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Mediterranean cloud system variability inferred from satellite observations

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Abstract. The variability of Mediterranean cloud systems is investigated using 8.5 years (from January 1987 to June 1995) of TIROS-N Operational Vertical Sounder (TOVS) observations acquired aboard the National Oceanic and Atmospheric Administration (NOAA) series of operational polar satellites. Cloud systems and troughs are detected using retrievals of cloud top pressure (CTP) and temperature of the lower stratosphere (TLS). Cloud systems have a typical size of a few hundred kilometres with a larger occurrence between March and October. The largest cloud systems occur preferentially in May and October and downstream of a midlatitude upper level trough. Finally, severe precipitation events over the Alpine region are associated to a warm TLS anomaly upstream the cloud system, showing once more the impact of the upper levels on the weather over the area.

1 Introduction

The Mediterranean basin is a region known for its cyclonic activity. Due to its specific orography (the Mediterranean Sea is surrounded by an almost continuous barrier of mountains) and the high sea surface temperature, the distribution of cyclones over this area is complex. The climatological studies focusing on the Mediterranean cyclones generally rely on reanalyses and cyclones are usually detected by identifying 1000 hPa height minima (e.g. Trigo et al., 1999; Maheras et al., 2001). An alternative source of data is used here in order to study both the climatological features and the associations with large scale patterns. It consists of satellite data as recently shown by Chaboureau and Claud (2003) who have investigated the wintertime variability of large precipitating weather systems over the North Atlantic Ocean. Their study was based on the signature of the storms on the water budget (cloud and precipitation) as observed from TOVS on board NOAA satellites. The objective is here to adapt this work to the Mediterranean cyclones, that is to provide a typology of cloud systems for each season, and to determine the proportion of lows for which the dynamics is dominated by the upper-level situation. In addition, the links between precipitation and the upper-level configuration will be studied for the Alpine region, for which a daily precipitation climatology exists.

2 Data and methodology

Observations used for this study are from NOAA-10 and NOAA-12 satellites and cover 8.5 years from 1 January 1987 to 30 June 1995. The raw TOVS data are converted into atmospheric parameters using the Improved Initialization Inversion algorithm (Chédin et al., 1985; Scott et al., 1999). Among a large number of variables, this physico-statistical method, relying on pattern recognition approach, determines the temperature of the lower stratosphere (TLS) and the cloud top pressure (CTP). All these variables are retrieved at a spatial resolution of $100\times100\,\mathrm{km}^2$ every 12 h at best, that is at 7:30 AM and PM local time. TLS provides a description of the thermal structures in the layer 1–4.5 km above the tropopause (Fourrié et al., 2000, 2003). In particular, warm anomalies of TLS can be used to detect upper level troughs. TLS is a linear combination of brightness temperatures from five TOVS channels which are the most sensitive to the temperature near the tropopause. CTP is obtained by a weighted-χ^2 method from four 15 μm CO_2 band radiances and the 11 μm atmospheric window radiance (Stubenrauch et al., 1999).

Weather systems with CTP less than 400 hPa and found between 30° N–48° N and 10° W–45° E, encompassing all the Mediterranean Sea and the surrounding regions, are considered here. Their variability is then investigated using a composite method. TLS and CTP fields are extracted in a square of 3600 km side length for which the y-axis is northward. To enlarge the view upstream of the cloud event (i.e. to the west), the box is shifted 900 km to the east from its

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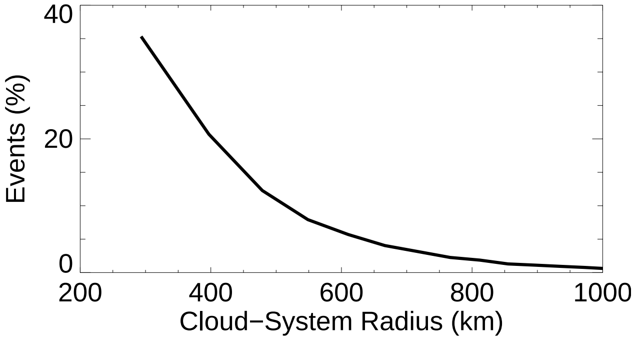

Fig. 1. Frequency distribution of the cloud-system radius.

