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Performance of A Limited Area Model For The Simulation of Western Disturbances

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A non-hydrostatic version of PSU/NCAR mesoscale model is used to simulate the characteristic features of the Western Disturbances (WDs) occurring over the Indian region during winter. For this study, four cases of very active WDs are selected. The model is integrated with 60 km resolution in simulating the WD features. Results showed that in all the four cases, the rate of movement of the system is in general, a little slower in the simulations. Examination of the differences between the predicted and analyzed zonal component of the wind reveal that the model simulated zonal winds are generally weaker/under-estimated in the location of the upper trough at 500 hPa or aloft and even in the position of the WDs at lower levels. These results suggest that the model has a systematic bias, though the magnitude is small. In other words the advection simulated in the model is not strong enough to advect the system with the observed speed.

INTRODUCTION

Western Disturbances (WDs) are important synoptic systems that affect the weather over northwest India throughout the year. During the winter season (Dec-Mar) they cause fog, rain, snow, cold waves and avalanches. In the pre-monsoon period (Apr-May), they can cause sever thunderstorms, squalls and hail-storms. During the summer monsoon (June-Sep), they may interact with the monsoon systems and influence the monsoon activity over India. Finally, during the postmonsoon period (Oct-Nov), the WDs may lead to early snowfall. They can also cause formation of cyclonic storms over the Indian seas, besides strengthening the existing storms there. Nonetheless, it is during the winter season that the WDs have their most pronounced effect on the weather of northwest India, which includes hilly regions and glacier basins of the Western Himalayas. It is known that tropical systems are mainly driven by the latent heat release in the mesoscale cloud clusters. In the mid-latitude synoptic scale systems, on the other hand, it is the available zonal potential energy associated with the latitudinal temperature gradient that is the main source of energy. Some of the earlier studies (Pisharoti and Desai, 1956; Kalsi, 1980; Kalsi and Halder, 1992 and others) have mentioned that WDs are manifestations of interaction between the tropics and mid-latitude systems, which are associated with extensive sheets of mid- and high-level clouds and maxima in the subtropical jets. Kalsi and Halder (1992) suggest that mobile cloud systems are related to short waves on the subtropical jets and facilitate the interaction between the tropics and mid-latitude systems by amplifying the long wave troughs, leading to a larger sway of mid latitude westerlies over the subtropics and lower latitudes. The WDs are not usually associated with clearcut fronts that are observed in the midlatitude winter synoptic systems.

Numerical weather prediction models are the main tools for the professional forecasters in their day-to-day job. But it is important to note that all numerical weather prediction model outputs have weaknesses that affect the quality of the forecast. To be able to use the model results more effectively , it is necessary to be aware of the characteristic features of the model outputs and their biases in the prediction of intensity and location of the predicted phenomena. One of the consequences of such studies is that, it helps the forecasters for better understanding the numerical prediction results biases and tendencies and hence intelligent use of the products.

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Table 1. MM5 configuration used in this study

Model	Fifth-Generation of Penn State/NCAR Mesoscale Model (MM5)version 2.12
Dynamics	Non-hydrostatic with 3-d Coriolis force
Main prognostic variables	u, v, w, T, p and q
Map projection	Lambert conformal mapping
Central point of the domain	Latitude: 38 ^{0} N; Longitude: 68 ^{0} E
Number of horizontal grid points	165,105 grid points for x , y respectively
Horizontal grid distance	30, 60 and 90 km
Number of vertical levels	23 half sigma levels
Horizontal grid system	Arakawa B-grid
Time integration scheme	Leapfrog scheme with time-splitting technique
Lateral boundary conditions	Nudging toward the NCEP/NCAR reanalysis
Radiation scheme	Cloud radiation scheme with radiation frequency of 30 minutes
Planetary boundary layer (PBL) parameterization schem	Hong-Pan as implemented in the NCEP MRF model. It includes vertical diffusion in the stable atmosphere and moist vertical diffusion in clouds.
Convection scheme	Betts-Miller
Soil model	Multi-layer soil model

The objective of the present study is to investigate the performance of a limited area model known as MM5 to simulate the behavior of active WDs occurring over Pakistan, Afghanistan, Iran and India. The model domain covers Southwest Asia, South China and Indian region, which is characterized by substantial variability of the Himalayas. However in the figures presented here all the fields are shown only over the region of interest. The numerical model is described in section 2. Descriptions of the experiments along with the data used in this study are given in section 3. Synoptic description of the cases used in this study along with the results presented in section 4. Section 5 sumarizes the conclusion drawn from the study.

