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# Glaciological research in King George Island: missions and developments in the 1990s

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**ABSTRACT**

In the 1990s, three international expeditions carried out extensive investigations on the King George Island (KGI) ice cap. They were organized and logistically supported by the Brazilian Antarctic Program, and in the scope of the ''Glaciology of the South Shetland (GLASS)'' program supported by the Scientific Committee on Antarctic Research (SCAR). Topics included: 1) Mapping and monitoring of glacial drainage basins fluctuations using remote sensing techniques, 2) A shallow firn and ice coring program, 3) Geophysical surveys to determine ice thickness and internal structure, and 4) Climatology of the ice cap. This paper outlines these investigations.

Results show an ice cover of 1,044 km$^2$ (91.7% of KGI) that reaches a maximum thickness of 395 m. The KGI ice cap lost 65 km$^2$ from 1956 to 2000, this is concomitant to an increase of the mean annual atmospheric temperature of 1.1°C from 1947 to 1995. Only the upper 2-3 m of the snow pack provide data that are representative of the original precipitation composition. A Geographic Information System to help monitor the ice cap as well as human activities in KGI is proposed and will be implemented by the *Institut für Physische Geographie, Universität Freiburg* (Germany) and the *Núcleo de Pesquisas Antárticas e Climáticas*, UFRGS (Brazil).

**Key words:** South Shetlands, glaciology, environmental studies, research program, Brazilian Antarctic Program.

## INTRODUCTION

The South Shetland Islands are at the mean position of the Antarctic atmospheric front, which is coupled to the extending limit of the sea-ice. Ice masses in this archipelago are highly sensitive to environmental changes because these islands are small and near or at the pressure melting point (Bintanja 1995). Therefore, they may have rapidly responded to a recent climatic warming in the region (Ferron et al. 2004, this volume).

The SCAR (Scientific Committee on Antarctic Research) Working Group on Glaciology, noticing this sensitivity and the need to not only monitor ice volume but also obtain environmental historic records in the area, recommended the support of the ''Glaciology of the South Shetlands (GLASS)'' program in the SCAR Bariloche meeting (June 1992). This program aims to coordinate, assist planning and

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improve international cooperation on glaciological activities in the archipelago. JC Simões has been acting as secretary of this program since that year.

King George Island (KGI), located between 57°35' and 59°02'W, 61°54' and 62°16'S (Figure 1), is the largest of the South Shetland Islands (1,139 km$^2$). This island is approximately 79 km long (from Southwest to Northeast) and, just north of Admiralty Bay, it has a maximum width of 27 km (Figure 2). The mean annual temperature in KGI, for the period of 1947–95, was −2.8°C (Ferron et al. 2004, this volume).

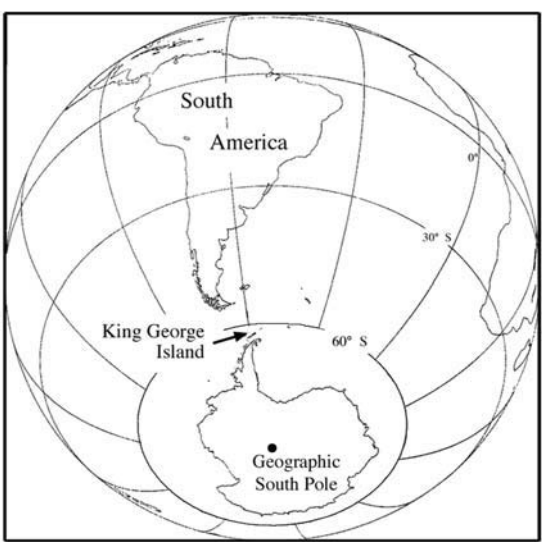


Fig. 1 – Location of King George Island in relation to South America.

