2
CLIMATE AND ENVIRONMENTAL MODELLING PROGRAMME (CEMP)

The main objective of CEMP research has been aimed at providing scientific and technological solutions for societal and industrial benefits. Research activities are designed to achieve institutional and national objectives by enabling outreach agencies to mitigate the adverse impacts of climate and environment. Major research activities of CEMP are: monsoon, climate and weather informatics, smart agriculture, renewable energy, high impact weather events and preventive healthcare. Group activities are aligned with missions of Government of India (Samarth Bharat, Renewable Energy, Swasthya Bharat). The team carried out its research and analysis through open-source codes, state-of-the-art models (LAMs, GCMs and NWPs), in-house algorithms and visualization tools. Major achievements of CEMP for 2016-17 include, CSIR Young Scientist Award for the team member, successful forecast of Monsoon-2016, publications in SCI journals, extension of 4 DST funded projects, and award of In-house project under CSIR YSA scheme.

Inside

- *Forecast skill and thermodynamic characterization and categorization of urban heavy rainfall events: A case study over Bengaluru*
- *Simulation of cloudburst events*
- *An integrated approach to study the LULC and run off estimation over Bengaluru city during 1995-2016*
- *The relationship between antecedent soil moisture and monsoon rainfall over the Indian region through observational analysis*
- *Impact of assimilation on heavy rainfall simulations using WRF Model: Sensitivity of assimilation results to background error statistics*
- *Simulation of tropical cyclones over the Indian Ocean: Forecast skill of a mesoscale model for cyclones of different intensities*
- *High resolution long-range dynamical forecasting of Indian monsoon 2016*
- *Evaluation of a variable resolution GCM in simulating the regional climate variability over Western Ghats*

- *Change detection study in Karnataka coastline using multi temporal satellite data and Geographical Information System (GIS)*
- *Analysis of cloud structure dynamics during cloud burst events over India*

2.1 Forecast skill and thermodynamic characterization and categorization of urban heavy rainfall events: A case study over Bengaluru

This study is about the characterization of rainfall events and associated thermodynamic processes predominantly occurred during monsoon season (2012 to 2014) over Bengaluru, the capital city of Karnataka. Simulations are carried out using Weather Research and Forecast model (WRFV3) in forecast mode. The innermost domain of approximately 3°x3° was centred over Bengaluru such that it covers 34 villages, clustered as one Hobli. The model was initialized with Global Forecast Fields (GFS) data and forecast was generated on hourly basis. Results are based on comparing rainfall forecasts (1.3 Km resolution) of 44 events spread over three years with high resolution rain gauge observations (34 rain gauges). The rainfall events are characterized in terms of their intensity and pattern of spatial distribution, time evolution and thermodynamic indices. Also, the forecast skill of the model was assessed for its ability to simulate these events in terms of Root Mean Square Error (RMSE), BIAS, and Absolute Error (AE). The RMSE, BIAS and AE for spatial distribution of rainfall averaged over 45 events and across 34 villages, in comparison with rain gauge observations, were found to be in the range of: 16-36, 6-20 and 80-102 respectively (Figure 2.1). This study also shows that simulated vertical profiles of temperature and moisture averaged over 44 events are found to be in agreement with profiles generated by MODIS data. Thermodynamic indices including CAPE, CIN, K-index, Lifted Index and Total Totals were derived from the model and validated by calculating those indices using MODIS Level 2 satellite observed data and analysed for all the events. Large-scale prevailing meteorological conditions (relative humidity, surface temperature and horizontal wind) were also analysed. Our results clearly demonstrated that the WRF model generated very robust and useful forecasts for heavy rainfall events.

