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13.4 Tropospheric Moistening by Oceanic Convection, Intra Seasonal Oscillation's and ENSO Warm Event Initiation.

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1. Introduction

Oceanic and continental convection have long been known to be different, specially in the intensities of updraft velocities (Lucas et al, 1994b). In this study open oceanic regions are shown to favor the formation of the very large intra seasonal oscillatory (ISO) convective events containing super clusters of deep convection in the TWP and mega westerly wind bursts (MWWB). The location of the warm pool centroid toward the dateline during the boreal spring is speculated to create the conditions favoring the formation of typically oceanic convection and hence of (ISO) and associated MWWB. Using a two layer model the Pacific ocean is also shown be barely at equilibrium when the western Pacific warm pool (WPWP) centroid is south of the equator during the boreal spring. The combination of the open ocean convection associated with the easterly location of the WPWP and instability of WPWP during the boreal spring is a probable mechanism that accounts for the seven of the fifteen ENSO warm events during 1951-1994 that were initiated between February and May based on Trenberth's (1997) ENSO definition.

2. Open Ocean, ISO's and Westerly Wind Bursts

Harrison and Vecchi (1997) examined 10 years (1986-1995) of 10m winds from the ECMWF data for the TWP. In the regions shown in Figure 1 of Harrison and Vecchi (1997) there were 11 MWWB where the wind anomalies exceeded 2ms^{-1} for 3 days. Figure 1 shows the total of occurrence of each event in these regions for the 11 MWWB events. It is clear that regions over land have the lowest occurrence of MWWB with only 2 observations. The regions adjacent to land have higher occurrence of MWWB ranging from 6-7. The south east Pacific open ocean region has the highest (8) occurrences of MWWE. As will be seen shown later this is the region in the TWP when the WPWP has its easternmost position. Harrison and Vecchi (1997) also observe that WWE are have the strongest measure toward the central and eastern regions of the study area.

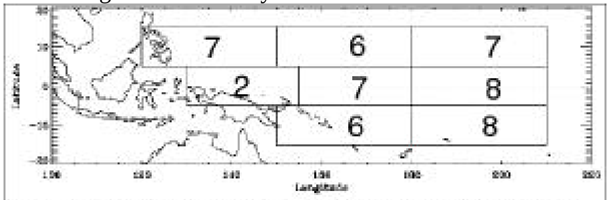

Figure 1. Total Number of Mega Westerly Wind Bursts (MWWB) between 1986 and 1995 as calculated by Harrison and Vecchi (1997). Harrison and Vecchi remark on the strongest measure being toward the central and eastern Regions. It is also clear from this cartoon that open ocean regions favor the formation of MWWE.

ENSO warm events where the SOI is negative, are clearly extreme condition where the WPWP is in the open ocean of the Central Pacific. If the hypothesis of open ocean conditions supporting large ISO's is valid there should be a positive correlation of ENSO warm event conditions with incidence of ISO's and WWB. Harrison and Vecchi (1997) show that strong WWB associate well with most negative SOI and no strong events occur when SOI is positive. Of 131 WWB in the TWP between 1980 and 1989 only 3 occurred when SOI was high (La-Nina) and were in the southern hemisphere, whereas during the warm events of 1982-83 and 1986-87, 25 and 29 bursts occurred respectively(Hartten, 1996).

Williams and Avery (1996) showed that with the exception of the January 28, 1991 event the other three WWB and the OLR patterns show that the deep convection associated with ISO's do not occur over Papua New Guinea (PNG). Similarly Chen and Houze (1997) show that very large scale events (> 500 km horizontal scale) tended to occur over either TWP ocean or Eastern Indian Oceanic regions, and not to occur over PNG and the maritime continent. Time longitude plots that do not contain these very large super cluster convective events do not show eastward moving events (Mapes and Houze, 1993), indicating that ISO's are tied to these very large super cluster convective events.