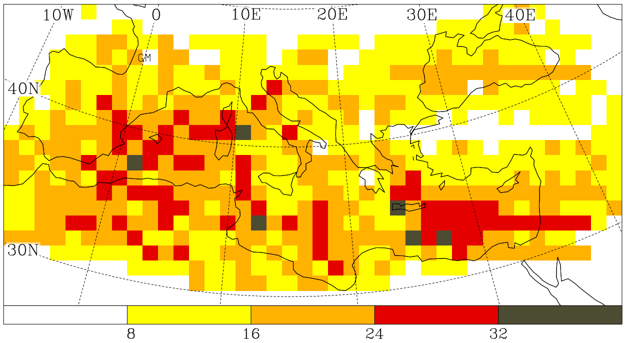

Fig. 2. Number of selected cloud systems per grid point for the full 8.5-year period.

geometric centre. A principal component analysis (PCA) is performed on the normalized fields of TLS and CTP. The latter are projected onto the components of the first eigenvectors which represent the larger variance. Thus the PCA allows for selecting only the pertinent information, that is, the field of variation around the average, and the large-scale structures as described by the first eigenvectors. The mean fields of TLS and CTP, and the small-scale structures are therefore filtered out. Here, we have chosen to retain the first components that represent 45% of the total variance. The retained components are clustered using an ascending hierarchical classification, which minimizes the intraclass variance, and each case is included in a class. Finally, composites within each class are built from averaging the original fields (i.e., not the filtered fields described by the first eigenvectors). This yields realistic structures as illustrated below.

3 Cloud system climatology

Over the 102 months, a total of 9906 cloud systems were identified, without any particular interannual variation. With two observations per day, this leaves about 48 systems per month. 35% of the cloud systems have an equivalent radius of 300 km, and over 70% less than 550 km (Fig. 1). This result is in agreement with the 65% of cyclones having a maximum radius less than 550 km obtained by Trigo et al. (1999) using reanalyses. This confirms that most of the Mediterranean lows are within the mesoscale, in contrast to synoptic North Atlantic cloud systems with typical sizes lying between 1000 and 3000 km (Chaboureau and Claud, 2003).

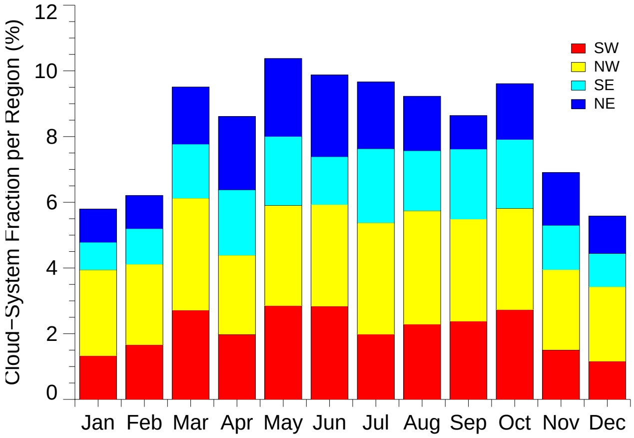

Fig. 3. Fraction of cloud systems per month for different geographical areas (see text).

The number of selected cloud systems per grid point for the whole period is shown in Fig. 2. The cloud systems are found in preferential areas: western North Africa, the east coast of the Iberian Peninsula, the Balearic Islands, the Gulf of Genoa, southern Italy, the Aegean Sea, and Cyprus. However, this geographical distribution is more spread out than the map of the first cyclone detections shown by Trigo et al. (1999) or those of the cyclonic occurrence by Maheras et al. (2001). Two reasons can explain this difference. First, in contrast to these studies, the present analysis groups not only cyclones, but also fronts and convective systems. Moreover, since there is no tracking procedure, this map does not correspond to the first detection but to the cumulated number of detections during the whole life-cycle of the cyclones. Second, less cyclones are found over the eastern Black Sea, and the Middle East, but for this latter region, Trigo et al. (1999) mention that the number is probably overestimated due to boundary effects on the tracking procedure. Concerning the Black Sea, differences might be due to the fact that satellite passes are at 7:30 and 19:30 local time while the frequency of cyclones increases over this area during the night, especially in summer (Maheras et al., 2001), which corresponds to a peak of activity.

