Pesquisa Antártica Brasileira (2004) 4: 49-56
(Brazilian Antarctic Research)
ISSN 0103-4049
www.cnpq.br/areas/terra_meioambiente/proantar/

Small cirque glaciers retreat on Keller Peninsula, Admiralty Bay, King George Island, Antarctica

JEFFERSON C. SIMÕES, NORBERTO DANI, ULISSES F. BREMER, FRANCISCO E. AQUINO and JORGE ARIGONY-NETO

Núcleo de Pesquisas Antárticas e Climáticas, Departamento de Geografia
Instituto de Geociências, Universidade Federal do Rio Grande do Sul – 91501-970 Porto Alegre, RS, Brasil

ABSTRACT

Variations in the total area covered by four small corrie glaciers in the eastern slopes of Keller Peninsula, Admiralty Bay, King George Island (KGI) are investigated using a topographical survey, carried out in the austral summers of 1992/93 and 1993/94. For this survey, aerial photographs, satellite images and mapping surveys (from the 1950s onwards) were compared. All four glaciers have lost between 44 to 83% of their areas from 1979 to 2000. At least two glaciers already have some stagnant parts and may disappear if the present climatic warming trend in the region persists.

Key words: Glaciology, glacier retreat, environmental monitoring.

INTRODUCTION

Recently, several studies have provided evidence of a general glacier retreat in the South Shetlands (Kejna et al. 1998, Park et al. 1998, Calvet et al. 1999, Simões et al. 1999, Bremer et al. 2004, this volume). Because of their small dimensions and thermal conditions, near or at the pressure melting point, these ice masses are very sensitive to environmental changes (Knap et al. 1996) and may be responding to a regional climatic warming (Ferron et al. 2004, this volume). However, a direct relationship between the glacier retreat and the present atmospheric warming has yet to be presented. Glaciers are known to respond with different time lags to environmental changes (Paterson 1983) and ice masses in the South Shetland Islands may still be retreating after an advance, the result of a regional Neoglacial maximum (i.e. the Little Ice Age) in early 18th century (Birkenmajer 1979). Furthermore, a great number of glaciers in the region terminate in fjords or directly into the sea (Simões et al. 1999), complicating further environmental interpretations on ice front position variations.

In this paper, we investigate variations in the total area covered by four small corrie glaciers on the eastern slopes of Keller Peninsula (Figure 1 and Figure 2), Admiralty Bay, King George Island (KGI). This small peninsula, about 3.8 km long and less than 2.0 km at its widest part, forms a divide between Martel and Mackellar Inlets. It is cut along its longitudinal axis by a range of hills, 250-360 m of maximum altitude.

There are 5 peaks marking Keller Peninsula. The western slopes of the peninsula are ice-free, on the eastern or southeastern side each peak maintains a small cirque glacier (Figure 2). The Ferguson and Flagstaff Glaciers (Figure 3b) occupy, respectively, the south-eastern slope and an eastward cirque of Flagstaff Hill, 278 m. Noble Glacier (Figure 3c), about 800 m long, occupies the south-eastern cirque of North Peak, 326 m. In the summer of 1993–94 its front was at about 110 m in altitude. Babylon Glacier (Figure 3c) is a small hanging glacier that avalanches over a steep rock face on to the western

