Convection and Circulation Anomalies over the Oceanic Warm Pool during 1981-1982

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ABSTRACT

An important issue in understanding the low frequency evolution of the atmospheric circulation and the ocean-atmosphere system is the role of transients during individual events. We examine this question from an observational point-of-view for two different time scales and speculate on the importance of transients from these two different perspectives. Our analysis period covers September 1981 - April 1982 which includes the development phase of the 1982-83 El Nino Southern Oscillation (ENSO) as well as six Madden-Julian (30-60 day) Oscillations (MJO). The latter include a strong event during December 1981 that is studied in detail. The self-similarity of these two time scales (Webster, 1989) is also highlighted.

1. Introduction

Intensive research in the last decade on the composite characteristics of El Nino/Southern Oscillation (ENSO) and the Madden-Julian (30-60 day) Oscillation (MJO) have been followed in recent years by attempts to forecast and understand individual events. A major issue for both oscillations concerns the relative importance of organized transient activity whose structure and evolution resembles aspects of the oscillation's life cycle (Weickmann, 1983; Lau and Chan, 1985; Nakazawa, 1986). For ENSO, the MJO and the annual cycle are the most prominent quasi-periodic and periodic transients. For the MJO, transients of 1-2 days (individual cloud clusters), 4-5 days (easterly waves) and 10-15 days (superclusters) populate the envelop of convective activity as it "moves" east. The role of this transient activity is the subject of numerous observational and modeling studies for both oscillations.

The results to be presented in this paper will focus primarily on the development phase of the 1982-83 ENSO, i.e., northern fall and winter 1981-82. This is well before any coupled instability of the type postulated for example by Philander (1985), van Loon and Shea (1987), Trenberth and Shea (1987), Lau and Shen (1988) is apparent. The SST anomalies are generally small at this time although systematic behavior of ocean and atmosphere anomalies is observed in composite studies. We report on an apparent link between a strong MJO, a change in western Pacific SSTs and the evolving warm event. The same MJO will then be investigated in more detail. The primary focus on this time scale will be on the shift of convection from the eastern Indian Ocean (EIO) to the western Pacific Ocean (WPO) which involves an equatorial transient feature, a re-distribution of low level moisture and possibly a CISK-type instability. We note that for both oscillations, eastward shifts of convection involve transient activity. The eastward shift of convection is linked with SST variability during ENSO and with low level moisture variations during MJO.

2. Composite life cycles

a. The El Nino/Southern Oscillation

The Southern Oscillation involves an ocean-atmosphere interaction having a broad period range from 2-7 years. During the development phase of a warm event (northern summer/fall of year-1; notation follows Rasmusson and Carpenter, 1982), small positive SST anomalies are observed in the Indian Ocean and extreme western Pacific which then shift east to the central Pacific during the northern winter of year 0 (Fu et al. 1986). The movement east has been ascribed to air-sea interaction over the western Pacific (e.g., Lau and Shen, 1988) and in vicinity of the South Pacific Convergence Zone (Van Loon and Shea, 1987). In composites of warm events, the SSTs gradually cool in the Indian Ocean and near Indonesia (Kiladis and Diaz, 1989) during the northern winter of year 0. The mature phase of ENSO is manifested by large SSTA in the central and eastern Pacific that develop rapidly during or after northern spring of year 0. As documented by Barnett (1984), van Loon and Shea (1987) and Kiladis and van Loon (1988), there is a systematic eastward shift of negative sea level pressure anomalies from Australia to the central South Pacific during this time. The largest anomalies in eastern Pacific SSTs (i.e., the El Nino region; see Wallace et al., 1987; Deser and Wallace, 1987) tend to occur in northern spring of year +1.

Many other oceanic and atmospheric precursors are observed prior to the development of a warm or cold event and it is now generally recognized that years preceding warm events tend to have cold event characteristics (and *vice versa*; Meehl, 1987; Ropelewski and Halpert, 1989; Kiladis and van Loon, 1988; Kiladis and Diaz, 1989). This result has been synthesized for the atmosphere by Meehl (1987) who noted a biennial tendency in the intensity of the annual cycle of convection and circulation, i.e., a strong annual cycle in one year reverses to a weak annual cycle in the following year. Hackert and Hastenrath (1986) demonstrate how anomalous air-sea interaction over the Indonesian region can lead to a reversal of sea level pressure (SLP) anomalies at the western pole of the Southern Oscillation Index. For example, given a positive SOI (negative SLP, positive SST anomalies near Indonesia), the implied surface wind anomalies would tend to increase SSTs and keep SLP low during May-October but decrease SSTs and increase pressure during November-April. Anomalies in latent heat flux, ocean stirring and cloud-radiation feedbacks may be involved. Similar positive and negative feedbacks between the atmosphere and ocean anomalies are postulated to take place all along the path followed by the tropical convective maximum (Meehl, 1987).

In this perspective, warm events tend to be extreme examples of weak annual cycles (convection suppressed over Indonesia) while cold events are extreme examples of strong annual cycles (convection enhanced over Indonesia). These results are in agreement with Gutzler and Harrison (1987) who showed that the northern fall (year -1) before a warm event is characterized by enhanced vertical motion over the eastern Indian ocean and Indonesia. The enhanced vertical motion then shifts east to the western Pacific during northern winter. This evolution is precisely that followed by the normal annual cycle and leads to the interpretation of a strong annual cycle before a warm event. The following northern winter is then characterized by weak vertical motion over the region. This alternating signal during adjacent years is also very pronounced in SLP, precipitation and cloudiness (Meehl, 1987; Kiladis and van Loon, 1988) although Trenberth and Shea (1987) show that this "biennial tendency" is not always present in the pre-1950 period.

