Variability in Latent Heat Flux over the Tropical Pacific in Association with Recent Two ENSO Events

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ABSTRACT

This paper analyzed the variations of latent heat flux (LHF) over the tropical Pacific in the period 1978–1988 by using COADS (Comprehensive Ocean and Atmospheric Data Set). It has been founded that the interannual variability of LHF exhibits strong ENSO signal, with the significant increasing LHF during the recent two warm events, i.e., 1982 / 83 and 1986 / 87 and decreasing LHF in the cold episodes. However the longitudinal distribution of the LHF departures varies from event to event. In the eastern Pacific, the specific humidity difference at air–sea interface ($q_s - q_a$) makes a dominant contribution to the interannual variability of LHF ($r = 0.73$), while in the western Pacific the surface wind speed, W and the $q_s - q_a$ make nearly equal contribution to that of LHF.

I. INTRODUCTION

Among the components of air–sea energy fluxes, the latent heat carried by evaporation is the most important and variable one on monthly time scale or longer over large scale ocean domains and therefore plays a crucial role in the climate variations.

The earlier hypothesis (Bjerknes, 1966 and 1969) on the mechanism of anomalous warming tropical ocean affecting the global atmospheric circulation proposed that the enhancement of water vapour transfer from warming sea surface into the atmosphere in conjunction with the development of surface wind field during El Nino period would produce the enhancement of tropical convection and the release of latent heat in the atmosphere which serves as the forcing function for the atmospheric circulation anomalies. By using the observed ship data from 1957 to 1976, Weare (1983) has reported an increasing latent heat flux up to about 40 W / m^2 over much of the eastern Pacific basin. He also pointed out that the increase of latent heat flux tends to follow those for SST by up to several months, the shortest lags being for regions near the equator. There are numbers of papers relating the heat fluxes to the variations of sea surface temperature. For instance, Reed (1985) and Stevenson and Niiler (1983) found high correlation between the surface heat fluxes and the sea surface temperature in the tropical Pacific except in the areas off the Peruvian coast and along the equator.

However, Ramage and Hori (1981) found that the variation of surface flux does not coincide with the maximum sea surface temperature anomalies during the periods preceding and following the 1972–73 ENSO. Khalsa (1983) also found that neither the rainfall anomalies nor the heat fluxes anomalies correlated with sea surface temperature anomalies during the 1972–73 ENSO event.

Liu (1988) recently studied the moisture and latent heat flux variabilities in the tropical Pacific derived from satellite data and pointed out the decrease in the evaporative cooling during the 1982–83 ENSO event in the eastern equatorial Pacific despite anomalous high sea surface temperature over there. While both Liu and Meyers et al. (1986) suggested that the cooling of the western tropical Pacific during the 1982–83 ENSO is due mainly to the enhanced evaporation by the anomalous wind. Liu also pointed out that his result derived from satellite data does not fit the GCM result (Simonot and Le Treut, 1987). Julian and Chervin (1978) derived the increase of surface latent heat flux over the eastern tropical Pacific during the ENSO period from GCM parameterization.

The controversy among the previous results requires further studies on this subject. Moreover, in the 1980's , there was a strongest ENSO event, the 1982–83 event, followed by another rather strong event of 1986–87 within same decade. So far, we still don't know why the event of 1982–83 was so strong and why it was followed by another rather strong event (1986–87) immediately without intermission?

The aim of this paper is to make a more completed study on the variability of latent heat flux (LHF) over the tropical Pacific in association with recent two ENSO events and make a comparison with the results from the satellite data for the 1982–83 event and with that of other ENSO events. Thereafter, a further understanding of ENSO development is anticipated.

The data and computational scheme used to calculate the latent heat flux over the ocean surface are given in Section 2. Following a general description of recent two ENSO events in the 1980's in Section 3, the time–longitude variabilities of latent heat flux over the tropical Pacific during the period of 1978–1988 and their relationship with the meteorological variables have been analyzed in Section 4. The time evolutions of the flux and the related variables in the eastern and western tropical Pacific, have been further analyzed respectively to understand the major factors for flux changes during the development of ENSO in Section 5. The relationship between the outgoing longwave radiation and the latent heat flux over the tropical Pacific is examined briefly in Section 6. A conclusion makes up last section.

