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(NCHG-2014)

30-31 October, 2014

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Abstract Volume

ORGANISED & HOSTED BY

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&

H.P. State Centre on Climate Change

(State Council for Science Technology & Environment) Shimla, H.P.

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NATIONAL CONFERENCE
ON
HIMALAYAN GLACIOLOGY
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AT
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HIMACHAL PRADESH, INDIA.

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STATE CENTRE ON CLIMATE CHANGE

SCIENCE AND ENGINEERING RESEARCH BOARD,
(DEPARTMENT OF SCIENCE & TECHNOLOGY)
GOVERNMENT OF INDIA, NEW DELHI
&
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Technical Session – I

Monitoring, Mapping and Inventory of Himalayan Glaciers

1. Role of Space Based Inputs for Monitoring the Himalayan Cryosphere

A.S. Rajawat[1], I.M. Bahuguna[1], A.K. Sharma[1], S.K. Singh[1], B.P. Rathore[1], Ritesh Agrawal[1], Manab Chakraborty[1] and Ajai[1]

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Himalayan mountain system extending NW-SE for about 2400 km in northern parts of the Indian landmass contains the largest area of frozen water outside the Polar Regions. Himalayan cryosphere consists of snowpack and glaciers occurring in the Himalayan mountain system and plays an important role as a sensitive indicator of climate changes as well on Indian monsoon. Melt water from Himalayan region is required for irrigation, generation of hydropower, fulfilling the domestic water requirements and in particular sustainability of bio-diversity and environment. Monitoring of Himalayan snow and glaciers is also important in view of associated natural hazards and consequent disasters. Monitoring and mapping of these natural frozen fresh water resources is required using space based measurements as conventional field based surveys require enormous efforts due to rugged terrain and extreme weather conditions. This presentation highlights salient results of utilizing space based techniques in monitoring the Himalayan Cryosphere and future plans.

Himalayan snow cover monitoring is being carried out for time frame 2004-14 using AWiFS data (every 5 days) of Resourcesat-1 and 2 satellites for the months starting from October of one year to June of consecutive year. An algorithm based on Normalised Difference Snow Index (NDSI) has been developed and is implemented for 35 Sub-basins of the Ganga, the Satluj, the Chenab, the Indus, the Tista & the Brahmaputra river basins. The outputs include 5 and 10 daily sub-basin wise snow cover maps, statistics and depletion curves for around 2835 snow cover products/year and compiled as 7 Atlases/Year. The data is used to analyze the snow accumulation and ablation patterns in different parts of Himalayan region and as input to snow melt forecast models.

Glaciers of entire Indian Himalayan region and those outside Indian territory but feeding rivers in India have been mapped on 1: 50,000 scale using recent images of Indian Remote Sensing Satellite for the first time in the country in a GIS environment. The GIS database contains 37 parameters as per the UNESCO/TTS format and 11 additional parameters as attribute information. The study has shown that there are 34919 glaciers covered in 1275 map sheets on 1:50, 000 scale. Around 2018 glaciers for time frame 2000-2010 have been monitored using multidate satellite data and the analysis show that 87 % of the glaciers are showing no change, 12 % are retreating and 1 % glaciers have advanced during the period 2000-2010. Positive mass balance is indicated for ~ 81 % of glaciers of 10 sub-sub-basins for the year 2010 and 2011 based on monitoring of snow line at the end of ablation season and Accumulation Area Ratio approach.

Several glacial expeditions have been organized and the activities carried out include glacial snout validation using GPS/DGPS, in-situ measurements of spectral properties of snow and glaciers using spectro-radiometers, glacial features identification, glacier thickness estimation using GPR, surface roughness measurements using profilometers, collection of other data such as temperature, humidity, wind, establishment of AWS and glacial lab near Chota Shigri glacier.

An attempt has been made to quantify the seasonal variability in the integrated water storage in Himalayan river basins using GRACE data for time frame 2003-2012. The preliminary finding suggest that the annual decrease in water storage in terms of equivalent water thickness for the Ganga and Brahamputra basins are -1.28 cm and -1.06 cm, whereas the Indus basin shows change of -0.07 cm.

Preliminary analysis of ICESat/GLAS laser altimetry data for Gangotri glacier in Ganga basin and Siachen, Baltoro and Drenmarg glaciers in Indus basin has been carried out and elevation changes during October 2003 to October 2009 have been measured using similar seasonal conditions and near-repeat track projection approach with the help of reference DEM. The mean elevation change computed over tracks of the Gangotri Glacier in Ganga Basin is +0.24 meters/year. While in Indus Basin, the mean rate of ice thickness change estimated for Siachen, Baltoro and Drenmarg glacier are +0.02 m/yr, +0.44 m/yr and -1.02 m/yr respectively.

Some of the ongoing and future plans to understand Himalayan Cryosphere include applications of RISAT/INSAT-3D/GISAT data for snow and glacier studies, development of Himalayan Glacier Information System (HGIS), modeling for Glacier Health Assessment, effect of carbon soot and contamination on snow and glacier ice, developing energy balance approach for snow and glacier melt, development of algorithm for auto extraction of debris cover, glacier mapping and monitoring on 1:10, 000 scale using high resolution satellite data, improvements in glacier mass balance estimation using satellite derived gravity, geodetic and AAR approach, use of SAR Interferometry & Photogrammetry in glacier flow determination and glacier mass balance, utilisation of hyperspectral data for snow cover/glacier studies and vulnerability and risk analysis of geo-hazards in Himalayan Region.

2. Inventory of Glaciers in Indus, Ganga and Brahmaputra Basins of the Himalaya

A. K. Sharma[1], S. K. Singh[1], Ajai[1], A.S. Rajawat[1] and Manab Chakraborty[1]
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The Resourcesat-1 satellite data of 2004–2007 period has been used to generate systematic glacier inventory on 1:50,000 scale of all the glaciers in the Indus, Ganga and the Brahmaputra basins contributing to Rivers in the Indian region. The study area encompassing the Himalayas, Transhimalaya and Karakoram regions and covering parts of India, Nepal, Bhutan, and Tibet /China is inventoried. Later the inventory has been extended to the remaining glacier of Indus basin falling in Pakistan and Afghanistan region. The data from Resourcesat-1 satellite of 2007–2010 period has been used in the extended region. The UNESCOTTS guidelines have been followed to create glacier inventory. Spatial data base in GIS environment is created for all glaciers by using modified global inventory standards and updated procedures. The inventory data is organised for easy understanding of glacier inventory data and characteristics of the glacial systems at sub-basin level. The inventory data for 55 sub-basins covering 34919 numbers of glaciers and 75779 km^2 glaciated area have been created in GIS environment.

The glacier features like accumulation area, Ablation area (both Ice exposed and debris covered), supra-glacier moraines, snow line, ice divide and the snout position are delineated based on on-screen interpretation of multi-date satellite data. The de-glaciated valley and associated moraine features are also delineated. The supra glacier lake and peri-glacial lakes at snout locations are also delineated. The decision on permanent snow fields and position of transient snow line is taken based on the two sets of consecutive year satellite data. It is observed that about 20 to 26 percent of the Himalayan glaciers are debris covered. The mean size of glaciers is larger in Ganga Basin as compared to the Indus and Brahmaputra Basins. Indus basin has more no of smaller glaciers as compared to other two basins. The number and area of glacial lakes both supra glacial and peri-glacial lakes are higher in Brahmaputra basin as compared to the other two basins.

This paper describes the satellite data based approach in preparing the glacier inventory map and data sheet. The highlights of the inventory results and some of the major issues in generating glacier inventory have are also discussed.

Keywords: Glacier inventory, Himalayas, Indus basin, Ganga basin, Brahmaputra basin, Remote sensing, GIS, glacier inventory map, Glacier Inventory data-sheet.

3. Himalaya - Karakoram Glaciers Monitoring from Space

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The Himalaya has one of the largest concentrations of glaciers outside the Polar Regions, hence called as “Third Pole”. The melt water discharge from Himalayan glaciers is of interest for several reasons (e.g. irrigation and hydropower generation). For water resources planning and management in northern India, it is essential to study the Himalayan glaciers. Field based glaciological work is highly recommended but time and capital intensive as well as involves enormous risks in remote and rugged mountainous areas. Multi-spectral and multi-temporal remote sensing data can be used to monitor several glaciers simultaneously. Therefore, satellite images and digital elevation models (DEMs) were used to map clean-ice, debris-covered ice and planimetric and volumetric glacier changes in Himalaya - Karakoram (H-K) region. A semi-automated mapping method for the debris-covered glaciers of the Garhwal Himalaya based on an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM and thermal data were developed. A detailed inventory for surging glaciers in Karakoram was completed and surge dynamics was also examined using spatial and temporal observations from DEM differencing and time series of surface velocities from satellite images.

The analysis provides a hint that the overall glacier area of Shyok valley slightly decreased until about 1989 (area 1973: 1613.6±43.6 km^2; area 1989: 1602.0±33.6 km^2) followed by an increase (area 2002: 1609.7±51.5 km^2; area 2011: 1615.8±35.5 km^2). Although the overall change in area is insignificant, advances in glacier tongues since the end of the 1980s are clearly visible. Detailed estimations of length changes for individual glaciers since the 1970s and for Central Rimo Glacier since the 1930s confirm the irregular retreat and advance. Conversely, Glacier area decreased from 599.9±15.6 km^2 (1968) to 572.5±18.0 km^2 (2006), a loss of 4.6±2.8% in Garhwal Himalaya. Glaciers in the Saraswati/Alaknanda basin and upper Bhagirathi basin lost 18.4±9.0 km^2 (5.7±2.7%) and 9.0±7.7 km^2 (3.3±2.8%), respectively, from 1968 to 2006. This suggests that glaciers in the Karakoram show long-term irregular behaviour with comparatively frequent and sudden advances as compared to central and eastern Himalayan glaciers. The database of DEM differencing and time series of surface velocities in the present research will facilitate to understand surge dynamics.

4. Debris Cover Glacier Inventorying Using Integrated Optical & Thermal Satellite Data in Parts of Ladakh Himalayas

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Automatic mapping and inventorying of glaciers is severely hampered by the presence of debris cover on the glacier's boundary. Debris cover on glaciers has a similar VIS/NIR spectral signature to the surrounding moraines due to similar reflectance at these wavelengths and spectral information alone is insufficient for mapping the debris covered glaciers. Thus thermal data in addition to optical data must be incorporated in the mapping of debris covered glaciers as considerable temperature differences are found to exist between supraglacial debris and periglacial debris. The present study aims at showing the potential of integrated multispectral data, thermal remote sensing data and geomorphometric parameters (slope and aspect) for mapping the major glacier components; derivation of the debris-covered glacier boundary, and finally preparing the glacier inventorying of the study area in Zanskar Valley, Ladakh Himalayas. In this study, ASTER image has been used due to its relatively high spatial resolution (30m) for glacier inventorying. The 14-band dataset so formed has been divided into shaded and illuminated regions and finally classification has been performed for both the groups separately into eight glacier terrain classes namely snow, water, mixed-ice debris, periglacial debris, supraglacial debris, mountain shadow, vegetation and valley rock. The maps so generated have been assessed for accuracy using reference data containing 500 pixels using stratified random sampling technique (derived from ASTER image, 15m spatial resolution). Accuracy result was found 81.84% with Kappa Coefficient of about 0.7815. Results also revealed that the debris was mainly found side by side of the ablation zone and on the glacier snouts, this clearly distinguished on the basis of temperature curves obtained from the TIR region of the ASTER sensor.
Keywords: ASTER, SGD, PGD, Illuminated image, Shaded image.

5. Moraine Dammed Lakes Inventory Using IRS LISS III Satellite Data in Satluj, Ravi, Chenab and Beas Basins of Himachal Pradesh, Western Himalaya, India

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Scientific insight gained from the analysis of multi spectral satellite images suggests that spatial extent of majority of glaciers is changing very fast leading to the formation of moraine dammed lakes. Formation of such lakes is posing potential threat to the infrastructure and human life thriving in the downstream areas of many drainage systems of the Himachal Pradesh State. Various studies carried out on this vital issue of climate change reveals that there is an alarming increase in numbers and size of the lakes observed over a period of time making vulnerable towards the potential risks of lakes outburst. The present study has been carried out using LISS III satellite data for the year 2013. The mapping has been carried out using remote sensing in the glaciated regions of Chenab, Beas, Ravi and Satluj basins of Himachal Pradesh for the delineation of all such lakes. A basin wise inventory of moraine dammed glacial lakes has been generated which forms the base line data for future monitoring as far as disaster preparedness in the state. Based on the studies, it is suggested that regular monitoring of all such moraine dammed lakes must be carried out to meet out any eventuality at the pre disaster level.

The analysis for the delineated glacial lakes in the Satluj basin reveals the presence of 391 lakes out of which 275 are of smaller dimensions (i.e. with area less than 5 hectare), 75 lakes with area between 5-10 hectare and 40 lakes with area more than 10 hectare. Likewise in Chenab basin (Chandra, Bhaga, Miyar) a total of 116 lakes have been identified which is almost double than the lakes which were identified earlier (55) using 2001 satellite data (Randhawa et al., 2005). In Chenab basin, maximum lakes (105) are less than 5 hectare, while 8 lakes are between 5-10 hectare and only 3 lakes are more than 10 hectare in area. In Beas basin(Jiwa, Parbati), total 67 lakes have been observed where 63 lakes are having area less than 5 hectare while 2 lakes with area between 5-10 hectare and only 2 lakes with area more than 10 hectare. In the upper part of the Beas basin, information could not be retrieved due to cloudy data. Likewise in Ravi basin, out of 22 lakes, 02 lakes are having area more than 10 hectare, only 01 lake is having area between 5-10 hectare and 19 lakes are with area less than 5 hectare.

Thus from the above analysis, it is inferred that formation of such lakes in the Higher Himalayan region reveals an increasing trend in number as well as size. The analysis further reveals that the higher number of smaller lake (area less than 5 hectare) is indicative of pronounced effect of the climatic variations on the glaciers of the Himalayan region that results in the formation of small lakes in front of the glacier snouts due to the damming of the morainic material. The recent tragedy of year 2013 in the Uttrakhand Himalaya has also been attributed to the bursting of a moraine dammed lake having a total area of about 08 hectare in front of the snout of the Chorabari glaciers that caused widespread damage and loss of life and property in the downstream areas in Bagirahi and Alakhnanda sub basins of Garhwal Himalayas (Dobhal et al., 2013). In view of the same, it can be inferred from the present study that the lakes with area >10 hectare and the lakes with area between 5-10 hectare are potentially vulnerable towards the glacial lake outburst flood (GLOF) either under high melting of glaciers or under heavy rainfall in the region. A regular monitoring of such lakes is

essential in order to avoid any eventuality that can happen due to their continued enlargement.

Key words: Himalayas, Glaciers, Moraine-dammed Lake, Remote sensing, Climate change

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6. Dynamics of the Gangotri Group of Glaciers Using SAR Offset-Tracking Methods

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I have analyzed Synthetic Aperture Radar data of two decades to elucidate the spatiotemporal dynamics of the Gangotri glacier region to measure displacement during a given time interval across the entire image region. Using time series analysis I estimated the seasonal variation in glacier flow rates and also the flow rate in specified sets of intervals based on the observed 3-dimensional velocity maps. For the Gangotri glacier, this analysis has revealed a significant increase in the surface velocity during summer months as compared to a background velocity during winter months. This annual variability in the velocity is expected in most glaciers but when the magnitude of change is significantly higher, e.g. above ~40 %, this signature may be interpreted as possible glacier surge activity and/or basal slip. These observations represent the first large-scale characterization of the spatiotemporal glacier dynamics in the Gangotri region.

7. Utilization of Optical & Microwave Satellite Records for Monitoring Gangotri Glacier, Central Himalaya, India, During Past 50 Years (1962-2012)

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Remote sensing techniques that have found applications in the field of glaciology can be categorized into two broad categories viz. Optical and Microwave. In optical remote sensing, imagery acquired in the visible and near infrared spectrum and from the high albedo of snow, makes it particularly easy to recognize. As optical imagery is confined only to daylight and cloud free conditions, can prove a major limitation. However, in microwave remote Sensing, radar imagery is invaluable due to microwave's ability to penetrate the cloud cover and its deployment especially for studying the Cryosphere that are frequently

obstructed by clouds plays a vital role. An attempt has been made towards utilization of optical and microwave satellite data for estimation of longitudinal retreat of terminus and vacated frontal area by Gangotri Glacier (30°43'22"N-30°55'49"N; 79°04'41"E-79°16'34"E), Central Himalaya during past 50 years (1962-2012). Glacier terminus and frontal area in 1962, derived using Survey of India Topographical map and fluctuations in terminus position and vacated frontal area were demarcated using Landsat Multispectral Scanner (1980), IRS P6 LISS III (2004) and TerraSAR-X (2008 & 2012) data. For identification of glacier terminus altitude in 1962 and 2012, generation of toposheet DEM (1962) and TanDEM-X DEM (2012) were also performed. An important feature of TanDEM-X data systems is their precise measurement of distances, which has been successfully used for the generation of DEMs using InSAR technique and demarcation of terminus altitude of Gangotri Glacier. Results indicate that estimated longitudinal retreat in terminus was ~1937.96 ± 17.90 m with mean retreat rate of 38.60 m a^{-1}. However, frontal area vacated by Gangotri Glacier from 1962 to 2012 was 1.48 ± 0.57 km^2 with mean rate of retreat 280.43 m^2 a^{-1}. In addition, altitude of glacier terminus during 1962 was identified at 3850 m asl whereas in 2012, it was marked at 4097 m asl, showing upliftment of 247 m. However, on the basis of 50 years of terminus monitoring, it has been observed that maximum recession expectedly has taken place along the centerline, followed by the eastern portion of the terminus. The western part of the terminus is retreating at a significantly lower rate. Our study suggested that the high resolution TerraSAR-X microwave data (up to 1 m spatial resolution) and TanDEM-X microwave data found to be very applicable in identifying and delineating the terminus of Gangotri Glacier which is suggesting that the Gangotri Glacier has undergone continuous longitudinal recession and terminus fluctuation during past 50 years.

Keywords: Himalaya, Glacier, Retreat, Optical and Microwave satellite data.

8. Glacier Ice Velocity Calculation Using Advanced Remote Sensing Techniques

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The surface ice velocity has a major impact on the health and fate of the glacier. Measurement of ice velocity can help in modeling the glacier dynamics. This article presents sub-pixel image correlation technique (COSI-Corr) for calculating ice velocity of Gangotri glacier from ASTER data.

It is difficult to obtain sufficient ice velocity data with conventional glaciological techniques (field measurements) due to the frequent loss of stakes and difficulty in the handling of measuring instruments at the site. A number of researchers have also used SAR interferometry/speckle tracking to map glacier ice velocities. However, it has been reported that SAR based works have limitations in highly rugged terrains like the Himalayas and especially for fast-moving glaciers like Gangotri glacier. The literature suggests that optical image based correlation techniques appear to be more successful and robust matching method

than SAR interferometry for the measurement of glacier ice velocity in Himalayan terrain, and therefore, the former is the focus in this study.

The principle involved in this technique is that two images acquired at different times are correlated to find out the shift in position of any moving object, which is then treated as displacement in this time interval. Though it has been used to measure ground deformation but it has been suggested that the proposed technique would also allow for the measurement of surface displacements due to ice-flow or geomorphic processes, or for any other change detection application. The algorithm works in four fundamental steps: In the first step each pixel from the satellite focal plane is projected onto a ground reference system. This operation utilizes knowledge from both the imaging systems and the ground topography. The second step involves optimizing the satellite viewing parameters with respect to some reference frame. The third step involves resampling of the acquired images with the previously calculated parameters. This yields ground-projected images, called orthorectified images. Then in the the fourth step, image correlation is run to calculate surface ice velocities. This algorithm has now been implemented in a software package, Co-registration of Optically Sensed Images and Correlation (COSI-Corr), developed with Interactive Data Language (IDL) and integrated under ENVI. The described approach allows for the correction of offsets due to attitude effects and sensor distortions, as well as elevation errors. This methodology is thus well suited to generate accurate, low-cost glacier-ice velocity data of remote regions like Himalayan glaciers where ground instrumentation is difficult to implement and terrain conditions are inhospitable.

9. Mapping Glacier Extents and Dynamics in Alpine Kashmir Himalayas using Remote Sensing

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Glaciers are typical elements of the mountain cryosphere, their variations are considered as reliable and easily understandable, natural indicator of climate change in areas where climate stations are rare or nonexistent. Glaciers are valuable sources of fresh water which sustain life and provide water for drinking, irrigation, hydropower generation, etc and play a very important role in the hydrological setup. Therefore, mapping and monitoring of the glaciers and thier dynamics is very important. This paper discusses an integrated approach of remote sensing and GIS combined with field survey adopted for glacier mapping and measuring parameters like, area, Equilibrium Line Altitude (ELA), Accumulation Area Ration (AAR), snout position changes, glacier volume, and mass balance.Various digital image processing techniques were used to derive information about these parameters,. The appropriate ratios of image bands were used to enhance various glacier features which were then mapped with quite high accuracy. A total of ten bench mark glaciers from Lidder valley in Kashmir Himalayas were studied in this research using satellite data from various sensors; LANDSAT(1979, 1992, 2001, 2013), LISS (2010). A total of 4.19km^2 of glacial area was lost from 1992 to 2013, out of which 0.19$km^2$from glaciers with less than 1km^2, 0.45km^2 from glaciers having area between 1 and 5km^2 and 0.79km^2 loss from glaciers having extents more than 10km^2. The average AAR of the glaciers with less than 1km^2 is 0.65 km^2, 0.63 for

glaciers between 1 and 5 km^2 while as $0.75km^2$ for glaciers more than 10 km^2 extent. AAR decrease ranges from $0.07\text{-}2.8km^2$. ELA change ranges from 30- 190m from year 1992 to 2013. Snout change ranges from 95-450m from 1992 to 2013. The estimated volume loss ranges from $0.01\text{-}0.21km^3$ from 1992 to 2013. The mass balance of the benchmark glaciers was estimated using AAR method. Most of the glaciers were showing the negative mass balance. Most of the glaciers in watershed are small except Kolahoi and Sheshram glaciers. Kolahoi glacier has shown a retreat of $2.20km^2$ from $14.1km^2$ in 1979 to $11.9km^2$ in 2013, with decrease in AAR of $0.14km^2$ from $0.77km^2$ in 1979 to $0.63km^2$ in 2013. Snout has shifted up by 380m from 1979 to 2013. While as the ELA has shifted up 150m from 1979 to 2013. Kolahoi glacier also experienced negative mass balance over 1979–2013, the mass balance has decreased from 67.07cm in the year 1979 to 33.02cm in 2013. The volume of the glacier has decreased from $1.81km^3$ in 1979 to $1.50km^3$ in 2013. Satellite data provides a useful means to map glacier boundaries and dynamics in remote regions that are difficult to access for topographical reasons.

Keywords: Remote Sensing, Glacier dynamics, ELA, AAR

10. Estimation of Ice Thickness using Surface Velocities and Slope: Case Study at the Samudra Tapu Glacier, India

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Volume of glacier stored water is an important parameter to assess the glacier's health and sustainability. In this investigation, we estimate the distribution of ice thickness of Samudra Tapu Glacier in Chandra Basin, Himalayas, using surface velocities and slope. Surface velocities over Samudra Tapu Glacier were estimated using sub-pixel correlation of ETM+ imagery for the years 2001 and 2002. The velocities range from 70-90 m a^{-1} in the accumulation region to 10-15 m a^{-1} near the snout region respectively. Ice thickness was then estimated using the equation of laminar flow of ice. It varied from 344 m in the upper reaches to 30 m near the snout. The volume of the glacier was estimated to be 11.06 ± 5.6 km^3.

Keywords: Samudra Tapu, Surface Velocity, Ice Thickness, Volume

11. Estimation of Ice Thickness Variations in the Himalayan Glaciers Using GLAS Data

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Glaciers are among the best indicators of terrestrial climate change, contribute importantly to water resources in many mountainous regions and in that respect glacier elevation change can also be used as climate indication. Himalayas have the highest concentration of glaciers outside the polar region and most important natural resources of water in frozen form. Himalayan glaciers also act as sensitive indicators of climate change.

