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THE INFLUENCE OF THE INITIAL SOIL MOISTURE AND VEGETATION COVER ON THE SHORT-TERM CLIMATE

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Abstract

The influence of the initial soil moisture and vegetation cover on the short-term climate was quantitatively assessed through the use of the limited area model. The sensitivity of the used Egypt-Eta (Egeta) model to changes in initial soil moisture (ISM) and vegetation cover is determined by repeating three months integration with the same initial and boundary conditions as the Normal Run (NR). It is found that, the changes in the three months mean forecasts of surface air temperature and surface evaporation depends on the ISM and vegetation cover. The impact on the upper atmosphere is small and is largely confined to lower levels. The sum of latent heat, sensible heat and soil heat fluxes are strongly governed by the net radiation at the earth's surface. The partitioning of energy between latent, sensible and soil heat fluxes is determined by the dryness of the ground and by the surface temperature. The associated rainfall was strongly influenced by the increase of the ISM and vegetation cover, where the increase of precipitation substantially is over the regions where the soil moisture is initially increased.

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 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. The understanding of land-atmosphere interactions is an important aspect for the issues of climate change, atmospheric predictability and the natural variability of the climate system. The vegetation is largely responsible for the partitioning of surface heat fluxes into latent and sensible heats contributions. Soils represent important seasonal water reservoirs for the hydrological cycle. The influence of land surface processes on the weather or short-term climate change has been analyzed 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 (Manabe, 1975; Walker and Rowntree, 1977; Kurbatkin et. al., 1979; Shukla and Mintz, 1982). Land use modifications by human activities, such as deforestation, urbanization, and agricultural practice, have long been believed to influence climate (Charney et.al. 1977). It is of interest from a climate point of view to examine impacts of

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modification in land use on basic meteorological variables. If humans can modify climate and weather inadvertently, they should be able to make intentional changes in surface characteristics that modify climate and weather in a constructive way. It is virtually certain that human activities, by altering the surface of the earth, have caused major changes in the weather and climate over widespread regions. In ETA model, the soil moisture is prognostic variable, so the land surface can provide feedback to the atmosphere by altering surface fluxes, in response to precipitation and surface heating. The link between soil moisture and the atmosphere is through surface temperature.

In this study, we will use the modified limited area model to assess the sensitivity of Egypt climate with vegetation cover and soil moisture changes during the autumn season of 2000. Also, we illustrate the effect of the soil wetness and vegetation cover on the amount of rainfall, surface evaporation, T-shelter, surface temperature, surface heat budget, thermal response of the atmosphere and persistence of soil moisture.

2. Model

The model used in our study is the regional model system Egeta (Egypt-Eta) which had been developed at Cairo centre for NWP. It is based on the hydrostatic primitive equations using the generalized vertical coordinate, which follow the orographic structure (Simmons and Burridge, 1981). The hybrid coordinate system combines the advantage terrain following sigma coordinate system near the surface, and the pressure system in the medium and upper troposphere and stratosphere, thereby reducing the error in the pressure gradient term. In the same time the numerical solutions are controlled by conservation of integral properties of the continuous equations. A split-explicit time differencing scheme has been used (Gadd, 1978) to save computation time. A semi-staggered horizontal E-grid combined with a technique for preventing separation of gravity wave solution in the pressure gradient terms was used (Janijc 1979) to conserves the basic principles of the dynamical part. A semi-lagrangian advection scheme (Faramawi 1996) with fourth order accuracy has been used to increase the stability of the computation. It uses full physical parameterisations package as a detail representation of radiation components and surface physical-soil hydrology processes. A comprehensive scheme for the planetary boundary layer with increase the number of layer under 1500 meter to 6 levels has been used to improve the forecasting of the surface temperature and capture well all process occurring in the PBL layer.

3. Data And Sensitivity Experiment:

The input data cover the area from 30°W to 60°E and from 5°N to 65°N. Normal integration (NR) for three months that represent the autumn of the year 2000 was compared against the corresponding experiment Wet Run (WR) for the same period with modified vegetation cover and initial soil moisture in two areas in Egypt. The first area is from 28° N to 31° N and from 26°E to 35°E (northern area) and the second one is from 22°N to 25°N and from 26°E to 32°E (southern area). For both experiments the initial data and the updating of the lateral boundary condition were taken from National Canter for Environmental Prediction (NCEP) Global output model with 1.25 Lat. x 1.25 Lon. and at every 12 hour.

The two 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 (0.648 volumetric unit), while in southern belt the initial value of soil moisture was set 0.434 volumetric unit which represent 67% from the 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. 1 shows the integration domain for the model and the two areas of changes in soil moisture and vegetation cover.

4. Validation of the control integration

To objectively assess the predictive skill of the model, the correlation coefficient (C.C) between the actual and forecasted heights of the three months (1 Sep. to 30 Nov., 2000) were computed at the standard pressure levels. Fig. 2 represents the values of C.C at 1200 UTC between actual and forecasted heights of 500 hPa. It shows that the C.C during the first two months is more than 90% for the most days and between 85% and 90% for some days. The C.C during November is equal and more than 95%. The mean monthly values of C.C at the other levels are shown in Table 1. It is clear that the model is very good in predicting the movement and the development of the systems up to three months.

