

ANTARCTIC CLIMATE VARIABILITY AND CHANGE: AN EXHAUSTIVE ANALYSIS OF THE TEMPERATURE DATASET FROM ORCADAS

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ABSTRACT: Antarctica is a key region from the perspective of climate change. There is evidence for substantial warming in the region of the Antarctic peninsula in recent decades, as well as some seasonal cooling on the high plateau of East Antarctica. Thompson and Solomon (2002) suggested that this unusual pattern of change was likely to be linked to ozone depletion and associated changes in the atmospheric wind field, and later studies have supported this finding. However, some recent studies have pointed towards slow variability of the Antarctic climate that may be linked to ocean circulation processes. The goal of the present study is to conduct a more detailed analysis of both the variability and the trends in Antarctic climate, using the most comprehensive data available. The only nearly-complete 20th century instrumental record of Antarctic climate is from Orcadas, the Argentine station, which has never been published. This work analyses the detailed daily temperature trends from this unique dataset which covers the period 1903-2008. Both climate means and extremes are analyzed. In addition, analysis of the daily trends at Orcadas will allow examination of the degree to which climate change may have altered the progression of the seasonal cycle in Antarctica.

1. INTRODUCTION

In the past several decades, some portions of west Antarctica have been subject to extremely large warming trends, while east Antarctica has exhibited cooling trends in some seasons (e.g., Comiso, 2000; Turner et al., 2005; Marshall et al., 2006, Marshall, 2007; Chapman and Walsh, 2007; see Figure 1). These contrasting trends have their origins in a strengthening of the westerly winds that encircle the south polar cap in recent decades, which in turn has been linked to stratospheric ozone depletion and greenhouse gas increases (Thompson and

Solomon, 2002; Gillett and Thompson, 2003; Marshall et al., 2004; Arblaster and Meehl, 2006; Cai and Cowan, 2007). Key questions have been raised, however, regarding how much such changes in climate and circulation patterns may occur through natural internal variability (Jones and Widmann, 2004; Fogt and Bromwich, 2006).

A number of Antarctic sites have reported daily and monthly instrumental climate observations since the International Geophysical Year (IGY) in 1958, and a few have records beginning in the 1940s with variable consistency and confidence, but only one station has an instrumental record of daily Antarctic surface temperature covering the entire 20th century: the Argentine station Orcadas at 60°44'S, 44°44'W. While only a single such long term site is available and it may not fully represent the average across Antarctica (Raper et al., 1984), the station lies in the heart of the region displaying strong summer season warming in recent decades as shown in Figure 1, and the observed changes there are correlated to circulation changes linked to the Southern Annular Mode (Marshall, 2004; Visbeck, 2008). The rapid summer warming observed in this region since about 1950 is evident, and far exceeds observed long-term global trends. Here we present daily data since the beginning of record keeping in 1903. The data was provided by the National Weather Service of Argentina in paper form prior to 1950. Changes in extremes of daily temperatures are of interest not only for physical climate science, but also because they may influence a range of climate impacts, such as retreat of glaciers, sea ice, and snow cover, as well as ecological effects on polar flora and fauna (Vaughan et al., 2001 and references therein). In this work, we explore this unique daily record of temporal and seasonal changes in averages and extremes in Antarctic climate since the beginning of the 20th century.

