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Air temperature time series for King George Island, Antarctica

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ABSTRACT

In this paper, we present a continuous time series of the mean annual and seasonal air temperatures for King George Island (KGI), for the period of 1947–1995, combining data from several meteorological stations in the South Shetland Islands. These series are analyzed for trends. The series are also compared with the mean monthly sea ice extent, recorded at 60°W. The mean annual temperature during this period was −2.8°C, with a minimum of −5.2°C, in 1959, and a maximum of −0.8°C, in 1989. This record shows a warming trend of 0.022°C a^{-1}, in the studied time interval, a rise of 1.1°C in 49 years. Winter shows the most pronounced seasonal warming trend, 0.038°C a^{-1}, or 1.9°C in the period. These trends are better defined than at the Faraday station. Abrupt variations in the mean annual temperature, up to 3.9°C over three years, have been recorded. Spectral analysis of these time series shows cycles of 5.3 and 9.6 years. A one-month lag is observed between the winter months mean temperatures in KGI and sea ice extent in the 60°W sector.

Key words: climatology, atmospheric temperature, time series.

INTRODUCTION

The Antarctic and Subantarctic regions have a greater degree of climatic interannual variability than observed at lower latitudes. This enhanced variability is due to a number of feedbacks that result from complex interactions between atmospheric circulation, oceans and cryosphere (King and Turner 1997). Difficulties in the understanding of these Antarctic processes arise partially from the small number of meteorological stations that existed in the region before the International Geophysical Year (1957/1958).

The most comprehensive meteorological records in the region are those of stations located along the west coast of the Antarctic Peninsula, generally in the form of a continuous record, dating back to the 1940s. Orcadas station (60°44'S, 44°44'W) located on the South Orkney Islands, has the longest continuous meteorological records for the entire Antarctic region, it dates back to 1903.

The warming trend over the west coast of the Antarctic Peninsula is greater than over the rest of the continent (Marshall et al. 2002), but their determination is limited due to the high level of interannual variability and the relative shortness of the available records (King 1994). An analysis of the annual mean temperature made by Raper et al. (1984), using several meteorological stations all around Antarctica,

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between 1957 and 1982, shows a warming trend of 0.029°C a^{-1}. The greatest contribution to this trend comes from stations on the Antarctic Peninsula.

In the last fifty years the warming trend in the west sector of the Antarctic Peninsula, especially between latitudes 65° and 70°S, was approximately 2°C (King and Harangozo 1998). The study of several meteorological stations in this region carried out by Smith et al. (1996) shows a strong warming trend, specially during winter months, in the last five decades and with a negative correlation between atmospheric temperature and sea ice extent.

In this paper, we present a continuous time series of the mean annual and seasonal atmospheric temperatures for KGI, from 1947 to 1995, combining data from different stations in the South Shetlands. These series are analysed for trends and compared with the mean monthly sea ice extent, recorded at 60°W.

CLIMATIC CONTEXT OF THE ANTARCTIC PENINSULA

The mountains of the Antarctic Peninsula act as a barrier for the atmospheric circulation, resulting in several climatic differences between the east and the west coast. The former has a maritime influence and the latter a continental one (Martin and Peel 1978). The east coast is characterised by strong cold winds (barrier winds) coming from the south and southeast of the northern part of the peninsula, originating from mountain blocking of cold air masses that is moving clockwise over the Weddell Sea. These air masses show a strong temperature inversion, bellow 1000 meters (Schwerdtfeger 1974, Martin and Peel 1978).

On the west coast, winds are predominantly from the north and northeast. This region is the most temperate and moist of all Antarctica. These winds move over the Pacific Ocean and reach the Bellingshausen Sea, bringing relatively warm and moist air (Carrasco et al. 1997). ''Inertial'' air fluxes are common in the Bransfield Strait. These fluxes originate in the westward curl of barrier winds and flow to the west and to the continent, after reaching the northern tip of the Antarctic Peninsula (Schwerdtfeger 1984). In this case, lower temperatures and a higher relative humidity are predominant (Schwerdtfeger 1984). Atmospheric depressions, over the west coast of the Antarctic Peninsula, originate over the southeast Pacific, near the coastal areas of the Antarctic Continent or next to the sea ice limit (King and Turner 1997). According to Carrasco and Bromwich (1993), mesoscale cyclones, over Bellingshausen and Amundsen seas, form in association with cold air fluxes coming from the interior lands of West Antarctica, and that are moving to the adjacent Pacific Ocean.

THE MARITIME SUBPOLAR CLIMATE OF KING GEORGE ISLAND

King George Island (KGI) is located in the South Shetland archipelago between 61°54'- 62°16'S and 57°35'- 59°02'W, off the Antarctic Peninsula northwestern sector (Figure 1). Its climate is determined by the passage of successive cyclonic systems, transporting relatively warm and humid air, and bringing strong winds and heavy precipitation (Bintanja 1995). The region has a typical maritime climate, with small variations in the atmospheric temperatures during the year; high relative humidity and constant cloud cover (Rakusa-Suszczewski et al. 1993, Wen et al. 1994). Its climate can be classified as a South Hemispheric Polar Oceanic or Etf (after Köppen's climatic classification). The atmospheric pressure is higher in the winter season, when the cyclonic pathway is disturbed by the development of high-pressure zones related to the Antarctic anticyclone or to the subtropical high-pressure area over South America (Setzer and Hungria 1994). As a result, air masses coming from the southeast and originating in the western part of the Weddell Sea reach the island (Martianov and Rakusa-Suszczewski 1990). The four main wind directions over KGI are: northwest, west, north and southeast (Setzer and Hungria 1994, Bintanja 1995, Braun et al. 2001). NW and W winds are more frequent, they reach the highest velocities and are relatively warm. In February they are more common, bring-

