Dynamic response of glaciers on the Tibetan Plateau to climate change
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A Glacier Inventory for Western Nyainqentanglha Mountains and Nam Co Basin, Tibet, and Glacier Changes 1976-2009

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Introduction

Often described as Asia's "water tower", the Tibetan Plateau (TiP) is the source of many major rivers and essential to millions of people living in the surrounding regions. Like in many other parts of the world the TiP's climate shows a temperature increase latest since the mid 1950s accompanied by an increase of precipitation while glaciers receded almost throughout the entire Tibetan Plateau during recent decades. Our study area, the western Nyainqentanglha range, located in the southeastern centre of the Tibetan Plateau, is 230 km long and rises from some 5000 to 7162 m (Fig.1). The area is of special interest for glacioclimatological research as this region is influenced by both the continental climate of central Asia and the Indian Monsoon system and it is situated at the transition zone between temperate and subcontinental glaciers.

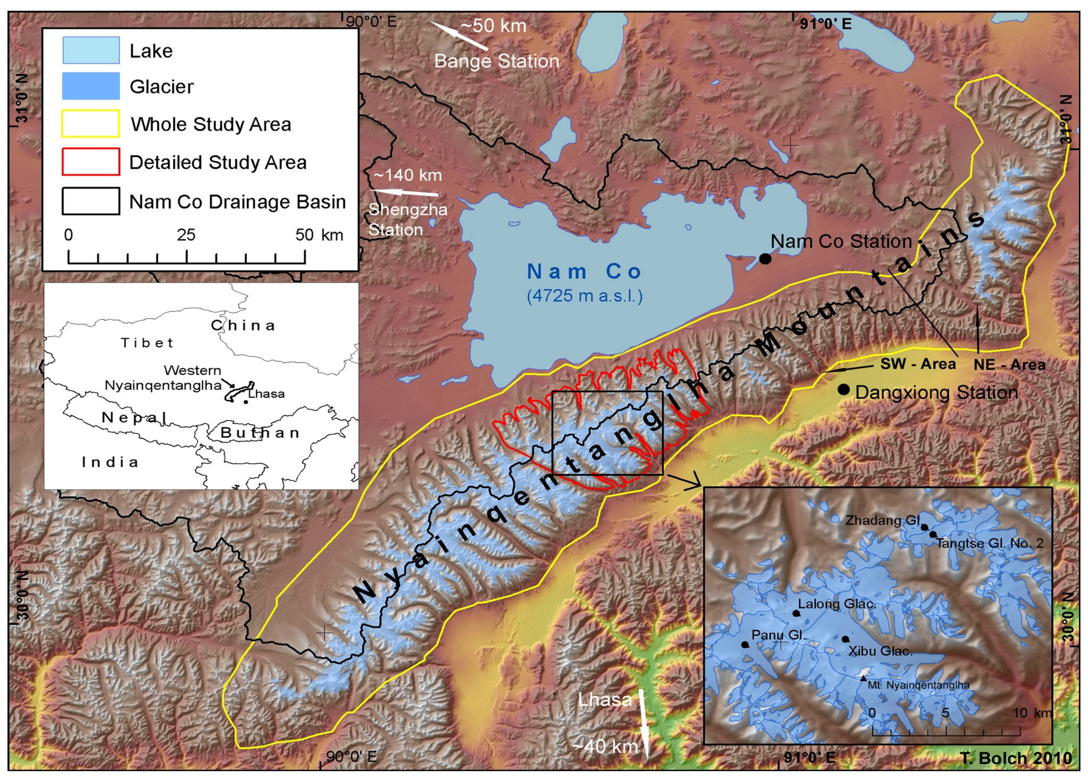

Figure 1. Study area.

Data

The analysis is mainly based on data from Hexagon KH-9, Landsat MSS (year 1976), Metric Camera (1984), and Landsat TM/ETM+ (1991, 2001, 2005, 2009) data (Table 1) as well as the SRTM3 digital elevation model. Several scenes were necessary to obtain full coverage due to partly cloud cover or seasonal snow (Figure 2).

