Daily atmospheric circulation patterns for Catalonia (northeast Iberian Peninsula) using a modified version of Jenkinson and Collison method

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ABSTRACT

The Western Mediterranean, in common with other subtropical regions, has certain characteristics that make a purely surface-based synoptic classification inadequate. Sometimes, despite the surface synoptic situation not being conducive to precipitation, a depression aloft can trigger convection and produce strong rains and flash floods. To account for this, we develop a new synoptic classification centred on Catalonia (north-east of the Iberian Peninsula) which combines upper air and surface pressure situations. The existing Jenkinson-Collison classification of the surface pressure field is combined with a new simplified upper air classification based on 500 hPa geopotential height. Despite a reduced number of types at 500 hPa, the combination of both surface and 500 hPa gives many potential combinations. A reduction in the overall number was achieved by adjusting the combined classification to replicate the manual classification of Martin-Vide. The final classification is reduced to 13 synoptic patterns each of which provides a clear and well-defined daily synoptic situation. It is used to characterize days with/without cold air pool (CAP) events, derived from a network of 50 temperature sensors distributed across Cerdanya in Eastern Pyrenees. We show our new classification to be better at discriminating strong CAP days from no-CAP days than classifications based on surface pressure alone. Thus there is potential for the classification to be used by forecasters as a first step for predicting temperature inversions and weather in the Eastern Pyrenees.

1. INTRODUCTION

Although an increase in computation power has facilitated the use of high-resolution atmospheric circulation models to examine local climate problems, this does not displace the need for synoptic meteorology. Still today, forecasting routines usually include a synoptic point of view (Athar and Sara, 2014) and the general recommendation in forecasting protocols is to downscale predictions from synoptic to local scales, to take interactions between scales into account (Snellman, 1982; Lanicci, 2003).

In the light of a continuing need for a synoptic approach, the action COST-733 attempted to unify criteria for developing reference synoptic classifications stating that the best synoptic classification depended on the application (Philipp et al, 2010). The project subsequently became a critical reference in synoptic meteorology, in particular identifying constraints that must be satisfied by a synoptic classification (Tveito et al, 2016). Any classification should be automated (objective), show physical sense and be straightforward to apply. Different synoptic types should produce different weather conditions on the ground and in cases where the surface and upper air are often decoupled, it is mandatory to include upper-level types (often 500 hPa).

The first manual attempts to catalogue synoptic types were in the 1940s and were dependent on human intervention, often involving some degree of subjectivity. Bauer et al (1944) developed a manual classification covering Central Europe, which was improved by Hess and Brezowsky (1952). Pédelaborde (1957) created a manual classification of “weather types” for Paris. Some years later, Lamb (1972) designed a manual synoptic classification for the British Isles based on air flow direction and isobaric curvature. Towards the end of the 20th century, the evolution of computing capabilities allowed the development of objective classifications based on pressure fields. Lund (1963) developed the first objective classification, relating charts through calculation of temporal correlations between grid points of daily sea level pressure charts. Some years later, Jenkinson and Collison (1977) built an objective classification to replicate the Lamb manual classification. Another example of objectivizing a manual classification was James (2017) for the Hess-Brezowsky manual classification (Hess and Brezowsky 1952). More recently, many classifications have been developed based on statistical methods, such as Principal Component Analysis (Von Storch and Zwiers, 1999; Yarnal, 1984;

Barry and Carleton, 2001), clustering (Valverde et al, 2015), synoptic objective processes (Fernández et al, 2003; Soriano et al, 2006), or machine learning algorithms such as Self-Organizing Maps (Michaelides, 2001; Michaelides et al, 2007; Nishiyama et al, 2007).

