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CLIMATE &ENVIRONMENT MODELLING

The research activities of CEMP have been aimed at providing solutions to weather and climate-related problems to minimize their adverse impact on the environment and public. Major research activities of CEMP are; Monsoon, climate and Weather Informatics, Smart Agriculture, modeling the impact of climate and weather on epidemiological diseases (malaria and chikungunya), and hydro-meteorological disasters. Group activities are also aligned with missions of Government of India (Samarth Bharat, 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.

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2.1 Impact of Land-use changes on the Genesis and Evolution of Extreme Rainfall Event: A case study over Uttarakhand, India

In this study, the impact of different land-use data sets on the simulation of an Extreme Rainfall Event (14th to 18th of June 2013,Uttarakhand) is analyzed using Weather Research and Forecast model (WRFV3.5) that was configured with 3-nest and 2-km horizontal resolution. One set of time-ensemble simulation (3 initial conditions) is carried out for each of the data set; USGS-24 category (1992-93), ISRO (2004-05) and (2012-13). Comparison of simulated rainfall which is averaged over the study region with that of IMD observed station data (averaged over 23 stations) showed that the simulations based on ISRO land-use data are comparatively more accurate with lesser simulation error when compared to simulations with USGS land-use data. The percentage of error in rainfall for the 3 simulations was found to be 24% (USGS), 9.5% (ISRO-2005) and 10 % (ISRO-2013) with respect to the IMD observation. This study shows that ISRO land-use data is a relatively more realistic representation of the study region than the USGS data, and found to be useful in reducing the model error in the simulation of such rare events over this kind of mountainous region.

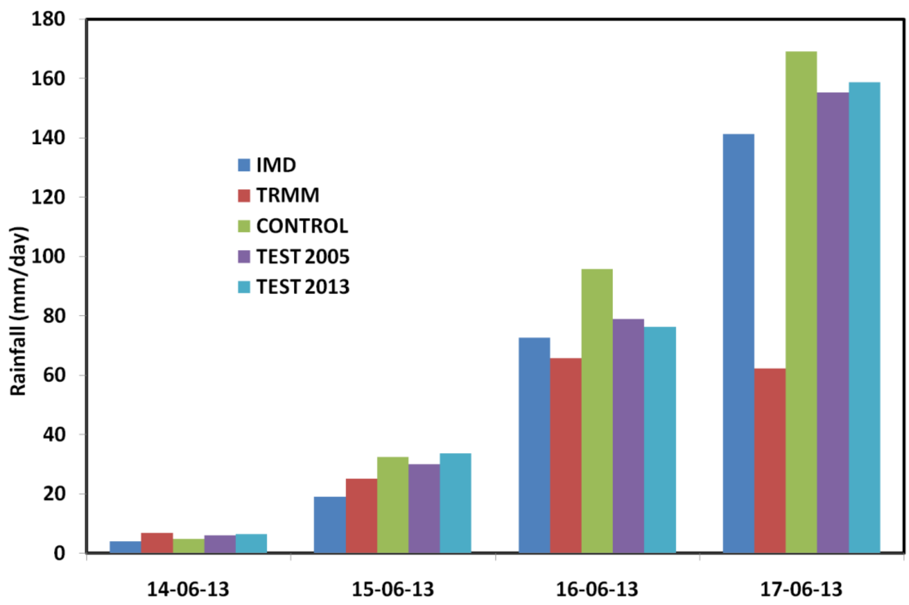

Figure 2.1 Comparison of area averaged (78ºE-80.5ºE, 28.5ºN-31ºN) simulated daily rainfall in mm with observations. All the simulations are consistently above TRMM estimate. Simulations based on ISRO data (Test-2005 and Test-2013) are closer station observations.

