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Research Article

ARPS MODEL SIMULATION OF SYNOPTIC SCALE WEATHER EVENTS

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ABSTRACT

During winter season the main weather producing weather system are Western Disturbances. These systems affecting India through out the year, but their effect is more prominent on mountainous regions. The capture of topographical features is a difficult task for the model. In-spite of their inherent limitations and complex interactions or processes involved, regional model simulation play a very important role in weather forecasting. Model predictability depends on how the various features like topography in this case are captured by the Model. In this paper a case of severe weather over western Himalaya from 01st January 2006 to 05th January 2006 has been simulated with Advanced Regional Prediction System (ARPS) model. The Initial and lateral boundary conditions for coarse resolution (30 Km horizontal resolution) were provided from National Centre for Medium Range Weather Forecasting (NCMRWF) data and fine resolution (10Km) were provided from ARPS 30 Km simulation. The coarse resolution could capture the weather system however; the fine features of the spatial distribution of precipitation were illustrated by using of high-resolution topography in model. The high-resolution simulation could simulate the range wise precipitation distribution over the different ranges of western Himalaya and effect of topographic barrier in precipitation.

Key Words: *Western Disturbance, Advanced Regional Prediction System, Low Pressure Area and Infra Red*

INTRODUCTION

Western Himalaya and part of Central Himalaya receives significant precipitation in the form of snow/rain during winter months (November to April). The weather system that affects the weather of western and central Himalaya during winter is known as western disturbance (WD). Pisharoty and Desai (1956) defined WD as 'eastward moving upper air trough in subtropical westerly which extends down to the lower troposphere of north Indian latitudes in winter months'. The complex structure of western disturbance was studied by Chitlangia (1976). He proposed mean model for western depression using moving coordinate technique. His study revealed that there is significant difference between the western depression, which affects the weather of north Indian region during winter, and extratropical system in midlatitude. His study further revealed that the pattern in the core of WD is somewhat complex and can not be explained simply by two layer beroclinic model. The associated jet with the WD was not observed at the core (surface centre) as the extratropical system but it was appeared in south of the surface centre of WD. This study also explained the vertical structure of the wind pattern in WD.

The development and intensification of synoptic weather system in mid-latitude and neighborhoods are associated with the beroclinic zone. The beroclinic zones are developed due to meeting of two different air masses having strong temperature gradient. These zones are the source of available potential energy (APE) that finally converted into the kinetic energy and utilized for the development and intensification of weather system. Singh (1977) published in his study that there are two beroclinic zone in north India during winter period, one at 25^0N and other 33^0N. The zone at 25^0N is the meeting point of tropical air mass (TA) and middle latitude air mass (MLA). The zone at 33^0N formed due to the merging of two branches of MLA, named as MLA-I and MLA-II. Singh first time pointed out the effect of long chain of high hills on the winter weather system over the north India. His study revealed that the hills from Elburz and Hindukush are responsible for the development of WDs over the north and central India. After bifurcation of MLA due to interaction of high hills, MLA-I flows from central Iran, south Afghanistan, Baluchistan and Sindh and MAL-II flows from the central Russian plains. MLA-II blocked by Pamirs, north of Kashmir, flows southward through Kabul valley and meet MAL-I. MLA-I has warmer nature due to its long sojourn in desert area. The meeting of MLA-I and MLA-II develops the beroclinic zone in south of Kashmir valley over 33^0N. The study revealed that the beroclinic zone of two branches of MLA(MLA-I and MLA-II) is stronger than the zone of MLA-I and TA at 700mb. These boclinic zones provide the dynamic explanation of formation and intensification of WDs over the Jammu & Kashmir, and Rajasthan area than the other part of north India. Kalsi and Haldar (1992) showed the interaction of tropical and middle latitude air mass using satellite observations and studied the weather phenomena including WDs over the north India. Their study revealed that the short waves in the interaction of mid-latitude air mass and tropical air mass amplifies the long wave trough and consequently leads to the severe weather over the western Himalaya.

Himalaya, being the difficult terrains and hostile weather conditions, remain unattended since long period and hence it is data sparse region for the meteorological interest. The complexity of Himalayan terrain and scarcity of data makes the weather prediction more difficult over this region. The earlier studies were subjected to the subjective study of winter weather system. A numerical (Objective) study requires three dimensional data array as initial and lateral boundary condition in the numerical models. Use of three dimensional data array from global model analysis and forecast as initial and lateral boundary condition in the mesoscale models in high resolution prediction is only the suitable solution at present to overcome from described problem. Azadi *et.al.*, (2001) used National Centre for Environmental Prediction(NCEP) global reanalysis data as initial field in MM5 for the study of precipitation prediction and effect of different parameterization scheme in predicted precipitation. Someshwar Das *et al*., (2002) and Srinivasan *et al.*, (2004) used National Centre for Medium Range Weather Forecast (NCMRWF), T-80 global spectral model data as initial and lateral boundary condition in MM5 model for the prediction of winter weather system in India.

