2

CLIMATE & ENVIRONMENTAL MODELLING

The main objective of CEMP research has been aimed at providing scientific and technological solutions to weather and climate related problems which adversely affects welfare of people. Research activities are designed to achieve institutional and national objectives by enabling outreach agencies to mitigate adverse impacts of climate and environment. Major research activities of CEMP are: Monsoon, Climate and Weather Informatics, Smart Agriculture, Renewable Energy, Preventive Healthcare and Hydro-meteorological Disasters. Group activities are aligned with missions of Government of India (Samarth Bharat, Renewable Energy, Swasthya Bharat). The team carries out its research and analysis through open-source codes, state-of-the-art models (LAMs, GCMs and NWPs), in-house algorithms and visualization tools, field and satellite data sets.

Inside

- Annual and seasonal trends in rainfall and temperature over major Indian cities
- Urban extreme rainfall events: categorical skill of WRF model simulations for localised and non-localised events
- Observational evidence for the relationship between spring soil moisture and June rainfall over the Indian region
- High resolution long-range dynamical forecasting of Indian monsoon 2016
- Simulation of extreme temperature over Odisha during May 2015
- Comparative study of monsoon rainfall variability over India and the Odisha state

2.1 Annual and seasonal trends in rainfall and temperature over major Indian cities

This study is about annual and seasonal trends of rainfall and surface temperature in some of the most populated and rapidly urbanizing cities of India. Analysis of trends across different categories of rainfall was also carried out. The study is based on 47 years (1961 to 2007) of 0.25°x0.25° resolution APHRODITE data. Standard statistical methods (Ordinary least squares regression, quantile regression, Non-parametric Mann–Kendall trend test, Sen's slope) are used to find trends and their significance in different categories of rainfall in selected cities.

