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Anticorrelated intensity change of the quasi-biweekly and 30–50-day oscillations over the South China Sea

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[1] Over the South China Sea, the year-to-year variations in the intensity of the quasi-biweekly (QBW) and 30–50-day oscillations during June–July are anti-correlated. An explanation is offered for the out-of-phase relationship. We found during strong QBW years, the June–July mean convection and easterly vertical shear are enhanced over the equatorial western-central Pacific, with corresponding low-level cyclonic meridional shear to the northwest. These conditions, concurring with the equatorial eastern Pacific warming, are favorable for emanation of moist Rossby waves from the equatorial western Pacific. On the other hand, the 30–50 day becomes active when the mean convection is enhanced over the eastern Indian Ocean and maritime continent where this mode stems from and develops, which often corresponds to cold western IO. One of these two large-scale settings often occurs in the absence of the other, so that when one mode is strong during June–July the other mode tends to be weak. **Citation:** Yang, J., B. Wang, and B. Wang (2008), Anticorrelated intensity change of the quasi-biweekly and 30–50-day oscillations over the South China Sea, *Geophys. Res. Lett.*, *35*, L16702, doi:10.1029/2008GL034449.

1. Introduction

[2] Two major types of atmospheric intraseasonal oscillations (ISO) have been widely recognized over the South China Sea (SCS) during boreal summer: the high-frequency and the low-frequency. The high-frequency ISO is generally characterized by westward/northwestward propagation from the tropical western Pacific [*Krishnamurti and Ardanuy*, 1980; *Chen and Chen*, 1995; *Fukutomi and Yasunari*, 1999; *Annamalai and Slingo*, 2001; *Mao and Chan,* 2004], although the detected frequency band differs slightly, e.g., 12–24 days given by *Chen and Chen* [1995], 10–25 days given by *Fukutomi and Yasunari* [1999], and 10–20 days given by *Annamalai and Slingo* [2001]. Hereafter, we will refer it to as quasi-biweekly (QBW) oscillation. On the other hand, the low-frequency ISO over the SCS generally exhibits northward propagation that is connected with the eastward propagating Madden-Julian Oscillation (MJO) [*Madden and Julian*, 1971] [e.g., *Chen and Murakami*, 1988; *Wang and Rui*, 1990; *Lawrence and Webster*, 2002; *Hsu et al.*, 2004] especially during early summer [*Kemball-Cook and Wang*, 2001; *Teng and Wang*, 2003]. The preferred frequency band for the lower frequency oscillation is also slightly different: for instance, 30–50 days given by *Chen and Murakami* [1988], 25–80 days given by *Lawrence and Webster* [2002], and 30–60 days given by *Hsu et al.* [2004]. For convenience, the low-frequency component will be referred to as 30–50-day oscillation. The slight diversity in the periodicities reflects the broad band nature of the oscillations and partly results from the differences among the datasets used, the length of the historical records and the analysis methods.

[3] The two types of ISO over the SCS experience large year-to-year variations [*Teng and Wang*, 2003; *Mao and Chan*, 2005], and their mean amplitudes in June and July tend to be anti-correlated [*Kajikawa and Yasunari*, 2005]. The year-to-year variation of the ISO has an impact on the frequency of the monsoon depression over Bay of Bengal [*Chen and Weng*, 1999], the onset date of the SCS summer monsoon [*Kajikawa and Yasunari*, 2005] and the occurrence of the flooding/drought events over Yangtze River Basin [*Ju and Zhao*, 2005]. Understanding of the causes of the year-to-year variation is important for prediction of ISO. However, the mechanisms for the year-to-year variation of the two ISO scenarios over the SCS have not been explained yet.

[4] This study aims to address the following questions: What controls the year-to-year variability of the two ISO modes over the SCS? And why are the mean strengths of the two modes in early summer (mainly June and July) anti-correlated? Our analysis is based on the hypothesis of the study by *Teng and Wang* [2003] that the changes in the seasonal mean states may affect the intensity of the ISO. In this paper, the atmospheric basic state characteristics favorable for active QBW and 30–50-day oscillations on year-to-year time scale are revealed. More important, effort is made to explain how the favorable mean states are linked to the intensity of the two ISO modes.