MODEL DESCRIPTION

The model used in this study is a non-hydrostatic version of the MM5 modeling system, developed by Anthes, Warner, Ying-HwaKuo, and their colleagues at Penn State University/National Center for atmospheric Research (PSU/NCAR) (e.g., Anthes and warner1978; Dudhia 1993 and others). The MM5 modeling system software is freely provided and supported by the Mesoscale Prediction Group in the Mesoscale and Microscale Meteorology Division, NCAR. It is a limited area, or non-hydrostatic model, which uses terrain-following sigma in pressure as the vertical coordinate and offers a wide variety of boundary layer schemes, cumulus parameterizations, and microphysical schemes. For full description of the model formulation refer to model description document (e. g. Grell et. al, 1994). A brief description of the model configuration used in this study is given in Table 1.

EXPERIMENTAL DESIGN

A series of experiments for producing 48-hour forecasts using the MM5 modeling system with Hong-Pan scheme, [2] as implemented in the NCEP MRF model [6], for the planetary boundary layer scheme and Betts-Miller scheme for the convection scheme are conducted. These two schemes have been selected based on the results obtained in an earlier study (Azadi et al, 2000), which showed that the combination of the two mentioned schemes is better among other possible combinations, for the simulation of WDs in the region considered in this study. The experiments have been conducted using 60 km grid spacing.

In the present study, initial conditions fed to the model are extracted from reanalyzed dataset provided by NCEP/NCAR and interpolated to the model domain in Mercator projection by the auxiliary program of TERRAIN provided in the MM5 modeling system. This raises a problem: since the spatial resolution of the NCEP/NCAR is too coarse to derive a mesoscale model, a procedure has to be devised to refine the data. The usual procedure is to use the reanalysis detasets as a first guess in the objective analysis of the observational data to get more accurate values. Note that interpolation by itself cannot produce small-scale features that have already smoothed out in the large-scale reanalyzes. To overcome the problem of low resolution of the data set, we adopt the folowing procedure: we use the first six-hour of the model with aids that nudge it towards the reanalysis data set;thereafter these aids are switched off and the model is used for forecasting purposes. In this way, at the end of the nudging period, the output of the mesoscle model is consistent with the reanalyzed large-scale datasets. In additin, the model physics generats the small-scale features at the scale used.

For verification of the model outputs, some variables including sea level pressure (SLP), geopotential height (GPH), horizontal and vertical wind velocity, temperature and relative humidity at 850, 700, 500, 300 and 200 hPa are compared against reanalyzed datasets provided by the NCEP/NCAR. Moreover, some important diagnostics such as vorticity, divergence, adiabatic heating, latent heat flux, vertically integrated moisture and many other diagnostic quantities are calculated using model output and reanalysis dataset mentioned above, and compared against each other. Statistical evaluation of the model results has been done through calculating some statistical skill scores. In addition some synoptic charts including those of sea level pressure and precipitation maps provided by India Meteorological department (IMD) are also used to verify the forecasts. In order to keep the number of the Figures in acceptable limits, only some selected important figures including those of SLP and difference between the predicted and analyzed wind are presented here.

RESULTS AND DISCUSSIONS

Sea Level Pressure

Case 1: Figures 1(a) and (e) show 24-hour model forecast and corresponding reanalysis map of SLP valid at 00 UTC of 24th March '93. Comparison of the figures shows that development of the low-pressure trough to southwest China is simulated fairly well but the depth of the low pressure is over-predicted. Also the movement of the low-pressure system towards east is a little slower in the forecast compared to the actual.

Case 2: 24-hour forecast of SLP valid at 00 UTC of 14th February '95 is given in figure 1(b). Comparison of the forecast with verification reanalysis given in figure 1(f) for this case indicates that the model was unable to predict the observed depth of the low pressure of 1008 hPa by 3 hPa. The direction of the movement was predicted reasonably well, but the rate of its movement was predicted a little slower than the actual.

Case 3: Figures 1(c) and (f) represent the 24-hour model forecast and the corresponding verification reanalysis respectively, valid at 00 UTC of 15th January '96. Comparison of the model forecast with the verification reanalysis shows that the model is able to predict the intensification of the system as well as the direction of its movement fairly well; however, the movement of the system is slightly slower in the simulation.

