ON CLIMATIC CHANGES DUE TO A DELIBERATE FLOODING OF THE QATTARA DEPRESSION (EGYPT)

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Abstract. A numerical mesoscale model has been applied to make a preliminary evaluation of the mesoscale climatic changes due to a deliberate flooding of the Qattara depression in Egypt. Simulation of a typical summer synoptic situation has indicated noticeable effects on the horizontal and vertical wind fields, and for the temperature and moisture patterns.

1. Introduction

The Qattara depression is located in the western desert of Egypt, about 90 km from the Mediterranean seashore (Figure 1). Its area is about 18 000 km^2, while the depth varies from several meters below MSL to as low as −133 m MSL. Its averaged depth is on the order of several tens of meters. Relatively low topographic relief is situated northeast of the depression, which makes its flooding by Mediterranean water potentially feasible.

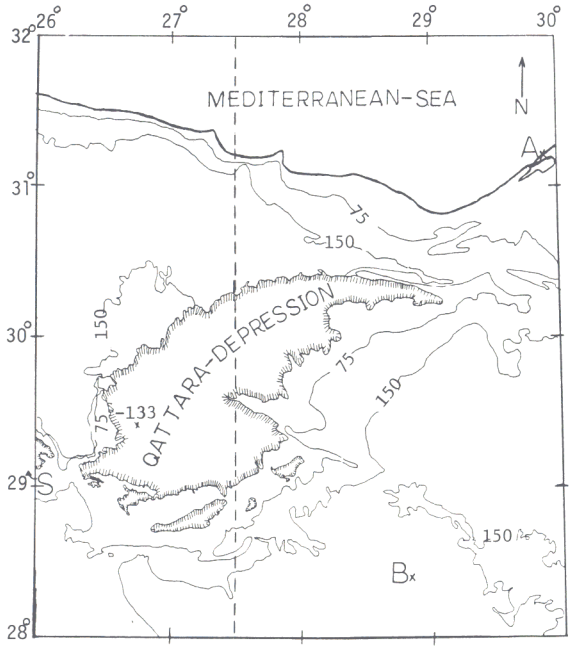

Fig. 1. An illustration of the Qattara depression area.

Climatic Change **5** (1983) 73–83. 0165–0009/83/0051–0073$01.65.
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Two possible benefits could be achieved by such a project: (1) generation of hydroelectric power, and (2) climatic modification. Due to the warm and dry atmospheric conditions, the expected large evaporation from an artificially created lake in this geographic region should balance a steady inflow of water from the Mediterranean, thereby providing a reasonable gain of hydroelectric energy. Equally attractive, however, are the possible climatic changes, mostly during the warm season. The possible reduction in temperature, increase in moisture or formation of some cloudiness around and over the depression during this season, could be beneficial for the existing or planned settlements in this arid region (at present only the southwest side of the depression is populated).

In the study reported by this paper, a numerical modelling approach has been adopted to provide some preliminary insight into the possible climatic changes in this area.

It should be noted that an additional approach could be a comparative one, i.e. evaluating the climatic modification by using meteorological data from geographic areas with equivalent characteristics, as the one under study. The limitations of such a methodology include the difficulty of finding two areas with reasonable equivalence (i.e. regions of the same terrain, synoptic conditions, latitude, etc.). Another limitation for most arid regions is the sparse meteorological observational data. Regions like the Baja California peninsula or the northern section of the Red Sea which seem attractive for such a comparison, in our specific case, suffer from both of these limitations.

In order to gain an appropriate insight into the mechanisms leading to changes of meteorological patterns at the surface level, it is essential to examine the whole boundary layer. For example, the creation or abolition of an upper layer inversion can affect surface moisture, while the creation of a horizontal wind convergence zone can affect surface temperature, as well as result in precipitation under appropriate meteorological conditions. As an initial step in this study, we have chosen to present patterns of modified horizontal wind, vertical wind, temperature and moisture during a typical summer day. Since the weather patterns in this region are quite persistent during the summer, an integration of the model for a representative day is characteristic of the local climate over most of this season.

