2
CLIMATE AND ENVIRONMENTAL MODELLING PROGRAMME (CEMP)

The CEMP with its core strength of multidisciplinary modeling has been continuously innovating and developing end-user driven and actionable knowledge products, which are target oriented and of direct societal benefits.

The emphasis continues to be on understanding of the climate system and applications through multi-disciplinary modelling by combining climate science with water, agriculture, health, energy and sustainability in general.

CEMP synergistically uses both open source as well as in-house codes, processes models, NWP models, global circulation models, visualization and analysis tools in HPC environment.

The CEMP has pioneered in generating demand based and farmer driven forecast at hobli-level in the state of Karnataka in collaboration with KSNMDC.

CEMP has been continuously developing innovative methodologies to improve high-resolution advance dynamical forecasting of the date of onset of monsoon. CEMP has been communicating its experimental forecasts of monsoon to various agencies since 2003 for post-forecast evaluation.

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2.1 An evaluation strategy of skill of high resolution rainfall forecast for specific agricultural applications

A strategy for validation of rainfall forecasts for specific agricultural applications is presented. Our focus is mainly on design of specific forecast advisories that are risk-free and useful in spite of their inherent errors. The strategy works for the specific applications because the forecast advisories are based on when NOT to irrigate or apply fertilizer/pesticide because rain is predicted (risk-free because wrong forecast only delays irrigation/application of fertilizer/pesticide within tolerance). Thus unlike in conventional forecast evaluation, we consider a forecast as valid if the forecasted rain (or no rain) is correct for the day of the forecast (D0C) or the next day or the day after (designated D1C and D2C, respectively), as the farmer can afford to postpone the field application for a couple of days beyond the scheduled date. The methodology has been evaluated for rainfall forecasts over Karnataka (a state in south-west India with nearly 56% of the workforce engaged in agriculture). Here, we present forecast validation against rain gauge observations at comparable model resolutions for the South-West (June-September) and the North-East (October-December) monsoon seasons during 2011-2014. Our analyses demonstrate that forecasts over several areas which may appear as less reliable based on conventional evaluation (D0C) are found to have useful skill for the specific agro-applications as evident from evaluation based on D1C and D2C criteria (Figure 2.1). Our analysis shows that the evaluation strategy presented is effective during non-rainy (January-May) season also. It is pointed out that such an approach can help to meet the challenges in designing and implementing best practices in agriculture by combining immediate gains for the end users.

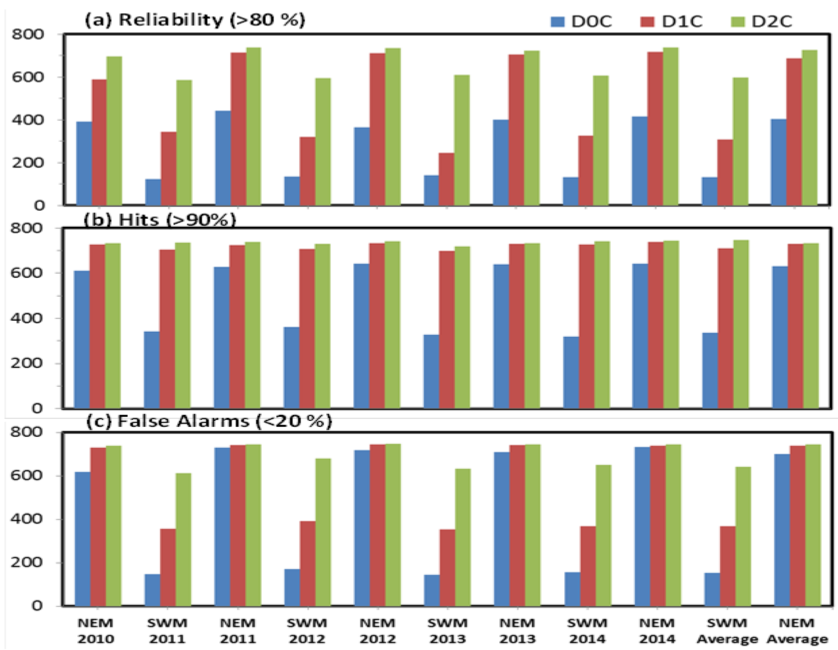

Figure 2.1 Number of hoblis that fall in (a) Reliability >80%, (b) Success/Hit Ratio > 90% and (c) False Alarm < 20% during the SWM and NEM for the years 2010-2014 along with seasonal averages. The three bars represent results for three forecast criteria; D0C (blue), D1C (red) and D2C (green).

Rakesh V and Goswami P

2.2 High resolution long-range dynamical forecasting of Indian monsoon 2015

Forecasting of monsoon at user-relevant lead and resolution continues to be a national priority and a scientific challenge. CSIR-4PI pioneered long-range dynamical forecasting of Monsopon in India with its experimental forecasts in 2001. The experimental forecasts, issued in April and validated after the monsoon, helped to create a robust proof of concept against the prevailing dogma. The mission of the CSIR-4PI team is now to develop and validate methodology for monsoon forecasting at user relevant spatial and temporal scales and to enhance the capabilities of India in monsoon forecasting through validated proof of concept.

The first outlook for monsoon 2015 (onset, monthly and regional rainfall anomalies) from long-range, high-resolution monsoon forecasting platform from CSIR-4PI was made available in the middle of April, 2015. These forecasts were based on information on the atmospheric state (initial conditions) available until beginning of April, 2015.

There have been, however, major changes in the atmospheric states in the subsequent period, making a deterministic forecast for monsoon 2015 more difficult. We have therefore generated probabilistic forecasts for monsoon 2015 based on the entire set of forecasts. The validation with IMD observations is presented in figure 2.2.

Seasonal (June-August) rainfall anomalies based on 4PI long-range forecasts (2nd Outlook) and IMD observation indicates there is good match over most regions; the error is generally limited to category one error.

The CSIR-4PI experimental forecasts are currently restricted to monthly spatial distributions, although we have explored climatological area-averaged daily rainfall as well as daily rainfall over Kerala for identification of date of onset of monsoon. The summary of spatial distribution of seasonal rainfall anomalies for JJA and their comparison with the corresponding observation is presented in Figure 2.2. Table 2.1 represents the comparison of the category forecast and observation both at monthly and seasonal scale for the different regions over India.

Seasonal (June-August) rainfall anomalies (% of respective mean)

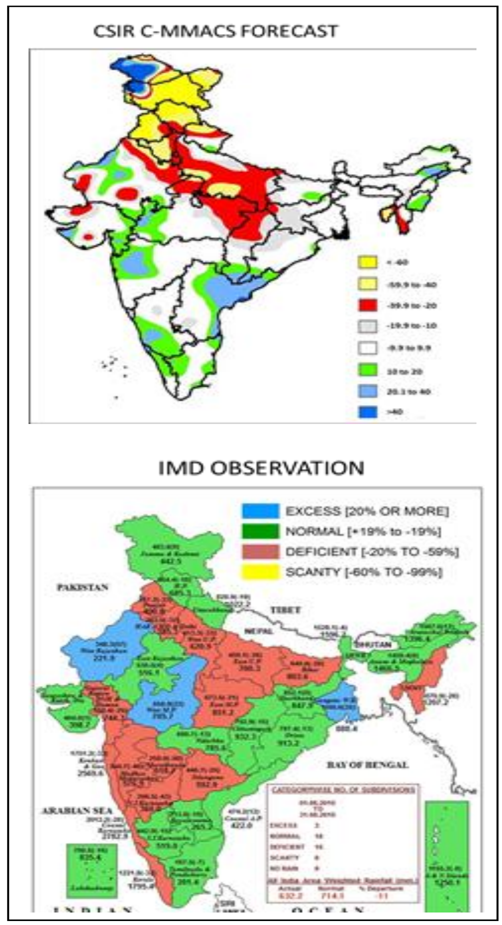

Figure 2.2 Seasonal (June-August) rainfall anomalies from CSIR-4PI long-range high resolution forecasts (top panel), IMD observation for Jun-Aug 2014 (bottom panel).

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

	JJA		June		July		August		% of agreement
Region	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	
All India	Deficit	Deficit	Normal	Normal	Normal	Deficit	Drought	Deficit	75
North-India	Deficit	Deficit	Normal	Normal	Deficit	Deficit	Drought	Deficit	100
South India	Normal	Normal	Normal	Normal	Normal	Deficit	Normal	Deficit	50
Central India	Normal	Deficit	Normal	Excess	Deficit	Normal	Normal	Deficit	0
North-east India	Normal	Normal	Normal	Normal	Deficit	Deficit	Normal	Normal	100
North-west India	Normal	Normal	Normal	Excess	Deficit	Normal	Deficit	Deficit	50

There is overall good agreement; only a few locations show error of more than category one. Thus the risk of using these forecasts, in principle, is minimal.

Gouda K C and Goswami P

2.3 Organization of vertical shear of wind and daily variability of monsoon rainfall

Very little is known about the mechanisms that govern the day-to-day variability of the Indian summer monsoon (ISM) rainfall; in the current dominant view, the daily rainfall is essentially a result of chaotic dynamics. Most studies in the past have thus considered monsoon in terms of its seasonal (June-September) or monthly rainfall. We show that the daily rainfall in June is associated with vertical shear of horizontal winds at specific scales. While vertical shear had been used in the past to investigate inter annual variability of seasonal rainfall, rarely any effort has been made to examine daily rainfall. Our work shows that, at least during June, the daily rainfall variability of ISM rainfall is associated with a large scale dynamical coherence in the sense that the vertical shear averaged over large spatial extents are significantly correlated with area-averaged daily rainfall. An important finding from our work is the existence of a clearly delineated monsoon shear domain (MSD) with strong coherence between area-averaged shear and area-averaged daily rainfall in June; this association of daily rainfall is not significant with shear over only MSD. Another important feature is that the association between daily rainfall and vertical shear is present only during the month of June. Thus while ISM (June-September) is a single seasonal system, it is important to consider the dynamics and variations of June independently of the seasonal ISM rainfall.