KGI is one of the most visited areas in Antarctica. Nine permanent research stations are in operation and several cabins and refuges have been constructed. Due to the easy access via a Chilean airstrip, the number of island inhabitants has risen rapidly in the past years. In the 1990s more than 500 people were in the island during the summer months. The large amount of wildlife, the magnificent landscape, the relatively easy access and secure harbors increasingly attract tourist ships to the area. In the summer of 1998/99, the number of tourists disembarked on the island reached 4,227 (IAATO 1999). Altogether, tourists, scientists, station personnel and related logistic operations cause a considerable impact on the local ecosystems. Sites of Special Scientific Interest (SSSI) and the first Antarctic Specially Managed Area (ASMA) have been designated in the island (Arigony-Neto et al. 2004, this volume) to mitigate these impacts and to coordinate activities in the area.

In spite of the intense human activity and environmental importance of the area, the interior of the island (an ice cap that covers 1044 km$^2$) was relatively unexplored until recently. Before the late 1980s only exploratory work and some traverses had been carried out on this ice cap (Govorukha et al. 1974, Orheim and Govorukha 1982). A series of Chinese expeditions in the mid and late 1980s explored the SW half of the island, drilled several ice cores (e.g. Wen et al. 1998, Han et al. 1998) and did mass balance measurements near Fildes Peninsula (Wen et al. 1994). The other half would remain relatively unexplored until an international glaciological expedition led by Brazil traversed KGI in 1995/96 to perform a radio echo-sounding (RES) survey and shallow ice coring (Macheret et al. 1997a, Simões et al. 2004c, this volume). Further, a detailed morphology of KGI was defined only in the late 1990s when Simões et al. (1999) produced the first satellite image mosaic for the entire island.

In this special number of ''Pesquisa Antártica Brasileira'', we report the main results of three international glaciological expeditions, during the 1990s, organized by the *Laboratório de Pesquisas Antárticas e Glaciológicas* (LAPAG/UFRGS – *Universidade Federal do Rio Grande do Sul*, Porto Alegre, Brazil; under the general coordination of JC Simões). Recently, LAPAG was re-structured as *Núcleo de Pesquisas Antárticas e Climáticas* (NUPAC), at the same institution. This publication includes studies in the KGI ice cap to obtain main glaciological variables and to examine its history and response to recent environmental changes. The Brazilian Antarctic Program (PROANTAR) logistically supported these three expeditions with the participation of the following groups.

