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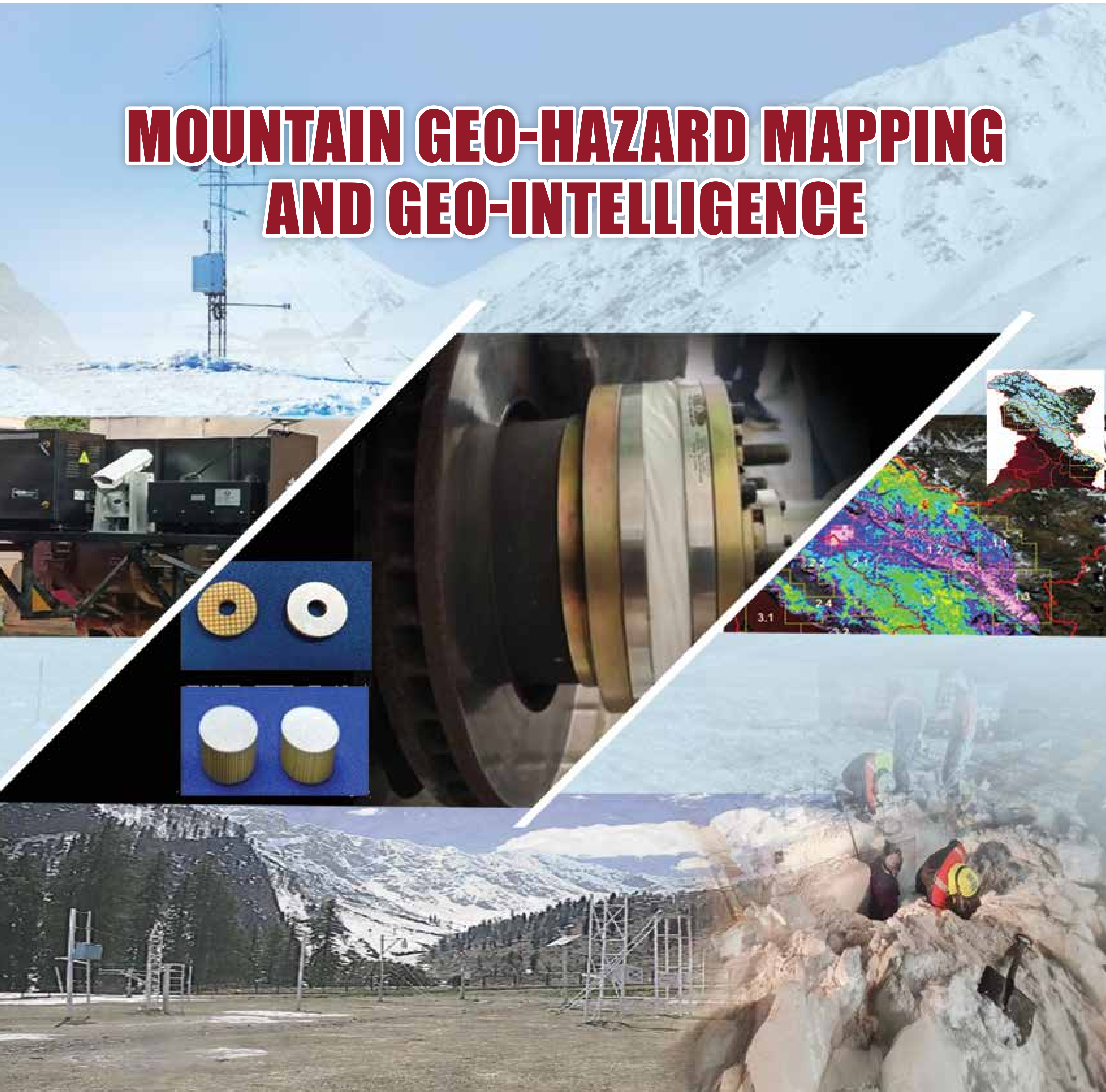
MOUNTAIN GEO-HAZARD MAPPING AND GEO-INTELLIGENCE



Technology Focus highlights on the technological achievements in the organization covering the products, processes and technologies.

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From the Desk of Special Editor

Defence Geoinformatics Research Establishment (DGRE) under Soldier Support Systems (SSS) has been raised on 15 November 2020. DGRE imbibes the responsibilities of erstwhile Snow & Avalanche Study Establishment (SASE), Chandigarh and Defence Terrain Research Laboratory (DTRL), Delhi. With its Headquarter at Chandigarh, DGRE has four Research & Development Centres (RDCs) and five Mountain Meteorological Centres (MMCs) spread over Northwest, Central, and Northeast regions of Indian Himalaya for in-depth geo-hazard research and management.

DGRE is working towards the development of broad spectrum of technologies for mountain geo-hazard mapping, monitoring, prediction, and mitigation. For the management of avalanche hazard in the Indian Himalayan snowbound regions, DGRE has developed technologies and models for weather & avalanche forecasting; snow & meteorological sensors; instrumentation for snow cover monitoring; communication network; and data links for near real-time dissemination of hazard information and critical alerts to the users.

To mitigate the avalanche hazard of strategic areas, DGRE has developed various control measures that includes implementation of avalanche control structures and artificial triggering of avalanches, etc. The development & implementation of geospatial tools and techniques for geo-hazard mapping, monitoring and geo-int generation is another technology domain of DGRE. DGRE is extensively employing multi-source remote sensing data (optical, thermal and microwave) for mapping, detection and monitoring of avalanches and landslides.

Physical and statistical modelling of the snow, avalanches and landslides is another important research domain of DGRE. These models provide the better insight to avalanche and landslide problems, which leads to effective implementation of geo-hazard mitigation measures.

This current edition of *Technology Focus,* Mountain Geo-hazard Mapping and Geo-intelligence as well as upcoming edition on Geo-hazard Monitoring, Modeling and Mitigation highlights the key enabling technologies developed by DGRE in recent years towards mountain geo-hazards management and are expected to serve the reference for future developments.

I am extremely delighted with the dedicated efforts that are continuously being put by DGRE team in developing technologies & products and services for geo-hazard management to fulfil the crucial operational requirements of the Users and exhort DGRE to continue the excellent work towards the complete safety from geo-hazards in Indian Himalaya.

Dr Upendra Kumar Singh
Distinguished Scientist & Director General
Soldier Support Systems (SSS)

From the Desk of Guest Editor

DGRE is the only establishment of its kind working on the technologies for geo-hazard management with a focus on avalanches and landslides for safe movement of the Armed Forces. DGRE is striving to ensure safe mobility of troops in inhospitable terrains with a focus on enhancing military potential and combat effectiveness in various types of terrains based on niche techniques. DGRE has its Area of Responsibility (AOR) along all major land border areas in states/UTs including Jammu & Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. Major users of DGRE are Armed Forces, Para-Military Forces, MoRTH, BRO and other Central and State Government Departments.

Snow avalanches are prominent natural hazards in mountainous regions of Indian Himalaya. DGRE has developed the technologies for identification, mapping, control of the mountain geo-hazards and it provides operational weather and avalanche forecasting services to the users. These technologies and services play a critical role in planning and decision-making by defence establishments as well as civil authorities in their operations.

Accurate observations of snow, meteorological and avalanche parameters are important inputs in the process of geo-hazard estimation, forecasting, and mitigation. To achieve this, DGRE has developed a network of manual snow-met observatories as well as Automatic Weather Stations (AWS) in the Himalayan region to collect data on a wide range of atmospheric and snow parameters. Further, DGRE has designed the network of 348 AWS keeping the geo-hazards in mind along with important road networks and community settlements.

Different kinds of avalanche control structures have been designed, developed and implemented by DGRE to mitigate avalanche hazards. DGRE has also provided technical consultancies to infrastructure development agencies for implantation of various avalanche mitigation measures.

The extensive analysis and susceptibility mapping of landslide prone regions and control release of weak zones prone to landslides has been demonstrated to the Users to achieve safe mobility in North-East regions.

Development of geospatial technologies and generation of geo-intelligence is another research domain of DGRE. To address the requirements of Indian Armed Forces, DGRE generates exhaustive terrain topographic and thematic database of Indian Himalayan regions and developed various GIS applications for geo-hazard analysis, mapping and monitoring. DGRE has also generated various GeoInt products such as DEMs (5 m resolution) of AOI, contour maps for high resolution data to be used for navigation.

