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STUDY OF A MESOSCALE CONVECTIVE COMPLEX OVER WESTERN AND SOUTHERN BALKANS

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Abstract: The purpose of this study is to thoroughly examine the conditions leading to the development of a mesoscale convective complex (MCC) on 24 May 2009 that affected the western and southern Balkan peninsula, its features and the manifestation of its activity at the surface. To this end, data from a variety of sources were used, such as weather maps, surface records and upper-air soundings, a hailpad network, satellite, lightning, precipitation and radar data. First, the evolution of the system was described, in terms of the track, timing, and areal extent. Second, the synoptic and thermodynamic environment that favored its development was studied. Special features at the surface, such as a cold pool and a mesohigh, were documented by surface observations. Finally, successive satellite, lightning and radar imagery revealed the organization of the system. All data together document well the categorization of this system as an MCC.

Keywords: mesoscale convective complex, western and southern Balkans, cold pool, mesohigh.

1. Definition

The concept and definition of MCC adopted worldwide are based on satellite imagery. Maddox (1980) proposed a definition based on areal extent and depth, as determined by the temperature of its capping cloud cover. More precisely, what is required is (a) a continuous cloud shield with IR temperature $\leq$ 241 K that must have an area $\geq$ 100,000 km^2, (b) an interior cold cloud region with temperature $\leq$ 221 K that must have an area $\geq$ 50,000 km^2, (c) these conditions must be met for a period $\geq$ 6 h and (d) the eccentricity of its shape must be $\geq$ 0.7 at the time of maximum extent.

An alternative definition, including dynamics, was proposed by Cotton et al. (1989) reading as follows: "a mature MCC represents an inertially stable mesoscale convective system which is nearly geostrophically balanced and whose horizontal scale is comparable to or greater than λ_R, the Rossby radius of deformation".

2. Special features and conceptual model

The climatology of MCCs indicates that they develop both in the tropics and midlatitudes, over land and sea. In midlatitudes they appear during spring and summer over continents, usually in late evening and night. They acquire their maximum extent (mature stage) around local midnight and dissipate just before sunrise. They often produce strong surface winds and lightning activity, heavy precipitation and big hail.

MCCs evolve from the merging of the anvils of neighboring orogenic cumulonimbus of meso-β scale organization, which leads to the formation of a stratiform cloud layer extending from the melting level up to the tropopause. A cold pool of meso-β dimensions is thus created due to precipitation evaporation and downdraft outflow. The level of strongest upward motion and of maximum heating then shifts upward to 300 hPa level (Wetzel et al., 1983). Finally, after sunset, a cooling of the cloud canopy occurs due to radiative effects (Fritsch and Brown, 1982). All these factors favor upscaling, namely the transition of the system to the meso-α scale.

The conceptual model distinguishes two regimes: a leading narrow area of strong convection and an extended trailing area of stratiform precipitation. The airflow is characterized by a warm, moist, low-level jet, an ascending front-to-rear flow of unstable air and a strong descending rear-inflow jet (Johnson et al., 1989). A mesohigh is generated in the boundary layer due to the cold pool at the surface, a mesolow in midlevels due to the stretching of the air column resulting from cooling at low levels and heating aloft and a mesohigh at tropopause level due to the mesoscale ascent in the stratiform area.

3. Track, timing and extent

The system started as a complex of 4-5 convective cells in the south end of the Pannonian Plain, the triggering mechanism being the orographic uplift along a line between the Dinaric Alps and the Carpathian Mountains. When the anvils of the individual cumulonimbus merged to form the MCC, the system started to move towards SSE and dissipated over south Aegean Sea, leaving its signature as a cyclonically rotating vortex (a PV anomaly) or MCV (mesoscale convective vortex) in the form of spiral cloud bands in the middle troposphere.

Surface observations (METARs) from weather stations along the track marked thunderstorm activity at 10:00 UTC over Belgrade, at 12:30-13:30 over Nis, at 14:30-16:00 over Skopje, at 18:00-19:00 along the line Florina-Thessaloniki-Kavala, at 19:30 over Larissa and finally at 20:00-21:00 over Lamia and Volos, Greece. Thereafter, the system started to dissipate gradually. The total length of its track was about 950 km.

Individual storms started to develop at about 10 UTC. The MCC formed at 15 UTC, reached maturity at 18 UTC and started dissipating at 21 UTC, its duration (6 h) lying within the typical values. The MCV (Bader et al., 1995), on the other hand, lasted for several hours (9 h), until 06 UTC next morning.

