Reliable Drought Projections over India for Twenty First Century

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ABSTRACT

Drought is one of the most frequently occurring natural disasters in India. In the recent years the frequency of drought is increasing and area coverage of drought is expanding. The Indian economy and agriculture is mainly depends on the rainfall. Hence it is very important to study the behavior of Indian summer monsoon rainfall (ISMR) and reliable projections of droughts for the future planning. There were 16 drought years from 1951-2015 in ISMR and out of this the recent decade was experienced abnormal increase in drought years. The regional studies on variability in ISMR and drought shows the spatial distribution of drought is also changing. In this study we develop a generic methodology to identify the reliability of CMIP5 climate models based on the historical simulations (1951-2005) based on multi-source observations/reanalysis to quantify. Results show that the identified climate models based on generic methodology (multi-model-ensemble, MME) is better simulated the mean and variability than all model ensemble. The identified climate models were used generate for the future projections using RCP scenarios for the period 2020-2100. The MME is showing an increasing trend in the frequency and intensity of drought in the coming decades.

***Keywords**: Drought, reliable, IPCC, projections*

1. Introduction

Indian monsoon is the most complex dynamical system, which has high spatio-temporal variability and change. The monsoon rainfall variability has profound impact on GDP and especially on agriculture sector (Gadgil and Gadgil, 2006, Mall et al. 2006) in India. Indian monsoon is unique in its behavior because of its orographic features. It is showing changes in its behavior due to the major global ocean-atmospheric phenomena like ENSO (Ashok et al. 2004, Krishnamurthy and Goswami, 2000, Chang et al. 2001, Torrence and Webster, 1999, Krishnakumar et al. 1999, etc.), IOD (Gadgil et al., 2004, Kripalani and Kumar, 2004, Ashok et al. 2001, etc), etc. The studies show weakening in ISMR in recent decades (Ramesh and Goswami, 2007; Goswami and Ramesh, 2008, Dash and Hunt, 2007, Naidu et al., 2000). The multi-source observational rainfall data provides evidence of increasing drought severity over the Indian continent (Goswami and Ramesh, 2008; Bollasina and Sumant, 2011). The weakening of ISMR and the increase in drought severity index is extremely disastrous for Indian agriculture and food security, thereby on Indian economy. IPCC CMIP5 models were used for the historical as well as future projections in different aspects of climate research. Several studies have shown that not all CMIP5 models have the ability to capture the observation features especially for Indian monsoon region (Li et al. 2016, Sabeerali et al. 2015, Li et al. 2015, Sabeerali et al. 2013, Kitoh et al. 2013, etc). Thus it is important to study the regional changes in ISMR in both temporal and spatial patterns to estimate the CMIP5 models ability to simulate the same. The assessment of reliability of climate projections is a major challenge especially in the regional scales. The accurate projections of regional climate systems are critical for assessing the sustainability of a large section of the world's population and to determine the future of the global climate system. The reliable drought studies and projections are also important for the planning and pro-active measurements in the regional scale.

Thus it is necessary to select the reliable climate models for the regional rainfall projections. Here we identify the reliable climate models based on their ability to simulate ISMR during extreme years in past. Based on the identified climate model simulations, reliable climate projections scenarios are generated.

2. Data and Methodology

Monthly global rainfall data from Climate Research Unit (CRU) (Mitchell and Jones 2005), Global Precipitation Climatology Project (GPCP) (Huffman et al. 2009), and 26 CMIP5 models (Taylor et al. 2012) are used in this study. The details of the model configuration are shown in the Table 1. The reanalysis is used as a bench mark for the selection of reliable climate models. The models and reanalysis were regridded for common grid ($1^o \times 1^o$) for comparison. The drought years were defined as per IMD definition and it is taken as the years at which the seasonal (JJAS) rainfall is less than 10% from long term mean. The drought years identified as per IITM were 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1986, 1987, 2002 and 2004. The models were tested using the seasonal trend, mean, and climatology patterns. The models were selected based on the ability to get the features in observation/reanalysis especially the extreme events (droughts). It is done in such a way that it should fall within the range of one standard deviation (SD) or two standard deviation and the dispersion within the observation (σ). The major selections are based on the models' response for the ranges like (i) 1SD+σ and (ii) 2SD+σ. The model which falls in these categories is treated as a successful model in that test.

