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THE EFFECT OF SOIL MOISTURE AND VEGETATION COVER ON ENERGY CONVERSIONS

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Abstract: The effect of changes in vegetation cover and initial soil moisture over Egypt have been examined through studying the energetics of a severe desert depression affecting the weather of Egypt during the period 14 to 17 March 1997 and caused numerous sand storms. Although its life cycle lasted about 4 days, its rapid development was associated with severe weather conditions over the southern Mediterranean coast. The energy contents and their changes in different atmospheric levels are discussed in the course of the cyclone's development. By integrating over the entire volume of the computational area, the complete energy cycle of the cyclone is obtained and discussed throughout the comparison between the results of energy and energy conversions in case of Normal Run (NR) and Wet Run (WR).

INTRODUCTION

The land surface represents an important boundary within the coupled system soil-atmosphere. This interactive boundary affects the dynamics and thermodynamics of the atmosphere through local exchange of heat, water and momentum. The energy and the water budgets at the land surface are closely related through latent heat exchange associated with evapotranspiration (evaporation and transpiration by vegetation) and precipitation. Vegetation is a continuously changing component of the earth’s system, and represents a key quantity that determines both surface properties and soil moisture availability. External factors impact on vegetation distribution and its physiological characteristics, but on the other hand vegetation may feedback on the climate system, through exchanges of heat, water and momentum across the soil-atmosphere interface, leading to complex land-atmosphere interactions.

The influence of land surface processes on the weather or short-term climate change has been analysed and discussed by Namias (1962, 1963), also more recent investigations have indicated that large changes of surface hydrologic conditions can lead to rather extensive variations of the hydrologic cycle. For example, Manabe (1975) Walker and Rowntree (1977), Kurbatkin *et al* (1979), Shukla and Mintz (1982), Rind (1982) and Rowntree and Bolton (1983) investigated this problem using different versions of models. Most of the works in energy diagnosis at the mid-latitude system were conducted in terms of case studies of individual cyclones. A partial list of significant contributions may include works by Fuelberg and Jedlovec (1982), Yousef (1998), Abdel Wahab and Abdel Basset (2000). It has been long recognized that the eddy disturbance assume a dominant role in the transfer and transformation of energy in the middle latitude. (e.g Wiin-Nielsen 1968; Michaelides 1992; Michaelides *et al.* 1996; H. Abdel Basset 2001).

In this research, aspects of land-atmosphere interaction have been investigated by a series of numerical experiments. The effect of changes in vegetation cover and initial soil moisture over Egypt have been examined through the studying the energetics of a severe desert depression affecting the weather of Egypt during its life cycle. The partition of available potential energy and kinetic energy into zonal and eddy component is adopted. The energy contents and their changes in different atmospheric levels are discussed in the course of the cyclone's development. Also a comparison between the results in case of wet and dry cases was provided.

ENERGY CONVERSIONS

A convenient and compact way of presenting energy calculations was suggested by Lorenz (1955, 1967). The potential energy, which is available to be converted into kinetic energy of motion, can be partitioned into, the energy in the zonal averaged state **AZ**, and energy in non-asymmetric flow **AE**. The kinetic energy can be treated similarly. **CA** is the conversion from zonal to eddy available potential energy, **CE** the conversion from eddy available potential to eddy kinetic energy, **CK** the conversion from zonal to eddy kinetic energy and **CZ** the conversion from zonal kinetic energy to zonal available potential. **GZ** and **GE** represent generation of zonal and eddy available potential energy, respectively. **DZ** and **DE** denote the dissipation of zonal and eddy kinetic energy. These budget equations are the result of a mathematical manipulation of the fundamental physical laws of dynamic meteorology in an open atmospheric system. In an open area of the atmosphere the energy budget is complicated by non-zero boundary transports of energy. To take account of these Muench (1965) investigated four new components of the energy budget representing the transport of AZ, AE, KZ and KE (BAZ, BAE, BKZ, BKE, respectively). In addition, Muench (1965) considers the appearance of KZ and KE within the volume of the limited region associated with the work produced at its boundaries (BϕZ and BϕE, respectively). The last term in both the KZ and KE equations, namely DZ and DE, denote the dissipation of KZ and KE, respectively. The energy cycle used in this research is shown in Fig. 1.

