Mountain weather forecasting using MM5 modelling system

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The importance of the Himalayan barrier on the weather and climate, ecology, hydrology, agriculture and environment of the developing nations around the mountain range is well known. The Himalayan region is frequently affected by eastward moving weather systems known as western disturbances. These weather systems give widespread rainfall and, at times, very heavy snowfall associated with squall speed winds, hail and severe cold waves. The heavy snowfall and the gale speed winds can cause snow avalanches and landslides. The windstorms, hailstorms, thunderbolts and droughts are among other common meteorological hazards in the mountain region. Among all the natural cycles, hydrological cycle is the most sensitive cycle, which is directly influenced by the atmospheric weather systems and general circulation.

A high resolution mesoscale (MM5) model has been studied for making accurate mountain weather forecasts over the Indian region. The model is run at triple nested domains at 90, 30 and 10 km resolutions. For mountain weather forecasting, four nested inner domains at 10 km resolutions are placed over the Northwest Himalayas, Central Himalayas, Northeast Himalayas and the Western Ghat mountains. Several cases of heavy rainfall events associated with western disturbances, thunderstorms and severe weather have been studied. Preliminary results indicate that the model has a good capability of making severe weather forecasts up to 72 hours. The outputs of the model can be used for planning agriculture, water resources, transportation, public safety, industry, recreation and, to address climate-related issues such as regional variations in precipitation characteristics, glacial shifts, intensity of droughts and floods over the mountain regions.

NORTHWEST India and the Himalayan region (Figure 1) are particularly prone to vagaries of severe weather claiming casualties every year. This region is influenced by western disturbances, which severely influence life over the Himalayas, by inducing widespread rainfall, heavy snowfall, squall winds, hail and severe cold waves. Snow avalanches and landslides result on account of gale winds and heavy rain/ snowfall.

Owing to its unique geographical position, the Himalayan mountain range influences the weather and climate in various ways. It acts as a strong barrier for the circulation pattern, as a heat source in summer and heat sink in winter. Its varying snow cover and vegetation affects the monsoon rainfall. The surface boundary conditions of the Himalayas determine the performance of the monsoon rainfall, which has immense impact on water resources and agricultural production. Every year more than 450 people are killed and properties amounting to more than US$ 2.5 million are lost due to hazards related to weather, in Nepal[1,2]. The total annual environmental hazards in Nepal amounts to the death of 1150 people, 4000 animals, destruction of 18,000 houses and properties amounting to more than 1476.7 million rupees[1]. On an average, the loss is equivalent to nearly 5% of the GDP and 13% of the total development expenditure of the government. In India, average annual loss of life due to floods is about 1450 and the total property damage is equivalent to 7683 million rupees[3]. On an average, about 5000 people are killed and 59 million get affected annually from various types of disasters. In China, landslides alone are estimated to cost US$ 15 billion in economic losses and 150 deaths annually[4].

More recently, a squall that hit Delhi on 27 May 2002 had uprooted around 2000 trees leading to traffic jams, water-logging and electric supply disruption. On 14 November 1986, combined effect of weather and avalanches claimed 70

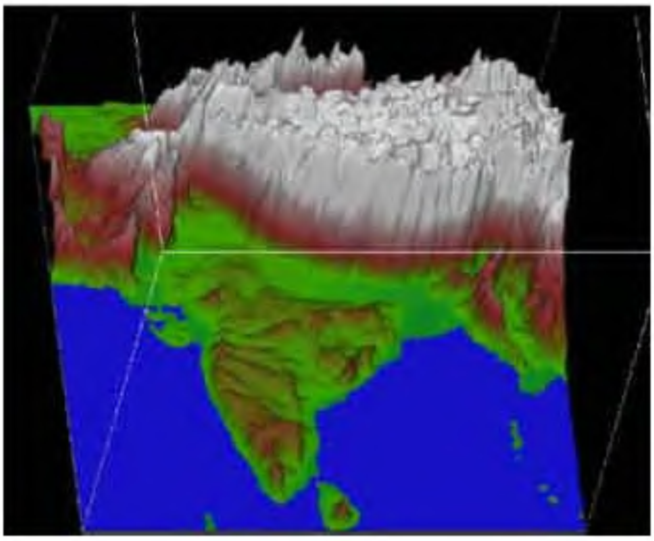

Figure 1. Topography over the Indian region.

