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QBO Features of Tropical Pacific wind Stress Field with the Relation to El Nino①

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ABSTRACT

Analysis has been implemented of 1970–1992 tropical Pacific wind stress anomaly and sea surface temperature anomaly (SSTA) datasets, indicating that quasi–biennial oscillation (QBO) of the tropical Pacific WS and SSTA is featured both by a standing and a progressive form, the former emerging in the most intense centers of action and the latter travelling east– or west–ward out of the SSTA sources. Results show that the SSTA is in the warm (cold) phase as zonal component of euqatorial wind stress anomaly gets weakened (reinforced) and the QBO of wind stress anomaly is well related to the El Nino cycle.

Key words; Wind stress, Quasi–biennial oscillation (QBO), Equatorial zonal easterly, El Nino cycle

I. INTRODUCTION

As far back as 1969, Bjerknes indicated that the decrease in equatorial trade wind will give rise to a slow rise of Pacific SST, which, in turn, will enfeeble the trade wind, resulting in further intensification of SST, and it is through the interaction that an El Nino eventually be generated, a mechanism for an unsteady sea–air interaction over the tropical Pacific. Based on increased accumulation of observational facts, studies (Rasmusson et al., 1982; Barnett, 1988) reported that a single cold or warm event has its occurrence partially to be phase locked with the annual cycle and partially to be biennial. Spectral analysis (Lau et al., 1988; Rasmusson et al., 1990) demonstrates that tropical SST, sea level pressure, zonal wind and precipitation are marked by two noticeable peaks in power spectra with the principal periods over the range of 3–6 years and the secondary corresponding to the QBO periods. Recent work of Barnett (1991) and Repeleski et al. (1992) indicated that the QBO is indeed part of an ENSO event, located largely over the Indian / Pacific and depending strongly on the annual cycle for genesis. And more evidence shows that the QBO is perhaps a basic mode of ENSO. Interestingly, the tropospheric QBO is assumed to be one of the members of the Southern Oscillation family, particularly the eastern Indian sea level wind QBO in phase locked more closely with the annual cycle, in the context of 1950–1987 Pacific / Indian near sea surface data (Rasmusson, 1982). Accordingly, he proposed a concept of ENSO genesis due to interaction among multiple time scales consisting of biennial oscillation mode, low frequency mode and annual cycle which should be borne out by more observational facts and theoretical efforts, however.

This paper presents the space structure and propagation features of the biennial

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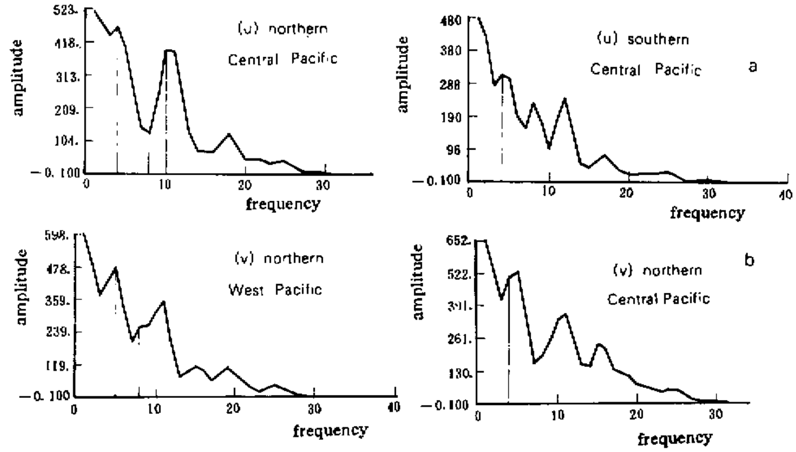

Fig. 1. A power spectrum for the zonal (meridional) component of wind stress anomaly, T_x (T_y), shown in a (b).

oscillation component for wind stress anomaly in the context of 1970–1992 monthly mean wind stress anomaly and SSTA data over the tropical Pacific, followed by the comparative examination of the relation of the wind stress anomaly to SSTA with regards to QBO, thereby documenting the role of the QBO of wind stress anomaly in an El Nino formation. Section 2 describes the data source and processing. The space structure and propagation features of the QBO of wind stress anomaly are illustrated in Section 3. Section 4 explores the QBO of the wind stress anomaly relative to that of SSTA. Section 5 investigates the role of wind stress anomaly in the El Nino production with the discussion given in the last section.

