

Simulation of Some Air Pollutants and Weather Parameters Using WRF/Chem Model in Cairo and Qena Cities/ Egypt

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Abstract Weather Research & Forecasting/ Chemistry model (WRF/Chem) has been used for simulation of air pollutants and weather parameters in Cairo (urban) and Qena (suburb) regions/ Egypt. Surface ozone (O_3), Nitrogen oxides (NO_x) and Nitrogen dioxide (NO_2) as well as Wind speed (WS), Wind direction (WD) and Temperature (T) have been simulated in Cairo. While in Qena, only (O_3), (WS), (WD) and (T) have been simulated. Different prediction performance measures have been used to assess the accuracy of estimation of these parameters. The study showed that the model can simulate the diurnal variation of ozone in Cairo better than that in Qena, although the best quantitative estimates of ozone were found in Qena. The model failed in quantitative and qualitative estimation of NO_x and NO_2 in Cairo as these pollutants affected directly by traffic intensity. The model estimated the weather parameters in acceptable accuracy in both Cairo and Qena especially WS and T. It is clear that WRF/Chem model cannot generally simulate the chemical parameters in high polluted regions such as Cairo. This may be resulted from the coarse resolution used for the input meteorological and emission data (1° latitude X 1° longitude). While, it can be used safely in rural and suburban regions such as Qena. Using fine coarse resolution for meteorology and emission data may improve the results.

Keywords WRF/Chem Model, Simulation, Air Pollutants, Weather Parameters, Cairo, Qena

1. Introduction

Recently, concentration of gaseous, liquid and solid pollutants has been increased in the atmosphere as a result of urbanization and increasing of population [1, 2, 3]. This increase may be lead to undesired environmental and climatic effects. Consequently, the need for measuring these pollutants (such as NO_x , NO_2 , O_3 and PM10) as well as the meteorological parameters affecting its concentrations such as WS, WD and T has been increased. Unfortunately, measurement networks cannot be established in all the necessary locations, especially in the development countries. So that, the need for estimating these parameters by using some established models became necessary.

Weather research and forecasting (WRF/Chem) model has been used in many studies for estimating and studying meteorological and chemical parameters for instance [4, 5, 6]. It has been developed as a collaborative effort among several research institutes including the NCAR Mesoscale and Microscale Meteorology (MMM) Division, the National

Oceanic and Atmospheric Administration's (NOAA) National centers for Environmental Prediction (NCEP) and Forecast System Laboratory (FSL), the Department of Defense's Air Force Weather Agency (AFWA), and Naval Research Laboratory (NRL), the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), along with the participation of a number of university scientists [7]. A detailed description of the WRF model can be found on the WRF web-site <http://www.wrf-model.org/index.php>.

In this paper we used WRF/Chem model version 2.1 to estimate some chemical and meteorological parameters in two different cities in Egypt, Cairo as a representative of urban region and Qena as a representative of suburb region. Performance of the model for estimation of O_3 , NO_x and NO_2 and the weather parameters WS, WD and T in Cairo and O_3 , WS, WD and T in Qena will be studied using the data recorded during July 2003.

2. Locations Description

As shown in figure 1, Cairo city (30.10° N, 31.29° E, 34 m) is located north of Egypt, about 120 km south of the Mediterranean Sea coast, between two hills of about 200 m height forming a valley through which the Nile River flows.

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The valley may affect the prevailing northerly wind by channeling it along the north south axis[8]. The meteorological situation of Cairo is largely determined by the vast surrounding desert; the west and the east deserts. Cairo city is highly populated; its inhabitants are more than 15 millions. About 52% of the industries and about 40% of electrical power stations in Egypt are found in Cairo. Consequently, it is considered as one of the most polluted mega cities in the world[9]. It characterized with narrow streets and high buildings, more than 1.5 million cars with the industrial regions represent the main sources of air pollution. In the other hand, Qena (26.20° N & 32.75° E) is a small city located about 600 Km south of Cairo. Its area is about 1,800 km², situated on the east bank of the Nile. Its climate is characterized by cold winter, and very hot but non-humid summer.

