in snow precipation and thermal insolation, which explains the recently observed glacier-mass loss (Arenillas and others, 1992).

Furthermore, Martínez de Pisón and Arenillas Parra (1988) included some glacierets in their catalogue. As these glacierets do not have crevasses, they do not consider them as glaciers, although they are remnants of previous ones (e.g. Punta Zarra glacieret). Likewise, a report of the Ministero de Obras Públicas y Transportes (1992) on the snow in the Spanish cordilleras includes some glaciers in the Spanish Pyrenees with dimensions similar to Glaciar Jou Negro, such as those of Punta Zarra, Balaitus and Taillón. All of them, located in the western part of the glacierized area, are small-size glaciers with an area of $2 \times 10^4\,m^2$. Regarding thickness, Glaciar Jou Negro is thicker than those in that report, the real values reaching 14 m at some points.

The presence of isolated glacier ice in the Picos de Europa is probably due to its slower response to recent climate changes due to the specific characteristics of its location, above 2200 m and with a northeast aspect and a shady topography, as it occupies an important karstic depression. Future research concerning the stage of evolution is planned and this includes the measurements of possible variations in ice thickness and in glacier extent, as well as modifications to the water-conduit system.

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SIR,

Compilation of long-term glacier-fluctuation data in China and a comparison with corresponding records from Switzerland

INTRODUCTION

Data on world-wide glacier fluctuations are being compared and interpreted in an increasing number of publications (Patzelt, 1985; Kislov and Koryakin, 1986; Makarevich and Rototayeva, 1986; Vallon and others, 1986; Haeberli and others, 1989a; Kick, 1989; Oerlemans and others, 1993; Williams and Ferrigno, 1993; Oerlemans, 1994). The surface areas of glaciers in China account for about 10% of the total surface area covered by ice caps and mountain glaciers on Earth, existing outside the large polar ice sheets (Haeberli and others, 1989b). With the exception of a few individual glaciers, however, most Chinese glaciers have been rarely monitored and measured. Consequently, data on glacier fluctuations in China are limited. The Chinese glacier monitored and measured in most detail is Ürümqi Glacier No. 1 within the Ürümqi River source region in the central Tien Shan. Since 1980, variations in the positions of glacier fronts (length change) during various time periods have been reported for about 200 glaciers (Zhang, 1980a, b: Karakoram; Zhang and Mi, 1981: Qilianshan, Kunlunshan and Tien Shan; Wu and others, 1983: Tien Shan; Xie and others, 1985: Qilianshan, Kunlunshan and Tien Shan; Wu and others, 1983: Tien Shan; Xie and others, 1985: Qilianshan; Ren, 1987: Kunlunshan; cf. also Shi and others, 1988, cf. Fig. 1). Glaciers in the Swiss Alps were chosen for a main comparison, because they have

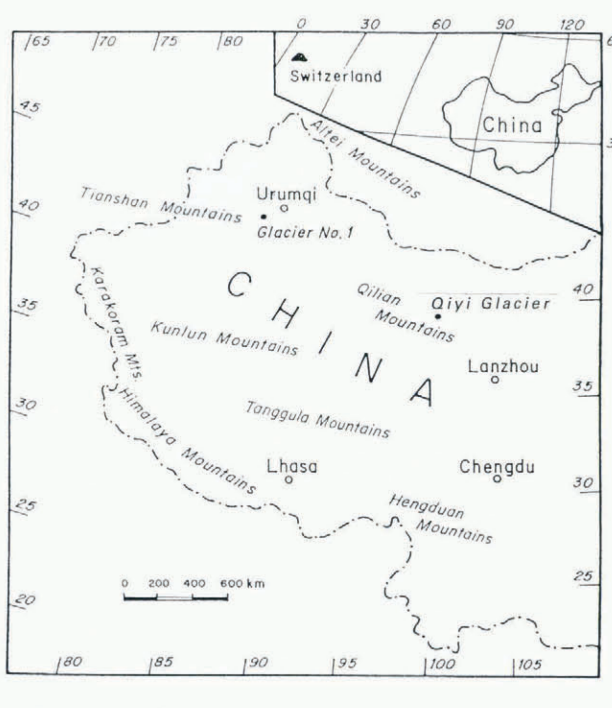

Fig. 1. Location of areas studied (inset) and of mountain ranges in China. The number of glaciers studied is: 55 in Tien Shan, 42 in Qilianshan, 40 in Kunlunshan, nine in the Himalaya, seven in Hengduanshan, six in the Karakoram, three in Tanggulashan and two in the Altai.

been monitored in considerable detail during the past century. In Switzerland, mass-balance information exists for five glaciers and extensive records on length change are available for more than 100 glaciers.

GLACIER MASS BALANCES

Although Ürümqi Glacier No. 1 has been measured and studied in detail, mass-balance observations were interrupted between 1967 and 1979. The mass-balance data used here for the time interval 1967–79 were reconstructed by J. H. Zhang (1981), Zhang and others (1984) and Shi and others (1988) on the basis of precipitation and air temperature recorded by a meteorological station situated 2.5 km from the glacier and at an altitude of 3589 m a.s.l. The mass-balance record of another glacier, Qiyi Glacier in the central Qilianshan, was reconstructed (Liu and Xie, 1987) after 5 years of field measurements using a relationship between accumulation, ablation and meteorological parameters (altitude of the 0°C isotherm, summer air temperature, etc.). Both glaciers are in areas of a continental climate. In Switzerland, the mass balance of Aletschgletscher has been estimated from a hydrological balance model calibrated by precision mapping in 1927 and 1957. The model uses precipitation and run-off measurements and assumes that annual evaporation remains constant.

Figure 2 compares annual mass balances since 1959 for glaciers in China and Switzerland. Annual variations in mass balance are quite synchronous for the Swiss glaciers, which are located in the same climatic region and are close together. On the other hand, short-term variations are *not* synchronous in Switzerland and China. Letréguilly and Reynaud (1990) discussed similar spatio-temporal patterns of mass-balance variability and pointed out that the identity of annual mass-balance variations cannot be recognized beyond individual mountain ranges. They further concluded that, beyond a distance of 500 m, synchroneity cannot be found at decadal time-scales but that the main secular trends seem to be common in Europe and High Asia. Close inspection of the records indicates that common negative balances during 1962–64 in Switzerland, for instance, correspond to highly positive balances of Ürümqi Glacier No. 1. An abrupt change to positive balances on Swiss glaciers since 1965, and continuing until about 1970, is accompanied by strong mass losses of Ürümqi Glacier No. 1.

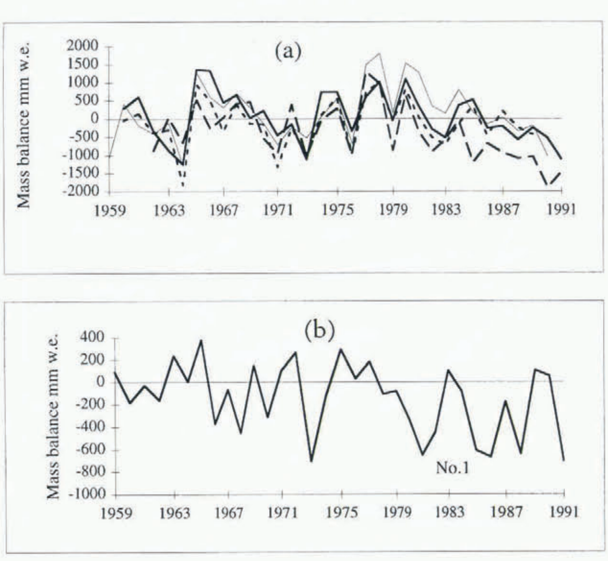

Fig. 2. Specific net mass balance (mm w.e.) for glaciers in Switzerland and China. (a) Swiss glaciers: Silvrettagletscher (solid line), Limmerngletscher (dotted line), Griesgletscher (dashed line) and Aletschgletscher (dashed/dotted line); (b) Ürümqi Glacier No. 1 in China.

