

Understanding the uncertainty cascaded in climate change projections for agricultural decision making

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(Received 20 January 2016, Accepted 6 October 2016)

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सार – जलवायु प्रक्षेपों से यह सुनिश्चित हो गया है कि बदलती जलवायु के साथ अनुकूलन आवश्यक है परन्तु इसे किस प्रकार से प्रभावी रूप से अनुकूलित किया जाए इसका कोई खास फायदा नहीं है। इसका कारण अनिश्चितता की स्थिति का होना है, भविष्य में ग्रीन हाउस गैसों के उत्सर्जन की परिकल्पना से स्थानीय स्तर पर जलवायु का वास्तविक निर्णय कर पाना कठिन है। इस प्रक्रिया के प्रत्येक चरण पर अनिश्चितता है और ये अनिश्चितताएं भिन्न-भिन्न स्तरों पर मूल्यांकन करने के बाद जात हुई हैं। अनिश्चितता के इस सोपानी पात (Cascade) में नीति निर्धारकों को भावी परिवर्तनों के बारे में सूचित करने के लिए अति सूक्ष्मता के साथ विश्लेषण किया जाना चाहिए। बेसियन और मोण्टे कार्लो सदृश अधिक व्यापक रूप से प्रयुक्त अभिगम प्राचलों के विशिष्ट मानों को बताते हैं और इनका विश्वास है कि इससे इन सीमाओं के अंतर्गत प्रत्येक बिन्दु पर इसके प्रभाव को समझने की आवश्यकता है, फिलहाल कृषि संबंधी निर्णय लेने में संभावित परिवर्तनों को लिया जा रहा है। इस शोध पत्र में इन बिन्दुओं पर विचार किया गया है और स्थानीय स्तर पर जलवायु प्रक्षेपों में अनिश्चितता की स्थिति की जांच की गई है। इस शोध पत्र में बिना किसी मॉडल्स, परिदृश्यों और समय खण्डों का सहारा लिए दो स्टेशनों (कोयंबटूर तथा तंजावुर) की ऋतु विभिन्नताओं के साथ अधिकतम तथा न्यूनतम तापमानों में वृद्धि को दर्शाया गया है। निश्चित रूप से कोयंबटूर में अधिकतम एवं न्यूनतम तापमान में क्रमशः 0.2 से 4.1° सेल्सियस एवं 0.3 से 5.3° सेल्सियस और तंजावुर में 0.3 से 4.6° सेल्सियस एवं 0.2 से 5.2° सेल्सियस की वृद्धि पाई गई है। 21^{वीं} शताब्दी के दौरान कोयंबटूर में प्रक्षेपित वर्षा में कमी एवं वृद्धि का प्रतिशत क्रमशः 15.0 एवं 73.1 प्रतिशत तथा तंजावुर में यह 15.3 एवं 80.7 प्रतिशत के बीच बदलता रहा है। इस शोध पत्र में दोनों स्थानों की मॉनसून ऋतुओं का तुलनात्मक अध्ययन करने पर पूर्वोत्तर मॉनसून से दक्षिणी-पश्चिमी मॉनसून (SWM) में अधिकतम और न्यूनतम दोनों तापमानों में उनके तात्कालिक ट्रेण्ड के समान अधिक वृद्धि देखी गई है। दक्षिणी-पश्चिमी मॉनसून (SWM) की तुलना में पूर्वोत्तर मॉनसून (NEM) की वर्षा में अधिक वृद्धि प्रक्षेपित की गई है।

ABSTRACT. Climate projections have confirmed the need to adapt to a changing climate, but have been less beneficial in guiding how to effectively adapt. The reason is the uncertainty cascade, from assumptions about future emissions of greenhouse gases to what that means for the climate to real decisions on a local scale. Each of the steps in the process contains uncertainty and these uncertainties from various levels of the assessment accumulate. This cascade of uncertainty should be critically analyzed to inform decision makers about the certain range of future changes. Most widely used approaches like Bayesian and Monte Carlo gives specific values of parameters and their confidence, yet for agricultural decision making the range of possible changes itself is required as such to understand impact at every point of these ranges. This paper addresses these issues and examines the uncertainties in climate projections at a local scale. In the study locations (Coimbatore and Thanjavur), irrespective of the models, scenarios and time slices, the maximum and minimum temperatures are projected to increase with seasonal variations. With certainty, the projected increase in maximum and minimum temperature over Coimbatore is 0.2 to 4.1 °C and 0.3 to 5.3 °C and over Thanjavur is 0.3 to 4.6 °C and 0.2 to 5.2 °C, respectively. Rainfall is projected to vary between a decrease of 15.0 to an increase of 73.1 percent for Coimbatore and a decrease of 15.3 to an increase of 80.7 per cent for Thanjavur during the 21st century. On comparing the monsoon seasons, southwest monsoon (SWM) is projected to have a higher increase in both maximum and minimum temperature than northeast monsoon (NEM) for both the study locations, similar to their current trends. Rainfall is projected to increase more in NEM than in SWM.

Key words – Climate, Uncertainty, Projections, Representative concentration pathways.

1. Introduction

Uncertainty is pervasive in the climate change problem, especially in estimating the most likely future climate. Understanding and analyzing these uncertainties

becomes a prime concern in present times. There is a lack of traceable and consistent treatment of uncertainties in climate change assessments and was noted as a major deficiency in current knowledge by the IPCC TAR (Carter *et al.*, 2001). The IPCC also noted that a major challenge

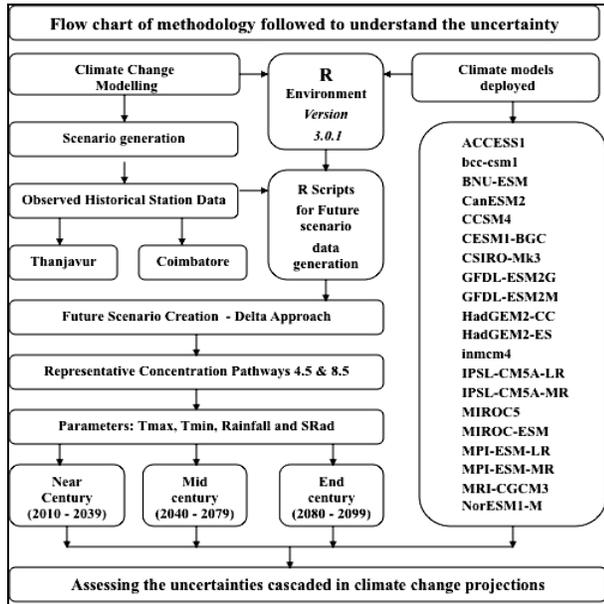


Fig. 1. Uncertainty cascaded in climate change projections

lies in addressing these uncertainties associated with adaptation (Ahmand *et al.*, 2001). Climate change impacts such as changes in temperature, precipitation, runoff, etc., is therefore characterized by major uncertainties regarding their magnitude, timing and spatial distribution, sometimes having opposite signs (e.g., some projections show more precipitation whereas others show less). These uncertainties pose major challenges for planners taking decisions on adaptation measures. Gagnon-Lebrun and Agrawala (2006) noted that the level of certainty associated with climate change and impact projections is often key to determining the extent to which such information can be used to formulate appropriate adaptation responses.