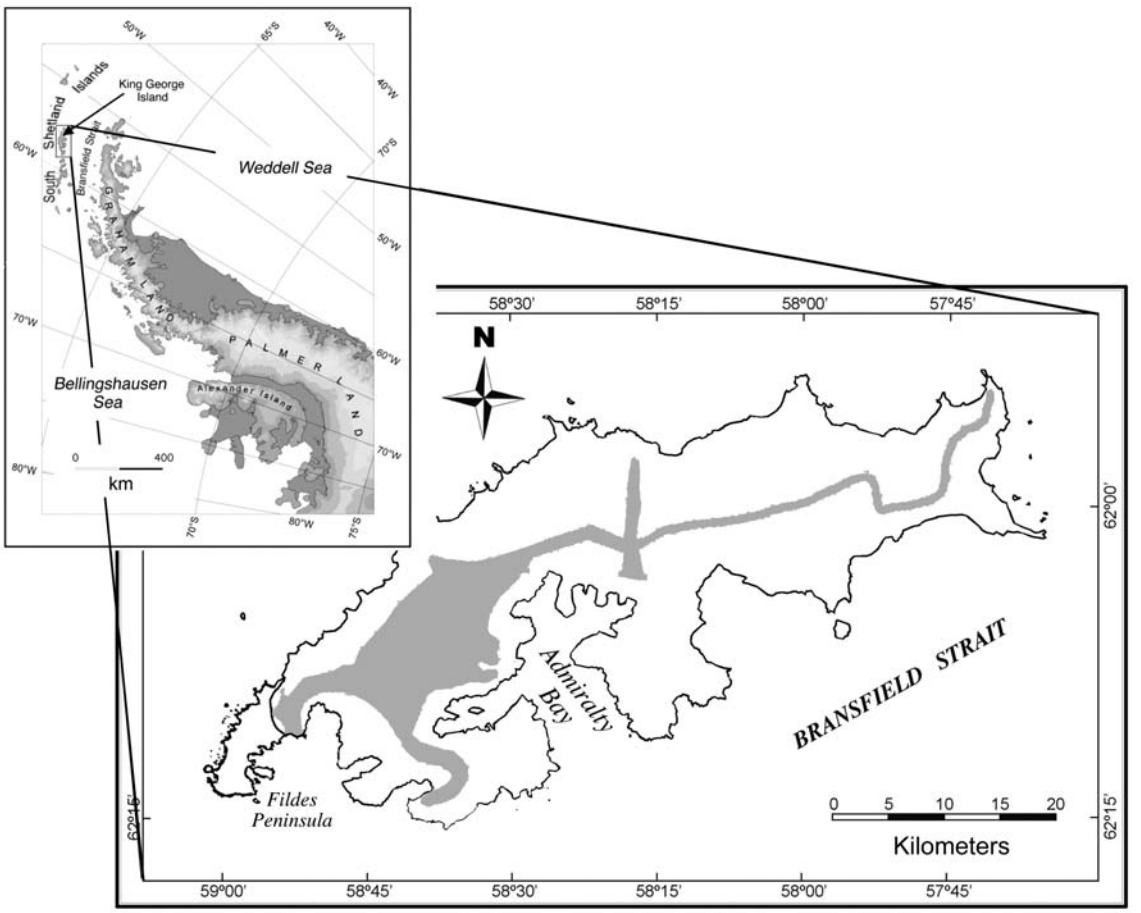


Fig. 2 – King George Island. Grey areas mark the spatial coverage of the field investigations carried out in the austral summers of 1995–96, 1997–98 and 1999–2000.

Austral summer 1995–1996 — Field Coordinator: Jefferson C. Simões (LAPAG/UFRGS, Brazil);

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This number of ''Pesquisa Antártica Brasileira'' also includes results from investigations run by LAPAG/UFRGS on KGI on other occasions during the 1990s, particularly in Admiralty Bay. The first glossary of snow and ice features in Portuguese, which gives equivalents in English, French, German and Spanish, is proposed by Simões (2004, this volume),

## OUTLINE OF RESEARCH TOPICS AND RESULTS

### Drainage Basins: Mapping and Fluctuations

Bremer et al. (2004, this volume) determined variations in ice front positions from 1956 to 2000, comparing maps produced from aerial photogrammetric surveys and satellite imagery (multispectral SPOT images in 1988, 1995, and 2000). For environmental monitoring and management of KGI, a new digital topographic database was added as a basic GIS-layer to improve data quality of earlier related studies (Simões et al. 1999). Seventy glacial drainage basins were identified covering 1,044 km$^2$ (91.7%) of the present area of KGI. A general retreat of ice fronts has been observed for 44 years, more intensely in Admiralty Bay and on the eastern side of the island. A total loss of 65 km$^2$ occurred from 1956 to 2000.

An article by Simões et al. (2004b, this volume) examines variations in the area covered by four small cirque glaciers on the eastern slopes of Keller Peninsula, Admiralty Bay. Comparisons made using aerial photographs, satellite images and mapping surveys, indicate that all four glaciers lost from 44 to 83% of their area, from 1956 to 2000. At least two glaciers have already stagnant ice and tend to disappear if the present climatic warming trend persists in the region.

Space borne remote sensing sensors are used by Vogt et al. (2004, this volume) to study meltwater processes that strongly control biological activity on the small ice-free areas (less than 8% of the KGI area). Active microwave data (SAR) are used to assess ablation patterns that indicate melt water discharge. Data from the visible spectrum are applied to the monitoring of sediment plumes in the coastal ecosystems. Another case study demonstrated the use of SAR and optical data to monitor the seasonal and inter-annual changes of the morphometry and location of lakes. There is also an example of how to use multi-spectral imagery to assess physical properties of lenticular water bodies.

Two short notes discuss the implementation process of the KGI Geographic Information System (KGIS), a project supported by the Geographic Information Program of the SCAR Standing Scientific Group on Geoscience. The database may be applicable to environmental management and to multidisciplinary research projects. Vogt et al. (2004, this volume) present the main objectives and tasks of the project. This paper discusses the develop-

ment of a standard spatial data model and of a www interface and the integration of spatial data sets.

