTs. Depending on the region where they are obtained, a similar algorithm might perform very differently, so it might be a good algorithm for certain regions and not as good for others (Beck and Philipp 2010; Philipp et al. 2010). Therefore, in order to select a good algorithm for the study region, in this section, a comparison study of the results obtained over the Iberian Peninsula is performed, using two methods: K-means, one of the most widely employed methods, and SANDRA, more recently used for this purpose (Philipp et al. 2006). Both methods were initialized using the results from previous PCAs applied to the data. The details about the PCA analysis are also explained in this section. To evaluate the results of both clustering methods, we have taken into account the quality and stability of the clusters. First, a summary discussion of these statistics is presented in this section. The definitive clustering method followed in order to obtain the CTs for this study is presented at the end of this section.

3.0.1 Principal component analysis

The PCA is a tool extensively used in climatological research. A more detailed description can be found in Storch and Zwiers (1999); Hannachi et al. (2007); Preisendorfer (1988). Its objective is the representation of the original data in a new orthogonal space of functions, representing the main variation modes of the system. Hence, the correlation degree existing in the initial data is removed and therefore eliminating a significant source of noise for other types of analysis like clustering. The variation modes are named empirical orthogonal functions (EOFs) and correspond to the eigenvectors of the correlation matrix or covariance of the anomalies of the original data. The projections of the original data in these new functions are called principal components. Their main characteristic is the nonexistence of correlation among them. For the projections, only the EOFs with a significant weight in the global variance are used and that corresponds to those whose eigenvalues associated have the highest values. The election of the number of representative EOFs involves a high degree of subjectivity, and therefore, different methodologies have been developed (Catell 1966; Wilks 1995).

In this study, the PCA has been carried out in the S-Mode of operation, considering the grid points as variables and the temporal stages as events. This configuration is adopted because of the lower number of dimensions in the correlation matrix, 300 (150 for SLP and 150 for Z500) vs. over 4,500 (number of episodes of each of the seasonal matrices) in the case of choosing a T-Mode configuration (temporal stages as variables). The joint use of SLP and Z500 in the PCA requires of a previous step of complete standardization by grid point for both variables in order to avoid the dominance of the variable with the largest variability in the PCA (in this case, Z500). For the standardization, long term mean and variance were considered for each grid point. The utilized method for retaining the number of EOFs uses the graphic log(eigenvalue) vs. number of PCs. (Wilks 1995). Its shape determines the number of PCs retained, which comes conditioned by the number of components to the right of a line extrapolated to the left from a significant discontinuity of the value of log(eigenvalue) (Fig. 2).

3.0.2 Testing methods

Any process whose objective is the clustering of elements in a series of ensembles should take into account that each cluster must be as homogeneous as possible and different from the rest. The ratio of the global explained cluster variance (ECV) is a quality index that allows assessing the goodness of the cluster (Eq. 1). This index is defined as the ratio between the sum of the internal variance of all the groups (with cluster sum of squares, WSS) and the total variance of all the elements without clustering (total sum of squares, TSS). It ranges between 0 and 1. The zero value indicates that the cluster obtained is worthless, meanwhile the unit value refers to a perfect clustering, generally obtained when considering as many groups as elements. Hence, the higher the number of clusters considered, the better the quality of the clustering.

$$ECV = 1 - (WSS/TSS) \quad (1)$$

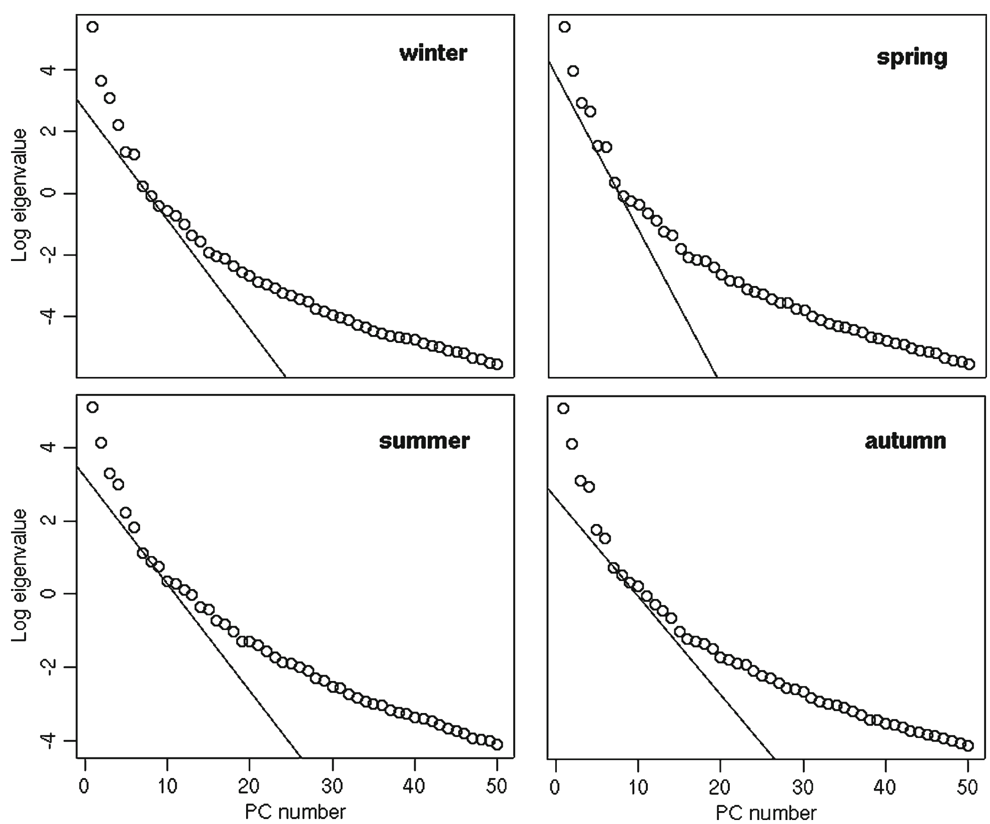

Fig. 2 Log(eigenvalue) vs. PC number used for the retention of the proper number of principal components. For all seasons, the value of log(eigenvalue) stabilizes from the sixth component

The aim of studies like this is to obtain a reduced number of clusters with an important representation of the variability observed. The election of a reduced but manageable number provokes that a fraction of the variance cannot be explained with the clustering, especially in those cases when the number of elements is high.

In addition to the ECV, there are more indices informing about other interesting aspects of the clustering obtained. One among them is that index measuring the degree of stability of the clustering, determining the robustness of the different clusters. Clustering is meaningless if we obtain different clusters every time we apply the clustering methodology to the same period or comparable temporal periods, whereas robust clustering methods can reproduce the same or very similar clusters in different temporal periods. This index can be obtained through the cross-validation technique that compares the clusters obtained for a long period with groups obtained for shorter times and contained in the former period and that can be selected specifically or randomly.

If we choose a number of clusters (for the short periods) identical to the clustering we are testing, we will be able to cross the common elements in each cluster of the short period with the long period. Hence, each short-period cluster will present a higher percentage of its days in common with any of the long-period cluster. The stability of the long-period clusters is defined as the percentage of common days with its most related short cluster, getting the percentage with respect to the total number of days of the short cluster. If the cross-validation test is made, considering more than a short period, the stability of each group is defined as the average of their stability. The stability of the whole clustering is defined as the average of the stability of all the clusters of the long period. Differently from the quality, the stability of a clustering increases when the number of considered clusters is lower, since the possibilities of assigning elements in different clusters is lower (Fereday et al. 2008; Michelangeli et al. 1995).

The skill of both algorithms, K-means and SANDRA, was tested over the study region for wintertime (DJF). A more detailed information of these algorithms can be found in Hartigan and Wong (1979) for K-means and in Philipp et al. (2006); Fereday et al. (2008) for SANDRA. Both were applied to the principal components of the data. For the initialization of both algorithms, we used the same seeds achieved trough a K-means multistart clustering, initialized 1,000 times with seeds randomly chosen in each run. SANDRA algorithm was specifically developed to allow relocation of 15 % of the furthest elements from each cluster. The consideration of these elements to form the neighborhood reduces the computational cost required by SANDRA and even more if we chose a cooling coefficient of 0.9 (as used in this study), which forces to run the algorithm an important number of times for a higher approach of the cluster to the global optimum (Fereday et al. 2008). Therefore, 1,000 runs were performed considering the highest quality run as the definitive clustering.