Focusing on the Iberian Peninsula, there have been several examples of manual synoptic classifications. The first was carried out by Albentosa (1973), inspired by the work of Pédelaborde, but applied to Catalonia. Some years later the Clavero and Raso (1979) classification covered the Iberian Peninsula and Balearic Islands. Finally, Martin-Vide (1987) developed a very simple manual synoptic classification for the Iberian Peninsula. Automated synoptic classifications over the Iberian Peninsula have included many based on PCA and cluster analysis (e.g. Romero et al, 1999; Serra et al, 1999, Lemus- Canovas et al, 2019). The most widely used was perhaps that of Esteban et al. (2006) which covers all of Western Europe. The Jenkinson-Collison classification has also been adapted for the Iberian Peninsula (Goodes and Palutikov, 1998; Trigo and DaCamara, 2000; Spellman, 2000; Pepin and Kidd, 2006; Grimalt et al, 2013; Ramos et al., 2011; Ramos et al., 2015; Martin-Vide, 2016). Despite its wide use, types are defined using only surface information and do not take into account the structures aloft, which are crucial in the Mediterranean area (Martín-Vide, 2001). This deficiency is particularly notable for synoptic surface types with airflow coming from the Mediterranean Sea, notably easterly and south-easterly flows, or in situations with a slack pressure gradient (often classed as undetermined pressure gradient). In such cases, very different weather types can result for the same surface synoptic type, depending on the stability above (Miró, 2017).

This paper therefore presents a new synoptic classification for the Western Mediterranean centred on Catalonia (the northeast of Iberian Peninsula) inspired by the Jenkinson and Collison classification (Miró, 2017), but modified taking into account 500hPa patterns. A reduction of the possible number of combined synoptic patterns is achieved through simulating the existing manual classification of Martin-Vide (1991).

Validation of the new classification is performed by assessing its ability to discriminate patterns conducive to cold air pool (CAP) formation in the Cerdanya Valley, located in Catalonia. During nights with clear skies and calm conditions, surface temperatures drop rapidly forming a thermal inversion layer that is also known as a CAP. Several studies have characterized this process in the region (Pepin & Kidd 2006, Lundquist et al 2008;

Pagès et al, 2017; Conangla et al, 2018, Miro et al. 2018). Synoptic conditions on days prone to CAP or no-CAP will be classified using the new classification and results compared with those based on the surface Jenkinson-Collision classification alone.

2. STUDY AREA

The study area is centred on Catalonia (north-eastern Iberian Peninsula) approximately from 41-43°N and 0-3.5°E. The climate is dominated by the seasonal cycle of mid-latitudes and by the temperate westerly jet stream, especially in winter, but sometimes sub-tropical influences appear, especially in summer. Catalonia has complex topography and is surrounded in the east and south by the Mediterranean Sea. The Pyrenees form a boundary in the north and the Ebro Valley in the west (Figure 1). The Cerdanya basin is located in the upper reaches of the river Segre, with an orientation running from east-northeast to west-southwest (Figure 1). The basin is approximately 45 km long, 15 km wide and is flat-bottomed. The valley floor lies at around 1000 m above sea level and the surrounding peaks are higher than 2000 m. Thus, although wide, the valley also has considerable elevation range. Due to the topographical setting, air masses coming from the Atlantic Ocean (from between south-west and north) are relatively dry due to the upstream protection of high-elevation central Iberia to the south-west and the Pyrenees range to the west and north. Most moisture is imported from the Mediterranean from the east.

The configuration of the Cerdanya basin encourages Cold-Air Pool (CAP) formation since valley narrowing to the south-west makes it difficult for down-valley flow to escape fast enough. Thus the basin, and its wider context, have been studied in terms of thermal inversions and CAP generation in past papers (Pepin and Kidd, 2006; Jimenez and Cuxart, 2014; Pages et al. 2017; Miró et al., 2018).

3. DATA

We used ERA-Interim reanalysis (Dee et al. 2006) for constructing and validating the synoptic classification. This was provided by the European Centre for Medium Range Weather Forecasts (ECMWF). Data covers 1979-2017 and the fields used were sea level pressure and geopotential height at 500 hPa at 00 UTC.

