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Changes of glaciation in the Sagarmatha National Park (Nepal) during the last 30 years

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Abstract: Author, as a scientific participant of the first Czech-Slovak Expedition to the Mt. Everest in 1984, focuses on the glaciation in the Sagarmatha National Park (the Central Himalayas, Nepal) in 1978 (Fig. 1 and Table 1) and compares it with the present-day state. Despite overwhelming majority of the papers bearing data on the fastest retreat of the Mt. Everest's glaciers it can be stated that obvious changes of the covering glaciers were not recorded in the Sagarmatha National Park (34.2% in the year of 1978 and 39.8% in the year of 2009).

At present, for 59 sections of 18 valley glaciers (*Nangpa, Melung, Lunag, Chhule, Sumna, Langmoche, Ngozumpa, Gyubanar, Lungsampa, Khumbu, Lobuche, Changri Shar, Imja, Nuptse, Lhotse Nup, Lhotse, Lhotse Shar* and *Ama Dablam*) their length of retreat during 30 years was recorded: at 5 sections from 267 m to 1,804 m (the width of retreat on 24 sections being from 1 m to 224 m), while for 7 sections an increase in length from 12 m to 741 m was noted (the increase of glacier width at 23 sections being from 1 m to 198 m).

More important than changes in length and/or width of valley glaciers are both the depletion of ice mass and an intensive growth of the number lakes: small supraglacial ponds, as well as dam moraine lakes situated below the snowline (289 lakes compared to 165 lakes in the year of 1978).

Key words: glaciation, snow-line, changes of glaciers, Sagarmatha National Park, Central Himalaya

Introduction

Numerous papers have been published on the world's glaciation, first of all from the climate global warming point of view, both in journals as well as in reports of organizations, web sites, etc. In general, papers concerning the retreat of glaciers dominate. In connection with the Himalayas even an opinion on the fastest retreat of glaciers all over the world is prevailing, although contradictory views have also been expressed.

The author was a scientific participant of the first Czech-Slovak Mount Everest expedition of the Slovak Geographical Society in Nepal 1984 *(Himalayas '84 – Sagarmatha)*. He chose in this paper a contemporary view of literature concerning glaciers' retreat in the Himalayas. However, the paper is updated by comparing both photos taken by the author in 1984 with views from the present-day Google Earth image and by measurements of some glacier's features by means of cartographic method in the territory of the Sagarmatha National Park.

Characteristics of glaciation in the Sagarmatha National Park from 30 years ago

Data pertaining to glaciation of the Sagarmatha National Park, such as they were recorded according to Schneider *et al.*'s (1978) map *Khumbu Himal 1:50,000* and slightly modified by the author (in 1984) and elaborated in a monograph by Drdoš *et al.* (1987), are presented in this part of the paper.

Snow-line

Snow-line is a key for the study of present as well as past glacier and frost-snow landforms (Höllermann, 1980). According to many glaciological works,

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it is not possible to consider it strictly as a line; actually it concerns a morphodynamic transient belt, sometimes hundreds metres vertically wide. Therefore, also for the eastern part of the Central Himalaya Mts. (the Khumbu region, where the Sagarmatha National Park is located), many authors report different altitudes of the snow-line. For example, according to isolines of the climatic snow-line in the mountains of High Asia (von Wissmann, 1959), it is possible to estimate the altitude of this line in the southern part of the Khumbu region at 5,200 m a.s.l., in the middle part at 5,400 m, and only in the NE part, bounded by Tibet, at 5,600 m a.s.l. Troll (1967) marks its average altitude extremely low, only 4900 m a.s.l., while Haffner (1972) – for a wider area of Chomolongma (Mt. Everest) – in the range from 5,000 to 5,800 m a.s.l. (but graphically averaged at 5,700 m for shaded slopes and for sunny slopes up to 6,000 m a.s.l.). Kalvoda (1984) states that snow-line's altitude on the slopes situated south of the Himalayan chain is in the range from 5,600 to 5,800 m a.s.l. (but graphically, according to geomorphological signs on the eastern slopes of Taboche – at 6,542 m a.s.l., at the end of the Imja Khola valley – at ca. 5,250 m a.s.l., and on the eastern slopes of the Makalu, 8,463 m a.s.l., at ca 5,450 m a.s.l.).

