# Classification of Cyclone Tracks over Apennines and the Adriatic Sea

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# Abstract

Cyclones that appear in the Adriatic Sea basin strongly influence the climate and weather conditions in the area. In particular, apart from the usually mild climate, cyclone activity in the Adriatic and the central Mediterranean provide the main hydrological forcing as well as trigger mechanisms for a range of extreme weather phenomena. Therefore, a basic understanding of the cyclogenesis over the Adriatic Sea is essential. In particular, the classification of different types of cyclogenesis in the area is fundamental since it will help the understanding and prediction of the relevant weather phenomena. In this study, based on the analysis of four year (2002 – 2005) operational ECMWF T511 dataset, we classify various types of cyclone tracks and isolate the mesocyclogenesis areas in the vicinity of the Adriatic basin.

Our analysis indicates that four types of cyclogenesis over the Adriatic Sea can be identified: (1) Type A: cyclones connected with pre-existing Genoa cyclones. Two subcategories are found: (I) continuous track: Genoa cyclones crossing over the Apennines to the Adriatic Sea and (II) discontinuous track: new surface cyclones generated over the Adriatic Sea under the influence of a parent cyclone generated in the Gulf of Genoa (Genoa cyclones) and moving towards the Adriatic but blocked by the Apennines. (2) Type B: cyclones developed in situ over the Adriatic Sea without any connections with other pre-existing cyclones in the surrounding area. (3) Type AB: mixed types A and B cyclones. In this type of cyclone, two cyclones co-exist and stride over the Apennines (twin or eyeglass cyclones). (4) Type C: cyclones moving from the Mediterranean Sea, but not from the Gulf of Genoa (non-Genoa cyclones). Two subcategories are found: (I) continuous track: a non-Genoa cyclone is able to cross over the Apennines to the Adriatic Sea continuously and (II) discontinuous track: a non-Genoa cyclone is blocked by the Apennines and a new surface cyclone is generated over the Adriatic Sea. The relevant dynamics of the above types of cyclones are discussed along with characteristics of the cyclones and their synoptic situations at lower and upper troposphere.

## 1. Introduction

The Adriatic Sea is a mesoscale NW-SE elongated basin in the central Mediterranean Sea, which is approximately 200 km wide and 1200 km long, almost entirely enclosed by high mountains (Fig. 1) – Apennines to the west and southwest, Alps to the north and Dinaric Alps on the east and southeast. Apart from the usually mild climate, cyclone activity in the Adriatic and the central Mediterranean provides a trigger mechanism for a range of extreme weather phenomena, such as local downslope windstorm Bora (known as "Bura" in Croatia) (e.g. Smith 1987; Klemp and Durran 1987; Bajić 1989; Jurčec 1989; Ivančan-Picek and Tutiš 1996; Grubišić 2004; Belušić et al.; 2004; Gohm and Mayr 2005), strong winds called Scirocco and Tramontana (Jurčec et al. 1996; Cavaleri et al. 1999; Pandžić and Likso 2005), heavy orographic precipitation, thunderstorms, supercells and mesoscale convective systems (Ivančan-Picek et al. 2003). The terrain geomorphology and viscous energy transport may then, in turn, cause storm surges in Venice (Trigo and Davies 2002; Lionello 2005), flash floods (De Zolt et al. 2006), high seas (Leder et al. 1998), avalanches and landslides (Lionello et al 2006). However, despite the development of the sophisticated high-resolution numerical mesoscale models, weather in the broad area of Alpine lee (Apennine and the Adriatic regions) is still characterized with a limited predictability, especially of processes on meso and sub-mesoscales. For these reasons, field experiments, such as the 1982 Alpine Experiment (ALPEX; see Kuettner, 1986) and the 1999 Mesoscale Alpine Program (MAP; e.g., Bougeault et al. 2001) were both designed to conduct meteorological measurements in the Adriatic region to allow for validation and error assessment of numerical models. Therefore, investigations of different cyclone types in the region and assessment of associated weather conditions including extreme weather are of a great importance, not only for the improvement of weather forecasting, but also for a more complete understanding of weather and climate impacts in the Mediterranean.

Climatology of the Mediterranean cyclone activities has been investigated in a considerable number of studies. Early subjective studies recognized the Gulf of Genoa as the main Mediterranean cyclogenesis area (Van Bebber 1891; Pettersen 1956). Such subjective synoptic studies dominated the early research until the appearance of model based datasets and objective cyclone detection and tracking algorithms. Such objective synoptic-scale classifications (models resolutions > 1 degree) commonly identified major cyclogenesis areas, such as the Gulf of Genoa, Cyprus, Northwest Africa and Iberian peninsula, as well as the secondary ones, such as Southern Italy and Aegean Sea (e.g. Alpert et al. 1990a; Trigo et al. 1999; Campins et al. 2000; Maheras et al. 2001). In a few recent mesoscale studies, other centers such as the Pyrenees, the Adriatic Sea, Alboran Sea, and Balearic Sea, have been detected (Picornell et al. 2001; Gil et al. 2002; Campins et al. 2006).

Due to the scales of the Adriatic basin and the surrounding complex terrain, cyclogenesis in the Adriatic Sea was traditionally inadequately detected by subjective synoptic analysis. The encouraging attempts of a subjective sub-synoptic analysis in the central Mediterranean (Radinović 1965, 1978, see 1987 for a review) indicated the existence of two rather separate areas of cyclone activities, the northern Adriatic and the middle Adriatic regions. However, Radinović's studies only covered a very short duration of time (1 year of surface data) and did not include surface data over the Adriatic Sea. Recent synoptic scale objective studies focused on larger Mediterranean cyclogenesis centers (e.g., Trigo et al. 1999; Maheras et al. 2001; Picornell et al. 2001; Gil et al. 2002) and presented a spectra of Adriatic-related results. While most of the studies did not refer to the Adriatic as a prominent Mediterranean cyclogenesis center, some studies nevertheless identified the Adriatic as the major area of explosive deepening in the cold season (Conte, 1985; Maheras, 2001). Using similar objective analysis with higher resolution model (basin well-resolving) datasets, the northern Adriatic was identified as a region of high cyclone activity (Campins et al. 2000, 2006: Picornell et al. 2001).

However, reliability of the current state-of-art objective algorithms diminishes as the resolution of complex terrain increases (Genoves and Campins, personal communication). For the entire western Mediterranean, significant variations for many important sub-synoptic or mesoscale cyclogenesis centers were shown in different studies in terms of the overall number of cyclones and their seasonal density (the Pyrenees, the Adriatic, inland Algeria, Southern Italy etc.). Many of these mesoscale cyclogenesis centers are located in the proximity of the mesoscale mountain ranges. Therefore, there is no doubt that to some extent these differences are due to resolutions of different datasets. However, it appears that the most significant mesoscale discrepancies come from different cyclone classification and tracking algorithms, where a certain degree of subjectivity and strong biases might be introduced by the choice of the algorithm details. An illustrative example showed that even with the same objective criteria, a simple Cressman smoothing, which is used in many climatology studies, can reduce the number of cyclones by an order of 10 and completely eliminate some strong cyclogenesis centers (Gil et al. 2002).

In addition, circulation is often not strictly defined in the cyclone detection and tracking criteria. Although mean sea level pressure (MSLP) and vorticity showed similar results for cyclone identification on the synoptic scales (Hoskins and Hodges, 2002), significant differences in cyclone circulations were present in the analysis of mesoscale cyclones. An air stream passing a mesoscale mountain may produce a pressure low in the lee, but without closed circulation or on the contrary a vortex without the pressure low (see, e.g., Lin 2007). Since the study of the cyclone activity in the Adriatic has to include meso-β scales (20-200km), the algorithm based solely on the MSLP might in turn introduce significant biases in the analysis. On the other hand, vorticity and circulation are very noisy on the mesoscale, which makes implementation of circulation criteria into the algorithm extremely difficult (Campins et al. 2006).

Yet another characteristic of the Adriatic area is that the majority of cyclones that appear in the basin actually traverse the mountain range, i.e. Apennines, from the west. This fact, rather unique in the Mediterranean area, has two important consequences: The surface low pressure weakens and may disappear completely over the mountain peak due to the presence of mountain-induced high pressure and reappear in the lee. This, in turn, might cause the overestimation of the deepening rates and the cyclone first appearance climatology in the lee of Apennines. This kind of behavior is known from fluid dynamics and was documented for mid-latitude cyclones crossing the Rocky Mountains and Appalachian Mountains (e.g. Chung et al. 1976) and tropical cyclones crossing the Central Mountain Range of Taiwan (Lin et al. 2005). Secondly, the cyclone may become discontinuous over the mountain range with two separate vorticity centers simultaneously present over the mountain. Once the parent cyclone disappears on the upstream side of the mountain, the lee daughter cyclone may strengthen, replace the parent cyclone and then resume the original track. This type of cyclone continuity analysis can have a noteworthy influence on the results of the climatology study in complex terrain (e.g., O'Handley and Bosart 1996). Recently, the continuity of the cyclone over the Apennine range was examined numerically using vortex Froude number analysis on two MAP IOP cases (Lin et al. 2007). Thus, the Adriatic oriented objective track algorithm needs to take into account the processes associated with the cyclone passage over the mountain so as not to overestimate the number of neither cyclogenesis events, nor the associated deepening rates over the lee of the Apennines.

Due to the discussed complexity of a reliable scale and geomorphology dependent objective algorithm in the inherently mesoscale area of interest, we choose to conduct a manual analysis fully devoted to the cyclone activity in the Adriatic basin. Furthermore, a focus on a smaller region gives more information on less frequent cyclone types and tracks providing a complete picture on the cyclone activity in the area.

