ABSTRACT

The Background Error Covariance Matrix (B) plays a crucial role in Data Assimilation (DA), influencing the accuracy of numerical weather predictions. In this study, we investigate the impact of different B formulations on the model Analysis (ANA) and the forecast quality, especially in case of intense precipitation events over the Indian region during the southwest (SW) monsoon season. DA experiments are conducted with 3DVAR, 3DEnVar, and 4DEnVar techniques at a horizontal grid spacing of 30 km. Four distinct B formulations are explored: (i) B-CLIM using the National Meteorological Center (NMC) method; (ii) B-MPCU using a 45-member ensemble generated by varying the microphysics (MP) and cumulus (CU) schemes; (iii) B-RAD by altering mp, cu, short and long-wave radiation schemes; and (iv) B-PERT by perturbing initial conditions while formulating 45-member ensembles. Model boundary conditions (BC) are derived from NCEP GFS at 6-hourly intervals at 0.25° × 0.25° spatial resolution. Surface, upper-air, and GPS radio occultation observations are utilized in DA. The focus is on ten extreme rainfall events during the SW monsoon season from 2018 to 2022, associated with severe weather systems (Depression or more severe) formed over the Bay of Bengal (BOB) region. Comparative analyses, including model ANA against radiosonde, METAR observations, and ERA-5 reanalysis data as well as model forecasts against the GPM 0.1° × 0.1° rainfall estimate, reveal that the Hybrid-3DEnVar technique with B-MPCU outperforms other approaches in all ten cases of heavy rainfall events considered in this study. Our experimental results indicate that the incorporation of flow-dependent B, derived by varying mp and cu in the assimilation technique, enhances the model's performance in the forecast of severe weather systems, by improving ANA and predictions, over the Indian region during SW Monsoon season.

This study also endeavors to enhance the performance of the Hybrid DA system, specifically focusing on the complex meteorological conditions. The optimization process involves adjusting five key factors/parameters: (i) incorporating Background Error Statistics dependent on FB; (ii) selecting different assimilation datasets; (iii) fine-tuning the optimal sample size for generating FB ensembles; (iv) establishing a detailed weighting scheme for FB against SB; and (v) refining convergence criteria for the DA process. Numerical DA experiments (using WRF-4.3.3) were carried out with a 30 km horizontal grid spacing, covering ten heavy rainfall cases from 2018 to

2022 during the SW Monsoon season, associated with Depressions or more significant weather systems over the BOB region.

A comparative analysis against ground truth, including radiosonde , real-time METAR observations and model forecasts with GPM 0.1° X 0.1° rainfall estimator outputs, established the superiority of Hybrid DA techniques under specific conditions: (i) using B-MPCU as FB; (ii) setting FB's contribution against SB at 99%; (iii) fixing the ensemble sample size for FB at 45; (iv) simultaneously assimilating a varied set of observational data (both conventional and satellite); and (v) setting the convergence criterion at 0.0001. This study not only advances our understanding of assimilation techniques but also provides a robust framework for its effective use in the complex meteorological conditions in the Indian region.