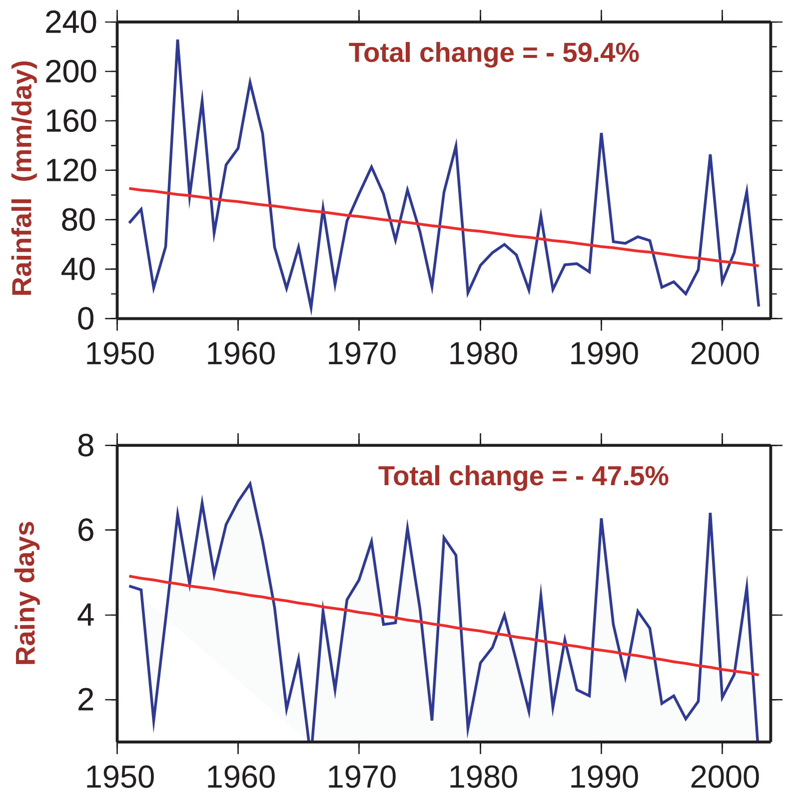
C-MMACS

The Shrinking Indian Summer Monsoon

Reduction in rainfall and number of rainy days during Indian Summer Monsoon

Pre Monsoon (May 15 - May 31)



K V Ramesh and P Goswami

CSIR Centre for Mathematical Modelling and Computer Simulation
Wind tunnel Road, Bangalore-560 037, India

Research Report RR CM 0709
June 2007

Publication Status: Internal Report
Published Reference: Geophysical Research Letters (in press)
Distribution: Unrestricted

CSIR Centre for Mathematical Modelling and Computer Simulation
Wind Tunnel Road, Bangalore-560 037, India
Tel No: +91 80 25224667   Fax +91 80 25220392
Website: http://www.cmmacs.ernet.in
E-mail: goswami@cmmacs.ernet.in

The Shrinking Indian Summer Monsoon

K V Ramesh and P Goswami

Abstract

In the backdrop of a changing climate, we investigate whether the Indian summer monsoon is changing either in terms of duration or spatial coverage. Such an analysis specifically for the continental Indian region has both conceptual and societal implications, and has been lacking. We show here, based on an analysis of daily gridded observed rainfall data for the period 1951–2003, that there are decreasing trends in both early and late monsoon rainfall and number of rainy days, implying a shorter monsoon over India. Similarly, there is a sharp decrease in the area that receives a certain amount of rainfall and number of rainy days during the season. These trends are consistent with other variables like OLR and rainfall from independent data sets; in particular, the land-ocean temperature contrast has a decreasing trend, consistent with a weakening monsoon. The results emphasize need for careful regional analysis in drawing conclusions regarding agro-ecological sustainability in a changing climate.

Introduction

The dependence of India on monsoon rainfall is well known; most of the Indian region receives about 80% of its annual rainfall from the southwest monsoon during June-September. Agricultural practices over most parts of India have thus evolved around a rainy season that lasts from June to September, although the day of the onset over Kerala has a standard deviation of about seven days. An important question is whether the length or spatial extent of the monsoon rainy season is changing. Although the all-India summer monsoon (ISM) rainfall doesn't seem to show any significant trend [*Rajeevan et. al., 2006, Goswami et. al., 2006*] in spite of an increasingly warmer environment, this stability may not hold at a local level. In fact, the spatial distribution of linear trends in ISM rainfall and the number of rainy days show tremendous variability, with opposite trends over different locations (Figure 1&2).

