2. Climate & Environmental Modelling Programme

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, Sustainability of water resources, modeling the impact of climate and weather on epidemiological diseases (malaria, COVID-19), Urban Air Quality Modeling, and hydro-meteorological disaster modelling. 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.

Inside:

- Multi-criteria ensemble approach to simulate flash floods
- Big data analytics and Artificial intelligence in agronomic research
- Assessment of potential economic benefits from weather forecast based irrigation scheduling for marginal farmers in Karnataka
- Analysis of the spatio-temporal variability of rainfall using Machine learning techniques
- Evaluation of the skill of the WRF model in the simulation of the spatial distribution of Rainfall over the metropolitan city of Bangalore, India
- An optimum initial manifold for improved skill and lead in long-range forecasting of monsoon variability.
- Impact of Urbanization on Heavy Rainfall Event: A Case Study over a megacity of Bengaluru, India

2.1 Multi-Criteria Ensembles for hydro-meteorological analysis of a flash flood event over the megacity of Bangalore

A novel ensemble forecast methodology is used in this study to conduct a hydro-meteorological assessment of a flash flood event that occurred on the morning of 15th August 2017 over the megacity of Bangalore, India. The flash flood was triggered by the intense short-duration rainfall that was associated with the passage of westward propagating low-pressure system, causing extensive damage across the city. A coupled hydro-meteorological (WRF/WRF-Hydro) modelling framework with extensive hydrologic parameterization (convective-permitting) and subgrid-scale (300 meters) resolution is used to generate short-range (0-12 hrs lead time) prediction of quantitative precipitation, and spatial runoff. Multi-criteria ensembles are generated with both stand-alone and fully coupled atmospheric- hydrological modelling frameworks to quantify the impact of different land surface parameterization schemes (partitioning co-efficient and the different planetary boundary layer schemes) on the skill of the model to simulate precipitation and runoff. The Spatio-temporal characteristics of the ensembles thus generated have been validated against a high-resolution Indian Monsoon Data Assimilation and Analysis (IMDAA).This study has demonstrated (Figure 2.1) the potential skill of the coupled model in simulating hydro-meteorological variables (rainfall and runoff) over the megacity of Bengaluru. The proposed methodology can be used to improve the skill of the model for the short-range prediction of flash floods.

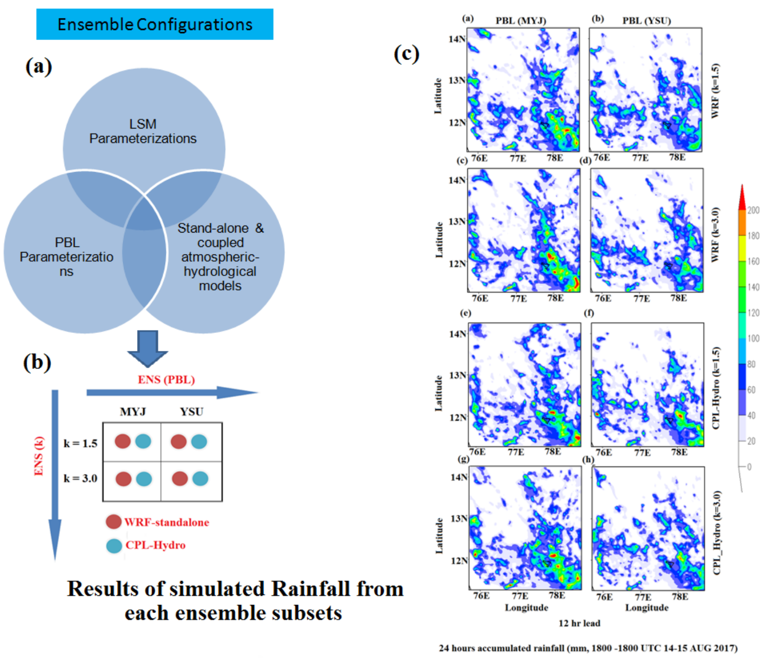


Figure 2.1: Schematics showing the multi-criteria ensembles (a, b) by using WRF -standalone and Coupled hydro (CPL-Hydro). Simulations have been carried out with two PBL schemes; MYJ and YSU. The panel c shows the spatial distribution of 24 hr accumulated simulated rainfall (from 1800 UTC of 14th August to 1800 UTC of 15th August) for the two ensemble configurations. It is shown that ENSCPL-Hydro configuration is better than ENSWRF ensemble configurations.

