2016

# 6th Third Pole Environment Workshop

***Understanding coupled physical, chemical, biological and social systems***

Columbus, OH, U.S.A., May 15-18, 2016

U.S. Third Pole Environment Office
Byrd Polar and Climate Research Center

Compiled in 2016 by the

**U.S. Third Pole Environment Office**

**Byrd Polar and Climate Research Center**

This report may be cited as:

Thompson, L.G., E. Mosley-Thompson and X.X. Yang, editors. 2016. *6th Third Pole Environment Workshop: Understanding Coupled Physical, Chemical, Biological and Social Systems*. BPCRC Technical Report 2016-02, U.S. Third Pole Environment Office, Byrd Polar and Climate Research Center, The Ohio State University, Columbus, Ohio, 85 pages.

# 6th TPE Workshop, Columbus, OH, USA

## *Understanding coupled physical, chemical, biological and social systems*

### May 15-18, 2016, Columbus, Ohio, U.S.A.

| ***Sunday, May 15, 2016*** | | |
|---|---|---|
| 6.30 - 8.30 pm | ** Registration & Ice Breaker | LOCATION - Hilton Garden Inn |

| ***Monday, May 16, 2016*** | | |
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| 8.00-8.50 am | ** Registration (continued) ** | LOCATION - Byrd Polar and Climate Research Center, Room 240, Scott Hall, OSU, West Campus |
| **Time** | **Speaker** | **Theme** |
| 9.00-9.05 am | Ellen Mosley-Thompson, Director, BPCRC | Welcome and Introduction to the BPCRC |
| 9.05-9.15 am | Caroline C. Whitacre, Vice President for Research, The Ohio State University | OSU welcome address |
| 9.15-9.20 am | Anil Mishra, Programme Specialist, Section of Hydrological Processes and Climate, International Hydrological Programme (IHP), UNESCO / Division of Water Sciences | Scientific cooperation within the framework of UNESCO-International Hydrological Programme (IHP) |
| 9.20-9.30 am | Tandong Yao, Professor and Director of Institute of Tibetan Plateau Research, Chinese Academy of Sciences | Introduction of the TPE program |
| 9.30-9.40 am | Volker Mosbrugger, Professor and Director-General of Senckenberg Museum for Natural Research | Introduction of the TPE global vision |

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| 9.40-9.50 am | Lonnie Thompson, Distinguished University Professor, The Ohio State University | Introduction of the TPE satellite office in US |
| 9.50-10.10 am | | ***Ceremony to open the TPE satellite office in the U.S. at the BPCRC*** ***(To be held on the front steps of Scott Hall)*** |
| 10.10-10.30 am | | **** Group Photo & Coffee Break **** |
| | | |
| ***Session 1*** | ***Chair: David Molden*** | ***Ecosystems*** |
| 10.30-10.50 am | Volker Mosbrugger | Third Pole Environment: Past, Present and Future |
| 10.50-11.10 am | Yangjian Zhang | Responses of vegetation phenology to global change on the Tibetan Plateau |
| 11.10-11.30 am | Eryuan Liang | Increased stem density and competition may diminish the positive effects of warming at alpine treeline |
| 11.30-11.50 am | Carina Hoorn | Why and how did steppe composition change on the NE Tibetan Plateau throughout the Cenozoic? |
| 11.50 am-12.10 pm | Fan Zhang | Sediment transport in the Yarlung Tsangpo River |
| 12.10 -1.10 pm | | ****** Lunch ****** |
| | | |
| ***Session 2*** | ***Chair: Jeffrey Kargel*** | ***Glacial fluctuation*** |
| 1.10-1.30 pm | Thamban Meloth | Integrated study of benchmark glaciers in Chandra Basin, western Himalaya, India |
| 1.30-1.50 pm | Ninglian Wang | Spatial pattern of the glacier shrinkages over the Tibetan Plateau since the Little Ice Age and the role of the summer freezing level |
| 1.50-2.10 pm | Pradeep Mool | Cryosphere monitoring in the Hindu Kush Himalaya by ICIMOD |
| 2.10-2.30 pm | Kadyrbek Sakiev | Conditions of modern glaciation in the territory of Kyrgyz Republic |
| 2.30-2.50 pm | Keqin Duan | Fate of glaciers in the eastern Tibetan Plateau by 2050 |
| 2.50-3.10 pm | Joseph Shea | Glaciological and hydrological sensitivities in the Hindu Kush – Himalaya |
| 3.10-3.25 pm | | ****** Coffee break ****** |

| *Session 3* | *Chair: Deliang Chen* | *Human impacts on and interplay with TPE* |
|---|---|---|
| 3.25-3.45 pm | Paolo Gabrielli | Tracing the global diffusion of the (a)nthropocene by using low latitude ice cores |
| 3.45-4.15 pm | Emilie Beaudon & Roxana Sierra-Hernandez | Characterization of atmospheric trace elements in the Puruogangri and Guliya ice cores: Tibetan Plateau environmental and contamination histories |
| 4.15-4.35 pm | Guangjian Wu | The majority of fine silt in mid-high tropospheric Asian dust: Evidence from ice cores on the Tibetan Plateau |
| 4.35-4:55 pm | Shresth Tayal | Snow cover variability in Western Himalayas and its implications for socio-economic livelihood of local communities |
| 4:55-5.15 pm | Jawad Nasir | Geochemical characteristics of headwaters and tributaries of Indus River, Karakoram-Himalaya Region, Pakistan: A baseline study for spatio-temporal mapping of major ions and trace elements |

| *Session 4* | *Chair: Ellen Mosley-Thompson* | *Oral introduction of posters, 3 minutes each* |
|---|---|---|
| 5.15-5:50 pm | *Oral introduction* | |
| | Joseph Shea | #01:Surface mass balance and the debris-covered area of Changrinup Glacier (Nepal) assessed from an ice flux method |
| | Sourav Saha | #02:An attempt to reconstruct high-resolution Holocene glacial fluctuations across the Himalayan-Karakoram-Tibetan orogeny |
| | Joel Barker | #03:Black carbon concentration in the Dasuopu ice core: 1782-1996 |
| | Elizabeth Orr | #04: Interaction between climate and erosion in high altitude mountain environments: The effect of precipitation gradients upon headwall erosion in Northern India, NW Himalaya |
| | | #05:Quaternary glaciation of Stok, Northern Zanskar Range, TransHimalaya, Northern India |
| | Melanie Perello | #06:Variability in the Indian summer monsoon precipitation and lake levels in Eastern Tibet |
| | Inka Koch | #07:Ice thickness and thermal structure of a high altitude Himalayan glacier |
| | Kun Shang | #08:Daily sampled mass fluxes in High Mountain Asia from satellite gravimetry |
| | Yuanyuan Jia | #09:Monitoring land subsidence and riverbank erosion in coastal Bangladesh using synthetic aperture radar interferometry and optical imageries |

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| | Chunli Dai | #10:Improved constraint on earthquakes source models from GRACE data |
| 5:50-6.30 pm | **Poster session (Note: The additional posters below will be displayed but were not introduced orally)** | |
| | Anna Wegner et al. | #11:Five centuries of trace element deposition at the top of the Himalaya: natural background vs. anthropogenic pollution |
| | M. Litt et al. | #12:The physical basis of temperature index melt models in the Himalayas |
| | D. Stumm et al. | #13:The seasonal in-situ mass balance of Yala Glacier, Langtang Valley, Nepal, from 2011 to 2015 |
| 6.45 pm | **Shuttle back to hotels for dinner at the Hilton** (*Buses will be waiting in the parking lot to the north of Scott Hall*) | |

## *Tuesday, May 17, 2016*

| **Time** | **Speaker** | **Theme** |
|---|---|---|
| ***Session 5*** | ***Chair: Yongkang Xue*** | ***Asian Monsoon*** |
| 8.30-8.50 am | Yaoming Ma | The study on the heat and water vapor transfer over heterogeneous landscape of the Third Pole region |
| 8.50-9.10 am | Lide Tian | Influence of large scale atmospheric circulation on interannual precipitation and ice core record in the Asian monsoon region |
| 9.10-9.30 am | Lochan P. Devkota | Connection of winter precipitation system in and around southern slope of the central Himalayas with Pacific and Indian Ocean indices |
| 9.30-9.50 am | Tao Wang | The past, present and future of South Asian summer monsoon |
| 9.50-10.10 am | Sebastian Ortega | The role of the Third Pole in global dynamics |
| 10.10-10.25 am | | ****** Coffee Break ****** |
| ***Session 6*** | ***Chair: Volker Mosbrugger*** | ***Climate changes on decadal to millennial time scales*** |
| 10.25-10.45 am | Lonnie Thompson | New Guliya ice cores provide records for understanding recent and millennial-scale glaciological and climatological processes on the Third Pole |
| 10.45-11.05 am | Broxton Bird | Lake sediment records of Holocene Indian Summer Monsoon variability from the Southeastern Tibetan Plateau |
| 11.05-11.25 am | Gerd Gleixner | Holocene moisture evolution at the TPE |

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| 11.25-11.45 am | Aubrey Hillman | A lacustrine record of Indian summer monsoon variability from the Yunnan Plateau: Its connections to the Tibetan Plateau and links to society |
| 11.45 am-12.05 pm | Daqing Yang | Qinghai lake long-term climate and hydrology changes |
| 12.05-1.15 pm | | ****** Lunch ****** |

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| ***Session 7*** | ***Chair: Lonnie Thompson*** | ***Hydrological observation and modeling on the Third Pole*** |
| 1.15-1.35 pm | David Molden | Implications of climate change on Hindu Kush Himalayan River Systems |
| 1.35-1.55 pm | Fengge Su | Response of annual and seasonal streamflow and daily extremes to the 21st century climate change for the headwater river basins in the Tibetan Plateau |
| 1.55 -2.15 pm | Gianni Tartari | Climate change increases the solutes in high elevated lakes |
| 2.15 -2.35 pm | Franco Salerno | Glacier melt and precipitation trends detected by surface area changes of Himalayan glacial ponds |
| 2.35 -2.55 pm | Anil Kulkarni | Identification and mapping of potential moraine dammed lake sites due to glacial retreat |
| 2.55-3.15 pm | John Pomeroy | Addressing the world climate research program grand challenges in high mountain environments-progress by the International Network for Alpine Research Catchment Hydrology |
| 3.15-3.30 pm | | ****** Coffee break ****** |

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| ***Session 8*** | ***Chair: Shilong Piao*** | ***Improving our understanding of basic mechanisms of TPE changes*** |
| 3.30-3.50 pm | Deliang Chen | Assessing the long term topographic effect on solar radiation over the Tibetan Plateau |
| 3.50-4.10 pm | Yongkang Xue | The development in modeling Tibetan Plateau land surface processes |
| 4.10-4.30 pm | Nick Pepin | Accelerated warming at high elevations: A review of the current evidence and proposals for future research |
| 4.30-4.50 pm | Kun Yang | Development of a water and enthalpy budget-based glacier mass balance model (WEB-GM) and its validation at a maritime glacier in southeast Tibetan Plateau |
| 4.50-5.10 pm | Tobias Bolch | Heterogeneous glacier thinning patterns in Langtang Himalaya (Nepal) since 1974 |
| 5.10-5.30 pm | Umesh Haritashya | Third Pole Region: Application of index model for estimating melt runoff in the era of climate change |
| 5.30-5.50 pm | Inka Koch | Snow-rain point temperatures from automatic weather station data at high elevations in the Nepal Himalayas |

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| 6.10 pm | Transportation from BPCRC to the OSU Faculty Club<br>(*Buses will be waiting in the parking lot to the north of Scott Hall*) |
| 6.30-8.30 pm | ******Dinner by the Local Organizing Committee at the OSU Faculty Club******<br>**(***Buses will start for the hotel at* ***8.50 pm*****)** |

## *Wednesday, May 18, 2016*

| **Time** | **Speaker** | **Theme** |
|---|---|---|
| ***Session 9*** | ***Chairs: Ninglian Wang*** | ***Geohazards and Earth System Interactions*** |
| 8.30-8.50 am | Jeffrey Kargel | The 2015 Gorkha earthquake's induced geohazards in the Higher and Lesser Himalaya |
| 8.50-9.10 am | Andreas Mulch | Where geodynamics meet atmosphere and biosphere: Paleoaltimetry of the Tibetan-Himalayan system |
| 9.10-9.30 am | Yunus Mamajanov | Climate change and natural disasters in Tajikistan |
| 9.30-9.50 am | Shichang Kang | Trans-boundary atmospheric pollutants and their effects on cryospheric change over the Third Pole |
| 9.50-10.10 am | Peter Van Oevelen | The WCRP water grand challenge, the GEWEX hydroclimate projects and the Third Pole Environment |
| 10.10-10.30 am | Tandong Yao | Glacier melt and multi-sphere interactions on the Third Pole |

***Group leaders will be assigned and the meeting room for each group announced***

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| 10.30-10.45 am | ******Coffee Break****** |
| ***Session 10*** | **Group Discussions in the assigned meeting rooms** |
| 10.45 am-Noon | Theme-based group discussions [Discussion questions will be defined prior to the Workshop] |
| ***Session 11*** | **Plenary Session, Auditorium (Room 240)** |
| Noon-1.00 pm | Plenary discussion and summary |
| 1.00-2.00 pm | ****** Lunch ****** |

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|---|---|
| 2.00-2.40 pm | **Tour of ice core paleoclimatology facilities of the BPCRC** |
| 3.00 pm | ******Shuttle back to Hotel****** |

Notes:

1. Lunch will be served in Room 177 of the Scott Hall.
2. Coffee breaks will be held outside the auditorium, Room 240.
3. Tour of the ice core paleoclimatology lab will be conducted in the basement of Scott Hall. Meet outside Room 82.

# 目录

# *Session 1*

# *Ecosystems*

# Third Pole Environment: past, present and future

V. Mosbrugger[1*], A. Favre[4], A. Muellner-Riehl[4], M. Päckert[2], A. Mulch[1]

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2. Senckenberg Naturhistorische Sammlungen, Dresden, Germany

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4. Department of Molecular Evolution and Plant Systematics, Institute of Biology, Leipzig University, Leipzig, Germany

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The Third Pole represents a key region of the Earth System with respect to geodynamics, climate dynamics, biodiversity evolution and human well-being. Here we will trace the evolution of geo-biodiversity in the Tibeto-Himalayan region since its formation in the Eocene to understand the present-day situation and future threats. We will use a systemic approach considering both the local abiotic and biotic dynamics, thus integrating the available geologic, climatic and biologic information. Thereby, our focus will be on general evolutionary patterns for which we can provide examples across a wide range of terrestrial organisms. For the establishment of the present-day biodiversity we identify several important phases: the early uplift of the Tibetan Plateau in the Eocene to Mid-Miocene did not lead to a rapid biodiversity increase; the first peak of biodiversity increase occurred during the Mid-Miocene (20–14 Ma) with a second peak towards the Miocene-Pliocene boundary and a third peak between 3 Ma and 150.000 ka. To explain this pattern we propose the "mountain-geobiodiversity-hypothesis". It postulates three boundary conditions that are required to allow for an impact of mountain formation and surface uplift on regional biodiversity patterns in mountainous regions: 1) presence of lowland, mountainous and alpine zones; 2) climatic oscillations that enable mountains to act as "species pumps"; 3) high relief terrain with large environmental gradients that minimize migration distances caused by climate oscillations, provide sufficient refugia and potential geographic barriers, and ultimately allow for both, survival of many species despite climatic oscillations as well as allopatric speciation. Finally we will discuss "lessons from the past" concerning the actual and future threats to these geoecosystems.