One reason for expecting shifts in the monsoon season is possibly warmer oceans in late spring or early winter to support and sustain deep organized convection necessary for the monsoon. Such a warming, and associated rainfall over the continental India can result in enhanced pre-June and post-September rainfall, effectively increasing the length of the rainy season, even if the all-India (June-September) rainfall doesn't show any significant trend. The reverse, a shrinking of the rainy season, may take place if the local trends conspire to change the land-ocean thermal gradients. Another possible scenario is one in which the spatial coverage of f the monsoon is smaller,

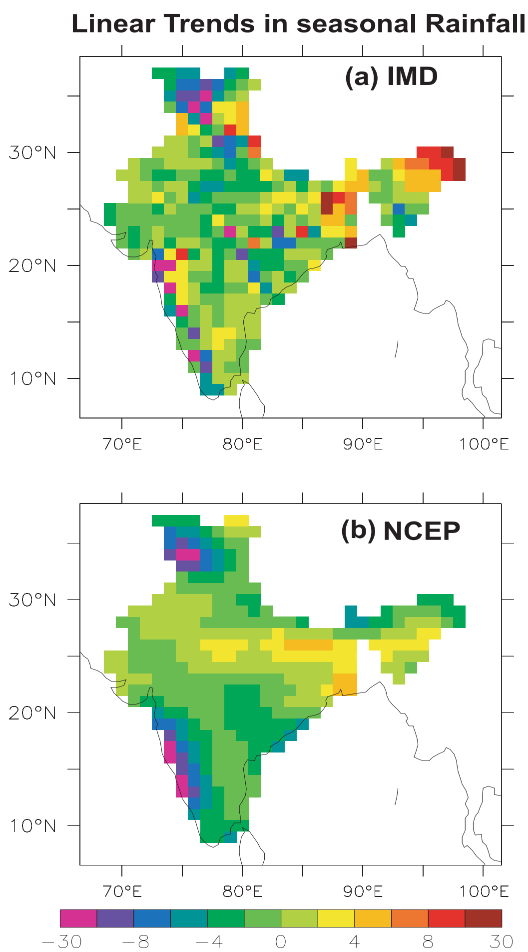


Figure 1 Spatial distribution of linear Trends in seasonal rainfall during June 1 to September 30. **(a)** 53-year gridded daily rainfall data from India Meteorological Department. **(b)** 53-year gridded daily rainfall data from NCEP Reanalyse

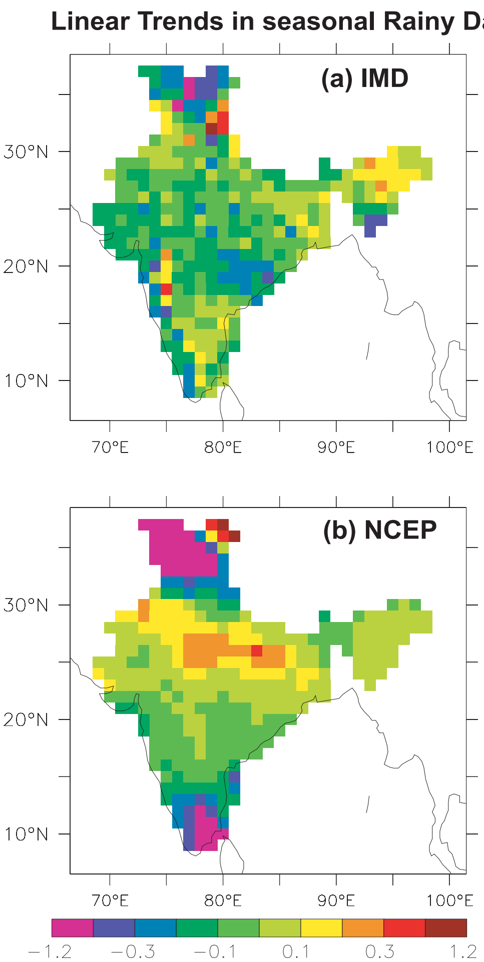


Figure 2 Spatial distribution in linear Trends in number of rainy days during June 1 to September 30. **(a)** 53-year gridded daily rainfall data from India Meteorological Department. **(b)** 53-year gridded daily rainfall data from NCEP Reanalyses

although the overall (area-averaged) seasonal rainfall remains essentially unchanged because of compensating contributions from areas with positive trends.While several works have addressed the issue of change (in duration) of the monsoon season [*Syroka and Toumi, 2002; Goswami and Xavier, 2005*], the question of any change in the spatial coverage of monsoon has not been addressed so far. ISM is, by definition, a regional system with certain geographical coverage, which, however, may change. A change in the spatial coverage of monsoon rainfall is an equally likely consequence of a change in regional circulation pattern; even a relatively small shift of location in the downward branch of the regional Hadley cell [*Annalisa and Antonio, 2007*] by a couple of degrees in longitude or latitude can have significant impact on monsoon rainfall due to inhibition of convection. Thus even if a quantity like the all- India rainfall may not change or even increase [*Syroka and Toumi, 2004*], the geographical coverage, in terms of number of locations that receive certain (monsoonal mean) rainfall, may decrease. Our focus on the continental India as the area of investigation is due, partially, to the tremendous socio-economic implications; a reduction of the monsoon season over India will have serious consequences for agro-ecological sustainability for a large ecosystem, even if there is a lengthening of the monsoon season over a wider area.

