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Synopsis of glacier researches in Patagonia, 1993

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Abstract

The Glacier Research Project in Patagonia with a theme of "Characteristics of Recent Glacier Variations in Patagonia, Southern Andes" was carried out in the field during the austral summer of 1993/94 : from 9 November to 28 December 1993 at and around Upsala, Ameghino, Moreno and Tyndall glaciers, outlet glaciers from the Southern Patagonia Icefield, and around the Northern Patagonia Icefield. The research topics accomplished include : 1) ice-thickness changes between 1990 and 1993, 2) flow of glaciers, 3) meteorological conditions and heat balance, 4) morphology and thickness of glaciers, 5) landforms around glaciers and Holocene glacier variations, and 6) aerial photographic survey (Northern Patagonia Icefield). As ancillary projects, the following topics were also studied : 7) lake- and glacier-sediments, dendrochronology and glacier fluctuations, 8) recent climatic changes in the Patagonia region. Outline of the project and summaries of the results are presented.

1. Introduction

A vast ice-covered area, which ranks the third in the world at present, exists in Patagonia, the southern part of South America. The ice masses are composed of two separate icefields : the larger one is called Southern Patagonia Icefield (SPI, Hielo Patagônico Sur) and the smaller one Northern Patagonia Icefield (NPI, Hielo Patagônico Norte). The SPI stretches for 350 km from 48°20′ S to 51°30′ S, with an area of 13,000 km^2 (Fig. 1) and the NPI is centered around 47°S and 73°30′ W, with an area of 4, 200 km^2 (Aniya, 1988). Numerous outlet glaciers discharge from the icefields in all directions. Most glaciers calve into fjords on the western side of the icefields and into lakes on the eastern side. Because of large amounts of precipitation, and ice melting and calving throughout the year, Patagonian glaciers are regarded as representing typical temperate characteristics.

Inventory works of glaciers in Patagonia were firstly undertaken by Lliboutry (1956) and Bertone (1960). Holocene glacier variations in southern Patagonia were studied by Mercer (1965, 1968, 1970, 1976) and geographical features of the SPI was described by Martinic (1982). Between 1983 and 1990, detailed glaciological, meteorological and geomorphological studies were carried out three times as joint projects of Japan with Chile and Argentina (Glacier Research Project in Patagonia : GRPP). At glaciers of Soler, San Rafael (NPI), Upsala, Moreno and Tyndall (SPI), abundant knowledge and basic data have been accumulated, especially on the frontal variations, ice flow, ice-thickness, meteorological features, heat balance, and also landforms around glaciers (Nakajima, 1987 ; Naruse and Aniya, 1992).

The GRPPs have revealed that the ablation area of Soler Glacier had thinned at a rate of 5.2 m/a from 1983 to 1985 (Aniya and Naruse, 1987) and that of Tyndall Glacier at a rate of 4.0 m/a from 1985 to 1990 (Kadota *et al.*, 1992). Also, by analyzing satellite data and air photographs, most outlet glaciers in Patagonia were found to have been retreating considerably during the last half century (Aniya, 1988; 1992a; 1992b ; Aniya *et al.*, 1992 ; Naruse *et al.*, in press). For example, San Rafael and Cachet glaciers (NPI),

