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Performance evaluation of daily Weather Generator ClimGen model in a mountainous watershed of Himalayan foothills

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ABSTRACT

Long-term series of daily weather data are required for the analysis of weather-impacted systems such as cropping management systems, hydrologic studies, environmental studies *etc.* Weather generators are used to produce long series of synthetic daily climatic data using existing weather records where observed climate data are limited. But before evaluating any hydrological, crop growth and other models, it is first required to evaluate the weather generator in-built in the model for its better efficiency. Therefore, in this study, mostly used weather data generator, ClimGen, was evaluated for generating daily information taking daily precipitation (1970-2008), maximum and minimum temperatures of two existing weather stations of a hilly watershed, located in Uttarakhand *i.e.* Tamadhaun (1989-2008) and Kedar (1989-2003). After doing parameterization, ClimGen was used to generate daily series of rainfall from 2004-2008, maximum and minimum temperature data for Tamadhaun from 2006-2008 and for Kedar from 2001-2003. The generated data then used to evaluate the performance of ClimGen model using minimum root mean square error (RMSE), maximum correlation coefficient (r) and coefficient of efficiency (CE). ClimGen performed well in generating the minimum and maximum temperatures. However, for precipitation, it clearly underestimated the daily rainfall in all two locations. Therefore, based on actual and generated rainfall, system response models may be evaluated very carefully for the hilly watersheds.

1. INTRODUCTION

Watershed management is accepted as a prime tool for development of any region. Proper watershed development converts the area into climate resilient and then leads to achieve the sustainable agriculture. Now-a-days hydrological and environmental models are also becoming important tools for natural resource and environmental management in the watersheds. However, these models and crop management systems require different long-term series daily input data (*i.e.* climatological, hydrological and soil water content). Daily precipitation and temperature are readily available climate data in mountainous watersheds (Waichler and Wigmosta, 2003). In some cases solar radiation, evaporation, relative humidity and wind speed may not be available at the sites of interest. Many climate monitoring stations have records of insufficient in length, or only summarized in monthly archives and often carry missing data in the time series. Weather generators are practical tools to bypass those problems (Johnson *et al.,* 1996). Hydrological parameters *viz.,* streamflow and sediments yield and concentration; crop water requirement and crop yield depend on weather parameters. Also future forecasting of these parameters can be possible after generating the future weather data. Examples include WGEN (Richardson and Wright, 1984), WXGEN (Sharpley and Williams, 1990), CLIGEN (Arnold and Elliot, 1996), USCLIMATE (Johnson *et al.,* 1996), CLIMAK (Danuso and Della, 1997) and ClimGen (Stöckle *et al*., 1999). The statistical properties of the generated data are expected to be similar to those of the actual data. Previous studies (McKague *et al.,* 2005; Stockle *et al.,* 1999) have shown that ClimGen allows greater flexibility in location-specific statistical parameterization and produces reasonable daily weather data. Safeeq and Fares (2011) evaluated ClimGen for generating information on daily precipitation, temperature, and wind speed at four tropical watersheds located in Hawaii, USA. Castellvi and Stockle (2001) reported that WGEN generates better monthly weather data means, whereas ClimGen was better in reproducing daily variability. Reddy *et al.* (2014) found that ClimGen and LARS-WG (Long Ashton Research Station Weather Generator) were well suited for semi-arid southern Telangana region out of several weather generators for simulation of long-term weather data. The same trend was observed by ClimGen model for the same region as per Reddy *et al.* (2012). Therefore, in Soil and Water Assessment Tool (SWAT) model extensively used in hydrology, ClimGen is used in the background for generating the future daily climate data. Tao *et al.* (2008) also used ClimGen model to generate daily weather data of 100 years which were used as input to the CERES-Rice model to simulate rice production and water use under baseline climate conditions. Abedinpour *et al.* (2014) used ClimGen model for future generation of rainfall and then used in AquaCrop model to predict maize yield under future water availability scenarios for Delhi. Similarly, Jalota *et al.* (2006) used Cropsyst model in Rice-wheat cropping system by generating future weather parameter through ClimGen model. Murray (2013) used the Land-surface Processes and exchanges Dynamic Global Vegetation Model (LPX-DGVM) to simulate present and future runoff in India using ClimGen pattern-scaled scenarios. But before evaluating any hydrological and crop growth models, it is first required to evaluate the weather generator in-built in the model for its better efficiency. The performance of ClimGen has been evaluated under different environments (Acutis *et al.*, 1999; Castellvi and Stockle, 2001; Stockle *et al.*, 1999); however, it has not been evaluated under sub-humid mountainous watershed conditions. The specific objective of this paper was to evaluate the performance of the long-term weather generator ClimGen under sub-humid mountainous watershed in Uttarakhand.