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lives and property worth millions of rupees on Srinagar–Leh highway. On 16 January 1995, Jammu–Srinagar highway was hit by a number of avalanches stranding more than 300 vehicles and 400 personnel in which 67 lives and property worth billions of rupees were lost. During Amarnath pilgrimage in August 1996, 194 people died owing to rough weather. Innumerable incidents of this nature are taking place over hilly areas. To combat the weather-induced disasters of this nature and to develop the capacity to predict them, observations and modelling on smaller spatial scale, i.e. mesoscale, is necessary. The weather and climate systems of mountain regions can be numerically predicted with good accuracy using high-resolution mesoscale models.

The weather phenomena like Norwesters (squall lines which affect Northeast India during pre-monsoon season), thunderstorms, cloudbursts, windstorms, hailstorms and thunderbolts that have high impact on human life and economy occurring on smaller spatial-temporal scale invite application of regional models with fine grid resolution.

Weather hazards over mountain regions

Severe weather has calamitous effect in the mountainous region as the terrain is complex, development is poor and economy is fragile. There are several types of weather hazards, which can affect life of people living in the mountains. They are (a) torrential rain, accompanied by landslides, overflowing dams, lake outbursts; (b) cloud bursts accompanied by lightning damage, flash floods, hailstorm and windstorm; (c) heavy snowfall accompanied by avalanches, surging glaciers and, (d) droughts causing damage to agriculture and drinking water problem.

Advance warning of adverse weather systems can prevent loss of valuable lives and property. Besides the weather hazards mentioned above, severe cold wave conditions during the passage of western disturbances can result in loss of life of poor people living in the area. The ground frost during winter season affects agriculture. Land slides are caused by several factors besides the cloud burst and intense precipitation, viz. steepness of slopes, seismicities, rock mechanics, loss of forest/vegetation cover, weakening of mountain slopes due to construction of roads and mining. Therefore, prediction of landslides requires models in which the weather factors can be used as one of the input parameters that affect geomorphology of the system. Similarly, flood forecasting models can be based on rainfall and snow melt forecasts besides other factors such as river discharge, width and depth of the river basins, etc.

Mesoscale atmospheric modelling

Mesoscale (< 50 km scale in horizontal dimension) modelling for real-time forecasting is evolving in India. At the National Center for Medium Range Weather Forecasting (NCMRWF), high-resolution mesoscale models such as MM5 and ETA are executed on real-time basis for forecasting mesoscale systems, viz. the western disturbances, severe thunderstorms, tropical cyclones and heavy rainfall episodes. MM5 model is run on triple nested domains at 90, 30 and 10 km resolutions using initial conditions from the T80 global model of NCMRWF. The time steps of model integration are 270, 90 and, 30 seconds for the three domains. For the purpose of mountain weather forecasting, four inner domains at 10 km resolutions are placed over Northwest Himalayas, Central Himalayas, Northeast Himalayas and the Western Ghat mountains on an experimental basis. The model uses staggered Arakawa B-Grid in the horizontal direction. It has 23 vertical levels (Sigma-Hybrid). The model uses USGS data (interpolated depending on resolution) with 25 categories for vegetation/land use. The model has U, V, T, q, Ps as prognostic variables with semi-implicit time integration scheme. It is a non-hydrostatic model with two-way nesting. The model uses fourth order horizontal diffusion for inner domains and second order diffusion for the coarse domain. Cumulus Parameterization of Grell[5] called Simplified Arakawa–Schubert scheme is used for convection and non-local closure scheme of Hong and Pan[6] is used for boundary layer parameterization in the model. Explicit treatment of cloud water, rainwater and ice has been performed using Dudhia[7]. Cloud radiation interaction has been allowed between explicit cloud and clear air. The initial and lateral boundary conditions are obtained from operational global T80 model of NCMRWF.