The results show the typical cyclone tracks related to the Adriatic area as well as the climatology of the intrinsic Adriatic cyclogenesis. In addition, typical cyclone cases belonging to the isolated cyclone tracks will be shown and discussed. Given in this fashion, the cyclone climatology and the cases presented will serve as a platform for the subsequent analysis of precipitation patterns associated with the different cyclone tracks in the Adriatic. A similar study has been performed in the case of tropical cyclones crossing Taiwan (Witcraft et al. 2005; Lin et al. 2002). In addition, this climatology study will be a background for future numerical modelling and analysis of the Adriatic cyclones. In Sec. 2, data and methodology will be described. Classification of Adriatic cyclones will be presented in Sec. 3, and their characteristics will be discussed in Sec. 4. Conclusions and remarks are made in Sec. 5.

## 2. Data and methodology

A manual subjective analysis technique was used to analyze the cyclone activity over the Apennine and Adriatic areas. In addition, the subjective analysis included objective guidance regarding the MSLP intensity and cyclone duration, while circulation criteria remained predominantly subjective. The present work is based on the 4-yr (2002-2005) T511 operational analysis data with 6-hr temporal resolution, acquired from the European Centre for Medium-range Weather Forecasts (ECMWF). Among the available model data archives, this dataset allows for the highest spatial resolution in the related mid-latitudes (~40 km).

As the first step, an occurrence of the pressure lows was identified based on the MSLP 2 hPa closed isobar, either in the wider Adriatic region (approx. 100 km around the basin), or traversing the area. Then, streamlines were analyzed to identify the associated circulation pattern in the pressure low area. If the pressure low was above the sea or flat land, closed circulation cyclone identification was required. However, if the cyclone was shallow or in the vicinity of the mountains, a strong surface convergence (significant streamline curvature) pattern was recognized. Namely, this type of streamline pattern is often present in the process of cyclone initiation in mountain areas as well as during its passage over the mountain range. In particular, e.g., in cases of weak cyclone initiation of the Alpine lee over northern Italy, where complex terrain strongly modifies the surface circulation, strong surface convergence was taken as sufficient criterion for cyclone detection if the system satisfied objective MSLP threshold. This choice kept the analysis somewhat subjective, but more in accordance with conceptual models as well as other climatology studies. Once a cyclone was detected in the area of interest, it was back-traced (traced) to the place of origin (deterioration or exit out of the domain).

With respect to the project goal discussed in the Introduction, the subjective cyclone detection and tracking criteria was aimed at isolating somewhat more significant and intense cyclones, both in terms of duration and intensity that are more important for the weather and climate in the region. In accordance, objective constraints included the 2 hPa closed isobar in duration of at least 6 hours for all the cyclones that appear in the Adriatic. However, very few cyclones were added to the classification, even if it did not fully satisfy the above MSLP closed isobar criteria. These exceptions belong to the twin cyclone type, as will be discussed in the next section, where the secondary center was sometimes well-defined in vorticity field but not in pressure field. In several such cases, at least 1 hPa closed secondary pressure low was required.

We designed these criteria in accordance with the spatial and temporal dimensions of the cyclones identified in the operational practice, conceptual models, and Adriatic cyclone case studies (e.g. Radinović 1987; Ivančan-Picek 1998; Brzović 1999). In particular, this type of mean sea level and circulation thresholds aims at improving the identification of cyclone initiation and tracking in the lee areas of the Alps and Apennines, in a dedicated regional cyclone analysis.

## 3. Classification of Adriatic cyclones

Based on the selected classification criteria, several types of cyclones that appear in the Adriatic basin and their associated tracks are detected and classified as the following types:

1. A – Genoa cyclones (the Gulf of Genoa and northern Italy)
    a. A-I – continuous Genoa cyclones
    b. A-II – discontinuous Genoa cyclones
2. B – Adriatic cyclones
    a. B-I – northern Adriatic cyclones
    b. B-II – middle Adriatic cyclones
3. AB – both Genoa and Adriatic cyclones exist (twin or eyeglass cyclones)

4. C – non-Genoa and non-Adriatic cyclones
    a. C-I – continuous cyclones
    b. C-II – discontinuous cyclones

Most of the cyclones that appear in the Adriatic are cyclones that originate in the Gulf of Genoa or northern Italy. These are commonly referred to as Genoa or Alpine lee cyclones and are here identified as the Type A cyclones (Fig. 2.a-b). This reflects the fact that in winter the area is the most active cyclogenesis region in the western Mediterranean (e.g., Trigo et al. 1999). Indeed, in our study the Genoa cyclones that occur in winter (DJF) are twice as frequent as those in other seasons (Table 1). This result resembles the outcome of several subjective studies (e.g. Radinović 1965, Campins et al. 2000). On the other hand, a number of objective studies (Campins et al. 2000; Campins et al. 2006, Maheras et al. 2001) indicated that summer is the main season for Genoa cyclone activity. It thus might be that deeper winter cyclones steered by the upper level trough have a stronger preference to traverse the Apennine range, whilst shallow summer cyclones are more stationary and have their paths along the western Apennine coast. However, regardless of the results of our study, it appears that different treatment of the summer lows was applied in the subjective and objective analyses, resulting in the differing results. Note that a cyclone may also move to a new location due to the upper-level forcings.

Two main sub-types of Type A Genoa cyclones that traverse to the Adriatic were detected according their continuity over the Apennine mountain range. Most of the Genoa cyclones initiate over the lee of the continental Alpine mountain range, close to the Gulf of Genoa, and retain their continuity during the traversal over the peninsula (Type A-I). These cyclones usually cross the northern, lower-elevation part of the Apennines along the Po Valley to the northern Adriatic where the tracks start to diverge (Fig. 2.a). While the main branch slides down the Adriatic basin, a subset of cyclones cross the northern Dinaric Alps and follow less well-defined eastward or northeastward sub-track. In addition, a number of shallower cyclones experience cyclolysis and do not propagate further. Occasionally, Genoa cyclones move along the western Italian coast to the Tyrrhenian Sea before crossing the peninsula to the Adriatic basin. It is interesting to note that these Genoa cyclones are initiated solely over the seawater of the Gulf of Genoa (not above the continent of northern Italy) and usually traverse to the Adriatic over the higher-elevation parts of the Apennines – preferably the middle Apennines (with highest peak Monte Corno at 2912 m). Such a cyclone track results in two separate MSLP and circulation centers that are present simultaneously on both sides of the mountain. In a subsequent development, typically the windward center experiences cyclolysis and the lee center strengthens and eventually replaces the parent cyclone. Although the temporal resolution of the dataset is rather coarse with respect to advection time scale over the mountain, such processes were identified over the Apennines, constituting the Type A-II Genoa cyclones (Fig. 2b). It is anticipated that the number of discontinuous cases would increase with the increase of the time resolution of the reanalysis dataset.

Discontinuous cyclone tracks over higher mountains were well-documented in cyclone climatology studies (e.g. O'Handley and Bosart 1996; Lin 2007). In their studies, the influence of Appalachian mountain range on cyclonic weather systems showed that most of the cyclones undergo redevelopment as they traverse over the range, with a high variation of exact redevelopment location. Similarly, roughly half of the cyclones crossing the middle Apennines show a discontinuity feature as they traverse over to the Adriatic basin. The location where discontinuous A-II cyclone tracks traverse the Apennines shows the importance of the mountain range height for the process. In other words, in the region with considerable mountain height, the cyclone tracks are more likely to be discontinuous across the Apennines. This implies that a criterion for the discontinuity over the middle-latitude mountain ranges might be evaluated in terms of the vortex Froude number, as done for tropical cyclones crossing over Taiwan (Lin et al. 2005).

The results show that annually 11 Genoa cyclones traverse over the Apennine peninsula to the Adriatic, contributing to more than 35% of the total number of cyclones detected in the region. This number at first sight seems to be exceedingly small compared to the number of Genoa cyclones detected in recent objective classifications. However, this difference is mostly explicable in terms of the Genoa cyclone track diffluence upon initiation: the first track slides to the west of the Apennines to the Ionian Sea and the second over the Apennine peninsula to the Adriatic while only the latter track is being of interest to this study.

In addition, according to Trigo et al. (1999) and Picornell et al. (2001), about 60% of cyclones in the Mediterranean last for less than 12 hours. According to the same studies, approximately half of the total number of Genoa cyclones is shallow cyclones that do not reach much higher than 850 hPa (Campins et al. 2006, their Fig. 4). These studies characterize shallow summer Mediterranean cyclogenesis by the prevailing thermal forcing and diurnal variations, implying an intrinsic quasi-stationarity. Moreover, a number of studies have rather loose pressure criteria and identify open lows as cyclones as well. Thus, a closed circulation and 6hr closed 2 hPa criteria significantly reduced the number of identified cyclones in our study. Having all of the above in mind and applying some simple conceptual numbers, we can easily speculate that the number of Genoa cyclones identified in other studies should be at least several times greater than the number of Genoa cyclones active in the Adriatic. The identified cases under these criteria can be compared with the results of Trigo et al. (1999, their Fig. 7), who identified approximately 35 cyclogenesis cases lasting for more than 12h in the Gulf of Genoa annually. Indeed, practically all of the Genoa cyclones identified in our study lasted for at least 12h, which is often the time period necessary for a Genoa cyclone to appear in the Adriatic. Another comparison can be made with the results of Campins et al. (2006, their Fig. 4) that identify 80 cyclones in the Gulf of Genoa annually. If we assume that on average it takes a cyclone 12h to leave the Gulf of Genoa area, which is the approximate duration of the first phase of Genoa cyclone development (e.g. Buzzi and Tibaldi 1978), the yearly number of cyclones in their study would be around 40. In a different approach, an observational study during the ALPEX period (Pichler and Steinacker 1987) identified 43 Genoa cyclones in 13 months. Therefore, the comparison with our results implies that approximately roughly 25-30% of Genoa cyclones traverse the Apennine peninsula to the Adriatic Sea.

