Validation of Climgen Weather Data Generator for Computing The Potential Evapotranspiration Using Penman-Monteith Equation

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ABSTRACT: A **ClimGen** weather data generator was tested for observed weather data from each of eleven meteorological stations (Alexandria, Mersa Matrouh, Asswan, Minya, Ismailia, Assuit, Bani Sweif, Fayoum, Kafr Al-Sheikh, Shbin Al-Koum and Al-Wadi Al-Gadid) to estimate reference evapotranspiration (ET_0). The results showed low error for means and variances of generated data of potential evapotranspiration (ET_0) using FAO Penman - Monteith equation. **ClimGen** appears to perform well across the range of spatial scales and climatic zones found within Egypt. The results showed that **ClimGen** is able for producing reasonable estimation. The **ClimGen** model showed a good performance, indicating that representative long-term weather data of reference evapotranspiration could in general, be generated from historical weather data. This finding has particular relevance for agricultural modeling applications in Egypt such as calculation the crop water requirements.
Keywords: ClimGen, FAO-PM, generated data, reference evapotranspiration, weather data generators

INTRODUCTION

Sustainable water management requires the information on spatial and temporal changes of hydrological processes. Evapotranspiration plays a major role in the hydrological cycle, ecological and climatic systems. Determination of evapotranspiration is an important in irrigation design, irrigation scheduling, water resource management, hydrology and cropping systems modeling. The Penman-Monteith (PM) formulation (Monteith, 1965) is regarded as a good ET estimator for a wide variety of climate conditions (Allen *et al.*, 1989; Ventura *et al.*, 1999). The United Nations Food and Agriculture Organization (FAO) adopted the PM method as a global standard to estimate reference crop evapotranspiration (PM-ET_0) from meteorological data (Allen *et al.*, 1998).

For daily ET_0 calculation, apart from the specific requirements of on-site conditions, the FAO-PM method requires daily data on maximum and minimum air temperatures (T_{max} and T_{min}), relative humidity (RH), solar radiation (R_s) and wind speed (U_2). For many locations, such meteorological variables are often incomplete and/or not available.

Daily weather data are commonly required as climate input to simulation models in agriculture and forestry. Historical observations are often short, incomplete, or simply unavailable. Thus, there is a need to generate synthetic weather sequences that statistically preserve the mean and variations found in historical observations.

Numerous attempts have been tried to overcome difficulties associated with data availability for ET_0 estimation such as weather generators. For irrigation scheduling purpose, software was developed to generate the climatic variables required to the FAO-PM equation, e.g. ClimGen, (Castellvi and Stöckle, 2001; Stöckle and Nelson, 1999) which is a weather generation program that produces daily estimates of air temperature, solar radiation, relative humidity and wind speed values (Stöckle *et al.*, 2004). Daily generated data include all the variables required by the FAO-PM method. ClimGen (Castellvi and Stöckle, 2002; Stöckle and Nelson, 1999; Stöckle *et al.*, 1994, 2003a,b).

Weather generators are now widely used and are becoming a standard component of decision support systems in agriculture, environmental management and hydrology. Generators may be used as supplied, which is dangerous, that is without sufficient validation being carried out for the sites at which they are applied. Testing and validation are necessary as we use weather data generators.

The objective of the present paper is to test the weather data generator (ClimGen version 4.1.05), Stöckle *et al.* (2001) for a range of climates in Egypt. Validation of this model at Egypt sites will offer the opportunity to evaluate long term effects of weather on potential evapotranspiration (ET_0) that use for calculate the crop evapotranspiration (ET_c).

MATERIALS AND METHODS

Observed weather data:

Daily weather data; precipitation, daily maximum and minimum temperature, daily maximum and minimum relative humidity, solar radiation and wind speed for a period of 16 years (1995-2010) at eleven locations overall of Egypt (Alexandria, Marsa Matrouh, Asswan, Minya, Ismailia, Assuit, Bani Sweif, Fayoum, Kafr Al-Sheikh, Shbin Al-Koum and Al-Wadi Al-Gadid) were extracted from the daily climate archive of Central Laboratory for Agricultural Climate (CLAC). The missing data were estimated by spatial interpolation. The geo-references of the eleven study sites are presented in Table (1) and Fig. (1). For each region, the data from one of the major weather stations was chosen as representative of the climate of that region. The locations were chosen to represent diverse agricultural climates.

Description of ClimGen stochastic weather generator:

ClimGen is a weather generator that uses principles similar to those in WGEN (Richardson and Wright, 1984), but with significant modification and additions. **ClimGen** is a daily time step stochastic model that generates daily precipitation, minimum and maximum temperature, solar radiation, humidity and wind speed data series with similar statistics to that of the historical weather data. The model requires inputs of daily series of these weather variables to calculate parameters used in the generation process for any length of period at a location of interest. Further information on ClimGen is well documented elsewhere (Castellvi and Stöckle, 2001, Stöckle *et al.*, 2001; Stöckle *et al.*, 2003 a,b,; Mckague and Rudra, 2003).

Table (1). Geo-references of the different study locations

Location	Latitude (degree)	Longitude (degree)	Elevation above m.s.l (m)	Mean annual maximum temperature (T_{max})	Mean annual minimum temperature (T_{min})
Alexandria	31.07	29.00	7.0	25.21	16.36
Marsa Matrouh	31.35	27.21	17.9	24.42	16.30
Asswan	24.02	32.53	108.0	33.63	14.26
Minya	28.05	30.44	40.0	27.71	14.26
Ismailia	30.36	32.14	10.0	27.59	18.45
Assuit	27.11	31.06	71.0	29.51	13.86
Bani Sweif	29.04	31.06	30.4	29.12	13.99
Fayoum	29.18	30.51	30.0	27.94	14.67
Kafr Al-Sheikh	31.07	30.57	20.0	24.40	14.73
Shbin Al-Koum	30.60	30.96	17.9	25.30	14.61
Al-Wadi Al-Gadid	25.26	30.34	72.0	33.11	15.40

ClimGen uses a Weibull distribution (Weibull, 1961) to generate precipitation amounts instead of the Gamma distribution used by WGEN. Selker and Haith (1990) showed the Weibull distribution to be superior to other probability distribution of daily precipitation amount. WGEN uses truncated Fourier series fits to produce daily values for monthly-calculated quantities of mean weather variables. ClimGen uses quadratic spline functions chosen to ensure that the average of the daily values is continuous across month boundaries, and that the first derivative of the function is continuous across month boundaries. Additive features of ClimGen include the generation of vapor pressure deficit (VPD) and wind speed. A temperature-based approach, developed by Bristow and Campbell (1984) is embedded in ClimGen allowing users to estimate solar radiation from existing temperature records in areas where solar radiation input data are not readily available.

