The spatial coherence of interannual temperature variations in the Antarctic Peninsula

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Abstract

The west coast of the Antarctic Peninsula is a region of extreme interannual variability in near-surface temperatures. Recently the region has also experienced more rapid warming than any other part of the Southern Hemisphere. In this paper we use a new dataset of satellite-derived surface temperatures to define the extent of the region of extreme variability more clearly than was possible using the sparse station data. The region in which satellite surface temperatures correlate strongly with west Peninsula station temperatures is largely confined to the seas just west of the Peninsula. Correlation of Peninsula surface temperatures with those over the rest of continental Antarctica is poor confirming that the west Peninsula is in a different climate regime. Our analysis suggests that only one of five existing ice cores from the region is likely to provide a proxy climate record that is representative of the west coast.

Popular Science Summary

The western part of theAntarctic Peninsula and adjacent region have been identified as a climatologically anomalous region in the Southern Hemisphere. These region has experienced more rapid warming than any other part of the Southern Hemisphere in recent years. The sea ice cover west of the Peninsula has also been receding at a relatively rapid rate while the sea ice cover in other areas, especially in the Ross Sea, has been increasing. In this paper, satellite-derived surface temperatures were used to examine the extent of the region of extreme temperature variability more clearly than was possible using the sparse station data. Our results show that the region where satellite surface temperatures correlate strongly with west Peninsula station temperatures is largely confined to the seas just west of the Peninsula. Correlation of Peninsula surface temperatures with those over the rest of continental Antarctica is poor confirming that the western Peninsula region is in a different climate regime. Insights into the long term variability and trend of the climate in the region can be obtained through the use of ice core data. Our analysis suggests that only one of five existing ice cores from the region is likely to provide a proxy climate record that is representative of the west coast.

Significant Findings

In this paper, satellite-derived surface temperatures are used investigate the large temperature variability and warming trend observed in Western Antarctic Peninsula. The extent of the climatologically anomalous region in the Antarctic Peninsula is not known because of poor spatial coverage by station data but in light of recent reports of cooling in east Antarctic, it is important to assess which other areas in the Antarctic are affected. Our results show that the region where satellite surface temperatures correlate strongly with west Peninsula station temperatures is largely confined to the seas just west of the Peninsula. Correlation of Peninsula surface temperatures with those over the rest of continental Antarctica is poor confirming that the western part of the Peninsula is in a different climate regime. This anomalous climate condition in the region can be studied on a long term basis through the use of ice cores. Our analysis suggests that one of five existing ice cores from the region could provide a proxy climate record that is representative of the western region.

Abstract

Over 50 years of observations from climate stations on the west coast of the Antarctic Peninsula show that this is a region of extreme interannual variability in near-surface temperatures. The region has also experienced more rapid warming than any other part of the Southern Hemisphere. In this paper we use a new dataset of satellite-derived surface temperatures to define the extent of the region of extreme variability more clearly than was possible using the sparse station data. The region in which satellite surface temperatures correlate strongly with west Peninsula station temperatures is found to be quite small and is largely confined to the seas just west of the Peninsula, with a northward and eastward extension into the Scotia Sea and a southward extension onto the western slopes of Palmer Land. Correlation of Peninsula surface temperatures with surface temperatures over the rest of continental Antarctica is poor confirming that the west Peninsula is in a different climate regime. The analysis has been used to identify sites where ice core proxy records might be representative of variations on the west coast of the Peninsula. Of the five existing core sites examined, only one is likely to provide a representative record for the west coast.

Introduction

Surface temperature records from the west coast of the Antarctic Peninsula exhibit a much higher degree of interannual and longer period variability than those from other Antarctic coastal locations [*King*, 1994]. The west coast of the Peninsula is the most rapidly warming region of the Southern Hemisphere [*Vaughan et al.*, 2001] and it is thus of considerable interest to determine whether the high degree of variability apparent at the coastal stations is a localised phenomenon or if it is characteristic of a broader area. Correlation of station temperature records suggests that temperature variations are reasonably coherent along the west coast of the Peninsula from around 62°S to around 68°S [*King*, 1994]. However, the lack of long temperature records from the interior or east coast of the Peninsula, or for the regions further south, have made it difficult to delimit the region of high variability completely.

