JKAU: Met., Env. & Arid Land Agric. Sci., **Vol. 20,** No. 2, pp: 95-109 (2009 A.D. / 1430 A.H.)

Numerical Simulation of a Severe Cold and Rainy Event over the East Mediterranean

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Abstract. The separation factor method is a simple approach used with the numerical model simulations to isolate the main effect of some prescribed factors affecting the formation and development of an event in the atmosphere. It is also used to isolate the effects of two or more interacting factors. In this study the effect of an increase of the sea surface temperature and a decrease of upper wind on the formation and development of an east Mediterranean cyclone is studied. The results indicate that the upper wind is the dominant factor compared to the sea surface temperature in the cyclogenesis.

Introduction

The Mediterranean region is considered to be one of the most cyclogenetic areas in the world, usually favoring the development of weak low-pressure systems. Occasionally these systems develop into deep cyclogenesis that cause a series of severe weather events as they cross the Mediterranean.

Kahana, *et al*. (2004) found that Mediterranean Sea cyclones deepen in general, in association with upper-level troughs. Upper level troughs are regarded as the key factors in activity of mid-latitude, such as the Mediterranean Sea system, particularly in their front sides, where positive vorticity advection and enhanced convection take place (Holton, 1992). Ferraris, *et al*. (2002), however, found that the polar continental air from central Asia moving toward the eastern Mediterranean, and interacting with the relatively warm Sea Surface Temperature (SST), produces enhanced lower-level instability.

Because of the importance of the Mediterranean cyclogenesis, many studies on weather systems in the region have been conducted. The dynamical cause of the Mediterranean cyclogenesis has been studied from observational (Buzzi and Tibaldi, 1978), theoretical (Speranza, *et al*., 1985; Buzzi and Speranza, 1986) and modeling perspectives (Tibaldi, *et al*., 1980; Tibaldi and Buzzi, 1983; Tosi, *et al*., 1983 and Buzzi, *et al*., 1994). Classification of Mediterranean cyclones has been made by Alpert, *et al.* (1990) and by Alpert and Neeman (1992). Furthermore, the roles of air-sea fluxes and latent heat release from the Mediterranean in amplifying the cyclone growth have been evaluated by several authors. In general, the role of air-sea fluxes is considered to be marginal or even negligible relative to the role played by baroclinic instability (Buzzi and Tibaldi, 1978). Also, Alpert, *et al*. (1996) investigated the roles of convection, sensible heat and heat fluxes in Alpine cyclogenesis. By splitting their contributions, they found that topographical blocking is the dominant factor, followed by convection then local moisture flux. While Abdel Basset and Awad (2001) investigated, beside the convection, the effect of the mountains. They found that the mountain is the dominant factor in the first stage of the lee cyclone, while the interaction of the mountain and convection dominates in the cyclone deepening.

The purpose of this paper is to analyze the development of a rainy Mediterranean cyclone event that originated in the eastern part of the basin Asian minor and caused a cold outbreak event in Egypt in January 2002, where the maximum temperature in Cairo station on January 10th, 2002 was 12ºC and the minimum 6ºC. The January climatologies corresponding to the maximum and minimum temperatures in Cairo were respectively 19 and 8.8ºC. Also, in Alexandria, on the Mediterranean coast, the maximum and minimum temperatures were respectively 14 and 7ºC compared to the associated climatological values of 18.5 and 9.1ºC. If we go far south to Aswan, the maximum and minimum temperatures were 16 and 6ºC, respectively, compared to the associated climatologies of 22.5 and 8.1ºC.

In this study, the Factor Separation method is applied to a model simulation to investigate the relative effects of SST and upper wind, as well, as their mutual interaction during the stage of cyclone development. The experiment is not an attempt to simulate the real cyclone, but is rather to assess the potential effect of some factors in supporting the formation and development of the cyclone.

Model and Data

The model used in the present study is the NCEP/ETA Hydrostatic model version (Janjic, *et al.*, 2001), with 32 sigma vertical levels and $0.33^o \times 0.33^o$ latitude-longitude horizontal resolution.

The meteorological data used in this case study are taken from the NCEP operational global weather forecast run. The boundary conditions are updated every 6h and the hourly output saved for a period of 72h forecast.