2. The Model

A detailed formulation of the model is given in Pielke (1974) and Mahrer and Pielke (1978), therefore in the present paper, only a brief description of the model is reported. In brief, the model is hydrostatic, consisting of equations of motion, heat, moisture and continuity in a terrain following coordinate system.

2.1. Boundary Layer

The calculations of the surface fluxes of momentum, heat, and moisture are based on the work of Businger (1973). The exchange coefficients in the planetary boundary layer above the surface layer utilize O'Brien's (1970) functional form. The planetary boundary layer top is predicted as a function of location according to Deardorff's (1974) prognostic

equation. The roughness parameter over the water is calculated according to the formula suggested by Clarke (1970).

2.2. Surface Heat Balance

The temperature at the soil-air interface is calculated using a heat balance equation, which includes terms relating to solar radiation, incoming atmospheric longwave radiation, latent, sensible and soil heat fluxes and the outgoing surface longwave radiation.

2.3. Radiation

The changes of air temperature, due to shortwave and longwave radiative flux divergence are parameterized following methods of Atwater and Brown (1974) and Sasamori (1972). Heating of the atmosphere by shortwave radiation is confined to water vapor while carbon dioxide and water vapor are considered in the longwave radiation heating/cooling.

3. Simulation Aspects

In the present study, a two-dimensional numerical mesoscale model has been applied along a cross section perpendicular to the Mediterranean seashore, as illustrated by the dashed line in Figure 1. The cross section consists of 110 km of the Mediterranean, 100 km of slightly elevated terrain between the Mediterranean and the Qattara depression, 90 km of average width for the Qattara depression and 130 km of slightly elevated terrain to the south. The two-dimensional symmetry assumption implies that the terrain is

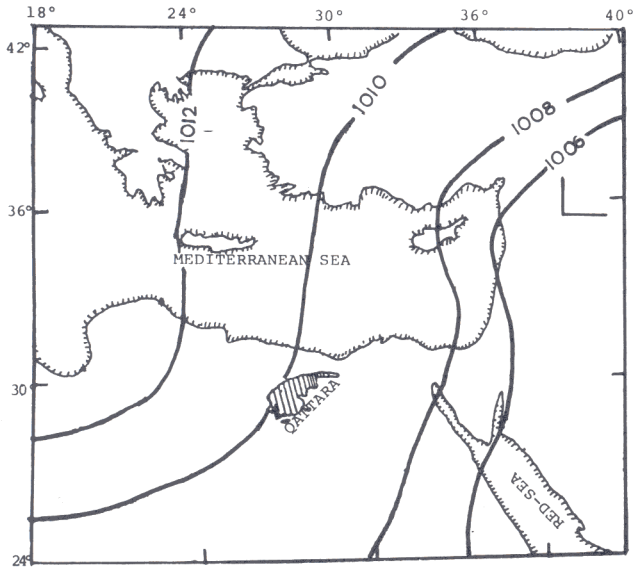

Fig. 2. Averaged July surface pressure map (based on Griffiths and Soliman, 1972).