Figure 3 shows time series of cumulative-balance variations. There is considerable variation among individual glaciers with respect to overall gain or loss in mass. Even though the reconstructed mass balance for Qiyi Glacier is very approximate, evidence of overall mass gain can be found. Four of the five annual mass balances determined in the field were positive and the average equilibrium-line altitude on the glacier decreased by about 100 m between the decade 1957–66 to the decade 1967–77 (Ding and Kang, 1985). The tendency towards a positive cumulative balance for Qiyi Glacier could therefore be real. In Switzerland, cumulative balances since 1960 were slightly positive on Silvrettagletscher and markedly negative on Griesgletscher. The phenomenon of highly variable cumulative mass-balance series and significantly different conditions of health appears to be common for glaciers in the Northern Hemisphere (Letréguilly and Reynaud, 1990). Amongst the reasons for this are the orientation of the glaciers and the distribution of glacier area with altitude (hypsometry). In Switzerland, mass balances appear to be more negative on glaciers that are exposed to the northeast (there appears to be a similar phenomenon for most glaciers in France and Austria; cf. the data given in Haeberli, (1985), Haeberli and Müller (1988); Haeberli and others (1994); Haeberli and Hoelzle (1995)). Unfavourable orientations of glaciers in the Tien Shan with respect to the predominant humidity source are the northeastern and southeastern quadrants (Table 1). Qiyi Glacier, however, has an unfavourable exposure but a positive

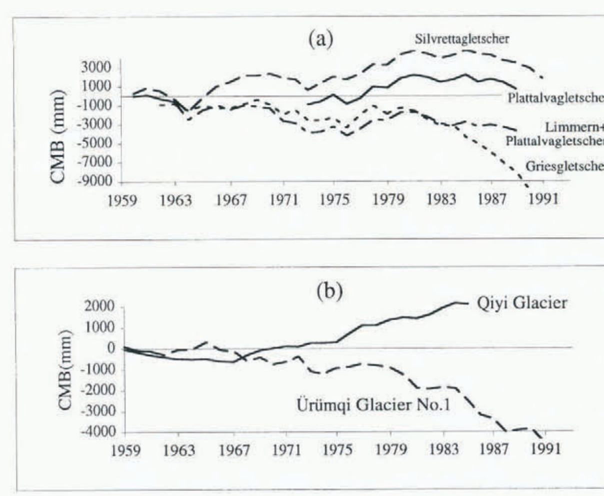

Fig. 3. Cumulative mass balance (CMB) vs time for glaciers in (a) Switzerland and (b) China.

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Table 1. Relationship between orientation of accumulation area and cumulative balance

Glaciers	*Latitude*	*Longitude*	*Exposure**		*Condition*†	*Balance*‡
			AC	AB		
Silvrettagletscher	46°51′ N	10°05′ E	NW	W	Favorable	Positive
Aletschgletscher	46°30′ N	08°02′ E	SE	S	Favorable	Positive
Plattalvagletscher	46°50′ N	08°59′ E	E	E	Favorable	Positive
Rhonegletscher	46°37′ N	08°24′ E	S	S	Favorable	Positive
Limmerngletscher	46°49′ N	08°59′ E	NE	NE	Unfavorable	Negative
Griesgletscher	46°26′ N	08°20′ E	NE	NE	Unfavorable	Negative
Qiyi Glacier	39°14′ N	97°54′ E	NW	NW	Unfavorable	Positive
Ürümqi No. 1 Glacier	43°05′ N	86°49′ E	NE	NE	Unfavorable	Negative
Tuyuksu§	43°03′ N	77°05′ E	N	N	Unfavorable	Negative
Kara B.**	42°08′ N	78°16′ E	N	N	Unfavorable	Negative

* AC, accumulation area, AB, ablation area; † Condition that glaciers capture humidity; ‡ Present cumulative mass balance; § Glacier in Kazakhstan; ** Glacier in Kirghizstan.

mass balance. Glacier orientation, therefore, cannot be the only or even the most important factor influencing the variability in cumulative mass balances. The highly positive balance of Qiyi Glacier could result from its hypsometry (Fig. 4); the wide firn basin is favourable for the accumulation of snow. In a comparable way, a relatively large firn basin seems to remedy the unfavourable northern exposure of Silvrettagletscher. Plattalva-

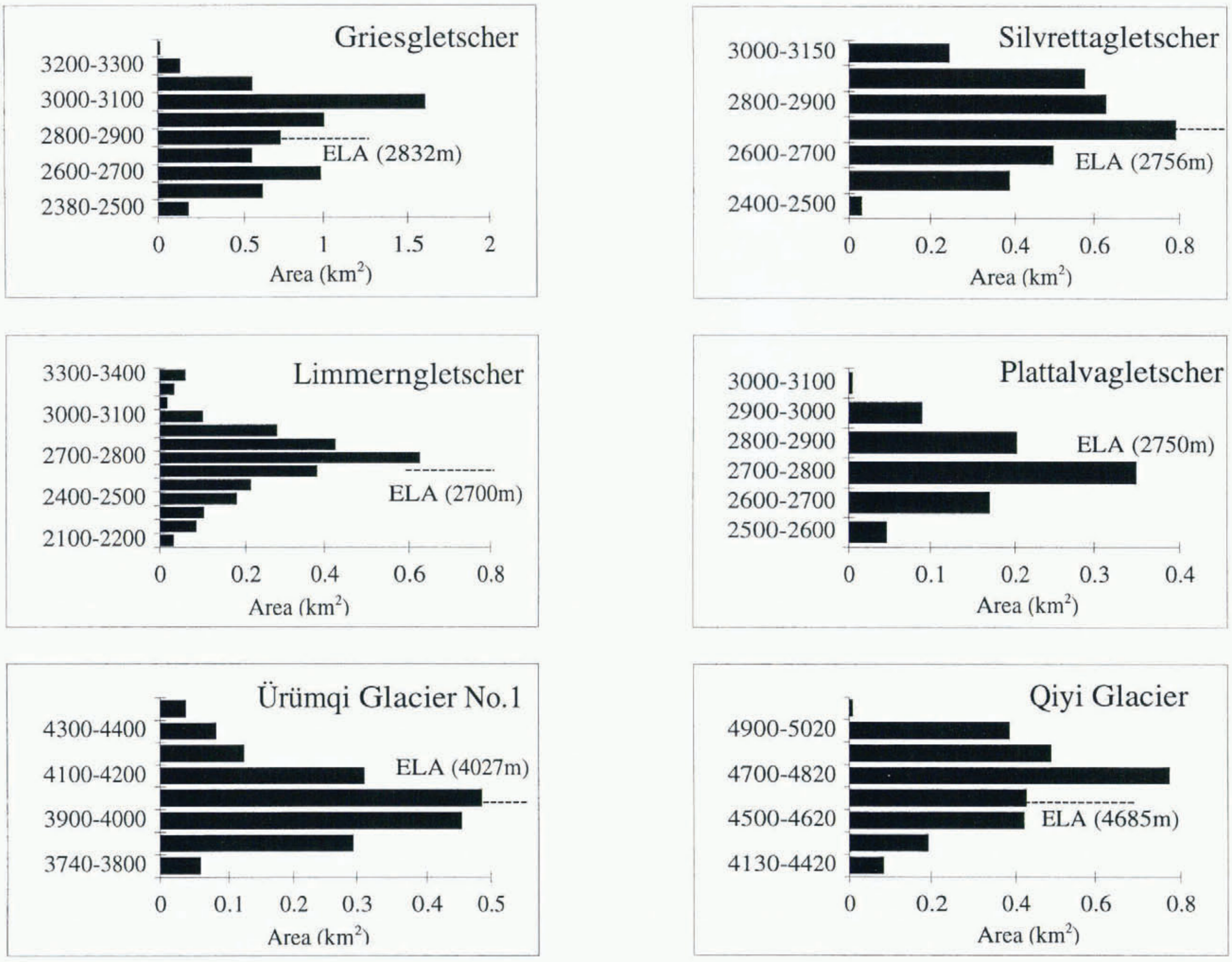

Fig. 4. Hypsometry of glaciers with negative (left) and positive (right) cumulative mass balance. Ordinate gives altitude interval in m a.s.l.

gletscher and Limmerngletscher are probably typical examples of the combined effects of orientation and hypsometry. These two small glaciers are immediately adjacent to each other but their mass balances are different. Their combined exposure and hypsometry may explain the different balances. A similar phenomenon can also be observed with Hintereis- and Kesselwandferner in Austria (Kuhn and others, 1985; Greuell, 1992).