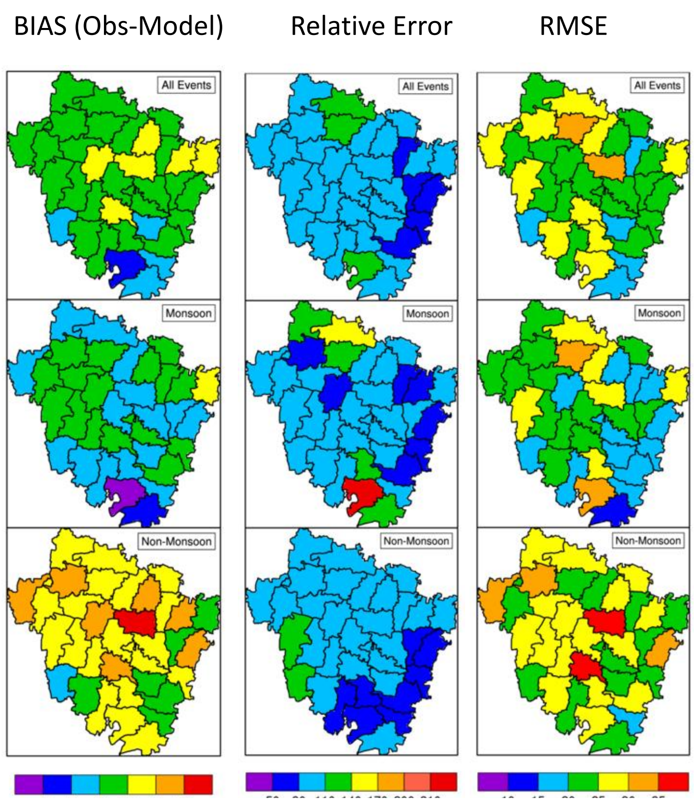

Figure 2.1 Spatial distribution of RMSE (mm), Bias (mm) and relative error (%) in forecasted rainfall averaged over all events (top panel), cases during monsoon season (middle panel), and cases during non-monsoon season (bottom panel).

2.2 Simulation of cloudburst events

The Himalayan region by virtue of its orography is one of the most vulnerable regions of cloudburst events. Recent decade has been witness to many cloudburst in the Himalaya region like Uttarakhand (UK) resulting in flash floods, with huge loss of lives and property. There have been instances of cloudburst events over cities in the interiors of India too. Prediction of these rare events well in advance remains a challenge. In this study, we have simulated cloudburst events over Himalayan region as well as over a city using WRFV3.5 model. We tested the model for 2 events over Himalaya (Ganvi and Pithoragarh) and one event over a city (Pune, Maharashtra). The model was configured with 3-nests, details of model configuration are shown in Table 2.1. The model is initialized with FNL (1^oX1^o) 6 hourly data and USGS (1992-1993) land use data. For each of the simulation, model was integrated for 72 hrs. Results are based on ensemble of three initial conditions. Figure 2.2 shows spatial distribution of simulated (24-hour accumulated) and observed (TRMM) rainfall for Ganvi and Pithoragarh events. As evident in figure, TRMM show high intensity discrete patches, whereas model shows widely distributed, continuous and high intensity rainfall pattern. Nevertheless, model simulated the event reasonably well (intensity and spatial extant). Simulated rainfall for Ganvi event error was 38 and 42% w.r.t. IMD and TRMM respectively. In case of Pithorgarh event, the error was 4.3 and 36.29% w.r.t. IMD and TRMM. The same configuration of the model, however, failed to reproduce the urban event, indicating the importance of the location specific configuration of model which incorporates dominant local processes.

Table 2.1 Model Configuration

Domain	No of Grids Himalayan Belt		Vertical Levels	Resolution(KM)
	X	Y		
D1	226	192	24	27
D2	364	310		09
D3	367	367		03
Microphysics		WSM6 scheme		
Radiation		RRTM: Longwave Dudhia: Shortwave		
Cumulus parameterization		New Kain–Fritsch scheme		
PBL parameterization		YSU scheme		
Land surface parameterization		Thermal Diffusion		

