Bulletin of Glacier Research 13 (1995) *127 – 132*

Recent climatic changes in western Patagonia

Benjamín ROSENBLÜTH[1], Gino CASASSA[2] and Humberto FUENZALIDA[1]
1 Departamento de Geofísica, Universidad de Chile, Casilla 2777, Santiago, Chile
2 Centro Austral Antártico, Universidad de Magallanes, Casilla 113-D, Punta Arenas, Chile

(Received December 7, 1994 ; Revised manuscript received January 30, 1995)

Abstract

Climatological data of long, reliable records between Puerto Montt (41°S) and Ushuaia (55°S) have been analyzed for detecting climatic trends, with special emphasis on western Patagonia. The data consist of mean annual values of temperature at 15 stations and precipitation at 5 stations collected since the beginning of this century. Temperature data show surface cooling at 41° and 42°S between the 1950's and 1970's on both sides of the Andes. However, the troposphere shows warming above the 2 km level at the same latitude. Between 43° and 45°S the surface temperature data show no significant trend during the last 100 years. South of 46°S a surface warming of 0.4 to 1.4°C since the beginning of the century can be observed. An important precipitation decrease of up to 1400 mm in the last 70 years has been observed at 52°–53°S on the Pacific side of the Andes. The generalized glacier retreat observed during this century in Patagonia is thought to be a response both to tropospheric warming and precipitation decrease.

1. Introduction

Climatically, Patagonia is located within the belt of the westerlies throughout the year, with high precipitation and strong winds. Because of its mid-latitude position, the climate in Patagonia is relatively warm and the ice is temperate. This results in a rapid turnover time for glacier ice, with high ablation and fast flow. Consequently, Patagonian glaciers are believed to respond rather quickly to climate changes.

Generalized glacier retreat has been observed in this century in Patagonia. Virtually all land-based glaciers and most calving glaciers in the Northern and Southern Patagonian Icefields are retreating and thinning at a fast rate (Naruse and Aniya, 1992). Glacier retreat is also evidenced by clear vegetation trimlines around Patagonian glaciers sometimes reaching over 100 m of the present ice surface, which correspond to a late neoglacial advance.

Although glacier retreat in Patagonia is probably a response to recent climatic change, care must be taken to interpret the behavior of calving glaciers, as pointed out by Warren and Sugden (1993), because they might not respond directly to climate but instead can be affected importantly by local topographic and dynamic causes. Such is the case of Moreno Glacier, which is nearly stable, and Pio XI (Brüggen) Glacier which is advancing (Aniya *et al.*, 1992).

In this paper long, reliable records of temperature and precipitation are analyzed for detecting recent climate changes in Patagonia and their relation with glacier variations.

2. Method

Temperature data include 10 Chilean stations and 5 Argentine stations, while precipitation data are composed of 5 Chilean stations, all of them south of 41°S. Chilean data were provided by Dirección Meteorológica de Chile and Argentine data were obtained from The World Weather Disc, version 2.0, May 15, 1990. Chilean stations are all located along the coast. Location of stations and record lengths are shown in Table 1 and Fig. 1.

Stations were selected as those having the longest and most complete records. Temperature data

Table 1. List of meteorological stations. Punta Arenas station corresponds to a combination of data of Radioestación Naval, airport at Bahía Catalina (both at Punta Arenas) and present airport at Chabunco, 24 km north of Punta Arenas. Punta Arenas — Fagnano is the station operated by the Salesianos (Catholic Church). TEM and PP. indicate temperature and precipitation data, respectively. ALT. is the elevation of the station.

STATION	TEM	PP.	PERIOD	LAT. °S	LON. °W	ALT.(m)	COUNTRY
PUERTO MONTT	YES	NO	1911—1988	41.4	73.1	110	CHILE
PUNTA CORONA	YES	NO	1910—1988	41.5	73.5	56	CHILE
ANCUD	NO	YES	1900—1988	41.9	73.8	20	CHILE
ISLA GUAFO	YES	YES	1908—1988	43.2	72.2	140	CHILE
PUERTO AYSEN	YES	NO	1931—1988	45.2	72.4	11	CHILE
CABO RAPER	YES	NO	1928—1988	46.5	75.4	40	CHILE
ISLA SAN PEDRO	YES	NO	1932—1988	47.4	74.6	22	CHILE
ISLOTE EVANGELISTAS	YES	YES	1899—1988	52.4	75.1	49	CHILE
BAHIA FELIX	NO	YES	1915—1984	53.0	74.1	15	CHILE
PUNTA ARENAS	YES	NO	1905—1988	53.0	70.9	34	CHILE
P. ARENAS at FAGNANO	YES	YES	1888—1988	53.1	70.5	28	CHILE
PUNTA DUNGENES	YES	NO	1900—1988	52.2	68.3	5	CHILE
BARILOCHE	YES	NO	1931—1987	41.2	71.2	836	ARGENTINA
ESQUEL	YES	NO	1931—1987	42.9	71.2	785	ARGENTINA
COMODORO RIVADAVIA	YES	NO	1931—1987	45.8	67.5	61	ARGENTINA
RIO GALLEGOS	YES	NO	1931—1987	51.6	69.3	17	ARGENTINA
USHUAIA	YES	NO	1931—1987	54.8	68.3	6	ARGENTINA