This current special issue of *Technology Focus* on Mountain Geo-hazard Mapping and Geo-intelligence and next special issue on Geo-hazard Monitoring, Modeling and Mitigation presents the glimpse of new technologies developed by DGRE in the ambit of geo-hazards Management. It is anticipated that this issue of *Technology Focus* will provide a cursory insight into the preparedness of DGRE to develop futuristic geo-hazard and geo-intelligence technologies for Indian Himalayan region.

Dr Pramod Kumar Satyawali
Outstanding Scientist & Director
DGRE

MOUNTAIN GEO-HAZARD MAPPING AND GEO-INTELLIGENCE

The spread of the geohazard footprints in Indian mountainous regions include Union Territory of J&K, Union Territory of Ladakh, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. This covers approximately 4.31 Lakh km^2 area of mountainous regions. Snow avalanches and landslides are two prominent geohazards affecting these regions. The initial estimates of the avalanche prone region revealed that ~1.5 Lakh km^2, which is 34% of total area falls under avalanche prone regions. A large spatial variability in the topographical, geomorphological, meteorological and snow variables have been observed over these hazard prone regions. Moreover, these regions have high strategical importance as geopolitical international border lines of India passes through these regions. Therefore, complete and accurate mapping and continuous monitoring of these regions is essential for the risk identification, vulnerability assessment and hazard mitigation.

DGRE area of work includes operational mountain weather & avalanche forecasting, mapping and modelling of geohazards, geohazard mitigation engineering solutions, sensors & instrumentation for data collection, Geospatial data & tools for mountain hazard assessment & situational awareness, systems for artificial triggering of avalanches, avalanche event and victim detection, terrain analysis for off-road trafficability, geo-hazard early warning, and safety and rescue trainings to users.

Being the only laboratory working in the area of mountain geohazard management, DGRE is extensively providing geohazard related services to various Civil and defence agencies. Some of these are operational mountain weather & avalanche forecast, safe camping sites selection and safety audit of user's camps and other installations, long term weather and snow projections for winters planning, and training on 'avalanche safety & rescue operations and snow meteorological data collection. DGRE also extends technical support to the users in implementing geohazard mitigation measures such as control structures and artificial triggering of avalanches.

Geospatial Technologies for Mapping and Monitoring of Geohazards

Satellite-based Mapping

Geospatial database related to snow cover, terrain, meteorological parameters and avalanche occurrences/debris information, etc. are required for the mapping and monitoring of avalanche hazard and to improve the accuracy of avalanche forecasting. It is difficult to collect snow cover and terrain information from high altitude ground observations due to vast rugged mountains and harsh climatic conditions of Himalayas. Geospatial technology provides an effective tool for mapping and monitoring of snow cover information of larger areas at high spatial and temporal resolution. DGRE has developed various algorithms to extract snow cover information using multi-spectral remote sensing and GIS techniques.

Snow Cover Area Mapping

Seasonal snow cover information over Himalayan region is very important for avalanche danger assessment and forecasting. Optical satellite Sentinel-3 is providing multispectral imageries on daily basis for the complete Himalayan region. For generation of Snow Cover Area (SCA) maps and snow cover distribution pattern, Normalized Difference Snow Index (NDSI) based method is adapted, which is based on reflectance of snow cover (as shown below Fig. 1).

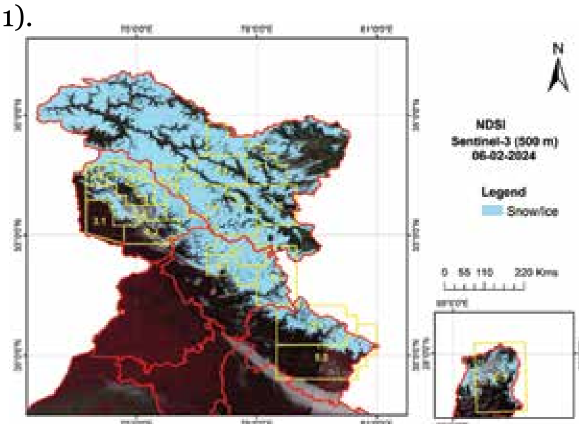


Figure 1. Sector-wise SCA Mapping using Optical Remote Sensing Satellite Data in Himalaya.

SCA products on daily basis are being generated during winter months for avalanche forecasting. Fig. 2 shows sector-wise total and aspect-wise SCA distribution. Snow cover distribution patterns observed for the winter period 2023-24 in Himalaya are shown in Fig. 3. Monthly average snow cover distribution indicates less snowfall occurred in 2023-24 early winter as compared to 2022-23, however similar pattern had been observed for late winter period (Fig. 4).

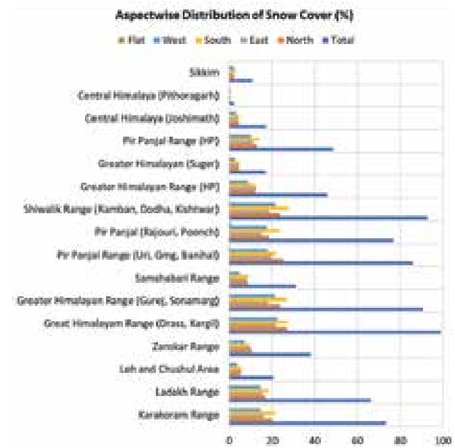


Figure 2. Sector-wise (total SCA and Aspect-wise) SCA distribution in Himalaya.

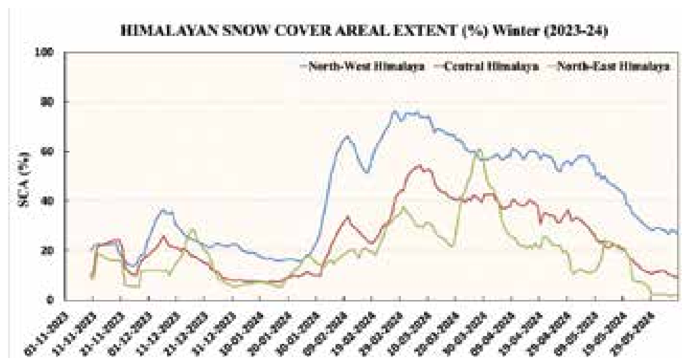


Figure 3. Seasonal Snow Cover Distribution for Winter Period 2022-23 and 2023-24 in Himalaya.

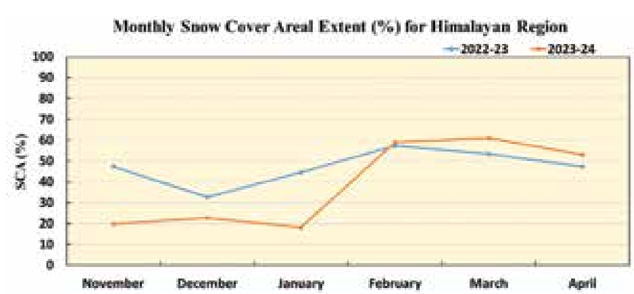


Figure 4. Month-wise Seasonal Snow Cover Distribution for Winter Period in Himalaya.

Snow-depth Estimation

Spatiotemporal Snow Depth (SD) estimation is essentially required for the forecast of avalanches, and also, for many applications pertaining to hydrology. Considering the high spatiotemporal variability in snow depth across Himalaya, region wise models have been developed to estimate SD at spatial resolution of 500 m for three different Himalayan zones, i.e., Lower Himalayan Zone (LHZ), Middle Himalayan Zone (MHZ), and Upper Himalayan Zone (UHZ). Multi-frequency brightness temperature (TB) observations from Advanced Microwave Scanning Radiometer 2 (AMSR2), Snow Cover Duration (SCDs) data, terrain parameters (i.e., elevation, slope and ruggedness, etc.) are used to develop the SD model. Generated SD products are shown in Fig. 5.