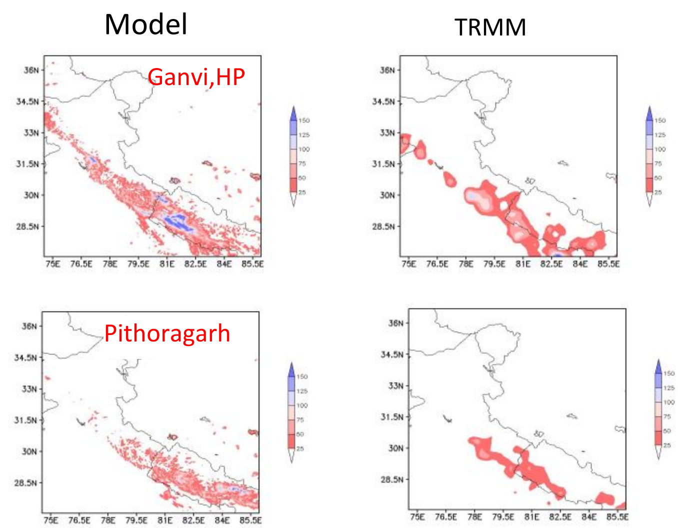

Figure 2.2 Spatial distribution of 24-hr accumulated model and Observed (TRMM) rainfall over Ganvi (31.55N, 77.77E), Himachal Pradesh on 14/08/2007 and over Pithoragarh (29.58N, 80.21E), Uttarakhand on 07/08/2009

2.3 An integrated approach to study the land use and land cover and run off estimation over Bengaluru city during 1995-2016

Here we have discussed about the existing drainage system functionality over a period of time in the fastest growing urban city like Bengaluru in India. It is evident from land use and land cover (LULC) map there is sharp decline (41%) of water bodies, while on the other hand there is very significant increase (43%) of infrastructure development with house, concrete road and illegal encroachment of Lake Area. We considered MODIS (Moderate-resolution Imaging Spectroradiometer) data (resolution 20m) for LULC analysis from the period 1995-2016 to have clear picture of the city regarding its environment conservation and protection. There is an accuracy calculation for all these supervised classification in the different category of waterbodies, wasteland, infrastructure and vegetation from 2000-2016 where the situation is alarming. In addition to this analysis, we estimated the annual run off and total rainfall over several Central Business District (CBD) of Bengaluru city to find out the status of storm water drainage system and the risk of flooding when there will be any heavy rainfall events (more than 70 mm rainfall accumulated). The run off estimation value of flood water is found to be very close to the total amount of precipitation during the monsoon season and there is a big gap in the value in pre and post monsoon seasons. All these runoff estimated based on the curve number and the type of soil texture in that particular region.

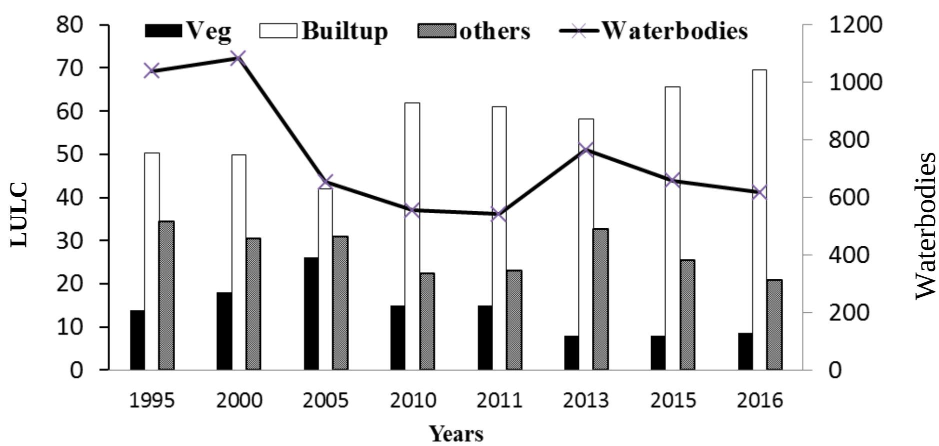

Figure 2.3 Distribution (%) of land use and land cover (LULC) pattern (1995 -2016) supervised classification of land sat images (left-side axis) and total amount of water bodies coverage (right-side axis) over Bengaluru city

2.4 The relationship between antecedent soil moisture and monsoon rainfall over the Indian region through observational analysis

The monsoon is manifested as a land-atmosphere-ocean interaction between continents and oceans in the seasonal cycle. Accurate seasonal forecasts mostly depend on simulating the atmospheric responses to slowly varying ocean state and land surface components that can be predicted weeks to months in advance.