It is important to note that in our study we clearly separated the cyclones that were advected to the Gulf of Genoa from those that originated in the region. This is especially important for a comparison of cyclone appearance statistics presented in other climatology studies, as well as operational practice, where sometimes this fact is overlooked. Due to high baroclinicity near the northern Mediterranean coast (e.g. Reiter 1975), many pre-existing winter cyclones follow the coastal lines and reach the Gulf of Genoa. Thus, a study that detects the presence of cyclones only might show a greater number of cyclones detected in the lee of Alps than the actual number of cyclones that originate in the area.

Figure 3 indicated that the Adriatic Sea is an area for moderate mesocyclogenesis, in terms of the annual cyclone frequencies. This type of intrinsic Adriatic cyclones is classified as a Type B cyclone in this study. Two major sub-types and tracks of intrinsic Adriatic cyclones are detected and contribute to 25% of the total number of detected cyclones in the region (Table 1). The first subcategory of Type B cyclones (i.e., Type B-I) initiates in the lee of Alps in the northern Adriatic Sea and moves southeastward along the basin. This type of cyclone seems to be qualitatively similar to the Genoa cyclones that move along the western Italian coast over the Tyrrhenian Sea. Most of these cyclones are generated in the colder season of the year, with cyclone tracks along the Adriatic basin channeled between the Apennines to the west and Dinaric Alps to the east.

The second subcategory of Adriatic cyclones (i.e., Type B-II cyclones) originates in the lee of the middle Apennines and quickly traverses the Adriatic almost perpendicular to the basin. This type of cyclone has a considerably shorter life-time scale and is less intense than the northern Adriatic type. The cyclone longevity and cyclolysis seem to be highly constrained with the Dinaric Alps mountain range. Most of these cyclones occur in the warmer season of the year, which implies that besides orographic effect, heat fluxes from the sea might be strong cyclogenetic factors. It should be noted that the number of cyclones detected would be much higher if a circulation criterion were not applied. Namely, our subjective analysis often identified 1 hPa pressure lows in the lee of middle Apennines.

These types of lows are a common feature of the middle Adriatic area and are often markedly decoupled from the vorticity centers (Ivančan-Picek 1998), not satisfying the cyclone detection guidance imposed in our study. Thus, if MSLP cyclone criterion is the only criterion used (no vorticity criterion), the middle and the southern Adriatic might appear to be more intense cyclogenesis centers than the northern Adriatic. This might have reflected on the results of the several objective studies that covered both regions (e.g. Trigo et al. 1999; Picornell et al. 2001). On the other hand, both ours and Radinović's subjective analysis show similar cyclogenesis intensity for both northern and the middle Adriatic areas.

There is an indication of a third group of cyclones that originate in the Adriatic region which appears to be attached to the western coast of the middle and southern parts of Dinaric Alps. In contrast to the northern part, the mountain height increases southward (highest top of Maja Jezercë at 2692 m). The geographical characteristics of genesis region of these cyclones imply that these cyclones are lee cyclones of Dinaric Alps. In addition, convergence of the local winds "Bura" (Bora wind blowing in Croatia) and "Jugo" (mountain channeled Sirocco wind) appears to be a generating factor for these cyclones and will be discussed in the next section.

In general, despite their high genesis frequency, Adriatic cyclones are usually rather weak compared to Genoa cyclones. While type B-I cyclones can occasionally reach significant deepening rates, type B-II cyclones rarely deepen more than 4-5 hPa throughout their Adriatic life-cycle (refer to discussion in Sec. 4). Probably for this reason, a well-defined genesis location of type B-II cyclones was not clearly identified in earlier studies.

Occasionally, two cyclones simultaneously exist, one over the Gulf of Genoa and the other over the northern or the middle Adriatic Sea. These cyclones are called twin or eyeglass cyclones in the literature (e.g. Brzović, 1999) and are classed as Type AB in this study (Fig. 4). On average, this type of rather rare event occurs less than twice a year according to our analysis. Typically, the twin cyclones simultaneously move from NW to SE along the western Italian coast and the Adriatic Sea, respectively.

Alternatively, the Adriatic member of the twin cyclone crosses the Dinaric Alps and moves to the east. This type of cyclone (Type AB) has not been identified in up-to-date climatology studies, although it is well-known to forecasters in the region and has already been numerically analyzed (to be discussed later). While both twin cyclone centers can be identified, it is more appropriate to treat them as one structure since they belong to the same system in the upper levels, similar to binary (e.g. Ziv and Alpert 1995) or discontinuous cyclones (e.g. Lin et al. 2005).

The number of Type AB cyclones is considerably smaller compared to that of B-I and B-II cyclones. Due to their low frequency and the fact that the Adriatic twin cyclones most often move from northern to southern part of the basin, there is no significant net effect of Type AB cyclone climatology on the comparison of relative frequencies of cyclone appearances in different parts of the Adriatic Sea. Nevertheless, for completeness, Type AB cyclone will be added in the Adriatic area cyclone climatology.

A non-Adriatic and non-Genoa type of cyclone is classified as a Type C cyclone, which is initiated further to the west (Figs. 5.a-b). These cyclones form in several cyclogenesis areas of the western Mediterranean, such as the Pyrenees, Iberia, Atlas, Alboran Sea and the Atlantic Ocean, as well as over the Mediterranean seawater mass. They contribute to about 35% of the total number of cyclones detected in the Adriatic area. These cyclones can often reach fierce intensities and cause a range of severe weather events as they move over the Mediterranean (e.g., Horvath et al. 2006). While these cyclones often occur in the wintertime, the most noteworthy fact is the very limited number of Type C cyclones present in the Adriatic during the summer. It is well known that summer cyclogenesis in the western Mediterranean is dominated by the Iberian thermal effect with no predominant upper-level influence. Notably, our results show that most of these cyclones do not traverse to the Adriatic area. This is in accordance with some earlier studies (e.g. Trigo et al. 1999, their Fig. 11) that show the main western Mediterranean summer cyclone tracks follow the northern Mediterranean coast and end near the Genoa Bay. This might imply that shallow summer Iberian cyclones may not protrude to the

Adriatic due to summer westerly and northwesterly winds over the Gulf of Genoa and the Tyrrhenian and the Adriatic Sea regions. Hence, it appears that the lack of upper-level steering flow and the predominant etesian summer circulations are the two dominant factors influencing the cyclone tracks in the region.

Similar to Genoa cyclones, the majority of Type C cyclones cross the Italian peninsula to the Adriatic Sea with no significant signs of discontinuity (Type C-I, Fig. 5a). However, some Type C cyclones become discontinuous and experience redevelopment over the Apennine mountain range (Type C-II, Fig. 5b). It should be noted that if the cyclones follow the wintertime high baroclinic zone of the northern Mediterranean coast, they often experience redevelopment over the Gulf of Genoa leading to difficulties in cyclone categorization. In addition, remnants of Atlantic cyclones at the end of the Atlantic storm track occasionally enter the Mediterranean and often redevelop over the sea. Thus, a chain-like series of cyclone redevelopments over the western Mediterranean longitudinally increases the complexity of track analysis.

The analysis of Type B-I, B-II and AB cyclones indicates a similar number of the northern Adriatic and the middle Adriatic cyclogenesis cases. Similarly, the total number of cyclone appearances in these regions is approximately the same. That is, the number of Genoa and Type B-I cyclones not entering the middle Adriatic Sea seem to be approximately equal to the number of B-II cyclones and Genoa cyclones entering the middle Adriatic (but not the northern Adriatic), resulting in no significant net effect. At the same time, locations of Type C cyclones traversal to the Adriatic are uniformly distributed over the peninsula axes. In addition, it is interesting to note that the usual NW-SE cyclone track along the Adriatic basin converge with the Genoa cyclone track along the western Italian coast. Partly for this reason and the common existence of pressure lows (as discussed above), this region of southern Italy and the southern Adriatic was identified as a pronounced center of the cyclone activity (Alpert et al. 1990a,b; Maheras et al. 2001).

## 4. Characteristics of cyclone types

In this section we will show the typical cases of the isolated cyclone tracks and discuss their properties, restricting the analysis to Adriatic and Genoa cyclones only. Since these track types (with an exception of Type A-I) did not gain much attention in terms of neither diagnostic nor analysis, we will propose and briefly discuss the associated genesis factors.

### 4.1 Type A – Genoa cyclones

The Genoa or Alpine lee cyclone is one of the Mediterranean cyclone types that have attained the most attention in literature. Numerous studies verified that Alpine lee cyclogenesis is a two-phase process (e.g. Buzzi and Tibaldi 1978; McGinley 1982). The first phase is associated with cold front retardation, a cold air outbreak into the Mediterranean Sea and a rapid creation of a shallow vortex in the Gulf of Genoa. The second phase follows the traditional baroclinic development and the interaction of lower-level and upper-level vortices (e.g., Hoskins et al 1985).

A Genoa cyclone with continuous track (Type A-I) took place on 03 March 2003 (Fig 6a-b). As an upper-level, short-wave streamer (Massacand et al. 1998; Hoinka et al. 2003) advected over the Alps, a vortex was created near the SW edge of the mountain ridge. This part of the lee is characterized with an existence of both a mountain scale warm anomaly and a low-level potential vorticity near the primary banner and the edge of the wake (not shown). This seems to be consistent with the recent findings which argue that besides a thermal anomaly, the low-level PV anomaly created by flow deformation on the obstacle might have a significant influence on the initiation and localization of a lee cyclone (Aebischer and Schär 1998). The finding theoretically follows from the invertibility principle (Hoskins et al. 1985) that states that any vortex contributing to the second phase of lee cyclogenesis could be either a thermal anomaly or a low-level PV anomaly.

