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CASE STUDY FOR PREDICTING EXTREME WEATHER PHENOMENON OVER CAIRO

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ABSTRACT- During the last few years the development of a second-generation of numerical weather prediction modeling system (Egypt-Eta) has been completed at Cairo numerical center. The Egypt-Eta includes improved formulation of boundary layer based on

a- Level 2.5-closure model of Mellor-Yamada hierarchy for simulating mixed layer.
b- Level-2 closure model for simulating surface layer.
c- Four layer under ground including soil texture

The model contains 32 vertical levels, eight of them for representing dynamical process in Planetary Boundary Layer (PBL). Diurnal variations have been tested and simulated in different situations for different range of stratifications starting from weak to strong stable or unstable and neutral atmospheric conditions. In the present work we selected extreme case representing a strong stable atmospheric condition where a case of dense smoke phenomenon-covering Cairo at 12/11/1999.

The model gives good capability for predicting the atmospheric stability parameters for heat and momentum flux. In addition the height of PBL and the inversion height in case of stable atmosphere are well captured. So, the model can be used as a monitoring for the extreme atmospheric events by adding model equations to simulate three-dimensional dispersion of a chemically inert pollutant.

Introduction

The greater Cairo about 16,000,000 inhabitants is facing, like most big cities in the world, serious air pollution problems. The rapid increase in population, large industrial areas, many traffic jam, and commercial activities resulted in high air pollution levels during the last years. The combined result of the horizontal and vertical pattern has generally caused this problem. For example, rapid updrafts are effective in venting the boundary layer and dispersing air pollutants through many kilometers in tens of minutes, downdrafts can be effective in bringing tracers from the middle troposphere to the surface levels, these mechanisms lead to a more polluted boundary layer and/or surface. During the last autumn the concentration of the smoke pollution was increased as a result of burning rice by the farmers in the areas surrounding Cairo. Observations must be coupled with Numerical Model (NM) simulation to clarify such problem. The meso-scale primitive model developed in Cairo center during the last years has been used to

1- Simulate the weather pattern dominant during two sequent days one with high concentration followed by one of low concentration.
2- Study the weather elements causing this problem.

1-Experimental Design

The model employed to simulate the smoke days is based on the Egypt-ETA model running operationally at NWP center twice a day for predicting the extreme cases of weather phenomenon in Cairo.

I-Model Description

The model is based on the hydrostatic primitive equations, using a generalized vertical coordinate, η which follow the orographic structure (Simmons, A.J. and Burridge 1981). In the hybrid system a linear relation between η and the atmospheric pressure ,P is defined as follow;

$P(\eta) = A(\eta) + B(\eta) * P$

Where $A(\eta) = P_o \eta$, $B(\eta) = 0$ **for** $0 \le \eta \le \eta_T$

$$A(\eta)=\frac{P_oP_T}{P_o-P_T}(1-\eta)\ ,\ B(\eta)=\frac{P_o\eta-P_T}{P_o-P_T}\ ,\ \eta_T\le\eta\le 1$$

$$P_O=1000\ hpa \qquad ,\ P_T=1000\ hpa$$

P_T, Ps and are pressure at the top and the surface of the model , P_0 is slandered pressure

The forecasting equation in vertical coordinate $\eta(p,p_s)$ where $\eta(0,P_S)=0$ and $\eta(P_S,P_S)=1$.

The basic prognostic variables are: surface pressure, temperature, specific humidity, liquid cloud water , u and v wind components and twice the turbulent kinetic energy, as required by the closure of turbulent scheme. The complete set of the equation solved in the model is given in Yousef (2000). The model vertical structure is consisted from 32 level, 8 from them are under 1500m, in addition to 4 soil of depth at 10, 20, 50, and 100 cm. So it well represents all the processes occurring in the (PBL). The model uses an E-staggered horizontal grid with resolution 0.24°*0.32° lat./long (25x25 km^2) coordinates.

Description of the physical parameterizations are summarized here as follows:

II-BOUNDARY LAYER MODEL

A one-dimensional model is used to solve the fundamental equation of momentum ,heat fluxes as well as variance of velocity and heat to simulate the turbulent structure of atmospheric boundary layer in different situations .The model used here is considered as Mellor and Yamada (1974) and (1983) 2.5 closure model which contain prognostic equation for turbulent kinetic energy and diagnostic equations for other turbulent fluxes.

The MODEL EQUATIONS

$$\frac{D}{Dt}\left(\frac{q^2}{2}\right)-\frac{\partial}{\partial z}\left[lqs_q\frac{\partial}{\partial z}\left(\frac{q^2}{2}\right)\right]=P_s+P_b-\varepsilon \qquad (1)$$

$$P_s=-\overline{uw}\frac{\partial U}{\partial z}-\overline{vw}\frac{\partial V}{\partial z}$$

$$P_b=\beta g\overline{w\theta}$$

$$\varepsilon=\frac{q^3}{\Lambda_1}$$

$$S_q=0.2$$

S_q is chosen to optimize the model result form experimental data at neutral boundary layer flow.

$$\overline{u\upsilon}=\frac{3l_1}{q}\left[-\overline{uw}\frac{\partial V}{\partial z}-\overline{\upsilon w}\frac{\partial U}{\partial z}\right] \qquad (2)$$

$$\overline{wu}=\frac{3l_1}{q}\left[-\left(\overline{w^2}-Cq^2\right)\frac{\partial U}{\partial z}+\beta g\overline{u\theta}\right] \qquad (3)$$

$$\overline{w\upsilon}=\frac{3l_1}{q}\left[-\left(\overline{w^2}-Cq^2\right)\frac{\partial V}{\partial z}+\beta g\overline{\upsilon\theta}\right] \qquad (4)$$

$$\overline{w\theta}=\frac{3l_2}{q}\left[\overline{w^2}\frac{\partial\Theta}{\partial z}+\beta g\overline{\theta^2}\right] \qquad (5)$$

$$\overline{\theta^2}=-\frac{\Lambda_2}{q}w\theta\frac{\partial\Theta}{\partial z} \qquad (6)$$

