WRF Model Sensitivity to Initial Conditions and Study of Some Important Features Associated with Intense Western Disturbances Over NW India.

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Abstract:
During winter season, the disturbances that dominate the weather over northern part of India is the western disturbances (WDs). This weather system is responsible for widespread radiation fog, cold waves, gusty winds, also heavy precipitation over the northern part of India during the season. The objective of this study is to examine Weather Research and Forecasting model (WRF) sensitivity to initial conditions. Two cases of intense western disturbances which affected the northwest India during 16-19 January 2013 (case-I) and 4-7 February 2013 (case-II) were simulated with different configurations. The model simulations (24hrs and 120Hrs simulation) are validated with observational datasets and error statistics are presented. It is found that the performance of the 24Hrs forecast are better compared to the 120Hrs forecast used in this study. Also, some important parameters associated with the WDs have been investigated. It is found that Outgoing longwave radiation (OLR) distribution over the region is well predicted by the model. The results of the simulation shows a very low value of OLR, significant increase in value of positive vorticity and CAPE over the region of heavy precipitation during these cases of WDs.

1. Introduction.
WD is an eastward moving extra-tropical upper air trough in the subtropical westerlies usually extending down to the lower atmospheric level of the north Indian latitudes during the winter months (Pisharoty and Desai 1956). As the WD approach a region from the west, it gives extensive cloudiness, gusty winds, rain and thunderstorm over the region followed by fog and cold as the disturbance passes over the region. (Rao and Srinivasan 1969).

Patil and Kumar (2016), Hatwar et al., (2005), Dimri et al., (2004) and Azadi et al., (2002) carried out simulation of western disturbance and associated mesoscale features using numerical model over North West India. Dimri and Chevuturi (2014) and Patil and Kumar (2016) have shown that, the model forecast is sensitive to choice of physical parameterization schemes over the North West India. They have provided the most appropriate set of parameterizations suited for the region during the Weather system. They studied Model sensitivity based on Physics. In the present paper, Model sensitivity has been studied based on different initial conditions and integration times.

16-19 January 2013 (case-I) and 4-7 February 2013 (case-II) have been considered for the study. Synoptic situation for the same cases have been discussed by Medha et al., (2014). Two experiments have been carried out using the different initial conditions (See Table 1) while keeping parameterization schemes constant. Two WD cases with two different model configurations (24hrs and 120Hrs simulation) are analyzed. Sensitivity and error statistics of rainfall, geopotential height and wind are studied to examine model sensitivity. The model simulation results of OLR, CAPE and relative vorticity are also investigated to study these cases of WDs.

2. Model, data and experimental design
2.1 Model used
The full description of the Weather Research and Forecasting (WRF) model is available in the model description document (Skamarock et al. 2008).

2.2 Data used
For the present study, Initial and boundary conditions for the model integration are taken from the GFS with 1° x 1° spatial resolution and temporal resolution of 6 hrs.

For model validation different observational datasets have been used. For precipitation verification,Tropical rainfall measuring mission (TRMM) (Huffman et al. 2007) 3B42 V7 daily derived precipitation dataset is used. The data has a spatial resolution 0.25° x 0.25° available from 1998 onwards.

Other parameters were validated with Reanalysis Project 2 (Kalnay et al. 1996) data by National Centre for Environmental Prediction/Prediction/National Centre for Atmospheric Research (NCEP/NCAR) at 2.5° x 2.5° spatial resolution is used.

2.3 Experimental design

The model was integrated for 24Hrs(Experiment 1) and 120Hrs (Experiment 2) from the different initial conditions.(see Table 1). Three nested domains of resolutions 81, 27 and 9 Km with the two experiments(24hrs and 120Hrs) were simulated for the two WDs. The combination of NSSL (National Severe Storms Laboratory) one moment, KF(Kain-Fritsch), Yonsei University (YSU), Rapid Radiative Transfer Model (RRTM) and Dudhiaschemesas a Microphysics, Cumulus, Planetary Boundary layer, Longwave Radiation and Shortwave Radiation parameterizations schemes respectively have been chosen and three nested domains of resolutions 81, 27 and 9 Km have been considered for the experiments as performed by Patil and Kumar (2016).

3. Results and discussion

3.1 Sensitivity of the Model forecast to initial conditions

Table 2 shows, values of Root mean squared error (RMSE) and RMSE-observations standard deviation ratio (RSR) based on the Model forecasts of precipitation (mm/day) (PREC), 500 hpa geopotential height (m) (GPH) and 500 hpa wind (m/s) (CIRC) from different experiments for WD cases 1 and 2 respectively.

RMSE and RSR are evaluated over the domain area 20° N - 40° N and 60°E- 90°E which covers the north west and north India. The Model accumulated rainfall was compared with TRMM observational dataset. For geopotential height and winds, NCEP/NCAR reanalysis dataset is used for comparison.

From Table 2, it is seen that Experiment 1 has lower RMSE than Experiment 2. The difference in RMSE may be attributed sensitivity of the Model to initial conditions. This effect is popularly known as the "butterfly effect" (Lorenz, 2000).

3.2 To study some important parameters associated with WDs

The model simulation results in terms of spatial distribution patterns of OLR, CAPE and vertical distribution patterns of relative vorticity, geopotential height anomaly have been plotted to study these cases of WDs.

