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Precipitation simulation of synoptic scale systems over western Himalayan region using Advanced Regional Prediction System (ARPS) model

GIRISH SEMWAL and R. K. GIRI*

Snow and Avalanche Study Establishment, Research and Development Centre,

Sector 37-A, Chandigarh - 160 036, India

**Mountain Met Centre, Srinagar - 913 970, India*

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***e mail : rkgiri_ccs@rediffmail.com**

सार – मौसम विज्ञान संबंधी आंकड़ों की दुर्लभता तथा जटिल एवं दुर्गम स्थलाकृति के कारण पष्चिमी हिमालय क्षेत्र के लिए सक्रियात्मक मौसम पूर्वानुमान जारी करना चुनौती पूर्ण कार्य है क्योंकि इससे मौसम आगमन की प्रक्रिया प्रभावित होती है। विविधतापूर्ण मौसम स्थितियों में सही पूर्वानुमान करने के लिए मौसम आंकड़ों के सघन संजाल की आवष्यकता होती है जिन्हें हिमालय की प्रतिकूल स्थितियों तथा जटिल एवं दुर्गम भू–भाग के कारण पहाड़ों पर संस्थापित करना कठिन है। इस समस्या के समाधान के लिए ग्लोबल मॉडल के विष्लेषण और पूर्वानुमान के आरंभिक मानों तथा मध्यमापक्रम संख्यात्मक मॉडल के पार्ष्व परिसीमा स्थितियों के त्रि–आयामी मौसम विविधताओं को अंतर्ग्रहित कर एक वैकल्पिक विधि तैयार की गई है। साथ ही साथ मौसम आंकड़ों का संग्रहण एक संचित संसाधन है जिसमें गैर पारंपरिक {उपग्रह, रेडार तथा स्वतः चालित मौसम स्टेषनों (ए. डब्ल्यू. एस.)} तथा पारंपरिक (सतह एवं उपरितन वायु प्रेक्षण) आंकड़ों को संख्यात्मक मॉडल में अंतर्निहित किया गया है ताकि मध्य मापक्रम मॉडल के सूत्रपात के लिए उच्च विभेदन और सटीक आरंभिक क्षेत्रों को तैयार किया जा सके। इस षोध पत्र में सिनॉप्टिक मौसम प्रणाली जिसे पष्चिमी विक्षोभ के नाम से जाना जाता है तथा जो सर्दी की अवधि (नवम्बर से अप्रैल तक) के दौरान पष्चिमी तथा मध्य हिमालय क्षेत्र के मौसम को प्रभावित करता है, का पूर्वानुमान करने के लिए विकसित क्षेत्रीय पूर्वानुमान प्रणाली (ए. आर. पी. एस.) का उपयोग किया गया है। इस षोध पत्र में ए. आर. पी. एस. मॉडल का चयन इसके वस्तुपूरक विष्लेषण तथा गुणवत्ता नियंत्रण प्रणाली की मौजूदगी के कारण किया गया है। इसमें उपग्रह, डॉपलर मौसम रेडार तथा अन्य प्रकार के प्रेक्षणों से प्राप्त आंकड़ों को अंतर्ग्रहित करने की क्षमता है। इसकी अंतर्ग्रहण प्रणाली का उपयोग हिमालय क्षेत्र में आंकड़ों की दुर्लभता की समस्या के समाधान के लिए भी किया जा सकता है। इस षोध पत्र में आरंभिक एवं पार्ष्व परिसीमा क्षेत्रों को टी–80 स्पेक्ट्रल ग्लोबल मॉडल से लिया गया है जिसका सक्रियात्मक उपयोग राष्ट्रीय मध्यअवधि मौसम पूर्वानुमान केंद्र (एन. सी. एम. आर. डब्ल्यू. एफ.) नोएडा (उ. प्र.) भारत द्वारा किया जाता है। पहले ग्लोबल मॉडल विष्लेषण आरंभिक स्थिति के पूर्वानुमान के लिए तथा 24 घंटे के अंतराल के पूर्वानुमान के लिए पार्ष्व परिसीमा स्थितियों को लिया जाता था। इस मॉडल का उपयोग 96 घंटे (चार दिनों) के लिए कुछ पष्चिमी विक्षोभों के अनुरूपण के लिए किया गया है। ए. आर. पी. एस. अनुरूपण का टी–80 पूर्वानुमान के साथ तुलना करने पर पता चला है कि ए. आर. पी. एस. मॉडल पष्चिमी विक्षोभों के परिसंचरण की तुलना में अच्छे परिणाम दे सकेगा इसलिए भारतीय क्षेत्र में सक्रियात्मक मौसम पूर्वानुमान करने के लिए इसका उपयोग किया जा सकता है।

ABSTRACT. Operational weather prediction over western Himalayan region is a challenging job due to scarcity of data and complex topography that interacts with approaching weather system. Accurate prediction of complex weather phenomena requires dense data network which is difficult to establish in mountain due to complex terrain and hostile weather conditions over Himalaya. The alternate method to overcome this problem is by ingesting three-dimensional meteorological variables from global model's analysis and forecast values as initial and lateral boundary conditions in meso-scale numerical models. Simultaneously, data assimilation is a potential tool in which non-conventional [satellite, radar and Automatic Weather Station (AWS)] and conventional (surface and upper air observations) data are ingested in the numerical models to generate high resolution and accurate initial fields for the initialization of the mesoscale model. In the present study, Advanced Regional Prediction System (ARPS) model has been used for the prediction of synoptic weather system known as Western Disturbance (WD) that affects the weather of western and central Himalaya during winter period (November – April).The ARPS model has been selected for this study because the model has its own objective analysis and quality control system. It has the capacity to ingest the satellite, Doppler weather radar data and other types of observations. Its assimilation system can also be used to overcome the problem of data scarcity in Himalayan region. In this study, initial and lateral boundary fields are taken from the T-80 spectral global model operationally used at National Centre for Medium Range Prediction (NCMRWF), Noida (UP), India. The global model's analysis was taken as the initial condition and 24 hour's interval forecasts as lateral boundary conditions. The model has been used for the simulation of few WDs for 96 hours (Four days). The comparison of ARPS simulation with T-80 forecast shows that the ARPS model could produce better results in respect of the circulation of WDs and hence it can be utilized for the operational weather prediction over the Indian region.

