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Impact of CO_2 Increase on East Asian Monsoon

R. H. Kripalani[1*], J. H. Oh[2] and H. S. Chaudhari[2]

[1]*Indian Institute of Tropical Meteorology, Pune, India*
[2]*Integrated Climate System Modeling Laboratory, Department of Environmental and Atmospheric Sciences, Pukyoung National University, Busan, South Korea*

1. Introduction

Climate Modeling Groups around the world have been performing an unprecedented set of coordinated 20^{th} and 21^{st} century climate change experiments, in addition to commitment experiments extending to the 22^{nd} century for the Inter-governmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) to be brought in the year 2007.

One of the aims of these simulations is to assess the ability of the global coupled climate models to make projections of future climate change. Such model evaluations have been under progress under the Atmospheric Model Inter-comparison Project (AMIP), Coupled Model Inter-comparison Project (CMIP) and the Climate Variability / Monsoon (CLIVAR/Monsoon) Inter-comparison Project. Current coupled models are able to simulate many aspects of the observed climate with a useful level of skill at hemispheric or continental space scales. At regional scales skill is lower. Most of these evaluations have shown that the models are able to capture the large-scale dynamic fluctuations better than the regional scale rainfall variations connected with the monsoons. The confidence in climate model precipitation projections will depend on how well the models are able to simulate the 20^{th} century monsoon rainfall. The Asian region with its high human population and significant monsoon related economy and food production could be highly vulnerable to climate change. Hence the variation in seasonal monsoon rainfall may be considered a measure to examine climate change over the Asian domain in the context of global warming. Here we focus on the East Asian region only (20-40^{0}N, 100-145^{0}E: Fig. 1)

In view of the above the 20^{th} century simulated summer (June July August : JJA) monsoon precipitation over the above identified East Asian domain for all the available models and runs are analyzed with respect to the annual cycle, spatial patterns and the inter-annual variability. Based on the performance of the models, these are selected to examine future precipitation projections under the idealized scenario of 1% increase in CO_2 until reaching double concentration and kept constant thereafter.

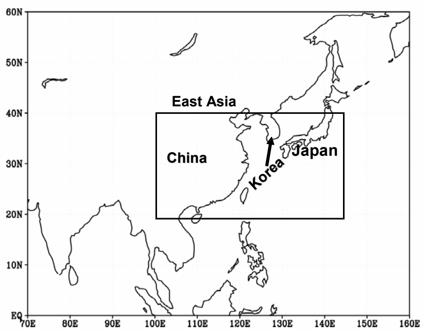

Fig.1. Map showing region of analysis over East Asia.

2. Models, data and methodology

The IPCC standard output from coupled ocean-atmosphere models is collected and archived by the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) at the Lawrence Livermore National

Table 1: Climate models and their versions used in this study along with the key reference for each model. The simplified 3-letter abbreviations are in general based on the first 3 characters of the respective Model Experiment acronym. These simplified 3-letter abbreviations will be used throughout the text to refer to a particular model.

Ser No	Model Experiment Acronym	IPCC ID	Simplified Abbreviation	Country	Key Reference
1	bcc_cm1	BCC-CM1	bcc	China	Not available
2	bccr_bcm2_0	BCCR-BCM2.0	bcr	Norway	Furevik et al 2003
3	cccma_cgcm3_1	CGCM3.1	ccm	Canada	Flato et al 2000
4	cnrm_cm3	CNRM-CM3	cnr	France	Salas-Melia et al 2005
5	csiro_mk3_0	CSIRO-MK3.0	csr	Australia	Gordon et al 2002
6	gfdl_cm2_0	GFDL-CM2.0	gf0	USA	Delworth et al 2004
7	gfdl_cm2_1	GFDL-CM2.1	gf1	USA	Delworth et al 2004
8	giss_aom	GISS-AOM	gao	USA	Russel et al 1995
9	giss_model_e_h	GISS-EH	gih	USA	Schmidt et al 2005
10	giss_model_e_r	GISS-ER	gir	USA	Schmidt et al 2005
11	iap_fgoals1_0_g	FGOALS-g1.0	iap	China	Yu et al 2004
12	inmcm3_0	INM-CM3.0	inm	Russia	Diansky & Volodon 2002
13	ipsl_cm4	IPSL-CM4	ips	France	Marti et al 2005
14	miroc3_2_hires	MIROC3.2 (hires)	mih	Japan	Hasumi et al 2004
15	miroc3_2_medres	MIROC3.2 (medres)	mim	Japan	Hasumi et al 2004
16	miub_echo_g	ECHO-G	miu	Germany	Not available
17	mpi_echam5	ECHAM5/MPI-OM	mpi	Germany	Jungclaus et al 2005
18	mri_cgcm2_3_2a	MRI-CGCM2.3.2	mri	Japan	Yukimoto & Noda 2002
19	ncar_ccsm3_0	CCSM3	ncc	USA	Collins et al 2005
20	ncar_pcm1	PCM	ncp	USA	Washington et al 2000
21	ukmo_hadcm3	UKMO-HadCM3	ukc	UK	Jones et al 2004
22	ukmo_hadgem1	UkMO-HadGEM1	ukg	UK	Johns et al 2005

Laboratory, USA. The climate models for which data are available are listed in Table 1. The monthly precipitation flux data for all the models (22 to date) and all the runs under the control run (acronym '20c3m') and under the 1% increase compounded until reaching double (acronym '1pctto2x') have been downloaded. The 20^{th} century control runs are available from about 1850 to 2000 while the transient runs under CO_2 increase extend until 2100.