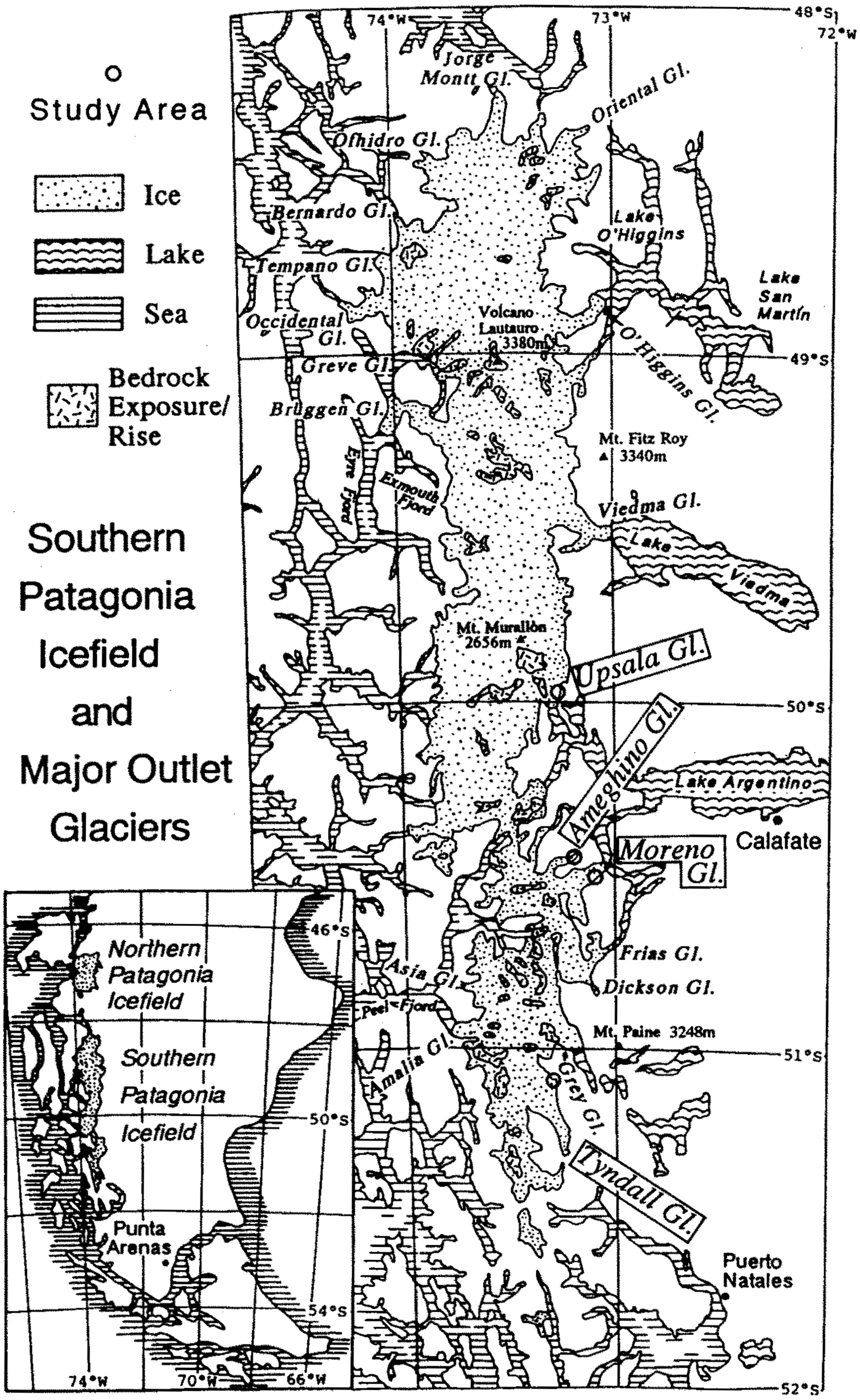

Fig. 1. Map of the Southern Patagonia Icefield (SPI), showing studied glaciers.

and Tyndall, Upsala and O'Higgins glaciers (SPI) retreated more than 3 km during 41 years from 1945. On the other hand, Brüggen (or Pio XI) Glacier (SPI) has advanced up to 8.5 km during the same period, and Moreno Glacier has been almost in a steady state.

Focusing particularly on a study of thickening or thinning of glaciers, the GRPP-93 was conducted in the austral summer of 1993/94 at four glaciers : Upsala, Ameghino, Moreno and Tyndall in the SPI (Fig. 1). This report presents the framework of the GRPP-93 and outlines of the results obtained.

2. Research topics

A research project entitled "A Study of Characteristics of Recent Glacier Variations in Patagonia, Southern Andes" aims at clarifying the processes and mechanisms of variations of Patagonian glaciers in response to global or regional climatic changes. In order to obtain characteristics of the recent behaviors of glaciers, the following researches were carried out in southern Patagonia in November and December 1993 :

1) Ice-thickness changes between 1990 and 1993,
2) Flow of glaciers,
3) Meteorological conditions and heat balance,
4) Morphology and thickness of glaciers,
5) Landforms around glaciers and Holocene glacier variations, and
6) Aerial photographic survey (Northern Patagonia Icefield: NPI).

As ancillary projects, the following topics were also studied :

7) Lake- and glacier-sediments, dendrochronology and glacier fluctuations, and
8) Recent climatic changes in Patagonia.