Algebraic solution of the system (1)-(6) has facilitated by the introduction of the *two independent* dimensionless variables G_M,G_H

$$G_M = \frac{l^2}{q^2}\left[\left(\frac{\partial U}{\partial z}\right) + \left(\frac{\partial V}{\partial z}\right)^2\right]$$

$$G_H = -\frac{l^2}{q^2}\beta g \frac{\partial \Theta}{\partial z}$$

$$-\overline{uw} = k_m \frac{\partial U}{\partial z} \quad , -\overline{\upsilon w} = k_m \frac{\partial V}{\partial z} \quad , -\overline{w\theta} = k_h \frac{\partial \Theta}{\partial z}$$

$$k_m = l q S_m \quad , k_h = l q S_h$$

Equations (1)-(6) has solved algebraically by considering G_M,G_H as independent variables since they represent the large scale flow .

then the solutions of the unknown turbulent stress are :

$$S_M = A_1 \frac{\phi_3 - 3C_1\phi_4}{D} \quad (7)$$

$$S_H = \frac{1}{3}\frac{N}{D} \quad (8)$$

$$\frac{w^2}{q^2} = \frac{1}{3}\frac{\phi_1 N}{D} \quad (9)$$

where U_i is the mean velocity $\check{U}(U,V,W)$, q^2 is turbulent kinetic energy.

u , v , w , and θ are the fluctuating component of velocity , and temperature

$\overline{u_i u_j}$, $\overline{u_i \theta}$ are turbulent fluxes for momentum and heat .K_H , S_H , k_M , S_M are eddy diffusivity and stability parameter for heat and momentum respectively

$$\phi_1 = 1 - 3A_2B_2G_H$$
$$\phi_2 = 1 - 9A_1A_2G_H$$
$$\phi_3 = \phi_1 + 9A_1^2G_H$$
$$\phi_4 = \phi_1 - 12A_1A_2G_H$$
$$\phi_5 = \phi_1 - 18A_1A_2G_H$$
$$N(G_M, G_H) = \phi_2 + 18C_1A_1^2G_M$$
$$D(G_M, G_H) = \phi_2\phi_4 + 6A_1^2\phi_3G_M$$

$$u_* = \sqrt{\rho\,\overline{uw}_s}$$

u_* horizontal momentum flux at the surface or friction velocity.

Since PBL is characterized by a series of physical process that causes the day time change from stable PBL to neutral or convective PBL. This process must be described correctly to get reliable results for its calculation ,this can be achieved by using a suitable parameterization in PBL turbulent fluxes. The parameterization of PBL in numerical weather prediction NWP model consists of the computation of the surface fluxes and their vertical distribution at various levels in the PBL. Predicting turbulent fluxes as well as the mixing height are important parameters for environmental monitoring as well as the prediction of pollutant concentration, especially the mixing height because it defines the height to which pollutants released at the ground are vertically dispersed by convection or mechanical turbulence which has certain time scale of about one hour or less ,so reliable value of the mixing height are needed .The mixing height is defined as the lowest level model at which the Turbulent Kinetic Energy (TKE) reaches its minimum value.The performance of the –PBL scheme in NWP model is evaluated by analyzing the simulation results of large scale fields ,it is also equally important to analyze the performance at individual points of the model which represent the final output of the model, it is helpful to analyze the simulation of different situations to test the capability of the model to provide accurate distribution of turbulent fluxes and PBL height .

III-Soil model

For the computation of the ground conditions, the atmospheric model is coupled an active four-layer soil model and a primitive plant canopy model (pan and Mahrt, 1991). Using this scheme for calculations the soil temperature and moisture proceed at four layers at 10,20,50 and 100 cm. The thermal conductivity is defined as (Pielke, 1984) from

$$DF_{soil} = \{420 \; . \exp\left(-\left(P_f + 2.7\right)\right) \quad , P_f \leq 5.2 \}$$

$$DF_{soil} = \{420 \; . \exp\left(-\left(P_f + 2.7\right)\right) \quad , P_f \phi \; 5.2 \}$$

$$Where \qquad P_f = \log\left[\Psi_s \left(\frac{SMC_{sat}}{SMC}\right)^b\right]$$

Ψ_s is the moisture potential for saturated soil representing the potential energy needed to extract water against capillary and adhesive forces in the soil. In this model, the vertical soil moisture gradient between the top and the lower soil layer is calculated using the definition of soil water diffusivity and hydraulic conductivity by Clapp and Hornberger(1978).

a} Bare soil: by solving the surface heat energy balance equation, the surface skin temperature and soil heat flux at the top layer thickness equal to 10 cm. The direct evaporation rate is calculated with the plant shading taken in consideration.

b) Vegetated surface: vegetation cover significantly influences the infiltration and evaporation processes. In case of light rainfall over vegetated areas, much of rainwater can be intercepted by the leaves and re-evaporated directly without ever reaching the ground. The effects of vegetation cover on the absorption of the solar radiation and exchange of sensible heat are considered. The total evaporation (from soil and canopy surface) is calculated. For reduction in transpiration due to internal plant physiology, the soil model uses a plant coefficient (Pc), which depends on the canopy resistance, incoming solar radiation, air temperature, and atmosphere water vapour pressure deficit at the lowest model level and soil moisture availability. It is calculated by using (Noilhan and Planton, 1989) method.

IV-Radiative transfer

The radiative transfer package of Egypt-ETA is that of GFDL scheme. It performs separate calculations of temperature tendencies, long-wave and short wave, upward and downward fluxes under clear and cloudy sky conditions.

