The 30–60 day intraseasonal oscillation over the western North Pacific Ocean and its impacts on summer flooding in China during 1998

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[1] Eastern China experienced a series of severe floods during the summer of 1998. These floods are shown to be consistent with the propagation and activity of the 30–60 day intraseasonal oscillation (ISO) over the western North Pacific (WNP), where the monsoon trough and the subtropical anti-cyclone appear as an anti-clockwise propagation with the enhanced and suppressed convective anomalies in a 30–60 day period. The Meiyu circulation pattern in the lower atmosphere successively dominates the WNP, which results in southern China and the Yangtze River valley suffering much more rainfall and floods than normal. There are remarkable signals of 30–60-day ISO in convective anomalies over the Bay of Bengal and east of Philippine Sea. During the cycle of the 30–60 day ISO, these convective anomalies move towards the South China Sea (SCS), where they affect the convective activity of the SCS summer monsoon, therefore maintaining the cycle of 30–60 day ISO over the WNP. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3314 Meteorology and Atmospheric Dynamics: Convective processes; 3319 Meteorology and Atmospheric Dynamics: General circulation; 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology. **Citation:** Zhu, C., T. Nakazawa, J. Li, and L. Chen, The 30–60 day intraseasonal oscillation over the western North Pacific Ocean and its impacts on summer flooding in China during 1998, *Geophys. Res. Lett.*, *30*(18), 1952, doi:10.1029/2003GL017817, 2003.

1. Introduction

[2] The 30–60 day intraseasonal oscillation (ISO) or Madden-Julian oscillation (MJO) is generally manifested as an eastward propagating, equatorially trapped, wave-number one, baroclinic oscillation in the tropical atmosphere, where it strongly modulates deep convective activity and exhibits its greatest variability and typically reaches its maximum amplitude over the eastern hemisphere [*Rui and Wang*, 1990; *Madden and Julian*, 1994]. Such interactions strongly influence the onset and activity of the Asian-Australian monsoon system [*Yasunari*, 1979, 1981; *Hendon and Liebmann*, 1990a, 1990b; *Wu et al.*, 1999; *Ding and Liu*, 2001; *Chan et al.*, 2002], and also affect extra-tropical regions by northward propagation [*Weickmann*, 1983; *Murakami et al.*, 1986; *Lau and Phillips*, 1986; *Wu et al.*, 1999; *Hsu and Weng*, 2001].

[3] China witnessed severe flooding in the summer of 1998. The region worst affected was the Yangtze River valley, which suffered devastating economic losses due to the floods. Analysis of the field data from the South China Sea Monsoon Experiment (SCSMEX) shows that the severe floods occurred partly because of a sequence of 30–60 day ISO pulses originating from the Indian Ocean [*Ding and Liu*, 2001]. However, a different analysis suggests that the floods over the Yangtze River valley was mainly affected by the 30–60 day ISO coming from the SCS and the WNP [*Chen et al.*, 2001]. Therefore, the origin of the 30–60 day ISO and its affects on the China summer floods are still open to question.

[4] The aim of this study is to explore the origination of the 30–60 day ISO, examine its characteristics in spatial propagation and address its impacts on the successive summer floods over eastern China during the summer (from May to August) of 1998. Here we use the daily geostationary meteorological satellite (GMS) infrared (IR) temperature [*Nakazawa*, 1988], outgoing longwave radiation (OLR) data obtained from NOAA polar-orbiting satellites and wind component from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis [*Kalnay et al.*, 1996] to present our findings. The climatological component is based on daily averaged data covering the period 1974 to 2000. The band-passed filter used in present study is after Murakami [*Murakami et al.*, 1986].