Table (1): The monthly mean value of the C.C between actual and forecasted values of heights at the standard pressure levels.

Level	September	October	November
1000	0.88	0.91	0.91
850	0.89	0.92	0.91
700	0.91	0.90	0.96
500	0.92	0.91	0.97
400	0.91	0.93	0.97
300	0.92	0.94	0.97
250	0.91	0.93	0.98
200	0.90	0.94	0.98
150	0.90	0.95	0.99
100	0.87	0.94	0.97

5. Surface climate changes

In this section we will illustrate the effect of soil moisture and vegetation cover-induced changes on the temperature and specific humidity at 2m.

A) T- shelter

Fig. 3a represents the zonal mean values of T-Shelter over the Egypt area for the mean of three months in the two experiments, Normal Run (NR) and Wet Run (WR), at 1200 UTC. It shows that the T-Shelter generally decreases from south to north and its values over the south region is larger than that over north region in two runs. Fig. 3b depict the difference in T-Shelter between the two cases (NR- WR). It illustrate that the difference in T-Shelter at the south latitudes is more than at the north latitudes and its values in NR is always greater than that corresponding of WR. It also shows that the difference between the two runs decreases from south to north. The maximum of this difference is amounting to 5° c over the south while it amounting 1.6 ° c over the north (Latitude 30° N) which indicate that the effect of the soil moisture and vegetation cover on T-shelter is clear over south region more than the north one. Over the central region (25 ° N to 28 ° N) there is also a considerable difference in T- Shelter, this difference is less than that over the north and south regions. This indicate that the effect of the soil moisture and vegetation cover changes appears not only in the south and north regions but also over the all area of Egypt.

B) Specific Humidity

Fig. 4a represents the latitudinal time mean integration of Specific humidity at 2m in two experiments (NR and WR). We note that in NR the values of specific humidity increases with increasing the latitudes, so it largest over the north region where the soil moisture content is higher than the south region while the temperature is lower than the south area. The maximum value of specific humidity is 7.79×10^{-3} Kg/Kg over latitude 31° N and the minimum is 2.67×10^{-3} Kg/Kg over latitude 25 ° N. In WR the specific humidity have the same behaviour as those corresponding of NR but its values are greater than that of NR over all latitudes. Over 30 ° N the value of specific humidity reaches 10.56×10^{-3} Kg/Kg while it reaches 7.89×10^{-3} Kg/Kg over 22 ° N.

Fig. 4b shows the latitudinal time mean difference (WR-NR) of specific humidity for the three months. The higher difference values occur over the south region with the greatest one (5.35×10^{-2} Kg/Kg) occurs at 23° N. The difference of specific humidity generally decreasing from south to north and so its values over the north region is less than that over the south region. This is due to the higher of temperature of air in south region. In the middle region (25 ° N to 28 ° N) there are also increase of specific humidity in WR, this increasing is less than that at the boundary areas.

Fig. 5 illustrates the area mean of T-shelter over Egypt in NR and WR throughout the period from 1 September to 30 November. It shows that during our period of study, the T-Shlter in WR is always less than that corresponding of NR. The difference of T-Shlter between the two runs is high and more pronounced during the period from 1 September to 18 October, where this period represent the first days of the autumn where the temperature is high. The mean differences between the two runs over the area for the three months (September, October and November) are 4.9° C, 3.6 ° C and 1.8° C respectively.

Fig. 6 shows that the specific humidity in WR is more than that in NR throughout the period of integration and it decreases slightly with time. This illustrates that the effect of the initial increasing of the soil moisture is persistent up to the end of the three months. The mean difference (WR-NR) over the interested area (Egypt) for September, October and November are 6.16×10^{-3} Kg/Kg, 4.87×10^{-3} Kg/Kg and 2.67×10^{-3} Kg/Kg respectively. In general, the difference in specific humidity at 2m is consequence to the change of the temperature at 2m. The changes of the T-shlter and specific humidity at 2m, as inferred from the simulations, are of substantial magnitude and depend on the location and considered month.

In order to understand the mechanisms leading to these changes, the hydrological cycle and the surface energy budget are investigated in the following sections. Both cycles are strongly interrelated, but will be treated separately.

6. Hydrological cycle:

6.1 Evaporation and precipitation

In a climatological sense the evaporation over the north region of Egypt is more than that over the south region where the soil moisture availability in south region is limited (Fig. 7b). Fig. 7b illustrates the latitudinal zonal mean values of the accumulated evaporation (mm/day) throughout the period of integration. It shows that the values of evaporation over the south region are very small while over the north is high. The mean values of evaporation are 0.1 mm/day and 0.75 mm/day over south and north regions respectively.

Generally the values of evaporation in WR are more than those corresponding of NR throughout our period of study. This difference are clear over the south region more than the north region where the amount of solar radiation absorbed by the earth's surface in the south region is more than those in north region. Over the middle region (25^{o} N and 28^{o} N) the rate of evaporation in WR is also increase in spite of there is no changes in vegetation and soil moisture. This increase of evaporation rate over the middle region is less than that of the north and south regions and it caused due to the diffusion of soil moisture from south and north regions to the middle region.

