Unravelling the Mechanism for Extreme Rain Events in Kerala, India

During both August 2018 and August 2019, the southern state of India, Kerala, received unprecedented heavy rainfall that led to widespread flooding. Rainfall departures from long-term daily climatological values as observed by the India Meteorological Department (IMD) during August 6–19 in both 2018 and 2019 are computed, and the majority of the stations show that the standard deviation (SD) of the actual rainfall is at least 30–50 times the climatological SD for the period, with daily average rainfall for both years exceeding climatology by 236% and 219%, respectively. As such, the events of August 2018 and August 2019 are termed as unprecedented in nature. We aim to characterize the convective nature of these events and the large-scale atmospheric forcing, while exploring their predictability by three state-of-the-art global prediction systems.

The ensemble predictions were more skillful than the deterministic forecasts, as they were able to predict rainfall anomalies.

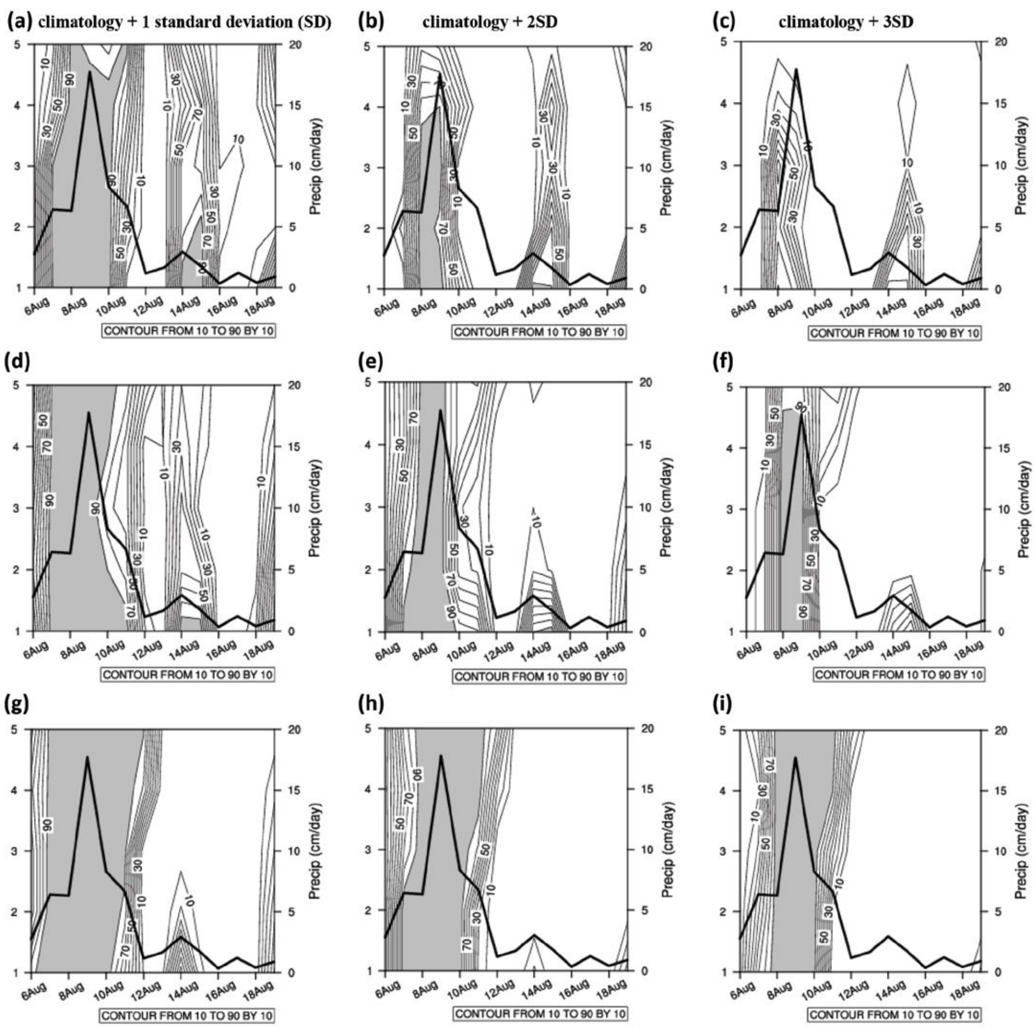
These modeling systems are the National Centers for Environmental Prediction (NCEP)-based IMD operational Global Forecast System (GFS), the European Centre for Medium Range Weather Forecast (ECMWF) integrated forecast system (IFS), and the Unified Model-based NCUM being run at the National Centre for Medium Range Weather Forecasting (NCMRWF).

