COMPEXITIES OF AVALANCHE FORCASTING IN WESTERN HIMALAYA - AN OVERVIEW

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Abstract: Himalaya, the longest chain of mountains in the world shows complex variations in snow and meteorological conditions as one traverses from east to west and from south to north. The paper presents the analysis of the past 25 years of snow precipitation and avalanche occurrence data of the Western Himalaya region and delineates the region into three principle zones, Lower, Middle, and Upper. While Upper Himalaya Zone is close to polar region characteristics, Lower and Middle Himalaya compares well with the Maritime and Continental Zones.

Avalanche forecasting in the Himalayan region is biased toward conventional knowledge-based approach. The variation in three zones on avalanche activity in the region has been discussed. Different approaches of avalanche forecasting developed so far, however, require experienced observers and forecasters, which causes a problem because of the temporary nature of avalanche jobs. It has been seen that each zone warrants separate treatment and models for prediction of avalanches at any one-time.

1. INTRODUCTION

Indian Himalaya stretches from east to west for about 2500 km across 72°E to 96°E longitudes and 26°N to 37°N latitude Fig1. The complex folding pattern that it has been subjected to during the upheaval of Himalaya in Pleistocene and subsequent period leading to thrusting of Indian plate with Eurasian plate has produced a long chain of mountain ranges having deep furrows in between. This major-geological event has lifted the rock structure to 8847 m above sea level. The interaction of global atmospheric circulation system with the tallest geological feature of the earth has produced diverse climatological, biological and snow climatic zones within Himalaya. This complex variation is unparalleled in the world. The diverse variation in snow climatic conditions makes it difficult for an avalanche forecaster to apply a unified code to predict avalanches even in western Himalayan region.

2. CLASSIFICATION OF SNOW CLIMATE IN GENERAL

For the purpose of classifying the avalanche activity with respect to weather pattern, McClung and Schaerer (1993) have classified the avalanche areas into two categories i.e. Maritime and Continental. As per them relatively heavy snowfall and mild temperatures characterize the maritime snow climate. Snow covers are deep while rain may fall at any time during the winter, and cold arctic air can also appear several times per winter. Avalanche formation in maritime snow climates usually takes place during or immediately following storms, with failures occurring in the new snow near the surface.

The prevalence of warm temperature promotes rapid stabilization of snow near the surface once it falls, thereby, limiting the instability period. Due to deep snow covers and warm snowpack temperatures, the persistence of buried structural weaknesses deep within the snowpack is less usually common in maritime snow climates as compared to continental snow climates. Weather observations are primary tools for predicting avalanches in a maritime snow climate. Typical examples are Cascade Range of western US, the Coastal range of British Columbia and the mountains of western Norway. The average annual snowfall in the maritime ranges of North America is about 15 to 25 m.

On the other hand, continental snow climate is characterized by relatively less snowfall, cold temperature and location is considerably inland from coastal areas. Snow covers are relatively shallow and often unstable due to persistence of structural weaknesses. Typical examples are Rocky Mountains (Canadian and Colorado), the Brooks Range of Alaska and the Pamir of Asia. The annual snowfall in the continental ranges of North America is usually less than 8 m. The avalanches in continental ranges occur mostly due to buried structural weaknesses in the snow

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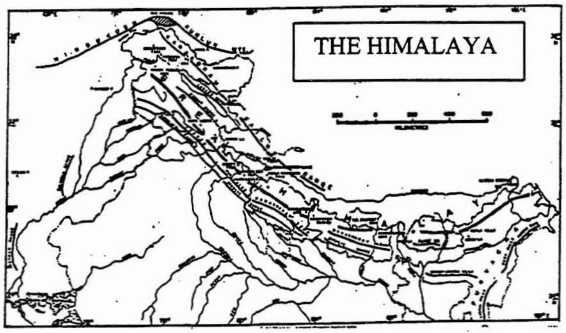

Fig1. The Himalayan Ranges

cover as well as due to the weather conditions that cause the failure of these layers. The avalanche frequency is generally low and the low temperatures generally allow structural weaknesses to persist for longer duration.