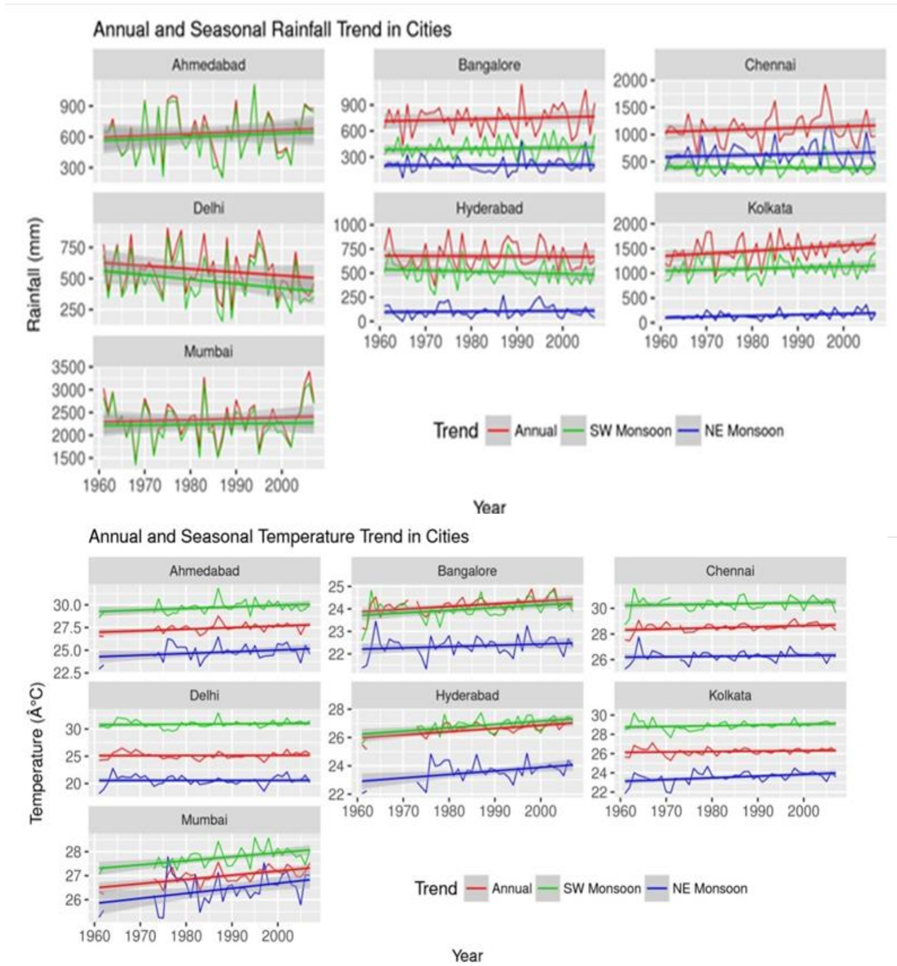


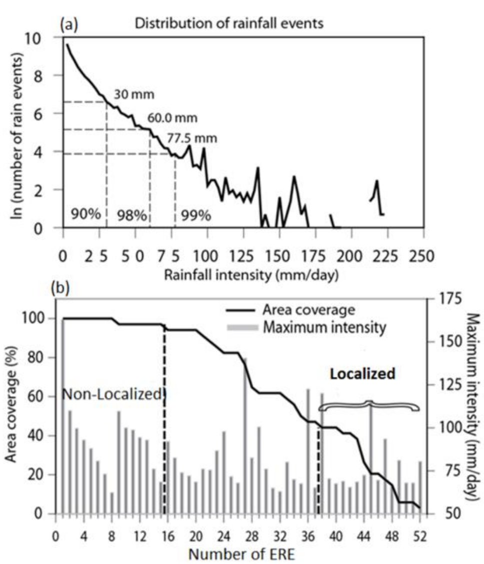
Figure 2.1 Seasonal variation of rainfall and temperature shown as linear trend (area averaged) over different cities for Annual (Red), SW monsoon (Green) and NE Monsoon (Blue) Seasons for the period 1961 to 2007

In case of annual rainfall (Figure 2.1), results show increasing trend with slope of more than 2.5-5 mm/year for Mumbai and Kolkata, whereas Delhi shows decreasing trend. Ahmedabad, Bangalore, and Chennai, show low positive trends, whereas Hyderabad shows a slight negative trend. In general there exists a large spatial and temporal inhomogeneity with increasing, decreasing or no trends over different cities. The influence of urbanization couldn't be clearly and consistently established as there are no consistent patterns in the trends observed over these cities.

In case of different categories of rainfall, on annual basis, there is significant increasing trend in the frequency of rainfall for categories of 2-5 and 20-30 mm/day. Whereas for South-West monsoon, the trend shifted to higher categories of 20-30 and 50-60, for North-East monsoon this shift continued further to higher categories like 40-50 and >60. The study also revealed that there is significant increasing trend in SW monsoon extreme rainfall events in coastal cities, predominant after 1980, which is also the period of rapid urbanization. For different categories of rainfall, in general, it is evident that significant trends show a shift from lower intensity to higher intensity through annual, SW monsoon and NE monsoon. The study also shown that rainfall trends over coastal and land-locked cities are remarkably different. Coastal cities seem to show high degree of increasing trend in rainfall as compared to land locked cities.

Analysis of temperature (Figure 2.1, bottom panel) trend indicates an increasing trend of the order of 0.02˚C/year over the cities of Ahmadabad and Mumbai, and 0.01˚C/year over Bangalore and Chennai. A decreasing trend in temperature is observed over Delhi and Kolkata.

