Three-dimensional structure of Western Mediterranean Cyclones

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Abstract

As many studies reveal, the Western Mediterranean exhibits a high frequency of cyclone centres. Most of them are small and weak, but in some cases they are related to heavy rain and/or strong wind events. The climatological study of Mediterranean cyclones is a first, crucial step to the better understanding and forecasting of such events.

In the present paper a method to objectively detect and track mean sea level (MSL) cyclones for the Western Mediterranean is described. Furthermore the three-dimensional characterization of each MSL cyclone is performed by means of several parameters. This includes the vorticity, thermal and humidity fields at different pressure levels where the cyclone is detected, as well as the wind speed profile and the moist stability over the MSL cyclone. Both methodologies are illustrated and validated by a real case: an intense event of the well-known Genoa cyclone. Detection, tracking and three-dimensional characterization are applied to an 8-year (from June 1995 to May 2003) database of numerical analyses. The result is a MSL cyclone database for the Western Mediterranean with a description of their three-dimensional structure. For a better analysis, cyclones are grouped in three different ways: by thickness, season and region of detection. Results show that Western Mediterranean cyclones are located in specific geographical regions, and their location depends on the season. Several cyclones are weak and shallow, mainly due to thermal and/or orographic causes. On the contrary, other cyclones are large and intense and extend throughout the whole troposphere. Differences in cyclone structure depending on the location and season are also discussed.

KEYWORDS: Western Mediterranean, Cyclones, Three-dimensional structure

1 Introduction

The climate of the Mediterranean is characterized by hot, dry summers and warm, relatively wet winters. This is due to the fact that the Mediterranean is located between the subtropical anticyclone belt and the midlatitude westerlies. This special geographical configuration, a warm sea surrounded by high mountain ranges, results in significant large regional variations. So, in spite of the generally pleasant weather the Mediterranean region is frequently affected by sudden events of severe weather, especially heavy rain and/or strong winds.

It is well known that Mediterranean cyclones exert a large influence on the weather and climate of their own and neighbouring regions (Radinovic, 1987). Thus, in the Mediterranean, local winds and rain distribution are in many cases related to cyclones. The relationship between heavy rain and cyclones has been demostrated in many case studies (e.g. Ramis *et al.* , 1994; Ramis *et al.* , 1998; Jansà *et al.* , 2000), and also for large sets of cases (Jansà *et al.* , 2001; Romero *et al.* , 1999).

The spatial and temporal distribution of extra-tropical cyclones, as well as the mechanisms of cyclogenesis and cyclone life-cycle have been, and still are, a major concern in dynamical meteorology. Petterssen (1956) showed that the Mediterranean in general, and the Gulf of Genoa in particular, are regions that present a high density of cyclones and cyclogenesis in winter for the Northern Hemisphere. More recently, Alpert *et al.* (1990) and Maheras *et al.* (2001) revealed two major cyclone regions, the Gulf of Genoa and Cyprus, as well as other secondary ones such as Southern Italy, North Africa, the Iberian Peninsula, and the Aegean Sea. Moreover, significant seasonal differences and important diurnal variations were found in those areas. The aforementioned studies focused on a synoptical point of view. Other studies, performed with high resolution data and thus able to detect meso-scale structures, such as Picornell *et al.* (2001), Trigo *et al.* (1999) and Campins *et al.* (2000), offered a more detailed vision of the spatial and temporal distribution of Mediterranean cyclones, identifying regions with a high frequency of meso-scale cyclones (such as the region to the south of the Pyrenees or the Alboran Sea) not found in earlier studies.

Although the spatial, seasonal and diurnal distribution of Mediterranean cyclones alone could suggest the mechanisms involved in how cyclones originate and are maintained, the systematic study of a large set of cases provides a better insight into those mechanisms. Trigo *et al.* (2002) showed that the cyclogenesis mechanisms for winter on the one hand, and for summer and spring on the other, are different. Thus, in winter cyclogenesis mainly occurs in the northern Mediterranean coast (the Gulf of Genoa, Aegean Sea and Black Sea), and is related to upper-level synoptic troughs, the orography and low-level baroclinity. On the contrary in spring, and especially in summer, cyclogenesis occurs over land (the Iberian Peninsula, North Africa and the Middle East) due to thermal effects. In these regions cyclogenesis exhibits a clear dependence on the diurnal cycle. Moreover, cyclogenesis in the Sahara during spring is also affected by orography and by the increase in low-level thermal gradients. A similar study was performed by Flocas *et al.* (2001), but adopted a different perspective. In that paper the horizontal and vertical distribution of geostrophic vorticity over the Mediterranean basin, as well as seasonal and diurnal variations, were analysed. The study of the vertical vorticity structure for the two major cyclonic vorticity maxima over the Mediterranean region (one in the Gulf of Genoa and Southern Italy and the other in the Aegean Sea and Cyprus area) revealed the different cyclogenesis mechanisms acting in the western and eastern basin. Another way to analyse the mechanisms involved in Mediterranean cyclogenesis is based on the diagnosis and numerical simulation of selected cases. The cyclogenetic role of orography was investigated for major mountain ranges such as the Alps or the Atlas (e.g. Buzzi and Tibaldi, 1978; Alpert *et al.* , 1996). Other cyclogenetical factors such as sea-surface sensible, latent heat fluxes, latent heat release due to the convection or upper-level forcing may also be mentioned (e.g. Alpert *et al.* , 1996; Romero *et al.* , 1997; Romero, 2001; Homar *et al.* , 2002; Homar *et al.* , 2003).

A better understanding of spatial and seasonal variability of Mediterranean cyclones as well as the mechanisms leading to cyclogenesis (lysis) are a major concern for the meteorology of the region, especially for those cyclones related to severe weather. MEDEX (MEDiterranean EXperiment on cyclones that produce high impact weather in the Mediterranean) is a Research and Development Project, framed into the World Weather Research Program of the World Meteorological Organization, whose main objective is to increase knowledge and improve forecasting of cyclones which produce high impact weather in the Mediterranean. To achieve this aim, among other specific objectives, to elaborate a dynamical climatology of Mediterranean cyclones was proposed (see MEDEX Science Plan Phase 1 at http://medex.inm.uib.es for further information). To advance towards this objective, in the preset paper the study of a large set of mean sea level (MSL) cyclones for the Western Mediterranean (WM) is performed. First, cyclones will be detected and tracked by an objective way by using an extended period of 8 years of numerical analyses. Later, each cyclone will be three-dimensionally described by a set of variables, such as the vertical extension, vorticity, thermal and humidity structure, vertical stability, wind shear, etc. As a result, a WM cyclone database, with a complete description of them is obtained. Finally, spatial and seasonal variations, as well as the main features of the three-dimensional structure of WM cyclones are explored, paying special attention to the enhanced cyclonic activity regions.

The present paper is structured as follows: in section 2 the data and the algorithm used to detect and track WM cyclones are described. In section 3 the methodology to three-dimensionally characterize WM cyclones is presented. The ability to detect and describe WM cyclones will be discussed by means of an example in section 4. Results are discussed in section 5. Finally, section 6 contains some concluding remarks.

2 Data and cyclone detection algorithm

The primary data used in this study are the operative analyses of the High Resolution Limited Area Model (HIRLAM) from the Instituto Nacional de Meteorologia (INM) at a resolution of $0.5^o x 0.5^o$ latitude-longitude (the so-called HIRLAM-INM-0.5^o). The analysis domain is bounded between 65^o N-15.5^o N and 66.5^o W-30^o E. The analysis is based on the optimum interpolation scheme, which is multivariate in three dimensions for the mass and wind fields and univariate for the relative humidity. As a first guess the H+6 model forecast is used (Gustafsson, 1991). An 8-year period, from June 1998 to May 2003, of 6-hourly (00, 06, 12 and 18 UTC) analyses of mean sea level pressure (MSLP), geopotential (Z), temperature (T), relative humidity (RH) and horizontal wind components are used.

Mediterranean cyclones spread from synoptic-scale cyclones (Alpert *et al.* , 1990; Maheras *et al.* , 2001) to meso-scale ones (Campins *et al.* , 2000; Picornell *et al.* , 2001). Some recent studies (Trigo *et al.* , 1999; Hoskins and Hodges, 2002) have revealed that Mediterranean cyclones are smaller in scale than their Atlantic counterparts. As is well-known, meteorological phenomena exhibit a large variety of spatial and temporal scales. The resolution of a Numerical Weather Prediction (NWP) model determines the scales that are detectable. Thus, for gridded NWP models the horizontal scale is determined by the grid-size, and the vertical resolution by the number of levels. Therefore, in order to precisely describe small-scale cyclones the use of high resolution original fields is best. However, some problems arise when calculations are made. Some derived fields, obtained by means of derivatives (such as vorticity) could be very noisy, and small-scale features can mask higher scales. Consistency between spatial (horizontal) and temporal scales is desirable if cyclone tracking is performed (Blender and Schubert, 2000). When looking for three-dimensional cyclone features, it seems logical to demand a similar consistency between the horizontal, vertical and temporal coordinates. The temporal resolution of HIRLAM-INM-0.5^o analyses is 6 hours. Seven levels (MSL and 1000, 925, 850, 700, 500 and 300 hPa) are chosen for the vertical resolution. Therefore, a horizontal scale of a few hundred km seems adequate. As the resolution of the original HIRLAM-INM-0.5^o fields is around 50 *km* filtering of the small scales is necessary. For the present study the Cressman filter was used (as in Picornell *et al.* , 2001 and Sinclair, 1997). This scheme (Cressman, 1959) is a distance-weighted algorithm widely used for objective spatial analyses, which averages each grid point with all the neighbouring grid points at a distance $r < r_0$ using weights of $({r_0}^2 - r^2)/({r_0}^2 + r^2)$. The selection of r_0 is obviously subjective and a certain number of values were tested. Finally it was determined that a value of $r_0 = 200$ *km* is considered to provide an accurate description of WM cyclones.