The short wave includes absorption by O_3, CO_2, and water vapor in the near ultra-violet visible and near infrared spectral regions using 12 bands to cover the solar spectrum. The transmission function and absorption for water vapor and O_3 given by Lacis and Hansen (1974). The transmission function due to the absorption of solar radiation by CO_2 is given by Sasamari(1972). Various cloud affects are included with Raleigh scattering by the clear atmosphere and multiple scattering by cloud droplets ,which is calculated layer by layer, are considered. Infrared radiative transfer calculation includes contributions of CO_2, O_3, H_2O and clouds. Falls and Schwarzkopf (1975) introduced the simplified exchange approximation, which produces accurate and rapid computations of infrared cooling rates and fluxes. The Egypt-ETA model include the updated version of the radiation scheme is described by Schwarzkopf and Fels (1991). It includes 15 combined frequency bands to calculate the emmisivities and cooling/heating rates.

V-Simulation and discussion:

The model integration has been performed on a domain extending from 10°w to 50°E and 10°N to 50°N with horizontal resolution 0.24°*0.36° lat./long. On Arakawa E-grid, 32 level in the vertical with 8 level under 1500m and 4 soil level to have good representation of the processes in the PBL layer. The initial and lateral boundary conditions, necessary for the simulation, have been extracted from NCEP archive of the analysis on ten standard pressure levels, from 1000 to 100 hPa, at 1.25°*1.25° degrees horizontal resolution. The boundary conditions have a time resolution of 6 hours.

The model integration started at 00 GMT up to 48 hour forecast to cover the period from 12/11/1999 to 13/11/1999 was chosen to represent 2 days of the smoke episode, which affected Cairo. The first day shows a high concentration of pollutants, while the second day , the concentration decreased. Various measurements were taken from separate places in Great Cairo as shown in figure (5-8). The analyses and simulated charts show that the country was affected by a high pressure whose center was found in south Europe with a value of 1025 mill bars in the direction of the northwest of Cairo and also by extension of low pressure Sudan in the direction of northeast. The velocity of the wind reached 3 m/sec in the direction from north to north east and decreased to less than 2 m/sec during night. In the upper air , Cairo was existed behind the trough line which an area of downward motion enhanced the concentration of the pollutants in the planetary boundary layer (PBL) due to reduction of PBL height to shallow thickness .To illustrate the factors affecting the increase of the pollutants in this period we will represent the results obtained from the numerical model . Figures (1-4)show the vertical profile of temperature distribution ,vertical turbulent motion w_* and the time series of variation boundary layer height (mixing height) ,turbulent eddy stress or friction velocity .To clarify the factors affecting the increase of concentration in PBL It is shown from figure (1) which represents that the PBL height is around 148-300 meters at 5:00 PM on 12/11/1999 local time, to 8 AM on 13/11/1999,which considered as long period of shallow PBL height ,while increasing during the day time to 1150 m under decrease the stability as appeared from fig (1) due to convection motion fig(4-a,b). Fig(2-a,3-a) show that the strength of the heat inversion reach 4.7 C° and temperature gradient 4.7/470 C°/m without any kind of turbulence while Fig(3-a)show that the temperature gradient on 13/11/1999 reach 3.7/1290 C°/m which lead to increased the vertical turbulent motion and the downward large scale motion associated with the decrease of stability. This gave the pollutants the chance of dispersion to higher levels of the boundary layer which agree with the measurements shown in figure (9).During daytime ,we notice that the vertical turbulent motion increased a large amount due to the convection motion which lead to the dispersion of the pollutants to higher layers reducing its concentration a great amount. Table (1) shows the vertical profile for temperature measured by radio sonde at (0200AM on13/11/1999) which agree the model output (154 m). Table (1) shows vertical profiles for temperature °at 00 and 1200 Universal time

Table (1)

12/11/1999 at time 1200 | 12/11/1999 at 00

H	T	TD	Pressure	H	T	TD	Pressure
0	18	15.4	9999.9	0	24.8	17.2	9999.9
152	17.2	5.5	1000	804	16.5	7.8	925
820	15.6	5.7	925	1524	10.3	4.6	850
1531	9.8	3.9	850	3113	2.1	7.5	700
3111	3.7	31.5	700				

13/11/1999 at 1200 | 13/11/1999 at 00

H	T	TD	Pressure	H	T	T	Pressure
0	33.8	16.6	9999.9	0	17.6	15	9999.9
149	23.2	14.1	1000	163	17.7	3.	1000
808	15.7	8.1	925	806	14.3	4.	925
152	9.3	4	850	153	9.9	7.	850
3128	4	23.7	700	312	3.1	16	700

The model integration started at 00 GMT of 12 Nov. 1999, which has high concentration of smog episode were observed, up to 48 hour forecast. Fig. (5,6 ,7and 8) show the analysis of the mean sea level pressure and 500 hPa at 00GMT 12 NOV. 24 and 48 hour forecast.