Correspondence to: Jefferson Cardia Simões
E-mail: jefferson.simoes@ufrgs.br

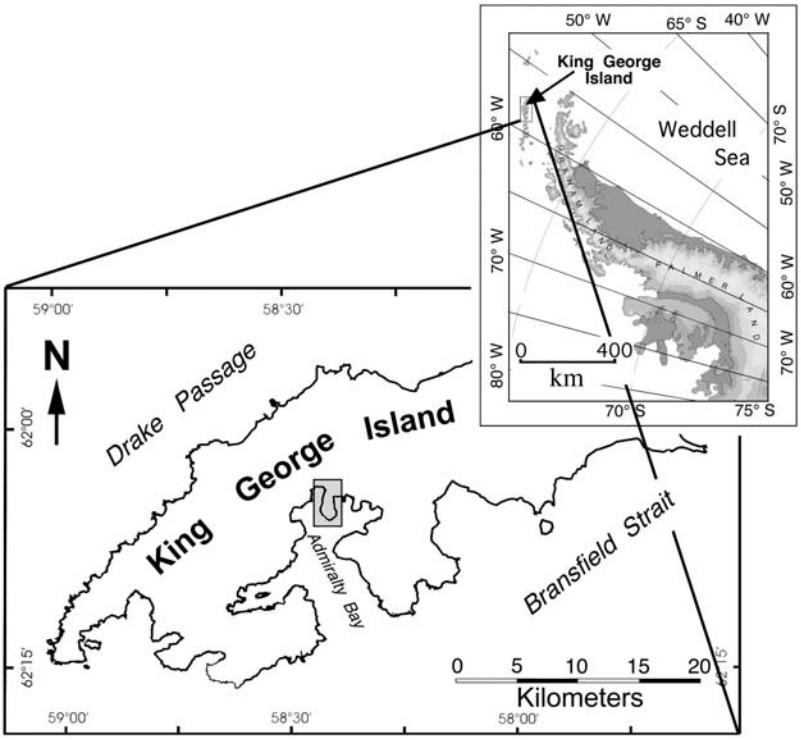


Fig. 1 – Location of Keller Peninsula (small grey square, Figure 2) in King George Island. Inset shows the position of KGI, west of the Antarctic Peninsula.

side of the Stenhouse Glacier (part of the main KGI ice cap). In total, the four glaciers cover presently only 296,186 m^2. They are located between the 120 m and 320 m contours. A complex series of lateral and terminal moraines mark their previous extent, except for the Babylon Glacier. Some of these moraines mark a glacier readvance at about 740 years ago (Birkenmajer 1979), a general retreat is recorded for the 20th century (Stansbury 1963 unpublished, Noble 1965).

Several characteristics are thought to guarantee the fast response of these glaciers to climatic variations:

a) They are small, the largest one, Noble Glacier (Figure 2), covers presently less than 0.14 km^2, having no connections with the KGI main ice cap;
b) they are at or near the pressure melting point;
c) their heads are at low elevation, 320 m for Noble Glacier.

Glaciological investigations done by the Falkland Islands Dependencies Survey (FIDS) began in the late 1940s. It was continued by its successor, the British Antarctic Survey (BAS), during the 1960s. Hattersley-Smith (1949 unpublished), Stansbury (1963 unpublished), and Noble (1965) provided data for the earlier part of this study. In the austral summers of 1992/93 and 1993/94 two field seasons were carried out by the *Laboratório de Pesquisas Antárticas e Glaciológicas* (LAPAG) of the *Universidade Federal do Rio Grande do Sul* (UFRGS) to re-survey the area. Recently, LAPAG was re-structured as *Núcleo de Pesquisas Antárticas e Climáticas* (NUPAC), at the same institution.

MATERIALS AND METHODS

Initially, the two glaciers that had been previously surveyed by British scientists, Flagstaff and Noble (Hattersley-Smith 1949 unpublished, Stansbury 1963 unpublished, Noble 1965) were chosen for this