In strong contrast to the remarkable scatter in annual and cumulative mass balance, changes in cumulative mass balance are similar over the time period considered (1959–90): during the latest decade (1980–90), an accelerating trend towards more negative mass balances appears in both regions (Fig. 3). Short-term local to regional variability is nevertheless superimposed on this general trend. A change towards markedly negative balance for Ürümqi Glacier No. 1 occurred in 1978 with the strongest loss in 1981 (Fig. 2), while Swiss glaciers at the same time maintained positive or zero balances. Rates of mass loss for the Swiss glaciers, on the other hand, have accelerated strongly since 1981. The trend towards negative balances then remains obvious for the entire decade of the 1980s in both regions. This observation may indicate that accelerated warming of the 1980s, as reflected by glacier and permafrost changes in the Alps (Haeberli, 1994), not only appears in mountain ranges with transitional to maritime climatic conditions but also affects areas of strong continentality.

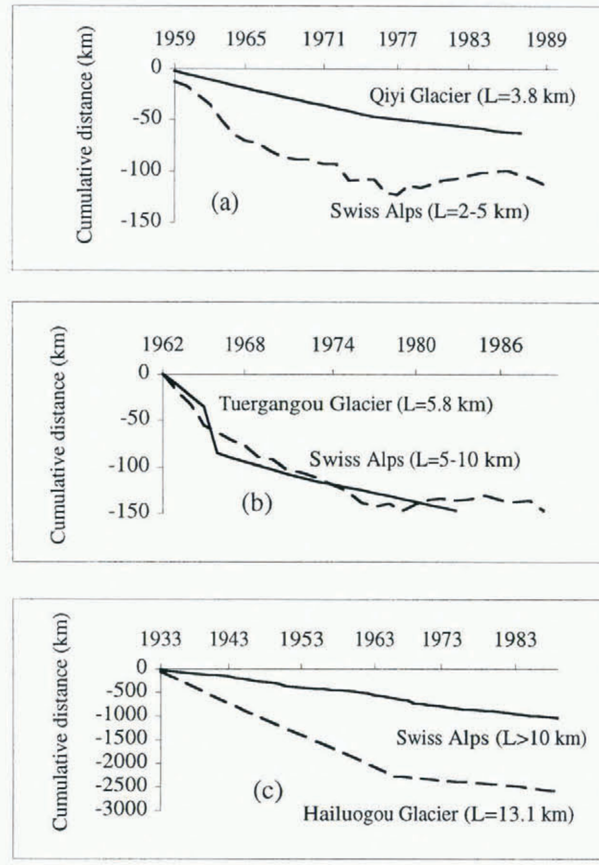

Fig. 5. Comparison between average change in length of Swiss glaciers and changes in length of individual Chinese glaciers.

VARIATIONS IN THE POSITIONS OF GLACIER FRONTS (GLACIER-LENGTH CHANGES)

There are no continuous data on annual variations in the positions of glacier fronts in China. Information on glacier-length changes over various longer time intervals, however, is available in a number of publications (Zhang, 1980a, b; Zhang and others, 1981; Wu and others, 1983; Haeberli, 1985; Xie and others, 1985; Ren, 1987; Haeberli, 1988; Shi and others, 1988; Haeberli and Hoelzle, 1993). With the exception of a few direct measurements, most of those data were obtained from topographic maps at scales of 1 : 50 000 and 1 : 100 000, from aerial photographs and from satellite imagery. Data on glacier-length changes in Switzerland were mainly extracted from the annual reports prepared by VAW/ETHZ for the Swiss Glacier Commission (Kasser and others, 1986; Aellen, 1988; Aellen and Herren, 1991, 1992a, b, 1993). Most of the time intervals considered are shorter than the dynamic response time of the glaciers involved. It is, therefore, necessary to analyse cumulative length changes of glaciers with comparable geometry (especially total length) in order to avoid comparing glaciers with highly different response characteristics (cf. Kuhn, 1978; Haeberli and others, 1989a; Haeberli, 1995).

Figure 5 compares cumulative length changes of three Chinese glaciers with average cumulative length changes determined for Swiss glaciers of more or less equal length. Tuergangou Glacier (Tien Shan) and Qiyi Glacier (Qilianshan) are continental glaciers but Hailuogou Glacier (Mount Gonga in the Hengduanshan) is somewhat maritime. These three glaciers are among the few in China which have been documented by repeated surveys over variable time intervals and hence may be compared with detailed Swiss records. A general trend towards retreat has obviously predominated during the past 30 years for the investigated glacier sizes in China as well as in Switzerland. It is also noteworthy that the continental Qiyi Glacier reacts less and the maritime Hailuogou Glacier more sensitively than Alpine glaciers with their transitional climate.

The similarity of long-term glacier-length changes in China and Switzerland also appears in the statistics for different classes of glacier length (Table 2). Increases and decreases in the percentage of retreating glacier snouts during different time intervals roughly follow the same pattern in both countries, especially with respect to glaciers shorter than 10 km. Glacier retreat clearly predominates, with the exception of the intermittent advance of long Chinese glaciers after the middle of the present century and during the period around 1980 when 2–5 km long glaciers advanced in both countries. In general, percentages and rates of retreat for glaciers shorter than 10 km were higher during the 1950s but decelerated since the 1960s, leading to a tendency towards intermittent advance in the 1970s with a peak from the middle of the 1970s to the beginning of the 1980s.

The retreat of the Chinese glaciers longer than 10 km during various time periods appears to be less steady and less homogenous than in Switzerland. In fact, there seems to be a distinct difference between the two countries with respect to the average rates of glacier-length changes and to percentages of advance/retreat for large glaciers. One

Table 2. Comparison of length changes for comparable length classes (km) of glaciers in China and Switzerland (% is percentage of retreating glaciers with number of glaciers in brackets; rate is average rate of length change in m a^{-1} for the entire sample of the size category and the considered time interval). The locations of the Chinese glaciers for the individual time intervals are as follows: (1) = Qilianshan (eight glaciers); (2) = Tien Shan (two glaciers) and Qilianshan (one glacier; (3) Qilianshan (nine glaciers); (4) Qilianshan (four glaciers) and Tien Shan (three glaciers); (5) Qilianshan (six glaciers), Tien Shan (one glacier) and Kunlunshan (seven glaciers); (6) Qilianshan (two glaciers) and Nianqingtanggulashan (one glacier); (7) Qilianshan (four glaciers) and Altaishan (one glacier); (8) Qilianshan (11 glaciers), Tien Shan (11 glaciers) and Kunlunshan (six glaciers); (9) Tien Shan (one glacier), Pamir (one glacier) and Kunlunshan (four glaciers); (10) Tien Shan (two glaciers) and Hengduanshan (one glacier); (11) Qilianshan (one glacier), Karakoram (four glaciers), Himalaya (one glacier) and Henduanshan (two glaciers); (12) Tien Shan (11 glaciers); (13) Qilianshan (one glacier), Tien Shan (11 glaciers), Kunlunshan (17 glaciers), Karakoram (two glaciers) and Himalaya (one glacier); (14) Qilianshan (one glacier), Tanggulashan (one glacier), Kunlunshan (two glaciers) and Hengduanshan (four glaciers); (15) Qilianshan (one glacier), Karakoram (one glacier), Hengduanshan (two glaciers); (16) Tien Shan (six glaciers); (17) Qilianshan (one glacier), Tien Shan (two glaciers), Kunlunshan (ten glaciers), Himalaya (one glacier) and Karakoram (one glacier); (18) Qilianshan (one glacier), Tanggulashan (one glacier), Hengduanshan (three glaciers) and Kunlunshan (one glacier)