Case studies of western disturbances over the Himalayan range and heavy rainfall events associated with active monsoon phase have shown that the model has reasonably good capability of forecasting severe weather up to 72 hours in advance[8–10]. For illustration, we present here a simulation of rainfall associated with a western disturbance during 14–16 January 2002 over different parts of the Himalayas. For the Western Ghat mountains, simulation of a heavy rainfall event associated with an active monsoon situation is presented.

Western disturbance

A western disturbance (WD) extending up to 4.5 km above sea level moved over to Jammu & Kashmir and neighborhood on 14 January 2002. The system moved eastward during the next three days dumping lots of precipitation and snowfall in its way over the high mountain regions. Cold wave conditions prevailed in most parts of northwest India. Rainfall forecasts based on the initial conditions of 14 January 2002 from the MM5 model are presented below and compared with observations over the Himalayan region.

Figure 2 shows the observed rainfall on 16 January as derived from satellite and rain gauge. The diagram shows widespread rainfall over north India along the Himalayas on this day. Rainfall reported at some of the stations in this period are shown in Table 1. Snowfall ranging from 15 to

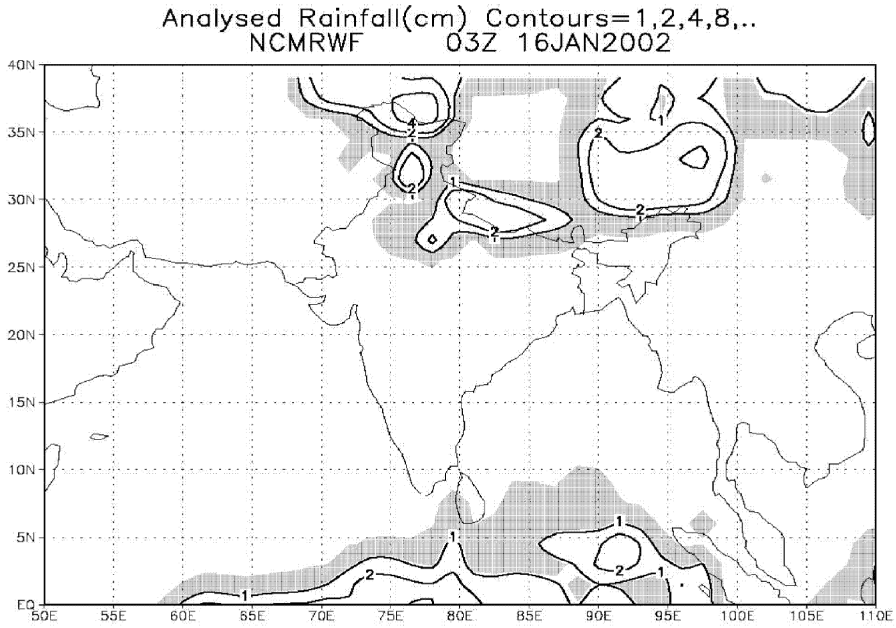

Figure 2. Observed rainfall derived from satellite and rain gauge at 03 UTC, 16 January 2002.

Table 1. Observed rainfall (January 2002)

Station (Western Himalayas)	Rainfall (mm) 16 January	Station (Central Himalayas)*	Rainfall (mm) 16 January	Rainfall (mm) 17 January	Station (Eastern Himalayas)	Rainfall (mm) 17 January
Delhi (Saf., Pal.)	15, 10	Dadeldhura	30.3	–	Guwahati	12
Chandigarh	5	Dipayal	30.8	–	Shillong	3
Bhuntar	24	Dhangadhi	28.5	–		
Shimla	7	Surkhe	35.4	–		
Srinagar	10	Nepalgunj	27.2	–		
Patiala	1	Jumla	38.5	–		
Jaipur	5	Dang	13.4	T		
Lucknow	8	Pokhara	30.6	1.6		
Dehradun	8	Bhairawa	17.6	1.6		
		Kathmandu	10.2	10.2		
		Okhaldhunga	3.6	6.6		
		Taplejung	5.4	19.2		
		Dhankuta	1.6	10.8		
		Nagarkot	16.0	13.5		
		Jiri	12.2	11.2		
		Bharatpur	16.5	2.5		

*Source: Nepal Meteorological Service.

