13.16 STRONG ENSO VARIABILITY IN THE DRAKE PASSAGE IN THE 1990s

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1. Introduction

Perhaps the most profound climate changes observed during the 20th Century are found along the Antarctic Peninsula, a region known to be highly influenced by the El-Niño Southern Oscillation [ENSO, *Turner and Marshall*, 2001]. Surface temperatures along the western peninsula warmed about 5K between the 1940s and 1990s [*Vaughan et al*., 2001]. More recently, several floating ice shelves have disintegrated in the Peninsula region [*Scambos et al*., 2000]. Historically, observations have been few and far between in the high southern latitudes, especially prior to the modern satellite era beginning in 1979. Thus, decadal-scale climate changes are difficult to verify in these latitudes. Nevertheless, *Bromwich et al.* [2000], using ECMWF and ERA-15 Reanalysis, have found that the ENSO signal in West Antarctic precipitation minus evaporation (P-E, which closely approximates snow accumulation over the ice sheet interior) does appear to vary decadally with an abrupt switch from a positive correlation between the Southern Oscillation Index (SOI) and P-E during the middle and late 1980s to a strong negative correlation after 1990.

Decadal ENSO-type variations are well known in the North Pacific [e.g., *Zhang et al*., 1997], and have also been found in the Southern Hemisphere [*Garreaud and Battisti* 1999]. Unfortunately, the limited observational base in high southern latitudes limits our ability to study decadal changes prior to 1979. There is one region in high southern latitudes, the Drake Passage including the Antarctic Peninsula and southern South America, with a relatively high density of observations going back at least until the 1950s that allows the variation of the ENSO teleconnection over multiple decades to be documented. The current study employs observations from the Drake Passage to demonstrate a strong decadal variation in the regional ENSO signal from the 1980s to the 1990s that parallels the signal in West Antarctic P-E shown by *Bromwich et al.* [2000].

2. Data Used

The study makes use of two main datasets, the National Centers for Environmental Prediction (NCEP) Department of Energy Atmospheric Model Intercomparison Project 2 Reanalysis fields (hereafter, NCEP2, http://wesley.wwb.noaa.gov/reanalysis2/index.html) and the Southern Oscillation Index (SOI). The NCEP2 is assimilated using a more advanced version of the NCEP atmospheric model and includes fixes for several errors, including some specific to the Southern Hemisphere, noted in the earlier NCEP – National Center for Atmospheric Research (NCEP/NCAR) Reanalysis. Monthly averaged values of mean sea level pressure (MSLP) and 500hPa zonal winds are provided on a 2.5 by 2.5 degree grid. Although the various reanalysis efforts have been shown to have many shortcomings in the high southern latitudes [e.g., *Bromwich et al.* 2000; *Marshall and Harangozo* 2000], more confidence can be placed in the fields during the period of this study (1980-1999) than earlier periods [*Kistler et al*., 2001] largely due to the assimilation of modern satellite data beginning in the late 1970s and automatic weather station (AWS) data beginning in the 1980s.

The SOI data were obtained from the Australian Bureau of Meteorology National Climate Centre Climate Analysis Section (CAS, ftp://ftp.bom.gov.au/anon/home/ncc/www/sco/soi/soiplaintext.html). The data are standardized using the *Troup* [1965] method, with values multiplied by 10 so that they may be expressed as a whole number. To remove the seasonal cycle, the monthly data of the two sets (SOI and NCEP2) were transformed into annual means (from May until April of the following year, based upon *Trenberth and Caron* [2000]), and then correlated. Statistical confidence of the correlation values is based upon equation 30 in *Bretherton et al*. [1999], which accounts for the autocorrelation of the data.

3. Decadal Variability of ENSO in Drake Passage

Verification of NCEP2 against the radiosonde sites at Punta Arenas, Chile (53.0°S 70.85°W) and Bellingshausen on King George Island off the far northern end of the Antarctic Peninsula (62.2°S 58.93°W) is shown in Figures 1a and 1b. The limited missing daily values in these radiosonde records were estimated using the NCEP2 values at the closest gridpoint, however, this patching does not affect the results on the annual timescales shown here. The plots demonstrate that NCEP2 captures the wind speed variability with high skill for both of these stations on annual timescales. The zonal and meridional components of the wind have been verified independently, and show similar skill to Figs. 1a and 1b. Figure 1c shows the annual means of the observed 500hPa wind speed vs. SOI for Punta Arenas while Fig. 1d shows the NCEP2 500hPa meridional wind speed vs. SOI for Bellingshausen. NCEP2 meridional winds were chosen in Fig. 1d so that the Bellingshausen record may be extended to capture the El-Niño event of 1997/1998; radiosonde data for