The objective of present study is to investigate the effect of high resolution, complex topography in predicted precipitation distribution over the western Himalaya. To fulfill the objective, Advanced Regional Prediction System (ARPS) has been used in this study. The model was selected because it was developed in z-coordinate system. Thus the both model's computational domain as well as the topography are in the same vertical coordinate (z as vertical coordinate) and it will illustrate the real terrain effect in model simulation.

MATERIALS AND METHODS

Data and Methodology

The initial data fields for the model simulation are taken from NCMRWF, Noida, Uttar Pradesh (India) T-80 model analysis data. The lateral boundary conditions from the 24 hours interval forecast field has been used for the same T-80 model. The satellite imagery of Kalpana -1 geostationary satellite and upper air analysed charts of regional specialized meteorological centre (RSMC) used in this study has been taken from India Meteorological Department Lodi Road New Delhi. The analysed surface charts for the above case has been taken from Mountain Met Centre, Srinagar. The brief description of the tuning of high resolution ARPS model with complex topography is given below.

Model Description

ARPS model has been developed by Centre for Analysis and Prediction of Storm (CAPS), University of Oklahoma, USA. It is compressible non-hydrostatic model, developed in generalized terrain following, z-coordinate system. Minimum approximations have been made in the equations of motion and other equations used in the model, for prediction of small scale meteorological events. The model has been developed for research as well as for real time prediction from micro-scale to regional scale atmospheric phenomena. The detail about ARPS model was documented by Ming Xue *et al.,* (1995). Model dynamics and real time forecast experiments were documented by Ming Xue *et al.*, (2000) and Xue *et al.,* (2001, 2003). The model has its own objective analysis and quality control algorithms. The model has ADAS (ARPS Data Assimilation Syatem) package for the assimilation and quality control of all type of data Case *et al.,* (2002). ARPS has its three dimensional variational assimilation package for data assimilation. Geo *et al.*, (2004) used three dimensional variational assimilation methods for ingesting Doppler weather radar data in the initial field of model.

Topography of Western and Central Himalaya

Weather disturbances passing over the western Himalaya are affected by the complex topography. The precipitation distribution becomes anisotropic and highly influenced by the orographic forces over this region. In broad scenario, the topography of western Himalaya has been categorized into five ranges. These ranges are named (From South-West to North-East) as Pir Panjal, Great Himalayan, Zaskar, Ladakh and Great Karakoram as shown in Fig. 1 (d). The orientations of these ranges are in NW to SE direction. It has been observed that within the individual mountain range there is spatial variability in precipitation distribution due to the local topography and circulation pattern.

Topographical features of western Himalaya in 30 km, 10 km and 1 km resolutions are shown in Figs. 1(a – d) respectively. United state geological survey (USGS) 30 second (approximately 925Meters) resolution global data has been used for present study and analysis. It has been preprocessed by ARPS terrain preprocessor and after that plotted in grid analysis and display system (GrADS) graphical package. However, the ARPS have its own graphical package that uses national centre for atmospheric research (NCAR) graphic interface. The complexity of Himalayan topography is clearly illustrated when the high resolution data has been used for plotting, 30 km resolution plot shows the broad outlook of the Himalayan ranges. However the high resolution complexity of topographic features has been clearly highlighted as the resolution increased. Two domains, 30 km and 10 km topography have been used for the model simulation in ARPS model for the analysis and study of the effect of high resolution topography in precipitation distribution over complex terrains.

Surface Characteristic Data

The boundary layer of the atmosphere consist versatile characteristic of soil and vegetation cover. The soil properties remain unchanged with time however, the vegetation properties having dynamic nature. The model has world soil data in 1^0X1^0 resolutions in its data bank. The soil properties have been retrieved from this data. The vegetation properties like vegetation fraction, leaf area index, roughness length etc. were derived from the NDVI (Normalized Deference Vegetation Index) data. The NDVI data of monthly averaged for ten years in 20 Km resolution over the world is available with model data bank. The 'arpssfc' preprocessor has been utilized to generate the surface characteristic data for model initial fields. These parameters were used in the model for the computation of heat, momentum and moisture flux in atmospheric boundary layer.

Initial and Lateral Boundary Conditions

Three dimensional meteorological variables as initial condition for the model simulation has been obtained from National Centre for Medium Range Weather Forecasting (NCMRWF), Noida,Uttar Pradesh (India), T-80 analysis data and lateral boundary condition from the 24 hours interval forecast field of same model. The original data was in 1.5°X1.5° horizontal resolution and twelve vertical pressure levels, which was interpolated in 30 Km horizontal resolution and 725 meters vertical resolution with twenty five vertical levels as per model configuration. The module "ext2arps", which generates the initial and boundary condition data for ARPS model from the large scale global model, has been modified to ingest the NCMRWF T-80 model data. 3-D array of meteorological parameters considered for initial and boundary conditions are geopotential height, horizontal and meridional components of wind, relative humidity and temperature. Two layers soil model has been used and soil model initial fields (two layer soil moisture and soil temperature) were obtained from same model of NCMRWF. However, the resolution of soil temperature and soil moisture was 1.48°X1.48°. The soil variable were first interpolated

in 1.5°X1.5° to ingest in the model with other variable described above and then interpolated at 30 Km horizontal resolution simultaneously with other meteorological variables using model preprocessor.
ARPS output of 30Km run for 96 hours (Four days) has been saved at 24 hour interval. Three dimensional arrays of meteorological variables as initial and lateral conditions for in 10 Km horizontal resolution have been generated from these files. The vertical levels remain same as the 30 Km resolution.