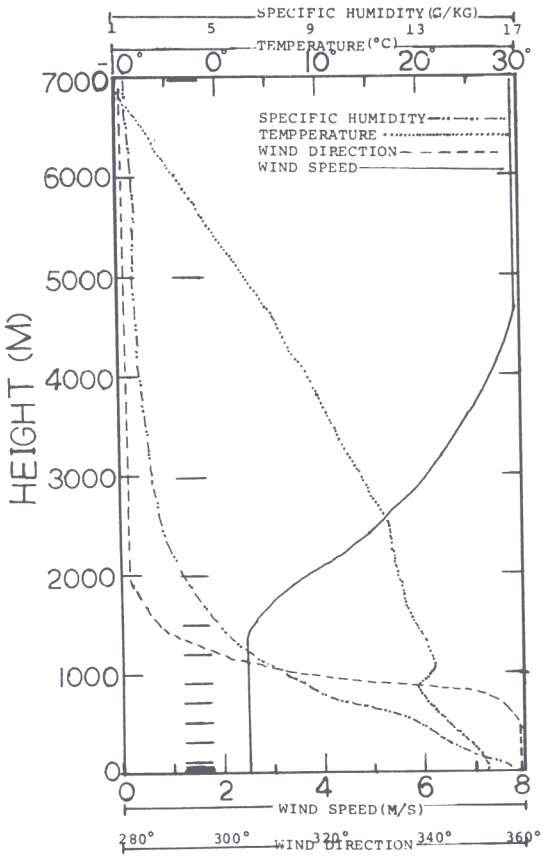

Fig. 3. Initial vertical profiles of wind, temperature and specific humidity. Dashes at the left indicate the vertical levels in the model.

homogeneous in the west-east direction. An accurate representation of the terrain requires the use of a three-dimensional model version; however, considerable insight regarding the effects of flooding the Qattara depression can be gained using a two-dimensional formulation. A horizontal grid interval of 10 km has been adopted, while in the vertical, the model consists of 14 levels (as indicated by the dashes on the left side of Figure 3). The simulations are based on prescribed meteorological conditions typical of the region during the summer. During this season the lower levels of the atmosphere are dominated by a persistent northerly flow associated with a trough extending westward from the Asiatic low located over northwestern India (Griffiths and Soliman, (1972)). Figure 2 illustrates a typical surface synoptic situation in this season. In the upper layers, the orientation of the subtropical high causes westerly flow, as well as large-scale subsidence. The persistency of this pattern during the summer causes an almost identical daily cycle for the various meteorological fields and implies that simulation results based on typical synoptic conditions are representative for the major portion of the season. Namely, it can provide, to a large extent, a seasonal (or monthly) climatic pattern.

Initial conditions for the simulations (Figure 3) are based on July averaged conditions as given by Ramage and Raman (1972), along with Synoptic weather maps (1972) as prepared by the NOAA Environmental Data Service. Initially, longitudinally homogeneous temperature and moisture profiles representative of the coastal areas were imposed throughout the model domain. However, their inland distribution is adjusted soon after the simulations begin because of the strong mesoscale forcing. The remainder of the initialization procedure, and boundary conditions, are as those reported by Mahrer and Pielke (1977). The simulation started at 2000 LST (following sunset) and lasted for 24 hr.

4. Results

Two simulations were carried out:

(1) Without water in the Qattara depression (no lake simulation; figures are indicated by N).

(2) With water in the Qattara depression (lake simulation; figures are indicated by L).

In the first simulation, we assumed a typical depression depth of −50 m, while, in the second one, the lake water surface was assumed to be 0 m. The Mediterranean surface sea water temperature was set at 28.5 °C (the typical July value), while, for the lake, a value of 30.5 °C was chosen.

The hour 1700 LST, when a relatively large difference between the simulated fields in the two experiments is expected, has been chosen for illustration. Because of the pre-

