Indian Institute of Technology Mandi
Himachal Pradesh, India

International Workshop on Climate Change and Extreme Events in Himalayan Region

18-20 April, 2019

C2E2 Himalaya

Ministry of Earth Sciences
Government of India

International Union of Geodesy and Geophysics
Union Géodésique et Géophysique Internationale

American Geophysical Union

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C2E2 Himalaya

International Workshop
on
CLIMATE CHANGE & EXTREME EVENTS IN HIMALAYAN REGION

18-20 April, 2019
Venue: IIT Mandi, Kamand, H.P.

Sponsors

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Prof. Timothy A. Gonsalves
Director

Indian Institute of Technology Mandi

IIT Mandi, 05 April 2019

Located in the sylvan Uhl River Valley in the Himalayas, IIT Mandi has a focus on the environment and ecology of the Himalayan Region. Faculty from a range of disciplines are engaged in R&D related to climate change, landslides, avalanches, earthquake-resistant structures, pollutants in soil etc. Several start-up companies are being incubated by IIT Mandi Catalyst.

In this context, IIT Mandi is pleased to host an International Workshop on Climate Change and Extreme Events (C2E2) in the Himalayan Region during 18-20 April 2019. The Workshop is led by Prof Ramesh Singh from Chapman University, USA. He is also Visiting Professor, IIT Mandi. He is assisted by a number of young faculty at IIT Mandi. I am sure that the Workshop will be trend setting and of relevance to the Himalayan and surrounding regions.

C2E2 Himalayas is an important platform for conservationists, researchers, specialists, leaders and students to meet each other, discuss discoveries, and talk about their exploration. This Workshop will provide a unique platform for the participants from far-flung corners of India and from abroad to discuss climate change and its impacts. An expected outcome of the brainstorming by the experts is devising of appropriate measures to make the Himalayan ecosystem sustainable for future generations.

Timothy A. Gonsalves

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Glenn M. Pfeiffer, Ph.D.
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California, 09 April 2019

Congratulations to IIT Mandi for organizing an international workshop on "Climate Change and Extreme Events in the Himalayan region (C2E2himalaya)" on April 18-20, 2019.

I want to welcome the scientists from the USA, Europe and Asia to this workshop organized by IIT Mandi and Chapman University. This event is possible due to sponsorships from Indian scientific agencies, the Committee on Space Research (France) and International Union of Geodesy and Geophysics (IUGG).

Climate change is an important topic being discussed around the world. This year's extreme weather conditions and heavy snowfall in some parts of the USA and Canada are direct examples of climate change. Additionally, the long term changes occurring in the glaciers of the Himalayan region provides evidence of climate change existing. Ground and satellite observations have shown retreating Himalayan glaciers, but the cause of the retreat is still a major question before all of us. During this workshop, I am sure you and other participating scientists will discuss, amongst other things, the cause for melting glaciers and the significant changes in water availability due to the melting of glaciers. I am confident that discussions held at this workshop will benefit the local communities of Himachal Pradesh and other Asian countries impacted by the Himalayan region.

Best wishes to you and your colleagues from IIT Mandi on a productive and successful workshop.

Sincerely,

Glenn M. Pfeiffer, Ph.D.

Provost and Executive Vice President for Academic Affairs

प्रकाश जावडेकर
Prakash Javdekar

सत्यमेव जयते

मंत्री
मानव संसाधन विकास
भारत सरकार

MINISTER
HUMAN RESOURCE DEVELOPMENT
GOVERNMENT OF INDIA

New Delhi, 10 April 2019

It is my great pleasure to know that "International Workshop on Climate Change and Extreme Events in The Himalayan Region (C2E2 Himalaya)" is being organized at Indian Institute of Technology Mandi, Himachal Pradesh.

The major visible effects of global warming are the extreme events occurring all around the world Increased anthropogenic activities such as crop residue burning have enhanced the atmospheric pollution and temperature in many parts of the world. This continuous change is anticipated to aggravate the intensity and frequency of the extreme events such as glacier melting, droughts, floods and rising sea level etc. Mountain regions are highly sensitive to this climate change. Deposits of aforementioned anthropogenic activities have given birth to dark glaciers at various places in Himalayas, which are melting at a faster rate. Such workshops / conferences gives an opportunity for scientists from India and abroad, not only for consultation, but to provide solutions of the problems. It is an exemplary start, though only a beginning in the form of this workshop. I am hopeful that, during the course of this workshop, some solution towards mitigating climate change and its adverse effect on Himalayas will be suggested.

The objective of Ministry of Human Resource Development is to encourage international cooperation in the field of education, including working closely with the UNESCO and foreign governments as well as Universities, to enhance the educational opportunities in our country. This workshop will be pivotal in achieving this goal.

On behalf of MHRD, I appreciate the efforts and hard work of the organizing team and the institute and wish them success in present and future endeavors.

(PRAKASH JAVADEKAR)

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सत्यमेव जयते

डॉ. एम. राजीवन
DR. M. RAJEEVAN

सचिव
भारत सरकार
पृथ्वी विज्ञान मंत्रालय
पृथ्वी भवन, लोदी रोड, नई दिल्ली-110 003
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAVAN, LODHI ROAD, NEW DELHI-110003

New Delhi, 10 April 2019

I am glad to know that an International Workshop on Climate Change and Extreme Events in the Himalayan Region is being held at the Indian Institute of Technology Mandi. I would like to congratulate the hard-working organizing team of C2E2-2019 for their efforts, and wish them success for this and future national and international workshops/conferences.

Climate Change has dawned upon humankind as a worldwide challenge requiring an integrated global approach and solutions. The present warming of climate is of a greater concern than previous events because it is a human instigated phenomenon. Numerous extreme events are ramifications of the current climate change. In the past 10 years, India has experienced several extreme events, for instance the Mumbai floods in 2005, the Jammu and Kashmir floods in 2014, the Uttarakhand flood in 2013 and Cyclone Alia in 2009 among others. The Uttarakhand disaster is regarded as the worst calamity of its kind in recent times, and the Jammu and Kashmir floods were the worst floods in the past 60 years in the state. These disasters have caused major destruction to life and property. Nature itself is pushing us to put a stop to such disasters in future. The Ministry of Earth Sciences of the Government of India provides the nation with the best possible services in forecasting weather parameters, natural disasters and other extreme events.

C2E2 Himalaya 2019 focuses on the extreme events occurring in the Himalayan region. In the fragile ecosystem of the Himalayas, the rate of glacier melting, glacier lake outburst floods (GLOF), avalanches, landslides etc. are triggered due to change in global environment.

I hope that participants of C2E2 Himalaya 2019 will propose workable solutions to this worrying scenario. Once again, I wish the organizers of C2E2 Himalaya 2019 great success.

(M. Rajeevan)

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प्रो0. संदीप वर्मा
सचिव
Prof. SANDEEP VERMA
SECRETARY

विज्ञान और इंजीनियरी अनुसंधान बोर्ड
(विज्ञान और प्रौद्योगिकी विभाग, भारत सरकार का एक सांविधिक निकाय)
SCIENCE & ENGINEERING RESEARCH BOARD
(A Statutory body of Department of Science and Technology, Govt. of India)

April 12, 2019

I am very pleased to learn that "International Workshop on Climate Change and Extreme Events" is being organized by Indian Institute of Technology Mandi from April 18-20, 2019.

Deep understanding of climate change, glacier melting, and the possibility of extreme atmospheric events due to global warming, with respect to our pristine Himalayan region, is of great importance. Such endeavours require ready availability of meteorological data over long time periods and large atmospheric data sets, which could be used to model and predict key climate indicators and looming environmental uncertainties affecting population living in the Himalayan region and the downstream effects.

It is hoped that this workshop would offer an interactive platform for climate scientists, academicians, and researchers and contribute toward capacity building in this key domain of earth sciences.

I wish this workshop success.

Sandeep Verma.

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सत्यमेव जयते

डा. अखिलेश गुप्ता
Dr. Akhilesh Gupta

सलाहकार एवं प्रमुख
कार्यनीतिगत कार्यक्रम वृहत पहल एवं
समन्वित कार्य समर्थकारक (स्पलाइस)
एवं जलवायु परिवर्तन कार्यक्रम
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भारत सरकार

Advisor & Head
Strategic Programmes, Large Initiatives &
Coordinated Action Enabler (SPLJCE)
Division and Climate Change Programme
Department of Science & Technology
Ministry of Science & Technology
Government of India

New Delhi, 10 April 2019

Climate change signals indicate increased climate variability over the Indian region during the last 50 years, which could accelerate in coming decades. The world has witnessed extreme temperatures, heavy rainfall, persistent droughts and frequent floods. India too is experiencing changes in climate in terms of increase in temperature, sea level rise and increase in frequency' and intensity of extreme events in different parts. The Himalayan region is being impacted much more than plain areas as it is more fragile and sensitive to global and local anthropogenic changes. This puts on risk the livelihoods of the communities of the Himalayan region.

Indians Nationally Determined Contribution (NDC) submitted to United Nations Framework Convention on Climate Change (UNFCCC), is an attestation of our commitment to global environmental concerns. The government is committed to enhancing investments in development programmes in sectors vulnerable to climate change, particularly' agriculture and water resources, in ecologically sensitive regions.

The Department of Science & Technology is coordinating and implementing two national missions on climate change under National Action Plan on Climate Change (NAPCC). These include; National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and National Mission on Strategic Knowledge for Climate Change (NMSKCC). Both these missions have broad objective of building S&T capacity and training of scholars and researchers to generate new knowledge to underpin government decision-making and for sustaining the Himalayan ecosystem. Under these missions, DST has positioned 11 Centre's of Excellence, 23 Major R&D Programmes, 7 Network Programmes, 7 Human Capacity Building Programmes, 8 Global Technology Watch Groups, 6 Thematic Task Forces in the Himalayan Region, State CC Cells in 24 States and Union Territories and several bi-lateral programmes.

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I am pleased to learn, IIT Mandi is organizing an International workshop on Climate Change and Extreme Events in the Himalayan region during 18-20 April 2019 wherein some leading national and international weather and climate scientists participating. I am confident the workshop will have in-depth discussion and debate the subject of climate change and extreme events especially in the context of Indian Himalayan region and come up with some specific recommendations.

I wish the workshop a grand success!

(Akhilesh Gupta)

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Lt Gen N C Marwah
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Member

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New Delhi, 04 April 2019

Climate Change and Extreme Events continue to be a matter of great concern, as the associated risks are too grave to be ignored. These have serious ramifications as our very survival depends upon our ability to manage the climate change and adapt to it. The significance of much desired study of potential impacts of climate change with particular reference to the Himalayan region cannot be overstated. It is very important for the economic growth in the region. It is also important in the backdrop of India's commitment to the **Sendai Framework for Disaster Risk Reduction (2015-2030), COP-21 Paris Agreement and the UN Sustainable Development Goals (SDGs).**

While the contemporary debate on Climate Change reflects varying degrees of uncertainty regarding the "scale" of its potential adverse impacts, the world is unanimous on the "wide range" of these adversities, which include fresh water shortage, reduction in food production, drought, demographic shift besides environmental degradation and increase in frequency and intensity of natural disasters leading to increase in loss to life and economic losses.

It could also lead to greater health risks due to vector borne and water borne diseases and malnutrition. It is pertinent to note that the countries of the Himalayan region, which have fewer means to address impacts of climate change, are likely to be affected the most.

The Climate Change is already manifesting in several ways across the globe. The **WMO "State of the Climate Report – 2019"** makes it amply clear that the impact of climate change has caused the carbon dioxide levels to go up from 357 parts per million (ppm) in 1993 to 405.5 ppm with significant impact on temperatures. The years 2015 to 2018 were the four warmest on record. It is no coincidence that most of the natural hazards that affected nearly 62 million people in 2018 were associated with extreme weather and climate events. Kerala in India suffered the heaviest rainfall and worst flooding in nearly a century. We are aware of the deadly heat wave in 2015 that killed thousands of people in India and Pakistan. We are now coming across frequent episodes of highly localized extreme precipitation in very short duration. Besides the sea level rise will have a

disastrous impact in the region, particularly on India, given its long coastline, and pockets of densely populated areas in the coastal region.

While substantial efforts are underway across the world to mitigate the impact of climate change, we need to arrive at Climate Change Adaptation Strategies relevant to the local environment. We also need to harness the traditional knowledge and practices and incorporate them suitably in the CCA plans at all levels.

It is very encouraging to note that an **International Workshop on Climate Change and Extreme Events in the Himalayan Region (C2E2 Himalaya)** is being hosted by **IIT Mandi** from 18-20 April 2019. It is significant as the climate change poses a growing threat to glaciers of Hindu Kush and Himalayan Ranges, which are critical water resource for several countries in the region. Rising temperatures coupled with air pollution from Indo-Gangetic plains are likely to hasten up melting of glaciers in the region.

It is important that the scientific community come out with data and information that will help nations draw out CCA plans of meeting the targets stipulated as per the Paris Agreement 2015.

I am happy to observe that the workshop will bring together acknowledged scientists and specialists to discuss wide ranging issues of concern to include glaciers retreat , pollution and application of science and technology in monitoring related geo-physical and geo climatic phenomena in the Himalayan Region.

On behalf of NDMA, I wish the workshop all the success and I am sure it will turn out to be a significant step towards our collective endeavours in mitigating climate change and evolving workable strategies for Climate Change Adaptation specific to the Himalayan Region.

Lt Gen N C Marwah (Retd)
Member, NDMA

COSPAR
ESTABLISHED BY ICSU:
THE INTERNATIONAL
COUNCIL FOR SCIENCE
COMMITTEE ON SPACE RESEARCH

President: Prof. L.A. Fisk
Executive Director: Dr. J.-L. Fellous

Paris, 26 March 2019

COSPAR, the Committee on space research, was established in 1958 by ICSU, now the International Science Council, as a platform for international cooperation in this nascent field in the times of Cold War. 1957-1958 was the period of the International Geophysical Year, which saw the launch of the first artificial satellites of the Earth. More than 60 years after, satellites have become an indispensable tool to monitor the Earth and Climate, as human activities and particularly the release of massive amounts of greenhouse gases into the atmosphere were found to cause global warming and climate change. COSPAR is proud to support the International Workshop on Climate Change and Extreme Events in the Himalayan Region that will take place from 18-20 April 2019 at the Indian Institute of Technology Mandi, Himachal Pradesh, India.

Among the multiple impacts of climate change are the melting of glaciers, increased frequency of extreme events, and disturbance of rain regimes, leading to such events as floods or glacial lake outbursts in mountainous regions. The melting fresh water from glaciers alters the ocean, not only by directly contributing to the global sea level rise as measured by altimetry satellites, but also because it pushes down the heavier salt water, thereby changing the thermohaline circulation. In addition, widespread loss of glaciers will likely alter climate patterns in other, complex ways. For example, glaciers' white surfaces reflect solar radiation, helping to keep our current climate mild. When glaciers melt, darker exposed surfaces absorb and release heat, raisingtemperatures.

While point measurements are collected from just a small number of reference glaciers, the advent of remote sensing opened up unique opportunities for glacier observation. Earth Observation satellites are taking pictures in various bands of the electromagnetic spectrum, from visible to thermal infrared. Large swath imagery is useful for regional assessments. Satellite optical images at different resolutions allow for the regular monitoring of glacier surface elevation, velocity, area, length, equilibrium line altitude, terminus position and more, thus enabling mapping glacier recession over several decades. Radar observations provide additional day and night, all-weather capabilities to map glaciers, ice caps and sea ice.

Additional data often mapped by satellite and added to glacier inventories include changing ice debris cover, rock glaciers, grounding zones and glacial lake extent. Volume-area scaling

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laws allow to calculate changing ice volume. Mapping glacier thinning and measuring regional glacier and ice stream velocity and its change through time are also important applications of glacier remote sensing. A wealth of satellites operated by research and operational agencies from the USA, Europe, India, China and other countries are now available which provide irreplaceable data about glaciers all over the world.

Space-based observations of glaciers in the Himalayan region are critical to assess the evolution of this highly sensitive region of the world. At least one-third of the Himalayan glaciers, among the world's most vital water resources, are projected to melt by the end of the century, even if the most ambitions steps to halt global warming were achieved. This massive ice store provides a source of water that sustains more than a quarter of the world's population. Sharing knowledge and understanding as well as ensuring free and open access to relevant data from satellites and ground-based observations are essential elements of capacity building to help society in this field.

COSPAR is willing to help disseminate the outcomes of the Workshop through its publications (*Advances in Space Research*, *Space Research Today*), its capacity building workshops, and through its Scientific Assemblies and Symposia where the role of space observations and research and the crucial importance of international cooperation are emphasized.

As stated in COSPAR's Strategic Action Plan 2019-2023 adopted in March 2019, "*Particular consideration should be given to the challenges associated with the identification, assessment and prediction of the impact of anthropogenic activity and natural phenomena on the Earth system and the role of space observations and research, as highlighted by the COSPAR Roadmap on Integrated Earth System Science. COSPAR will pursue and extend its partnership within GEO and with other organizations (e.g., CEOS, WMO), to push this scientific agenda of utmost societal importance*."

I wish you every success with this important workshop.

Sincerely,

Lennard A. Fisk
President of COSPAR

Germany, 20 March 2019

It is a great pleasure to address to the participants of the International Workshop on Climate Change and Extreme Events in the Himalayan Region to be held 18-20 April 2019 in Mandi, India.

Humans face climatic, hydro-meteorological, and geological hazards on different scales in time and space. In particular, natural hazard events in the Himalayan region, such as earthquakes, landslides, avalanches, floods and others, may influence human life and health as well as impact dramatically on the sustainable development. Extreme hazards represent a pending danger for vulnerable infrastructure and the agricultural systems that depend on the water supply, reservoirs, pipelines, and power plants. Compared to developed countries, the impact is disproportionate within the countries of developing economies. Extreme natural events such as large earthquakes or great floods can change the life and economic development of developing nations and stifle their development for decades.

There is a deep belief in the community of natural scientists that with a progress of science and scientific ability to predict extreme events the problem of disaster risk reduction will be resolved. That is perhaps true but only to some extent. Recent extreme natural events showed clearly, that despite significant scientific knowledge and predictive capacity accumulated, the associated disasters were not prevented and even significantly mitigated. Social scientists explain that both physical and social vulnerabilities to extreme events and significant exposure in the regions prone to natural hazards play a crucial role in the disaster occurrences. Synergy among scientific fields and interdisciplinary work would help in resolving challenging problems.

The importance of scientific understanding to society has never been greater, as humanity faces with the problems of living sustainably on our planet. In 2015, United States nations adopted several ambitious agendas, such as the 2030 Agenda on Sustainable Development, Sendai Framework for Disaster Risk Reduction, and Paris Agreement on Climate Change. Scientific knowledge and evidences are vital components in successful implementation of the agendas.

For a century, the International Union of Geodesy and Geophysics (IUGG) promotes an international research cooperation in almost all disciplines of geo- and space sciences, from the Earth's deep interior to its space environment. IUGG is dedicated to advancing fundamental sciences as well as to solving challenging problems of the society such as climatic

and environmental changes, disaster risk reduction, water security and quality, energy, and others.

IUGG recognizes that communication between experts dealing with disaster risk reduction and climate change needs to be strengthened. In addition, this workshop is a bright example of the important communication.

I wishing the meeting a big success!

Sincerely,

Prof. Alik Ismail-Zadeh

IUGG Secretary General

Indian Institute of Technology Mandi
Mandi, Himachal Pradesh-175005

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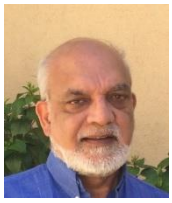


IIT Mandi, 10 April 2019

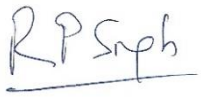
Welcome message from Conveners

Welcome to the ***International Workshop on Climate Change and Extreme Events in the Himalayan Region***, on the campus of IIT Mandi, located in the Himalaya, during 18-20 April 2019. The Himalayan snow/glaciers are among the large water resources in the Indo-Gangetic plains (IGP), and play an important role in daily weather conditions as well as dynamics of the Indian monsoon. The Himalayan region is also known to be vulnerable to a diverse set of extreme events – cloud bursts, glacial lake outbursts, earthquakes, landslides snow avalanches and related loss of lives and property damages. The effects of climate change are being directly observed in the Himalayan snow and glaciers, and the associated downstream river basins. Recent ground and satellite observations have indicated in general a retreat of Himalayan glaciers, with some parts reportedly advancing – thus making the study and attribution to climate change in the Himalaya even interesting and complex. The C2E2Himalaya workshop will provide a platform to national and international scientists and early career researchers to discuss the observed and ongoing changes in the Himalayan environment against the backdrop of climate change. The workshop is also designed to help develop strategies on how to make Himalayan resources, environment and ecology sustainable. As conference organizers, we are pleasantly overwhelmed with the positive response from scientists across the country. We very much appreciate the interest shown by the scientists and young researchers from all corners of India present here, including participants from neighboring countries and across continents. The national and international agencies/institutions - Ministry of Earth Sciences (MoES), Science and Engineering Research Board (SERB), National Disaster Management Authority (NDMA), Defense Research Organization (DRDO), International Union of Geodesy and Geophysics (IUGG), Committee on Space Research (COSPAR), American Geophysical Union (AGU), Chapman University (Orange, California), Taylor and Francis, UK and IIT Mandi, extended generous support.

We have received more than 175 scientific papers. In addition to oral and poster presentation, there are two Panel Discussions "**Are we prepared for the Big One?", and "Retreat of**

Himalayan Glaciers - Is It Real? The workshop has also encouraged participation of students and early career scientists and we are delighted to have them here. We anticipate this three-day workshop will give us an opportunity to exchange ideas for future studies and long-term collaborations.

We hope that participants will enjoy their stay on IIT Mandi campus. We welcome all of you on this scenic campus of IIT Mandi.



Ramesh P Singh
On behalf of the Conveners

Plenary Talks

Initiatives in Climate Change Research in India: Retrospect and Prospect

Akhilesh Gupta

Climate Change Programme
Strategic Programmes, Large Initiatives and Coordinated Action Enabler (SPLICE)
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Abstract

Responding to the global concerns for climate change impacts, India practively initiated systematic research after the publication of first and second assessment reports of IPCC. The Department of Science & Technology launched an extra-mural funding programme called Indian Climate Research Programme (ICRP) in 1997. Several multi-disciplinary and multi-institutional field observational programmes were also conducted in the Indian sub-continent region that included Monsoon Trough Boundary Layer Experiment (MONTBLEX); Land Surface Process Experiment (LASPEX); Bay of Bengal Monsoon Experiment (BOBMEX), ARMEX (Arabian sea Monsoon EXperiment) and Indian Ocean Experiment (INDOEX). Under Intensive Research in High Priority Areas (IRHPA) programme of DST a Global Climate Modelling Project was supported to develop a general circulation model (GCM) to predict the Climate at seasonal scale. A Centre on Global Change was positioned at National Physical Laboratory (NPL), New Delhi to study the Green House Gas emissions and related activities. The IPCC adopted this Centre's Methane budget estimates for India.

Responding to 4th Assessment Report of IPCC (AR4) brought out in 2007, India released its National Action Plan on Climate Change (NAPCC) in the 2008. The NAPCC contained some major initiatives that included launch of 8 national missions on climate change. DST was entrusted with the responsibility of coordinating two out of these eight national missions on climate change. These are: (a) National Mission for Sustaining Himalayan Ecosystem (NMSHE) and (b) National Mission on Strategic Knowledge for Climate Change (NMSKCC). Both these missions were launched with broad objectives of building S&T Capacity for sustenance of Himalayan Ecosystem and for developing strategic knowledge system. The missions implemented by DST made good progress in recent years which included establishment of 11 Centres of Excellence; 23 Major R&D Programme; 7 Human Capacity Building Programmes in Climate Change adaptation and mitigation; 8 Global Technology Watch Groups (GTWGs); State Climate Change Cells in 22 States/Union Territories; 7 National Network programmes in the areas of climate modeling, climate change & human health, aerosols, coastal vulnerability and urban climate; 6 Thematic Task Forces; An Inter-University Consortium of 4 universities on Cryospheric research, an Indo-Swiss bilateral programme on capacity building in glaciology and an Indo-US Fulbright-Kalam Doctoral and Post-Doctoral Fellowship programme in Climate Change.

During past 5 years the DST-sponsored programmes have made a significant impact and resulted in a large number of useful publications in national and international journals. Over 900research publications have come out of these programmes so far, out of which a large number are in international journals of high impact factors. About 60 new techniques have been developed as part of programmes under two

missions. Nearly 1000 scientists, experts and students and 200 institutions in the country have been associated with climate change programme of DST. Nearly 150 PhD and PG students have been enrolled as part of two missions. More than 200 Workshops were organized wherein over 5500 personnel were trained. State CC Centres conducted 250 training programmes wherein over 50000 personnel were trained.

India has over the years built a strong climate change research base in terms of number of quality researchers, long term data and infrastructure. The Climate Change Programme of DST has achieved considerable progress during past 5 years. Plans are afoot to strengthen the programme by building human and institutional capacities, developing greater linkages among the institutions and widening the network of researchers.

Arc-Parallel Inequality in Crustal Structures and Seismicity in the Himalaya

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Abstract

Crustal structures and physical state of material, imaged by high-resolution geophysical studies, are combined with seismicity distribution to constraint the processes of seismogenesisin the Himalayan collision zone. Passive seismic and magetotelluric studies across central Himalaya, where litho-tectonic divisions are best developed, the top of the down going Indian plate (Main Himalayan Thrust-MHT) is imaged as low-angle northeast dipping high velocity/resistivity interface with well-developed ramp beneath the surface trace of the Main Central Thrust Zone. Located in the depth range of 13-15 km. all along the interface is capped by a thin low velocity/ high conducting layer, symbolising fluids-filled zone. Modulation of frictional coupling and mechanical weakening by high-pore pressure fluids counteract the arc-normal stresses creating conditions for failure and nucleation of thrust-type large and great earthquakes on the MHT beneath Sub- and Lesser-Himalaya, which remains locked during inter-seismic period. The 1991-Uttakashi, 1999-Chamoli and 2015-Gorkha earthquakes are the examples caused by the unzipping of the MHT. Breaching of fluids along high-pressure shear zones or hidden out-of sequence under conditions of accumulating stresses or sudden stress transfer account for more frequent occurrence of moderate earthquakes straddling the ramp structure or large aftershocks following main shock. The May 12 Mw7.3 earthquake, 17 days after the April 25, 2015 Gorkha earthquake is characteristic example.

In contrast to the central Himalaya, the NW Himalaya is marked by seismic quiescence since the1905 M8.0 Kangra earthquake. This marked the onset of a new earthquake cycle as the current day moderate magnitude seismic activity is commesurate with 1.5-2.0 m of slip accummulated since 1905. Seismic tomographic images of the region swamped by southward migrated Chambanappe reveals that moderate activity is controlled by normal-faulting and reverse thrust-type movement on the north and south binding fault of the nappe. Given this evidence of confinement of seismicity to the Himalayan wedge, while the detachments (MHT) beneath remains locked, the Kishwar-Kangra-Chamba region provides testing platform to study the time evolution of strains leading to catastrophic event.

The medieval cluster of great earthquakes: Implications for the earthquake hazard of the central Himalaya

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Abstract

The timing and size of the last great earthquake in the central Himalaya continues to excite scientific interest, and the paleo-seismological studies in the region often reaching conflicting conclusions. Here we review the available database from the region to determine the timing of the last faulting event on the frontal thrust of the central Himalaya and how the overlapping segments in the region have been behaving in terms of generating large and great earthquakes. From the historic perspective, the Indian sources hint at a restoration phase for the mid-14th century monuments located in Delhi and a contemporaneous destruction to the ancient temples located in the central Indian Himalaya. The constraints generated from such earthquake proxies and the data from multiple trenches across the frontal thrust in the central Himalaya converge on a mid-14th century rupture that extends for a length of ~600 km of the central Indian Himalaya, with an average slip of 15 m, consistent with moment magnitude of Mw ≥8.5. The regional data from Nepal and India, in general, indicate evidence for a medieval cluster of great earthquakes (14, 13 and 11th centuries) spreading across the adjacent segments along the central Himalayan front, followed by quiescence extending to the present. The medieval cluster of great earthquakes within the central Himalaya indicates episodic nature of earthquake occurrence separated by long temporal gap of 700 to 1000 years. The present study underlines the fact that the frontal thrust in central Himalaya (covering the Indian and eastern Nepal parts) has remained seismically quiet, since the medieval pulse of great earthquakes, and a seismic gap in temporal as well as spatial sense is real. And, if the past is the key, the long-elapsed time (600-700 years) implying enormous stacking up of strain in the region portends at least one M ≥8.5 earthquake in one of these overlapping segments of the central Himalaya, anytime in future.

Seismological Network in the Himalayan Region: Achievements and Future Plans

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Abstract

The process of dealing with earthquake disasters essentially involves two important and inter-dependent components, namely, i) comprehensive understanding of the earthquake generation processes and its prediction and ii) mitigative and preventive measures. The basic and primary requirement towards addressing these tasks is high quality seismological data, which is homogeneous and complete in time and space. A National Seismological Network consisting of 115 observatories is being operated and maintained by the National Centre for Seismology. This network includes 25 station V-SAT based telemetry system around National Capital Territory (NCT) of Delhi, 20 station telemetry systems in NE region and 17 stations Real Time Seismic Monitoring Network (RTSMN) for monitoring large magnitude under-sea earthquakes capable of generating tsunamis on the Indian coastal regions. The Centre also receives data from 40 additional seismological stations maintained by other organizations in project mode. All the 115 seismological observatories are equipped with broadband seismometers and accelerometers and are connected to Central Receiving Station at New Delhi through VSAT communication. The present network is capable of detecting the earthquake of magnitude 3.0 and above in any part of the country and providing moment tensor solutions (CMT / MT) for large ($M \geq 5.5$) magnitude earthquakes, to help quantify the faulting mechanism, using incoming real time continuous data. The present response time of earthquake reporting is <10 minutes after its occurrence. It is planned to augment the network by adding 35 more observatories by the next year.

Spatio-temporal patterns of mass changes in Himalayan Glaciated Region from EOF analyses of GRACE data

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Abstract

The nature of hydrological seasonality over the Himalayan Glaciated Region (HGR) is complex due to varied climatic and precipitation patterns. The present study attempts to exemplify the spatio-temporal variation of hydrological mass over the HGR using time-variable gravity from the Gravity Recovery and Climate Experiment (GRACE) satellite for the period 2002-16 on seasonal and inter-annual timescales. The mass signal derived from GRACE data is decomposed using empirical orthogonal functions (EOFs), allowing us to identify the causes of mass change within HGR and delineate the three broad divisions, i.e. western, central and eastern, of HGR based on the seasonal mass gain or loss that corresponds to prevailing climatic models. Causative relationships between climatic variables and the EOF modes are explored using the Granger causality algorithm. It is shown that a causal relationship exists between total precipitation, i.e. rain+ snow, and correlation with stored snow from GRACE. EOF modes also indicate certain regional anomalies such as the Karakoram mass gain representing snow accumulation. Our causality result shows that the excessive snowfall in 2005-2008 has initiated this mass gain. However, as our results indicate, in spite of dampening of snowfall rates after 2008, mass has been steadily increasing, this is attributed to lowering and to stabilizing of temperature increase in this region after 2008.

The investigation of Indian-Himalaya ground water Aquifer depletion by space geodesy and its geological/hydrological contexts

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Abstract

The increasing water demand in the states of Punjab and Haryana located at northwest India has been causing one of the most significant groundwater depletion globally at Indian-Himalaya Aquifer. To observe its long-term and seasonal subsidence behavior, we processed a sequence of interferometric synthetic aperture radar (InSAR) time series of ENVISAT ASAR ScanSAR and Advanced Land Observing Satellite (ALOS) Phased Array Type L-band Synthetic Aperture Radar (PALSAR) with advanced error deduction algorithm. It was revealed that almost all Punjab and Haryana provinces have been under influences of ground subsidence induced by groundwater depletion due to aquifer deterioration which matches with the amount of water thickness change estimated by Gravity Recovery and Climate Experiment (GRACE) satellites. Especially, the largest cumulative subsidence up to ~0.2 meters was identified near Ambala city.

From the InSAR time series and GRACE data analysis, we concluded as below regarding to the findings of Himalayan water aquifer and its environmental consequences.

- The extensive ground deformation was induced mainly by the water depletion for the irrigation and the urban usage but the time lag correlation between surface displacement and precipitation derived from ERA-interim model was also detected. It was interpreted as an effect of percolation time.

- However, the surface deformation and the change in water storage are NOT directly correlated because of geological contexts and anthropogenic effects such as water injections and consumption patterns

- What is interesting of this study is that though minor subsidence is generally reported in areas around Ambala city. It is worth noting that such large scale, high subsidence has not been reported so far in a geomorphic setting of interfan with its characteristic thin aquifers that are often laterally discontinuous.

The intensive InSAR time series analyses focusing on the very recent years since 2015 are undergoing employing new SAR sensor constellations such as PALSAR-2 ScanSAR and Sentinel-1. The intermediate outcomes demonstrated that the subsidence by the ground water depletions is now propagating to the Chandigarh area. Thus we propose the necessity to exploit not only InSAR and GRACE but also the ground observation network such as GNSS and on-site measurement for the prediction of imminent risk by the Indian-Himalaya Aquifer depletion.

Kinematics of Himalayan Neotectonics

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Abstract

Neotectonic studies in the frontal Himalaya are important as they point to (i) deformation associated with slip transfer along the basal Himalayan décollement from the hinterland all the way to the foreland (ii) great earthquake events (iii) critical state of the Himalayan wedge during and after the Quaternary period. The Main Frontal thrust (MFT) is typically activated during such events resulting in fault related folding in the MFT sheet and consequent topographic growth along the MFT. The Himalayan front remains locked during the interseismic periods when the wedge remains subcritical as evident from Global Positioning System geodetic measurements. During the interseismic period, the topography generated by frontal deformation is eroded till the next frontal activation. Within this overall framework, neotectonic studies involve the study of fault related uplift and topography generation during the Quaternary period through direct or inferred signatures.

We found direct evidence of neotectonic activity along the Main Frontal thrust (MFT) in the west-central Mohand Range in the NW Himalaya. The fault zone of the emergent MFT is well exposed here and consists of powdery, fine-grained, incohesive gouge in the fault core at the range front. The fault core is flanked by the hanging wall damage zone. The proximal part of the damage zone is a fault gouge dominated region containing islands of folded and fractured Middle Siwalik rocks within the gouge. The distal damage zone is a zone dominated by fractured Middle Siwalik rocks with bands of fault gouge within them. The entire fault zone is capped by uplifted Quaternary gravels suggesting neotectonic uplift along the MFT. Dismembered folds in the fault zone suggest fault propagation folding associated in the MFT hanging wall or thrust sheet.

Indirect signatures of neotectonic activity are typically obtained from computation of geomorphic indices from basins affected by tectonic activity. We adopted a new approach to computing geomorphic indices along with their uncertainties to identify geomorphic signatures of neotectonic deformation in the Gorubathan recess of the Darjiling Himalaya. In addition, we observed neotectonic warping of alluvial fans due to blind slip along the Ramgarh and the Main Boundary thrusts in the Gorubathan recess and studied the landform evolution using a boundary element method based dislocation model

Through these studies we conclude that neotectonic deformation is an important component of the Himalayan deformation and the kinematics of neotectonic deformation should be studied in conjunction with younger and older deformation signatures to understand its role in the evolution of the actively deforming Himalayan wedge.

Earth Observation (EO) program of ISRO

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Abstract

Remote Sensing of the planet Earth often also referred as Earth Observation (EO) involves monitoring of earth surface features and estimating their geophysical properties using electromagnetic radiation and its interaction with medium. Space based earth observation systems with their ability for a synoptic view, repetitive observations at different resolutions provides a better alternative for natural resource management when compared to traditional methods of assessing natural resources. Considering India's resource richness and the mounting pressure from the large population on the natural resources, the country needs a sustainable resources development plan. Towards this, mapping and monitoring of existing natural resources and forecasting the future scenarios are highly important. Satellite observations of land, oceans, atmosphere, and specifically, during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development.

Over the last five decades, India has evolved a comprehensive Earth Observation (EO) program, which started with a modest experiment of detection of coconut root wilt disease in 1970s. The Indian EO program is self-reliant in every aspect of the technology and is considered as a role model in the world for its applications driven nature. The major components of the EO activity in India are the space segment, ground segment, applications programme and capacity building. The space segment comprises the indigenous development of electro-optical and microwave sensors, spacecraft platforms for both low earth orbit and geo-synchronous orbits and satellite launch vehicles. The talk will highlight currently operating EO sensors of ISRO and future program like NISAR, CARTOSAT-3 and other important EO missions of India.

Paleo-seismological study in the Himalayan region and its importance

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Abstract

Paleo-seismic studies have been conducted during the last decade to begin understanding the timing, size, rupture extent, return period, and mechanics of the faulting associated with the occurrence of large surface rupturing earthquakes along the ~2500 km long Himalayan Frontal Thrust (HFT) or Main Frontal Thrust (MFT) System. Defining the rupture segments and magnitudes of earthquakes has been a challenge because of the scarcity of both historical records of the events and paleo-seismic data. There remains a clear need to investigate the morphology of the HFT fault scarps and document co-seismic slip directly, as calculations of co-seismic slip from scarp heights may introduce uncertainty. Boundary-element modeling has demonstrated that a >20-m-slip event with a 1000 years strain accumulation is theoretically possible on the HF. Alternatively, the large fault scarps along the HFT may represent two or more events instead of one surface-rupturing earthquake. I argue that because the paleo-seismic trenches are neither long enough nor deep enough on the footwall block, that what looks like a one-event scarp may actually be a multi-event scarp. Thus, the possibility that the HFT could rupture in a mega thrust earthquake remains controversial. However, a consensus that a great Himalayan earthquake occurred on blind faults has been recently challenged by discovering evidence for a surface breaking fault of the 15th August, 1950 Tibet-Assam earthquake (Mw ~8.6) along eastern Himalayan front that produced a co-seismic slip of 5.5±0.7 meters.

Discrete paleo-seismological database along different segments of the HFT suggest that evidence of a closely spaced succession of earthquakes has been found in the NW Indian Himalaya (A.D. 1344; 1505; 1555?), in the Nepal Himalaya (A.D.1255; 1505; and1934), and in the eastern Himalaya including Bhutan (A.D.1697; 1713; and 1950): Thus earthquakes in the Himalaya are characterized neither by constant displacement nor by constant recurrence. This suggests a rather random release of seismic energy; great earthquakes could occur anytime. However, considering an apparent long-term quiescence together with modern geodetic elastic strain accumulation rate suggest that the potential for impending large-scale rupture especially in the CSG (Central Seismic Gap), and between E of Kathmandu and the west of Bhutan.

The implications of these studies in respect of disaster are: Great earthquakes thus transfer the convergence between southern Tibet and stable India along the Main Himalayan Thrust (MHT) to the HFT in the Himalaya. Developing a calendar of paleo-earthquake history of the Himalayan region is an issue of great academic importance and practical applications in providing input parameters for SHA (Seismic Hazard Assessment) that will have implications for the safety of the Himalayan foothills.

Future great earthquakes in the Himalaya

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Abstract

The current convergence rate between India and southern Tibet is sufficient to generate a great (Mw=8) earthquake in each of a dozen 180-km-long segments of the Himalaya once per century. The implication is that on average we might anticipate that, once every ten years or so, a Mw=8 earthquake will occur in any one of these segments. Instead, we know of just four Mw>8 earthquakes in the past 500 years (1505, 1714, 1934, 1950), the parameters of which we know astonishingly little. Geodetic observations indicate that nowhere on the Main Himalayan Thrust is this geodetically-quantified convergence being released aseismically, except in the northern transition zone beneath southern Tibet where a zone of microseismicity at 18-20 km depth signifies the development of significant strain accumulation and insignificant release. The rate of productivity of earthquakes with Mw<7.9 nucleating in this region is far lower than necessary to keep pace with this growing slip deficit. In consequence, we are forced to conclude that more than 2/3 of the Himalaya have a slip potential that will be released in one or more great earthquakes with magnitudes Mw>8.0. The paleoseismic record of earthquakes prior to the 16th century, despite its incomplete coverage and the possibility that some great earthquakes terminate in the subsurface short of, or south of, the Main Frontal thrusts, confirms that earthquakes with slip exceeding tens of meters (Mw≥8.4) are ubiquitous and recur at intervals of several centuries. A recent evaluation of the current slip potential of the Himalaya based on historical earthquakes since 1500 reveals 7 locations where a Mw≥8.4 could occur today, two of which could exceed Mw=8.7 should rupture of contiguous segments occur. Should these ruptures be further delayed there are good reasons to suppose that the magnitude of a forthcoming multi-segment Himalayan earthquake could attain Mw=9. Despite these clear seismic hazards, we remain remarkably ignorant as to the timing of future great earthquakes. The recent Mw=7.8 Nepal earthquake indicates that many major earthquakes transfer strain energy from the locked/creeping transition to the mid Himalaya, where this elastic strain remains dormant awaiting release in future great earthquakes. A working hypothesis is that past 8.2<Mw<9 earthquakes have nucleated from a Mw>7source region along the locked/creeping transition at 18 km depth, and that the study of these source regions may offer clues as to the timing of future great ruptures.

