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ENSO: THE EQUATOR AND THE SOUTHERN MID-LATITUDES MUST WORK TOGETHER

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1. INTRODUCTION

When Bjerknes (1966,1969) linked El Nino and the Southern Oscillation, he attributed the primary cause of warming to a weakening of the Pacific trade winds and oceanic upwelling of the Southern Hemisphere. Bjerknes (1966) speculated that reasons for this warming must be sought south of the equator, as the southeasterly trades associated with the South Pacific high dominate the equatorial flow in the central and eastern Pacific.

Of critical importance to this issue, is the observation by van Loon (1984) that the South Pacific circumpolar trough extends farthest northward and most influences the trades between April-July. In the year leading into El Niño, van Loon and Shea (1985, 1987) have shown that a large see-saw in pressure, related to the 'Southern Oscillation', turns over at 30°S between Australia and the central South Pacific. At the end of the see-saw turnover (April-July year (0)), a quasi-stationary trough in the South Pacific directs southwesterly winds against the South Pacific high, and this is proposed to weaken the trades across the Pacific (van Loon, 1984). Northerly wind and warm SST anomalies along the South Pacific Convergence Zone in Austral summer (year –1,0) appeared to play an important role in changing pressures in the South Pacific (van Loon and Shea, 1985;1987).

More recent ENSO research has focused on the Madden-Julian Oscillation (MJO), with an enhanced MJO activity linked to westerly wind bursts and a proposed weakening of the low-level easterly winds across the Pacific. However, very strong MJO activity occurs in a number of years where the trade winds stay strong (Bergman et al., 2001). Also, strong MJO activity 6-12 months prior to ENSO warm events in the period 1980-99 is not observed between 1950-79 (Zang and Gottschalck, 2002).

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Evidence for van Loon's hypothesis appears to be strongest for stronger ENSO events. In the rapid warming/cooling related to the intense 1997/98 El Nino/La Nina, Wang and Weisburg (2000) found strong off-equatorial pressure anomalies played an important forcing role in adjusting wind speeds and oceanic temperature changes. SST anomalies in the off-equatorial regions were again shown to be important.

Over a 50-year period, Stephens and Lamond (2001) found clear long-lead indications of stronger ENSO events. In particular, the largest negative pressure anomalies over southeastern Australia in winter/spring (-1), preceded the largest pressure reversals (see-saw) between Australia and the South Pacific, the development of the strongest troughs in the South Pacific (April-July(0)), the greatest weakening of the trades, and the strongest El Nino events i.e. 1997, 1982 and 1972. The importance of the southern mid-latitudes was further highlighted in El Nino years by the finding that: 1) maximum warming in NINO-3 occurs between April-July when the South Pacific trough extends farthest north as part of the semi-annual oscillation, 2) warm (cold) SST near Rapa Island assists in a fall (rise) in pressure which leads a similar fall further north at Tahiti, 3) a strengthening subtropical ridge over cool SST in the South Pacific leads the demise of the warm events by 6-8 months.

In this study, the relationship between the circumpolar trough (or subtropical ridge) in the central south Pacific (Rapa Island, 27°S, 144°W) and the strength of the trade winds in the western equatorial Pacific (5°N-5°S, 135°E-180°W) was investigated. Also, a mid-latitude Southern Oscillation Index (MLSOI) was derived and compared to the SOI and the EQSOI. A method of determining whether ENSO events are developing was derived.

2. RESULTS

Figure 1 shows that the trade winds in the western equatorial Pacific are significantly correlated to the strength of the South Pacific trough (or ridge) between March and November. Weaker correlations are found in Austral summer when the

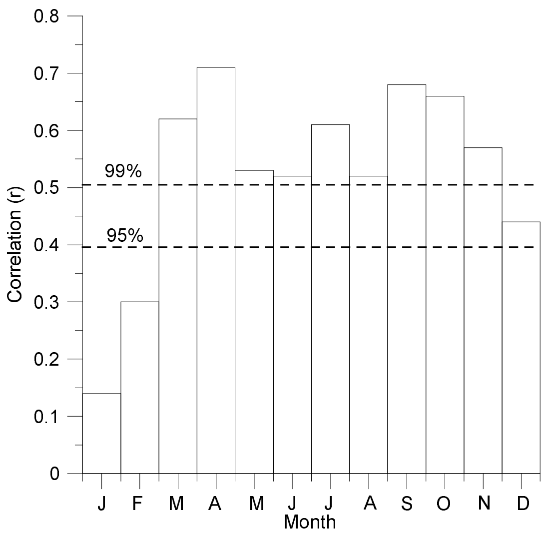

Figure 1. Correlations between bi-monthly standardized trade wind anomalies in the Western equatorial Pacific and bi-monthly standardized pressure anomalies at Rapa Island. Dashed lines represent the 99% and 95% significance levels.

circumpolar trough is farthest south in the annual cycle. These correlations suggest that as the south Pacific trough strengthens and extends further north than normal, the ridge in the South Pacific weakens and the associated trades reaching the western equatorial Pacific are weaker. This would allow westerly wind bursts and MJO activity to progress further east and stimulate Kelvin wave activity and ocean warming further east in the Pacific.

Stephens and Lamond (2001) show that normalised anomalies in trade winds and trough strength tend to coincide with each other at the transition stages of El Niño (1982, 1986-87, 1991 and 1997) and La Niña events (1988, 1995, 1998). When enhanced MJO activity coincides with an enhanced South Pacific trough, El Niño events follow. When enhanced MJO activity meets a strengthened South Pacific ridge, as in May 1990, then the signs of a developing El Nino event are aborted.