2.2 Urban extreme rainfall events: Categorical skill of WRF model simulations for localised and non-localised events



An objective method is used for determining the rainfall threshold for identifying extreme rainfall events (EREs) over an urban city using the observed rainfall data for a period of 35 years (1971-2005). Using this threshold, 52 EREs were identified during the period 2010-2014 using the high resolution rain-gauge observations over the Bangalore. From these EREs, 15 localised and non-localised events were chosen, by taking into account their area distribution over the Bangalore city (Figure 2.2), to examine the forecast skill of Weather Research and Forecasting (WRF) model in simulating those EREs. In general, forecast under-predicted the magnitude of localised and non-localised EREs for majority of cases; however, model over-predicted light rainfall (≤ 10 mm/day). Model showed a success rate of 59% in

Figure 2.2 (a) Distribution of rainfall events in different categories of intensity (mm/day) estimated for the period 1971-2005 from IMD daily gridded rainfall data (0.5˚ x 0.5˚) over the Bangalore city. Those events where rainfall intensity (mm/day) is above 98% percent of total number of events (60 mm/day) are considered as extreme rainfall events (ERE), (b) Distribution of KSNDMC rain-gauge observed EREs in terms of maximum intensity (right axis) and area coverage (left axis) during the period 2010-2014; The EREs covering below 45% of total Bangalore area are categorized as localised events and those having area coverage above 95% is categorized as non-localised events

simulating light rainfall for localised EREs while 12% of events were missed and 29% were wrongly predicted. The success rate has significantly reduced at higher rainfall categories for localised and non-localised EREs, where forecast missed majority rainfall events. The Reliability Index (RI) clearly showed that model skill is relatively higher for non-localised EREs compared to localised EREs. The average forecast reliability for non-localised and localised EREs are 74% and 47%, respectively. For localised EREs, model skill is relatively higher in rainfall location prediction (61%) compared to area (45%) and intensity (36%) prediction; while in case of non-localised EREs, model skill is similar for location, intensity and area prediction.

2.3 Observational evidence for the relationship between spring soil moisture and June rainfall over the Indian region

Understanding the relationship between gradually varying soil moisture (SM) conditions and monsoon rainfall anomalies is crucial for seasonal prediction. Though, it is an important issue, very few studies in the past attempted to diagnose the linkages between the antecedent SM and Indian summer monsoon rainfall. This study examined the relationship between spring (April-May) SM and June rainfall using observed data during the period 1979-2010. The Empirical Orthogonal Function (EOF) analyses showed that the spring SM plays a significant role in June rainfall over the Central India (CI), South India (SI) and North East India (NEI) regions. The composite anomaly of the spring SM and June rainfall showed that excess (deficit) June rainfall over the CI was preceded by wet (dry) spring SM. The anomalies in surface specific humidity, air temperature, and surface radiation fluxes also supported the existence of a positive SM-precipitation feedback over the CI (Figure 2.3). On the contrary, excess (deficit) June rainfall over the SI and NEI region were preceded by dry (wet) spring SM. The abnormal wet (dry) SM over the SI and NEI decreased (increased) the 2m-air temperature and increased (decreased) the surface pressure compared to the surrounding oceans which resulted in less (more) moisture transport from oceans to land (negative SM-precipitation feedback over the Indian monsoon region).

