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Recent thickening trend of Glaciar Perito Moreno, southern Patagonia

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Abstract

Surface elevations were measured five times at the ablation area of Glaciar Perito Moreno, southern Patagonia, *i.e.* in austral summers 1990, 1993, 1996, 1999 and 2002. The mean ice-thickness along a transverse line slightly decreased from 1990 to 1996, but increased by about 5 m from 1996 to 2002. Whereas, the ice-thickness along a longitudinal line increased about 1.5 m from 1990 to 1993, remained almost unchanged between 1993 and 1999, and increased significantly (more than 6 m) from 1999 to 2002. The average thickening rates at eight points along both lines in the mid-reaches were $+0.2$ m a^{-1} in 1990-93, -0.1 m a^{-1} in 1993-96, $+0.5$ m a^{-1} in 1996-99, and $+1.4$ m a^{-1} in 1999-2002. Thus, while the glacier was almost in equilibrium in the early half of the 1990s, it has been thickening recently at accelerating rates. Based on field observations of surface structures and on information of terminus fluctuations, this current thickening trend is unlikely related to a surge. Though it may be due to dynamic causes of the glacier or positive mass-balance, the detailed mechanisms are not yet clear. As a probable result of detected glacier thickening, an ice-dam has formed in 2003 and the water level in Brazo Rico started to rise from November, indicating that a possible rupture may occur again in the near future.

1. Introduction

Thickening or thinning rate of a glacier can be derived from the difference in surface elevations measured in different times at a point fixed to the space. At Glaciar Soler in northern Patagonia, mean thinning rates were obtained as 5.2 m a^{-1} between 1983 and 1985 (Aniya and Naruse, 1987) and 3.2 m a^{-1} between 1985 and 1998 (Naruse *et al.*, 2000). In southern Patagonia, a considerably large thinning rate of 11.1 m a^{-1} was measured near the terminus of Glaciar Upsala between 1990 and 1993 (Skvarca *et al.*, 1995) and in the upper part of Glaciar Tyndall ablation area 4.0 m a^{-1} between 1985 and 1990 (Kadota *et al.*, 1992) and 3.1 m a^{-1} between 1990 and 1993 (Nishida *et al.*, 1995). These thinning rates are much larger than values measured at other glaciers around the world (IAHS/UNESCO, 1998). On the other hand, the ice thickness of Glaciar Perito Moreno has remained almost unchanged from 1990 to 1996 (Skvarca and Naruse, 1997).

The present paper reports on new results of surface profile of Glaciar Perito Moreno measured in December 1999 and 2002, and on detailed analyses of changes in ice-thickness from 1990 to 2002.

2. Glaciar Perito Moreno

Glaciar Perito Moreno flows along a distance of about 25 km as an eastward outlet glacier of Hielo Patagónico Sur, the larger one of the two icefields in southern South America. The drainage area was estimated at 257 km² (Aniya and Skvarca, 1992); the accumulation and ablation areas comprise about 70% and 30% of the total glacier area, respectively. The ablation area is a valley-type glacier with about 15 km in length and 4 km in width (Fig. 1). The terminus of the glacier calves into Canal de los Témpanos and Brazo Rico (Fig. 2), the southwestern arm of Lago (lake) Argentino at an altitude of about 180 m a.s.l.

According to Raffo *et al.* (1953), Liss (1970), Aniya and Skvarca (1992), and Skvarca and Naruse (1997), the glacier had been steadily advancing from the end of 19th century to 1917, and the ice-dam formations and ruptures occurred at intervals of one to five years during the period 1930-1990, being the 1988 break-up event the last recorded. Since 1990 to the present (2003), the glacier terminus is almost stable, touching in occasions the opposite bank at península Magallanes with a huge tunnel-channel through which the lake water is drained from Brazo Rico to Canal de los Témpanos, as shown in Fig. 2. However, the size and diameter of the tunnel or the width of the channel,