2.2 Simulation of Urban extreme rainfall events: Impact of increasing horizontal resolution beyond convection-permitting resolution on model skill

Urban extreme rainfall events (UEREs) are one of the weather hazards where modelers struggle for accurate advance prediction despite recent advances in forecasting techniques. In this study, the skill of sub-kilometer forecasts from the Weather Research and Forecasting (WRF) model in simulating these UEREs is examined. Through this study, we aimed at answering many scientific questions relevant to the operational forecasting of UEREs over the Indian city, Bangalore. It is interesting to know that whether an ultra-high-resolution model configuration can simulate the rainfall intensity and distribution associated with UEREs. Similarly, an important question when it comes to design an operational forecast system having many forecast cycles for giving a advance warning for extreme rainfall over a city is to know the optimum time of the day to initialize the forecast. Another important aspect in forecasting rainfall at high resolution is whether to deploy a cumulus parameterization at convection-permitting resolution. Our examination for two UERE cases showed that forecast initialized at 0600 UTC yielded the best forecast in terms of forecasting spatial distribution and intensity of rainfall. Our analysis also indicated that increasing model resolution further in convection-permitting scale (<4 km) has led to only marginal improvement in forecasting rainfall intensity. The results of this study pointed out that simulation by not deploying a cumulus scheme at cloud-resolving resolution doesn't significantly differ from those which used a cumulus scheme.

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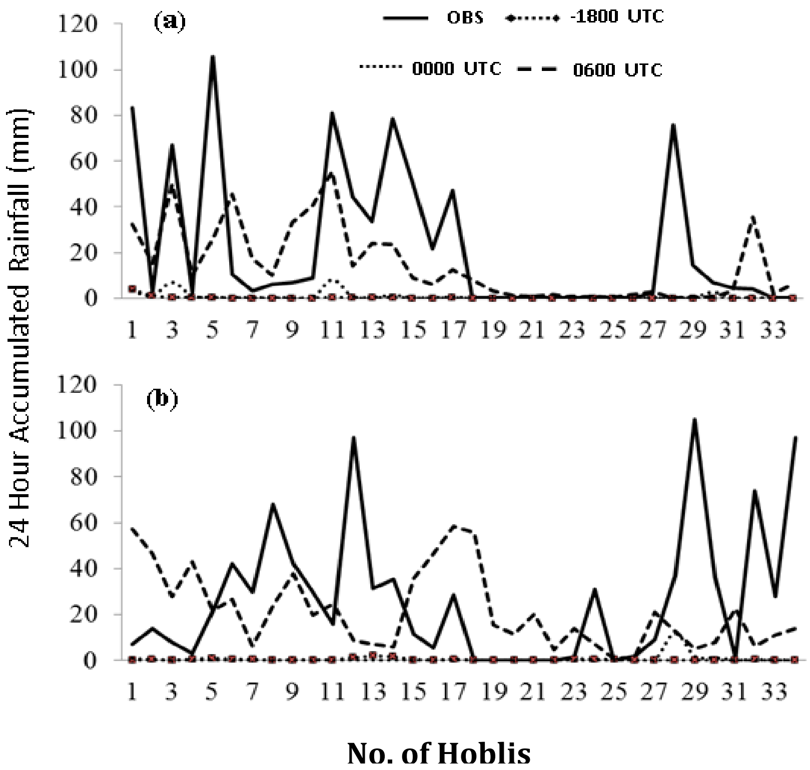

Figure 2.2 Distribution of observed and model-simulated 24 hours accumulated rainfall (mm) over different hoblis in the Bangalore city for the period, (a) 0600 UTC 14 to 0600 UTC 15 August 2017, (b) 0600 UTC 15 to 0600 UTC 16 August 2017. – Sign in the figure legend indicates the previous day.

2.3 High-resolution simulation of hydro-meteorological variables using integrated Weather research and forecasting (WRF)-hydro modeling set up: A case study over Cauvery River Catchment

Reliable estimates of surface and sub-surface lateral redistribution of runoff, in a coupled atmospheric-hydrologic modeling framework, are important in generating the basic hydro-meteorological conditions over a river basin. Due to the lack of adequate high-resolution forecast of real-time hydro-meteorological variables; the monsoon driven river basins are more vulnerable to flash-floods triggered by intense rainfall activities. One plausible way to generate such a high-resolution forecast is to use a coupled atmospheric and hydrologic modeling framework. The Coupling of hydrological models with atmospheric models provides a deeper understanding of the influence of the atmospheric variables on the hydrological processes and systems.