II. DATA PROCESSING AND SPECTRAL CHARACTERISTICS

The data used come from the tropical Pacific wind stress anomaly and SSTA on a monthly mean basis for 1970–92 with the wind stress anomaly (SSTA) covering 29°N–29°S, 129°E–73°W (29°N–29°S, 124°E–70°W) and gridpoints of 29 × 30 (84 × 30).

First of all, power spectral analysis is performed of the data. The zonal belt is divided into 3 equispaced subbelts: 29–10°N, 10°N–10°S and 10–29°S, followed by a meridional division of the belt into 3 equal parts, too, thus making for 9 regions for the research area, distributed separately over the northern West Pacific, equatorial West Pacific, southern West Pacific, northern Central Pacific, equatorial Central Pacific, southern Central Pacific, etc. Next, regional averaging is done of all the gridded data inside the box to construct a time series for power spectral analysis.Results show that found in the spectrum of the zonal and meridional components of wind stress anomaly for much of the study area are two strong peaks, one being the 3 to 4–year oscillation and the other being QBO (Fig. 1) with the equatorial Central Pacific zonal component wind stress anomaly, T_x, showing the strongest QBO power spectrum (figure not shown), which is an indicator of active QBO there. T_x in the equatorial eastern Pacific (figure omitted) has intense signal of 3 to 4–year oscillation and QBO, similar to whose form is the distribution of the SSTA power spectrum, both characterizing essentially the low frequency variation pertinent to the El Nino cycle. For the equatorial western Pacific (figure left out), T_x displays higher frequency oscillation (with the period

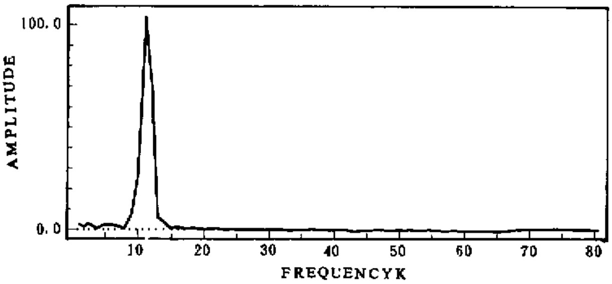

Fig. 2. QBO signal of filtered wind stress anomaly.

approaching 60 days) in addition to the 3 to 4 year oscillation and QBO with T_y (meridional component wind stress anomaly) exhibiting a roughly analogous power spectrum to that of T_x except that the most vigorous QBO signal is observed in the eastern Pacific near Peru's coast.

In order to give prominence to the tropical Pacific QBO signal, we employ the quadri–pole lowpass filter of Kaylor (1977) to remove the high–frequency portion (greater than QBO) and get low–frequency signal A, from which subtracted is low–frequency portion B (smaller than QBO), thus resulting in the QBO signal A–B. Fig. 2 portrays the power spectrum obtained by filtering twice with the technique, and it is evident therefrom that the QBO signal is fully retained.

The filtered data are utilized to compute the QBO variance of wind stress anomaly contribution with $\sigma_1 = \sum \overline{X_1^2} - \overline{X_1}^2$ ($\sigma_2 = \sum \overline{X_2^2} - \overline{X_2}^2$) denoting the variance prior (subsequent) to filtering and the ratio $\frac{\sigma_1}{\sigma_2} \times 100\% = 18\%$ suggests that the QBO variance contribution accounts for 18% of the total, thus representing an innegligible component of the wind stress anomaly field which may be related to El Nino formation.