Synoptic Studies of Control Run

We can analyze the synoptic situation of the case study by following the development of the sub-tropical jet stream at upper troposphere step by step.

The case started with the existence of sub-tropical jet stream as one zonal branch with maximum speed between 150 to 160 knots (Fig. 1a), with the southern extension of the polar jet to the east of the Mediterranean.

Figure 1 shows the wind speed of the sub-tropical branch of the jet stream at 200hPa for 4 consecutive days from January 8^{th} to 11 January 11^{th}, 2002.

The case started with the existence of a sub-tropical jet stream as one zonal branch with maximum speed between 150 to 160 knots (Fig. 1a), with the southern extension of the polar jet to the east of the Mediterranean. In the next 24 hours the sub-tropical jet has weakened, shifted to the south, and divided into two branches a south-westerly branch to the east and a north westerly branch to the west (Fig. 1c).

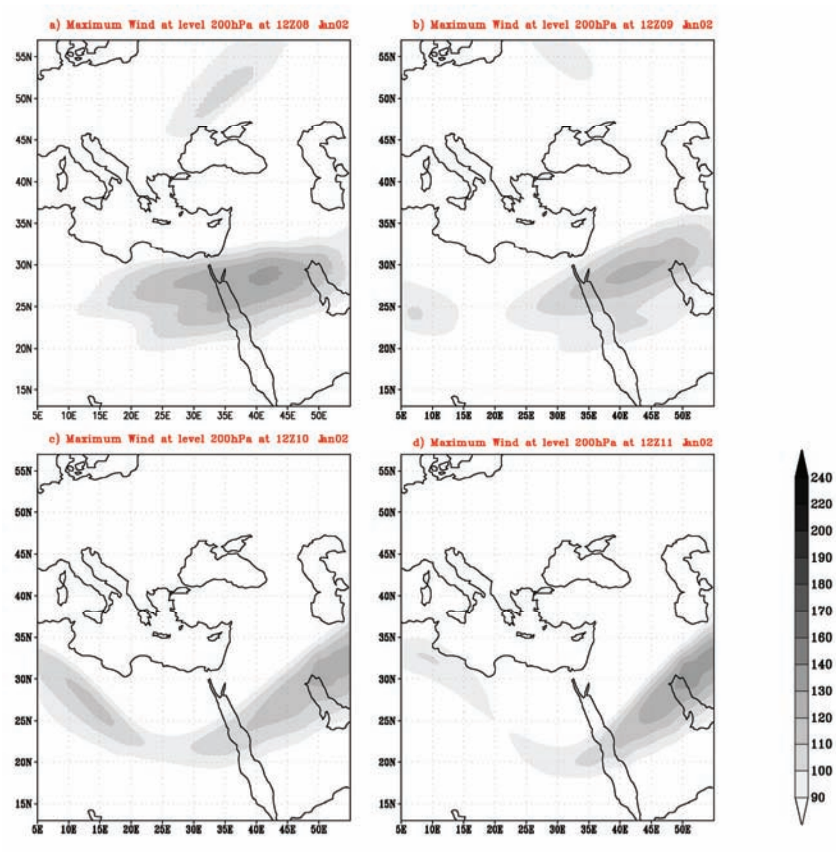

Fig. 1. Maximum wind at 200hPa level, every 24h from 12GMT Jan. 8th, to 12GMT Jan. 11th, 2002.

The east branch of the jet was stronger than the east branch. The polar jet, however, does not appear to have significantly affected the area when the sub-tropical jet shifted south.

The synoptic situation can also be analyzed by referring to the mid-troposphere. Figure 2 shows the geo-potential height, temperature and wind field at 500hPa level for the same days of Fig. 1. The synoptic system at 500hPa level also follows the sub-tropical jet development. The axis of the trough line of the low-pressure located over east Europe (Fig. 2a) shifts south-east and the trough intensifies and extends south-west (Fig. 2b&c).

