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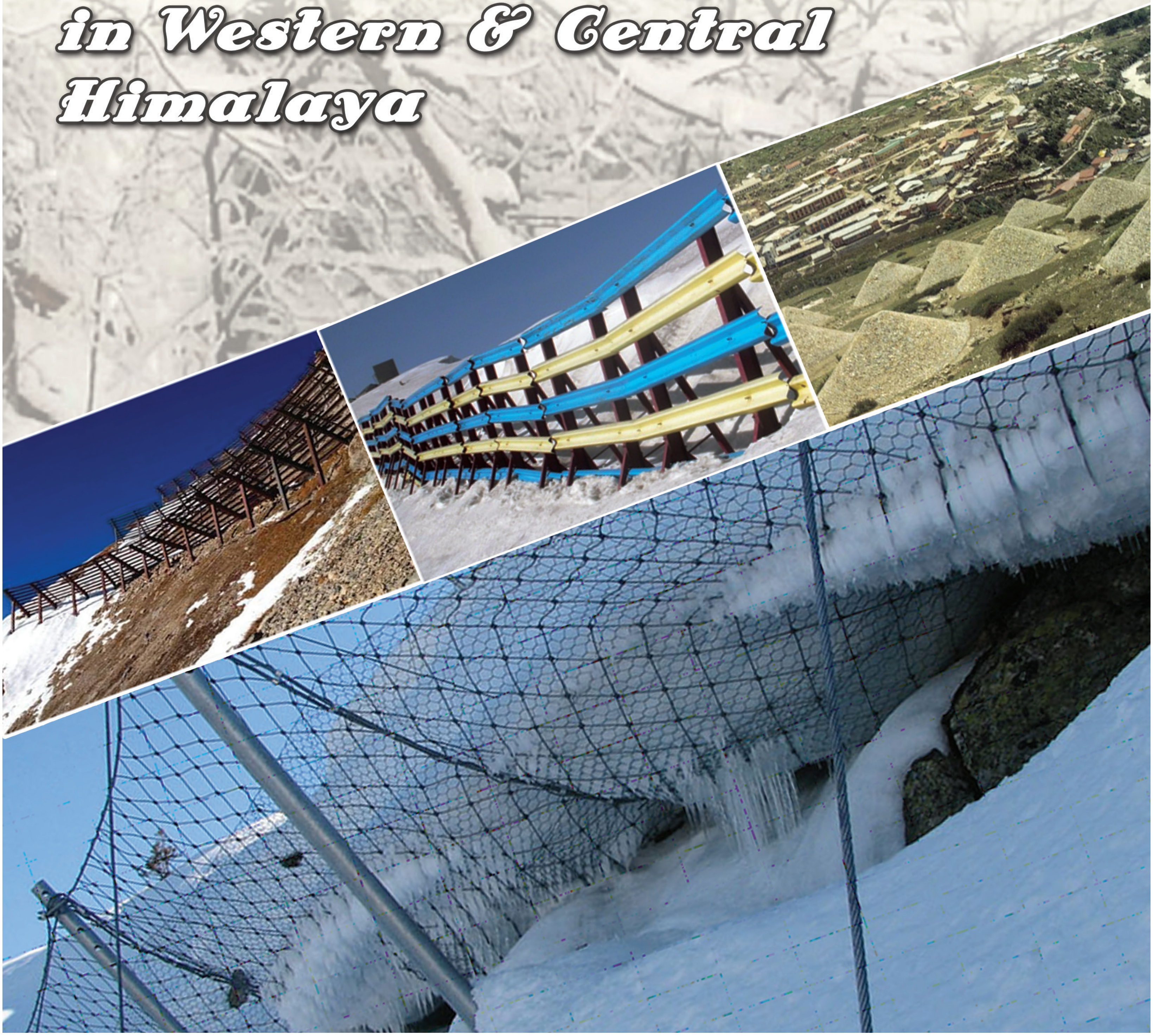
Avalanche Hazard Mitigation in Western & Central Himalaya



From the Desk of Guest Editor

Snow & Avalanche Study Establishment (SASE) is committed to minimise avalanche hazards due to snow avalanches in Indian Himalayas. The increased military activities in the snow bound areas of Himalaya, large turnover of Army units and realising the importance of keeping snow-bound border roads open for maximum duration necessitated the opening of a dedicated laboratory vested with the development of science and technology to assess and mitigate the avalanche hazards. SASE was raised under the aegis of DRDO in 1969.

SASE registered steady growth since its inception and enlarged its role with the development of science and technology for mitigating avalanche hazard in Himalaya. SASE developed avalanche prediction models for Himalaya, designed and developed avalanche hazard control structures, mapped avalanche sites affecting various road/tracks using satellite images in 2D and 3D GIS environment, developed various techniques and models to study snow physical characteristics and avalanche flow parameters, etc.

NARESH KUMAR
Outstanding Scientist & Director, SASE

Realising the importance of snow-meteorological data in the development of methods and techniques to mitigate avalanche hazard, SASE has developed a network of observatories in the Himalayas over a period of time. At present more than forty manned observatories and more than fifty automatic weather stations are working for continuous snow-meteorological data observations in the western and central Himalaya and efforts are on for automated data observations at high-spatial resolution on micro-scale using wireless sensor network technology.

A large area of western and central Himalaya, comprising numerous major road axes and tracks are being covered to forewarn the troops and civil population of the impending avalanche danger. Avalanche Forecasting Centre (AFC) and Mountain Met Centre (MMC) have been set up at various places. SASE has developed a number of statistical and expert based avalanche prediction models for different sectors of western Himalaya. These models are being used for drawing the daily avalanche predictions in the snow bound regions.

SASE has developed avalanche hazard mitigation scheme using control structures. These structures are installed at various places of strategic importance. SASE is also providing solutions to many important projects of hilly states of India as well as central government agencies on designing of avalanche hazard mitigation schemes along highway, ropeway, railway line, protection of transmission line, etc. in the avalanche prone regions of Himalaya. SASE has created a snow chute facility at Dhundi research station in Pir-Panjal range of Himachal Pradesh for measurement of various avalanche flow parameters under controlled conditions. The experiments involve the interaction of control structures with avalanche mass for energy dissipation capability. These experiments are useful for improvement in existing design of structures to enhance energy dissipation characteristics and development of a comprehensive avalanche dynamics model.

This issue of *Technology Focus* is dedicated to the various techniques/methods of predicting snow avalanches and mitigating avalanche hazard using control structures in Indian Western and Central Himalaya by SASE.

Avalanche Hazard Mitigation in Western and Central Himalaya

Snow and Avalanche Study Establishment (SASE) is an ISO 9001:2015 certified laboratory established in 1969 under the aegis of Defence Research and Development Organisation (DRDO) with a vision 'Be a centre of excellence in Cryospheric Science and Technology and facilitate high operational mobility for troops in snow bound regions of Himalayas' and mission to 'Provide precision avalanche forecasting support to the Services including advice on avalanche control measures, enhance avalanche forecasting capability through systematic data collection and development of new technologies'.

SASE has its HQ at Manali (Himanchal Pradesh) and Research & Development Centre (RDC) at Chandigarh. Area of responsibility (AoR) of SASE covers Himalayan region of Jammu & Kashmir, Himachal Pradesh and Uttarakhand. SASE operates in Jammu & Kashmir and Uttarakhand Himalaya through its Mountain Meteorological Centres at Srinagar (J&K), Jammu (J&K), Sasoma (J&K) and Joshimath (U.K.), while in Himanchal Pradesh Himalaya, it operates through HQ SASE Manali. About two lakh square kilometre area of these states are covered with snow during winter season, out of which about fifty thousand square kilometre area falls in active snow avalanche zones. SASE assesses the avalanche danger in the active snow avalanche zones daily using various avalanche prediction models and issue avalanche danger warning to these areas. As snow-meteorological parameters from avalanche prone areas are used in prediction models to assess the avalanche danger, SASE has established a vast network of observatories and automatic weather stations in these regions at various elevation levels up to 5500 m (m.s.l) in Siachen Glacier.