III. SPACE STRUCTURE AND OSCILLATION FEATURES OF QBO OF WIND STRESS ANOMALY

EOF expansion is made of the filtered wind stress anomaly data. The first four principal components illustrate the QBO space pattern (Fig. 3) and make up 79% of the total variance, with the contribution of 31.4, 22.5, 13.4 and 11.3% for the 1st, 2nd, 3rd and 4th eigenvector, respectively.

One can sea that the first eigenvector field (Fig. 3a) is marked by the weakening and intensification of equatorial zonal easterly, especially in the Central Pacific, where the change of wind stress anomaly may cause oceanic current to be altered equatorially through sea–air interaction, thereby controlling SST pattern adjustment in the Pacific as a whole, responsible for El Nino genesis and Fig. 3b gives the spatial distribution of the second eigenvector, indicating that the western North Pacific is characterized by a particularly intense cyclonic anomaly circulation centered around 15°N, 160°E, with the equatorial eastern Pacific zonal wind anomaly change as its second feature of importance. Inspection in conjunction with the related temporal curve shows that the cyclonic anomaly circulation is indicative of convergence / divergence in the lower troposphere wind field in the study area. Obviously, the cyclonic anomaly has its change in close relation to the equatorial eastern Pacific zonal wind. Of particular interest is the 1982–1983 increased amplitude of anomaly in time coefficients of

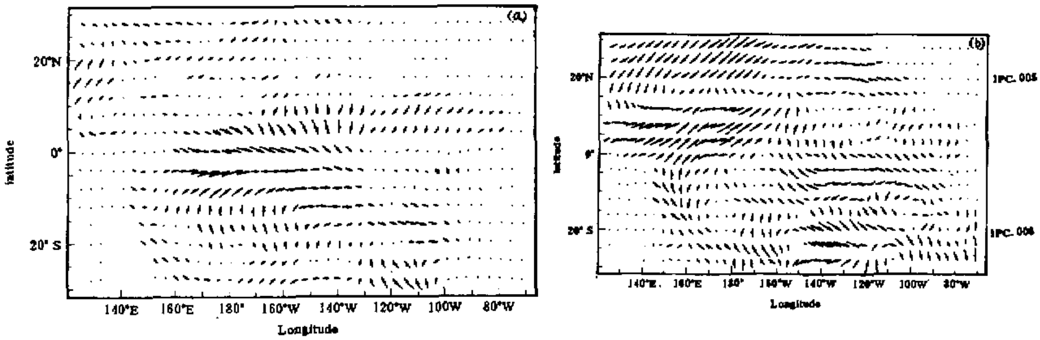

Fig. 3. The first (second) eigenvector field QBO of the Pacific wind stress anomaly, shown in a (b).

the second eigenvector (figure not shown) in strong contrast to the subsequent cases, a situation that is probably associated with the 1982–1983 El Nino event observed, indicating that prior to the event the eastern North Pacific anomaly cyclone was quite active, in relation to the equatorial eastern Pacific easterly departure, and as time went on, the anomaly cyclone (easterly departure) changed to an anomaly anticyclone (westerly departure), allowing the event to take place. Also, from the unpublished plot one can see that the QBO of wind stress anomaly has an anticyclonic anomaly circulation centred around 25°S, 100°W over the eastern South Pacific which shows the convergence / divergence in the lower troposphere wind stress anomaly field over that area. It is noted that the convergence / divergence bear close relation to the zonal wind anomaly in the equatorial eastern Pacific; the eastern South Pacific anticyclonic anomaly circulation is just opposite to the cyclonic counterpart in the western North Pacific, viz., the eastern South Pacific divergence gets intensified as the lower troposphere convergence does so in the western North Pacific and V.V., forming a NW–SE anomaly circulation oscillation across the equator—an oscillation that is likely to be associated with Southern Oscillation and Asian monsoon activities.