Upon generation, the cyclone crossed the Italian peninsula to the northern Adriatic over the northern Apennine mountains and Po Valley, in coherence with advection of the upper-level disturbance (Figs. 6c-d). In general, the diffluence of Genoa cyclone tracks upon generation and at a later stage is primarily influenced by the upper-level flow steering, but also seems to be modified by diabatic effects. In particular, numerical simulations of an ALPEX case showed that convection seems to drift the Genoa cyclones to the east and northeast, while surface heat fluxes tend to move it towards the southeast warmer water bodies (Alpert et al. 1996). Thus, it appears that latent and sensible heat fluxes from the sea might have played an important role in influencing the track. In subsequent hours, the cyclone was steered to the southeast and moved along the basin in a typical NW-SE path (Figs. 6e-f). This type of cyclone often causes severe weather events in the Adriatic. More specifically, a strong Scirocco wind (i.e. a localized mountain Scirocco wind known as "Jugo") usually blows along the basin from the SE in front of the cyclone, while northeasterly downslope Bora develops after the frontal (cyclone) passage. Thus, a region of strong "Jugo" typically moves southeastward, in favor to Bora that develops on the northern Dinaric Alps firstly, and spreads over towards the southern Dinaric Alps. There is indication that the typical convergence of these two wind systems might contribute to cyclone deepening (Ivančan-Picek 1998). In the latter phase of cyclone development, a deep and well-defined Genoa cyclone left the Adriatic basin and continued its life cycle in the Ionian Sea.

Genesis locations and mechanisms of Type A-II Genoa cyclones with discontinuous track are similar to those of Type A-I Genoa cyclones with continuous track (Figs. 7a-b). Upon generation on 12 UTC 5 March 2005, the cyclone moved over to the Tyrrhenian Sea, following the well-known Genoa cyclone track along the western Italian coast. However, instead of taking the usual path to the Ionian Sea without crossing the Apennines, the cyclone traversed over the middle Apennines to the Adriatic basin. Besides the steering from the upper-level flow, as mentioned earlier, convection over the middle Apennines might contribute to cyclone track deflection to the east. While the cyclone was traversing the mountain range, two separate cyclone centers were detected (Figs. 7c-d). In contrast to Type A-I cyclone that kept its continuity over the peninsula (Fig. 8a), both centers of this cyclone had a closed 2 hPa isobar and separate vorticity cores (Fig. 8b) on both sides of the peninsula, present at the same time and separated by the mountain range. In subsequent hours, the windward center experienced a cyclolysis, while the lee center continued the life-cycle. Finally, the cyclone moved over the Adriatic Sea and impinged on the southern part of Croatian Dinaric Alps, while a new system was already generating in the Gulf of Genoa (Figs. 7e-f). This type of analyzed cyclone often results in a cyclonic Bora and severe weather conditions along the middle and southern Dinaric Alps, while there is a lack of strong Bora in the northern Adriatic, which is the area where Bora duration and frequency reach the climatological maximum.

### 4.2 Type B - Adriatic cyclones

The analyzed B-I northern Adriatic cyclone was generated on 04 November 2002 (Figs. 9a-b). The upper-level trough started to traverse the Alps on 18 UTC 03 November. The trough penetrated southwestward with a more gradual positive axis tilt i.e. shifting from NW-SE to NE-SW. At lower levels, seasonal and nighttime thermal effects created a mesoscale thermal anomaly over the Adriatic Sea, while westerly and northwesterly flow dominated the Alpine region. Blocking and stagnation took place on the west-northwest (windward) side of the Alps. The southern branch entered the Mediterranean causing a weak thermal effect and the associated thermal anomaly in the Gulf of Genoa. The northern branch of the airflow partly circumvented and partly crossed the Alps, creating a moderate cold air outbreak in the Dinaric (Eastern) Alps region. Therefore, both dynamical and thermal effects seem to contribute to the created low level thermal anomaly in the northern Adriatic area. Upon generation, the subsequent cyclone movement (Figs. 9c-d) resembles the Type A-I cyclones described above. In general, it appears that to a certain extent, B-I cyclogenesis and deepening dynamics follow the essential principles of the Alpine lee cyclones (e.g., Aebischer and Schär 1998). Accordingly, the weather conditions and the related chain of events regarding local winds Bora and "Jugo" during the cyclone movement along the basin resemble the ones of Genoa cyclone (discussed above).

A typical B-II middle Adriatic cyclone has the smallest scale among different types of cyclones in the region. Due to its dimensions and weak intensity (the cyclone discussed below is one of the most intense detected), this type of cyclone is not associated with severe weather. Nevertheless, the seasonal distribution of these cyclones has a peak in summer, when these cyclones can cause high impact weather, especially in case of poor forecasts. The case shown was related with summer storms that produced ~30mm in 12 hours on the southern Adriatic islands where weather conditions are characterized with mild, fair and very dry weather in summer.

At the upper levels, a meso-shortwave trough propagated eastward over the northern Mediterranean, with no surface cold front associated. At 18 UTC 24 July, the trough reached the middle Apennine mountain range (Figs. 10a-b). In subsequent hours a well localized cyclone formed in the lee of the mountain. The cyclone quickly traversed the Adriatic Sea and deepened to its maximum intensity. Preliminary numerical analysis indicates that the surrounding mountains acted as scale contractors and confined the cyclone size to one comparable to those in the Adriatic basin. Upon reaching the eastern Adriatic coast, the surface cyclone was blocked by the Dinaric Alps and the system shifted from upshear tilt to downshear tilt (Figs. 10c-d). A subsequent decoupling of the system was not associated with the immediate cyclolysis; instead it appears that the heat fluxes from the sea might have served as a source of energy for further cyclone life-cycle maintenance. In addition, convergence of the local Bora and "Jugo" winds and CISK were proposed as additional cyclone deepening mechanisms (Ivančan-Picek 1998).

Overall, the mechanism of cyclone initiation seems to be similar to the lee cyclogenesis. However, the scales of the motion, which are controlled by different ingredients of cyclone formation and deepening, are much smaller than in well-investigated cases of typical examples of orographical cyclogenesis (e.g., Alps, Rocky Mountains).

### 4.3 Type AB - "Twin" cyclones

The twin or eyeglass AB type of cyclone was associated with advection of a wide trough over the broad Alpine area on 18 UTC 13 Feb 2005 (Figs. 11a-b). At this time, two lows are simultaneously present in the Gulf of Genoa and the northern Adriatic. Concurrently, a fast moving potential vorticity streamer started to cross the Alps. The axis of this elongated geopotential trough was directed WSW-ENE, with both Genoa Bay and the northern Adriatic on the front side of the streamer at the same time. In subsequent hours, the Genoa low evolved into a fast moving cyclone while the northern Adriatic low advected along the Adriatic basin and merged with the cyclonic system in the lee of middle Apennines (Figs. 11c-d). The time resolution of the analysis does not allow us to examine the details of this merge, but the middle Apennines appear to be the main contributor in the initial phase of the middle Apennine system creation (00 UTC, not shown). However, a numerical analysis of a twin cyclone case (Brzović 1999) indicates that the Adriatic twin is a consequence of the influence of Dinaric Alps on the northeasterly flow, thus being the lee cyclone with respect to Dinaric Alps. Yet based on the insufficient number of studies, it is not completely clear to what extent this conclusion is case dependent. Further on in the lifecycle, the Genoa twin moved down the western Italian coast, steered by the upper-level streamer while mature Adriatic twin traversed the Dinaric Alps to the east.

## 4.4 Common characteristics

Note that a common feature of all the typical cyclone types initiated in the region is an upper-level trough. This is in accordance with the ALPEX study (Pichler and Steinacker 1987) in which the authors analyzed 40 events of Alpine lee cyclogenesis that emerged during the 13 months of the experiment. Among the results, it was evidenced that upstream upper-level vorticity maximum was a necessary ingredient of Alpine lee cyclogenesis. Thus, together with the preferred genesis locations of Type A and Type B cyclones, this might imply that lee cyclogenesis is the dominant formation process in the region for all the cyclone types identified. However, there are significant differences in dimensions of the upper-level troughs for all the types detected, ranging from almost meso-β (for Type

B-II) to macro-scales (Type A and Type C). Similarly, a small-scale vorticity core embedded in a broader scale upper-level disturbance appears to be the key process in some occasions. Moreover, it remains to be further investigated what the role of low- and upper-level vortex interaction may be on the Apennine lee cyclogenesis in considering meso-β scale of the cyclone and the lack of characteristic and strong cold air blocking. This implies that at least the B-II formation process might be the result of a more complex interaction. For conclusions of this type, numerical analysis and factor separation methods will be performed in the forthcoming experiments.

## 5. Conclusions and final remarks

Operational analyses of the European Centre for Medium-Range Forecast (ECMWF) on a T511 spectral resolution were subjectively analyzed throughout the 4-yr period in order to evaluate the cyclone activity over the Adriatic Sea. Detection and tracking procedure included objective MSLP and cyclone duration thresholds and a subjective vorticity analysis, with closed circulation as a guidance criterion.

Cyclone types identified include cyclones that initiated in the Gulf of Genoa (Type A), Adriatic (Type B), both Genoa and Adriatic simultaneously (Type AB) and cyclones that originated elsewhere (Type C). In addition, cyclones that traversed the Apennine peninsula were classified based on their continuity on the Apennine range (for Type A and Type C cyclones). The inclusion of discontinuous cyclone types is a specific necessity of the cyclone climatology classification in the Adriatic area where the greatest majority of cyclones cross the Apennine mountain range on their way to the region.

Cyclones initiated in the Gulf of Genoa or northern Italy (Type A) constitute more than 35% of the cyclones that enter the Adriatic basin and most often occur in the winter. This type of cyclone usually traverses to the northern Adriatic through northern Italy and Po Valley, without a significant disturbance of vorticity pattern above the peninsula (Type A-I). Once in the northern Adriatic, the cyclone tracks diverge: whilst the main path slides down the basin, a subset of cyclones follow the secondary tracks by crossing the northern Dinaric Alps and advecting either eastward or northeastward. In addition, a subset of the Genoa cyclones slides along the western Italian coast to the Tyrrhenian Sea and traverse the Middle Apennines on the way to the Adriatic. Due to the height of the Middle Apennines range (2912 m), a subset of these cyclones becomes discontinuous over the mountain (Type A-II). This process is accompanied by the presence of two cyclone centers on the upstream and downstream parts of the mountain simultaneously.