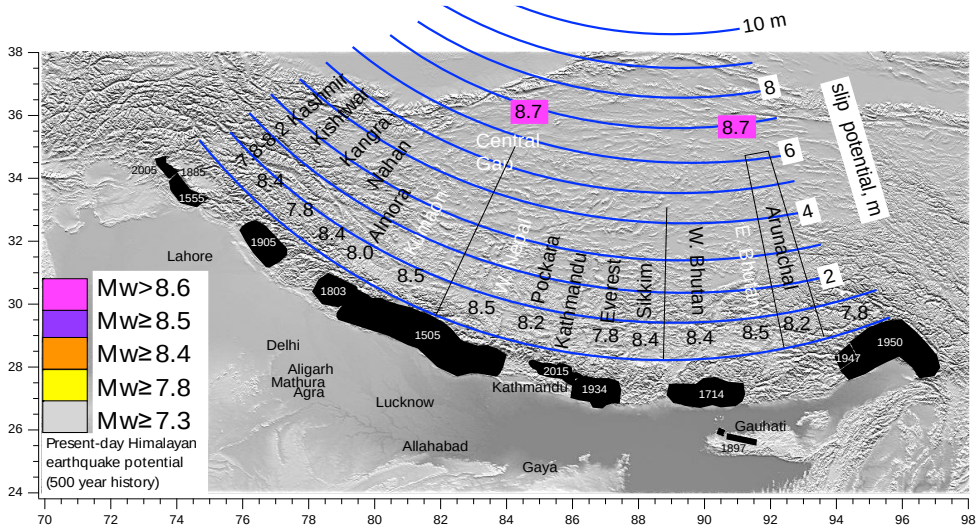

Figure caption:

Rupture zones of historical earthquakes in the Himalaya, and the current slip potential of 15 segments along the arc (meter slip deficit scale right). Color bars indicate the maximum moment magnitude of earthquakes in individual segments, should they occur today and completely release their accumulated slip potential. Segments that have recently experienced a major earthquake have a lower potential for slip, but the failure of contiguous segments will add to the future magnitude of earthquakes that will shake these regions. An example is the Kathmandu segment poised for a Mw 7.3 earthquakes, should rupture be confined to this region, but which will experience and Mw.8.3 earthquake should it rupture simultaneously with the Pockara segment to the west. In some areas (Kashmir and Arunachal) the absence of written or paleo-seismic history of great earthquakes in the past millennium renders the proposed segmentation uncertain

Unmanned Aircraft System (UAS) Based Radars for Measurements of Snow and Ice in Himalayas

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Abstract

Measurements of snow water equivalent (SWE) and monitoring melt onset are important to managing water resources in a warming climate. More than a billion people worldwide depend on seasonal snow for water resources and the value of water from snow is estimated to be in the trillions of dollars. Monitoring seasonal snow is important to water resources management, hydropower generation, forecasting of floods and droughts, and avalanches. Even now, snow at higher elevations is poorly monitored. Currently, estimates of daily snowfall over land are available from the National Oceanic and Atmospheric Administration (NOAA) from space borne passive microwave sensors. However, these sensors over-estimate the SWE in areas with rough terrain and vegetation cover. In addition, the brightness temperature saturates for snow cover exceeding 150 mm of SWE. Ultra-wideband (UWB) radars operating over a frequency range of 2-18 GHz with quad-polarization have great potential to estimate SWE and melt.

Himalayan glaciers are undergoing large changes; most glaciers in India currently show evidence of retreat. but key information about ice thickness and annual mass balance is not readily available. More accurate estimates of the mass balance of the Himalayan glaciers are required to reduce the large uncertainty in IPCC reported estimates—from a 29% loss to a 2% gain by 2035. This requires ice thickness measurements over in addition to continued satellite observations to determine surface elevation and surface velocity over large areas. Low-frequency radars integrated onto small Unmanned Aircraft Systems (UAS) with 2-D aperture synthesis have great potential to make critical ice thickness measurements,

We are developing compact ultra-wideband (UWB) radars with range resolutions of approximately 2-3 cm for operation on UAS to measure surface elevation and snow thickness in complex hilly terrain. We are also developing a dual low-frequency sounder at 14 and 30 MHz for operating on UAS for sounding and imaging of temperate ice. We will use UAS for collecting data needed to perform 2-D Synthetic Aperture Radar (SAR) processing to obtain fine resolution both in the along-track and track-tracking to suppress surface clutter for sounding mountain glaciers.

We developed multichannel UWB microwave radars for airborne measurements of snow over land and sea ice over the last few years and collected data with these radars using long-range and short-range aircraft. We also developed a dual low-frequency radar for sounding of mountain glaciers. We collected data over glaciers with extremely rough surface and temperate ice in Greenland using this low-frequency radar. We will present results from these measurements and discuss our plans for UAS-based radars development and their operation over the next few years.

Earthquake hazard in the Himalaya: Lessons learnt from recent earthquakes

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Abstract

The Indian peninsula is surrounded by the tectonically active plate boundaries of the Himalayan mountains and Andaman-Sumatra subduction zone. The Himalayan mountains have produced some of the most devastating earthquakes over the last century, namely Kangra (1905), Assam (1950), Uttarkashi (1991), Chamoli (1999), Kashmir (2005), Sikkim (2011) and Nepal (2015). These earthquakes have caused enormous loss of lives and property, highlighting the vulnerability of civilizations in areas where major earthquakes occur. More than a sixth of the world's population lives in India. The population is growing rapidly and this growth is accompanied by rapid urban development in these regions of high seismic hazard potential.

Over the past two decades, geoscientists have started to understand the urgency of the situation and have taken significant steps towards quantification of seismic hazard. Recent advances in instrumentation and computational techniques are being used by geoscientists, particularly seismologists, structural geologists and tectonic geomorphologists, to study active faults, earthquake source properties, seismic velocity structure and attenuation of seismic energy. This knowledge is used to quantify seismic hazard in the Himalaya and the adjacent Indo-Gangetic plains, which is the most densely populated region of the country. Through my presentation, I will highlight the lessons learnt from recent devastating earthquakes in the Himalaya, sharing of knowledge and expertise with earthquake scientists across the globe and implementation of best practices in quantification of seismic hazard.

Tectonics of the Himalaya: an overview

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Abstract

A vast NeoTethys ocean between India and south Eurasia was closed as a consequence of subduction of the oceanic lithosphere of Indian plate under the south Eurasian continent. In Northwest Himalaya, Ladakh and Kohistan display a classic example of different paleotectonic regimes generated during the closing of the NeoTethys ocean. Based on petrotectonic assemblages and their temporal – spatial relationship, and backed by geochemical and sedimentological analysis and isotopic dating; different paleotectonic regimes are recognized. The Dras -Kohistanarc complex represents an Early Cretaceous intra-oceanic volcanic arc produced as a result of subduction of the oceanic lithosphere of the northward moving Indian plate within the NeoTethys Ocean. The Shergol – Zildatophiolitic mélanges were generated under the trench environment in subduction zone. The Nidarophiolite complex comprising an ophiolite slab and island arc volcanics suggest a supra-subduction tectonic setting. The Ladakh plutonic complex batholith was evolved in an Andean – type margin. The Indus Group sedimentaries were deposited in a fore - arc basin south of the Ladakh plutonic- volcanic arc during Eocene – Miocene. The Shyok Suture zone represents a back arc marginal basin developed between the Ladakh magmatic arc and the southern margin of the Karakoram block of south Eurasian plate.

Himalaya originated as a consequence of collision between the Indian plate and the south Eurasian plate during ~50 Ma. Northward convergence of the Indian plate produced crustal thickening as a result of shortening induced by imbrication of the northern margin of Indian continent. The Main Central Thrust (MCT) was initiated first at mid-crustal level and was responsible for exhuming the High Himalaya Crystallines and their cover of Tethyan sedimentaries during ~33 Ma – 22 Ma. The ongoing convergence subsequently produced the Main Boundary Thrust (MBT) further south of the MCT during ~ 10 Ma that gave rise to foreland propagating thrust system, with the formation of duplexes of the Lesser Himalayan sequence between the Ramgarh (=Chail) Thrust as the roof thrust and the Main Himalayan Thrust (MHT) as the floor Thrust. South of the MBT, fold-thrust system of Tertiary foreland basin was developed during Pliocene - Quaternary time as fault propagated fold-thrust system of the Himalayan Frontal Thrust (HFT). The MHT represents a decollement between the top of the northward subducting Indian plate and the southward propagating fold-thrust system of Himalaya. The HFT represents the surface expression of the MHT defining an active deformation zone. In Himalaya, the frontal Sub-Himalayan zone is characterized by active late Quaternary – Holocene deformation. In this zone, the frontal Siwalik range abuts against the alluvial plain with an abrupt physiographic break along the Himalayan Frontal Thrust (HFT), defines the present day plate tectonic boundary between the Indian plate and the Himalayan orogenic prism. The frontal Siwalik range is characterized by large active anticline structures, which were developed as fault propagated / bend folds over the HFT, e.g. Mohand, Chandigarh and Janauri anticlines. The HFT is active in Holocene - recent time as evidenced by fault scarps showing surface ruptures and offsets of present

geomorphic surfaces observed in the field mapping and excavated trenches. In the hinterland between the HFT and the MBT, reactivation and out-of-sequence faulting displaces the late Quaternary –Holocene sediments. In the past one hundred plus decade years the Himalayan region has been devastated by the three great earthquakes: 1905 Kangra, 1934 Bihar – Nepal, and 1950 Assam (now Arunachal). Paleo-seismological investigations reveal that the surface ruptures produced by the 1934 and 1950 and other historical earthquakes are recorded on the Sub Himalaya front. The surface ruptures marked by fault scarps represent imbricate splays branching out of the HFT, whereas the hypocentres of these earthquakes are located in the hinterland Lesser Himalaya. Instrumental recorded seismicity shows clustering of events within ~ 50 km wide belt located at 10 – 20 km depth along the topographic front of the Higher Himalaya. There are at least two types of large earthquakes in the Himalaya. The 2015 Gorkha and others (1255,1833, 1934) Mw > 7 earthquakes of Nepal in central Himalaya are plate boundary events invoking slip over the MHT. The 2005 Kashmir and 1905 Kangra earthquakes in northwest Himalaya reactivated the out – of – sequence thrusts, and their surface ruptures remained restricted within the hinterland.

There is a debate that uplift of the Himalaya is not solely through thrust –thickening. The climate response through erosion may be coupled with the tectonics in raising the mountain topography. The role of erosion is emphasized by explaining the rise of highest peaks due to isostatic recovery driven by incision of large valleys in the Himalaya. The occurrence of low velocity zone beneath the southern Tibet is modelled as to propose that the High Himalaya zone rocks are extruded at mid-crustal channel flow between the South Tibetan Detachment and the Main Central Thrust, driven by rapid erosion at the topographic front. The out of sequence faulting at the front of the High Himalaya is attributed due to focused precipitation driven erosion on the topographic front.

Geodetic evidence of strong seismic coupling underneath Garhwal-Kumaun region, NW Himalaya

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Abstract

More than two thirds of the Himalayan arc have not experienced a great earthquake in the past 200 years and most of the unruptured Himalayan segments may have the potential to generate great earthquakes. The Garhwal-Kumaun segment of the NW Himalaya in India and part of western Nepal has not experienced a great earthquake since at least 1505. In fact, it has been debated whether the rupture of the 1505 earthquake in western Nepal actually extended westward into the Garhwal-Kumaun Himalaya and if it didn't, then the Garhwal-Kumaun segment of the Himalayan arc has not ruptured since at least ~1344 and could be the most vulnerable Himalayan segment along its 2400-km long length. We report results of continuous GPS measurements from 28 sites from the region to suggest that the convergence rate in this part of the Himalaya is about 18 mm/year which is leading to strain accumulation in the region. The Main Himalayan Thrust (MHT) in the frontal part of the Himalaya under the Outer and southern Lesser Himalaya is strongly coupled for a width of about 85 km. The mid crustal ramp where earthquakes of Himalayan seismic belt occur, exhibits low coupling. Strong coupling on the MHT beneath the Outer and Lesser Himalaya is homogeneous except in the very shallow updip part of the MHT. Subduction of sediments of the Indo-Gangetic plains or the Delhi Hardwar ridge does not seem to influence coupling. A high rate of strain accumulation, which has continued for more than 500 years on a strongly coupled MHT makes this one of the most earthquake-vulnerable segments of the Himalayan arc.

36th International Geological Congress

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Abstract

India is hosting 36th International Geological Congress, during March 2- 8, 2020 in Delhi. Four neighbouring countries, Nepal, Bangladesh, Sri Lanka and Pakistan are co-hosting the congress. The main theme of the conference is the Basic Science for a Sustainable Future, which has 44 scientific themes covering Near Surface Geoscience, Resource Generation Geoscience for Societal Use, Basic Geosciences, Himalayan studies, Non-linear geoscience etc. There are about 261 symposia and many other symposia from IUGS affiliated organizations including YES. 71 field trips to showcase the geologically spectacular features in the Indian subcontinent have been planned. There will be field trips in Nepal, Bangladesh and Sri Lanka also. A Geo-host program has been finalized under which our 1000 delegates will be given registration-waiver, free travel and local hospitality. Minimum requirement is that abstract of the delegate has to be accepted. First and second circular have been released and the third circular is expected in the month of April-2019. For details one can see these circulars and the website of IGC.

Playing with Water & Water Bodies: For Life & For Business

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Abstract

Inadequate water supply and poor water quality, increasing demand of water for domestic, agriculture, as well as industrial purposes, continuous degradation of water resources, etc. are some of the most common concerns. To address these concerns, we need to understand (i) the water-food-waste-pollution-health-economy nexus and (ii) our water bodies and importance of preserving/protecting them. All this depends on how we play with water to fulfil our basic needs i.e. for life, and for business i.e. water as a commodity. We need to have paradigm shift in our thinking about managing wastes and pollution, pursue the policy of zero waste discharge in water bodies and reuse/ recycle more seriously. This can be achieved if Industry/ Academia/ CSO/ NGO come together and do the front door lobbying for seriously and meaningfully dealing with water and water bodies. The speaker would like to illustrate this in the context of Ganga River Basin Management Plan prepared by the consortium of 7 IITs.

Invited Talks

Forest fire hotspot prediction by integrating mapping of socio-economy, geographical factors and climatic parameters in Arunachal Pradesh

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Abstract

Fire is one among major threats for the world's forests which leads to tremendous loss to the bio-diversity and changes in several ecosystems. Arunachal Pradesh, with over 80 % forests are known for Himalayan biodiversity. Forest fire destroys millions of hectares of the world's forests every year. Forest fire frequency in India has greatly increased in last few decades due to drought, hot weather, and accumulated Chir Pine needles.

The objective was to analyze forest fire data on GIS platform towards visualization and evaluation of spatial and temporal dimension of fire pattern, to understand distribution across different vegetation types, topographical gradient, & socio-economy. And, to develop integrated mapping towards predictive modelling along with correlation with the real time data, in order to extract potentially affected villages for the strategic allocation of Govt resources.

Spatial analysis of forest fires was carried out based upon decadal (2008-2016) forest fire count datasets, which was assessed for spatial variability over the known Himalayan biodiversity where the point density based forest fire hotspot was generated to predict fire hotspots. Data such as MODIS, SPOT4, ASTER-DEM were used. The study revealed, annual frequency of forest fire during 2008–2016; total occurrence of forest fire was 4429 out of which maximum 777 forest fire was found in the year 2009 and lowest (293) during year 2016. District wise analysis of forest fire data revealed that East and West Kameng, West Siang and Papum Pare districts had 25.2, 17.8 and 10.8% of fire incidences, respectively. 560 villages/settlement were found to be most fire vulnerable out of 5,258 extracted. Fire vulnerability was perfectly correlated with geo-economic vulnerability.

All districts showed high fire incidences, therefore an urgent intervention is required by the policy makers towards conservation and management of forest fire prevention and control by adopting focused intervention, strategic allocation of limited resources in potent areas revealed in the study in order to safeguard Himalayan region of rich bio-diversity. Apart from topographical and metrological factors, forest fire largely depends upon shifting cultivation practices. The study is very useful to the Government officials as it predicted forest fire hotspots with greater accuracy (63 %) and equally useful for the forest-fringe areas population as early warning system during the event of fire break.

Current state and future changes in Himalayan Glaciers

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Abstract

The Himalaya has one of the largest concentrations of mountain glaciers, many rivers like Indus, Ganga and Brahmaputra and their numerous tributaries originate from the region. However, this source of water may be influenced in future, as Himalayan cryosphere is constantly changing due to climate change. Therefore, retreat of Himalayan glaciers is discussed extensively in various scientific and public forums in India. The contribution of snow and glacier melt in annual stream runoff is almost 72 % in the Upper Indus river basin and 59 % at Bhakra reservoir. The overall contribution is lower in the Ganga and Brahmaputra basins. However, well developed canal network in the Indus basin produces almost 96% and 26% of food production in Pakistan and India, respectively. Therefore, changes in runoff pattern in the Indus basin due to glacier melting can significantly influence the water and food security of India and Pakistan.

In this presentation, we will discuss state of Himalayan glaciers and possible changes in glacier extent due to climate change. Glacier mass balance is one of the key parameters to determine the glacier's health and field-based estimates are available for relatively few glaciers and for short duration. Therefore, a new method to estimate mass loss was developed and applied to the Satluj basin. The Satluj basin presently stores 62.3Gt of water in approximately two thousand glaciers, covering an area of 1426 km^2. The glaciers in the Himalayan region are losing mass approximately at the rate of 9.8 Gt per year. By the end of this century, glaciers in the Satluj river basin, are likely to lose 53% and 81% of area, based on climate projection of CNRM-CM5 and GFDL-CM3 model respectively, under RCP 8.5 scenario. According to these modelled estimates mass balance will be more negative by the end of century as-0.42 $m.w.e.a^{-1}$ (CNRM-CM5) and-1.1$m.w.e.a^{-1}$ (GFDL-CM3). In addition, glacial retreat will also be influenced by numerous local factors like Black Carbon deposition in accumulation areas and debris cover. This provides unique challenge in understanding future changes in Himalayan glaciers. This will have profound impact on water availability in micro, mini and major river basins of the Himalaya. In addition, glacier retreat leads to the formation of moraine – dammed glacier lakes which can be a source of glacier lake outburst flood. Mountain communities are highly vulnerable to such natural hazards and this will be discussed in detail.

Mathematical Modelling of Snow Avalanches in Himalayan Region

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Abstract

The interest in the dynamics of snow avalanches in the Himalayan region is gaining considerable momentum because of increased frequency of avalanche occurrences in the recent past causing huge loss to lives and property, disruption in the movements of military and public in the snow bound regions and the risk to the people visiting pilgrim centres located in the avalanche prone areas of Himalayan region. The pilgrim centres located in Uttarakhand, Himachal Pradesh and Jammu and Kashmir have greater risks due to destructive potential associated with the avalanches and the manifestations resulting from the combined effect of avalanches and debris flow due to landslides. The avalanches may trigger glacial outburst flood and flash flood which will have devastating consequences at the downstream. It is therefore essential to have precise mathematical models for improved understanding of snow avalanches so that appropriate structural and non-structural mitigating measures could be evolved and the guidelines could be developed for fixing the layouts and designing the infrastructures in the avalanche prone areas. This paper presents the state-of-art on the mathematical models currently used for the study of dynamics of snow avalanches and examines the terrain, geomorphology and climatic conditions of Himalayan region that complicates the modelling task. The mathematical models considered in the analysis show wide variations in the conceptualization and model building blocks, and thus they are grouped based on the underlying mechanics of snow mass movement.

It is observed that the temperature, snowfall and precipitation patterns in the avalanche affected Indian Himalayan region vary widely which results into the considerable spatiotemporal variations in the snowpack properties and thereby avalanche events. The study shows that the weather, snow density and snow metamorphism significantly influence the avalanche mechanisms, and thus the complexities get involved in the description of constitutive equations of moving snow mass. It also explores how medium and high resolution remote sensing data could be utilized to enhance the capability of mathematical models in terms of better representation of avalanche catchment and runout pathways and the simulation of velocity, runout distance and destructive energy of snow avalanches. Some applications of mathematical models for simulating avalanche runout distances in the Beas river basin located in Himachal Pradesh and delineating the avalanche paths and fixing the alignment of avalanche resilient ropeway infrastructure in Uttarakhand are also discussed.

Geomorphological processes for glacial lake damming preceding burst in different regions of Indian Himalaya: Comparative study

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Abstract

There are numerous lakes proximal to glaciated regions of Indian Himalaya that may become disturbingly dangerous as a result of the effect of climate change in future. The formation and release mechanism of such lakes may be different but the devastation that it may cause downstream is dreaded to be colossal. An analysis of glacial lakes in three different regions of Himalaya throws light on the varied nature of the development of such lakes and so is the release mechanism.

South Lohnak Glacier in eastern Himalaya, Sikkim has produced a massive lake that got subsequently filled to the brim behind terminal moraine of the receding glacier. The breaching of the lake at any time was a cause of concern because of presence of appreciable amount of ice matrix within the terminal morainic material. Yet the lake did not breach fully at any time so far due to the overflowing of water over the moraine at one side. This gradually caused further melting of a portion of the ice filled moraine and reduced the chance of bursting of the lake. However, precautionary intervention was required to reduce the volume of water stored behind the moraine.

Chorabari Lake at Kedarnath in central Himalaya Uttarakhand had formed alongside a lateral-terminal moraine that would normally get filled in the melting and monsoon season and drain occasionally in waning melting period as well as during retreating monsoon phase. The sudden downpour in June 2013 in Uttarakhand region and subsequent release of old snow beds in the lake caused a breach that proved very devastating downstream.

Phuktal, a tributary of Zanskar in western Himalaya, J&K on damming by a landslide produced a huge lake behind the landslide. Sudden bursting of the river had become a cause of concern since the damming had happened during winter and it was expected the summer glacial melting would eventually breach the dam and produce extensive floods downstream. To prevent such devastation, an artificial breach was attempted with success during peak winter period.

The study suggests advance preparation of such eventualities at potentially destructive sites and preventive measures required to be taken to reduce the damage to the minimal.

Clouds Anomalies Detection and Earthquake Prediction Prior to Earthquakes Using Landsat Imageries: Cases of China, Nepal and India

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Abstract

Earthquake prediction is quite challenging in nature though several scientists were tried to predict earthquake through interaction of thermal and cloud anomalies with some success and limitations. The present study was attempted for earthquake prediction in four different geographical sensitive areas in the Asia regions by observing the cloud anomalies before three moments magnitude category earthquakes. Moreover, the specific reason of conducting this study was to test similar cloud abnormality was presence or not in all four reported earthquakes. In this study, we considered Landsat 5 TM multi-temporal satellite images for 2008 (Wenchuan), 2010 (Yushu) and Landsat 8 OLI images for 2015 (Gorkha) and 2016 (Imphal) earthquakes, respectively. For each case, three successive satellite imageries were analyzed to observe before earthquake anomaly and one image used for after earthquake scenario. This experiment done with atmospheric corrected enhanced false color composite images of Landsat scene generated through ENVI 5.3 software, later visual interpretation, overlay, layer swiping technique of ArcGIS 10.5 software were applied and possible relation of earthquake clouds with major geological fault lines interaction were observed, targeted and analyzed based on two circles drawing. The research results witnessed presence of cloud anomalies in all four regions approximately 3-29 days before earthquake occurrences and remains unchanged for few days especially around epicenter and close adjoining areas. Furthermore, data anomalies indicated that the great and major earthquakes occurrence need more time than strong earthquake. However, through our results, we can say that, successive Landsat data have strong power to detect the cloud anomaly at earliest before its occurrence. Therefore, we suggest that, this method might be considered as an alternative method for future earthquake prediction.

Vulnerability of buildings in the Himalayan and surrounding regions - are we prepared for the big one?

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Abstract

Indian sub-continent has witnessed some of the most destructive earthquakes during the last century including four great (M>8) earthquakes and a number of major earthquakes. The combination of high hazards due to large earthquakes of the Himalayan collision boundary and ever growing vulnerable built and human environment creates a situation of unacceptably high levels of risk in the Himalayan region and adjoining areas of densely populated Indo-Gangetic basin.

Recent Himalayan earthquakes of 2005 Kashmir, 2006 and 2011 Sikkim, 2015 Gorkha and 2016 Imphal have underscored the seismic vulnerability of modern buildings even for an intensity of shaking much below the design levels. Many dramatic collapses and damages including publicly-funded buildings were disproportionate to the observed intensity of shaking. This is primarily due to poor compliance with building codes of earthquake-resistant design, inferior quality of raw materials, unsound construction practices, shoddy workmanship, unstable slopes and sites. These past events should be regarded as a preview of what is likely to happen in the event of a greater shaking due to a big earthquake expected for the Himalayan region.

The talk will provide an overview of the past seismic damages as applied to buildings and identify the vulnerabilities across various building typologies prevalent in Himalayas and its neighboring regions. This is necessary not only to clearly understand the needed structural intervention to remedy these vulnerabilities, but also to have an estimate of economic loss and damages that can be averted with appropriate mitigation effort.

In summary, despite the available knowledge base, the communities in high seismic regions of the Himalayas are not adequately prepared due to lack of implementation of earthquake-resistant building technology. However, with adherence to seismic codes and recommended construction practices, it is possible to mitigate large-scale disasters in these regions of high seismic activity. This paper will summarize these aspects in the context of experiences gained in recent Himalayan earthquakes.

Himalaya: The hot spots of climate change

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Abstract

The Himalaya, which literally means abode of snow is the greatest east-west oriented mountain range of the world constituting of the youngest mountain system on earth, still rising and very slowly drifting northwards These mountain ranges are extensively spread from west to east in a total length of about 2500 km roughly separating the tropical and extra-tropical regions over south Asian subcontinent and have an average north-south extent of about 200 km. The Tibetan Plateau at the top of the mountain acts as a high-level heat source for the large-scale monsoon circulation to its southern side. The snow-covered mountains ranges provide high reflectivity to the incoming solar radiation and steep slopes and sharp gradients provide the orographic influence to the weather systems for sudden and high intensity events to build up. Thus, the meteorology of Himalaya, the core element of its climate, is a unique and direct interaction of high-altitude mountains with complex terrain and locally originating weather systems as well as the large-scale migratory weather system from the west and penetrating northern most edge of the south-west monsoon. It also acts as a gigantic barrier to the cold winter outflow from the Tibetan Plateau directly to the south Asian sub-continent. Large variations in topography, elevation, soil, rock structure, river, glaciers and vegetation cover result into contrasting climates within short distances making the region conducive for initiation and intensification of short duration extreme weather events.

The perturbation of the Earth's natural climate system caused by the anthropogenic influences resulting in minor aberrations in the radiation balance of the earth has indicated that there are significant changes in the climate leading to increased temperature known as global warming. Comprehensive data on surface temperature of the earth from all over the globe for almost a century has indicated that there is continuous increase in the mean temperature of the earth's surface with enhanced increase during last few decades attributed to increase in greenhouse gases of the atmosphere mainly due to anthropogenic sources. Himalaya generally referred as the third pole of the earth is an important hot spot of the earth as far as climate change is concerned. The region is most sensitive to subtle changes of climate with impact on water resources, forests, glaciers and fragile biodiversity and ecosystem.

The presentation will focus on the major climate change issues of the Himalaya including its impacts, mitigation, adaptation and remedial measures specifically with example for western and central Himalaya. Data will be presented for long term temperature change over the western and central Himalaya using tree-ring analysis and globally generated data sets. It is proposed to give special emphasis to the extreme weather events of the Himalayan region such as the cloud burst, lightening, flash floods, snow storms and avalanches and retreating glaciers will be discussed in the context of climate change. Feedback interaction and scientific discussions.

Geomatics applications in gathering information on alpine vegetation to support climate change studies- A case study of Uttarakhand

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Abstract

Climate change, extreme events and impact of these on the natural resources and environment are area of concern for global community. Gathering the evidence of climate change, which can be trusted and used, for modeling the impact as well as planning the mitigation strategy are the areas where Geomatics application could play an important role. Availability of remote sensing satellite data from 1970's has potential to support such studies. Time series observations of Indian Himalaya using remote sensing data have shown changes in snow cover, glaciers and alpine vegetation. While change in snow and glaciers often get ascribed to climate change, but the questions remain unanswered whether these are just the cyclic pattern or the changes are real and persistent. Changes in land cover type over time, particularly receding snowline and colonization of area so vacated by alpine vegetation could be treated as definite results of change in the habitat condition.

This study reports the use of remote sensing data for mapping the alpine vegetation, quantifying changes from 1970s to 2006 and use of environmental niche modelling, taking an example of Uttarakhand state. Landsat MSS data of 1972-76 and IRS LISS-III of October to December 2006 have been used to map the vegetation. Elevation and contours have been generated using the Global Digital Elevation Model of ASTER. Alpine treeline and other vegetation have been mapped using NDVI threshold of >0.4 for tree and 0.25-0.4 for other vegetation. Isoline for the tree and vegetation have been generated and compared with the station height generated with 30m ground sampling of DEM. Shift in alpine treeline ecotone (ATE) between the two period derived with GIS indicated that, treeline stretched for about 2962km surface distance in 2006 between Uttarkashi in the northwestern parts of state to Pithoragarh in northeastern parts at an average elevation of 3542m. It covered about 1650km surface distance at average elevation of 3166m in 1970s. Chamoli District had the largest share of the treeline (30.62%), followed by Uttarkashi (29.12%). Around 98% of the treeline were found in the elevation range 3000–4000m. Mean upward shift of 388 ± 80 m has occurred over the period and it varied between 430m (Chmoli district) and 360m (Uttarkashi and Bageshwar districts). However, the highest treeline located at 4573m in Gangotri region has not changed during the same period.

Analysis of field data on change dynamics and species composition covered Bedini Bugyal in Chamoli district. It has shown treeline location at 4120m ASL and maximum shift of 600m, mostly composed of fir-birch up to 3500m and birch-rhododendron up to 4120m. Alpine pastures are found at 4425m on the southern aspect while pastures are located below 3000m on the northern aspect. Thin and sparse vegetation, apart from mosses and lichens has been found near snowline and in the proximity of glaciers. Vegetation could be well identified using NDVI threshold, but the mosses and lichens overlapped with scree. Thus, the vegetation line identified covered only the well-developed vegetation. The other

vegetation line stretched about 5274km surface distance at an average elevation of 4158m and maximum elevation of 6157m in 2006. During 1970s, the other vegetation line covered about 2010 km surface distance with an average elevation of 3447m indicating 700m upward shift.

Modelling of environmental niche of a dominant treeline species (Himalayan birch or Betula utilis) for alpine region of Indian Himalaya and its validation using ground truth supported satellite remote sensing data has also been attempted. It dealt with the generation of 19 bioclimatic indices using temperature and precipitation data of 1950-2000. To predict the B. utilis distribution from presence-only occurrence data, GARP (Genetic Algorithm for Rule-set Production) model has been used. GARP uses a set of rules (e.g. adaptations of regression and range specifications) that best predicts the species distribution. Betula utilis bioclimatic envelop overlapped 84 % of the remotely sensed treeline ecotone. This establishes the fact that the environmental conditions of the alpine zone of Uttarakhand are conducive for the dominance of B utilis as a treeline species. There is paucity of regular 'in situ' observation system in the Indian Himalaya, and program like GLORIA (Global Observation and Research Initiative on Alpine vegetation) are imperative to support the climate change studies of the region.

Masking of triggered seismicity in high strain accumulation rate region: a case of Tehri reservoir in NW Himalaya

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Abstract

Reservoir impoundments due to construction of hydroelectric dams certainly influence the stress state in the neighboring region and may stabilize/destabilize some pre-existing faults of the region which were sufficiently close to failure under the ambient tectonic stresses. This in turn has a great influence on the background seismicity of the region and sometimes may also lead to occurrence of large earthquakes. More than 100 cases have been reported worldwide where impounded reservoirs influenced the seismicity in the nearby region. But in spite of the fact that many larger reservoirs have been impounded in the Himalayan region, no case of Reservoir triggered seismicity (RTS) has been reported from Himalayan region. The 260.5-meter-high Tehri dam in the NW Himalaya is the tallest dam in India. Impoundment of the reservoir started in October 2005and a local network of 40 broadband stations in the Garhwal-Kumaun Himalaya was established in April 2005, i.e., just 5 months before the impoundment began, which operated until June 2008. The first earthquake in the vicinity of the reservoir was recorded by this network in December 2005. Majority of the earthquakes recorded by this network were located farther north of the Tehri dam in the Main Central Thrust (MCT) zone, where earthquakes of Himalayan Seismic belt are concentrated. But a cluster of earthquakes was located immediate south of the dam with no earthquakes immediately north of it. However, no earthquakes in the global catalogue (1967-2014) are located to the south of the dam. To analyze the effect of the Tehri reservoir impoundment on the post-impoundment south cluster identified by the local seismic network, a fault stability analysis has been done. Assuming that all these earthquakes occurred on the Main Himalayan Thrust (MHT), change in stress and pore pressure have been simulated on it due to the reservoir impoundment. The analysis shows that the reservoir impoundment has destabilizing and stabilizing effect on the MHT to the south and north of the dam, respectively. The absence of seismicity in the pre-impoundment period in the region south of the dam implies that the Tehri reservoir impoundment triggered earthquakes of south cluster. However, immediately north of the dam a few earthquakes are reported by some Himalayan networks and in the ISC catalogue in the pre-impoundment period which suggests that either the reservoir inhibited occurrence of earthquakes in this region or the pre-impoundment seismicity is mislocated and actually belonged to the Himalayan seismic belt, farther north of the reservoir. The possibility of them being mislocated appears to be quite likely.

A general lack in the report of RTS for the Himalayan reservoirs is probably due to the fact that in the region of low rate of stress accumulation and where background seismicity is almost very low (e.g. stable continental regions), a small increase in the frequency of earthquakes triggered by reservoir is noticeable, but in the region like Himalaya where stress accumulation rate and background seismicity are high, there is a possibility that small increase in earthquake frequency due to reservoir triggering might get unnoticed if there is no good seismological network close to the reservoir region operating before and after the

reservoir impoundment. Thus data from a local continuous and dense seismic network in the Tehri reservoir region is very much necessary to understand the phenomenon of RTS in more detail. In fact, in general a local network before and after the impoundment of any hydroelectric power reservoir is essential for safety and scientific reasons, as knowledge of background seismicity is necessary to define and understand the earthquakes near the reservoir after its impoundment and also to understand the RTS phenomenon scientifically.

The Famous Halji GLOF, Nepal: State of Research, and Conjectures, Particularities and Generalizing Findings

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Abstract

Rinchen Ling Monastery, founded in 1015, is the oldest and most valuable Buddhist monastery of Nepal. Between 2004 and 2011 it has been threatened and partly damaged by a series of six GLOFs. The monastery is located at the rim of Halji Village in the Limi Valley, at the south-eastern slopes of the Gurla Mandhata Massif (7694 m) at an altitude of 3740 m a.s.l. Motivated by the Norwegian cultural anthropologist Astrid Hovden, a German research group form Dresden, Tuebingen, Aachen and Berlin studied these GLOFs both by means of multi-temporal RS imagery and three field campaigns. Since April 2018 an automatic weather station **(**AWS**)** with remote data transfer to Germany and a time-lapse camera allow the monitoring of the supraglacial lakeon the Halji Glacier at 5300 m a.s.l. that due to its temporally irregular fillings caused the outburst floods. Still, the subglacial siphon(s) and the possible triggering of the GLOFs through earthquakes have not yet been studied.

White roofing – A potent mitigation strategy to combat climate change in the Himalayan Mountains

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Abstract

The Himalayan Mountains have warmed significantly in the last century. The rate of warming during winter season is higher than in the summer/monsoon. Consequent depletion of winter snow covers during winter and higher rates of summer melting of glaciers due to rising temperatures affect micro-climatological and hydro-meteorological regimes of many river basins in Himalayas and livelihood of millions of people inhabiting the Indo-Gangetic Plains of Northern India.

Large-scale urbanization and deforestation, particularly in the Siwalik, Pirpanjal and parts of greater Himalayas, have altered the hilly landscapes substantially. Besides removing healthy vegetation cover that adorned these mountain ranges, they are now covered at places with either greyish concrete roof-tops of house-holds or have exposed the barren ground beneath with very low surface reflectivity or albedo values. A pilot study of temporal changes in landscape features in Upper Beas catchment from 1968 to 2014 using satellite imageries has revealed significant increase in area under urbanization (by more than 100%) and drastic reduction in permanent snow cover over this period of time. This modification has resulted in significant change in radiation regime of this basin and has contributed in the warming process, both in winter as well as summer. In order to arrest the warming trend and bring it down, suitable techniques to induce and enhance "negative radiative forcing" are needed to be devised and adopted.

Short-wave radiation (insolation) component, which is albedo/reflectivity dependant, is an important contributor to the energy balance process in the tropical climate of the Himalayas. A time-tested method like covering the roof-tops with highly reflecting material or painting them white in all river basins which are sensitive to climate change, can prove to be an immensely effective method in artificially increasing the reflectance/albedo values of urbanized areas and reduce the contribution by short-wave radiation in the energy balance process.

Differential ablation pattern in adjoining glaciers: Response to debris cover

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Abstract

Two adjoining glaciers, namely Batal and Sutri Dhaka glaciers, located in Chandra basin of Lahaul and Spiti District, Himachal Pradesh were investigated for comparative study as both the glaciers are placed in similar geographic setting but exhibit different ablation patterns. The Batal glacier is 6.6 km long with 2.6 km of accumulation zone and 4 km ablation zone, whereas the Sutri Dhaka glacier is 11 km long with 2.1 km of accumulation zone and 8.9 km ablation zone. Apart from the difference in length and width of the two glaciers, these glaciers differ in terms of debris cover. The role of supra-glacial debris on ice melt has been a subject of many studies extending to cryosphere regions world over. While the ablation area of Batal glacier shows extensive debris cover, the Sutri Dhaka glacier presents a relatively debris free ablation zone. In Batal glacier, debris of varying thickness cover more than 90% of total ablation area, while in Sutri Dhaka glacier it is less than 5% of the ablation area. In the case of former, the debris covers decreases with increasing altitudes whereas in case of the latter, the glacier is mostly a clean one except the snout area. Accumulation area in both the glaciers is free from the debris cover. The Field observation data over Batal glacier indicate that the debris thickness increases from a few centimetres in upper ablation zone to hundreds of centimetres at or near the terminus. The variation in debris thickness is pronounced in the lower ablation zone, whereas it is subdued in the upper ablation zone.

The study reveals that both the glaciers have experienced retreat and mass loss during the time span of 51 years between 1962 and 2013. The rate of retreat is higher in case of Sutri Dhaka than that of Batal glacier. A terminus retreats of 373 ± 33.5 m (an average of 7.3 ± 0.7 m a−1) and 579 ± 33.5 m (an average of 11.4 ± 0.7 m a−1) for Batal and Sutri Dhaka glaciers), respectively, has been interpreted during this period based on the Survey of India topographic maps (1962) on 1: 50,000 scale and the field measurement in 2013.

Better understanding Natural Disasters arising out of the Himalayan: Urgency to adopt and apply modern technology at a much faster speed

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Abstract

The uniqueness of the Himalaya, originated as a direct consequence of the India-Asia convergence process, is wide ranging. The continental-continental collisional tectonics, producing and supporting the load of highly elevated crustal mass of the Tibetan plateau, also produces the greatest earthquakes. The highest mountain range continues to play as the main driving force behind the Asian climate, played the decisive role in forming the geography and developing the vast human civilization in the Indian subcontinent. The ongoing mountain building process and current climate change associated with the global warming phenomena has immediate and direct effects affecting lives of hundreds of millions of people living in major river flood plains and deltas, covering the entire northern India and Bangladesh. The hazards arising from potential great earthquakes fall into a different category in terms of predictability and time scale of the effective damage-recovery cycle. Whereas climate change related hazards like floods and draughts are predictable but irreversible process, earthquakes are less-predictable but the infrastructure damages are repairable and reversible. In both the cases, preparedness is the key to mitigate the risk, and generation of knowledge is key to the preparedness. Other than being a natural phenomenon, another uniqueness that can be attributed to the Himalayan belt is that, it is the least monitored, high risk active tectonic feature on the earth. Compared to all other active and disaster prone tectonically active regions of the earth like Japan, Western coast of USA, Indonesian islands, Western coast of South America, the Himalayan range has least number of GPS monitoring network, seismic network, gravity measurements, SAR or LIDAR coverage. Inspite of being the unique place producing the lowest gravity anomaly and the birthplace of the Isostatic theory, gravity measurements, the fundamental and primary of all geophysical studies, from the Himalaya, are also uniquely sparse, or even rare. There are not more than few hundreds of surface gravity measurements data available from the entire Himalayan belt.

