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RECONSTRUCTING THE MID-TWENTIETH CENTURY CLIMATE OF THE ANTARCTIC PENINSULA REGION

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1. INTRODUCTION

The Antarctic Peninsula region (Fig. 1) has experienced remarkable climatic changes over recent decades as near-surface air temperatures on the western side of the peninsula have risen more over the last 50 years than anywhere else in the Southern Hemisphere (King et al., 2003). In parallel with the temperature rise, there has been the disintegration of several major floating ice shelves on both the Bellingshausen and Weddell Sea sides and a decrease in the amount of sea ice over the Bellingshausen Sea (Zwally et al., 2002). The area experiences strong ocean-atmosphere interactions and changes in the atmospheric and oceanic conditions have both been put forward as possibly playing a role in the recent changes (Vaughan et al., 2003).

While we have high quality records of in-situ meteorological observations from a number of stations on the peninsula that extend back into the 1950s, it has proved much more difficult to determine the atmospheric circulation during the middle of the last century. In this paper the in-situ records and proxy data are used to infer the atmospheric circulation during the 1950s when temperatures were much colder across the Antarctic Peninsula.

2. DATA AVAILABILITY

The first permanent stations on the Peninsula were established during the 1940s, but the meteorological observations are rather sparse in the early days and the records incomplete. However, essentially complete time series of the basic meteorological parameters are available as follows: Faraday (later called Vernadsky) (1951), Esperanza (1961), Bellingshausen (1969), Marambio (1971) and Rothera (1978). Details of these records and the mean conditions are given in Turner et al. (2004).

The re-analysis fields produced recently by NCEP and ECMWF provide a very powerful tool for investigation of atmospheric circulation changes over recent decades. However, although the fields cover the period from IGY in 1957/58 to the present, very few observations were available over the Southern Ocean in the pre-satellite era before the availability of satellite sounder data. Marshall (2003) compared the ERA-40 fields against the available Antarctic surface and upper air in-situ observations and found that the fields could only be used with confidence in the period after 1973. Before that time the ERA-40 fields essentially represent the climatological state of the model used in the re-analysis process. The ERA-40 fields are therefore of little value in investigating the atmospheric conditions during the critical mid-Twentieth Century period.

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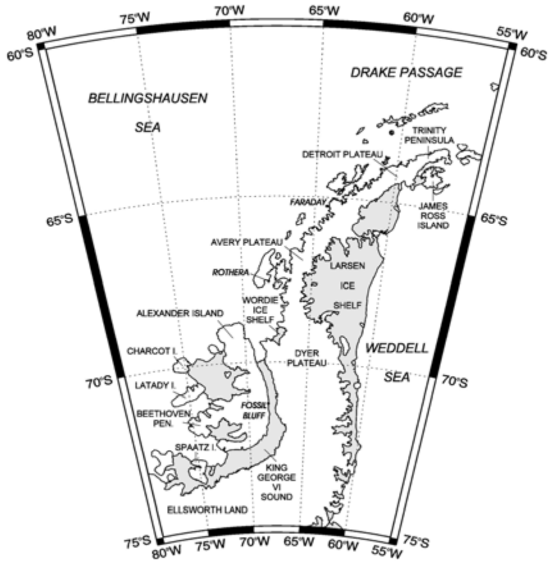

Fig. 1. The Antarctic Peninsula region.

3. THE CHANGES OBSERVED VIA THE STATION DATA

Faraday/Vernadsky provides the longest record of conditions on the Peninsula and changes at this location will be considered first. As shown in Fig. 2, the inter-annual variability of the annual mean temperature is large and temperatures have been rising since the 1950s. The increase in annual mean temperature over 1951-2000 was $+0.56 \pm 0.43^{o}$ C $(10\ yr)^{-1}$, with an increase during the winter season (June-August) of $+1.09 \pm 0.88^{o}$ C $(10\ yr)^{-1}$. However, it is clear that the 1950s were characterised by a number of very cold years that have not been experienced since that time. But it should also be noted that very warm years, such as 1956, also occurred during this period.