The intensity of the air-sea interaction postulated by Hackert and Hastenrath (1986) could be one relevant factor for determining the occurrence of a warm event. MJOs represent strong transient perturbations within the annual cycle whose characteristics (e.g., through wind-evaporation feedback; Emanuel, 1987; Neelin et al.,

1987) could be systematically affected by the strong annual cycle base state. These short-period oscillations may contribute (in large part) to local air-sea interaction through wind-stress forcing, radiational effects and changes in surface fluxes.

Alternatively, the MJO has been implicated in triggering ENSO or conditioning the eastern Pacific through remote oceanic responses to wind stress forcing. The actual trigger mechanism is ascribed to short period westerly wind bursts (5-10 day duration) that may be clustered at a certain phase of the oscillation. These wind stress bursts generate downwelling oceanic Kelvin waves that can affect the depth of the thermocline and sea level in the central and eastern tropical Pacific Ocean (Lukas, et al., 1984). Anomalous currents induced by the bursts can also give rise to warmer SSTs via zonal advection (Harrison and Schopf, 1984). The effect that the convectively active and suppressed phases of a strong MJO have on the ocean is poorly known and will be an area of research within TOGA-COARE.

We have emphasized the meteorological viewpoint in the preceding discussion, although other oceanic precursors to warm events besides SSTs are also prominent. Unfortunately, a synthesis of the ocean-atmosphere features has not been attempted. In the western Pacific Ocean, the period before a warm event is usually characterized by positive anomalies in oceanic heat content (high sea level, deep thermocline) whose source is a matter of debate. Downwelling Rossby waves reflecting off the western boundary or net heat inflow from the west are some mechanisms under consideration. Low frequency, quasi-periodic (3-4 year periods) oscillations involving equatorial Rossby and Kelvin modes are also believed important. The strong annual cycle with its embedded MJOs may provide atmospheric perturbations that - in conjunction with an anomalous oceanic state - help shift the warm waters in the western Pacific Ocean eastward.

b. The Madden-Julian Oscillation

The Madden-Julian Oscillation is primarily an atmospheric phenomenon having a broad period range from 30-60 days. During an oscillation, convection intensifies over the Indian Ocean and shifts eastward discontinuously, eventually reaching the central Pacific Ocean. Over the oceanic warm pool, convection "moves" east at an average speed of 4-6 $m.s^{-1}$ and is associated with regional circulation anomalies over southeast China and the western North Pacific (Knutson and Weickmann, 1987). Over the remainder of the globe, a remote dynamical component (e.g., Rossby wave dispersion, equatorial Kelvin wave, etc.) is observed that moves eastward at 10-15 m/s. This component appears to be excited as convection shifts into the western Pacific and while the transition in the regional circulation is underway. Possible transient interaction between the regional and remote circulation anomalies may give rise to the observed wavenumber 1 and 0 spatial structures.

Similar qualitative arguments can be made for the role of transients in MJOs as were made above for MJOs in ENSO. Rather than speculating on intraseasonal transients in ENSO, we now consider 1-10 day transients in the MJO. In ENSO we seek to understand the mechanisms that give rise to oceanic anomalies over the western Pacific and those that shift the anomalies east. In the MJO we seek mechanisms that give rise to convective anomalies over the Indian Ocean and those that shift these anomalies east. In both cases, the eastward shift of oceanic or convective anomalies is preceded by amplification of an atmospheric circulation pattern (Indian Ocean subtropical anticyclones, Pacific Ocean subtropical cyclones) that resembles the annual mean. This pattern may favor anomalous transient activity that eventually helps bring about a reversal (or eastward shift) of the pattern. Viewed from this perspective, the transients serve primarily a timing (and possibly catalytic) role in the evolution of the low frequency modes and thus are important at least for forecasting purposes. We will provide a specific example of these ideas in the next section.

3. Results from 1981-82

a. The developing warm event and the MJO

Figure 1 shows selected 3-month running means of the anomalous 150 mb winds (1979-1987 base period) during the development phase of the 1982-83 warm event. ORL anomalies for the same period are superimposed on each map. During October-November-December 1981 (OND 81, Fig. 1a), twin anticyclones are prominent north and south of Indonesia with easterly anomalies extending into the Indian Ocean. Westerly anomalies cover the remainder of the equatorial belt. The OLR anomalies indicate enhanced equatorial convection from the eastern Indian Ocean to north of New Guinea. This general pattern of equatorially symmetric anomalies (i.e., small meridional components) is also present during NDJ (Fig. 1b) and represents an example of the enhanced convection and circulation that accompany a strong annual cycle. At this time, positive sea surface temperature anomalies between 0.5-1.0° C cover the tropics from the Indian Ocean to 140°E (Arkin et al., 1983) and presumably help force the anomalous convection and circulation.