50 cm was reported at many places in J&K and Himachal Pradesh during the period. Figures 3–5 show the rainfall forecasts valid on 16 January over different parts of the Himalayas. Results indicate that the model was able to forecast the rainfall distributions over different parts of the Himalayas reasonably well as compared to observations. The western disturbance had not reached over the eastern Himalayas on 16 January. Therefore, the model predicted mostly clear weather over the northeastern states of India on 16th as seen from Figure 5. The WD weakened on 17 January producing only 3 and 17 mm rainfall at Shillong and Guwahati on that day.

Active monsoon rainfall

Monsoon was very active during 13–17 August 2001 over most parts of India including the west coast covering Gujarat region, Konkan and Goa, coastal Karnataka and Kerala. Figure 6 depicts the analysed rainfall based on satellite and rain gauge on 15 August 2001. Table 2 shows the major amount of rainfall recorded at some of the stations over the west coast on 15 and 16 August 2001. Rainfall amount as much as 10–11 cm were recorded at many places over the western Ghat region during the period. These values are not seen in Figure 6 as it is a coarse resolution analysis. Figure 7

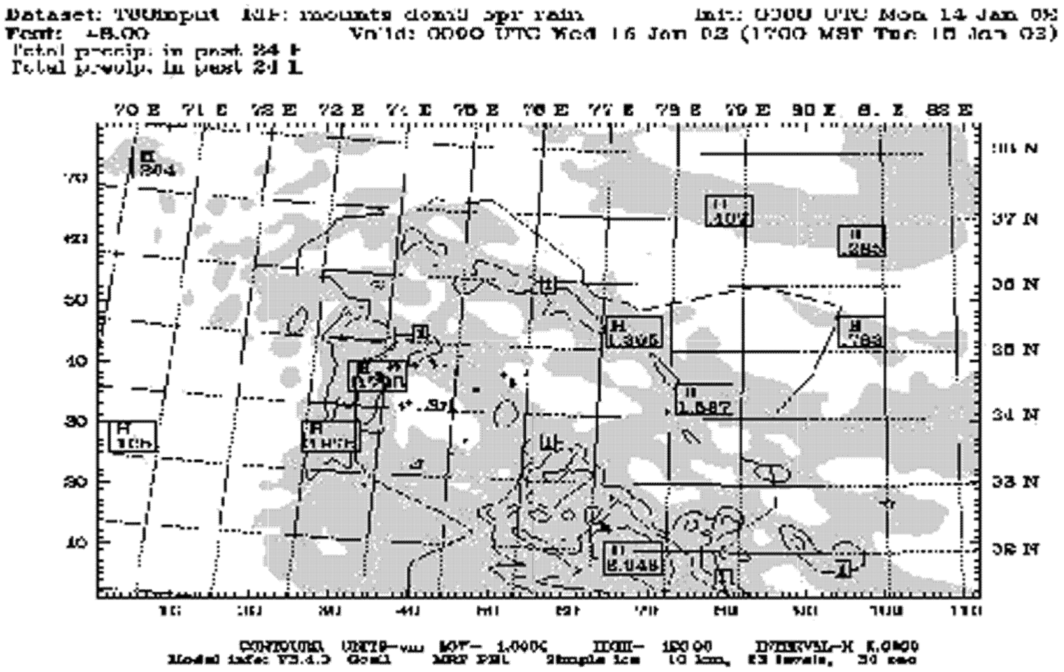

Figure 3. Rainfall forecast (48 h) for 16 January 2002 over the western Himalayas.

