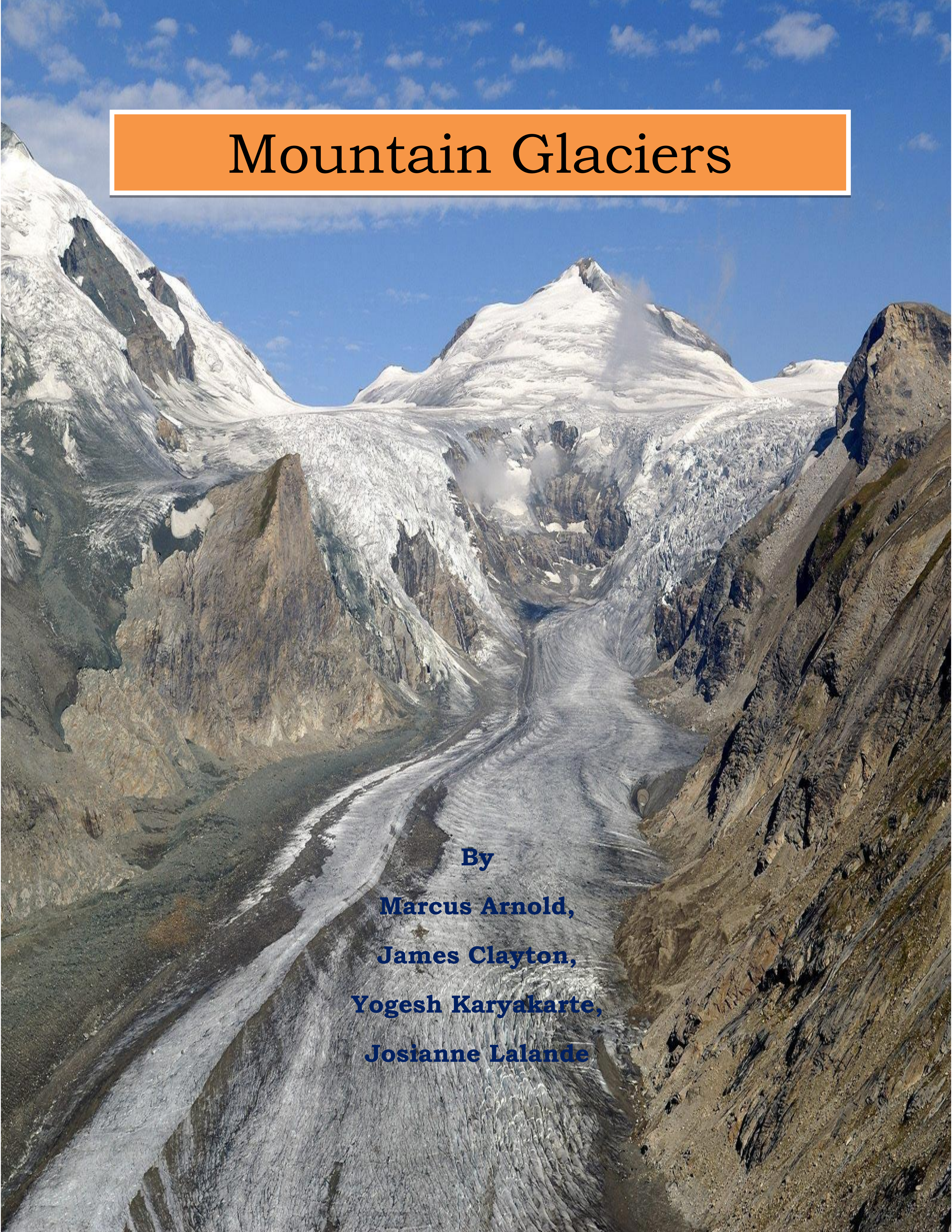
Mountain Glaciers



By

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1. Introduction:

A glacier cannot form unless is it above the snowline, the lowest elevation at which snow can survive year round. Precipitation and temperature plays main role in formation and survival of snow/ ice which form the glacier. Mountain glaciers are relatively well distributed worldwide and are found on every continent except for Australia. Most glaciers form in high mountain regions such as the Himalayas of Southern Asia or the Alps of Western Europe where regular snow and extremely cold temperatures are present. Mountain glaciers are also found in Antarctica, Greenland, Iceland, Canada, Alaska, and even South America (the Andes), California (the Sierra Nevada), and Mount Kilimanjaro in Tanzania. Figure 1 shows the locations of Mountain glaciers. The World Glaciological Inventory data shape file of 2012 used to prepare this map in ArcGIS 9.2.

Z. Zuo and J. Oerlemans (1997) have estimated the surface area of glaciers from all part of the world (Figure. 2). The highest surface area was near Quttinirpaaq National Park of Canada followed by Svalbard and Himalayan glaciers.

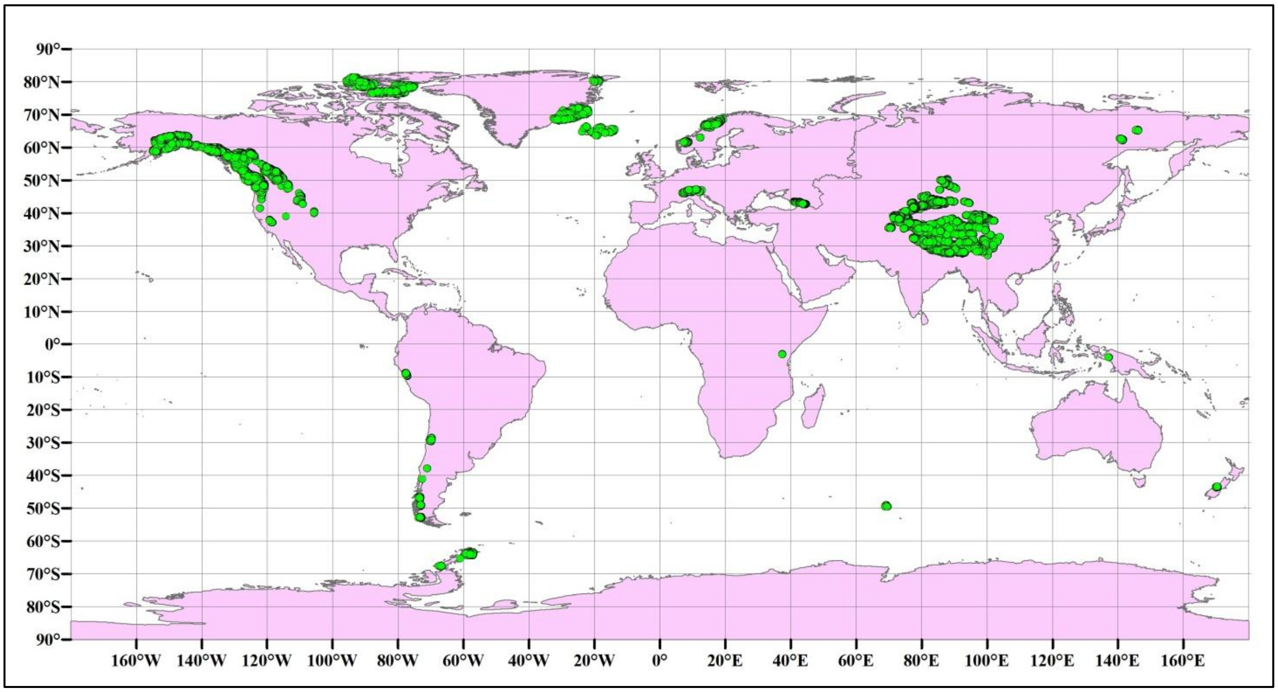


Figure 1. Locations of mountain glacier - (Shape file = WGI- 2012, s/w: ArcGIS 9.2)

