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HAS SAO BEEN DECREASING OVER THE SOUTHERN OCEAN?

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1. INTRODUCTION

The atmosphere over the Southern Ocean is characterized by a circumpolar trough of low pressure around Antarctica, which shows seasonal variations in its intensity and position. It moves south during austral autumn and spring and north during austral winter and summer. This half-yearly movement is known as the Semiannual Oscillation (SAO). Van Loon (1967) showed that the SAO arises from the different surface heat budget in the oceanic mid and continental polar latitudes. It causes different annual cycles of temperature between the Antarctic continent and the surrounding mid-latitude southern, which in turn reflects in sea level pressure (SLP). More details can be obtained in Meehl (1991), who provides a thorough re-examination of the mechanisms involved in the SAO.

Interannual variability of the SAO has been subject of growing interest (Hurrell and Van Loon, 1994, Meehl et al., 1998; Simmonds and Jones, 1998). Before the 1970's, the second harmonic explained more than 50% of the annual variance in SLP at mid and high latitudes of the Southern Hemisphere. However, Van Loon and Rogers (1984) detected a significant decrease in the SAO magnitude since 1979. Meehl et al. (1998) has attributed this weakening to a change in the seasonal cycle of temperature at mid and high southern latitudes. In this study we show that this decrease is not homogenous across all longitudes.

This work aims to investigate changes in the SAO variability from the 1970s to the present by updating the earlier studies. We will show that SAO changes seem to be basin dependent.

2. DATA AND METHODOLOGY

The study uses the 2.5ºx2.5º monthly mean SLP data from the National Centers for Environmental Prediction (NCEP) – National Center for Atmospheric Research (NCAR) Reanalysis (Kalnay et al., 1996; Kistler et al. 2001). We used SLP from January/1968 to December/2005, when the number of surface observations incorporated into the Reanalysis increased considerably. In order to minimize errors found in SLP Reanalysis trends over the Southern Ocean and Antarctica, we have removed a long-term trend in the data, consistent with Hines et al. (2000).

Harmonic analysis is used to examine the seasonal cycle of SLP as well as to characterize the mean behavior of the SAO, with special attention to the latitude band between 50ºS and 65ºS.

Focusing on the interannual variability of the SAO, the seasonal means for the entire record have been removed to define the anomaly time series. A power spectrum analysis was done by implementing the SSA-MTM Toolkit (Singular-Spectrum Analysis - Multi-Taper Method), described in Ghil (1997). The MTM technique attempts to reduce the variance of spectral estimates by multiplying the time series by a small set of orthogonal window functions rather than the unique data taper. The result is a set of independent spectral estimates that provides a final spectrum based on the ensemble average. Detailed description of the MTM may be found in Percival and Walden (1993).

3. RESULTS

3.1. The Semi-Annual Oscillation in SLP

Figure 1a shows the latitude vs. time evolution of the second harmonic of the monthly mean, zonally-averaged SLP for each year. The zonal mean amplitudes are higher in the southern latitudes, reaching 5hPa at approximately 67ºS in 1975 and 1982, while at 50ºS the amplitudes range between 1 and 3hPa. These results are consistent with van Loon et al. (1993) work, where they used the SLP data set from Australian Bureau of Meteorology covering the period of 1974 to 1988 to create a similar diagram. Here we expanded their analysis by including the later 17 years and the earlier 6 years of SLP data based on the NCEP/NCAR Reanalysis. This diagram also agrees with Simmonds and Jones (1998) findings.

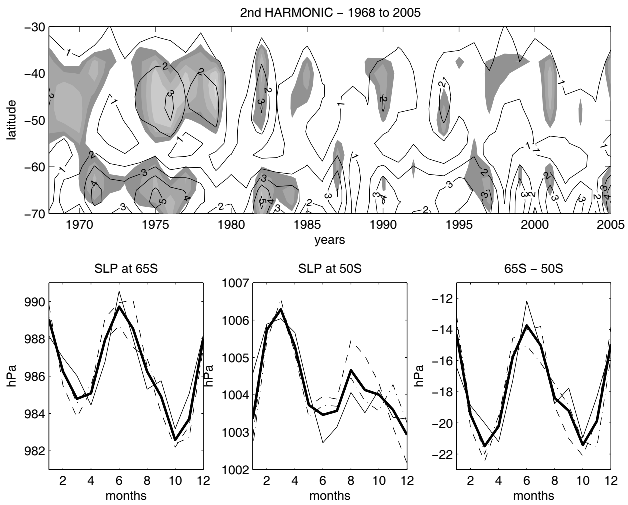

Figure 1: (a) Amplitude of the second harmonic for each year of the monthly mean, zonally averaged SLP from 1968 to 2003. Shaded areas indicate values greater than 40% of the explained variance. Contour intervals are 1hPa and 10%, respectively. Annual cycle of zonal mean