This helps in reducing the uncertainties associated with the location and timing of heavy rainfall driven floods and their impact. Thus, a physically-based, fully distributed, multi-scale hydrologic modeling framework, WRF-Hydro is optimally configured to simulate the important hydro-meteorological variables (precipitation, temperature, Evapotranspiration, runoff, soil moisture, and land surface heat fluxes) over Cauvery river basin during an extreme hydrological event that occurred during 08-09 August 2019. In this study, the WRF-Hydro modeling system is configured and calibrated (stand-alone and coupled-mode). The high-resolution (0.25°x0.25°, 3 hourly) GLDAS was used as forcing data. The innermost domain of WRF-hydro in conjunction with a high- resolution hydrological routing grid (300 meters) is used to include subgrid-scale disaggregation-aggregation weighting procedure to model the effects of land-atmospheric feedbacks on the hydro-meteorological variables.

The simulated variables from both models have been compared and validated against observations. The overall performance of the coupled WRF-Hydro is shown to be performed better than WRF-only simulations. The inclusion of the process of lateral redistribution and re-infiltration of precipitation in the WRF-hydro coupled model does seem to have played an important role in improving the prediction skill of the coupled model when compared to the WRF-only model. Such coupled atmospheric-hydrologic models are very useful in predicting peak river discharge and flash floods. The Fig 1 shows model domain (top panel) and the processes calibration and optimum model configuration (bottom panel). The optimum configuration of the model was arrived at using series of experimental simulations (Exp-1 to Exp-5) of river discharge with different set of parameters. Based on performance metrics like Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS) and Pearson Correlation Coefficient (CC), the river discharge simulated by experiment-5 was found to be in better agreement with observation when compared to other experiments, but still over estimates. Performance of the model can be further improved with advanced auto-calibration techniques and high-resolution precipitation forcing data