# Responses of vegetation phenology to global change on the Tibetan Plateau

Yangjian Zhang

CAS Center for Excellence in Tibetan Plateau Earth Sciences

Phenology is a sensitive and critical feature of vegetation, and it could reflect the effects of climate variability and change on vegetation growth. Thus, monitoring the vegetation phenology changes could help quantify the effects of climate change on terrestrial ecosystems. The Tibetan Plateau, the largest plateau in the world, has formed a unique climate system. Climate warming magnitude has been greater on the plateau than the other surrounding areas. By integrating manipulative experiments at a plot scale and remote sensing modeling at a regional scale, this study systematically addressed how vegetation phenology responds to each global change associated factor and the underlying mechanism on the plateau. At a plot scale, nitrogen addition obviously advanced vegetation green-up; fast warming delayed vegetation green-up and shortened growing season length; enriched CO2 concentration alleviated the negative effects caused by warming on vegetation phenology. Due to the thicker litter layer and improved soil moisture conditions, banned-grazing can obviously advance vegetation green-up. At a regional scale, vegetation greening up date has obviously advanced in response to climate warming in the past decades. This study revealed that moisture inadequacy caused by fast warming can significantly delay vegetation green-up, while a gradual warming can advance vegetation green-up on the Tibetan Plateau.

# Increased stem density and competition may diminish the positive effects of warming at alpine treeline

Eryuan Liang[1,2*], Yafeng Wang[1], Neil Pederson[3], Aaron M. Ellison[3], Hannah L. Buckley[3, 4], Bradley S. Case[3,5], J. Julio Camarero[6]

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The most widespread response to global warming among alpine treeline ecotones is not an upward shift, but an increase in tree density. However, the impact of increasing density on interactions among trees at treeline is not well understood. Here, we test if treeline densification induced by climatic warming leads to increasing intraspecific competition. We mapped and measured the size and age of Smith fir trees growing in two treelines located in the southeastern Tibetan Plateau. We used spatial point-pattern and codispersion analyses to describe the spatial association and covariation among seedlings, juveniles, and adults grouped in 30-year age classes from the 1860s to the present. Effects of competition on tree height and regeneration were inferred from bivariate mark-correlations. Since the 1950s, a rapid densification occurred at both sites in response to climatic warming. Competition between adults and juveniles or seedlings at small scales intensified as density increased. Encroachment negatively affected height growth and further reduced recruitment around mature trees. We infer that tree recruitment at the study treelines was more cold-limited prior to 1950 and shifted to a less temperature-constrained regime in response to climatic warming. Therefore, the ongoing densification and encroachment of alpine treelines could alter the way climate drives their transitions towards subalpine forests.

# Why and how did steppe composition change on the NE Tibetan Plateau throughout the Cenozoic?

Hoorn, C.(1), Han, F.(2), Woutersen, A.(1), Rydin, C.(3), Bolinder, K.(3), Koutsodendris, A.(4), Zhang, M.(5, 6), Antonelli, A.(7), Silvestro, D.(7, 8), Abels, H.(9), Dupont-Nivet, G.(10,11)

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(11) Géosciences Rennes, Université de Rennes 1, Rennes, France

The modern steppe of the NE Tibetan Plateau is characterized by Poaceae, Asteraceae, Chenopodiaceae, and minor amounts of Ephedraceae and Nitrariaceae (among others). However, in the past the steppe composition was quite different. Ephedraceae and Nitrariaceae were the predominant taxa on the NE Tibetan Plateau until the end of the Eocene (34 Ma), and later replaced by the modern steppe. Here we report on a palynological study of the Cenozoic sedimentary record in the Xining and Qaidam basins in which we documented the composition and abundances of Ephedraceae and Nitrariaceae throughout this period. To fully understand the evolutionary history of the selected steppe taxa, we integrated the paleo-palynological data into a molecular phylogenetic framework while using a timeline based on magnetostratigraphy, and regional geological and climatic events. Our data suggest that the ancestral steppe thrived on NE Tibetan Plateau under the relatively humid, warm climatic conditions that existed until the end of the Eocene. Coinciding with the earliest monsoonal records -during the Eocene- a major change occurred in Ephedraceae

composition. Finally, climatic cooling at the Eocene-Oligocene put an end to the diverse Ephedraceae/Nitrariaceae dominated steppe with taxon diversity and abundances dwindling. Modern Ephedraceae/Nitrariaceae are but a shadow when compared with the former diversity of the pre-Oligocene steppe.

# Sediment transport in the Yarlung Tsangpo River

Fan Zhang*, Xiaonan Shi, Chen Zeng

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The Yarlung Tsangpo River (YTR) flowing from west to east across the southern part of the Tibetan Plateau is the longest river in Tibet. Suspended sediment in large rivers has been widely used as a proxy to evaluate regional soil erosion severity and ecological environment condition. However, sediment transport in the YTR is rarely reported due to data scarcity. This study collected daily runoff and suspended sediment concentration (*SSC*) data for three years from four hydrological stations along mainstream of YTR. Data analysis showed that sediment process mainly occurred from July to September during the rainy season and the time of intensive glacier melt, with highest erosion intensity in the upper middle reach between the Lhaze and the Yangcun stations and large deposition in the lower middle reach between the Yangcun and the Nuxia stations. Annual sediment transported to the Nuxia station, i.e., the terminus of middle reach was 10.43 Mt with a catchment average sediment yield of 54.4 $t/km^2/yr$. In addition, modeling the sediment dynamics in the YTR is important for practical river management. Due to the unique topography and climate features of the Tibetan Plateau, traditional sediment rating curves (SRCs) and subdivision methods such as discharge classes (low, normal and high flow) and discharge stages (rising and falling limbs) have various shortcomings in estimating SSC when applied to the YZR. As a result, new SRC subdivision methods based on flood ranks (FR) and SSC stages (SSCS) were proposed in this study. Results showed that the proposed methods were more accurate for estimation of SSC and subsequent sediment load in the YZR, and could also be helpful for sediment transport study in other alpine river basins under similar conditions.

# *Session 2*

# *Glacial Fluctuation*

# Integrated study of benchmark glaciers in Chandra Basin, Western Himalaya, India

Parmanand Sharma and Thamban Meloth*

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Himalayan glaciers are unique in many respects and in view of their socio economic importance and complex environmental settings, there are many key questions which are either unanswered or have poor understanding may need a proper investigation. The lack of in-situ data and longer term records is also an issue. 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 behaviours and their interrelationship, NCAOR has initiated a long term integrated glaciological monitoring programme on Chandra basin, Himachal Pradesh since 2013. Based on criteria like the accessibility, topographic and climate regime, length, aspect, altitude, six glaciers (Sutri Dhaka, Batal, Samudra Tapu, Bara Shigri, Gepang and Kunzam) covering 306 $km^2$ glacier areas (43% of glacier area with altitudinal range of 3500-6800m amsl) of Chandra basin, Lahaul-Spiti, Himachal Pradesh (India) were selected for various glaciological studies. The main thrust of this programme is to understand glacier dynamics processes and their link with hydrology and climate. The Chandra basin, one of the major basin of Indus River systems, having 706 $km^2$ glacier area (30% of catchment area) with 187$km^3$ ice reserve has experienced a basin wide negative balance and observed a significant increment in discharge of 7% during a span of 28years between 1972 -2000. Although the Chandra basin falls into the monsoon-arid transition zone which is alternatively influenced by the summer Asian monsoon and the mid-latitude westerlies, this basin has experienced lee-ward effect, preventing part of the monsoon precipitation reaching the valley. Since, Indus has highest snow/glacier melt contribution in river flow, glaciers fluctuations in Chandra basin have significant impact on river discharge. In order to understand the role of climate forcing on various aspects of glacier dynamics and hydrological processes, we have installed modern in-situ observational stations, and use geodetic and geospatial techniques to understand the snow cover, mass balance, energy balance, hydrological balance over this part of Western Himalaya.

Further to understand the past changes in environmental conditions and climate in this part of the Himalaya, we propose to undertake preparatory surveys and shallow ice core drilling in some of the glaciers and ice caps of Western Himalaya during the summer of 2016.

# Spatial Pattern of the Glacier Shrinkages over the Tibetan Plateau since the Little Ice Age and the Role of the Summer Freezing Level

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Many Asian large rivers originate from glaciers over the Tibetan Plateau. The changes of glaciers in this region have a significant impact on water supply. In recent years, the Karakoram Anomaly, i.e., the glaciers in Karakoram remained stable and even expanded in contrast to the receding of the glaciers nearby and worldwide, has attracted much attention. There have been many attempts to explain this phenomenon. In order to better understand the causes of this phenomenon, the spatial pattern of the variations of the glaciers in the whole Tibetan Plateau should be explored on a longer time scale. During the Little Ice Age (LIA), the glaciers over the Tibetan Plateau advanced and formed easily recognizable end and lateral moraines, which could be used to identify the extents of glaciers. Using remote sensing images and aerial photos, along with field works, we recognized the distributions of the LIA's moraines of about 2000 glaciers over the Tibetan Plateau. It was found that the glacier areas have reduced by larger than 25% in the southeast Tibetan Plateau and the northeast margin of the Tibetan Plateau while less than 10% in the northwest Tibetan Plateau (including the Karakoram) since the LIA. A similar spatial pattern of the shrinkages of the glaciers was also revealed over the past decades. It's noted that the summer freezing level is much higher than the glacier median elevation in the southeast Tibetan Plateau while much lower in the northwest Tibetan Plateau, and the summer freezing level showed a decreasing trend in the northwest Tibetan Plateau (including the Karakoram) while increasing in the southeast Tibetan Plateau over the past decades. These imply that the summer freezing level play an important role in the spatial variations of the glaciers over the Tibetan Plateau.

# Cryosphere Monitoring in the Hindu Kush Himalaya by ICIMOD

Pradeep Mool
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With the goal to contribute significantly to improve knowledge and understanding on cryosphere by analysing the changes in glaciers, snow, permafrost and glacio-hydrology in relation to impacts of climate change for water resources management in the Hindu Kush Himalaya (HKH), the International Centre for Integrated Mountain Development (ICIMOD) has been implementing the Cryosphere Monitoring Programme.

The Cryosphere Monitoring Programme at ICIMOD has a multilevel and integrative approach and consists of the following five components: (1) Field based glacier and snow monitoring; (2) Glacio-hydrological modelling and water availability scenario analysis; (3) Remote sensing based snow, glaciers, glacial lakes, permafrost, and glacial hazards monitoring; (4) Development of cryosphere knowledge hub; and (5) Capacity building.

In collaboration with national partners in the Regional Member Countries of ICIMOD, glacier mass balance measurement of Thana glacier in Bhutan; Langtang, Rikha Samba, Mera, Pokalde and Changri Nup glaciers in Nepal, as well as glacier mass balance measurement with geodetic method and using UAV of Lirung, Changri Nup and Cholo Cho glaciers in Nepal are being carried out. Similarly, automatic weather stations and hydrological stations were established in those glacier catchments and hydro-meteorological data generated are being used for the glacio-hydrological modelling and water availability scenario analysis. Rehabilitation of the hydro-met equipment installations in the Langtang valley after the 2015 April - May Nepal Earthquake and the Langtang Avalanche blast has been made by repairing and replacement of damaged equipment during the Fall 2015. For glacio-hydrological modelling and water resources scenario analysis, installation of equipment at various locations in Langtang Valley under ‘Snow Accumulation and Melt Processes’ (SnowAMP) project was also carried out during Fall 2015 and regular data are generated from the equipment installed. Snow cover assessment of the HKH region is continuously carried out using MODIS data received through MODIS Satellite Receiving Station established at ICIMOD. Glaciers mapping, decadal glacier change analyses, and glacial lakes change mapping of river basins of the HKH region using remote sensing images were carried out. Assessment of permafrost distribution in the Hindu Kush Himalayan region along with the preparation of permafrost distribution map in Google Earth environment was carried out. As a capacity development activities, ICIMOD is supporting the MS Glaciology degree programme at Kathmandu University since 2011 and organizing various short term training programmes for the partner organizations of the HKH. For knowledge sharing, ICIMOD has been providing a platform called as the 'Regional Cryosphere Knowledge Hub' a web based portal at ICIMOD. ICIMOD is also providing platform by organizing various knowledge sharing events such as international conferences, seminars and workshops. In this regard, the latest event has been the hosting of the International Symposium on Glaciology in High-Mountain Asia (IGS 2015 Symposium) by ICIMOD in Kathmandu, Nepal in March 2015.

# Conditions of a modern glaciation in the territory of the Kyrgyz Republic

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There are several periods of activization and degradation during the glacial evolution of the mountains in Kyrgyzstan. After end of the last "small Ice Age" (1450-1850 AD), the glaciation of Tien Shan and Pamiro-Alay passes into the next stage of degradation with the periods of short-term activization of glaciers.

The modern climate warming in the territory of Kyrgyzstan, as well as in other regions of Central Asia, started from the middle of the 60th years of the twentieth century. The current global warming of a ground layer of atmospheric air and ambiguous change of rainfall in a mountain zone (decrease or remain within climatic norm) gives rise to steady reduction of a modern glaciation. Despite regional distinctions in climatic conditions, the background nature of climate in the Kyrgyz Republic is same and the general tendency of degradation of a glaciation is observed which occurring in mountain systems of all its territory.

We will consider conditions of a modern glaciation in the territory of the Kyrgyz Republic based on the changes of the glaciers areas. Depending on a linear change of length of glaciers, the areas of glaciers will decrease or increase. It should be noted that change of spatial distribution of glaciers happens not only near its end and on its boards, but quite often intensive change can occur at the top sites of glaciers, as well.

The main information on the change of the area of glaciers of Tien Shan is available for certain ridges and river basins for Northern, Middle Tien Shan and the Yssyk-Kol basin, and also for some glaciers located in different parts of the mountain system.

Comparison of cartographic materials and numerous observations over the spatial distribution of glaciers of Tien-Shan leads to a conclusion that there is tendency of reduction of the area of most of glaciers.

**Northern Tien Shan**. For 24 years (1955-1979) the area of a glaciation of the southern slope of Zailiysky Ala-Too Range, in the basin of Chong-Kemin river, were reduced by 3,5 km$^2$ or for 9,1% [2]. At the same time, the similar rates of degradation of a glaciation were noted for other glacial systems of ridges in Northern Tien Shan. According to V. B. Ayzin [1], in the basin of the Ala-Archa river (northern slope of Kyrgyz Ala-Too range), during 1955-1981 thawed 9 glaciers (with 0.1-0.3 km area) out of 33, and the area of a glaciation was reduced from 45,9 to 35,8 km$^2$, in other words for 10,1 km$^2$ or for 22%. These data were based on the analysis of maps with scale 1:25000

In the basin of Sokuluk river, during the period from 1963 to 1986, the average annual speed of recession of glaciers was – 0,6%. From 1986 to 2000 that value increased twice – 1,2%. From 1963 to 1986 the area of glaciers decreased by 13,3%, and from 1986 to 2000 – for 17,1%. The total area of a glaciation for the period from 1963 to 2000 decreased by 28%. Eight glaciers disappeared completely.

**Issyk-Kol basin**. Data about changes of the area of glaciers in the Issyk-Kol hollow is scarce, and the information is available for glaciers in the eastern part of northern slope of Teskei Ala-Too range.