Table 1. Utilized remote sensing data

Date	Instrument	Resol.	Bands	Utilization
21/11/70	Corona KH4-B	~4m	PAN	Inv. `76, add. Info
07/01/76	Hexagon KH-9	~8m	PAN	Invent. 1976
07/12/76	Landsat MSS	79m	VNIR	Inv. `76, add. Info
23/11/84	Metric Camera	~16m	VIS	Length changes
14/09/91	Landsat TM	30m	VNIR, MIR	Length changes
17/11/00	Landsat ETM+	15/30m	VNIR, MIR	Invent. 2001
02/05/01	Landsat ETM+	15/30m	VNIR, MIR	Invent. 2001
06/12/01	Landsat ETM+	15/30m	VNIR, MIR	Invent. 2001
07/10/05	Landsat SLCoff	15/30m	VNIR, MIR	Length changes
01/08/07	Landsat SLCoff	15/30m	VNIR, MIR	Invent. NE-Part
06/01/08	Landsat SLCoff	15/30m	VNIR, MIR	Invent. 2009
19/06/09	Landsat SLCoff	15/30m	VNIR, MIR	Invent. 2009
21/07/09	Landsat SLCoff	15/30m	VNIR, MIR	Invent. 2009
19/09/09	Landsat SLCoff	15/30m	VNIR, MIR	Invent. 2009

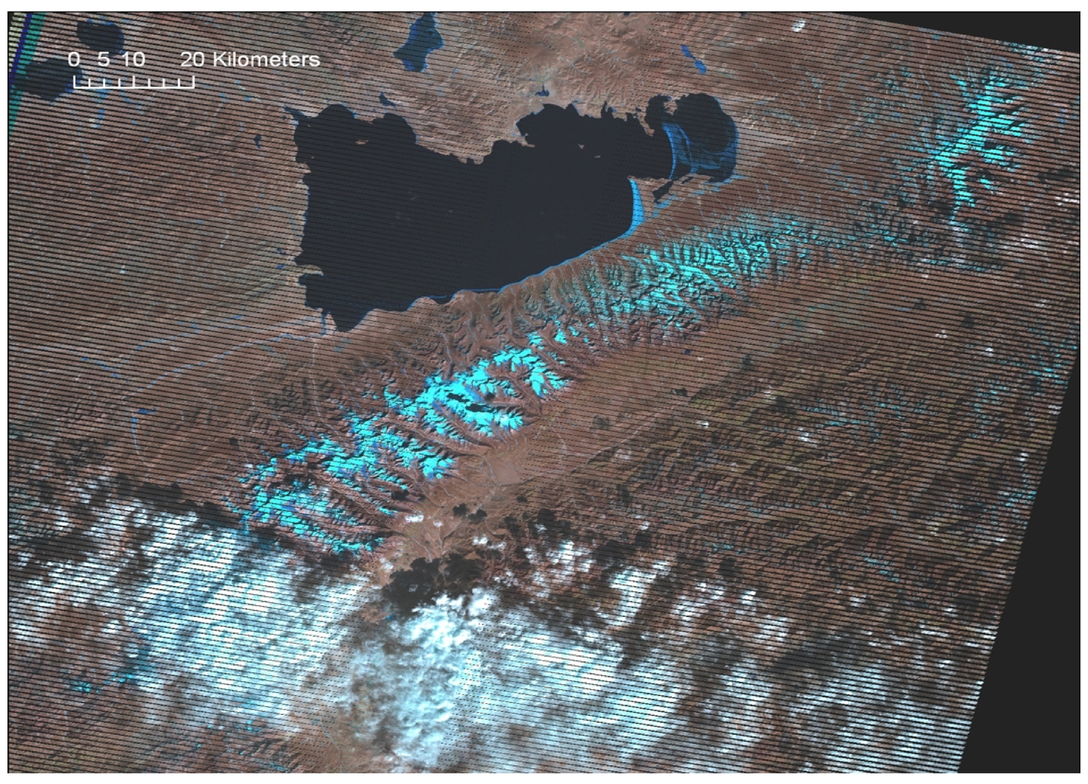

Figure 2. Typical situation of a Landsat scene: Part of the study area is suitable, while seasonal snow hampers correct mapping in the NE region, and clouds covers the SW region. The region of highest interest in the center is not affected by the scanline error.