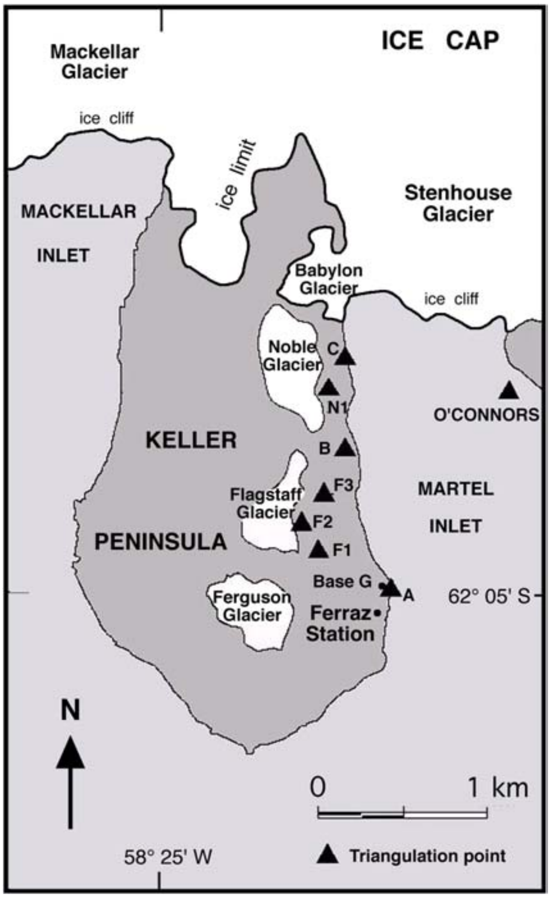


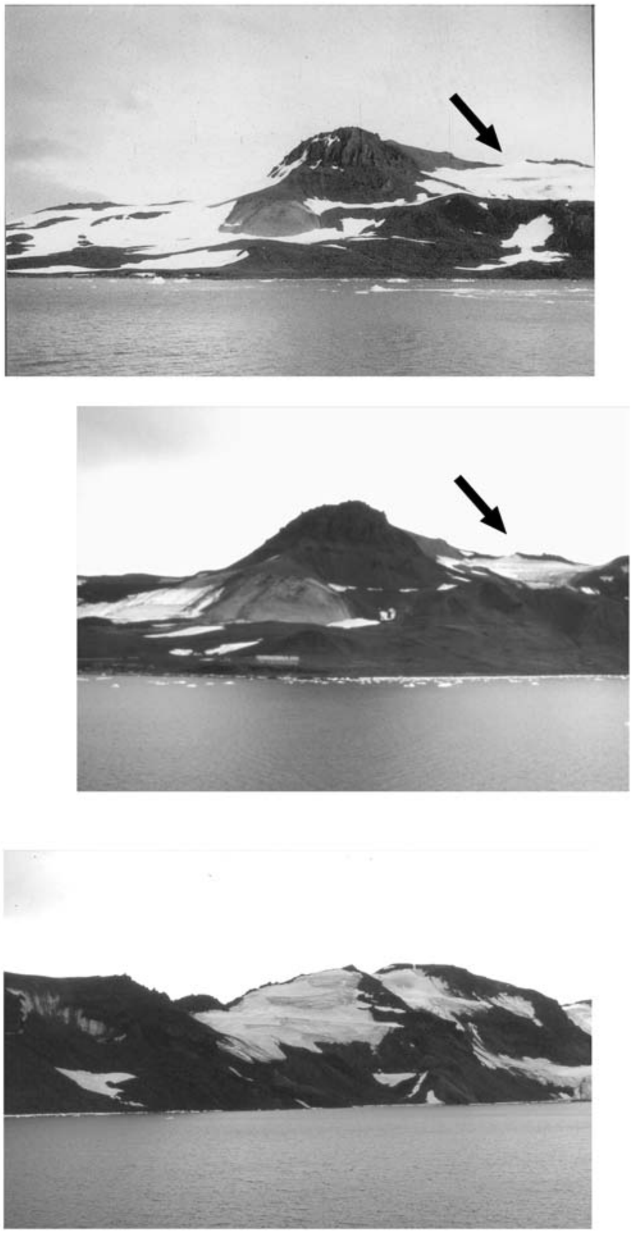
Fig. 2 – Keller Peninsula: Location of the four cirque glaciers (Babylon, Ferguson, Flagstaff and Noble) studied in this paper. Note also the position of the triangulation points. The figure also locates the Brazilian Station Comandante Ferraz and the former site of the British Base G (now removed).

study. However, preliminary fieldwork in December 1992, including the determination of stake movements, concluded that Flagstaff Glacier (Figure 3b) was already a mass of stagnant or quasi-stagnant ice, fast disappearing. Therefore, the complete study was only carried out on the Noble Glacier.