As mentioned above, we are interested in the main features of MSL cyclones, as well as in their three-dimensional structure. For that reason a method for detecting cyclones throughout the troposphere is needed. Next, a method for detecting cyclones at MSL and at the pressure levels is described. It is important to remark that the present procedure is based on MSL cyclones that are three-dimensionally characterized and it is not a cyclone climatology for different isobaric levels.

2.1 Three-dimensional detection of MSL cyclones

In general, cyclone climatologies are performed at a single level, mainly MSL or 1000 hPa (Alpert *et al.* , 1990; Sinclair, 1997; Trigo *et al.* , 1999; Maheras *et al.* , 2001), but they may also be conducted at upper levels (Bell and Bosart, 1989; Lefevre and Nielsen-Gammon, 1995). To define a cyclone, MSLP or Z (Alpert *et al.* , 1990; Trigo *et al.* , 1999; Maheras *et al.* , 2001; Bell and Bosart, 1989) and vorticity (Sinclair, 1997; Lefevre and Nielsen-Gammon, 1995) are used. In Murray and Simmonds (1991), MSL cyclones are detected as closed centres (minimum of MSLP) and also as open ones (maximum of Laplacian of MSLP). In Hoskins and Hodges (2002) both approaches, low and upper levels and MSLP or Z and vorticity (amongst other parameters) are used to characterize winter Northern Hemisphere storm tracks. These authors found small differences between MSLP (or Z) and vorticity, although smaller-scale features were detected with vorticity.

2.1.1 Cyclones at MSL

The objective detection method of cyclones from MSLP is based on Picornell *et al.* (2001). In that study, WM cyclones were detected as a relative MSLP minimum for a 4-year set of HIRLAM-INM-0.5^o analyses. As the study was focused on small-scale cyclones, low pressure centres were detected from the original fields, although to avoid very weak centres a threshold was imposed ($0.5\ hPa/100\ km$) on the mean pressure gradient around the cyclone centre. However in the present study, we are interested in the three-dimensional description of WM cyclones, and then as previously mentioned MSLP are smoothed using the Cressman filter (with $r_0 = 200\ km$). Thus a cyclone centre is detected as a minimum in the smoothed MSLP field, overcoming the same pressure gradient threshold.

Finally, each cyclone centre is tracked throughout its life-cycle. A wide variety of procedures are available for the tracking of cyclones. From the 'simple' nearest neighbour search procedure (Trigo *et al.* , 1999; Blender *et al.* , 1997 and Serreze *et al.* , 1995) to more sophisticated techniques based on the synoptics and physics of the cyclones. An example of the latter approach is the scheme proposed in Murray and Simmonds (1991), and subsequent refinements (Simmonds and Murray, 1999; Simmonds *et al.* , 1999). In that scheme a three stage process is proposed. In the first stage the next position of the cyclone is predicted by means of steering. Next, the probability of identification between the projected cyclone and each cyclone at the new time is calculated. Finally matching is performed to maximise the calculated probabilities. In the present paper an intermediate procedure is used. It is based upon Alpert *et al.* (1990) with some of the modifications applied in Picornell *et al.* (2001). When a cyclone centre is detected at certain time then we search for its presence in the next analysis (in this case 6 hours later) in an elliptical domain. This domain extends along the wind direction at 700 hPa (considered as the steering level) over the cyclone centre, and spreads depending on the mean wind speed at this level. If a cyclone centre is found inside the elliptical domain, then it is assumed to be the same cyclone, if not, cyclolysis occurs (for more details the reader is referred to Picornell *et al.* , 2001).

2.1.2 Cyclones at isobaric levels

The detection algorithm of cyclone centres at a certain pressure level is similar to that used for MSL: a minimum value is required in the smoothed Z field, overcoming a certain Z gradient (4 $gpm/100\ km$). However, in some cases, especially at upper levels and with strong mean flow, cyclones are not closed. Thus, the cyclone definition at isobaric levels has to be enlarged in order to allow for open centres or troughs. An open cyclone is characterized by a local maximum of geostrophic vorticity (ζ_g). However, although smoothed fields are used, a large number of ζ_g maxima are found, due to the shear and/or curvature of the Z field. Thus, to remove small-scale ζ_g maxima, a criterion based on geostrophic circulation (hereafter GC; see Appendix) is adopted. As a threshold, a value of 0.5 $10^7 m^2 s^{-1}$ is imposed. Both thresholds, for closed and open cyclones, are empirically chosen for their ability to reject weak centres.

2.1.3 Connection of cyclone centres at different pressure levels

Once all the 'potential' cyclones (open or closed) are obtained at MSL and at the different pressure levels, the vertical connection between them is performed. First of all, starting from the MSL, we look for the presence of a cyclone in the upper-next level within a circular region around the cyclone centre, which is called the 'search radius'. If a centre is found then the upper-next level is examined; if not the vertical top of the cyclone is reached. This level is the so-called the 'top pressure level' of the cyclone and determines its thickness. When two or more centres are found in the 'search radius' the one which is closest to the cyclone centre is selected. Furthermore, closed centres are prioritized although when a centre changes from closed to open, only open centres are then looked for. This procedure is repeated, if necessary, up to the 300 hPa level.

The 'search radius' has to take into account the tilt of the cyclone's vertical axis, and should not be excessively large, as that would allow different cyclone centres to be connected. The 'search radius' is not constant, and increases with height. From the analysis of several case studies (not shown) the values in

Table 1 are adopted.

2.2 Study area

To determine the study area to detect cyclones in the WM, some factors have to be taken into account: i) the area of HIRLAM-INM-0.5^o , especially its eastern border (at 30^o E), ii) the vertical tilt of the cyclone's axis and iii) the need for an additional area around the study area in order to calculate the cyclone domain. Under these restrictions, the study area for the detection of cyclones at MSL extends between 29^o N and 49^o N and between 12^o W and 18^o E. To detect cyclone centres at isobaric levels, the study area is extended 5^o latitude/longitude beyond the MSL area, except for the eastern border, which remains at 18^o E. The area thus extends between 24^o N and 54^o N, and between 17^o W and 18^o E (see Figure 1). Obviously, some problems could arise for cyclones located close to the boundaries, but this only affects a very reduced number of centres. Although a clear limit between the western and eastern basins does not exist, it is assumed that the study area comprises the so-called WM.

3 Three-dimensional cyclone characterization

Once MSL cyclone centres are detected and tracked in the vertical (at successive isobaric levels) and in time (at successive analyses), the next step is to characterize them. An initial group of parameters describe general features of cyclones, for instances the date of appearance, and these are listed in Table 2. Another set of parameters describe the vertical structure of MSL cyclone centres, which are then calculated at MSL, as well as at isobaric levels. Although a complete list is presented in Table 3, next a more detailed description is provided for some of these parameters.

A key parameter is the cyclone domain, as this allow one to calculate not just the size of cyclones, but also the domain where mean values of several parameters are calculated. As in Picornell *et al.* (2001) the cyclone domain is defined as the region around the cyclone centre with cyclonic circulation, that is with $\zeta_g > 0$. Thus, starting from the cyclone centre, a search is made radially outward looking for the location where $\zeta_g = 0$. In contrast to Picornell *et al.* (2001), where only 4 directions were explored, this procedure searches radially in 16 directions around a complete circle (thus with a radial increment of 22.5^o). The cyclone domain is composed joining the ends of successive radii R_i (i=1,16). The increase in radial directions from 4 to 16 signifies an increase in the accuracy of the calculation of the cyclone domain. Finally, two parameters are calculated: the area enclosed by the cyclone domain (A) and the mean radius (R), which is the mean value of the 16 R_i.

However, in some cases the cyclone domain can include more than one cyclone centre. In these cases the most intense centre is considered to be the principal centre and the other(s) is (are) categorised as being as secondary(ries). For secondary cyclones the cyclone domain is obtained by searching radially in 16 directions until $\zeta_g = 0$ or until the radial ζ_g gradient changes sign (whichever occurs first).

Another key parameter is the cyclone strength. The MSLP at the low centre, the MSLP deepening rate, the vorticity or the MSLP Laplacian averaged over around the cyclone centre have been used to measure the cyclone intensity (e.g. Maheras *et al.* , 2001; Serreze *et al.* , 1997; Trigo *et al.* , 1999; Murray and Simmonds, 1991). In contrast, Sinclair (1997) and Picornell *et al.* , (2001) used circulation, which combines local values of vorticity and the size of the cyclone. In the present study the geostrophic value of circulation (GC) is used, although MSLP and ζ_g are also recorded.

Some parameters listed in Table 3 are obtained as grid-point values at the cyclone centre (e.g. MSLP), and others as the mean value around the cyclone centre (e.g. RH). Initially, mean values into the cyclone domain were obtained, but for large domains the outlying values smoothed the result. For that reason, mean values are finally calculated for the set of grid-point values included in an inner cyclone domain, defined as the domain resulting from 16 shorter radii $R_i' (= R_i/2)$.

To determine the presence of thermal discontinuities, such as fronts within the cyclone domain the temperature and equivalent temperature gradients ($|\nabla T|$ and $|\nabla T_e|$) are calculated. In addition, the Laplacian of temperature ($\nabla^2 T$) is recorded to discriminate between warm-core cyclones (e.g. thermal or orographic lows) and cold-core cyclones (cut-off lows). A warm (cold)-core cyclone is characterized by warmer (colder) air near its centre than around its periphery, and thus by negative (positive) $\nabla^2 T$ values.

