academicJournals

Vol. 8(32), pp. 4334-4344, 22 August, 2013
DOI: 10.5897/AJAR2013.7618
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Uncertainty in seasonal climate projection over Tamil Nadu for 21st century

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Accepted 8 August, 2013

Climate change is likely to impact every sector including agriculture. To understand the impact on agricultural production, future climate change projections are imperative, but these are uncertain. Quantifying uncertainties in the projection of future climate has been identified as critical research need in impact studies. So, a study was carried out at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to quantify the uncertainty in seasonal climate under A1B scenario and the results suggested that solar radiation, wind speed and relative humidity had either no consistent increase or decrease in the PRECIS ensembles and RegCM4 regional climate models studied. Maximum temperature and minimum temperature had definite increase adding confidence to the range predicted. The information about rainfall was consistent for North East Monsoon (NEM), which showed an increasing trend.

Key words: Uncertainty, seasonal climate, A1B scenario, Tamil Nadu.

INTRODUCTION

Climate change becomes a major concern in countries where food production is a fundamental component of its economy. This is because climate change and agriculture are interrelated and they have significant effect on crop production and food security (Gahukar, 2009). Despite technical advances, weather and climate plays a key role in agricultural productivity. Hence, it is necessary for us to empathize the changing climate over a period of time to feed the growing population.

The future climate is uncertain and impossible to predict (Schenk and Lensink, 2007). To overcome such uncertainties, scenarios are used for future climate projections by employing different global and regional climate models around the world. These models have different types of uncertainties viz., unpredictability, structural and value uncertainty (IPCC, 2005). The Global Climate Models (GCMs) have coarse resolutions (Giorgi and Mearns, 1991), andhence Regional Climate Models (RCMs) with finer resolutions (IPCC, 2007) are employed for regional climate studies. Future climate projections, used for decision making carry uncertainty. These uncertainties are characterized normally into two viz., aleatoric and epistemic uncertainties. Aleatoric uncertainty arises from randomness in computational predictions, which are irreducible. However, in many cases, the dominant uncertainties arise from lack of knowledge (particularly lack of knowledge of physical model parameters and imperfections in the mathematical models themselves). These are epistemic uncertainties, which can in principle be reduced (Oden et al., 2010).

A better understanding of the range of possible future change may be derived from estimates of full range of their possible outcomes (Webster and Sokolov, 2000). This range of possible outcomes can be obtained using ensemble technique, which demonstrated a significant success in climate simulations during the last decade (Broccoli et al., 2003; Murphy et al., 2004; Stainforth et al., 2005; Yoshimori et al., 2005). By using these climate

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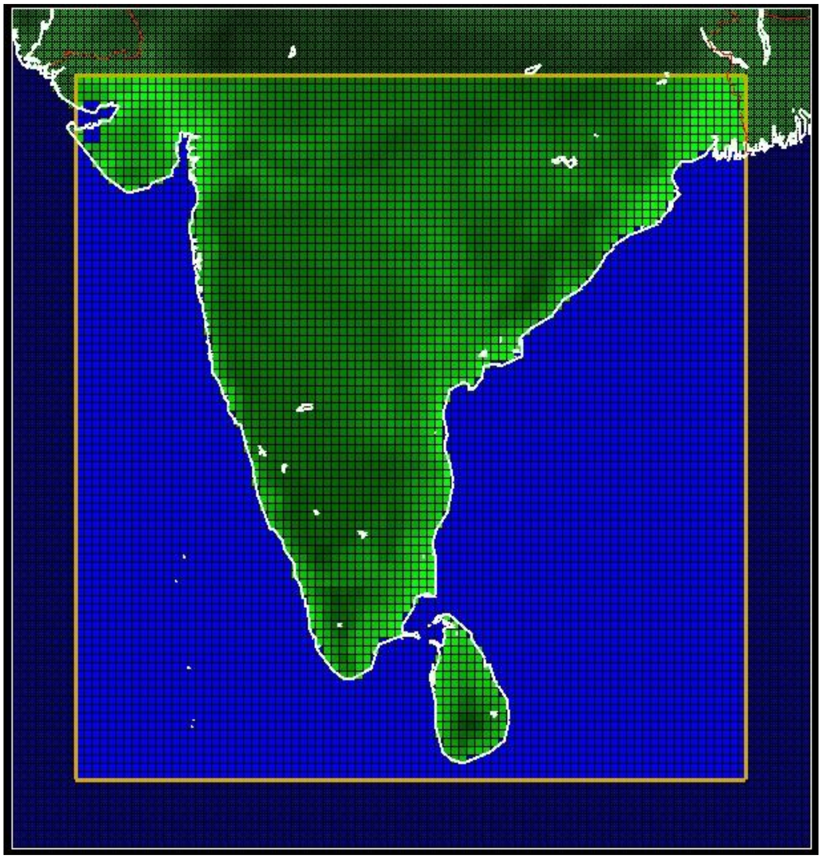

Figure 1. PRECIS domain.

uncertainty over a region can be predicted/obtained for further impact studies on different fields of science viz., agriculture and also to help stakeholders and policy makers to take decisions on adaptation and mitigation strategies in the face of many uncertainties about the future. In the present study seasonal climate projection uncertainty over Tamil Nadu State was assessed by using Providing Regional Climate for Impact Studies (PRECIS) and Regional Climate Model Version 4.0 (RegCM4) models.

MATERIALS AND METHODS

Regional climate models

The study employed two Regional Climate Models (RCMs), one was from the UK Met Office Hadley Centre's PRECIS and another one (RegCM4) was from the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy.