Key words – Western Disturbance (WD), Snow Avalanches, Advanced Regional Prediction System and Automatic Weather Station (AWS).

1. Introduction

Snow avalanches are the devastating natural calamity in snow covered regions. Snow avalanches are caused by the accumulation of snow over the mountain terrains and then sudden downward movements of huge snow mass with the speed of approximately 60 km/hr and force approximately 1 ton/m^2 to 60 ton/m^2. Habitation areas of western and central Himalaya are prone to the snow avalanche in winter period. Snow and Avalanche Study Establishment (SASE), Chandigarh, India, is involved in the mitigation of avalanches using different active and passive methods. Avalanche forecasting is one of the thrust areas of avalanche mitigation using passive method. Meteorological parameters are key components in the assessment of avalanche hazard as well as inputs in the avalanche forecasting models. Quantitative prediction of meteorological parameters especially the precipitation (Mainly snowfall in winter) has its importance to the avalanche forecaster for the assessment of the potential of avalanche hazard and safe mobility of people in snow bound region.

Western Himalaya and part of central Himalaya receives significant precipitation in winter due to the movement of weather system popularly know as the Western Disturbance (WD). These synoptically induced systems originate as a small low pressure at the surface and cyclonic circulation or trough above the surface over Iraq/Iran region. While moving eastward they fetch moisture from Arabian Sea and further intensified. The complex interaction of these weather systems with topography of mountains and orographic forces in western Himalaya gives the intense and non-uniform spatial distribution of precipitation.

Two cases of moderate to heavy and widespread precipitation over the complex topography of western Himalaya have been studied using Advanced Regional Prediction System (ARPS). ARPS model was developed by Centre for Analysis and Prediction of Storm (CAPS), University of Oklahoma, USA. The model can be used for research as well as operational purpose. The scales of horizontal resolution for which model can be used vary from storm scale to regional scale. The model is well documented and tested by Ming Xue *et al.* (2000) and Ming Xue *et al.* (2001). ARPS model has its own objective analysis, quality control and assimilation system. Ming Xue *et al*. (2003) described the comparisons of two assimilation system ADAS (ARPS Data Assimilation System) and 3DVAR. Its ADAS assimilation system with all conventional and non conventional data sets (includes Doppler radar and satellite data) was used by Case *et al*. (2002). Yoo *et al.* (2002) used ARPS for the study of heavy rainfall events over Korean Peninsula using Radar data assimilation system. Gao *et al.* (2004) described the three dimensional variational assimilation methods of ARPS for Doppler radar in detail. Instead of ingesting initial and lateral boundary condition from different global and mesoscale models, ARPS has its own assimilation system which ingests initial and lateral boundary fields from its own model output. In view of the real time numerical forecast problem (operational weather forecast problem) in Indian Region, ARPS model requires initial and lateral boundary conditions from global/mesoscale models which are operationally used in India and required initial and lateral boundary field are available on operational basis.

In the present work, ARPS model was tested with NCMRWF T-80 spectral global model's analysis as initial condition and 24 hours forecast of same model as lateral boundary conditions. With this, ARPS model was simulated for a few cases of WDs, which have given widespread precipitation in the form of snow over Western Himalaya. Model predicted precipitation has been compared with the observations at different stations over Western Himalaya and large scale (T-80) model's output. ARPS model performance is discussed in the paper.

2. Data and methodology

The Kalpana-1 satellite imagery data used for the present study is taken from the website, http://www.imd.ernet.in. The Initial and lateral boundary fields of NCMRWF T-80 spectral global model original data was in 1.5° × 1.5° horizontal resolution with twelve vertical pressure levels, which was interpolated in 30 km horizontal resolution and 1.5 km vertical resolution with eleven 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 lateral boundary conditions were geopotential height (*z*), *u* and *v* components of wind, relative humidity (RH) and temperature (*t* °K). Two layers soil model has been used and soil model initial field (two layer soil moisture and