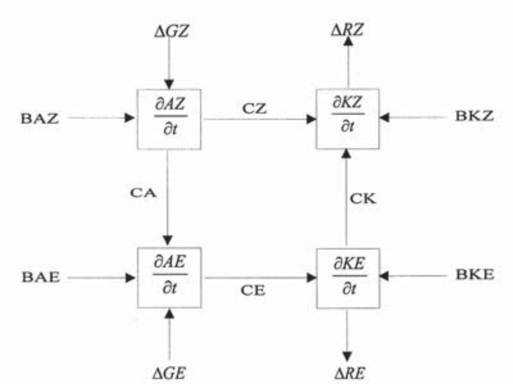


Fig. 1. The energy cycle.

DATA AND SENSITIVITY

The model used in our study is the regional model system Egeta (Egypt- Eta) which had been developed at Cairo Centre for Numerical Weather Prediction. Aspects of land-atmosphere interaction have been investigated by a series of numerical experiments.

The effect of changes in vegetation cover and initial soil moisture over Egypt have been examined through the studying of the energetics of a severe desert depression affecting the weather of Egypt during its life cycle. The input data cover the area from 30ºW to 60ºE and from 5ºN to 65ºN. Normal integration (NR) for the present study, that represent the life cycle of our desert depression was compared against the corresponding experiment Wet Run (WR) for the same time period with modified vegetation cover and initial soil moisture in the two belts in Egypt. The first belt is from 28°N to 31°N and from 26°E to 35°E (northern belt) and the other is from 22°N to 25°N and from 26°E to 32°E (southern belt). For both experiments the initial data and the updating of the lateral boundary condition were taken from National Centre for Environmental Prediction (NCEP) Global output model with 1.25 x 1.25 Lat. x Lon. and it is available at every 12 hour. So that, both experiments are characterised by a similar synoptic-scale development but different conditions at the land surface.

The second experiment, wet run (WR) prescribes over the two regions (north and south area of Egypt) where the soil moisture was initially set to be maximum in the northern area, which is equal 0.648 volumetric unit, while in southern belt, the initial value of soil moisture was set 0.434 volumetric unit which represent 67% from maximum value. Also for the vegetation cover, the north area is set with land cover by short cultivation (grass) with albedo is 0.19 and the root is 0.08m, while over the south area it covered by long trees with albedo 0.13 and the root is about 1.09m and the plant shading factor is 0.85 over the two areas. Fig. 2. shows the integration domain for the model and the areas of changes in soil moisture and vegetation cover.

Because the model utilizes ETA (η) coordinates, all variables from forecast history tapes were interpolated to pressure surfaces so that the energy contents could be evaluated in pressure coordinates. The output products are carried out on 32 η levels in the model. Horizontal and vertical wind components (u, v and ω, temperature (T), relative humidity (R.H) and geopotential heights (Z), were interpolated to the pressure surfaces 1000, 850, 700, 500, 400, 300, 250, 200, 150 and 100 hPa on regular latitude-longitude grid resolution of 0.5^{o} x 0.75^{o}. The result data are also available at 0000, 0600, 1200 and 1800 UTC during the period 14 to 17 March 1998. The domain of the present study is extended from 20^{o} to 45^{o}N and from 10^{o} to 45^{o} E.