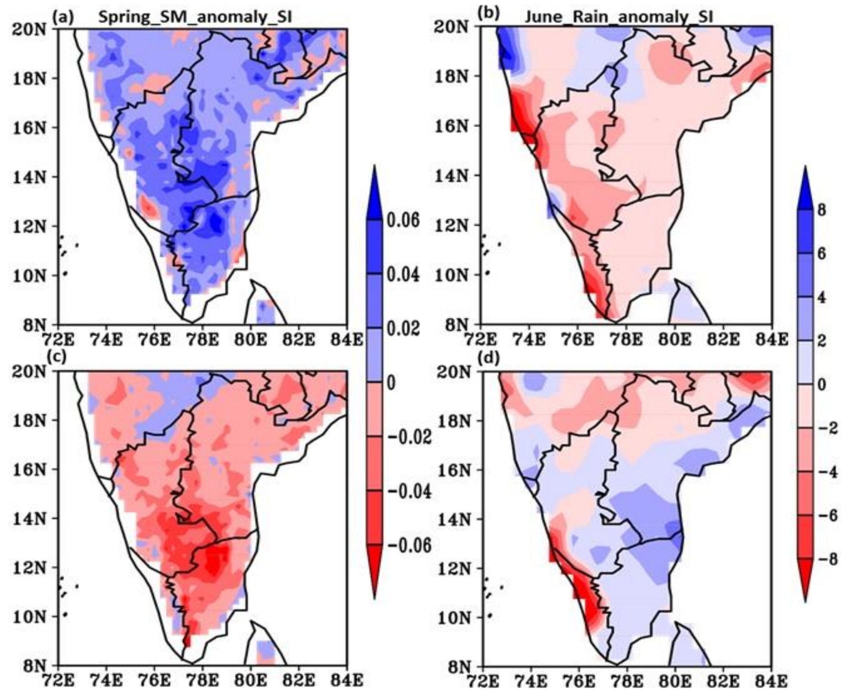

Figure 2.4 Composite anomaly of spring soil moisture (m^3/m^3) for (a) excess and (c) deficit soil moisture years over the South India with corresponding June rainfall (cm) anomaly (b, d)

Understanding the relationship between gradually varying soil moisture (SM) conditions and monsoon rainfall anomalies is crucial for seasonal prediction. The key to understand the SM-precipitation interactions lies more in the impact of SM anomalies on the boundary layer stability and precipitation formation than in the absolute moisture input resulting from modified evapotranspiration. For example, the neighboring oceans or land regions may induce the precipitation over some regions, but the triggering of precipitation may be the result of enhanced instability induced by the wet soil conditions. 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. Our 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. 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).

2.5 Impact of assimilation on heavy rainfall simulations using WRF Model: Sensitivity of assimilation results to background error statistics

Data assimilation is considered as one of the effective tools for improving forecast skill of mesoscale models. However, for optimum utilization and effective assimilation of observations, many factors need to be taken into account while designing data assimilation methodology. One of the critical components that determine the amount and propagation observation information into the analysis is model background error statistics (BES). The objective of this study is to quantify how BES in data assimilation impact on simulation of heavy rainfall events over a southern state in India, Karnataka. Simulations of 40 heavy rainfall events were carried out using Weather Research and Forecasting (WRF) Model with and without data assimilation. The assimilation experiments were conducted using global and regional BES while the experiment with no assimilation was used as the baseline for assessing the impact of data assimilation. The simulated rainfall is verified against high-resolution rain-gauge observations over Karnataka. Statistical evaluation using several accuracy and skill measures show that data assimilation has improved the heavy rainfall simulation. Our results showed that experiment using regional BES outperformed the one used global BES (Figure 2.5). Critical thermo-dynamic variables conducive for heavy rainfall like convective available potential energy simulated using regional BES is more realistic compared to global BES. It is pointed out that these results have important practical implications in design of forecast platforms while decision making during extreme weather events