It is also important to examine recent climate variability in the Peninsula region in the context of the longer term regional climate record. One of the best potential proxies for temperature is the stable isotope record that can be obtained from ice cores. The Antarctic Peninsula is a region of relatively high snow accumulation and thus offers the possibility of obtaining climate records with quite high temporal resolution. Unfortunately, low-lying parts of the west coast of the Peninsula experience temperatures well above freezing during the summer season which cause significant snowmelt, making the interpretation of stable isotope records problematic. Most ice cores from this region have therefore been taken from the high interior of the Peninsula or the colder east coast [*Peel et al.*, 1996]. It is clearly important to determine whether the climate variations recorded in such ice cores are likely to be related to those observed on the west coast where we have long instrumental records.

In this paper, we use a new Antarctic-wide dataset of monthly mean surface temperatures at high spatial resolution obtained from satellite infrared radiometer data to study the spatial coherence of temperature variations around the Antarctic Peninsula. We use the data to identify areas for which existing ice cores may provide a representative climate record and discuss which of these records are likely to be suitable for studying the longer term climate history of the west coast of the Peninsula.

Data

Comiso [2000] describes the construction of a dataset of monthly mean surface temperatures on a 6.25 km x 6.25 km polar stereographic grid for the Antarctic region using satellite infrared radiometer data. In this study we use data for the period 1982-2000 when temperatures were obtained from the Advanced Very High Resolution Radiometer (AVHRR) carried on National Oceanographic and Atmospheric Administration (NOAA) polar-orbiting meteorological satellites. Monthly average surface brightness temperatures were calculated from the 5 km x 3 km resolution Global Area Coverage (GAC) data from this instrument after application of the cloud-clearing techniques described in *Comiso* [2000].

Monthly mean surface temperatures derived from satellite observations may differ from near-surface air temperatures measured at a climatological observatory for a number of reasons. Most importantly, the satellite-derived temperature is conditionally sampled for clear-sky conditions. During the Antarctic winter, near-surface temperatures are generally lower during clear sky conditions than during cloudy conditions so the satellite-derived monthly mean temperatures may be biased cold and may not properly reflect temperature variations associated with varying cloud cover.

Comiso [2000] compared temperatures from this dataset with monthly mean surface air temperatures from a number of Antarctic stations. He concluded that the satellite-derived surface temperatures represent seasonal and interannual fluctuations well and that biases in monthly mean temperatures due to conditionally sampling clear-sky conditions are less than 0.5 °C. The west coast of the Antarctic Peninsula is affected by cyclones moving across the Bellingshausen Sea and thus has a very cloudy climate. At the coastal station Faraday (65.25°S, 64.26°W), only 19% of three-hourly synoptic observations during the winter months (July-August) recorded 2/8 or less total cloud cover during 1982-1997, while 66% recorded 7/8 or greater. During summer (December-February), even cloudier conditions prevailed and the corresponding figures are 10% and 84% respectively. The satellite record will thus be a highly conditionally sampled record of surface temperatures in this region. However, it does appear to represent interannual variations quite accurately. Table 1 summarises the results of a comparison of Faraday monthly mean air temperatures with satellite surface temperatures from a neighbouring grid point. The correlation is reasonable during the winter months although, as expected, the satellite temperatures are biased cold. The correlation becomes poor during the summer, when interannual temperature variations are much smaller [*King*, 1994]. If the comparison is repeated using monthly mean Faraday temperatures computed only from observations when the cloud cover was 3/8 or less, the cold bias is reduced and the correlation coefficient for the winter months is slightly improved.