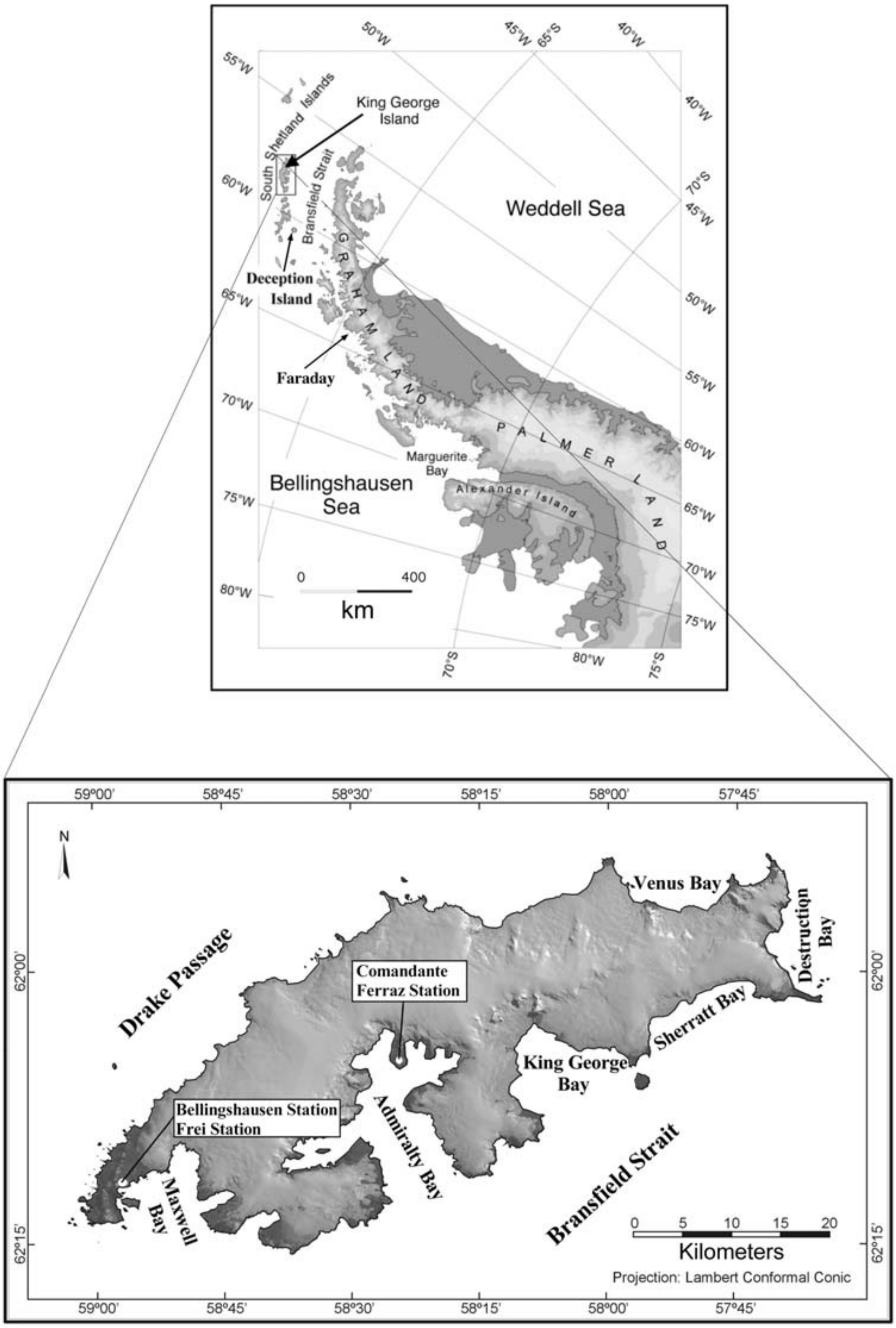

Fig. 1 – Maps of the Antarctic Peninsula and King George Island (KGI) showing the location of the main meteorological stations used in this study.

ing heavy precipitation, relative humidity and cloud cover (Rakusa-Suszczewski et al. 1993). SE winds are less common, being less intense and colder.

The role of the ocean is very important, as a climatic control in the KGI region. Water masses are warmer than the lowest atmospheric layers in winter, thus, warming the boundary layer. In the summer, currents flowing from the Bellingshausen Sea reach the South Shetlands. It is divided in two branches, one flowing towards the Drake Passage and a much smaller one that flows towards the Bransfield Strait. The low temperatures of these superficial waters decrease the air temperature in KGI (Szafrãnski and Lipski 1982).

MATERIALS AND METHODS AND DATA ACQUISITION

King George Island Time Series

A continuous mean monthly temperature time series for the period 1947–95 was obtained for the KGI, using data from different stations. The main database used for the time series construction was the one published by Jones and Limbert (1987), up to 1986, with data from the former British station in Deception Island, DI – 1947–1967 (62°58.2'S, 60°39'W) and from the Bellingshausen Russian station, BELL – 1968–1986 (62°12'S, 58°56'W) in KGI. This database was updated with data from BELL – 1987 to 1992, provided by the Physical Sciences Division of the British Antarctic Survey (BAS), available on the Internet at the following address: ''http://www.nerc - bas.ac.uk / public / icd / data.html''. The distance between DI and BELL is 123 km.

After the database was updated, some gaps that remained in the period 1985–92 were filled with data from a meteorological station at the Presidente Eduardo Frei Montalva Chilean base, FREI (62°15'S, 58°56'W). The linear correlation between BELL and FREI over the period with overlapping data (i.e., 1970–1991) presents little scattering, with a $R^2 = 0.96$ at 99% confidence level ($\alpha = 0.01$). These two weather stations are about 150 m apart.

For the period 1992–1995, the database was updated using the continuous meteorological record from the Brazilian Antarctic Station, *Estação Antártica Comandante Ferraz*, EACF (62°05'S, 58°23.5'W). The meteorological station is maintained by the Brazilian *Instituto Nacional de Pesquisas Espaciais* (INPE), and data are available at the following Internet address: ''http://www.met.inpe.br / htmldoc / antarctica / index.htm#Top''. The linear correlation over the period with simultaneous records between BELL and EACF (1986–94) has a $R^2 = 0.92$ at 99% confidence level ($\alpha = 0.01$). The distance between BELL and EACF stations is 31.5 km.