The close association between vertical shear and rainfall in June is also clear from the abrupt rise from essentially non-significant CC between area-averaged all India daily rainfall (Figure 2.3a) and shear at 850 hPa averaged over MSD to significant CC; this CC again falls below significance in the post-monsoon months (Figure 2.3a). This conclusion also holds for an independent rainfall data set (TRMM) for the period 1998-2012; once again, ISM daily rainfall and vertical shear averaged over MSD show strong CC but only in June (Figure 2.3b). In contrast, there are few days with significant CC between daily rainfall (IMD) and shear averaged over the continental India (Figure 2.3c).

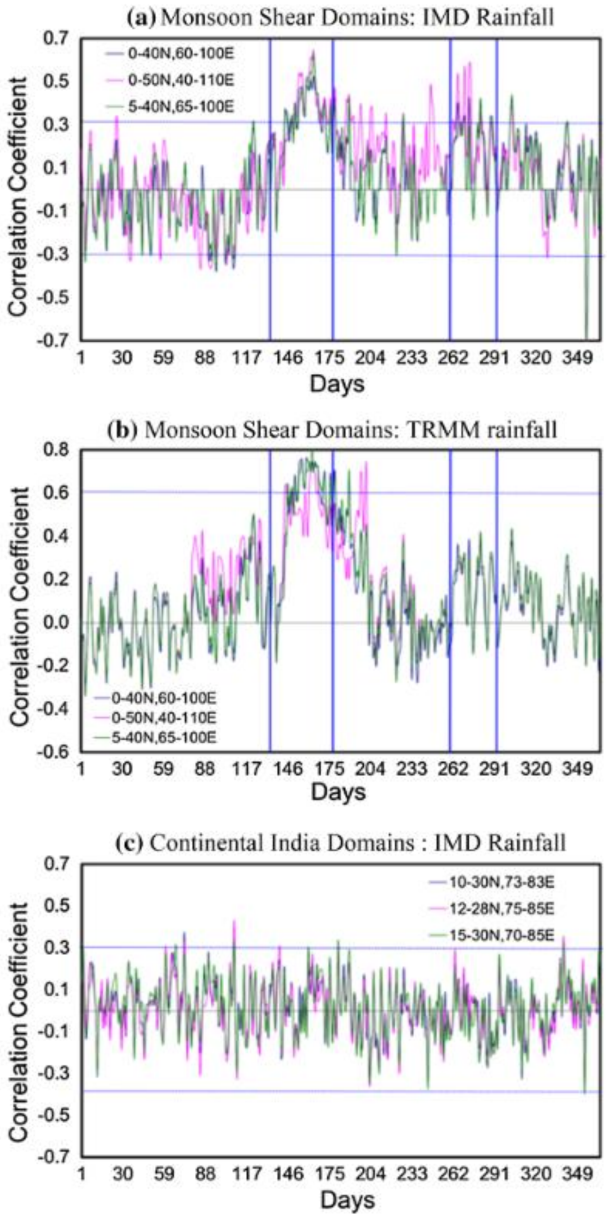

Figure 2.3 Annual cycle of correlation co-efficient between all India daily rainfall (IMD Gridded Data) and vertical shear of horizontal wind (850mb) from NCEP reanalysis over different domains (MSD) and (b) over smaller domains (ISM). The horizontal dash lines indicate the 99 % significance of correlation (CC > 0.32).The analysis is carried out for the period 1951-2003. (c) Annual cycle of correlation co-efficient between domain averaged rainfall and vertical shear of horizontal wind (850 hPa) over different domains (optimum). The horizontal line indicates the 99 % significance of correlation (CC > 0.66).

The association between large-scale organization of circulation and daily rainfall is suggested as a basis for attempting prediction of daily rainfall by ensuring accurate simulation of wind shear.

Gouda K C and Goswami P

2.4 High resolution regional dynamical downscaling of climate over South Asia

The high resolution spatio-temporal climate information is essential to quantify the climate impact on different sectors like renewable energy, agriculture, vector borne diseases etc. However, these studies are limited by its spatial resolution due to lack of high resolution simulations and lack of high density observations. For this purpose, climate is dynamically downscaled using Weather Research and Forecasting (WRF) regional atmospheric model over south Asian region. For this the WRF model at 4-km horizontal resolution is forced with NCEP FNL Operational Global Analysis data as the initial and boundary condition (reinforced for every single day) and integrated for a period of 15 years (2001 to 2015). The downscaled data is archived on hourly timescale. The downscaled rainfall data is compared with multiple observations like IITM and TRMM rainfall on meteorological sub-division over India on monthly time scale. The correlation coefficient between monthly rainfall data with sub divisional observed rainfall is shown in Figure 2.4. Results show the observed characteristics of large scale mean features and spatial variations of rainfall over different region.

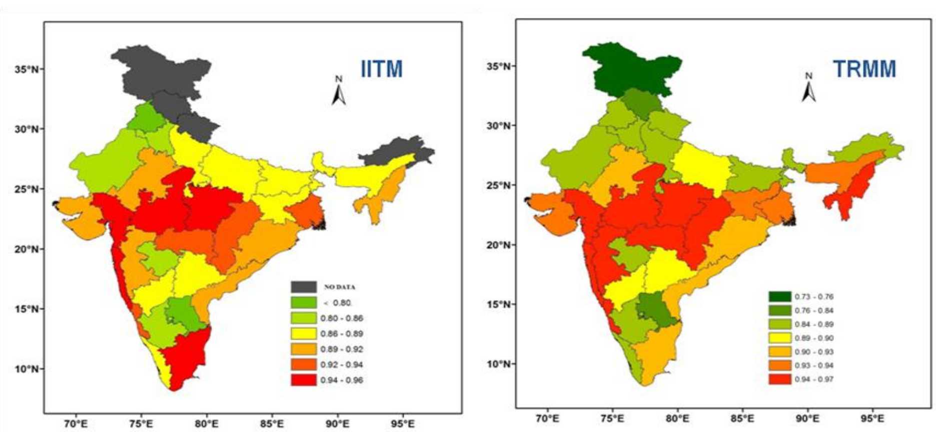

Figure 2.4 Spatial correlation coefficient between observation (IITM, TRMM) and High resolution downscaled data.

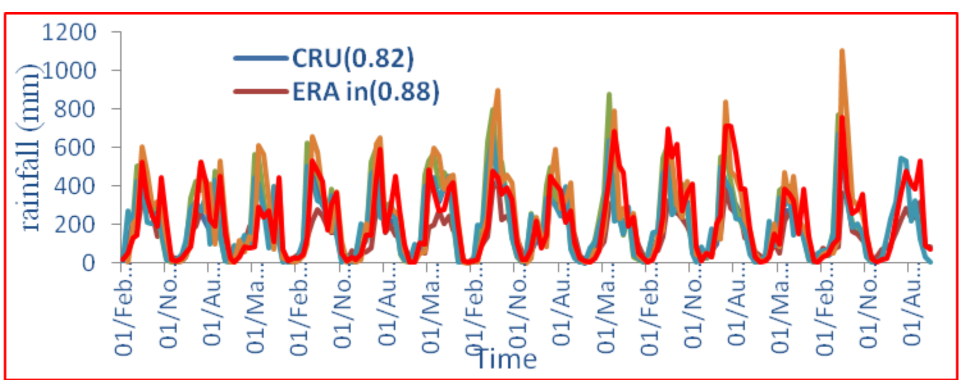

Figure 2.5 All India monthly area averaged rainfall is compared with multiple observations. The red colour line represents the high resolution rainfall.

Figure 2.5 shows the time series of the rainfall comparison and the correlation with different data sets. The monthly downscaled rainfall is significantly correlated with most of the multisource observations. The spatial distribution of high resolution data shows the seasonal cycle and inter-annual variability.

High resolution rainfall is used to understand and quantify the relationship between climate variables and energy potential (wind and hydro). This data is also used to develop multidisciplinary applications like; renewable energy estimates (wind, solar and hydro), impact studies on agriculture and hydrology.