Methods

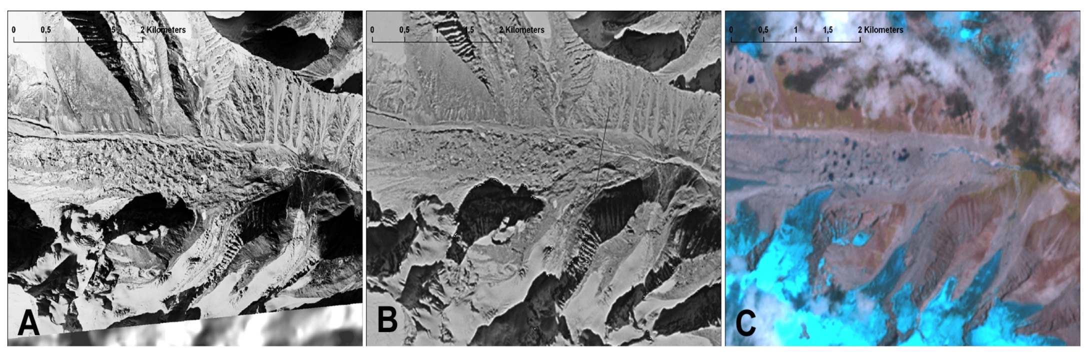

Figure 3. Terminus of debris-covered Xibu Glacier; Corona (year 1970, A), Hexagon (1976, B), Landsat ETM+, 5-4-3-pan (2009, C).

The snow and ice cover was automatically classified with the TM and ETM+ scenes using the TM3 by TM5 band ratio. The contiguous ice masses were divided into their drainage basins based on hydrological analysis of the SRTM3 DEM within a one-kilometre-buffer around each glacier. The results were visually checked for gross errors using additional imagery (e.g. higher resolution Corona KH4- B (Figure 3) or a Landsat MSS / Hexagon KH-9 resolution merge (Figure 4). Manual adjustment was especially necessary for debris covered glaciers and for the 1976 inventory based on the panchromatic Hexagon data. Lenght changes were obtained visually. No 1976 inventory could be obtained for the NE section due to unfavorable snow conditions.

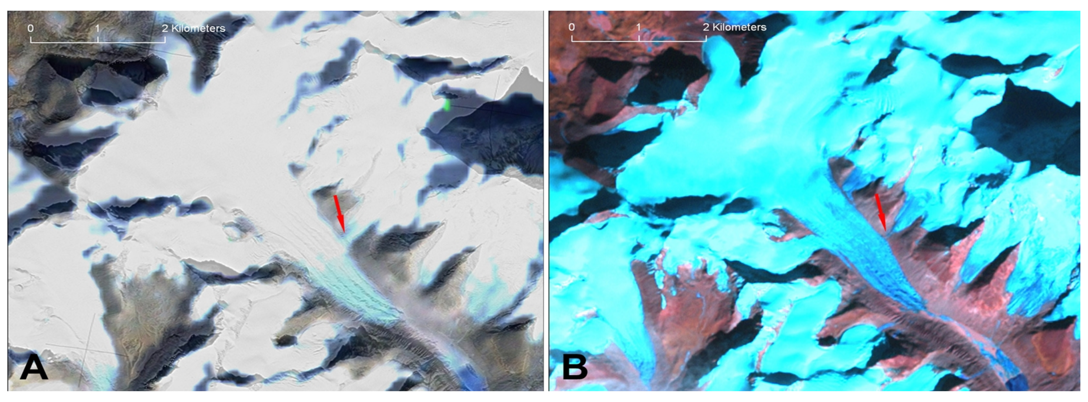

Figure 4. Panu Glacier 1976 (merge of Landsat MSS and Hexagon, A), 2001 (Landsat ETM+, 5-4-3-PAN, B)..

Results

The whole mountain range contains about 960 glaciers covering an area of 795.6 ± 22.3 km² while the catchment area of Nam Co covers 198.1 ± 5.6 km². The median elevation of the glaciers is ~5800 m with the majority terminating around 5600 m.
Five glaciers with debris-covered tongues terminate lower than 5200 m. The study reveals a long-term trend of glacier shrinkage and retreat in the western Nyainqentanglha Range since 1976 (Table 2).
The glacier area decreased between 1976 and 2001 by about 6 ± 3%, which is less than presented in previous studies based on topographic maps from the 1970s and Landsat data from 2000.
The shrinkage rate probably increased in the period 2001 – 2009. No advancing glaciers were detected.