Fig. 4a, b show time cross sections of Pacific wind stress anomaly / SSTA QBO's averaged separately along the equator, both displaying standing wave oscillation and progressive wave propagation. By referring to the time cross–section, one can see that the QBO of wind stress anomaly has its vigorous core of action in the equatorial Central Pacific while the SSTA QBO has one such core in the same region and another in the eastern Paicific; strong standing wave oscillation is observed in the area of the action center with eastward (westward) propagation of the departure sector of Central (eastern) Pacific origin, as in 1981–84(1989–90). These facts deserve our particular attention.

From the foregoing analysis, the QBO of Pacific wind stress anomaly space pattern has the strongest activity in the equatorial Central Pacific shown largely by the reinforced / lessened easterly wind equatorially and intensified or weakened convergence / divergence of the wind stress anomaly field in the lower troposphere over the western North and eastern South Pacific, with the strengthening or subsidence relation to the corresponding change of the zonal wind anomaly in the equatorial eastern Pacific;the wind stress anomaly / SSTA QBO's exhibit both standing–wave oscillation and progressive–wave except that the direction may differ, depending on a cold or warm event.

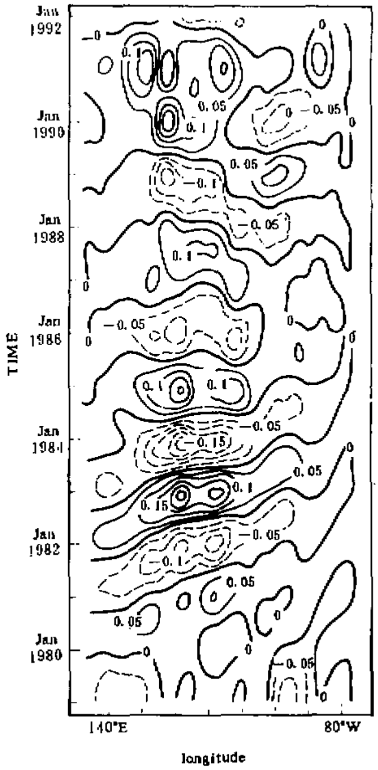

Fig. 4a. Time cross section of QBO of Pacific wind stress anomaly averaged along the equator.

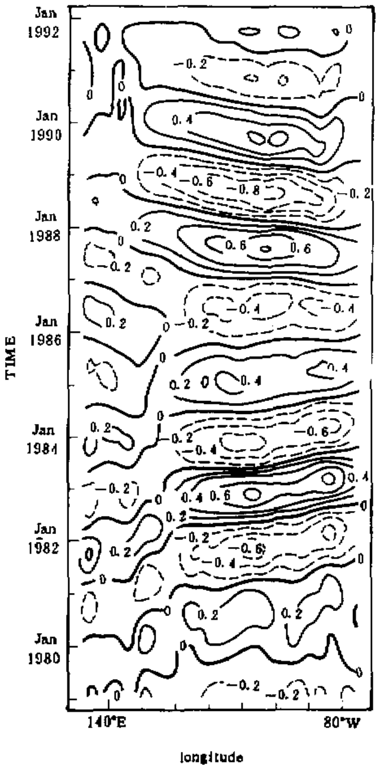

Fig. 4b. As in Fig.4a but for SSTA QBO.