Dataset

One of the primary constraints in analyzing trends in spatio-temporal coverage of ISM has been the lack of a continuous (gridded) data set with sufficiently high resolution. While daily observations of rainfall exist at a number of stations over India, the question of a change of spatial extent, of course, can not be addressed with isolated station data. Similarly, although there exist rainfall series with spatial coverage at monthly, seasonal and annual scale [*Parthasarathy et. al., 1994*], the coarse resolution (meteorological subdivision) can not be expected to yield meaningful information on (likely) slow trend in the spatial coverage. Although a number of studies exist on rainfall trends based on station data [*Parthasarathy and Mooley, 1978; Thapliyal and Kulshrestha, 199*] and specifically region-wise for the southwest coast [*Koteswaram and Alvi, 1969*] and Gujarat [*Chowdhury and Abhayankar, 1979*], these may not represent large-scale trends. In particular, only gridded rainfall data at sufficiently high spatial resolution and daily scale can allow a quantification of any change in the spatial coverage or reveal slow trend of the monsoon. The primary requirement of such a rainfall dataset was only recently developed by the India Meteorological Department (IMD) for the period 1951-2003 over India at a resolution of $1^{o}X1^{o}$ [*Rajeevan et. al., 2006*]. The IMD dataset is based on rainfall records of 1803 stations which had a minimum 90% data availability during the analysis period (1951–2003). The station rainfall data have been projected onto a rectangular grid (1^{o} X 1^{o}) for each day for the period 1951–2003. In this gridding method, the interpolated values are computed from a weighted sum of the observations *[Shepard, 1968]*. Given a grid point, the search distance is defined as the distance from this point to a given station. The interpolation is restricted to the radius of influence; for search distances equal to or greater than the radius of influence, the grid point value is assigned a missing code when there is no station located within this distance. A predetermined maximum value limits the number of data points used which, in the case of high data density, reduces the effective radius of influence. The starting point of the grid is 6.5^{o}N and 66.5^{o}E. From this point, there are 35 points towards east and 32 points towards north. In addition, we have also used gridded daily rainfall and OLR data for the period 1950-2003 from NCEP Reanalysis [*Kistler et al. 2001*] on a 1.87x1.4 Gaussian grid; pentad rainfall (2.5x2.5) data from CMAP *[Xie and Arkin, 1997]*. The estimates of trends in surface temperatures are based on data prepared by *Hansen [1999*].

Results and Conclusions

As mentioned above, one possibility is an increase (decrease) in the amount of rainfall or the number of rainy days during the pre-June period, signifying an effective increase (decrease) in the rainy season. Examination of the amount of rainfall and the number of rainy days over Kerala (72.5 - 77.5^{o}E; 8.5 - 15.5^{o}N) in the pre-onset (May 15-May 31) period, however, shows only a decreasing trend (figure 3a, top and bottom panels respectively). A similar analysis over central India (70.5 - 80.5^{o}E; 17.5 – 35.5^{o}N) for the (post-withdrawal) period (September 15-October 10) also shows significant decreasing trends (figure 3b, top and bottom panels respectively). Thus there is no early onset, while the monsoon is shrinking in terms of withdrawal. For the pre-June period, the decrease in the area-averaged rainfall and the number of rainy days are 59% and 47%, respectively of the mean values. For the post monsoon period the corresponding values are smaller (39% and 24%, respectively) but still significant.