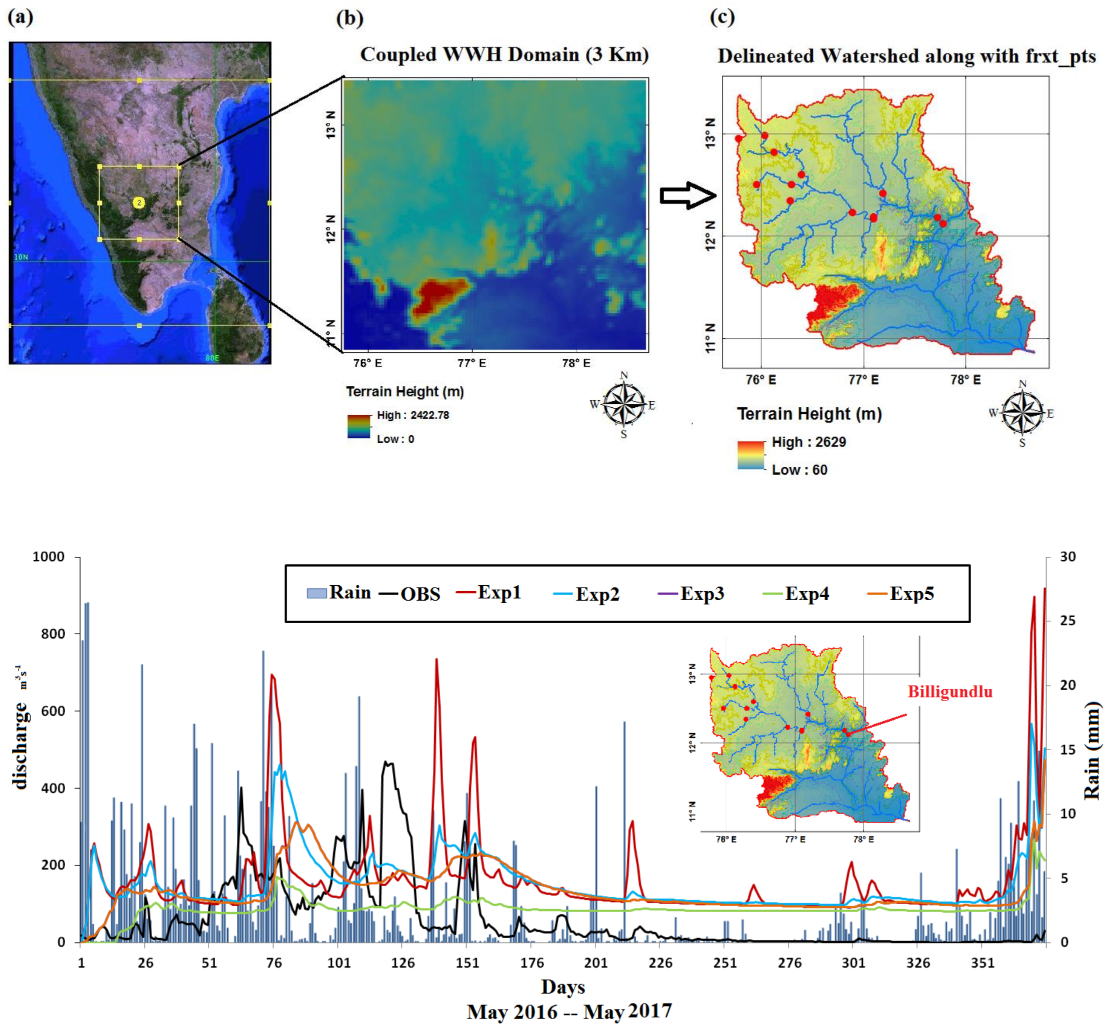

Figure 2.3 Top panel shows model domain and study region:(a) The study area with the nested configuration of coupled WRF/WRF-hydro (WWH) domains at 9 Km (outer) and 3 Km resolution, (b) Topography for the inner domain and (c) delineated Corresponding watershed characteristics along with the gauge sites. The bottom panel shows the processes model configuration based on different set of model parameters calibration using simulated river discharge.

2.4 Vegetation dynamics over India using satellite remote sensing data

The spatio-temporal anomalies in vegetation play a significant role in the surface energy budget, hydrological cycle, biogeochemical cycles, and climate change. Several researchers utilized the NDVI (Normalized Difference Vegetation Index) as a proxy to study the vegetation dynamics and applied for drought assessment, crop yield estimation over India. The present study adopted the MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI data to study the recent (2000-2016) vegetation trends and major driving factors over different meteorological sub-divisions in India during the summer monsoon period. To understand the spatial variability, we have conducted the empirical orthogonal function (EOF) analysis and found that the maximum variance in vegetation occurred in semi-arid regions located in North-West India and South India. The robust trend analysis test of Mann-Kendall applied to find the NDVI trends and the results show that the significant increasing trend over most of the sub-divisions in India. To understand the climatic impact on vegetation dynamics, we have correlated the NDVI with rainfall and soil moisture data for the selected period and found that the soil moisture has a good association with NDVI compared to the rainfall for most of the regions in India.

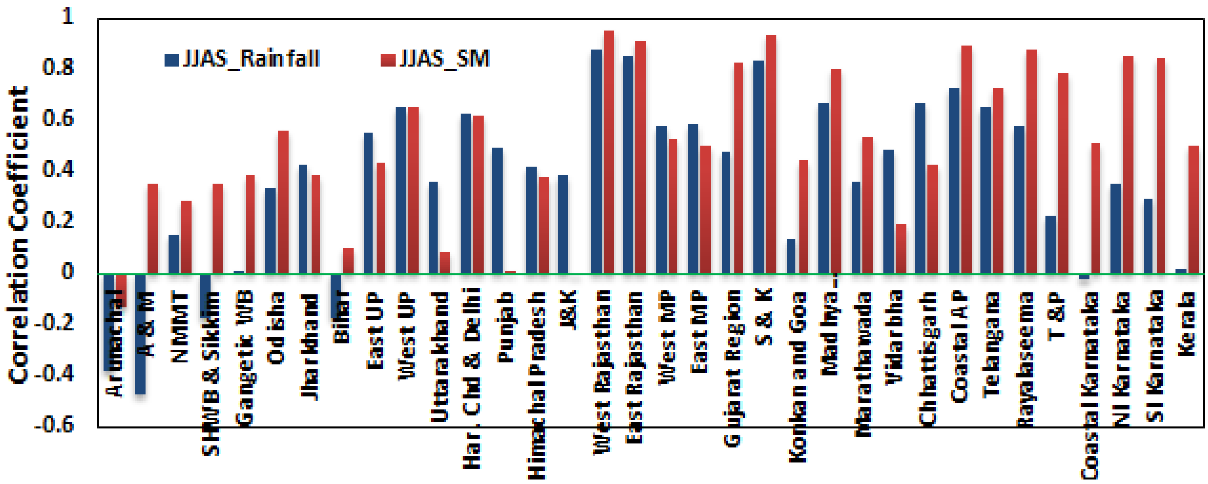

Figure 2.4 Correlation between NDVI and rainfall, NDVI and soil moisture over different meteorological sub-divisions in India during the period 2000-2016.