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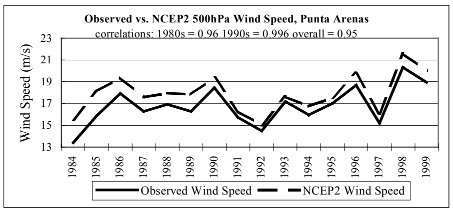
Bellingshausen were unavailable after 1996. Further, the meridional component at Bellingshausen was chosen due to a study conducted by *Carleton* [1988]. He found significant changes (at 99% confidence level) only in the direction of the October meridional wind component based upon the Grytviken-Ushuaia SLP gradient; Bellingshausen lies near the middle of this station pair. It is evident from Figures 1c and 1d that the ENSO signal is much stronger and better correlated in the 1990s than in the 1980s for both sites. The decadal differences are especially large at Punta Arenas; other variables at this site (e.g., 300hPa wind speed, not shown) show similar results.

1a



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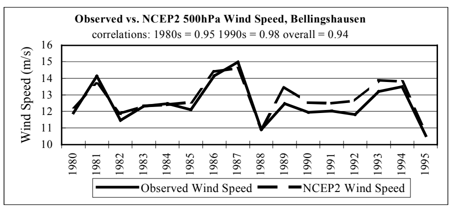

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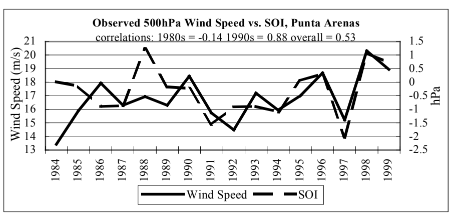

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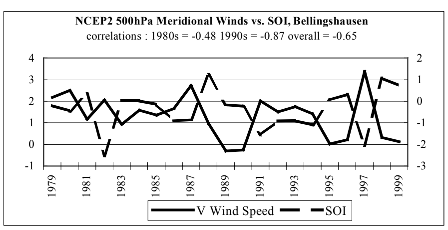

Figure 1. (a) Verification of NCEP2 500hPa wind speed with observed 500hPa wind speed for Punta Arenas. Data are shown using annual mean (May-April of following year), with wind speeds in ms^{-1}. (b) Same as in (a), but for Bellingshausen. (c) Annual mean plot of 500hPa wind speeds and the SOI at Punta Arenas, with the correlation values given by decades. (d) Annual mean plot of 500hPa meridional wind speeds and the SOI at Bellingshausen, with the correlation values given by decades.

Figure 2 shows the spatial correlation to the SOI of NCEP2 MSLP (Figures 2a and 2b) and the 500hPa zonal wind component (Figs. 2c and 2d) during the 1980s and the 1990s. These plots display the broadscale spatial structure of the decadal ENSO modulation as well as the locations of the stations referenced in this paper in Fig. 2a. A remarkable change is observed in both the position and magnitude of the correlations; the regions with strong correlations/anticorrelations move farther east and slightly south from the 1980s to the 1990s and strengthen significantly. The position of the negative correlations bands in the 1990s MSLP (Fig. 2b) is a large eastward deviation of the *van Loon and Shea* [1987] propagation of the positive SLP anomalies in ENSO warm events, when the SOI < 0. During La Niña events in the 1990s (SOI > 0), MSLP and geopotential heights throughout the troposphere near the Drake Passage are lower than in the 1980s, with the zonal winds being stronger across southern South America, and weaker across the Antarctic Peninsula. The MSLP correlation isolines can be thought of as isobars with stronger (weaker) westerly geostrophic winds for La Niña events to the north (south) of the Drake Passage. Meridional geostrophic winds at Bellingshausen in the 1990s should be more northerly (V < 0) when the SOI is positive. The reverse happens during El Niño events. The 500hPa geopotential height changes (not shown) are similar in pattern to those for MSLP, and this is expected for the quasi-barotropic atmosphere that exists in the Drake Passage region. Thus the results shown in Fig. 2 are in agreement with the observed 500hPa winds at Punta Arenas and Bellingshausen (Figs. 1c and d). The ENSO signal is not simply stronger in the 1990s than in the 1980s, but it also demonstrates a distinct seasonality, peaking in DJF while showing little correlation in JJA (not shown), findings that are compatible with previous work [*Karoly* 1989; *Renwick* 1998]. *van Loon and Shea* [1987] find that during MJJ, SLP anomalies associated with ENSO warm events are the weakest, supporting the above finding that the JJA correlations are also the weakest.

