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Three evolution patterns of Central-Pacific El Niño

Jin-Yi Yu[1] and Seon Tae Kim[1]

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[1] Three evolution patterns are identified for the Central-Pacific (CP) type of El Niño based on events that occurred during 1958–2007: (1) a symmetric-decaying pattern whose sea surface temperature anomalies grow and decay symmetrically with respect to a peak phase; (2) a prolonged-decaying pattern that decays slowly and is followed by a warm event in the eastern Pacific (EP); and (3) an abrupt-decaying pattern that terminates rapidly after the peak and is followed by a cold event in the EP. The depth of the equatorial thermocline is found to determine which evolution pattern occurs. If the CP El Niño occurs in a recharged thermocline state (i.e., deeper-than-normal depth), an EP warming may appear in the decaying phase of the CP event to slow down the decay, giving rise to the prolonged-decaying pattern. If the thermocline is in a discharged state (i.e., shallower-than-normal depth), an EP cooling may occur to abruptly terminate the CP El Niño. If the thermocline is in a neutral state (i.e., normal depth), the CP event may have a symmetric pattern of growth and decay. Although a few exceptions exist, these results indicate that the equatorial thermocline state at the peak phase of a CP El Niño event can be a potential predictor of the way the event may decay. **Citation:** Yu, J.-Y., and S. Tae Kim (2010), Three evolution patterns of Central-Pacific El Niño, *Geophys. Res. Lett.*, *37*, L08706, doi:10.1029/2010GL042810.

1. Introduction

[2] Recent studies have suggested that there are two different types of interannual sea surface temperature (SST) variability in the tropical Pacific [*Larkin and Harrison*, 2005; *Yu and Kao*, 2007; *Ashok et al.*, 2007; *Kao and Yu*, 2009; *Kug et al.*, 2009]. One of them is the conventional type that has most of its (SST) anomalies centered in the eastern Pacific, and the other is a non-conventional type that has SST anomalies confined more to the central Pacific. *Kao and Yu* [2009] refer to these two types as the Eastern-Pacific (EP) and Central-Pacific (CP) types, respectively. Studies have shown that these two types have different impacts on global weather and climate [e.g., *Larkin and Harrison*, 2005; *Kao and Yu*, 2009; *Weng et al.*, 2009; *Kim et al.*, 2009; *Yeh et al.*, 2009]. It was argued that the CP El Niño events have become more frequent during recent decades [*Ashok et al.*, 2007; *Kao and Yu*, 2009; *Yeh et al.*, 2009; *Yu et al.*, 2010]. Thus, interest in the dynamical processes responsible for the CP El Niño events has been increasing rapidly.

[1] Department of Earth System Science, University of California, Irvine, California, USA.

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[3] By examining the associated subsurface ocean temperature variations, *Kao and Yu* [2009] concluded that the EP type is produced by basin-wide thermocline variations similar to those described by the recharge-discharge oscillator [*Wyrtki*, 1985; *Jin*, 1997] theory, while the CP type involves only local air-sea interactions. According to the recharge-discharge theory, the EP type of El Niño acts as a mechanism to remove excess ocean heat content from the equatorial to the off-equatorial Pacific. After an EP El Niño event, the equatorial thermocline is in a discharged state that is characterized by above-normal depths and is ready to produce an EP type of La Niña event. After an EP La Niña event, the thermocline is recharged to below-normal depths, and is ready to produce the EP type of El Niño again.

[4] As for the CP type, its specific generation mechanism is not fully understood yet. *Yu et al.* [2009] used numerical experiments to argue that the CP type can be generated by Asian and Australian monsoon forcing. *Kug et al.* [2009] argued that the zonal ocean advection plays a key role in developing the CP El Niño. *Yu et al.* [2010] further suggested that the ocean advection processes are important only after the CP type SST anomalies onset at the equator, and that the initial establishment of the equatorial SST anomalies is forced by subtropical atmospheric forcing. Despite some differences, these studies agree that equatorial thermocline variations are not crucial to producing CP El Niño/La Niña events, although *Ashok et al.* [2007] still emphasized the importance of wind-induced thermocline variations within the tropical Pacific to the SST evolution of their Modoki.

