Preconditions for El Niño and La Niña onsets and their relation to the Indian Ocean

Jong-Seong Kug,[1] Soon-Il An,[2] Fei-Fei Jin,[3] and In-Sik Kang[1]

Received 5 October 2004; revised 20 November 2004; accepted 3 February 2005; published 3 March 2005.

[1] El Niño/La Niña onset is a challenging problem of ENSO prediction. In this study, we introduce two precursors of El Niño and La Niña onsets. One is the equatorial heat content, and the other is the Western Pacific (WP) wind. When the two precursors are considered together, both the El Niño and La Niña onsets can be highly predictable. In particular, the persistence of the WP wind is more important for the onset than sporadic wind events. The persistent WP westerly (easterly) wind tends to be concurrent with the Indian Ocean SST cooling (warming). The Indian Ocean SST anomaly is partly correlated to an ENSO event during the previous winter. We demonstrate that an asymmetric relation between the Indian Ocean SST and ENSO can result in asymmetric progress of onset in the opposite ENSO phases. **Citation:** Kug, J.-S., S.-I. An, F.-F. Jin, and I.-S. Kang (2005), Preconditions for El Niño and La Niña onsets and their relation to the Indian Ocean, *Geophys. Res. Lett.*, *32*, L05706, doi:10.1029/2004GL021674.

1. Introduction

[2] Significant progress has been made in understanding, modeling, and prediction of El Niño and La Niña events. Several theoretical models have been suggested to explain the self-sustained oscillation of ENSO. In particular, the recharge paradigm, suggested by *Jin* [1997], reasonably explained the oscillating mechanism of ENSO, inferred from the slow ocean adjustment process via the heat content exchange between the equatorial and off equatorial regions. However, some observational studies pointed out that the observed ENSO onsets are not reasonably matched to the hypothesis as much as the developing and decaying processes of ENSO are [*Kessler and McPhaden*, 1995]. For example, *Kessler and McPhaden* [2002] argued that El Niños are event-like disturbances with respect to a stable basic state, requiring an initiating impulse not contained in the dynamics of the cycle itself. The initiation may be carried out by MJO activity [e.g., *McPhaden*, 1999] or other climate variation.

[3] Most El Niño prediction models failed to predict the excessive growth of the largest 1997/98 El Niño, when it was forecasted from the point prior to El Niño onset in early 1997, while the prediction, performed from the point after El Niño onset, captured well its rapid development [*Barnston et al.*, 1999; *Kang and Kug*, 2000]. Generally, the predictive skills of the dynamical and statistical models are degraded for ENSO onset period. Therefore, the El Niño onset is a challenging problem of ENSO prediction. If we can predict the El Niño onset correctly, it will be possible to predict the tropical Pacific SST with up to 18–24 months lead time because the models have greater predictive skill for the developing and decaying periods of ENSO. In order to predict ENSO onset, it is important to find its precursors. The heat content, residing oceanic memory, is one of the precursors as mentioned by *Jin* [1997], but may be not a sufficient condition for the onset of ENSO. The equatorial Western Pacific (WP) wind is another precursor, which is regarded as a critical factor for ENSO phase transition suggested by many studies [*Weisberg and Wang*, 1997; J.-S. Kug, and I.-S. Kang, Interactive feedback between the Indian Ocean and ENSO, submitted to *Journal of Climate*, 2004, hereinafter referred to as Kug and Kang, submitted manuscript, 2004]. In this study, we will show that these two factors are reasonable precursors of El Niño and La Niña onsets, and the onsets are linked to the Indian Ocean SST.

2. Observational Analysis

[4] During the period 1970–1999, there were 6 El Niño onsets (1972, 1976, 1982, 1986, 1991, and 1997) and 6 La Niña onsets (1970, 1973, 1983, 1988, 1995 and 1998). We excluded the 1994 El Niño case because of its short period. In addition, we defined a prolonged event as those representing an extension of the previous year's state, and these are not regarded as onset events. For example, El Niño years 1977 and 1987, and La Niña years 1974, 1975, 1984, 1985, 1999, and 2000 can hardly be regarded as events that started from the onset, but are better considered as a continuation of the previous year's state. We will discuss later why these events were prolonged longer than the others.