According to an analysis of 25 cirque glaciers, performed by the author following the method of Embleton and King (1968) on the territory of the Sagarmatha National Park, the average altitude of snow-line (firn-line in case of these glaciers) is 5,393 m a.s.l. By delineating the local snow-line on the whole territory, the average altitude was calculated at 5,497 m a.s.l. (min. 4,800 m and max. 6,050 m) (Fig. 1). In the Sagarmatha National Park, 307 km^2 of acreage is situated above the snow-line, that is 27.2% of the total area (which is 1,127 km^2), its biggest part (760 km^2; 67.5%) being occupied by an area comprised between the snow-line and upper timberline, and finally 60 km^2 (5.3%) of the territory is below the timberline, in the forest zone.

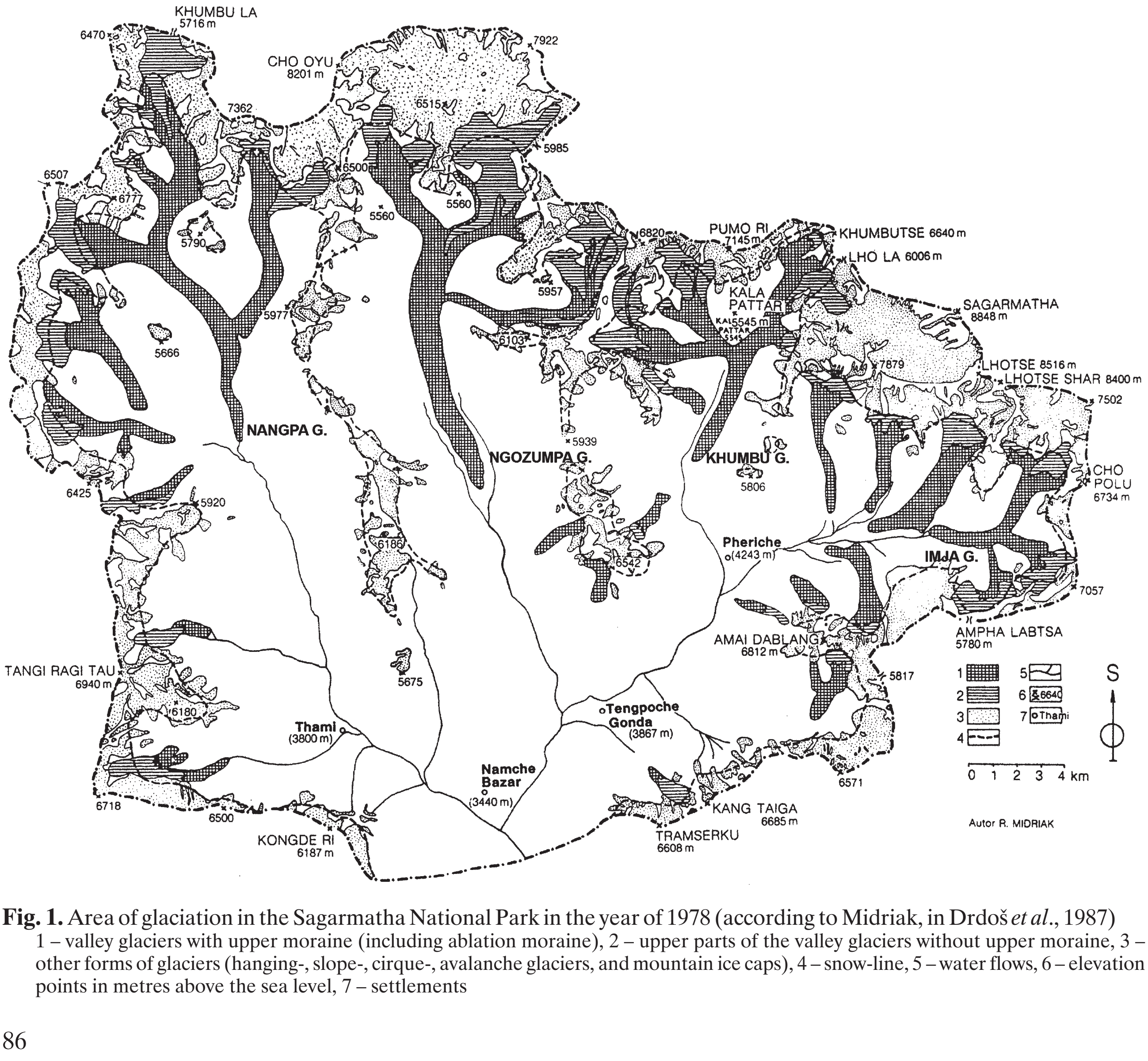

Fig. 1. Area of glaciation in the Sagarmatha National Park in the year of 1978 (according to Midriak, in Drdoš *et al.*, 1987)
1 – valley glaciers with upper moraine (including ablation moraine), 2 – upper parts of the valley glaciers without upper moraine, 3 – other forms of glaciers (hanging-, slope-, cirque-, avalanche glaciers, and mountain ice caps), 4 – snow-line, 5 – water flows, 6 – elevation points in metres above the sea level, 7 – settlements

Glaciation and glaciers

The whole area above the snow-line is not glacial, and contrary, many glaciers extend below this line. Fig. 1 gives a general view about the glaciation of the Sagarmatha National Park roughly 30 years ago. Numerical data concerning the area occupied by glacial ice in the Sagarmatha National Park, obtained from planimetric analysis of the Khumbu Himal map 1:50,000 (Schneider *et al*., 1978, slightly modified by Midriak in Drdoš *et al.,* 1987), created by method of universal photogrammetry from aerial photographs, are presented in Table 1.