The different criteria are defined as follows:

i. All criteria: The model should succeed in all the statistical tests viz, seasonal trend, climatology (1SD), climatology (2SD) and seasonal v/s annual mean.
ii. Criteria 1: The model should succeed in at least 3 test from the above 4.
iii. Criteria 2: The model should succeed in seasonal analysis (trend and mean).

The models were selected based on the above three criteria and the selected model ensemble is used for future projections of rainfall. The medium (RCP45) and extreme (RCP85) scenarios from CMIP5 are used in this study for future projections.

3. Results and Discussions

The CMIP5 simulations exhibit large spreads in simulations of average monsoon rainfall and their interannual variability, in comparison with observations (Fig 1). On the other hand the gridded observations also show significant spread in terms of its mean and variability (Fig 2). The spatial distribution and magnitude of mean or anomaly during drought years also exhibit significant variability between different observations. The detailed number of extreme years in each individual models and the model ensemble based on different criteria are shown in the Table 2. There is dispersion within the observations as well as for the 24 models and for the selected models for getting the seasonal mean rainfall for Indian region for the time period 1951-2005. The temporal dispersion for seasonal (JJAS) rainfall is shown in Fig 1. It is clearly evident that the models are behaving in diverse manner, which depends on their physical characteristics.

The individual model simulations of the spatial distribution during drought years are shown in Fig 3. Some models are not able to capture the observed features during the weak monsoon years. But some other models are over/under estimating the features too. Thus it is important to select the models, which are reliable to get the observed features intensity and spatial distribution. To get reliable observed features we use mean rainfall, standard deviation and trend to select the reliable models. The spatial distribution patterns based on selected model composite with different criteria's are shown in Fig 4. But the criteria selection is making the ensemble and the results better when compared with the results from individual model results. The models were selected using different criteria as described in the previous session. The selected models are

(i) All criteria- NorESM1-M (X)
(ii) Criteria 1- GFDL-ESM2M (M), INMCM4 (O) and NorESM1-M (X)
(iii) Criteria 2- GFDL-ESM2M (M), INMCM4

(O), MPI-ESM-MR (W) and NorESM1-M

The ensembles based on different criteria are showing better representation of observed features. The weakening of rainfall is associated with increased rainfall over Northeast region. The selected models were used to create for the future projection scenarios of ISMR for 2020-2100. The linear trend shows significant decreasing trend for the period 2020-2100 (Fig. 5). RCP85 rainfall projection scenarios show significant reduction than RCP45 scenario. Thus the reliable projections indicate significant reduction in spatio-temporal distribution over India.

4. Conclusions

As the historical CMIP5 models simulations of ISMR show huge dispersion between models, it is important to assess the reliability of individual climate models before using them for regional applications. The models should be tested in different time slices viz, long term and short term to get the exact response of a particular model and for the comparison with the observations. The statistical analysis is a better option to check the reliability of climate models and the dispersion between the observations also should be included for the better understanding. We are suggesting some basic criteria based on (i) annual and seasonal trend, (ii) mean seasonal and annual rainfall and (iii) long term climatology. This methodology can be applied for other regions and other climatic parameters.

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Table. 1 Details of the 24 Models that participated in the CMIP5 Project, which used in this study