Arigony-Neto et al. (2004, this volume) present the case study for the Antarctic Specially Managed Area (ASMA) Admiralty Bay in KGI. The GIS for this area already includes seven information layers (topography, bathymetry, coastline, glaciology, ice-free areas, human presence and placenames). This GIS is also important for the ASMA management plan and for assessing the human impact in the area.

One of the main products from the surveys carried out in the second half of 1990s by the IPG and LAPAG groups is a map (satellite image chart) at the 1: 100.000 scale for all KGI. Braun et al. (2001, 2004) combined data from two differential GPS surveys, up-dated SPOT satellite imagery and information from the Antarctic Digital Database to produce a map that is appended to the back cover of this volume.

### Ice Cores: Glaciochemistry and Stratigraphy

In the South Shetlands (KGI and Livingston Island), several snow trenches and shallow ice cores were sampled to obtain information on the distribution of stable isotope ratios, major ions, trace metals, and of the mean annual net accumulation rate. Simões et al. (2004c, this volume) report on the major results of the investigations of a 49.9 m firn-ice core recovered from the KGI ice cap (690 m a.s.l.) in the summer of 1995–96. They discuss reference values for the region and also problems to interpret the core environmental record due to post-depositional processes (i.e. partial melting, percolation and refreezing), reaching the conclusion that chemical and isotopic composition of the upper 2-3 m of ice cores recovered in the South Shetlands, above 600 m of elevation, are representative of the original regional precipitation. Doubts remain about the net accumulation rate in the region; values vary from 0.60 to 2.48 m water equivalent per year. These investigations are part of the ITASE (International Trans-Antarctic Expedition) traverse for the South Shetlands. A full discussion will be published elsewhere.

Dalia et al. (2004, this volume) used samples from the 49.9 m core to discuss the atmospheric and ice-deposited aerosol concentrations and elemental composition in KGI. The elemental composition was determined on coarse mode aerosol by employing an energy dispersive spectrometer. Results showed a systematic influence of marine and crustal aerosol contribution through the whole core.

### Glacier Geophysics: Ice Dynamics, RES and GPR Surveys

Missions associated to the GLASS program have produced four radar surveys over the KGI ice cap; results have been reported elsewhere (Macheret and Moskalevsky 1999, Macheret et al. 1997a,b, 1998).

In December 1995, Macheret et al. (1997a,b, 1998) carried out a ground-based radio echo-sounding survey, using mono-pulse radar with a central frequency of 40 Mhz, along 55 km of the main ice divide of the KGI ice cap (mean ice thickness varies from 180 to 230 m). This survey was associated with the 41st Russian Antarctic Expedition and with the 1995 International Glaciological Expedition. Internal reflections attributed to water tables were found in the ice cap (Macheret et al. 1998). In the summer of 1996–97, Macheret and Moskalevsky (1999) returned to the top of the KGI to perform a detailed survey of the upper reaches of the tidewater and outlet Lange Glacier (62°7'S, 58°36'W). Four RES profiles, with total length of 28 km, were collected in the upper non-crevassed area of the glacier. They detected a complex subglacial topography with three bed rises and two subglacial hollows, and with bedrock differences of up to 100 m. Maximum measured ice thickness reaches 308 m near the Lange Glacier ice divide.

In the summer of 1997–98, during the first Brazilian-German Glaciological Expedition, Norbert Blindow and Marion Pfender (*Universität Münster*, Germany) surveyed 250 km$^2$ of the southwestern KGI ice cap using a high-resolution radio echo-sounder (central frequency 50 MHz, one 2.5 kV pulse per meter). This study generated 450 km of profiles, providing information on ice thickness,

subglacial topography, water tables, water pockets, intraglacial and subglacial channels. Full details on techniques and results are given in Pfender (1999), and show an ice cap thickness of up to 395 m (Norbert Blindow, written communication).