FAO- Penman-Monteith reference evapotranspiration (FAO-PM):

The FAO-PM equation recommended for daily ET_0 (mm/day) estimation (Allen *et al.*, 1998) may be written as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

Where:

R_n is the net radiation at the crop surface (MJ/m^2/day),
G is the soil heat flux density (MJ/m^2/day),
T is the mean air temperature at 2 m height (°C),
u_2 is the wind speed at 2 m height (m/s),
e_s is the vapour pressure of the air at saturation (kPa),
e_a is the actual vapour pressure (kPa),

Δ is the slope of the vapour pressure - temperature curve (kPa/°C)and
γ is the psychrometric constant (kPa/°C)

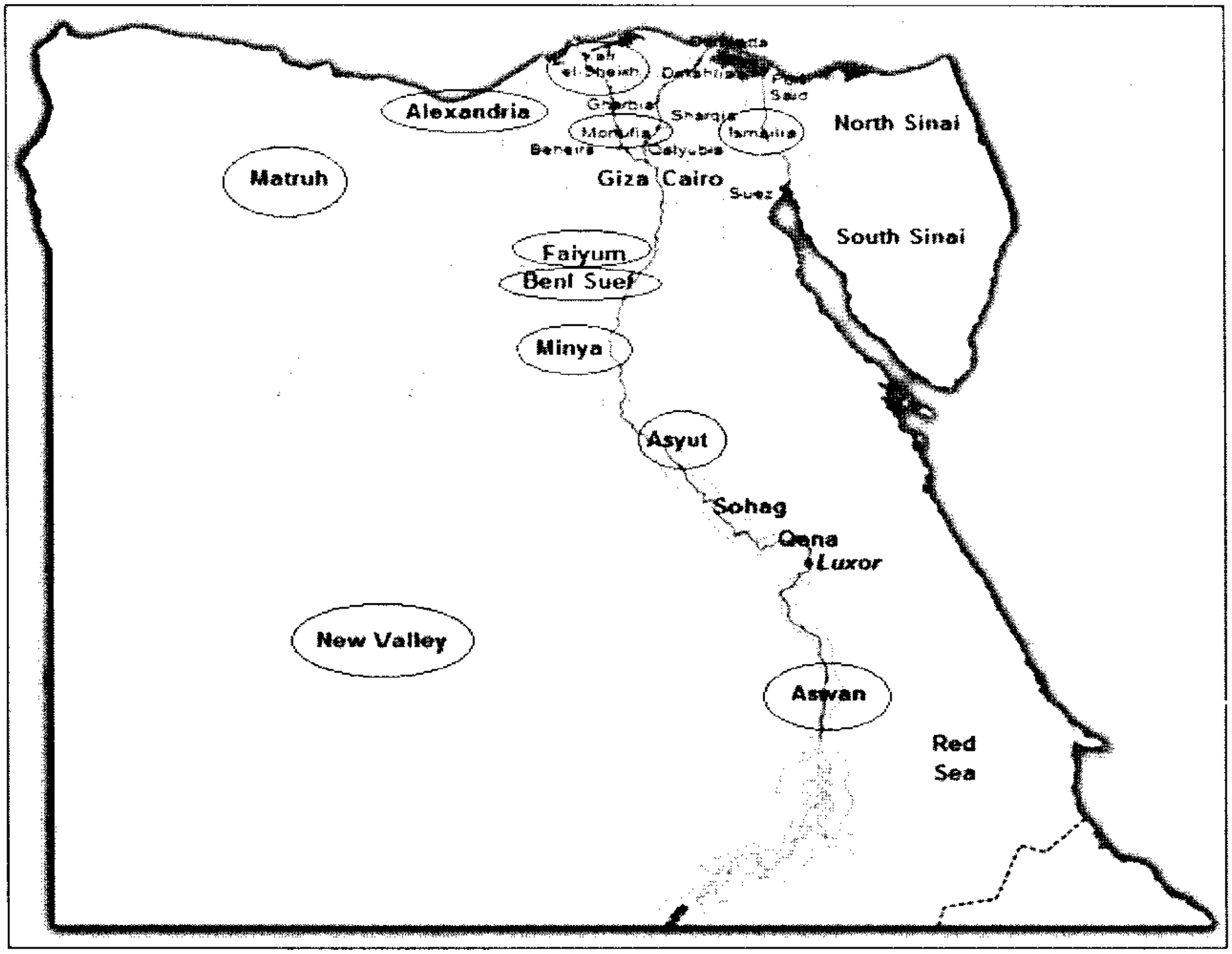


Figure 1. Egypt map described the study locations

A complete set of equations is proposed by Allen *et al.* (1998) to compute the parameters of Eq. 1 according to the available weather data, which constitute the so called FAO-PM method. the soil heat flux density (G) may be ignored for daily time step computation. The ET_0 estimation procedure using generated weather data (PM-Gen) consists of estimating the parameters of Eq. 1 from the ClimGen output (the generated weather data).

Statistical indices used for evaluate the goodness of fitting:

ET_0 estimates with observed and generated weather data, respectively ET_0(Observed) and ET_0(Generated), were compared and the accuracy of Gen-predictions were evaluated through selected statistical indicators: the root mean square error, the relative error, the Willmott index of agreement, and the modeling efficiency (Willmott, 1982; Loague and Green, 1991; Liu *et al.*, 1998; Legates and MacCabe, 1999; Alexandris and Kerkides, 2003; Stöckle *et al.*, 2004; Pereira, 2004; Cholpankulov *et al.*, 2008). The mentioned statistical indicators are defined as follows:

- **Coefficient of regression, b** (when the regression is forced to the origin):

$$b = \frac{\sum_{i=1}^{m} Oi \times Pi}{\sum_{i=1}^{m} O_i^2} \tag{2}$$

- Coefficient of determination, R^2

$$R^2 = \left\langle \frac{\sum_{i=1}^{m} (O_i - \overline{O})(P_i - \overline{P})}{\left[\sum_{i=1}^{m} (O_i - \overline{O})^2\right]\left[\sum_{i=1}^{m} (P_i - \overline{P})^2\right]} \right\rangle \tag{3}$$

- Root Mean Square Error, RMSE

$$\text{RMSE} = \left[\frac{\sum_{i=1}^{m} (P_i - \overline{P})^2}{m}\right]^{0.5} \tag{4}$$

- Relative Error, RE

$$\text{RE} = \frac{\text{RMSE}}{\overline{O}} \tag{5}$$

-The mean bias error, MBE

$$\text{MBE} = \frac{\sum_{i=1}^{m} (P_i - O_i)}{m} \tag{6}$$

-Standard Deviation (SD): expresses the variability of (P-O) distribution about MBE and is derived using the following equation:

$$\text{SD} = \sqrt{\frac{\sum_{i=1}^{m} (P_i - O_i - \text{MBE})^2}{m-1}} \tag{7}$$

The MBE and SD are mainly expressed as percentage of the mean value of corresponding variables.