Model Configuration

ARPS version 5.1.5 has been configured in 30Km horizontal resolution and 725 meters vertical resolution with centre of domain at 75°E and 35°N and total domain size 101X81X25. The vertical grid was stretched using the terrain following coordinate with the help of terrain data. Fourth order advection scheme was used in both horizontal and vertical direction for spatial integration. Time integration was carried out by mode splitting method, in which large time step was integrated with central difference scheme and small time step was integrated in forward-backward method. For this configuration, a large time step of 90 seconds and small time step of integration 30 seconds was taken. Vertical pressure and vertical velocity solver were integrated using Crank-Nicholson's implicit method. Radiation forcing was updated in every 900 seconds and convective parameterization was updated in every 900 seconds using WRF Kain-Fritsch. The grid resolved rain was computed using Kessler's warm rain approximation. 1.5 TKE approximation has been used for turbulence computation. Two layers soil model has been used to predict the soil temperature and soil moisture. The domain size 101X101X25 with centre of domain at 77°E and 32°N for 10 Km resolution has been used. The vertical resolution remains same as the 30 Km grid. For this configuration, a large time step of 30 seconds and small time step of integration 10 seconds was taken. Rest configuration remains same as the 30 Km simulation.

RESULTS AND DISCUSSION

The widespread distribution of precipitation mainly snowfall observed over western Himalaya region is given in Table (1). This was associated mainly due to synoptically induced eastward moving system affected over that area during 01 January, 2006 to 04 January, 2006. On 1st January, 2006 the WD as an upper system lies over north Pakistan and neighborhood Fig. 2 (a). The induced low pressure area which is associated with cyclonic circulation extending up to 3.1 Km also lies over that area. The system remains almost quasi-stationary up to 3rd January, 2006. On 2nd and 3rd January, 2006 the cyclonic circulation extending up to 2.1 Km above mean sea level (MSL) with trough aloft Fig. 2(b). On 4th January the system moved further eastward and lies over Himachal Pradesh (HP) and adjoining areas Fig. 2 (c). The induced low pressure area also shifted over west Uttar Pradesh and associated cyclonic circulation with trough aloft have become less marked. On 5th January, 2006 the system further moved away and less marked Fig. 2 (d). The upper air chart analysis done by RSMC, New Delhi at 500 hPa are shown in Figs. 3(a – d) shows the deep trough in westerlies and its persistency during the period of study. The moisture incursion is also done from Arabian Sea which further strengthen the system. This feature is also supported by the Kalpana-1 geostationary satellite images in Infra- Red region Figs. 4 (a – d). It is clear from the satellite images of subsequent days that intense to very intense convection is embedded with multilayer clouds. The intense cloud pattern remains almost quasi-stationary on 2nd and 3rd January, 2006 and produced wide spread precipitation over the area. On 4th and 5th January, 2006 this cloud pattern is further moved away eastward and less marked.
The development of upper air minor trough in westerly and consequently leading to the development of cut-off low over the western Himalaya was explained by Singh (1979). The development and movement of mid-tropospheric cyclone in westerlies over India was revealed in the study of Singh *et al.*, (1981). ARPS 5.1.5 version has been used here for the simulation of this active weather system. NCMRWF analysis of 01January has been interpolated in 30 Km using "ext2arps" preprocessors. The lateral boundary condition has been generated from the 24 hours interval prediction of same model of NCMRWF. The predicted precipitation output of ARPS model has been plotted in Figs. 5(a – d). The precipitation output was plotted in liquid water equivalent in centimeters. The precipitation pattern from

the model output was illustrating that on 01st January 2006, the weather system was active over the J & K region and Part of HP. On 02nd and 03rd January, it was extended over the Uttaranchal Hills and part of Nepal. 04th January the intensity of system dissipated. The broad features of the precipitation distribution were captured by model's simulation in 30Km resolution.

The model was configured in 10 Km resolution in one way nesting for predicting precipitation. The initial conditions were obtained from the ARPS 30 Km resolution at 00 UTC data. The lateral boundary conditions were interpolated from the 24 hours interval prediction of 30 Km resolution of ARPS model. The initial and lateral boundary conditions for 10Km configuration were taken from ARPS 30 Km simulation instead of directly interpolation from NCMRWF Model. The region is obvious; because some mesoscale features would not be available in the large scale model and those would be capture by the mesoscale model. Thus the benefits of capturing of mesoscale features in initial and lateral boundary conditions in mesoscale models has been ustilised for high resolution simulation instead of obtaining these conditions directly from large scale model. In this simulation, high resolution topography has been utilized. The topography modified the mountain weather in two ways.

