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PROCEEDINGS

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On Warm Rossby Waves and their Relations to ENSO Events

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ABSTRACT

The hypothesis suggested by several simple air-sea coupled models is examined with an ocean numerical model driven by FSU wind stress for the period from 1963 to 1987. The examined hypothesis is that warm Rossby waves generated by stronger trades associating with cold events following warm episodes are responsible for triggering the next warm events. As results, followings are found.

1) Warm Rossby waves are always found approaching the western boundary of the tropical Pacific in the preceding winters of the warm events.
2) However, some winters are not followed by warm episodes even though warm Rossby waves are found near the western boundary.
3) The warm Rossby waves are mostly generated in the central and western tropical Pacific in the preceding years and no clear relations have been found between the previous warm events.

1. Introduction

Is ENSO cyclic or random ? This is the most fundamental question about ENSO. If ENSO is cyclic, the previous warm event is the causes of the next cold event which in turn gives rise to the next warm event. On the other hand, if ENSO is essentially random, the trigger of an event has no relation to the previous events.

Recently, several simple atmosphere-ocean coupled models succeeded to reproduce ENSO-like vacillations (Cane and Zebiak, 1985; Schopf and Suarez, 1987; Xie, 1988). One notable common feature of their results is that warm events are triggered by warm Kelvin waves which are generated by reflection of warm Rossby waves at the western boundary. The warm Rossby waves are forced by stronger than usual Trades in the cold events following the previous warm events. So, these results suggest ENSO is cyclic.

It has been already pointed out by several authors that the warm water pile-ups in the western tropical Pacific are nearly always found in the previous northern winter of the beginning of warm events (White et al., 1985; Matsumoto and Takeuchi, 1988). However, relations between these pile-ups and the previous events are still not clear. Observational data are not enough to examine them.

Therefore, in the present study, a numerical model is used to examine the formation process of the warm water pile-ups in the western tropical Pacific, for the period from 1969 to 1984.

2. MODEL

The model simulates the tropical Pacific Ocean between 30°S and 30°N. The model ocean has realistic coastline at western and eastern sides of the model, but no bottom topography. The numerical procedure for the integration is similar to that described in Bryan (1969). The model specifications are:

Coordinate :	Cartesian delta-plane
Horizontal resolution :	2/3° in both direction
Vertical resolution :	15 levels, 25 m in upper 250 m
Horizontal mixing :	Bi-harmonic
Vertical mixing :	Richardson number dependent mixing coefficient, similar to Pacanowski and Philander (1981)
Salinity :	Not included
Sea surface heat flux :	Haney (1971)'s type
Wind stress :	FSU (Goldenberg and O'Brien 1981)