	%	Rate	%	Rate	%	Rate	%	Rate
Length ≤2 km								
China	100(8)	–12.8	67(2)	–7.2				
Switzerland	84(32)	–3.5	63(24)	–1.1				
Duration	1956–76(1)		1965–77(2)					
Length = 2–5 km								
China	100(9)	–10.4	43(3)	–6.5	36(5)	–4.3	33(1)	2.7
Switzerland	83(38)	–8.4	64(28)	–4.7	61(28)	–4.6	39(18)	3.2
Duration	1956–77(3)		1966–73(4)		1966–76(5)		1977–84(6)	
Length = 5–10 km								
China	100(5)	–5.8	54(15)	–4.5	33(2)	–3.9	33(1)	–1.9
Switzerland	77(24)	–14.8	74(23)	–8.2	58(18)	–4.5	55(17)	–2.5
Duration	1956–77(7)		1966–76(8)		1973–80(9)		1973–84(10)	
Length >10 km								
China	63(5)	–61.8	55(6)	–11.3	61(20)	–19.8	63(5)	–9.9
Switzerland	100(5)	–18.7	100(5)	–20.0	100(5)	–23.4	80(4)	–17.3
Duration	1937–68(11)		1942–76(12)		1963–76(13)		1968–89(14)	
Length = 10–20 km								
China	100(4)	–93.5	83(5)	4.4	80(12)	–21.8	83(5)	–13.2
Switzerland	100(4)	–17.9	100(4)	–19.2	100(4)	–21.7	75(3)	–17.5
Duration	1937–68(15)		1942–76(16)		1963–76(17)		1968–89(18)	

reason may be that 51 Chinese glaciers with lengths exceeding 10 km, including 18 glaciers longer than 20 km, are used for the analysis, whereas there are only five Swiss glaciers longer than 10 km and only one (Aletschgletscher) longer than 20 km. Another reason may be the larger errors for glaciers in China, because data on length changes of large glaciers in China are mostly estimated from satellite imagery with resolutions and accuracies of about 100 m. Comparing percentages of retreating glaciers therefore may be more representative in this special case of large glaciers and indeed gives somewhat similar results for both regions.

Figure 6 summarizes percentages of advance/retreat for all glaciers monitored in China and Switzerland over decadal time intervals. Historically, this approach has

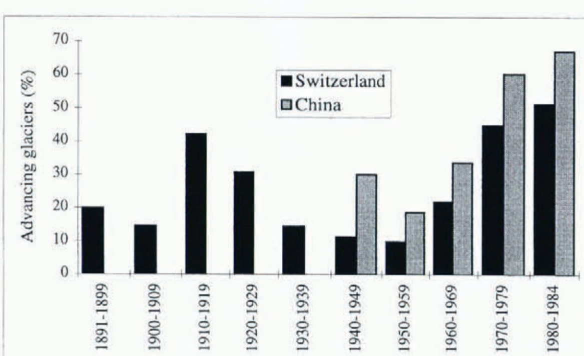

Fig. 6. Variation in the position of fronts for about 200 glaciers in China and 160 glaciers in Switzerland.

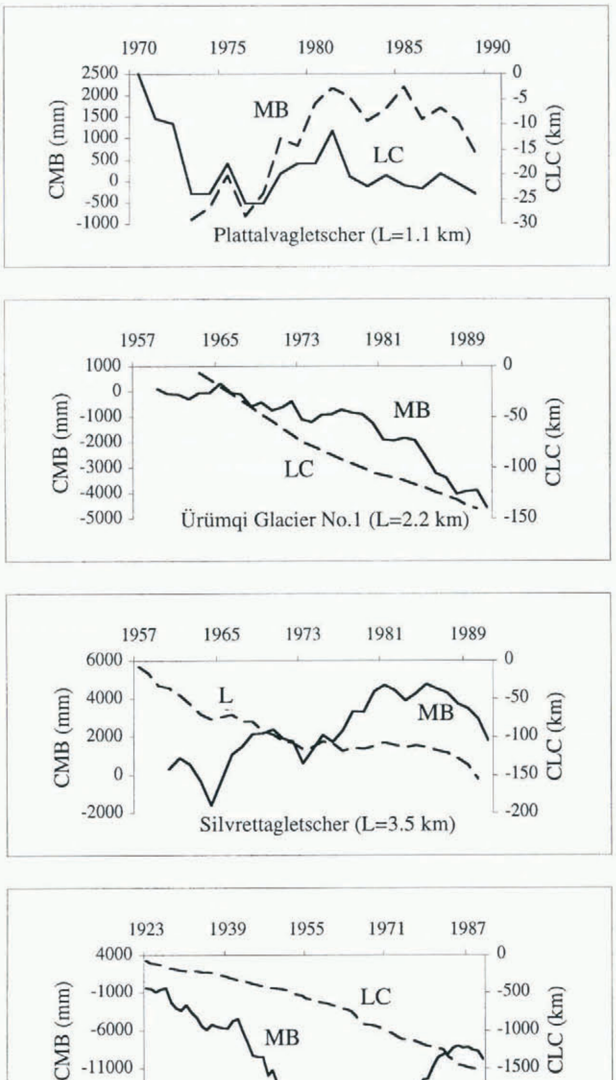

Fig. 7. Relationship between cumulative mass balance (CMB) and cumulative length change (CLC) for glaciers of different lengths.

been popular. It is, however, highly problematic, because of the different response types involved and can, at best, give only a very general outline. Because of the somewhat steady retreat for large glaciers, Figure 6 shows principally decadal reactions of smaller glaciers and, as such, tends to confirm the similarity of glacier changes in both countries beyond the time-scale of one or a few years.

RELATION BETWEEN MASS BALANCE AND GLACIER-LENGTH CHANGES

The reactions of glaciers to climatic change involve a complex chain of processes. Mass balance is the direct, undelayed consequence of climatic forcing, while the length change is an indirect, delayed reaction. The fluctuations described above for smaller glaciers in both countries demonstrate their sensitive reactions to climatic change. Actually, length reactions to mass-balance forcing for small glaciers are very quick (Fig. 7). Length changes for the small Plattalvagletscher, for instance, are almost synchronous with balance variations and the curve of (cumulative) glacier-length changes is not much smoother than the one of (cumulative) mass balance. Almost synchronous changes in length and mass balance can also be found over various time intervals at Ürümqi Glacier No. 1, though its length changes have not been continuously measured. With increasing glacier length, tongue reactions seem to be slower and the smoothing of curves from cumulative length change with respect to mass-balance records are more pronounced. For Silvrettagletscher, synchronous variations still exist but are less obvious. No short-term (yearly to multi-annual) relation between length change and mass balance exists for Aletschgletscher, a glacier more than 20 km long. Its reaction time, i.e. the time lag between a marked change in cumulative mass balance and the onset of the corresponding advance/retreat of the glacier snout, may be 30 years or more; time for full dynamic response and adjustment to a new equilibrium length is estimated at about 70–80 years (Haeberli, 1994; Haeberli and Hoelzle, 1995). Such long delays will essentially smooth out short-term effects of climate and mass-balance forcing on glacier-length changes, so that yearly to decadal glacier-terminus reactions to climatic change will be unclear.