PRECIS

The UK Met Office Hadley centre has provided boundary data for four simulations from a 17-member Perturbed Physics Ensemble (PPE), produced using HadCM3 under Quantifying Uncertainties in Model Projections (QUMP) project. The PPE members designated as HadCM3Q0 to Q16 in which Q0 has the standard parameter setting while the remaining 16 were simultaneously perturbed with 29 of the atmospheric component parameters. These PPEs were formulated systematically to sample parameter uncertainties under the A1B scenario. The Hadley Centre after preliminary evaluation made a sub-selection (McSweeney and Jones, 2010) of four of its simulations viz., Q0, Q1, Q3 and Q16 and provided the Lateral Boundary Conditions (LBCs) to TNAU for running with PRECIS 1.9.2. The climate simulations were made for 129 years from 1970 to 2098 leaving the year 1970 for spin-up.

Open Software und System-Entwicklung (SuSE) was used as Linux operating system for the model as recommended by the Hadley centre (Wilson et al., 2008). The boundary data used in this study were:

HadCM3 Q0, Q1, Q3, Q16: A1B: Ensembles of SRES (Special Report on Emissions Scenarios) A1B scenario experiment (1970 - 2099).

PRECIS domain selection

The PRECIS model used rotated latitude map projection and was run with 0.22 × 0.22 degree resolution (~25 km). Domain selected covered 101 grids on EW direction and 104 grids on NS direction encompassing southern and central part of India. The extent of the boundary for the domain was 3.25 to 22.71°N latitude and 69.56°E to 89.81°E longitude (Figure 1).

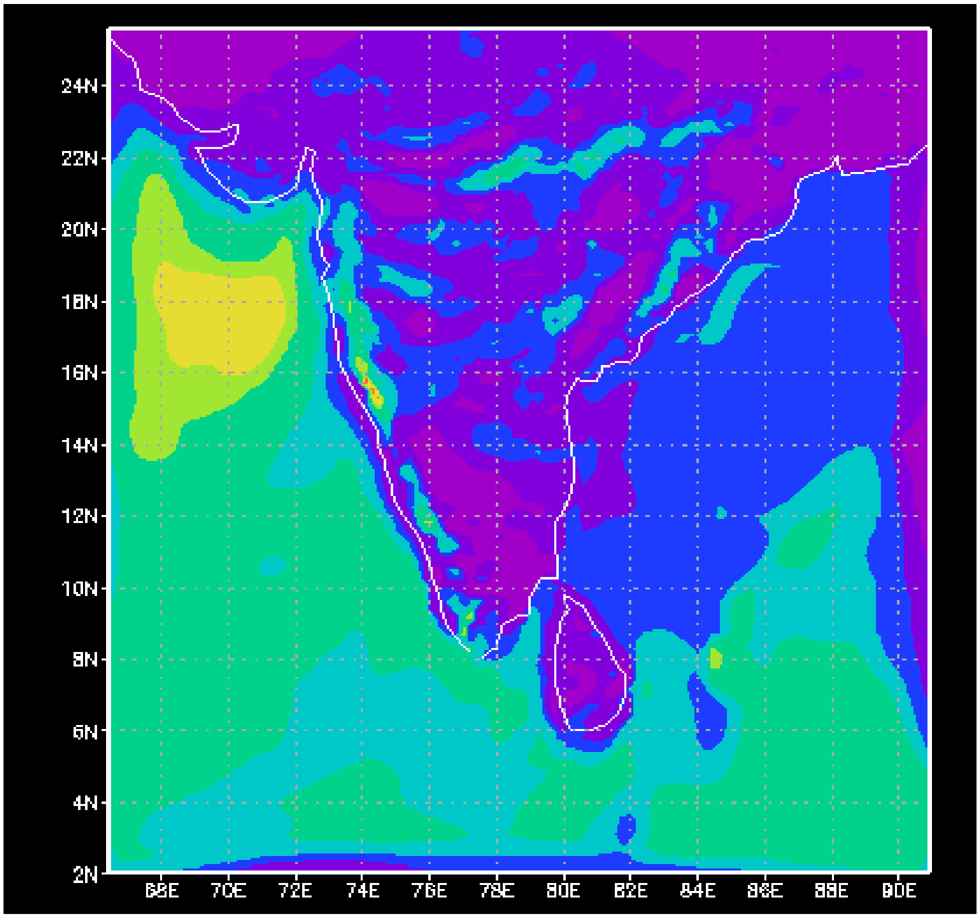

Figure 2. RegCM4 domain.

RegCM4

Regional Climate Model Version 4 released in 2010 (Elguindi et al., 2010) was used in the study. It is an open source RCM that can be used for climate simulation over different areas of interest. The 20th Century A1B ensemble was prepared from ECHAM5-MPIOM model of Max Plank Institute of Meteorology, Germany (hosted by ICTP as EH5OM) and its boundaries were downloaded and used to drive RegCM4 model. Simulations were also done with future climate using the same model's A1B scenario. The climate run started with 20th century boundaries from 1970 and continued upto 2100 for a total of 130 years.

RegCM4 domain selection

A domain covering most of the India was selected. The extent of the boundary for the domain was 2.00°N to 25.61°N latitude and 66.45°E to 90.9628°E longitude. The domain used was depicted in Figure 2. This covered 112 EW and 112 NS points. The horizontal resolution was 25 km.

Parameters retrieved

Both models generated large numbers of weather parameter as output from the simulations. However, only the solar radiation (MJm^{-2}), maximum temperature (°C), minimum temperature (°C), rainfall (mm), wind speed (kmph) and relative humidity (%) were retrieved as these parameters were normally used for impact studies in agriculture.

Study area

The study area covered the State of Tamil Nadu in southern Peninsular India lies between 7.91°N to 13.65°N latitude and 76.17°E to 80.82°E longitude, an agriculturally predominant region and its climate favors majority of the crops cultivation. This covers 220 grid points in PRECIS and 218 grid points in RegCM4 models (Figure 3).

Study period

PRECIS was run for 128 years from 1971 to 2098 and RegCM4 was run for 130 years from 1971-2100. Data were retrieved to analyze the climate change in Tamil Nadu and as well for studying its impact.

