Advances in Geosciences, 6, 83–86, 2006
SRef-ID: 1680-7359/adgeo/2006-6-83
European Geosciences Union

Opposing oceanic and atmospheric ENSO influences on the Ross Sea Region, Antarctica

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Received: 22 June 2005 – Revised: 4 October 2005 – Accepted: 18 October 2005 – Published: 9 January 2006

Abstract. Here we discuss the cause and effect of opposing atmospheric and oceanic ENSO forcings in the Ross Sea, that lead to a net warming in the eastern Ross Sea and a net cooling in the western Ross Sea during El Niño years. During La Niña years the opposite is observed. The oceanic ENSO effect causes a ∼1 K warming with a 3 month lag during El Niño years in comparison to La Niña time periods. During El Niño events, the atmospheric ENSO effect leads to a shift and weakening of the Amundsen Sea Low, causing enhanced import of colder West Antarctic air masses into the western Ross Sea. We find that this indirect ENSO effect is about one order of magnitude stronger (up to 15 K) in the western Ross Sea than the direct effect (∼1 K), leading to a net cooling during El Niño and net warming during La Niña events.

1 Introduction

The atmosphere above the Antarctic continent is thin, dry, and clean, minimizing total longwave radiation received at the surface. Furthermore, the high albedo of snow and ice is responsible for the reflection of 80–96% of received radiation into space (King and Turner, 1997). As a result, Antarctica exhibits substantial vertical and horizontal temperature gradients between the continent and its immediate surroundings causing its temporal temperature trends to be especially sensitive to changes in low-level atmospheric circulation (van den Broeke, 2000). On interannual to decadal time scales tropospheric Antarctic circulation is driven primarily by El Niño Southern Oscillation (ENSO) (e.g. Turner, 2004), Antarctic Oscillation or Southern Annular Mode (AAO) (e.g. Hall and Visbeck, 2002; Thompson and Solomon, 2002), and Antarctic Circumpolar Wave (ACW) (e.g. Gloersen and White, 2001; White et al., 2002; Venegas, 2003; White and Annis, 2004; White et al., 2004) but there is widespread disagreement on their relative influences, temporal robustness, and teleconnections between them. Strongest correlations between ENSO and Antarctica have been found in the Amundsen and Ross Seas (Renwick, 1998; Kwok and Comiso, 2002b; Kwok and Comiso, 2002a; Carleton, 2003; Ribera and Mann, 2003; Turner, 2004). However, most areas of Antarctica, even as far interior as South Pole (Savage et al., 1988; Meyerson et al., 2002), have been shown to be influenced by ENSO.

Turner (2004) provides an in-depth review of ENSO influences on Antarctica and the Southern Ocean. This paper aims to add to this review by describing and explaining the apparently contradicting findings of ENSO effects in the Ross Sea Region that are presumably caused by separate oceanic and atmospheric ENSO related phenomena in the Amundsen/Ross Sea Region.

While ENSO is discussed widely in the literature, there is no agreed upon definition on El Niño and La Niña events. Trenberth (1997) defined an El Niño event when the 5 month running mean anomaly of SST in the Niño 3.4 region exceeds 0.4 K for at least 6 months. Applying this definition since 1950 the ENSO was in El Niño mode for ∼31%, in La Niña mode for 23% and in neutral mode for 56% (Turner, 2004). A commonly used index for ENSO is the Southern Oscillation (SOI), which is the normalised difference in surface pressure between Darwin and Tahiti, with positive extremes representing La Niña and negative extremes indicating El Niño time periods (Parker, 1983).