The possibility of temperature data sharing from one station to another (FREI-BELL and EACF-BELL) was verified using a statistical t-test, as recommended by Smith et al. (1996). The temperature conversion from DI to BELL was done by Jones and Limbert (1987) subtracting 0.3°C from the former record. The annual and seasonal warming trends were calculated using a simple linear correlation.

Other Records

For comparison with our final time series, the temperature database from Faraday station, FAR (65°15'S, 64°16'W), for the same period (i.e., 1947–95), was obtained. As in the case of KGI, we used data from Jones and Limbert (1987) for the 1947–1986 period, and from 1988 to 1995, the data were provided by the BAS. To note, the Faraday station was renamed Vernadsky after its symbolic acquisition by Ukraine. The mean annual temperature data are also available from the Jones and Limbert database for the Orcadas station, OS (60°44'S, 44°44'W) until 1986. From 1987 to 1995, mean temperature data are from the nearby Signy station (60°45'S; 46°30'W). Both stations are located on the South Orkney Islands. Distances are: Orcadas-Signy, 96 km; Orcadas-EACF, 743 km; Faraday-EACF, 456 km.

Mean monthly sea ice extent records, at the 60ºW longitude, for the period 1976–1995, provided by the Australian Antarctic Division, are available at

TABLE I

Mean annual temperatures for different periods at King George Island.

Period	Mean annual temperature	Reference
1947–1995	–2.8	This work
1948–1987	–2.0	Rakusa-Suszczewski et al. (1993)
1948–1957	–2.7	Noble (1959)
1968–1970	–2.9	Simonov (1977)
1970–1991	–2.4	Wen et al (1994)
1978–1987	–2.0	Bintanja (1995)

the following Internet address: ''http://www.antcrc.utas.edu.au/~jacka/seaice_monthly.html''.

KING GEORGE ISLAND TEMPERATURE TIME SERIES AND THE CLIMATIC RECORD OF THE WEST SECTOR OF THE ANTARCTIC PENINSULA

General Trends

The annual mean atmospheric temperature record of KGI shows a warming trend of 0.022°C a^{-1} for the period 1947–1995. It represents a temperature rise of 1.1°C in 49 years. The mean temperature in this period was −2.8°C, with minimum of −5.2°C in 1959 and maximum of −0.8°C in 1989. The mean atmospheric temperature for KGI, cited in the literature before this work, ranges from –2.0 to −2.9°C (Table I).

Three different periods were distinguished as indicated in Table II:

(1) From 1947 to 1959: A mean temperature of –3.4°C, well bellow the overall mean, –2.8°C, with a standard deviation (σ) of 1.3°C, indicating a large interannual variability with 3.8°C of difference between minimum (−5.2°C) and the maximum (−1.4°C) mean annual temperatures. The mean atmospheric temperature varied significantly in very short time intervals, for example, a 2.8°C variation from 1949 to 1951 and a 3.8°C from 1956 to 1959;

(2) Between 1960 and 1980, the mean temperature was identical to the overall mean, with little scattering ($\sigma = 0.7$°C); in this period, the difference between the maximum (−4.2°C) and the minimum (−1.3°C) mean annual temperature was lower (2.9°C) than in the previous period;

(3) From 1981 to 1995: This period shows a mean temperature of −2.4°C and a standard deviation, slightly higher than in the previous interval (0.9°C). The great majority of the points, 67% (10 points), have values equal or greater than the overall mean (−2.8°C) and 47% (7 points) have values higher than the mean temperature for the period. As in the first period, mean temperatures varied abruptly in short-time intervals, as for example, from 1985 to 1987 (2.4°C), from 1987 to 1989 (2.8°C), and from 1989 to 1991 (2.9°C).

The warming occurred mainly between 1949 and 1979, with a trend of 0.031°C a^{-1}, resulting in a temperature rise of 1.0°C. This trend is better vizualised when subtracting the general mean of each mean annual temperature, as plotted in Figure 2a for KGI and 2b and 2c for FAR and OS, respectively.

During the 1947- 95 period, FAR shows a stronger trend (0.051°C a^{-1}) than in KGI, or an increase of 2.5°C in 49 years. On the other hand, the mean annual temperature time series is very similar to the one for KGI, but has a greater interannual variability ($\sigma = 1.6$°C), and a lower mean tempera-

TABLE II

Temperature data from the King George Island time series (KGI), Faraday Station (FAR) and Orcadas-Signy Station (OS).

Station	Period	Mean Temp. (°C)	Minima Temp. (°C)	Maxima Temp. (°C)	Standard Dev. (°C)
KGI	1947–95	–2.8	–5.2 (1959)	–0.8 (1989)	1.0
	1947–59	–3.4	–5.2 (1959)	–1.4 (1956)	1.3
	1960–80	–2.8	–4.2 (1980)	–1.3 (1962)	0.7
	1981–95	–2.4	–3.7 (1991)	–0.8 (1989)	0.9
FAR	1947–95	–4.3	–8.1 (1959)	–1.1 (1989)	1.6
	1947–59	–5.4	–8.1 (1959)	–1.9 (1956)	1.8
	1960–80	–4.2	–6.1 (1980)	–1.9 (1971)	1.2
	1981–95	–3.3	–5.7 (1987)	–1.1 (1989)	1.2
OS	1947–94	–3.7	–6.1 (1980)	–1.4 (1956)	1.0
	1947–59	–4.0	–6.0 (1949)	–1.4 (1956)	1.3
	1960–80	–3.8	–6.1 (1980)	–2.1 (1962)	0.9
	1981–94	–3.3	–4.2 (1991)(1987)	–1.7 (1989)	0.7

ture (−4.3°C). In the FAR record, it is also possible to recognize the three periods found in the KGI series, with coincident mean temperature variations and years of maximum and minimum (Table II).