Fig. 7a illustrates the effect of changes in surface parameters on the precipitation. It shows that the amount of precipitation increases over the two belts with maximum effect over the north region. Over the central region (26^{o} N-28^{o} N) precipitation difference (WR-NR) is very small. It is interesting to note that at the middle of the north region (29.5^{o} N) the rate of increase in precipitation is about 0.3 mmday^{-1} while it is about 0.15 mmday^{-1} over 23.5^{o} N (the middle of south region) during the period of study. This mean that in WR the precipitation was increased latitudnally by approximately 7-10 mm/month over the north region and about 5-7 mm/month over the south region.

Comparing the amounts of rainfall and precipitation at the different regions throughout the period of study we found that the amount of precipitation is less than that corresponding of evaporation which means that there is moisture divergence over the area during all times of integration. This result is agreement with Pamela

Heck (1999), he has found that there is moisture divergence in the Mediterranean region during the period from May to August.

Fig. 8a represents the daily mean value of precipitation over the area during the period of integration in the two runs by mmday^{-1}. The figure shows that the effect of increase the Initial Soil Wetness (ISW) and vegetation cover is clear in the first month (September) more than the other two months, this due to the decrease of the effect of Soil Moisture Content (SMC) with time.

Fig. 8b shows that the evaporation in WR is more than in NR and the difference between the two runs are decreases with time where the decreases of SMC in WR tends to decrease the evaporation with time. Generally, Fig. 8 illustrates that the feedback between soil moisture and vegetation cover on the precipitation and evaporation remains positive during all three months. Also the maximum increase of precipitation is in September where evaporation is largest.

6.2 Soil moisture

Fig. 9a represents the latitude-time distribution of the zonal mean of the soil moisture content (SMC) during the three months in WR. It shows that the maximum values occurs over the north region up to the end of integration and the values of SMC in south region are very small relative to the north region. While the minimum values occurs in the central region between 25 ^{o}N and 28 ^{o} N.

Fig. 9b represent the latitude-time distribution of zonal mean difference of SMC between WR and NR (WR-NR). It can be notice that the positive anomaly of soil moisture content resulting from increasing Initial Soil Wetness (ISW) persists throughout the period of study and its values over north region are more than those in south region. Where its known that the north region is characterised by large precipitation rate and lowest surface temperature than south region. This result is agreement with Manabe. et al. (1983), they found that the anomalies of soil moisture created by irrigation for latitude zone between 0-30^{o} N could persist for at least four months. The second feature can be noticed from Fig. 9b is that the increase of soil moisture is not only at the two belts where the ISW are increased but also observed at the middle region between 25^{o}N and 28^{o}N. Also the distribution of the zonal mean difference is symmetric with respect to the central region.

The above analysis illustrate that the amount of absorbed energy is essentially for the rate of evaporation and controls the time of disappearance of a soil moisture anomaly. Also, since the amount of incoming short wave radiation is usually large in low latitudes, so it is found that the duration of soil moisture anomaly tends to be shorter with decreasing latitudes. The results also illustrate that the vegetation cover and soil moisture invokes substantial changes in the hydrological cycle (especially in northern Egypt), also both the evaporation and precipitation are increased with increasing vegetation cover and ISW.

6.3 Surface energy budget

The surface energy budget over land can be approximately written in the following form,

$$R_n = S + H + L_v\, E\, T_a$$

where R_n is the net radiation , S is the soil heat flux, H is the sensible heat flux and $L_v\, E\, T_a$ is latent heat flux. Note that the fluxes directed downwards are positive. Since the Incoming Short Wave Radiation (ISWR) substantially depends on cloud albedo and its amplitude it is considerably different from southern to northern Egypt. The atmospheric conditions in northern Egypt are characterized by synoptic activity associated with large values of cloud coverage and shielding of the incoming short wave radiation.

Fig. 10 illustrates the time mean values of the latitude- zonal mean values of incoming short wave radiation and net long wave radiation over Egypt for the period of study. Fig. 10a shows that the mean value of ISWR at 31°N throughout the period of integration in NR is about 700 wm^{-2}, it increases with decreasing latitude to reach about 815 wm^{-2} at 22 ° N. In WR there is a decrease in ISWR over all latitudes, its value over south latitudes is more than north. The middle region has less effect from the boundary region.

Fig. 10b represents the latitudinal mean values of Net Long Wave Radiation (NLWR) of the three months in two runs at 12000 UTC. It is clear that the values of NLWR in NR are greater than those corresponding in WR at the all latitudes. In NR the maximum values occurs at the north region it reaches –172 wm^{-2} at 22° N and it decreases gradually from latitude 27° N to reach its minimum value at 31° N. This higher values of NLWR at north than that at south is due to that the surface temperature in south is higher than in north. In WR the maximum values of NLWR are located over the middle region where the decrease of surface temperature is very small relative to the other regions (north and south).

Fig. 11a illustrates the mean values of incoming short wave radiation flux at 1200 UTC over the interested area throughout the period of integration. The values of ISWR in NR are more than those corresponding in WR and it decreases gradually with time from September to November. Its maximum values (NR) occur at the start of integration with amount 980 wm^{-2} while the minimum values are occurred at the end of our period with amount of 600 wm^{-2}.