Shafeer K B and Ramesh K V

2.5 Sensitivity of heavy rainfall to landuse changes: A case study over Uttarakhand

This study is about the impact analysis of different land use data on the simulation of an unusually rare heavy rainfall event which occurred between 14^{th} and 18^{th} of June 2013, over Uttarakhand, one of the north-western state of India. This is a 20 year rare extreme rainfall event that sustained over large spatial extent (about 50,000 sq km) for over 3-4 days. The highest daily average rainfall of 13.3 cm occurred between 03 UTC-16^{th} and 03 UTC 17^{th} June 2013 over the entire state of Uttarakhand and a single station (Dehradun) received maximum rainfall (37cm) on 17^{th} June 2013. This event resulted in huge loss of lives and property. In the present work, high-resolution (2-km) time ensemble simulations were carried out using Weather Research and Forecast model (WRFV3) with 3-nest configuration. The model was initialized with 1°x1° FNL data. The TRMM (0.25°x0.25°) and rain gauge observations (by India Meteorological Department) are used to compare and validate the simulated rainfall. In order to study the impact of land use change on the heavy rainfall simulation, different vegetation

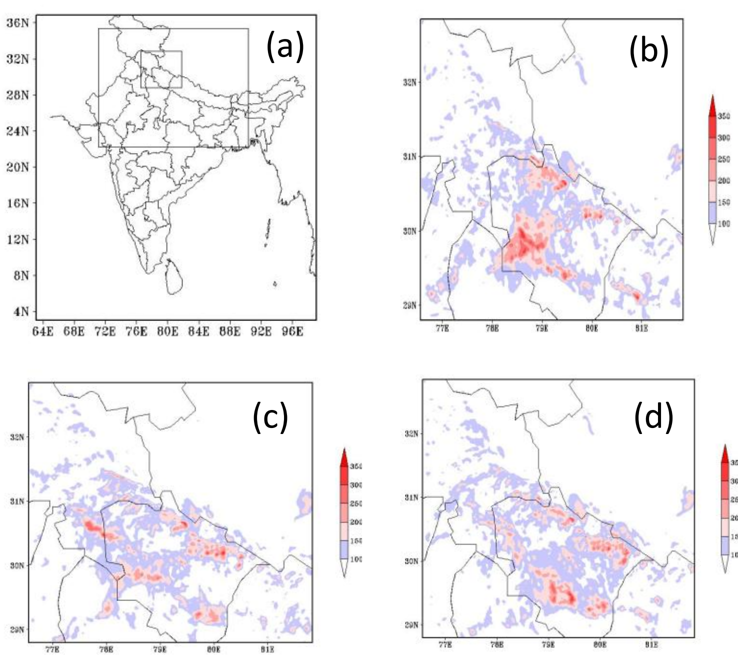

Figure 2.6 Model domain (a) and Spatial distribution of total accumulated rainfall in mm (14^{th} -17^{th}) June 2013 over Uttarakhand for different land use scenarios: (a)- (2012-13) ISRO, (b) (2004-05) ISRO, (c) USGS 24-category. Strikingly different pattern of spatial distribution is evident. Simulations based on ISRO data are found be more accurate than USGS based simulations.

data sets are used for the simulation. The sensitivity analysis of simulated rainfall to different vegetation data sets was performed using 3 sets of land use data; USGS-24 category (1992-93) and 2 data sets from National Remote Sensing Centre, India i.e. IRS-P6, AWiFS (2004-05) and AWiFS (2012-13). Simulated rainfall was found to be remarkably sensitive to different vegetation data sets (Figure 2.6). Comparison of simulated rainfall averaged over Uttarakand (78E-80.5E, 28.5N-31N) with that of station data (averaged over 23 raingauge stations) indicated that AWiFS based simulation are comparatively more accurate with less % simulation error; 18.6 % (USGS), 2.1% (AWiFS, 2004-5) and 4.4 % (2012-13 respectively. Another interesting aspect is that TRMM was found to be underestimated when compared to rain-gauge by over 40%. These results will be used further to evaluate and quantify impacts of the event in-terms of the vulnerability and damage potential through geospatial analysis to identify and delineate high-risk zones.

Himesh S, Sahoo S K, Gouda K C, Rakesh V, Ramesh K V,
Kantha Rao, Mohapatra G , Ajilesh P, Samantray P P

2.6 Northeast Monsoon Extreme 2015: Simulation of Heavy Rainfall event over Chennai during 27th November to 2nd December 2015

An Industrial metropolitan city of Chennai, the capital city of the state of Tamil Nadu in Southern India was flooded due to sustained rainfall and multiple extreme rainfall events during 2015 North-East monsoon season. The total cumulative rainfall between 7th Nov - 7th Dec 2015 was around 1400 mm. The city witnessed the heaviest rainfall of the century with 490 mm of rain in 24 hours over many parts of Chennai on 1st December 2015. In this study, this rare event has been simulated using the state-of-the-art Weather Research and Forecasting model (WRFV3.5) in 3-nest configuration, with innermost domain (2-km) centered over Chennai. Simulation experiment was carried out with different parameterization schemes and initial conditions (FNL, 1^ox1^o re-analysis fields). Ensemble average rainfall of the simulated event is compared with the satellite observation (TRMM) and Indian Meteorological Department (IMD) observations.

Analysis of the results has shown that the WRF model successfully simulated the extreme rainfall events both in terms of intensity, time evolution, spatial patterns and location. The percentage of simulation error for the event in terms total accumulated rain with respect to TRMM and IMD data are 8.5% and 12% respectively. Prevailing large-scale meteorological conditions like pressure and wind patterns were also analyzed by comparing the simulated fields with FNL re-analysis fields. This configuration of the Model was also able to simulate the patterns of these large-scale conditions reasonably well. The Figure 2.7 shows model domains the observed rainfall (IMD data) during Nov 7th to Dec 7th 2015 and comparison of simulated rain with observations. The spike shown by pink oval is simulated here (27th Nov to 2nd Dec 2015).

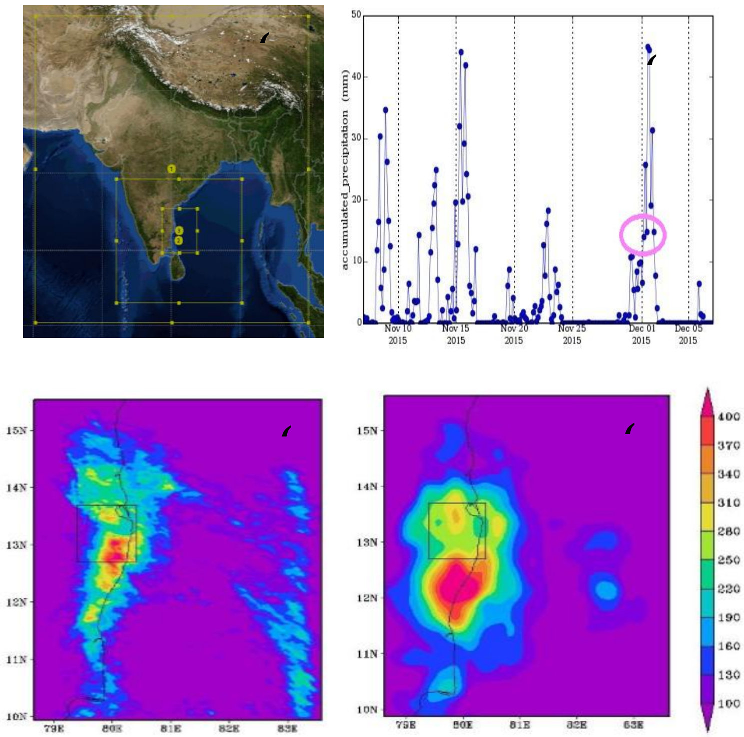

Figure 2.7 The panel (a) show model domains over Chennai and the right panel shows observed rainfall (IMD) during 7^{th} Nov to Dec 7^{th} 2015. Panel (c) is simulated 3-day accumulated (29^{th} Nov 00 hr to 2^{nd} Dec 00 hr) rain (mm), TRMM rain is shown in (d) for comparison.

Himesh S, Sahoo S K, Gouda K C, Rakesh V, Ramesh K V, Kantha Rao Mohapatra G N, Ajilesh P, P P Samantray

2.7 Trends in rainfall and surface temperature over different Indian urban cities

This study is aimed at looking for plausible signature of the impact of urbanization on rainfall and surface temperature trend over different Indian cities which have undergone massive urbanization since independence. The analysis was focused on studying rainfall patterns of different intensity and surface temperature. This analysis is based on 47 years (1961 to 2007) of APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources) data, which is 0.25° resolution. The rainfall and temperature trends are studied for JJAS period using computational boxes of different sizes (2^{o}x2^{o}, 1^{o}x1^{o}, 0.5^{o}x0.5^{o}, 0.25^{o}x0.25^{o}) centered over cities. Daily rainfall intensities of different categories (A:2-5, B:5-10, C:10-20, D:20-30, E:30-40, F:40-50 and G:>50 mm/day) are considered in the analysis. Annual and decadal trends are also analysed. It was found that different categories of rainfall events show different trends over different cities. In the case of Bengaluru and Ahmedabad increasing trend was evident for D to G categories. The Kolkata had shown increasing trend for A to E categories. Chennai predominantly showed increasing trend for F and G categories. Mumbai, on the other hand showed significant increasing trend in G-category (>50 mm/day). Interestingly, Cochin and Delhi have shown decreasing trend across categories, except for A category. In general, this pattern was similar for different computational boxes. Analysis of temperature trend indicates positive trend of 0.02^{o}C /year for Ahmadabad and Mumbai and 0.01^{o}C/year for Bangalore, Chennai and Cochin. Delhi and Kolkata on the other hand have shown neutral trend.