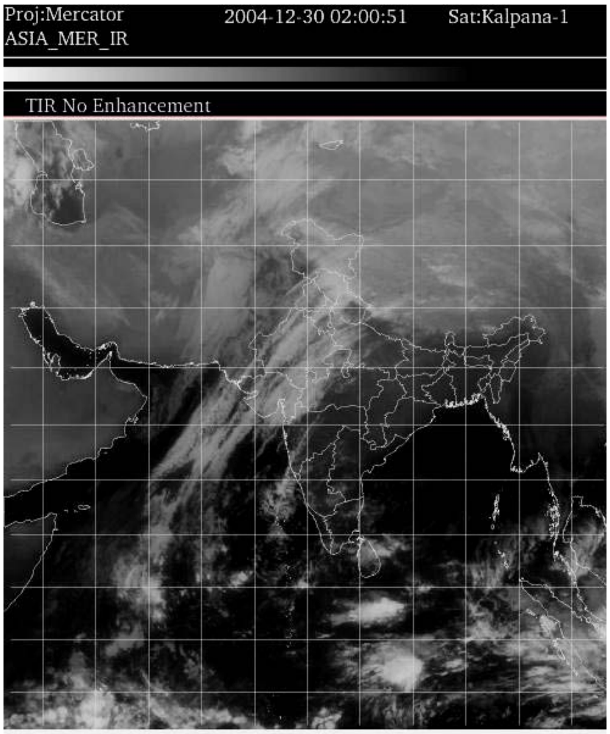


Fig. 1 (a). Kalpana-1 IR image of 0200 UTC 30 December, 2004

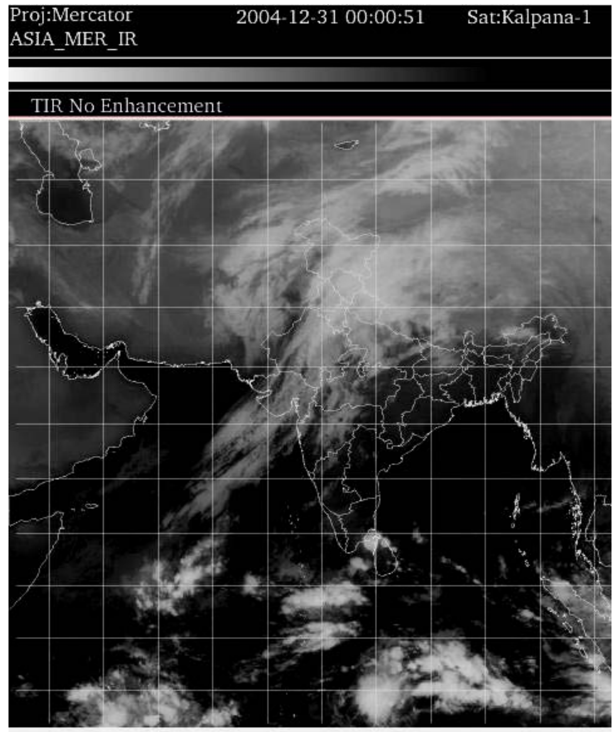


Fig. 1 (b). Kalpana-1 IR image of 0000 UTC of 31 December, 2004

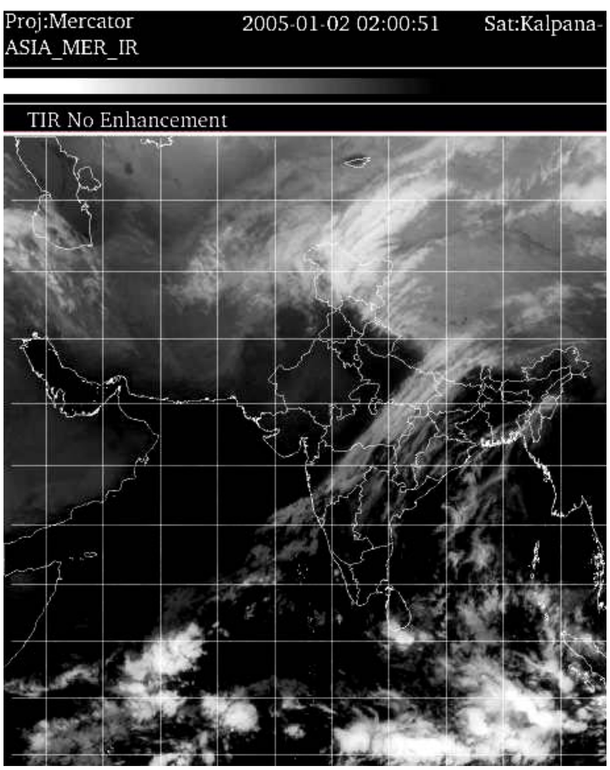


Fig. 1 (c). Kalpana-1 IR image of 0200 UTC of 02 January, 2005

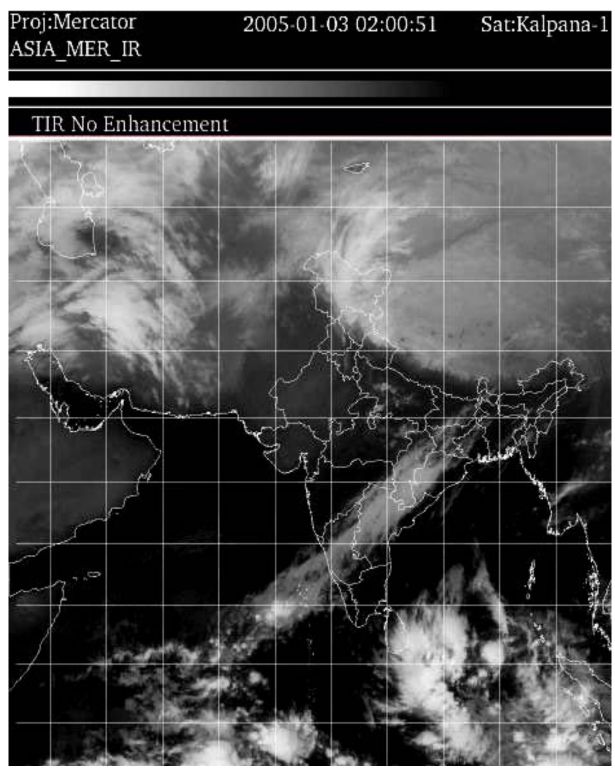


Fig. 1 (d). Kalpana-1 IR image of 0200 UTC of 03 January, 2005

TABLE 1

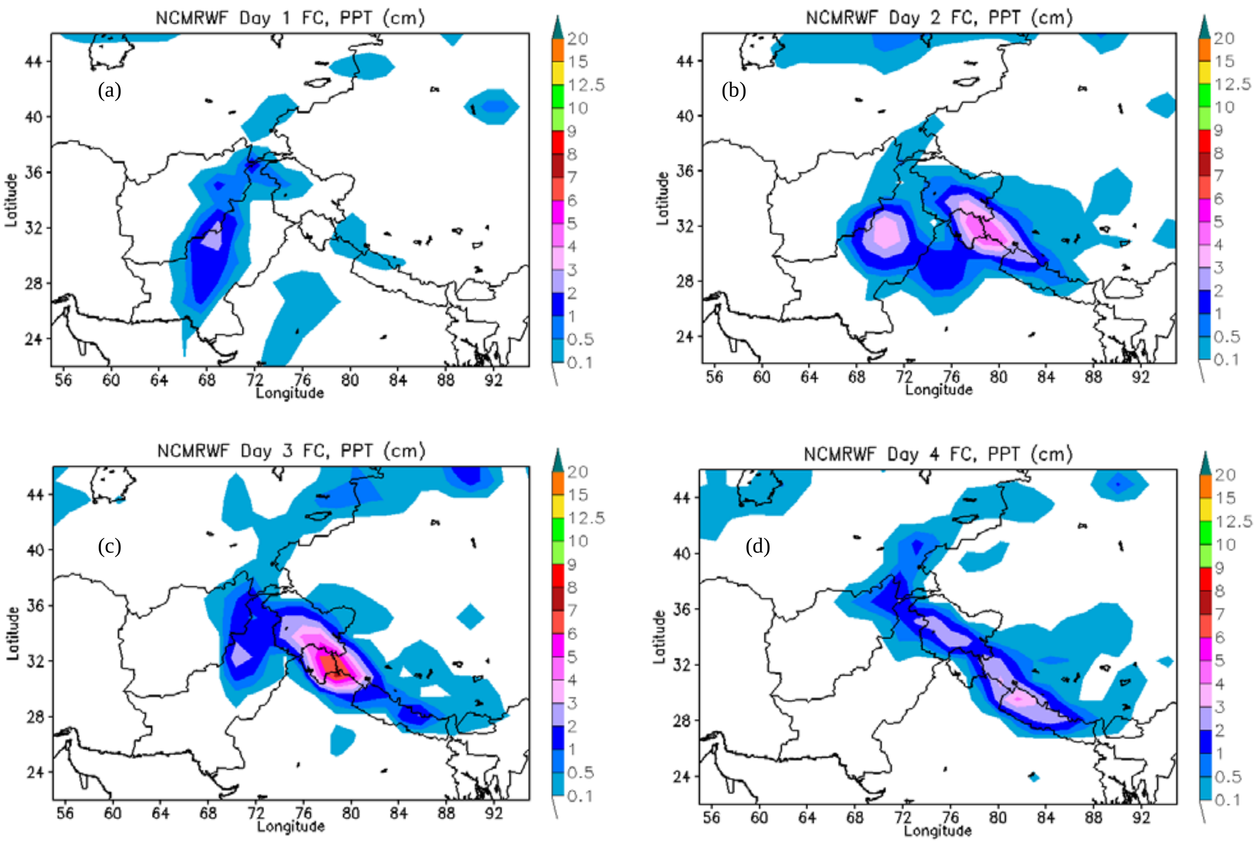
Snowfall data (cm) and liquid water equivalent (cm) in bracket of different observatories from 31 December 2004 to 04 January 2005

Station	Altitude	31 Dec 2004	01 Jan 2005	02 Jan 2005	03 Jan 2005	04 Jan 2005
			J & K Sector			
Banihal Top	3250	11(1.1)	32(3.2)	10(1.0)	10(1.0)	-
Gulmarg	2800	27(2.7)	53(5.3)	07(0.7)	04(0.4)	-
Stage-II	2650	37(3.7)	70(7.0)	29(2.9)	14(1.4)	-
Haddan Taj	3250	33(3.3)	40(4.0)	02(0.2)	-	-
Pharkiyan	2960	18(1.8)	41(4.1)	05(0.5)	-	-
Z-Gali	3100	29(2.9)	35(3.5)	17(1.7)	01(0.1)	-