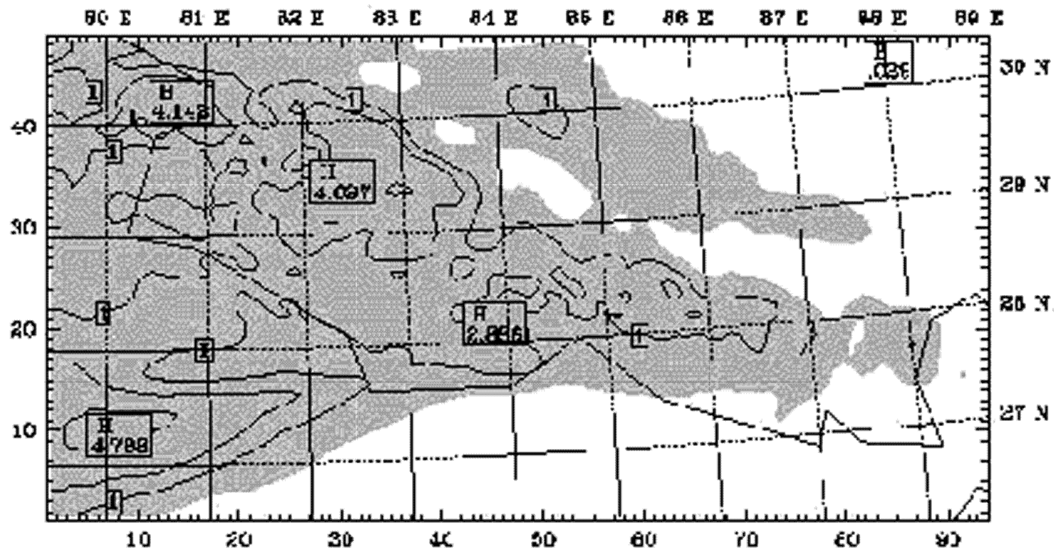

Figure 4. Rainfall forecast (48 h) for 16 January 2002 over the Central Himalayas.

Table 2. Major rainfall recorded (cm) over the west coast, August 2001

Station	Date 15	Date 16	Stations	Date 15	Date 16
Konkan and Goa			Coastal Karnataka		
Dharavi	11	NA	Shirali	3	NA
Bhira	10	11	Honnavar	3	4
Panvel	10	NA	Karkala	NA	6
Malabar Hill	9	3	Uppinangady	NA	5
Mumbai: SCZ, CLB	9, 7	NA	Kerala		
Khalpur	6	NA	Kozhikode	NA	3
Panjim	4	NA	Kannur	2	2