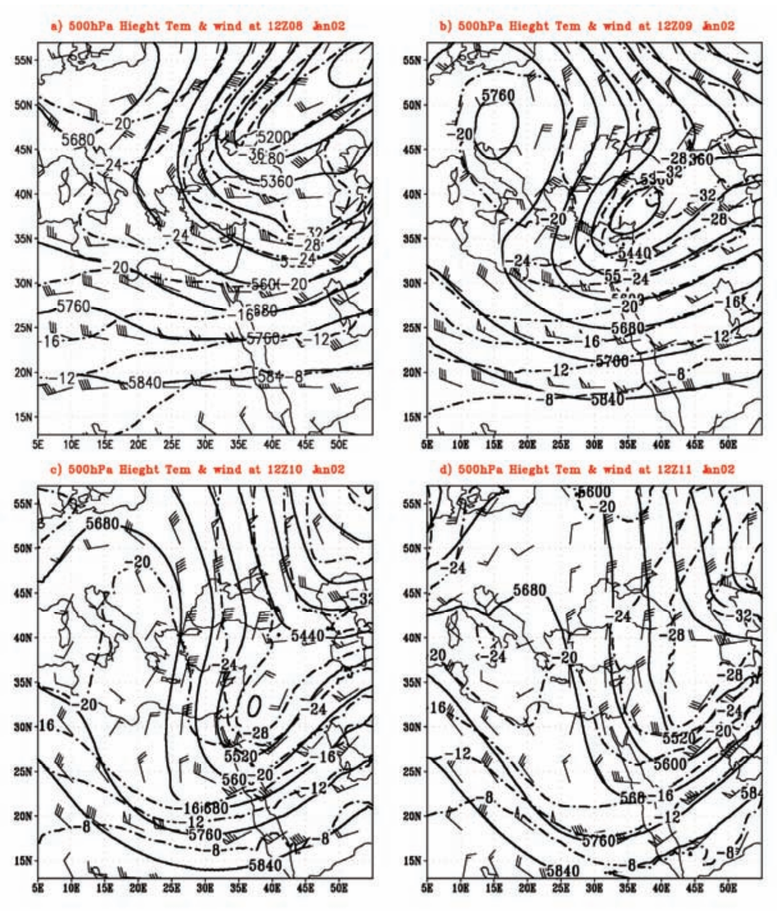

Fig. 2. Geopotential height (solid line) and temperature (dashed line) and wind (barber) at 500hPa level, every 24h from 12GMT Jan. 8th to 12GMT Jan. 11th, 2002.

This trough line orientation indicates that the affected area has extended and engulfed the whole east Mediterranean area. This development agrees with Krichak, *et al*. (1997a,b) and Krichak and Alpert (1998) in that the meridinal orientation of the upper trough line represents the major synoptic process of the development of the East Mediterranean cyclone.

At 850hPa level, the development of the synoptic situation is related to the shrinking of the high pressure system located over the western part of the domain (Fig. 3). As the subtropical jet stream shifts south and splits (Fig. 1) the high system moves west ward (follow, for example, the contour line 1520gmp contour), and allows the development of a low system in the east Mediterranean, as shown in Fig. 3a&b.