India and other Himalayan countries are at a advantage of tapping into the recent leap in space based technology in studying and monitoring earth's natural processes. Airborne LIDAR can now provide bare-earth digital terrain model with cm level precision providing an unique tool to the geomorphologists to study paleo-seismological terraces, to trace the frontal faults hidden underneath the vegetation, and allows glaciologists to accurately estimates the rate of loss of ice from the specific glaciers. Upcoming low-cost, daily coverage SAR will provide unique capability to monitor vertical deformation, spanning the entire seismic cycle. Airborne gravity survey is the only solution to measure gravity anomalies over the rough and inaccessible terrains of the Himalaya. Satellite based geodesy, including GNSS, GRACE and GOCE has brought about revolutionary changes in the precision and speed of monitoring changes on earth's surfaces, leading to appreciate natural hazards in an unprecedented way. We need to adopt these changes and apply to better understand the Himalaya at a much faster speed, in fact on urgent basis.

Extreme Rainfall Episode/Intense Rain spell/Cloudburst occurrences across Western Himalayan Region and other parts of India and Status of Early Warning

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Abstract

In Indian meteorological parlance, though, particularly cloudburst events are frequently referred across in numerous researches, but are not well defined and lack in their assessment and understanding. These events are governed by much unknown complex convective and orographic processes. Hence, so far no set definition leading to cloudburst is provided. It is primarily linked to the high precipitation event over much localized area in very short time span. As per the IMD, cloudburst phenomenon though explicitly still has not been mentioned in hourly rainfall classification, but an amount of 5-10cm in an hour if recorded by any station, called as Very Intense Spell to Extremely Intense Spell. In the present study, we have briefly analyzed all major extreme rain episodes; those lasted for few hours to 3-5 days and caused very high impact in terms of damage impact during 2005-2018 for Himalayan hills and plains of India.

We performed Rain storm analysis for each of these extreme rain events from meso- to large-scale at hour to days (3-5 days) to define them cloudburst (CB)/ mini cloudburst (MCB)/Very Intense Spell to Extremely Intense Spell, various new terminology as defined by IMD and other scientists. Rainfall data from IMD/State Govt, and TRMM data for each event were analyzed for finding location and timing of rainfall maxima or cloudburst if any. Duration based rain amounts as realized during respective events for major locations where surface rain data are available, were made at meso-scale and compared with past climatological data, for finding trends if any on total number of cases of high rainfall events over a region or a state. Followings are list of major extreme Rain storms of 2005-2018 and associated damages in terms lives and properties lost:

- Mumbai 26-27 July 2005 had 400 people lost their lives, and city was without phone, transport and electricity for a week, damage 5000 crores

- The sudden Leh cloud burst on 6 August, 2010 leading to flash flood and mud slides leading to over 200 deaths and huge loss to normal life, civic amenities and infrastructure.

- The devastating flash flood and series of landslides triggered by UTK severe rainstorm June 2013, killed around 6000 people. Made 100,000 people stranded latter were rescued by Govt.

- On 30 July 2014, Malin was hit by mud flow/land slide early in the morning while residents were asleep and it was caused by a burst of heavy rainfall, and killed at least 134 people.

- During 3-7 Sept of monsoon 2014, J & K, had rainfall upto 30 to 61cm in 3 to 4 days with worst effect at capital town of Srinagar. Around 250 lives lost and affected whole city for 15 days. Country's another biggest rescue operation by Govt for 250,000 people who were stranded

- 16-17 Nov and 1-2 Dec 2015 Chennai Flood: It was hard-hit with more than 500 people were killed and damages and losses ranging from nearly 15000 crores. This is the most severe urban flooding in Modern times where we have progressed a lot in Apps, E-Media and internet penetration of almost 20-30 times to that of 2005 of Mumbai flood. This was almost uniform over three-four district covering large areas where Chennai main urban pocket was a part of it. Impact was longer and larger areas: Chennai AP closed for 6 days and many MNC closed their offices and works were shifted for temp operation to other part of India. Compared to Mumbai flood 2005, its impact was much higher.

- Kerala Extreme rains and Floods of Aug 2018- 14-16 Aug 2018 was the worst rain episode by which 483 people died, and 14 are missing. Property lost is ₹40,000 crores. Highest rain touched/number of stations reported>7cm and the respective numbers are 11cm/7, 27cm/50, 35cm/50, 19cm/30 and 11cm/3 for 12-13, 14-15, 15-16, 16-17 and 17-18 Aug, respectively with most extreme part of rainfall spell occurred in 14-16 Aug 2018.

We have discussed uniqueness of respective extreme rainfall events in terms of meso-scale as well as their synoptic and large-scale rainfall distributions aspects if any and then role of atmospheric process/systems at respective scale those have triggered them. For Western Himalayan region, we provided a list of cloudburst/extreme rain spells as published in various research papers and media as observationally the area has been highly under reported being still lies on the most data sparse region of India. We also listed damages those respective events had caused. We have provided conceptual Models leading to cloudburst mechanism over the southern rim of the Indian Himalayas. Finally, we have discussed issue and challenges IMD have been facing concern to starting an early warnings system for Western Himalayan region by setting up a DWR network and innovative products from NWP-DWR-AWS-Satellite based nowcast.

Monitoring of Glacier Hazards in the Himalaya-Karakoram: Potentials and Challenges

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Abstract

The Himalaya-Karakoram (H-K) has one of the largest concentrations of glaciers outside the Polar Regions. The melt water discharge from these glaciers is of interest for several reasons (e.g. irrigation and hydropower generation). These glaciers also pose significantly larger hazards in the downstream areas. Avalanches, debris flow and glacial lake outburst floods (GLOFs) are the most destructive types of glacier disasters that have affected people in mountain ranges. For water resource planning and hazards mitigation in Indian sub-continent, it is essential to monitor the H-K glaciers. Therefore, we present the fluctuation (e.g. length, area and volume) of selected glaciers in the H-K region using ground and space observations.

Glaciers in the Karakoram exhibit irregular behavior as compared to central and eastern Himalayan glaciers. Terminus fluctuations of individual glaciers lack consistency and, unlike other parts of the Himalaya, total ice mass remains stable or indicate slight increase since the 1970s. These seeming anomalies are addressed through a comprehensive mapping of surge-type glaciers and surge-related impacts, based on multiple satellite images (e.g. Landsat and ASTER), DEMs (e.g. SRTM, ASTER and Cartosat 1), ground observations, and archival material since the 1840s. Active phases range from some months to over 15 years. Surge intervals are identified for 27 glaciers with two or more surges, including nine not reported previously. Surge cycle timing, intervals and mass transfers are unique to each glacier and largely out-of-phase with climate.

Mass balance of Central and Eastern Himalayan glaciers show mass reductions in recent decades that destabilize the pro-glacial area and influencing the occurrence of glacier hazards. Some case studies of glacier hazards in the Central Himalaya (e.g. Gangotri Glacier) and Karakoram (Kumdan group of glaciers) are also presented. In the Karakoram, about 150 floods from ice-dammed lakes are identified in historical records and remote sensing images. These ice-dammed lakes generated through the barriers made by the advancing/surging glaciers. This differs from Himalayan GLOFs highlighted recently, attributed to climate change with rapidly retreating or thinning glaciers and mainly originate due to the failure of moraine dams. The former occurs in the Karakoram, but episodes of glacier thickening and advance still occur making ice dams a continuing threat. We also addressed challenges in the monitoring of glacier hazards in the H-K region.

Impact of Emissions from Indo-Gangetic Plains on the Himalayan Snow/Glacier and Climate Change

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Abstract

Himalaya lies in the north of the Indo-Gangetic plains (IGP) which is hotspot region for atmospheric pollution. The IGP is one of the densely populated areas in the world, home of 900 million people. The sources of air pollution are due to dense coal-based power plants, brick kilns, crop residue burning, vehicular emissions, anthropogenic activities, long range dust storms and forest fires etc., which impact air quality (PM2.5, PM10, trace gases etc.), meteorological parameters (relative humidity, air temperature, water vapor etc.) and human health. Poor air quality over the IGP are being observed during winter (mid Oct-Jan) and pre-monsoon (Feb – June) seasons. We have made efforts to analyze ground and satellite data to observe the outflow of air mass from IGP over the Himalaya. In this talk, we will present an overview of the growing pollution, anthropogenic activities and dust storm activities over the IGP and how these activities are influencing melting of snow/glaciers, climate change, landslides, snow avalanches and cloud bursts. The backward and forward trajectories clearly show long range transport of air mass from the IGP. We have recently deployed ground sensors and are carrying out detailed analysis of multi satellite sensors data to study the spatio-temporal variability of surface, meteorological and atmospheric parameters to map the vulnerable areas (snow avalanches, landslides, cloud bursts and flash floods).

Adaptation Strategies for Groundwater Sustainability in the Face of Climate Change in India

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Abstract

The importance of climate change impacts on water resources has been well brought in the Third Assessment Report of the Intergovernmental Panel on climate Change, which says "Climate Change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply". Rising global temperatures are expected to raise sea level and change precipitation and other local climate conditions. Changing regional climate could affect forests, crop yields, and water supplies. It could also threaten human health, and harm living beings and the ecosystem. As per key findings of climate change projections for India, the increase in the frequency of extreme precipitation, will also mean that much of the monsoon rain would be lost as direct run-off resulting in reduced groundwater recharge and increased ground water withdrawal, which might further exasperate the present scenario of imbalanced development.

India's National Action on Climate Change (NAPCC), unveiled by the Prime Minister's Office, highlights the increasing stress on water resources due to climate change, and points to the need to increase efficiency of water use, explore options to augment water supply in critical areas, and ensure more efficient management of water resources. It calls for measures to enhance recharge of the sources and recharge zones of deeper groundwater aquifers, mandating water harvesting and artificial recharge in relevant urban areas, incentives to promote recharging of ground water, optimize water use by increasing water use efficiency by 20%, regulation of power tariffs for irrigation and to augment storage capacities of surface water storage structures, including through the renovation of existing tanks.

In this paper the adaptation strategies proposed for mitigating the increasing stress on ground water resources due to climate change for enhancing recharge of groundwater aquifers, mandating water harvesting and artificial recharge in urban areas, ground water governance, incentivising to promote recharging of ground water, intelligent power rationing for irrigation ,optimizing water use efficiency, conjunctive management etc. have been examined at great length in terms of the technical feasibility as well as social relevance of implementation in the light of extensive experience gained in the country. Sustainable development of ground water resources and various mitigation programs required in the event of possible climate change in the country can be accomplished only with the help and active cooperation of all stakeholders such as the Ministries of Government of India for Water Resources, Environment & Forests, Power, Rural Development, Agriculture, Science & Technology and the institutions working under them; State Governments & their organizations; Associations of Industry, Non-Government Organizations, District Administrations and Panchayati Raj Institutions and the individuals users. To be successful in this mission we also have to create conditions for complete synergy in the activities of all the stakeholders. The role and space for various stakeholders namely Farmers, NGOs, local communities, Canal system managers and Groundwater Recharge SPV, in groundwater recharge strategy as a major response to climate change is outlined.

Climate Change Induced Hazards threat: An emerging challenge in the Mountain Ecosystem of Himachal Pradesh

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Abstract

Susceptibility of the State of Himachal Pradesh to vagaries of climate change has now been well documented and appreciated. 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 glacier lakes. Formation of such lakes is posing potential threat to the infrastructure and human life thriving in the downstream areas of many drainage systems originating from the snow and mountain ranges of the state. Various studies have been carried out on this vital issue of climate change and reveals that there is an alarming increase in such potential lakes which can be disastrous in the event of any break due to one or the other reasons.

The satellite data analysis of year 1993-94 revealed that there were 38 lakes out of which 14 lakes were part of the Himachal Himalaya and the remaining were in Tibet Himalaya. In another study based on the satellite data of 2001 in Chenab Basin of Himachal Himalaya reported the presence of 50 moraine dammed lakes and five supra-glacier lakes with largest lake area of about 1.053 Sq. km and smallest lake area of about 0.002 Sq. km. Further to this, a study was carried out by National Remote Sensing Centre, Hyderabad based on the AWIFS satellite data of the year 2007 in the Satluj River basin reported that there were 197 lakes (40 lakes with area more than 10ha) right from its origin in the Tibetan catchment, are now being monitored regularly for their spatial variations. Formation of such lakes at the terminus of glaciers has now been attributed as the direct consequence of changing climate.

Highlighting the case studies of two most devastating disasters i.e. 2000 Satluj Cloud burst floods in which 135 people lost their lives and caused loss to the Govt. exchequer to the tune of Rs.1466.26 Crores and in 2005 Parechu lake breach causing total loss to the Govt. exchequer to the tune of Rs.610 Crores. The present study attempts to delineate and assess the threat and risk posed by the potentiality dangerous lakes basin wise that have been identified as possible GLOF threat in the State of Himachal Pradesh. The study also traces the linkage of seismicity, Slope failure, Climate Change, GLOFs phenomena on one hand and human induced environmental degradation on the other. As part of the disaster risk reduction mandate from the state's perspective, such lakes are being monitored regularly in order to avoid any situation like that of the Kedarnath tragedy of Uttrakhand Himalaya during 2013.

Based on the LISS III satellite data observation for the year 2015, 2016 & 2017 in Chenab, Beas, Ravi and Satluj basins in H.P., wherein the Satluj basin has been investigated right from its origin in Tibetan Himalayan region, where as the other basins comprises of their areas in Himachal Himalaya only. Based on the satellite data analysis, the Satluj basin reveals the presence of total 390 lakes in 2015 which further

increased to 581 in 2016 and 642 in 2017 which includes few high altitude wetlands also. The Chenab basin which mainly originates from the Himachal Himalaya reveals the presence of total 192 lakes in the year 2015, which has now been reduced to 133 in the year 2016 and 220 in 2017 respectively. Likewise, in the Beas basin, in 2017 a total of 101 lakes have been mapped in comparison to 89 (2015) and 63 (2016). The Ravi basin wherein a total of 54 lakes mapped in 2017 in comparison to 28 (2016) and 34 (2015). The variation in total number of lakes in some of the cases is mainly because of the good quality data availability. These lakes further have been classified in all the basins based on their aerial extents i.e. less than 5 ha, 5-10 ha and more than 10 ha.

The present study concludes with the fact that there is a considerable increase in the number of lakes in the higher Himachal Himalaya since the last decades. This further be related with the effect of the climatic variations being more pronounced in the glaciated region of Himalaya resulting in the formation of small lakes in front of the glacier snouts due to the damming of the morainic material. The lakes with area >10 hectare and the area between 5-10 hectare can be seen as the potential vulnerable sites with the possibilities of converting into glacial lake outburst flood (GLOF) and causing damage to downstream. Thus from the disaster risk reduction perspective considering climate induced hazards threat in Himachal Pradesh, a proper monitoring of all such lakes in higher Himalayan region is critical for averting any future eventuality so that the precious human lives are saved. Study reviews the overall vulnerability of the State of Himachal Pradesh to Climate Change environment degradation induced hazards and also suggests various policy level measures that are required to be taken for mitigating and managing the impending threat of such disasters in mountain eco-system in general and in the State of Himachal Pradesh in particular.

Exploring drivers of glaciers and glacial lakes evolution in Nepal Himalaya

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Abstract

This contribution focuses on the status of glaciers and glacial lakes based on remote sensing-based analysis in the last few decades' and discuss the climatic drivers of the changes in the Nepal Himalaya. Glaciers in the Nepal Himalaya have a loss of about 15% surface area in the last 50 yrs. glacial lakes show heterogeneous rates of expansion in different river basins and by elevation zones of Nepal, with apparent decadal emergences and disappearances. Overall, the glacial lakes (size ≥0.36 ha) exhibited ~25% expansion (including 404 new lakes) of surface areas from 1987 to 2017. For the period from 1987 to 2017, proglacial lakes with ice contact, among others, exhibited the highest incremental changes in terms of number (181%) and surface area (82%). A continuous amplified mass loss of glaciers is expected to accompany glacial lake expansion in the future, increasing the risk of glacial lake outburst floods (GLOFs). We emphasize that the rapidly increasing glacial lakes in the Nepal Himalaya can pose potential GLOF threats to downstream population and infrastructure. A significant elevation-dependent warming of maximum near-surface air temperature and diurnal temperature range over the last four decades (1976–2015) in Nepal. During this period, on average across all the country, maximum air temperature increased (+0.045 °C/yr, $p < 0.001$) much more than the minimum temperature (+0.009 °C/yr, $p < 0.05$) and, as a consequence, the diurnal temperature ranges even increased significantly (+0.034 °C/yr, $p < 0.001$). Maximum temperature increases significantly affected all the seasons of the year. We point out that the warming pattern could have more serious impacts in Nepal than in other regions of the world, just thinking about consequences of associated warm maximum-temperature extremes (heatwaves, hot days) on human life, increased primary production, and enhancement of the hydrological cycle. Further, we point out that the observed asymmetric maximum temperature trend and DTR increase could be attributed to decreases in precipitation amount and rainy days observed in the region in the last decades, which could have favored a decreasing of cloudiness and a consequent increasing of solar radiation.

Role of orography and aerosols in inducing high lightning flash rate at the foothills of Himalaya

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Abstract

Over the past few years, there are reports of increasing incidences of lightning which cause huge damages to human life and livestock. Some parts of the country, especially, Himalayan States and regions in foothills of Himalayas experience severe lightning during pre-monsoon periods. Many field experiments and laboratory studies have shown that the magnitude of updraft of a thundercloud is a major factor that is responsible for large-scale electrification of thunderclouds and hence lightning. In addition, aerosols and orography significantly influence the charge generation processes inside thunderclouds and thereby the lightning. Our studies over foothills of Himalayas have shown that most of these thunderstorms over this region exhibit distinct features which are discussed here. Tall mountains of Himalayas interact with prevailing winds and can produce deep convections over that region at late night hours. Radiative cooling at high mountaintops can generate moisture conversions at the foothills and they may be responsible for deep midnight convections over that region. Our observations suggest that moisture conversion at foothills due to radiative cooling at mountaintops during nighttime may be responsible for triggering of such deep convections and severe thunderstorms.

Thunderstorms have short life-term and due to its short lead time, forecast of lightning still remains a challenge. However, concrete efforts are being made by Ministry of earth Sciences, Government of India to give warning about impending lightning strikes with a reasonable lead time. These steps are discussed in detailed here.

Modeling extremes on a climate scale: Challenges and opportunities

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Abstract

Developing projections for climate extremes (temperature and precipitation) remains challenging. To accomplish this task, we need models that can capture the spatial and temporal scales of the phenomena and multi-decadal simulations to build robust statistic. These remain outside the scope of current generation of climate models. Here, we use an approach known as dynamic downscaling to develop a multi-decadal high-resolution model output for North America. These simulations were performed at a spatial resolution of 12km, for RCP4.5 and RCP8.5 and using boundary conditions from three different climate models. The total data size from these simulations is approximately 700Tb and covers about 300 individual years. This data was used to perform a series of studies to understand the statistics of extreme events, their intensity, frequency and duration (IDF) and developing projections of these changes under a changing climate. I will describe results from these studies show that the increasing intensity of precipitation results from (a) decrease in spatial size of storms producing larger precipitation over smaller regions, demonstrated using a novel storm tracking algorithm (b) increase in the surface temperature that leads to an increase in moisture content of the atmosphere (Clausius – Clapery on relationship) (c) changes in low level jet strength over the central plains of USA. Temperature extreme shows a distinct increase in IDF by mid-century and more dramatically by the end of the century over many parts of the USA. I will also discuss the challenges in modeling precipitation over complex terrain and recommendations for possible model configuration for regional scale climate model simulations.

Contributory Abstracts

A study on hydro-climatic variability of Himalayan glaciers using a high resolution dynamically coupled glacier-climate regional model

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Abstract

A regional high-resolution dynamically coupled glacier-climate model REMO glacier has been used to carry out transient climate simulations over South-Asia. It consists of an online glacier parameterization scheme that is fully coupled to the atmospheric and land surface component of atmospheric regional model REMO. The scheme represents surface glacier cover on a subgrid scale and calculates the energy and mass balance of the glacierized part of a grid box. The glacier fraction can grow and shrink dynamically depending on the simulated mass balance but is restricted to the total land surface area of the respective grid box. Preliminary analysis suggests high statistically significant correlation between observed data for various model parameters such as precipitation (both rain and snow) and temperature for the Himalayan region. The model is also able to capture the annual cycle for most of the parameters significantly. Further, the study shows very little change in the amount of precipitation received over the region across 28 years (1989-2016) with prolonged dry spells and subsequently increased number of extreme events. All the results discussed above are preliminary and will be discussed in detail during the workshop and presented accordingly.

Paleo-environmental shifts spanning the last ~6000 years and recent anthropogenic controls inferred from Anchar Lake, NW Himalaya

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Abstract

Integrating multi-proxy results (geochemistry, mineral magnetics, grain size, and C/N ratio variability supported by ^{14}C AMS dating), obtained from a 1.4-m sediment core retrieved from high-altitude Anchar Lake, Kashmir Valley, NW Himalaya, we present a 6000 years' record of paleo-environmental and paleo-limnological shifts. The Phase-1 (6000-4700 calyr BP) revealed wetter climate with significant terrestrial input corresponding to gradual strengthening of the westerlies. Phase-2 (4700-3900 calyrBP) reflects an overall improved westerly precipitation and autochthonous sources of organic matter (OM). Magnetic parameters also indicate higher lake levels and reducing conditions during this phase. Phase-2 was followed by gradual diminishing pattern of the westerlies as also represented by phase-3 (3900-2500 calyrBP) and phase-4 (2500- 1600) indicating moderate precipitation conditions, catchment stability and

temperate and/or cold-dry climatic conditions. Phase-5 (1600-500) revealed prevalence of moderately cold/dry and further subdued westerly precipitation. Phase-6 (500-Present) is represented by reduced westerly precipitation, shrinking lake margins and intense terrestrial/anthropogenic controls over the lake basin. Mineral magnetic parameters indicate reducing lake-bottom water conditions and eutrophication during this phase owing to anthropogenic activities. These paleo-environmental shifts reveal near synchronous changes (within dating uncertainties) with other regional paleo-climate records close to the present Anchar lake location and reflects the gradual late Holocene diminishment of the amount of winter/early summer moisture provided by the mid-latitude westerlies.

Role of shallow structure in seismic hazard assessment

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Abstract

Several parts of India are vulnerable to seismic hazard from earthquakes in continental and oceanic regions. Large and major earthquakes occur most often along the plate boundaries and subduction zones. However, intra-continental earthquakes in India due to stress buildup along faults and lineaments are not uncommon, causing a major part of the country to be classified as seismic zone-II and III. In the recent past, neo-tectonic earthquake activity has reportedly caused damage to infrastructure and monuments. We use, study of the geomorphic features to identify areas of accumulation of unconsolidated soil in the study area which are of great importance for seismic hazard studies. Furthermore, analysis of spectral amplitude ratio of horizontal and vertical component (HVSR) of the ambient noise data, and multi-channel surface wave phase velocity (MASW) data collected at various locations of coastal Odisha indicates that the dominant frequency varies between ~0.16 and ~3.0Hz as we move away from the coast. Inversion of dispersion curves computed from multi-channel surface wave data indicates that the shear-wave speed within the top 30m of soil i.e. Vs_{30} is ~500m/s in the coastal region, and ~700m/s in the areas away from coast. These values classify the coastal region of Odisha as class 'C' (360-760m/s) sites on the basis of NEHRP recommendations, and could be a valuable input for further development of the region. Teleseismic receiver function also indicate a region of lower velocity in the shallow crust. Our study indicates that parameters of shallow seismic structure are critical to the assessment of seismic hazard in any region.

Dust storm characteristics over Indo – Gangetic Basin and their climatic implications

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Abstract

The present study is focused to examine the impacts of two intense dust storms on aerosol characteristics and their climatic implications, occurred in pre-monsoon season of 2018 (i.e. 17 May and 14 June 2018) over Kanpur (26.51^0 N, 80.23^0 E, 123 above msl). Moderate Resolution Imaging Spectroradiometer (MODIS) true color images, trajectory pathways of dust storm along with satellite observation and AErosolROboticNETwork (AERONET) measurements confirms that both the dust storms are either originated from or transported over the Thar Desert, causing a higher aerosol loading which spread over entire IGB and modifying the aerosol optical (i.e. aerosol optical depth, angstrom exponent, refractive index etc.), physical (i.e. size distribution) and radiative properties (i.e. single scattering albedo, asymmetric parameter). The space-borne Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)-retrieved aerosol measurements reveal the presence of elevated dust/polluted dust aerosol (up to 3 – 5 km) over IGB which is well corroborated with aerosol characteristics observed by MODIS, Ozone Monitoring Instrument (OMI) and Atmospheric Infrared Sounder (AIRS). The Dust Regional Atmospheric Model (BSC-DREAM8b) shows a good agreement with satellite retrievals with higher value of surface dust concentration in the range of 320 – 640 $\mu g/m^3$ over Kanpur during the dust storm days. An enhancement in monthly mean outgoing longwave radiation (up to 60 Wm^{-2}) is observed over IGB and downwind flow region during the dust storm days. The atmospheric aerosol radiative forcing is found 124 Wm^{-2} and 84 Wm^{-2} during both the dust storm days (17 May and 14 June 2018) associated with heating rate 2.69 K $day^{-1}$and 1.84 K day^{-1} respectively which may be significant to affect the regional atmospheric dynamics and hence the climate system also.

Regional Coupled Ocean-Atmosphere model (RSM-ROMS) for Climate change studies over Himalayas: Preliminary Result

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Abstract

Since the inception of World Climate Research Program (WCRP)'s Climate Model Inter- comparison Project (CMIP3 and CMIP5) several studies have been carried out on the topic of global climate change. Few among them were focused on South-East Asia and India. Indian mainland is geographically unique because of its long coastlines and Himalaya in the North. Most of the studies were focused on effect of

climate change on Indian Monsoon. This study focuses on study of dynamically downscaled CMIP5 product over Himalaya region. Data from CMIP5 model (CCSM4) is used and dynamically downscaled products were validated against observation for the CMIP5's "historical" (1986-2005) period. This study also shows the impact of coupled air-sea interaction on the downscaling of the region. More commonly, dynamic downscaling has been conducted with regional atmospheric models to generate relatively high-resolution regional climate of the area. In this study we show that dynamical downscaling with a coupled regional ocean-atmosphere model has a significant impact on the hydro-climate of the Himalaya. Given the bias in majority of the global coupled climate models with very warm SST in the northern Indian Ocean, our study shows that the uncoupled (to ocean) regional atmospheric model overestimate (underestimate) the oceanic (continental) precipitation of the Indian monsoon. The analysis of this study reveals that air-sea coupling in the regional domain acts like a damping scheme on the atmospheric variability over the ocean and thereby modifying the regional Hadley cell toincrease the atmospheric variability and rainfall over the Indian sub-continent. This damping effect comes from cloud radiative impacts on the surface as well as small scale eddies in the ocean that generate local upwelling of cold waters to the surface.

Impact of Cyclone Hudhud over atmospheric and meteorological parameters close to Himalaya

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Abstract

In India, there are many natural hazards that affect various parts of nation throughout the year. They affect directly to a large population living in the connected region but sometime impact is also seen over distant places. Tropical cyclones are some of those natural hazards which create devastative effect along their paths and also changes meteorological condition of larger region. India has a long costal border with Bay of Bengal in East, Arabian Sea in west and Indian Ocean in south. Every year average 5 cyclone hit the eastern and southern coast of India during monsoon and post-monsoon seasons. They are generated over Bay of Bengal and Arabian Sea which affect large population living along the coasts, infrastructure and also they affect the inland area. On 12 October 2014, a strong cyclone "Hudhud" hit the east coast of India that caused a high degree of devastation along the coast. The impact of this cyclone was observed over the Himalayan region. The analysis of atmospheric and meteorological parameter along the path of cyclone show a strong coupling between land-ocean-atmosphere associated with the Hudhud cyclone. The contrast of land and ocean temperature is closely related with the formation of cyclone and all along the path of cyclone. Pronounced changes have been observed in the ocean, land, atmospheric, and meteorological parameters with the development of the cyclone and its landfall. We found significant change in aerosol properties during the cyclonic conditions over India.

Augmentation of Snowdrift for Water Resource and Avalanche Hazard Management in Himalayan passes

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Abstract

Quantity of precipitation across the ridge lines of Himalayan ranges changes considerably resulting different climate pattern in both sides of ridge line. Kullu valley and Keylong / Lahul Spiti Valley are located in the opposite sides of Pirpanjal Rang and the former one receives 2 to 3 times more annual precipitation than Keylong valley. Certain part of ridge lines at Rohtang pass Manali (HP) and Banihal pass J&K have mild slope spread in 100 m to 300 m width followed with steep slope both sides of ridge favorable for initiation of frequent avalanches during winter. The temperature of Banihal pass during winter is near -5° to -15° having the snowpack characteristics close to the marine climate which is compacted by wind. The snow drift changes the snow deposition pattern along the ridge and valley lines and considerable Snow mass is eroded from windward southern slope of formation zone and deposited on northern leeward slope resulting increase in avalanche activities towards leeward sides which also reduces the availability of water at higher altitude resulting decrease in soil moisture contents necessary for the growth of forest in certain region.

The major catchment area of avalanche site affecting north and south Portals of Jawahar Tunnel originate from Banihal top and their length of ridge is about 2000 m. At the most of places the width of ridgeline is limited to few meters except central depression where its width is about 150m to 200 m having average slope near 5 to 12 degree towards both sides i.e. windward and leeward directions.

In order to increase snowdrift deposition on stable slope of Banihal top, 120 m continuous snow fence of 50 percent porosity and 4.0 m height were installed. The snow deposition observed in the range of 13 to 15 times of snow fence height in leeward direction and 2 to 3 times in windward direction. The drifted snow mass abridged on mild slope and helped in reducing snow mass deposition in the avalanche initiation zone resulting reduction in avalanche frequency at North Portal of Jawahar Tunnel. About 105 m^3 compacted snow mass of average density about 500 Kg/m^3 was collected and deposited on stable slope for every meter length of structure. The melt water of these snow can be stored by developing suitable drainage and storage system for its use during dry period. Total water equivalent snow deposited per meter length of snow fence is about 52500 liters.

A GIS based comparative study of landslide susceptibility using certainty factor model and artificial neural network of Rishikesh-Mana route, India

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Abstract

The present study aims to compare the performance of landslide susceptibility map (LSM) for Rishikesh–Badrinath Mana route of India generated using certainty factor model (CF) and Artificial Neural Network (ANN). Total of 700 landslides including active and old slides were mapped using satellite image and field investigation. The landslide inventory was then randomly split into training dataset (70%) and testing dataset (30%). Geographic information system was used to correlate the relation between landslides and various conditioning factors through spatial data analysis. The present study identified 13 conditioning factors including distance to anthropogenic activity, slope-aspect, distance to fault, geomorphology, Land Use, distance to Lineament, Lithology, distance to River, distance to Road, distance to Settlement, slope, slope morphology and Weathering. Using these factors and ground truth data, LSM were generated based on the obtained weights and ranking of each factors by CF model and four-layer architecture of Back-propagation neural network (BPNN). Developed Model performance was checked on an independent validation set of landslide events and the accuracy was determined using the receiver operating characteristics (ROC) including the area under the curve (AUC) and Confusion Matrix. The calculated AUC values were 80% for the CF model and 84% for BPNN. Hence, it is concluded that the landslide susceptibility map obtained by the BPNN gives satisfactory results for the prediction of future landslide zones in the study area. The result obtained was further verified by field visit.

Shortening and uplift rate of Surin Mastgarh Anticline, Jammu and Kashmir, India: Evidences from field, tectonic geomorphology and stream length index

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Abstract

In the sub-Himalaya, strain release is mainly by major earthquakes that are caused by surface faulting along the Himalayan Frontal Thrust (HFT) or by out-of-sequence thrust. When earthquake fails to produce surface faulting, the strain is being accommodated in the form of fold scarp. Toward understanding the pattern of strain release rate, we studied Surin Mastgarh anticline (SMA) that marks the southern limit of non-emergent sub- Himalayan frontal fold belt of Jammu &Kashmir. SMA extends along its strike for ~200 km in length continuously, between Rivers Beas in the east and Munawar-Tawi in the west, without producing fault on its forelimb (i.e. southern limb).

We estimate geological shortening rate of SMA using fluvial strath terraces along River Chenab which flows across the growing anticline. The different levels of terraces were surveyed using high resolution RTK- GPS. The long profiles of terraces suggest that they have been progressively folded and uplifted above the current grade of Chenab River, with focused uplift along its fold axis. Deformed fluvial terraces were dated using Optically Stimulated Luminescence technique. By using abandonment age of terraces, we infer geological shortening rate across the SMA as ~4-6 mm/yr with ~2 mm/yr vertical uplift rate at the hinge. Our results together with seismic data suggest that SMA is a through going detachment fold, without ramp structure beneath it. The SMA consumes ongoing shortening with active flexural slip faulting along either limb with migrating hinge mechanism.

Low-cost landslide monitoring system and associated machine learning

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Abstract

Landslides and associated soil movements cause major damages to life and property in hilly areas. Soil movements on hill slopes are influenced by both the prevailing weather conditions (rain) as well as the susceptibility of the area (soil and geology) to landslides. Thus, one needs to monitor soil movements, and prevailing weather and soil conditions at remote locations that are prone to landslides. Current landslide monitoring systems are accurate; however, this accuracy comes at a high cost. Furthermore, there is a need for predicting soil movements ahead of time; however, there is currently less literature on prediction of soil movements via machine learning and deep learning methods. In this paper, we overcome these literature gaps by developing a low-cost landslide monitoring and warning system. The developed system is capable of monitoring soil movements, soil properties, and prevailing weather remotely via an Internet cloud with a reasonable accuracy. Also, the system is capable of alerting vehicular traffic locally by the hooters and blinkers, and alerting different stakeholders globally via SMSes. In addition, we develop of a number of machine learning and deep learning algorithms (e.g., decision trees, regression, neural network, and LSTM models) for predicting soil movements in data collected from the low-cost landslide monitoring and warning system. In this talk, we will discuss the development and deployment of the low-cost landslide monitoring and warning system at the several locations in Himachal Pradesh state. Also, we will discuss the ability of different machine learning and deep learning algorithms in predicting soil movements in data collected by the deployed systems. We discuss the implications of the developed system and the machine learning algorithms in monitoring and warning against impending landslides in the real world.

Role of Krishi Vigyan Kendra's in Combating Health Problems associated with Climate Change

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Abstract

In 1948, WHO defined health as "a state of complete physical, mental and social well-being, and not merely the absence of disease". Health plays a crucial role in our life, more the immunity less are the chances of getting diseases. In the 21st century the health status of the Indian population has considerably declined. There is a noticeable increase in health and occupational hazards. This decline in human health is due to various reasons viz. unawareness, poverty, unemployment, poor nutrition, intake of Reversible Osmosis water, adoption of urbanization, use of allopathic medicines for bare minimum need, growing population with land shrinkage, excessive consumption of chemically treated fruit and vegetables, pollution, like and spurts of automobiles, factories, industries burning of the crop residues etc.

The health of individuals has deteriorated in general, particularly in women. Infertility in women is a pressing issue with the increased usage of genetically modified seeds. There are other problems like acidity, upset stomach, breathing issues that leads to asthmatic attacks. The reasons for the asthmatic attacks would be mainly combustion of waste biomass or excess food/ crops, passive smoking, automobiles, factories, industries etc. Emissions from biomass burning significantly affects the composition of the atmosphere, and the increased methane emission impact extends across multiple scales, from regional to global.

The most appropriate group for handling this kind of multidimensional issues are the Krishi Vigyan Kendra (KVKs). This paper focuses on the multifaceted problems bringing the climate change, its impact on health and global environment and enumerates how KVKs are the best suited centre available with the nation to tackle the problem by social marketings the solutions and disseminating useful practices for the global problems / alerts. These 680 KVKs scattered all over India are working under the National Agricultural Research and Education System are the real carriers of frontline technologies and impart knowledge with critical support for the famers for their betterment and quality life.

Dynamics of the Upper Mantle beneath the Northwest Himalaya and Ladakh-Karakoram Zone Based on SKS Splitting

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Abstract

The northwest Himalaya and Ladakh-Karakoram zone is the western extremity of the Himalaya-Tibet orogeny provides a unique opportunity to study the interaction between the two continental plates. The dynamics of the upper mantle has been studied with the help of tele seismic earthquakes recorded by 29 broadband seismological stations which extend from the Himalayan frontal thrust to the Karakoram shear zone (KSZ), covering all the important tectonic features of the Himalayan collision belt and trans Himalaya. We have used, core refracted and radially polarized SKS waves to understand the anisotropic structure of the upper mantle. We have obtained 213 pairs of splitting parameters by analyzing the SKS splitting of 122 teleseismic events. The *SKS* splitting parameters (Φ and δt) shows a significant strength of anisotropy with a wide range of delay time of split waves (~0.75-3.50 s). The study shows that the FPDs are aligned in the NE- SW direction almost throughout the upper mantle of the Himalayan collision belt up to the Ladakh batholith. However, the trend of anisotropy near the KSZ follows a NW-SE trend. The distinct variations in Fast Polarization Directions (FPDs) along the study profile suggest a complex source of anisotropy which cannot be explained by a simple model. In the frontal part of the Himalaya, the FPDs are mostly parallel or sub-parallel to the strike of the Himalayan orogeny which indicates that anisotropy is largely due to lithospheric strain induced by compression at the collision front. In contrast, over a large part of the northwest Himalaya, the FPDs are largely NE orientated and roughly coincide with the direction of absolute plate motion (APM) of the Indian plate supporting the asthenospheric flow model. The anisotropy in this section of the Himalaya can be attributed to basal shear as the Indian plate moves over the asthenospheric mantle with a minor contribution from lithospheric sources. The FPDs observed near the Indus Suture Zone clearly suggests combined effects anisotropy originated due to Indian plate motion over asthenosphere and lithospheric deformation. The FPDs near the Karakoram Fault Zone (KFZ) are parallel or sub-parallel to the strike of the KF. The study reveals that strike-slip or transpressional deformation in the lithospheric mantle in the KFZ is the major source of anisotropy beneath the KFZ. It can be envisaged that the KF is a lithospheric scale fault that largely accommodates the India-Asia collision and extrusion in the Tibetan Plateau.

Impact of Climate Change on Horticultural Crops

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Abstract

Climate change has emerged as a serious global environmental issue having impact on all forms of life. It disturbs the composition of greenhouse gases like carbon dioxide, nitrous oxide, ozone and methane that increases the temperature of the earth, demand for water and increase in biotic and abiotic stresses. Due to rapid climate change such as global warming, change in seasonal pattern of weather, excessive rain, melting of ice cap, low production of horticultural crops is observed. Decrease in potential yields is likely to be caused by shortening of the growth period, decrease in water availability and poor vernalization. An important statistic in the apple production in Himachal Pradesh has shown a decreasing trend in the past couple of decades. The effects have extended to the loss of vigor, fruit bearing ability, reduction in size of fruits, less juice content, inferior peel color, reduced shelf life and increasing attack of pests resulting in low production and quality of apples. Specific chilling requirements of pome and stone fruits gets affected if higher temperature prevails longer resulting in early dormancy breaking. Higher atmospheric temperature affects pollination, floral abortions and fruit drop. Crops like peach, plum, which require low chilling temperature also exhibit decline in productivity. Abnormal high temperature during winter cause poor flowering, irregularity in flowering duration, pattern of flowering and poor yield in pear due to non-availability of sufficient chilling hours during winter months. As a result of rising temperature and decline in rainfall, the apricot and cherries are fast disappearing from some of the areas in Kashmir valley. In Himachal Pradesh, apple cultivation is shifting towards higher altitudes due to climate change.

The horticulturists have an immense responsibility in helping with the current climate scenario. Proper strategies have to be envisaged for saving horticultural crops from further turmoil. Development of temperature tolerant cultivars and improved yield under stress conditions as well as adoption of hi-tech horticulture and judicious management of land use resources will be the main strategies to meet these challenges.

Absorbing aerosol characterization over a high altitude sub-Himalayan station in north eastern region of India

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Abstract

Understanding carbonaceous aerosol is very important to know the role of atmospheric processes and the effect of anthropogenic activities over any region. Black Carbon (BC) concentration at Tawang (located at 27.591^0 N, 91.874^0 E at a height of 2886 m above mean sea level), a remote site in North East Indian state of Arunachal Pradesh has been measured for the first time using a seven channel Aethalometer. The data for the period from June 2017 to Dec 2018 has been used to characterize the carbonaceous aerosol over the measurement location. Annual Average BC concentration was found to be 1.53 ± 0.83 μg/m^{3}which is quite higher compared to the reported BC concentrations of similar high altitude remote places globally. The concentration shows strong seasonality with maximum average value of 2.15 ± 0.58 μg/m^{3}in winter. In pre-monsoon, monsoon and post-monsoon seasons, the mean value is 1.49 ± 0.52 μg/m^3, 0.78 ± 0.15 μg/m^{3}and 1.69 ± 0.41 μg/m^{3}respectively. Diurnal variation of average BC concentration showed prominent morning and evening peak for every season, though in monsoon it did not vary considerably over a day. The minimum value is observed just after the midnight irrespective of seasons. The diurnal variation could be influenced by the local lifestyle, typical of a high altitude hilly station. On an average, BC concentration increases more than 4 times during morning and evening peaks, compared to night hours in all seasons. In general, the day time concentrations are found higher than night time values except in post-monsoon where it is almost comparable. Efforts have been made to provide insight into the sources and evolution of BC aerosol over Tawang. The absorption Angstorm exponent (alpha) values over the present location are more than unity throughout the year which indicate probable sources are of fine mode origin. Over a day, this alpha gets more strength during evening hours reaching as close to 2 especially in winter. Spectral optical analysis also supports the above mentioned fact of biomass burning signature. Cluster analysis and a concentration weighted trajectory model connect emissions from North West India to the high BC loadings of this region, but the effects of internal sources cannot be overlooked.