In WR the maximum decrease of ISWR was occurred during the period from 8 September to 10 October, it is due to increasing the moisture in the atmosphere by large increase of evaporation. The differences of ISWR between the two cases (NR and WR) becomes very small for the period from 11 October to the end of integration due to the decrease of evaporation in this period.

Fig. 11b illustrates that the values of net long wave radiation decreases slightly with time and its maximum values occur between 10 September to 15 October. Also it is clear that the values of NLWR in NR are less than that corresponding in NR during the period of study, and the period of maximum decrease in NLWR is consistent with the period of maximum decrease of in ISWR. This decrease in NLWR is due to the decrease of the emission from ground out going long wave (as a result from decrease the surface temperature and the emissivity of the surface) and increase the incoming long wave radiation (as a result from increase the water vapor in the atmosphere). The difference of NLWR between two cases decreases with time where the surface temperature increases in WR as a result from the depletion of soil moisture.

Fig. 12 shows the latitudinal time mean values of the latent heat flux and sensible heat flux in the two runs (NR and WR). Over land the sum of latent heat flux and sensible heat flux is strongly governed by the net radiation at the earth's surface. It is clear that the latent heat flux in NR is very small at all latitudes except between 29^o N and 31^o N, and the mean values over the south and north region are about 10 wm^{-2} and 40 wm^{-2} respectively. Due to the small values of the latent heat flux in NR the corresponding values of sensible heat flux are high especially over the south region where the soil is very dry and the earth's surface temperature is high (Fig.12b). In WR the soil moisture content was increased which increasing the latent heat flux, while the surface temperature and sensible heat flux decreased (Fig.13a). The region between 25^o N and 28^o N has less effect of decreasing sensible heat flux.

In WR and during the period of integration the values of soil moisture content decreases gradually with time, this tend to decrease the corresponding value of latent heat flux (Fig.13a). The corresponding values of soil moisture content in NR is small and the mean value over the period is about 30 wm^{-2} correspond to 120 wm^{-2} in WR.

The values of sensible heat flux in NR decreases gradually with time from September to November due to the decreasing of the amount of solar radiation absorbed in earth's surface (Fig.13b). The decrease of net short wave radiation tends to reduce the earth's surface temperature and sensible heat flux from September to November. The maximum value is about 320 wm-2 at 10 September decreases to reach about 165 wm-2 at the end of integration. In WR the sensible heat flux was decreased slightly and the corresponding values of latent heat flux are somewhat larger (due to larger evaporation than in NR). The mean value throughout the period is about 160 wm-2. In WR the minimum value of sensible heat is corresponding to the maximum value of latent heat at the start of integration. From Fig. 13 we can note that in NR the sensible heat loss over the interested area is larger than latent heat loss. In WR the latent heat flux loss larger than sensible heat flux loss.

6.4 Vertical profile of temperature

The 2m temperature of NR and WR were discussed in section 5. Here we will illustrate the vertical profile of the average temperature over Egypt area for each month (September, October and November) in the two experiments NR and WR (Fig. 14a -c). Also the differences between two cases are shown in Fig. 14d.

In September, Fig.14a, at first level (1000hPa) the corresponding values of averaged temperature are equal to 30.7o C and 26.4o C for NR and WR respectively. This mean that at 1000 hPa the soil moisture and vegetation cover induced the temperature differences amount to 4.4o C throughout the month. This difference has maximum values in the boundary layer between 1000 and 700 hPa

(Fig.14d). The atmospheric sensitivity to soil moisture and vegetation cover changes its sign in the layer between 600 and 400 hPa (i.e., temperature in WR is more than in NR). Above 400 hPa the temperature in WR is less than in NR which means that there are slightly cooling above 400 hPa in WR relative to NR.

In October the layer with maximum difference lies between 1000hPa and 850hPa (Fig.14b). In the middle of atmosphere the effect of changes in soil moisture and vegetation cover is more than in September. In the layer between 700 hPa and 100 hPa the temperature in WR is more than in NR except at 150 hPa where there is cooling in WR relative to NR.

In November the temperature at 1000 hPa in NR and WR are 22.76 ^{o} C and 21.22^{o} C respectively (Fig. 14c). The significant heating occurs between 700 hPa and 300 hPa, and the maximum difference is located at 400 hPa with amount 0.93^{o} C (Fig.14d).

Generally, the above discussion shows that the effect of changes in soil moisture and vegetation cover on temperature profile can be noticed as decreasing in boundary layers, heating in the middle layers and cooling in the upper layers. This results are due to the decreasing of surface temperature, increasing of the latent heat released from water vapour condenses to form clouds and precipitation, radiative cooling in the upper layers and the absence of moist convective activity.