VI-Conclusion

The persistent system occurs during the months of Oct. and Nov. 1999, which consists from subtropical high extended over the southern part of Europe and Mediterranean, Sudan monsoon low and weak upper trough. This system associated with weak horizontal wind and downdraft helps in the development of mixed inversion layer from the late of the day and extended to the early Morgan of the next day for at least 10-hour. In such cases the ventilation is poor, the PBL is shallow and the air pollution potential increases. So, the hour of the start of the inversion and its duration must be taken in the calculation and forecast of pollution concentration

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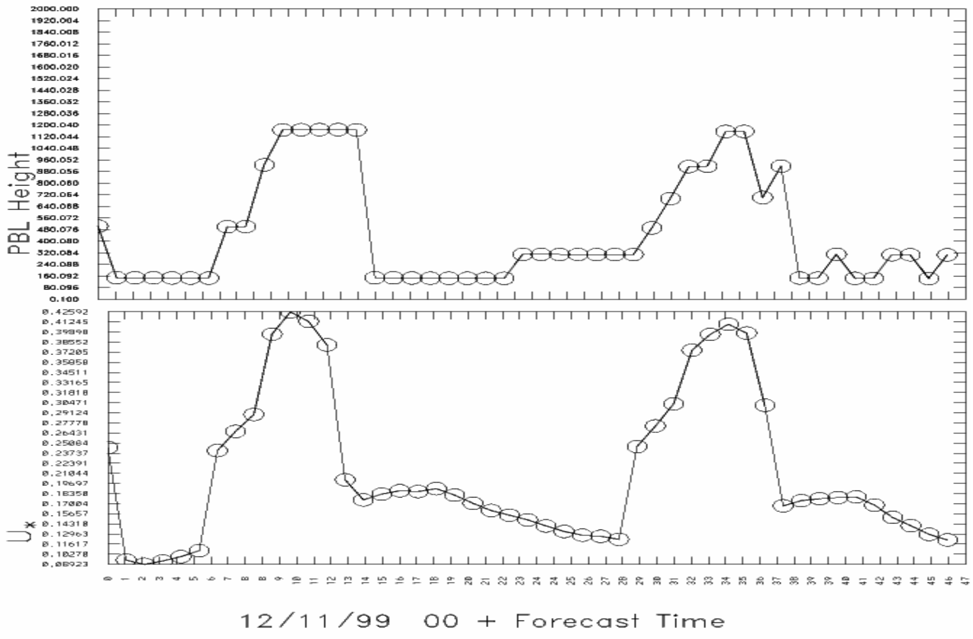
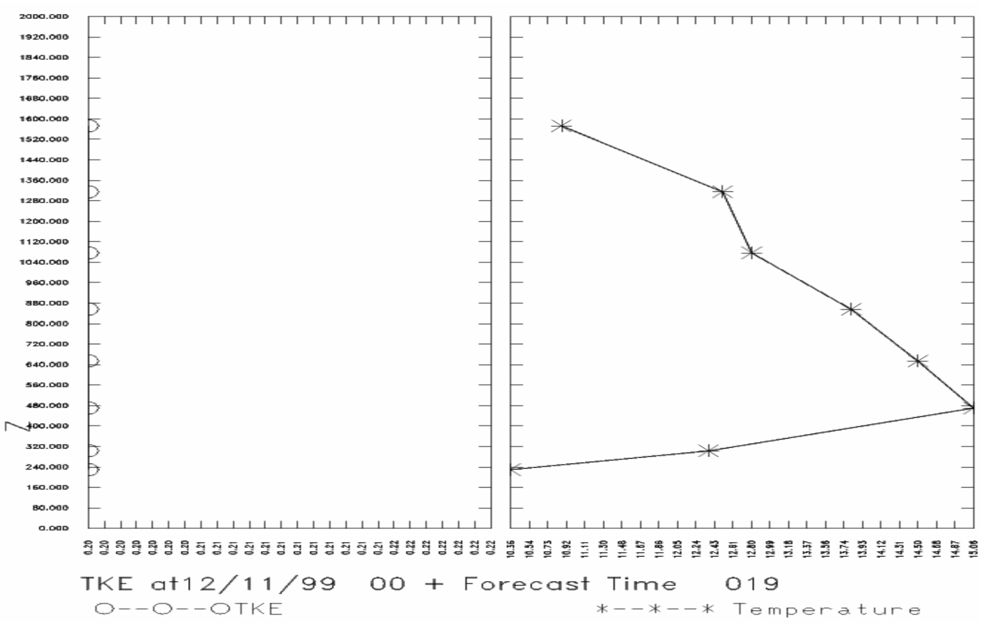
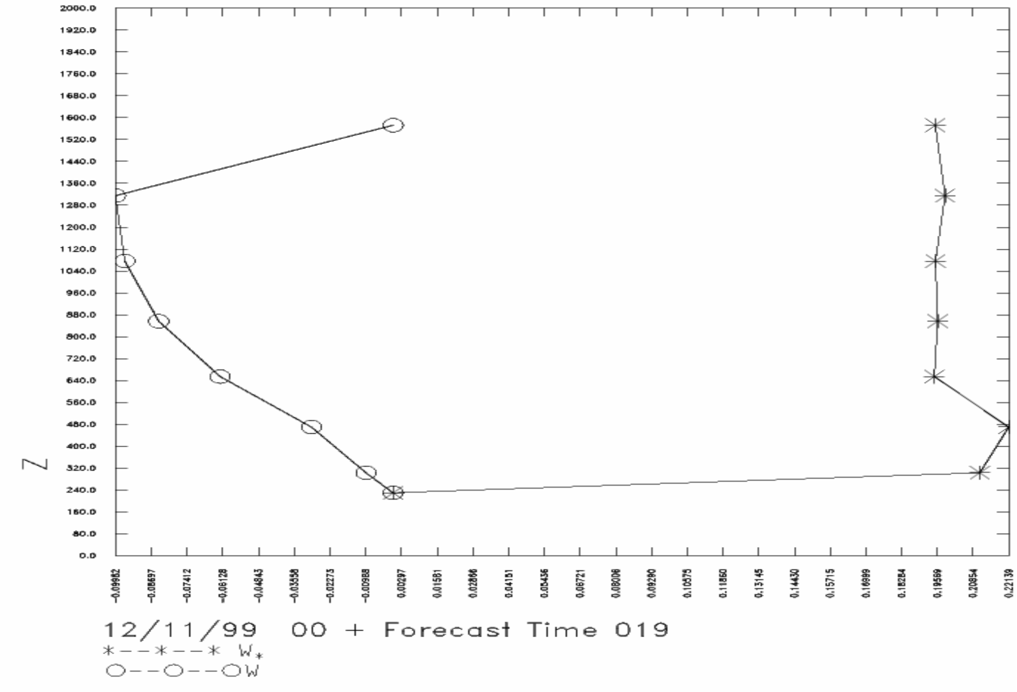