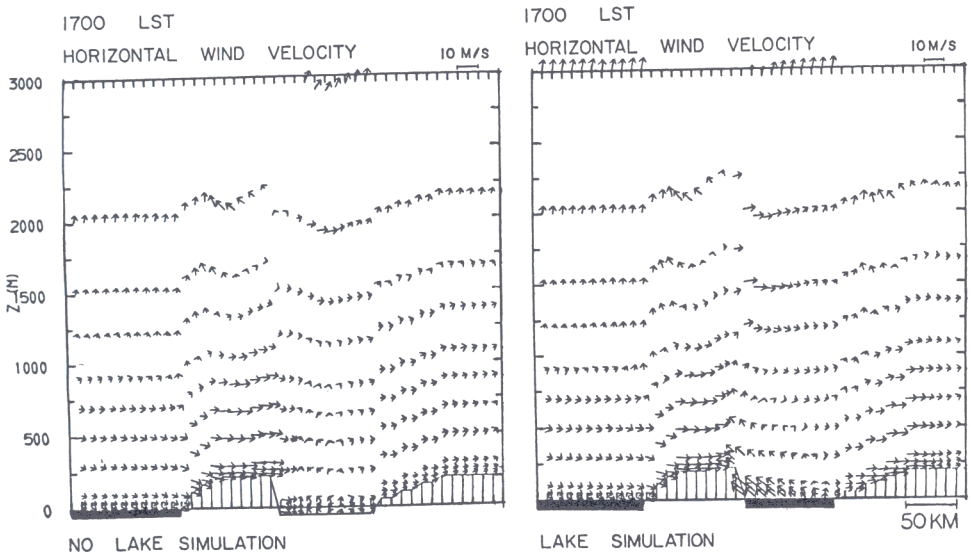

Fig. 4. Predicted horizontal wind velocities at 1700 LST along a north-south vertical cross section, perpendicular to the Mediterranean. A component of the wind velocity vector to right indicates northerly flow, while an upward pointing component is for westerly flow. The topography is illustrated by a solid line with the water section of the Mediterranean and the 'hypothesized lake' indicated by a heavier dark line.

liminary nature of the present study and the difficulties in gathering observational data, no verification analysis has been carried out. Previous studies with the model, however, (e.g. Pielke and Mahrer, 1978; Mahrer and Segal, 1979; Segal and Pielke, 1981; and Segal *et al.*, 1981) have indicated that the model accurately simulates land and sea breeze circulations, as well as, mountain and valley winds.

4.1. HORIZONTAL WIND VELOCITY

In the no-lake simulation (Figure 4N), the Mediterranean sea breeze (SB) dominates the flow north of the depression. An intense SB above 7 m s^{-1} (superimposed on the onshore 2.5 m s^{-1} synoptic flow within the boundary layer) had developed within the lower planetary boundary layer and had penetrated almost 10 km into the Qattara depression. The depth of penetration is indicated by the flow direction change associated with the SB front. On the other hand, in the lake simulation (Figure 4L), there is a sharp convergence zone between the Mediterranean SB and the lake breeze about 20 km north of the depression. The result is the establishment there of a narrow strip of calm winds. The lake breeze dominates the flow tens of kilometers south of the lake. Thermally induced upslope winds reinforce the lake breeze along the southern shore of the lake.

4.2. VERTICAL WIND VELOCITY

The vertical wind associated with the mesoscale forcing acts locally to weaken the existing upper layer thermally stable layer. In addition, the upward transport of moisture, under