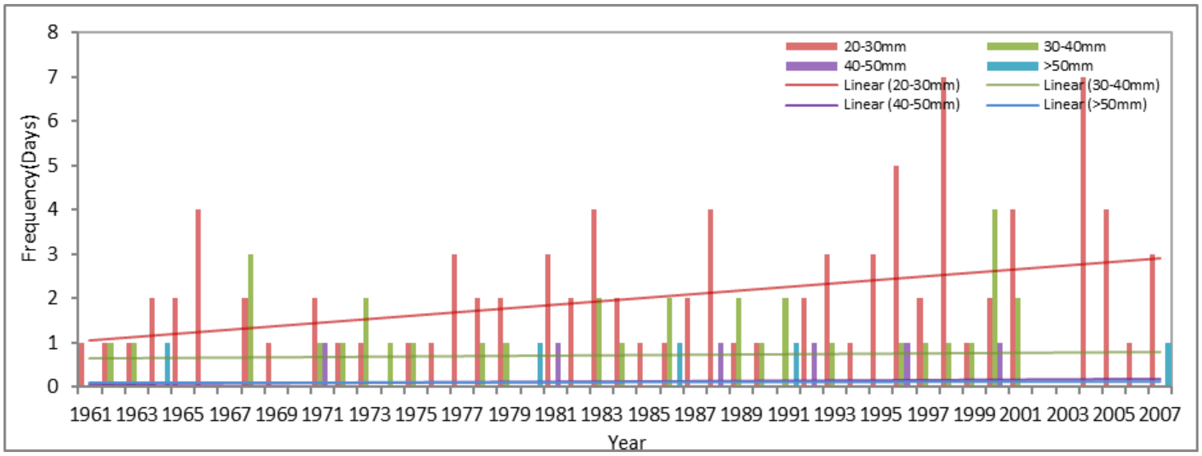

Figure 2.8 Trend of annual rainfall: Bangalore shows an increasing trend in low intensity rainfall (20-30mm/day) category

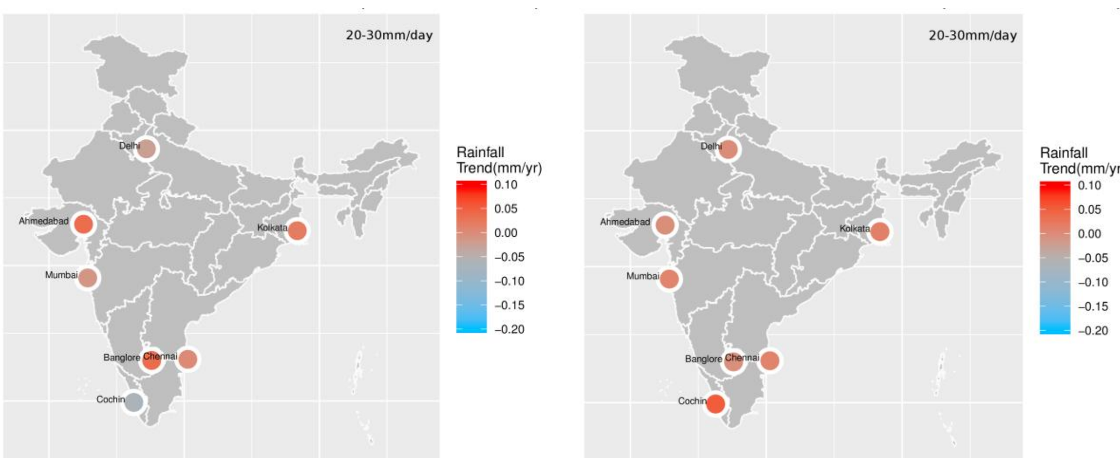

Figure 2.9 Trend analysis of South West (Left panel) and North East (Right panel) monsoon rainfall for the category 20-30mm/day for different cities in India.

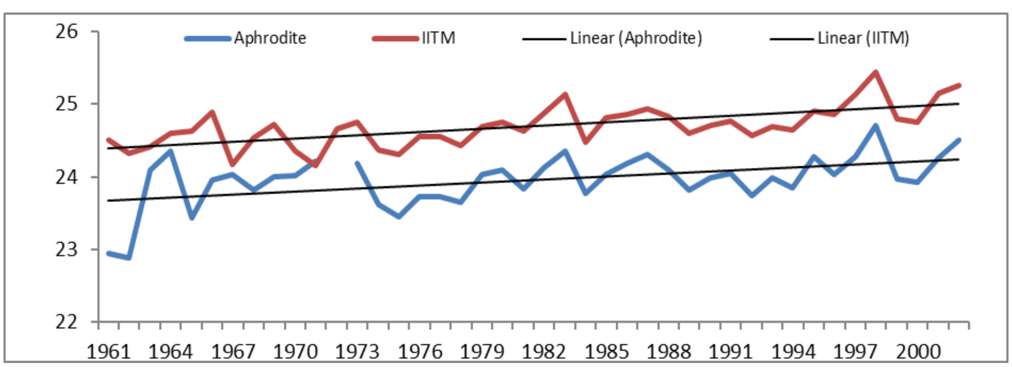

Figure 2.10 Temperature trend for Bangalore using Aphrodite and IITM Temperature data.

The annual rainfall trend for different categories is shown in Figure 2.8, rainfall trend (20-30 mm/day) for SW and NE monsoon is shown in Figure 2.9. Comparison of temperature trend between Aphrodite and IITM data for Bangalore is shown in Figure 2.10, both data sets show similar trend.

Himesh S, Ajilesh P, Gouda K C, Rakesh V, Ramesh K V, Kantha Rao, Mohapatra G , Sahoo S K, Samantray P P

2.8 Study of extreme rainfall events over Indian domain

Extreme rainfall events (ERE) are hydro meteorological disasters which cause potential catastrophic effects on human activities and infrastructure. The frequency and intensity of the ERE over India shows an increasing trend. The potential use of a calibrated LMDZ Variable resolution General Circulation Model (GCM) which provides high resolution over the Indian domain is tested in this work for the advance and accurate prediction of rainfall during ERE over Indian region.

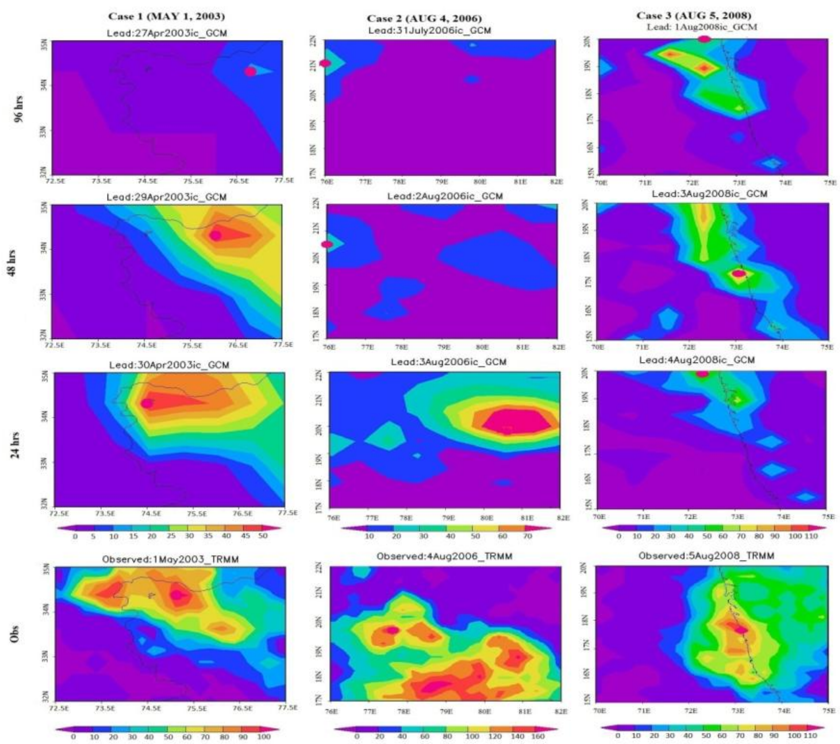

Figure 2.11 Comparison of model simulated and TRMM observed rainfall during EREs

In the present work three EREs (case1: 1st May 2003 over Uttarakhand, case 2: 4th August 2006 over Kaleswaram and case 3: 5th August 2008 over Mumbai) are being simulated using the GCM. The simulations are carried out with three initial conditions i.e. 24 hr, 48 hr and 96 hr before the events. The results obtained from the simulations of different leads 96hr, 48hr and 24hr are presented in the 1st, 2nd, 3rd row and the corresponding observation from Tropical Ra (TRMM) is presented in the 4th row in figure 2.11. Three events case wise are presented column wise i.e. column 1 to 3 represent the case 1, 2 and 3 events respectively. It is found that model could capture the intense heavy rainfall well in advance i.e., 24 to 48 hours but with some locational error.

Nahak S, Gouda K C and Goswami P

2.9 Forecasting of monsoon extreme rainfall events associated with tropical disturbances over the Arabian Sea and Bay of Bengal

Even though monsoon rainfall over the India is mostly governed by large-scale circulations, it exhibits tremendous variability in spatio-temporal distribution within a monsoon season. Recent studies show that there is an increasing trend in extreme rainfall within a monsoon season. Though, a good monsoon rainfall is good for agricultural and economic sectors, extreme rainfall events can cause severe socio-economic damage especially in places of high population and infrastructure. Hence, predicting such extreme rainfall events is very important and challenging problem. During the south-west (June-September) and north-east (October-December) monsoon season in India, tropical depressions which formed over the Bay of Bengal and the Arabian Sea are one of the major causes for such extreme rainfall events. Many studies have shown that the presence of tropical disturbances (low pressure systems) contribute significantly to the seasonal monsoon rainfall. In this study, capability of one of the widely used mesoscale model called Weather Research and Forecasting (WRF) model in simulating such extreme rainfall events during the two monsoon (south-west and north-east) seasons is examined. Nested domain WRF simulations were conducted for selected tropical disturbances occurred during the period 2003 to 2012 over the Arabian Sea and Bay of Bengal. We have verified the model forecasted rainfall against TRMM and IMD observations. The forecast skill of WRF model in simulating rainfall is evaluated in terms of location, magnitude and spatial distribution. WRF model under-predicted (average difference less than -10 mm over land area) the magnitude of rainfall over the land region while it over-predicted (average difference more than 10 mm over land area) rainfall over ocean for majority of cases. Over the land area, WRF model under-predicted the area of rainfall (area of rainfall less than 30% compared to observation) for majority of the cases. For 2 cyclone cases, model over-predicted (area of rainfall more than 30% compared to observation) area of rainfall. Out of the 9 cases examined, location error in maximum rainfall intensity is more than 150 km in 6 cases; only for 2 cyclone cases location error in maximum rainfall is below 100 km. These results point towards the necessity of improvement in model forecast through improved initial condition (data assimilation) and improved model configuration (higher resolution in horizontal and vertical).