II. DATA AND COMPUTATIONAL SCHEME

The COADS (Comprehensive Ocean–Atmospheric Data Set) for the period 1978–1989 is used in this study. The data for the 1980's are an interim version of COADS which has undergone a similar processing as the previous version for the period through 1979 (see Woodruff et al.,1987).

The bulk formula for the monthly mean air–sea latent heat flux Q_e is given by

$$Q_e = \rho L C_e (q_s - q_a) W \ .$$

Here q_a and q_s are the specific humidities of the air and its saturation value at sea surface temperature, respectively; ρ and L are the air density and latent heat of evaporation respectively which are taken as constants, $\rho = 1.2\ \mathrm{kg/m^3}$ and $l = 2.5 \times 10^6\ \mathrm{J/kg}$. C_e is the bulk transfer coefficient for water vapor.

For a given month and given year, the monthly mean latent heat flux Q_e is calculated by using the existing monthly file of $(q_s - q_a)W$ which is calculated from each individual ship measurement, not from the mean fields. While the C_e in this paper is parameterized as a function of monthly mean wind speed W and the sea–air temperature difference, $T_s - T_a$ (a stability parameter), rather than applied to each individual measurement. The actual values of C_e are taken from Bunker's table (1976).

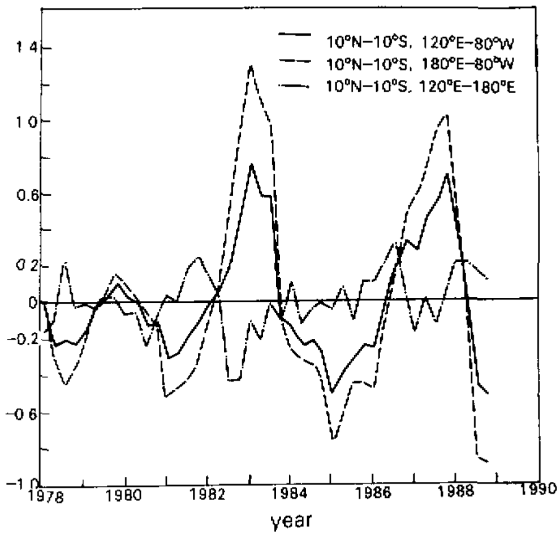

Fig.1. Time series of sea surface temperature departures of the tropical Pacific (10°N–10°S) in 1978–1988 (a) 120°E–80°W; (b) 180°E–80°W; (c) 120°E–180°.

III. GENERAL FEATURES OF TWO ENSO EVENTS DURING 1978–1988

It is well known that the 1982–83 warm event is the strongest one in this century,which is shown clearly in the curves of Fig.1, interannual variation of the area–averaged SST departures in whole tropical Pacific (10°N–10°S, 120°E–80°W) in 1978–1988. What seems to be more interesting is that the 1986–87 warm event is also rather strong with the persistent warming period even longer than that of 1982–83 event as marked by heavy black lines. The weak event of 1979 is also shown in this figure. Curves *b* and *c* in this Figure are the SST departures for eastern and western tropical Pacific respectively. The warming during 1982–83 is significantly stronger than that during 1986–87 in the eastern Pacific, while the cooling in the west during 1982–83 is stronger than that in 1986–87.

It should be noted that all three curves show an increasing trend of about 0.2°C warming during this period.

IV. TIME–LONGITUDE VARIABILITY OF LHF AND RELATED VARIABLES OVER THE TROPICAL PACIFIC

The climatology of LHF distribution over the tropical Pacific is characterized by a maximum near the dateline and a decreasing trend towards both east and west, no significant change along the north–south direction within the tropical zone (Fig.2). Therefore the time–longitude variability is analyzed by using the Hovmoller diagram of seasonal mean departure of LHF over the tropical Pacific (120°E–80°W, 10°N–10°S) (Fig.3a). Here the departures are calculated from the mean of the period 1978–1989.