To monitor the strength of the South Pacific trough, a Mid-Latitude Southern Oscillation Index (MLSOI) was devised based on pressure differences between southeastern Australia and Rapa Island near 30°S. This index normally leads the SOI and EQSOI into, and out of, extreme phases (Figure 2). It also reaches a minimum at the time of maximum temperature increases in NINO-3 and returns to near normal at the time of maximum NINO-3 temperature anomalies. If the mid-latitudes were responding to equatorial pressure and SST anomalies, the MSLOI should lag the other two indices and reach a minimum when NINO-3 SST reach a maximum. Instead, the MLSOI leads the other two indices with the equatorial pressures the last to respond to the development of El Nino conditions. The MLSO leads the other two indices back to normal values by a number of months as the El Nino begins to decay. This is mainly due to the South Pacific high starting to strengthen over cold sub-tropical SST anomalies, especially when strong El Ninos are in place (Stephens and Lamond, 2001).

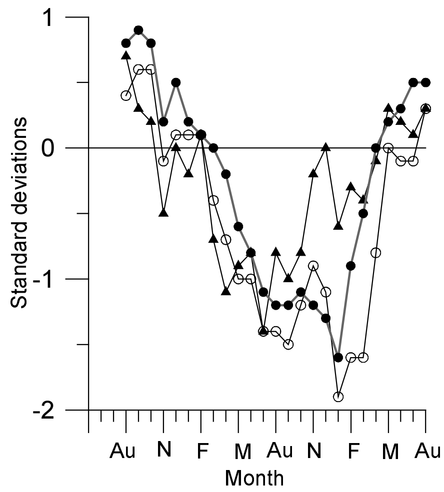

Figure 2. Time-series of normalized monthly SOI (open circles), equatorial SOI (solid circles) and mid-latitude SOI (solid triangles) averaged for the recent 8 El Nino events (1965 to 1997).

The importance of pressure changes along the equator working together with pressure changes in the southern mid-latitudes is emphasized with a new predictive index of ENSO. Based on the simple average of the Equatorial SOI (EQSOI), the SOI at 15°S and the MLSOI at 30°S, a stable MeanSOI is formed that more accurately determines if an ENSO event is forming. When all 3 SOIs at different latitudes decline into negative territory between October (–1) and May (0), the MeanSOI falls dramatically and El Niño events develop. The eight largest declines in the MeanSOI since 1958 were all El Nino years with major droughts across Australia (Table 1). The years that have the next largest falls (1967, 1977, 1980) were also severe drought years across Australia, highlighting the importance of the Southern Oscillation to Australian rainfall.

More importantly, the fact that larger variations of the Southern Oscillation complete the sequence of pressure reversal at the critical period leading into El Nino onset, suggests that pressure changes in the Southern Hemisphere are the critical process to monitor in ENSO prediction. An enhanced South Pacific trough is critical for the following reasons.

Firstly, the increased equator-ward flow on the south-west (rear) side of the trough adds to the westerly

Table 1

	MeanSOI trend October(-1) to May	
	YEAR	**TREND**
1	El 1997	-22.1 •
2	El 1972	-18.2 ••
3	El 1976	-13.0 •
4	El 1991	-12.7 •
5	El 1994	-11.4 ••
6	El 1987	-10.7 •
7	El 1965	-10.0 ••
8	El 2002	-9.5 ••
9	El 1982	-7.8 ••
10	1967	-7.7 ••
11	1977	-6.4 ••
12	1980	-5.6 ••
13	1981	-5.1
14	1961	-4.9

Table 1. A listing of the 14 largest declines in the MeanSOI from October to the following May for data from 1958-2002. El = El Nino years. Double dots – major drought years in Australia, single dots smaller scale droughts in Australia. Note: EQSOI only available from 1958.

momentum change occurring further north along the equator. Secondly, the westerly wind anomalies to the north of the trough weaken the South Pacific high and the pressure gradient across the equatorial Pacific which reduces the transfer of air (trades) from the south-eastern Pacific to the Indonesian low. This change in momentum in the Western Pacific and weakened South Pacific High combine to: (a) assist westerly wind bursts and Kelvin wave activity to extend further east, (b) weaken equatorial undercurrent transport in the themocline; and (c) weaken upwelling all the way along the equator from South America to the mid-Pacific. These all add to deepen the thermocline and increase SST in the eastern and central Pacific.

Thus, when these factors combine, there is a broad-scale favourable pattern for El Nino development with processes along the equator and the mid-latitudes interacting and working together. More rapid warming will occur in the eastern equatorial Pacific if all these interactions occur in the critical El Nino onset stage when the South Pacific trough most influences the Pacific trade winds. For La Nina, maximum cooling was also found to occur around the April –July period when the South Pacific trough is very weak.

3. Conclusions

Pressure anomalies in the central South Pacific are important in ENSO because they: 1) are strongly correlated to the strength of the Pacific trade winds, and 2) generally lead similar anomalies further north. These results, and those from Stephens and Lamond (2001), support the notion that ENSO events occur through a combination of interactions between the air and the sea, and between the southern mid-latitudes and the equator. The stronger the ENSO event, the greater the external forcing from the southern mid-latitudes.

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