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El Nino Suppresses Aantarctic Warming

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[1] Here we present new isotope records derived from snow samples from the McMurdo Dry Valleys, Antarctica and re-analysis data of the European Centre for Medium-Range Weather Forecasts (ERA-40) to explain the connection between the warming of the Pacific sector of the Southern Ocean [*Jacka and Budd*, 1998; *Jacobs et al.*, 2002] and the current cooling of the terrestrial Ross Sea region [*Doran et al.*, 2002a]. Our analysis confirms previous findings that the warming is linked to the El Niño Southern Oscillation (ENSO) [*Kwok and Comiso*, 2002a, 2002b; *Carleton*, 2003; *Ribera and Mann*, 2003; *Turner*, 2004], and provides new evidence that the terrestrial cooling is caused by a simultaneous ENSO driven change in atmospheric circulation, sourced in the Amundsen Sea and West Antarctica. *INDEX TERMS:* 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology; 3349 Meteorology and Atmospheric Dynamics: Polar meteorology; 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; 4215 Oceanography: General: Climate and interannual variability (3309); 4522 Oceanography: Physical: El Niño. **Citation:** Bertler, N. A. N., P. J. Barrett, P. A. Mayewski, R. L. Fogt, K. J. Kreutz, and J. Shulmeister (2004), El Niño suppresses Antarctic warming, *Geophys. Res. Lett.*, *31*, L15207, doi:10.1029/2004GL020749.

1. Introduction

[2] Antarctic temperatures are especially sensitive to changes in the low-level atmospheric circulation due to strong gradients between the continent and the surrounding ocean [*van den Broeke*, 2000]. For the recent past measurements from surface stations and satellites have given new insights into the functioning of the climate system for high spatial and temporal resolution especially for the troposphere [*Jones et al.*, 1999; *Comiso*, 2000] and have revealed the occurrence of oscillating climate patterns, such as the Antarctic Oscillation [*Thompson and Solomon*, 2002], and the Antarctic Circumpolar Wave [*White and Peterson*, 1996]. Here we report the discovery of the double-sided effect of ENSO-driven climate variability in the Ross Sea Region.

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2. Observations

[3] The McMurdo Dry Valleys (MDV) are a small ice-free sector of the Transantarctic Mountains west of McMurdo Sound (Figure 1). Temporal and spatial mean annual temperature variations range from −14°C to −30°C within less than 100 km [*Doran et al.*, 2002b]. The cause of these large contrasts is that the MDV are influenced by three significantly different regions: the relatively warm, humid Ross Sea; the cold, dry East Antarctic Ice Sheet (EAIS); and the low elevation Ross Ice Shelf system [*Bertler et al.*, 2004]. The Transantarctic Mountains are a natural barrier for weather systems, and their steep change in orography further enhances the climatic contrasts. A shift in the relative contribution from any of these three adjacent climate systems will result in significant changes of the MDV climate, amplifying regional climate change at local scales [*Bertler et al.*, 2004]. For this reason the MDV provide an excellent location to investigate changes in regional atmospheric circulation and the mechanisms causing them.

[4] Continuous meteorological observations in this region are sparse, but are available from McMurdo Station and Scott Base since 1958 and from Marble Point (MP) since 1981 (Figure 2 and Table 1). We prefer Scott Base (SB) temperatures over the nearby McMurdo Station record, as the former have been shown to be more reliable [*Stearns et al.*, 1993]. We include new isotope data from a snow pit from Victoria Lower Glacier (VLG_{snow}) in the MDV (Figure 1). The VLG_{snow} data represents predominantly summer temperatures, the main seasons for precipitation in McMurdo Sound [*Bromwich*, 1988] and as seen in comparison with SB and MP summer temperature data (Figure 2). Seasonal variations in the chemistry input and gross beta activity measurements were used to date the snow profile record with ±1 year accuracy [*Bertler et al.*, 2004]. The isotopic values were converted to temperature in Table 1 using 2 m surface temperature data from Lake Vida ($T(°C) = 0.1113 \bullet \delta^{18}O_{VLGsnow} - 1.9746$, Figure 3). The comparison between Scott Base, Marble Point and VLG_{snow} summer temperatures indicates a common climate history (Figure 2). The longer-term records show a warming, but only SB annual temperature and VLG_{snow} are statistically significant (Table 1).