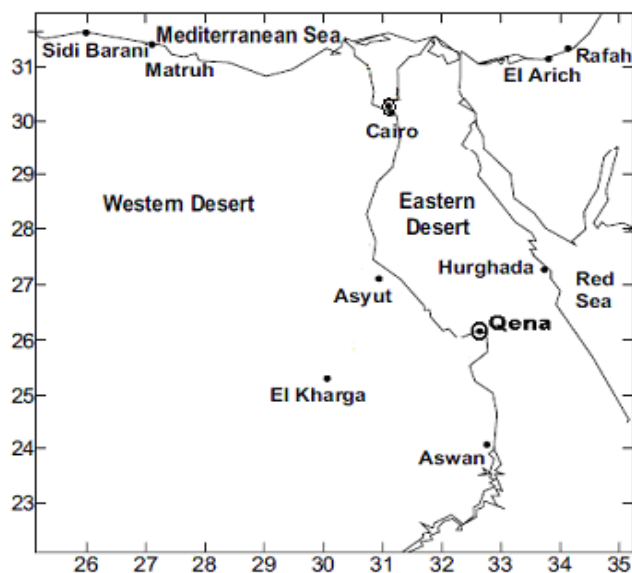


Figure 1. Map of Egypt

3. Data and Methodology

In Cairo, data have been monitored by Egyptian Environmental Affairs Agency, Environmental Information and Monitoring Program EEAA-EIMP. We used O₃ values measured in El Abbassia station. Instruments were located in a shelter on the top of 3 floors building. Air intake was 1 m from the Wall, about 16-m above the street level. The area was considered as regional residential area. It is normally up-wind from Cairo city center, but down-wind from the Shoubra industrial area and Shoubra urban area. There was no immediate local sources, but regionally exposed. So, this station was considered as representative for regional urban area. O₃ was measured by UV-Photometric Absorption instrument model TEL M 49 C. Meteorological parameters were measured by Automatic Weather Station (AWS). NO₂ and NO_x were measured by Chemiluminescence instrument model TEL M 42 C in Maadi, about 15 Km south of Abbassia station. Instruments were located in the first floor of EEAA building, Intake about 4m from the ground. This

area was polluted mainly by traffic and general activities of people.

In Qena, O₃ and meteorological parameters have been monitored in South valley university (SVU)-meteorological research station. O₃ measurements were carried out by the Model 49C UV Photometric Ozone Analyzer. The station is located about 6 KM northeast of Qena city in the eastern desert.

3.1. WRF/Chem Configuration

We used WRF/Chem model version 2.1[10] for simulation of the chemical and meteorological parameters in Cairo and Qena. Configuration of the model is illustrated in table 1.

Table 1. WRF/Chem model configuration

Options	Scheme
Advection scheme	Runge-Kuta 3rd order
Microphysics	NCEP 3-class simple ice
Long-wave radiation	RRTM
Short-wave radiation	Dudhia
Surface layer	Monin-Obukhov (Janjic Eta)
Land-surface model	OSU
Boundary layer scheme	Mellor-Yamada-Janjic TKE
Cumulus parameterization	Betts-Miller-Janjic
Photolysis scheme	[11]
Chemistry option	RADM2
Aerosol option	MADE/SORGAM

Surface emission data are taken from EDGAR (Emission Database for Global Atmospheric Research) with 1°X1° resolution[12] Meteorological data are taken from NCEP reanalysis data with 1°X1° resolution (<http://www.cdc.noaa.gov/>). Two domains have been used as illustrated in figure (2a, b); the outer domain with dimensions X = 150, dx = 81 Km and Y = 140, dy = 81 Km. The inner domain has the dimensions X = 85, dx = 27 Km and Y = 91, dy = 27 Km. The vertical grid includes 31 layers up to 50 (mb) pressure level.

Different prediction performance measures are used to assess the accuracy of estimation of these parameters including Mean Normalized Bias Error (MNBE) often just called the bias, Mean Absolute Normalized Gross Error (MANGE). It quantifies the mean absolute deviation of the residuals and indicates the average unsigned discrepancy between hourly estimates and observations. It is a robust measure of overall model performance (<http://www.tva.gov/sami/met/eval/ch5.pdf>). The model efficiency (ME) is proposed as the best overall measure of agreement between observed and simulated values. The following formulas are used for calculating these measures:

$$MNBE = (1/N) \sum (((Y_e - Y_m) / Y_m) * 100\%) \quad (1)$$

Where, Y_e: is the model estimated (modeled) value,
Y_m: is the measured value,
N: is the number of observations.

$$MANGE = (1/N) \sum (((|Y_e - Y_m|) / Y_m) * 100\%) \quad (2)$$

$$ME = 1 - \left[\frac{\sum (Y_m - Y_e)^2}{\sum (Y_m - \bar{Y}_m)^2} \right] \quad (3)$$

Where, \bar{Y}_m : is the mean of the measured values.

