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Outline of Glacier Research Project in Patagonia, 1990

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Abstract

The research project entitled "A Study of Characteristics of Recent Glacier Variations in Patagonia, Southern Andes" was carried out in Patagonia during the period from 9 November to 27 December 1990. The project aims at investigating the processes and mechanisms of variations of temperate glaciers in response to climatic changes. Study areas are Upsala and Moreno glaciers, which are eastern outlet glaciers from the Southern Patagonia Icefield, and Tyndall Glacier, a southern outlet glacier from the icefield. The research topics accomplished include : 1) surface elevation of the glaciers, 2) variations in the glacier fronts, 3) flow of the glaciers, 4) ice thickness and glacier surface structure, 5) meteorological conditions and ablation of ice, 6) geomorphology around the glaciers, and 7) aerial photographic survey. Outline of the project, the research procedure and brief notes about the results are presented.

1. Introduction

In Patagonia, the southern part of South America, there is a vast ice-covered area called the Patagonia Icefield (Hielo Patagónico). The icefield is composed of two separate ice masses : the larger one (Southern Patagonia Icefield : SPI) stretches for 350 km from 48° 20'S to 51°30'S, its area being 13000 km² (Figs. 1 and 2) ; while the smaller one (Northern Patagonia Icefield : NPI) is centered around 47°S and 73°30'W, its area being 4200 km² (Aniya, 1988). In terms of the total area or the volume, the Patagonia Icefield ranks the third in the globe at present. A number of outlet glaciers discharge from the icefields in all directions. The fronts of the glaciers reach close to sea level on the western side, and to about 150–400 m a.s.l. on the eastern side.

The Patagonia Icefield is located in the "Roaring Forties", that is a region with strong westerlies throughout the year. Because much water vapor is transported from the Pacific Ocean to the Patagonian Andes, a large amount of precipitation (mostly snow) is supplied to the icefields, which is estimated at more than 5000 mm/a (Dirección General de Aguas, 1987). Due to the relatively warm air temperature in Patagonia, the annual amount of ablation is also very large. Therefore, Patagonian glaciers can be characterized by the most typical temperate condition in the world.

Maps of distribution of Patagonian glaciers were first compiled by Lliboutry (1956), and an inventory work of glaciers in the Argentine side was made by Bertone (1960). Geographical descriptions and exploration history of the SPI were published by Martinic (1982). From 1983 to 1986, detailed glaciological and meteorological studies were carried out by the Japanese Glaciological Research Project in Patagonia (GRPP-83/84 and -85/86). The project concentrated its research sites at Soler Glacier on the eastern side of the NPI, San Rafael Glacier on the western side of the NPI, and Tyndall Glacier on the southern side of the SPI. Abundant knowledge and features on these glaciers were obtained (Nakajima *ed.*, 1985 ; Bulletin of Glacier Research No.4, 1987), including, 1) contribution of heat balance to ablation, 2) characteristics of glacier winds and Föhn, 3) ice-flow velocities and their variations within short time intervals, 4) hydrological characteristics of water discharge, and 5)