Note the strong ENSO signal is shown in the interannual variability of the LHF in the tropical Pacific:

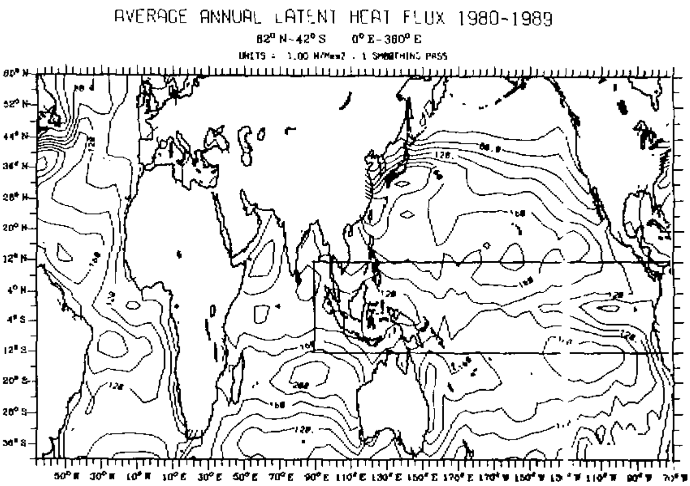

Fig.2. Map of average annual latent heat flux for 1978–1988. (W / m^2).

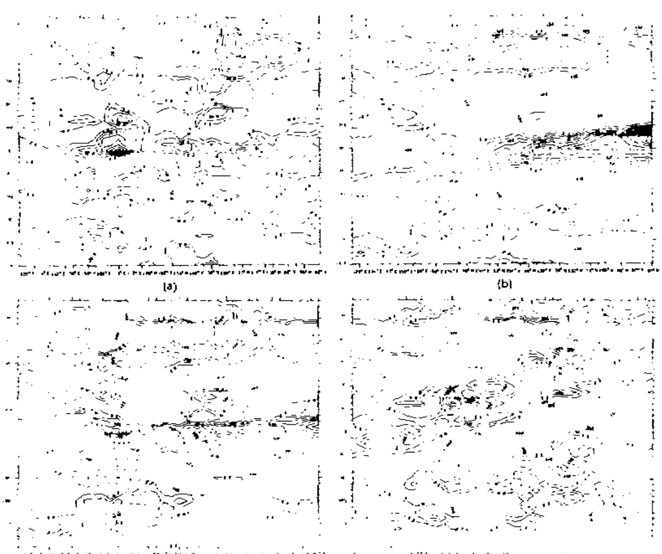

Fig.3. A time–longitude variation of seasonal mean LHF departures (W / m^2) (a); sea surface temperature (℃) (b); specific humidity difference at air–sea interface ($q_s - q_a$) (g / kg) (c); and scale wind, W(m / s) (d) over the tropical Pacific (reference to 1978–1988).

(1) There is an enhancement trend of the LHF averaged over the whole tropical Pacific during the warm episode of the events, such as the 1982–83 and 1986–87 and even in the weak one of 1979. While the LHF decreased in the cold episode of the events, especially in the cold ENSO events, such as in 1984.

(2) The maximum LHF anomalies occurred in different areas in different events. For instance, the 1979 weak event had its positive maximum to the west of dateline. In the strong event of 1982–83, the LHF enhanced significantly over the whole Pacific having the maximum near the dateline. While the event of 1986–87, another rather strong event, was characterized by a persistent positive anomaly in far eastern Pacific, and a negative anomaly near dateline. Thus, the longitudinal distribution of LHF anomalies during the ENSO events from this study is quite different from Liu's model in which he used the satellite data to derive the latent heat flux for the event of 1982–83 (Liu,1988). The composite modes of LHF variation related to the development presented by Weare (1983) have, of course, taken the differences off among the different events. A GCM simulation experiment shows that the enhancement of latent heat flux occurs only in the eastern Pacific during El Nino period (Julian and Chervin, 1978), because only the eastern Pacific anomalies are included.