Figure 3 presents the monthly fraction of cloud systems for the 8.5 years. The domain has been partitioned off according to the latitude of 36° N and the longitude of 20° E yielding four regions (SW, NW, SE, NE). Overall, the fraction is the largest between March and October with local maxima in May and October. The fraction of cloud systems is during the whole year larger in the western part of the Mediterranean basin compared to the eastern part. This is due to a peak of activity in May and June over the SW region (Sahara). Also a higher activity is found in the NW region, with a maximum in March and August, over the Balearic Islands and the Iberian

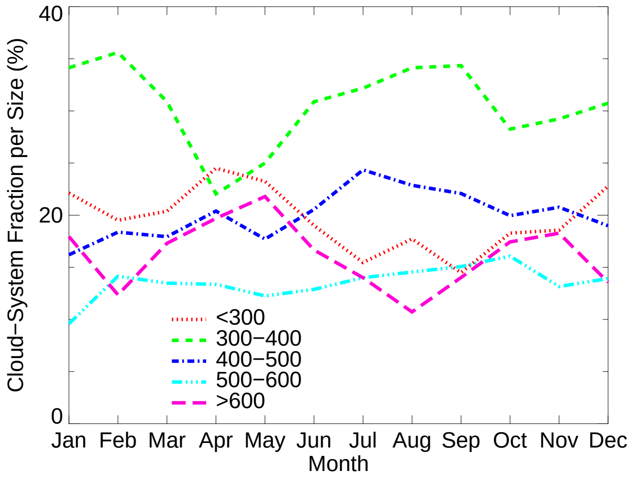

Fig. 4. Fraction of cloud systems per month for different categories of cloud-system radius.

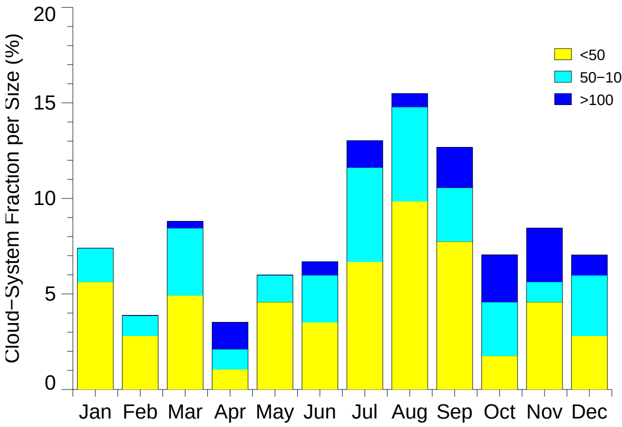

Fig. 5. Monthly fraction of cloud systems per different categories of daily precipitation.

Peninsula, respectively. The cloud system occurrence in the SE region (Cyprus and Middle East) is maximum between April and October with a peak in July. In the NE region, the maximum activity peaks between April and July.

Moreover, the monthly distribution is shown according to different size classes depending on the equivalent radius (Fig. 4). Around 35% of the systems fall into the category 300–400 km, independently of the month with the exception of April. Systems within categories 300–400 km and 400–500 km are more frequent in spring and summer. On the other hand systems within categories less than 300 km and larger than 600 km occur preferentially during spring, but present also a peak in October.

