COLLINS GLACIER RETREAT PROCESS AND REGIONAL CLIMATIC VARIATIONS, KING GEORGE ISLAND, ANTARCTICA*

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ABSTRACT. This paper investigates the recent climatic variability and changes in snow line and ice front position in Collins Glacier, King George Island, South Shetland Islands, Antarctic Peninsula. This region has recorded one of the largest temperature increases in the past fifty years and has been demonstrated to be highly sensitive to climate changes. To monitor recent changes (1983–2006), we determined the fluctuations of the terminus and snow line of the glacier via remote sensing data and field observation in the summer of 2013. We conclude that the Collins Glacier has responded slowly to regional climate changes (decades or even centuries), as glacial responses to climatic events do not depend solely on one environmental variable. The glacier presented more retreat and elevation of the snow line in the north sector. The retreat data are correlated with the mean monthly temperature and annual number of days of melting-degree variations. *Keywords: climate change*, *snow line*, *glacier retraction*, *Antarctica*.

Most glaciers on the King George Island (KGI) ice cap have experienced a negative mass balance for the last six decades, with general ice-front retreat and diminishing ice thickness. As a result, there are generations of glaciers with termini on land, such as the Wanda, Dragon, Ecology, Collins, and Professor glaciers. These glacial environments are important tools for monitoring the ice-free areas of Antarctica. Spatial landform distribution mapping is also useful in identifying proglacial zones, and for the reconstruction of glacial erosion and retreat processes (Lowe and Walker 1997; Glasser and others 2005; Gustavsson and others 2006; Benn and Evans 2010).

This paper aims to investigate recent climatic variability and changes in snow line and ice-front position in the Collins Glacier, KGI. The KGI (latitude 61°54' – 62°16' S and longitude 57°35' – 59°02' W) is located in South

*This work was supported by the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) and Brazilian National Council for Scientific and Technological Development (CNPq). Field logistics provided by the Physical Geography Laboratory – Federal Fluminense University, INACH and Ricardo Jaña Obregón, and the Brazilian Antarctic Program (PROANTAR). QUICKBIRD image was provided by André Medeiros de Andrade.

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Geographical Review 105 (4): 462–471, October 2015
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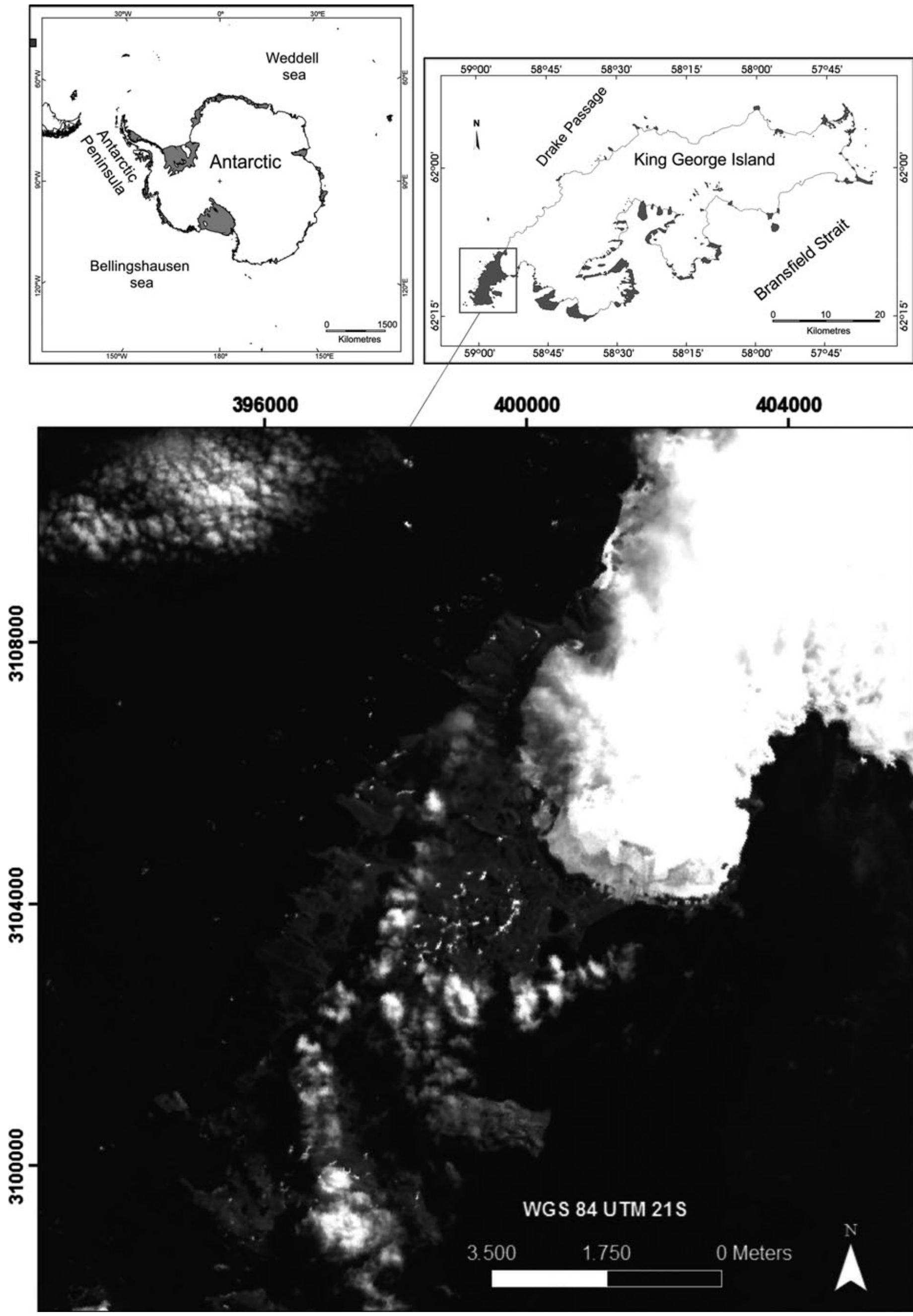