[5] Our analysis will focus on the period of June–July for two reasons. The properties of the ISO in the early summer (May–July) and the late summer (Aug–Oct) are quite different [*Kemball-Cook and Wang*, 2001; *LinHo and Wang*, 2002; *Hsu et al.*, 2004]. There is an anti-correlation between the intensities of the two ISO modes on interannual time scale, which has been found most significant during June–July [*Kajikawa and Yasunari*, 2005].

2. Periodicity and Life Cycle of the SCS QBW and 30–50-Day Modes

[6] In this study, the 30–50-day and the 12–25-day bandpass filters are used to extract signals for the two

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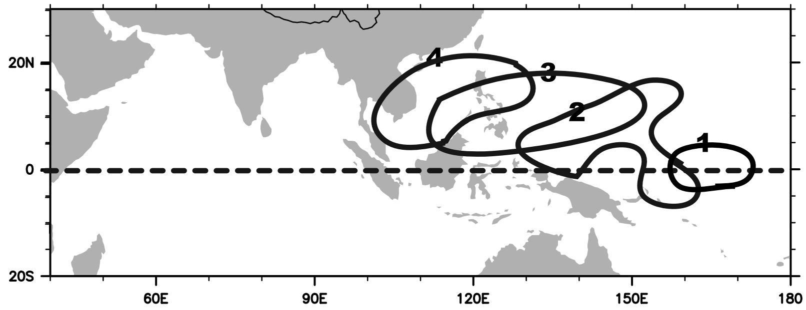

(a) QBW

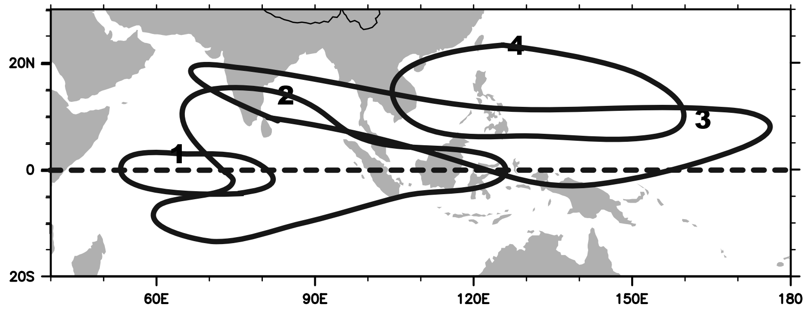

(b) 30-50-day

Figure 1. Schematic diagrams illustrating the first half life cycles of (a) QBW and (b) the 30–50-day SCS ISO modes. The enclosed curves with numbers indicate the boundaries of major convective anomalies at different stages. The curve with the number of "4" corresponds to the maximum ISO wet phase over SCS.

ISO modes. This choice of frequency bands is mainly based on multi-year mean power spectrum of the daily Outgoing Longwave Radiation (OLR) over the central-northern SCS (10°–20°N, 110°–120°N) in the last 29 boreal summers (May to Oct.) from 1979 to 2007. The selected frequency bands are generally consistent with the previous studies.

[7] To obtain the life cycles for the two ISO modes, we made two types of statistic analysis based on daily time series of SCS convective anomalies during June–July from 1979 to 2007. One is composite analysis of strong wet/dry ISO cases selected from the last 29 early summers (June–July). The other is one-point lead-lag correlation analysis of convective anomalies with respect to the maximum ISO wet/dry phase. Both the composite sequences and the lead-lag correlation patterns demonstrate a similar life cycle for the same ISO mode. For convenience, we only show the first half life cycle against the maximum SCS wet phase for the two ISO modes in Figure 1, and the dry phase repeats the same process. Generally speaking, the convective anomalies associated with the QBW mode originate from the equatorial western Pacific, emanate and propagate northwestward to the SCS (Figure 1a). In contrast, the convective anomalies associated with the 30–50-day mode initiate from the central and eastern equatorial Indian Ocean (IO), and propagate northeastward through the maritime continent to the SCS (Figure 1b). The features shown here also summarized the results from many previous studies (see section 1). The mechanism, which will be proposed in this study, is primarily based on the characteristics depicted by the schematic diagrams in Figure 1.