In all the above statistical tests of accuracy, except ME, The smaller the value, the better the efficiency of the Model, while value of ME closer to 1 indicates the superior model performance[13].

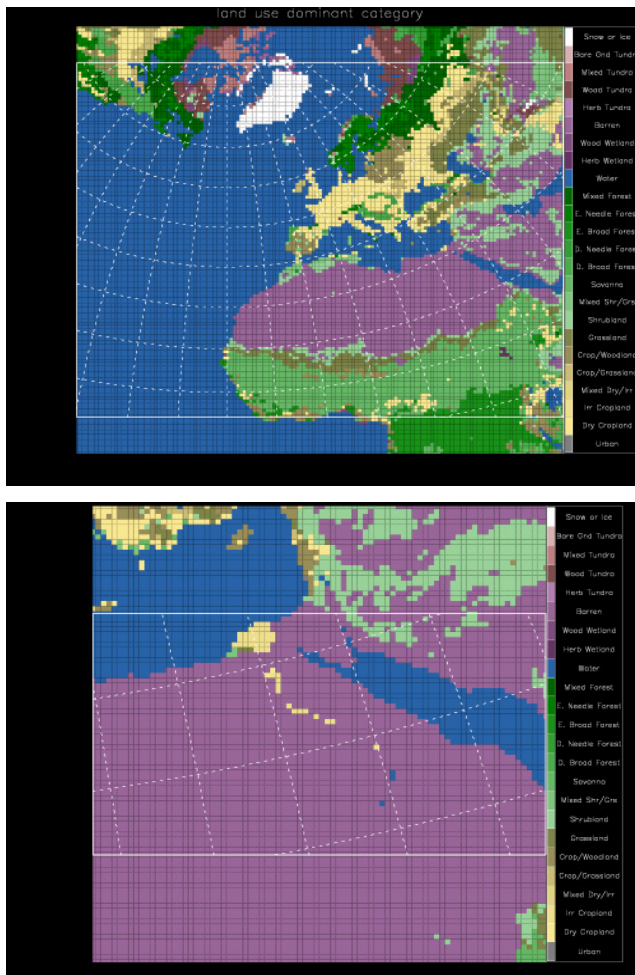


Figure 2. Land use in the outer domain (a) and inner domain (b)

4. Results and Discussion

4.1. In Cairo

Hourly values of O_3 , NO_2 , NO_x , WS, WD and T have been estimated during July - 2003. Diurnal variations of the measured and estimated data are illustrated in Figure 3. It is clear that the model can simulate the diurnal variation of O_3 with acceptable accuracy with correlation coefficient 0.67 (Figure 3a). There is over estimation for the maximum diurnal values in some days and over estimation for the

minimum diurnal values in other days. The model can not simulate diurnal variation of both NO_2 and NO_x as shown in figures (3b) and (3c). There is generally low estimation by the model as illustrated in figures (4b and 4c). This may be resulted of two reasons: the first is the fact that these pollutants are affected strongly by traffic intensity. The second is the coarse resolution of emission and meteorological data that have been used as inputs for the model, 1° latitude X 1° Longitude. The correlation coefficients between measured and estimated data are -0.08 and -0.05, respectively. WS diurnal variation can be simulated so far well with correlation coefficient 0.79 as shown in figure (3d) but with over estimation for the diurnal maximum values and low estimation for minimum diurnal values in most of the days. The same result is found with respect to WD, figure (3e), but with low correlation coefficient 0.27, this low correlation may be resulted of 0° and 360° directions overlap and the over estimation for the values near 360° which will be near 0° (for instance 2° , 3° , 4° ...etc), and the low estimation for the values near 0° which will be near 360° (for instance 359° , 358° , 357° , etc). This leads to high scatter in the estimated with respect to the measured data. Temperature is simulated very well with correlation coefficient 0.96 but with low estimation for the maximum and minimum diurnal values as shown in figure (3f).