2. Signal of 30–60 day ISO

[5] Figure 1 shows the time-latitude cross-section of GMS IR temperature averaged between 110°E and 120°E in summer 1998. It is found that the enhanced super cloud
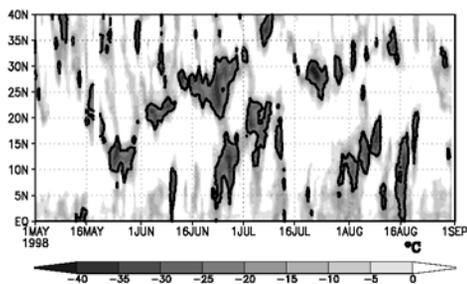
Figure 1. Time-latitude cross-section of GMS IR temperature between 110–120°E, the temperature less than −25°C is enclosed by the thick lines.

cluster shown by the GMS IR temperature (<−25°C) first appears over the SCS (5°–20°N) in late May, jumps to the south China (20°–25°N) in early June, and then moves to the Yangtze River valley (25°–32°N) in late June. Meanwhile, another super cloud cluster is observed over the SCS once again, followed by enhanced convection over the south China and Yangtze River valley in early and late July. In early August the third super cloud cluster appears over the SCS. Thus, the convective activities in the summer of 1998 over eastern China exhibit remarkable 30–60 days oscillations and shift over the SCS, south China and the Yangtze River valley, but no significant northward propagation of convection is found as in the previous study of *Hsu and Weng* [2001].

[6] To detect the signal of the 30–60-day ISO, the wavelet analysis [*Torrence and Compo*, 1998] is applied to the 20–120 day filtered convective index over the SCS (averaged OLR between 110–120°E and 5–20°N). Figure 2 shows the time evolution of the local wavelet power spectrum during 1998. The spectrum shows that there is a significant 30–60-day ISO, centered around 40 days, which dominates the SCS, and the spectrum reaches its maximum amplitude during the period of early June to August, which agrees with the previous analysis based on the seasonal OLR index of the SCS [*Chan et al.*, 2002].
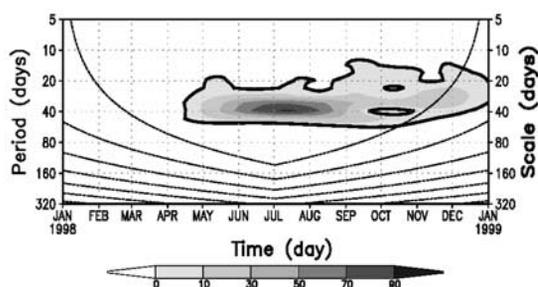

Figure 2. The local wavelet power spectrum of the normalized and 20–120-day filtered convective index over the SCS in 1998 using the Morlet wavelet. The left axis is the Fourier period (in day) corresponding to the wavelet scale on the right axis. The bottom axis is time (day). The thick contour encloses regions of greater than 99% confidence for a red-noise process with a lag-1 coefficient of 0.98. The dotted line covered regions on either end indicate the "cone of influence," where edge effects become important.