The aforementioned parameters are calculated for each isobaric level where the cyclone centre is present; that is, from MSL (or 1000 hPa for thermal and humidity parameters) to the cyclone top pressure level.

It has to be taken into account that vertical profiles are not performed over the MSL cyclone centre, as a certain tilt usually is present. However, by means of summary, a mean value of those parameters at some layers are also obtained. Thus, a shallow-layer value is obtained by averaging values from MSL (or 1000 hPa) to 850 hPa, and a medium-layer value from 700 hPa to 500 hPa. At the upper-layer the 300 hPa value is considered. As an example the temporal evolution of GC for low (GC_L), medium (GC_M) and upper (GC_U) levels is presented in Figure 3.

Finally, in order to characterize the air column over the MSL cyclone, and in spite of its vertical thickness, two more parameters are calculated over each MSL cyclone centre: moist static stability (σ_e) and the vertical profile of the horizontal wind speed (V). Moist static stability is calculated using equivalent potential temperature θ_e for three different layers: 1000-850 hPa, 850-500 hPa and 925-500 hPa. Conversely, V is obtained for all the isobaric levels, from 1000 hPa to 300 hPa. In addition, the wind speed shear of the air column over the MSL cyclone centre can be obtained, and may be regarded as a measure of baroclinity.

4 Example. Intense Genoa cyclone

To illustrate the application of the aforementioned methodologies a real case will be analyzed: an intense Genoa cyclone, which took place from the 6th to the 9th of November 1999. It is a well studied and documented case as it was selected as the IOP 15 of MAP (Buzzi *et al.* , 2003) and as a main MEDEX case (http://medex.inm.uib.es), since it produced strong wind and heavy precipitation in Italy and Croatia.

The Genoa cyclogenesis began on the south side of the Alps and moved south-eastwards, along the Tyrrhenian Sea (see Figure 2). The procedure correctly detected the cyclone from the beginning, on the 6th at 12 UTC, and tracked it up to the 9th at 06 UTC when it left the study area (although it seems that the cyclone continued moving towards the Eastern Mediterranean).

In the beginning (6th at 12 UTC) the cyclone centre was composed by a closed centre from MSL up to 850 hPa (the lee cyclone), connected with a maximum of ζ_g , related to an upper-level trough reaching the Alps. As a consequence, at that moment the cyclone centre exhibited a certain vertical axis tilt. Six hours later (the 6th at 18 UTC) the upper-level trough evolved to a cut-off centre and the cyclone was closed at all levels, but axis tilt remained. From this moment up to the end of the event the cyclone centre was closed at all levels, and practically vertically aligned. During the first 18 hours (the intensifing phase) MSLP at the cyclone centre (see Figure 3(a)) rapidly decreased, accompanied by an intense increase of the low-level ζ_g , cyclone size and the *GC*. The filling phase of the cyclone was more gradual, with a slow increase in the MSLP centre and a decrease in the ζ_g , cyclone size and the *GC*. This evolution resembles the two phases for Genoa cyclogenesis described in Buzzi and Tibaldi, 1978 and Alpert *et al.* ., 1996, which are a rapid 'trigger' phase due to the interaction of the Alps with the frontal layer and a more usual 'baroclinic development' phase. At upper levels (500 and 300 hPa) the *GC* increased to its maximum 30 hours after the cyclogenesis (and 12 hours from the minimum MSLP). The thermal structure revealed a warm-core (a lee cyclone) at low levels, decreasing to neutral or cold-core as the episode progressed. This was probably due to the warm anomaly on the lee side of the range and the subsequent spreading of cold air into the Mediterranean, although strong thermal gradients were not detected. At upper levels the cyclone centre was cold-core (a cut-off), with intense thermal gradients (probably due to the jet streak), decreasing with time. The evolution over time of several parameters at low, middle and upper levels are presented in Figure 3.

5 Results

As may be seen in panel a) of Figure 7, cyclone centres spread across the whole WM area, although some areas exhibit higher frequency, with the outstanding maximum being around the Gulf of Genoa. A large number of cyclone centres are also detected in the Iberian Peninsula, Palos, inland Algeria and the Atlantic coast of Morocco. With an appreciable number of centres, but to a lesser extent, the Balearic and the Adriatic Seas may also be mentioned. The aforementioned regions with a high density of cyclone centres agree with other studies, performed at a similar or lower resolution (e.g. Alpert *et al.* , 1990; Trigo *et al.* , 1999; Maheras *et al.* , 2001). Conversely, some regions with a high density of small-scale cyclone centres, such as the region at the south of the Pyrenees (e.g. Campins *et al.* , 2000; Picornell *et al.* , 2001) are not detected at the present spatial resolution as they have been filtered out.

Summer (winter) exhibits the highest (lowest) frequency of cyclone centres (33.3 % and 18.2 % respectively). In spring the frequency is similar to summer (27.5 %) and in autumn similar to winter (21.0 %). In terms of vertical extension, WM cyclones are mainly shallow (51.1 %), although an important portion of them occupies the whole troposphere (37.8 %).

A more detailed exploration of the objective cyclone database reveals considerable variability. Cyclone centres are located in some preferred regions, but this is season dependant. Furthermore some cyclones are intense and occupy the whole troposphere, while others are weak and shallow. For a better understanding of the cyclone database, especially of the cyclones' three-dimensional structure, the cyclones are grouped in three different, yet complementary, ways: by thickness, season and region of detection. Next, the mean features of each grouping are studied.

5.1 Grouping by thickness

Shallow cyclones are considered to be those that extend from MSL up to 850 hPa, middle-depth up to 500 hPa and deep up to 300 hPa. Some cautions should be taken with very shallow cyclones, especially those over land, as due to interpolation they could in fact be false, and should perhaps be removed from the database.

5.1.1 Seasonal distribution

The seasonal distribution of cyclone centres for each thickness group is clearly different (see Table 4). Thus, shallow cyclones develop mainly in summer, while only a small porcentage of them appear in winter. Conversely, deep centres are present in all seasons, but to a lesser extent in summer. Finally middle-depth centres are predominant in summer and autumn. These distributions are obviously related to the main cyclogenetical mechanism acting in each season, but also to general atmospheric circulation. During summer, anticyclonic circulation dominates the WM at upper levels and only the Gulf of Genoa region and the western coast of the Iberian Peninsula are influenced by cyclonic vorticity. So, although many shallow cyclones are generated they can not extend vertically (neither closed nor open cyclone centres). Conversely in winter, and also to a lesser extent in autumn and spring, cyclonic circulation dominates, due to upper-level troughs moving from west to east (see Flocas *et al.* , 2001) and so many MSL cyclones can reach the 300 hPa level.

5.1.2 Mean three-dimensional structure

Mean vertical profiles of some variables are calculated for all the cyclone centres grouped by thickness (shallow, middle-depth and deep), except for V, which vertical profiles are obtained from 1000 to 300 hPa. Comparisons between groups may only be performed for variables calculated at common isobaric levels: for instances, it is not possible to compare the *GC* at 700 hPa for deep and shallow cyclones, because in the latter case no value can be obtained. Mean vertical profiles are displayed in Figure 4 and summarized in Table 6.

Mean values of ζ_g are larger as cyclone thickness increases, except at low levels where mean values are similar for the three groups. Clearer differences are observed for R and *GC*. Thus, on average, shallow cyclones are smaller and less intense than deep ones at all levels. This reflects the consistency between the horizontal and vertical scales.

Shallow centres exhibit a stronger warm-core character than middle-depth and deep ones. At 700 and 500 hPa middle-depth centres are warm-core while deep ones are cold-core, especially at 500 hPa. Also mean values of $|\nabla T|$ and $|\nabla T_e|$ (not shown) are larger at low levels for shallow and middle-depth cyclones than for deep ones, except at 500 hPa where deep cyclone gradients are larger than middle-depth ones; however the differences are small.

The balance between geostrophy and hidrostaty (thermal wind) is useful to find some relationships between pressure and temperature fields. Thus, warm-core (cold-core) cyclone strength decreases (increases) with height. As such, most typical warm-core cyclones such as thermal lows or lee depressions are shallow. On the contrary, cold-core cyclones, such as those found in mid-latitudes in winter, extend throughout the whole troposphere (Bluestein, 1992).

Shallow and middle-depth cyclones present lower *RH* at all levels than deep ones, except at 500 hPa where mean values are the same. The differences are larger at low levels. This is probably due to the fact that many shallow (deep) cyclone centres are located over land (sea).

When comparing the mean vertical profiles of V, small differences between groups may be observed. However, shallow cyclones present a weaker mean V vertical profile than middle-depth and deep cyclones. Mean wind speed shear is also smaller for shallow cyclones than for middle-depth and deep cyclones.

Finally, a different vertical stratification is obtained for shallow centres on the one hand and middle-depth and deep ones on the other (see Table 6). Thus, on average, shallow centres present low σ_e (for both 1000-850 and 850-500 hPa layers). Conversely, middle-depth and deep centres present a stable vertical profile. In the later case this is due to the high stability of the 850-500 hPa layer. In the 1000-850 hPa layer centres exhibit weak stability (for middle-depth centres) or even potential instability (for deep centres).

5.2 Seasonal grouping

Temporal grouping is performed by separating the cyclone centres into seasons. Perhaps, a more accurate vision would be obtained if grouping by months were to be used, but in that case the high number of groups would hinder the analysis. Other possible temporary grouping criteria, such as years and hours, may be considered in later studies.

In the present study summer is composed by June, July and August; autumn consists in September, October and November; winter in December, January an February and finally spring includes March, April and May.