[5] Here, we examine two possible precursors of El Niño and La Niña onsets: equatorial heat content from SODA data [*Carton et al.*, 2000] and the WP wind from NCEP/NCAR reanalysis data. Since the El Niño/La Niña has a strong seasonal tendency in their initiation and peaks, for the precursors the average has been taken from January to March (JFM), prior to typical ENSO onset season (MAM). For the same reason, ENSO event is defined as the NINO3.4 SST averaged over Nov. through following Jan. (NDJ). The SST data were obtained from NCEP [*Reynolds and Smith*, 1994]. Figure 1 (top) shows three time series of JFM equatorial heat content, referring the subsurface temperature averaged between the surface and 500 m depth, JFM WP wind, and NDJ NINO3.4 SST. The heat content

[1]Climate Environment System Research Center, Seoul National University, Seoul, Korea.
[2]International Pacific Research Center, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii, USA.
[3]Department of Meteorology, Florida State University, Tallahassee, Florida, USA.

0094-8276/05/2004GL021674$05.00

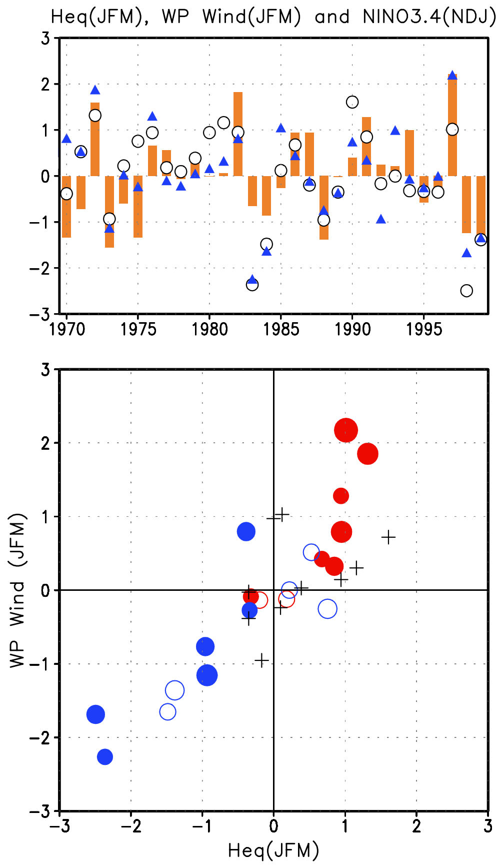

Figure 1. (top) Time series of normalized Heq (circle) and Western Pacific wind (triangle) during JFM, and NINO3.4 SST (Bar) during NDJ. (bottom) Scatter diagram of Heq and WP wind. Red and blue circles denote El Niño and La Niña events, respectively. Cross denotes normal state. Closed and open circles indicate onset events and prolonged events, respectively. The size of the circle is proportional to the magnitude of NINO3.4 SST.

index indicates the value averaged over 150°E–150°W and 4°S–4°N (hereafter, 'Heq'). The WP wind index denotes 925 hPa zonal wind averaged over 120–160°E, 5°S–5°N. These two precursor indices lead the NINO3.4 SST by approximately 10 months. The correlations of the Heq and WP wind with the NINO3.4 SST are 0.62 and 0.64 with 99% significant level, respectively.

[6] Figure 1 (bottom) shows the relationship between the NINO3.4 SST and the two indices. Red and blue circles denote warm and cold events, respectively, and the size of the circle represents magnitude of NINO3.4 SST. Closed and open circles denote onset events and prolonged events according to the previous definition, respectively. Every onset of El Niño is accompanied by the positive Heq anomaly. Similarly, every onset of La Niña coincides with a negative Heq anomaly. However, the larger positive Heq cases, which did not develop to the El Niño, are also detected. In addition, strong Heq anomalies are not necessarily consistent with strong ENSO events. Thus, the Heq, rather than a sufficient condition, is a necessary condition for onsets of El Niño or La Niña. The WP wind is also a good indicator of El Niño/La Niña onset. Most El Niño (La Niña) onset events coincide with positive (negative) WP wind events, but the WP wind alone cannot be considered as a sufficient condition for ENSO onset. When the Heq and WP wind are considered together, however, the onset is more obvious. For example, when both Heq and WP wind exceed 0.5 standard deviations simultaneously, either an El Niño or La Niña occurred depending on the sign of the two indicators with only one exception.