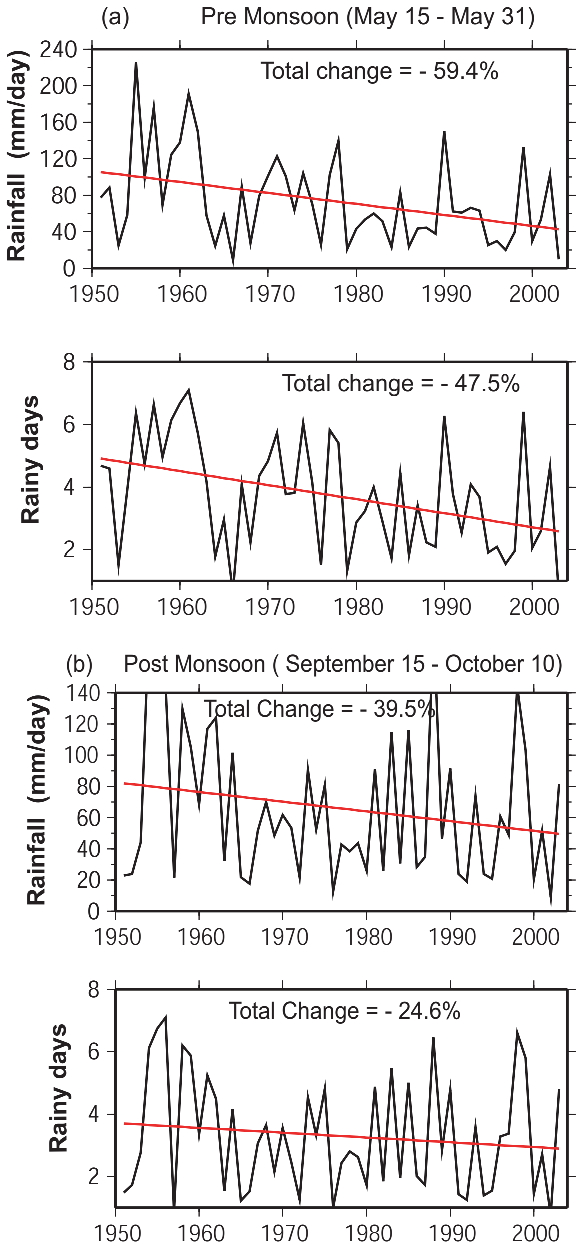


Figure 3 Linear least square trends in **(a)** pre monsoon (May 15-May 31) rainfall (mm/year, top panel) and number of rain days (greater than 5 mm/day, bottom panel) over Kerala (72.5°E-77.5°E and 8.5°N-15.5°N) based on 53 years of gridded daily rainfall data from India Meteorological Department (IMD). **(b)** post monsoon (September 15-October 10) rainfall (mm/year, top panel) and number of rain days (greater than 5 mm/day, bottom panel) over central India (70.5°E-80.5°E and 17.5°N-35.5°N) based on 53 years of gridded daily rainfall data from IMD.

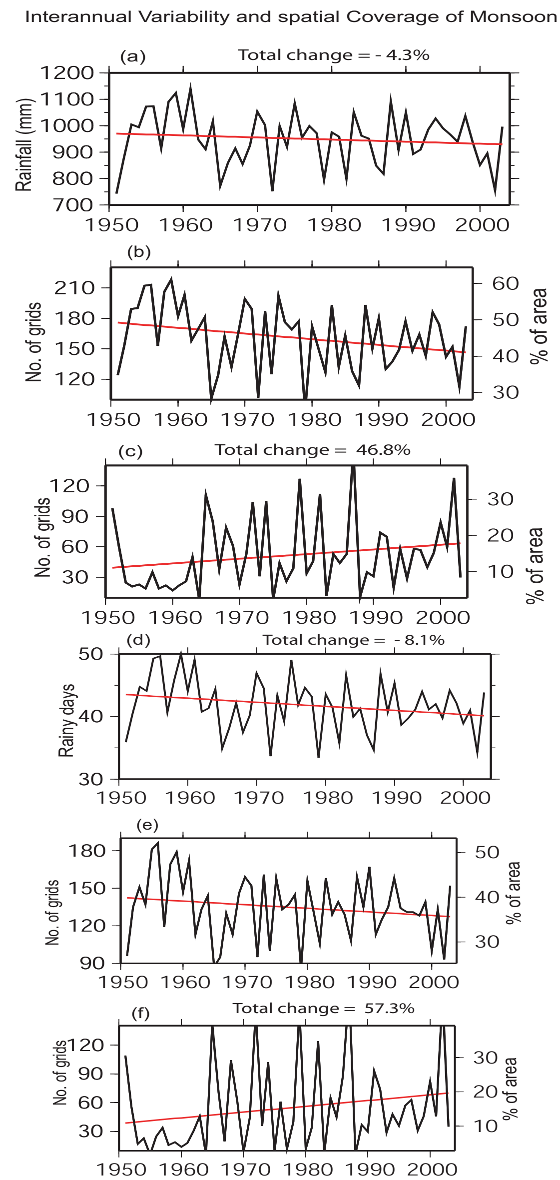


Figure 4 Inter annual variability and linear trend in the spatial coverage of monsoon, in terms of number of grid points (left axis) and percentage of area (right axis) that receive **(a)** seasonal mean monsoonal rainfall **(b)** receives rainfall more than or equal to all India averaged mean seasonal rainfall **(c)** rainfall one standard deviation below the current seasonal mean over the location. **(d)** Current mean number of rainy days **(e)** receives rainfall more than or equal to all India averaged mean seasonal rainy days **(f)** number of rainy days one standard deviation below the current seasonal mean over the location. The period considered is May 15 to October 10.

As noted earlier, the all-India summer monsoon rainfall and the number of rainy days do not exhibit significant trend, as shown in the top panels of figure 4. As mentioned above, even though the total monsoonal rainfall (June-September) for the country may not change significantly due to a complex combination and spatial distribution of trends, the area (number of grid points) that receive current mean monsoonal rainfall may change. In terms of spatial coverage, shown in the middle panels of figure 4 as the number of grid points (left axis) and % of area (right axis) that receives the current mean seasonal rainfall (figure 4a) and the current mean number of rainy days (24-hour rainfall >= 5 mm, figure 4.b), however, there are significant decreasing trends. Similarly, number of grid points (% of area) that receive rainfall or number of rainy days one standard deviation below the 53-year seasonal mean are increasing. In terms of amount of rainfall, this shrinkage is as much as 30% between 1950 and 2003, while the corresponding shrinkage in terms of number of rainy days is close to 40%.