In this paper, an attempt has been made to explore the potential of GLAS data along with a reference DEM to find out change in glacier ice thickness for three glaciers in Indus basin. This estimation has been done for the period between October 2003 and October 2009 using ICESat/GLAS laser altimetry data and CartoDEM. Until now, ICESat data has been, mainly, used in Antarctica and Greenland to find the changes in ice sheets. Here, ICESat laser altimetry proved to be a highly valuable dataset for computing regional scale elevation changes for smaller glaciers with mountainous topography. Similar seasonal conditions of the ICESat/GLAS data has been taken for analysis. Near-repeat track projection approach along with the help of reference DEM has been used for estimating variation in glacier thickness. In Indus Basin, the mean rate of ice thickness change estimated for Siachen, Baltoro and Drenmarg glacier are +0.02 m/yr, +0.44 m/yr and -1.02 m/yr respectively. The study also shows an applicability of the future ICESat mission.

Keywords: GLAS, ICESat, Himalayas, glacier thickness

12. Knowledge Based Classification for Debris Cover Glacier Mapping - A Case Study of Chhota-Shigri Glacier

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Mapping of debris-covered glacier boundaries using remote sensing technique is restricted by the presence of supraglacial debris since it has similar spectral properties than that of periglacial debris. However, earlier studies have suggested that the temperature differences between the supraglacial and periglacial debris and/or geo-morphometric parameters can be used to map the extent of these two classes. Several automated and semi-automated approaches have been developed for the mapping of debris-covered glacial boundaries utilizing thermal information and/or geo-morphometric parameters. Most of the techniques utilizing multisource datasets uses semi-automated method of classification which are time consuming. In this article, a novel hybrid classification scheme utilizing both the maximum likelihood classification and knowledge based classification has been used which integrates inputs from ASTER optical, thermal and DEM remote sensing data for mapping debris-covered glacier boundary.

Study area belongs to the Chotta-Shigri glacier, which is situated in the Lahaul-Spiti valley of Himachal Pradesh, India. It extends from Latitude 32.17˚ N to 32.28˚ N and Longitude 77.46˚ E to 77.55˚ E and is located on the Chandra-Bhaga River basin - a sub basin of Chenab river basin, Himalayas, India. It is a small glacier in which lower and the lateral portions are covered with debris making it a perfect test site for this type of study.

Further, cloud is also considered as one of the major hindrance in mapping of the glaciers due to its similar reflectance as of snow. Additionally, the low radiometric resolution of most of the optical remote sensing data may sometimes cause serious problem in mapping

glacial terrain classes due to saturation towards higher DN values due to higher reflectance of snow. A contrast enhancement using band transformation has been proposed in this remote sensing based study to resolve such problems.

13. Fluctuation in Equilibrium Line Altitude

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Glaciers are important natural resource to human kind because they are fresh water in frozen state and sensitive indicator of climate change. High altitude of the Himalaya is engraved with multitudes of glaciers, ranging in size from less than one sq km to tens of sq km. Though the glacier's advancement and retreat are related to long term climatic variations but there has been a serious concern on the general state of the health of glaciers not only in Himalayas but also world over. Health of glaciers is studied by monitoring its mass balance which means the total gain and loss of ice at the end of ablation season. However, snow line altitude at the end of the ablation season which is known as equilibrium line altitude can be used as indicator of the glacier's health. This paper represents the knowledge and information about the variation in equilibrium line altitude (ELA). The study shows that the glaciers having similar altitude show great level of variation in ELA. Warwan-Bhut sub-basin of Chenab basin, H.P. has been considered for this study. A series of satellite images of AWiFS sensor were analyzed for extraction of snowline on the glaciers for the period of 2010-2011. Furthermore, using Aster data, altitude of ELA was computed and it has been found that within the basin it shows the significant variation in altitude. Thus, influencing parameters such as slope of glaciers and its orientation was derived using Aster data and visual interpretation respectively. These parameters were analyzed with ELA to understand its role. However, it was found that the glaciers having Northern orientation found having relatively lower ELA. Moreover, the glaciers having steep or high slope have shown lower ELA as well. Therefore, the glaciers having steep slope and Northern orientation found to be favorable for the glacier's health.

Key word: ELA, glaciers, slope, aspect

14. Evolution of moraine-dammed glacial lakes in Uttarakhand Himalaya from Corona to LISS IV

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The climate change of the 20th century had a pronounced effect on glacier environments of the Himalaya. A glacial lake is defined as water mass exists in a sufficient amount and extends in, under, besides and/or in front of a glacier and originated by glacier activities. The formation of supraglacial lakes and moraine dammed glacial lakes and glacial lakes outburst flood (GLOF) is major concern in countries such as Bhutan, Tibet (China), India, Nepal and

Pakistan. The glacial lakes are situated in remote, inaccessible areas and are very difficult to monitor through ground surveys due to rugged terrain and extreme climatic conditions. Remote sensing based observations of the inaccessible regions provide a rapid and qualitative assessment of glacial lakes. This paper depicts the evolution of moraine-dammed glacial lakes in Uttarakhand Himalaya, based on the observations made from temporal satellite data of 1960- Corona data and Resourcesat- 2 LISS IV satellite data. The 21 moraine-dammed lakes seen in the LISS IV data compared with the oldest available Corona data for the evolution of the lakes. The analysis shows the rapid growth of moraine-dammed lakes and formation of new moraine-dammed lakes and formation of new moraine-dammed lakesand recession of glacier. This paper presents the utility of remote sensing in detecting and monitoring the nature of glacial lakes in highly glaciated terrain of Indian Himalaya.

15. Snow Cover Variability of Bhaga Basin from 2010-2013 using AWIFS Data

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Snow covers almost 40% of the Earth's land surface during winter in Northern Hemisphere. Moreover, seasonal snow cover is an important natural Resource in Himalayan region. Snow cover monitoring is very important at global level as well as regional level. Snow cover is considered as significant parameter for climate change studies. It is also an important parameter to study availability of water in Himalayan River, forecast & assessment of avalanche and various other applications. Currently, Remote Sensing is the most promising method for studying the snow cover. Various Satellite sensors like LISS-I, LISS-III, AWIFS, AVHRR, MODIS are used for snow cover monitoring. However, in this study AWiFS scenes were used to monitor the snow cover variability in Bhaga sub-basin for consecutive three years starting from October 2010. This investigation was carried out using Normalized Difference Snow Index (NDSI) for 2010, 2011 and 2013. An algorithm based on NDSI is used for monitoring snow. This method provides more accurate results compare to supervised classification. The monitoring was done for Bhaga sub –basin of Chenab basin for an interval of 5 days and 10 days. In the 5-daily product, snow extent has been generated scene-wise. In the 10-daily product, three consecutive scenes have been analyzed and a basin-wise .It is observed that extend of snow cover in early winter i.e. October to January of 2010-11, 2011-12 as well as 2012-13 is substantially different. Areal extent of snow for year 2011-12 from October to January is lower compare to 2010-11 and 2012-13 due to lower snowfall in early winter and high temperature. However, it has been observed that ablation pattern of snow is similar for monitoring periods as melting of snow starts in early or mid April for each year.
Key Words: Remote Sensing, Snow, NDSI, Awifs

16. Climate change and Glacier Retreat of Siachen Glacier using Remote Sensing Data

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Himalayas has one of the largest resources of snow and ice, which act as a freshwater reservoir for all the rivers originating from it. Monitoring of these resources is important for the assessment of availability of water in the Himalayan Rivers. The mapping of Glaciers is very difficult task because of the inaccessibility and remoteness of the terrain. Remote sensing techniques are often the only way to analyze glaciers in remote mountains. This paper analyses the changes in snout of Siachen Glacier, over the past one decade, using multi-temporal Landsat MSS, TM and ETM+ images. Snout or the lowest extremity of a glacier undoubtedly reflects the health of a glacier whether the glacier is advancing, stand still or retreating. The study reveals that the snout of the glacier is continuously retreating however frontal recession shows variability in the amount, rate and time of occurrence during the study period.

Key Words: Glacier, Snout, Recession, Multi-temporal, Landsat, Retreat.

17. Semi-Automated Approach For Extraction Of Glacier Extents From Satellite Images: A Case Study of part of Chenab Basin

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Monitoring of glaciers is a vital component of global hydrological and climate change studies. A number of studies on the glacier mapping and change detection of glacier extents have been carried out world over using multispectral optical data with a spatial resolution varying from 20 to 30m. But in most of the studies, mapping is based on digitization of glacier extents using visual interpretation techniques. Visual interpretation techniques are subjective and depend on the experience of analyst and are therefore subject to errors. The interpretation becomes debatable when glaciers are heavily debris covered on their ablation zones. Many Himalayan glaciers are debris covered partially or completely on their ablation zones. The implications of errors in mapping are reflected in the magnitude of retreat or advance of glaciers. In view of this, it has been attempted to develop a semi-automatic approach to extract glacier extents. A semi automatic approach can also be demonstrated by using thermal data. However thermal data is not available on many satellites and if available the spatial resolution is very coarse. We divide this problem in two classes i.e. i) when the glaciers are debris free and ice of the glacier is exposed on the surface and ii) when the glaciers are partially or fully covered with rock debris. Additionally it is normally understood that glaciers which are debris free retreat faster than glaciers with debris cover. It happens so as the debris cover over the glacier block the incoming solar heat, sensible heat etc. Therefore debris free glaciers can be considered as the better indicators of climatic variation than debris covered glaciers. If the glaciers are debris covered the actual extent of the glaciers cannot be extracted automatically as the signature of rocks and debris cover appear similarly.

To extract debris free glaciers, two methods were used i.e. unsupervised classification, and generating NDSI image. Two IRS LISS-III scenes of ablation season

acquired on 02August 2001 and 03 October 2011 covering Chandra, Bhaga and part of Spiti basins were taken up for the study. This data covers more than 100 glaciers. The images were co-registered with ortho-rectified Landsat data. The basis of using unsupervised classification is that snow and ice have clear signatures as compared to the surrounding surfaces of rocks, soil or vegetation and therefore can be picked up directly by the remote sensing images. It uses the ISODATA algorithm to perform an unsupervised classification. In the method using NDSI as the basis, the snow and ice verses non-snow and ice area was classified using the NDSI threshold value of 0.4.

For debris covered glaciers, ASTER DEM was used along with NDSI image. ASTER DEM has a foot print of 30m with approximate vertical accuracy of ±15m. DEM has been downloaded from website of USGS. It has been generated based on photogrammetric approach using ASTER stereo data. DEM was converted to a slope image. A threshold of > 2º and < 14º on the slope image was taken to subtract the slope of mountains surrounding the glaciers. The net area> 0.4 threshold value of NDSI and slope image within the specified thresholds was taken as glaciated area. This method also helps in estimating the debris cover over glacier. After the generation of area of each glacier corresponding to two time frames, the coordinates of the snouts of the glaciers were noted and difference in the position of the snout was measured. Snout is considered as the indicator of change in glaciers, as the change in long term mass balances are reflected on the position of snout. Hundred glaciers were monitored in the entire scene. Their total area has been estimated as 660.61 Km^2. Among them 35 glaciers are debris free. The total area of debris covered glaciers has been found as 500 Km^2.The maximum area of debris cover (%) on an individual glacier (32º 42’ N latitude and 77º 19’ E longitude) comes out to be 60.18%. The registration error of two corresponding images was 0.5 pixel. The uncertainty between 2001-2011 datasets comes out to be ±45m. The average shifts in the snout of debris covered and debris free glaciers has been found as 71±45m and 57±45m respectively using trigonometric methods. The area of few glaciers was compared with already prepared maps of this region using visual techniques. The difference was found to be 0.4 % for debris free and 5.58 % for debris covered glaciers respectively. However the threshold has to be improved to reduce the deviations. The purpose of using the semi-automated approach is to demonstrate that in the studies of glacier retreat/advance, the inaccuracies due to interpretation errors are ruled out and automated methods save lot of time and efforts.

18. Changes at Zing-Zing-Bar glacier, Patsio Region, Great Himalaya in Last Four Decades Using Remote Sensing and Field Observations

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This study presents the changes in last four decades at Zing-Zing-Bar glacier located in Patsio region, Great Himalaya, India. Glacier outlines were mapped using Corona KH4 data of 28 September 1971 and Landsat, ETM+ satellite image of 28 September 2011. Multi-temporal Landsat satellite data of end of the ablation period were analysed on decadal basis to monitor the variations in the glacier area and terminus. The LISS-IV and Cartosat-1 data

were also used to find the uncertainty in glacier mapping. Moreover, the glacier outline was verified by GPS survey on glacier in 2011. The loss in glacier area was observed (13.7 ± 1.58%) in forty years between 1971 and 2011. Further based on the decadal analysis, maximum loss in glacier area was found in early decades i.e. 1979-1989 and 1971-1979 respectively. The rate of glacier loss in last two decades (1989-2000 and 2000-2011) is less and was found approximately similar to other glaciers of the region. The average rate of glacier frontal retreat was found to be 22.5 ma^{-1} (± 2.72%) between years 1971 and 2011, whereas this average rate of retreat was found to be approximately 5 ma^{-1} in last 22 years i.e. between years 1989 and 2011. The annual snow line derived using the 14 satellite scenes of different years from 1971 to 2011 showed an increasing trend in annual snow line altitude. Overall negative specific mass balance was observed in last decade using area accumulation area (AAR). The climate data collected at Snow and Avalanche Study Establishment (SASE) meteorological station, Patsio (3800m) between 1983 and 2011 suggest the increasing trend in the mean annual temperature and decreasing winter precipitation. These evidences support the effect of climatic variability on glacier spatial variations. In additions, field visits to this glacier have been conducted in last four years successively. Apart from climatic factors, the study bring that the non-climatic factors such as altitude position of terminus and slope variation of the glacier may be major possible drivers for the significant loss in the glacier area in early decades.

Key words: Glacier, Himalaya, Remote Sensing, Landsat, annual Snow line altitude,

19. Pattern of Contemporary Glacier Retreat Around the Southeast-Facing Slopes of Kanchenjunga in the Sikkim Himalaya

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This paper is based on the findings of a systematic research upon the Quaternary history of the high altitude environment around the HMI Base Camp (4,500m), Onglakthang and Lambi (4,080m) in Churang Chhu and Prek Chhu valley on the southeast-facing slopes of Kanchenjunga summit area in Sikkim Himalaya. An assessment of Quaternary history has been made using the Landsat and IRS LISS – III data and on the basis of analysis of records obtained through extensive field work carried out in the years of 1988, 1995, 1997, 2005, 2008, 2009, 2012, 2013, and 2014 respectively. Over the last 25 years meticulous field observation was made on the conditions of East Rathong and Onglakthang glaciers, nourished from the neveé field of Kanchenjunga as well as the streams emerging from the glaciers. It has been calculated that East Rathong and Onglakthang glaciers have retreated of the order of 1.0 km and 1.5 km respectively. Studies with projection of morainic trim-line have revealed that these two glaciers have also experienced remarkable volume reduction of the order of 87% and 89% respectively since the termination of the Little Ice Age, a rate which is much greater than those existing in any other part of the Himalaya. Owing to rapid

deglaciation, several mullin lakes and proglacial lakes in an around the said glaciers have developed. Some of the pro-glacial lakes have become shallow due to continuous sediment deposition by numerous melt-water streams. Evidences of burst of a moraine-dammed lake near Jemathang (at about 4,600m) on the Onglaktang and some others around the HMI Base camp on the East Rathong in the recent past have been observed through the GLOF sediments deposited in the Jemathang area, Prek Chhu valley and the Churang Chhu valley. The contemporary rapid retreat of the glaciers have been attributed to the increased in the atmospheric temperature, increasing forest fire incidences in the eco-region of Teesta, annual increase in extreme event days by 0.0-1.0 and rapid increase in the number of grazing animals (yaks) as well as mountain trekkers in the areas around the Kanchenjunga National Park.

Keywords: Quaternary, Landsat data, IRS LISS–III data, mullin lake, pro-glacial lake, neveé field, Little Ice Age, trim-line

20. Climate Change Impacts in Alpine Region of Central Himalayas (Uttarakhand): An Analysis Based on Remote Sensing Satellite Data and Ground Observations

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The state of Uttarakhand located in the lap of Central Himalayan region has been identified to be the most vulnerable to climate change mediated risk. The natural resources of the region provide life supporting, provisioning, regulating, and cultural 'eco-system' services to millions of local as well as downstream population. In During the last few decades, the central Himalayan region of the greater Himalaya is observing the cascading effects of the climate change induced changes like depletion of snow and receding of glaciers, change in snow cover, upwardly moving snowline, formation of glacial lakes, reduction in snow in winter, rise in temperature, erratic precipitation patterns etc. These climatic changes have increased the impact on occurrence of Glacial Lake Outburst (GLOF), number and size of glacier/high altitude lakes, runoff river discharge pattern and hydropower potential, intensity and frequency of flash floods, landslides, changes in plant phenology and flowering behavior, extinction of vegetation and affect on alpine meadows, shifting of cultivation zones of apple and other crops, advancing cropping seasons, drying up of perennial streams and scarcity of water and effect on ecosystem and livelihood of the mountainous community and downstream area.

In order to observe the climate change trend indicator and its impact and consequences in Himalayan region of Uttarakhand, studies on snow and glaciers, upward shift in timberline and vegetation, formation of high altitude/glacial lakes and land use/land cover etc. and recent impact of climate induced devastation occurred in the state of Uttarakhand are some of the examples being carried out using multi-temporal satellite data, ground-based measurements and collateral data with the collaboration of Uttarakhand Space

Applications Centre (USAC). Some of the studies and observations are summarized as follows:

Snow cover monitoring NSDI algorithm was used to monitor seasonal snow cover in Alaknanda, Bhagirathi and Yamuna basin using IRS-AWiFS data in every 5 and 10-daily intervals from 2008 to 2014. Snow covers monitoring show variation in pattern of snow accumulation and ablation and overall change in snow cover in different months and years. The maximum annual average snow cover area was in the year 2013 (in the month of February) and the minimum in 2010 (in the months June-July). Melting of snow and ice contributes about 70% of river summer flow. Glacier change monitoring studies carried for estimation of loss in glacial area and retreat using medium to high resolution satellite data, field photographs, Survey of India Topographic maps and field excursions shows the depletion and receding of glaciers in all basin.

To understand the sensitivity of climate in tree line of Himalayas, a study was carried out in high altitude central Himalayan ranges in a part of World Heritage Site (the Nanda Devi Biosphere Reserve) using temporal satellite remote sensing data. Analysis of survey map of 1960 showed glaciers, snow and scree were the dominant land cover types of the area. Vegetation was reported in the form of scrub and scattered trees. The timberline was at 3900m AMSL in 1960. Analysis of the remote sensing data of March 1986 showed no significant deviation from the baseline information obtained from topographic map. The 1999 data showed indications of reduction of snow and ice cover and increase in vegetation cover in areas above 4000m. Data of 2004 showed significant increase in vegetation cover in alpine zone. The elevation contours overlaid on the image showed that now the timberline is at 4300m AMSL, scrub line is at 4900m AMSL and tundra vegetation line is at 5300m AMSL. Further Space Applications Centre (SAC) with the collaboration of USAC has extended this study to alpine zone of Indian Himalayas (Uttarakhand). The finding of results have indicated substantial upward shift of alpine tree line of the order of 388m+80 m in the last three decades using satellite and other archived data.

In recent years, there has been a rapid melting and retreat of snow and glaciers which has created many precarious glacial lakes in the Himalayan region. The formation of such lakes could be dangerous as these lakes may contain a large quantity of water and can cause flash floods in the downstream areas. A detail inventory of HALs (above 3000m) were initiated at USAC, Dehradun at 1: 10,000 scale using pre- and post-Uttarakhand disaster (15-17th June, 2013) high-resolution data (LISS-IV, Cartosat-1/2, and IKONOS) in GIS environment. Preliminary results of the inventory show the formation of about 800 water bodies of different sizes in different basin and altitudes. Maximum were observed in Alaknanda and Bhagirathi basin. One of the findings of this study is the high concentration of small lakes (<10 ha) and altitudinal analysis of distribution pattern of lakes has shown that most of the small lakes are in the higher altitudinal range above 5000m.

Comparison of different inventories of HAL/Glacier lakes revealed that in a short span of time enormous number of lakes had been formed in the higher Himalayan reaches of Uttarakhand which is a matter of great concern towards the vulnerability of risk and threshold for potential occurrence of Glacial Lake Outburst Flood (GLOF) in the region.

Severity of the crisis can be gauged from the fact that during the monsoon, some region or other in the Central Himalaya experiences catastrophic disaster and with every passing year that frequency and magnitudes becoming more and more severe. A recent tragedy due to antecedent rainfall and cloud burst during 15--17th June, 2013, hit several parts of higher reaches of the Himalayas in the state of Uttarakhand. This unprecedented rainfall resulted in a sudden increase in water levels, giving rise to flash floods all along the Mandakini, Alaknanda, Bhagirathi and other river basins causing extensive damage to life, property, infrastructure and landscape of the State and the downstream of these river basins is an example of such catastrophic disasters in the State. Adding to this, the continuous rains and the melting of the Chorabari glacier caused waters in the Chorabari Lake to rise. The Lake's weak moraine barrier gave way and a huge volume of water along with large glacial boulders came down the channel to the east, devastating Kedarnath town, Rambara, Gaurikund and other places in its wake. According to official sources, over 900,000 people have been affected by the event in the State of Uttarakhand. This calamity hit the State and has surpassed all the past records of the damages in the area. Viewing the calamity due to torrential rainfall during 15-17th June 2013, pre- and post-disaster satellite (IRS-AWiFS, IRS-LISS-IV, Cartosat-1/2, Quickbird, Landsat-8) data in conjunction with collateral and field data were used to frame out the most possible and scientific set of connections, which had lead to such devastation in the regions and also to understand the causes and impact of such disaster. All these derived information were utilized by State Government during rehabilitation under post-disaster reconstruction programme.

The study proposed that the challenges brought about by climate change in higher Himalayas can be addressed through integrated and collaborative scientific research in Himalayas using satellite and field data at regional/national and local levels and also suggested the need for setting up of extensive in-situ observational measurement network for weather and climate in alpine or tree line areas of Himalayas for understanding of long term impact through simulation studies and forewarning risk models.

21. On Upgradation of RGI Inventory: Indian Himalaya

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Glacier inventories are compilation of glacier outlines aiding in documentation of glaciers. They reconcile data from different sources and provide standardized data for further glacier related calculations. These inventories are essential to monitor glaciers and synthesize a bigger picture on on-going changes. In this light, efforts are made since 1980's to publish guidelines and develop inventory of glaciers around the globe by world glacier monitoring services (WGMS). One such initiative is Randolph Glacier Inventory (RGI) which is a global inventory of glacier outlines mainly motivated by fifth assessment report of intergovernmental panel on climate change (IPCC AR5) in 2012. Despite Himalaya housing the largest number of glaciers outside the polar region, they are not very well documented in the inventory. Though, regional inventories by Glaciological Survey of India (GSI) and International Centre for Integrated Mountain Development (ICIMOD) document the glaciers in Indian Himalaya, they are not entirely adequate. GSI inventory provides details of glaciers such as maximum elevation, minimum elevation, area, length, but it does not provide digital glacier outlines. Moreover, elevation data for large number of glaciers are not available. On the other hand, though digital glacier outlines are provided by ICIMOD inventory, they are derived by semiautomatic delineation. Furthermore, these inventories cover area on a regional scale and fail to aid studies addressing global issues. A global inventory like RGI is crucial in addressing global issues such as global climate and sea level rise. Hence, this calls for upgradation of current RGI inventory. Many individual studies have been carried out in detail at basin and sub basin scale in various parts of Indian Himalaya. Integrating datasets from these studies can help in filling the knowledgegap. With this in view, studies carried out at our centre will be analysed, updated and compared with current RGI inventory. The basins in Himachal Pradesh viz Chandra basin, Parbati basin, Baspa basin and Tista basin in Sikkim are the regions under consideration. The datasets will be submitted if found to be contributing towards upgradation of current RGI inventory. This upgradation will contribute towards completeness of the inventory which will in turn significantly aid in detailed and thorough assessment of glacier resources.

Technical Session – II

Glacier Mass Balance and modelling Studies

1. Dynamics of Hamtah glacier, Lahaul & Spiti district, Himachal Pradesh

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Hamtah (5Q212 12 180), is a northwesterly flowing valley glacier which lies in Chandra fifth order basin (5Q212 12), of fourth order Chenab basin (5Q212). It is 6.0 km in length with an average width of 0.50 km and covers an area of about 3.3 sq km . Originating at an elevation of 5000 m asl, it descends with a gentle gradient with its terminus at about 4000 m asl. The glacier has a large ablation zone covered with thick blanket of morainic debris. Its very small accumulation zone is characterised by a small ice stream located in the left part of the glacier and avalanche cones originating from the two small hanging glaciers and surrounding snow capped peaks.