A network of points was established on the east side of Keller Peninsula (Figure 2), using the triangulation method. Each point position was carefully implanted, considering parameters such as visibility of the glaciers, best triangle resolution (equilateral or near equilateral triangles) and optimal ground conditions (fixed substrate). Point A, origin of the network, was close to the Brazilian Comandante Ferraz Station, 62°05'S, 58°23.5'W (Figure 2). This base line was measured using an electronic distance meter (Wild DI10), with a nominal error of 1: 100,000. Angles were evaluated using a theodolite Wild T2, with direct reading of one second (1"). From point A, coordinates were transported to all others points of the network by computing triangles. When possible, distances were checked by direct measurements using DI10. At each point, angles were measured by the reiteration method, covering the four limb sectors of the theodolite. The adopted angle was the median of the reiteration values, only the determinations with differences not superior to 5" were considered. Additionally, the sum of angles of each triangle was verified. When the sum of the internal angles differed by more than 10", the measurement was discarded.

Two lines of 5-m stakes (buried 2 m into the snow) were implanted in the Noble Glacier surface, one following roughly the direction of the ice flow and the other line perpendicular to it, following the monitoring method described by Paterson (1983). Intersections of these stakes, on the Noble Glacier, were made from B, N1, and C. The movement of each stake was calculated by means of a local coordinate grid system that used B, N1 and C as its base line. Observations on the movement of the Noble Glacier stakes were limited to readings in January and February of 1993 and repeated one year later in January and February of 1994. In this period, the stakes A and C were lost. These readings covering a time span of one year are considered sufficient for calculations of glacier movement to be made.

The position of the Noble Glacier ice front, in January 1993, was measured using the radial method centered on points N1 and C. Each point of the ice front was determined by an angle and a distance. This was later evaluated by tachometry. Points were transformed to the same coordinate system found on the base map of Stansbury (1963 unpublished) and then plotted to compare with the same map (Figure 4). To determine the front position of a main outlet glacier, Stenhouse, intersections were made from points C and O'Connors.



3a

3b

3c

Fig. 3 – Photographs of the study area: 3a) Keller Peninsula, photograph taken by the Falkland Island Dependencies Survey on 18 January 1948 from Martel Inlet. Notice the limits of the Flagstaff Glacier (arrow); 3b) Flagstaff glacier (arrow) as observed in mid January of 1996. By then this glacier was a mass of quasi-stagnant ice. The authors took this photograph also from Martel Inlet but at slight different angle; 3c) Noble glacier is in the center and Babylon Glacier in the extreme right of the photograph taken at the some moment of 3b.

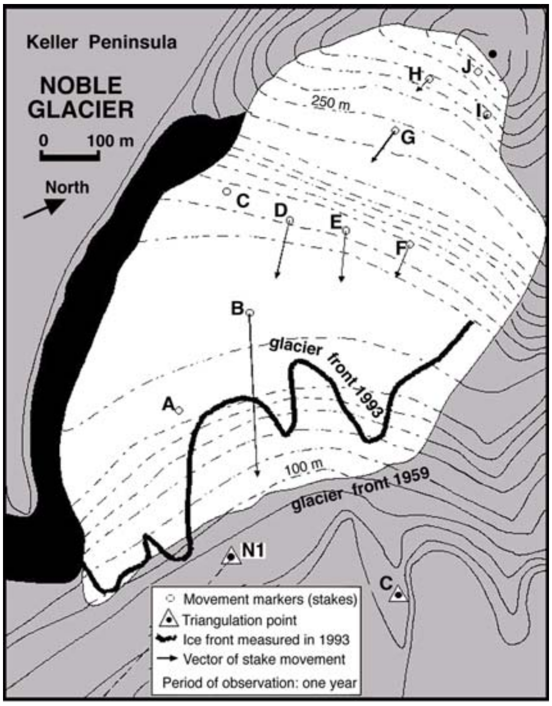


Fig. 4 – Topographical map of the Noble Glacier as surveyed by the Falkland Islands Dependencies Survey (presently, the British Antarctic Survey) in 1959 (source: Stansbury 1963 unpublished). The map also shows the position of the stakes implanted in 1993 and the one-year movement vectors, at a scale of 1: 200 (see Table I for exact values). The glacier front, as surveyed in the summer of 1992–93, is also shown.