Figure 8 summarizes the relation between mean mass balance and mean annual length change for four length classes of Swiss glaciers. The length changes for the shortest glaciers (≤2 km) are indeed almost perfectly synchronous with variations in mass balance. Length changes for larger glaciers (total length = 2–5 km and 5–10 km) appear to follow after a time lag of a few years. The length changes for 5–10 km long glaciers have a slightly longer time lag combined with more pronounced smoothing but the differences with respect to the 2–5 km long glaciers are too small to make sharp distinctions. Interpretation of the length-change signal of glaciers longer than 10 km and for the time interval covered by

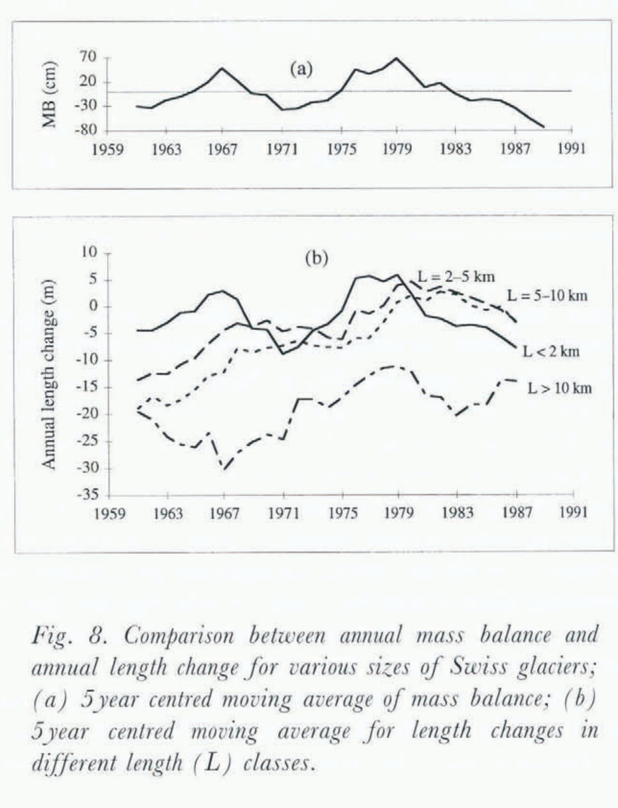

Fig. 8. Comparison between annual mass balance and annual length change for various sizes of Swiss glaciers; (a) 5 year centred moving average of mass balance; (b) 5 year centred moving average for length changes in different length (L) classes.

direct mass-balance measurements is more difficult. Reaction times are most likely to be in the decade range. Most remarkably, however, and in contrast to the shorter glaciers, average rates of change remained negative (retreat) throughout the observation period. The longest glaciers were not (yet?) able to re-advance as a reaction to the positive mass balances in the late 1960s and late 1970s.

The time period considered in Figure 8 is about 30 years and, hence, shorter than the characteristic dynamic response time of most mountain glaciers. By looking at time intervals, which correspond to the dynamic response time (t_a) of individual glaciers, the long-term mean mass balance ($\langle b \rangle$) can be inferred from cumulative length change caused by a step change in mass balance (δb) on the basis of assumed steady-state conditions before and after response, linear adjustment of mass balance to new equilibrium conditions during response and continuity (cf. Johannesson and others, 1989; Haeberli, 1990, 1994; Haeberli and Hoelzle, 1995, for background and calibration):

$$t_a = h_{max}/b_t \quad (1)$$

$$\delta b = b_t \cdot L/L_0 \quad (2)$$

$$\langle b \rangle \approx \delta b/2 \quad (3)$$

where b_t is the (annual) ablation at the glacier terminus, δb is the assumed step change in mass balance leading to the length change δL over the time period t_a starting from the original glacier length L_0 and h_{max} is maximum glacier thickness (all values in water equivalent).

Table 3 compares average mass balances calculated in this way for the Alpine Rhonegletscher and the Chinese Ürümqi Glacier No. 1. The agreement between the directly measured mass balance and the mass balance inferred from cumulative length change is striking for Rhonegletscher (measured: −0.25/inferred: −0.28 m w.e. year^{-1}) as well as for Ürümqi Glacier No. 1 (measured: −0.14/inferred: −0.11 m w.e. year^{-1}). The dynamic response time of Rhonegletscher is about twice as long as that of Ürümqi Glacier No. 1. For direct comparison of the two glaciers and their secular mass changes inferred from cumulative length change, equally long time intervals should be considered. Ürümqi Glacier No. 1 began to retreat from its Little Ice Age maximum in 1876; by 1990, it had lost 0.5 km in length. With this historical retreat, the secular balance change (δb) and average secular balance ($\langle b \rangle$) calculated from Equation (2) become −0.8 and −0.4 m w.e. year^{-1}, respectively. However, the glacier was probably able to adjust fully twice or even three times as a reaction to (assumed step-type) mass-balance changes since the end of the last century. The calculated secular mass-balance changes and average secular mass-balance values must, therefore, be reduced correspondingly. The resulting average secular mass loss of Ürümqi Glacier No. 1 is 0.1–0.2 m w.e. year^{-1}. Such a value is roughly half the characteristic values obtained for Alpine glaciers (Rhonegletscher in Table 3; cf. also the data given by Haeberli (1994) and Haeberli and Hoelzle (1995)) — a fact which may be explained by the lower climatic sensitivity of the continental-type Ürümqi Glacier No. 1. It is especially important to note that the cold firn area of Ürümqi Glacier No. 1 (Haeberli and others, 1994) probably reacted to 20th-century atmospheric warming by increased meltwater refreezing and firn warming; mass loss was therefore restricted to the ablation area or about half the glacier area. Characteristic rates of secular glacier mass loss are in any case in the range of dm year^{-1} and, hence, closely comparable in both regions.

Table 3. Comparison of measured and estimated glacier mass changes. Sources: Aellen (1981), Wang (1981), Zhang, Z. S. (1981), Funk (1985), You (1988), Chen and Funk (1990), Haeberli and Hoelzle (1995)

	Rhonegletscher	*Ürümqi No. 1 Glacier*
Measured average b (m w.e. a^{-1})	−0.25	−0.14
Total length today (km)	10	2
Estimated maximum thickness today (m)	500	130
Ablation at snout (m w.e. a^{-1})	5.5	3.2
Estimated response time (a)	90	40
Considered time interval	c.1890–1980	1963–91
Length change (km)	1	0.14
Inferred balance change δb (m w.e. a^{-1})	−0.55	−0.22
Inferred $\langle b \rangle$ (m w.e. a^{-1})	−0.28	−0.11

CONCLUSIONS

Effects of climatic forcing on glaciers are different during various time periods and strongly depend on topographic and glaciological factors. Variations in the mass balance of individual glaciers at present depend mainly on humidity conditions and topographic factors (hypsometry and orientation with respect to the main humidity source). Comparisons between glacier evolution in China and the Swiss Alps nevertheless demonstrate that some characteristics of glacier fluctuations are similar in both regions during past decades. The overall trend is one of mass loss and glacier retreat with a modest intermittent growth and re-advance between 1970 and 1980. The similarity of variations in the positions of glacier fronts between the two countries points to comparable climatic forcing over decadal time intervals on the Eurasian continent. Inter-annual variations in mass balances, however, are different and remain partly unexplained. Further investigation of such differences is necessary and intercomparison of glacier fluctuations should be expanded to other regions of the world.