7. CONCLUSION

In this work aspects of land-atmosphere interaction have been investigated by a numerical experiment simulating the effect of changes in vegetation cover and initial soil moisture over Egypt. The most significant findings are as following:

- The positive anomaly of soil moisture content persists about 3 months and it persists over north region longer than south region where the north region is characterized by large precipitation rate and lowest earth's surface temperature than south region.
- The increase of soil moisture is not limited to the north and south regions only, where the initial soil moisture is increased, but extended to the other regions of the interested area as a result from diffusion of moisture from wet soil to dry.
- When the soil moisture content and vegetation cover were increased, the large amounts of net radiation lead to strong evaporation over the north region decreases gradually with decreasing latitudes, and convection may be triggered in response to the daytime build-up of the boundary layer.
- The transports of moisture into the higher atmosphere as a result from increasing the rate of evaporation is considered more efficiently and favor the formation of clouds. This in turn increases the precipitation as a result of increases the cloud cover.
- The modification of land surface conditions enhances the hydrological processes not only in the two regions where the change takes place but also in the central region especially the nearby latitudes. Since some soil moisture transported out of the region, this feedback can only last for a certain length of time.
- The change in the soil moisture and vegetation cover tends to changes in the surface energy budget of the soil. Also it is found that there is increase of

ventilation in the interested area caused by the relatively large increase of evaporation, which reduces the earth's surface temperature and T-shelter especially during the first 50 days from the integration.

- The soil moisture and vegetation cover induced effects were not only at the surface, but also within the whole boundary layer and lower troposphere. The thermal state of the atmosphere is also influenced by the changes in the initial soil moisture and vegetation cover.
- The soil wetness and earth's surface temperature determine the partitioning of the energy between latent heat, sensible heat and soil heat fluxes. In turn, any excess of radiation, not balanced by latent heat (evaporation), sensible heat and soil heat fluxes gives rise in earth's surface temperature.

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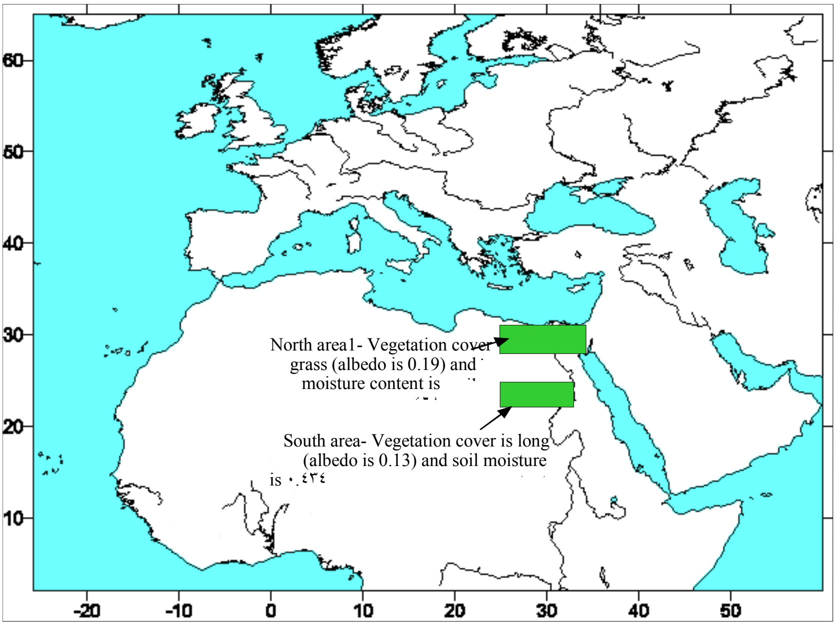


Fig. ١: The integration domain of the Model and areas of changes.

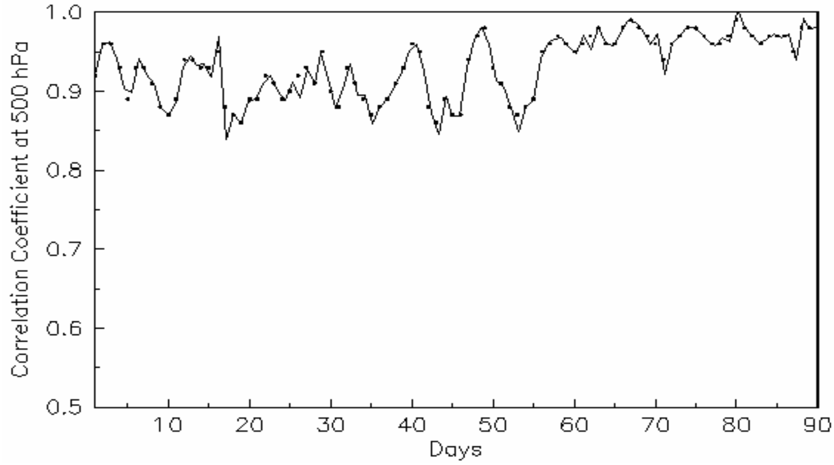


Fig. 2: The values of C.C between actual and forecasted of 500 hPa heights at 1200 UTC during the period of study.