2 Atmospheric ENSO expression in the Ross/Amundsen Sea region

The ENSO influence on Antarctic atmospheric circulation is seen especially in the strength and position of the Amundsen Sea Low (L_{AS}) (Cullather et al., 1996; Bromwich et al., 2000; Meyerson et al., 2002; Carleton, 2003; Bertler et al., 2004; Turner, 2004). The L_{AS} is a semi-permanent low pressure system centred north of Marie Byrd Land in the Ross/Amundsen Seas and governs the direction and

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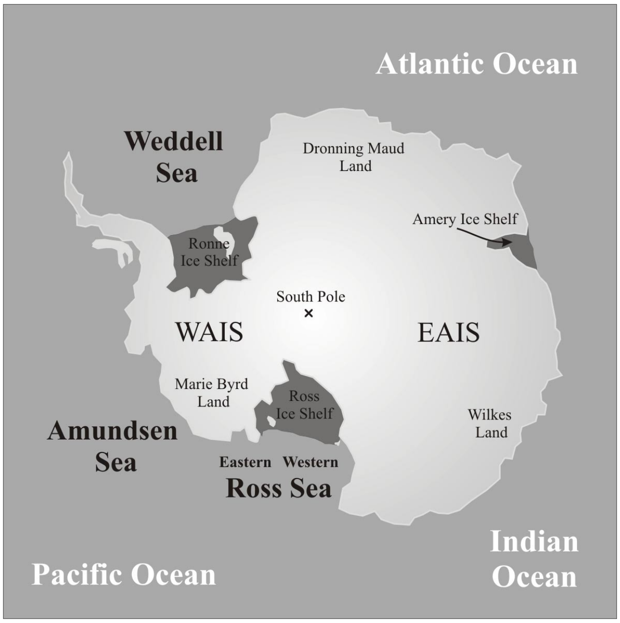

Fig. 1. Overview of the Antarctic continent and Southern Ocean. WAIS = West Antarctic Ice Sheet, EAIS = East Antarctic Ice Sheet.

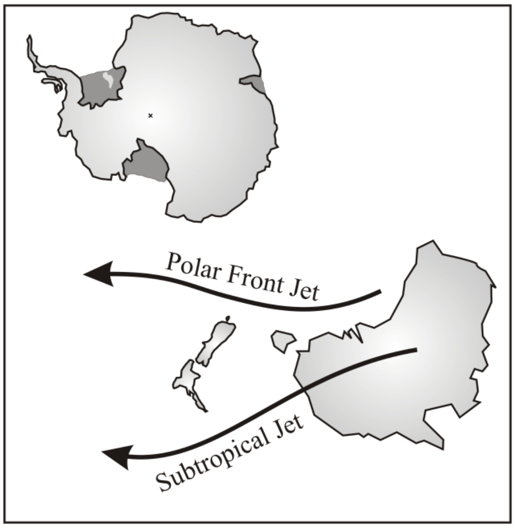

Fig. 2. Approximate location of the split jet (polar front jet and subtropical jet), which develops each year in March through to early Southern Hemispheric spring.

magnitude of the meridional moisture flux between the Ross and Bellingshausen Seas. During El Niño events the L_{AS} is weakened and can shift as much as 1400 km to the east in comparison to La Niña time periods (Chen et al., 1996; Cullather et al., 1996). It has been suggested that the cause for this lies in ENSO driven changes of the split jet (Fig. 2).

Beginning in March and through the Southern Hemispheric winter and early spring, the split jet develops in the vicinity of New Zealand (Fig. 2), with the subtropical (STJ) and polar front (PFJ) jets located at 30° S and 60° S, respectively (Chen et al., 1996; Carleton, 2003; Turner, 2004).

During La Niña events sea-surface temperatures (SST) in the tropical Pacific are cool and the South Pacific Convergence Zone (SPCZ) is relatively weak. This leads to a weakening of the STJ and a strengthening of the PFJ (Chen et al., 1996; Carleton, 2003; Turner, 2004). The strengthening of the PFJ causes a deeper (stronger) L_{AS}, which in turns enhances the low-level easterly jet (Bromwich et al., 1993; Chen et al., 1996; Turner, 2004) and hence encourages katabatic flow from the Antarctic continent (Bromwich et al., 1993; Bertler et al., 2004; Patterson et al., 2005). In contrast, during El Niño events the SPCZ is strengthened due to warmer SST, which intensifies the STJ and weakens the PFJ (Chen et al., 1996; Carleton, 2003; Turner, 2004). As a result the L_{AS} is also weakened and shifts further east (Bromwich et al., 1993; Cullather et al., 1996; Bertler et al., 2004; Patterson et al., 2005) accompanied by waning low-elevation easterlies. Furthermore, the weakening of the L_{AS} is associated with a reduced cyclone density in the Amundsen Sea (Carleton, 2003) and more frequent blocking (Renwick, 1998; Renwick and Revell, 1999). The ENSO driven changes in the location and strength of the L_{AS} are shown schematically in Fig. 3.

