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Characteristics and variations of Upsala and Moreno glaciers, southern Patagonia

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Abstract

Terminating currently around 50°S and 73°W of the Southern Patagonia Icefield, Upsala Glacier has a drainage area of 870 km^2, the largest in South America, with an AAR (Accumulation Area Ratio) of 0.63, while Moreno Glacier has a drainage area of 257 km^2 with an AAR of 0.71. Both glaciers are calving in a lake.

Utilizing aerial photographs and satellite images of multiyears and field observation, the variation of Upsala Glacier between early 1960s to 1990 was elucidated. Likewise the variation of Moreno Glacier was obtained for a period from 1947 to 1990. At Upsala Glacier, between 1968 and 1970, the eastern part advanced about 150 m while the western part retreated 250-350 m. Between 1970 and 1978, the eastern part had advanced up to 400 m, while the western part showed a little retreat. After 1978, the glacier has started retreating and a large recession had occurred between 1981 and 1984, during that time a maximum of 2100 m break-up occurred at the eastern margin. Since then the glacier has retreated steadily at a considerably fast rate of about 200 m/a to 1990.

Moreno Glacier has started advancing at the end of the last century and is noted for the repeated damming-up of the Brazo Rico of Lago (Lake) Argentino by reaching the opposite bank (Península Magallanes). Since the variation of the snout in recent years is oscillating, without consecutive, yearly surveillance from air or ground, it is difficult to obtain the meaningful interpretation of the change in the snout position as revealed in this study. The comparison of the multidated images revealed that the amount of the snout fluctuation was up to on the order of 500 m during the last 40 years. The hypsometric curve indicates that the glacier may not be so susceptible to climatic variations. Consequently, there is a possibility that the glacier has been more or less in equilibrium and the oscillation of the snout has been largely controlled by calving which is in turn affected by lake conditions.

1. Introduction

In light of an apparent global warming trend in recent years, the world-wide behavior of glaciers has attracted attention and the world glacier inventory has been recently published (IAHS-UNEP-UNESCO, 1989). In this inventory, data on Patagonian glaciers are notably lacking, despite the fact that the Patagonia icefields are one of the most important ice bodies in the world from a glaciological point of view, with a combined area of more than 17000 km^2. The Patagonia icefields consist of the Northern and Southern icefields, each with an area of about 4200 km^2 and 13000 km^2, respectively. For the Northern Patagonia Icefield, Aniya (1988) completed an inventory of 22 outlet glaciers and elucidated their variations between 1944/45 and 1985/86. He now updates their variations to 1990/91 (Aniya, 1992). As for the recent variation of outlet glaciers in the Southern Patagonia Icefield (Fig. 1), very little studies have been carried out, except for few glaciers such as Moreno (e.g., Nichols and Miller, 1952 ; Raffo *et al.*, 1953 ; Mercer, 1962, 1968 ; Denisov *et al.*, 1987), Brüggen (or Pio XI, e.g., Mercer, 1964 ; Iwata, 1983), Tyndall (Naruse *et al.*, 1987 ; Aniya *et al.*, 1991). Aniya and Naruse (1991) studied recent variations of Brüggen, Jorge

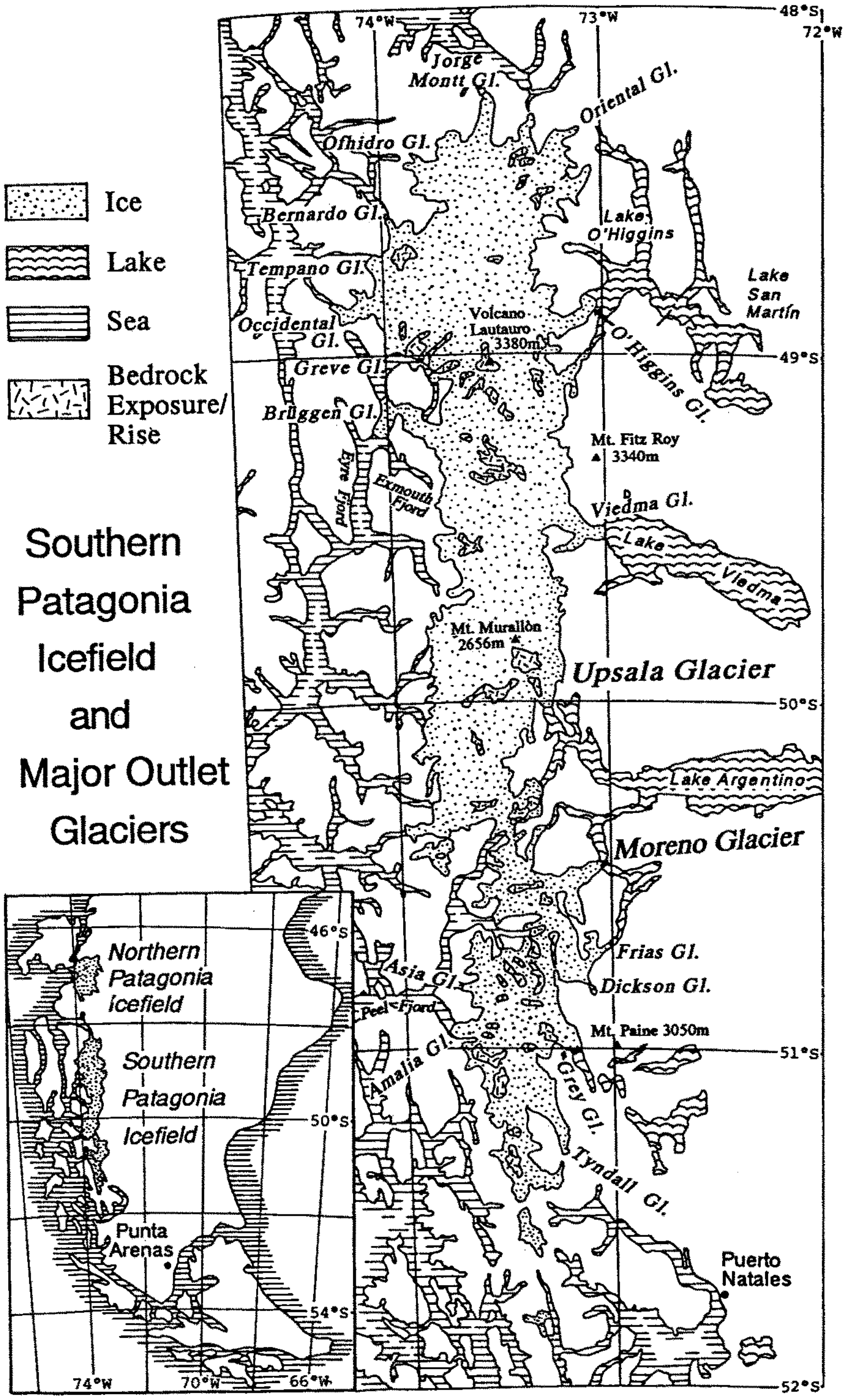

Fig. 1. Map of the Southern Patagonia Icefield and location of Upsala and Moreno glaciers, based on Lliboutry (1956) and elevations modified after Argentine topographic maps published by Instituto Geográfico Militar.