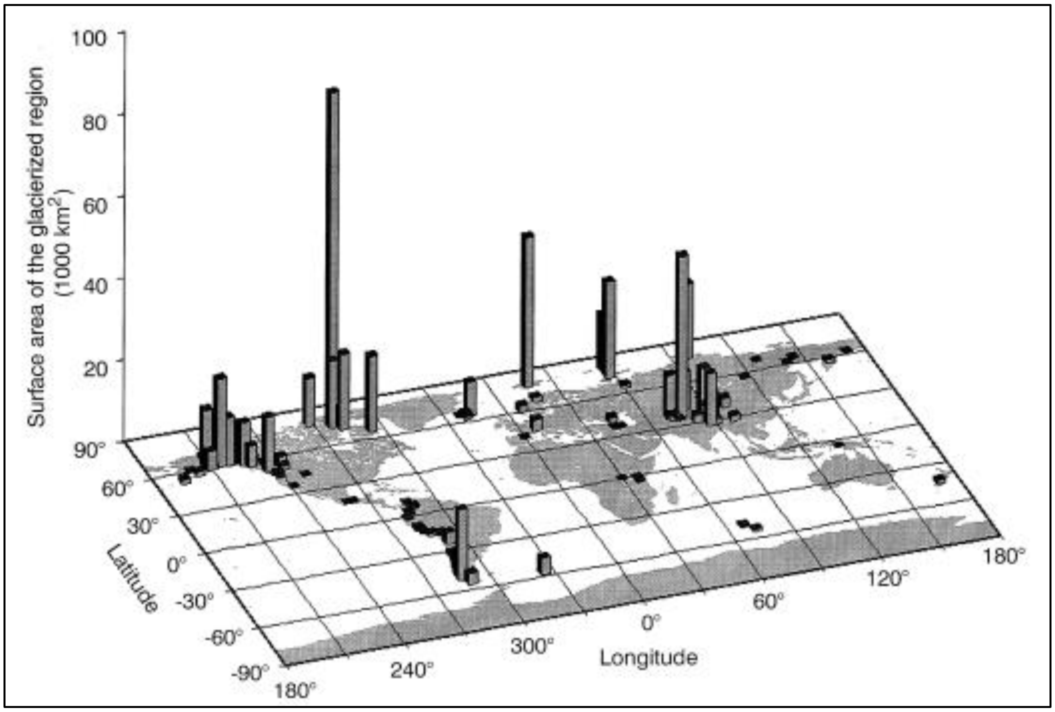
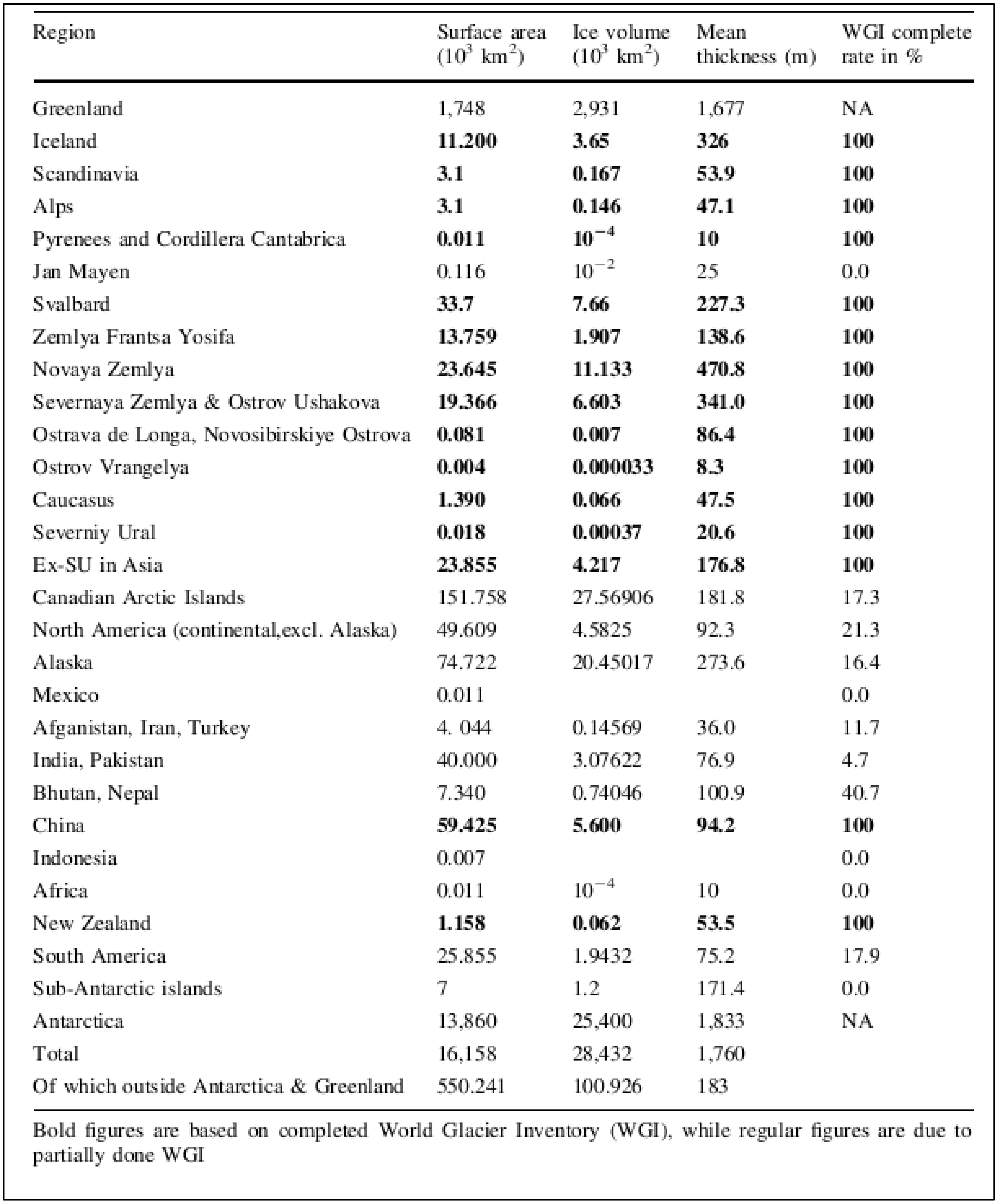


Figure 2. Global distribution and surface area of glaciers (excluding the Greenland and Antarctic). Glaciers are divided into 100 regions (shown in solid bars); each region may represent one or many individual glaciers (Z. Zuo and J. Oerlemans, 1997)

Though the temperate and tropical mountain glaciers have very few mass compared to very large ice sheets and icecaps, they play major role in the environmental and social well-being of the mountain ranges in which they exist and the watersheds to which they drain. The general information about surface area, volume and thickness of glaciers is given in table 1 (Atsumu Ohmura, 2011).

The Himalaya encompasses the world's third largest glacier systems after Antarctica and Greenland occupying about 15% of the mountain terrene. Glaciers are a source of continuous water supply to perennial river systems and two of the world's largest rivers, the Indus and Brahmaputra originate from these glacial lake systems and there by ensure round the year irrigation facility to agriculture, which is the main string of economy of the developing nations like of India.

Table 1. WGI - Glacier surface area, volume, and mean thickness (Atsumu Ohmura, 2011).



Region	Surface area (10^3 km^2)	Ice volume (10^3 km^2)	Mean thickness (m)	WGI complete rate in %
Greenland	1,748	2,931	1,677	NA
Iceland	**11.200**	**3.65**	**326**	**100**
Scandinavia	**3.1**	**0.167**	**53.9**	**100**
Alps	**3.1**	**0.146**	**47.1**	**100**
Pyrenees and Cordillera Cantabrica	**0.011**	**10^{-4}**	**10**	**100**
Jan Mayen	0.116	10^{-2}	25	0.0
Svalbard	**33.7**	**7.66**	**227.3**	**100**
Zemlya Frantsa Yosifa	**13.759**	**1.907**	**138.6**	**100**
Novaya Zemlya	**23.645**	**11.133**	**470.8**	**100**
Severnaya Zemlya & Ostrov Ushakova	**19.366**	**6.603**	**341.0**	**100**
Ostrava de Longa, Novosibirskiye Ostrova	**0.081**	**0.007**	**86.4**	**100**
Ostrov Vrangelya	**0.004**	**0.000033**	**8.3**	**100**
Caucasus	**1.390**	**0.066**	**47.5**	**100**
Severniy Ural	**0.018**	**0.00037**	**20.6**	**100**
Ex-SU in Asia	**23.855**	**4.217**	**176.8**	**100**
Canadian Arctic Islands	151.758	27.56906	181.8	17.3
North America (continental,excl. Alaska)	49.609	4.5825	92.3	21.3
Alaska	74.722	20.45017	273.6	16.4
Mexico	0.011			0.0
Afganistan, Iran, Turkey	4. 044	0.14569	36.0	11.7
India, Pakistan	40.000	3.07622	76.9	4.7
Bhutan, Nepal	7.340	0.74046	100.9	40.7
China	**59.425**	**5.600**	**94.2**	**100**
Indonesia	0.007			0.0
Africa	0.011	10^{-4}	10	0.0
New Zealand	**1.158**	**0.062**	**53.5**	**100**
South America	25.855	1.9432	75.2	17.9
Sub-Antarctic islands	7	1.2	171.4	0.0
Antarctica	13,860	25,400	1,833	NA
Total	16,158	28,432	1,760	
Of which outside Antarctica & Greenland	550.241	100.926	183	

Bold figures are based on completed World Glacier Inventory (WGI), while regular figures are due to partially done WGI

2. Purpose of study:

Mountain glaciers are source of crucial water required by hundreds of millions of people, particularly in Asia and South America, with as many as one-sixth of the world's population residing in glacierized river basins. The water from these rivers is required for agriculture, industries and hydroelectricity power plants.

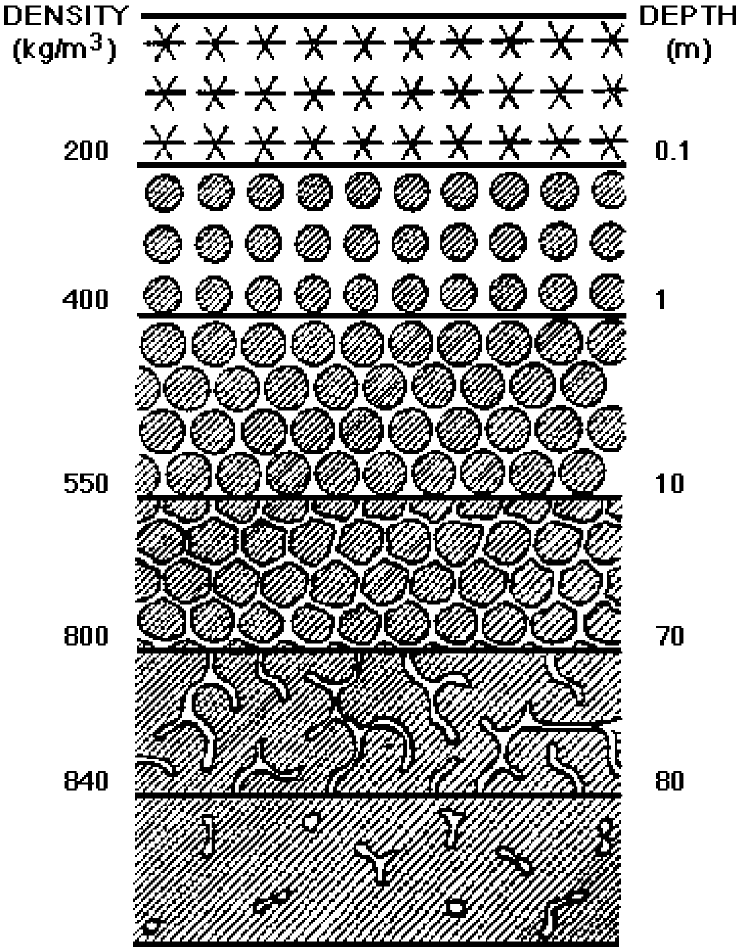
Mountain glaciers are highly sensitive to climate change (Hoelzle et al. 2003) and as such, their study is of critical import for understanding and forecasting global environmental change (Knight 2006).

Mountain glaciers are sensitive indicators of climate change, although which parameter is playing an important role and quantitative relationship between climate change and glacier fluctuations is still ambiguous, but it corresponded to a warming of ~ 0 .3 ºC in the first half of the 20th century in the northern hemisphere (Anthwal, et al, 2006). On the global scale, air temperature is considered to be the most important factor reflecting glacier retreat, but this has not been demonstrated for tropical glaciers (IPCC, 2001). So it is necessary to study these glaciers of different parts of world.

Mountain glaciers are often the foci of tourism-based economies in otherwise impoverished communities, and their potential disappearance could have profound effect.

3. Formation of a glacier:

Now that we have looked at the factors which influence the formation of a mountain glacier, we will look at how the glacier itself is actually formed. Assuming that the conditions favourable to formation are met, we must look at how the transformation of snow to glacier ice occurs. As each accumulation season passes and more snow is deposited on top of the previous season, more pressure is applied to the underlying snow, or firn (which can be defined as snow which has survived one full ablation season (Furse, J, 2011)). This compression forces the snow to re-crystallize, forming grains similar in size and shape to grains of sugar (National Snow & Ice Data Centre 2012). With time, the grains continue to grow and the region of air surrounding the growing grains becomes smaller resulting in the snow compacting and becoming denser (National Snow & Ice Data Centre 2012). Firn is the intermediate stage between snow and glacier ice. As this process continues, glacier ice is formed, and once it reaches a density of 817kg/m cubed, it is referred to as glacier ice. It is also worth noting that very dry, cold snow is unfavourable to the birth of a glacier, as it is very un-cohesive, and will result in a longer time frame of snow to ice formation (Fig. 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.

