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Atmospheric Research 53 (2000) 45–62

ATMOSPHERIC RESEARCH

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November 2, 1994, severe storms in the southeastern Mediterranean

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Abstract

The available data archive over the Middle East is complemented with mesoscale fields from simulations for 1–2 November 1994 event of hazardous rains in the southeastern Mediterranean with the aim of exploring the mechanisms of this extraordinary phenomena. The associated severe weather was not predicted at all by the present operational models. A global/limited area modeling system is used for numerical simulation of the process. The system consists of the Florida State University (FSU) Global Spectral Model (FSUGSM) and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) MM5 model. The accuracy of the numerical simulation is found very sensitive to the moist processes in the model. The development was a consequence of intensive non-adiabatic processes caused by northward propagation of large quantities of warm and moist tropical air. Local terrain of northeastern Africa also played a significant role in the development of a Mesoscale Convective System (MCS) in the Mediterranean region on November 2, 1994. Over Israel, the system had a character of relatively large-scale trough with a narrow frontal system accompanied by rapidly developing small cyclonic vortices in the eastern Mediterranean.

Keywords: Storm; Southeastern Mediterranean; Tropical

1. Introduction

Intensive weather processes took place in Egypt and Israel on November 2, 1994. As is stated by Obasi (1997), the developments were characterized by ‘‘exceptional and extremely heavy rains’’, which ‘‘affected a wide part of Egypt, including the Sinai Peninsula . . . more than 500 people lost their lives and large areas were inundated’’. The rains were accompanied by strong winds. In several hours the system with rainy weather

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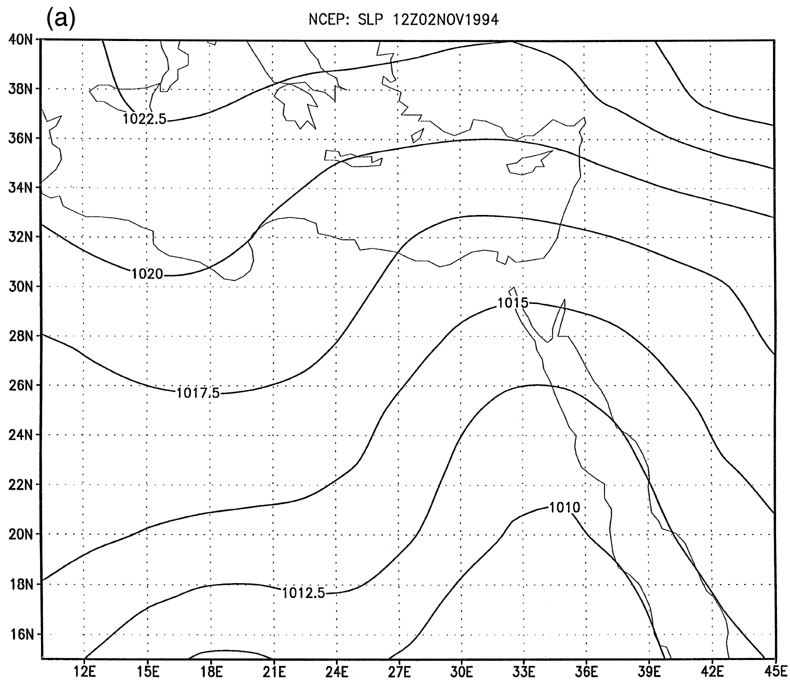
0169-8095/00/$ - see front matter
PII: S0169-8095(99)00045-9

propagated to Israel, where heavy rains were also observed. The severe weather conditions have not been predicted at all. The standard synoptic analyses also have not allowed any definite explanation of the mechanisms involved, and, especially, for the unusual intensity of the processes of the case. According to the analysis made in Egypt (Abu-Taleb, 1996), the flash flood were associated with the northward penetration of a zone with unusually strong convergence. As is stated in the same work, before the rainy day of November 2, 1994, there were several periods when the Inter Tropical Convergence Zone (ITCZ) was located to the north of its usual position over the tropical part of the eastern Africa in the Northern Hemisphere. This could be the reason for excessive pumping of the tropical area air moisture into the mid-latitudes. Another peculiarity of the period was the high Sea Surface Temperature (SST) anomaly — the October 1994 SST in the whole Mediterranean Sea and especially in its northeastern part was characterized by anomalies of up to 3°C as follows from the SST anomaly analysis (Reynolds and Smith, 1994). In the southeastern part of the Sea the anomalies were also high — about 1.5°C. This factor could play its role in intensification of the weather processes in October–November — exceptionally strong rains were also reported in the Mediterranean area before and after November 2, 1994 (Lionetti, 1996; Lagouvardos et al, 1997).

The aim of the work was to analyze the processes responsible for the weather developments in the eastern Mediterranean on November 2, 1994, and the possible causes of the unsuccessful prediction of the phenomena. The case was associated with the process of the Red Sea Trough (RST) development in the eastern Mediterranean region (Krichak et al. 1997a,b; Krichak and Alpert 1998), as well as Ashbel (1938), Dayan and Sharon (1980), Itzikson (1995) and Saaroni at al. (1997). Such processes are quite typical in the area, especially during the late autumn and early spring seasons. The periods are often characterized by rains. Detailed investigation of the processes associated with the southeastern Mediterranean torrential rains of November 2, 1994 may allow a better understanding of the physics of such rainy periods in the area.

The authors of the present study possess quite a limited information on the timing of the processes that took place in Egypt after the November 1, 1994, 12:00 UTC. Surface data and radar pictures are available for the subsequent part of the period, when the rains had already covered Israel. Satellite based pictures and results of a recent National Center for Environmental Predictions (NCEP) reanalysis (Kalnay et al. 1996) are also available. All these data are used here for exploration of the exceptional processes of the November 1–2, 1994 period in the southeastern Mediterranean. Mesoscale simulation of the phenomena is performed using the Penn State and National Center for Atmospheric Research (Penn State/NCAR) MM5 model. The model simulated data are also used as a source of an additional information for understanding the mechanisms involved in the developments with an emphasis on those happened over Israel.

