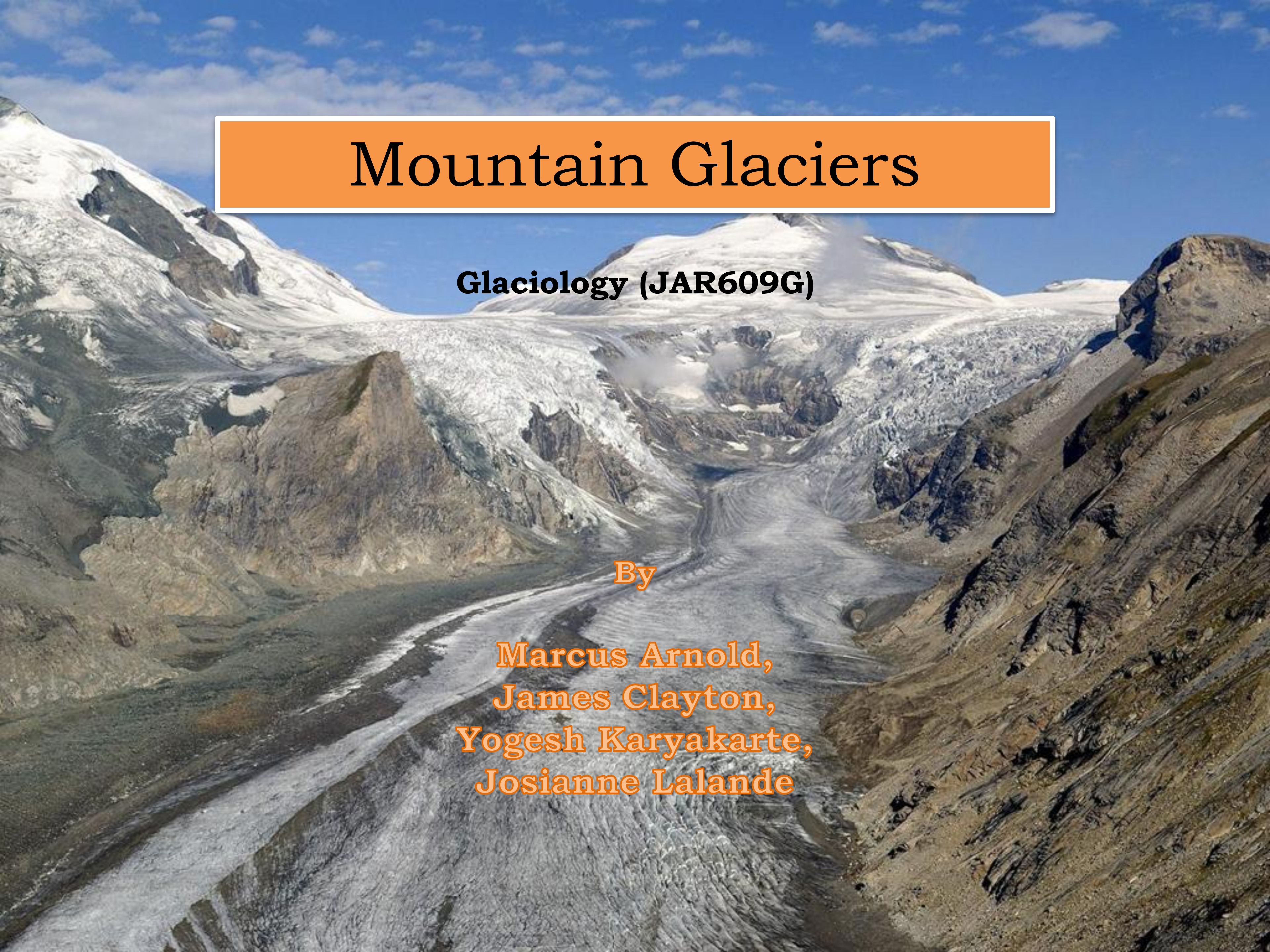


Mountain Glaciers

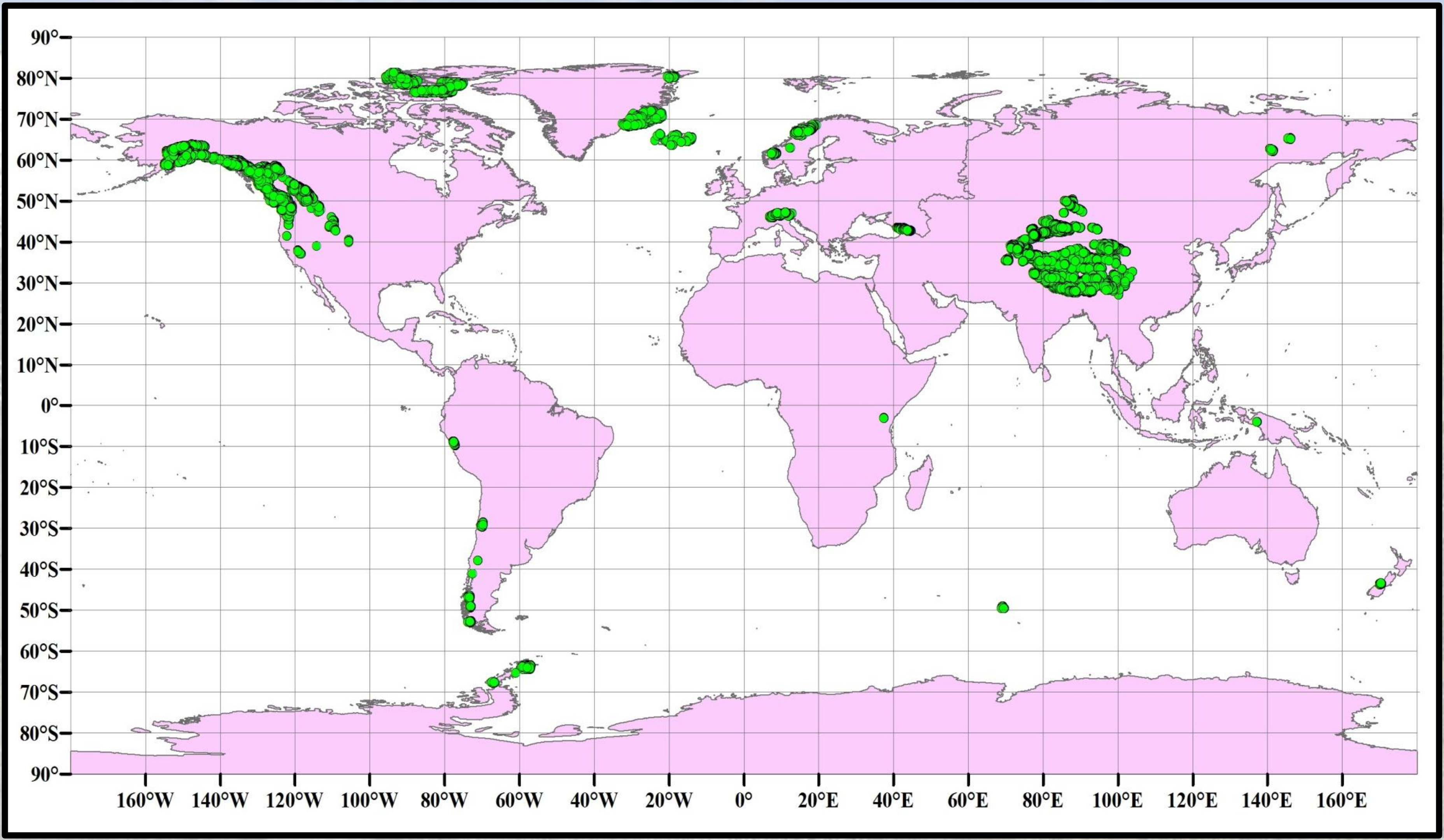
Glaciology (JAR609G)

By

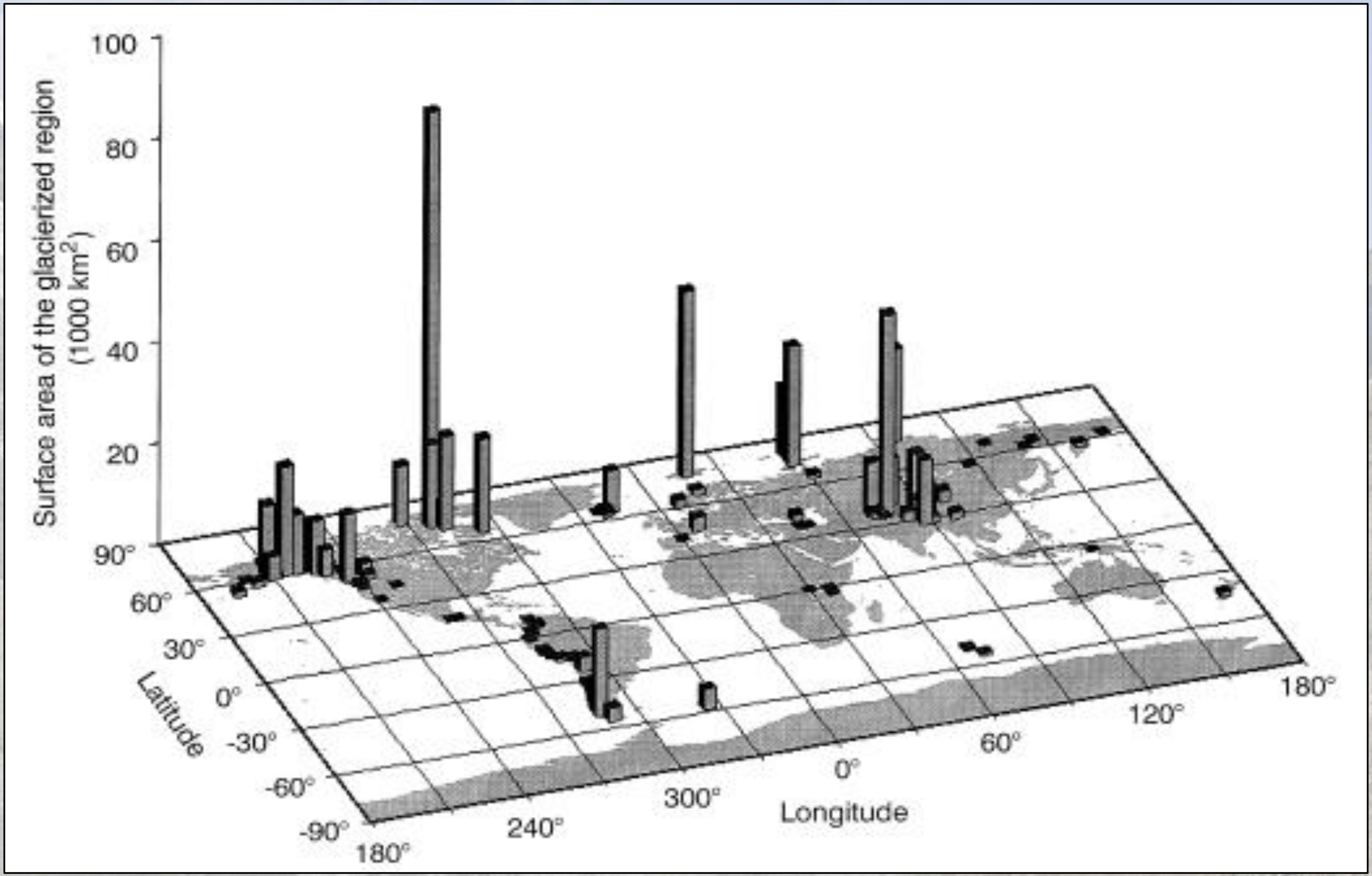
Marcus Arnold,
James Clayton,
Yogesh Karyakarte,
Josianne Lalande

Content

- Where are they located…
- How they have formed..
- Mountain glacier landsystem..
- Mass balance..
- Retreat..
- Effect on Human beings..
- Some issues regarding mountain glaciers..



