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Identification of disturbed and undisturbed snow using optical satellite data

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Abstract- **In Himalaya during winter season, large region is covered by snow. Amount of snow influences the hydrological and climatological conditions of region and is responsible for avalanches which are destructive for life and property. For reducing the avalanches hazard, a accurate understanding of this phenomenon is required. Initiation of Avalanche depends on various parameters i.e. terrain, ground cover and meteorological conditions of the region. In avalanche-prone regions, it is necessary to alert the population about such events in advance to decrease the effects. Many regions of Indian Himalaya were affected by avalanches. In Himalaya, it is very difficult to collect the information of avalanche activity using manual methods due to the inaccessible terrain, harsh climatic conditions and vast region. Remote Sensing satellite data based techniques are found useful to collect the information of rugged and inaccessible areas. This paper presents the general overview of avalanche, techniques to identify the avalanche incidents or debris and the analysis of the past avalanche occurrence data of the world.**

Keywords: Avalanche occurrence, Himalaya, Optical Satellite data, Remote Sensing

I. INTRODUCTION

Snow avalanches are natural hazards and can cause loss of human life and damage to infrastructure such as buildings and roads. It is a mass of snow that moves rapidly down a steep mountain slope. In mountainous regions as winter progresses more and more snow deposits in consecutive layers. These layers may have different physical properties. An avalanche trigger when there is a failure in these layers [6]. When snow starts moving down below it moves through an avalanche path. Generally, an avalanche path can be divided into three zones, as shown in fig 1, with respect to slope angle.

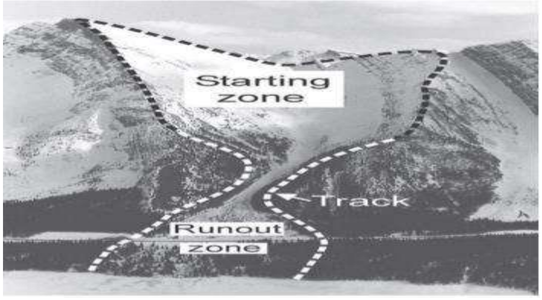

Fig 1. Avalanche path

(a) Starting or formation zone, with a slope angle of 30–50 degree, (b) track or middle or transition zone, with a slope angle of 15–30 degree and (c) run out zone, with a slope angle of less than 15 degree.

Basically, an avalanche begins at formation zone, attains a maximum speed at middle zone and comes to stop at run out zone by depositing the snow mass, that came down along with the avalanche [5]. Initiation of snow avalanches depends on different parameters i.e. terrain parameters (Slope, roughness, vegetation cover), snow pack parameters (existence of weak layers, bonding between layers, free water content and grain size) and meteorological conditions (wind, temperature, humidity) of the region and hence very difficult to forecast [18]. Formation of an avalanche mainly depends on the type of snow. Avalanches are mainly of two types: Loose snow avalanche and Slab avalanche as shown in fig 2.

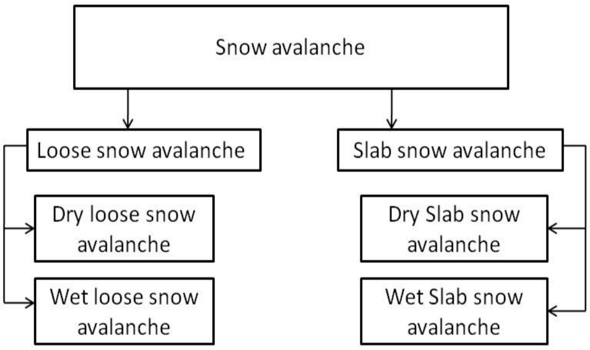

Fig 2 : Classification of Avalanche types

Loose snow avalanche starts at a single point on a slope and gathers cohesion less snow on the surface of the pack as it descends. The two most essential conditions for the formation of loose snow avalanches are (a) the snow is in weak cohesion, and (b) it is lying on a steep slope. When these two conditions are prevailing, a small crystal/particle of snow loses contact with its neighboring counterpart due to lack of cohesion and collects mass and momentum. As the particle run down with increased mass, it disturbs other crystals/particles which also start moving down with the already moving snow mass. The avalanche comes to stop as it reaches flat ground where its kinetic energy is converted into frictional energy [23].