FIG. 1—Location map of the Collins Glacier in King George Island.

Shetland archipelago, in the northwestern sector of the Antarctic Peninsula (AP) region, and is characterized by both land-terminus and tidewater glaciers (Figure 1).

The ice cap of KGI is located under a polar oceanic climate regime (Barsch and others 1985) where summer temperatures at sea level are often above 0°C (Rakusa-Suszczewski and others 1993; Ferron and others 2004). Ice-temperature measurements have indicated that ice masses in the accumulation areas of KGI are near or at pressure melting points (Machert and others 1997; Pfender 1999; Simoes and others 2004; Travassos and Simoes 2004).

The western AP has experienced some of the most significant atmospheric heating of the planet—up to 3.0°C in the last sixty years—resulting in decreases to 87 percent of glacial fronts.

The South Shetland archipelago has experienced similar heating; since 1958, King George Island has lost 7 percent of its ice cover (Simões 2011). 212 of the 224 glaciers analyzed on the AP have shown overall retreat since 1953 (Cook and others, 2005). The remaining 32 glaciers have shown an overall advance. Since 1945, the mean rate of retreat across the AP has been increasing. Between 1956 and 1995, KGI lost eighty-nine square km (7.1 percent) of ice cover to the fronts of forty-five of their seventy drainage basins (Bremer and others 2004).

The Collins Glacier, or Bellingshausen Dome, is part of the KGI ice cap, which is located on the northeast of Fildes Peninsula. During the implementation of the Madrid Protocol, the Fildes Peninsula was found to be one of the most polluted areas of Antarctica (2007). (The Madrid Protocol was signed in 1991 in order to protect the Antarctic environment, and dependent and associated ecosystems. It designated Antarctica as a natural reserve, devoted to peace and science (Lambrecht and others 2012)).

The Collins Glacier is a small ice dome centered at approximately latitude 62° 12’ S, longitude 58° 57’ W, with an area of fifteen square km and a maximum altitude of 270 meters. The northeast region of Collins Glacier has both its highest altitudes and maximum ice speed: 3.72 m a^{-1}. The flatter regions, at the front and at the top of the glacier, have a lower rate of ice speed, with a minimum of 0.3 m a^{-1} (Braun and Rau 2000). According Ruckamp and his collaborators, the Collins Glacier’s ice-flow velocity is small—less than four meters per year (2011). This study was restricted to the frontal parts of the Collins Glacier, covering 7.021 square km.

The Collins Glacier is relatively sensitive to regional climatic variations, as it is small and near the pressure melting point. Changes to the glacier are a bellwether for the future of other glacially covered areas around the globe (Knap and others 1996). In addition, the near future should find an increase in land-terminating glaciers on the AP, as tidewater glaciers retreat onto land (Carrivick 2012).