Model Name	Institute	Symbol	Horizontal Resolution (lat×lon)
ACCESS-1.0	CSIRO-BOM, Australia	A	$1.25^o \times 1.875^o$
ACCESS-1.3	CSIRO-BOM, Australia	B	$1.25^o \times 1.875^o$
BCC-CSM1-1	BCC,CMA,China	C	$2.8^o \times 2.8^o$
BNU-ESM	GCESS, China	D	$2.8^o \times 2.8^o$
CanESM2	CCCMA,Canada	E	$2.8^o \times 2.8^o$
CCSM4	NCAR,CO,USA	F	$0.94^o \times 1.25^o$
CESM1-CAM5	NSF-DOE-NCAR,USA	G	$0.94^o \times 1.25^o$
CESM1-FASTCHEM	NSF-DOE-NCAR,USA	H	$0.94^o \times 1.25^o$
CESM1-WACCM	NSF-DOE-NCAR,USA	I	$0.94^o \times 1.25^o$
CNRM-CM5	CNRM-CERFACS, France	J	$1.4^o \times 1.4^o$
CSIRO-Mk3-6-0	CSIRO-QCCCE, Australia	K	$1.9^o \times 1.9^o$
FIO-ESM	FIO,SOA,China	L	$2.8^o \times 2.8^o$
GFDL-ESM2M	NOAA-GFDL, USA	M	$2.0^o \times 2.5^o$
HadGEM2-AO	NIMR-KMA, Korea	N	$1.25^o \times 1.875^o$
INMCM4	INM, Russia	O	$1.5^o \times 2.0^o$
IPSL-CM5A-LR	IPSL, France	P	$1.875^o \times 3.75^o$
IPSL-CM5A-MR	IPSL, France	Q	$1.25^o \times 2.5^o$
IPSL-CM5B-LR	IPSL, France	R	$1.875^o \times 3.75^o$
MIROC-5	AORI-NIES-JAMSTEC, Japan	S	$1.4^o \times 1.4^o$
MIROC-ESM	AORI-NIES-JAMSTEC, Japan	T	$2.8^o \times 2.8^o$
MIROC-ESM-CHEM	AORI-NIES-JAMSTEC, Japan	U	$2.8^o \times 2.8^o$
MPI-ESM-LR	MPI-N, Germany	V	$1.9^o \times 1.9^o$
MPI-ESM-MR	MPI-N, Germany	W	$1.9^o \times 1.9^o$
NorESM1-M	NCC, Norway	X	$1.875^o \times 2.5^o$

Table.2 The number of drought, excess and normal years in reanalysis, models and in different criteria

Model	Excess	Drought	Normal
ACCESS-1.0	8	8	39
ACCESS-1.3	10	9	36
BCC-CSM1-1	7	6	42
BNU-ESM	6	8	41
CanESM2	7	7	41
CCSM4	7	6	42
CESM1-CAM5	8	12	35
CESM1-FASTCHEM	7	10	38
CESM1-WACCM	7	4	44
CNRM-CM5	8	7	40
CSIRO-Mk3-6-0	7	9	39
FIO-ESM	6	5	44
GFDL-ESM2M	7	8	40
HadGEM2-AO	7	10	38
INMCM4	7	7	41
IPSL-CM5A-LR	8	7	40
IPSL-CM5A-MR	8	7	40
IPSL-CM5B-LR	10	6	39
MIROC-5	10	11	34
MIROC-ESM	9	9	37
MIROC-ESM-CHEM	7	7	41
MPI-ESM-LR	6	8	41
MPI-ESM-MR	9	8	38
NorESM1-M	10	12	33
CRU	9	8	38
CPCC	9	10	36
COMP_MOD	8	7	40
ALL_CRI	10	12	33
CRI_1	8	11	36
CRI_2	10	10	35

