Himalayan Cryosphere in a changing climate

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Three Poles: The Arctic, the Antarctic and the Himalayas
Global distribution of glaciers, their mass balance

Worldwide glacier monitoring. The global distribution of ice on the land surface (blue) is shown with locations of glacier front variation (black circles) and mass balance measurements (red triangles: direct glaciologic; yellow squares: geodetic) (Zemp et al, 2014)

Mountain glacier mass balance since 1970, excluding the Greenland and Antarctic ice sheets (From the Global Warming Art Project, 2017)

Cumulative mass change relative to 1976 for regional and global means based on data from reference glaciers. Cumulative values are given on the y-axis in the unit meter water equivalent (m w.e.).

Source: WGMS, (2017, updated and earlier reports)

Total number of glaciers worldwide -1,60,000
Total area 741x10² km² (Valentina R. & Regine H, 2010)

Total ice volume 241x10³ km³
The unique geographic region centred around the Himalayas and Tibetan Plateau is known as the Third Pole, because its ice fields contain the largest reserve of fresh water outside the polar regions. This region is the source of the 10 major river systems that form the lifeline of over 1.9 billion people in Asia – nearly 20% of the world’s population.
Why is it important?

- Approximately 1.9 billion people are depend on snowmelt- or glacier-fed rivers for various socio-industrial activities
- Glaciers continue to melt as temperature rises
- Some glaciers will be fragmented in a few decades, some within the century
- Reduction of water availability for irrigation and agriculture
- Can form catastrophic glacial lakes which threatens lives and infrastructure
Major characteristics of Himalayan Glaciers (Climate zones)

Zone 1- westerlies dominated precipitation, glaciers grow mainly by winter snow accumulation, Lakes growth, less glacier disintegration
Zone 2- both westerlies and summer monsoon.
Zone 3-glaciers are highly debris covered and retreat rate is high.
Zone 4- summer monsoon is dominated and glaciers are growing by summer snow accumulation and are most unstable

Kargel et al., 2010
### Glacier cover and volume estimates for the Indus, Ganges and Brahmaputra basins from different Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Indus</th>
<th>Ganges</th>
<th>Brahmaputra</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin area (km²)</td>
<td>11,16,086</td>
<td>10,01,019</td>
<td>5,28,079</td>
<td>26,45,174</td>
</tr>
<tr>
<td>Number of glaciers</td>
<td>18,495</td>
<td>7,963</td>
<td>11,497</td>
<td>38,055</td>
</tr>
<tr>
<td>Glacier area (km²)</td>
<td>21,193 (1.9%)</td>
<td>9,012 (0.9%)</td>
<td>14,020 (2.7%)</td>
<td>44,226</td>
</tr>
<tr>
<td>Volume(Km³)</td>
<td>2,696</td>
<td>794</td>
<td>1,303</td>
<td>4,193</td>
</tr>
</tbody>
</table>

### Glacier volume estimates for the whole HKH region from different studies (km³)

<table>
<thead>
<tr>
<th>Karakoram</th>
<th>Western Himalaya</th>
<th>Central Himalaya</th>
<th>Eastern Himalaya</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,537 -2,965</td>
<td>394-759</td>
<td>345-723</td>
<td>147-283</td>
<td>2,453-4,731</td>
</tr>
<tr>
<td>2,748</td>
<td>611</td>
<td>771</td>
<td>279</td>
<td>4,409</td>
</tr>
<tr>
<td>1,896</td>
<td>584</td>
<td>714</td>
<td>265</td>
<td>3,459</td>
</tr>
<tr>
<td>2,953</td>
<td>657</td>
<td>828</td>
<td>300</td>
<td>4,738</td>
</tr>
</tbody>
</table>
Questions to be answered:

- On what timescale does Glacier respond to climate warming in HKH region?
- Which one has the most significant control for glacier behavior in both the region - global or regional or local climates?
- Is micro climate of glaciers effect the dynamics?
- How is glacier response regulated by changes in the rate and mechanism of ice flow? If so, what causes these changes?
- How does the local climate control the glacier health?
- How do monsoon and westerlies effect mass balance of HKH region?
- How do these changes amplify those caused by surface mass balance alone?
- Estimate the impact on local/regional community induced by change in glacier regime?
Glaciers in different regions of the Himalaya respond differently.

(Kulkarni and Karyakarte, 2014)
Himalayan glaciers may vanish in long run

9575 Total Himalayan glaciers (GSI)

94.9%  Glacial retreating

0.1%  Advancing

5%  Not retreating

Vincent et al., 2013

Azam et al., 2018

Pratap et al., 2016

Himalayan glaciers may vanish in long run
- Glaciated area: 40,000 km²
- Loss in glacier area: 13% (1960's-2000)

- Almost 4–30% overall loss in glacier area in the last 40 years (1960-2000), depending upon terrain and geomorphological parameters

- Mean loss in glacier mass in the Indian Himalaya has accelerated from –9 +/-4 to –20 +/- 4 Gt/year from the decade 1975–1985 to 2000–2010

(Kulkarni and Karyakarte, 2014)
Changes in the timing or amount of snowmelt due to increasing temperatures or decreasing winter precipitation may have far-reaching societal consequences.