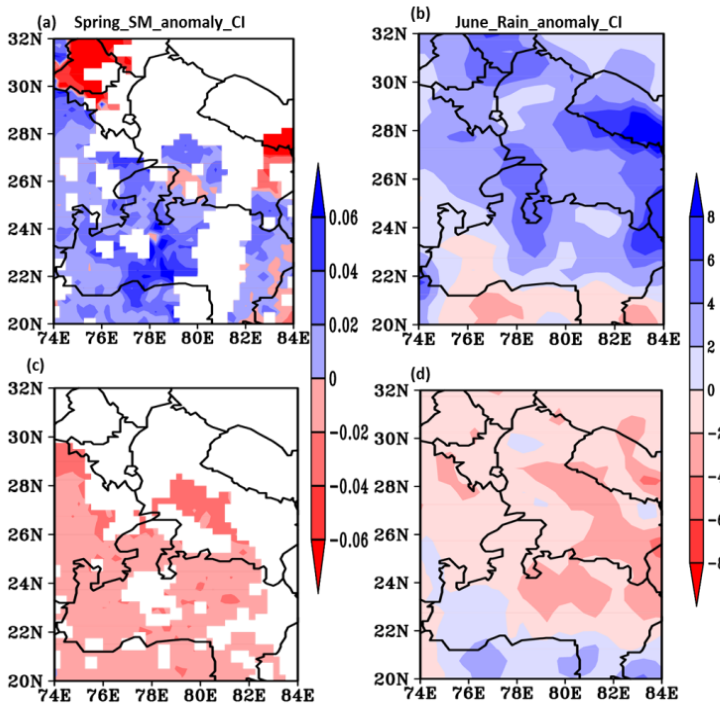


Figure 2.3 Composite anomaly of spring soil moisture (m3/m3) for (a) excess and (c) deficit soil moisture years over the Central India with corresponding June rainfall (cm) anomaly (b, d)

2.4 High resolution long-range dynamical forecasting of Indian monsoon 2016

Long range forecasting of Indian summer monsoon is important because it has directly impact on various sectors like agriculture, health, energy, water resource management, disaster management etc. CSIR-4PI has been successfully predicting the long-range monsoon over continental India since last 15 years. This year also the prediction of monsoon is carried out using the in-house developed ensemble methodology and a variable resolution GCM with high resolution over Indian region.

The first outlook of the Monsoon 2017 from long-range, high resolution monsoon forecasting platform from CSIR-4PI was made available in the middle of April, 2017. The date of onset of monsoon over Kerala and the seasonal (JJA) as well as monthly rainfall anomalies are forecasted using the variable resolution general circulation model (GCM). These forecasts were based on an ensemble (5 member) consisting of information on the atmospheric state (initial conditions) from 15th March 2016 to 15th April 2017. The forecasts are also communicated to IMD in mid-April; IMD also acknowledged these forecasts.

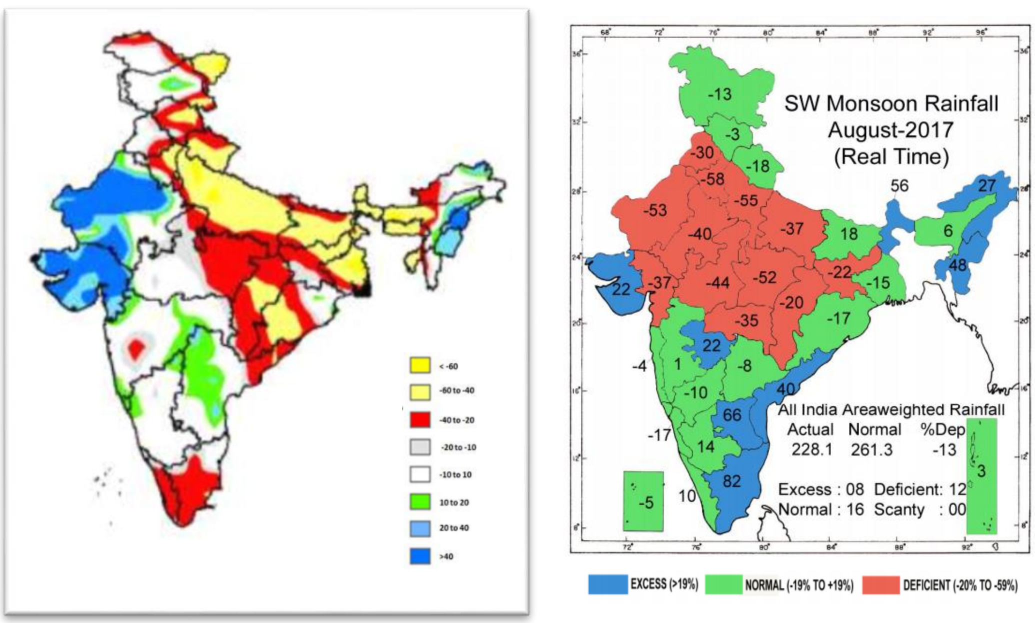


Figure 2.4 Monthly rainfall anomalies from CSIR-4PI long range high resolution forecasts (left panel) and IMD observation for August, 2017 (right panel)

CSIR-4PI forecast of the date of onset of Monsoon was on 31st May, 2017 while the southwest monsoon set in over Kerala on 30th May, 2017 as per the announcement by IMD. The post season validation of the spatial distribution of monthly and seasonal rainfall anomalies shows good agreement of the forecast and observation over many regions of the country. The monthly scale validation of rainfall anomaly for August 2017 is presented in figure 2.4.

