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Evaluation of RegCM4 climate model for assessment of climate change impact on crop production

NIDHI SINGH, R. K. MALL, GEETIKA SONKAR, K. K. SINGH* and A. GUPTA**

DST-Mahamana Centre of Excellence in Climate Change Research, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi – 221 005, India

**India Meteorological Department, New Delhi – 110 003, India*

***Department of Science and Technology, New Delhi – 110 016, India*

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e mail : mall_raj@rediffmail.com

सार - फसल की पैदावार पर जलवायु परिवर्तन के प्रभावों का मूल्यांकन करने के लिए अब क्षेत्रीय जलवायु मॉडलों (आर सी एम) को सामान्य परिसंचरण मॉडलों (GCMs) से बेहतर माना जाता है। आर सी एम-रेग सी एम 4.0 (RCM-RegCM4.0) का जलवायु उत्पाद कितना प्रभावित है इसका मूल्यांकान करने के लिए आधारभूत अनुरूपों दैनिक मौसम की उसी वर्ष की (1971-2000) वाराणसी में प्रेक्षित मौसम आंकडों के साथ तुलना करके विश्लेषण किया गया। इनसे प्राप्त हुए परिणामों से पता चला है कि आर सी एम के उत्पाद निचले वार्षिक अधिकतम और वार्षिक न्यूनतम तापमान क्रमशः 5.4° सेल्सियस और 1.7° सेल्सियस तक प्रभावित हैं ऋतुनिष्ठ विश्लेषण से पता चलता है कि आर सी एम के आउटपुट में खरीफ (चावल) के मौसम अधिकतम और न्युनतम तापमान क्रमश: 3.0° सेल्सियस और 1.5° सेल्सियस तथा रबी (गेहूँ) के मौसम में अधिकतम और न्युनतम तापमान क्रमश: 6.4° सेल्सियस और 1.4° सेल्सियस कम कर के आंका जाता है। आर सी एम का उत्पाद रबी के मौसम के वार्षिक वर्षा को अधिक आंकता है जबकि यह खरीफ ऋतु की वार्षिक वर्षा को कम आंकता है। यह खरीफ और रबी की ऋतु में वार्षिक वर्षा के दिनों को भी अधिक आंकता है। इसमें महत्वपूर्ण बात यह है कि यह मॉडल चरम परिघटनाओं जैसेः अत्यधिक तापमान और भारी वर्षा को कम करके आंकता है। इस अध्ययन में गेहूँ और चावल की उपज में पूर्वाग्रह का आकलन शामिल है जिसमे CERES - गेहूँ और CERES - चावल की फसल मॉडल का उपयोग किया गया है और आर सी एम के अनुरुपित मौसम डेटा का उपयोग किया है। आर सी एम बेसलाइन डेटा में चरम परिघटनाओं में पूर्वाग्रह के कारण कई वर्षों में अनुरूपित गेहूँ और चावल अनाज की पैदावार वास्तविक पैदावार से अधिक आंकी गई थी। वर्तमान आर सी एम आउटपुट वर्तमान समय में प्रेक्षित वार्षिक और ऋतुनिष्ठ जलवायु कि तुलना में भिन्न-भिन्न प्रकार के जलवायविक भिन्नताओं को अधिक महत्व दे रहा है। इसलिये बेहतर प्रबंधन के लिए जलवायु मॉडल पर आधारित प्रशमन कार्यक्रम तथा योजना एवं नीति तैयार करने के लिए विश्वसनीय और मान्य आर सी एम जलवायु उत्पाद प्राप्त करना सुनिशिचत किया जाना चाहिये। इसके लिये हमें जलवायु मॉडलिंग में अधिक शोध के माध्यम से अधिक सटीक और बेहतर क्षेत्रिय जलवायु मॉडल की आवश्यकता है।

ABSTRACT. For evaluating the impacts of climate change on crop yields regional climate models (RCMs) are now considered better than general circulation models (GCMs). In order to assess what extent the climate output of RCM-RegCM4.0 is biased, this is analysed by comparing the base line simulated daily weather with the observed weather for the corresponding year (1971-2000) over Varanasi. The result shows that the RCM output is biased towards lower annual maximum and minimum temperature by 5.4 °C and 1.7 °C respectively. Seasonal analysis shows that the RCM output is underestimating the kharif (Rice) season maximum and minimum temperature by 3.0 °C and 1.5 °C respectively and the rabi (wheat) season maximum and minimum temperature by 6.7 °C and 1.4 °C respectively. The RCM output overestimates the annual and rabi rainfall while it underestimates kharif rainfall. It is also overestimating the annual, kharif and rabi season rainy days. Most importantly, model underestimates the extreme events, *i.e*., extreme temperature and heavy rainfall. The study also includes assessment of biasness in yields of wheat and rice simulated using CERES-wheat and CERES-rice crop models employing observed and RCM simulated weather data. Due to biasness in the extreme events in RCM baseline data the simulated wheat and rice grain yield during several years were overestimated compared to observed yield. The present RCM output is overestimating the different climatic variables in comparison to present observed climate for annual as well as seasonal. Therefore, framing of better management practices, mitigation programme and planning and policy making based on climate model output must ensure to get the reliable and validated RCM climate output. For that we need more precise and improved regional climate models through more research in climate modelling.

Key words – Climate change, Agriculture, RegCM4.0, DSSAT, Rice, Wheat.