Fig. 1. NCEP reanalysis data for 12:00 UTC November 2, 1994. (a) Sea level pressure; (b) temperature at the 850 hPa isobaric surface; (c) geopotential height of the 500 hPa surface; (d) precipitation for November 2, 1994 (contour intervals 2.5 hPa, 2°C, 20 m and 4 mm day^{-1}, respectively). The boxed area in (d) represents the model domain shown in Figs. 3–6.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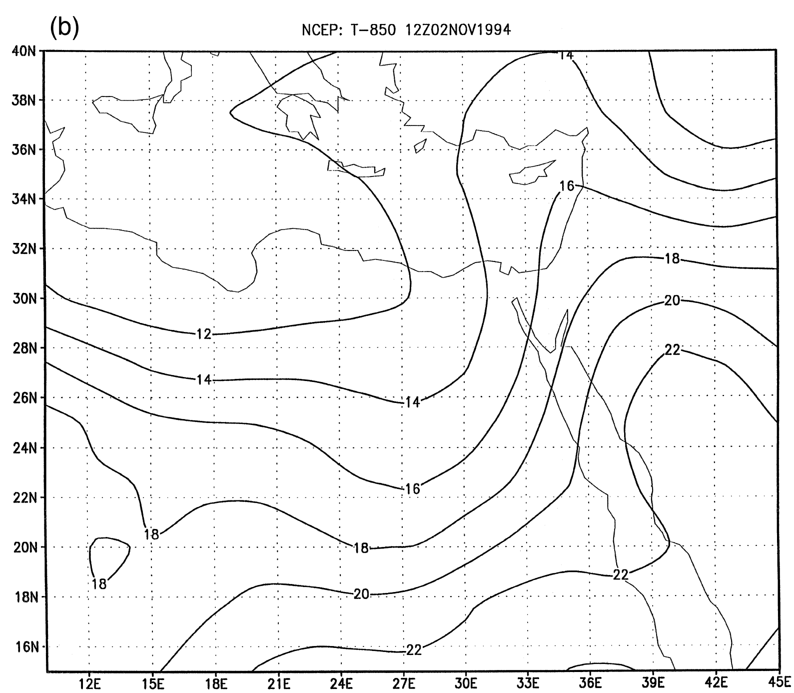
(b)
NCEP: T-850 12Z02NOV1994
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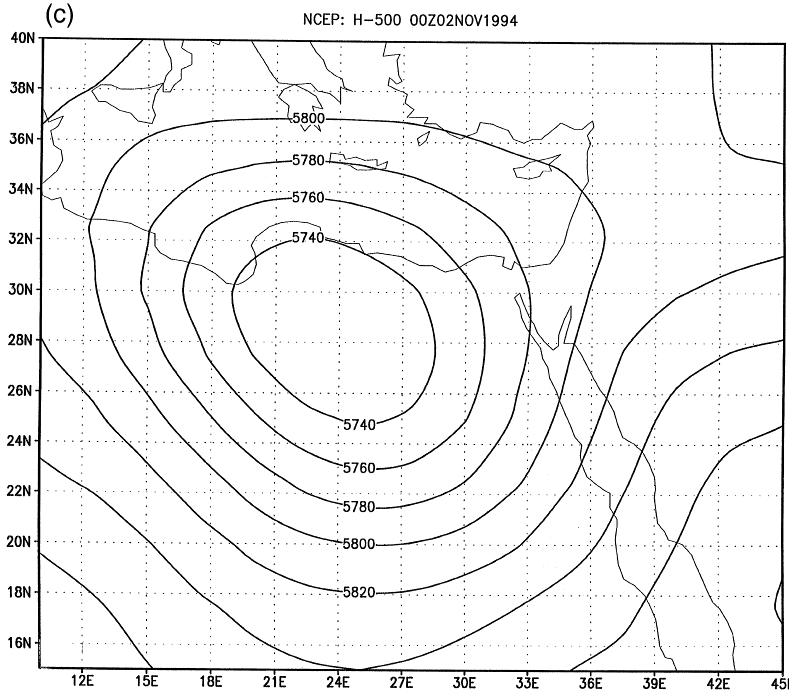

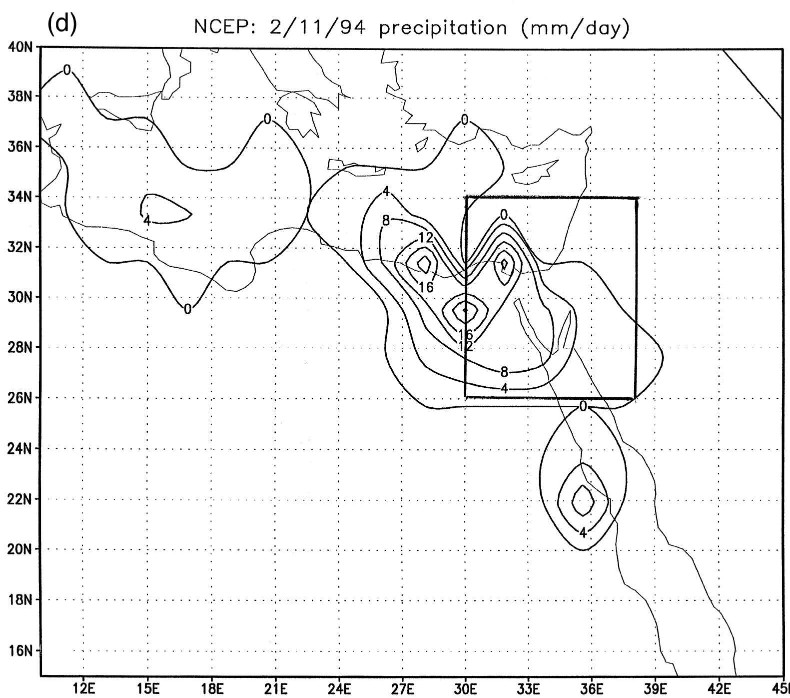

Fig. 1 (*continued*).

2. Synoptic overview

Since October 20, 1994 the weather conditions of the Red Sea area were characterized by intensive propagation of air masses from the Arabian Sea over the Arabian peninsula and northeastern Africa (Lagouvardos et al. 1996; Krichak and Alpert, 1998). Patterns with the sea level pressure, air temperature at 850 hPa surface, geopotential heights of 500 hPa isobaric surface and precipitation for 12:00 UTC of November 2, 1994 from the NCEP re-analysis data set are given in Fig. 1a–d. The horizontal resolution of the analyses is comparatively coarse (about 210 km). It should also be pointed out that the NCEP re-analysis precipitation patterns (Fig. 1d) are generated by the model in the process of the data assimilation at NCEP. Due to this, the data give mainly a qualitatively accurate representation of the real meteorological fields and, especially, of the precipitation in the area.