Praveen S and Rakesh V

2.10 Role of large scale circulation dynamics in cloudburst over India

In the recent decade there has been increasing trend in the Extreme Rainfall Events (ERE) due to the cloud burst over India, particularly over the Himalaya region. The locations of the cloud burst events over the Himalayan region during 2003-2014 are presented in the Figure 2.12, which clearly shows there are quite high number of cloud burst events well distributed in the latitude 28^{o}-31^{o} N and longitude ranging 77^{o} -80^{o}E.

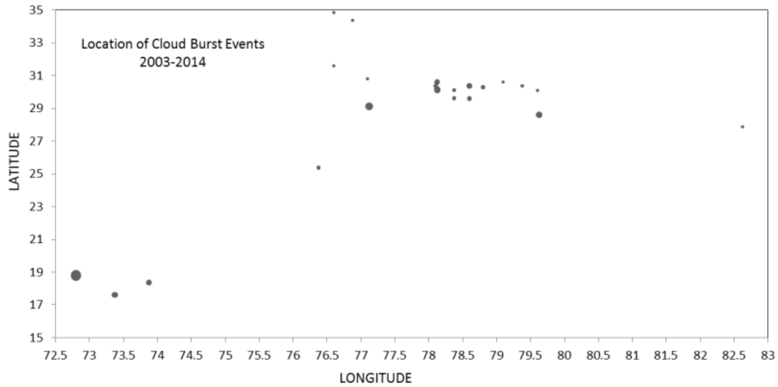

Figure 2.12 Spatial distribution of location where ERE due to cloud burst occurred during 2003 to 2014

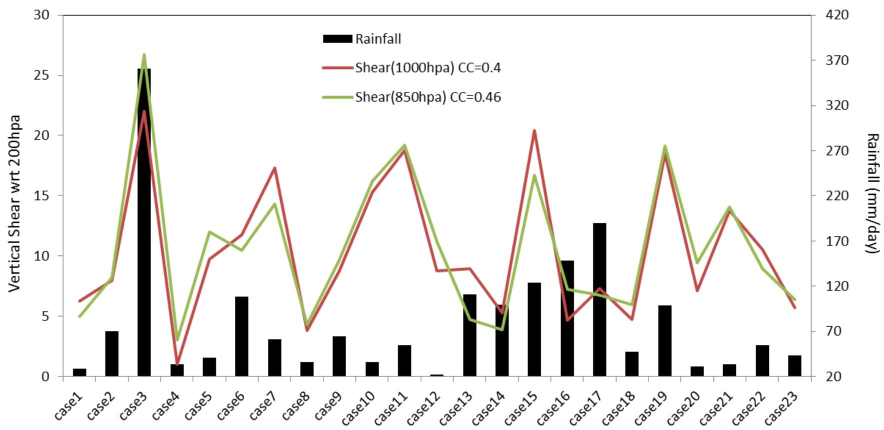

Figure 2.13 Comparison of Rainfall and Shear (1000 & 850hpa with respect to 200hpa) at the location of ERE due to cloud burst.

To understand the large scale wind structure, the vertical wind at all the levels are analyzed for the cloud burst cases and it is observed that there is strong vertical shear distribution. In the present study where the organization of vertical shear of wind and daily variability of monsoon rainfall over ISMR is well correlated. This indicates that the association between large-scale organization of circulation and daily rainfall is suggested as a basis for attempting prediction of daily rainfall by ensuring accurate simulation of wind shear. For the localized extreme rainfall due to cloud burst events also needs to be related with the vertical wind shear. So the vertical wind shear at two levels i.e. 850 hpa and 1000 hpa with respect to 200 hpa levels are computed for the selected cloud burst events and the localized area averaged shear is compared with the rainfall in figure 2.13 below, which shows there is strong positive correlation between the rainfall due to cloud burst events and the vertical wind shear. This study needs to investigate more to understand the dynamics of the cloud burst.

2.11 Evaluation of mesoscale model skill with different leads in predicting tropical cyclones over the north Indian Ocean

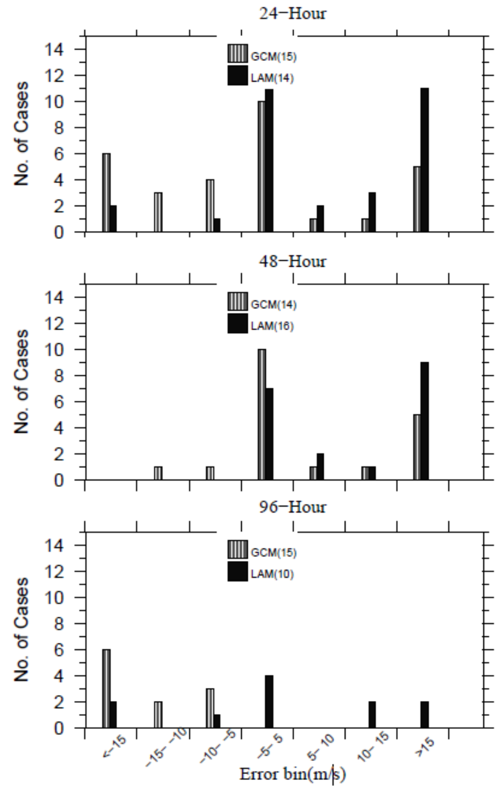

Figure 2.14 Histogram of error in forecasting maximum intensity with mesoscale model and GCM at 24-hour, 48-hour and 96-hour lead for 30 cyclone cases. The number in the bracket represents the number of cases in the error bin -10 to +10 m/s for the respective cases.

With rapid enhancement in computing power as well as rise in user requirements, there is a thrust to adopt new forecast strategies for tropical cyclones. Although, mesoscale models with their high resolutions appear to be the first choice to simulate tropical cyclones, careful treatment is needed while configuring them for practical applications. One important aspect is selecting proper lead time to initiate a cyclone forecast as model spin up has an important influence on model dynamics and physics. In this study, we have conducted simulations with different lead times for several cyclone cases of different intensities. Our results demonstrate that for majority of low intensity cyclones (14 and 16 out of 30 cyclone cases) model error falls in the error bin of ± 10m/s in 24 and 48-hour lead while errors are high in many cases where simulations are carried out with 96-hour lead time. In case of moderate cyclones, for 7 out of 19 cases model errors are coming under the error bin of ± 10m/s with 24 and 48 hour lead. However, errors are very high for simulations with 96 hour lead time. These conclusions hold for severe cyclone cases also. Once again, intensity and track errors are relatively less with 24 and 48 hour leads when compared to 96 hour lead. Our results show that mesoscale model are reliable candidate for cyclone simulation especially at the shorter lead (<24 hours). In order to see whether a global circulation model (GCM) can simulate cyclones with better accuracy compared to mesoscale models, we repeated the experiments with GCM also. Results show that though mesoscale model is superior to GCM in terms of accuracy at shorter leads, at higher leads (>96 hour) GCM performs better than mesoscale model (Figure 2.14). These results points towards the necessity of coupling GCM with mesoscale models for more reliable cyclone prediction at longer leads. Similarly, assimilation of observations may further improve forecast skill.

Mohapatra G N and Rakesh V

2.12 Evaluation of ASCAT soil moisture data with in-situ observations over different agro-climatic regions in Indian

Soil moisture is widely recognized as a key variable in studies related to environment, meteorology, hydrology, agriculture and climate change. Spatial and temporal variations of soil moisture are critical inputs to many applications like sowing schedule, irrigation requirements, and ground water storage. Soil moisture plays a critical role in surface radiation budget through partitioning of sensible and latent heat fluxes and also plays an important role in partitioning of rainfall into runoff and infiltration. Unfortunately, in-situ soil moisture observations are sparse worldwide because of the difficulties involved in resources, logistics and maintenance. However, the recent advances in satellite remote sensing technology have allowed measurement of soil moisture at high spatial and temporal resolutions. A long term sustained soil moisture observation at four vertical levels (5cm, 15cm, 50cm and 100cm) is now available at several locations over India under a multi-institutional program Climate Observations and Modelling Network (COMoN) led by CSIR, India. At the same time, a high resolution (0.1°x0.1°) daily (moving 5-day mean) surface relative soil moisture data set has now become available from the Advanced Scatterometer (ASCAT). There is a need to compare remotely sensed observations with in situ observations to ensure consistency and quantify uncertainties. We present (Figure 2.15) a comparative analysis of gridded ASCAT soil moisture data and in situ COMoN station data over six locations (Almora, Hyderabad, Cochin, Gulbarga, linganamakki, Tezpur) in India during the period 2010-2013. Analyses show that the two data sets are generally consistent, although there are seasonalities in the agreement, the correlation coefficient is higher for the wet season (summer, autumn), and moderate for dry season (winter, spring). The correlation coefficients are in the range of 0.73 to 0.91 and above 99% significance level.