Few data are available for checking the reliability of satellite temperatures over the high interior of the Antarctic Peninsula. Table 2 summarises the results of a comparison of satellite temperatures with those from an automatic weather station (AWS) at Siple station (75.92°S, 83.92°W, 1054 masl). AWS data are available for 1982-84 and 1988-91 [*Stearns et al.*, 1993]. The correlation of satellite and AWS temperatures is high throughout the year. In summary, we conclude that the satellite surface temperature dataset provides a reasonable representation of interannual variations in winter temperature on the west coast of the Peninsula and a good representation of temperature variations in all seasons in the interior of the Peninsula. In what follows, we restrict our attention to the winter season, when interannual temperature variations on the west coast are at their largest.

Methods

We have assessed the spatial coherence of temperature variations by correlating the time series of temperature at a base point with the corresponding time series at all other points in the satellite temperature dataset. The resulting field of correlation coefficients can then be plotted on a map to highlight regions with which the base point is highly correlated and for which it may thus be considered representative. The analysis has been carried out using winter (June-August) mean temperatures calculated from the original monthly mean data.

If there is no serial autocorrelation of the data, correlation of the 19 year time series at two points has 17 degrees of freedom so correlation coefficients greater than about 0.6 are significant at the 1% level. Autocorrelation reduces the number of effective degrees of freedom. Using the methodology of *Trenberth* [1984] we estimate that correlations in the vicinity of the Antarctic Peninsula have about 10 effective degrees of freedom, giving a threshold of $r=0.71$ for the 1% significance level. We choose to highlight areas where correlation coefficients exceed 0.75 .

Results

Figure 1 shows correlation coefficients, r, of the time series of winter mean temperature at each point in the satellite dataset with that at a point close to Faraday. The region with $r > 0.5$ is quite large, extending northwards into the Drake Passage and eastwards into the Weddell and Scotia Seas. However, the highest correlations ($r > 0.75$) are mostly restricted to a narrow crescent running from southern Palmer Land, through Alexander Island then northward along the Peninsula coast to the South Shetland Islands with some indication of an extension towards the South Orkney Islands. This is consistent with correlation coefficients derived from station observations by *King* [1994]. Except in the southern part of the Peninsula, correlation coefficients drop off rapidly moving eastward from the west coast into the high interior and remain generally low on the east coast.

Correlation coefficients drop off rapidly west of 90°W and are small over most of the Antarctic continent. A secondary maximum of positive correlation around 135°E, together with non-significant maxima of negative correlation between 0-45°E and around 135°W are reminiscent of the Antarctic Circumpolar Wave described by *White and Petersen* [1996].

We have produced similar correlation maps (figure 2) for base points located at the sites of the major ice cores obtained from the Peninsula [*Peel et al.*, 1996]. The locations of these cores are given in Table 3. Correlations with winter temperatures at Dolleman Island are highest across the Weddell Sea to the east of the core site. The correlation with temperatures on the west coast of the Peninsula is generally weaker. This is consistent with the finding [*Peel et al.*, 1996] that oxygen isotope -derived temperatures from this core do not correlate strongly with station temperatures on the west coast of the Peninsula. James Ross Island temperatures appear to be representative of the northern tip of the Peninsula and the South Shetland Islands. While correlations with this site are low immediately adjacent to the central west coast of the Peninsula, higher correlations are found further out into the Bellingshausen Sea.

Of the interior sites, Siple (not shown) and Dyer show rather low correlation with the west coast although the former appears to be representative of temperature fluctuations over a large area of Ellsworth Land. Gomez, however, correlates strongly with temperatures in a region stretching from the core site through Alexander Island and then northwards up the west coast of the Peninsula. This core site is at a relatively low elevation (1130 m) and, being situated well to the west of the topographic divide, will be influenced by the same weather systems and air masses that affect stations on the west coast.