Type A cyclones cause a chain of related weather conditions on the eastern Adriatic coast, where strong “Jugo” and mountain induced precipitation (on western slopes of Dinaric Alps) precede strong Bora wind, that starts at the northern Adriatic and gradually spreads towards the southern Adriatic as the cyclone moves down the basin. These cyclones are moderately well predicted, although Bora wind speed and gustiness as well as precipitation site-specific forecasts over the eastern Adriatic coast are sometimes rather poorly forecasted, due to erroneous forecast of the exact cyclone location.

Adriatic cyclones (Type B) are the smallest scale cyclones analyzed, often with horizontal dimensions of the basin width (200 km). These cyclones are initiated in localized areas of the northern Adriatic (B-I) and western part of the middle Adriatic (B-II) and contribute 25% to the total number of cyclones detected in the basin. Type B-I cyclones typically initiate in the northern Adriatic and move southeast over the basin. The initiation process of this type of cyclone seems to be qualitatively similar to the Genoa lee cyclogenesis process. These cyclones form mostly in the cold part of the year and can deepen considerably. Type B-II initiates in the lee of the middle Apennines and quickly traverses the Adriatic Sea perpendicular to the main axis. The cyclones tend to form more often in the warmer part of the year and usually do not deepen more than 4-5 hPa in the Adriatic area. This type of rather shallow cyclone often gets blocked by the Dinaric Alps and decoupled from the short-wave upper-level disturbance simultaneously. As a whole, the northern and the middle Adriatic regions have similar frequency of cyclone appearances. While the weather conditions of Type B-I cyclones are similar to those of Type A cyclones, Type B-II cyclones, due to their shallowness cause high impact weather (e.g.

summer storms) only in summer (when their seasonal distribution has a maximum). However, probably due to their scale and weak intensity, these cyclones are the least predictable of all cyclone types identified in the study. Therefore, knowledge about their climatology and physical mechanisms might have a potential use in everyday operational forecast practice.

Another type of cyclone initiated in the region is the twin or eyeglass cyclone type (Type AB). These cyclones are characterized with the simultaneous presence and evolution of two cyclones, one in the Adriatic and one in the Gulf of Genoa. This rather rare type of cyclone usually slides down along the western and eastern part the Apennine peninsula, and occasionally an Adriatic twin member crosses the Dinaric Alps to the east.

Type C cyclones have initiation areas other than Genoa or Adriatic and contribute 35% to the total number of cyclones that are detected in the Adriatic. The migration areas include the Atlantic Ocean, Atlas, the Pyrenees, Iberian peninsula, Alboran Sea and others. Due to their dimension and remote location of initiation, these cyclones and related weather (that highly depends on the location of the cyclone entrance in the Adriatic basin) are usually well forecasted. These cyclones occur most often in winter and the least during the summer. Since the main summer cyclogenetic area is the Iberian peninsula it is noteworthy that their tracks diminish as they approach the Genoa Bay and the Adriatic along their northeastward track (Trigo et al. 1999). This seems to be a consequence of the lack of upper-level forcing and the existence of predominant etesian circulation that disable the further cyclone northeastward protrusion to the Adriatic. In addition, Type C cyclones occasionally experience a chain-like series of redevelopments along the Mediterranean. This amplifies the complexity of the analysis and might longitudinally increase the uncertainty of the Mediterranean cyclone climatology.

Generation mechanisms of Genoa and Adriatic cyclones are inherently associated with an advecting upper-level trough over the mountain lee area and the associated cold air blocking and creation of thermal anomalies, which are a predominant ingredient of the first phase of the lee cyclogenesis. Additionally, it seems that the effect of sea heat fluxes and the associated heat capacities of the regional geomorphologic elements might have an effect in creating the thermal anomalies over the almost completely mountain enclosed Adriatic basin. In general, these two processes result in a high frequency of thermal anomalies over the basin. Regardless of the possibly differing formation mechanisms, the presence of thermal anomaly and upper-level trough seem to imply a certain similarity between Adriatic and Alpine cyclogenesis. In addition, heat fluxes and convergence of local winds "Bura" (Bora wind blowing in Croatia) and "Jugo" (mountain channeled Sirocco wind) might contribute to cyclone deepening over the Adriatic Sea. However, only a numerical analysis of cyclone properties can elucidate the formation and deepening mechanisms of the discussed cyclone types in the region in more detail.

This study could not avoid the uncertainties due to the length of the analyzed period. For example, the period of 2002-2005 was one of the warmest 4-year periods since the onset of conventional measurements. In 2002, the increased meridional Mediterranean cyclone movement, flood-causing Mediterranean cyclones in Czech republic, failure of the Asian monsoon which is related to ENSO, and large-scale circulation patters in the Mediterranean (e.g., Webster and Yang 1992; Blackburn et al. 2003), seem to imply that this year was characterized with an anomalous macroscale flow circulation pattern. Such a deviation might result in deviations from the long-term cyclone climatology if the analyzed period is not sufficiently long.

In future work, this climatology study and the presented cases will serve as a platform for the analysis of precipitation patterns of different cyclone tracks in the Adriatic as well as a background for numerical modelling and analysis, and will be a tool for understanding the dynamical and physical properties of the Adriatic cyclones.

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## Figure captions

Figure 1: The western and middle Mediterranean with sites of interest mentioned in the text. The area corresponds to an ECMWF T511 resolution model orography in the domain. The terrain contour interval is 200 m starting from 200 m.

Figure 2: Track plots of Genoa (a) Type A-I continuous and (b) Type A-II discontinuous cyclones. Most of the A-I cyclones cross the Apennine peninsula in the north, whilst most of the A-II cyclones traverse to Adriatic over the middle Apennines.

Figure 3: Track plots of Adriatic cyclone types: Type B-I continuous cyclones move from north to south along the Adriatic Sea and Type B-II discontinuous cyclones initiate in the lee of Middle Apennines and traverse the Adriatic perpendicular to the main basin axes.

Figure 4: Track plots of Type AB twin or eyeglass cyclones with two coexisting cyclonic centers: the first in the Adriatic Sea and the second in the Gulf of Genoa (or Tyrrhenian Sea). The centers usually move along the main peninsula axes.

Figure 5: Track plots of non-Adriatic and non-Genoa (a) Type C-I continuous and (b) Type C-II discontinuous cyclones. This type of cyclone is initiated in the areas of the Pyrenees, Iberia, Atlas, Alboran Sea and Atlantic as well as over the Mediterranean.

Figure 6: A continuous Genoa cyclone (Type A-I) surface MSLP and wind fields (left) and geopotential and wind fields on 300 hPa (right) on (a-b) 02 March 2003 18 UTC, (c-d) 03 March 2003 00 UTC and (e-f) 03 March 2003 12 UTC.

Figure 7: A discontinuous Genoa cyclone (Type A-II) surface MSLP and wind fields (left) and geopotential and wind fields on 300 hPa (right) on (a-b) 05 March 2005 12 UTC, (c-d) 06 March 2005 00 UTC and (e-f) 06 March 2005 12 UTC. At the last time instant shown, a new cyclone already forms in the Gulf of Genoa.

Figure 8: Streamlines of the (a) continuous (00 UTC 3 March 2003) and (b) discontinuous (00 UTC 6 March 2005) Genoa cyclones (see Fig. 6 and Fig. 7) at the moment the cyclones traversed the Apennine peninsula. Discontinuous cyclone, besides having separate MSLP centers, also has two separate vorticity centers.

Figure 9: A northern Adriatic cyclone (Type B-I) surface MSLP and wind fields (left) and geopotential and wind fields on 300 hPa (right) on (a-b) 00 UTC 4 November 2002, (c-d) 12 UTC 4 November 2002.

Figure 10: A middle Adriatic cyclone (Type B-II) surface MSLP and wind fields (left) and geopotential and wind fields on 300 hPa (right) on (a-b) 18 UTC 24 July 2002, (c-d) 06 UTC 25 July 2002.

Figure 11: A twin/eyeglass cyclone (Type AB) surface MSLP and wind fields (left) and geopotential and wind fields on 300 hPa (right) on (a-b) 18 UTC 13 February 2005, (c-d) 06 UTC 14 February 2005.

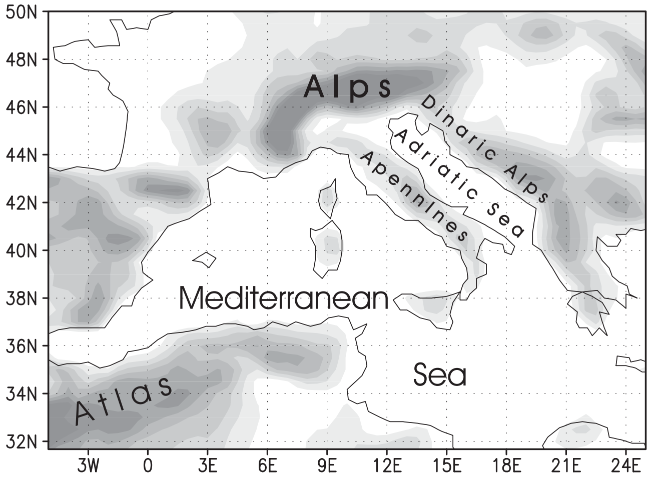

Figure 1: The western and middle Mediterranean with sites of interest mentioned in the text. The area corresponds to ECMWF T511 resolution model orography in the domain. The terrain contour interval is 200 m starting from 200 m.