2. MATERIALS AND METHODS

Study Area

The study was conducted in Bino watershed (29617.75 ha) situated in North-Eastern part of Ramganga catchment in middle and outer ranges of Himalayas between $79^0 6'14.4''$ to $79^0 17'16.8''$ E longitude and $29^0 47'6''$ to $30^0 02'9.6''$ N latitude in Almora and Pauri Garhwal districts of Uttarakhand. The watershed drains into river Bino, a tributary of river Ramganga. Climate of the watershed varies from Himalayan sub-tropical to sub-temperate having average annual rainfall of 931.3 mm. Maximum and minimum air temperatures are 30^0C and 18^0C, respectively. Maximum and minimum average monthly rainfall was observed as 215.1 and 22.3 mm in the month of August and December, respectively, whereas, daily mean temperature remains high during months of May and June and minimum in December and January and more than 70% of the rainfall occurs from South-West monsoon. Non-recording raingauges have been set up at Tamadhaun and Kedar for the measurement of daily rainfall.

Data Acquisition, Processing and Model Evaluation

Climatic parameters like daily rainfall (1970-2008), maximum and minimum temperatures data for two weather stations *i.e.* Tamadhaun (1989-2008) and Kedar (1989-2003) were obtained from Forest department of Ranikhet division. ClimGen 4.0 model used for the study was first parameterized after geolocating the locations of two stations and using daily precipitation for 1970-2003, maximum (T_{max}) and minimum (T_{min}) temperature data for 1989-2005 in case of Tamadhaun and for 1989-2000 for Kedar which were stored in Universal Environmental Database (UED) format. ClimGen wizard (Fig. 1) helped to prepare and analyze weather data for parameterization and generation. After parameterization, ClimGen was used to generate daily series of rainfall from 2004-2008, maximum and minimum temperature data for Tamadhaun from 2006-2008 and for Kedar from 2001-2003. The generated data then used to evaluate the performance of ClimGen model by comparing with respective observed data. To evaluate the agreement between actual and generated weather data minimum root mean square error (RMSE), maximum correlation coefficient (r) and coefficient of efficiency (CE) were taken as criteria. Again it was also evaluated by observing the scattered plotting of observed and predicted climate data.

Coefficient of Efficiency

Nash and Sutcliffe (1970) proposed coefficient of efficiency (CE) non-dimensional criterion on the basis of standardization of the residual variance with initial variance. It provided a relative performance of the model and is expressed as:

$$CE = \left\{1 - \frac{\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2}{\sum_{j=1}^{n}\left(y_j - \bar{y}\right)}\right\} \times 100 \qquad \ldots (1)$$

A perfect agreement between the observed and estimated values yields the coefficient of efficiency as 100%. For zero agreement, all the estimated values must be equal to the observed mean. A negative efficiency indicates that the estimated values are less than the observed mean.

Root Mean Square Error (RMSE)

The root mean square error (RMSE) was calculated to determine prediction accuracy of the developed models. The RMSE is zero for perfect fit and increased values of RMSE indicate higher discrepancies between predicted and observed values. The root mean square error between observed and predicted values was determined by the following relationship:

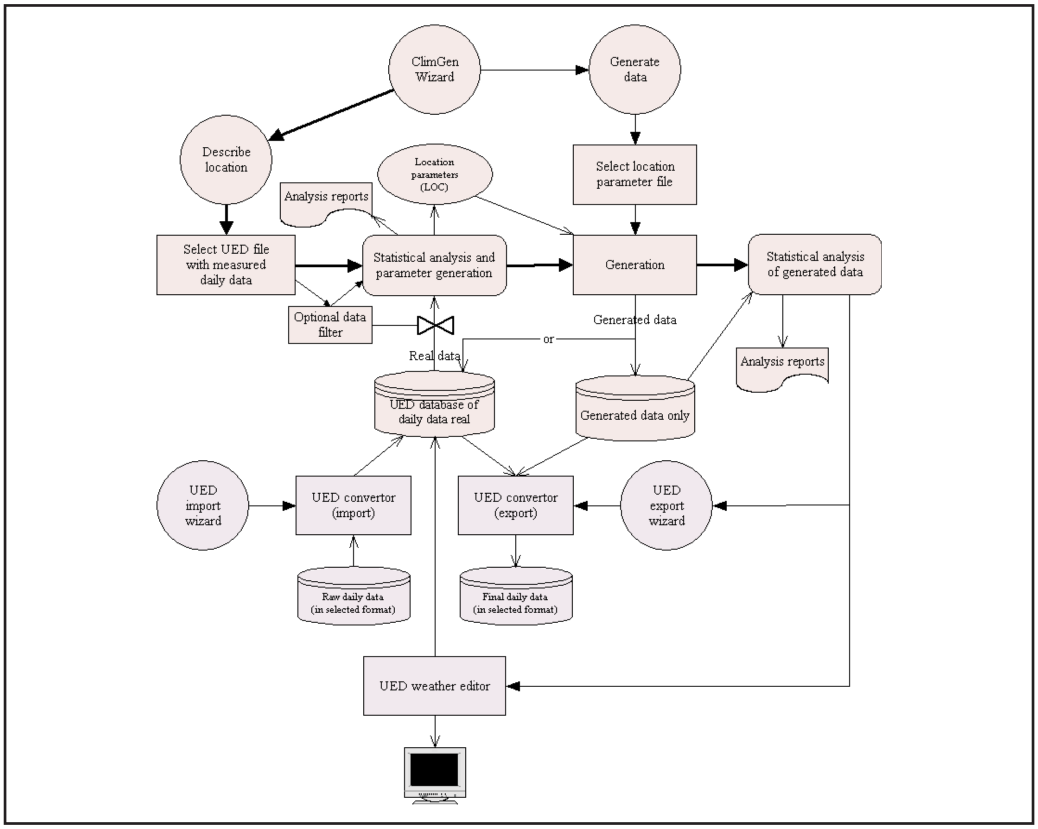

Fig. 1. ClimGen wizard for data entry, parameterization and generation of daily weather data (Source: ClimGen model Developer)

$$RMSE = \sqrt{\frac{\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2}{n}} \quad \ldots (2)$$

Coefficient of Determination (R^2)

The coefficient of determination (R^2) or correlation coefficient (r) is an indicator of degree of closeness between observed and predicted values. If observed and predicted values are completely independent, the R^2 will be zero. The coefficient of determination was estimated by the following equation:

$$r = \frac{\sum_{j=1}^{n}\left\{\left(y_j - \bar{y}\right)\left(\hat{y}_j - \bar{\hat{y}}\right)\right\}}{\left\{\sum_{j=1}^{n}\left(y_j - \bar{y}\right)^2 \sum_{j=1}^{n}\left(\hat{y}_j - \bar{\hat{y}}\right)^2\right\}^{1/2}} \quad \ldots (3)$$

Where, y_j and $\hat{y}_j$ are observed and predicted values, $\bar{y}$ and $\bar{\hat{y}}$ are mean of observed and predicted values, respectively, n is the number of observations and j is an integer varying from 1 to n.

3. RESULTS AND DISCUSSION

ClimGen model was evaluated for studying its performance in generating future daily rainfall, maximum and minimum temperatures by using available data for two weather stations of Tamadhuan and Kedar in Bino watershed under a mountainous Ramganga catchment of Uttarakhand. The area experiences three distinct seasons, *viz.*, long winter (October to March), summer (April to mid-June) and monsoon (mid-June to September). It was found that mean rainfall for Tamadhaun and Kedar during monsoon season varies from 107 to 192 mm and 98 to 159 mm, respectively. Mean maximum and minimum temperatures vary from 17 to 34^{0}C and 6.5 to 20^{0}C in Tamadhaun and 11 to 31^{0}C and 6.6 to 27.7^{o}C, in Kedar, respectively (Table 1). The qualitative and quantitative performance evaluation of ClimGen model was performed by comparing and judging the observed and predicted weather values.