Uncertainty in future climate change derives from three main sources: forcing, model response, and internal variability (Hawkins and Sutton, 2009; Tebaldi and Knutti, 2007). Forcing uncertainty arises from an incomplete knowledge of external factors influencing the climate system, including future trajectories of anthropogenic emissions of green-house gases (GHG), stratospheric ozone concentrations, land use change, etc. Model uncertainty, also termed response uncertainty, occurs because different models may yield different responses to the same external forcing as a result of differences in, for example, physical and numerical formulations. Internal variability is the natural variability of the climate system that occurs in the absence of external forcing and includes processes intrinsic to the atmosphere, the ocean, and the coupled ocean-atmosphere system.

The nature of uncertainty can be epistemic, aleatory and ambiguity. Epistemic uncertainty is the uncertainty due to imperfect knowledge and is reducible by gaining more knowledge *via* research, data collection and modeling. Aleatory uncertainty, also termed ontological or stochastic uncertainty, is due to inherent variability. It can be quantified, but is stochastic and irreducible. Ambiguity results from the presence of multiple ways of understanding or interpreting a system. It can originate from differences in professional backgrounds, scientific disciplines, value systems and interests (Brugnach *et al.*, 2007). Thus, quantification of uncertainty in projection of future climate scenarios for climate change impact assessment forms a prime research focus. This paper addresses these shortcomings and tries to examine the uncertainties in climate projections through specific case studies.

2. Materials and method

The overall methodology followed to understand the uncertainty cascaded in climate change projections are presented in the flowchart (Fig.1).

2.1. Study area

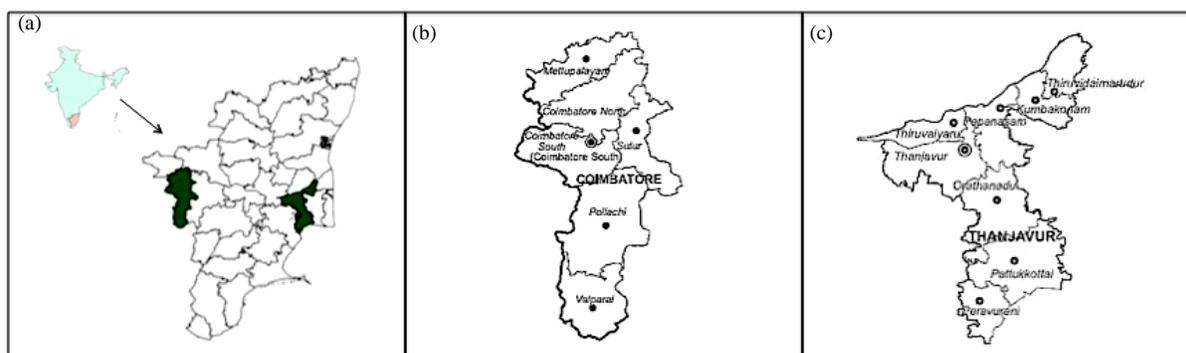
The uncertainty in climate projections was studied for the locations Coimbatore and Thanjavur. The study area was represented in the Figs. 2(a-c). Coimbatore [Fig. 2(b)] bounded by 10.22° N latitude, 76.65° E longitude and 11.40° N latitude, 77.50° E longitude was studied. Thanjavur [Fig. 2(c)] was bounded by 10.99° N latitude, 79.47° E longitude and 11.02° N latitude, 79.49° E longitude.

2.2. Baseline climate series

The observed baseline data from each study location serve as the basic input for future scenario creation. For Coimbatore, Tamil Nadu, 30-year (1980-2010) of observed daily weather series was obtained from Tamil Nadu Agricultural University Agromet observatory located at 11° N latitude and 77° E longitude at an altitude of 426.7 MSL. For Thanjavur, Tamil Nadu, 30-year (1980-2010) of observed daily weather series was obtained from Tamil Nadu Rice Research Institute agromet observatory located at 11.39° N latitude and 79° E longitude and 19.5 MSL.

3. Scenarios selection: Representative Concentration Pathways (RCPs)

IPCC published the SRES scenarios in 2000 and the underlying economic and policy assumptions for these scenarios were fixed as early as 1997 (Moss *et al.*, 2010).



Figs. 2(a-c). (a) Map of Tamil Nadu highlighting Coimbatore and Thanjavur districts (b) District map of Coimbatore (c) District map of Thanjavur

Now, the scientific community has developed a set of new-emission scenarios termed as representative concentration pathways (RCPs). In contrast to the SRES scenarios, RCPs represent pathways of radiative forcing, not detailed socioeconomic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result from a diverse range of socioeconomic and technological development scenarios. There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These scenarios are formulated such that they represent the full range of stabilization, mitigation and baseline emission scenarios available in the literature (Hibbard *et al.*, 2011). The naming convention reflects socioeconomic pathways that reach a specific radiative forcing by 2100. RCP-based climate projections are now available from a number of climate models under the Coupled Model Inter-comparison Project 5 (CMIP5) experiment. CMIP5 includes a broader variety of experiments and application of more comprehensive models compared to CMIP3 (Rajivkumar *et al.*, 2012). RCP 4.5 and 8.5 have been utilized in the present study.

3.1. Representative Concentration Pathways 4.5

It is a stabilization scenario where total radiative forcing will be stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions developed by the MiniCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (Wise, 2009). This scenario is expected to reach more than 650-ppm Carbon dioxide equivalents by 2100 (Moss *et al.*, 2010).

3.2. Representative Concentration Pathways 8.5

It is characterized by increasing GHG emissions over time leading to high GHG concentration levels. The 8.5 pathways arise from little effort to reduce emissions and represent a failure to curb warming by 2100. Developed by MESSAGE modeling team and the Integrated

Assessment Framework at the International Institute for Applied Systems Analysis (IIASA), Austria (Riahi *et al.*, 2007). This scenario is expected to reach more than 1,370-ppm Carbon dioxide equivalents by 2100 (Moss *et al.*, 2010).

4. Future Climate generation with R

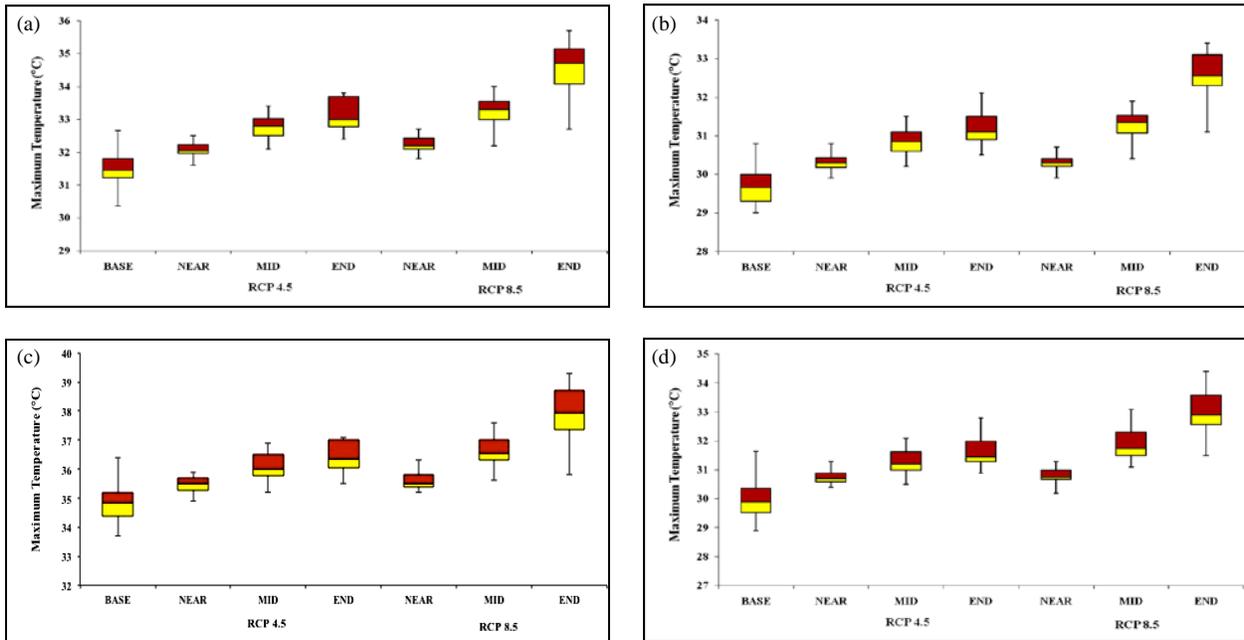
As the research work has been carried out under the Agricultural Model Intercomparison and Improvement Project (AgMIP). The procedures outlined by climate modeling team for Climate scenario data generation was followed (Cynthia *et al.*, 2013).