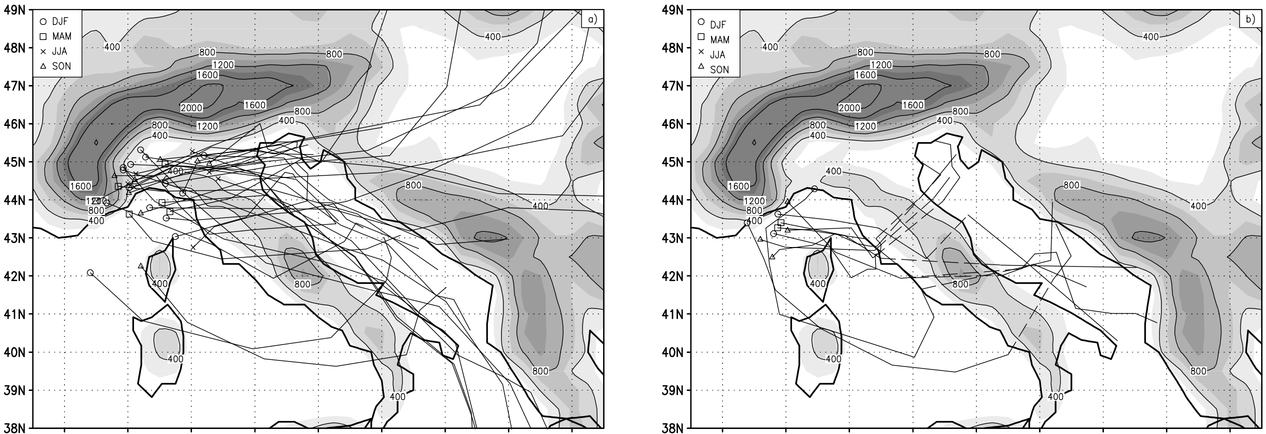

Figure 2: Track plots of Genoa (a) continuous A-I and (b) discontinuous A-II cyclones. Most of the A-I cyclones cross the Apennine peninsula in the north, while most of the A-II cyclones traverse to Adriatic over the middle Apennines.

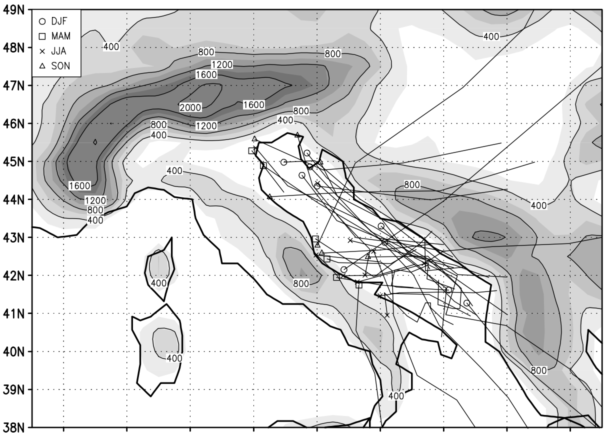

Figure 3: Track plots of Adriatic cyclone types: B-I from north to south along the Adriatic Sea and B-II initiating in the lee of Middle Apennines and traversing the Adriatic perpendicular to the main basin axes.

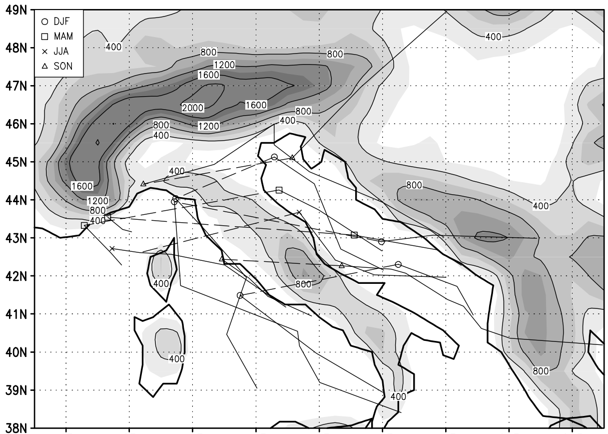

Figure 4: Track plots of twin or eyeglass cyclones (Type AB) with two coexisting cyclonic centers: the first in the Adriatic Sea and the second in the Gulf of Genoa (or Tyrrhenian Sea). The centers usually move along the main peninsula axes.

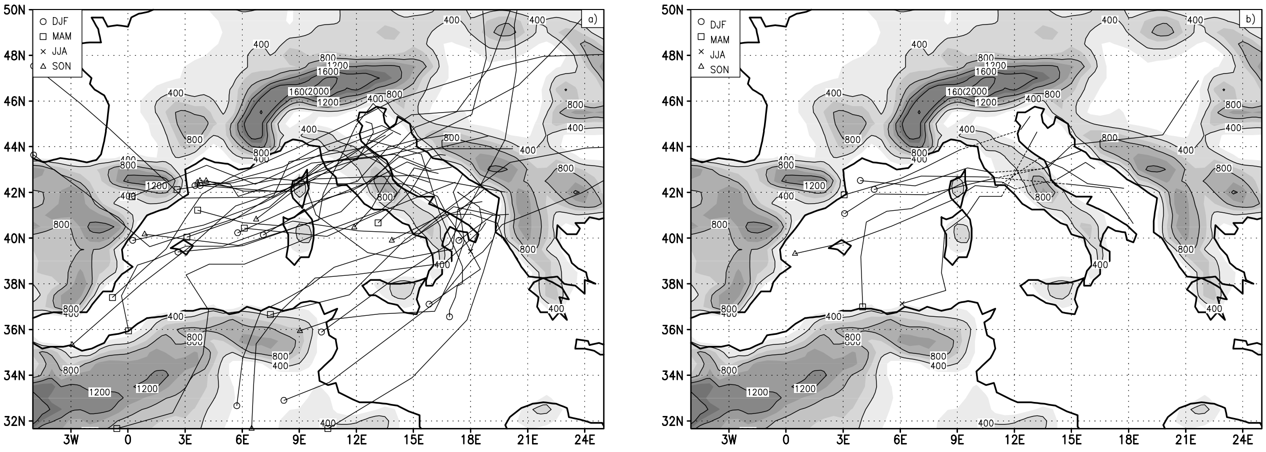

Figure 5: Track plots of non-Adriatic and non-Genoa (a) continues C-I and (b) discontinuous C-II cyclones. This type of cyclone is initiated in the areas of the Pyrenees, Iberia, Atlas, Alboran Sea and Atlantic as well as over the Mediterranean.

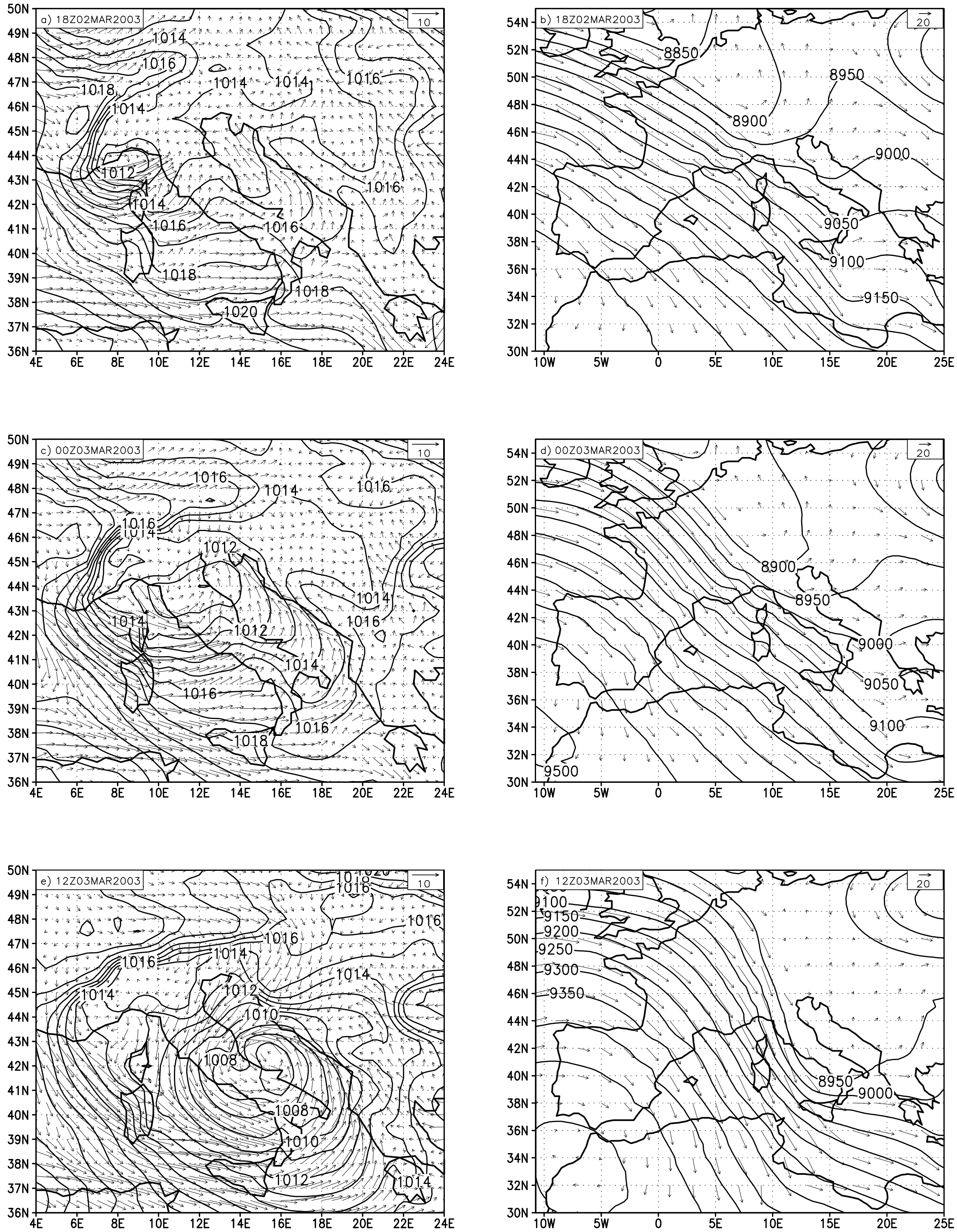

Figure 6: A continuous Genoa cyclone (Type A-I) surface MSLP and wind fields (left) and geopotential and wind fields at 300 hPa (right) on (a-b) 02 March 2003 18 UTC, (c-d) 03 March 2003 00 UTC and (e-f) 03 March 2003 12 UTC.