2.2 Application of big data analytics and artificial intelligence in Agronomic research

Modern statistical tools complemented in designing field experiments and immensely contributed to drawing useful inferences for developing good agronomic practices for increased crop production, input use efficiencies, and environmental sustainability. To enhance the reach of agronomic research, the use of emerging tools of big data analytics, geo-referenced satellite information, and imaging, and artificial intelligence (AI) based techniques that can process large data sets are described which could be validated by agronomic field experiments. Some areas of data science for use in agronomy include: satellite and Unmanned Aerial Vehicle (UAV) based data acquisition, Internet of Things (IoT), AI (machine and deep learning), and big data analytics. For example, the rice blast disease was captured by UAV based multispectral image of 5 mm ground resolution, placing the UAV at 10m height (Figure 2.2). Recent studies demonstrated that using the AI-based algorithms the accuracy in yield prediction and image classification is enhanced up to 85%. Our study using all India wheat production data for a period of 58 years showed that Bi-directional Long Short-Term Memory (LSTM) model reduced error in time series prediction to the order of 50% in comparison with conventional statistical models. Since agronomists aim for a holistic understanding of agro-ecosystems, System Dynamic Model (SDM) of specific agricultural systems wherein the topography, climate, hydrology, natural resources, and societal requirements are coupled along with their feedback impacts on agronomic systems has been introduced and discussed.

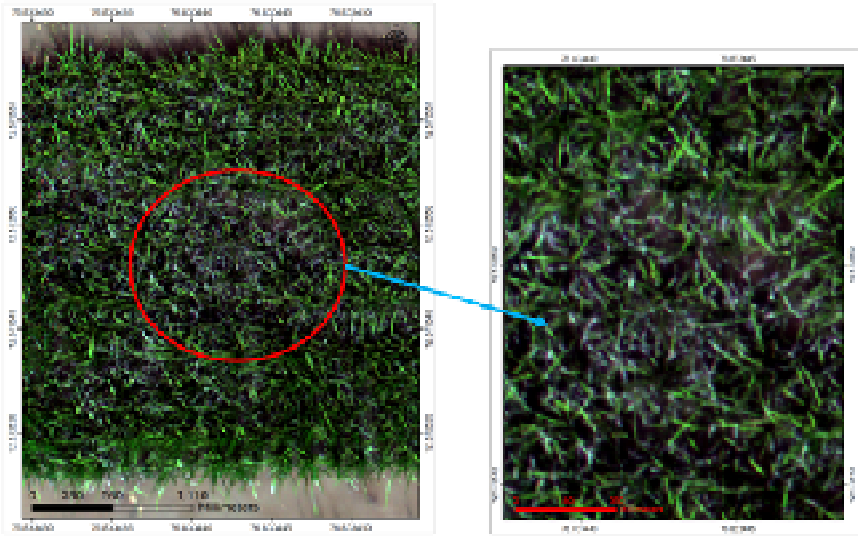


Figure 2.2: UAV based multispectral imaging of rice field; 5 mm resolution image taken from multi spectral camera (left), rice blast disease is clearly visible in the enhanced image (right).

2.3 An assessment of potential economic gain from weather forecast based irrigation scheduling for marginal farmers in Karnataka, a southern state in India

This study is aimed to assess the usefulness of weather forecasts for irrigation scheduling in crops to economise water use. The short-term gains for the farmers come from reducing costs of irrigation with the help of advisory for when not to irrigate because rain is predicted (risk-free because the wrong forecast only delays irrigation within tolerance). Here, a quantitative assessment of saving (indirect income) if irrigation is avoided as rain is imminent (as per forecast), using a five-year archived forecast data over Karnataka state at hobli (a cluster of small villages) level is presented. Estimates showed that the economic benefits to the farmers from such advisories were significant. The potential gain in annual income from such forecast based irrigation scheduling was of the order of 10-15% (Figure 2.3). Our analysis also indicated that the use of advisory by a small percentage of more than 10 million marginal farmers (land holding <3 acres) in Karnataka could lead to huge cumulative savings of the order of many crores.