- The percent difference (E) between observed and generated data

$$E(\%) = \frac{\text{Gen-Obs}}{\text{Obs}} \times 100 \tag{8}$$

-The Willmott index of agreement (Willmott, 1982), d

$$d = 1 - \frac{\sum_{i=1}^{m} (O_i - P_i)^2}{\sum_{i=1}^{m} \left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2} \tag{9}$$

where the m is the number of observations, O_i and P_i are respectively the i-th observed and generated data, $\overline{O}$ is the average value for O_i with i=1,2,....., m , $\overline{P}$ is the average of the data array of P_i.

The value of **d** varies from 0 to 1.0 according to the quality of model fitting and is desirably close to 1.0. The estimation error indicators RE and RMSE are hoped to be as small as possible. The coefficient b may be larger or smaller than 1.0 when there is respectively overestimation or underestimation of the target variable. When R^2 is close to 1.0 the variance of the estimation error is small.

The performance of the model is good when d ≥ 0.95 and **RE** ≤ 0.20 (Stöckle *et al.*, 2004), and when b is close to 1.0 (1.0±0.10) and $\mathbf{R}^2 > 0.80$.

For the interpretation of the performance indices, the following criteria were used (Stöckle *et al.*, 2004):

d ≥ 0.95 and RE ≤ 0.10 very good
d ≥ 0.95 and 0.15 ≥ RE > 0.10 good
d ≥ 0.95 and 0.20 ≥ RE > 0.15 acceptable
d ≥ 0.95 and 0.25 ≥ RE > 0.20 marginal

Multivariate time series model:

The model used for the deterministic components is described as following (Peiris and McNicol, 1996; Silva *et al.*, 2010):

$$Y_{fit}(J) = C_0 + C_1 \times COS\left(\frac{2\pi(J-T)}{366}\right) \qquad \textbf{(10)}$$

Where: C_0 is mean value ($C_0 = \frac{T_{max}+T_{min}}{2}$);

C_1 is amplitude ($C_1 = \frac{T_{max}-T_{min}}{2}$);

J is a day of the year; and
T is phase (considered as the peak value)

RESULTS AND DISCUSSION

A comparison is made between the measured and the generated data (ClimGen). This is done to ascertain and quantify any benefits of using the ClimGen. FAO56 PM ET_0 is calculated using the meteorological variables.

Table (2) shows the values of potential evapotranspiration (ET_0) estimated from observed data (ET_0- Obs) and generated data (ET_0 -Gen). The average observed values are close up the average generated values, in which the percent differences are ranged between -0.13% (for Bani Sweif) to 9.77% (for Kafer Al-Sheikh).

Figure (2) shows the regression through the origin between ET_0 (Observed) and ET_0 (Generated) at all locations. The figures show that the ET_0 values estimated from ClimGen model agree well with those computed with observed data sets. The differences between observed and generated values are small (the percent difference ranged between -0.15 and 5.98%). However, the regression coefficient **b** is closer to 1.0 for all locations, in which **b** values ranged between 0.9279 for Kafr Al-Sheikh and 1.0303 for Alexandria.

The variation of the generated means of daily reference evapotranspiration (ET_0) was not significantly different from the observed for all sites indicating that the daily variation was well reproduced by ClimGen (Fig. 2). There is a very close match between observed and simulated data across the whole range of daily means.

Table (2). Observed and generated potential evapotranspiration, ET_0 (mm/day) at all locations

Locations	Minimum ET_0 (mm/day)		Maximum ET_0 (mm/day)		Average ET_0 (mm/day)		STDEV of ET_0 (mm/day)		Percent difference (%)
	Observed	Generated	Observed	Generated	Observed	Generated	Observed	Generated	
Alexandria	1.85	2.37	7.81	6.37	4.63	4.56	1.55	1.14	-1.51
Marsa Matrouh	2.25	2.41	7.10	6.43	4.51	4.42	1.26	1.09	-2.00
Asswan	4.81	3.32	17.16	17.79	10.80	10.50	3.27	3.57	-2.78
Minya	3.67	2.91	10.36	11.81	7.39	7.10	2.08	2.54	-3.92
Ismailia	3.40	2.68	10.18	10.70	6.92	6.70	2.00	2.43	-3.18
Assuit	3.31	2.53	14.23	13.95	8.28	8.09	2.67	2.97	-2.29
Bani Sweif	3.32	3.35	12.90	12.64	7.83	7.84	3.01	2.99	0.13
Fayoum	2.49	2.45	10.99	10.68	6.68	6.69	2.60	2.60	0.15
Kafr Al-Sheikh	2.73	1.64	7.28	8.14	5.22	4.71	1.31	1.81	-9.77
Shbin Al-Koum	2.75	2.20	7.75	9.15	5.63	5.29	1.49	1.98	-6.04
Al-Wadi Al-Gadid	4.31	5.20	17.35	15.32	10.70	10.57	3.28	3.36	-1.21

$$\text{Percent difference} = \frac{(\text{generated-observed})}{\text{observed}} \times 100$$