In looking at the relationship between the change of LHF and that of sea surface temperature, Fig.3b shows a Hovmoller diagram of SST departures as a comparison of Fig.3a. Note the maximum of positive departure of LHF did not appear in the maximum of SST warming, although the large portion of positive departure of LHF coincides with that of positive SST departure.

It is more obviously that the variation of specific humidity difference at the air–sea interface makes dominant contribution to the time–longitude variability of LHF over the tropical Pacific (see Fig.3c). While the significant enhancement of the LHF during the 1982–83 can also be attributed to the enhancement of surface wind speed (see Fig.3d).

Fig.3d shows another spectacular feature, a very low frequency eastward propagation, taking about six years going through from western to eastern Pacific. What is the dynamics of this very low frequency motion? what is the role of this type of motion in the interannual variability of tropical atmospheric circulation or in even longer scale? These are the fundamental questions need to be addressed in the further studies.

V. COMPARISON OF THE TIME EVOLUTION OF LHF IN THE EASTERN TROPICAL PACIFIC WITH THAT IN THE WEST

Since the atmospheric and the oceanic conditions are shown significant difference in the western tropical Pacific with that in the east, the variation of the LHF and the factors which affect the LHF changes are expected to be different.

Fig. 4a, the time series of seasonal mean departures of LHF in the eastern Pacific during the period of 1978–1988 and its quadratic fitting curve, is characterized by two main features:

(a) an increasing trend of about 15 W/m^2 during 11–year period.

(b) the significant enhancement of LHF during recent two ENSO events (1982–83 and 1986–87) and decreasing in the cold episodes, especially in 1984.

While in the western Pacific (Fig.4b), there is no increasing trend in the LHF changes, but only an non–periodical oscillation. The LHF reached its maximum in early 1983 which may be related to the strong event of 1982–83. Although the averaged LHF in the warm episodes, such as in 1979, 1983, 1986 and 1987 are above the mean of this period, there seems to be other types of oscillation superimposed on the Southern Oscillation. For instance, The LHF over there was enhanced during the 1981 and even in the cold episode of 1984.

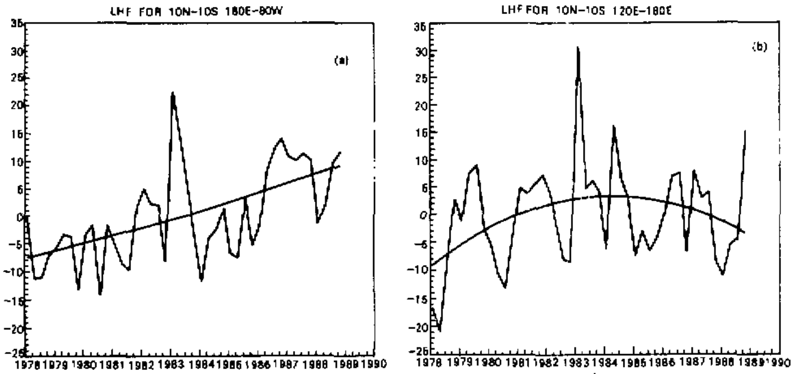

Fig.4. Time series of seasonal mean departures of LHF in the eastern tropical Pacifiic (10°N–10°S, 180°E–80°W) (a) and in the western tropical Pacific (10°N–10°S, 120°E–180°E) (b) in 1978–1988.

In order to assess the control factors of the LHF variation, the time series and their quadratic fitting curves of $q_s - q_a$ and W over the western and eastern tropical Pacific are compared with the variations of LHF over these two regions, the control factor of LHF variability in the eastern Pacific seems to be different from that in the west. In the eastern tropical Pacific, the specific humidity difference makes a dominant contribution to the interannual variability of LHF, while the over all increasing trend seems to be determined by both $q_s - q_a$ and W. As shown in Table 1, the correlation coefficient between LHF and $q_s - q_a$ in the eastern tropical Pacific reaches 0.73, much higher than that with W (0.17). In the western Pacific, however, the $q_s - q_a$ and W seem to have almost equal contribution to the interannual variability of LHF. The correlation coefficient between LHF and W is a little higher than that with $q_s - q_a$ (0.55 versus 0.53).