For OS the warming trend is less pronounced (0.016°C a^{-1}), i.e., an increase of 0.8°C from 1947 to 1994. The three distinct periods identified above for KGI and FAR are less clearly seen for OS, even if some years of minimum and maximum temperatures are coincident with the two former stations. Figure 3 plots the mean annual temperatures and warming trends for KGI, FAR and OS. The correlations between these three time series are shown in Table IIIa.

Mean Temperature Extremes

As shown in Table II and Figure 3, several years in the three time series have similar mean temperature extremes (values greater than overall mean $\pm 1\sigma$). Minima years are 1949, 1959 and 1980, maxima are the years of 1962 (only for KGI and OS), 1956, 1985 and 1989.

In KGI, we observe a 3.8°C temperature drop from 1956 to 1959, followed by an abrupt rise (3.9°C) until 1962. This six-year cycle agrees with the results of the KGI time series spectral analysis (Figure 4). This shows a largely dominant cycle of 5.3 years followed by a second one of 9.6 years, similarly to the results found by Stark (1994) for the FAR record from 1947 to 1990 (cycles of 5 and 9 years). The 5.6 and 9.0-year cyclicities were identified by Yiou et al. (1996) and similar ones by the IPCC temperature global change records (Houghton et al. 1990).

The 9.6-year cycle is apparent in the record, having years with low mean temperatures as in 1949 (−4.9°C), 1959 (−5.2°C) and 1969 (−3.8°C) intercalated with periods of higher temperatures. The other years with low temperatures, however, are directly related to the maximum sea ice extent (see below), for example, 1980 (−4.2°C), 1987 (−3.6°C), 1991 (−3.7°C) and 1995 (−3.3°C). In general, similar relatively low temperatures occurred in FAR, 1949 (−6.9°C), 1959 (−8.1°C), 1980 (−6.1°C) and 1987 (−5.7°C).

The highest mean annual temperatures in KGI were reached in 1956 (−1.4°C), 1962 (−1.3°C), 1985 (−1.2°C) and 1989 (−0.8°C). In FAR the years with highest temperatures were

TABLE III

Correlation coefficients (R^2) between the three times series used in this work (A) and for each season between KGI and FAR.

A – Correlation coefficients – KGI × FAR × OS			
Station	KGI	FAR	OS
KGI	X	0.60	0.73
FAR	X	X	0.33
B – Correlations Seasons KGI × FAR			
Summer	Winter	Spring	Autunm
0.32	0.62	0.62	0.48

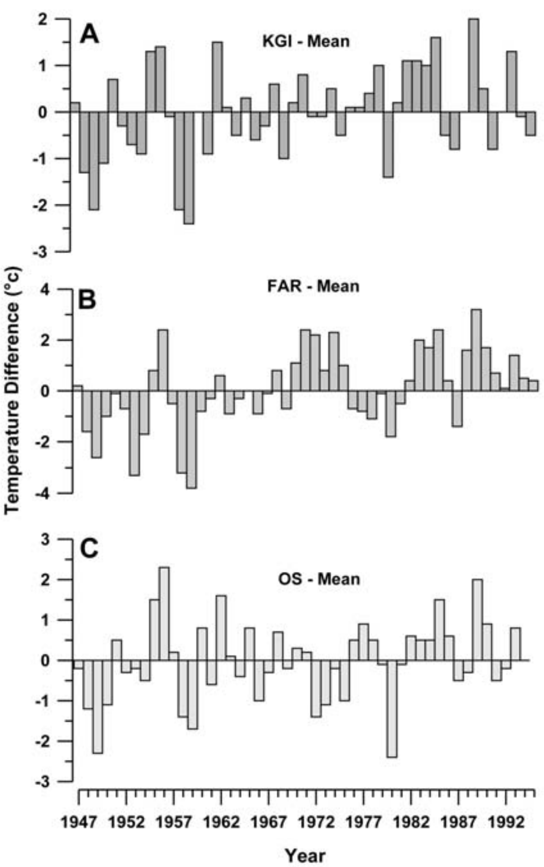

Fig. 2 – Differences between mean annual and overall mean air temperature over the period 1947–95 for (A) King George Island (KGI), (B) Faraday (FAR) and (C) Orcadas-Signy (ORC/SIG).

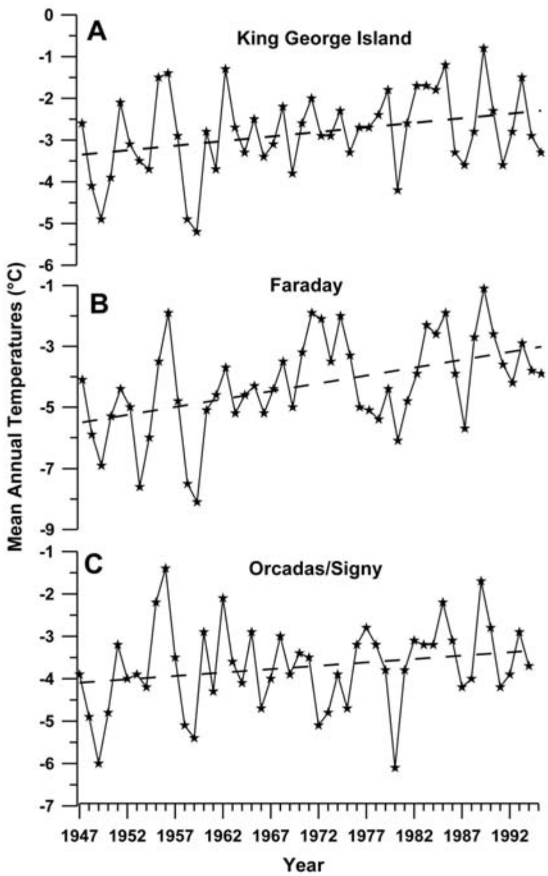

Fig. 3 – Mean interannual temperature time series for King George Island (KGI), Faraday (FAR), and Orcadas-Signy (ORC/SIG) meteorological stations. Warming trend is plotted as a dotted line.