4 Cloud systems, upper-level forcing and precipitation in the Alpine Region

The detection of a warm TLS anomaly upstream of a cloud system suggests a strong upper-level forcing, and potentially more intense precipitation. The daily Alpine precipitation climatology of Frei and Schär (1998) allows for examining such a scenario. This climatology consists of gridded daily precipitation analyses, constructed by spatial aggregation of rain gauge observations onto a regular latitude-longitude 0.5° grid-spacing. It covers the Alpine area, between 43° N–49° N and 2° E–17° E. A selection of cloud systems in the same area has been carried out, providing 284 cloud systems for which the composite fields are shown in Fig. 6a. On average, a warm TLS pattern is present to the northwest of the cloud system.

A similar analysis has been performed, restricted to precipitating events larger than 50 mm/day on a grid point of the precipitation climatology (Fig. 6b). The threshold of 50 mm/day corresponds to the 90% quantile over where heavy precipitation occur in three distinct regions: southeast of the Central Massif, south central Alps, and north of the Adriatic Sea (Frei et al., 2003). The 129 selected events occurred mainly in summer and in autumn (Fig. 5). Composites show a warmer TLS field to the west of the CTP field, compared to the full set. Cloud systems also have a more elongated shape. This is a typical configuration for baroclinic interaction.

The analysis is done one step further by selecting only the events with rainrate higher than 100 mm/day. This leaves 44 events that occurred mainly in autumn (Fig. 5). The associated composite fields resemble those of the previous subset, but with even more elongated cloud system shape and a southernmore warm TLS anomaly (Fig. 6c).

5 Conclusions

The variability of Mediterranean systems has been investigated using polar satellite data covering the period January 1987-June 1995, in contrast with previous studies which all made us of reanalyses. An automatic detection of cloud systems is performed, based on retrievals of cloud top pressure (CTP). Over the 102 months, a total of 9906 cloud systems (storms, fronts, and convective systems) were identified, with a rather low interannual variation. 35% of the systems have an equivalent radius of 300 km, and over 70% less than 550 km, which is agreement with previous studies, and confirms the fact that over the Mediterranean, most of the lows are within the mesoscale or subsynoptic range, in contrast to North-Atlantic systems. Cloud systems are preferentially detected over western North Africa, the east coast of Spain, the Balearic Islands, the gulf of Genoa, southern Italy, the Aegean Sea and Cyprus. Their most frequent occurrence is between March and October.

In a last section, this study concentrated on the Alpine region in order to investigate the relationship between precipitation and the upper-level features. It was found that severe precipitation events over this region are associated to a warm TLS anomaly upstream of the cyclone, showing once more the impact of the upper levels on the weather over this