1. Introduction

The climate has shown an unequivocal change throughout the globe with observed increase in mean annual temperature of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012 (IPCC, 2014). This warming has exaggerated the extreme events, sea surface rise and caused negative impact on important sectors such as water, health and agriculture. Importantly, the global surface temperature is expected to rise by 1.5 °C up to the end of 21st century relative to 1850 to 1900 for all RCP scenarios except RCP2.6 (IPCC 2014). This expected rise in mean annual temperature would lead to decrease in the crop duration, grain yield and may also lead to increase in disease and pest attacks (Mall *et al*., 2006; Roudier *et al*., 2011; Swaminathan *et al*., 2012; Mendelsohn, 2014; Tripathi *et al*., 2016; Mall *et al*., 2017). Apart from increase in temperature change in rainfall pattern has led to decline in yield too. The decline in monsoon rainfall and increase in heavy rainfall events (Ramanathan *et al*., 2005; Ramesh and Goswami 2007; Dash *et al*., 2009) have caused intense hydrometeorological disasters across India and may lead to decline in rice yield (Auffhammer *et al*., 2012). A study by Pathak *et al*. (2003) shows significant declining trend in wheat and rice potential yield which is mainly attributed to the decrease in solar radiation and increase in minimum temperature. Uttar Pradesh, a major wheat and rice producing Indian state contributes largest to wheat production by 30.6% (30.06 MT) and second largest in rice production by 11.8% (12.9 MT) of India during 2016-2017 (DES, 2017; Mall *et al*., 2016a). Wheat and rice production projected under Climate change scenario for 2030s and 2050s for Uttar Pradesh shows a declining trend (Dasgupta *et al*., 2013). Temperature above 34 °C have caused substantial decline in the wheat yield and is projected to reduce by 7% up to 2020, by 11% up to 2050 and by 32% up to 2080 (Shinde and Modak, 2013; WBG, 2013).

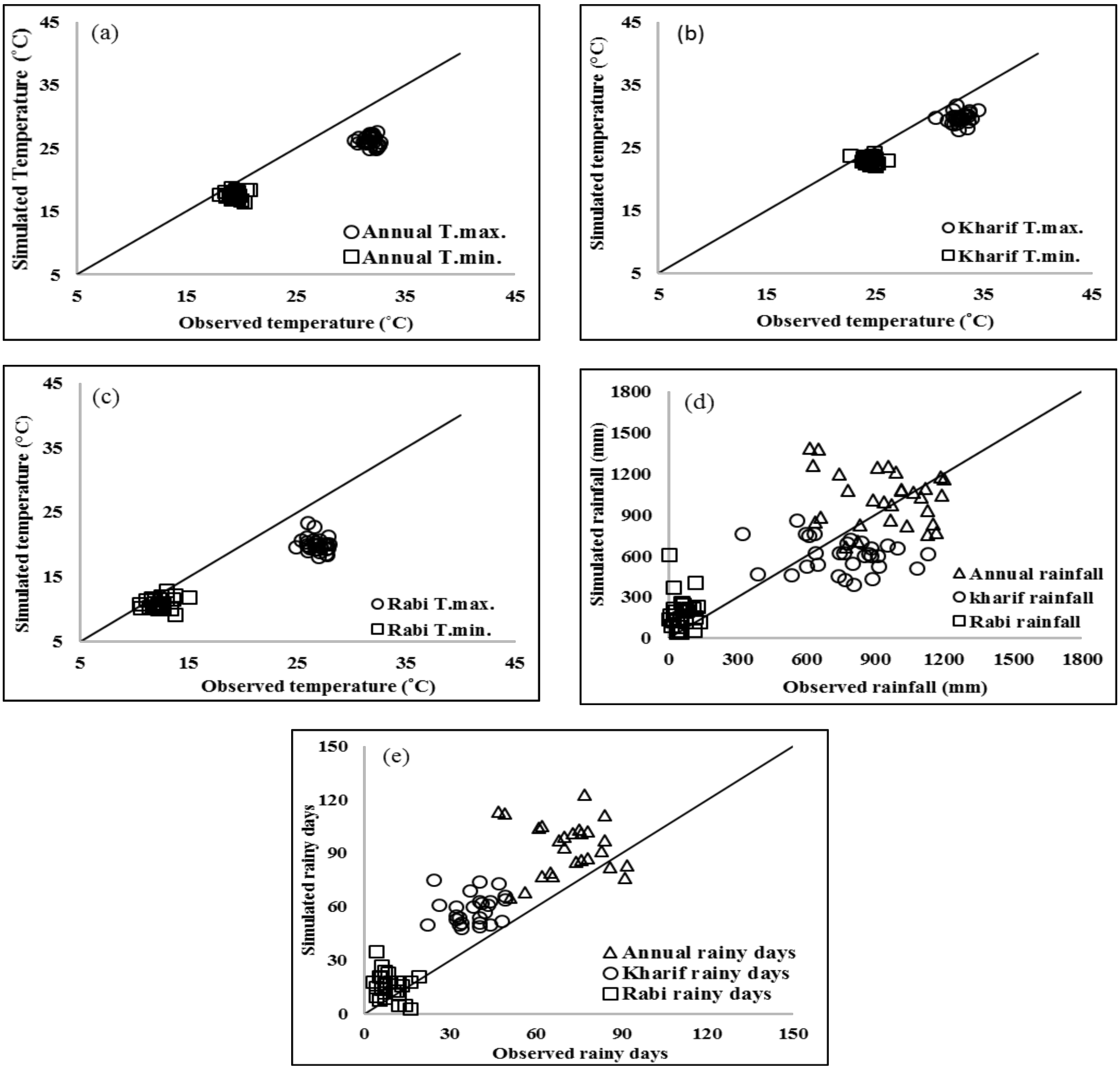
To quantify the impact of climate change on crop productivity, crop growth simulation models have been developed, improved and are in large use in research studies (Mall and Gupta, 2000; Mall *et al*., 2001; Anwar et al., 2007; Hundal and Kaur, 2007; Ohta and Kimura, 2007; Challinor *et al*., 2007; Chapman, 2008; Boomiraj *et al*., 2010; Singh *et al*., 2010; Tao *et al*., 2014). The impact of climate change on rice production in Asia using crop models, general circulation models (GCMs) and regional climate models (RCMs) shows decline in the crop yield in future (Masutomi *et al*., 2009; Chattaraj *et al*., 2014). Global warming is projected to cause annual damage to crops up to 4-26% in India. India is projected to a damage of more than 20% of its crop revenue and was assessed to be responsible for two thirds of the lost net revenue in Asia in present scenario (Sanghi and Mendelsohn, 2008; Mendelsohn, 2014).