Although the glaciated area in the Himalaya Mts., according to Kalvoda (1976, 1979), does not square with the size of accumulating area above the snow-line on the territory of the Sagarmatha National Park, forming the highest elevation of Himalayan mountain range, the glaciers covered 385.6 km^2, i.e. 34.2% of the whole area of the Sagarmatha National Park. The glaciers occur here already from an altitude of 4,200 m a.s.l. and reach to the highest peaks, i.e. 8,848 m a.s.l. Most of them are situated in the zone between 5,000 – 6,800 m a.s.l. (more than 86% of the area).

The valley glaciers carry on their surfaces a large amount of debris material (Fig. 2), which is much thicker in the Himalayas than on the glaciers of any other part of the Earth. The dirty glaciers comprise almost 28% of the total glaciated area. Their highest parts, mostly at the beginnings of the valleys, where they are not accompanied by moraines yet (i.e., glaciers made of the clean ice), comprise more than 21% of the glacial area. Other types of glaciers, like slope-, hanging-, peak-, cirque-, avalanche ones (so called Turkmen type), and – in a smaller amount – also mountain ice caps cover 51% of the glaciated area (Fig. 3).

A relatively deep sliding of the valley glaciers below the snow-line is an interesting phenomenon of glaciation in this area. While the proportion between glaciated area situated below and above this line is 1:3 in the Alpine countries, in the Khumbu area (according to Černík & Sekyra, 1969, in the whole Himalayas as well as in Karakorum) this rate is 1.4:1 (Table 1), and in the case of valley glaciers it is even higher.