Discussion

Analysis of a new, satellite-derived surface temperature dataset has enabled us to define the geographical limits of the region of exceptionally high interannual temperature variability that was apparent in west Antarctic Peninsula climate records. The region of coherent temperature fluctuations was found to be largely confined to the west coast of the Peninsula, with a southward extension through Alexander Island into southern Palmer Land and a northward extension through the South Shetland Islands. Temperatures on the eastern side of the Peninsula were found to correlate rather poorly with those on the west, confirming that the high and steep orography of the Peninsula is an effective barrier to air masses originating in the Pacific sector of the Southern Ocean, leading to very different climatic regimes on the two sides of the Peninsula [*Martin and Peel,* 1978]. Our results highlight the lack of correlation between temperature variations in the Peninsula with those over the rest of continental Antarctica [*Raper et al.*, 1984] for the first time in good spatial detail.

The majority of ice core records from this region have been obtained from the east coast or high interior of the Peninsula. Temperatures at most of these sites show a rather low correlation with those measured along the west coast. The exception is the record from

Gomez. This region - the western slopes of the southern part of Palmer Land - would appear to offer the best possibility for obtaining ice core records that will be representative of conditions at low elevations on the west coast. We hypothesise that this region is influenced by the same air masses that determine the climate at stations on the west coast of the Peninsula. This needs to be tested using high-resolution regional atmospheric models. Given the importance of producing a long proxy climate record for the west coast, obtaining further ice cores from this region should be a high priority.

While the results of this study may usefully identify areas where ice core records will not be representative of Peninsula west coast conditions, a high correlation at a location on figure 2 does not imply the inverse. The stable isotope record in an ice core is related to the surface temperature at the core site through a complex transfer function that is dependent on the local and regional meteorology and the source region for the moisture that formed the precipitation. The present study thus only offers a starting point for choosing representative ice core sites. A further limitation of the study is that it is only based on 19 years of data It is possible that the spatial coherence of interdecadal and longer timescale temperature variations is larger than that of the predominantly interannual fluctuations studied here. In an attempt to address this question, we recreated figure 1 after first smoothing the winter mean temperature timeseries at each point in the dataset using a 5-point binomial filter. The correlation pattern that emerges (not shown) is reassuringly similar to that seen in figure 1. In particular, there is very little increase in the area of the region of highest correlation ($r \geq 0.75$), suggesting that our findings may hold for longer timescales.

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Table 1. Correlation coefficients, r, mean differences and standard deviation of the differences between monthly mean air temperatures, T_A, at Faraday and satellite-derived surface temperatures, T_S, at a neighbouring grid point. T_A has been calculated for all Faraday synoptic observations during 1982-2000 and also just for those observations for which the reported total cloud amount was 3/8 or less. Long-term monthly means were subtracted from both the satellite and air temperature time series before calculating correlation coefficients.

Months	Cloud amount	r	$\overline{T_S-T_A}$ (K)	σ (T_S-T_A) (K)
All	All	0.57	-4.71	3.33
JJA	All	0.72	-4.41	3.28
DJF	All	0.29	-3.55	1.90
All	$\leq$ 3/8	0.84	-2.28	3.20
JJA	$\leq$ 3/8	0.76	-0.77	3.00
DJF	$\leq$ 3/8	0.22	-3.04	2.01

Table 2. Correlation coefficients, r, mean differences and standard deviation of the differences between monthly mean air temperatures, T_A, at the Siple AWS and satellite-derived surface temperatures, T_S, at a neighbouring grid point. AWS observations are available for 1982-84 and 1988-91.

Months	r	$\overline{T_S-T_A}$ (K)	σ (T_S-T_A) (K)
All	0.97	-0.49	2.00
JJA	0.90	0.37	1.63
DJF	0.82	-0.95	1.71

Table 3. Locations of ice cores in the Antarctic Peninsula region.