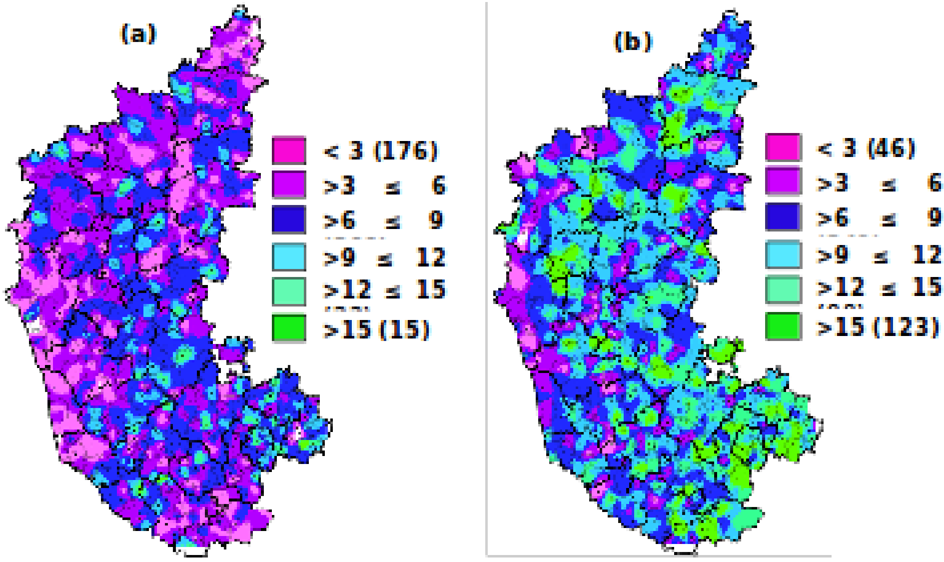


Figure 2.3: Assessment of the economic impact of forecast based irrigation scheduling; (a) for 10 days and (b) 7-day continuous dry spell scenario; these figures show the percentage potential gain in annual income (Indian rupees, Rs 1,20,000 per year is considered as annual income) for a farmer over different parts of Karnataka cumulative for the five years (2011-2015). The number in the bracket shows the number of hoblis in each range.

2.4 Spatio-temporal rainfall variability over different meteorological subdivisions in India: analysis using different machine learning techniques

Understanding and quantifying the long-term variability of rainfall at the regional scale is important for a country like India where economic growth is very much dependent on the agricultural production which in turn is closely linked to rainfall distribution. Using machine learning techniques viz., cluster analysis (CA), and principal component analysis (PCA), the spatial and temporal rainfall patterns over the meteorological subdivisions in India are examined. Monthly rainfall data of 117 years (1901–2017) from the Indian Meteorological Department over 36 meteorological subdivisions in India is used in this study. Using the hierarchical clustering method, six homogeneous rainfall clusters were identified in India. Among the rainfall clusters, Group 1 had 30% dissimilarity with Groups 2, 3, and 4, while Group 5 and 6 are highly dissimilar (more than 90%dissimilarity) compared to the rest of the groups. Rainfall seasons in each group were further classified into dry, wet, and transition periods (Figure 2.4). The duration of the dry period is smaller in the group which consists of subdivisions from the southern part of the country. The transition period between the dry and wet periods was found to be smaller for subdivisions in the coastal region. Both CA and PCA showed high rainfall variability in Groups 5 and 6, which comprise subdivisions from the northeast, Kerala, Konkan, and coastal Karnataka, and low rainfall variability in Groups 1 and 2 which comprise subdivisions from the east, north, and central part of the country. A Strong negative trend in annual and Indian summer monsoon rainfall is seen in northeast India and Kerala, while a positive trend is observed over the costal Karnataka and Konkan region. The negative trend in post-monsoon rainfall, particularly over the peninsular and northeast India, indicates a weakening of northeast monsoon rainfall in the country.