Glacier flow movement studies on Hamtah glacier, which constitute a very important parameter in understanding the dynamics of the glacier, were initiated during the year 2000. The stake network fixed on the glacier surface for mass balance studies was used for determination of various ice flow parameters, through coordination by Electronic Distance Measuring (EDM)/ survey unit. For this purpose an array of survey stations were fixed on the valley wall/ stabilised lateral moraines. Each year the stake network, which has two rows, *i.e.*, left and right having eight stakes each, was coordinated twice, during August and September, for computation of annual and summer flow components respectively. The difference in easting and northing of the stake coordinates of two successive observations yielded the horizontal component of velocity.

Annual horizontal component of velocity (Ua) was computed with a view to understand its dynamics vis-à-vis its recession and mass balance recorded through field based studies undertaken during 2000-01 to 2005-06 assessment years. The Ua was also compared with the monthly horizontal component of velocity (Um) recorded during the summer ablation season. The studies revealed that:-

i. Higher velocities were recorded along the right row of stakes vis-à-vis left row of stakes, probably attributed to the drainage network and higher accumulation from the hanging glaciers. The alternate pattern of stakes network with right row of stakes fixed at relatively higher elevations, also resulted in higher velocities.
ii. Higher ice mass transfer from the upper reaches as evidenced by the faster movement of the glacier is well compensated in the lower altitudes, with reduced flow velocities.
iii. Majority of stakes show successive decline in Ua from 2000-01 to 2005-06 which could be attributed to the thinning of the glacier due to continuous negative mass balance and recession of the glacier during the period of observation.
iv. Highest velocities were recorded during 2006-07 and 2007-08 along the C1-C3 stakes, fixed along the centre of the glacier in the higher reaches in 2006. This could be due to the maximum thickness obtained along the central portion (varying from around 80m in the central part to 35m close to the margins) deduced through GPR surveys in the area close to the accumulation zone.
v. Ratio between annual horizontal component of velocity (Ua) and annualised summer monthly horizontal component of velocity (Um*12 months) shows considerable variation including along the left and right row of stakes. This could be ascribed to the

drainage pattern and the consequent effect of basal sliding on account of availability of water in the basal layer during the summer ablation season.

2. Annual Mass Balance Measurements on Chhota Shigri Glacier Since 2002

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In the Lahaul-Spiti (one of the most densely glaciated regions) of Himachal Pradesh, western Himalaya, a ground-based long-term monitoring programme was started on Chhota Shigri glacier (32.28 N, 77.58 E; 15.7 km^2, 6263-4050 m a.s.l., 9 km long) in 2002. While, the lowermost part of the glacier is debris covered (~3% of total glacierized area), the remaining glacier surface is in direct contact with the atmosphere. This glacier lies in the monsoon–arid transition zone (in western Himalaya), which is alternately influenced by Indian monsoon in summer and the mid-latitude westerlies in winter. Annual mass balance of Chhota Shigri glacier has been monitored during the period 2002-2013, during which the glacier experienced a negative glacier-wide mass balance of -0.59±0.40 m w.e. a^{-1}. Chhota Shigri glacier found similar to mid-latitude glaciers, with an ablation season limited to the summer months and a mean vertical gradient of mass balance in the ablation zone (debris-free part) of 0.7 m w.e. $(100\ m)^{-1}$, similar to those reported in the Alps. However, in the lowermost part, the thick layer of debris over the ice surface protects it from solar radiation and reduces ablation. During the study period, mean Equilibrium Line Altitude (ELA) and Accumulation Area Ratio (AAR) was found to be ~5050 m and 0.48 respectively. Specific mass balances are mostly negative during the study period and ranges from a minimum value of -1.42±0.40 m w.e. in 2002-03 (ELA 5188 m a.s.l. and AAR 0.28) to a maximum value of +0.33±0.40 m w.e. in 2009-10 (ELA 4941 m a.s.l. and AAR 0.64). Spatial distribution of ablation measured through a well distributed bamboo stake network suggest that mass balance is strongly dependent on debris cover, exposure and the shading effect of surrounding steep slopes.

3. Winter and Summer Mass Balance of Phuche Glacier, Ladakh Range

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Asynchronous glacier response across the Himalayan arc is manifested by the mass gaining glaciers of the Karakorum region in the west and significant mass loss in the central and eastern glaciers. This highlights the huge variability in the climate-glacier interaction across the Himalaya. However, little effort is being made to map and study this variability, leading to huge knowledge gap on the processes driving the regional climate and glacier response. Deficiency in the research initiatives stems from lack of appreciation of various glacio-hydrologic regimes and its varying climate-cryoshere dynamics. To bridge some of these gaps, Phuche glacier in the Ladakh Range representing the cold-arid glacio-hydrological regime has been selected for long-term mass balance studies under the SERB Programme on Dynamics of Glaciers in the Himalaya. Phuche glacier is a small cirque glacier with an area of 0.62 km^2 and extend from 5400-5745 m a.s.l., representing around 227 small glaciers of the Ladakh and Zanskar ranges feeding the river Indus. Higher dependency of Ladakhi population on these glacier streams was also a key factor in the selection process. It is appreciated that one of the limitations of mass balance measurement programme in the Himalaya is due to its limited focus on the annual mass balance estimation. Annual mass balance or net mass balance did not provide any significant insight on glacier accumulation and melt processes or glacier melt runoff contribution to the downstream river flow. Hence, a mass balance measurement programme including the winter mass balance measurements and monitoring of winter snowpack and glacier melting throughout the summer has been implemented. This comprehensive research strategy is being operational on the Phuche glacier since 2010. Here we present the winter, summer and annual mass balance of Phuche glacier during the past four mass balance years (2010-2013). During the course of these four years, Phuche glacier experienced winter accumulation in the range of 590-620 mm w.e. as compared to the mean annual precipitation of 115 mm at Leh demonstrating the huge precipitation gradient existing in the Ladakh region during winter months. While winter mass balance have limited inter-annual variability, the summer mass balance showed wide range of fluctuation ranging from 590-1050 mm w.e. These has resulted into significant year to year variations in the annual mass balance ranging from (+)72 to (-)430 mm w.e. Phuche glacier experienced two slightly positive mass balance years and two hugely negative mass balance years resulting into 670 mm w.e. net water loss from this glaciers during the four year study period.

4. Explaining the Observed Changes in the Himalayan Cryosphere on the Basis of Varying Climatology and Topography

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The Himalaya possesses one of the largest resources of snow and ice, which act as a huge freshwater reservoir. The recent contradictory reports about the glacier melt in Himalayas have been a cause of worry to scientific community. However, the observed glacier changes, as shown in this research, vary across different Himalayan ranges as a function of changing climate and topographic regimes. In present investigation, we studied 30 glaciers over the North-Western Himalayas situated in six topographic and climatic regimes to understand the differential glacier dynamics. Time series satellite images between 1990 and 2011 along with digital elevation model was used to map the glacier boundaries, ELA, AAR and a few other glacier parameters like debris cover etc. Since majority of the glaciers in the study area are debris covered, it becomes imperative to use DEM derived morphometeric parameters like elevation, slope, and aspect to map the glacier boundary. For the accurate boundary delineation, SOI topographic maps were also used. The study indicated a loud and clear influence of differential climatology and topography on glacier dynamics. The glaciers in the Karakoram range have witnessed the least retreat of 1.59% in terms of area from 1990-2011 owing to extreme cold average temperatures of -18^{o}C (Oct-April) that sustain and preserve the huge glacial resources in the region. Other glacial geometric parameters like snout, ELA and glacier volume also showed very little changes in the Karakorum Range. The glaciers in the Ladakh range with an average temperature of -6^{o}c (Oct-April) have retreated by on an average by 4.19 % during the 2 decades of observation, followed by the glaciers in the Zanaskar range where the glaciers have shown a loss of 5.46% in area from 1990-2011. The average snout and ELA retreat for Ladakh range was 97m, 40m respectively and 116m and 40.83m respectively for the Zanaskar range during the observation period. The highest glacier retreat of 7.72% and 6.94% was witnessed in the Greater Himalayan and Shamasabari range with the average temperature of -1.3^{o}c and -6.2^{o}c (Oct-April) respectively. The average snout retreat of 253m and 202.5m was observed over these mountain ranges respectively. The variations in ELA and glacier volume were found maximum for Greater Himalaya and Shamasbari ranges. The analysis of the glacial retreat and other glacial parameters in all the six ranges in different altitudinal zones revealed a clear control of topography. The study indicated that the maximum recession of glacial area 97.12%) was found in mountainous ranges below 4500m asl followed by the glaciers in the mean altitudinal range of 4500-5000m (5.43%). The glaciers in the altitudinal range of 5000-6000m and above 6000m showed the lowest rate of glacial retreat in area, i.e., 4.58% and 1% respectively. The snout retreat in all the six observed ranges also showed strong correlation with the changes in the altitude/topography. The highest snout retreat of 243m was observed in the glaciers in the regions with less than 4500m asl altitude while as the glaciers with mean altitude more than 6000m showed the lowest retreat. The glaciers with mean altitude between 4500-5000m and 5000-6000m have retreated by 217m and 204m respectively. The control of topography is quite visible on the observed changes in the ELA and volume estimates. The glaciers at altitude below 4500m exhibited the largest changes in the ELA, i.e. 54m during the observation period. The glaciers located at altitudes greater than 6000m on the other hand showed the lowest changes in the ELA (Im). The influence of topography on glacier volume changes observed for glaciers in all the six mountain ranges was evident from the fact that glaciers located below 4500m mean altitude showed the highest loss of 9.68% while as the glaciers situated above 6000m altitude experienced the lowest volume loss of 1.77% from 1990-2011. However, the AAR based specific mass balance for the benchmark glaciers in the identified mountain ranges doesn’t follow any significant trend w.r.t the climate and topographic variability despite the fact that most of the studied glaciers in the six ranges are in a retreating phase.

Keywords: Topographic and climatic regime, ELA, AAR, mass balance, snout

5. Mass and Energy Balance study of Naradu Glacier, Himachal Himalaya

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It is evident that the glaciers are excellent climate recorders and their study is critically important to understand global environmental change. Forth Assessment Report by IPCC clearly mentioned that continued loss of ice has been noticed and according to IPCC report 2013 satellite records indicate that snow cover extent has decreased significantly in the Northern Hemisphere. Mass and energy balance are the ways to study the glacier variation in response to weather and climate. Energy balance involves the measurement of the energy difference between incoming and outgoing energies whereas mass balance is simply the gain and loss of ice from the glacier system in a particular year. The energy supply for melting glacier comes from several sources like net radiation, sensible heat flux, latent heat flux etc. in which net radiation is the largest energy source responsible for melting in most of the glaciers. Annual mass balance measurement by using glaciological method for the year 2011-12 and 2012-13 are (–) 1.1 and (–) 1.15 m we respectively while the melting calculated for the year 2012-13 through the energy balance method is (-)1.22 m we.

Keywords: Naradu glacier; Mass Balance; Energy Balance, Himachal Himalaya

6. Estimation of Glacier Stored Water in Parbati basin, Himachal Pradesh, India

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Himalaya has one of the largest numbers of glaciers after poles. Major perennial rivers such as the Indus, Ganga, Brahmaputra, Amu Darya, Irrawaddy, Salween, Mekong, Yangtze, Yellow and Tarim, originating from Himalayas are fed by snow and glacier melt water and its contribution is significant in the lean flow season when the rain water is not directly available. The glacial mass loss in the Himalaya is reported to be increased in few decades and expected to accelerate in future. Therefore, the assessment of water stored in the mountain glaciers is useful, to understand its long term availability. An attempt has been made to estimate the volume of water stored in glaciers of Parbati basin. The glaciers were delineated using Landsat TM imageries of year 2009 and 204 glaciers covering area of 329± 25 sq km were mapped. ASTER GDEM v2 is used to calculate mean slope. The volume estimation using slope-volume relationship (Cuffey and Paterson, 2010) gave an availability of ~13 Gt of water. According to the area-volume relationship (Chen and Ohmura 1990, Bahr

1997, and Arendt et al, 2006) ~23 - 41 Gt of water is available in the glaciers while depth-volume relationship (Chaohai and Sharma, 1988) gave the water availability of ~32 Gt. The difference in the values is due to the different representative equations used in these methods. The scaling relationships used in this analysis are originally developed for glaciers of Alps and Alaska with different geomorphological characteristics. Due to unavailability of depth measurements, no special relationships developed for Indian glaciers. These processes are required to be further investigated in Indian Himalayan glaciers to have a better estimation.

Keywords: Parbati basin, glacial stored water, volume area scaling, slope-volume relationship, depth area scaling.

7. Understanding the Climatic Response of Debris Covered Himalayan Glaciers from simple Models

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The climatic response of clean glaciers is well explained by one dimensional flowline models (e.g. Oerlemans, 2001). But debris covered glaciers, which are abundant in the Himalaya, are not so well understood. A supraglacial debris layer modifies the heat fluxes at the glacier surface and consequently affects the mass balance processes. A thin debris layer found at higher elevations reduces albedo causing enhanced melting, while a thicker debris layer in the lower part of the glacier inhibits melting due to its insulating properties (Nicholson and Benn, 2006).We discuss a modified simple effective mass balance model description for debris covered glaciers that helps us understand their behaviour better (Banerjee and Shankar, 2013). We show that these glaciers have larger climate sensitivity and obtain an approximate analytic expression for the climate sensitivity. Our simulations show that these glaciers, when responding to a warming climate, may go into a stagnant phase. In this phase, the glacier loses ice mass due to thinning of debris covered lower ablation zone without any reduction in the total length. These insights into the nature of the climatic response of debris covered glaciers are exploited to explain some of the peculiarities in the response of Himalayan glaciers to climate change as seen in a large scale remote sensing study by Scherler et al. (2011). For example, we show that the fraction of shrinking glaciers among the clean glaciers is comparable to that among the debris covered glaciers. We also show that the observed inhomogeneity in the response of the clean glaciers can be ascribed to a spatially fluctuating warming rate.

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8. Mass Balance Sensitivity of Himalayan Glaciers

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Modelling the response of glaciers to climate change is important for many reasons including predicting changes in global sea level rise and water resources. One can measure the health of a glacier by the annual net mass balance, whether in a given year there has been a net loss or gain of ice from the entire glacier. The mass balance reflects all of the meteorological forcing of the glacier - both the snow added over the course of the year and the losses dealt by the combined effects of the ablation and sublimation. Using the methods in Radic and Hock (2010), we calculate the mass balance change of chosen Himalayan glaciers in response to temperature and precipitation. The mass balance model calibration is carried out for 12 chosen glaciers over the Himalayan region and compared against 36 glaciers from other regions used by Radic and Hock (2010). We use available mass balance observations between 1961 and 2001, and examine the sensitivity of the mass balance model results to choice of temperature and precipitation datasets. We use ERA-40, NCEP-NCAR, and ECMWF Analysis for temperature and VASClimO (GPCC) data at different (0.5ºx0.5º and 2.5ºx2.5º) resolutions to calibrate the mass balance model.

9. Quantification of changes in Epiglacial Morphology and Annual Mass Balance of Dokriani Glacier, Central Himalaya, India.

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Dokriani Glacier is a small NNW oriented glacier in the Bhagirathi basin, India. Glacier area covers of 7 km², extends from 3965 m to 6600 m asl. Dokriani is a compound type valley glacier originated one on the northern slopes of Draupadi Ka Danda (5716 m asl) and second on the western slopes of Janoli peak (6632 m asl) on which settled winter snow tends to last far into the summer months. The present study describes the results of the mass balance and length changes observed during 2007-2013 and compare with the previous observations of 1990-2000. To evaluate the winter accumulation on the glacier a winter survey was performed every first week of May and ablation was measured for entire ablation period with an interval of 15 days. The mass balance results have been resumed in terms of annual balance (b_a), winter accumulation (C_w), winter ablation (a_w), summer ablation (a_s), total ablation (a_t), Equilibrium Line Altitude (ELA) and Accumulation Area Ratio (AAR). The six balance years (2008-13) brought a total volume loss of $-14.12*10^6$ m^3 w.e. The cumulative mass balance since 1992 to 2000 (six balance years) was -1.94 m w.e. with -0.32 m w.e. a^{-1} and from 2008-2013, it is (-1.99 m w.e. and -0.33 m w.e. a^{-1}). The spatial variability of melt rates is very high, clean ice and debris-covered ice shows different order of melting magnitude than the average melting. The ELA was fluctuated from 5030 to 5100 m a.s.l. during study period. The ELA_0 and AAR_0 were found to be 4965 m a.s.l and 0.72 respectively. The higher value of AAR comprises due to flat and broader accumulation area (4.67 km^2) of the glacier. Although, having larger accumulation area, the glacier has faced strong mass wasting with average annual ablation of -1.82 m w.e. a^{-1} in the ablation zone compare to residual average annual accumulation of 0.41 m w.e. a^{-1} .The recession rate of 21.3 m a^{-1} during 2008-2013 is much higher than the retreat rate of 16.5 m a^{-1} (1962-91), 17.8 m a^{-1} (1991-2000) and 15.5 m a^{-1} (2000-2007) respectively. Substantial surface melting below 4300 m a.s.l is due to exposition (NNW) direction of the ablation zone. The progressive retreat of the glacier affects its extension and volume and is covered by continuous enhancement of debris in the lower ablation part.

10. Evaluation of Glacier Stored Water Estimates by Different Techniques in Indian Himalaya

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Glaciers in the Himalaya are a source of water for many important Indian River systems like the Indus, the Ganga and the Brahmaputra. These rivers have huge economic significance and provide water security to a large number of populations. The Himalayan glaciers are undergoing changes in response to the ongoing climate change and these changes, subsequently, affect the run-off in the downstream. However, there is a large gap in our understanding of these changes and their influence on water security in the future. There are also uncertainties in estimation of glacier volume in the region. Ground penetrating radar (GPR) system is used to estimate the glacier depth and due to lack of this technology in India, in-situ measurements are sparse. Hence, different empirical models are used to estimate the glacier stored water. This study uses inventory by Geological Survey of India (GSI) as primary source of data. Information of 9,040 glaciers covering an area of ~18,534 sq km is digitized. GSI inventory suggest the volume of stored water to be ~1199 Gt in Indus, Ganga, and Brahmaputra basins. However volume can also be estimated using different approaches. These approaches are based on slope-volume relationship, volume-area relationship and mean depth area scaling. The study suggests that the estimate of glacier stored water by different approaches varies from ~1068 Gt to ~2569 Gt, suggesting large variability. This causes hindrance in assessing and forecasting changes, hence further investigation is needed to address this uncertainty.

Keywords: Glacial stored water, Geological Survey of India (GSI), Indian Himalaya, Slope-volume relationship, Volume-area relationship, Mean depth area scaling.

11. Winter Surface Energy Balance in Chhota Shigri Glacier, Himachal Pradesh, India

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Daily time series of six months dataset (01 November 2012 – 30 April 2013) from an automatic weather station (AWS) located on a moraine close to equilibrium line altitude (ELA) at 4863m a.s.l. of the Chhota Shigri Glacier, Himachal Pradesh, India, was analysed to study the winter surface energy balance. The AWS measured basic meteorological parameters including incoming and outgoing shortwave radiation (W/m^2), incoming and outgoing longwave radiation (W/m^2), and albedo (%). Analysis of incoming and outgoing shortwave radiation and extra-terrestrial irradiance suggests that around 25.43% of the energy available on top of the atmosphere was actually absorbed by the surface in winter, indicating high albedo because of snow cover at the landscape. Surface energy balance (SEB) was calculated using Simple Energy Balance Model and turbulent fluxes using Bulk Method. The anti-correlation of mean daily variation of SEB with the mean daily variation of sum of turbulent fluxes, and a direct relationship with the mean daily variation of net all wave radiation (R) supports the idea that the net all wave radiation was driving the surface energy balance (SEB) on Chhota Shigri Glacier during winter. In diurnal variation also, the surface energy balance followed the same trend as net all wave radiation and the sum of turbulent energy fluxes was behaving inversely to SEB. The negative values of latent heat flux and sensible heat flux suggests the loss of mass through sublimation process.

12. Enhanced Temperature-Index Model for Dokriani Glacier, Garhwal Himalaya, India

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Present study reveals the effect of regional climatic factors responsible for glacier surface melting. Consequently, models correlating melting with temperature and rainfall are generated for Dokriani Glacier ($30^0$49'to $30^0$52'N and $78^0$47'to $78^0$51'E), Central Himalaya. Dokriani glacier is a medium sized valley glacier lies in Bhagirathi river basin in Garhwal Himalaya. The glacier has a length of 5.5 km with varying ice thickness of 25 m to 120 m between snout and accumulation zone. Average thickness of glacier is 50 m and area is 7 km^2. The ablation area is covered with debris, closed by highly elevated lateral moraines on both sides. Lateral moraines exist along the glacier up to Equilibrium Line altitude (ELA). The centre line of ablation zone of the Dokriani Glacier comprises clean ice, while the undistributed debris cover is located along the side margins.

The data are recorded from July 2011 to October 2013 at Base Camp (3763 m asl) situated ~1 km below the snout and Advanced Base Camp (4364 m asl) near ELA of Dokriani Glacier. An analytical study has been made for three ablation seasons of years 2011, 2012 and 2013 employing data of temperature, rainfall and melting. Since, the data are

available only for two locations of glacier; interpolation has been made to get a series of data over the glacier. Further, temperature and rainfall are constructed between these two positions of the glacier at an interval of 100m up to Advanced Base Camp.

In melt modelling, the models are mainly categorized into two types: temperature-index models and energy-balance models. We have used enhanced temperature-index modelling to predict melting from snout to ELA. To investigate the effect of rainfall on glacier surface melting along with temperature, model incorporating temperature and rainfall is proposed for Dokriani Glacier and performance of the developed formulation is assessed through different statistical criterions.

Key words: Himalaya, Dokriani Glacier, melt modelling, temperature-index modelling, statistical criterions.

13. A Model for Calculating the Thickness and Volume of Gangotri Glacier

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Now-a-days the retreat of glaciers is taken as an important parameter to understand climate change. However, an attempt has been made in the present study to calculate the thickness and volume through satellite data which is more economical and less time consuming then normal traditional methods.

Several past studies in this area have used the glacier thickness and area for calculating the volume. The inherent flaw of this methodology is that it considers constant average thickness for glaciers which differs from the ground reality. In the present model, ice volume of the Gangotri glacier has been calculated by considering it as a parabolic surface which will take care of variable thickness of the glacier. Using the width and length available from the landsat imagery, the curvature of the glacier is calculated. The model tries to make a more precise estimation of the varying glacier thickness by establishing a relationship with the changing glacier width. The study validates the accuracy of the model by comparing the results with the available data from GSI and past models. The steps for the model are as follows,

Step I – Find the focus (F) and the ice thickness (d) (depth of the parabola) $F=D2$

Where D is the width of the glacier $d=(D2)24F$

Step II – Formula of the parabola.

To find the formula we use a simple characteristic of a parabola that is DF [the distance between the focus (h, k) and any point on the parabola (x, y)] is equals DL [the distance between (x, y) and a line known as directrix (0, b)]

DF=DL … (2.1)

$\sqrt{}(x-h)2+(y-k)2=\sqrt{}(y-b)2$….. (2.2)

Step III – Find the area within the parabola. Here we do a finite integral over the width of the glacier. $y=\int(x)w0\ dw$

Step IV – Calculate the volume.

Volume = Area within parabola ×Length of the glacier

We know the width will never remain constant throughout the glacier so we divide the glacier into various sectors having similar width. Thus thickness can be calculated separately for each sector and we use this thickness to calculate the volume for respective sector. The resultant glacier volume is arrived by summing up the volumes of each sector.

The volume of Gangotri glacier (26.12 km3) which is calculated by using this model is almost matching (±3 km3) with GSI's volume (27 km3) year and Kulkarni's volume (23.32 km3) year.

With the help of this model a parabolic equation for each Himalayan glacier can be made depending on its width. Thus this model gives a new understanding to find out the thickness and volume of any Himalayan glacier.