To measure temperature profiles, forty HOBO U23-001 sensors (temperature/relative humidity) were installed along the Cerdanya valley and in areas immediately outside the watershed, in several transects (Miró et al., 2018) (Figure 1). Observations were recorded every 30 minutes from July 2012 until July 2017. The accuracy of the temperature sensor is ± 0.21 °C and the operating range from -40 °C to 70 °C, adequate for local scale temperature monitoring (Whiteman et al., 2000). In mid-latitudes there are large contrasts in radiation regimes between north and south facing slopes and therefore three transects were installed on each aspect (north and south side of Cerdanya). One transect was installed in the adjacent Conflent valley, starting at Fontpedrouse (Figure 1).

4. METHODOLOGY: SYNOPTIC CLASSIFICATION

The Jenkinson and Collinson objective classification at the surface was combined with one following a similar scheme applied to geopotential height at 500 hPa. As the traditional Jenkinson-Collinson classification has 27 types, a simple cross-tabulation will result in 27×27 (i.e. 729) possible combinations meaning that a consolidation is necessary. As the synoptic structures at 500 hPa tended to be more clearly defined, several types at 500 hPa could be combined, but this simplification was not enough. We therefore used the manual classification created by Martin-Vide (1991) to consolidate different surface/upper air combinations further.

4.1. Jenkinson and Collinson: surface level (JC_{sfc})

The Jenkinson-Collinson classification is based in calculating approximations of some atmospheric parameters over a simplified grid, that could be of 9 or 16 points. Some authors use the original 16 grid points (Jenkinson and Collinson, 1977), but others use a 9 grid point version, developed by El Dessouky and Jenkinson (1975). Rarely are technical reasons given for choosing the exact configuration. Over the Iberian Peninsula, some authors have used a 9 point grid (Grimalt et al, 2013) centred over the Western Mediterranean, while others have used a 16 point grid (Trigo and DaCamara, 2000; Vicente-Serrano & López-Moreno, 2006) over the Western Iberian Peninsula. It is not easy to compare these schemes directly because each grid type is focused on a different climatic area. Only one paper mentions sensitivity of the Jenkinson-Collinson classification to the grid chosen (Demuzere et al, 2009). Working with more grid points reduces the number of unclassified cases, but this work also concluded that it is important

to choose a resolution related to the typical synoptic structure being examined. Differences between a grid spacing of 10° and 5° were not significant in this regard in the above study in terms of discriminating unclassified structures.

In this study therefore, after comparing results using grids of 9 and 16 points and observing slight differences (not shown), the 9 point grid (based on El Dessouky and Jenkinson (1975)) was chosen as better for our area of study and purpose, after comparing case by case with weather charts. Typical synoptic structures in Catalonia and the western Mediterranean are smaller than in the Atlantic and Northern Europe and do not tend to follow the jet stream from west to east, but are often decoupled from the main circulation and stagnate or form in the western Mediterranean. Taking a less extensive 9 point grid therefore has advantages, discriminating between systems related to the upper westerly jet vs those formed due to local influences prevalent in the Mediterranean.

Using values of Sea Level Pressure (SLP) covering Western Europe, a sub grid of 3x3 points was chosen (Figure 2a). Flow strength (F), flow direction (D) and vorticity (Z) of the airflow are calculated applying the following equations:

$$W = 0.25[(P7+2P8+P9)-(P1+2P2+P3)] \quad (1)$$

$$S = 0.653[0.25(P3+2P6+P9)-0.25(P1+2P4+P7)] \quad (2)$$

$$D = \arctan(W/S) \quad (3)$$

$$F = [(W^2+S^2)^{(1/2)}] \quad (4)$$

$$ZW = 1.056[(P7+2P8+P9)-(P4+2P5+P6)]-0.951[(P4+2P5+P6)-(P1+2P2+P3)] \quad (5)$$

$$ZS=1.305[0.25(P3+2P6+P9)-0.25(P2+2P5+P8)-0.25(P2+2P5+P8)+0.25(P1+2P4+P7)] \quad (6)$$

$$Z = ZW+ZS \quad (7)$$

P1 to P9 are the pressure values in the points of the 3x3 grid domain used to calculate the different parameters. In our case the domain is defined by 35°N- 45°N and 10°W-10°E (Figure 2a). The scaling factors that appear in the formulae are dependent on geographical latitude where the grid is centred and number of grid points used (see previous discussion). Therefore, they are slightly different than the original scaling factors given by Jenkinson & Collison (1977). Based on the values of F, D and Z, the synoptic classification is defined by 4 rules:

1. If $|Z| < F$, the type is pure advective and labelled by the flow direction, one of: N (North), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), Northwest (NW)
2. If $|Z| > 2F$, this represents strong vorticity and the type is pure cyclonic (C) if $Z > 0$ or pure anticyclonic (A) if $Z < 0$.
3. If $F < |Z| < 2F$ then flow direction is combined with vorticity in a hybrid type, one of: CN, CNE, CE, CSE, CS, CSW, CW, CNW, AN, ANE, AE, ASE, AS, ASW, AW and ANW.
4. If $F < 6$ and $|Z| < 6$ the resultant type is called unclassified (U).

One of 27 possible synoptic types can be derived for each sea-level surface pressure field.

4.2. Jenkinson and Collison: 500 hPa (JC₅₀₀)

To classify upper-air pressure patterns, a similar methodology was applied using 500 hPa geopotential heights, but the grid was displaced five degrees to the west (Figure 2b). At 500 hPa structures tend to move from west to east and often it is the approaching upper air pattern which controls the atmospheric (in)stability. The equations to calculate F , D and Z remain unchanged.

The most critical information that the 500 hPa level provides is the division into stable (ridge) and unstable (trough) types. The direction of the upper air flux is not that critical, and often has a westerly component. Thus, as a first attempt to simplify types at 500 hPa we considered five types: a) cyclone, b) trough: merging all the cyclonic hybrid types, c) anticyclone, d) ridge: merging all the anticyclonic hybrid types, and e) pure advective types. The thresholds which separate pure cyclonic/anticyclonic types from hybrid types, and in turn hybrid types from pure advective types, needed to be changed with respect to those used at the surface. Indeed as values of F and Z do not show any clustering, the thresholds chosen can be seen as arbitrary values imposed on a smooth distribution (Goodess and Palutikoff, 1998). The structures that appear at 500 hPa in general are different to those at the surface so it is perfectly reasonable to use modified thresholds in the upper air to discriminate between pure anticyclones and ridges for example. We therefore used the thresholds below:

1. If $Z > 0$ and $|Z| < (1/3)*F$ or $Z < 0$ and $|Z| < (4/3)*F$ the cases are considered as pure advection (N, NE, E, SE, S, SW, W, NW).

2. If $|Z| > 6F$, a cyclone ($Z > 0$) or anticyclone ($Z < 0$) was defined.
3. If $(1/3) * F < |Z| < 6F$ and $Z > 0$ (cyclonic) a trough above was defined (N, NE, E, SE, S, SW, W, NW).
4. If $(4/3) * F < |Z| < 6F$ and $Z < 0$ (anti-cyclonic) a ridge above was defined (N, NE, E, SE, S, SW, W, NW).
5. If $F < 6$ and $|Z| < 6$ the type is unclassified (U).

In the upper air, curvature tends to increase more than flow strength and thus the threshold for discriminating between pure cyclonic/anticyclonic and hybrid classifications was increased from 2 (at the surface) to 6. This new threshold was obtained after sensitivity analysis with alternative thresholds. The thresholds between hybrid and pure advective cases were also changed, but in a different sense depending whether the isohypses displayed anticyclonic or cyclonic curvature.

In summer, even when there is a weak trough aloft, the presence of strong heating or the uplift created by a mountain barrier can produce storms and rainy weather. To catch this, the threshold discriminating between a trough and pure advection was lowered to $1/3$, lower than the surface Jenkinson-Collison classification threshold (1), enabling weak troughs to be captured. On the other hand, the threshold separating a ridge from pure advection was fixed at $4/3$, larger than the original Jenkinson Collison threshold (1). This later change helps to discriminate amongst stable situations, mainly in winter, in which in some cases despite the anticyclonic curvature the presence of strong wind aloft means it should be considered as advection.