The older and more complete data set on the position, size of cirque glaciers and ice front on Keller Peninsula pertains to the map published by the Polish Academy of Science (Furmanczyk and Marsz 1980), scale 1: 25,000. The resulting map was elaborated from aerial photographs obtained in the antarctic summer of 1979 and complemented by topographical methods. The Polish map was adopted as a base map for this work (Figure 5), after verifying map fidelity with aerial photographs (taken by the Royal Navy in 1975, at a scale of about 1: 11,000).

The position of these glaciers in the summer of 2000 was obtained using a SPOT satellite image (SPOT-4 XS 725-477 of 23 March 2000). This image was taken in an exceptionally warm snowless period when only glacier ice was exposed, Braun et al. (2001) georeferred this image. The SPOT image was prepared and reduced to the same map projection used by the base map (Arigony-Neto 2001 unpublished) and the glaciers' limits were identified manually using ESRI ARC/INFO software. For the glaciers' areas, the mean estimated error, determined by this methodology, is 23%.

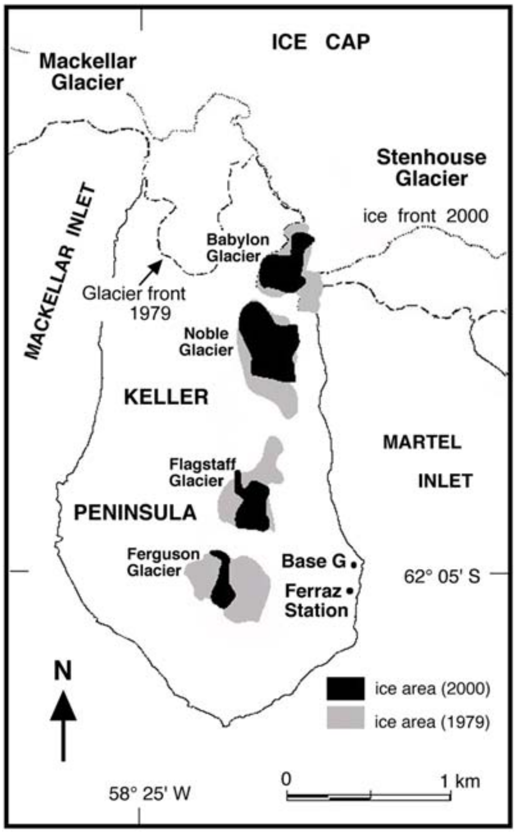


Fig. 5 – The map of Keller Peninsula showing the ice covered area in 1979 and 2000 (see text for details). Note the fast area reduction of the four cirque glaciers (Babylon, Ferguson, Flagstaff and Noble). The figure also shows the ice front of the Stenhouse Glacier in the same years.

The two sets of information have an age difference of twenty-one years; both were calibrated using a previously digitized map, derived from a FIDS survey (Stansbury 1963 unpublished). The shape of each glacier was copied using Micrografx Designer software. A methodology of pixel counts was employed to estimate the glaciers' areas.