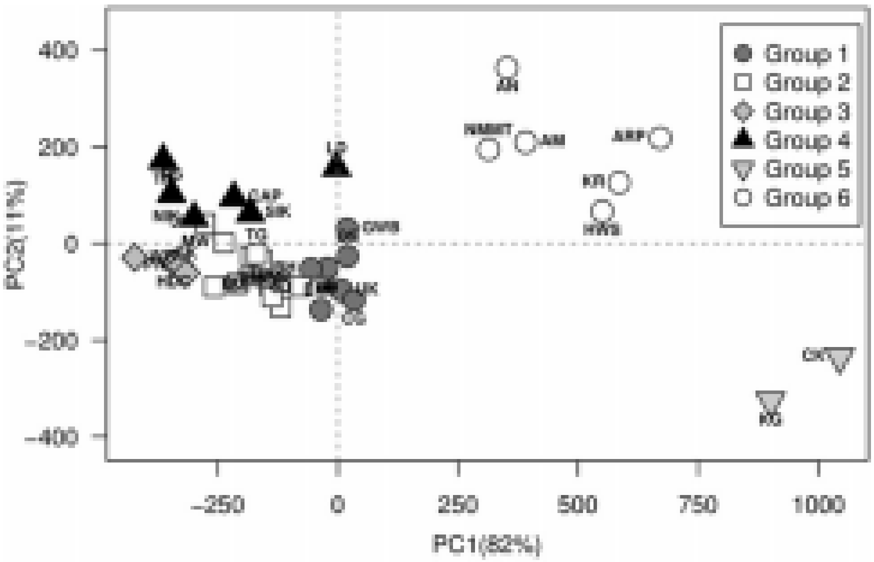


Figure 2.4: First factorial plane of the principal components PC1 and PC2 for different spatial groups showing rainfall variability for the period 1901–2017.

2.5 Evaluation of the skill of the WRF model in the simulation of the spatial distribution of Rainfall over the metropolitan city of Bangalore, India.

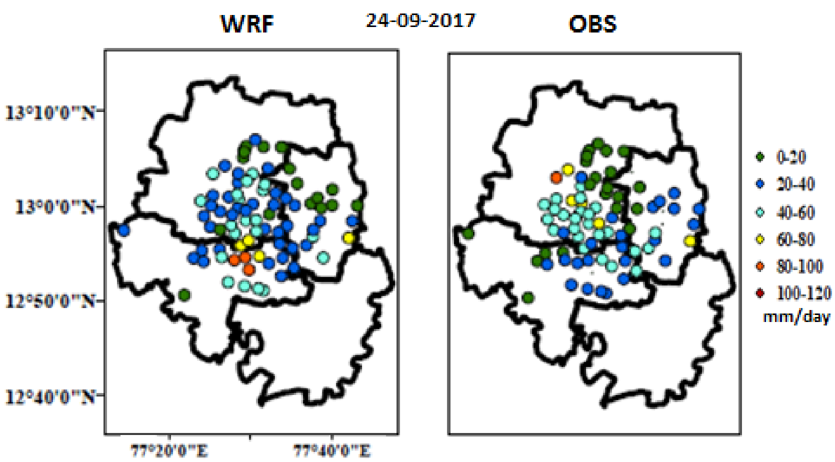


Figure 2.5: Comparison between the WRF model simulated (left panel) and observed (right panel) 24 hour accumulated rainfall at 81 rain-gauge stations over Bangalore.

Urbanization alters the natural land cover with an impervious surface like concrete and asphalt, forms the urban canopy due to the building structures, and modifies the thermal and dynamic characteristics of the surface layer. These changes in turn significantly influence the surface heat balance, exchange of water vapor and momentum between the surface layer and atmosphere, and urban precipitation. The present study evaluates the skill of the Weather Research and Forecasting (WRF) model to simulate the spatial distribution of rainfall over the metropolitan city of Bangalore, India. The novelty of the present study is that the WRF model simulations were compared with a high-density rain gauge network (81 rain gauge stations) over Bangalore. Our analysis shows that the model under-estimated (Bias score <1) the rainfall for most (87%) of the stations and the model accuracy in the forecasting of rainfall was more than 70% for 16% of stations in the city. The RMSE values were ranging between 18 and 28 mm/day for most of the rainfall events (Figure 2.5). Our analysis also found that the under-estimation of the Convective Available Potential Energy (CAPE <2000J/kg) may be the possible reason for the simulation of low-intensity rainfall (<10mm/day) in most of the stations in Bangalore. Proper representation of the urban morphology, air pollution, and anthropogenic heat data in the WRF modelling system may improve the model skill to capture the spatial variability in rainfall over highly urbanized cities in India.