To protect buildings, highways, power transmission towers, ropeways and other important structures from snow avalanches in snow bound regions, SASE has designed and developed different avalanche control structures for different avalanche zones. SASE has mapped avalanche sites along various routes/road axes in avalanche prone areas where Army and civilian movement takes place routinely using remote sensing and GIS technology. SASE has developed avalanche hazard data cards and digital avalanche atlases containing detailed information on avalanche activity, avalanche accidents and terrain. Avalanche and terrain related information is realised in a 2-D and 3-D GIS environment. One of the thrust area for SASE is snow and avalanche physics. SASE has developed models for simulation of snow cover properties and avalanche dynamics. Acoustic emissions based instrumentations and techniques are under trials for monitoring snowpack failure and site specific predictions of avalanches. Avalanche awareness material and products were developed in the form of books, brochures, posters, CDs & DVDs for the Army and civilian population residing in avalanche prone snow bound regions of Western Himalaya. Two volumes of *Technology Focus* are dedicated to avalanche hazard mitigation in Central and Western Himalaya and divided into following sections:

- ◊ Computational avalanche forecasting and prediction of mountain weather
- ◊ Avalanche hazard mitigation using control structures and artificial triggering of avalanches
- ◊ Remote sensing and GIS technology for terrain visualisation, snow cover information extraction and product generation
- ◊ Snow cover and avalanche physics: Modelling and simulations
- ◊ High altitude observations network and instrumentation

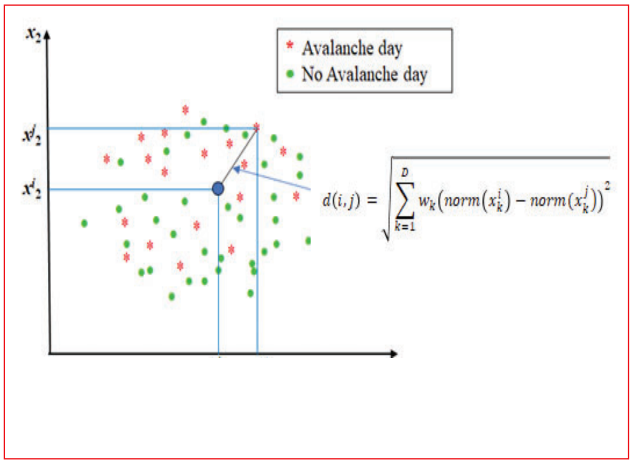
This issue of *Technology Focus* will cover first two sections and will be focusing on avalanche prediction and mitigating avalanche hazard using control structures in Himalayas.

Computational Avalanche Forecasting and Prediction of Mountain Weather

Among the various methods of avalanche hazard mitigation, the indirect or passive method is avalanche prediction. Avalanche forecasting is most economically viable, effective and practically suitable method, as it can be applied to a larger area and requires much lesser investments as compared to direct or active methods. Avalanche forecasting may be practiced at various spatial scale levels as per the requirement of users. Broadly this scale has three levels– micro (varies from a single avalanche slope to a group of avalanche slopes), meso (varies from a group of avalanche slopes to a major road axis or AoR of an Army Brigade) and macro (varying from Army Brigade AoR to an entire mountain range). Avalanche forecasting models require snow-met variables of the next 1-day to 6-days as input, which need weather prediction of the region in advance. Mountain weather prediction and prediction of snowfall amount is an integral part of the avalanche forecasting. With the advancements in computing technologies, database management tools and decision making algorithms, avalanche forecasting has benefitted a lot and following is a brief account of computational tools developed to aid decision making for avalanche forecasting and prediction of mountain weather.

k-NN Method for Avalanche Forecasting

World-over, probabilistic approach of avalanche forecasting has been very popular especially for meso-scale avalanche forecast as it is relatively matured and easier to implement due to its modest data requirement. k-Nearest Neighbours (k-NN) is the most popular technique used in this field. SASE has developed a k-NN method based model to aid avalanche forecasting at meso-scale level for Indian Western Himalaya. The model has been named as eNN10. The eNN10 model uses data of previous dates to find out similar features and their corresponding labels to predict the snow avalanche for present day. The model uses direct and derived snow-meteorological variables, collected from representative observatory, as inputs to find similar events in the past through employing Euclidean distance metric. An important feature of the model is the introduction of weight parameters corresponding to each input variables. This feature facilitates the incorporation of effect of relative influence of various variables on the process of avalanching. Earlier, the values of weights used to be fixed by experts on the basis of their experiences and subjective understanding of relationship between various variables and avalanche occurrences. Thus maximised model forecast accuracy was not ensured.



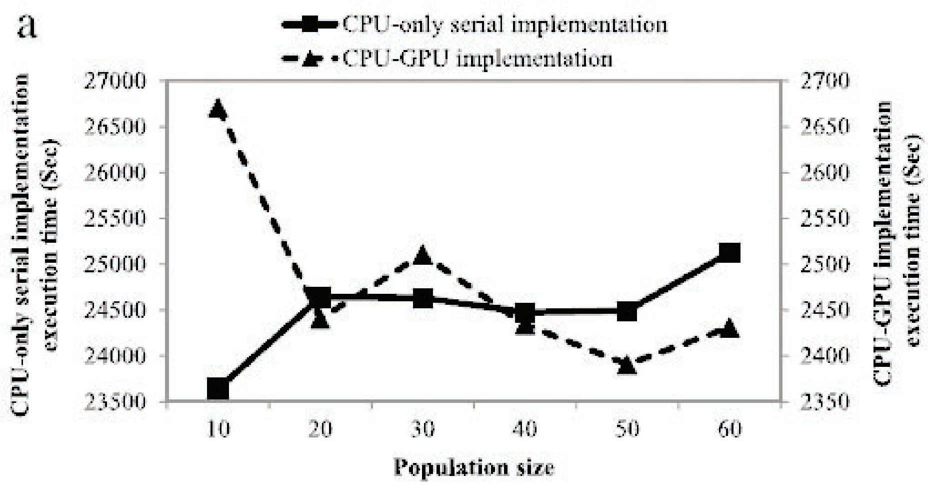
k-Nearest neighbours method for avalanche forecasting

The problem of finding the optimal values of weights for maximised model accuracy is referred to as model calibration. It is a complex optimisation problem and any classical analytical optimisation algorithm is not applicable. Therefore, the modern Nature Inspired Optimisation (NIO) techniques have been adopted to determine the (near-) global optima of this non-linear optimisation problem as these techniques are proven to provide good approximations of global optima for such problems. The techniques explored are Genetic Algorithms, Particle Swarm Optimisation (PSO) and Artificial Bee Colony (ABC) algorithm. Results obtained are indicative of substantial improvement in forecast accuracy in terms of statistical skill scores.

Another important feature of eNN10 model is that it has been linked with meso-scale numerical weather prediction model WRF, operational at SASE. WRF model is able to predict weather parameter quantitatively for up to next six days. As a result of this linking, the prediction period of eNN10 model can also be extended up to six days.

Accelerated Calibration of eNN10 Model

General purpose data parallel computing with Graphical Processing Unit (GPU) is much straightforward today with NVIDIA® CUDA and other parallel programming frameworks. Exploiting the CUDA programming framework, a novel methodology has been formulated around the GPU hardware architecture and memory hierarchy to accelerate the calibration process of k-NN method based eNN10 model used for avalanche forecasting in Indian Himalaya. The model is required to be calibrated regularly to ensure higher degree of forecast accuracy in terms of statistical skill score. The calibration of eNN10 is carried out using population based Nature Inspired Optimisation (NIO) techniques such as Artificial Bee Colony (ABC) algorithm. The calibration process is highly compute intensive. While a MATLAB sequential code for calibration runs for over 400 minutes, the proposed methodology delivered about 10×acceleration in calibration process. The methodology combines primitives of parallel implementations of brute force k-NN algorithm with that of population based metaheuristic algorithms and is scalable to deal with other similar real-world problems.