Glacier mass balance estimation in Baspa basin using Improved Accumulation Area Ratio method

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Abstract

Glacier melt in Himalaya flourishes stream discharge in major river basins such as Indus, Ganga and Brahmaputra. Most of the mountain communities in Himalaya are depending up on these glacier-fed rivers for their livelihood. The water availability will be influenced by changes in glacier extent and it can be estimated using mass balance, which is depicting the quantitative changes in glacier stored water. Field-based mass balance estimates are availablefor relatively few glaciers and for short duration only. Therefore, Improved Accumulation Area Ratio (IAAR) method is adopted here for basin wise mass balance estimation in Baspa basin.

Baspa is one of the sub basins of Satluj with 127 glaciers covering 182 sq.km area. In the IAAR method, transient snow line, temperature index model and precipitation data are used for the estimation. Transient snow line was estimated for the glaciers above 0.5 sq.km area using Landsat data. Temperature and precipitation were taken from Rakccham observatory, which is located at 3050 masl height. ELA of the basin is estimated as 5108 m. The mass balance is estimated using AAR-mass balance regression equation (Tawde et. al, 2016). Area-weighted average mass balance of the Baspa basin is estimated as -0.09 m.w.e.a^{-1} from 1984 to 2013. Positive mass balance is estimated during the years 1988-92, 1994, 1996-98, 2002 and 2013. Total mass loss of the basin is calculated as 0.48 Gt for this period. The loss of glaciers in the mountain area will also increase the vulnerability of communities living in the region. This suggests a need for better adaptation strategies to improve the resilience of high mountain communities and adopt necessary water management practices in the basin itself.

Interaction between baroclinic cool-dry trough and barotropic warm-moist low- pressure field caused disastrous rains over subtropical Himalayan Kedarnath range (India) on 16-17 June 2013

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Abstract

Weather extremes are of serious concern to everyone across the globe. In recent decades' occurrences of unusual, unprecedented or extreme weather events were generally attributed to global warming. Attempts have been made to understand underlying mechanism of the weather systems those produced extreme rain events (EREs). Perhaps most unusual atmospheric thermal structure developed during 1-

20 June 2013 (peaked on 16-17 2013) with warmer-thicker (than equator) troposphere over Tibet- China sector and another over Middle East – Mediterranean sector, and cooler-thinner over central Asia – Afghanistan – Pakistan – northwestern India. A deep subtropical high evolved over Middle East – Mediterranean sector and lower tropospheric convergence and upper tropospheric divergence over Tibet – China, while a deep trough over central Asia – Afghanistan - Pakistan – northwestern India. Three flows got merged over western slopes of the Tibet – Himalaya sector during 16-17 June 2013; i) eastern side of the cool-dry deep trough over central Asia – India sector; ii) rising warm-moist airs from convergences across Arabian Sea – India - Bay of Bengal of Bengal – Indochina – South China Sea – Philippines Sea; and rotating warm-dry airs of the anticyclonic cell over Tibet – China. Squeezing of the combined three flows and their lifting due to orography and pumping-suction effects produced unprecedented rains over Kedarnath range (western slope of Tibet – Himalaya). After short spurt of confluence, converging and condensing, the central Asia – India trough weakened and moved eastward over Tibetan plateau which destroyed warm-high Tibet – China anticyclonic cell and rainfall activities virtually subsided. Formation and intensification of troughs in the temperate westerlies is a short period phenomenon. Therefore, condensation and intense rainfall in subtropical mountainous terrain involving confluence and convergence of huge air masses of contrasting characteristics are short lived. The phenomenon is popularly known as 'cloud burst'.

Meteorological causes of the disastrous rains of June 16-17, 2013 over Kedarnath range has been investigated by comparing actual with normal global 3-D structure of following atmospheric parameters: equatorially-conditioned pressure, precipitable water, and level wise (1000-100-hPa) temperature and geopotential height, unconditioned streamlines and globally-conditioned horizontal wind speed. Normally during this time, warmest-thickest troposphere occurs over subtropical Afroeurasia, and lower tropospheric flows are directed northeastward over Indian subcontinent. In lower levels (1000-850-hPa), cross- equatorial flows over Indian Ocean cover Arabian Sea, Indian peninsula, Bay of Bengal and South China Sea, blow over eastern Tibet-China, and then northern North Pacific. In middle levels (700-500-hPa), north temperate westerlies enter into Indian domain through Afghanistan-Pakistan, evolved into garland-like trough around Tibet-Himalaya, and make exit toward northeast Tibet-China and further northern North Pacific. An elliptical anti-cyclonic circulation occurs over subtropical Afroasia in the layer 300-100-hPa with major axis along 25°N latitude. During 15-18 June 2013 (peaked on 16-17 June), there was development of peculiar atmospheric thermal structure over Afroeurasian landmass with warmer-thicker (than normal) troposphere over Tibet-China and over Afroeurasia - Middle East, and cooler-thinner over central Asia-India. During 16-17 June 2013, lower tropospheric flows were directed northwestward. There was confluence of three huge airflows of contrasting characteristics over western slopes of Tibet-Himalayan massif: eastern side of cool-low-dry central Asia-India trough, warm-low-moist airs rising from convergences across Arabian Sea - Philippine Sea, and warm-high rotating airflows of Tibet-China anticyclone. Enhanced convergence and condensation due to orographic and pumping-suction effects produced unprecedented rains over Kedarnath range.

An elaborate scheme has been developed for monitoring heavy rainfall activities over given area/basin by considering optimum number of standardized global weather charts of sea-level pressure, precipitable water, equatorially/globally-conditioned level wise temperature, geopotential height and wind speed as well as unconditioned streamlines, and global, hemispheric, zonal and sub-geodomain area- averaged sea-level pressure, precipitable water, and tropospheric (1000-250-hPa) temperature and geopotential thickness.

Temporal Analysis of Glacier Retreat in Central Himalaya region

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Abstract

During last few decades, advancement in space borne sensors has been recognized as a useful tool for monitoring the glaciers for hydrology and climate studies. The series of satellite datasets e.g. Landsat data, CORONA, IRS series, Aster, Hyperspectral imageries, are used to monitor the changes in Himalayan glaciers. Present study aimed to estimate the retreat rate using satellite datasets to analysis the movement of glacier surfaces using offset Tracking technique. Uncertainty in glacier snout retreat is taken in account as the glacial extent demarcated from CORONA, LISS-IV and Sentinel dataset with different spatial resolution. This study focused on upper Alaknanda watershed part of the central Himalayan region. It lies between the latitudes 30° 48'59.842'' to 30° 46' 28.223''N longitude and covers an area of 222.045 km^2. Preliminary information of glacier boundaries, snout position are drawn from Randolph Glacier Inventory version-5 (RGI v5) and verified from SOI maps (1962). The glacier snow velocity mapping is carried out using Sentinel-1A-S1A-IW-GRDH-1SDV and S1A-IW-GRDH-1SDV dataset with 12day interval. Low ice/snow moment observed in month of Sept-Oct, which signifies that the less snow cover extent over the region. The maximum and minimum snow velocity is also calculated 0.165md^{-1} and 0.038$md^{-1}$for Sept. and Oct. months respectively. The analysis of retreat reveals the frontal rate of glacial retreat is reduced up to 5.02m/y, but the retreating process of glacier is only from the right margin. The change observed in snout position of Satopanth and Bhagirathi Kharak glaciers during 1968-2017 is 235m and 182m with 3.25m and 4.0m average retreats per year, respectively. Glacier ice velocity is also being correlated with other factors such as the debris covered area which augment researcher understating in glacier retreat especially over the central Himalaya.

SPAC method of seismic hazard estimation for Northeast India

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Abstract

Seismic hazard of Northeast region of India is high, mainly due to presence of active faults and high ground amplification characteristics. In addition, local geological condition leads to high seismic vulnerability and risk. Therefore, several techniques have been adopted to minimize the seismic hazard. One of them is estimation of shear wave velocity (Vs) profile with the help of ambient vibration technique for any study region. This shear wave velocity helps in understanding the subsurface structure, which is also useful for earthquake engineers, to assess local ground motion amplification and its damaging effects for populated areas. Here in this study Spatial Autocorrelation (SPAC) method has been selected. By SPAC method, one-

dimensional (1D) shallow shear wave velocity profile estimated from inversion of dispersion curve for stationery ambient noise in space and time. We have optimized the result to get the two-layer best fit model of shear wave velocity structure with standard inversion procedure. Finally, the result suggests the presence of shallow layer, where if an earthquake occurs, will lead to disastrous effect at distant places.

Changes in rainfall pattern over Central India

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Abstract

In this paper, a comprehensive study has been performed to investigate the changes in the seasonal rainfall pattern over central India (16.5°N to 26.5°N, 74.5°E to 86.5°E) within past 114 years (1901-2014). In this study, all investigations have been performed for summer monsoon rainfall using high resolution (0.5°×0.5°) CRU TS3.23 (Climate Research Unit Time-Series version 3.23) gridded, monthly rainfall (mm per day) data set. Further to this, the significance of the trends of the inter-annual variability of rainfall has been analyzed using student's t-test at 5% significance level. An overall decreasing rainfall trend is observed in the past 114 years and in this period average rainfall is observed about 225 mm/month (~ 900 mm in season). Different trends have been observed for different time periods. Based on robust K-S test, significant changes in the rainfall pattern are noted during various time periods as compared to 1951-1975. CDFs are calculated for the fitting distribution to calculate the probability that the event is equaled or exceeded in any single year. Rainfall pattern for 1976-2000 and 2001-2014 have been compared with 1951-1975 rainfall. The results suggest that the distribution of rainfall has been changed significantly after 1975. It is also observed that the probability of extreme events is continuously increasing. In the climate change context, it is very important to monitor these changes for better management in the field of water resources, natural disaster, and agriculture.

Development of Cryospheric Services for Management of Hydropower Utilities in the Himalayan region

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Abstract

The Himalayan region has a large hydropower potential because of the altitudinal drop and perennial source of water from snow and glacier melt. The state of Himachal Pradesh has 33 major and 666 small-scale hydropower plants with cumulative installed capacity of 10,519 MW. This electricity is provided to around 7 million people living in the state. These plants are primarily sustained by water originating from

snow and glacier melt, rainfall and groundwater. Glaciers in Himalayan region are losing mass over the past few decades and a recent study in Satluj basin, where the plants are based, suggests a cumulative loss of 78% of ice mass from 1985 to 2090 based on GFDL-CM3 in RCP8.5 scenarios. These changes in cryosphere will alter the seasonality of snow and glacier melt, which will have profound impact on water available for power generation. However, this impact will differ from catchment to catchment, depending on their source of water. It will affect the small glaciers more because of their short response time, making the hydropower projects located on these glaciers vulnerable. In this work, we present a methodology to assess the present and future hydropower generation for micro, mini and small-scale plants that are sustained by small glaciers. Our initial focus is on 3 MW Aleo Manali Hydropower plant in Manali. The catchment area of the plant is 140 $km^2$with an altitudinal range of 1860 m to 6017 m and consists of 22 glaciers covering an area of 10.9 km^2.We simulate total monthly runoff and hydropower potential using soil water balance in Water Evaluation and Planning (WEAP) model. We will be investigating the future changes in hydro-meteorological parameters using climate models, its influence on cryosphere and eventually on the operation and sustainability of the power plants. Furthermore, we aim to expand this method to various catchments in Himalaya to benefit the local communities and help utility managers to take informed decisions.

Variability in the past precipitation over Northwest Himalaya from ~4.0 to 1.9 ka BP with probable collapse of civilization in the foreland areas

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Abstract

To understand the past climatic changes responsible for collapsing or crumbling of ancient civilization and culture, it is essential that high resolution archives and proxies must be employed. Cave structures, particularly stalagmites (made up of calcium carbonate) produce annual rings like those in trees and are regarded as one of the most valuable archives of climate proxy recorder and are also excellent archives for multi-annual to decadal scale climatic changes. Their dating by U/Th delivers a reliable chronology for the periods of stalagmite formation. Growth rates ranging from some microns to several hundred microns per year allow high temporal resolution. For a sub-sample of about 100mg and ^{238}U concentration of about 1 ppm, current TIMS and ICP-MS capabilities translate to precision (2σ errors) and age errors of about 500±8 years, 10,000±45 years, 50,000±180 years, 500,000±15,000 years—clearly expressing that speleothems are most ideal continental candidates to reconstruct the past precipitation and vegetational changes within sufficient time duration. At present, various aspects of climate change, e.g., precipitation variability and vegetational composition are being studied using stalagmites on the basis of measurable proxies such as stable isotope ratios and growth rates.

We present a stalagmite based high resolution climatic record between ~4.0 and 1.9 kaBP from Dharamjali Cave in Pithoragarh (Kumaun Himalaya), an area which is influenced primarily by the Indian Summer Monsoon (ISM) and supplemented by the Indian Winter Monsoon (IWM). The chronology of the 41.5 cm long DH-1 stalagmite was constructed using a StalAge model on six 230 Th/U dates. However,

some samples have higher 232Th concentrations, leading to an increase in the final age uncertainties. The significance of this work lies in its being one of the rare studies of speleothems to reconstruct high resolution climatic changes in the NW India for the Upper Holocene. The $\delta^{18}O$ values, ranging between -5.3‰ to -10‰, show a large variation, compared to the areas dominated by a single monsoon, and this can be ascribed to the two sources of moisture (e.g., ISM and IWM) in the study area during the Upper Holocene. The sample consists of aragonite except for two sections of calcite growth from 0-7.3 cm and 8.5-13.5 cm from the top. The climatic reconstruction indicates strengthened precipitation from 4.0 ka BP with a sharp drop (>-2‰) in $\delta^{18}O$ values, peaking at ~3.7 ka BP. A gradual decline in precipitation is observed from ~3.7- 3.0 kaBP with droughts, centered at ~3.4, ~3.2 and ~3.0 ka BP. Subsequently, climatic amelioration took place between ~3.0-2.9 ka BP, showing fluctuating trend in $\delta^{18}O$values with comparatively more rainfall, possibly generated by the IWM in the form of thunderstorms and hailstorms from ~2.9-2.7 ka BP. Precipitation declined from ~2.7 to2.4 ka BP with a decadal scale major drought event, strongest in the present data set, at ~2.5-2.4 ka BP, whereas, an abrupt drop in stalagmite $\delta^{18}O$ values from ~2.4-2.3 ka BP points to increased precipitation intensity. Thereafter, the precipitation gradually decreased until ca. 2.1 ka BP with one of the driest events at ~2.1 ka BP. A century scale increasing trend in the precipitation intensity is observed from ~2.1-2.0 ka BP, following which the precipitation again declined. Accordingly, five sudden drought events are documented, centering at ~3.4, ~3.2, ~3.0, ~2.5-2.4 and ~2.1 ka BP. A gradual reduction in precipitation from ~3.7-3.0 ka BP coincides with reduction and deurbanisation and step-wise disintegration of the Harappan civilization along the Indus-Ghaggar-Sarasvati valleys in the foreland areas of northwestern India.

We opine that the increasing aridity and droughts between ~3.7 and 3.0 ka BP contributed to the gradual decline in the Harappan civilization, its breakdown in steps and complete collapse around ~3.0 ka BP. During this period, the shift of Harappan settlements from large urban cities to lesser villages as well as migration of population may have also been a result of limited resources brought on by mounting aridity and scarcity of water. Further, the IWM may have played a critical role in the Holocene climate of the Indian Himalaya. Therefore, IWM produced winter crop failure may also have been responsible for the gradual demise of the Harappan society. We believe that the Harappan culture was faded away gradually and mainly due to the failure of monsoon resulting in climate deterioration and not due to any abrupt event, e.g., tectonic activity or seismic phenomenon in the Himalayan foothills.

Hydrological load induced seasonal deformation and earthquake modulation along the Main Himalayan Thrust

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Abstract

After the Amazon basin, the second largest hydrological load of the Southeast Asia is located over the Himalayan deformation front. It has observed that seasonal mass oscillation can significantly modulate the tectonic deformation process along this plate boundary. However, the exact interaction between the tectonic and such non-tectonic deformation process remains elusive. Here we explore seasonal mass

oscillations process by continuous Global Positioning System (cGPS) measurements and satellite data from the Gravity Recovery and Climate Experiment (GRACE). We observe that substantially high cGPS transient above the base of the seismogenic zone (i.e., mid-crustal ramp) during hydrological loading period, which indicate a possible role of change in aseismic-slips on the Himalayan megathrust. Such abnormally high seasonal transients are in excess of model predictions from hydrological and atmospheric loading. Further, it has appeared that cGPS sites having anomalous seasonal transients are located over the fluid rich pockets along the mid-crustal ramp. These isolated fluid rich pockets are also associated with several repetitive earthquakes swarm's activity in the Nepal Himalaya. In order to explain these abnormal seasonal transients along with repetitive earthquake swarm's activity, we invoke a possible fault resonance process, induced by periodic seasonal mass oscillation. We have suggested that the mid-crustal ramp is more sensitive to periodic stress oscillation and associated slip resonance process. We further argue that such fluid rich crust is more sensitive for amplitude velocity perturbation with increasing substantially higher pore-fluid pressure.

Impacts of Hydro Power Projects on Ambient Air Quality in the Sutlej Basin, Northwestern Himalaya, India

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Abstract

Hydropower is one of the important sources of energy in the Indian Himalayan Region (IHR). The IHR is characterized with steep topography, glacier fed perennial rivers with potential scope of economic development in terms of hill agriculture (crop farming, horticulture, animal husbandry, etc.), tourism and hydropower development. But studies pertaining to environmental impact assessment of hydropower projects reveal that increasing number of projects within a limited geographic entity has multiplied environmental impacts. Ambient air pollution, in particular, is not only limited to the Himalayan urban towns of Himachal Pradesh rather it is also significant in the construction sites of the hydropower projects. Particulate pollutants such as particulate matter below 10 micron (PM_{10}) and gaseous pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ammonia (NH_3) are the important parameters to be monitored. In and around a commissioned hydroelectric project Rampur, PM_{10} concentration was found as low as 46.9±6.6 μg m^{-3} ranging from 17.8 to 65.5 μg m^{-3}. On the other hand, Shongtong-Karcham hydroelectric project (HEP) under construction has relatively higher PM_{10} pollution with a mean value of 106.4±1.2 μg m^{-3} ranging from 102.8 μg m^{-3} to 111.9 μg m^{-3}. It is found that particulate pollution is higher in the surrounding of Shongtong-Karcham HEP which is under construction as compared to Rampur HEP-a commissioned project. Because the Shongtong-Karcham project under construction phase is also lying relatively in a larger area. The two other projects-Shyang and Tangling overlapped each other's ecological boundaries (i.e. 5 km aerial distance in case of small projects and 7 km in case of large projects). At contrary, gaseous pollutants in ambient environment were found higher in Rampur HEP as compared to Shongtong-Karcham HEP. It is noted that Shongtong-Karcham HEP and its surrounding affected area, the

particulate pollutants have crossed its permissible limit (100 μg m^{-3}) as set by National Ambient Air Quality Standards (NAAQS), India. However, gaseous pollutants except particulate pollutants at every study site were under permissible limit. It is again made clear with the help of HYSPLIT and CALIPSO analysis that Shongtong had more particulate pollutants while Rampur had more gaseous pollutants indicating existence of both sources -local as well as external.

Rainfall in Sikkim - Critical Analysis

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Abstract

Sikkim (27°05′ to 28°07′N and 87°59′ to 88°56′E), wedged between Nepal and Bhutan, is a small state of India well known for its scenic beauty, immensely rich biological diversity, very diverse climatic conditions, and large altitudinal variation (300–8598 m). The state, being part of the Inner Himalayan mountain ranges, has elevations ranging from 300 m to 8,600 m above Mean Sea Level (MSL). The rainfall pattern is also unique in itself, the heavy rainfall occurring in the mid and the lowers hills while alpine, temperate and lower valleys get less rainfall. The rainfall in these hills is again influenced by the direction of the wind and the aspects of the hill slopes. In the present study, daily rainfall data since 2004 to 2014 of six rain-gauge stations (Damthang, Namthang, Tadong, Khanitar, Chungthang and Gangtok) and monthly rainfall data of eight rain-gauge stations, procured from the India Meteorological Department (IMD), Gangtok have been analysed. These data were used to assess meteorological drought in Sikkim during 2004–2014. Two meteorological indices, namely the Standardized Precipitation Index (SPI) and the percent departure from normal rainfall (PDN) were computed for the pre-monsoon (March - May), monsoon (June - September), post-monsoon (October - November) and winter (December - February) seasons. Besides, number of rainy days and extreme rainy days were also calculated. Number of extreme rainfall days in a month offers a fair idea about how uniformly is the rainfall distributed over the rainy days in that particular month. Daily rainfall values of a month are compared with extreme rainfall value of that particular month and number of extreme rainfall days is found for that month.

This study through critical analysis of rainfall has revealed that:

- For most of the rain gauge stations although number of rainy days and amount of rainfall are positively associated, the association is not very strong ($R^2 < 0.4$) in cases of pre-monsoon, monsoon and post-monsoon rainfall. Chungthang is the only station showing strong positive correlation ($R = 0.75$) between monsoon rainfall and number of rainy days.

- Rainfall in Sikkim varies significantly, both temporally and spatially. The altitude of the station also influences the coefficient of variation (CV). The coefficient of variation is generally found to increase with higher altitude.

- An interesting finding of this study is that at Namthang, monsoon rainfall and number of rainy days

is inversely proportional. This indicates that in certain years there were several rainy days when rainfall was insignificant. Conversely, there were years in which fewer rainy days contributed to significantly higher amount of rainfall.

- Another interesting fact that was revealed through this study is that winter rainfall is positively correlated with the number of rainy days at all the rain-gauge stations except Chungthang ($R \geq 0.71$).

- Overall there is a decreasing trend in rainfall amount across Sikkim during the pre-monsoon, post-monsoon and winter period whereas rainfall shows increasing trend during monsoon period over the years.

- Mangan and Chungthang from North district were not affected at all during Indian drought year of 2014. Damthang from South district and Gangtok from East district received mild to moderate rainfall during 2014. Overall, Sikkim was least effected by drought in the year 2014. In fact, for four stations 2014 was moderately wet year as revealed by the SPI and the PDN. The other wet years were 2007, 2008, 2010 and 2011 for most of the stations.

- Chungthang and Tadong faced severe to extreme drought during the Indian drought year of 2004 along with Gangtok which experienced moderate drought. Rest of the five stations experienced mild drought in 2004 and hence 2004 was significantly effective Indian drought year in Sikkim.

- Damthang, Gangtok and Majitar experienced severe to extreme drought in the Indian drought year of 2009 along with Khanitar which faced moderate drought. Chungthang, Tadong and Namthang faced mild drought in 2009 and hence 2009 was the most effective Indian drought year in Sikkim. Namthang of South Sikkim faced mild drought continuously throughout the 11 years considered for analysis, during the winter period.

- There is a decrease in the precipitation towards the north-west direction in Sikkim which may be caused due to the orographic effects of the Himalayas. There was no shift of the onset or retreat of the Monsoon in Sikkim.

The simplified account of the distribution of rainfall, while broadly true, is strongly influenced by local orographic effects. Actually, the Himalayan orography is of complex type and it is difficult to carry out any detailed study without having a dense network of observatories which is rare in the Eastern Himalayas. It is necessary to establish a dense network of meteorological stations to carry out a detailed analysis of rainfall.

Effect of rainfall patterns on the infiltration and groundwater responses and its consequence on the rainfall-induced landslide

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Abstract

Rainfall infiltration is the most widespread triggering factor for landslide occurrence. Though there are several literatures where this problem has been addressed, yet most of them have been confined to the intensity and duration of the rainfall event and their effect on the slope instability. The pattern or distribution of the rainfall has not received adequate attention. The unsaturated hydraulic conductivity is a function of the soil moisture content which, in turn, controls the rain water infiltration. With time, as rain water wets the soil, the hydraulic conductivity and the rate of infiltration increases. Many rainfall-induced slope failures have been attributed to antecedent rainfall conditions. In this study, a numerical model for natural hill-slope is developed to investigate the effects of rainfall intensity and its pattern on slope stability. Parametric studies were performed by using typical rainfall patterns, identified by the analysis of available rainfall data for Guwahati region. Two different soil types were chosen to represent the high- and low-conductivity residual soils of Guwahati. Antecedent rainfall patterns were applied on soil slopes and a transient seepage analysis was conducted. The computed pore-water pressures were used in stability analyses to calculate the safety factor of the slope. Results indicated that antecedent rainfall affected the stability of both high-conductivity and low-conductivity soil slopes. However, the antecedent conditions and the rainfall pattern played a significant role in the failure of the low-conductivity soil slopes. Patterns of antecedent rainfall controlled the rate of decrease in the factor of safety. The analysis result highlights the fact that rainfall pattern has a significant influence on the landslide triggering. In addition, it was observed and reconfirmed that increasing trend of rainfall intensity has severe effect on landslide occurrence, since in such rainfall events, the higher infiltration lead to significant build-up of pore water pressure and rise in the ground water table, which is the primary triggering mechanism of rainfall-induced landslides.

Satellite-sensor calibration for automated retrieval of snow surface temperature at fine resolution and its validation with wireless sensor network data in Lower Himalaya, India

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Abstract

Spatio-temporal variability of snow surface temperature (SST) over a large area is an important parameter for the study of ecology, environment, climatology, glaciology, hydrology, physical processes,

surface characteristics, melt estimation, flood forecasting, hazard assessment etc. on the earth surface. Of the modern technologies in cryospheric monitoring, the remote sensing technology that can instantaneously form large-scale images has become much more important in helping acquire parameters such as the freezing and melting of ice as well as the surface temperature etc., which can be used in the research of global climate change, avalanche feedback information system and evolution.

Nowadays, data from different earth observation systems are available and widely used in estimation of surface temperature using thermal data, e.g., Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Landsat series. Passive microwave data can also be used to estimate surface temperature, but at coarse resolution. Thermal data of different multi-spectral satellite sensors have advantage of having high spatial resolution as compared to passive microwave data.

In this study, Landsat-8 satellite-sensor has been calibration for automated retrieval of SST at fine resolution in Beas River Basin, India. Split-window technique has been proposed to derive SST over study area using thermal images of Landsat-8 satellite. Cloud free Landsat-8 data for winter period of 2017 has been used to estimate SST. Snow and Avalanche Study Establishment (SASE) has established a wireless sensor network (WSN) near Creep & Glide avalanche prone slope in Beas River Basin, India. Landsat-8 derived SST has been compared and validated with recorded SST at different elevation of WSN stations. The retrieved SST using split-window technique was in good agreement with SST recorded on ground by WSN. The mean absolute error (MAE) and root-mean-square error (RMSE) between satellite-derived and recorded SST has been observed as ~ 1.4 K and ~ 1.7 K during winter period of 2017. The efficacy of the proposed model has also been tested vis-à-vis for other SST models proposed for thermal sensors data. High correlation coefficient (R^2 ~ 0.91–0.84) has been observed between the SST values obtained from proposed model using Landsat-8 images and SST-derived. The proposed algorithm. Model has shown a potential for automated mapping of snow and ice surface temperature using Landsat-8 data for snow cover and glaciers in Himalaya.

Effect of climate change on Himalayan Glaciers

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Abstract

Himalayas have long been under the radar due to its continuous deglaciation in response to the changing climate. Different parameters like change in area, elevation and mass, help us quantify the extent of these changes in the glaciers in terms of freshwater loss. Nevertheless, it is very difficult to monitor these glaciers continuously using the conventional ground- based methods. Remote sensing technology provides the means to keep a real-time observatory with data being collected continuously. For example, the Landsat legacy mission has been collecting data from the past forty-seven years (1972- present) at a moderate resolution of 30m which gives us an idea about the changes in glacier length, area and snout

position. However, with coverage in the optical region, it is sometimes unable to continue its data capturing capability during cloud cover especially during the monsoon season after the maximum melt of the glaciers has taken place. Hence, Synthetic Aperture Radar (SAR) satellites are a useful alternate which have been utilized in this study for estimation of elevation and mass changes. TanDEM-X mission, is the first high resolution (7 m) space-borne interferometric SAR satellite pair from which Digital Elevation Models (DEMs) have been developed since 2011. For Himalayas, which extends up to 40000 sq. km, global DEMs are required and currently, SRTM and TanDEM-X data are the only dataset that have been able to provide wall-to-wall height map. Hence, for decadal (2000-2014) elevation and mass changes in the Himalayas, global DEM from SRTM (of the year 2000) and TanDEM-X data (2011-2014) have been utilized. The net mass loss of Himalayas has been found to be -154.72 ± 19.04 Gt which accounts for more than 5% of the total glacial stored water.

To assess the effect of climate change, these parameters need to be monitored over a longer duration. Pre-historic and predictive models are required for this purpose. In this study, we utilized regional climate model to downscale historical run of Community Climate System Model (CCSM4) of Climate Model Inter-comparison Project (CMIP-5), at very high resolution of 10 and 15 Km respectively. Model used in this study is Regional Spectral Model (RSM) coupled with Regional Ocean Modelling System (ROMS), which accounts for the coupling of ocean-land and the glaciated terrain. Using the mass balance model, we estimated the annual mass changes over the entire area for the historic and current period from 1986-2005. A temperature and precipitation negative bias observed at higher elevation. However, the trend of lower mass change at higher altitudes is being captured in this model. This scheme of mass balance estimation has been applied for the Himalayas for the first time at this grid-scale. With this approach, at such high resolution we expect that that it could be utilized for future climate simulations as well. We plan to carry out this study on further high resolution of 1-2 km.

Seasonal and Altitudinal variation of Snow cover Area (SCA) over Parvati Basin, India using MODIS data during 2001-2017

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Abstract

The snow cover area found higher latitude and higher altitude region on the earth surface. In terms of the spatial extent, snow cover is the second largest component of the cryosphere and covers approximately 40–50% of the earth's land surface in Northern Hemisphere during winter. The Snow cover study is more important parameter for understanding the regional climate. The extent of snow cover is considered an important parameter for numerous climatological and hydrological applications because snow cover is very sensitive to climate change, e.g., atmospheric circulation, air temperature, precipitation, wind, and solar radiation. In comparison, air temperature and precipitation are the most important factors for the variability of snow cover, which can identify the temporal climatic controls and enable long-term versus short-term trend detection. Snow cover dynamics in mountainous regions is a vital source for study of

glacier mass balance, climate change, energy balance and hydrological behaviour of the river. Satellite based remote sensing is a convenient tool for the study of cryosphere that allows to carry out investigations over large and inaccessible areas. The present investigation has been carried out to monitor seasonal, temporal and Altitudinal variation of snow cover area (SCA) in the Parvati basin which is situated in western and west-central Himalayas. This analysis has been done using Moderate-Resolution Imaging Spectroradiometer (MODIS) satellite data for the past 17 years (2001– 2017); the temporal snow cover being derived using the Normalized Difference Snow Index (NDSI). The entire study basin has been divided into five elevation zones, on the basis of Digital Elevation Model (DEM), for estimating the SCA for each zone. Zones 1–5 cover different elevation ranges: (1) Below 2000 m, (2) 2,000-3000 m, (3) 3000–4000 m, (4) 4000–5000 m, (5) Above 5,000 m. Mann Kendall and linear regression methods have been employed to identify trends in the SCA during the period 2001–2017. Results are as follows: (1) the snow cover areal extent had increased over Parvati basin. It indicates that precipitation (Snowfall) increased over the time of period in study area. (2) The variability of SCA was higher in the post-monsoon season and in the winter, season was observed less variability in the snow cover. (3) The snow cover positive trend was observed statistically insignificant for summer, winter and post-monsoon seasons and statistically significant negative trend was observed in the monsoon season with linear regression test. (4) The snow cover ablation is more constant than accumulation in the Parvati basin. In the Zone 4 and 5 was observed higher negative anomalies during the study period. This has harmful effect on the cryosphere of Parvati basin. The regions more prone to snow-related disaster in western-central Himalayas becoming key zone of snow-cover monitoring and disaster prevention and mitigation

Water soluble ionic species in atmospheric aerosols over Dhauladhar region of North-Western Himalaya

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Abstract

Water soluble ionic species (WSIS) have been used as potential markers for different source(s) and underlining process(es) for the formation of ambient aerosols. Study of aerosol associated WSIS has also been crucial to understand direct and indirect effects of aerosols on regional climate and human health. North-Western Himalayan region (NWHR) with sizable population and attractive tourist destinations have been facing ever increasing problem of gaseous and particulate air pollution from exponential increase in vehicular traffic and other anthropogenic emissions. Though, several studies focusing on chemical characterization and source identification of aerosols have already been conducted over various urban and rural locations in India and worldwide, but, very few studies based on long-term systematic measurement of ionic composition of atmospheric aerosols over NWHR are available. The present study has been planned to perform simultaneous measurement of ionic composition of ambient aerosols at an urban (Dharamshala) and a rural (Pohara) location over the Dhauladhar region in North-Western Himalaya leading to investigate the nature and the strength of various source(s) and different atmospheric process(es) responsible for the formation of WSIS.24-hourly PM_{10} aerosol samples were collected every week on pre-baked and pre-weighed quartz–microfiber filter paper (Whatman) using

Respirable Dust Sampler (Envirotech, model APM 460 BL) simultaneously at an urban location Dharamshala (32°20'N, 76°32'E; 1350 m amsl) and a rural site Pohara (32°22'N, 76°25'E; 750 m amsl) in Dhauladhar region of North-Western Himalaya from January 2015 to January 2016.These samples were analyzed for major anions (F^-, Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-}) and cations (Na^+, NH_4^+, K^+ , Ca^{2+} and Mg^{2+}) using Metrohm Ion Chromatograph (IC) model 883 basic IC plus with conductivity detector. On annual average basis, WSIS accounted for 15.6% and 14.2% of PM_{10} aerosols load at urban location Dharamshala and at rural location Pohara, respectively. At Dharamshala, SO_4^{2-} ions contribute maximum (52%) followed by NO_3^- (12%) and NH_4^+ (11%) to the total concentration of WSIS analyzed. Similarly, at Pohara SO_4^{2-} dominated among all WSIS analyzed, contributing 56% followed by NO_3^- and NH_4^+ each contributing 12%. Seasonal average concentrations of PM_{10} and associated WSIS were observed to be higher at rural location Pohara than urban location Dharamshala in all the seasons. This could be due to the low altitude and proximity with a National Highway of the sampling site at the rural location Puhara. The total WSIS concentration was noted to be the highest during winter season over both the locations, plausibly due to lowering of mixing height coupled with the increase in the activity of source(s) viz. coal and biomass combustion for surrounding heating. At Dharamshala, strong correlation between NH_4^+ and SO_4^{2-}, in all the seasons, indicates the formation of Secondary Inorganic Aerosols (SIA). Their high proportions in WSIS and considerable thermodynamic stability at ambient temperatures, made $(NH_4)_2SO_2$ the major contributor to SIA over NH_4NO_3 and NH_4Cl at this urban location. Moreover, low ambient temperature in winter season favoured formation of NH_4NO_3 with significant contribution to SIA. Good correlations were observed between NO_3^-, PO_4^{3-} and K^+ during winter and autumn season over both the locations. This observation suggests contribution of inorganic (NPK) fertilizers that could be re-suspended along with the loose soil from the agricultural fields present in the vicinity. The results of the Principal Component Analysis (PCA) performed on the concentration of different WSIS analyzed suggested three major sources of aerosol associated WSIS over the urban location of Dharamshala viz. re-suspension of soil or local sediments; conversion of pollutant gases (SO_x, NO_x and NH_3) to particles i.e. SIA formation and re-suspension of inorganic (NPK) fertilizers' residues. In addition to these three sources, biomass-burning emissions are also contributing to aerosol associated WSIS over the rural location of Pohara in the Dhauladhar region of North Western Himalaya.

Lightning distribution in relation with topography and vegetation cover over the dry and moist regions in the Himalayas

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Abstract

The impacts of elevation, terrain slope and vegetation cover on lightning activity are investigated for contrasting environments in the northeast (NE) and the northwest (NW) regions of the Himalayan range. Lightning activity is more at higher terrain slope/ elevation in the dry NW region where vegetation cover is less whereas, it is more at lower terrain slope/elevation in the moist NE region where vegetation cover is more. In the wet NE, 86% (84%) of the annual lightning flash rate density (LFRD) occurs at elevations of < 500 m (terrain slope < 2%) and then sharply falls off at higher elevations (terrain slope). However,

only 49% (47%) of LFRD occurs at elevations of < 500 m (terrain slope < 2%) and then rather gradually falls off at higher elevations (terrain slope) in the dry NW. The ratio of the percentages of LFRD and elevation points is much higher in the NW than in the NE above an elevation of ~ 1000 m. The impacts of terrain slope and elevation in enhancing the lightning activity are stronger in the dry NW than in the moist NE. The correlation coefficient of the LFRD with normalized difference vegetation index is higher in the NW than in the NE on both, the regional and annual scales. Results are discussed as a caution in using any single climate variable as a proxy for projecting a change in the lightning–climate relationships in the scenario of global warming.

Evidence of extreme mass movement in Meru glacier region during 2017, Garhwal Himalaya, India

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Abstract

Meru glacier is a small tributary glacier in Gangotri catchment of Garhwal Himalaya region. It was considered that the Meru glacier is an active feeding agency of the main glacier (Gangotri glacier) from the left during past. But currently it has been separated from the main glacier and treated as Inactive tributary glacier. The field Photograph and satellite Imagery clearly suggest that the lower most surface of the Meru glacier suffered extreme event of mass movement during 2017. This mass movement modified the topography of the main glaciated valley and influenced the initial course of Bhagirathi River at great extent. The analysis suggests that nearly about 1559 m length of the river and around 360714.11 m^2 area of the river valley has influenced (from Gaumukh to downward) by this event. There are 26 different locations, where the course of the Bhagirathi River shows minimum 2 m to maximum 175 m lateral shift from the earlier position. The analysis of different satellite data set (between 2015 and 2017) clearly suggest that this event is not a result of single day phenomenon and the initiation of this events has already been started in 2015 after a formation of small temporary lake in the lower most part of the Meru glacier. The data analysis further unveils that secondary stream emerged from this temporary lake in 2016. This stream acts as a lubricant for loose and unconsolidated debris materials of Meru glacier and major slope failure occurred along this secondary stream during 2017.In addition high slope angle, extreme rainfall (July – August 2017) and debris dominated ablation zone also play a significant role for this extreme events.

Oblique convergence, strain partitioning and associated geodynamic complexities in NW and NE Himalaya

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Abstract

Himalayan-Tibetan orogeny has considered as a natural black box in the context of geodynamic evolution and tectonic complexity. In order to explain the complex deformation process, several geodynamic models are proposed among which the lateral extrusion and oblique convergence model are the popular ones. The lateral extrusion model deals with the lateral/eastward flow and deformation of the Tibetan crust, while the oblique convergence model describes the deformation along the Himalayan arc. With respect to central Himalayan plate convergence rate, there is a significant deficit in motion of around 20-35% in the NE and NW-Himalaya. Invoking the oblique convergence model in NW-Himalaya, it is proposed that the oblique motion between India-southern Tibet is partitioned in the back arc along the Karakoram fault and remaining motion is accommodated along the Himalayan frontal arc, leading to the formation of NW-Himalayan sliver. Similarly, in NE-Himalaya (Bhutan/Arunachal region) in order to accommodate the oblique motion, another sliver in the back arc with prominent left-lateral strike-slip fault system is required. However, geomorphic offsets, geodetic estimates and available earthquake data do not support the presence of any active left-lateral fault system in the back arc region. Thus, the applicability of oblique convergence model in NE-Himalaya seems debatable and it appears that the eastward extrusion model contradicts with the oblique convergence model. Therefore, in order to solve the contradiction between the lateral extrusion and oblique convergence model in NE-Himalaya, we propose that instead of partitioning in the back arc the NE-Himalaya has developed an active sliver along the Assam-Brahmaputra valley in the outer deformation front. Further, we argued that the strong eastward extrusion of Tibetan crust along NE-Himalaya is the main driving force for such unusual development of the Assam-Brahmaputra sliver in the outer deformation front. This new hypothesis can explain several geodynamic processes like; (i) active convergence along EHS, (ii) geometrical and spatial existence of the Assam-Brahmaputra valley, (iii) kinematic and space-problem of Indo-Burmese wedge, (iv) low convergence and subdued topography in Bhutan and Arunachal Himalaya, and (v) finally solves the contradiction between Tibetan extrusion and oblique convergence model of the Himalayan-Tibetan orogeny.