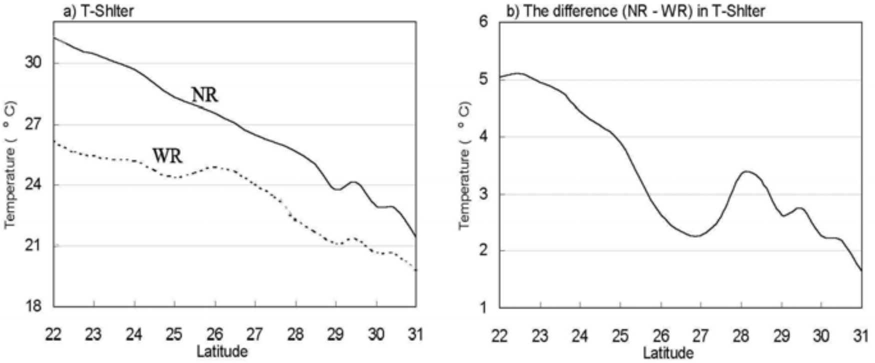


Fig. 3: Latitude- zonal mean of T shelter for three months over Egypt area in two cases NR (solid line) and WR Dashed line) at time 1200 UTC. b) as in a) but for the difference between the two runs (NR- WR).

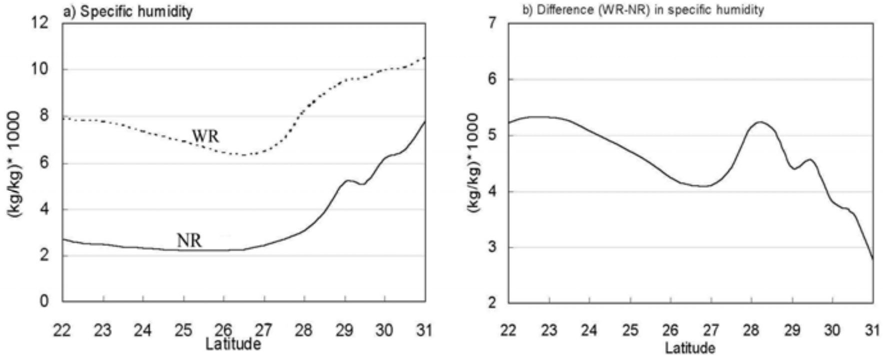


Fig. 4: as in Fig. 3 but for specifiv humidity, the difference is WR - NR.

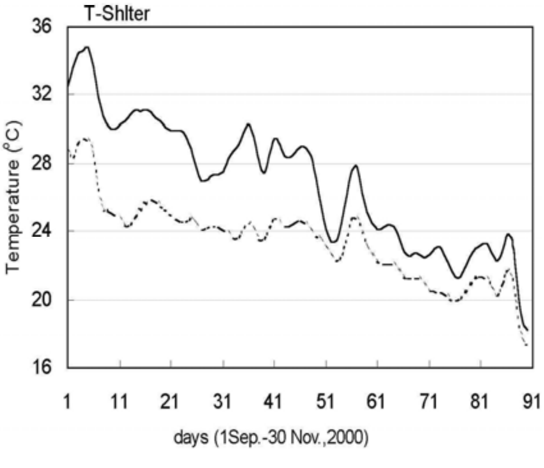


Fig. 5: Area mean of T shelter over Egypt area in NR (solid line) and WR (Dashed line) during the period from 1 Sep. to 30 Nov., 2000.

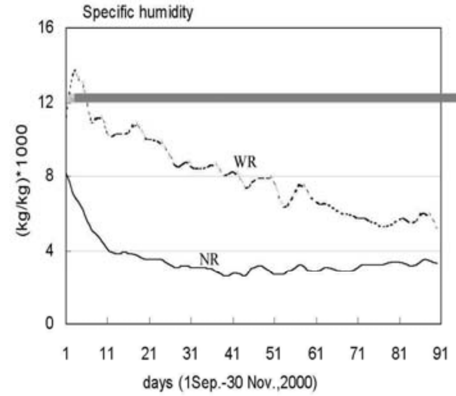


Fig. 6: As in Fig. 5 but for Specific humidity at 2m.

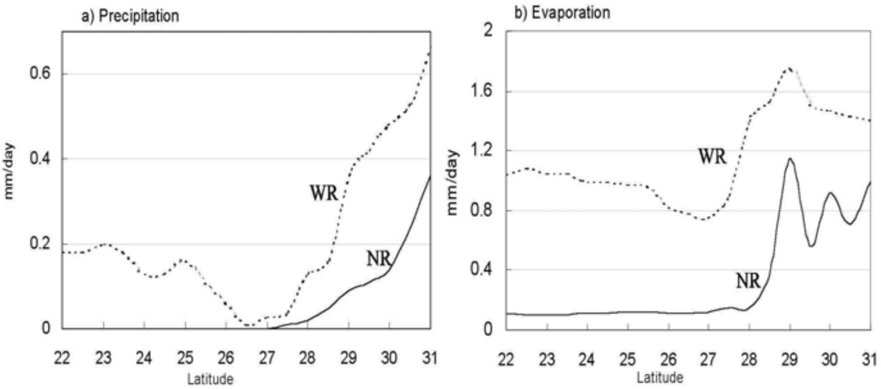


Fig. 7: The time mean values of the Latitude- zonal mean of precipitation over Egypt for three months (1 September to 30 November, 2000) in two runs, NR (solid line) and WR (dahsed line), b: as in a) but for evaporation.