Most importantly, the impact of climatic variables on crops is heterogeneous and they gain importance as a factor of interest differently for different agro climatic zones. Therefore, there is a need for more location specific research that could bring more knowledge about the impact of certain climatic variables on a crop over that place. That will help in designing a consolidated policy making and management practices (Barnwal and Kotani *et al*., 2013). That would be possible with a refined projection estimates by GCMs or RCMs. Moreover, the RCM gives a better estimate than a GCM due to a region specific coverage. But the quantification of GCM and RCM model bias is important to figure out the uncertainty associated with the climate change projection to improve models otherwise it hampers the analysis and decision making and in assessing and understanding the climate change and variability and its impact on crop production. In one such study RegCM4 was used in evaluating the simulated rainfall through a comparison of several observations using Asian Precipitation-Highly Resolved Observational Data Integration towards Evaluation (APHRODITE) and Climate Research Unit (CRU) in 19-year simulation period of 1982-2000 in Kalimantan (Arini *et al*., 2015) where the model underestimated the rainfall. For testing of RCM output, comparison between the observed and the RCM output were studied by Zacharias *et al*. (2015) and Teng *et al*. (2015).

In this paper, we present the comparison of RegCM4 output with the observed climate data over Varanasi and the effect of biasness on the crop yield simulation using crop model by comparing it with the observed yield. The major objectives of the paper were: (*i*) Comparison of simulated baseline weather data with observed weather data over a period of 30 years from 1971-2000 *viz*., (a) comparison of annual and seasonal (kharif and rabi) maximum and minimum temperature, (b) comparison of number of days with maximum temperature >45 °C, >40 °C and <20 °C and days with minimum temperature <5 °C, (c) comparison of annual and seasonal (kharif and rabi) rainfall and rainy days (rainfall >2.5 mm/day), (d) comparison of annual rainy days with rainfall >15 mm/day, >50 but <100 mm/day,>100 but <150 mm/day and >150 mm/day, (e) annual and seasonal (rabi and kharif) rainfall intensity (total rainfall/number of rainy-day), (*ii*) Comparison of simulated potential, irrigated and rainfed wheat and rice yield using observed climate (Observed) and RCM output (Model).

2. Materials and method

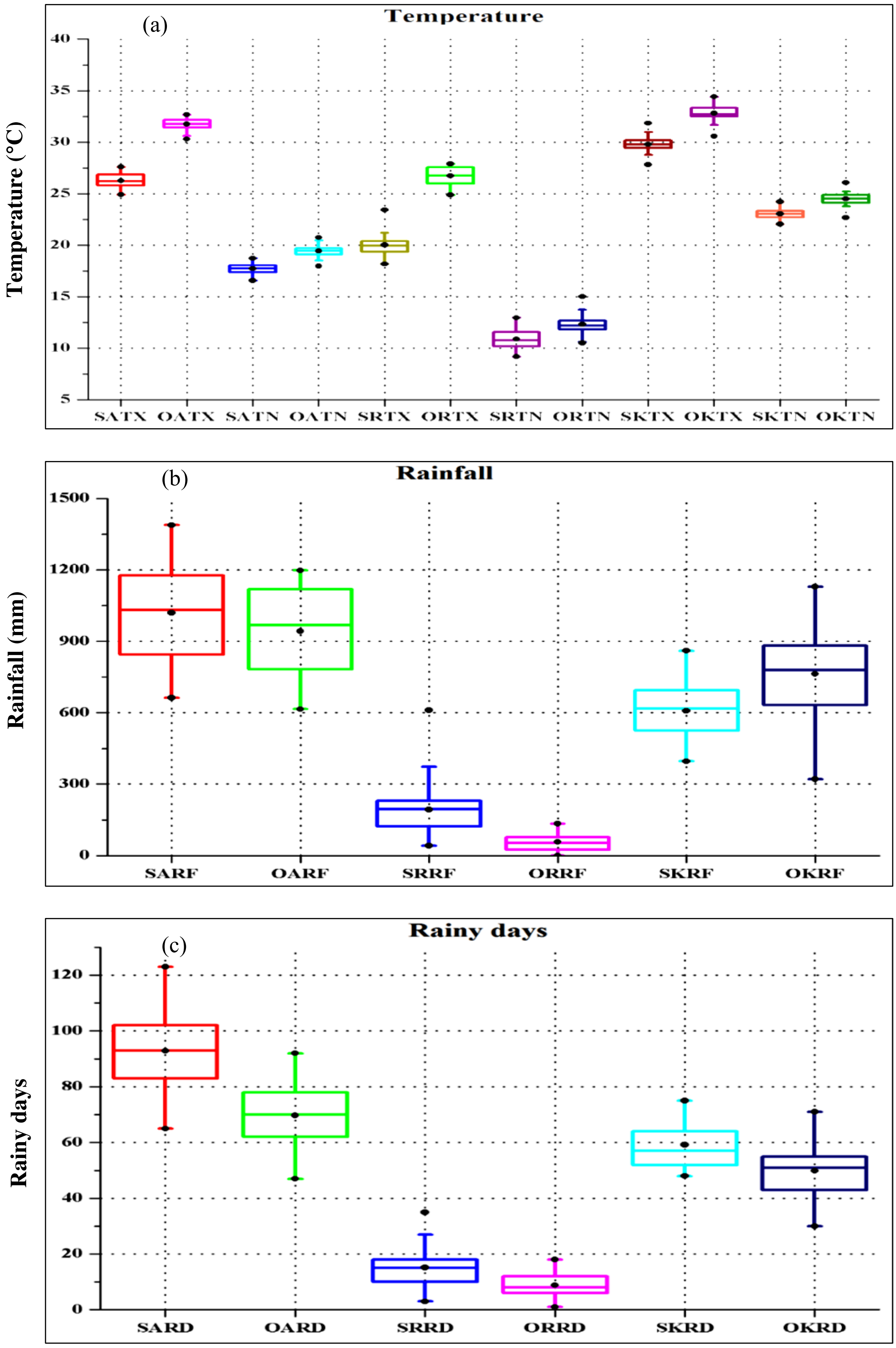
The study was conducted at Varanasi, a humid subtropical climate located in eastern agro-climatic zone of Uttar Pradesh, India at an elevation of 80.71 meters. It is situated in the center of the Indo-Gangetic plains