SLP: (b) at 50ºS, (c) at 65ºS and (d) the difference between them. Dashed line: 1968-1978; dashed-dotted line: 1979-1990; solid line: 1991-2005. Thick solid line represents the mean over the entire period 1963-2005. Units in hPa.

Due to the half-yearly circumpolar trough contraction/expansion and deepening/weakening movement, the second harmonic is more important than the first one (not shown) across 65ºS, where it explains variance as high as 70% for some periods [1971, 1975-1976, 1982, 1984, 1997 and 2005]. It is worth to highlight that in 2005 both amplitude and explained variance increases again at 65ºS. Another important characteristic of Figure 1a is the minimum amplitude located between 55ºS and 60ºS where the phase reverses. The consistent out--of--phase annual cycles for SLP at 50ºS and 65ºS can be seen in Figure 1b,c (thick solid line) respectively.

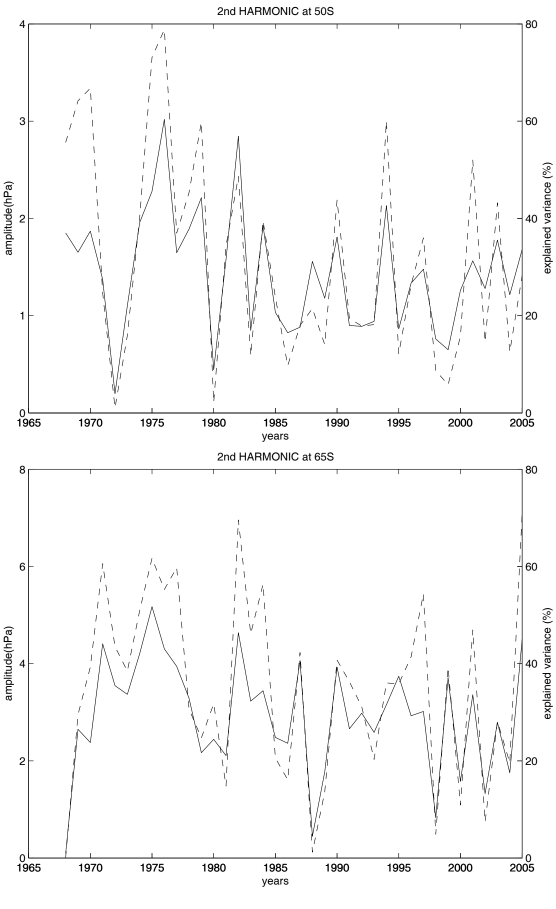

Figure 2. Harmonic analysis applied for each year of zonal mean SLP from 1968 to 2005: amplitude (solid line) and percentage of explained variance (dashed line) at (a) 50ºS (upper panel); and (b) at 65ºS (lower panel).

Variability from one decade to the next can be seen in the annual cycle of the zonally averaged SLP at 50ºS (Figure 1b-d) for 1968-1978 (dashed line), 1979-1990 (dot-dashed line) and 1991-2005 (solid line) with respect to the mean for the entire period (thick solid line). The SLP cycle at 65ºS does not weaken significantly during the whole period. The decrease of the second harmonic is evident at 50ºS (Figure 1c), but not at 65ºS. During the first decadal period (1968-1978, dashed line), the annual cycle at 50ºS shows a strong SAO. The following decades show a reduction in the amplitude of the zonally-averaged SLP in spring and consequently a weakening of the second harmonic. The changes at 50ºS mainly occur during the austral spring (September-October-November).

The importance of the second harmonic can be seen in Figure 2 at 50ºS and 65ºS. Time series of amplitudes (solid line) and explained variance (dashed line) are similar which indicates that the second harmonic is very strong. From Figure 2a it is also possible to note the decrease in the second harmonic after earlier-80s, especially at 50ºS. The decrease of second harmonic is overwhelmed by an increase of first harmonic (note shown).

