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SOUTHERN HEMISPHERE OCEAN-ATMOSPHERE INTERACTION

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1. Introduction

The extra tropical atmospheric circulation of the Southern Hemisphere is primarily influenced by two patterns of variability. The leading pattern of atmospheric variability on interannual time scales is characterized by a redistribution of mass between the polar region and a zonally symmetric ring around 45º-50ºS. This mode of variability is commonly referred to as the Southern Annular Mode (SAM; Thompson and Wallace 2000). On lower frequency time scales, variability in the extra tropical atmospheric circulation is characterized by a dipole structure over the South Pacific driven remotely by the El Nino Southern Oscillation (ENSO; Kiladis and Mo 1998; Kidson 1999).

Coupled ocean-atmosphere models have simulated the response of extra tropical SST anomalies to the SAM, demonstrating that the positive phase of the SAM leads to increase in the circumpolar westerlies, which gives rise to a stronger circumpolar current as well as an increase (decrease) in poleward heat flux at 30ºS (60ºS) (Hall and Visbeck 2002; Oke and England 2004). Analysis of monthly mean SST observations has also shown that a substantial fraction of variability in the SST field can be interpreted as a linear response to surface forcing by the SAM and remote forcing by ENSO (Renwick 1998; Verdy et al. 2006). These relationships tend to be strongest at the zero lags and have demonstrated little evidence of forcing of the large-scale atmospheric circulation by extra tropical SST anomalies (Renwick 1998). However, there is still a lack of observational analysis of Southern Hemisphere ocean-atmosphere interaction because a comprehensive set of SST observations was not available until recently. Thus, the goal of this research is to provide a more comprehensive analysis of ocean-atmosphere interaction in the Southern Hemisphere. The analysis will emphasize the lagged and contemporaneous relationships between the SAM and observed variations in Southern Ocean SSTs on weekly and monthly time scales. Further more, the analysis is broken down into warm (November-April) and cold (May-October) seasons to examine the seasonal variations in these relationships.

The primary data used in the analysis are 25 years (1981-2005) of monthly and weekly mean SSTs as described in Reynolds et al. (2002). The data are available on a 1ºx1º latitude/longitude grid and were smoothed with a 3-point binomial filter applied in both space and time, as per discussions in O'Neill et al. (2003) and Reynolds et al. (2002). Atmospheric variables were obtained from the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) re-analysis (Kalnay et al., 1996) and are provided on a 2.5ºx2.5º latitude/longitude mesh. Time series of the annular modes and ENSO were obtained from the Climate Prediction Center (CPC) and have been standardized by subtracting the mean and dividing by the standard deviation.

2. Monthly Mean Regressions

Contemporaneous regressions of monthly mean Z_{500} (contours) and SST (shaded) anomalies onto the SAM and ENSO are plotted in the top and bottom rows of Figure 1, respectively. Left (right) column denotes cold (warm) season. The ENSO index has been inverted to allow for a more direct comparison between regression maps. Both SST patterns associated with the variability in the SAM and ENSO exhibit similar features, but they are not identical. For example, the SST patterns associated with the SAM and ENSO share a dipole structure in the South Pacific during warm season. However, in the eastern Pacific the SST pattern associated with ENSO is marked by a band of variability at 30º-40ºS, extending to the South American continent. The SST pattern associated with the SAM also exhibits variability in the same region but it is isolated from the continent. The SST pattern associated with ENSO exhibits stronger amplitude and projects more strongly onto leading Empirical Orthogonal Function (EOF) of SST anomalies in the Southern Ocean, which is consistent with previous results (Renwick 2000, 2002).

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Figure 1. Monthly mean SST (shaded) and Z500 (contours) anomalies regressed onto the (top row) SAM index and (bottom row) ENSO index. Positive (negative) contours are denoted by solid (dashed) lines and are drawn at (-5, 5, 15….m). Left column denotes cold season (May-October) and right column denotes warm season (November-April).