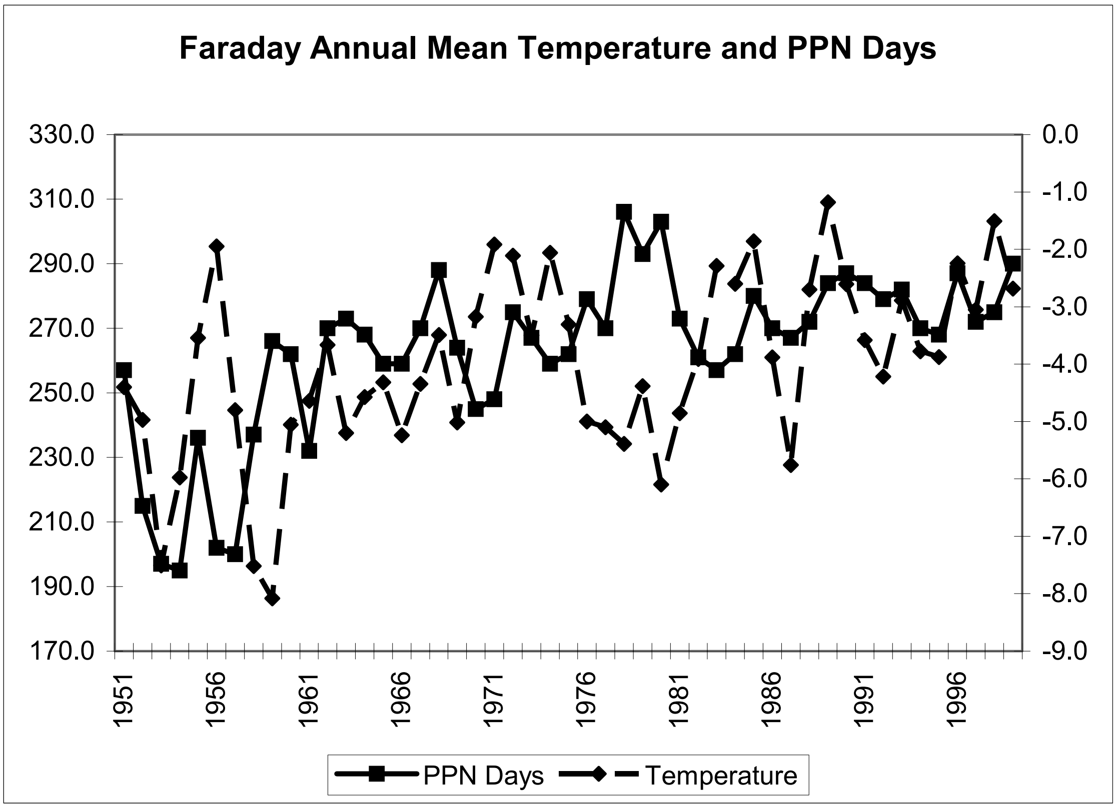

Fig. 2. Mean annual temperatures and annual total of precipitation days for Faraday/Vernadsky station for 1951-99.

It would also be very valuable to know what accumulation occurred over the last 50 years, but snow gauges have not been used with any great deal of success in the Antarctic and no ice cores have been collected from the critical coastal area because of summer melt. Instead, here we have used the total number of precipitation days in any season or year as an indicator of the accumulation. A precipitation day is taken as any day on which there was at least one report of snow, rain, drizzle, hail or a shower in the past or present synoptic reports. Fig. 2 indicates that during the 1950s and 1960s there were fewer reports of precipitation than in the subsequent decades.

The increase in the number of precipitation days at Faraday has not been uniform throughout the year, but has been greatest in the summer and autumn, and less in the winter and spring, although the increase in July was quite large (Fig. 3).

The climatic changes experienced over recent decades have been quite different near the tip of the peninsula. For example, at Esperanza and Bellingshausen stations, where the records extend back to 1961 and 1969 respectively, the largest statistically significant temperature increases are during the summer season.

4. THE USE OF PRECIPITATION DAYS DATA AS A PROXY FOR SURFACE PRESSURE

Since the re-analysis fields are not felt to be realistic around the Antarctic in the pre-satellite era and we have very little in-situ data over the ocean areas, attempts have been made to find proxies for indicators of atmospheric conditions over the ocean areas. Since we know that most of the precipitation on the western side of the Peninsula comes from synoptic-scale low pressure systems over the Bellingshausen Sea, we have attempted to relate the number of precipitation days to the atmospheric conditions over the ocean areas to the west of the Peninsula and the broader Southern Hemisphere environment. The annual total of the number of precipitation days at Faraday was therefore correlated with the annual mean values of MSLP across the whole of the Southern Hemisphere (Fig. 4). The period used was 1979-2000 when the re-analysis fields are of high quality. The highest negative correlations – indicating a large number of precipitation days associated with low MSLP – are over the Amundsen-Bellingshausen Sea (ABS) with values of -0.6 to -0.8 being present.