In the basin of Chong-Kyzyl-Suu river, according to V.A. Kuzmichenka [3] during 1955-1977 the area of a glacier of Keldike (No. 260) decreased by 0,35 km$^2$ (6% from total), Ailama glacier(No. 267) by 0,12 km$^2$ or for 1,5%. The same rates of degradation of glaciers were noted in other river pools. So, a glacier East Kol-Tor (No. 339) in the basin of Karakol and glacier Ak-Suu (No. 405) in the basin of Ak-Suu river were reduced by 0,12 and 0,22 km$^2$ or for 2,9 and 8,8%, respectively.

The results obtained at the inspection of glaciers from five river pools of a northern slope of Teskei Ala-Too range testify considerable reduction of the areas of glaciers. In the basin of Chong-Kyzyl-Suu river, in some cases, they decreased by 40%, and in other river pools (rivers of Kichi-Kyzyl-Suu, Chychkan, etc.) total disappearance can be noted. Valley glaciers experienced reductions for 2-5% of total area. In the western part Teskei Ala-Too range, during the period from 1971 to 2002, the area of glaciers were reduced by 8%.

**Internal and the Central Tien Shan**. From 178 glaciers in the Ak-Shyirak massif, from 1943 for 1977, the area of 149 glaciers were decreased, 22 practically didn't change, at 7 increased, i.e. the majority of glaciers was reduced in their sizes. However, the scales of reduction of the areas, here it is less in comparison with northern ridges of Tien Shan. The total area of glacial system decreased by 14,4 km$^2$ or for 3,4%. In average, annually the area of glaciers decreased by 0,424 km$^2$. The greatest relative sizes of reduction of the area are noted in glacial systems of east, southern and northern frames of ridge.

On the southern slope of Teskei Ala-Too range, within Internal and the Central Tien Shan, for the last 150 years the total area of glaciers was reduced by 19% - from 404 $km^2$ to 328 $km^2$. By 2003 the total amount of glaciers increased to 335 because of disintegration of large valley glaciers since small ice age when 297 glaciers were present on that time. The amount of valley glaciers increased from 47 in the middle of the XIX century to 71 in 2003, and 16 glaciers of the small size completely thawed for the XX century. Glaciers with more than 10 $km^2$ lost on the average 10% of the area, thus large glaciers lost the big area. Glaciers with less than 1 $km^2$ in size reduces the area on the average by 30%. Between 1990 and 2003, the greatest speed of reduction is revealed at glaciers of flat tops – they lost annually on the average by 0,6% [4].

Thus, in the second half of the XX century, the greatest reduction of the area was experienced by valley glaciers of Tien Shan. The maximum degradation is characteristic to glaciers of the slopes, having rather small sizes. They lost the area 10-20% more, than glaciers of valley type, and some of them absolutely thawed.

In regional scale, higher rates of reduction of the areas of a xc are noted on ridges of Northern Tien Shan – from 1,1 to 2,4 $km^2$/year, minimum, in internal areas of the mountain system – 0,45 $km^2$/year.

**Pamiro-Alay.** Detailed observations over fluctuations of glaciers in Pamiro-Alay began in 1950 - 1960, during implementation of large international projects: MGG (1957 - 1958) and MGD (1965 - 1974). The data obtained in numerous researches confirm the general tendency of reduction of a glaciation of Pamiro-Alay since the end of the XIX century up to now. According to these data on a northern slope of Alay ridge, in rivers of Ak-Buura, Aravan and Isfairam-Sai, the most part of glaciers recedes. From 1914 to 1963 a glacier Gezart receded about 1 km, Bakalak – on 450 m. For 15 years (1948 – 1963), the area of glaciers in Ak-Buura and Isfairam-Sai's sources were reduced by 3,7 $km^2$. During the period from 1912 to 1984 the process of degradation is noted in the river basin of Kok-Suu (the southern slope of Alay ridge) on glaciers Allautdin Severnyi and Yujnyi. They were reduced by 1900 and 900 m, respectively [43]. During the period from 1957 to 1980, total reduction of the area of glaciers of Gissaro-Alay made 15,6% at the area of a glaciation of the mountain system of 2183 $km^2$.

Glacier Abramov is a representative glacier in studying of a glaciation of Pamiro-Alay. According to geomorphological researches, with using materials of aero-photo shoots, the maximum length the glacier reached in 1860, and according to other data in 1850 – 11 km. In the general reduction of a glacier's size, for 125 years two large oscillations are known. The first occurred in 1936 when the glacier promoted on distance about 380 m, the second – by 1971, and by 1973. Then it moved for more than 400 m. Total reduction of length of a glacier from 1860 to 1984 was about 1700 m. Thus the glacier lost 630 million $m^3$ of ice or 20% of total amount by 1984. During the period from 1968 to 1982 the glacier lost ice on average about 17 million $m^3$/year.

Modern dynamics and evolution of a glaciation, on the example of glacial systems of two river basins of Alay ridge – Aravan and Ak-Buury, we can study by the results received at a decoding of polyzonal satelite image (Landsat, for 2000) with further calculation of the area of glaciers, and topographic maps of 1965. As a result of the analysis of vector layers and calculation of geometrical parameters the following results are received. For 35 years, the area of open part of the glaciers located in a river basin of Ak-Buura and partially in a river basin Aravan was reduced by 50,66 $km^2$ that makes 29,1%. In 2000, the amount of glaciers in comparison with 1965 increased by 46 units, as a result of crushing of big glaciers on slightly small. Some small glaciers, mainly, located at lower hypsometric levels disappeared completely. Similar works were carried out and for other glacial systems of river basins of northern slopes of Turkestan and Alay ridges.

From 1957 to 1980 the number of small glaciers are increased due to disintegration (division) of glaciers of the average size. For the period of 1980-2001, reduction of number of glaciers at the expense of a thawing of the small is characteristic. From 1957 to 1980, the areas of glaciers with more than 2-5 $km^2$ in size were most of all reduced, the area of glaciers with less than 2 $km^2$ changed insignificantly. In 45 years glaciers of a northern slope of Turkestan and Alay ridges in three river pools were reduced for 18,3%. As a whole, during the period from 1957 to 2001, the area of glaciers of a northern slope of Turkestan and Alay ridges in considered river pools was reduced on the average by 21%.

It should be noted that along with an recession of glaciers, there were also short-term periods of their activization. For example, many glaciers of the basin of Soh river, during the period from 1960 to 1978 are increased in size. Most significantly – for about 100-120 m – increased the sizes glaciers Tyutek, Klyueva, Raigorodskogo. Only one of seven glaciers – Kok-Beles recessed for 18 m. In the late 1950 and to the middle of the 1960th in a nival-glacial belt of the region climatic conditions were colder than norm with a significant amount of a precipitation. 1964, 1972 and 1975 were also the coldest years.

In summary we note the followings. In the conditions of the modern warming of a ground layer of atmospheric air in the mountain zones Gissaro-Alay, for example, on the Alay ridge more intensive temperature increase of air in comparison with regions of Internal Tien Shan is found. At the same time growth of the average annual sums of a precipitation is found. But, despite the scale of a glaciation of the studied areas are exposed to stronger reduction in comparison even with nearby glacial systems of Mountains Tien Shan and Pamiro-Alay that is caused probably by significant increase in air temperature.

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# Fate of glaciers in the eastern Tibetan Plateau by2050

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As the third polar on the Earth, the Tibetan plateau holds more than 40,000 glaciers which have experienced a rapid retreat in recent decades. Glacier loss has increased concern for water resources around the Tibetan plateau. The variability of equilibrium line altitude (ELA) indicates expansion and wastage of glacier directly. Here we simulated the ELA variability in the eastern Tibetan Plateau based on a full surface energy and mass balance model. The simulation results are agreement with the observations. The ELAs have risen at a rate of 2-8m/a since 1970 throughout the eastern Plateau, especially in the Qilian Mountain and the southeastern Plateau where the ELAs have risen to or over the top altitude of glacier, indicating the glaciers are accelerating to melting over there. Two typical glacier, Xiaodongkemadi glacier in the center of the Plateau and Qiyi glacier in the Qilian Mountain are chosen to simulate its future ELA variability in the scenarios of RCP2.6, RCP4.5 and RCP 8.5 given by IPCC. The results show the ELAs will arrive to its maximum in around 2040 in the scenario of RCP2.6, while the ELAs will be over the top altitude of glaciers in 2035-2045 in the scenarios of RCP4.5 and RCP8.5, suggesting the glaciers in the eastern plateau will be melting until to disappearance.

# Glaciological and hydrological sensitivities in the Hindu Kush - Himalaya

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Glacier responses to future climate change will affect hydrology at subbasin-scales. The main goal of this study is to assess glaciological and hydrological sensitivities of sub-basins throughout the Hindu Kush - Himalaya (HKH) region. We use a simple geometrical analysis based on a full glacier inventory and digital elevation model (DEM) to estimate sub-basin equilibrium line altitudes (ELA) from assumptions of steady-state accumulation area ratios (AARs). The ELA response to an increase in temperature is expressed as a function of mean annual precipitation, derived from a range of high-altitude studies. Changes in glacier contributions to streamflow in response to increased temperatures are examined for scenarios of both static and adjusted glacier geometries. On average, glacier contributions to streamflow increase by approximately 50% for a +1K warming based on a static geometry. Large decreases (-60% on average) occur in all basins when glacier geometries are instantaneously adjusted to reflect the new ELA. Finally, we provide estimates of sub-basin glacier response times that suggest a majority of basins will experience declining glacier contributions by the year 2100.

# *Session 3*

# *Human impacts on and interplay with TPE*

# Tracing the global diffusion of the (a)nthropocene by using low latitude ice cores.

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While it is generally well accepted that the human action is impacting the Earth system at global scale, the ongoing scientific debate is now focused on when the current epoch, the Anthropocene, started. In this respect, the beginning of the Holocene (～11 kyr BP), the start of the industrial revolution (1860 AD) and the incept of the nuclear era (1945 AD) are often considered by geologists the “golden spike”. However, it has recently been proposed by Ruddiman and colleagues that a formal definition of this period as a geological epoch (the Anthropocene, “A” in upper case) would not acknowledge many other widespread and diffuse impacts that, although not global, unequivocally characterized the human action on the environment during the Earth’s history. Accordingly, a formal starting date of this epoch would be misleading and a more general definition for this period (the anthropocene, “a” in lower case) would be more appropriate. We concur with this vision and we argue that that this epoch emerged discontinuously through space and time during the human history. In this respect, we present the most recent ice core evidences obtained from high elevation drilling sites in Himalaya-Tibet (the so called “Third Pole”), Kilimanjaro in Africa, Quelccaya in the Andes and Mt. Ortles in the European Alps. We show how low latitude cores highlight the differential onset, in space and time, of the human impact on the Earth’s atmosphere. In particular we provide compelling evidence that mining operations caused an unequivocal widespread human impact on the atmosphere well before the advent of the industrial revolution and that the impact of successive industrial activities emerged at different times in various areas around the world.

# Characterization of atmospheric trace elements in the Puruogangri ice core: Tibetan Plateau environmental and contamination histories

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Asia is facing enormous challenges including large-scale environmental changes, rapid population growth and industrialization. The inherent generated pollution contributes to half of all Earth's anthropogenic trace metals emissions that, when deposited to glaciers of the surrounding mountains of the Third Pole region, leave a characteristic chemical fingerprint. Records of past atmospheric deposition preserved in snow and ice from Third Pole glaciers provide unique insights into changes of the chemical composition of the atmosphere and into the nature and intensity of the regional atmospheric circulation systems. The determination of the elemental composition of aeolian dust stored in Himalayan and Tibetan Plateau glaciers can help to qualify the potential contamination of glacial meltwater as a part of the greater fresh Asian water source. The 215 m long Puruogangri ice core retrieved in 2000 at 6500 m a.s.l. in central Tibetan Plateau (Western Tanggula Shan, China) provides one of the first multi-millennium-long environmental archives (spanning the last 7000 years and annually resolved for the last 400 years) obtained from the Tibetan Plateau region. The Puruogangri area is climatologically of particular interest because of its location at the boundary between the monsoon (wet) and the westerly (dry) dominated atmospheric circulation. To characterize the atmospheric aerosols entrapped in the ice, we determined the concentration of trace and ultra-trace elements in the Puruogangri ice core between 1500 and 2000 AD. Particular attention is given to assess the amount of trace elements originating from anthropogenic sources during both the pre-industrial and industrial periods. When compared with records from the Guliya ice cap (Kunlun Shan) and from the Dasuopu glacier (Himalaya), our results bring a new perspective to the climate spatial variability across the Tibetan Plateau.

# Trace Element Determination from the Guliya Ice Core to Characterize Aerosol Deposition over the Western Tibetan Plateau

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The Tibetan Plateau or Third Pole covers over 5 million $km^2$, and has ~46,000 glaciers that collectively contain one of the Earth's largest stores of fresh water. The Guliya ice cap located in the western Kunlun Shan on the Qinghai-Tibetan Plateau, China, is the largest (> 200 $km^2$) ice cap in the subtropical zone. In 1992, a 308.6 m ice core to bedrock was recovered from the Guliya ice cap.

Because of its continental location on the northwestern side of the Tibetan Plateau, the atmospheric circulation over the Guliya ice cap is dominated by westerlies from the Eurasian region.

Here we present the results of the determination of 29 trace elements, Li, Na, Mg, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Nb, Mo, Ag, Cd, Sn, Sb, Cs, Ba, Tl, Pb, Bi, and U from Guliya ice core samples spanning the period 1650 – 1991 AD. This Guliya trace element record would complement the records from the Dasuopu glacier, central Himalaya, and from the Puruogangri ice cap in the western Tanggula Shan in central Tibetan Plateau, which in contrast to Guliya are influenced by the monsoon. We investigate the possible sources both natural and anthropogenic of atmospheric trace elements and their fluxes over the Tibetan Plateau during the last 340 years.

# The majority of fine silt in mid-high tropospheric Asian dust: evidence from ice cores on the Tibetan Plateau

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Dust plays an important role in climate system, but also is the one of greatest uncertainty. Dust particle size is the fundamental property to assess its climate effect. The dust particles size distribution between 1-30 um was measured by Coulter Counter for ice cores from 13 sites on the Tibetan Plateau, where is adjacent to the Asian arid region, which is one of the major dust source in the world. Our results reveal that whether the volume distribution fits the log-normal function or not largely depends on the dust concentration and the specific dust-storm event but is independent of physiographical location and season. Only high-concentration samples obey the log-normal distribution in volume, with mode sizes ranging from 3 to 16 um, with an average of 7 um. The log-normal distribution was largely attributed to the fine silt particles between 3 and 15 um, which contribute most of the total volume. The mass size distribution characteristics for mineral dust particles from Tibetan ice cores reveal that the majority (>70%) of fine silt in mid-high tropospheric Asian dust. These dust size features demonstrate that coarse particles are common in the atmosphere and have a longer lifetime, which can affect the long-rang transport and long-time radiation effect. useful to advance our understanding of dust effects on climate, and provide clues to better characterize atmospheric dynamics of dust transport that will help to improve the current atmospheric models.

# Snow cover variability in Western Himalayas and its implications on socio-economic status and livelihood of local communities

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Evaluation of Snow Covered Areas is important for hydrological and climatological studies (Zhang, et.al., 2010). However, this is equally important for socio-economic studies and developing policies and programs affecting the livelihood of local communities. Western Himalayas receive limited precipitation through monsoon during the summer season, and western disturbances during the winter season are primarily responsible for moisture availability in the region. Hence, snow/ ice melt contributes about 56% of water to rivers flowing from western Himalayas, especially during the early and mid summer season, in Jhelum basin.