Lutz, et al, 2014,
Upstream basins of Indus, Ganges, Brahmaputra, Salween and Mekong

• TR: Average runoff (1997-2007)
• PTR: Mean Projected runoff (2014-2050 – RCP 4.5)
• BF: Baseflow
• GM: Glacier melt
• SM: Snow melt
• RR: Rainfall runoff

• Model is forced with an ensemble of 4 GCMs

Lutz, et al, 2014
Modelled changes in mass loss conditions in HKH region under various scenarios

(Chaturvedi et al, 2014)
The 1.5 °C global increase implies a warming of around 2.1° C for the glacierized areas in HMA.

- Possible explanations for this elevation-dependent warming in mountains include the effects of snow albedo and surface-based feedback, water vapour changes and latent heat release, radiative flux changes, surface heat loss and temperature change, and aerosols.
Projected Warming and HKH Glacier mass loss

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mass Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{2005}$</td>
<td>14</td>
</tr>
<tr>
<td>1.5 °C</td>
<td>36±7</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>49±7</td>
</tr>
<tr>
<td>RCP6.0</td>
<td>51±6</td>
</tr>
<tr>
<td>RCP8.5</td>
<td>64±5</td>
</tr>
</tbody>
</table>

HMA—High mountains of Asia

Kraaijenbrink et al, 2017
Glaciers in most of the HKH region are losing mass in response to climate warming. Glaciers in the Karakoram region have been expanding in recent years, but the underlying reasons for this anomaly are not yet fully understood. Total ice volume measurements vary considerably because of the difficulties in measuring ice volumes in situ or from remote sensing products, and uncertainties in volume-area scaling relationships. No strong trends have been observed in snow cover; minor increases or decreases have been reported for different areas. Little is known about the distribution of permafrost in the HKH region and its importance for regional hydrology remains unclear. Estimates of future glacier volume and area are uncertain and hampered because thus far modelling of ice flow has been restricted to catchment scale studies. However, strong decreases in glacier volume and area are projected for the entire HKH region.
Key limitations to measure glacier changes, snow cover area, ice thickness etc.

- Not enough long-term in situ observations and insufficient spatial coverage
- Insufficient representation of climatic conditions and glacier types
- No consensus on measuring methods
- Lack of in situ measurements of glacier volume to validate the widespread use of area-volume parameterizations
- Shortage of energy balance measurements in the region
- IceSAT: uncertainty about penetration of radiation into the snow and reliance on assumptions of density to determine glacier losses
- Airborne sensing is efficient but poorly used (LiDar, photogrammetry) in Himalaya
- Lack of relevant input information, for example glacier thickness, climatic data
- Precipitation gradients and snow/rain transitions affect glacier dynamics
- Spatial distributions in debris thickness and thermal conductivity are nearly impossible to measure
Objectives:

1. To study the Antarctic climate variability and its global linkages during the past 2000 years using ice core records.

2. To study the biogeochemical cycling within the supraglacial ecosystems like snow, ice, etc.;

3. To study the glaciological processes, dynamics, and evolution of Antarctic ice shelves and ice rises;

4. To study the glacier processes and mass balance in selected glaciers of Svalbard, Arctic;

5. To study the dynamics and the rate of change of selected Himalayan glaciers to understand its impact on hydrology.
HIMANSH – Field Station @ 4000 m, Lahaul-Spiti
Ongoing Major Activities

- **Long term monitoring** programme for glaciological observations and modelling in Western Himalaya for better understanding of glacier dynamics and their link with hydrology and climate:
  - *Mass balance (SMB, Ice Flux, Glacier Flow)*
  - *Energy/Heat Balance (Energy Budget, Degree Day Model)*
  - *Hydrological Balance (discharge measurements and modelling)*

- **Mass balance studies** – *field glaciological, geodetic, geospatial data based*
  Regular monitoring of an extensive stake network for annual, spring and summer mass balance are carried out for all six glaciers (Sutri Dhaka, Batal, Samudra Tapu, Bara Shigri, Gepang Gath and Kunzam); Ice thickness measurements by GPR

- **Energy balance studies** – *a network of AWS systems*
  Surface energy fluxes near the glacier areas measured using 4 AWS systems installed at Sutri Dhaka (ELA), Bara Sigri (4300m), Gepang Gath (4400 m) and the Himansh station

- **Hydrological balance studies** – *a network of water level recorders in Chandra R.*
  Five recorders (Waterlog Radar series) at Sutri Dhaka, Chatru, Chota Dhara, Sissu, Tandi)
Ablation/accumulation process on the different glaciers