[5] By inspecting the evolution of SST anomalies in the tropical Pacific, it has come to our attention that the CP El Niño tends to evolve differently from event to event and can be followed by a warm or cold phase of the EP type. There is a need to summarize these evolution patterns and explore their possible causes. In particular, we want to know if these evolution patterns occur randomly or they are determined by certain oceanic conditions. Answers to these questions are important to further understanding the generation mechanism of the CP type of El Niño/La Niña.

2. Data

[6] For SST information, we use the National Oceanic and Atmospheric Administration Extended Reconstruction of Historical Sea Surface Temperature version 3 (ERSST V3) data [*Smith and Reynolds*, 2003] from the National Climate Data Center (NCDC) and the Met Office Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST) [*Rayner et al.*, 2003]. For subsurface ocean temperature information, we use the dataset taken from the Simple Ocean Data Assimilation Reanalysis (SODA) [*Carton et al.*, 2000]. We choose to analyze the period 1958–2007, during which both the ERSST and SODA are available. Anomalous quantities are computed by removing the monthly-mean

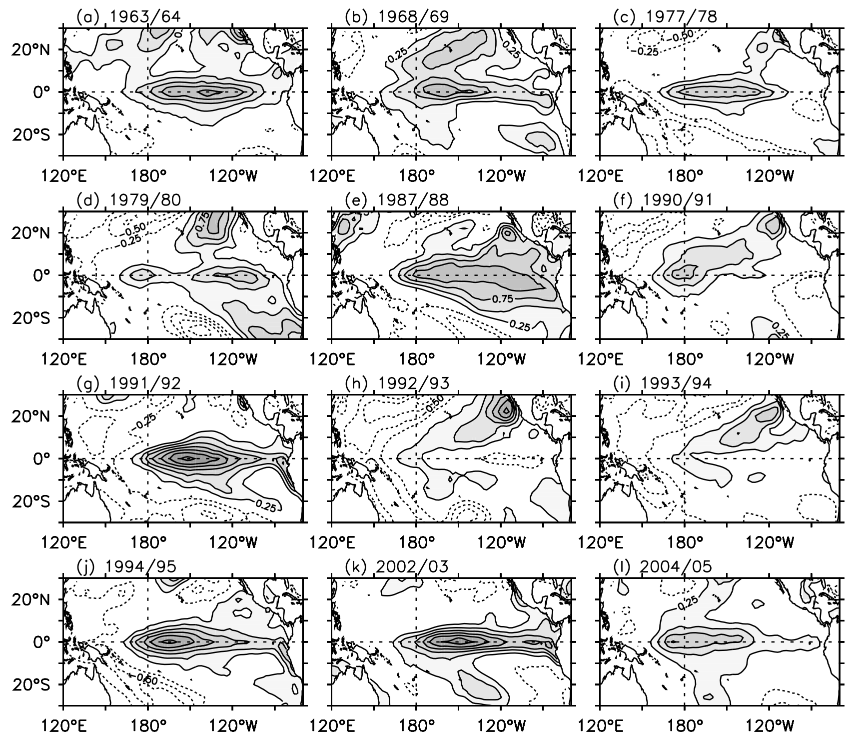

Figure 1. SONDJF-averaged SST anomalies for the CP El Niño events occurred during 1958–2007. Zero contour lines are removed and shaded regions denote positive SST anomalies. Contour intervals are 0.25°C.

climatology and the trend. We also use the observed anomalous 20°C isothermal depth from the Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) arrays [*McPhaden*, 1995] from June 1986 to February 2010.