Because the Drake Passage region is one where observations date back for many decades, we are able to examine the ENSO modulation over long time scales. For this study, MSLP data from Faraday (back to 1950) and Orcadas (back to 1903) were collected from the British Antarctic Survey (BAS) Reader website, http://www.antarctica.ac.uk/met/READER/, and correlated with the SOI by decade (Fig. 3). Correlation values were also studied at both Orcadas and Faraday using a ten-year moving window in which correlations were calculated for running ten-year timescales. These results (not shown) indicate that examining correlation values for the decades only (e.g., 1970-79), as in Fig. 3, yield essentially the same result. From Fig. 3 we clearly see that not only are the 1990s impressively different from the 1980s (as noted earlier), but that the 1990s differ from the rest of the time series. The ENSO teleconnection in the Drake Passage region has not been as strong as it was in the 1990s since the 1920s, however it cannot yet be evaluated if this represents climate variability or climate change. It is important to note that these results match up well with the spatial plots presented in Fig. 2b, which show Orcadas and Faraday within a band of strong negative correlations in the 1990s.

Carleton [1988] studied long term (1929-1983) observed MSLP records during ENSO warm (SOI < 0)

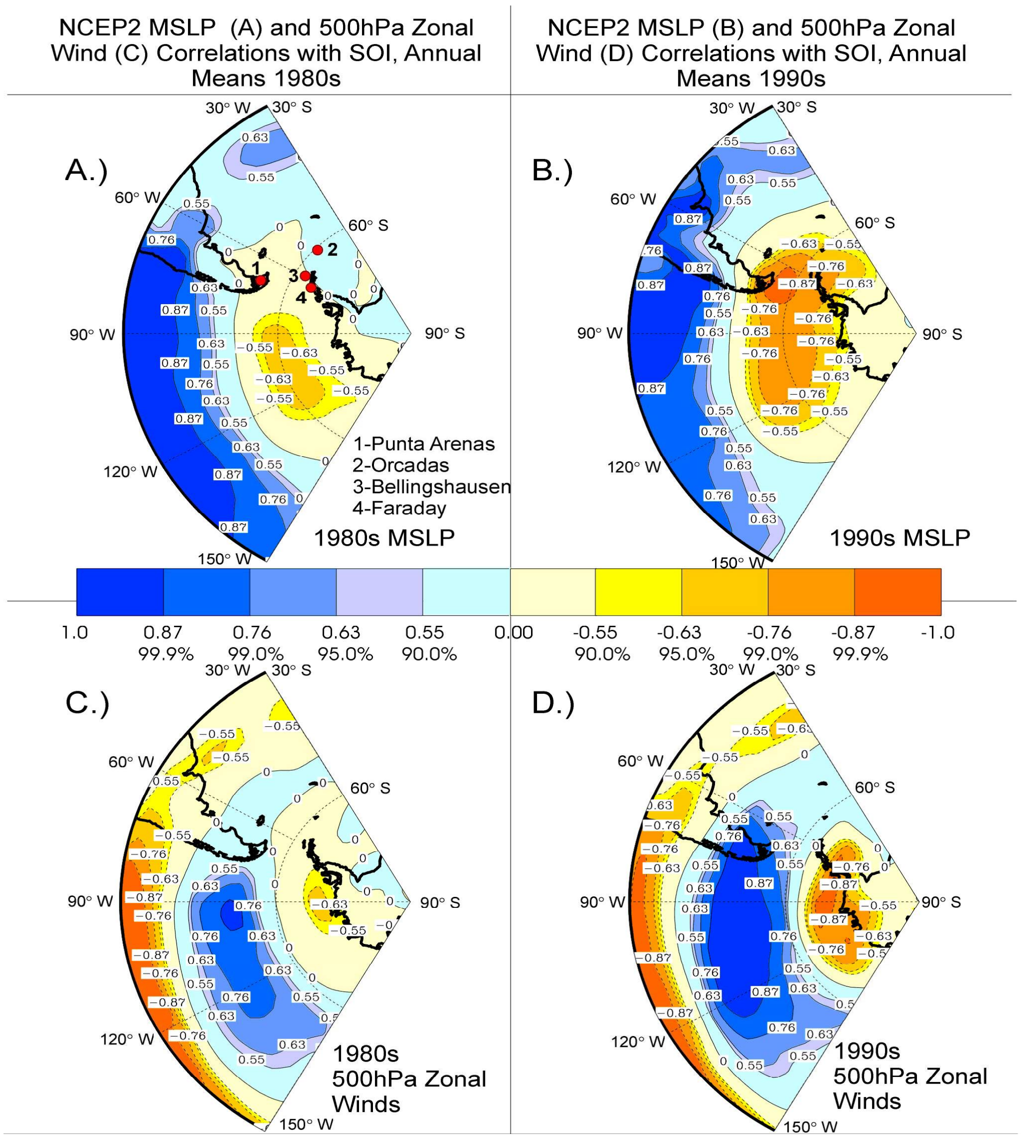

Figure 2. Spatial correlation plots of the SOI and the annual means of NCEP2 (a) MSLP for the 1980s (b) MSLP for the 1990s (c) 500hPa zonal winds for the 1980s and (d) 500hPa zonal winds for the 1990s. The confidence level for each of the respective correlation values is given in the center below the label bar, determined from Eq. 30 in *Bretherton et al*. [1999], which accounts for the autocorrelation of the data.