2.5 Deterministic Seasonal Quantitative Precipitation Forecasts using a General Circulation Model (GCM)

The seasonal quantitative precipitation forecasts (QPF) upto 3-5 months ahead are required for many applications, from agricultural planning (such as crop choice) to estimation of hydro-power and surface water availability. This work represents the benchmark skill of an atmospheric Variable Resolution General Circulation Model (VRGCM) for QPF during monsoon season over India and different regions like Central and North India, South India, North East India. The forecast skill is appreciable, with significant correlation at all India, South India and North East India regions. The Root Mean Square Error of VRGCM in forecasting quantitative rainfall overall India and Central North India is very low and bit high over South and North East region of India In terms of the interannual variability (IAV) in area-averaged seasonal rainfall over all the four regions there is significant (0.31; 95% significance) correlation between VRGCM simulated QPF and IMD observation (Fig. 2.5) for the period 1980–2013. In particular the correlation over continental India in AI scale is 0.41, where as it is 0.1, 0.3 and 0.3 over Central North India, South India and North East India, respectively showing the model performance in capturing IAV of QPF better in all regions except Central North India.

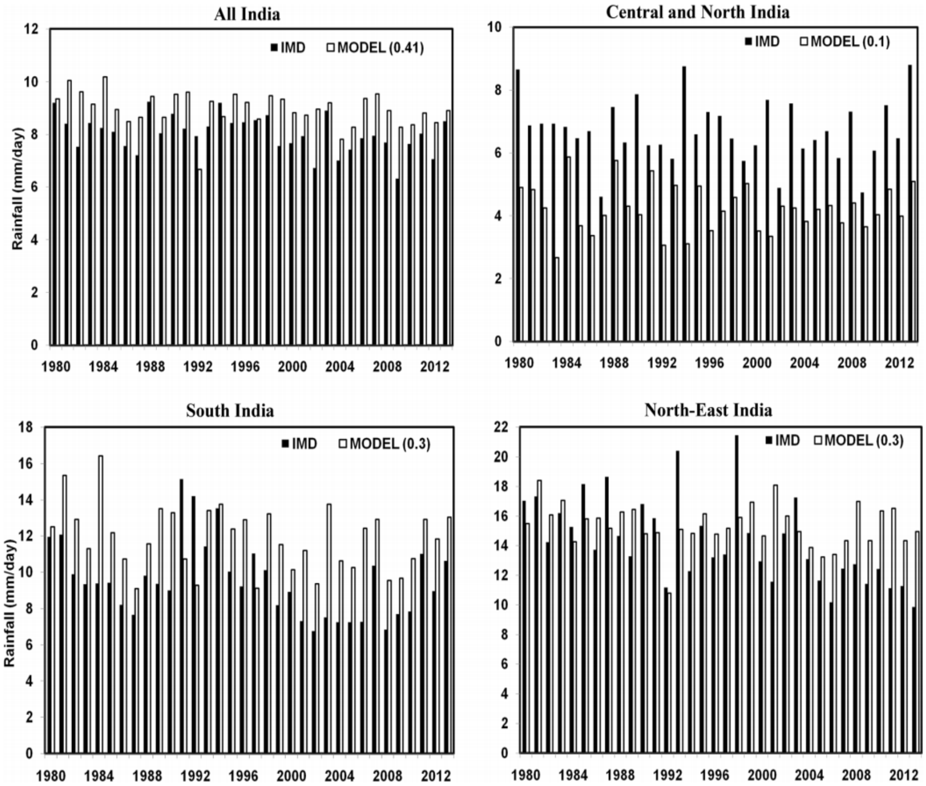

Figure 2.5 Inter-annual variability of area averaged seasonal rainfall (JJA) over the four regions from VRGCM simulation and IMD observation for the period 1980–2013. The numbers in the bracket in each panel represents correlation coefficient between VRGCM simulation and IMD observation for the respective case; the 95% level of significance is 0.3.