5.2.1 Spatial distribution

From Figure 5 it is clear that WM cyclones are locates in different regions depending on the season. In summer cyclone centres tend to concentrate over land: the Iberian Peninsula, inland Algeria and the Moroccan coast. However, a high density of centres is also detected in the Gulf of Genoa, the Gulf of Venice, and Palos, and to a lesser extent in the Balearic Sea. Conversely in winter, cyclone centres tend to be found over the sea, with an outstanding maximum in the Gulf of Genoa. In spring spatial cyclone distribution is similar to summer and in autumn spatial cyclone distribution is similar to winter .

If we focus on the areas of maximum frequency, the aforementioned seasonality is even more evident (see Table 4). Thus, in the Gulf of Genoa many cyclones are detected along the whole year, but especially during the summer. The large number of Genoa cyclones in summer contrasts with previous studies (based on synoptic-scale cyclones) and further supports the importance of data resolution in the Mediterranean region. On the contrary, the Iberian Peninsula exhibits a high concentration of cyclone centres only in summer. In winter and spring a maximum is also detected, but shifted to the SE. The presence of a thermal low in the Iberian Peninsula during summer, but also during the late spring and early autumn, is frequent (Portela and Castro, 1996; Hoinka and Castro, 2003). In inland Algeria cyclones are mostly detected in summer, and to a lesser extent in spring. However in autumn and especially in winter cyclones are practically absent. Finally, in Palos cyclones predominante in summer, but an appreciable frequency is also detected in autumn.

These distributions once again demostrate the thermal character of many WM cyclones. During summer, and to a lesser extent spring, the different response of land and sea to the strong thermal heating produces relative low pressure over the mainland. On the contrary, during winter the Mediterranean Sea forms a warm pool against the cold continental land and a depressionary tendency over the sea is produced. Both thermal contrasts, in winter and summer, are in fact observed in MSLP charts (for a general discussion of MSLP and mean surface temperature over the Mediterranean basin see Radinovic, 1987).

5.2.2 Mean three-dimensional structure

As Figure 6 shows there are clear differences between summer and winter mean vertical profiles. Spring and autumn profiles (not shown) fall in between summer and winter ones. Table 6 summarizes the main results.

For both seasons vertical profiles of ζ_g exhibit high values at lower and upper levels, where ζ_g maxima sources are located, and small values in middle ones. However, the mean profile of ζ_g is larger in winter that in summer, except at MSL and 1000 hPa. Also R increases with height in both seasons and is larger in winter than in summer at all levels. As GC is based on ζ_g and cyclone size, the vertical profile of GC presents features of both the aforementioned variables; that is, a small decrease from MSL up to 850 hPa and from 850 hPa level up to 300 hPa a clear increase is obtained. Cyclones are more intense at all levels in winter than in summer.

For a certain parameter (for instance GC) and for a certain group (for instance summer cyclone centres), mean vertical profile is obtained by averaging for each isobaric level the values of all the centres detected at that level. Then, in general, the average for lower levels is determine considering almost all the elements of the group, while for upper levels only some of them are used. In the present case, in summer less than 20 % of cyclone centres reach the 300 hPa level, and so the mean value at this level is calculated using a small part of the total number of cyclones. This does not reflect that in summer the majority of centres are shallow, with no cyclone centre at upper levels. To 'correct' this, the values of ζ_g and GC at each pressure level are weighted to the relative number of cyclones that reach this level (see Table 7). Thus, while values at low levels are very similar (but lower), weighted values at upper levels are considerably lower (compare Tables 6 and 7). Thus, in summer, cyclones are very weak compared with winter ones, especially at upper levels.

Mean $\nabla^2 T$ exhibits negative (warm-core) for low levels and positive (cold-core) for upper ones. The separation ($\nabla^2 T = 0$) is located at 700 hPa and also at 300 hPa, where the presence of the tropopause can be observed (on average in winter the tropopause is below the 300 hPa level and in summer it is above that isobaric level). Mean profiles of $\nabla^2 T$ are similar throughout the whole year except at low levels (925 and 850 hPa) where the warm character is greater for summer and at 500 hPa where the cold character is stronger in winter. A clearer separation between seasons is obtained for the mean vertical profile of $|\nabla T|$ (not shown). Cyclones exhibit larger values at the low levels (1000 and 925 hPa) in summer and at upper levels (500 and 300 hPa) in winter.

Mean seasonal profiles of RH are also clearly different, especially at low levels, with the highest ones in winter and the lowest in summer. Again this is probably due to the maritime (continental) location of most of the winter (summer) cyclone centres.

The mean vertical profile of V shows an increase with height. Mean values of wind speed and wind speed shear are very similar in all seasons except in summer where they are the lowest.

Finally vertical stratification over MSL cyclone centres is considered. When the 925-500 hPa layer is analysed (see Table 6), summer centres present, on average, the lowest stability, while winter centres the highest. In more detail (not shown), the 1000-850 hPa layer is potentially unstable in summer and especially so in autumn. For the 850-500 hPa layer, in summer stability is still low but in winter this is very high.

5.3 Grouping by regions

As mentioned before, although cyclones are spread along the whole WM basin in some regions their frequency is heightened. These regions are the well-known cyclogenetical regions and it may be interesting to investigate their main characteristics. To do that four regions have been selected: the Gulf of Genoa, the Iberian Peninsula, Palos and inland Algeria. For simplicity 2^{o}x2^{o} lat/lon squared regions are selected (see Figure 1), which may be considered as representative of their surrounding areas. These regions represent more than 12 % of the total number of cyclone centres.

5.3.1 Distribution by thickness

The spatial distribution of cyclone centres depending on their vertical thickness again shows relevant differences for the WM in general and for the selected regions in particular (see Figure 7 and Table 5). On one hand, many cyclones in the Gulf of Genoa are deep, although a high frequency of them are also shallow. However on the other hand cyclones located in the Iberian Peninsula, Palos and Algeria are mainly ($> 75\%$) shallow or even very shallow and only very few of them occupy the whole troposphere. The frequency of middle-depth cyclones is appreciable in the Gulf of Genoa and to a lesser extent in Algeria.

In the Gulf of Genoa both orography and thermal-forcing (especially in winter when the differences between sea surface and surrounding continental air temperature are higher) suggest the existence of shallow lows throughout the whole year. Also, but to a lesser extent, deep and intense cyclones are observed, usually related to upper-level troughs (for a general review see ”Cyclogenesis in the lee of the Alps”, Buzzi and Speranza,1983). Based on profiles of negative geopotential anomalies and ζ_g , Maheras *et al.* (2002) have shown that in winter synoptic-scale Genoa cyclones are very intense and connected to thermal contrast between sea and air. In addition, the upper-level dynamics seem to be more important in spring and autumn while the orographic effect seems to contribute more significantly in winter and spring. However, in the present study many deep cyclones are not intense, as they are composed by shallow cyclones that connect with upper-level ζ_g maxima. As a consequence a deep cyclone is not equivalent to an intense one.

Conversely, in the Iberian Peninsula thermal low is mainly a shallow cyclone as Hoinka and Castro (2003) showed. They found a mean depth close to 2800 m above MSL (between 850 and 700 hPa) when the

Laplacian of potential temperature was considered as a measure of the cyclone thickness and around 2300 m above MSL when the divergence of the wind was used. In the present study the mean vertical thickness for Iberian Peninsula lows is a little smaller than in the Hoinka and Castro (2003) results.

5.3.2 Mean three-dimensional structure

As in the other cases, mean vertical profiles for different variables are obtained for each one of the selected regions. These profiles determine the three-dimensional state of the 'mean cyclone' for each region. The following comments are based on Figure 8 and some results are also summarized in Table 6.

Mean vertical profiles of ζ_g are very similar for all regions, except at 300 hPa for Algerian cyclones, where ζ_g is lower. With regard to mean vertical profiles of R and GC clear differences between Algeria and the other regions appear. In Algeria, at low levels, cyclones are larger and more intense that in the other regions. On the contrary, at upper levels, these centres are the smallest and weakest.

Although $\nabla^2 T$ values are negative (that is warm-core cyclones) at low levels (except at 1000 hPa for those from Palos) and positive (cold-core cyclones) at upper levels in the four regions, some differences can be underlined, notably at low levels. Cyclones located in the Iberian Peninsula present the strongest warm-core character. On the contrary, although positive values are obtained at 500 hPa in all regions, in the Gulf of Genoa stronger cold-core features stand out. Thermal gradients (not shown) are very similar in all the regions: large at low levels and small at upper levels, except in the Gulf of Genoa where the reverse is true.

As we mentioned before, at low and middle levels the mean vertical profiles of RH mainly depend on the area where cyclones are detected. Thus, cyclones in the Gulf of Genoa (over the sea) exhibit the largest values and those in Algeria (inland) the lowest. In between we have cyclones in the Iberian Peninsula and Palos (although at 1000 hPa values are larger in Palos than in Iberia because they are located over sea and land). At upper levels mean values are similar for all the regions.

The mean vertical profile of V is similar for all regions except in the Gulf of Genoa, where values are larger, especially at upper levels. Wind speed shear is small in Palos, the Iberian Peninsula and Algeria but large in the Gulf of Genoa.

And finally σ_e also presents, on average, clear differences between regions (see Table 6). Thus, the centres in both the Iberian Peninsula and Algeria present weak stability, especially for the 850-500 hPa layer (not shown). On the contrary, for centres in the Gulf of Genoa and in Palos, cyclones present larger σ_e, but the contribution from lower and upper levels is different. For the Gulf of Genoa cyclone centres, there is potential instability for the 1000-850 hPa layer and high stability for the 850-500 hPa layer but for centres located in Palos, there is stability at the lower layer and weak stability in the upper one.