During the 2 days preceding the storms, an upper level closed cyclone moved eastward along the north African coastal region and entered western Egypt during November 1, 1994. The sea surface pressure pattern (Fig. 1a) demonstrates the existence of a RST system. The lower levels are dominated by a semi-permanent RST and the Levant region is subjected to an easterly warm and dry flow (Fig. 1b). Fig. 1c,d demonstrates the H-500 patterns and intensive rains for November 2, 1994, over a large area in the southeastern Mediterranean, respectively. Large amounts of precipitation (up to 20–24 mm) are found in Fig. 1d over northeastern Africa and adjacent areas.

On November 1, spiral cloud lines passed over Egypt, resulting in severe thunderstorm, accompanied by rain showers. Development and a gradual eastward displacement of a cloud system with the horizontal scale of about 300–500 km was observed in the satellite images (not presented). The press reported a harmful fire that was initiated by a lightning over Asyut, along the Nile river. In Egypt, where the normal annual precipitation is about 24 mm (Cairo), the observed rainfall of more than 20 mm day^{-1} (Fig. 1d) is an extraordinary phenomena. During this period medium convective clouds accompanied by local thunderstorms and rains were reported over Israel, mainly in its eastern parts. On November 2, 1994, the synoptic situation in Egypt remained similar. Some intensification of the storm occurred. This resulted in an increase of the wind speeds, especially at the lower levels, where the winds reached at least 35 knots (about 20 m s^{-1}) at 900 hPa level. This value should be compared to less then 20 knots (10 m s^{-1}) in the previous day. In the morning hours of November 2, 1994, a sharp line of cumulonimbi, with a southeast northwest orientation was identified in the satellite images over Egypt (not presented).

From this time on, this line progressed toward the north–northeast following the winds at the medium levels there (700–500 hPa). Satellite pictures showed formation of a vortex with the counterclockwise circulation at 07:00 LT. Its front was oriented in the northwest to southeast direction, extending from the Suez Canal. On November 2, 1994, a thunder cloud front, accompanied by heavy rain showers combined with exceptional intense sand storms crossed the southern and central parts of Israel. It penetrated the southern part of the Negev desert at about 14:00 LT, as seen in the radar measured rain intensities and has swamped Israel within less than 6 h. Radar patterns are characterized by existence of an intensively precipitating frontal system (more than 14 mm h^{-1})on the first several hours of the storm over Israel (from 14:00 to 16:30 LT, Fig. 2a–d). The line of thunderstorms indicates positioning of the pre-frontal zone. An additional mesoscale subjective analysis (not presented) showed the passage of a surface trough that was not detectable in the standard synoptic scale analysis. The trough was separated between a section of southeasterly winds of 15–30 knots (7–15 m s^{-1}), and the sector of southwest winds of 20–40 knots (10–20 m s^{-1}), with gusts exceeding 50 knots (25 m s^{-1}). (The southwest winds indicate the existence over the region of a mesoscale cyclone which is not represented in the NCEP re-analyzed data given in Fig. 1a–d). Dust, sand and severe thunderstorms were observed in this area. The trough was not found at the later maps, 18:00 UTC onward. The cloud front attained its maximum intensity at the beginning of the episode and decayed after 17:00 LT.

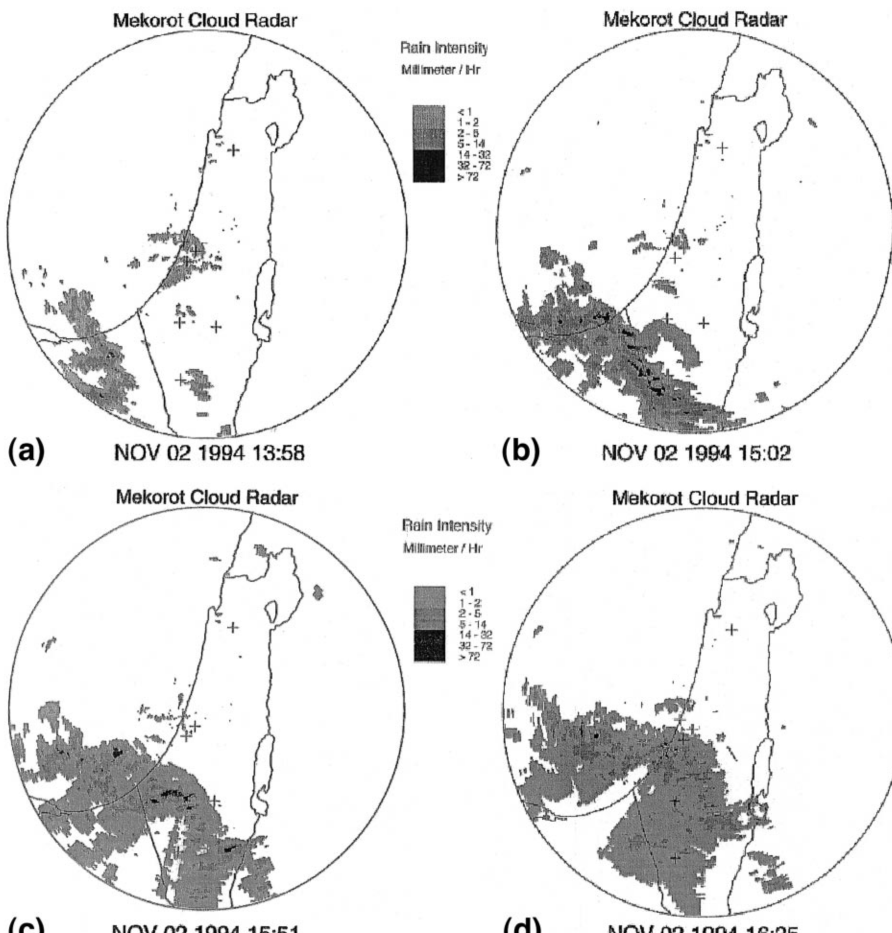

Fig. 2. Rain intensities over Israel, determined from the Cloud Radar System for November 2, 1994 — (a) 13:58 LT; (b) 15:02 LT; (c) 15:51 LT; (d) 16:25 LT.