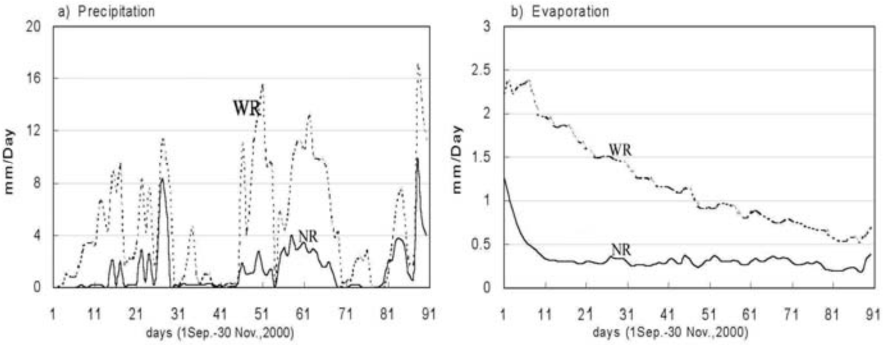
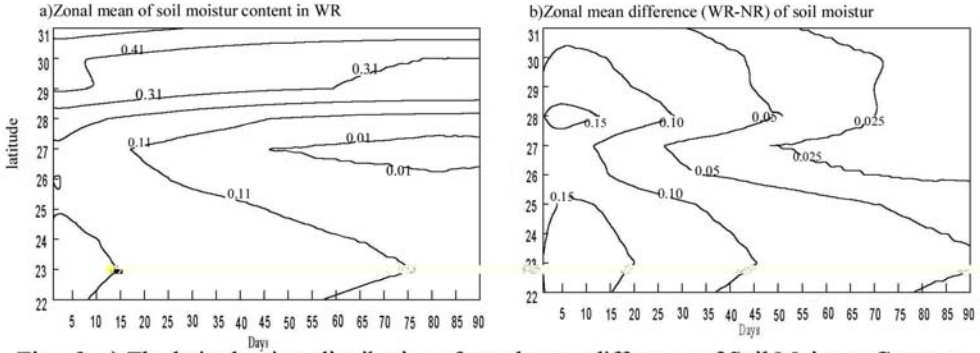
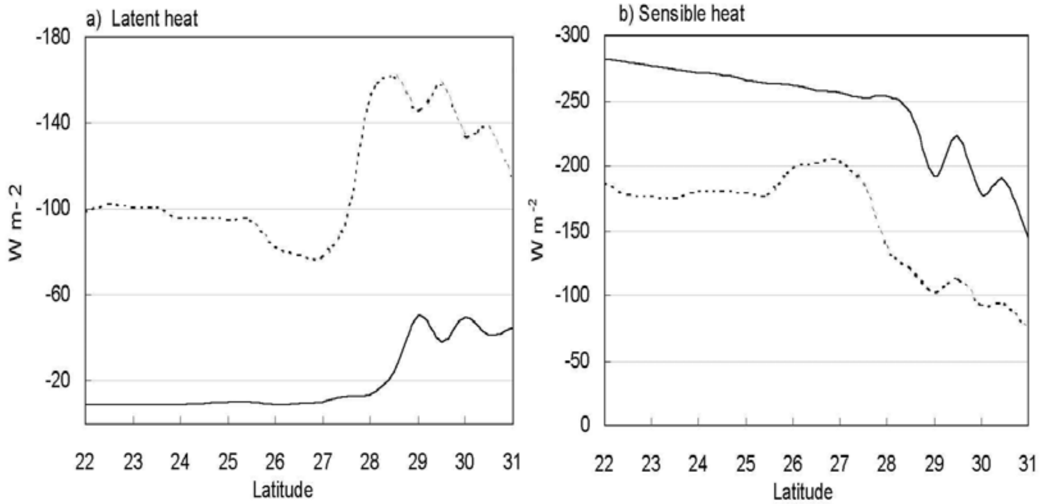


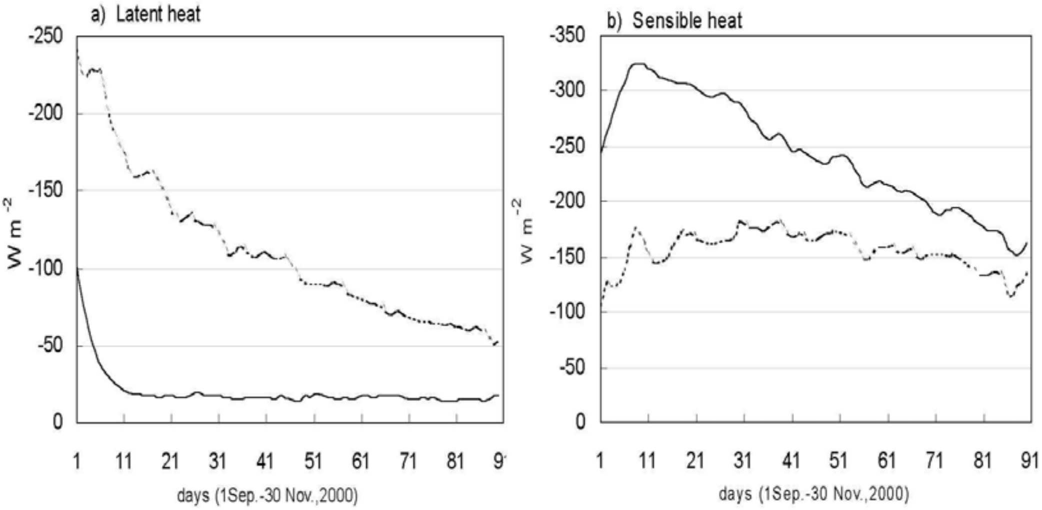
Fig. 8a: a) The sum of the zonal mean values of precipitation over Egypt for three months (1 September to 30 October 2000) in NR (solid line) and WR (dashed line). b) as in a) but for evaporation.