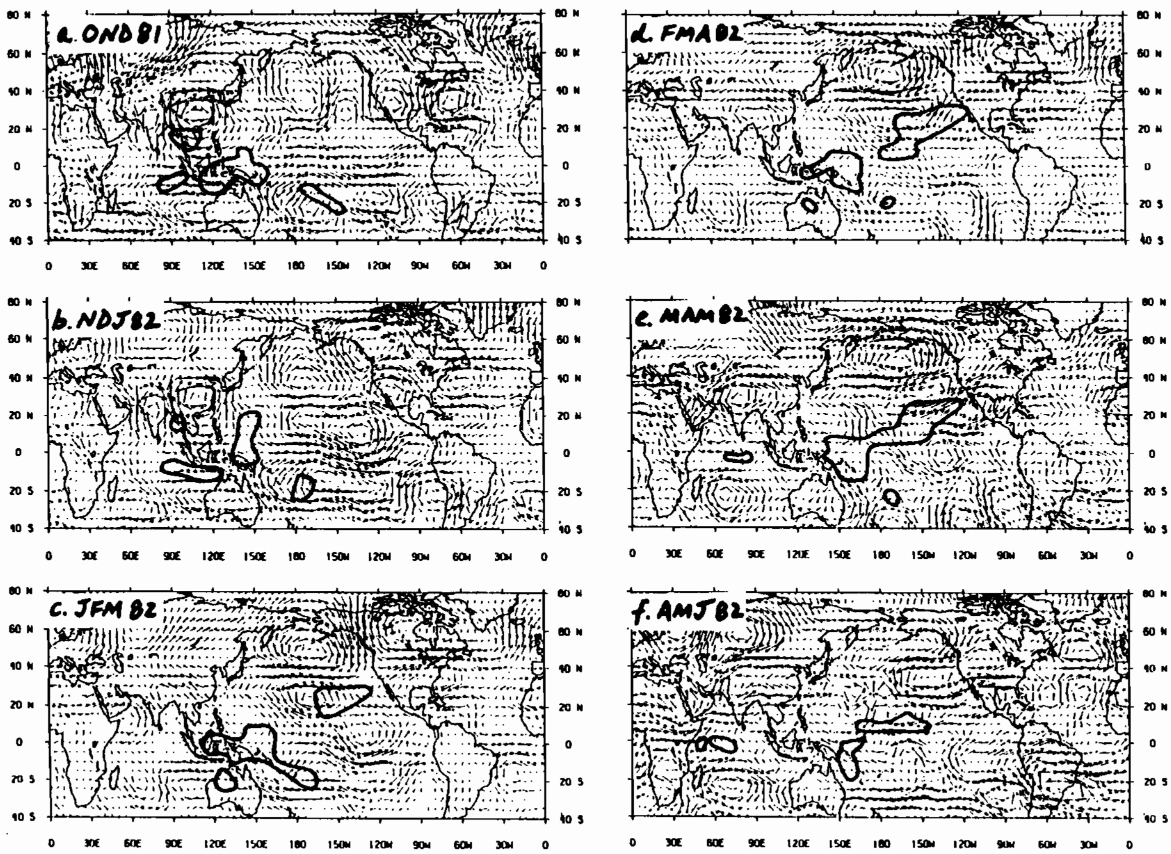

FIG. 1. Wind anomalies at 150 mb relative to 1979-87 base period: a) October-November 1981, b) November-January 1982, c) January-March 1982, d) February-April 1982, e) March-May 1982 and f) April-June 1982. The arrows are scaled by the largest wind magnitude on each map which are : a) $10.5 m.s^{-1}$, b) $11.8 m.s^{-1}$, c) $16.6 m.s^{-1}$, d) $15 m.s^{-1}$, e) $9 m.s^{-1}$ and f) $8 m.s^{-1}$. Corresponding OLR anomalies $< -10 W.m^{-2}$ are superimposed on each map.

By northern winter (DJF 82, Fig. 1c), the subtropical circulation anomalies have developed a distinctly asymmetric or monsoonal structure. Anomalous convection has shifted eastward to the western Pacific Ocean and strong twin cyclones have developed over the central-eastern Pacific indicating an enhanced Walker Circulation. This transition in the circulation represents a typical precursor in the development of a warm event as shown by Gutzler and Harrison (1987) as well as continuation of the strong annual cycle patterns postulated by Meehl (1987). It is accompanied by a cooling of SSTs from the Indian Ocean to Indonesia and an eastward shift of positive SST anomalies (~1°C) to west of the dateline. Intensified convection is located near 150°E and extends southeast in the SPCZ.

Figure 2 shows a detailed picture of the convection and 30-60 day variability during the period September 1981 to April 1982. The interannual transition described above occurs rapidly in association with a strong 30-60 day oscillation during December 1981 (Fig. 2a). This oscillation appears to be embedded within a more slowly evolving zonal circulation cell moving out of the Indian Ocean at about 2 $m.s^{-1}$ (not shown). The cell starts over the western Indian Ocean following the September 1981 MJO (Fig. 2a) and has the November and December 1981 MJOs embedded within it. The convective activity associated with this slower-moving cell is more clearly defined in the southern tropics (5°S-15°S) than in equatorial regions. Several westerly wind bursts were observed along the equator during the December 1981 period of more rapid eastward shift of convection.