3. CLASSIFICATION OF SNOW CLIMATE FOR WESTERN HIMALAYA

The classification given by McClung et al (1993) is generally applicable to the USA and Europe. In India due to widespread mountains covering 26 degrees of longitudes and 11 degrees of latitudes with snow precipitation and avalanche activity experienced from 2000 m to 6000 m, the classification given by McClung does not apply for Himalaya in its present form. In the opinion of the authors, the snow climate from the point of view of avalanche activity of Himalaya may be

TABLE-1

<u>Terrain and Meteorological Factors: Lower Himalayan Zone</u>

<u>Terrain (Avalanche Sites)</u>

*Altitude	: 3200-4100 m (76%)
*Slope	: 30-38^0 (64%)
	: 38-42^0 (13%)
*Aspect	: SE-SW (63%)
	: S (34%)
	: N (19%)
*Ground	: Tall grassy cover up to 300m, forested, Bushes, Boulders

<u>Meteorology</u>

*Snowfall in Major Storms:	20-80 cm (56%)
	: 80-200 cm (30%)
*Average P.I. (mm/hr)	: 0.5-3.5 (90%)
	: 3.5-5.5(10%)
*Temperature in winter (°C):	
Highest Max. 19	Mean Max. 10.8
Mean Min. 10.8	Lowest Min. - 11

classified as, Lower Himalayan Zone or Subtropical Zone, Middle Himalayan Zone and Upper Himalayan Zone or High latitude zone. A brief description of each of them is given in the succeeding paragraphs.

4. LOWER HIMALAYAN ZONE OR SUB TROPICAL ZONE

This zone could be classified as the zone of warm temperature, high precipitation and short winter periods of three months. The precipitation is generally concentrated between December-March with the periods before and after experiencing wet snow precipitation or rains. Due to prevalence of warmer temperatures, the snow cover very soon changes into isothermal snow pack at zero degrees Celsius.

The avalanche activity is quite high, with most of the avalanches triggering during snowfall as direct action avalanches due to excessive overburden or within 24 hours after a major snow fall on a clear sunny day. The peak winter avalanches are generally moist slab avalanches and late winter avalanches are melt avalanches (Thaw avalanches) containing snow, mud and stones.

The mountainous areas falling in this category are the Pir Panjal ranges in Jammu and Kashmir and lower altitudes on the windward side of the same range in Himachal Pradesh Fig 2. These areas have an average height of 2000m to 4000m with seventy six per cent of the total registered avalanches between 3200-4100 m. This semi-arcuate range has about sixty per cent avalanches slopes in the slope range of 30°-38°. Most of the hazardous avalanche slopes have southern aspect and only 20 per cent have northern aspect. Most of the slopes up to 3000m are forested. Avalanche slopes have tall grassy surface with occasional bushes and boulders in their paths.

These areas are heavily populated because of prevalence of pleasant climatic conditions. The moist snowstorms that this area receives from mid December to February end are generally moderate in nature with 50% of snow spells in the precipitation range of 20-80 cm and 30% touching 200 cm.

The salient points describing the characteristics of Lower Himalayan zone are given in Table-1.

4.1 *Deductions:*

Major avalanches occur:

-During snowstorm when overburden exceeds 200-Kg m^{-2} after terrain irregularities get filled up