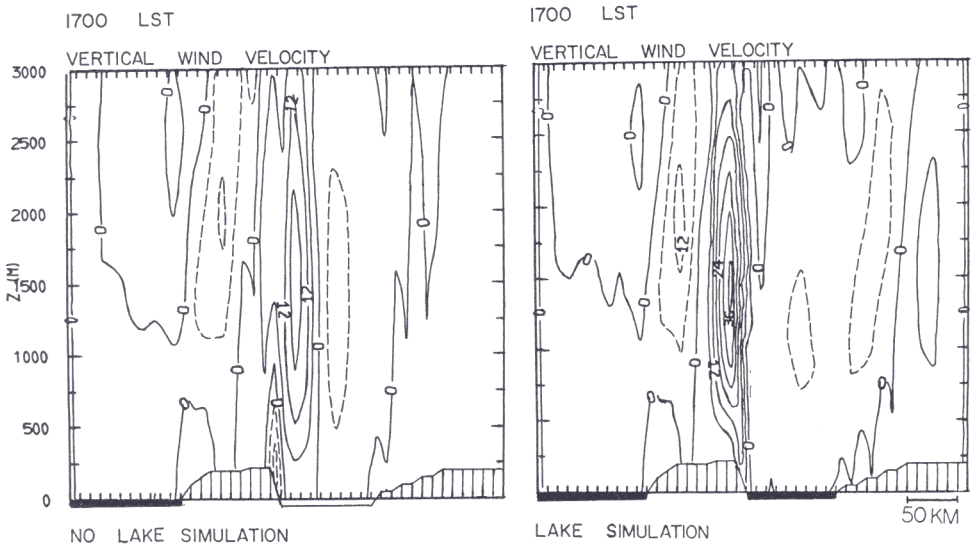

Fig. 5. Predicted vertical velocities (in cm s^{-1}) at 1700 LST along a north-south vertical cross section perpendicular to the Mediterranean (dashed contours indicate downward velocities). The topography is illustrated by a solid line, the water section of the Mediterranean and the 'hypothesized lake' are indicated by a heavier dark line.

such conditions, could cause some cloudiness to form. The aridity of this region and the strong and persistent ridging at upper levels during the summer, however, should prevent any extensive cloud formation during this season. Cloud formation treatment which has been incorporated into the current model (Kessler and Pielke, 1982) will enable the quantitative evaluation of this aspect in future studies.

The vertical velocities associated with the SB updraft cell in the no lake simulation are as high as 18 cm s^{-1} (Figure 5N). In the lake simulation (Figure 5L), the maximum vertical wind velocities are doubled where the Mediterranean and the lake sea breezes converge.

4.3. Temperature

In both simulations, an upper layer temperature inversion over the Mediterranean persisted throughout the entire simulation. Over the inland region, however, it diminished while moving onshore because of the well developed convective planetary boundary layer during the daylight hours (Figures 6N, 6L). In the lake simulation, some stable thermal stratification is induced over the lake because of the relatively cool surface water temperature (the resultant reduction in the sensible heat fluxes in the lake simulation yields a planetary boundary layer which is shallower over the depression area). No major changes in thermal stability aloft, however, are associated with the updraft cell in the lake simulation.

At the ground level, the cooling effect of the lake breeze is significant along the lake's northern boundary, as well as for a considerable distance south of the lake (Figure 6L). At the convergence zone of both the Mediterranean and lake breezes, some slight warming is observed because of the reduction in vertical mixing of heat as a result of the weak surface layer winds.

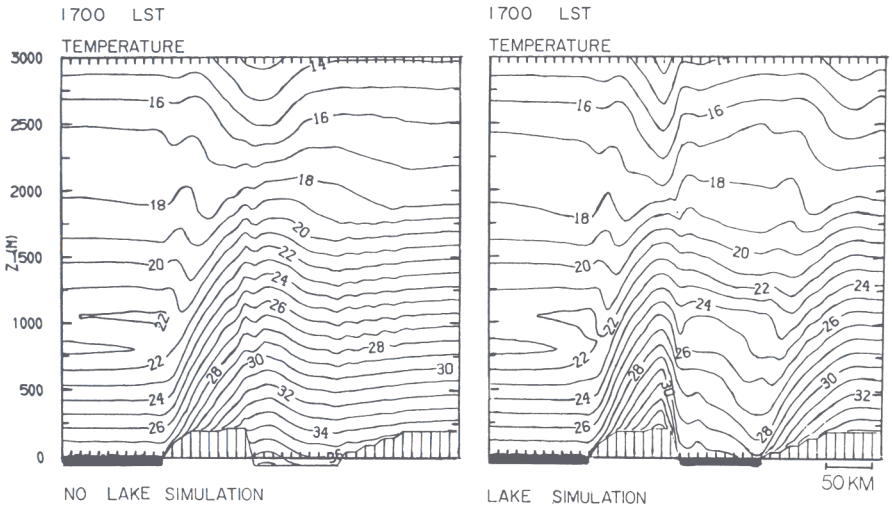

Fig. 6. The same as in Figure 5, except for temperature (in °C).