The evaluation of Snow cover area using the MODIS8-day composite snow cover data has been done by researchers in the Himalayan regions (Immerzeel, et.al., 2009, Negi et.al., 2009; Gurung et.al., 2011; Joshi et.al., 2015; Rathore et.al., 2015; Singh et.al., 2014). Similarly, studies on vulnerability of local communities to climate change induced environmental hazards have been conducted adopting an index based approach to quantify impacts (Shukla et.al., 2003; Pandey and Jha 2012; Rajesh et.al. 2014). While snow cover variability studies have limited applicability for socio-economic planners due to their regional approach, socio-economic studies are limited to adaptation measures for climate change and associated disasters like heavy precipitation events and flash floods. This study is an attempt to identify linkages between assessment of snow cover variability and its applicability to adapt normal livelihood patterns of local communities.

MODIS Terra 8-day maximum snow products freely available at NSIDC of NASA, for the past 15 year (2001–2015) was used in this study, to examine the snow cover variability in Jhelum basin of western Himalayas. Simultaneously, this study aimed to quantify the degree of dependence of local communities on melt water by linking their income generating activities to the indicators identified through socio-economic survey in the region. A zone of impact and a zone of influence was delineated to define the spatial variability in livelihood vulnerability.

Annual range of snow cover in Jhelum basin was found to be 1%-52% but a general variation of maximum and minimum SCA was found to be ±15% for the study period. While SCA was found to be increasing during both summers and winters seasons, within the winter season it varied from 24%-46%-30% during early, mid and late winters in Jhelum basin.

As defined by Chambers and Conway (1992), *'a livelihood comprises of capabilities, assets (stores, resources, claims and access) and activities required for a means of living'*. Snow cover being the direct indicator of water availability in the regions with little liquid precipitation, its variability affects livelihood. In Jhelum basin, education levels are low and general family size is >6. As a result, major source of household income to the local population is through cultivation of crops like apple, walnuts and saffron. Another prominent source of income is tourism and atleast 1 member of every family is associated with tourism limited to spring months of a year. These two constitute about 95% dependence of local income on snow melt.

Almost 70% area of Jhelum basin is less than 3000 m in elevation, which is also the inhabited zone. But the rate of SCA depletion is very fast reducing by almost 50% within 2 months of late winters-early summers from their peak, limiting time horizon of action for policy makers. This study established SCA variability range indicating a reference for adaptation measures required to be developed by policy makers.

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# Geochemical Characteristics of Headwaters and Tributaries of Indus River, Karakoram-Himalaya Region, Pakistan: A baseline study for Spatio-temporal Mapping of Major ions and Trace Elements

Jawad Nasir

SUPARCO

The geochemical studies are useful integrator of chemical and physical reactions within catchment ecosystems. The small catchments located at the headwaters or uplands of larger drainage areas served as early warning systems of ecological change. A comprehensive parametric investigation of geochemical characteristics of headwaters and tributaries located in Upper Indus Basin (UIB) of Karakoram-Himalaya Region was carried out. The objective was to develop the baseline of freshwater quality in order to detect temporal changes in characteristics due to climate change, anthropogenic pressures as well as transboundary pollution from neighboring countries. In present study, seasonal water sampling was carried out in five basins including Hunza Basin, Astore Basin, Indus sub-basin and Baltoro Glacier in Shigar Basin **(Fig 1)** during summer and winter seasons in year 2015. More than forty samples were collected in each season. The samples were analyzed for ionic nutrients (Calcium Ca, Magnesium Mg, Sodium *Na*, Chlorine *Cl*, Sulphate $SO_4$ and Silicate $SiO_2$) using Ion Chromatography while trace elements (Arsenic *As*, Cadmium *Cd*, Chromium *Cr*, Mercury *Hg*, Lead *Pb and* Uranium *U*) were analyzed at Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Major cations concentrations in water from the Indus Basin shown the trends as: Ca>Mg>K>Na. Excess Ca over Na indicates that Ca has other sources, such as weathering of gypsum (or anhydrite), whereas Na is derived from silicate weathering. On the other hand, in anions, higher concentration of $SO_4$ was observed as compared to Cl. As $SO_4$ and Cl are derived mainly from Gypsum and Halite deposits respectively, higher concentrations of $SO_4$ further verified the dominant role of Gypsum weathering over Silicate weathering in Indus waters. Average levels of $SiO_2$ were found lower than the other high altitude rivers draining the Himalaya, such as Ching Jiang, Brahamputra and Ganges. Detection of Arsenic, Cadmium, Chromium and Lead in all samples indicates the impact of anthropogenic activities *e.g.* mining, road / dam construction and atmospheric deposition of pollutants. Conclusively, the geochemistry of Indus River and its tributaries, and freshwater lakes is influenced by intense physical weathering (natural phenomenon) as well as by anthropogenic activities. The anthropogenic activities like damming, roads construction, farming, grazing and tourism are undertaken in large parts of the region. Due to China Pakistan Economic Corridor (CPEC), a significant surge in anthropogenic activities is foreseeable. Therefore it is felt appropriate to develop a national water surveillance system in glaciated region of Pakistan to detect spatio-temporal changes in freshwater ecosystem either due to natural or anthropogenic pressures.

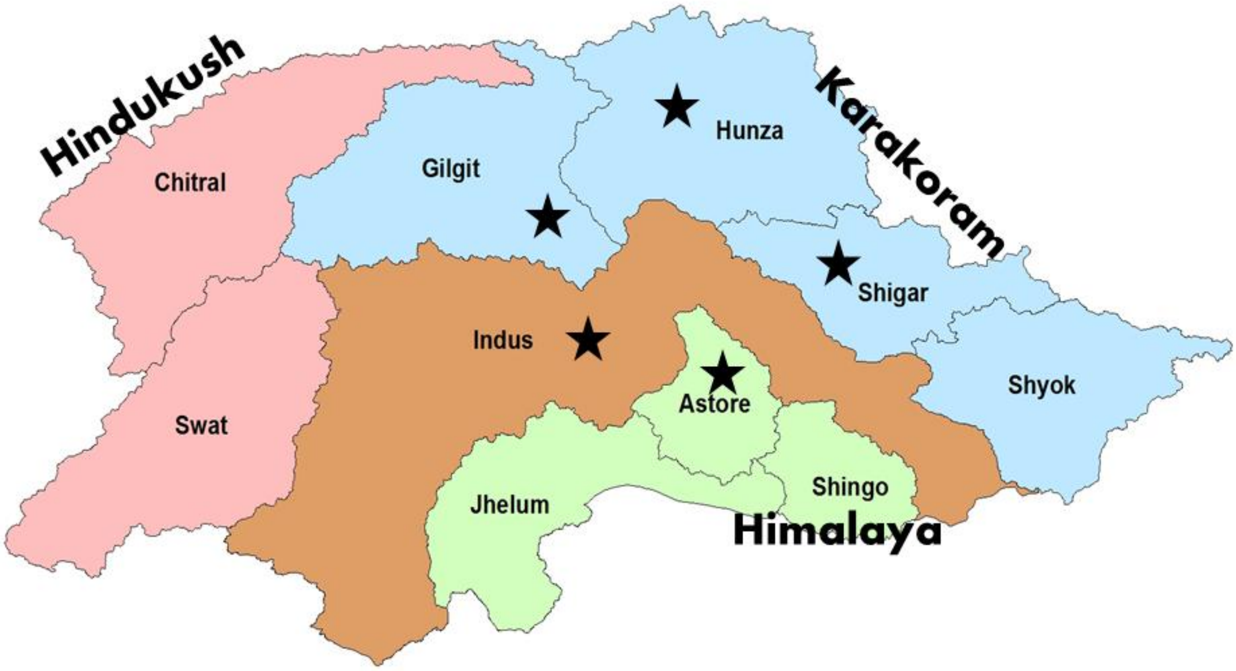


**Figure 1: Three mountainous ranges in northern Pakistan. "Star marks" depict the basins in focus**

# ***Session 4***

# ***Posters***

# Surface mass balance of the debris-covered area of Changrinup Glacier (Nepal) assessed from an ice flux method

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Debris-covered glaciers occupy more than 1/4 of the total glacierized area in the Everest region of Nepal, yet the surface mass balance of these glaciers has not been measured directly. In this study, ground-based measurements of surface elevation and ice depth are combined with terrestrial photogrammetry and unmanned aerial vehicle (UAV) elevation models to derive the surface mass balance of the debris-covered Changri Nup Glacier, located in the Everest region. Over the debris-covered tongue, the mean elevation change between 2011 and 2015 is -0.93 m ice/year or -0.84 m water equivalent per year (w.e. $a^{-1}$). The mean emergence velocity over this region, estimated from the total ice flux through a cross-section immediately above the debris-covered zone, is +0.37 m w.e. $a^{-1}$. The debris-covered portion of the glacier thus has an area-averaged mass balance of -1.21 ±0.2 m w.e. $a^{-1}$ between 5240 and 5525 m above sea level. The surface mass balances observed on nearby debris-free glaciers suggest that the ablation is strongly reduced (by ca. 1.8 m w.e. $a^{-1}$) by the debris cover. The insulating effect of the debris cover largely dominates the enhanced ice ablation due to the supra-glacial ponds and exposed ice cliffs. This finding has major implications for modeling the future evolution of debris-covered glaciers.

# An attempt to reconstruct high-resolution Holocene glacial fluctuations across the Himalayan-Karakoram-Tibetan orogen

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Regionally variable responses of Himalayan-Tibetan-Karakoram (HKT) glaciers highlighted their complexity and dynamics to present climate change. This raises the question as to whether short-term changes of HKT glaciers are due to secular (e.g. global atmospheric/oceanic circulation), periodic (e.g. orbital forcing), or accidental changes (e.g. surging). To gain insight of recent HKT glacial fluctuations, young Holocene moraines are being mapped using high-resolution (40 cm) Google Earth satellite imagery, ASTER DEM (30 m) and GPS and dated using cosmogenic $^{10}$Be surface exposure dating in the NW Himalaya. Seventy three new moraine erratic samples were collected in ten different glaciated valleys of the Zanskar, the Greater Himalaya and the Pir Panjal ranges for $^{10}$Be analysis. Forty one of the total samples has already been measured. These new and 424 published Holocene $^{10}$Be ages are compiled to reconstruct high-resolution Holocene glacial advances across the HKT orogen. In addition, to gain insight of spatial pattern of Holocene glacial advances, glaciated valleys with similar present climate are clustered together into eight groups using the climate data generated from the CRU CL 2.0 surface climate data series (period 1961-1990) and Tropical Rainfall Measuring Mission precipitation data (period 1998 to 2009) and applying Cluster Analysis and Principal component analysis (PCA). Preliminary reconstruction of regional glacial stages based on probability density function (PDF), however, indicate several short-lived regional glacial advances during the Holocene across the orogen. These short-term glacial advances may occur at ~10, ~7.7, ~6 (tentative), ~4.4, ~3.2, ~2.8, ~2.0, 1.0, ~0.7, and ~0.3 ka. In contrast to the northern hemisphere high-latitude glaciers, glacial advances were limited (mostly less than 30 km from present glacier termini) during the Holocene in the orogen with progressively restricted advances over time. HKT glaciers were highly restrictive (<5 km) during the Little Ice Age (LIA) cold period and largest advancement occurred during the early Holocene optimum. Regional analysis also confirms that continental sub-polar glaciers in the NW Himalaya and Tibet experienced relatively limited change in ΔELA during the Holocene than the warm-wet temperate glaciers in the S and SE and cold and wet glaciers of the Karakoram. Overall, glacial advances during the Holocene in the HKT region indicate sensitivity to short-term relapses in both global and regional climate and no relation to orbital forcing.

# Black Carbon Concentration in the Dasuopu Ice Core: 1782-1996

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Black carbon (BC) is a product of incomplete biofuel, hydrocarbon, and biomass combustion. BC affects climate by absorbing solar radiation in the atmosphere and decreases the albedo of snow covered surfaces. Studies have highlighted the importance of BC concentration and its subsequent deposition onto glacier surfaces to regional water resource sustainability and global climate warming. BC emission regulation has been targeted to combat climate change because of its short atmospheric residence time and primarily anthropogenic source.

We use the Dasuopu Glacier ice core (central Himalaya) to quantify the concentration of BC deposited onto the glacier over the past 200 years at annual/sub-annual resolution and we compare the BC record to a trace element record obtained from the same core to infer BC source.

The BC record indicates that deposition onto the glacier has increased with time towards the present. BC particle size has also increased with time suggesting that potentially a) the size of particles deposited onto the Dasuopu Glacier surface have increased, b) that particles undergo a physical size modification in the glacier. BC concentration is weakly ($r^2$=0.4), but significantly ($p<0.05$), correlated with barium and lead, suggesting diesel fuel burning as a BC source.

# Interaction between climate and erosion in high altitude mountain environments: the affect of precipitation gradients upon headwall erosion in Northern Indian, NW Himalaya

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The interaction between tectonics, erosion and climate is integral to defining rates and styles of landscape evolution within high altitude mountain belts. Although compelling evidence suggests that long-term erosion rates are primarily governed by spatiotemporal variations in precipitation, few studies have systematically tested this hypothesis along a precipitation gradient within the Himalayan-Tibetan orogen. Critically there is an absence of substantiated research focused upon landscape change with respect to climate within the upper extent of glaciated catchments. More specifically, the strength of coupling between precipitation and erosional headwall processes in the NW Himalayas is unknown. The aim of this project is therefore to determine the affect of the steep S-N precipitation gradient upon rates of glacial headwall erosion in northern India. To accomplish this, cosmogenic nuclide dating (TCN) methods are used to examine supraglacial debris collected from ten glaciated catchments between the warm, wet conditions of the Greater Himalayan Range in the south and the hyper-arid environment of the Transhimalaya in the north. The TCN concentrations in the supraglacial debris collected from each of these catchments will be directly proportional to the duration of rock exposure to cosmic rays and inversely proportional to the rate of glacial headwall erosion. The erosion dataset generated from this project will test whether glacial headwall erosion is related to precipitation magnitude, and thus if the headwall erosion rates is greater in the wetter regions of the Himalaya. This study compliments other projects as a measure of landscape change; future research into sediment transfer, mass displacements, avalanching and paraglacial and periglacial processes within the upper extents of glaciated catchments. This research will help to address questions related to the control of environmental and climatic conditions upon landscape evolution and surface processes within high altitude, active mountain belts.

# Variability in the Indian Summer Monsoon Precipitation and Lake Levels in Eastern Tibet

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The Indian summer monsoon (ISM) is the primary source of precipitation to the Tibetan Plateau. Surface waters and glaciers within the *Third Pole Environment* are the headwaters for some of the largest rivers throughout southern Asia. Predicting variability in the ISM is limited when reliant on modern monitoring data for a process that can have annual and decadal variability. Expanding on precipitation records using paleoclimate data makes it possible to track variability on a decadal scale. This study is using sediment cores and surface sediments to assess paleo precipitation and lake levels. Samples were collected from three small lakes in Eastern Tibet: Galang Co, Nir 'Pa Co, and Paru Co in 2011 and 2015. Initial analyses include bulk density, organic carbon and total carbonate concentrations, and grain sizes while future work will focus on leaf wax isotopes for precipitation inferences. The 2011 core from Nir 'Pa Co showed shifts in grain size and composition that indicate periods of wet and dry climate and correlate with other regional climate records that are focused on ISM precipitation variability. By expanding the record with additional cores, we aim to provide a more thorough assessment of decadal variability in the ISM. Shifts in ISM is relevant for future climate predictions and management in light of changing precipitation levels and reservoir reserves.