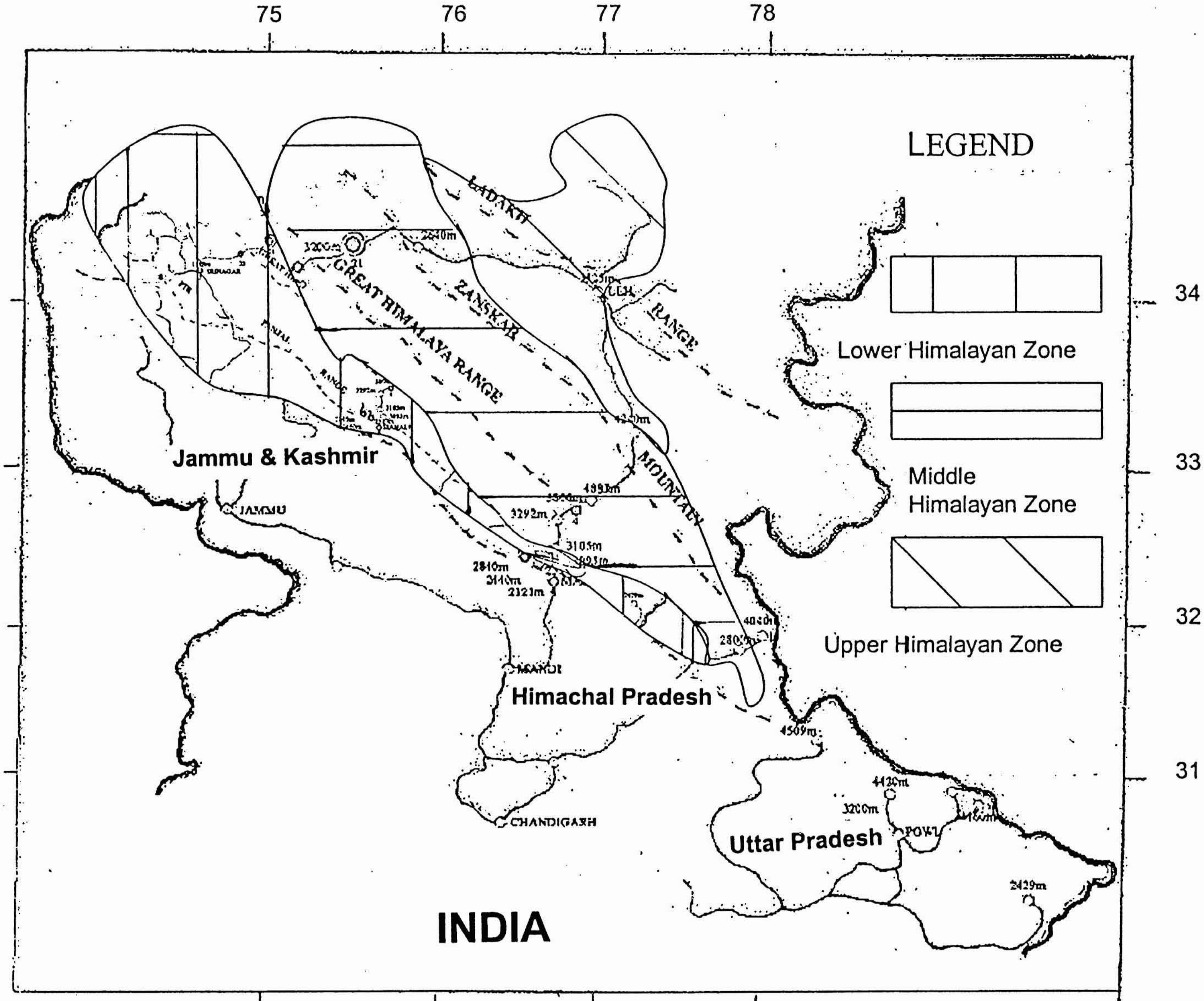

Fig 2. Snow Avalanche Climatic Zones of Himalaya

with 150 cm of standing snow.

- Within 24 hours of storm on a clear sunny/windy day.
- Radiation may cause loose snow surface avalanches
- In spring-after snowpack becomes 0°C isothermal, full depth or even surface avalanches trigger
- Few delayed actions avalanches on northern slopes trigger.

The climograph of a representative observatory in Pir Panjal range along with frequency distribution of avalanche activity observed in a representative area is given in Fig-3.