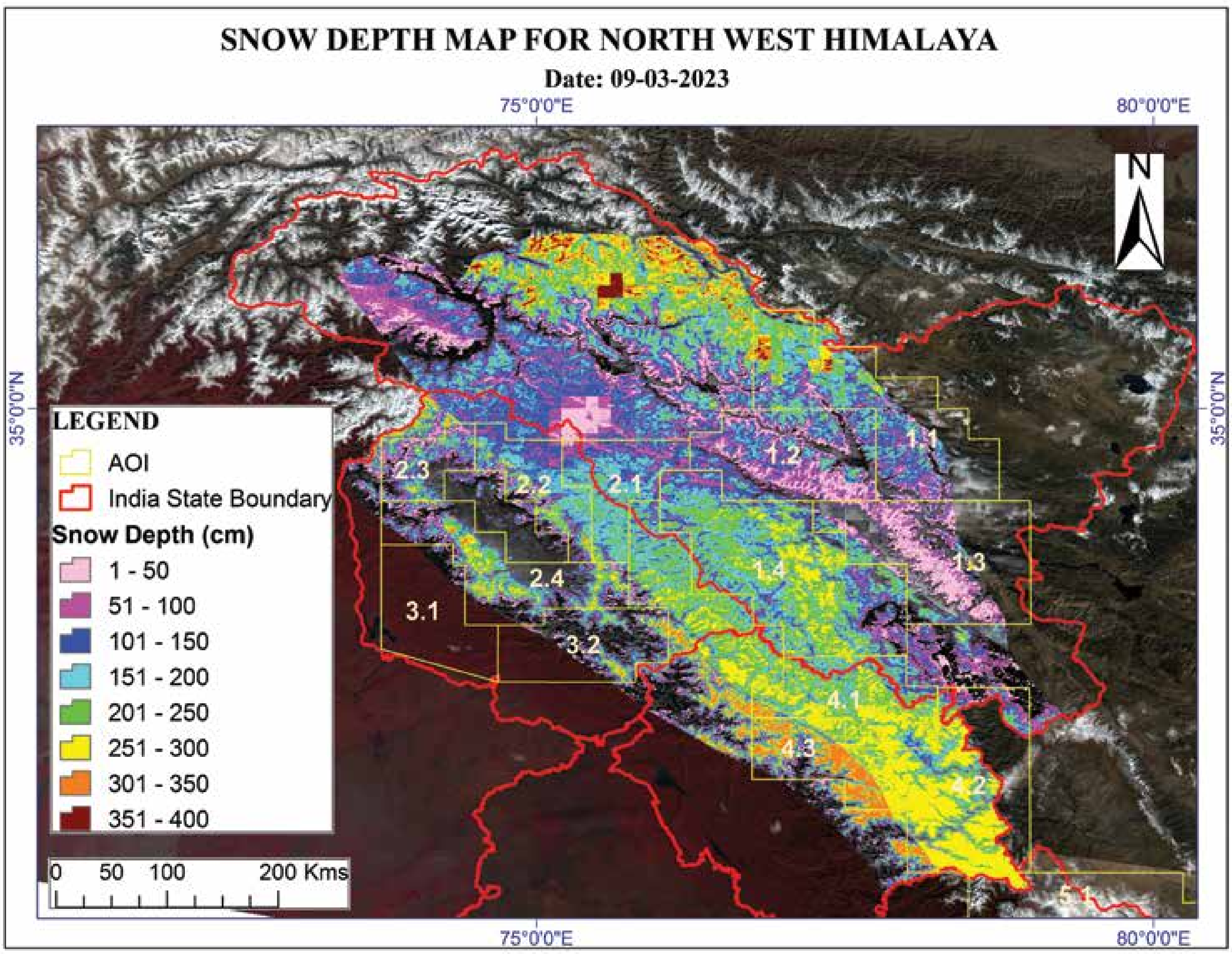


Figure 5. Snow-depth Distribution in North-West Himalaya.

Automated Avalanche Debris Detection

An automated avalanche occurrence zone detection methodology is developed using deep learning technique. High-resolution (0.5 m) images from GeoEye-1 satellite are used for model development. The model was trained using annotated satellite images in three different patch sizes using a U-Net deep learning architecture. The ideal patch size for avalanche occurrence zone identification is found to be 256 x 256 with F1 score of 0.97. The trained deep learning model is now being applied for avalanche occurrence zone detection. Some results of the developed model are shown in Fig. 6.

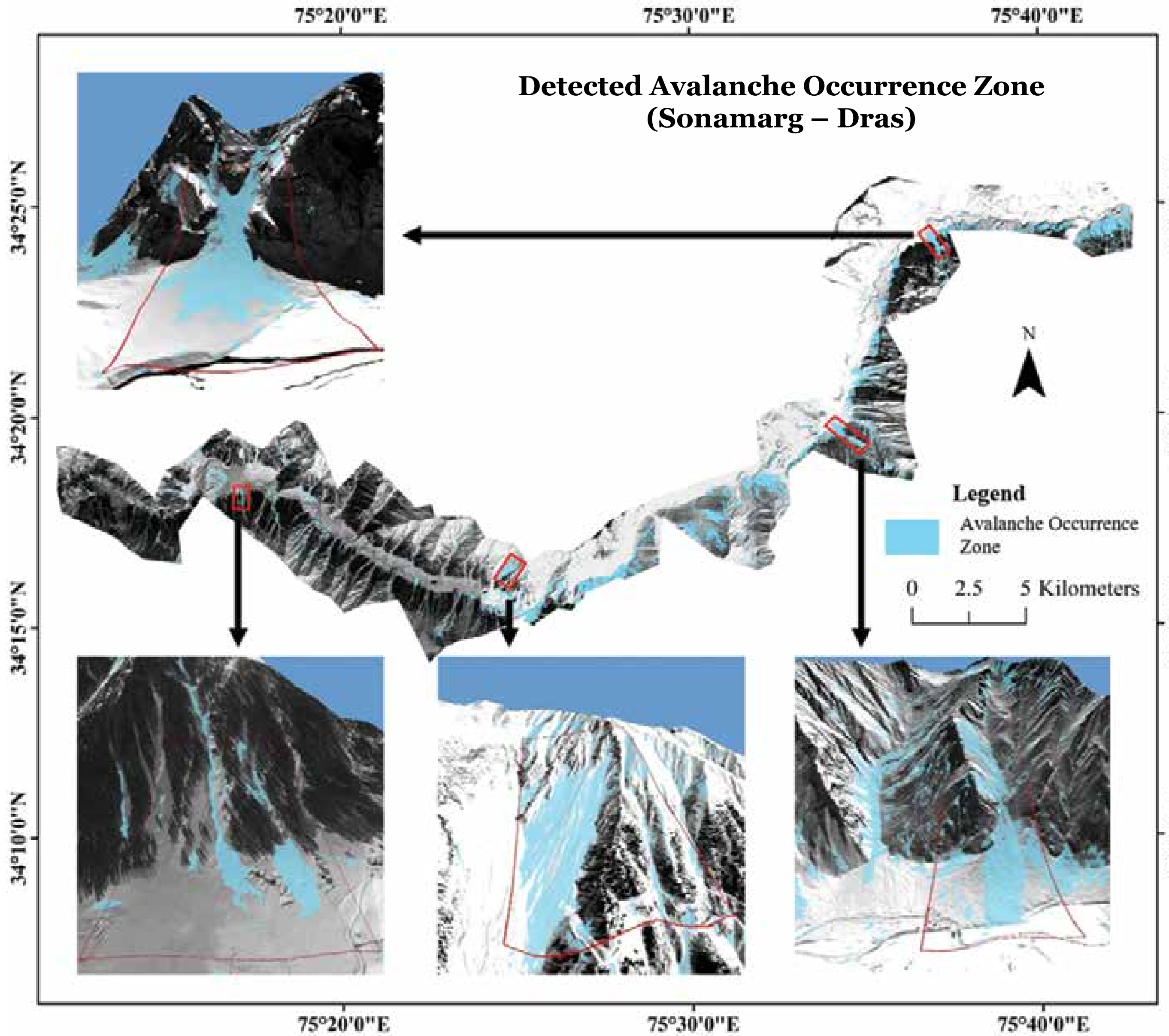


Figure 6. Automated Avalanche Occurrence Zone detection from North-Western Himalaya using U-Net Deep Learning Technique.

UAV-based Mapping

Structure-from-motion (SFM) is a photogrammetric technique for the estimation of 3D structure from 2D multi-view image sequences coupled with motion vectors that describes the transformation between these overlapping images. To reconstruct topographic surfaces or features at high resolution, the multi-view overlapped images of the study area are required to be captured. UAV with a camera is used to acquire images of the area of interest. This reconstructed 3D surface is Digital Surface Model (DSM) of surveyed area. Time-lapse photogrammetry is primarily used to monitor the temporal changes of a 3D surface. It very useful in snow depth estimation, avalanche deposit detection and characterization and many more hazard mapping and monitoring applications. In DGRE, the high-resolution DSM generation, snow depth mapping and avalanche occurrence detection techniques have been developed using UAV survey data.