Linear regression models have been constructed between measured and estimated values for each parameter for testing the quantitative relation. Figure 4 illustrates these relations and table 2 summarizes the values of the error parameters (MNBE), (MANGE) (Correl.) as well as ME). It is clear that the model can simulate the hourly values of O_3 , WS and T better than that of NO_2 , NO_x and WD. This may be attributed to the fact that measured NO_2 and NO_x are affected strongly by local traffic emissions. While simulated WD is affected by 0° and 360° overlap. For all parameters except T, the general high values of error factors and low values of correlation and model efficiency may be attributed to the coarse resolution of the emission and meteorological data that have been used as inputs for the model.

Table 2. The model performance parameters MNBE, MANGE, Correl. and ME in Cairo

	O_3	NO_x	NO_2	T K	WS	WD
MNBE%	69.54	-39.12	-22.30	-1.21	-0.79	1602.41
MANGE	79.41	68.17	75.14	1.22	26.21	1624.10
Cor. Coef.	0.67	-0.05	-0.08	0.96	0.79	0.27
ME	-0.33	-1.90	-2.45	0.46	0.50	0.46

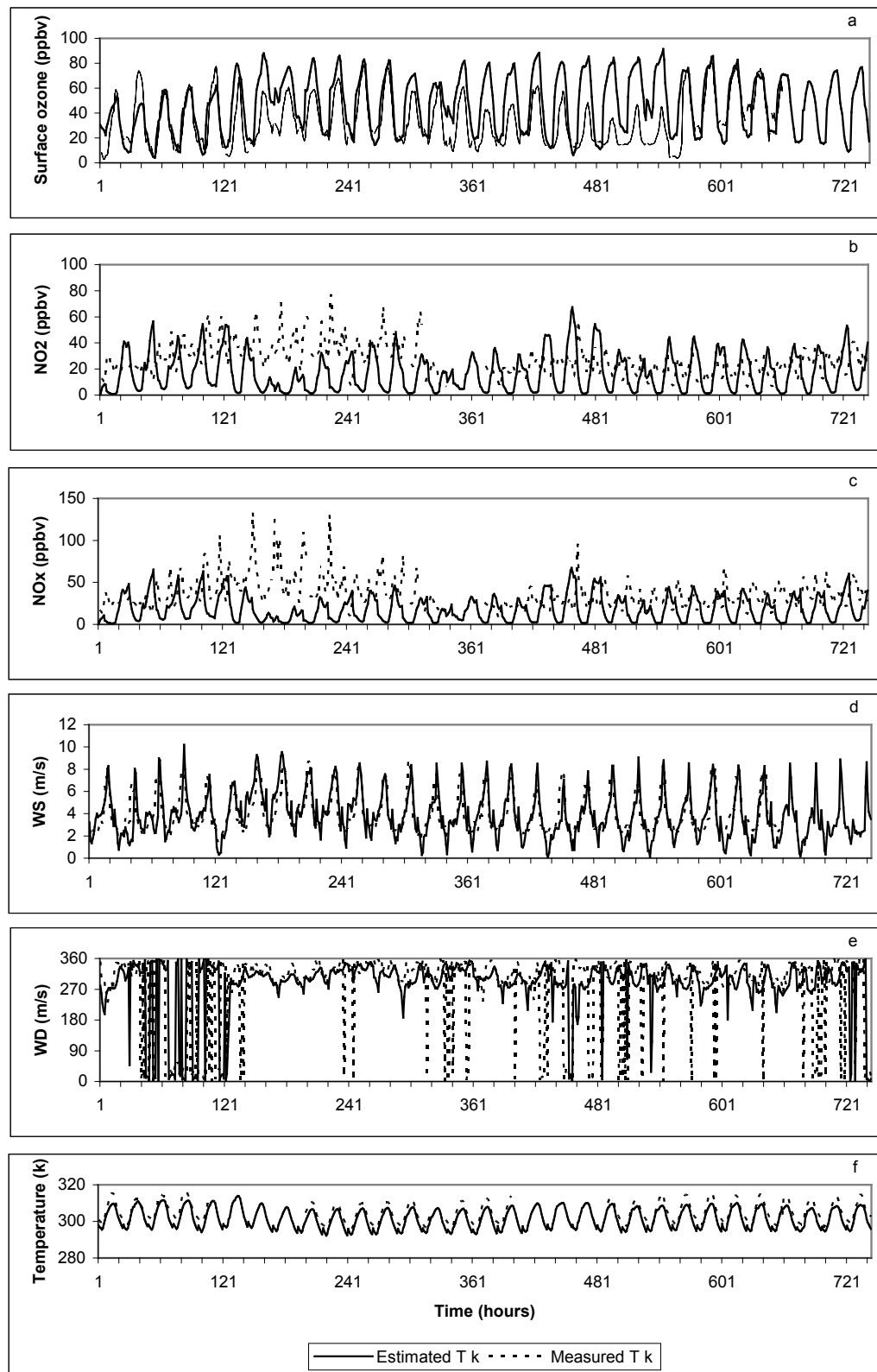


Figure 3. Diurnal variation of measured and estimated values of O₃ (a), NO₂ (b), NO_x (c), WS (d), WD (e) and T (f) in Cairo during July 2003