Landforms and changes of glaciers

The present-day climatic-morphogenetic altitudinal levels determinate a complex of processes that control the type of relief formation. The area above

Table 1. Area of glaciation in the Sagarmatha National Park according to glacial types and altitude in 1978

Altitude in m	Type of glacier			Area		
a.s.l.	A	B	C	ha	%	
4,200–4,400	64.3	–	–	64.3	0.2	
4,400–4,600	214.6	32.8	5.4	252.8	0.7	
4,600–4,800	598.8	65.3	52.0	716.1	1.9	
4,800–5,000	1,743.6	136.3	195.4	2,075.3	5.4	below snow-line cca 58%
5,000–5,200	4,144.5	522.9	615.5	5,282.9	13.7	
5,200–5,400	3,239.0	1,906.4	2,215.4	7,360.8	19.1	
5,400–5,600	618.9	2,868.3	3,124.2	6,611.4	17.1	
5,600-5,800	74.1	1,974.6	2,392.6	4,441.6	11.5	
5,800–6,000	8.8	729.1	2,253.8	2,991.7	7.8	
6,000–6,400	2.5	69.2	3,836.1	3,907.8	10.1	
6,400–6,800	2.0	–	2,615.4	2,617.4	6.8	
6,800–7,200	–	–	1,321.9	1,321.9	3.4	above snow-line cca 42%
7,200–7,600	–	–	620.3	620.3	1.6	
7,600–8,000	–	–	240.8	240.8	0.6	
8,000–8,400	–	–	39.2	39.2	0.1	
8,400–8,800	–	–	12.0	12.0	0.0	
Together ha	10,711.1	8,304.9	19,540.3	38,556.3	–	
Together %	27.8	21.5	50.7	–	100.0	

A – the valley glaciers with upper moraine (including ablation moraine); B – upper parts of the valley glaciers without upper moraine ("clean type" glaciers); C – other types of glaciers (hanging-, slope- and cirque glaciers, mountain ice caps); – – snow-line

Fig. 2. Middle part of the Khumbu Glacier with debris cover. Photo by R. Midriak in 1984

Fig. 3. Hanging slope glaciers (from "clean-ice") on Mt. Lhotse Shar. Photo by R. Midriak in 1984

the snow-line is modelled by glacial or snow processes. Periglacial processes predominate in relief modelling both below the snow-line and above it, as far as the upper limit of the alpine belt (i.e. ca. 4,900–5,100 m a.s.l. or even lower in individual parts of the Sagarmatha National Park), so in the range of the higher part of the subnival belt (following Troll's, 1973 classification of global geoecological belts). However, these processes are combined with or interrupted by other slope-modelling processes, typical for lower locations. According to an universal system of categories of destructive phenomena, which I elaborated with respect to the landforms of high mountain surfaces (Midriak, 1983), the most characteristic of the present-day processes and their landforms below the snow-line can also be characterised. These are morphogenetic processes from the category of erosion, gravitational-erosion, slope movements, cryogenic and anthropogenic phenomena.

Processes of glacial and snow erosion as well as water and wind erosion are represented in the Sagarmatha National Park. The present-day rates of movement of the valley glaciers do not exceed 50 m yr^{-1} (max. 100 m yr^{-1}, according to Scherler *et al.,* 2007), being below 50–60 m yr^{-1} in the ablation part, with predominating processes of ice melting. The height of moraine mounds exceeds 150 m. The long-profile inclination fluctuates in the ablation zone of the four longest glaciers *(Ngozumpa, Nangpa, Khumbu* and *Imja)* only between 2.5° and 3.5°. An inclination of the outside of lateral moraines reaches 32° and more, their inside forms vertical walls, of which debris material falls on glaciers' surface (it is occurring at ice volume decreasing owing to present-day deglaciation; a relative surface retreat of the valley glaciers was usually in 40–60 m in the year of 1984, on some places in 80–120 m). The longitudinal profiles of valley glaciers as well as the arrangement of moraines refer to glacier fluctuations, which are expressed mainly by ice volume changes and – to a smaller extent – by changes of glacier lengths (see also Kalvoda, 1979).