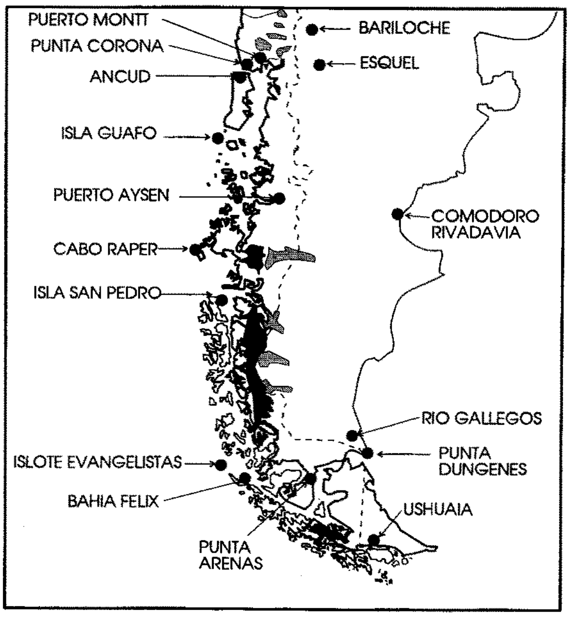

Fig. 1. Location of meteorological stations.

records have been inspected in detail and corrected by Rosenblüth and Fuenzalida (1991) and Aceituno *et al.* (1993) using a homogenization technique. For this purpose temperature series with high correlation were grouped as follows :

CHILE

Group 1 : Puerto Montt, Punta Corona, Valdivia and Temuco (Valdivia and Temuco have only been used here for homogenization).

Group 2 : Cabo Raper, San Pedro, Puerto Aysên and Isla Guafo.

Group 3 : Punta Arenas at Fagnano, Punta Arenas, Islote Evangelistas and Punta Dungenes.

ARGENTINA

Group 1 : Esquel, Maquinchao and Bariloche (Maquinchao has only been used here for homogenization).

Group 2 : Ushuaia, Río Gallegos and Comodoro Rivadavia.

Gap filling of temperature data was performed by means of time-series modeling (Rosenblüth and Fuenzalida, 1991). The series with largest changes are :

- Punta Arenas at Fagnano (1902—1906)
- Punta Arenas (1969—1971)
- Punta Corona (1910—1941)

Only isolated changes were performed to other stations. Homogenization and gap filling techniques are described in Rosenblüth and Fuenzalida (1991). No homogenization or gap filling was performed to precipitation series because of lack of long nearby records.

Both temperature and precipitation data have been smoothed with an exponential filter of the form (Essenwanger, 1986) :

$$y_t = cx_t + (1-c)y_{t-1},$$

where x_t is the original data at time t, y_t is the smoothed value at time t, and c is a coefficient between 0 (maximum smoothing) and 1 (no smoothing). A value of 0.25 for c was chosen because it resulted in suitable high-frequency smoothing without filtering excessively important multi-annual variations. The exponential smoothing was applied twice to each data set for better performance and is shown with a thick curve in Figs. 2, 3, 4 and 5. All the comments regarding climatic trends refer to this exponential filtering.

3. Temperature trends

A significant cooling of 1.4°C is observed at Puerto Montt and Punta Corona from 1953 to 1974 (Fig. 2). A similar cooling of about 1°C is also observed at Bariloche and Esquel from the 1940s to the 1970s (Fig. 3). This cooling appears clearly as well at Valdivia (39.8°S) and Temuco (38.5°S), and can be detected as north as Valparaíso (33°S), as reported by Aceituno *et al.* (1993). The cooling seems to correspond to the hemispheric cooling observed at the latitudinal belt of 30°–60°(Angell, 1988). The probable forcing mechanism of such cooling is a lowering of sea surface temperature (SST), as suggested from analysis of surface temperature and SST data for Valparaíso (Aceituno *et al.*, 1993). In Patagonia, south of 43°S no significant surface cooling is observed (Figs. 2, 3 and 4).