Materials and Methods

Remote sensing imagery and visual interpretation techniques were used to generate past snow line and ice front positions: RGB432 SPOT satellite image from

TABLE 1—SOURCES OF THE DATA USED FOR THE DETERMINATION OF THE VARIATIONS IN THE FRONT OF COLLINS GLACIER AND THE SNOW LINE ALTITUDE

IMAGE	YEAR	SPATIAL SCALE/ RESOLUTION	COORDINATES/ DATUM	SOURCE	INTEGRATED DATA TO GIS
Image TM 5 do satellite Landsat 2	1989	30 meters	UTM, WGS 84	http://glcf.umd.edu/data/landat/	Positions of the fronts of the ice and snow lines
Contour	2000	Quotas with equidistance of 50 meters	UTM, WGS 84	Braun and Rau (2000)	Elevation data
MDE of King George Island	1995 and 2009	100 meters	UTM, WGS 84	Braun and Rau (2000)	Elevation data
Mosaic of SPOT XS	2000	20 meters	UTM, WGS 84	CPC – *Centro Polar e Climatico*	Fronts of the ice position and the snow line
Charter topographic of King George Island, Fildes Peninsula	1983	1: 8000	UTM, WGS 84	Military Geographic Institute of Chile (IGM) and INACH	Ice front position
Aerial Photography Fildes Peninsula	2003	1:50000	UTM, WGS 84	SHOA – *Servicio de la Armada de Chile*	Positions of the fronts of the ice and snow lines
Quickbird	2006	0.6 meters	UTM, WGS 94	CPC	Positions of the fronts of the ice and snow lines

Table 2—Front height of the snow line of the collins glacier, 1969-2006

YEAR	PERIOD	SNOW LINE ALTITUDE (M)	SOURCE	DATA OBTAINED
1970	Summer 1969/70	140	Orheim and Govorukha (1982)	The equilibrium line altitude
1971	Summer 1970/71	170	Orheim and Govorukha (1982)	The equilibrium line altitude
1986	Summer 1985/86	150	Jiawen and others (1995)	The equilibrium line altitude
1989	Summer 1988/89	~120	Landsat RGB 432	Positions of the fronts of the ice and snow lines
1992	Summer 1991/92	140	Jiahong and others (1994)	The equilibrium line altitude
1997	Summer 1996/97	250	Braun and Rau (2000)	The equilibrium line altitude
1998	January 1998	>200	Braun and Rau (2000)	The equilibrium line altitude
2000	Summer 1999/2000	100–150	SPOT RGB 432	Positions of the fronts of the ice and snow lines
2003	Summer 2002/03	100–150	Aerial photography SHOA	Positions of the fronts of the ice and snow lines
2006	Summer 2005/06	~150	Quickbird RGB 432	Positions of the fronts of the ice and snow lines

23 February 2000, Landsat RGB 432 image from 8 February 1989, QUICKBIRD RGB 432 from 21 February 2006, a pair of Fildes Peninsula aerial photographs from February 2003, and a 1983 Fildes Peninsula topographic map (Chilean). The snow line altitude variations were obtained based on the digital elevation model, with a spatial resolution of the 100 meters, by Braun and Rau (2000) (Table 1).

Monthly surface air temperature data (1970–2012) were obtained from the Chilean Eduardo Frei Montalva Station; we also used the mean annual temperature data from the Russian Bellingshausen Station. Both time series were then compared to the variations in the Collins Glacier ice-front position from 1983–2006 and also to the snow line altitude variations. We compared the position of the glacier and the snow line altitude for different years with snow line altitude estimations by several authors (Table 2). The fieldwork was carried out on fifteen days in March of 2013.

Results and Discussion

The data collected show a general shrinkage of the glacier; approximately 8.42 percent (0.639 square km) of the 1983 front area has been lost by 2012 (Figure 2 and Figure 3; Table 3). This retreat occurred mainly in the northern and west-central sectors.