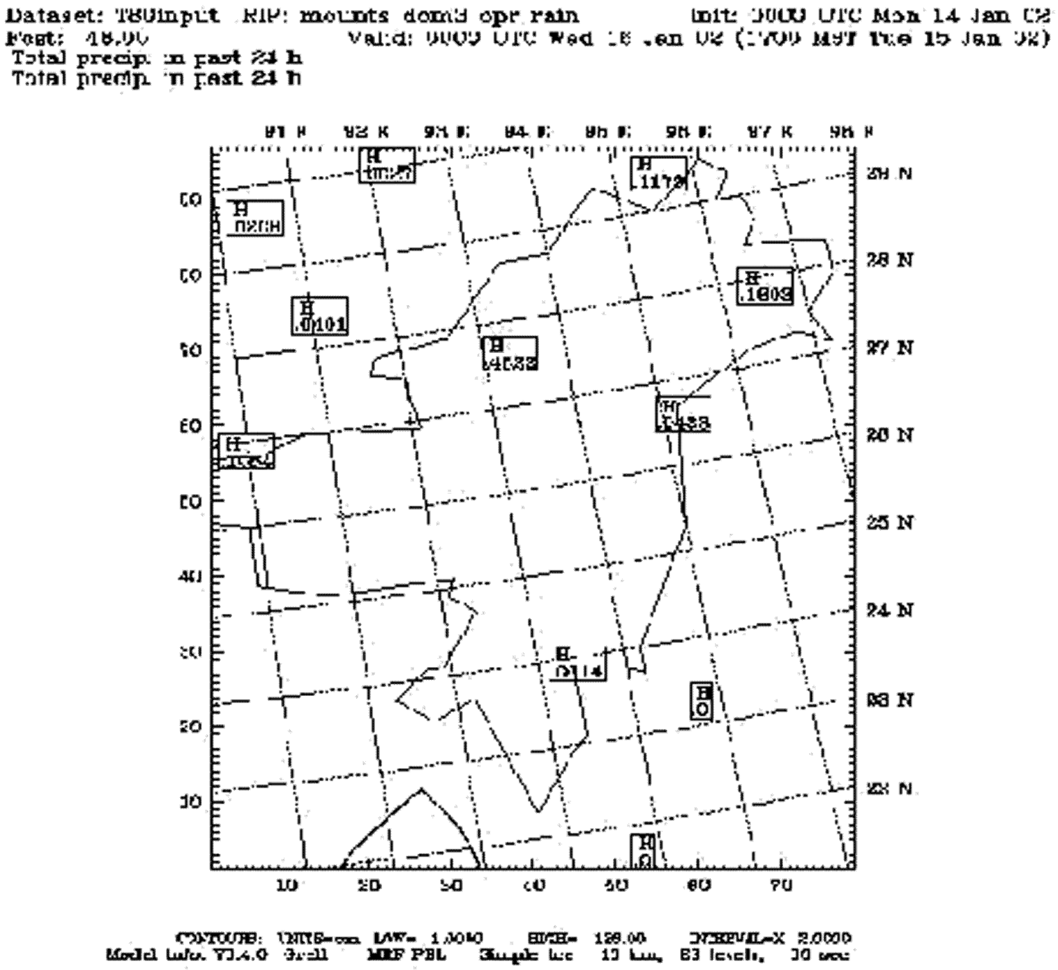

Figure 5. Rainfall forecast (48 h) for 16 January 2002 over the Northeast Himalayas.