The glaciers of older (but also present-day) glaciation often blocked the valleys by their moraines or deepened hollows, in which lakes were created (Fig. 4). In the Sagarmatha National Park there are 57 of such glacial lakes of total acreage of 330 ha. They are most frequent in the altitudinal range of 4,600–5,200 m a.s.l., mainly in the region of the Ngozumpa Glacier. Smaller lakes (supraglacial ponds) have also been formed on the surface of valley glaciers. There were 108 of such ablation lakes, most of them being

Fig. 4. Glacial lake Tshola Tsho formed by bare moraine dam under Mt. Taboche. Photo by R. Midriak in 1984

Fig. 5. Two small shallow glacial lakes on the rocky slope of Mt. Pumo Ri. Photo by R. Midriak in 1984

situated at the altitudes of 5,000–5,200 m a.s.l., and their total area was only 66.4 ha in 1978.

On older deglaciated places (e.g. NW slope of Tramserku, 6,608 m a.s.l., SW slope of Pumo Ri, 7,145 m a.s.l., and other places), on a rocky base rising at 4,800 to 5,400 m a.s.l., smooth surfaces have been formed by glaciers bearing a system of fissures or shallow lakes (Fig. 5), above which talus rocky slopes are not situated yet. Snow erosion in the form of surface abrasion is not a typical phenomenon on the territory placed below the snow-line. Only at some places above side moraines of the valley glaciers it is possible to recognise smaller alluvial mounds. Even snow avalanches do not occur below the snow-line, because of a relatively very low precipitation (especially in winter time) in the higher part of the Khumbu region. Winter precipitation starts to fall here mainly in the area situated at altitudes exceeding 3,700 m a.s.l., and where slopes extending up to 5,000 m a.s.l. are not covered by snow even in February (Haffner, 1972). The so-called avalanche type of glaciers, with an accumulating area in the shape of a funnel above the snow-line and with a pseudo-accumulating conical part below this line, frequently produce glacial striae. The typical examples are in the sections Pumo Ri (7,145 m a.s.l.), Lingtren (6,697 m), Khumbutse (6,640 m) as far as saddle Lho La (6,006 m), and Nuptse (7,879 m), but also at other places in the Sagarmatha National Park.

Selected literature data on modern global warming and retreat of the Himalayan glaciers

About 300, 000 records on the Himalayan glaciers do exist in Google. However, many pieces of the same information are frequently being uncritically repeated. From the data pertaining to the retreat or melting of the Himalayan glaciers as a result of global climate change, I prefer to chose the following:

- Various studies suggest that the warming in the Himalayas has been greater than the global average. While the map "Changing Climate" (NGS, 2007) shows the surface temperature change of 0.5–1°C in the Himalayas during 30 years between 1976 and 2006, according to Morgan, WWF (BBC, 2005), Nepal's annual average temperature has risen by 0.06°C. Mahat (2007), in turn, reports that warming in Nepal increased progressively within a range of 0.2–0.6°C per decade between 1951 and 2001, particularly during autumn and winter. Cyranoski (in: Chan, 2007), using a climate change model, predicts a rise in temperature in Nepal by further 1.2°C up to 2050. However, many controversial aspects of global warming theory do exist (Pribullová, 2006).
- Yamada *et al.* (1992) reviewed terminus fluctuations of 7 clean-type glaciers in the Khumbu region for the time-span between the1970s and 1989. The majority of the glaciers were found to have retreated in the range of 30 to 60 m during the observed period (i.e. retreating at ca. 1.6–3.2 m yr^{-1}).
- Watanabe *et al.* (1994) conclude about a rapid growth of a lake on the Imja glacier in Khumbu Himal, in connection with a prospect for a catastrophic flood. The lake area was 0.54 km^2 in 1984, and had become slightly larger by 1991. Recent observations indicated a maximum depth of more than 90 m and average depth of 40–50 m. Ives (2005) noticed that the 'Imja Lake' was 1.1 km long in 1991, its lateral and end moraines being ice cored, and that it is still enlarging (Fig. 6).
- Shrestha (in: Khadka, 2004) wrote: "There are 3,300 glaciers in the Nepalese Himalayas and 2,300 of them *(i.e. 70%)* contain glacial lakes… A glacial lake burst in Khumbu, Nepal (*Dig Tsho in Langmoche valley, Bhote Kosi – note by Midriak)*, in 1985, killing at least 20 people…"
- Ren *et al.* (2004) noticed: "Repeat measurements of glacier terminus positions show that glaciers in the central Himalayas have been in a continuous retreat situation in the past decades. The average retreat rate is 5.5–8.7 m/a in Mt. Qomolangma (Everest) since the 1960s…"
- WWF (2005): The Khumbu glacier has retreated over 5 km from where Sir E. Hillary and T. Norgay set out to conquer the world's highest mountain in 1953 (i.e. ca. 96 m yr^{-1}).
- UN report (2008): "The trend in the Himalayas is reflective of glaciers worldwide that are melting at more than double the rates existing until a few years ago, warns the report, based on data from 30 locations across nine mountain ranges. The average glacier shrank 1.4 m in 2006, compared to half a metre in 2005 and 0.3 m in the eighties and the nineties."
- Bierling (2007): "The Khumbu Icefall… has become easier to traverse because the seracs are