Individual thunderstorm organization started as a meso-β scale feature, whereas the MCC resulted in meso-α scale. At maturity time the system had a more or less oval shape, its eccentricity being $\varepsilon \approx 0.75$, the area covered by the cirriform anvil was estimated to be about 235,000 km^2 (at 241 K) and the corresponding area covered by overshooting tops reached about 90,000 km^2 (at 221 K), as identified by enhanced IR imagery. These values are within the standard theoretical extent and shape, according to the MCC definition. It is to be noted that large MCCs acquire a horizontal scale comparable to Rossby radius of deformation, which for midlatitudes (where earth's rotation dominates) is 300 km. This value agrees indeed with the area of 300 X 300 = 90,000 km^2 found above.

4. The pre-storm environment

The large-scale environment characterizing the MCC genesis region shows a pronounced anticyclonically curved jet streak to the north of the MCC (Maddox, 1983). Favorable conditions also comprise absence of synoptic forcing, weak vertical shear of the horizontal wind and a large convective available potential energy (CAPE). Necessary requirements also include strong warm advection (WA) at low levels and existence of abundant moisture through a deep layer of the troposphere, resulting in strong potential instability (Cotton et al., 1989).

These features were actually verified, in the case under consideration, with the aid of a variety of data. First, a jet streak was present at 250 hPa to the NNE of genesis area at 00 UTC (Fig. 1). Second, a warm air mass of 20^{o}C at 850 hPa at the same time from Central Mediterranean was advected towards NNE into the region (Fig. 1). As for the vertical profile, the most representative sounding of Belgrade at 12 UTC (Fig. 2) was examined. This showed a weak vertical shear, moisture all the way

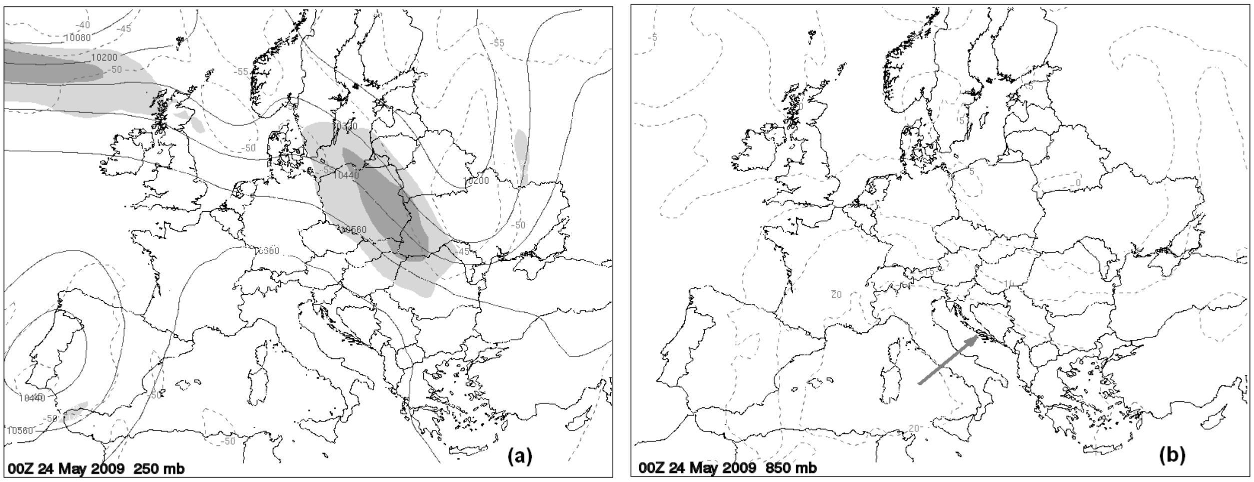

Fig. 1. Maps of (a) 250 and (b) 850 hPa at 00 UTC of 24-5-2009 depicting the pre-storm environment.

up to about 300 hPa, significant instability with CAPE = 995 J kg^{-1} and high enough instability indices (KI = 32 ^{o}C and TT = 50 ^{o}C).