4.1. R Environment

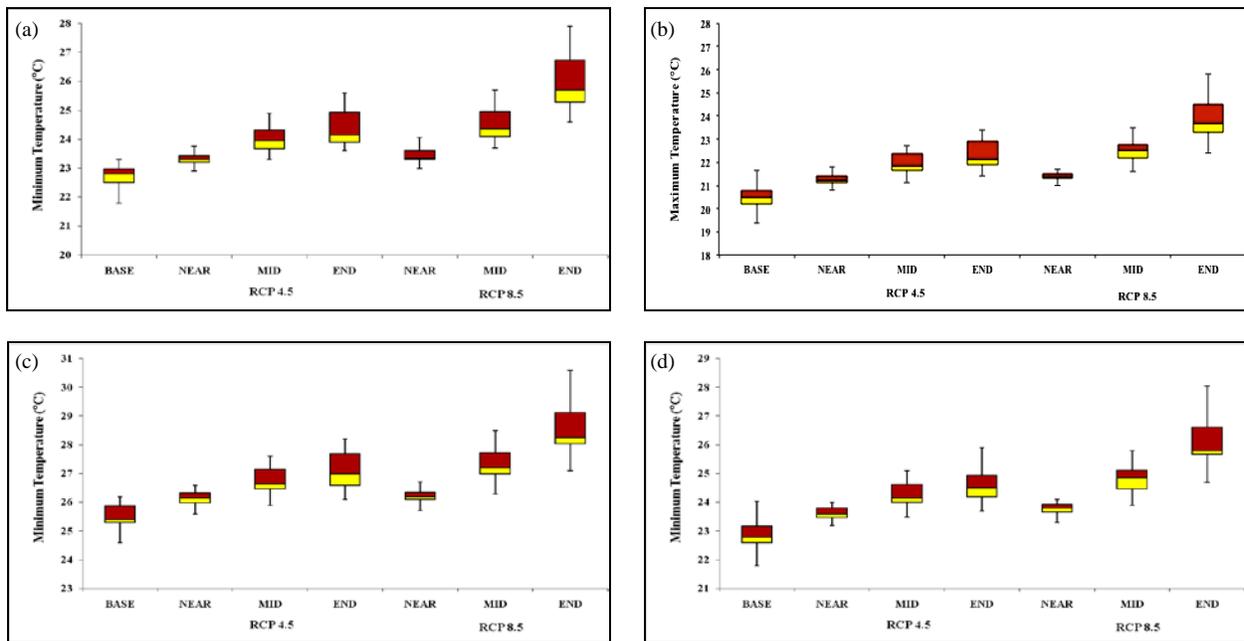
R is a free environment that can be used for statistical analysis and graphic development. To run the scripts properly, packages are required to add functionality to R. These packages are free, easy to download, and importantly must be loaded at the beginning of the session every time. The Climate Scenario Generation scripts from AgMIP were used through R 3.0.1 to generate future climate. The most recent version R 3.0.1 (Installation during November 2013) was downloaded from the website <http://cran.r-project.org/bin/windows/base/>. The downloaded .exe file was run under windows operating system to complete installation. Packages such as R.matlab, R.utils and dependent packages R.oo and R.methodsS3 were also installed, as they are required to load R scripts for climate scenario generation as per the guidelines of AgMIP (www.agmip.org).

4.2. Running R Scripts

R scripts and GCM files for RCP 4.5 and RCP 8.5 as well as the latitude and longitude files required to properly read the GCM files were downloaded from the link <https://webdrive.gsfc.nasa.gov/longauth/600/alexander.c.r.uan/hWono4C>. These scripts were run under R console



Figs. 3(a-d). The Southwest monsoon (SWM) and northeast monsoon (NEM) maximum temperature projected by the 20 GCMS was utilized to make box plots for near, mid and end century time slices for RCP 4.5 and RCP 8.5. Temperature range of base period was also plotted to understand the change (a) SWM (b) NEM T_{max} over Coimbatore (c) SWM and (d) NEM T_{max} over Thanjavur



Figs. 4(a-d). The Southwest monsoon (SWM) and northeast monsoon (NEM) minimum temperature projected by the 20 GCMS was utilized to make box plots for near, mid and end century time slices for RCP 4.5 and RCP 8.5. Temperature range of base period was also plotted to understand the change (a) SWM (b) NEM T_{min} over Coimbatore (c) SWM and (d) NEM T_{min} over Thanjavur

as per the guidelines devised by AgMIP (www.agmip.org - Alex Ruane *et al.*, 2013). R scripts utilize the baseline data and GCM data files for future climate projection.

4.3. Climate projections

Future climate projections created through R is by utilizing a “delta” approach, in which the mean monthly