For the stability tests, two periods of 50 and 25 years were used; the latter included in the former. For both periods, the seeds were those obtained through K-means multistart in the shorter period. The quality results obtained by SANDRA were slightly better, but the stability of the clusters found for K-means was notably higher (stabilities over 75 % in 75 % of the clusters; with SANDRA just 40 % of the clusters achieved that stability). The stability results essential for analyzing other characteristics of the CTs (frequency, persistence, and transitions), together with the higher computational time required by SANDRA, led us to consider K-means as clustering algorithm.

3.1 Final clustering method

Albeit the comparison tests described before used the seeds from the K-means multistart, for the final clustering, we decided to use seeds coming from a PC-ModeT clustering whose ability to form groups with physical sense has been demonstrated elsewhere (Huth 1996). The PC-ModeT method uses the T-Mode EOFs obtained from the PCs of the S-Mode used here (Section 3.0.1), normalizing the components by the squared root of their associated eigenvalue. To provide a higher physical sense, the T-Mode EOFs were rotated using the varimax method (Richman 1981). The T-Mode EOFs represent temporal variability patterns, so that the days with a weight contribution similar to those modes also present similar spatial patterns. PC-ModeT utilizes this property to assign the elements to different clusters. So, the days whose highest weight presents the same sign in the same EOF are grouped together. The positive or negative sign of the weights defines the number of clusters to consider, twice as many as the number of the PCs retained, allowing a simple and objective election of the number of clusters. The projections onto the EOF S-mode of the centroids obtained from the PC-ModeT were used as seeds for the initialization of K-means run over the PCs of the S-mode.

4 Results

4.1 Seasonal circulation types

Figure 2 depicts the PCA results when applied to the reanalysis data for each season. According to the retention method of PCs (Section 3.0.1), in all of them, six components are enough for an accurate representation of the variance, retaining with them the 97 % of the variance for spring, autumn, and summer, and 94 % for summertime. Taking into account the clustering method explained in the Section 3.1, six PCAs define 12 CTs or clusters. In Figs. 3, 4, 5, and 6, the centroids of each cluster obtained for each season are represented. The numbering corresponds to the number (frequency) of situations clustered, so that CT1 is the most crowded. Their relative seasonal frequencies are shown in Table 1.

If we analyze the centroids obtained from a synoptic point of view, some of them belonging to different seasons have a very similar pattern. Hence, the spring and autumn patterns become a mixture of winter and summer patterns. An example of this behavior is shown in the cyclonic situations at the northwestern region of the IP during winter, spring, and autumn (CT6-wi, CT7-sp, and CT8-au), as well as in conditions of low-pressure gradient over the IP, which are more frequent during the warm months (CT2-sp, CT4/9-su, and CT8-au). In order to simplify the interpretation of the 48 CTs obtained, they have been regrouped subjectively (clusters with similar synoptic patterns) into 21 situations (Table 2) with diverse synoptic characteristics over the IP. The naming and order of each of these situations refer to a more generalist clustering in five groups: Anticyclonic (A), cyclonic (C), zonal (Z), summertime (S), and hybrid-mixed (M). The groups A and C cover the CTs presenting an important degree of cyclonity (both negative and positive, respectively) in the surface (SLP) and height variables (Z500). Z group is considered when the patterns defined by Z500 show an important western circulation. S group is related to the summertime situations where mesoscale centers of low pressure appear over the IP, resulting from the strong surface heating inland of the IP. Within these summer types, also similar situations appearing during spring and autumn have been included. They are those with a negligible pressure gradient over the IP. Last, M situations cover those CTs related to the existence of low pressures at the surface and high pressures aloft (or vice versa); that is, situations with a clear disconnection between the low and high levels of the atmosphere.

The CTs obtained form a cluster of synoptic patterns that can be recognized in other previous classifications over the IP. Those classifications were obtained through subjective (Font-Tullot 2000; Gallego 1995) and objective methods (Petisco 2003; Rasilla 2003; Romero et al. 1999). The comparison with all of them is a complex exercise due to the diverse methodologies, atmospheric variables, time periods, and geographic windows considered and also because of the different applications they were designed for. If the comparison is done vs. the classifications obtained with larger windows and lower resolution (5°) (Petisco 2003; Rasilla 2003), a better representation of the extratropical disturbances is obtained in the surroundings of the IP in our classification, together with a higher level of detail in mesoscale meteorological structures. An example is observed in the CTs related to summertime situations where the usual position of the thermal lows formed inland of the IP is clearly depicted (CT1/3-su). Another mesoscale perturbation is the Mediterranean coastal trough, which is a well-known print of the surface pressure field originated by orographic effects after the pass of frontal system through the eastern IP (CT7/8-wi). On the other hand, if comparing with the classification obtained by using similar windows and variables, such as that of Romero et al. (1999), generally a high coincidence is observed between those patterns related to the existence of extratropical cyclones over the IP. The classification of Romero et al. (1999) was developed with the aim of characterizing the CTs responsible for the precipitations over the Mediterranean slope of the IP, therefore it presents an important bias towards cyclonic situations (they only used rainfall days) which hampers the comparison of the rest of CTs obtained here. Last, if we compare subjectively with the 23 situations obtained by Font-Tullot (2000), there are very similar patterns to those observed with the pseudo-subjective 21 generic situations obtained in this work (Table 2). Anyway, several differences are appreciated especially in those patterns related to the presence of deep low-pressure systems located at the Northern Atlantic Ocean, far from the geographic window considered in our classification.

4.2 Seasonal frequency

The seasonal frequency of the different CTs dominating over a region is associated, more or less directly, with the annual cycle of climatic elements (precipitation, temperature, etc.). Here, we will try to relate in a descriptive way the seasonal frequency obtained for each of the five large situations obtained