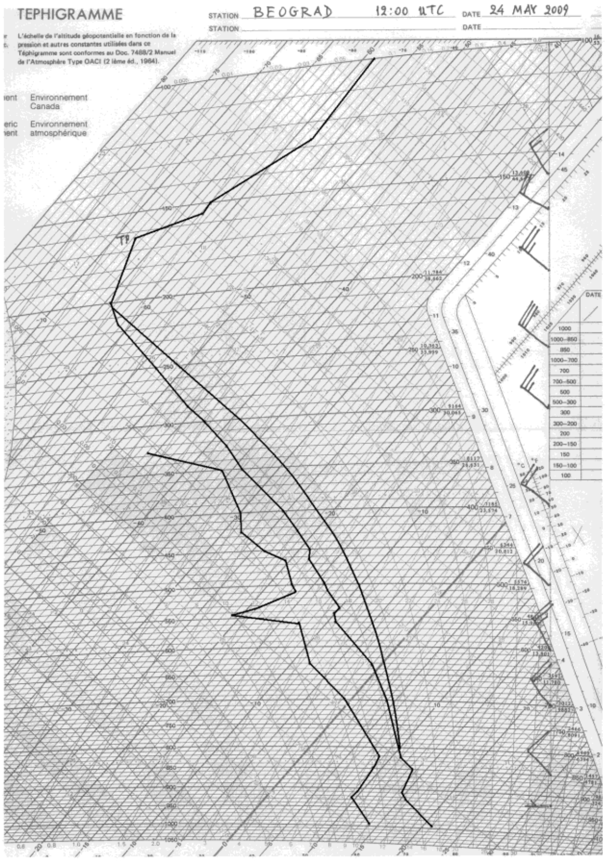

Fig. 2. Belgrade 12 UTC sounding of 24-5-2009.

5. Manifestation at the surface

Surface observations along the track revealed several common features, like the significant drop in temperature and pressure, strong winds and heavy precipitation. A temperature drop of 8^{o}C in 2 h was observed in Belgrade, of 9^{o}C in 1.5 h in Nis and of 12^{o}C in 1.5 h in Skopje. Wind gusts up to 40 kt were also recorded in Skopje.

Surface manifestations of MCC features were documented from two automatic meteorological stations installed west of Thessaloniki, namely Galatades (north) and Meliki (south). Graphs of the daily march of temperature at both stations (Fig. 3) show a considerable drop in temperature, indicative of the cold pool which was created near the surface. This, in turn, formed a mesohigh in the pressure field, marked in the graph by the significant rise in pressure after its drop. The mesohigh is not an anticyclone, since there exists no anticyclonic circulation, and its extent usually ranges from 100 to 500 km (Djuric, 1994). This extent was in the present case estimated to be 200 km, from the mean velocity of the system (50 km h^{-1}) and the time elapsed (4 h) for the pressure to adjust to the average prestorm passage value. The MCC passage was also manifested in the wind speeds recorded, where successive spikes indicated surface gust fronts and consequent divergence from the individual convective cells. Heavy rainfall, resulting from the leading convective cells (27.2 mm in half-an-hour) was recorded, followed by 6.2 mm in one hour due to the trailing stratiform precipitation.

The MCC moves typically partly with the environmental wind, but deviates from it, since new convective cells develop on the side with the most

