Understanding the Predictablity of Extreme Weather Events using Ensemble-Based Data Assimilation

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Abstract

The predictability and dynamics of two extreme weather events are explored using ensemble forecast initialized from an ensemble Kalman Filter (EnKF) data assimilation system. The tropical cyclone Nargis over the Bay of Bengal and the heavy rainfall over the Uttarakhand on June 2013 are the two events considered. For Nargis, ensemble members indicate faster movement of TC and large uncertainty in landfall location as compared to the JTWC estimate. The detailed analysis shows that the uncertainties in the steering wind has led to the faster movement of TC in the model forecasts. The ensemble based sensitivity analysis reveals that the uncertainty in the position and strength of the trough is closely linked to the precipitation over the Uttarakhand.

1 Introduction

The tropical Nargis, formed over the Bay of Bengal during April 2008 is one of the worst natural disasters in the recorded history of Myanmar. Tropical cyclone Nargis is unique in many aspects. After initial westward movement, it recurved eastward and made its landfall over Myanmar resulting in a loss of more than 1,00,000 lives. The storm, which intensified initially, has weakened thereafter and has undergone rapid intensification 24 h prior to the landfall. The objective of the study is to understand the factors affecting the predictability of Nargis using ensemble forecast generated from the Ensemble Kalman Filter (EnKF) data assimilation system.

Another objective of the study is to quantify the predictability characteristics of Uttarakhand heavy rainfall event during June 2013 using the ensemble framework. The ensemble sensitivity analysis (ESA) approach is used to identify the key synoptic and convective elements that produces uncertainties in the position and intensity of the precipitation bands over the Uttarakhand.

2 Ensemble Sensitivity Analysis

A sensitivity analysis is performed to understand the dynamics of the heavy rainfall event over the Uttarakhand. The method as suggested in [4] is utilized in this study. The equations is shown as below

$$\text{ES} = \text{covariance}\,(\mathbf{J}, x_i)/\text{variance}(x_i) \quad (1)$$

where $\mathbf{J}$ is the forecast metric and x_i is state variable.

Physically, ES provides information about the changes in forecast metric due to the changes in state variables over a targeted domain. The ensemble sensitivity (ES) defined by the above equation describes the change in the forecast metric corresponding to one standard deviation change in the chosen state variable ([1]). The sensitivity calculations may be subjected to sampling errors, and hence the regression coefficient is tested for statistical significance.

3 Experimental design

The Advanced Research WRF (ARW-WRF) of version 3.6.1([2]) is used as the NWP model in both studies. The WRF employs a suite of parameterization schemes to represent unresolved/unknown quantities. The current study utilizes Yonsei State University (YSU) for planetary boundary layer parameterization, WRF single-moment five-class for microphysics, Unified Noah Land Surface Model, Rapid Radiative Transfer Model for longwave radiation and Dudhia scheme for shortwave calculations. The model domain is configured with 350 × 350 grid points in east-west and north-south directions with 27 km horizontal grid spacing and 31 non-uniformly spaced levels in the vertical. The initial and lateral boundary conditions are generated from the National Center for Environmental Prediction (NCEP) Global Forecast. The Data Assimilation Research Testbud (DART) Ensemble Adjustment Kalman Filter (EAKF; [3]) system is employed to assimilate observations.

4. Results

The results for the tropical cyclone Nargis indicates that the presence of strong steering flow is responsible for the faster movement of tropical cyclones in the model simulations as compared to that of JTWC estimates. The presence of horizontal temperature gradient in the meridional direction generates strong geostrophic wind in the zonal direction (thermal wind relations). Therefore even a slight variation in the depiction of north-south gradient of temperature will result in the substantial variation in the magnitude of zonal flow (steering wind). We hypothesize that the presence of such strong meridional temperature gradient is responsible for the eastward recurving, faster moving Nargis. To test the hypothesis, the horizontal temperature gradient has been modified by suppressing its gradient in the meridional direction. The result indicates that the suppression of horizontal temperature gradient has weakened the westerlies as well as the translational speed of the Nargis (Figure 1).

Figure 2 depicts the sensitivity of 24 h accumulated precipitation valid at 1200 UTC of 17 June 2013 to the geopotential height at 500 hPa. A prominent sensitivity dipole region is observed far south of Uttarakhand at 6 h forecast, which then progresses northeastward during the later hours of the forecast. The area of negativity sensitivity indicate that the decrease in geopotential height in those regions will increase the forecast metric over the targeted region. In the present study, the 24 h accumulated precipitation over Uttarakhand is used as the forecast metric.

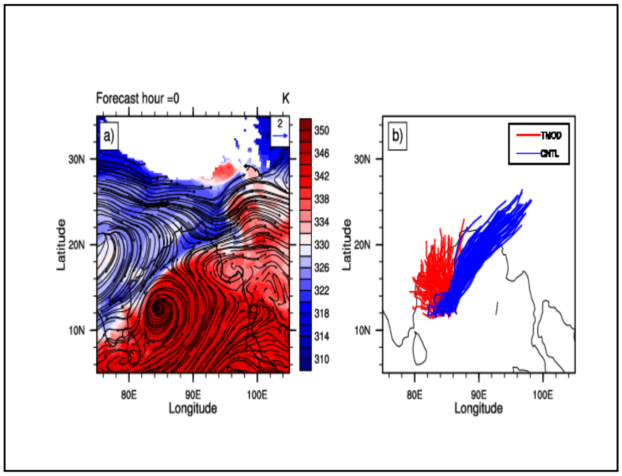

Figure 1: Geographical distribution of equivalent potential temperature and ensemble track forecast from control experiment and temperature modified experiment

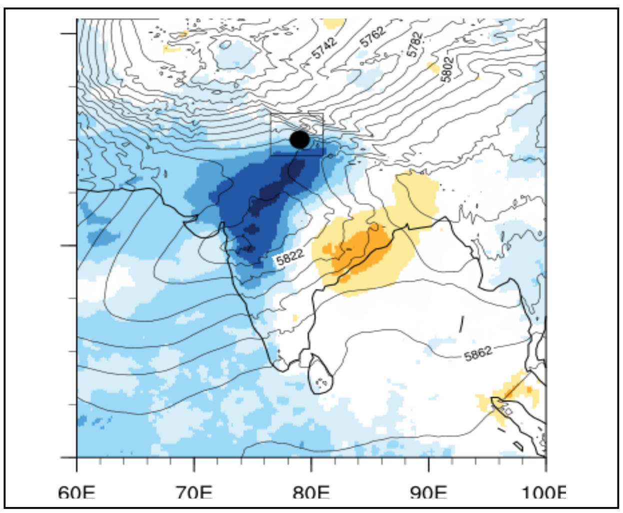

Figure 2: Sensitivity (shading) of area-averaged precipitation over the Uttarakhand to 500hPa geopotential heights

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