6 Concluding remarks

A method to objectively detect and track MSL cyclones has been presented. Furthermore, this methodology has been extended to isobaric levels, where not only closed centres (minimum of Z) but also open ones (maximum of ζ_g) are allowed. From MSL, the presence of a cyclone centre is searched for in the upper-next level, up to 300 hPa. Then MSL cyclones are vertically connected up to their top pressure level and as a result the cyclone thickness is obtained. Besides, MSL cyclones are three-dimensionally characterized by a set of variables. These algorithms have been tested for a real case and are intended to provide a complete description of the evolution of WM cyclones as well as their three-dimensional structure.

The aforementioned algorithms (detection, tracking and three-dimensional characterization) have been applied to an 8-year HIRLAM-INM-0.5^o analysis dataset. As a result a WM cyclone database has been built. The WM exhibits a high frequency of cyclone centres, but cyclone centres are located at preferred regions, depending on the season. Furthermore, most of the cyclone centres are shallow, but an important number of deep cyclones are found in certain regions during certain seasons. A threefold grouping is proposed to explore cyclone centre characteristics more deeply: by thickness, season and regions.

Shallow cyclones are smaller, with weaker intensity and weaker wind speed profile than deep ones. In addition, shallow centres exhibit a stronger warm-core character, higher thermal gradients and lower relative humidity than deep ones.

In summer, and to a lesser extent in spring, cyclones are mostly found over land. Most of them are shallow and warm-core, and seem to be related to thermal effects. Conversely, in winter and autumn, cyclones are found preferably over the sea and many of them extend throughout the whole troposphere. Furthermore, although the thermal effect at low levels is also appreciable, it is weaker. At upper levels the cold-core character of cyclones is present throughout the whole year, but is more apparent in winter.

Cyclones located in the Iberian Peninsula, Palos and Algeria are, in general, shallow cyclones, related to thermal effects. Conversely, cyclones in the Gulf of Genoa exhibit a more widespread variety of typologies: from shallow and warm-core cyclones, related to thermal heat fluxes and lee conditions, to deep and well-developed ones, related to upper-level troughs.

Many WM cyclone centres concentrate close to main mountain ranges. In addition, most of these are shallow and warm-core. Although these facts do not demostrate the role of orography in the generation and maintenance of that cyclones, it does seem to be relevant. This supposition is supported by many theoretical and practical studies (e.g. Buzzi and Tibaldi, 1978; Homar *et al.* , 2002; Genovés *et al.* , 1997).

In principle, thermal gradients ($|\nabla T|$ and $|\nabla T_e|$) were introduced to distinguish between frontal and non-frontal (barotropic) cyclones. In the first case high values of the temperature gradient were expected, while for barotropic cyclones (such as heat or shallow orographic lows) small values of the thermal gradient were anticipated. However this general pattern is not observed for WM cyclones. This is probably due to the methodology used. Indeed a frontal region, if it exists, occupies a small portion of the total cyclone domain. Then when a front is present in the cyclone domain, the associated high $|\nabla T|$ (or $|\nabla T_e|$) values are averaged with lower ones. On the contrary, barotropic cyclones exhibit low values of $|\nabla T|$ around the cyclone centre, but these small values are ’increased’ when averaged with higher values located at the periphery of the cyclone domain, where stronger gradients are observed. The final result is that for frontal cyclones mean $|\nabla T|$ and $|\nabla T_e|$ decrease and for barotropic lows they increase. As a consequence, neither $|\nabla T|$ nor $|\nabla T_e|$ discriminate between frontal and barotropic lows and for future studies other variables, such as the thermal wind, could be tested.

To explore the WM cyclone centre database, three different grouping ways were selected. However, other grouping criteria could be utilised. Thus, a cluster analysis based on variables that describe the three-dimensional structure of cyclones could reveal several cyclone ’typologies’ and could allow one to investigate the relationship between those typologies and heavy rain and strong wind events. Other methodologies such as principal components analysis could be also investigated.

The WM cyclone database could also be used to study and analyse selected cyclogenesis cases, their three-dimensional structure and life cycles (in a similar way to the example seen in Section 4). In the framework of the MEDEX project a list of cyclones that produced hazardous weather was conducted. The detailed analysis of such events could reveal the importance of the involved cyclogenetical mechanisms and allow them to be classified in well-known schemes or allow new schemes to be formulated (similar to Baehr *et al.* , 1999; Deveson *et al.* , 2002; Plant *et al.* , 2003 for FASTEX cases).

The present cyclone database is for the WM basin. Another MEDEX goal is to extend the cyclone database for the whole Mediterranean. Then, the same methodology has been applied for the whole Mediterranean to a 5-year period (from June 1998 to May 2003) of the operational analyses of the European Centre for Medium-Range Weather Forecast (ECMWF). Preliminary results of comparison between cyclones in the western and eastern basin (Gil *et al.* , 2003a) as well as a comparison between HIRLAM-INM-0.5^o and ECMWF analyses for the western basin (Gil *et al.* , 2003b) have been performed. Furthermore we intend to apply the same methodology for the whole Mediterranean basin to a large analysis dataset, such as the ERA-40. This will allow us to extend the present study and give to the results a more realistic climatological basis. In addition the evolution of the number of Mediterranean cyclones and their main features could be studied over a large period along with the possible impact of climate change.

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Appendix

Geostrophic vorticity and geostrophic circulation

In isobaric coordinates, the vertical component of the geostrophic vorticity (ζ_g) is proportional to the Laplacian of the geopotential Z

$$\zeta_g = \nabla \times \vec{V}_g = \frac{1}{f}\nabla^2 Z$$

where f is the Coriolis parameter ($= 2\Omega \sin\varphi$), Ω is the earth angular velocity ($= 7.292\ 10^{-5}\ s^{-1}$) and φ the latitude.

In general, the circulation C is defined as the line integral of the tangential component of the velocity around a closed path (Holton, 1972), that is

$$C = \oint_{\vec{l}} \vec{V} \cdot d\vec{l}$$

Applying the Stokes theorem, the path integral becomes and area integral of the vorticity vector, where A is the area of the enclosed path.

$$C = \int_A \int (\nabla \times \vec{V}) \cdot d\vec{A} = \int_A \int \vec{\zeta} \cdot d\vec{A}$$

For small areas, the f-plane approximation can be performed. Furthermore, if the vorticity (in fact its third component) is replaced by its geostrophic value, the geostrophic circulation (GC) is

$$GC = \int_A \int \zeta_g \cdot dA \approx \overline{\zeta_g} \cdot A$$

Thus, GC is roughly equal to the area enclosed by the curve (A) times the mean geostrophic vorticity over the area ($\overline{\zeta_g}$). Then, CG measures the strength (by means of the $\overline{\zeta_g}$) and the size (by means of the area A) of the cyclone and it could be used as a measure of the intensity (Sincalir, 1997; Picornell *et al.* , 2001).

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Level (hPa)	Radius (km)
1000	200
925	200
850	250
700	350
500	400
300	500

Table 1: 'Search radius' (in km) for cyclone centres for each pressure level (in hPa)

Parameter	Description	Units
Date	year, month and day of the cyclone centre appearance	
Time	of the cyclone appearance (00, 06, 12 or 18 UTC)	hours
Code	an arbitrary number which identifies each cyclone along its life-cycle	
Top pressure level	highest pressure level at which the cyclone centre is detected	hPa
Shift distance	distance from the cyclone centre at MSL and the cyclone centre at the top pressure level	km
Shift angle	direction between the cyclone centre at MSL and the cyclone centre at the top pressure level	in degrees 0^o is the north direction

Table 2: Parameters that describe general cyclone features.

Parameter	Description	Units
Latitude-longitude	coordinates of the cyclone centre	degrees
MSLP or Z	at the cyclone centre	hPa or gpm
Open/Closed	if the cyclone is a MSLP/Z minimum or a ζ_g maximum	
Principal/Secondary	if the cyclone is principal or secondary (see text)	
R	mean radius of the cyclone domain	km
A	area of the cyclone domain	$10^4\ km^2$
ζ_g	geostrophic vorticity	$10^{-6}\ s^{-1}$
GC	geostrophic circulation	$10^7\ m^2\ s^{-1}$
$\lvert\nabla T\rvert$	absolute value of the temperature gradient	$°C\ (100\ km)^{-1}$
$\lvert\nabla T_e\rvert$	absolute value of the equivalent temperature gradient	$°C\ (100\ km)^{-1}$
$\nabla^2 T$	Laplacian of temperature	$10^{-6}\ °C\ km^{-2}$
RH	relative humidity	%
σ_e	moist static stability	$10^{-7}\ m^4\ s^2\ kg^{-2}$
V	horizontal wind speed	$m\ s^{-1}$

Table 3: Parameters that describe the vertical cyclone structure.

	Summer	Autumn	Winter	Spring
Shallow	45.7	17.9	11.0	25.4
Middle-depth	29.5	22.8	18.7	29.0
Deep	17.6	24.6	27.7	29.9
Gulf of Genoa	31.2	22.8	20.4	25.6
Iberian Peninsula	66.5	6.2	5.6	21.7
Palos	54.5	23.5	9.3	12.7
Algeria	65.4	10.7	2.9	20.9
Western Mediterranean	33.3	21.0	18.2	27.5

Table 4: Seasonal frequency (in %) of cyclone centres for thickness groups (shallow, middle-depth and deep), the selected regions (Gulf of Genoa, Iberian Peninsula, Palos and Algeria) and the whole study area (Western Mediterranean).