3. Results

[7] We first use the CP index produced by *Kao and Yu* [2009, Figure 6a] to identify CP El Niño events during the analysis period. *Kao and Yu* [2009] used a combined regression-EOF (Empirical Orthogonal Function) method to separate the CP and EP types of El Niño/La Niña. To obtain the SST anomaly pattern of the CP type, they first removed the SST anomalies regressed with the Niño1+2 (0°–10°S; 80°W–90°W) SST index (which represent the influence of the EP type) and then applied EOF analysis to the residual anomalies. The monthly values of the principal component of this CP-EOF are the CP index and are used to indicate the strength of the CP events. We analyze only strong CP El Niño events defined as those whose CP index averaged seasonally from September to the following February (SONDJF) has a magnitude larger than one standard deviation. Based on this selection criterion, we identify a total of twelve CP El Niño events. Figure 1 displays the spatial patterns of the SONDJF-averaged tropical Pacific SST anomalies for each of the twelve events. Most of the events show a peak warming in the central Pacific, except the 1979/80, 1992/93 and 1993/94 events whose SST anomalies occur mostly in the subtropics extending from the northeastern Pacific to the central equatorial Pacific. This region is part of the horseshoe-like EOF pattern identified by *Kao and Yu* [2009] for the CP type of tropical Pacific SST variability. Since these three events do not have large SST anomalies in the equatorial Pacific, we decided not to include them in our analysis that focuses on the SST evolution patterns in the tropical Pacific.

[8] We next inspect the evolution of SST anomalies along the equatorial Pacific (averaged between 5°S and 5°N) for the nine selected events, shown in Figure 2. We notice that the evolution can be separated into three different groups. In the first group (Figures 2a–2c), the CP El Niño events are followed by a significant warming in the eastern Pacific. This group includes the 1968/69, 1990/91, and 1991/92 events. All three events reached their peak intensities in boreal winter and decayed during the following spring. During their decaying phase, an EP type of El Niño emerged and produced significant positive SST anomalies during boreal summer off the South American coast. In the second group (Figures 2d–2f), the CP El Niño events are followed by significant cooling in the eastern Pacific. This group includes the 1963/64, 1977/78, and 1987/88 CP events. These events reached their peak intensities near boreal winter (except the 1987/88 event) and the EP type of cooling developed after the demise of the CP events. The third group (Figures 2g–2i) has warming occurring more-or-less simultaneously in both the central and eastern Pacific. This group includes the 1994/95, 2002/03, and 2004/05 CP El Niño events. All three groups show similar warm peak timing for most of the CP events but very different SST evolutions during the decaying phase. Therefore, our analysis focuses on understanding what determines the different decaying phases.

[9] A composite analysis is performed from July of the CP El Niño year (year 0) to June of the following year (year +1). The composites are used to identify common features in each of the three groups. Figure 3 shows the composite SST anomalies along the equatorial Pacific (5°S–5°N). One

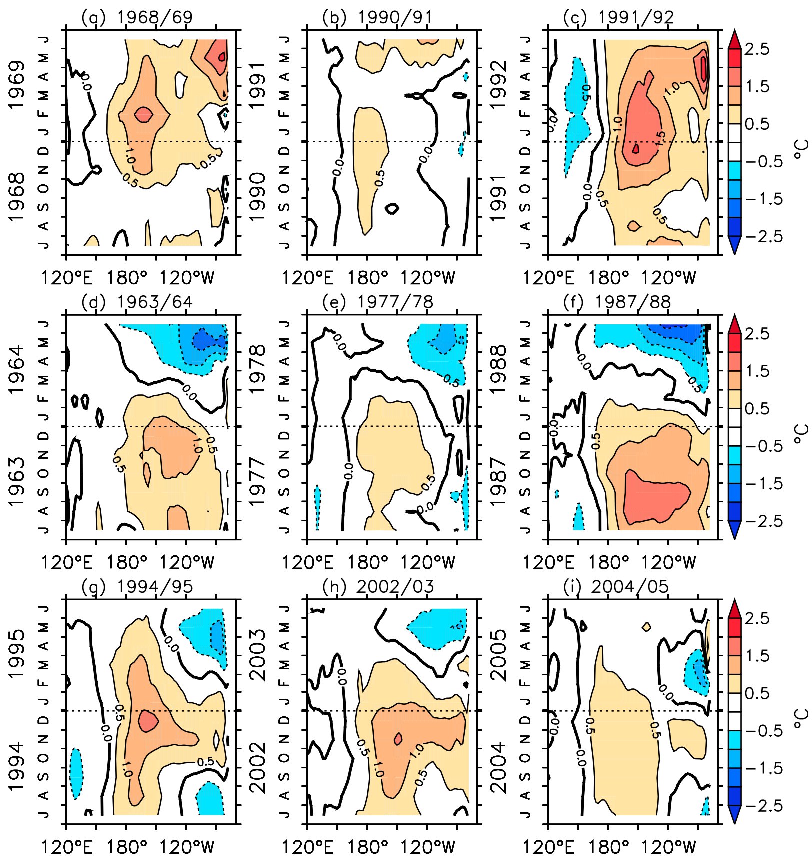

Figure 2. Evolution of equatorial Pacific (5°S–5°N) SST anomalies for CP El Niño events from July of the El Niño year to June of the following year.