Figs. 1(a-e). Comparison of RegCM4.0 baseline climate data with the observed climate (1971-2000) in Varanasi (a) Annual maximum and minimum temperature, (b) Kharif maximum and minimum temperature and (c) Rabi maximum and minimum temperature, (d) Annual and seasonal rainfall and (e) Annual and seasonal rainy days (Tmax - Maximum temperature, Tmin - Minimum temperature)

at 25° 18′ N latitude, 83° 01′ E longitude and 82.20 m above sea level with a population of 3.4 million. Main cereals produced are wheat and rice. The mean annual rainfall is 1100 mm. The soil in Varanasi is alluvial type (Sandy loam). Electrical Conductivity of the Soil varies from 0.923 to 1.225 ds/m. Bulk density and particle density varied from 1.30 to 1.46 (g/cm^3) and 2.11 to 2.44 (g/cm^3) respectively with 0.404 to 0.765% soil organic carbon and 184 kg/ha available nitrogen.

Daily climate data (1971-2000) were obtained from Indian Meteorological Department (IMD). Baseline RCM climate data for the period 1971-2000 were obtained from CCCR-IITM through its participation in the domain CORDEX-South Asia using RegCM4 (LMDZ) experiment (Giorgi *et al.*, 2012). RegCM4 is a fourth version regional climate modeling system developed by National Center for Atmospheric Research (NCAR) in ICTP-Italy in 2010 (Bhatla *et al.*, 2016). The RegCM4 were selected based on extensive set of preliminary



Figs. 2(a-c). Difference in the observed and RegCM4.0 climatic parameters (a) Annual and seasonal maximum and minimum temperature, (b) rainfall and (c) rainy days. The boxes mark the 25% and 75% quartiles while the whiskers give the minimum and maximum values. The point above the whiskers shows the outliers. Abbreviations used- S-simulated, O- observed, A-annual, K- kharif, R-rabi, TX-maximum temperature, TN- minimum temperature, RF- rainfall, RD-rainy days

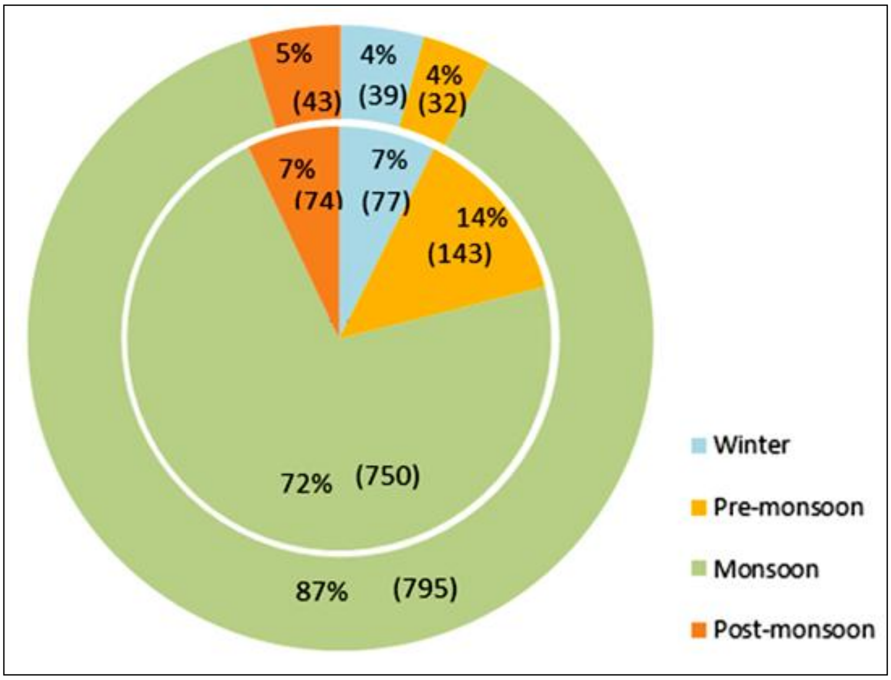


Fig. 3. The pie diagram shows the percentage distribution of seasonal rainfall of observed and RCM data. The outer circle represents the observed data and the inner circle represents the RCM data. The values in the bracket represent the rainfall (mm)

experiments which provided a realistic representation of the South Asia climate in present day conditions that provides simulations for past, present and future climate states.

The calibrated and validated CERES Wheat and CERES Rice crop models by Mall and Aggarwal (2002); Yadav *et al*. (2015) and Mall *et al*. (2016b) were used for simulating the rice and wheat potential, irrigated and rainfed yields from 1983-2000. The crop yield was simulated for wheat and rice at three levels of treatment: Potential yield simulation was done considering no water and nitrogen stress. Irrigated wheat yield was simulated considering application of 120 kg N/ha in three split doses of 60 kg/ha at zero day, 30 kg/ha at twenty days and 30 kg/ha, at sixty days after sowing and 5 irrigations on required date, whereas, for rice three split doses of nitrogen of 35 kg/ha at zero day, 60 kg/ha at twenty-five days and 60 kg/ha at forty-five days after sowing with irrigation on required date. Rainfed crop simulation was done considering 30 kg/ha basal nitrogen application and assuming no irrigation for wheat and rice and are free from any insect, pest and disease effects. The Decision Support System for Agro-technology Transfer (DSSAT) Version 4.5 is a software based application program. DSSAT is supported by data base management programs for soil, weather and crop management and experimental programs. It also includes crop modules (CERES, CROPGRO, CROPSIM and SUBSTOR modules) that are widely used for simulating the crop growth, development and yield along with impact assessment of climate variability and climate change on crop yield by comparing simulated outcomes with observed results (Hoogenboom *et al*., 2010).