Satellite, radar, and lightning observations suggest that these rain events were dominated by cumulus congestus and shallow convection with strong zonal flow leading to orographically enhanced rainfall over the Ghats mountain range, while sporadic deep convection was also present during the 2019 event. Moisture budget analyses using the ERA5 (ECMWF Reanalyses version 5) reanalyses and forecast output of all three models (GFS, IFS, NCUM) revealed significantly increased moisture convergence below 800 hPa during the main rain events compared to August climatology. The total column integrated precipitable water tendency, however, is found to be small throughout the month of August, indicating a balance between moisture convergence and drying by precipitation. By applying a Rossby wave filter to the rainfall anomalies, it is shown that the large-scale moisture convergence is associated with westward propagating barotropic Rossby waves over Kerala, leading to increased predictability of these events, especially for 2019.

Evaluation of the deterministic and ensemble rainfall predictions revealed systematic rainfall differences over the Ghats mountains and the coastline. To explore the probabilistic predictions, we first consider the probability of rainfall exceeding the threshold of one SD above the observed climatology. The daily climatological value for Kerala is around 20 mm day^{-1}, with one SD corresponding to 15 mm day^{-1}. Using as a measure a probability of occurrence of 50%, it is found that for August 15 all model forecasts are skillful up to 5 days. Increasing the rainfall threshold further to two SD reduces the predictive skill of the ensemble systems to around 3 days, with the NCMRWF Ensemble Prediction System (NEPS) showing a second peak in prediction skill beyond day 3. Finally, increasing the precipitation threshold to three SD reduces the predictive skill of the ensemble systems to 1–2 days.

The above analysis has been repeated for the August 2019 event. Now all models exhibit considerable skill, predicting the two-SD rainfall anomalies up to day 5 with a probability of 90%, with the IFS and NEPS being able to predict reliably even the three-SD anomalies beyond day 5. Thus, the ensemble predictions were more skillful than the deterministic forecasts, as they were able to predict rainfall anomalies (>3 standard deviations from climatology) beyond day 5 for August 2019 and up to day 3 for 2018.—Parthasarathi Mukhopadhyay

(Indian Institute of Tropical Meteorology), P. Bechtold, Y. Zhu, R. P. M. Krishna, S. Kumar, M. Ganai, S. Tirkey, T. Goswami, M. Mahakur, M. Deshpande, V. S. Prasad, C. J. Johny, A. Mitra, R. Ashrit, A. Sarkar, S. Sarkar, K. Roy, E. Andrews, R. Kanase, S. Malviya, S. Abhilash, M. Domkawle, S. D. Pawar, A. Mamgain, V. R. Durai, R. S. Nanjundiah, A. K. Mitra, E. N. Rajagopal, M. Mohapatra, and M. Rajeevan, "Unravelling the mechanism of extreme (more than 30 sigma) precipitation during August 2018 and 2019 over Kerala, India," in a forthcoming issue of *Weather and Forecasting*. ●



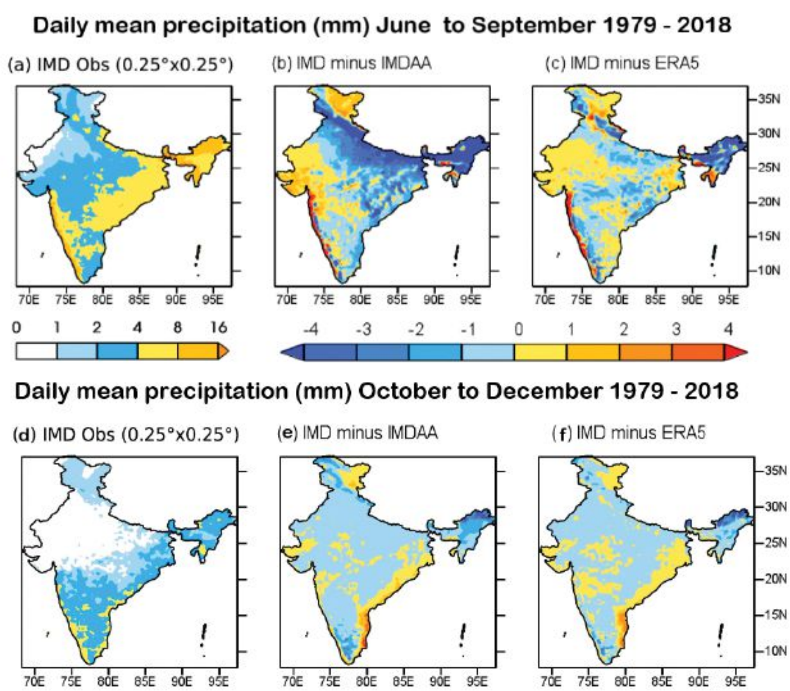
Considerable forecasting skill. Forecast lead time diagram of the probability for (top row) the GEFS forecast, (middle row) ECMWF, and (bottom row) NEPS for the daily accumulated rain over Kerala (10°–12°N, 75.5°–77°E) exceeding the observed daily climatology plus (first column) one SD, (middle column) two SD, and (third column) three SD. The black line represents the IMD-GPM rainfall (cm day^{-1}) averaged for the same region for the period Aug 6–19 2019.