Montt and O'Higgins glaciers by comparing digital Landsat MSS (1976) and Landsat TM (1986) data.

In addition to the 1986 Landsat TM data covering Upsala and Moreno glaciers and field observation in 1990, we obtained a series of aerial photographs covering the snout area of Upsala and Moreno glaciers taken by Argentine and Chilean agencies, and some other satellite data. Also topographic maps covering these glaciers have just become available recently, from which we can derive some statistics about the drainage area. It is the purpose of this paper, first, to describe the drainage characteristics of these glaciers, and second, to present the variation of Upsala Glacier from early 1960s to 1990 and that of Moreno Glacier from 1947 to 1990.

2. Source and method

The Instituto Geográfico Militar of Argentina has just published topographic maps at a scale of 1 : 100, 000 with a contour interval of 50 m for Moreno Glacier (quadrangle: Glaciar Perito Moreno in 1989) and for Upsala Glacier (quadrangle : Glaciar Viedma, 1989 and Glaciar Upsala, 1991). Using these topographic maps, we measured some drainage parameters with a digital planimeter to obtain the characteristics of these glaciers. For Moreno Glacier, a fraction of the southern end of the drainage is not covered. The divide there was located from interpretation of the Chilean aerial photographs taken in 1984, and several contours were drawn in for the measurement of hypsometry.

Table 1 lists the source of information employed to study the recent variation of Upsala and Moreno glaciers. We mostly used vertical aerial photographs with nominal scales of 1 : 65,000 – 1 : 87,000, supplemented by satellite images and field observations. In order to map accurately the snout position of glaciers using aerial photographs or from field observations, it is essential to have a large scale topographic map showing sufficient details of the area with which to correlate the photographic features.

The oldest image record of Upsala Glacier we employed is an oblique photograph taken from the right bank (western side) and shown in a Bertone's book (1972, p. 111), although without the photographing date. A very similar photograph is shown in an article by Mercer (1965, p. 401), and from the experi-

Table 1. List of sources employed to study the glacier variation

Upsala Glacier	
Date	source
early 1960s	Oblique photograph (Bertone, 1972)
1968 (Nov. 18)	Vertical aerial photograph (1 : 71,000, IGM[1], Argentina)
1970 (Mar. 11)	Vertical aerial photograph (1 : 75,000, IGM, Argentina)
1978 (Jan. 1)	Salyut-6 space photograph (1 : 320,000, USSR)
1979 (Mar. 8)	Landsat RBV (1 : 125,000)
1981 (Feb. 24)	Vertical aerial photograph (1 : 87,000, IGM, Argentina)
1984 (Dec. 14)	Vertical aerial photograph (1 : 75,000, FACH[2], Chile)
1986 (Jan. 14)	Landsat TM
1990 (Nov. 16)	in situ observation
Moreno Glacier	
Date	
1947 (no date)	Vertical aerial photograph (1 : 38,000, IGM, Argentina)
1968 (Nov. 18)	Vertical aerial photograph (1 : 65,000, IGM, Argentina)
1970 (Mar. 11)	Vertical aerial photograph (1 : 70,000, IGM, Argnetina)
1975 (Mar. 11)	Vertical aerial photograph (1 : 80,000, FACH, Chile)
1984 (Dec. 20)	Vertical aerial photograph (1 : 70,000, FACH, Chile)
1986 (Jan. 14)	Landsat TM
1990 (Nov.29)	in situ observation

Scales of images are nominal.
1) Instituto Geográfico Militar.
2) Servicio Aerofotogramētrico, Fuerza Aēreo Chileno.

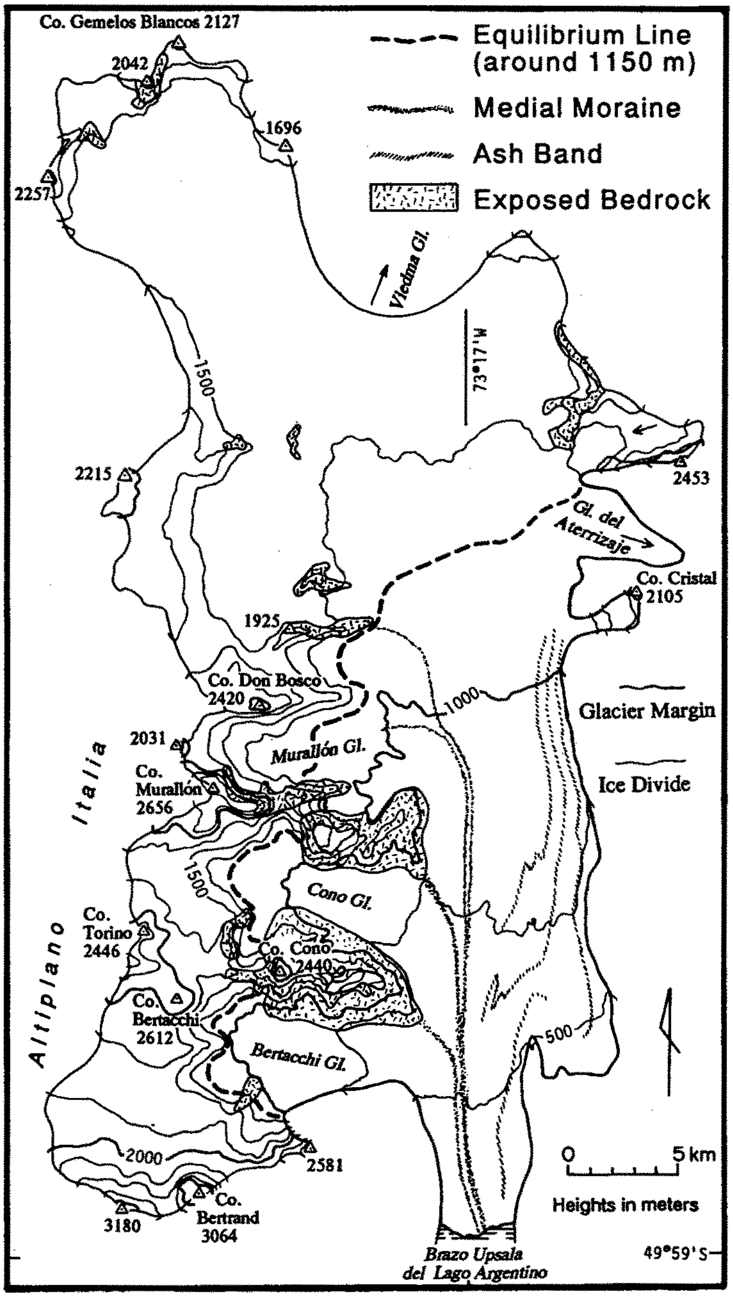

Fig. 2. The drainage area of Upsala Glacier (source : quadrangle Glaciar Viedma and Glaciar Upsala, both at a scale of 1 : 100,000). Co. (Cerro) means peak or mountain. The highest peak (3180 m) is listed as Co. Agassiz on the topographic map ; however, we believe that it is erroneously located. According to Lliboutry (1956) this is Co. Roma, and Co. Agassiz is given to a peak located due south. Co. Roma is renamed as Co. Vivod in 1969 by J. I. Skvarca after the first ascent. For these reasons we left out the name. Although the topographic maps do not differentiate medial moraines from ash bands, we indicated them separately because they could be easily identified on the aerial photographs. Ash layers are believed to have been deposited by eruptions of Volcan Lautaro, about 110 km to the north. Patterns of ash bands vary slightly on the aerial photographs of different dates.