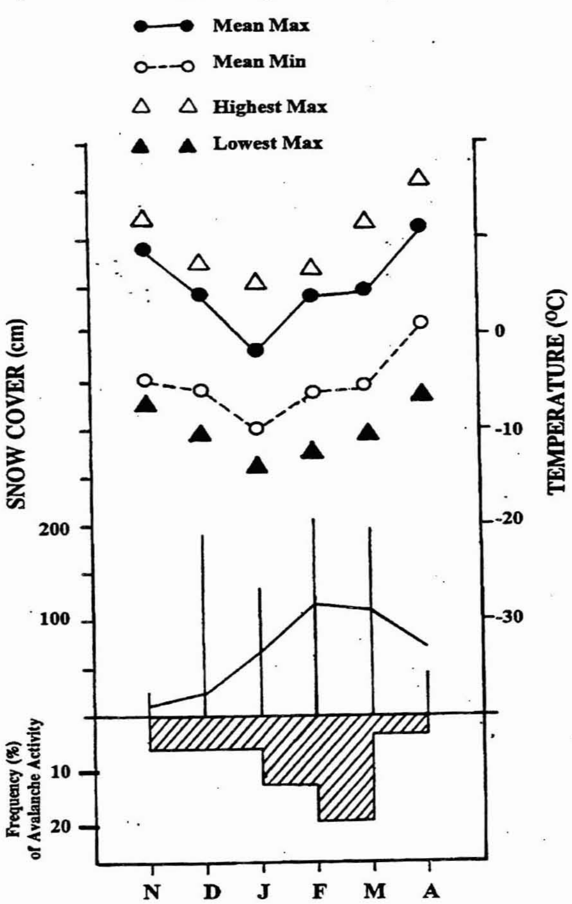

Fig 3. Climograph of a representative observatory in Pir-Panjal Range along with frequency distribution of avalanche activity observed.

5. THE MIDDLE HIMALAYAN ZONE OR MID LATITUDINAL ZONE

The middle Himalayan zone is characterized by the highest mountain peaks and numerous glaciers. The terrain is rugged and is generally devoid of vegetation except in few preferred areas where slopes up to 3000 m is sparsely forested. The zone has an average height of 3500 m with maximum avalanche slopes in 3500 - 5300 m ranges. This mid-latitudinal Himalayan range has almost seventy five percent hazardous avalanches in the slope range of 32-40 degrees. About 58 per cent of these avalanche slopes have southern aspect and a sizeable number (35 per cent) have northern aspect. Avalanche slopes in western flank of this range have grassy ground cover, open forest up to 3000 m whereas the eastern flank of same range has generally barren slopes with scree or boulder filled.

The areas falling in this zone are windward side of the Great Himalayan range in Jammu and Kashmir and upper reaches of Pir Panjal range in Himachal Pradesh Fig 2. This zone is sparsely populated by virtue of being rugged, cold and mostly glaciated. This range receives good amount of total snowfall during winter, eighty per cent of which is through moderate snow spell of 20-80 cm. Entire middle Himalayan range receives dry snow between mid December and end January. The general rise in temperature from mid February onwards generally moistens fresh snowfall, and after March the fresh snowfall is often accompanied with light rain or wet snow precipitation. Unlike in lower Himalayan zone, where sudden spurts of high precipitation intensity are observed occasionally, this range generally receives precipitation at moderate rate throughout the winter. Severe wind activity redistributes snow from avalanche slopes very frequently in this zone.

Severe avalanche activity is reported in this range throughout the winter. The initial avalanches are mainly due to the failure of TG layer, which gets formed in the shallow snow pack during early winter. The massive slab avalanches from drift loaded slopes are also observed. Thaw avalanche activity is also observed from a few slopes in the months of April and May.

The salient points describing the characteristics of Middle Himalayan zone are given in Table-2

5.1 *Deductions:*

_*Initial Avalanches occur:

-Due to the failure of TG layer formed in shallow snowpack.

*Subsequent avalanches occur:

-From steep formation zones

-Due to creep deformation of metamorphosed snow.

-Loose snow avalanches and sloughing is also prevalent.
-Spring avalanches. Thaw avalanches are in April-May.