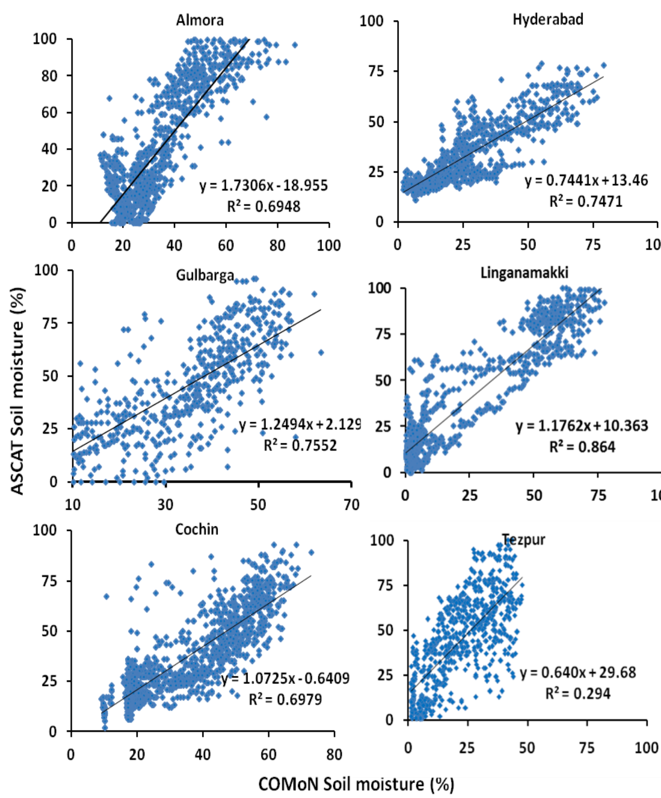

Figure 2.15 Scatter plot shows the agreement between ASCAT and COMoN soil moisture observations at daily scale, x-axis represents the COMoN while y-axis represents the ASCAT.

Kantha Rao Bhimala

2.13 Relationship of winter fog frequency over Indo-Gangetic Plains of India and regional climate variability

Over northern India, most of the fog formation is due to radiative cooling but, advection fog has also been observed. Radiation fog usually forms near the surface under clear skies in stagnant air in association with an anticyclone. Conditions favoring the formation of radiation fog include a clear sky and very light wind. This is generally associated with an inversion structure caused by radiation cooling of the ground and/or near-ground air and the heating of upper layers by adiabatic compression in the course of extensive anti-cyclonic development. When considering the overall fog phenomenon, mechanisms leading to its formation are in many ways conditioned by the large-scale environment (flow conditions, cloudiness, presence of precipitation etc.). Therefore, characterizing the large-scale weather patterns associated with the onset of events represents a useful baseline in establishing the character of environmental conditions leading to fog.

To investigate the long-term variation in fog frequency (FF), we have compiled daily FF reports recorded at Delhi, Lucknow, Allahabad and Hissar since 1980. A 24-h period from 00 UTC to 00 UTC of the next day is characterized as a fog day if in one or more of the 8 3-hourly synoptic reported fog for the present weather (WW=41 to 49). To assess regional inter-annual variability, all records were aggregated into a single IG plain FF series covering winters (DJ) from 1980 through 2012.

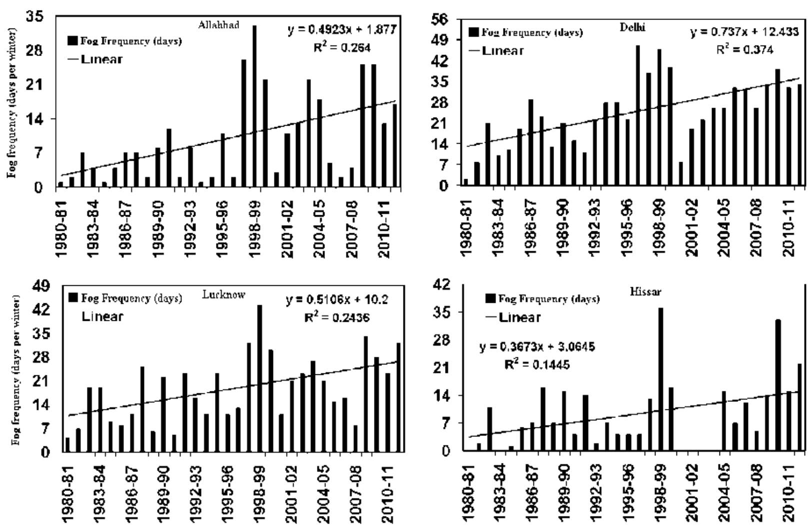

Figure 2.16 Inter-annual variability in winter (December-January) Fog frequency (visibility < 1 Km) days at Allahabad, Delhi, Lucknow and Hissar from 1980 to 2012.

Figure 2.16 shows inter-annual variation in the DJ total FF recorded at the four observatories over 1980–2012 with linear trends. Inter-annual FF series from the four stations are compared among themselves and found to be strongly correlated (r ~ 0.7), suggesting the importance of common response to synoptic-scale climate forcing. From 1980 to 1989 the FF varied around a mean of 16%, followed by a gradual increase through 1990s and 2000s with a mean of 27.6% and 30.3% respectively. The record maximum was observed in the year 1998-1999 with FF 63%.

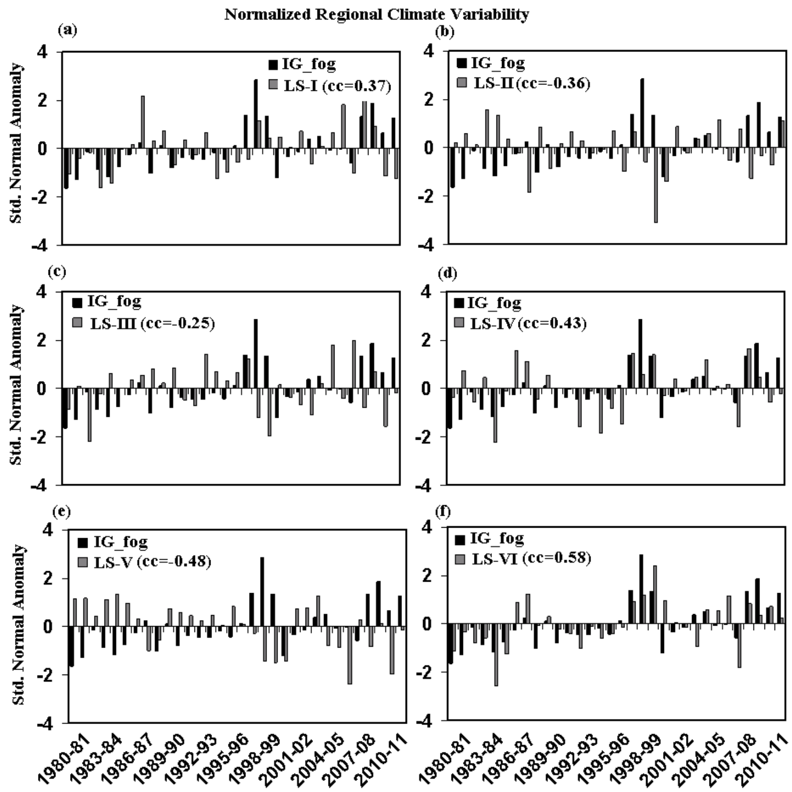

Figure 2.17 Inter-annual variability of winter time (December-January) IG fog frequency and other regional (averaged over 20°N- 35°N and 70°E- 92°E) climate variables from NCEP; plot includes: (a) 500 mb geopotential height anomaly (LS-I), (b) v-wind component at 1000 mb (LS-II), (c) wind divergence at 1000 mb(LS-III), (d) difference in specific humidity between 925 and 700 mb (LS-IV), (e) difference in temperature between 850 and 700 mb (LS-V), (f) difference in relative humidity between 850 and 700 mb (LS-VI) during the period 1980-2012. All series normalized to zero mean and unit variance. The numbers inside the brackets represent correlation coefficient between IG fog frequency and the large scale variables for the respective cases. The 95% significance of correlation is 0.3.

To investigate the relationship between the winter FF and local atmospheric environmental changes in December and January, the inter-annual variations in 500 geopotential height anomalies, meridional wind and wind divergence at 1000 mb, difference in specific humidity between 925 and 700 mb, difference in temperature and relative humidity between 850 and 700 mb were examined across the IG plain for the period 1980-2012. These large-scale fields have been derived from NCEP with areal average (20°N- 35°N and 70°E- 92°E) across IG plain. Large-scale meteorological variables such as geopotential heights, sea level pressure (SLP), zonal and meridional wind component at surface and higher pressure levels, 850-mb temperature, specific humidity and relative humidity were obtained from the National Centre for Environmental Prediction (NCEP) reanalysis which is a retroactive record of more than 50 years' worth of global analyses of atmospheric fields.

Figure 2.17 shows that various large-scale variables are significantly correlated with the FF variability over IG plains of India.

2.14 Wind-generated electricity potential for Andaman and Nicobar islands

The potential of wind power as a source of electricity, which is an alternative to conventional fossil fuels, are generally used in remote regions, like islands for electricity generation. Utilization of renewable energy can make us less dependent on fossil fuels, which in turn can help us to reduce carbon emissions. This study focuses on quantifying a realistic assessment of the potential for wind-generated electricity in Andaman and Nicobar islands, which experiences two monsoon wind regimes. Wind fields are derived from high resolution hourly winds from dynamically downscaled climate for the period 2001-2015 to estimate the potential.

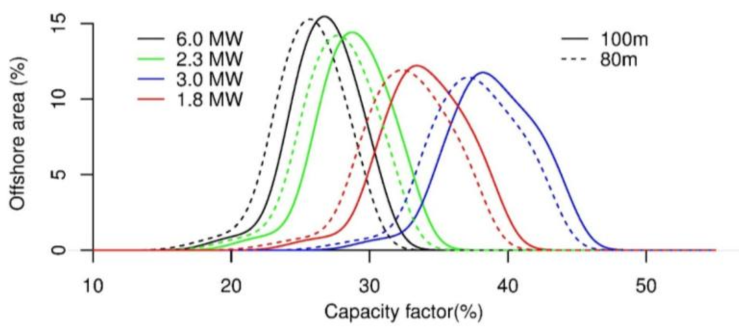

Figure 2.18 The distribution of offshore potential area based on the capacity factor for different capacity offshore wind turbines at 80m and 100m heights.