# Ice thickness and thermal structure of a high altitude Himalayan glacier

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There are still large uncertainties in the ice volume estimates of Himalayan glaciers due to lack of reliable ice thickness data. Ice volume estimates in the region are mainly based on area-volume scaling and modeling ice thickness and subglacial topography but ice thickness measurements are essential for calibrating and validating these methods. In addition, very little is known about the thermal structure of Himalayan glaciers, and this can play an important role in glacier dynamics and consequently impact the glacier's response to the changing climate.

Here, we present ground penetrating radar (GPR) data from Rikha Samba, a medium size glacier (5.5 km2) in central Nepal with an elevation range from 5380 to 6560 m a.s.l. We combine GPR data from two field campaigns carried out in 2010 and 2015, measured with center frequencies of 5 MHz and 30 MHz, respectively. Our results reveal that Rikha Samba is a polythermal glacier with a layer of temperate ice up to 100 m thick below the cold ice, and a maximum observed thickness of about 180 m. Our analysis also highlights that commonly used GPR point measurements on polythermal mountain glaciers may lead to misinterpretation of glacier thickness due to intense volume scattering from the temperate ice below the cold ice.

# Daily Sampled Mass Fluxes in High Mountain Asia from Satellite Gravimetry

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The High Mountain Asia (HMA) encompassing the Qinghai-Tibetan Plateau has the largest glaciated regions in the world outside of Greenland and Antarctica. The Tibetan Plateau is the source or headwater of many major river systems, which provide water resources to more than a billion people downstream. The impact of climate change on the Tibetan Plateau physical processes, including mountain glacier wastage, permafrost active layer thickening, the timing and the quantity of the perennial snowpack melt affecting upstream catchments, river runoffs, land-use, have significant effects on downstream water resources.

Satellite gravimetric measurements from the Gravity Recovery and Climate Experiment (GRACE) twin-satellite mission, have allowed decadal estimates mountain glacier mass balance in the HMA at coarse spatial coverage longer than 300 km. The energy balance approach for GRACE gravity solutions, which has been developed and recently improved at the Ohio State University [Shang et al., 2015; Guo et al, 2015], would allow the flexibility and efficient gravity inversions as short as 10 days, depending on the location and magnitudes of the transient signal of interest. This approach generates in situ disturbance potential observables at a function of time at the GRACE satellite altitude, allowing flexible user-tailored gravity inversion time spans, using global or regional solutions, to enhance temporal and spatial resolutions and accuracy of the transient temporal gravity signals. Here, we present new solutions of HMA mass flux estimates using GRACE, at daily sampled rate, to study various transient time-variable mass change signal mainly caused by the abrupt weather episodes or natural disaster events.

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# Monitoring Land Subsidence and Riverbank Erosion in Coastal Bangladesh Using Synthetic Aperture Radar Interferometry and Optical Imageries

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Bangladesh is a low-lying country with over 160 million people, and located at the confluence of three large rivers – Ganges, Brahmaputra and Meghna, where its complex hydrologic regime is significantly affected by High Mountain Asia's or Tibetan Plateau's downstream cryospheric-hydrologic processes. These processes include sediment transport, monsoonal flooding, along with sea-level rise, and potentially aggravated by more frequent and intensified cyclones resulting from anthropogenic climate change in downstream Bangladesh. In Bangladesh, about 46% of the Bangladesh population lives within 10 meters of the average sea level and 80% of the country is flood plain. Because of the flat topography of the floodplain, on average ~20% or more of the country is inundated annually by floods. In the 1960s, Bangladesh government constructed 123 embankments or polders around much of the low-lying coastal regions to mitigate relative sea-level rise and flood risks. Sediment load and groundwater extraction induced land uplift/subsidence, and riverbank erosion, have exacerbated Bangladesh's coastal vulnerability. The subsidence rate of the polders due primarily to erosions tidally-driven sediment compaction and loading are arguably not well known at the spatial and temporal scale needed to mitigate or adapt to the Bay of Bengal coastal vulnerability. In addition, the polders in coastal Bangladesh can easily breach and be damaged by riverbank erosion that caused by high monsoon wind, waves, strong tidal actions and storm surges, and most of embankments in coastal region have experienced breaching more than once since their completion. It is estimated that about 5% of the total floodplain of Bangladesh is directly affected by erosion and millions of people are affected by erosion that destroys standing crops, farmland and homestead land every year. Here we use the Persistent Scatterer Interferometric SAR (PSInSAR) techniques employing long-term ALOS-1/-2 PALSAR L-band data to estimate the land subsidence over example polders. PSInSAR is a new InSAR processing method, which relies on isolating pixels with consistent and stable radar reflections and is designed to accurately measure small spatial-scale land deformation signals in non-urban areas, allowing one to more accurately mitigate errors towards more accurately constructing land subsidence time series. In addition, we use optical imageries from the Planet Labs constellation of over 100 cube-sats at daily sampling and 3–5 m spatial resolution, to demonstrate the feasibility to effectively monitor Bangladesh coastal riverbank change at high temporal and spatial resolutions.

# Improved Constraint on Earthquakes Source Models from GRACE Data

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The seismic source models are estimated using Gravity Recovery And Climate Experiment (GRACE) data for several undersea earthquakes, including the 2004 Sumatra-Andaman earthquake, the 2010 Maule, Chile earthquake, the 2011 Tohoku earthquake, the 2012 Indian Ocean earthquakes, the 2007 Bengkulu earthquake, and the 2013 Mw 8.3 Okhotsk deep-focus earthquake. The innovative processing of GRACE data using only the north component of gravity change and its corresponding gravity gradient changes allows the enhancement of the spatial resolution for coseismic deformation signals. Single double couple inversions are conducted, which demonstrates the unique constraint on source models from GRACE data as compared to models inverted using other data sources. For the 2004 Sumatra-Andaman earthquake, GRACE inverted model produce a shallower centroid depth (9 km), as compared to the depth (28 km) from GPS inverted model. For the 2011 Tohoku earthquake, the GRACE-estimated centroid location is southwest of the GPS/seismic solutions, and the slip azimuth is about 10$^{\circ}$ clockwise from the published GPS/seismic slip models. This advanced data processing by using the north component of gravity and gravity gradient change will be further adapted to the study of Tibetan Plateau Geodynamics. Specifically, the all components of gravity and gravity gradient change will be analyzed in response to the Tibetan Plateau tectonic deformation.

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# Origins and long-term evolution of *Nitraria* in the NE Tibetan Plateau: An integrative study of molecular based phylogenies and fossil pollen

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*Nitraria* is a steppe-desert plant that worldwide tends to grow in coastal areas of arid regions. In China, however, this taxon occurs on the Tibetan Plateau, a strictly continental environment. Little is known about the evolution of *Nitraria*, but pollen with botanical affinity to *Nitraria* (*Nitrariapollenites* or *Nitrariadites*) are abundant in the Paleocene-Eocene palynological record of northern Tibet, which coincides with a more humid regional climate and the existence of the Parathetys Sea that until then covered extensive areas in Asia. After the Eocene the taxon seems to dwindle, coinciding with regional and global climatic change. The present study focuses on how *Nitraria* evolved through time and if its origins, changes through time, and modern distribution are linked to the Paratethys Sea, climate change and/or plateau exhumation. To achieve this we compare changes in pollen morphology, taxonomic diversity, and abundances with molecular data and place these in a phylogenetic framework. We hypothesize that *Nitraria* originated at the coast of the Paratethys and from there migrated to other coastal areas. This would make the modern *Nitraria* in Tibet a relic of the former marine conditions.

# Five centuries of trace element deposition at the top of the Himalaya: natural background vs. anthropogenic pollution

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South East Asia is one of the fastest developing regions on Earth and has experienced a recent large increase in atmospheric pollution. Glaciers of the nearby Himalayan mountains represent a unique archive that provides the potential to be used to determine the strength and timing of the onset of anthropogenic atmospheric pollution in the region.

Within the Third Pole Project several ice cores from the Tibetan Plateau and the Himalaya are analyzed for their trace element concentrations. Here we present results of a new trace element record from the Dasuopu ice core spanning 1500 - 1993 AD. The Dasuopu ice core was drilled in 1997 at 7200 m altitude in the Himalaya and provides the highest elevation ice core record ever obtained. Due to the high altitude this site has the potential to archive not only contamination records of regional significance, but possibly also long distant pollution from, for example, Europe and climatic signals influenced by the North Atlantic. This area is heavily influenced by the monsoon regime providing seasonally and highly variable snow accumulation rates. The upper 50 m of the core covering the time interval from 1950 to 1997 consist of Firn and is sampled non-continuously in a resolution of approximately one sample/year. The time interval between 1790 and 1950 is presented by a continuous record in subannual resolution. Crustal enrichment factors are used to discriminate between the terrigenous and the anthropogenic contributions. In this study we focus two research topics: (1) determine the onset of the earliest anthropogenic contamination from trace elements at this elevation (7200 m) Himalayan site and (2) determine intra-annual variations of atmospheric trace elements, with a focus on discriminating between pre-monsoon season (when the aerosol input is governed by the high dust input in spring) and the monsoon and dry season.

We find trace element concentrations to be very low and very variable throughout the year with concentration changes of up to 2-3 orders of magnitude (e.g. Pb concentrations range from 0.1 ppt to 1000 ppt). Average concentration levels are comparable to those recorded at some polar sites. We find an increase in elements of crustal origin in the second half of the 20th century.

# The physical basis of temperature index models in the Himalayas

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Due to scarce data availability and for computational convenience, most glaciological projections in the Himalayan region derive ice melt from temperature index (TI) or enhanced temperature index (ETI) parametrizations, which require only temperature and solar radiation as inputs. Still, the processes linking these variables to melt remain poorly documented under high-altitude climates, where the air is cold, and the main input is shortwave radiation. In this study, we question the physical basis of TI and ETI melt parameterizations based on observations collected in Langtang Valley and Khumbu Valley, in the Nepal Himalayas.

Using automatic weather stations installed on Yala glacier at 5090 m a.s.l and Naulek glaciers at 5450 m a.s.l., we study the surface energy balance (SEB) during various melt seasons, i.e, the monsoon and surrounding weeks, from 2013 to 2015. The SEB is validated against melt measurements and provides insights into the atmospheric controls on the glaciers. We study the variability of the SEB and the correlation coefficients linking daily means of temperature, SEB components and meteorological parameters to understand the processes linking temperature and solar radiation to the melt. We then calibrate TI and ETI models for each site and seasons and compare between sites. In the light of our understanding of the controls of temperature, solar radiation, and other parameters on the melt, we discuss the performance and transferability of these models.

# The seasonal in-situ mass balance of Yala Glacier, Langtang Valley, Nepal, from 2011 to 2015

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In-situ glacier mass balance measurements are still scarce in the Hindu Kush Himalayan (HKH) region and little is known about the seasonal balances. The glaciers in the Nepalese Himalaya have been considered summer accumulation glacier types because of the assumption that the majority of the accumulation occurs in the summer months during the monsoon. The glacier mass balance of Yala Glacier in the Langtang Valley of Nepal has been measured using the glaciological method since autumn 2011. Stakes were measured biannually in pre- and post-monsoon, usually in early May and in November, respectively. The measured mass balance gradient for the summer balance was larger than the winter balance, which is typical for glaciers with distinct ablation and accumulation seasons. On Yala Glacier, the summer balance was negative, and the winter balance was positive in all years with measurements. However, the annual net balance was negative forall four mass balance years from 2011 to 2015.

Mass balances were further compared to temperature and precipitation data measured at nearby climate stations during the same time periods. In October 2013 and 2014, the Central Himalayas received large amounts of precipitation brought by the cyclones Phailin and Hudhud. These precipitation events contributed to the summer balance since the measurements were taken after the cyclones passed. In conclusion, on Yala Glacier accumulation processes dominated ablation processes during the winter, and ablation processes dominated during the summer, which could be explained by the low elevation range of Yala Glacier and precipitation from westerlies in the winter. For future research in the HKH region, seasonal mass balances should be measured, and the processes impacting the mass balance and the role of winter precipitation should be investigated for other glaciers in the HKH region.

# *Session 5*

# *Asian Monsoon*

# The study on the heat and water vapor transfer over heterogeneous landscape of the Third Pole region

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The exchange of heat and water vapor between land surface and atmosphere over the Tibetan Plateau and surrounding region (Third Pole region) play an important role in the Asian monsoon system, which in turn is a major component of both the energy and water cycles of the global climate system. Supported by the Chinese Academy of Sciences and some domestic and international organizations, a Third Pole Environment (TPE) Research Platform (TPEP) is now implementing over the Third Pole region. The background of the establishment of the TPEP, the establishing and monitoring plan of long-term scale (5-10-20 years) of the TPEP will be shown firstly. Then the preliminary observational analysis results, such as the characteristics of land surface heat fluxes, and evapotranspiration (ET) partitioning, the characteristics of atmospheric variables, the structure of the Atmospheric Boundary Layer (ABL) and the turbulent characteristics have also been shown in this study.

The study on the regional distribution of land surface heat fluxes and ET are of paramount importance over heterogeneous landscape of the Third Pole region. The parameterization method based on satellite data and the ABL observations has been proposed and tested for deriving regional distribution and their thirteen years variations of land surface heat fluxes and ET over heterogeneous landscape of the whole Tibetan Plateau area and Nepal. To validate the proposed method, the ground-measured land surface heat fluxes in the TPEP are compared to the derived values. The results show that the derived land surface heat fluxes and ET over the study area are in good accordance with the land surface status. These parameters show a wide range due to the strong contrast of surface features. The sensible heat flux is decreasing while the latent heat flux is increasing from 2001 to 2013 over the whole Tibetan Plateau and Nepal. And the estimated land surface heat fluxes are in good agreement with ground measurements, and all their absolute percent difference is less than 10% in the validation sites. It is therefore concluded that the proposed methods are successful for the retrieval of land surface heat fluxes and ET over heterogeneous landscape of the Third Pole region.

# Influence of large scale atmospheric circulation on interannual precipitation and ice core record in Asian monsoon region

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Understanding variations in isotopic composition of precipitation from monsoon regions is crucial for its utilization in paleoclimate studies. We explore the relations between precipitation $\delta^{18}O$ data for the East Asian Monsoon (EAM) region archived in GNIP and the cloud data archived in ISCCP and their linkage with large-scale atmospheric circulation patterns. Results show that precipitation $\delta^{18}O$ are significantly and positively correlated with cloud top pressure (CTP) on both local and regional scales. We explained this phenomenon as: the stronger the monsoon convection precipitation, the higher the cloud and the lower the condensation temperature, and thus the lower the precipitation $\delta^{18}O$. This result implies that the sharp drop in precipitation $\delta^{18}O$ in the early summer in monsoonal Asia is related to the atmospheric circulation pattern, rather than the different moisture sources, as was previously assumed. A comparison of atmospheric circulation patterns with precipitation $\delta^{18}O$ on an interannual scale shows that the positive CTP anomalies in the Central Indo-Pacific within the weak Walker Circulation (El Niño) can be associated with positive $\delta^{18}O$ anomalies, while negative CTP anomalies in the Central Indo-Pacific within the strong Walker Circulation (La Niña) can be linked to negative $\delta^{18}O$ anomalies. An internannual ice core isotope record on Qiangtang No. 1 glacier drilled in 2014 in the middle of the Tibetan Plateau, was discussed to reveal the controlling factors. The time scale in the upper part of the ice core is dedicatedly established by radioactivity layer detection, and compared with another ice core drilled in 2011. The ice core signal was compared with local climate condition and South Oscillation Index. Comparison shows that the ice core isotope fluctuation in the past decade is in close relation with SOI, rather than with the local meteorological data. This results imply that the internauual variation of $\delta^{18}O$ in the middle of the Tibetan Plateau is influenced by the large scale atmosphere circulation through the ENSO cycle, and the impact is possibly in much large spatial scale.