Fig. 6. Imja Glacier with Imja Tsho ('Imja Lake') as the Google Earth (2009) seen it in 2003 (about 1.8 km in length and 0.5 km in width). From above this lake some supraglacial pond formations were created on both the Imja Glacier and Lhotse Shar Glacier (upper right)

smaller… The Ama Dablam glacier has retreated more than 500 m in the past 50 years (i.e. 10 m yr^{-1})…The Imja glacier…is the fastest receding glacier in Nepal, and is melting at 70 m a year… Khumbu glacier is also retreating at an average of 20 m per year. The length of the glacier has shrunk from 12,040 m in the 1960s to 11,200 m in 2001 (i.e. ca. 20.5 m yr^{-1}) and Everest Base Camp has actually dropped from 5,320 m to 5,280 m since Hillary and Tenzing first set up camp there" (it means that the depletion of the glacier proceeded at 0.75 m yr^{-1}).

- Kulkarni *et al.* (2007): "Loss in glaciated area depends on areal extent of the glaciers…In the Himalayas, if glaciers are not heavily covered by debris, areal extent of glaciers is less than 1 sq. km and rate of melting around the snout is around 6 ma^{-1}; then response time is estimated to be between 4 and 11 years…. (Response time is defined as the amount of time taken by the glacier do adjust to a change in its mass balance)…"
- Hambrey *et al.* (2008): "Khumbu Glacier is at the earliest stage of supraglacial pond formation and shows no sign yet of developing a major lake, although one is likely to develop behind its 250 m high composite terminal moraine. Imja Glacier terminates in a substantial body of water behind a partially ice-cored moraine dam…, but morphologically appears unlikely to be an immediate threat… The terminus of Khumbu Glacier has not receded significantly according to Byers (2007), based on photographic comparison with archival photographs taken by Müller in 1956…"
- Taylor (2006): "Glaciers are growing in the Himalayan Mountains, confounding global warming alarmists who have recently claimed the glaciers were shrinking and that global warming was to blame…CNN, Reuters, ABC News, and *National Geographic*, among others, unquestioningly and uncritically reported the WWF assertions, despite WWF's clear status as an advocacy group…"
- Kremmer (2007): "Although India's glaciers are retreating, in Pakistan there are some that are actually growing in size…"
- openDemocracy (2007): "Raina points out that only 50 out of India's 9,575 glaciers have been properly studied! Nearly 200 years of data coming from these 50 glaciers have not shown anything abnormal…"
- Cook (2009): "While globally, glaciers are shrinking, there are isolated cases where glaciers are growing…Overall, Himalayan glaciers are retreating – satellite measurements have observed an overall deglaciation of 21%" from 1962 to 2007…" (i.e. by an average of 0.47% yearly).