Kanzakwan	2440	24(2.4)	41(4.1)	33(3.3)	10(1.0)	-
Drass	3250	09(0.9)	26(2.6)	04(0.4)	09(0.9)	-
Base Camp	3350	-	04(0.4)	-	-	01(0.1)
Kumar	3800	02(0.2)	02(0.2)	-	-	02(0.2)
Billabase	5215	01(0.1)	01(0.1)	02(0.2)	02(0.2)	-
Siala	5995	-	07(0.7)	04(0.4)	13(1.3)	07(0.7)
Chandan	5320	02(0.1)	08(0.8)	12(1.2)	07(0.7)	04(0.4)
Jawala	5400	-	-	01(0.1)	02(0.2)	01(0.1)
Zullu	5600	01(0.1)	05(0.5)	-	01(0.1)	02(0.2)
Bahadur	5450	02(0.2)	02(0.2)	01(0.1)	01(0.1)	-
Rewari	5040	03(0.3)	07(0.7)	04(0.4)	-	03(0.3)
CHQ	4200	02(0.2)	04(0.4)	-	02(0.2)	02(0.2)
Talwar	5000	04(0.4)	16(1.4)	08(0.8)	02(0.2)	-
			HP Sector			
Bahang	2003	11(1.14)	33(3.3)	5.0(0.5)	04(0.4)	-
Solang	2480	04(0.4)	-	-	11(1.1)	-
Dhundi	3050	50(5.0)	13(1.3)	03(0.3)	17(1.7)	-
Patseo	3800	23(2.3)	36(3.6)	26(2.6)	14(1.4)	-

soil temperature) was obtained from NCMRWF. However, the resolution of soil temperature and soil moisture was 1.48° × 1.48°. The soil variable were first interpolated in 1.5° × 1.5° 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.