Fig.1 (a-d) shows the Outgoing Long wave Radiation based on NCEP data. (e-h) shows the OLR but based on model simulation in domain 2 for WD case-I. The low values of OLR over the region represent extensive cloud cover and the possibility of precipitation over the region. On 17th and 18th January the model simulated OLR and observed OLR shows a low value over Jammu and Kashmir, Himachal Pradesh, Punjab and Uttarakhand which indicates occurrence of rainfall over the region. On 19th January, moderate value of OLR is seen over Himachal Pradesh, Punjab and Uttarakhand. Fig.2 (a-d) shows the Outgoing Long wave Radiation based on NCEP data. Fig.2 (e-h) shows the OLR but based on model simulation within domain 2 for WD case-II. On 4th and 5th February the model simulated OLR shows a very low value over Jammu and Kashmir Himachal Pradesh, Uttarakhand and the Western Himalayan region (see fig.2a and fig.2b). On 7th February moderate value of OLR is seen over Himachal Pradesh, Punjab and Uttarakhand.

Figures 3(a-d) show the vertical distribution of geopotential height anomaly (m) averaged over latitude (25°N-40°N) for WD case-I and Figures 3(e-h) show for WD case-II. Geopotential height anomalies consist of deviations in the geopotential height field from average values. These figures display the geopotential height anomalies from long term (1979-2010) monthly average. It is found that areas with lower geopotential heights correlate with negative geopotential height anomalies. These figures of the height anomalies show negative values (shaded by faint to dark blue colors) which indicates that the geopotential height is below the average and implies colder than average temperatures across this region. The negative values of anomalies are seen over 66°E to 68°E during the initial days of the WDs and this pattern is moves eastward indicating an eastward movement of WDs during the next consecutive days.
Fig. 4(a-d) show the vertical distribution of Vorticity ($X 10^5 s^{-1}$) along 28.6°N latitude (along Delhi) for WD case-I and Fig. 4(e-h) shows same but for WD case-II along 31.1° N latitude (along Shimla) in model domain 3. On the first day of the WD a very low Vorticity is seen and on next consecutive days strong vorticity is seen. This increase in vorticity might be attributed to intensification on cyclonic circulation. On the last day low value of Vorticity is seen (see fig 4d and fig.4h). Figures 5(a-d) shows Convective Available Potential Energy-(CAPE in J/Kg) in model simulated Domain 3 for WD case-I and Fig. 5 (i-l) shows the same for WD case-II in model simulated Domain 3. CAPE represents the amount of buoyant energy available to speed up a parcel vertically and is an indicator of atmospheric instability, which makes it very valuable in predicting severe weather. During the WD case-I on 16th January very low value of CAPE is seen over the region (see fig.5a). On 16th and 17th January the CAPE value lies between 0 to 250 (J/Kg) over the region. The existence of significant CAPE is considered to be favorable for development of severe convection over the North West India. On 18th January low values of CAPE are seen over the region and WD weakened on the same day. During the WD case-II, on 4th February 2013 low values of CAPE are seen over the region. On 5th and 6th February 2013, increase in values of CAPE (0 to 500 (J/Kg)) is seen over the region (see fig.5j and fig.5k).

4. Conclusions
The present study shows that performance of 24Hrs forecast is better than 120Hrs forecast. Some important parameters associated with the WDs have been studied. It is seen that Outgoing longwave radiation (OLR) distribution over the region is well predicted by the model and it shows low values on the days of occurrence of precipitation during these cases of WDs. During both cases of WD, Geopotential height anomalies have negative values which indicates that the geopotential height is below the average and implies colder than average temperatures across this region. The pattern moves eastward indicating and eastward movement of WD’s. A high value of CAPE is seen on the days of occurrence of precipitation during these cases of WDs.

5. Acknowledgement
We acknowledge NCEP/NCAR for the use of their reanalysis and GFS datasets. We also acknowledge NASA for providing TRMM rainfall data for this study.

6. References


Table 1. Initial conditions taken for the forecast for case-1(western disturbance, 16-19 January 2013) and case-2(western disturbance, 04-07 February 2013) in the Experiments.

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Table 2 RMSE and RSR in bracket based on the Model forecasts of precipitation (mm/day) (PREC), 500 hpa geopotential height (m) (GPH) and 500 hPa wind (m/s) (CIRC) from different experiments for WD case 1,2
Fig. 1 Daily OLR based on (a-d) NCEP data, (e-h) Model simulated OLR in domain 2 for WD case 1.
Fig. 2 Daily OLR based on (a-d) NCEP data, (e-h) Model simulated OLR in domain 2 for WD case 2.
Fig. 3 Vertical distribution of geopotential height anomaly (m) averaged over latitude (25°N-40°N) for WD case I (a–d) and WD case II (e–h)
Fig. 4  Vertical distribution of Vorticity ($X \times 10^5 \text{s}^{-1}$) (a-d) along 28.6°N latitude (along Delhi) for WD case 1, (e-h) same but for WD case 2 along 31.1° N latitude (along Shimla)
Fig. 5 Convective available potential energy (J/Kg) (a–d) in model simulation domain 3 for WD case 1. CAPE (J/Kg) (i–l) in model simulation domain 3 for WD case 2.