Uncertainties in future projections of extreme precipitation in the Asian monsoon regions

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Background

Climate models suggest the mean summer monsoon remains robust in future scenarios but little is known about changes on short timescales.

- In the HadCM3 coupled model, Turner *et al*. (2007) showed the monsoon over India to increase by around 5%, relating to strengthening of the meridional temperature gradient and increased moisture supply over the warmer Indian Ocean.
- Turner & Slingo (2009a) examined changes to the spatial distribution of subseasonal monsoon precipitation extremes during the monsoon in a 2xCO_2 integration of HadCM3. Fig 1 describes heavier extremes of monsoon rainfall over north India/Bay of Bengal and much of East Asia. However the pattern of these changes is strongly tied to changes in the mean.
- In HadCM3, changes to the heaviest monsoon rainfall counted over all Indian gridpoints are strongly predictable based on the Clausius-Clapeyron relation and the degree of atmospheric warming in the region (see Eqn. 1 and Fig 2).
- This study examines these features in the coupled models of the CMIP3 database.

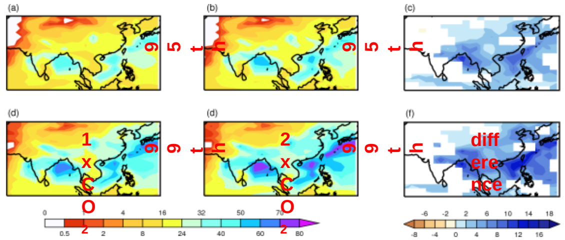


Fig 1: Precipitation at the 95[th] and 99[th] subseasonal percentiles during JJAS in HadCM3. Differences exceeding 95% significance are shown.

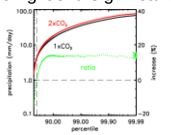


Fig 2: Extreme rainfall during JJAS for all gridpoints over India in HadCM3. Absolute levels are shown on the left log-scale; ratio is shown on the right. After Allen & Ingram (2002). Asterisk indicates predicted increase.

Eqn. 1: Clausius-Clapeyron predicted increase to heaviest rainfall in HadCM3.

$$14\% \approx 2.27\mathrm{K} \times 6.5\% / \mathrm{K}$$

CMIP3 data (used below): daily coupled model data was obtained for picntrl* and 1pctto2x scenarios from the PCMDI CMIP3 website at http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php:

- 40 years picntrl run. *miub_echo_g and mri_cgcm2_3_2a use pdcntrl instead.
- 20 years data centred at the time of CO_2 doubling. Some groups also provide 20 years data from the end of the 1pctto2x integration after CO_2 stabilization.

Spatial distribution of changes to subseasonal extremes of monsoon precipitation

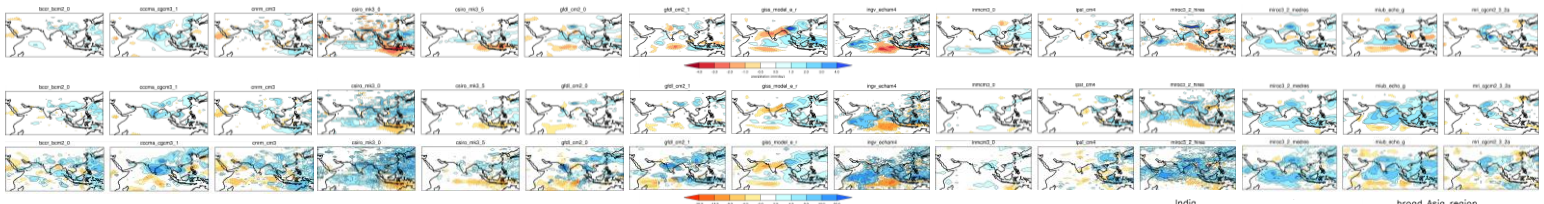


Fig 3 (above): Asian monsoon region JJA mean precipitation difference between 1pctto2x and control integrations from the CMIP3 database (top) and differences in their subseasonal precipitation extremes at the 95[th] (middle) and 99[th] percentiles (bottom). Near-zero changes blanked out for clarity. Middle and bottom panels share the bottom colour scale.