Case 4: Figures 1(d) and (h) show the 24-hour forecast of SLP, and the corresponding verification reanalysis map valid at 00 UTC of 12th March '98 respectively. Comparison of the figures indicates that the model was able to simulate the intensity of the low-pressure system quite well. However, the model predicted a relatively slower movement for the system as compared to the actual, but the direction of the movement agreed.

According to the results described above, the overall model simulation is reasonably well for all the cases. But generally the rate of the movement of the system is a little slower in the simulation. In the first case, the depth of the system is over-predicted. The reason for this is that reanalysis itself, at the initial time, is not matching with the analysis map of IMD, such that low pressure in the initial condition fed to the model has a closed isobar of 1002 hPa but in the analysis map of IMD, low pressure system is less deep by almost two hPa (figures not shown here).

Difference Between The Predicted And Analyzed Wind

Figure 2 shows the difference between the predicted and analyzed value for the zonal wind component (left panel) and horizontal wind vector for the 200 hPa (right panel), for the four cases. It is noticed that the model simulating zonal wind component is a little weaker compared to the actual. Especially the right panel of figure 2 shows that the model has an easterly bias. Examining the results for 850 and 500 hPa levels again confirms that the model simulating zonal wind is slightly weaker than the actual.

As mentioned earlier in (a), location of the system is slightly shifted towards west when compared to the corresponding field in the reanalysis map. Under estimating the wind in the location of the WD center at lower levels and associated upper trough and jet stream at higher levels (figures not shown here) suggest that the advection in the model is not strong enough to move the system with the observed speed.

The under estimation of the zonal movement of the WD's can not be explained fully and more experiments have to be designed and implemented. However, it is most likely due to deficiencies in the dynamical part of the model which in turn is triggered by improper initialization of the model by low resolution NCEP/NCAR reanalysis datasets. To overcome the problem and to run the model with