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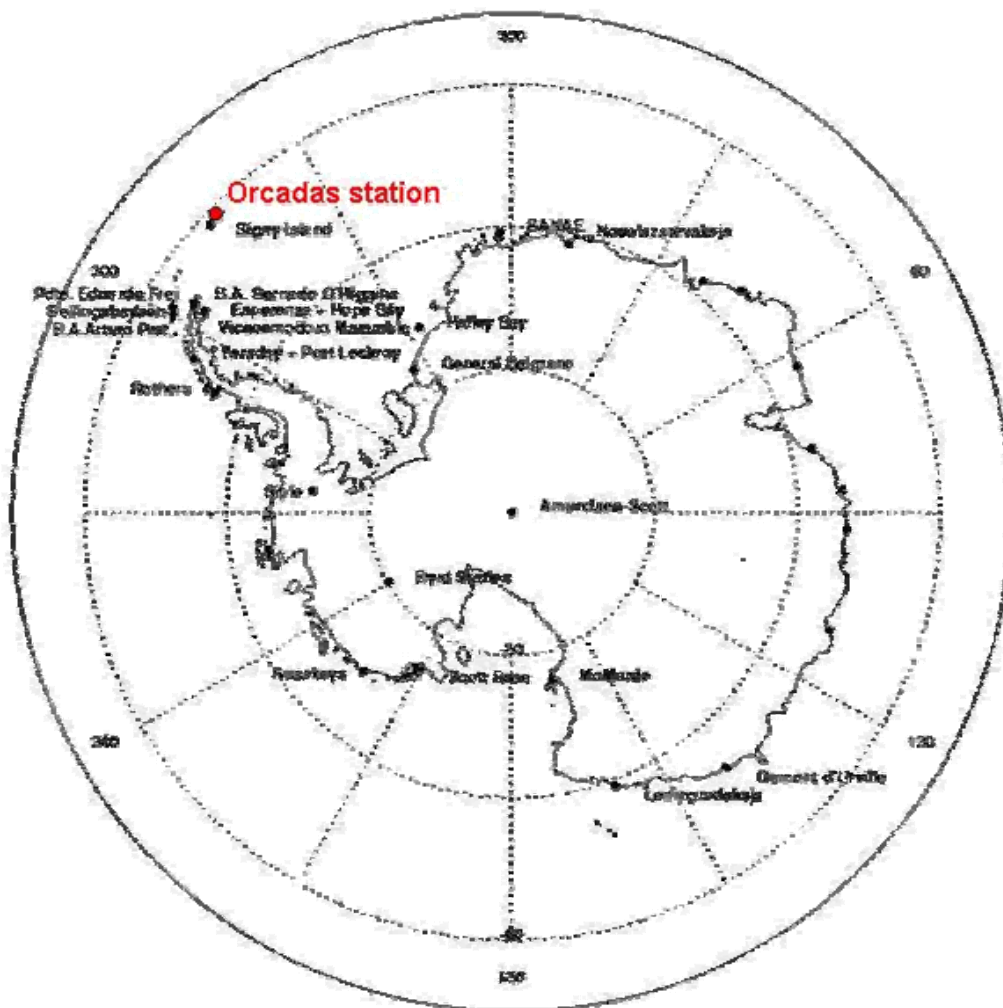


Figure 1. The location of Orcadas is indicated with a red dot.

2. DATA AVAILABILITY AND THE SEASONAL CYCLE IN DIFFERENT PERIODS

Beginning with the Scotia expedition in 1903, daily measurements of temperature are available from Orcadas (the earliest data are compared to other expeditionary records by Jones, 1990). Prior to 1950, observations were reported hourly, and the daily means represent the averages over 24 hours, while after 1950 the daily means are constructed from observations of the daily maximum plus minimum divided by two. The comparability of these two approaches for temperature trend analyses has been shown in previous studies (Karl et al., 1993). Further, because temperatures change very little over the course of a typical day in Antarctica due to

nearly constant solar illumination, this change is negligible for this location.

Figure 2 shows the seasonal cycle of daily temperatures observed at Orcadas for each of five 20-year periods. Strong warming is evident at Orcadas from late spring through the early fall season, November-March, particularly since the 1980s. The length of the season over which atmospheric temperatures exceed 0°C has substantially increased. Variability is greater relative to the trends in colder seasons, but the period since 1982 appears to be warmest throughout nearly the entire year, including the late fall and winter season of April-August (see Table 1 below).