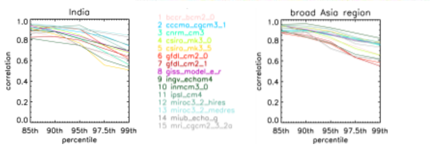


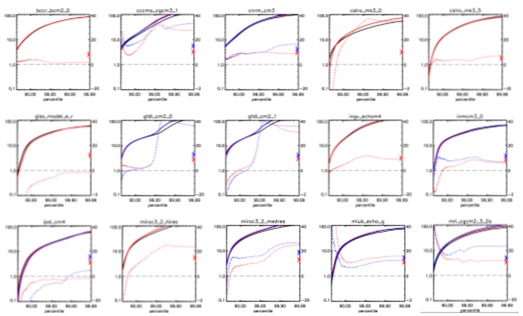
Fig 4 (right): Spatial correlations between mean JJA precipitation change and change to subseasonal extremes (*e.g.*, as shown in Fig 3) for various percentiles. Regions: India (65-90°E, 10-30°N), broad Asia-Pacific (40-180°E, 25°S-40°N).

CMIP3 shows large uncertainties in changes to subseasonal precipitation extremes.

- Large uncertainties in both magnitude and distribution of changes over South and East Asia (Fig 3). Only giss_model_e_r shows mostly drier conditions over India.
- Patterns are larger than, but qualitatively similar to, changes in the mean summer precipitation.
- At the 90[th] percentile, around 80% of the spatial variance of extreme change can be explained by the projected change in the mean pattern (Fig 4).

Magnitude of change of the heaviest extremes and its possible predictability

Fig 5: Precipitation associated with the upper two quartiles measured over India during JJA (solid curves, left scale). Dotted curves show the percentage change (right scale). Colours represent control (black), 1pctto2x at time of CO_2 doubling (red), and stabilization (blue). Asterisk indicates predicted increase in heaviest rainfall based on model local climate sensitivity (measured over the Arabian Sea: 55-70°E, 5-20°N) and Clausius-Clapeyron, as in Eqn. 1.



CMIP3 reveals large spread in projections of heaviest monsoon rainfall but clear predictability in some models.

- In some models changes to the heaviest monsoon rainfall vary following the local climate sensitivity (Fig 5), just as HadCM3 in Fig 2. These tend to use bulk mass-flux schemes (Table 1), closely dependent on surface conditions. Others such as giss_model_e_r show weakening extremes, in conjunction with drier mean conditions.
- Models in which measured changes far exceed predicted values (*e.g.* GFDL models) tend to have variants on the Arakawa-Schubert convection scheme.
- Results are found to be independent of horizontal resolution, changes in monsoon dynamics or zonal windshear in the monsoon domain (not shown).

Table 1: Measured and predicted increases in heaviest rainfall over India, ranked by their ratio. Colours reveal models sharing the same convection scheme.

model	measured (%)	predicted (%)	ratio	convection
gfdl_cm2_0	50.71	8.65	5.86	Moorthi-Suarez relaxed AS
csiro_mk3_0	34.16	9.97	3.43	Gregory-Rowntree mass flux
gfdl_cm2_1	30.24	9.30	3.25	Moorthi-Suarez relaxed AS
cccma_cgcm3_1	27.26	10.26	2.66	Zhang-MacFarlane variant on AS
miroc3_2_medres	24.72	13.02	1.90	Pan-Randall prognostic AS
miroc3_2_hires	23.33	14.81	1.58	Pan-Randall prognostic AS
miub_echo_g	15.89	11.11	1.43	Tiedke mass flux
csiro_mk3_5	7.09	5.23	1.36	Gregory-Rowntree mass flux
mri_cgcm2_3_2a	12.07	10.79	1.12	Pan-Randall prognostic AS
cnrm_cm3	8.92	9.78	0.91	mass flux with Kuo closure
ingv_echam4	8.87	9.93	0.89	Tiedke mass flux
inmcm3_0	6.15	8.51	0.72	Betts; convective adjustment
bccr_bcm2_0	1.87	8.15	0.23	mass flux with Kuo closure
ipsl_cm4	-1.06	11.31	-0.09	Grandpeix variant on Emanuel mass flux
giss_model_e_r	-1.33	12.21	-0.11	Del Genio-Yao mass flux

References: Allen MR, Ingram WJ (2002) *Nature* **419**. // Meehl G & 13 co-authors (2007) *Global Climate Projections,* ch10, IPCC AR4, *Cambridge University Press*. // Turner AG, Inness PM, Slingo JM (2007) *QJRMS* **133**. // Turner AG, Slingo JM (2009a) *QJRMS* **137**. // Turner AG, Slingo JM (2008b, this work), *ASL*, **submitted**. Model details from http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php

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