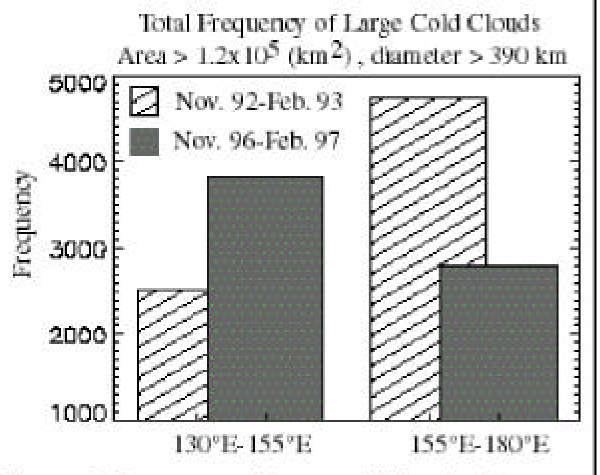

Figure 2 Frequency of large cold clouds closer to land (130°E-155°E) and in open ocean (155°E-180°E). Note that large clouds are more frequent over open ocean during ENSO warm event of 1992/93

Open ocean conditions also favor the formation of ISO's which contain very large super clusters. In Figure 2 it can be seen that during Nov., 1996-Feb. 1997 (an ENSO cold event year) the frequency of very large cold clouds (>1.2x10^5 km^2) over the equatorial 130°E-150°E do not reach the very high frequency observed over 155°E-180°E during the Nov 1992 –1Feb 1993 and ENSO warm event year. The data used are 10 km resolution hourly Infra Red (IR) GMS satellite imagery, and cold cloud size determined based on IR temperature of less than 223K. This difference of frequency of very large cold clouds can be attributed to the open ocean location of the WPWP during ENSO warm event of 1992/93 and adjacent to land location during the 1996/97 cold event,

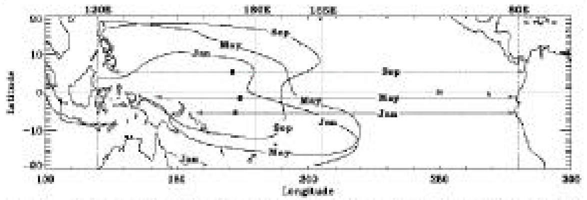

Figure 1. Contour of 28°C SST east of 120°E for January, May and September of "normal year" climatology. The ■ symbol is used to show the calculated warm pool centroid locations for the months of January, May and September. The dashed east west lines through the centroid represents the effective width for the warm pool for that month. Note that January has the narrowest effective width for the warm pool. The symbol * marks the location of the TOGA-TAO buoy with longest time series of temperature and depth data.

2. Location of WPWP Centroid and Stability of Equatorial Pacific

It has been shown that the western Pacific Warm Pool (WPWP) migrates north and south about the equator, and east and west in a sun synchronous movement (Yan et al., 1997) (Figure 3). The same north-south (meridional) and east-west (zonal) migration of the centroid is shown in Figure 3 and Figure 4, using 1°x1° resolution SST data from the Hadley Met Office (Rayner et al., 1996). The size of the WPWP as shown by the 28°C isotherm also varies with the annual migration of the WPWP. The easternmost position and largest surface area size occurs when the WPWP is south of the equator in the boreal spring (Figure 3 and Figure 4). This time period also correspond to the time when the Pacific ocean width is narrowest at WPWP centroid latitude (Figure 3 and Figure 4).

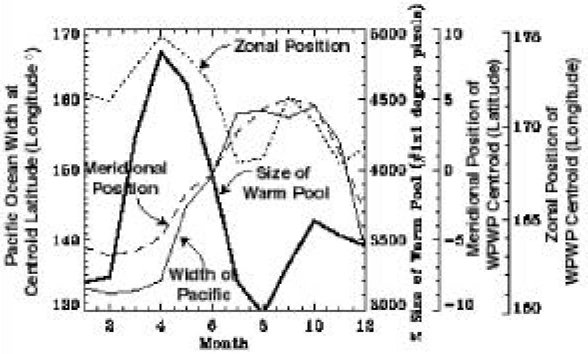

Figure 4. The WPWP as defined by SST > 28°C SST variation for "normal years'. Shown are WPWP centroid zonal position, meridional position, and size. Also shown is the width of the Pacific Ocean at centroid meridional position. Note that the during January to May, the WPWP is south of the equator at its easternmost position and has the largest size. This time period also corresponds to the time is also when the Pacific Ocean width at WPWP centroid is at its narrowest.