3. Model configuration

ARPS version 5.1.5 has been configured in 30 km horizontal resolution and 1.5 km vertical resolution with centre of domain at 75° E and 35° N and total domain size 101 × 81 × 11. The vertical grid was first stretched using the terrain following coordinate with the help of terrain data and again stretched in vertical direction using tangent hyperbolic function Xue *et al*. (1995). The vertical grid spacing becomes non-uniform due to stretching of grids with tangent hyperbolic function. The minimum spacing near the surface is required to define the stretching and this spacing must be less that or equal to the vertical grid resolution. The stretching generates closer spacing between grids near surface and wider spacing as vertical extend of computational domain increases. In this configuration, minimum spacing was defined as 150 m which generates the grid spacing 150 m near the surface and 2850 m at the top of the computational domain. 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 differencing scheme and small time step was integrated in forward-backward method. For this configuration, a large time step was taken as 120 sec and small time step of integration was taken 40 sec. Vertical pressure and vertical velocity solver were integrated using



Figs. 2(a-d). NCMRWF precipitation forecast for (a) 31 December 2004, (b) 01 January 2005, (c) 02 January 2005 and (d) 03 January 2005

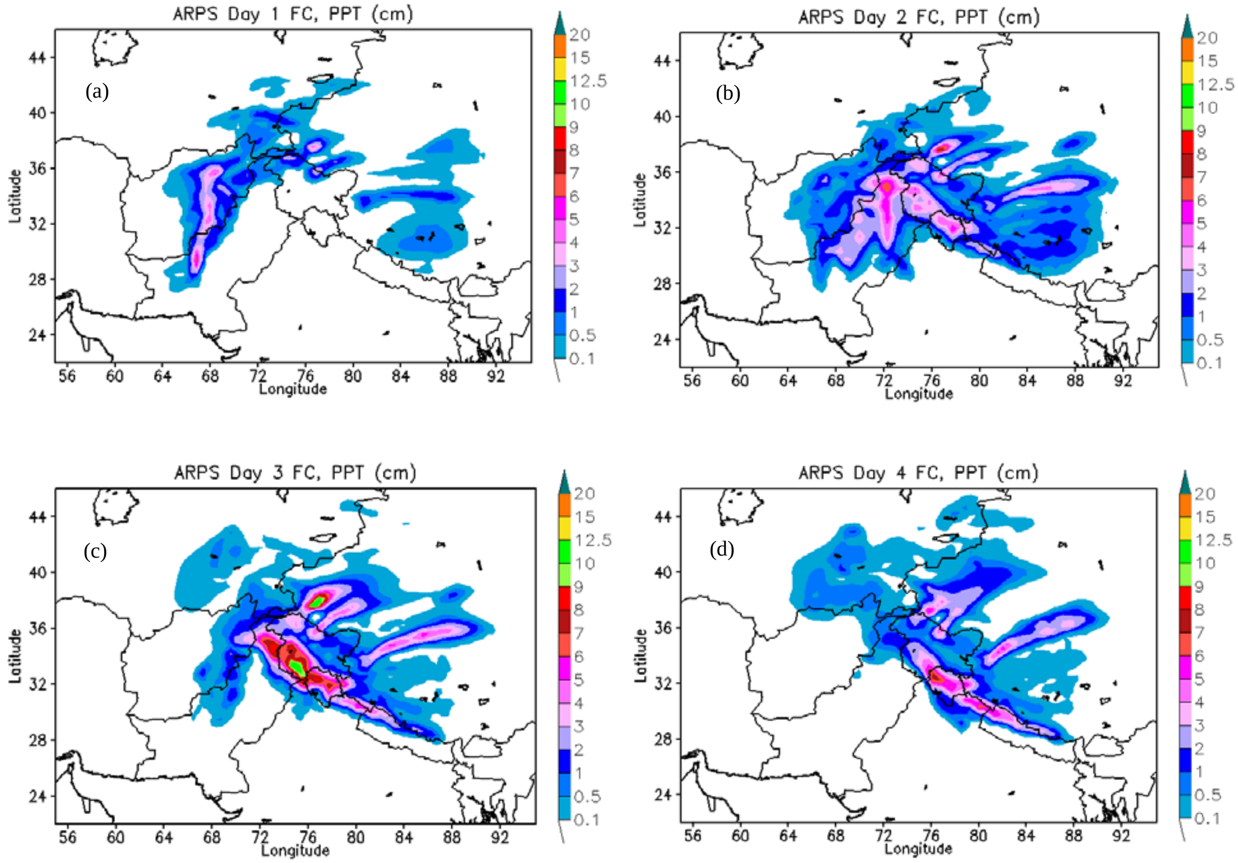
Crank-Nicholson's implicit method. Radiation forcing was updated in every 10 minutes and convective parameterization was updated in every 120 sec using WRF (Kain 2004). The grid resolved rain was computed using Kessler's warm rain approximation. 1.5 turbulent kinetic energy (TKE) approximation has been used for sub grid turbulence computation. Two layers soil model has been used to predict the soil temperature and soil moisture. To compute the heat and momentum fluxes in atmospheric boundary layer, roughness length and vegetation fraction has been computed from normalized difference of vegetation index (NDVI) data available with ARPS data bank.