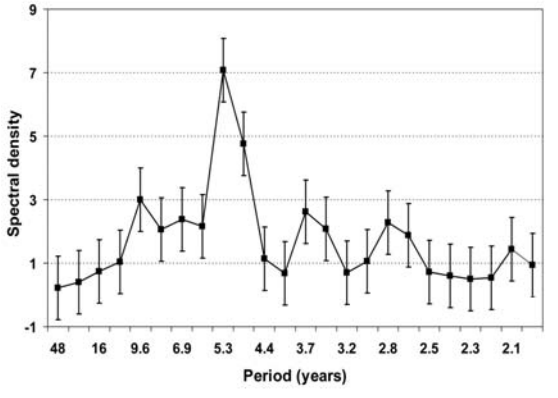

Fig. 4 – Result of the spectral analysis of the King George Island (KGI) mean annual temperature time series. Vertical lines represent the confidence limits; spectral density is a dimensionless unity.

1956 (−1.9°C), 1971 (−1.9°C), 1974 (−2.0°C), 1985 (−1.9°C) and 1989 (−1.1°C). For OS the warmest years are in general the same as KGI: 1956 (−1.4°C), 1962 (−2.1°C), 1985 (−2.2°C) and 1989 (−1.7°C). For 1995, our series is incomplete for OS.

Seasonal Warming Trends and Climatic Variability

The most pronounced seasonal warming trend in KGI was in the winter (0.038°C a^{-1}), having an increase of 1.9°C in 49 years, about two times stronger than in the other seasons (Table IV). Interannual variability is also greater in winter, as shown by standard deviations in Table IV and by Figure 5a. Yearly mean monthly temperature and standard deviations are shown in Figure 6a. July is the month with the greatest interannual variability ($\sigma = 3.2$°C) and the lowest mean temperature (−7.6°C), followed by August (−7.1°C, $\sigma = 2.9$°C) and June (−6.3°C, $\sigma = 2.2$°C). From October to March the temperature variability is greatly reduced ($\sigma = 0.9$°C), the lowest variability occurs in December and January ($\sigma = 0.6$ and 0.7°C, respectively).

FAR has a more pronounced winter warming trend (0.090°C a^{-1}) than KGI, and a temperature rise of 4.4°C, three times higher than in spring and summer. Autumn also shows an important warming, a trend of 0.063°C a^{-1} (i.e., a warming of 3.1°C, Table IV). August has the lowest mean temperature (−10.1°C) and July the greatest variability, $\sigma = 4.7$°C (Figure 6b). Similarly, as for KGI, October to March is a period of low temperature variability (mean $\sigma = 1.2$°C), if compared to the April to September period ($\sigma = 3.4$°C) or with the winter months ($\sigma = 3.9$°C). The lowest variability occurs in December and January ($\sigma = 0.6$ and 0.8°C, respectively). KGI and FAR have both small temperature differences between winter and summer, 7.9°C and 9.3°C, respectively.

The mean temperature differences between KGI and FAR in summer, winter, autumn and spring are, respectively, 0.7, 2.2, 0.8 and 2.1°C. Figure 7 illustrates temperature differences (**td**) between KGI and FAR, over the seasons.

Winter temperature differences between KGI and FAR, from 1947 to 1970, can roughly be divided into two groups: an increase until the end of 1950s, and then a decrease until 1970. Five years are characterized by relatively low **td** (0 < **td** < 2°C): 1950 (0.9°C), 1956 (1.1°C), 1961 (1.8°C), 1964 (0.5°C) and 1970 (0.9°C). The higher **td** (greater than 4°C) throughout the period are recorded in 1953 (5.8°C), 1957 (4.9°C), 1958 (5.2°C), 1960 (4.8°C) and 1963 (4.4°C). For the remaining years recorded temperatures are between 2 and 4°C. The ones in KGI are higher than FAR all along the mentioned period.

The years between 1971 and 1975 are characterized by lower temperatures in KGI than FAR, except 1973, when the temperature in FAR was 0.6°C greater than KGI. From 1976 to 1986, there was a progressive decrease in **td** from 4.8°C in 1976 to 0.6°C in 1986. Except for 1983, all the years show greater temperatures on KGI. An abrupt increase was recorded from 1986 (0.6°C) to 1987 (5.1°C) and, afterwards, the winter **td** decreased until the middle 1990s.

Temperatures were colder in KGI than FAR over the following years: 1971 (0.5°C), 1972 (1.8°C), 1974 (1.3°C), 1975 (1.6°C), 1983 (0.7°C), 1990 (0.3°C), 1991 (2.1°C) and 1995 (1.1°C). Two

TABLE IV

Temperature data for King George Island (KGI) and Faraday (FAR) separated by seasons.

Station	Season	Warming trend (°C a^{-1})	Mean Temp. (°C)	σ (°C)	Minima (°C)	Maxima (°C)	**Warming** (°**C**)
KGI	Summer	0.016	0.9	0.5	–1.3	2.7	0.8
	Winter	0.038	–7.0	2.3	–15.5	–1.0	1.9
	Spring	0.015	–3.0	0.9	–9.0	0.1	0.7
	Autunm	0.017	–2.2	1.2	–8.3	2.4	0.8
FAR	Summer	0.025	0.2	0.6	–2.9	2.3	1.2
	Winter	0.090	–9.1	3.3	–20.1	–1.9	4.4
	Spring	0.028	–5.1	1.5	–14.1	0.1	1.4
	Autumn	0.063	–3.0	2.0	–13.8	1.4	3.1

reversals (KGI was colder than FAR) with great **td** amplitude in 1975/76 and 1991/92 should be mentioned.

For summer and autumn, the time series show roughly similar behavior until the late 1960s and over the period 1971- 75. The year of 1972 is very peculiar. It shows generally colder temperatures in KGI during winter, summer and autumn. During spring, FAR is colder, but it is the lowest **td** in the whole record and marks a transition between two periods. From late 1970s to mid 1990s, only summer shows a different trend, with a decreasing temperature difference until mid 1980s, increasing afterwards. Autumn also reveals several years with the mean monthly temperature in KGI lower than FAR, specially from mid 1980s to early 1990s.