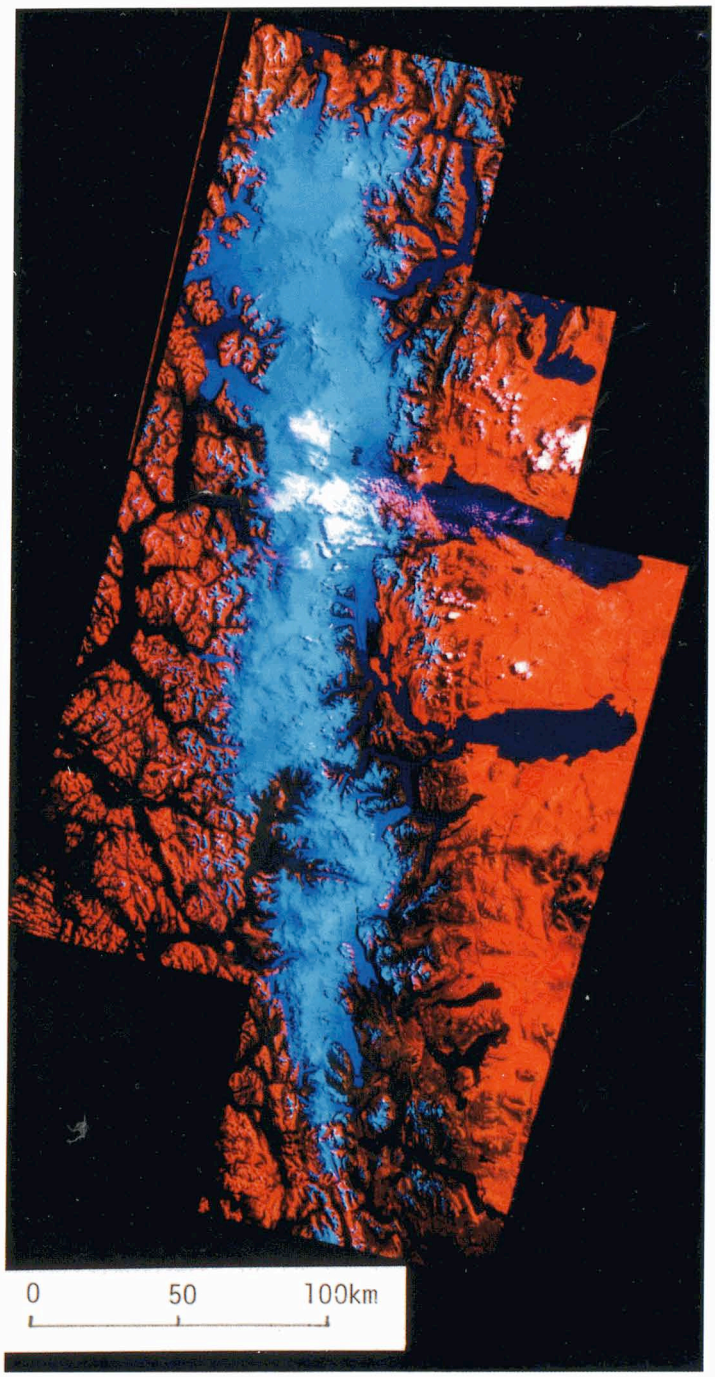

Fig. 1. Landsat TM mosaic of the Southern Patagonia Icefield (14 January 1986). Three consecutive scenes were pieced together, to which a geometric correction was applied using Carta Preliminar of Chile. Band 1 (0.45–0.52 μm, Blue), band 4 (0.76–0.90 μm, Green) and band 5 (1.55–1.75 μm, Red) were used to generate this image. Band 5 clearly separates ice-snow from clouds. The blue area is the icefield, where light blue is mostly snow-covered area and darker blue is mostly bare ice. White patches are clouds. Land with bare rock/soil is indicated with red and the green tint east of the icefield indicates vegetation (forest). Dark navy blue is lake, while dark channels to the west of the icefield are fjords (sea). Based on this Landsat image, the area of the Southern Icefield was measured as about 13000 km^2.