Uncertainty

Uncertainty in seasonal climate projections over Tamil Nadu was

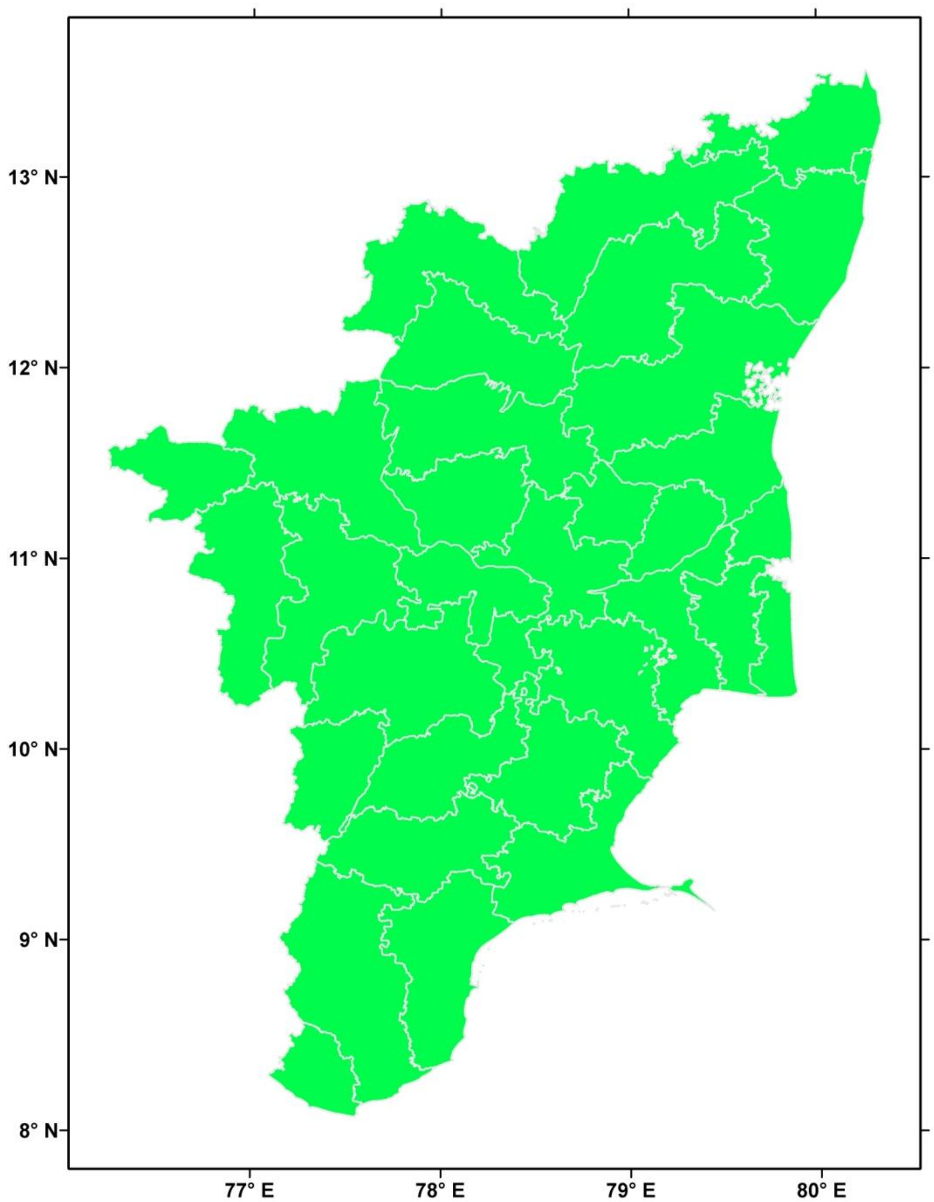

Figure 3. Tamilnadu.

carried out by converting daily data to seasonal output viz., winter, summer, south west monsoon and north east monsoon seasons for PRECIS ensembles and RegCM4 models by using perl programme. To find out the increase or decrease range at the end of the century, difference between 2091-2100 decade and base years (1971-2000) are considered.

RESULTS AND DISCUSSION

The RCM outputs of both the model were analyzed on season basis for all the six parameters to understand the uncertainty in these projections. Difference in seasonal averages during the end of the century over the base period was arrived. These seasonal values were compared and the ranges of uncertainty arising out of these model comparisons are presented in this paper.

Uncertainty in intra season climate projections

Winter season

The period of two months, January and February is termed as winter season over Tamil Nadu. The Maximum temperature projected by the RCMs ranged from 2.54 to 3.96°C. In this Q16 (3.96°C) had the highest warming

Table 1. Uncertainty in winter climate projections at the end of 21st century over Tamilnadu.

Parameter/models	Q0	Q1	Q3	Q16	RegCM4
Solar radiation (MJm^{-2})	0.18	-0.02	-0.02	0.04	0.38
Maximum temperature (°C)	3.80	2.54	3.77	3.96	3.62
Minimum temperature (°C)	4.40	3.40	4.15	4.63	3.85
Rainfall (mm)	-6.95	-4.38	1.34	-29.22	-7.45
Wind speed (kmph)	0.06	0.06	-0.15	0.21	-0.57
Relative humidity (%)	-1.74	-0.66	-1.83	-2.02	0.70

Table 2. Uncertainty in summer climate projections at the end of 21st century over Tamilnadu.

Parameter/models	Q0	Q1	Q3	Q16	RegCM4
Solar radiation (MJm^{-2})	-0.17	-0.10	0.04	-0.49	0.41
Maximum temperature (°C)	3.62	2.50	3.96	3.98	3.58
Minimum temperature (°C)	4.34	3.07	4.33	5.04	3.86
Rainfall (mm)	3.97	-7.02	-27.11	-24.15	-30.14
Wind speed (kmph)	0.26	0.20	0.34	0.28	-0.58
Relative humidity (%)	-1.63	-0.87	-4.59	-0.73	-1.11

followed by Q0, Q3, RegCM4 and Q1 (2.54°C) respectively. Minimum temperature ranged from 3.4 to 4.63 while Q16 (4.63°C) had the highest value followed by Q0, Q3, RegCM4 and Q1 (3.40°C) respectively. The increase in range of minimum temperature was higher than the maximum temperature in the projections, similar to the projections as reported by Ramaraj et al. (2009) (Table 1).