ence of one of the authors (Skvarca) who had crossed this area in February 1966, we inferred the date of the photograph to be early 1960s. The snout position on this oblique photograph was drawn onto the 1968 vertical aerial photograph using the configuration of islands, and it was then transferred onto the topographic map. The eastern two-thirds of the snout position was thus fairly correctly located ; but the western one-third could not possibly be delineated with the same accuracy.

The Salyut-6 space photograph was taken with a Hasselblad 500 EL/M camera (Williams, 1987) at an approximate scale of 1 : 1,600,000. We enlarged it in order to compare with the 1970 aerial photograph. The snout position marked on the 1970 photograph was transferred onto the topographic map. Thus the snout position is not as accurate as those determined from aerial photographs. The Landsat RBV image was enlarged and the snout was drawn onto the 1981 aerial photograph, which was then transferred onto the topographic map.

The Argentine aerial photographs were taken with a super wide angle lens (focal length 85–88 mm) and those by the Chilean agency were taken with a wide angle lens (f. l., 152 mm). Consequently, they contain large relief displacements due to considerable reliefs (1500–2000 m) within a single photograph. Therefore the simple sketch of a single photograph onto the topographic map may not show the correct position. For this reason, except for the Chilean photographs and the satellite images which do not cover the area in a stereopair, a stereozoom transferscope was used to align the stereo-pair of the photographs onto the map (enlarged to 1 : 50,000) and draw in the snout position.

The snout position of Upsala Glacier in 1990 was drawn from ground observations, with some bearings to prominent points of glaciers from locations that could be identified on the aerial photograph. Although an aerial survey was planned, inclement weather prevented it. Thus the position is naturally the best estimate.

3. Characteristics of glaciers

3. 1. Upsala Glacier

Upsala Glacier is about 60 km long and 4 km wide near the snout with a drainage area of 870 km² (excluding bedrock exposures in the ablation area), the largest in South America (Fig. 2). It flows southward from the icefield, terminating currently in Brazo Upsala of Lago Argentino (or Bahia Upsala), at an elevation of about 180 m a.s.l. around 49°59'S and 73°17'W. The height of the calving front is probably on the order of several tens of meters. There are two big medial moraines (actually consisting of several closely-spaced moraines) located near the median of the glacier. The eastern part is fed by ice coming from the icefield south of the Upsala-Viedma divide, while the western part is fed mainly by Bertacchi Glacier draining part of Altiplano Italia and joining from the western side. Ice bodies from Cono and Murallón glaciers, joining also from the western side, are squeezed very tight as the main glacier body flows down and occupy the width of only several tens of meters near the snout. The height of the divide between Upsala Glacier and Viedma Glacier is only 1300–1350 m, while the surrounding mountains and ridges are generally 2000–2200 m high. The highest peak in the entire drainage area is 3180 m at the head of Bertacchi Glacier and located almost due west of the snout.

The equilibrium line altitude (ELA) was estimated in the following way. On the topographic map, medial moraines (actually they are volcanic-ash bands) are shown from the elevation of about 1150 m down, which emerge due to snow-cover melting. The Chilean aerial photographs, taken on December 14, 1984, indicate that the glacier surface conditions (bare ice or snow cover) changed around 1100 m. From these two data, the ELA is taken at about 1150 m in this area. Then the drainage area can be broken into the accumulation area of 545 km² and the ablation area of 325 km², with an AAR (Accumulation Area Ratio) of 0.63. A glacier response to a climatic change is revealed as a change in the snout position, surface level and/or ELA. Since the hypsometry of the drainage area is important to the long-term stability of the glacier as a frontal change and a shift in the ELA are influenced by the geometry of the glacier drainage area (Furbish and Andrews, 1984), a hypsometric curve was constructed from the area measurements at every 50 m contour on the topographic map (Fig. 3). The figure indicates that a slight up or down shift in the ELA would cause a substantial change in the AAR, suggesting that the glacier is susceptible to climatic variations,

On the aerial photographs taken on November 18, 1968 and March 11, 1970, the identical lump of debris can be recognized on the medial moraine about 4-5

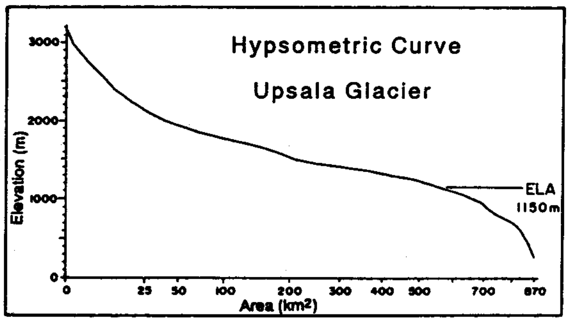

Fig. 3. The hypsometric curve of Upsala Glacier. The X axis is drawn on a scale of square root of the area so that the curve indicates a hypothetical profile of the drainage area when all the contours are drawn in concentric circles proportional to the respective areas. Since the slope of the curve around 1150 m (ELA) is gentle, a small shift of the ELA would cause a large change in the accumulation/ablation area.

km up from the snout (see Fig.6, A, B). This feature was plotted on the topographic map enlarged to a scale of 1 : 50,000 and the distance was measured to be about 900 m. Since the time interval between the two dates is about 16 months, the mean annual surface flow velocity would be 675 m, or roughly taken to be around 700 m.