Broecker, W.S. The Glacial World According to Wally, Copyright ©1993 by Eldigio Press. Reproduced by permission.

Figure 3. Snow to Ice transformation. Source: http://www.thenakedscientists.com/forum/index.php?topic=38675.50

Glacial Landforms/Geomorphological Structures:

Cirques (corries) and Tarns:

A cirque is a bowl-shaped basin that is created in the side of a mountain where glacial plucking has occurred (Fig. 4). Often a cirque forms where a glacier begins (Wilson Science, 2012). A cirque is the results of alpine glaciers, and can be up to around a square kilometre in size. They are formed when a glacier, with a presence of a large headwall depresses and erodes the land in a small area underneath it. Cirques are often situated at the beginning of a valley glacier. A cirque is often also home to a tarn, which is a lake caused by erosion and melt from the glacier (Fig. 5).

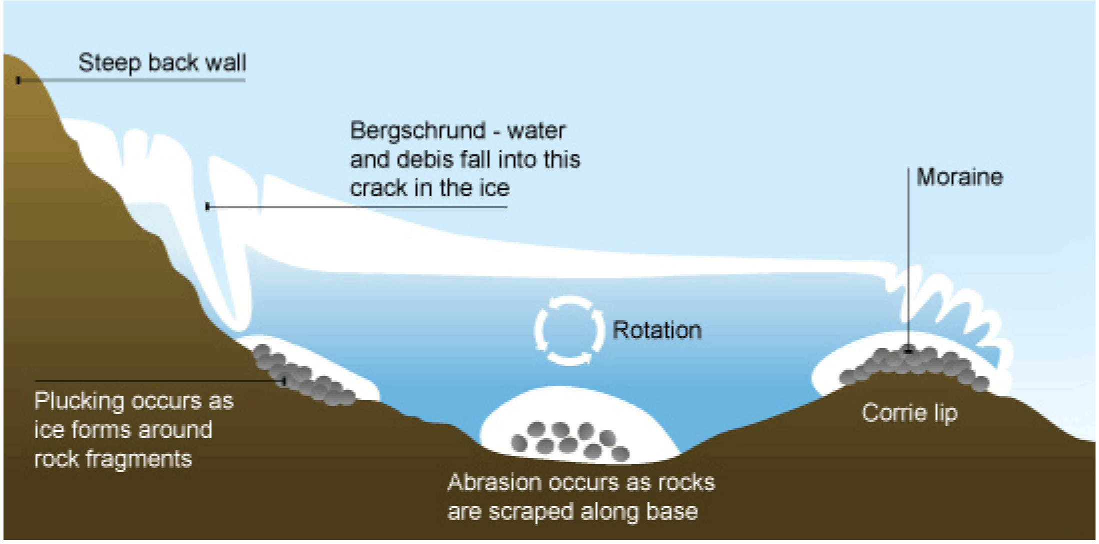


Figure 4. Image depicting the formation of a Cirque. Source: http://www.bbc.co.uk/schools/gcsebitesize/geography/glacial_landscapes/glacial_erosion_landforms_rev1.shtml

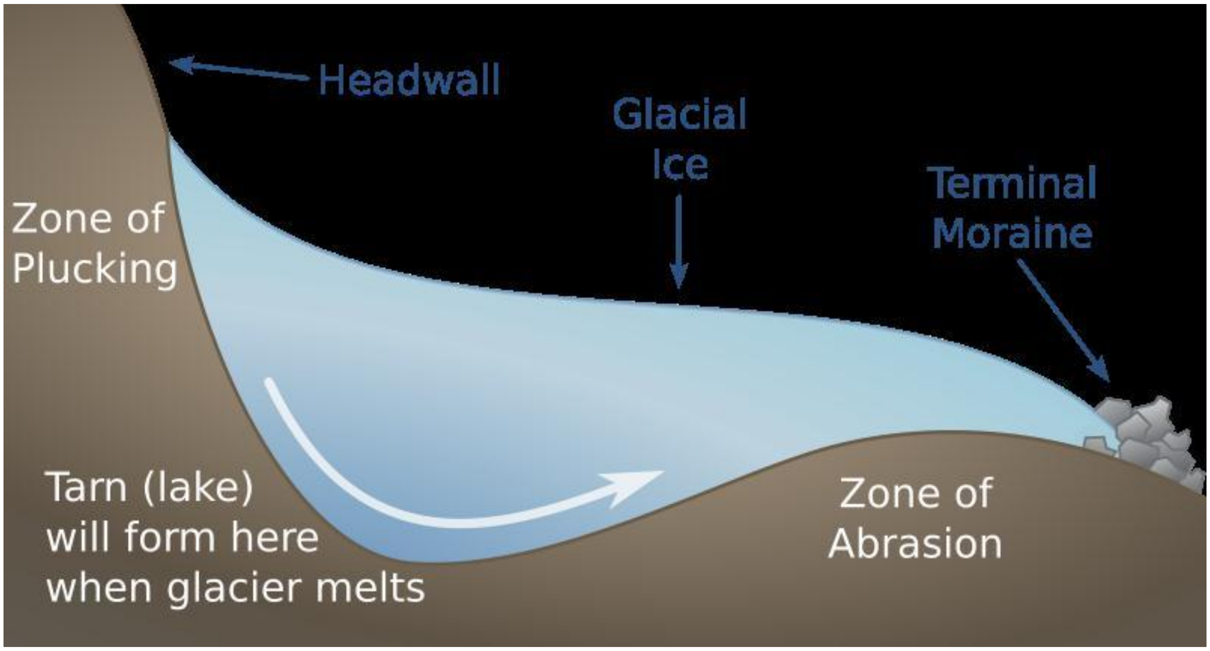


Figure 5. Image depicting the formation of a tarn. Source: http://www.geocaching.com/seek/cache_details.aspx?guid=83c76e57-5727-4e83-adde-bb0e35717819

Figure 6. : A cirque and cirque glacier. Source: http://www.prairie.illinois.edu/shilts/gallery/shilts-0004.shtml

Figure 7. Evidence of past cirque glaciers in Iceland Photo: Mats Wibe Lund www.myndasafn.is

Arete:

An arête is the result of two cirque glaciers forming next to each other and eroding two side of a mountain leaving a knife like ridge between them as they erode backwards (Geography Site, 2006). Common features are extremely steep sides and a sharp top edge, as seen in figure 8 and 9 (Geography Site, 2006).

Figure 8. Cirques and Arete's. Source: http://resources.teachnet.ie/ajordan/arete.jpg

Figure 9. Large Arete. Source: http://www.nps.gov/glac/gallery/parkpics.htm

Horn:

A horn or pyramidal peak is formed when multiple glaciers erode the same mountain (Lemke, K, 2010). As cirque retreat, if there is 3 or more acting upon the same mountain, a pyramidal peak, or horn will form. A classic example of this is the Matterhorn, in Valais, Switzerland (Fig. 10).

Figure 10. The Matterhorn. Source: http://countries-of-europe.com/wp-content/uploads/2011/02/Matterhorn1.jpg

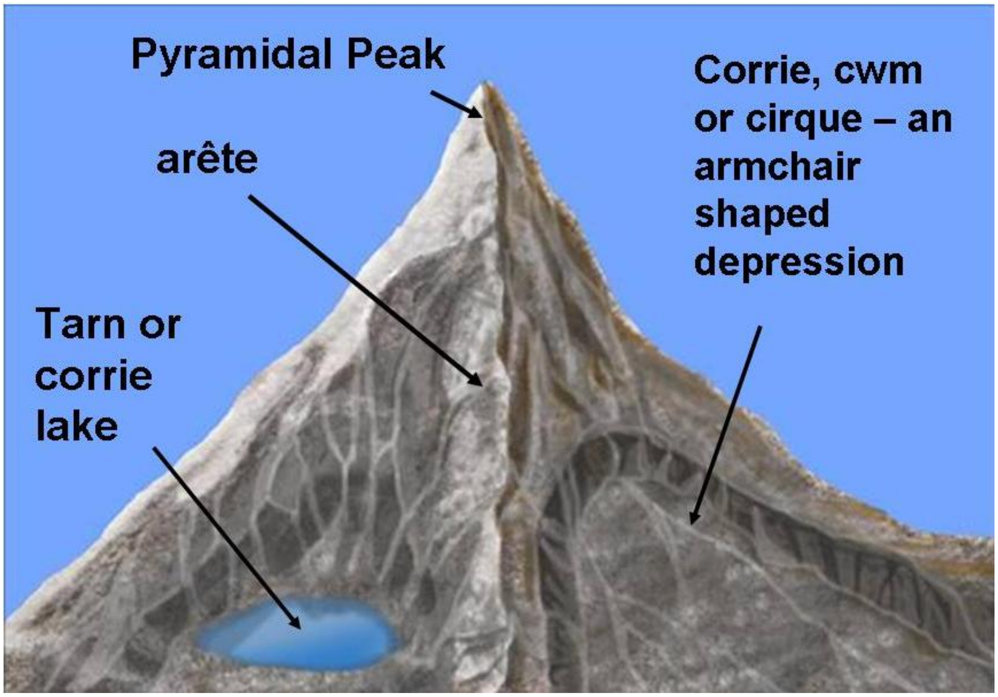


Figure 11. Pyramidal Peak formation. Source: http://www.revisionworld.co.uk/files/pyramidal%20peak_0.jpg

Piedmont Glaciers:

Piedmont Glaciers occur when steep valley glaciers flow out into a relatively flat plain, where they spread out, somewhat resembling a light bulb (NSIDC, 2012).

Figure 12. Large piedmont glaciers in the Canadian Arctic. Source: http://www.swisseduc.ch/glaciers/glossary/piedmont-glacier-en.html

4. Mountain glacier landsystem:

Plateau ice field

They can be found at the fringe of the North Atlantic and Canadian Archipelago. It's a permanent snowfield at the onset of glacial conditions. When there is a very steep drop in a fjord, the glaciers are nourished below the ELA by dry calving from the glacier on the edge of the cliff. The landforms will be mostly produced at an advanced stage of local glaciations, in valleys between the plateaux. Since the glaciers are often cold-based, they leave little landmarks and do not transport much extra glacial debris. On the other side, some patches of warm-based ice, as seen around valley heads, drain the plateau summits eroding the land and creating debris that are transported which develops in marginal moraines. There is also the erratic that are emplaced by a regional ice flow over the plateaux. The largest accumulation will happen on lateral and latero-frontal moraines in valleys draining the plateaux. Push moraines can be found at valley heads. Valley moraines are large cobble to boulder size angular material. Also, the active free faces can create enough debris to produce supra-glacial moraines and finally, the advance of outlet lobes into the lowlands filled with sediments will create large end moraines sequences. Some of these features can be found in the figure 13.