IV. RELATIONSHIP BETWEEN QBO'S OF PACIFIC WIND STRESS ANOMALY AND SSTA

Based on the time cross–section and EOF expansion of the QBO of wind stress anomaly, the semi–period is separated into 5 phases, followed by preparation of composite diagrams for all the phases of the QBO of wind stress anomaly (Fig. 5) and of the SSTA QBO (Fig. 6) by compositing. It is apparent that the QBO of wind stress anomaly at phases 1 and 2 (0 and 45°, respectively) has as its feature the increased equatorial easterly, predominantly in the Central Pacific east of 160°E and west of 130°W, with low–lever intense convergence at Southern subtropics and the related phases 1 and 2 of the SSTA QBO are of cold nature with negative SSTA over the equatorial eastern to Central Pacific, maximizing at 0.5℃; for phase 3 (90°) the QBO of wind stress anomaly is marked by a decreased equatorial easterly and an strengthened cyclonic anomaly circulation in the western North Pacific subtropics, with the associated negative SSTA sharply reduced and shrunk into the eastern Paicfic; at phase 4 (135°) the equatorial Central Pacific easterly anomaly has changed into westerly analog, with the positive SSTA changed into a negative anomaly region in the equatorial Central to eastern Pacific, peaking at as high as 0.2℃; for phase 5 (180°), the equatorial Central Pacific westerly departure reaches its climax, which suggests the phase change as compared to the situation of phase 1, the same being true of the SSTA in the Central / eastern Pacific. Of interest is

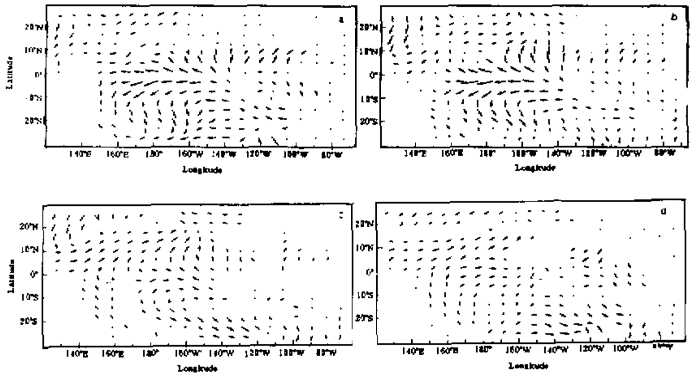

Fig. 5. Composite diagrams of all phases of QBO of the Pacific wind stress anomaly.

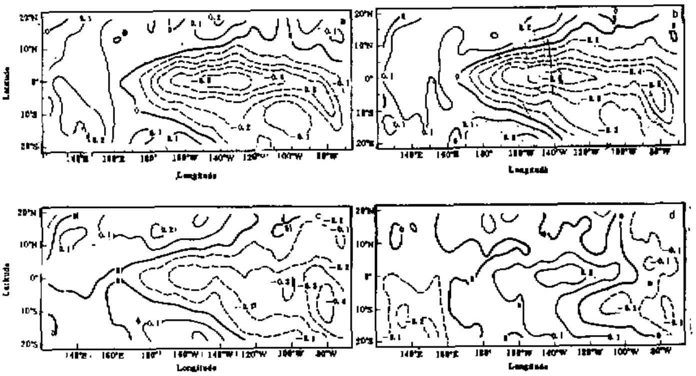

Fig.6. As in Fig. 5 but for SSTA.

that the SSTA pattern bears close resemblance to the abnormal SSTA distribution for an El Nino event. As such, the QBO of wind stress anomaly is most likely to act as a basic oscillation mode responsible for the event. As shown by Rasmusson et al., (1990), the QBO's modified by low–frequency oscillation will produce amplified rise and drop in amplitude, leading to an El Nino happening in the end.

Based on the QBO of wind stress anomaly at the various phases and the relation to the SSTA QBO at the corresponding phases, it follows that the sea–air interaction and the feature of ecah of the components at a particular phase are highly visible. When equatorial easterly stress increases, the oceanic current there does so, forming a warm water pool in the western North Pacific by driving the surface–layer warm water from the eastern / Central to the western Pacific equatorially, and giving rise to cold water upwelling in the eastern Pacific which results in a cold water region there. And as the equatorial easterly wind stress anomaly is weakened and changed to the westerly counterpart, warm water is made to flow eastward on account of the wind stress anomaly alteration such that the western North Pacific warm pool will become feeble and equatorial eastern Pacific SST rise. Thus we are led to believe that the QBO, low–frequency (3–4 year) oscillation and annual cycle of the cold / warm events interact with each other and may act as a mechanism for an EL Nino cycle.