3. Organization of the simulations

The study is focused on numerical simulation of the weather developments of the period using a mesoscale atmospheric model. A global/limited area modeling system recently suggested at Tel Aviv University by Krichak et al. (1997c) is used for the simulations. The system consists of the Florida State University (FSU) nonadiabatic primitive equation Global Spectral Model (FSUGSM, Krishnamurti et al., 1998) and the PSU/NCAR nonadiabatic nonhydrostatic Mesoscale Model (MM5, Grell et al., 1994). The one-way interaction approach is adapted — the global model runs for 36 h starting from initial data determined for 1200 UTC of November 1, 1994. Analysis of results of the FSUGSM simulation during the November 1–5, 1994 period is given by Krichak and Alpert (1998). The mesoscale model run is then performed. The coarse mesh data from the FSUGSM for determination of the time dependent lateral boundary conditions in the mesoscale run are available with 3-h time resolution.

Results of the European Center for Medium Range Weather Forecasts (ECMWF) objective analysis with 1.15° horizontal resolution determined on 14 isobaric surfaces (1000, 950, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150 and 100 hPa) are adapted as initial data for the global run without any additional data assimilation. Preliminary processing of this data was performed at the FSU. Results of the FSUGSM simulation are stored on the eight isobaric surfaces (1000, 850, 700, 500, 400, 300, 200 and 100 hPa) with 1° horizontal resolution.

4. Model simulations

The MM5 nonhydrostatic mesoscale modeling system allows simulation of a wide spectra of real atmospheric processes of the scales from several to several thousand kilometers. Appropriate computational tools and parameterization methods of the sub-grid scale processes should be selected for a particular application. The choice of the model parameters for a simulation provides a useful information for understanding the physics of the processes involved.

Two-way nesting is applied. The atmosphere is represented by 27 vertical layers. Two nested grids of 40×40 and 73×73 (60 and 20 km horizontal resolution) points at each of the model surfaces used. The vertical resolution at the lowest layer is about 50 m. The following effects are taken into account (necessary references are available in Grell et al. 1994): (1) Cloud and rain water fields predicted explicitly with simple ice phase microphysics; (2) Fritch and Kain cumulus parameterization scheme; (3) The MRF (Medium Range Forecast) type planetary boundary layer parameterization; (4) Five-layer soil model with temperature prediction in 1, 2, 4, 8, 16 cm layers with mixed substrate below using vertical diffusion Eq. (5) surface fluxes; (6) surface temperature prediction; (7) cloud effects on the short-wave radiation processes.

The adapted model parameters have been chosen in the process of numerous sensitivity tests. Results of three such experiments are presented here. One of the experiments (A2) is considered as the control run. It includes all the non-adiabatic effects listed above and is based on application of the FSUGSM outputs for determination of the lateral boundary conditions. Another simulation experiment (A1) differs from the A2 only by one factor — it is completely dry (no moisture effects are included). The third experiment (A3) is equivalent to A2 but uses the ECMWF analysis data for determination of the boundary conditions.

The model terrain is presented in Fig. 3. Development of the eastern Mediterranean cyclone is represented in the Fig. 4a–c where the simulated 1000 hPa winds are given for 2, 18 and 24 h of the control run. It appears that the cyclone in the eastern Mediterranean develops out a system that originates over the mountainous area located near to the Gulf of Suez. After 2 h of the simulation, the wind pattern (Fig. 4a) demonstrates the existence of several convergence lines propagating to the northwest and northeastern directions. After 18 h of the integration (Fig. 4b) the area of most intensive developments has already shifted to the Sinai Peninsula. A developing center of counterclockwise circulation is found over the eastern Mediterranean. In the 24-h wind pattern (Fig. 4c), the cyclone is already developed and the southwestern and southeastern air flows over Israel are separated by an intensive frontal zone. The simulated wind pattern satisfactory describes the observed developments in the area (see Section 2).

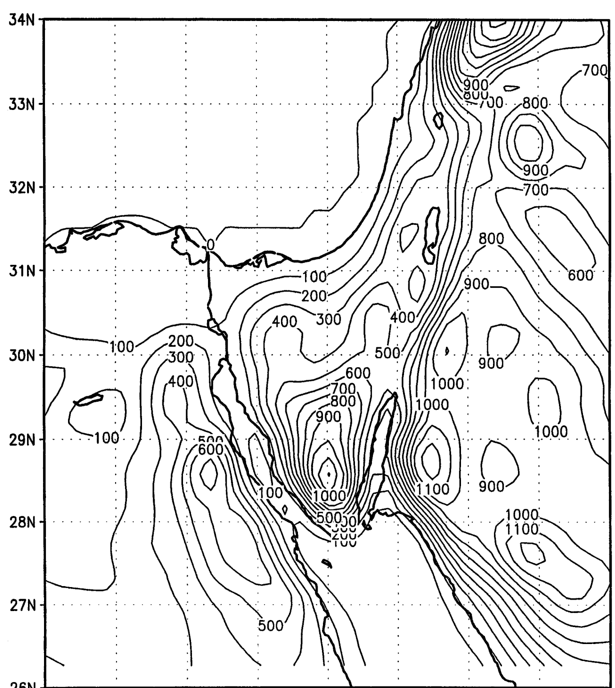

Fig. 3. Terrain field adapted in the simulations (contour interval 100 m).