Locations of mountain glacier - (Shape file = WGI- 2012, s/w: ArcGIS 9.2)



Global distribution and surface area of glaciers (excluding the Greenland and Antarctic). Glaciers are divided into 100 regions (shown in solid bars); each region may represent one or many individual glaciers (Z. Zuo and J. Oerlemans, 1997)

Why?

- Hundreds of millions of people, particularly in Asia and South America, are residing in glacierized river basins.

- Water for agriculture, industries and hydroelectricity power plants.

- Mountain glaciers are highly sensitive to climate change (Hoelzle et al. 2003)

- Quantitative relationship between climate change and glacier fluctuations

Formation factors

- High Elevation
- Cool Temperatures
- Winter’s snow does not melt entirely
- Annual average temperature at or below 0°C
- Solar radiation
- Earth’s axis tilt and Solar Rotation
- Mass Balance
- Latitude

Altitude vs Latitude

- Snow-Line
- 4500m at Equator
- Up to 5700m at Tropics of Capricorn & Cancer
- Around 3000m in NZ, parts of South America and North America and Europe
- Gradually falls to sea-level at the poles

Other factors

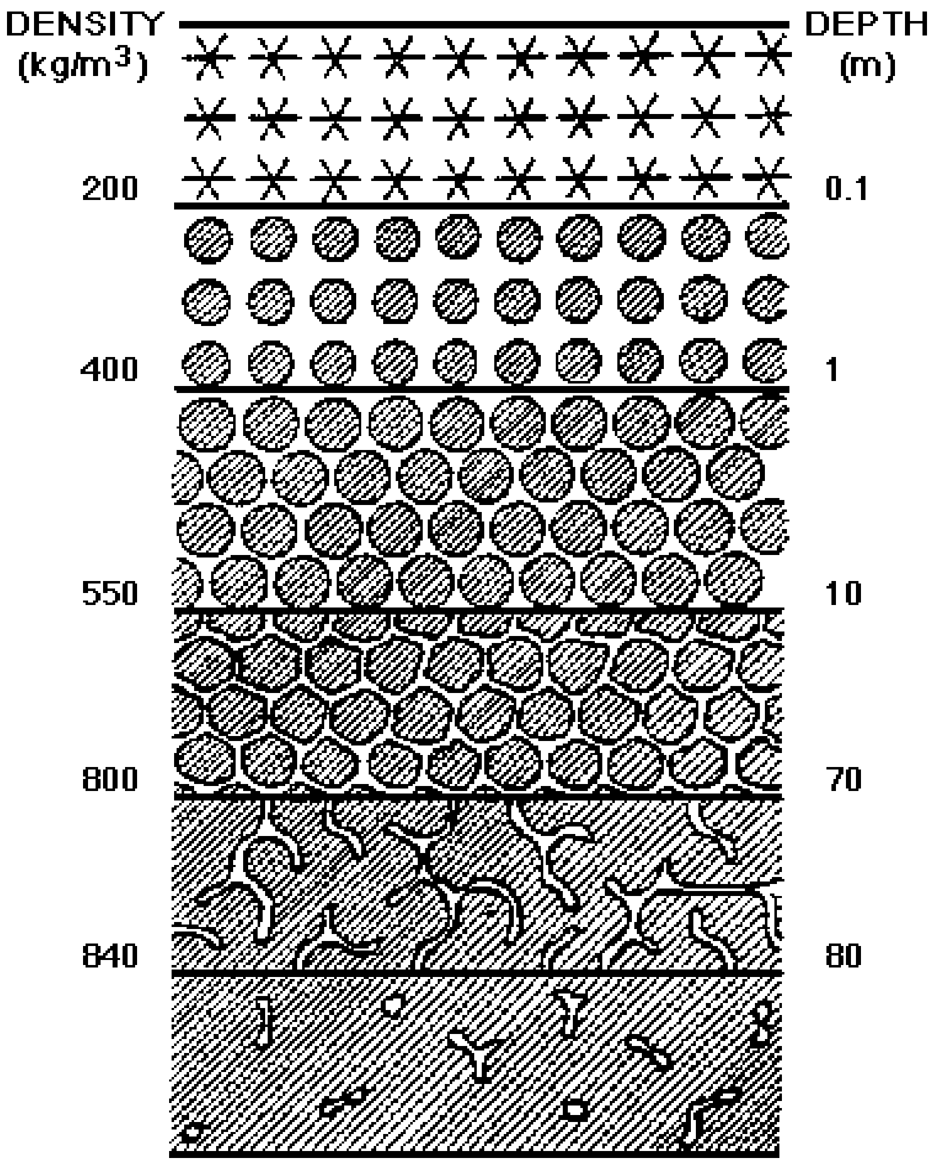
Other factors include:

- Aridity
- Distance from Coastline
- Diurnal Temperature Ranges

Glacier formation

Assuming favourable conditions are met:

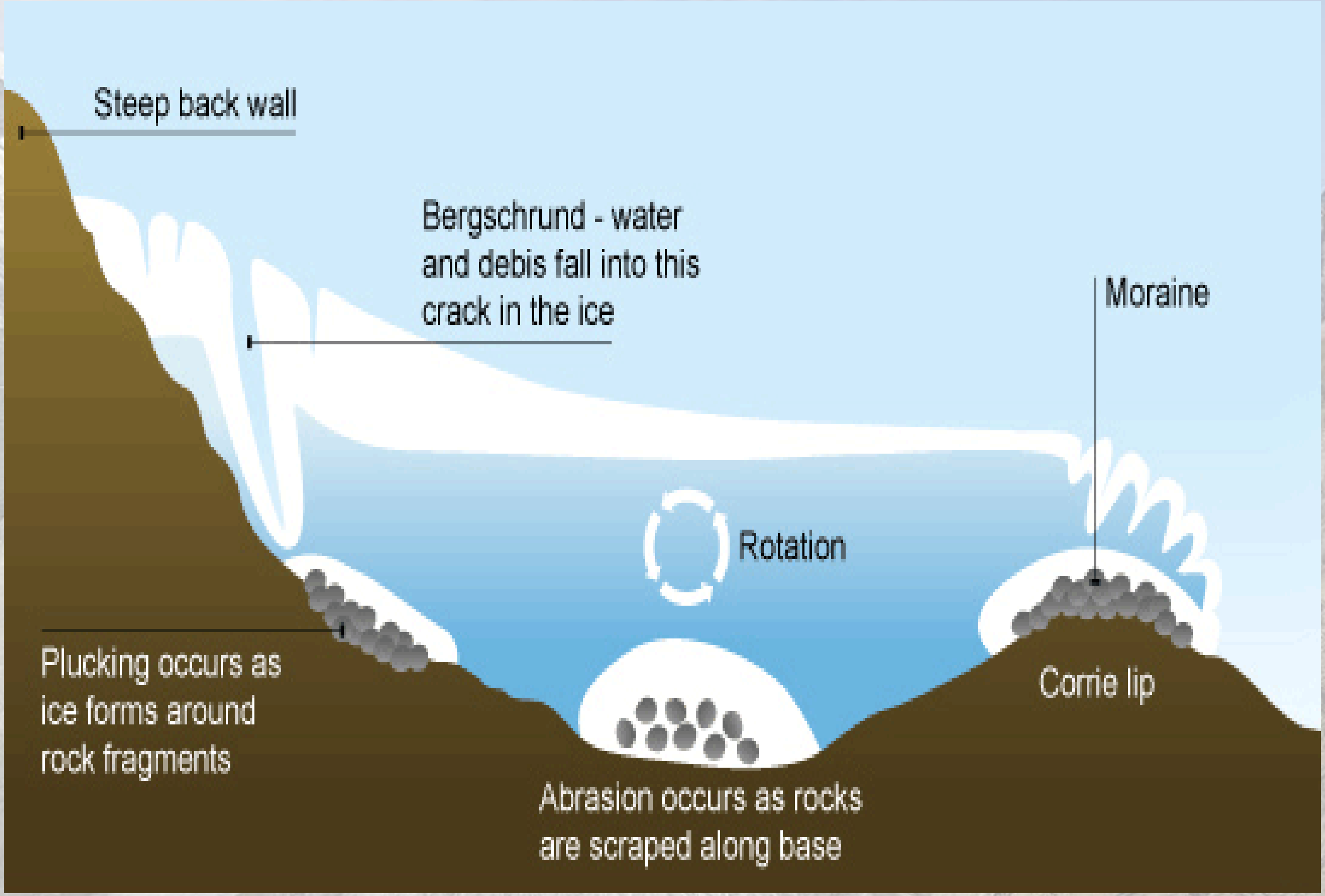
- More snow accumulated = more pressure = compression
- Firn is reached (snow that has survived 1 ablation season)
- Snow grains increase in size with time, and air pockets between them become smaller
- Eventually glacier ice formed, at 817kg/m^3



Diagramatic depiction of the gradual lithification of the snow which falls on polar ice caps. The snow recrystalizes to firn which has passages through which air can circulate. When the firn is fully lithified, the air passages are sealed off becoming bubbles.