Spring shows a different tendency from 1947 to the end of the 1960s. Values decrease until mid 1950s and then increase until late 1960s. From 1968 to 1972, there is a progressive decrease of **td**, and then a progressive increase until 1977. Over the entire period, temperatures were higher in KGI, except in 1988, when KGI was 0.4°C colder.

Correlation coefficients over the seasons between KGI and FAR, are shown in Table IIIb. The best correlations between the two time series are obtained during winter and spring, with a $R^2 = 0.62$ for both seasons.

TEMPERATURE RECORDS AND SEA ICE EXTENT

In this section, we examined the relationships between the KGI temperature time series and sea ice extent in the 60°W longitude. From 1976 to 1995, the mean monthly sea ice cover at this longitude shows the greatest extent, reaching 60°06'S, and interannual variability in August (Figure 8), which has $\sigma = 1.8$ degrees (more than three times greater than the mean, 0.5 degree). Sea ice in July and September also show great variability ($\sigma = 1.4$ and 1.3 degrees, respectively). The mean annual difference between the maximum (August) and the minimum (January) sea ice extent is 3°30', a variation of more than 300 km. The sea ice extent from July to September is well correlated with winter (June, July and August) mean temperatures in KGI, with a slope of 0.5 degree/°C and a correlation coefficient (R^2) of 0.75 (Figure 9). Cross-correlation analysis of these two time series shows that there is a one-month lag between the lowest temperatures (July) and the maximum sea ice extent (August). Generally, sea ice is observed in the KGI latitude between mid June (or early July) and the end of October (or early November).

The mean annual position of the sea ice limit is at 62°30'S, reaching 61°12'S in winter and retreating in summer to 63°36'S. The minimum sea ice extent was 63°06'S in 1985 and 1989, and

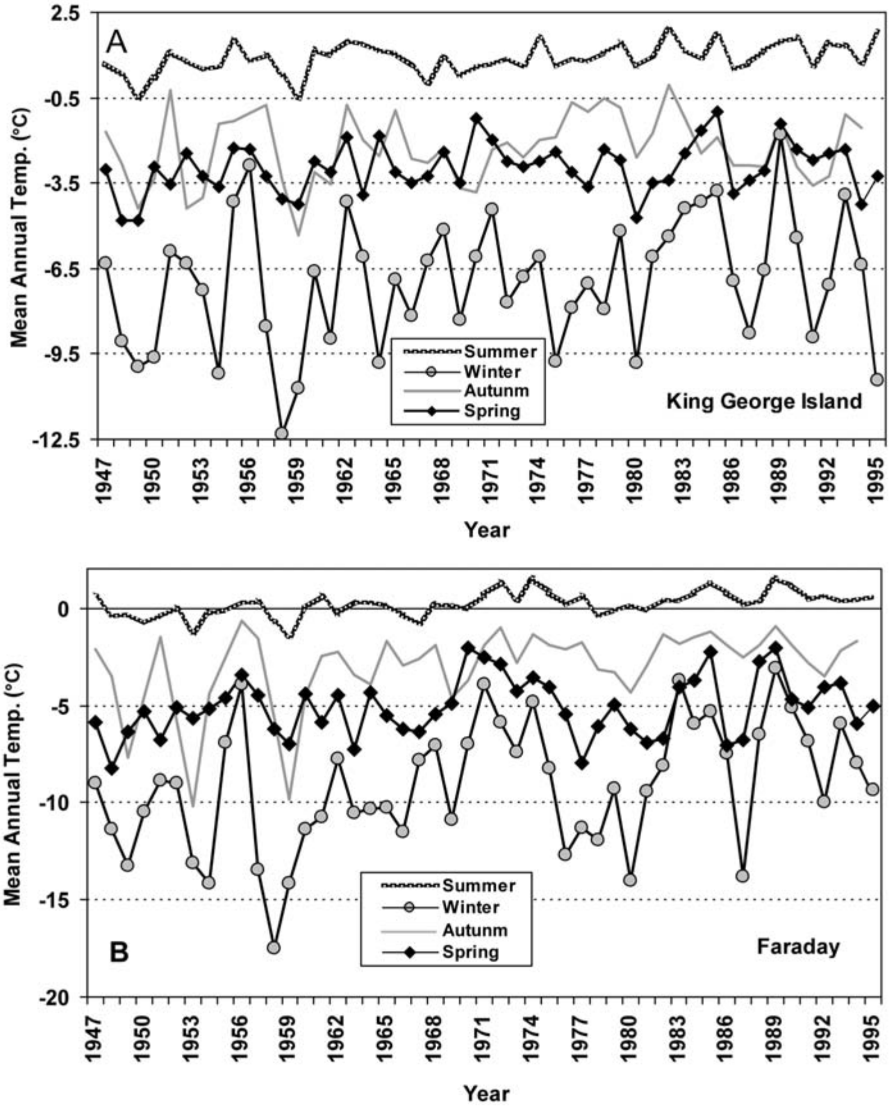

Fig. 5 – Mean annual seasonal temperatures in (A) King George Island (KGI) and (B) Faraday (FAR).

the maximum 61°42'S in 1986 and 1987. Figure 10 compares the sea ice extent at 60° longitude, from July to September, to mean winter temperatures for KGI. Four years are characterized by a maximum sea ice extent associated with relatively low mean temperatures: 1980 (58°54'S, −9.8°C), 1987 (58°42'S, −8.8°C), 1991 (59°54'S, −8.9°C) and 1995 (58°30'S, −10.4°C). In 1989, the sea ice limit reached only 62°54'S and the mean winter temperature was −1.8°C.

DISCUSSION AND CONCLUSION

A warming trend of 0.022°C a^{-1}, resulting in a mean air temperature rise of 1.1°C over 49 years, from 1947 to 1995, was recorded at King George Island. For comparison, Faraday had an increase of 2.5°C for this period. More than 90% of the warming in KGI was found to occur between 1947 and 1979. This warming may result from an increase in warm air mass advections from the north, happening since the 1950s, as demonstrated by King (1994).