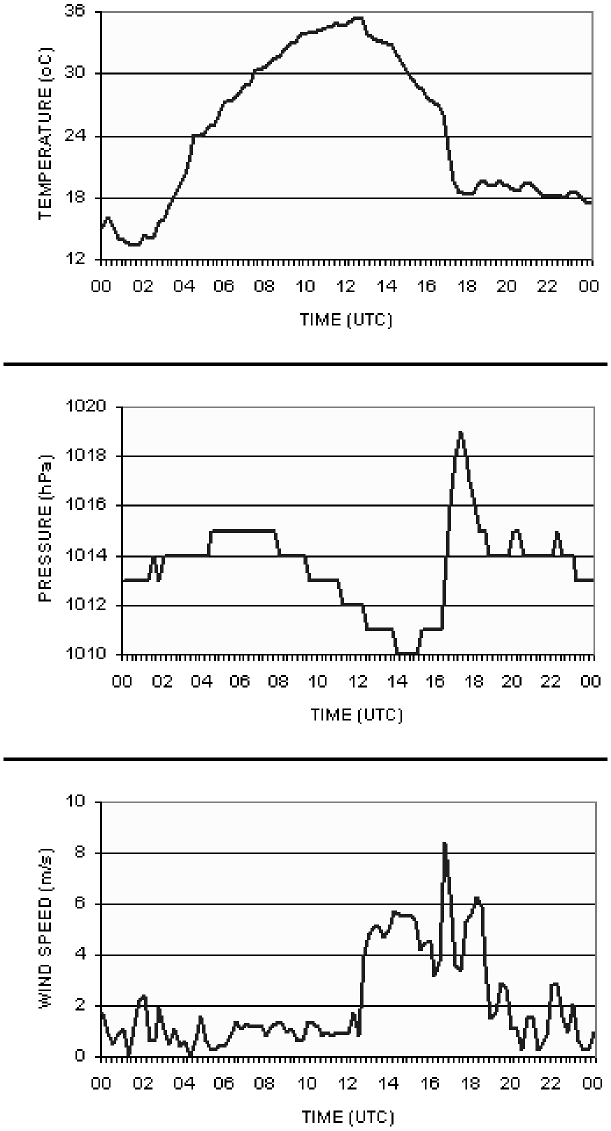

Fig. 3. Meliki (south station) daily records of 24-5-2009 for temperature, pressure and wind speed. Similar graphs exist for Galatades (north station).

low-level warm inflow (Djuric, 1994). In the present case, the steering wind was from 320°, while the actual motion was from 340°. New cells developed in the west end of the line of convective cells, according to warm advection from Adriatic Sea. The MCC moved at 14 m s^{-1}, much faster than average (5 m s^{-1}), that is why flash flooding did not occur, since precipitation was not delivered over the same area but, instead, was distributed over a long stretch.

6. Satellite, lightning and radar history

Satellite IR (11.2 μ) images (Fig. 4) reveal the special features related to MCC lifecycle. At 13 UTC the individual convective clouds could be easily identified, while at 15 UTC the anvils emanating