PBL Height
U*
12/11/99 00 + Forecast Time

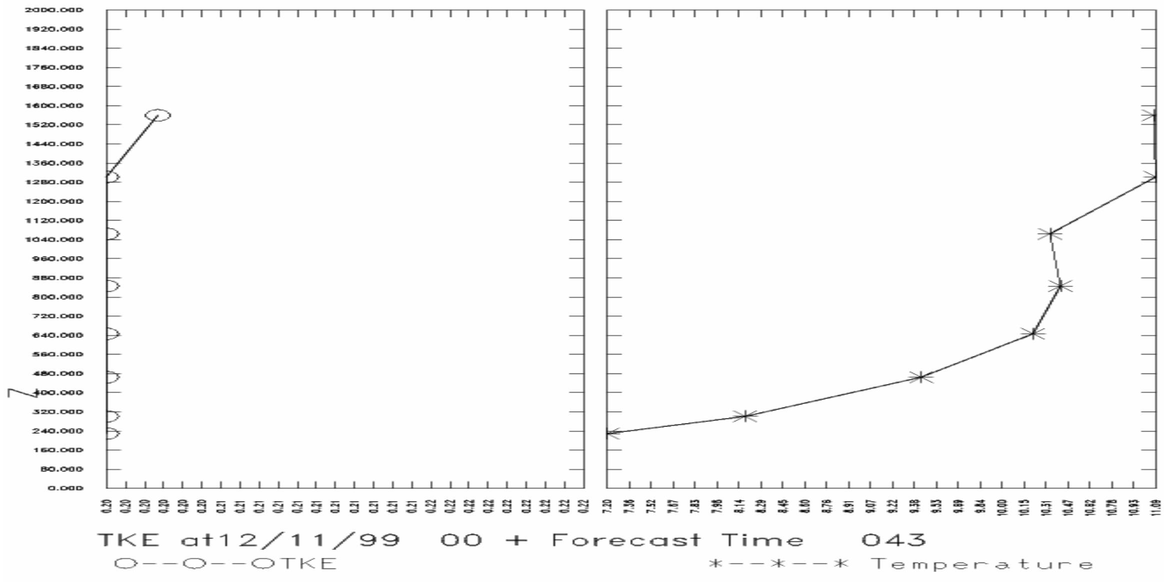
Fig(1)


Z
TKE at12/11/99 00 + Forecast Time 019
O--O--OTKE
----* Temperature

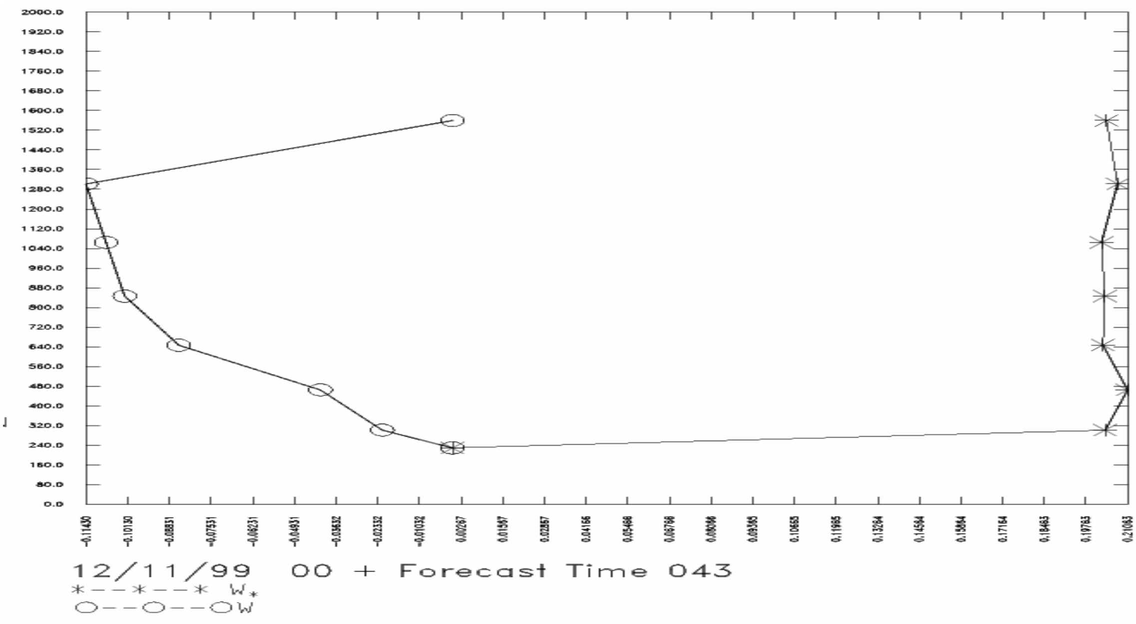
Fig(2-a)


Z
12/11/99 00 + Forecast Time 019
----* W*
O--O--OW

Fig(2b)