Computation of biasness associated with RCM output were done by comparing means of observed and RCM climate data. To compare the simulated potential, irrigated and rainfed yields using observed and RegCM4.0 weather data (1983-2000) following goodness- of- fit statistics were used:

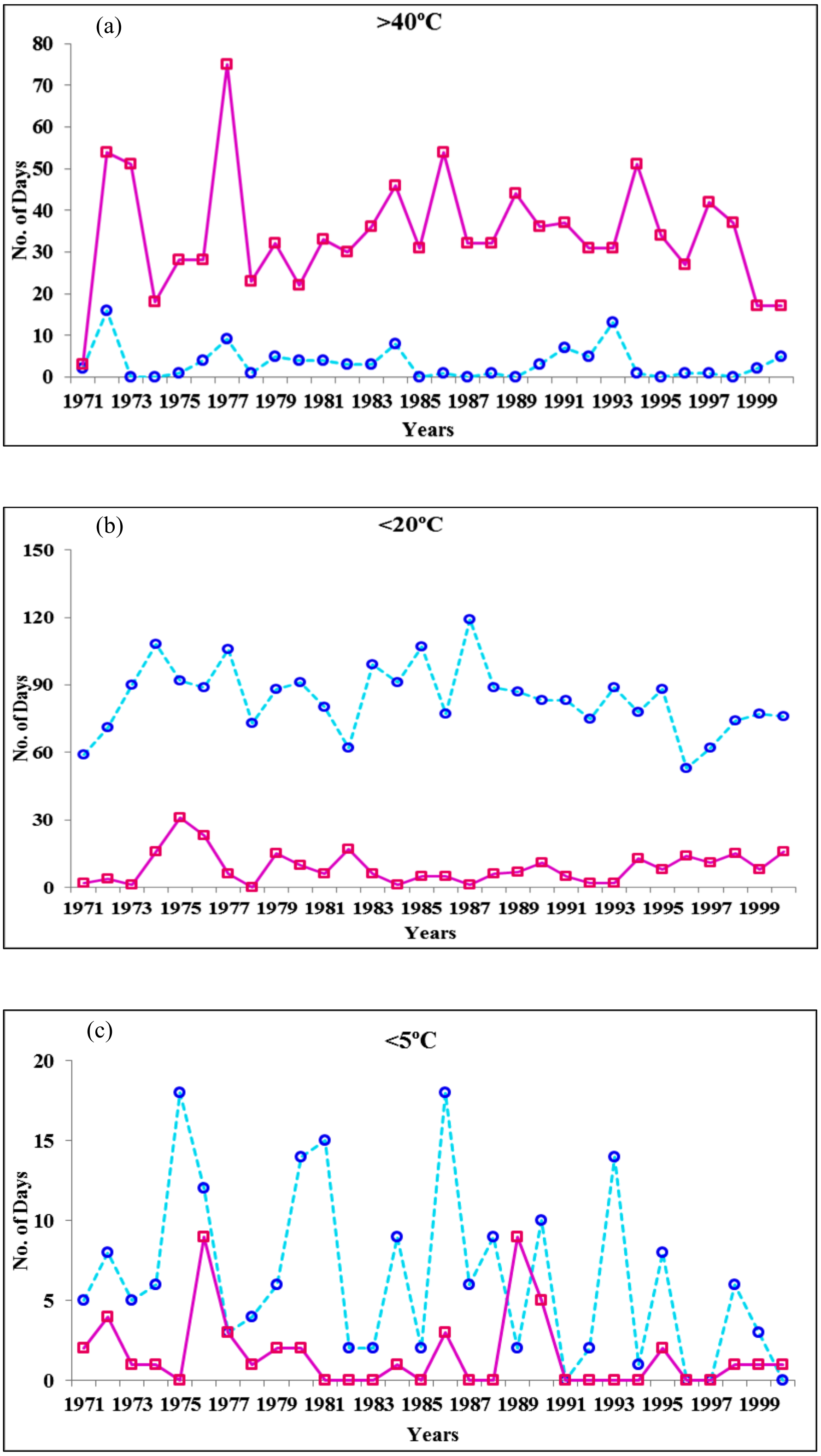
Percent of deviation (D%)