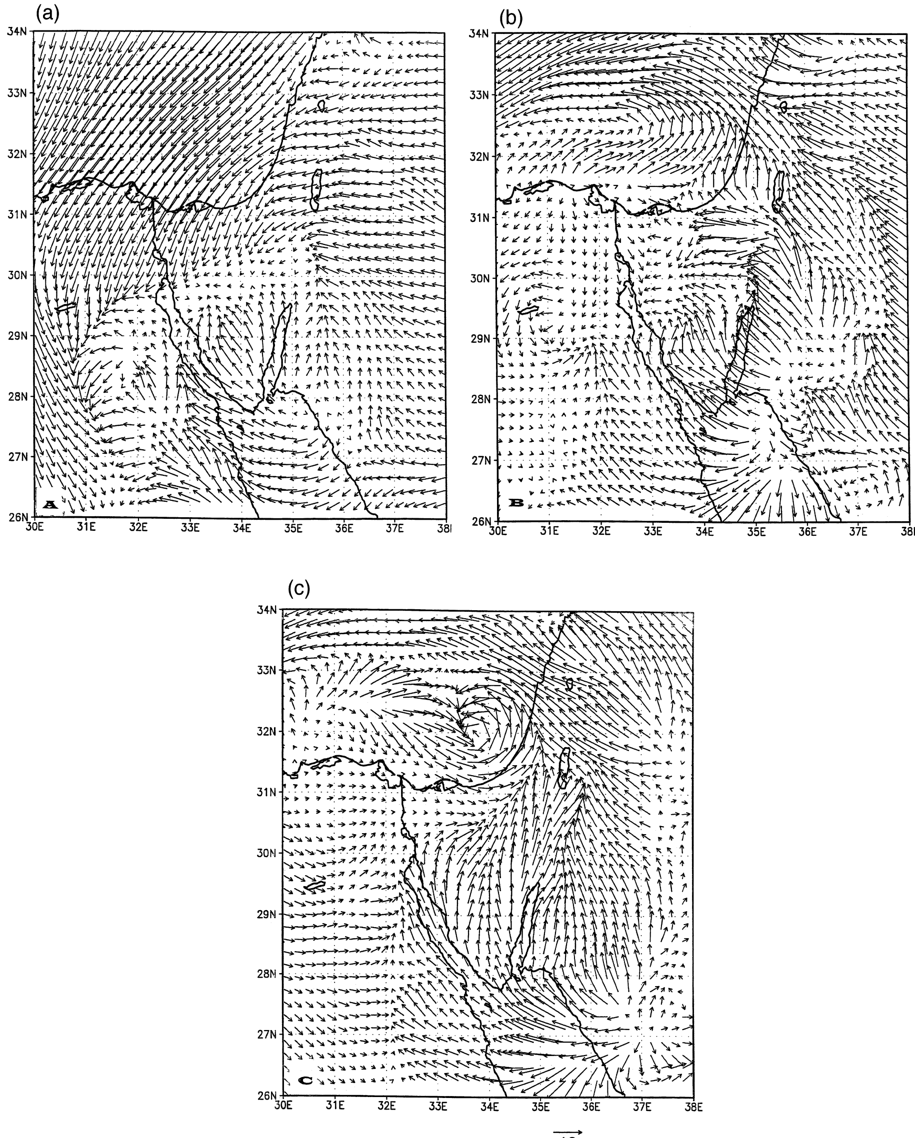

Fig. 4. Results of the (a) 2-h, (b) 18-h and (c) 24-h simulation of 1000 hPa wind fields in the A2 experiment.

Simulated relative vorticity (RV) and the wind patterns at 970 hPa are given in Fig. 5A,B for the two sensitivity runs (A1 and A2). Location of the RV maxima shows the positions of the cyclonic vortices after 24 h of the model simulation. The RV fields differ significantly in the experiments. In the dry (A1) experiment a relatively large area with a RV maximum of 12.6 10^{-5} s^{-1} is located over the southeastern part of the

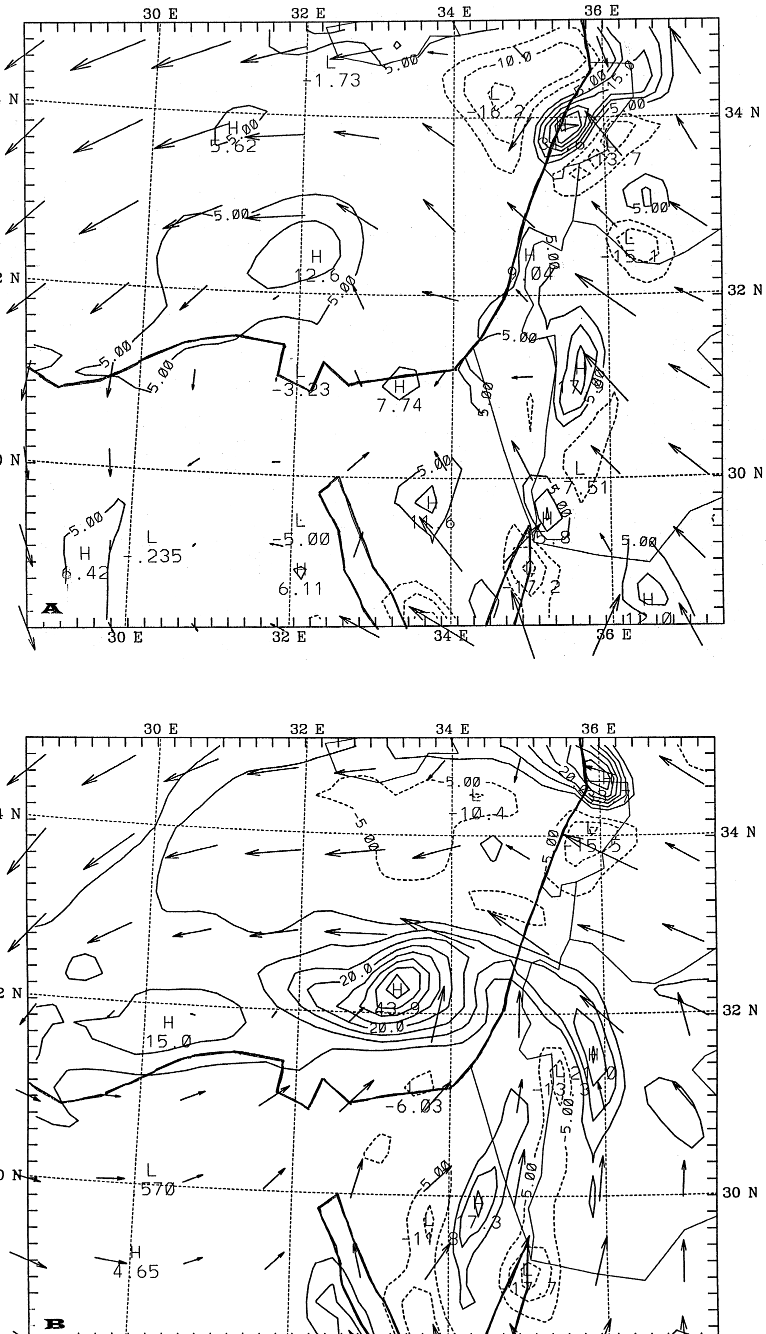

Fig. 5. Simulated 24 h relative vorticity and wind vectors at 970 hPa isobaric surface (in s^{-1} 10^5) on 13:00 UTC November 2, 1994; contour interval — 0.5 m s^{-1}; (A) A1 (dry) experiment; (B) A2 (moist) experiment.