Figure 3 shows the monthly mean SSTs before, during and after the strong MJO (November, December 1981 and January 1982 respectively). Prominent features include the retreat of 29°C water from 100°E to 150°E, the strong cooling over the South China Sea and the southward shift of 29°C water from near the equator to 5°S. These are features of the normal annual cycle but monthly and seasonal (e.g., from September-November to December-February; Arkin et al., 1983) SST anomalies show a similar cooling in western and warming in eastern portions of the region in Figure 3. The anomalous SLP fields also undergo a large change from November 1981 to January 1982 as shown by Barnett (1985). We postulate that the strong MJO contributed substantially to the evolving SST and SLP anomaly features.

Returning to Figure 1, the next major transition in the anomalous 150 mb wind begins over the South Pacific Ocean to the northeast of New Zealand during MAM 82 (Fig. 1e) and becomes well-defined in equatorial regions during AMJ 82 (Fig. 1f). The latter includes the first upper level easterly anomalies over the central equatorial Pacific which increase dramatically during MJJ 82 (not shown). By this time, the warm event is well underway as the monthly mean SOI falls abruptly from -0.6 in May 1982 to -2.5 in June 1982.

This transition is again closely linked with a strong 30-60 day oscillation that develops over the Indian Ocean in late May 1982 and propagates into the western Pacific in June 1982. The equatorial OLR anomalies shown in Fig. 4 for September 1981 through September 1983 indicate that this event may have initiated (or provided the perturbation for) an ocean-atmosphere instability that evolved into the slow eastward propagating mode characteristic of the 1982-83 ENSO event.

We have presented qualitative evidence that a strong 30-60 day oscillation, occurring at a transition time in the seasonal cycle, probably contributed to cooling of SSTs over the extreme western Pacific and possibly to warming of SSTs west of the dateline. The phase of oceanic waves both in equatorial and subtropical regions as well as sea level and ocean current anomalies did not display simple patterns during this time although a further comparisons and a synthesis is required. We speculate that the perturbation to the ocean-atmosphere system from the warmest SSTs shifting east provided the conditions for an instability that was realized during northern spring of