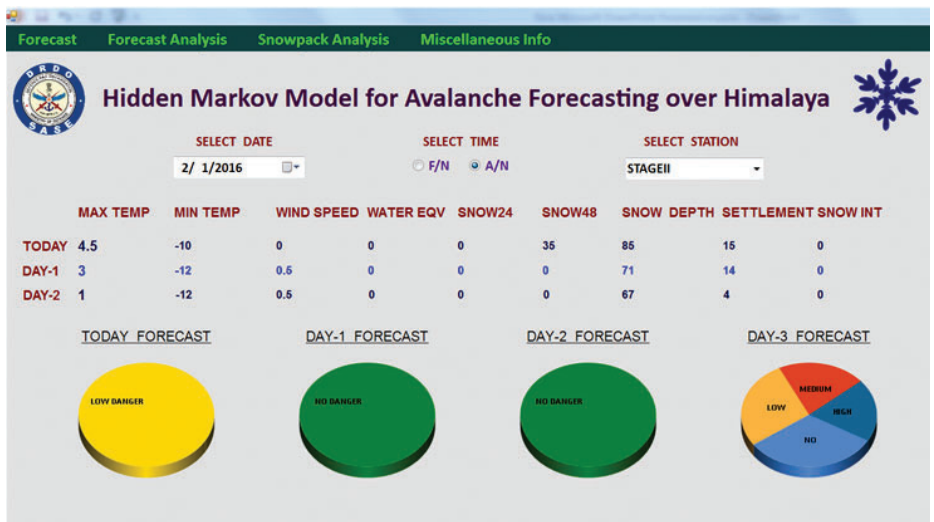


Calibration processing time (in seconds) with CPU–GPU parallel implementation in comparison to the processing time in CPU-only serial implementation for varying population sizes

Hidden Markov Model for Avalanche Forecasting

Hidden Markov Model (HMM) for avalanche forecasting in Pir-Panjal and Great Himalaya and a Decision Support System (DSS) for Karakoram Himalaya has been developed. The HMM gives avalanche forecasting with a lead time of four days and the DSS for one day. It has been developed using snow and meteorological data collected during past twenty winters.

It is based on the prediction of most probable observation and state sequences. The HMM has been optimised using Baum-Welch algorithm.



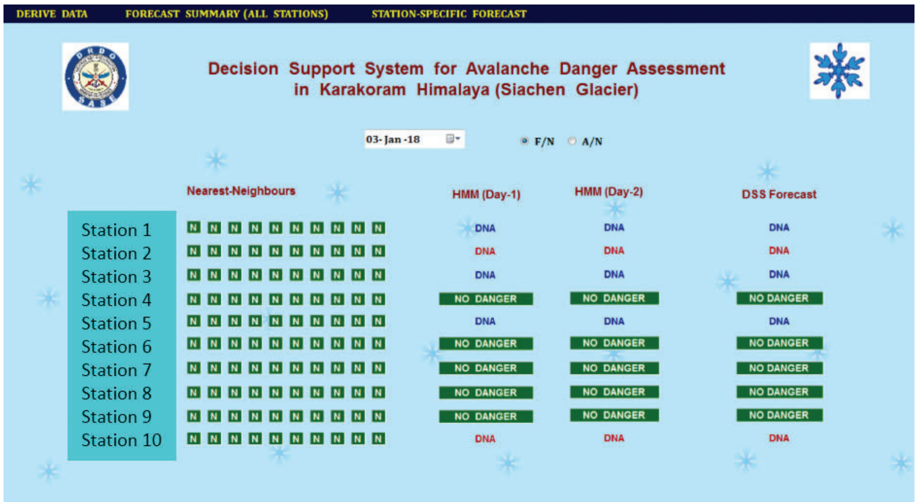
Avalanche forecasting in Pir-Panjal and Great Himalaya using HMM

Ensemble Avalanche Forecasting

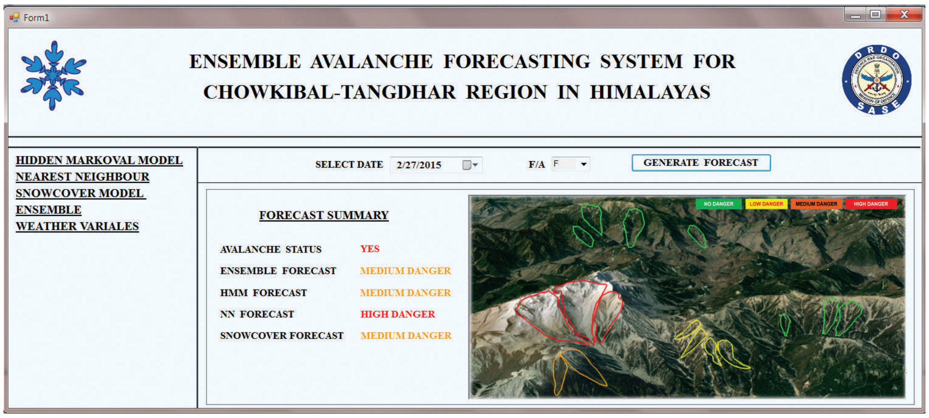
Individual avalanche forecasting model has its own limitation, a decision based on more than one model can be more reliable than a single one. The ensemble approach reduces bias and error of individual classifiers. In ensemble approach, multiple models are to be generated from the given data set and prediction is done by combining votes-majority vote in case of classification and average in case of prediction. Presently an ensemble of three models-Hidden Markov Model, Nearest-Neighbour Model and snow cover model-HIM-STRAT has been developed under project *Him Sandesh* using data of Stage-II observatory on Chowkibal-Tangdhar region in North-West Himalaya. The model will also be developed for other regions of Western Himalaya in near future.

Expert System for Prediction of Avalanches

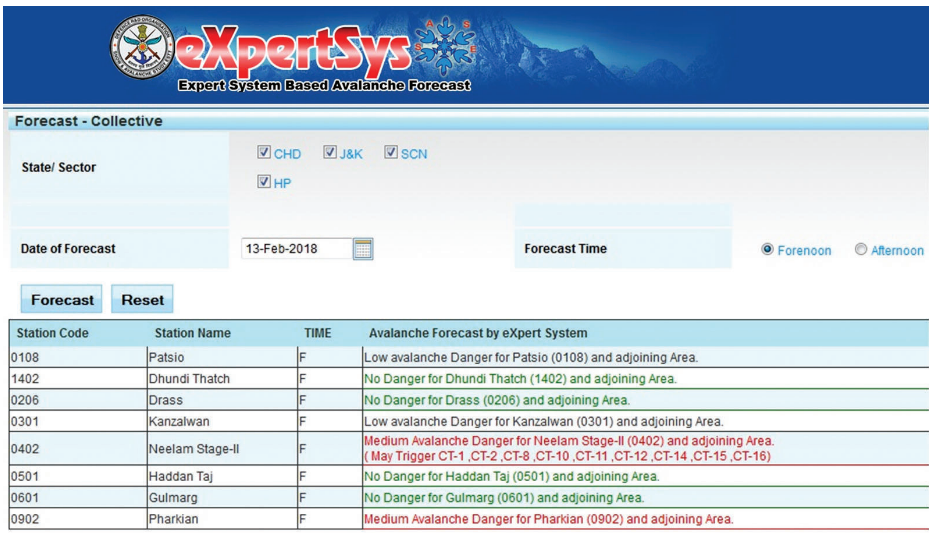
An expert system for prediction of avalanches along various road axis in the Shamshawari Range, Pir-Panjal Range and Great Himalayan Range in Jammu & Kashmir has been developed. Expert system uses data of various snow and meteorological variables and avalanche occurrences of a region to generate user friendly avalanche forecast for that particular region. Expert system is developed using 'If then Rules' and it generates rules automatically for each day as per prevailing snow and meteorological