1) It interacts with large scale circulation and modifies the large scale weather pattern due to the orographic forces.

2) The elevated mountain peaks behave as elevated heat source during day time and heat sink during the night time. The local circulation pattern modifies due to the differential heating and cooling of valley and peaks in mountain regions. The topographically generated valley and slope wind pattern consequently modifies the local weather.

In the present study, the effect of first factor will be evaluated in detail using the advantage of available of high resolution topography and use of vertical z coordinate in the model. As discussed earlier, the western Himalaya is a configured chain of different mountain ranges. The first mountain chain that interacts with approaching WD is the Pir Panjal Range. The Kashmir bowl (Kashmir valley) is enclosed with two prominent mountain ranges named as Pir Panjal and Great Himalayan Ranges and one broken mountain range known as Shmsawari range. The large scale weather system known as WD interacts with Pir Panjal range with plenty of moisture. The topographic barrier of the range generates the upward lifting force and consequently accelerates the condensation process. The Pir Panjal and Shamsawari ranges should receive the maximum precipitation intensity as they are the first interacting barrier with weather system in the western Himalaya. Again, the distribution should be different in Lee ward side and wind ward side of the individual range. The next range is the Great Himalayan range which receives the next higher value of precipitation. The Zansker and Laddakh ranges are lower than the Great Himalayan range so these are the rain shadow area and receive less precipitation. The Muskoh valley and Laddakh area is known and cold desert due to its dry and cold climatic conditions. The Great Karakoram range, the highest range of Himalayan mountain chains, experiences more precipitation intensity as compare to these two ranges (Zansker and Laddakh). Because it has highly elevated mountain peaks those are reaching up to the 400mb. The remaining moisture in the weather system can not penetrate these ranges and precipitates in this area.

Model outputs of the simulated precipitation have been shown in Figs. 6(a – d). Here we will investigate the spatial distribution of the simulated precipitation pattern over the complex topography. Fig. 6(a) is the simulated precipitation for 24 hours. The precipitation pattern showing that maximum value of precipitation was received in Shamsawari range and part of Pir Panjal Range in day one simulation. The day two precipitation (02nd January, 2006 to 03rd January, 2006, 00UTC) was illustrating the clear range wise distribution of the precipitation. It was showing that first range receives maximum precipitation and decreases toward the North-East direction. It is minimum is Muskoh, Drash and Leh area and then increasing in Great Karakoram Range. Similar pattern of the precipitation distribution was observed in day three predicted precipitation. Thus the Figs. 6(a – d) represents fairly well the spatial distribution of precipitation over the complex topography in Himalayan ranges.

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Table 1: Actual observed rainfall during the period 01 January 2006 to 05 January 2006.

S. No.	Station	Latitude ˚N	Longitude ˚E	Altitude (m)	Snowfall (cm)	Snowfall (cm)	Snowfall (cm)	Snowfall (cm)	Snowfall (cm)
	Western - Himalaya				01.01.06	02.01.06	03.01.06	04.01.06	05.01.06
1	Srinagar	33.59	74.47	1512	-	11	33	-	-
2	Banihal Top	33.52	75.20	3250	-	-	8.6	-	-
3	Himmat	33.39	74.28	3697	14	-	-	-	-
4	Haddan Taj	34.31	74.05	3250	20	67	41	02	-
5	Stage-II	34.42	73.99	2650	22	121	76	-	-
6	NC Pass	34.40	73.95	3138	25	40	70	01	01
7	Ragini	34.46	73.92	3160	20	146	98	05	-
8	Pharkiyan	34.58	74.08	2960	14	79	33	-	-
9	Z-Gali	34.62	74.43	3100	06	59	54	08	-
10	Sonapindi	34.69	74.32	3180	12	-	40	01	Trace
11	Gugaldhar	34.62	74.15	3360	14	-	18	-	-
12	MOP	34.08	74.06	4250	30	-	-	-	-
13	Kanzalwan	34.64	74.70	2440	12	86	67	10	02
14	Pant	34.70	74.65	4040	-	81	57	13	05
15	Dawar	34.63	74.83	2414	-	60	55	03	01
16	Niru	34.56	75.03	2630	07	59	62	13	15
17	Sonamarg	34.30	75.30	2745	02	53	-	Trace	-
18	Drass	34.43	75.77	3250	02	19	24	01	04
19	Pather	34.50	75.67	4250	06	-	35	01	04
20	Kaksar	34.52	75.98	2960	-	03	09	-	03
21	Bimbat LC	34.43	75.81	4950	10	28	40	01	02
22	Firm Base	34.53	75.66	4760	-	-	45	01	06
23	Gulmarg	33.42	73.57	2800	07	136	96	-	-
24	Puttakhan	34.59	74.09	2972	14	59	19	-	-
25	Chakwali	33.78	75.26	--	01	60	75	02	10
26	Killnala	34.61	74.76	--	06	35	42	02	12