Focusing on the SLP distribution over ocean basins, Figure 3 depicts the amplitude and variance of the second harmonic over the Southern Ocean for the different decades. It is noticeable that before 1978 (Figure 3a) the second harmonic was very prominent over the three oceanic basins at mid-latitudes and around the Antarctic continent. The period between 1979 and 1990 (Figure 3b) was characterized by a significant reduction of the SAO signal at the mid southern latitudes and around the Antarctic Peninsula. In the most recent period (1991 to 2005, Figure 3c) the second harmonic is still weak, especially in the Pacific sector. Although the SAO has been weakening since the late 1970s over the Pacific and Indian Ocean sectors, the same cannot be seen at mid-latitudes over the Atlantic Ocean. In fact, Figure 3c suggests that the second harmonic is still strong in the 1990s over the South Atlantic Ocean.

These behaviors can be seen from the annual cycle of SLP at 50ºS averaged over the three oceanic regions in Figure 4. SAO is well-defined for the 1968-1979 period (dashed line) in all oceans. The following decades shows a reduction of the amplitude of the second peak, except for the South Atlantic Ocean where the SAO remains strong (Figure 4b). The weakening of the SAO, which began in the late 1970s, has continued in the Pacific and Indian Ocean sectors but not over the South Atlantic.

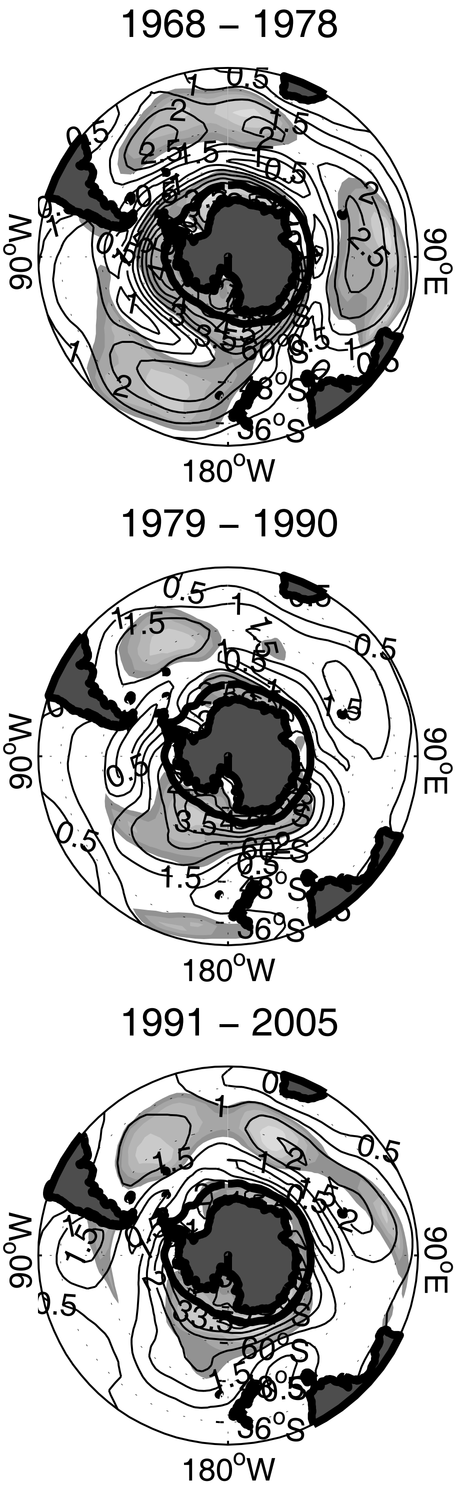

Figure 3: Amplitude of the second harmonic for three periods: (a) 1968-1978, (b) 1979-1990 and (c) 1991-2005. Shaded areas indicate values greater than 40% of the explained variance. Contour intervals are 0.5hPa and 20%, respectively.