Quantitative Evaluation

In order to conduct an objective assessment and to arrive at a precise evaluation, ClimGen model was put to more rigorous quantitative evaluation by determining statistical indices such as root mean square error (RMSE), Correlation Coefficient (r) and Coefficient of Efficiency

Table: 1
Mean monthly rainfall, maximum and minimum temperature for two weather stations of Bino watershed

Month	Tamadhaun			Kedar		
	Rainfall (mm)	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Rainfall (mm)	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)
January	41.2	17.4	6.5	41.1	11.0	6.6
February	52.9	19.8	8.1	58.7	14.2	9.2
March	43.5	23.3	10.7	44.3	19.3	13.5
April	29.7	27.8	14.2	27.3	24.8	18.5
May	50.0	31.8	16.9	47.1	29.7	24.2
June	108.5	33.6	20.1	100.0	31.1	26.4
July	180.0	32.9	19.9	161.2	31.0	27.7
August	192.3	31.8	20.1	158.6	29.3	26.1
September	106.9	30.3	19.2	98.2	27.8	23.6
October	21.3	27.9	16.8	19.6	24.0	19.3
November	6.3	24.3	12.7	6.7	18.3	13.0
December	22.9	19.6	9.1	19.9	13.0	8.2

(CE). Results of comparisons between generated and actual daily weather, analyzed separately for daily periods at Tamadhuan and Kedar, are given in Table 2. Validation of the model in maximum and minimum temperatures for Tamadhaun showed that the coefficient of efficiency, correlation coefficient and root mean square error were 62.56 and 66.60, 0.76 and 0.81, 4.77 and 3.82, respectively, whereas at Kedar, parameters were 82.94 and 87.18, 0.92 and 0.94, 2.40 and 2.18, respectively. Though it is showing in the acceptable range between observed and predicted temperature values, but the values of different performance evaluation parameters were less for Tamadhaun compared to Kedar. This may be due to location of Tamadhaun at higher elevation than Kedar in the watershed. Again higher RMSE (upto 11.0) and very low values (0.02) of correlation coefficients (Table 2) were observed for daily rainfall generation. Even coefficient efficiency was observed negative showing the under estimation of generated data. Overall, the results of this evaluation showed that the generation methods in ClimGen were sound for maximum and minimum temperatures but not for daily rainfall generation at considered weather stations of the watershed. Similar observations were also found by Safeeq and Fares (2011) when they evaluated ClimGen model for four tropical watersheds at USA.

Qualitative Evaluation

The visual observation based on graphical comparison between the observed and predicted values is one of the simplest methods for assessing the qualitative performance of a model. Accordingly, the future weather generating performances of ClimGen model were evaluated by comparing observed and generated values of maximum and minimum temperatures of Tamadhuan and Kedar during validation periods and are shown in scattered diagrams (Fig. 2 to Fig. 5). Figures show a more closure of observed and predicted maximum and minimum temperature in case of Kedar than Tamadhaun which corroborates the data got in quantitative form. Since there is very poor agreement between observed and generated rainfall (Table 2), therefore, qualitative evaluation of ClimGen model was not made for daily rainfall. This implies that for this type of hilly watershed, hydrological and crop growth modeling may be done very carefully in which ClimGen model is used as in-built model for future generation of rainfall.

Table: 2
Performance indices for validation of ClimGen model

Stations	Indices	Parameters		
		Rainfall	Maximum temperature	Minimum temperature
Tamadhuan	RMSE	11.305	4.771	3.822
	CC	0.022	0.762	0.807
	CE	-78.860	62.559	66.602
Kedar	RMSE	10.485	2.398	2.183
	CC	0.0193	0.924	0.940
	CE	-81.257	82.943	87.184

RMSE: Root Mean Square Error, CC: Correlation Coefficient, CE: Coefficient of Efficiency

4. CONCLUSIONS

ClimGen appears to perform well for maximum and minimum temperatures. The results indicated a good performance of the Clim Gen weather generator. Tests of daily rainfall showed significant departures between generated and actual values. Further investigation is required to determine why the model performed so poorly for rainfall in hilly watershed. Therefore, the agreement between system responses based on actual and generated rainfall may be