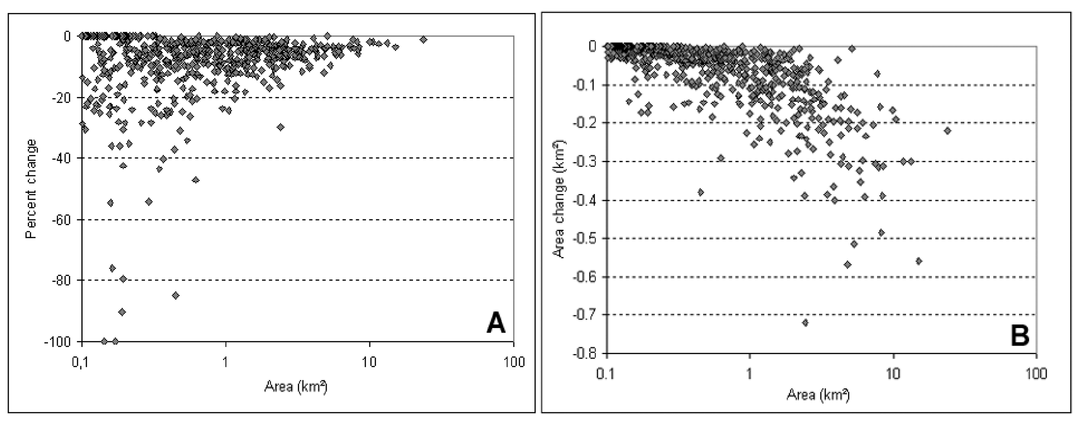

Figure 5. Relative change (A) and absolute change (B) in glacier area 1976-2001 versus initial glacier area.

Table 2. Glacier area changes 1976 - 2001 - 2009.

Region	Area			1976 - 2001		2001 - 2009	
	1976	2001	2009	dA (km²)	dA/a (%)	dA (km²)	dA/a (%)
SW-Range	734.1 ±25.7	692.4 ±19.4	n.a.	-41.7 ±22.4	-0.23 ±0.12	n.a.	n.a.
Nam Co Basin	212.5 ±7.4	198.1 ±5.5	n.a.	-14.4 ±6.5	-0.27 ±0.12	n.a.	n.a.
Detailed Study Ar.	207.1 ±7.2	194.5 ±5.5	186.6 ±5.4	-12.6 ±6.4	-0.24 ±0.12	-7.8 ±5.4	-0.50 ±0.34

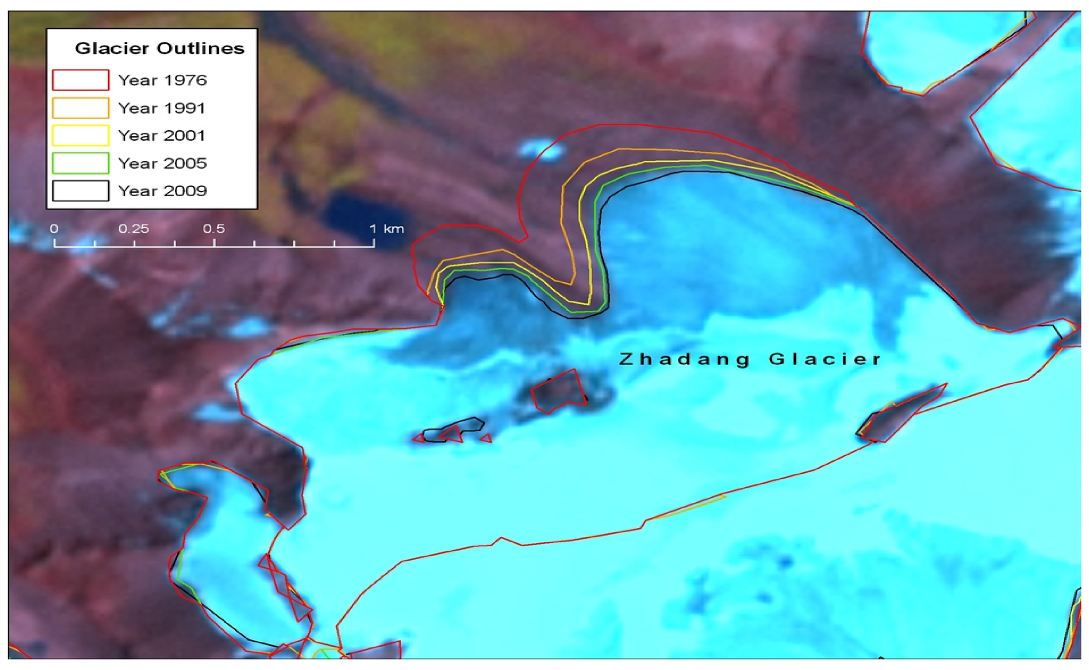

Figure 6. Area changes of Zhadang Glacier (1976-2009).