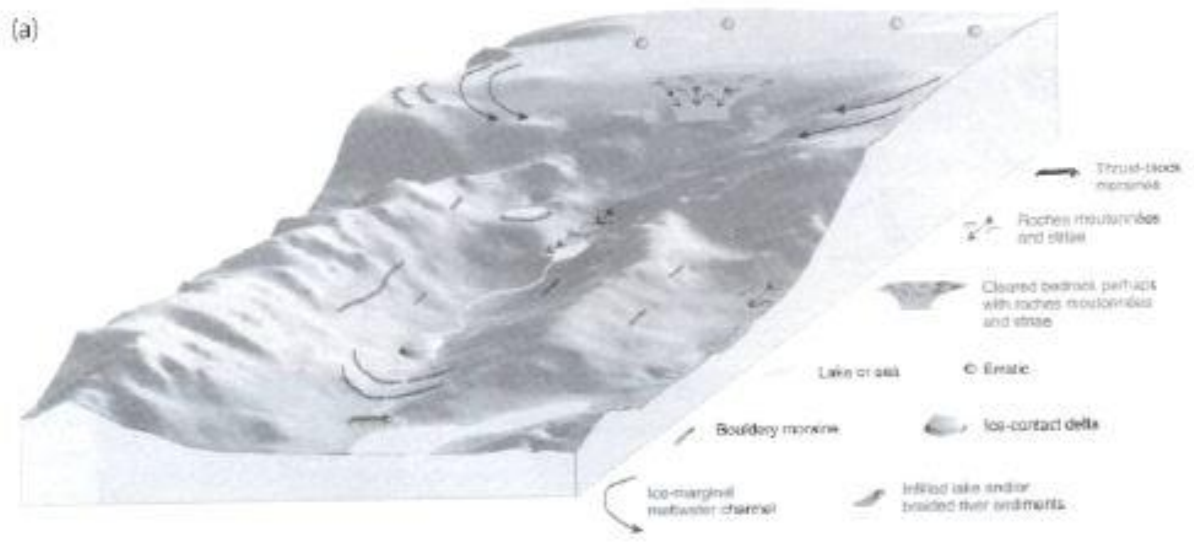


Figure 13. Schematic diagram of landforms produced by plateau ice field landsystem (source : Benn & Evans, 2010)

Glaciated valley systems

There are very distinctive assemblages of sediments in this landform: ice-marginal, supra-glacial, sub-glacial, pro-glacial, sub-aquatic landform sediments. This system is unique since the valley sides are very important in the debris sources and topographic confinement of deposition. We can separate the system in two: high-relief and low-relief. The low-relief settings are found where the vertical distance between the two ridges is less than 1000 meters. For example, there are some in the glaciated valleys of Scotland, Norway and Labrador. The High-relief settings are characterized by steep valley sides, thousand of meters above the valley floor. They are associated with young or tectonically active mountain folds like in European and New Zealand Alps, High Andes and Himalaya.

The beds of cirques glaciers can be separated into three zones: the erosional zone on the upper part. This zone is characterized by ice-moulded bedrock and bed erosion where one can find striations, roches moutonnées and abrasion. Second, the intermediate zone is down valley and is characterized by both depositional material and erosion. Thin tills can be found between the roche moutonnées and inside cavities. Third is the depositional zone, the lower part of the cirque covered by till. This pattern is similar to subglacial erosion found on continental ice sheet, but it’s on a smaller scale that shows transport of debris down the margin of the glacier. Although the margins of the valley are often delimited by lateral-frontal moraines, it is important to consider the impact of melt water reworking the debris.

In the high-relief settings, we find margins well covered with supra glacial debris and sedimentation forming huge lateral-frontal dump moraines and ice contact fans and ramps. This forms a barrier for the glacier flow that can be 100 meters high. All the moraines left by the glacier usually do not last very long, they are eroded and all is left is erratic.

These glaciers and not too much affected by minor climate change due to lateral-frontal moraine that keeps them from advancing and supra glacial debris covers that inhibits the ablation of the ice.

A common feature of mountain glacier environment is temporary lakes that rapidly fill with sediments stretching into the valleys. When the dam retaining the water breaches, it can cause many damages to the villages established down the valley. The sediments accumulated will create terraces in the valley. These formations will easily be reworked and eroded with time, making it difficult to study.

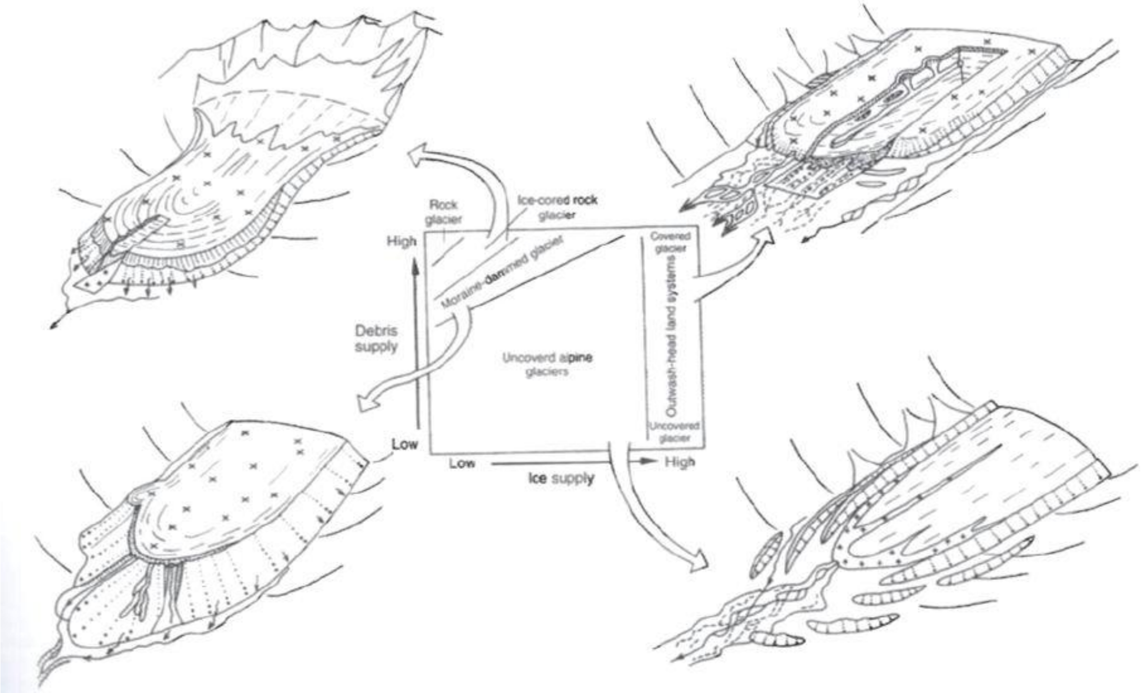


Figure 14. End members of the glaciated valley landsystem continuum defined by debris and ice supply (source: Benn & Evans, 2010)

Trimlines and weathering zones

Trimlines are the upper limit or valley sides of preserved erosion in glaciated valleys. Where deglaciation is recent, they are recognized by a limit of vegetation: striped off under the limit and developed vegetation above. In older glacial landscape, periglacial trimlines are preserved by studing the bedrock, where weathering or glacier advancing shows the upper limit. Several criteria are used to identify the trimlimes, which vary a lot depending on the rock type and structure and the slope activity. It is possible, coupled with lateral moraines and ice marginal landforms on the terrain to use the trimlines to reconstruct glaciological models and paleoclimatic studies. This has been used in Scotland to show with more accuracy the glacial feature of the region.

Mountain ice field landsystem

Mountain ice field landsystem cover large areas of very different topography, and they develop in different climate ranges. Therefore, they can modify, disturb elements of smaller-scale landsystems and pre-existing deposits. Their margins carry large amounts of glaciagenic material; those are well seen from the Quaternary advances of piedmont glacier in Patagonia Icefield. It is very frequent to observe ice-dammed lakes that accumulate tons of sediments. These landforms will be best preserved in relatively low-relief settings.

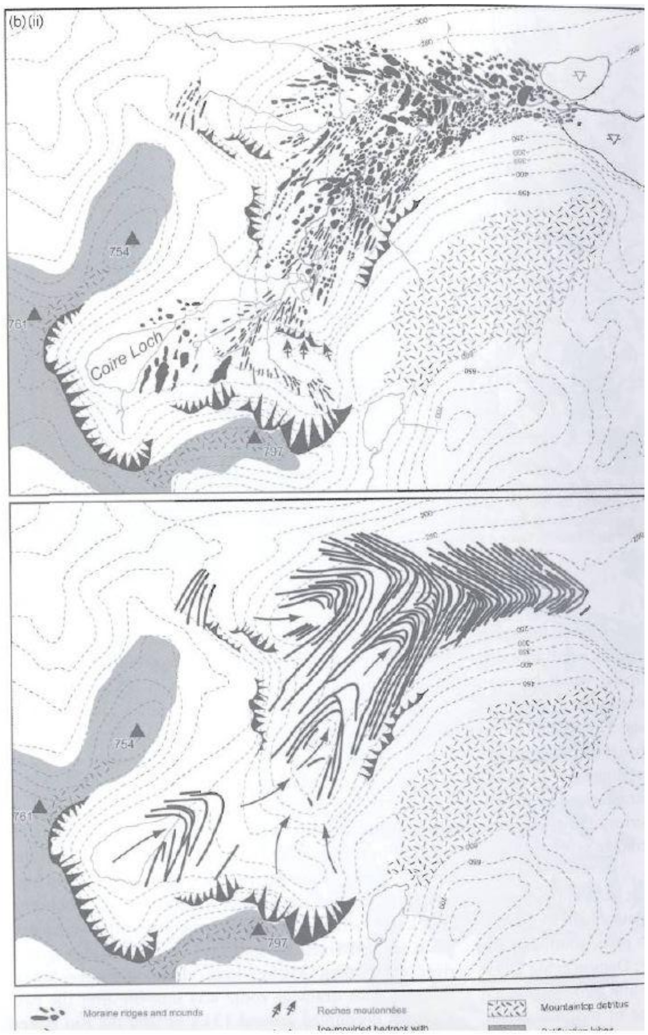


Figure 15. Glacial geomorphology from Scottish Highlands. Map of moraine ridges and mounds in valleys (source : Benn & Evans, 2010)

5. Mass Balance of Mountain Glaciers:-

Specific mass balance is the change in the mass per unit area relative to the previous summer surface. Specific balance at the end of the balance year defines the annual balance or net balance for that year (The Physics of Glaciers). It is typically measured in units of mm of water equivalent depth.