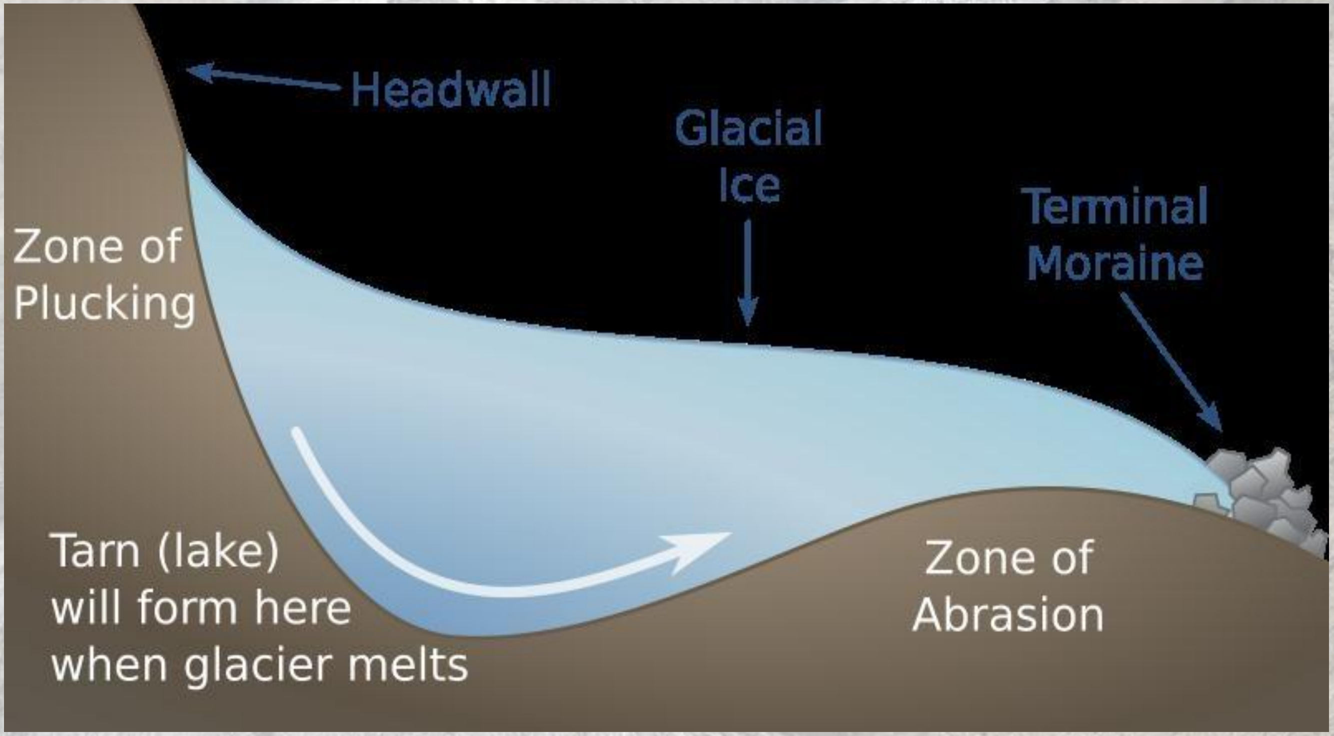
Mountain Glacier Landforms - Cirques

- Bowl-like basin
- Often formed where a glacier begins
- Formed where a large headwall is present, depresses and erodes substratum


Steep back wall
Bergschrund - water
and debis fall into this
crack in the ice
Moraine
Rotation
Plucking occurs as
ice forms around
rock fragments
Corrie lip
Abrasion occurs as rocks
are scraped along base

Mountain Glacier Landforms - Tarn

- A tarn is often formed where a cirque is present;
- A tarn is a lake formed by erosion and melt of a cirque



Mountain Glacier Landforms - Arete

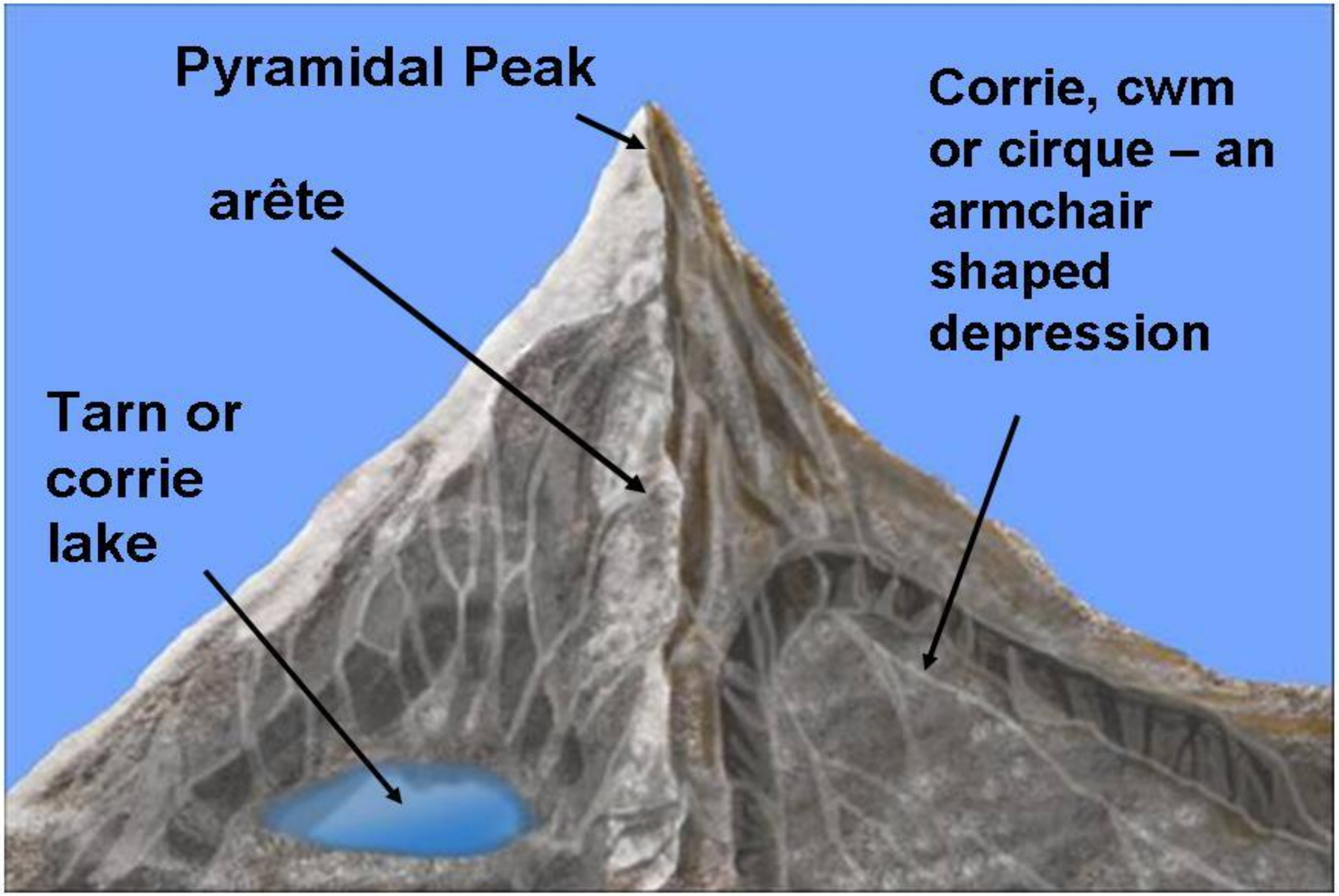
- Result of two cirque's next to each other
- Erosion results in knife-like ridge between them
- Result in steep sides and sharp top edge

Arete's

Mountain Glacier Landforms – Horn's

- Also known as pyramidal peak
- Formed when multiple glaciers erode the same mountain
- If 3 or more cirques erode the same mountain, a horn is formed

The Matterhorn, Zermatt, CH. (A great place for a beer!)



revisionworld

Piedmont glaciers

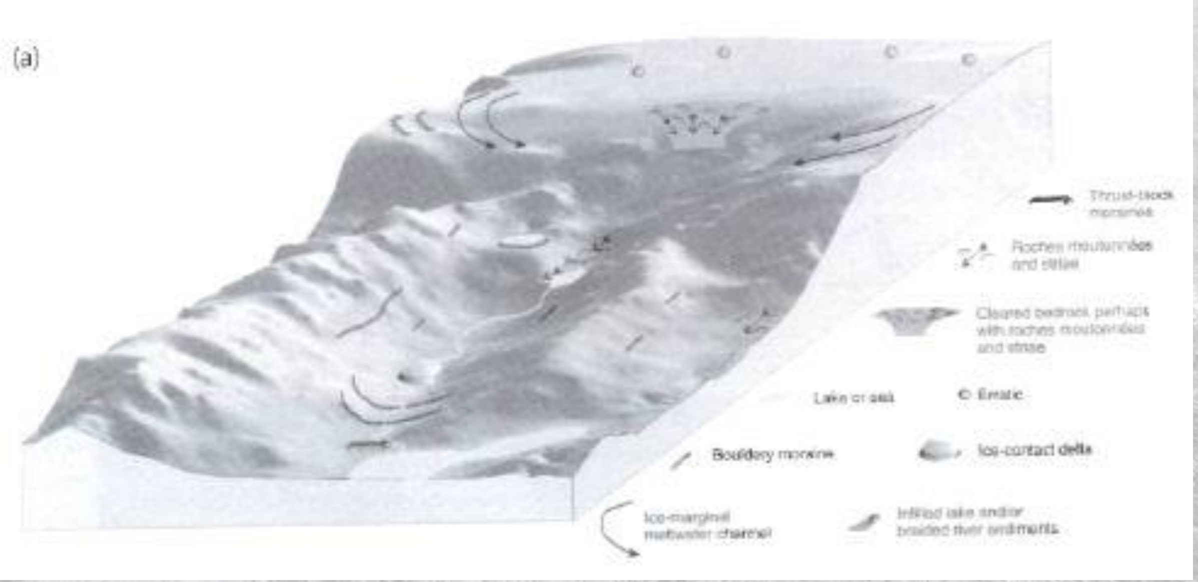
- Occur when steep valley glaciers flow into a relatively flat plain and spread out

Mountain glacier landsystem – 1 –

Plateau ice-fields

- Nourished under ELA by dry calving
- Cold-based -> not much debris transportation
- Warm-based -> marginal moraines

- Regional ice flow -> erratic
- Lateral + latero-frontal moraines + push moraines
  - Large cobble to boulder size angular material

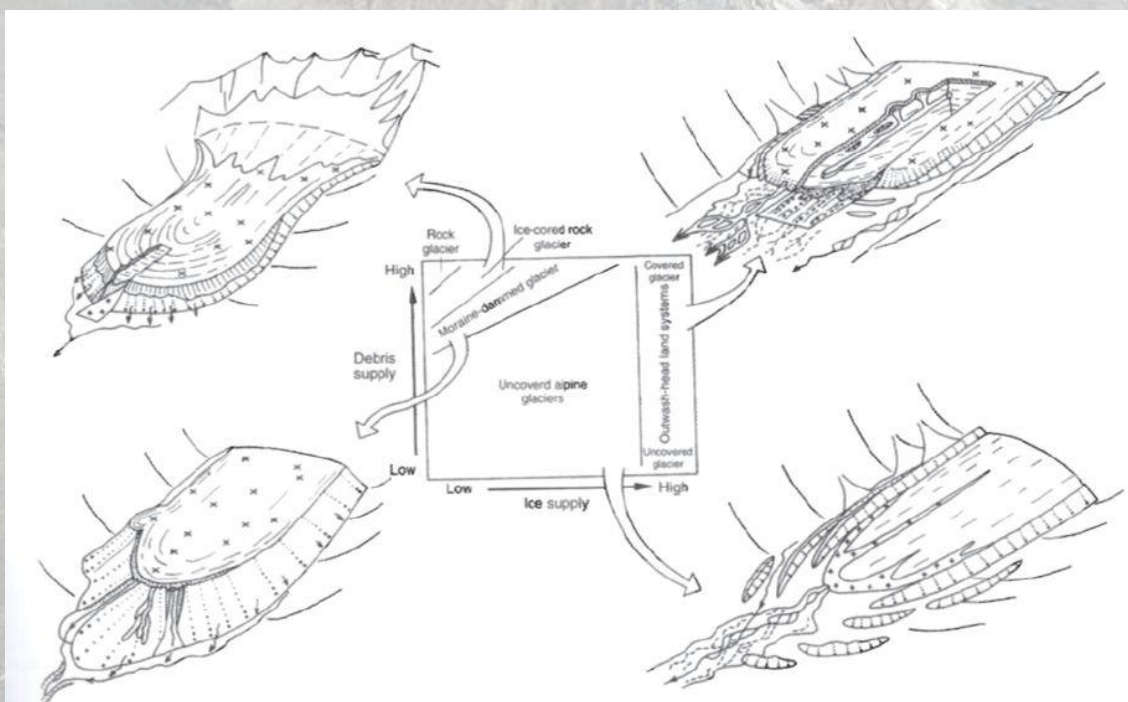


(Reference : Benn and Evans, 2010)