Table 2.1 Comparison of the forecast and observation of 2017 monsoon rainfall both at monthly and seasonal scale for the different regions over India

Comparison of Model predicted and IMD observed Regional Rainfall Categories for 2017 Monsoon

Region	Extent	June		July		August		JJA	
		Model	Obs	Model	Obs	Model	Obs	Model	Obs
All India		N	N	N	N	D	D	N	N
North-India	(72-84 °E, 24-30 °N)	N	N	N	N	D	D	D	D
South India	(75-78°E, 8-12°N)	N	N	D	D	N	N	N	N
Central India	(72-84°E, 20-28°N)	D	N	N	N	D	D	N	N
North-east India	(92-96°E, 24-30°N)	D	D	E	N	D	N	D	N
North-west India	(68-75°E, 24-30°N)	D	N	E	E	N	D	N	D

The validation of monthly and seasonal rainfall anomalies over different regions are being carried out and presented in Table 2.1. There is very good agreement between distribution of monthly and seasonal rainfall from forecast and observation; there are only a few locations of large errors. Out of the 24 cases (six sectors, three months and one season for each), the categories (Excess: E/ Normal: N/ Deficit: D) forecasts match observations for almost 17 cases; 7 cases show only 1 category error and no cases show more than one category of error (Table 2.1).

2.5 Simulation of extreme temperature over Odisha during May 2015

An extreme temperature event (heat wave) over the state of Odisha was unique as it lasted for about 2 weeks in the 3rd and 4th weeks of May 2015. There was a similar severe heat wave in western and central Odisha in the month of April 1998. The interesting feature of the recent episodic heat wave is that it prevailed in the late pre-monsoon season with wider spread in the state of Odisha. Around 12–15 cities experienced a daily maximum temperature of over 45 °C during the strong heat wave period, and 25th −27th May was declared as the red box zone. In this study, we first analysed the intense summer temperature of 2015 May using India Meteorological Department observations of daily maximum temperature. The observed heat wave phenomenon was then simulated using the Weather Research and Forecast Model (WRFV3) at 2-km horizontal resolution to assess its ability to forecast such a rare event. The observational analysis clearly indicated that this episodic event was unique both in terms of intensity, geographical spread and duration. An optimized configuration of the WRF model is proposed and implemented for the simulation of the episodic heat wave phenomenon (daily maximum temperature) over the state of Odisha. The Spatial distribution of maximum temperatures simulated for 900hr for 25th and 26th

May, 2015 are presented in figure 2.5. The time-ensemble simulation of the temperature is shown to be in close agreement with the station-scale observations.

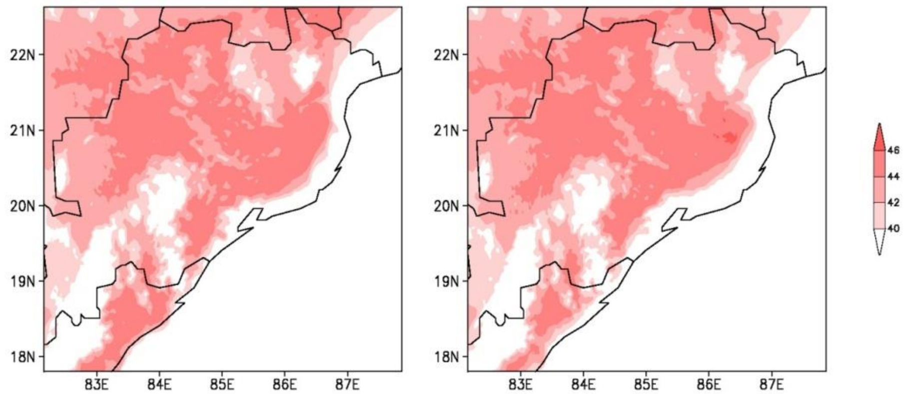


Figure 2.5 Spatial distribution of maximum temperatures simulated for 0900hr for 25th (left) and 26th (right) May, 2015