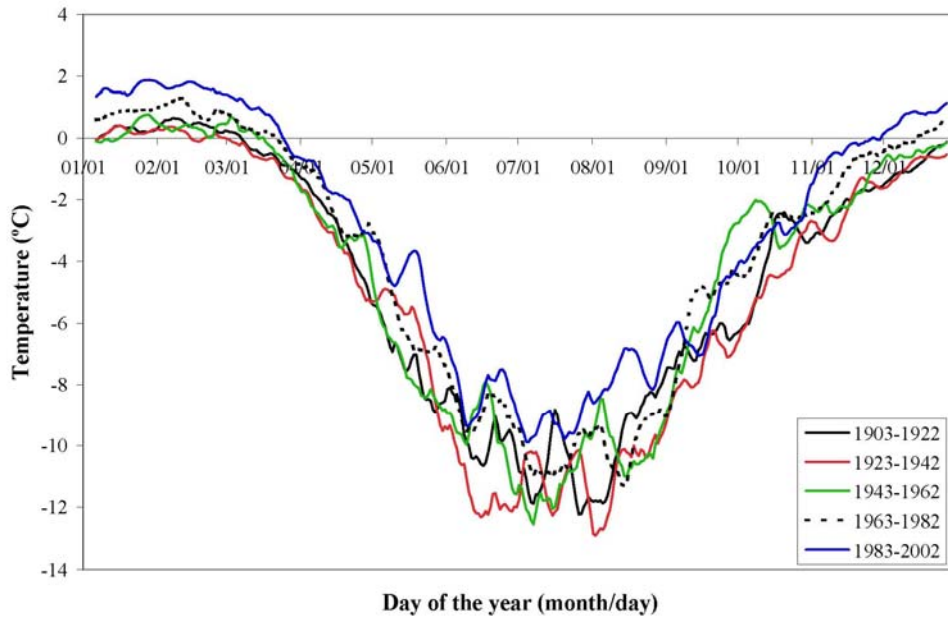


Figure 2. Mean annual cycle of temperatures at Orcadas over 20 year intervals beginning in 1903. A 10-day smoothing has been applied.

3. RESULTS AND DISCUSSION: CHANGES IN THE DISTRIBUTION OF TEMPERATURES IN VARIOUS SEASONS

The availability of a century of daily temperature measurements allows study of the probability distribution of climate observed in each season, and its changes. Changes in extreme temperatures can sometimes be more readily detected than changes in the mean, and can also provide insight into climate processes such as shifting circulation patterns (e.g. Thompson and Wallace, 2001).

Figure 3 presents the probability distribution functions (PDFs) for daily summer (Dec-Jan-Feb) temperatures at Orcadas over each 20-year period since 1903/4. While the shape of the distribution has been nearly constant in this season, the mean temperatures have systematically shifted in recent decades, producing a large change in the frequency of occurrence of cold and warm extremes. For example, the figure shows that temperatures warmer than 4°C are now observed with increasing regularity, but were obtained only extremely rarely prior to the 1980s. The large warming and limited variability in the summer season at Orcadas make the changes particularly easy to identify compared to many other locations and is a motivating factor for the present analysis.

The strengthening of the westerlies in association with the SAM changes has rendered

the summer Antarctic peninsula region climate increasingly dominated by warm maritime conditions and less influenced by cold air from Antarctica. The sharp onset of sustained changes in summer extremes in the past few decades is broadly consistent with the emergence of the Antarctic ozone hole as the likely dominant cause.

Figures 3 thus indicate that while some summer warming occurred prior to 1970 for a few years, the sustained shift in Antarctic summer climate of the past several decades is unprecedented in the instrumental record since 1903, not only in terms of the mean changes (see Turner et al., 2005), but also in the changes in both hot and cold extremes.

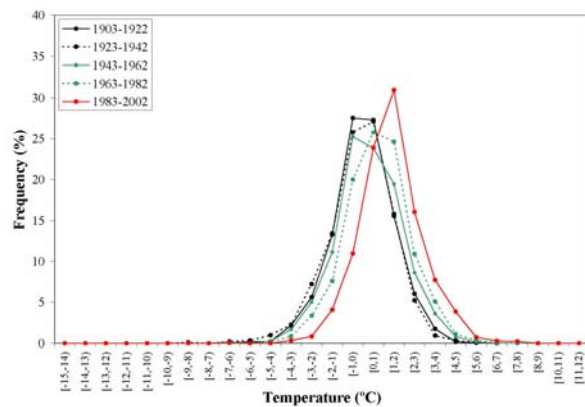


Figure 3. Distribution of frequencies of observations of daily temperatures during the summer season (Dec-Jan-Feb) for each 20 year period since 1903. One degree bins have been used as shown.