Avalanche forecasting in Karakoram Himalaya using DSS



Schematic of development of ensemble avalanche forecasting system



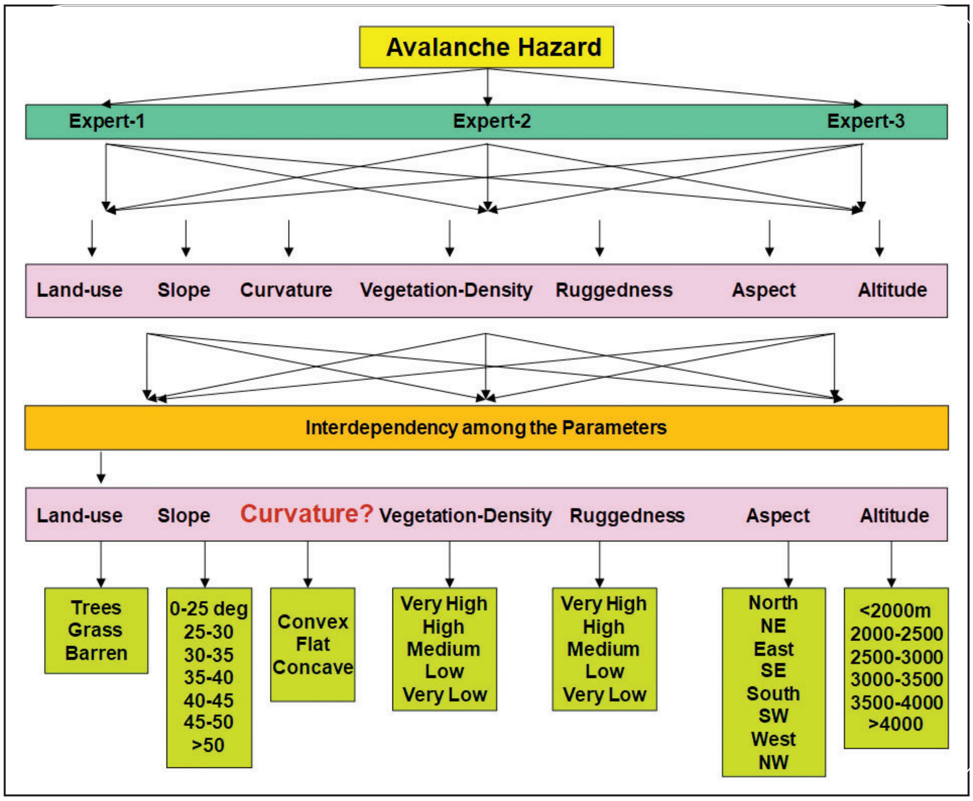
Avalanche forecast generated with the help of expert system for different road axis of Jammu and Kashmir and Himachal Pradesh

conditions in the region. Developed expert system has capability to learn with inclusion of new data into its database. The system produces avalanche forecasts for different avalanche prone road axis of Jammu & Kashmir and Himachal Pradesh in an easy to understand format.

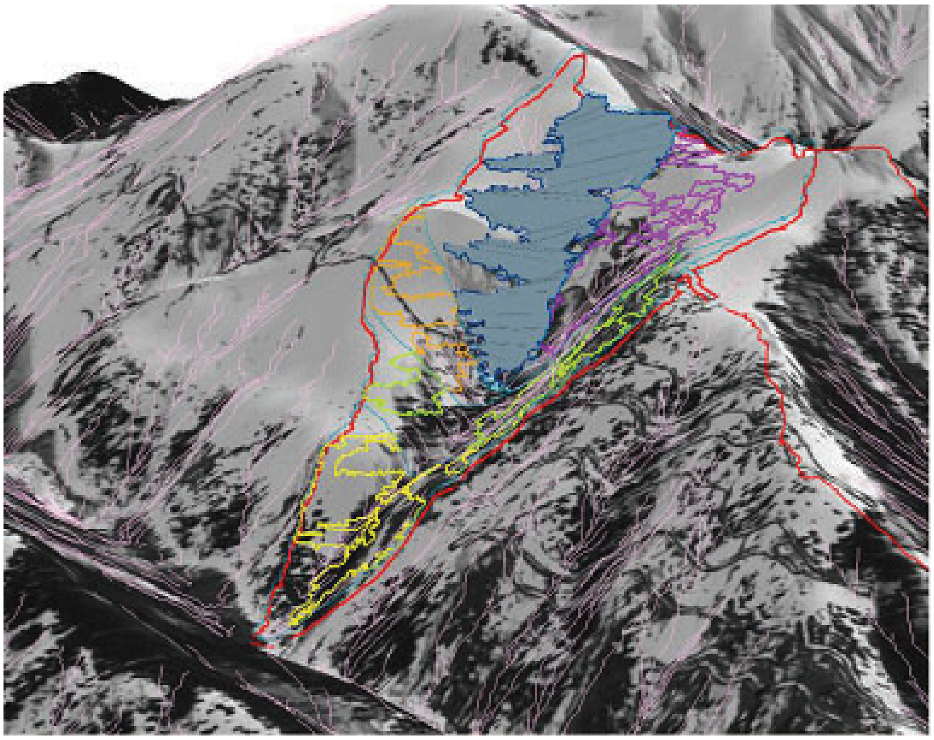
Spatio-temporal Assessment of Avalanche Danger

Avalanches are geophysical phenomena. Spatial variability of terrain, snow pack, and weather parameters play a critical role in the avalanche release process. It is evident that the avalanche problem has to be addressed both in spatial and time domain together. Multi Criteria Decision Making (MCDM) problems such as the prediction of time and place of occurrence of avalanches, involve a set of alternatives that may be evaluated on the basis of a set of evaluation criteria.

MCDM techniques offer solutions to decision problems characterised by multiple choice alternatives, which can be evaluated by means of performance characteristics called decision criteria. Because much of this modelling approach deals with evaluating location choice alternatives on the basis of suitability criteria, considerable attention in the last decades has been devoted to integrating MCDM with GIS software. Combining different factors, some exclusionary and some expedient, requires a weighting factor. Analytic Hierarchy Process (AHP) technique may be used to determine the relative importance of a set of activities or criteria. Through this approach, an attempt is being made for avalanche hazard zonation, identification of



Knowledge engineering by AHP



Perspective view of the slope and hazard polygons generated through GIS-based spatial model

avalanche triggering/formation zone, delineation of avalanche paths, determination of risk along the roads and finally avalanche danger assessment by integrating snowmet data.

This attempt thus aims at integrating the static terrain related parameters, and dynamic snow-meteorological parameters within a single modeling framework. MCDM techniques are found to be suitable to handle avalanche hazard zonation problems. Multiple criteria which would influence avalanche hazard zonation would include terrain related parameters like slope, aspect, morphology, land use/cover, etc.