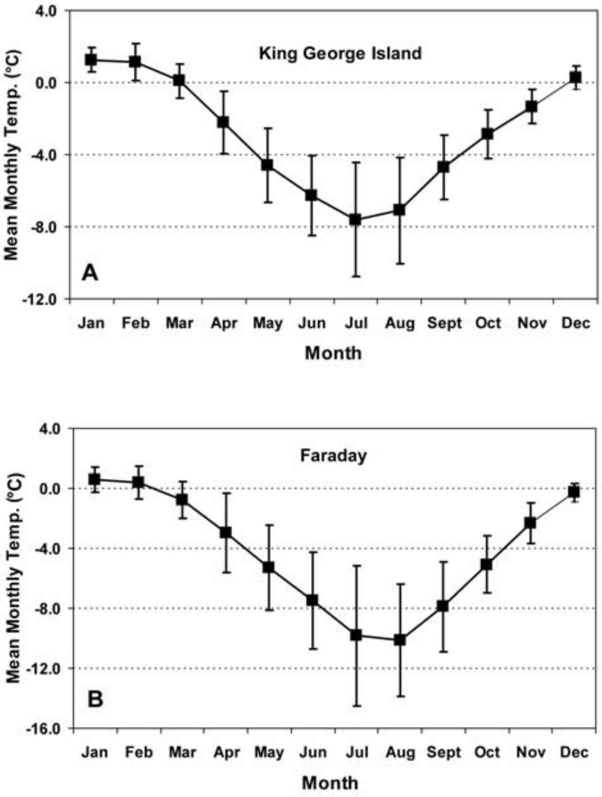

Fig. 6 – Mean monthly temperatures in the period 1947–95 in (A) King George Island (KGI) and (B) Faraday (FAR).

The greatest statistical significance for the warming trend is found at sites located to the north of the Antarctic Peninsula, where the temperature variability is lower than in the rest of the region. At Faraday, this trend is more pronounced than KGI, but is less clearly seen when the overall mean temperature is subtracted from each mean annual temperature. Sansom (1989) points out that warming trends measured at Faraday, the former area, are not statistically significant. The large warming trends and interannual variability observed in KGI and Faraday records are also recorded at stations located further south, like Marguerite Bay (King 1994) and Alexander Island (Harangozo et al. 1994).

In KGI, winter temperature has a lower interannual variability than at Faraday, as expected for the strong maritime climate of an island. The interannual variability in the west coast of the Antarctica Peninsula can be explained by two factors (King 1994): 1) atmosphere-ice-ocean interactions, which is apparent from the strong negative correlations between winter temperatures and sea ice extent; 2) variability in the advection of warm air masses with an anomalous northerly circulation associated with warm winters.

A one-month lag is observed between mean temperatures in KGI and sea ice extent. We found a good correlation ($R^2 = 0.75$) between sea ice extent from July to September and mean winter temperatures between June and August. On four occasions, the sea ice limit was recorded north of 60°S (1980, 1987, 1991 and 1995). King and Harangozo (1998) also recorded maximum sea ice extent for the first three years mentioned above at 70°W longitude.

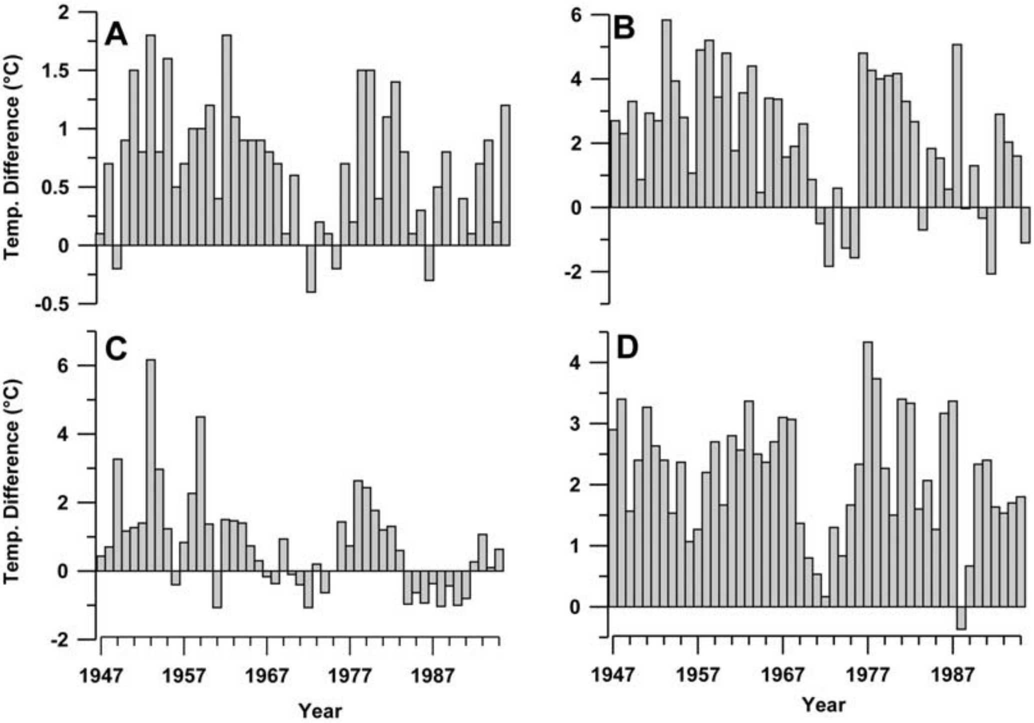

Fig. 7 – Temperature differences between King George Island (KGI) and Faraday (FAR) in (A) summer, (B) winter, (C) autumn and (D) spring. The values above zero indicate higher temperatures in KGI than Faraday.