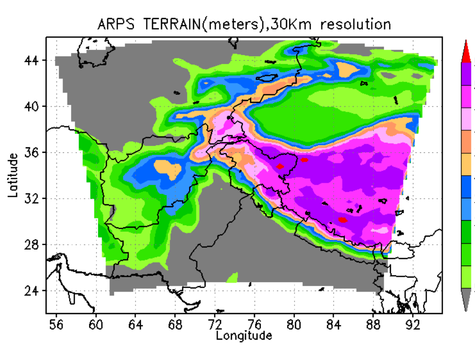

Figure 1(a): Topography of western Himalaya in 30 Km resolution

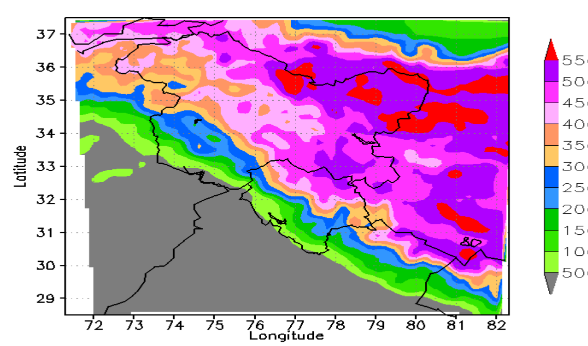

Figure 1(b): Topography of western Himalaya in 10 Km resolution

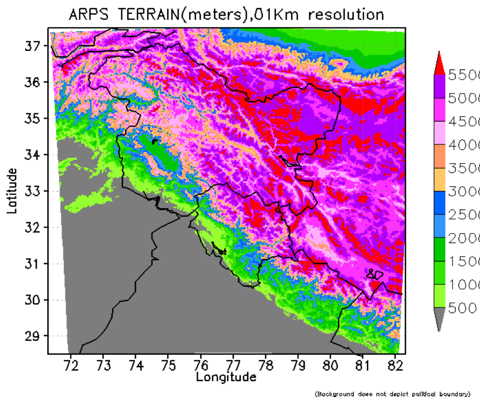

Figure 1(c): Topography of western Himalaya in 1 Km resolution

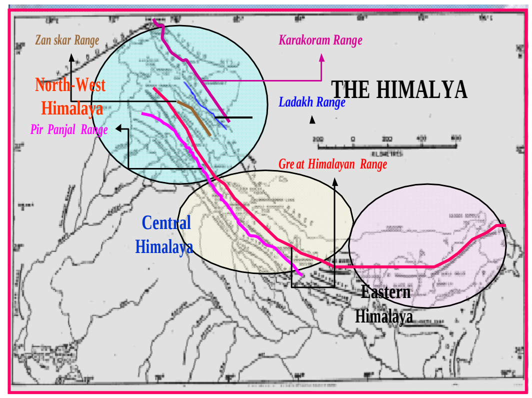

Figure 1(d): Five ranges of Himalaya

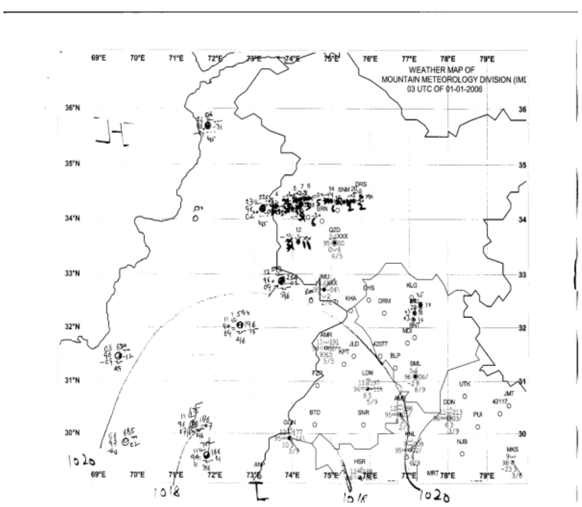

Figure 2(a): WD lies over north Pakistan and neighborhood and a low pressure area (LOPAR) (01st January, 2006)

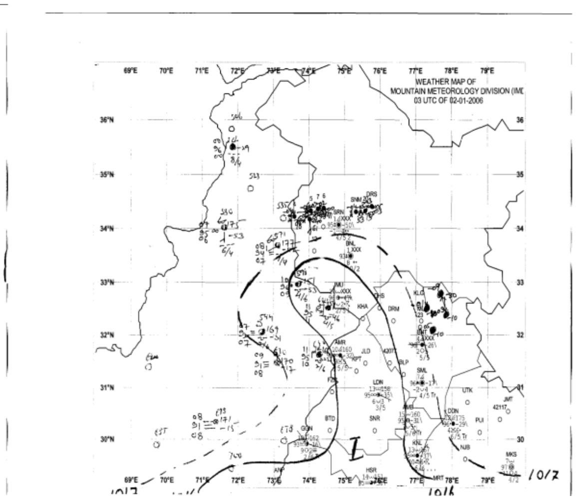

Figure 2(b): WD still persists and induced LOPAR further strengthened. (2nd January, 2006)