Table 1. Correlation Coefficients between LHF and W, $q_s - q_a$ over the Tropical Pacific

	$q_s - q_a$	W
LHF (East)	0.73	0.17
LHF (West)	0.53	0.55

VI. RELATIONSHIP BETWEEN LHF DEPARTURES AND OLR DEPARTURES

As mentioned before, the enhancement of tropical convection during the El Nino event is supposed to be related to the enhancement of water vapour transfer from warming sea surface into the atmosphere (Bjerknes, 1969). With the existed OLR (outgoing longwave radiation) data for period 1979–1988, here the relationship between the latent heat flux and the tropical convection on seasonal scale is analyzed.

Fig.5 is the Hovmoller diagram of seasonal mean OLR departures from DJF 1979 to JJA 1988 over the tropical Pacific, which is calculated from the 5–day mean data. The enhancement of tropical convection during two recent ENSO events, i.e., 1982 / 83 and 1986 / 87, was shown obviously on the seasonal scale, although the maximum enhanced OLR

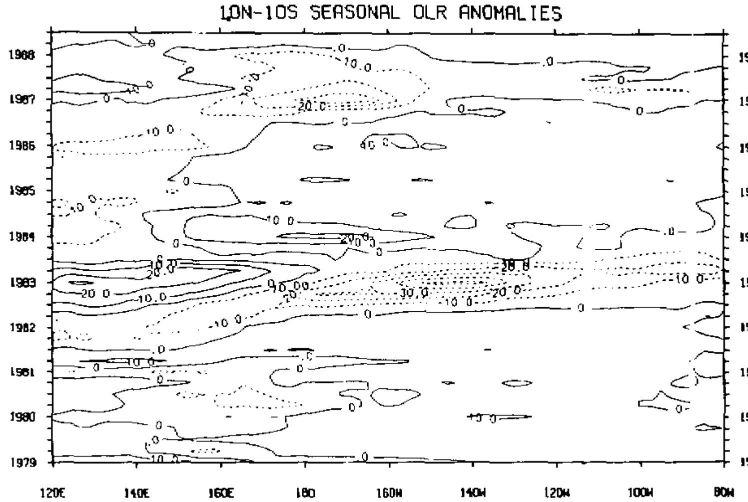

Fig.5. Time–longitude variation of outgoing longwave radiation (OLR) over the tropical Pacific (W / m^2), 1979–1988.

area was located in different longitude. The OLR departure pattern during 1982 / 83 seems to match with that of LHF (Fig.3a), the enhancement of tropical convection over most of the tropical Pacific occurred over the area where the LHF was enhanced, but the centers of their maximum do not coincide each other. However, there is no clear relationship between OLR and LHF in the 1986 / 87 event. By a comparison with sea surface temperature departures (Fig.3b), the OLR departures seem to relate more closely with that of SST than that of LHF.

VII. CONCLUSIONS

In summarizing the previous results, we conclude that:

The ENSO signal shows strongly in the interannual variability of latent heat flux over the tropical Pacific which is characterized by the increasing LHF during the warm episode of the event and the decreasing LHF during the cold episode. However, the longitudinal distribution of LHF departures varies from event to event. On the average, the variation of specific humidity difference at air–sea interface makes a dominant contribution to that of LHF in the eastern Pacific, while the variation of surface wind speed makes nearly equal contribution to that of LHF in comparison with that of the humidity difference in the western Pacific.

There seems to be no significant relationship between the LHF and OLR in their interannual variability, although both of them were enhanced during the warm episode. The longitudinal locations of their maximum anomalies do not coincide each other.

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