	Shallow	Middle-depth	Deep
Gulf of Genoa	41.6	14.1	44.3
Iberian Peninsula	81.5	7.6	10.9
Palos	80.2	5.7	14.1
Algeria	79.3	10.2	10.5
Western Mediterranean	51.1	11.1	37.8

Table 5: Frequency (in %) of cyclone centres per thickness for the selected regions (Gulf of Genoa, Iberian Peninsula, Palos and Algeria) and the whole study area (Western Mediterranean).

	ζ_g L	ζ_g U	GC L	GC U	R L	R U	$\nabla^2 T$ L	$\nabla^2 T$ M	RH L	RH M	V L	V U	σ_e 925-500
Shallow	51.2	-	2.5	-	386	-	-69.0	-	52	-	5.8	20.8	3.8
Middle-depth	56.7	-	3.3	-	425	-	-50.5	-6.3	58	47	7.2	24.7	5.3
Deep	58.2	104.0	4.0	11.1	465	556	-30.3	19.9	72	54	7.9	24.6	5.0
Summer	53.3	98.1	2.6	8.8	393	512	-51.9	14.8	52	44	5.8	19.0	2.3
Autumn	54.3	108.7	3.4	11.1	438	549	-37.9	16.1	67	54	7.1	23.4	4.3
Winter	57.0	107.1	4.0	12.6	464	586	-41.5	19.4	75	57	7.8	24.5	7.4
Spring	56.9	100.7	3.4	11.0	430	561	-55.6	15.5	59	52	7.2	25.5	5.2
Palos	53.4	93.6	2.1	8.7	353	505	-28.6	18.6	56	46	5.8	17.8	5.8
Algeria	55.4	68.8	3.6	5.1	450	450	-62.5	1.2	23	42	6.3	17.4	3.5
G. Genoa	58.7	100.8	2.5	10.2	366	549	-62.1	14.5	71	52	6.4	28.1	5.1
Iberian P.	47.0	100.4	2.5	9.7	404	521	-95.5	15.8	49	44	4.2	16.3	0.9

Table 6: Mean values of some parameters at low (L) and medium (M) or upper (U) levels for different cyclone groupings.

	ζ_g L	ζ_g U	GC L	GC U
Shallow	42.4	-	2.0	-
Middle-depth	56.7	-	3.3	-
Deep	58.2	104.0	4.0	11.1
Summer	46.0	19.6	2.2	1.8
Autumn	49.6	48.4	3.1	4.9
Winter	53.9	61.7	3.8	7.3
Spring	52.5	41.4	3.1	4.5
Palos	47.8	13.2	1.9	1.2
Algeria	44.4	7.2	2.9	0.5
G. Genoa	56.7	44.6	2.4	4.5
Iberian P.	40.1	10.9	2.0	1.1

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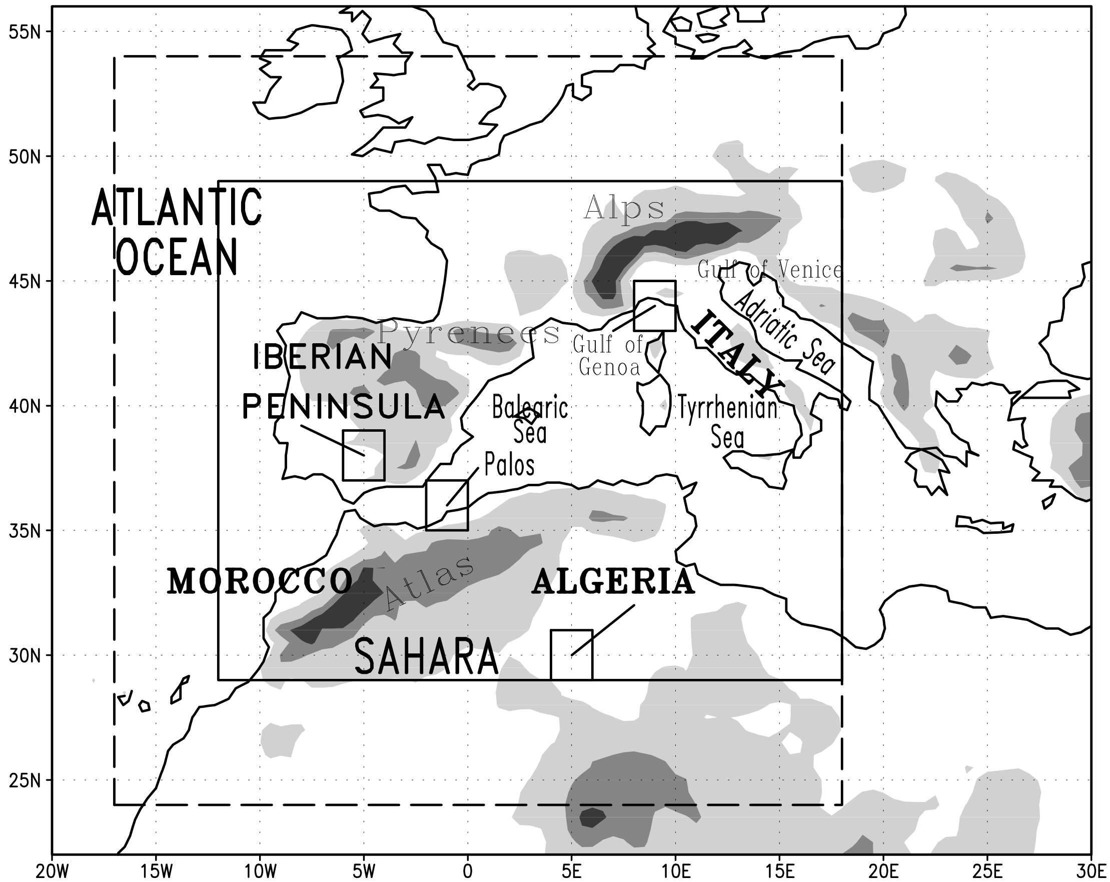

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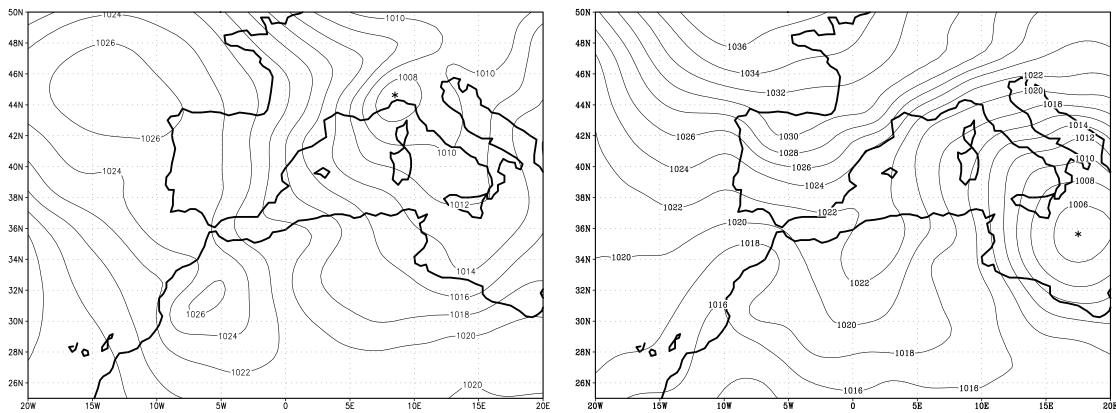

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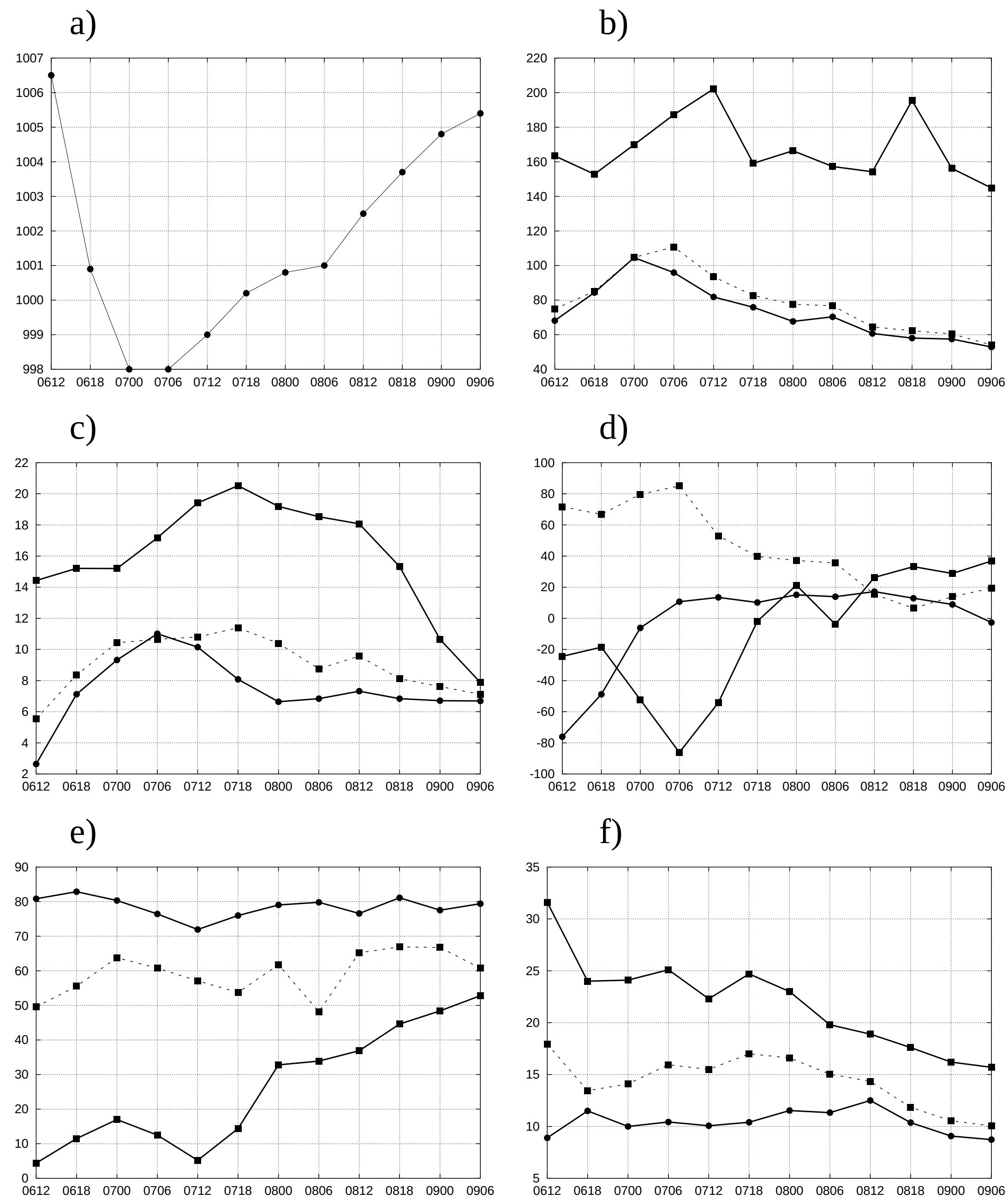