[5] In 1986 the Long-Term Ecological Research (LTER) project established a network of automatic weather stations throughout the MDV. The data show a strong, seasonally dependent cooling (−0.7°Cpd) [*Doran et al.*, 2002a, 2002b] and were used to support the view that the entire continent is cooling [*Doran et al.*, 2002a]. This cooling trend is also present in the longer-term data, but superimposed on the longer-term warming trend. Since 1986 AD VLG_{snow}, MP autumn, SB autumn and summer temperatures show a

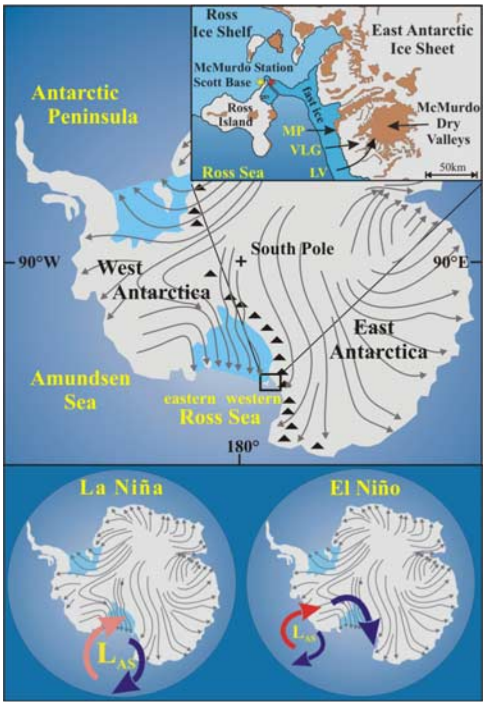

Figure 1. Map of surface wind pattern in Antarctica (modified after *King and Turner*, 1997). Grey arrows indicate wind flow direction. Triangles represent Transantarctic Mountain range. Top inset: McMurdo Sound region and location of the McMurdo Dry Valleys; Marble Point (MP), Victoria Lower Glacier (VLG), and Lake Vida (LV). Bottom inset: typical position of Amundsen Sea Low (L_{AS}) during La Niña and El Niño events (modified after *Cullather et al.*, 1996). Red arrows indicates relatively warm airmasses (even warmer during El Niño) and blue arrow indicates cold airmasses. The size of 'L_{AS}' indicates its strength.

statistically significant decrease (Figure 2 and Table 1). The coincidence of the recent onset of the cooling with the start of meteorological measurements in the MDV since 1986 AD [*Doran et al.*, 2002a] explains why only the cooling is seen in those shorter time series. The longer records, however, suggest that the observed decrease in temperature in the MDV is a recent trend superimposed on a longer-term warming signal that started no later than 1958 and/or is perhaps part of a multi-decadal oscillation in the Antarctic climate system.

3. Discussion

[6] ENSO has been suggested as an important driver of Antarctic climate and oceanic variability on inter-annual to decadal variability [*Kwok and Comiso*, 2002a, 2002b; *Carleton*, 2003; *Ribera and Mann*, 2003; *Turner*, 2004]. We correlate ERA-40 reanalysis data of 2 m temperature variability with the Southern Oscillation Index (SOI, zero-lag, Figure 4) to identify spatial and temporal ENSO teleconnections in the Ross Sea region. We use annual averages from November to October, which capture best the two seasons (March to April and June to August) with the highest temperature-ENSO correlation (Figure 4). We focus on the time period from 1971 to 2000, due to uncertainties in the Antarctic reanalysis data in the pre-satellite era. The data quality improves during the 1970s and become excellent from the 1980s onwards [*Bromwich and Fogt*, 2004]. The correlation spanning the entire time period is shown in Figure 4a. As ENSO exhibits variability on a decadal time scale [*Bromwich et al.*, 2000; *Genthon et al.*, 2003], three separate decadal time periods are also plotted (Figures 4b–4d) to detect temporal changes in the relationship.