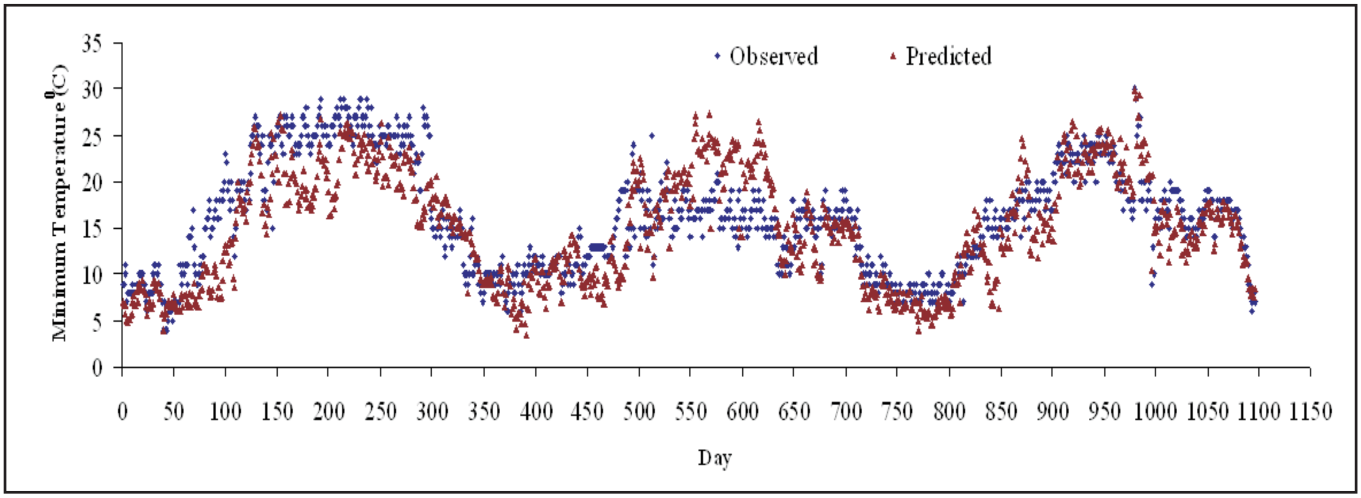

Fig. 2. Comparison between observed and generated minimum temperature for validation of ClimGen model at Tamadhuan

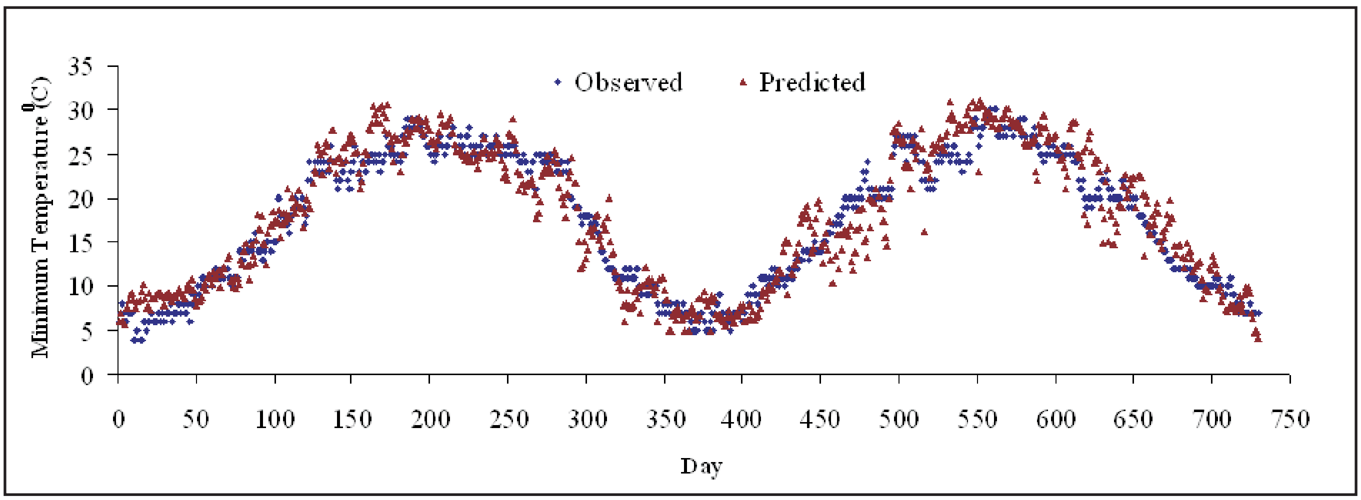

Fig. 3. Comparison between observed and generated minimum temperature for validation of ClimGen model at Kedar