Loose snow avalanche can be dry or wet snow avalanche. Dry loose snow avalanches trigger generally under cold relatively windless conditions in which both temperature and relatively calm wind conditions avoids the snow crystals to form tight bond between each other and responsible for random deposition on the ground.

Wet loose snow avalanche occur by heavy melt due to warming by sun or rainfall on the snow pack [10].Slab avalanche encloses a larger volume of snow and travel longer distances and originated by failure associated with thin weak layer at the depth in the snow cover, ultimately resulting in a block of snow in a shape of rectangle. Slab avalanches can be dry or wet slab avalanches. Dry slab avalanches trigger in the early part of winter and wet snow avalanches trigger in the later part of the winter [5].In avalanche forecasting, human experience is important not only to evaluate the state of the snow cover but also to support decisions and to avoid dangerous human biases and to make objective forecasts. Today, most fatal accidents in North America and Western Europe are due to people triggering the avalanches themselves [2].

In comparison to the other natural hazards, snow avalanche is a relatively less known due to the remoteness of the scene of catastrophe away in the mountains [3]. Between year 1995 to 2006, the largest number of accident occur in India, where in total, more than 565 people were killed [7].Snow avalanches occur during winter months in the Western and Central Himalaya and to some extent in Eastern Himalaya. The avalanche areas of India lay along the northern part of Himalaya consisting states of Jammu & Kashmir, Himachal Pradesh, Uttarakhand and Sikkim where 109 villages in Himachal Pradesh, 91 in Jammu & Kashmir and 16 in Uttarakhand get affected by avalanches throughout the winter season [4]. The largest number of accidents occurs on the Greater-Himalaya range, Pir Panjal range and in the Karakoram [3]. In only three states, Jammu and Kashmir, Himachal Pradesh and Uttarakhand there are 216 settlements and 11 major roads under avalanche slopes [11] and 46 % of avalanche occur due to heavy snowfall [3]. In Switzerland, 223 people died due to avalanches during past 10 years. In the European Alps, during the winter seasons of 1996/1997 to 2005/2006 avalanches caused approximately 1020 fatal causalities [9]. During winter, fatal avalanche accidents trigger in Canada where an average of 10- 15 people die every year [12]. Moreover, it is estimated that approximately 10% of Asia is affected by avalanche.

To limit the number of future fatalities, avalanche release information is necessary to secure life and property. There are various types of avalanche forecast models used by experienced avalanche experts. In 1969, Snow and Avalanche Study establishment was established in Manali, Himachal Pradesh to solve snow and avalanche related problems [10]. Now, remote sensing satellite data based techniques are found useful to collect the information of inaccessible and rugged areas including snow cover.

II. SATELLITE DATA USED for AVALANCHE STUDY

Numerous ground, air and space borne remote sensing data from optical, laser and radar sensors are used for monitoring of temporal and spatial snow cover and to detect the avalanche. A brief list of space borne SAR and optical sensors is provided in Table 1 and 2.

TABLE 1. PROPERTIES OF SPACE BORNE SAR SENSORS USED for AVALANCHE DETECTION

Space-borne SAR Sensor	**Swath width (Km)**	**Resolution (m)**	**Revisit time**
Radarsat-2U	20	3*3	1 day
Radarsat-2 SCW	500	100*100	1 day
Radarsat-2U SCN	300	50*50	1 day
Sentinel-1	250	20*20	12 days