and cold (SOI > 0) events along Antarctic Peninsula region and extending into the Weddell Sea, including both Orcadas and Faraday stations. The study showed significant results in October and February that indicate positive (negative) sea level pressure anomalies during the cold events and the years preceding warm events (warm events), suggesting a positive correlation with the SOI within this region. The results for the current study during the same period are consistent with *Carleton's* [1988] findings: Orcadas MSLP is positively correlated with the SOI (Fig. 3) from the 1940s until 1983, and highly dominated by the spring (SON) and summer (DJF) correlations. The 1930s are marked with only a slight negative correlation (-0.08) and as a whole represent a transition decade that is probably masked in the long term averages used by *Carleton* [1988]. However, it is notable that the correlation sharply changes in the

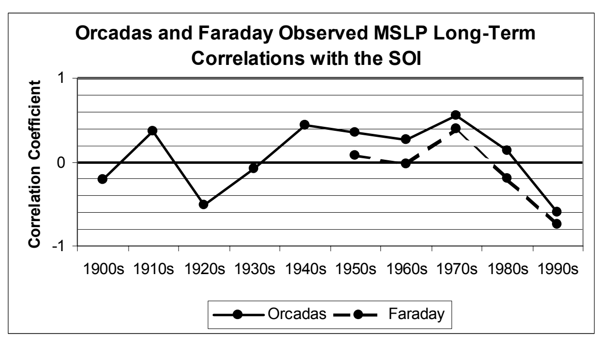

Figure 3. Orcadas and Faraday observed annual mean MSLP correlations with the SOI. Correlations were calculated by decade, with the decade ending in the odd year, e.g., the 1970s span 1970-1979.

1990s, counter to the long-term (1929-1983) trend found in *Carleton* [1988]. This change would indicate a different MSLP configuration in the Antarctic Peninsula region, which is clearly evident in Figs. 2a and 2b.

It is important not only to look at the ENSO variability in the Drake Passage region, but also in the Southern Hemisphere as a whole to put the 1990s in perspective. *van Loon and Madden* [1981], using summer (DJF) long term (1899/1900 – 1977/78) zonal mean pressure values, find that both the subtropical high (25-55°S) and the subantarctic low (60-65°S) are weak during ENSO warm events. When the subtropical high (subantarctic low) is weak, the central pressures are lower (higher), suggesting a positive (negative) correlation of SLP with the SOI in warm events. *van Loon and Madden's* [1981] findings are in agreement with the correlation bands in the MSLP plots shown in Figs. 2a and b, both of which dominate the zonal mean pressure pattern in the Southern Hemisphere, especially in DJF. These SLP anomalies are further amplified by the very high correlations noted in the 1990s (Fig. 2b), notably in the range and position of the subantarctic low. This supports the findings for the Drake Passage and suggests that the ENSO teleconnection in the 1990s is much different than previous decades (after at least 1920) over the entire Southern Hemisphere.

4. Conclusions

An analysis of the ENSO signal affecting the Drake Passage region over many decades has been presented. The results indicate that the 1990s were a decade in which the ENSO teleconnection was remarkably strong, the strongest in at least 70 years. The ENSO signal appears especially strong in the MSLP and 500hPa geopotential height fields (due to the quasi-barotropic environment in this area), setting up gradients that produce impressive correlation changes in upper level (both 500hPa and 300hPa, for example) wind patterns. These changes are noted in the observational records at Punta Arenas, Chile, and Bellingshausen, Antarctica, and are also well captured by NCEP2. The change in the ENSO signal from the 1980s to the 1990s noted in this study parallels the abrupt change at roughly the same time in the P-E/SOI correlations shown in *Bromwich et al.* [2000] in West Antarctica. By contrasting the 1990s with the long term SLP patterns in *Carleton* [1988] and *van Loon and Madden* [1981], the different SLP configuration in the 1990s is placed in a historical perspective, however, it is uncertain whether this decade represents climate variability or climate change. This study is intended to stimulate future research on the nature and causality of such a drastic change for a better understanding of the climate forcings affecting the Drake Passage, especially in light of the recent Larsen B ice-shelf disintegration.

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