TABLE 2

Terrain and Meteorological Factors:
Middle Himalayan Zone
Terrain (Avalanche Sites)

*Altitude	: 3500-5300 m (100%)
*Slope	: 32-40^0(75%)
*Aspect	: SE-SW (58%)
	: SE (37%)
	: NE-NW (35%)
*Ground cover	: Scree , Boulders

Meteorology

*Snow in Major Storm:	20-80 cm (81%)
Average total snow fall in a year	: 12-15m
*Average P.I. (mm/hr)	: 0.5-3.5 (98%)
	: 3.5-5.5 (2%)

Temperature in (°C):

Highest Max.13	Mean Max. 0.5
Mean Min. -11.7	Lowest Min. -27

The climograph of a representative observatory in this zone lying in Great Himalayan range along with frequency distribution of avalanche activity observed in a representative area is given in Fig 4.

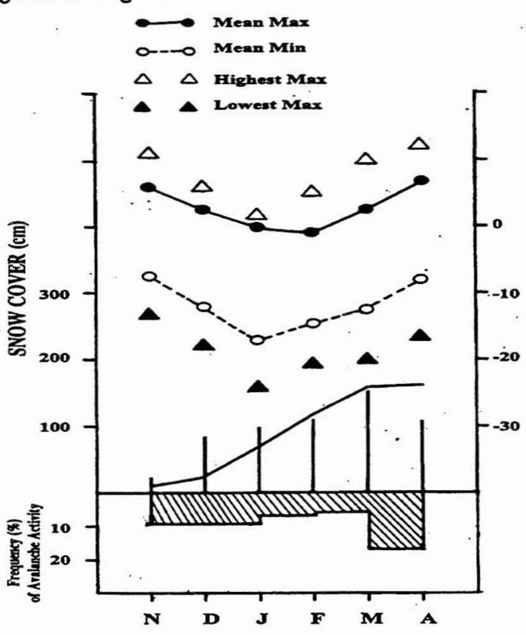

Fig 4. Climograph of a representative observatory in Great Himalayan Range along with frequency distribution of avalanche

6. UPPER HIMALAYAN ZONE OR HIGH LATITUDINAL ZONE

The average height of this zone is about 5000 m and it houses some of the longest glaciers of the world. This zone is characterized by steep peaks and glaciated valleys. The rugged terrain and extremely cold climate makes it the most inhospitable area in the Himalaya. All hazardous avalanche slopes in this range have formation zone altitudes more than 5000m. A good per cent of avalanche slopes (33%) have slope angles of 32-40 degrees. Almost all avalanche slopes have northern aspect and thus, remain dangerous throughout the season.
The areas falling in this category are a few slopes in the leeward side of Great Himalayan range (Jammu and Kashmir and Himachal Pradesh), Zanskar range, and Karakoram Range Fig 2.
This part of the Himalaya is very thinly populated. Small villages are located in sheltered valley regions, where congenial environment supports growth of single crop during brief summer period. The climatic conditions are closer to polar conditions. Snowfall in this zone is generally scanty but it is extended almost throughout the year. About fifty per cent of the storms precipitate less than 20 cm snow in a stretch, however, fresh snow up to 80 cm in a storm has also been reported at an observatory in this region. The snowfall is mostly dry and bonds poorly with the glaciated surface or with old snow. Although steep rise in temperatures has been observed to commence from mid February onwards but that hardly crosses freezing level on glaciated terrain. It rarely rains in this region, and whatever little liquid precipitation takes place during peak summer period, is in the valley region only. The total precipitation as well as the precipitation intensity remains low in this region. However, whatever little precipitation that takes place remains for longer duration till the melt season starts in May. Since snow on slopes remains mostly loosely bonded, the redistribution due to wind activity takes place very frequently.
Avalanches occur from steep slopes in this region, however, their frequency is not very high. Since the ground conditions are not conducive to anchor good snow pack, avalanches from glaciated and steep rocky surfaces start with as little as 30-40 cm of fresh snow. However, in certain areas where rugged, undulating avalanche slopes offer good anchorage, delayed action avalanches have been observed.

The salient points describing the characteristics of upper Himalayan climatic zone are given in Table-3.