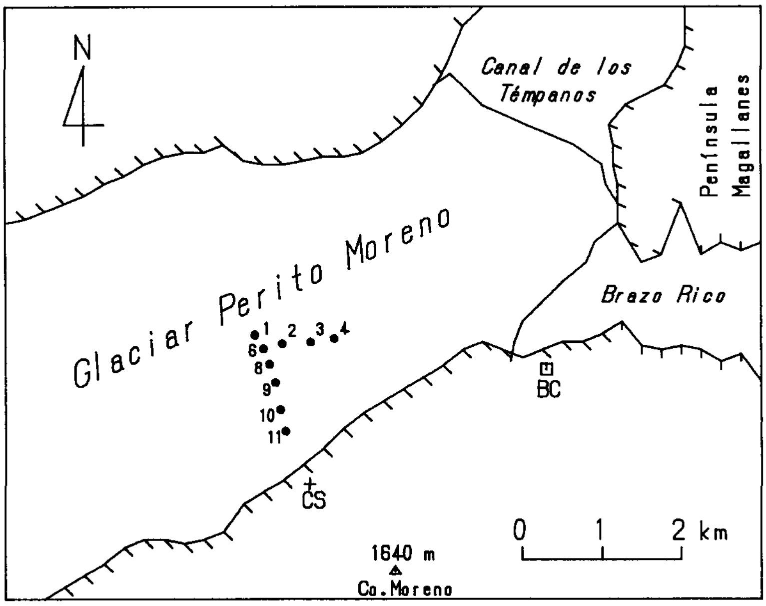

Fig. 1. Map of the ablation area of Glaciar Perito Moreno. The shape of the glacier terminus roughly represents that in 1990–95. Solid circles with numbers from 1 to 11 indicate the survey points. Of 11 points measured in 1990, the points 5 and 7 were never accessible hereafter due to existence of heavy crevasses and large ponds. Mark + indicates the control station (CS) for the surveys, and BC is the base camp.

Fig. 2. Glaciar Perito Moreno terminus viewed from Co. Moreno on 24 February 2000. To the left (north) is Canal de los Témpanos and to the right Brazo Rico. Between the two lake arms is península Magallanes, where an ice-dam is formed when the glacier overrides the rock of the opposite bank. The lack of vegetation (bare rock) along the coast of Brazo Rico is by water erosion, indicating the maximum lake level reached in the past due to formation of an ice-dam.

whichever is formed, change seasonally.

In contrast to major calving glaciers in Patagonia which have been retreating considerably at a range from 1 km to 13 km during the last 50 years (Aniya *et al.*, 1992; Aniya, 1999; Naruse *et al.*, 1995a), Glaciar Perito Moreno seems to have been in a rather stable state (Warren, 1994; Skvarca and Naruse, 1997; Rott *et al.*, 1998; Stuefer, 1999).

3. Method

Surveys of surface elevation were made five times at middle reaches of Glaciar Perito Moreno ablation area, i.e. in November 1990, November 1993, April 1996, December 1999 and November 2002.

A control station (CS) was established in 1990 at about 430 m a.s.l. on the southern (right-side) bank about 5 km from the glacier terminus (Fig. 1). An azimuth point was set up at about 100 m apart from CS. For the surveys, an electronic distance meter (Topcon EDM-Theodolite Guppy), or a laser distance meter (GeoFennel, Model: Pulsar 50) and a theodolite (Zeiss Th-2) or a digital distance-angle meter (Pentax PTS-V3) were utilized at the control station; a reflector was placed by a mobile team at survey points around 350–360 m a.s.l. on the glacier.

Three dimensional coordinates of 11 points along a half-transverse line and the longitudinal center line (Fig. 1) were determined by the first measurement carried out in November 1990. In the second, third, fourth and fifth measurements (1993, 1996, 1999 and 2002), the same survey points as in 1990 were located with an accuracy of one foot (about 30 cm) by using the raw data of the horizontal angles and distances measured in 1990. Of 11 points, a few localities were not accessible due to the existence of heavy crevasses or large supraglacial ponds.

4. Results

Mean annual ice-thickness changes deduced from the difference of surface elevations are shown in Fig. 3, separately for the four periods 1990-1993, 1993-1996, 1996-1999, and 1999-2002. Since the 1996-survey was made in April, the measured elevation was rectified to the probable value in November, assuming the emergence velocity (12 $\mathrm{m\,a^{-1}}$) and the summer ablation (9 m of ice), based on Naruse *et al.* (1997). Since there are numerous crevasses, depressions, and ice mounds up to several meters high on the glacier surface, the measured surface elevation changes are partly caused by the development or decay of the surface undulations. Judging from the surface conditions around the survey points, we roughly estimate this effect as smaller than $\pm 0.5\ \mathrm{m\,a^{-1}}$.

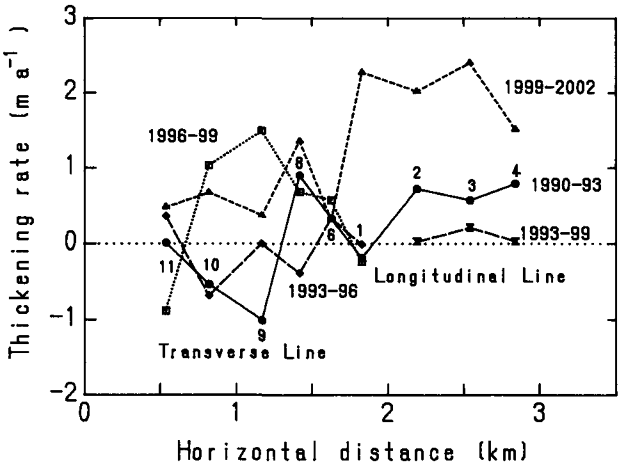

Fig. 3. Distribution of the annual thickness change rates during the periods November 1990 - November 1993 (Naruse *et al.*, 1995b), November 1993 - April 1996 (Skvarca and Naruse, 1997), April 1996 - December 1999, and December 1999 - November 2002 (present study). The positive sign indicates thickening and the negative sign thinning. Numbers (1, 2, ... and 11) attached to solid circles indicate survey point numbers from 1 to 11 (see Fig. 1).