High Resolution Digital Terrain Models and Digital Surface Models

The Laboratory has used UAV SFM photogrammetry method to create 10 cm DSM of very high resolution for various areas around Manali. Fixed wing survey grade UAV (SenseFly e-Bee X) was deployed for the purpose. Images of regions of interest were captured using different sensors—optical imagery (RGB), multispectral scanner (MSS), and Thermal Infrared (TIR). For creating high resolution DSM for Dhundhi Region (near Atal Tunnel, Manali) 12 flights in four days were made to cover the 12.0 km2 area. The available Cartosat DEM (at 10m resolution) of the study area was used as an elevation source. The average flight height was kept at 212 m Above Ground Level (AGL) to achieve 5 cm GSD of RGB images. The flight lines were designed for RGB images with 60/80 % overlap. A total of 2023 images were captured during each survey (Fig. 7). The RGB images were captured by a 20 MP camera. The UAV imageries were processed for deriving DSMs.

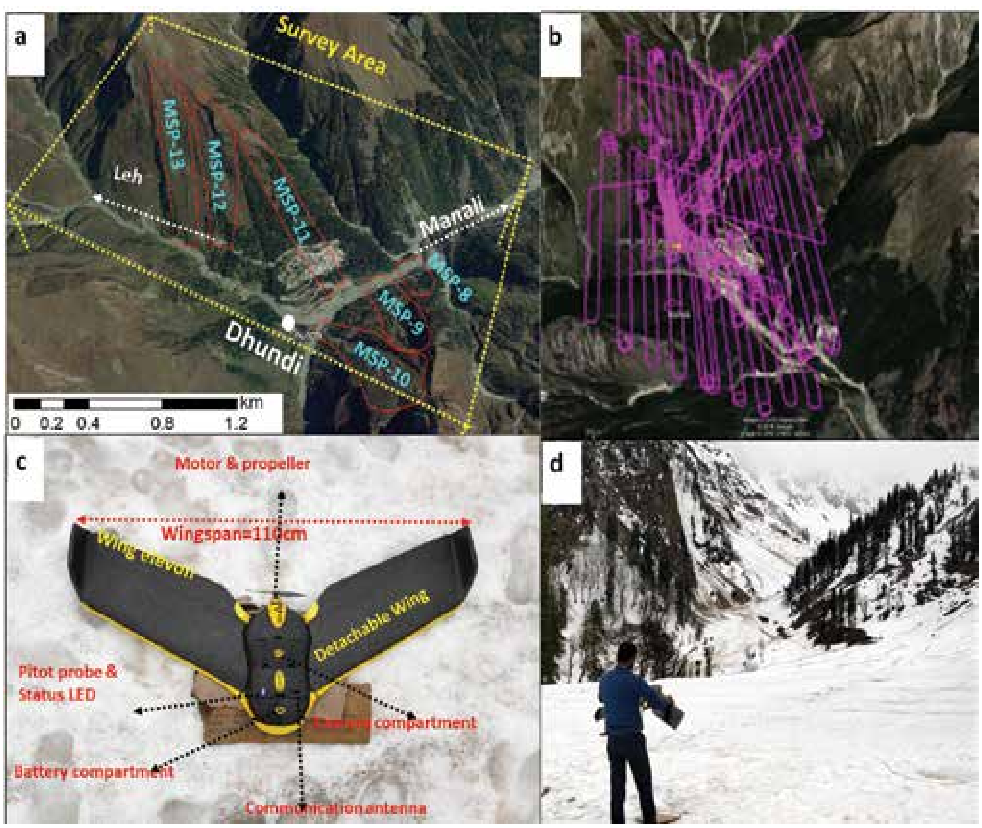


Figure7. (a) UAV Survey Area Covering Major Avalanche Sites (MSP (Manali South Portal)-8 to MSP-13) Near Dhundi Region, (b) Winter Survey Flight Path of UAV, (c) Schematic of the e-Bee X UAV with Labels Indicating Sensors and Major Components and (d) Field Photograph of Launching UAV by Hand.

A DSM having 10 cm spatial resolution with 0.45 m horizontal accuracy and 0.85 m vertical accuracy was generated without incorporating any Ground Control Points (GCPs). To further improve the accuracy; five well-defined, prominent, and distributed GCPs were used in the data processing. The locations for GCPs were chosen in such a way that these features were clearly visible in images. The position of GCPs was surveyed using Leica GS18 T Real-Time-Kinematic (RTK) GNSS measurements with the base station setup near Dhundi observatory. The baseline processing of the base station and rover data was carried out using the Leica Infinity post processing tool. With GCPs, the accuracy of 10 cm DSM improved to 0.09 m horizontal accuracy and 0.14 m vertical accuracy.

Similar DSM, with high vertical and horizontal accuracy are being prepared for critical hazard sites for further analysis like flow simulations, control structure designs, etc.

UAV SFM-based Snow Depth Mapping

Accurate snow depth observations are one of the most important inputs in the process of avalanche hazard estimation, forecasting, and mitigation. This development presents the high-resolution snow depth mapping of avalanche-prone regions of the Manali–Dhundi area, Himachal Pradesh (HP), India, using, repeated UAV Photogrammetric surveys. The images captured by an RGB camera mounted on a fixed-wing UAV (e-Bee X) were used to generate the high-resolution (DSM) and Orthophotos of the study area. A snow depth map was generated by differencing co-registered snow-covered DSM and bare surface DSM. UAV-derived snow depth values have been validated with the point snow depth measurements of Wireless Sensor Networks (WSN), manual observation station, and snow depth around a structure of known height in the survey area. The UAV-retrieved snow depth values were found in good correlation with field-measured snow depth. The analysis of data suggests that regular monitoring (before and after every snow storm) of the snow depth using a UAV-based method is quick, cost-effective, and provides accurate snow conditions for operational use and planning in snow-bound regions. The method developed for snow depth estimation and results are shown in the Fig. 8.

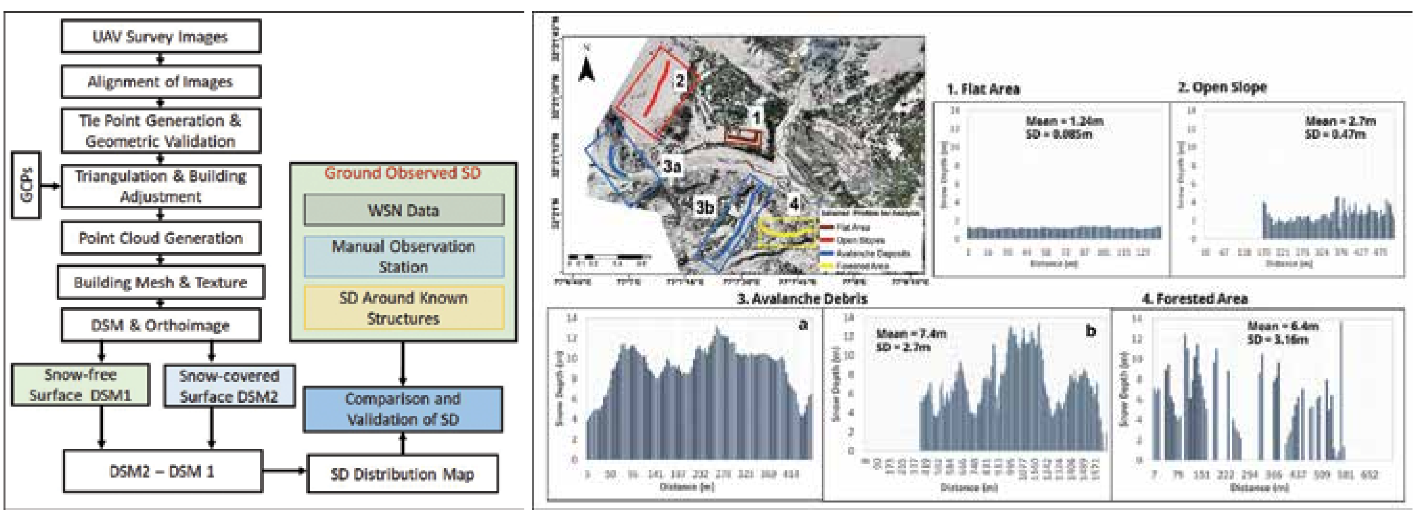


Figure 8. Overview of the Methodology used for Snow Depth Estimation and Model Results.

