IMPACT OF INCREASED CO_2 ON RAINFALL OVER INDIAN MONSOON REGION IN IPCC-AR4 CGCM SIMULATIONS

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ABSTRACT:

An attempt is made to study the spatial and temporal changes in meteorological parameters that are likely to take place over the Indian monsoon region when CO_2 doubles from the present level. We use the most comprehensive multi-model perspectives of climate changes as of today generated as part of IPCC-AR4, archived at the Program for Climate Change Model Diagnosis and Inter comparison (PCMDI) at the Lawrence Livermore National Laboratory, USA for this purpose. We selected 6 out of 15 models for the CO_2 doubling studies that produce the annual cycle of rainfall over the Indian summer monsoon region reasonably well in the 20th century experiments. The CO_2 doubling simulations by these 6 models suggest that the rainfall rate over the India monsoon region is likely to increase during the entire year except the spring season. During summer monsoon season, peak rainfall increase (>3 mm day^{-1}) is seen over the head Bay of Bengal and adjacent regions.

1. INTRODUCTION

Assessment Report-4 of the Intergovernmental Panel on Climate Change (AR4-IPCC) suggests that the global mean surface temperature is likely to increase at the rate of 0.2°Cdecade^{-1} for the next two decades due to various anthropogenic activities (IPCC, 2007). According to physical laws, this increase in surface temperature is expected to increase the moisture content of the atmosphere (Trenberth et al, 2005) and ultimately rainfall. The climate models help us to estimate the changes in meteorological parameters due to this likely increase in surface temperature up to some confidence. Studies suggest that though general circulation models are improving in simulating the mean global climate, their performance at regional scale still remains challenging (e.g. Randall et al. 2007, Bollasina and Nigam, 2009).In this work, we attempt to study the spatial and temporal changes in rainfall that is expected to take place over the Indian monsoon region when CO_2 doubles from the present level using Coupled Global Climate Models (CGCMs) that have participated in the IPCC-AR4.

2. DATA

We use the most comprehensive multi-model perspectives of climate changes as of today generated as part of IPCC-AR4, archived at the Program for Climate Change Model Diagnosis and Inter-comparison (PCMDI) at the Lawrence Livermore National Laboratory, USA for this purpose (http://www.pcmdi.llnl.gov/ipcc). Standard outputs of two experiments namely 20th Century simulation (20c3m) and 1% CO_2 increase (1pctto2x) simulation of 15 Coupled Global Climate Models (CGCM) were collected for analysis from PCMDI (Table. 1). There is a fairly large range in the horizontal resolution of these models varying from 1.125° lat. ×1.25° lon. to 4° lat. ×5° lon. The 20c3m simulations attempt to replicate the overall climate variations during 1850 – present by imposing best estimates of natural (solar radiation, volcanic aerosols) and anthropogenic climate forcing (green house gases, sulfate aerosols, ozone, etc). In the 1pctto2x experiments CO_2 concentration is increased by 1% every year until it doubles (70th year) and then hold the CO_2 concentration at this constant level for an additional 150 years.

3. RESULT AND DISCUSSION

3.1 Comparison of Rainfall Simulations by CGCMs Over Indian Monsoon Region in 20th Century Experiment with Observation

In Fig-1(a-b), 30-year (1971-2000) average annual cycle of rainfall rate simulated by these 15 models over the Indian monsoon region [65°E-95°E; 5°N-35°N] in 20c3m simulations are shown along with satellite observed rainfall from Global Precipitation Climatology Project (GPCP, Gu et al, 2007). Out of the 15 models, 6 models capture the annual cycle of rainfall well (Fig. 1a) and the remaining 9 models (Fig. 1b) capture it poorly (e.g. shift in rainfall peak, absence of annual cycle, etc) when compared with the GPCP rainfall.

In Fig. 2, 30-year mean rainfall rate averaged during the summer monsoon season (June to September) by the 6-models that captured the annual cycle reasonably well along with GPCP rainfall rate are shown. Though there are large discrepancies among the models in simulating the spatial distribution and rate of rainfall, they reproduce the large scale features such as heavy rainfall rate over windward side of western ghats, north Bay of Bengal and less or no rainfall over the Pakistan/North Arabian sea regions well. The GISS models overestimate rainfall over the head Bay of Bengal and adjacent land regions and underestimate it over north India.