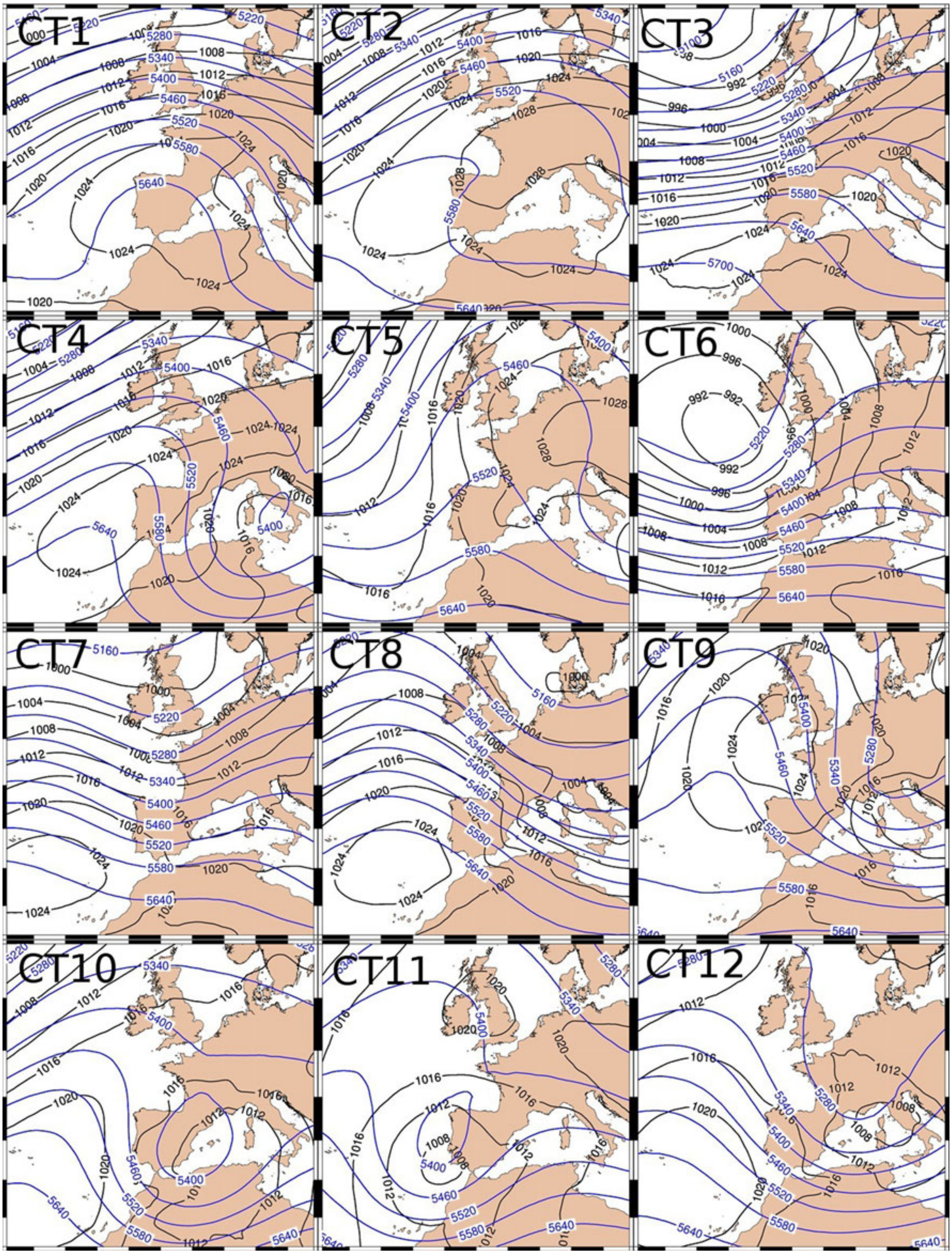

Fig. 3 Wintertime CTs. The order corresponds to the higher or lower number of days grouped within each cluster. *CT1* clusters the largest number of days. *Black* contours show SLP isobars and *blue* contours, Z500

(Section 4.1) to the annual cycle observed over the IP of some climatic elements such as precipitation. It is important to remind that over most of the regions in the IP, a Mediterranean climate dominates, whose essential characteristic is the scarce precipitation during summertime. However, in its northern border (and

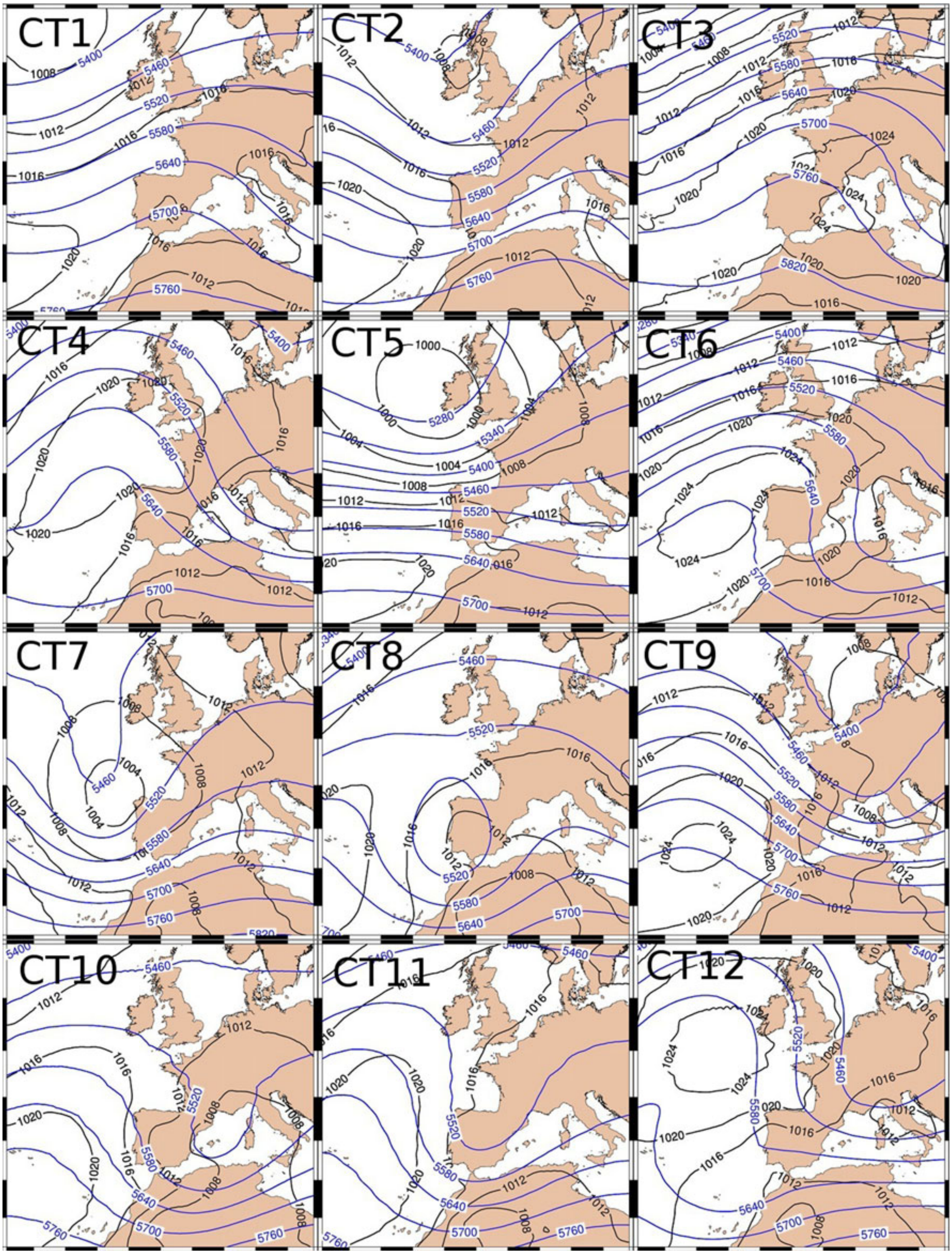

Fig. 4 As Fig. 3 for spring

also in some regions in its western half), they present an Atlantic-influenced climate and therefore a more regular precipitation regimen throughout all the year (Font-Tullot 2000).

Table 1 shows the seasonal frequencies for each of the CTs obtained, whereas Table 3 depicts the seasonal frequencies for each of the five general situations (Table 2). Generally, a dominance of anticyclonic