$$D\% = \left[\frac{S_i - O_i}{O_i}\right] \times 100\% \quad (1)$$

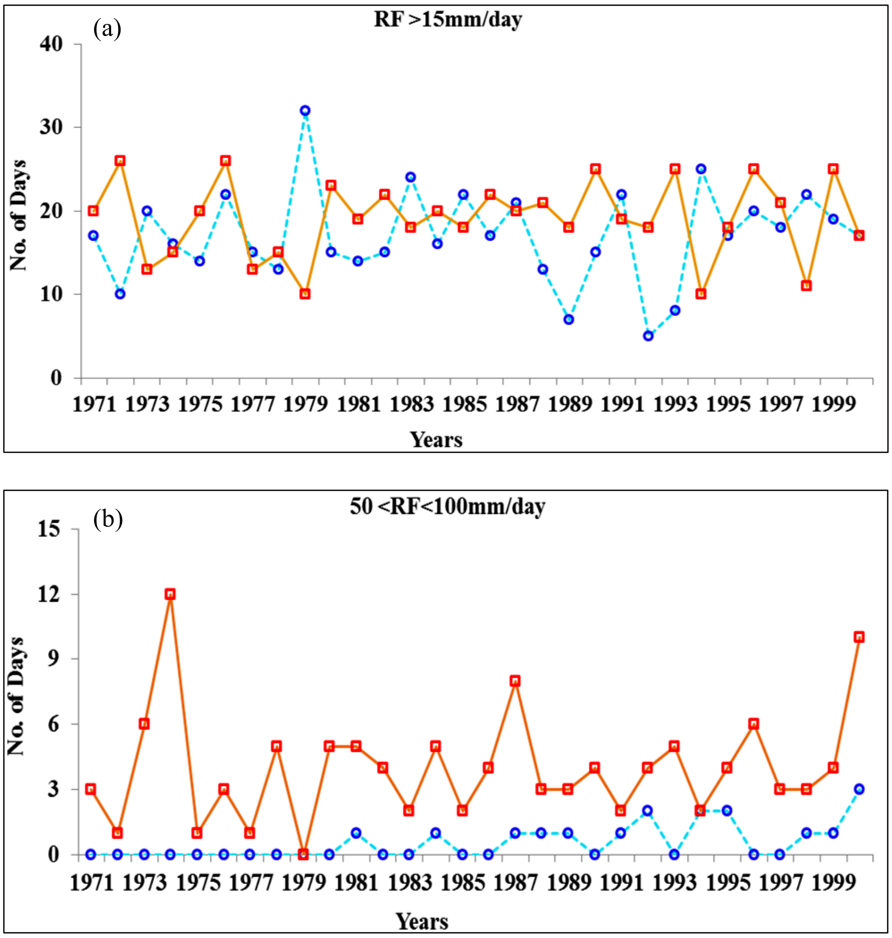
S_i and O_i represent simulated and observed yield (t/ha) respectively. D% is the deviation of simulated yield from observed yield. The value of D% close to zero refers brilliant agreement (Araya *et al*., 2015).

Index of Agreement (I)

$$\mathrm{I} = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(|S_i - S_m| + |O_i - O_m|)^2} \quad (2)$$



Figs. 4(a-c). The graph represents the comparison of total numbers of extreme temperature days between observed and RCM (RegCM4.0) data for the period 1971-2000. Pink solid line represents the observed data and blue dashed line RegCM4.0 data



Figs. 5(a&b). The graph represents the comparison of total numbers of extreme rainfall between observed and model (RegCM4.0) data for the period 1971-2000.Orange solid line represents the observed data and Blue dashed line represent RegCM4.0 data, RF- rainfall

S_m and O_m represent means of simulated and observed yield respectively. The values of I vary from negative infinity to 1. Values of I near to 1 refer better agreement between the observed and simulated yield (Willmott, 1982).

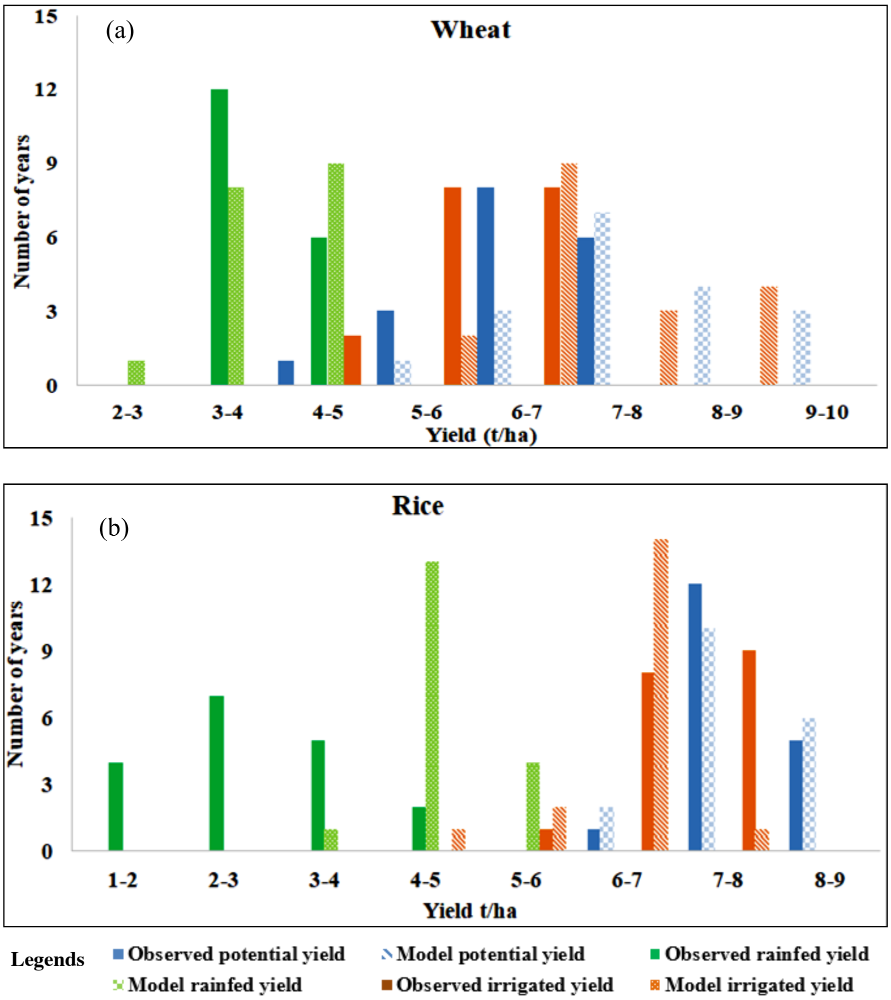
Root mean squared error (RMSE)

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n}} \quad (3)$$

RMSE defines statistical error in model. RMSE close to zero correspond to brilliant agreement and good performance of the model.