# Connection of Winter Precipitation System in and Around Southern Slope of the Central Himalayas with Pacific and Indian Ocean indices

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In winter months (December-March), Southern slope of the central Himalayas receives less amount of precipitation compared to summer. The winter precipitation system in this slope is linked to the atmospheric variables associated with western disturbances. Additionally, this study covers larger-scale atmospheric circulation over the Indian and Pacific Oceans. The winter precipitation variability was found to be inflated by the westerly circulation passing through western Asia and moist air from the Arabian Sea. The winter precipitation (dryness) was related with positive (negative) Dipole Mode Index (DMI) and negative (positive) Southern Oscillation Index (SOI) with comparable correlations of about 0.4. Both DMI and Sea Surface Temperature (SST) of Indian Ocean revealed that they are in agreement with excess and deficit wintertime precipitation over the southern slope of the central Himalayas.

Keywords*: Wintertime, precipitation, DMI, SOI*

# The past, present and future of South Asian summer monsoon

Tao Wang, Shilong Piao, Baiqing Xu et al.

Precipitation associated with south Asia monsoon supports local rain-fed agriculture, and provides water resources that are critical to more than one-fifth of the world population living in this area. Observations show that South Asia experiences a widespread summertime drying over the last century, but the underlying processes for the observed changes are not entirely clear. Here we bring together ice core accumulation, different precipitation products and various CMIP5 model experiments to identify that increasing aerosols is the largest contributor to the weakening of summertime monsoon rainfall over the last century. This, together with deforestation, largely offsets atmosphere moistening induced by increasing greenhouse gases and ozone depletion. Observation-constrained projection of south Asian monsoon rainfall through the twenty-first century indicates that summertime monsoon rainfall will not continue to weaken but reverse to a widespread wetting mainly due to a significant drop in anthropogenic aerosols and an increase in greenhouse gases.

# The Role of the Third Pole in Global Dynamics

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The largest and most extensive circulation feature on the planet is the upper tropospheric anticyclonic gyre that dominates the eastern hemisphere from west of Africa to near the date line. A careful examination of the annual evolution of the gyre and its formation coinciding with a surface cyclonic circulation on the Himalayan Tibetan Plateau (HTP) in May clarifies the role of elevated heating in its genesis. The anticyclone is also dynamically unstable and gives birth to extratropical disturbances that rotate around the anticyclone entering the tropics through the deep trough to the east of the anticyclone bringing biweekly precipitation variability to South Asia. Further, it is hypothesized that the interaction of the HTP surface heating and the near-equatorial dynamics that produce the Intertropical Convergence Zone (ITCZ) produce a longer timescale oscillation between near-equatorial precipitation and precipitation over South Asia. These oscillations control the active (rainy) and break (mini-drought) over South Asia on time scales of 20-40 days. Without the influence of the HTP, it is argued that South Asia would be arid similar to other regions at the same latitude around the planet. Here, we examine the basic dynamical controls the HTP has on the circulation of the planet and its variability and how these variations may be predicted.

# *Session 6*

## *Climate change on decadal to millennial scales*

# New Guliya ice cores provide records for understanding recent and millennial-scale glaciological and climatological processes on the Third Pole

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We present preliminary results from the flagship project of the Third Pole Environment Program, the 2015 Sino-American cooperative ice core drilling of the Guliya ice cap located in the Kunlun Mountains in the western Tibetan Plateau near the northern limit of the southwest monsoon influence. A team of 60 people from six countries recovered three ice cores, each ~51 meters in length, from the summit (~6700 masl) and two deeper cores, one to bedrock (~310 meters in length) from the plateau (~6200 masl) of Guliya. Initial analyses indicate that net balance (accumulation) has increased across the ice cap over the last three decades compared with the previous 2½ decades. This contrasts with recent ablation on the surface of the Naimona'nyi glacier in the western Himalaya located ~530 km due south of Guliya. The anomalous warming of the last 50 years, compared with the previous 500 years, is recorded throughout the TP as enriched $\delta^{18}O$ in cores from both the northern and western continental and the southern monsoon-dominated regions.

Holocene records have been recovered from ice fields in the arid, continental central TP and from the monsoon-dominated Himalaya where the annual snow accumulation is much higher than in the west. However, a continuous climate record from a core drilled on Guliya in 1992 contains Eemian ice, and basal temperatures measured that year, as during the 2015 drilling, confirmed that the record was not compromised by basal melting. Oxygen isotopic ratios throughout Marine Isotope Stage 2 display high-amplitude (~20‰) climatic oscillations of ~200-year periodicity, and aerosol concentrations suggest that snow cover, regional vegetation and fire frequency varied concomitantly. The proposed use of new dating techniques ($^{40}Ar/^{38}Ar$ and $O_{2atm}$, $^{36}Cl$, $^{10}Be$, U-series) that were not available for the 1992 deep plateau core should establish better age constraints on the bottom ice of the 310-m Guliya plateau core which may span well over ~500,000 years.

# Lake Sediment Records of Holocene Indian Summer Monsoon Variability from the Southeastern Tibetan Plateau

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The Indian summer monsoon (ISM) is a central feature of the Earth's climate system that directly impacts the daily lives of more than 20% of the world's population. Despite its importance, there is limited information about ISM variability at decadal and longer timescales during the Holocene and the responsible driving mechanisms. Here, we present sedimentological and leaf wax n-alkane hydrogen isotopic results from Tibetan alpine lake sediment archives (Paru Co and Nir'pa Co; > 4700 m asl) that detail local and synoptic-scale ISM variability during the last 11,000 and 3000 years, respectively. Also presented are initial sedimentological results from Galang Co, which is a lower altitude lake (2700 m asl) in the Parlung Zangbo River Valley. In concert with other paleoclimate records from the Third Pole Environment, we use these new records to explore spatial and temporal patters of Holocene hydroclimate variability associated with changes in the ISM.

# Late Quaternary Asian Monsoon Dynamics recorded in Tibetan lake systems by compound-specific isotopes of terrestrial and aquatic biomarkers

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In this study we examined the interplay between the Indian Ocean Summer Monsoon (IOSM) and the Westerlies at lakes Nam Co, Tangra Yumco and Taro Co to understand the climatic effects on the ecosystem. The lakes are located in an east west transect on the southern Tibetan Plateau and enable spatial temporal comparison of monsoon development. Different organic geochemical proxies (n-alkanes, glycerol dialkyl glycerol tetraethers, $\delta D$, $\delta^{13}C_{org}$, $\delta^{15}N$) are applied to reconstruct the environmental and hydrological changes on these paleorecords. Based on our paleohydrological $\delta D$ proxies, the aquatic signal lags the terrestrial one due to specific ecological thresholds, which, in addition to climatic changes, can influence aquatic organisms. The aquatic organisms' response strongly depends on temperature and associated lake size, as well as pH and nutrient availability. Because the terrestrial vegetation reacts faster and more sensitively to changes in the monsoonal and climatic system, the $\delta D$ of n-C29 and the reconstructed inflow water signal represent an appropriate IOSM proxy.

We applied hydrogen isotopes of aquatic and terrestrial n alkanes to quantify lake volume changes of Tangra Yumco and compared values to lake volumes of Nam Co. The water volume of Tangra Yumco changed by 146 $km^3$ in the past 17.42 cal ka. Lake volume increased in two steps, the first mainly initiated by glacial meltwater input after 16 cal ka BP, and to a minor extent by first strengthening of the Asian Summer Monsoon (ASM). The second increase was caused by intensified summer monsoon precipitation at 11.45 cal ka BP. After 8.0 cal ka BP, lake volume decreased because of arid conditions, until an increase at 0.8 cal ka BP that was probably linked to a wet spell during the Little Ice Age. The lake level changes of Tangra Yumco and Nam Co were affected simultaneously by the ASM, although their amplitudes differed because of different local conditions, such as basin morphology or the blocking effect of neighboring mountains, which influences the rainout of air masses and wind-induced evaporation.

We concluded that the interplay of the different air masses seems to be primarily controlled by solar insolation. In the Holocene, the high insolation generates a large land-ocean pressure gradient associated with strong monsoonal winds and the strongest IOSM. In the Last Glacial period, however, the weak insolation promoted the Westerlies, thereby increasing their influence at the Tibetan Plateau. We suggest that the Tibetan Plateau reacts as an orographic switch between the two modes of the Monsoon_Westerly system.

# A Lacustrine Record of Indian Summer Monsoon Variability from the Yunnan Plateau: its Connections to the Tibetan Plateau and Links to Society

Aubrey L. Hillman, Mark B. Abbott, Lonnie G. Thompson, Jun QingYu

Holocene terrestrial archives of the Indian Summer Monsoon (ISM) have been produced from ice cores, lake sediments, and cave records on the Tibetan Plateau, but relatively few continuous records have been produced from the Yunnan Plateau in Southwestern China. Understanding how the ISM system responds over a wide spatial gradient over multi-decadal time scales will be critical to predicting water resource availability and its impacts on society. This paper will present a semi-quantitative estimate of lake-level changes from Yunnan through the Holocene using sedimentology and stable isotopes of carbonate. Particular emphasis will be placed on the last several thousand years and will focus on the connection between lake-level change, human settlement, and the expansion of rice agriculture. A key finding is that anthropogenic modification of lake hydrology prior to the 20$^{th}$ century was substantial, complicated, and occurred during multiple time periods. The need for improved control of water resources during the arid Little Ice Age was a possible driver behind these changes. This emphasizes the complex, continually shifting relationship between climatic change and human impact on the environment.

# Qinghai Lake long-term climate and hydrology changes

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The Qinghai Lake, located at 3194 m asl in the arid-semiarid area of the Qinghai-Tibet plateau, is the largest saline lake in China, This lake has experienced decline in both water level and lake area over the past 5 decades, but it has rebounded over the last 10 years. This study investigates lake hydrology under a changing climate, with a focus on the causes for the variations and changes in lake water level. This study found 3 m decline in water level with an average of 5.8 cm/year for the period from 1961 to 2012. During 2004 to 2012, lake water level, however, increased by 1.1 m, average of 12.7 cm/year. Water level varies over the season, i.e. maximum in September (3914.4 m) and minimum in April (3194.1 m). Water level changed very suddenly in 2009. Long-term climatic records show that annual mean temperature near the lake has increased from -1.5 ℃ in 1961 to -0.2℃ in 2012. Water level dropped in every month during 1961-2003, and significantly increased from 2004 to 2012. Mean annual precipitation between 1961 and 2012 was 366±8 mm and it had a weak increasing trend. Annual precipitation is always above 350mm between 2004 and 2012, with an average of 408.8 mm. Annual river discharge has a weak upward trend, with two dramatic increases from1979 to 1989 and during 2001 to 2012. Precipitation changes at seasonal and annual time scale strongly relate with river flow and lake level fluctuations. River discharge change due to precipitation variation is the key factor for lake water level. Precipitation is the main cause for Qinghai Lake water level change, including the abrupt jumps of water level in summers of 2005 and 2012.

# *Session 7*

## *Hydrological observation and modeling on the Third Pole*

# Implications of Climate Change on Hindu Kush Himalayan River Systems

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The Hindu Kush Himalayas (HKH), part of the Third Pole region, covering the mountains and associated hills of Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan, is the source of 10 major river basins serving over 200 million people in the mountains and 1.3 billion people downstream. With reports of rapidly melting glaciers and snow, there is concern about the changes in the hydrology of these river systems and related social, economic and environmental impacts. In recent years, considerable scientific studies have allowed us to understand more about the HKH cryosphere dynamics and the potential downstream impact of changes in the cryosphere. This presentation reviews the scientific evidence on the HKH cryosphere changes and associated downstream hydrology, and draws out implications for socio-economic development in the region. Studies show that while the cryosphere in the HKH is undergoing rapid change, there may not be significant change in the total annual volume in rivers at the basin scale. However, people closer to glaciers are likely to be adversely affected, and at the basin scale other factors like changing monsoon patterns could lead to increased flood and drought hazards, and that overall natural storage is being lost. The presentation highlights areas that need further research to get a better picture of the important question of implications of climate change on water resources in the region.

# Response of annual and seasonal streamflow and daily extremes to the 21st century climate change for the headwater river basins in the Tibetan Plateau

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The source regions of the Yellow, Yangtze, Salween, Mekong, and Brahmaputra river basins in the Tibetan Plateau are the main body of Asian water towers. The distributed VIC land surface hydrological model linked with a simple degree-day glacier algorithm was used to investigate the potential response of annual and seasonal streamflow, and daily extremes to the 21st century climate change for the five source river basins. Outputs from 15 CMIP5 General Circulation Model (GCMs) for RCP45 were statistically downscaled and used to drive the VIC-glacier model to generate 94-year daily transient hydrological projections. The analysis of the results focuses on the transient changes in annul total runoff, glacier runoff, and snow-melt runoff, seasonal changes in each runoff component during 2020-2049 and 2070-2099 relative to the 1970-2000, and hydrological extremes in each time periods for each basin. The statistical downscaling approach and the transient projections from the 15 GCMs allow a better understanding for the uncertainties in the hydrological projections for the five source river basins in the Tibetan Plateau.

# Climate change increases the solutes in high elevated lakes

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Lakes record and integrate the effects of natural and anthropogenic human pressures, including those related to climate change. The main and most direct evidence of the impact of climate change is the warming of lakes water temperature. However, there are other phenomena connected with climate-driven modifications of the hydrological regime, which may interest high altitude lakes, as changes in the ionic concentration. The biological responses to climate change in several types of lakes have been widely studied, while documented changes in water chemistry are less common.

In stream water the enrichment of dissolved ions due, e.g. to glacier melting and thawing permafrost, determines the chemical variability of downstream lakes, which provide an integrated response to overall action played by climate change at a basin scale.

Hydrochemical signals associated with glaciers melt have been recently highlighted in central southern Himalaya, in the Alps and in other remote regions. The change of lakes chemistry mainly consists in an increase of ionic concentrations and, in some cases, of trace metals.

In this contribution, we present the results obtained from twenty years of monitoring of twenty lakes located on the southern slopes of Mt. Everest. The results will be compared with those of other studies in high altitude areas.

The general aim is to increase awareness on the importance of hydro-chemical studies of high altitude lakes as a tool that can help to better understand the consequences of climate change impacts on remote mountain ecosystems.

# Glacier melt and precipitation trends detected by surface area changes Himalayan glacial ponds

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Climatic time series for high-elevation Himalayan regions are decidedly scarce. Although glacier shrinkage is now sufficiently well described, the changes in precipitation and temperature at these elevations are less clear. This contribution shows that the surface area variations of unconnected glacial ponds, i.e., ponds not directly connected to glaciers, can be considered suitable proxies for detecting changes in the main hydrological components of the water balance on the south side of Mt. Everest. Glacier melt and precipitation trends have been inferred by analyzing the surface area variations of ponds with various degrees of glacial coverage within the basin. In general, unconnected ponds over the last fifty years (1963-2013 period) have decreased significantly by approximately 10%. We inferred an increase in precipitation occurred until the mid-1990s followed by a decrease until recent years. Until the 1990s, glacier melt was constant. An increase occurred in the early 2000s, and in the recent years, contrasting the observed glacier reduction, a declining trend in maximum temperature has decreased the glacier melt.