This region experiences high spatio-temporal variability in winds at 80 and 100m heights. Both the monsoon seasons and pre-monsoon period experience high speed wind regimes. The orographic distribution shows there is no suitable space for onshore wind turbine, hence this study examines the offshore potential for wind generated electricity for different capacity turbines. Most of the selected locations (depth less than 250 m) have the average capacity 20%, while low capacity turbines (3.0 MW and 1.8 MW) have high capacity factor (Figure 2.18). The annual distribution of wind shows that 62+-2% can be utilized for electricity generation. The offshore location, turbine cost and electricity potential are used to quantify the economic viability to identify the offshore locations. This region has high capacity factor, which shows that 66% of electricity can be generated from wind. The projections of electricity requirement in the island is used to quantify the optimum requirement of turbines up to 2050, so that 66% requirement is met by offshore wind turbines on the identified locations. This study will be extended to Indian main land to identify viable areas of onshore and offshore wind generated electricity potential.

Shafeer K B and Ramesh K V

2.15 Dynamics of land-atmosphere coupling during heat waves in 2015

Heat-wave is one of major natural health hazard, which is identified as, not only merely due to series of days with extremely hot temperature, but also due to periods when sustained heat produces an excess mortality. Studies have shown that the heat waves are formed due to progressive accumulation of heat, which is enhanced with soil desiccation and lead to further increase in air temperature over mid-latitudes. However, there are few studies which attempted to understand the evolution of heat waves over tropics, especially South Asia, which is dominated by monsoon climate. The studies are few due to non-availability of high-resolution observations. In this study, we examine the evolution of mega heat wave. For this purpose, we develop a high-resolution (4x4 Km) downscaled of climate data for the period of 2001-2015 from Weather Research and Forecasting (WRF) Simulations. The high-resolution data is validated with available station observations Global summary of the Day (GSOD), which is prepared by the National Climatic Data Center. The results show that there is a strong accumulation of heat (Figure 2.19) over Telangana, Orissa, West Bengal, Bangladesh, Uttar Pradesh, Bihar region, which started heat accumulation from 10 May onwards, continue to increase and persisted till 30th May 2015 with the help of high-resolution soil and atmospheric data. We quantify the relative roles of soil moisture-temperature coupling, and contributions of large scale features in the evolution of the mega heat wave.

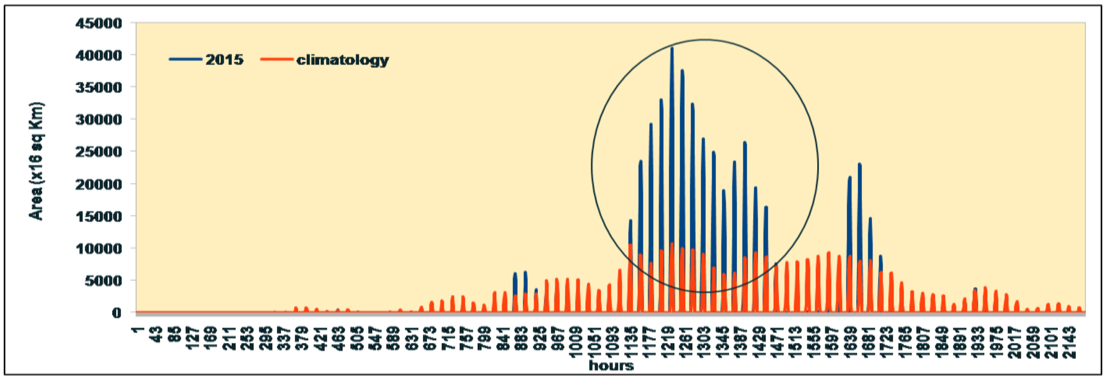

Figure 2.19 Temporal Evolution of heat wave 2015 (blue) during April 01 00UTC to June 30 23UTC is compared with same days climatology (red) of 2001-2015. The Y-axis shows the area coverage of the grid points above 45°C.

Over south Asia, pre-monsoon is the warmest season of the year with anomalously high daily temperatures and if relative humidity is also increased, then it will adversely affect the human health and comfort. For example, May 2015 mega heat wave over India took more than 2500 lives. So, identification of types of heat waves, role of vegetation, soil moisture and its long-term changes are of critical importance to the development of an appropriate risk management and mitigation strategies.

Neethu C, Shafeer K B and Ramesh K V

2.16 Projected changes in vector borne diseases (Malaria) over India

Malaria, a mosquito-borne infectious disease caused by parasitic protozoans of the *Plasmodium* genus, is detrimental to public health and affected countries. Studies have documented that the potential days for malaria occurrence and transmission depend on weather variables. The objective of this study is to explore the relationship between climate variables and the occurrences of Vector Borne Diseases (VBD), especially malaria in India. Current evidence suggests that inter-annual and climate change (trends) have a direct influence on the epidemiology of vector-borne diseases (VBD). Malaria, dengue, Filariasis, Kala-azar, Chikungunya and Japanese Encephalitis are among the most important vector-borne diseases in the tropics, which causes high mortality in India. The rainfall/temperature/humidity of the region play an important role in the occurrence/spreading of VBD. We use CMIP3 and CMIP5 model simulations to analyse the disease occurrence in historical as well as for future projections over India. We adopted different criteria for calculating the potential days region-wise depending on the weather variables. The criteria are for Temperature (18^{o}C-32^{o}C), Rainfall (1.5-20 mm/day) and Relative Humidity (20-80%).

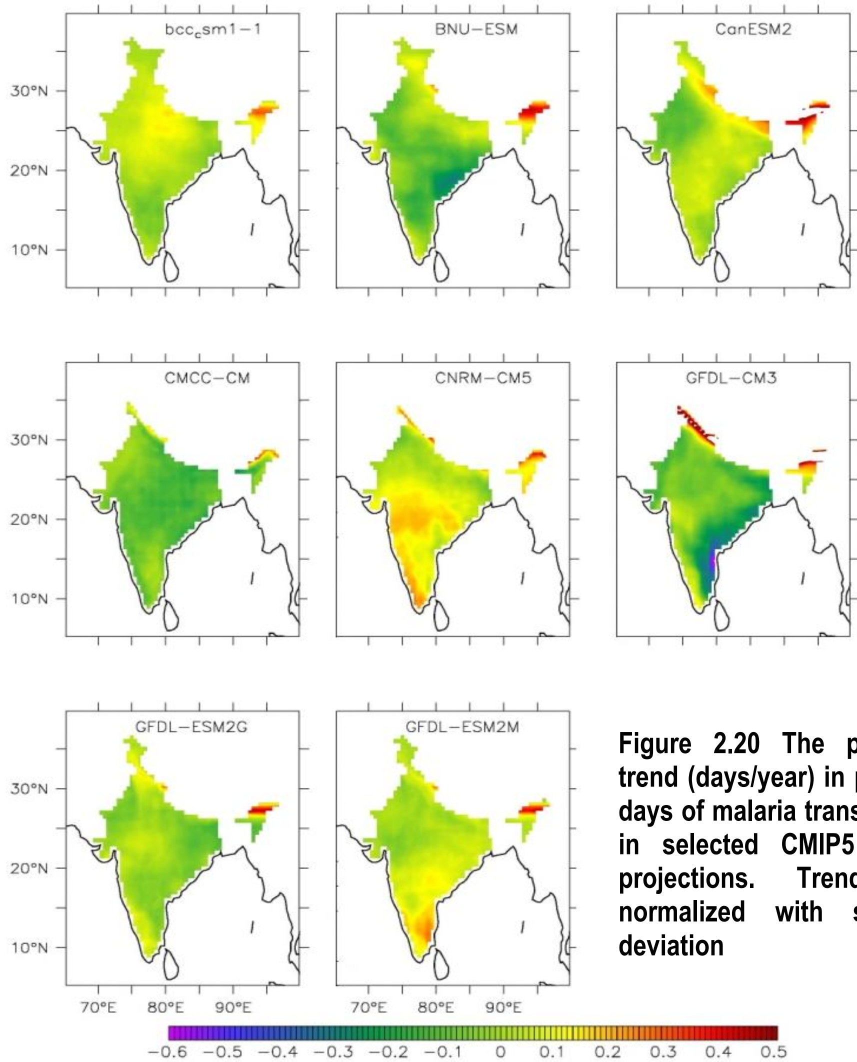

Figure 2.20 The projected trend (days/year) in potential days of malaria transmission in selected CMIP5 RCP45 projections. Trends are normalized with standard deviation

The state-wise data of disease cases/deaths reported for India is obtained from Indiastat. The climate variables (rainfall, temperature and humidity) from different reanalysis (MERRA, ERA40, ERA Interim, NCEP and JRA55) are used to validate the IPCC historical model simulations. The variables are used in the time period of 1951-2005 to find out the number of potential days for the malaria occurrence and transmission. The IPCC models were selected based on the performance and capturing of features in observations/reanalysis. We calculated the correlation coefficient between the disease cases reported (state-wise and region-wise) and the weather variables. The selected models were used for future projections (2016-2099).

Results show that future climate is going to be highly conducive for malaria transmission over the West-coast of India, central India and northeast India (Figure 2.20). As climate models show higher dispersion, it is necessary to quantify the reliability of projections.