The cooling from 33°S to 41°S only seems to occur at the lower troposphere below the 2 km level, as reported by Aceituno *et al.* (1993), who analyzed upper-air temperature from Puerto Montt and Quintero (33°S). Above 2 km, a tropospheric warming of about 0.04°C/a has been observed from 1958 to 1988. Inspection of the upper-air data shows that stratospheric cooling has been occurring above the tropopause (ca. 15 km level). This pattern, i.e. tropospheric warming and stratospheric cooling, is consistent with a scenario of enhanced greenhouse effect (Aceituno *et al.*, 1993).

At Isla Guafo and Puerto Aysén (43°–45°S) the temperature data (Fig. 2) show no significant trend, even though a slight warming of 0.1°C can be detected in the 80 and 60-year record at these two stations, respectively. This confirms the earlier result of

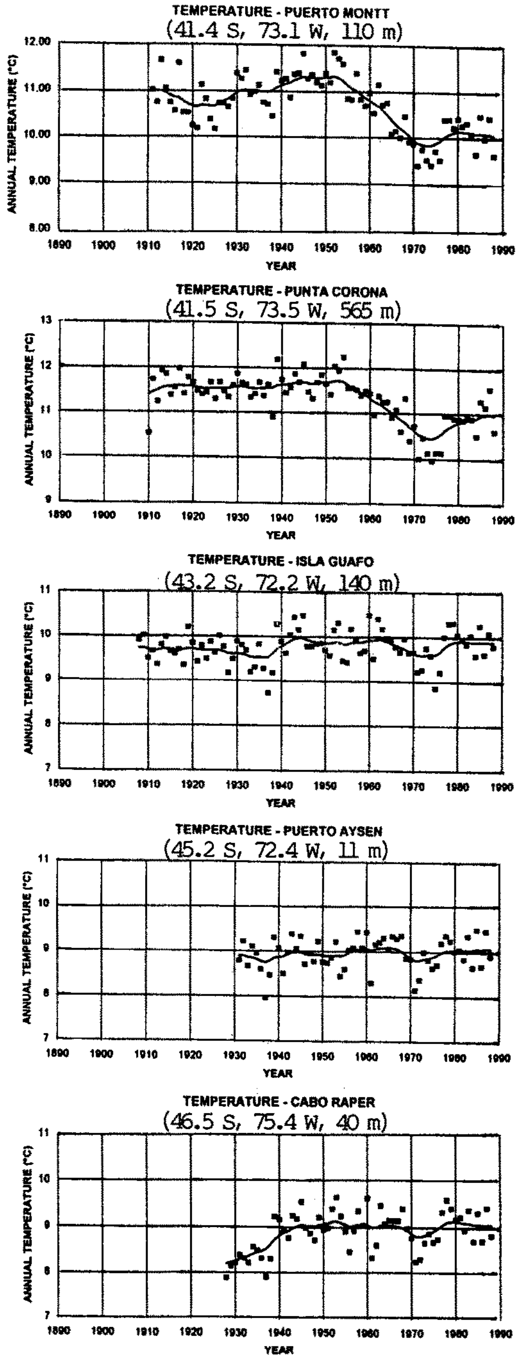

Fig. 2. Mean annual temperature data on the Chilean side from 41° to 46°S. The thick curves, also drawn on Figs. 3, 4 and 5, represent the exponential smoothing with $c=0.25$ as described in the text.