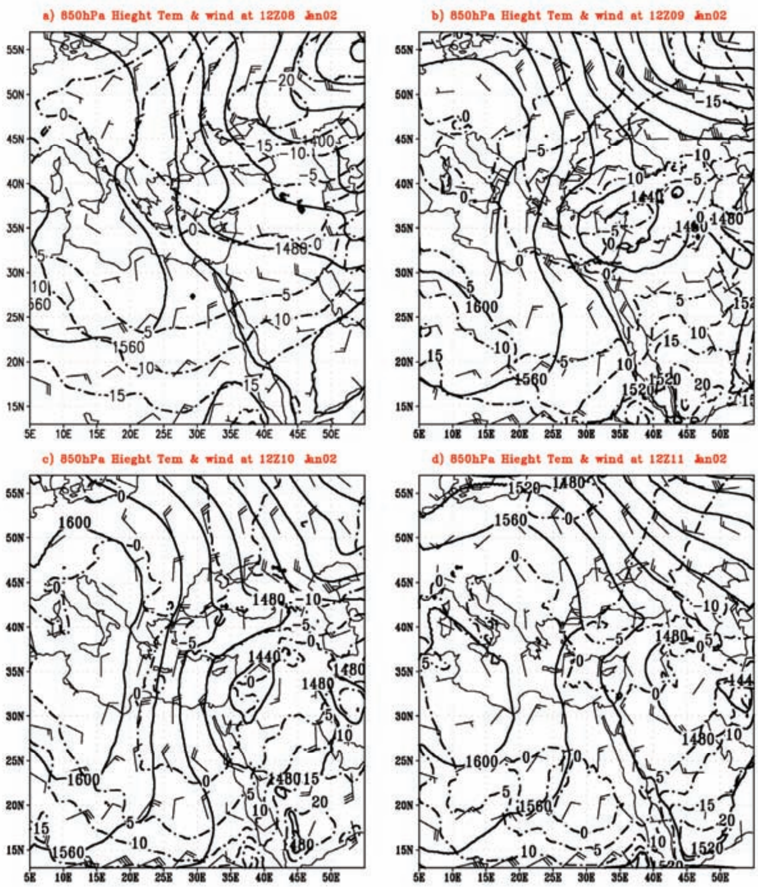

Fig. 3. **Geopotential height (solid line) and temperature (dashed line) and wind (barber) at 850hPa level, every 24h from 12GMT Jan. 8th to 12GMT Jan. 11th, 2002.**

From Fig. 3, we can also follow the temperature advection. Note, for example, the southward warm advection in the eastern part of the domain corresponding to the east branch of the sub-tropical jet, (follow, for example, the 5ºC isotherm), and the eastward cold advection in the north eastern part of the domain, associated with the west branch (follow, for example, –5ºC isothermal). These are consistent with the results of Charney (1947), Holton (1992a,b) and Bluestein (1992), where the growth of mid-latitude cyclone is associated with a meridional gradient of temperature. We can expect that, the cold advection on the west of the cyclone is responsible for the decreasing of temperature over Egypt in that period.

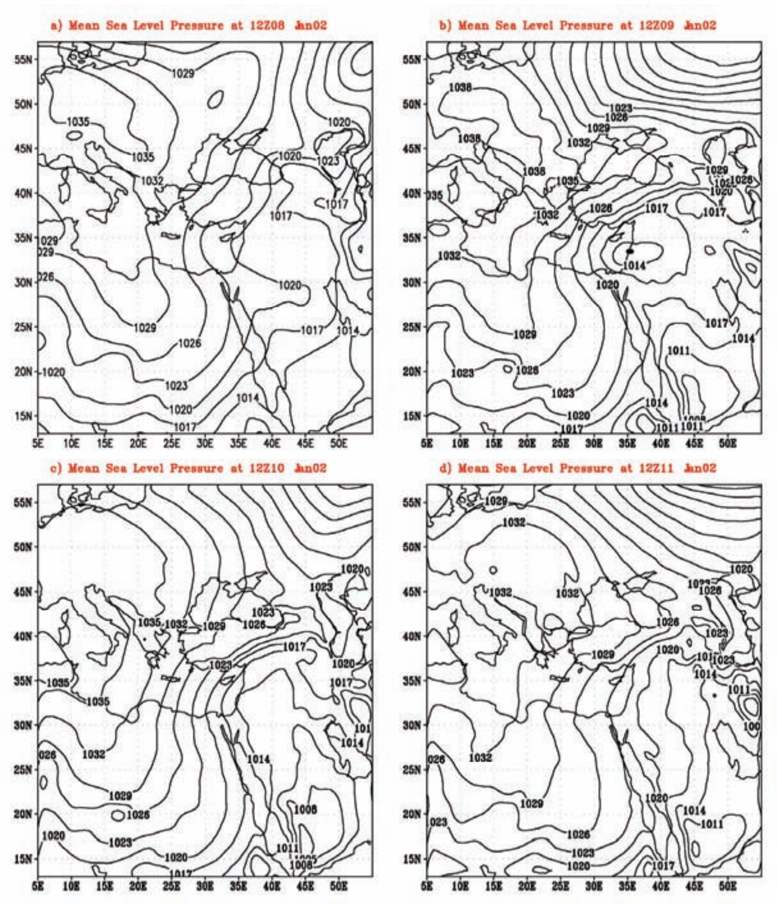

Fig. 4. Mean sea level pressure, every 24h from 12GMT Jan. 8th to 12GMT Jan. 11th, 2002.