Statistical analysis of Relationship between rainfall and yield (estimated from Remote sensing during last 19 years) of Wheat crop in Hilly state of Uttarakhand

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Abstract

The population of the Uttarakhand primarily depends on Agriculture for their Livelihood which is influenced by spatio- temporal variability of Rainfall. Kharif and Rabi are the two main crop growing seasons which require major properties of rainfall. This study is mainly focused on understanding the variation of rainfall and its impact on Rabi wheat crop yield over Uttarakhand state.

Co-relation analysis reveals that a large of state exhibits positive relationship between rainfall and yield of wheat crop in hilly region. This study shows that for Wheat Rabi season crop rainfall period from October to march, Maximum positive relationship with January season Rainfall has been observed. The study showing rainfall during January is most favorable among October to march for wheat crop high yield. The study showing rainfall during February is also favorable for some district for wheat crop yield.

Inter-annual climate variability based on high resolution stable isotope (δ18O & δ13C) records of Tridacna maxima bivalves, Minicoy Island, Lakshadweep Archipelago

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Abstract

In the present study detailed isotopic profiles were constructed for a specimen of giant clam-*Tridacna maxima (T-maxima)* collected from a depth of ~2 meters from the Minicoy Island (8°16′23.84″N, 73°01′34.71″E), Arabian Sea. A total of (n=192) sub samples were retrieved from the annual bands and analyzed to examine the isotopic ($^{13}C/^{12}C$), ($^{18}O/^{16}O$) relationship with the growth pattern of the clam and the environmental parameters. A 25-year chronology was established using the $\delta^{18}O$ record obtained from the internal layers near the hinge area along the radial sections extending from umbo to the outer shell layer margin (initial to later growth). The annual growth rate varies from 0.2 mm to 2 mm with an average growth rate of 0.78mm/yr. The $\delta^{18}O$ varies from -0.64‰ to -4.40‰ with an average of -1.85‰ and characterized by a strong seasonality. The average $\delta^{18}O$ values during the early summer (March-August) and during late winter (Sep-Feb) seasons are -2.05 ‰ and -1.54‰ respectively reflecting distinct seasonal cycles. The amplitude of $\delta^{18}O$ is about 0.5‰, which is consistent with the total seasonal

variation of the SST (29.81-28.22°C). However, $\delta^{13}C$ does not show any seasonality; rather it showed an increasing trend towards the positive values with time. Two polymorphs of $CaCO_3$-calcite and aragonite were found associated with the initial and later stages of the shell ontology. Furthermore, we have compared our isotopic records with a coral $\delta^{18}O$ profile having 23 years of growth collected from the same lagoon. The $\delta^{13}C_{shell}$ and $\delta^{18}O_{shell}$ values show weak or no significant correlations ($r=0.30$, $p>0.05$) suggesting that there is no kinetic effect. Since the calcification process in giant clam is known to take place in isotopic equilibrium while that in the reef building corals is kinetically controlled, the comparison of the isotopic profiles between these two organisms helps to estimate the so called 'vital effect' in corals. This is estimated as -2.70‰. Since the Minicoy region harbors massive coralline community, estimation of this offset value would be useful to use the coralline isotope records in studying the variability of past ocean surface conditions.

Numerical simulation and dynamics analysis of a cloud burst event on 8 August, 2015 over Mandi district, Himachal Pradesh using high resolution WRF model

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Abstract

Confined deep cumulus convective clouds are capable of giving a massive amount of rainfall over a limited area in a short period. Intense precipitation events over the Himalaya lead to secondary events like landslides and flash-floods. Such extreme rainfall events commonly occur over the high topographical regions of Northern India during the Indian Summer Monsoon Rainfall season. Thus predicting these events well in advance can reduce the associated damages. A recent heavy precipitation event on 8 August 2015 is one of the most severe calamities that occurred over the Mandi district in Himachal Pradesh, India. Study objectives are to present dynamical fields of cloud burst, and understand the underlying processes, using the Weather Research and Forecasting (WRF version 3.8) model. A two-way nested (with 9-km and 3-km horizontal resolution) WRF model is configured over the study region centered over Dharampur (31.6^0 N; 76.6^0 E), where the heavy precipitation event is reported. Two cloud microphysics parameterization schemes and planetary boundary layer schemes have been used for the sensitivity experiments. The results have been analyzed and validated with TRMM and IMD observations to examine the performance of both kinds of schemes in capturing such extreme localized heavy rainfall events.

Glacial Lakes and Glacial Lakes Outburst Floods in Himachal Pradesh, India using Remote Sensing and GIS

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Abstract

In high mountainous terrains, with the melting of glaciers, the risk of glacial related hazards increase. One of these risks is Glacial Lake Outburst Floods (GLOFs). As glaciers retreat, glacial lakes form behind moraine or ice 'dams'. These 'dams' are comparatively weak and can breach suddenly, leading to a discharge of huge volume of water and debris. Such outbursts have the potential of releasing millions of cubic meters of water in a few hours causing catastrophic flooding downstream with serious damage to life and property. Glacier thinning and retreat in the Western Himalayas has resulted in the formation of new glacial lakes and the enlargement of existing ones due to the accumulation of melt-water. Hence a time-series study will be carried out using satellite imageries, published maps and reports to understand the impacts of GLOFs. The study will be focused on finding the potential glacial lakes in Satluj River basin that may be vulnerable to GLOF. Though extensive research is required to predict GLOFs, it is recommending that an early warning system, comprising of deployment of real time sensors network at vulnerable lakes, coupled with GLOF simulation models, be installed for the study area. Glacial hazards relate to hazards associated with glaciers and glacial lakes in high mountain areas and their impacts in the downstream. The study deals with the estimation of GLOF for Satluj River basin located in the Western Himalaya, Himachal Pradesh, India using Remote Sensing and GIS.

Snow cover area distribution and accuracy assessment in Beas River basin, India using Landsat-8 and MODIS-Terra satellite data

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Abstract

Snow cover area (SCA) plays a significant role in high-altitude regions of mountainous hydrology. The Beas River located in the western Himalayas as a part of the Indus River system is a mainly snow-fed river. The variability in the SCA of the Beas river basin affects the spatiotemporal flow and avalanche events. By considering this, the present study focuses on the SCA variability and its relationship with various topographical features such as elevation, slope and aspect. The SCA information is an essential parameter for a wide variety of scientific studies and management applications, especially in snowmelt runoff modeling. Remote sensing technology has various applications in different domains including the utilization in the context of snow and glaciers. Landsat and MODIS data are being widely and effectively used for the SCA estimation in several Himalayan basins. The present study has been carried with the aim of assessing the accuracy of the moderate resolution imaging spectroradiometer (MODIS)-Terra

(MOD10A1) and Landsat-8 data in snow cover mapping under Himalayan conditions. The total SCA has been estimated using these two datasets over 3 years. In this study, snow cover in the Beas River basin region has been determined by applying the normalized difference snow index (NDSI) algorithm from Landsat-8 and MODIS-Terra satellite which detects snow cover area. The snow cover mapping, which is an essential process in the snow hydrological modeling, involves image processing to distinguish snow and non-snow pixels. This methodology has been implemented in the Beas River basin of the western Himalayas, India. Totally twelve Landsat-8 and MODIS images have been used for the snow cover mapping during the melting seasons on the monthly basis from April to October of the years 2013 to 2015. The advanced space borne thermal emission and reflection radiometer (ASTER) global digital elevation model (GDEM) with the spatial resolution of 30 m has been used to delineate the catchment boundary, stream network, slope and aspect maps. In this study, we have used the NDSI method for snow cover mapping. The NDSI maps have been further classified into snowy and snow-free areas based on a threshold value. For threshold value greater than 0.4, the area is regarded as snowy. Otherwise, it is deemed as snow-free area. This type of classification provides an advantage of SCA estimation under mountain shadow condition. It has been noticed that the average SCA in this part of the Beas River basin varies from 40.31 to 51.29% with an average of about 44.29% for Landsat-8 data and for MODIS-Terra SCA varies from 41.7 to 50.64% with an average of about 46.78% of the total basin area of 5383.17 km^2. Further, snow accumulation and depletion curves have been suggested for assessing the SCA in the study area.

Earthquake Early Warning System for Northern India: A Review

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Abstract

Northern Indian is situated very near to Indian plate and Eurasian plate convergent boundary. Indian plate is moving in north-east direction at about few centimeters per year and striking the Eurasian Plate. This is causing development of strain in both tectonic plates. Almost all segments of Himalayan range have seen release of these strains through large size earthquakes. However central Himalaya, which is Uttrakhand, has not seen a large size earthquake in known history. This continuous accumulation of strain is the main reason to suggest that Central Himalaya has potential to generate a large size earthquake in near future. For this reason, Ministry of Earth Science (MoES) has started a pilot project "Development of Earthquake Early Warning System" with Indian Institute of Technology Roorkee (IITR), which is further supported by Uttarakhand Government. IIT Roorkee has established first operational regional earthquake early warning system in Uttarakhand for mitigation of the effects of large earthquakes in near future. Currently, 175 accelerometer sensors have been installed in Kumaun and Garhwal region for real time data streaming and processing of ground motion data. There are 55 EEW sirens have been installed for warning dissemination to public. We have also developed an android app for warning dissemination to user. This system is in operational mode from last 3 years for warning dissemination and has not given any false warning till now, which is a great success for this system.

Application of Geospatial Techniques for Snow Cover Mapping and Snow Load Estimation in Western Himalaya

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Abstract

Himalayan snow cover has an important contribution in the socio-economic development of the northern Indian states. Snow cover area and extent in the inaccessible Himalayan region can be estimated using geospatial techniques. In the present study, snow cover area (SCA) has been estimated for western Himalayan climate zones i.e. Lower Himalayan Zone (LHZ), Middle Himalayan Zone (MHZ) and Upper Himalayan Zone (UHZ) using MODIS sensor images for the period 2001 to 2016. SCA has been estimated by generating 10-day maximum snow cover products from MODIS images. Large inter annual as well as intra-annual variation has been observed in the SCA of climate zones. Mean annual SCA in LHZ, MHZ and UHZ varied from 5,445 km^2 to 9,348 km^2; 31,325 km^2 to 38,273 km^2; and 18,704 km^2 to 23,709 km^2 respectively. Maximum SCA has been obtained for February/March months while least SCA has been obtained for August/September months during each year. Spatio-temporal variability of SCA in climatic zones has been estimated for two different time periods i.e. first decade of the twenty first century (2001 to 2010) and after 2010 i.e. 2010-2016. A decreasing trend in SCA has been observed in LHZ and MHZ during the period 2001 to 2010, although the trends were statistically non-significant. Interestingly, trends in SCA obtained during 2001-2010 in LHZ and MHZ has been observed changing after 2010 and an increasing trend in SCA variation has been observed. Although, the trends observed were statistically non-significant. SCA in UHZ had shown increasing trend at the rate of 241 km^2 $year^{-1}$ during 2001-2016 and the trend observed was statistically significant.

Snow load estimation is important for designing of structures in the Himalayan region. Spatial interpolation technique has been used to estimate spatial snow depth using in-situ snow depth measurements. Snow load has been estimated at each location of the western Himalaya using spatial snow depth maps and snow density. Snow load varies from ~ 3 kNm^{-2} in the Lower Himalayan region at an altitude lower than 3000 m to ~ 42 kNm^{-2} in the high peaks of Karakoram Himalaya where snowfall is received even during Indian summer months.

Temporal variations of glaciers in Bhagirathi basin: A remote sensing approach

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Abstract

Bhagirathi river basin is an important river basin of central Himalaya and is source of river Ganges, which feed water to most of the north Indian states. In the present paper, glaciers of Bhagirathi river basin are monitored using remote sensing for more than a decade period and status of the glaciers are presented. The catchment area of the Bhagirathi basin is approximately 7600km^2 and housed about 288 glaciers. The basin has been categorized into six sub-basins i.e. Bhagirathi, Bhilangana, Pilang, Jahnvi, Jalandhari and Kaldi. During this study, all the glaciers having area more than 5 km^2 have been selected, as these glaciers' contribute to the 2/3rd of the total glaciated region of the basin. Few small glaciers have also been studied. Thus, overall 29 glaciers are selected for this study, which may be regarded as the representative glaciers of the whole Bhagirathi River Basin. The length of the selected glaciers varies approximately from 3 km to 29 km and snout elevation varies approximately from 3800 m m.s.l to 5200 m m.s.l. Remote Sensing images (Landsat TM & OLI) from the year 2000 and 2015 were used for the monitoring. ASTER GDEM V2 has been used for extraction of glacier terrain features e.g. elevation, slope, area, orientation etc. It has been observed that Bhagirathi sub-basin has maximum glaciated area about 35% followed by Jalandhari, Jahnvi, Bhilangana, and Pilang with 13%, 9%, 4.5% and 3.2% respectively. Kaldi is the only sub-basin having no glacier. Out of 29 glaciers, 25 glaciers have shown retreat while 4 glaciers have shown advancement during last 15 years. The total glacier area shows loss of ~0.5% glacier ice during the study period. Results show that the retreat rate varies from 0.06 m per year to maximum 19.4 m per year. Glaciers with north as well as south aspect orientations have shown retreat. It has also been observed that during the study period, area change is highly correlated with the glacier length. The study covers more than 65% of the total glaciated area in the basin and as per our knowledge based on the existing literature; this is one of the initial exhaustive studies to cover highest number of glaciers in all sub-basins of Bhagirathi basin.

Methodologies for Assessment of Urban Micro-Climate

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Abstract

Rapid urbanization, industrial developments have affected climatic conditions of cities. While city expansion is a sign of development, high population, infrastructure development, industrialization has led to deterioration of micro-climate within the city limits and considerable difference can be seen once the city limits are crossed. This difference has significant effect on the overall environmental quality and

human health, keeping aside the overall impact on biodiversity. One of the examples of urban microclimate is Urban Heat Island (UHI) in which the city temperatures are higher than the surrounding regions. UHI can also lead to the additional direct or indirect generation of greenhouse gases and as well as other pollutants such as sulfur dioxide, carbon monoxide and particulate matter etc. which causes climate change and global warming with negative impact on human health as well as the air quality.

The urban microclimate is being widely studied worldwide. However, these studies have different approaches with respect to specific objective parameter. The current work has researched on various methodologies available for understanding urban micro climate. The goal is to critically analyze all the published works in order to the asses the subject development in the field and to search the best methodology suitable for the urban microclimate study especially in context of India.

Critical analysis of published works shows these studies of urban microclimate are nescient stages in across the globe and required the further developments. The Modeling with Computational Fluid Dynamics (CFD) and Weather Research and Forecasting (WRF) is being widely used worldwide to measure urban microclimate impact. Apart from these techniques, it can also be determined using various Remote Sensing techniques. Recent developments in computation and software has boosted the study and its easiness so that software such as ENVI-met which creates a 3D and 2D model using information about urban surface e.g. building height, Vegetation and Weather condition is acquiring its importance due to ability to high grade simulation and prediction. This study suggests that the urban climatic studies cannot be concluded based on temperature and rainfall properties alone. There are other neglected factors such as the humidity, wind speed etc. which have significant effect on urban microclimate and it has to take into consideration using various computational techniques.

Litho-tectonic implications of landslides: Case study of Yamuna valley, Northwest Himalaya

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Abstract

In this study, an attempt is made to explain the relationship between various geological factors with landslides, to understand the relative influence of different landslide causative factors and to perceive intrinsic pattern of landslide dimensions. The Yamuna River valley in the Northwest Himalaya that traverses through the Higher Himalaya (HH) and Lesser Himalaya (LH) rock mass, endures frequent occurrence of disastrous landslides and hence it is taken as the case study. A quantitative analysis of the stream profile to determine the tectonic regime of the region was resorted to, from the various geomorphic indices such as stream length gradient, topographic swath profile, channel steepness index and ratio of valley floor width to valley height, while rainfall data and Normalized Difference Vegetation Index are used to determine spatial precipitation variability. Influence of the rock mass is inferred using Geological Strength Index and Schmidt Hammer Rebound values. Intra-relationship of landslides is

determined by using scaling relationship of landslide area and volume.

The landslides in the area are mostly found in regions exhibiting high stream length gradient index and channel steepness index, and low valley floor width to height ratio, implying that landslides are prone in regions with narrow, V-shaped valleys where the slopes are relatively steep, with lithologic variations such as transition from resistant to weaker rocks. This indicates a close relationship of landslide with tectonic structures of the region. The higher reaches of the HH and lowest part of the LH consist of rockfall dominance due to tectonic uplift, whereas most of the debris slides coincide with the regional thrusts i.e., Main Central Thrust and North Almora Thrust. Total area and volume occupied by the landslides are ~1.5 x $10^6 m^2$ and ~4.7 x 10^6 m^3, respectively. Debris slides are found to be least influenced by the spatially varying litho-tectonic and precipitation regime in their dimensional pattern in view of scaling exponent of 1.43. However, rockfalls are found more sensitive to these conditions, considering a scaling exponent of 0.92.

Holocene Shortening Rate along the Mishmi Thrust, Eastern Flank of the Eastern Himalayan Syntaxis (EHS)

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Abstract

The Eastern Himalayan Syntaxis (EHS) is complex, and hosted the largest continental earthquake Mw 8.6 in 1950. The Eastern flank of the EHS is the continuation of the ~E-W Himalayan range, and at the Nizamghat, Dibang valley, it takes a knee bend turn with ~N-S strike, where Lesser Himalayan rocks directly thrust over the Brahmaputra alluvium plains along the Mishmi Thrust (MT).

Geological rate and the Quaternary deformation pattern along the Mishmi Thrust is not known due to its remoteness. Toward understanding, we have conducted a detailed field mapping and high resolution Real Time Kinematics-Global Positioning System (RTK-GPS) surveys together with tectonic geomorphological investigations along the frontal Mishmi thrust. We mapped thrust fault exposure between the pre-Tertiary and Quaternary Formation in (Sessari and Iphipani) tributaries of Dibang River in the northern segment. Numerous discontinuous active fault scarps of heights from 14m-18m are mapped using RTK-GPS along the MT at Wakro and Kamlang River valley (southern segment). In Lohit River valley (central segment of MT), four levels of terraces (T1, T2, T3 and T4) are well-preserved on the left bank. T1 is a strath terrace and shows 14-m bedrock incision from the current river grade of Lohit River. The RTK-GPS profile shows a gentle gradient across the T1 terrace with insignificant levels of variation that infers bedrock uplift as rigid body without folding. We collected both Optically Stimulated Luminescence (OSL) sediment samples (PK-1 and PK-2) and burnt organic sediments (PKB1) from the strath contact and at the top of the T1 strath terrace surface to infer its abandonment age. OSL dating of strath terrace samples

collected from the top, and at the strath contact yielded 3±0.9 ka and 10±0.9 ka ages, respectively. The top strath surface of the burnt organic unit gave cal. radiocarbon age of 4090-3900 BP, and it is comparable with the OSL age. Using abandonment age with relative height of bedrock, we estimated 1.4-3.5 mm/yr of bedrock incision, and assuming 30º dip of the MT, we found 2.8-9.3 mm/yr fault slip rate and 2.4-8.1 mm/yr shortening rate.

Our geological investigation suggests that the MT is corollary to the MBT (Main Boundary Thrust) of the ~E-W striking Himalayan range. An oblique with minimum convergence rate of 20±4.0 mm/yr estimated earlier, while a recent geodetic study across the MT shows 32.4±2.0 mm/yr normal convergence with a 5.2±2.0 mm/yr oblique component. These estimated convergence rates across MT are higher than the ~E-W striking Himalayan range. Our results attributes that a maximum 40% fraction of total shortening is accommodated by the MT. However, given a 65 km locking width, close spacing of different thrust sheets, and absence of significant geomorphologic surface expression, such as perched terrace, and fault scarp east of MT at the hinterland reduces the possibility of accommodation of remaining strain by the hinterland structures. This highlights the potential for a new nascent, west verging frontal fault towards the foreland of Mishmi range to accommodate the strain partitioning (i.e. distributed deformation), and the Manabhum anticline may be the case.

Tracking back the high resolution multi-decadal climate changes in the Indian Himalaya: role of winter Westerlies

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Abstract

The past 2,000 years are characterized by a number of abrupt climatic variations and rapid warming which provides a valuable opportunity to study this period using proxy data. These variations are the most recent example of dynamic natural global change in Earth's history. The northern Indian region receives 70-75% of its annual precipitation due to Indian summer monsoon (ISM) and almost 25-30% is received during winters mostly in the form of snow in higher altitudes by eastward moving extratropical cyclone called "western disturbances" or "westerlies". Westerlies play an important role to sustain the Himalayan glaciers and to recharge the ground water distribution in the foothills. To understand the role of westerlies during Holocene, a stalagmite was studied from Central Himalaya. An absolutely dated (U/Th series) stalagmite was drilled at 0.8mm to obtain the high resolution record of climatic variations using multiple proxies. The results obtained from stable isotopes petrography, geochemistry and SEM studies suggests a number of climatic fluctuations during the last 2,000 yrs. The results reveal a phase of gradual increased precipitation from ~200 to 800 AD and punctuated by three multi-decadal dry events. The period between ~800 to 900 AD, shows higher precipitation and subsequently advanced growth rate of the stalagmite. An extremely dry event at ~1080 to 1160 AD, has been recorded followed by the wetter climatic conditions from ~1440 to 1880 AD. The results show low precipitation from ~1880 AD onwards. The growth of the stalagmite accelerated during the ~1440 to 1880 AD due to the more precipitation in this period. Whereas, the decline in Indian Summer Monsoon (ISM) during this period brought drought

conditions to the core ISM area but triggered more monsoon 'breaks' that brought higher precipitation to the Himalayas. At the same time, the weaker ISM may also have pushed more depressions along the path of the southern winter jet which brought more winter precipitation to the Himalayas and therefore, this period represents more precipitation. The stronger precipitation over the Himalaya may be explained as due to the stronger westerlies in the Himalaya during this period. This issue needs to be addressed, because any changes in the nature of the influencing factors or the magnitude of their impact are critical for land-use planning in a global warming scenario.

Space based Inputs to Study Land Use Dynamics of Dehradun Area for last 40 years

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Abstract

Space based inputs through the advanced technology of Remote Sensing have changed the way to study and analyze the issues pertaining to Indian Himalayan Region (IHR). Himalayan region is known for its eco-sensitivity and fragility to even the slightest change either natural or due to anthropogenic activities. The issue of outmigration has been the hot topic in IHR but the other side of the story is less being discussed. The migrating population is getting concentrated to nearest city for ease of life, better amenities, infrastructure, job options, etc. This has given rise to a common issue known as "Urban sprawl" in the cities of Uttarakhand. The problem is required to be well studied as it lays a heavy pressure on the sustainability of the existing system, natural resources, triggers to disasters, becomes a factor of climate change, increased urban pollution, environment degradation, etc. (Guneet Kaur, 44th ISOCARP Congress 2008). The urban expansion cannot be ignored however it may surely be planned and controlled. Many a times the population of the region increases heavily without much increase in the built up area. In such systems the population density increases and sometimes even reaches the saturation level with respect to availability of resources and amenities.

Images, which are also known as the Time lapses, when obtained through a suitable platform such as satellites and well georeferenced may be temporally studied for obtaining the dynamics of a particular system. The study is therefore being proposed to study the dynamics of land use land cover pattern of the capital region of Uttarakhand using the remote sensing and GIS technology for classification & change detection using temporal datasets. The study will utilize the freely available satellite datasets, topographic map would be procured at 1:50k, Census data to analyze the population influx over a period of time. The entropy of the system may be calculated to understand the type of expansion is also to be analyzed. Also, it is expected to bring out the comparative study of pixel based and object-based classification through the error matrix.

High altitude glacier mapping in Eastern Himalayan cryosphere using remote sensing data

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Abstract

When impact of climate change has been the prime concern, the Himalayan cryosphere has also not been untouched rather has been affected even more by the warming of the climate. Observations in the Himalayan glaciers show the clear evidences of warming. The Himalayan glaciers are major water source and sitting in the highest regions in the world which are extremely vulnerable to climate change. This study quantifies high altitude snow cover area (SCA) in Khangri glacier which is based on Sentinel 2Aimagery, ALOS Palsar DEM and intra annual detailed field observation data. The assessment shows that the extent of snow cover at Khangri glacier is 178 km^2 during the study period (December 2017 to December 2019). SCA has been mapped using pixel based classification (PBC), Supervised based Classification (SBC) and Normalized Difference Snow Index (NDSI) technique. The results of different classification had shown that NDSI produced best agreement rather than SBC and PBC.

Upper mantle anisotropy beneath Sikkim Himalaya from shear-wave-Splitting analysis

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Abstract

Teleseismic earthquake data recorded at six broadband seismograph stations across the Sikkim Himalaya are analyzed for shear-wave splitting to investigate the seismic anisotropy of the crust and upper mantle. Four of our stations (NAMC, RABN, GTOK and CHTG) are located on the Lesser Himalaya while the other two (LCHG and YUMT) are located on the Greater Himalaya. Shear-wave splitting parameters, derived from the analysis of core-refracted SKS phases provide information about seismic anisotropy and deformation of the crust and upper mantle beneath each site. For every station we estimate (a) the orientation of the polarization plane of the fast S-wave (fast polarization direction – FPD) and (b) the delay time between fast and slow S-wave vibration directions. These parameters are known to be a proxy for the orientation of the a-axis of olivine in the upper mantle. Our analysis shows considerable strength of anisotropy (delay time ranging between 0.65 s and 1.9 s) with sharp change in lateral variations of the FPDs. For stations located on the Lesser Himalaya the FPDs are oriented in the NW-SE direction sub-parallel to the strike of the Himalaya, while for stations sited on the Greater Himalaya, the FPDs are oriented in the NE-SW direction, sub-parallel to the direction of the motion of the Indian plate (NUVEL1A). Our observations are in broad agreement with the asthenospheric flow in the sheared lithosphere–asthenosphere boundary layer and resulting alignment of olivine mineral grains (lattice preferred

orientation). For the region below the Lesser Himalaya, where the Indian plate is strongly flexed and acts as a barrier, the direction of flow in the asthenosphere is parallel to the strike of the flexed plate. Whereas for the region underneath the Greater Himalaya, the flow reverts back to the direction of plate motion. This is also in agreement with previous observations from the Indian shield and the Nepal Himalaya. Our study will provide new constraints on the nature of seismic anisotropy beneath the Sikkim Himalaya and its implications for the India-Eurasia collision process at depth.

Applications of Ground Penetrating Radar for Cryospheric Studies

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Abstract

Non-destructive techniques for cryospheric studies are of great interest for development of fast and automated measurement. The impulse radar systems such as Ground Penetrating Radar (GPR) has been used extensively in North West Himalaya for glaciers and snowpack investigations.

GPR with antenna frequencies 40 to 50 MHz has been used for glacier depth estimation at Patseo, SamudraTapu, Parbati (HP Himalaya) and SASE La (Karakoram Himalaya) glaciers. The bed topography of Patseo and SASEr La glacier was successfully detected, however, due to higher depth of Samudra Tapu and Parbati, it was observed that GPR with lower frequency antennas would provide the desired results.

The glaciers are changing their shape and extent due to global warming. In order to assess the future changes, information of moraine cover over the glaciated ice is very important. GPR antenna with 500 MHz frequency was found suitable for this purpose and was used successfully for moraine depth estimation at Samudra Tapu glacier. Temporal change in glacier area has been reported widely in literature, but change in glacier ice thickness is rarely mentioned. In Himalayas, a study was conducted using GPR for estimation of change in ice thickness in Patseo glacier between year 2004 and 2013.

Apart from glaciers; GPR has also been used to estimate snowpack parameters. Snow depth and snowpack stratigraphy along with its temporal and spatial evolution are important input parameters for operational avalanche forecasting and snow water equivalent assessment for hydrological applications. GPR with antenna frequencies 1 GHz, 1.6 GHz and 2.6 GHz was used for snowpack characterization (snow depth and snow stratigraphic delineation) in Pir Panjal and Greater Himalayan region. Snow depth and snow layer information was estimated at various locations in both the ranges and was further validated with the ground measurements.

Crevasses have been a big problem in Glaciers. Identification and mapping of crevasses in glaciated regions is very important for the safe movement of persons. The feasibility and reliability of ground-based and air-borne GPR was investigated for the same. The emphasis of the investigations was to develop a simple and fast methodology for crevasse detection, and future assessment & management of glacial hazards. This hybrid technique consisting of Radar in ground and air, along with high resolution satellite

imageries, Survey of India (SoI) maps and active microwave satellite data was found to be very useful and successful in crevasse detection and mapping.

Overall, the GPR based non-destructive technique has the potential to provide the useful information of snow, ice and glaciers in faster way. The results have been promising in all the studies, and these can further be used to develop a better understanding of the changing climate.

Records on geodynamic evolution of Himalaya from a review of detrital thermochronological studies in the Himalayan foreland basin sediments

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Abstract

Detrital mineral thermochronology is a relatively new technique which is widely used to investigate tectonic and erosional history of orogens, stratigraphic age, source area characterization and thermal evolution of sedimentary basin. A wide array of researchers has shown in particular that detrital thermochronolgy is a robust, reliable tool in low temperature sedimentary realms in deducing sediment provenance, exhumation and thermal history as well as landscape evolution. The Himalayan orogeny has greatly fascinated researchers due to multiple reasons and the peripheral Himalayan foreland basin (HFB) sediments can be easily investigated by such thermochronological studies. Detrital thermochronological studies have also been carried out in the Himalayan foreland basin sediments. Therefore, a review has been done on the so far use of these studies in the HFB sediments for geodynamic investigations. Though such studies in the Himalayan foreland basin sediments have been extensively done in the adjoining Nepal and Pakistan regions, however the extensively long HFB in Indian part lacks such detailed studies. In particular, the Kangra sub-basin of the HFB lacks such detailed investigations compared to the adjacent Subathu and Dehradun sub-basins whereas the Ramnagar sub-basin shows no report of such investigations. Further, majority of these studies comprise the Paleogene HFB sediments. This review paves the way for the much needed future investigations of these Himalayan sediments in the Kangra and Ramnagar sub-basins of the Himalayan foreland basin.

Observing Large Scale Glacial Surface Changes Using Object-Based Image Analysis

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Abstract

Glacial surface mapping using remote sensing technique has seen a long developmental phase starting form onscreen digitization to modern and advanced techniques like Object-based image analysis (OBIA). For the last two-decade glacial mapping is one of the important applications in which the scientific community is interested given the importance of glaciers in food security, natural hazards (glacial lake outburst floods (GLOF)) and most importantly as an indicator of climate change. In this paper some examples of large-scale glacial mapping are presented utilizing OBIA and high-resolution WorldView-2 and LISS-IV images. OBIA utilizes not only the spectral information of the ground objects but also the other image elements which would assist in delineation of the glacial classes. This is mainly beneficial in demarcating the spectrally similar classes such as supra- and peri-glacial debris covers. The high-resolution image also provides a powerful medium to delineate the small features such as supra-glacial lakes and exposed ice faces (EIFs). These EIFs are important features as they regulate the formation and expansion of glacial lakes. Supra-glacial lakes may lead to catastrophic GLOF; also, they increase the ablation by providing medium for high absorption of solar heat flux. The mapping results clearly show that the OBIA is a powerful tool for large scale mapping of glacial surface using high-resolution images.

Disaster Risk Reduction in the Indian Himalaya: 'Film' a Pathway to Developing Enhanced Resilience?

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Abstract

Natural hazards such as landslides, floods, forest fires and earthquakes pose severe risks to exposed and vulnerable communities. These risks are dynamic, evolving with variability and change in environmental systems and changing anthropogenic activities. This combination is particularly prevalent in mountain regions which are experiencing the impacts of climate warming, settlement expansion (typically associated with tourism), and the development of infrastructure such as roads and hydro-electric power facilities. In challenging these risks, international, multi-national and national Disaster Risk Reduction (DRR) frameworks are driving transitions to resilience in which people and communities are central to

achieving disaster reduction. It is therefore critical to translate these policy ideas into local action, to deliver reduced vulnerability and increased resilience to hazard and risk conditions. Such DRR frameworks include the Sendai Framework 2015-2030; Asian Regional Plan, re-appraised at the July 2018 AMCDRR (Asian Ministerial Conference on Disaster Risk Reduction); and Indian National Disaster Management Plan 2016

Our research in the Kullu District, Himachal Pradesh (India) is investigating interrelated aspects of flood hazard, local vulnerability and resilience to disasters. This has focused on the Phojal Nalla catchment (a tributary of the River Beas), and in particular the 1994 flood disaster which heavily impacted the community at the time and continues to influence their outlook on disaster risk. In partnership with local communities and the Kullu DDMA (District Disaster Management Authority) semi-structured interviews/ questionnaires, village workshops, stakeholder policy workshops and public engagement events have provided insight into local knowledge, life priorities and opportunities for resilience generation. Foremost findings relate to the importance of religious infrastructure/ activities; vernacular architecture; multi-generational attachments to place; use of modern communication technologies and local governance via Village Disaster Management Committees (VDMCs).

The Hindi language Film *'Pathways to Resilience',* (2018) has been showcased at local, state and national public engagement events in India, including the 2018 Kullu Dussehra, and via social media. We argue that film is a powerful way of engaging hearts and minds to empower improved futures in the face of disaster risk. It is a tool for sharing/ reconnecting people with local knowledge and a platform for local people to articulate their own views and aspirations within their own environment. More broadly film is a universal means of connecting people across cultures to encourage new ways of thinking and acting.

Flood Modelling Through Remote Sensing and GIS over Pong Dam, Kangra District, Himachal Pradesh

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Abstract

Pong Dam also a reservoir is constructed on River Beas of Shivalik hills in Kangra District of Himachal Pradesh. Pong Dam Lake Wildlife Sanctuary was declared as a reservoir in 1975 and is one of the 25 international wetland sites (Ramsar) in India. It was declared a Ramsar site on November 2002. The total volume of the dam is 35,500,000 m^3 (46,432,247 cu yd.) and it its crest sits at an elevation of 435.86 m (1,430 ft.) ASL. The reservoir has an elevation of 426.72 m (1,400 ft.) and catchment area of 12,560 km^2 (4,849 sq. mi). Kangra District received 428.8 mm of rainfall in the month of September 2018 which is 83% above normal rainfall. The volume of water reached approximately 5 billion cubic m and submerged 242 km^2 of area reaching upto a height of 1390ft. This study estimated, reaching the water level upto 1430 feet which is the crest of the dam volume of water would reach 8 billion cubic m and submerge 258 km^2 of area. This study could be used to minimize the extent of damage to the surrounding villages and land cover.

A sensitivity study on medium range forecast of extreme severe cyclonic storm Hudhud using WRF model

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Abstract

Land-falling tropical cyclones (TCs) are one of the most devastating weather phenomena in the nature. The devastations are mainly due to strong wind, heavy rainfall and associated storm surges. The prediction of heavy rainfall is one of the challenging tasks in the NWP model. In this study, seven-day simulation of a very severe land-falling Bay of Bengal cyclone 'Hudhud' during 2014 are investigated using Advanced Research core of Weather Research and Forecasting (ARW-WRF) model. For this purpose, the impact of six micro-physical parameterization schemes is investigated to evaluate the performance of the ARW-WRF model to predict the rainfall of the storm. The model initial condition and lateral boundary condition is derived from the ECMWF datasets. There are 62 vertical levels with higher resolution in boundary layer and upper levels and the pressure top of the model is taken up to 1 hPa. The model initial condition is improved with WRF-3DVAR data assimilation using PREPBUFR data sets. In this study the gravity wave drag option and surface sensible and latent heat flux options are also investigated. The model predicted track and intensity of the storms are compared with the India Meteorological Department (IMD) best-fit track. It is also found that the WRF model simulations are sensitive with data assimilation, model top up to 1 hPa, gravity wave drag option and surface sensible and latent heat flux options. Results indicate that the track, landfall and intensity of the storm is well simulated by the model with the micro-physical parameterization schemes. The model simulated accumulated rainfall and structure of rainfall is compared with TRMM rainfall and maximum reflectivity of the storm is also compared with Doppler Weather Radar (DWR) observations from Visakhapatnam. The magnitude of rainfall is usually over-predicted by the model near the core region of the storm. Comparisons with available radar reflectivity and TRMM rainfall indicates that the features of the cloud band and precipitation of the storm are well predicted by the model during the landfall time. The model simulated diabatic heating, surface fluxes (sensible heat and latent heat and moisture flux), horizontal eddy diffusivity of heat, divergence, surface exchange coefficient of heat and moisture are also evaluated.

Detecting the Permafrost Distribution with the help of Remote Sensing and GIS in the North-West Himalaya

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Abstract

Permafrost is neither a procedure nor an effect, it is a frozen state of the ground. When an area holds Mean Annual Air Temperature (MAAT) of 0°C or less continuously for two or more years it considered as Permafrost region. It covers 24% of the Northern Hemisphere land and is also found in a lesser extent in

Southern Hemisphere. It lies buried under rocks or boulders does not catch anybody's attention. However, the most alarming aspect of permafrost thawing is the fact that when permafrost melts, the trapped carbon is released into the atmosphere in the form of methane, a powerful greenhouse gas. This process has been already begun in some part of the world, including western Siberia, and it is expected to increase in earnest by the year 2020. Permafrost degradation has an impact on surface and subsurface hydrologic conditions, soil strength properties, and ecosystems. When permafrost melts, the land above it sinks or changes shape, and the shifting ground could potentially damage buildings and infrastructure such as roads, airports, and water and sewer pipes, it also causes landslides, slope collapse, and glacial lake outburst floods (GLOFs) and topples trees. Our objective is to find out the permafrost zones or the areas in the North-Western Himalayan region and factors leading to its rapid increase in its thawing. Our study area is known as "Cold Desert" during summer the temperature during the day remains above 0° and at night temperature reaches below -30 °C. Throughout winter the temperature remains below -40 °C most of the time. The rainfall in this region is as low as 10 cm annually due to the reason it lies in the rain shadow of the Himalayas. In the present work, we attempt to identify and map the potential permafrost zones in the North-West Himalaya by employing Land Surface Temperature (LST) and Normalized Differential Snow Index derived from remote sensing data. The results have been compared with the Permafrost Zonation Index (PZI) and the International Permafrost Association (IPA).

Dynamics of widespread atmospheric brown clouds over the Indo-Gangetic Plains

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Abstract

Indo-Gangetic Plains (IGP) is one of the prevalent hotspots of atmospheric brown clouds (ABCs), which also provides habitat for millions of human populations and various ecosystems. The degrading air quality via buildup of widespread pollution layer (i.e., ABCs) over the region is not only impacting the human health but have several other climatic implications. Being nearest to Himalayan (southern slope) region, the ABCs over the IGP have also great implications to Himalayan cryosphere through its radiative effects. The peculiar characteristics of ABCs and its location over the IGP warrant detailed study of its spatio-temporal occurrences and associated radiative properties over the region. A total of ~5750 days of aerosol-data from five Aerosol Robotic Network (AERONET) sites across the IGP is used to study the dynamics of ABCs occurrences and its spatio-temporal variability. An algorithm based on absorbing and scattering properties of aerosols are applied to define the ABCs days over the region.

The occurrences of ABCs are found to have strong seasonality and spatial differences across the IGP. The western most location shows relatively lower frequency of ABCs occurrences in winter season than those situated in eastern part. The pre-monsoon seasons are accompanied with maximum frequency of ABCs in western part than those in eastern. On the other hand, the minimum frequencies of ABCs have season-specific locations. The optical signatures show two dominants aerosol types contributing to ABCs i.e., soil dust and mixed absorbing aerosols mainly originated from urban-industrial-biomass burning activities. The climatological analyses of optical/microphysical properties of ABCs along with meteorological parameters are used to study the dynamics of ABCs over the region.

Study of Himalayan cryosphere elements for understanding the dynamics of Chipa glacier using remote sensing technology

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Abstract

Remote Sensing technology has opened the new dimensions of analysis of dynamics of physical processes that were earlier only possible to be studied through ground survey. In context of Indian Himalayan Region (IHR) which is known for its undulating topography, accessibility issues and changing landforms were left mostly untouched to analyze the key factors driving the change. Though the importance of ground survey cannot be denied completely to better understand the sub surface phenomenon, yet the scientific application of remote sensing has made it quite possible to relate and understand these using the temporal analysis of the surface features.

The effect of climatic parameters and other physical processes drives the glacier landforms and its cryospheric elements. To better study these cryospheric elements, remote sensing technology has been used on a benchmark glacier "Chipa" located in the district of Pithoragarh, Uttarakhand state in India. The best possible freely available temporal datasets (Sentinal2B) ranging from the satellite imagery and digital elevation model (DEM) has been used to analyze and understand the dynamics of Chipa glacier over a period of time. The snow episode during 2018 was analyzed in detail using bi- spectral NDSI technique. It was found that on 27 Jan, 2018 snow cover was maximum of accumulation period and it was minimum on 24 October, 2018 during end of ablation period. Determination of snow line has been accomplished by using number of spatial data monitoring and it was found that snow line lies at an elevation of 3990 m in 2018.

Glacier Health Assessment in Upper Alaknanda-Saraswati Basin Using Remote Sensing

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Abstract

Climate change is currently on the top of the different discussions which are going among various policy makers and scientific community. "*Take urgent action to combat climate change and its impacts*" is one of the sustainable development goals. So there is a need of scientific assessment of the climate change. Glaciers are sensitive to climate change. Their health assessment can contribute in understanding climate change. Glaciers are very important for the survival of human, animal and plant community on the earth.