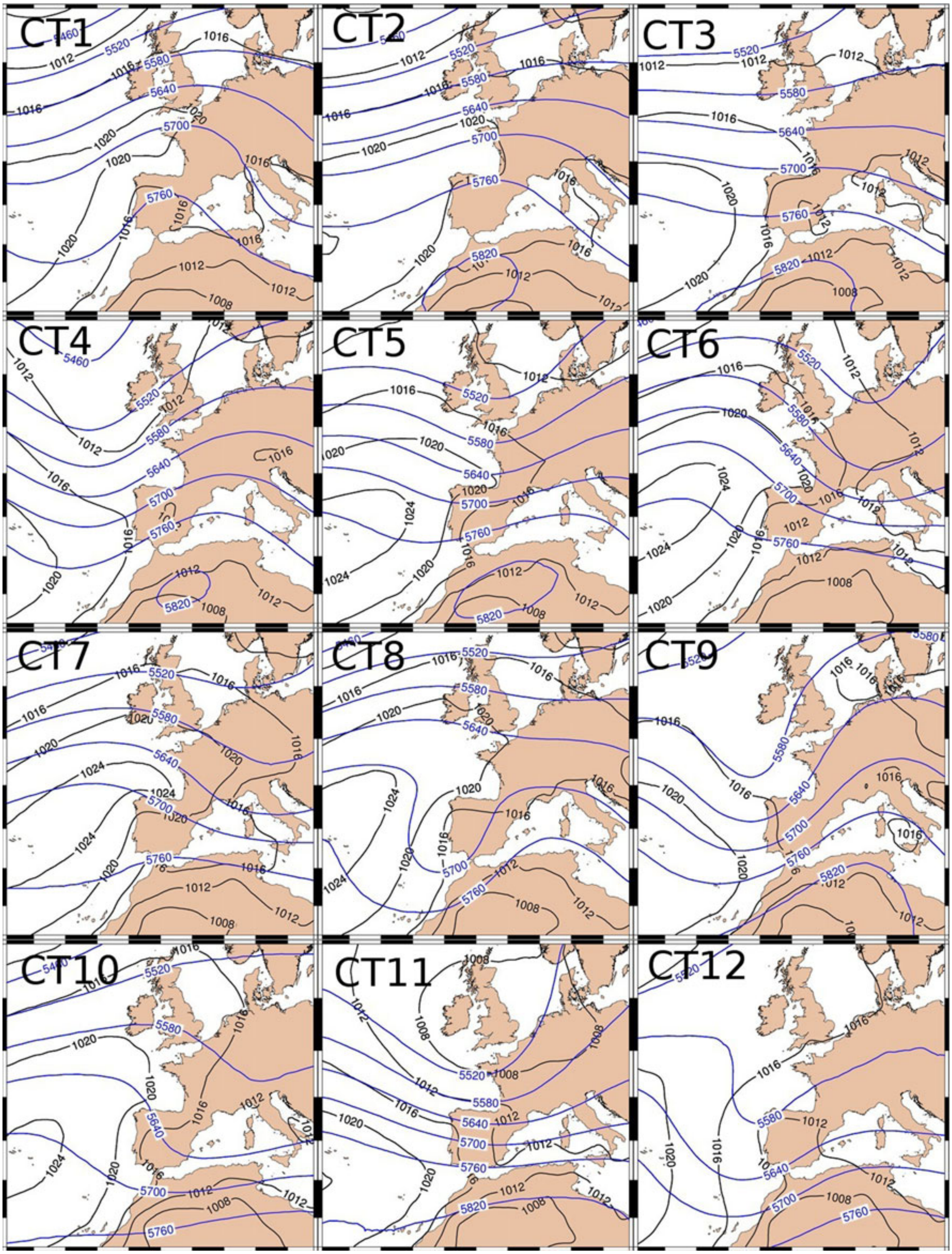

Fig. 5 As Fig. 3 for summer

patterns is observed during most of the year (except during summertime), especially in winter, when their frequency is close to 50 % of the total frequency of the rest of situations. Also in winter, the zonal situations present a higher frequency (around 20 %) which is the highest value of the year for this kind of situations. During wintertime, the frequency of cyclonic situations is similar to that of the zonal; however, they suffer a

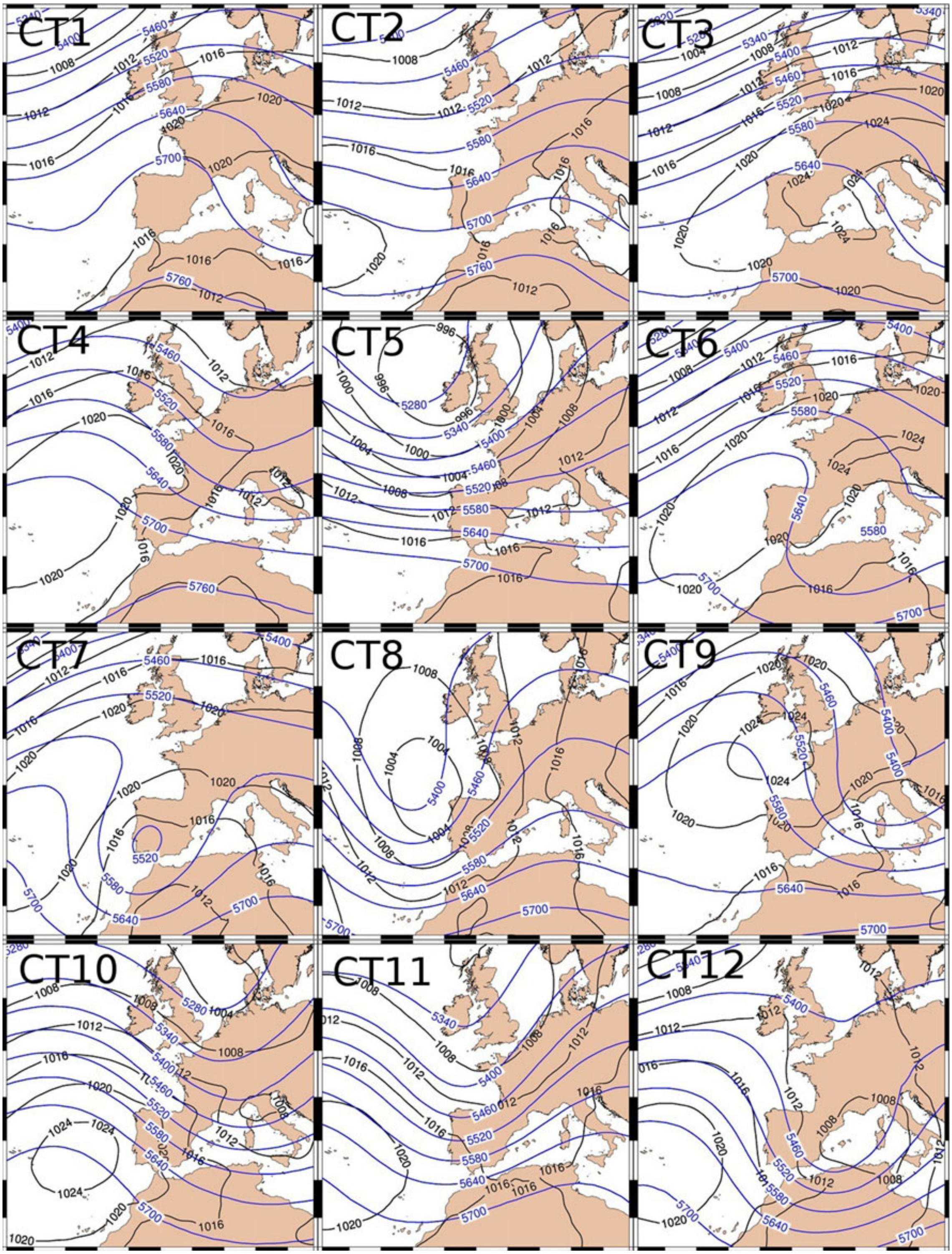

Fig. 6 As Fig. 3 for autumn

significant increase in springtime, reaching its highest annual value, 30 %. Similarly, the patterns with negligible pressure gradient over the IP (stagnant situations) acquire a higher leadership, conversely to what happens with zonal and anticyclonic situations. The increase during springtime of cyclonic and stagnant situations favors the development of atmospheric instability, which is related to the increase of the precipitation days

Table 1 Relative seasonal frequencies of CTs

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10	CT11	CT12
Winter	13.9	12.3	9.5	9.0	8.0	7.5	7.3	7.0	6.8	6.4	6.3	5.8
Spring	13.7	9.7	9.2	9.2	8.9	8.5	7.8	7.4	6.8	6.6	6.2	5.9
Summer	12.5	12.4	10.9	9.9	9.7	8.6	8.1	6.6	6.3	6.0	4.9	4.0
Autumn	15.2	13.6	12.4	8.9	7.7	7.3	6.5	6.3	6.1	5.8	5.8	4.4

Units are percentage

observed in several regions of eastern part of the IP (Font-Tullot 2000). In summer, the low-pressure gradients dominate; at the same time, there is a nearly complete absence of the cyclonic perturbations and a notable decrease of the zonal circulation. This enhances the atmospheric stability and weak surface winds, favoring the formation of breezes, helping to the cooling of the continental mass of the IP. This atmospheric situation, very unfavorable for the development of precipitation, only allows the development of thunderstorms at certain regions that, because of their geographic characteristics, enhance the convergence of surface land and sea winds. In autumn, an increase in the frequency of anticyclonic and stagnant situations is produced, reaching similar values to those during springtime. On the other hand, the frequency of cyclonic and zonal situations is still very low. Regarding the annual distribution of the frequency of hybrid situations, it is low in spring and autumn. In winter and summer, it presents important values. In winter, cold anticyclones can be generated (high continental pressures and lows aloft). Instead, in summer, one warm cyclone appears (warm low pressure at surface and highs aloft). Both situations keep an stable atmosphere over IP.