RESULTS AND DISCUSSION

Based on the FIDS mapping (Stansbury 1963 unpublished), all four glaciers have retreated and lost a great part of their area since the late 1950s. Noble Glacier (Figure 3c) is now a slow moving glacier, maximum measured velocity < 5 m year^{-1} (Table I). Its ice front has retreated up to 100 m, from 1956 to 1993 (Figure 4), losing 103,564 m^2, 44%, of its area since 1979 (Table II), or 69% since 1959. The elevation range of this glacier (110-320 m) seems to be the reason for a smaller reduction rate when compared to the other 3 studied glaciers. Initially, a complete mass balance study of this glacier was devised, but field observations indicated that this area to be of a complex snow accumulation nature. Glacial ice is apparent on the glacier surface step between 190-220 m a.s.l., but it is under at least 1 m of firn, between 170-190 m a.s.l. (stakes D to F). This is observed at the end of the ablation season, from late January to early February. Firn is exposed even at the head of the glacier, altitude of 320 m, in late January (stake H). Early work, done by Orheim and Govorukha (1982), indicated the equilibrium line altitude (ELA) at about 150 m above sea level (a.s.l.), in 1970, for the KGI ice cap. Presently, mid-1990's, this is not the case, at least for the small glaciers on Keller Peninsula. Stake A (Figure 4) was lost after a year, indicating a negative mass balance of at least 2 m year^{-1}, at 150 m a.s.l.

The small Flagstaff Glacier, early identified by Stansbury (1963 unpublished) as a slow moving glacier with a strong negative balance, has additionally lost 111,473 m^2, 66% of its area (Table II), since 1979 (Figure 3a and 3b, Figure 5). It is fast disappearing, field evidence indicates that some parts of this ice mass are stagnant.

Babylon glacier is reduced to only 96,768 m^2, having lost 57% of its area since 1979. However, as it was difficult to separate the glacier from the seasonal snow cover, seen in the aerial photographs taken in 1975, this reduction may have been overestimated. Finally, Ferguson Glacier has lost 83% (i.e. 164,251 m^2) of its area, since 1979. No velocity measurements were taken, but visual observations at the site, in 1996, indicated that this ice mass has been reduced to a thin ice layer in several places, and is heavily covered by morainic material.

The ice front position of the Stenhouse outlet Glacier has remained relatively stable, retreating up to 110 m in the western part, near the Stenhouse Bluff (Figure 6). Near Keller Peninsula, in the eastern part, it advanced up to 75 m. Recent work by Arigony-Neto (2001 unpublished) recorded a general area loss of 0.44 km^2 from 1956 to 2000, particularly during the 1990s. This was concomitant to a general retreat of tidewater glaciers terminating in Admiralty Bay. Two factors may account for the relative stability of the Stenhouse Glacier: 1) it is a major outlet glacier of the KGI ice cap, covering 9.2 km^2. Its head is at 600 m a.s.l., 2) the present front position is near a steep bedrock step, marked at the surface by a 150-m icefall.

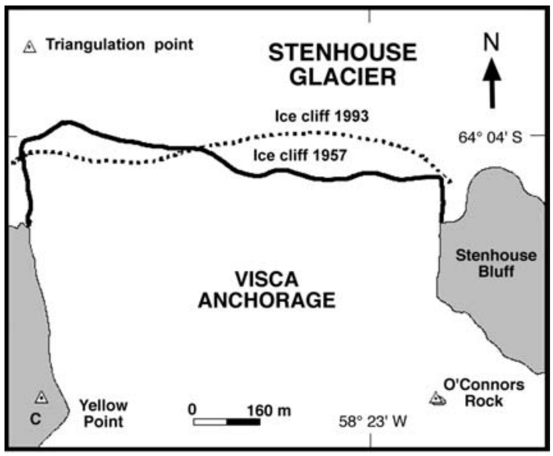


Fig. 6 – The Stenhouse Glacier ice front as measured in 1957 (source: Noble 1965) and in 1993 (this work). This is an outlet glacier from the King George Island ice cap. Its front position was stable until the early 1990s (see text for details).