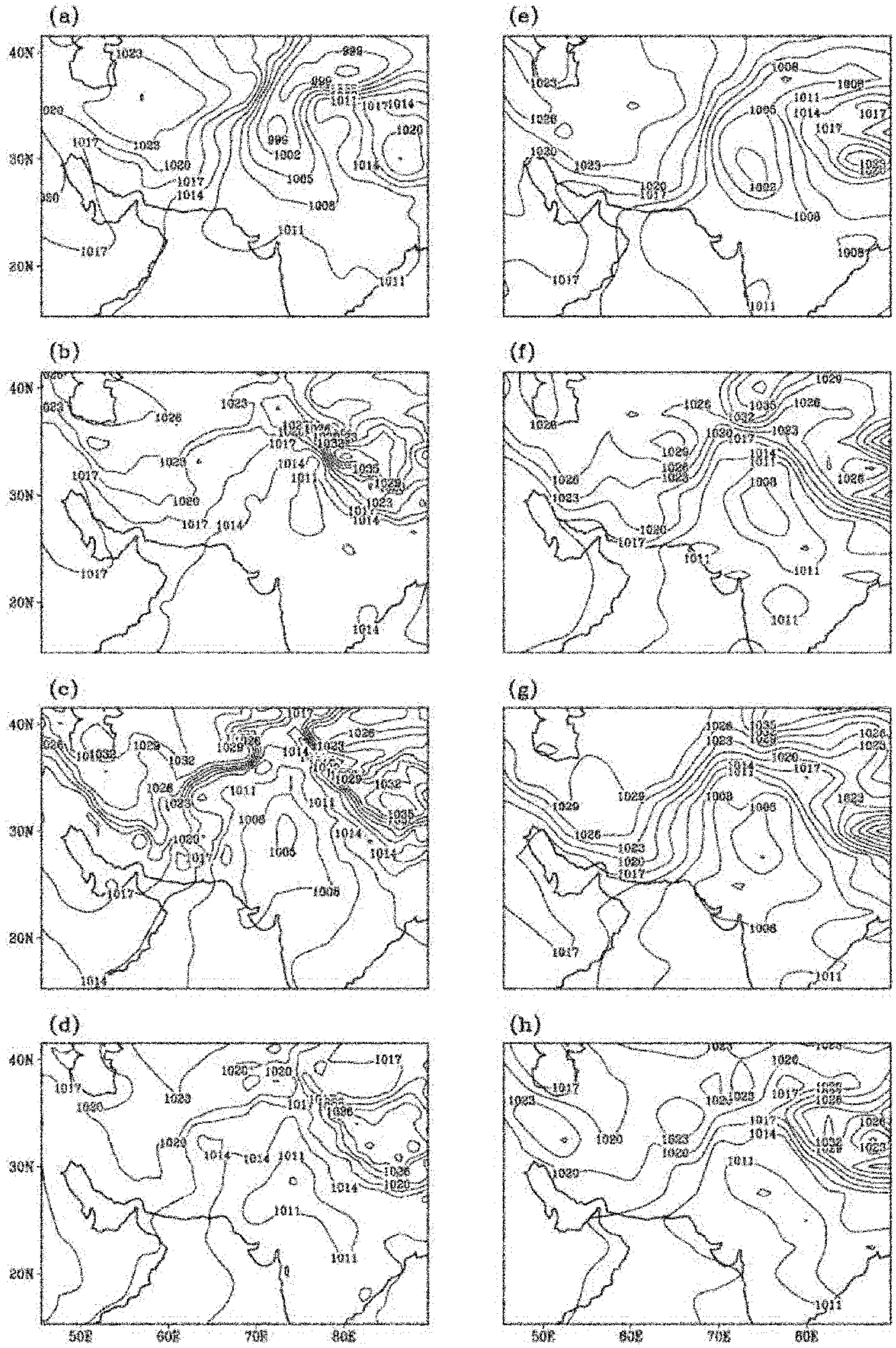

Figure 1. 24-hour forecast of SLP with contour interval of 3 mb valid at 0000 UTC on (a) 24 March 1993 (b) 14 February 1995 (c) 15 January 1996 and (d) 12 March 1998. (e)-(f) are the corresponding verification reanalysis for (a)-(d) respectively.