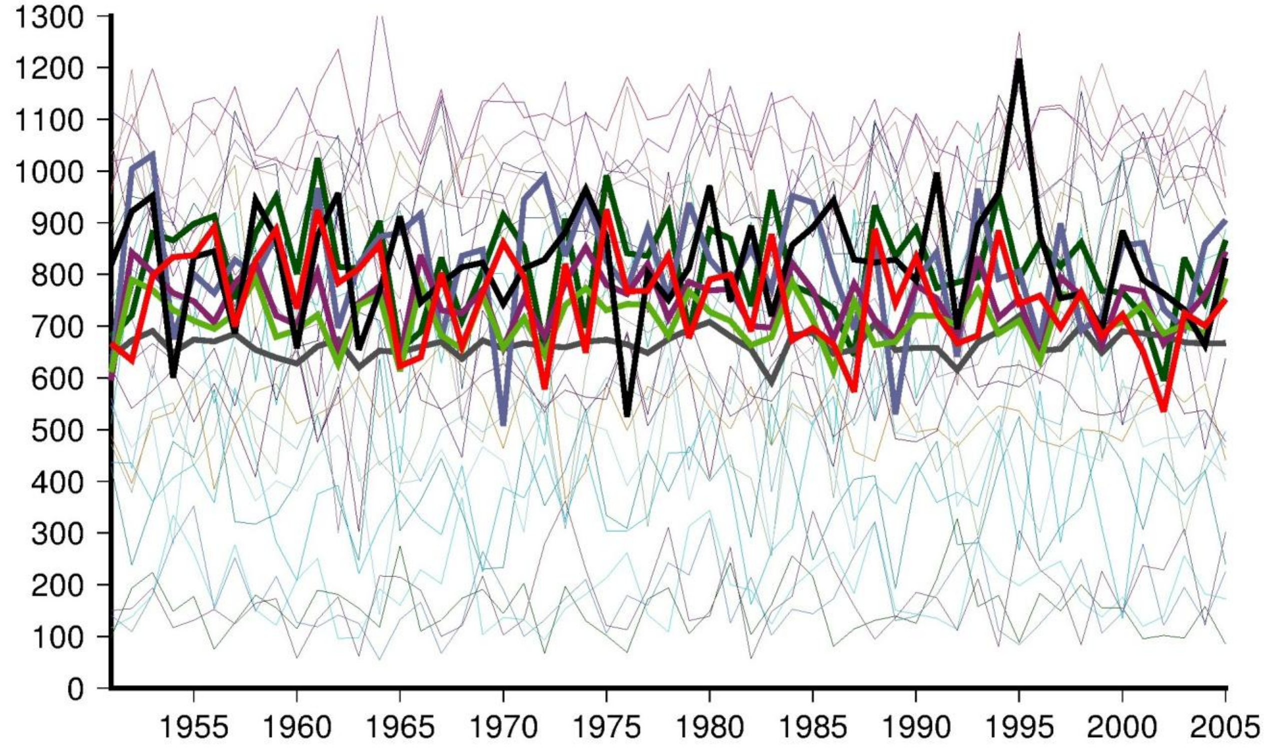

Figure 1. The dispersion showing the mean rainfall in mm for the time period 1951-2005 for JJAS in different CMIP5 models and for CRU (Black) and GPCC (Red) and for selected models based on different criteria. All model average (Dark Gray), All Criteria (Magenta), Criteria 1(dark green), and Criteria 2 (light green)