3. Characteristics of research areas

Table 1 summarizes morphological parameters of Upsala, Ameghino, Moreno and Tyndall glaciers, where the field researches were conducted in 1993/94, as well as Brüggen Glacier of which glacier fluctuations were studied.

1) Upsala Glacier (Fig. 2)

The glacier flows southward from the eastern part of the SPI, and is calving into Lake Brazo Upsala, a western channel of Lake (Lago) Argentino. Two clear medial moraines can be recognized on the ablation area, 4 km wide near the glacier terminus. The eastern part of the ice body is fed from the icefield south of the Upsala-Viedma divide, which lies at 1300–1350 m in altitude (Aniya and Skvarca, 1992), while the western part is mostly fed from Bertacchi Glacier. The surface is heavily crevassed in the ablation area.

2) Ameghino Glacier (Fig. 3)

The glacier is currently calving into Lake (Laguna) Ameghino, about 7 km from the western shore of Lago Argentino. The accumulation area is bordered to the west by Mayo Glacier with a distinctive ridge about 1500–2000 m in altitude, and to the south by Moreno Glacier with a vague ice divide (Aniya and Sato, 1995a). The major directions of glacier flow are eastward and northward in the accumulation area, and the flow direction is eastward in the valley-confined ablation area.

Table 1. Inventory of five outlet glaciers in the Southern Patagonia Icefeld.

Glacier Name	Position of Terminus		Length (km)	Altitude (m a. s. l)			Area (km^2)		AAR
	Latitude (S)	Longitude (W)		Highest	Terminus	Equilibrium Line	Accumulation	Ablation	
Upsala[1)]	49° 59′	73° 17′	60	3180	175	1150	545	325	0.63
Ameghino[2)]	50° 26′	73° 10′	19	2260	200	1000	33	44	0.43
Moreno[1)]	50° 30′	73° 00′	30	2950	175	1150	182	75	0.71
Tyndall[3)]	51° 15′	73° 15′	32	–	50	900	219	118	0.65
Brüggen[3)]	49° 13′	74° 00′	64	3380	0	–	1024	251	0.80

(Note) AAR : Accumulation area ratio. "–" indicates "uncertain".
Data source : 1) Aniya and Skvarca (1992), 2) Aniya and Sato (1995a), 3) Sato and Aniya (unpublished).

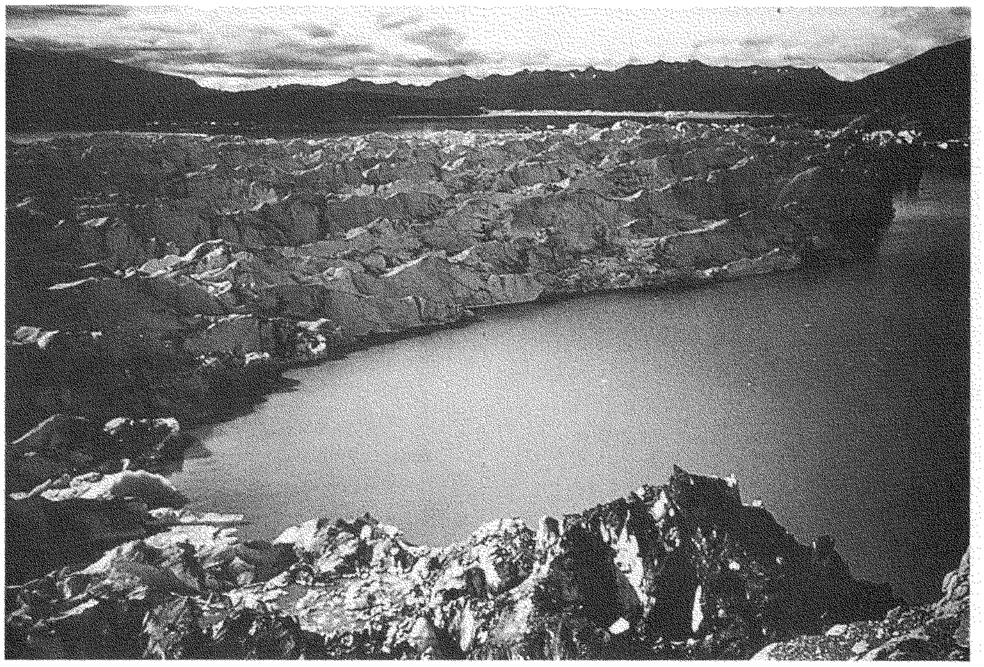

Fig. 2. Calving front of Upsala Glacier in November 1993, viewed from the right (western) bank (Photo by K. Satow).