In short, the ice-covered area in Keller Peninsula has been reduced by 476,058 m^2, 62%, in 21 years. This reduction correlates with a general glacier retreat on KGI, reported by Simões et al. (1999) and of a mean atmospheric temperature rise of 1.1°C, estimated for the Brazilian Ferraz Station site from 1947 to 1995 (Ferron et al. 2004, this volume). Further, energy flux and ablation modeling for the Ecology Glacier, situated in the south-eastern

TABLE I
Ice movement on the surface of the Noble Glacier between December 1993 and January 1995. Measurement errors are < 0.10 m.

Stake	A	B	C	D	E	F	G	H	I	J
Movement (m $year^{-1}$)	lost due to melting	4.49	lost	1.69	1.33	0.97	1.12	0.32	0.13	< 0.01

TABLE II
Ice covered areas by the four cirque glaciers on the Keller Peninsula, in 1979 and 2000. Note that for Noble Glacier data is provided for 1959, source: Stansbury (1963 unpublished).

Glacier	Area in 1959 (m^2)	Area in 1979 (m^2)	Area in 2000 (m^2)	Percentage of area lost in 21 years
Babylon	—	169,289	72,521	57
Ferguson	—	196,775	32,524	83
Flagstaff	—	168,900	57,425	66
Noble	420,870	237,277	133,713	44

coast of Admiralty Bay, estimates an increase of 15% in the ablation for each 1°C warming (Bintanja 1995) at the elevation of 100 m a.s.l. Therefore, it is reasonable to attribute a greater increase in the ablation rate for the smaller and lower glaciers on Keller Peninsula. It is tempting to associate these ice losses to the local atmospheric warming since 1947. Its is also clear from field evidence that at least the two glaciers at lower altitudes, Ferguson and Flagstaff, will quickly disappear, if the present warming trend persists. In addition, Birkenmajer (1979), based on dated terminal moraines, concludes that the reduction of these glaciers began as early as the end of the 18th and has accelerated since the mid-twentieth century. Furthermore, a conservative note is necessary – It is known that the mass balance of the three cirque glaciers (Babylon, Flagstaff and Noble) on the Keller Peninsula are heavily controlled by the precipitation associated to westerly winds, caused by the eastward-moving low pressure systems over the Drake Passage. Therefore, changes in the circumpolar circulation pattern, especially in regional meridional circulation (King 1994), may be more important for the demise or preservation of the Keller Peninsula glaciers than the present atmospheric temperature rise. In the summer of 2000–2001, an anomalous circulation pattern resulted in heavy snow precipitation, thus, a thick snow cover on this peninsula.

CONCLUSION

The four glaciers studied in this work have lost a great part of their area, from 44 to 83%, since the mid-twentieth century. The ice-covered area on Keller Peninsula was reduced by 476,058 m^2, 62%, from 1979 to 2000. Noble Glacier has retreated up to 100 m, from 1956 to 1993, losing 69% of its area from 1959 to 2000. At least two glaciers, Ferguson and Flagstaff, may disappear if the present climatic conditions persist. Parts of these two glaciers are already stagnant. The retreat process may have begun as early as the end of the 18th century (Birkenmajer 1979) and has been accelerating concomitantly with the atmospheric climatic warming that has been recorded for Admiralty Bay, since 1947. As expected, the four corrie glaciers are responding faster than the KGI ice cap to this climatic trend.

ACKNOWLEDGMENTS

The Brazilian National Council for Scientific and Technological Development – CNPq supported this work through the Brazilian Antarctic Program (PROANTAR), research project 48.0310/93-9. UF Bremer and FE Aquino thank CNPq for their studentship. We thank Nelson LS Gruber for participating in the 1993 fieldwork.

RESUMO

Variações na área total de quatro geleiras de pequeno porte na face leste da península Keller, baía do Almirantado, ilha Rei George são investigadas usando um levantamento topográfico realizado nos verões austrais de 1992/93 e 1993/94. A este levantamento foram comparados fotografias áreas, imagens de satélite e mapeamentos realizados a partir da década de 1950. As quatro geleiras estão diminuindo rapidamente de tamanho, perdendo entre 44 e 83% de suas áreas de 1979 a 2000. Pelo menos duas das geleiras já têm parte do seu gelo estagnado e tendem a desaparecer, se a tendência de aquecimento climático na região persistir.