Similar correlation maps relating Faraday precipitation days and Southern Hemisphere MSLP have been produced for each month of the year. In some months the area of high correlation has a near-circular or wave number 3 form with correlation values in excess of 0.6 being found around much of the Antarctic coastal region. This was particularly the case for the summer and autumn, as can be seen from the January chart shown in Fig. 5. In January there is still a maximum of correlation over the ABS, but high correlation values are found around the whole of the

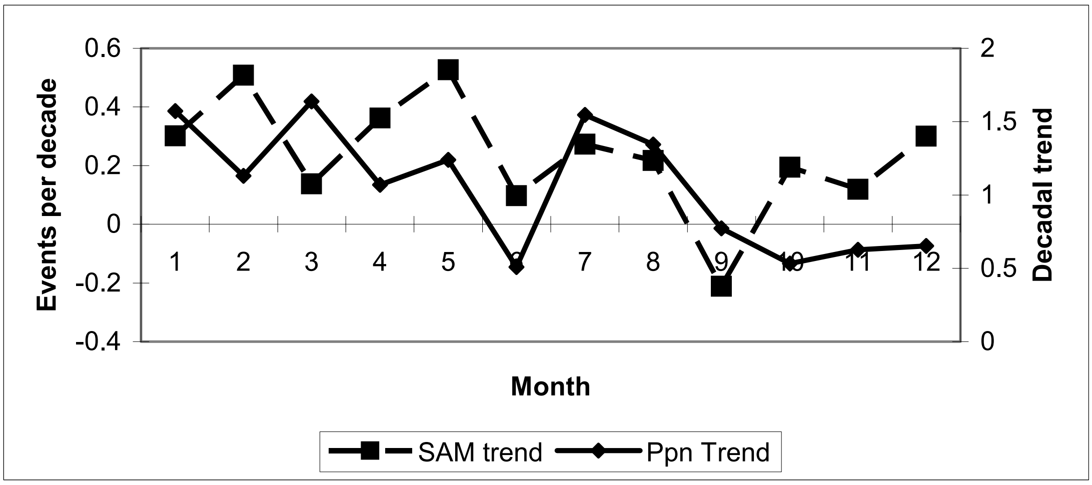

Fig. 3. The monthly trends in the SAM and the number of Faraday precipitation reports 1958-99.

Antarctic. This suggests that the number of precipitation days at Faraday is linked to Antarctic-wide factors, as well as synoptic-scale activity over the ABS. Fig. 5 also indicates that at this time of year there are a number of areas of high, positive correlation ringed around the Antarctic in the zone 40-60^o S, suggesting that conditions in mid-latitudes play a role in modulating conditions at Faraday.

During the winter and spring the maximum correlation values are generally located over the southeastern corner of the Bellingshausen Sea, with only low correlation values around the rest of the Antarctic, suggesting that in these seasons local synoptic forcing factors play a more important role in dictating precipitation at Faraday.

5. THE MECHANISMS RESPONSIBLE FOR CHANGES IN THE ANTARCTIC COASTAL ZONE

The principal mode of variability of the atmospheric circulation of the Southern Hemisphere extra-tropics is the Southern Hemisphere Annular Mode (SAM). This involves synchronous anomalies of opposite sign in Antarctica and in mid-latitudes. Over recent decades the SAM has shifted into its positive phase, with decreasing MSLP values over the Antarctic and increasing values in mid-latitudes. There has also been an increase in the westerlies, which can be seen at all of the Antarctic coastal stations. The SAM has changed most during the summer and autumn seasons, and less in the second half of the year, and particularly in the spring.

Fig. 5, and the large trends in the SAM and number of Faraday precipitation days in January, suggest that the SAM has played a role in modifying the amount of precipitation on the western side of the Peninsula. However, it is interesting to explore how this could come about. Faraday is at the latitude of the circumpolar trough, the belt of low pressure ringing the Antarctic over 60-70^o S. The MSLP values at this latitude are low because of the large number of depressions in this zone that have moved south from mid-latitudes or developed at the latitude of the trough. We know that MSLP values have dropped at the Antarctic coastal stations since the middle of the Twentieth Century, but because of the poor quality of