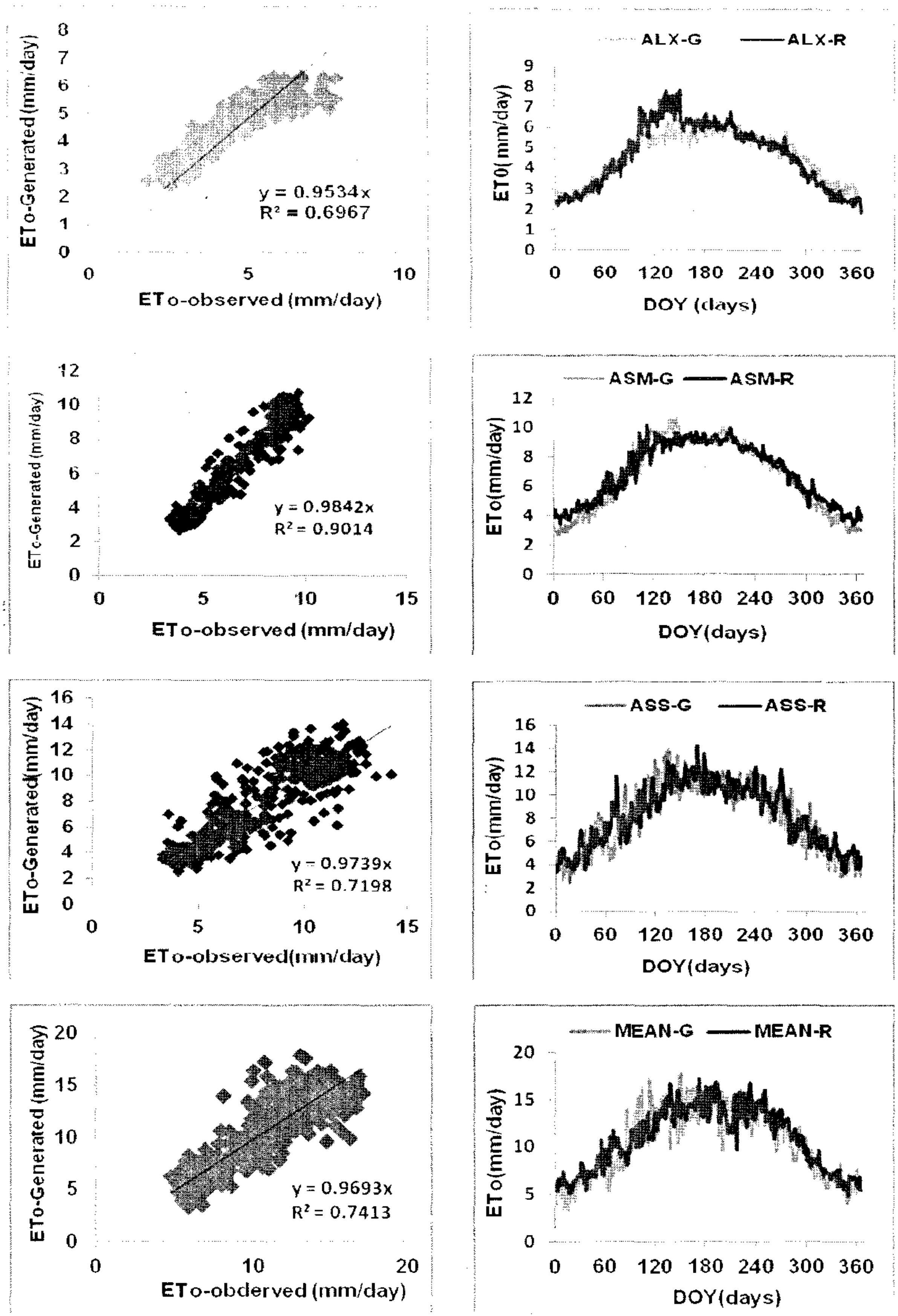
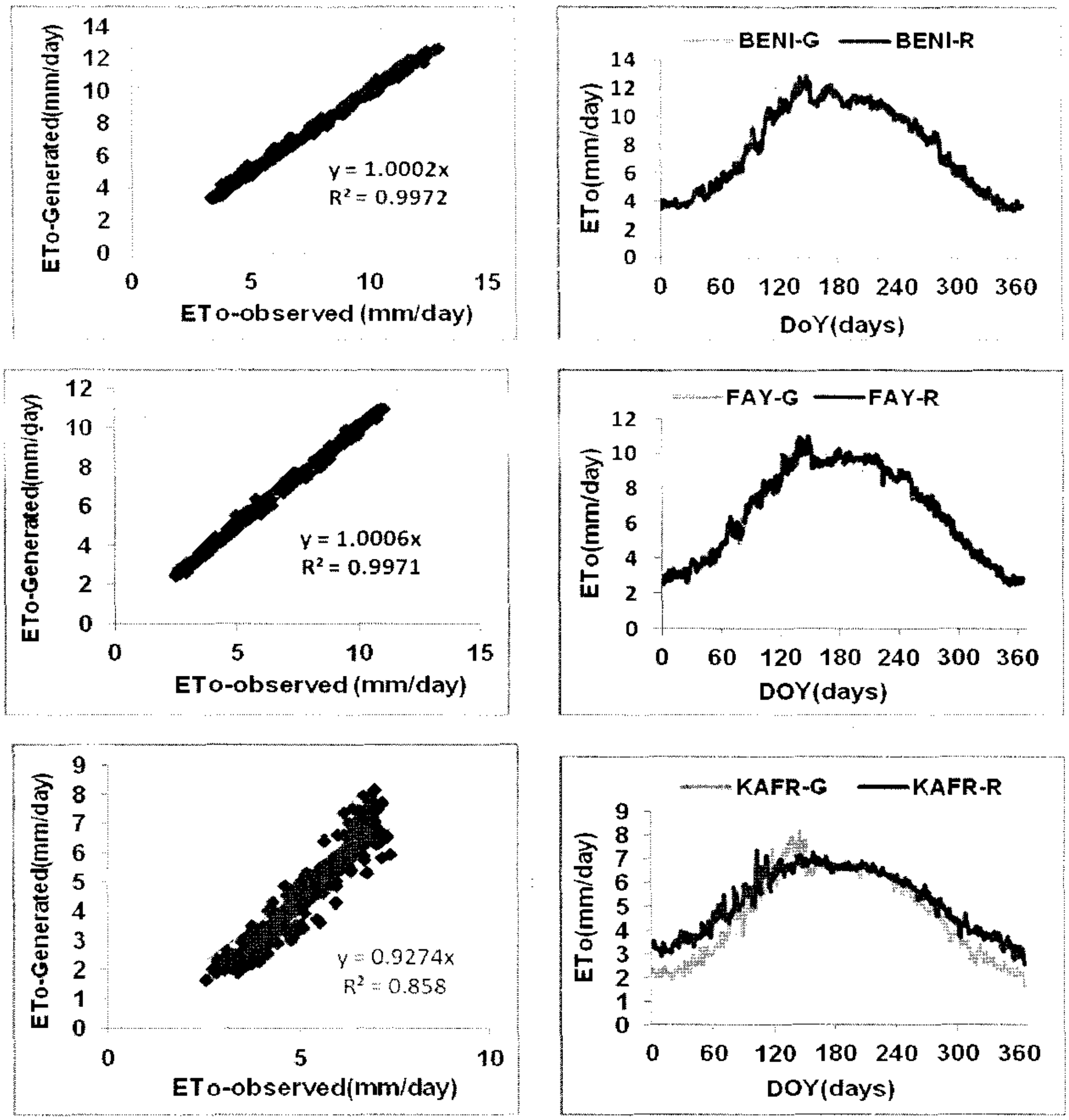

ETo-Generated (mm/day)
ETo-observed (mm/day)
y = 0.9534x
R² = 0.6967
ALX-G
ALX-R
ET0(mm/day)
DOY (days)
ETo-Generated (mm/day)
ETo-observed (mm/day)
y = 0.9842x
R² = 0.9014
ASM-G
ASM-R
ETo(mm/day)
DOY(days)
ETo-Generated(mm/day)
ETo-observed(mm/day)
y = 0.9739x
R² = 0.7198
ASS-G
ASS-R
ETo(mm/day)
DOY(days)
ETo-Generated (mm/day)
ETo-obderved (mm/day)
y = 0.9693x
R² = 0.7413
MEAN-G
MEAN-R
ETo(mm/day)
DOY(days)

Figure 2. Regression line (left) and scatter plot (right) for ET_0 estimated from observed and generated weather data in the 16 years period