4.3 Quality and stability of CTs

This section depicts the quality and stability indices (see Section 3.0.2) of the different CTs obtained. Taking into account the quality results, the best (worst) indices are obtained in winter (summer), with values of 53.9 % (47.2 %). In equinoctial seasons, the values are similar, 52.2 % in autumn and 51.1 % in spring. These results highlight an important fraction of the original

Table 2 Patterns described by the CTs

Description	CTs
A1. Anticyclone over the IP at all levels	CT1-wi, CT3-sp
A2. Anticyclone of meridian axis at the eastern Azores	CT8/12-wi, CT9-sp, CT10-au
A3. Anticyclone at the SW UK with anticyclonic circulation aloft over the IP	CT9-wi, CT4-sp, CT9-au
A4. Anticyclone at the NW IP of tilted axis (SW-NE) with northern circulation aloft	CT4-wi, CT6-sp
A5. Anticyclone over the Azores of tilted axis (SW-NE) with NW circulation aloft over the IP	CT6/7-su, CT4-au
A6. Anticyclone of zonal axis over central Europe with anticyclonic circulation aloft over the IP	CT5-wi, CT3-au
C1. Extratropical Cyclone at the NW IP	CT6-wi, CT7-sp, CT8-au
C2. Extratropical Cyclone towards the S IP	CT11-wi, CT8-sp, CT12-su, CT7-au
C3. Extratropical Cyclone at the E IP	CT10-wi, CT10-sp, CT12-au
C4. High-amplitude trough over the IP	CT11-sp
Z1. Extratropical Cyclone close to the UK with zonal circulation aloft over the IP	CT3/7-wi, CT5-sp, CT11-su, CT5/11-au
M1. Anticyclone of zonal axis over central Europe with cyclonic circulation aloft over the IP	CT2-wi, CT6-au
M2. Anticyclone at the SW UK with cyclonic circulation aloft over the IP	CT12-sp
M3. Anticyclone of tilted axis (SW-NE) over the Azores with SW circulation aloft over the IP	CT5-su
S1. Stagnant situation over the IP and anticyclonic ridge aloft	CT1-sp, CT1-au
S2. Stagnant situation with SW circulation aloft	CT2-sp, CT4/9-su, CT2-au
S3. Thermal low at the SW IP	CT1-su
S4. Thermal low at the central IP	CT2-su
S5. Thermal low at the SE IP	CT3-su
S6. Thermal low at the central-S IP and trough aloft	CT8/10-su

Five general situations were used for the classification: *C* cyclonic, *A* anticyclonic, *Z* zonal, *M* hybrid-mixed, and *S* summer patterns

Table 3 Seasonal frequencies of general situations

	A	C	Z	M	S
Winter	50.5	20.2	16.9	12.3	0.0
Spring	33.9	28	8.9	5.9	23.4
Summer	16.7	4	4.9	9.7	64.7
Autumn	33.2	12.8	13.5	7.3	28.8

variance not explained by the clusters, indicating the existence of a strong heterogeneity with respect to the type of situations within each cluster, which is normal when taking into account the high number of grouped episodes. When comparing the results to other similar studies, small differences can be found. Philipp et al. (2006) obtained a value of 51.7 % for 12 CTs clustering for wintertime months (DJF) during an exercise of comparison among different clustering algorithms. This value, the best of all those obtained with each method utilized, was obtained with SANDRA algorithm. Together with the results obtained here, this fact reveals that values around 50 % could be usual in this kind of clustering works. Unfortunately, there is a lack of studies to help confirm robustly this hypothesis.

Regarding the stability analysis, a cross-validation process similar to Fereday et al. (2008) has been used. We have crossed the dates of the clusters obtained in the 50-year classification with those others of the clusters obtained with the half of years. They were considered 100 short-periods in which days were randomly selected among the days of the long period. The classifications for each subsample was performed using the seeds obtained for the whole period. The stability results obtained can be found in Table 4. Some CTs present stabilities around 90 % (CT1/2/10-wi, CT4-sp, CT8/10-su, and CT1/2/3/10-au), while some other CTs do not exceed 55 % (CT11-sp). If we analyze the mean seasonal stability of each of the seasonal classifications (mean of the stabilities of the clusters, last column in Table 4), the results indicate higher stability in autumn (82.8 %) and summer (78 %), meanwhile stabilities decrease in winter (77.6 %) and spring (72.0 %). Comparing the wintertime stability value with that of Fereday et al. (2008) (73 %), obtained for 10 CTs in January and February 1949–1999, in our case, is slightly higher. Again, the limited available number of classification studies hampers further criticism about the obtained results.

4.4 Trends in the CTs

The analysis of the series of seasonal frequency of the CTs may help on understanding some of the dynamical causes compatible with the observed changes in variables like precipitation and temperature over the IP throughout the second half of the twentieth century. Table 5 depicts the trends of the series, together with the *p* values obtained by the Mann–Kendall test (Kendall 1970). Results highlight that just a few CTs present significant trends at 95 %: two winter CTs (cyclonic, CT6/10-wi) and one CT in spring, also cyclonic (CT5-sp). All of them have a negative trend but present a different intensity. In CT6-wi, the trend (−0.13 day/year) is twice as much as that obtained for the other two patterns. If taking into account a lower significance level (90 %), three additional patterns appear with significant trends: two in winter (CT2/3-wi), anticyclonic and zonal, respectively, and one in summer, CT3-su. In this case, all of them show a positive trend. An interesting result is that there is no significant trend at all in the autumn CTs.

When comparing these results to those of other previous studies, we can find some similarities. In particular, the decrease of the number of CT6-wi situations and the increase of CT3-wi is a result compatible with the movement towards the north of the storm-track observed in Paredes et al. (2006). It could be related to the decrease of winter precipitation measured in most of the IP (Serrano et al. 1999). Another result compatible with that of other author (e.g., López-Bustins et al. (2008)) is the positive (negative) trend (despite not significant) observed in most of the winter anticyclonic (cyclonic) patterns. The decrease of the frequency springtime of CT5-sp, as well as the nonsignificant increase in the blocking situations over the IP (CT3/6/9-sp) may be related to the decrease observed for precipitation during this season.

Although the trends obtained are just valid for the IP, their positive or negative sense is similar to the results of Kyselý and Huth (2006), who observed a significant increase of the frequency of anticyclonic

Table 4 Stability (%) of the diverse CTs

	CT1	CT2	CT3C	CT4	CT5	CT6	CT7	CT8	CT9	CT10	CT11	CT12	Mean
Winter	88.7	88.4	73.9	75.6	68.0	78.3	81.6	73.2	65.0	88.5	74.3	76.5	77.6
Spring	78.6	71.0	86.1	59.7	84.4	70.1	80.4	72.3	63.5	80.1	55.2	62.5	72.0
Summer	72.3	83.0	78.7	70.1	78.6	82.3	80.1	90.1	75.3	90.1	84.9	77.2	80.2
Autumn	87.3	87.0	92.4	73.1	85.1	76.0	84.3	90.1	77.2	80.1	82.4	79.0	82.8