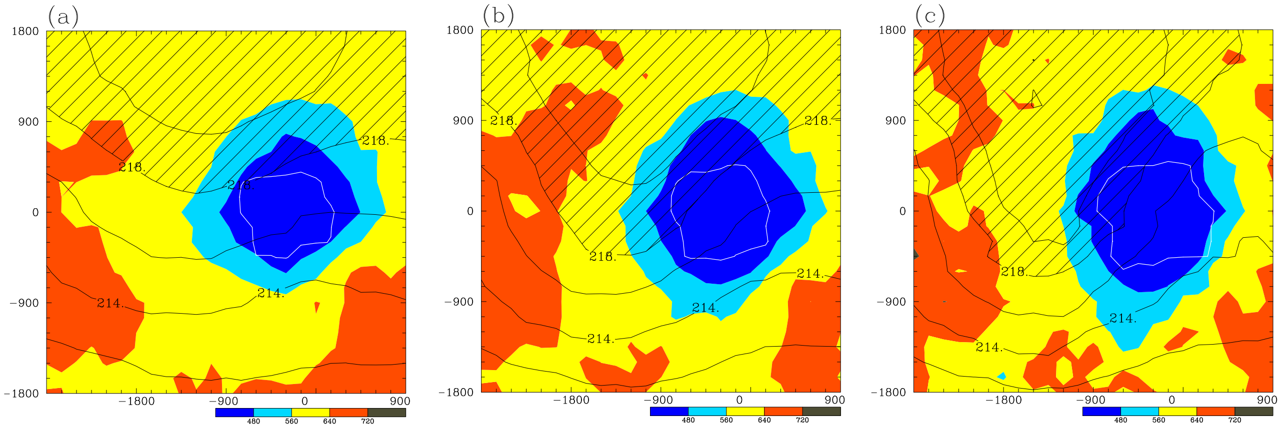

Fig. 6. Alpine composite fields from **(a)** the full set, and the sets restricted to events with rainrate higher than **(b)** 50 mm/day and **(c)** 100 mm/day within a 50 km grid point. The white line indicates rainrate higher than 1 mm/day. The ordinate (abscissa) of the coordinate system corresponds to northward (westward) displacements in km from the cloud system centre located at (0,0) km. The colours indicate CTP every 80 hPa, the black contours TLS every 2 K, and the hatched patterns TLS over 218 K.

area. While this study consolidates previous ones, it also complements them especially in terms of establishing large scale configurations that are prone to development over the Mediterranean Basin.

This study illustrates the potential of satellite sounder data for the study of storms. Further work will consist in considering the whole period of time during which TOVS data are available (since 1979), and also using higher resolution data like the Advance Microwave Sounding Unit (AMSU), which will offer possibilities of rain detection. Last, more results concerning the variability of cloud systems with season and north Atlantic regimes can be found in Chaboureau and Claud (2006).

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References

Chaboureau, J.-P. and Claud, C.: Observed variability of North Atlantic oceanic precipitating systems during winter, J. Geophys. Res., 108(D14), 4435, doi:10.1029/2002JD003343, 2003.

Chaboureau, J.-P. and Claud, C.: Satellite-based climatology of Mediterranean cloud systems and their association with large-scale circulation, J. Geophys. Res., 111, D01102, doi:10.1029/2005JD006460, 2006.

Chédin, A., Scott, N. A., Wahiche, C., and Moulinier, P.: The Improved Initialization Inversion Method: a high resolution physical method for temperature retrievals from the TIROS-N series, J. Climate. Appl. Meteorol., 24, 124–143, 1985.

Fourrié, N., Claud, C., Donnadille, J., Cammas, J.-P., Pouponneau, B., and Scott, N. A.: The use of TOVS observations for the identification of tropopause-level thermal anomalies, Quart. J. Roy. Meteor. Soc., 126, 1473–1494, 2000.

Fourrié, N., Claud, C., and Chédin, A.: On the depiction of upper-level precursors of the December 1999 storms from TOVS observations, Wea. Forecasting, 18, 417–430, 2003.

Frei, C. and Schär, C.: A precipitation climatology of the Alps from high-resolution rain-gauge observations, Int. J. Climatol., 18, 873–900, 1998.

Frei, C., Christensen, J. H., Déqué, M., Jacob, D., Jones, R. G., and Vidale, P. L.: Daily precipitation statistics in regional climate models: Evaluation and intercomparison for the European Alps, J. Geophys. Res., 108(D3), doi:10.1029/2002JD002287, 2003.

Maheras, P., Flocas, H. A., Patrikas, I., and Anagnostopoulou, C.: A 40 year objective climatology of surface cyclones in the Mediterranean region: Spatial and temporal distribution, Int. J. Climatol., 21, 109–130, 2001.

Scott, N. A., Chédin, A., Armante, R., Francis, J., Stubenrauch, C. J., Chaboureau, J.-P., Chevallier, F., Claud, C., and Chéruy, F.: Characteristics of the TOVS Pathfinder Path-B dataset, Bull. Amer. Meteo. Soc., 80, 2679–2702, 1999.

Stubenrauch, C. J., Chédin, A., Armante, R., and Scott, N. A.: Clouds as seen by infrared sounders (3I) and imagers (ISCCP), II, A new approach for cloud parameter determination in the 3I algorithms, J. Clim., 12, 2214–2223, 1999.

Trigo, I. F., Davies, T. D., and Bigg, G. R.: Objective climatology of cyclones in the Mediterranean region, J. Clim., 12, 1685–1696, 1999.