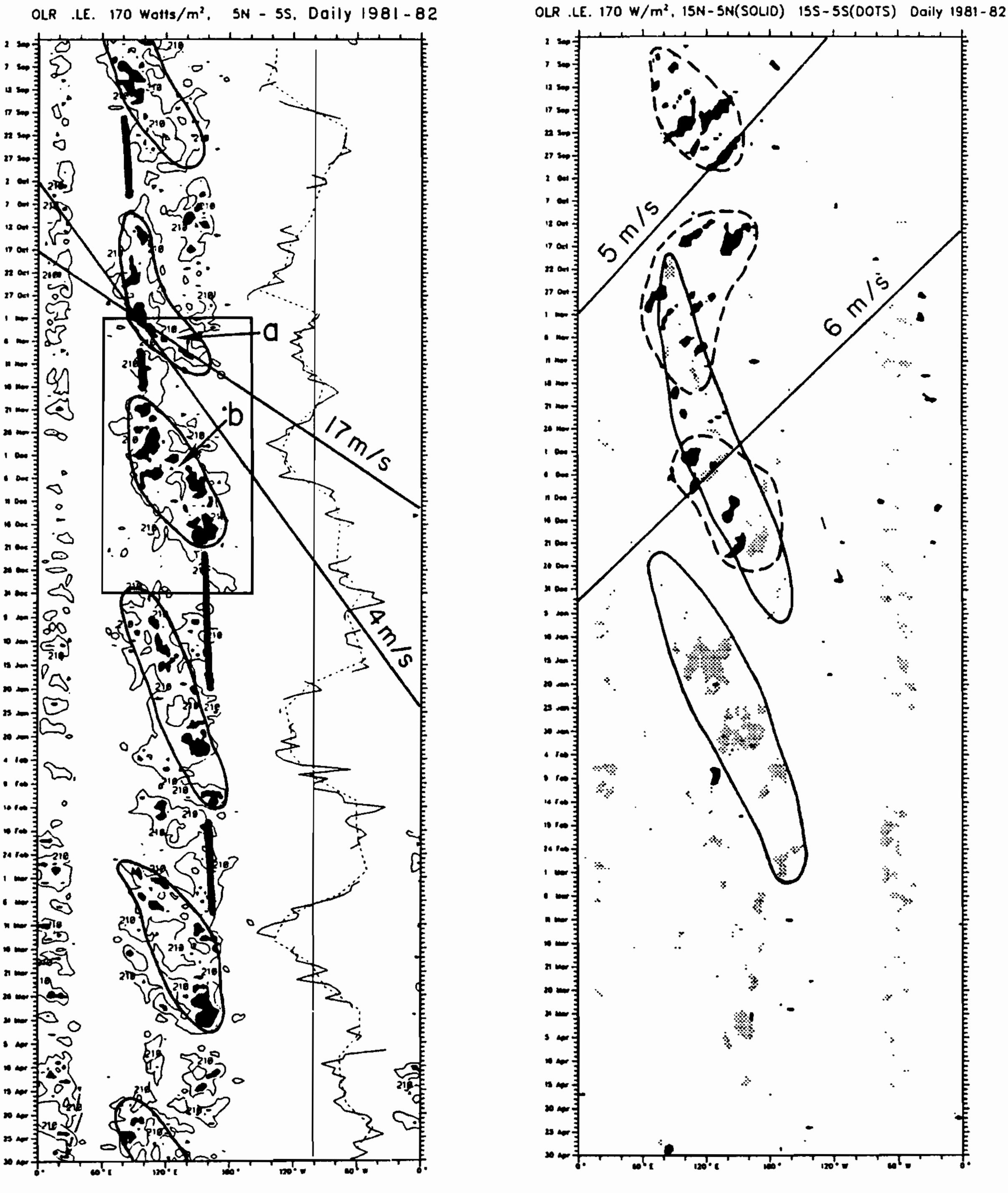

FIG. 2. Hovmollers of daily outgoing longwave radiation (OLR) for 1 September 1981 to 30 April 1982 averaged for a) 5°N-5°S and b) 5°N-15°N (solid) and 5°S-15°S (dots). In a) the 210 W.m^{-2} contour is shown and OLR < 170° W.m^{-2} is darkly shaded. In b) only OLR < 170 W.m^{-2} is shown. Envelopes of low OLR (most intense convection) are highlighted with solid lines. The time series on Fig. 2a represent Northern Hemisphere angular momentum anomalies for both daily and pentad averages. The sloping lines represent the speed of movement of individual OLR elements or of the envelop of OLR activity. The rectangle shows the region that will be studied in detail. The heavy solid line segments highlight the shift east of the most intense convection from the Indian ocean to the western Pacific Ocean. (From Weickmann et al., 1989).

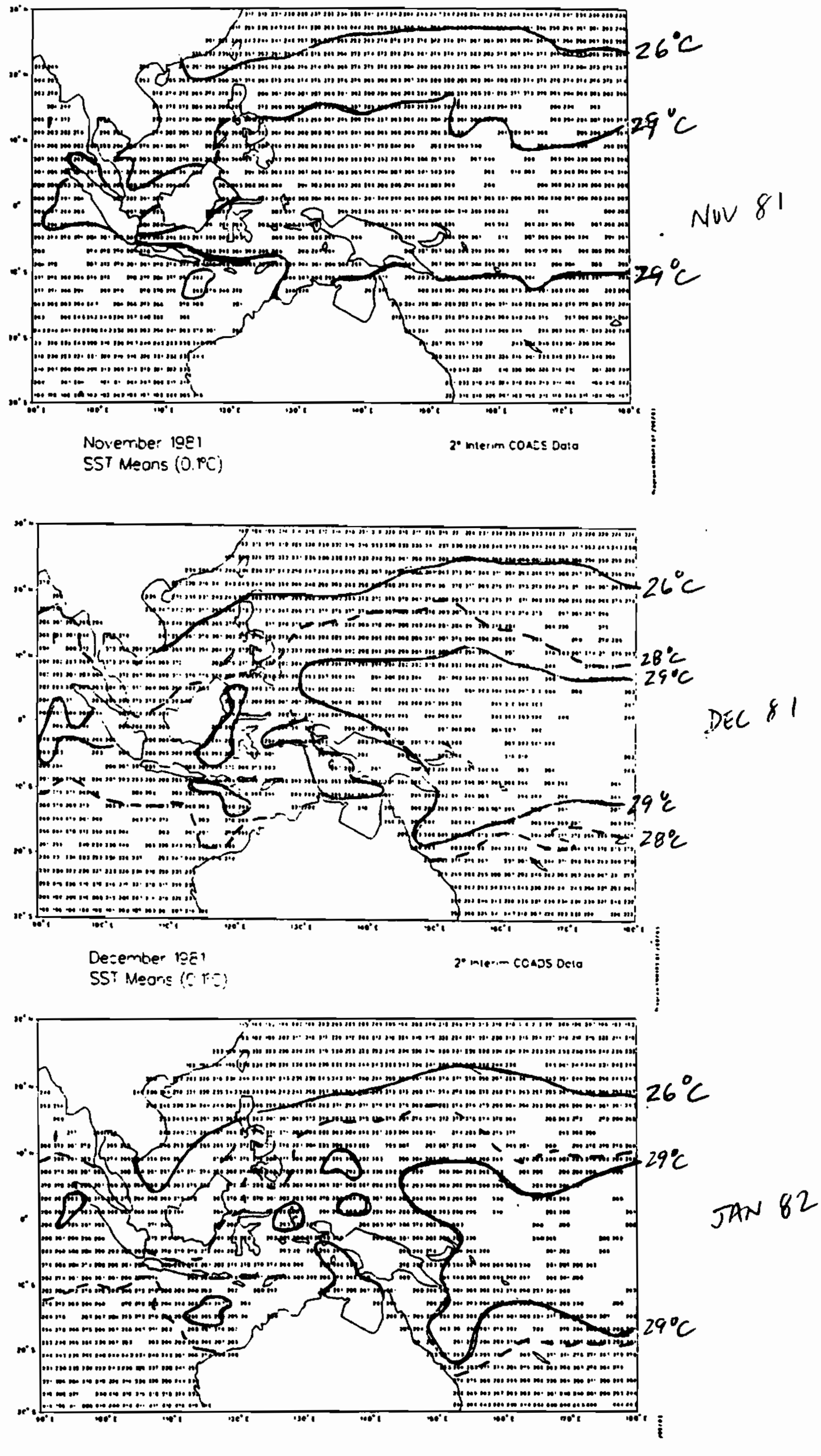

FIG. 3. Sea surface temperature in 2° squares from COADS for November 1981, December 1981 and January 1982. Selected contours have been drawn at 29°C, 28°C and 26°C.