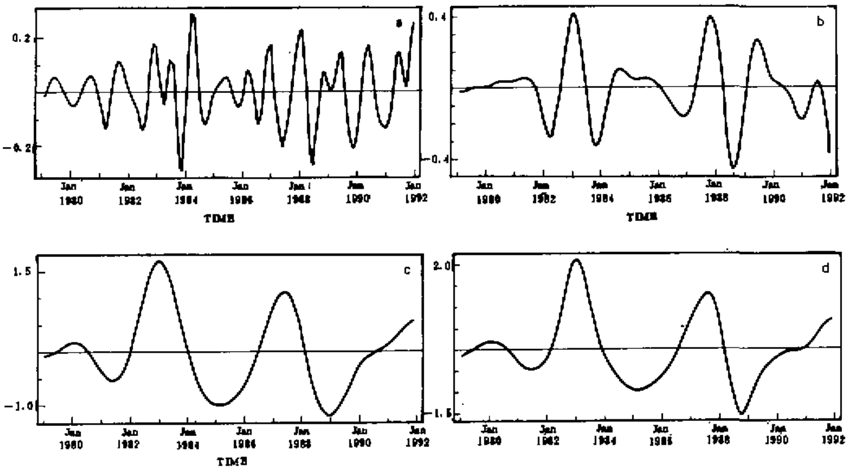

Fig. 7. Components of annual cycle, QBO and LFO of the Nino–3 index.

V. QBO OF WIND STRESS ANOMALY RELATIVE TO EL NINO GENESIS

For this purpose, the mean SSTA as the Nino–3 index is obtained by computing the Pacific monthly anomalies over 5°N–5°S, 150–90°W. Then we proceed to carry out power spectral analysis of the index. Result shows that for the index there really exist a pronounced QBO, 3–4 year oscillation (LFO, figure not shown) with the components of the annual cycle, QBO and LFO (see Fig.7) acquired through filtering. It is clear that the phase and amplitude of the annual cycle and particularly QBO are greatly LFO modified.

When the warm phases of the Nino–3 index QBO and LFO components, if just in agreement with each other will make the amplitudes to be imposed linearly, arriving at a maximum, which suggests that a SST warming would occur. *Associated with that, the Nino–3 index* shows its maximal QBO amplitude, as in the El Nino episode of 1983 and 1987. And when the index QBO amplitude is nagative, imposed on that of a LFO cold phase, a SST cooling will happen, as in the 1986 La Nina period.

Now the wind stress anomaly field is dealt with by filtering, resulting in the components of the annual, QBO and LFO (figure omitted), with the basic features similar to those of the Nino–3 index. The westerly (easterly) phases of the QBO / LFO components when they are in concert indicate their relation to a warm (cold) phase of the index. It follows that the QBO is one of the principal modes of the stress anomaly field in the El Nino and La Nina episodes and hence plays a major role in El Nino genesis.

VI. CONCLUDING REMARKS

From the foregoing analysis we come to the following conclusions. 1. The Pacific QBO of wind stress anomaly is most intense and active in the equatorial Central portion, which is shown by weakened or amplified easterly equatorially and the intensified lower troposphere convergence or divergence in the tropical Pacific and eastern South Pacific.

2. The wind stress anomaly / SSTA QBO's are featured by standing–wave oscillation and progressive wave propagation in the tropical Pacific, the former shown largely in the strongest centres of action and the latter mainly by the east– or westward shift of the anomaly

source.

3. A good collocation is between the QBO's of the wind stress anomaly and SSTA, i. e., with the equatorial easterly component reduced (amplified), the SSTA exhibits a warm (cold) phase.

The El Nino formation is rather a complicated problem, covering sea−air interaction and nonlinear effects among a variety of time scales. The present article has focus on the tropical Pacific QBO of wind stress anomaly with the investigation of SSTA effects and possible mechanism for producing El Nino. Therefore, how these kinds of interaction proceed and what laws they follow await deeper and detailed exploration.

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