4. Case studies

4.1. *30 December, 2004 to 04 January 2005*

A Western disturbance as an upper air system appeared over Pakistan and adjoining Afghanistan area on 30 December 2004 [Fig. 1(a)]. The system was seen as multi-layers clouds with moderate to intense convection over Jammu and Kashmir region [Figs. 1 (a&b)]. The system remains almost quasi-stationary up to 02 January, 2005 and was associated with the low and middle level moisture spreading over the large area. Further intensification was also supported by the south-westerly cloud patterns which was associated with moisture from Arabian Sea [Fig. 1(b)]. The high pressure system appeared over Bay of Bengal also supported the spreading of moisture over the large area. On subsequent days it was well marked over the western Himalaya and further extending to the central Himalaya. All these features were clearly indicated in Kalpana-1 satellite IR imageries [Figs. 1 (a-d)]. The brightness of cloud bands in the subsequent days increased and extended over the Central Himalaya region. Indirectly, the brightness intensity is the probable indicator of the amount of the moisture over the area. The moisture build up was extended up to the foot hills of Himalaya across Gujarat coast, Rajasthan, Delhi and Punjab.

The precipitation amount in the form of snow and corresponding liquid water equivalent in bracket during the persistence of western disturbance recorded at different sector and cooperative observatories are presented in Table 1. In the computation of liquid water equivalent from fresh snow, the density of fresh snow was

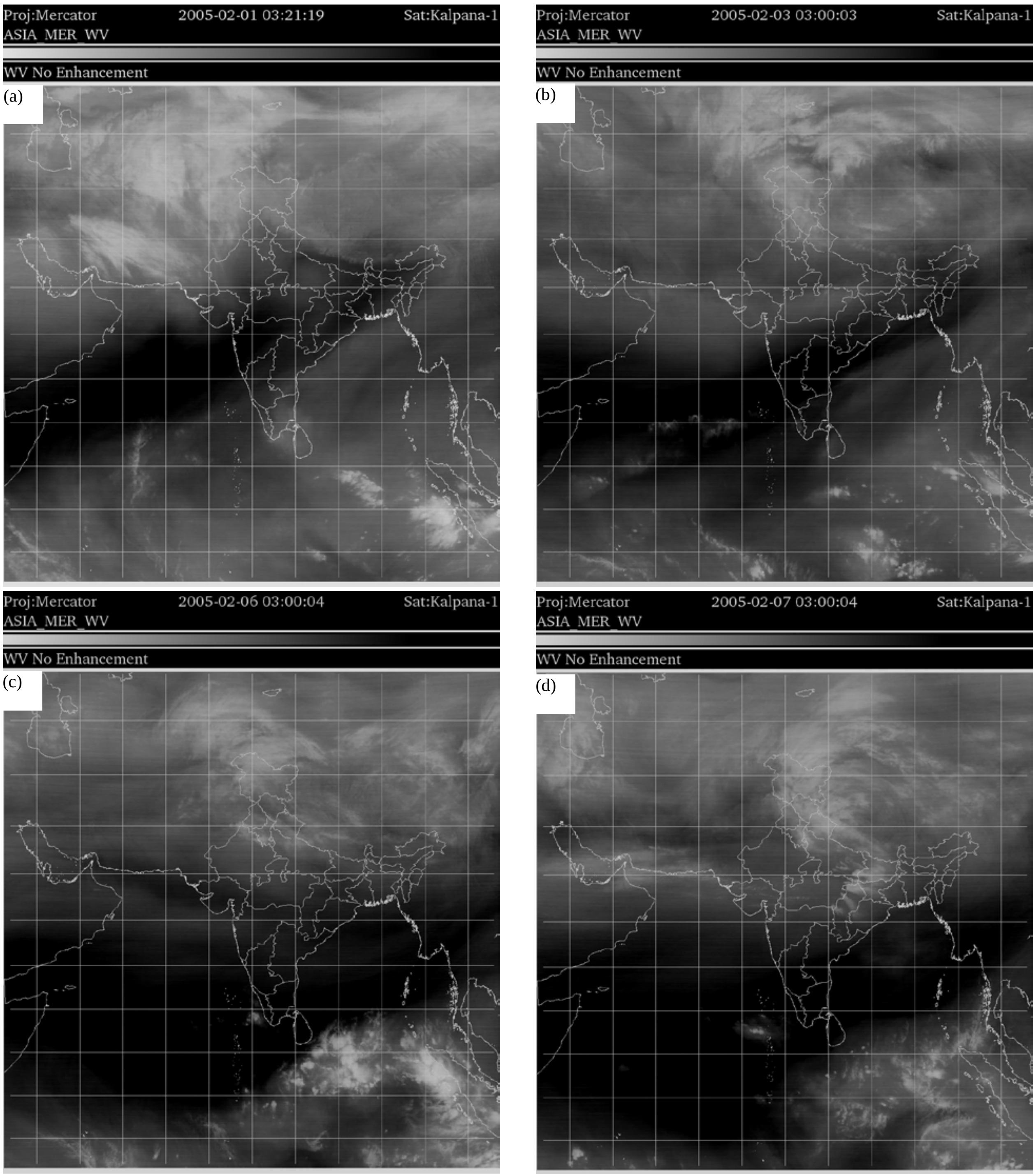


Figs. 3(a-d). ARPS Precipitation forecast (a) 31 December 2004, (b) 01 January 2005, (c) 02 January 2005 and (d) 03 January 2005

considered as 0.1 kg/m^3. The variation of fresh snow density with the change of location was not taken into account. The precipitation distribution was not uniform over the region. Some stations, though being very near to one another (Solange and Dhundi, Bahang and Solang etc.), there is significant difference in the amount of precipitation in those stations. This non-uniform distribution in the amount of precipitation is due to the complex topography of Himalaya. The amount of precipitation at individual station depends upon orientation of surrounding topography and its interaction with local circulation.