For King and Harangozo (1998), these modifications in atmospheric circulation are driving variations in temperature, with sea ice-atmosphere interactions enhancing the sensitivity to changes. The strongest correlations are found in autumn and winter for areas surrounding the Antarctic Peninsula (Smith et al. 1996). The ocean-ice-atmosphere interaction in the Bellingshausen Sea is exerting the main control on the climate of the Antarctic Peninsula west coast. Evidence for the role of sea ice in surface warming at Faraday is given by Marshall et al. (2002) who report marked surface and tropospheric temperature differences in winter. Annual warming trend in troposphere at Faraday is 0.027°C a^{-1} (from 1956 to 1999), about a half that observed in the surface.

We observed no overall trend in sea ice extent data, but a great interannual variability. According to King and Harangozo (1998), air temperatures in the Antarctic Peninsula are sensitive to small changes in the sea ice limit position, and these are too small to account for the observed warming. Sea ice influences temperatures by reducing both the heat fluxes from ocean to atmosphere and the solar radiation absorbed at the ocean surface. It seems that the climatic sensitivity of this region results in part from

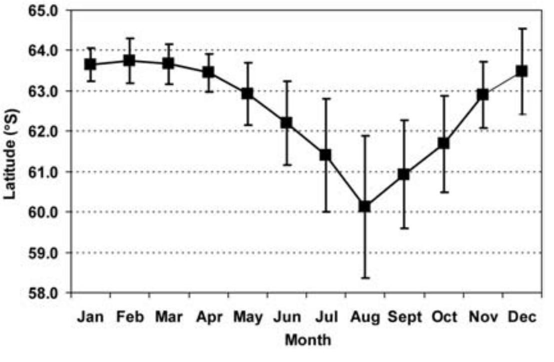

Fig. 8 – Mean monthly sea ice extent on 60°W longitude, for the 1976–1995 period. Vertical lines are standard deviations (σ).

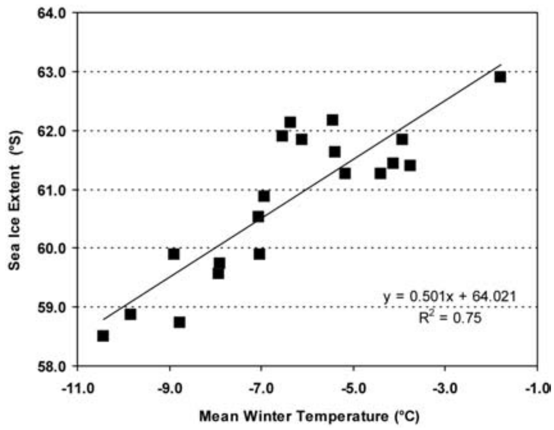

Fig. 9 – Linear correlation between sea ice extent, from June to August, at 60°W longitude and mean winter temperature in King George Island (KGI), for the period 1976–1995.

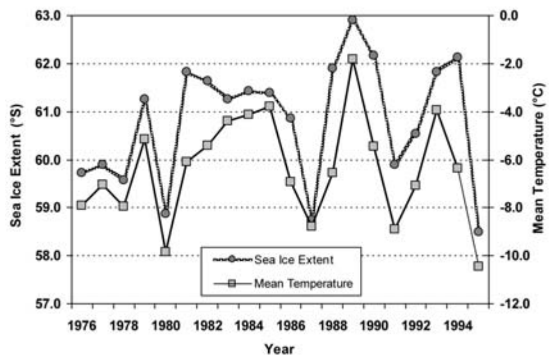

Fig. 10 – Mean sea ice extent, from June to August, at 60°W longitude and mean winter temperature in King George Island (KGI), time series for the period 1976–1995.

the effects of a positive feedback. Lower temperatures lead to the growth of sea ice, and are strongly affected by the position of the ice limit (King and Turner 1997).

In KGI, the period from 1981 to 1995 has mean temperatures greater than the overall mean. The warmest year in the mentioned period, and in the entire record, is 1989 (−0.8°C). Skvarca et al. (1998) detected a warm period between 1981 and 1995, at stations in the east side of the Antarctica Peninsula. Smith et al. (1996) assert that this relatively high mean temperature in 1989 may be related to below average sea ice extent in the West Antarctic Peninsula caused by the strength and duration of the 1988 La Niña event.

On the West Antarctic Peninsula Doake and Vaughan (1991) recorded the retreat of the Wordie Ice Shelf, apparently caused by increased amounts of melt water, resulting from a warming trend recorded at Marguerite Bay. Ice cliff and glacier retreats were documented in KGI from the mid 50s to mid 90s (Park et al. 1998, Simões et al. 1999). KGI has lost about 7% of the ice cover area during the period 1956–95. More than 50% of the outlet glaciers retreated from hundreds of meters to 1 km, over these 40 years (Simões et al. 1999). We did not find evidence, in our time series, to account for the ice retreat in KGI. More detailed studies are needed to find out if these ice retreats are directly related to the warming trends recorded in KGI and Antarctic Peninsula.

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RESUMO

Este trabalho apresenta as séries temporais continuas da temperatura do ar, média anual e sazonal, na ilha Rei George (IRG) para o período de 1947–1995, combinando dados de várias estações meteorológicas das ilhas Shetland do Sul. Estas séries são analisadas para detecção de tendências. As séries também são comparadas com a extensão mensal do gelo marinho, registrado a 60°W. A temperatura anual média no período foi de –2,8°C, com mínima de –5,2°C, em 1959, e máxima de –0,8°C, em 1989. Este registro mostra tendência de aquecimento de 0,022°C a^{-1}, no intervalo de tempo estudado, ou seja, uma elevação de 1,1°C em 49 anos. O inverno mostra a maior tendência de aquecimento (0,038°C a^{-1}), ou 1,9°C no período. No período, observam-se variações abruptas da temperatura média anual, com valores que chegam a 3,9°C. Estas tendências são melhor definidas do que na estação Faraday. Análises espectrais destas séries mostram ciclos de 5,3 e 9,6 anos. Uma diferença de tempo (*lag*) de um mês é observada entre a temperatura média dos meses de inverno na IRG e a extensão do gelo marinho no setor 60°W.

Palavras-chave: climatologia, temperatura atmosférica, séries temporais.

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