Numerical Weather Prediction

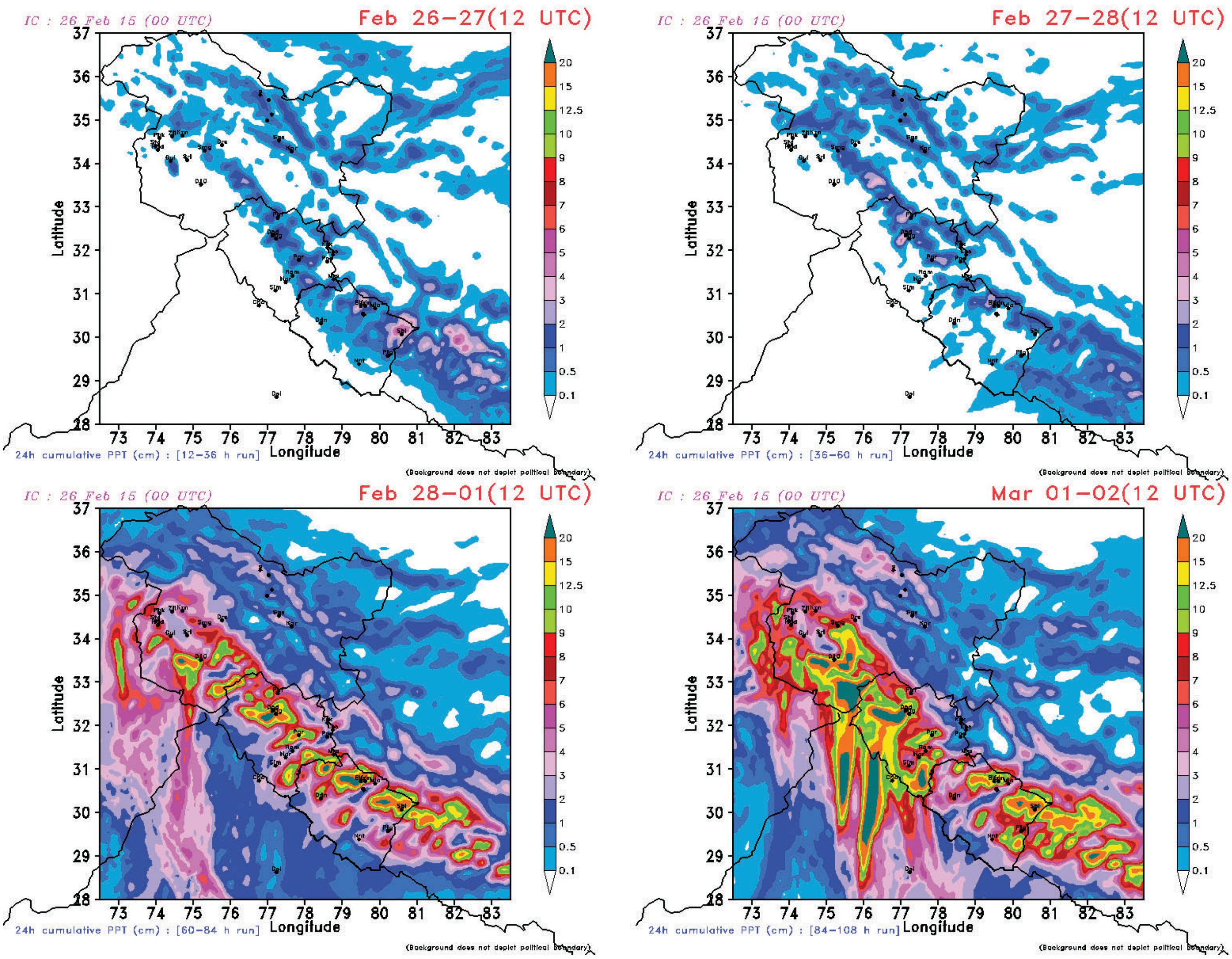
During winter, Western Himalayan region is particularly prone to severe weather events due to the movement of synoptic systems known as Western Disturbances (WDs). Heavy snowfall and gale winds associated with these WDs can cause snow avalanches. Accurate prediction of WDs and associated precipitation plays an important role in prediction of avalanches in snow bound areas of the Western and Central Himalayan region. Since there are a large data gap areas in the Western and Central Himalayan region where there are no observation available, Numerical weather prediction models along with the satellite data assimilation are being used to simulate and forecast weather.

The Weather Research and Forecasting (ARW-WRF) model version 3.9 is being used at SASE for operational mountain weather forecast. 3DVAR data assimilation technique is being adopted for improving the initial condition in the model. NCEP GFS data at 0.250x0.250 is being used in the model as initial and boundary condition.

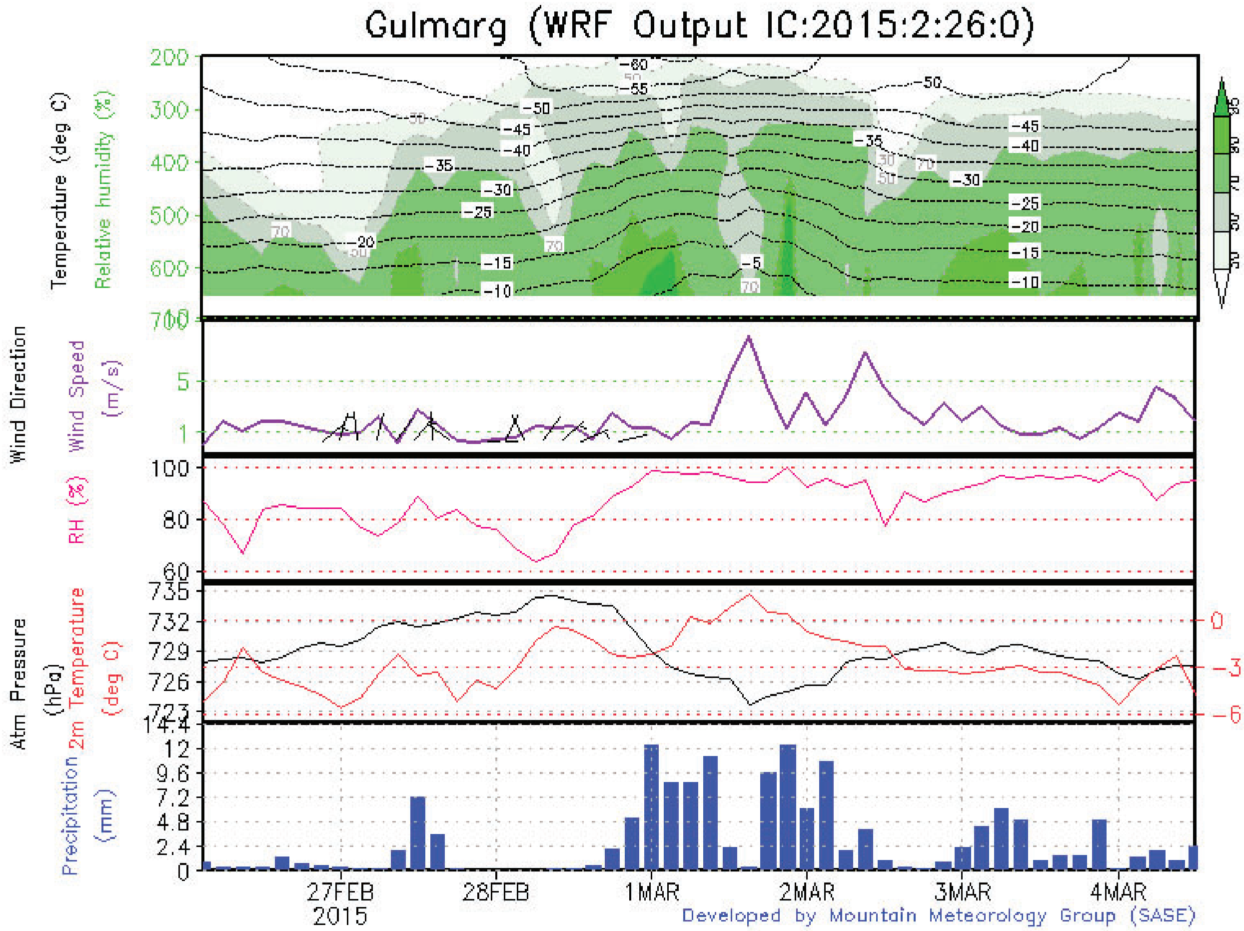
The precipitation (mm water equivalent) predicted by the models for day one to day six is being used to generate meteograms for all the station locations over Western and Central Himalaya. The final forecast along with the WRF model output is provided to the users in Jammu and Kashmir, Himanchal Pradesh and Uttrakhand Himalaya.