2.6 Seasonal rainfall forecast skill over Central Himalaya with an atmospheric general circulation model

Seasonal forecasts of monsoon over a land-locked regions with large orography, like the Himalayas using a general circulation model (GCM) is presented to explore the hypothesis that over such regions the intrinsic dynamics may play the dominant role in interannual variability of monsoon rainfall; this would imply that even a GCM without interannual variability in lower boundary forcing through SST may produce appreciable skill. The GCM is used for simulations with multiple initial conditions and multi-scale validation of seasonal forecasts is carried out at regional (Uttarakhand) to station scale over Central Himalaya with multi-source observations. The climatological (1980–2003) seasonal cycles of area-averaged daily rainfall from observation and simulation show significant (above 99%) correlation (Fig. 2.6). The ensemble average simulation is well correlated (significance level 99%) with both individual (IMD and APHRODITE) as well as with the composite observed climatology. At regional (Uttarakhand) scale, the interannual variability in composite observation and ensemble simulation are correlated at 99% significant level, with phase synchronization of about 75%. These results thus provide an effective methodology for seasonal forecasting at regional scale over certain geographical locations like Himalaya.

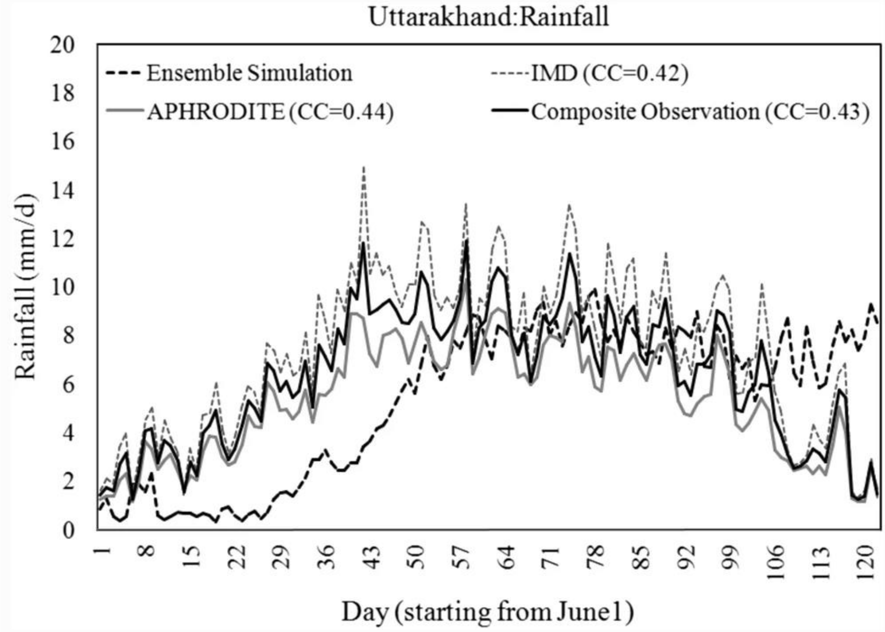

Figure 2.6 Comparison of seasonal cycle of rainfall averaged over Uttarakhand averaged over the period 1980–2003 from observations (IMD and APHRODITE) and GCM simulation; the thick solid line represents the composite of the IMD and APHRODITE observations. The 95% (99%) level of significance of correlation coefficient for degree of freedom involved is 0.10 (0.15).

2.7 Long-range dynamical forecasting of Indian monsoon 2019

The long range seasonal prediction of south west monsoon over India is carried out using the general circulation model simulation and ensemble (5 member) forecast methodology at CSIR 4PI during April 2019. The date of onset of monsoon (DOM) over Kerala was forecasted for 6th June 2019 which has 2 day error with actual DOM announcement by IMD i.e. 8th June 2019, but the late onset was accurately predicted with error less than the standard deviation in the DOM. The seasonal (June-August) and monthly distribution of rainfall anomalies over the different regions in India also generated using the model simulations and a good agreement in the forecast and observed rainfall pattern in rainfall categories (Excess/Normal/Deficit) was found almost in all regions and months (Table 2.1).

Table 2.1 Comparison of the forecast and observation of 2019 monsoon rainfall both at monthly and seasonal scale for the different regions over India. The colors indicate the rainfall category i.e. Excess, Normal and Deficit

Region	June-August		June		July		August	
	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
All-India	N	N	D	D	N	N	N	N
North-India	D	D	D	D	N	N	N	D
South India	N	D	N	D	D	D	N	N
Central India	N	E	D	D	N	N	N	N
North-east India	N	N	N	D	N	N	N	D
North-west India	D	N	D	D	D	N	N	N
South-east India	N	N	D	D	D	D	D	N