Palavras-chave: Glaciologia, retração de geleiras, monitoramento ambiental.

REFERENCES

ARIGONY-NETO J. 2001. Determinação e interpretação de características glaciológicas e geográficas com sistema de informações geográficas na Área Antártica Especialmente Gerenciada Baía do Almirantado, Ilha Rei George, Antártica. Porto Alegre, Universidade Federal do Rio Grande do Sul, 84 p. Unpublished M.Sc. dissertation.

BINTANJA R. 1995. The local surface energy balance of the Ecology Glacier, King George Island, Antarctica: measurements and modelling. Antarct Sci 7: 315–325.

BIRKENMAJER K. 1979. Lichenometric dating of raised marine beaches at Admiralty Bay, King George Island (South Shetland Islands, West Antarctica). Bull Polish Acad Sci – Earth 29: 119–127.

BRAUN M, SIMÕES JC, VOGT S, BREMER UF, BLINDOW N, PFENDER M, SAURER H, AQUINO FE AND FERRON FA. 2001. An improved topographic database for King George Island: compilation, application and outlook. Antarct Sci 13: 41–52.

CALVET J, GARCÍA SELLÉS D AND CORBERA J. 1999. Fluctuaciones de la extensión del casquete glacial de la Isla Livingston (Shetland del Sur) desde 1956 hasta 1996. Acta Geol Hispanica 34: 365–374.

FERRON FA, SIMÕES JC, AQUINO FE AND SETZER AW. 2004. Air temperature time series for King George Island, Antarctica. Pesq Antart Bras 4: 155–169.

FURMANCZYK K AND MARSZ A. 1980. Zatoka Admiralicji, Map, 1: 25,000. Warzsaw: Polskiej Akademii Nauk.

HATTERSLEY-SMITH GH. 1949. King George Island Glaciological Report for 1948–1949. Cambridge: Falkland Islands Dependencies Survey. Unpublished Report.

KEJNA M, LÁSKA K AND CAPUTA Z. 1998. Recession of the Ecology Glacier (King George Island) in the period 1961–1996. In: GLOWACKI P AND BEDNAREK J. (Eds.), International Polar Symposium, 25., the 100th anniversary of Prof. Henry Arctowski's and Prof. Antoni Boleslaw Dobrowolski's participation in the Belgica expedition to the Antarctic in 1887–1889. Warsaw: Polish Academy of Sciences, p. 121–128.

KING JC. 1994. Recent climate variability in the vicinity of the Antarctic Peninsula. Int J Climatol 14: 357–369.

KNAP WH, OERLEMANS J AND CADÉE M. 1996. Climate sensitivity of the ice cap of king George Island, South Shetland Islands, Antarctica. Ann Glaciol 23: 154–159.

NOBLE HM. 1965. Glaciological observations at Admiralty Bay, King George Island, in 1957–1958. Brit Antarct Surv B 5: 1–11.

ORHEIM O AND GOVORUKHA LS. 1982. Present-day glaciation in the South Shetland Islands. Ann Glaciol 3: 233–238.

PARK B-K, CHANG S-K, YOON HI AND CHUNG H. 1998. Recent retreat of ice cliffs, King George Island, South Shetland Islands, Antarctic Peninsula. Ann Glaciol 27: 633–635.

PATERSON WSB. 1983. The Physics of Glaciers, 2nd ed., Oxford: Elsevier, 380 p.

SIMÕES JC, BREMER UF, AQUINO FE AND FERRON FA. 1999. Morphology and variations of glacial basins in the King George Island ice field, Antarctica. Ann Glaciol 29: 220–223.

STANSBURY MJ. 1963. Glaciological observations upon two cirque glaciers in the Falkland Islands Dependencies, Antarctica. Birmingham: University of Birmingham. Unpublished M.Sc. dissertation.