[7] From 1971 to 2000 (Figure 4a) a statistically significant negative correlation between temperature in the Amundsen Sea and SOI can be observed. This suggests that during ENSO warm events (SOI < 0) temperatures in the Amundsen Sea region are warmer, and cooler during ENSO cold events. In contrast the western Ross Sea, including the MDV, is a distinct area where this relationship fails, and no significant correlation can be observed, suggestive of additional or different forces driving temperature variability in this region. Examining the correlations by decade, we find that during 1971–1980 the relationship is similar. During 1981–1990 decade the negative correlation in the Amundsen Sea persists, although its centre shifted further to the northwest. The Ross Sea region and West Antarctica now show a marginal significant positive correlation, indicating cooler temperatures during ENSO warm events. During the 1991–2000 decade, the centre of the Amundsen Sea correlation is shifted southeast, now also encapsulating the adjacent Marie Byrd Land in West Antarctica. The western Ross Sea region displays a highly significant positive correlation, indicating cooler temperatures during ENSO warm events. Together, Figure 4 shows that while the ENSO surface temperature correlation is variable in most regions in Antarctica, the relationship in the Amundsen Sea remains positive and is statistically significant during the last 30 years confirming previous studies [*Kwok and Comiso*, 2002a, 2002b; *Carleton*, 2003; *Ribera and Mann*, 2003; *Turner*, 2004]. The western Ross Sea, however, exhibits a positive correlation with ENSO at

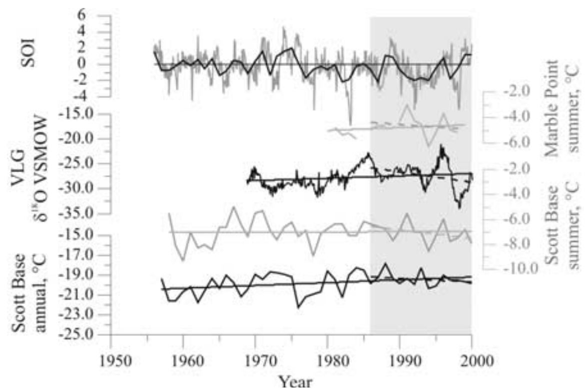

Figure 2. Temperature trends from Scott Base (annual and summer) and Victoria Lower Glacier (represents summer temperature), and Marble Point (summer temperature) and the Southern Oscillation Index (SOI, monthly and annually averaged, showing zero-line). Longer-term temperature trends are indicated with solid line, and since 1986 with dashed lines. The grey area marks the time period 1986–2000, for which an Antarctic-wide cooling was reported [*Doran et al.*, 2002a].

Table 1. Temperatures Shown in °C Per Decade From Scott Base (SB), Victoria Lower Glacier (VLG), and Marble Point (MP)[a]

Temperature Record		Trend °C Per Decade Entire Record	P-Value	Trend °C Per Decade Since 1986	P-Value
SB (annual)	1958–2000	**+0.29**	**<0.02**	−0.45	<0.2
SB (autumn, MAM)	1958–2000	+0.14	>0.1	**−1.82**	**<0.05**
SB (winter, JJA)	1958–2000	+0.44	<0.1	+0.61	>0.1
SB (spring, SON)	1958–2000	+0.44	<0.1	+0.50	>0.1
SB (summer, DJF)	1958–2000	+0.05	>0.1	**−0.83**	**<0.05**
VLG (DJF, isotope)	1969–2000	**+0.49**	**<0.01**	**−0.32**	**<0.001**
MP (autumn, MAM)	1980–1999	**−2.54**	**<0.01**	**−2.65**	**<0.05**

[a]The temperature record from Victoria Lower Glacier is inferred from isotope data ($\delta^{18}O$ VSMOW). Statistically significant trends are printed bold.

least since 1981. This is consistent with observations of ENSO-correlated increase in sea ice and meridional winds, accompanied by sea surface temperature cooling and lengthening of the sea-ice season in the western Ross Sea and opposing trends in the eastern Ross Sea since 1982 [*Kwok and Comiso*, 2002b].