Keywords: Model, Volume Calculation, Satellite data, Gangotri glacier

14. Preliminary Mass Balance Study of the Patsio Glacier, Lahaul, Himachal Pradesh, India.

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Glacier studies have become one of the key parameters for climate change. Various studies around the world have made it clear that climate change is already going on with an accelerating pace. The Himalayas constitutes largest concentrations of glaciers as it possesses a huge ice resource and permanent snow field. The melt water from these components is the main source of many important rivers in the region. The complex and uneven distribution of glaciers in the Himalayas is primarily due to variable climatic conditions and criss cross topography which is reflected in fluctuations in the snowfall. Very sparse field based data is available on the changes of glaciers. The mass balance studies on Patsio glacier was initiated in the year of 2010. Initially 7 stakes were installed and in 2012 it was increased to 17 and in 2013 it was again increased to 22 stakes. Numbers of stakes were increased to get the better resolution of the ablation at each altitude. Winter mass balance was calculated by measuring snow depth, snow pit and snow core on different position of the glacier. Snow depths were almost similar at lower elevation range that signifies the homogeneous ablation and at upper elevation again same pattern follows. The snow depth gradient was around 27 cm per 100 m. Summer ablation of the Patsio glacier found to be short but very significant. It shows that mean ablation decrease as the elevation increases. But ablation pattern in different months and days depict different trends. Ablation doesn't vary much with altitude in the peak ablation period as compare to early and late ablation period. Two days daily ablation in the early August shows the almost homogeneous melting at every altitude (i.e 4085-5300m amsl). During the period 2012-2013 the glacier wide annual mass balance of Patsio glacier was slightly negative. The Accumulation Area Ratio was found to be 47%.

15. Temporal and Spatial analysis of the Cryosphere - Atmosphere - Biosphere Interaction over Garhwal Himalaya using MODIS Images

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A long term relationship among night time (LST), Snow cover fraction, NDVI and AOD in different eco-regions of the Central Himalaya has been determined using MODIS weekly and biweekly images. The trends were evaluated using linear regression methods for different seasons and region using time series data. It is observed that the trends of the nigh time LST are similar between Lowest and Higher Himalaya because of similar abundant free rock faces.

The impact of increase in night time LST reflected in trends of the snow cover fraction in upper Himalaya. While increase in snow cover fraction in upper Himalaya during post monsoon seasons is showing sufficient cooling for early snow precipitation by late monsoon or western disturbances.

Phenomenal increase in rate of NDVI is observed at upper Himalaya because of improvements in atmospheric temperature as limiting factor for growth of vegetation. However, cooling impact of intense monsoon favored the post monsoon snow precipitation and lead highest decreasing trends for the NDVI in Higher Himalaya in post monsoon time.
The coupled effect of increase in atmospheric temperature, decrease snowcover/ice cover and less vegetation cover resulted in availability of more dust in high altitude atmosphere in higher Himalaya than middle Himalaya. The trajectory of Hysplit model suggests that higher rate of increase in AOD at higher Himalaya than middle Himalaya may results of local mobilization of dust at higher altitude.
Keywords: LST (Land Surfaec Temperature), Snow Cover Fraction, NDVI (Normalized Difference Vegetation Index), AOD (Atmospheric Optical Depth). Himalaya , Garhwal Himalaya. Climate Change.

16. Topographic Influence on Glacier Change under Climate Warming in Gangotri Basin in Garhwal Himalaya, India

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Comparative mapping of the glacier surface in 1968 and 2001 using old topographic sheet and LANDSAT ETM+ suggested 8% decrease with high variation. The spatial variation indicate a higher degree of shrinkage in glacier areas situated in outer boundary of the valley, while glaciers situated in the main valley shows least shrinkage. Relative changes in terrain parameters for the glacier suggest that the particular type of curvature and elevation favors the stability of the glacier body under warming conditions. The glaciers studied in Garhwal Himalaya shows that the glaciers with high relief, larger length and high maximum height are less vulnerable to de-glaciated than others.

The glaciers with small area showing improvement in correlation coefficient between mean elevation and glacier cover and become weakens as the size of the glacier increases. It is found that the curvatures are important for the big glacier and relationship between curvature indices of the new and old glacier surface cover varies with size and showed less significant relationship with small glaciers and strong relationship with big glaciers. The topographic and profile curvature are important for existing of the big glacier, because formation of the big glaciers accumulation of the snow and ice is important, which further turn as glacier stream and flow in downstream. The energy received by old and new glaciers for various classes suggests that newer glacier areas are controlled by terrain characteristics and correlation coefficient is negative and positive for the old glaciers surface.

Keywords: Gangotri glacier, Garhwal Himalaya, De-glaciation, Climate Change, global warming.

Technical Session – III

Display of Posters

Technical Session – IV

Glacier Hydrological Processes and Hazard

1. Hydrology and Suspended Sediment of Melt Water Draining from the Gangotri Glacier System, Garhwal Himalaya, India

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Snowmelt discharge and concentration of suspended sediment of Gangotri glacier, Garhwal Himalaya, was monitored during the ablation periods (June- September) of 1999 - 2009. Large variations in discharge and SS levels are observed in different years. In some years, discharge volume and suspended sediment load is low mainly in response to lower snow and glacier ice melt. Marked variations are noticed in the mean daily discharge and suspended sediment concentrations in different months under the influence of seasonal flushing events. The rate of decline of suspended sediment is much greater than that of the discharge from its peak value indicating exhaustion effect even with apparently unlimited sources of sediments. However, the mean daily discharge and suspended sediment concentration are correlated on the seasonal scale. Tributary glaciers behave differently depending on their location and size. Log transformed sediment-rating curves for the season and rising and falling limbs of hydrographs are developed for each year. It indicated significantly different slope coefficient and constant (at $p<0.05$ in both cases), which means single rating curve is not possible for all these years.

2. An Analysis of Snow-Meteorological Parameters in Gangotri Glacier Region of Uttarakhand Himalaya

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Gangotri glacier is one of the main sources of water to the river Ganga. This is one of the well studied glaciers of India and many studies have been conducted for analyses of glacier retreat, glacier dynamics, geomorphological features etc. of this glacier. However, little is known about the temporal variation of snow-meteorological parameters in the region which directly impacts the glacier retreat and dynamics. In this paper, an analysis of the snow-meteorological parameters recorded in the Gangotri glacier region has been presented. Parameters viz. maximum temperature, minimum temperature and snowfall have been recorded manually at observation station 'Bhojbasa' (30°56'5.59" N, 79°4'26.41" E, ~3900 m asl), nearly 5 km south of Gangotri glacier snout called 'Gaumukh'. Meteorological data for 12 years from 2000-2012 have been presented for annual and seasonal variations. Four seasons winter (December month of previous year, January, February months of year under consideration), pre-monsoon (March, April, May), monsoon (June, July, August, September) and post-monsoon (October, November) have been considered for analysis. Means of the maximum and minimum temperatures have been calculated for each year and each season. Annual mean maximum and annual mean minimum temperatures have been observed to be

11.13±0.68°C (mean ± SD) and -2.24±0.37°C respectively during the past 12 years. Mean of annual snowfall has been observed to be 257.5±81.6cm at the observation station. It was found that the year 2004 was the warmest (mean maximum temperature 12.02°C) in the last 12 years and it also recorded the least snowfall (156 cm). Mean maximum and minimum temperatures for winter season were found to be 3.0±1.0°C and -10.4±1.3°C respectively. Although we do not have a long term data (~ 30 years) to deduce the climatic trends, however, trends in the snow-meteorological parameters during past twelve years have been analysed. Analyses of annual mean maximum and minimum temperature data reveal a warming trend of 0.09°C yr^{-1} and 0.02°C yr^{-1} respectively. A decreasing trend of 3.7cm yr^{-1} has been observed in the annual snowfall. Warming trends in maximum and minimum temperature has also been observed for monsoon season with a rate of 0.11 °C yr^{-1} and 0.008°C yr^{-1} respectively. Interestingly, winter temperature trends have differed from annual and monsoon season trends. During winter season, maximum and minimum temperature reveal a decreasing trend of 0.036°C yr^{-1} and 0.15°C yr^{-1} respectively. The annual and seasonal meteorological trends have been tested for statistical significance using Mann-Kendall and Spearman t-test. Spearman t-test revealed that trends are statistically non-significant within 95% confidence limit and Mann-Kendall test found no-trend in the data.

3. An Analysis Forecasting of Monthly Discharge for Gangotri Glacier Melt Stream using Time Series Analysisof Snow-Meteorological Parameters in Gangotri Glacier Region of Uttarakhand Himalaya

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Mathematical models are often employed to forecast the future trend of flow discharge. The long term prediction results can be widely used in areas such as environmental protection, flood prevention, reservoir control and water resource distribution. Time series analysis is one of the most commonly used method. The Gangotri Glacier (Lat. 30°43′ N–31°01′ N and Long. 79°00′ E–79°17′ E) is the largest glacier of the Garhwal Himalayas. The proglacial meltwater stream, known as the Bhagirathi River, originates from the snout of the Gangotri Glacier at an elevation of 4000 masl. The Gangotri Glacier system (most commonly known as Gangotri Glacier), is a cluster of many glaciers with the main Gangotri Glacier (length: 30.20 km; width: 0.20–2.35 km; area: 86.32 km^2) as its trunk. It is a temperate mountain valley glacier, which flows in the northwest direction. The total catchment area of the study basin up to the gauging site is about 556 km^2, of which more than 50% is covered by ice. The paper considers the problem of forecasting of monthly discharge series. In this analysis the monthly discharge data of 4 years (2010 – 2013) is used and the seasonality and trend components are determined. The series is deseasonalized and subsequently the forecasted monthy discharge series is obtained. The forecasted values for ablation season of 2014 for the months May, June, July, August and September are 27.2, 73.5, 11.8, 104.5 and 55.2 Cumec respectively. The forecasted values can be compared with the observed values and this series can be extended for long term prediction.

4. Assessment of Snowmelt Runoff in the Eastern Himalayan Region Under Climate Change Scenarios

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The increasing trends of near surface temperature have significant impact on glaciers and snow covered regions around the world. With remote sensing and GIS technologies, the extent of snow covered area can be monitored and mapped quite accurately. Use of normalized difference snow index (NDSI) has simplified the determination of snow covered area percentage (SCA%) in the inaccessible basins. Eastern Himalayan region of India is lacking behind in the studies related to snow and glacier melt modelling and impact of climate change to water resources. Nuranang river basin located at Tawang district of Arunachal Pradesh was selected for the present study. The hydro-meteorological data for 2000–2010 were collected from CWC. Satellite images (LISS-III/AWiFS) for five block years (2005–06, 2006–07, 2008–09, 2009–10, and 2010–11) of snow accumulation and depletion period (October–May) were procured from NRSC. Average of snow accumulation and depletion patterns of the basin showed two distinct peaks: a smaller peak in the month of November and a larger one in April. In this study, the snowmelt runoff model was set up using Windows-based Snowmelt Runoff Model (WinSRM). The model was calibrated for depletion period of 2006, 2007, and 2009. During calibration, the selected performance criteria, modelling efficiency (ME) and coefficient of residual mass (CRM) were obtained as 0.65, -0.19; 0.69, -0.08; and 0.63, -0.05 for the years 2006, 2007, and 2009, respectively. Validation of the model was performed for the year 2004 using average values of calibration parameters as obtained for calibration years. From validation results, the ME and CRM were obtained as 0.66 and -0.04, respectively. From the calibration and validation results, it can be said that under limited data availability condition, the WinSRM is satisfactorily modelled the snowmelt runoff process in a representative river basin in eastern Himalayan region. For this study, to evaluate the impact of climate change on snow depletion and snowmelt runoff, projected temperature and precipitation data were downloaded from NCAR's GIS Program Climate Change Scenarios GIS data portal for different emission scenarios, viz., A1B, A2, B1, and IPCC commitment for different future years (2020, 2030, 2040, and 2050). Results showed that change in cumulative snowmelt depth and snow depletion for different future years is highest under A1B and lowest under IPCC Commitment scenarios whereas A2 and B1 values are in-between A1B and IPCC Commitment. It also showed that change in depletion pattern of the basin under climate change affected the time shifting of peak runoff in early spring months. The model indicated that the percentage increase in stream flow for different future years follow almost the same trend as change in precipitation from present climate under all projected climatic scenarios. For the present river basin having seasonal

snow cover, the total stream flow under projected climatic scenarios in future years will be primarily governed by the change in precipitation but the effect of change in cumulative snowmelt depth is visible on change in streamflow when increase in precipitation is almost same for two future scenarios.

Keywords: Climate change, snow covered area, snow cover depletion curve, normalized difference snow index (NDSI), IRS LISS-III/AWiFS, WinSRM, emission scenarios, eastern Himalayan region.

5. Distribution and Variations in Particle Size of Suspended Sediment in Meltwater Discharge Draining from Chorabari Glacier, Mandakni Basin (Central Himalaya))

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Major Himalayan rivers, namely, the Brahmaputra, the Ganges and the Indus originate from Himalaya. These rivers have significant contribution from snow and ice which makes these rivers perennial in nature. Meltwater draining from glacierized basins transports high suspended sediment loads. Glacier meltwater has been extensively used as a resource in the production of hydropower and important factor in the sustainable development of water resources management. The meltwater often carries large amounts of sediment, with a variety of particle sizes ranging from clay (suspended load) to large boulders (bed load) affecting the efficiency of hydropower schemes in variety of ways such as reduction in reservoir water storage capacity, which in turn reduces hydropower generation, erosion of hydraulic structures, damage to hydromechanical and electromechanical parts etc. This is a major problem in the Himalayan region where most of the glaciers are covered by thick debris in the lower ablation zones. The study region has also observed recent increase in number of river valley projects with the primary objectives of storing water for irrigation, power generation and host of other activities at downstream. The major source of water for these projects are proglacial meltwater during the summer season, however, that carries considerable amount of suspended sediment because of the supraglacial debris, subglacial debris, debris entrapped within the ice mass, and formation of sediments due to erosion by the movement of the ice, posing immediate threat to these projects. The objective of the study is to analyze the characteristics and variations in particle size of suspended sediment from a high-altitude debris cover Himalayan glacier (Chorabari Glacier) during the ablation period (June-September) of two consecutive years (2011 and 2012). Textural analysis of sediment supports that mean particle size fraction ranges between 4Φ–5Φ, which is coarser in nature and represents poorly sorted. Particles were found to be symmetrically skewed and kurtosis of mesokurtic texture. The particle size distribution suggests the dominance of coarse silt to fine sand particles (60–70%) without any significant seasonal variation.

Key words: Himalaya, Mandakni basin**,** Chorabari Glacier, Particle size, suspended sediment.

6. Glacial Lake inventory and Risk Assessment in Lahaul-Spiti region, Himachal Pradesh, India

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Glaciers during Holocene Maximum and at Little Ice Age Maxima have advanced and blocked the trunk valleys at various locations. Subsequent thinning and retreat of glaciers has produced glacial lakes in the Himalayas. Evidences are also shows the enlargement of existing lakes in recent decades due to the climate change. The state of Himachal Pradesh has undergone tremendous infrastructural development in past few decades in the higher areas as well. Given the large network of highways and bridges on many of these glacier-fed rivers and streams, it is advisable not only to assess but also to monitor these potential glacial lakes.

Present study deals with preparing inventory of glacial lakes for the Lahaul & Spiti district of Himachal Pradesh on a temporal scale for the years 1989, 2000 and 2013. For glacial lake identification from satellite images, it is preferable to have images with least snow cover and should be cloud free. Least snow cover occurs in the period between July and September in the western Himalayas and best month for glaciological studies is the month of September because this marks the end of melting season. For the present study, cloud free satellite data of September-October months (Landsat TM, ETM) was downloaded from USGS website (www.earthexplorer.usgs.gov) which is freely available.

The glacial lakes & water bodies were first extracted by using Normalized Difference Water Index (NDWI) and then various techniques have been applied to delineate glacial lakes as per the definition of a glacial lake i.e. a water body in close proximity of glacier and dammed by moraine or ice. NDWI method didn't work very well because of the intense shadows in high altitude region of Lahaul-Spiti. Remote Sensing and GIS techniques have been applied to extract actual glacial lakes. First of all shadow effect was removed from NDWI 1 bit map by Raster overlay with the 1 bit slope map. Basic assumption for this was that the lakes can't be located at slopes. After removing the slope pixels from NDWI map, it was converted to polygon feature. Now the second criterion for glacial lakes was taken as the altitude of glacial lakes should be above 3500 meter. For this, 3500 meter contour line was generated from ASTER GDEM and then the line feature was converted into Polygon. Then Polygon overlay analysis was done to exclude the lake polygons below 3500 meters. Third criterion was taken for the size of glacial lakes. Those lake polygons which have a size below 1 hectare were excluded. Finally, the visual interpretation of satellite images was carried out for every remaining lake polygon for manual verification.

All lakes were categorized into three categories based on their temporal behavior. Those lakes which are constant in their size and shape over the years are considered as least potential for GLOF. Intermediate lakes are those which are dynamic and oscillating in their shape and size and the most potential lakes are those which are increasing in size constantly over the years. There are 20 glacial lakes identified in 2013 varying in size from about 1 hectare to 114 hectare. 2 lakes are continuously increasing in size and therefore considered as most potential for GLOF. 5 lakes are considered having least potential. 13 lakes are assigned to having intermediate potential for GLOF. Among the identified two Glacial Lakes, the lake at Sissu glacier has been identified most vulnerable to GLOF because of the proximity to settlement and National highway. Sissu village is only 10 km from the lake directly downstream from the lake. Stretegic Manali-Leh highway (NH-21) which is the only link to Ladakh from Himachal side is directly downstream to Sissu Nala. New emerging lake (Arjun Lake) in Neelkanth valley is also considered potentially disastrous on the basis of its increasing size and proximity to settlements. Thirot Hydal Power station is directly downstream from this new lake therefore needs attention for disaster mitigation.

7. Spatio-temporal Variation of Black Carbon Across Altitudinal, Climatic and Latitudinal Gradients in Kashmir Himalaya, India

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Aerosol black carbon (BC) is highly heat absorbing material and contributes significantly to the atmospheric warming. In this research, spatio-temporal variability of atmospheric BC concentration was monitored across Kashmir valley during 2013-14. However, BC concentration is being continuously monitored at University Campus, Srinagar since 2012. The University BC observation station provides a high temporal resolution BC concentrations (5 minute). Further, spatio-temporal measurements of BC across Kashmir valley were monitored at 42 sites to asses the altitudinal, climatic and latitudinal variation of BC. The analysis of the observed data reveals that BC concentration is negatively correlated with altitude. For example, the observed average BC measurements from Lidder valley are 7098, 3387, 2386, 1338 nanograms (ng) at altitudes of 2127, 2351, 2833, 3363 m (asl) respectively. BC observations from other places show a similar relationship. The highest concentration of BC was found in Srinagar city, located at an altitude of 1580m, ranging 1600 to 18000 ng in spring and winter respectively. Similarly, the lowest BC concentration was observed at the high altitude glacier site, Kolahai, located at an altitude of 3700m asl and the concentration ranged from 114 to 1034 ng. There is also a clear positive relation between the observed BC concentration in atmosphere and climate. Winter season shows the highest concentration ranging from 2300 to 18000 ng at Srinagar which can be attributed to high rate of biomass burning and relatively stable atmospheric conditions. Lowest BC concentration, ranging from 1049 to 4508 ng, was observed during the summer season. Similarly, the analysis of the yearly BC data at Srinagar shows the diurnal peak concentration between 7 AM -11 AM and 6 PM – 11 PM. The analysis of the BC data across the Kashmir valley also showed latitudinal variations that are attributed to the space-time changes of the observed data. In view of the likely impacts of the BC on various atmospheric and land surface processes, it is essential to regularly monitor its concentration so that we could develop a better understanding of the BC impacts on various land surface processes including snow-and glacier melt processes

Keywords: Black Carbon, Kashmir Himalaya, Himalayan cryosphere, land surface processes, spatio-temporal variation

8. Monitoring Glacial Lakes in parts of Northwestern Zanskar Basin, Jammu and Kashmir

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Glacial lakes exercise considerable influence on various important glacier processes such as ablation, energy balance, areal and longitudinal changes. Occurrence and dimensions of glacial lakes is particularly significant with reference to vulnerability to glacial lake outburst floods (GLOFs), which have become a serious natural disaster in Himalayas. Therefore, regular monitoring of glacial lakes is vital for understanding of glacier dynamics and their response to climate change. Satellite remote sensing coupled with relevant image processing techniques greatly facilitates the retrieval of the important glacier parameters including dimensions of glacial lakes.

In the present study, five glaciers of Zanskar basin including Pensilungpa (G1), Durung Drung (G2), G4, Kangi (G4), Hogshu (G5) have been studied with the aim of monitoring the number and dimensions of associated glacial lakes and relate these with retreat, mass balance and debris extent of the these glaciers. For this purpose multi-temporal satellite data of ablation period for years 1977, 1992, 1999/2000, 2011 and 2013 from LANDSAT MSS, TM, ETM+ and OLI sensors and ASTER DEM have been used as primary datasets. G1 and G2 represent the debris-free glaciers while the other three are heavily debris-covered. Mass balance has been estimated using the accumulation area ratio (AAR) approach, snowline has been derived semi-automatically using normalized difference glacier index (NDGI) technique and DEM together with some manual rectifications. Glacier boundaries and glacial lakes have been derived by manual digitization.

Study reveals presence of periglacial (PGL), supraglacial (SGL) and proglacial (PROGL) lakes in the study area. It has been found that the number and dimensions of glacial lakes, in general, and supraglacial lakes in particular have increased in recent years. From 1977 to 2013 number of PGL, SGL & PROGL increased from 0 to 7, 12 to 83 & 0 to 3, respectively. In the same time period, the area covered by supraglacial lakes has increased from 0.034 to 2.31 km^2. Results show that the debris-free glaciers in the region are devoid of supraglacial lakes, however, periglacial and proglacial lakes are found associated with them. Debris-free glaciers in the area are also characterized by higher rates of retreat (G2: 18.47m/yr) and only marginal increase in debris-cover (3.36% in 34 yrs). In recent years, these glaciers have also shown development of some supraglacial lakes and increase in dimensions of the existing ones. The phenomenon of ice-calving has also been observed in the proglacial lake, associated with Durung Drung glacier which may be responsible for its accelerated retreat. Most of the supraglacial lakes (73) have been found to be associated with the debris-covered glaciers and probably a major reason behind their pronounced mass loss (G4: -5.19cm w.e. in 2011) and restricted frontal retreat (G4: 9.1m/yr). Out of the three debris-covered glaciers in the study area, maximum supraglacial lakes (40) are associated with Kangi glacier. With favorable conditions for lake extension , such as extensive debris cover (~ 26% in 2011) and very low surface inclination (2.86°), it is quite possible that in future the small supraglacial lakes on this glacier may coalesce to form a large one. These preliminary findings suggest effective and regular monitoring of glacial lakes is very important in this region.

Keywords: Periglacial lakes, Supraglacial lakes, Proglacial lakes Glacier parameters, Normalized Difference Glacier Index (NDGI), Accumulation Area Ratio (AAR), Mass balance, Glacier retreat.

9. The Influence of Lakes and Debris Cover on Retreat of Glaciers in Sikkim Himalaya

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In recent years, there has been stress on the changing dimensions of glaciers worldwide. The possible cause of this change is climatic, resulting in melting rates of glaciers. However, the regional changes in climate and geomorphologic changes in glaciers can also influence retreat. Thus, in this study, we have explored the role of debris-cover and formation of moraine dam lakes on the glacier area changes, in the data scarce Sikkim Himalayas, between 1990 and 2010, using Landsat TM and IRS images. A new technique of estimating 'interpretation uncertainty' while mapping glacier terminus on satellite images, is introduced, important for the assessment of the results. The study showed (i) a glacier area loss of 3 ± 0.8 % in 20 years. We also observed the presence of lakes on many debris-covered glaciers, and its expansion speeded glacier retreat by 9 ±1.4 %, suggesting an influence of lakes on glacier retreat. Though some 'debris-covered glaciers' showed stable fronts, the gradual development and coalescence of supraglacial lakes led to the formation of moraine dam lakes at the terminus. This investigation suggests that 'debris cover' on glaciers can enhance the development of glacial lakes. As a consequence, the retreat of debris-covered glaciers associated with lakes is clearly higher than that of debris-free glaciers.

Keyword: Sikkim, Debris cover, Lakes.

Initially a glacier inventory was prepared from old topographical map, for an understanding of the distribution of snow, glaciers and lakes in the basin. This was used as baseline information and further study on snow and glaciers area changes were carried out using (i) enhanced MODIS 8 daily snow product, between 2002 and 2010 and (ii) Landsat and LISS III images, between 1990 and 2010.

The estimation of error is crucial for assessing the significance of the results and to avoid misinterpretation. In addition, field observations also helped in the identification and accurate delineation of glacier boundaries.