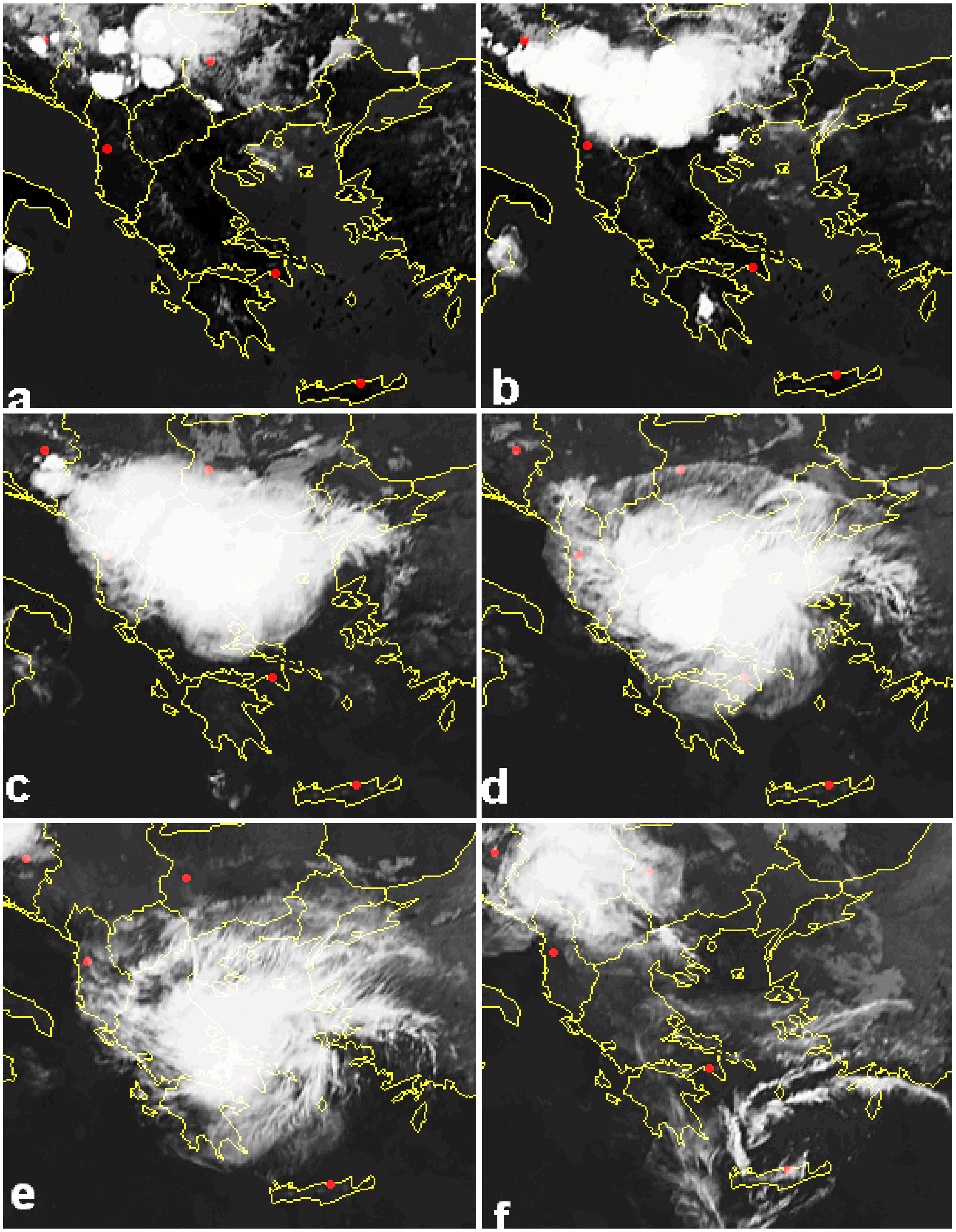

Fig. 4. Successive satellite IR pictures during the MCC lifecycle at (a) 13, (b) 15, (c) 18, (d) 20, (e) 22 UTC of 24-5-2009 and (f) of 04 UTC of 25-5-2009.

from meso-β thunderstorm elements merged. At 18 UTC the MCC reached maturity and its maximum extent (from Sarajevo to Athens), while at 20 UTC the dissipation stage started from the MCC outer cirriform boundary. Dissipation continued at 22 UTC inwards, with spiral bands becoming evident. At 04 UTC the MCV signature was the remnant of the system. At the same time, a new, weaker and smaller MCC appeared to follow the same path. This is not unusual, since MCCs may form in episodes on several consecutive days (Wetzel et al., 1983).

Lightning activity (Fig. 5) is exclusively related to convective cells. Each picture represents the total lightning that occurred within the previous hour. Thus, at 17 UTC, this indicates the alignment of leading thunderstorms along an arc-shaped line, with the convex toward the leading edge (Houze, 1993). At 19 UTC the maximum lightning activity took place, just after the MCC had reached maturity, in compliance with the time of transition from convective to stratiform precipitation (Goodman and MacGorman, 1986).

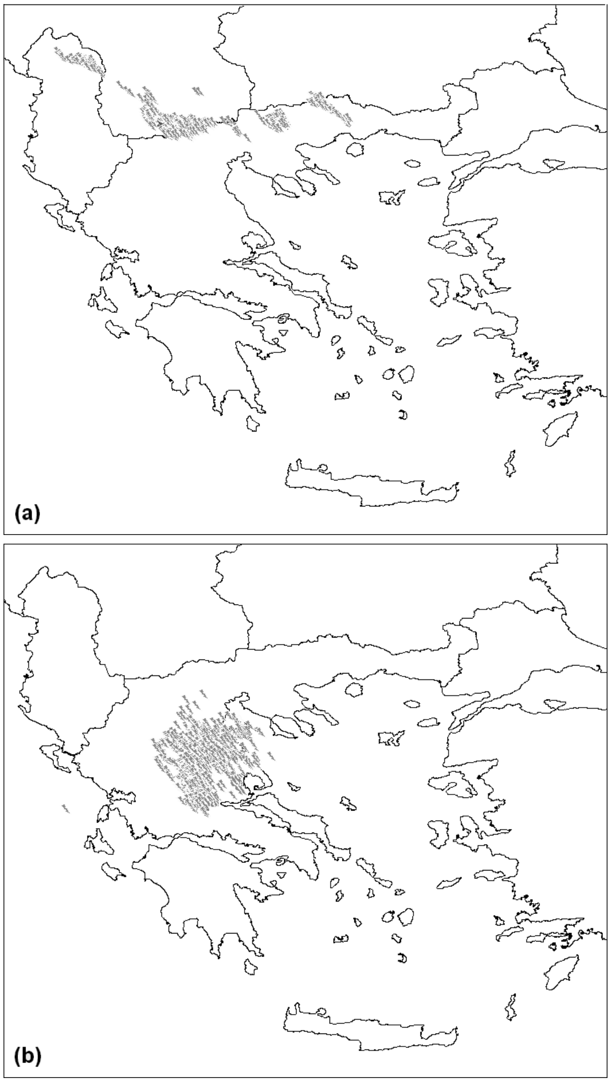

Fig. 5. Lightning activity at (a) 17 and (b) 19 UTC of 24-5-2009.