3. 2. Moreno Glacier

Moreno (officially called Perito Moreno, but customarily called simply Moreno) Glacier occupies an area of about 257 km^2, with a length of 30 km from the southern divide and a width of 4 km in the valley-confined area (Fig. 4). The general height of the divide is around 2000 m with the highest peak of 2950m. The glacier currently terminates in a channel of Lago Argentino at an elevation of about 180 m, dividing the channel into the Canal de los Tēmpanos

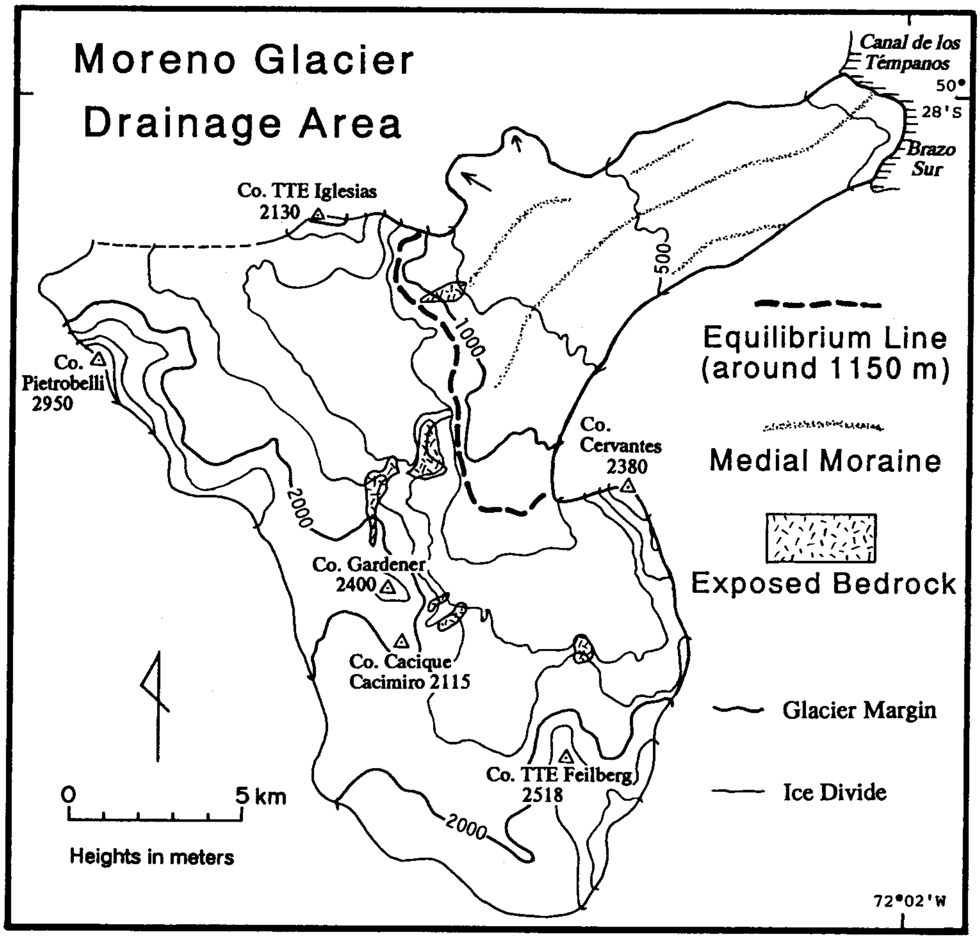

Fig. 4. The drainage area of Moreno Glacier (source : quadrange Glaciar Perito Moreno at a scale of 1 : 100,000 and Chilean aerial photographs taken in 1984).

to the north and the Brazo Rico to the south. The location of the snout is around 50°28'S and 73°02'W. The glacier is noted for the repeated damming-up of the Brazo Rico by reaching the opposite bank (Península Magallanes) in this century. The height of the calving front is on the order of several tens of meters. The glacier surface is very clean, and medial moraines cannot be tracked on the ground. There is, however, one medial moraine which can be recognized and traced on aerial photographs along the median of the glacier all the way down near the snout.

As for the ELA at Moreno Glacier, the Chilean aerial photographs, taken on December 20, 1984, was the only source to locate it, as there is no ash band on this glacier. The photographs indicate that the glacier surface condition drastically changed at the elevation of around 1100 m. Since the photographing date is early summer, the zone of the change in the surface condition would go up as the summer progressed. Taking the ELA at Upsala Glacier into consideration, the ELA at Moreno Glacier was also taken to be 1150 m. Then the accumulation and ablation areas are 182 km^2 and 75 km^2, respectively, with an AAR of 0.71. Figure 5 indicates a hypsometry of Moreno Glacier, which shows that slight changes in the ELA would not cause significant changes in the area of accumulation; thereby suggesting that the glacier should be fairly stable.

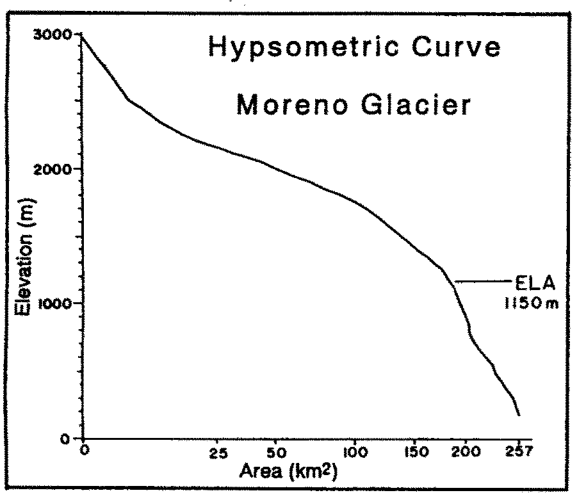

Fig. 5. The hypsometric curve of Moreno Glacier. The X axis is the same as the Upsala's. The curve indicates that slight variations of the ELA would not cause a significant change in the AAR. In the ablation area, there are two steep portions at 800 m and 500 m.

4. Glacier variation

4. 1. Upsala Glacier

The snout positions as appeared on the images are shown in Fig. 6, and the variation is indicated in Fig. 7 with a summary in Table 2. The recession of the western part during the 1960s is large, amounting to a maximum of about 1000 m. On the other hand, the eastern one-third had advanced about 150 m between 1968 and 1970. It was interesting to have found that the middle part of the glacier had advanced up to about 400 m between 1970 and 1978, while the western part showed a little retreat in the same period. A comparison of the Salyut-6 image of 1978 and the Landsat RBV image of 1979 indicates that the glacier has started retreating during this period.

The largest recession occurred between 1981 and 1984, with a maximum of 2100 m break-up at the eastern margin, while at the western half it was only about 150 m. A rapid recession probably occurred in 1981-82, because late Herbert Masters of Estancia "La Cristina", which was located at the head of the Brazo Norte, Lago Argentino, told (January, 1982) one of the authors (Skvarca) that there were many large icebergs in the lake and the summer then was one of the warmest he could remember. From 1984 onward, the glacier has receded at a considerably fast rate of about 200 m/a. For example, large icebergs were again observed in a US Space Shuttle photograph taken in October 1985 (Williams, 1987). In 1990, all small islands, parts of which were still buried under the glacier in 1986, are completely exposed and the glacier snout is calving in the lake across the entire front (Fig. 8).

Retreating patterns are different for the western and eastern parts of the glacier. Up to 1984, the western part had retreated steadily at a rate of about 60 m/a, while the eastern part showed an advance between 1968 and 1978, before turning into a retreat phase with a very rapid recession from 1981 to 1984. Between 1984 and 1990, the recession occurred fairly evenly across the entire front. These retreating patterns are probably influenced by islands located at the western one-third of the Brazo Upsala.