Observed July averaged maximum* temperatures of 30 °C at Alexandria, 37 °C at Bawiti and 38 °C at Siwa (*Climatological Atlas of Africa*, 1961) indicate the sharp contrast between the coastal area and the inland temperature regime in this region (the sites are indicated by A, B, and S, respectively, on Figure 1). Such a pattern is also predicted by the model.

It is worth noting that model predictions within the surface layer also enable the determination of biometeorological heat load conditions (namely, the possible stress imposed on humans due to such meteorological factors as air temperature, air moisture, solar radiation, and wind speed; qualitatively, the stress becomes worse as the first three parameters increase, or as the wind speed reduces), as described in Segal and Mahrer (1979) and Segal and Pielke (1981).

4.4. Specific Humidity

The specific humidity fields (Figures 7L, 7N) indicate the moistening effects at ground level due to the creation of a lake in the Qattara depression. In the no-lake case, the north-south distribution of the specific humidity at the ground level is similar to the averaged observed July pattern (*Climatological Atlas of Africa*, 1961). This pattern is significantly perturbed in the immediate vicinity of the hypothesized lake. Advection of moisture southward by the lake breeze is also evident. North of the lake, moistening is predicted as far inland as the location of the wind convergence zone.

In the upper layers, a well marked change from the 'no-lake' simulation occured at the 'lake' area. The induced mesoscale subsidence by the lake breeze circulation, in addition to reduced turbulence because of the thermally stable stratification there,

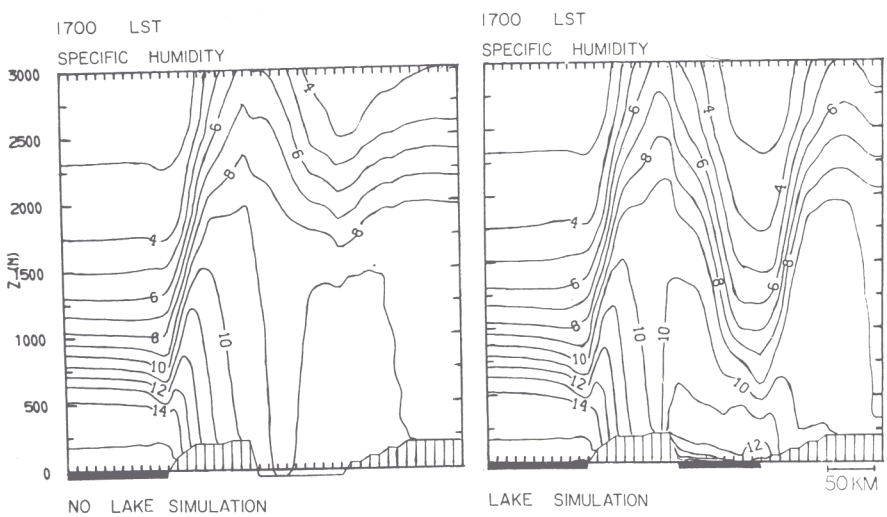

Fig. 7. The same as in Figure 5, except for specific humidity (in gr kg^{-1}).

* The maximum temperature in this region is typically around noon hour in the coastal area, while it occurs during the afternoon hours over the inland area.