Z
TKE at12/11/99 00 + Forecast Time 043
O--O--OTKE
----* Temperature

Fig(3a)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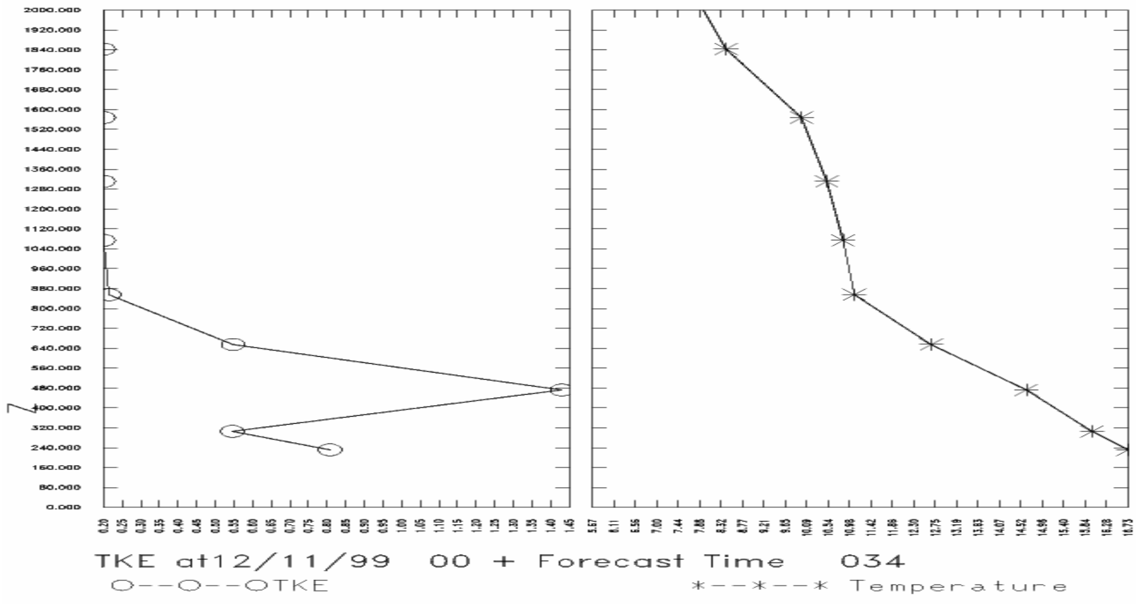
----* W*
O--O--OW

Fig(3-b)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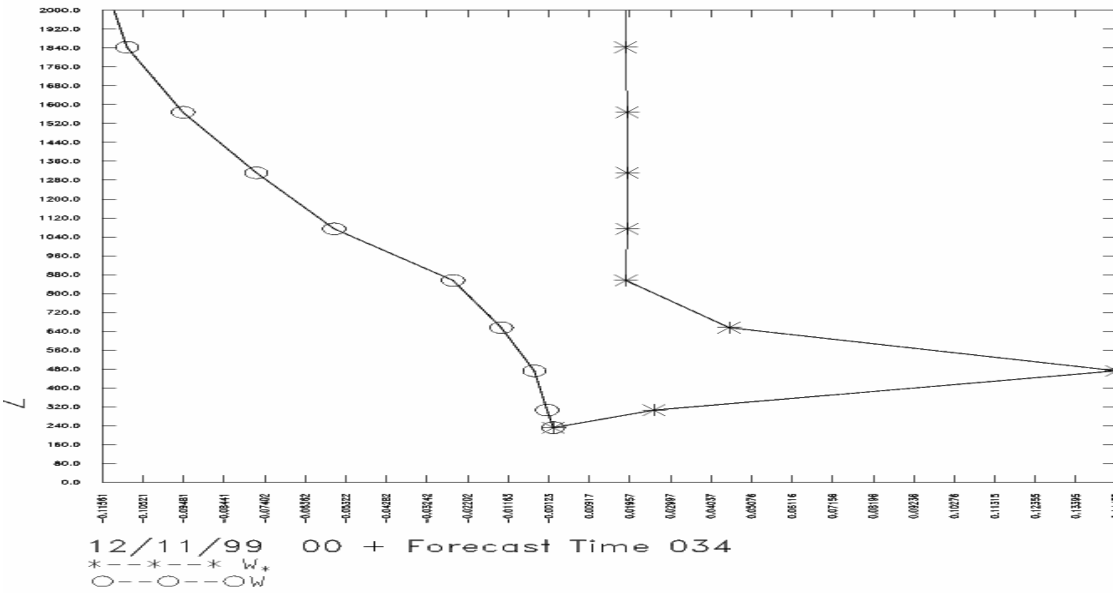
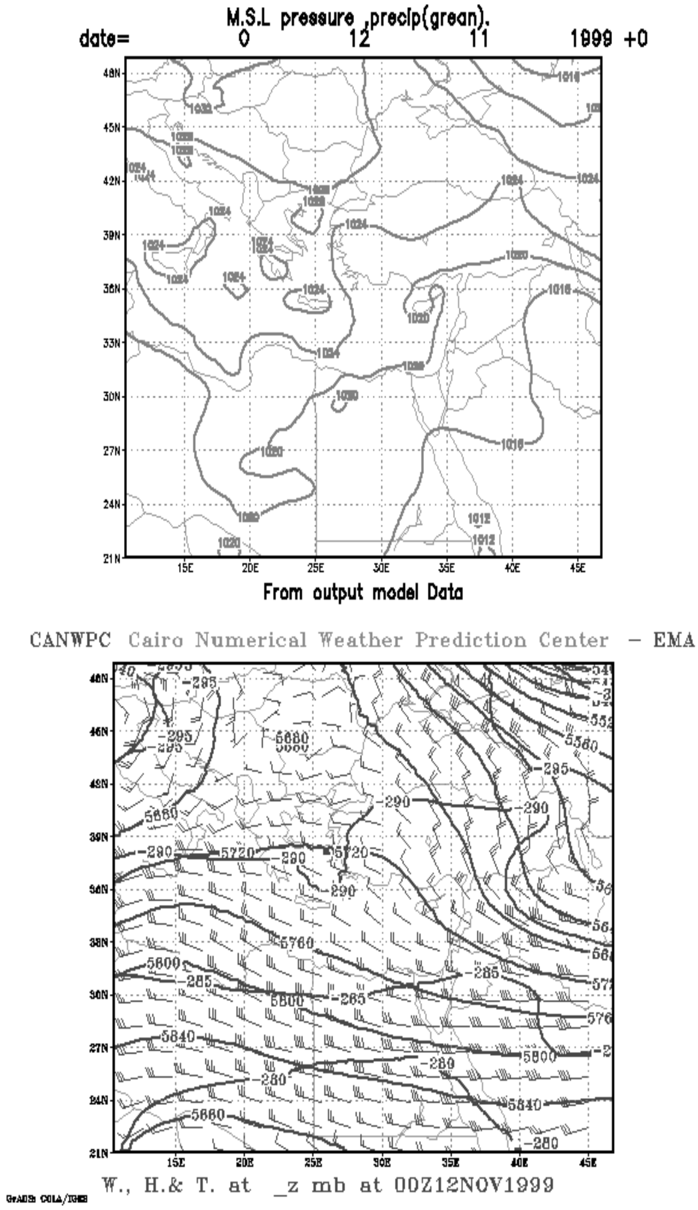
O--O--OTKE
----* Temperature