The shift of the L_{AS} is expected to cause higher accumulation rates in Marie Byrd Land during El Niño time periods, as warmer air masses now dominate especially the coastal regions (Fig. 3). Bromwich et al. (2000) used ECMWF reanalyses and ice core data and found a positive correlation between higher accumulation rates and El Niño events during the 1990s. However, during the 1980's this relationship was reversed, with less precipitation during El Niño events. A similar reversal was also observed by Bertler et al. (2004) using ERA-40 reanalysis data. Investigating decadal trends from 1970 to 2000, they found that surface temperature correlated positively with the SOI in Marie Byrd Land during 1971–1980 and 1991 to 2000, but anti-correlated during 1981–1990. The reason for this is unclear, but it appears from the ERA-40 reanalysis data that it is connected with a continent-wide cooling event (Bertler et al., 2004).

In the Ross Sea, the western and eastern regions appear to show opposing relationships to ENSO (Bertler et al., 2004). While surface temperatures in the eastern Ross Sea show predominantly a positive (or no statistically significant) correlation with the SOI, in the western Ross Sea they show a negative (or no statistically significant) correlation (Bertler et al., 2004). Furthermore, the correlation with surface temperature in the L_{AS} region remains positive (statistically significant) throughout the 1970–2000 time period, with warmer temperatures during El Niño years due to warmer sea-surface temperatures (SST, see Sect. 3). While the warming in the eastern Ross Sea is a direct response to warmer sea surface temperatures and hence warmer temperatures in the lower troposphere, the cooling is initiated by the shift of the L_{AS} to Marie Byrd Land. Bromwich et al. (1993) showed in a case study that during an El Niño event, the juxtaposition of the L_{AS} off Marie Byrd Land caused katabatic surges across the Ross Ice Shelf (Fig. 3). This katabatic air mass originates predominantly from the interior of the West Antarctic Ice

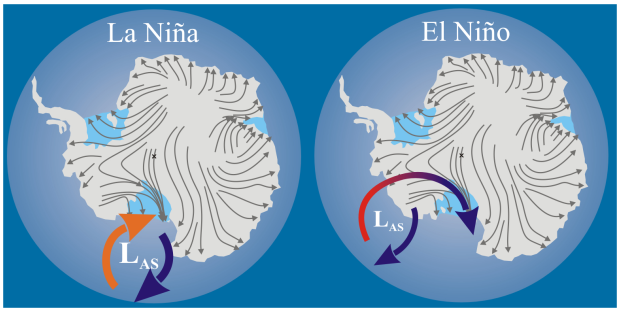

Fig. 3. Size of the L_{AS} and thickness of the arrows indicate strength of the L_{AS}. The different shades of red of the warm air arrow indicates relatively cooler air during La Niña events than during El Niño time periods. However, both red arrows indicate significantly warmer air masses than the blue arrows. The grey arrows indicate katabatic wind flow (modified after Bertler et al., 2004).

Sheet (WAIS). While the air in the Ross Sea has warmed by about 1K during an El Niño event, the air descending from WAIS is up to 15 K cooler (Fig. 3). Therefore, this indirect ENSO-cooling effect in the western Ross Sea, more than compensates the direct ENSO-warming effect, causing a net cooling (Bertler et al., 2004).