Table 5 Trends and *p* values of the seasonal frequency of CTs

CTs	Winter		Spring		Summer		Autumn	
	p value	Trend	*p* value	Trend	*p* value	Trend	*p* value	Trend
CT1	0.2376	+0.080	0.5628	+0.003	0.8830	+0.020	0.4993	–0.028
CT2	0.1275[a]	+0.128	0.4682	+0.035	0.4533	–0.033	0.8961	–0.011
CT3	0.1081[a]	+0.045	0.2157	+0.064	0.1062[a]	+0.070	0.7200	+0.001
CT4	0.2193	+0.041	0.3280	–0.017	0.6652	+0.045	0.4281	+0.038
CT5	0.4778	+0.048	0.0481[b]	–0.059	0.7257	+0.028	0.8129	–0.004
CT6	0.0075[b]	–0.132	0.8831	+0.013	0.6304	–0.013	0.8703	+0.012
CT7	0.6703	–0.019	0.8829	–0.001	0.4314	–0.028	1.0000	+0.002
CT8	0.3104	–0.038	0.4988	+0.020	0.9350	+0.007	0.7313	–0.017
CT9	0.6173	–0.028	0.6526	+0.002	0.7802	+0.004	0.7616	+0.001
CT10	0.0025[b]	–0.057	0.6650	–0.011	0.1721	–0.040	0.3754	–0.023
CT11	0.3561	–0.025	0.9935	–0.022	0.7191	–0.030	0.7009	+0.015
CT12	0.3154	–0.042	0.5785	–0.032	0.1560	–0.033	0.6643	+0.010

The *p* values shown comes from applying the Mann–Kendall test to the seasonal frequency series of the CTs. The trend is expressed in days/year

[a] Denote the values with a 90 % significance level

[b] 95 % significance level

and blocking over the Western and Central Europe, together with a decrease of the cyclonic patterns. Last, we should highlight the negative trend found for CT6-wi, identical to the trend detected for the period of 1850–2000 of the CT6 winter pattern of Philipp et al. (2006), whose synoptic configuration is similar to our pattern.

4.5 Persistence of CTs

An interesting characteristic of the global circulation is the tendency of several situations to persist during a large number of days, provoking blocking situations. Persistence is defined as the duration (or average life) of the events within a same situation. Event is taken as the noninterrupted sequence of days belonging to a situation (CT). Nonetheless, this definition, which takes into account the mean value, can mask that some patterns can present lasting blocking events albeit they have low mean persistence values. Therefore, for a more complete description of the persistence, other parameters of its distribution function have been considered, like extreme values or some percentiles. Shown in Table 6 are the median, mean, third quartile values, and maximum duration of events obtained for the diverse CTs during the different seasons.

The analysis of Table 6 indicates that the anticyclonic situations CT2/1-wi are the most persistent in winter, if we consider the mean values (2.7 and 2.5 days, respectively), with CT2-wi being the pattern with an event that lasts the longest (17 days). Conversely, the zonal situation CT7-wi is the least persistent (mean value 1.2 days). In spring, CT1/3/12-sp are the most persistent types, highlighting the lack of correlation between persistence and frequency for CT12-sp. During springtime there is, generally, a higher persistence of the patterns than in winter. On the other hand, the situations CT1/3/5-sp present the events with the longest duration (13 days), meanwhile CT9-sp (Atlantic blocking) is the least persistent situation (1.5 days). In summertime, the mean persistence of situations presents the lowest spread in all the year, between 1.5 and 2.1 days. In this case, we have considered not only the mean value of the persistence but also its median value in order to discriminate the persistence of the situations. With this criterion, CT10/2-su are the most persistent patterns. In both cases, the surface pattern (SLP) is very similar, but the pattern of the former is related to a trough of SW-NE axis; the latter is related to a ridge of which axis is oriented in the same direction. In this case, the longest event is CT6-su (12 days). The least persistent situations are CT4/5/9/12-su, reflecting a similar Z500 configuration (SW flow over the IP). Regarding autumn, the anticyclonic situation CT3-au has the longest persistence, and CT11-au (related to the pass of a trough over the IP) shows the shortest persistence.

In summary, the main conclusions of this analysis are the following: in autumn and winter, the most persistent situations are those related to an anticyclonic situation with a large extension over Central- and South-Western Europe (CT2-wi and CT3-au), while in summer and spring, they are the stagnant or thermal low situations. On the contrary, the situations with a shorter persistence in autumn and winter are zonal (CT7-wi and CT11-au), in spring related to anticyclonic types and in summer, to a SW circulation in medium–high levels.

Table 6 Persistence for the CTs

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10	CT11	CT12	Mean
Winter													
Median	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	–
Mean	2.5	2.7	1.4	1.5	1.7	1.9	1.2	1.5	1.6	1.5	1.8	1.6	–
3qt	3.0	3.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.1
Max	12	17	6	5	13	9	4	8	6	6	9	5	8
Spring													
Median	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	–
Mean	2.9	1.8	2.4	2.0	1.7	1.9	1.8	2.0	1.5	1.6	1.6	2.0	–
3qt	4.0	2.0	3.0	3.0	2.0	2.0	2.0	2.8	2.0	2.0	2.0	2.0	2.4
Max	13	10	13	11	13	9	8	6	11	7	8	6	9.6
Summer													
Median	1.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0	1.0	–
Mean	2.0	1.9	1.8	1.5	1.6	1.8	1.8	1.8	1.6	2.1	1.9	1.6	–
3qt	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.1
Max	9	7	10	8	6	12	6	7	6	11	7	8	8.1
Autumn													
Median	2.0	2.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	–
Mean	2.4	2.2	2.7	1.8	1.6	2.0	2.0	1.9	2.0	1.6	1.4	1.8	–
3qt	3.0	3.0	3.0	2.0	2.0	2.0	3.0	2.0	3.0	2.0	2.0	2.0	2.4
Max	14	13	25	10	7	9	7	11	6	7	5	5	9.9

Rows show the median, mean, third quartile (3qt), and max values of the persistence (number of days) of the CTs (columns) for each season. Last column depicts the mean value (considering all CTs) of the 3qt and max values.

Last, if we compare the mean seasonal value of the third quartile for different seasons, autumn and spring situations present a longer duration than for winter and summer.

Another interesting aspect of the persistence is the analysis of its interannual variability. For that, the mean annual persistence of the diverse CTs has been obtained; that will allow analyzing the existence of trends in some CTs. Furthermore, averaging the annual values obtained for the diverse patterns belonging to a same season permits the analysis of the season in which the atmospheric circulation presents the highest (or lowest) variability of the persistence.

Results obtained for the analysis of the annual trend (not shown here) indicate the existence of a significant trend at 95 % in two patterns, CT6-wi and CT9-sp. The former has a negative trend similar to that obtained for its frequency series (see Section 4.4). For the latter, a pattern less persistent of springtime (CT9-sp), the trend obtained is positive. If the significance for the trend test is 90 %, there are trends for three more patterns: two in spring (CT3/12-sp, with positive and negative trends, respectively) and one in summer (CT2-su) showing a positive trend.

All trends obtained in spring depict, on the one hand, an increase of the persistence in situations of atmospheric stability (related to scarce precipitations); and on the other hand, there is a decrease in the persistence of those patterns related to precipitation episodes. This result is compatible with the decrease of precipitation measured in the IP during the second half of the twentieth century (Bladé et al. 2010; Serrano et al. 1999; Paredes et al. 2006).

Finally, results regarding interannual variability averaged for all the CTs belonging to the same season highlight that spring and autumn are the periods with a higher variability (Fig. 7), with a standard deviation of 0.90 and 0.85 days, in that order. The values obtained for winter and summer are 0.74 and 0.67 days, respectively.

4.6 Transitions of CTs

Knowing the probability of transition from a CT to another is a useful tool for atmospheric predictability at medium term (James 2007). The transitions resulting from very complex internal processes of the atmospheric dynamics, related to phase changes of the intraseasonal atmospheric waves (Sanchez-Gómez and Terray 2005), can be estimated as the mean probability in which a determined CT evolves towards others.