The mean sea level pressure (MSLP) of the case study is shown in Fig. 4 and follows the system development at the 850hPa level as shown by the heat advection (Fig. 3).

The intensification of Azores high, to the west of the region, produces a favorable condition for the low system to develop in the east Mediterranean region (Fig. 4b). In addition, this produces a larger air mass temperature difference between the east and west of the low trough line, and allows the Red Sea trough to extend northward. The Red Sea trough extension and the meridional orientation of the upper trough permit favorable conditions for the formation and development of the east Mediterranean cyclone, as shown in Fig. 2, 3 and 4.

Figure 5 shows the total precipitation associated with the east Mediterranean storm. The rain fall amount increases as the Azores high shifts westward and the low pressure system deepens, particularly in day January 10th (Fig. 5b) when the precipitation area has extended eastward following the surface low.

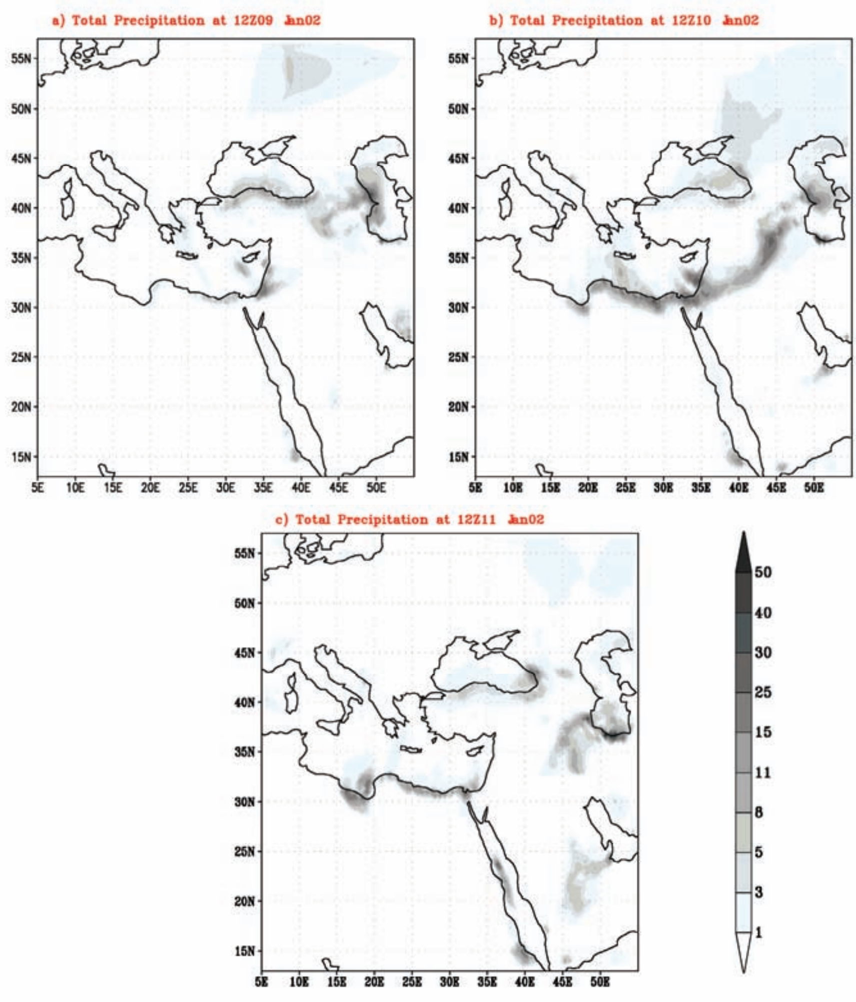

Fig. 5. Total precipitation every 24h in mm/6h from 12GMT Jan. 9th to 12GMT Jan. 11th, 2002.