Mediterranean Sea. Its center is found at 32.4°N, 32°E. In the control run (A2) the value of the vorticity maximum is 3.5 times larger (43.9 10^{-5} s^{-1}). The center is located further to the east (32.4°N, 33.4°E). The RV values are also higher for the moist run over Israel. Positioning as well as intensity of the new cyclone in the Mediterranean were evidently the main factors responsible for the strong frontal type rains in Israel during the November 2, 1994 storm. The rains in Israel would be much weaker in the case of less intense moist processes. Very significant differences are also found in the simulated wind fields. In case of the dry run (A1, Fig. 5A) the 24-h winds have strong southeastern components over whole Israel. The results are in contrast to the observations. The real situation is better described in the (A2-moist) run (Fig. 5B), where the observed southwestern winds (see Section 2) are successfully simulated over the southern Israel.

Role of the lateral boundaries is important in the mesoscale simulations of the Mediterranean cyclones (Alpert et al., 1996). To test the role of this effect in the November 2, 1994 storm, an additional simulation (A3) has been performed. As is already stated, the ECMWF objective analysis data available with 12-h time interval are used for the lateral boundary computation. The differences between the A2 and A3 experiments (not presented) are not very significant but the timing of the process and the orientation of the rain belt over Israel are better represented in the FSUGSM forced A2 simulation.

This experiment was also the most realistic one in the determination of the amount of precipitation from the cyclone developed in the eastern Mediterranean. Accumulated total precipitation patterns for 12, 24 and 36 h are presented in Fig. 6A–C. The model simulation gives quite reasonable results. During the first 12 h of the run the rains fall mainly over Egypt. A maximum of 29 mm rain (Fig. 6A) is reached in central Egypt (30.4°N, 31.5°E). The location of this rainy area is in reasonable agreement with the re-analysis data (Fig. 1d). A small amount of precipitation (about 1 mm) is found also over Israel. During the following 12-h period, rains continue to fall over central Egypt, but an additional area with intensive precipitation (17.4 mm, Fig. 6B) develops over the eastern part of the Mediterranean Sea (31.5°N, 33.3°E). Intensive rains are also simulated over the southern part of Israel. Over the Negev desert the rains are weaker — maximum amount of total precipitation reaches 10 mm for the second 12-h period of the run (by the way, less than 6 mm of rain in 24 h is produced for this location in the A3 simulation experiment (not presented)). During the following 12-h period, the area with rains propagates further to the north over the Israeli territory. Maximum of the total precipitation over the Mediterranean sea reaches 49.3 mm for 36 h (32.4°N, 32.5°E) (Fig. 6C). The results are supported by the available observations (Fig. 2a–d). The simulated 36 h precipitation pattern is characterized by the existence of several areas with intensive rains — over central Egypt and over the eastern Mediterranean. Quite a similar pattern is found in the re-analysis data presented in Fig. 1d. According to the model simulation results, the precipitation pattern over Israel demonstrates a significant role of the local topography — the rains propagate from the southern Israel to the north along a narrow coastal plain.

The whole synoptic development appears to be a consequence of intensive non-adiabatic processes caused by an intensive propagation of warm and moist air mass to the region. According to the model simulations, intensive rains in Egypt took place mainly before 04:00 LT November 2, 1994. In the southern Israel (31.4°N, 35°E) the rains are simulated in the time interval of 07:00 LT, November 2, 1994 to 13:00 LT, November 2, 1994, while the simulated rains over central Israel (32.3°N, 35°E) are found in the 13:00 LT to 18:00 LT time interval of November 2, 1994. The rains over Egypt and the southern Israel are essentially of the convective type — the sub-grid processes contribute about 50% of the total precipitation. The percentage is much lower over central Israel. Available radar observation of the rain intensity in Negev (Fig. 2b; 17 mm h^{-1}) is quite close to the simulated value of 12 mm h^{-1}. The value of simulated maximal rain intensity over central Israel (Fig. 2d; 1–2 mm h^{-1}) is a reasonable approximation to the observed by radar rain intensity (4 mm h^{-1}). According to the model results, intensity of the simulated precipitation decreases with time — in Egypt and in southern Israel, the system produces more than 10 mm h^{-1} of rain, but in central Israel the rains are less intensive (about 1 mm h^{-1}). Qualitatively, these values are in good agreement with the observations discussed in Section 2.

The meridional cross-section made along the 34.5°E between two locations in the southern and central Israel (Fig. 6C) gives additional information for understanding the vertical structure of the process in Israel. Results of the 18-h simulation of the RH and the vertical (W)/horizontal velocities (Fig. 7A and B, respectively) are presented. The

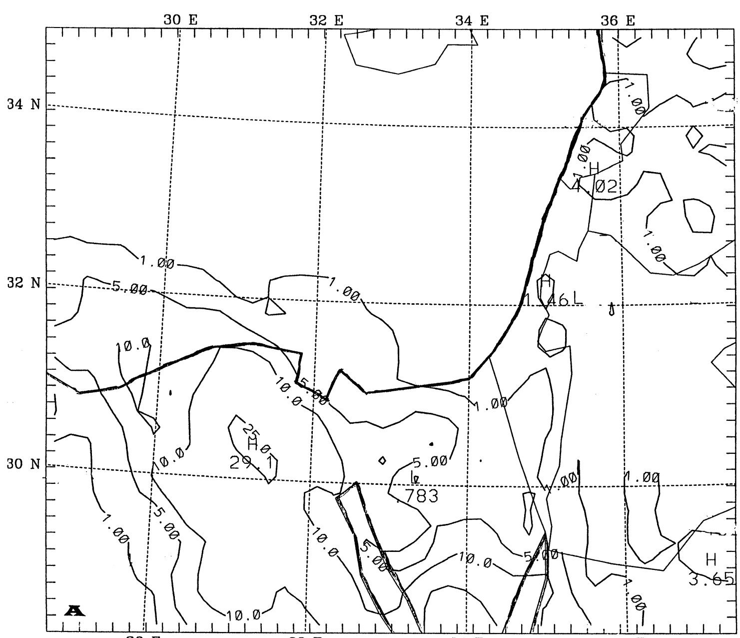

Fig. 6. Model simulated accumulated total rains (Initial data of 1200 UTC November 1, 1994) in mm day^{-1}. Pictures A, B and C are for 12-, 24- and 36-h simulations, respectively. The line between the two locations in the southern and central Israel is for the cross-section presented in Fig. 7A,B.