3. Seasonal Mean States Favorable for the Two ISO Modes

3.1. Favorable Atmospheric Conditions

[8] The fractional variance of the daily anomaly averaged over SCS (10°–20°N, 110°–120°N) region is used as a measure of the ISO intensity, which is defined as a ratio of the variances of each ISO mode to the total ISO during June–July of each individual year. And the resultant time series from 1979 to 2007 is used as an "intensity index" hereafter, which is applied to depict the year-to-year variation of the amplitude of each ISO mode. The correlation coefficient between the intensity indices of the two ISO modes is -0.69.

[9] The simultaneous regression patterns with reference to the intensity index are shown, respectively, for the OLR (convective activity), lower-level total wind and vertical shear of the zonal winds (Figure 2). These fields are relevant to the genesis and propagation of the ISO modes. These regression maps help to identify favorable seasonal mean anomalies for the two ISO modes during June–July.

[10] The tropical western Pacific is the key region to the genesis and development of the QBW mode according to Figure 1a. We found that when the QBW mode is active over the SCS, the convective activity is evidently enhanced over the equatorial west-central Pacific (Figure 2a) with a low-level cyclonic meridional shear to its northwest (Figure 2b). Meanwhile, the significant anomalous easterly

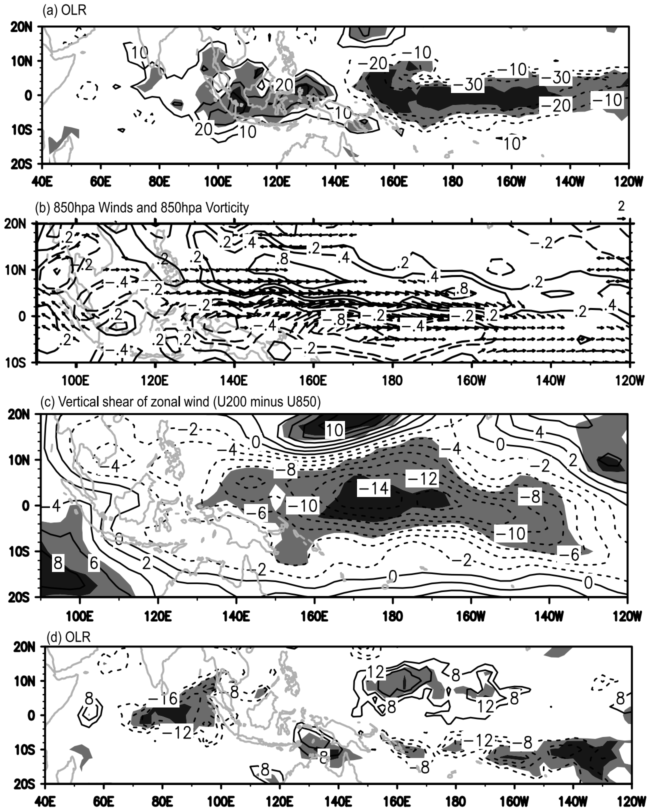


Figure 2. Regression patterns of time mean (a) OLR (*W*/*m*^{2}), (b) 850 hpa winds (vectors: *m/s*) & vorticity (contours: 10^{-5} s^{-1}), (c) vertical shear of zonal winds (*m/s*) against the intensity index of QBW, as well as (d) OLR (*W*/*m*^{2}) against the intensity index of 30–50 days during June–July. The shadings and vectors are only shown above 95% confidence level. Note that negative value of OLR corresponds to enhanced convection.

vertical shears appear over the tropical western-central Pacific particularly north of equator (Figure 2c).

[11] Why do such environmental states favor for the enhancement of the SCS QBW mode? The previous theoretical studies have demonstrated that the vertical shears of zonal flow may have a remarkable impact on the equatorial Rossby waves and westward propagating mixed Rossby gravity wave [*Wang and Xie*, 1996]. The easterly vertical shear can trap Rossby waves in the lower troposphere, whereas the westerly shear tends to trap Rossby waves in the upper troposphere. Therefore, in the presence of moist convection over the tropics, enhanced lower-level perturbation due to the easterly vertical shear increase the boundary layer moisture convergence, which in turn feedbacks to the convective heating [*Xie and Wang*, 1996]. Therefore, the enhanced easterly shear favors amplifications of the convectively coupled equatorial Rossby waves over tropical western Pacific [*Wheeler and Kiladis*, 1999]. The cyclonic meridional shear over the western Pacific region also facilitates the genesis and development of perturbation. The aforementioned factors provide a favorable condition for the westward propagating QBW mode.