Factor Separation on the East Mediterranean Sea Cyclogenesis

The factor separation (FS) method allows us to quantify not only the contributions of individual factors in the cyclone development, but also of their mutual synergies. It is particularly useful if interactions among investigated factors are expected. The method is fully described in Stein and Alpert (1993), and has been used in many studies (*e.g*. Alpert, *et al*., 1996; Romero, *et al*., 1997 & Abdel Basset and Awad, 2001).

In this study, two factors were used in the analysis of the Mediterranean cyclone: A 3ºC increase in Mediterranean SST and a 0.1(m/s) and 0.15(m/s) decrease in atmospheric wind speed at levels below and above 500hPa, respectively. While the first factor influences the cyclone formation and deepening in the east Mediterranean Sea through sensible heat increase at lower layers, the second one acts to decrease the effect of the jet stream.

The forecast model is then run by incorporating the previous factors. These runs are then compared to a control run without factors changes. We discuss next the effect of the separation factors by looking at two variables:

First considered are the changes in sea level pressure at the dark point located at 35ºE and 33ºN, as shown in Fig. 4b. This location had the largest SLP change. The evaluation of SLP at this location for the four experiments is shown in Fig. 6 for the next 72 hours starting 12GMT 8Jan. 8th, 2002.

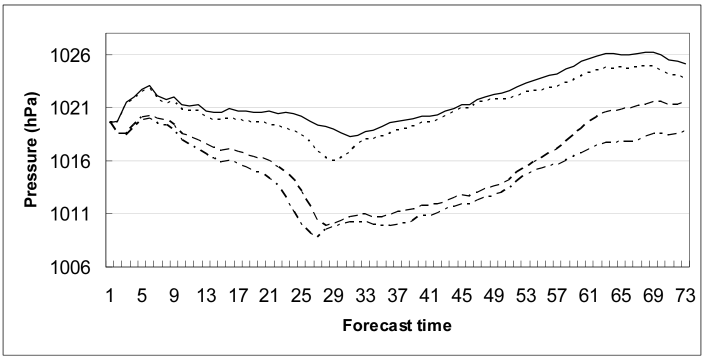

Fig. 6. MSLP forecast time in hours at point 33^{o}N and 35^{o}E, for the four experiments.

The dashed curve represents the control run (CT-run), the dashed-dotted curve corresponds to the SST change run (SE-run), the solid curve represents the wind change run (JE-run), and the dotted curve corresponds to the run with SST and wind changes (SJ-run). From Fig. 6, it is clear that the SE-run shows a pressure decrease through the forecast time larger than the pressure decrease of the control run. This is consistent with the results of Genovés and Jansà (2002) who showed that latent heat release linked with increasing surface heat fluxes play a crucial role in the evolution of the 2001 low over the Mediterranean Sea. The other runs show less deepening on pressure when wind speed in the jet stream has changed, or when both wind speed and SST have changed. In these cases, the cut-off low in the east Mediterranean was either absent or very weak.

Next, we consider the effect on precipitation resulting from the separation factors. Figure 7 shows the difference in precipitation between the control run and the SE-run. There is a clear increase in precipitation in the first two days of forecast (Fig. 7a&b) when the low was located near the east Mediterranean Sea and a decrease in the third forecast day when the low pressure center has left the east Mediterranean Sea (Fig. 7c).