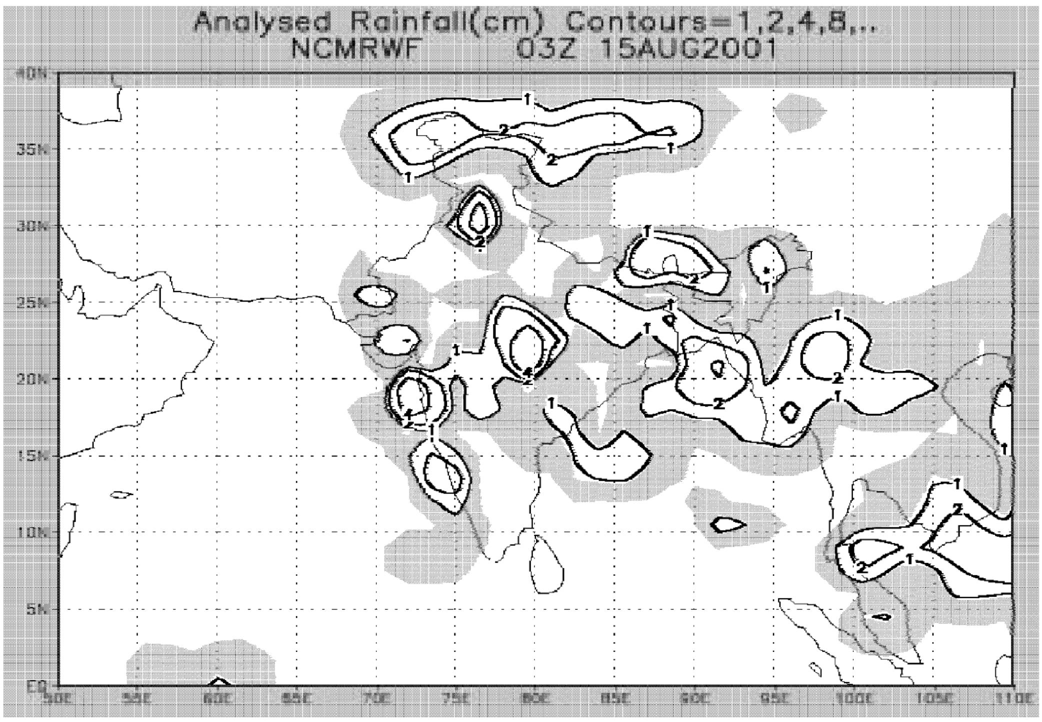

Figure 6. Observed rainfall derived from satellite and rain gauge for 03Z 15 August 2001.

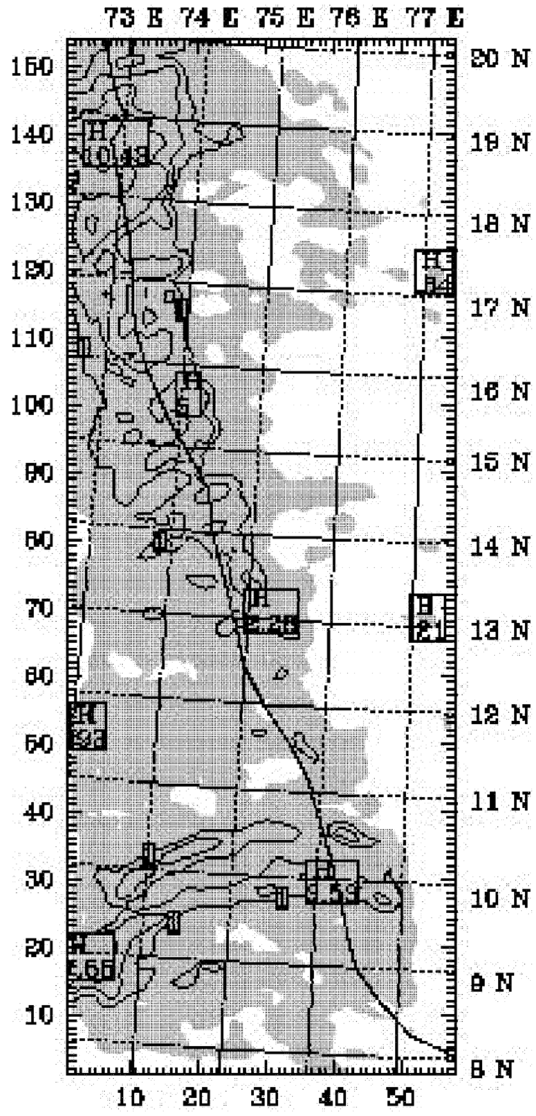

Figure 7. Rainfall forecast (48 h) for 15 August 2001 over the Western Ghats.

shows the 48 h forecast valid for 15 August as obtained from the 10 km resolution run over the Western Ghat mountains. The figure shows that the model is able to predict the rainfall amount as much as 10.48 cm comparing well with the observations. The predicted rainfall is also very well distributed all over the west coast having higher values on the northern side and lower values towards Kerala as corroborated from observations.

Satellite and radar applications for mesoscale observations

One of the major problems of mesoscale modelling is paucity of data at very high spatial resolution. The present day operational observing system comprising surface, radiosonde, satellite-derived cloud drift wind data and satellite soundings are well below the scales required by mesoscale models. Mesoscale analyses therefore have increasing reliance on additional new and high resolution satellite-based data and other remote sensing observing systems such as radars capable of monitoring and recording the atmospheric state. One of the most remarkable applications of radar technology is the meteorological observation of the atmosphere. Detection of precipitation by radar has allowed analysis of structure of the precipitation and provided information on intensity, rain rate, vertical extent and drop size distribution, etc. After the advent of Doppler Weather Radar (DWR) it became possible to measure the velocity fields in a weather system.

Mesoscale observations from automatic weather stations, and remote sensing platforms such as satellites and radars can be processed and assimilated in the weather prediction models for advance warning of severe weather conditions.