[7] To identify the source of the 30–60 day ISO related to the activity of the SCS summer monsoon, the lagged positive correlations at the 99% confidence level between 30–60 days averaged SCS convective index and the 20–120 day filtered OLR field from day −20 to day 20 in 5 day intervals are calculated and presented in Figure 3. From this we can observe that the signals of 30–60 day ISO over the SCS originate from the south of Japan, the Bay of Bengal, and east of the Philippine Sea, and exhibit shifting towards the SCS in lagged time. At the time period of −20 days, these signals appear over the south of Japan, east of the Philippine Sea, and southeast of Sumatra. At −15 days, belt-like correlation is observed over the Bay of Bengal to east of Philippine Sea, and the Yangtze River valley starts to be controlled by the southwestward shift correlation from the south of Japan. These correlations are connected to each other at the −10 day time period over the SCS when the area of remarkable correlation over the Bay of Bengal to the east of the Philippine Sea becomes large. At the beginning of day −5, the SCS starts to be dominated by the correlation until it moves towards the WNP by the end of day 10. At day 15, the correlation begins to dominate south of Japan and starts to shift southwestward at day 20 when a similar pattern as −20 days appears once again. During the period, a significant westward propagating correlation is found over the domain of north of China. Thus, the 30–60 day ISO, which is closely related with the convective activity of the SCS summer monsoon, is respectively coming from the Bay of Bengal, east Philippine Sea, and the WNP as well. It should be noted that there are also significant correlations over North Africa and the east Pacific Ocean, but no
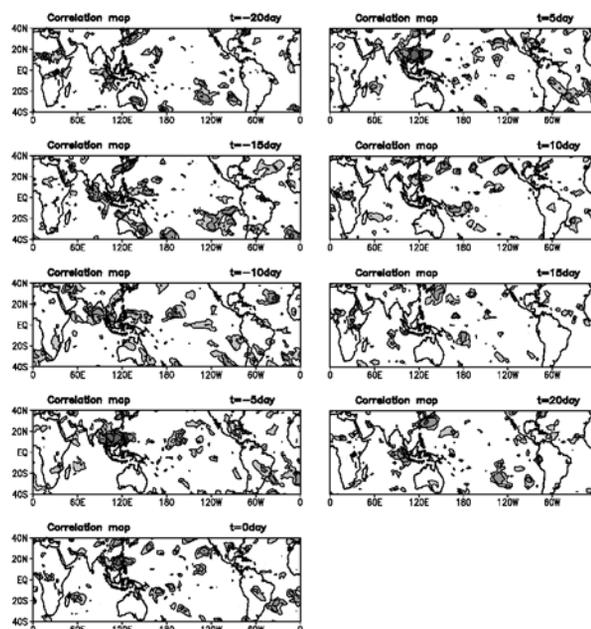

Figure 3. Lagged correlation maps of positive coefficients, greater than 99% confidence between the 30–60-day SCS convective index and 20–120-day filtered OLR in the summer of 1998 for the day −20 to day 20 with 5 days intervals. The contour interval is 0.1; the first positive contour is at 0.4.
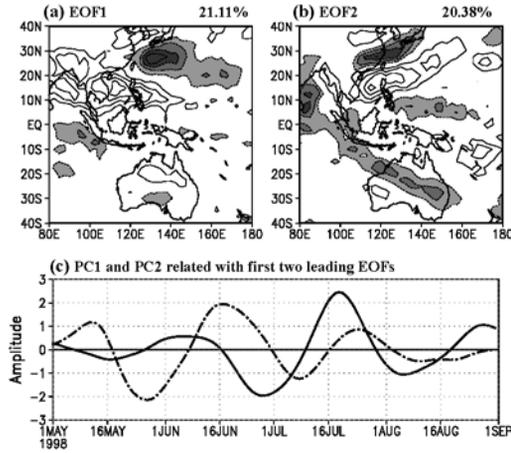
Figure 4. Empirical orthogonal function (EOF) analysis of 20–120-day filtered OLR. (a) EOF1, (b) EOF2; contour interval is 5 W m^{-2}; the zero contour is omitted; shading is shown by the legend. (c) PC1 (solid line) and PC2 (dashed line) from 1 May to 31 August 1998.

evidence is found to support the conclusion that these signals have propagated into the SCS.

3. Propagation and Impact on Floods

[8] OLR as a proxy for deep tropical convection has been extensively used in MJO convective anomalies analysis in the past. Recently, *Matthews* [2000] used the Empirical Orthogonal Function (EOF) analysis of the OLR data to define the cycle of the MJO and its spatial propagation. The state of the MJO on any given day can be defined by the first two leading EOFs of 20–200 days filtered tropical OLR. The MJO can be represented by a vector **Z** in a two-dimensional phase space, which is defined by the two leading principal component (PC) time series of EOF1 and EOF2 [*Matthews*, 2000] as,

$$\mathbf{Z}(t) = [PC1(t), PC2(t)], \quad (1)$$

where the PC1 and PC2 are the PC time series of EOF1 and EOF2. The amplitude of MJO is then given by