[7] We also found differences between El Niño and La Niña onsets. First, positive Heq does not always develop to El Niño. For example, there are 10 cases in which the Heq is larger than 0.5 standard deviations. Only 6 cases out of 10 developed into El Niño. In contrast, every negative Heq event (6 cases) leads to La Niña events. In terms of the WP wind, a similar asymmetry is found. When the WP wind is larger than 0.5 standard deviation, only 4 cases out of 8 lead to El Niño events. The 6 negative WP wind cases out of 7 lead to La Niña events. This indicates that the onset of El Niño is less predictable than that of La Niña.

[8] Figure 2 shows time series of daily WP wind for 5 extreme WP wind cases. A contrasting feature between the positive and negative WP wind cases is found. In the case of the positive WP wind events, the WP wind seems to result from short-time scale variability such as the Westerly Wind Burst (WWB) as shown in a number of studies that have reported that the WWB is related to El Niño onset [e.g., *Curtis et al.*, 2004; many others]. In the case of the negative WP wind, however, the easterly wind anomalies are more likely to be persistent rather than intermittent. Naturally, one may raise the question of how the easterly wind can be maintained for several months.

[9] In order to compare the asymmetric feature of the WP wind events, we carried out composite analysis for positive

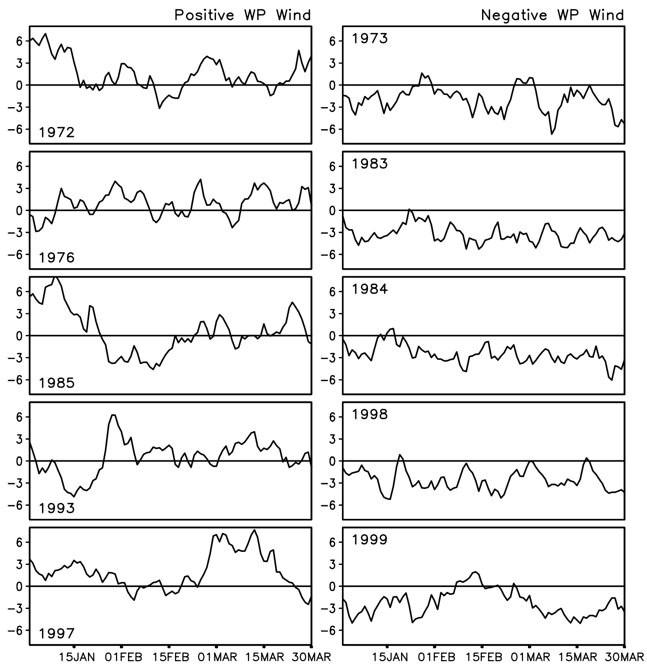

Figure 2. Time series of daily mean WP wind for 5 extreme cases of (left) positive and (right) negative WP wind events. The anomaly is calculated from JFM mean climatology. Unit is m s^{-1}.

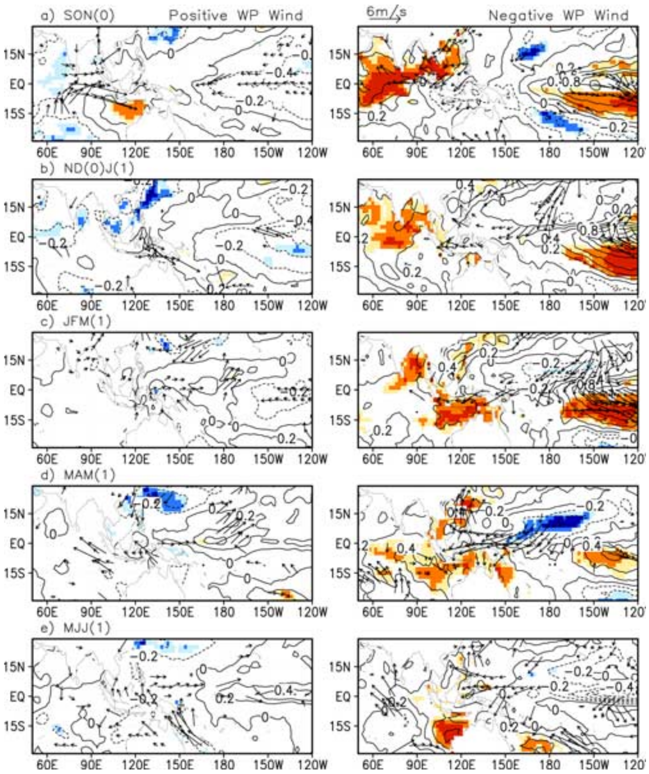

Figure 3. Composite of SST (contour) and 925 hPa wind (vector) for (left) positive and (right) negative WP wind events. Shaded areas represent 90%, 95% and 99% confidence levels. The significant level is from student t-test and the degree of freedom is obtained by assuming the unequal variances. Year 0 and year 1 denote the year during which an El Niño develops and the following year, respectively.