Figure 8 shows the transition matrices between CTs. Each cell represents the probability that a given CT (row) evolves to another CT (column). Generally, when analyzing the transitions from any CT towards the rest for each season, we observe the existence of some transitions more probable than the rest, as well as an

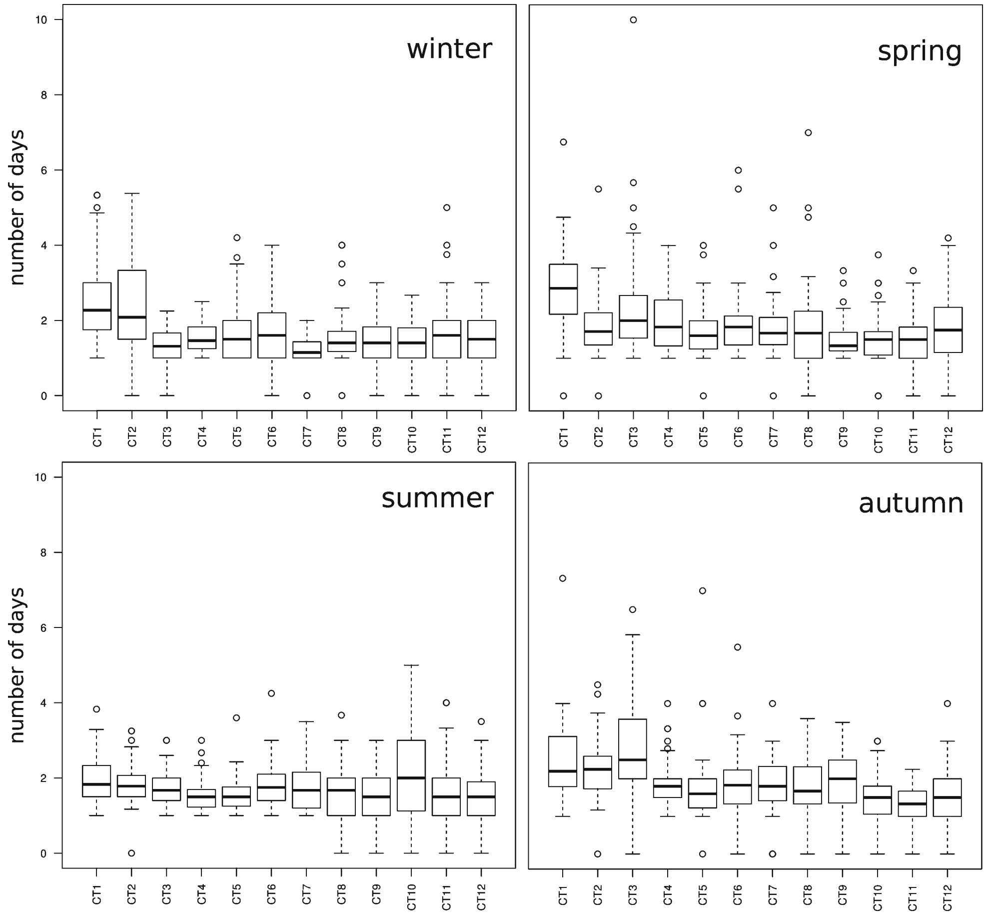

Fig. 7 Boxplot of the interannual variability of the CTs persistence. Period: 1958–2008

important number of transitions with a low probability. Here, it is worth reminding that the matrices include an important noise signal due to the large heterogeneity of each cluster defining the diverse CTs. The noisy mixture of situations can provoke the appearance of fictitious residual transitions with no physical sense.

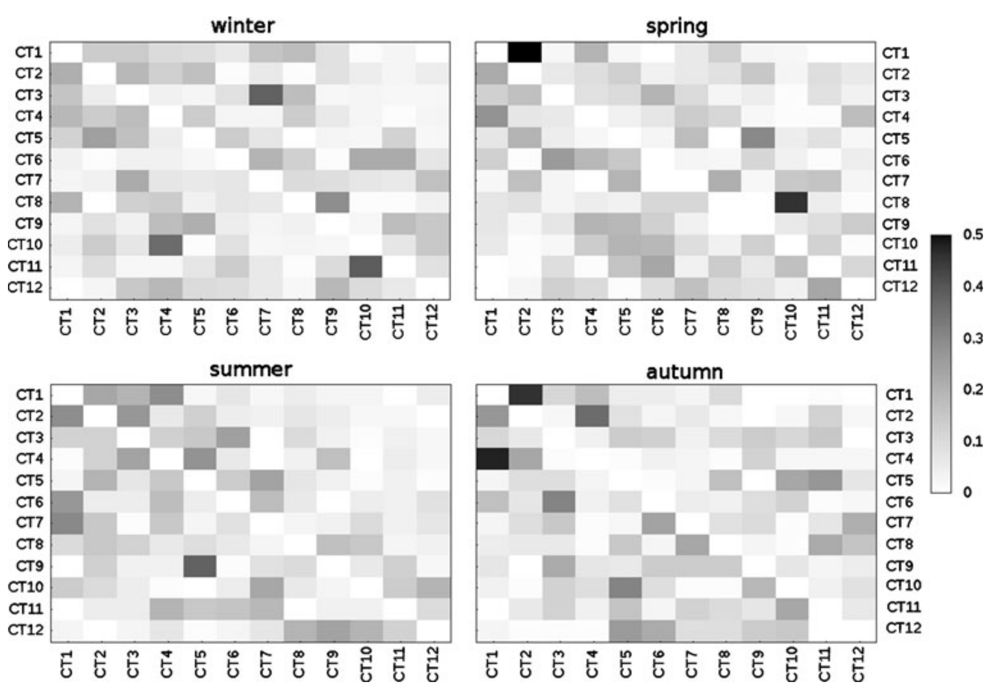

Fig. 8 Transition matrices obtained for CTs in winter (*top left*), spring (*top right*), summer (*bottom left*), and autumn (*bottom right*). The *darker* or *lighter* tone is related to a greater or lesser probability, respectively, of transition from a CT (*row*) towards another CT (*column*)

Hence, the analysis of transitions included here has just considered the most probable transitions, admitting the hypothesis that, in these cases, the ratio signal/noise will be higher.

The analysis of the most probable transition sequences (starting from any of the CTs) indicates that some of them respond to cyclic sequences (origin and end at the same CT), meanwhile the rest are just linear sequences finishing at some CT leading to a cyclic transition. Considering all the most probable transition sequences, a total of seven cycles are obtained: two in winter, spring, and autumn, and one in summer. One of the winter cycles represents a sequence of transitions including exclusively anticyclonic situations (winter CT1→8→9→5→2→1), while in the other, the transitions are between zonal situations (winter CT3→7→3). The anticyclonic cycle seems to describe a clockwise movement of a high pressure system (Fig. 9, left), which is located initially over the IP and then moves to the Atlantic and the SW UK, and from there, it moves to Central-Northern Europe, with the end of the cycle in the western part of Central Europe. The second winter cycle is related to the alternation of the zonal situation (CT3-wi) and the pass of troughs with a low amplitude over the IP (CT7-wi). The configuration of the pressure systems playing a role in this cycle is analogous to the negative phase of the variability mode of the North Atlantic, whose most notable influence over the IP is the appearance of very wet winters in the Atlantic face of the IP.

Two cycles appear in springtime. The first includes the two most frequent CTs, (spring CT1→2→1) and stands for a transition between stagnant situation at the surface with the alternation of ridges and troughs over the IP. The second incorporates just two anticyclonic situations (spring CT3→6→3). The former is a meteorological situation provoking a great atmospheric stability over the IP, but in the latter, a cold air mass with a northern component is observed in the eastern part of the IP (see Z500 field for CT6-sp) and that it can enhance the development of instability over this region. This result can explain, in part, the higher number of rainy days observed in this region in spring. During the summer, the cycle is mixed and is formed by two stagnant situations and two anticyclonic situations (summer CT1→4→5→7→1). It describes the west–east evolution of trough aloft over the IP, with corresponding modifications in the SLP field (movement of a region of low relative pressures initially at the SW of the IP towards the center and from there to SE Spain). In autumn there are, once more, two cycles. The first is very similar to the summer cycle (autumn CT1→2→4→1→), while the second (autumn CT5→11→10) describes the transitions from the zonal circulation to the deepening of troughs over the IP and the later atmospheric stabilization with the appearance at the end of the cycle of an anticyclonic region at the western IP. None of the cyclic sequences described responds exclusively to cyclonic cycles.