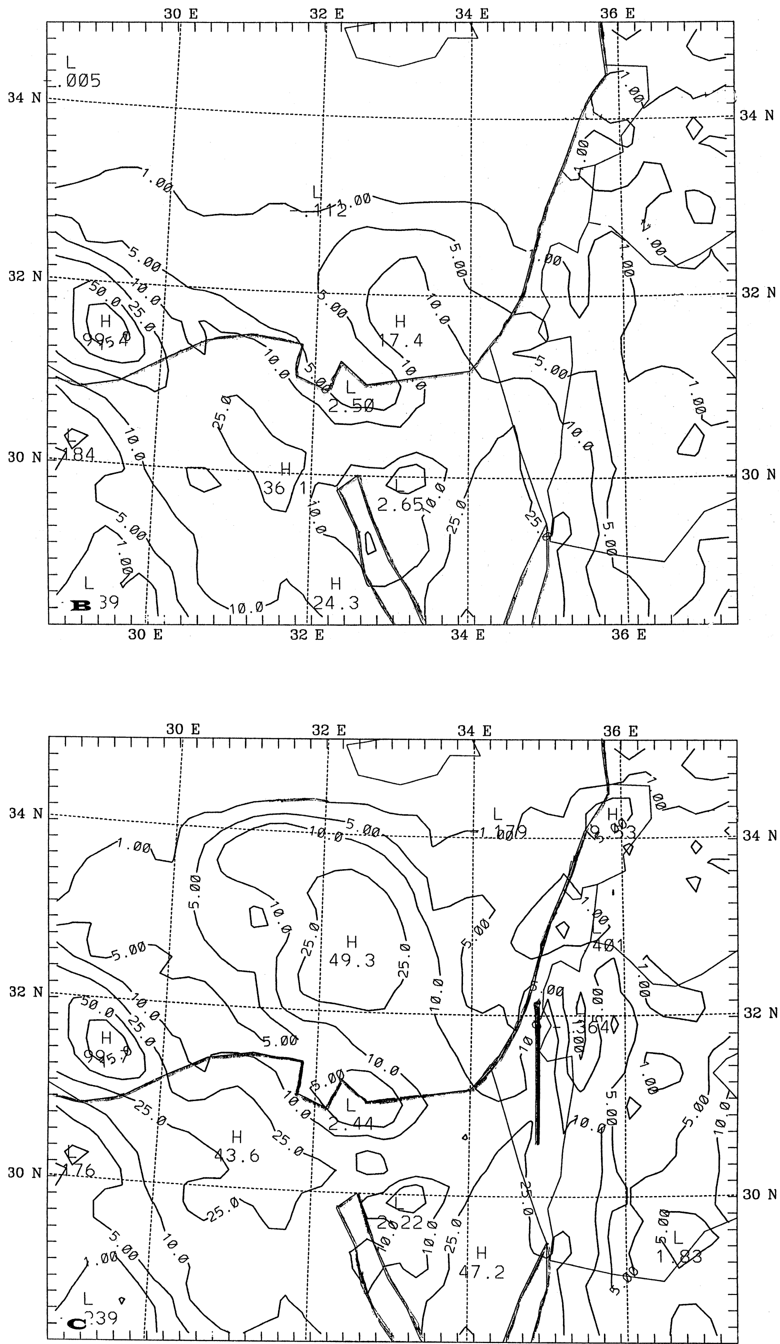

Fig. 6 (*continued*).

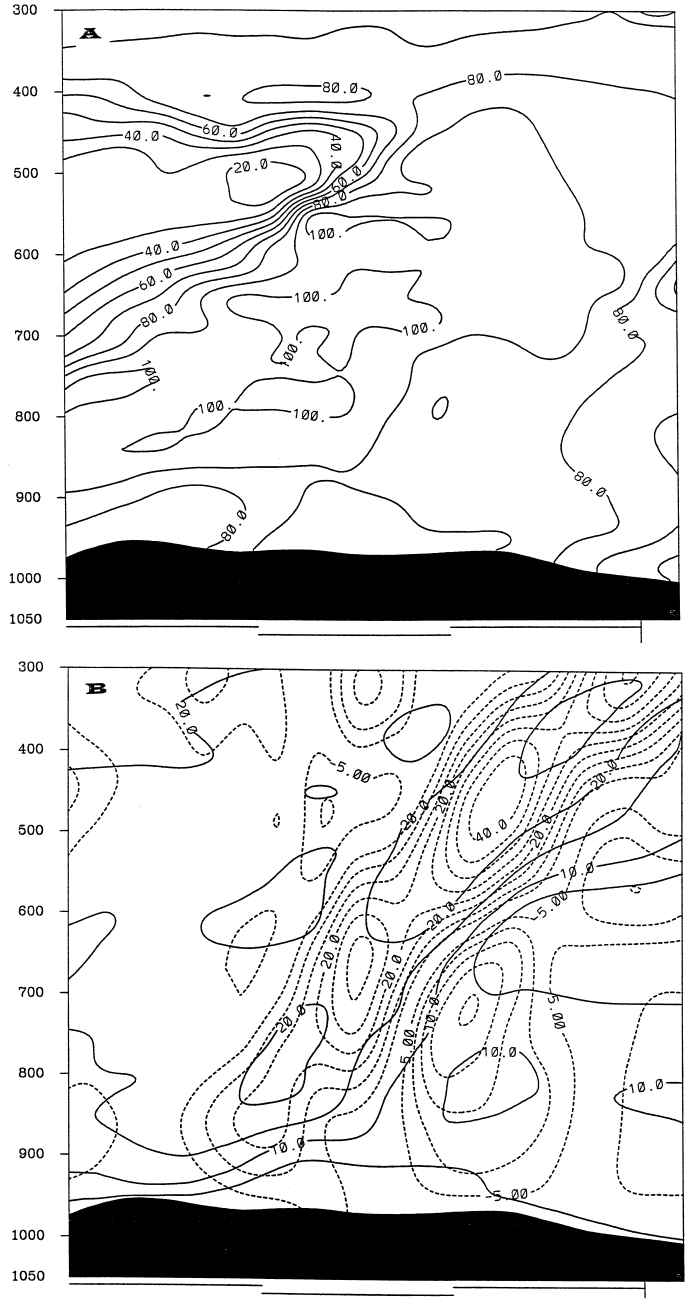

Fig. 7. Simulated S–N cross-sections along 35°E (the line of cross section is indicated in Fig. 6C) made for the results of the 24-h simulation starting from 12:00 UTC, November 1, 1994: (A) relative humidity; (B) wind (solid) and vertical (dashed) velocities.

figures illustrate the intensive pumping of the moist air masses into the upper troposphere in the process of the system propagation over Israel. According to the results, the southern areas of Israel were occupied by a deep updrafting layer of very moist air surrounded by the slightly less humid regions in the downdraft zone before the frontal system. A layer of dry air is found in the upper troposphere behind the system. The high horizontal gradients of relative humidity at such altitudes (about 6 km) illustrate the intensity of simulated process.