Analysis of the relative area change against the initial glacier area indicates greater percentage loss for smaller glaciers, whereas the absolute area loss is higher for larger glaciers (Figure 5). Analysis of the glacier hypsometry shows that ice coverage above 6000 m remains almost unchanged while the highest absolute ice loss occurs between 5500 and 5700 m (Figure 7). Detailed length measurements for five glaciers indicate a retreat of the tongues of around 10 m per year (1976-2009, Figure 6) with higher absolute but lower relative values for the larger glaciers. No consistent trend was found for the rate of change within the investigation period which might indicate different response times of individual glaciers.

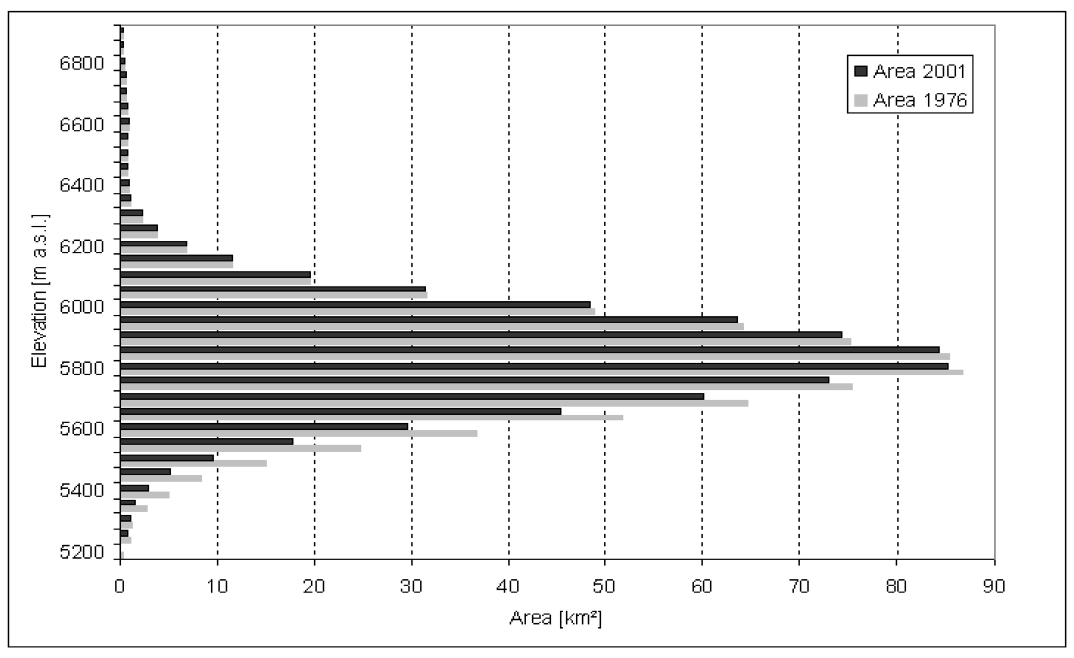

Figure 7. Changes in glacier hypsometry 1976 – 2001.

Discussion and conclusions

The availability of different optical satellite imageries from earlier years, especially the low cost Hexagon KH-9 from the 1970s and Landsat TM scenes from the 1980s and 1990s is of high value for glacier investigations. This allows evaluating existing data or glacier outlines from older topographic maps and deriving multitemporal glacier inventories dating back several decades. The use of different satellite data revealed a continuously glacier shrinkage of about 7.7 % from 1976 until 2009. These values are lower than previously published results. The Chinese Glacier Inventory from the 1970 is a valuable source of information but the data has inaccuracies and geolocation errors. The main cause of glacier wastage is likely the temperature increase but the complex glacierclimate interactions needs to be further investigated.

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Reference

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