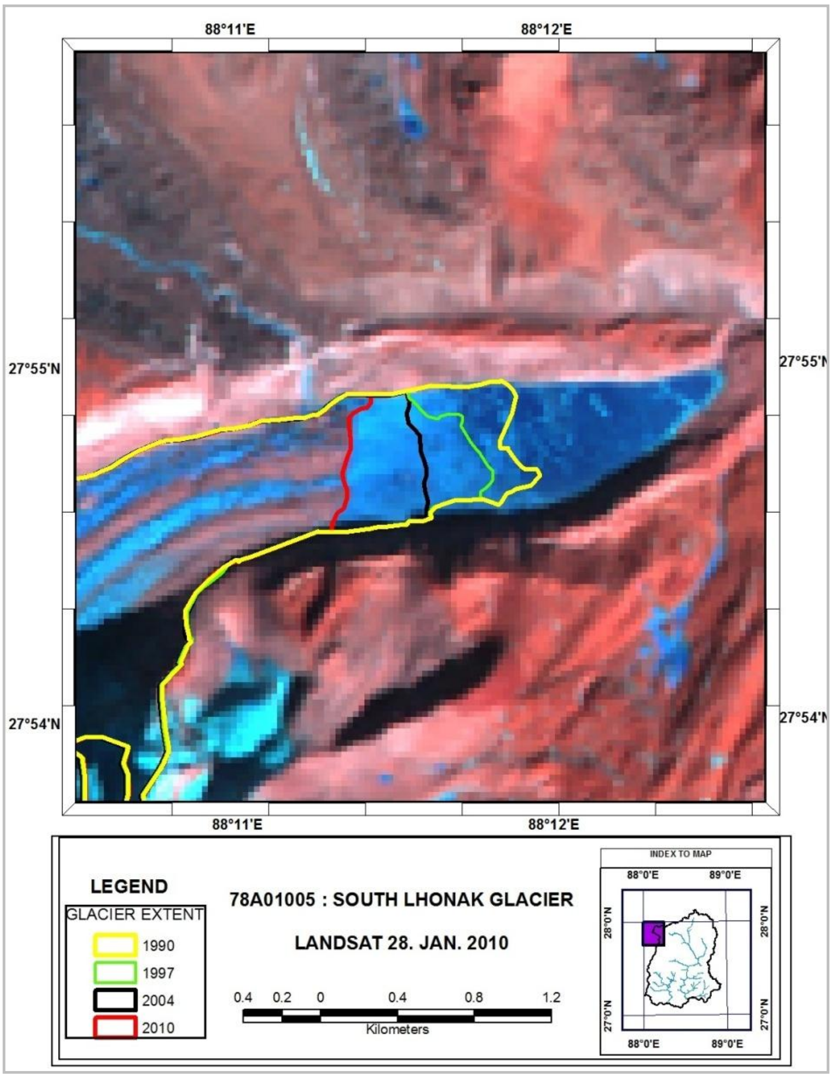

Figure: The moraine-dammed lake at the terminus of the South Lhonak glacier has expanded from 0.44 to 0.72 km^2, between 1990 and 2010. The expansion of the lake has reduced the glacier area by 4.39 %.

The overall investigation showed: (i) an overall decline of 0.3 ± 0.18 % per annum in the snow cover area, (ii) a glacier retreat of 0.16 % per annum, (iii) expansion of lakes, (ii) coalescence of supraglacial lakes into moraine dam lakes, on many debris covered glaciers. These changes are closely related to the a rise 1.0° C rise in the summer minimum temperature and a 2.0° C rise in the winter minimum temperature, for a temperature data analysed between 1987 and 2012, for Gangtok station (1812 m). The results indicate hotter summers and warmer winters.

Warmer temperatures influence the snow fall patterns, as it raises the zero degree isotherm line, which causes snow to fall as rain in the lower and middle regions of the glaciers. The precipitation in the form of rain accelerates melting and further reduces accumulation feed to the glacier system, which weakens the health of a glacier. Moreover the early melting of seasonal snow cover and a significant decadal decline in winter snow cover (- 8.30 ± 5.19 % in December), as observed in this study, could influence the expansion of lakes, as the melt from snow and glaciers drains into the lakes, influencing chances of GLOF (glacial lake outburst floods), in the region. The formation of lakes near the glacier terminus also accelerates glacier retreat, especially at the interface of water and ice, as lake can absorb more solar radiation due to the lower albedo of water.

A need for further investigation on debris cover and lakes is important, as most of the glaciers in Sikkim are covered by debris and are associated with moraine dam lakes. Moreover, many debris-covered glaciers showing stable fronts do not reflect the loss in mass (Kulkarni, 2010, Bolch et al. 2011), thus, volume detection on debris-covered glaciers is important while studying glacier retreat and advance and in predicting future water availability. The region also lacks information on snow precipitation. In addition, most of the regional weather stations are located below 2000 m in Sikkim and may not provide applicable comparisons to the glacier environment. Thus, setting up a glacier observatory would fill the data gap.

10. Simulating Daily Streamflow and Suspended Sediments Load for Gangotri Glacier Using Soft Computing Techniques

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Himalayan rivers are the source of fresh water supply for millions living in the mountains and the downstream regions. The proportion of annual stream flow generated from snowmelt is about 30-50 % of the major rivers of the Himalaya. The interannual variability in streamflow presents challenges in managing the associated risks and opportunities of water resources systems oh Himalaya. Streamflow forecasting is, therefore, of vital importance to water resources planning and management. While short-term (hourly or daily) forecasting is crucial for flood warning, long-term forecasting (i.e. monthly, seasonal or annual) is very useful in reservoir operations and irrigation management decisions such as scheduling releases, allocating water to downstream users, and drought mitigation. The seasonal volumetric streamflow represents an important hydrologic parameter for water supply purposes; it represents spring-summer snowmelt runoff which accounts for a large portion of annual runoff. Hence, seasonal snowmelt runoff forecasting is particularly important in improving water management efficiency and benefiting various water use needs. Further, the large magnitudes of suspended sediment load (SSL) generated from melt runoff forms a part of glacier erosion and sedimentary deposits in the Himalayan foothills and Indo-Gangatic plains. The SSL delivery has important implications on channel morphology, material fluxes, geochemical cycling, water quality, and the aquatic ecosystems supported by the river. Therefore, the sediment transported by glacier-melt streams has received attention because of its impacts on water resources planning and management, designing of reservoirs, transport of pollutants, etc.

Accurate estimation of streamflow and SSL on regional scale is essential to address planning and management of water resources projects in wide spectrum. The dynamics of streamflow and suspended sediment involves inherent non-linearity and complexity due to existence of both spatial variability of the basin characteristics and temporal climatic patterns. This complexity, therefore, leads to inaccurate prediction by the conventional stochastic &

empirical methods. Artificial neural networks (ANNs), over past few decades, have emerged as one of the advanced modelling technique employed in hydrological and water resources. In the present study, simulations for daily streamflow and SSL have been carried out for Gangotri glacier using Feed Forward Back Propagation (FFBP) and Multilayer Perceptron (MLP) algorithms of Artificial Neural Networks (ANNs). The ablation season (May-September) hydro-meteorological data for 10 years (2000-09), collected near the snout of the glacier, have been used. 80% of the data are used for training and remaining 20% are used for validation of the network model. Different input vectors (viz. rainfall, stage, discharge, and sediment load) are considered for examining the effects of input data vector and lastly a suitable modeling approach with appropriate model input structure is suggested on the basis of various model performance indices. The estimated results were compared with the regression and empirical models. The model performances were evaluated by various statistical indices such as coefficient of determination (R^2) and Root Mean Square Error (RMSE) values. The forecasting performance of ANN techniques is found to be advanced to the other statistical and stochastic methods in terms of the selected performance standard in simulating the streamflow and suspended sediment load.

Keywords: ANN, simulation, streamflow, suspended sediment load, water resources, Gangotri glacier

11. Preliminary Study of Stable Isotope in Chhota Shigri Glacier (H.P) India

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To infer the variation in isotopic composition, stable – water isotope data ($\delta^{18}O$ and δD) from five groups of samples (Fresh snow, old snow, snow core, rain water and melt water samples) collected from ChhotaShigri glacier during summer (2013) were presented. Snow core sample traces the variation of $\delta^{18}O$ with depth. Fresh snow, old snow and melt water collected at different altitude has been focused to explore the altitudinal effect on isotopic composition of these samples. Altitude effect on the variation of isotopic composition is best marked by fresh and old snow while melt water did not encounter such effect. Different pattern of $\delta^{18}O$ variation is observed with altitude for the fresh and old snow. Different trend in the depletion of $\delta^{18}O$ of fresh snow and old snow with altitude shows clear demarcation of changes for winter and summer snow fall. This study shows that large variation of d-excess (-1.14‰ to 24.9‰) of all rain water events reflects the influence of local climatic factors as well as south-west monsoon precipitation. Deuterium excess (d-excess) value (1.92‰ to 7.41‰) of fresh snow confirms influence of south-west monsoonal precipitation. Linear regression analysis was applied to stable hydrogen and oxygen isotope data sets for snow core, precipitation and melt water samples in order to establish the local meteoric water line (LMWL) for ChhotaShigri glacier (HP) India. The LMWL was derived with a regression value of 0.99. The LMWL shows an equation $\delta D = 8.5\ \delta^{18}O+12.9$.

12. Spatial and Temporal Change in Glacier Lake Area, Lahaul Valley: Indicator of Temperature rise in Western Himalaya

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Abstract

The direct relationship between glaciers and climate is now known and established. Several studies have been carried out to show that changes occurring to glaciers are the reflections of climatic changes. The global temperature has been reported to be rising in the last century. Analysis of observed data has shown that the temperature of Himalaya has increased more than the global average. Due to rise in temperature, the glaciers of the Himalaya are prone to recede and melt. The melting of glaciers has given rise to the increase in number and area of glacier lakes. The monitoring of glacial lake area thus gives a clear indication of temperature change. Several glaciers are associated with lakes located downstream and are dammed by unstable moraines. These are called as moraine dammed lakes. Due to enhance melting of glaciers, these lakes are on the verge of bursting and causing devastation known as glacial lake outburst flood (GLOF). One such lake is located downstream of Samudra Tapu glacier in Chandra basin, Lahaul valley, Himachal Pradesh. The moraine dammed lake located in downstream of the Samudra Tapu glacier has been monitored from the remote sensing data for its areal expansion between 1980 and 2010. . It is found that the lake is expanding at an increased rate increasing in recent decade. The expansion of the lake downstream of Samudra Tapu glacier can possibly be related with the melting of the glacier in response to the rising temperature of the region. Rapid retreat of glaciers increases run-off, contributes to the growth of glacial lakes. The Samudra Tapu glacier is retreating at a significant rate and it can be argued that the run-off from the glacier is most likely the reason for rapid expansion of the moraine damned lake downstream the glacier.

13. Hydrochemistry of Meltwater Draining from Patsio Glacier,Western Himalaya, India

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Hydrogeochemical investigation of the Patsio glacier meltwater was carried out to understand the sources of dissolved ions in the meltwater. HCO_3^- is the dominant anion followed by SO_4^{2-}, Cl^- and NO_3^-. Whereas Ca^{2+} is the dominant cation followed by Mg^{2+}, K^+ and Na^+. High (Ca+Mg)/TZ+, (Ca+Mg)/(Na+K) ratios and low contribution of (Na+K) to the total cations show that dissolved ions chemistry of the study area are mainly controlled by carbonate weathering with minor contribution from silicate weathering. The C- ratio of the meltwater shows that coupled reactions involving carbonation dissolution and protons derived primarily from the oxidation of sulphide.

The average ratios of Na/Cl and K/Cl in the meltwater are significantly higher than the marine aerosols indicating relatively small contribution of these ions from the atmospheric input to the total dissolved ions budget of the study area. Correlation matrix and principal component analysis were used for identification of various factors controlling major ions chemistry of meltwater.

14. Factors Controlling Meltwater Discharge from Chhota Shigri Glacier, Himachal Pradesh, Monsoon-Arid Transition Zone, Western Himalaya

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Meltwater discharge from Chhota Shigri Glacier, Himachal Pradesh has been monitored during the ablation months of 2010, 2011, 2012 and 2013 at the discharge station established at about 1.5 Km downstream of the glacier terminus using the area-velocity method. While the peak discharges were observed during July-August, the inter-annual variability of meltwater discharge has been quite significant during the observation period. An attempt has also been made to prioritize the factors controlling meltwater generation in the glacier catchment. While the stream discharge closely followed solar radiation and air temperature measured near the Equilibrium Line Altitude of the glacier, it displayed variable time lag for early and late ablation periods, signifying variable temporary storage in the glacier body. During the early ablation period, secondary discharge peaks came after 2-3 days of air temperature peaks, suggesting that it was predominantly snow-melt generated. The influence of precipitation events on discharge was more complex as inferred from the study. Whereas in general moderate rainfall had a dampening effect on discharge, major rainfall events that were observed near the discharge station, either significantly augmented the discharge or dampened it depending on the placement of the event in the ablation season. Changes in surface albedo were found to play a critical role in bringing about these sub-seasonal discharge fluctuations. Solar Radiation was the dominant driver controlling snow and ice ablation and consequently the most important factor that determined the quantity of melt water discharge emerging from the glacier catchment, with secondary contribution from liquid precipitation events.

15. Isotopic Characterisation of Precipitation at South Pullu, Leh & Ladakh, J&K

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Precipitation acts as a primary source of water on land. The meteoric processes modify the isotopic signature of precipitation at a given location. Thus, it becomes imperative to understand the variation in the stable isotopic composition of precipitation to understand the hydrological processes.

Globally many studies have been carried out to understand the source of precipitation and the factors controlling their composition using stable isotopes of oxygen and hydrogen. Factors influencing isotopic composition of precipitation are source of moisture, evaporation,

condensation and moisture exchange between land and atmosphere during transport of moisture. These processes result in variation in isotopic signatures of precipitation from regional to continental scale.

The precipitation samples collected at South Pullu, Leh during the June 2010 to September 2013 are analysed for $\delta^{18}O$ and $\delta^{2}H$. The results show that the $\delta^{18}O$ of precipitation in study are varies from -285‰ to 0.6‰ and corresponding $\delta^{2}H$ -222.6‰ to 28.0‰. The temporal variations are also noticed. It is found that during pre-monsoon the $\delta^{18}O$ of precipitation varied from -17.0‰ to 0.6‰, during monsoon months (July to September) -26.6‰ to -2.9‰ and during winter -28.5‰ to -8.2‰. The maximum depleted rainfall in terms of oxygen isotope ($\delta^{18}O$) is observed in the month of December, August, November and January are -28.5‰, -26.6‰, -24.7‰ and -27.7‰, respectively during study period. Similarly, the maximum enriched $\delta^{18}O$ in rainfall observed in the month of June 2010, June and July from -6.0‰ to 1.2‰. The LMWL of study area is $\delta^{2}H = 8.4 \times \delta^{18}O + 17.2$; $R^2 = 0.98$ which shows slightly higher slope 8.4 and high intercept 17.9 in comparison to GMWL ($\delta^{2}H = 8.17 \times \delta^{18}O + 11.27$) and IMWL-North ($\delta^{2}H = 8.15 \times \delta^{18}O + 9.55$). It is similar with LMWL of Tuotuohe stations of Tibetan Plateu with slope of 8.2 and intercept of 17.5. The higher slope and intercept of precipitation is due to source of vapor from the western disturbances whose source is Mediterranean Sea.

16. A Preliminary Study on the Growth of Lhonak Glacial Lake in Sikkim Himalaya, India.

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The paper deals with the study of South Lhonak glacial lake located in extreme North western part of Sikkim Himalaya, India. The lake has rapidly increased in its size within a few decades. The lake has increased from 17.9 ha in 1976 to 126 ha in 2013 as per time series satellite images. So it has drawn attention of the people working in the field of glaciers and glacial lake outburst floods (GLOF) studies. Glacial lake outburst flood is a major glacial hazard that can cause huge damages of life and property in the downstream valley. In the present study, effort are made to present the ground condition and surrounding areas of the lake based on remote sensing and field based studies. Through the cross section generated from topographic map of South Lhonak Glacier, we try to find out the probable expansion in area of the lake in the future. A theoretical approach on the development of the lake has been discussed in the paper based on the topography of the lake. Precautionary measures are suggested in order to minimize the future risk of GLOFs based on the field visit. Though the study is limited to preliminary field observation and lab based work, the study will provide vital input for mitigation and adaptation if incase of future GLOF events.

17. The Importance of Temperature Lapse Rate for Snow Hydrology.

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In the present study, an attempt was made to estimate Land Surface Temperature (LST) and its lapse rate over Kashmir Himalayas using MODIS LST data and relate it with in-situ observational data of air temperature (T_{air}) from Indian Metrological Department (IMD). Observation network. Comparison between MODIS LST and ground-observed air temperature (T_{air}) shows a very close agreement with the maximum error of ± 2^0C . The calculated correlation coefficient between T_{air} and MODIS LST is above 0.9. The analysis shows that the LST is showing an increasing trend during the observation period (2002-2012) at all locations except at Qazigund located in Southeastern part of Kashmir valley.. The operational use of the satellite derived LST could improve the quantification of the land surface processes in mountainous Himalayas where the meteorological observation network is very poor. Using the ASTER Digital Elevation Model (DEM), MODIS LST data was used to estimate the Lapse rate along various transects across the mountainous Kashmir Himalaya, which showed variations ranging from 0.3^0C to 1.2^0C per 100m changes in the altitude depending upon the space and time. This observation is at variance with the commonly used uniform lapse rate of 0.65^0C in most of the hydrological and other land surface models over the mountainous regions when the observations are scanty. The snowmelt runoff models are sensitive to the temperature and the use of wrong lapse rate in mountainous regions, where the observation network is scanty, could affect the estimation of the snowmelt runoff in a substantial way. It is hoped that the satellite derived information about the LST and the lapse rate is going to improve the understanding and quantifications of various processes related to climate, hydrology and ecosystem where the use of temperature and lapse rate is an important and critical driving force as demonstrated in this research. The LST determined Lapse Rate when used in the SRM model gave a much better agreement with the observed discharge compared to the simulations run with the standard temperature lapse rate of 0.65^0C.

Keywords: MODIS, Land Surface Temperature, IMD, T_{air}, Lapse Rate, Ecosystem dynamics. ASTER DEM.

18. Glacier Surface Velocity: Spatio-Temporal Monitoring of Landslide Debris

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Glacier surface velocities provide vital information about glacier dynamics. Fluctuations in these velocities are deciding factor for glacier advances or retreats and play an important role in glacier mass balance. Slopes adjacent to glaciers are susceptible to landslides and can deposit huge amount of debris over glacier. This landslide induced debris deposit over glacier can significantly alter glacier activities such as ablation rate and flow

rate. Spatial variations in margins of these debris deposits over the time can give direct indication of surface velocity of underlying glacier. Landslides are very common in mountainous regions but are rare phenomenon in Karakoram Himalaya due to glacial conditions. But few landslide events have been reported from this region. One such landslide was reported from North Terong glacier in 2000. Recently, in 2010, a large landslide has been reported from Siachen glacier. Due to least accessibility and limited field work possibilities in Karakoram Himalaya glaciers, regular in-situ monitoring or surface velocity observations are not feasible. Satellite remote sensing offers practical approach for obtaining data and allows studying such inaccessible glaciers. This paper presents the glacier surface velocity estimation for North Terong glacier and Siachen glacier using landslide induced debris deposit over these glaciers. Spatio-temporal changes in landslide induced debris deposit were mapped using satellite data of Landsat TM, ETM+ and OLI. Carefully marked debris margin gave position of debris for different dates. Surface velocities estimated from these debris margin positions showed variations for different periods. Landslide debris over North Terong glacier traversed a distance of more than 1.5 km and found to be surging, whereas, Siachen glacier showed relative stagnancy. Study also puts a research prospect to study such landslide events in Karakoram Himalaya and their impacts on glaciers under global climate change scenario.
Keywords: Glacier surface velocity, Landslide Debris, Karakoram Himalaya, Remote Sensing.

Technical Session – V

Geomorphology, Paleo-glaciation & Climate Change

1. Late Quaternary Glaciations in Indian Himalaya: An Overview

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The pronounced oscillations in global climate during the late Quaternary witnessed major changes in types and rates of operation of geomorphological processes, among these the most spectacular manifestations of climatic changes were the expansion and contraction of glaciers which caused widespread modification of land surfaces. Caused due to the natural forcing factors, the late Quaternary glacier fluctuations can provide important background information for our understanding of natural forcing factors in modulating the behavior of valley glaciers. The study would be helpful towards understanding the response of Himalayan glaciers under the warm earth scenario.

Reconstruction of past glaciations is based on the mapping of the evidences of past glaciations such as extent of the glaciated valleys, trim line and most importantly the accurate mapping of the lateral and or terminal moraines. These features allow us to reconstruct the shape and magnitude of the former valley glaciers. However, moraine which are the direct expression of former ice cover are at times discontinuous (particularly in monsoon dominated regions) and at times relatively younger and larger advances of a glacier can destroy older and less extensive moraines, leaving an incomplete geomorphic record (Benn et al., 2005). With these limitations, however, in the recent past, some progress has been made towards understanding the nature and extent of glaciations during the late Quaternary. The reasonable chronology obtained on moraines allows ascertaining the nature of climatic variability more specifically the temporal changes in moisture condition (Owen et al., 2006; Dortch et al., 2010; Nagar et al., 2013; Nawaz et al., 2013; Nawaz and Juyal, 2013; Sati et al., 2014).

In this presentation a broad summary of the work done in the Indian Himalaya on the Quaternary glaciations will be presented. Considering that chronology of moraine constitutes a major component for climatic reconstruction, a brief introduction to three major dating techniques that are routinely used will be discussed. This will be followed by a synthesis of the work done on Quaternary glaciations in the Indian Himalaya. Finally, tentative inferences followed by future prospective are suggested.

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2. Geomorphological Complexity of Glaciation in the Himalaya

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There are unequivocal records of multiple glaciations in the Himalaya in the shape of variety of landforms. Be it the trough, hanging valleys or the glacigenic deposits, these all and are exist all over. Chronological comparison of these glaciations and climate events still remain elusive for "*want*" of acceptable ages across the mountain. There is no certainty as to which of the precipitation regimes dominated the Indian Himalaya during the glacials and inter-glacials. But erratics of Potwar (Cotter, 1929), Bara Shigri and Kangra (Egerton 1864; Theobald 1880) are still there, waiting to be dated for deciphering the magnanimity and magnitude of glaciations across the Himalaya!! The Indus valley around Ladakh is reported to have a mega glacier sometime half a million years ago only; fragments of that glacial still exist. Were these glacial of the same phase, we are yet to know? But what is clear is that the Himalayan glaciers once descended to unimaginably low altitudes of just 750 meters above sea level! It is understood now that the successive glacial were many degrees smaller than the previous ones. As the later episodes were many fold smaller than the previous glacial, these advances should not to have obliterated the last record. In such a situation, one should have had plenty of sites, landforms and deposits suitable for establishing magnitude and chronologies. It is only at few sites that such remains are still intact but for the post-glacial reworking in dynamic environments such as the Himalayas. Geomorphological relicts present today are the troughs, trimlines and drumlins which indicate not only the closest possible terminal position at least at the maximum expansion but also the waxing and waning of the ice mass of the very same glaciers that exist even today. But these features are also few and far between in different geographical locations. The backland-foreland relationship of the glacials and river terraces has not been attempted as yet but these that hold the greatest of potential to build on the perfect chronologies and magnitude of the past episodes. These midlands and forelands areas are the true repositories of the past depositions, along with the strath terraces and many sets of high up benches. Since the technologies/techniques for chronological reconstruction are abundant now, a complete scenario would emerge by fusing disciplines and enquiries.

The dimension of the past episodes of glacial is not correlative across the Himalayan valleys. This paper would synthesize the geomorphological records and dimension of glaciation across the Himalaya vis a vis the timings and correlations wherever available; and try to relate with the precipitation regimes that dominated at the time of these episodes. This paper would cover only those areas which have been personally investigated over past three decades. The current understanding of recent glacial fluctuations, both positive and negative, would be the central theme, along with societal relevance of glaciers and de-glaciation over time and space.

3. Late Quaternary Glacial Advances and Palaeo-Climatic Reconstruction in the Pindari Glacier Valley, Kumaun Himalyaw

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The timing and the extent of various episodes of Late Quaternary glaciations is not very well documented in the Indian Himalayan region. Based on the need for accurate reconstructions of the former extent of glaciers in the monsoon dominated central Himalayan glaciated terrain, systematic studies related to the Quaternary glacial advances and Palaeo-climatic reconstruction have been carried out in the Pindari glacier valley located in the Kumaun Himalaya.

