Climate Change and Himalayan Glaciers; Observations and Facts

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Glaciers and ice sheets are considered as proxy records of climate change.

Sensitive to climate and wide-spread distribution in space and time makes them most suitable as proxy records of climate change.

The trails left by the advancing/retreating glaciers viz. erosional & depositional features. Which are the best available indicators of climatic variations in the past and may form the basis for connecting the dis-continuous time series of glacier fluctuations.

Glacier advance and retreat are both a consequence and cause of the climate change.
GLACIERS RETREAT - FACTS

- Glacier retreat is a natural phenomenon/real
- Glaciers have been retreating worldwide
- Accelerated retreat reported after 1980
- Sensitive to climate, and to be considered an indicator of climate change
Major Research Questions

- Are the Himalayan glaciers receding rapidly?
  - What are the main controlling factors

- Is the recession more to global warming or due to the inadequate precipitation?

- What is the relationship between mass balance and frontal fluctuation?
  - What are the main influencing agents

- Is it possible to decipher influence of each factor?
• Are Himalayan glaciers affected by naturally occurring cause of ‘Climate Change’ or present recession trends are transient expressions of long term cyclic variation?

• Can relationship between mass balance and climate change be used to understand mechanism of glacier recession?

• What methodology is best suited to assess the recession of Himalayan glaciers?
Two thoughts – process of retreating Glaciers

- The recession of the glaciers across the earth is a natural phenomena
- Global warming and anthropogenic climate change are responsible
Regarding melting glaciers of the Himalaya, IPCC (2007) observed that:

- Average surface temperature has increased by 0.74°C in last 150 years, due to that.

- Glaciers and snow cover expected to decline, reducing water availability in countries supplied by melt water.

- Glaciers in the Himalayas are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 (?)
UNDP Report- Observations

In its 2007-08 developmental report UNDP has highlighted the effect of climate change on the different regions of the world covering all the aspects including water availability, rising sea level, flooding, biodiversity, human health, etc.

• The report has indicated that the seven of Asia’s great river systems will experience an increase in flow over the short term, followed by decline due to reduction in the glacier melt.

• The report has suggested the prevention, mitigation and adaptation strategies and recommended that

  (i) Multilateral framework for avoiding its dangers,
  (ii) Sustainable carbon budgeting,
  (iii) Strengthening international cooperation and
  (iv) Putting climate change adaptation at the centre of the post-2012 Kyoto framework.
Like many worldwide glaciers, the Himalayan glaciers also show general state of decline in the last couple of decades.

Rates of glacier retreat vary considerably; a few glaciers have retreated with an average rate of 18 to 20 m/year, while few show retreat rate of only 7 m/year like Chhota Shigri, Chorabari and Bhagirath Kharak glaciers.

It has also reported that several glaciers in central Karakoram have advanced and/or thickened at their tongues probably due to enhanced precipitation.
Studies based on remote sensing show loss of surface area of glaciers by 21% (Kulkarni et al. 2005, 2007).

Recession also leads to volume loss in glaciers, for example Dokriani glacier has registered 18% volume loss over a period of 33 years (1962-95) (Dobhal et al., 2004).

Himalayas are believed to have grown warmer with an estimated increase of about 2.2°C in the last two decades (SASE report).

All the glaciers under observation, during the last three decades of 20th century shows cumulative negative mass balance.
Characteristics of Himalayan Glaciers

- Confined to narrow valleys (Geometry and slope of valley makes Himalayan glaciers more dynamic)

- Nourished by prolonged and intense Monsoon (SW, NE as well as Westerlies)

- Higher altitude and hence are mostly below the sub-zero temperature

- Himalayan glaciers are invariably covered with debris (moraine) and hence less vulnerable to solar radiations

- Various climate types ranging from temperate to cold climate zones and from humid to arid types can be found in the Himalaya
Typical view of Himalayan glacier

Chorabari Glacier, Kedarnath
Length : 6.5km
Thickness : 30-75m
Small Mountain Glaciers

- Cirque glacier
  - Thickness: 20-90m

- Hanging glacier
  - Thickness: 10-50m

- Mountain Cape
  - Thickness: 20-30m

- Glacieret
  - Thickness: 10-20m
Glacier mass fluctuation – Signature of Climate change

Glaciers - product of climate & climate change

Changes through time that can be detected in mass, volume, area and lengths of the glaciers provide some of the clearest evidence of climate change
Climate - Cryosphere system, forcing and feedback

General Climate → Local Climate Of Glacier → Mass & Energy exchange → Net Mass Balance → Glacier response → Advance or Retreat

Climate - Cryosphere system, forcing and feedback
Impact of climate change on Glacier Regime