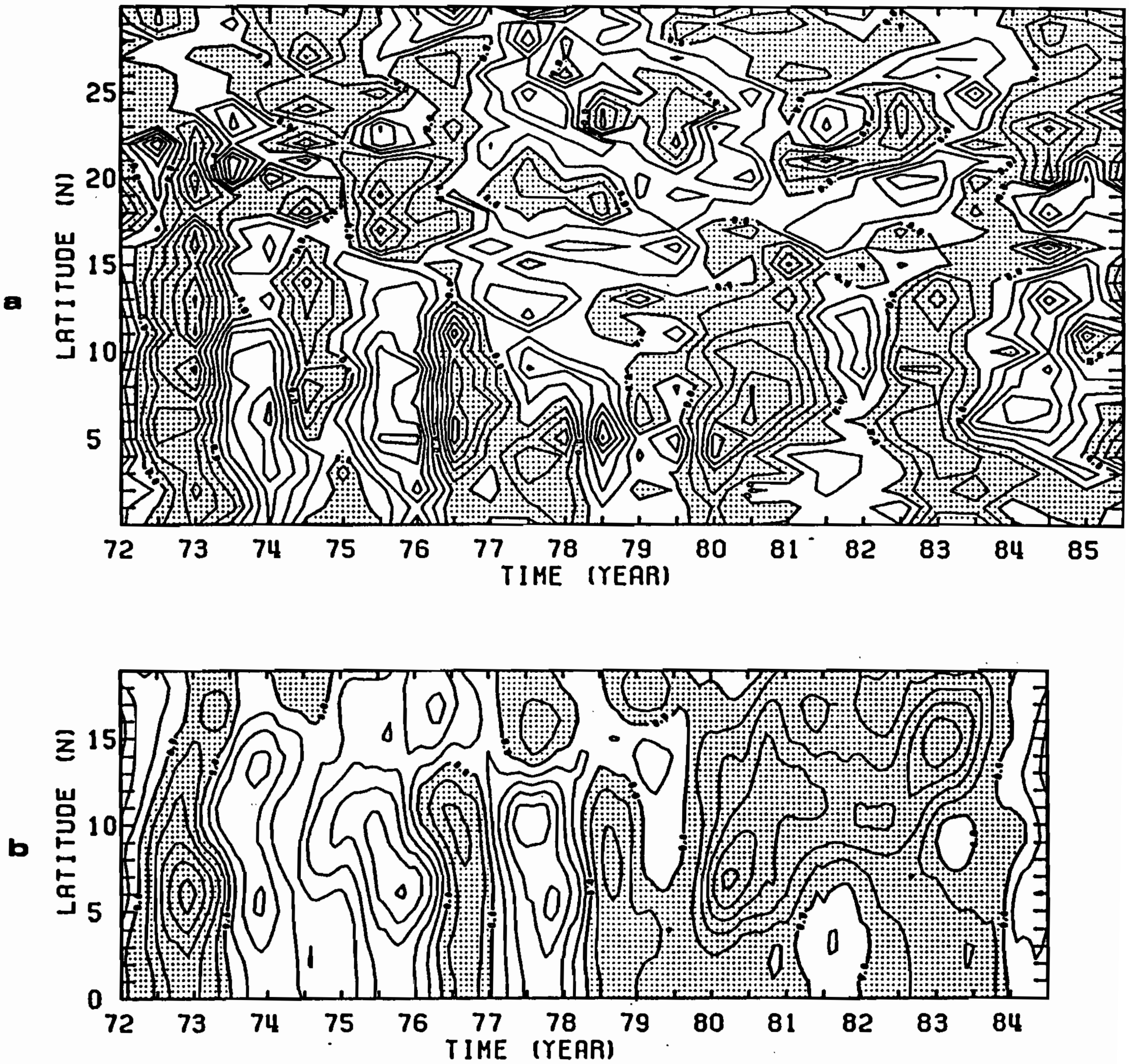

FIG.1. Surface dynamic height anomaly (re. 400db) along 137°E, as derived from (a) observed data taken by Japan Meteorological Agency, and (b) the model.

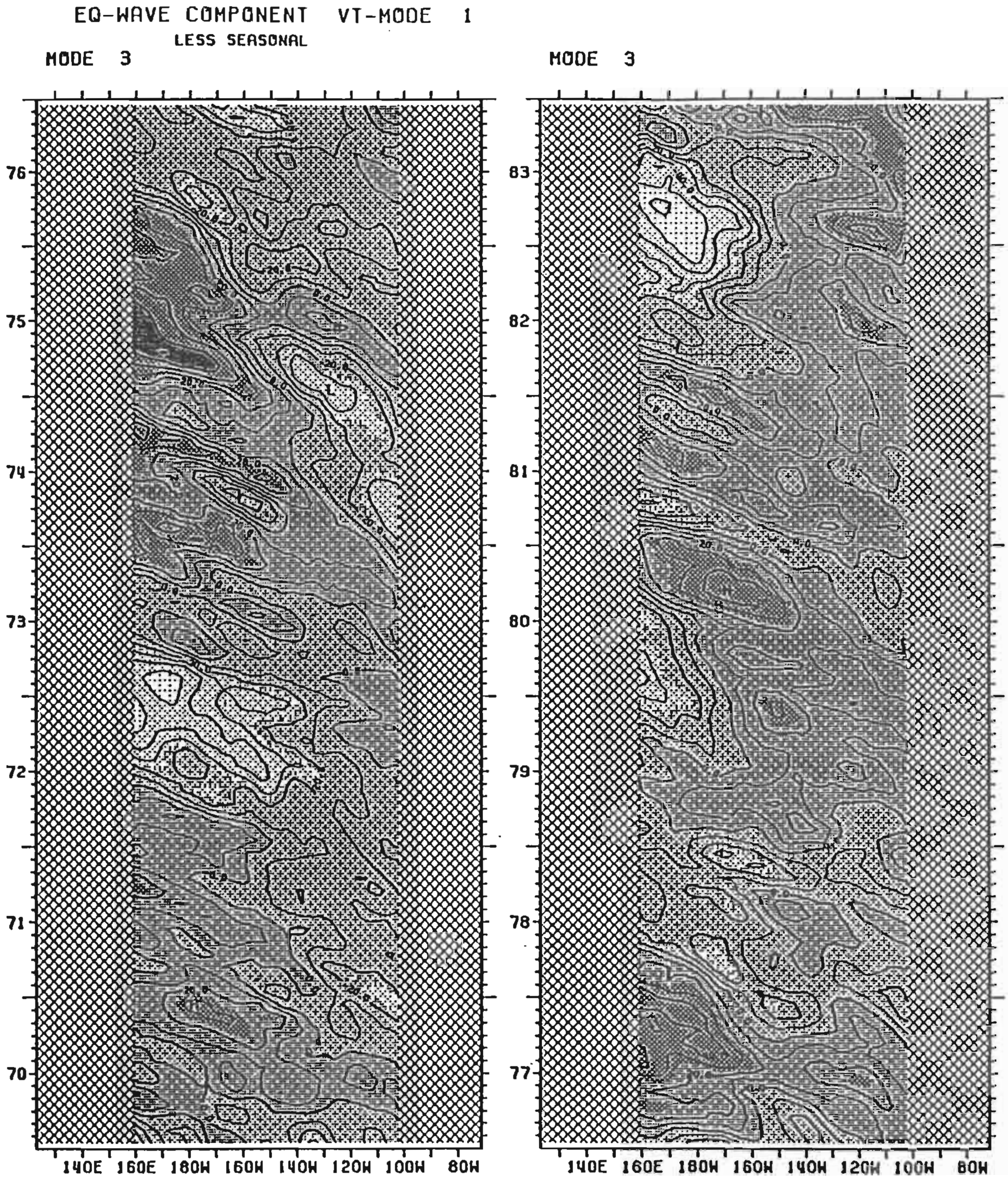

FIG.2. Time versus longitude diagram showing the amplitude of the 3rd meridional first vertical mode Rossby wave. Big tip-marks on the vertical axis are boundaries between years. Darker shade indicate warm Rossby wave.