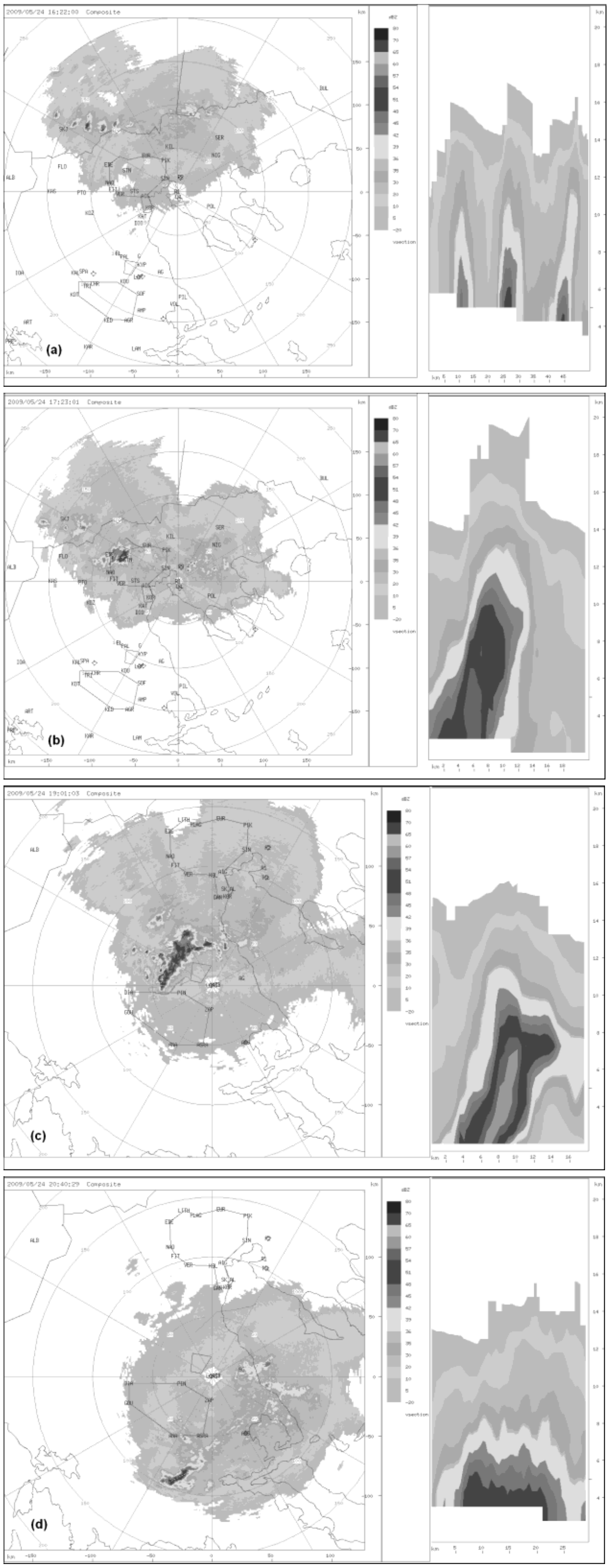

Fig. 6. Successive radar CAPPIs and cross-sections at (a) 16:22, (b) 17:23, (c) 19:01 and (d) 20:30 UTC of 24-5-2009.

Radar imagery (Fig. 6) reveals MCC features beneath the anvil shield. Two S-band radars located at Thessaloniki and Larissa were monitoring the track of the system with the aid of the radar recording system TITAN. At 16:22 UTC a west-to-east alignment of leading convective elements was recorded, with the decaying ones to the east and the newly formed ones to the west, in agreement with the warm inflow region. This is a typical pattern of the asymmetric development of convective elements on the leading edge (Houze, 1993). At 17:23 UTC a particular thunderstorm NW of Thessaloniki reached the maximum recorded height of 16 km (as seen in the relevant cross-section) and pea-size but quite dense hail was recorded on hailpads installed in this area. At 19:01 UTC, close to maturity, the pattern of convective cells changed to a NNE-SSW orientation, and the maximum reflectivity of 62 dBZ was then recorded. At 20:30 UTC the stratiform precipitation dominated, marked by moderate reflectivities (Cotton and Anthes, 1989) and the presence of bright band, typical of this precipitation type. All horizontal sections were taken at -5^{o}C and the echo was more or less circular with a diameter of 200 km.