The use of Ground Penetrating Radar (GPR) gave further information on the Lange Glacier internal structure, including the mapping of internal layers and water tables along a 1.2-km profile (Travassos and Simões 2004, this volume). Barboza et al. (2004, this volume) used results from these geophysical surveys to derive a profile along Lange Glacier's main axis that was used as input data for a simple bidimensional ice flow model.

### Climatology and other studies

A study (Braun et al. 2004a, this volume) reviews the general characteristics of the climatic settings of King George Island taking into consideration recent climatic and glacial changes at the Antarctic Peninsula. Based on the analysis of data from automatic weather stations (AWS), the strong influence of large-scale synoptic weather patterns on the meteorological variables is outlined. In particular, air mass advection from westerly and northerly directions caused higher air temperatures and ablation rates, whereas temperature lapse rates were lower during these situations. Braun et al. (2004a, this volume) show that the observed ablation rates are considerably higher in comparison to previously published data, defending a revision of the ablation sensitivity used in previous estimations of the contribution of Antarctic Peninsula ice to global sea level rise.

Ferron et al. (2004, this volume) derive a continuous time series of the KGI mean annual and seasonal air temperatures (1947–1995), combining data from several meteorological stations in the South Shetland Islands. The record shows a mean annual temperature of $-2.8°C$, with minimum of $-5.2°C$ (1959) and maximum of $-0.8°C$ (1989). A rise of $1.1°C$ in the mean annual temperature was recorded in 49 years. Finally, Setzer and Härter (2004, this volume) discuss a low atmospheric temperature event in July 1995.

The suspended sediment concentrations were measured in Admiralty Bay, in February 2000, in front of the Lange Glacier ice cliff and in Martel Inlet, to study the extensive plumes observed on satellite imagery (Simões et al. 1999). Pichlmaier et al. (2004, this volume) concluded that temporal variations of sediment concentrations revealed the influence of rain and storm events, which increased freshwater discharge and denudation. Furthermore, wind-induced resuspension of previously deposited material on the sea floor was considered to be a main reason for the high concentrations measured at the Martel sampling site. Vogt and Braun (2004, this volume) use remote sensing to address the influence of snow and ice melt water on terrestrial and marine ecosystems in King George Island.

In a short note about the use of Antarctic maps and charts in scientific publications, Simões et al. (2004a, this volume) provide six updated maps for the geographical areas where the Brazilian Antarctic Program centers its fieldwork.

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**RESUMO**

Três expedições internacionais, organizadas e apoiadas logisticamente pelo Programa Antártico Brasileiro, e no âmbito do programa ''Glaciologia das Shetlands do Sul (GLASS)'' apoiado pelo Comitê Científico de Pesquisas Antárticas (SCAR, sigla em inglês), realizaram extensas investigações na calota de gelo da ilha Rei George (IRG) durante a década de 1990. Tópicos incluíram: 1) Mapeamento e monitoramento das flutuações das bacias de drenagem das geleiras através de técnicas de sensoriamento remoto, 2) Um programa de perfuração de testemunhos raso do firn e do gelo, 3) Levantamentos geofísicos para determinar a espessura e a estrutura interna do gelo e 4) A Climatologia da calota de gelo. Este trabalho apresenta os pontos básicos destas investigações.

Resultados mostram uma cobertura de gelo de 1.044 km$^2$ (91,7% da IRG) e com espessura máxima de 395 m. A calota de gelo da IRG perdeu 65 km$^2$ entre 1956 e 2000. Esta perda foi concomitante ao aumento da temperatura média anual da atmosfera da IRG em 1,1°C (1947–1995), Somente os 2-3 m superiores do pacote de neve provêem dados químicos representativos da precipitação original. Um Sistema de Informações Geográficas é proposto para ajudar no monitoramento da calota de gelo assim como das atividades humanas na IRG e será implementado pelo *Institut für Physische Geographie, Universität Freiburg* (Alemanha) e o Núcleo de Pesquisas Antárticas e Climáticas da UFRGS (Brasil).

**Palavras-chave:** Shetlands do Sul, glaciologia, estudos ambientais, programa de pesquisa, Programa Antártico Brasileiro, PROANTAR.

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