Mountain glacier landsystem – 2 –

Glaciated valley systems

- Very distinctive and unique
- Valley sides important in debris sources and topographic confinement of deposition



- Continuum defined by debris supply and ice supply
- Importance of sediment transport in construction of landform-sediment association, regardless of relief

(Reference : Benn and Evans, 2010)

Mountain glacier landsystem – 2 –

Glaciated valley systems

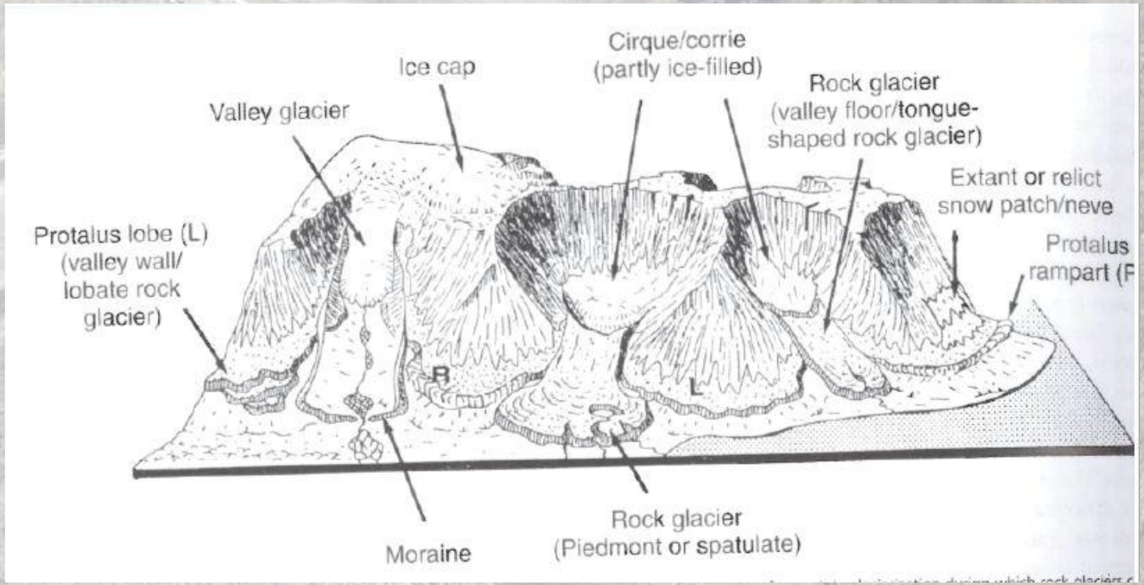
- High relief
  - Steep valley sides, 1000 m above valley floor
  - Young or tectonically active mountain folds
    - European and New Zealand Alps, High Andes, Himalaya
  - Margins covered with supra glacial debris -> latero-frontal moraines
- Low relief
  - Less than 1000 m between two ridges
  - Scotland, Norway, Labrador
- Protected from minor climate change : latero-frontal moraines limits advance and supra glacial inhibits the ablation

(Reference : Benn and Evans, 2010)

Mountain glacier landsystem – 2 –

Glaciated valley systems

- Cirque glaciers
  - Erosional zone -> ice moulded bedrock and bed erosion
  - Intermediate zone -> depositional material and erosion
  - Depositional zone -> covered by till
- Temporary lakes



(Reference : Benn and Evans, 2010)

Mountain glacier landsystem – 3 –

Trimlines and weathering zones

- Upper limit or valley sides of preserved erosion
- Limit of vegetation
- Periglacial trimline : upper level to which glacial erosion has removed a pre-existing regolith cover in glaciated mountain environments

- Englacial transition between erosive warm-based and cold-based glacier on plateau

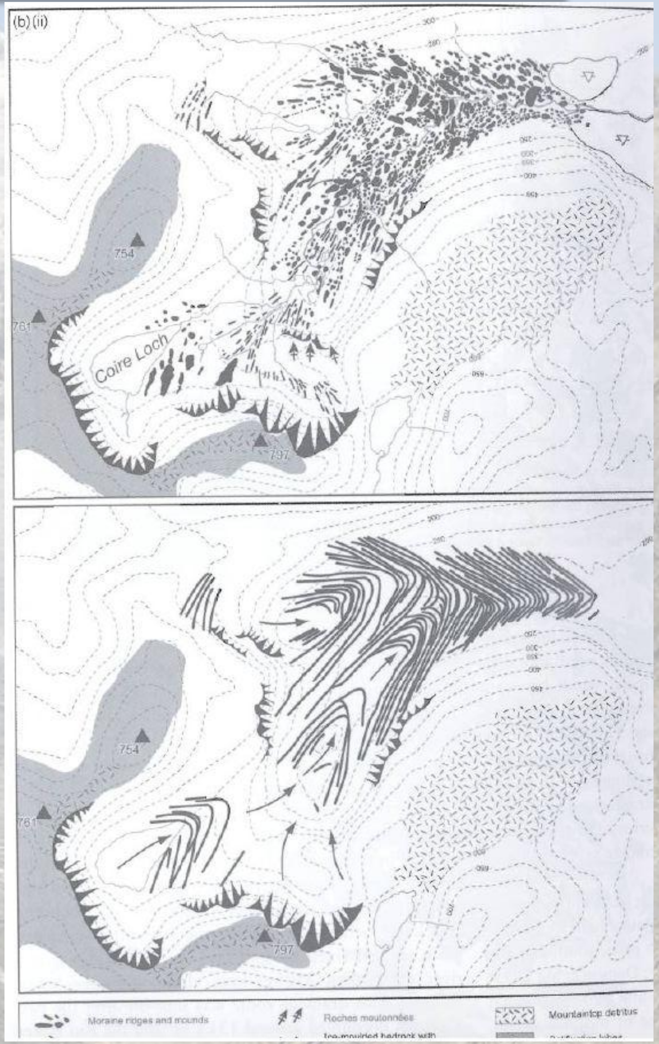
Adhesive strength on rock substrate interface **>** basal shear stress

= protection of regolith

(Reference : Ballantyne et all, 2011; Benn and Evans, 2010)

Mountain glacier landsystem – 4 –

- Mountain ice field landsystem
  - Cover large areas of diverse topography and can develop in a range of climatic settings
  - Margins carry large amounts of glaciagenic material
  - Ice-dammed lakes



(Reference : Benn and Evans, 2010)

Mass balance

- Mass balance = Accumulation – Ablation
- Specific mass balance is the change in the mass per unit area relative to the previous summer surface. (The Physics of Glaciers).
- Units = mm of water equivalent depth.
- Cumulative mass balance changes measured by summing the net balance of multiple years.

Mass balance measurements - Types

1. Direct measurements.

2. Remotely-sensed techniques.

Mass balance measurements - Types

- Direct measurements:-

Carried out on glacier itself

1. Stake method
2. Geodetic surveys
3. Hydrological balance method

Stake method (Wagnon et al, 2007)

- Placing iron rod.
- Marking elevation of snow/ice.
- Change in surface elevation determine how much mass is being added or removed.

Image source :- http://environmentalresearchweb.org/blog/2010/08/strange-and-beautiful-ice.html

Geodetic surveys (Robert M. Krimmel, 1999)

- Changes in the x, y, and z angles and distances used.
- Calculate topographic changes of a glacier's surface area and elevation.
- Addition or subtraction of glacial volume.
- GPS/ DGPS.

Image source :- http://buildipedia.com/knowledgebase/division-02-existing-conditions/02-20-00-assessment/02-21-00-surveys/surveys?print=1&tmpl=component

Hydrological balance (Regine Hock , 2005)

- Mass Balance = Precipitation - Evaporation – Runoff
- Precipitation is measured at meteorological stations in water equivalent.
- Evaporation / sublimation rates are calculated by measurements of temperature, wind velocity and wind speed.
- Runoff is measured near snout at gauging stations.
- But snow may be added to glacial mass via wind or avalanche deposition as well (Hubbard and Glasser 2005).

Mass balance measurements - Types

- Remotely-sensed techniques:-

  Aerial and satellite-based images

  1. Changes in surface elevation

  2. Relationship between AAR and specific mass balance

Changes in surface elevation

- Digital elevation model (DEM)
- Use of Stereo pair satellite images like SPOT5, LIDAR (Jóhannesson et al, 2011) or SAR interferometry (Yu et al, 2010).
- Elevation change is calculated by subtracting one DEM from another.