- Climate Change
  - Glacier regime
    - Volume
    - Length
    - Area
  - Advancement & Retreat
    - Impact on Environment
      - Water Resource
      - Production of Debris
      - Microclimate & Vegetation
      - Floods and Siltation
### Himalayan Glaciers System (India)

<table>
<thead>
<tr>
<th>State</th>
<th>Glaciers</th>
<th>Area (km²)</th>
<th>Average Size (km²)</th>
<th>Glacier%</th>
</tr>
</thead>
<tbody>
<tr>
<td>J&amp;K</td>
<td>5262</td>
<td>29163</td>
<td>10.24</td>
<td>61.8</td>
</tr>
<tr>
<td>Himachal</td>
<td>2735</td>
<td>4516</td>
<td>3.35</td>
<td>8.1</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>968</td>
<td>2857</td>
<td>3.87</td>
<td>18.1</td>
</tr>
<tr>
<td>Sikkim</td>
<td>449</td>
<td>706</td>
<td>1.50</td>
<td>8.7</td>
</tr>
<tr>
<td>Arunachal</td>
<td>162</td>
<td>223</td>
<td>1.40</td>
<td>3.2</td>
</tr>
</tbody>
</table>

- **Number of glacier**: 9575
- **Glacierised area**: 37465 km²
- **Total ice volume**: 142.88 km³

*Source: GSI, 2009*
Glaciers in Bhagirathi, Garhwal Himalaya

1. Total basin area (km²) 7502
2. Number of glacier 238
3. Glacierised area (km²) 755
4. Glacierised area (%) 10
5. Distribution of glaciers
   a. Area-wise (Numbers)
      - <1 km² 147
      - >1 <5 km² 61
      - >5<10 km² 17
      - >10<15 km² 04
      - >15 km² 09
   b. Length wise (Numbers)
      - <1 km 70
      - >1 km 136
      - >5 km 32
6. Total ice volume (km²) 67.02
7. Largest glacier
   - Area (km²) 143.58
   - Length (km) 30.0
Satellite view of Glaciers - Ganga basin
Gangotri is one of glacier in the Himalayas, that have long observation receding records.
## Recession Trend of Gangotri Glacier

### Snout Retreat of Gangotri Glacier

<table>
<thead>
<tr>
<th>Period</th>
<th>Annual snout retreat (m/year)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1935-1956</td>
<td>4.35 (small cave) 10.16 (large cave)</td>
<td>Vohra &amp; Jangpangi (1956)</td>
</tr>
<tr>
<td>1956-1971</td>
<td>27.33</td>
<td>Vohra (1971)</td>
</tr>
<tr>
<td>1974-1975</td>
<td>35.00</td>
<td>Puri (1975)</td>
</tr>
<tr>
<td>1975-1976</td>
<td>38.00</td>
<td>Puri (1976)</td>
</tr>
<tr>
<td>1976-1977</td>
<td>30.00</td>
<td>Puri (1977)</td>
</tr>
</tbody>
</table>
Recession of Dokriani glacier - 1962 to 2009

Frontal recession constitutes just 10% overall shrinkage

1962 – 1995 = 550m
1995 – 2009 = 260m

1962 - 2009 = 810 m (17.2 ma⁻¹)
Annual Snout Retreat of Dokriani Glacier 1991-2007
Snout Recession of Dokriani Glacier

Length: 5.5km
Area: 7Km²
Recession rate: 15-18 m/annum

<table>
<thead>
<tr>
<th>Period</th>
<th>Retreat of glacier</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (m)</td>
<td>Annual (m/year)</td>
</tr>
<tr>
<td>1962-1991</td>
<td>480</td>
<td>16.6</td>
</tr>
<tr>
<td>1991-2000</td>
<td>161</td>
<td>17.8</td>
</tr>
<tr>
<td>2000-2007</td>
<td>110</td>
<td>15.7</td>
</tr>
</tbody>
</table>
### Snout Recession of Chorabari Glacier

#### Retreat of glacier:

<table>
<thead>
<tr>
<th>Period</th>
<th>Total (m)</th>
<th>Annual (m)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960-1990</td>
<td>180</td>
<td>6</td>
<td>Dobhal, WIHG</td>
</tr>
<tr>
<td>1990-2003</td>
<td>82</td>
<td>6.31</td>
<td></td>
</tr>
<tr>
<td>2003-2004</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>2004-2005</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2005-2006</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>2006-2007</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

#### Snout Retreat (m/year):

Bar chart showing the annual retreat from 1960 to 2007.
Recession Trends of Pindari Glacier

Snout Retreat of Pindari Glacier

<table>
<thead>
<tr>
<th>Period</th>
<th>Total (m)</th>
<th>Annual (m)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1845-1906</td>
<td>1,600</td>
<td>26.23</td>
<td>Cotter (1906)</td>
</tr>
<tr>
<td>1906-1958</td>
<td>1040</td>
<td>20.00</td>
<td>Tiwari (1958)</td>
</tr>
<tr>
<td>1958-1966</td>
<td>200</td>
<td>25.00</td>
<td>Tiwari (1972)</td>
</tr>
</tbody>
</table>
Recession of Pindari Glacier