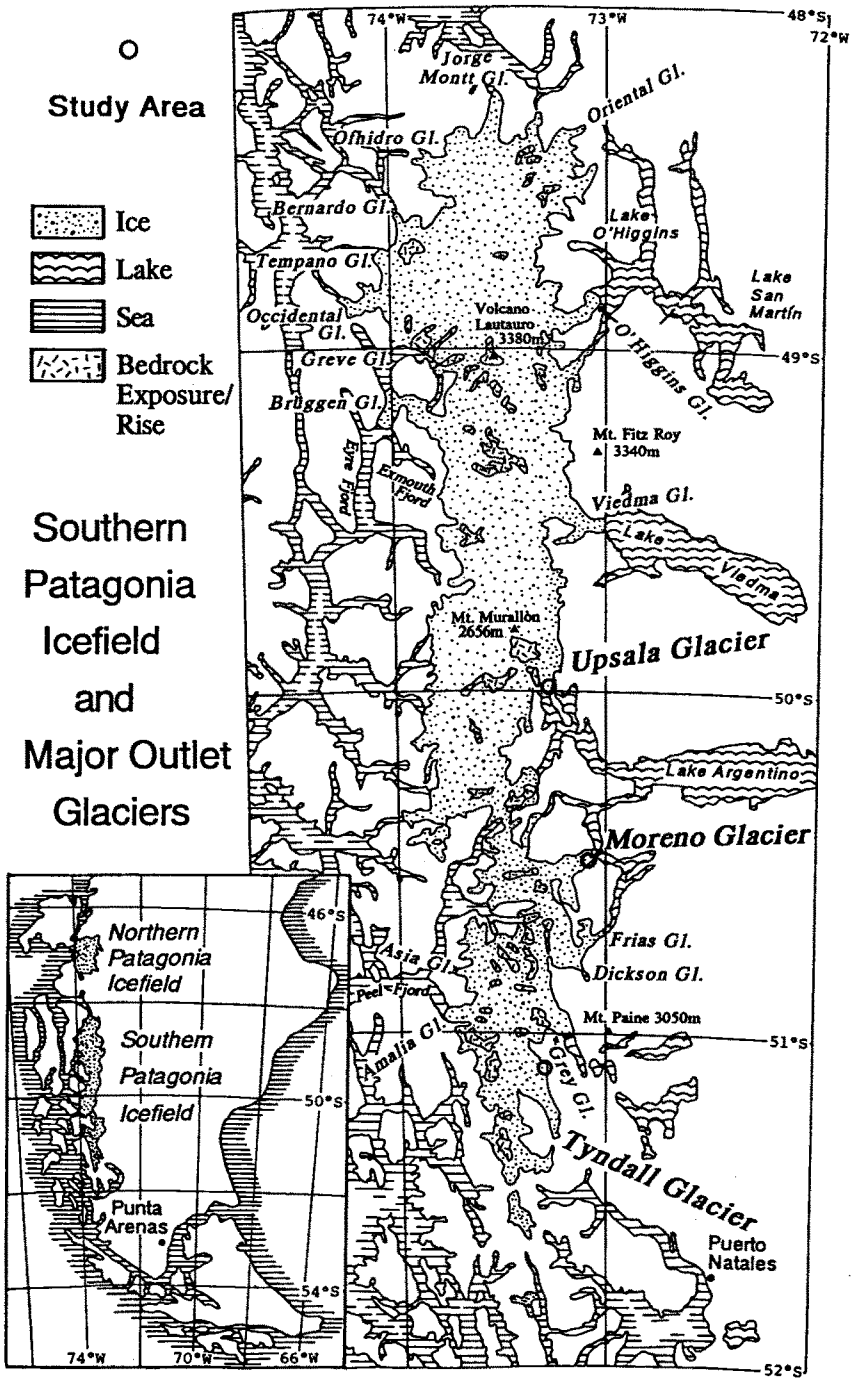

Fig. 2. Map of the Southern Patagonia Icefield, based on Lliboutry (1956) and elevations modified after Argentine topographic maps published by Instituto Geográfico Militar.

distributions and features of moraines around glaciers. Especially, it was revealed that most outlet glaciers around the Patagonia icefields have retreated extensively in recent years ; namely, 200 m/a at San Rafael Glacier from 1974 to 1986 (Aniya, 1988), and 85 m/a at Tyndall Glacier from 1975 to 1985 (Naruse *et al.*, 1987). It was also found that the ablation area of Soler Glacier thinned at a rate of 5.2 m/a from 1983 to 1985 (Aniya and Naruse, 1987). Also, by analyzing Landsat MSS (1976) and TM (1986) data, recent remarkable variations of Jorge Montt, Brüggen, O' Higgins and other glaciers in the SPI (see Figs. 1 and 2) were studied in detail (Aniya and Naruse, 1991).

These results motivated us to commence a research project "A Study of Characteristics of Recent Glacier Variations in Patagonia, Southern Andes" in the austral summer of 1990/91 at three glaciers : Upsala, Moreno and Tyndall glaciers. The present report gives the outline of the project (GRPP-90).

2. Objectives

The project aims ultimately at clarifying the processes and mechanisms of variations of temperate glaciers in response to climatic changes. In order to obtain the basic information on the recent behaviors of Patagonian glaciers, it was planned to carry out the following research topics :

1) Surface elevation of glaciers,
2) Variations in glacier fronts,
3) Flow of glaciers,
4) Ice thickness and glacier surface structure,
5) Meteorological conditions and ablation of ice,
6) Geomorphology around glaciers, and
7) Aerial photographic survey.