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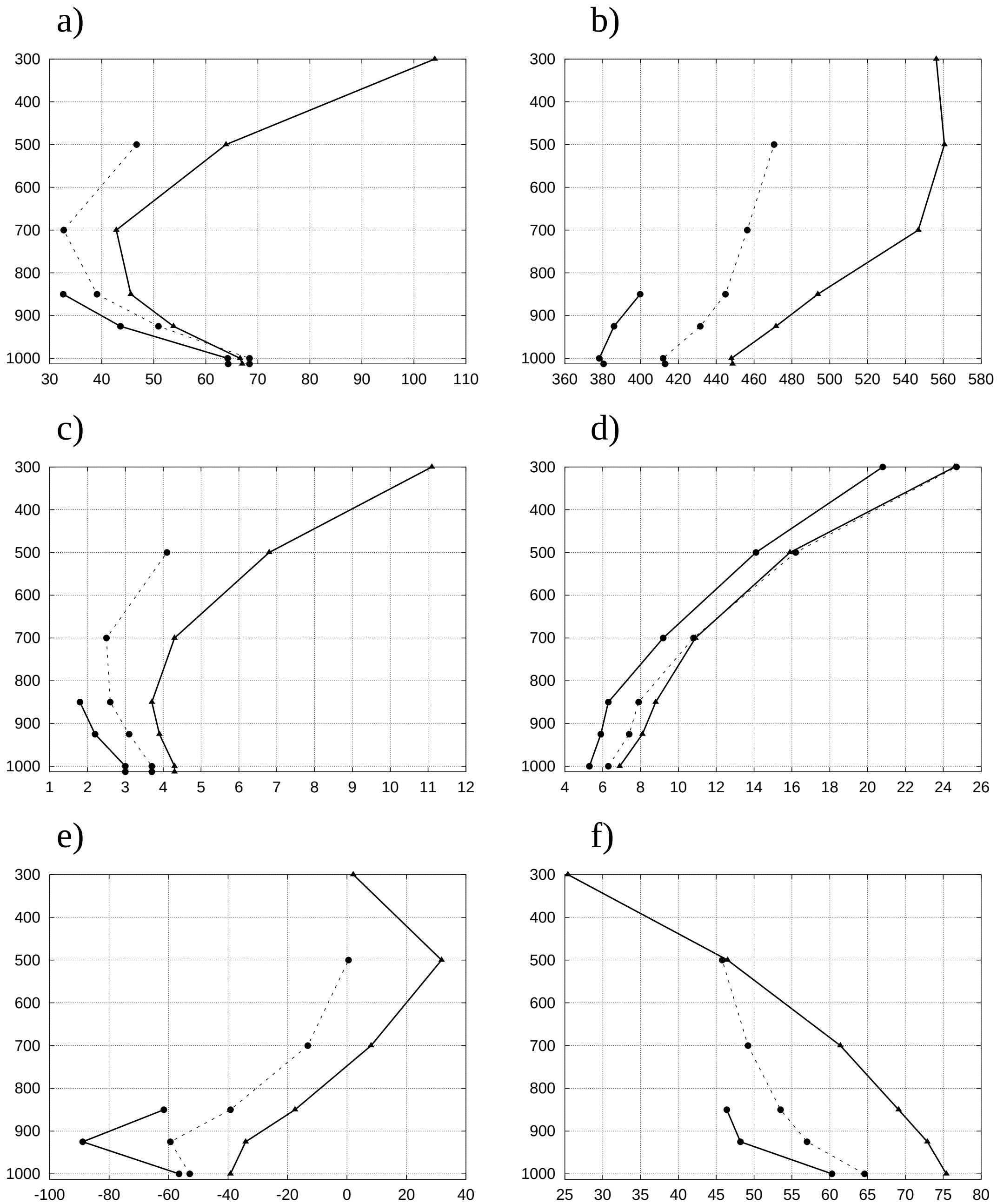

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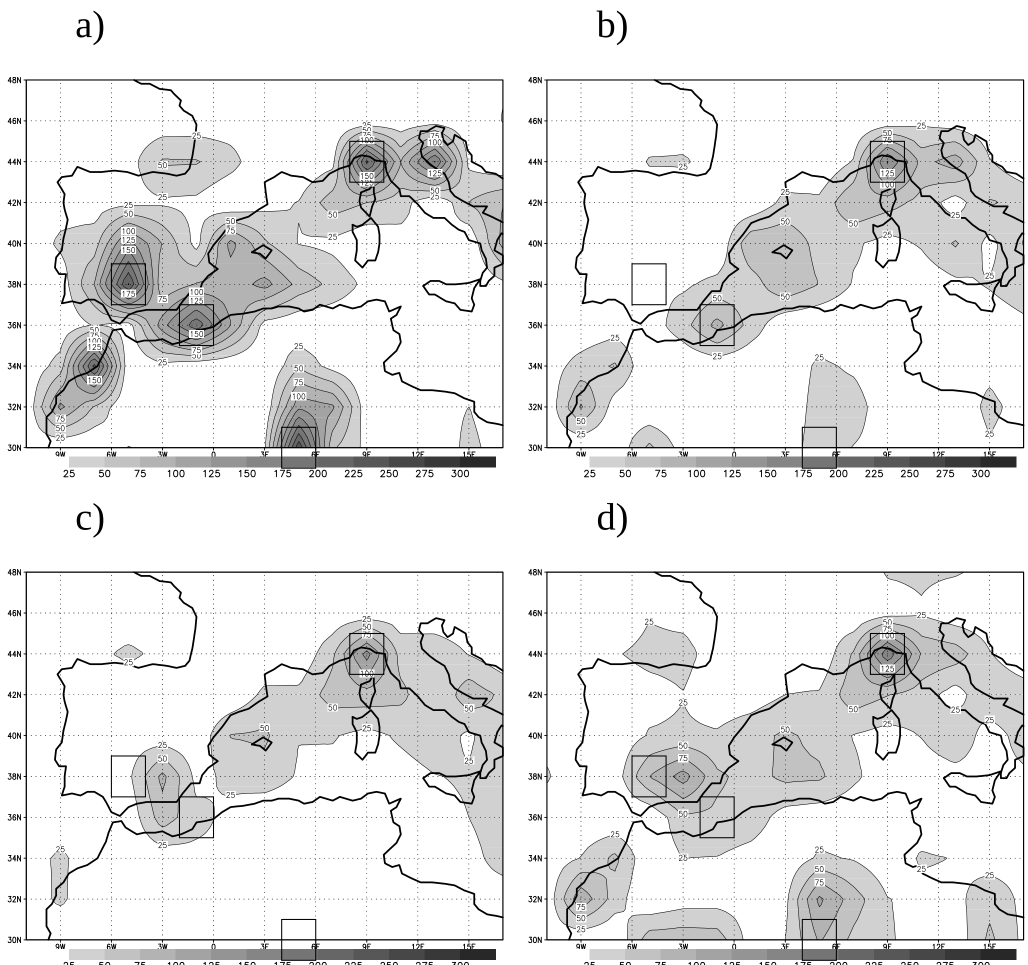