The trends in rainfall over India derived from the IMD data are consistent with those in fields like OLR from NCEP Reanalysis. Figure 5 shows the year-longitude structures of time-averaged and latitudinally averaged OLR fields for three cases. The left, middle and the right panel in figure 5 represent, respectively, pre-monsoon (May 15-May 31), latitudinally averaged between 5 – 15°N, June-September, latitudinally averaged between 5 – 25°N and post-monsoon (Sept 15, Oct 10), latitudinally averaged between 15 – 25°N. Increasing trends in OLR, consistent with decreasing trends in rainfall, are seen not only over India but also west of the ISMR region. The top panels in figure 5 show the standard deviations in yearly values of OLR; it can be seen that the changes in OLR are much larger than the corresponding natural variability.

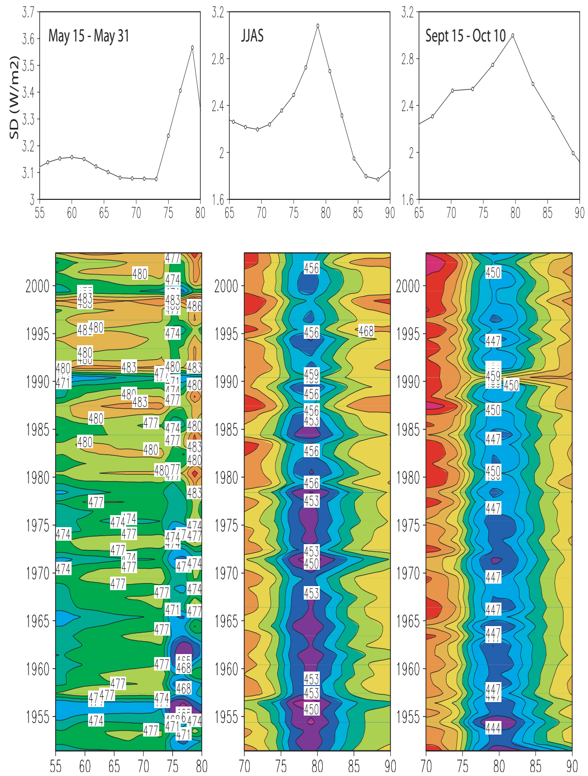


Figure 5 Year-longitude structure of latitudinal and time averaged OLR field for 53 years from NCEP Reanalysis. Pre-monsoon (May 15 – May 31), monsoon (June 1 – September 30), post monsoon (September 15 – October 10). The top panels show standard deviation in OLR for the fifty three years as a function of Longitude.

It may not be easy, however, to identify a single dominant mechanism for the decreasing trends in pre-onset and the post-withdrawal rainfall or rainy days. A comparison of trends in the rainfall over the global tropics calculated from NCEP daily data shows that (figure 6) the decreasing trends are a part of similar global trends, with the characteristic regime shift around 1975 [*Stephens, 2001*] evident in the rainfall as well as the number of rainy days during June-September. It may be mentioned that although NCEP data has much coarser resolution and significant model bias, it provides a good representation of observed rainfall [*Goswami and Ramesh, 2006*].