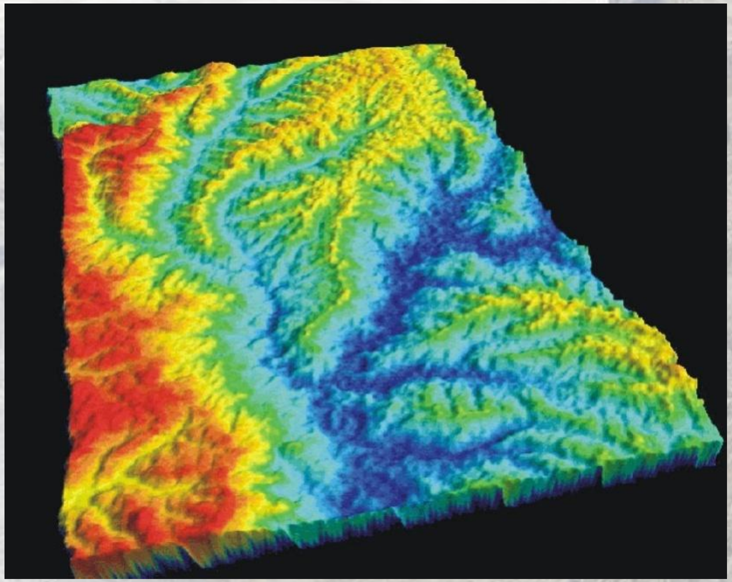
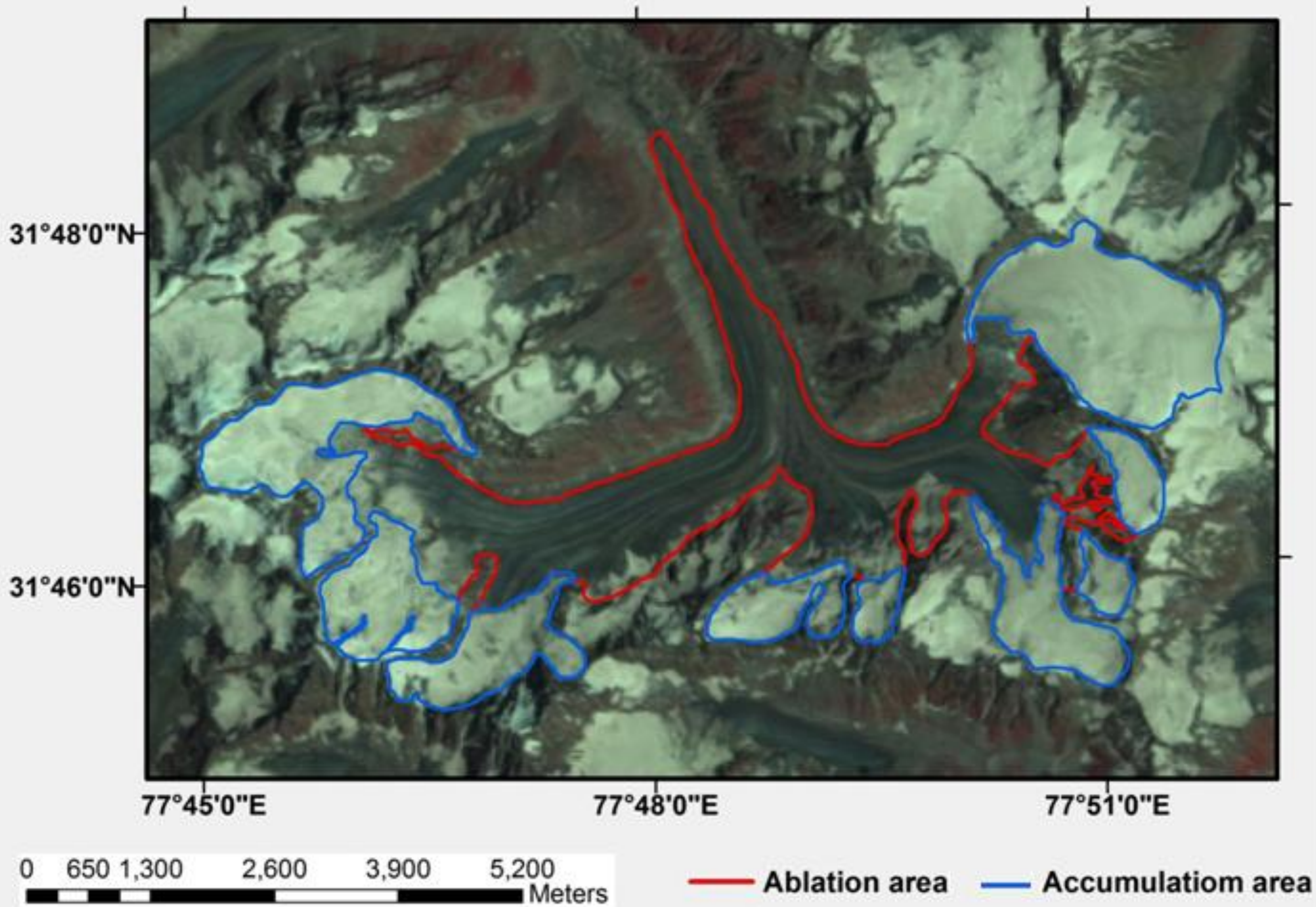


Image source :- http://alloverthemapproject.blogspot.com/2011/04/digital-elevation-model-dem.html

AAR and specific mass balance

- AAR is a ratio between accumulation area and total glacier area (Meier et al, 1962).
- A regression relationship between AAR and specific mass balance is established using field data of different years.
- That equation can be used for estimation of specific mass balance of other glaciers of that region (Kulkarni et al, 2004).

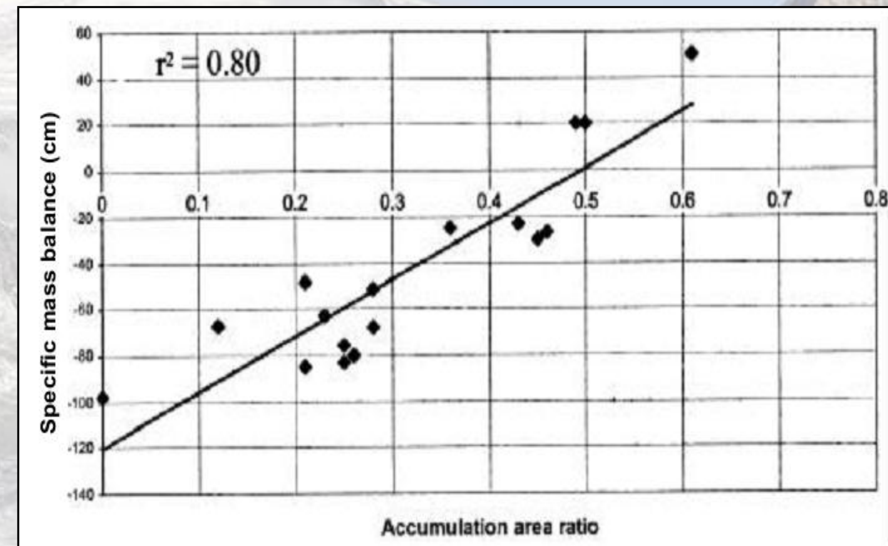
Parbati glacier 2009



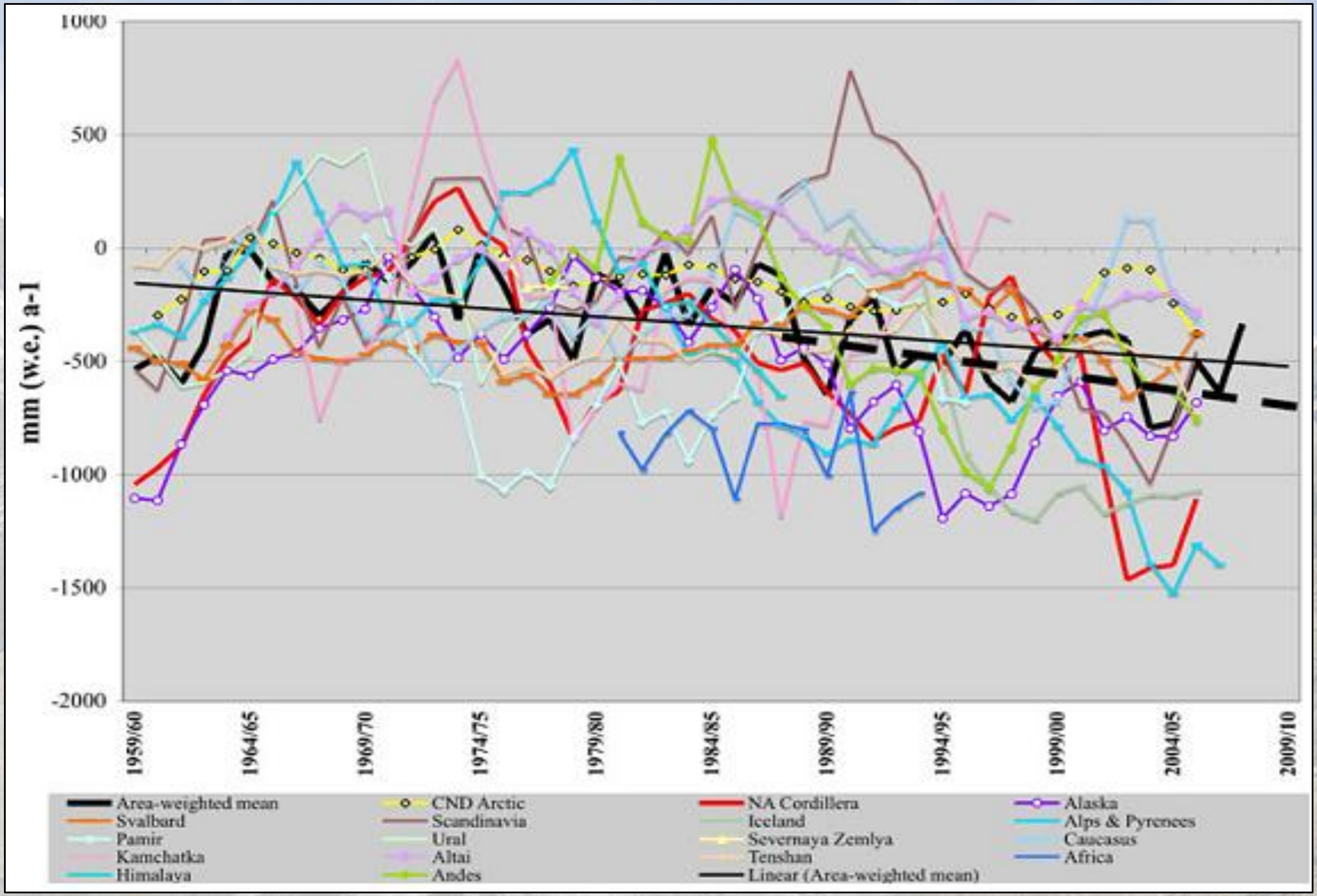
AAR and specific mass balance (Kulkarni et al, 2004)

Y = 243.01 * X – 120.187

Where, Y is the specific mass balance in water equivalent (cm) and X is the accumulation area ratio.



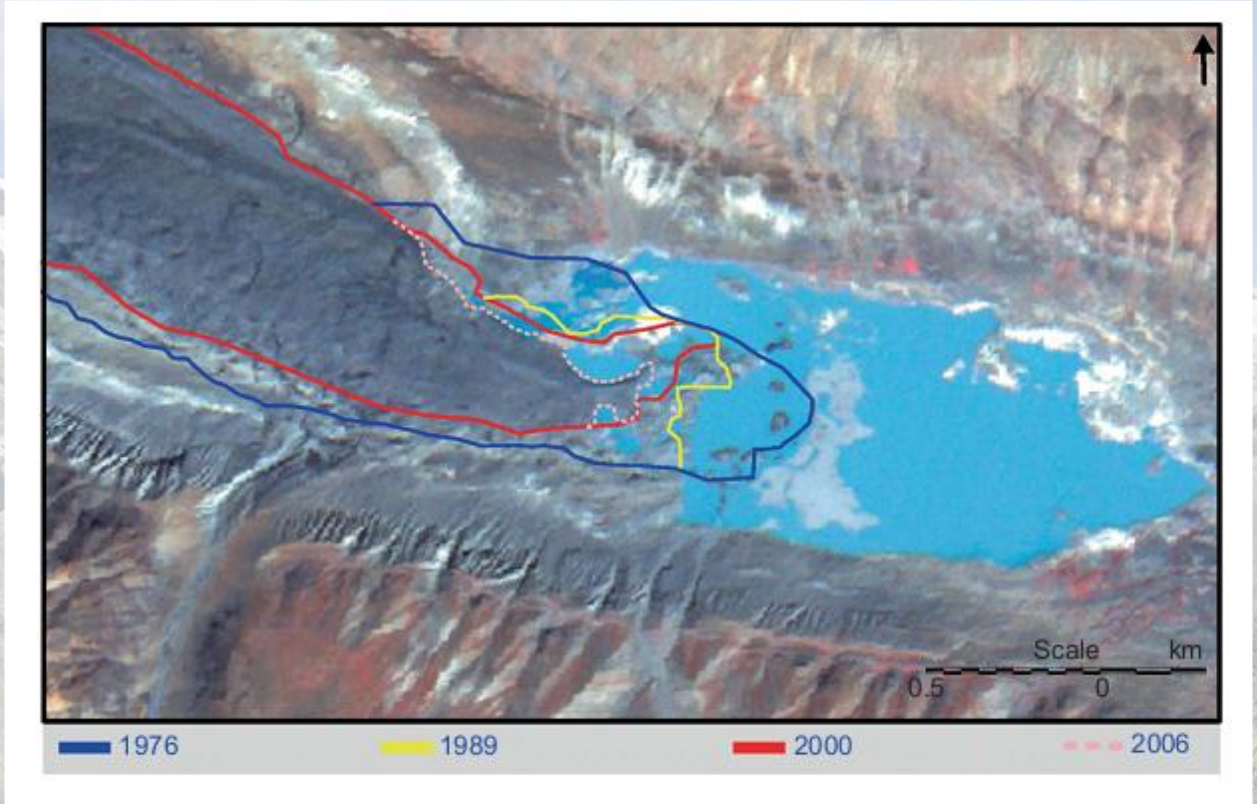
Regression relationship between accumulation area ratio and mass balance for Shaune Garang and Gor Garang glaciers. (Kulkarni et al, 2004).