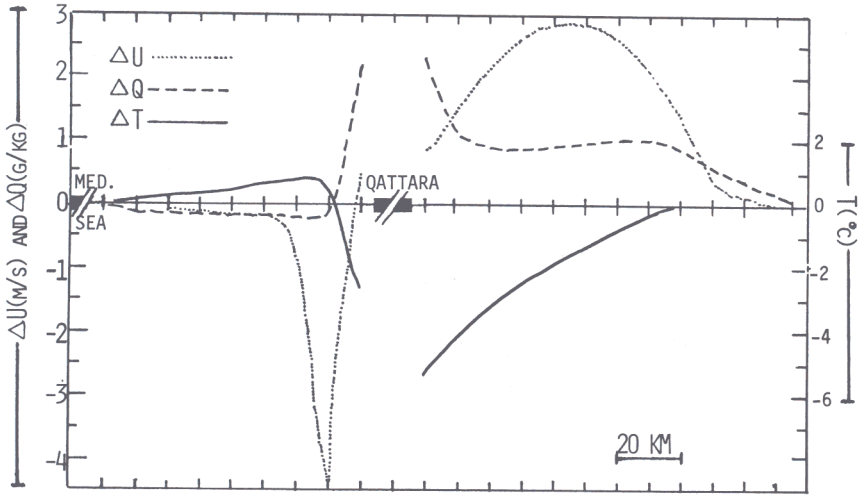

Fig. 8. Differences between both simulations in temperature (°C) and specific humidity (g kg^{-1}) at 2 m height, and of wind speed (m s^{-1}) at 10 m height (indicated by ΔT, ΔQ, and ΔU respectively), for 1700 LST.

created an accumulation of moisture in the lower levels. Consequently, moisture reduced considerably aloft. Over the narrow zone of the updraft cell in the lake simulation, only a slight moisture increase is predicted and is confined to lower than 2500 m.

4.5. Surface Modified Temperature, Moisture and Wind Speed

In order to emphasize the surface modified meteorological properties, differences between both simulations of temperature and moisture at 2 m level (the standard height of meteorological shelters) and the wind speed at 10 m were calculated (Figure 8). At the very near vicinity of the 'lake' these differences could not be resolved accurately with the current relatively coarse grid resolution of the model, and therefore are not given in that location. However, the illustrated trends of large decrease in temperature and increase in moisture near the 'lake', are likely even more enhanced very close to the 'lake'. With regards, for example, to the possible modification in the biometeorological heat load conditions in the region, the prominent meteorological parameters are the temperature and the wind speed (assuming no major changes in incoming solar radiation, and small effects of humidity changes in the relatively dry air). Hence, as indicated by Figure 8, a limited narrow area 15 to 30 km north of the 'lake' would attain more severe biometeorological heat load conditions due to the lighter winds in the 'lake breeze' convergence zone and the resultant increase of temperature in that location. Over a relatively extensive area south of the 'lake', however, conditions would be improved according to the model simulation. This pattern was found to be typical of the afternoon hours (that time period is regarded as the most inconvenient part of the day in the deep inland regions during the summer).

5. Conclusions

A preliminary numerical evaluation of potential climatic changes during the summer due to the conversion of the Qattara depression to a lake has indicated considerable changes in the horizontal and vertical wind, temperature and moisture patterns within the planetary boundary layer. The possible implications of such changes of the climate have been qualitatively evaluated. To the authors' knowledge, although there are no immediate plans for flooding this depression, experiments such as presented here can provide guidance as to the impact on the mesoclimate, if such a plan is determined to be feasible in the future. Applying such a model in its three-dimensional version, as well as incorporating a more detailed specification of the initial meteorological and soil characteristics, would refine the results. Simulations for other seasons, and pertinent synoptic conditions, could provide a comprehensive insight as to the expected climatic modification due to the flooding of the Qattara depression.

Acknowledgments

Acknowledgment is made to the Atmospheric Science Section of the National Science Foundation under Grant #ATM-8242931, and also to the Bi-National Israel United-States Science Foundation which supported one of the authors (Y.M.). Computer simulations presented in this study were performed at the National Center for Atmospheric Research, which is supported by the National Science Foundation. We wish to thank Adel Hanna and Robert Kessler for their comments and Patrick J. Michaels who provided us with helpful satellite data. We would also like to thank Sara Rumley and Ann Gaynor for editing and typing the manuscript.