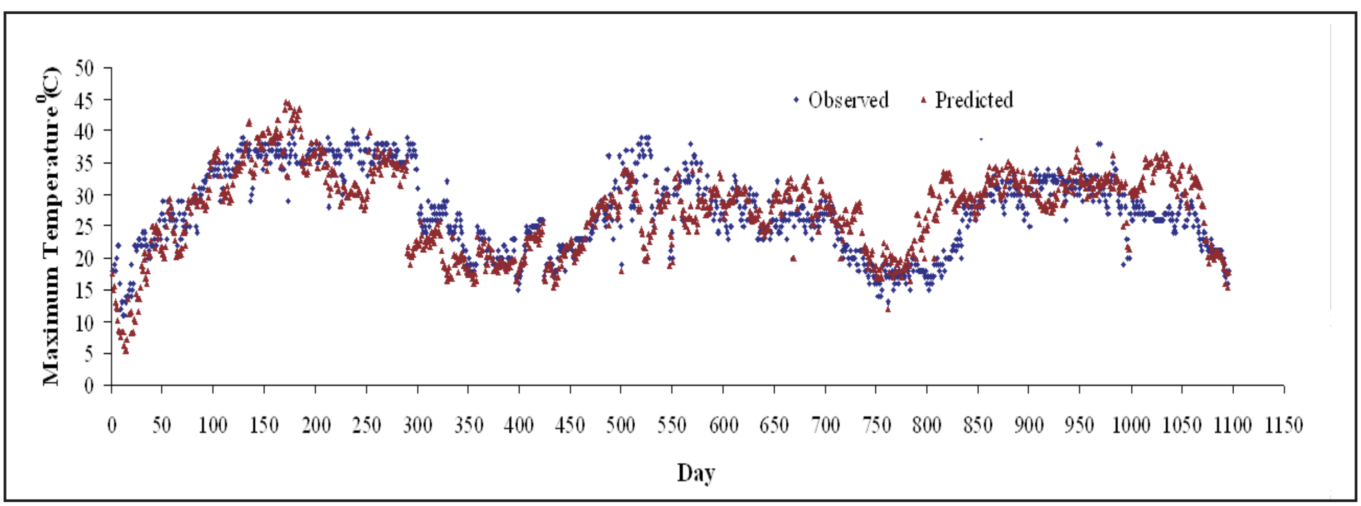

Fig. 4. Comparison between observed and generated maximum temperature for validation of ClimGen model at Tamadhuan

evaluated very carefully using hydrological and crop growth models for the hilly watersheds, as the result serves as a reminder of the need for assessment prior to data use.

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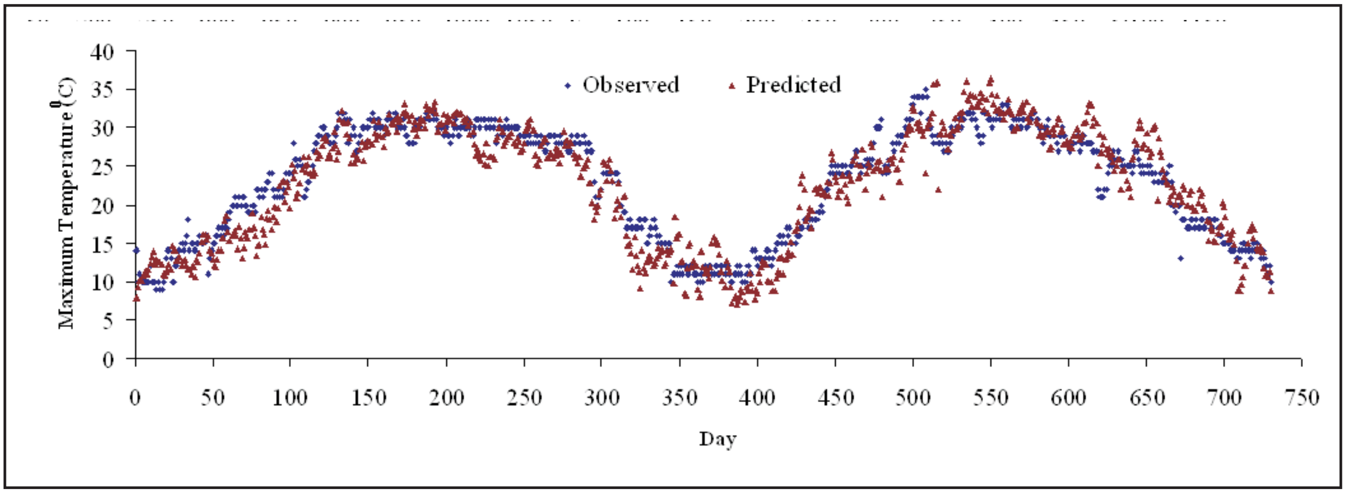