For longer linear sequences with a higher number of CTs, their origin is analogous for winter, spring, and autumn (extratropical cyclone at the NW IP, CT6-wi, CT7-sp, and CT8-au), and their end is an anticyclonic situation leading to a cyclic sequence (see Fig. 9, right). Overall, the sequence describes the stabilization process of the atmosphere over the IP. Conversely,

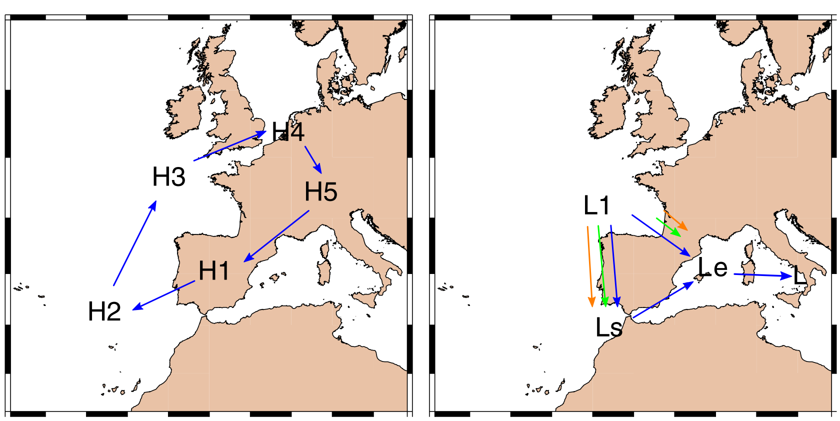

Fig. 9 *Left*: Winter anticyclonic cycle. We can see the clockwise movement of a high-pressure system located initially over the IP (*H1*), and finally in the western part of Central Europe (*H5*). *Right*: Transition of a low-pressure system from the NW of the IP (*L1*) to the South (*Ls*) or to the East (*Le*). The length of the arrows indicates the greater probability of transition (*long arrows*) or lesser (*short arrows*). The colors of the arrows represent the seasons (*blue*: winter, *green*: spring, *orange*: autumn)

none of the CTs transits at the maximum probability level towards the situation originating this longer sequence. On the other hand, this particular situation evolves to two cyclonic situations, cyclone at the south IP (CT11-wi, CT8-sp and CT7-au) and extratropical disturbance at the east IP (CT10-wi, CT10-sp, and CT12-au) showing both transitions a strong seasonal dependency. Therefore, the transition towards both situations in winter has the same level of probability (22 %); while in summer and autumn, the probability is higher towards the low located to the south (21 % vs. 15 % in spring; 23 % vs. 15 % in autumn). Hence, the equinoctial seasons the atmospheric dynamics seems to present a more meridional component, the southern movement of the extratropical cyclone being frequent. These results are in agreement with the lasting persistence of the situations obtained for these seasons, because the meridional circulation leads to a higher persistence of the situations. Finally, following the longest linear sequence, the transition from a extratropical cyclone located at the south IP towards the low located at the east presents one of the highest probabilities (40 % in winter and spring) among those obtained for all the CTs. The result confirms the usual eastern movement of this type of extratropical perturbations developed at mid-latitudes. Conversely, the opposite transition is not very likely (Fig. 8).

5 Conclusions

This work presents a new seasonal classification of CTs centered over the IP. The classification updates and completes others developed previously for the IP. For that, we used a clustering of the PCs obtained jointly for the daily reanalysis and analysis fields of SLP and Z500 (ERA40) covering the period 1958–2008. As a clustering method, we used K-means, initialized from seeds coming from a PC-ModeT cluster, which allows a less subjective selection of the number of clusters than other methods. K-means provides more stable clusters when starting from a specific group of seeds, as shown in a previous exercise of comparison against SANDRA clustering method. The stability of the clusters provided by K-means turns it into a reliable method for analyzing some of the characteristics of the clusters, such as frequency, persistence, and transitions.

Overall, 12 CTs were obtained for each season. Most of them were very similar to those obtained in other previous classifications. The main differences are caused by the classification method followed (geographical window, atmospheric variables used, spatial resolution of reanalysis data, clustering method, etc.). The CTs obtained for wintertime are different from summer, meanwhile autumn and spring show a hybrid/mixed pattern between the winter and summer. Hence, the proposed pseudo-subjective classification of the CTs in 21 situations groups those patterns whose centroids are very similar along the year. The situations of this latter classification are included within another more general classification that divides the situations in anticyclonic, cyclonic, zonal, summertime and hybrid-mixed.

The analysis of the frequency of the CTs describes accurately the annual cycle observed for the main synoptic structures over the IP. The high frequency of anticyclonic and zonal situations in winter, cyclonic in spring, and situations with a low-pressure gradient in summer are some of the results derived from the joint analysis of the frequency of the patterns belonging to each general category. On the other hand, the trend analysis of the frequency of the diverse CTs reveals the nonexistence of significant trends (95 %) in most of them, except for three cyclonic CTs occurring in winter and spring. The most important among them (decreasing) is produced in the winter pattern, whose centroid depicts a deep low northwestern the IP. However, some trends have been found (although not very significant) in other patterns. In this sense, an increase of the frequency of most of the anticyclonic situations in winter and spring has been observed, together with a decrease in cyclonic situations. This result is similar to other studies, justifying some of the likely causes of the decrease observed in winter and spring precipitation over the IP in the last 50 years.

With respect to the analysis of persistence, generally the most persistent CTs are the most frequent too (formed by a greater number of episodes), albeit this rule does not always occur, as in CT12-sp, a blocking situation in the North Atlantic Ocean, whose persistence is high against its low frequency . Generally, the most persistent situations in winter and autumn are those related to an anticyclonic region with a noticeable extension over the Central- and Southern-Western Europe; meanwhile, for summer and spring, these persistent situations show low-pressure gradients in surface and aloft fields. Conversely, the least persistent situations in autumn and winter are zonal (CT7-wi and CT11-au), in spring, they are anticyclonic, and in summer, they are related to a southwestern circulation in medium–high levels. Broadly, when focusing on the averaged value of the third quartile of the persistence for every CTs of a season, results indicate that in spring and autumn, the patterns may result more persistent than in winter and summer. The interannual variability of the mean persistence has been analyzed, giving a higher value in spring and autumn. Also, the trend of the mean persistence of the CTs shows a negative trend very significant in the same winter pattern as that experiencing a similar trend in the frequency (CT6-wi). Moreover, in spring, there is a very significant positive trend of the least persistent pattern (CT9-sp), which is related with a situation depicting blocking in the North Atlantic Ocean. The rest of the CTs do not show significant trends.

The analysis of the transition sequences among the different CTs has also been shown in this work. In order to avoid the noise of each cluster, we have just considered in the analysis those transitions with the highest probability. We have observed cyclic and linear sequences. Those cycles are present in all seasons. The largest cycle, involving a higher degree of CTs, is produced in winter and is formed exclusively by anticyclonic situations justifying the high frequency of this type of situations obtained for wintertime. The rest of the cycles represent the destabilization and later stabilization of the atmosphere, alternating patterns related to zonal circulation and with troughs and ridges over the IP. It is important to highlight the nonexistence of cyclonic cycles. With respect to the linear sequences, the longest (that involving a higher number of patterns) has the extratropical cyclone located at the northwest of the IP as origin. This usually moves towards other two situations: extratropical cyclone at the south of the IP (sagging of the trough to low latitudes) or extratropical disturbance at the east of the IP (trough moving eastwards). The probability of transition towards both situations is identical in winter; however, moving to the south is more probable in spring and autumn. This fact suggests that in spring and autumn, the atmospheric circulation presents a meridional component which is more important than in winter, supporting the previous results obtained regarding the higher mean persistence of the spring and autumn patterns.

The classification proposed not only describes accurately some of the known characteristics of the circulation over the IP, as its seasonal distribution, but also presents some new concepts related to the persistence and the transition among patterns. On the other hand, it is beyond the scope of the paper to quantitatively describe the degree of correlation with variables like precipitation and temperatures; however, some of the future works currently going on are related to the development of a downscaling method based on the degree of correlation between the CTs obtained and the anomaly patterns observed in precipitation and temperature at a regional scale. The analysis of those correlations will allow discussing about the trends observed in the CTs and their influence in climatic variables. It will also complement the assessment of the CT classification obtained here.

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