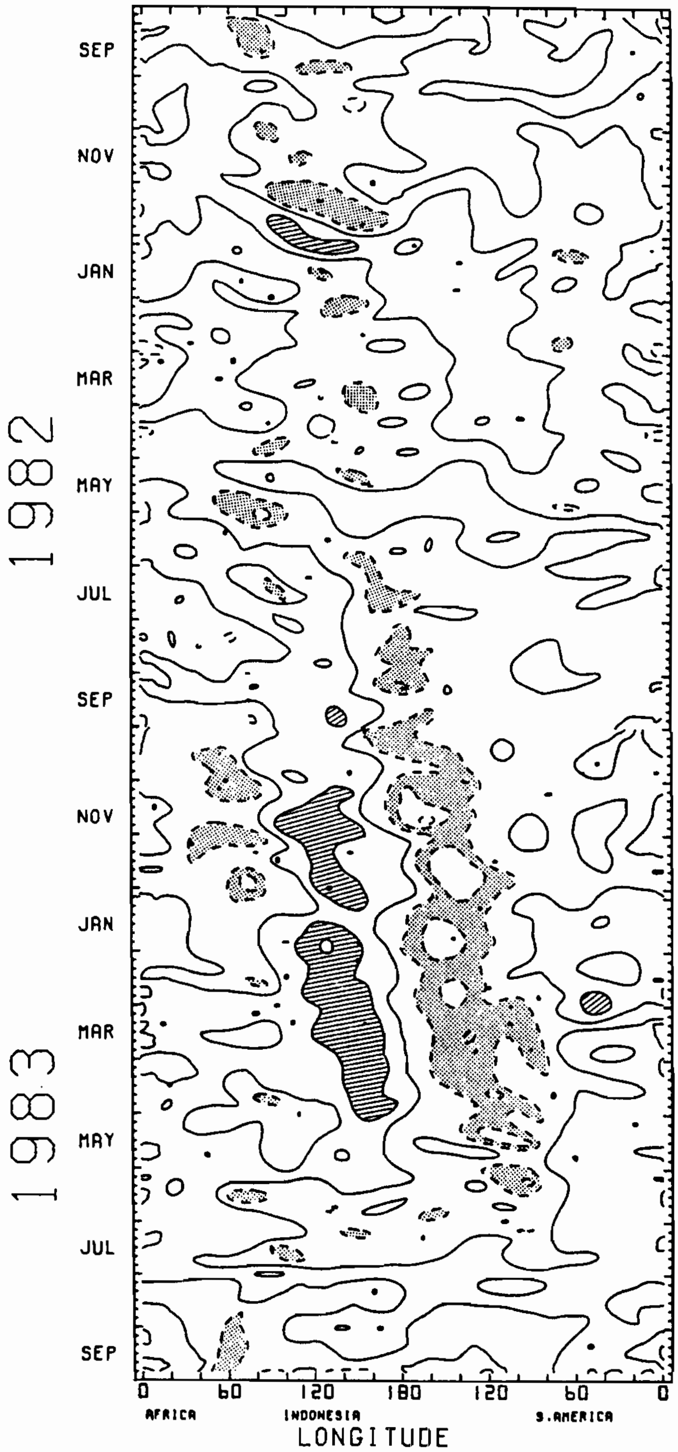

FIG. 4. Pentad OLR anomalies averaged between 10°N- 10°S for September 1981 to September 1983. Negative (positive) anomalies between 20 and 40 W.m^{-2} are stippled (hatched).

1982 and resulted in the 1982-83 warm event (Lau and Shen, 1988). Such an SST perturbation (i.e., cooling the western edge of the warm pool and warming the eastern edge) may lead to more direct coupling between deep convection, zonal surface wind and SSTs over the central Pacific as suggested by Gutzler and Wood (1989).

b. The December 1981 Madden-Julian Oscillation

In the previous section, one transition in the chain of events leading to the 1982-1983 warm event and the possible role of a strong MJO in the evolution of ENSO-related SST anomalies was described. In this section, we show that a much higher frequency transient may have played an analogous role in a chain of events normally observed during a strong MJO; namely, the shift of convection from the EIO to the WPO. Rather than influencing the pattern of SSTs as with the MJO in ENSO, the transients within the MJO influence the pattern of low level moisture. In both cases perturbations to the pattern of convection result.