	James Ross Is.	Dolleman Island	Dyer	Gomez	Siple
Latitude	64.22°S	70.58°S	70.67°S	74.02°S	75.92°S
Longitude	57.67°W	60.93°W	64.5°W	70.63°W	84.25°W
Elevation (m)	1640	398	2000	1130	1054

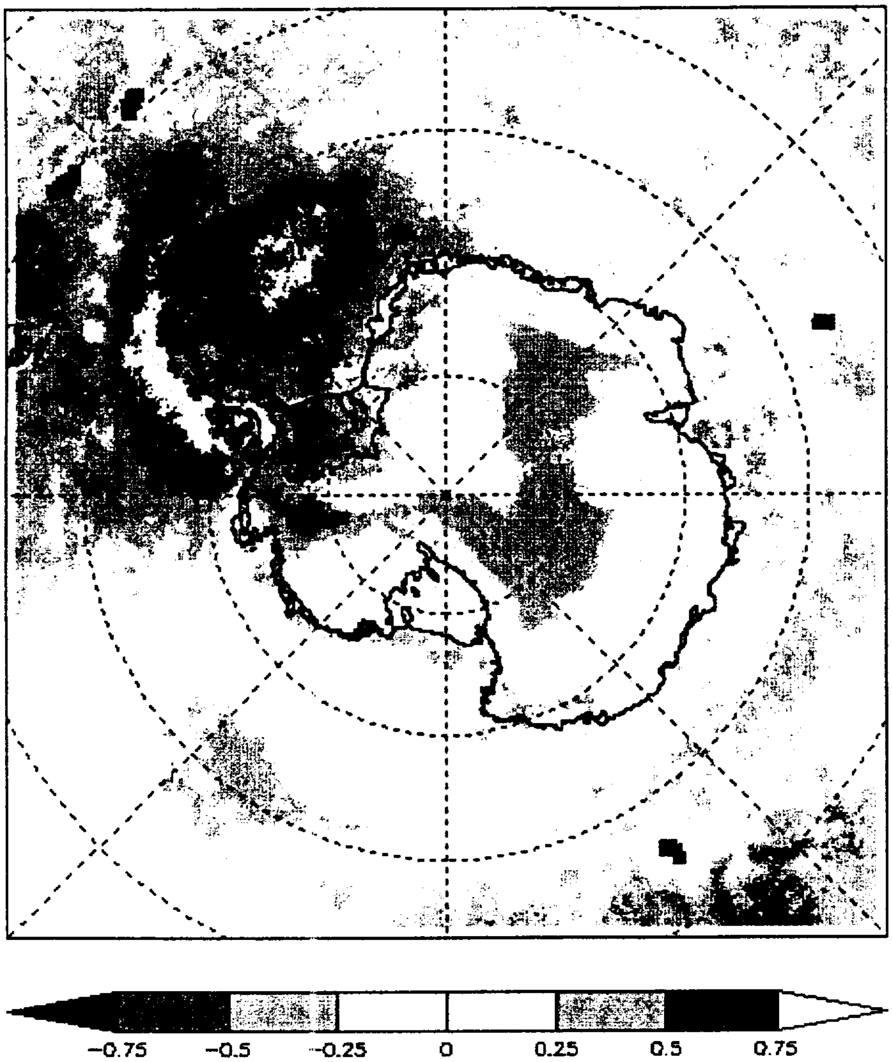

Figure 1. Correlation coefficients of the timeseries of winter (June-August) mean temperatures at all points in the satellite-derived surface temperature dataset with the timeseries at a point close to Faraday station (green cross).