Fig. 3. Ameghino Glacier calving into Lake (Laguna) Ameghino in November 1993, viewed from the terminal moraine (Photo by H. Sato).

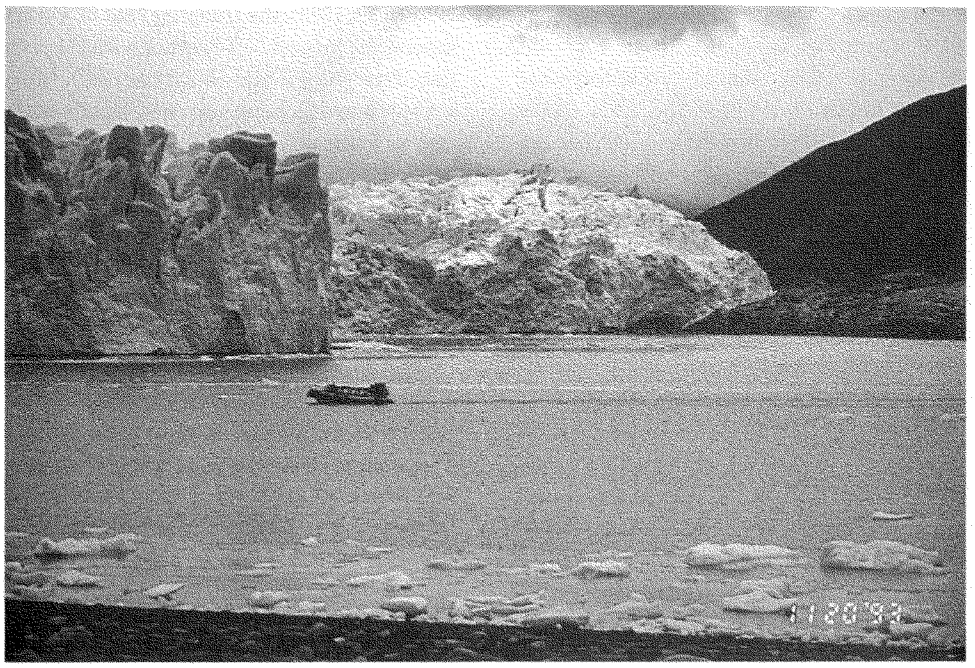

Fig. 4. Frontal part of Moreno Glacier in November 1993, viewed from the southern beach of Lake Brazo Rico. The tip of the glacier currently touches the opposite bank (Península Magallanes) with a drainage tunnel from Lake Brazo Rico to Lake (Lago) Argentino.

3) Moreno Glacier (Fig. 4)

The glacier (also called Glaciar Perito Moreno) flows out northeastward from the eastern part of the SPI and currently terminates in a southwestern channel of Lago Argentino, dividing the channel into the Canal de los Tēmpanos to the north and Lake Brazo Rico to the south. The glacier is well-known for the repeated damming-up of Lake Brazo Rico due to reaching the opposite bank (Península Magallanes) in this century. The heights of the calving front were measured as 55–70 m (Naruse *et al.*, 1992). The glacier surface is very clean, and medial moraines cannot be tracked on the glacier surface.

4) Tyndall Glacier (Fig. 5)

The glacier, the southernmost major outlet glacier in the SPI, flows southward from the icefield and currently calves into a proglacial lake. The ablation area is mostly valley-confined, about 16–22 km long and 3.5–10 km wide. There is a nunatak in the middle of the glacier, from which a distinctive medial moraine can be traced toward the terminus. The glacier surface of the upper ablation area, where the survey was made, is relatively flat with few crevasses.