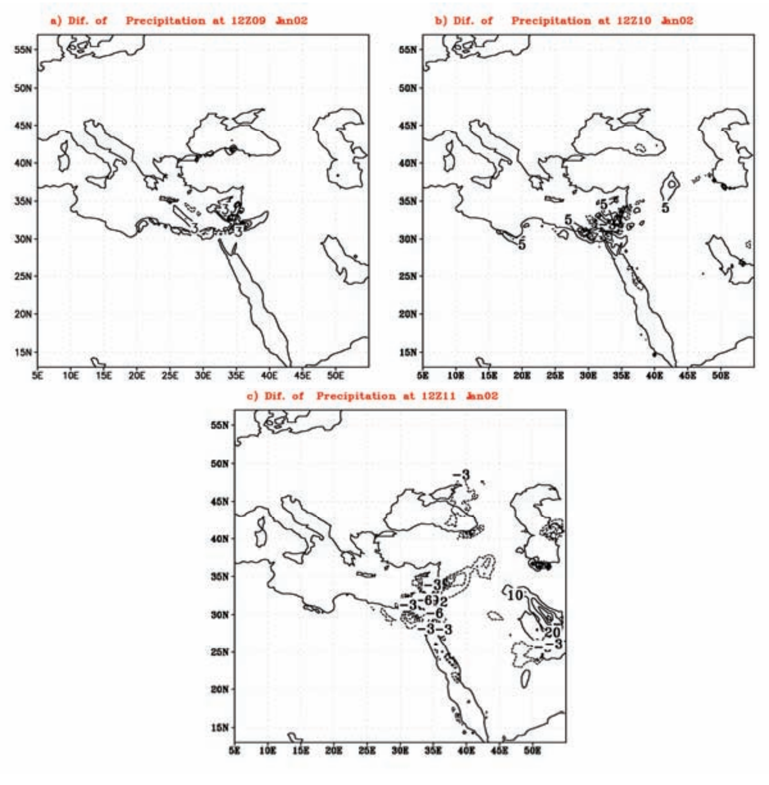

Fig. 7. Amount of precipitation contributed by SE-run.

Figure 8 shows precipitation changes due to wind speed decrease. The amount of precipitation from the JE-run is always less than that from the CT-run, and this is consistent with the weak deepening of the cyclone in this run.

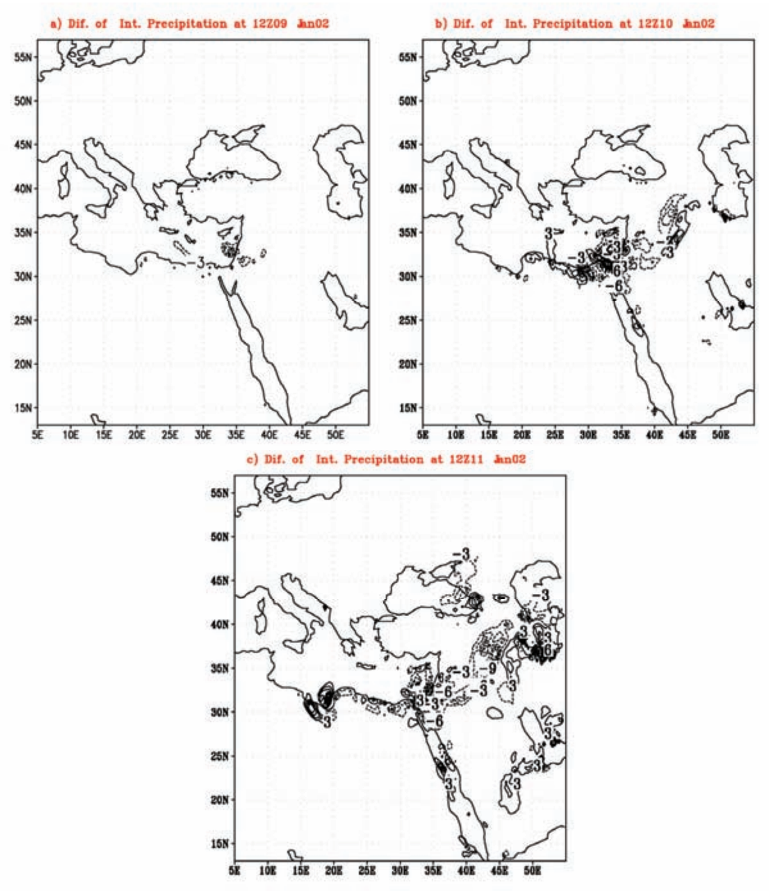

Fig. 8. Amount of precipitation contributed by JE-run.

To separate the combined effects of both factors from their individual effects, we calculated the amount of precipitation resulting from the mutual SST-wind synergies. Figure 9 shows the precipitation change for the SST-run. It clearly shows a negative precipitation change over most of the domain in agreement with SLP forecast shown in Fig. 6 (dotted line).