The relationships between variations in observed SSTs and the atmospheric patterns of variability are consistent with previous results (Lovenduski and Gruber 2005; Verdy et al. 2006), but also show seasonal variations in these relationships that have not been documented. The analyses above show a discrepancy in the seasonal variations between the atmospheric variables and the SST field. The amplitude of the SST variability shown in all three analyses presented in Figure 1 is relatively stronger during the warm season. However, the Z_{500} anomalies associated with the SAM and ENSO show much smaller seasonal variations and are slightly stronger during the cold season. It is possible that the observed seasonal variations in the SST field may be indicative of an error in the collection or processing of the data.

3. Lagged Relationships on Weekly Timescales

To examine the temporal relationships between the SAM and its associated pattern in SSTs, we use lagged regression/correlation analysis on weekly SST anomalies and the SAM index. Results are based on the 26-week cold (warm) season extending from the first week of May (November) to the last week in October (April). The regressions/correlations are centered about the middle 10 weeks of each season and are lagged from -8 (SST leads) to +8 (SST lags) weeks. Because ENSO variability is strongest on seasonal time scales, we focus the weekly analysis primarily on the lagged relationships between SST anomalies and the SAM. The SST patterns evident in the top row of Figure 1 are also evident in all lags of the lagged regressions of weekly SST anomalies onto the SAM (not shown). The strength of the lagged relationships between the SAM and its

Figure 2. Lag correlation coefficients between warm (dashed line) and cold (solid line) season values of the SAM index and expansion coefficient time series of the contemporaneous regression map of weekly SST anomalies onto the SAM. The 95% confidence level is denoted by the dotted line (r~0.26).

associated SST pattern is demonstrated in the lag correlations shown in Figure 2. The strength of the relationship between the SAM and expansion coefficient time series of the associated SST pattern does not differ significantly between warm and cold seasons. Correlations are strongest and most statistically significant when variations in the SAM precede variations in SSTs by 1 week and are weakest when SST leads by 4-8 weeks. However, 8 weeks after peak amplitude in the SAM, the correlations are still statistically significant.

The persistence in the SST field inferred from Figure 2 is further investigated through lag autocorrelations of the SST pattern associated with the SAM. We then compare these to the lag autocorrelations of the SST pattern associated with NAM (hereafter referred to as the tripole; Marshall et al. 2001) for both cold and warm seasons (Figure 3). The autocorrelations were lagged from 0 to 13 weeks for both warm and cold seasons. The SST pattern associated with the SAM index exhibits a much higher degree of persistence than the tripole during the first three months of both the warm and cold seasons. The lag autocorrelation of the SST anomalies associated with the SAM is qualitatively similar in both seasons, but the tripole exhibits a stronger degree of persistence in the warm season.

The lag autocorrelations of the NAM and SAM (Figure 4) exhibit much less persistence than the associated SST patterns because they have e-folding time scales of ~10 days (Hartmann and Lo 1998; Felstein 2000). There exists little difference in the lag autocorrelations between the NAM and the SAM except during the austral summer, when the SAM exhibits a pronounced persistence during the first several weeks that is not observed in the NAM.

The results above suggest a degree of persistence in the SST anomalies associated with the SAM not observed in the North Atlantic sector. A fraction of the persistence observed in the variations in SSTs associated with the SAM could be indirectly driven by ENSO. Variability in ENSO, which occurs on monthly time scales and longer, describes approximately 25% of the variability in the SAM, which, in turn, gives rise to fluctuations

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Figure 3. Lag autocorrelations of the expansion coefficient time series of the SST pattern asosociated with the SAM (solid line) and NAM (dashed line) for hemispheric cold (top) and warm (bottom) seasons.

in observed SSTs (L'Heureux and Thompson 2006). However, the relationship between the SAM and ENSO is evident in the warm season and does not explain the observed persistence in Southern Ocean SST anomalies associated with the SAM in the cold season. We are currently investigating the following: a) Why the SST pattern associated with the SAM persists longer than its Northern Hemisphere counterpart and b) why the SAM has such pronounced persistence in the austral summer.

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Figure 4. Lag autocorrelations of the SAM (solid line) and the NAM (dashed line) indices for hemispheric cold (top) and warm (bottom) seasons.

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