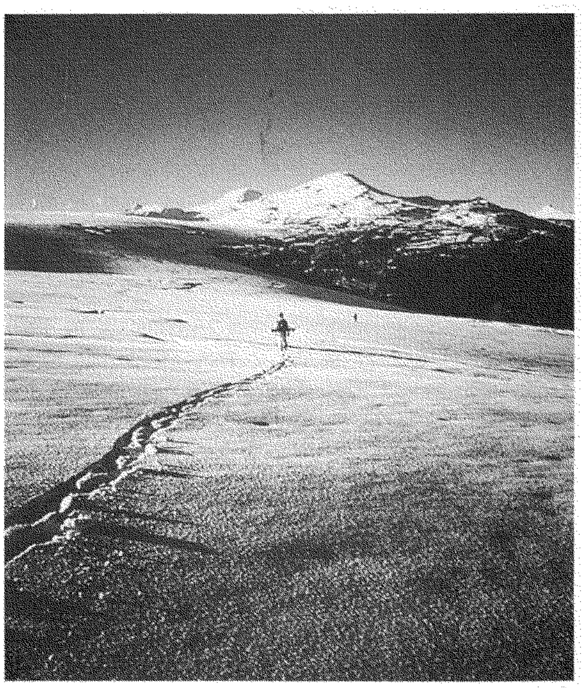

Fig. 5. Surveyed area of Tyndall Glacier covered with new snow on 18 December 1993 (Photo by K. Satow).

5) Northern Patagonia Icefield (NPI)

The NPI is about 100 km long and 45 km wide, with about 28 outlet glaciers. About half of them had been calving into fjords or lakes in the early 1940s, however some glaciers have retreated since and are currently terminating on land, apart from water. Monte (Mt.) San Valentin (3910 m), located at the northeast corner of the area, is the highest mountain in the entire Patagonia region. A large part of the icefield lies from 1000 m on the western side to 1500 m on the eastern side.

4. Outline of research topics and their results

Researches were carried out at Moreno Glacier from 9 to 29 November 1993, at the Ameghino Glacier region from 9 to 16 November, at the Upsala Glacier region (in the National Park Los Glaciares, Argentina) from 19 to 29 November, and at the Tyndall Glacier region (in the National Park Torres del Paine, Chile) from 5 to 19 December.

4.1. Ice-thickness changes between 1990 and 1993

For the profile surveys at three glaciers in 1993, the same control stations and azimuth points were utilized as those set up in the 1990 surveys ; namely, on the left (eastern) bank near the terminus of Upsala Glacier, on the right (southern) bank in the mid-reach of the ablation area of Moreno Glacier, and on the left (eastern) bank in the upper ablation area of Tyndall Glacier.

An electronic distance meter (EDM) was installed at the control station of each glacier, and an EDM reflector was placed at survey points on the glacier. Guided by the original data (1990) of horizontal angles and distances, measurements could be made at almost the same points (within a few meters) as in 1990. From the difference in the surface elevations of ice between 1990 and 1993, the ice-thickness change during three years was obtained.

At Upsala Glacier a mean thinning rate of 11 m/a was obtained from seven points along a 2 km long transverse profile (Skvarca *et al.*, 1995), and at Tyndall Glacier a mean thinning rate of 3.1 m/a was obtained from twelve points along a 5 km long transverse profile (Nishida *et al.*, 1995). On the other hand, at Moreno Glacier, the mean thickness of eight points has unchanged along a 3 km survey line (Naruse *et al.*, 1995). Compared with the thickness changes at 42 glaciers in the world (IAHS/UNEP/UNESCO, 1993), the thinning rate of Upsala Glacier is among the largest. Together with the frontal fluctuation data (Aniya and Skvarca, 1992), Moreno Glacier is considered to have been in a steady state during the last 50 years.

4.2. Flow of glaciers

Distributions of flow velocities were measured along the above survey lines at the three glaciers. Considerably rapid flow of 4.4 m/d was observed near the medial line of Upsala Glacier (Skvarca *et al.*, 1995). Seasonal and daily variations in ice flow were also obtained at Moreno Glacier. It was found that velocities were larger in late spring or early summer (November) than mid-summer (January-February), and larger in the afternoon and smaller in the morning (Naruse *et al.*, 1995). These seasonal and short-term fluctuations in ice flow can be attributed to variations in the basal sliding velocity which is strongly controlled by the subglacial water network. From the measurement of surface strain rate at Tyndall Glacier, an emergence velocity was estimated at 10 m/a (Nishida *et al.*, 1995).