Rainfall was predicted to decrease in RegCM4 and in all the PRECIS ensembles except Q3, which had an increment of 1.34 mm. Q16 had the highest decrement (-29.22 mm) followed by RegCM4, Q0 and Q1 (-4.38 mm). Solar radiation had declining trend in Q1 and Q3 but showed increasing trend in Q0, Q16 and RegCM4. RegCM4 had the highest increase of 0.38 MJm^{-2} followed by Q0 and Q16 (0.04 MJm^{-2}). The ensembles Q1 and Q3 had a decrement of (-)0.02 MJm^{-2}. The QUMP ensembles of PRECIS with varying initial conditions of Q1 and Q3 had same values showcasing some certainty of occurrence. Wind speed was predicted to increase for Q16 (0.21 Kmph) followed by Q0 and Q1 (0.06 Kmph). The ensemble Q3 and RegCM4 predicted a decline of (-)0.15 Kmph and (-)0.57 Kmph, respectively. Relative humidity was predicted to decrease by all the ensembles of PRECIS, where as RegCM4 predicted an increment of 0.70%. The ensemble Q16 (-2.02) had the highest decrement followed by Q3, Q0 and Q1 (0.66), respectively.

Summer season

The period of three months, March, April and May is termed as summer season over Tamil Nadu. The Maximum temperature projected by the RCMs ranged from 2.5 to 3.98°C. In this Q16 (3.98°C) had the highest warming followed by Q3, Q0, RegCM4 and Q1, respectively. Minimum temperature ranged from 3.07 to 5.04°C while Q16 (5.04°C) had the highest value followed by Q0, Q3, RegCM4 and Q1, respectively. The range of increase in minimum temperature was higher than maximum temperature in all the ensembles. These ranges of temperature increase were in accordance with the findings of Geethalakshmi et al. (2011) for Cauvery Delta Zone and Lakshmanan et al. (2011) for Bhavani basin of Tamil Nadu (Table 2).

Rainfall was predicted to decrease in all the ensembles except Q0, which had an increment of 3.97 mm. RegCM4 had the highest decrement (-30.14 mm) followed by Q3, Q16 and Q1 (-7.02). Solar radiation had declining trend in Q0 and Q1and Q16 projection and had increasing trend in Q3 and RegCM4. RegCM4 had the highest increase of 0.41 MJm^{-2} followed by Q3 (0.04 MJm^{-2}). The ensembles Q16, Q1, Q0 had a decrement of -0.49, -0.17 and -0.10 MJm^{-2}, respectively. Wind speed was predicted to increase in Q3 (0.34 Kmph) followed by Q16, Q0 and Q1 (0.20). RegCM4 predicted a decline of (-)0.58 Kmph. Relative humidity was predicted to decrease in all the ensembles, were Q3 (-4.59) had the highest decrement followed by Q0, RegCM4, Q1 and Q16, respectively.

South West Monsoon (SWM)

The period of four months from June to September is termed as south west monsoon season over Tamil Nadu.

Table 3. Uncertainty in SWM climate projections at the end of 21st century over Tamilnadu.

Parameter/models	Q0	Q1	Q3	Q16	RegCM4
Solar radiation (MJm^{-2})	-0.06	-1.38	0.30	-1.20	-0.63
Maximum temperature (°C)	3.38	1.78	3.43	3.28	3.04
Minimum temperature (°C)	3.38	2.42	3.30	3.99	3.29
Rainfall (mm)	-18.59	-21.22	-33.77	28.94	113.12
Wind speed (kmph)	0.18	0.19	0.10	-0.26	0.17
Relative humidity (%)	-2.55	-0.59	-2.99	1.11	-0.42

The maximum temperature as projected by the RCMs found ranged from 1.78 to 3.43°C. In this Q3 (3.43°C) had the highest warming followed by Q0, Q16, RegCM4 and Q1 (1.78°C), respectively. Minimum temperature did range from 2.42 to 3.99 while Q16 (3.99°C) had the highest value followed by Q0, Q3, RegCM4 and Q1, respectively. The range of increase in minimum temperature was higher than maximum temperature in all the ensembles (Table 3). Rainfall was predicted to decrease in Q0, Q1 and Q3, while Q16 and RegCM4 predicted an increment in rainfall, which was similar to the findings of Rupa et al. (2006) for Indian region under A2 and B2 scenarios.

Solar radiation had shown declining trend in all the ensembles except Q3, which had an increment of 0.04 MJm^{-2}. The decrement was highest in Q1 (-1.38 MJm^{-2}) followed by Q16, RegCM4 and Q0 (-0.06 MJm^{-2}), respectively. Wind speed was predicted to increase in Q1 (0.19 Kmph) followed by Q0, RegCM4 and Q3 while Q16 predicted a decline of (-)0.26 Kmph. Relative humidity was predicted to get decrease by all the ensembles except Q16 (1.11). The Q3 (-2.99) had highest decrement followed by Q0, Q1 and RegCM4, respectively.

North East Monsoon (NEM)

The period of three months from October to December is termed as north east monsoon season over Tamil Nadu. The maximum temperature projected by the RCMs found ranged from 2.63 to 3.84°C. In this Q0 (3.84°C) had the highest warming followed by Q3 (3.17°C), Q16 (2.92°°C), Q1 (2.80°C) and RegCM4 (2.63°C). Minimum temperature did range from 2.0 to 4.33°C while Q16 (4.33°C) had the highest value followed by Q3, Q0, RegCM4 and Q1 (2.0°C), respectively. The range of increase in minimum temperature was higher than the values of maximum temperature in all the ensembles (Table 4).