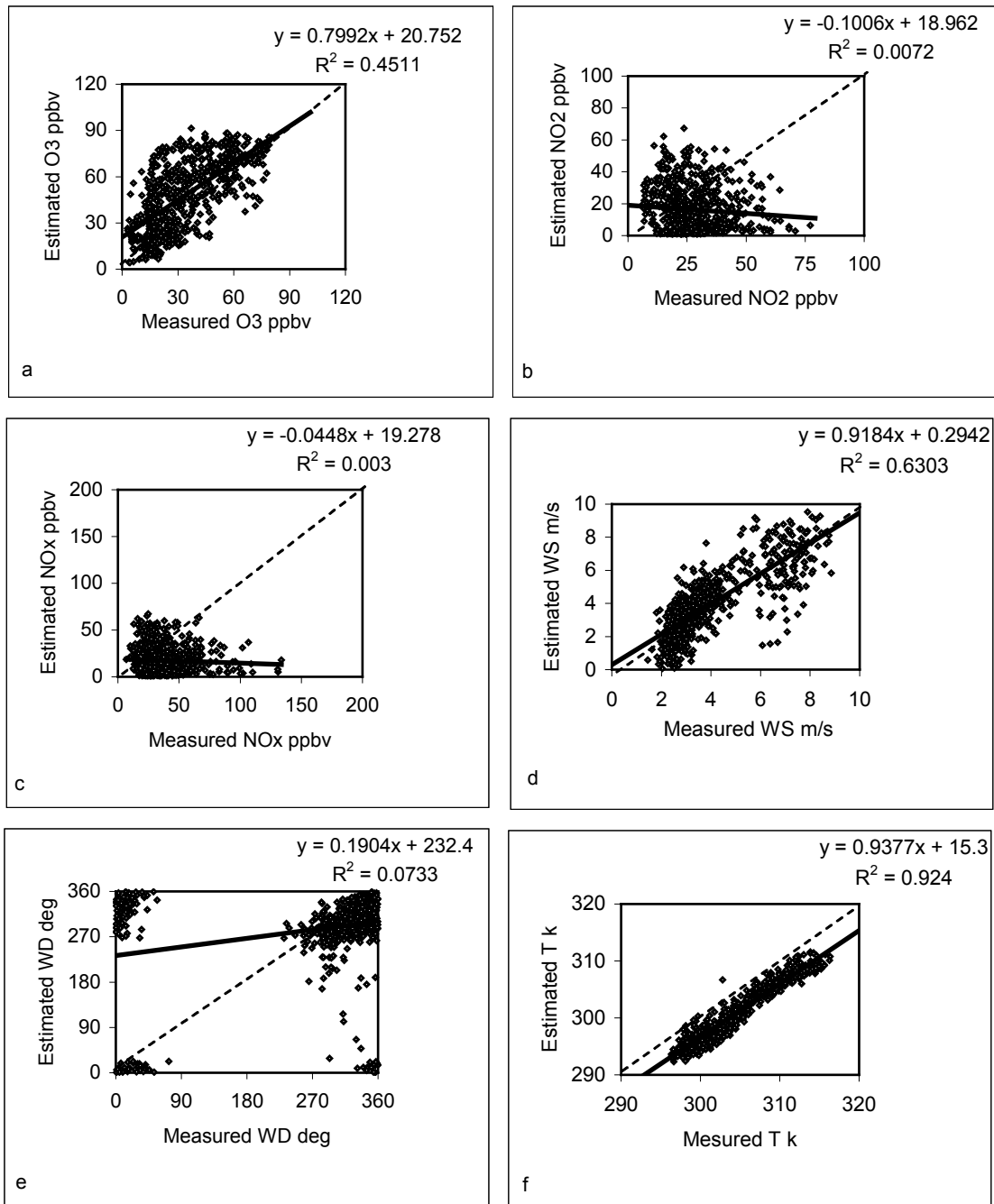


Figure 4. Scatter plot between measured and estimated hourly values of O₃ (a), NO₂ (b), NO_x (c), WS (d), WD (e) and T (f) in Cairo during July 2003. Solid line is the regression line and dashed line is the 1:1 line

4.2. In Qena

WRF/Chem model has been used for simulating hourly data of O₃, WS, WD and T during July - 2003. Diurnal variations of the measured and estimated data are illustrated in Figure 5. It is clear that the model can simulate diurnal variation patterns of O₃ with less accuracy than that in Cairo. There is over estimation for the maximum O₃ diurnal values and low estimation for the minimum diurnal values in most of the days. Correlation coefficient between the two variables decreased to 0.54. WS diurnal variation can be

simulated also with less accuracy than that occurred in Cairo where the correlation coefficient decreased to 0.49 as shown in figure (5b) and with low estimation for the maximum diurnal values and high estimation for the minimum diurnal values. The same result is found with respect to WD figure (5c), but with lower correlation coefficient (0.09). Diurnal variation of T is simulated very well with correlation coefficient 0.93, as illustrated in figures (5d). It is clear that the correlation coefficient of T in Qena is also less than that found in Cairo.