[8] While mechanisms for the ENSO-caused warming in the Pacific sector of Antarctica have been suggested [*Chen et al.*, 1996; *Turner*, 2004], our results lead to a new question: how do ENSO warm events *cool* the western Ross Sea? *Cullather et al.* [1996] and *Bromwich et al.* [2000] showed that the position of the Amundsen Sea Low (L_{AS}) shifted during 1980–1990 1400 km further to the east during El Niño events compared to its normal position (Figure 1). *Renwick* [1998] added to the complexity by showing that during an ENSO warm event a South Pacific Blocking hinders the L_{AS} to migrate east during the austral spring and summer. However, during autumn and especially winter this relationship changes polarity and the blocking is suppressed. This corresponds well with our results, as winter and autumn seasonal temperature plots gain highest correlation with SOI, while summer and spring correlations are weaker or reversed (data not shown). Furthermore, the L_{AS} deepens during ENSO cold events, and weakens during warm events [*Chen et al.*, 1996; *Kreutz et al.*, 2000; *Turner*, 2004] (Figure 1). Averaged over longer (decadal) time periods (Figure 3) it appears that during ENSO cold events the L_{AS} is stronger and typically located just north of the Ross Sea (Figure 1) and thus its associated low pressure systems transport relatively warm and moist air from the north into the Ross Sea region. However, this air is by about 1°C (mean temperature) cooler than during El Niño events [*Kwok and Comiso*, 2002b], causing a cooling in the eastern Ross Sea. In a case study, *Bromwich et al.* [1993] showed that during an ENSO warm event, the juxtaposition of the L_{AS} off Marie Byrd Land (Figure 1) enhanced katabatic flow from the Siple Coast and the EAIS across the Ross Ice Shelf into the western Ross Sea. Consequently, the flow from the warmer Ross Sea to the western Ross Sea region is not only decreased, but flow from the colder Siple Coast and EAIS enhanced. Although katabatic surges raise the local surface temperature in the lower 50 m of the atmosphere due to friction, they import significantly colder than ambient air above 50 m [*Bromwich et al.*, 1993]. Averaged over months (or years) the import of southern air leads to cooler and drier conditions in the western Ross Sea area. The temperature difference between the two competing airmasses in the western Ross Sea (Southern Ocean versus West Antarctica $\Delta\sim-15$°C [*King and Turner*, 1997] Figure 1) exceeds by approximately one order of magnitude the temperature difference of the Southern Ocean airmass between a La Niña and El Niño events ($\Delta\sim+1$°C [*Kwok and Comiso*, 2002b], red arrows in Figure 1). Since 1977 SOI index has a negative bias, with more and deeper El Niño events, promoting increased import of colder West

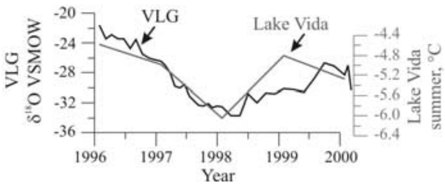

Figure 3. Comparison between Victoria Lower Glacier isotope record and summer temperature data from the nearby LTER automatic weather station at Lake Vida. The isotope record was converted into temperature data (Table 1) using the conversion formula T(°C) = 0.1113•δ^{18}O VLG_{snow} − 1.9746. The isotope record has been dated independently with ±1 year accuracy [*Bertler et al.*, 2004].

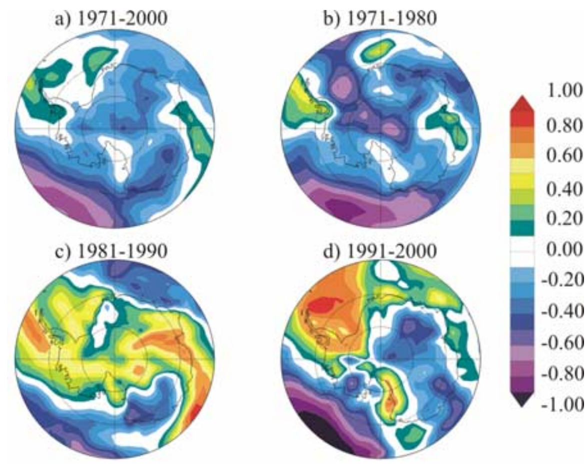

Figure 4. Correlation between annual (November–October) ERA-40 reanalysis 2 m surface temperature data and the SOI for a) 1971–2000 b) 1971–1980, c) 1981–1990, d) 1991–2000. The colour bar indicates level of correlation. For 1971–2000 (n = 30) 90%, 95%, 99%, and 99.9% significance levels are achieved at 0.32, 0.35, 0.45, and 0.55, respectively. For decadal correlations (n = 10) 90%, 95%, 99%, and 99.9% significance levels are achieved at 0.55, 0.63, 0.77, and 0.87, respectively.

Antarctic air into the western Ross Sea, which dominates the overall warming trend and leads to the observed cooling.

4. Conclusions

[9] Clearly, more research is needed to understand the temporal and spatial variability of the ENSO-Antarctic relationship, its feedbacks and temporal robustness and its links with the Antarctic Oscillation and Circumpolar Wave. However, our results show that the ENSO forcing, primarily in the form of El Niño events, is largely responsible for the observed cooling in the western Ross Sea. It is important to note that the temperature change does not reflect a regional cooling, but a change of the atmospheric circulation that results in an apparent regional cooling. Our data do not support a longer-term cooling of the MDV as suggested by *Doran et al.* [2002a].

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