Avalanche Deposits Detection and Characterization

Avalanche activities in the snow-covered mountainous slopes are very frequent and stochastically distributed over time and geographical extents. Conventional methods of avalanche occurrence reporting in these areas are inefficient and incomplete due to inhospitable weather and inaccessible topographic conditions. A novel framework using Object Based Image Analysis-Convolution Neural Network (OBIA-CNN) for the detection and analysis of avalanche deposits using UAV-RGB images is developed to overcome these limitations. Initially, the OBIA-based multi-scale multi-resolution segmentation technique is used for UAV image segmentation, then the classification of these image segments was performed using a CNN classifier to detect the avalanche deposits. The avalanche deposits detected using the proposed method were found in good correlation with manually delineated deposits. Finally, the surface area and snow volume-based characterization of the detected deposits was performed. The proposed framework will be useful for the automated detection of avalanche deposits and their characterization for the regions of specific interest. Fig. 9 show the CNN architecture used for deposit detection and detected deposits and their characteristics are shown in Fig. 10.

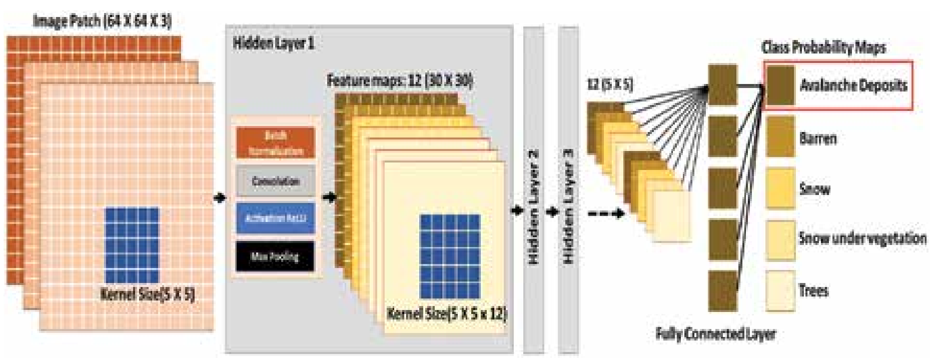


Figure 9. CNN Architecture used for Avalanche Deposit Detection.

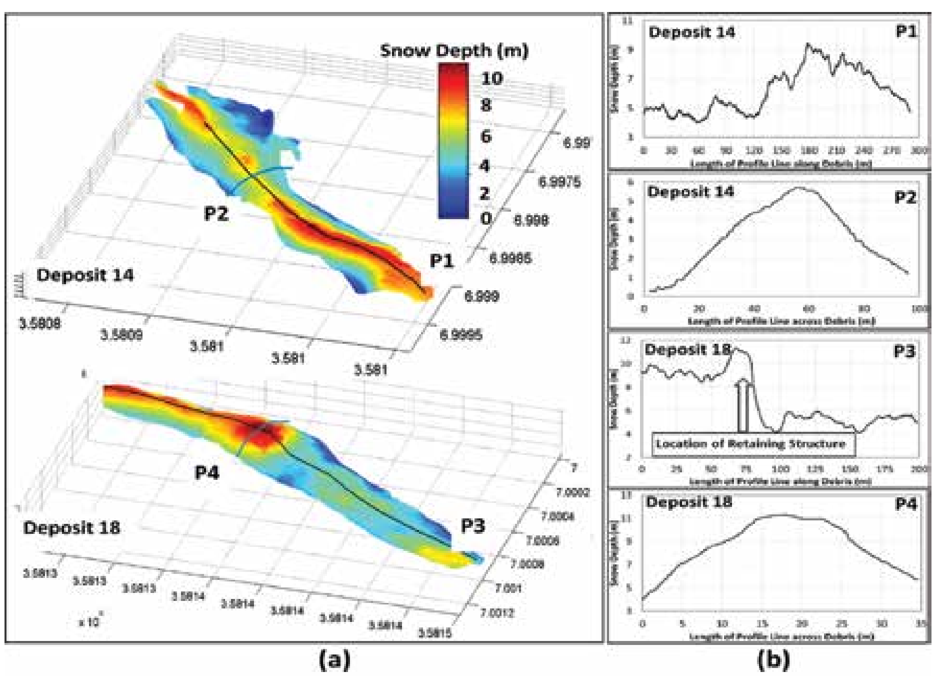


Figure 10. Detected Deposits Characterization.

Technologies for Geo-Intelligence Generation and Dissemination

Target Detection and Characterization

Exploitation of geo-spatial technology for detection, identification and characterization of objects of interest (target) which are spatially unresolvable/mixed or camouflaged or decoyed is essence of many civilian and defence/military type of applications. Target detection and characterization relies on number of parameters like spatial/spectral variability of features, spatial mixing of features, type of background, spectral/backscattering response of features, etc. Though different techniques are available depending upon target detection/characterization application scenario, however discussions here are restricted to hyperspectral geospatial data.

Hyperspectral (HX) image in reflective VNIR and SWIR region (350 - 2500 nm) of electromagnetic spectrum with hundreds of contiguous spectral bands has potential to provide spectral signatures characterizing many materials of interest.

HX Data Exploitation

Currently, many countries have operational space borne hyperspectral sensors (PRISMA by Italy, ENMAP by Germany and HySIS by India, etc.). Hyperspectral Imaging Satellite (HySIS) is an Indian earth observation satellite that was launched on 29 November 2018 to capture hyperspectral data in range 400 - 2400 nm in 316 bands at 10 nm spectral and 30 m spatial resolution. Exploitation of HySIS data was carried out for performance analysis for identification and characterization of the targets for defence applications. The different aspects related to HySIS sensor data pre-processing, identification and characterization of target material were explored by conducting field experiments in synchronization with HySIS passes for different scenarios such as unknown target material, full pixel, sub-pixel, and mixed pixel. Overall general processing flow includes Hx raw data acquisition, pre-processing to correct for radiometric, geometric distortions and atmospheric effects, spectral library generation, usage of spectral library for development and validation of models and algorithms for detection and characterization of targets of interest Fig. 11.

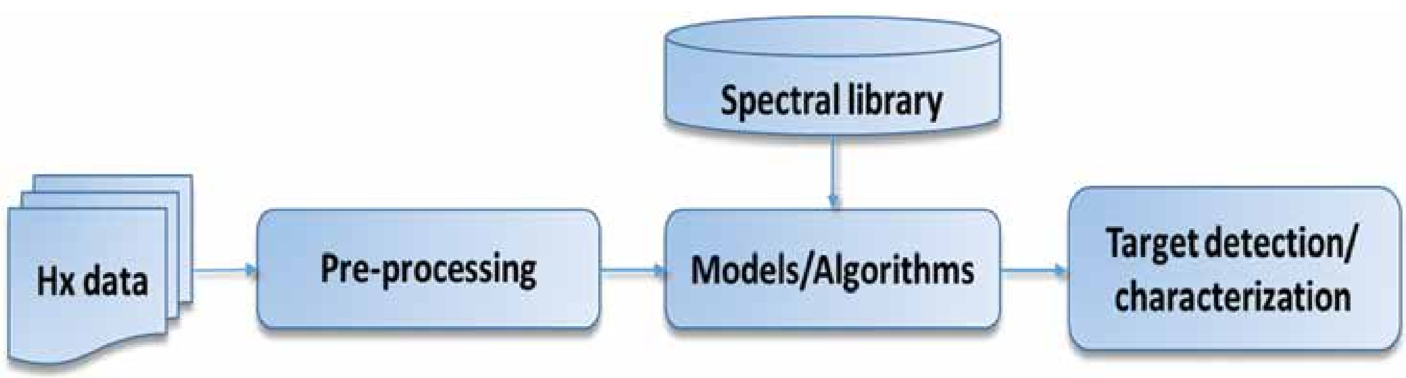
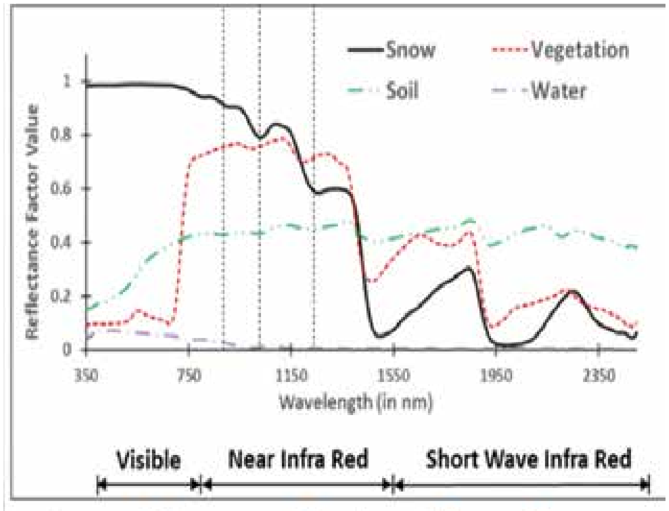


Figure11. Hyperspectral Data Processing Workflow.