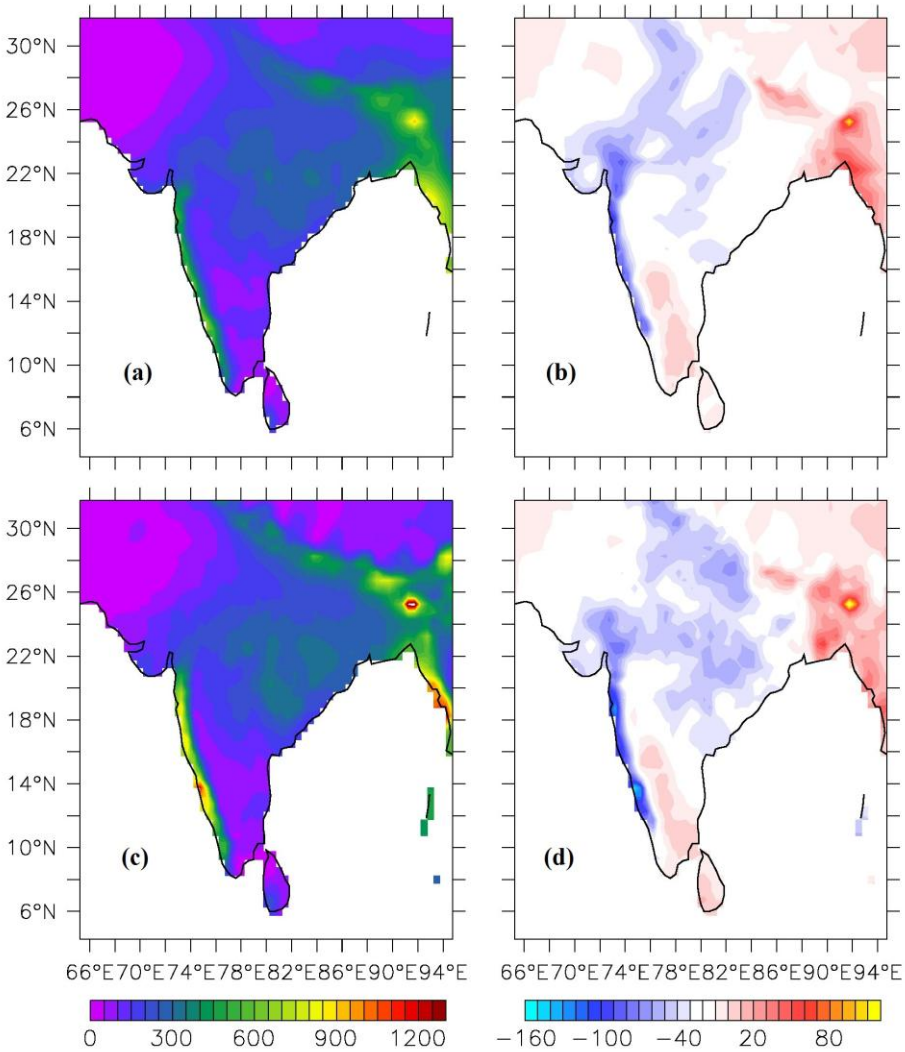

Figure 2 The mean rainfall (mm) for the time period 1951-2005 for (a) CRU and (c) GPCC. The rainfall anomaly (mm) for the drought years for (b) CRU and (d) GPCC