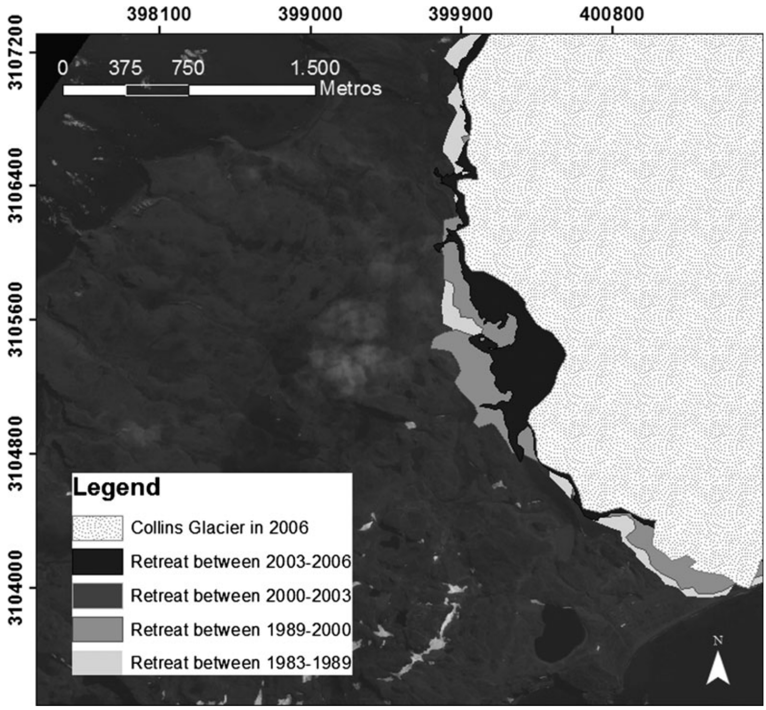

FIG. 2—Front retraction of the Collins Glacier in the years 1989, 2000, 2003, and 2006.

In 1989, the snow line was at approximately 120 meters above sea level (Figure 3). In 2000, this line position varied between 100 to 150 meters above sea level. In 2003 and 2006, the snow line contours were at approximately 150 meters. Thus, the greatest variation was observed in the snow line altitude rather than in the area loss.

Table 3 presents the values of the areas for selected years between 1983 and 2006. The table also presents the decrease in area between these years and the loss of area (data in square km and in percentage). From 1983 to 1989, the Collins Glacier lost 0.078 square km of its ice front (1.01 percent of the 7.66 square km total surface area); from 1989 to 2000, it lost another 0.28 square km of its ice front (3.67 percent of the 7.58 square km of total surface area); from 2000 to 2003, the glacier's ice fronts advanced some 0.15 square km (2.01 percent of the 7.30 square km of total surface area); and from 2003 to 2006, it lost another 0.43 square km of its ice fronts (5.75 percent of the 7.02 square km of total surface area).

Moraine deposits, proglacial meltwater channels, and lakes in front of the land glacier have resulted from these retreat processes. Rapid postdepositional paraglacial reworked ice-free areas are evidence of recent changes in geomorphological processes (Figure 4).

The average annual surface temperature is correlated to the Collins Glacier area variations; however, this variable does not adequately represent those days

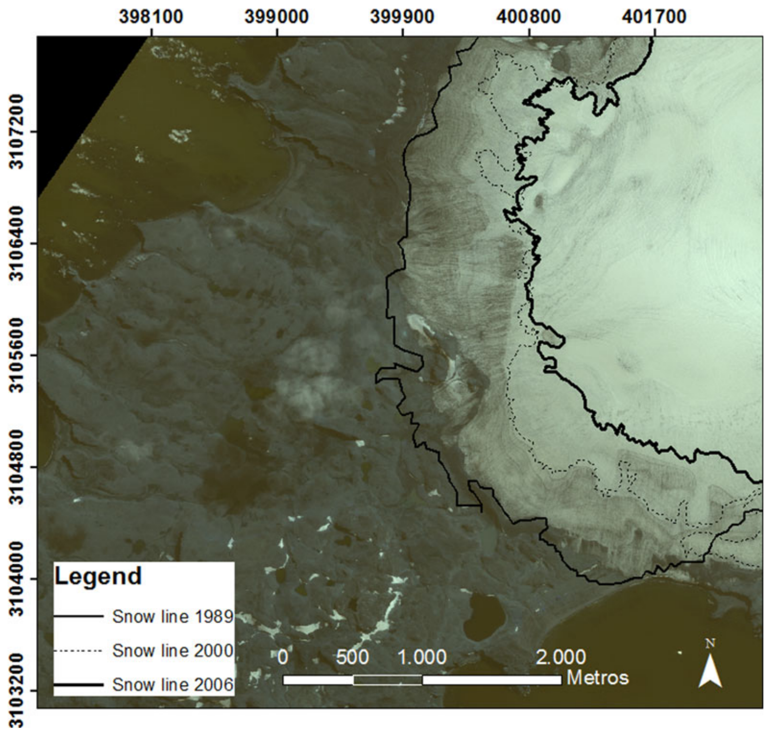

FIG. 3—Snow line in years 1989, 2000, and 2006 (based on QUICKBIRD satellite image obtained in 2006).