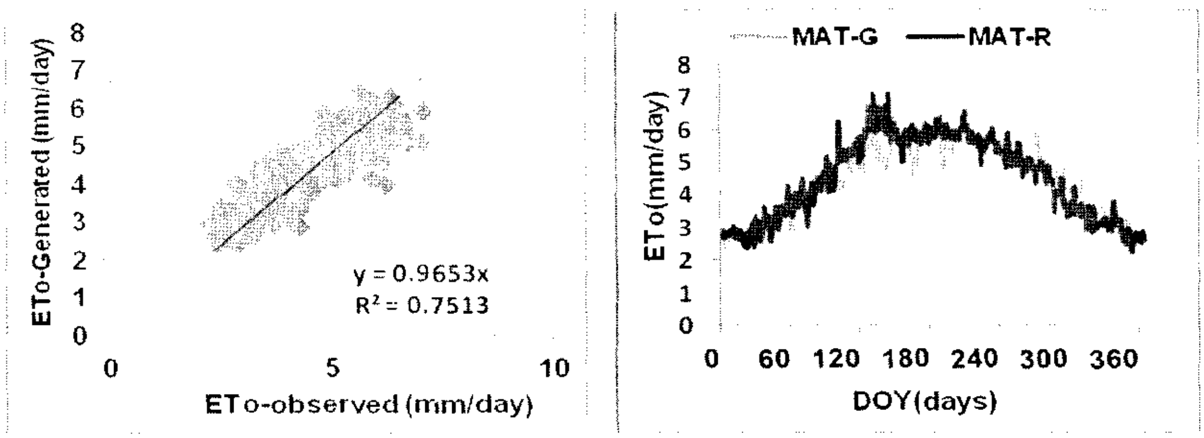
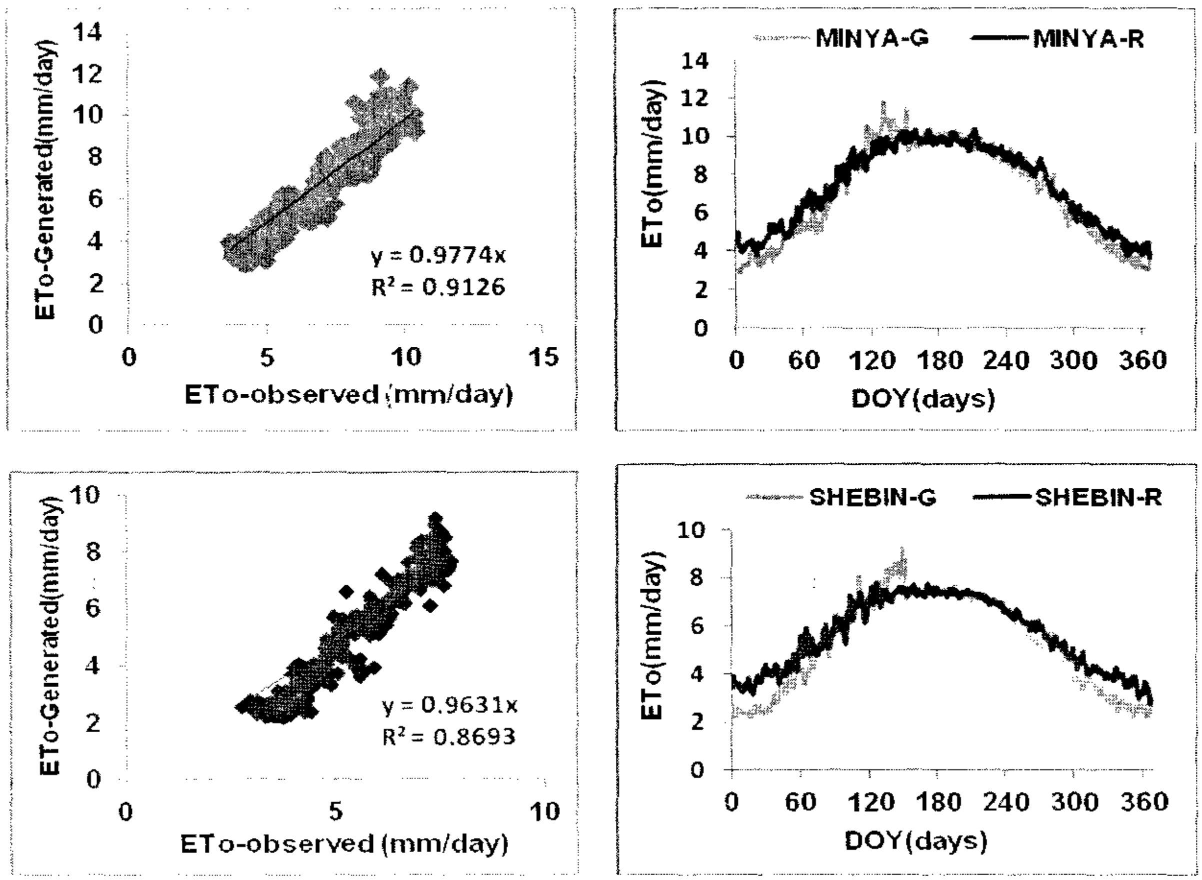


Figure 2. Cont.



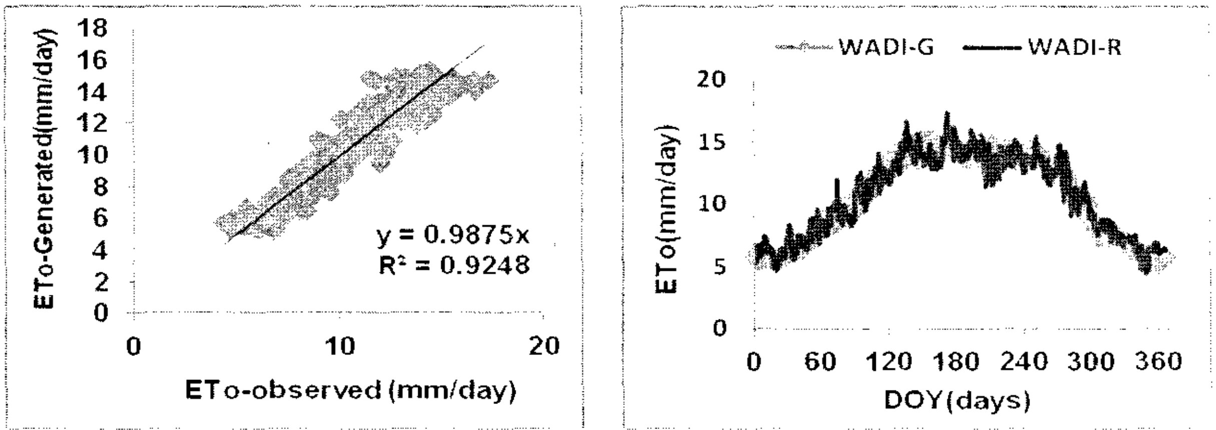


Figure 2. Cont.