3. Characteristics of research areas

3.1. Upsala Glacier

Upsala Glacier is about 60 km long and 4 km wide near the snout with a drainage area of 870 km^2 (excluding bedrock exposures in the ablation area), the largest in South America. It flows southward from the icefield, terminating currently in Brazo (or Bahía) Upsala of Lago (Lake) Argentino, at an elevation of about 180 m a.s.l. around 49°59'S and 73°17'W. There are two big medial 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 joining from the western side. 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) is estimated at around 1150 m, which gives an AAR (Accumulation Area Ratio) of 0.63.

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. The general height of the divide is around 2000 m with the highest peak of 2950 m. The glacier flows out northeastward and currently terminates in a channel of Lago Argentino at an elevation of about 180 m, dividing the channel into the Canal de los Témpanos 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 dammingup of the Brazo Rico by reaching the opposite bank (Península Magallanes) in this century. The heights of the calving front are 50-70 m. The glacier surface is very clean, and medial moraines cannot be tracked on the ground. The ELA is also taken to be about 1150 m, and the AAR is 0.71.

3.3. Tyndall Glacier

Tyndall Glacier, flowing southward from the icefield and currently terminating in a proglacial lake at an elevation of about 50 m around 51°15'S and 73°15'W, is the southernmost major outlet glacier in the SPI. The area is estimated at about 355 km^2, and it is about 40 km long. The elevation of the accumulation area in the icefield is around 1500 m. The ablation area is mostly valley-confined, about 16-22 km long and 3.5-10 km wide. It has two small side lobes on the left bank about 17 km and 20 km from the present snout. There is one big cluster of nunataks (1400-1600 m high) in the middle of the glacier, from which a distinctive medial moraine can be traced all the way down to the snout. The ELA is estimated to lie around 1000 m, giving an AAR of about 0.59.

3.4. Northern Patagonia Icefield (NPI)

The Northern Patagonia Icefield is about 100 km

long and 45 km wide, with more than 20 temperate outlet glaciers. Monte (Mt.) San Valentín, located at the northeast corner of the area, is the highest mountain in this area with an elevation of 3910 m, which is also highest in the entire Patagonia region. A large part of the icefield lies between 1000 m on the western side and 1500 m on the eastern side. The eastern (leeward) side is relatively dry, whereas the western side is very wet due to the prevailing westerlies. Reflecting these climatic conditions and the location of the divide (to the east of the center), western outlet glaciers are generally larger and more active than the eastern ones.

4. Outline of field research

Researches were made at the Upsala Glacier region in the National Park Los Glaciares, Argentina, from 9 to 19 November 1990, at the Moreno Glacier region in the same Park from 21 to 29 November, and at the Tyndall Glacier region, in the National Park Torres del Paine, Chile, from 5 to 19 December. Outlines of field researches are given in the following sections.

4.1. Surface elevations of glaciers

The primary objective of this project is to obtain thickening or thinning rates of glaciers by repeated geodetic surveys with an interval of few years. As the first survey of the project, measurements of surface elevations were made at Upsala, Moreno and Tyndall glaciers. A control station and an azimuth point were established on bare-rocks at the side margin in the ablation area of each glacier. An electronic distance meter (Topcon EDM-Guppy) was set at the control station, and a mobile team placed an EDM reflector on the glacier surface. At each survey point, a distance, a vertical angle and an azimuth were measured from the control station. Three dimensional coordinates of each point can be determined from these measurements.

Upsala Glacier : Almost all over the ablation area of the glacier, there existed numerous large crevasses and seracs of several meters high. There were water streams and lakes along the border between the glacier and the eastern (left-side) bank, and a line of survey points were selected at about 2.5 km from the present glacier front, where we could reach easily. Although the survey was impeded sometimes by strong winds, rains and fogs, it was accomplished on 14 November at eight points in a distance of about 1.8 km along an approximate transverse profile from the vicinity (point U-1) of the left margin of the glacier to the right-hand edge (point U-8) of the medial moraine. Surface elevations were obtained as 521 m at point U-1, 551 m at the left-hand edge of the medial moraine, and 563 m at point U-8, assuming the elevation of the control station on the left bank to be 600 m a.s.l.