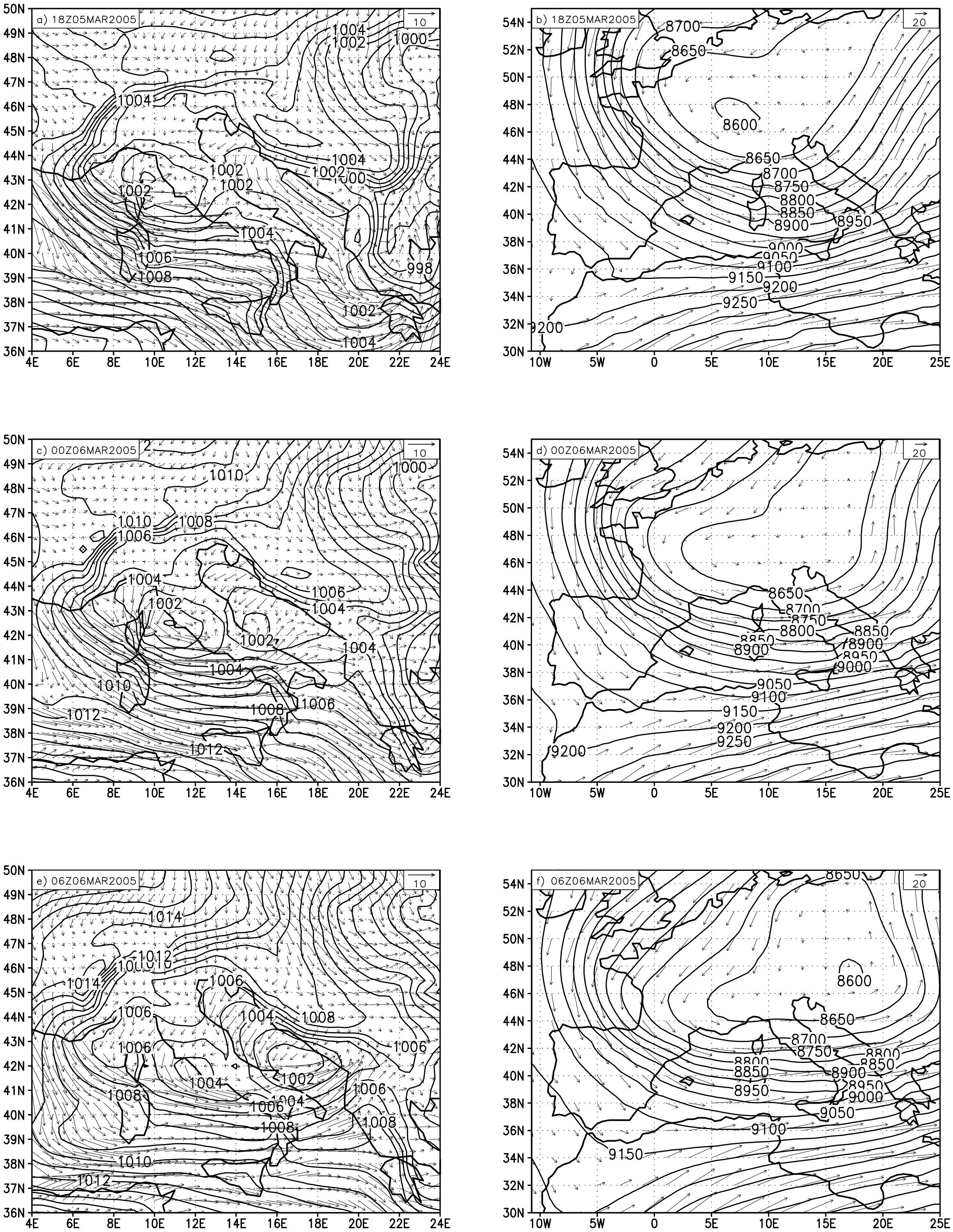

Figure 7: A discontinuous Genoa cyclone (Type A-II) surface MSLP and wind fields (left) and geopotential and wind fields at 300 hPa (right) on (a-b) 05 March 2005 12 UTC, (c-d) 06 March 2005 00 UTC and (e-f) 06 March 2005 12 UTC. At the last time instant shown, a new cyclone already forms in the Gulf of Genoa.

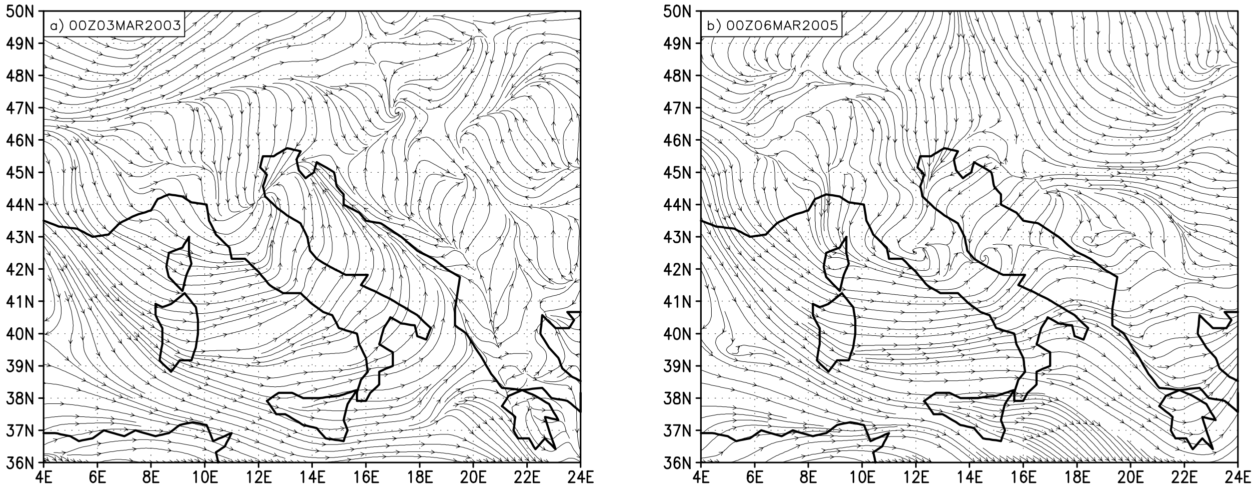

Figure 8: Streamlines of the (a) continuous (00 UTC 3 March 2003) and (b) discontinuous (00 UTC 6 March 2005) Genoa cyclones (see Fig. 6 and Fig. 7) at the moment the cyclones traversed the Apennine peninsula. Discontinuous cyclone, besides having separate MSLP centers, also has two separate vorticity centers.

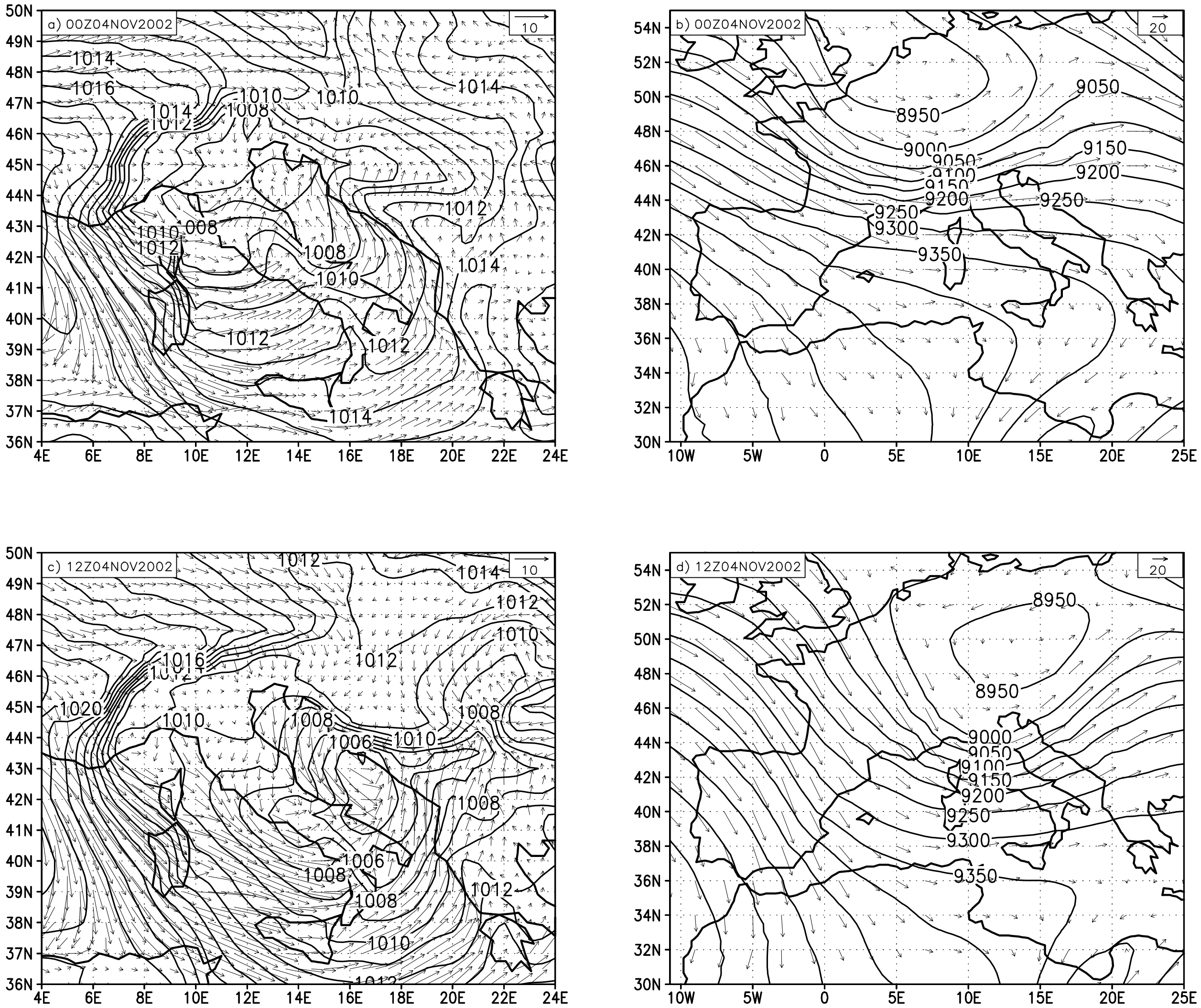

Figure 9: A northern Adriatic cyclone (Type B-I) surface MSLP and wind fields (left) and geopotential and wind fields at 300 hPa (right) on (a-b) 00 UTC 4 November 2002, (c-d) 12 UTC 4 November 2002.