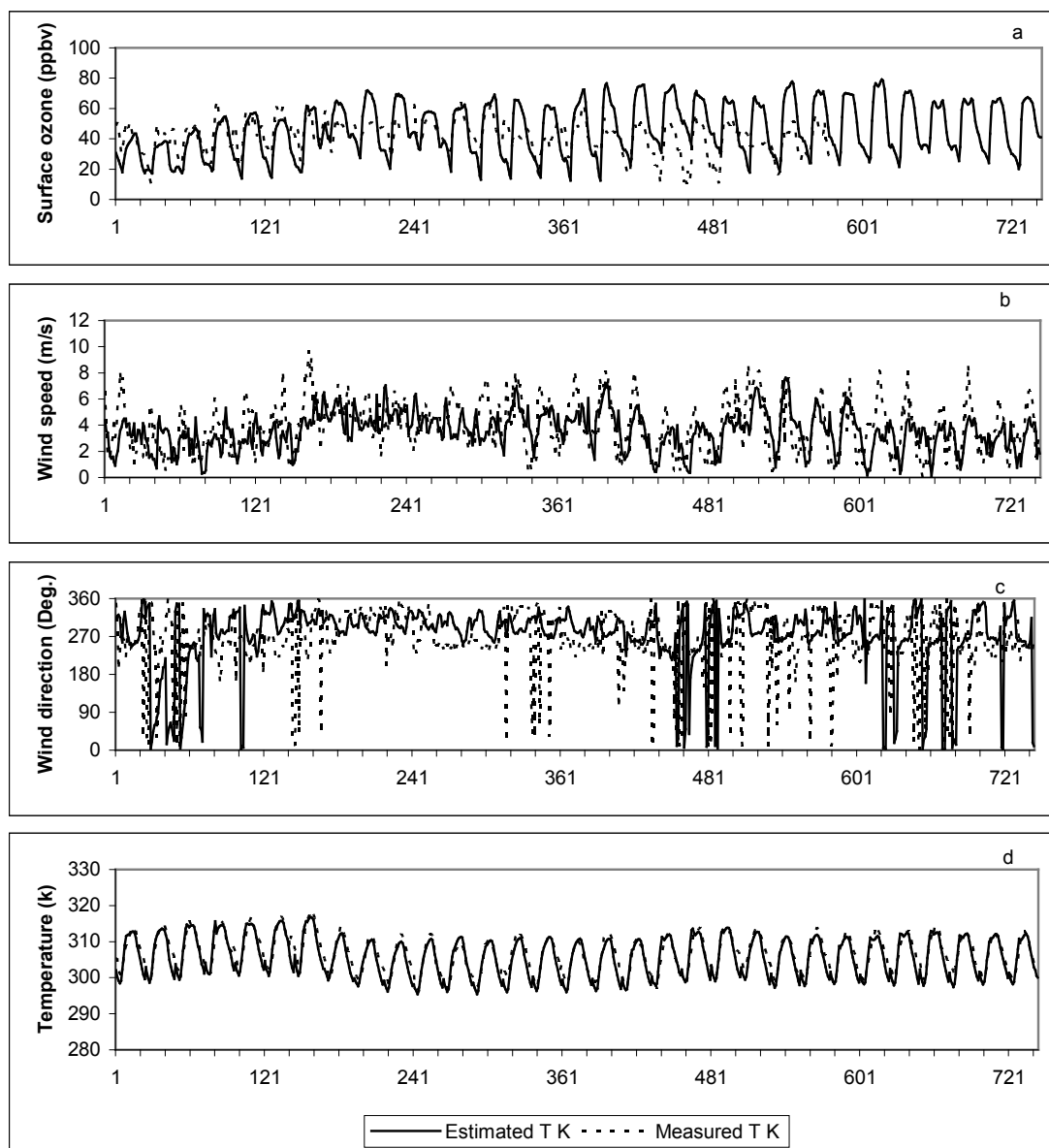


Figure 5. Diurnal variation of measured and estimated values of O_3 (a), WS (b), WD (c), and T (d) in Qena during July 2003

Linear regression models between measured and estimated values of these parameters are illustrated in figure 6. The error parameters (MNBE), (MANGE), (Correl.) as well as (ME) are summarized in table 3. It is clear that the model can simulate the hourly values of O_3 better than that of WS, and WD. Where, the values of MABE and MANGE become less in the case of O_3 . Meanwhile, the relatively high scattering of the O_3 data around the regression line decreased the correlation coefficient. As occurred in Cairo, simulated WD is affected by 0° and 360° overlap. There is low estimation for T. This low estimation increases with increasing of T.

These findings agree with many studies that have been achieved for using WRF/chem model for simulation air pollutants and weather parameters. For instance, the model represented the diurnal temperature cycle on the west of the Mexico City well, though surface temperatures were

generally underestimated. Overall, the timing and amplitudes of the calculated diurnal variations of NO_x , and O_3 agreed well with measurements, especially for O_3 [14]. Also, the WRF/Chem model statistically showed better skill in forecasting O_3 than MM5/chem model with no appreciable differences between models in terms of bias with the observations. Also, the WRF/Chem model consistently exhibited better skill at forecasting the O_3 precursors CO and NO_y at all of the surface sites. However, the WRF/Chem model biases of these precursors and other gas-phase species were persistently higher than for MM5/Chem, and were most often biased high compared to observations [15]. Also, the comparison between simulated and observed temperature and wind fields showed that the Weather Research and Forecasting Model succeeded in generation of meteorological inputs required for AERMOD model in Pune, India [16].