Moreno Glacier : Two survey lines in the form of a cross were set up in the middle reach of the ablation area around 5 km from the present glacier front, along a longitudinal line at the center where a thin medial moraine stretches and along a transverse line from the southern (right-hand) margin to the median line. Each survey line consists of six survey points in a distance of 1.5 km. There were no large crevasses along the survey lines, but existed several large water ponds on the ice surface. Surveys were made on 25 and 26 November. Along the longitudinal profile the surface elevation decreased gently from 368 m to 352 m, and along the transverse line it decreased from 362 m near the median line to 355 m at the closest survey point to the right margin, assuming the elevation of the control station at the right bank to be 420 m a.s.l.

Moreno Glacier extrudes its tongue about 2 km in length into the Brazo Rico (or Lago Rico), a southwestern arm of Lago Argentino. No detailed information on the height of the ice cliff at the glacier front had been obtained before. A short base line, 160 m long, was established on the lake beach, and the surface profile of the frontal portion of the glacier was measured by the triangulation method on 28 November. The height of the glacier surface above the present lake level was found to be 55 m at the eastern edge of the calving front and 77 m at about 1 km from the front, as shown in Fig. 3.

Tyndall Glacier : A transverse survey line was set up along the almost same line as in the previous survey (Naruse *et al.*, 1987). From the eastern (left-hand) margin in the middle reach of the ablation area, 13 points along a 5 km long profile were subjected for measurements on 7, 10, 13 and 15 December 1990. Surface elevations were 637 m at the survey point T-1 near to the left margin, 673 m at the medial moraine (T-10), and 690 m at point T-12 (640 m west of T-10), assuming the elevation of the control station at the left bank to be 678 m a.s.l.

By comparing the surface profile obtained in December 1990 with that in December 1985, it was

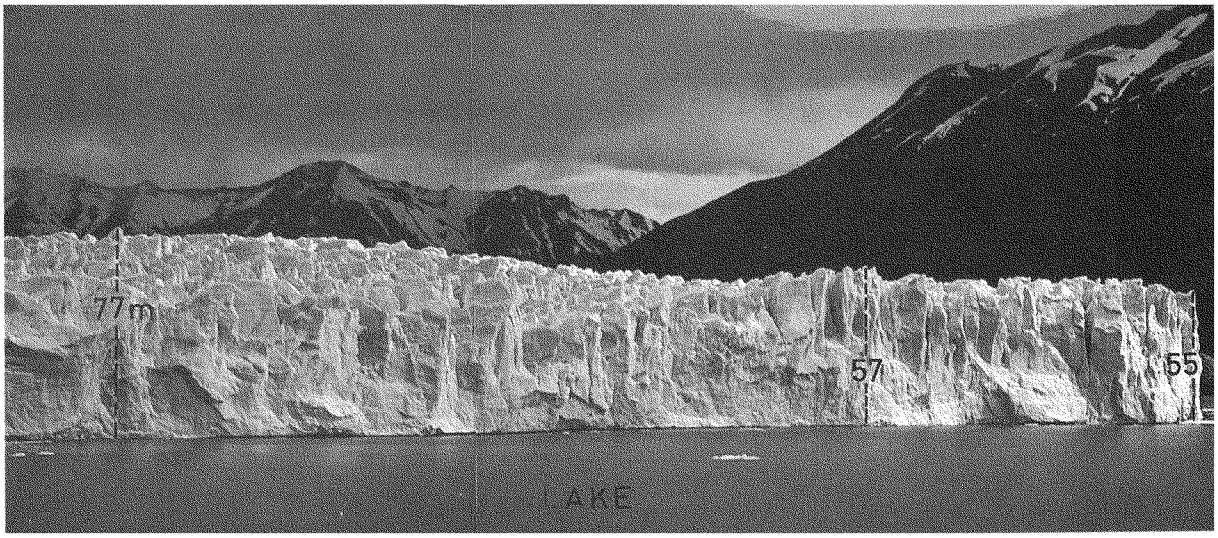

Fig. 3. Photograph showing the frontal part of Moreno Glacier taken on 28 November 1990 from the southern beach of the Brazo Rico. Numbers in the photograph indicate heights (m) above the present lake level.

found that the glacier surface in this area has lowered by about 20 m, or at a rate of about 4.0 m/a during these five years, a considerably large thinning rate (Kadota *et al.*, 1992).