Invariably rainfall was predicted to increase in all the ensembles. RegCM4 (51.85 mm) had the highest increment followed by Q3, Q16, Q0 and Q1, respectively. This might be due to the intensification of rainfall in the Indian region during the monsoon season, as a consequence of the anticipated increase in the greenhouse gas concentrations as reported by May (2002). Solar radiation had shown declining trend in Q3 (-0.09 MJm^{-2}), Q16 (-0.90 MJm^{-2}), RegCM4 (-1.22 MJm^{-2}), which might be due to solar dimming caused by increased aerosol concentrations and greenhouse gases as observed by Singh et al. (2009). Similar results were obtained by Rajalakshmi et al. (2012) for decadal mean projection over Cauvery Delta Zone and increasing trend in Q0 (0.90 MJm^{-2}) and Q1 (0.50 MJm^{-2}).

Wind speed was predicted to increase in Q0 (0.19 Kmph). Decrease in wind speed was predicted by Q16 (-0.18 Kmph) followed by Q3, Q1 and RegCM4 (-0.01), respectively. Relative humidity was projected to decrease in Q0 (-2.57), Q1 (-0.63) and Q3 (-0.10) while the same was projected to increase in Q16 (1.91) and RegCM4 (1.69).

Uncertainty in inter season climate projections

Overall comparison of all the four seasons revealed that maximum temperature over the seasons ranged from 3.43 to 3.98°C, in which summer season the highest temperature value of 3.98°C had followed by winter (3.96°C), NEM (3.84°C) and SWM (3.43°C) (Figure 4). In respect of minimum temperature, the variation was same as that of maximum temperature with highest minimum temperature projected during summer was 5.04°C followed by winter (4.63°C), NEM (4.33°C) and SWM (3.99°C) (Figure 5). Similar findings were also reported by Wiltshire et al. (2010) in which they analyzed AR4 multi-model ensemble as well as the RCM ensemble and found that there is confidence in a trend towards increasing temperature under the SRES A1B scenario. The increase in temperature as projected by the models would affect the crop production over Tamil Nadu. This was evident from the studies of Aggarwal and Mall (2002) for rice that a 2°C increase resulted in decrease in grain yield of rice. Another study by Lin et al. (2005) over China revealed that increase in temperature without carbon dioxide fertilization could reduce the rice, maize and wheat yields by up to 37% in the next 20 to 80 years.

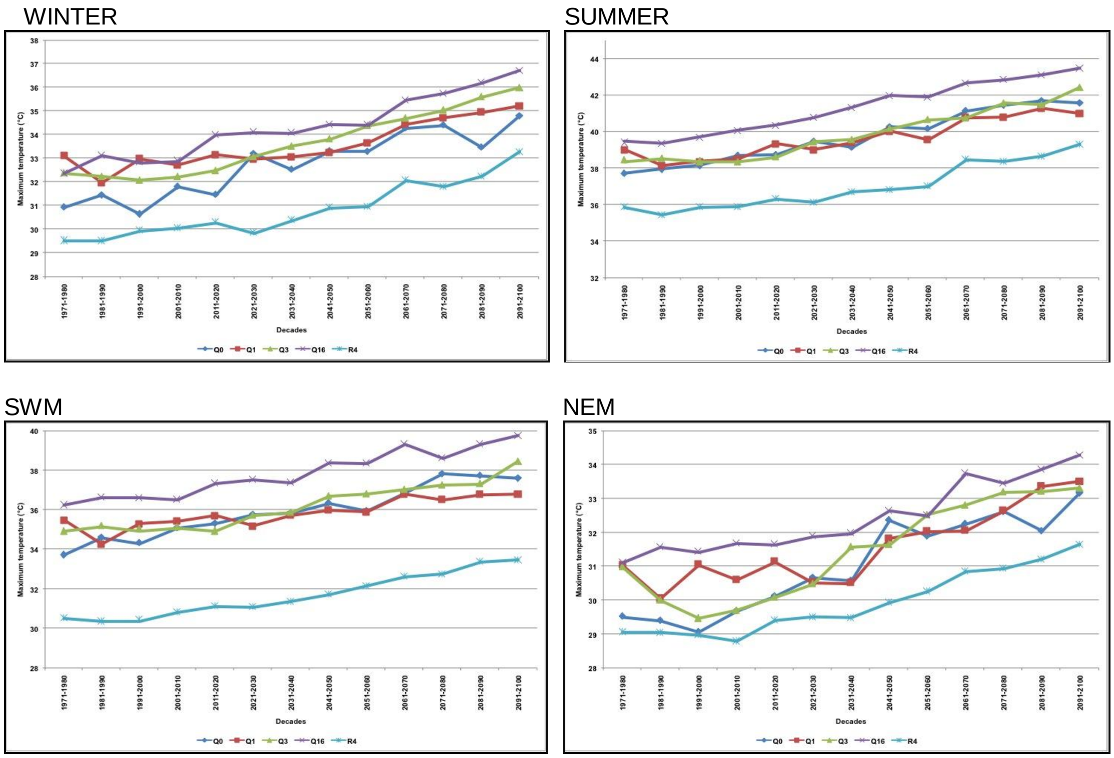

Figure 4. Maximum temperature projections at different time scales over Tamilnadu.