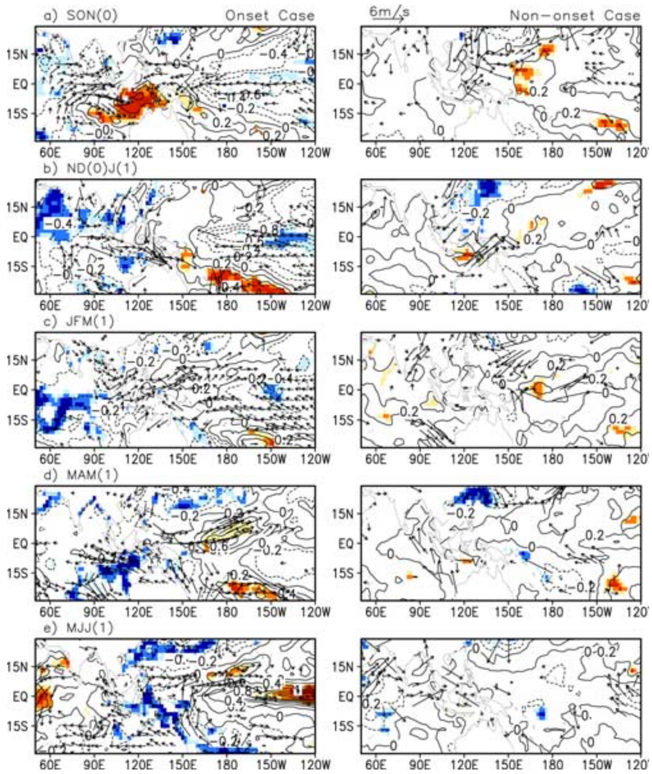

Figure 4. Same as Figure 3 except for (left) onset case and (right) non-onset case associated with the positive WP wind events.

and negative WP wind events. From a criterion of 0.5 standard deviations for the WP wind during JFM, 8 and 7 cases are selected for positive and negative composites, respectively. Note that 6 cases among 7 negative events developed into La Niña, while only 4 cases among the 8 positive events developed into El Niño. Figure 3 shows the composite plots of SST and 925 hPa wind for the positive (left panel) and negative (right panel) events. During SON prior to the positive WP wind events, the weak negative SSTs and westerly wind anomalies over the Indian Ocean are observed in which anomalies do not persist to the following season. At JFM, a westerly wind anomaly appears in the WP but the signal of SST anomaly in that region is not significant. After JFM passed, the wind anomaly becomes weaker. This feature can be linked to the strong short-time scale variation in Figure 2. Accordingly, a positive WP wind event rarely accompanies the development of El Niño.

[10] For the negative case, there is a significant increase of SST anomalies over the Indian Ocean and the eastern Pacific during the previous fall and winter (Figure 3). Along with the SST anomalies, a significant anticyclonic flow also appears over the Philippine Sea. Recent studies have suggested that the Indian Ocean warming plays a role in development of the Philippine Sea anticyclone as much as the local SST does [*Watanabe and Jin*, 2003]. To some extent, these patterns are similar to those of the El Niño mature phase. During JFM, the easterly wind anomaly appears over the equatorial eastern Pacific, and the eastern Pacific SST starts to decay. Note that the Indian Ocean SST warming persists unlike the positive composite. The persistent SST warming is accompanied by an enhanced convection over the Indian Ocean, which can induce the anomalous WP wind by modulating the Walker circulation [*Misra*, 2004; Kug and Kang, submitted manuscript, 2004]. Although the eastern Pacific SST is very weak during MAM, the WP wind is further developed, which induces negative SST anomalies over the western and central Pacific. Once the off-equatorial SST cooling is established by the WP wind, the cold SST can enhance the WP wind by atmospheric response of the Rossby wave type to the cold SST [*Wang et al.*, 2000]. Owing to persistent easterly wind anomalies over the WP, La Niña can easily develop.

[11] In summary, we found two significant differences between the positive and negative composites from Figure 3. These are the persistence of the WP wind and the significance of SST anomalies over the Indian Ocean, and they are physically linked. It seems that the differences determine whether the onset will progress.