TABLE II. PROPERTIES OF SPACE BORNE OPTICAL SENSORS USED for AVALANCHE DETECTION

Space-borne optical Sensor	**Swath width (Km)**	**Resolution (m)**	**Revisit time**
Sentinel-2A & 2B	290	10*10 (Red, Green, Blue, NIR)	5 days
Landsat -8	185	15*15 (Panchromatic Band)	16 days
Quick Bird	16.5 / 18	0.6 (Panchromatic Band)	1-3.5 days

III. TECHNIQUES for SNOW AVALANCHE DETECTION

In recent past, numerous techniques have been used to detect the avalanches. Previous research regarding automatic detection of avalanche deposit have been carried by [13] with the help of VHR (very high resolution) optical data collected by ADS40 instrument for a test site at Davos in Switzerland. Due to its high spatial and radiometric resolution, the sensor is able to detect small variations within snow cover even in shadowed regions and therefore has great potential for the detection of avalanche deposits.

Auxiliary data was used to exclude regions where avalanches were not occur. Numerical simulation tool RAMMS (Rapid Mass Movement Simulation) was used to exclude slopes >35° from the runout calculation, as it was assumed that these slopes could not accumulate snow-avalanche debris. Spectral thresholds was also used to exclude snow-free areas. The applicability ADS40 instrument is restricted by a) weather conditions and b) mis-classifications due to other rough surfaces i.e artificial snow piles, wind modelled snowpack and sparsely vegetated area. The space borne SAR-Sensors (Sentinel-1,Radarsat-2), acquiring data with a spatial resolution of close to one meter, overcome the limitations imposed by weather conditions. But, its operational usage are limited because of uncertain data availability, high acquisition costs, small ground swaths and long repeat passes.

Lato et al. [15] applied object based image analysis techniques to map avalanche debris on space borne imagery from the Quick Bird satellite, over Western Norway and on airborne platform from Leica ADS40-SH52 imaging unit, over Davos, South-eastern Switzerland. Each image was run through a sequential segmentation and classification workflow to distinguish snow avalanche from trees, rocks etc. Recently, researchers have used gray-level co-occurrence matrix (GLCM) and directional filters techniques followed by feature extraction and classifications stages to detect the avalanche with the help of optical satellite data [14].

Malnes et al [17] collected two Radarsat-2 Ultrafine Mode (RS-2 U), C-band images with 3 × 3 m spatial resolution and 20 × 20 km ground swath, after large, catastrophic avalanches occur in the beginning of April 2013 in Northern Norway. The avalanches were identified in the RS-2 U images due to a high backscatter contrast between avalanche debris and the surrounding snow in the order of 1.5–2.3 dB.Radarsat-2 scenes with pixel resolution 3m were obviously best suited for avalanche debris detection. However, RS-2 Scenes are costly, availability is not consistent and the swath is small. Eckerstorfer et al. [19] and Eckerstorfer and Malnes [20] acquired 12 RS-2 U images during an avalanche cycle in March 2014 in the county of Troms, Northern Norway. Small sized avalanche debris was manually detected based on high backscatter contrast between avalanche debris and surrounding, undisturbed snowpack. The problems of poor temporal availability and high acquisition costs are largely solved by data from the Sentinel-1A (S1A).S1A provides freely available C-band SAR data with a spatial resolution of 10 × 10 m and a swath of 250 × 150 km with a repeat time of 12 days. . Malnes et al. [21] showed for the first time, that medium sized avalanche debris are detectable in S1A images. Vickers et al [24] applied K-means clustering algorithm on Tamokdalen areas in Troms using Sentinel -1 images which segment data into avalanche and non avalanche areas. In comparison to the very high-resolution RS-2 U image, the avalanches are more difficult to distinguish visually. While Eckerstorfer and Malnes [21] covered with 12 RS-2 U images only 12% of the county of Troms, a single S1A image covers the entire county completely within such a S1A image ground swath.