Results for **d** (index of agreement) ranged between 0.9160 (for Asswan) and 0.9993 (for Bani Sweif and Fayoum) and relative error (**RE**) ranged between 0.0200 mm/day (for Bani Swief) and 0.1915 mm/day (for Asswan). All locations have **RE** less than 0.15 indicated a good performance of the model. Also, the **d** value (index of agreement) for most locations, have a value more than 0.95 indicated a very good performance of the model and the rest locations have values between 0.9160 and 0.95 indicated acceptable model (Table 3).

Comparison of simulated weather data with 30 years of weather data for six stations (McKague *et al.*, 2005) indicated that ClimGen performed with

Table (3). Statistical indices of daily ET_0 (mm/day) computed from observed and ClimGen data at all locations

location	RMSE	RE	d	MRE	MBE	SD	R^2	b	Model Performance
Alexandria	0.6647	0.1434	0.9365	0.1099	-0.0726	0.6616	0.8554	1.0303	Good
Marsa Matrouh	0.5675	0.1259	0.9392	0.0965	-0.0895	0.5612	0.8035	0.9653	Good
Asswan	1.5851	0.1915	0.9160	0.1486	-0.1908	1.5757	0.7205	0.9693	Good
Minya	0.7692	0.1041	0.9719	0.0832	-0.2884	0.7141	0.9439	0.9774	Good
Ismailia	0.7694	0.1112	0.9692	0.0889	-0.2158	0.7395	0.9265	0.9842	Good
Assuit	1.8445	0.1707	0.9228	0.1327	-0.3022	1.8221	0.7421	0.9739	Good
Bani Sweif	0.1566	0.0200	0.9993	0.0150	0.0114	0.1564	0.9973	1.0002	Very Good
Fayoum	0.1398	0.0209	0.9993	0.0153	0.0042	0.1399	0.9971	1.0006	Very Good
Kafr Al-Sheikh	0.8138	0.1560	0.9327	0.1260	-0.5114	0.6339	0.9354	0.9279	Good
Shbin Al-Koum	0.7452	0.1324	0.9530	0.1008	-0.3369	0.6656	0.9367	0.9631	Good
Al-Wadi Al-Gadid	0.9317	0.0871	0.9799	0.0686	-0.1311	0.9237	0.9248	0.9876	Very Good

reasonable accuracy with some limitations in generating rainfall intensities and solar radiation, particularly for the winter season. Also, ClimGen's simulations were better for daily temperature and solar radiation (Castellvi and Stöckle, 2001). Therefore, ClimGen is well simulated the weather parameters for various climatic conditions as reported by Stöckle *et al.* (2004).

Multivariate time series model:

The time series analysis of Penman-Monteith evapotranspiration (ET_0) calculated with observed and generated weather data are illustrated in Table (4). The results illustrated in Table (4) and Fig.(3) show good agreement between fitted parameters; C_0 and C_1 and observed data with R^2 ranged from 0.85 to 0.99. Also, Table (4) shows that phase parameters (T) reached 187 to 188 days indicated that the peak value the same for all locations. The phase parameter expressed the maximum value of ET_0 during the annual period.

Finally, the results demonstrate that **ClimGen** was able for producing good estimation. Thus, care is required to assess the data quality in advance of it being used for crop, hydrology or ecological modeling. Comparisons between observed and simulated data were a vital part of overall validation and provide valuable information on the behavior of the data (Kuchar, 2004). Knowing the scale of errors (percent difference and variance) was important when interpreting outputs from simulation models that have used to synthetic data as input. **ClimGen** appears to perform well across the range of spatial scales and climatic zones found within Egypt. The results also suggeste that stochastic weather data generators such as **ClimGen** can be useful in case of basic historical weather data are available. The potential evapotranspiration generated using the ClimGen model was shown to have a lower standard deviation than observed data.

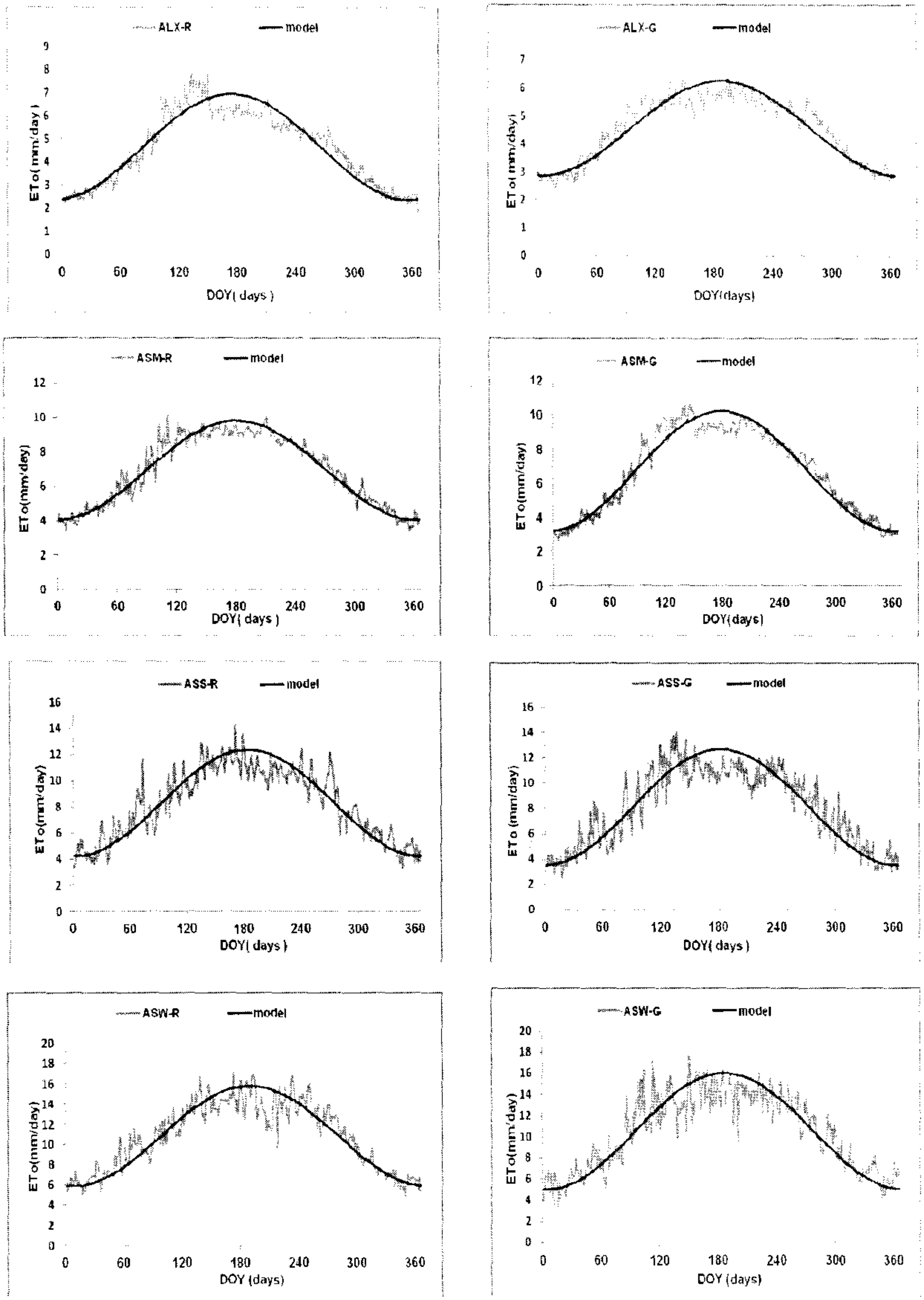
CONCLOSION

ClimGen showed a good performance, indicating that representative long-term weather data of reference evapotranspiration could in general, be generated from historical weather data. This finding had particular relevance for agricultural modeling applications in Egypt.
The key findings of this study were as follows:

- ClimGen was a user-friendly tool to prepare weather input files for continuous hydrologic models. The statistical analysis showed that the simulated weather data are largely statistically representative of historical weather data.
- The analysis of generated weather data for **ClimGen** showed that, the differences of observed weather data were less than 5% in most locations, indicating that **ClimGen** has performed well.

Table (4). Time series parameters of ET_0 calculated from observed and generated weather data at all locations

Location	Case	C_0	C_1	T	R^2
Alexandria	Observed	4.63	2.25	187.82	0.9051
	Generated	4.56	1.69	187.37	0.8965
Marsa Matrouh	Observed	4.51	1.85	187.83	0.9166
	Generated	4.42	1.58	187.38	0.9146
Asswan	Observed	10.82	4.96	188.07	0.8658
	Generated	10.52	5.49	187.35	0.8398
Minya	Observed	7.39	2.98	287.25	0.9605
	Generated	7.10	3.66	187.24	0.9485
Ismailia	Observed	6.93	2.88	188.01	0.9428
	Generated	6.71	3.49	187.29	0.9432
Assuit	Observed	8.29	4.05	188.03	0.8568
	Generated	8.10	4.56	187.31	0.8351
Bani Sweif	Observed	7.84	4.31	188.02	0.9634
	Generated	7.86	4.27	187.32	0.9680
Fayoum	Observed	6.69	3.71	188.01	0.9664
	Generated	6.70	3.71	187.31	0.9692
Kafr Al-Sheikh	Observed	5.21	1.94	187.24	0.9478
	Generated	4.71	2.60	187.23	0.9466
Shbin Al-Koum	Observed	5.63	2.09	187.98	0.9610
	Generated	5.30	2.81	187.69	0.9512
Al-Wadi Al-Gadid	Observed	10.70	4.91	188.76	0.8899
	Generated	10.57	4.85	188.74	0.9586


ALX-R
model
ETo(mm/day)
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ASW-R
model
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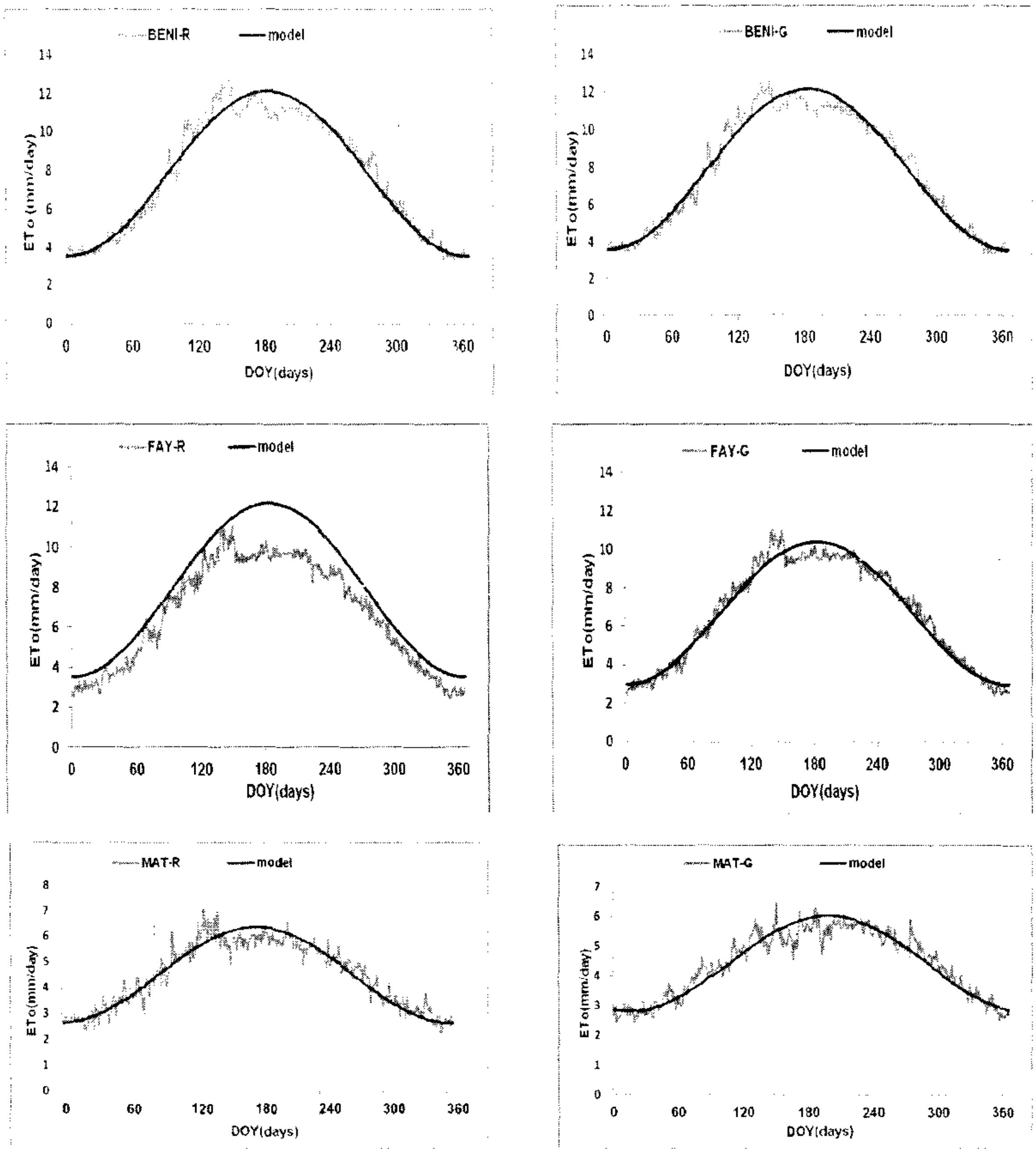
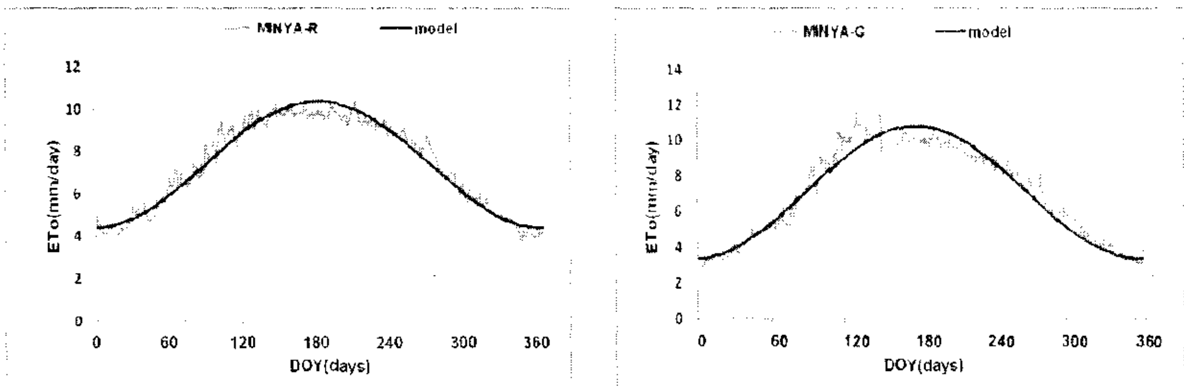
ETo(mm/day)
DOY (days)