3 Oceanic ENSO expression in the Ross/Amundsen Seas

One of the strongest extra-tropical correlations of the SOI is found with SST in the Ross Sea (Kwok and Comiso, 2002b). Rossby waves have been suggested as propagation mechanism of the tropical signal to the high latitudes, as a modest change in tropical SST could result in a large extratropical response (Turner, 2004). Although Rossby waves are closely linked to tropical SST changes, this relationship sometimes breaks down (Turner, 2004). In addition, the Rossby wave response in the high latitudes is sensitive to westerly winds which complicates the Antarctic – ENSO relationship (Turner, 2004). In general, during El Niño events higher SST are observed in the Ross/Amundsen Seas (Fig. 4) along with a retreat in sea-ice extent and concentration (Li, 2000; Turner et al., 2002; Carleton, 2003; Turner, 2004). Ledley and Huang (1997) found that SST in the Niño 3 region lead by 3 months the Ross Sea SST and a 3–10% reduction in sea ice extent. In addition, Kwok and Comiso (2002a) found a positive correlation with meridional ice motion in the Ross and Amundsen Seas and a negative correlation with zonal ice motion in the Amundsen Sea. Overall, sea-ice correlation with ENSO has to be considered carefully, due to its yearly growth during winter and its sensitivity to atmospheric circulation (Turner, 2004). Furthermore, Antarctic sea ice has a quasi-11 year cycle and, in addition, Ross Sea ice has a 1.5 year lag oscillation with the Weddell sea ice (Turner, 2004) which add complexity to the Antarctic-ENSO sea ice relationship.

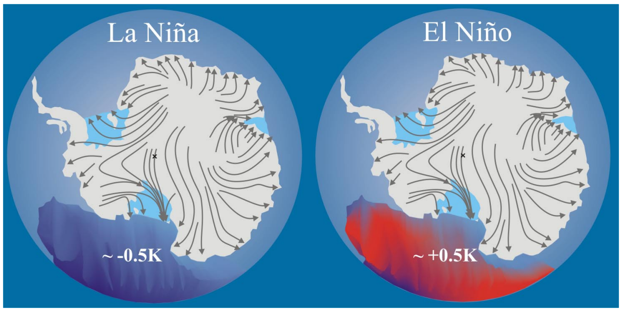

Fig. 4. During La Niña events a cooling is observed in the Amundsen and Ross Seas. In contrast the region shows a warming during El Niño events. The difference between La Niña and El Niño events is about 1 K.

Similar to the atmospheric ENSO expression the oceanic response also shows significant spatial variability in the Ross Sea. During El Niño events the eastern Ross Sea experiences in phase with the regional trend higher SST, reduced sea-ice concentration and a shortening of the sea-ice season. In contrast, the western Ross Sea shows the opposite (Kwok and Comiso, 2002a). During La Niña time periods the relationship between the eastern and western Ross Sea is reversed (Kwok and Comiso, 2002a).

4 Conclusion

The double sided effect of ENSO in the Ross Sea Region is due to a direct oceanic ENSO effect that causes SST and surface temperature to warm during El Niño and cool during La Niña time periods (Fig. 4). However, in addition to the direct ENSO influence, the indirect atmospheric ENSO influence in the western Ross caused by the eastern shift of the L_{AS} and subsequent enhanced katabatic outflow (Fig. 3) more than compensates the direct ENSO effect, leading to a negative correlation with colder temperatures during El Niño and warmer temperatures during La Niña. While the direct ENSO effect causes a ~1 K difference between El Niño and La Niña time periods the indirect ENSO effect is more than one order of magnitude stronger and can import air into the region that is up to 15 K colder. For this reason the indirect effect masks the direct effect in the western Ross Sea. As the eastern Ross Sea is not affected by katabatics of the indirect effect it shows the direct/positive correlation with ENSO, with warmer surface and sea surface temperatures and less sea ice during El Niño and the opposite during La Niña.

Acknowledgements. This project is funded by Victoria University of Wellington, Institute for Geological and Nuclear Sciences, the Royal Society of New Zealand (Grant No. 00-CSP-21-BERT), and the Foundation for Research, Science, and Technology (contract number VUWX0203).

Edited by: P. Fabian and J. L. Santos
Reviewed by: two anonymous referees

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