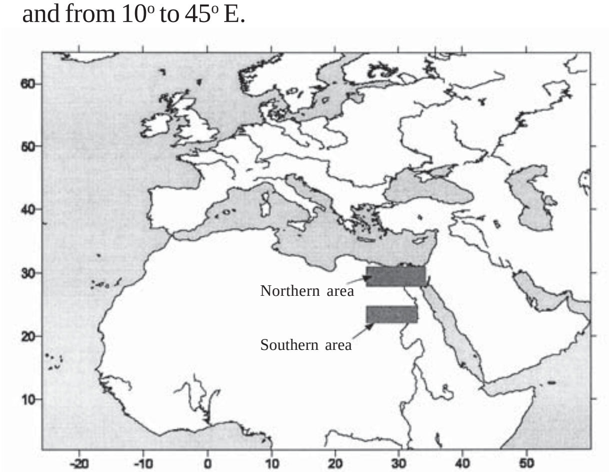
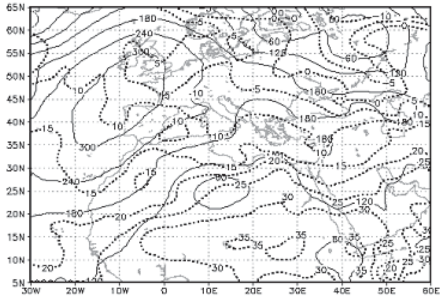


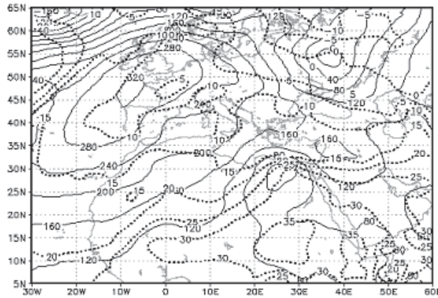
Fig. 2. The integration domain of the model and areas of change

Northern area - vegetation cover is grass (albedo is 0.19) and soil moisture content is 0.468

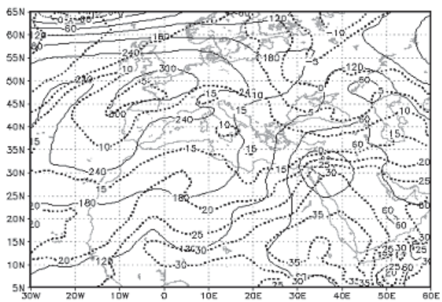
Southern area - vegetation cover is long trees (albedo is 0.13) and soil moisture content is 0.434



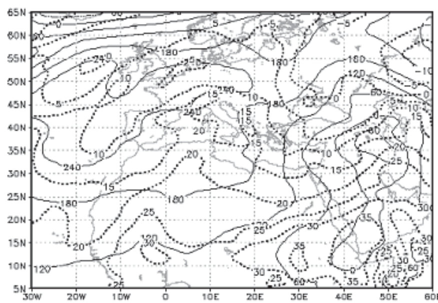
a) 13 March 1998 1000 hPa



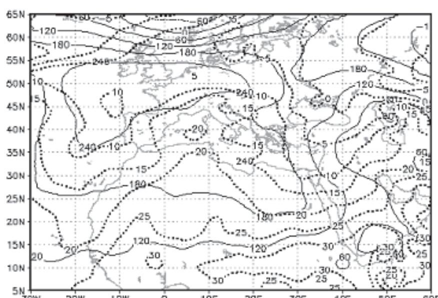
b) 14 March 1998 1000 hPa



c) 15 March 1998 1000 hPa



d) 16 March 1998 1000 hPa

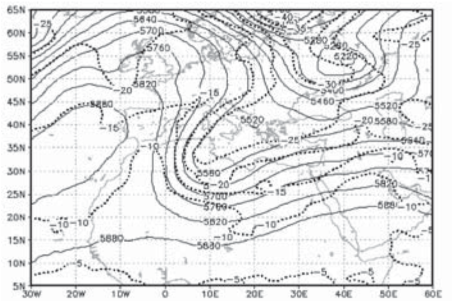


e) 17 March 1998 1000 hPa

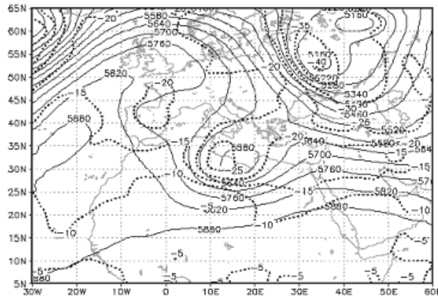
Fig. 3: 1000 hPa height contours in 20 m intervals (solid) and temperature (dotted) in 5°C increments for 1200 UTC 13- 17 March 1998.