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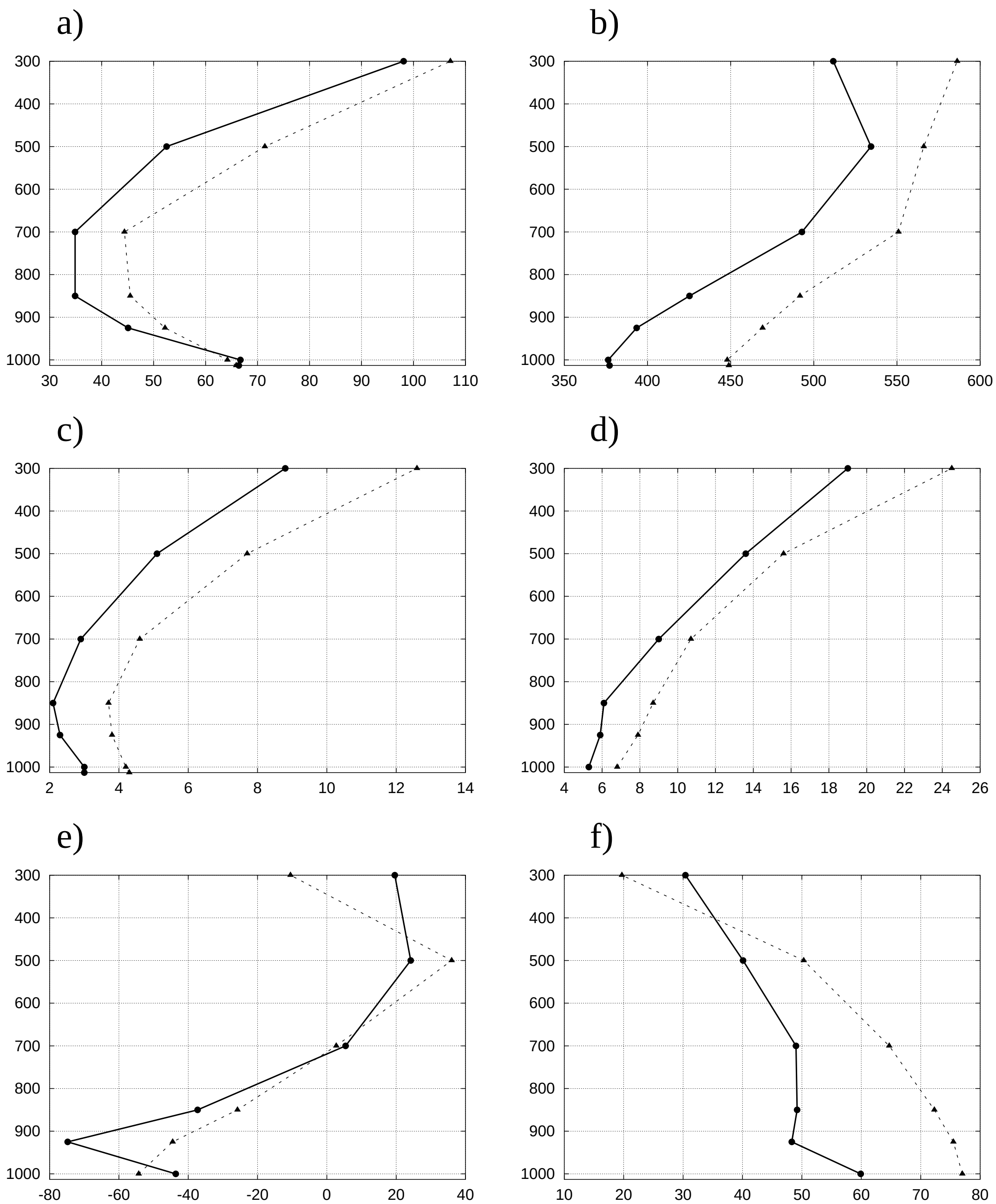

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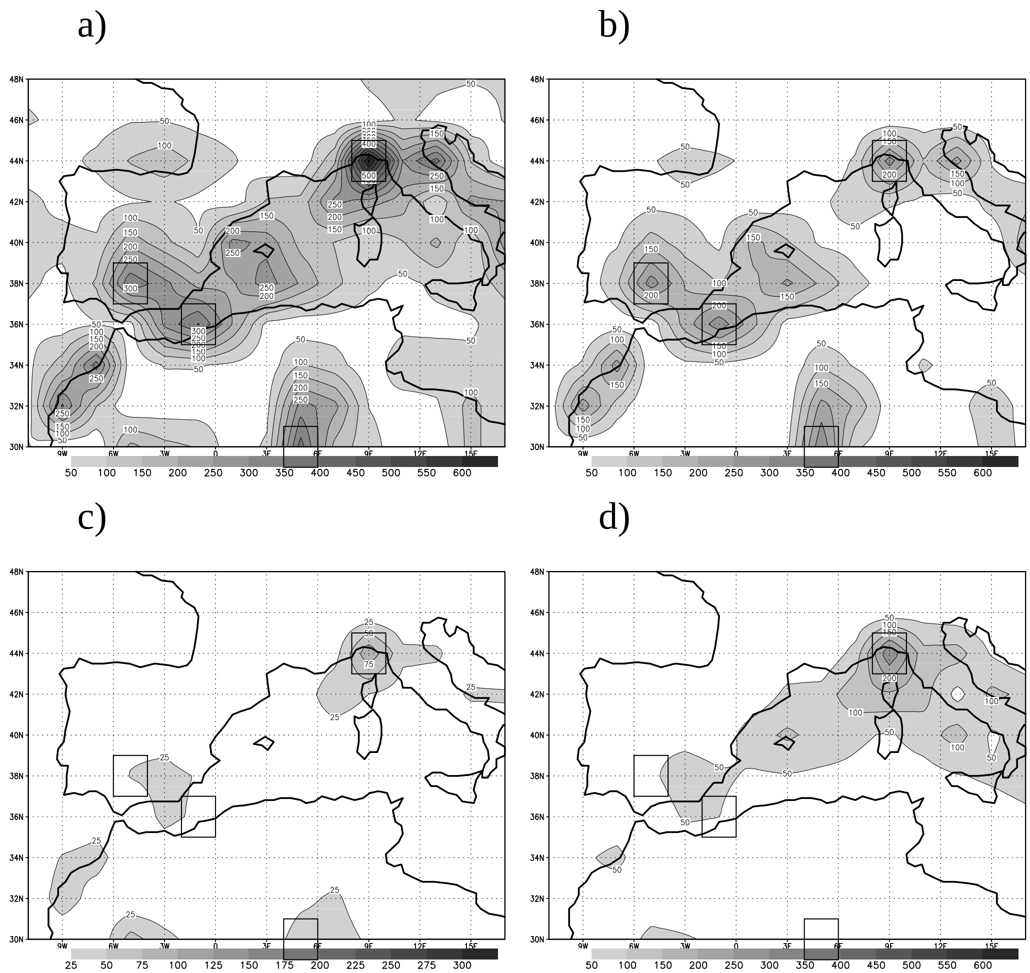

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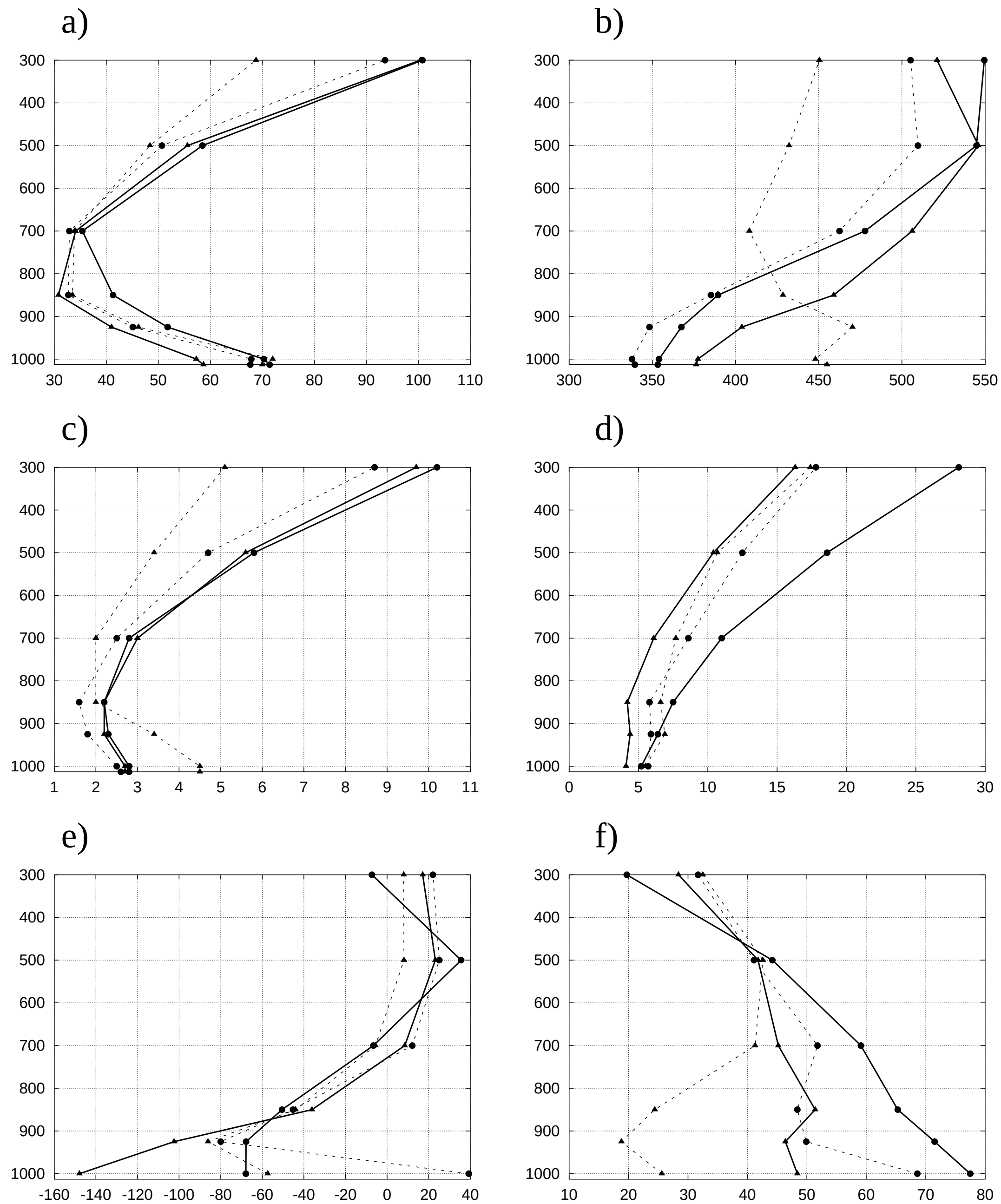

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