An increase in accumulation and or decrease in ablation will result in the addition of ice mass while increase in ablation and or decrease in accumulation will leads to the loss in mass of Glacier (Hagen and Reeh 2003).

Net mass balance is typically calculated for the a single hydrological year (from the season of minimum ice mass in one year to the season of minimum ice mass in the next), with cumulative mass balance changes measured by summing the net balance of multiple years.

Mass balance measurements techniques:-

Mass Balance measurements are mainly of two types, viz. direct measurements and remotely-sensed measurements.

Direct measurements:-

Direct measurement techniques consist of measurements carried out on the glacier itself. These provide the most accurate and detailed quantifications of mass balance changes (Kaser et al 2003). But these techniques are restricted by economic and environmental difficulties.

Direct measurements are carried out by following methods:-

1) Stake method:-

Stake measurements are made by placing iron rod into the glacier’s surface. The snow/ice level marked on this rod. The repeatedly to determine how much mass is being added or removed between measurements. The ultimate variation from the beginning of one hydrologic year to the next represents the mass balance change for that year. Sometimes winter and summer mass balances are also measured separately.

Multiple stake measurements made on different parts of the glacier are necessary for a relatively accurate estimate of total glacier change. The minimum number of ablation stakes needed to obtain a representative sample has been somewhat controversial, but generally it is assumed that 10 is sufficient for small valley glaciers (less than 20 km²), with 10-20 necessary for larger glaciers up to 500 km² (Hagen and Reeh 2003).

2) Geodetic surveys:-

The other direct measurement technique is the use of geodetic surveys to calculate topographic changes of a glacier’s surface area and elevation. Known points on the glacier surface are surveyed from fixed stations off the glacier, with changes in the x, y, and z angles and distances used to measure addition or subtraction of glacial volume. The use of precise Global Position Satellite (GPS/ DGPS) survey techniques has been used to increase the accuracy.

3) Hydrological balance method:-

In the hydrological balance method, difference between accumulation by precipitation and ablation by evaporation, sublimation and runoff is estimated. 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.

$$\text{Mass Balance} = \text{Precipitation} - \text{Evaporation} - \text{Runoff}$$

Hydrological balance occurs when the amount of precipitation that falls on the glacier is matched by the volume of water lost via runoff and evaporation from the glacier. A positive difference reflects an increase in storage and thus a presumed increase in glacial mass; a negative difference represents a loss of storage and presumed wastage of glacial mass.

But main disadvantage of this technique is snow may be added to glacial mass via wind or avalanche deposition as well (Hubbard and Glasser 2005).

Remotely-sensed techniques:-

Measurements of glacial mass balance changes utilize both aerial and satellite-based images to monitor variations in glacial surface area and surface elevation over time. This technique is very useful in that a significant time-series of images is often available, providing a means to monitor areal and volumetric changes of a glacier at a relatively fine temporal scale Acquisition of imagery is often easier and much less expensive than organizing field research on the subject glacier, especially in remote mountain ranges.

Mass balance is measured by generally two ways.

1) Estimation of changes in surface elevation:-

In this methodology, Digital elevation model (DEM) is prepared by stereo pair satellite images like SPOT5, LIDAR (Jóhannesson et al, 2011) or SAR interferometry (Yu et al, 2010). DEMs are prepared for different time and the elevation change is calculated by subtracting one DEM from another.

2) Relationship between AAR and specific mass balance

AAR is a ratio between accumulation area and total glacier area (Meier et al, 1962). AAR is estimated by delineating snowline at the end of ablation season. A regression relationship between AAR and specific mass balance is established using field data of different years. If Regression analysis suggests a good correlation between AAR and mass balance, that equation can be used for estimation of specific mass balance of other glaciers of that region (Kulkarni et al, 2004).

Kulkarni and coworkers (2004) have obtained regression equation for Shaune Garang and Gor Garang glaciers of Baspa Basin, Himachal Pradesh, India, which is then used to estimate specific mass balance of others glacier of that area. The correlation between accumulation area ratio and mass balance is plotted in Figure 16.

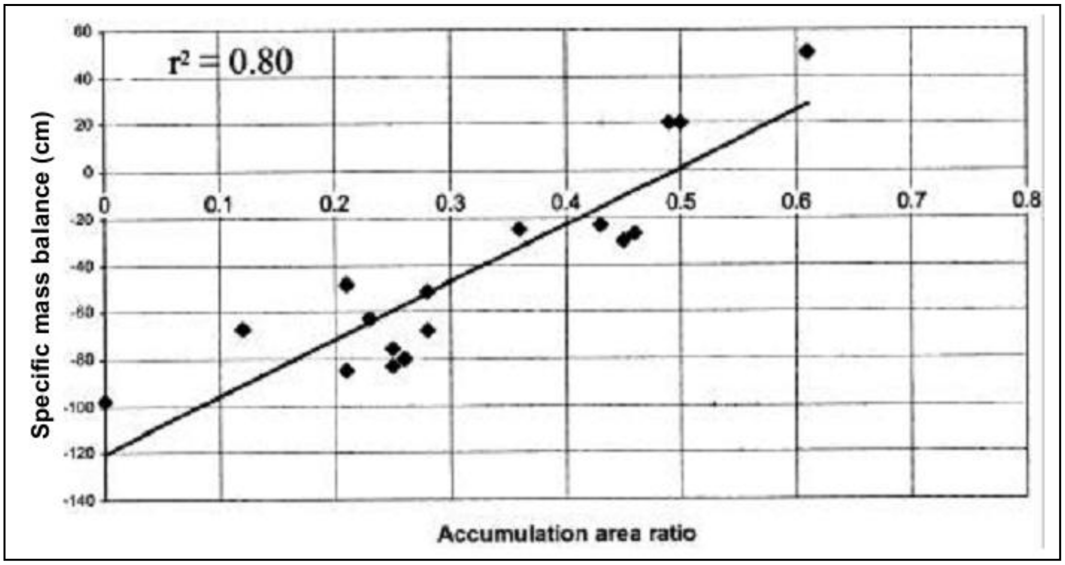


Figure 16. Regression relationship between accumulation area ratio and mass balance for Shaune Garang and Gor Garang glaciers. (Kulkarni et al, 2004)

The relationship between accumulation area ratio and mass balance is as follows.
Y = 243.01 * X – 120.187

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

Hock et al (2009) have used a grid-based modeling approach to estimate changes in surface mass balance on a global scale for Mountain glaciers and Ice caps. They have computed the global glacier surface mass balances on regular 1x1°global grid and converted into Sea level equivalent (SLE) (Sea level equivalent or SLE is defined as minus specific mass balance multiplied by glacier area divided by global ocean area) assuming that all glacier mass loss directly contributing to sea level. They have determined glacier area from the GGHYDRO 2.3 global hydro graphic data set, which gives the percentage of glacierization in a 1x1° global grid. The modeled surface mass balance from all glacierized grid cells for the period of 1961 – 2004 is shown in Figure 17.

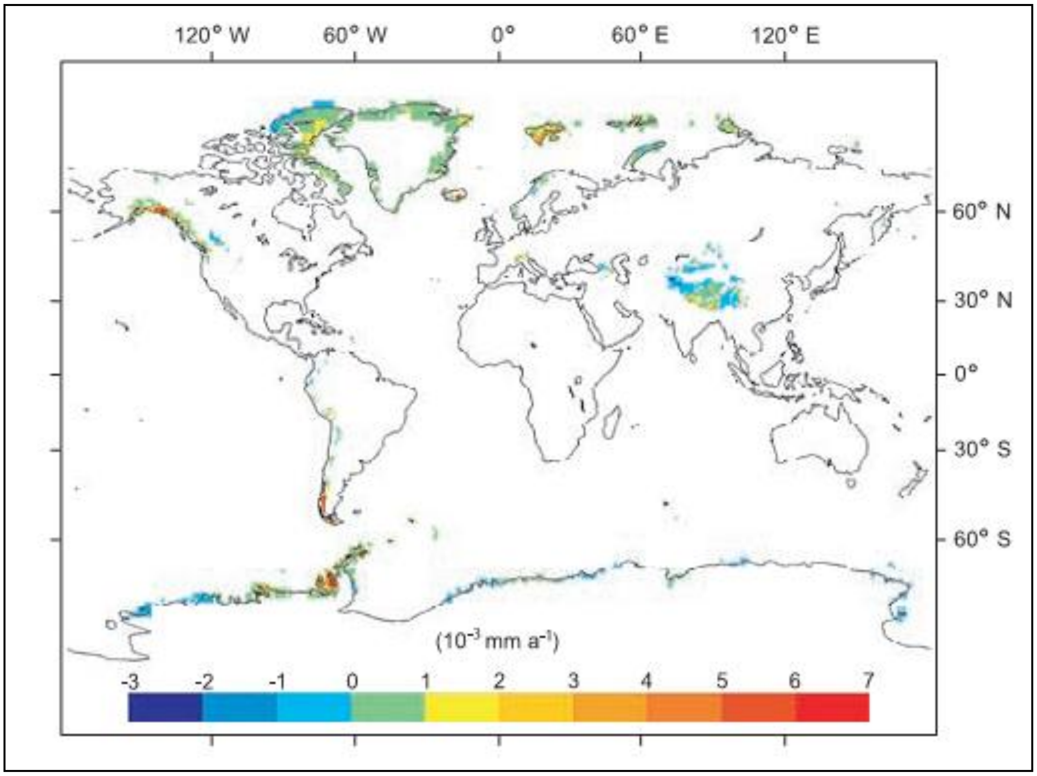


Figure 17. Modeled surface mass balance from all glacierized grid cells 1961 – 2004 (10-3 mm SLE a-1). (Hock et al 2009)

This observation indicates that almost all part of the world showing the negative mass balance trend except a few in Svalbard, Chilean Patagonia, and Canada. Surface mass loss due to changes in temperature and precipitation for the period 1961 – 2004 was 0.49 ± 0.30 mm SLE a-1, assuming the surface mass balance was zero at the start of the simulation.

Atsumu Ohmura (2011) has studied 137 glaciers from 17 glaciered regions to calculate the annual net balance. These glaciers are located in the Andes (7), North American Cordillera (24), Canadian Arctic Islands (8), Alaska (4), Kamchatka (2), the Himalayas (4), the Tienshians/Dzungaria (14), Altai (4), Pamir (1), Polar Ural (2), Caucasus (7), the Alps/Pyrenees (21), Iceland (9), Scandinavia (23), Svalbard (5), Severnaya Zemlya (1), and Africa (1). Since the density of the observed glaciers is very inhomogeneous, he used the total surface areas of the glaciered regions as weights for calculating the global mean balance. This mass balance investigation is shown in Figure 18.

