Abstract

The impact of different formulations of background error covariances (BECs) are examined for the simulation of Uttarakhand heavy rainfall episode with a regional 4-dimensional variational (4DVar) data assimilation (DA) system. These BEC formulations are analyzed, in which two of them employ streamfunction and velocity potential (ψ and χ) as momentum variables and the third one uses zonal and meridional velocity components (u and v) as momentum variables. Results from the study show that the ψχ based experiments have better skill in reproducing the observed rainfall distribution, particularly when the moisture variable is also analyzed in the multivariate balance relations.

Introduction

A major challenge in employing the variational data assimilation system is the formulation of a realistic error statistics of the forward model. This is usually achieved through the modeling of background error covariance (BEC) matrix. Different sets of control variables are being used in the formulation of BEC.1 The present study focuses on the impact of different control variables used in the BEC formulation on the simulation of Uttarakhand heavy rainfall event that occurred in 2013.

Uttarakhand heavy rainfall event: An overview

- Exceptionally heavy rainfall occurred over Uttarakhand during 14-17 June 2013.
- More than 350 mm rainfall was recorded on 17 June 2013.
- The heavy rainfall events are attributed to the manifestation of dynamical interaction between the tropical, monsoon circulation and the mid-latitude western disturbances.

Figure 1: NOAA satellite image of the cloud cover over Uttarakhand, valid at 00Z 17 June 2013

Model configuration

The WRF ARW model version 3.8.1 has been used in this study.

- 3 domains with 27, 9, and 3 km horizontal resolution.
- 36 vertical levels.
- Kain-Fritsch scheme for convection (except for domain 3).
-Eta-Ferrier scheme for microphysics parameterization.
-YSU scheme for boundary layer processes.
-Noah scheme for land surface processes.
-RRTM model and Dudhia scheme for longwave and shortwave parameterization.

Rainfall forecast verification

Table 1. Use of experiments and corresponding control variables

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Control variables used</th>
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<tbody>
<tr>
<td>ψχ-BE</td>
<td>ψ, χ, T, ρ, υ, ω, ρv, rh</td>
</tr>
<tr>
<td>ψχ-MBE</td>
<td>ψ, χ, T, ρ, υ, ω, ρv, rh</td>
</tr>
<tr>
<td>U/V-BE</td>
<td>u, v, x, y, ρ, υ, ω, ρv, rh</td>
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</tbody>
</table>

Initial and boundary conditions are derived from NCEP-GFS forecast fields. Surface and upper-air conventional observations and satellite derived winds are utilized for assimilation.

Sensitivity of the WRF-4DVar Assimilation System to the Control Variables: A Case Study on Uttarakhand Heavy Rainfall Event

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Single observation experiments

Figure 2: Model domain

Figure 3: Analysis increment in ψ, χ, T, and υ for assimilation of single χ observation when ψχ-BE, ψχ-MBE, and ψχ-BE are employed.

Assimilation of single χ observation utilizing all the three BECs reveals the univariate nature of the ψχ-BE (Fig. 3). The multivariate nature of humidity variable in ψχ-MBE enables that wind information to influence the moisture field also. The additional regression coefficients introduced in ψχ-BE also show notable impact on ψ and T fields.

The most striking feature is the difference in information spread with the ψχ-BE.

Improvement in the analysis fields

Analysis fields show that the ψχ-BE fields are more closer to the radiosonde observations (Fig. 5). The distribution of observation minus analysis (O-A) fields (with respect to surface synoptic observations) also shows lower standard deviation for the ψχ-BE analysis (Fig. 6).

Skill scores for 24h accumulated rainfall for ψχ-BE, ψχ-MBE, ψχ-BE, and TRMM observation

Figure 4: Vertical variation of horizontal length scale for all the control variables. In legend, ‘1’, ‘2’, and ‘3’ indicate ψχ-BE, ψχ-MBE, and ψχ-BE respectively.

Figure 5: RMS fit to radiosonde observations

Figure 6: Standard deviation of O-A fields with respect to synoptic observations

Figure 7: 24h accumulated rainfall for ψχ-BE, ψχ-MBE, ψχ-BE, and TRMM observation

Figure 8: Skill scores for 24h accumulated rainfall for ψχ-BE, ψχ-MBE, ψχ-BE

Even though the analysis fields found to be better for the ψχ-BE experiment, the same did not yield the best rainfall forecast (Fig. 7). Quantitative skill scores indicate that the ψχ-MBE forecast have better rainfall forecast skill, especially for the higher rainfall thresholds (Fig. 8).

Conclusions

- There is a significant difference in the spread of assimilated observations among the ψχ-based BEC and ψχ-BE base BECs.
- The ψχ-BE analysis fields show closer closeness to the radiosonde observations.
- The ψχ-MBE experiment shows appreciable improvement in rainfall 24h forecast.