$$A(t) = \left[PC1^2(t) + PC2^2(t)\right]^{1/2}, \quad (2)$$

and the phase is exhibited by

$$\alpha(t) = \tan^{-1}\left[PC2(t)/PC1(t)\right]. \quad (3)$$

[9] Following the same method, but focusing on the domain 80°E–180°E, 40°S to 40°N, where signals of 30–60-day ISO are found to be correlated with the SCS summer monsoon activity in Figure 3, the EOF is applied to a seasonal, variation trend removed and 20–120-day filtered, OLR for the summer of 1998. Figure 4 shows the first two leading EOF1 and EOF2 that correspond to the PC time series of PC1 (t) and PC2 (t). The EOF1 and EOF2 account for 21.11% and 20.38%, respectively, of total variance, and

remarkably a 30–60-days period is shown in both PC1 and PC2.

[10] A dipole of convective anomalies appears in the EOF1, where the enhanced convection with low OLR, and the suppressed counterparts with high OLR, respectively dominates the WNP south of Japan and the Bay of Bengal, the SCS and the east Philippine Sea. In the EOF2, there is a belt-like enhanced convection, which dominates the area from the Yangtze River valley to the southern island of Japan with a suppressed convection to the south. In addition, the enhanced convective anomalies can be also found over the west of Bay of Bengal, east of the Philippine Sea and south of Sumatra to central Australia. During a period of 30–60 day ISO activity, when the PC1 (t) leads the PC2 (t) by a quarter of a 30–60 day ISO cycle over the WNP, the variation of the PCs suggests the propagation and activity of the 30–60-day ISO.

[11] Table 1 shows the category of 30–60 day ISO phase α(t) in each 45° period and its corresponding times in the summer of 1998. During the time periods of phase 3 to 5, corresponding to 8 to 23 June and 17 to 30 July, severe floods were observed over the Yangtze River valley [*China National Climate Center*, 1998], but during the periods of phase 6 to 8, corresponding to 24 June to 9 July and 31 July to 18 August, more rainfall and floods were found over the south of China including the SCS. There was no flooding in May, but the period of 17 to 26 May corresponds to the onset of the SCS summer monsoon.

[12] To clearly identify the cycle of 30–60 day ISO in spatial propagation and its impacts on the summer floods, we composite the OLR, which is regressed by the first two EOFs and the 30–60-days filtered wind vector anomalies at the low-level of 850 hPa in every category and present these maps in Figure 5. During phase 1, a monsoon trough with low OLR appears over the WNP, the Yangtze River valley to the southern island of Japan is dominated by a subtropical anti-cyclone with high OLR, and the Bay of Bengal and east of the Philippine Sea is also respectively controlled by an isolated tropical anti-cyclone with high OLR. During the phase 2, the previous monsoon trough with lower OLR moves towards the north, but its center is still over the WNP; the subtropical anti-cyclone previously over the Yangtze River valley starts to move to the south and affects the SCS, where it connects with two tropical anti-cyclones, respectively coming from the Bay of Bengal and east Philippine Sea. From phases 3 to 5, the monsoon trough with enhanced convection begins to shift to the southwest and affects the Yangtze River valley and south of Japan Island. The enhanced anti-cyclone previously formed over

Table 1. Phase Category and Time Period of the 30–60 Day ISO During 1 May to 31 August 1998