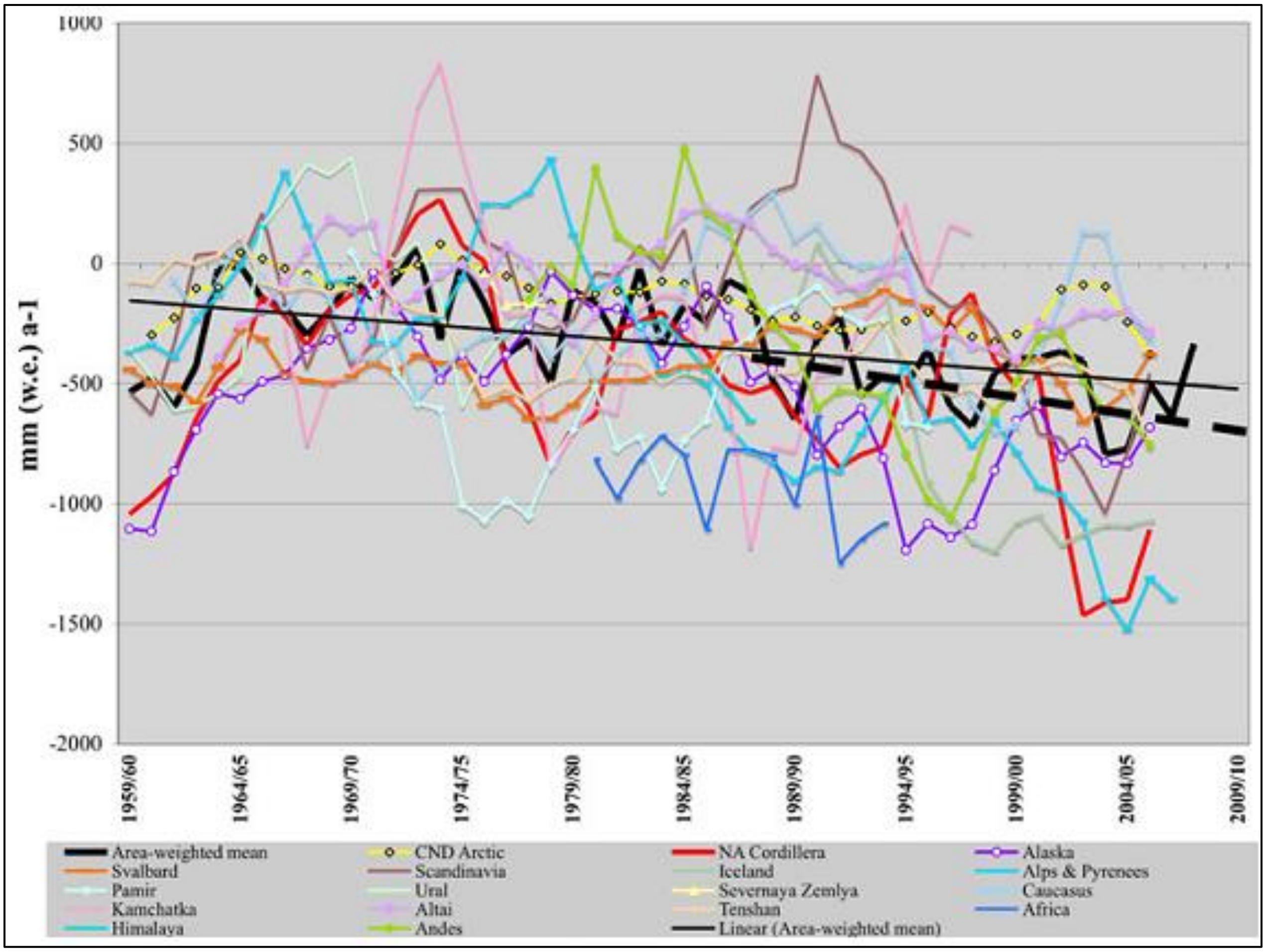


Figure 18. 5 year running means of the annual mean net balance for 50 years for 17 regions. The bold black line indicates the area-weighted global mean, while the black straight lines indicate the accelerations for the periods of the last 50 years 1961–2010 (thin line) and for the last 20 years 1991–2010 (thick broken line)

6. Retreat of glaciers:-

Retreat of glaciers and corresponding changes in landscape and scenery could, in fact, be some of the most directly visible and most easily understandable signals of global warming. (Haeberli et a l, 1998).

The growth or retreat of glacier depends on mass balance of that glacier (Hubbard and Glasser 2005). Due to the mass loss, glacier starts retreating. Tobias Bolch (2007) (Figure 19) have compared the curve of the cumulative mass balance of the Tuyuksu glacier with the area retreat and found that they have similar tendency. Mountain glaciers are generally small, making them highly susceptible to impact from even modest adjustments in local climatic conditions (Beniston, 2003).

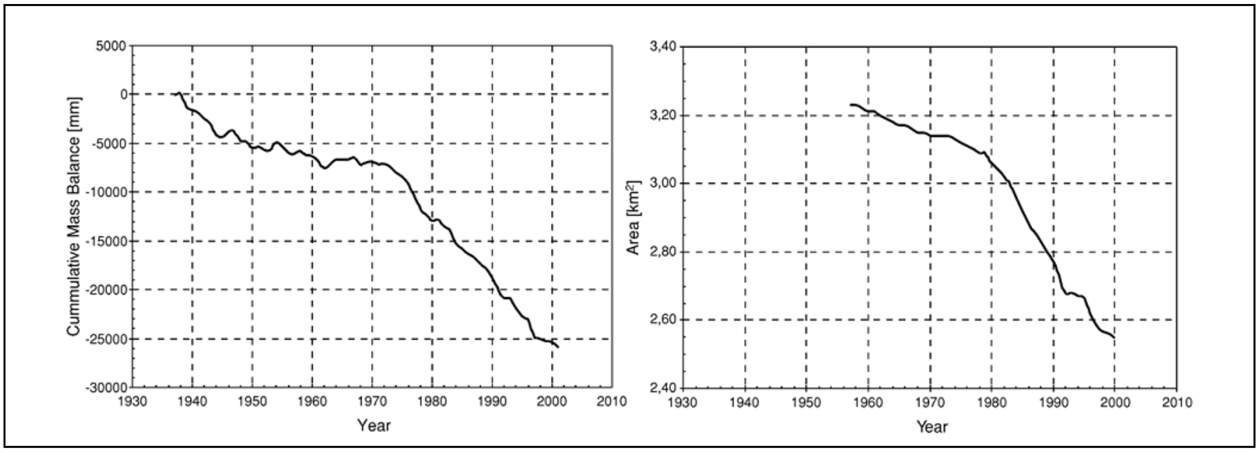


Figure 19. Left: cumulative mass balance of the Tuyuksu glacier, 1937 –56 calculated from climate data, from 1957 measured data; right: area change since 1957 (sources: Dyurgerov et al., 1996, WGMS, http://www.geo.unizh.ch/wgms/). From Tobias Bolch, 2007

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) On the global scale, air temperature is considered to be the most important factor reflecting glacier retreat except tropical glaciers (IPCC, 2001)

Smaller glaciers are more vulnerable to climate change and retreating rapidly. Bhambri et al (2011) shown that smaller glaciers are retreating rapidly than larger glaciers (Fig. 20). Larger compound basin glaciers are less sensitive to climate change due to contributions from tributary glaciers in accumulation zones.

Similar study is done by A. V. Kulkarni (2007) on Chenab Basin, India. They also found that the smaller glaciers are retreating rapidly than larger glaciers as shown in following table 2.

A general trend of retreat of Samudra tapu glacier studied by satellite imageries is shown in figure 21.

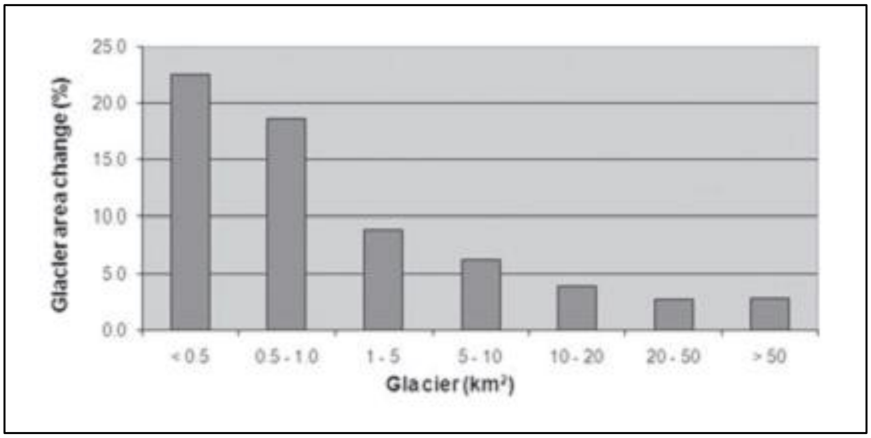


Figure 20. Glacier area change and area measurements (%) based on Corona (27 September 1968) and ASTER (2006)

Table 2. Change in glacier area for Chenab basin, India - indicating higher loss of area in smaller glaciers

Glacier area (km^2)	Number of glaciers in 1962	Glacier area (km^2)		Change in %
		1962	2001/04	
< 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