Based on the relative position of the lateral moraines, degree of lithification, vegetation cover, morphology and soil formation, five glacial stages (Stage-I-V) have been identified between the modern glacier snout (3740 masl) and up to 23 km downstream (2200 masl) (Bali et al., 2013). Poorly preserved moraines belonging to Stage-I (MIS IV?) glaciation occur as linear degraded patches at 2200 masl, ~ 23 km downstream of the snout. The Stage-II glaciations (25 ± 2 ka) represented by moderately consolidated, sharp crested linear latero-frontal morainic ridges are deposited at 3200 masl. Stage-III glaciation is represented by degraded linear moraine ridges (6 ± 1 ka), disposed around 3850 masl. The Stage-IV glaciations (3 ± 1 ka), is manifested by the presence of sharp crested lateral moraines. These can be traced laterally to a distance of ~3.5 km (from around 3650 masl to 3900 masl) from the present day glacier snout. Set of cresentric shaped recessional moraines constituted of dominantly large boulders mark Stage-V, possibly in response to the Little Ice age.

A 435 cm deep Glacio-lacustrine deposit has been analysed using multiproxy data. Correlation of the Palynological and Environmental magnetic parameters aided with ^{14}C and Optically Stimulated Luminescence (OSL) dates has helped in deducing six discrete climatic zones (PG-I to PG-VI) (Bali et al., 2014). In PG -1, the presence of an alpine meadow with scattered arboreal taxa along with the lower values of χlf, χARM and SIRM at around 7 ka BP suggests the existence of colder and relatively drier climatic conditions. In the second zone (PG-II), between 7.0–4.9 ka BP, an event of amelioration of the climate (prevalence of warmer and humid climate) is witnessed. This is evident from the dominance of arboreals over the local non arboreals and fern allies as well as higher concentration of the magnetic minerals. In PG-III, the warm and humid phase in the Pindari valley is followed by cold and drier climate between 4.9 ka to 1.75 ka BP as evidenced by the dominance of non-arboreals over the arboreals and low concentration of magnetic minerals indicating the existence of vast Alpine meadow. In the fourth zone, PG- IV, between 1.75 ka to 0.9 ka BP (~Medieval Warm Period), the climate of the area was warm and humid (dominance of arboreal with higher concentration of magnetic minerals). During PG-V that prevailed between 0.9 ka to

0.3 ka BP, a drastic climatic change has been witnessed (~Little Ice Age) as evidenced by the relative decline in conifers and broad leaved taxa. The sediments of this zone also show lower values of the magnetic susceptibility. In the last zone, PG- VI, since the last 300 yr BP onwards, the vegetation complex along with high magnetic susceptibility indicates warm and moist climatic regime.

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4. Optical Chronology Suggests Trans Himalayan Glaciers Responded to the Enhanced Mid-latitude Westerly During the Last 30 ka

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Compared to the monsoon dominated central Himalaya, where the high surface erosion, constrain the preservation of older glacial deposits (Sati et al., 2014, Owen et al., 2006), the Trans-Himalayan glaciers provides unique opportunity to understand the Quaternary climatic history. Considering, above we have investigated one of the most spectacular glaciated Khardung valley which is located in the north of Leh town (Fig. 1). The Khardung valley was carved by the Khardung and its tributary glaciers during the late Quaternary. Presently the Khardung glacier has shrunk towards the northwest and is confined to the Ladakh Batholith dominated Khardung Ridge at an elevation of ~5400 m (Fig.1). Detailed field mapping using Total Station Survey (TSS) supported by the satellite imagery indicated presence of two distinct events of glacier expansion of decreasing magnitude. The older event which is named as the Khardung Glacial Advance-I (KGA-I) descended down to a distance of ~14 km and terminates near Ganglas village (3783 m). Geomorphologically, KGA-I is expressed in the form of a distinct laterofrontal moraine ridge and can be traced upstream at an elevation of ~4000 m. (Fig. 1). The younger KGA-II advance terminates around South Pullu (4507 m) and is significantly modified by the paraglacial processes particularly the frost shattered debris flow fans.

In order to ascertain the chronology of Khardung valley glaciations, four samples viz. three from KGA-I and one from KGA-II have been optically dated. The older KGA-I is bracketed between 30±3 ka to 24±2 ka whereas the younger KGA-II gave an age of 18±3 ka (Fig. 1). The age estimates imply that the Khardung glacier responded to the winnowing phase of the humid Marine Isotopic Strage-3 (MIS-3) and the expansion persisted during the early part of the MIS-2. Interestingly, the younger advance (KGA-II) broadly corresponds to the Global Last Glacial Maximum (LGM). Our observations are at variance with the exposure ages obtained by Brown et al., (2002) and Owen et al., (2006) but confirm the observation of Burbank and Fort (1985), and more recently by Nagar et al., (2013) that in the mid-latitude westerlies dominated Trans Himalayan glaciers responded synchronously with the global LGM.

The presentation will discuss the climatic implications of the new chronology obtained from the Khardung valley.

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5. Towards improving our understanding of Holocene glaciations in monsoon dominated regions of Himalaya: evidence from Dronagiri valley, Garhwal Himalaya, Uttarakhand, India

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Detailed field observation supported by optical and radiocarbon dating are being present for Dronagiri Valley which is a small monsoon dominated tributary of Dhauliganga upper alaknanda Catchment Garhwal Himalaya. Field stratigraphy and optical and radiocarbon dating of lateral moraines provide evidence for three major glaciations during the last 12 ka.

The Bangni Glacial Stage-I (BGS-I)has been the oldest and most extensive one, which is dated between 12 and 9 ka. It terminates aroud 3200 msl. The Bangni Glacial Stage-I has been followed by the BGS-II glaciation (7.5 and 4.5 ka) and the BGS-III glaciation (_1 ka).

In addition, discrete moraine mounds proximal to the present day glacier snout are attributed to the Little Ice Age (LIA). BGS-I started around the Younger Dryas (YD) cooling event and persisted till the early Holocene when the Indian Summer Monsoon (ISM) strengthened. The less extensive BGS-II glaciation, which occurred during the early to mid-Holocene, is ascribed to lower temperature and decreased precipitation. Further reduction in ice volume during BGS-III is attributed to a late Holocene warm and moist climate.

Although the glaciers respond to a combination of temperature and precipitation changes, in the Dunagiri valley decreased temperature seems to be the major driver of glaciations during the Holocene.

6. Evidences of Two Phase of Glaciation in Yunam lake, During the Last Glacial Maximum NW Himalaya, India

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The Yunam palaeo-lake basin (32o 47’ 59.76” N and 77o 26’ 18.54” E) is located at an altitude of 4, 573 m asl toward north of Baralacha Pass in Lahual and Spiti district. Yunam Lake has been reconstructed using field observations, satellite image and GIS analysis. The area has preserved extensive glacial landforms including glacial valley fill deposits, moraines, kettle holes and varved sections. Field observation suggests that Kilang Sarai region has experienced two stages of glacial advancement during Last Glacial Maximum (LGM). During glacier advancement the debris from the glacier, blocked the Yunam River and formed the Yunam palaeolake basin, which is confirmed by the preservation of 8 m thick varve laminated section within the basin. The presence of glacial outwash under bottommost part of the varve laminated section show earlier phase of deglaciation when debris-laden water transported the morainic sediments from the upper valleys during the glacial recession phase. Radiocarbon dating of the laminated varves section suggested the blockade of Yunam River took place around 25 ka and the topmost part of the lake section was dated 3 ka signifies the breaching of lake at 3 ka. Since the Yunam basin is situated between the two flanking moraine ridges, we suggest that there existed a wide basin which supported a lake till the recent past, called Yunam Lake.

Key words: Yunam Lake, LGM, Himalaya, Baralacha, Radiocarbon

7. Influence of Climate Change on Glaciers in Baspa Basin, India.

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Glaciers and snow cover in the Himalaya play an important role in the water resource management in North India, as large number of people relied on the melt water from glaciers for hydro-power generation, agriculture and domestic purpose. However, this source of water is not permanent as its availability depends on the distribution of glaciers. Therefore, monitoring the glacier retreat and mass balance is important. In the present study, a total of 19 glaciers in Baspa basin are selected to estimate the glacial retreat and mass balance. The retreat is carried out between 1962 and 2009. The surface area in 1962 is obtained using topographic maps of survey of India; for the years 1998 and 2009 by using Landsat TM imagery. The areal extents were estimated as 173, 145.2 ± 10.1 and 131.9 ± 8.37 km^2, respectively. An overall de-glaciation of 24% (41.1 ± 8.37 km^2) has been observed from 1962 to 2009. Between 1962 and 1998, the loss in glacial area is 0.45 %/a and it got increased by 1.55 times after 1998.

The hypsometry obtained from ASTER DEM and a polynomial fit are used to calculate the ELA, for five years between 1998 and 2011. The mean ELA varies between 5146 ± 178 and 5320 ± 172 m, respectively. Then Mass balance is calculated using Accumulation Area Ratio (AAR) method and the negative mass balance is estimated for all five years. In addition, the temperature data of Raksham (3050m) and precipitation data of Kaza (3600m) are analyzed to understand long-term trend. This suggests an increasing trend in annual temperature and decreasing trend in annual precipitation between 1984 and 2009. Thus, all the observations suggest a continuous loss of glacial mass which influences the future distribution of glaciers and water resource availability in Baspa basin.

Keywords: Baspa, Retreat, mass balance, ELA, Remote Sensing.

8. Extension of Snowfall Records for Western Himalaya, India Using Tree Ring Data.

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Understanding snowfall variations in high-elevation cold-arid regions of the western Himalaya is important as the snowmelt water is the main source of water to meet the scores of socioeconomic needs. The ground-based observational data, though limited to last two decades, show decreasing snowfall raising the concern of looming water scarcity in the region. The short span of snowfall data constrains our understanding on the natural variability in snowfall and its future predictability. The tree-ring data of Himalayan cedar from high-elevation cold-arid sites in the western Himalaya, where snowmelt water is the sole source of soil moisture available for tree growth, were used for the first time to develop November-April snowfall anomalies back to AD 1565. The decadal variability in snowfall anomalies out-of-phase with the independently developed mean summer temperature record for the same region underscores the strength of the reconstruction. The North Atlantic Oscillation (NAO) and El Nino Southern Oscillation (ENSO) show competing non-stationary relationship with snowfall anomalies over the western Himalaya. The strength of NAO and ENSO relationships with snowfall has fluctuated in tandem with the 20-year oscillatory mode in Pacific Decadal Oscillation (PDO) indicating that slowly evolving PDO can modulate the NAO/ENSO related climate predictability of the region.

9. Holocene Climate and Glacier Extent within Gangotri valley, Garhwal Himalaya: Review

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Monitoring of some Himalayan glaciers shows a continuous retreat of their snouts at various rates in response to present climate. To better understand and correlate the glacial response to the changing climate, knowledge of past glacial extent beyond the instrumental

records is important, which are available only through proxy data analyses from various geomorphological features left behind within the glaciated valleys. Here we generalize the longitudinal and lateral extent of the Gangotri glacier during Holocene in correlation with the reconstructed climatic episodes. Palynology based climatic reconstruction shows intermittent cool phases during Holocene, encountered around 8.3 ka, 2 ka, 1 ka and 800 – 200 yrs BP (Ranhotra and Kar 2011). During early Holocene the glacier snout was probably much downstream from the study sites and under retreating condition, but the lateral extent of the glacial ice remained lower than the altitudes (~4,300 and ~4,000 masl) of study sites. Also the glacier never elevated to these altitudes during entire Holocene despite few advancing episodes. Bernard et al., 2004 documented Kedar glacial stage around 7 ka BP, which may be the end stage of a transient cool event recorded from ~8.3 ka to 7.1 ka BP. This was followed by the paraglacial activity coinciding with the subsequent warm phase. The middle Holocene, when Shivling advance has been documented around 5 ka BP, cannot be well resolved climatically due to low time resolution of the palynological samples and date constrains. However the recent efforts on the reconstruction of glacier extent from the other Himalayan valleys viz. Rukti, Sangla valley in Himachal Pradesh (Ranhotra and Bhattacharyya 2010) and Kedarnath in Uttarakhand (Mehta et al., 2012) suggests the extent of glacier snouts at the altitudes of 3,300 to 3,500 masl during 7 to 5 ka BP respectively. Considering these longitudinal extents as an analogue, the snout position of the glacier within Gangotri valley during mid Holocene also might have been ~9 km downstream around the altitude of 3,500 masl from the present altitude of 3,900 masl. During Late Holocene the two short lived glacial stages viz. Gangotri Stage and Bhojbasa Stage around 1 ka and 300-200 yrs BP coincide with the Medieval Warm Period (MWP) and Little Ice Age (LIA) climatic phases respectively. The palynological investigation of a sedimentary sequence from the Bhojbasa outwash plain suggests the cool moist conditions since ~2000 yrs BP and subsequent warm conditions during 1700 to 800 yrs BP. The Bhojbasa Stage reported around 1000 yrs BP might be the result of added moisture to the glacier during cool-moist conditions preceding MWP.

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10. Application of Tree Ring Data in Analyzing Glacier Movement from the Himalayan region

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Analysis of tree ring data from trees growing close to snout of Glacier of the Himalayan Region has profound importance in the study of glacier movements from both Eastern and Western Himalayan region. They are potential indicator to date the recent evidences of glacial fluctuations in terms of absolute time scale by changing their growth pattern in response to long-term climatic changes responsible to variations of glacier fluctuations. Tree-ring data of some conifers viz. *Pinus wallichiana* growing in the sub-alpine region of the Kinnaur (Bhattacharyya & Yadav 1996), *Abies pindrow* confined to the snout of the Dokriani Bamak Glacier (Bhattacharyya *et al.* 2001), *Cedrus deodara* (Borgaonkar, et al., 2009) and *Pinus wallichiana* (Singh & Yadav 2000) close to Gangotri glacier exhibited low growths during years with a positive glacial mass balance and with glacial advances reported during the recent past in the Himalayan and Trans-Himalayan region Western Himalaya. Tree rings of birch (*Betula utilis*) growing along moraines around Bhojbasa, close to the snout of the Gangotri glacier exhibit increased tree growth in recent years coincide with the rapid retreat of the Gangotri glacier. This believed to be the cumulative effect of several climatic parameters that enhanced tree growth, i.e., increased precipitation in March, April and June, increased winter temperature and low snowfall which seem also to be responsible for rapid retreat of glacier (Bhattacharyya *et al.*, 2006). Reconstructed tree-ring-based snowfall record of November–April extending back to A.D.1460 (Yadav et al., 2013) based on tree-ring data of *Cedrus deodara* may provide insight to glacier movement indirectly since high snow fall favors positive mass balance. Available, tree ring based glacial study in the Eastern Himalaya reveals that *Abies densa* growing close to tree line of North Sikkim exhibits a negative relationship with the glacier movement recorded earlier by GSI from Zemu glacier, and also with mass balance records of glaciers of China.The foregoing review of tree ring/glacier analysis of the Himalayan region reveals that tree ring data could be a pivotal tool for the analysis of tree growth/climate glacier analysis in the Himalayan region. In future, in addition to trees (both broad leaved trees/ conifers), analysis from trees/shrubs growing close to existing glacier would also provide the information on climatic changes vis-a-vis glacier fluctuation of the region during the recent past. There is huge possibility to get sensitive trees from both Western and Eastern Himalaya and it will also possible to reconstruct longer past glacier movement which is vital for understanding of climate change. This information would also provide database for the effective management of water resources of this region by realistic estimation of the impact of the climatic changes in glacial accumulation and ablation in the discharge of water in the river.

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11. Discrimination of Aeolian Dust from Fluvio-Glacial Sediments Using Environment Magnetism, Texture and Visual Evidences from Chorabari Glacier, Central Higher Himalaya, India

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The study discriminates the aeolian dust embedded with glacio-fluvial sediments using environmental magnetism, granulometry, SEM and field evidences from Chorabari glacier. The bivariate ratios of SIRM/χlf to B_{CR} suggest ferrimagnetic (magnetite) minerals in nearby Chorabari Lake while Chorabari fluvio-glacial profile exhibits both ferrimagnetic and anti-ferrimagnetic (Hematite) minerals assemblage in alternative layers. Despite the similar source of sediments, the variation in the magnetic mineralogy in both the sites indicates that the anti-ferromagnetic fraction seems to be contributed by aeolian dust of exterior source. On the basis of two OSL ages, the Chorabari glacier witnessed six aeolian phases during 1.3 to 2.9 ka (kilo years) which are synchronized with heavy snowfall events. The semi angular grain and visual evidences of aeolian dust layer in fresh snowfall supports the interpretation.

Key words: Aeolian, Glacial deposits, fluvio-glacial, Environmental magnetism, Magnetic minerals and Himalaya.

12. Aerosol Asymmetry During Contrasting Monsoon Seasons Over Shimla Region

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Atmospheric aerosols and gases influence weather, climate and hydrological cycle directly through scattering and absorption of solar and terrestrial radiation, and indirectly by their effect through clouds. The monsoon circulation influences the natural spatiotemporal variation pattern of aerosols and its modulation by anthropogenic activities. These feedback processes are bi-directional. In some regions such as Himalayas, the impact of black carbon (BC) on melting snowpack and glaciers may be equal to that of CO_2 (Ramanathan et al., 2013). By absorbing the solar radiation and mixing with anthropogenic aerosols such as BC, dust can also increase the rate of glacial melting by deposition on the glaciers' surface (Lau et al., 2010). Each year, during pre-monsoon and monsoon seasons, large quantities of sand and dust are emitted from the Thar desert or long-range transported from the Middle East, Arabian Peninsula and south-west Asia, affecting nearly the whole Indo-Gangetic basin (Dey et al., 2004; Aher et al., 2014) and western Himalayan range (Dumka et al., 2014). In this paper, combination of active and passive remote sensing techniques from ground-based and satellite platforms has been applied to investigate the seminal changes in aerosol distributions during successive contrasting south-west monsoon seasons. For this purpose, ground-based data from AErosol RObotic NETwork

(AERONET), and concurrent satellite data products from Moderate resolution Imaging Spectrometer (MODIS), Ozone Monitoring Instrument (OMI-TOMS) sensors, Cloud-Aerosol and Infrared Pathfinder Satellite Observation (CALIPSO, Version 3.1), over a high-altitude station located in the middle ranges of Himalayas viz., Shimla (31.06^{o}N, 77.13^{o}E, 2100 m AMSL) India, during normal (2008) and drought (2009) monsoon seasons were analyzed. The results show higher values of columnar aerosol optical depth, effective radius, single scattering albedo, and smaller Angstrom exponent during normal monsoon season, and vice-versa in the case of drought year. These features are consistent with those derived from the MODIS and OMI satellite data. Various aerosol and cloud parameters, retrieved from the CALIPSO data, during normal monsoon year depict low total attenuated backscatter, more spherical particles in the lower altitudes and non-spherical at upper altitudes, dust-free clouds and more vertically extended ice clouds during normal monsoon years as opposed to drought years. Aerosol type analysis indicates less abundance of urban industrial/biomass burning aerosols during normal monsoon years. The large-scale meteorological fields and long-range air-mass transport characteristics, derived from ECMWF/NCEP/NCAR re-analysis data and NOAA-HYSPLIT model, respectively, have been examined. The above results would play significant role in our understanding of the complex aerosol-glacier-climate interactions, particularly the modeling efforts in this direction.

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13. Late Quaternary Glaciations and Climatic Records along Triloknath Glacier Area, Lahul Himalaya

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Triloknath is a north-westerly flowing glacier (5Q21209) and is located in the fourth order Chenab basin in Lahul and Spiti district of Himachal Pradesh. The present glaciological studies initiated in this area seem to be very significant as the area lies in the transitional zone receiving precipitation dominantly from the Indian Summer monsoon and also having contributions from the mid-latitude westerlies. The preliminary morphostratigraphy established on the basis of present day disposition of the lateral moraines, recessional moraines and associated landforms suggests that the area has been subjected to multiple glaciations. A geomorphological map is being prepared after going through the glaciogeomorphic disposition of the area in general and detailed investigation of the different sets of lateral moraines, recessional moraines and associated geomorphic features in particular.

Based on the relative position of the lateral moraines, degree of lithification, vegetation cover, morphology and soil formation, at least four phases of glaciations have been identified between the modern glacier snout. A latero-frontal moraine found to be well preserved along an adjacent valley at Jhalma suggests the maximum advancement of the glaciers in the Chandra Bhaga valley to have taken place sometime during the pre- LGM / LGM times. Dating of the different sets of moraines is still under process.

Two palaeolacustrine deposits have been located within the Kame terraces along the left and right valley wall. A 2.14 m pit along the right valley wall ((32° 39′ 57″ Lat. And 76° 40′ 08″ Long.) shows sub-angular matrix supported lithoclasts at the base followed by alternating layers of medium to fine sand/ coarse sand/ intercalations of silt and clay. Prominent layers of charcoal have been found at various levels. Charcoal at 122 cms from the base has been AMS dated at 2430 ± 30 years BP. High resolution sampling for palynological, geochemical, environmental magnetic and grain size analysis has been collected. Similar sampling has also been carried out for another 4.14 m deep pit located along the Left valley wall. The multiproxy study currently under process will provide a detailed information about the middle to late Holocene climatic changes as well as the timing of glacial maxima in the Lahul Himalaya.

14. Aerosol Over the Parbati Glacier: A Major Threatening for Future

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The Parbati glacier is one of the largest glacier in the Parbati basin, a major tributary of the River Beas, which is fed by almost thirty-six small glaciers covering an aerial extent of 188 km^2. Due to steep slope in the upslope region from the mouth of the Parbati glacier, this basin is highly potential for hydropower development and water supply. Here, some major hydropower projects (Parbati II- 800 MW and Parbati-III 520 MW) are under construction. Based on past studies of the Parbati glacier, its retreat was considered to be fast. Recently, based on landsat data it is found that average retreat of this glacier between the period 1980 to 2013 was 4.92 km^2 which is about 33.02% decrease of its total glacier surface area.This rate of retreat seems to be notable. To find some of the causes about retreating the Parbati Glacier, the snow samples from the glacier area were collected for ion analysis. Aerosol is considered to be one of the major reasons to trap the heat in snow environment, reducing albedo and melting faster the glaciers. In this regard, aerosol optical thickness (AOT) and columnar ozone in the Parbati glacier was measured from 5 July 2014 to 13 July 2014. The mean AOT value at 500 nm was observed to be 0.17, while this value ranged from 0.08 to 0.25 as minimum and maximum respectively. This fast retreat of the Parbati glacier may affect the downstream availability of water in coming future.

Keywords: Glacier retreat, ionic concentration, Aerosol Optical Thickness, Parbati glacier

15. Aerosols and Snow Chemistry Over the Beas Kund Glacier, Himachal Pradesh

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Aerosols are solid, liquid and gaseous pollutants which remain under suspension within the atmosphere. These pollutants have a great potential to perturb the radiative balance of the Earth-Atmosphere system. This results in forcing the regional climate in a numerous pathways leading to complex responses in the Earth-Climate system. In addition, direct radiative interaction with solar and terrestrial radiation by means of scattering and absorption, aerosols modify the cloud microphysical properties (indirect and semi-direct effect) and reduce the albedo of the snow due to deposition of anthropogenic aerosols and black carbon (BC) on it. Beas Kund Glacier (32 º 36' N, 77 º 08' E, 3610 m) is one of the debris fall or rock covered glacier in the Himalaya. This glacier played an important role to influence River Beas basin or the Kullu valley for many ways like irrigation, hydropower generation, tourism activities and horticulture. This glacier has a glacier lake named Beas Kund which fed River Beas whole of the year. This glacier is very small in size and melting faster. So impact of deposited particles on this glacier and their sources are very important to study. In snow samples of the Beas Kund glacier, major water soluble inorganic ions such as NO_2^- (73.0 μeq/L), Ca^{2+} (40.3 μeq/L), NH_4^+ (26.6 μeq/L) and SO_4^{2-} (19.6 μeq/L), Mg^{2+} (14.8 μeq/L) and Na^+ (8.9 μeq/L) were first time reported in a glacier of the north-western part of the Himalaya. The highest AOD value was 0.22 at Beas Kund Glacier. Among anions, NO_2^- and among cations NH_4^+ were observed to be most important loaded species in snow. While Ca^{2+} was found to be high at a depth of 0-20 cm or on the surface of glacier which could possibly be due to transport of mineral dust from outside sources. According to HYsplit backward trajectories, it indicates that Arabian and other dust contribute to ionic concentration in the snow samples of the Beas Kund Glacier and its surroundings. In essence, it is found that both the sources- local and external have been playing their role in contributing aerosols in the present region.