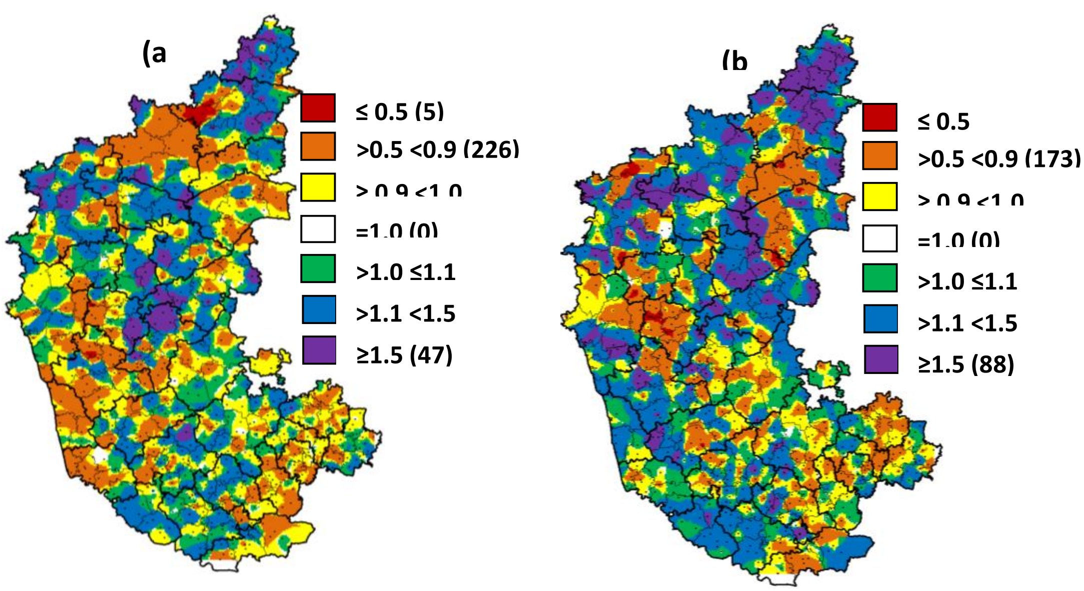

Figure 2.5 Spatial distribution of impact ratio in rainfall prediction over Karnataka compared to rain-gauge observations for (a) assimilation using EXP-GBES (b) assimilation using EXP-RBES; values >1 (<1) shows improvement (degradation) due to assimilation as compared to control simulation (without assimilation) simulation. The numbers in bracket shows the number of hoblis in each range.

2.6 Simulation of tropical cyclones over the Indian Ocean: Forecast skill of a mesoscale model for cyclones of different intensities

Over the past years, several numerical weather prediction (NWP) models capable of simulating tropical cyclone (TC) have been emerged. Worldwide, Tropical cyclones (TCs) landfalls are the most feared and deadly meteorological phenomena in the coastal regions. The devastation of this landfall is mainly due to the strong wind, heavy rainfall and associated storm surges. Validation of NWP models is the most crucial aspect before using them for operational forecasting for predicting such land-falling cyclones. The forecast skill of these NWP models varies for different ocean basins. The focus of this study is to verify the skill of one of the widely used mesoscale NWP model called Advanced Research Weather Research and Forecasting (WRF-ARW) model in simulating tropical cyclones of different intensities over the north-Indian ocean. High resolution WRF simulations were conducted for cyclone cases during 2003 to 2014 formed over the Arabian Sea and Bay of Bengal. The cyclone cases during this period are categorized according to the maximum wind speed as low intensity (Category 1; wind speed ≤40 knots), medium intensity (Category 2; wind speed maximum between 40-70 knot) and high intensity (Category 3; wind speed maximum ≥70 knots). The forecast skill of the model is assessed for these three categories of cyclones in terms of their capability in predicting intensity (wind speed and pressure drop) and track by comparing with observations from India Meteorological Department and Joint Typhoon Warning Center (JTWC). The error in cyclone track prediction by model is higher for category 1 (low intensity) cyclones compared to category 2 and 3. Similarly, the relative error in intensity (maximum wind speed) was lowest in category 3 when compared to category 2 and 1 (Figure 2.6).

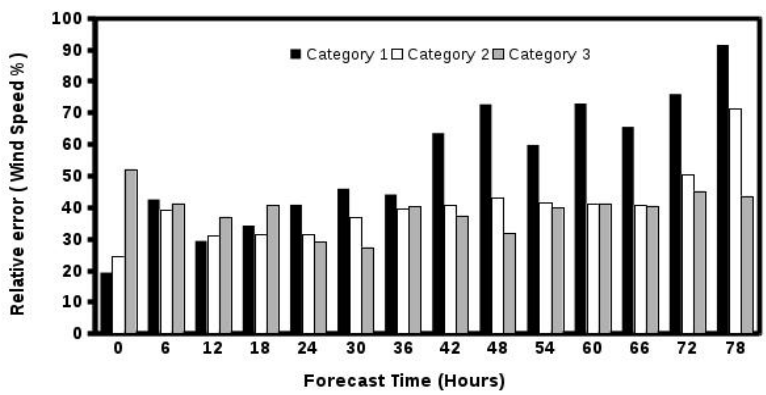

Figure 2.6 Relative error in intensity (wind speed) prediction for different cyclone cases (a) Category 1 (low intensity) (b) Category 2 (medium intensity) (c) Category 3 (high intensity)