common feature among all three groups is the winter peak of the CP El Niño events, which is consistent with the phase locking property of the CP type noted by *Kao and Yu* [2009]. Also consistent with Figure 1, the composite CP El Niño can be followed by an EP warming (Group 1; Figure 3a) or cooling (Group 2; Figure 3b) or occur at the same time with an EP El Niño (Group 3; Figure 3c). Furthermore, it is apparent that Group 1 has a slow and prolonged decay phase compared to the duration of warming in its growth phase. In contrast, Group 2 has an abrupt decay phase. The event terminates rapidly after reaching its peak intensity. As for Group 3, its decay and growth phases tend to be more symmetric with respect to the peak phase. Therefore, the three evolution patterns of the CP El Niño can be characterized as a prolonged-decaying pattern (i.e., Group 1), an abrupt-decaying pattern (i.e., Group 2), and a symmetric-decaying pattern (i.e., Group 3). Since only three events are used in the composite of each group, there is a concern that the composite may be dominated by one particularly strong event. Therefore, we also perform a composite using the anomalies scaled by the peak value of each event. Similar results are obtained (not shown). We also repeated the analysis with the HadISST and obtained similar composites as shown in Figures 3d–3f. The similarity increases our confidence that the three different evolution patterns we identified are not due to particular SST dataset used.

[10] We further examine in Figure 4a the composite thermocline evolution, (represented by the 20°C isotherm depth; D20C) in the equatorial Pacific for the three groups of CP El Niño events. The in-situ D20C anomalies observed by TAO/TRITON are averaged between 5°S and 5°N and between 120°E and 80°W to indicate the zonal-mean thermocline depth variations. It is interesting to notice from Figure 4 that the prolonged-decaying pattern (i.e. Group 1) occurs with a mean equatorial thermocline depth that is deeper than normal (i.e., positive D20C anomalies). As explained in the introduction, such an equatorial thermocline is in a *recharged state* in which an excessive amount of ocean heat content at the equator is ready to produce an EP type of El Niño. After the CP events in Group 1 reach their peak phase in boreal winter, the excessive ocean heat content propagates from western to eastern equatorial Pacific to produce a warming in the eastern Pacific (not shown). In contrast to Group 1, the abrupt-decaying pattern (i.e., Group 2) occurs with a shallower-than-normal equatorial thermocline depth (i.e., negative D20C anomalies). Therefore, the equatorial Pacific can be considered to be in a *discharged state* that has anomalously low ocean heat content and is ready to produce an EP type of La Niña according to the recharge-discharge theory. Figure 4a shows that this discharged state continues to develop during the decaying of the CP El Niño from the winter, D(0)JF(+1), and reaches its minimum depth in the following year (year +1) spring, when an EP La Niña onsets in the eastern Pacific. As for the symmetric-decaying pattern (i.e., Group 3), it is different from the previous two evolution patterns. Its mean thermocline depth is near a *neutral state* when the CP El Niño peaks during boreal winter. As a result, the decay of the Group 3 CP El Niño is influenced less by SST variations