3. Results and discussion

The simulated annual mean maximum and minimum temperature are showing a large underestimation by 5.4 ± 0.2 °C and 1.7 ± 0.2 °C respectively compared to observed [Figs. 1(a) & 2(a)]. Similarly, simulated rabi and kharif maximum and minimum temperature are underestimated as well. The Kharif simulated mean annual maximum and minimum temperatures are underestimated by 3.0 ± 0.1 °C and 1.5 ± 0.1 °C respectively [Figs. 1(b) & 2(a)] whereas the simulated rabi mean annual maximum and minimum temperature was underestimated by 6.7 ± 0.3 °C and 1.4 ± 0.1 °C respectively [Figs. 1(c) & 2(a)]. This underestimation shows the biasness associated with model output. In this study, rabi (wheat) and kharif (rice) seasons are divided into three broad crop sub - phases - vegetative, reproductive and ripening phases. The sub-phases were analyzed in a similar manner. The simulated rabi vegetative, reproductive and ripening phase maximum and minimum temperatures were underestimated as well. The maximum temperature was underestimated by 6.3 ± 0.3 °C, 6.6 ± 0.5 °C and 7.1 ± 1.1 °C respectively



Figs. 6(a&b). Comparison of frequency distribution of (a) Wheat and (b) Rice using observed and model (RegCM4.0) data for Varanasi

while the minimum temperature was underestimated by 0.3 ± 0.3 °C, 2.2 ± 0.2 °C and 2.7 ± 0.4 °C respectively for the three sub phases. In a similar manner the kharif sub-phases maximum temperature was underestimated by 1.9 ± 0.6 °C, 2.8 ± 0.3 °C and 5.4 ± 1.3 °C whereas, its minimum temperature was underestimated by 0.7 ± 0.2 °C, 1.9 ± 0.0 °C and 2.3 ± 0.4 °C respectively.

The annual temperature was analyzed for the extreme temperature, *i.e.*, maximum temperature >40 °C, >45 °C and <20 °C and minimum temperature <5 °C and were compared with the observed. The extreme temperature days showed a noticeable underestimation by RCM output during 30-year comparison period. The model didn't show any day with maximum temperature >45 °C within the study period while observed data showed 36 days with maximum temperature >45 °C, whereas number of days with maximum temperature >40 °C were highly underestimated by 932 days [Fig. 4(a)]. Contrary to this, the simulated days with maximum temperature <20 °C and minimum temperature <5 °C were overestimated by 2249 and 142 days respectively [Figs. 4(b&c)]. This indicates that the model failed to satisfactorily simulate the extreme temperature. In another study using the PRECIS model baseline simulation showed a contrary result where the baseline temperature shows an overestimation of extreme temperature (Zacharias *et al.*, 2015). The temperature extremes have also been studied for the vegetative, reproductive and ripening phases for wheat and rice. Based on different literatures, the extremes set for rabi maximum temperature were >32 °C, >31 °C and >35 °C and minimum temperature <10 °C respectively for the three sub-phases in chronological order, which are critical for crop growth and yield. The rabi maximum temperature

TABLE 1

Deviation (D%), Index of agreement (I) and root mean squared error (RMSE) for wheat and rice potential, irrigated and rainfed yield calculated using DSSAT crop model with the help of observed and RegCM4.0 weather data

Treatments	Wheat			Rice		
	D%	I	RMSE	D%	I	RMSE
Potential	-10 to 89 (25)*	-0.2	2	-21 to 17 (0)*	0.6	1
Irrigated	-7 to 92 (27)*	-0.3	2	-27 to 4 (-9)*	0.1	1
Rainfed	-14 to 28 (6)*	-0.1	1	11-408 (112)*	-3	2

D%, percent of deviation; I, Index of agreement; RMSE, Root Mean Squared Error

*The values in the bracket represent the average deviation values

>32 °C, >31 °C and >35 °C were underestimated by 4, 17 and 82 days respectively. Similarly, the rabi minimum temperature <10 °C were underestimated by 170 days for vegetative phase while it is overestimated by 623 and 232 days respectively for reproductive and ripening phase in comparison to the observed for the study period of 1971-2000. The extremes set for Kharif maximum temperature were >38 °C, >35 °C and >30 °C and minimum temperature <20 °C, <22 °C and <18 °C respectively for the three sub-phases. The Kharif maximum temperature >38 °C, >35 °C and >30 °C were underestimated by 63, 43 and 439 days respectively. The Kharif minimum temperature <20 °C were underestimated by 2 days while it is overestimated by 127 and 177 days for kharif minimum temperature <22 °C and <18 °C respectively.

The simulated rainfall is showing a shift in the rainfall pattern that shows more rabi rainfall than monsoon or kharif rainfall [Fig. 2(b)]. The simulated annual and rabi rainfall is overestimated by 77 mm and 135 mm respectively in comparison to observed whereas the kharif simulated rainfall is showing an underestimation of 155 mm for the period 1971-2000 [Figs. 1(d) & 2(b)]. The sub-phases of rabi and kharif were also analyzed for their biasness in the simulated rainfall in comparison to the observed. The rabi vegetative, ripening and reproductive phase rainfall were overestimated by 60 mm 30 mm and 45 mm respectively. Contrary to this, the kharif vegetative, ripening and reproductive sub-phase rainfall were underestimated by 44 mm, 109 mm and 11.6 mm respectively. The result is in contradiction with the analysis conducted by Zacharias *et al*. (2015) using another RCM-PRECIS model output that showed an overall overestimation in the kharif rainfall and underestimation of rabi rainfall. This shows the uncertainties in simulation of climate by different RCMs at same location. The rainfall has also been analyzed for the seasonal rainfall of winter, pre-monsoon, monsoon and post-monsoon. The contribution of monsoon rainfall in the annual rainfall is showing a decline from 89% (836 ± 198 mm) in the observed to 71% (723 ± 177 mm) in the model output (Fig. 3). However, the contribution of winter, pre-monsoon and post monsoon rainfall of the RCM output has increased in the annual rainfall compared to observed values. It has increased to 8% (78 ± 45 mm) from 4% (38 ± 33 mm) in post-monsoon, to 8% increase (79 ± 60 mm) from 4% (38 ± 29 mm) in winter and to 13% (132 ± 75 mm) from 3% (30 ± 27 mm) in pre-monsoon season (Fig. 3). The importance of this analysis reflects that the simulated and observed rainfall are showing a small difference in their mean despite of high differences in the means of simulated and observed rabi and kharif rainfall along or differences in seasonal rainfall. This is because the overestimation in simulated rabi rainfall or overestimation in pre-monsoon, winter and post-monsoon rainfall and the underestimation in the kharif or monsoon rainfall balances the annual rainfall.