At the northern and southern boundaries, the meridional volume transport is calculated assuming Sverdrup relation. Otherwise, there is no derivative in north and south direction. Newtonian dumping is applied for temperature near the boundaries to the climatology.

Initially, the ocean is at rest and uniformly stratified. First, the model is driven by annual mean wind for more than ten years, using one degree resolution model, then three years using 2/3 degree resolution model. The integration is continued for three years using climatological seasonal wind, and then interannual run take over the integration.

3. Warm water pile-up in the model and the real ocean

Analyses of the model results are meaningless unless the model simulates the real ocean well enough. As the purpose of the present study is to examine the pile up processes of warm water in the western tropical Pacific, comparison between model and observation is made for dynamic height anomaly along the 137°E (Fig. 1). Observed dynamic height is calculated from data taken by Japanese Meteorology Agency in cruises carried out routinely twice a year.

Quasi-biannual variations can be seen in both figures in lower latitudes in the 70's. Positive anomalies at the beginning of 1972 and 1976 are followed by warm events. For the 1982-1983 event, preceding positive anomalies are not strong, but are still visible. Therefore, as far as these periods are concerned, all warm events are preceded by positive anomaly in dynamic height, which is a consequence of the warm water pile up. However, the contrary is not true. For example, strong positive anomaly found at the beginning of 1974 is not followed by a warm event.

Two conclusions can be derived. First, warm water pile up is a necessary precondition for a warm event, but not a sufficient condition. Second, the model simulate the warm water pile up well enough to suggest that analyses of the model is meaningful.

4. Equatorial wave analysis

The piling up process can be either dynamical or thermal. However, the thermal process is suggested to be not essential as the positive dynamic height anomalies are also reproduced in 1.5 layer model which doesnot include any thermal process at all (Takeuchi, 1987).

If the process is dynamical, and if non-linear effects are not too strong, the process may be understood in terms of wave dynamics. From the wave dynamic point of view, the warm water piling up process can be seen as formation process of warm Rossby wave, thus generation and propagation can better be seen.

For the purpose, each equatorial wave component is isolated. First, the mean density field is calculated, and vertical mode functions are computed at every location using the mean density distribution. Next, pressure anomaly distribution is decomposed onto vertical modes. Finally, each meridional mode is isolated using hyperbolic cylindrical functions.

Fig. 2 shows time versus longitude distribution of the third Rossby wave component of the first vertical mode. In this figure, we can see warm Rossby waves are approaching the western boundary in the periods when positive dynamic height anomalies are found in Fig. 1. Other lower mode Rossby wave show similar behavior. It indicates that the warm water pile up is not formed locally. Then the problem is where and when the warm Rossby waves are generated. The figure shows that the formation area is the central Pacific, say, between the date line and 150°W. They are generated in the previous years of the beginning of warm events.

Also very notable is the similarity between the one to tow year periods preceding the major warm events, 1972-1973 and 1982-1983. Three warm Rossby packets are propagating from central Pacific to the western boundary in each period. The first packets are strongest but tend to die out before reaching the western boundary. The second ones are responsible for the positive anomaly appeared in Fig. 1. The similarity also can be seen to some extent for the 1976 minor warm event.

Another common feature is that each warm event is followed by positive dynamic height anomaly in the western tropical Pacific, as seen in Fig. 1. Warm Rossby waves are also found in Fig. 2. However, in the period analyzed in the present study, no warm event follow the warm water piling up.

5. Discussion and conclusion

Through the present study, the followings are found.

1) Piling up of warm water in the western tropical Pacific is a necessary precondition for a warm event to develop, but not an efficient condition.
2) The piling up of warm water is formed in the central Pacific in the previous year of the beginning of each warm event and propagates to the west as warm Rossby wave.
3) The longitude versus time distribution of Rossby wave component shows similar pattern in each 1 to 2 year period previous to the beginning of warm event.
4) In the following years of warm events, formation of warm Rossby waves are always found, but not followed by the next warm event.

These results suggest that ENSO cycle is not as simple as simple coupled models indicate, even if it is a cycle. After a warm event terminates, a cold phase appears and stronger than usual trade winds generate warm Rossby waves in the central Pacific which propagate westward resulting in an anomalous warm water piling up in the western Tropical Pacific. However, at least in the period examined in the present study, no warm event developed in such a situation.

On the other hand, generation of warm Rossby waves in the previous year of each warm event seems to have no apparent relation with the previous warm event. We still have missing rings to be found. The similarity of the behavior of central to western tropical Pacific in the previous year of 1972-73 and 1982-83 events seems to be very suggestive.

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