Spectral Library Generation

Spectral library is a collection of spectral signatures of objects/targets of interest along with metadata and plays crucial role in detection, identification and characterization of targets using geo-spatial data. Spectral library of various targets of general and defence interest was generated using sophisticated field instrument spectral-radiometer in the wavelength range 350 - 2500 nm Fig. 12.



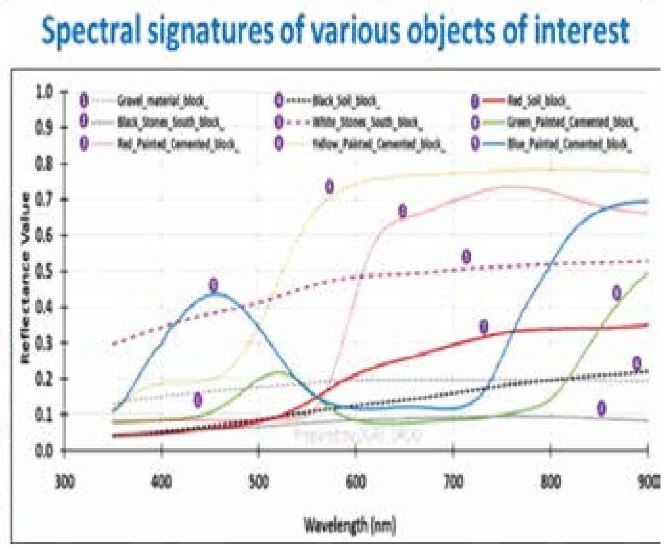


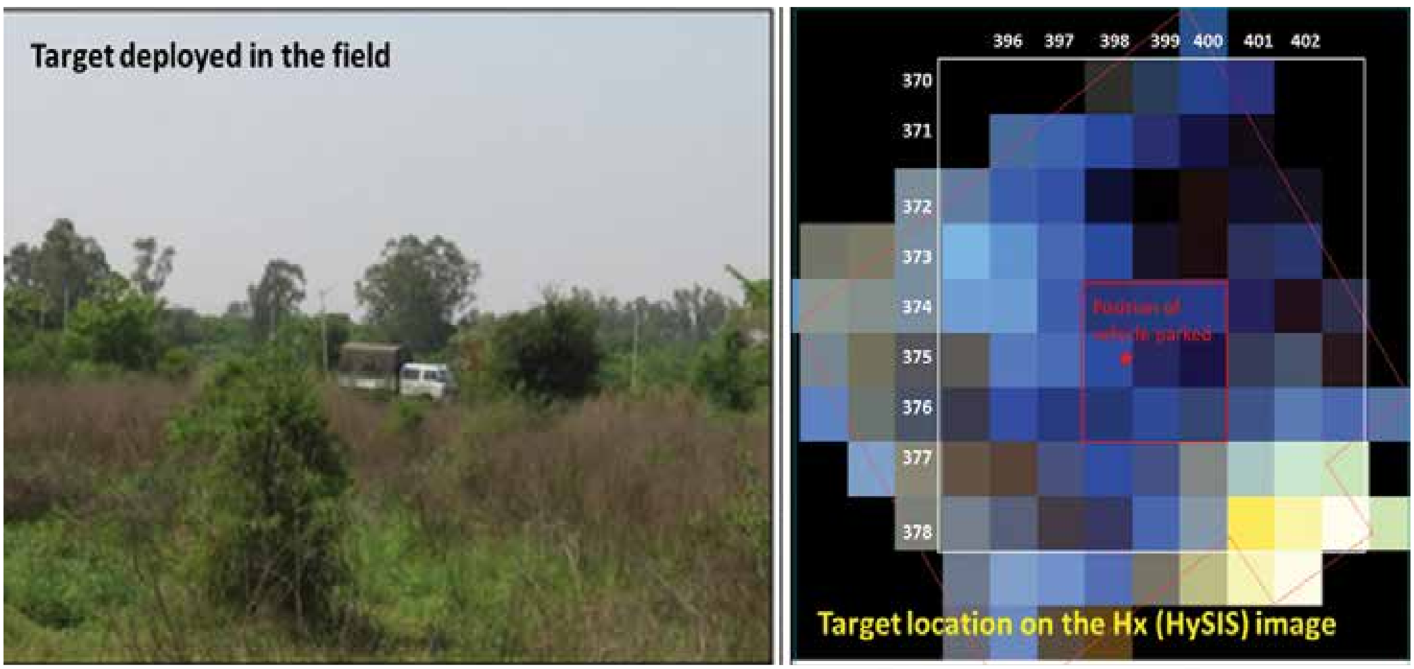
Figure12. Spectral Library Generation.

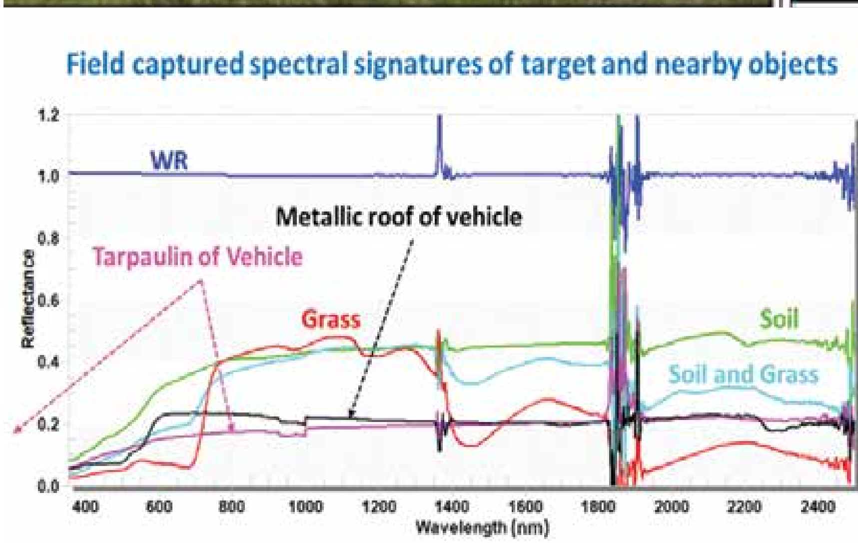
Development of In-house Software HYPEX for Hx Data Analysis

An in-house software for hyperspectral data processing and analysis has also been developed at DGRE. It has various modules like visual user interface to display the geospatial data, spectral library viewer, end-member extraction tools, spectral matching module for Hx data, etc.

Target Detection/Characterization

Experiments were performed in recent past to detect the presence of targets having either full pixel or sub/mixed pixel presence in the HYSIS satellite sensor image. Targets were deployed in to the field location and spectral library of target and surrounding objects was created. Spectral measure-based algorithms (SAM, ACE, CEM, etc.) were implemented on the HYSIS geospatial data to detect, identify and estimate abundance of targets in the pixels of interest and encouraging results were found Fig. 13.





Pixel location: Column_Row →	399_375
Spectral signature ID_Name ↓	Spectral Distance ↓
ID_69_Vegetation_1	0.1256
ID_68_Vegetation_1	0.1271
ID_71_Vegetation_1	0.1337
ID_70_Vegetation_1	0.1392
ID_67_Vegetation	0.1559
ID_26_Vegetation	0.1828
ID_27_Vegetation	0.1859
ID_30_Vegetation	0.1876
ID_28_Vegetation	0.1878
ID_29_Vegetation	0.1888
ID_85_Vehicle Sumo	0.3642
ID_82_Vehicle Sumo	0.3642
ID_84_Vehicle Sumo	0.3643
ID_83_Vehicle Sumo	0.3649
ID_19_Soil	0.3803
ID_17_Soil	0.3823

Figure13. Validation with Field Observations.