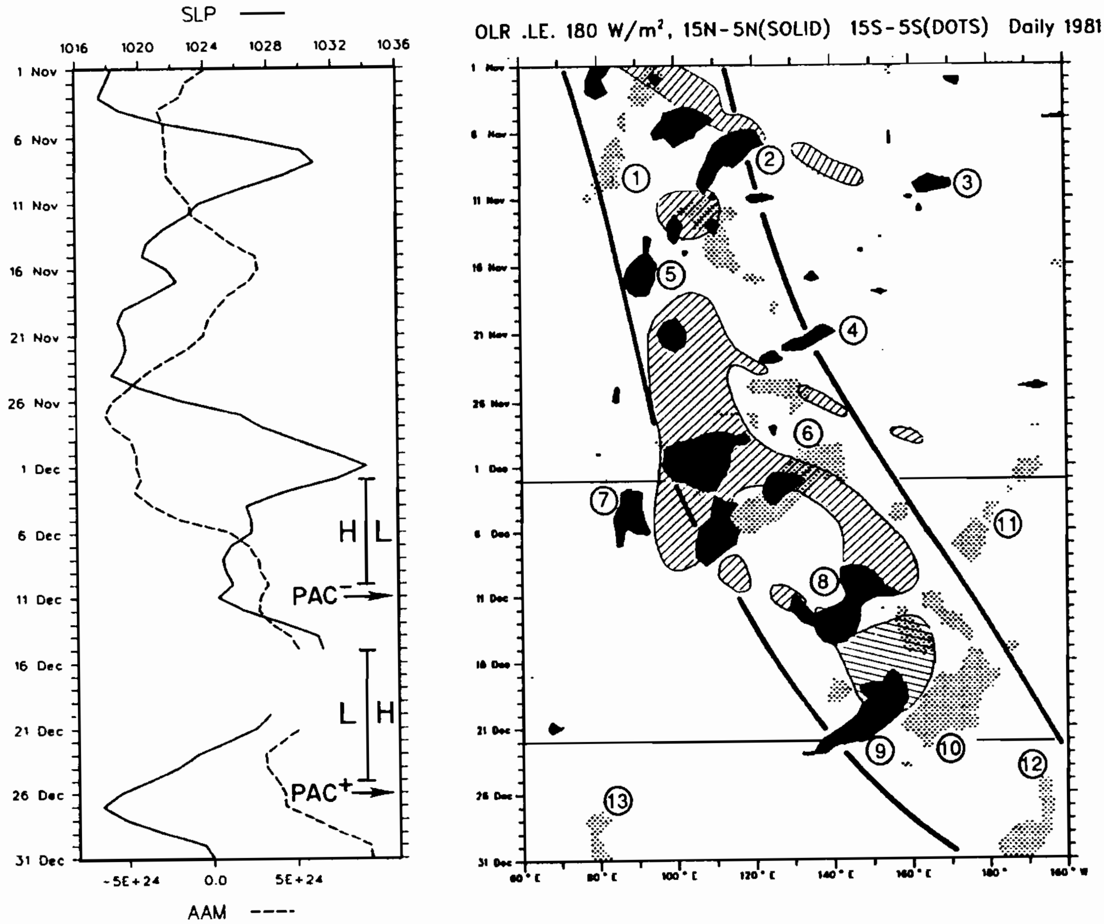

FIG. 5. a) an enlargement of Fig. 2b with the most intense convection (OLR < 170 W.m^{-2}) from Fig. 2a schematically superimposed (hatched areas). OLR < 180 W.m^{-2} is shown in the northern 15°N-5°N, solid) and southern (5°S-15°S) tropics. The circled numbers refer to tropical storms and other synoptic features. See text. b) sea level pressure over southeast China (25-35°N, 100-120°E; solid line, top axis) and Northern Hemisphere atmospheric angular momentum anomalies (dashed line, bottom axis). The time series have been smoothed with a 3-day running mean. The phase and duration of the regional circulation anomalies are shown by H/L and vertical lines, respectively. PAC$^-$ and PAC$^+$ refer to the onset of persistent extratropical circulation anomalies over the North Pacific.