4.3. Meteorological conditions and heat balance

Meteorological conditions and heat balance characteristics on ice were studied at Moreno Glacier (Fig. 6) from 12 to 27 November 1993 and at Tyndall Glacier from 9 to 17 December. A Föhn-like rise in air temperature accompanied by the wind-speed increase was observed at Moreno Glacier. Correlations between air tempera-ture and global radiation or wind speed were found to be different between the two glaciers (Takeuchi *et al.*, 1995a). The heat source for ice melting consisted mostly of net radiation and sensible heat flux at both glaciers. However, the mean sensible heat flux at Moreno Glacier was slightly larger than that at Tyndall Glacier, and evaporation predominated at Moreno Glacier, while condensation at Tyndall Glacier (Takeuchi *et al.*, 1995b). At Moreno Glacier, the amount of ablation of 6.3 m in water equivalent was measured in 110 days during the summer (Naruse *et al.*, 1995).

Chemical compositions of precipitation were analyzed at Tyndall Glacier. The pH values were around 6.0 and the concentrations of anions and cations, especially nitrate, were relatively low (Satow, 1995). Experiments on the sinking of stones into the surface ice due to the differential melting were carried out at Moreno and Tyndall glaciers (Matsuoka *et al.*, 1995).

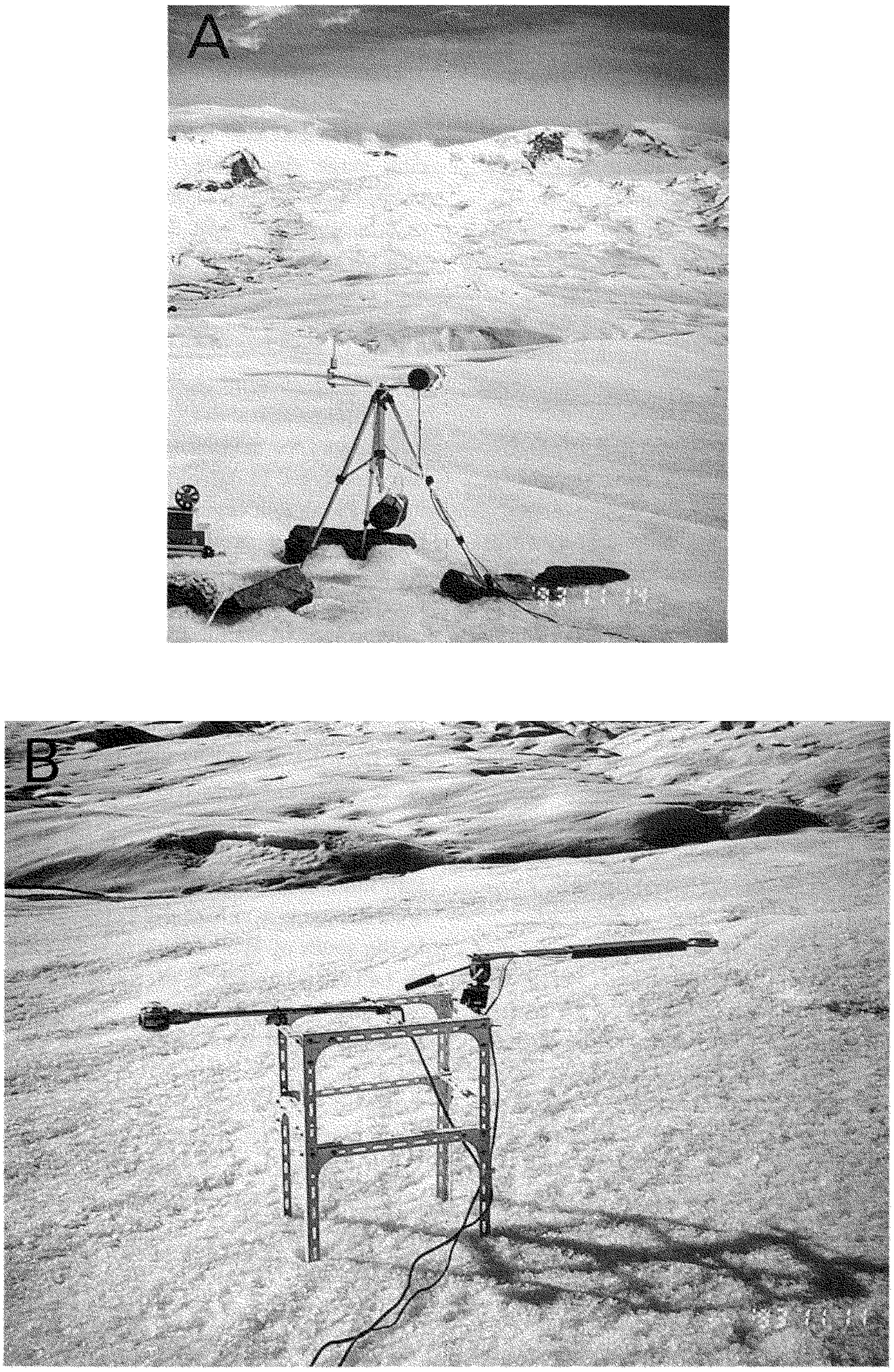

Fig. 6. Meteorological station at Moreno Glacier in November 1993. (A) A three-cup anemometer (left) and a hygro-thermometer covered with a ventilation pipe (right). (B) An albedo meter (left) and a net radiometer (right).

4.4. Morphology and thickness of glaciers

Morphology of Ameghino Glacier was firstly studied and basic parameters are shown in Table 1. From the number of ogive waves in the upper ablation area, flow velocity was estimated at about 200 m/a. The glacier retreated at a rate of 152 m/a between 1970 and 1993 (Aniya and Sato, 1995a).

Ice thicknesses were measured with a digital radio-echo sounder along the same transverse line as the glacier surface profiling in the upper ablation area of Tyndall Glacier. A maximum thickness of 569 m was obtained at about 2.5 km from the left margin. No return echo could be received beyond a 3 km point (Casassa and Rivera, unpublished).

4.5. Landforms around glaciers and Holocene glacier variations

Geomorphological researches were performed at Peninsula Herminita near the terminus of Upsala Glacier, the Ameghino Valley in the proglacial area of Ameghino Glacier, and the eastern side of Tyndall Glacier. Based on the ^{14}C dating and features of landforms, four Holocene glacier variations were for the first time recognized in Patagonia. Namely, at the Upsala and Tyndall regions, the first Neoglaciation occurred ca. 3600 yr B.P., the second ca. 2400−2200 yr B.P., the third ca. 1600−1400 yr B.P. and the fourth ca. A.D. 1600−1760 (Aniya and Sato, 1995b ; 1995c).