# Identification and Mapping of Potential Moraine Dammed Lake Sites due to Glacial Retreat

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The Himalayan glaciers feed major Asian river systems sustaining the lives of more than 800 million people. Though there is uncertainty in the rates of retreat of individual glaciers, on the whole the Himalayan glaciers have been losing mass at an increasing rate over the past few decades. With the changing climate glaciers will continue to shrink and the rates of retreat may increase even further. Retreating glaciers may lead to the formation of moraine dammed glacial lakes. These lakes have a potential to cause outburst floods (GLOFs) upon failure of the dam, catastrophic to human life and infrastructure downstream. Therefore identification and mapping of potential lake sites is useful to develop mitigation strategy. In this study a new method is developed for identification of potential glacial lake sites. Surface velocity and slope is used to estimate the spatial distribution of ice thickness and subsequently the bed topography. Thereafter, potential lake sites are identified by detecting over-deepening in the bedrock with a theoretical uncertainty of 15%. The validation was performed on Chhota Shigri and the results suggest an uncertainty of 30% for maximum ice thickness, but the limited data warrants further field investigation. The model is then applied to Samudra Tapu and Drang drung in the Western Himalayas. Twelve potential lake sites were identified with mean depths varying between 33±5m and 93±14m, out of which five lakes have a volume greater than $0.01km^3$.

# Addressing the World Climate Research Program Grand Challenges in High Mountain Environments – Progress by the International Network for Alpine Research Catchment Hydrology

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The World Climate Research Programme (WCRP) has established several Grand Challenges that are pertinent to the long term scientific problems of understanding how the atmosphere, topography, and cryosphere interact to form streamflow from high mountain catchments and how this varies with time and space. The International Network for Alpine Research Catchment Hydrology (INARCH) was formed as a cross-cut project of the Global Energy and Water Exchanges (GEWEX) project of WCRP in order to better understand alpine cold regions hydrological processes, improve their prediction, diagnose their sensitivities to global change and find consistent measurement strategies. In addressing this objective INARCH has consolidated 22 high mountain research sites from around the world including the Qilian Mountains and Tibetan Plateau, China and Langtang Catchment, Nepal (www.usask.ca/inarch). INARCH investigators are using these sites to address questions such as how do different measurement standards affect scientific findings, how do the predictability, uncertainty and sensitivity of alpine catchment energy and water exchange vary with changing atmospheric dynamics, what improvements to alpine energy and water exchange predictability are possible through improved physics, downscaling, data collection and assimilation in models, do existing model routines have a global validity, how do transient changes in perennial snowpacks, glaciers, ground frost, soil stability, and vegetation impact alpine water and energy models? By addressing these questions INARCH scientists are also addressing WCRP's Grand Challenges such as the uncertainty of climate sensitivity over mountains, understanding and predicting extremes, changes in water availability with rising temperature and changing precipitation patterns. This talk will detail some early scientific results from INARCH research.

# *Session 8*

## *Improving our understanding of basic mechanisms of TPE changes*

# Assessing the long term topographic effect on solar radiation over the Tibetan Plateau

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Many factors and processes interact to determine the amount of solar radiation received at a given point on the Earth's surface. Particularly, it has been recognized that topography is a major factor. Variability in elevation, slope, slope orientation (azimuth or aspect), and shadowing, can create strong local gradients in solar radiation that directly and indirectly affect such biophysical processes as air and soil heating, land–atmosphere interactions, boundary layer processes, and atmospheric heating/cooling rates and circulations, and primary production. Previous studies have demonstrated the importance of terrain inhomogeneity and irregularity to surface solar radiation fluxes over the Tibetan Plateau. However, the existing calculations are usually based on theoretical studies for selected days. This study proposes a methodology to assess the long term climatic effects of topography on solar radiations based on measured surface radiation fluxes at the existing monitoring stations and topographic data. It involves three steps: 1) climatological direct atmospheric transmissivity (T) and proportion of diffuse radiation (P) at stations with solar radiation measurements are calculated, 2) T and P at other stations without solar radiation measurement but with sunshine hour data are estimated by empirical relationship between T/P and sunshine hour, 3) the Solar Analyst Model implemented in ArcGIS with elevation data and the estimated T and P is used to estimate the topographic effect on the solar radiation over a region. The methodology is tested in the Lhasa and Golmud regions.

# The Development in modeling Tibetan Plateau Land Surface processes

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Tibetan Plateau (TP) plays an important role in influencing the continental and planetary scale climate, including East Asian and South Asian monsoon, circulation and precipitation over West Pacific and Indian Oceans. The numerical study has identified TP as the area with strongest land/atmosphere interactions over the mid- latitude lands. Despite the importance of TP land process in the climate system, the TP land surface processes are poorly modeled due to lack of data available for model validation. To better understand, simulate, and project the role of Tibetan Plateau land surface processes, better parameterizations of the Tibetan Land surface processes have been developed and evaluated. The recently available field measurement there and satellite observation have greatly helped this development. This paper presents these new developments and preliminary results using the newly developed biophysical/dynamic vegetation model, frozen soil model, and glacier model.

In recent CMIP5 simulation, the CMIP5 models with dynamic vegetation model show poor performance in simulating the TP vegetation and climate. To better simulate the TP vegetation condition and its interaction with climate, we have developed biophysical/dynamic vegetation model, the Simplified Simple Biosphere Model version 4/Top-down Representation of Interactive Foliage and Flora Including Dynamics Model (SSiB4/TRIFFID), based on water, carbon, and energy balance (Zhang et al., 2015). The simulated vegetation variables are updates, driven by carbon assimilation, allocation, and accumulation, as well as competition between plant functional types. The model has been validated with the station data, including those measured over the TP. The offline SSiB4/TRIFFID is integrated using the observed precipitation and reanalysis-based meteorological forcing from 1948 to 2008 with 1 degree horizontal resolution. The simulated vegetation conditions and surface hydrology are compared well with observational data with some bias, and shows strong decadal and interannual variabilities with a linear trend associated with the global warming.

The TP region is covered by both discontinuous and sporadic permafrost with irregular snow layers above. A frozen soil model (Zhang et al., 2007; Li et al., 2010) is developed to take the coupling effect of mass and heat transport into consideration and includes a detailed description of mass balances of volumetric liquid water, ice, as well as vapor content. It also considers contributions of heat conduction to the energy balance. The model has been extensively tested using a number of TP station data sets, which included soil temperature and soil water measurements. The results suggest that it is important to include the frozen sol process to adequately simulate the surface energy balance during the freezing and thawing periods and surface temperature variability, including its diurnal variation. Issues in simulating permafrost process will also be addressed.

Snow albedo is known to have a significant impact on the water cycle and energy budget by modulating land-atmosphere flux exchanges. In recent decades, anthropogenic activities that cause dust and soot emission and deposition on snow-covered areas have led to the alteration of the snow albedo and cover extent, causing changes in the surface energy balance, with significant implications to the hydrologic cycle. We have coupled SSiB3 with a snow-radiative transfer model, Snow, Ice, and Aerosol Radiative (SNICAR) model, which considers the effects of snow grain size and aerosols-in-snow on snow albedo evolution, and test it in a regional model WRF, to exam the effect of aerosol in snow on surface water energy balance, temperature, and runoff.

To better understand the glacier variations under climate change scenarios, an integrated modeling system with an energy budget-based multilayer scheme for clean glaciers, a single-layer scheme for debris-covered glaciers and multilayer scheme for seasonal snow over glacier, soil and forest are developed within a distributed biosphere hydrological modeling framework (WEB-DHM-S model, Shrestha et al., 2015)). Discharge simulations using this model show good agreement with observations for Hunza River Basin (13,733 $km^2$) in the Karakoram region of Pakistan for three hydrologic years (2002–2004). Flow composition analysis reveals that the runoff regime is strongly controlled by the snow and glacier melt runoff (50% snowmelt and 33% glacier melt) and suggests that both topography and glacier hypsometry play key roles in glacier mass balance. This study provides a basis for potential application of such an integrated model to the entire Hindu-Kush-Karakoram-Himalaya region.

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# Accelerated warming at high elevations: a review of the current evidence and proposals for future research

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Arctic amplification, whereby enhanced warming is evident at high latitudes, is well accepted amongst the scientific community. There is also increased theoretical reasoning to support the idea of elevational-dependent warming (EDW) across the globe but current observational evidence is relatively weak. Surface stations are biased towards low elevations, satellite data measures local surface temperature (which shows extreme local variability), and models, although very powerful tools, are usually not of high enough resolution to capture the complexities of high elevation terrain.

Strong physical mechanisms have been identified which could encourage EDW. These include snow and ice feedback and treeline migration upslope (decrease in surface albedo), changes in cloud cover and atmospheric moisture content, the dependence of temperature sensitivity to radiation exchange on absolute temperature, aerosol loadings, and changes in free-air lapse rate. Each mechanism will be discussed in detail and applied to the TPE to consider its possible effects. So far there has been limited attempt to separate out the relative importance and contribution of each mechanism to EDW in various climate zones across the world, and for the Third Pole region. Understanding the relative importance of various physical causes will allow improved prediction of EDW over the 21st century. Proposals for a methodology to address this challenge will be introduced, including targeted field campaigns, in coordination with careful use of satellite data and computer modelling.

# Development of a Water and Enthalpy Budget-based Glacier mass balance Model (WEB-GM) and its validation at a maritime glacier in Southeast Tibetan Plateau

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This paper presents a new water and energy budget-based glacier mass balance model. Enthalpy, rather than temperature, is used in the energy balance equations to simplify the computation for the energy transfer through water phase transition and within-snow liquid water movement. Heat transfer is computed in both snow and ice layers. In order to describe the temperature profiles better, snow-ice column is layered inhomogeneously, with thin layers at the snow-air and snow-ice interfaces and thick layers away from the interfaces. In addition, parameterization schemes for rainfall/snowfall type identification, turbulent heat flux calculation, and albedo estimation over glacier surfaces are developed and/or refined. This model was evaluated against the data collected through a field experiment implemented in the ablation zone of the Parlung No. 4 Glacier in the Southeast Tibetan Plateau during 2009. The evaluation shows that the model can reproduce the observed surface temperature, sensible heat flux, latent heat flux, and ablation depth with high accuracy. Therefore, this enthalpy-based model can reasonably simulate the energy budget process of glacier melting in this region and may be used as a component of land surface models and hydrological models.

# Heterogeneous glacier thinning patterns in Langtang Himalaya (Nepal) since 1974

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Himalayan glaciers are losing mass at rates similar to glaciers elsewhere, but heavily debris-covered glaciers are receding less than debris-free glaciers or even have stable fronts (Bolch et al. 2011, 2012). There is a need for multi-temporal mass balance data to investigate the characteristics of glacier changes and to determine if glacier wastage of debris-covered glaciers is accelerating. Here, we present glacier volume and surface elevation changes of seven glaciers (5 partially debris-covered, 2 debris-free) in the upper Langtang catchment in Nepal of 28 different periods between 1974 and 2015 based on eight digital elevation models (DEMs) derived from high-resolution stereo satellite imagery such as Hexagon KH-9, Cartosat-1 and SPOT6. We show that glacier surface elevation decreased during all investigated periods between 2006 and 2015 (2006 - 2015: $-0.53 \pm 0.21$ m $a^{-1}$) and probably at higher rates than between 1974 and 2006 ($-0.25 \pm 0.08$ m $a^{-1}$). However, the behavior of glaciers in the study area was heterogeneous, and the presence of debris itself does not seem to be a good predictor for mass balance trends. Debris-covered tongues have non-linear thinning profiles. We show that local accelerations in thinning correlate with complex thinning patterns characteristic of areas with a high concentration of supraglacial cliffs and lakes. At stagnating glacier area near the glacier front, on the other hand, thinning rates may even decrease over time. The two investigated debris-free glaciers showed also a different signal. Yala Glacier with a small high elevation accumulation area experienced an increasing mass loss while the mass loss was stable for Kimoshung Glacier with a large high elevation accumulation area. We conclude that trends of glacier mass loss rates in this part of the Himalaya cannot be generalized, neither for debris-covered nor for debris-free glaciers.

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# Third Pole Region: Application of Index Model for Estimating Melt Runoff in the era of Climate Change

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Third pole region contains one of the largest number of mountain glacier and acts as water tower supporting billions of people in Asia. Most of the rivers originating from high altitude mountain basin receive input from snowmelt, icemelt and rainfall. However, these basins are complex in nature due to summer monsoon influencing rain, westerlies impacting snowfall, and debris covered ice impacting contribution from icemelt. Furthermore, climate change is impacting these glaciers more than ever. Quantifying and modeling various inputs for melt runoff are challenging and "one size fits all" approach based either on energy balance or index model is difficult to be adopted. Given the large scale basin variability but paucity of field data characterizing these variations, it is better to use modified version of temperature index model. Despite considerable effort in utilizing conventional index models there is still a need to refine and develop models with high spatial and temporal resolution based on limited input data requirements. This presentation will summarize various index balance approaches and discuss how simulation of streamflow from a glacierized basin requires proper assessment of meltwater generating zones, storage and routing. Three other important aspects that will be discussed with specific case studies include: (1) accurate assessment of debris cover and its impact on modelling melt runoff; (2) considering entire melt generating area as one homogeneous body *vs* distributive approach; and (3) sudden drainage of supraglacial lakes and its impact on the hydrology of streamflow. This is an important aspect since accelerated retreat and downwasting of the third pole glaciers due to climate change has led to the formation of large supraglacial lakes and increased urgency of incorporating it in modeling approaches.

# Snow-rain point temperatures from automatic weather station data at high elevations in the Nepal Himalayas

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A high percentage of precipitation at high altitude in the Himalayas falls as snow, nourishing glaciers and allowing for seasonal water storage in snow packs. To accurately predict direct runoff and snow accumulation for hydrological and glaciological modeling, a correct estimate of precipitation state (liquid or solid) is required. Since precipitation measurements are sparse at high altitude and continuous classification of precipitation type by an observer is impractical, an air temperature threshold - the so-called snow-rain point - has often been used to determine precipitation type without verification.

We aim to determine the snow-rain temperature threshold using automatic weather station data collected at various sites over 3500 m in the Langtang Valley and the Khumbu region of Nepal. These data cover a period of three years. Using hourly data, we classify precipitation events as either snow or rain using weighing gauge data and surface height measurements, and filter our classified data using additional meteorological parameters. Snow events are differentiated from rain events by an increase in surface height and an increase in daily albedo, though our method cannot be used to detect mixed-precipitation events. This allows us to derive a probability estimate for snow and rain at different temperatures, which is a critical variable for glacier mass balance and operational hydrological models.

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# *Session 9*

# *Geohazards and Earth Science Interactions*

# The 2015 Gorkha earthquake's induced geohazards in the Himalaya

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On 25 April 2015, a magnitude 7.8 earthquake struck Nepal. Subsequently many large aftershocks shook the region, including one of magnitude 7.3 on 12 May 2015. Much damage and over 4300 landslides were triggered (Kargel et al. 2016). The landslides were mapped using mainly satellite optical remote sensing by volunteer analysts. The number of landslides is fewer than expected for such a large quake, the reasons possibly including lack of a surface rupture, rapid surface-wave attenuation due to rugged surface topography, the energy-frequency distribution of shaking, and the mainly high grade of metamorphism or other petrological characteristics of the upper crust. The landslides are of several basic types: most abundant are thin-skinned ridge-top or ridge-side failures; other major types are ice and debris avalanches, and valley-bottom rotational slumps and slides of poorly consolidated fluvial, glacial, and old landslide deposits. Within each type, cases occurred where severe damage and loss of life took place or disaster-mitigating evacuations occurred. The great majority of landslides, however, resulted in either no damage except to forests or minor damage to small areas of agricultural land and rangeland. Fortunately, with a few tragic exceptions, the landslides involved thin-skinned failures or comparatively small volumes of poorly consolidated materials.