TABLE 3

Terrain and Meteorological Factors: Upper Himalayan Zone	
Terrain	
*Altitude	: 5000-5600m(100%)
*Slope	: 28-32 (°C) (67%)
	: 32-40 (°C) (33%)
*Aspect	: NW (42%)
	: N-NW (34%)
*Ground Cover	: Rocky, Scree, and Glacial
Meteorology	
*Average Total snow fall in a year	: 700-800 cm
*Snow in Major Storms	: 10-20 cm (51%)
	: 20-30cm (25%)
	: 30-80 cm (24%)
*Temperature (°C)	
: Highest Max. 9	: Mean Max. -8.1
: Mean Min. -27.7	: Lowest Min. 41

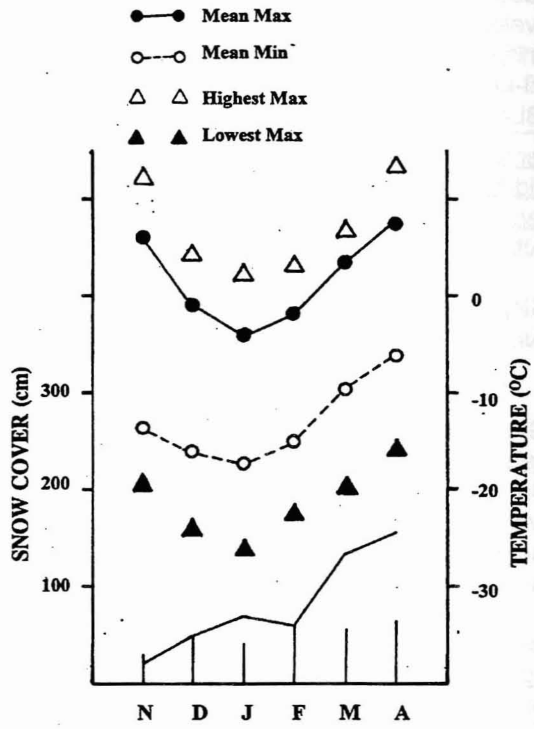

Fig 5. Climograph of a representative observatory in Karakoram Range

6.1 *Deductions:*

Avalanche occur:
- When overburden exceeded 30 Kg/m^2
- Due to failure of TG layers (Delayed action)

The climograph of a representative observatory in this zone lying in Upper Himalayan range along with frequency distribution of avalanche activity observed in a representative area is given in Fig 5.

7. INFERENCE

From the above the following is inferred:
The conditions prevailing in lower Himalayan Zone are somewhat closer to maritime snow conditions, the short winter with heavy moist snow precipitation during winter cautions a forecaster to remain on continuous watch for forecasting avalanches during snow storms. Since this zone is heavily populated and continuous traffic plies on highways, a very accurate continuous avalanche forecast is warranted.
The conditions encountered in Middle Himalayan Zone warrant a detail study of snow cover from its inception to ablation for an accurate assessment of avalanche danger. This warrants a very accurate monitoring of meteorological parameters in accessible as well as in inaccessible areas. The very fact that this area is often in use by civil population and troops, accurate models for timely warning for the pedestrians on winter routes are required.
The conditions encountered on Upper Himalayan range are somewhat close to continental snow conditions with the salient difference being in altitude, unstable terrain, and absence of vegetation and total absence of liquid precipitation throughout the year. This warrants continuous study of snow not only during the winter periods but also throughout the year.

7. RECOMMENDATIONS AND CONCLUSION

The snow conditions in Himalaya are complex and require continuous monitoring of snow and meteorological parameters with a denser network of observatories. Also, the observatory locations for correct assessment of snow conditions have to be meticulously planned in order to obtain realistic data for avalanche forecast. This can be conveniently implemented in lower Himalayan region, but for other two regions automatic weather stations have to be installed.

Various models developed so far in Europe and North America cater for the areas where meteorological conditions are fairly stable and predictable, and where educated-trained observers are available who are very sincere in recording and transmitting data. This aspect is totally absent in India. In order to accurately predict avalanches for Indian conditions, separate models for separate areas catering for the quality of observations and gradation of observers have to be developed.

Remote sensing through satellite photographs and other means provide a great promise. Such means should be developed and utilized.

A very accurate weather prediction can greatly influence forecast. In order to cater for this, mountain meteorology as a science with meso-scale models to cater for 10x10-km resolution is suggested.

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