Here, ARPS model's predicted precipitation distribution was compared with large scale model's (T-80) precipitation distribution to verify the proper ingestion of initial and lateral boundary conditions into the model. Figs. 2 (a-d) are depicting the four days forecast of precipitation distribution from T-80 models. It is clear from the forecast analysis that the large scale model was showing the approach of weather system in Jammu and Kashmir region [Fig. 2 (a) and Fig. 3 (a)]. On subsequent days, the intensity of precipitation and its area coverage gradually increased. It has given the widespread precipitation distribution over the western Himalaya, extending up to the central Himalaya (Uttaranchal Hills and Nepal).

The ARPS model simulation has been carried for 96 hours with initial fields of 30 December 2004 from NCMRWF and lateral boundary condition from the forecast value in 24 hours intervals for consecutive four days. The day one forecast *i.e*. forecast for 31 December 2004 from the model simulation was showing the approach of WD in the neighborhood of Jammu and Kashmir region. Gradually, it was moving eastward and the intensity and spatial coverage of surface precipitation also agrees reasonably in the subsequent days. On the fourth day the system was mostly centered in central Himalaya and this feature is very well captured by the ARPS model [Figs. 3 (a-d)] The broad features of the predicted surface precipitation pattern was same in both model (NCMRWF and ARPS) however, the ARPS was illustrating the fine scale features of the precipitation over the complex topography.



Figs. 4 (a-d). Kalpana-1 WV image of 0300 UTC (a) 01 February, 2005, (b) 03 February 2005, (c) 06 February 2005 and (d) 07 February 2005

4.2. *03 February, 2005 to 07 February, 2005*

A Western Disturbance was appeared over north Pakistan and adjoining Jammu and Kashmir on 1^{st} February 2005. Its initial North - Easterly Movement gradually changes into eastward and caused widespread snowfall over the western and part of central Himalaya. The distribution of moisture in mid and upper troposphere is clearly seen in Kalpana -1 satellite Water Vapour (WV) imageries [Figs. 4 (a-d)]. The tremendous accumulation of

TABLE 2

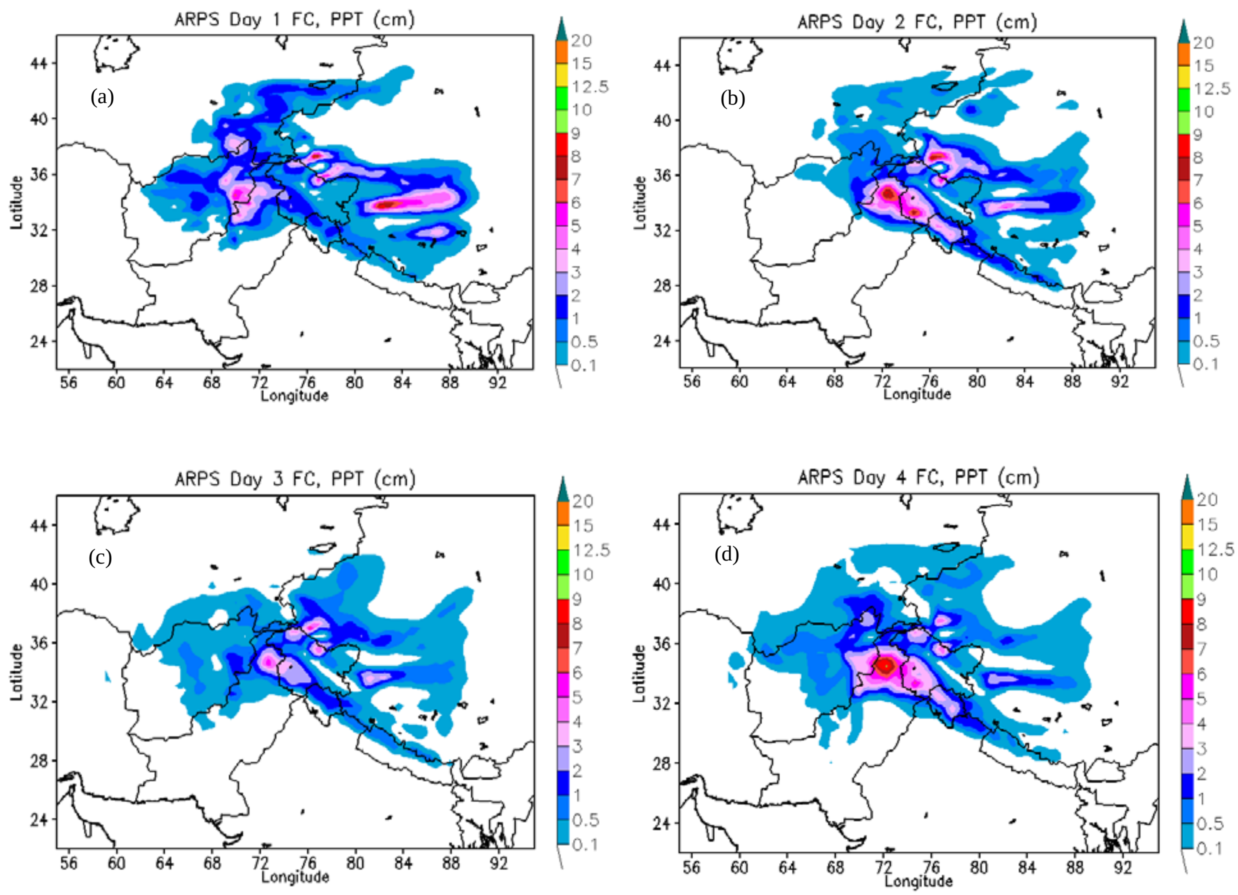
Snowfall data (cm) and liquid water equivalent in bracket (cm) for different observatories from 03 February 2005 to 07 February 2005