It is found that target size vis-a-vis pixel size, a good contrast between target and background spectra is important in sub-pixel and mixed-pixel target detection applications.

Off-road Trafficability Assessment

Trafficability assessment in terms of going maps has utility for strategic planning. Many of the operational issues like effect of flooding, terrain dynamics, vehicle specific mobility, permitted number of vehicle passes in a terrain, etc., need to be addressed. The traditionally used cone penetrometer-based tool has limitation of point information, subjectivity and need to infer the results. The existing systems are improvised to provide on-board mobility guidance for movement both in snow and other terrains.

DGRE has designed and developed the system for On-the-Go measurement of terrain-vehicle interaction behaviour. Field tests were conducted for monitoring the response of developed system on varied terrain conditions.

Key Features

Snow and Terrain Mobility Evaluation Tool (STMET), On-board System for Torque measurement and its Geotagging (STAG), Single-wheel Trafficability Assessment Rig (STAR), Real Time Terrain Characterisation System (RTTCS), and 3-D LiDAR-based Rut Measurement System.

The specific subsystem of this system are as follows:

On-board System for Torque Measurement and its Geotagging (STAG)

Resistances faced by the vehicle on account of soil type, surface condition, slope, obstacles, meandering, etc. are negotiated by power/torque transmitted at wheel. Further, the torque required to steer the wheel is reflective of terrain condition. The torque transmitted at wheel and steering is measured using customised torque sensors duly geo-tagged to correlate with the terrain dynamics (Fig. 14).

Figure14. Different Components of STAR and their Assembly in Vehicle Platform.

Torque measurement and data logging system had been developed and tested in laboratories as well as at field and a new test method was developed to evaluate the dynamically varying terrain conditions.

Real-Time Terrain Characterisation System (RTTCS)

The resistance faced by any vehicle for negotiating a given terrain provide useful information about vehicle performance on any terrain. The precise measurement of Roll-Pitch-Yaw along with its geo-tagging is necessary to characterise and quantify the terrain resistances. System to assess terra-mechanical behaviour is therefore developed for measuring various resistances encountered by vehicle during its motion (Fig. 15).

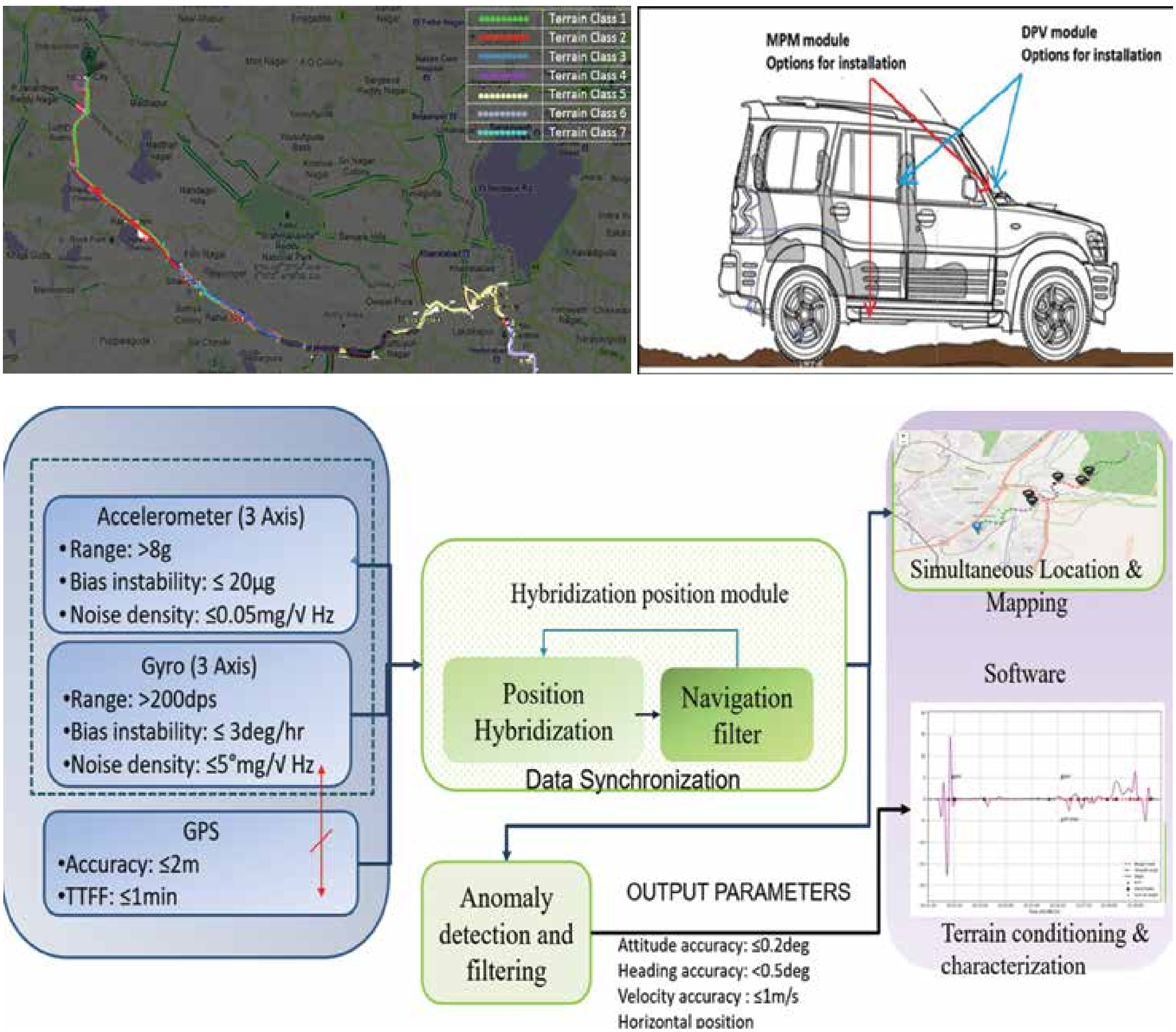


Figure15. Different Components of RTTCS Subsystem with Visualization Module for Near Real-Time Assessment of Terra-mechanical Behavior.

Key Features

the systems include H/W of INS-based motion parameter measurement unit, portable-compact data acquisition system. Real-Time GUI visualization with feature to display data in charts, graphs. maps assisted user interpretation. Terrain characterisation, ground resistances and data processing at high speed with visual streaming. Indigenous design of software and hardware interfaces.

GSM-based Integrated Avalanche Warning & Navigation System

To augment the safe mobility in avalanche prone regions (Fig. 16), a real-time information of avalanche and weather forecast, accurate marking of avalanche prone zones and mountain routes is required. To achieves this IAWNS series of systems are being developed.

Figure 16. Snow Avalanches in Indian Himalaya.

Mobile Application IAWNS-G and Server Application

A mobile android application "Integrated Avalanche Warning & Navigation System-GSM" was developed and tested for dissemination of avalanche and weather forecast using GSM mobile network. It also has a GIS interface which host and displays potential avalanche zones and safe routes to the user. It uses commercially available android mobile phones and GSM networks to utilize the functionality of the proposed system.

In this development activity, a GIS-based android application, Server software, and a GSM modem (Fig. 17) were developed and tested in avalanche-prone regions. This application runs in offline mode and only uses SMS protocol to exchange location, avalanche & weather forecast, and SOS request between mobile application and server software.

Features of IAWNS-G

- Continuous location reporting at server
- Daily weather and avalanche forecast from server
- Weather data from the application to server
- Automatic distress command (SOS) handling
- Real-time avalanche path warning

Figure17. Developed IAWNS-G Android Application Along with Server Software and GSM Modem.

Network Architecture

Developed system can be deployed using commercial mobile phone; it can be utilized by armed forces or paramilitary forces for non-critical areas and also by civilian users moving in avalanche prone snow bound regions. The utilization of system is limited by the availability of commercial mobile coverage in the region. However, it can still be utilized for offline navigation and avalanche area awareness in the areas with no or limited active mobile coverage (Fig. 18).

Trial Results: System was tested on Manali-Leh highway to check the efficacy of the mobile application and server software on move (Fig. 19).