Keywords: Aerosols, Radiative forcing, Albedo, Inorganic ions and HYsplit model

16. Preliminary Optical Chronology Suggests Early Holocene Glacier Expansion in Monsoon Dominate Sarswati Valley Garhwal Himalaya

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Detailed reconstruction of the chronology of Holocene glaciation provides a proxy for the quantification of regional and global climatic changes. In monsoon dominated Himalayan region, the glacial history is being increasingly used for studying the monsoon response to

Holocene climate variability (Sati et al., 2014 and reference therein). Additionally these studies areimportant considering the sensitivity ofHimalayan glacier to climate changes,which are required to understand thepotential evolution of the glaciatedregions in response to global warming(Gayer et al., 2006).In the present study weinvestigated a monsoon dominatedSarswati valley (north of Mana village)for reconstructing the Holocene glacierhistory. Sarswati valley is fed bymultiple glacier streams that emanatesfrom the the east and west facingglaciers (Fig. 1). We sampled thelateral moraine that was depositee in temperature is attributed to a dynamic response which resulted in both a decrease inincoming shortwave radiation at surface due to an increase in cloudiness and an increase inevaporative cooling. Additionally our data indicate that the increase in ice volume (glacieradvance) during the Holocene in the Sarswati valley which began during the Younger Dryascooling was sustained due to the albedo driven positive feedback mechanism.

17. Effect of Black Carbon Aerosol on Himalayan Glaciers and Climate Variability: A Review

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In this paper, formation and growth of black carbon aerosols (BC) and its influences on the atmosphere and retreat pattern of Himalayan glaciers is summarized. Effect of black carbon aerosols on Earth's Radiation Balance that in turn influence the optical properties (albedo and optical thickness) of cloud formation and their effect on climate are examined. It is considered that in higher altitudes direct and indirect radiative forcing is very small due to low concentration ofrs and their distribution over Himalayan glaciers is also one of the important aspects of climate change. The precipitation pattern has been changed due to direct effect of Black Carbon aerosols over tropical oceans. Growing industrialization, urbanizations and anthropogenic activities has enhanced the aerosol concentrations over the foot hills regions of Himalaya and Indo Gangetic Plain (IGP) throughout the year and advection of BC about various formation mechanisms operating in different environments.

18. Impact of Climate Change on Acridoids Diversity and Status in Shiwalik Himalayas of Himachal Pradesh

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As time and money is limited, explicit, cost-effective, quick, and appropriate methods are needed to assist conservation planners and managers for making quick decisions. Insects promise to be a good model for rapid assessment and habitat monitoring studies because they are widespread, conspicuous, and easily recognizable and they are effective indicators of all ecosystem health. We conducted a rapid assessment of Acridoids insects in Shiwalik Himalayas of Himachal Pradesh. Shiwalik hills is very rich and diversified, primarily due to varied climatic conditions and symbolize one of most fragile natural ecosystem situated at

29° - 33° North latitude and 74° - 80.5° East longitude, in the southernmost zone of Himalaya. Current Scenario present bio-ecological studies in Shiwalik Himalayas of Himachal Pradesh revealed the presence of 30 species of Acridoids belonging 25 genera and 2 families. In the present investigations it was observed that Acrididae, represented by 26(87%) species, spread over 21(84%) genera and 9 subfamilies and Pyrgomorphidae represents only 4(13%) species belonging 4(16%) genera. Analysis of seasonal fluctuations in the diversity of acridoids revealed that there were significant increase in the orthopteran diversity from December (16-species) to September-October (28-species) and then a decrease to December/January. During the course of present investigation, relative abundance studies showed that hills are very rich in Acridoids fauna and acts as a home to a total of 30 species, out of which, 15(50%) were very common, 7(23%) common, 6 (20%) uncommon and 2(7%) rare species. Moreover, the Current scenario indicated that there is 0.276% per year average increase trends in pest population of *Hieroglyphus oryzivorus* in a decade. There is an alarming increase of pest population in this region i.e. from 2001-2010.

Verma et.al. (2009) studied the total snowfall received during 1973-75 period was 190.53 cm which in 1981-85 increased to 827.38 cm, declined to 101.9 cm in 1986-1990 further reduced to 78 cm in 2006-07, and it was only 15 cm in the year 2009 and about 17% decrease in rainfall in Shimla was observed from 1996-2000 onwards till 2007 in Shimla and Solan. Bhutiyani et.al. (2007) the gross rise in the mean air temperature during 1980-2002 periods in north western Himalayas as a whole was about 2.2^0C. Such rapid climate change will not give plants and animals enough time to adapt to the new situations. Biodiversity loss, besides the immediate impact on species, will affect the health, wellbeing and livelihoods of the people who rely on such resources. Climate change may pose serious threats to the biological diversity of the planet, and is projected to become an increasingly important driver of change in the coming decades. Pollution from nutrients, the introduction of alien invasive species and the over-harvesting of wild animals through hunting or fishing can all reduce the resilience of ecosystems, and thus the likelihood that they will adapt naturally to climate change.

For any effective measure it is necessary to have a sound knowledge of the diversity, bioecology, status and impact of climate change on the target group. Himalayan ecosystems face mounting threats to biodiversity from anthropogenic disturbance. In recent decades, urbanization, commercial activities, and excessive resource use has reduced most natural forest habitats of this area to degraded remnants. Because of these threats, modern studies of biodiversity are critical for conservation of the Himalayan ecosystems.

Technical Session – VI

Societal Impacts and Adaptation Strategies

1. Shrinkage of Satopanth and Bhagirath Kharak Glaciers in the Recent Past

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In the context of recent trend of global warming in Himalaya, we have discussed about the recession of the Satopanth (SPG) and Bhagirath Kharak (BKG) glaciers. Long term records of glacier fluctuations are scarce in Indian part of the Himalaya. In most of the records of changes in length of glaciers 1962 Survey of India (SOI) topographic map is used as a baseline. Thereafter, more or less regular data is available during end of the 20th century and beginning of this century, often because of the availability of good quality satellite images. So, there is a clear need for concerted efforts to collate existing scattered information on recent glacial extents for various glaciers in Indian Himalaya and also to cross-check with other independent measurements whenever they are available.

A number of studies have discussed the effect of recent warming on Uttarakhand glaciers. Several studies have been done on Satopanth (SPG) and Bhagirath Kharak (BKG) However, a systematic study incorporating all these data is lacking. Studies also indicate that glaciers with a thick debris cover respond qualitatively differently to a warming climate as compared to debris free glaciers. Debris free glaciers approximately retain their shape (thickness profile), consequently, the changes in their length reflect the changes in their volume. On the other hand, debris covered glaciers change their shape in response to warming and there is considerable thinning in the lower ablation zone. Consequently, the length changes do not necessarily reflect the ice volume loss. Hence, for debris covered glaciers like SPG and BKG there are need to study the thickness changes in the lower ablation zone as well. Thus we studied the shrinkage, i.e. length and thickness loss of these two glaciers.

In this paper, we have used accounts and maps produced by past explorers in the region, published/unpublished records, satellite images, and our own field data to obtain a coherent picture of the shrinkage of the twin glaciers. We have investigated the accuracy of the 1962 SOI Toposheet boundaries for these glaciers and have revised the previously reported retreat rates of the twin glaciers in the recent past.

During 1936-2013, we estimated the mean retreat rates of the snouts of SPG and BKG 10.9 m/yr and 6.6 m/yr respectively. The study revealed a volume loss of 0.012 km^3 in the lower ablation zone of SPG, with a corresponding thinning of glacial ice by 36 m in past 51 years. We interpreted the shrinkage in terms of the regional climate changes as well as local geo-morphological factors. We observed that the glacier fronts as depicted in the Survey of India Toposheet published in 1962 are inconsistent with other available records and current observations.

2. A Critical Assessment of Glacial Melt Fraction in River Water in the Bhagirathi basin

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The Bhagirathi basin is a relatively small subbasin of the Ganga basin which merits attention on account of two major reasons in the context of glacial melt fraction estimation.

1. It has a large glacier (the Gangotri glacier) which is considered to be one of the fastest receding glaciers globally, thereby, providing limiting conditions for glacial melt contribution in the Himalayan rivers.
2. There is a reasonable possibility of relating of the estimation of melt component of the glacial mass balance/retreat measurements which actually span for ~100 years for this glacier and represent one of the longest monitored glaciers in the world.

In view of above, especially the second rationale, reverse calculation can also allow us to establish a relationship between glacial melt estimated using isotope based hydrograph separation and that derived from mass retreat measurement.

Total glaciarized Area of the Gangotri group of glaciers is 755.47km^2 out of which the area of Gangotri Glacier is 143.58 km^2. Thus, ~19% of the total ice covered area of the Gangotri is represented by the Gangotri glacier for which detailed measurements of 60 years are available. Using topographic sheets, surveying records and satellite imagery data it has been estimated that the Gangotri glacier has vacated ~ 5,78,100m^2 in 61 (1935-1996) years (Shrivastava, 2012) which implies an annual retreat of 9477 m^2. If the retreat rate of Gangotri glacier is projected over the entire Gangotri glacierized area or the glacierized area than annual ice retreat for the Bhagirathi basin works out to be 0.0502km^2(9477m^{2}x 5.3). The estimates of melt water contribution in Ganga vary considerably (Bookhagen and Burbank, 2010, Immerzeel et al., 2010, Ericsson et al., 2011) widely. One of the studies carried out at Rishikesh and upstream of Rishikesh indicates this contribution to be ~30% (Maurya et al., 2011).Annual Water flow of Bhagirathi River at Gaumukh is approximately 1km^3. At Midstream it increases to 4.2km^3. Further downstream at Devprayag it is 6.3km^3**.** Considering a specific gravity of 0.9 the Bhagirathi discharge in ice equivalent= 6.93km^3. With nearly 1/3rd of discharge of the Bhagirathi River, upstream of Rishikesh the ice equivalent works out to be ~2.06km^3. Following this annual average vertical loss (h = Volume /area) works out to 41.2 m (2.06km^3/0.0502 m^2= 41.2 m) which appears to be an unrealistic figure as such vertical ablation almost never reaches double figure.

Isotopic analysis of pre and post monsoon samples was carried out using a 3-component mixing model with modified end member component. The minimum estimate for glacial melt fraction appears to be ~9% at the exit point of the Bhairathi River. Post monsoon samples indicate significantly higher and unrealistic glacial melt fraction (~44%) using this method and are considered unsuitable. Wide variability in the oxygen isotopic composition of precipitation (δ^{18} 3 to -30 parts per mil), especially in a basin with relief of the order of few kilometers, has been inferred to be the cause of this anomaly.

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3. Understanding the Floristic and Agri-horticultural Diversity Behavior in Response Climate Change in the Naradu Glacier of Baspa Basin in Himachal Pradesh

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High mountain regions of Himalayas are globally important biodiversity hotspots and are facing rapid loss in floristic diversity and changing pattern of vegetation due to various biotic and abiotic factors. Therefore the present study was conducted in the Baspa valley of Kinnaur in NW Himalaya in the backdrop of Naradu Glacier having total area of *c.a.* 3.7 km^2. We sampled 34 sites occurring between 1950-4500m for vegetation analysis. Sites were selected based on different topographical features such as habitat types, altitude, aspects, slope, and different vegetation types. Delineation of 15 forest and alpine communities (9 tree, 5 shrub and 1 herb community) was done based on Importance Value Index for the tree communities and relative density for the shrub and herb communities. Total tree density ranged from 205-600 Ind/ha and total basal area, 08.70-42.41 m^2/ha Shrubs and herbs densities ranged from 105.0-1030.00 Ind/ha and 22.08-48.73 Ind/m, respectively. Saplings and seedlings densities ranged from 40.0-1040.00 Ind/ha and 20.0-1313.00 Ind/ha respectively. Shrub density is maximum in *Cedrus deodara-Picea smithiana* mixed community and herbs density is maximum in *Poa alpina-Agrostis stolonifera-Bistorta affinis-Aconitum violaceum* community. Among five major shrub communities, *Spiraea canescens-Lonicera hypoleuca* mixed community has highest shrub and herb density i.e. 540.00 Ind/ha and 48.73 Ind/m^2 respectively. Species richness ranged from 19-96 and it was highest in *Pinus wallichiana* (96 spp.) community. Climate change due to declining /erratic snow fall behaviors has impacted regeneration of several species at mid to higher elevations. Poor regeneration was observed in *Pinus gerardiana*, *Quercus floribunda* communities and in tree line species like *Betula utilis* making these community highly unstable and species vulnerable. We observed that poor number of *Betula utilis* seedlings at lower elevations compared to higher elevations. There was also an upward movement of *Pinus wallichiana* along treeline species like *Betula utilis* showing the broad altitudinal range of Pinus species.

High species diversity and species richness was recorded in northeastern aspect as compared to the southeast aspect because these slopes have lower temperatures and higher soil and air moisture contents as compared southern and other slopes at the same altitude due to high solar exposure, poor soil and air moisture and high evapo-transpiration. The species richness of new invasive weeds like *Conyza*, *Bidens*, *Erigerons* and *Ageratum* is increasing in linear fashion replacing local plant diversity continuously and posing a serious threat to the regional ecosystem. Low relative densities of rare and high value medicinal plants *viz*., *Aconitum heterophyllum*, *Aconitum violaceum*, *Picrorhiza kurrooa*, *Podophyllum hexandrum*, *Saussurea obvallata*, *Saussurea gossypiphora* has necessitated the focus of site specific study on these species. In Baspa valley apple belt has been shifted by about 300m during last 20 years and this increased growing period at higher altitudes is showing the impact of the climate change. The frequency of occurrence of new insect-pest in various agri-horticulture crops have increased significantly. Other climatic events such as increase in cloudy, rainy and frost days, and declining /erratic snow falls, drying natural water sources are being noticed frequently.

4. Long Term Trend of Heavy Precipitation Events Over Northwest Himalayas

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In present study, the frequency of rather heavy (>34.4 mm) and heavy (>64.4 mm) precipitation events over northwest Himalayas has been studied using the available long term meteorological surface data (1901-2010) from India Meteorological Department (IMD). Three stations namely Srinagar, Qazi Gund and Banihal stations over northwest Himalayas have been considered due to their consistent long term daily data.

The study shows that the frequencies of rather heavy precipitation events are maximum in the month of March over all the three stations. But in case of frequencies of heavy precipitation events, Qazi Gund & Banihal receives in month of March and Srinagar receives in month of December. The least number of rather heavy and heavy precipitation events occur in month of October over Qazi Gund & Banihal and in month of November over Srinagar. November month was found free from heavy precipitation events over Srinagar and in October over Banihal.

Analysis of data shows that there is an increasing trend in rather heavy and heavy annual precipitation events over Srinagar and decreasing trend over Banihal & Qazi Gund.

Seasonwise, there is an increasing trend in rather heavy precipitation events over Srinagar in all the seasons except winter. However, trend is statistically significant (95% confidence level) for post-monsoon season only. But in case of Banihal, there is opposite trend in rather heavy precipitation events, which shows a decreasing trend in all the seasons except winter. Over Qazi Gund, trend is increasing for winter & monsoon seasons and decreasing trend for pre-monsoon & post-monsoon seasons. Trend of heavy precipitation events also studied in the paper. Results are presented in detail in the paper.
Keywords: Heavy precipitation, northwest Himalayas, rather heavy precipitation and trend.

5. Development vs. Conservation: A study of Socio-economic Vulnerability of Bhagirathi Basin in Context of Sustainable Development

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A mountain system bound to have a different path of development owing to its fragile ecological and geological setup. Any drastic and abrupt changes in this system can have repercussion beyond mitigation in form of natural disasters. Remote sensing can play a key role in risk assessment and management, especially when a few simultaneous reasons coincide, for example, susceptibility to natural disaster and the urban sprawl, spreading over highly vulnerable regions. The present study furnish socio-economic vulnerability mapping of the Bhagirathi basin through computation of the Socio vulnerability Index (SoVI). SoVI correlates vulnerability to natural or anthropogenic disasters to socio-economic development and illustrates how developmental parameters alter equation of potential effect and recovery in event of a natural catastrophe in the study region. An analytical framework has been imparted to understand possible triggering factors of disasters. Built up area expansion; land use land cover change (LULCC) – deforestation, conversion of forested land into agricultural land and residential settlements, and dam project area; road network development; urbanization; population growth & migration and pilgrimage activities are major drivers which put burden on limited carrying capacity of the natural resources. A guideline for policy making has been presented for an integrated and wholesome development incorporating regional developmental aspiration of the people and ingredients of sustainable development.
Keywords: Social Vulnerability Index; Land Use Land Cover Change; Conservation; Sustainable development.

6. Glaciers of Himachal Himalaya- Their Sustenance and Adaptive Measures in Climate Change Scenario.

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Himachal Himalaya comprises of different ranges from Siwalik in South, Pir Panjal, Dhauldhar, Great Himalayan Range and Zanskar in north. The major drainages are Satluj,Beas,Chenab and Ravi. Himachal has different climatic zones which varied from warm and moist to cold and dry, the precipitation is both in liquid and solid form brought by active winds as Western Disturbance Convection(WDC) and south-west monsoon. Precipitation due to south west monsoon is mainly in form of rains only except in higher reaches as graupel/slit most of which melts away as the ablation season of the glacier is active in the area.

Himachal Pradesh has an area of 55673 sq km and administratively there are twelve districts. Six of these districts are namely Kangra, Kullu, Kinnaur, Shimala, Chamba and Lahaul & Spiti district are glacierised. The total glacierised area is 3799.07 sq km which constitutes 6.82% of the total area. There are 2100 glaciers and the locked-up ice resources is 227.06 cu km.,Bara Shigri glacier is the largest glacier with a length of 27 km.

Lahaul & Spiti is the most glacierised district with 1127 glaciers covering 15.37% of the total district area. Other glacierised districts are Kinnaur-396 glaciers,Kullu-267 glaciers,Chamba-205 glaciers,Kangra-87 glaciers and Shimala-18 glaciers(Sangewar,2008).
Primarily, glacier sustenance is mainly dependent on the amount of mass added(precipitation in solid form) and its periodicity. The variations in the average area per glacier in the Satluj basin is reflective of the precipitation inputs in the area(Sangewar and Shukla,2001).

Geological Survey of India had initiated assessment of mass balance of glacier since 1973(Sangewar and Siddiqui, 2010) and presently Hamtah glacier is being monitored. Himalayan glaciers were also being studied for its recessions over the years since 1906.
The in-situ observations of mass balance and secular movement of glaciers in the present day climate change scenario needs to be enlarged in different climatic zone to have a comphrensive assessment of 'health' of glaciers and assess the impact of climate change over a period of time.

Now a day the faster pace of developmental activities closer to the glacierised area needs judicious planning, constant monitoring of active geomorphic processes and awareness programme for the Masses.

7. Assessment and Analysis of Average Annual Precipitation of the Indus, the Ganges and the Brahmaputra Basin, India

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Three major rivers namely the Indus, the Ganges and the Brahmaputra draining the southern Tibetan plateau and the Himalaya contribute more than 50% of the river discharge of India. The Upstream or elevated areas of these major basins has variable but significant Cryosphere cover. The total discharge is a function of the precipitation associated with the southwest monsoon, snow/glacier melt water and ground water.

There is a wide variability in reported average annual precipitation data for these three basins with the values for the Indus varying from 423 mm to 1035 mm and from 1097 mm to more than 2500 mm for the Brahmaputra basin it varies. To address this Tropical measurement Mission(TRMM) generated radar precipitation raw data pixel size (apprx 27x27 km2) for eleven years period from 2000 - 2010 was used for estimating the annual precipitation. The results indicate 434mm, 1094mm and 2143mm annual precipitation for the Indus, the Ganges and the Brahmaputra Basin respectively. There is significant basin scale variability in the precipitation. The Contoured distribution of precipitation indicates the orographic control as the primary factor on the summer monsoon precipitation in the Ganges and Brahmaputra basins. Indus basin behaves largely independent of the Indian summer monsoon. The isohytes of three basins show that there is a decreased influence of Indian summer monsoon. Using a combination of digital elevation models and contoured precipitation maps the secondary influence of the heated Tibetan plateau and similar features on the dissipation of summer monsoon is evident in the elevation controlled distribution of the Precipitation.

8. Trends of Snowfall over Catchments of Sutlej River in Himachal Pradesh

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The importance of energy in national development hardly needs any emphasis. Of all the sources of energy, the hydro-energy ranks only next to solar energy in environmental friendly option. India is blessed with immense amount of hydroelectric potential and ranks 5th in terms of exploitable hydro-potential on global scenario. As per assessment made by CEA, India is endowed with economically exploitable hydro-power potential to the tune of 1,48,700 megawatt (MW) of installed capacity of which the Indus Basin in northwest India has the probable installed capacity of about 33,832 MW. Sutlej and Beas are the two important tributaries, which are perennial rivers. Sutlej rises from beyond Indian borders in the Southern slopes of the Kailash Mountain. It enters India in Himachal Pradesh at Shipki (altitude of 6,608 metres) and flows in southwesterly direction through Kinnaur, Shimla, Kullu, Solan, Mandi and Bilaspur districts. It is the largest among the five rivers of Himachal Pradesh. Its course in Himachal Pradesh is 320 km. The catchment area of Sutlej in Himachal is 20,000 sq. km. A large share of the inflow into these rivers comes from the monsoon rains. However, the snowmelt from the catchments contributes significantly towards inflow during the dry season from March to June. Large parts of these catchments receive heavy snowfall during the winter season. The storage of snowfall in the form of snow and glaciers in the mountains provides a large amount of potentially available water and also regulates the annual distribution of the water. To study the trends over catchments of Sutlej Rivers in Himachal Pradesh, daily snowfall data of 37 winter seasons (viz from 1977-78 to 2013-14) of 13 snowfall recoding stations for the months of November to April is used to analyzed snowfall trends. Data is analyzed on monthly and seasonal basis.

Average seasonal snowfall for the entire catchment was found to be 262.9 cm; the highest being for the month of February (78.8 cm) followed by March (68.1 cm). The months of February and March together contributed about 55.9% of the total seasonal snowfall. The total seasonal snowfall showed a decreasing trend of 3.8 cm per year. This trend, however, was not found to be statistically significant. Trend analysis carried out for each month brought out that the trends were not statistically significant for any of the month. These were negative for all other months, the highest negative trend is observed in the month of March (2.3cm per year). The season was divided into three parts –early (November-December), middle (January-February) and late (March-April) to further analyze the trends. It has been found that the ending part of the season had the highest negative trends (-2.5 cm/year) followed by beginning part (-1.1cm/year) and middle part (-0.1 cm/decade). This analysis brings out that the decreasing tendency in snowfall was higher during early and late parts of the season whereas snowfall in the middle part was stable. Further analyses of beginning and end of snowfall season brought out that there was none significant tendency for the season to begin late by three days per decade where as the cessation of the season was practically trendless.

Decadal analyses of snowfall pattern has brought out that the both of total snowfall and total number of snowfall days have decreased in the last decade as compared to the previous two decades except for the month of February where the snowfall has increased slightly.

Key words: Winter, snowfall, snowfall days, Sutlej Catchment

9. Variation in Monsoon Rainfall Intensity Over Himachal Pradesh During Last Century

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Study of rainfall intensity is very essential over Himachal Pradesh region of Himalayas in many aspects like climate change, modeling of soil erosion, design structures etc. As Himachal Pradesh received precipitation due to mid-tropospheric westerlies systems in winter and due to low level easterlies or due to interaction of easterlies and westerlies in monsoon season. A study is carried out to find the variation in monsoon season rainfall intensity over Himachal Pradesh during last century. For this purpose, daily rainfall data of seven stations of Himachal Pradesh namely Dehra Gopipur, Kangra, Kangra (Palampur), Kilba, Hamirpur, Kotkhai and Nurpur between the period 1901 to 2003. Intensity of particular month is calculated by dividing the total monthly rainfall by total rainy days of that particular month. Analysis of data is done by using parametric and non-parameteric techniques like linear regression methods and Mann-Kendall test respectively. In the series test is said to be significant if confidence level is 90% and more. Analysis of data shows that in general rainfall intensity has increased over Himachal Pradesh during the study period. The significant increasing are observed over Dehra Gopipur, Kangra, Kangra (Palampur) and Hamirpur between the period 1901 to 2003.