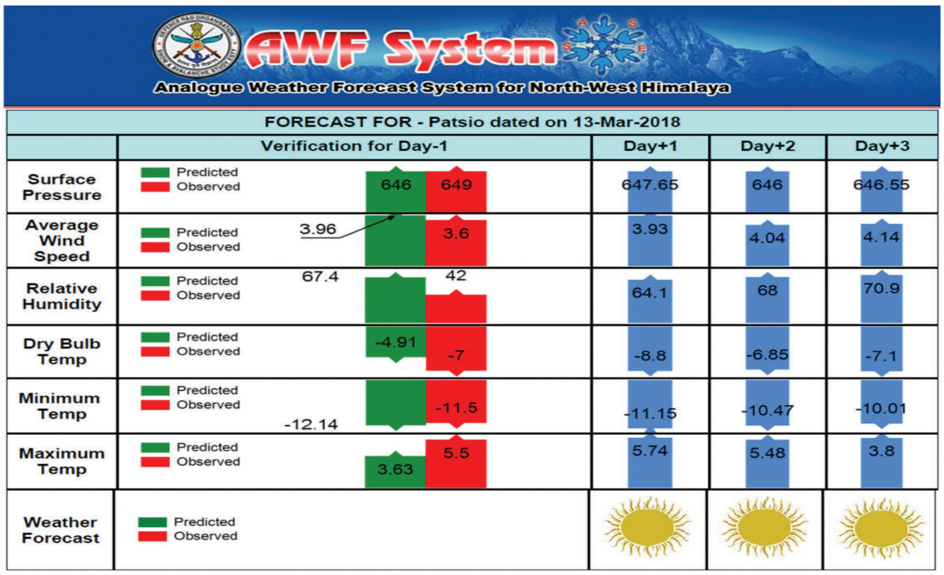
Analog Ensemble System for Short Range Local Scale Weather Forecasting

SASE has developed Analog Ensemble Weather Forecast System (AE System) for local scale weather forecasting at six stations belonging to the Shamshawari Range, Pir-Panjal Range, Great Himalayan Range and Karakoram Range in the Northwest Himalaya (NWH), India. Developed AE system utilises *in-situ* surface meteorological observations for generating local scale weather forecasts three days in advance and verification of previous days' weather forecast generated by it. AE system functions as an independent local scale weather forecast system and it is not dependent on data/forecast products from external sources. AE system predicts air temperatures (maximum air temperature, minimum air temperature, ambient air temperature), surface atmospheric pressure, wind speed, relative humidity and categorical qualitative weather forecasts/quantitative precipitation amount forecasts three days in advance at local scale over the NWH.



Precipitation forecast over western and central Himalaya by WRF mesoscale model in 9 X 9 km resolution





FORECAST FOR - Patsio dated on 13-Mar-2018

	Verification for Day-1		Day+1	Day+2	Day+3
	Predicted	Observed			
Surface Pressure	646	649	647.65	646	646.55
Average Wind Speed	3.96	3.6	3.93	4.04	4.14
Relative Humidity	67.4	42	64.1	68	70.9
Dry Bulb Temp	-4.91	-7	-8.8	-6.85	-7.1
Minimum Temp	-12.14	-11.5	-11.15	-10.47	-10.01
Maximum Temp	3.63	5.5	5.74	5.48	3.8
Weather Forecast					

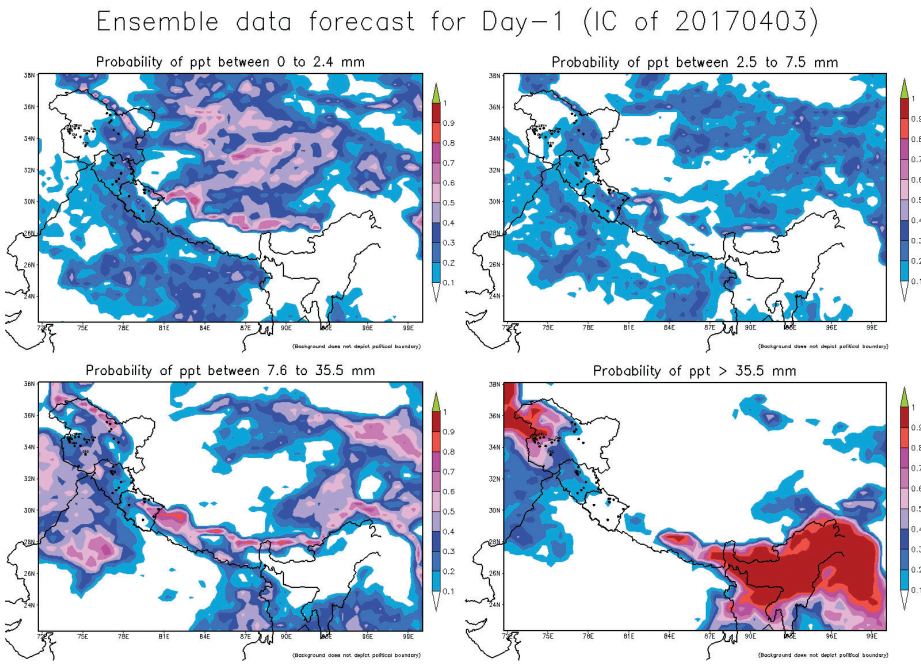
Generation of three days weather forecasts and verification of previous day's weather forecast by AE system

Ensemble Mountain Weather Prediction

The inaccuracies in the representation of dynamical and physical processes of the atmosphere in the model introduce an additional error, called model error. The extent of uncertainty varies from day to day, depending on the atmospheric conditions at the start of the forecast. Ensemble Prediction System (EPS) is used all around the world to predict forecast in confidence.

In this forecasting system, together with a single forecast from the best guess initial conditions, a number of additional forecasts are made starting from slightly perturbed initial conditions, with each forecast created with a slightly perturbed model. Ensemble prediction provides a quantitative basis for probabilistic forecasting. SASE has recently started developing model for ensemble mountain precipitation forecast for Western and Central Himalaya with the collaboration of National Centre for Medium Range Weather Forecasting (NCMRWF) at Noida Uttar Pradesh.

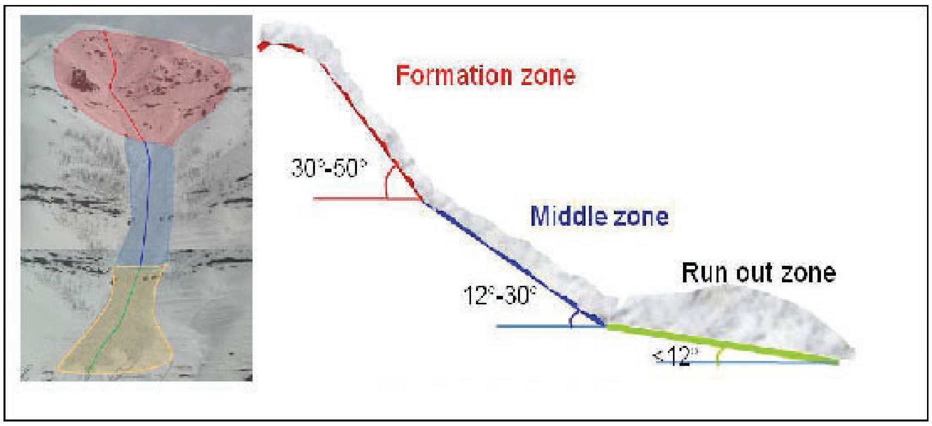
The forecast is being analysed regularly inhouse since last two years on experimental basis. The probabilistic forecast, issued ten days in advance, is being referred for mountain weather and avalanche forecasting. A high resolution EPS can provide very useful location specific probabilistic forecast through ensemble meteogram.



Avalanche Zone	Active Hazard Mitigation Measures
Formation Zone	Snow Bridges, Snow Rakes, Snow Nets, Snow Fence, Jet Roof, Baffle Wall
Middle Zone	Deflecting Structures, Snow Gallery
Runout Zone	Retarding or Diverting Structures, Catch Dams

Avalanche Hazard Mitigation using Control Structures and Artificial Triggering of Avalanches

Snow avalanche is a rapid flow of snow mass along a mountain slope that can contain rocks, soil or ice. In Indian Himalaya huge avalanches have been reported having avalanche sites length of more than one km and snow volume of thousands of metre cube. An avalanche path consists of Formation Zone, Middle Zone and Runout Zone. Avalanche hazard can be mitigated by active and passive measures.



Demarcation of avalanche zones

Active measures prevent avalanches from starting or act directly on the flow process. It includes various control structures schemes which are designed based on the avalanche zone considered for defence. Various control structures are categorised based on the avalanche zone. These control structures are designed keeping in view of the specific nature of particular avalanche sites.

Formation Zone Control Structures

It is the area where avalanche is released. Slope with an inclination

>30^0 are categorised as formation or starting zone.

SASE has designed and installed various formation zone control structures in the formation zone of avalanche sites affecting Jammu-Srinagar National Highway.

Snow Bridges

Snow bridges are snow supporting structures with a grate consisting of crossbeams. The classic snow bridge consists of supports, girders and varying number of crossbeams. The angle between girders and supports is 60^0-70^0. Generally, the snow bridges are erected with a lateral distance of 2 m. Snow Bridges are predominantly erected for a snow cover thickness between 2.5 m and 4.5 m.