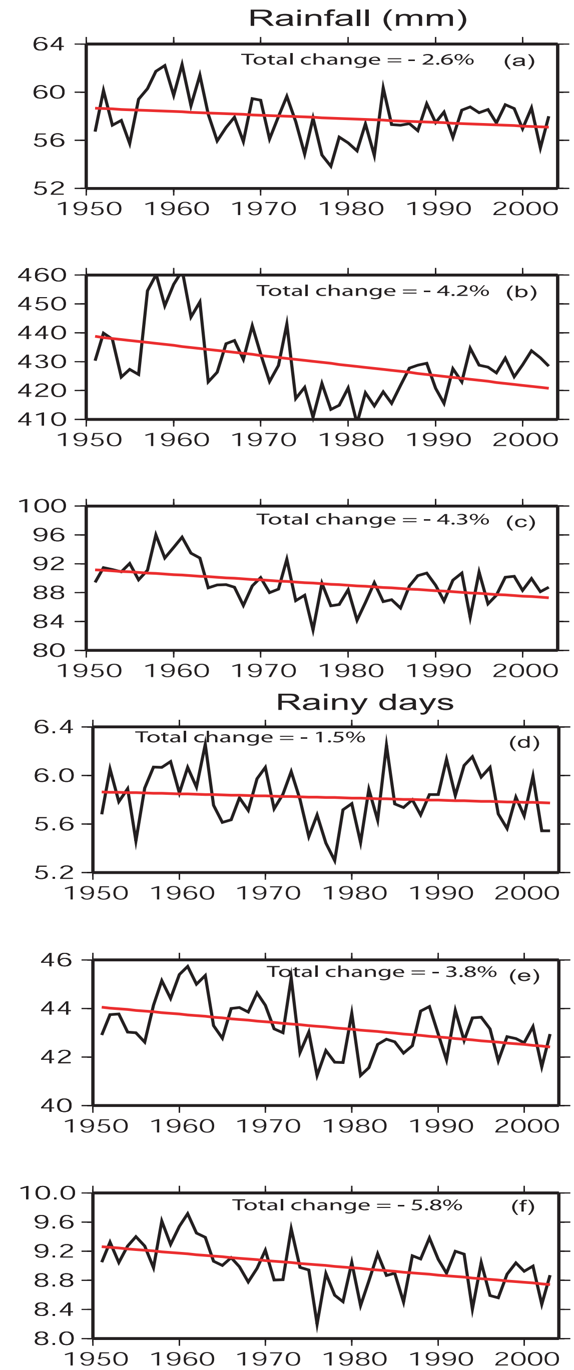


Figure 6 Linear least squares trends in (a) rainfall (mm/year) and (b) number of rainy days (greater than 5 mm/day) over global tropics (0^oE-360^oE and 30^oS-30^oN) based on 53 years of gridded daily rainfall data from NCEP. The top, middle and bottom panels on the left (a-c) are for rainfall for **(a)** pre monsoon (May 15-May 31) **(b)** monsoon (June 1- September 30) and **(c)** post monsoon (September 15-October 10).

Conclusions

Our analysis with multiple data sets shows that the length and the coverage of the Indian summer monsoon are decreasing. This may appear counter-intuitive in view of increasingly warmer oceans and associated increase in tropospheric moisture [*Udea et.al., 2006*]. However, one reason why the pre-onset and post-withdrawal rainfall may not be increasing in spite of an increasingly warmer environment (ocean) could be found in the tremendous spatial inhomogenity in the trends in surface temperature (Figure 7). Although there are warming trends over both the ocean basins and the Indian land mass, there are significant differences in the trends. This results in a reduced land-ocean temperature contrast (figure 8), which can weaken the strength of organized

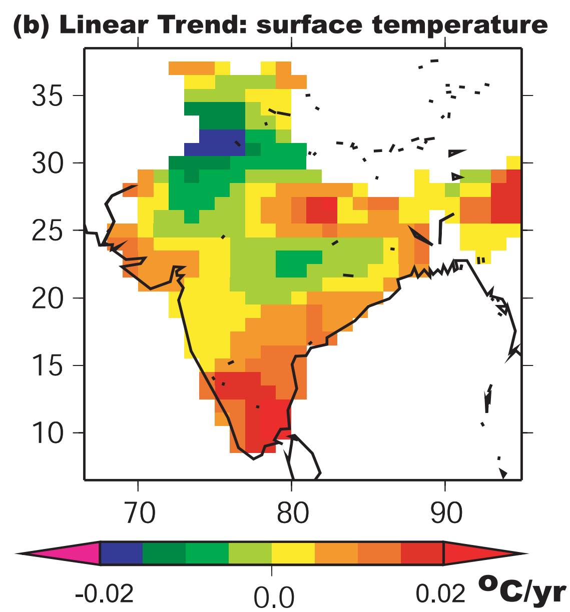


Figure 7 Spatial distribution of Linear Trends in surface temperature.

convergence over India. Thus even if the average trend in surface temperature over the Indian ocean is positive, the spatial distribution of trends does not encourage spatially coherent warm SST or the organized dynamics necessary for the monsoon (*Goswami and Patra, 2004*). However, such a scenario needs to be evaluated through carefully designed numerical experiments.

While a precise definition of the monsoon season may not have much hydrological significance, it is important from the point of agricultural prospects. Agricultural practices are based on the expected amount of rainfall and number of rainy days during the monsoon season; significant shortening of the duration of the monsoon can make certain crops unviable. Agricultural prospects, and in particular parameters like crop choice, sowing schedule and irrigation requirement, critically depend upon the quantum of rainfall as well as its temporal distribution. Any significant change in the amount of rainfall or the number of rainy days, for example, can make certain crops unviable over a region even if the total amount remains essentially unchanged due to, say, increased occurrence of higher intensity events.

One of the important findings of our work is that ISM is shrinking not only in its duration but also in its spatial coverage. A change (especially reduction) in the spatial extent in the monsoon rainfall can have much more severe impact on agro-ecological sustainability than that due to a reduction in temporal extent. While a change in, say, the number of rainy days can be somewhat offset by change in the crop choice or irrigation policy, even a reduction of spatial extent of 100 Km in coverage by monsoon rainfall can result in drying of life supporting aquatic system.