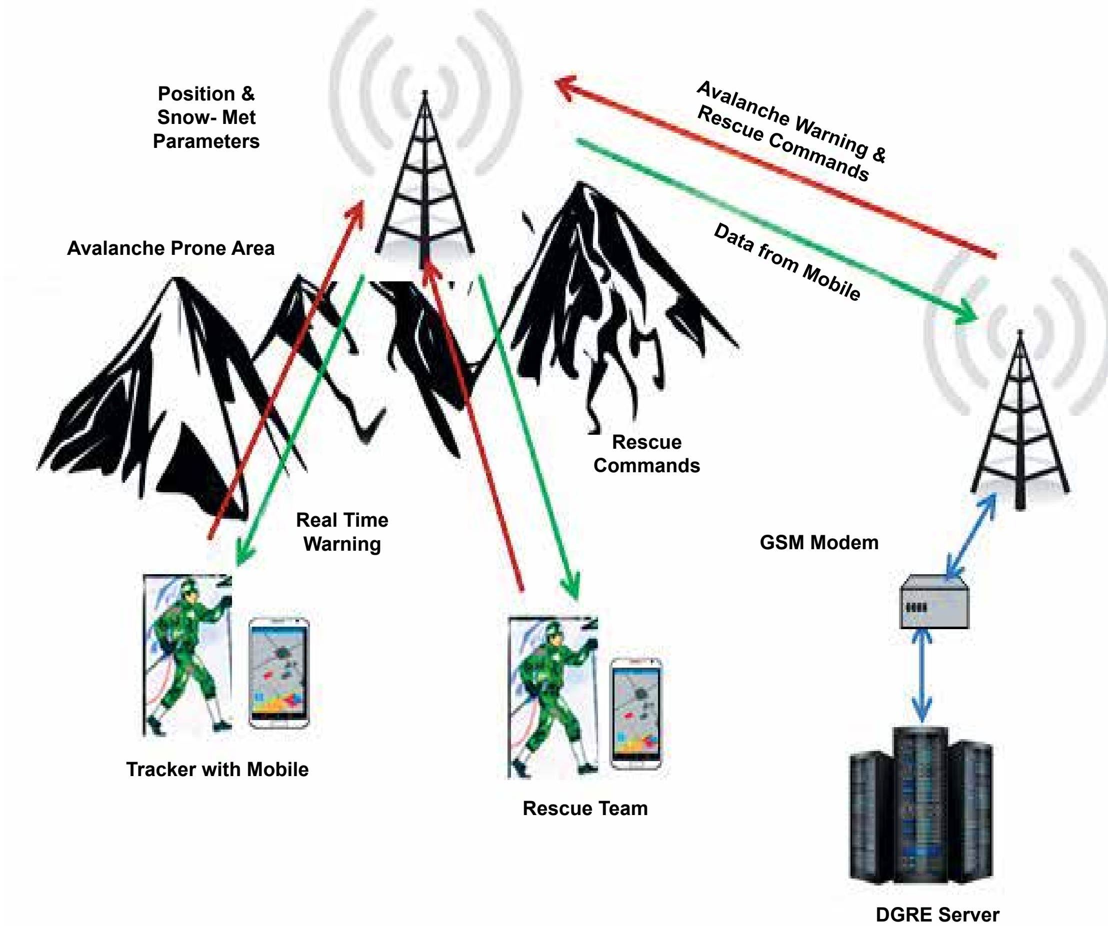


Figure18. Deployment Scenario of IAWNS-G.

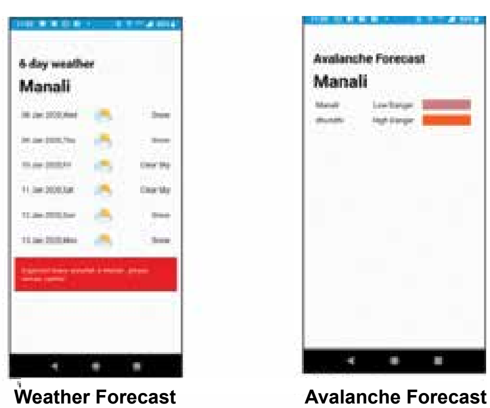


Figure19. Screenshots of IAWNS-G during Feasibility Trials.

Situational Awareness and Decision Support Tools

Situational Awareness and Decision Support Tools in Geographical Information System (GIS) are revolutionizing the geospatial data interpretation for efficient decisions making. The objective of the activity is to develop a prototype software framework for integrated visualization and analysis of multisource snow and avalanche information and to provide spatial decision support for avalanche hazard assessment through various geo-processing tools.

This application provides a platform for the different users and researchers for qualitative as well as quantitative analysis of the snow-covered avalanche-prone regions.

The key contribution of the present work is to identify and implement various data and models in this application and make them available to users on the web. It is a JavaScript and ArcGIS-based web-GIS application that allows the user to create, view, edit, and query snow and avalanche-related (GIS, remote sensing, and ancillary) data and geospatial models for avalanche hazard prediction. Multiple tools and technologies (ArcGIS Server, ArcGIS Desktop, Visual Studio, JavaScript, etc.) were used to develop the application.

These WebGIS based Situational Awareness and Decision Support platforms are developed by DGRE for various areas including Siachen, Drass, Kargil, Batalik and Sikkim (Fig. 20) and have following capabilities.

- High Resolution Satellite Imagery in a dynamic 3D environment
- Information Layers like road network, habitation, points of interest, geographic features like rivers, lakes, peaks, etc.
- Layers corresponding to Geo Hazards – e.g. Avalanche Sites, their detailed characteristics, Avalanche Flow Simulations, interaction with man-made structures, etc.
- GIS Analytics tools like measurements, viewshed analysis, buffer analysis, network analysis, terrain feature extraction, etc.
- Integration of data from various sources like daily avalanche forecast, weather forecast, live data from automatic weather stations and met observatories, and time-series satellite data.
- Decision support tools like generation of avalanche susceptibility maps, potential release areas for artificial triggering of avalanches, avalanche forecasting, etc.

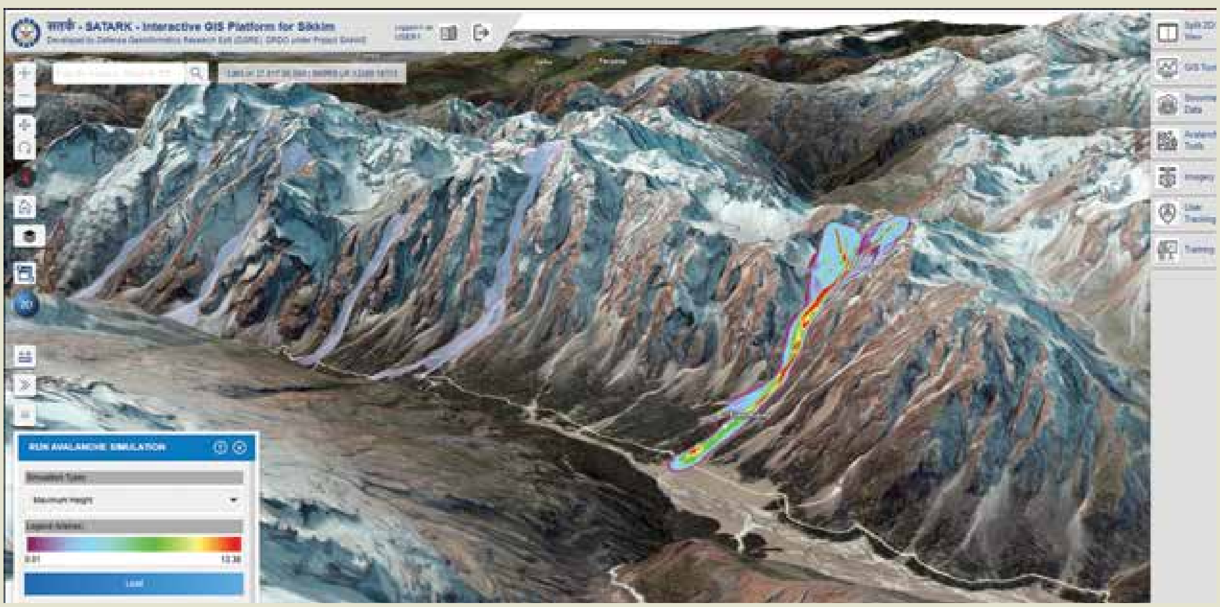


Figure20. Situational Awareness & Decision Support Platform 'Satark' developed for Sikkim.

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