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

Huge socio-economic impacts of accurate and advance forecast of monsoon rainfall have been well recognized and appreciated. However, for such forecasts to be useful, they must be at spatial scales and lead that provide actionable knowledge; forecasts averaged over large spatio-temporal scales do not provide user-relevant forecasts. The most potential tools for such high-resolution forecasts are dynamical models.

As a routine practice, the first outlook of high resolution long-range forecast of the Monsoon 2016 was made available in the middle of April, 2016. The date of onset of monsoon over Kerala, the seasonal (JJA) as well as monthly rainfall anomalies are forecasted using the variable resolution general circulation model (GCM). These forecasts are based on an ensemble (5 member) consisting of information on the atmospheric state (initial conditions) from 15th March 2016 to 15th April 2016. The forecasts are also presented in the pre-season meeting organized by IMD in mid-April; IMD acknowledged these forecasts.

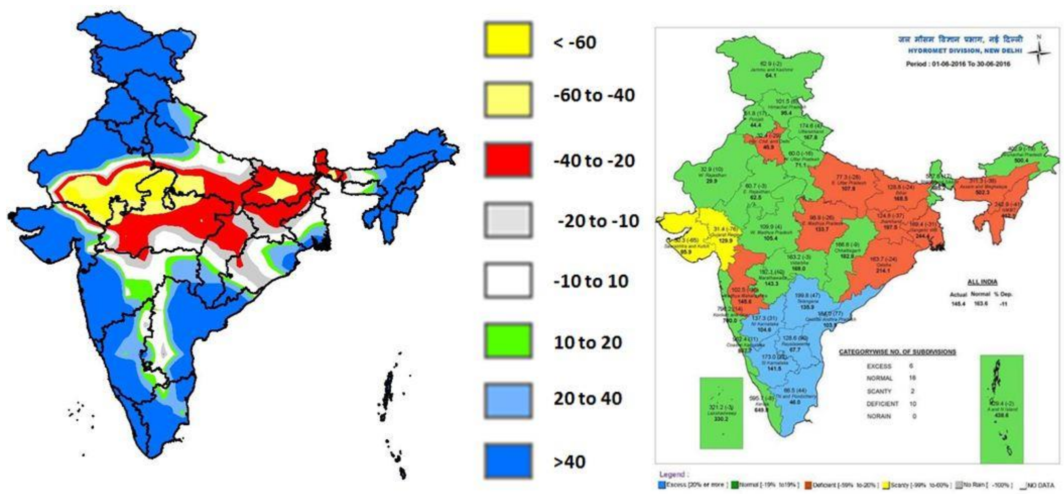

Figure 2.7 Monthly rainfall anomalies from CSIR-4PI long range high resolution forecasts (left panel) and IMD observation for June 2016 (right panel)

For 2016, the CSIR-4PI forecast of the date of Onset of Monsoon was June 02, while that of IMD was 8th June. The post season validation of the spatial distribution of monthly and seasonal rainfall anomalies show good agreement of the forecast with observation over many regions of the country. The monthly scale validation of rainfall anomaly for June 2016 is presented in Figure 2.7.

Table 2.2 Comparison of the forecast and observation of 2016 Monsoon rainfall both at monthly and seasonal scale for the different regions over India

Region	June		July		August		JJA	
	Model	Obs	Model	Obs	Model	Obs	Model	Obs
All India	N	D	D	N	N	N	N	N
North-India	N	N	N	N	E	N	N	N
South India	E	E	D	N	N	D	N	N
Central India	D	D	D	E	N	N	D	N
North-east India	E	D	D	N	N	D	N	D
North-west India	N	N	N	D	E	E	N	N

The validation of monthly and seasonal rainfall anomalies over different regions are carried out and presented in table 2.2. There is very good agreement between distribution of monthly and seasonal forecast with observation. However, 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 12 cases.