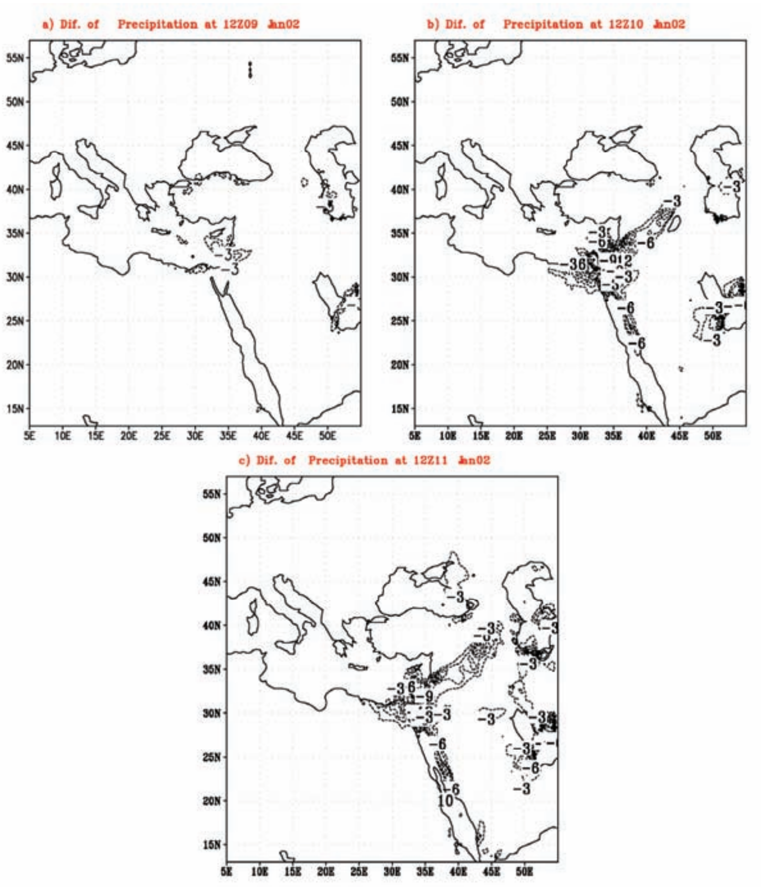

Fig. 9. Amount of precipitation contributed by SJ-run.

Conclusion

This work investigates the relative importance of various mechanisms in the formation and development of an east Mediterranean cyclone on January 10th, 2002. The study is based on the analysis of the synoptic situation, and the use of the separation factors method.

The analysis is based on the NCEP operational weather forecast system and the NCEP/ETA hydrostatic model. The results show that the meridional orientation of the upper trough and the northward extension of the Red Sea trough play an important role in the formation and development of the cyclone.

The separation factors method indicates that the sub-tropical jet stream intensity is the dominant factor in the development of the cyclone and the precipitation amount. The SST, however, is found to be the second dominant factor affecting the development of the cyclone and the amount of precipitation. An increase of SST and upper jet will of course provide favorable conditions for the development of the east Mediterranean cyclone.

A weakening of the upper winds produces a negative effect on the formation of the cyclone over east Mediterranean and an increase in SST strengthens the cyclone development.

The interaction of the two factors is a mechanism that could not be isolated except for the separation factors on model simulation. The experiment declares that the mechanism of interaction between SST and the upper wind factors produces a negative contribution on precipitation and development of the cyclone.

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تمثيل عددي لحالة ممطرة وشديدة البرودة على شرق البحر المتوسط

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جدة – المملكة العربية السعودية

المستخلص. طريقة فصل العوامل وسيلة بسيطة تستخدم في عمليات التمثيل العددي لفصل تأثير العوامل المختلفة، والتأثير المشترك بين هذه العوامل على تكوين وتطوير الظاهرة في الغلاف الجوى. ندرس في هذه الحالة تأثير ارتفاع درجة حرارة سطح البحر، وضعف رياح الطبقات العليا على تكون وتطور منخفض ممطر، ومسبب لانخفاض واضح في درجة الحرارة شرق البحر المتوسط. وقد أظهرت النتائج أن الرياح في الطبقات العليا تلعب الدور الأساسي الأول في تكون وتطور المنخفض، بينما يلعب ارتفاع درجة حرارة سطح البحر الدور الأساسي الثاني لهذا المنخفض.