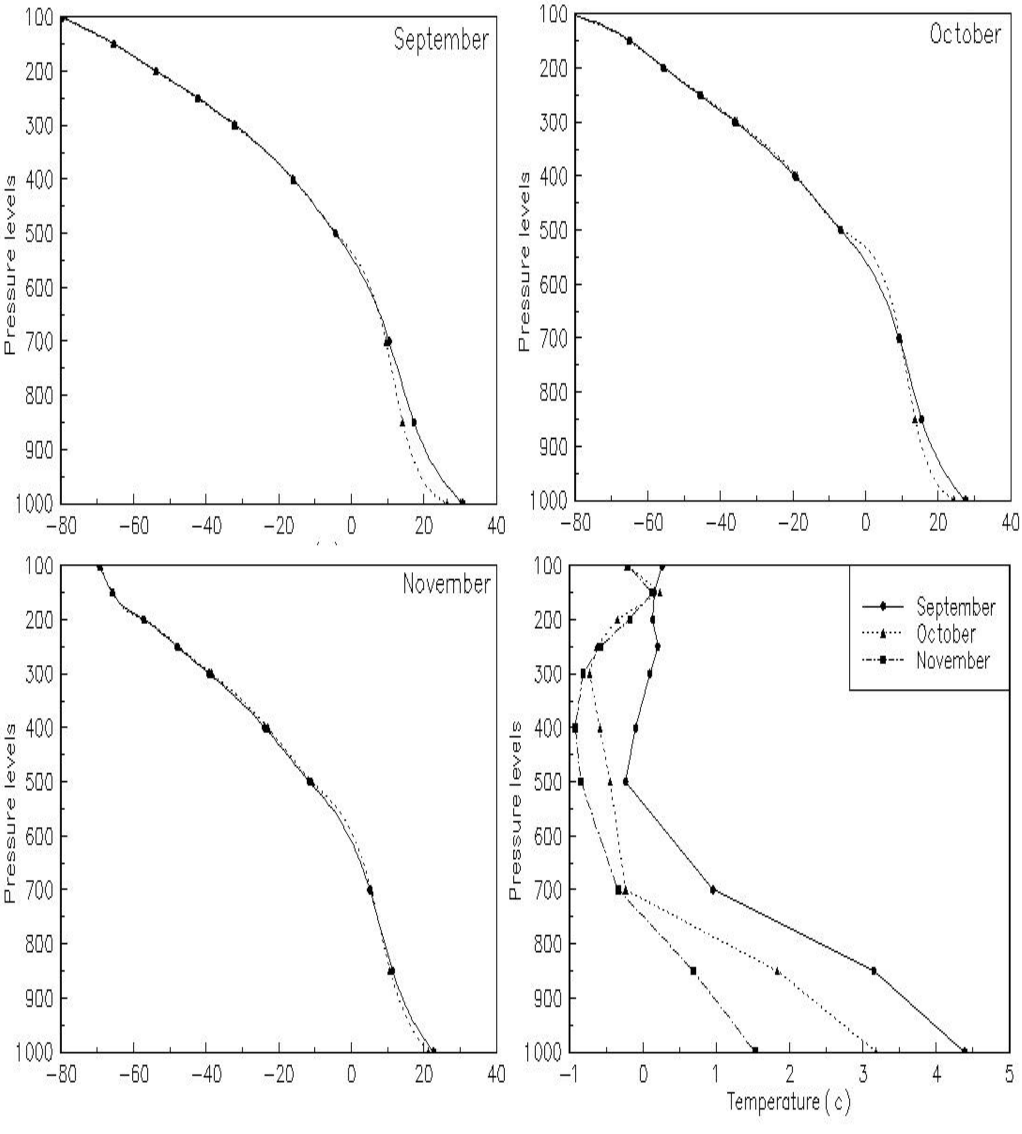
Figs. 9: a) The latitude- time distribution of zonal mean difference of Soil Moisture Content in WR during the three months (1 September to 30 October 2000). b) As in a) but for the difference (WR-NR).



Figs. 12: a) The time- zonal mean values of Latent heat flux over Egypt for the three months (1 September to 30 October 2000) in NR (solid line) and WR (dashed line).
b) As in a) but for sensible heat flux.



Figs. 13: a) The zonal mean values of Latent heat flux over Egypt for the three months (1 September to 30 October 2000) in NR (solid line) and WR (dashed line).
b) As in a) but for sensible heat flux.



Figs. 14 : a) The mean vertical profile of temperature over the Egypt area for September in NR (solid line) and WR (dashed line). b) As in a) but for October. c) As in a) but for November. d) Represents the difference between NR and WR for the three months