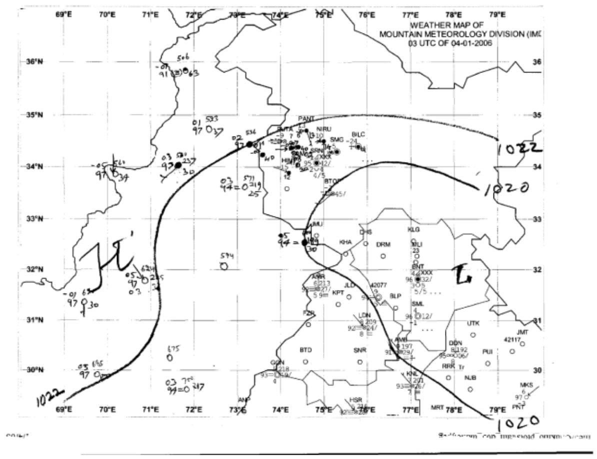

Figure 2(c): WD moved eastward and lies over Himachal Pradesh and west UP and LOPAR is less marked. (3rd January, 2006)

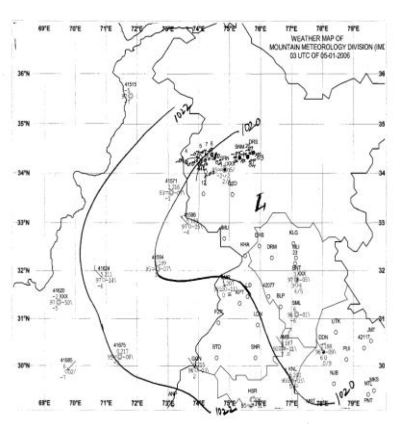

Figure 2(d): WD lies over UP and HP LOPAR and induced ciclonic Circulation is less marked. (5th January, 2006)

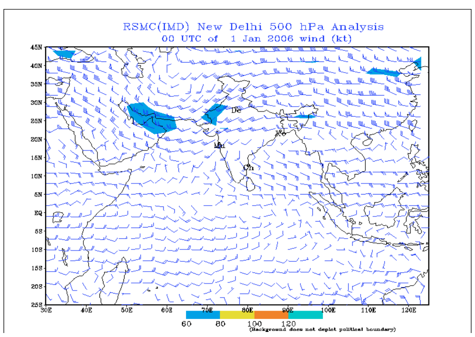

Figure 3(a): 500 hPa winds analysis chart at 01st January, 2006.

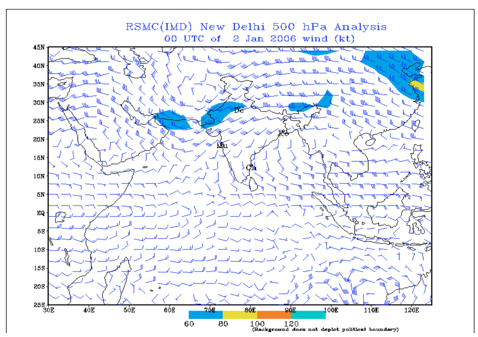

Figure 3(b): 500 hPa winds analysis chart at 2nd January, 2006

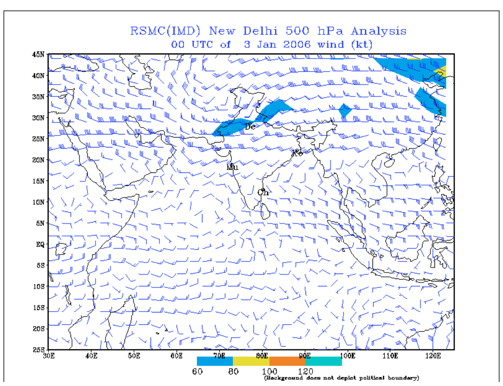

Figure 3(c): 500 hPa winds analysis chart at 3rd January, 2006.