They have a direct and indirect contribution in the existence of life on the blue planet. They regulate the heat budget of the earth and also worked as natural resources. Many studies have been carried out to understand the glaciers sensitivity to ongoing changes in temperature and precipitation, but confined to the limited geographical extent. Presented work has been done by keeping this in the mind. Himalaya is a home of a large number of glaciers. The Study of these glaciers in the field is a very tough task. Many glaciers are very big and it is impossible to study them manually in the field. A large number of glaciers are inaccessible because of difficult terrain. Remote sensing has proved a valuable tool for glacier studies. In this work the health assessment of the glaciers of Upper Alaknanda-Saraswati basin has been done with the help of remote sensing techniques. The change in the glaciers has been investigated. Glacier retreat has been calculated over the period of 22 years from 1994 to 2016. The work is based on the remote sensing data. The satellite images from LANDSAT TM, LANDSAT ETM and LANDSAT OLI have been used. All the required pre- processing of images was completed before using them for further investigations. The glaciers are manually digitized on the base satellite image of 1994 and then glaciers boundary were shifted accordingly on the satellite image of 2016. Some other digital methods like NDSI and Band-Ratio has been used with the manual digitization. The satellite images of ablation period with the less cloud cover were used. Shadow and the clouds were the challenges in the demarcation of the glacier boundary. The debris covered glaciers were mapped very carefully. It has been tried to establish a relation with the temperature change and the glacier change.

Sources, aerosols chemical composition, and their radiative effects over Hindu Kush–Himalayan (HKH) region

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Abstract

We present an analysis of aerosol transport simulations carried out in Laboratoire de Me´te´orologie Dynamique (LMD-ZT) General Circulation Model (GCM) over Hindu Kush–Himalayan (HKH) region. Spatial distribution of winter season (December to February) mean aerosol optical depth (AOD) simulated in the model showed spatial gradient with the highest value (0.08-0.12) being near the foothills adjoining the Indo-Gangetic plain (IGP) and the lowest (0.03-0.04) being over east to 85°E and north to 22°N. Seasonal mean GCM estimated AOD (0.06-0.14) mirrored well the measured AOD (0.05- 0.08). The pre-monsoon mean value of AOD was estimated to be slightly higher (20%) than that of the winter mean. About 75% of the simulated AOD was from anthropogenic emissions and was mostly constituted of sulphate (45-65%), followed by organic carbon (40-50%), and black carbon, BC (4-8%). One of the striking features was the distinct spatial gradient in distribution of sulphate and BC aerosols thereby indicating their origin from different source regions, possibly far-off region for sulphate and that from neighboring IGP for BC. A large gradient was also seen in the spatial distribution of aerosol single scattering albedo (SSA) between HKH region (0.94-0.98) and the neighboring region of IGP (0.8-0.94). GCM estimates of seasonal mean SSA (0.92-0.96) agreed relatively well with that obtained from observations (0.88-0.96) at sites over HKH region. The lowest value of SSA over HKH region was inferred due to emissions from biomass combustion; it was also found to be relatively lower due to aerosol

emissions originating in Africa/west Asia (0.92-0.96), and India (0.94- 0.98) than that due to rest of the world (greater than 0.98). Aerosol all-sky radiative effects were found to be positive at the top-of-atmosphere (TOA) indicating the net warming effect. Notably, the value of TOA aerosol radiative effects during pre- monsoon was about 4-6 times the value during winter season. A strong influence of transport from far-off regions which contributed as high as 60% of the total positive radiative effects was inferred. The relative percentage of snow albedo reduction and annual increase in surface runoff due to BC deposition were the highest over the region confined between 27°N-29°N and 78°E-82°E with their values being respectively 13-15% and 5-7 inches of water equivalent. The radiative transfer calculations is further used as input to hydrological model and sensitivity studies of surface run off to aerosol deposition and melt rates of the frozen water storage to deposition is carried out and validated with available observational data.

Significant precursory signatures in different Geophysical parameters related to Mw 7.8 Gorkha Nepal earthquake of 25 April 2015

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Abstract

In 2015, Mw 7.8 Gorkha earthquake occurred in the Nepal Himalaya. It is an extreme seismic event of Himalaya after 65 years, earlier in 1950 Assam, the biggest earthquake (M 8.7) of the India-Eurasia collision occurred in the eastern part of Himalaya. Detailed analysis of continuous geophysical time series at the time of occurrence of strong and larger magnitude earthquake enhances our understanding about earthquake precursory research. In 2007, Wadia Institute of Himalayan Geology installed State-of-the-Art, Multi Parametric Geophysical Observatory (MPGO) at Ghuttu in the Garhwal Himalaya to collect different geophysical time series variation continuously. The observatory is to the west of the epicenter of Gorkha earthquake at ~ 635 km. A careful scrutiny of the radon, gravity and sub-surface temperature changes for the period of over 10 years including pre- and post-data suggests significant precursory signatures before the occurrence of Gorkha earthquake. A cycle of radon concentration decrease (started ~57 days before in soil and ~52 days in underground water) followed by increase (~12 days before in soil and ~10 days in underground water) is noticed at MPGO. This change is simultaneously observed in soil and groundwater radon data for a sufficient time which is the only one occasion in a long continuous time series of the Himalayan region. Significant anomalous changes in the pre-, co- and post-seismic period are also observed in the gravity measured through superconducting gravimeter, the first equipment of the Indian continent installed at this site in 2007. Additive to this, the underground temperature record at 10 m depth has anomalous changes coinciding with the radon change. Also the radon data collected within soil at 10 m depth shows high concentration before the earthquake occurrence for over one year period. Post-earthquake, the soil radon concentration is low indicating the release of stress due to occurrence of this large earthquake. These anomalous changes are significant and unique features in different continuous time series. Simultaneous anomalous changes in geophysical field are likely to be precursory signatures identified at regional distance.

Nearly 50 years ago, in 1966, at the time of occurrence of Tashkent earthquake, the precursory behaviour of inert radon gas was perceived. It began the era of radon gas monitoring around the globe as one of the earthquake precursory tools. Another most cited example of precursor as anomalous changes in radon is the Kobe earthquake of 1975. Since then the unusual changes in the radon concentration has been monitored and many times reported as earthquake precursor. Now, observations of radon in the underground water and soil is extensively utilized at different places for earthquake precursory research. In this regard, a physical mechanism of earthquake generation and occurrence is considered which can justify the temporal alteration in different geophysical data at particular recording site close to epicentre. The lithosphere rocks are subjected to various degrees of stress during phases of earthquake preparatory cycle resulting changes in physical/chemical properties close to earthquake focus. These expectations are due to opening of minor cracks, in-flux of fluids and material strengthening prior to the occurrence of strong earthquake. In this analysis of present data set, the dilatancy diffusion phenomenon is mainly utilized which suggests development of strain and its change surrounding to the hypocentre zone of the Gorkha earthquake. Anomalous changes in the radon time series has also been reported in the Himalaya during the time of occurrence of strong and moderate magnitude earthquake at local epicenter distance. The phenomenon is also proved convincing aspect of earthquake precursory search for other physical parameters recorded simultaneously at this site. A high quality present data is a step forward to understand the earthquake precursory studies.

A study of Collapse Potential on soils collected from Mandi region

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Abstract

The triggering mechanisms of the natural slope failures are governed by a complex interaction between hydrological and geotechnical processes, it depends on irregular topography, hydro-geotechnical properties such as permeability, initial state conditions of the slope. Most of these slope failures are mainly occurred due to a decrease in effective stress with the loss of matric suction caused by rainfall infiltration resulted in a decrease in volume, settlement due to wetting or loading conditions. Collapse is a process of reduction in the natural soil deposits on inundation, no change in applied stress. Collapse is primarily due to loss of soil suction upon wetting. Oedometer tests have been conducted for studying collapse potential of soils collected from Kamand to Mandi region. It has been observed that, the collapse increases with the increase in inundation stress and decreases with increasing in percentage of fines content.

Variability and trends in Karakoram climate till year 2100

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Abstract

Karakoram Himalaya, the highest mountain region in the world possesses a complex topography which makes it difficult to understand the climate dynamics in the region very precisely. Predicting the evolution of climate especially precipitation in upcoming decades for policy making is even more difficult. However, few modelling centers in the world are putting in great efforts to simulate the global climate accurately and projecting future climate under various warming scenarios, i.e. Representative Concentration Pathways (RCPs). Since each Global Climate Model (GCM) is based on a different forcing, it becomes imperative to test the suitability of GCMs in simulating temperature and precipitation conditions precisely for area of interest. This study aims to compare GCM outputs with field observed data (SASE Observatories) and selection of appropriate models and then projecting future precipitation trends till year 2100 as simulated by selected GCMs. Future precipitation projections will be based on extreme warming scenario, i.e. RCP 8.5. For suitability analysis, historical data (1985-2005) of Mean temperature and Precipitation of 15 models viz. BCC-CSM 1.1 m, CMCC-CM, CCSM4, CNRM-CM5, GISS-E2H, GISS-E2H-CC, GISSE2R, MIROC5, MPI-LR, CESM1-BGC, CESM1-CAM5, MIROC 4h, MRI-CGCM3, CMCC-CMS and MRI-ESM1 were compared with field observed data. Selection of good models was based upon statistical measures like Bias, Mean Absolute error etc. Every model provides futuristic values of climatic parameters from year 2006 till year 2100. The future projections (RCP 8.5) of selected models were then averaged to create a multi-model ensemble (MME) mean. The analysis was conducted at various temporal scales i.e., Monthly, Annual and seasonal. Results indicate that for temperature, models which best simulate temperature are: BCC-CSM-1.1m, CMCC-CM, MPI-LR, MIROC5 and CMCC-CMS. For precipitation, best performing models are: MIROC5, CESM1-BGC, CNRM-CM5, CCSM4, MIROC-4h and CMCC-CMS. Long term (2020-2100) temperature trends as projected by MME of selected models indicate significant warming (~0.06 °C per annum; approx. 6 °C rise in temperature as compared to present normal value) in annual mean temperature and consequent rise in annual precipitation. Results also indicates that maximum rise in precipitation is projected for late winter and spring season. This is coherent with projected rise in temperature during late April till July. This increase in liquid precipitation could adversely affect the cryosphere of the region by altering albedo values. Hence more deliberation in this regard is need of the hour.

Micromorphology and clay mineralogy of the early Oligocene fossil soils from Himalaya: implications for origin and intensification of monsoonal conditions over the Indian sub-continent

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Abstract

The Himalayas have major impact on Asian monsoon system as well as on global and regional climate. The origin of the Asian monsoon system and the tectonic evolution of the Himalayan mountain belt make Himalayan foreland basin an ideal platform to study interactions between tectonics, climate and erosion. In the present study we report macro-morphology and clay mineralogy of the oldest fossil soils (~31Ma) from Dharamshala group of the Himalayan Foreland. The paleosols within the fluvial sequences exposed along the JoginderNagar to Dharampur section, NW Himalaya show red and yellow paleosols with varying degree of development. Despite burial diagenesis (~ 7.5 km), evidences for paleopedogenesisare still well-preserved in these paleosols in the form of structural elements, clay coating, rhizocretions, mottles, bioturbation, Fe-Mn concretions and pedogenic carbonates. The paleosols are categorized into four types (type A to D) pedofacies. Thin section analysis showed 50-60% paleopedo features are preserved as microstructures, b-fabric, pedogenic carbonate, bioturbation and clay coatings. Clay mineralogy of the total clay (<2 μm) and fine clay (<0.2 μm) for these paleosols show strong and sharp 14 Å, 7 Å, 10 Å, 3.5 Å, 3.3 Å minerals along with interstratification and alteration of 14 Å and 10 Å minerals. Some of the horizons show alteration of 14 A° to 12 A° as hydroxyl interlayering of vermiculite (HIV) present in total clay fraction. The paleopedological characteristic of the paleosols and clay minerals provide evidence of monsoonal conditions during early Oligocene. Similar observations recorded in paleosols form adjacent parts of the Himalayan foreland are consistent with regional and global paleoclimate conditions during Paleogene.

Impact of Climate Change on the Glacier-Fed and Non-Glacier Fed Ecosystems of the Indian Himalayan Region: a Study of People's Perception and Adaptive Strategies

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Abstract

The Himalayan ecosystems are assumed to be undergoing a variety of changes in terms of its environmental, social and cultural scenario. Rising temperatures are expected to have greater impact from high mountains to downstream in terms of melting of glacier / snow and dramatic change in seasonal surface run-off. Climate change impacts have its inference on agriculture, natural ecosystem, water quality& its demand, existing developmental interventions in the form of hydropower projects, land use components and livelihood options. There is widespread feeling that summer and winter seasons is getting warmer, water sources are drying up, the onset and length of summer and monsoon season has increased during last 20 years and snow fed areas turned into rain fed and less snowfall occurs on the mountains than before. However, the impact of climate change on biodiversity included early fruiting and flowering, new agricultural pests and weeds and appearance of mosquitoes. Not only this, it's also affecting the livelihood options of the local community. As mountains are the early indicators of climate change. Thus, understanding of climate change from peoples' perspective can be an asset that can allow policy makers to design mitigation and adaptation strategies to combat climate change impacts.

A case study on application of GIS based Analytical Hierarchy Process (AHP) for landslide hazard zonation in urban agglomerations of Gangtok, the capital city of Sikkim

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Abstract

Himalayan cities are particularly hazardous to disaster and extreme events. Rapid increase in population and growing concentration of capital in urban areas has escalated both severity and long term impact of natural disaster. Current city development master plans focus mostly on the demand and supply side of infrastructure and not about its inherent hazard, risk, resilience and coping capacity of the resident population. Gangtok, the capital of Sikkim located in the North-Eastern part of India has total area of

approximately 35 square kilometres and it lies in seismic zone-IV. Unplanned urbanization and rapid construction in hill slope has aggravated its disaster proneness and increased the risk of multi hazards like landslide, earthquake and flash floods. Hazard zonation being the first logical step towards evaluation of risk and proposal for resilience, a fine resolution hazard zonation map is an important pre requisite. There are a good number of multi-criteria based hazard zonation techniques presently being used by researchers world-wide. Present study attempts to demonstrate the applicability and strength of GIS based Analytical Hierarchy Process (AHP) with criteria such as Land-use/ Land cover, slope and Aspect for generation of high resolution Landslide Hazard Zonation maps of Gangtok city. This Landslide Hazard Zonation map is expected to be useful for calculating risk assessment and also making disaster mitigation plans to reduce and mitigate the Landslide risk for Gangtok city. This study focuses to mapping at 1:4000 scale using high resolution Worldview-3 satellite imagery for developing site-level disaster hazard map.

Investigation of aerosol size distribution, aerosol concentration and optical properties at the high altitude stations in the North-Eastern Himalayan region of India

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Abstract

In order to study the aerosol physical and optical properties along the sub-Himalayan region of northeastern India. A land campaign was conducted from 1st February to 20th February 2018. Measurements have been taken in three different stations in Arunachal Pradesh [Tawang (2990 m a.s.l), New Palin (1300 m a.s.l.), and Geku (200 m a.s.l.). Techniques of Ångström exponent's curvature effect has been used to decrement the aerosol size distribution over the stations. The mean BC concentration was 3.98±1.03 μg m^{-3}, 4.27±1.22 μg m^{-3} and 2.38±1.05 μg m^{-3} at Tawang, New Palin, and Geku, respectively. The daily mean absorption coefficient at 370 nm (σ_{370}) is (1.46±0.56) ×10^{-4}, (1.84±0.42) ×10^{-4}, and (1.85±1.8) ×10^{-4} at Tawang, New Palin, and Geku, respectively. Whereas daily mean absorption coefficient at 880 nm (σ_{880}) is (0.33±0.08) ×10^{-4}, (0.42±0.05) ×10^{-4}, and (0.2±0.17) ×10^{-4}. The σ_{370} is 126%, 125%, and 164% higher than the absorption at the longer wavelength (880 nm) which indicates a higher biomass burning BC. The average Absorption Ångström Exponent (AAE) at 370-880 nm were 1.59±0.23, 1.63±0.23 and 2.28±0.57 at Tawang, New Palin, and Geku. In addition, at Tawang, New Palin, and Geku, the average AAE in the shorter spectral range (370-520 nm) were 2.43±0.97, 2.41±1.22 and 3.09±1.54, whereas in longer spectral range (520-880 nm) were 1.05±0.05, 1.13±0.18 and 1.44±0.33, respectively.

Spatially Distributed Ice Thickness Modelling using Satellite Remote Sensing Inputs: A Study on Glaciers of Teesta River Basin, Eastern Indian Himalayas

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Abstract

Glacier ice-thickness distribution, glacier volume and bed topography profile are essential prerequisites to address various glacial-hydrological problems. However, across the Indian Himalayan Region (IHR), only fewer glaciers have ice-thickness information based on field measurements. Notably, in Eastern Indian Himalayas (EIH) there are no proper reports available on field measured ice-thickness or spatially distributed high-resolution glacier ice thickness information. To overcome this gap, in this study a method has been proposed for ice thickness modelling which uses Lamellar ice flow model. The method is an improved version, wherein a calibration module is incorporated to obtain optimal parameterisation, which does not require any field ice thickness estimates to calibrate the model parameters. The method requires only the glacier surface velocity, surface topography and glacier outline as input data. A validation of the modelled ice thickness with field observations in East Rathong glacier show 12% error in simulations and found that the model results are better than the estimates obtained in other studies reported in literature. At the same time, it is significant to state that the Ground Penetrating RADAR (GPR) based field measurements used in this study, which was carried out during 2016-2017 is the first successful attempt to measure glacier ice thickness in the EIH region. The validated model is then successfully implemented on other 16 glaciers (>5 km^3) in the Teesta basin to map their bottom topography and to estimate their glacier stored ice volume. The simulation results revealed that the 17 glaciers combinedly hold 22.15 ± 3.32 km^3 of ice volume.

Improvements in the model results obtained due to the optimization module and the successful application of the model on other 16 glaciers indicate its reliability and potential and for estimating spatially distributed ice thickness in other data sparse glaciers across the Himalayas.

Recent Seismotectonics and Coulomb Stress changes observation for North East Indian region

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Abstract

The main goal of this work is to compute the probability occurrence of future large earthquakes in the Northeastern region of India. For this purpose, we have adopted the methodology based on the rate-and-state friction law for forecasting the seismicity rate changes for $M_W \geq 5.0$ during the period 20013-2018 by utilizing the homogenous earthquake catalogue ($M_W \geq 4.0$), covering the period 1976-2008.In this model, the principle component is the coulomb stress changes (ΔCFF) associated with the earthquake ruptured from the receiver's fault. The reason behind considering the coulomb stress changes lies on the fact that the seismicity rate increases where the stress increase and decreases. Here, we observed that high ΔCFF values that are found widespread along the Indo-Burman range. Moreover, highest b-value is observed near or to the Indo-Burman range (zone 7, 8) and the adjoining regions of Sikkim Himalaya (zone-1) with average value equal to 0.93. However, the highest background seismicity rate is also obtained in the zone 1, 7 and 8 with values ranging from 0 to 4.0. Finally, we have considered the consecutive fault parameter (Aσ=0.05 MPa) for computing the forecast model with variable ΔCFF and heterogeneous b-value. So, the combination of this coulomb stress changes with other constituent parameters (b-value, background seismicity rate, ΔCFF, stressing rate, aftershock duration), this model captures the forecast seismicity rate during the period 2013-2018.Then, the statistical test known as (Statistical-Test) have been explored to check the consistency between the spatial distributions of observed earthquakes and forecast seismicity rates. The result from the observed log-likelihood and the simulated log-likelihood confirms that the distribution of observed earthquakes matches well with the forecast seismicity rates, thereby showing the reliability and skillfulness of our model.

The response of Himalayan glaciers to climate variability and climatic change

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Abstract

The Karakoram and the Himalayan mountain range accommodate a large number of glaciers and are the major source of several perennial rivers downstream. A glacier parameterisation scheme is dynamically coupled to a regional climate model and applied over the South Asian Himalayan

mountain range. The glacier scheme interactively simulates the mass balance as well as changes in the areal extent of glaciers on a sub-grid scale. The simulated spatial patterns of glacier area change show a remarkable decrease but do show some regions of increase especially over the Karakoram (western Himalaya), a region for which available observations-based estimates also indicate a positive mass balance anomaly. Our results suggest that observed glacier changes could be approximately reproduced within a regional climate model based on simplified concepts of glacier-climate interaction. This, in turn, underlines the general applicability of the model system for scenarios of 21st century climate and glacier change.

A Low-Powered Earthquake Monitoring and Warning System

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Abstract

Earthquakes cause massive damages to life and property world over. In an earthquake, the primary (P) waves travel twice as fast as the damaging secondary (S) waves. Thus, detecting P-waves could give people a few seconds to take cover before the damaging S-waves arrive. To sense P-waves and record earthquake activity, there exist several very accurate seismic monitoring systems; however, these systems are costly. In this project, we have developed a low-cost earthquake monitoring and warning system (EMWS) of reasonable accuracy, which could detect P-waves, timely warn people and log earthquake activity for the duration of an earthquake event. The EMWS uses a single-axis vertical 4.5 Hz geophone sensor as well as a triaxial accelerometer and a gyroscope sensor. These sensors are connected to a microcontroller and a Wi-Fi module for enabling local and remote data logging of earthquake waves. The microcontroller is connected to a hooter and light for intimating people about P-waves in the vicinity of the system. In addition, the system is capable of alerting people located at a distance via SMSes in case of a P-wave event. The EMWS is ultra-low powered. While awake, the system consumes 150-200 mA current; whereas, when in sleep, it consumes only 600 uA current. Thus, the EMWS could run on a pocket-sized low-cost rechargeable 1500 mAh battery for months. We have evaluated the EMWS for detecting waves with frequency between 0 Hz and 20 Hz (the typical frequency range of a P-wave) and the system is successful in detecting this frequency range. We highlight the implications of using the low-powered EMWS for sensing P-waves and discuss our future work on improving this system.

Climate change and glacier mass thinning in the western Himalaya: A prospective challenge

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Abstract

Glaciers are widely known as one of the best indicators of climate change over recent centuries and these glaciers are melting across the globe, including Himalaya. Himalaya is abode of densely distributed snow and ice covered region and estimated total glaciers area and volume of Himalaya are approximately 38000 km2 and 3000 km3 respectively. Climate change has potentially control on glaciers mass loss and retreats in the Himalaya and having vital impact on hydrology of that region. For the past two decades, the process of glacier retreat has been enhanced and also projected to continue with higher magnitude in the Himalayan, raising alarm among regional water resources managers and poses a challenge for reducing the vulnerability for more than 1.3 billion people living in the major river basins downstream. There are many key questions which are either unanswered or has poor understanding due to lack of in-situ data and long term records of Himalayan glaciers. The uniqueness and complex environmental settings of Himalayan region is also one of the causes to poor data set. Considering above, to answer some of the key questions including to get the comprehensive knowledge of local, regional and global climate impact on Himalayan glaciers behaviors and their interrelationship, NCAOR has initiated a long term integrated glaciological monitoring program on Chandra basin, Himachal Pradesh since 2013. Based on various data an average mass loss for Western Himalaya has been estimated between -0.5 m we to -0.7 m we during last two decades and revealed a significant increment (10-60%) in glacier mass losses. As per the projection, Himalayan glacier may lose 60-90% of their mass by 21st century due to changing climate (snow fall reduction, increase in wet precipitation, high ELA, temperature increase, longer melt season, etc) including anthropogenic impact. Increase in mean Equilibrium Line Altitude (ELA >200m) during last two decades has a potential impact to increase mass loss by changing Accumulation Area Ratio (AAR) of majority of glaciers and also imposed critical threats for disappearing of many lower elevation glaciers. Although solar radiation is the main climatic parameter that critically controls glacier surface mass loss but precipitation seasonality has also potential influence the mass balance. A warming test (+1K) reveals higher sensitivities of mass balance for summer accumulation than winter accumulation. However, the rate of retreat of individual glaciers is highly dependent on glacier characteristics and topographical location. In consequences of high mass loss from glaciers, numerous new lakes have formed and show significant increase (2 -3 times) in number as well as in area of lakes in Himalaya during last two decades and increase the threats of GLOFs in Himalayan regions. In addition, "Dark snow" layer over glaciers due to various anthropogenic activities alter the albedo by significant dimming of the brightness of the snow, leading to higher melt and also longer melt season. A minor decrease in the brightness of the snow and ice can double the average rate of ice loss. The glaciers mass change has hit the humans and the environment of Himalaya the hardest and effects fresh water supply, electricity, agriculture practices, flooding, frequency of flash flooding, local weather and climate, biodiversity of flora and fauna etc. Changing of ice-melt inputs to mountain rivers are changing their physicochemical characteristics and, in turn, aquatic communities. Glacier-fed rivers serve as model systems for investigations of climate-change effects on ecosystems because of their strong atmospheric-cryospheric links. Thus the loosing mass of glaciers will badly affect humans and slowly it will lead to destruction of mankind if it is not taken care of.

Productive Utilization of Hazardous Dry Pine Needle Biomass for Social Benefits

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Abstract

Making efficient utilization and proper disposal of forest and agro-residue as biomass is today's era most starving need as it caveats a major problem to the environment, forest-biodiversity and the economy in the entire hilly region all across the world due to their large quantity and highly inflammable nature. In hilly regions, a surfeit of Pine Needles waste is a major issue, being non-biodegradable, even its transportation is also not so easy. In past few decades, the forest departments of hilly areas such as Himachal and Uttarakhand etc have tried various ways for collection and disposal of pine needles to avoid the forest fires. Despite such efforts bearing great social value, these have not yielded significant results as of now, but have surely highlighted the gravity of the situation and motivated numerous organizations (for-profit/not-for-profit) to look into the possibility to solve the problem. In the meantime, forest departments have taken a safer route of burning pine needles in a controlled manner far away from their origin. They spend Crores of rupees every year to address the first half of the challenge- to prevent forest fires, while the other half- to make something constructive from pine needles- remains unsolved. For instance, the Himachal Government allocated a budget of Rs 422 Crores in 2013-2016 to protect its forest from fires by cleaning/maintaining its 1000 km long fire line.

The process of briquetting is very common technique based on the principle of compression. There have been many briquetting attempts of various biomasses nationally as well as internationally but interestingly no standardization for dry pine needles and pine needles. However, the process of briquetting becomes difficult in case of dry pine needles due to the hassles involved in the collection of pine, storage problem as these are prone to catching fire, and also they require large space for storage. Also, the pine needle properties and its physical state make them difficult to bind or compress. The product resulting from the conventional process is neither of acceptable quality nor easy to make. Thus, it is important to maintain the appropriate moisture content of the pine needles so that which facilitates the binding of the pine needles. There is a high need for an efficient method of converting waste and loose biomass, particularly pine needles, into resourceful and compact bio-fuel for domestic and industrial utilization.

The article, in particular, provides an efficient method of converting waste and loose biomasses, particularly pine needles, into resourceful and compact bio-fuel for domestic and industrial utilization as well. The article relates to a method of preparation of the compact biomass briquette/pellet by briquette machine setup. Optically combining of chopped dry pine needle with agriculture residues and other biomasses was performed. Briquetting of organic waste material was performed by using compression technique. Briquetting of pine needle was performed under varies combination in the ratio (pine needle: other biomasses) of 1:4, 2:3, 3:2 and 4:1. Other biomasses used for the study were sawdust, sugar cane waste, walnut waste, rice husk, food waste etc. The experiment was also carried out under varies moisture content (5 to 20 %) to determine the optimal conditions. In another aspect of the article is to provide a solid-fuel product comprising 100% pine needle obtained from briquetting of said pine needle.

The diameter, length and bulk density of the pure pine needle briquettes are 33 mm, approx.70 mm and 1079 kg/m^3 respectively. Calorific value and ash content data indicate higher calorific value and low ash content as compared to other biomass briquettes. The calorific value and ash content of pure pine needle briquette is 5368 kcal/kg and 3.18% respectively. CHNSO data of briquettes indicated less sulphur content (approx. 0.1%) which makes this fuel eco-friendly and ideal fuel for the industry. TGA analysis and proximate analysis was also carried out to determine the moisture, volatile compounds, fixed carbon and heating time of the briquettes. The major greenhouses gases emitted by the burning of pine needle briquette are lesser than the greenhouse gases emitted by the burning of loose dry pine needle biomass. This property has a positive impact on climate change. The chemical and physical property of pine needle biomass briquette makes it an ideal fuel for industrial and domestic utilization.

Change Detection in Land Surface Temperature and Land Use Land Cover Over Shimla City, Himachal Pradesh, India

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Abstract

The geophysical parameter such as Land Surface Temperature (LST) plays important role in studies related to hydrological processes, climate change and Land Use/Land Cover (LULC) changes. The satellite data of Landsat 7 (ETM+), Landsat 5-TM and Landsat 8 (OLI) has been used for mapping of LULC and extracting LST for the years 2001, 2011 and 2016 respectively. Linear regression analysis was carried out to generate relationships between LST with Normalized Difference Vegetation index (NDVI) and Normalized Difference Built-up Index (NDBI). The LST for Landsat-7 (ETM+) of 18 October, 2001 ranged from minimum 12.10°C to maximum 36.05°C with a mean of 20.73° and Landsat-5 (TM) of 22 October, 2011 ranged from minimum 10.09°C to maximum 28.91°C with a mean of 18.45°C; whereas, for Landsat-8 (OLI), of 19 October. 2016, LST ranged from minimum 13.37°C to maximum 30.81°C with a mean of 20.05°C. The higher temperature was found in barren land and built-up areas; whereas, lower temperature was observed in water bodies and forests/vegetation land. The linear relationship detected a positive correlation between NDBI and LST with a correlation coefficient of $R^2 = 0.92$, $R^2 = 0.97$ and $R^2 = 0.97$ for 2001, 2011 and 2016 respectively. Also, negative correlation between NDVI and LST exists with a correlation coefficient of $R^2 = 0.94$, $R^2 = 0.93$ and $R^2 = 0.92$ for 2001, 2011 and 2016 respectively. The outcome of the study also indicates that the changes in LULC have a significant role in the Land Surface Temperatures.

Landslide susceptibility mapping for the hilly township of Mussoorie and its surroundings, Uttarakhand Himalaya

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Abstract

Landslide is a normal geomorphic process and common in the hilly region of Himalaya. These are caused by natural as well as anthropogenic factors. These become hazardous when they interfere with any development activity. Recently it has been noted that there is an increased developmental activity in the hilly townships, particularly in the hilly region located in the outer Lesser Himalaya. This results into greater number of landslides and related mass movement activities in the region. This demands that the large scale landslide hazard, risk and vulnerability assessment (HRVA) of the hilly townships be carried out. Therefore, in the present case, Mussoorie township and its surroundings covering an area of ~84 km^2 located in the Lesser Himalaya has been chosen for the study and Landslide Susceptibility Mapping (LSM) has been carried out.

There are many methods for the LSM, but in the present work bivariate statistical Yule Coefficient (YC) method has been chosen utilizing GIS and high resolution satellite imageries. Various possible causative factors of landslides in the study area include lithology, landuse-landcover (LULC), slope, aspect, curvature, elevation, road-cut drainage, and lineament and the YC calculate the binary association of landslide with all the causative factors. Landslide Occurrence Favourability Score (LOFS) for a particular class of the causal factor of landslide has been obtained, subsequently the weight of each factor of landslide has been calculated. Finally, Landslide Susceptible Index (LSI) has been generated in GIS platform. This has been reclassified into five zones using natural break criteria.

The results indicate that ~15% of the study area falls under very high to high landslide susceptible zone and ~29% in the moderate landslide susceptible zone and ~56% in low to very low landslide susceptible zone. The dominant part of the area falling under very high and high landslide susceptible zone lies in the settlement area viz. Bhataghat, George Everest, Kempty fall, Khattapani, Library road, Galogidhar, and Hathipaon and are covered by highly fractured Krol limestone exhibiting slope $>60^0$. The accuracy of this map was verified by using Success Rate Curve (SRC) and Predication Rate Curve (PRC) exhibiting the Area Under Curve (AUC) for SRC is 0.75 and for PRC is 0.70. This indicates that there is good correlation between different landslide susceptible zones and the occurrence of landslides.

Simulation of future evolution of glaciers in the Chandra basin, Western Indian Himalayas

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Abstract

In this study, a numerical flowline model has been used to simulate the past retreat and future evolution of glaciers in the Chandra basin. The glaciers that were chosen for this study are the Chhota Shigri glacier, the Bara Shigri glacier and the Samudra-tapu glacier. Before simulating retreat, the altitudinal profile of the surface mass balance was estimated for the three glaciers using Energy Balance Modelling (EBM). This mass balance profile and 134 years of temperature and precipitation records from a meteorological observatory are used to force the flowline model to simulate the past and future glacier length fluctuations. The simulated front positions were in good agreement with those observed. After a successful simulation of the past retreat, the model was also used to predict future evolution of the glaciers for the next 100 years under different climatic scenarios. These simulations indicate that the Chhota Shigri glacier may lose ~90% of its present volume by 2100 if the local temperature increases by 2.4 K, and for a temperature rise of 5.5 K, the glacier loses almost all its volume. In addition to future evolution, the time of formation of new pro-glacial lakes was also determined.

Vulnerability assessment of farming community of Kullu district to climate change

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Abstract

Agriculture sector is one of the most vulnerable sectors to the effects of climate change, owing to its sensitivity to extreme and sudden variations in temperature and precipitation. In Himachal Pradesh, around 71 per cent of 6.86 million people in the state are dependent on the agriculture sector as an income source and employment, thus exhibiting a heightened exposure and vulnerability to climate induced variations. Therefore, the study was conceptualized to assess the vulnerability of farming community to climate change. The study employed evidence from 210 households based on a questionnaire based survey conducted in five blocks (Kullu, Naggar, Anni, Banjar, and Nirmand) in District Kullu, to assess the vulnerability of target population for their exposure and sensitivity to current and historic climate risks. The study developed a vulnerability assessment framework which is a composite function of *adaptive capacity* and climate *sensitivity* under *exposure* to climate variability. Results indicated highest vulnerability of farmers of Nimand and Anni blocks to climate change due to low adaptive capacity, whereas, Naggar was least vulnerable block with low exposure and sensitivity while higher adaptive capacity.

Performance analysis of IMD rainfall gridded data and high-resolution satellite estimates for monitoring extreme events over Northwest Himalayas

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Abstract

A high resolution near real-time data is crucial for monitoring extreme events like cloudbursts over Northwest Himalayas (NWH). Towards this end, we evaluate the performance of Indian Meteorological Department (IMD) ground-based gridded rainfall observations of 0.25°x 0.25° resolution, and five high-resolution satellite estimates, namely, CMORPH, GPM, INSAT-3D, PERSIANN-CDR, and TRMM for seven cloudburst events that occurred during 2014-2016 over NWH. Using percentiles to represent extreme rainfall events, the result reveals the efficiency of satellite product decreases significantly from 95 to 99.99 percentile and is low in detecting cloudburst events. Particularly at 99.99 percentile, the following results are obtained: (1) IMD data captures the magnitude and spatial location of four events out of seven, whereas TRMM captures spatial location of three, and GPM and CMORPH do so even less. (2) The maximum rainfall amount captured by the satellite products is much below the threshold value, and each has a large bias with respect to the IMD data set, especially the data received from INSAT-3D and CMORPH. (3) The contingency statistics reveal the probability of detection (POD) of TRMM over time varies from$0-23\%$, followed by PERSIANN $0-12\%$ and GPM$0-6\%$. (4) The volumetric hit index shows that TRMM captures $0-40.3\%$ of the total volume of rainfall followed by PERSIANN $0-13.7\%$ and GPM$0-4\%$. (5) Using a new metric defined as adjusted POD, a significant improvement is seen in TRMM$(11.11-52.6\%)$, GPM$(0-15.8\%)$, and PERSIANN $(0-28.6\%)$ in detection of cloudburst events, while CMORPH and INSAT-3D perform very poorly.

Exploration of Microwave Data for Monitoring and Estimation of snow & Avalanches in NW-Himalaya

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Abstract

Remote sensing has proved its utility in various applications. For mapping, land- use classification, snow characterization and forest monitoring optical satellite and airborne images are used operationally. However, this is not the case with snow and avalanche monitoring. Currently only ground-based in situ, weather measurements and passive microwave data are used operationally for snow monitoring in India. Ground based measurements are conducted after long time course on snow fall seasons. These measurements are used for snow and avalanche research and prediction of avalanche prone regions which serves inputs to the prediction model that simulates and gives output. Recently optical images (NOAA AVHRR MODIS etc.) have been tested to derive a map of the areal extent of snow and avalanche effected areas. However, during the snow melt, which is the most crucial period for hydrology studies,

there are few cloudless days and, therefore, the availability of optical data is limited. That is why microwave remote sensing can play an important role in snow and avalanche monitoring due to its unique capability to provide data independent of sun light and in almost all weather conditions. The synthetic aperture radar (SAR) data may make a significant contribution to satellite observations of snow and avalanches studies by bridging the period between the on-set and end of snow melt. Microwave radiometers can be used to retrieve the snow water equivalent, snow depth of dry snow, but they cannot be used to distinguish wet snow and wet ground during the melting period. The results of the paper prove that, (1) wet snow can be distinguished from dry snow and bare ground, (2) snow-free areas can be identified, (3) seasonal evolution of snow cover and avalanche areas can be Monitored and (4) snow-depth maps showing the fraction of snow-free ground (wet ground) and snow (wet snow) can be derived from SAR images.

Reconstructing glacier fluctuations since the end of Little Ice Age (LIA) in the North-Western Himalaya: an overview and specific examples

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Abstract

The Himalaya comprises one of the largest glacier-covered areas outside the polar-regions. Several studies reported that Himalayan glaciers responded to the global cooling associated with the Little Ice Age (LIA), however, there is no realistic estimate to suggest how the recession occurred after the termination of this globally important climatic event with few exceptions. Besides, the pattern of deglaciation following the LIA is important towards understanding the role of natural verses anthropogenic contribution in glaciers response, considering significant debate pertaining to the rising global temperature and its likely impact on the mountain glaciers. Thus, the present study document, analyse and reconstruction the fluctuation of selected glacier (based on glacier location, size, geometry, characterise of debris cover and their geomorphology) located in the North-Western Himalaya since LIA maximum advance using multi-data integrative analysis (MDIA) includes historical records, repeated photographs, remote sensing data, geochronology and field observations including geomorphological evidence. Preliminary results show an advance in glacier terminus during the late 18th-early 19th century. After mid-19th century, general state of glacier retreat has been observed for the studied glaciers in this region with varying recession rate from one glacier to other. The advance of studied glaciers in the late 18th-early 19th century can be attributed to cold climate whereas recession trend from mid-19th century associated with rising temperature and reducing precipitation in the north-western Himalaya as same observed from reanalysis data and field data and same reported by previous studies based on filed based. Moreover, the varying retreat rate between glaciers can be attributed to the influences of topographical factors, individual glacier morphology and the nature of debris cover. Further analyses are under way by incorporating the glacier equilibrium line altitude (ELA) calculations, volume estimations and short to long term in-situ and geodetic glacier mass balance measurements to look into the overall response of climate and topography on the glacier dynamics in different climatic zone of this region and will be addressed.

Tracing back carbon aerosols: source characterization using long term observations of EC, eBC, OC and CO from ARIES, Nainital, a high altitude site in the Central Himalayas

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Abstract

Carbonaceous aerosols are important short term climate forcers, due to their direct effects on radiation budget and their indirect effect in altering cloud properties. Simultaneous measurements of OC, EC, eBC and CO have particular importance in terms of radiation budget, constraining emission sources and tropospheric chemistry, but such measurements are quite limited especially in the Himalayan region. In this reference, extensive real time simultaneous measurements of these species are carried in ARIES, Manora Peak (29.4°N, 79.5°E, 1958 m amsl). Analysis for the period 2014-2017 has been presented here. Seasonal, diurnal, day and night time variations of these species shall be discussed. Region of emissions and its seasonal variations is identified based on statistical analysis of five particle back air HYSPLIT trajectories. Site specific absorption coefficients for eBC are quantified. Combustion type identification (fossil fuel and biomass burning) and its quantification for both CO and eBC is done using spectral and statistical model. Effect of long range transport and effect of high and low fire activity period at the site is also assessed.