[12] In order to know what is crucial factor for determining of developing El Niño or not, we divided the positive WP wind events into onset cases (the years 1972, 1976, 1982, and 1997) and non-onset cases (the years 1970, 1985, 1990 and 1993). Figure 4 shows the composites for the two cases. Though the positive WP wind occurs in both cases, the two composites show clearly different features in SST anomalies over the Indian Ocean. In the onset composite,

the cold SST anomalies over the Indian Ocean persist from one season before to one season after the WP wind events (JFM). These SST and wind anomalies over the Indian and WP oceans are similar to Figures 3 and 4 of *Reason et al.* [2000], who used longer data set from the period of 1878–1989. On the other hand, in the non-onset composite the Indian Ocean SST anomaly is not significant throughout. It is interesting that the composites of the onset case are very similar to those of the negative WP wind composite (Figure 3) except for the opposite sign. This indicates that those patterns represent pre-conditions for development into El Niño or La Niña events.

3. Discussion

[13] We suggested two factors as precursors of El Niño and La Niña onsets. One is the equatorial heat content, and the other is the WP wind. We found that each by itself is a necessary but not sufficient condition for El Niño onset. When the two factors are considered together, however, both El Niño and La Niña onsets become highly predictable. The persistent westerly (easterly) WP wind tends to be concurrent with the Indian Ocean SST cooling (warming). Therefore, the Indian Ocean SST can be a good indicator of El Niño and La Niña onsets.

[14] For most previous ENSO composite analysis [e.g., *Ramusson and Carpenter*, 1982; *Harrison and Larkin*, 1996; *Reason et al.*, 2000], they selected the cases on the basis of ENSO index during its mature phase. So, they can give reliable information for developing and decaying phase, but it is hard to give precise information for the onset. Because some El Niño/La Niña events were prolonged from previous year events. So, the signals can be contaminated. In particular, most La Niña events tend to be prolonged for 2–3 years. Since the onset events and prolonged events are divided in this study, we can give further precise information for ENSO onset. Accordingly, we can show more clearly the relationship between ENSO onset and Indian Ocean SST for both El Niño and La Niña cases.

[15] To some extent, the WP wind can be understood as a part of ENSO system. *Weisberg and Wang* [1997] suggested that the WP wind is a major transition mechanism of ENSO. They argued that the WP wind driven by the local WP SST is directly related to ENSO. However, it is still unclear whether the local SST can fully drive the WP wind. For example, our composite analyses show that the WP SST is of little significance during the occurrence of the WP wind events (Figures 3 and 4). Recently, Kug and Kang (submitted manuscript, 2004) showed that the WP wind is closely related to the Indian Ocean SST. They emphasized an interactive feedback between ENSO and the Indian Ocean. Their argument is applicable, especially for most La Niña onset events. That is, the La Niña onsets that followed El Niño event were almost always accompanied by Indian Ocean warming.

[16] However, most but not all El Niño (La Niña) events were accompanied by the Indian Ocean SST warming (cooling). When ENSO events did not coincide with the changes in the SST over the Indian Ocean, most of these events were prolonged into the following year. In particular, La Niña events are weakly correlated with the Indian Ocean surface cooling compared to the counterpart of El Niño events, inferring that La Niña is more favorable to prolongation. For example, the 1973/1974, 1983/1984, and 1998/1999 La Niña events were not accompanied by the Indian Ocean SST cooling, and thus the La Niña events were prolonged for 2–3 years.

[17] We also found a distinctive asymmetric feature between the El Niño and La Niña onsets. It seems that the asymmetry is connected to the asymmetric coherency between the Indian Ocean and ENSO as we mentioned before. The El Niño events were mostly accompanied by Indian Ocean warming, while the La Niña events were less significantly related to the Indian Ocean SST cooling. Therefore, following the El Niño mature phase, La Niña onset more clearly progresses along with Indian Ocean warming. On the other hand, El Niño onset is less clear because the Indian Ocean SST is not always generated during the La Niña mature phase. This asymmetric coherency may be caused by asymmetric atmospheric response to SST forcing [*Kang and Kug*, 2002] and skewness of ENSO magnitude [*Burgers and Stephenson*, 1999]. However, further research efforts are required to resolve the detailed mechanism responsible for the asymmetric coherency.