Figure 3 exhibits that thickening rates fluctuate between $+1.5\ \mathrm{m\,a^{-1}}$ and $-1\ \mathrm{m\,a^{-1}}$ from point to point, except at the points 1, 2 and 3 in 1999-2002. Data at the point 11, the nearest to the lateral margin, exhibits a different trend to other points, that may be due to the different flow pattern and surface melting. Therefore, omitting the point 11, we take averages of thickness change over four points 10, 9, 8 and 6 along a line that we call the transverse profile, and over four points 1, 2, 3 and 4 along a line that we call the longitudinal profile.

The temporal changes in mean surface elevations along these two lines since 1990 are shown in Fig. 4. Though the transverse line slightly thinned from 1990 to 1996, it has thickened by about 5 m from 1996 to 2002. Whereas, the longitudinal line thickened by

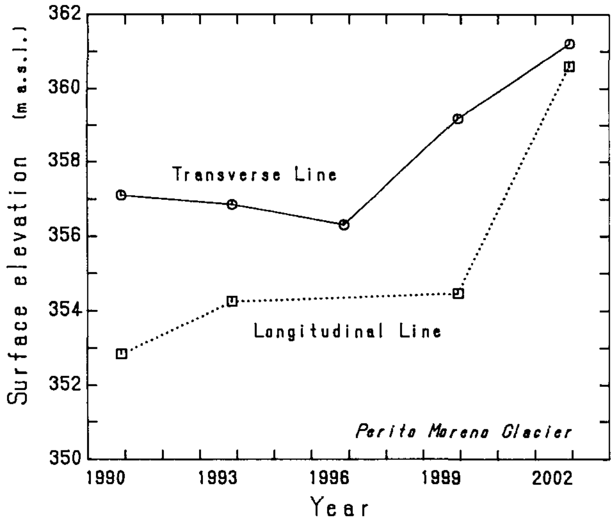

Fig. 4. Changes in the mean surface elevations along the transverse and longitudinal lines in the middle-reaches of the ablation area of Glaciar Perito Moreno from 1990 to 2002.

about 1.5 m from 1990 to 1993, then almost remained unchanged until 1999, and thickened more than 6 m from 1999 to 2002.

The average thickening rates of eight points on the both lines in the mid-reaches were calculated as $+0.2\ \mathrm{m\,a^{-1}}$ in 1990-93, $-0.1\ \mathrm{m\,a^{-1}}$ in 1993-96, $+0.5\ \mathrm{m\,a^{-1}}$ in 1996-99 (assuming the constant thickening rates in 1993-99 at the points 2, 3 and 4), and $+1.4\ \mathrm{m\,a^{-1}}$ in 1999-2002. Thus, while the glacier exhibited almost a steady state profile in the early half of the 1990s, it is recently thickening with an accelerating rate, that is significantly larger than the measurement errors. This thickening trend was also qualitatively confirmed through field observations which indicated that the southern lateral margin was approximately 10 to 20 m higher in December 1996 and 1999 than in November 1990 and 1993. In addition, probably due to the observed glacier thickening an ice-dam has formed again in 2003, impeding the water drainage from Brazo Rico to Canal de los Tĕmpanos. As a result, the water level started to rise in Brazo Rico from November 2003, predicting a possible future collapse of the ice-dam, an event not observed since 1988.

5. Discussion and conclusions

At Glaciar Pĭo XI, a very high flow speed of up to 50 $\mathrm{m\ a^{-1}}$ was measured near the calving terminus in 1995 (Rivera *et al.*, 1997), and the average thickening of ice of 44 m was recognized over the ablation area by comparing the digital terrain models between 1975 and 1995, which represents a mean thickening rate of 2.2 $\mathrm{m\,a^{-1}}$ (Rivera and Casassa, 1999). Based on these data with the looped pattern of medial moraines, they suggested a possibility of surging in 1976 and 1992-94.

In many surging glaciers, thickening is often observed first in the upper reaches and the bulges propagate down-glacier as a surge front with a speed of a few times the normal ice flow speeds. Before the surge in 1982-83 at Variegated Glacier (Alaska), the ice thickened more than 50 m during 8 years (Raymond and Harrison, 1988), and at Trapridge Glacier (Canada) a wave-like bulge propagated with a speed of about 30 m a^{-1} between 1980 and 1989 (Clarke and Blake, 1991).

Because at Glaciar Perito Moreno the measurements were made only at a few profiles located in the ablation area, we have no information on whether this thickening trend is a phenomenon occurring all over the glacier or only a local one, like a bulge traveling down the glacier. However, there are no evidences of surge-like behaviors or any signs of surge on the glacier surface and at the margins of Glaciar Perito Moreno during the last 20 to 30 years.

Thus, we conclude that this current thickening trend is not likely related to a surge, but may be attributed to dynamic causes or positive mass-balance of the glacier. The detailed mechanisms are left unclear until more elaborate studies are made in the future.

Acknowledgments

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