TABLE 1

Annual climate projections for Coimbatore

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	-3.8	-6.3	21.6	6.7	-9.7	19	0.9	1.7	2.1	0.9	2.4	3.7	0.9	1.8	2.6	1.1	2.7	4.6
bcc-csm1	16.8	19.3	23.9	13	27	25.8	0.5	1	1.1	0.6	1.4	2.6	0.6	1.1	1.3	0.7	1.6	2.7
BNU-ESM	5.6	-0.7	12.3	3.8	2.5	24.6	0.6	1.2	1.4	0.6	1.7	2.7	0.6	1.2	1.5	0.6	1.7	2.8
CanESM2	-2.1	3.9	11.2	7.3	-1.5	15.5	0.8	1.5	1.9	1	2.1	3.4	0.8	1.5	1.8	0.9	2	3.3
CCSM4	6.6	1.3	5.9	6.3	3.8	15	0.5	1.2	1.4	0.7	1.8	3.2	0.5	1	1.2	0.7	1.7	2.9
CESM1-BGC	0.8	2.4	6.3	-2	9	7.3	0.7	1.3	1.6	0.9	1.8	3.2	0.8	1.3	1.5	0.9	1.8	3
CSIRO-Mk3	9.2	48.3	73.1	50.7	59.2	64.4	0.7	1.6	2.2	0.5	1.9	3.5	0.7	2	2.6	0.8	2.3	4.2
GFDL-ESM2G	-9	6.3	12.9	9.5	33.9	33.2	0.3	0.8	1	0.6	1.4	2.4	0.7	0.9	1.1	0.8	1.7	2.7
GFDL-ESM2M	-15.5	3.9	2	18.3	15.4	15.7	0.4	0.9	1.4	0.6	1.5	2.7	0.7	1	1.3	0.7	1.6	2.7
HadGEM2-CC	12.3	-11.8	-2.1	-12.3	9.2	16	0.8	1.7	2.3	1	2.3	4.1	1.1	2.1	2.7	1.3	3	5.3
HadGEM2-ES	0.7	23.2	15.5	10.2	34	26.3	0.8	1.8	2.4	1	2.3	4.1	1.2	2.2	3	1.3	3	5.3
inmcm4	8.7	-2.5	0.6	-5.2	6.9	6.7	0.2	0.8	1	0.6	1	2.1	0.3	0.5	1.1	0.3	1.3	2.4
IPSL-CM5A-LR	16.1	20.6	20.7	14.8	22.4	38	0.9	1.6	2.1	1	2.2	3.7	1	1.9	2.3	1.1	2.6	4.3
IPSL-CM5A-MR	-0.7	27.6	18.1	16.8	27	50.8	0.6	1.3	2.2	0.8	2.1	3.8	0.9	1.8	2.6	1	2.6	4.7
MIROC5	3.9	19.7	24.1	4.5	16	44.4	0.6	0.9	1.3	0.4	0.8	1	0.9	1.2	1.5	0.8	1.6	2.5
MIROC-ESM	10.5	17.1	14.7	3.9	17.8	14.1	0.8	1.4	2	0.8	1.9	3.6	0.8	1.5	1.9	0.7	2	3.6
MPI-ESM-LR	-6.6	-2	12.7	-0.8	7.7	35.7	0.6	1.5	1.6	0.8	1.9	3.3	0.7	1.5	1.7	0.8	2.1	3.6
MPI-ESM-MR	-5.6	16.2	0.1	-2.1	8	4.5	0.9	1.4	1.8	0.9	1.9	3.5	0.8	1.5	1.8	0.9	2.1	3.7
MRI-CGCM3	8.5	20.2	28.9	22	8	38.4	0.4	0.7	1.4	0.3	1.4	2.5	0.6	1.1	1.6	0.6	1.8	3
NorESM1-M	2.7	10.5	18.9	2.7	15.3	29.6	0.5	1.1	1.4	0.7	1.5	2.7	0.7	1.1	1.3	0.8	1.6	2.8
E Average	3.0	10.9	16.1	8.4	15.6	26.3	0.6	1.3	1.7	0.7	1.8	3.1	0.8	1.4	1.8	0.8	2.0	3.5

% d – Percent deviation, N-Near century, M-Mid century and E-End century

changes (from baseline) under RCP 4.5, RCP 8.5 for Near, Mid and End Century time slices that is centered around 2030, 2055 and 2080 respectively were applied to the daily baseline weather series as described by Villegas and Jarvis, 2010. These scenarios of future projections were referred to as “mean change scenarios”. This procedure was repeated for each of the 20 global climate models (GCMs) studied.

4.4. Study period

The future scenario data were generated for all the models and for parameters such as maximum temperature, minimum temperature, rainfall and solar radiation for near (2011-2039), mid (2040-2069) and end centuries (2070-2099) as separate files.

4.5. Uncertainty in climate projection

Uncertainty in climate projections over the study locations was analyzed from all the climate models for RCP4.5 and RCP8.5. The daily output of the models was

converted to decadal, seasonal *viz.*, southwest Monsoon (June, July, August, September) and Northeast Monsoon (October, November, December) as this coincides with the cropping season over the study area. The deviations from base year (1980-2010) were calculated by obtaining the difference between the Near, Mid and End century with the base years. The deviations were calculated for each location and for all the models. These ranges of maximum, minimum temperature and rainfall projected by individual models are uncertain, if considered individually for impact assessment. The whole possible range of all the models represents the possible range of future changes in climate projections. Considering the importance of impact assessment in agriculture, the possible ranges as projected by all these models, scenarios were presented here.

5. Results and discussion

5.1. Baseline climatology of study area

Annual and seasonal normals for maximum temperature, minimum temperature, rainfall and rainy

TABLE 2
Southwest monsoon climate projections for Coimbatore

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	-1.2	-12.6	-1.6	1.4	0.1	17.5	1	1.9	2.3	1.2	2.5	3.9	1	1.9	2.4	1.2	2.8	4.6
bcc-csm1	17.8	9.3	12	10.3	13.4	16.9	0.5	1	1.2	0.6	1.5	2.5	0.6	1.1	1.2	0.6	1.5	2.6
BNU-ESM	11.6	12.8	19.5	9.4	12.6	13.3	0.5	1	1.2	0.6	1.5	2.7	0.6	1.2	1.4	0.6	1.6	2.8
CanESM2	2.5	9.9	13.1	6.9	16.1	24.3	0.7	1.5	1.9	1	2	3.5	0.6	1.4	1.8	0.9	1.9	3.3
CCSM4	3.8	7.1	6.1	-0.9	3.3	6.5	0.3	1.1	1.1	0.4	1.5	3.1	0.4	0.9	1.1	0.5	1.4	2.6
CESM1-BGC	0.8	-1.1	3.4	4.5	3.6	8.1	0.7	1.3	1.5	0.8	1.9	3.1	0.6	1	1.2	0.7	1.5	2.7
CSIRO-Mk3	10.1	27.3	80.8	30.5	51.5	94.3	0.6	1.6	2.2	0.7	1.9	3.6	0.7	1.8	2.5	0.7	2.2	4.1
GFDL-ESM2G	0.1	4.5	3.9	2.6	-2.4	3.1	0.4	0.8	0.9	0.6	1.4	2.5	0.5	0.8	0.9	0.6	1.3	2.5
GFDL-ESM2M	-1.2	0.6	5.6	-0.4	3	8.3	0.4	0.8	1.3	0.5	1.6	2.6	0.5	0.9	1.2	0.5	1.4	2.5
HadGEM2-CC	5.3	-6.4	-1.7	1.5	32.3	37.6	0.7	1.7	2.2	1	2.2	4	1.2	2.1	2.7	1.4	3	5.1
HadGEM2-ES	7.1	33.6	18.5	27.6	25.8	46.8	0.9	1.8	2.3	1	2.4	4.2	1.1	2.2	2.9	1.3	3	5.2
inmcm4	-0.2	-0.1	0.2	-4.2	2.3	5	0.1	0.6	0.9	0.6	1	1.9	0.2	0.6	0.9	0.3	1	1.9
IPSL-CM5A-LR	-4.6	3.4	6.1	-6	5.8	24	1	1.7	2.2	1.2	2.2	3.8	0.9	1.7	2.2	1	2.4	4
IPSL-CM5A-MR	5.4	8.3	3.3	-3	0.8	28.3	0.7	1.4	2.3	0.9	2.3	4	0.8	1.6	2.3	0.9	2.5	4.5
MIROC5	6.4	19.2	35.1	22.6	29.8	61.4	0.5	1.1	1.4	0.3	0.7	1.2	0.6	1	1.3	0.6	1.3	2.2
MIROC-ESM	0.4	0.3	-0.5	-0.5	-2	-7.7	0.8	1.4	1.9	0.7	1.9	3.5	0.7	1.3	1.7	0.6	1.8	3.4
MPI-ESM-LR	12.1	10.4	21.8	14.5	5	49.6	0.5	1.3	1.5	0.7	1.8	3.3	0.7	1.3	1.5	0.8	1.9	3.4
MPI-ESM-MR	-1.9	13.6	23.7	-0.1	22.6	33.1	0.8	1.4	1.9	0.9	1.8	3.4	0.6	1.3	1.6	0.7	1.7	3.2
MRI-CGCM3	2.7	22.6	13.7	6.9	22.6	16	0.4	0.7	1.5	0.5	1.4	2.5	0.4	0.9	1.4	0.5	1.4	2.7
NorESM1-M	0.2	7.3	3.1	-5.3	4	11.9	0.5	1.2	1.5	0.7	1.5	2.8	0.5	1	1.1	0.6	1.4	2.5
E Average	3.9	8.5	13.3	5.9	12.5	24.9	0.6	1.3	1.7	0.7	1.8	3.1	0.7	1.3	1.7	0.8	1.9	3.3

% d – Percent deviation, N-Near century, M-Mid century and E-End century

days for a period of thirty years from 1980 to 2009 were derived as this data was utilized in future scenario generation.