[12] In contrast, for the 30–50-day mode the equatorial central-eastern IO and the maritime continent are the key regions (Figure 1b). From the regression pattern, we do find that the most noticeable anomaly is the enhanced convection over the equatorial central-eastern IO and the western maritime continent (west of 120°E) (Figure 2d). The presence of the mean anomalous convection is favorable for the generation and development of ISO perturbation over these regions where the 30–50-day mode stems from and develops.

[13] Also noticeable is that the favorable basic state conditions for the two ISO modes exhibit an out-of-phase relationship, which is especially revealed from their anomalous convective conditions. Namely, the convection is suppressed over the eastern equatorial IO and maritime continent when the QBW mode is active, thus the SCS 30–50-day mode is suppressed. When the 30–50-day mode is enhanced, the convection over the central-western Pacific is suppressed, which is unfavorable for the generation of the QBW mode. Thereby, the year-to-year intensity variations of these two ISO modes have anti-correlation.

[14] The common feature of the two SCS ISO modes is the northward propagation, i.e., northwestward propagation in quasi-biweekly mode and northeastward propagation in 30–50-day mode. What causes the northward propagation? Two types of mechanisms have been recognized: the air-sea interaction [*Fu et al.*, 2003; *Fu and Wang*, 2004] and atmospheric internal mechanisms. The easterly vertical shear plays an important role for supporting northward propagation of the moist Rossby waves and ISO mode. According to the vorticity equations for the barotropic component of the motion [*Wang and Xie*, 1997], in the presence of vertical easterly shear, a northward decrease in the perturbation upward motion can generate positive barotropic vorticity to the north of the convection. And the positive vorticity in turn induces convergence in the boundary layer, which would destabilize the atmosphere and trigger new convection to the north of the convection [*Wang*, 2005]. This atmospheric internal mechanism for northward propagation has been demonstrated in an intermediate model for boreal summer intraseasonal oscillation [*Wang and Xie*, 1997] and elaborated in more details by *Jiang et al.* [2004] and *Drbohlav and Wang* [2005]. Since the strong easterly vertical shear prevails over IO between 7°S and 25°N (Figure 3) in climatological seasonal mean state during June–July, the year-to-year variation of easterly vertical shear over IO tends to have weaker impact on northward propagation of the 30–50-day mode compared to the climatology. However, the tropical western-central Pacific is climatologically controlled by the vertical shear

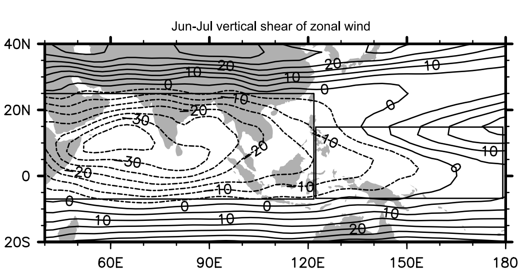
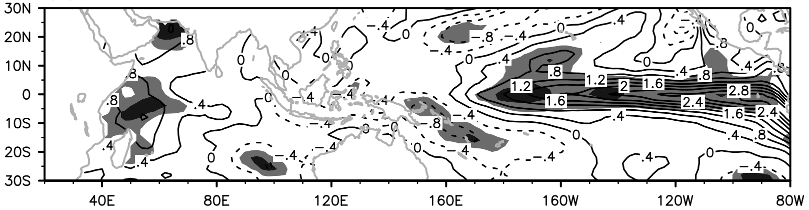


Figure 3. Climatological vertical shear of zonal winds (U200-U850) during June–July in the last 29 years (1979–2007) with unit of m/s.