TABLE 3—FRONT RETRACTION OF THE COLLINS GLACIER BETWEEN 1989 AND 2006

YEAR	TOTAL AREA (SQUARE KM)	PERIOD	LOSS OF AREA (SQUARE KM) DURING THE PERIOD	AREA LOSS (%) DURING THE PERIOD
1983	7.660	-	-	
1989	7.582	1983–1989	0.078	1.01
2000	7.303	1989–2000	0.279	3.67
2003	7.450	2000–2003	+0.147	+2.01
2006	7.021	2003–2006	0.429	5.75
Total	37.016	1983–2006	0.639	8.42

when the surface snow and ice melting occurs. As a result, we calculated the number of melting-degree days, which is the annual sum of the daily mean temperatures when the temperatures are above 0°C (Figure 5).

The time series of the mean annual air temperature and the number of melting-degree days in the area surrounding the Collins Glacier, from 1989-2012, do not exhibit well-defined trends; no relationship appears to exist between the increasing altitude of the snow line and the retreat of the Collins Glacier front.

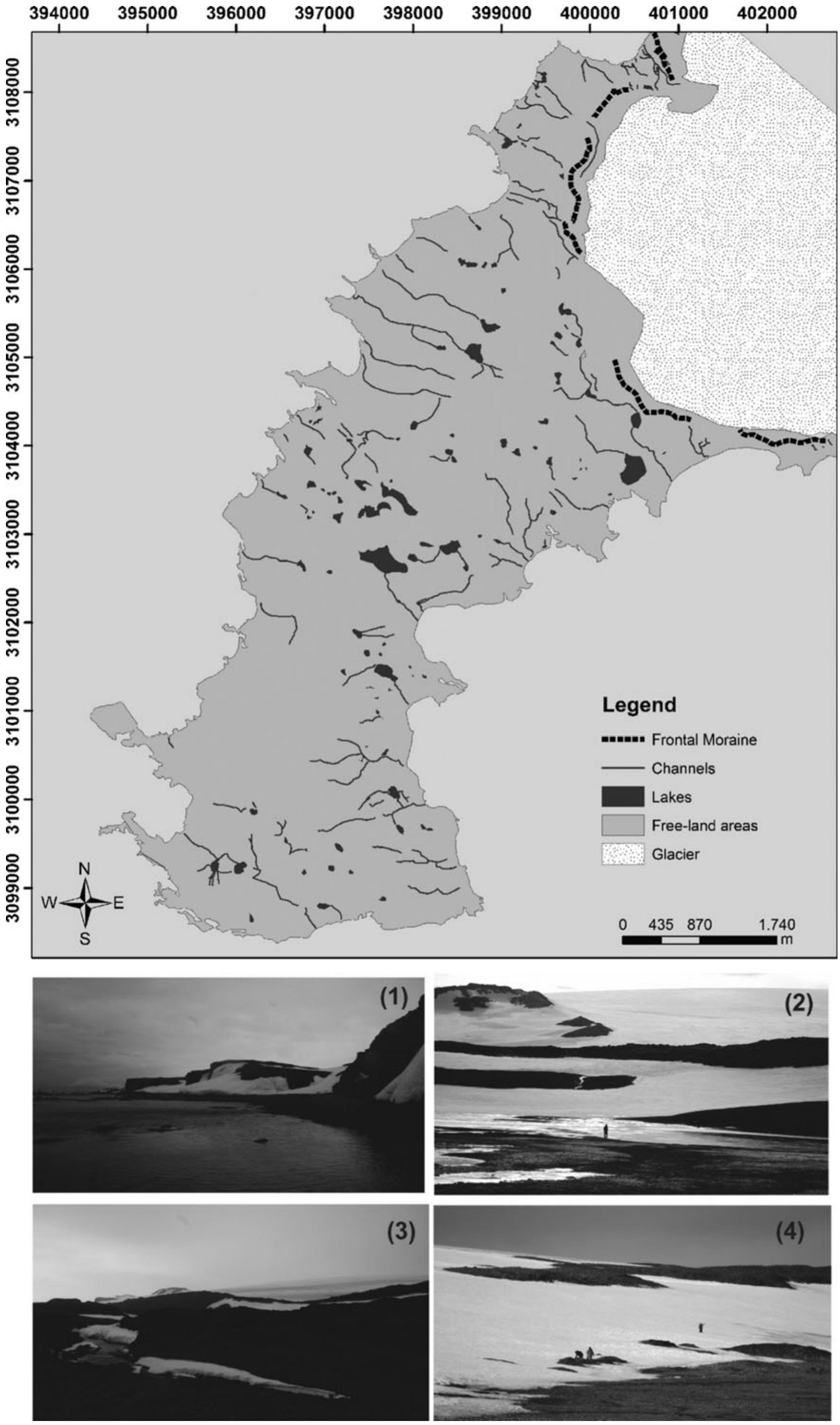

FIG. 4—Meltwater drainage, lakes, and moraine deposits in the proglacial are generated by the Collins Glacier retreat. The photographs were captured during the yield activities of February 2013.

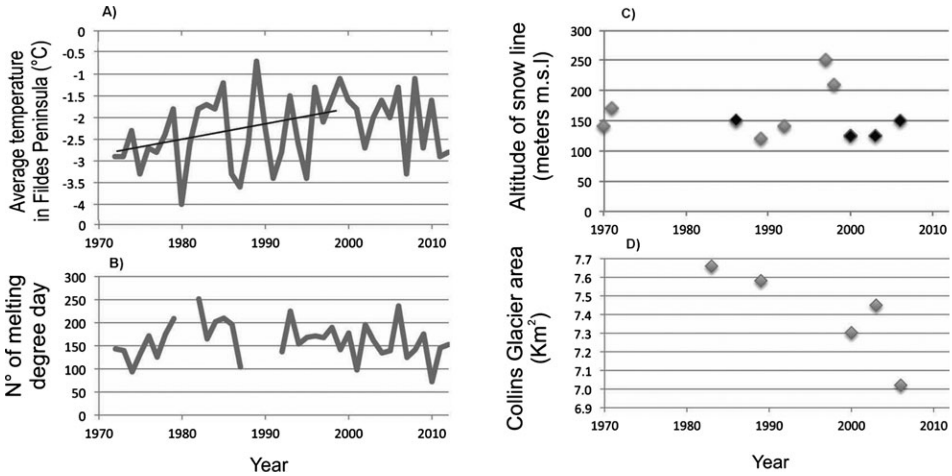

FIG. 5—Comparison of climatic variables calculated for the Fildes Peninsula, King George Island and glaciological variables: (a) variation of the average temperature in the Fildes Peninsula, using data from Frei weather station; (b) variation of the number of melting-degree days (graph represent failures without data years); (c) change in the altitude of snow; and (d) changes in area of glacier Collins (as determined by this work).