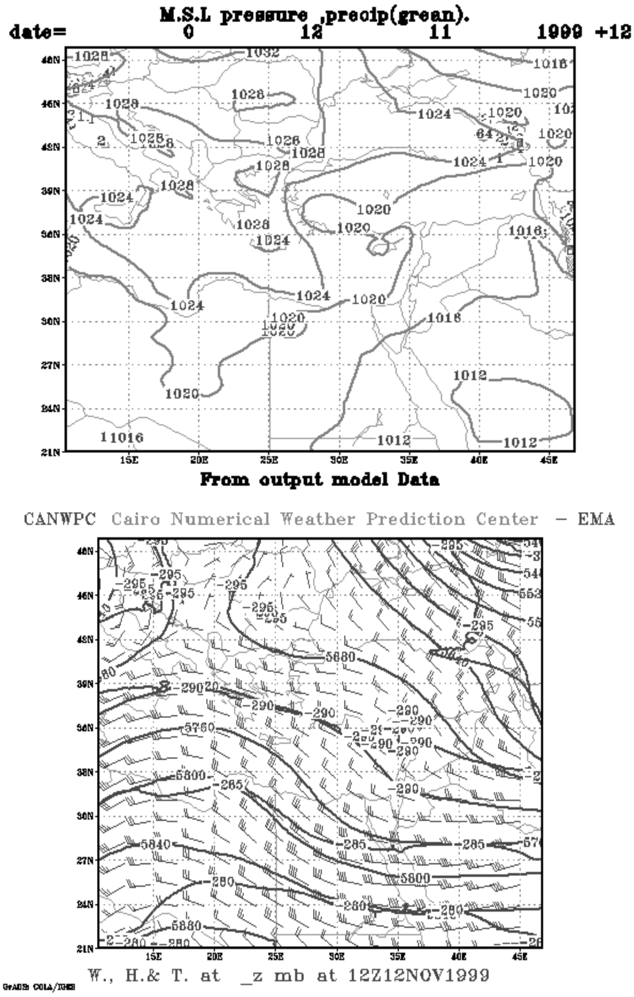
Fig(4-a)



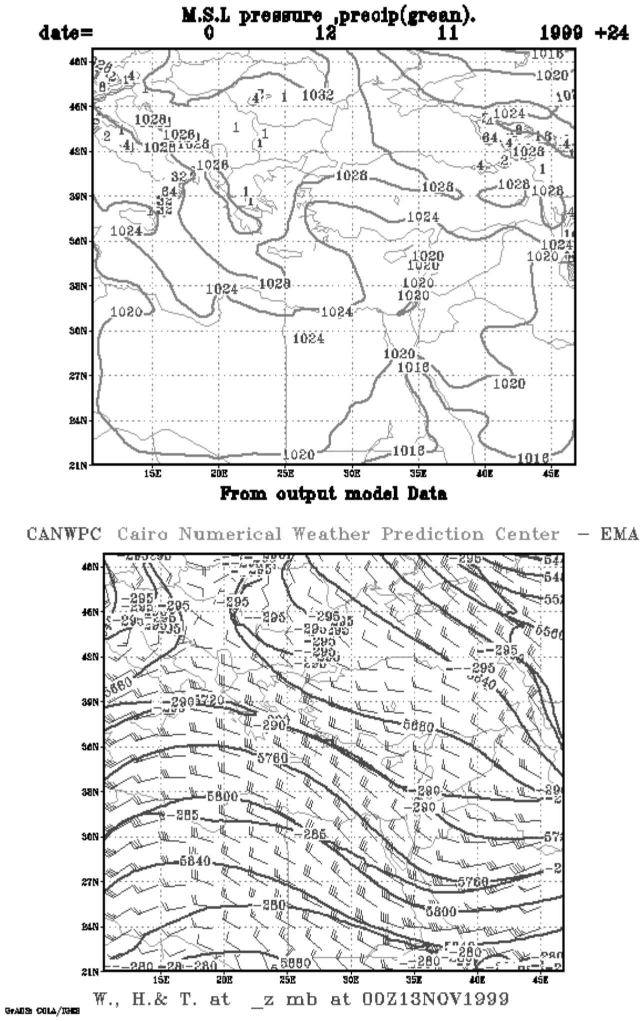
Fig(4-b)


M.S.L pressure ,precip(grean).
date= 0 12 11 1999 +0
From output model Data
CANWPC Cairo Numerical Weather Prediction Center - EMA
W., H.& T. at _z mb at 00Z12NOV1999