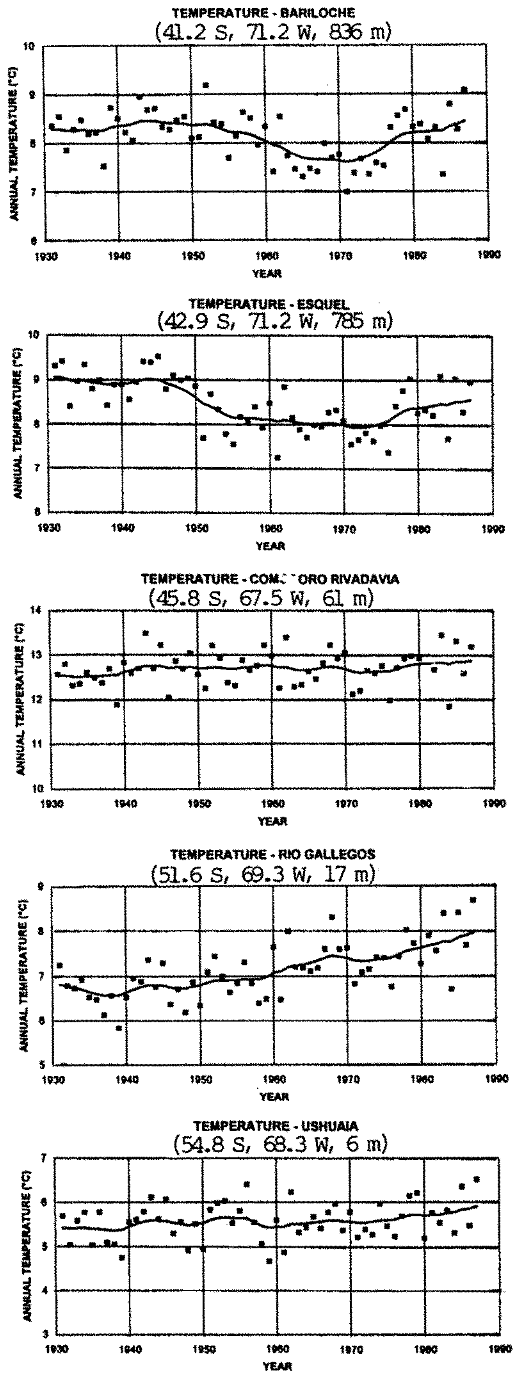

Fig. 3. Mean annual temperature data on the Argentine side from 41° to 55°S.

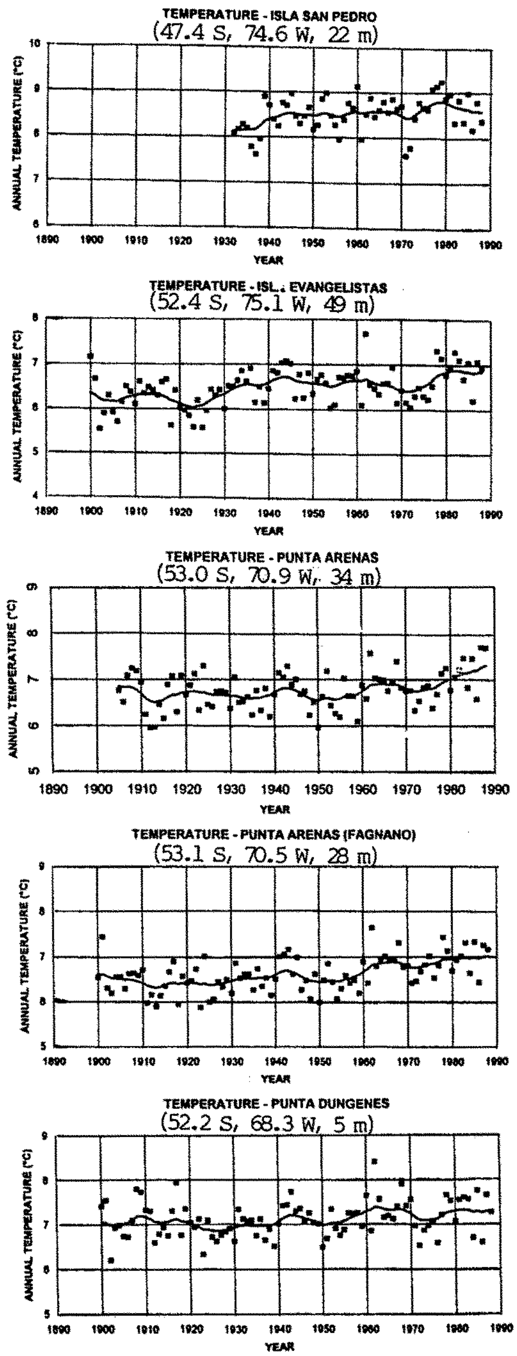

Fig. 4. Mean annual temperature data on the Chilean side from 47° to 53°S.

Aniya and Enomoto (1986), who found no temperature trend at Puerto Aysén.

South of 46°S a definite warming trend appears in the records, both on the Pacific and the Atlantic coast, especially in the last two decades. This warming is more pronounced at Río Gallegos, where a warming of 1.4°C from 1938 to 1988 is observed (Fig. 3). Curiously, the weakest warming occurs at Punta Dúngenes, only 100 km southeast from Río Gallegos, with an increase of only 0.3°C from 1900 to 1988 (Fig. 4). The warming trend south of 46°S is consistent with the global warming of about 0.6°C observed in the southern hemisphere in the last 130 years (Jones *et al.*, 1990).