The simulated rainy days were overestimated annually by 23 days, 9 days in kharif and 6 days in rabi [Figs. 1(e) & 2(c)]. The normal, extreme or heavy rainfall in four categories *viz*., >15 mm/day, >50 mm but <100 mm/day, >100 mm but <150 mm/day and >150 mm/day rainfall were analyzed. Rainfall >50 mm but <100 mm/day, >100 mm but <150 mm/day and >150 mm/day are considered extreme rainfall. The simulated rainy days with >15 mm/day, >50 but <100 mm/day, >100 but <150 and >150 mm/day rainfall were underestimated by 62, 103, 15 and 5 days respectively [Figs. 5(a&b)]. Rainfall >100 mm but <150 mm/day and >150 mm/day in RCM output showed very few days and thus were not shown in graph. The rainfall intensity analysis shows the model underestimates the annual and kharif season rainfall intensity by 3 ± 1 and 5 ± 22 mm/rainy-day while the rabi season rainfall intensity was overestimated by 6 ± 0 mm/rainy-day. The result brings out the fact that the model is highly underestimating the extreme rainfall days and annual and kharif rainfall intensity.

Crops show decrease in yield beyond certain maximum and minimum temperature. Most of the times they are exposed to the extreme temperature, the cumulative effect would be an adverse impact on the crop physiology followed by decrease in yield. This decrease in yield is important to be analyzed so that the desired mitigation measures could be taken to reduce adverse impacts. With this objective the CERES wheat and CERES rice crop models were used to simulate potential, irrigated and rainfed yield and were compared that were simulated through using observed and RCM data. The average simulated potential wheat yield was 7.8 ± 1.1 t/ ha which was 1.4 t/ha (22%) higher than the average observed potential yield (6.4 ± 0.8 t/ha). Similarly, the average simulated irrigated wheat yield (7.0 ± 0.8 t/ha) was overestimated by 1.3 t/ha (23%) higher than the observed irrigated yield (5.7 ± 0.7 t/ha). This shows that overall the simulated wheat yield is overestimated. The Fig. 6(a) shows the frequency distribution of wheat yield from 1983-2000. The figure clearly shows that the simulated potential, irrigated and rainfed yield has gone up to the higher yield range in comparison to the observed resulting in high average yield. The percent deviation of model potential, rainfed and irrigated yield with the observed yield shows a large deviation from -10% up to 92% (Table 1) supported by low index of agreement. The average simulated and observed potential rice yield were showing good agreement, followed by irrigated yield where model yield was underestimated by 0.6 t/ha about 9% higher in comparison to the observed. However, the simulated rainfed rice yield was showing an overestimation of 2.1 t/ha (higher by 78%) in comparison to the observed [Fig. 6(b)]. The average deviation for model and observed potential and irrigated rice yield was comparatively less varying from -21% to 17% and thus shows close index of agreement (Table 1). Moreover, the deviation of simulated rainfed rice yield was very high going up to 408% with an average deviation of 103% thus showing very poor index of agreement (Table 1). The difference between the mean simulated and observed wheat yield were comparatively high in comparison to the rice except the high overestimation of simulated rice rainfed yield despite of the low simulated kharif rainfall. The reason could be the extended number of simulated rainy days that provides the necessary irrigation on the required days with less extreme events.

4. Conclusions

The above results show that the current RCM have restricted ability to predict changes in the inter-annual and intra-seasonal variability of the weather and the associated extreme events that would be important in determining crop yield projection in the future scenario. The model failed to simulate the extreme temperature at both the ends in comparison to observe that shows more cold events during the month of December and January which is a time of late tillering and panicle initiation stage in wheat. Thus damaging the crop in the vegetative phase, a most sensitive stage and that is why the observe yield falls in to a low yield range comparative to the simulated. The impact of extreme hot temperature on kharif crop is rarely seen because it is sown in late June and planted in July and most of the extreme hot temperature is evident during April, May and starting of June and therefore the potential and the model rice yield showed good agreement in average yield. The model underestimated the kharif rainfall while overestimated the annual and rabi rainfall. The model largely underestimated the extreme rainfall intensity and therefore, the impact of more extreme rainfall intensity and less number of rainy day's comparative to the model weather data was probably the cause for less observed rainfed rice yield. Uncertainties associated with the global climate models are due to unsatisfactory knowledge about physical processes, restrictions due to the numerical approximation of the model's equations, uncomplicated and effortless assumptions in the models and/or advancement, internal model variability and inter-model or inter-method differences in the simulation of climate response to given forcing (Mall *et al.*, 2004) that may be inherited in the RCM also. To reduce the inherent uncertainties in the GCMs and RCMs simulations will demand key advancement in scientific knowledge about the physical processes. The projected outcome for likelihood, frequency and severity of extreme weather events needs to be carefully evaluated. The effect of climate variability on crops needs to be monitored on the daily basis so that any change in crop physiology can be marked instantaneously that would allow better adaptation measures taken to increase the crop yield, including new and resistant varieties change in sowing and harvest date and proper management facilities. The monitoring would further help in determining the key variants influencing agricultural production. Along with it the time demands a more efficient GCMs and RCMs that can proficiently simulate the future climate that is needed to cope up with the detrimental impact of climate change by taking the requisite prevention measures.

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