2.6 Comparative Study of monsoon rainfall variability over India and the Odisha state

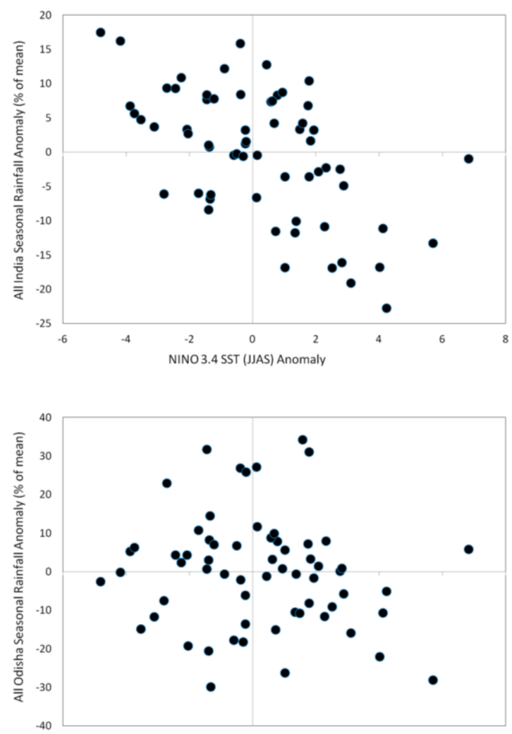


Figure 2.6 Scatter plot of the JJAS NINO 3.4 SST anomaly and the JJAS rainfall anomaly over all of India (top) and Odisha (bottom) for the period 1951–2013

Indian Summer Monsoon (ISM) plays an important role in the weather and climate system over India. The rainfall during monsoon season controls many sectors from agriculture, food, energy, and water, to the management of disasters. Being a coastal province on the eastern side of India, Odisha is one of the most important states affected by the monsoon rainfall and associated hydro-meteorological systems. The variability of monsoon rainfall is highly unpredictable at multiple scales both in space and time. In this study, the monsoon variability over the state of Odisha is studied using the daily gridded rainfall data from India Meteorological Department (IMD). A comparative analysis of the behavior of monsoon rainfall at a larger scale (India), regional scale (Odisha), and sub-regional scale (zones of Odisha) is carried out in terms of the seasonal cycle of monsoon rainfall and its Interannual Variability (IAV). It is seen that there is no synchronization in the seasonal monsoon category (normal/excess/deficit) when analysed over large (India) and regional (Odisha) scales. The impact of El Niño, La Niña, and the Indian Ocean Dipole (IOD) on the monsoon rainfall at both scales (large scale and regional scale) is analysed and compared. Figure 2.6 presents the relation of NINO 3.4 SST (average equatorial SST across Pacific region; 5N-5S, 170W-120W, one of the most commonly used indices to define global phenomenon like El Nino) anomaly and the JJAS rainfall anomaly during monsoon (JJAS) over all of India and Odisha for the period 1951–2013.The results show that the impact is much more for rainfall over India, but it has no such relation with the rainfall over Odisha. It is also observed that there is a positive (negative) relation of the IOD with the seasonal monsoon rainfall variability over Odisha (India). The correlation between the IAV of monsoon rainfall between the large scale and regional scale was found to be 0.46 with a phase synchronization of 63%. IAV on a sub-regional scale is also presented (Figure 2.6, bottom panel).