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3.2 Projected Rainfall Change due to CO_2 Doubling

We analyze the "1pctto2x" experiments of 6 select models that have simulated the annual cycle reasonably well to study the rainfall changes over Indian summer monsoon region due to CO_2 doubling.

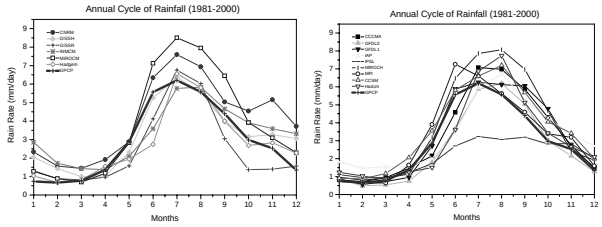
In Fig. 3, the annual cycle of rainfall rate over Indian monsoon region (a) before and (b) during CO2 doubling by 6-selected models are shown. The multi model ensemble (MME) of rainfall averaged during 1981-2000 in the 20c3m experiments (represents the CO2 of present level) and MME of rainfall averaged during 51-70th years of 1pctto2x (represents the CO2 during doubling) simulation are shown in this figure. It is obvious in Fig. 3 that the overall shape of annual cycle and the seasonal march of rainfall would not change in a warming environment caused by CO2 doubling. This means that the monsoon season will be during June to September months with peak rainfall during July and August months. But the rainfall rate would increase by ~0.5 mm/day particularly during the monsoon season due to doubling of CO2.

No	IPCC Model ID	Modeling Group	Description
1	cccma_cgcm3_1	Candian Centre for Climate Modeling	T63L31
2	cnrm_cm3	CNRM, France	T47L31
3	gfdl_cm2_0	GFDL, US	2.5latx2.0lat, L24
4	gfdl_cm2_1	GFDL, US	2.5 atx2.0lat, L24
5	giss_model_e_h	GISS/NASA, USA	4latx5lon
6	giss_model_e_r	GISS/NASA, USA	4latx5lon
7	iap_fgoals1_0_g	IAP, China	2.8latx2.8lon L26
8	inmcm3_0	INM, Russia	5lonx4lat, L21
9	ipsl_cm4_v1	Institut Pierre Simon Laplace, France	3.75lonx2.5lat
10	miroc3_2_hires	CCSR, University of Tokyo & JAMSTEC	T106L56
11	miroc3_2_medres	CCSR, University of Tokyo & JAMSTEC	T42L20
12	mpi_echam5	Max Planck Institute Meteorology, Germany	T63L31
13	ncar_ccsm3_0	NCAR, USA	T85L26
14	ukmo_hadcm3	Hadley Center for Climate Prediction Research, K	2.75latx1.875lon
15	ukmo_hadgem1	Hadley Center for Climate Prediction Research, K	2.75latx1.875lon

Table 1: Climate Modeling Groups Participated in IPCC-AR4

3.3 Projected Changes in Rainfall Pattern due to CO_2 Doubling

The changes in rainfall rate simulated by the select 6-models during summer monsoon season (June to September) before (first 10-years) and after CO_2 doubling (last 10 years) are shown in Fig.4. All the models suggest an increase in rainfall over head Bay of Bengal and adjoining regions. This increase suggests that the Bay of Bengal branch of monsoon current may intensify due to global warming by doubling of CO2. Only the MIROC3_MEDRES model shows considerable decrease in rainfall over central and northern parts of India.



(a) (b)

Figure 1. The 30-year Average Monthly Mean Rain Rate (mm/day) Simulated by 15 CGCMs in 20c3m Simulations Along with Observation. (a) Models Simulate the Shape of the Annual Cycle Well; (b) Models Simulate the Annual Cycle Wrong