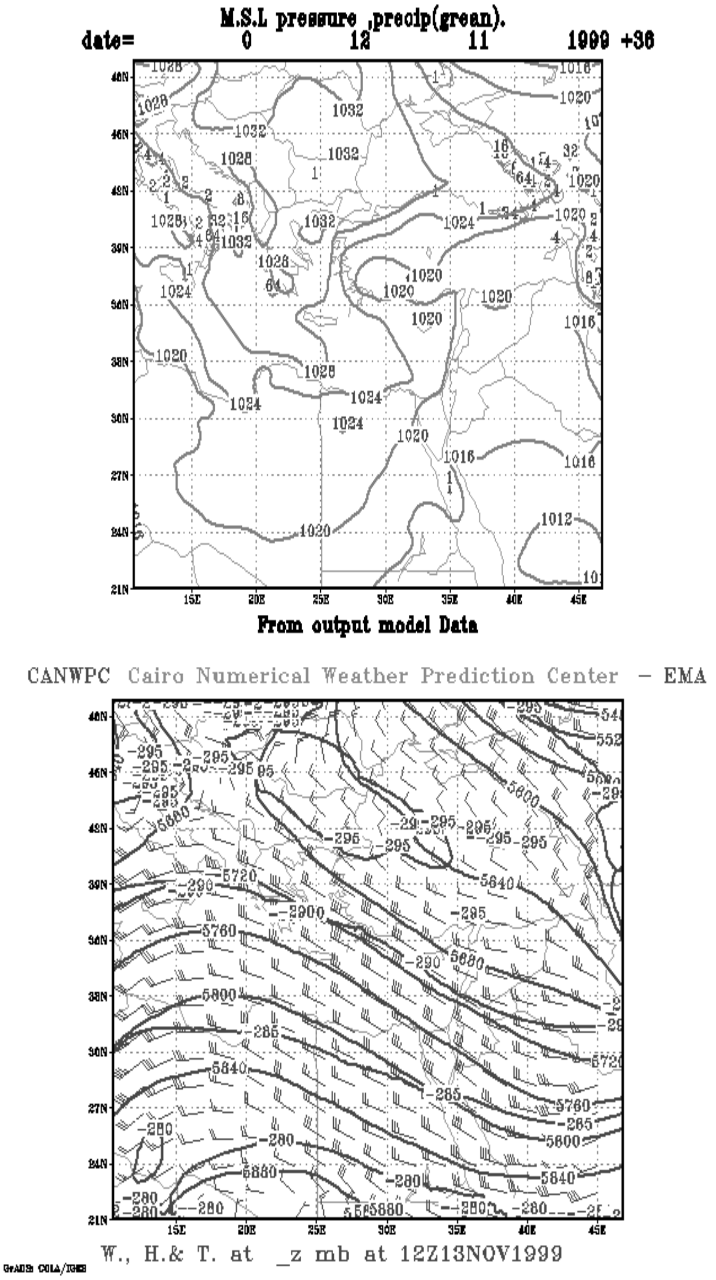
Fig(5)


M.S.L pressure ,precip(grean).
date= 0 12 11 1999 +12
From output model Data
CANWPC Cairo Numerical Weather Prediction Center – EMA
W., H.& T. at _z mb at 12Z12NOV1999

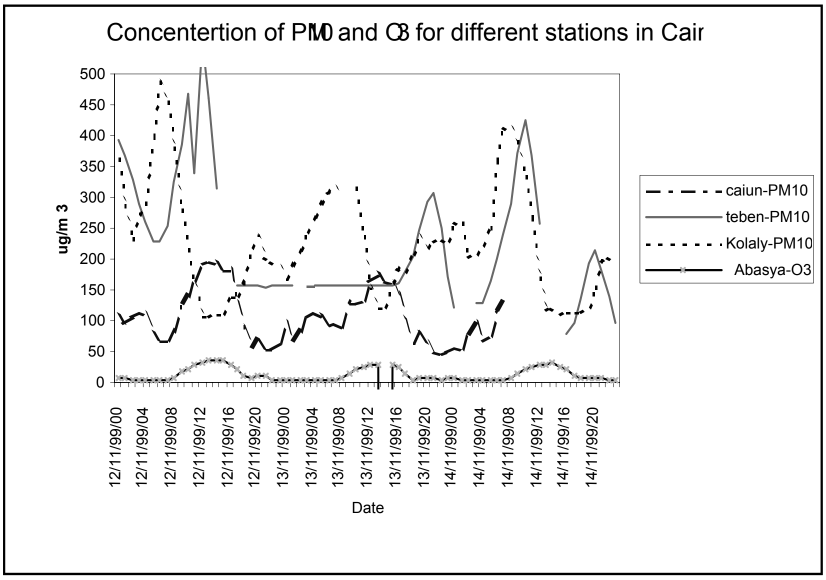
Fig(6)


M.S.L pressure ,precip(grean).
date= 0 12 11 1999 +24
From output model Data
CANWPC Cairo Numerical Weather Prediction Center – EMA
W., H.& T. at _z mb at 00Z13NOV1999

Fig(7)


M.S.L pressure ,precip(green).
date= 0 12 11 1999 +36
From output model Data
CANWPC Cairo Numerical Weather Prediction Center – EMA
W., H.& T. at _z mb at 12Z13NOV1999

Fig(8)


Concentertion of PM10 and O3 for different stations in Cair
500
450
400
350
300
250
200
150
100
50
0
ug/m 3
12/11/99/00
12/11/99/04
12/11/99/08
12/11/99/12
12/11/99/16
12/11/99/20
13/11/99/00
13/11/99/04
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13/11/99/20
14/11/99/00
14/11/99/04
14/11/99/08
14/11/99/12
14/11/99/16
14/11/99/20
Date
caiun-PM10
teben-PM10
Kolaly-PM10
Abasya-O3

Fig(9)