[18] **Acknowledgments.** This research was supported by the SRC program of the Korean Science and Engineering Foundation. I.-S. Kang is partly supported by the project 'Development of forecast techniques for the East Asia monsoon-Changma circulation system', one of the Meteorological and Earthquake R&D programs funded by the Korea Meteorological Administration (KMA). S.-I. An is also supported by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) through its sponsorship of the International Pacific Research Center. SOEST contribution #6521 and IPRC contribution IPRC-306.

References

Barnston, A. G., M. H. Glantz, and Y. He (1999), Predictive skill of statistical and dynamical climate models in SST forecasts during the 1997–98 El Niño episode and the 1998 La Niña onset, *Bull. Am. Meteorol. Soc.*, *80*, 217–244.

Burgers, G., and D. B. Stephenson (1999), The "normality" of El Niño, *Geophys. Res. Lett.*, *26*, 1027–1030.

Carton, J. A., G. Chepurin, X. Cao, and B. Giese (2000), A simple ocean data assimilation analysis of the global upper ocean 1950–95. Part I: Methodology, *J. Phys. Oceanogr.*, *30*, 294–309.

Curtis, S., R. F. Adler, G. J. Huffman, and G. Gu (2004), Westerly wind events and precipitation in the eastern Indian Ocean as predictors for El Niño: Climatology and case study for the 2002–2003 El Niño, *J. Geophys. Res.*, *109*, D20104, doi:10.1029/2004JD004663.

Harrison, D. E., and N. K. Larkin (1996), The COADS sea level pressure signal: A near-global El Niño composite and time series view, 1946–1993, *J. Clim.*, *9*, 3025–3055.

Jin, F.-F. (1997), An equatorial ocean recharge paradigm for ENSO. Part I: Conceptual model, *J. Atmos. Sci.*, *54*, 811–829.

Kang, I.-S., and J.-S. Kug (2000), An El Niño prediction system with an intermediate ocean and statistical atmosphere model, *Geophys. Res. Lett.*, *27*, 1167–1170.

Kang, I. S., and J. S. Kug (2002), El Niño and La Niña sea surface temperature anomalies: Asymmetry characteristics associated with their wind stress anomalies, *J. Geophys. Res.*, *107*(D19), 4372, doi:10.1029/2001JD000393.

Kessler, W. S., and M. J. McPhaden (1995), Oceanic equatorial waves and the 1991–93 El Niño, *J. Clim.*, *7*, 1757–1774.

Kessler, W. S., and M. J. McPhaden (2002), Is ENSO a cycle or a series of events?, *Geophys. Res. Lett.*, *29*(23), 2125, doi:10.1029/2002GL015924.

McPhaden, M. J. (1999), Genesis and evolution of the 1997–98 El Niño, *Science*, *283*, 950–954.

Misra, V. (2004), The teleconnection between the western Indian and the western Pacific oceans, *Mon. Weather Rev.*, *132*, 445–455.

Ramusson, E. M., and T. H. Carpenter (1982), Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño, *Mon. Weather Rev.*, *110*, 354–384.

Reason, C. J. C., R. J. Allan, J. A. Lindesay, and T. J. Ansell (2000), ENSO and climate signals across the Indian Ocean basin in the global contest: Part I. Interannual composite patterns, *Int. J. Climatol.*, *20*, 1285–1327.

Reynolds, R. W., and T. M. Smith (1994), Improved global sea surface temperature analysis using optimum interpolation, *J. Clim.*, *8*, 929–948.

Wang, B., R. Wu, and X. Fu (2000), Pacific-East Asia teleconnection: How does ENSO affect East Asian climate?, *J. Clim.*, *13*, 1517–1536.

Watanabe, M., and F.-F. Jin (2003), A moist linear baroclinic model: Coupled dynamical-convective response to El Niño, *J. Clim.*, *16*, 1121–1140.

Weisberg, R. H., and C. Wang (1997), A western Pacific oscillator paradigm for the El Niño–Southern Oscillation, *Geophys. Res. Lett.*, *24*, 779–782.

S.-I. An, International Pacific Research Center, SOEST, University of Hawaii at Manoa, Honolulu, HI 96822, USA.

F.-F. Jin, Department of Meteorology, Florida State University, Tallahassee, FL 32306, USA.

I.-S. Kang and J.-S. Kug, Climate Environment System Research Center, Seoul National University, Kwanwak-Ku, 151-742 Seoul, Korea. (jskug@climate.snu.ac.kr)