IMDAA: A Regional Reanalysis for the Indian Monsoon

A high-resolution satellite-era regional reanalysis produced by the Indian Monsoon Data Assimilation and Analysis (IMDAA) project has recently been made available to researchers (https://rds.ncmrwf.gov.in). This 40-year reanalysis (1979–2018) at 12-km resolution covers a large geographical domain (30°E–120°E, and 15°S–45°N) affected by monsoons. The IMDAA reanalysis was produced by the collaborative efforts of the National Centre for Medium Range Weather Forecasting (NCMRWF), India, the UK Met Office, and the India Meteorological Department (IMD), under the National Monsoon Mission project of the Ministry of Earth Sciences, Government of India. It presently is the highest-resolution atmospheric reanalysis available for the Indian monsoon region, and can be used for research on weather and climate over southern and southwest Asia.

The IMDAA reanalysis was prepared using the 4D-Var data assimilation method and the UK Met Unified Model.

The IMDAA reanalysis was prepared using the 4D-Var data assimilation method and the UK Met Unified Model. Conventional and satellite observations from different sources were used, including Indian surface and upper-air observations, some of which were not used in any previous global or regional reanalyses. IMDAA primarily used the meteorological observations collated by ECMWF for reanalysis. Lateral boundary conditions for the IMDAA runs were provided by the ECMWF global reanalysis of ERA-Interim.



IMDAA precipitation verification. Comparison of IMDAA and ERA5 daily mean precipitation (mm) with IMD observations, during the southwest or summer (June–September) and northeast or winter (October–December) monsoon seasons, for 1979–2018.

The IMDAA reanalysis time frame was highly challenging because of the rapid developments in observing systems, especially satellites. A continuous increase in the number of assimilated observations (both conventional and satellite) has been seen during the IMDAA period. New satellite instruments with high spatial and temporal resolution contributed to the accuracy of the atmospheric analysis, but this highly varying observing system can lead to discontinuities in the reanalysis. Satellite radiances from almost 25 instruments, onboard more than 40 different satellites, have been assimilated after initial, background, and redundancy quality controls. An effective bias correction procedure, the variational bias correction (VarBC), has been applied to the satellite radiances. The VarBC adjusts the biases for satellite radiance observations based on other assimilated observations such as radiosondes and aircraft and rejects observations that are too far from analysis after successive minimization.

Salient features of the Indian monsoons estimated from IMDAA match up with the IMD observations and compare well with the ERA5 reanalysis. The Indian summer monsoon onset date estimates from both IMDAA and ERA5 agree well with the observations. Similarly, the monsoon withdrawal date estimates from IMDAA are closer to observations and are highly correlated with ERA5. Monsoon semipermanent features like the Low-Level Jet (LLJ) and Tropical Easterly Jet (TEJ) estimated from IMDAA are highly correlated with ERA5 and agree with existing observational findings. The interannual and intraseasonal variability of the summer monsoon rainfall is well represented in IMDAA; however, in general, IMDAA is wet, particularly over the Himalayan foothills. However, IMDAA realistically reproduces the orographic rainfall along the Western Ghats, which is better than ERA5 when compared with the IMD observations. The rainfall estimates from both IMDAA and ERA5 are close to each other during the winter monsoon period. IMDAA produces a slightly cooler winter and a hotter summer than the observations, which is the opposite of ERA5. A case study of extreme rainfall over complex terrain shows that IMDAA captured the finescale features associated with a notable heavy rainfall episode.

Salient features of the Indian monsoons estimated from IMDAA match up with the IMD observations and compare well with the ERA5 reanalysis

The hourly and three-hourly IMDAA reanalysis products are accessible to researchers through the NCMRWF reanalysis portal. Details of the IMDAA reanalysis, including the observations used and their quality control procedures, data assimilation system, the forecast model, postprocessing, and the performance of IMDAA reanalysis during various seasons over India in comparison with IMD observations and ERA5 reanalysis, are available in the full paper.—S. Indira Rani (National Centre for Medium Range Weather Forecasting), Arulalan T., J. P. George, E. N. Rajagopal, R. Renshaw, A. Maycock, D. M. Barker, and M. Rajeevan, "IMDAA: High-resolution satellite-era reanalysis for the Indian monsoon region," in a forthcoming issue of the *Journal of Climate*.