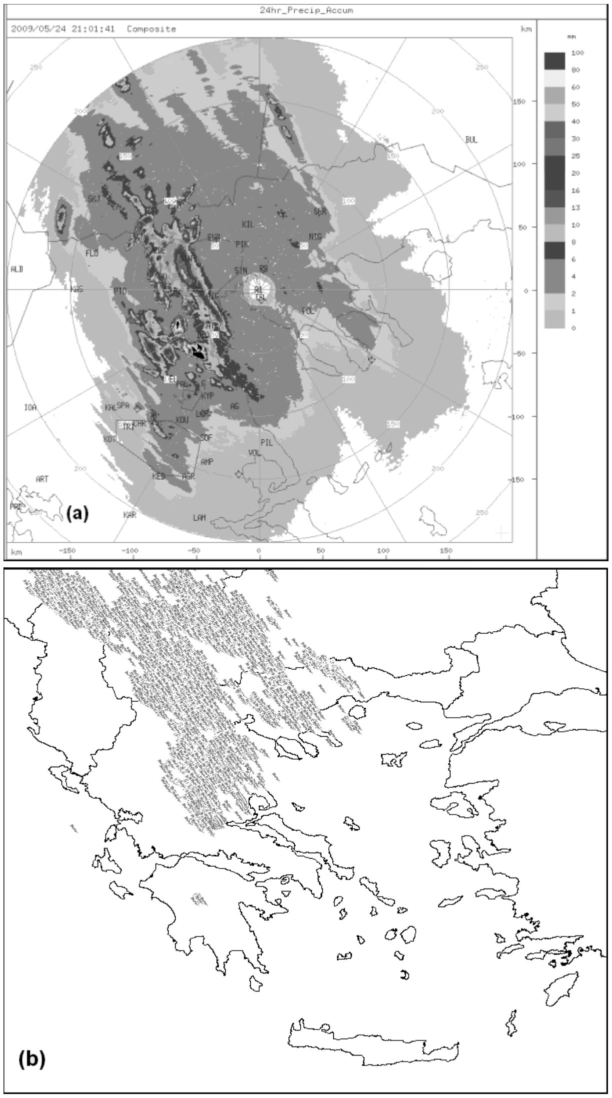

Fig. 7. Precipitation accumulation (a) and total lightning (b) during MCC lifecycle.

It has to be noted here that the convective elements of the system were seeded for almost 3 h close to maturity time (between 17 and 20 UTC), with three aircraft missions that delivered a total of 13270 g of seeding material (silver iodide being the seeding agent). Apparently, seeding had no or little effect. This is due to the violent turbulence the aircrafts encountered that prohibited their approach to the appropriate areas for effective seeding.

The accumulated precipitation over the MCC lifecycle (Fig. 7) shows a maximum of more than 100 mm near the place where maturity occurred. The precipitation pattern reveals the motion of the system and is in good accordance with the total lightning activity recorded (Fig. 7).

Moreover, radar data indicate a mean velocity of 49,2 km h^{-1} (maximum 59), a mean maximum reflectivity of 53 dBZ (maximum 62) and top height of 13 km (maximum 16) at maturity. Maximum vertically integrated liquid water (VIL) was 108.3 kg m^{-2} and hail mass aloft reached a maximum of 452 ktons.

7. Conclusions

Mesoscale convective complexes are important atmospheric phenomena. Due to their large size and long duration they are driven by a combination of interacting cumulus, mesoscale and larger scale dynamic and thermodynamic processes and affect their environment long after their decay.

Indeed, most of the features exhibited by the system of 24 May 2009 agree with what was predicted by the MCC conceptual model. It was orogenic in nature, acquired an oval shape with classical dimensions and produced heavy precipitation, hail and strong lightning activity. The initiation and maturity timing and the duration were also correct. There was evidence of the cold pool and mesohigh and the synoptic and thermodynamic environment was as expected. Finally, satellite and radar data revealed all the relevant features. All the above conclusions place the system of 24 May 2009 unquestionably in the typical MCC regime.

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