SYNOPTIC DISCUSSION

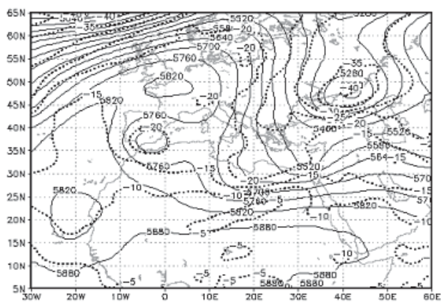
The main synoptic feature at 1200 UTC 13 March 1998 consisted of an anticyclone centred over west Europe extending to northwest as an upper level ridge, and a cyclone over northern Europe appearing as a trough in the upper levels (Fig.3a). An inverted weak trough was located on the northern west coast of Africa associated with a thermal ridge which is part of the dominant baroclinic zone extending parallel to the southern Mediterranean coast. During the next 24 hours, short wave in the mid and lower troposphere developed. Meanwhile, this short wave trough is moved eastward towards Egypt and by 14 March 1998, a closed cyclone developed (Fig. 3b). Differential heating across the baroclinic zone appears to have reinforced the southerly flow.



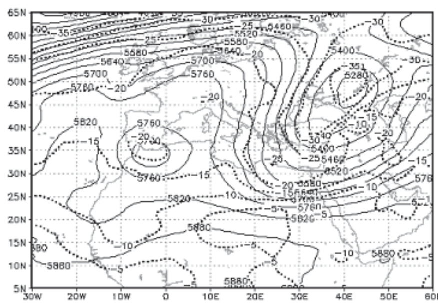
a) 13 March 1998 500 hPa



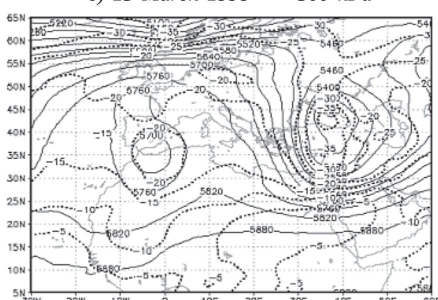
b) 14 March 1998 500 hPa



c) 15 March 1998 500 hPa



d) 16 March 1998 500 hPa



e) 17 March 1998 500 hPa

Fig. 4: 500 hPa height contours in 60 m intervals (solid) and temperature (dotted) in 5°C increments for 1200 UTC 13- 17 March 1998.

The net result is that the boundary layer air is warmed and dried, while an anticyclone developed behind the depression over the Mediterranean accompanied with cold advection. Tracing the synoptic situation associated with this phenomenon (Figs. 3 and 4), we see that as soon as the cyclone moved eastward and affected the Northern coast of Africa on the 14th of March at 1200 UTC, it elongated southward and westward. The cyclone moved with a speed more than 60 km/hr over the coast producing a storm over north Sahara reaching northeast of Egypt by 15 March (Fig. 3c). Although the centre of the cyclone was over the Mediterranean to the north of Egypt, during the next day (16 March), a moderate sandstorm continued with a gradual decrease in its activity. Fig. 3b also show that the temperature field was nearly zonal on 14 March at 1200 UTC and that one can clearly see a front over the Sahara.

The disturbance developed during the next 12 hrs with a marked surface front. The cold trough at 1000 and 850 hPa intensified and extended towards the west. Simultaneously, the temperature gradient increased, especially in the lower layer, and reached its maximum by 15 March at 12 00 UTC. After that, the warm air extended farther to the north at all levels while the temperature gradient in the lower layers decreased by 16 March at 1200 UTC, as it is clear from Fig. 3d.

The 500 hPa trough appeared as an extension of the travelling depression over northern Europe at 1200 UTC 14 March (Fig. 4). A cut-off low formed at 1200 UTC 15 March and a well-defined cyclonic depression is apparent over the east and middle of Europe. A decrease in the height contours of 500 hPa level has taken place in conjunction with the deepening surface cyclone, and by 1200 UTC 16 March, the 500 hPa circulation consists of large cut off low over north Mediterranean. During the next 24 hours the depression started to fill and its central pressure increased gradually. Finally, the cyclone drifted slowly northeastward and was out of the computational domain by 17 March.