4.6. Aerial photographic survey in the NPI

An aerial survey around the Northern Patagonia Icefield was successfully accomplished on 27 December 1993. Utilizing the oblique aerial photographs taken, the frontal variations of 18 outlet glaciers were elucidated between 1990/91 and 1993/94. Although most glaciers have retreated during this 3-year period, the recession rates of most glaciers have generally declined when compared with the period of 1985−90 (Wada and Aniya, 1995).

4.7. Lake- and glacier-sediments, dendrochronology and glacier fluctuations

Four piston cores (the longest one: 13 m) were recovered from Lake Brazo Sur, the southern channel of Lake Brazo Rico in December 1993. Sedimentary signals indicate repeated floods due to ice-damming by Moreno Glacier in this century. Also pyroclastic deposits assigned to three major Late Holocene volcanic events were identified (Valle *et al.*, 1995).

Fluctuations of Brüggen (Pio XI) Glacier during the last several decades were revealed in detail from analyses of satellite images and aerial photographs, sediments on the glacier, and dendrochronology around the glacier. The glacier has been in an advancing stage since 1945. The advancing rates were obtained as follows : 750 m/a between 1945−51, 142 m/a between 1951−69, 345 m/a between 1969−76, 60 m/a between 1976−92, and 400 m/a between February 1992 and November 1993 (Rivera and Aravena, unpublished).

4.8. Recent climatic changes

Climatological data, precipitation and air temperature, from the southern parts of Argentina and Chile were analyzed to detect trends in the climatic change in the Patagonia region. The majority of stations in the Santa Cruz province show a long term positive trends in both precipitation and temperature. However, at Station Lago Argentino, which is the nearest meteorological station to the eastern outlet glaciers in the SPI, the precipitation has decreased while air temperature has risen significantly during the last half century (Ibârzabal, unpublished).

Between the 1950s and 1970s, temperature data show a trend of surface cooling at 41° and 42°S, while the troposphere shows a warming trend above the 2 km level. During this century, the surface temperature indicates no significant trend between 43° and 45° S on the western side of the Patagonia Andes, whereas in the south of 46°S, the surface was warming by 0.4° to 1.4°C (Rosenblüth *et al.*, 1995).

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