Given the serious consequences of a spatially and/or temporally shrinking monsoon, and important socio-economic policy decisions it warrants, an important issue is that of cross verification with independent data and model simulations. Neither approach is going to be easy. Climate models still suffer from significant inadequacies in simulating monsoon rainfall, and an observed data set with length and resolution comparable to those of the IMD dataset doesn't yet exist. However, we have

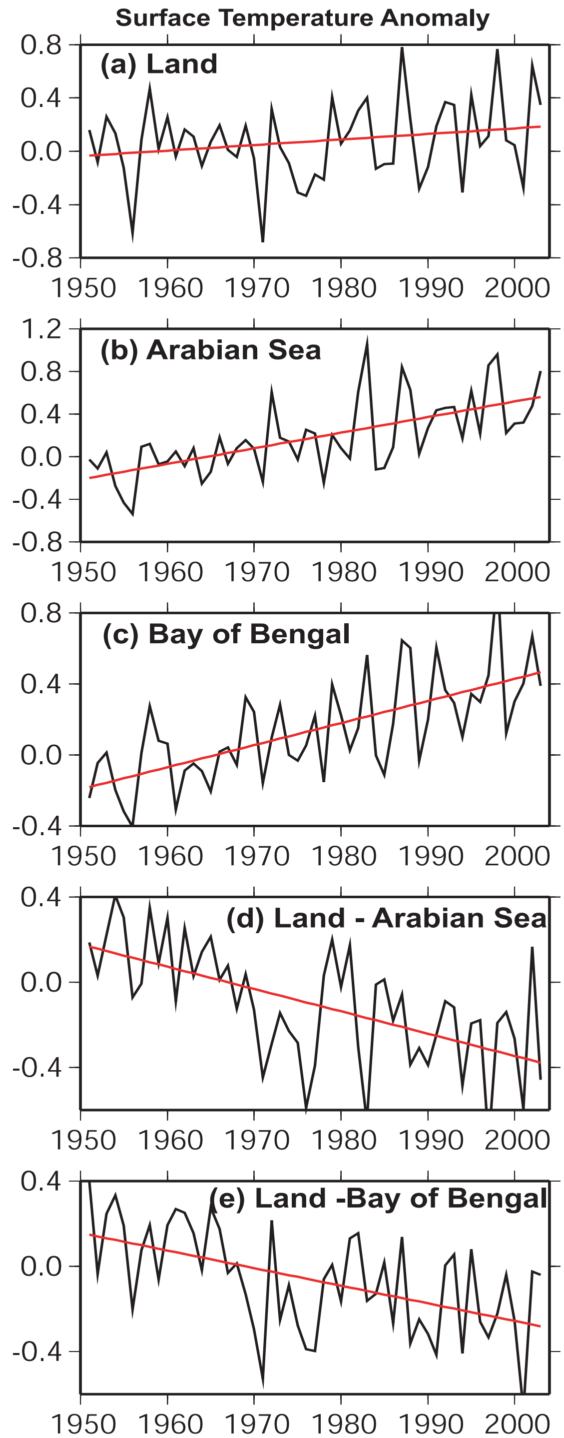


Figure 8 Inter annual variability and linear trend in the area averaged surface temperature Indian land mass **(a)** and the two ocean basins **(b&c)** during 1950-2003. The bottom panel show interannual variability and linear trend in the contrasts in surface temperatures between land and ocean.

carried out an analysis with CMAP pentad rainfall data available for the period 1979-2003 as well as the NCEP daily Reanalysis. A comparison of trends in different quantities (Table 1) from the three data sets shows that the trends predicted from the IMD data set are generally the lowest. The trends predicted by CMAP data project much grimmer scenario; however the short span of the CMAP data and the likely model bias in NCEP Reanalysis make the results from these two sets less reliable. Even the lowest trends from IMD data, however, imply a significant decreasing trend in the monsoon season over India.

Table 1: Comparison of annual trends in rainfall and rainy days for various monsoon periods based on pentad rainfall.

Coefficient of Linear trend per year	**Rainfall Datasets**		
	IMD	**CMAP**	**NCEP**
Pre-monsoon Rainfall (mm) 72.5 - 77.5^{o}E; 8.5 -5.5^{o}N	-1.4	-0.54	-2.0
Pre-monsoon Rainy days	-0.05	-0.07	-0.03
All India Seasonal Rainfall (mm)	-0.45	-40.79	-16.06
All India Seasonal Rainy days	-0.14	-3.28	-0.46
Post-monsoon Rainfall (mm) 70.5 - 0.5^{o}E; 17.5-5.5^{o}N	-4.48	-3.34	-4.77
Post-monsoon Rainy days	-0.04	-0.14	-0.07