4. 2. Moreno Glacier

Since access to Moreno Glacier is relatively easy, there are a number of reports on the variation since 1899, which Nichols and Miller (1952) and Mercer (1962, 1968) summarized as follows, with their own

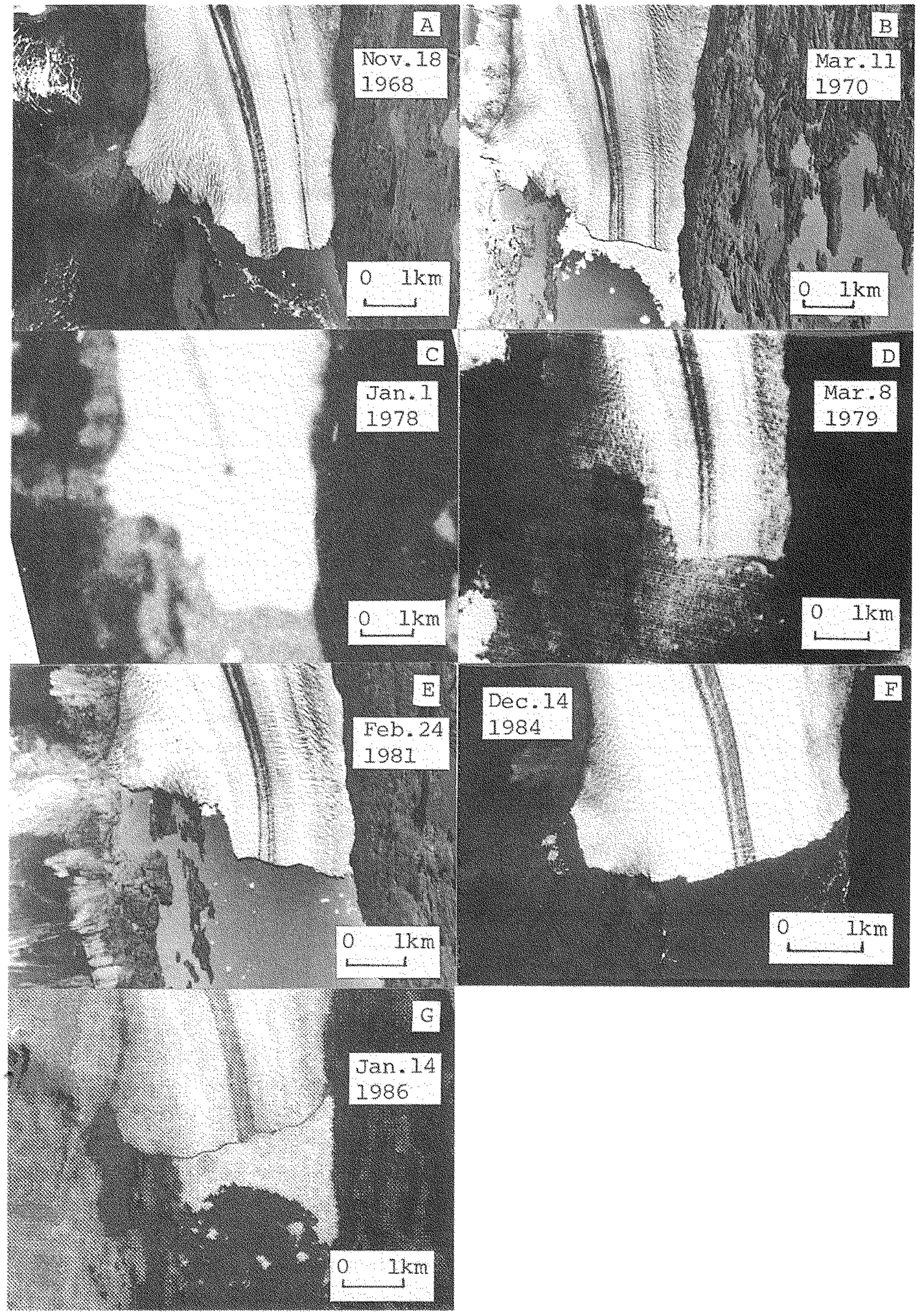

Fig. 6. Snout positions of Upsala Glacier in respective years. A, B, E, Argentine (IGM) photographs : C, Salyut-6 space photograph : D, Landsat RBV : F, Chilean (FACH) photograph : G, Landsat TM. Since these images are not rectified, scales are naturally approximate, and north is approximately top direction. As can be seen, islands are good reference features to compare the snout positions. In A and B, the same lump can be clearly recognized on the medial moraine, from which an average annual surface-flow velocity was derived.

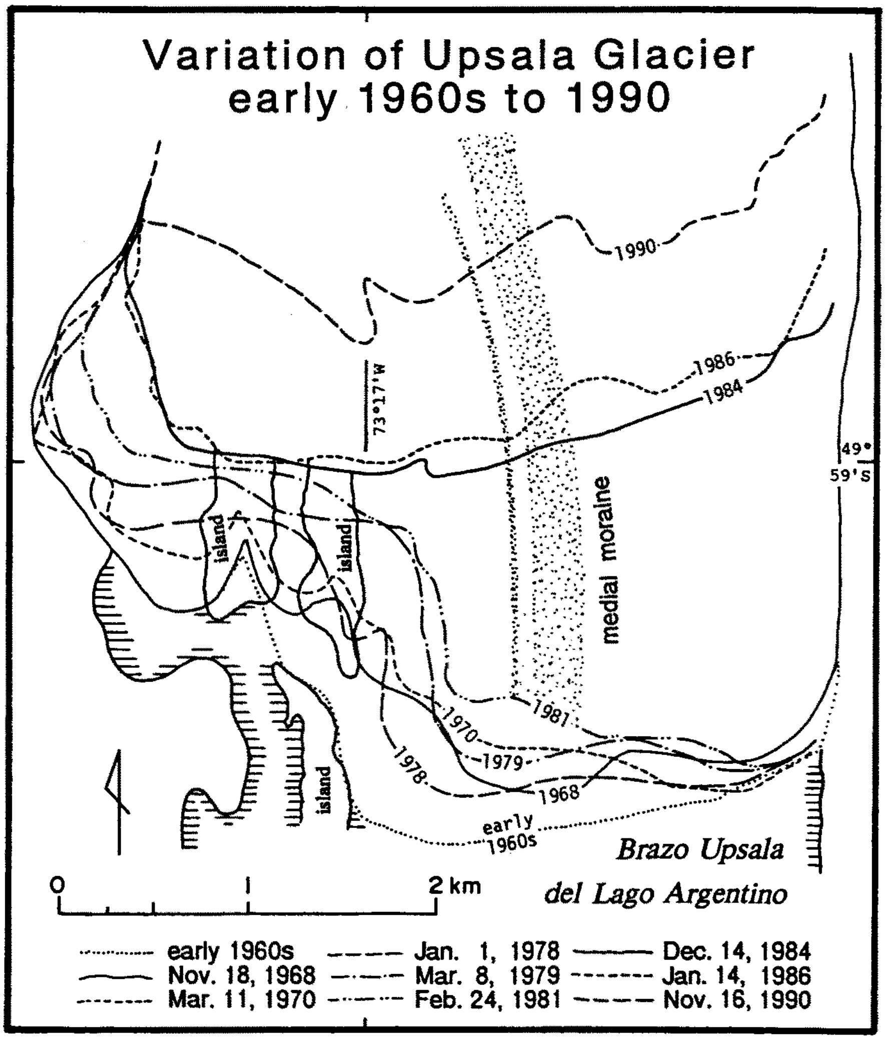

Fig. 7. Snout variation of Upsala Glacier, early 1960s to 1990. Two islands partly covered with the glacier in 1984 have had completely emerged, as of November 1990. Their shapes could not be accurately drawn in the field though.