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APPENDIX

Table 4. Variations in the frontal positions of Chinese glaciers. Nos 1–14 are glaciers with lengths shorter than or equal to 2 km, Nos 15–51 between 2 and 5 km, Nos 52–96 between 5 and 10 km, and Nos 97–153 longer than 10 km; for Nos 154–167 length and/or rate are not clear. "+" sign means advance and "–" sign means retreat

No.	*Glacier name*	*Coordinates*		*Length* km	*Area* km^2	*Rate* m $year^{-1}$	*Interval*	*Source*
1	Lapate No. 51	43.70° N	84.40° E	1.7	1.48	0.0	1964–81	Haeberli and Müller (1988)
2	Wawusi No. 11	38.63° N	98.15° E	1.7	1.19	–2.5	1956–75	Zhang and Mi (1981)
3	Dahaizi No. 4	39.22° N	98.55° E	1.2	0.52	–1.9	1956–76	Zhang and Mi (1981)
4	Heidabangou No. 4	39.25° N	97.77° E	1.4	0.34	–2.7	1956–77	Zhang and Mi (1981)
5	Kekeluke No. 10	42.52° N	83.60° E	1.8	1.98	0.0	1963–72	Zhang and Mi (1981)
6	Colliery	35.40° N	94.11° E	1.9	1.18	2.0	1969–89	Haeberli and Hoelzle (1993)
7	Ningchanghe No. 3	37.52° N	101.80° E	1.9	1.41	–20.0	1956–76	Xie and others (1985)
8	Ningchanghe No. 4	37.52° N	101.82° E	1.9	1.32	–20.0	1956–76	Xie and others (1985)
9	Ningchanghe No. 7	37.52° N	101.85° E	0.9	0.18	–10.0	1956–76	Xie and others (1985)
10	Shuiguanhe No. 1	37.53° N	101.78° E	1.4	0.52	–15.5	1956–76	Xie and others (1985)
11	Laohugoudaban	37.55° N	101.73° E	1.8	2.10	–12.5	1956–77	Xie and others (1985)
12	Haolalisha No. 10	42.52° N	81.63° E	1.7	1.20	–8.0	1965–77	Zhang and Mi (1981)
13	Haolalisha No. 15	41.38° N	81.62° E	1.7	1.00	0.0	1965–77	Zhang and Mi (1981)
14	Shanchonghe 41	43.13° N	86.70° E	2.0	1.22	–21.0	1964–78	Zhang and Mi (1981)
15	Lapate No. 53	43.72° N	84.40° E	2.7	1.80	–4.6	1964–81	Haeberli and Müller (1988)
16	Xidatan	35.40° N	94.16° E	4.9	6.13	–2.3	1969–89	Haeberli and Hoelzle (1993)
17	Shuiguanhe No. 4	37.54° N	101.75° E	2.1	1.36	–14.6	1966–76	Haeberli (1985)
						–8.9	1977–84	Haeberli and Müller (1988)
18	Shuiguanhe No. 2	37.54° N	101.77° E	2.7	3.18	–22.5	1956–76	Xie and others (1985)
19	Laohugou No. 20	39.47° N	96.48° E	3.1	3.07	–2.2	1962–76	Xie and others (1985)
20	Yanglonghe No. 9	39.25° N	98.57° E	2.6	1.79	–4.8	1956–77	Xie and others (1985)
21	Yanglonghe No. 5	39.23° N	98.55° E	2.5	1.46	–1.2	1956–77	Xie and others (1985)
22	Yanglonghe No. 11	39.23° N	98.56° E	2.2	1.46	–1.9	1956–78	Xie and others (1985)
23	Ganglalu No. 9	38.44° N	97.80° E	2.2	1.71	0.0	1966–73	Xie and others (1985)
24	Qiyi	39.24° N	99.76° E	3.8	2.78	–2.8	1958–75	Haeberli (1985)
						–1.0	1975–76	Xie and others (1985)
						–1.0	1976–77	Xie and others (1985)
						–1.3	1977–84	Haeberli and Müller (1988)
						–2.3	1984–85	Haeberli and Müller (1988)
						–1.0	1985–86	Haeberli and Hoelzle (1993)
						–0.8	1986–87	Haeberli and Hoelzle (1993)
25	Shuzhulian (west)	Qilian Mts		3.6	1.98	–3.3	1956–77	Xie and others (1985)
26	Waqu No. 2	Qilian Mts		4.0		0.0	1966–73	Xie and others (1985)
27	Gangger. No. 1	Qilian Mts		3.0		–28.6	1966–73	Xie and others (1985)
28	Gangger. No. 2	Qilian Mts		4.0		–28.6	1966–73	Xie and others (1985)
29	Denglong No. 56	Qilian Mts		5.0		28.6	1966–73	Xie and others (1985)
30	Nagedergeleyou	Qilian Mts		5.0		0.0	1966–76	Xie and others (1985)
31	Nagedergeleyzue	Qilian Mts		5.0		0.0	1966–76	Xie and others (1985)
32	Bayizilegen	Qilian Mts		5.0		0.0	1966–76	Xie and others (1985)
33	Shifanghe No. 2	39.13° N	98.60° E	4.0	2.53	–4.7	1956–76	Zhang and Mi (1981)
34	Qiangyong	28.85° N	90.23° E	4.3	8.70	3.1	1975–79	Shi and others (1988)
						14.0	1979–80	Haeberli (1985)
35	Langtouhe No. 23	Qilian Mts		4.3	2.63	–4.8	1956–77	Xie and others (1985)
36	Wulaluxong No. 2	43.12° N	83.83° E	3.8	4.42	0.0	1966–72	Zhang and Mi (1981)
37	Qokele No. 1	43.13° N	83.75° E	3.2	2.31	–17.0	1966–72	Zhang and Mi (1981)
38	Meheeralatisitan	42.75° N	82.93° E	4.6	3.90	0.0	1963–72	Zhang and Mi (1981)
39	Shanchonghe 22	43.17° N	86.83° E	2.2	1.75	–36.0	1964–77	Zhang and Mi (1981)
40	Yulong	27.12° N	100.20° E	2.7	1.52	0.0	1930–82	Haeberli and Müller (1988)
41	Shuiguanhe No. 3	37.53° N	101.75° E	2.3	1.41	–18.0	1956–76	Xie and others (1985)