Mitigation of weather hazards

Figure 8 shows a flow diagram illustrating strategy for mitigation of weather hazards over the mountain regions. The strategy involves setting up of meso network of automatic weather stations (AWS), Doppler Weather Radar (DWR), upper air radiosonde stations, satellite receiving stations, a high resolution (1–10 km) model and data assimilation system together with a high performance computer for data processing, quality control and model integration on real-time basis. Outputs from the NWP models such as, quantitative rainfall/snowfall, wind and temperature forecasts obtained from the model can be fed into several other application models for avalanche, flood and landslide predictions. The forecasts obtained from this system can be disseminated to public via disaster management cell and district administrative offices for saving life and properties.

Summary

Meteorological hazards due to severe weather such as cloud burst, torrential rain causing landslides, overflowing dams, lake outburst, lightning damage, flash floods and, heavy snowfall resulting in avalanches, surging glaciers over the mountains can be mitigated using high resolution numerical weather prediction models together with observations from satellites, radars and meso network of automatic weather stations. Advance warning of adverse weather systems can prevent loss of valuable life and properties and can be used for planning agriculture, water resources, transportation, public safety, industry and disaster management.

A mesoscale model (MM5) has been used to investigate the predictability of rainfall over different parts of the Himalayas and the Western Ghat mountains during the passage of a western disturbance and an active monsoon spell respectively. The model has been integrated at triple-nested resolutions of 90, 30 and 10 km over 6 domains. The four

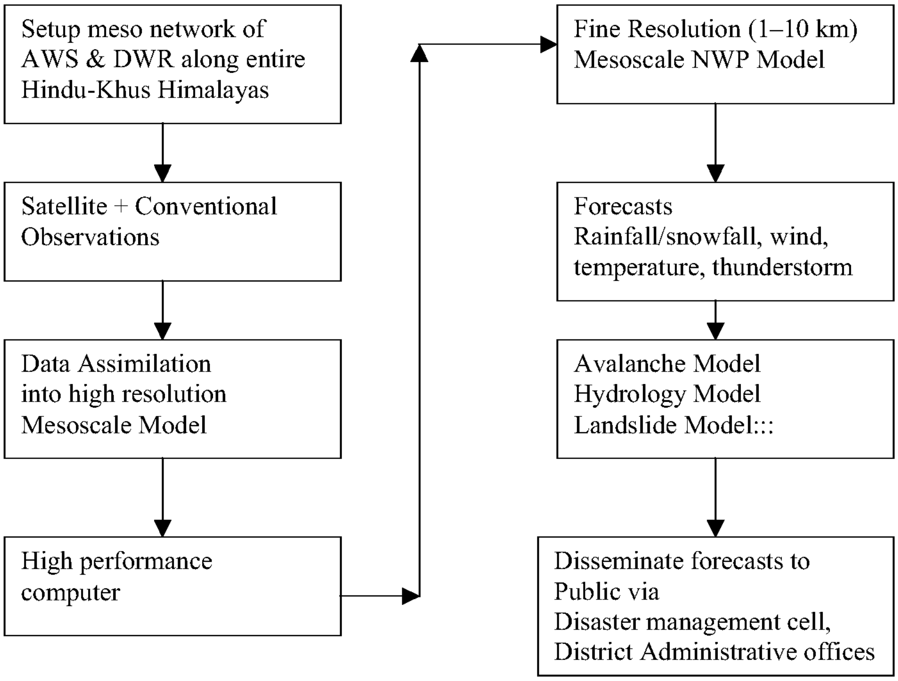

Figure 8. Flow diagram illustrating strategy for mitigation of weather hazards.

inner domains at 10 km resolutions were placed over the western, central and eastern Himalayas and the Western Ghat mountains. Case studies of heavy rainfall events associated with the western disturbance and active monsoon conditions indicate that the model has a good capability to predict rainfall over the mountains for at least 48–72 h in advance at high model resolutions.

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