With regard to earlier analyses on lengthening of the (withdrawal phase of) summer monsoon, careful note needs to be taken of the area considered for investigation. For example, an increase in the rainfall in October over the entire south Asian region, such as over 0-30 N and 50-100 E considered by *Syroka and Toumi [2002]*, or 30-110 longitudinal extent considered by *Goswami and Xavier [2005]* may not necessarily apply to the continental Indian region. The Indian region is characterized by strong land-ocean contrast and surface processes including orographic forcing, and requires a separate analysis. Indeed, the analysis of Syroka and Toumi [2002] brings out this point clearly; the trends are mostly negative over the continental Indian region, although there are strong positive trends over oceanic and costal regions. However the coarse resolution and possible model bias in the NCEP reanalysis make the results over land-ocean barrier less reliable. Besides, as noted earlier (table 1), the trends may differ significantly for data for shorter periods such as CMAP. Similarly, although analysis based on parameters like all India rainfall index reveals (Syroka and Toumi, 2004) possible lengthening of the monsoon, the results may change, as shown here, when the pre-monsoon and the post-monsoon periods are considered separately; in particular, an increase in the withdrawal period can be compensated by a decrease in the onset period. A scrutiny of figure 1 shows that this is indeed the case; the decreasing trend in the onset period is much higher than that in the withdrawal period. It may be noted that the spatial distribution of trends in rainfall and rainy days are quite complex. In general and especially for the southern India, the trends in rainfall over west coast are negative while those over the east coast are positive. As the onset is over the western coast, a negative trend over this region can result in significant decrease in the monsoonal rainfall.

It is possible that the trends revealed in the 53-year data are part of lower frequency climate variability, and thus the linearity does not hold over longer periods. It is clear, however, that the present trends are those of a shrinking monsoon, and this is dynamically consistent with trends in surface temperature.

References

Annalisa, C. and Antonio N. (2007). Sensitivity of the Asian summer monsoon to the horizontal resolution: differences between AMIP-type and coupled model experiments**.** Climate Dynamics, 18**,** 273-290.

Chowdhury, A. and Abhayankar, V. P. (1979). Does precipitation pattern foretell Gujarat climate becoming arid? Mausam, 30: 85–90.

Goswami, B.N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan and Prince K. Xavier (2006), Increasing Trend of Extreme Rain Events Over India in a Warming Environment. Science, 314, 1442 – 1445, DOI: 10.1126/science.1132027.

Goswami, B.N., and P. K. Xavier (2005), ENSO control on the South Asian Monsoon through the length of the rainy season, Geophys. Res. Lett**.** 32, L18717, doi: 10.1029/ 2005GL023216.

Goswami, P., and G. K. Patra (2004), Characteristic scale of convective organization and monsoon intensity, Geophys. Res. Lett., 31, L24109, doi:10.1029/2004GL020268.

Goswami, P., and K. V. Ramesh (2006), A comparison of interpolated NCEP (I-NCEP) rainfall with high-resolution satellite observations, Geophys. Res. Lett., 33, L19821, doi:10.1029/2006GL027594.

Hansen, J., Ruedy, R., Glascoe, J. & Sato, M. GISS analysis of surface temperature change. J. Geophys. Res. 104, 30997-31022 (1999).

Kistler, R., et. al., (2001), The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. *Bull. Amer. Meteor. Soc.,* ***82,*** *247-268.*

Koteswaram, P. and Alvi, S. M. A. (1969). Trends and periodicities in rainfall at west coast stations in India. Curr. Sci., 38: 229–231.

Parthasarathy, B. and Mooley, D. A. (1978). Some features of a long homogeneous series of Indian summer monsoon rainfall. Mon. Wea. Rev., 106: 771–781.

Parthasarathy, B. Munot, A.A. and Kothawale, D.R. (1994), All-India monthly and seasonal rainfall series: 1871–1993, Theoretical and Applied Climatology, 49, 217-224.

Rajeevan et. al., 2006, High resolution daily gridded rainfall data for Indian region: Analysis of break and active monsoon spells, *current science*, 91, 3, 296-306.

Shepard, D. (1968), A two-dimensional interpolation function for irregularly spaced data, *In Proc. 1968 ACM Natl. Conf.*, 517-524.

Stephens, C., S. Levitus, J. Antonov, and T. P. Boyer (2001), On the Pacific Ocean regime shift, *Geophys. Res. Lett.*, *28*(19), 3721–3724.

Syroka, J., and R. Toumi (2002), Recent lengthening of the south Asian summer monsoon season, *Geophys. Res. Lett.*, *29*(10), 1458, doi:10.1029/2002GL015053.

Syroka, J., and R. Toumi (2004), On the withdrawal of the Indian summer monsoon, *Q. J. R. Meteorol. Soc.*, 130, 989-1008.

Thapliyal, V. and Kulshrestha, S. M. (1991). Climatic changes and trends over India. Mausam, 42: 333–338.

Ueda H., A. Iwai, K. Kuwako and M. E. Hori (2006). Impact of anthropogenic forcing on the Asian summer monsoon as simulated by eight GCMs. Geo Phys. Res. Lett., 33, L06703, doi:10.1029/2005GL025336.

Xie, P., and P. A. Arkin, (1997), Global Precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numberical model outputs. *Bull. Amer. Meteor. Soc.,* **78,** 2539-2558.