The model simulated precipitation is compared with the observed CMAP (Climate Prediction Center Merged Analysis Precipitation) estimates.

3. Simulations and Projections

3.1 Annual Cycles

As recommended by the IPCC AR4 panel, the models mean climate will be defined based on the 1981-2000 period of the "all forcings 20th century runs" i.e. experiment designated as '20c3m'. Hence for comparison the observed annual cycle is also prepared for the same period. To examine the impact of CO_2 increase on the annual cycle, annual cycles for the '1pctto2x' experiments are based on the 20 years (Years 61-80) centered at the time of CO_2 doubling (year 70). These annual cycles are shown in Fig. 2.

The observed annual cycle for precipitation over East Asia shows a gradual increase from spring with peak in summer thereafter a gradual decrease in autumn. The peak value in JJA is about 180-190 mm/month (Fig. 2). On comparison with the observed, the simulated model annual cycles can be roughly categorized into 4 sets:

(i) 5 models (ccm, inm, mih, mpi, ncp) show similar annual cycle in shape as well as magnitude

(ii) 3 models (gir, ukc, ukg) show similar annual cycle in shape but magnitude is higher than the observed

(iii) 4 models (csr, gf0, gf1, ips) show similar annual cycle in shape but magnitude is lower than observed

(iv) 3 models (iap, miu, ncc) shows that the maximum occurs a month later and even the magnitudes are lower than observed

Only one model (bcc) considerably underestimates the annual cycle with maximum of about 50 mm for the month of August. The remaining 6 models show some variations from the observed. Hence the projected annual cycles under the CO_2 increase experiments are examined on the averages of the models falling in each of the above 4 sets. The observed, simulated and projected annual cycles are also shown in Fig. 2. Figure reveals the following

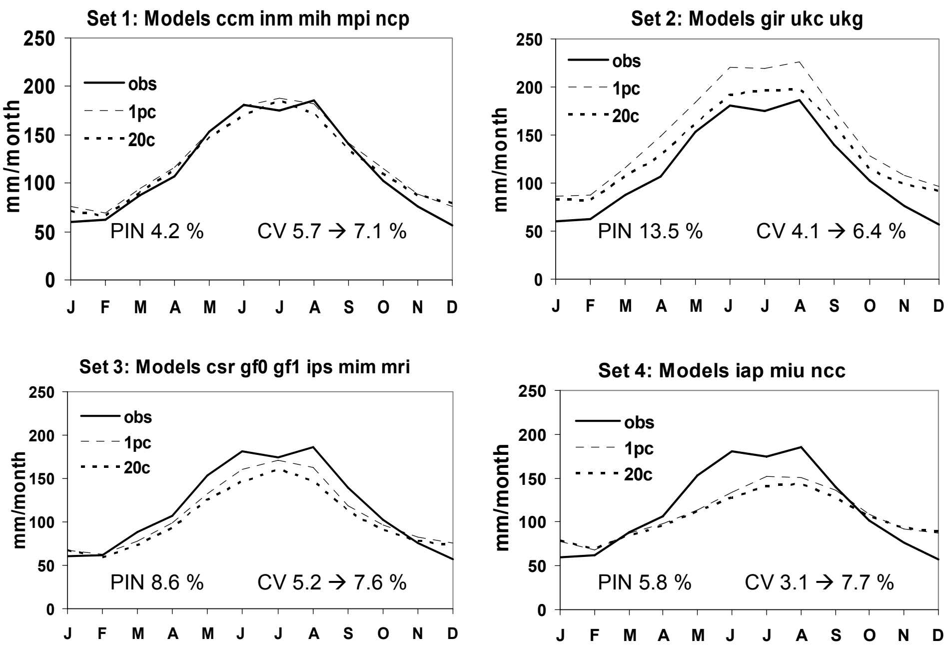

Fig.2 Annual cycles observed (continuous solid) control 20c3m runs (bold dotted line) and transient 1pctto2x runs (dotted line) based on the averages of models for the 4 sets. The percentage increase (PIN) and coefficient of variation (CV) for each set are also indicated.

:(a) For all the 4 sets precipitation is estimated to increase throughout the year with maximum in summer

(b) The mean summer precipitation is estimated to increase by 4.2, 13.5, 8.6 and 5.8 % respectively for the above 4 sets respectively. Models which over estimate the annual cycle also project more increase in precipitation during summer.

(c) Even the summer precipitation variability is expected to increase in the warming world as is evident from the estimates of coefficient of variability (CV). For set 1 CV is projected to vary from 5.7 to 7.1%, set 2 from 4.1 to 6.4%, set 3 from 5.2 to 7.6% finally for set 4 from 3.1 to 7.7%.