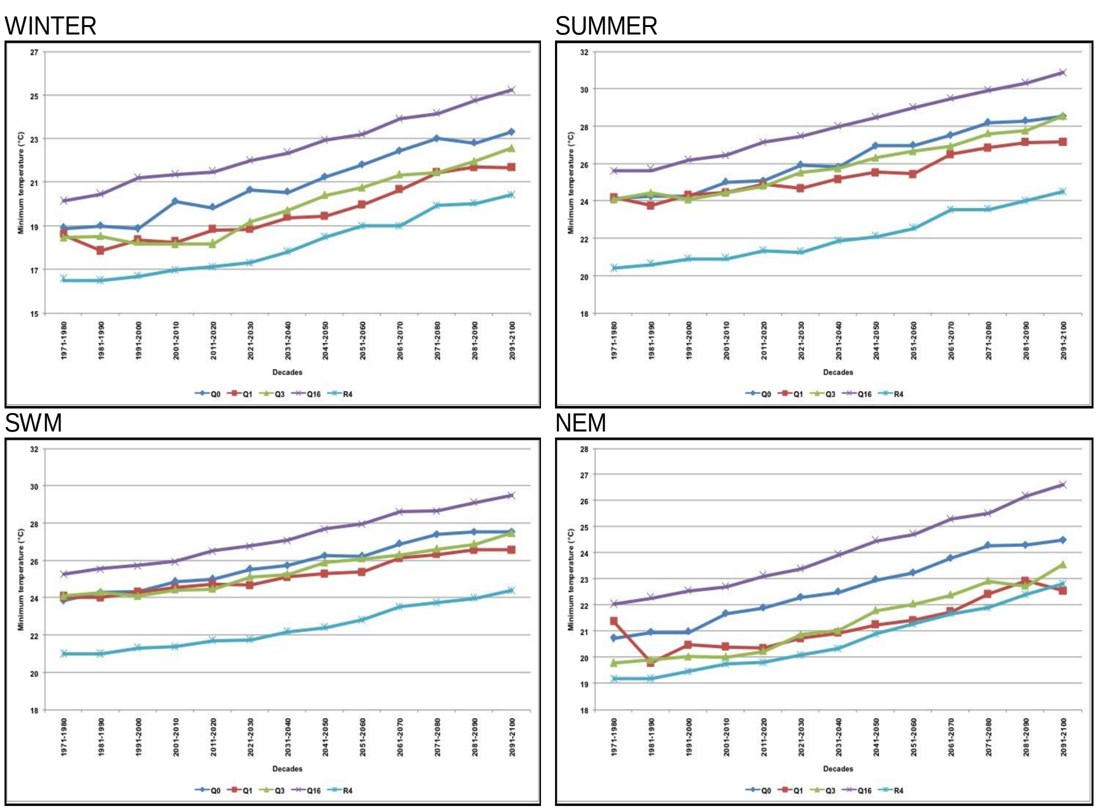

Figure 5. Minimum temperature projections at different time scales over Tamilnadu.

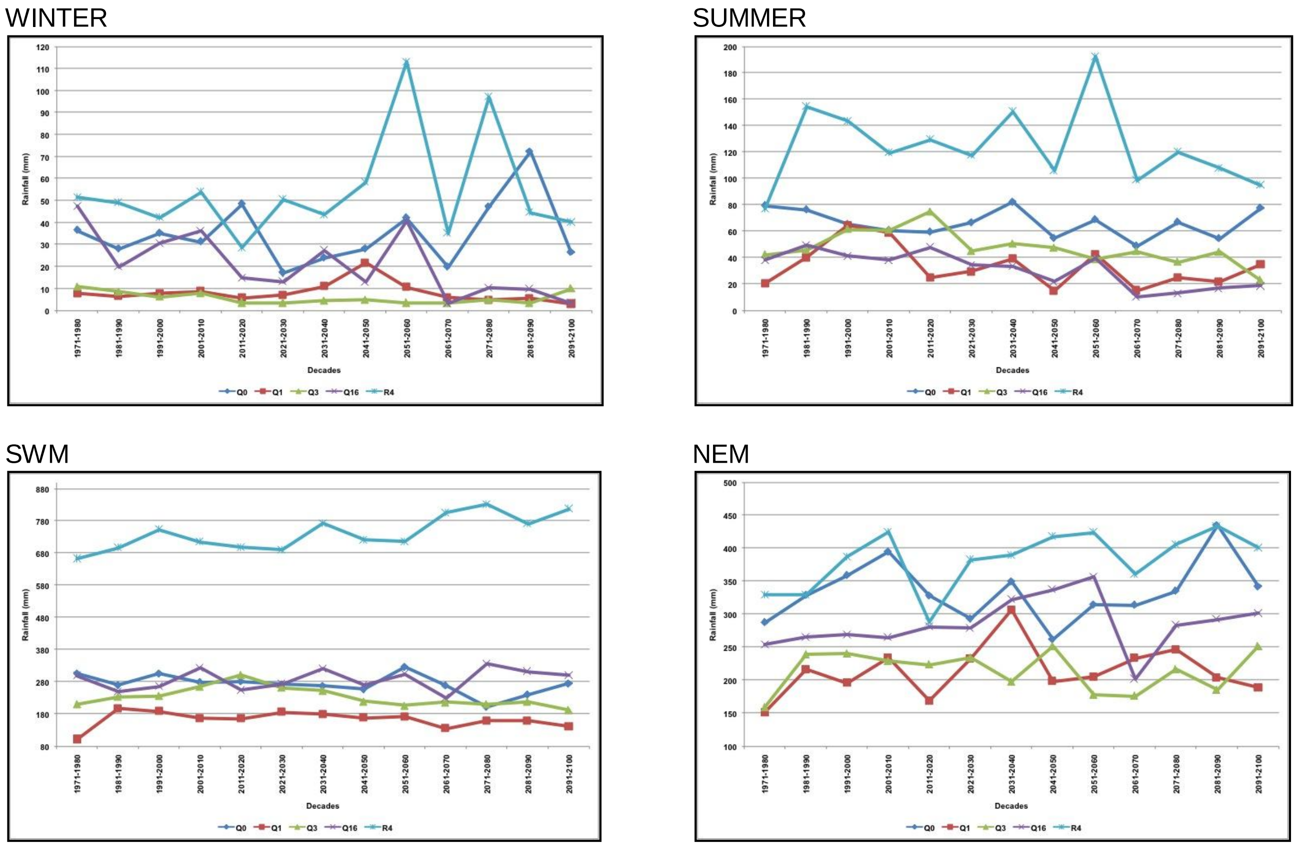

Figure 6. Rainfall projections at different time scales over Tamilnadu.