5.1.1. Coimbatore

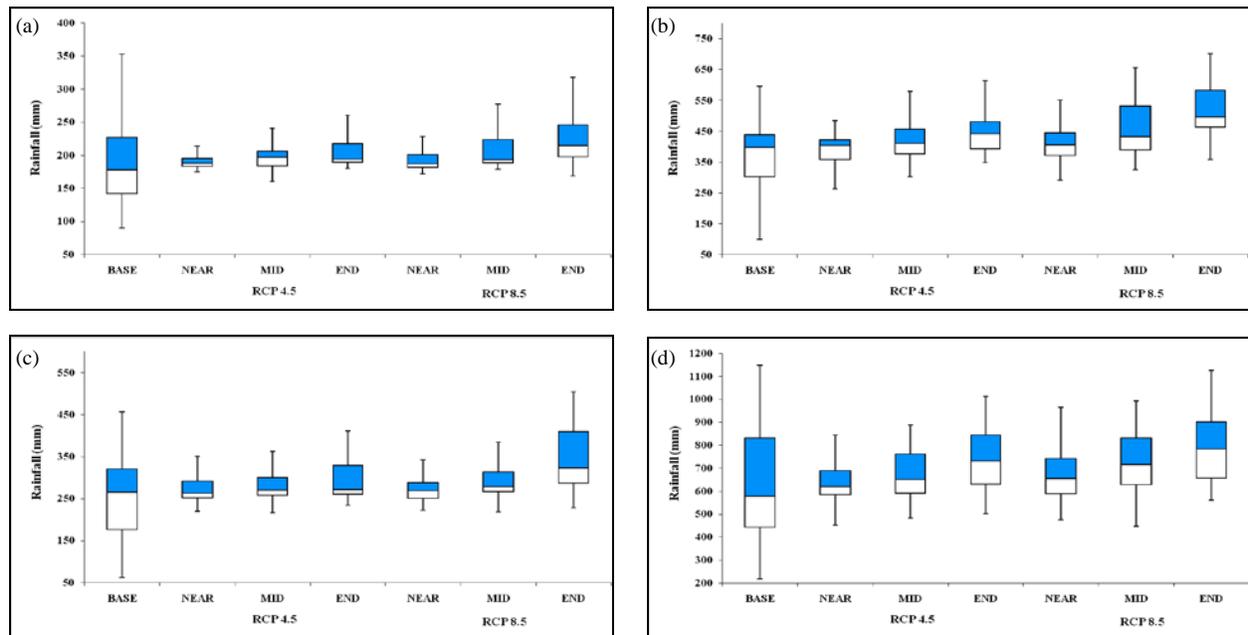
Normal annual maximum temperature of Coimbatore is found to be 31.8 °C and that of minimum temperature is 21.5 °C. Normal annual rainfall of Coimbatore is 714 mm. As far as seasonal distribution is concerned, maximum temperatures is highest during summer (34.9 °C) followed by southwest monsoon season (31.5 °C), winter (31.1 °C) and northeast monsoon season (29.7). Minimum temperature is the lowest during winter (18.9 °C), followed by northeast monsoon (20.6 °C), southwest monsoon (22.7 °C) and summer (22.8 °C) seasons.

Seasonal distribution of rainfall and rainydays that the Northeast monsoon receives 373 mm contributing to 52.2 per cent to annual rainfall followed by southwest

monsoon season, which receives 183 mm contributing to 25.6 per cent to annual rainfall and then by summer rainfall about 140 mm with a contribution of 19.6 per cent to the annual rainfall. Thus Coimbatore comes under mono-model rainfall pattern. Average rainfall received during winter season is only 18 mm (2.5 percent of annual rainfall).

5.1.2. Thanjavur

Annual normal maximum and minimum temperatures of Thanjavur is 33.0 °C and 23.7 °C respectively and annual average rainfall is 1023 mm. As far as seasonal distribution is concerned, maximum temperatures is the highest during summer (35.6 °C) followed by southwest monsoon season (34.9 °C), northeast monsoon season (30.1) and winter (30.0 °C). Lowest minimum temperature is recorded during winter (20.3 °C), followed by northeast monsoon (22.9 °C), summer (24.2 °C) and southwest monsoon (25.4 °C) seasons.



Figs. 5(a-d). The Southwest monsoon (SWM) and northeast monsoon (NEM) rainfall projected by the 20 GCMS was utilized to make boxplots for near, mid and end century time slices for RCP 4.5 and RCP 8.5. Rainfall range of base period was also plotted to understand the change (a) SWM (b) NEM rainfall over Coimbatore (c) SWM and (d) NEM rainfall over Thanjavur