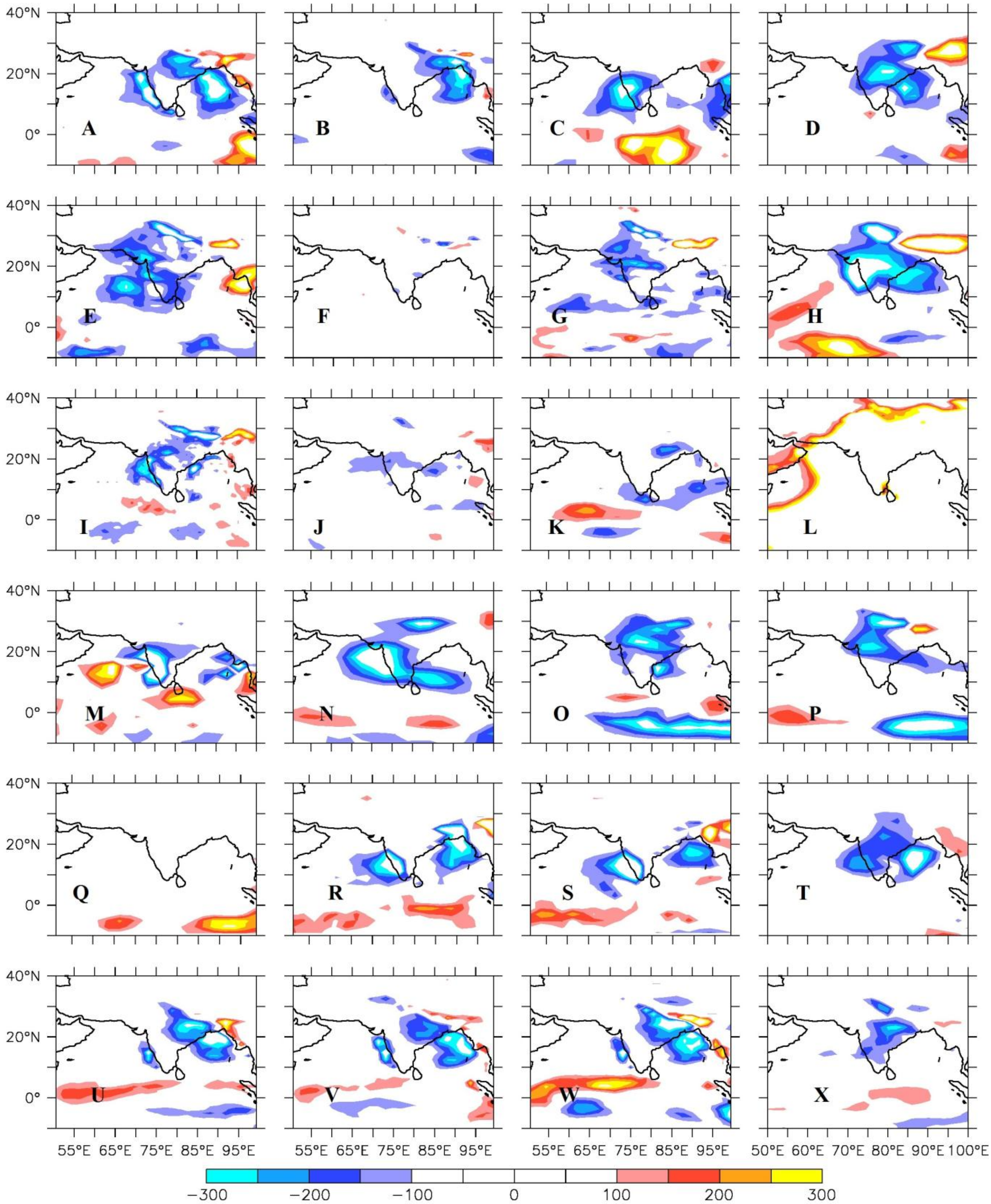

Figure 3 Weak (drought) years rainfall anomaly (mm) for different climate models

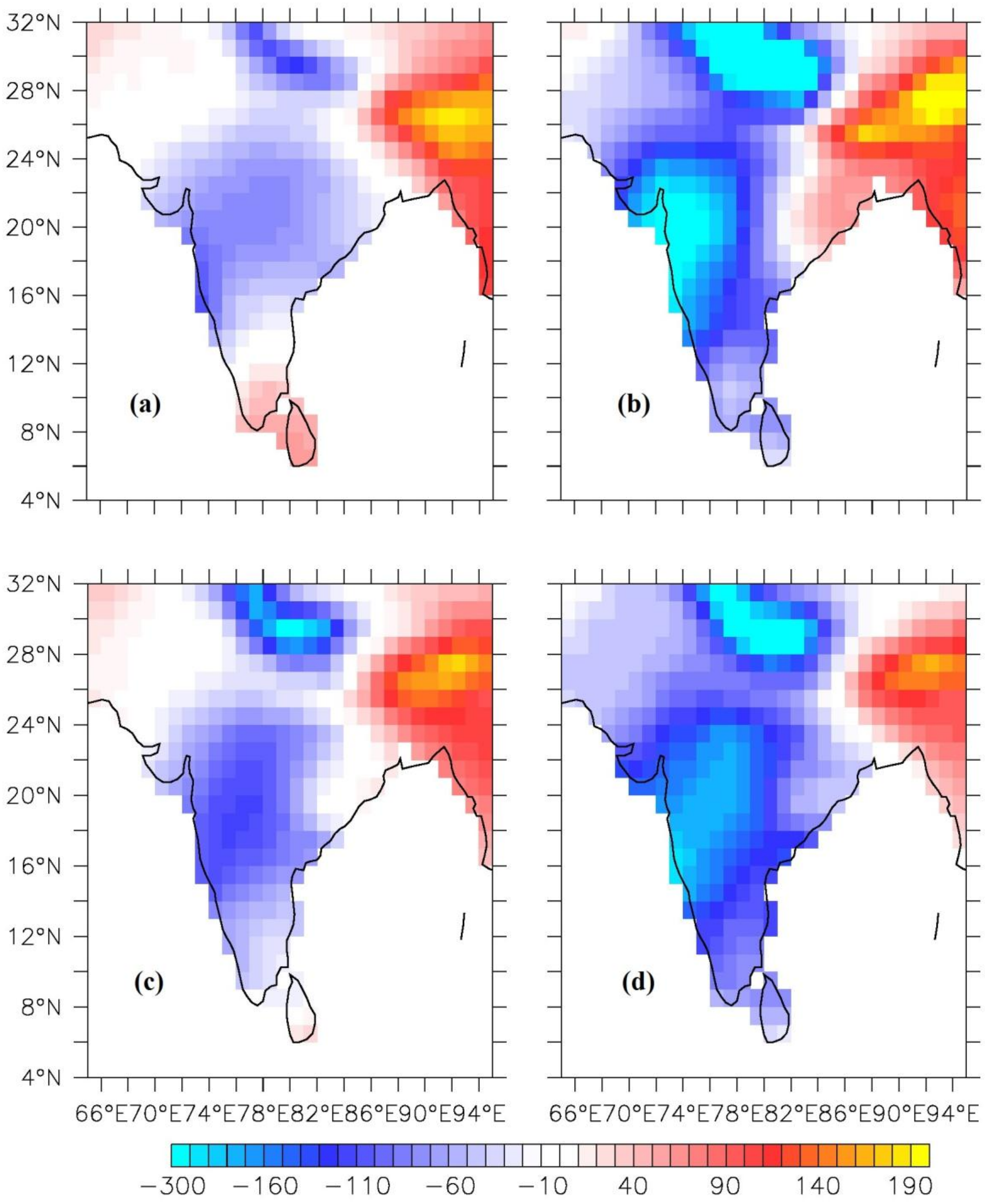

Figure 4 The JJAS rainfall anomaly (mm) for the drought years for the time period 1951-2005 for (a) all model average, (b) all criteria, (c) Criteria_1 and (d) Criteria_2