Because there are many possible combinations of surface and upper air types, the next step was to combine both classifications to replicate the manual classification of Martin-Vide (1991).

4.3 The new classification proposed.

In a similar way to the work of Jones et al. (1993), which reproduced Lamb's manual classification with the objective Jenkinson-Collison scheme, our new classification is tuned to provide an objective version of Martin-Vide (1987, 1991). Martin-Vide's manual classification was designed for the Iberian Peninsula and Balearic Islands, based on both surface and 500 hPa configurations. It identifies 16 synoptic types (Table 1), each of

which was now compared with the combined types we obtained from automatic classification at the two levels. The contingency table (Table 2) shows that for each surface Jenkinson-Collison type, the corresponding types at 500 hPa are usually limited and we can develop some rules to transfer our surface/upper air combination to the Martin-Vide equivalent classification:

- Surface types NE,N,NW,W,SW and S (both pure and hybrid) usually have a similar flow direction at 500 hPa and form Martin-Vide types 5,4,3,1,9 and 8 respectively. For example the surface northerly types (pure and hybrid) usually correspond to types N, NW (pure and hybrid) at 500 hPa which corresponds with “North Advection” (TYPE04).
- The surface types E, SE are associated with more confused patterns in the upper air. As well as expected related types (upper level easterly and south-easterly flow (TYPE06)), they also occur with hybrid and closed cyclonic types aloft (TYPE07). This corresponds to “East Advection” and “East Advection with cut-off above” respectively.
- For the Anticyclonic types at the surface there are two common corresponding structures aloft; a closed anticyclone (TYPE15), and westerly winds (hybrid or pure) (TYPE02) which relates to the Martin-Vide types: “Anticyclone” and “Anticyclonic Western Advection” respectively. More rarely a cyclone appears above which corresponds with “Thermal Anticyclone” (TYPE16).
- Surface cyclones are often also cyclonic circulation (hybrid or pure) at 500 hPa (TYPE12) but there are also pure advection types (mainly West and South West) (TYPE13). These are the “Cyclone” and “Thermal low” of Martin-Vide’s types respectively.
- Finally if there is an unclassified type at surface, the upper air related types are usually pure and hybrid W/SW advection. An unclassified situation with cyclonic circulation above is related to instability and related to the “Trough” type of Martin-Vide (TYPE10). If the circulation is related to upper cyclonic SW advection in upper levels the overall classification is “Upper cyclone in SW Peninsula Ibèrica” (TYPE11). The remainder usually have westerly advection at upper levels and are considered as “Undetermined pressure gradient” (TYPE14).

Following the above rules we automatically assigned our surface/upper air combination to one of Martin-Vide’s 16 manual classifications (Table 3). However, a detailed comparison between types obtained using these rules and the manual Martin-Vide classification revealed some mismatches, meaning that some fine-tuning was necessary:

- Surface AW and CW types were associated in a first attempt to TYPE03, but looking in more detail they were always reassigned to TYPE02 in case of AW and TYPE10 in case CW.
- Martin-Vide's "Thermal Low" (TYPE 13) has a surface cyclone but stable (pure or hybrid) or advective types above and forms mainly in summer. This situation is difficult to characterize with the automatic classification, because in winter, low pressure can form in the Gulf of Genoa after a frontal passage, which is also associated with stable conditions (mainly hybrid) and/or pure advective types aloft. These winter situations also get classified as "Thermal Low" under the rules. As TYPE13 represented only 6% of cases, each example was examined in detail and was discriminated as follows: Upper flow from N, NW and NE (hybrid or pure) was reassigned as TYPE12, and upper flow with directions W, SW, SE and E (hybrid or pure) was kept assigned as TYPE13.

To prove that the combined surface/upper level automatic classification and Martin Vide's manual one are statistically comparable, a Chi-squared test was applied, using 10 years of data from September 1957 until August 1967. This corroborated that both classifications could be considered similar. They were shown to coincide in 84% of cases.