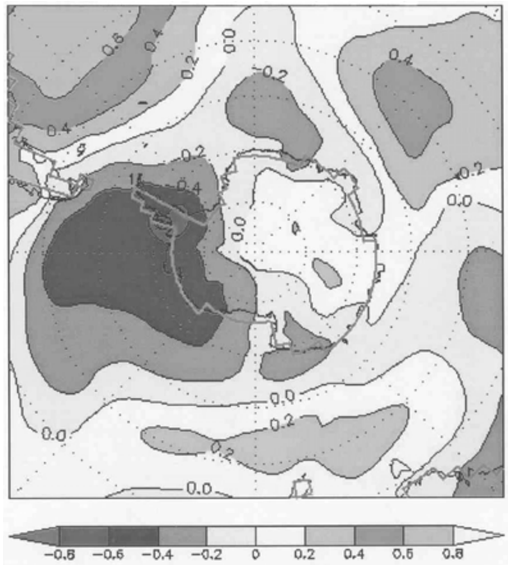

Fig. 4. The correlation of the annual total of precipitation days from Faraday with the ERA-40 annual mean MSLP

the re-analysis fields at this time, it is still unclear whether the number of depressions has increased or whether the depth of the storms has decreased with the number of lows remaining unchanged. But with lower pressures in the Antarctic coastal zone and a ready supply of moisture over the Southern Ocean, the lower atmospheric pressures will result in greater dynamical lifting and increased precipitation.

Although changes in the SAM are felt to have played an important role in modulating the Faraday precipitation data during the summer, the greatest temperature increase has been during the winter. At this time of year the correlation maps relating Faraday number of precipitation days and MSLP across the Southern Hemisphere (not shown) show a maximum in the ABS. This is consistent with the small changes in the SAM at this time of year and suggest that a change in MSLP and therefore cyclonic activity over the ABS has been responsible for the change in the number of precipitation days at Faraday. This suggests that MSLP values were considerably higher

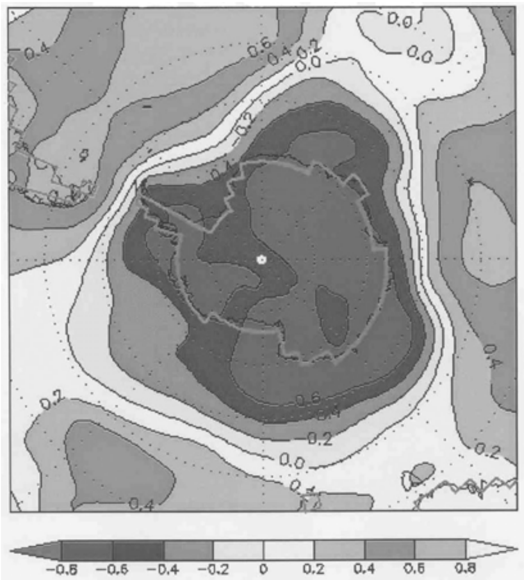

Fig. 5. The correlation of the January total of precipitation days from Faraday with the ERA-40 January mean MSLP

over the ABS during the 1950s, resulting in fewer precipitation days at Faraday. The weaker northerly component of the wind will have allowed the sea ice to advance to a more northerly location, so giving colder temperatures on the western side of the Peninsula.

During this season the sea ice edge is close to the latitude of Faraday so that temperatures are particularly sensitive to the latitude of the edge of the ice. The location of the edge of the sea ice over the ABS is affected by both oceanographic and atmospheric factors, but is very sensitive to the near-surface wind direction. Northerlies will generally advect the sea ice southwards, with southerlies moving the ice away from the coast. Since northerly (southerly) winds will bring relatively warm (cold) air to the western side of the Peninsula, the movement of the sea ice will amplify the changes of temperature by exposing or capping the ocean.

6. CONCLUSIONS

With the lack of observations (particularly upper air data) over the ABS before 1973 it seems unlikely that we will ever have good analyses of this area in the markedly cold period during the middle of the Twentieth Century. We will therefore need to use model experiments and proxy data to explain the low air temperatures at this time. The record of the number of precipitation days from Faraday does seem to provide a good proxy of MSLP values over the ABS and allows us to estimate the values during the mid-Twentieth Century. The hypothesis of higher MSLP values and weaker northerly winds with a more northerly sea ice edge in the 1950s could explain the lower temperatures recorded at Faraday. However, of course we do not at present know why MSLP values were higher over the ABS during the 1950s, but these results do suggest that atmospheric changes may have been the major factor behind the peninsula warming.

7. REFERENCE

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