COMPARATIVE ANALYSES BETWEEN NR AND WR ENERGY COMPONENTS

A detailed energy budget has been calculated for each 6 hour in the period from 1200 UTC 14 March to 1200 UTC 17 March 1998 in the domain of our calculations. The area-mean energy variables, integrated from 1000 hPa to 100 hPa presented in Figs. 5, 6 and 7. Fig. 5 illustrates the amounts of AZ, AE, KZ and KE for each of the 6-hour times from 1200 UTC 14 to 1200 UTC 17 March. Fig. 5c represents the behaviour of AZ in case of normal and wet runs. It shows that AZ decreasing gradually throughout the period of study in case of NR. AZ have the same behaviour in case of WR except at 0000 UTC 15 and 0000 UTC 16. The maximum difference between the two cases occurs during the period from 1200 UTC 16 to 1200 UTC 17.

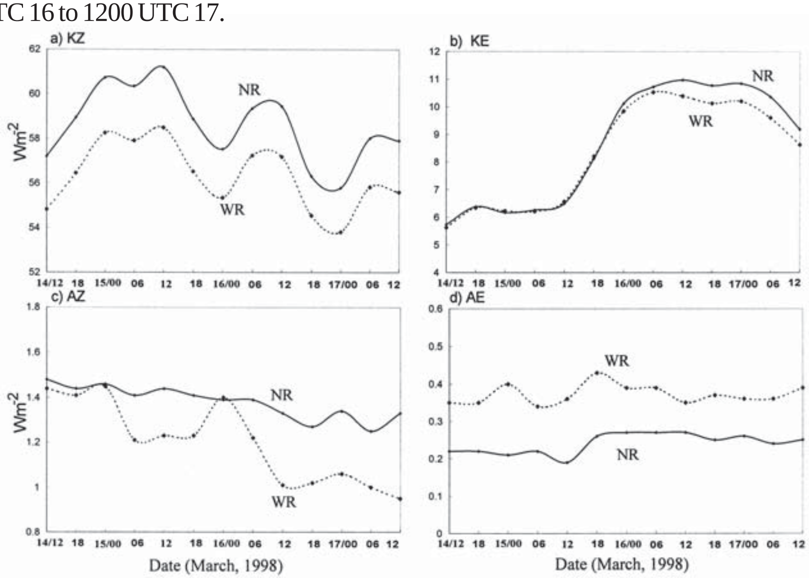


Fig. 5. Area mean average integrated from 1000 hPa to 100 hPa for the energy contents of Normal run (solid lines) and Wet run (dashed lines). Units: Wm^{-2} .

The decrease of AZ in WR than in NR occurs since the major source of energy to AZ is the generation by large-scale surface heating. The surface heating in NR is more than in WR and so there exist a difference in radiative processes in the two cases. Fig. 5d shows the behaviour of AE in case of normal and wet runs. It illustrates that the values of AE in WR are more than those corresponding in NR. The reason of this is that the conversion of AE to AZ (CA) in NR is slightly more than in WR, and also the generation of AE which is by the latent heat release during condensation in WR greater than those in NR.