Table 2. Frontal variation of Upsala Glacier, early 1960s–1990

Period	Variation
early 1960s to 1968	200-700 m retreat at the eastern 2/3. western 1/3 unknown.
1968-1970	250-350 m (63-250) retreat. about 150 m (107) advance at the eastern margin.
1970-1978a	maximum of 400 m (50) advance at just west of the medial moraine. western part some retreat.
1978-1979	100-300 m general retreat.
1979-1981	a maximum of 300 m (150) retreat near the medial moraine.
1981-1984	a maximum of 2100 m (525) retreat at the eastern margin. about 150 m (38) retreat at the western half.
1984-1986	150-300 m (136-273) retreat at the eastern half. western half little change.
1986-1990	700-1000 m (140-200) general retreat.

The number in parentheses indicates an average annual rate.

information added. Moreno Glacier started advancing in 1899 and reached the opposite bank for the first time this century in 1917, and impounded the Brazo Rico to the south. Since then, ice-dammed lakes were formed several times, in 1934-35, 1939-40, 1941-42, 1946 (Dec.), 1947 (Nov), 1948 (April-Dec.), 1951-52, 1952-53, 1954-56, then at least three occasions for more than two-year duration (dates unknown, Mercer, 1968) and 1964-66. Raffo *et al.* (1953) made detailed triangulation surveys of the snout area at about one year interval between November 1947 and March 1952. There seems no data on the variation after Mercer (1968) except one by Denisov *et al.* (1987). Utilizing Salyut-6 orbital photographs taken in October 1978, they found that the tip of the glacier had reached the opposite bank then.

The snout positions as appeared on the images are shown in Fig. 9 and the variation is indicated in Fig. 10. Since the snout area has been oscillating in short periods of time and, in the same period, some parts of the snout advanced while other parts retreated as illustrated in Fig. 9, its behavior was summarized as in Table 3. For Moreno Glacier, the oldest aerial photograph available was taken in 1947, and the shape of the snout then was triangular with the tip reaching the opposite bank. According to Raffo *et al.* (1953, p. 332), this photograph was taken in sometime between January and March 1947. In the same

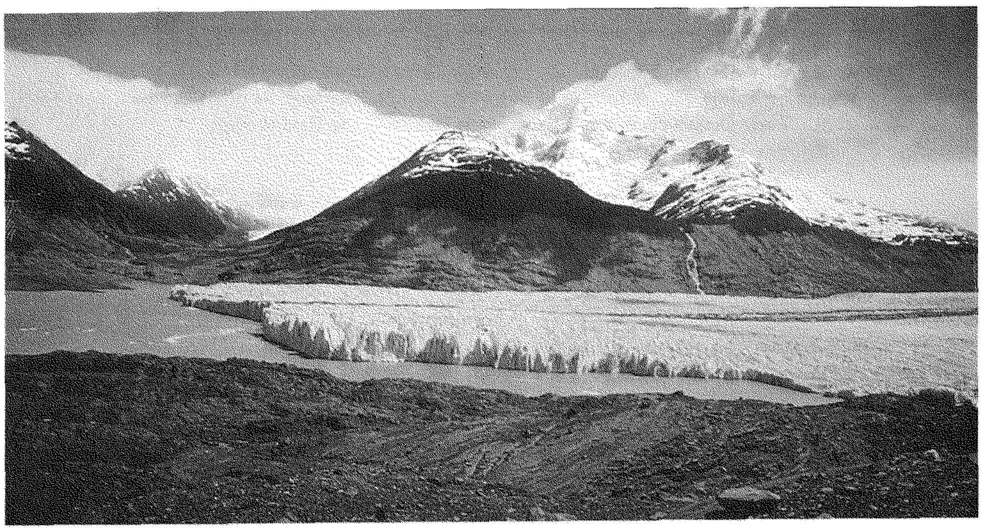

Fig. 8. Snout of Upsala Glacier in 1990 (Nov. 17), taken from the left bank. The northern end of islands can be seen on the left.