1890

1990

Pindari Glacier

3875 m
# Snout Recession of Milam Glacier

![Snout Recession of Milam Glacier](image.jpg)

### Snout Retreat of Milam Glacier

<table>
<thead>
<tr>
<th>Period</th>
<th>Total (m)</th>
<th>Annual (m)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1849-1906</td>
<td>732</td>
<td>12.8</td>
<td>Cotter &amp; Brown (1907)</td>
</tr>
<tr>
<td>1906-1938</td>
<td>512</td>
<td>16.0</td>
<td>Mason (1938)</td>
</tr>
<tr>
<td>1938-1957</td>
<td>106</td>
<td>5.6</td>
<td>Jangpangi &amp; Vohra (1959)</td>
</tr>
<tr>
<td>1957-1966</td>
<td>182</td>
<td>20.2</td>
<td>Jangpangi (1975)</td>
</tr>
</tbody>
</table>
### Snout Recession Trends of Glaciers in Garhwal Himalaya

<table>
<thead>
<tr>
<th>Name of glacier</th>
<th>Area Km²</th>
<th>Observation Period</th>
<th>No of years</th>
<th>Recession (m)</th>
<th>Average rate (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milam glacier</td>
<td>20</td>
<td>1849-1957</td>
<td>108</td>
<td>1350</td>
<td>12.50</td>
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<tr>
<td>Pindari glacier</td>
<td>5.0</td>
<td>1845-1966</td>
<td>121</td>
<td>2840</td>
<td>23.40</td>
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<tr>
<td>Gangotri glacier</td>
<td>143</td>
<td>1935-1990-1996</td>
<td>55-06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chorabari glacier</td>
<td>6.9</td>
<td>1962-2003-2007</td>
<td>41-04</td>
<td>196-41</td>
<td>4.8-10.2</td>
</tr>
<tr>
<td>Shankulpa glacier</td>
<td></td>
<td>1881-1957</td>
<td>76</td>
<td>518</td>
<td>6.8</td>
</tr>
<tr>
<td>Poting glacier</td>
<td>5.0</td>
<td>1906-1957</td>
<td>51</td>
<td>262</td>
<td>5.13</td>
</tr>
<tr>
<td>Glacier No-3</td>
<td></td>
<td>1932-56</td>
<td>24</td>
<td>198</td>
<td>8.25</td>
</tr>
<tr>
<td>Bhagirathi kharak</td>
<td>15</td>
<td>2005-06</td>
<td>01</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Dunagiri</td>
<td>2.56</td>
<td>1992-1997</td>
<td>05</td>
<td>15.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Meru</td>
<td></td>
<td>1997-2000</td>
<td>32</td>
<td>395</td>
<td>17.17</td>
</tr>
</tbody>
</table>

(Source cf, Dobhal et al., 2004, Nainwal et al., 2008)
Glacier Melting at higher altitudes
Small glacier Hurra (Din Gad) – October, 2005

Photo Dobhal, WIHG, 2005
Tremendous changes in surface features observed in Dokriani glacier during a period of 13 years.

i) Thinning of ice surface
ii) Decrease of snow cover (transition snowline)
iii) Increment of debris cover in lower ablation area.
Changes in snout (Terminus position) of Dokriani Glacier
Crumbling of Rataban Glacier from Tipra Glacier

Photo Manish, WIHG, 2003
Morpho-dynamic changes in Tipra glacier, Alaknanda Basin
Changing in surface morphology

Avalanche

Supra glacial Lake

Snow depletion

Snow/ice melting
Snow cover depletion and Area vacated

Snow depletion

Area Vacated

Photo Dobhal, WIHG, 2004
Retreating scenario of Himalayan Glacier-
Chorabari Glacier in Uttarakhand

*Kedarnath Town just below the Chorabari Glacier, source of Mandakini River*
Receding snow line and ascending Timber line
Depleting snow cover in high mountain areas
(Om Parvat, Nabi Dang, Pithoragarh, UK)
Out of total glaciers (9575), 60-70% glacier are less than 5 km$^2$ and are debris covered.

Recession rate fluctuating between 05 and 20 m/yr, but

Rate of recession in different glacier is found to be variable in different years.

This variable rate of recession may be attributed to winter precipitation.
No significant relationship observed between temperature and snout retreat rate but Melting is more than accumulation results disequilibrium in glacier health (mass balance) and Summer period expended and winter shrink, consequence less winter snow accumulation
THANK YOU

Chorabari Glacier, Kedarnath Base camp (3815m asl). Garhwal Himalaya