TABLE 3

Northeast monsoon climate projections for Coimbatore

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	-4.8	-8.2	32.2	11.2	-13	32	0.8	1.7	1.8	0.5	2.2	3.2	0.9	1.8	2.5	1.1	2.4	4.8
bcc-csm1	14.2	10.9	22.8	12.1	25	12	0.5	0.9	1.1	0.6	1.3	2.6	0.6	1.1	1.3	0.7	1.5	2.7
BNU-ESM	6.9	-4.8	15.4	6	5.1	51.6	0.6	1.3	1.5	0.5	1.7	2.6	0.6	1.1	1.3	0.5	1.6	2.7
CanESM2	4.7	3.4	22.2	7.7	-0.6	25.3	0.9	1.5	1.8	1	2.1	3.4	0.8	1.4	1.7	0.9	1.9	3.3
CCSM4	12.7	1.9	9.5	11.4	13.6	34.2	0.5	1.1	1.4	0.6	1.6	2.9	0.3	0.9	1.1	0.6	1.4	2.8
CESM1-BGC	3.3	0.2	8.8	-5.2	18.1	17.9	0.6	1.2	1.4	0.7	1.5	2.9	0.5	1.1	1.3	0.7	1.5	2.7
CSIRO-Mk3	14	59	81.6	47.9	75.9	88.3	0.4	1	1.1	0	1	2.2	0.6	1.8	2.3	0.8	2.1	3.7
GFDL-ESM2G	9.8	3.8	13.9	15.7	53.3	58.3	0.3	0.9	1.2	0.6	1.8	2.7	0.5	1	1.2	0.8	1.9	2.9
GFDL-ESM2M	-3.6	10.7	5.3	42.4	43.2	40.4	0.2	0.9	1.3	0.6	1.6	2.8	0.5	1	1.4	0.9	1.9	2.8
HadGEM2-CC	-33.7	-19	0.8	-21.9	5.4	20.1	0.9	1.8	2.2	1	2.1	3.6	0.7	2	2.6	1	2.8	5.2
HadGEM2-ES	13	22.5	5.1	0.1	48.7	27.3	0.6	1.4	2.4	0.7	1.8	3.7	0.9	2.1	2.8	1	2.9	5.2
inmcm4	-1.7	-5.1	-3.2	-0.8	2	5.8	0.2	0.5	0.8	0.3	0.9	1.8	0.2	0.5	0.8	0.4	1	1.8
IPSL-CM5A-LR	24	40.2	32.1	35.3	42.2	68.9	2.7	1.5	2	0.8	2.2	3.6	1.2	1.9	2.3	1.1	2.6	4.5
IPSL-CM5A-MR	30.1	46.4	29.7	33.9	50.2	80.9	0.6	1.4	2.1	0.7	1.9	3.6	1	2	2.6	1.1	2.5	4.7
MIROC5	-11.7	22.9	21.8	-3.4	16.9	50.7	1.1	0.6	1.1	0.4	0.6	0.7	0.9	1.2	1.6	0.8	1.6	2.6
MIROC-ESM	9.4	28.4	28.6	10.1	29.4	32	0.7	1.3	1.7	0.7	1.8	3.4	0.7	1.4	1.8	0.7	1.9	3.4
MPI-ESM-LR	13.6	1.1	4	4.7	10	55.4	0.5	1.3	1.4	0.6	1.7	2.7	0.5	1.3	1.4	0.6	1.8	3.3
MPI-ESM-MR	-7.9	16.7	-6.6	-2.2	2.1	-3.7	0.7	1	1.4	0.6	1.6	3.1	0.7	1.3	1.6	0.7	2	3.5
MRI-CGCM3	-10.3	21.2	43.8	30.5	2.1	69.8	0.3	0.6	1.3	0.2	1.1	2.1	0.5	1.1	1.5	0.7	1.6	2.8
NorESM1-M	9.6	9.7	22	4.3	14.5	25.7	0.5	1	1.2	0.5	1.4	2.6	0.6	1	1.2	0.7	1.5	2.6
E Average	4.6	13.1	19.5	12	22.2	39.6	0.7	1.1	1.5	0.6	1.6	2.8	0.7	1.4	1.7	0.8	1.9	3.4

% d – Percent deviation, N-Near century, M-Mid century and E-End century

TABLE 4
Annual climate projections for Thanjavur

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	-1.5	-3.9	21.7	1.4	-10.4	31.4	0.8	1.5	2.1	0.9	0.9	3.5	0.8	1.7	2.3	1	1	4.1
bcc-csm1	-0.3	0.4	11.1	-5.1	9.4	3	0.5	1	1.3	0.6	0.6	2.6	0.6	1.1	1.3	0.7	0.7	2.8
BNU-ESM	10.7	-2.1	19.6	2.4	3.1	31.4	0.6	1.1	1.3	0.6	0.6	2.7	0.5	1.1	1.4	0.5	0.5	2.8
CanESM2	-14.3	-5.8	-1.4	-4.4	-20.4	-2.2	1.3	2	2.3	1.2	1.2	4.3	0.9	1.7	2	1	1	3.8
CCSM4	4.9	2.7	6.2	6.6	2	13.8	0.5	1.2	1.5	0.7	0.7	3.2	0.5	1	1.3	0.7	0.7	2.8
CESM1-BGC	-1.3	4.2	4.6	-5.4	12.3	7.8	0.6	1.2	1.4	0.9	0.9	3	0.6	1	1.1	0.7	0.7	2.6
CSIRO-Mk3	-5.9	22.7	63.6	27.2	31.1	51.8	0.9	1.7	2.2	0.6	0.6	3.6	0.7	1.9	2.6	0.8	0.8	4.2
GFDL-ESM2G	6.1	-0.3	10.5	13.8	22.7	19.9	0.3	0.9	1.2	0.3	0.3	2.2	0.5	0.9	1	0.8	0.8	2.5
GFDL-ESM2M	-15.3	-1.3	-1	9.5	1.2	5.4	1.1	1.4	1.5	0.7	0.7	2.9	0.7	1.1	1.3	0.8	0.8	2.8
HadGEM2-CC	-12.2	-10.4	-0.4	-10.8	-4.7	31.8	0.8	1.7	2.3	1	1	4.1	0.8	2.1	2.7	1.1	1.1	5.2
HadGEM2-ES	4	27.1	35.8	4.8	31.7	50.4	0.9	1.8	2.5	1	1	4.2	1	2.1	2.9	1.2	1.2	5.1
inmcm4	-1.1	-2.6	-3.4	-3.6	-1.6	-1.9	0.3	0.6	0.8	0.4	0.4	1.6	0.2	0.4	0.7	0.2	0.2	1.6
IPSL-CM5A-LR	17.6	26.9	30.4	24.1	31.4	51.7	1	1.7	2.1	1.1	1.1	3.7	0.9	1.8	2.3	1	1	4.3
IPSL-CM5A-MR	22.9	20.7	12.8	14.8	36.1	27.4	0.7	1.3	2	0.8	0.8	3.5	0.7	1.3	2	0.7	0.7	3.6
MIROC5	13	35.8	12.8	11.2	33.9	80.7	0.7	0.9	1.1	0.6	0.6	1.4	0.8	1.1	1.4	0.7	0.7	2.4
MIROC-ESM	6	15.6	54.7	3	14.3	-0.8	1.1	2	2.2	1.5	1.5	4.6	0.8	1.6	2.1	0.8	0.8	3.9
MPI-ESM-LR	-0.9	-8.3	14.4	-3.9	-1.9	6.6	0.7	1.4	1.5	0.8	0.8	3.1	0.6	1.3	1.5	0.7	0.7	3.2
MPI-ESM-MR	20.7	33.2	-2.3	22.9	25.2	25.6	0.8	1.3	1.7	0.8	0.8	3.3	0.7	1.4	1.7	0.8	0.8	3.5
MRI-CGCM3	5	24.5	26.1	31	26.6	48.1	0.3	0.6	1.5	0.4	0.4	2.4	0.5	1	1.6	0.6	0.6	3
NorESM1-M	16.3	22.5	40.5	13.3	22.6	42.7	0.6	1.1	1.3	0.6	0.6	2.6	0.5	0.9	1.2	0.6	0.6	2.5
E Average	3.7	10.1	17.8	7.6	13.2	26.2	0.7	1.3	1.7	0.8	0.8	3.1	0.7	1.3	1.7	0.8	0.8	3.3

% d – Percent deviation, N-Near century, M-Mid century and E-End century

Seasonal distribution of rainfall and rainy days indicated that the northeast monsoon receives 630 mm (61.6% of the annual rainfall) followed by the southwest monsoon (250 mm contributing to 24.4% of annual rainfall). Thus Thanjavur also comes under mono-model rainfall. Summer season receives only 68 mm contributing 6.6 per cent, followed by winter rainfall about 75 mm with a contribution of 7.3 per cent to the annual rainfall. This baseline data of coimbatore and thanjavur was utilized to produce climate projections and these projections were analyzed for their cascaded uncertainty.