For our study area some types occurred very rarely and to avoid small numbers some types were combined: TYPE11 was rare (1.7% of cases) and tended to be similar to TYPE09 (also fairly infrequent at 5.1%) and thus both were combined. Because some TYPE13 situations had been reclassified as TYPE12, it was also infrequent (2.3%). Due to similarity with TYPE14 (15.1 % of cases), both types were combined. Finally, the anticyclonic types TYPE15 and TYPE16 were combined because TYPE16 appeared only in very few cases (only 0.4%). Applying these changes reduced the number of patterns to 13. To avoid confusion with the original types we refer to the final types as TYPE_s_NN where NN is the number (see Table 4).

5. Results

Composites of each synoptic type were created and the charts obtained are as expected for each manual type of the Martin-Vide's classification (Figure 3). Some types are more common in winter, including those associated with deep Atlantic cyclones (TYPE_s_01,

TYPE_s_03, TYPE_s_04) or pure anticyclonic situations (TYPE_s_13). On the other hand, undefined situations at the surface are more typical in summer (TYPE_s_10 and TYPE_s_12) (Figure 3).

A validation of the classification using CAP and no-CAP days was performed to examine its success at discriminating such events. Using the EOF methodology proposed by Miró et al. (2017), each day from July 2012-July 2017 ($n=1826$) was classified as prone to CAP or to no-CAP using the HOBO data. Figure 4 shows that CAP days occur mainly under anticyclonic types, especially TYPE_s_02 and TYPE_s_13, as expected. Such days often have calm winds and clear skies. CAP is also frequent with TYPE_s_12, which although not anticyclonic, is characterised by slack isobars, lack of wind and often clear skies, especially in winter. TYPE_s_09 which corresponds to SW advection is also prone to develop CAP. These results are compatible with those of Miró et al (2018).

Days prone to no-CAP are expected to be dominated by situations in which winds are strong and skies are usually cloudy. TYPE_s_11 is common, and corresponds to a cyclone, usually forming in the western Mediterranean. This can form as the upper level westerly flow interacts with the Pyrenees, or as a synoptic low steered by the jet stream (Trigo et al, 2002). Types related to winds coming the north or north-west (TYPE_s_03, TYPE_s_04, TYPE_s_05) and less frequently from the west (TYPE_s_01) are also prone to no-CAP. These are also consistent with the types obtained in Miró et al (2018).

Discussion

Comparing our classification with existing objective synoptic classifications oriented to the Mediterranean (Serra et al, 1999; Fernández et al, 2003; Esteban et al, 2006), many of the basic types (anticyclone, cyclone, north-westerly advection, easterly advection) are similar. The mentioned classifications are based in statistical and mathematical approach and some synoptic types appear as transitional types, which in general are not synoptically relevant. The main advantage of using a classification with thresholds is that discriminates better having all the types synoptically significant.

Comparing our new combined classification with the classical surface-based Jenkinson-Collison, the main advantage is that it allows differentiation within the unclassified type,

common in the latitudes of the Iberian Peninsula, especially in summer when the general flow is weak (Spellman, 2000). To illustrate this, we re-run the CAP analysis using the surface classification alone, see Figure 5. The main types prone to CAP events are A and U (Figure 5a) which means that despite anticyclonic days being dominant, there is a large number of CAP days that are unclassified. An additional 500 hPa classification is required to discriminate stable from unstable cases. In addition, days prone to no-CAP are mainly C (cyclone) (Figure 5b), or hybrid flows coming from the N, NE, NW, in-line with the results obtained with the new classification.

In contrast to the surface classification, the new classification is more precise at determining the necessary types for CAP, as well as reducing the number of unclassified situations which were frequent when using surface type alone. For our new classification, for nearly all synoptic types, either CAP or no-CAP is dominant and there are no types which have roughly 50:50 distribution of CAP/no CAP occurrences. This demonstrates that the new classification is extremely efficient at differentiating between CAP and no-CAP synoptic situations.