- Spatial distribution of ice density over glacier surface

- Annual net SMB of studied glaciers of Chandra basin

- Specific ablation/accumulation over Chandra basin glaciers

- Accumulation measurement

- Stakes network over glaciers surface
Glacier retreat observed by satellite monitoring between 1960’s and 2014 in Western Himalaya – retreat of glaciers and expansion of proglacial lakes

Gaddam et al., 2016; Patel et al., 2017
Development of glaciers lake in Samudra Tapu glacier since 1973
Geospatial studies carried out in two major proglacial lakes of Samudra Tapu and Gepang Gath (Chandra basin, Western Himalaya) showed substantial expansion in their area and volume over the last four decades (1971-2014).

The results show that increased melting of the feeder glaciers over this period is major contributor to expand the volumes approximately 20 times of both the lakes Samudra Tapu and Gepang Gath.
Mean Mass Balance of glaciers in Baspa basin (1900 – 2010)

(Gaddam et al. 2017a)
Evaluation of Modeled and Observed Melting

Sutri Dhaka Glacier surface ice melts during 2015–16 and 2016–17 (a, c) cumulative winter and summer ablation (m w.e.) (b, d) annual ablation, circled values are measurements at the stakes installed on the debris-covered parts of the glacier.

Comparative plot of observed and modeled surface melting for (a,b) Sutri Dhaka Glacier as a function of elevation corresponds to the cumulative positive degree days (CPDD) and degree day factor of ice and debris.
Energy fluxes at the glacier surface and proportional contribution of each flux.

Winter 2015-16

Summer 2015-16

Winter 2016-17

Summer 2016-17

Energy Fluxes [%]

Energy Fluxes Component
In this study, an attempt has been made to understand the role of topographical parameters and debris cover for glacier recession in Miyar basin.

A total of 29 glaciers covering an area of ~227 km² were studied.

Observations revealed that almost 9 km² ± 0.7 km² recessions in glacier area (4%) for studied glaciers of Miyar basin during 1989-2014.

In Miyar basin glaciers with large size, having a steep slope with high debris cover and northward aspect showed low retreat than glaciers of small size, gentle slope, and low debris cover with southward aspect.
Mean mass loss for the Chandra basin -0.67±0.14 m w.e./year during last two decades
- It was much less in nineties (1990-1999) and estimated observed cumulative mass loss was close to zero.
- The mean annual mass balance of Chandra basin is -0.77±0.14 m w.e. with loss of 5.05±0.60 Gigatons of glacial mass during 2013 – 2017
- Mean ELA has significantly shifted (>200m) up during last two decades
- Some of the glaciers have experienced four positive balance year between 2000-2013 but experienced negative mass balance during last five years (2013-2018)
- There has been a gradual warming with an apparent stronger trend observed in Himalayan region during the last two decades
- The temperature trends are much more pronounced for the winter seasons than for the summer seasons.
- Solid precipitation is most dominant factor to control the ablation during peak ablation
- Most of the glaciers of Chandra basin are in state of instability and their volume may significantly reduce if the climate stabilizes at its present state
- Increase in number and volume of glacier lakes has increase the threat of GLOFs in Chandra basin region.
HiCOM Project

(Himalayan Cryospheric Observations and Modeling)

NCAOR coordinated, multi-organizational project for study of benchmark Himalayan glaciers to understand the impact on glaciers and hydrology.
HiCom: Objective

Major Questions to be addressed
• Why there are differential glacier responses across Himalaya and what are the driving forces?
• What are the dynamics and control of snow cover changes in Himalaya?
• What is the response of Himalayan cryosphere to climate change/variability and associated hydrological impacts?

Work Plan [NCAOR, IISER(Pune, Kolkata), IIT (Bombay, Roorke), University (JNU, Himachal, J&K, Jharkhand....)]
• Integrated mass balance studies on benchmark glaciers from sub-basins of Western, Central and Eastern Himalaya using glaciological, geodetic, geospatial and modelling approaches;
• Glacio-hydrological budgeting and modelling of selected basins
• Snow cover and volume estimation in major basins of Himalaya
Challenges and Way forward

- Himalayan region is consistently warming more than Global average
- Glaciers and permanent snows are melting rapidly in the recent years
- Shrinkage and melting of glaciers /Formation and expansion of glacial lakes
- Increased Risks and Hazard: Glacial lake outburst flood (GLOF) is a serious problem.

- Investigate and Enhanced Monitoring network (in-situ and Remote sensing-satellites/Drone)
- Strengthening Modeling efforts to understand and forecast
- Knowledge generation and understand the possible impacts of cryosphere changes
- Need effective adaptive and mitigation strategy to prevent risks and uncertainties
- Strengthening Capacity building
- Regional collaboration and Data & Information exchange
Thank you for your attention.

The global threat
of Polar ice melting