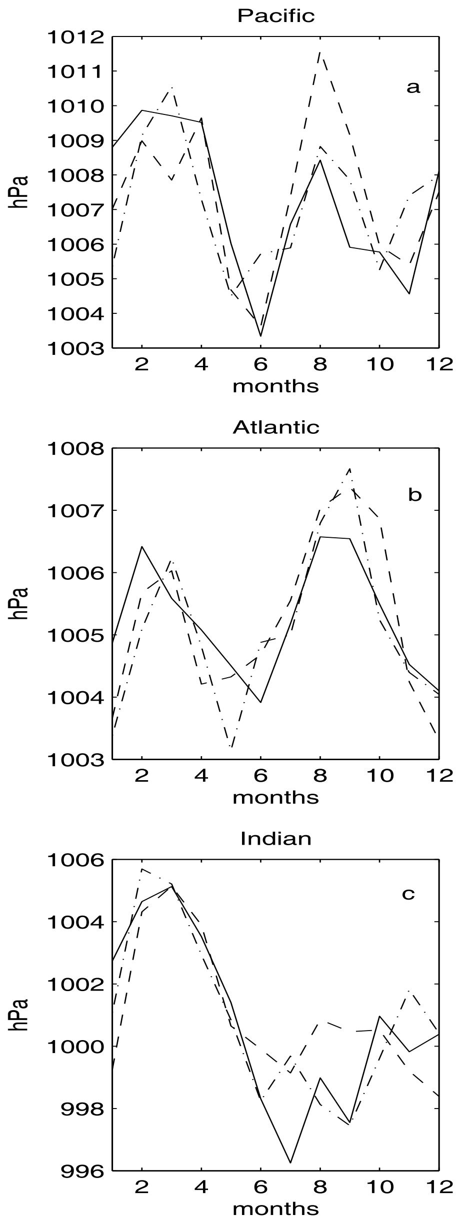

Figure 4: Annual cycle of SLP at 50ºS for the three averaged oceanic regions: (a) Pacific (180ºW-225ºW), (b) Atlantic (55ºW-0ºE) and (c) Indian (45ºE-110ºE). Dashed line: 1968-1978; dashed-dotted line: 1979-1990; solid line: 1991-2005. Units in hPa.

3.2. The variability of SLP

The MTM spectral analysis (Figure 5) of the SLP anomalies time series for 50ºS and 65ºS and their difference show a spectral peak at approximately 4 years (0.02 cycles/month) significant at 95%. Since the contraction (expansion) and deepening (weakening) of the circumpolar trough (CPT) is a fundamental feature of the SAO, spectral analysis was also applied to the anomalies time series of the CPT (solid black line on Figure 3) to determine if it shows similar variability. Figure 5d demonstrates that it does. Since Meehl (1991) suggest that ENSO and the Indian Monsoon could affect variability of the circumpolar trough it may be that ENSO influences the SAO through the CPT.

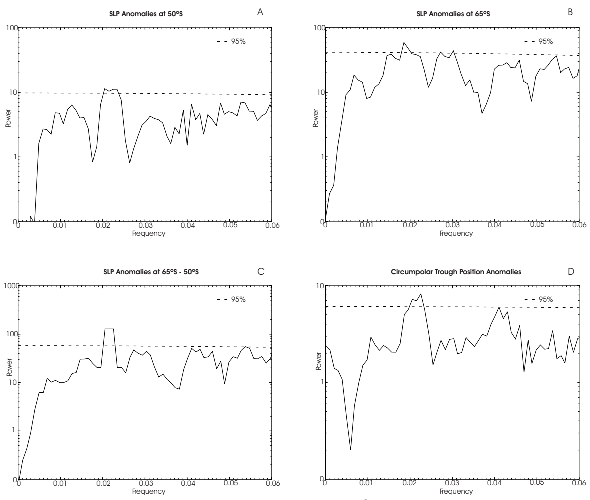

Figure 5: MTM spectra for the monthly mean, zonally averaged SLP anomalies: (a) at 50ºS; (b) at 65ºS; (c) for the difference between 65ºS and 50ºS; and, (d) for the zonally averaged position of the circumpolar trough. Square peak in (c) is result of harmonic analysis. Only frequencies lower than 0.06 cycles/month are presented.

4. DISCUSSIONS AND CONCLUSIONS

The SAO in SLP was examined using NCEP/NCAR Reanalysis data set from 1968 to 2005. This study expands the previous findings of van Loon works by not only extending the analysis of the SAO behavior over the last decade but most importantly, by examining the SAO variability over the three oceanic basins separately. A continuous decrease of the second harmonic in the zonally averaged SLP can be seen. This weakening is not homogeneously distributed across all longitudes but it is pronounced over the mid-latitudes of the Pacific and Indian Oceans. The SAO signal is evident and clear at mid-latitudes over the Atlantic sector during the last decade, different to what is happening in the other basins. Further investigation is underway to explore these physical mechanisms and to better understand how the South Atlantic is immune to them.

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