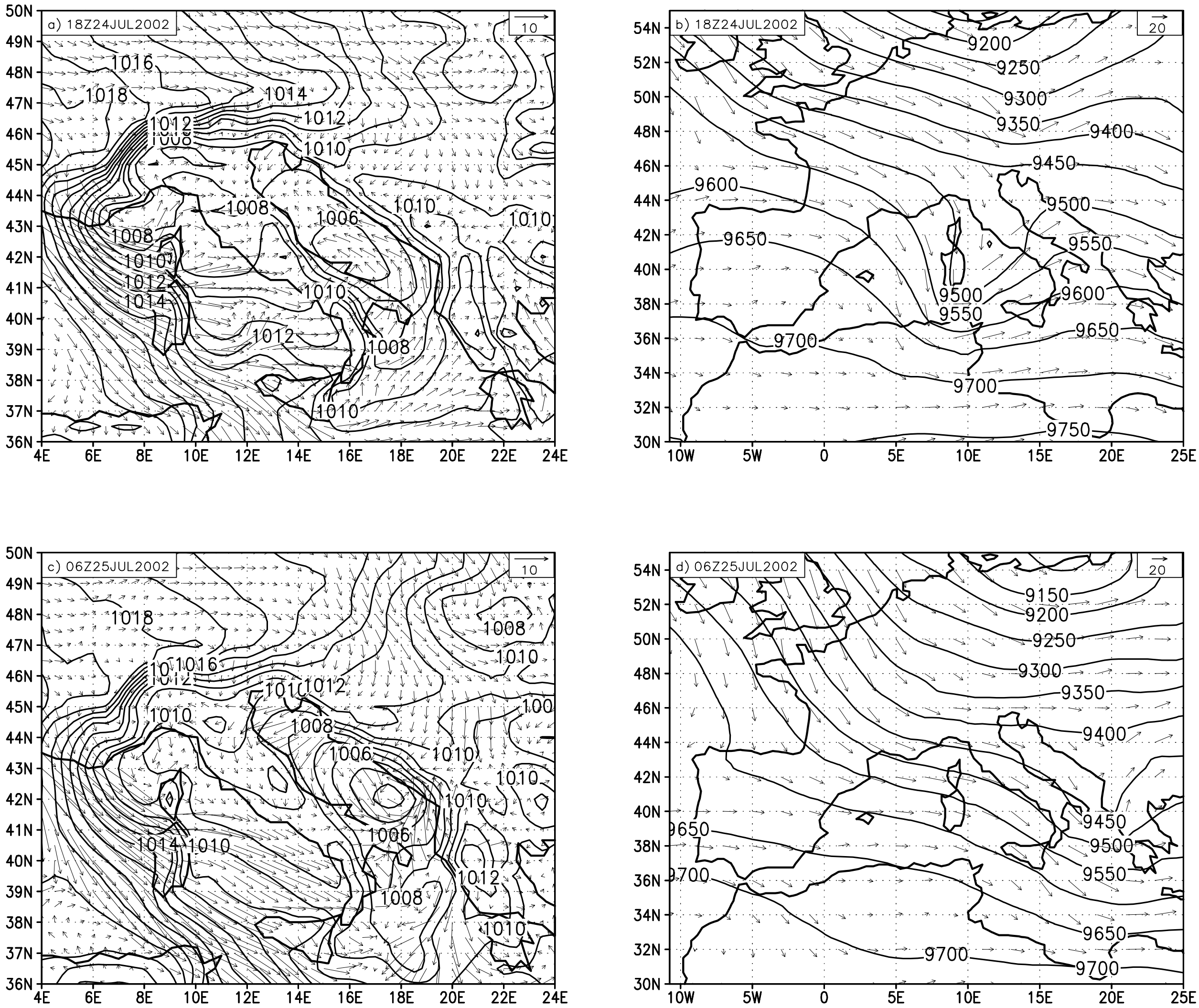

Figure 10: A middle Adriatic cyclone (Type B-II) surface MSLP and wind fields (left) and geopotential and wind fields at 300 hPa (right) on (a-b) 18 UTC 24 July 2002, (c-d) 06 UTC 25 July 2002.

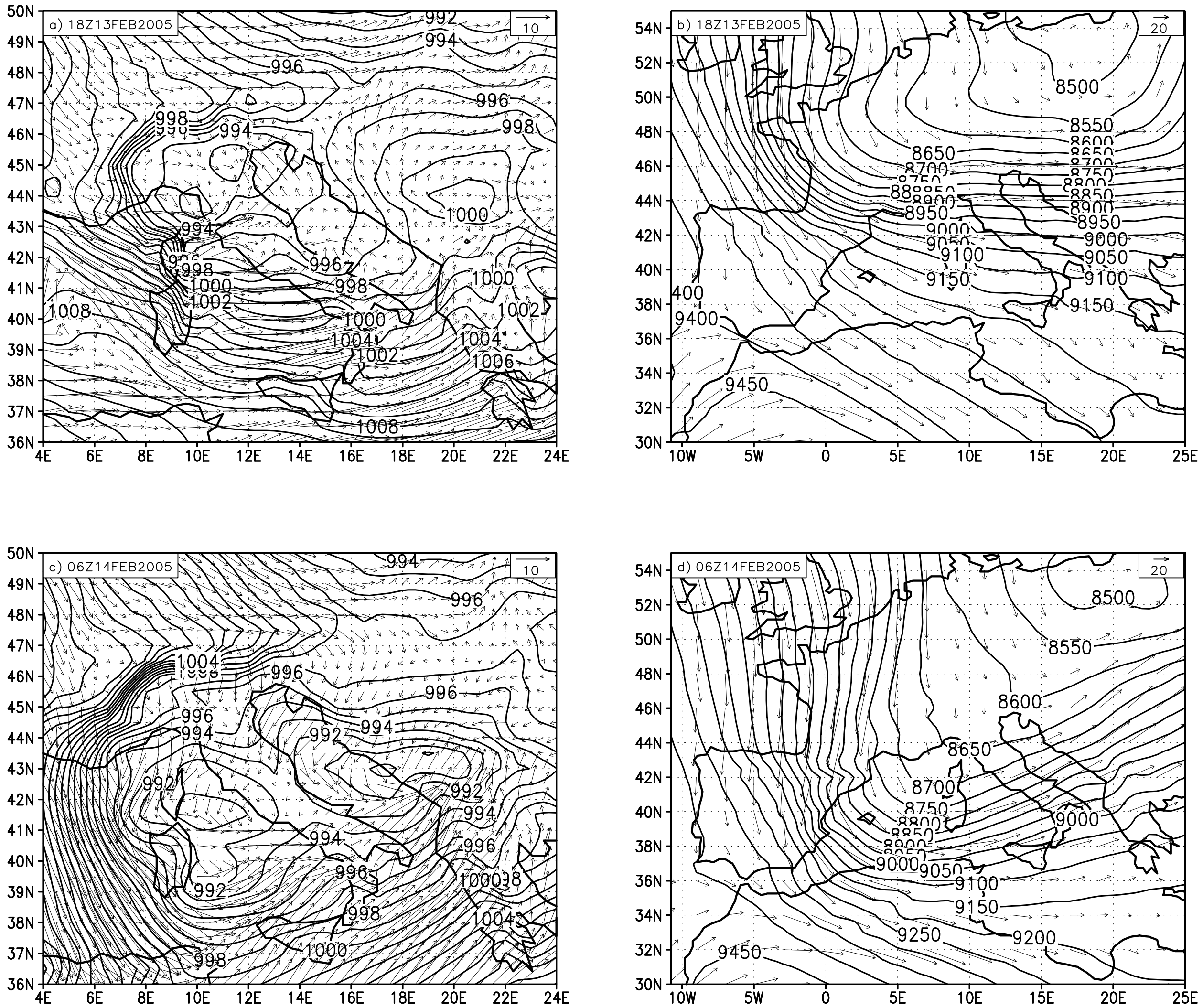

Figure 11: A twin/eyeglass cyclone (Type AB) surface MSLP and wind fields (left) and geopotential and wind fields at 300 hPa (right) on (a-b) 18 UTC 13 February 2005, (c-d) 06 UTC 14 February 2005.

Table 1. Seasonal variability of the cyclone types in the Adriatic region detected in period 2002-2005

| | A-I | A-II | B | AB | C-I | C-II | **TOTAL** |
|---|---|---|---|---|---|---|---|
| DJF | 14 | 4 | 10 | 3 | 14 | 3 | **48** |
| MAM | 6 | 2 | 6 | 2 | 11 | 2 | **29** |
| JJA | 7 | 0 | 11 | 1 | 1 | 1 | **21** |
| SON | 8 | 4 | 7 | 2 | 10 | 1 | **32** |
| **TOTAL** | **35** | **10** | **34** | **8** | **36** | **7** | **130** |