5.2. Uncertainty in climate projection

To find the uncertainty in climate projections over the study area, three most important weather parameters were extracted *viz.*, maximum temperature, minimum temperature and rainfall and the results of individual parameters are discussed below:

5.2.1. Maximum temperature

Maximum temperature of Coimbatore (Table 1) and Thanjavur (Table 4) was projected to increase by all the 20 GCMs studied with varying magnitude. Considering the whole range of projections of the models and scenarios, the possible increase in maximum temperature will be from 0.2 to 1.0 °C, 0.7 to 2.4 °C and 1.0 to 4.1 °C during near, mid and end century for Coimbatore. In case of Thanjavur, the increase was between 0.3 to 1.5 °C, 0.6 to 2.0 °C and 0.8 to 4.6 °C for the same time slices. Similar kind of projection for India was also observed by Rajiv Kumar *et al.* (2012).

Monsoon season temperatures [Figs. 3(a-d)] for the two study regions is also projected to increase. In coimbatore, SWM (Table 2) is found to have highest increase than NEM (Table 3) during mid and end century, NEM had highest increase during near century. In Thanjavur, In near and end century SWM (Table 5) might

TABLE 5
Southwest monsoon climate projections for Thanjavur

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	3.4	4.1	14	10.9	21	42.3	0.8	1.6	2.1	1	2.1	3.5	1.1	2.1	2.3	1.3	2.6	4.1
bcc-csm1	21	13	8.2	6.4	14.3	22	0.4	0.9	1.2	0.5	1.4	2.5	0.7	1.2	1.3	0.7	1.7	2.7
BNU-ESM	15.5	19.5	27.6	13.4	21.4	28.6	0.3	0.8	0.9	0.5	1.3	2.5	0.7	1.2	1.5	0.8	1.8	2.9
CanESM2	-6	-1.2	3.6	3	11	30.2	1	1.7	2.1	1	2.5	3.8	1	1.7	2.1	1.1	2.3	3.6
CCSM4	5.3	8	8.6	4	10.2	14	0.2	1	1.3	0.5	1.6	3.1	0.5	1	1.2	0.6	1.6	2.8
CESM1-BGC	2	2.6	7.9	7.4	10.5	16.6	0.6	1.1	1.3	0.9	1.7	3	0.6	1.1	1.2	0.8	1.6	2.7
CSIRO-Mk3	40.2	2.7	64.5	11.6	18	68.9	0.6	1.7	2.1	0.6	2	2.4	0.8	2	2.6	0.8	2.4	2.5
GFDL-ESM2G	5.3	3.6	3.1	16.1	-12.7	2.3	0	0.4	0.7	0.5	1.6	2.5	0.5	0.8	0.9	0.8	1.6	2.8
GFDL-ESM2M	-11.9	-13.7	0.1	-11.1	-8.6	-3.1	0.8	1.1	0.8	0.5	1.7	3.8	0.9	1.1	1.2	0.7	1.7	5.2
HadGEM2-CC	38.7	14	23.7	30.6	54.1	94.3	0.6	1.5	2.1	0.9	2.1	3.9	1.1	2.1	2.8	1.3	3	5.1
HadGEM2-ES	21.1	45.4	47.1	36.7	51.7	88.3	0.8	1.7	2.1	0.9	2.3	1.6	1.2	2.2	2.8	1.5	3.1	1.7
inmcm4	-1.6	-6.1	-6.5	-2.5	-2.9	-5.9	0.1	0.4	0.6	0.3	0.8	3.8	0.2	0.5	0.7	0.3	0.9	4.2
IPSL-CM5A-LR	-3.8	4.4	7.4	-4.1	6.7	25	1	1.7	2.2	1.2	2.2	3.8	1	1.9	2.4	1.1	2.5	4.1
IPSL-CM5A-MR	9	8.5	-5.3	-9.3	7.6	32.4	0.8	1.4	2.1	0.8	2.1	0.9	0.9	1.6	2.3	0.9	2.3	2.1
MIROC5	12.3	33.6	63.1	31.3	48.6	101.8	0.4	0.6	0.6	0.3	0.7	4.4	0.7	1.1	1.3	0.7	1.3	3.6
MIROC-ESM	1.6	3.4	4.4	1.3	0.3	-8.7	1	2	2	1.4	2.7	3.1	0.8	1.5	1.9	0.8	2.1	3.3
MPI-ESM-LR	15.4	21.2	38.5	31.2	11.9	62.9	0.5	1.1	1.4	0.5	1.6	3.1	0.7	1.3	1.6	0.8	1.9	3.2
MPI-ESM-MR	0.2	32	47.2	15.4	37.2	66.1	0.8	1.3	1.6	0.7	1.6	2.4	0.8	1.4	1.7	0.8	1.8	2.8
MRI-CGCM3	32.2	60.7	29.8	7.8	41.6	47.7	0	0.3	1.5	0.4	1.3	2.6	0.5	0.8	1.6	0.7	1.6	2.5
NorESM1-M	1.2	11.9	7.2	-2.2	6.6	15	0.5	1	1.3	0.6	1.4	2.3	0.5	1	1.2	0.6	1.4	2.5
E Average	10.1	13.4	19.7	9.9	17.4	37	0.6	1.2	1.5	0.7	1.7	3	0.8	1.4	1.7	0.9	2	3.2

% d – Percent deviation, N-Near century, M-Mid century and E-End century

witness a higher increase in maximum temperature than that of NEM (Table 6), while in mid century NEM might witness a higher increase. This wide range of temperature projection of various climate models might be attributed to the difference in the model physics and the parameters considered by individual models (Diallo *et al.*, 2012). On comparing the locations, Thanjavur is expected to witness a higher increase than that of Coimbatore. The difference in the temperature increase between the seasons and locations could be due to higher elevation (Karmalkar *et al.*, 2008) and dense forest cover on the western ghats for coimbatore and the nearness to coast for Thanjavur region. Similar patterns of increased warming over east coastal region that of Western Ghats have been reported by Rajalakshmi *et al.* (2013).

5.2.2. Minimum temperature

Minimum temperature of Coimbatore (Table 1) and Thanjavur (Table 4) is projected to increase by all the models studied. In Coimbatore, irrespective of the models

and scenarios studied, the possible increase in minimum temperature is found to be 0.3 to 1.3 °C, 0.5 to 3 °C and 1.1 to 5.3 °C during near, mid and end century. For Thanjavur, the possible increase in minimum temperature might be from 0.2 to 1.2 °C, 0.2 to 2.1 °C and 0.7 to 5.2 °C during near, mid and end century. A similar increase in minimum temperature was also reported by Rupakumar *et al.* (2006); Ramaraj *et al.* (2009) and Geethalakshmi *et al.* (2011).

Based on seasonal analysis, In Coimbatore, minimum temperature [Figs. 4(a-d)] during SWM (Table 2) is expected to exhibit more warming compared to NEM (Table 3) in all the timescales. In Thanjavur, minimum temperature of SWM and NEM was projected to increase by all the models studied. SWM (Table 5) exhibits a higher range of increase than NEM (Table 6) in all the timescales.