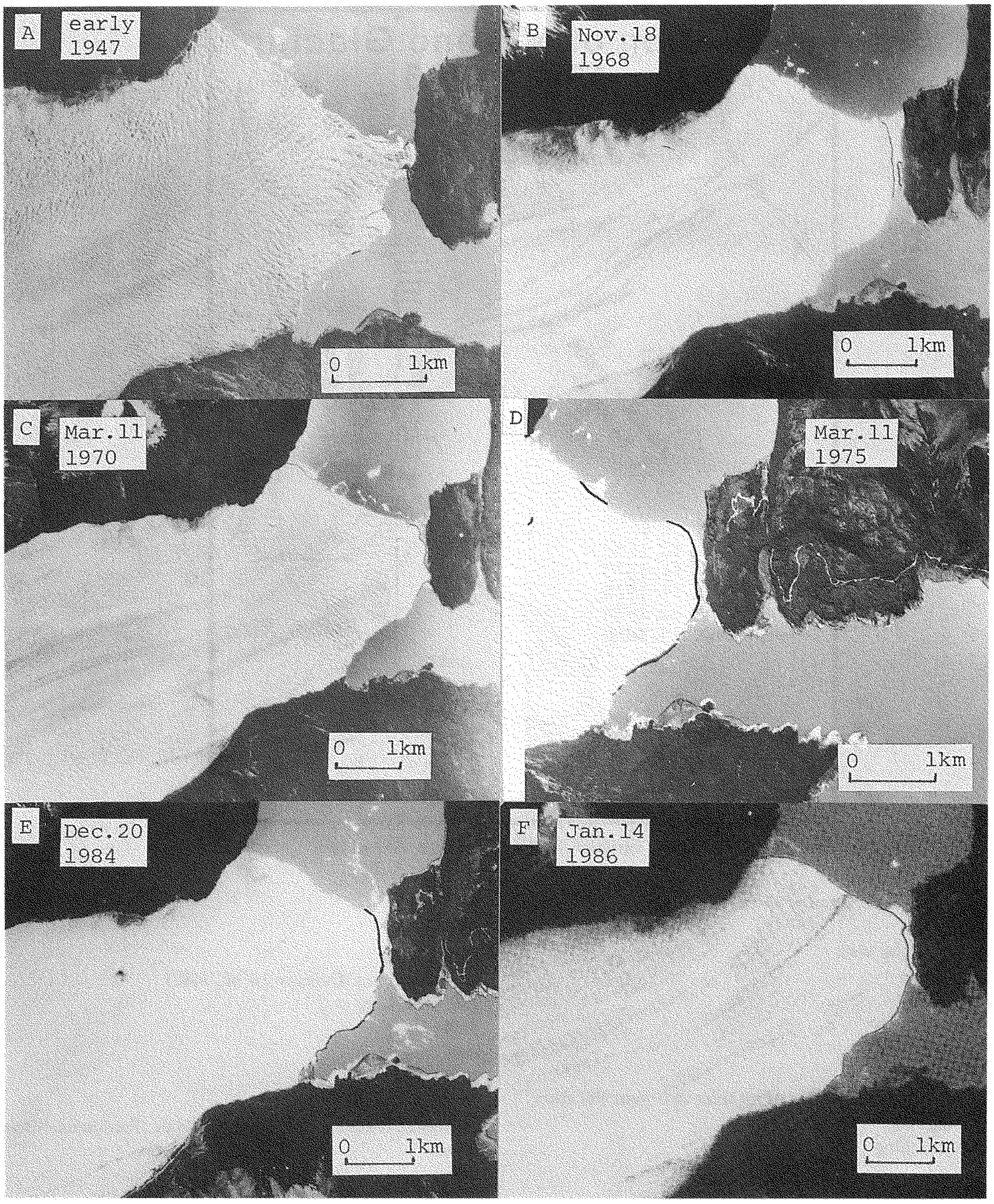

Fig. 9. Snout positions of Moreno Glacier in respective years. A, B, C, Argentine (IGM) photographs : D, E, Chilean (FACH) photographs : F, Landsat TM. Since these images are not rectified, scales are naturally approximate, and north is approximately top direction.

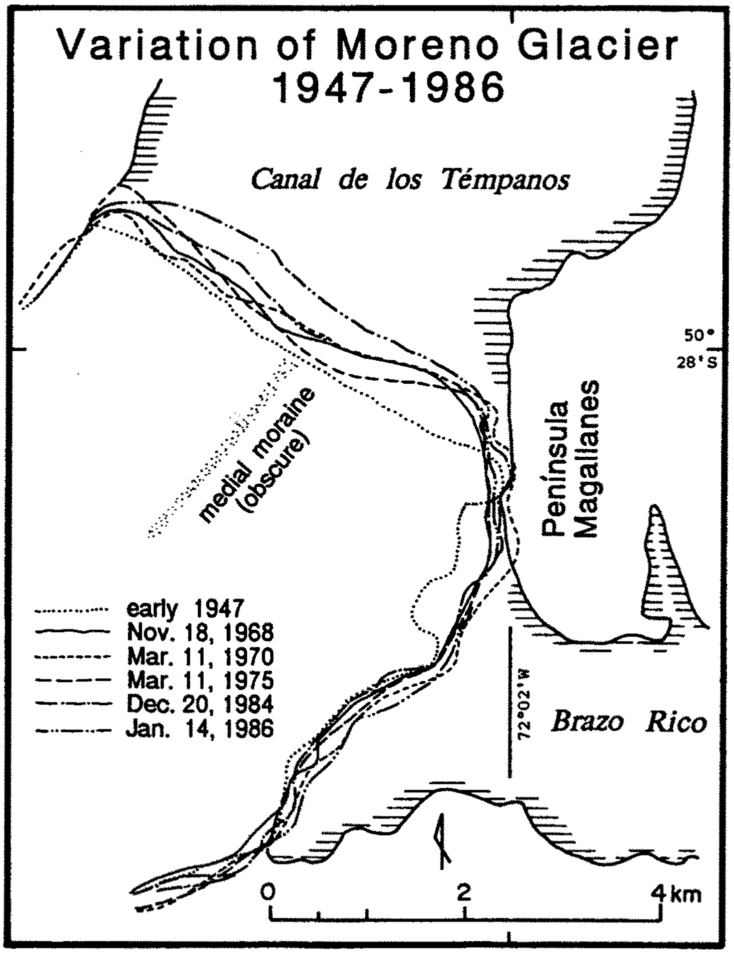

Fig. 10. Snout variation of Moreno Glacier, 1947 to 1986.

Table 3. Frontal variation of Moreno Glacier, 1947-1990

Tip of the snouo was
1947 : reaching
1948 : reaching*
1951-52 : reaching*
1952-53 : reaching*
1954-56 : reaching*
At least three occations for more than two-year duration of reaching*
1964-66 : reaching*
1968 : away
1970 : reaching
1975 : away
1978 : reaching (Denisov *et. al.*, 1987)
1984 : reaching
1986 : away
1990 : reaching

*Mercer (1962)
reaching : reaching the opposite bank (Península Magallanes)
away : away from the opposite Bank

figure, they show that the position of the snout in November 1947 was further advanced since the photographing date. Accordingly, it seems probable that the snout had been reaching (advancing) the opposite bank from January-March through November, rather than just November only as listed by Mercer (1962). Or it could be that the damming started December 1946 and lasted until November 1947. In 1968, the general position of the snout is more advanced than in 1947 ; however, there is a long channel between the tip of the snout and the opposite bank. In 1970, the tip of the snout was touching the opposite bank although the snout area to the north of the medial moraine retreated little since 1968. This is because that the touching part of the glacier (advancing part) is fed by ice from the southern part of the drainage area, while ice of the

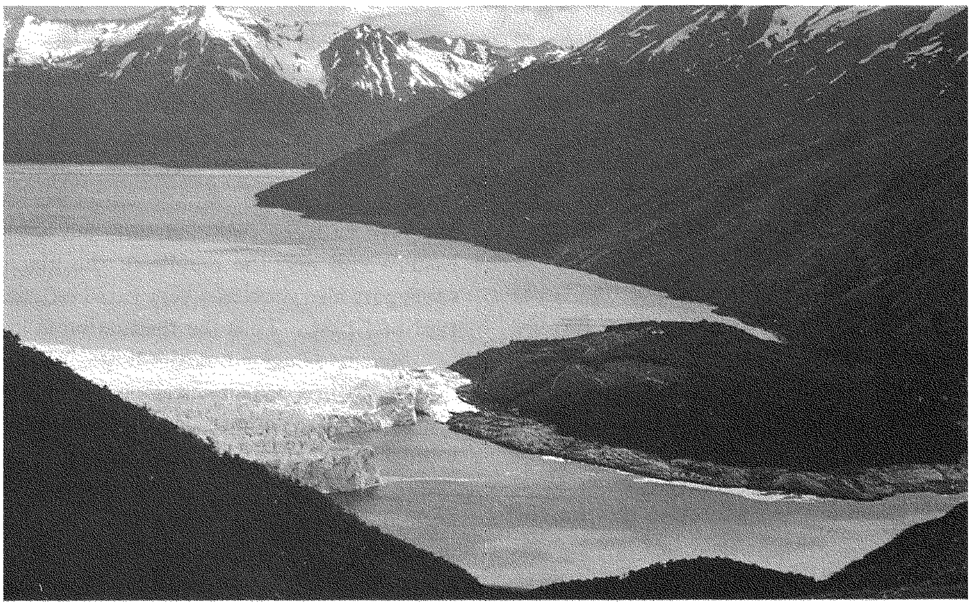

Fig. 11. Snout area of Moreno Glacier in November 24, 1990, from south about 500 m high. The near and far sides of the snout are the Brazo Rico and Canal de los Têmpanos, respectively. The water mark, about 20 m high, on the Brazo Rico side of the Península Magallanes has been caused by repeated impounding by the glacier.