Resurveys of the surface elevations at these three glaciers are planned in 1993/94.

4.2. Variations in glacier fronts

Frontal positions of Upsala and Moreno glaciers were mapped by field observations. By using aerial photographs and satellite images available, the variation of Upsala Glacier during a period from the early 1960s to 1990 and that of Moreno Glacier from 1947 to 1990 were studied. It became clear that Upsala Glacier has been in a recessive stage, particularly the eastern part of the front, which has retreated about 5 km during the last 10 years. On the other hand, Moreno Glacier is considered to have been nearly in the equilibrium condition and only the frontal part has been oscillating frequently (Aniya and Skvarca, 1992).

4.3. Flow of glaciers

During our stays in these three glacier areas, remeasurements of some survey points described above *4.1.* were successfully carried out and surface ice-flow velocities were obtained. At Upsala Glacier, a considerably rapid velocity of about 3.6 m/d averaged over four days was obtained near the medial moraine. At Moreno Glacier, velocities were obtained at 11 points with an interval of one day. The rate increased from 0.38 m/d near the right margin to about 2 m/d at the center. No significant changes in velocities were observed at points aligned along the median line, with values ranging from 1.9 to 2.1 m/d (Naruse *et al.*, 1992). At Tyndall Glacier, the distribution of velocities along a transverse line ranged from 0.07 m/d near the left lateral margin to 0.51 m/d at a point 2.5 km from the margin. Velocity value at each point increased by about 0.1 m/d within several days (Kadota *et al.*, 1992).

4.4. Ice thickness and glacier surface structure

At Tyndall Glacier, two types of impulse radars with frequencies of 2.5 and 1.25 MHz were tried for the first time in Patagonia to measure the thickness of temperate ice. Measurements were successfully made at seven points along the transverse line in the ablation area in December 1990. A parabolic profile of the bed was deduced, with a maximum thickness of about 600 m at a point 3 km from the left margin (Casassa, 1992a).

Distribution of foliation patterns in the surface ice was investigated at Tyndall Glacier (Casassa, 1992b). Topographical characteristics of drainages of Upsala and Moreno glaciers, and the surface pattern of medial moraines were also analyzed using aerial photographs and Landsat images (Aniya and Skvarca, 1992 ; Naruse *et al.*, 1992).

4.5 Meteorological conditions and ablation of ice

Measurements were made at an observation site installed on the bare-ice (in the ablation area) of Tyndall Glacier, during a period from 8 to 18 December 1990. Meteorological elements measured include (a) air temperature, (b) wind speed, (c) solar radiation, (d) all-wave radiation balance, (e) surface albedo and (f) ablation rate. In spite of the short period of observation, some characteristics were obtained about a relation between the surface ablation and air temperature, and the heat balance which caused the ablation in summer (Koizumi and Naruse, 1992).

4.6. Geomorphology around glaciers

Geomorphological research was made at the left bank of Upsala Glacier and at the Herminita Peninsula. Based on the glacial deposits and three main moraine systems recognized, variation of Upsala Glacier since the late Holocene to the present was elucidated (Malagnino and Strelin, 1992). Also glacial geomorphology was studied in the right bank area near the snout of Moreno Glacier.

Distributions of moraines and ice-scoured topography were investigated in the eastern area of Tyndall Glacier. Moraines were classified into three groups based mainly on the degree of vegetation covers (Yamada, 1992).

4.7. Aerial photographic survey

An aerial survey around the Northern Patagonia Icefield was successfully accomplished on 23 December. Utilizing the oblique aerial photographs taken, the variations of 21 outlet glaciers were elucidated for a period from 1985/86 to 1990/91. Glaciers on the western side of the icefield have retreated in greater degree than those on the eastern side (Aniya, 1992).

5. Members of the Project

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