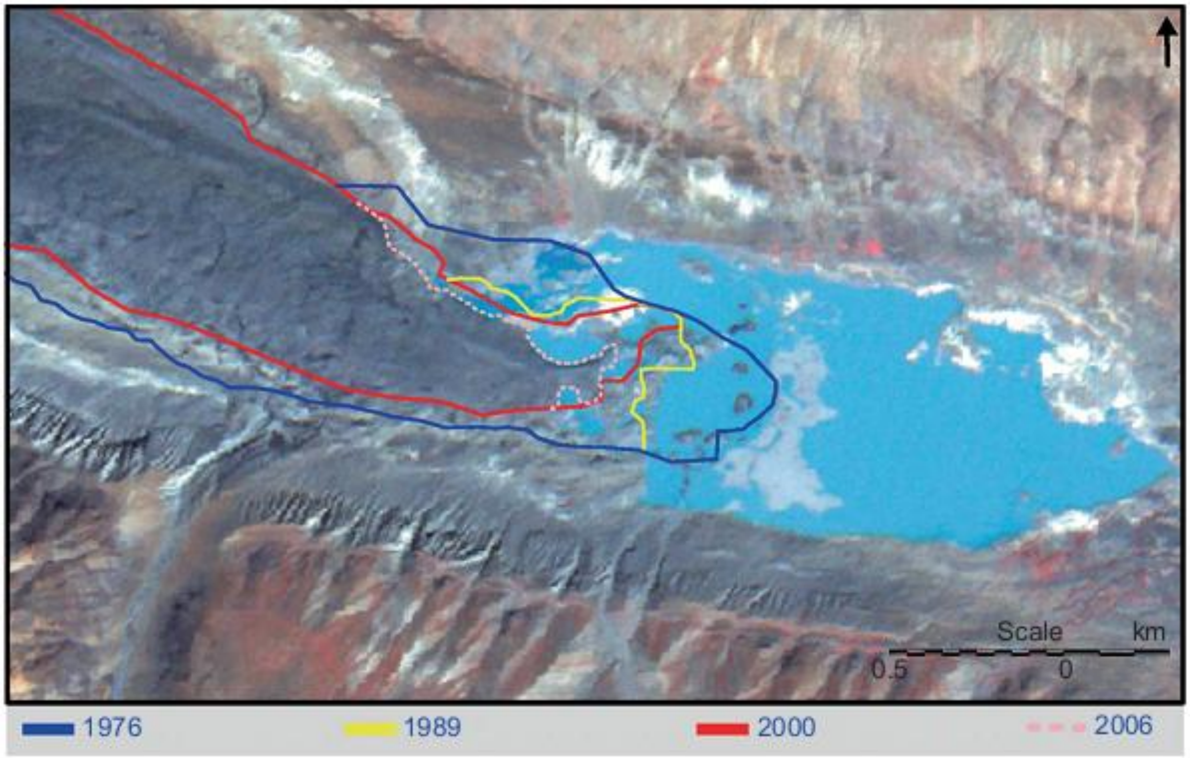


Figure 21. Satellite imagery of IRS LISS-IV sensor from 16 September 2006 showing retreat of the Samudra Tapu glacier, Himachal Pradesh, India from 1976 (Kulkarni et al, 2011)

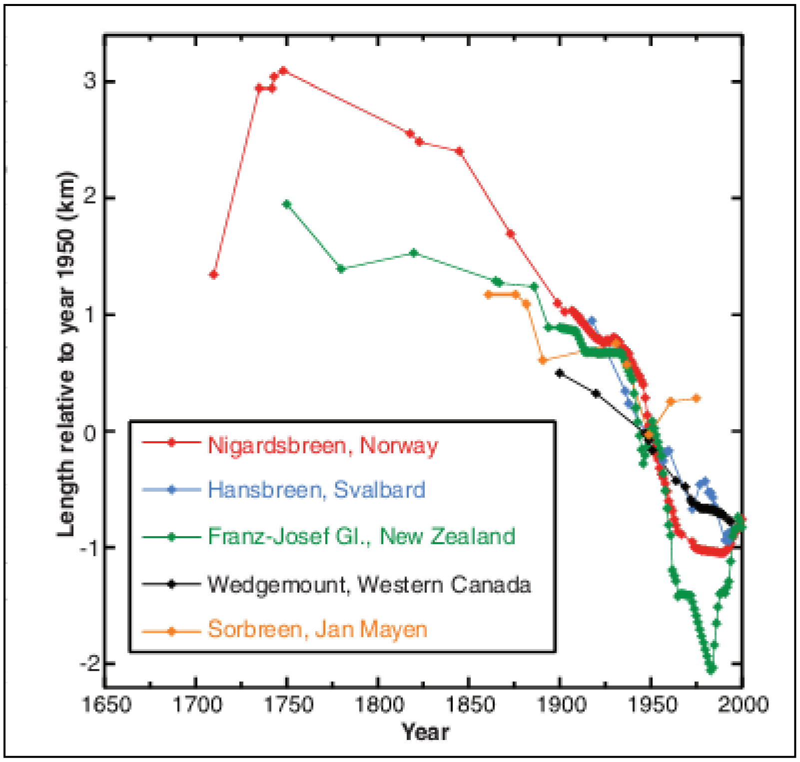


Figure 22. Glacier length records from different parts of the world. (Orlemans , 2005)

Glaciers of all over world are retreating. Orlemans (2005) has analyzed 169 glaciers from different part of world and estimated retreats. The 169 glaciers in the data set are located in the European Alps (93 records), Caucasus (8), tropical Africa (5), Central Asia (9), Irian Jaya (2), New Zealand (2), Patagonia (6), Northwest America (27), South Greenland (1), Iceland (4), Jan Mayen (1), Svalbard (3), and Scandinavia (8). The retreats in length for 6 glaciers from different part of world are shown in figure 22. It is obvious from the figure that all glaciers except the glacier from New Zealand are retreating.

As published in IPCC Third Assessment Report, 20 glaciers from the various part of the world which have different lengths, are retreating (Figure 23). So it is confirmed that the glaciers of all over world are retreating. According to this report glacierized area in the Alps has decreased by 40% since 1850, with an estimated volume loss of 50%. Spain has 13 glaciers remaining, a decline from 27 glaciers in 1980.

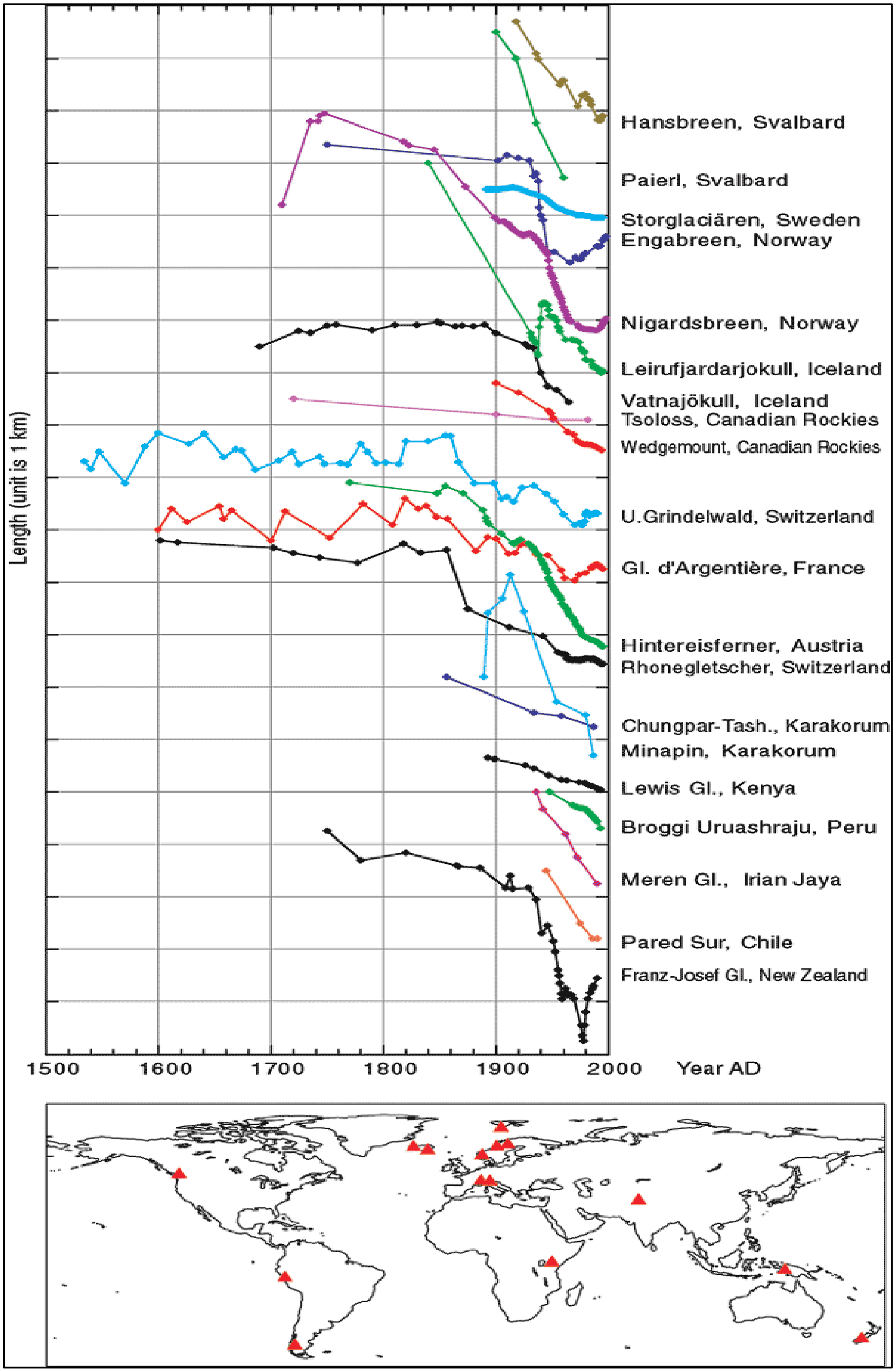
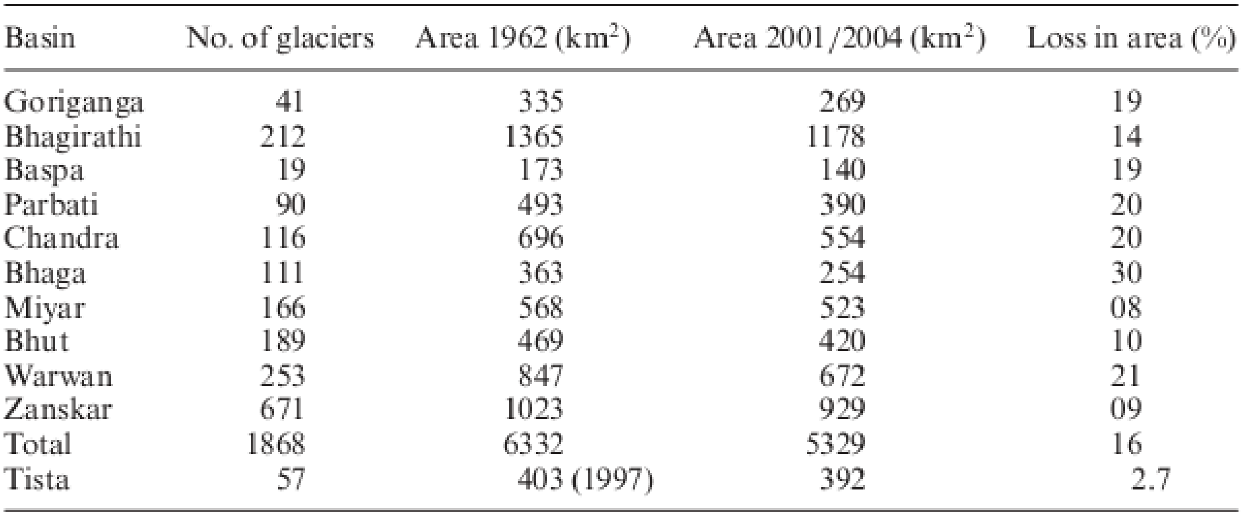


Figure 23. : A collection of twenty glacier length records from different parts of the world. (IPCC Third Assessment Report, 2001)

Himalayan glaciers are retreating faster. A study by Kulkarni et al (2011) on 11 different basins in Western Himalayas shows high retreat rates as shown in table 3.