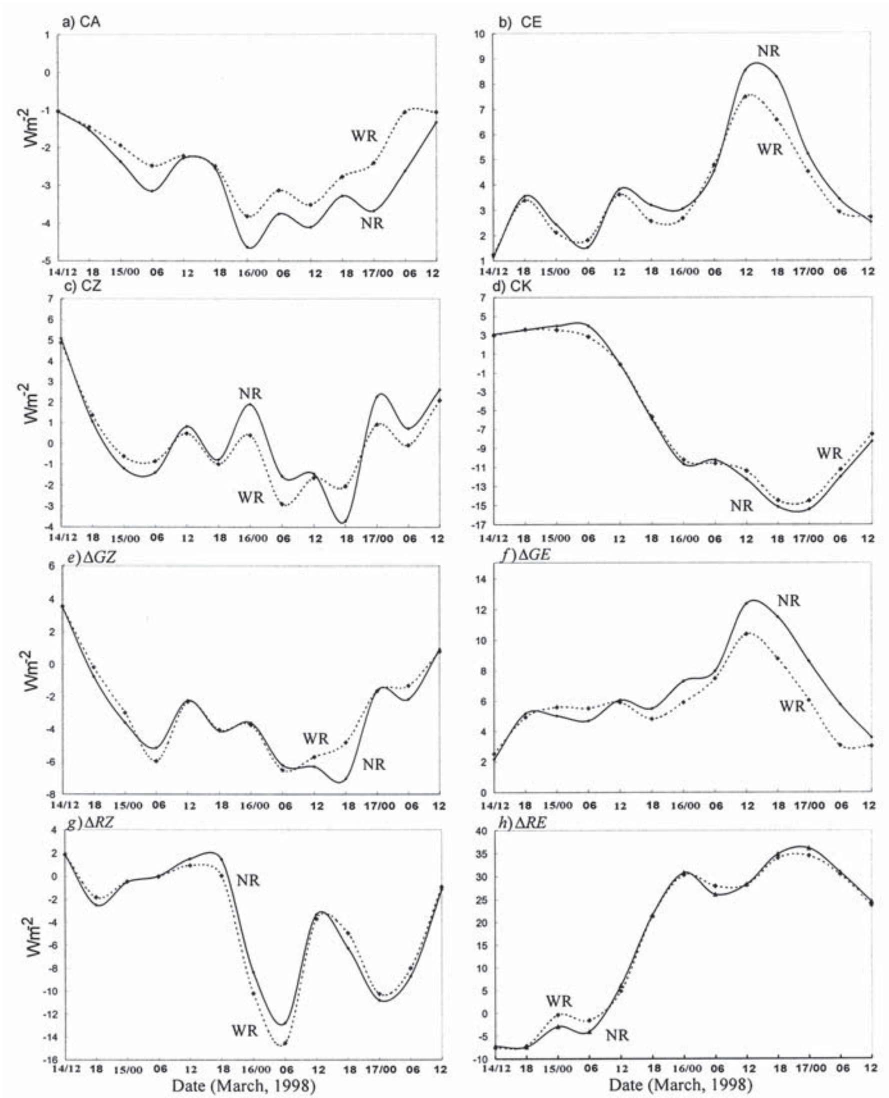


Fig. 6: Area mean average integrated from 1000 hPa to 100 hPa for energy conversions solid lines for Normal Run and dashed line for Wet Run. Units: Wm^{-2}

The kinetic energy associated with the zonal flow, KZ, is undoubtedly the major form of energy at all stages. It roughly follows the same time evolution as its zonal counterpart, namely AZ. It increases after the formation of the surface cyclone and is subject to a continuous decrease after 1200 UTC 15 from a peak quantity of 61.2 $x10^5$ Jm^{-2} to reach 55.79 x 10^5 Jm^{-2} in at 0000 UTC 17 in case of NR (Fig. 5a). Moreover, KZ exhibits the highest rates of energy increase compared to the other three forms of energy. The values of KZ in WR are less than those in NR at all times with maximum decrease also at 0000 UTC 17 (2.3 x 10^5 Jm^{-2}). The values of KE increase gradually from the first time to the end of our period in case of NR and WR (Fig. 5b). The maximum values of KE occur from 0000 UTC 16 to 1200 UTC 17 March in both NR and WR. While the generation term ΔGZ operate as a source of AZ at the first, second and the last times only it makes as a sink of energy at the other times. Generally, it is clear that the energy destroyed by ΔGZ in case of WR is less than those corresponding in NR (Fig. 6e). The generation term ΔGE acts as a major source of energy to the system at all time steps (Fig. 6f). Throughout the period of study the values of ΔGE in case of NR is greater than those corresponding in WR except at 0000 UTC 15 and 0600 UTC 15 March.