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No.	*Glacier name*	*Coordinates*		*Length* km	*Area* km²	*Rate* m year⁻¹	*Interval*	*Source*
42	Shanchakou No. 16	39.18° N	98.53° E	3.7	1.64	–3.3	1956–77	Zhang and Mi (1981)
43	Sigonghe No. 4	43.82° N	88.32° E	4.3	3.47	–9.5	1956–72	Haeberli (1985)
44	Malanshantaijhe 5	35.86° N	90.79° E	4.3	14.70	–28.0	1970–76	Zhang and Mi (1981)
45	Daxuefeng No. 3	35.83° N	91.94° E	3.5	3.20	0.0	1969–76	Zhang and Mi (1981)
46	Daxuefeng No. 7	35.85° N	91.99° E	2.1	1.60	26.0	1969–76	Zhang and Mi (1981)
47	Daxuefeng No. 6	35.53° N	91.98° E	3.3	5.00	0.0	1969–76	Zhang and Mi (1981)
48	Daxuefeng No. 1	35.85° N	91.90° E	2.7	2.40	0.0	1969–76	Zhang and Mi (1981)
49	Xuejianshan No. 5	36.27° N	91.94° E	2.7	2.20	0.0	1969–76	Zhang and Mi (1981)
50	Gaoxuexi No. 4	36.23° N	91.93° E	3.7	3.60	0.0	1969–76	Zhang and Mi (1981)
51	Rongbu No. 9	28.10° N	86.92° E	2.1	1.30	–10.6	1921–68	Zhang and Mi (1981)
52	Tuergangou	43.10° N	94.33° E	5.8	4.81	–12.0	1960–65	Haeberli and Müller (1988)
53						–50.0	1965–66	Shi and others (1988)
54						–4.3	1966–73	
55						–3.1	1973–84	
56	Yiehelong	36.73° N	99.55° E	9.4	19.40	–10.7	1966–81	Haeberli and Müller (1988)
57	Beishenian	Qilian Mts		6.0	7.18	–7.1	1956–77	Xie and others (1985)
58	Shuzhulian (east)	Qilian Mts		5.6	4.82	–5.2	1956–77	Xie and others (1985)
59	Ganglalu No. 5	Qilian Mts		8.0		0.0	1966–73	Xie and others (1985)
60	Ganggeer. No. 15	Qilian Mts		8.0		–28.6	1966–73	Xie and others (1985)
61	Denlong No. 53	Qilian Mts		6.0		0.0	1966–73	Xie and others (1985)
62	Kelendehe No. 7	Qilian Mts		8.0		30.0	1966–76	Xie and others (1985)
63	Kelendehe No. 8	Qilian Mts		7.0		40.0	1966–76	Xie and others (1985)
64	Kemixiahalegai 3	Qilian Mts		8.0		30.0	1966–76	Xie and others (1985)
65	Kemixiahalegai 7	Qilian Mts		8.0		40.0	1966–76	Xie and others (1985)
66	Guerbanguole 13	Qilian Mts		8.0		30.0	1966–76	Xie and others (1985)
67	Haoerbafahalegai	Qilian Mts		8.0		30.0	1966–76	Xie and others (1985)
68	Hailasihe No. 18	49.17° N	87.78° E	6.1	12.99	–4.3	1956–80	Ren (1982)
69	Qierganbulak	38.23° N	75.10° E	9.6	13.00	–266.0	1973–79	Haeberli (1985)
70	AZha	29.10° N	96.75° E	9.2		–10.8	1933–73	Zhang and Mi (1981);
						–65.0	1973–76	Shi and others (1988)
						–37.5	1976–80	
71	Shanchakou No. 12	39.20° N	98.53° E	5.5	7.02	–7.1	1956–77	Zhang and Mi (1981)
72	Shanchakou No. 18	39.18° N	98.55° E	5.7	4.43	–5.3	1956–77	Zhang and Mi (1981)
73	Husitaigoule 122	43.58° N	85.07° E	7.0	15.50	0.0	1964–72	Zhang and Mi (1981)
74	Husitaigoule 123	43.58° N	85.83° E	6.0	12.00	–12.5	1964–72	Zhang and Mi (1981)
75	Yitixite No. 2	42.72° N	82.80° E	5.9	5.50	–17.0	1963–72	Zhang and Mi (1981)
76	Qingshuihe No. 26	43.52° N	85.98° E	7.6	8.50	–23.0	1964–77	Zhang and Mi (1981)
77	Qingshuihe No. 27	43.52° N	85.93° E	6.8	6.20	–23.0	1964–77	Zhang and Mi (1981)
78	Kelande-Ye. No. 29	43.52° N	85.90° E	6.0	6.70	0.0	1964–77	Zhang and Mi (1981)
79	Kelande-Ye. No. 30	43.53° N	85.88° E	6.3	5.20	–8.0	1964–77	Zhang and Mi (1981)
80	Kelande-Ye. No. 33	42.57° N	85.87° E	5.2	2.70	–31.0	1964–77	Zhang and Mi (1981)
81	Halong	36.75° N	99.50° E	7.7	23.49	52.7	1966–81	Haeberli and Müller (1988)
82	Xiagonba	29.60° N	101.85° E	6.9	6.46	0.0	1981–84	Haeberli and Müller (1988)
						–2.5	1984–90	
83	Wuzhongtushi 115	41.03° N	77.63° E	7.2	9.50	–23.0	1963–77	Zhang and Mi (1981)
84	Wuzhongtushi 135	41.03° N	77.57° E	8.6	11.14	–62.0	1963–76	Zhang and Mi (1981)
85	Kenshu No. 7	41.00° N	77.40° E	7.4	9.42	–31.0	1963–76	Zhang and Mi (1981)
86	Malanshan No. 3	35.78° N	90.77° E	5.4	4.70	28.0	1970–76	Zhang and Mi (1981)
87	Malanshantaiji. 7	35.86° N	90.68° E	7.3	9.70	0.0	1970–76	Zhang and Mi (1981)
88	Meluomahahsan 3	36.01° N	90.94° E	7.3	13.20	0.0	1970–76	Zhang and Mi (1981)
89	Daxuefen No. 4	35.81° N	91.97° E	5.1	7.70	0.0	1969–76	Zhang and Mi (1981)
90	Lingshui	36.33° N	87.30° E	9.5	29.60	40.0	1961–76	Zhang and Mi (1981)
91	Shuturi	36.18° N	79.28° E	8.0	19.40	–12.5	1968–76	Zhang and Mi (1981)
92	Depujieke	36.17° N	79.43° E	9.0	25.00	–31.2	1968–76	Zhang and Mi (1981)
93	Akeshayihe No. 38	36.05° N	79.40° E	7.4	14.00	–60.0	1968–76	Zhang and Mi (1981)
94	Akeshayihe No. 49	36.05° N	79.35° E	9.2	19.00	–20.0	1968–76	Zhang and Mi (1981)
95	Bingshuigou No. 1	35.43° N	80.43° E	6.4	8.75	1.2	1968–76	Zhang and Mi (1981)
96	Kekeqi	42.07° N	80.62° E	10.0	17.80	0.0	1970–76	Zhang and Mi (1981)
97	Nainuogeru	28.45° N	98.72° E	11.5	12.55	–77.0	1932–59	Haeberli and Müller (1988)
						75.5	1959–71	
						7.0	1971–82	
98	Weigele Dangxi	36.83° N	88.45° E	10.5	15.99	–20.0	1966–81	Haeberli and Müller (1988)
99	Laohugou No. 12	39.44° N	96.54° E	10.1	21.91	–5.1	1958–62	Haeberli (1985); Haeberli and
						–5.0	1962–76	Müller (1988)
						–1.4	1976–85	
100	Qongtailan	41.97° N	80.12° E	32.8	165.38	–3.6	1962–73	Haeberli (1985)
101	Tugebieliqi	42.17° N	80.33° E	33.7	313.69	–30.0	1959–64	Haeberli (1985)
						–12.5	1964–76	Zhang and Mi (1981)
102	Kegiker	41.83° N	80.15° E	26.0	83.56	25.0	1942–76	Haeberli (1985)
103	Sayigapeir	41.87° N	80.20° E	10.7	14.07	61.8	1942–76	Haeberli (1985)