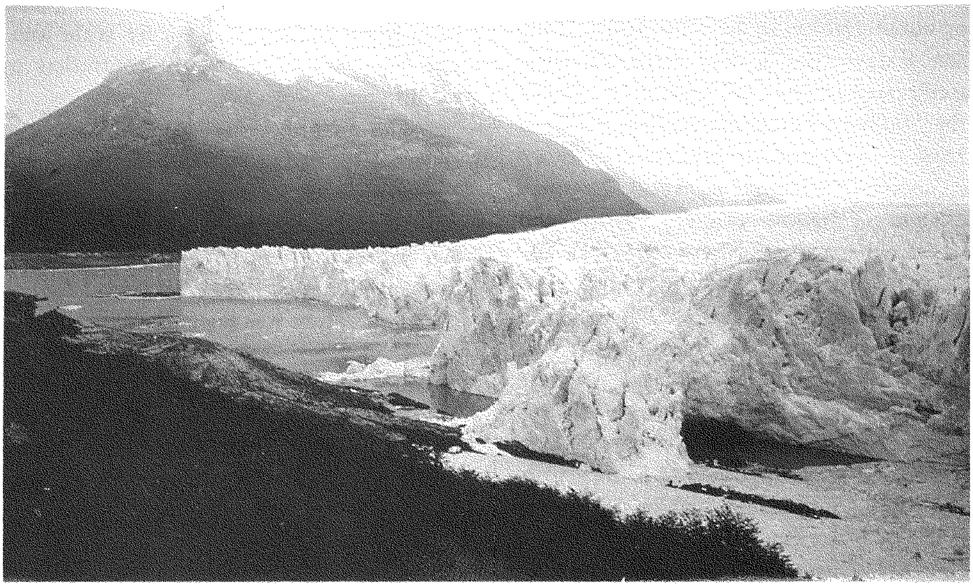

Fig. 12. A tunnel at the snout of Moreno Glacier as seen from NE, connecting the Brazo Rico (left) and Canal de los Têmpanos (right).

left bank area (retreated part) comes form the drainage area located to the west. The general shape of the snout in 1974 is very similar to that in 1968, with a long channel between the front and the opposite bank. In 1984, the tip of the snout is again reaching the opposite bank. General frontal position of the glacier in 1984 was more advanced than in 1974. In 1986, there was a narrow channel between the tip of the snout and the opposite bank, indicating a small retreat since 1984. However, the flanks of the snout tip had advanced up to 200 m in the Canal de los Tēmpanos and slightly in the Brazo Rico.

In November 1990 the glacier was observed from the observation deck and a point about 500 m high to the south (Fig. 11) ; however the snout position could not be mapped with a sufficient accuracy for the comparison with other years. The tip was touching the opposite bank with a tunnel of the connecting channel (Fig. 12) and it seems that the glacier condition was similar to that in 1947. Pablo Kuntzle, a park ranger in this area, told us (November 29, 1991) that the glacier condition had been like this for the last 2-3 years.

5. Discussion

The retreat of Upsala Glacier since 1984 at a rate of about 200 m/a is comparable to that of San Rafael Glacier in the Northern Patagonia Icefield (NPI) between 1974/75 and 1985/86, which was by far the fastest among outlet glaciers in the NPI (Aniya, 1988). However, San Rafael Glacier had retreated since 1985/86 at accelerated rates of 190−300 m/a. Outlet glaciers in the Southern Patagonia Icefield (SPI), of which the variation in the comparable period is known are Tyndall Glacier (Naruse *et al.*, 1987), Brüggen, Jorge Montt and O'Higgins glaciers (Aniya and Naruse, 1991). Of these, the northern half of O'Higgins Glacier had retreated at very fast rates of 200−300 m/a from 1976 to 1986. During the same period, Jorge Montt Glacier retreated at a much smaller rate of 40 m/a , while at Brüggen Glacier, the northern tongue advanced at rates of up to 140 m/a and the southern tongue retreated at rates of 60 m/a. Tyndall Glacier retreated at a rate of about 64 m/a from 1975 to 1986. O'Higgins Glacier, which showed a comparable with or faster recession rate than that of Upsala Glacier, is located on the eastern side of the SPI, the same side as and 120 km north of Upsala Glacier. Between these two glaciers, Viedma Glacier is located. A cursory comparison of 1968 and 1981 aerial photographs (IGM, Argentina) covering the snout area indicates that Viedma Glacier had not fluctuated significantly. The ice body to the east of the medial moraine of Upsala Glacier, which shares the common accumulation region with Viedma Glacier, had been also fairly stable during the same period. The advance between 1970 and 1978 occurred just west of the medial moraine, which was fed by Bertacchi Glacier. The location of the present ELA on the hypsometric curve suggests that Upsala Glacier is susceptible to the climatic variation. An advance observed between 1968 and 1978 had occurred at the eastern half and the middle of the glacier, and the same part also showed a very rapid recession between 1981 and 1984. Thus the fluctuation is very quick.

Moreno Glacier has the large AAR of 0.71, and the shape of the hypsometric curve and the location of the present ELA on it suggest that the supply of ice is more stable than at Upsala Glacier. Throughout this century, the glacier snout has been oscillating, and periodically reaching the opposite bank and impounding the lake to the south. The amount of the variation is up to 500 m during the last 40 years. Since the snout is calving in a lake, the snout variation is affected by changes not only in precipitation and temperature which would reflect on the ELA, but also in lake conditions such as water temperature, water circulation, and roughness of the water surface. Therefore it seems possible that the glacier itself has been more or less in a steady state and the recent variation has been mostly controlled by the lake conditions.

The nearest meteorological station with a long record is located in Punta Arenas, about 390 km to the south of these glaciers. Endlicher and Aguila (1988) published the precipitation and temperature records. According to these data, the amount of the annual precipitation was larger between 1935 and 1960, and the temperature was lower between mid 1960s and mid 1970s. These trends would seemingly explain the advance of Upsala Glacier between 1968 and 1978. However, the station is located far away in a different climatic zone, and we do not know the mass balance of Upsala Glacier yet, it may be premature to conclude as such.

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