The problems of poor temporal availability and high acquisition costs are solved by data from Sentinel-2. Sentinel-2A is a European optical imaging satellite launched 23 June, 2015 and Sentinel-2B was launched on 7 March 2017. Sentinel-2 satellites deliver high-resolution optical images globally. It has visible, near infrared and shortwave infrared sensors comprising 13 spectral bands at 10 m, 20 m, and 60 m spatial resolutions, with a swath width of 290 km with revisit time 5 days.

IV. PREVIOUS WORK

Robert M. Haralick et al. [1] reported some easily computable textural features based on gray tone spatial dependencies and applied these textures on three different kinds of data sets: photomicrographs, aerial photographs, and high altitude satellite picture of earth. In each experiment the data set was divided into two parts, a training set and a test set. Test set identification accuracy is 89 percent for the photomicrographs, 82 percent for the aerial photographic imagery and 83 percent for the satellite imagery.

M. M. Mokji et al. [8] proposed a new computation for GLCM which is based on Haar wavelet transform to reduce the computation burden of the original GLCM computation. It is seen that it reduced the computational burden in terms of pixel entries up to 62.5%.

Siri Øyen Larsen et al. [14] reported the detection of avalanche is possible with the help of high resolution optical satellite data by using two texture segmentation method: GLCM, directional filters. To further enhance the performance, process the mapped avalanche objects in feature extraction and classifications stages by reducing the number of false detections. The segmentation results indicates that GLCM approach unable to separate the sparse tree from avalanches but extract the boundaries better than directional filters.

P. Mohanaiah et al. [16] presents an application of GLCM to extract second order statistical texture features for motion estimation of images. The Four features namely, Angular Second Moment, Correlation, Inverse Difference Moment, and Entropy are computed. The results show that these texture features have high discrimination accuracy, requires less computation time and hence efficiently used for real time Pattern recognition applications.

Markus Eckerstorferet al. [19] presents that the use of multi temporal and multi-sensor, satellite-borne SAR remote sensing can map the avalanche activity based on backscatter differences. RS-2 U scenes with a pixel resolution of 3 m were best suited for avalanche debris detection. However, RS-2 U scenes are costly and the swath is small. But, freely available LS-8 scenes with a pixel resolution of 15 m were usable for avalanche debris detection. The swath of a LS-8 scene is large, but, cloud cover and shadows are a problem. The Sentinel-1 satellite(s) deliver high-resolution SAR data, with a large swath (250km) and a short repeat time

Markus Eckerstorfer et al. [22] discussed avalanche detection using ground based, air-and space borne remote sensing data from optical, laser and radar sensors and also discuss opportunities and limitations and applicability of these instruments and techniques.

H. Vickers et al. [24] proposed the operational monitoring of avalanche occurrence has first become possible through the launch of the Sentinel-1A and 1B Synthetic Aperture Radar (SAR) satellites that provide near-daily coverage of the area surrounding Troms. A test version for an automatic avalanche forecasting algorithm was developed, based on change detection and K-means classification methods and tested on the Tamokdalen area in Troms using Sentinel-1A images at 20 m resolution. Results indicate that a correct detection rate of over 60% can be achieved.

V. CONCLUSION

The snow conditions in the Himalaya are complex and require continuous monitoring of snow and meteorological parameters. The problems of avalanches, their prediction and control in the Himalayas have assumed great relevance and importance not only for the Army but also for the progress of the Himalayan States. In Himalaya, it is very difficult to collect the information of avalanche activity using manual methods due to the inaccessible terrain, harsh climatic conditions and vast region. Now, remote sensing satellite data based techniques are found useful to collect the information of rugged and inaccessible areas including snow cover. Remote sensors provides data with high spatial and temporal resolution. Radar as well as optical data can be used to detect the avalanches. However, operational usage of Radar data is limited because of high acquisition costs, small ground swath and uncertain data availability. A large number of high-resolution, large swath and free, optical satellite data has become available. However, the trade off for the high spatial resolution is small swath width. Recently launched, Sentinel-2 combines high spatial resolution with large swath, data is free and has high revisit time. These factors point towards its high potential for avalanche detectability.

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