Table 3. Glacier retreat in Himalayas, Kulkarni et al, 2011



Basin	No. of glaciers	Area 1962 (km^2)	Area 2001/2004 (km^2)	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 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)

As glaciers retreat due to warming, drainage will increase for short term but decline once the glaciers disappear. (Barnett et al ., 2005)

Shifts in climatic regimes, particularly precipitation, in space or seasonally in a changing global climate, would impact on the river systems originating in mountain areas. Thereby, socioeconomic structures of populations living within the mountains and those living downstream would be affected. (Haeberli et al, 1998)

Anthropogenic climate changes have a significant impact on the cryosphere. (Rosenzweig et al, 2008)

7. Impacts on humans

Although glaciers are often far from population centers, their loss will impact communities significantly, especially in mountainous regions of the world. There are areas where glacial meltwater is a significant contributor to settlements water supplies. Melting glaciers also cause sea level to rise, which will affect coastal regions, all around the globe.

Small glaciers retreating in the Himalayas threaten local communities and people downstream who depend on the water coming down from the mountains. Two billion people rely on the meltwater from this area, but 21% glacial mass lost has been observed since 1962 (Kormann 2009). Five major river systems are fed by Himalayan glaciers, which go on to irrigate much of China, India and Pakistan rice and wheat as well as being used for drinking water.

- Ganges: 407 million people
- Indus: 178 million people
- Brahmaputra: 118 million people
- Yangtze: 367 million people
- Yellow: 147 million people
-

Combined with the rapidly increasing population of these countries, the less and less meltwater could result in famine and conflict. It's not just in this area that meltwater is important; areas in the Andes also rely on it. Glacial retreat would affect up to 77 million people who rely on the water from glacier here. Although the rapid melting has brought temporary increases in stream flow and contributed to flooding, it is predicted that within the next decade as the glaciers shrink further there will be a shortage of water during the dry season. Farmers have already begun to report shortages. Precipitation in Bolivia largely occurs during part of the year; this water is then normally stored on the glaciers and released throughout the year due to melt. If the glacier disappears, there would be no natural storage of water. Because of this threat, there is a question of compensation in this area, Bolivia is responsible for only 0.02% of global greenhouse emissions, yet the country is set to suffer more than many others that produce much of the emissions (Kormann 2009).

Furthermore the disappearance of the glacial coverage is the cause of many local issues within the Kilimanjaro region. As the glaciers have retreated and lost size, the flow of glacial melt water has decreased significantly resulting in a fight for water throughout the towns on the Pangani River Basin (Hetherington 2010). The Pangani River Basin is home to roughly 3.7 million people, and is around 43000-square-kilometers in area. It begins on the high slopes of Kilimanjaro and meanders towards an estuary in the tropical town of Pangani. In the year 2000 violence broke out in regions which depend upon the water of the Pangani 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."

The cause of the conflict and violence quite simply comes down to access to water. For hundreds of years, the people of the townships which depended upon the water from Kilimanjaro's snows had an unwritten law of local knowledge, "that the highlands of the Pangani River Basin receive markedly more rainfall than its lowlands, and acknowledged the need to secure water for downstream users and the overall health of the ecosystem" (Hetherington 2010). In 1972 however, increased political control of the region was enforced, and water flow downstream was heavily choked. It has since then been getting worse as the glaciers on Kilimanjaro are receding, providing less and less water every year. Consequently, violence and social unrest within the region has increased and will continue to do so as the glacier further recedes (Hetherington 2010).

It is important to note that this not only effects human population within the area. The Pangani River also provides water to very bio diverse regions of forest, particularly the Eastern Arc Mountains which is considered as one of earths 25 biodiversity hotspots. Around thirty per cent of roughly two thousand plant species are considered endemic, and approximately eighty per cent of the regions spider and other small insect populations are occasionally limited to one mountain of the region (Hetherington 2010). If water flow to these regions slows, the biodiversity will be at a great threat. The biodiversity of Kilimanjaro itself is extremely interesting, ranging from banana trees to alpine pine trees, and from tropical species to species living on an ice cap.

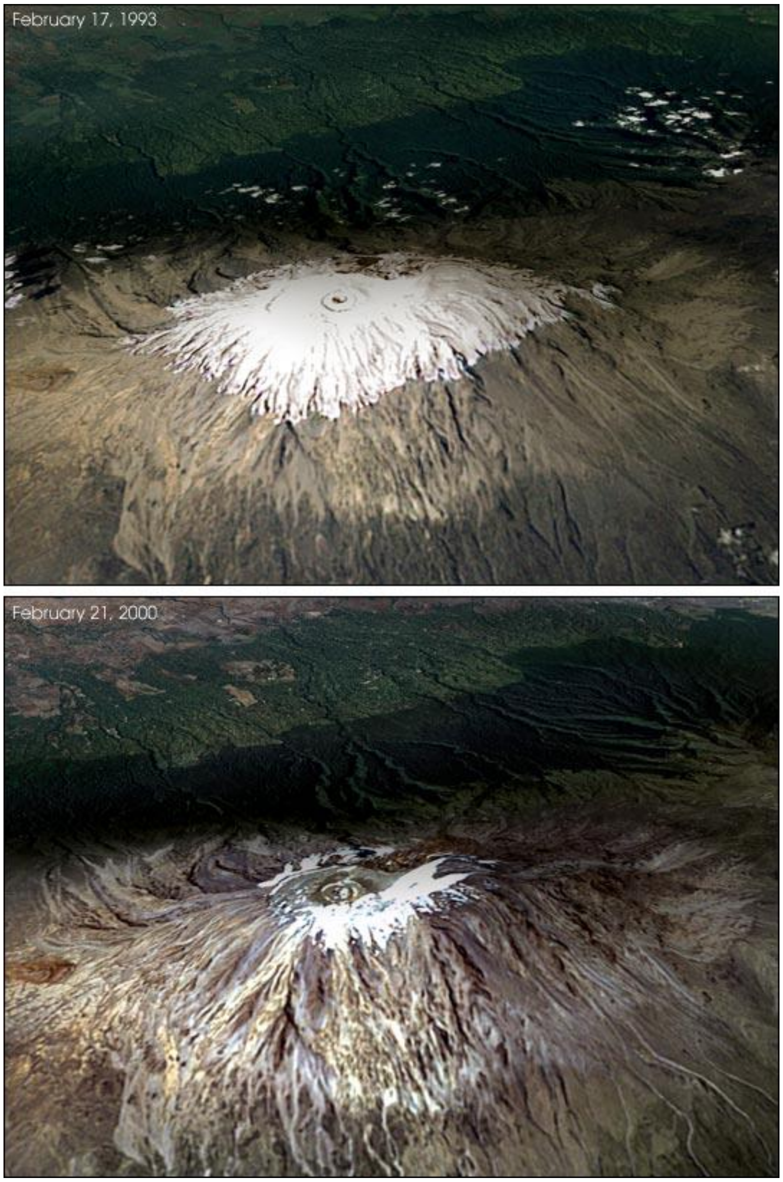


Figure 24. . Mount Kilimanjaro satellite images from 1993 and 2000, showing the rapid retreat of the glacier (NASA Earth Observatory 2000).

The disappearance of glaciers also affects humans by causing sea level rise. Many of the world's largest cities are in coastal regions, as are arable regions. Defenses against sea level rise are unavailable in many areas and even when a country could potential put defenses into place they are still extremely costly.

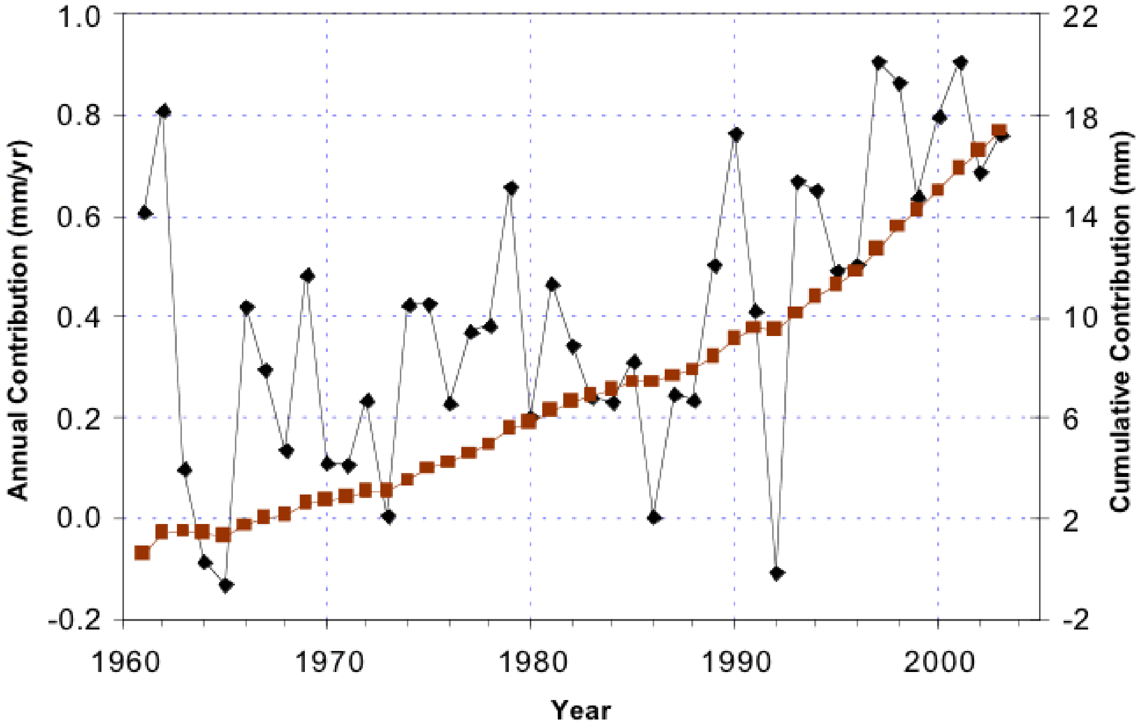


Figure 25. The annual contribution from glaciers to sea level change (left axis, mm/yr), and cumulative value (right axis, mm) based on area-weighted averaged mass balance (National Snow and Ice Data Center 2006).

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