Predictability and Dynamics of Extreme Weather Events Over the Indian Subcontinent using Ensemble Sensitivity Analysis in EnKF Data Assimilation System

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by

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Abstract

Forecasting extreme weather events using Numerical Weather Prediction (NWP) model is challenging due to the uncertainties associated with the growth of initial errors under chaotic dynamics. Therefore, it is essential to initialize a model with the best estimate of the atmosphere and understand how errors in this initial condition will affect the subsequent forecast. Statistically reliable ensemble predictions from the different realization of initial conditions of the atmosphere are found to be robust in forecasting extreme weather events. The predictability of weather events can be quantified through sensitivity analysis, which essentially indicates how forecast from an NWP system responds to changes in initial conditions. Ensemble sensitivity analysis (ESA) is a linear approach to sensitivity analysis that uses sample statistics to estimate how a scalar forecast function changes with respect to initial conditions. In this research work, ESA is applied to understand the nature and predictability of extreme weather events over the Indian subcontinent by using ensemble analyses and forecasts from an Ensemble Kalman filter (EnKF) data assimilation system. The Weather Research and Forecasting (WRF) is used as the NWP model in this study. In addition, the ensembles from TIGGE European Centre for Medium-Range Weather Forecasts and National Centers for Environmental Prediction Ensemble Prediction Systems have also been employed.

ESA often uses a diagonal approximation to the multivariate regression, leading it to a simple univariate regression, and it is often referred to as univariate ensemble sensitivity analysis. Univariate ESA applied to extreme rainfall event over the Uttarakhand state located in the Western Himalayas indicates that the heavy precipitation is sensitive to the mid-tropospheric trough and moisture fields from the Arabian Sea and the Bay of Bengal. Perturbed initial condition experiments reveal that the initial condition perturbations in the maximum sensitive region can have a large impact on the rainfall. Further, two extreme rainfall events over Kerala in August 2018 (KF18) and 2019 (KF19) are analysed using univariate ESA. In the case of Kerala rainfall in 2018, the results show that the circulations positioned farther east of its mean position over the Western

North Pacific (WNP) are related to stronger precipitation over the response function region. However, in the case of Kerala rainfall in 2019, the moisture-laden low-level flow was more substantial, which favored the development of deep convective clouds and caused extreme rain.

The presence of sampling error can cause the univariate ESA to overestimate the response of a forecast metric to initial conditions. Therefore, univariate ESA is extended to multivariate ESA that utilizes the full covariance matrix. The performance of multivariate ESA over univariate is examined by applying the method to a heavy rainfall event that happened over Chennai in December 2015. The multivariate ESA shows more organized sensitive patterns, unlike univariate sensitivity in which the sensitivity patterns are broadly distributed. Both methods are validated using the perturbed initial condition approach, and it is found that multivariate is more effective in predicting the forecast response closest to the actual model response compared to the univariate ESA.

Further experiments were performed using the multivariate ESA to investigate the general predictability characteristics of tropical cyclones over the Bay of Bengal. Results show that intense, fast-moving, and north-landfalling tropical cyclones exhibit low predictability in its intensity forecast. Intense storms exhibit large initial condition sensitivity than the analysis spread indicating that the low predictability of intense cyclones is likely due to large dynamical perturbation growth. The results of the perturbed initial condition experiment show that the dynamical error growth is faster if the perturbations are smaller in magnitude. It is also found that the error growth associated with moist perturbations is higher for the less predictable tropical cyclones.

Towards the end, we have determined the climatological ensemble sensitivity to identify the optimal locations for deploying the observation network during the Indian summer monsoon. Results show that the precipitation forecasts during the Indian summer monsoon season benefit from the assimilation of observations located over the upstream regions of the forecast metric box.