The conversion CA (Fig. 6a), between zonal AZ and eddy AE, is associated with the eddy transport of sensible heat. At all time steps there is a conversion of AE into AZ. With the beginning of cyclogenesis small conversion of AE into AZ appears and increased with time. The value of CA in NR is slightly greater than in WR, where the conversion CA is dependent on meridional temperature gradient and eddy heat flux. The average values of conversion term CE throughout the period of study are 3.94 Wm^{-2} and 3.57 Wm^{-2} in case of NR and WR respectively. Which indicate that, on the whole, AE is converted into KE through the thermally direct forced circulation acting in the longitudinal sense, the conversion of AE into KE in NR is greater than in WR. The maximum conversion of AE into KE occurs at 1200 UTC 16 for NR and WR (Fig.6b). With the exception of the first five times, the energy conversion term CK, reveals a conversion of KZ onto KE. The highest of this conversion, is observed at 1800 UTC 16 and 0000 UTC 17 March in case of NR and WR. These results suggest that the eddy transport of momentum operate in the direction of the maintenance of the kinetic energy of the disturbance at the expense of the zonal kinetic energy. Comparing these results with those of Michaelides (1987), it appears that, in the area of a mid-latitude cyclone, the feeding of the eddy motion by the zonal flow could be a predominant feature.

The rest of energy conversion term, namely CZ (Fig. 6c), reveals a conversion of AZ into KZ, during the first two times, 1200 UTC 15, 0000 UTC 16 and from 0000 UTC 17 to 1200 UTC 17 March. The maximum of this conversion observed on 1200 UTC 14 March, it amounts 5.09 Wm^{-2} and 4.88 Wm^{-2} for NR and WR respectively. For the other times, the conversion is from KZ into AZ. The average value of the residual term DRE (Fig. 6h), throughout the period of study is 16.74 Wm^{-2} in NR which implies continuous transfer of eddy kinetic energy outside the region of the system. In WR the average value is 16.81 Wm^{-2}, this mean that the energy transfer is increased. The average values of the residual term ΔRZ (Fig. 6g), throughout the period of study are -3.8 Wm^{-2} and -4.0 Wm^{-2} in case of NR and WR respectively, which implies a greater import of the zonal kinetic energy to the region of system. This import in WR is more than in NR.