References

Atwater, M. A. and Brown, Jr., P. S.: 1974, 'Numerical Calculations of Latitudinal Variation of Solar Radiation for an Atmosphere Varying Capacity', *J. App. Meteor.* **13**, 289–297.

Businger, J. A.: 1973, 'Turbulent Transfer in the Atmospheric Layer', *Workshop on Micrometeorology*, Amer. Meteor. Soc., 67–100.

Clarke, R. H.: 1970, 'Recommended Methods for the Treatment of Boundary Layer in Numerical Models', *Aust. Meteor. Mag.* **18**, 51–73.

Climatological Atlas of Africa, 1961: Jackson, S. P. (ed.), CCTA/CSA, Lagos-Nairobi.

Deardorff, J.: 1974, 'Three Dimensional Numerical Study of the Height and Mean Structure of Heated Planetary Boundary Layer', *Boundary Layer Meteor.* **7**, 81–106.

Griffiths, J. F. and Soliman, K. H.: 1972, *Climates of Africa*, World Survey of Climatology, Elsevier Publishing Co., **10**, 75–132.

Kessler, R. C. and Pielke, R. A.: 1982, 'A Numerical Study of the Effect of Latent Heat Release on the Airflow over a Mountain'. (In revision for *Monthly Weather Rev.*)

Mahrer, Y. and Pielke, R. A.: 1977, 'A Numerical Study of the Airflow over Irregular Terrain', *Contr. Atmos. Phys.* **50**, 98–113.

Mahrer, Y. and Pielke, R. A.: 1978, 'A Test of an Upstream Spline Interpolation Technique for Advective Terms in a Numerical Mesoscale Model', *Monthly Weather Rev.* **106**, 818–830.

Mahrer, Y. and Segal, M.: 1979, 'A Numerical Study of the Airflow over Israel Using a Two-Dimensional Mesoscale Model', Reprints 4th Conference on Numerical Weather Prediction, AMS, 256–258.

O'Brien, J. J.: 1970, 'A Note on the Vertical Structure of the Eddy Exchange Coefficient in the Planetary Boundary Layer', *J. Atm. Sci.* 1213–1215.

Pielke, R. A.: 1974, 'A Three-Dimensional Numerical Model of the Sea Breezes over South Florida', *Monthly Weather Rev.* **102**, 115–139.

Pielke, R. A. and Mahrer, Y.: 1978, 'Verification Analysis of the University of Virginia Mesoscale Three-Dimensional Mesoscale Model over South Florida for July 1, 1973. *Monthly Weather Rev.* **106**, 1568–1589.

Ramage, C. S. and Raman, C. V. R.: 1972, 'Meteorological Atlas of the International Indian Ocean Expedition', Vol. 2, Upper Air. Available from U.S. Government Printing Office, Washington, D.C. 20402.

Sasamori, T.: 1972, 'A Linear Harmonic Analysis of Atmospheric Motion with Radiative Dissipation', *J. Meteor. Soc. Japan* **50**, 505–512.

Segal, M. and Mahrer, Y.: 1979, 'Heat Load Conditions in Israel – A Numerical Mesoscale Study', *Int. J. Biometeor.* **23**, 279–284.

Segal, M. and Pielke, R. A.: 1981, 'Numerical Model Simulation of Human Biometeorological Heat Load Conditions – Summer Day Case Study for the Chesapeake Bay Area', *J. App. Meteor.* **7**, 735–749.

Segal, M., McNider, R. T., Pielke, R. A., and McDougal, D. S.: 1982, 'A Numerical Model Study of Regional Air Pollution Meteorology of the Greater Chesapeake Bay Area – Summer Day Case Study', *Atm. Env.* **16**, 1381–1397.

Synoptic weather maps: 1972, Part 1. 'Northern Hemisphere Sea Level and 500 mb Charts', NOAA, Environmental Data Service.

(Received 5 February, 1982; in revised form 19 April, 1982)