Measured data on changes of glaciation and some glaciers in the Sagarmatha National Park after 30 years

The present-day state of glaciation in the Sagarmatha National Park, according to the Google Earth (2009), is shown in Figure 7. By planimetric analysis I recorded that there is no deglaciation of territory, but on the contrary, the present-day glaciated area comprises even 39.8% of the entire Sagarmatha National Park area (i.e. about 5.6% greater compared to year 1978).

Individual glaciers show different rates of retreat or growth owing to different altitude, aspect of slopes or valleys, longitudinal inclination of glacier, etc. Measurements performed at 59 sections on 18 glaciers revealed changes in glaciers' length and/or width, as shown in Table 2. The increase in length was found at 7 glaciers, ranging in size from 12 m to 741 m during the last 30 years, while the retreat was noted only at 5 glaciers, from 267 m to 1,804 m. The growth of glacier's width was recorded on 9 glaciers at 23 sections, and width's reduction was found to characterise 24 sections on 13 glaciers. Measurements were done on the surface of debris-mantle covered valley glaciers, showing the following averages:

- the mean yearly retreat of glacier terminal position of 35.3 m
- the mean yearly growth of glacier terminal position of 9.6 m
- the mean yearly retreat of glacier lateral position of 2.3 m
- the mean yearly growth of glacier lateral position of 3.0 m.

The results of a survey of the dam moraine lakes, in relation to watersheds in the Sagarmatha National Park 30 years ago and at present, are given in Table 3. Finally, Table 4 shows an example of a survey of small supraglacial pond formations (>3 m in diame-

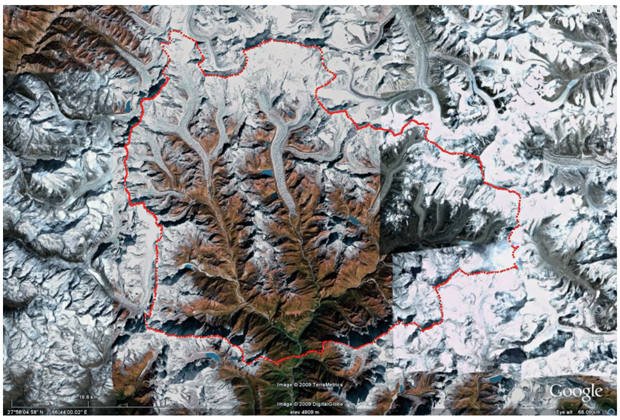

Fig. 7. Glaciation of the Sagarmatha National Park according to Google Earth (2009)

Table 2. Changes in length and width of glaciers in the Sagarmatha National Park

Glacier	Change (*in metres*) in comparison with year of 1978				Water-shed
	Length of glacier		Width of glacier		
	growth	retreat	growth	retreat	
Nangpa		1,655	71	130	Bhote Kosi
				4	
Melung		847	3		Bhote Kosi
Lunag				205	Bhote Kosi
Chhule	340				Bhote Kosi
Sumna			100	143	Bhote Kosi
Langmoche		1,804[1)]			Dudh Kosi
Ngozumpa		730		50	Dudh Kosi
				224	
				34	
				6	
Gyubanar			60	72	Dudh Kosi
Lungsampa				11	Khumbu
Khumbu	264			12	Khumbu (Imja Khola)
				41	
				1	
				176	
Lobuche	12				Khumbu (Imja Khola)
Changri Shar	15			45	Khumbu (Imja Khola)
Imja	27			68	Imja Khola
				13	
Nuptse	610		139	18	Imja Khola
			86		
			75		
			188		
			184		
Lhotse Nup	741		43	150	Imja Khola
				81	
				142	
				1	
Lhotse			58	10	Imja Khola
			198		
			1		
			79		
			8		
Lhotse Shar			152		Imja Khola
			75		
			144		
			117		
Ama Dablam		267	37	2	Imja Khola
			38		
			126		
			83		

[1)]At the locality of retreated Langmoche Glacier, the Dig Tsho lake was created ter) created on some valley glaciers in the north-eastern part of the Sagarmatha National Park.