There are number of rows of snow bridges and snow rakes installed in the formation zone of D-10 avalanche site on Jammu-Srinagar National Highway.

Snow bridges

Snow Nets

It consist of flexible-mounted swivel supports kept downslope with guywires and upslope with triangular or rectangular, flexible steel cable nets, which are connected to the upslope anchors by connecting cables. These cable connections can be adjusted lengthwise and thus there is a certain amount of flexibility when choosing the exact position of the upslope and downslope anchor points, which is advantageous under difficult topographical conditions. Snow nets are installed in formation zone and it can't be installed on a normal foundation.

A special technology called as Anchor Pile Technology is developed by SASE to provide strong foundation for snow nets.

Snow nets

Anchor Pile Technology for Snow Nets

Anchor piles are long slender members with small diameter (150 mm) for transferring the heavy tensile force to the inclined terrain. It is reinforced with single anchor rod and grouted with cement grouting with pressure. Anchor pile foundation was pioneered at MSP-4 avalanche site between Solang in Himanchal Pradesh to South Portal of Rohtang tunnel near Manali. Anchor pile has been designed as 98 mm diameter and 5 m length for transferring the heavy snow load to

Anchor Pile Foundation

Design parameter	Value
Height of Snow fence	4m
Porosity	50%
Rafter	Road Crash Barrier W Shape
Bottom Gap	0.57m (14%)
Material	Mild Steel, Structural Steel

the inclined terrain. At the same time, it reinforces the different soil strata underneath and make a composite block around pile shaft.

In this way, it stabilises the overburden strata which consist of soil and boulder mix matrix. Total 132 running metre of snow nets have been installed in MSP-4 avalanche site for stabilising the snow cover. It consist of 37 Nos. of uphill anchor piles and 33 Nos. of downhill anchor pile foundation. It has minimal impact to surface environment and little or no excavation is required for its installation.

Snow Fence

One of the major causes of avalanche activities and blockage of highway in snow bound areas is snowdrift. Snowdrift is a phenomenon in which naturally precipitated snow is transported from one place to another place due to wind. SASE has developed snow fences which are primarily employed to minimise the snowdrift quantity on highways/roadways/railways/pedestrian tracks, etc. A snow fence is a structure used to control snowdrift by depositing drifted snow mass in a predictable place. A permanent snow fence is generally of larger wooden/steel/iron poles set deeply into the ground with large wooden/steel/iron planks running horizontally across them.

It is also used to prevent snow drifting in lee ward side of mountain slope. Snow fences are installed to overcome cornice formation and road blockage due to snow drifting. The behaviour of blowing wind can be considerably modified using the snow drift control structures. The snow fence height, porosity and bottom gap are main critical factors which control snow deposition pattern near the structures and snow is captured depending on the storage capacity of snow fence. The flatter portion of ridge is selected near the cornice formation area to install the snow fence. Snow fences of height 4 m in a single row length have been erected to shift the snow deposition pattern. Design parameters of the snow fence are given in Table.

Jet Roof

Jet roofs are used to prevent the formation of cornices along ridges. Through the positioning in the beginning of the leeward, the wind speed in the nozzle increases, and the snow drifts far away onto the slope. Jet roofs do not reduce the total amount of snow that is blown in, however the roof has the effect that the snow is transported far away from the initial deposition point.

Jet roofs are constructed together with snow supporting structures to prevent excessive snow or damage to the top rows. Jet roofs are constructed and installed by SASE at Banihal Top on the formation zone of D-10 avalanche site to prevent the formation of cornices.

Snow fence

Jet roof

Baffle Wall

Baffle walls are placed in areas of potential cornice formations. The baffle walls affect the airflow and therefore influence the currents, high turbulences in the immediate vicinity of the walls create snow erosion; a scour is formed. The snow is deposited around the scour. The thickness and density of the snow deposition are inhomogeneous. Thereby the formation of a continuous cornice is prevented. Baffle walls are constructed in combination with snow supporting structures.

Middle Zone Control Structures

Middle zone is the area where avalanche travels and flowing snow mass exert high impact pressure. Slope with an inclination between 12°-30° are categorized as middle zone. Various control structure schemes in this zone are discussed below.

Deflecting Structures

Deflecting structures are constructed in the form of dams or walls, which contain the avalanche in its path directionally stable, or for deflecting it in another direction, or to deflect it away from objects that need to be protected.

Galleries

Avalanche galleries are direct defence measures for roads or highways in the middle zone. They protect roads or railroad tracks against the effect of avalanches by bypassing them. There are many places across the Himalayan region where highways are prone to number of geo-hazards such as avalanches, floods, landslides, etc. One such site is located at about 20 km from Manali on the approach

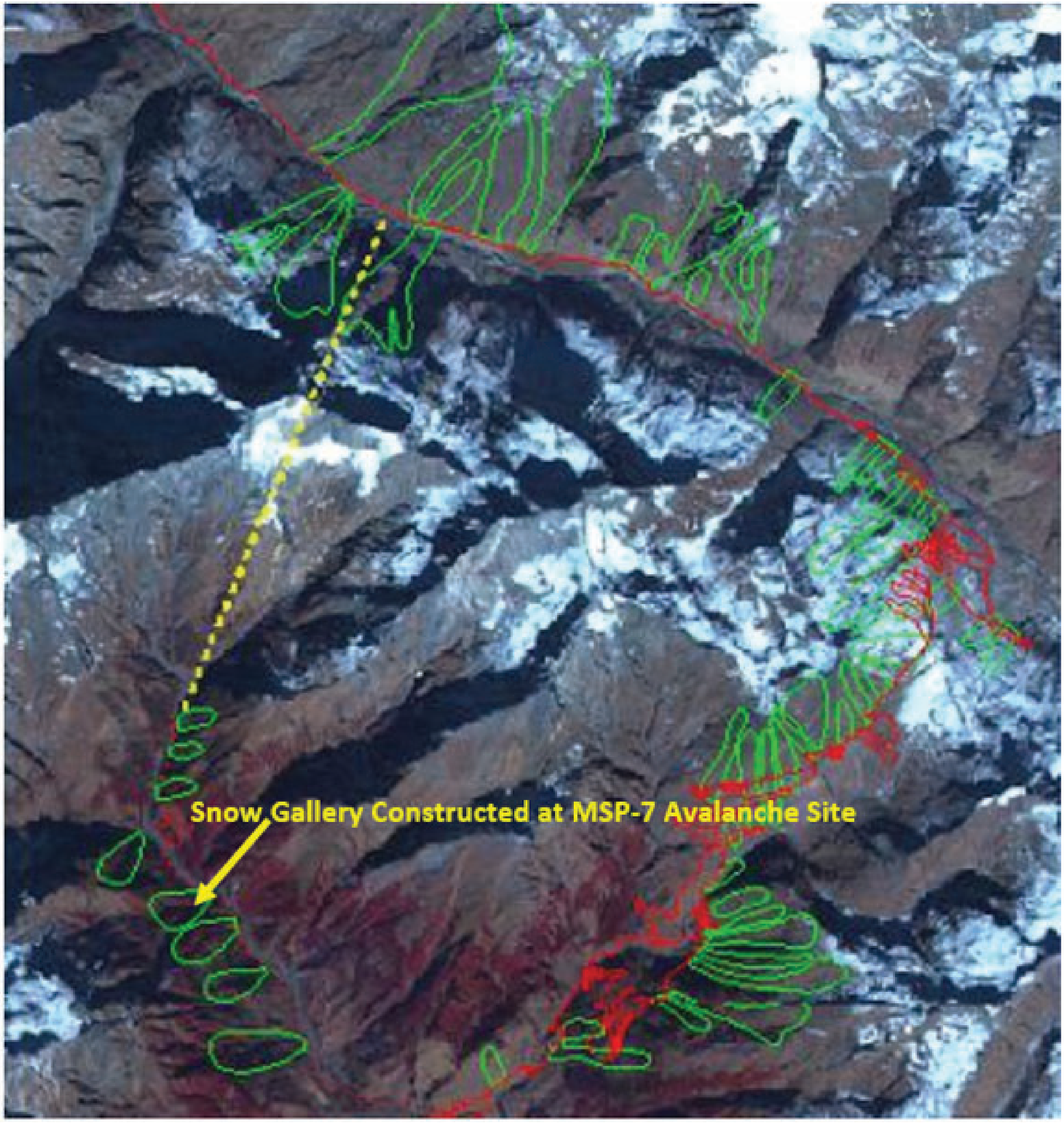
Baffle wall

Design of snow gallery on Manali–Leh Highway

road to South Portal of Rohtang tunnel. The site has a perennial nalla with minimum 1 to 2 cumec discharge. The site is also located in the middle of cloudburst zone and experience two to three flash floods every year. Catchment area of this site is very large and consists of huge boulders packed in loose soil at 15° to 55° slope; it causes flow of boulders and deposition of enormous debris on highway each time a flash flood occurs. The site also falls in snow bound area and in past number of avalanches were registered.