Rainfall (Figure 6) was projected to increase in few members of the ensemble, whereas it was not seen in other members of the ensemble for the same season. There was no consistency for providing information in respect of summer, winter and SWM rainfall projected by these ensembles. Interestingly NEM was projected to increase (1.2 to 51.85 mm) by all the ensembles studied. For precipitation the uncertainty is much larger, with significant natural variability. These findings are consistent with those published elsewhere (Akhtar et al., 2010). Improved rainfall projections represent a key bottleneck to reduce uncertainties in projections for impact studies. In crop growing season, rainfall is able to explain two-thirds of the variation in crop production. With a change in growing season precipitation, as much as a 10% change in production was reported by Lobell and Burke (2008).

Solar radiation (Figure 7) ranged between -0.02 to 0.38 MJm^{-2} for winter, -0.49 to 0.41 MJm^{-2} for summer, -1.38 to 0.30 MJm^{-2} for SWM and -1.22 to 0.90 MJm^{-2} for NEM. Wind speed (Figure 8) ranged between -0.57 to 0.21 Kmph for winter, -0.58 to 0.34 Kmph for summer, -0.26 to 0.19 Kmph for SWM and 0.18 to 0.19 Kmph for NEM. Relative humidity (Figure 9) ranged between -2.02 to 0.70% for winter, -4.59 to -0.87% for summer, -2.99 to1.11% in SWM and -2.57 to 1.91% in NEM. Hence, the result of seasonal climate projections for maximum temperature, minimum temperature, rainfall, solar radiation, wind speed and relative humidity can be further used for impact studies on agriculture, for planning adaptation and mitigation strategies to sustain the agriculture production over the study area.

Conclusion

Solar radiation, wind speed and relative humidity had no consistent increase or decrease in the PRECIS ensembles and RegCM4 projections studied. The projection indicated that maximum temperature and minimum temperature did show definite increase adding confidence to the range predicted. The information about rainfall is consistent only for NEM. It can be concluded from the study that uncertainty in climate projections can be sorted out to some extent by using PRECIS ensembles and RegCM4 models. These ranges of uncertainty have to be taken into account while framing adaption strategies, since seasonal climate plays vital role in most of the food crops production.

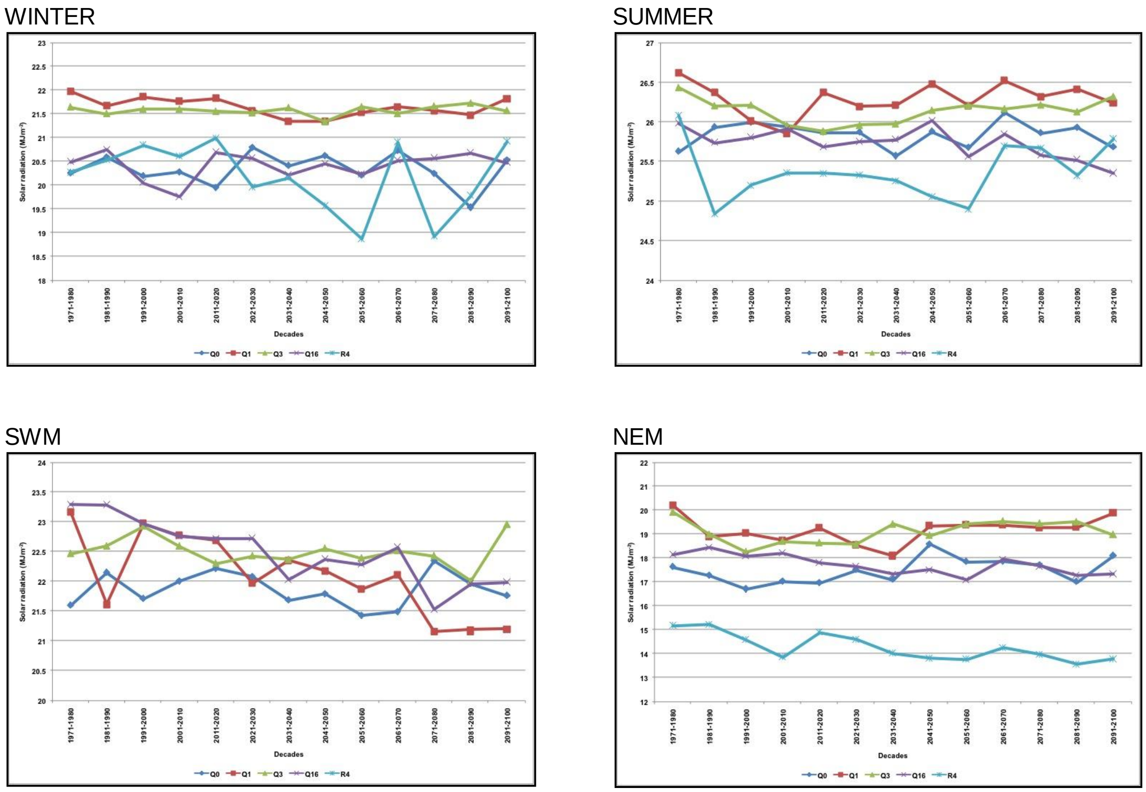

Figure 7. Solar radiation projections at different time scales over Tamilnadu.