Figure 4 presents PDFs of the temperature data for the other three seasons, September-November (SON), March-May (MAM), and June-August (JJA). The figure shows that there has been an increase in hot extremes at Orcadas in all seasons since 1980, similar to but generally smaller than DJF. In contrast to the summer season, the winter season temperature distribution is strongly skewed. The long tail of cold winter extremes is linked to flow from the cold continent while the sharp cutoff of warm

extremes is linked to the thermal stability of sub-Antarctic maritime temperatures close to the freezing point. Thus the strong trend in cold winter extremes suggests decreased southerly flow. Figure 6 also shows decreases in cold extremes in fall (MAM), with a clear and systematic decline in the frequency of occurrence of the coldest winter season extremes below, for example, -15°C .

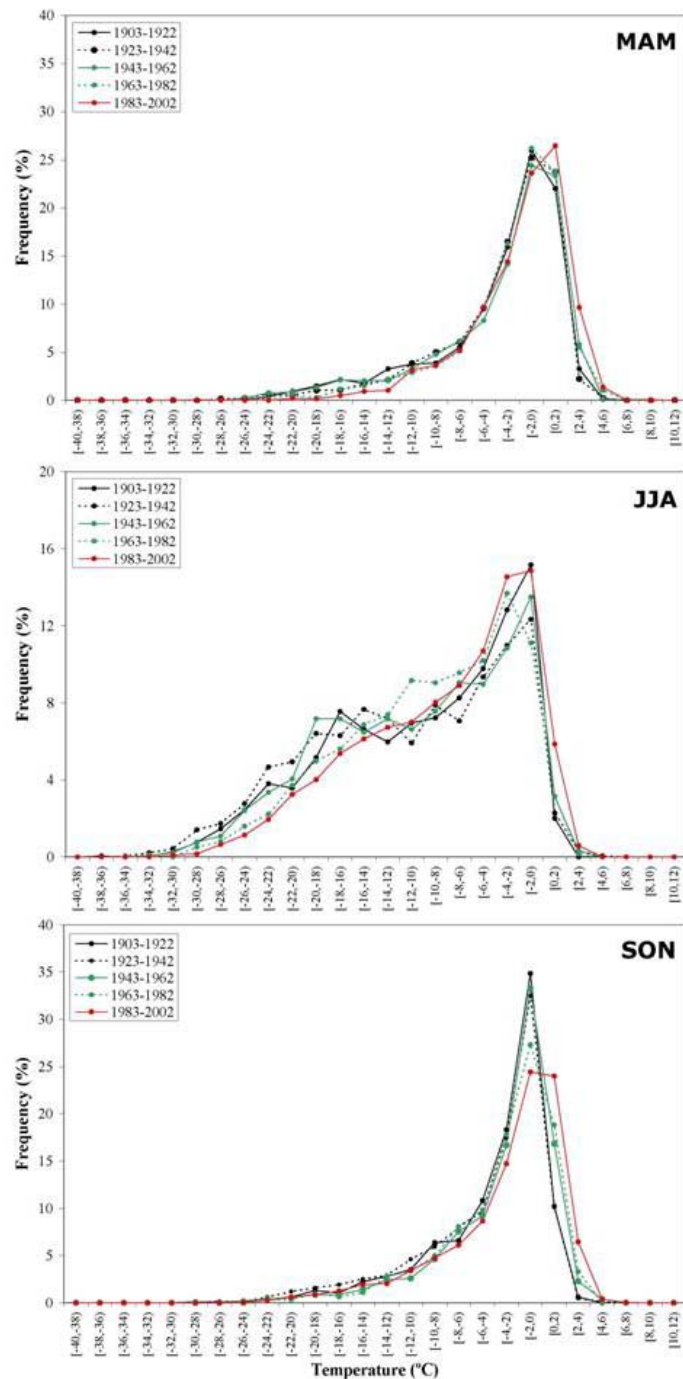


Figure 4. Distribution of frequencies of observations of daily temperatures during the fall (March-April-May), winter (June-July-August) and spring (September-October-November) seasons, for each 20 year period since 1903. Two degree bins have been used as shown.