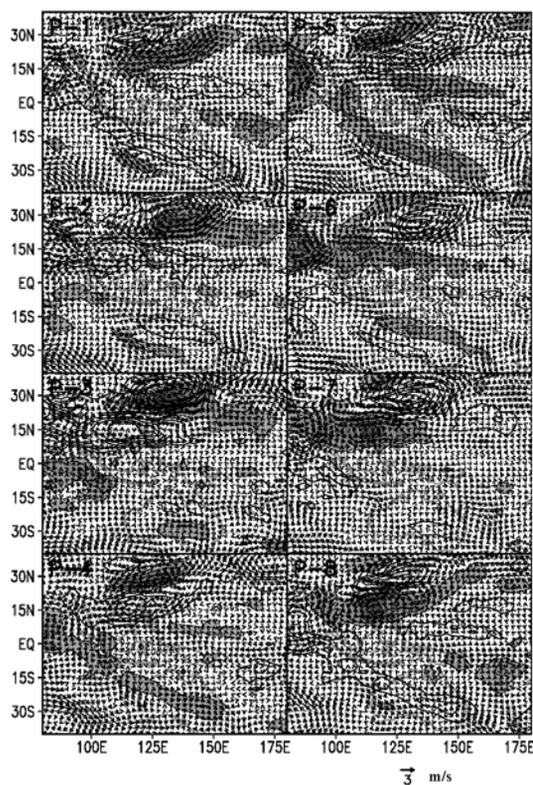| Category	α	ISO-1	ISO-2	ISO-3	ISO-4
1	0–45°		27/5–5/6	10/7–12/7	19/8–21/8
2	45°–90°		6/6–7/6	13/7–16/7	22/8–31/8
3	90°–135°		8/6–9/6	17/7–26/7	
4	135°–180°	1/5–7/5	10/6–15/6	27/7–29/7	
5	180°–225°	8/5–16/5	16/6–23/6	30/7	
6	225°–270°	17/5	24/6–30/6	31/7–3/8	
7	270°–315°	18/5	1/7–5/7	4/8–16/8	
8	315°–360°	19/5–26/5	6/7–9/7	17/8–18/8	

Figure 5. Regression maps of OLR based on the first two EOFs and 30–60-day filtered wind vector at low-level of 850 hPa for every 45° of phase α of 30–60 day ISO. The OLR contour interval is 5 W m^{-2}; the first positive contour is at 5 W m^{-2}; negative contours are dotted; shading is shown by the legend. The category of phase number of P-1 to 8 is also shown in the maps.

the SCS starts to propagate towards the WNP when the Bay of Bengal and east Philippine Sea begins to be controlled by the enhanced convection with low OLR. The reverse pattern of phase 2 is found during phase 6. The monsoon trough previously dominating the Yangtze River valleys and southern island of Japan begins to shift to the SCS, where it combines with those convections coming from the Bay of Bengal and east Philippine Sea, enhancing the monsoon trough over the SCS. The enhanced tropical anti-cyclone coming from the SCS with high OLR starts to dominate the WNP. From phases 7 to 8, the anti-cyclone begins to shift to the southwest and affects the Yangtze River valley and southern islands of Japan. During these periods the previously enhanced monsoon trough, centered over the SCS, begins to propagate towards the WNP when the Bay of Bengal and the eastern Philippine Sea once again starts to be controlled respectively by an anti-cyclone with high OLR. During the cycle of 30–60 day ISO, the monsoon trough and the anti-cyclone with enhanced and suppressed convective anomalies successively dominate the SCS, southern China and the Yangtze River valley. During phases 3 to 5, the typical pattern of summer Meiyu circulation is found to dominate areas of east China. Therefore, the Yangtze River valley would suffer more rainfall and flooding, being affected by the monsoon trough and the enhanced subtropical anti-cyclone to its south. During phases 6 to 8 however,

when the reverse pattern of Meiyu circulation begins to control these regions, there would be much more rainfall and flooding over the SCS and southern and northeastern China.

4. Summary

[13] The East Asian summer monsoon in 1998 was mainly dominated by the activity of the 30–60 day ISO, which exhibits different propagation characteristics over the tropical and extra-tropical regions. The successive floods in eastern China are shown to be related to the activity of the 30–60 day ISO over the WNP, where the 30–60 day ISO exhibited by the monsoon trough and the subtropical anti-cyclone appears as an anti-clockwise (in spatial) propagation with enhanced and suppressed convective anomalies. The Meiyu circulation pattern in the lower atmosphere dominates in East Asia in 30–60-days period, which results in successive floods over the SCS, southern China, and the Yangtze River valley. The influence of convective anomalies over the SCS came partly from the Bay of Bengal and the east Philippine Sea, where the 30–60 day ISO in convective anomalies appears as a zonal shift towards the SCS and enhances the monsoon trough and anti-cyclone, therefore maintaining the cycle of 30–60 day ISO over the WNP. The 30–60 day ISO in summer of 1998 over East Asia exhibits a very unique propagation character rather than appearing as the typical equatorially trapped eastward shift or northward movement. The mechanism responsible for the propagation of the 30–60 day ISO, for example, influence by the 1997/98 ENSO cycle is a very interesting issue that will be examined in a future study.