(a) QBW

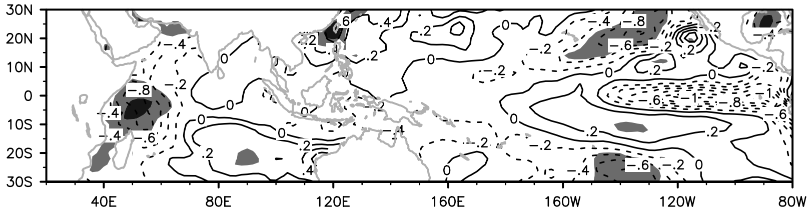

(b) 30-50 day

Figure 4. Regression patterns of time mean SSTA (Unit: K) with reference to the intensity indices of the two modes during Jun–Jul. Above 95% confidence level is shaded.

of weak easterly and even westerly in June–July. Thereby, the easterly vertical shear anomaly over tropical western-central Pacific may enhance the northward propagation of the QBW mode more significantly (Figure 2c).

3.2. Favorable SST Condition

[15] Figure 4 presents regressed seasonal mean SST anomalies in respect to the intensity index of each ISO mode. The favorable SSTA associated with the active QBW mode exhibits a pattern similar to El Nino. The most significant positive SSTA occurs over the equatorial central and eastern Pacific (Figure 4a). In contrast, the strong 30–50-day oscillation over the SCS does not show evident relationship with the tropical Pacific SSTA. The most relevant SSTA associated with the 30–50-day mode is located over the western equatorial IO (Figure 4b). When the 30–50-day mode is enhanced over the SCS, negative SSTA appears in the tropical western IO. The negative SSTA in the western IO may generate westerly anomalies over the equatorial central IO and enhance convection in the eastern IO and western maritime continent.

4. Conclusion and Discussion

[16] The intraseasonal oscillations over the South China Sea (SCS) have two prominent components: the QBW (12–25-day) and 30–50-day. Both components have large year-to-year variations. During June and July, the year-to-year intensity variation of the two components tends to be 180 degrees out-of phase, i.e., when the 30–50-day mode is strong the QBW mode tends to be weak or vice versa. In this paper, we explain what affect the intensity of the two ISO modes and why the strengths of the two modes tend to be anti-correlated. The intensity changes of the two ISO modes over SCS are influenced respectively by mean atmospheric conditions in different key regions during June–July. The QBW oscillation is largely associated with the emanation of the moist equatorial Rossby waves from the equatorial western Pacific. Therefore, the critical region for the QBW mode is over the tropical western Pacific. The easterly vertical shear anomaly and enhanced convection over the equatorial western Pacific, and the associated cyclonic meridional shear north of the equatorial western Pacific are favorable for the enhancement of the QBW mode. On the other hand, the SCS 30–50-day mode propagates northeastward from the central and eastern equatorial IO and maritime continent. Thereby, a key region for the formation and development of the ISO disturbances on this time scale is located in the eastern equatorial IO and maritime continent. The favorable environmental states for the active 30–50-day mode are the enhanced convection over the eastern equatorial IO and western maritime continent.

[17] The relationship between the tropical SSTA and the intensity of the two ISO modes has also been studied. The intensity change of the QBW mode is mainly related with the equatorial central and eastern Pacific SSTA, whereas the intensity of the 30–50-day mode is primarily linked with the western IO SSTA. The correlation coefficient between the simultaneous Nino3.4 SSTA and the ISO intensity index is significant (0.48) for QBW mode but poor (drops to −0.1) for the 30–50-day mode, namely that the impact of ENSO on the intensity of the SCS ISO is mainly through the QBW mode. SSTA is assumed to be the most possible reason to essentially induce the favorable atmospheric circulation and convection conditions for the two ISO modes. The proposed mechanism needs to be further investigated by numerical model experiments in the future.

[18] One important issue is the breakdown of the out-of-phase relationship between the intensity changes of the two modes after July, suggesting that the favorable background conditions for the two modes may be season-dependent. One possible explanation is the seasonality of the ISO behavior between the early and late summer. *Kemball-Cook and Wang* [2001] have proposed that the ISO in August–October has a weaker eastward-propagating signal along the equator and shows strong northwestward propagation of convection in the western Pacific. Therefore the 30–50-day mode over the SCS could involve more northwestward propagating component from tropical western Pacific during the late summer. The seasonal dependence of ISO over this region calls for further study.

[19] The two ISO modes together account for almost 70% of the total ISO variances over the SCS during boreal summer. Thereby, better understanding of the key factors determining the intensity change of the two ISO modes will help to predict the year-to-year or long-term variation of the ISO over the SCS.

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