5 years running means of the annual mean net balance for 50 years for the 17 regions. The bold black line indicates the area-weighted global mean, while the black straight lines indicate the accelerations for the periods of the last 50 years 1961–2010 (thin line) and for the last 20 years 1991–2010 (thick broken line), Atsumu Ohmura (2011)

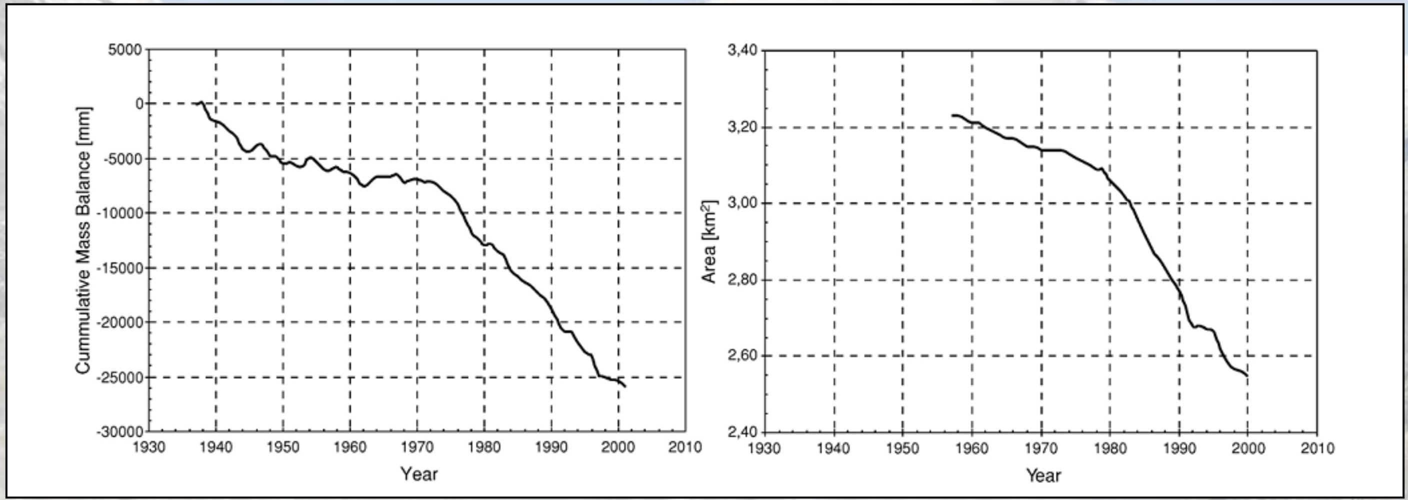
Glacier retreat

- The growth or retreat of glacier depends on mass balance of that glacier (Hubbard and Glasser 2005).
- Amount of retreat varies from glacier to glacier.
- Due to the mass loss, glacier starts retreating.



Satellite imagery of IRS LISS-IV sensor from 16 September 2006 showing retreat of the Samudra Tapu glacier, Himachal Pradesh, India from 1976 (Kulkarni et al, 2011)

Glacier retreat (Tobias Bolch, 2007)



- **Left: cumulative mass balance of the Tuyuksu glacier, 1937 –56 calculated from climate data, from 1957 measured data**
- **Right: area change since 1957**

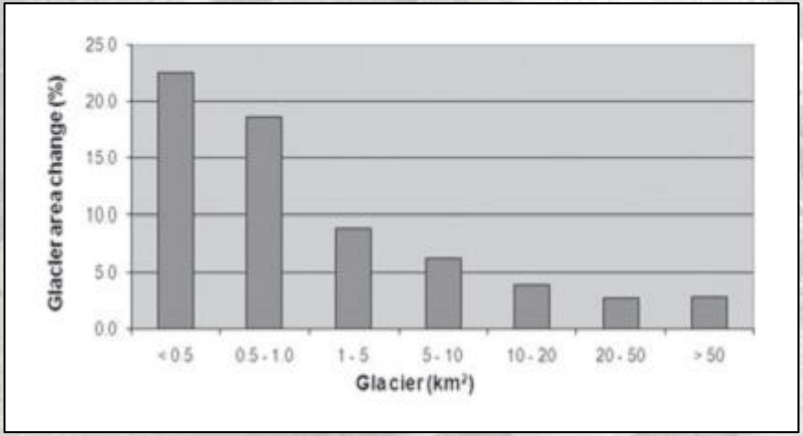
Glacier retreat

- Amount of retreat varies from glacier to glacier and from basin to basin depending on parameters such as maximum thickness, mass balance and rate of melting at terminus. (Kulkarni et al 2005).

- Glacier retreat is also influence by area altitude distribution, as snow and ice ablation is influenced by altitude. If large area is below the snowline at the end of ablation season negative mass balance and will lead to the retreat. (Kulkarni 2007)

Glacier retreat

- Smaller glaciers are more vulnerable to climate change and retreating rapidly.



Glacier area change and area measurements (%) based on Corona (27 September 1968) and ASTER (2006), Bhambri et al (2011).

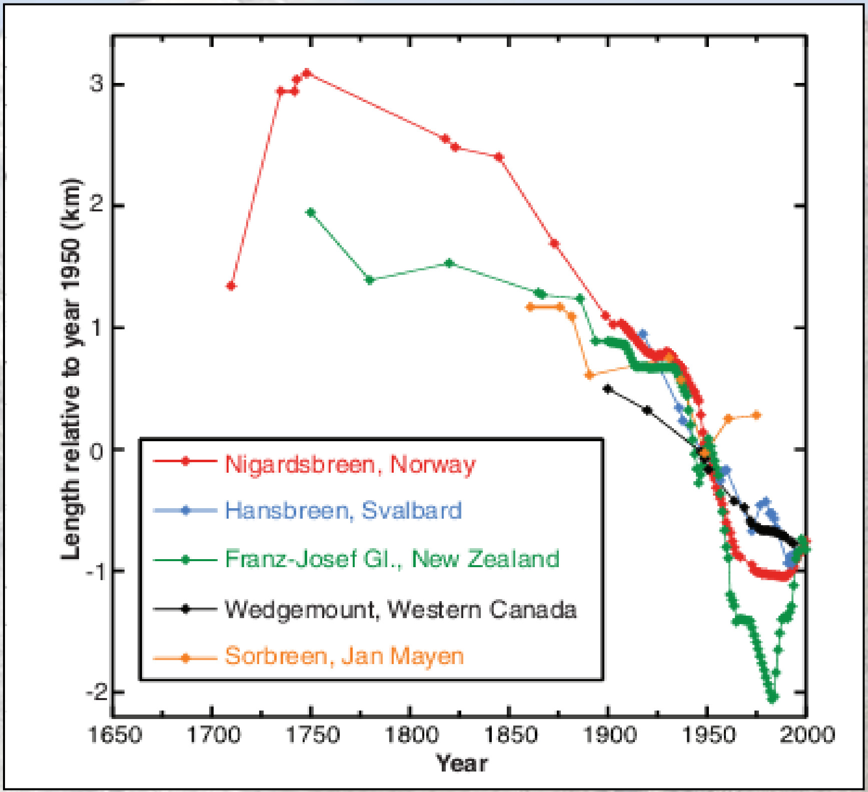
Glacier area (km^2)	Number of glaciers in 1962	Glacier area (km^2) 1962	Glacier area (km^2) 2001/04	Change in %
< 1	127	68	42	38
1-5	159	382	269	29
5-10	48	329	240	27
> 10	25	635	559	12
Total	359	1414	1110	21

Change in glacier area for Chenab basin, India - indicating higher loss of area in smaller glaciers. (Kulkarni et al)

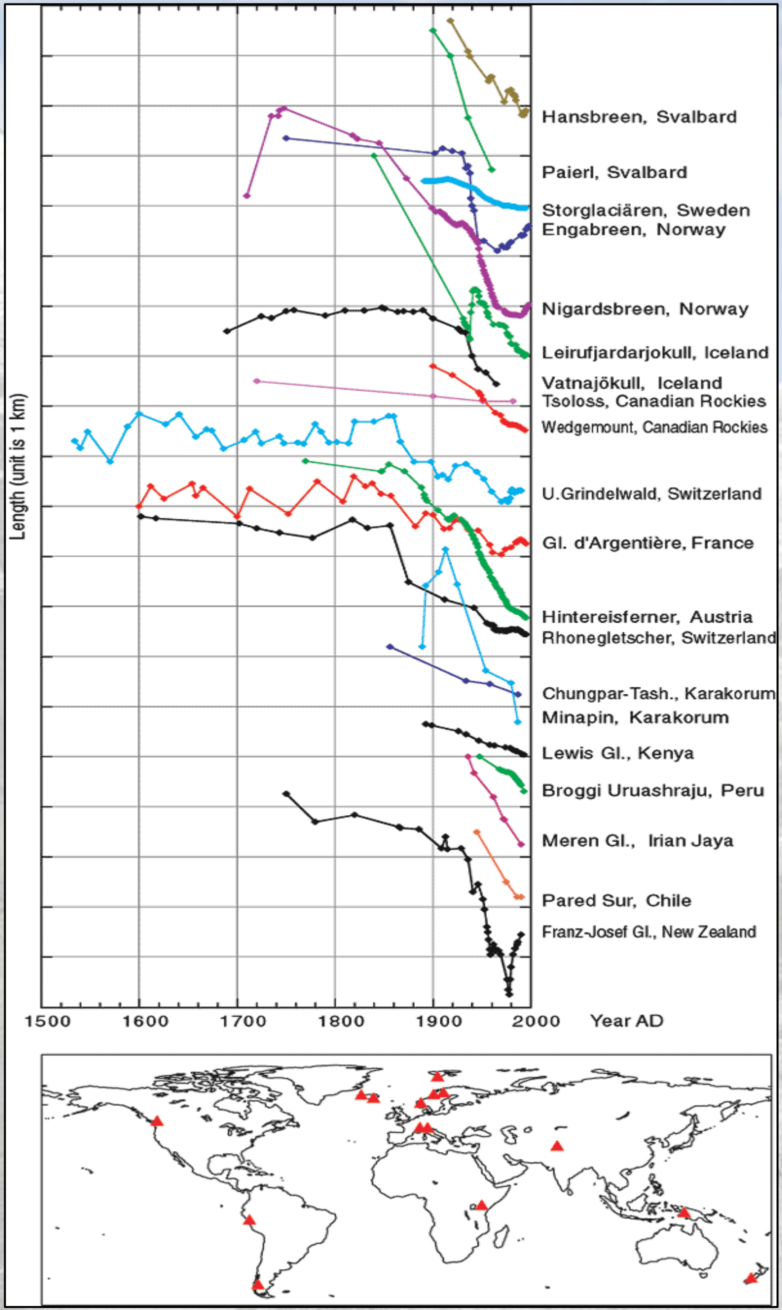
Glacier retreat

- Orlemans (2005) has analyzed 169 glaciers from different part of world for estimation of retreat.