Table 3. Dam moraine glacial lakes in the Sagarmatha National Park

Watershed of glaciers	Number of glacial lakes	
	In the year 1978	After 30 years
Bhote Kosi	15	75
Dudh Kosi	62	91
Khumbu	35	55
Imja Khola	53	68
Total	165	289

Table 4. Small supraglacial pond formations (ablation lakes with diameter > 3 m) on the valley glaciers in NE part of the Sagarmatha National Park

Glacier		Total
Nuptse glacier		212
≤ 5,000 m a.s.l.	12	
5,000–5,100	21	
5,100–5,200	45	
5,200–5,300	66	
5,300–5,400	54	
above 5,400	14	
Lhotse Nup glacier		145
≤ 5,000 m a.s.l.	18	
5,000–5,100	36	
5,100–5,200	85	
5,200–5,300	6	
Lhotse glacier		245
4,900–5,000 m a.s.l.	40	
5,000–5,100	54	
5,100–5,200	104	
5,200–5,300	47	
Lhotse Shar glacier		210
5,000–5,100 m a.s.l.	23	
5,100–5,200	77	
5,200–5,300	74	
5,300–5,400	36	
Khumbu glacier		282
≤ 5,000 m a.s.l.	48	
5,000–5,100	75	
5,100–5,200	67	
5,200–5,300	47	
5,300–5,400	39	
5,400–5,500	6	
Changri Shar glacier		14
5,300–5,400 m a.s.l.	10	
5,400–5,500 m a.s.l.	4	

Discussion and conclusions

1) There are only few data on a diversity of climate influence upon the glaciers in different environment of the Himalayas; therefore, the present-day state of glaciation and/or glacial retreat must be evaluated carefully, without emotions (Reynolds, in: Mahat, 2007). High priority should be given to scientifically objective work (Mahat, 2007).
2) The extent of glaciation in the Sagarmatha National Park in Mt. Everest region/Nepal, according to our measurements, has not been reduced since 1978, i.e. during the past 30 years. However, according to Cook (2009), average rate of deglaciation in the Himalayas was ca. 4.7% per year during the last 45 years. Thus, the present-day (in 2009) extent of glaciers in the Sagarmatha National Park should be ca. 20.2%, instead of the value of 39.8%, which was measured from the Google Earth images. The measured figures depend on glacier forms, which were calculated in the per cent of coverage. I took into consideration all forms of glaciers, i.e. valley-, slope-, hanging- and cirque glaciers as well as ice caps, and not only valley glaciers.
   Anyway, some valley glaciers in the Mt. Everest region are also retreating according to my measurements, while others have grown during the evaluated period. However, the reason for different results obtained in this study compared to those of other authors can be different methods of measuring the reduction in length and/or width of valley glaciers. Very important is also determination of the ice-cored end moraine (contrary to "dead frontal moraine"), because the results are very different. For instance, the results concerning the Khumbu Glacier reported in WWW (2005), cited above, are absolutely unrealistic in my view.
   Another interesting phenomenon is that glaciers exposed to increased warming at higher altitudes on the slopes are moving more quickly and that they should be treated as "growing" glaciers, instead of the retreating ones. Measurements of glacier mass dynamics are so precise nowadays that they enable one to evaluate not only the rate of increase/decrease in length/width, but also the rate of lowering of the glacier surface. I have not performed such measurements in the Sagarmatha National Park.
3) Among most important changes, the formation of glacier dam moraine lakes under the snow-line and of small supraglacial ponds on the valley glacier surfaces should be listed. I found 1.75 times more of glacier dam moraine lakes compared to their number in 1978. These lakes are potential natural hazards (as bursting glacial lakes) for lower situated localities, where rapidly drained

waters may have a disastrous effect (see, e.g. Watanabe *et al.*, 1994).

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