Figure 3. Graphical time series of ET_0 estimated from observed and generated weather data





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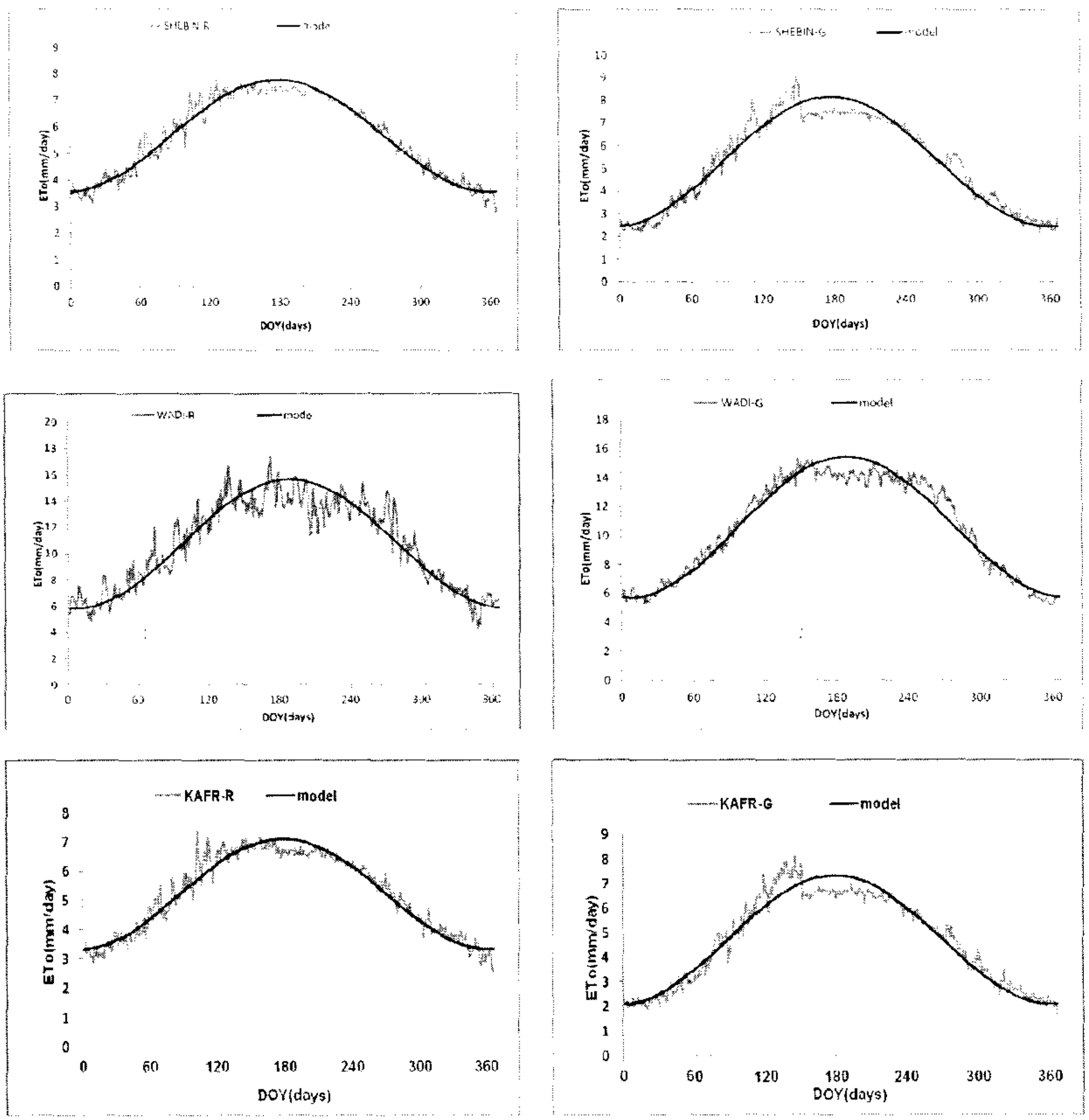

Figure 3. Cont......

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الملخص العربي

صلاحية مولد بيانات الطقس (ClimGen) لحساب جهد البخر-نتح بإستخدام معادلة بنمان مونتيث

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تم إختبار مولد بيانات الطقس (**ClimGen**) على البيانات المناخية المسجلة فى 11 محطة مناخية (الأسكندرية – مرسى مطروح – أسوان – المنيا – الأسماعيلية – أسيوط – بني سويف – الفيوم – كفر الشيخ – شبين الكوم – الوادي الجديد) لحساب جهد البخر – نتح (ET_0). النتائج توضح انخفاض الخطأ للمتوسطات والتباين للبيانات المولدة لجهد البخر-نتح بإستخدام معادلة بنمان – منونتيث. يوضح نموذج ال **ClimGen** أنه قادر على الأداء بجودة عالية على مدى من التباين المناخي الموجود فى مصر. النتائج توضح أن ال **ClimGen** قادر على إعطاء قيم جيدة لجهد البخر – نتح المحسوب من البيانات المناخية المولدة. نموذج ال **ClimGen** أوضح أداء جيد حيث أن جهد البخر-نتح المحسوب من البيانات المناخية المسجلة بصفة عامة يمكن توليده من السجلات المناخية السابقة. النتائج الحالية لها أهمية خاصة فى تطبيقات النماذج الزراعية فى مصرومنها حساب الاحتياجات المائية للمحاصيل.