The warming observed in Fig. 4 since 1970 at Punta Arenas and Punta Arenas-Fagnano does not appear in the records of Endlicher and Santana (1988), which is the same record reported by Warren and Sugden (1993). This is because a different data source was used by Endlicher and Santana and no homogenization was carried out. In fact, the data set of Endlicher and Santana is a combination of the following three stations (Santana, personal communication) :

1888–1940 Punta Arenas at Fagnano, Salesianos observatory
1941–1969 Punta Arenas at Bahía Catalina
1970-present Punta Arenas at Schythe, Instituto de la Patagonia.

In general, warming increases with latitude, especially along the eastern side of the Andes (Fig. 3). The same latitudinal increase has been observed by Hoffman (1990). This warming trend has also been detected in the Antarctic Peninsula, where it is very pronounced in recent years (Morrison, 1990) and is thought to be the cause of extensive ice shelf retreat (Doake and Vaughan, 1991).

4. Precipitation trends

Precipitation records are shown in Fig. 5. Because these series have not been homogenized or completed for gaps, trends must be interpreted cautiously.

A conspicuous precipitation increase of 700 mm is evident at Ancud from 1963 to 1977. At Isla Guafo an increase and subsequent decrease of 800 mm is observed between 1928 and 1965. At Punta Arenas a strong cyclicity with a period of about 35 years is observed until 1965. Overall, no trend is observed at

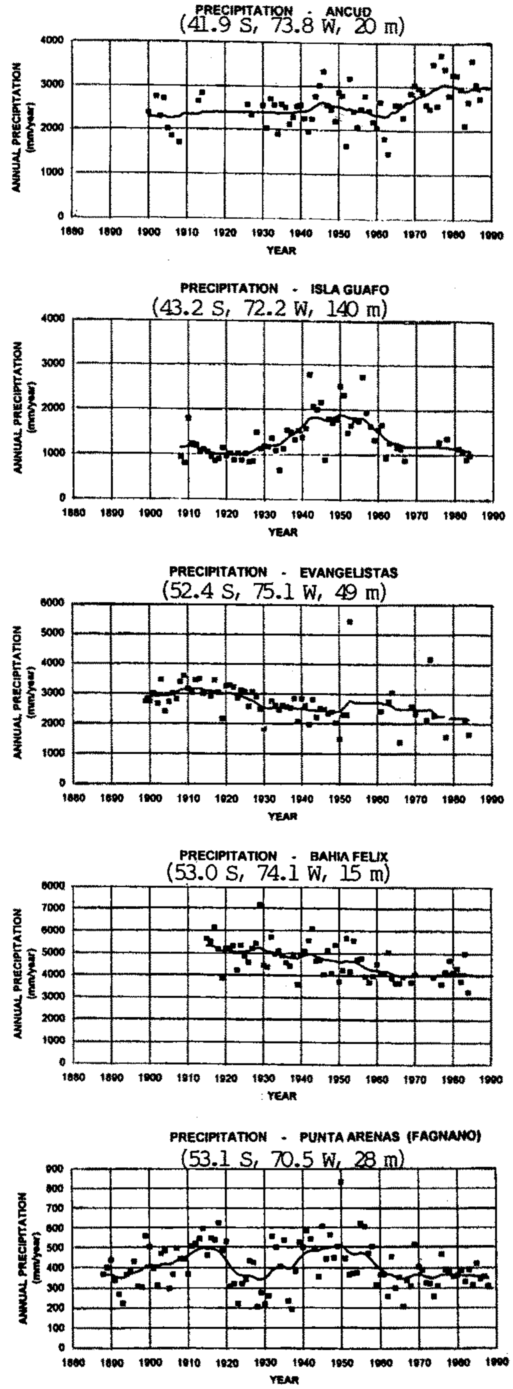

Fig. 5. Annual precipitation data on the Chilean side from 42° to 53°S. The data correspond to raw values which have not been homogenized and some years are missing in the records. Therefore, in a strict sense the exponential smoothing cannot be applied. However, in order to have an idea of the general precipitation trend, the exponential smoothing was calculated by assuming a value identical to the annual precipitation before the data gap for the missing years.

Punta Arenas between 1888 and 1988.