The Collins Glacier study area responds slowly to regional climate changes in decades or even centuries. It became clear during this study that glacier response to climatic events are complex and depend on factors additional to air temperature variations. The higher melting and retreat of one small part of the Collins Glacier may be explained by a combination of two particular factors: it is an area of low ice thickness, and it is exposed to greater solar radiation (west face) with attendant low ice intake.

CONCLUSION

Our study's conclusion is that the Collins Glacier responds slowly to regional climate changes, to the tempo of decades or even centuries, as the response of a glacier to climatic events depends on more than one environmental variable. However, the current continuous and rapid retreat phase is attributable to recent regional warming. In addition, these ice-free areas were susceptible to rapid postdepositional changes.

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TY - JOUR
AU - Simoes, Carolina Lorenz
AU - Rosa, Katia Kellem da
AU - Czapela, Fabiane Fernanda
AU - Vieira, Rosemary
AU - Simoes, Jefferson Cardia
TI - Collins Glacier Retreat Process and Regional Climatic Variations, King George Island, Antarctica
JO - Geographical Review
JA - Geogr Rev
VL - 105
IS - 4
SN - 1931-0846
UR - http://dx.doi.org/10.1111/j.1931-0846.2015.12091.x
DO - 10.1111/j.1931-0846.2015.12091.x
SP - 462
EP - 471
KW - climate change
KW - snow line
KW - glacier retraction
KW - Antarctica
PY - 2015
ER -