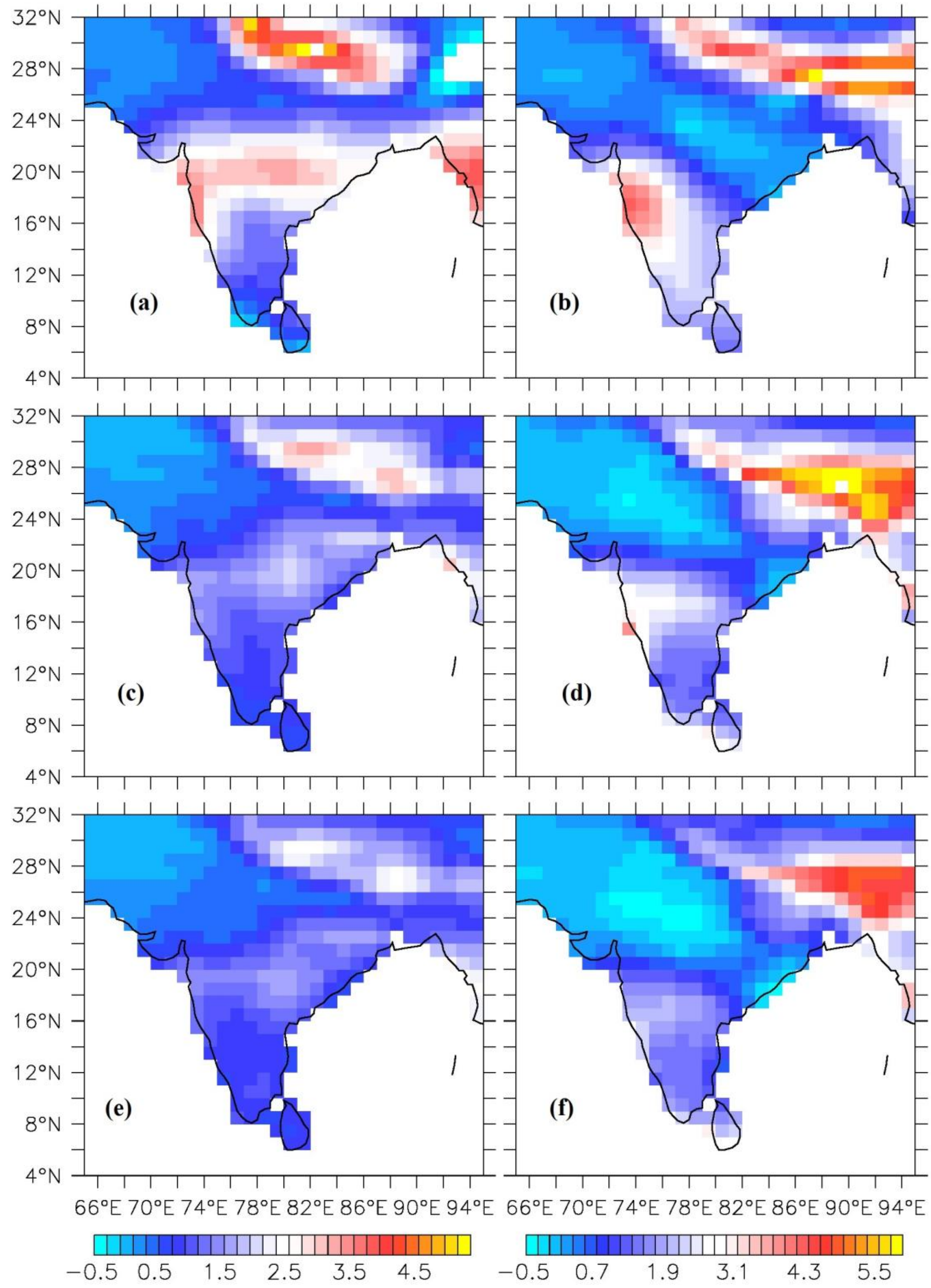

Figure 5 The linear trend for RCP 45 (a, c and e) and RCP85 (b, d and f). "a" and "c" are linear trend for the models falling in all_criteria, "b" and "d" are for CRI_1 and 'e" and "f" for CRI_2