Dynamics of Bhagirath Kharak glacier, central Himalaya in relation to changing facies

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Abstract

Though the climate change is the prime driver of glacier changes, local surface conditions substantially influence the melt rates by altering the energy intake. Glaciers are characterized by several facies including fresh/wet-snow (FWS), firn, clean-ice, ice-mixed debris (IMD) and supraglacial debris (SGD). Each facie has different reflectance and water retention property and hence absorb/reflect different amount of solar radiation. For instance, SGD has the lowest albedo while the snow facies have the highest albedo. Present study aims to assess the impact of facies changes on the overall glacier response to climate change. For this, the Bhagirath Kharak glacier (34.12 ±1.94 km2 in 2015), central Himalaya has been selected, which is one of the source glaciers of the Alaknanda River. Along with the variability in glacier facies outlined above, multiple glacier parameters including length, area, surface ice velocity (SIV) and surface elevation change have been studied to comprehend the glacier health using time-series satellite

data acquired during 1990-2016. Results show that the glacier has retreated and deglaciated by 10.61 ±2.31 m/y and 1.36 ± 0.62%, respectively, during 1990-2016 with glacier wastage higher during 1990-2000 (retreat: 14.41 ±7.49 m/y; deglaciation: 1.10 ±0.76%) than2000-2016 (retreat: 6.82 ±3.46 m/y; deglaciation: 0.27 ±3.17%). The glacier has also thinned down significantly by−0.73 0.08 m/y between 2000 and 2015 with maximum lowering having occurred in the middle portion of the glacier leading to a slope inversion. This slope inversion coupled with other responsible factors such as less mass supply from upper reaches resulted in notable slowdown of glacier by 23.81% (0.92%/y) during the study period (1990-2016). The slowdown was also higher during 1990-2000 (1.42%/y) than 2000-2016 (0.70%/y). Systematic assessment of facies variability reveals that, concomitant with the glacier recession; remarkable changes in various facies have taken place during the study period (1994-2016). While FWS and firn have shrunk by 27.27%, and 39.25% respectively, extents of exposed ice and SGD have increased respectively by 27.79% and 17.99%. Interestingly, maximum expansion of 133.07% has been observed in IMD facie. On decadal scale, facies variations are consistent with the observed glacier changes. The maximum variation in glacier facies also occurred during 1994-2001 when the glacier wastage was higher. In subsequent decade (2000-2016), as the recession rate decreased, facies variations were also trivial. Overall the study reveals an active feedback process operates in the glacier, wherein, the glacier recession leads to changes in facies, which in turn trigger the melt process by augmenting solar intake. The results also reveal that the glacier is mainly loosing mass through down wasting, causing significant SIV reduction, which in turn coupled with extensive growth in SGD and IMD has led to glacier wastage.

Susceptible river reaches and sediment transport during an extreme hydrological event in the mountainous basin

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Abstract

The geological and metrological (i.e. climate change) mechanisms are normally associated with extreme hydrological events in the mountainous river basins e.g. heavy precipitation, cloud burst, GLOF, LLOF etc. An extreme hydrological event may have a lower frequency, yet, it carries out maximum geomorphic work, i.e. erosion, deposition, and transportation of sediments. Through large sediment flux and high discharge, escalated sediment transport rates are observed during these extreme hydrological events. The increased sediment flux and transport rates modify landscape by depositing sediments along the channels, affecting the human population and the riparian ecosystem. The global occurrence of such extreme hydrological events highlights the importance of developing a robust approach for predicting susceptible river reaches and understanding of sediment transport during such events in a mountainous basin.

In the present study, we used the Upper Ganga River basin (UGRB) (~ 19,000 km^2) as a test site to study extreme hydrological events between the year 2011 and 2014. To extract susceptible river reaches in the UGRB, we used river steepness of streams in the UGRB. Our results show that several riverreachs in the UGRB are susceptible during an extreme hydrological event. We present five river reaches in the Asiganga, Bhilangna, Mandakini, Garudganga and Alaknanda Rivers to show the relationship between river

steepness and sediment deposition. Further, to understand the sediment transport mechanism during an extreme hydrological event we choose two different river reaches in the in the UGRB i.e. Kedarnath and Srinagar valley. We used published literature, satellite imageries, field data, and geomorphological mapping to understand sediment transfer during an extreme hydrological event. Our results suggest that during an extreme hydrological event, both rivers reaches encoutred sediment deposition and erosion on a massive scale; which leads to the evolution of a sediment pulse in the river reaches.

Generally, the mountainous river basins have few monitoring stations observing discharge and sediment flux. Therefore, we suggest there is a need to study the susceptible reaches and sediment transport mechanism during extreme hydrological events in the mountainous river basins for better disaster management plans in the mountainous river basins.

Impact of aerosol–radiation interaction on climate in Indian Himalayas

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Abstract

In recent decade a tremendous progress has been made in characterization of aerosol properties. In spite of that, yet our understanding about aerosols and their potential impact on climate is limited, possibly due to large data gap and incompletely understood mechanisms. The main mechanisms by which aerosols affect weather and climate are aerosol- radiation interaction and aerosol-cloud interaction. Aerosols scatter or/ absorb a large fraction of incoming solar radiation this results loss in surface reaching solar radiation. The scattering and absorption of solar radiation are associated with cooling and heating within the aerosol layer, respectively thereby modifies the vertical thermal profile. Based on model results we found that the surface cooling effect of aerosol is strengthened with the increase in absorbing aerosol particles in the atmosphere in response to warming. Study confirm that the regional radiative perturbations are several Wm-2 due to changes in aerosol emissions particularly black carbon, which indicate that if the black carbon emission is checked out may lead to a sudden change in the normal pattern of warming/cooling. The global distribution pattern of aerosol clearly showed their region specific behavior. Observations and model capture some major all year-round aerosol hotspots, which found adjacent to major monsoon regions of the world. The HYSPLIT trajectory analysis showed that the air masses originate or/pass-through over western regions has played an important role in modifying incoming solar radiation and atmospheric thermal profile. Kanpur (26.51˚N, 80.23˚E; 123 m amsl) and Mohal (31.9˚N, 77.12˚E; 1154 m amsl) are important sites under aerosol measurement program in the foothills of Himalayas, which are providing data since long time. At Kanpur, during dust aerosol transport day the aerosol radiative forcing at surface change by-112.2 Wm-2, when compared with low aerosol loading day. This results a large reduction in the surface-reaching solar radiation by 207%. At Mohal, the transport of desert dust and anthropogenic aerosol during high aerosol loading days caused a significant reduction in surface-reaching solar radiation by 149 and 117%, respectively. These results indicate that the accumulation of transported aerosols along the elevated site of Himalayas have profound impact on incoming solar radiation, which may produce a remarkable effect on the regional atmospheric stability.

Strain budget of the Northwest Himalaya using GPS measurements

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Abstract

Himalayan belt has experienced six devastating earthquakes (1897 Shillong Plateau earthquake, 1905 Kangra earthquake, 1934 Bihar Nepal earthquakes, 1950 Assam earthquake, 2005 Kashmir earthquake and 2015 Gorkha Nepal earthquake) in past one century. Among them, Northwest Himalaya has experienced one major to great earthquake of 1905 Kangra (~Mw7.8) and 2005 Kashmir earthquakes (Mw7.6) was an out-of-thrust earthquake and not occurred on detachment. Past studies suggest that the potential of future major to great earthquake in NW Himalaya is quite high. Here, we have analysed continuous Global Positioning System (GPS) data, having time span at least 3 years, from 38 (10- Kashmir Himalaya and 28-Garhwal Kumaun Himalaya) newly installed sites in the Northwest Himalaya to assess the seismic hazard of the region. We estimate the secular rate after removal of seasonal variation in the displacement time series using the periodic function. The site velocity is used in the estimation of the plate convergence rate in the NW Himalaya based on elastic dislocation theory. The grid search approach provides an oblique plate convergence rate of 13.6 ± 1 mm/yr towards N198°E and locking width of 175 ± 20 km in the frontal part of Kashmir Himalaya. The rate of plate convergence in the Garhwal Kumaun Himalaya is 18 ± 0.7 mm/yr towards N213°E and width of locking is 100 ± 15 km. A weighted least square inversion approach used to estimate the slip deficit rate along the ramp-shaped plate interface in the Garhwal Kumaun Himalaya. A high rate of strain accumulation, which has continued from several centuries on strongly coupled MHT, makes this one of the most earthquake-vulnerable segments of the Himalayan arc.

Mass and energy balance of Naradu Glacier, Western Himalaya, India

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Abstract

The observations of glacier mass balance provide the direct response against changing climate and helps in understanding the climate system. The present work is a result of seven years of annual mass balance carried out using in-situ glaciological mass balance method for Naradu glacier, western Himalaya. In addition, the energy balance model based approach was also used to deduce the glacier mass balance of the Naradu glacier. The comparison of mass and energy balance approach helped in understanding the robustness of the energy balance model. The glacier response is continuous negative mass balance during the year 2011 to 2017. The results were compared with the energy balance approach for five years which also gave the similar kind of trend with significantly closer values of mass balance.

Temporal scaling of GPS measured differential Total Electron Content (DTEC) with precursor day windows of Major earthquakes

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Abstract

Changes in Ionospheric Total Electron Content (TEC) associated with Great Magnitude earthquakes had observed in the past through ground based Ionosonde as well as space based GPS measurements. Recently, Global Navigational Satellite Systems (GNSS) based continues observation on ionosphere TEC revealed how this parameter changes during the inter- seismic, co- and post seismic phases of a Great Magnitude earthquake (eg., 2011, Mw 9.0 Tohoku-Oki earthquake). In this work we attempted to scale the GPS measured differential TEC anomalies with time in terms of number of pre- and post- seismic days from the co-seismic day of Major Magnitude earthquakes occurred at Mexico, Japan and Nepal during the period 2014 to 2017. Major Magnitude earthquakes occurred in the Mexico and Japan regions were in the oceanic regime while the 2015 Gorkha-Nepal earthquake was along the Nepal Himalaya continent-continent convergence zone. Sixty days of continues GPS data from these three networks have been acquired; such that for the case of each earthquake, minimum thirty days of prior and post event data window has been maintained to get the continuity of TEC anomalies. Data from multiple stations (Mexico event: 20 stations, Japan event: 7 IGS stations and for the Nepal event 6 stations) distributed at various radial distances ranging from 50 to 1000 km from the respective epicenters were considered. For the case of Nepal network, the selected six stations are very close and less than 200 km from the epicenter of the Gorkha-Nepal event.

The propagation of GPS signals L1 (1575.42 MHz) and L2 (1227.6 MHz) through ionosphere cause group delay and phase advances as ionosphere is a dispersive medium. The delay and phase advancement of the signal depend upon the integrated columnar electron density or TEC which has been obtained by considering a spherical shell model ionosphere. We estimated the integrated TEC or Slant TEC (STEC) variations along the satellite-receiver path on the basis of TEC phase measurements from L1 and L2 carrier signals and then calculated the mean TEC of all receiver-satellite pairs. The observed mean TEC values are compared with the data of available Geomagnetic Indices like 'Kp' and 'DST' to identify Geomagnetic Storm days and weighed out their effects while computing the differential TEC. The differential TEC is the difference of daily TEC with the day average TEC computed for every hour for a span of total 60 days.

Results on the radial distribution of differential TEC from the respective epicentres of Major earthquakes occurred from 2014 to 2017 in the aforementioned networks have been analysed with the number of days prior and post to the main event. We got clustered distribution of positive and negative differential anomalies at specific day windows before the Major Magnitude Main event irrespective of the geographic locations of the networks. We modelled one such positive cluster or the first order positive differential TEC anomaly and obtained a parabolic relation with number of days prior to the Mexico, Japan and the Nepal main events. Scaling relationships show that the saddle point or the low amplitude in the differential TEC of the positive cluster was formed 5.1 and 6.3 days before the main Mexico and Japan events. Interestingly, isolated sharp clusters of negative deviation of differential TEC from the mean TEC are also observed within day windows of 8- 10 days, 16-18 days and 26-28 days for the case of Mexico, while the same is 4-

6 days and 8-10 days for the case of Japan events. Similarly, the 2015 Nepal event also show clustering of negative differential TEC on day windows of 8-9 days, 13-18 days and 23-30 days, although the region had witnessed only a single Major main event on 25 April 2015. Nevertheless, in all these cases 8-10-day window is found to be common. This work although addresses the TEC variation and its scaling using global Major earthquakes; but explains a methodology to quantify and temporally scale differential TEC with days prior to any future such events that may occur in the Himalayan plate convergence zone.

Study of uncertainty impact on Himalayan region in context with climate change

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Abstract

Global climate change is one of the major concerns of the today's world. This situation seems to be a crisis, where the uncertainties of predicted global change scenarios combine with the risk and adverse nature. In order to resolve the problem of certainty, components in the complex of uncertainties that characterize the whole problem. This paper argues that such certainty components can be projected by altering the current skewed perspectives on the problem. Recent conceptual work on "cumulative change," against with "systemic change," which properly understand the global environmental change. In the presents approach identification of certainty components with reference to the semi-arid tropical region of India and, its limit is extent to the Himalayan mountain region. This work on sustainable environment in fragile resource zones in South Asia. This paper identifies concrete current problems and their possible solutions.at current problems and their remedial measures linked with climate change in this measures to solve current climate problems will have the potential to facilitate adaptation to future climatic impacts, without exclusively planning for "uncertain" impacts.

Glacial Retreat: Climate Change is Responsible - Geomorphology Hastens the Process

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Abstract

Glacial Retreat in different climatic regimes of the world has now been a fact. However, the rate and pattern at which it is retreating depend on many factors. Secondly, the glacial retreat should not be concluded only from the change in the position of snout, i.e. horizontal changes. Many times, the changes may not be lateralbut only vertical changes are visible, which is also ice volume loss. Therefore, before reaching any conclusion, all types of glacial dynamics must be carefully ascertained. As stated earlier,

variation in the ascertained glacial changes depends on a number of factors, therefore, it is essential to identify the geomorphic parameters which could lead to faster or sluggish changes. In this study, Glaciers of Lahaul-Spiti valley were studied to characterise the changes given different general geomorphic conditions. Well established remote sensing techniques were used to generate glacial parameters. It is found that despite being exposed to similarclimate, these glaciers exhibited variation in the magnitude of retreat and important parameter like surface ice velocity. These variations could be directly linked to the geomorphic characteristics such as debris cover, slope and aspect, size, etc.

Induced soft sediment deformation along Trans Yamuna Active Fault System (TYAFS) in Doon valley, north western Himalaya

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Abstract

Himalaya is one of the youngest folded mountains in the world and also the region of large magnitude earthquakes. Documented active faults in northwest Himalaya provide evidences of continuous strain release in between faulted zone of Main Boundary Thrust(MBT) and Himalayan Frontal Thrust (HFT). Active tectonic signatures in this segment are recognized through deformed and/or newly created tectonic landforms such as uplifted and faulted river terraces and alluvial fans, stream off sets, dislocated ridges, sag ponds, triangular facets, pressure ridges and abandoned/controlled drainage pattern etc. In the present study an attempt has been made to correlate paleo-earthquakes and active tectonics along the Trans Yamuna Active Fault (TYAF) systems in NW Himalaya. TYAF system recognised in between MBT and HFT isa ~ 13km long NE-SW trending fault trace which has three main segments and can be clearly recognisable on the satellite image. The subdued expression of TYAF can be further extended on either direction. Two trenches were excavated on the NE end (at Bharli) and at SW end (at Sirmuri Tal) towards paleo-seismological investigations. The trenches at Bharli Active Fault (BAF) and Sirmuri Tal Fault (STF) occupy dissimilar lithological units including the Quaternary deposits. It has been observed in both the trenches that there are prominent deformation features in the soft sediments. The phenomenon that involved in the deformation of soft sediment deposits has been attributed mainly due to the increase in pore-pressure by liquefaction process and fluidization mechanism. The various induced deformation features (also known as seismites) are mainly in the form of sand boils, clastic dykes, flame structures, clay bursts and water escape structures etc. The deformation in soft sediments will only possible due to strong ground shaking, generally because of an earthquake (>5.5.M) indicating a tectonic activity in the Quaternary period. Since the above soft sediment structures are not syn-sedimentary in origin, they must have genetic link with the ancient earthquakes. The deformation recognised in the soft sediments suggests in the TYAF also suggest its reactivation of in the recent past.

Estimation of Aerosol properties over Himalayan region: A Review

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Abstract

Aerosols are the minute suspended particles present in the atmosphere. They can affect the Earth's climate in many ways: absorb/scatter the solar radiation (direct effect), increase the cloud life-time and decrease precipitation (indirect effect) and absorb/ re-emit thermal radiation and evaporation of clouds (semi direct effect). It was stated in some studies that the aerosols produced in parts of Indo-Gangetic Plain could mark an effect on the cloud formation in the eastern part of Himalaya. The modification in cloud properties is observed due to the increase in number of aerosols. The aerosol loading in the atmosphere is quantified in the form of aerosol optical depth (AOD). Some recent studies conducted in the foothills of central Himalayas near Kathmandu, Nepal estimated average AOD to be around 0.5 and observed that the aerosol types were identified mostly because of natural sources, anthropogenic activities and biomass burning. Along with AOD (at 500 nm), volume size distribution (VSD), single scattering albedo (SSA) and asymmetry parameter (AP) were also studied. Using a multi-wavelength solar radiometer, AOD over Manora Peak, Nainital was also estimated in a study and it concluded that mostly the AOD was 0.08 over the region, followed by the observation that AOD results were extremely low during winters whereas during summers, relatively higher values were recorded along with a remarkable change the spectral dependencies of AODs from steeper during winters to shallower during summers. A study performing estimation of AOD using a radiative transfer approach, SMART (Simple Model for Atmospheric Radiative Transfer) with Resourcesat-2 Advanced Wide Field Sensor (AWiFS) data followed by Land surface albedo product from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor estimated AOD over various features of Dehradun, Uttarakhand region and found the value to be ranging from 0.4 to 0.7. The studies carried out so far identify research gap zones from where Aerosols get advected towards Himalayas which calls for long term investigation to understand and characterize the nature of aerosols by establishing multiple sites over the same.

Landslide hazard zonation mapping of slopes bounding the reservoir

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Abstract

Landslides cause severe destruction to humans and geo-environment in Indian Himalaya. Major causes of landslides in Indian Himalaya are high precipitation, adverse topography, fragile geologic material, complex geological structure and anthropogenic activities. Infrastructure and public welfare initiatives namely, construction of all-weather roads, rail track, dams, reservoirs, tunnels, bridges, housing, etc., are being executed in Himalaya. A number of reports have revealed that infrastructure development projects

put serious stress on adjoining terrain.

This study has been carried out with the objective of identifying landslide prone zone on slopes which are put under stresses due to reservoir impoundment. Koteshwar reservoir (18 km long) has developed between Tehri dam and Koteshwar dam in a very narrow valley. Reservoir water fluctuation leads to number of slope failure incidents. In this work, landslide hazard zonation (LHZ) mapping of reservoir bounding slopes was attempted using a dynamic approach.

We have followed Bureau of Indian Standard (BIS) guidelines (1S 14496 part-2) for LHZ mapping. The guideline is based on landslide hazard evaluation factor (LHEF) rating scheme, which is an empirical rating scheme assigned to following six causative factors: Lithology, structure, slope morphometry, relative relief, land use and land cover and hydrogeological condition. As per the guidelines, we have used slope facet as mapping unit for the LHZ mapping. In this work, we have clubbed slope morphometry with relative relief and considered a single factor. We have introduced slope movement factor at the place of relative relief in the rating scheme. Slope movements have been identified on the basis of PS- InSAR technique. Synthetic Aperture Radar (SAR) data of Sentinel-1 sensor for the period between May 2015 and December 2018 (59 SLCs) have been used to determine slope movement in each slope facets. Pixels representing vertical slope movement in each slope facet have been averaged and a mean slope movement for each slope facet was calculated. In the next step, mean slope movement has been normalized in range of LHEF rating. Finally, total hazard estimate (TEHD) was calculated for each slope facet. TEHD values have been reclassified into following five relative hazard zones: very low, low, moderate, high and very high as per LHEF rating scheme. LHZ results have been compared with existing landslide inventory in order to validate the LHZ map.

Results have indicated a high correlation between landslide density and LHZ. High landslide densities have been observed in slope facets representing high and very high hazard zones. Low landslide densities have been observed in slope facets representing low and very low hazard zones. This study exhibits the potential PS-InSAR technique in predicting landslide hazard zones. Slope movements derived from PS-InSAR analysis was successfully used to assign ratings. Comparison between landslide inventory and LHZ showed the robustness of the adopted method.

Estimation of efflux of CO2 from the Tributaries of Ganga River

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Abstract

The carbon cycle has important applications in monitoring global climate change. Atmospheric CO_2-pressure is a major component of this cycle. It is possible to calculate the partial pressure of CO_2 (pCO_2) in the river from a geochemical interpretation of temperature, pH and bicarbonate alkalinity. Most of the rivers are the source of atmospheric CO_2 because of higher riverine CO_2 partial pressure (pCO_2) as compared to atmosphere. Thus, outgassing of CO_2 from river is a major global process. Understanding the sources and dynamics ofpCO_2 and CO_2 fluxes from river systems to the atmosphere is important for

assessing the role of river systems on global carbon cycle and hence on climate change. This study aims to study the variability of pCO_2 and CO_2 fluxes in the Ramganga, Gomati, Kosi, Gandak and Gharghara rivers which are the tributaries of the Ganga River. The average pCO_2 is estimated to be 2272 µatm for the entire watershed. This value is nearly6 times higher than pCO_2 of atmosphere (350-410 µatm). This is because high-CO_2 ground water enters the river and the rate of dissolution of CO_2 in river water is faster than the rate of release of excessCO_2 back to the atmosphere. This has important implications for the carbon Cycle and climate change. The estimated average CO_2 flux in these tributaries is 353 mmol CO_2 $m^{-2}h^{-1}$. The average values of pCO_2 and CO_2 fluxes vary from 1855 to 2628 µatm and 274 to 420 mmol CO_2 $m^{-2}h^{-1}$respectively. Though there is large spatio-temporal variation in the efflux of CO_2 but higher values are generally shown in the monsoon season.

Harmonizing different geo-spatial datasets to study the snow cover-albedo interactions over different boreal forests

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Abstract

Cryosphere as an essential part of the earth system has an important role in controlling the climate. Albedo over the high latitude boreal forests has large seasonal and interannual variability as a result of the complex snow-albedo interactions. Moreover, this complexity increases as the elevation and its slope and aspect, also forest species, and its age, and volume are influencing the albedo variability. Here, we used very sophisticated and detailed method to harmonize 13 years of datasets that are different in spatial and temporal resolution over Norway. The datasets are: (1) satellite retrievals of sinusoidal tile gridded MODIS surface albedo (MCD43A3) with 500 meter resolution; (2) high resolution (16 meter) forest inventory from SAT-SKOG database and also land use datasets from Norwegian mapping authority; (3) daily observations of meteorological information on air temperature, precipitation, and Snow Water Equivalent (SWE) are produced at 1 km resolution from interpolation of meteorological weather stations in Norway; and (4) the topography. A python based data parsing model is employed to harmonize the datasets to match the same spatial and temporal resolution of the MODIS albedo grids. It also computed the percentage of each forest types and the forest inventory parameters representing the MODIS grid. We studied albedo variations in Norway across latitude, seasons, land cover type (deciduous forests, coniferous forests and cropland), and topography. The coherent variations of SWE and albedo over different land use types are also studied using wavelet analysis. From the wavelet analysis, albedo missing its coherence with SWE over the forest regions in the second half of the winter season. Snow- albedo coherence is high in the coastal location and missing in the high-elevated region.

Landslide susceptibility mapping of the Kullu Valley, Himachal Himalayas, India: A GIS-based comparative study of FR, AHP and SMCE methods

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Abstract

The present study demonstrates the results of three GIS-based statistical methods for landslide susceptibility mapping (LSM) and their comparison for the Larji-Kullu Tectonic Window (LKTW), Kullu Valley, Higher Himachal Himalayas, and northern India. We used nine geological, geomorphological and topographical conditioning factors: lithology, terrain slope, slope aspect, elevation, and distance to drainage, distance to faults, distance to lineaments, and distance to roads. Our landslide inventory data set with 149 GPS points of landslide locations was generated during a field survey in July 2018. The relationships between the landslide locations and the nine conditioning factors were determined by three GIS-based statistical methods, i.e. the analytical hierarchy process (AHP) the frequency ratio (FR), and the hybrid spatial multi-criteria evaluation (SMCE) method. We also compared and evaluated the performance of the applied methods. 70% of the landslide inventory was used for training the statistical methods, and the remaining 30% was used for validation purpose. The area under the curve (AUC) of the success plot was used for the validation of the results. The SMCE method gives 0.910 accuracy rate compared to the other two other methods, AHP and FR 0.790 and 0.905 accuracy rate, respectively. Resulting LSMs can be useful for risk mitigation and spatial planning purposes in the Kullu district, Himachal Himalayas.

Temporal variation in snow cover and backscatter values of SCATSAT-1 data in Western Himalaya

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Abstract

Snow cover is one of the essential element affecting the climate system. Large temporal and spatial variability has been observed in the snow cover of the globe as well as corresponding response of the backscattered values in the microwave region. In present study, temporal variation in backscattered values of Ku-band microwave remote sensing data has been studied over western Himalayan region. Scatsat-1 satellite carries scatterometer payload operating in Ku band at 13.515 GHz frequency. Scatsat-1 provides three types of data (i) brightness temperature (ii) gamma_0 and (iii) sigma_0. Gamma_0 and sigma_0 values are obtained at spatial resolution of 2 Km. Scatsat-1 data are available daily and it has an advantage over optical data as it can scan the study area during cloud cover. The main objective of the present study is to explore the variability in the backscattered values of the Scatsat-1 data with variation in snow cover in Himalaya. The study has application in mapping snow cover in Himalaya in the presence of cloud cover. Backscattered values were observed low during summer months compared to the winter months in all the Himalayan ranges. After snowfall backscattered values increases due to high scattering of Ku-band in the snow cover. High backscattered values were obtained for snow cover in a comparatively colder climate.

Stream Profiles and Drainage Morphometry Reveal Active Tectonic Deformation of the Sub-Himalayan Belt

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Abstract

Stream profiles tend to exhibit a concave upward longitudinal profile, as long as it is in equilibrium with its environment. However, the drainage is extremely sensitive to subtle changes in its environment which could be either tectonic or climatic. In order to reorganize itself to adjust to the new equilibrium conditions position the stream will modify its long profile in accordance with the perturbation. These modifications can be easily mapped from the channel geometries. In the Sub-Himalaya of Western India, the modifications in stream long profiles have been confidently attributed to the active tectonic deformation which could also be manifested in surface topography. We present a comprehensive account of integrating the drainage characters spatially through morphometry and geomorphic features to demonstrate the active deformation of the outermost ranges of the Sub-Himalayan belt, proximal to the Himalayan Frontal Thrust (HFT). The streams here are smaller (lower order) and mostly ephemeral in nature. In particular, the analyses benefits from the fact that the streams flow over similar lithologies of Upper Siwalik rocks and could permit spontaneous correlation with active surface deformation. The inferences drawn from morphometric analyses enabled detailed investigations using remote sensing imageries. Further based on geomorphic features, it is concluded that the manifestations reported here relate to recent/young tectonic activity as young as 38-40 ka. Implications of the analyses on the geological structure, tectonics and modulation of seismic hazard would be also discussed.

Particulate-bound Non-Polar Organic Species over Dhauladhar region of North-Western Himalaya: Variations in Sources and Processes

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Abstract

Carbonaceous aerosols represent the major fraction of the total aerosol load present in the ambient environment. Compositionally, this fraction portrays complexity because of the presence of large diversity of organic compounds. Some of these organics are used as source tracers, which further manifests temporal variations and bears location specific imprints. The Himalayan region with its unique location acts as a climate regulator in South East Asia. Though the mighty Himalayas play a unique and vital role in governing climate of the region and especially that of India, it is still the least studied region of our country. Keeping in mind the limited knowledge about the sources and composition of organic aerosols in this region, aerosol associated organic tracers: n-alkanes, Polycyclic Aromatic Hydrocarbons (PAHs), Isoprenoid hydrocarbons, and particulate bound nicotine have been investigated in PM_{10} samples

collected in rural (village Pohara) and urban (Dharamshala town) locations in the Dhauladhar region of North Western Himalaya. The aerosol sampling was conducted from January 2015 to January, 2016. The analysis of monthly representative aerosol samples was done using Thermal Desorption Gas Chromatography Mass Spectrometry (TDGCMS). Established organic markers, associated diagnostic parameters, and molecular diagnostic ratios were used to assess and discern the contributing biogenic, petrogenic and pyrogenic sources in the region. The n-alkane based diagnostic parameters include—mass weighted Averaged Chain Length (ACL); Carbon number with maximum concentration (Cmax); Petroleum derived n-alkanes (PNA%), Carbon Preference Index (CPI) and the percentage contribution of Wax n-alkanes from plants (WNA%). The average value of ACL at rural and urban location is 29 ± 0.86 and 30 ± 1.15 respectively. A significant predominance of high molecular weight congeners C29, C30 and C31 indicates contributions from leaf plant wax and other mixed sources like road dust, garden soil, cooking oil and cigarette smoke. Irrespective of the difference in altitude and land use pattern, CPI and WNA% clearly indicated the predominance of petrogenic sources in both the locations. At Dharamshala, annual average CPI was estimated 0.92. Whereas, at Pohara, due to biogenic spurts (CPI>1) during harvesting seasons, annual average CPI was 1.51. The monthly ring based preferential distribution profiles of PAHs indicated wood burning and waste incineration as dominant contributors apart from fossil fuel burning. Strong seasonal variations were noticed in determined n-alkanes, isoprenoid hydrocarbons and selected PAHs over both the locations. Particulate bound Tracers for Environment Tobacco Smoke (ETS) like nicotine were noticed in all the samples and their significant concentration raise serious concerns.

Assessment of Ambient Air Quality in the Ecologically Sensitive Tirthan Valley of the Great Himalayan National Park, India

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Abstract

Ambient air quality is one of the major concerns in the developing countries for the well-being of humans and its environment. The present study assesses the ambient air quality in the ecologically sensitive area of the Tirthan Valley. The valley is in the ecozone area of Great Himalayan National Park which was declared as UNESCO World Heritage Site in June 2014 for its unique biological diversity. After declaration of the park as World Heritage Site, there is increase in tourism activities especially in Tirthan Valley causing various negative impacts such as deterioration in air quality. Air quality was assessed based on air pollutants like particulate matter less than 10 micron (PM_{10}) in size, black carbon (BC), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and aerosol optical depth (AOD). The study was carried out for the period of 3 years from January, 2015 to December, 2017 in the Gahidhar village of the Tirthan Valley. Concentration of all the pollutants during the reporting period was found under permissible limit prescribed by National Ambient Air Quality Standards (NAAQS). The study provides baseline data in terms of air quality index in ecologically sensitive area of the valley which will be useful for future air quality assessment, planning and sustainable development of the region.

Aerosol optical properties along with particulate matter (PM) concentration during an intense dust storm in Indo-Gangetic Plain

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Abstract

The Indo-Gangetic Plain (IGP) experiences several dust storms during the summer season and that affects the air quality of region for 2-3 days. But in the summer of 2018 during 12-17 June an unusual dust storm occurred which lasts more than a week and affect the air quality of IGP and Himalayan foothills very severely and due to this, the Delhi NCR region plunged into an air quality emergency. The air pollution level in NCR region had reached to an alarming "severe plus" category on 12-14th June 2018 due to heavy and surface elevated dust storm originating from neighboring areas of the Thar Desert and adjoining areas of Pakistan resulting in a thick cover of haze and dust. This storm increased coarser particles (PM10 and above) rapidly in the air. To study aerosol optical and physical properties we have used ground and satellite-based measurements. We have used data from ground-based AERONET and satellite-based MODIS and CALIPSO for the Aerosol optical depth (AOD), Single scattering albedo (SSA), Angstrom exponent (AE), vertical profile and types of the aerosols. We have also used particulate matter (PM) data from the ground-based air quality monitoring system SAFAR for Delhi region. We found an elevated level of AOD, 2-3 times higher than the usual distribution in both ground and satellite observation. MODIS AOD shows AOD more than the 1.5 during peak storm days. CALIPSO observation shows that the aerosol is spread up to a height of 5 km from the surface and the type of aerosol is mainly the dust and polluted dust type. Surface observation of PM also shows the unusual increase in the bigger size of particles mainly PM 10 and higher. The 24 h average of PM10 over Delhi touch a peak of 1200 μg/m3 (~3 times the severe limit on 13th June) and PM2.5 level peak touched 240 μg/m3 (very poor). We have also studied the WRF-Chem simulated PM during this dust storm. The high abundance of bigger particles of dust (> PM10) and meteorological conditions opposes the flush out of dust which made dust to hang 5-6 days. These types of severe dust storms are important to study of air quality in this region and can have adverse effect on the monsoon in India.

Early 21st century glacier elevation and mass change patterns in the Himalaya-Karakoram

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Abstract

This study presents the comprehensive and spatially detailed glacier elevation changes in various sub-regions (e.g. Lahaul-Spiti, Himachal Pradesh) of the Himalaya-Karakoram mountain ranges. For this, we employed two global radar remote sensing data – Shuttle Radar Topographic Mission (SRTM) C-band DEM from 2000 and TerraSAR-X add-on for Digital Elevation Measurement X-band bistatic data

(TanDEM-X) from 2012-2018. We processed TanDEM-X data using bistatic radar interferometry in order to generate high resolution DEMs for our study regions. Previous studies have reported regional heterogeneity of glacier elevation and mass changes in high-mountain Asia. Our results further confirm this heterogeneity with much better spatial details. For instance, on an average the Jammu & Kashmir East (Karakoram) showed less negative elevation change (0.19 ± 0.22 m yr^{-1}) during 2000-2012 compared to the Himalayan regions – Lahaul-Spiti (0.65 ± 0.43 m yr^{-1}) and Jammu & Kashmir West (0.50 ± 0.28 m yr^{-1}). This heterogeneous glacier response appears to be primarily linked with regional climate variations (e.g. Indian summer monsoon, Mid-latitude winter westerlies). However, the debris-covered glaciers within the same regions show two different patterns and reveal the role of supraglacial features (debris cover, lakes, ponds and ice cliffs) on glacier scale changes. These supraglacial features coexist on glacier ablation zones and affect the energy available for ice melt. First pattern shows maximum thinning upstream indicating the insulating effects of thick debris-cover at lower altitudes. The second pattern shows maximum thinning at the glacier terminus, which is most likely because of enhanced ice melt due to supraglacial water bodies and ice cliffs.

Karakoram is known for glacier surge events – a rapid advance of glacier front and transfer of ice mass from up-glacier to lower catchments within weeks to several years, threatening to the community in downstream regions. We reviewed the status of surge-type glaciers in the Karakoram and found out that the glaciers were going through different surge phases (quiescent and surge) for the period after 2000. Our high spatial resolution data also identified 16 new surge-type glaciers that were not documented before.

Aerosol Climate Forcing Agents in the Indo-Gangetic Plain: Impacts of Regional Biomass Burning Emissions and Atmospheric Transport

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Abstract

The Indo-Gangetic Plain (IGP) is the predominant area source in India of a wide variety of atmospheric pollutants, especially, carbonaceous aerosols. The high population density, presence of numerous small-scale industrial units with little or no emission control technology, rampant agricultural residue burning (mostly in the northwestern IGP), and intensive residential biofuel use in this region lead to enhanced aerosol emissions, which are regionally transported by prevailing winds to downwind areas – most importantly, the Himalayas. An understanding of the potential impacts of the transported aerosols on Himalayan ecosystems, air quality and climate, a comprehensive characterization of IGP emission outflow itself is required as the first measure. Among potential species of interest, aerosol black carbon (BC), brown carbon (BrC) and humic-like substances (HULIS) are significant in terms of their impacts on regional and global direct climate forcing, cloud properties, tropospheric chemistry, and human health. In India, large heterogeneities exist for BC emission inventories, measurement coverage is weak, and field-based data on BrC and HULIS optical properties are almost non-existent. We therefore focus here on these carbonaceous aerosol fractions and report their chemical and optical properties, potential sources and transport pathways in a rural area in the eastern IGP. We focus on the role of atmospherically transported biomass burning emissions from the northwestern IGP on constraining BC, BrC and HULIS chemical-

optical characteristics in the eastern IGP. We believe results from this study provide important potential insights into air quality and regional climate forcing in the southern and central Himalayas that are affected by this IGP outflow. To this end, we performed ground-based aerosol measurements during summer, monsoon and post-monsoon seasons (May-November) of 2018 in Mohanpur (21º84'N, 87º42'E, 17 m a.m.s.l.), a rural area in the eastern IGP. A 7-wavelength Aethalometer was used for time-resolved measurements of BC mass, and absorption coefficients (b_{abs}) and Angstrom exponent (AE) for BrC. This was supplemented by UV-Vis, fluorescence, and Fourier-transformed infrared (FTIR) measurements of time-integrated (24 h) $PM_{2.5}$ aqueous and organic BrC fractions. Similar optical measurements were carried out for HULIS chemical fractions: namely, neutral (HULIS-n), acidic (HULIS-a), and highly-polar water soluble organic matter (HP-WSOM). This led to a comparative characterization of BrC and HULIS optical properties during regional agricultural residue burning in post-monsoon, and from local biomass burning and secondary formation in summer. Concentration-weighted trajectories (CWTs) were used to identify aerosol transport pathways and source sectors.

The daily averaged BC doubled during post-monsoon (8.2±2.0 μg m^{-3}) as compared to summer (4.2±0.8 μg m^{-3}), while its diurnal profile was similar among seasons, with early morning (0700-0800 h) peaks characterized by high fossil fuel BC, and late evening (1900-2100 h) peaks from residential fuel use reflected by enhanced biomass burning (BB-BC). The diurnal profile of $b_{abs(BrC)}$ tracked the BC-BB fraction, with a concurrent peak during 1900-2100 h in all seasons. Observations such as: i) increased contribution of BB-BC during post-monsoon (23±3%) compared to summer (17±5%); ii) a significant and co-located enhancement in post-monsoon b_{abs} (BrC) (23 Mm^{-1} vs 12-13 Mm^{-1}); ii) a corresponding high AE_{BrC} of 3.6; and iv) the occurrence of BC and BrC CWTs centered over fire spots in the northwestern IGP indicated that seasonal agricultural residue burning results in a significant outflow of BC and BrC over the entire stretch of the IGP. Averaged AE_{BrC} for water and methanol extracts were 7.2 and 6.2, respectively, during summer (n=20), and 5.4 and 5.2, respectively, during post-monsoon (n=20). This confirmed a substantial presence of both aqueous- and organic-soluble BrC chromophores, and also indicated that regionally transported aged BB aerosol possibly produces BrC species with comparatively weaker wavelength dependence compared to that from fresh BB and secondary formation. HULIS-n dominated $b_{abs(BrC)}$ at 370 nm with contributions of 64% in summer and 55% in post-monsoon; however, b_{abs} of HULIS-n and HULIS-a were enhanced by 78% and 26%, respectively, during post-monsoon. The substantial presence of HULIS was confirmed by the fluorescence spectra for aqueous extracts showing a strong peak at ~430 nm for both seasons with significant enhancement for post-monsoon. In comparison, organic extracts exhibited a broader and more intense peak suggesting water-insoluble BrC chromophores. Moreover, the UV-Vis absorption spectra of BrC extracts showed a significant enhancement in the higher wavelengths (~400 nm) during post-monsoon, which strongly suggests enhanced formation of nitro-aromatic compounds. These clearly show greater emission of HULIS and aromatic species from biomass fires in the IGP. BrC FTIR spectra for both summer and post-monsoon samples show peaks at 3400 cm^{-1} and 3200 cm^{-1}, suggesting the presence of intermolecular bonded alcohol and carboxylic acid groups. Two sharp peaks corresponding to C=O and C=C were also observed at 1710 cm^{-1} and 1643 cm^{-1}, respectively, with the C=O peak showing considerable enhancement during post-monsoon biomass burning events. This study establishes that BrC and HULIS are important components of light absorbing aerosol in the atmospheric outflow of the IGP, especially during agricultural residue burning periods, and their transport to and potential impacts on Himalayan ecosystems.

Dynamics of burnt areas in Himalayan region and their influence to snow cover

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Abstract

Biomass burning is an important environmental process with a strong influence on vegetation and on the atmospheric composition and on state of glaciers in the Himalayas. To better understand and predict global fire occurrence in the area, fire models have been developed and coupled to Dynamic Global Vegetation Models (DGVMs) and Earth System Models (ESMs). We use in this study SEVER-FIRE (Socio-Economic and natural Vegetation Experimental global fire model which is incorporated into the SEVER-DGVM to predict dynamic of areas burnt in Himalayan region. One of the major focuses of SEVER-FIRE model is an implementation of pyrogenic behaviour of humans (timing of their activities and their willingness/necessity to ignite or supress fire), related to socio-economic and demographic conditions in a geographical domain of the model application. Burned areas and emissions from the SEVER model in Himalayas are compared to the Global Fire Emission Database version 2 (GFED), derived from satellite observations, while number of fires are compared with regional historical fire statistics. We found that dynamics of areas burnt may influence melting of ice and snow in the area recently.

De-sustainability in Himalayan cryosphere: A Comparative Study of Exploitation of Cryospheric Service Functions in the Past and the Present

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Abstract

With more than 9,500 glaciers Himalayan Cryosphere, also known as the “third pole”, forms the largest area covered under cryosphere outside the Polar Regions. Often described as barren and lifeless, these systems on contrary, sustain life above, below and within ice. This unexplored kingdom of anomalies and diversity provides humanity various services for its well-being. Humankind has been using these services since time immemorial but the way they are exploited has changed from need-based to greed-induced. This has resulted in the change of status-quo ante i.e. from sustainability to unsustainability through a process which is defined in the paper as “De-sustainability”.