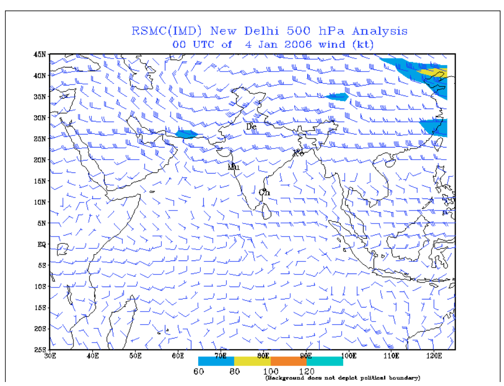

Figure 3(b): 500 hPa winds analysis chart at 4th January, 2006

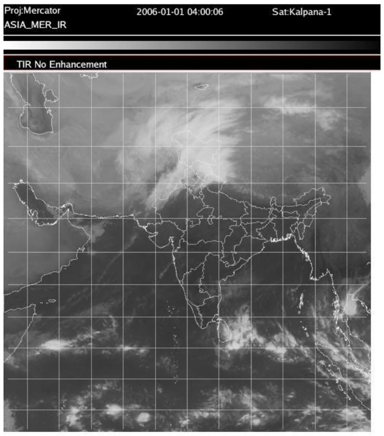

Figure 4(a): Kalpana-1 IR image on 01st January, 2006.

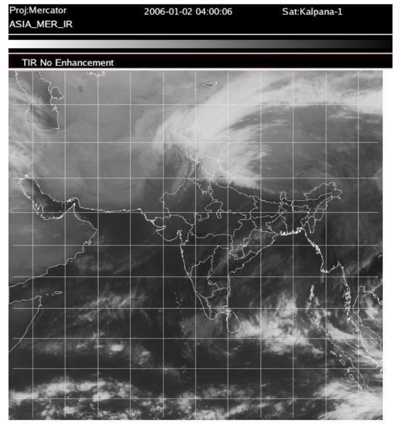

Figure 4(b): Kalpana-1 IR image on 2nd January, 2006.

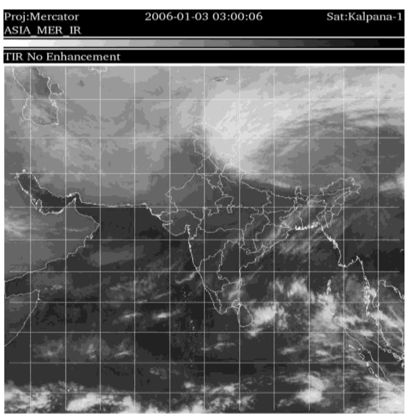

Figure 4 (c): Kalpana-1 IR image on 03rd January, 2006.

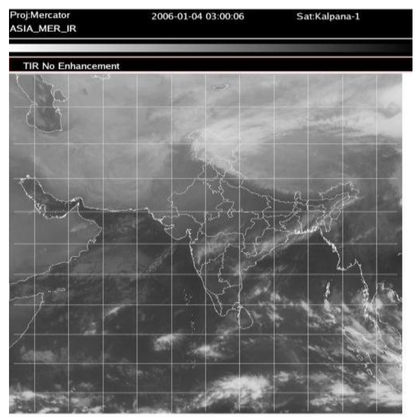

Figure 4 (d): Kalpana-1 IR image on 4th January, 2006.

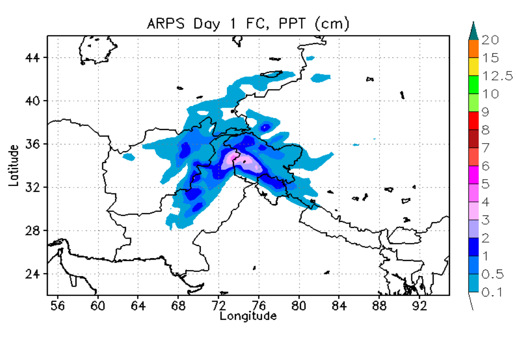

Figure 5 (a): Day 1 (01st January, 2006) ARPS model forecast at 30 Km resolution.

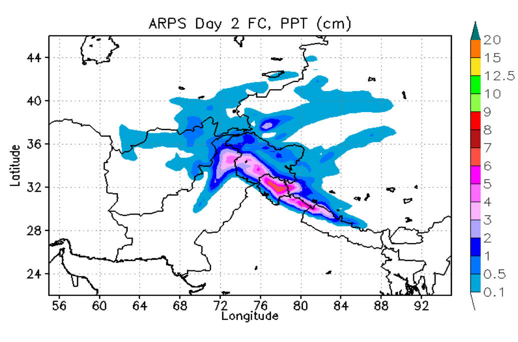

Figure 5 (b): Day 2 (2nd January, 2006) ARPS model forecast at 30 Km resolution

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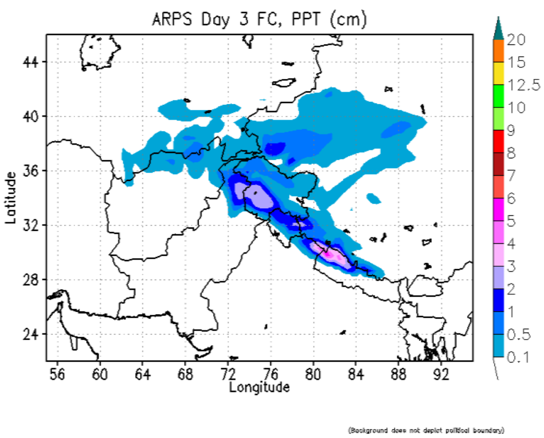

Figure 5(c): Day 3 (3rd January, 2006) ARPS model forecast at 30 Km resolution.