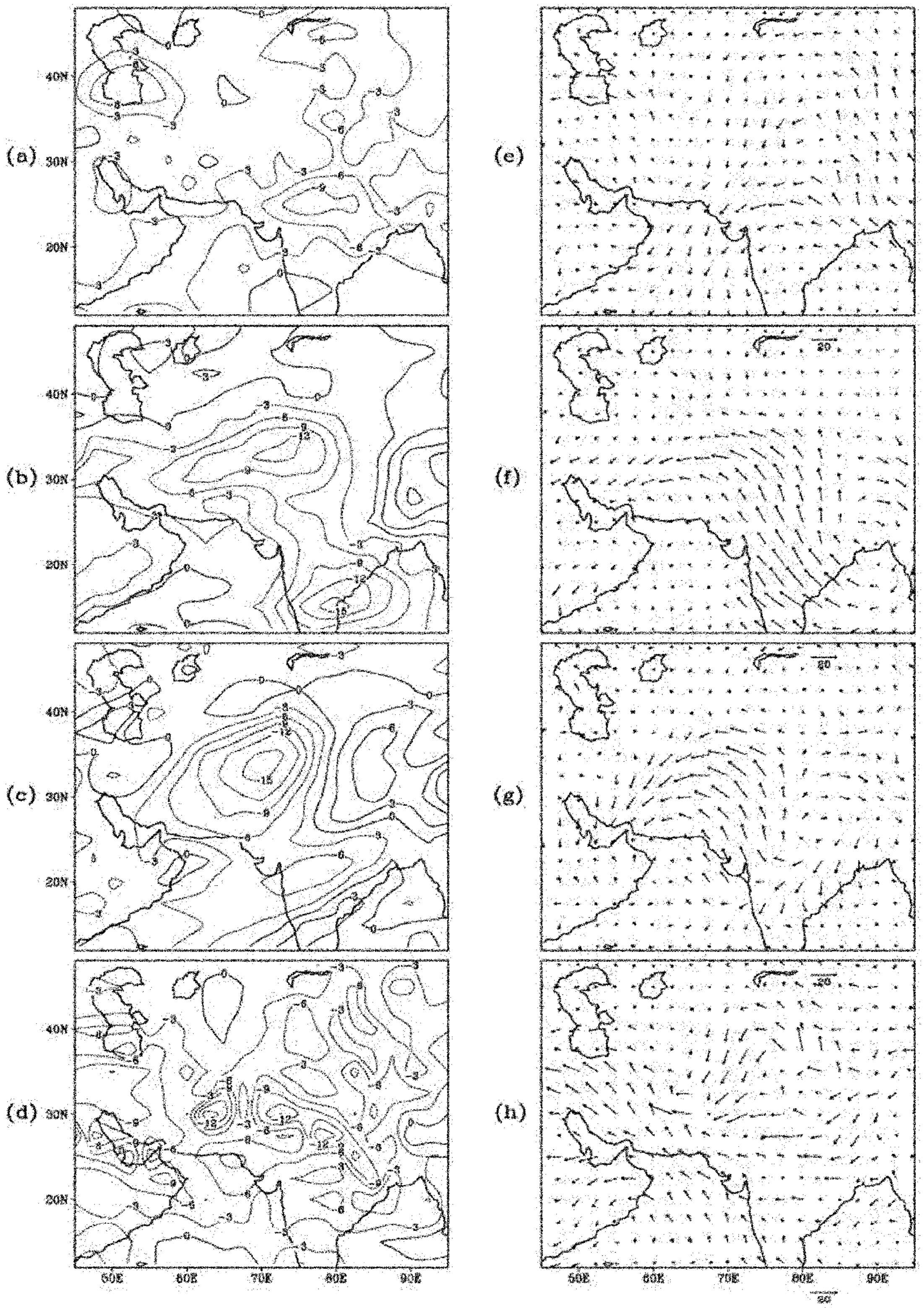

Figure 2. (a-d) Difference between the 24-hour forecast and analyzed values of the zonal wind component for the four cases at 200 mb with contour 3 ms^{-1}. (e)-(f) are the same as (a)-(d) except for the wind vector.

higher resolutions either a nest down procedure has to be implemented [9] or a data assimilation scheme should be added such that the model can be used with higher resolutions. To define a feature in a grid point model and preserve its characteristic features at least eight to ten grid point models are needed. This means here that only features with 480-km horizontal scale or above can be represented in the model. Yet, if a feature meets the resolvable size criteria, it may still inadequately resolved based on its orientation and juxtaposition within the model grid. Grid spacing, affects the amount of truncation error which propagates through the model integration and contaminates the final forecast. With higher resolutions, we believe that topography-associated features can be better captured and hence the model performance is improved. Moreover, temperature gradient intensity is limited by the model resolution, since the temperature gradient pack behind a strong cold front is a small scale feature and only large scale feature around the cold front is represented in the model. On the other hand, if the model does not represent the horizontal temperature gradient details, then its associated advection will be weaker than is expected. In such cases, the model is likely capable to detect the features, but their intensity will be too weak and their location misplaced which in turn results in inaccurate forecasts.

Various studies have been done to verify the model results using higher resolutions. Brian et al, for example, conducted a study for the verification of model generated precipitation using resolutions of 12 and 36-km. Their results showed that the 12-km precipitation forecasts are slightly better on average for the heavy precipitation events. It is to be noted that, just as adequate horizontal resolution is needed to resolve the features of the weather phenomena, it is necessary to run the model with enough vertical resolutions such that the vertical structure of the atmospheric phenomena can be simulated. In fact, it the ratio of the atmospheric phenomena can be simulated. In fact, it the ratio of the horizontal and vertical resolutions in the model that is to be consistent with the slope of the weather phenomena of interest. Since virtually all NWP models use discrete vertical structure, they produce simulation for each layer of the atmosphere contained between the vertical coordinate surfaces. It is interesting to note that increasing the resolution in one dimension only, may result in worse forecasts.

CONCLUSIONS

In this paper, the results of the simulation of four active WD cases, using non-hydrostatic version of the MM5 modeling system, are presented. The following broad conclusions are drawn from this study:

- By and large the model is successful in the prediction of the important characteristic features related to WDs. Also the model successfully simulates some small-scale features that are not present in the large-scale reanalysis.
- Overall movement of the synoptic systems namely the low pressure in the SLP map and its associated upper trough at 500 hPa, is slightly slower when compared with the analysis. Examining the differences in the zonal component of the horizontal wind vector reveals that the model is having a small but systematic easterly bias, which could be the reason for the slow movement of the system. considering the discussions given in the previous section, in order to investigate the result of the model biases, it seems necessary to examine the temperature gradients simulated by the model. It is suggested that the energetic of the model have to be examined carefully too.

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