- All glaciers except the glacier from New Zealand are retreating.



The retreats in length for 6 glacier from different part of world are shown in figure .



- IPCC Third Assessment Report
- 20 glaciers from the various part of the world which have different lengths, are retreating.
- So it is confirmed that the glaciers of all over world are retreating.
- Glacierized area in the Alps has decreased by 40% since 1850

Basin	No. of glaciers	Area 1962 (km²)	Area 2001/2004 (km²)	Loss in area (%)
Goriganga	41	335	269	19
Bhagirathi	212	1365	1178	14
Baspa	19	173	140	19
Parbati	90	493	390	20
Chandra	116	696	554	20
Bhaga	111	363	254	30
Miyar	166	568	523	08
Bhut	189	469	420	10
Warwan	253	847	672	21
Zanskar	671	1023	929	09
Total	1868	6332	5329	16
Tista	57	403 (1997)	392	2.7

Glacier retreat in Himalayas, Kulkarni et al, 2011

Impact on humans

- Although mountain glaciers are often far from population centres, their loss will impact communities all around the world. Impacts range from:
  - Loss of water supplies due to a reduction in glacial meltwater
  - Conflict over the dimishing supply of meltwater
  - Rising sea levels, which will affect people in coastal regions everywhere

Loss of water supplies

- In many areas, such as the Himalayas, communities downstream of small mountain glaciers often depend on glacial meltwater

- Two billion people live in regions close to the rivers which are fed by this mountain range

- However since 1962 a 21% loss in glacial mass has been observed

Rivers fed by Himalayan glaciers

- These five major river systems support a large amount of people, both through meltwater used for drinking and for irrigation in China, India and Pakistan’s wheat and rice fields.

    1. Ganges: 407 million
    2. Yangtze: 367 million
    3. Indus: 178 million
    4. Yellow: 147 million
    5. Brahmaputra: 118 million

Effects of less meltwater in other areas

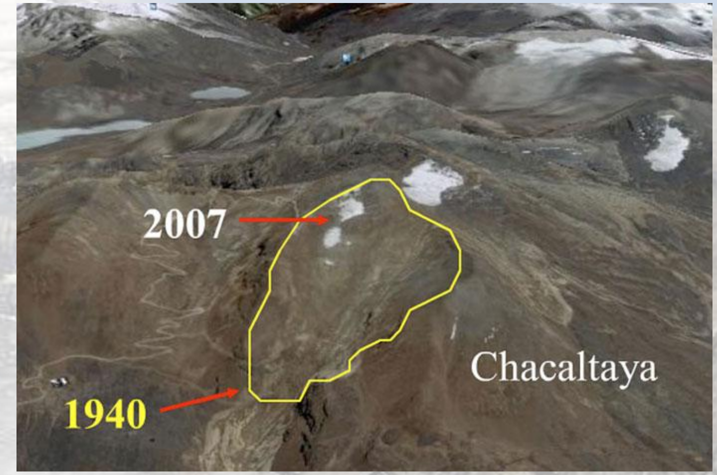
- It's not just the Himalayan area that would be effected by a lack of meltwater
- Rapid melting of glaciers in Bolivia has caused temporary increases in stream flow and contributed to flooding, but within the next decade it is predicted that there will be water shortages
- Some farmers already reporting shortage, 77 million others also at risk

Why glacial meltwater is important

- Precipitation in Bolivia occurs only during part of the year; this water is then stored on glaciers and released throughout the year due to melt
- If glaciers disappear, there is no storage, therefore for part of the year there would be no water
- This threat is causing Bolivia to ask questions of many of the more developed countries in the world. This area is due to be hugely effected by climate change but only contributes 0.02% of global greenhouse emissions

Chacaltaya glacier, Bolivia

- Chacaltaya is one glacier which has lost much of its mass
- This glacier is one of many that feeds a reservoir that provides water for the one million residents of El Alto



- This mountain, at 17,388 feet, was once the home of the worlds highest ski slope

Conflict

- The disappearance of glaciers is a major cause of conflict in the areas around Kilimanjaro

- The Pangani River Basin is home to around 3.7million people, it begins on the slopes of the mountain and meanders towards an estuary in the town of Pangani

- In 2000 violence broke out in regions along the river, during this “district police were called in to calm the situation and restore order, while administrative authorities embarked on a lengthy process of dialogue and conflict resolution.”

Politics

- Local knowledge in the past had prevailed, the local people knew that the highlands provided much of the water and acknowledged that for the sake those downstream and the overall ecosystem it should be able to flow freely
- However since 1972 increasing political divisions have led to the flow downstream being heavily choked
- Combined with the less total availability of water due to glacial retreat violence and social unrest is set to increase

Damage to the environment

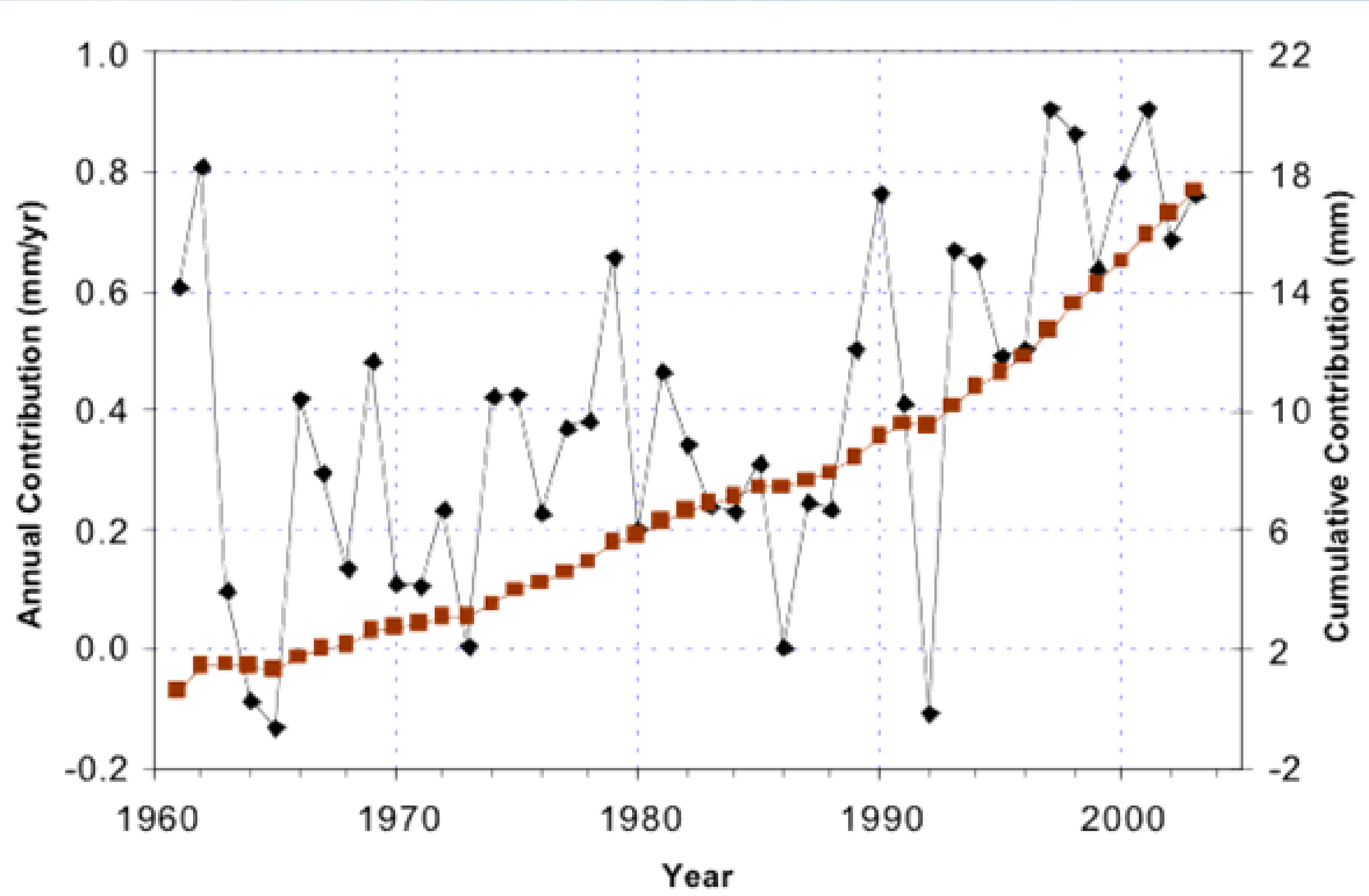
- The lack of water flowing downstream doesn’t just effect humanity, but also the environment
- The Pangani river also provides water to areas such as the Eastern Arc Mountains, considered one of the Earth’s 25 biodiversity hotspots.
- Around eighty percent of the regions spiders and insects are limited to a few mountains in the area, a loss of water supply to here would threaten the biodiversity

Kilimanjaro Ice Retreat

- Mount Kilimanjaro satellite images from 1993 and 2000, showing the rapid retreat of the glacier

Sea level rise

- Another impact on humans is that melting glaciers contributes to a rise in sea level
- Many large cities and arable regions in the world are located in coastal regions
- Defences are often unavailable in many regions, and even where they are they would be expensive



The annual contribution from glaciers to sea level change (left axis, mm/yr), and cumulative value (right axis, mm) based on area-weighted averaged mass balance