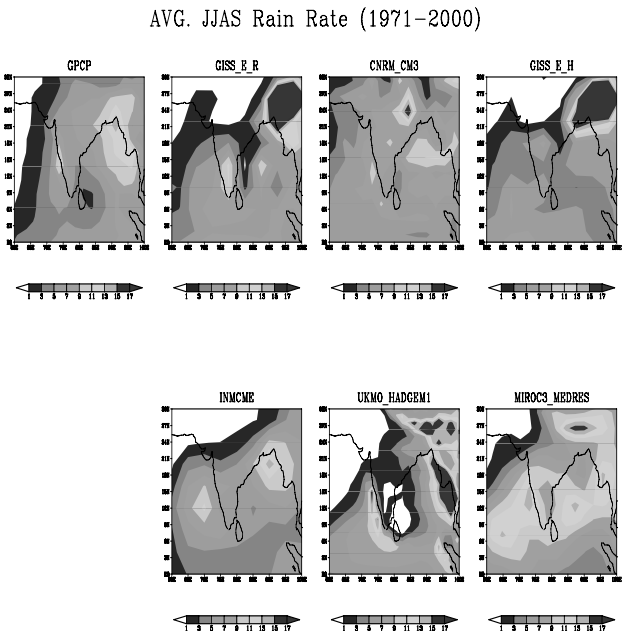
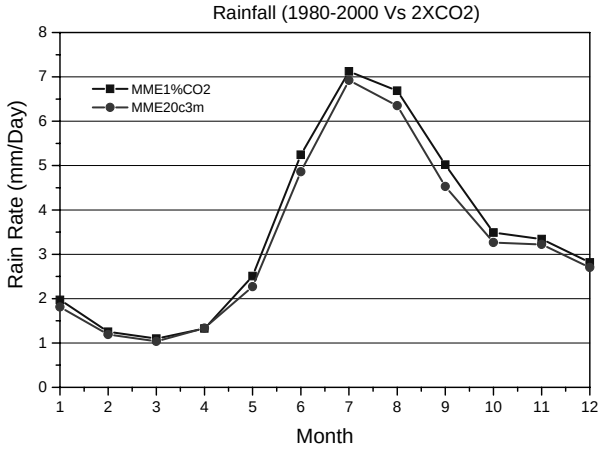


Figure 2. The 30-Year Mean Rain Rate (mm/day) Averaged During the Summer Monsoon Season (June to September) by the 6 Models (20c3m runs) that have been Selected for Analysis along with GPCP Rain Rate



Fi.gure 3. Annual Cycle of Rainfall Rate (mm/day) Simulated by 6 Models (Multi Model Average) in 20th Century and During CO_2 Doubling

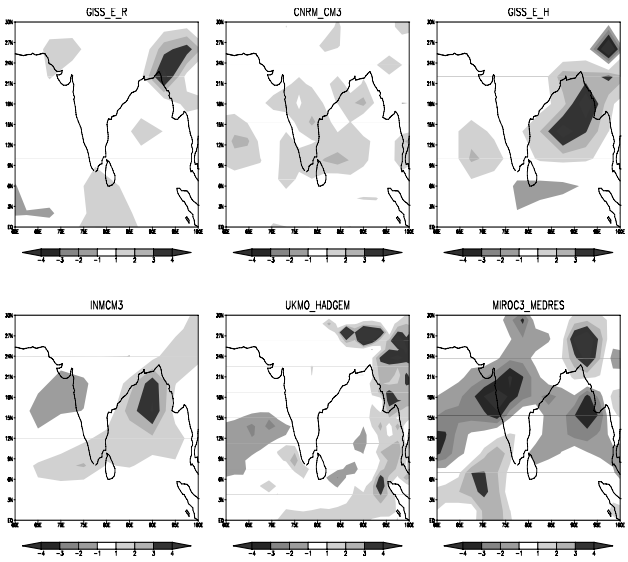


Figure 4. Spatial Distribution of Rainfall Change before and During the Doubling of CO_2 Simulated by 6 Select Models

4. SUMMARY

We analysed rainfall simulated by 15 models that have participated in the IPCC-AR4 to study the likely changes in rainfall over India during the summer monsoon season due to doubling of CO_2. We selected 6 out of 15 models that have simulated the annual cycle of rainfall reasonably well over the Indian region in the 20th century experiments for rainfall projection study. The multi-model ensemble of rainfall simulated by 6-selected models in the doubling of CO_2 experiment suggest an increase in rainfall rate over the Indian summer monsoon region during entire year expect spring. Also 5 out of the 6 models suggest an increase in rainfall over the head Bay of Bengal and adjoining regions.

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