2.8 Evaluation of a variable resolution GCM in simulating the regional climate variability over Western Ghats

A study is being carried out to know the variability of rainfall both on the spatial and temporal scales over the Western Ghats region. A Variable Resolution General Circulation Model (VRGCM) is used for rainfall simulation, which provides relatively high (~ 50 km) resolution over the Western Ghats domain. Rainfall analysis from IMD (1980-2003), TRMM (1998-2013), APHRODITE (1980-2007) observation and model simulation is carried out for the period of 1980 to 2003. In order to minimize the forecast error, an ensemble forecast methodology is adopted which uses 5 member initial conditions from NCEP reanalysis. It is shown that this model configuration along with ensemble approach is able to capture the regional rainfall variability over the Western Ghat region. Figure 2.8 shows significant correlation of GCM simulated monthly and seasonal rainfall with TRMM rainfall observation.

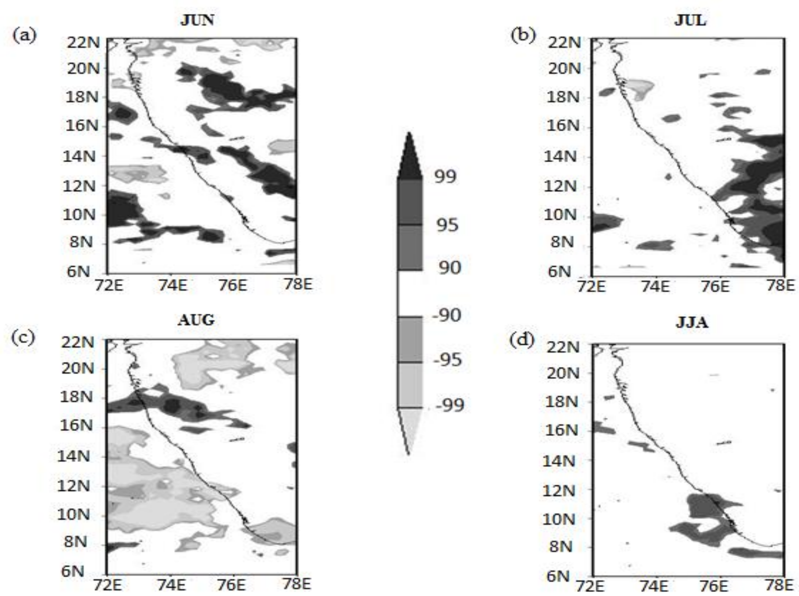

Figure 2.8 Spatial Correlation analysis of monthly (June, July, Aug) and Seasonal (JJA) rainfall from Model Simulation and TRMM observation for the period of (1998-2007). The bar indicates the significant levels of correlation.

2.9 Change detection study in Karnataka coastline using multi temporal satellite data and Geographical Information System (GIS)

Mangalore coast in Dhakshina Kannada district of Karnataka keeps varying due to changes in wind, wave, tidal and anthropogenic effects, which are seasonal. The Coastline mapping and detection of changes are important for coastal resource management, environment protection, safe navigation, sustainable coastal management and planning. Over the past 33 years, Mangalore coast have been under intensive strain associated with population pressure, urbanization and industrialization.

Analysis of coastline evolution, monitoring and estimation of potential changes using geospatial techniques and multi-temporal satellite images are presented in this work. Coastline changes were extracted by using Soltopo sheet (1982), radio metrically and geometrically corrected satellite imageries for the period 1989 to 2015. Overlay analysis of historical coastline maps of vector layers are carried out in GIS environment and analyzed changes along the coastline. Erosion and accretion were determined for entire coast by using 1km X 1km grid in four different Zones. All along the Mangalore coast, south to north, large variation in erosion and accretion processes was detected. This study reveals that all along the Netravati-Gurpur estuary there is a net deposition. Accretion is specifically observed at zone 3 and zone 4 and erosion is mainly observed at zone 2. From the change analysis of 33 years, it can be concluded that the largest variation in the coastline occurred in Mangalore south coast, Talipadi to north Sashihithlu.

The erosion and deposition map of Mangalore coast during the period 1989 to 2015 (Figure 2.9) shows net erosion during the period, around 0.47 km^2 along the coast. During the period from 1982 to 2015, erosion occurred in Zone 2 along the coastline which is southern side of Netravati-Gurpur estuary. It is also observed that northern side of this Zone 2, the Bengre accretion is occurred during this period.