The paper explains various Cryospheric Service Functions (CSFs) of the Himalayan Cryosphere and compares the present trend of their exploitation with the past. This preliminary study shows how De-sustainability has been caused in the Himalayan Cryosphere. Learning’s from the past and lessons learnt from the present are integrated to provide suggestions for sustainably designing the future and set the clock back to sustainable times where all 17 United Nations Sustainable Development Goals can be met.

Climate Change and its Impact in Western Himalaya (Naradu Valley)

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Abstract

Present study deals with temperature and snowfall trend analysis for the period of 1979/80 to 2012/13 in Naradu Valley, western Himalaya. An attempt has also been made to find the snowline by establishing a multiple regression equation by taking annual temperature and precipitation and corresponding snowline of few years into consideration. Long-term trend direction and magnitude of change over time (annual and seasonal) were detected and analyzed by Mann–Kendall test, Spearman Rank Correlation, Sen's slope estimator and Sequential Mann–Kendall test. Temperature trend analysis shows the rise of 0.9 °C whereas snowfall trend analysis shows decrease of 112.03 cm and the estimated annual snowline shows an increase of 75.65 m for study period. The applied statistical tests show significant increase in annual temperature and snowline data whereas significant decreasing trend was found in annual snowfall data. SQMK test shows that 1997/98 is the beginning of the change point for temperature and snowline whereas the same has been failed to deduct the change point for snowfall.

Estimates of black carbon (BC) aerosol transport over Hindu Kush Himalayan sites: validation, sources, and implications on glacier runoff

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Abstract

Black carbon (BC) impacts the climate through a direct effect by absorbing sunlight and an indirect effect through cloud alterations in precipitation efficiency. Another impact due to absorbing aerosols such as BC exists on the cryosphere by altering the ablation rate of ice. Deposited BC over snow enhances absorption of solar radiation, darkens the upper mixing layers of the snowpack thereby reducing the snow albedo and leading to accelerated melting of snow. The influence of the albedo changes on the glacial mass balance due to an excess and preponed snow melting and thereby the glacier runoff is expected to affect the downstream hydrology. This impact is specifically of concern for the Hindukush Himalayan (HKH) region as the Himalayan glaciers are the source of major rivers in South Asia namely Ganges, Indus, Yamuna, and Brahmaputra (also known as Tsangpo). The inaccessible terrain and severe weather conditions in the higher Himalayan region hinder the measurement of atmospheric BC concentration and

BC concentration in the snow at regular spatial as well as temporal intervals. The measured data may thus serve as a location and time specific primary data and not a representative sample of the regional distribution. The simulated BC concentration, using atmospheric chemical transport models (CTMs), which is validated by measurements, can be utilized to predict the spatial mapping of BC distribution over the HKH region. In order to spatially map as adequately as possible, the estimates of atmospheric BC concentration and BC concentration in snow (BC_c) including the corresponding snow albedo reduction (SAR) over the HKH region, an integrated approach merging the relevant information from observations with a relatively consistent atmospheric chemical transport model estimates is applied in the present study. Numerical simulations of annual glacier runoff height and snow-albedo are carried out using glacial mass balance model to evaluate the impact of BC-induced SAR on increase in annual snowmelt runoff from glaciers.

Estimates of the spatial distribution of BC concentration in the snowpack (BCc) over the HKH region led to identifying a hot-spot zone located around Manora Peak. Among glaciers over this zone, BCc (> 60 μg kg^{-1}) and BC-induced snow albedo reduction (~5 %) were estimated explicitly being high during the pre-monsoon for Pindari, Poting, Chorabari, and Gangotri glaciers (which are major sources of fresh water for the Indian subcontinent). The rate of increase of BCc in recent years (i.e., over the period 1961–2010) was, however, estimated to be the highest for the Zemu Glacier. Sensitivity analysis with a glacial mass balance model indicated the increase in annual runoff from debris-free glacier areas due to BC-induced snow albedo reduction (SAR) corresponding to the BCc estimated for the HKH glaciers was 4 %–18 %, with the highest being for the Milam and Pindari glaciers. The rate of increase in annual glacier runoff per unit BC-induced percentage SAR was specifically high for Milam, Pindari, and Sankalpa glaciers. The source-specific contribution to atmospheric BC aerosols by emission sources led to identifying the potential emission source being primarily from the biofuel combustion in the Indo-Gangetic Plain south of 30°N, but also from open burning in a more remote region north of 30°N.

Geomorphic and climatic affinity of Holocene mega-floods in the western Himalaya, India

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Abstract

Sedimentological evidence of Holocene mega floods are investigated in the Satluj river valley and its trans-Himalayan tributaries. The idea is to understand the geomorphic and climatic processes responsible for the generation of the mega floods in the western Himalaya. Based on the sedimentological and textural criteria ~16 flood events of increasing magnitude are dated which cluster in two major time domains. The older phase (seven events) occurred before ~11 ka while the younger phase (nine events) is dated between ~8 and 6 ka. The younger flood phase is regional in nature (catchment wide) but does not overtop the older flood phase (>11 ka) in the para-glacial zone of the Spiti river implying that the former were either of lesser magnitude or did not originate in the trans-Himalayan region. The former seems to

be the likely possibility as indicated by the $^{87/86}Sr$ ratio and major element data suggesting dominance of higher Himalayan crystalline in the flood sediment. Climatically, we ascribe the younger phase to the phases of negative Arctic Oscillation (−AO) and negative North Atlantic Oscillation (−NAO) during which a coupling between the moisture-laden monsoon circulation and southward penetrating mid-latitude westerly troughs occurred. As a consequence, the floods were triggered by the extreme precipitation events causing slope instability leading to the Landslide Lake Outburst Floods (LLOFs) particularly in the higher Himalaya (orographic barrier)- a conducive geomorphic setting for cloud condensation and torrential precipitation. On the other hand, the events in older phase seems to be triggered by melting of glaciers/rain on snow and GLOFs generated thereof by rising temperatures in early Holocene.

Response of glaciers since last 20 ka in the transitional climate zone of the Southern Zanskar Ranges (NW Himalaya)

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Abstract

The transitional climatic zone of the Southern Zanskar Range, NW Himalaya is investigated for the relics of glacier advances and retreats as glaciers responded to the temporal changes in the Indian Summer Monsoon (ISM) and mid-latitude westerlies. Four glacier advances named from the oldest to youngest as the Southern Zanskar Glacier Stage-4 (SZS-4) to SZS-1 are identified. The SZS-4 remains undated, however based on the existing chronology of the stratigraphically equivalent moraines/trimlines in the region; it is conjectured to the Marine Isotope Stage-4 (MIS-4). The SZS-3 is dated using optical chronology to 22.8 ± 1.9 -19.1 ± 1.9 ka and corresponds to the Last Glacial Maxima (LGM). The SZS-2 is dated to 15.7 ± 1.3-14.3 ± 1.3 ka (late Glacial period) whereas, based on the chronology of the recessional moraines (4.9 ± 0.4-4.5 ± 0.3 ka) the youngest SZS-1 is assigned to ~6 ka (mid-Holocene). The snout proximal moraines are attributed to the Little Ice Age (LIA)/historical times. The recessional moraines and outwash gravel terraces represent the pulsating deglaciation associated with each advance in last 20 ka. The older gravel terrace is dated between 10.8 ± 0.9 and 6.5 ± 0.5 ka and is attributed to SZS-2 retreat which is also manifested by the deposition of sandy facies in a relict lake sequence (6.7 ± 0.6 ka) and development of palaeosol (5.6 ± 0.5 ka). We propose that the glacial advances were triggered by the millennial scale cooling events during the periods of strengthened westerlies and thus, suggest a synoptic scale coupling with the Northern Atlantic. The glacier retreat is suggested to occur during the warmer ISM dominated phases. The late Holocene climatic instability that followed the recession of SZS-1 is manifested by the development of rhythmites (3.8 ± 0.5 ka), loess (2.5 ± 0.2 ka), and palaeosol (2189 ± 296 cal yr BP).

Climate Change Vulnerability Assessment in the Indian Himalayan Region based on a Common Methodological Framework

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Abstract

Indian Himalayan Region (IHR) is one of the most sensitive regions to climate change and variability. Most parts of the region underwent significant long-term changes in frequencies of extreme temperature events over the last decades. Annual intense precipitation days and annual intense precipitation intensity have been showing increasing trends. Therefore, their threat to climate change is beyond doubt. It is therefore important to develop vulnerability profiles of the states in IHR in such a manner that they are comparable and adhere to the vulnerably framework adopted in IPCC Fifth Assessment Report. Against this backdrop, a state level vulnerability assessment is carried out for Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, Arunachal Pradesh, Sikkim and West Bengal in the eastern part and Himachal Pradesh, Uttarakhand and Jammu and Kashmir in the Western part of IHR. The findings are also supplemented by the district level vulnerability assessments carried out by each of the states based on the same methodology.

The indicator-based methodology followed in the study has been developed by based on a set of common indicators. This set of indicators is identified based on rigorous discussion with the state representatives, experts and other stakeholders. After normalization of the indicators, the weighted average is used to calculate the composite vulnerability index. There are four broad categories of indicators used 1) socio-economic, demographic status and health, 2) sensitivity of agricultural production, 3) forest dependent livelihoods and 4) access to information, services and infrastructure. Each of these broad indicators has two to six sub-indicators. Following a Tier I approach data was collected from secondary sources.

Major drivers of vulnerability: Based on the composite vulnerability index values, the states have been ranked from highest vulnerability to lowest vulnerability. The vulnerability index is highest for Assam (0.72) and Mizoram (0.71), followed by Jammu & Kashmir (0.62), Manipur (0.59), Meghalaya and West Bengal (both 0.58), Nagaland (0.57), Himachal Pradesh and Tripura (0.51 both), Arunachal Pradesh (0.47) and Uttarakhand (0.45). Sikkim is the least vulnerable state with the index being 0.42. From an array of different drivers of vulnerability, the most important drivers are identified are low per capita income, lack of area under irrigation, lack of forest cover and low availability of forest dependent livelihood are the most dominant drivers for the states in the IHR. The drivers of vulnerability also varied across districts of the states.

This work has laid down a preliminary framework of vulnerability assessment across the states in IHR. This assessment will typically be helpful in identification of the geographical location and socio-economic sectors that requires special attention during adaptation planning in future. Also, it has implications towards allocation of competitive funds and investments in climate change adaptation in the area.

Spatiotemporal Analysis of Snow Cover Variation over Western Himalayan Basins using improved MODIS Snow Cover Area Maps

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Abstract

More than 1.4 billion people across multiple countries in South Asia depend on water from the rivers of the Himalayas, a vital reserve storing water in the form of ice, snow, and rain. In the western Himalayan river basins, snowmelt forms a significant component of the streamflow, thus, making it crucial to understand the Himalayan hydrological system and its response to the changing climate. The sparse and unevenly distributed ground-based snow gauge records over these basins render it difficult to perform a detailed study on the temporal and spatial variation of snow-cover across this region. In this scenario, satellite-based snow-cover products, like the MODIS snow-cover area maps are useful; however, they are associated with large local inaccuracies. A number of processing methods are used to improve the data quality and reduce noise for the snow-cover products derived from MODIS Terra and Aqua products, however, they largely focus on filling cloud-covered pixels and misclassification of snow as cloud is often disregarded. Therefore, in this study, we have used a novel 4-step MODIS snow-cover correction algorithm to obtain improved snow cover images which are further used for spatiotemporal analysis of snow cover variation over Western Himalayan basins covering a total area of 3,20,911 Km2, for the years 2002 to 2017. The 4-step correction algorithm includes, (i) 8-day MODIS Aqua and Terra snow data combination, (ii) false snow-cover detection using the 8-Day minimum ground temperature (min. Ground-T), (iii) Neighborhood analysis to reclassify a cloud pixel, and (iv) Snow-line altitude to correct the misclassified pixels. This correction algorithm is entirely based on the satellite-derived data, thus reducing the requirement of ground-based instrument data. Based on the snow-gauge station data for 2002 to 2007, the correction algorithm has been shown to improve the overall accuracy of the MODIS snow cover data to 91.4% after using the successive improvement steps, in comparison to the initial accuracy of 75% and 81% for Aqua and Terra snow products, respectively. Using the improved products, the preliminary assessment of spatiotemporal distribution of snow cover shows little variation in the minimum and maximum snow-cover during the study period. However, there is an earlier shift in the maximum snow-cover date over these years, reducing the total number of snow-days over the years and showing a possible increase in the melting period. A detailed sub-basin-wise analysis of variation of snow-days, mean snow-cover and snow-line altitude is being conducted which would provide deeper insights into the snow cover fluctuations over the Western-Himalayan basins in the last one and a half decade and its possible implications on regional water resources.

Investigations on Extreme Rainfall Events: Role of Atmospheric Dynamics

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Abstract

Atmospheric gravity waves play vital roles in a variety of dynamical processes in the Earth's neutral atmosphere. These waves are generated mostly in the troposphere due to orography, deep convection, wind shear, etc. Once generated, these waves are propagating to the stratosphere, mesosphere, and thermosphere along with ambient temperature and wind fields. Gravity waves are playing an important role in transferring energy and momentum from the lower atmosphere to the upper atmosphere. In a way these waves are working as a connecting wires between lower and upper atmosphere. Gravity waves do play a significant role in the dynamical coupling in the atmosphere. These waves are also responsible for modulating the mesospheric jets in the summer and winter hemispheres, and driving a residual meridional inter-hemispheric circulation that results in the cold summer mesopause at higher latitudes. As one of the major causes for the generation of gravity waves is strong/deep convection; so these waves are play crucial role in a broad range of atmospheric processes and may be useful as one the tracers for the extreme events. Extreme rainfall plays an important role in the Indian monsoon seasons in addition to its devastating socioeconomic impacts. The continuing amplification of these extremes through global warming may have severe concerns in terms of an increase in its frequency and magnitude. Extreme rainfall events over the Indian region showed a significant increase since last few decades. Many studies have been carried out focussing on the extreme events during summer as the major portion of the annual rainfall in our country is during summer period. Winter extreme rainfall events have received less attention in spite of the fact that they are of prime importance for human kind. These events are having enormous mortality impacts due to the high floods and landslides they create, and which occur especially over the complex topographical regions in the Northern India and the foothills of the Himalayan regions. Consequently, winter extreme events should be well-thought and should be equally important since few events are sporadic and few are associated with extreme weather conditions such as western disturbances which are very dominant during winter. Therefore, a comprehensive investigation of the dynamical (role of variety of waves) and thermo-dynamical processes of extreme rainfall events that occurred over the Central and Northern Indian region using a suite of observations from satellites, ground based instruments, and reanalysis datasets has been done. This investigation also categorizes the significant consequences of tropical and extra-tropical influences which generate the thermodynamical and wave dynamical instabilities for the occurrence of the extreme rainfall events over the Central and Northern parts of India. In this talk, a complex associated between rainfall and atmospheric dynamical processes will be discussed and presented.

Uncertainties in observations and climate projections for the North East India

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Abstract

The Northeast-India has undergone many changes in climatic-vegetation related issues in the last few decades due to increased human activities. However, lack of observations makes it difficult to ascertain the climate change. The study involves the mean, seasonal cycle, trend and extreme-month analysis for summer-monsoon and winter seasons of observed climate data from Indian Meteorological Department ($1^0 \times 1^0$) and Aphrodite & CRU-reanalysis (both $0.5^0 \times 0.5^0$), and five regional-climate-model simulations (LMDZ, MPI, GFDL, CNRM and ACCESS) data from AR5/CORDEX-South-Asia ($0.5^0 \times 0.5^0$). Long-term (1970-2005) observed, minimum and maximum monthly temperature and precipitation, and the corresponding CORDEX-South-Asia data for historical (1970-2005) and future-projections of RCP4.5 (2011-2060) have been analyzed for long-term trends. A large spread is found across the models in spatial distributions of various mean maximum/minimum climate statistics, though models capture a similar trend in the corresponding area-averaged seasonal cycles qualitatively. Our observational analysis broadly suggests that there is no significant trend in rainfall. Significant trends are observed in the area-averaged minimum temperature during winter. All the CORDEX-South-Asia simulations for the future project either a decreasing insignificant trend in seasonal precipitation, but increasing trend for both seasonal maximum and minimum temperature over the northeast India. The frequency of extreme monthly maximum and minimum temperature are projected to increase. It is not clear from future projections how the extreme rainfall months during JJAS may change. The results show the uncertainty exists in the CORDEX-South-Asia model projections over the region in spite of the relatively high resolution.

Measurements of PM 2.5 concentration using smart and compact sensor in Delhi NCR during 2016-2018

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Abstract

We focus our study area of research in Delhi and the National Capital Region (Delhi-NCR) initially and shall expand it in the neighboring regions. For past few years crop residue burning is a significant cause of concern in Delhi-NCR and Ganges Valley where air pollution increased and air quality became worsen especially during Oct-Nov months. Continuous real time observations are required to examine this vulnerable situation, so that appropriate actions can be taken by the governmental agencies or others on time. No systematic observations have been done in the past, and the work of tapping different local sources is still pending, which we have taken up two years ago by installation of smart and compact PM 2.5 sensors (which are developed and provided by Nagoya University, Japan) at a few locations in Delhi, Haridwar, Nainital etc.

In this presentation, we would like to show the preliminary results at a few locations that describe the real time scenario during different seasons. A very high concentration (> 200 – 800 μg/m^3) observed during several episodes in winter. During and after mid-October, one can see the gradual rise in the concentration of PM 2.5 every day. There is a clean diurnal variation observed with rise in the morning hours (2-3 times larger) and late evening. Impact of wind speed and sun light reduces the concentration considerably. During fog days, clear rise in concentration is seen on several occasions. A big rise in the concentration observed on Diwali and subsequent days (>1000 μg/m^3). Seasonal and diurnal variability will also be shown and discussed in the presentation. Future line of observations and contributions from many sources on a dense network basis will be addressed.

Findings of WIHG Seismic Network and Geophysical studies carried out in the Himalayan Region

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Abstract

The Himalaya is seismically one of the most active intracontinental regions in the world. During 1897 to 1950 there was a phase of very high seismic activity when 14 major earthquakes (M≥7.5) including 4 Great earthquakes of M≥8 have occurred. No Great or Major earthquake have occurred after 1950. Comparison of various earthquake catalogues has confirmed that quiescence of a major to the great earthquake since 1950 is real. Considering these facts WIHG has been operating a regional seismic network in the Himalayan region since 2007 to understand the convergence tectonics, sub-surface structures and associated seismic hazard. The Seismic Network have 54 Broadband seismographs (BBS) and 15 accelerographs. 20 seismic stations (six channels) are connected through VSAT to get the earthquakes data in real time at Dehradun. In this paper some of the important results obtained using the earthquake catalogue will be presented. These are about evolution of the sub-surface structure in the Himalayan and adjoining regions using different techniques as Local earthquake tomography (LET), Surface wave tomography, Receiver function and Magneto-telluric (MT) techniques. The existing dense seismic network makes it feasible to investigate area specific crustal/lithospheric velocity structure of NW Himalayan region. Ongoing different profiles of BBS and MT stations across major tectonic discontinuities of Himalaya make it feasible for understanding convergence tectonics and sub-surface structures Study carried out of some earthquake source processes to understand the earthquake source processes of Himalayan earthquakes using broad spectrum of seismic velocities recorded by local seismographs. This is carried out using different approaches e.g. P-wave first motion method and Waveform Inversion technique. The Stress Tensor Inversion (STI) technique is also used to study the regional stress pattern Strain energy budget analysis in the Garhwal Kumaon region of Central Seismic Gap in Himalaya has been carried out Frequency dependent attenuation characteristics in the Himalayan Region.

In a recent study on Micro-seismicity, Tectonics and Seismic potential in the Western Himalayan segment, Northwest Himalayan (30-33°N; 76- 80°E) in order to evaluate the potential of the seismic hazard in this region. The hypocentral parameters estimated incorporating the local crustal velocity model derived utilizing 20 seismic stations and relocated 462 earthquakes triggered in the NW Himalaya during 2004 and 2015 using 945 P-phase and 893 S-phase. We have also determined moment tensor solutions for nine (Mw>4.0) earthquakes using waveform inversion. The advantage of utilizing the waveform inversion technique, which utilizes low frequencies, thus, it makes modelling of waveforms less dependent on the inherently incomplete knowledge of the crustal structure. This method is highly advantageous in determining the exact fault plane characteristics pertaining to its Strike angle, Dip angle and rake or slip of the earthquake focus over other methods such as FPFIT, P-wave first motion polarization methods which require a greater number of stations and wide azimuthal coverage of earthquake hypocenter to determine the fault plane characteristics of the desired earthquake event.

The geometry of the MHT plane has also been deduced in this study which varies along the strike of the Himalaya in flat and ramp segments with a dip ranging from 4° to 19° below the HFT in south to STD in the north. There are also two new crustal ramps reported in this study having a depth range from 10 to 22 km below the MCT (31.0°N, 77.5°E) and 30 to 40 km beneath the STD (32.2°N, 78.4°E) respectively. The earthquake potential prevailing in the western Himalayan seismic gap lying between the epicentral zone of the 1905 Kangra earthquake and the 1975 Kinnaur earthquake has also been estimated utilizing Kanamori method. The total amount of energy released since the last great event has estimated is only a fraction (3-5%) of the accumulated total energy (95-98%). This indicates that the energy stored in this region can generate in future an earthquake of Mw > 8.0.

Extreme Forest Fire Event of April 2016 in Himalayan Region and its Effect on Pollutants

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Abstract

An extreme forest fire event of April 2016 has been investigated in the Southern Himalayan region to assess the effect of biomass burning aerosols on emission of organic carbon (OC), black carbon (BC), and trace gases like non-methane volatile organic compounds (NMVOCs), carbon monoxide (CO) and oxides of nitrogen (NOx) etc. We have used multiple datasets derived from different satellite based platforms like, MODIS (Moderate Resolution Spectroradiometer) and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) and reanalysis models like GFAS (Global Fire Assimilation System), MERRA-2 (Second Modern-Era Retrospective analysis for Research and Application) and ERA-interim for this purpose. Fourteen years (2003-2016) of data for the month of April was studied to see the impact of the extreme forest fire event of April 2016. It was found that the OC and BC emission enhanced drastically during the biomass burning event of April 2016 and reached up to ~$3x10^4$ and ~$2x10^3$ μg/m^2/day, respectively. Similarly, mean CO and NOx emission rates also increased significantly to 533.81 and 13.66 mg/m^2/day, respectively during the event. The NMVOCs, CO and NOx were found to increase by about 90.4, 110.6 and 132.5 % with respect to the non-burning month of April 2015 and reached up to 121.1, 958.3 and 25.3 mg/m2/day in April 2016. The large amount of BC and OC from biomass burning is found to significantly modulate the atmospheric radiation budget of the region. It is found to increase the columnar heating rate which could potentially heat up the atmosphere on an average by ~0.04-0.06 K/day in April-2016 when compared with non-burning month of April-2015. Similarly, the Ozone forming potentials (OFP) of NMVOCs are also found to increase by ~2 times during the April-2016 forest fire event as compared to April-2015.

The linkages between active faults, earthquake focal mechanisms, and surface topography

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Abstract

The seismotectonics of the Himalaya is highly variable along its strike across its various segments. However, individual segments also demonstrate variability in terms of the nature of active faulting, earthquake focal mechanisms and surface topography. The strike of active faults ranges from normal to almost parallel to the tectonic transport direction. This change in strike gives rise to an obliquity component of tectonic stress being accommodated in the rocks which often fail by varying mechanisms as manifested by the earthquake focal mechanisms i.e. thrust faulting to normal faulting and also strike-slip faulting in response to the applied stress field. The surface faulting readily modifies the surface topography often accompanied with landforms typical of the style and kinematics of faulting. These variations have been appreciated across different scales of investigation using observations on outcrops to regional maps and satellite imageries. We further explore the linkages between the active faults, earthquake focal mechanisms and the surface topography.

Aerosol characteristics at high-altitude location over western trans-Himalayan region

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Abstract

In the present work, we analyze the multi-year (2008-2018) measurements of aerosols optical properties over two SKY radiometer network (SKYNET) sites at high altitude (4300-4500 m above mean sea level) western Trans-Himalayas. The preliminary results indicate that the seasonal mean aerosol optical depth (AOD at 500 nm) are 0.032, 0.060, 0.049, and 0.03 during winter (December to February), spring/pre-monsoon (March to May), summer/monsoon (June to August) and autumn/post-monsoon (September to November), respectively. The corresponding Ångström exponent 400-870 nm are below 1, suggest the low abundance of fine/accumulation mode aerosols. The accumulation mode aerosols may associate from new-particle formation from gaseous precursors through photochemical reaction over the region. However, the observing sites are also experienced long-range transported aerosols from Cloud-Aerosol

LiDAR and Infrared Pathfinder Satellite observation (CALIPSO) data and Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) analysis. Further, the relationship between α and AOD shows the α varies greatly with a narrow range of AOD, indicates the occurrence of different type of aerosols over the sites. The climatological mean of $AOD_{500\,nm}$ and $SSA_{500\,nm}$ is 0.043 (± 0.028) and 0.948 (± 0.050), demonstrate the pristine environment throughout the period under consideration with scattering type aerosols. The moderate high values of SSA are associated by the dominance of scattering aerosols. The volume size distribution shows the tri-modal distribution for all the four seasons and during the whole period of study with the primary, secondary and tertiary peaks are at~0.2, 1.5 and 11 μm, respectively. Further details about the measurements, data analysis and its implication to climate change will be discussed during conference.

Threats to Himalayan Ecosystem due to Long Range Transport of Pollutants and Land Use Changes

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Abstract

The energy and food needs of mankind have significant impacts on the atmosphere and ecosystems in various manners. One of these impacts is the change in air composition which in turn affects sensitive ecosystems through atmospheric depositions. Himalayan ecosystem is also not an exception to it. This study highlights the rate and sources of deposition of acidifying species at the Himalayan sites located in the Jammu & Kashmir, Himachal Pradesh and Uttaranchal states. Trajectory analysis showed that a large amount of sulphate and nitrate is transported to the Himalayan ranges through the long range transport from far Europe. However, local sources including land use changes and agriculture also contribute such substances. Some samples of snowmelt had relatively low pH indicating higher acidity which may be a threat to the Himalayan ecosystem in due course of time. Developmental activities in the Himalayan ranges are the dominating sources of crustal aerosols which are also responsible for poor air quality in the region. The construction and deforestation contribute huge amount of dust particles which are rich in calcium. Hence, the interaction of calcium aerosols with different gaseous species has a great significance in the region. The study suggests a need of comprehensive research about different air pollutants, their transport, transformation and deposition on to the mountains. There is a need of integrated assessment of the possible impacts of atmospheric deposition including the reactive nitrogen species in the Himalayan ecosystem.

Assessment of Climate Change Impact on Glacier Health using Geospatial Techniques

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Abstract

The most widely reported manifestation of climate change impact on glaciers are the rapid retreat of glaciers, shift in snow line altitude and reduced mass balance. The impact of climate change on glaciers is already realised in the Himalaya. However, due to paucity in the availability of field data, particularly in this regions, it could not be well addressed. In the present study, an attempt has been made to study the impact of climate change on Mrigthuni Glacier, part of Pindari group of glaciers using geospatial techniques. The trend analysis of temperature and precipitation revealed an increasing trend in temperature and precipitation at annual scale. However, decreasing trend in precipitation and increasing trend in temperature was observed during winter months (accumulation period). Such changes lead to reduction snowfall and its accumulation; and impact the glaciers negatively. To study the changes in the glacier due to climatic forcing, the temporal remote sensing data has been used for snout and glacier mapping. The study results depicted that the glacier has retreated around 840 m during the period from 1990 to 2015. Its equilibrium line altitude has moved upwards by around 66 m. There is accumulation area ratio change from 59.6% in the year 1994-1995 to 56.4% in the year 2015-2016. Subsequently, the mass balance has reduced from -0.82 m w.e. to -1 m w.e. during the period of analysis. The consistent negative mass balance indicates the deteriorating health of the glacier. The work highlighted the importance of geospatial technology in the study of glacier dynamics in Himalayan region.

Airborne Hyper-spectral Sensor (AVIRIS- NG) data analysis for Snow Surface Characteristics – Case Study for a Part of North-West Himalaya

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Abstract

Spatial distribution of snow surface properties is essential for hydrology and climatology applications. Retrieval of spatial information of snow parameters from optical remote sensors depends on the understanding of spectral response of snow. Hyperspectral technology provides contiguous spectral information over large wavelength range of EM spectrum which can be used to comprehend spectral response of snow and further retrieval of snow surface parameters. In this direction, **A**irborne **V**isible and **I**nfra-**R**ed **I**maging **S**pectro-radiometer – **N**ext **G**eneration (i.e. AVIRIS-NG), hyper-spectral sensor operating in the range 350-2500 nm was flown over the Indian North-west Himalayas for the first time during February 2016. In the present study, data acquired by the airborne hyperspectral sensor was explored for retrieval of snow surface characteristics i.e. snow grain size and fractional snow cover area.

Snow grain size (SGS) is an indicator of metamorphic state of snow and was mapped using Spectral Angle Mapper (SAM) technique. Based on SGS, snow was classified into three classes i.e. fine, medium and coarse grain snow. End-members corresponding to these three classes were derived using nD visualizer in ENVI software. Matching of derived image end members with USGS library lead to similarity scores of 0.76, 0.82 and 0.74 for fine, medium and coarse grain snow classes respectively. Further, image was classified into three snow classes using SAM and Grain Index method. It was found that fine grain size class was dominant over other grain classes in terms of areal coverage and overall matching area was 80% for the classification performed using both the methods. Further, uncertainty in snow cover area estimation due to mixed pixels in the image was analyzed. For this task, depending on season of data acquisition and field observations, two abundant end members were considered i.e. snow and rock. Constrained linear un-mixing approach was applied to derive the abundance map of end-members in mixed pixels. This work will help to reduce the uncertainties in snow cover area estimation due to mixed pixels in image.

Reconstruction of palaeo-glaciation and equilibrium line altitude (ela) changes in the Suru River basin, Western Himalaya

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Abstract

Here, we present the glacial history of the Suru river basin and contributing sub valleys (Achambur, Kangriz, Shafat and Pensilugnpa), western Himalaya. The present study reveals significant changes in the glacier extent and ice thickness during the late Quaternary, driven by regional and global climatic changes. Based on the field surveys, geomorphological mapping and OSL ages of morainic sediments, six glacial advancement stages have been identified in the Suru river basin. These glacier advance stages in the basin belong to Marine Isotope Stage (MIS) 3 to 4 and Little Ice Age (LIA). During the oldest stage the Suru river basin was occupied by ~173 m thick ice cover (beyond the Pensilungpa, Shafat, Kangriz and Achambur valleys) which decreased ~86 m with an insignificant lateral and vertical shrinking that continued till present day snout positions. It is also observed that the present-day mean equilibrium-line altitude (ELA) has risen to 5374 m asl as compared to 4836 m asl during oldest stage in the basin. This implies an ELA change of ~538 m which is commensurate with the maximum extent of the glaciers (down valley) to present day. The glacier reconstructions for the Suru river basin and its tributaries demonstrate that glaciations have become progressively less extensive through time. This work provides important insights into the paleoclimate pattern and indicate that the Suru river basin has a glacier advances driven by a decrease in temperature with increase in moisture supply due to the enhanced mid-latitude westerlies during MIS 3 to 4, MIS-2 and consistent with the cold Northern Hemisphere air temperature sustained by increased snowfall during the LIA cooling phase.

Regional slope instability regime, Satluj River valley, Northwest Himalaya

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Abstract

Regional slope stability evaluation of the landslides has been attempted mostly using the Geographical Information System (GIS) approach that comprises uncertainties due to the generalization of material properties. However, Finite Element Method (FEM) based analysis of individual landslide slopes, if were performed at regional scale may avoid such generalization and associated uncertainties. This study involves the FEM approach to evaluate the regional instability pattern by considering the Satluj River valley, Northwest (NW) Himalaya as the case study area. This river valley has claimed ~350 lives and loss of ~ 30 million USD due to the landslides and floods in the last four decades and holds potential for further socio-economic loss. In this study, total forty-four (44) active landslides; 20 debris slides, 13 rockfalls, and 11 rock avalanches are modeled using the 2D plane strain FEM approach in which Shear Strength Reduction (SSR) technique is used to find out the Factor of safety (FS). To account the uncertainty caused by the selection of 2D slope section and value of input parameters, multiple slope sections, and parametric study are also performed, respectively.

Results indicated that ~38% of the total area occupied by the all 44 landslides belong to unstable slopes (FS<1), whereas remaining ~ 62% is subjected to metastable slopes (1<FS>2). Most of these unstable landslide slopes are also among the most voluminous. About ~70 % of the total human population along the study area reside in the ~500 m vicinity of these unstable landslides and is exposed to the existing landslide hazard. An inverse relation between the FS and landslide dimension is also observed. The FS and Total Displacement (TD) of the landslide slopes are noted to be most sensitive towards frictional parameter of the soil/rock and in situ field stress conditions. This study provides detailed insight into regional instability pattern and associated uncertainty evaluation and will be useful in future prospects involving mitigation of the disastrous influence of the landslides.

Analysis of combined seismic catalog in NW Himalaya: Mapping of b-value and investigating the anomalous quiescence-activation between two strong earthquakes

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Abstract

The ongoing shortening/thrusting due to a high rate of convergence between the Indian and Eurasian plates within the Himalayan wedge make Himalaya one of the most seismo-tectonically active regions in the world. The present study is to address the high seismicity observed in the NW Himalaya region using

the parameters such as magnitude of completeness, b-value and cumulative energy release. It is based on the compilation of the combined earthquake catalog for the period 1551 to 2017. Analysis of seismicity using aforementioned parameters is useful to understand the general trend in the heterogeneity and most seismically active regions in the study area. Improved picture of space-depth distribution of earthquakes recorded by temporary and permanent local seismic networks, past data regional and global networks, historical records shed new insight on the linkage of observed diverse seismic characters with the mega-thrusts and local active tectonic features of the Himalaya. Data of some specially designed campaign mode seismic monitoring experiments have strengthened the pioneering observation of seismicity in the Himalaya providing detailed information of seismicity controlled by local tectonic features.

The seismic catalog (1551-2017) for the Northwest Himalayan region (26ºN-34ºN and 74ºE-82ºE) compiled by combining the Wadia Institute of Himalayan Geology, Dehradun (WIHG), India Meteorological Department (IMD) and International Seismological Centre (ISC)network records and processed. Analyzed the magnitude of completeness of the catalog for the different time periods. The space-time magnitude flow of earthquake sequences for the period of 1963-2017 and 1991-2017 complete for earthquakes M ≥ 4.5 and M ≥ 3.3 respectively. The data include 29 strong and higher magnitude earthquakes including Mw 7.8 great Kangra earthquake of 1905. The recent instrumental seismicity data indicates that moderate and micro-earthquake seismicity has high concentration for ~50 km stretch around the surface trace of Main Central Thrust. The seismicity is mainly focused in the upper crust up to 20-25 km depth and mostly located around the Main Himalayan Thrust. The study area is divided into three sectors and analyzed it for the time–frequency spectral composition for the period 1991- 2017 and observed the intensification of the periodic components in association with the two large earthquakes; namely the October 19, 1991 Uttarakashi earthquake (Mb=6.6) and March 29, 1999 Chamoli earthquake (Ms = 6.6). This enhancement in the periodic component amplitude in the period range more than 1095 days, apparently related with the consolidation and the dialatancy hardening in the focal zone of earthquake. For the well-defined precursors during the earthquake sequences the real time monitoring of the time-frequency dynamic spectra is a suggestive solution. Mapped the spatial variation of b value of the period 1991-2017.Calculated the cumulative energy release by earthquakes for the entire catalogue and mapped it for the study region.

Climate Impact on the Cryosphere Changes and Aridity in Pamir

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Abstract

We analysed the modern impact of climate change on the aridity, seasonal snow cover, and glacier dynamics at the Pamir mountains (AmuDar'ya River basin) using data of meteorological and glaciological observation from 1945 to 2016 and remote sensing data between 1970 and 2016. The maximum air temperature changes were observed in the Western Pamir below 1000m, minimum in Central and Eastern Pamir above 4000m. The difference between the means of the annual air temperatures for the two periods of 1977-2016 and 1945-1976 in Pamir is two times lower than in all central Asia. The

difference in annual precipitation for the two periods in Pamir is more than twice larger than the difference over central Asia. The positive difference in annual precipitation increases with an increase in elevation. The largest positive difference is observed in the winter, in the Western Pamir. The main climatic features that distinguish Pamir from other central Asian regions are the major contributions of moisture in the winter-spring while summer precipitations are minimal. There are insignificant increases in air temperatures and in annual precipitation between 1977 and 2016, compared to the period from 1945 to 1976. We did not find significant changes in aridity during two considered periods in Pamir. The coupling between large-scale atmospheric patterns and modifications of regional precipitation revealed the intensified influence of *Arctic Oscillations* and the loss of influence of the *Pacific North American mode*, which caused an increase of the winter precipitation between 1977 and 2016. The weakened impact of *North Atlantic modes* caused the decrease of spring precipitation in all of Pamir's regions.

Analysis of AVHRR and MODIS satellite images from 1986 to 2016 revealed the highest snow cover duration (over 240 days of perennial snow cover) above 3000m with a maximum at Central Pamir. Low elevations at Western Pamir and Eastern Pamir have less than 30 days of snow cover duration. Areas above 3000m show decreasing snow cover durations (-1.59 days/year) while the Pamir-Altai and Western Pamir ridges exhibit increases in snow cover duration (1.24 days/year).

Analysis of high resolution satellite images (KH-9, Landsat ETM+, SRTM DEM, ALOS PRISm, Quick Bird and SPOT) between 1970 and 2016demonstrated that Pamir glacier area has decreased on average by 5% or 615km^2. The glacier area changed in Pamir mainly due to the recession and disappearance of small-sized glaciers with areas between 0.5 and 2.0km^2. The medium- sized glaciers, from 2.1 to 10.0km^2, and particularly large glaciers with areas more than100km^2 in Central Pamir changed only by 2-3%. The largest glacier area changes (up to 10%) appeared in the northwestern and southwestern Pamir. There are 35 glaciers in Central Pamir that have been observed to be increasing in area between 1970 and 2016. The changes in the volumes of the glaciers are more significant rather than changes in glacier areas, up to 15%.

Highway Slope Management for Climate Resilient Infrastructure

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Abstract

A large network of highway infrastructure already built across the hilly areas of the country including Himalayan states witnesses the increasing incidences of the mass movement, including landslide hazards. The increasing trend of such hazards coincides with the increasing climate variability and change which has become a major concern all over the world. The direct, as well as the indirect losses from the climate induced disasters on the highways, are escalating with a rapid pace. The damage and disruption of the highways due to landslides is so frequent and widely distributed in the rainy season that the concerning agencies find it difficult to take any proactive measures except the temporary restoration,

leading to a prolonged unprotected slopes which repeatedly fail during the subsequent years and become the cause of unbearable loss of taxpayer's revenue. In this paper, part of the Garhwal region is taken as an example for discussion.

Rainfall is one of the major triggering factors for landslide occurrence world over. In the Garhwal region of Uttarakhand, 88 % of landslides reported have occurred during four months of the monsoon season, due to extreme rainfall events, prolonged heavy rainfall and/or the cumulative effect of rainy days. As widely reported, any changes in rainfall and temperature pattern will likely alter long-term climatic averages, frequency, and severity of extreme weather events, which will also have physical impact on various infrastructures including the highways. The evidence of the preceding has already been reflected through increased frequency of disruption/damage to hill highways. Increase in the unpredictable variability pattern and extreme climatic events have further aggravated the problems causing severe unpredicted damage to lives and properties. In the present study, spatial and temporal variability patterns of rainfall and temperature in hilly regions of Garhwal has been studied. The occurrence of heavy rainfall (>100 mm/day rainfall) was separately noted for past 50 years to check the variability in their frequency, amount, and affected areas over past years with respect to the frequency of rainy days. The widespread impact of the single rainfall event was also studied over the region. Landslides, due to heavy rains, have been happening during monsoon season but, over the years as revealed from the study, their extent of distribution and losses, have become more widespread in spite of decreasing rainy days but increasing frequency of extreme events.

The increasing climate variability and the change with their physical impact on the infrastructures are already visible and possibly irreversible. Therefore, the planning, design, operations, maintenance, and management of infrastructure should be in a way that foresees, prepares for, and adapts to the changing climate. To construct climate resilient highways, assessment of climate risk causing slope failure is done not only to provide climate resilient and environmentally optimized design of highways for better slope stability but also, for long-term, climate resilient highway-slope maintenance practices. The highway-slope maintenance practices should be made an integral part of the highway so that both the highways and their slopes are maintained together to lessen the climate risk and avoid frequent damage to the highways.

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Nestled in the Shivalik Range of the Himalayas, away from the bustle of the metropolis, a new abode of learning has germinated. A few hours before the Himalayan resort Kullu in Himachal Pradesh, IIT Mandi has been established with the vision to be a leader in science and technology education, knowledge creation and innovation, in an India marching towards a just, inclusive and sustainable society.