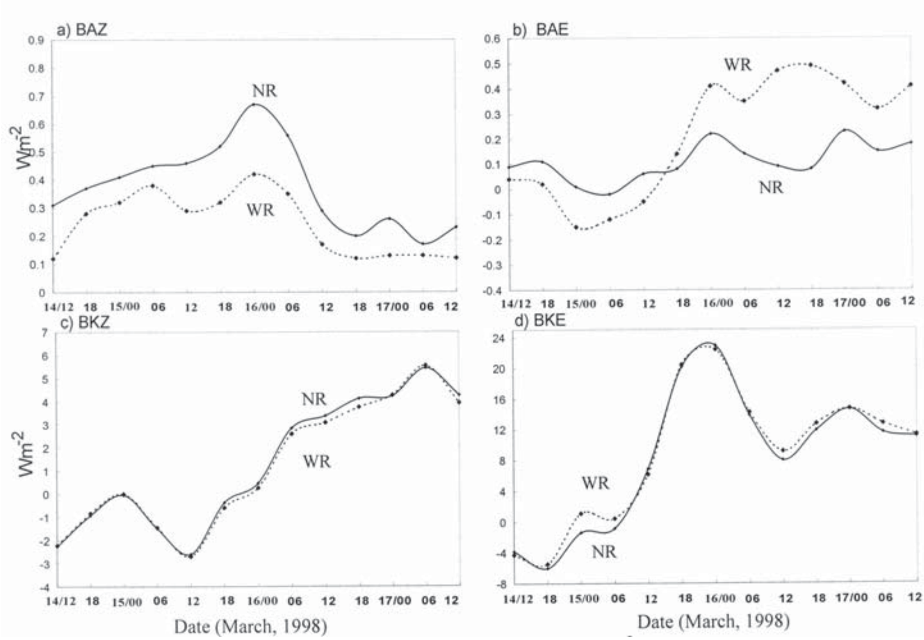


Fig. 7: As in Fig.6, except for boundary transports. Units: Wm^{-2}

The transfer term BAZ, acts as a source at all time steps and the transfer in NR is greater than in WR (Fig. 7a). The mean average values of BAZ throughout the period of interest are 0.38 Wm^{-2} and 0.24 Wm^{-2} in case of NR and WR respectively. The transfer term BAE acts as a source of eddy APE in all periods except at 0600 UTC 15 in NR and during the period 0000 UTC 15 to 1200 UTC 15 in WR (Fig.7b). In the period from 1200 UTC 14 to 1800 UTC 15 March the energy is continuously transferred outside the region, while from 0000 UTC 16 to the end of the period the energy is continuously transferred inside the region (Fig. 7c). More intense rates of this transfer occur in 0600 UTC 17 March, which imply that the deepening of the depression is associated with a significant supply of kinetic energy to the region of the system. The contribution of BKE to KE is negative in the first four times in NR while in WR it is negative for only the first two steps, at the other times the contribution is positive (Fig. 7d). The maximum positive contribution occurs at 0000 UTC 16 March in NR with value 22.9 Wm^{-2} and 22.4 Wm^{-2} in WR.

CONCLUSION

The analysis of synoptic charts and the results of energy budget show that the Khamsin depression is a baroclinic one. The baroclinic zone along the south coast of the Mediterranean is always a suitable place for the development and the transformation from available potential energy to kinetic energy during the life cycle of the Khamsin depression. Assuming the persistence of the initiating disturbance, the extremely hot air coming from the Sahara in the lower layers leads to decreased static stability.

This hot air together with the fresh air coming from the Mediterranean intensifies the baroclinicity near the coast. The increase of baroclinicity with the decrease of static stability makes the atmosphere baroclinically unstable even for the sub-synoptic motion. This instability is characterised by a large amount of eddy available potential energy to eddy kinetic energy. In this work, aspects of land-atmosphere interaction have been investigated by a series of numerical experiments simulating the effect of changes in vegetation cover and initial soil moisture over Egypt. The main findings of the experiments and the studying of energy and energy conversion can be summarized as following:

a) The conversion term CE show that, on the whole, AE is converted into KE through the direct thermally circulation acting in the longitudinal sense. Along one and the same latitude circle in the zonal vertical plane, warm air rises and cold air sinks. AE is converted into KE. KE gets dissipated by ΔRE. It is clear that the conversion of AE to KE is the baroclinic process that is most active in the middle latitudes. Baroclinic instability process sets in and generates the cyclone.

b) In the present study, the barotrobic conversion was found to feed the eddy motion at the expensive of the zonal field. The ability of the atmosphere to convert KZ into KE and vice versa has been discussed by Wiin-Nielsen (1965). In contrast to the expected behaviour of the baroclinic component, the eddy APE was found to feed the zonal APE throughout the life cycle of the desert depression.

c) The generation term GE appears to be the major input of the energy to the system at all days except at the first day, and its role in the local generation of APE is considerably greater than that of GZ. The role of this generation becomes increasingly important as the system develops, indicating that the AE reservoir is continuously replenished through an intense diabatic generation on the local scale. This seems to be the most important conclusion of this work.

d) The comparison between the results of energy and energy conversion in case of NR and WR shows that:

1) The values of AZ in case of WR are greater than those corresponding in the case of NR, since the major source for AZ is the large-scale surface heating .

2) The values of AE in WR is more than those corresponding in NR throughout the period of study, where the conversion of AE to AZ in NR is slightly more than in WR and the generation of AE by latent heat release during condensation is higher in WR than in NR.

3) The conversion term CA in NR is slightly greater than in WR, since CA depends on the meridional temperature gradient and eddy flux of heat by disturbances.

4) In WR the transfer of eddy kinetic energy (ΔRE) outside the region of the system is slightly more than in NR. Also for the import of the zonal kinetic energy to the region of the system, there are increase in WR.

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