4. DISCUSSION AND SUMMARY

Table 1 summarizes the results by season, showing trends in the seasonal means throughout the year as well as the warmest and coolest 5% and 10% of the daily data (where P95 and P90 denote the 5 and 10% warmest days while P5 and P10 denote the corresponding coldest days). These trends are among the strongest seen anywhere on Earth over the course of the 20th century. The total warming since 1903 is about 2°C for the seasonal averages (comparable to values in previous studies such as Turner et al., 2005) and up to 5°C in the coldest winter and fall extremes. Trends significant at 95% confidence (2-sigma) are obtained for mean temperatures in all seasons of the year over the full period of 1903-2007. Statistically significant trends are also obtained for the 20th century in both the 5% and 10% warmest and coolest portions of the temperature distributions over much of the year, with the exception of the coolest temperatures in spring (SON). The winter warming is most pronounced in the cold extremes, while the summer season changes represent a shift rather than a change in shape of the distribution,

underscoring differences in the character of the climatic changes with season.

If only the period from 1903-1950 is considered, there is no trend at Orcadas. However, consideration of the seasonal data for the period from 1903-1970 provides additional information not possible with other annual records. Significant trends are obtained in cold extremes in winter for 1903-1970, and for both warm extremes and means in summer and fall. The change in winter cold extremes is marked, and suggests a circulation change in that season. This provides important support for significant trends in Antarctic climate occurring too early in the season and too early in the 20th century to be attributable to ozone depletion. While internal variability cannot be ruled out as a cause of some of these changes (particularly on a seasonal basis), the long record at Orcadas shows that the recent climate at this site (see Figures 2 and 4, and Table 1) is distinctly different from that obtained in any previous 20-year period in all seasons, suggesting a contribution due to greenhouse gas increases.

Table 1. Trends (°C/30 years) in temperature observed at Orcadas for various seasons and periods. 2-sigma uncertainties are indicated. P95 and P90 denote the 5 and 10% warmest days while P5 and P10 denote the corresponding coldest days.

		1903-2007	2σ	1957-2007	2σ	1903-70	2σ
DJF	mean	0,53	0,12	0,59	0,32	0,30	0,25
	P95	0,64	0,14	0,75	0,39	0,34	0,26
	P90	0,58	0,12	0,68	0,33	0,32	0,23
	P10	0,57	0,15	0,64	0,46	0,37	0,30
	P5	0,62	0,18	0,70	0,54	0,39	0,37
MAM	mean	0,65	0,31	0,86	0,81	0,35	0,66
	P95	0,40	0,14	0,46	0,49	0,22	0,24
	P90	0,36	0,13	0,46	0,45	0,20	0,24
	P10	1,40	0,77	1,59	1,98	0,86	1,66
	P5	1,58	0,83	1,42	2,23	1,16	1,77
JJA	mean	0,68	0,45	1,04	1,17	0,42	0,96
	P95	0,26	0,16	0,56	0,47	0,14	0,33
	P90	0,26	0,20	0,65	0,52	0,12	0,43
	P10	1,07	0,58	0,44	1,66	1,24	1,14
	P5	1,00	0,60	0,42	1,83	1,22	1,08
SON	mean	0,52	0,27	-0,04	0,77	0,72	0,55
	P95	0,60	0,13	0,15	0,40	0,64	0,25
	P90	0,54	0,12	0,20	0,39	0,51	0,20
	P10	0,67	0,66	-0,77	1,77	1,40	1,40
	P5	0,70	0,75	-1,05	2,08	1,48	1,55

The ozone hole emerged in the late-1970s, and is expected to exert its greatest effect on Antarctic surface climate in the summer season (i.e., displaying a several-month lag relative to the stratosphere). The summer warming at Orcadas strengthened after about the mid-1970s concurrent with the development of the ozone hole, consistent with model simulations (e.g., Arblaster and Meehl; Cai and Cowan, Perlwitz et al). A new result of this study is the marked increase in the summertime frequency of warm extremes and decrease in cold extremes that also occurred around this time (Figure 3), and is likely linked to ozone depletion.

Acknowledgements

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