Previous work has shown a strong advantage in using the combined classification to improve forecasts of precipitation events where similar types at the surface (easterly advection or undetermined pressure gradient situations) could produce very different results dependent on the upper air flow structures (Miró, 2017). This work has shown that the classification also has advantages over a surface based classification at predicting CAP events in eastern Cerdanya. Most notably it is able to discriminate between the large number of unclassified days based on a surface classification alone which may or may not lead to CAP.

6. Conclusions

The simple classification developed in this paper has only 13 types, each one with a clear synoptic configuration, which is very useful for forecasters. Reducing the number of types gives clarity and is advantageous because there will be more case studies available for each type. Despite this simplicity, this classification has the advantage of separating broadly similar types at the surface, but with upper air differences, that tend to have

different consequences for both precipitation forecasting and for CAP and atmospheric stability.

This classification therefore provides a straightforward tool for daily use by forecasters as a first step for developing a weather forecast (Snellman, 1982; 1982; Lanicci, 2003; Athar and Sara, 2014). This classification could also be used for downscaling future climate forecasts, in particular studying the temporal evolution of the relative frequencies of various synoptic types and thus the potential influence of circulation changes on climate change in contrasting micro-environments. For example, understanding the changing frequency of CAP events in the Cerdanya Valley by relating cold pool events to changing synoptic patterns would be a useful area for further research.

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Tables

Martin-Vide manual classification	Description
West advection	The isobars at the surface and the isohypses at 500 hPa produce westerly winds.
Anticyclonic western advection	Anticyclone at the surface and isohypse configuration at 500 hPa disposed to produce westerly winds
Northwest advection	Both surface isobars and isohypses at 500 hPa produce north-westerly winds
North advection	Both surface isobars and isohypses at 500 hPa produce northerly winds
Northeast advection	Both surface isobars and isohypses at 500 hPa produce north-easterly winds
East advection	Surface isobars produce easterly winds while at 500 hPa the isohypses relate to stability or easterly advection
East Advection with instability above	Surface isobars produce easterly winds while at 500 hPa there is instability (cyclone or trough).
South advection	Both surface isobars and isohypses at 500 hPa produce southerly winds
Southwest advection	Both surface isobars and isohypses at 500 hPa produce south-westerly winds
Upper cyclone in SW Iberian Peninsula	Cyclone above the Southwest of Iberian Peninsula coupled with an undefined situation at the surface.
Trough	A trough crossing the Iberian Peninsula from West to East with an undefined situation at surface
Low or Cyclone	A cyclone at 500 hPa and at the Surface
Thermal Low	A shallow cyclone at the surface which disappears with height appearing an unclassified situation at 500 hPa. More typical in summer months
Undetermined pressure gradient	There is no well-defined isobaric configuration at the surface (often a col or undetermined pressure gradient) and at 500 hPa there is a ridge or undefined situation
Anticyclone	An anticyclone appears both at surface and at 500 hPa.
Thermal anticyclone	Over Central Europe there is cold air which produces surface high pressure but this disappears with height (analogous to thermal low).

Table 1. Types of Martin-Vide's manual classification (left) and a description of the related surface and 500 hPa patterns expected for each type.

Column\	S	AS	CS	SW	ASW	CSW	W	AW	CW	NW	ANW	CNW	N	AN	CN	NE	ANE	CNE	SE	ASE	CSE	E	AE	CE	A	C	U
A	50	62	46	428	415	157	730	807	144	164	279	43	29	81	16	21	48	24	28	46	33	16	38	28	285	172	43
S		7	16	51	76	4	1	5																			
AS			12	3	4	57	14	31	6	5	4																
CS				8	3	59	1	5																			
SW					207	7	169	150	5	50																	
ASW						122	22	24	47	24	4																
CSW							14	66	17	0	72																
W								19	4	13	694	122	214	40	17	6											
AW									3	8	3	106	106	3	3	9											
CW										4	20	147	7	156	10	1	11										
NW																											
ANW																											
CNW																											
N																											
AN																											
CN																											
NE																											
ANE																											
CNE																											
SE																											
ASE																											
CSE																											
E																											
AE																											
CE																											
A																											
C																											
U																											

Table 2. Contingency table counting coincident occurrences for every synoptic type for the Jenkinson and Collison classifications at the surface (rows) and 500 hPa (columns). This is split in two parts in order to better show how types are clustered.