5. Discussion and conclusions

One of the main aims of the study was to prove the ability of the MM5 weather prediction system to describe the severe, though operationally unpredicted, mesoscale processes responsible for development of the unusually intensive southeastern Mediterranean storm of November 1–2, 1994. The use of the ECMWF objective analysis data and the FSUGSM forecasts allowed to provide the simulation with the accurate initial and boundary conditions. Specially arranged sensitivity tests allowed determination of an optimal MM5 model configuration for the simulation. Simulated values of the meteorological parameters are in good agreement with the available observations. Results of the experiments show that the most important factors for successful simulation of the storm were the accuracy in determination of the lateral boundary conditions, space resolution, terrain and especially, the representation of the moist effects.

The fact that an area with positive RV values has been produced over the eastern Mediterranean after 24 h of the simulation even in the ‘dry’ simulation run (Fig. 4a) proves that not only the local moist processes participated in the development. Some of the ‘moist’ effects evidently existed already in the initial data for the run. The lateral boundaries also experienced intensive advection of moisture. Accurate description of the moist dynamics and especially high space resolution of the model (including representation of the terrain) was necessary for the successful prediction of the storm intensity. (As was already stated, the coarser resolution operational numerical weather forecasts also describing the moist effects were unable to produce the development). Accurate determination of the lateral boundary conditions is very important, especially for accurate prediction of the timing of the processes. The zone with high vorticity values penetrated into the forecast area mainly from the south during the first hours of the simulation. The lack of accuracy in describing this effect was evidently among the causes for the unsuccessful operational predictions of the case.

At the initial stage of the storm development, the system had characteristics that may be attributed to a Mesoscale Convective System (MCS) (Maddox, 1980; Cotton, 1990). Among the characteristics are the low gradients, medium scale, specific vertical structure, importance of the role of cumulus convection and the high relative humidity values up to the upper troposphere, etc. The process started over Egypt. Results of the model simulation show that the rain intensity was especially high during this early stage of the development when the role of convection processes was dominant. The intensity of the storm has rapidly diminished with time during the second stage, when the system was converting to a relatively large scale mid-latitude atmospheric vortex. The role of convective processes in the system also decreased with time. During the first, most active, stage of the system development in Egypt, the sub-grid effects were responsible for 50% of the rain intensity. The system rapidly loosened up its convective character as it transformed into the eastern Mediterranean system. Similar processes were earlier observed in the eastern Mediterranean by Shay-El and Alpert (1991) and Alpert and Neeman (1992). The fact that the model results predict the observed decrease of amount of precipitation supports the suggestion on the role of the transformation of the MCS into the eastern Mediterranean cyclone in this process.

According to the earlier studies by Krichak et al. (1997a,b), Dayan and Sharon (1980), Itzikson (1995) and Saaroni at al. (1998), the area over the Red Sea quite often plays the role of a corridor for transporting the air masses from the Arabian Sea and tropical Africa into the Mediterranean region. Global model investigation of the November 1–5, 1994 Mediterranean weather has been performed recently by Krichak and Alpert (1998). It is shown there that the November 1–5, 1994 Mediterranean weather conditions were seriously affected by the tropical area–mid-latitude interaction. Intensive rains took place not only in the eastern Mediterranean but also in Italy and southern France. Large quantities of warm and moist air penetrated to the area from the both Atlantic and Indian oceans. Anomalies of the SST in the Mediterranean Sea in October 1994 could be one of the factors for the intensification of the tropical area–mid-latitude interaction processes in the region during the October–beginning of November 1994 period. Analysis of role of this factor has not been performed due to evident limitations of the adapted short-range approach.

The following scenario of the process may be suggested. The warm and moist air masses that arrived into the eastern Mediterranean region on November 1, 1994 have originated from the Arabian sea area (Krichak et al., 1997; Krichak and Alpert, 1998). Intensive convective processes in the tropics created the situation that was characterized by large relative humidity values in the upper troposphere. These conditions were appropriate for formation of an unusually intensive warm core MCS. Similar cases were already registered in the Mediterranean area (Reiter, 1975; Ernst and Matson, 1983). The process of transformation of the system into mesoscale frontal type phenomena took place over Egypt and Israel. Over Israel, the system already had the character of a relatively large-scale trough with a frontal system which was characterized by rapidly developing cyclonic vortices in the eastern Mediterranean. High horizontal gradients of moisture played a role of one of important factors for intensification of the frontal activity. Two factors responsible for the low skill of the operational predictions of the processes may be suggested. First, the area (Africa and the southeastern Mediterranean region) of the unusually intensive developments is poorly covered by the operationally available observational data and the necessary information on the land use conditions. The second factor is the insufficient spatial resolution of the operational models used for weather prediction in this region. Especially crucial is the lack of accuracy in determination of the lateral boundary conditions. It is possible that the large quantities of dust in the air also stimulated the development. This parameter is not included into consideration in the existing atmospheric models. No special analysis of the role of this factor in the process has been performed up to now.

Acknowledgements

This work has been supported by the Bi-national US–Israel Foundation (BSF) Grant No. 92-00275 and the Israeli Ministry of Science Grants No. 9620-1-95 and No. 9470-1-97. Synoptic analysis of the situation has been performed with participation of B. Ziv of the Open University, Tel Aviv. The radar patterns are from Mekorot, Israel. We thank the Israel Meteorological Service for the meteorological data provided for our study. ECMWF analyses for 1200 UTC November 1, 1994, are used in the simulations. Initial processing of the data has been performed at the FSU as a part of the aforementioned BSF project. The presented MM5 simulations were performed on Cray J932 computer of the Inter University Computer Center, Israel. Additional simulation runs were performed by S. Krichak and M. Tsidulko on the Origin 2000 computer at the CINECA Computer Center, Bologna, Italy during their work on Icarus project in June–August 1998. The Icarus program is supported by the European Community. The referenced in the text SST pictures were obtained from the Integrated Global Ocean Service System (IGOSS) Internet site: http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS/).

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