Station	Altitude	03 Feb 2005	04 Feb 2005	05 Feb 2005	06 Feb 2005	07 Feb 2005
			J&K Sector			
Banihal Top	3250	05(0.5)	25(2.5)	04(0.4)	17(1.7)	70(7.0)
Gulmarg	2800	28(2.8)	16(1.6)	19(1.9)	50(5.0)	70(7.0)
Stage-II	2650	32(3.2)	35(3.5)	32(3.2)	53(5.3)	53(5.3)
Haddan Taj	3250	35(3.5)	25(2.5)	28(2.8)	58(5.8)	31(3.1)
Pharkiyan	2960	16(1.6)	23(2.3)	22(2.2)	21(2.1)	49(4.9)
Z-Gali	3100	16(1.6)	25(2.5)	10(1.0)	24(2.4)	21(2.1)
Kanzakwan	2440	34(3.4)	49(4.9)	48(4.8)	76(7.6)	45(4.5)
Drass	3250	01(0.1)	04(0.4)	02(0.2)	03(0.3)	34(3.4)
Base Camp	3350	-	-	-	-	-
Kumar	3800	-	-	-	-	-
Billabase	5215	02(0.2)	-	-	01(0.1)	-
Siala	5995	14(1.4)	-	12(1.2)	10(1.0)	-
Chandan	5320	03(0.3)	-	-	-	-
Jawala	5400	02(0.2)	01(0.1)	-	01(0.1)	03(0.3)
Zullu	5600	03(0.3)	-	-	-	-
Bahadur	5450	03(0.3)	03(0.3)	02(0.2)	02(0.2)	05(0.5)
Rewari	5040	07(0.7)	06(0.6)	05(0.5)	07(0.7)	09(0.9)
CHQ	4200	01(0.1)	-	01(0.1)	11(1.1)	09(0.9)
Talwar	5000	03(0.3)	02(0.2)	01(0.1)	10(1.0)	10(1.0)
			HP Sector			
Bahang	2003	1.5(0.15)	02(0.2)	-	02(0.2)	61(6.1)
Solang	2480	07(0.7)	27(2.7)	06(0.6)	20(2.0)	99(9.9)
Dhundi	3050	05(0.5)	42(4.2)	10(1.0)	18(1.8)	107(10.7)
Patseo	3800	02(0.2)	07(0.7)	02(0.2)	01(0.1)	11(1.1)

snow over the mountain terrains resulted into the snow avalanches and consequently, the huge economic damage as well as the loss of human lives.

The spatial and temporal distribution of snowfall in different ranges of western Himalaya is shown in Table 2. The observations were collected from the scattered network of observatories in western Himalayan region. The morphology of distribution of snowfall with space and time was depicting the persistence of the WD in the region for long period. The tabulated value of snowfall shows that, there was continuous and widespread snowfall from 03 February 2005 to 07 February 2005 over western and part of central Himalaya. The intensity of precipitation increased again over the Kashmir region on 7th February 2005. It was the indication of approach of fresh WD in Jammu and Kashmir region. Another WD gradually merged with previous one that resulted into the continuous snowfall. The accumulated snow at some observatories exceeded more than 2 m. The average snow accumulation during five days period exceeded more than 1.5 m. The measured value of accumulated snow further increased in subsequent days as a result of merging of fresh WDs with previous one. All catastrophic avalanches triggered due to the unprecedented accumulation of snow over the terrains in the habitation area of Jammu and Kashmir.

ARPS model has been initialized with 03 February 2005 analysis data of T-80 global spectral model and lateral boundary conditions have been provided from the forecast value of T-80 model at 24 hours interval to simulate WD of 03 February, 2005. Surface precipitation from the model simulation for four days in 24 hours



Figs. 5(a-d). ARPS precipitation forecast (a) 03 February 2005, (b) 04 February 2005, (c) 05 February 2005 and (d) 06 February 2005

interval is shown in Figs. 5 (a-d). The simulated value of precipitation was showing that WD was well marked over the Jammu & Kashmir (J&K), Himachal Pradesh and Uttaranchal. Its intensity gradually increased over the J&K area on 05 February 2005. On 06 February 2005, the intensity of precipitation started receding over the western Himalaya region. On 07 February 2005, the intensity of simulate precipitation increased in J&K area. The increased value of simulated precipitation over J&K region resembled with the ground observations (Table 2) and also supported by the moisture distribution in satellite imageries of 07 February 2005.

5. Conclusions

Two prominent WDs were identified and simulated with ARPS model. The simulation results shows that the ARPS model could predict the precipitation well in advance over the western Himalayan region with initial and lateral boundary conditions from NCMRWF data. The study reveals that though the spatial distribution of precipitation from both models output is nearly same, however, ARPS is showing the more clearly the heterogeneous precipitation distribution. The heterogeneity arises due to the non-hydrostatic nature of the ARPS model and the better parameterization schemes for meso-scale phenomena were used in model. The non-hydrostatic nature of the model in *z*-coordinate system is capable to simulate the meso-scale circulations and terrain induced circulation over the complex topography. These circulation patterns are responsible for the heterogeneous distribution of precipitation. The observations at different observatories are also supporting the anisotropic distribution of precipitation over complex terrain in western Himalaya.

The simulation results also show that the ARPS model is capable to capture and predict two subsequent WDs over the western Himalayan regions. The merging of two WDs leads to the continuous precipitation that persists for longer period without any discontinuity in precipitation period.

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