3.2 Inter-annual Variability

The simulated inter-annual variability is estimated by computing the mean summer monsoon seasonal rainfall and CV for each of the 22 models. In general the mean seasonal precipitation is well simulated by most of the models (Fig. 3). Based on these, 3 models (ccm, inm, mpi) are selected to examine the inter-annual variations in the warming world.

3.3 Multi-Model Projections

To examine projections based on the multi-models, average summer monsoon rainfall series are prepared by averaging the outputs of 3 models (ccm, inm, mpi). For these 3 models control runs are available for 130 years (1871-2000) and transient runs under the CO_2 doubling scenario are available for 220 years (1871-2090). A plot of these two series is shown in Fig. 4. The solid line super-imposed on the inter-annual fluctuations is a smoothed curve using a 21-year running mean low-pass filter. This multi-model series reveals a gradual increase in precipitation with an increase of 4-5% at the time of CO_2 doubling. During the period CO_2 is held constant and allowed to stabilize, there is an indication of slight increase in precipitation for a decade or so thereafter remains constant. Once the system reaches a state of equilibrium, the increase in precipitation will also remain practically constant. This suggests that with increase in CO_2, warming may increase resulting in more evaporation, more moisture in the atmosphere, ultimately resulting in more precipitation.

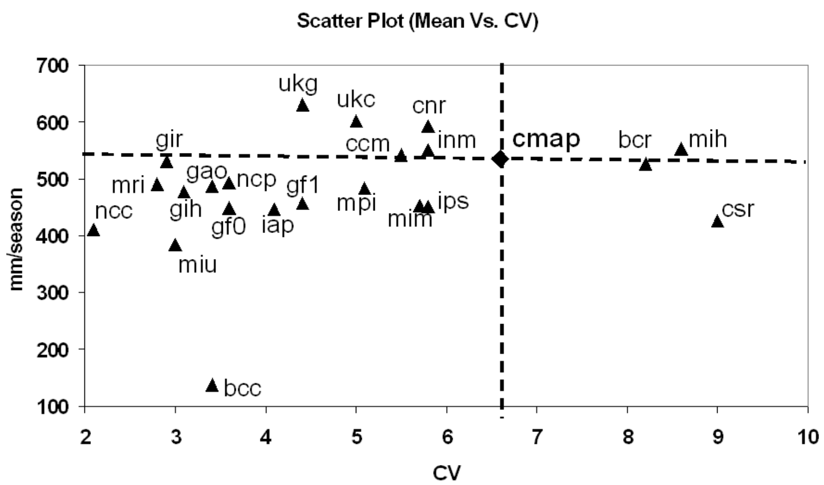

Fig.3 Scatter Plot of mean seasonal rainfall and CV simulated by each model. The values are depicted by the 3 letter acronym for each model. CMAP represents observed mean and CV.

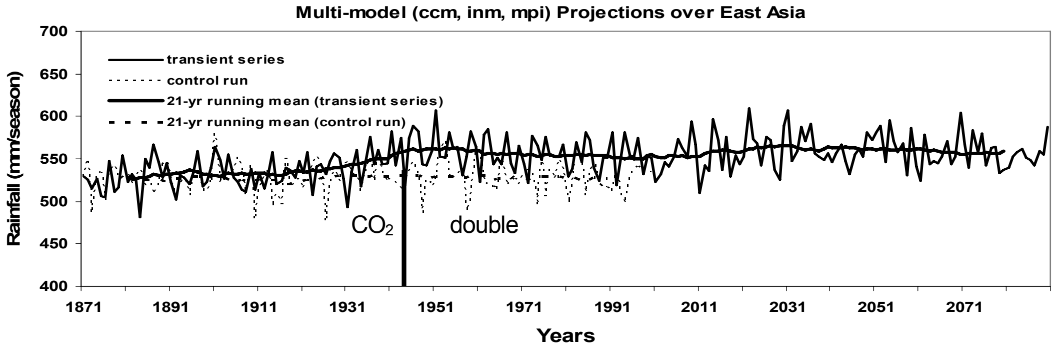

Fig.4 Time series plot of the summer monsoon rainfall (JJA) over East Asia for the control 20c3m run (dotted) and for the transient 1pctto2x run (continuous). The thick line super-imposed on the inter-annual variations are running 21-year mean low pass filter.

4. SUMMARY

Some basic summer precipitation features over East Asia during the 20th -21st century as simulated / projected by the 22 coupled climate models under the IPCC AR4 program are investigated. Keeping in view that these are climate runs without prescribed SSTs, models perform well in simulating the regional annual cycle, spatial patterns (not shown) and the inter-annual variability. The projections under the 1% increase in CO_2 compounded until reaching double and held constant thereafter reveal that

(a) Precipitation is likely to increase in all the months in particular during the summer monsoon (JJA) months.

(b) The mean summer monsoon rainfall can increase from 4.2 to 13.5% and its variability is also likely to increase in the warming world due to increase in CO_2

(c) Extreme excess and deficient seasonal monsoons are likely to become more intense (not shown here)

(d) Once the increase in CO_2 is cut-off, the system will reach a state of equilibrium, and then the rate of increase in precipitation is also expected to remain constant.

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