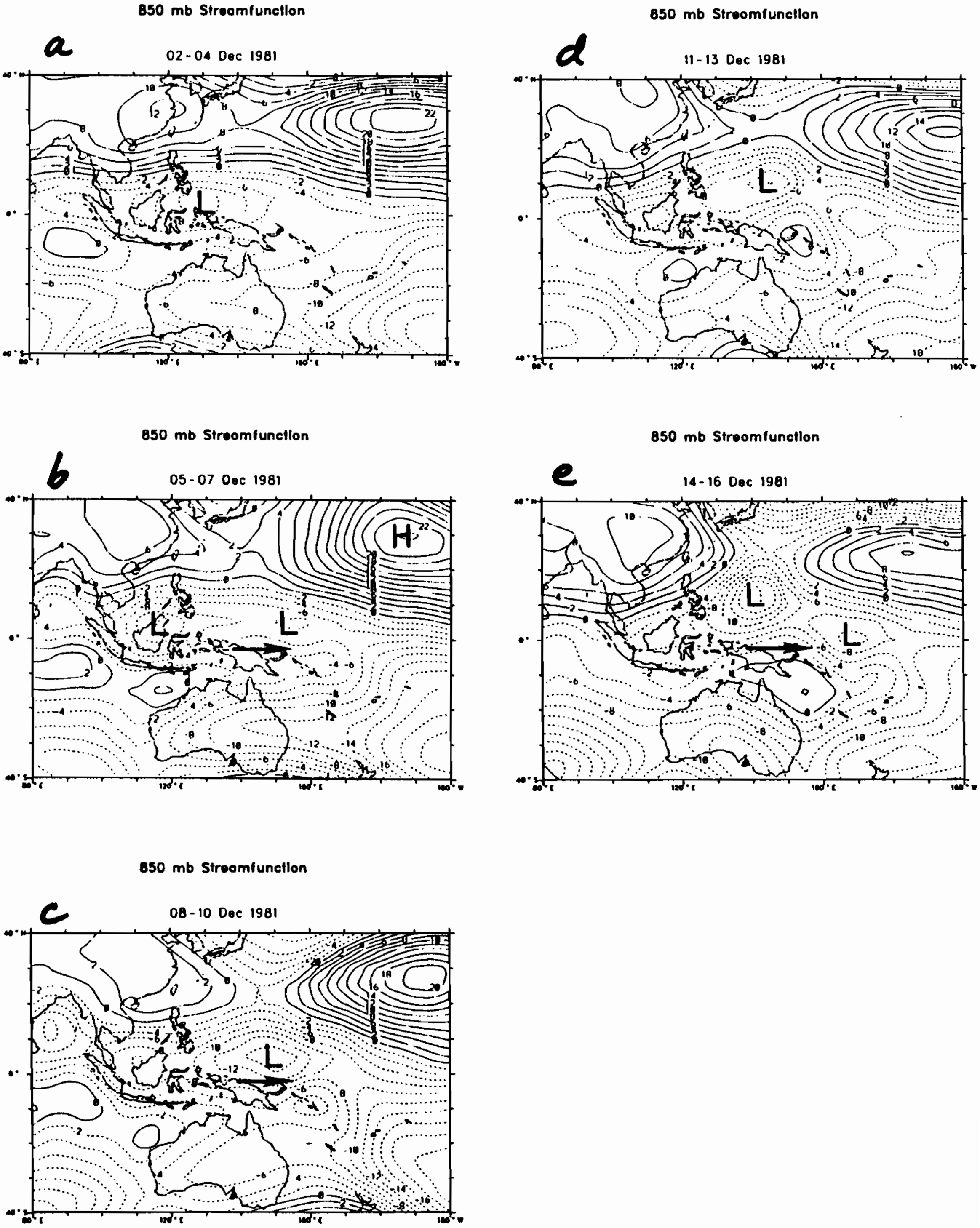

FIG. 6. Total streamfunction at 850 mb for five 3-day averages from 2-4 December (a) through 14-16 December 1981 (e). The contour interval is $2.0 \times 10^5 m^2.s^{-1}$ and negative contours are dashed. Hs and Ls highlight anticyclonic and cyclonis circulation features respectively. The arrows represent the location of westerly wind bursts based on the definition used by Keen (1982).

Figure 5a shows an enlargement of the Hovmoller shown in Figure 2b with the Figure 2a Hovmoller schematically superimposed. Although the picture is complex, the gross features of the combined Hovmoller show quasi-stationary convection near 100°E before early December 1981, a rapid shift east to 150°E during mid-December 1981 and then suppressed convection over the warm pool region after 22 December 1981. The most prominent transients during the period display eastward phase propagation in equatorial regions (hatched areas) and westward phase propagation in off-equatorial regions (dotted and solid areas). A large portion of the off-equatorial convective activity can be attributed to tropical storms (the circled numbers on Fig. 5a).

Important events in the general circulation of the region are shown in Figure 5b (see Weickmann et al., 1989 for a detailed discussion); the time series represent Northern Hemisphere atmospheric angular momentum and southeast China sea level pressure. An outstanding feature of Figure 4 is the link between the strong cold surge that peaks on 1 December 1981, the convective increase in the northern tropics near 105°E (solid areas) and the subsequent intensification of the regional subtropical circulation over southeast China and the western North Pacific. An eastward moving equatorial convective mode (hatched area connecting EIO and WPO convection from 1-6 december 1981) appears to emanate from the tropical region south of the cold surge following the convective increase over the northern tropics (Fig. 5). Low level westerly winds accompany the mode as it moves to the east.

The synoptic evolution of the 850 mb streamfunction for five 3-day averages following the cold surge and convective flareup near 100°E is shown in Figure 6. The downstream regional response to the convection near 100°E involves an intensification and amplification of the 850 mb anticyclone at 30°N, 175°W (Figs. 6 a,b). This development may be linked with an equivalent barotropic Rossby wavetrain that either emanates from the subtropical North Pacific or develops through barotropic interactions over the mid-latitude North Pacific (Weickmann, et al., 1989). In either case, the 850 mb anticyclone is accompanied by a surge in equatorial trades during an 8-day period following the 100°E convective flareup.

Over the western Pacific, an eastward surge of equatorial westerlies occurs during the same period as the trade surge (Fig. 6b; also see OLR signature on Fig. 5a). These westerlies, in conjunction with the surging trades produce strong low level moisture convergence and provide favorable conditions for intensifing convection near 150-160°E (see Weickmann, et al., for more details). The westerly winds intensify as convection increases and westerly wind bursts are observed on 5-10 and 14-18 December 1981. An interplay between the bursts and tropical cyclone formation is also evident in Figures 6 d,e.

4. Summary

We have presented synoptic evidence that the convectively active phase of a strong Madden-Julian (30-60 day) Oscillation is linked with a pattern of cooling/warming SSTs similar to that observed during the development phase of a warm event. The phasing of the various components (winds, OLR, SST) resembles Lau and Shen's advective mode although zonal SST gradients are small from the eastern Indian Ocean to the western Pacific Ocean. Similarly, for the Madden-Julian Oscillation an equatorial transient provides partial forcing for a low level drying/moistening pattern that precedes the shift of convection from the eastern Indian to the western Pacific Ocean. In both cases, these interactions occur within an anomalous basic state (strong annual cycle for ENSO, regional circulation enhancement for the MJO) that subsequently shifts east or reverses when convection shifts east. Additional analyses of individual events are required to substantiate these results.

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