Some issues in research of Mountain Glaciers

- **Accessibility**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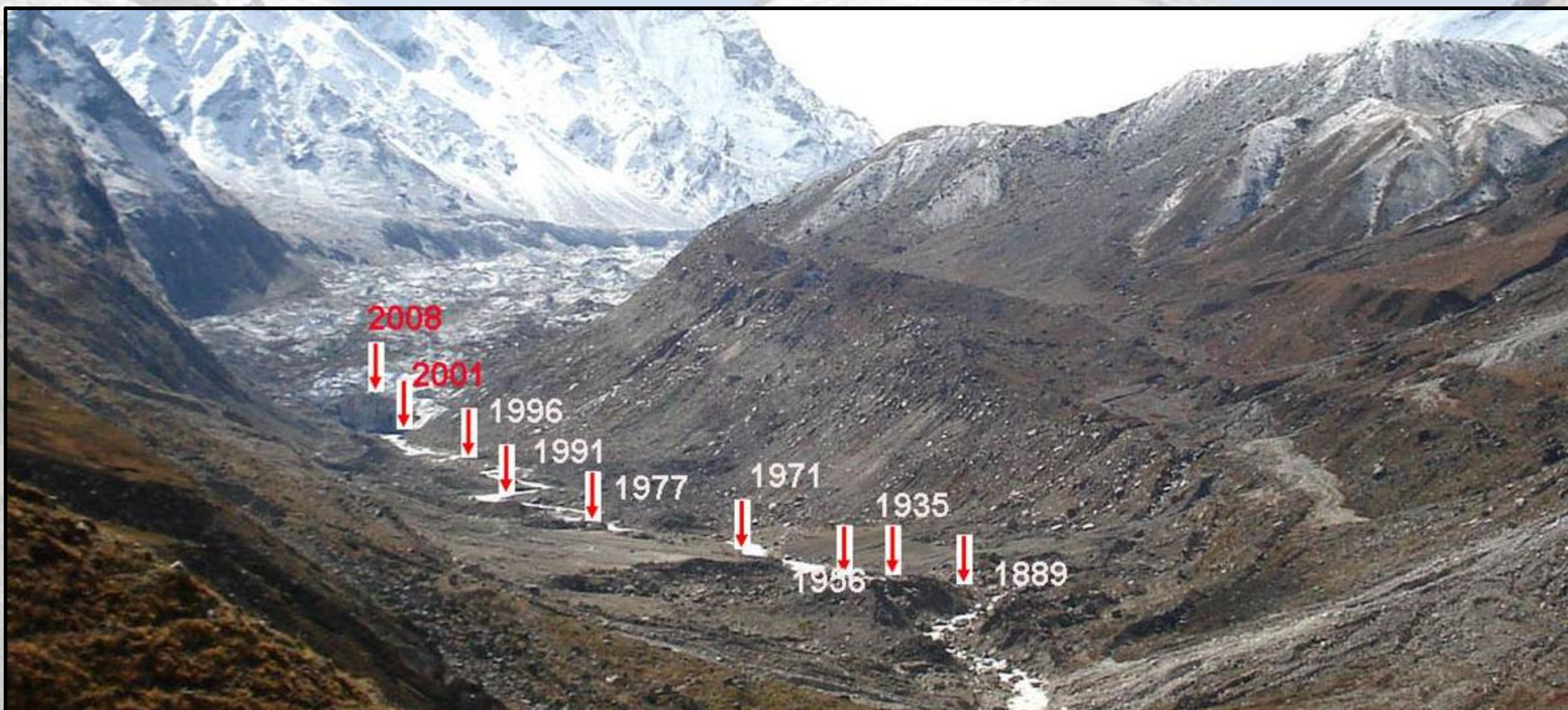
Some issues in research of Mountain Glaciers

- **Accessibility**
- **Which method to follow? Field / Remote sensing?**

Some issues in research of Mountain Glaciers

- **Accessibility**
- **Which method to follow? Field / Remote sensing?**
- **Locations of snout - In history**

Wealth of photography…



Some issues in research of Mountain Glaciers

- **Accessibility**
- **Which method to follow? Field / Remote sensing?**
- **Locations of snout - In history**
- **Climate change.. Which is affecting mountain glaciers -- consequences?**


USGS

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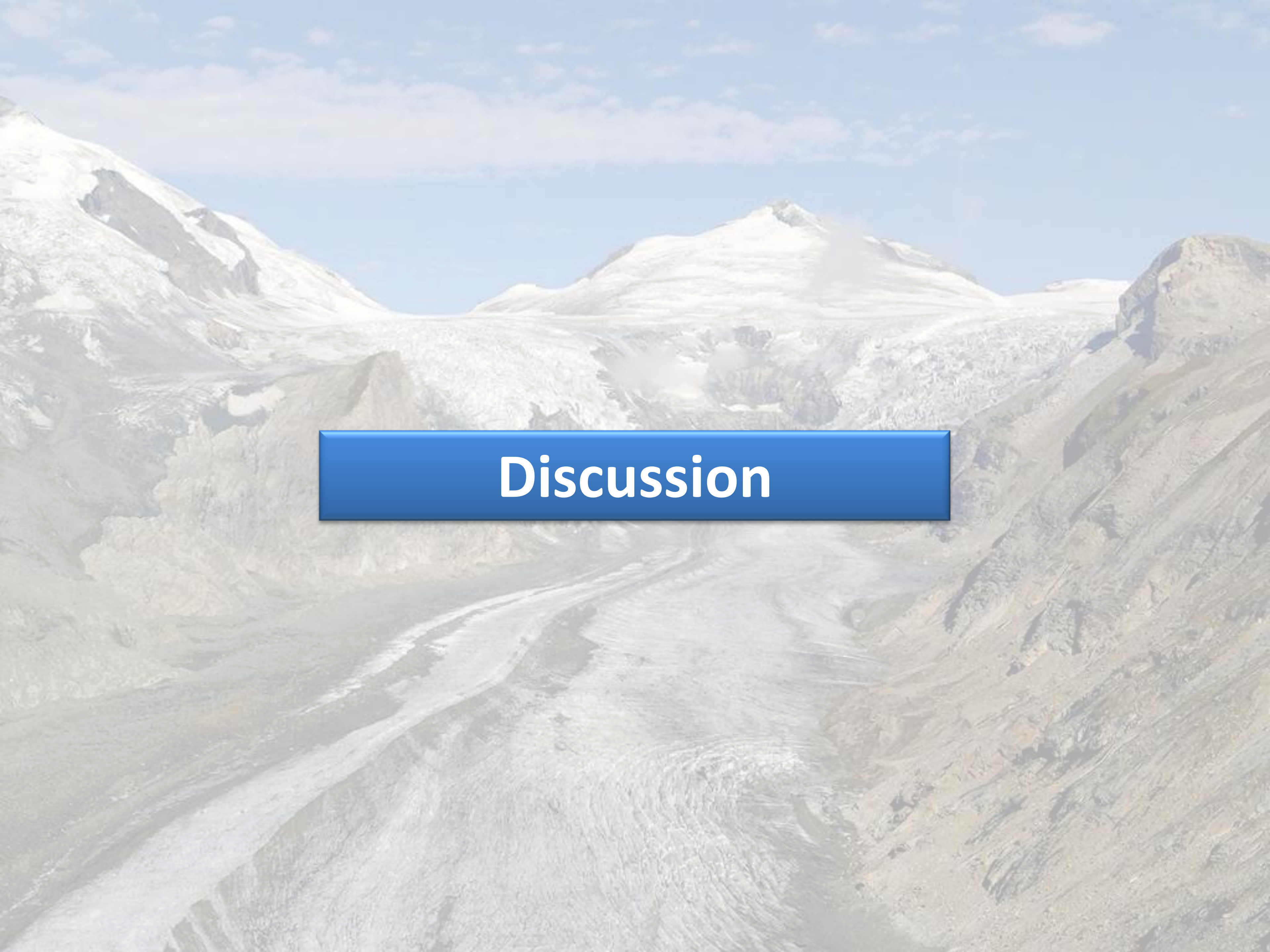
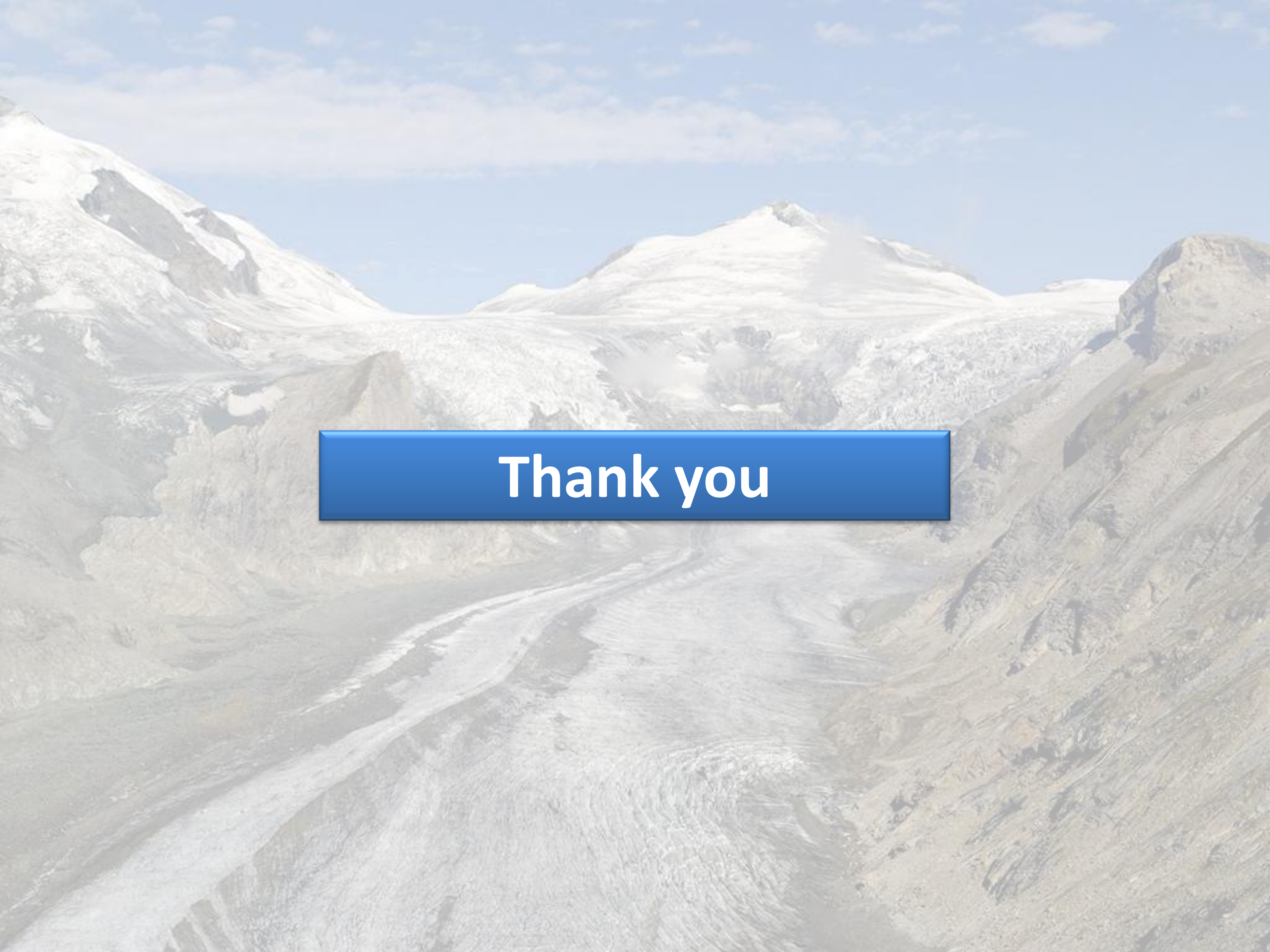
Image at the back ground of all the slides : Baltoro glacier (http://www.traveltop.net/baltoro-glacier-mountain-glacier/)


Discussion


Thank you