To protect the highway from snow avalanche and other geo-hazards a special type of structure known as snow gallery is designed with provisions to pass flowing water, flash flood and debris and avalanche without disturbing the flow of traffic. It is basically a tunnel type of structure in which there are provisions to allow the flowing water to pass underneath the carriage way, while flash flood and avalanche over the top of roof.

A folded grating is provided on the upstream side of structure to avoid damage to main structure from the impact of flowing boulders and for safe rolling down of these boulders grating is also provided on the downstream side. Further, a cellular raft is designed at the downstream to avoid damage to main foundation raft from the free flowing boulders in case of major cloudburst. Some other features of this unique structure are ogee spillway for smooth passage of flowing water, retaining wall to take care of soil pressure. A snow gallery designed by the laboratory has been constructed by Border Roads Organisation (BRO) on Manali-Leh highway to protect the highway from Snow Avalanche and Flash Flood.



Runout Zone Control Structures

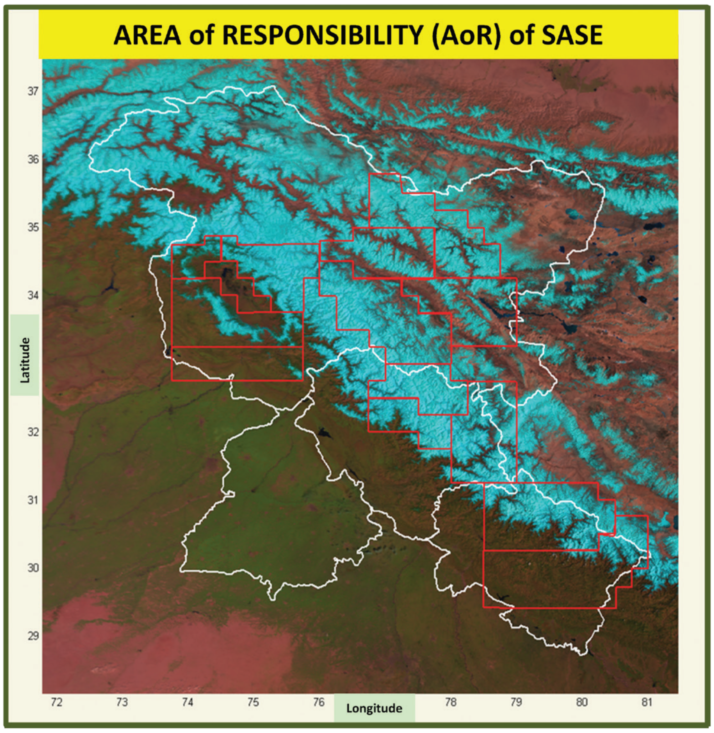
Slope with an inclination less than 12° are categorised as runout zone and snow avalanche debris is deposited in this zone. Various control structure schemes to protect important buildings or highways from snow avalanches in this zone are discussed below.

Retarding Mounds

Retarding mounds are constructed from earth material and erected offset in large numbers. The offset set-up is supposed to cause a branching of the avalanche in the runout zone and a

Retarding mounds near Shri Badrinath temple

Retarding mounds in runout zone of an avalnche



Snow Avalanche at Malari, Uttarakhand

reduction of the runout distance. The height of the avalanche retarding mounds is generally two to three times higher than the avalanche flow height. The retarding mounds are placed in the avalanche runout area.

Catching Dam

The main idea of the catching dam is to stop the avalanche with the help of an artificial obstacle and then avalanche debris will be deposited around artificial obstacle. Catching dams are constructed in places where the avalanche velocity is already low. The geotechnical requirements, such as sufficient compaction of the cover material and drainage of the storage capacity are taken into account when constructing a dam. Volume of the snow mass deposited in the form of debris plays a defining role in designing the catching dams. Catching and retarding systems can be combined in an effective manner.

The avalanche flow velocity can be reduced by avalanche retarding defence systems, and then effective dam height of the catching system can be reduced.

Feedback for Technology Focus

We have been receiving a tremendous appreciation & good words on the contents, quality, and presentation of Technology Focus and we intend to continue with our efforts. The editorial team requests your support to further improving it. The feedback form as below would be one of the resource that would provide us your level of satisfaction and newer aspects you would want to incorporate in the Technology Focus.

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☐ Excellent ☐ Good ☐ Satisfactory ☐ Needs improvement

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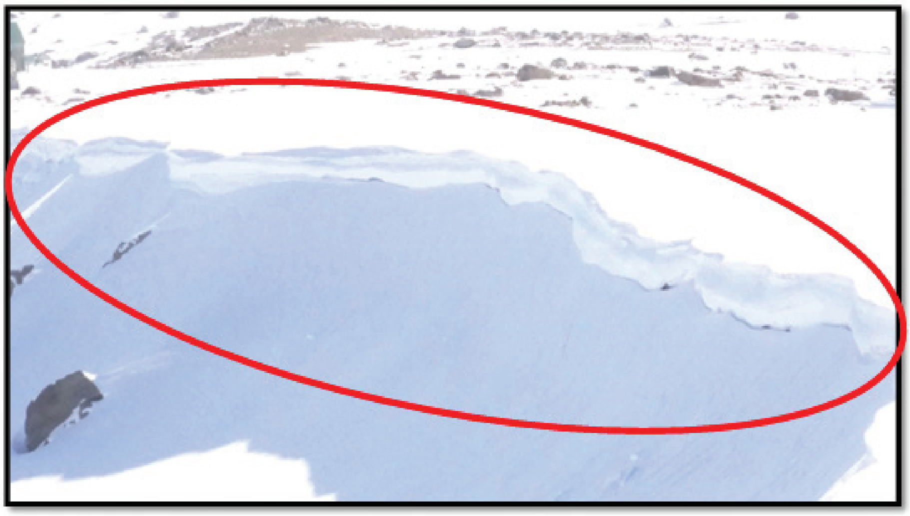
Artificial Triggering of Avalanches using Explosives

Artificial triggering of avalanches is an active and cost-effective method of mitigation of avalanche hazard. It helps in controlling the time of release and size of avalanche. Artificial triggering involves use of blast waves generated by explosion to apply additional pressure loading at high strain rates to the snow layers. It causes release of unstable snow mass in the form of snow avalanche. Successful artificial triggering involves continuous evaluation of snowpack conditions to identify the suitable window for application of explosive loading.

The laboratory has collaborated with other DRDO laboratories Armament Research and Development Establishment (ARDE) and High Energy Materials Research Laboratory (HEMRL) Pune to develop specialised ammunition for 84 mm RL (Carl-Gustav) to be used for Artificial triggering of avalanches. 84 mm RL is an infantry weapon, light weight and is available in good numbers with soldiers deployed in the forward areas.

SASE is also developing methodologies for identification of aim zones in avalanche release areas, safe launch location, time window of artificial triggering and safe artificial triggering practices. Preliminary trials were conducted at an avalanche site in Gulmarg, J&K in February of 2018 and further trials are planned during upcoming winter season.



Cornice prone target area for artificial triggering in Gulmarg sector

Trial of Artificial Avalanche Triggering using 84MM RL by Indian Army in Collaboration of SASE

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