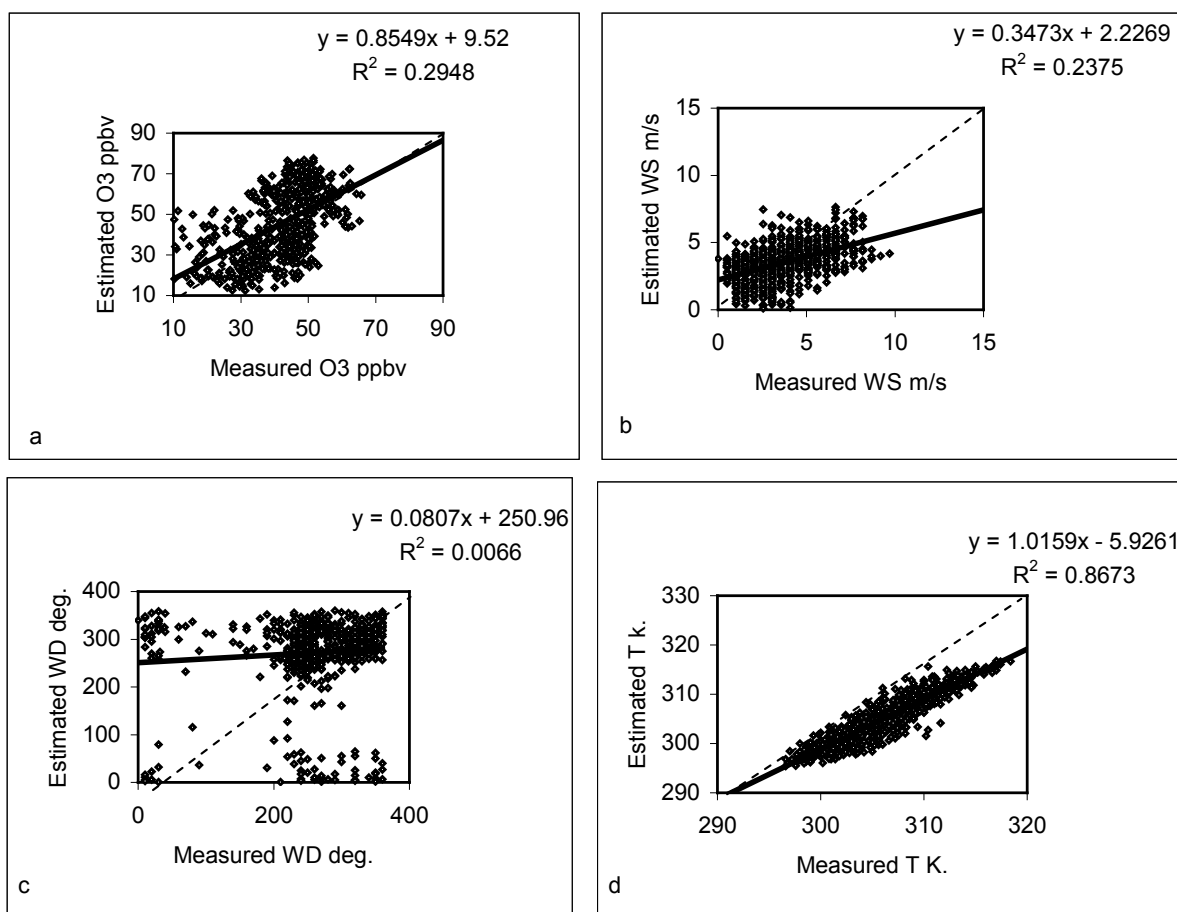


Figure 6. Scatter plot between measured and estimated hourly values of surface ozone (O_3), wind speed (WS), wind direction (WD) and temperature (T) in Qena during July 2003. Solid line is the regression line and dashed line is the 1:1 line

Table 3. The model performance parameters MNBE, MANGE, Correl. and ME in Qena

	O_3	T K	WS	WD
MNBE%	12.30	-0.35	22.45	76.39
MANGE	33.45	0.57	58.66	96.77
Cor. Coef.	0.54	0.93	0.49	0.09
ME	-0.87	0.80	0.17	-0.84

5. Conclusions

WRF/Chem version 2.1 has been used for simulation of air pollutants and weather parameters in Cairo and Qena/ Egypt. O_3 , NO_x and NO_2 as well as WS, WD and T have been simulated in Cairo. While in Qena, only O_3 , WS, WD and T have been simulated during July 2003. Different prediction performance measures have been used to assess the accuracy of estimation of these parameters.

It is found that WRF/Chem model can simulate diurnal variation of O_3 values in Cairo better than that in Qena, although, the quantitative estimation in Qena is better than that in Cairo. Simulation of NO_x and NO_2 in Cairo was not good neither quantitative nor qualitative. This may be

resulted from the coarse resolution used for the input meteorological and emission data (1° latitude X 1° Longitude) as well as the fact that these pollutants affected directly by local emissions. The model simulated the weather parameters in acceptable accuracy in both Cairo and Qena especially WS and T. It is clear that WRF/Chem model can not generally simulate the chemical parameters in high polluted regions. While, it can be used safely in rural and suburban regions. Using fine resolution for meteorology and emission data can improve the results. WRF/Chem model can be used in Egypt for estimation weather and chemical parameters required for pollutant sources and sinks study. Where, in most of the Egyptian Cities there are shortage in direct measurements of these parameters.

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