The most significant precipitation trend occurs at Islotes Evangelistas and Bahía Felix, on the western margin of the Straits of Magellan, where a near-monotonic precipitation decrease is observed in this century. This precipitation decrease is 1,000 mm at Islotes Evangelistas from 1900 to 1985, and 1,400 mm at Bahía Felix from 1915 to 1985.

5. Concluding remarks

The most significant temperature trends are : 1) Surface cooling of 1.4°C from 1953 to 1974 and upper-air warming of about 0.04°C/a in the troposphere above 2 km at 41°S ; 2) No significant surface change at 43°to 45°S ; and 3) Clear surface warming of 0.003 to 0.03°C/a observed during this century from 46° to 55°S. Regarding precipitation, the only reliable trend is a strong precipitation decrease of 1,000 to 1,400 mm during this century at 53°S on the western end of the Straits of Magellan.

Although there is a near-zero variation of surface temperature at 43° to 45°S, in view of the upper-air warming at Puerto Montt, which is also observed at Quintero (33°S) and Antofagasta (24°S) (Aceituno *et al.*, 1993), it is possible that tropospheric warming might be occurring as well at 43° to 45°S.

From the above climatic trends it is most probable that generalized glacier retreat observed in Patagonia during this century is largely due to an observed temperature increase from 41° to 55°S. At least around 53°S, this glacier retreat must also be affected by an important precipitation decrease which has been observed on the Pacific coast.

Acknowledgments

Most of the Chilean data has been provided by Dirección Meteorológica de Chile. Data analysis was partially supported through FONDECYT grant 1177-89. Fig. 1 was drafted by Alejandro Oyaneder of Universidad de Magallanes. Valuable discussions were held with Ariel Santana of Instituto de la Patagonia, Universidad de Magallanes.

References

1. Aceituno, P., Fuenzalida, H. and Rosenblüth, B. (1993) : Climate along the extratropical west coast of South America. In : Earth System Responses to Global Change : Contrasts between North and South America, Academic Press, 61-69.
2. Angell, J.K. (1988) : On the functioning of the Southern Oscillation in the South American sector. I surface climate. Mon. Wea. Rev., **116**, 505-523.
3. Aniya, M. and Enomoto, H. (1986) : Glacier variations and their causes in the Northern Patagonia Icefield, Chile, since 1944. Arc. Alpine Res., **18**(3), 307-316.
4. Aniya, M., Naruse, R., Shizukuishi, M., Skvarca, P. and Casassa, G. (1992) : Monitoring recent glacier variations in the Southern Patagonia Icefield, utilizing remote sensing data. Proceedings, XVII International Congress for Photogrammetry and Remote Sensing, **XXIX**(B7), 87-94.
5. Doake, C.S.M. and Vaughan, D.G. (1991) : Rapid disintegration of the Wordie Ice Shelf in response to atmospheric warming. Nature, **350**, 328-330.
6. Endlicher, W. and Santana, A. (1988) : El clima del sur de la Patagonia y sus aspectos ecológicos. Un siglo de mediciones climatológicas en Punta Arenas. Anales Instituto de la Patagonia, **18**, 57-86.
7. Essenwanger, O.M. (1986) : Elements of Statistical Analysis. World Survey of Climatology, Vol. **1B**, H.E.Landsber (*ed.*), Elsevier, Amsterdam.
8. Hoffman, A.J. (1990) : De las variaciones de la temperatura del aire en la Argentina y estaciones de la zona subantártica adyacente, desde 1903 hasta 1989 inclusive. Actas, Primera Conferencia Latinoamericana sobre Geofísica, Geodesia e Investigación Espacial Antárticas, Buenos Aires, 30 Julio al 3 Agosto 1990, 160-168.
9. Jones, P.D., Wigley, T.M.L. and Wright, P.B. (1990) : Global and hemispheric global temperature variations between 1861 and 1988. NDP-022/R1, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
10. Morrison, S.J. (1990) : Warmest year on record on the Antarctic Peninsula? Weather, **45**, 231-232.
11. Naruse, R. and Aniya, M. (1992) : Outline of Glacier Research Project in Patagonia, 1990. Bull. Glacier Res., **10**, 31-38.
12. Rosenblüth, R. and Fuenzalida, F. (1991) : Recent temperature variations in austral South America. 2nd International Congress of the Brazilian Geophysical Society, Salvador, Bahía, Oct. 27-Nov. 1, 1991, 1006-1011.
13. Warren, C.R. and Sugden, D.E. (1993) : The patagonian icefields : a glaciological review. Arc. Alpine Res., **25**(4), 316-331.