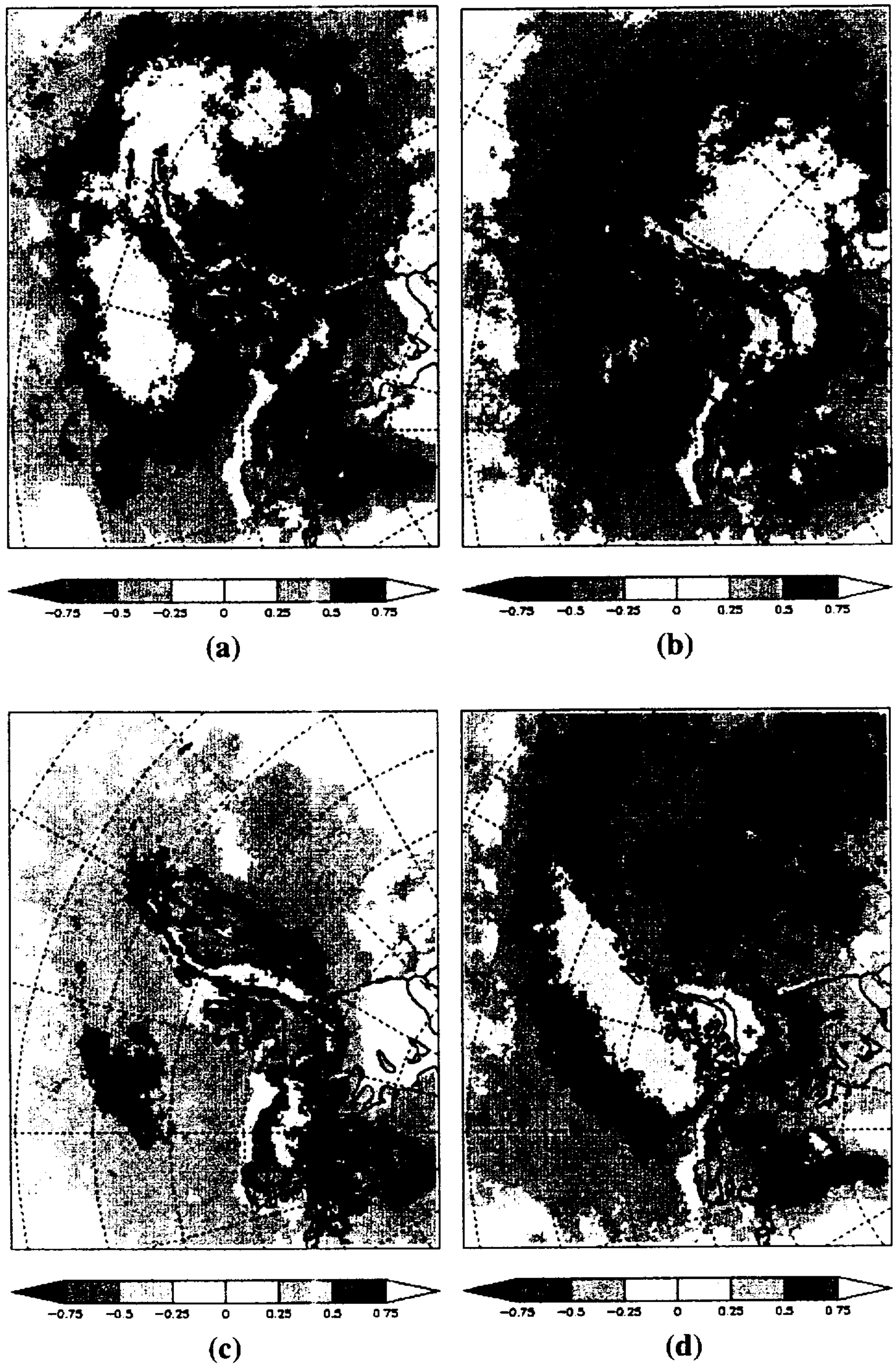

Figure 2. Correlation coefficients of winter (June-August) mean surface temperatures at (a) James Ross Island, (b) Dolleman Island, (c) Dyer, and (d) Gomez with other points in the satellite-derived surface temperature dataset. The base point for each map is marked with a green cross.