Between the locations, Coimbatore is expected to witness a higher increase than that of Thanjavur in all the

TABLE 6
Northeast monsoon climate projections for Thanjavur

GCMs	Rainfall (% d)						Maximum temperature (°C)						Minimum temperature (°C)					
	RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5			RCP 4.5			RCP 8.5		
	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E
ACCESS1	1.4	-6.2	23.2	-1.6	-18.6	35.9	0.8	1.5	1.9	0.9	2.2	3.2	1.1	1.8	2.4	1.2	2.4	4.3
bcc-csm1	-6.8	-7.3	12.9	-8.5	7.9	-6	0.4	1	1.2	0.7	1.4	2.7	0.6	1.2	1.5	0.9	1.8	2.9
BNU-ESM	12.5	-8.1	19.7	3.7	-0.2	46.8	0.6	1.4	1.5	0.5	1.8	2.5	0.7	1.2	1.4	0.7	1.7	2.9
CanESM2	-15.7	-6.1	-1.5	-7.8	-29	-9.5	1.2	2	2.1	1.2	3	4.3	0.9	1.7	2	1.1	2.3	3.7
CCSM4	6.9	2.1	6.9	9.9	5.8	21.5	0.6	1.1	1.4	0.6	1.7	3	0.5	1	1.3	0.8	1.5	2.8
CESM1-BGC	-2	0	0.8	-13.1	14.3	10	0.6	1.2	1.4	0.6	1.6	2.9	0.5	1	1.2	0.6	1.4	2.5
CSIRO-Mk3	-13.7	20.5	60.9	23.6	44.4	67.5	0.5	0.9	0.9	0.2	1.1	2.6	0.6	1.8	2.2	1	2.2	3.1
GFDL-ESM2G	0.4	-5.1	8.2	9.6	31.3	27.1	0.6	1.1	1.3	0.6	1.6	2.8	0.6	1.1	1.2	0.9	1.9	2.9
GFDL-ESM2M	-11.3	4.6	1.1	21.3	12.9	17.7	0.4	0.9	1.3	0.7	1.7	3.9	0.5	1.1	1.4	1.1	2	5.1
HadGEM2-CC	-28.4	-23.5	-9.9	-24.4	-28.1	20.8	1	1.9	2.6	1.1	2.5	4.2	0.7	1.8	2.6	1	2.8	5.2
HadGEM2-ES	-4.1	26.4	33.7	-6.2	33.8	42.1	0.8	1.8	2.7	1.1	2.3	1.8	0.9	2.2	3	1.2	2.9	1.8
inmcm4	-1.1	-0.5	-2	-2.1	-0.6	0.9	0.3	0.6	0.8	0.3	1	3.7	0.3	0.6	0.8	0.3	1	4.6
IPSL-CM5A-LR	31.9	41.1	38.1	37.5	48.4	78.7	0.8	1.6	2	0.9	2.2	3.4	1	2.1	2.4	1.2	2.8	3.7
IPSL-CM5A-MR	35.5	27.9	25.1	29.4	57.7	34	0.7	1.4	1.9	0.8	1.9	1.4	0.8	1.5	2	0.9	2	2.7
MIROC5	-5.1	22.1	39.9	-2.7	26.7	67.6	1	0.9	1.3	0.7	1	4	0.9	1.3	1.7	0.9	1.6	3.8
MIROC-ESM	8.3	20.8	19.5	4.2	16.1	5.6	0.8	1.6	1.8	1.1	2.3	2.4	0.9	1.6	2	0.9	2.1	2.9
MPI-ESM-LR	-8.6	-16	-20.2	-11	-6.2	-8.5	0.5	1	1.1	0.4	1.4	2.8	0.6	1.1	1.3	0.5	1.5	3.3
MPI-ESM-MR	16.2	15.2	-4.4	4	6.4	-11.1	0.6	0.9	1.2	0.6	1.6	1.9	0.7	1.3	1.6	0.8	2	2.9
MRI-CGCM3	-2.8	17.4	59.8	53.1	34.4	72.8	0.3	0.4	1.2	0.1	1.1	2.5	0.7	1.1	1.6	0.8	1.7	2.5
NorESM1-M	17.3	21.4	35.9	16.6	22.6	41	0.5	0.9	1.2	0.6	1.4	2	0.5	1	1.2	0.7	1.4	2.7
E Average	1.5	7.3	17.4	6.8	14	27.7	0.7	1.2	1.5	0.7	1.7	2.9	0.7	1.4	1.7	0.9	2	3.3

% d – Percent deviation, N-Near century, M-Mid century and E-End century

time scales, which is contrasted to the variation exhibited for maximum temperature by these locations. As far as Tamil Nadu is concerned, NEM activity is accompanied by cyclonic activity in most of the times. Along with monsoon clouds, cyclones add to the cloudiness during the monsoon period, resulting in decreased insolation and a phenomenal reduction in minimum temperature. On comparing the monsoons, both the regions had a higher range of increase in SWM and interestingly for both the monsoons the end century increase was typically 5.2 °C. Kothawale and Rupakumar (2005); Rupakumar *et al.* (2006) also reported a similar increase over parts of India.

On comparing the maximum and minimum temperature, the rate of increase in minimum temperature is higher than that of maximum temperature and was in agreement with Houghton *et al.* (2001); Ramaraj *et al.* (2009) for Tamil Nadu; Krishna kumar *et al.* (2011) for India; Geethalakshmi *et al.* (2011) for Cauvery Basin and Lakshmanan *et al.* (2011) for Bhavani basin.

5.2.3. Rainfall

Coimbatore (Table 1) annual rainfall is projected to increase by few models and decrease by other models from the normal rainfall. Variation in rainfall is expected between -15 to 50.7 per cent, -9.7 to 59.2 per cent and -2.1 to 73.1 per cent during near, mid and end century. In Thanjavur (Table 2), it varies between -15.3 to 31.0 per cent, -20.4 to 36.1 per cent and -3.4 to 80.7 per cent during near, mid and end century. These wide variations may be due to the variations in model physics and also enhanced hydrological cycle expected due to warming of atmosphere. An increase in rainfall over Tamil Nadu in the future years is also reported by Rupa Kumar *et al.* (2003). Broader range of precipitation change has also been reported by Rajiv kumar *et al.* (2012).

Seasonal variation in projected rainfall [Figs. 5(a-d)] over Coimbatore revealed that, NEM (Table 3) is expected to witness a wide range of variation during near and mid

century while for SWM (Table 2), during the end century. Similar to these findings, Rajalakshmi *et al.* (2013) also projected increase in NEM rainfall. In Thanjavur, NEM (Table 6) had a wide range of variation in model prediction during near and mid century, while SWM (Table 5) had a wide range for the end century. The appreciable difference in the rainfall projection for both the monsoon seasons in both the locations could be attributed to the seasonal wind shifts during the monsoon period and the nature of orography in Tamil Nadu (Jegankumar *et al.*, 2012). The current observed rainfall behavior of Coimbatore and Thanjavur is also in agreement with this.

The increase in rate of precipitation for Thanjavur, which is nearer to east coast might be due to increased cyclonic activity and changes in monsoon circulation that is expected to enhance moisture supply over Bay of Bengal which becomes conducive for deep convection to increase the precipitation in the east coast. A similar opinion was also expressed by Ashfaq *et al.* (2009). The increase in rainfall near the coast might also happen due to increased temperature near the coasts, which increases the evaporation and intensifies the hydrological cycle near the sea (Ramanathan *et al.*, 2001).

6. Conclusion

(i) The mean change scenarios obtained through delta approach can successfully be employed in impact assessments. Multi-model assessment can bring certainty to these projections by giving a range of expected conditions.

(ii) Among the climatic parameters, maximum and minimum temperatures are projected to continuously increase over time.

(iii) Rainfall is also projected to increase, but with different magnitude in the southwest and northeast monsoon seasons.

(iv) A higher increase is expected in future during NEM compared to SWM in the study locations.

(v) The possible ranges projected by these models should be considered for agricultural decision making to have a better understanding of future changes.

Acknowledgement

The authors like to acknowledge the AgMIP team for their technical and financial support throughout the study.

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