10. Temperature Analysis in Naradu Valley, Himachal Himalaya

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Looking into the scarcity of temperature data in the high altitudes of Himalaya, a satellite based temperature data for Naradu glacier, Himachal Pradesh, available at Giovanni website (developed by GES DISC, NASA) has been analyzed for twenty five years (1985-2009). This data has been validated with the lower altitude temperature records in the Baspa basin of H.P. The analysis is to determine the changes in the maximum, minimum, and mean air temperatures. Different statistical tests like Mann-Kendall test, Spearman Rank Correlation (SRC) Test, Sen's Slope (SS) and Sequential Mann Kendall Test has been applied on the air temperature data and their results are in agreement. The analysis subjected for monthly seasonal, and annual data revealed a tendency of warming with significantly warmer winter and more significant increase in minimum temperatures. The annual

maximum, minimum and mean temperatures have increased by 1.41°C, 1.63 °C and 1.49 °C respectively. The seasonal analysis indicates that the tendency is more pronounced in winter followed by post-monsoon, pre-monsoon and monsoon season. The monthly analysis showed a significant warming in all the months for mean, minimum and maximum temperatures except February during the period of 1985-2009.

Keywords: Higher Himalaya; Naradu; Annual temperature trends; Seasonal temperature trend, Himachal Himalaya

11. Indicators of Glacial Retreat From Jorya Garang Glacier of Baspa Valley, India.

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Himalayan glaciers are considered to be one of the potential natural reserves of freshwater which sustain perennial flow in Indian rivers. Glaciers develop characteristic landforms of erosional and depositional nature, which withhold the imprints of glacial processes and are sensitive indicators of climate change. The present retreating trend of the glaciers will have manifold impact over discharge of rivers, irrigation and hydel power generation. Therefore, monitoring the health of glacier is of utmost importance and requires serious attention. Monitoring of glaciers due to rugged terrain and inclement weather conditions is difficult with traditional field techniques. Hence, an attempt has been made to measure the retreat of Jorya garang glacier by mapping geomorphic indicators of glacial retreat through remote sensing techniques. The geomorphic features which are mapped through LISS- III + PAN merged data of IRS 1D satellite are viz. accumulation zone, ablation zone, snout, deglaciated U-shaped valley, trimlines, hanging valley and most important are morainic ridges. The north facing Jorya garang glacier is characterized by large accumulation zone and gently sloping ablation zone covered with huge amount of debris. These debris are further carried by the glacier and are accumulated in the form of morainic ridges.

The 3 sets of terminal moraines and 2 sets of lateral moraines are prominently seen from satellite data and are varified in the field. These morainic ridges are found to be an important glacial geomorphic indicators and their number of sets can be correlated with the stages of deglaciation. The stage 1 lateral and terminal moraines are covered with vegetation and at places by debris or rock falls. Stage 2 and 3 terminal and stage 2 lateral morains are less weathered and suggest later stage of their formation. These moraines does not breach the stage 1 lateral and terminal moraines, indicating the gradual lengthwise and widthwise recession of the glacier. This retreat is also supported by hanging valley, U-shaped deglaciated valley and trimlines on the sides of valley wall. These trim lines can be a very good indicator of the thickness of glacier in the past. The total lengthwise evacuation measured for Jorya Garang glacier up to the year 2005 from maximum glacial limit comes to about 3880 m. The snout elevation since past glacial maxima as demarcated from satellite data is shifted from 3886 m to 4209m and shows surface evacuation of 3.22 sq km area.

Keywords: Remote sensing, Geomorphic indicators, glacial retreat.

12. Recession of Milam glacier, Kumaon Himalaya from Stereo data of CORONA to CAROSAT

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The Himalaya is the adobe of world's largest and mostly inaccessible area of glaciers outside the Polar Regions and provides glacier-stored water to the major Indian rivers. Various studies suggest that many of the Himalayan glaciers have receded in recent decades due to climate change.

In the field of glaciology, satellite remote sensing has proven to be the best tool because, many of the glaciers are located at very high altitude, cold weather and rugged terrain conditions, making it a tedious, hazardous and time-consuming task to monitor by conventional field methods. Satellite remote sensing technology facilitates to study the behaviour of ice masses of the Himalaya systematically with a cost to time benefit ratio.

CORONA and Cartosat-1 satellite aft and fore images are mainly used in research. CORONA and Cartosat-1 aft and fore stereo image is acquired on 26th September1968 and 12th December 2011 respectively. These data are useful to identify the changes in recession rate of Milam glacier during the year of 1968 to 2011. DEM (Digital Elevation Model) and ortho image generated from both Cartosat -1 and CORONA stereo images. DEM of both images is created in using LPS software in Erdas 2013 version. These data were analyzed to find out the altitude and snout position of Milam glacier.

The data analysis shows that the Milam Glacier in the Goriganga Basin, Kumaon Himalaya have receded 1100 m laterally and 106.69 m vertically from 1968 to 2011

13. Long Term Monitoring of the Deteriorating Health of Satopanth and Bhagirath Kharak Glaciers in Upper Alaknanda valley, Chamoli District, Uttarakhand Himalaya, through Integration of Conventional and Remote Sensing Techniques

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Chaukhamba group of peaks (7138 mts.) separate the two largest stored fresh water reserves of Uttrakhand Himalaya. Gangotri group of glaciers descend to the west of the water divide giving rise to Bhagirathi river while the Satopanth and Bhagirath Kharak glaciers descend on the eastern slopes and are the source of the mighty Alaknanda river. Satopanth glacier (5O13206020) is 16.40 Km. long, while the Bhagirath Kharak glacier (5O13206028) is 18.10 Km. long, and the melt water from these twin glaciers, separated by the Balakun ridge, together give rise to Alaknanda river.

Unlike the Gangotri glacier, which has a recorded history of almost 125 years, the Satopanth-Bhagirath Kharak glaciers have the authentic database for the last less than a century. These twin glaciers were first studied by Smythe and Greone in 1931. Subsequently, Gilbert and Auden (1932) and Heim and Gansser (1936) demonstrated that the frontal parts of both the Satopanth and Bhagirath Kharak glaciers were merging together forming a single glacier front. Jangpangi (1956) presented the first field sketch of the area which demonstrated that the twin glaciers had separated apart and each had an independent snout. However this sketch could not be used for subsequent references because of the absence of the coordinates. Corona satellite data of 1968 is the first authentic image of these twin glaciers with their specific coordinates. Subsequently multi-date satellite data from 1988 to 2013 have been used in the present exercise.

Multi-date satellite data in conjunction with conventional techniques have helped in monitoring the deteriorating health of both the Satopanth and the Bhagirath Kharak glaciers, principally in terms of three parameters viz the retreat of their frontal parts, frontal area vacated and the increase in the number and total area of supra-glacial lakes in the ablation zones of these glaciers.

Retreat of the frontal parts:

The average yearly rate of retreat of Satopanth glacier front between 1968 and 1988 has been 1.87 meter per year. Late nineties witnessed the erosion of the right bank of Satopanth glacier by the drainage descending down the Narayan Parvat side. This enhances the erosion and hence the retreat of the frontal part of Satopanth glacier and the retreat monitored is 18.37 m/y by the year 2004. Between 2004 and 2010 the average yearly rate of retreat is 11.66 m/y and again increases to 14.16 m/y between 2010 and 2013. The average annual rate of retreat of the Satopanth glacier front between 1968 and 2013 is 9.86 m/yr..

The Bhagirath Kharak glacier front also demonstrates a continuous retreating trend between 1968 and 2013. The average rate of retreat between 1968 and 1988 is 2.04 m/y, between 1988 and 2004 the retreat monitored is 9.25 m/y and this drastically increases to 22.33 m/y between 2004 and 2010. However the retreat of the frontal part slows down to 14.36 m/y between 2010 and 2013. The average annual rate of retreat of the Bhagirath Kharak glacier front between 1968 and 2013 is 8.13 m/yr..

Area vacated in the frontal parts:

The retreat of these twin glaciers has resulted in the frontal parts being vacated year after year. Multidate satellite data has enabled monitoring the yearly area vacated in these twin glaciers. Satopanth glacier has vacated an area of 0.396 sq. km. between 1968 and 2013, while the Bhagirath Kharak glacier has vacated an area of 0.242 sq. km. during the same period. The higher index of area vacated on the Satopanth glacier side is primarily because of the lateral erosion of the right bank of glaciers by the descending drainage from the Narayan Parvat.

Increase in number and area of the supra-glacial lakes in the ablation zones ;

The health of both the Satopanth and Bhagirath Kharak glaciers is deteriorating year after year as is also indicated by the increase in the number and areas of the supra- glacier lakes present in the ablation zone of these glaciers. Multidate satellite data and GIS techniques have enabled monitoring the super glacier lakes in the study area. In 1994, 14 supra-glacial lakes with total spatial extent of 90,063.34 sq. meter area were present in the ablation zone of Satopanth glacier. This number, in 2013, increased to 24 lakes with a total area of 1,27,281.30 sq. meter. The ablation zone of Bhagirath Kharak glacier in 1994 has 16 super glacier lakes with a total area of 52,926.71 sq. meter, while the 2013 satellite data shows the presence of 29 super glacier lakes with a total area of 1,45,839.60 sq. meter.

The continuous retreat of the Satopanth and Bhagirath Kharak Kharak glaciers resulting in the frontal areas being vacated year after year, coupled with the increasing presence of supra-glacial lakes, is a definite indicator of the adverse impacts of the climatic variations on the health of the glaciers. However, the extent to which the climate change has impact over the different glacial parameters can best be understood through integration of the different meteorological parameters, hydrology of the system and the numerous glacial parameters. Accordingly, a multi-temporal monitoring of the different glacial parameters through the presently available high resolution satellite data coupled with a continuous long term monitoring of the hydrology of the system and the meteorological parameters through a network of Automatic Weather Monitoring Stations, would in the ultimate analysis help in achieving this goal.

14. Sustainability of Dams on River Alaknanda

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The Indian Himalayan region is abode of three major river systems viz Indus, Ganga and Brahmaputra river system. These river systems provides with large volumes of water. This large volume of water has harnessed the present basic needs like availing water for the irrigation, domestic, industrial purpose and for the development of hydropower potential. The development of dams serves as a basic tool for properly channelizing these basic needs. Based on the importance of development of dams, the sustainability of construction of dams on the river Alaknanda has been analysed in this paper. River Alaknanda is one of the two head streams with river Bhagirathi which joins together at Devparyag in Uttrakhand forming the river Ganga. The river Alaknanda basin consists 82.2% of the area to be mountainous ranging between 1000 to 4000 m above sea level. These mountains consists three tectonically separable major litho-stratgraphical units known as Dudhatoli group, the Garhwal group and the Central Crystaline group. The Garhwal group consists of several shear and fracture zones which makes these region fragile to hold the large dams. The development of dams in the fragile and geo-dynamically sensitive zones will result in increased landslides, drying of the river or floods. In return it will result in ecological disturbances, loss of biodiversity, loss of productive lands, damage to forests, social and cultural change, change in socioeconomic status, etc. Thus this study focuses on the sustainability of construction of dams on river Alaknanda by analysing dams being built on river Alaknanda and measures for sustainable development of dams

Keywords: Indian Himalayan region, dams, sustainability, river Alaknanda, Garhwal group

15. Retreat of Glaciers in Bhaga Basin, Lahaul and Spiti District, Himachal Pradesh, India

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Chandra-Bhaga basin is the largest snow/ice fed area of Himachal Pradesh situated between Pir Punjal range in south and the Great Himalayan range in north and occupies an area of about 7510 sq km. Glaciated region of Bhaga Basin falls in the Great Himalayan range with a few glaciers in the Zanaskar range of Himalayas. The number of glaciers in the Bhaga basin is about 74. ELA observations between 1989 to 2007 have been recorded for 22 important glaciers of the study area. It has been observed that for all the glaciers the ELA deciphers rise in the altitude for the period between 1989 to 2007. The average ELA for the glaciers in the year 1989 is at 5220.90 meters and it is at 5273.45 meters in the year 2007. Of the total vacated area 34.7 percent got vacated during 1989-1999 and during 1999-2007, 64.70 percent area in the Bhaga basin got vacated due to deglaciation. This means a rise of 186.45 percent. Results of the present study reveal that during the decade 1989 to 1999 the degree of deglaciation of almost all the glaciers is less than the corresponding period of 1999-2007.

16. Precipitation Variability over the Glacierized Regime of Central Himalaya, India

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Meteorological variables especially; solid and liquid precipitation and their interaction with glacierized regime are the main factors which controls the development of glaciers. However, fresh snowfall plays a vital role in the study of an annual glacier mass balance modeling. Information on precipitation distribution helps to provide realistic assessment of water resources, estimation of net precipitation and hydrological modeling for mountainous areas. In the complex terrain of the Himalaya, data on fresh snowfall and rainfall data are very sparse. Present study focused on the time series record of snowfall and rainfall over the Chorabari Glacier (30°46’9.9”N-79°02’45.8”E), Mandakini basin, Central Himalaya during the two hydrological years (2011-12 and 2012-13).

A sonic ranging sensor was placed near the equilibrium line (4270 m asl) and an ordinary rain gauge was positioned at glacier snout (3820 m asl) for the measurement of snowfall and rainfall. Air temperature compensation has also been applied to the sensor output for the acquisition of the accurate snow depth. Further, study of the influence of air temperature, barometric air pressure and wind speed on the measurement gives a quantification of snowfall at 1-hour time step, with a sensitivity of 1 cm of snow.

The acquired data indicates that the snowfall events are associated with a wind of light speed from the valley (less than 2 ms^{-1}). Density profiling was also performed which shows that density of fresh snow was measured low during dry winter, about 70-90 kg m^{-3} whereas; it was measured high for the period of summer monsoon, about 120-180 kg m^{-3} as a result of the high air temperature and moisture content. The high snow density and the light wind speeds during humid summer monsoon prevent snow drifting conditions resulting in low spatial variability of the accumulation over the tropical glaciers. The preliminary results suggest that the total winter snowfall during 2011-12 was observed to be 21.05 m (1789.25 mm w.e.) and 23.05 m (1959.25 mm w.e.) during 2012-13 whereas, it was 3.96 (633.6 mm w.e.) and 5.11 m (817.6 mm w.e.) for summer monsoon of 2012 and 2013 respectively. However, total rainfall for the summer months was observed to be 933.2 mm and 1488.5 mm for the year 2012 and 2013 respectively.

Accurate recording of snowfall at a short time step is very important for the study of mass balance and energy fluxes over the glacier surface. Solar radiation is generally the main source of melting and the snowfall events significantly increases the albedo which protects underneath glacier ice from melting. Hence, the distribution of precipitation over glacierized regime is important parameter for understanding the pattern of glacier mass balance.

I - LIST OF PARTICIPANTS

Sr. No.	Abstract Title	Author's Name	Name of the Instiution
1	**Role of Space Based Inputs for Monitoring the Himalayan Cryosphere**	A.S. Rajawat	Space Applications Centre (ISRO), Ahmedabad -380015, India
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2	**Inventory of Glaciers in Indus, Ganga and Brahmaputra Basins of the Himalaya**	A. K. Sharma	Space Applications Centre (ISRO), Ahmedabad -380015, India
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5	**Moraine Dammed Lakes Inventory Using IRS LISS III Satellite Data in Satluj, Ravi, Chenab and Beas Basins of Himachal Pradesh, Western Himalaya, India**	S.S. Randhawa	State Centre on Climate Change (State Council for Science Technology and Environment), Shimla, Himachal Pradesh
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7	**Utilization of Optical & Microwave Satellite Records for Monitoring Gangotri Glacier, Central Himalaya, India, During Past 50 Years (1962-2012)**	Farjana Birajdar	Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Mumbai-40076, Maharashtra, India
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		Pinki Bisht	-----------------------------do------------------
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		Sunil Singh	HNB Garhwal University, Srinagar, Garhwal, Uttrakhand
		Yashpal Sundriyal	-----------------------------do------------------
		Navin Juyal	Physical Research Laboratory, Navrangpura, Ahmedabad-380009
74	**Effect of Black Carbon Aerosol on Himalayan Glaciers and Climate Variability: A Review**	Alok Sagar Gautam	Department of Physics, HNB Garhwal University, Srinagar, Garhwal, Uttrakhand
		R.S. Negi	Department of Rural Technology, HNB Garhwal University, Srinagar, Garhwal, Uttrakhand
		H.C. Nainwal	Department of Geology, HNB Garhwal University, Srinagar, Garhwal, Uttrakhand.
75	**Impact of Climate Change on Acridoids Diversity and Status in Shiwalik Himalayas of Himachal Pradesh**	K.L. Sharma	Socio-biology and Bahavioural Ecology Research Lab, Department of Biosciences, Himachal Pradesh University, Shimla (H.P.)-171005, India
76	**Shrinkage of Satopanth and Bhagirath Kharak Glaciers in the Recent Past**	H.C. Nainwal	Hemwati Nandan Bahuguna Garhwal University (A Central University), Srinagar (Garhwal) 246174, India
		Argha Banerjee	Indian Institute of Science Education Research Kolkata, Mohanpur 741246, India
		R. Shankar	The Institute of Mathematical Sciences, Chennai 600113, India
		Prabhat Semwal	Hemwati Nandan Bahuguna Garhwal University (A Central University), Srinagar (Garhwal) 246174, India
		Tushar Sharma	-----------------------------do------------------
	A Critical Assessment of Glacial Melt Fraction in	Abul Amir Khan	University of Delhi

77	**River Water in the Bhagirathi**	Naresh C. Pant	-----------------------------do------------------
		A. Sarkar	IIT Kharagpur
78	**Understanding the Floristic and Agri-horticultural Diversity Behavior in Response Climate Change in the Naradu Glacier of Baspa Basin in Himachal Pradesh**	JC Rana	National Bureau of Plant Genetic Resources, Regional Station, Phagli, Shimla (HP), 171 004
		Pankaj Sharma	-----------------------------do------------------
		Usha Devi	-----------------------------do------------------
		Pooja Pathania	-----------------------------do------------------
79	**Long Term Trend of Heavy Precipitation Events Over Northwest Himalayas**	N.P.S. Kalha	Indian Meteorological Department, Lodi Road, New Delhi-110003
		Naresh Kuma	-----------------------------do------------------
		B.P. Yadav	-----------------------------do------------------
80	**Development vs. Conservation: A study of Socio-economic Vulnerability of Bhagirathi Basin in Context of Sustainable Development**	Nisha	Jawaharlal Nehru University, Centre for the Study of Regional Development, New Delhi-110067, India
		Milap Punia	-----------------------------do------------------
81	**Glaciers of Himachal Himalaya- Their Sustenance and Adaptive Measures in Climate Change Scenario.**	C.V. Sangewar	154, Rajiv Nagar, Indiranagar, Lucknow-226016(UP).
82	**Assessment and Analysis of Average Annual Precipitation of the Indus, the Ganges and the Brahmaputra Basin, India**	Abul Amir Khan	University of Delhi
		Naresh chandra Pant	-----------------------------do------------------
		Ravish Lal	-----------------------------do------------------
83	**Variation in Monsoon Rainfall Intensity Over Himachal Pradesh During Last Century**	Davinder Sharma	India Meteorological Department, Lodi Road, New Delhi
		Naresh Kumar	-----------------------------do------------------
		B. P. Yadav	-----------------------------do------------------
84	**Temperature Analysis in Naradu Valley, Himachal Himalaya**	Shruti Singh	Department of Environmental Sciences, School of Basic Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh, India
		Rajesh Kumar	-----------------------------do------------------
		S.S. Randhawa	State Council for Science Technology and Environment, Shimla, Himachal Pradesh, India
		K.K Singh	India Meteorological Department, Lodhi Road, New Delhi, India
85	**Indicators of Glacial Retreat From Jorya Garang Glacier of Baspa Valley, India**.	Yogi N. Trivedi	The M.S. University of Baroda, Vadodara-390002. India
		Bhushan S. Deota	-----------------------------do------------------
		Ishmohan M. Bahuguna	Space Applications Centre, Indian Space Research Organization, Ahmedabad-380015.
		Anil V. Kulkarni	Divecha Centre for Climate Change, Indian Institute of

			Science, Bangalore
		Mudit D. Mankad	The M.S. University of Baroda, Vadodara-390002. India
86	**Recession of Milam glacier, Kumaon Himalaya from Stereo data of CORONA to CAROSAT**	Remya S. N	[1]ndian Institute of Surveying and Mapping (IISM), Survey of India (SoI), Hyderabad.
		K. Babu Govindha Raj	Geosciences Group, National Remote Sensing Centre (NRSC) Indian Space Research Organisation (ISRO), Hyderabad
87	**Sustainability of Dams on River Alaknanda**	Sandhya	Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India.
88	**Retreat of Glaciers in Bhaga Basin, Lahaul and Spiti District, Himachal Pradesh, India**	Sunil Dhar	Department of Geology, Government PG College, Dharamshala, Himachal Pradesh, India, 176215.
		Vikas Pathania	----------------------------do------------------
		Harvinder Singh	----------------------------do------------------
89	**Precipitation Variability over the Glacierized Regime of Central Himalaya, India**	Kapil Kesarwani	[1]Centre for Glaciology, Wadia Institute of Himalayan Geology, Dehra Dun - 248001, Uttarakhand, India
		D.P. Dobhal	----------------------------do------------------
		Alok Durgapal	[2]D.S.B. Campus, Kumaun University, Nainital - 263001, Uttarakhand, India
		Manish Mehta	[1]Centre for Glaciology, Wadia Institute of Himalayan Geology, Dehra Dun - 248001, Uttarakhand, India
		Anshuman Misra	----------------------------do------------------

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Serial No.	Institutions
1	Space Applications Centre (ISRO) Ahmedabad -380015, India
2	Centre for Glaciology, Wadia Institute of Himalayan Geology, Dehra Dun-248001, India
3	Department of Earth Sciences, Kashmir University, India
4	State Centre on Climate Change (State Council for Science Technology and Environment), Shimla, Himachal Pradesh
5	Department of Environmental Sciences, SBSR, Sharda University, Gr. Noida, U.P.
6	Divecha Center for Climate Change, Indin Institute of Science, Bangalore
7	Centre of Studies in Resources Engineering, Indian Institute of Technology Bombay, Mumbai-40076, Maharashtra, India
8	Department of Geology, St. Xavier's College (Autonomous), Mumbai-400001, Maharashtra, India
9	PEC University of Technology, Chandigarh 160012, India
10	Snow & Avalanche Study Establishment- RDC (DRDO), Chandigarh 160037, India
11	M.G. Science Institute, Ahmedabad, India
12	Meteorological Centre Shimla
13	India Meteorological Department, New Delhi
14	Bhakra Beas Management Board, Chandigarh
15	CEPT University Ahmedabad
16	Himachal Pradesh University, Shimla

17	Department of Geography, Visva-Bharati, Santiniketan, 231735, West Bengal
18	Department of Geography, Visva-Bharati & Department of Science & Technology & Climate Change, Deorali, East Sikkim-737102
19	Uttarakhand Space Application Centre, Dehradun-248006
20	Remote Sensing Applications Centre, U.P.,Lucknow-226021
21	School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India
22	IRD / UJF - Grenoble 1 / CNRS / G-INP, LGGE UMR 5183, LTHE UMR 5564, Grenoble, F-38402, France
23	ICIMOD, GPO Box 3226, Kathmandu, Nepal
24	National Centre for Antarctic and Ocean Research, Headland Sada, Goa 403804, India
25	Central University of Himachal Pradesh, Himachal Pradesh, India
26	UJF – Grenoble I/CNRS, LGGE UMR 5183, 38041 Grenoble Cedex, France
27	Geological Survey of India
28	National Institute of Hydrology, Roorkee
29	Indian Institute of Science Education and Research, Kolkata, Mohanpur campus, India
30	The Institute of Mathematical Sciences, Chennai, India
31	Center for Atmospheric Sciences, Indian Institute of Technology Delhi, NewDelhi.
32	Maharaja Sayajirao University of Baroda, Vadodara
33	Department of Geology, Aligarh Muslim University, Aligarh, India
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37	Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi-110067
38	Centre of Studies in Resources Engineering, IIT Bombay
39	Department of Earth Science, Annamalai University, Chidambaram, Tamil Nadu, India
40	Sikkim State Council of Science and Technology, Vigyan Bhawan, Deorali, Gangtok, 737102
41	Defence Terrain Research Laboratory, Defence Research and Development Organisation, Delhi, India
42	RS – Applications Area,National Remote Sensing Centre (NRSC) Indian Space Research rganisation (ISRO) Dept of Space, Govt. of India, Balanagar, Hyderabad – 500 037, India
43	Geological Survey of India, Faridabad, Haryana, India
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47	Birbal Sahni Institute of Palaeobotany, Lucknow
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56	The Institute of Mathematical Sciences, Chennai 600113, India

57	University of Delhi
58	IIT Kharagpur
59	National Bureau of Plant Genetic Resources, Regional Station, Phagli, Shimla (HP), 171 004
60	154, Rajiv Nagar, Indiranagar, Lucknow-226016(UP).
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