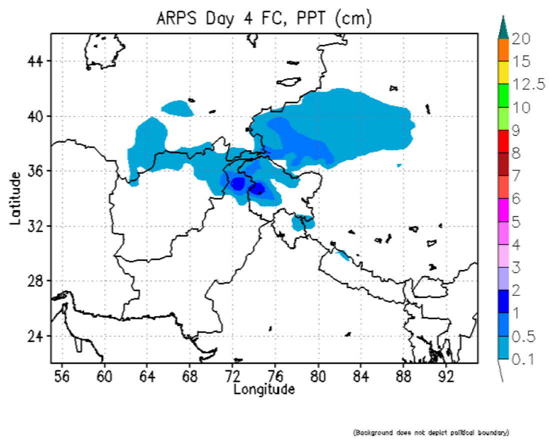

Figure 5(b): Day 4 (4th January, 2006) ARPS model forecast at 30 Km resolution.

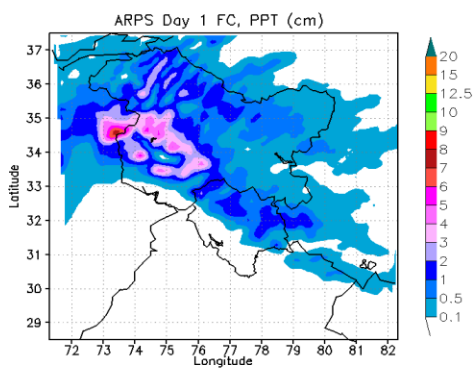

Figure 6(a): Day 1 (01st January, 2006) ARPS model forecast at 10 Km resolution.

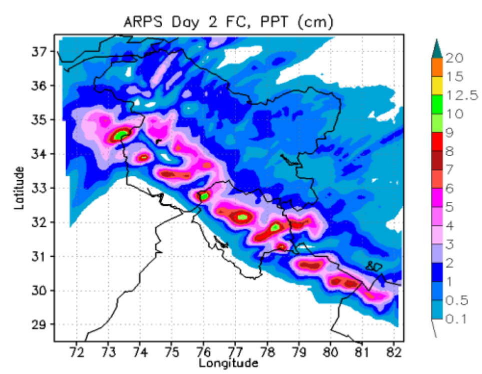

Figure 6(b): Day 2 (2nd January, 2006) ARPS model forecast at 10 Km resolution.

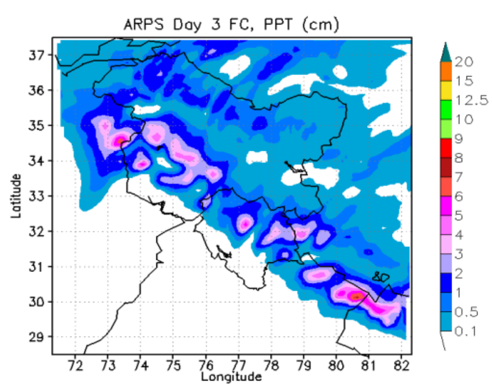

Figure 6(c): Day 3 (3rd January, 2006) ARPS model forecast at 10 Km resolution.

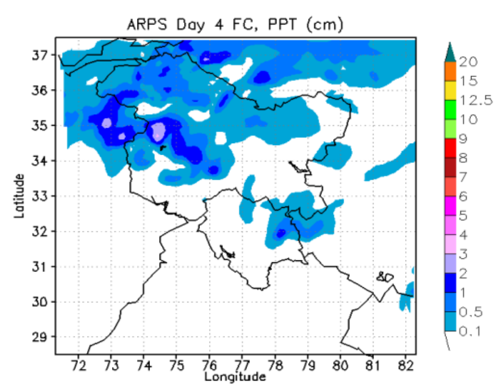

Figure 6(d): Day 4 (4th January, 2006) ARPS model forecast at 10 Km resolution.

Conclusions

The active WD was simulated using meso-scale numerical model ARPS. The output of the simulated precipitation in two domains leads to the following conclusion.

1. The model simulated precipitation in 30Km resolution is capable to capture the active weather system and could predict well in advance with initial and lateral boundary condition from NCMRWF T-80 spectral global model. The simulated precipitation is showing the broad spatial distribution of predicted precipitation.
2. The model could simulate the effect of high resolution topography in the precipitation distribution. The simulated precipitation distribution over the complex topography of western Himalaya was following the similar pattern as explained on the theoretical as well as the observational basis. The simulated precipitation shows the spatial heterogeneity in the mountain range. The heterogeneity in spatial distribution in the individual range was due to the heterogeneous complexity of mountain peaks.
3. Model simulated forecast precipitation pattern in 10 Km resolutions is very well captured spatially with the observed precipitation over the area.

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