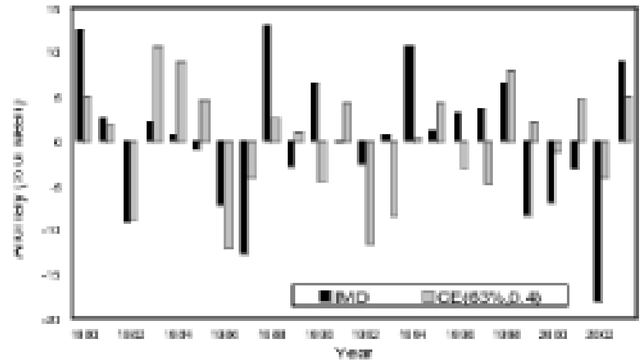
2.6 An optimum initial manifold for improved skill and lead in long-range forecasting of monsoon variability.

Using an initial manifold approach, an ensemble forecast methodology is shown to simultaneously increase lead and realizable skill in long-range forecasting of monsoon over continental India. Initial manifold approach distinguishes the initial states that have coherence from a collection of unrelated states. In this work, an optimized and validated variable resolution general circulation model is being adopted for long-range forecasting of monsoon using the multi-lead ensemble methodology. In terms of realizable skill (as against potential) at resolution (60km) and lead (2–5 months) considered here, the present method performs very well. The skill of the improved methodology is significant, capturing 9 of the 12 extreme years of monsoon during 1980–2003 in seasonal (June–August) scale. Eight-member ensemble-average hindcasts carried out for realizable skill with lead of 2 (for June) to 5 (for August) months and an optimum ensemble is presented. In terms of inter-annual variability in area-averaged (75-85oE, 8-28oN) seasonal (June-August) rainfall, defined as departure from corresponding 24 years (1980-2003) mean, Optimum initial Manifold (OIM) outperforms both Compact Ensemble and Large Ensemble (Figure 2.6). The OIM has a phase synchronization of 67% with a correlation coefficient of 0.44 between all-India seasonal (JJA) rainfall anomalies, significant at 99% confidence level for the degrees of freedom involved.

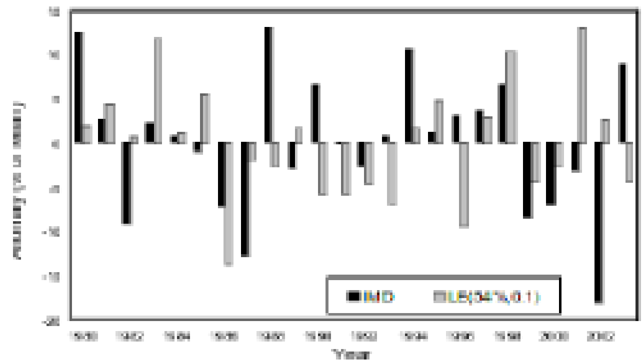
2.7 Impact of Urbanization on Heavy Rainfall Event: A Case Study over a Megacity of Bengaluru, India

This study is about the simulation and observational analysis of a heavy rainfall event (HRE) and its sensitivity to land-use changes. The impact of urbanization on processes and mechanisms of rainfall including cloud processes is discussed. This study is based on high-resolution (2 km), time-ensemble simulation of one of the HREs that occurred on 27 May 2017 over the city of Bengaluru in the southern part of India. The simulations are carried out using the Weather Research and Forecasting (WRF) model, which is coupled with a single-layer urban canopy model (UCM). The high-resolution (30 s) land-use data derived from the Indian Space Research Organization (ISRO) for the year 2016–2017 is shown to be realistic in representing the current land-use scenario with a threefold increase in urbanization when compared to USGS land-use data of 1991–1992. Simulated rainfall was found to be remarkably sensitive to land-use changes as shown by control (USGS) and test (ISRO) simulations. The rainfall intensity and spatial distribution are close to observation in test simulations with relatively less error at station scale with a correlation of 0.49 (95% significance) when compared to control simulations, indicating the importance of realistic