Fig. 5. Comparison between observed and generated maximum temperature for validation of ClimGen model at Kedar

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REFERENCES

Abedinpour, M., Sarangi, A., Rajput, T.B.S. and Singh, Man. 2014. Prediction of maize yield under future water availability scenarios using AquaCrop model. *J. Agric. Sci*., 152(4): 558-574 DOI: http://dx.doi.org/10.1017/S0021859614000094

Acutis, M, Donatelli, M. and Stockle, C.O. 1999. Performance of two weather generators as a function of the number of available years of measured climatic data. Proceedings First International Symposium on Modelling Cropping Systems, Lleida, Spain, 21-23 June. pp.129-130.

Arnold, C.D. and Elliot, W.J. 1996. CLIGEN Weather Generator Predictions of Seasonal Wet and Dry Spells in Uganda. *Trans. of ASAE*., 39(3): 969-972.

Castellvi, F. and Stockle, C.O. 2001. Comparing the performance of WGEN and ClimGen in the generation of temperature and solar radiation. *Trans. of ASAE*. 44: 1683-1687.

Danuso, F. and Della, M.V. 1997. CLIMAK reference manual. DPVTA, University of Udine, Italy, 36 p.

Jalota, S.K., Singh, G.B., Ray, S.S., Sood, Anil and Panigrahy, S. 2006. Performance of Cropsyst Model in Rice-Wheat cropping system. *Jour. Agric. Physics*., 6(1): 7-13.

Johnson, G.L., Hanson, C.L., Hardegree, S.P. and Ballard, E.B. 1996. Stochastic Weather Simulation: Overview and analysis of two commonly used models. *J. Applied Met.,* 35: 1878-1896.

McKague, K., Rudra, R., Ogilvie, J., Ahmed, I. and Gharabaghi, B. 2005. Evaluation of weather generator ClimGen for Southern Ontario. *Can. Water Resour. J.,* 30(4): 315-330.

Matalas, N.C. 1967. Mathematical assessment of synthetic hydrology. *Water Resour. Res.,* 3(4): 937-945.

Murray, S.J. 2013. Present and future water resources in India: Insights from satellite remote sensing and a dynamic global vegetation model. *J. Earth Syst. Sci.*, 122(1):1-13.

Nash, J.E. and Sutcliffe, J.V. 1970. River flow forecasting through conceptual models. *J. Hydrol.,* 10: 282-290.

Reddy, K.S., Kumar, M., Marithi, V., Umesha, B., Vijaylaxmi and Nageswar Rao, C.V.K. 2014. Climate change analysis in southern Telangana region, Andhra Pradesh using LARS-WG model. *Curr. Sci.,* 107(1): 54-62.

Reddy, K.S., Kumar, M., Nagarjuna Kumar, R., Umesha, B., Vijayalakshmi and Venkateswarlu, B. 2012. Long term rainfall and temperature analysis through ClimGen model in Ranga Reddy district of Andhra Pradesh. *J. Agrometeorol.* (Spec. Issue-I). 15: 45-50.

Richardson, C.W. and Wright, D.A. 1984. WGEN: A model for generating daily weather variables. USDA-ARS, 235 p.

Safeeq, M. and Fares, A. 2011. Accuracy evaluation of ClimGen weather generator and daily to hourly disaggregation methods in tropical conditions. *Theor. Appl. Climatol.,* 106: 321-341.

Sharpley, A.N. and Williams, J.R. 1990. EPIC-Erosion/Productivity Impact Calculator: 1. Model Documentation. US Department of Agriculture Technical Bulletin No. 1768: 235 p.

Stöckle, C.O., Campbell, G.S. and Nelson, R. 1999. ClimGen manual. Biological Systems Engineering Department, Washington State University, Pullman, WA, 28 p.

Tao, F., Hayashi, Y., Zhang, Z., Sakamoto, T. and Yokozawa, M. 2008. Global warming, rice production, and water use in China: Developing a probabilistic assessment. *Agril. Forest Met*., 148: 94-110.

Waichler, S.R. and Wigmosta, M.S. 2003. Development of hourly meteorological values from daily data and significance to hydrological modeling at H. J. Andrews Experimental Forest. *J. Hydrometeor*. 4: 251-263.