JiC sfc	JiC 500 hPa	New classification
A	Anticyclone or Unclassified	TYPE15
	Ridge (SW,W,NW)	TYPE01
	Ridge (S,SE,E,NE,N)	TYPE15
	Cyclone	TYPE16
	Trough (SW,W,NW)	TYPE01
	Trough (N,NE)	TYPE16
	Trough (S,SE,E)	TYPE15
	Pure Advection(S,SE,E,NE,N)	TYPE15
	Pure Advection (SW,W,NW)	TYPE01
AE / ASE	Any type except (Cyclone or Trough)	TYPE06
	Cyclone or Trough	TYPE07
AS	Any type	TYPE08
ASW	Any type	TYPE09
AW	Any type	TYPE01
ANW	Any type	TYPE03
AN	Any type	TYPE04
ANE	Any type	TYPE05
C	Anticyclone or Unclassified	TYPE13
	Pure Advection (W,SW,SE,E)	TYPE13
	Pure Advection (NE,N,NW)	TYPE12
	Ridge (W,SW,SE,E)	TYPE13
	Ridge (NE,N,NW)	TYPE12
	Cyclone or Trough	TYPE12
CE / CSE	Any type except (Cyclone or Trough)	TYPE06
	Cyclone or Trough	TYPE07
CS	Any type	TYPE08
CSW	Any type	TYPE09
CW	Any type except (Cyclone or Trough)	TYPE02
	Cyclone or Trough	TYPE10
CNW	Any type	TYPE03
CN	Any type	TYPE04
CNE	Any type	TYPE05
E / SE	Anticyclone or Ridge	TYPE06
	Cyclone or Through	TYPE07
	Pure advection or Unclassified	TYPE06
S	Any type	TYPE08
SW	Any type	TYPE09
W	Any type	TYPE02
NW	Any type	TYPE03
N	Any type	TYPE04
NE	Any type	TYPE05
U	Anticyclone + Ridge	TYPE14
	Cyclone or Trough (E,NE,N,NW,W)	TYPE10
	Trough (S,SW,SE)	TYPE11
	Unclassified	TYPE14

Table 3. The mapping of combined Jenkinson and Collison types onto Martin Vide's manual classification. The first column shows surface, and second column 500 hPa, Jenkinson and Collison types. The third column represents the new classification type obtained combining columns one and two.

New classification	Description
TYPE_s_01	West advection
TYPE_s_02	Anticyclonic western advection
TYPE_s_03	Northwest advection
TYPE_s_04	North advection
TYPE_s_05	Northeast advection
TYPE_s_06	East advection
TYPE_s_07	East Advection with cut-off low above
TYPE_s_08	South advection
TYPE_s_09	Southwest advection
TYPE_s_10	Trough
TYPE_s_11	Low or Cyclone
TYPE_s_12	Shallow Cyclone or Undetermined pressure gradient
TYPE_s_13	Anticyclone

Table 4. The new simplified synoptic classification with short names (left column) and a brief description (right column).

Figures

Figure 1. Location of the Cerdanya valley in the context of Catalonia and the north-east Iberian peninsula. The lower panel shows a detailed view of the Cerdanya valley and sensor locations.

Figure 2. Grids used to calculate Jenkinson and Collision at a) surface and b) 500 hPa.

Figure 3. Monthly frequencies for each of the 13 final synoptic types (left), and typical synoptic charts associated with each type (based on composites of all cases), including surface pressure (centre) and geopotential height at 500 hPa (right).

Figure 4. Number of CAP days (dashed) and no-CAP days (diagonal lines) for each type of the new classification. In nearly all cases either CAP or no-CAP is dominant.

Figure 5. Number of CAP days (dashed) and number of no-CAP days (diagonal lines), for the original Jenkinson Collison classification based on surface pressure alone.