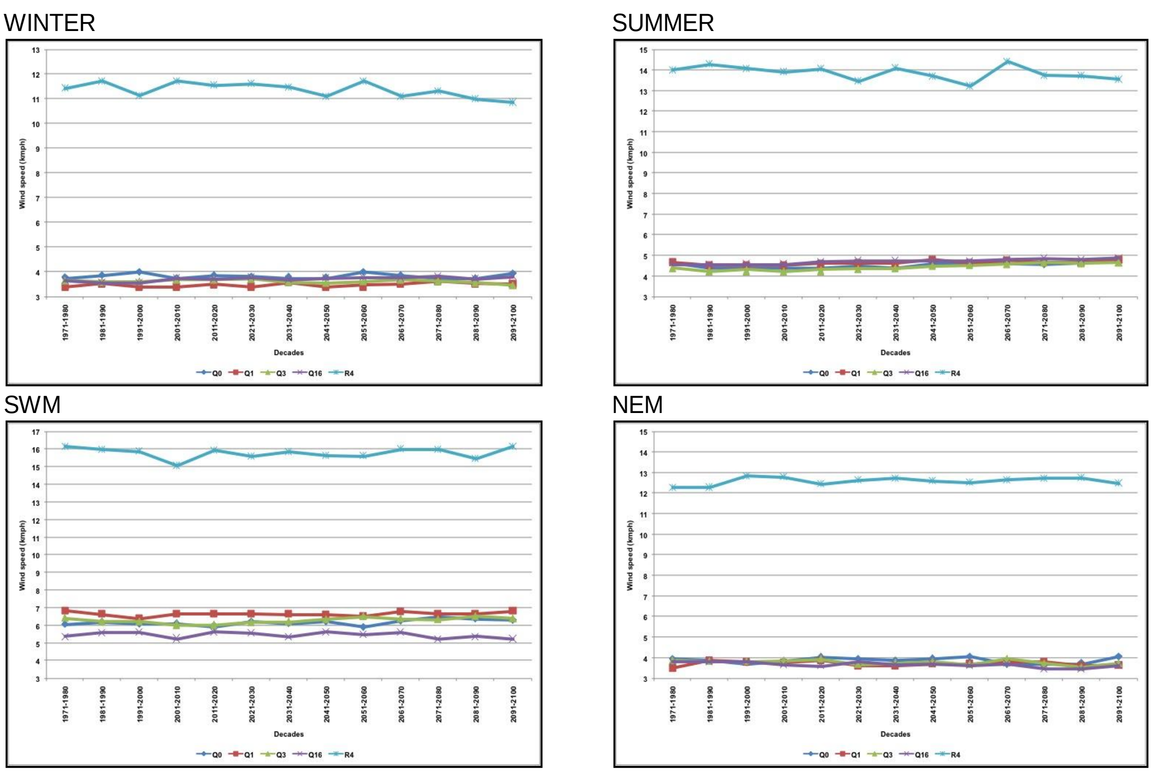

Figure 8. Wind speed projections at different time scales over Tamilnadu.

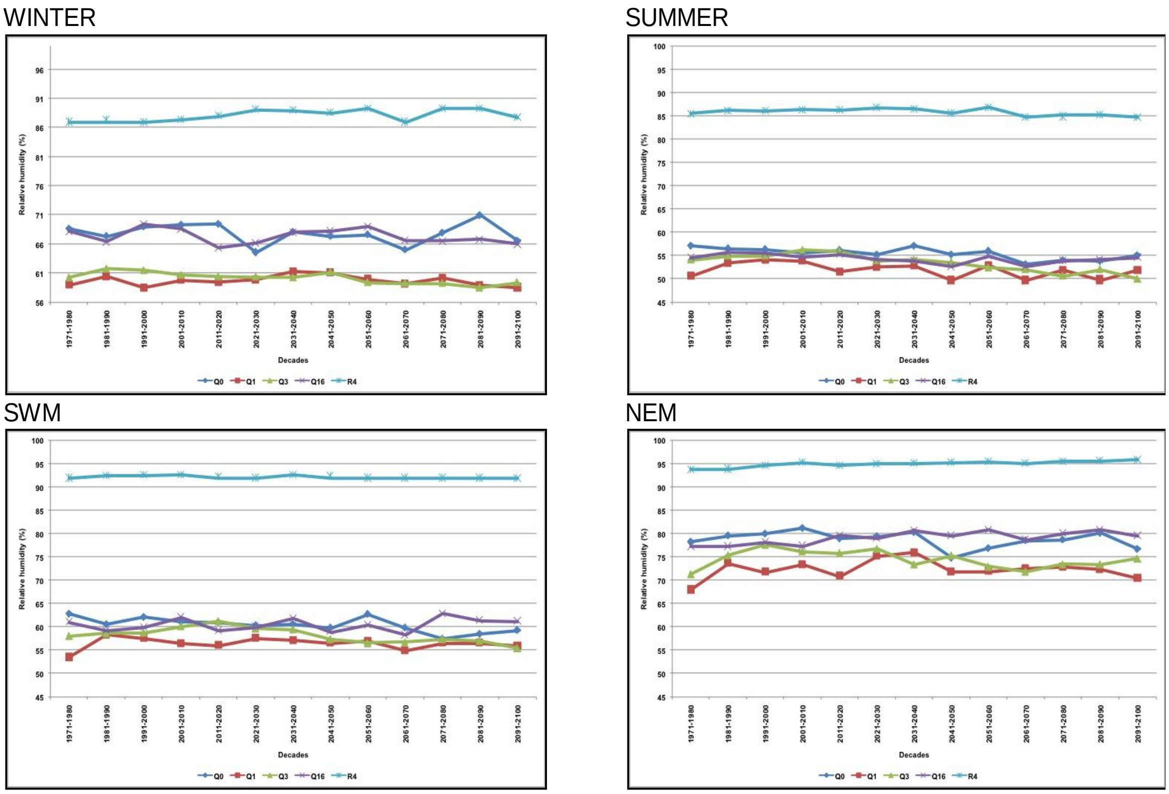

Figure 9. Relative humidity projections at different time scales over Tamilnadu.

ACKNOWLEDGEMENTS

Authors are thankful to Hadley Centre, UK Met office for providing boundary conditions for the study and the Ministry of Foreign Affairs, Norway and the Royal Norwegian Embassy, New Delhi for financial support to undertake the study through ClimaRice project.

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