Alfred Johny and Ramesh K V

2.17 Analysis of vector borne disease across Karnataka using geospatial technique

The outbreak of vector borne diseases in different parts of Karnataka has created a serious health concerns. There were many incidents of deaths reported in some of the rural areas due to lack of health amenities, poor intervention and lack of awareness. There are various factors like the geographical location, local environmental conditions, climate change which contribute to the spread of the vectors resulting in disease outbreak. Apart from that the factors like socio economic and high population density, which in turn aggravate the problem.

In the present study, the spatio-temporal analysis of the spread in vector borne diseases over different regions of Karnataka is carried out using multi-source observation and geospatial analysis. Here, for the analysis, Dengue Fever, Chikungunya, Malaria and Japanese Encephalitis for the periods 2001 to 2014 are carried out, using the availability of disease-wise data for the entire Karnataka Region at district scale.

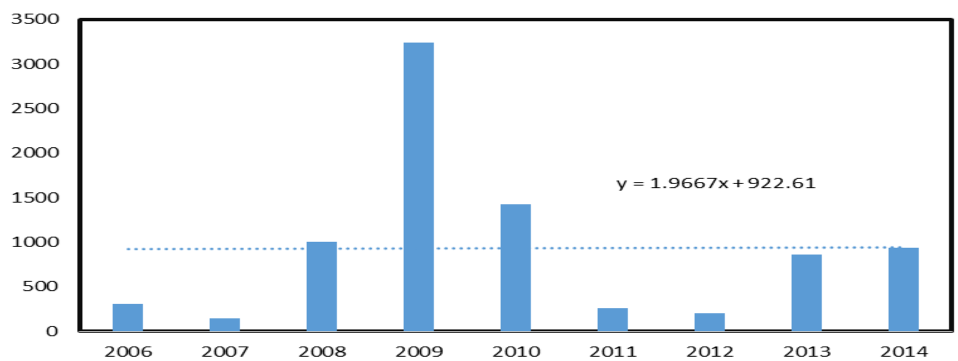

Figure 2.21 Annual frequency distribution (number of cases reported) of Chikungunya patients over Karnataka for the period 2006-2014. The line indicates the trend line for the period of analysis.

The data for the analysis of Vector Borne disease was collected for all the districts of Karnataka from NVBDC Karnataka. Here, the data analysis was mainly carried out for Dengue, Chikungunya, Malaria and Japanese Encephalitis using the statistics and the trend analysis (Figure 2.21). GIS based frequency maps (using Arc GIS 10.0) show the positive trend in the cases of occurrences of the various vector borne diseases. In these maps Red tone indicates the high incidence (>500 cases), Blue tone indicates moderately high (100-500 cases), Yellow tone indicates low (1-100 cases) and Green indicates no incidence at all (Figure 2.22). The Spatio-temporal analysis was also performed to find out the most affected region, so that control measures can be adopted to prevent the diseases.

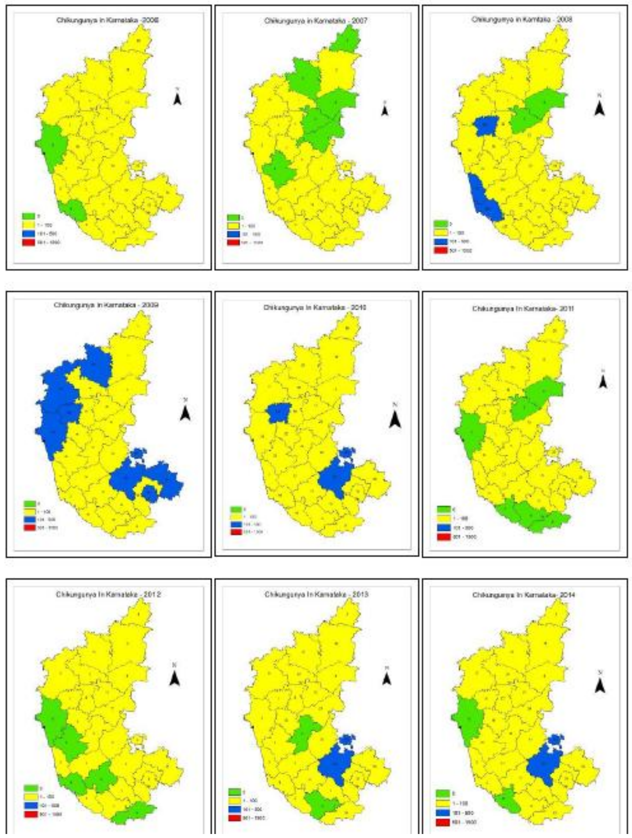

Figure 2.22 Annual frequency distribution (number of cases reported) of Chikungunya patients over Karnataka for the period 2006-2014.

The trend analysis of the various cluster of vector borne diseases can be used to study the correlation of the diseases with weather variables like climate, rainfall and temperature to develop a predictive model for vector borne disease.

Gouda K C and Shashikala[1], Pavithra[1] and Lakshmikanth B P[1]
[1]Karnataka State Remote Sensing Application Centre, Bangalore

2.18 Relation between Rainfall and on Occurrences of Dengue cases over India

There is increasing trend in Dengue, one of the most dangerous VBD over some parts of India. Analysis of observed data shows the spreadability and occurrence of Dengue is more during 1998-2012 over 6 states (Delhi, Haryana, Punjab, Gujarat, Rajasthan and Goa) in India. This study analyzed the relationship between rainfall and occurrence of dengue cases at the state scale. It is found that the increasing trend in the extreme rainfall events generally leads to accumulation of water and these are conducive for the vectors to spread Dengue.

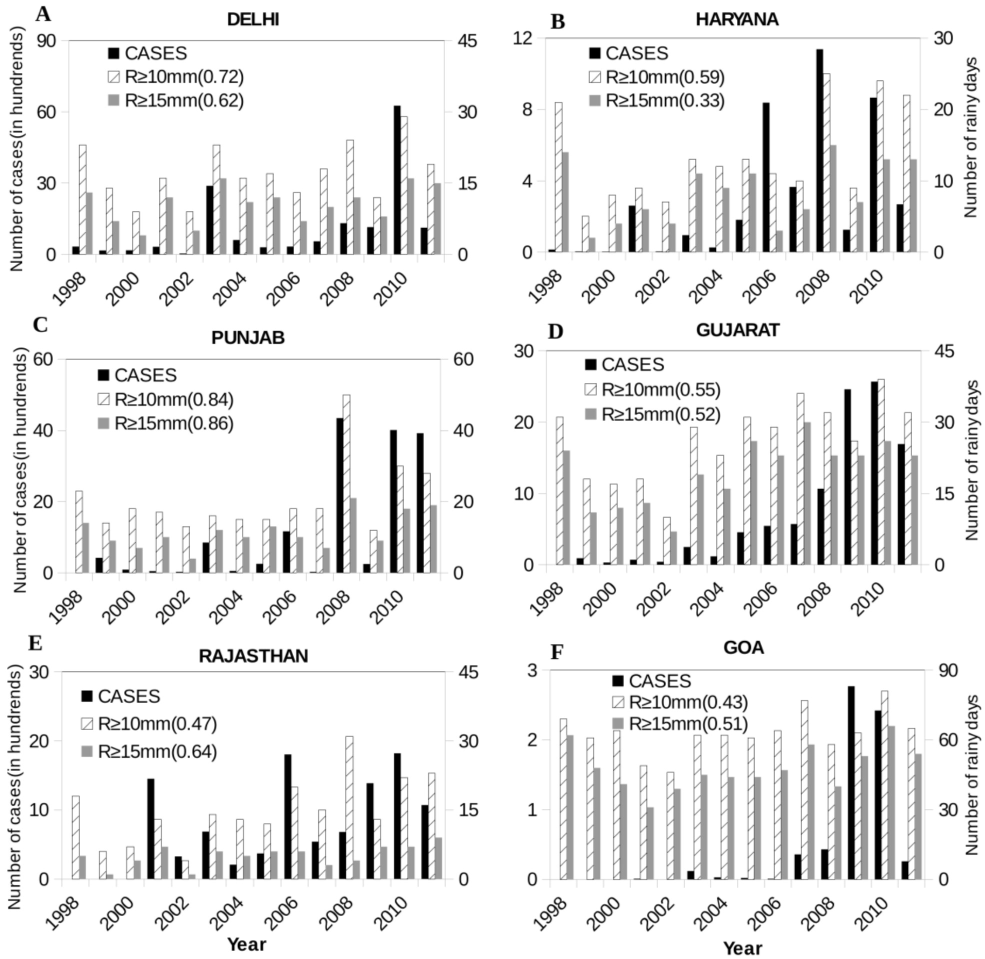

Figure 2.23 Inter annual variability in the annual number of heavy rainfall days and the annual dengue cases for the six states. The numbers in the brackets represent correlation coefficients between dengue cases and the annual number of rainy days for the respective rainfall categories for the period of 1998-2011; the 95% significance of correlation is 0.497.

On a year-to-year basis also, each state exhibits significant (≥95%) correlation between the annual number of dengue cases and the heavy rainfall days (Figure 2.23). It may be noted that for each of the states and for each of the 15 years, there is non-zero number of heavy rainfall (R≥10mm/day) days; however, there are examples like, for Haryana, Goa and Rajasthan during 1998-2000, for which the number of dengue cases were essentially zero (Figure 2.23). It may be also noted that for states like Goa, Gujarat and Punjab, there are indications of sharp increases in the number of dengue cases.

Barik P S, Gouda K C and Goswami P