The heat content of the WPWP either remains constant or is steadily increasing between heat content discharge during a ENSO warm event and the subsequent warm event (Wyrtki 1985; Zebiak and Cane, 1987). Then surface area changes WPWP (Figure 3 and Figure 4) can be attributed to migration of the WPWP to regions of Pacific Ocean with varying width at different latitudes near the equator (Figure 3). Hence, the surface area changes seen in the annual cycle (Figure 4) has to be compensated with changes in the thermocline depth if the heat content is to remain constant. Using the west-east temperature difference to be (T_w-T_e), the sea-level height difference at 130°E ($2\Delta h_{130E}$) can be given by $(T_w-T_e)*\alpha*H$ where α is the expansion coefficient of water and H the thermocline depth represented by the 20°C depth. Based on a constant volume of the WPWP migrating in a Pacific ocean of varying width, the change in the thermocline depth in the WPWP will be ΔD_{130E}=H (300/b - 2). Based on a two layer model (Wyrtki, 1979; Tomczak and Godfrey, 1994) sea surface elevation anomaly (Δh_{130E}) is related to the 20°C depth anomaly ΔH_{130E} by $\rho_w\ \Delta h_{130E} = (\rho_{20°C}-\rho_{(w+e)/2})\ \Delta H_{130E}$. Then the 20°C depth at 110°W based on purely thermodynamic considerations can be given as

$$\Delta H_{tot,110W} = [-0.6\Delta H_{130E} + 0.2\Delta D_{130E}] \qquad (1)$$

In a similar manner it can be shown that the 20°C depth at 165°E and the meridional location of WPWP centroid can be given by

$$\Delta H_{tot,165E} = [0.8\Delta H_{130E} + 0.8\Delta D_{130E}] \qquad (2)$$

The thermodynamically calculated 20°C will correspond to the observed 20°C depth only if the easterly surface wind stress can just balance the sea surface difference calculated from thermodynamic consideration. It is clear that if the easterly wind stress is over and above that needed to balance the sea surface difference then the system will be very stable and the observed 20°C depth at 110°W shallower than that calculated by thermodynamic considerations (see Barr-Kumarakulasinghe, 1997 for greater details on methodology).

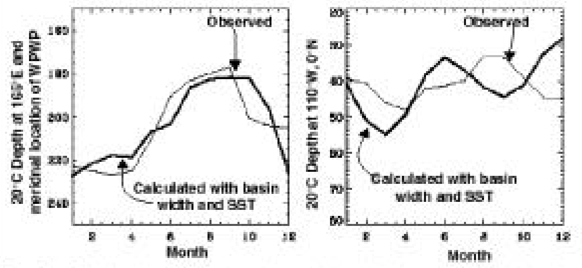

Figure 5 a) Calculated 20°C depth due to due to basin width changes and "normal year" zonal SST difference (solid line) and measured at 165°W, 0°N TOGA-TAO buoy (thin line) b) Calculated 20°C depth due to basin width changes and normal year" zonal SST difference (solid line) and measured at 110°W, 0°N TOGA-TAO buoy (thin line)

The observed 20°C depth from the TOGA-TAO buoys at 110°W is shown in Figure 5. Using "normal year" climatology from the Hadley Met Office (Rayner et al., 1996) to calculate monthly east west SST differences of the Pacific Ocean (T_w-T_e), and a mean 20°C depth (H) of 140m, the annual cycle of the 20°C depth as calculated from (1) is shown in Figure 4.

The differences in the calculated and observed depth at 110°W show that the Pacific Ocean is stable from July to December as the observed thermocline at 110°W is shallower than that observed (Figure 5). The close correspondence of the observed depth to that calculated from (equation 1) during January to February indicates (Figure 5) that the system is just at equilibrium during this period..

3. Conclusion

Over open ocean it is more likely to have mega WWB and ISO's containing super clusters. It has also been shown that the annual migration of the WPWP causes its centroid to be in a more easterly position. The annual migration of the WPWP, and the narrower width of the Pacific Ocean south of the equator has also results in the system being just at equilibrium during January to July, whereas during July - December the system is very stable.

It is proposed that these observations can explain why seven of the fifteen ENSO warm events during 1951-1994 were initiated between February and May (Trenberth, 1997). When the WPWP is south of the equator it is in more open ocean waters, which favors the formation of WWB. As the WPWP is just at equilibrium when south of the equator, WWB can then initiate advection of the WPWP water toward the central Pacific initiating an ENSO warm event.

Open ocean conditions favoring formation of ISO super clusters has been attributed to differences in perimeter moistening and down draft drying of oceanic deep convection and land based convection (Barr-Kumarakulasinghe, 1998). These differences in perimeter moistening and downdraft drying between oceanic and land convection ultimately arise due to differences in convective intensity (Lucas, et al., 1994b). Hence, it is imperative to understand the causes for the differences in in convective intensity over land and ocean which are still unknown (Lucas, et al., 1994a)

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