Although river blockages occurred, none involved very large lakes comparable to the formation of Lake Gojal due to the 2010 Atabad landslide. Thus, landslide dammed lake outbursts prompted much anxiety but ultimately were of limited consequence, though some small villages were destroyed and only timely evacuations circumvented high death tolls.

As expected, slope magnitudes and distances from epicenters of the two largest shocks account for much of the variable landslide density over the heavily affected region. The observed landslides were primarily in the southern half of the Himalaya where the steepest slopes occur and where peak ground accelerations (PGAs) were relatively high. The landslides are also concentrated on the tectonically downdropped block. However, the distribution is complex and varies dramatically from valley to valley. Furthermore, different types of landslides are concentrated in different geologic materials, which suggests local topography and lithologic factors controled the valley-scale attenuation or amplification of seismic waves or wave coupling to local surface geologic materials. Landslides may also initiate near sharp lithologic contacts. Across the earthquake-affected zone, net downdrop and uplift may also explain much about the distribution of landslides. Deconvolving the controlling factors is a challenge. We will show the regional distribution of landslides and some case studies to illustrate possible controlling factors.

The most destructive of this quake's induced events involved high-elevation failures of ice and debris. In Langtang Valley, ice-debris landslides took over 220 lives by direct effects and associated air blasts. Strong earthquakes produce much hidden damage to the rock and soil structure, so landslides are apt to continue for several years, triggered commonly by monsoon flooding, spring snowmelt, freeze-thaw activity, and construction.

Fortunately few earthquake effects on glacier lakes have been identified and no large glacier lake outburst floods (GLOFs) have been clearly attributed to the Gorkha quake and aftershocks. We will consider why specifically the Gorkha earthquake (and aftershocks) caused very few and mild effects on glacial lakes.

Large mass movements into glacial lakes are a common trigger for GLOFs. However, worldwide there is little evidence, now reinforced by the Gorkha quake, and contrary to speculation, that earthquakes—even big ones happening near glacier lakes—are a common trigger of GLOFs. There may be several explanations. The Gorkha earthquake might have caused less shaking than usual for its total released energy, thus sparing the Himalayan lakes from catastrophe. Furthermore, glacial lakes mainly occur far up alpine valleys; it is known from other quakes that when there is shallow slip and rugged relief, surface wave modes tend to be absorbed and scattered as these waves propagate across mountain ranges, and body waves are focused into ridges, thus reducing PGAs on valley floors (where lakes occur) and increasing PGA along some ridges. Extreme Himalayan relief may accentuate topographic control of wave scattering and amplitude diminution/enhancement, as known from other regions having less relief. Future big earthquakes occurring near glacial lakes remain a GLOF threat, but climate change may be the bigger problem.

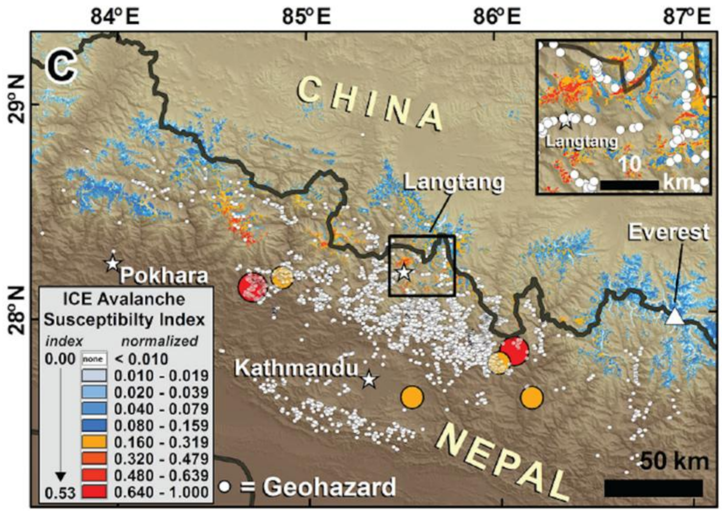

**Figure 1. Distribution of landslides (white dots) due to the Gorkha earthquake and aftershocks (epicenters of shocks > M7 and M6-7 shown by red and orange circles, respectively) in relation to a glacier/ice avalanche susceptibility index. The index, units of *g*, is the sine of slope times PGA (in *g*) intersected with the GLIMS glacier database (see Fig. 2C of Kargel et al. 2016).**

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# Where geodynamics meet atmosphere and biosphere: Paleoaltimetry of the Tibetan-Himalayan System:

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The Himalaya and Tibetan Plateau represent key regions where combined tectonic, geodynamic, and paleoclimatic records provide insight into the global environmental impact of high elevation mountain regions. The dynamics of such an evolving orogenic system not only affect local (distribution of rainfall, biodiversity and climatic gradients) but also global environmental conditions e.g. through atmospheric tele-connections. Understanding the origin and history of these impacts of surface elevation on global and regional climate and biodiversity is one key aspect of stable isotope paleoaltimetry. Similarly important, the topography of the region is a key element in deciphering the competing roles of geodynamic processes and erosion at the Earth's surface and, therefore, an important link in reconstructing the interactions among lithospheric, atmospheric and biospheric processes. Yet, the topographic history of both, the Tibetan plateau and the Himalayas is still poorly constrained for most of its Cenozoic history [e.g. 1, 2, 3, 4]. Stable isotope paleoaltimetry as a tool to recovering elevation histories of mountain ranges and continental plateau regions has gained significant momentum over the past decade mainly because such topographic histories of high elevation regions are otherwise largely elusive from the geologic record.

Stable isotope paleoaltimetry based on oxygen ($\delta^{18}O$) or hydrogen ($\delta D$) isotopes in precipitation relies on the systematic decrease in the heavy isotope ($^{18}O$ or D) of precipitation due to cooling of air parcels and associated condensation of water vapor during uplift. The resulting (empirically determined) isotope-elevation relationships are commonly robust and permit to relate surface uplift histories to changes in the isotopic composition of past rainfall. For a variety of reasons, however, single-site records of $\delta^{18}O$ or $\delta D$ in precipitation can be affected by climatic and topographic parameters some of which may have magnitudes much larger than can be accounted for by changes in regional surface uplift alone. This is particularly troublesome in high-elevation plateau regions that have reached threshold dimensions such that atmospheric circulation patterns change through topographic forcing.

Another common challenge are the different timescales involved in atmospheric circulation and rainfall patterns and recovery of “isotope-in-precipitation signals” in mineral proxies. Climate modeling approaches are therefore extremely useful when interpreting the geologic proxy record and quantifying the rates associated with either the growth or hydration of proxy minerals. These rates can vary over several orders of magnitude but in general are much longer than seasonal variations in rainfall, or even individual storm events and thus integrate precipitation signals in the isotope record over relatively long time scales. Especially for regionally extensive high-elevation areas such as the Tibetan-Himalayan system, uncertainties in reconstructing past rainfall-topography relationships can arise with the interplay of climatic and/or topographic conditions such as (1) upstream changes in the source of water vapor, (2) variable air parcel trajectories, (3) mixing of air masses or evaporation of meteoric waters under (semi-)arid climate regimes, or (4) changes in stable isotope in precipitation-elevation relationships ("isotopic lapse rate") over geologic time.

One challenge in recovering paleotopography and addressing pitfalls (1) through (4) mentioned above is that commonly used stable isotope proxy materials have low preservation potential in rapidly eroding orogens. We have pioneered approaches that exploit the hydrogen isotope record in fault and detachments zones and have coupled these to near-sea level reference points [e.g. 5, 6]. This approach of determining relative changes in the isotopic composition of rainfall between low and high elevation sites eliminates some of the pitfalls typically encountered in stable isotope paleoaltimetry. As one example, we could document that Miocene meteoric water infiltrated extensional detachment fabrics associated with the Southern Tibetan Detachment (STD) in the Mt. Everest region [7]. Hydrogen isotope ratios of 15-17 Ma synkinematic muscovite from individual structural levels of the STD are strongly D-depleted indicative of interaction with precipitation sourced at high elevation. When compared to oxygen isotope records from the Himalayan foreland, these hydrogen isotope data require Miocene elevations similar or higher than today for the Everest region.

Recovering surface uplift and relief histories, however, has also important implications for understanding the history of biodiversity in the Himalayan-Tibetan region. In particular the plateau margins with their pronounced environmental gradients are likely to play an important role in generating and maintaining high levels of biodiversity.

Here, we present current results on changes in surface elevation of the Tibetan plateau over time and contrast these with stable isotope paleoaltimetry results from the Himalayan chain, in particular the Mt. Everest region.

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# Trans-boundary atmospheric pollutants and their effects on cryospheric change over the Third Pole

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The Tibetan Plateau (TP) and surrounding mountains hold the largest aggregate of glaciers outside the pole regions and have therefore been designated the Third Pole. Recent monitoring and projection have indicated an accelerated decline of glacier and increasing glacier runoff in the Third Pole region, and a remarkable phenomenon has been recognized that long-range transport of South Asian atmospheric pollutants, among which light absorbing impurities (LAIs) such as black carbon (BC) and mineral dust (MD), can significantly absorb the solar radiation in the atmosphere, and reduce albedo after being deposited into the cryosphere (e.g., glaciers, snow cover), thereby can promote glacier and snow melt, and in turns may liberate historical contaminant legacy in glaciers into downward ecosystems.

A coordinated atmospheric pollution monitoring network has been launched since 2013 and operated covering the Third Pole region with emphasis on trans-Himalayan transects (from Nepal to inland TP). Atmospheric total suspended particles (TSP < 100 μm) are collected for 24h at an interval of 3-6 days at all sites. Black carbon, typical persistent organic pollutants (PAHs) and heavy metals are measured to reveal their spatio-temporal distributions. Results revealed a consistent gradient decrease in almost all analyzed parameters (e.g., BC, PAHs, Particulate-bounded Hg) along south-north gradient across the Himalayas, with a clear seasonal variation of higher values in pre-monsoon season. Analysis of geochemical signatures of carbonaceous aerosols indicated dominant sources from biomass burning and vehicle exhaust.

Concentrations and signatures of PAHs in aerosols indicated dominant source of biomass burning and vehicular activities, low molecular weight PAHs can readily transport across the Himalayas. Integrated analysis of satellite images and air mass trajectories suggested the trans-boundary air pollution over the Himalayas was episodic and concentrated in pre-monsoon season via upper air circulation, through-valley wind, and local convection.

BC and organic carbon (OC) over the Third Pole regions were simulated using a regional climate model (RegCM4.3) coupled with a chemistry-aerosol module. Results showed that mixed carbonaceous aerosols produced positive shortwave radiative forcing in the atmosphere and negative forcing at the surface. Aerosols increased surface air temperatures by 0.1-0.5℃ over the TP and decreased temperatures in South Asia during the monsoon season. Further, to estimate the impacts of LAIs on glacier and snow cover melt, surface snow/ice samples have been in-situ collected from five benchmark glaciers and snow cove in the TP during 2013-2015, using SNICAR model and a distributed energy-mass balance model. The sensitivity analysis showed that contributions of BC and MD were less than 37 % and 32 %, respectively, of summer melting on Laohugou Glacier No. 12 in the northeast of the TP. While MD (38%) contributed more glacier melt than BC (11%) on Zhadang Glacier, Mt. Nyainqengtanglh in the southern TP.

The monitoring network and studies provide basis for understanding the trans-boundary air pollution and highlighted their impacts on the cryosphere and other surface ecosystems over the Third Pole region.

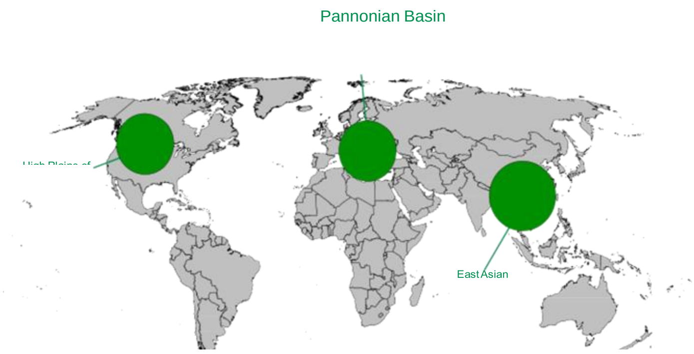
# The WCRP Water Grand Challenge, the GEWEX Hydroclimate Projects and Third Pole Environment

Peter Van Oevelen

The Global Energy and Water Cycle Exchanges Project (GEWEX)

Water is a basic human need at both the individual as well as societal level and hence to every aspect of human life. Fresh water is key to ecosystems, health, agriculture, transport, industry, energy etc. Every major economic sector is reliant on water in some form. On the other hand, excessive amounts of water can be a threat to human health and livelihoods, infrastructure, agricultural crops, thus affecting diverse sectors. The changes in availability of fresh water at the local and regional scale due to natural climate variability at different timescales, as well as regional and global environmental change, are key human challenges. The processes in the hydrological cycle involve both vertical and horizontal transports important to the (re)distribution of water on both global and regional scales.

Within the World Climate Research Programme's Grand Challenge on Water Availability the focus will be on assessing how fresh water availability will change in some of the major food producing regions of the world due to climatic change. The main regions we are going to tackle are the Central Valley and Great Plains of North America, the Pannonian Basin in Europe and the wheat and rice production regions of Southern and Eastern Asia. Each of these regions have distinctly different hydrological regimes and associated issues and hence provide a unique opportunity to study the affects of global climatic change on water related phenomena. Water availability in this context relates to both availability to humans and their consumption as well as the ecological environment and its needs.



# Glacier melt and multi-sphere interactions on the Third Pole

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With an average elevation above 4,000 meters, the Third Pole (TP) is sensitive to climate and hydrological change and has been experiencing rapid warming over the past few decades. Glacier melt is one of the most significant environmental changes under the rapid warming observed on the TP. Over the past decades, most of the glaciers on the TP have undergone considerable melt. The Third Pole Environment (TPE) has focused on the causes of the glacier melt by conducting large-scale ground in-situ observation and monitoring, analyzing satellite images and remote sensing data, and applying numerical modeling to environmental research on the TP. The studies of the TPE have revealed different features glacier status with regions, thus proposing significant influence of atmospheric circulations on spatial precipitation pattern over the TP. Validation of the result by isotope-equipped general circulation models confirms the spatial distribution of different atmospheric circulation dominances on the TP, with northern part dominated by the westerlies, southern part by the Indian monsoon, and central part featuring the influences of both circulation systems. The studies therefore found the largest glacier melt in the monsoon-dominated southern part, moderate melt in the central part of transition, and the least melt, or even slight advance in the westerlies dominated northern TP. The unique circulation patterns also bear directly on the status of lakes over the TP and its surroundings. The glacier melt on the TP is causing to more intensified water cycles, including lake expansion, glacial lake outburst and discharge flood. We found 99 new lakes and extensive lake expansion on the T Pl between the 1970s and 2013, caused by cryospheric contributions along with increased precipitation to the water balance. Glacier melt is not an isolated process on the Third Pole. It is a multi-sphere interaction process. Our society needs quickly response to the process and to its potential consequences.