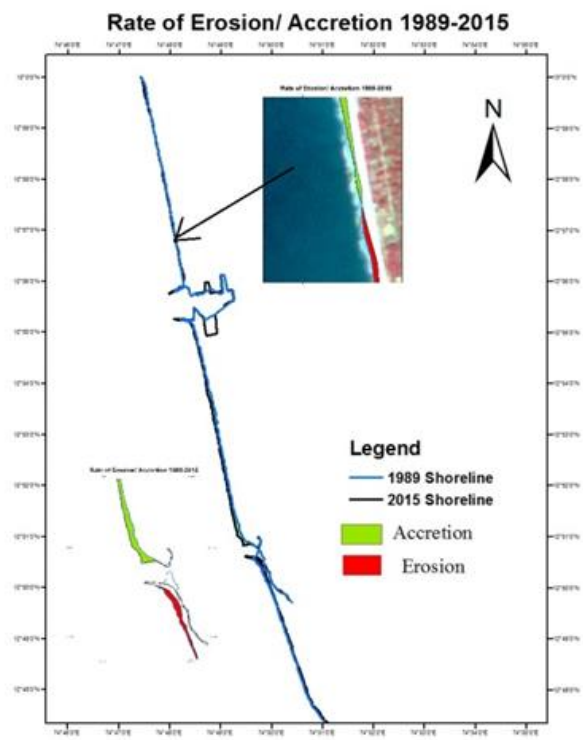

Figure 2.9 Erosion/accretion along Mangalore coast during 1989 to 2015

2.10 Analysis of cloud structure dynamics during cloud burst events over India

The extreme rainfall events related to cloud bursts over the continental India show an increasing trend in the recent decades compared to past. The disaster vulnerability is very high due to the direct impact of cloud burst events which result in torrential rains, urban flooding, landslides and post-rain epidemics. It is therefore necessary to understand the dynamical structure of the cloud, which in turn can be well represented in the numerical weather prediction models for accurate prediction of such events. In the present study the satellite derived cloud structures during the cloud burst events over India for the period 2009-2015 are analyzed to study the relation between cloud structure and TRMM surface rainfall. It is observed that the cloud burst events are well defined by the cloud structure anomaly both horizontally and vertically. The cluster analysis of the events based on different seasons (pre-monsoon, monsoon and post-monsoon) and regions (southern India and northern India) are carried out. The contrast in the distribution of cloud and the resulting rainfall was studied; a sample results of rainfall-cloud relation during monsoon and post monsoon season are shown in Figure 2.10 below. These results can be integrated in the NWP models for the accurate prediction of cloud burst events.

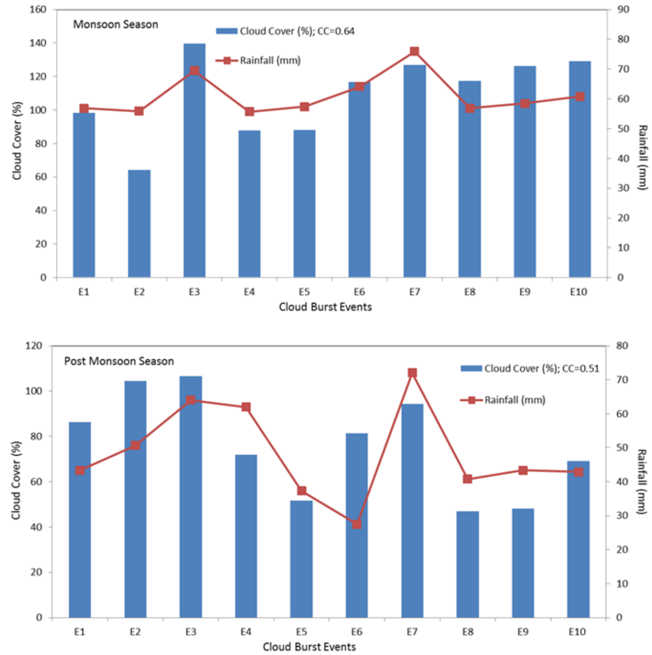

Figure 2.10 Cloud cover – Rainfall relationship during cloud burst events in monsoon (top) and post monsoon (bottom) season in India