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No.	*Glacier name*	*Coordinates*		*Length* km	*Area* km²	*Rate* m year⁻¹	*Interval*	*Source*
104	Yinshugaiti	36.03° N	76.00° E	41.5	329.82	0.0	1937–68	Zhang and Mi (1981)
105	Qogir	36.00° N	76.47° E	24.0	55.81	54.8	1937–68	Zhang and Mi (1981)
106	Sikanyang	36.00° N	76.55° E	18.0	23.13	−137.0	1937–68	Zhang and Mi (1981)
						−200.0	1968–73	Shi and others (1988)
107	Jouda	Mount Qomolangma N		10.4	13.95	−43.3	1970–76	Shi and others (1988)
108	Rongbu	28.07° N	86.87° E	22.2	86.89	0.0	1921–66	Shi and others (1988)
						0.0	1968–80	Haeberli (1985)
109	Halasi	49.10° N	87.82° E	10.8	30.13	−19.3	1959–80	Haeberli and Müller (1988)
110	Baixindegoule 13	43.70° N	85.08° E	10.5	25.50	−56.3	1964–72	Shi and others (1988)
111	Muzhaert	42.32° N	80.83° E	29.0	131.00	−15.0	1906–59	Zhang and Mi (1981)
						−2.1	1964–78	Haeberli (1985)
112	Tuomuer	41.90° N	79.95° E	36.7	293.40	−1.3	1946–78	Zhang and Mi (1981)
113	Wuzhongtushi 163	41.05° N	77.47° E	12.5	21.80	23.1	1963–76	Shi and others (1988)
114	Wuzhongtushi 166	41.08° N	77.43° E	10.7	14.56	46.2	1963–76	Shi and others (1988)
115	Ayilangshu	41.92° N	79.83° E	15.6	44.80	52.9	1964–76	Shi and others (1988)
116	Kalageyule	42.27° N	80.45° E	32.0	184.50	−15.8	1964–76	Zhang and Mi (1981)
117	Akedasi	43.65° N	85.17° E	14.0	32.00	−188.0	1964–72	Zhang and Mi (1981)
118	Buteoushayi No. 8	42.42° N	81.67° E	14.2	41.80	0.0	1965–77	Zhang and Mi (1981)
119	Guliya	35.17° N	81.29° E	12.4	119.33	0.0	1970–90	Haeberli and Hoelzle (1993)
120	Gozha	35.16° N	81.05° E	13.1	33.47	0.0	1970–87	Haeberli and Hoelzle (1993)
121	Dagongba	29.35° N	101.52° E	11.0	20.21	0.0	1957–84	Haeberli and Müller (1988)
						−4.2	1984–90	Haeberli and Hoelzle (1993)
122	Yanzigou	29.63° N	101.88° E	10.5	32.15	−93.0	1930–66	Haeberli and Müller (1988)
						−34.4	1966–83	
						−28.6	1983–90	Haeberli and Hoelzle (1993)
123	Hailuogou	29.58° N	101.93° E	13.1	25.71	−67.0	1930–66	Haeberli and Müller (1988)
						−12.0	1966–82	
						−16.0	1982–83	
						−19.0	1983–89	Haeberli and Hoelzle (1993)
						−22.7	1989–90	
124	Kuoqikaerbaxi	41.75° N	80.12° E	25.5	83.50	25.0	1942–76	Zhang and Mi (1981)
125	Shayinieba	41.85° N	80.20° E	11.0	16.50	61.7	1942–76	Zhang and Mi (1981)
126	Xitailan	41.95° N	80.17° E	25.0	113.20	−17.6	1942–76	Zhang and Mi (1981)
127	Dongtailan	41.95° N	80.27° E	19.0	60.00	−5.0	1942–78	Zhang and Mi (1981)
128	Keqiketielie	42.02° N	80.38° E	17.5	104.00	0.0	1942–78	Zhang and Mi (1981)
129	Keqiketailiekeshu	41.98° N	80.47° E	11.8	31.00	−8.8	1942–78	Zhang and Mi (1981)
130	Keqiketaizibaishu	41.95° N	80.55° E	12.0	28.00	−14.7	1942–78	Zhang and Mi (1981)
131	Qongkuozibayi	42.00° N	80.62° E	20.5	81.00	−2.9	1942–78	Zhang and Mi (1981)
132	Nanyilaoerqieke	42.18° N	79.80° E	59.5		0.0	1942–76	Zhang and Mi (1981)
133	Malanshan No. 2	35.81° N	90.73° E	10.9	39.10	16.0	1970–76	Zhang and Mi (1981)
134	Melaomahan. N 4	36.10° N	90.93° E	12.8	31.20	0.0	1971–76	Zhang and Mi (1981)
135	Melaomahan. S 1	36.04° N	91.00° E	23.9	131.80	0.0	1971–76	Zhang and Mi (1981)
136	Melaomahan. S 4	36.08° N	90.81° E	15.8	64.50	0.0	1971–76	Zhang and Mi (1981)
137	Keliyang	36.73° N	77.78° E	13.2	35.20	−137.5	1968–76	Zhang and Mi (1981)
138	Yueyahe No. 1	36.42° N	87.42° E	18.5	65.90	45.0	1971–76	Zhang and Mi (1981)
139	Yueyahe No. 2	36.43° N	87.43° E	11.5	21.30	30.0	1971–76	Zhang and Mi (1981)
140	Linglong	36.33° N	87.33° E	11.2	38.60	40.0	1971–76	Zhang and Mi (1981)
141	Panglazi	36.15° N	79.40° E	14.0	51.00	−18.7	1968–76	Zhang and Mi (1981)
142	Akeshayi No. 29	36.05° N	79.45° E	12.1	42.00	25.0	1968–76	Zhang and Mi (1981)
143	Yulongkashi 34-1	35.45° N	81.28° E	13.1	33.29	−130.0	1970–76	Zhang and Mi (1981)
144	Yulongkashi 34-2	35.43° N	81.35° E	32.4	131.26	−50.0	1970–76	Zhang and Mi (1981)
145	Yulonkashi 31	36.43° N	81.22° E	14.4	22.06	−60.0	1970–76	Zhang and Mi (1981)
146	Yulongkashi 20	35.43° N	81.18° E	24.1	80.96	−115.0	1970–76	Zhang and Mi (1981)
147	Yulongkashi 72	35.42° N	80.97° E	27.8	229.71	−50.0	1970–76	Zhang and Mi (1981)
148	Yulongkashi 60	35.42° N	80.88° E	18.5	76.07	−40.0	1970–76	Zhang and Mi (1981)
149	Yulongkashi 48	35.40° N	80.75° E	19.5	177.96	−37.5	1970–76	Zhang and Mi (1981)
150	Yulongkashi 39	35.43° N	80.68° E	20.5	115.99	−40.0	1970–76	Zhang and Mi (1981)
151	East Rongbu	28.09° N	86.95° E	14.0	48.45	0.0	1921–68	Zhang and Mi (1981)
152	Braldu	36.09° N	75.85° E	35.0	144.62	0.0	1937–69	Zhang and Mi (1981)
						180.0	1968–78	Zhang and Mi (1981)
153	Mixigongtong	Nianqintanggula		9.0		−18.0	1958–75	Shi and others (1988)
154	Qaodumake	Muztag-Gonggur				−3.5	1956–60	Shi and others (1988)
155	Shumukaer	Muztag-Gonggur				−3.8	1956–60	Shi and others (1988)
156	Gonggeer	Muztag-Gonggur				−1.7	1956–60	Shi and others (1988)
157	Qiemegan	Muztag-Gonggur		20.0		−240.0	1973–79	Shi and others (1988)
158	Musitage	Muztag-Gonggur				–	1959–60	Shi and others (1988)
						−2.2	1946–78	Shi and others (1988)
159	Bulongkou No. 3	Muztag-Gonggur				+	1971–74	Shi and others (1988)
						–	1977–80	Shi and others (1988)
160	East Kekesili	Muztag-Gonggur		21.6		+	1973–79	Shi and others (1988)
161	Kaiyaja	Karakoram				+	1976–78	Shi and others (1988)
162	Laigu	Nianqingtanggula		20.0		–	1942–73	Shi and others (1988)

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No.	Glacier name	Coordinates		Length km	Area km^2	Rate m year^{-1}	Interval	Source
163	Gangotri	30.93° N	79.07° E	30.0		–	1850–79	Shi and others (1988)
164	Jabula	Himalaya		21.0	76.09	–	1969–76	Shi and others (1988)
165	Kungbu	Himalaya		18.0	39.24	–	1930–56	Shi and others (1988)
166	Gechongba	Himalaya		20.0	80.83	–	1959–79	Shi and others (1988)
167	Bula	Himalaya				–	1959–79	Shi and others (1988)

ERRATUM

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We apologise for misspelling R.J. Motyka's name in the paper by Nolan and others. The correct form is given below.

Ice-thickness measurements of Taku Glacier, Alaska, U.S.A., and their relevance to its recent behavior

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