Compact Ensemble (Apr23-May01)



Large Ensemble (Mar01-April 30)



Optimum Initial Manifold (Mar18-April15)

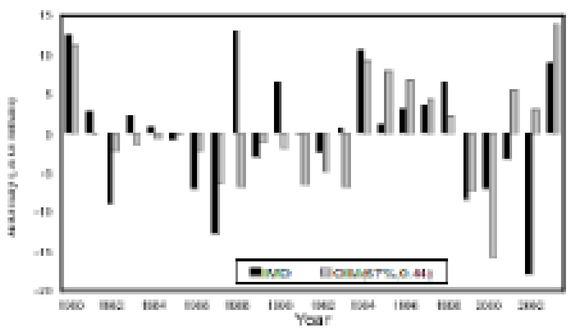


Figure 2.6: Inter annual variability in the all India monsoon seasonal (June-August) rainfall anomaly (expressed as % of respective mean) for (a) Compact Ensemble (b) Large ensemble and OIM. The two numbers in the bracket in each panel represent, respectively, the phase synchronization (%) and correlation coefficient with observed (IMD) rainfall anomalies.

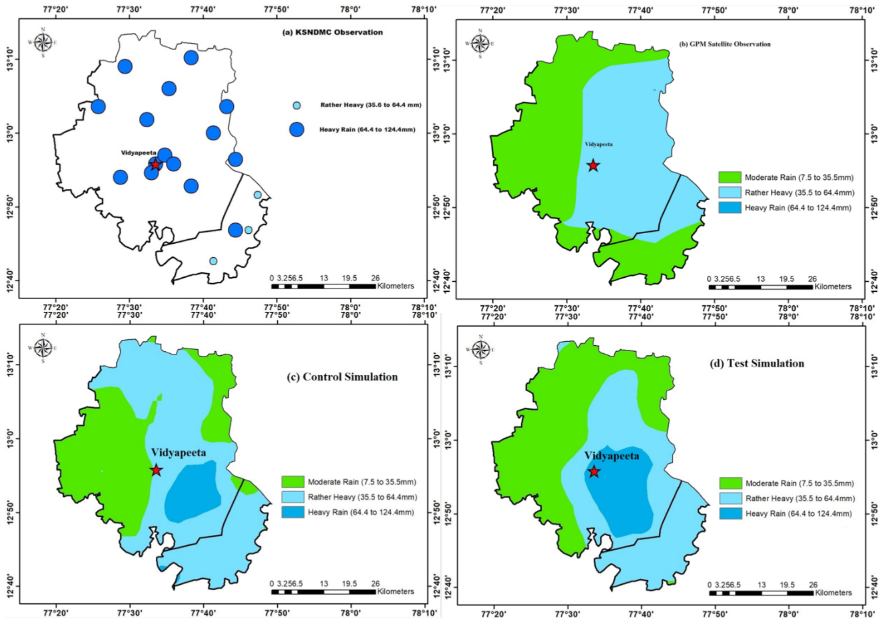


Figure 2.7: Comparison of 24-hr accumulated rainfall (mm) from (a) KSNDMC station observation (b) GPM Satellite observation and (c) control & (d) test simulations during 00UTC 27thMay 2017 to 00UTC 28th May 2017. Red star represents Vidyapeetha, the location of maximum rainfall (120 mm) observed by KSNDMC station observation.

representation of land use in the model and its impact on heavy rainfall processes (Figure 2.7). The test simulation which represents the current urbanization scenario has shown a significant increase in rainfall by over 100–200%. The surface energy fluxes and thermodynamic indices as shown by test simulations are favorable to HREs, and also consistent with the current land-use scenario with increased urbanization. This study demonstrated how a realistic representation of land-use data in the model can help to improve model skill. The main limitation of this research work is that it is based on the generic parameterization of urbanization using single-layer UCM. An in-depth study based on multi-layer UCM and city-specific parameterization of urbanization using sub-kilometer-scale land-use data including buildings would further enhance our understanding on this subject.