References

Chan, J. C. L., W. Ai, and J. Xu, Mechanisms responsible for the maintenance of the 1998 South China Sea summer monsoon, *J. Meteorol. Soc. Japan*, 80, 1103–1113, 2002.

Chen, L., C. Zhu, and W. Wang, et al., Analysis of the characteristics of 30–60 day low frequency oscillation over Asia during 1998 SCSMEX, *Adv. Atmos. Sci.*, 18, 623–638, 2001.

China National Climate Center, China great flood and climate anomaly, *Meteorological Press*, Beijing, 4–30, (In Chinese), 1998.

Ding, Y. H., and Y. Liu, Onset and the evolution of the summer monsoon over the South China Sea during SCSMEX field experiment in 1998, *J. Meteorol. Soc. Japan.*, 79, 255–276, 2001.

Hendon, H. H., and B. Liebmann, A composite study of onset of the Australian summer monsoon, *J. Atmos. Sci.*, 47, 2227–2240, 1990a.

Hendon, H. H., and B. Liebmann, The intraseasonal (30–50 day) oscillation of the Australian summer monsoon, *J. Atmos. Sci.*, 47, 2909–2923, 1990b.

Hsu, H.-H., and C.-H. Weng, Northwestward propagation of the intraseasonal oscillation in the western Pacific during the boreal summer: Structure and mechanism, *J. Clim.*, 14, 3834–3850, 2001.

Kalnay, E., et al., The NCEP/NCAR 40-year reanalysis project, *Bull. Am. Meteorol. Soc.*, 77, 437–471, 1996.

Lau, K.-M., and T. J. Phillips, Coherent fluctuations of extratropical geopotential height and tropical convection in intraseasonal time scales, *J. Atmos. Sci.*, 43, 1164–1181, 1986.

Madden, R. A., and P. R. Julian, Observations of the 40–50 day tropical oscillation: A review, *Mon. Wea. Rev.*, *122*, 814–837, 1994.

Matthews, A. J., Propagation mechanisms for the Madden-Julian Oscillation, *Q. J. R. Meteorol. Soc.*, *126*, 2637–2652, 2000.

Murakami, T., L.-X. Chen, and A. Xie, Eastward propagation of 30–60 day perturbations as revealed from OLR data, *J. Atmos. Sci.*, *43*, 961–971, 1986.

Nakazawa, T., Tropical super clusters within intraseasonal variations over the western Pacific, *J. Meteorol. Soc. Japan*, *66*, 823–839, 1988.

Rui, H., and B. Wang, Development characteristics and dynamic structure of tropical intraseasonal convective anomalies, *J. Atmos. Sci.*, *47*, 357–379, 1990.

Torrence, C., and G. P. Compo, A practical guide to wavelet analysis, *Bull. Am. Meteorol. Soc.*, *79*, 61–78, 1998.

Weickmann, K. M., Intraseasonal circulation and outgoing longwave radiation modes during Northern Hemisphere winter, *Mon. Wea. Rev.*, *111*, 1838–1858, 1983.

Wu, M. L. C., S. Schubert, and N. E. Huang, The development of the South Asian summer monsoon and the intraseasonal oscillation, *J. Clim.*, *12*, 2054–2075, 1999.

Yasunari, T., Cloudiness fluctuation associated with the Northern hemisphere summer monsoon, *J. Meteorol. Soc. Japan*, *57*, 227–242, 1979.

Yasunari, T., Structure of an Indian summer monsoon system with around 40-day period, *J. Meteorol. Soc. Japan*, *59*, 336–354, 1981.

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