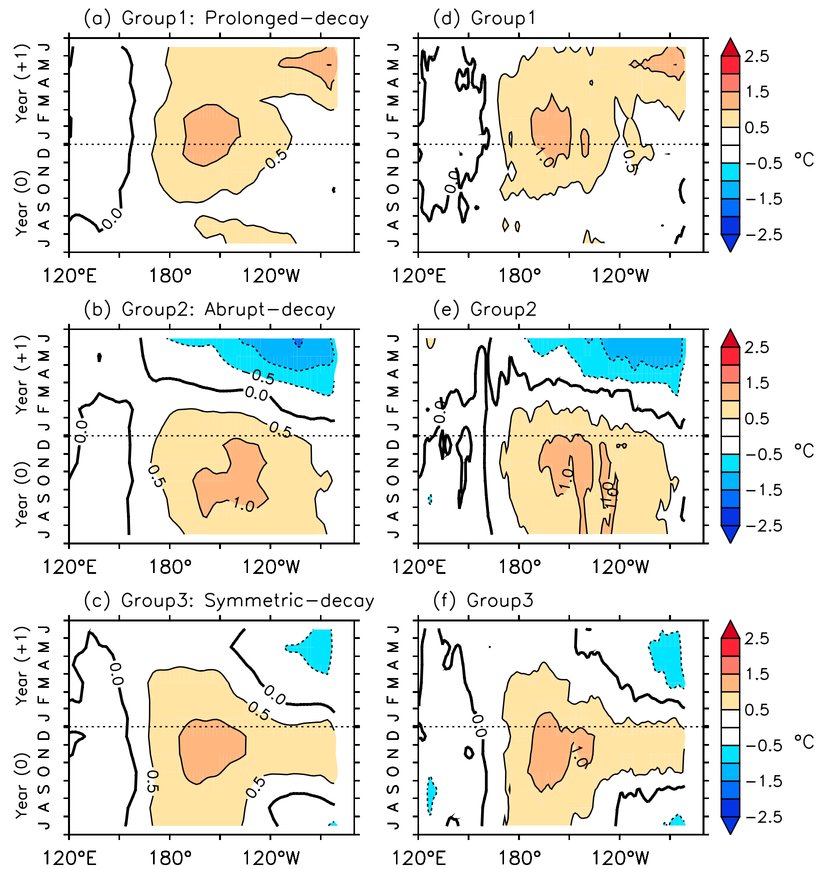

Figure 3. Evolution of equatorial Pacific (5°S–5°N) SST anomalies composite for the three groups of CP El Niño from July of the El Niño year (0) to June of the following year (+1) calculated from the (left) ERSST and (right) HadISST datasets.

in the eastern Pacific and tends to have a decaying phase more symmetric to its growing phase.

[11] It should be noted that due to the availability of the TAO/TRITON thermocline data, the composites are produced using only two CP events for Group 1, one event for Group 2, and three events for Group 3. Figures 4b–4d show the individual D20C evolution for the available CP events in the three groups. The general features of the individual evolution are consistent with the composite shown in Figure 4a, although discrepancies exist. For example in the 2004/05 event of Group 3, the D20C anomalies decrease near the peak phase of the event, but the anomalies do not decrease all the way to negative values. Due to the limited length of the TAO/TRITON observations, we choose to repeat the analysis with the SODA assimilation product that can provide D20C information for all the nine CP events. The composite D20C evolution for the three groups and the individual evolution of each event are shown in Figure 4e and in Figures 4f–4h, respectively. The assimilation data show the thermocline evolution for all three events in Group 1, two events (1977/78 and 1987/88) in Group 2, and two events (1994/95 and 2002/03) in Group 3 are consistent with the composite ones. The 1963/64 event in Group 2 does not show negative anomaly values in the first half of the event evolution and the 2004/05 event in Group 3 does not reach the zero anomaly value at its peak, both of which deviate from the composite evolution of their groups. Nevertheless, Figure 4e shows that the composite D20C calculated from SODA are consistent with those obtained from the TAO/TRITON observations: the zonal mean thermocline depth at the equator is in a recharged state (i.e., above normal depth) for the Group 1 events, in a discharged state (i.e., below normal depth) for most of the Group 2 events, and near the neutral state for most of the Group 3 events. We also repeated the analysis with another assimilation product, the NCEP Global Ocean Data Assimilation System (GODAS) [*Saha et al.*, 2006] reanalysis, and found similar results (not shown).

[12] Therefore, Figure 4 indicates that it is the equatorial Pacific thermocline structure that determines whether a CP El Niño event will develop a prolonged-decaying, abrupt-decaying, or symmetric-decaying pattern. This finding can be very valuable for the prediction of the decay of CP El Niño events and is another major finding of this study, in addition to the identification of the three evolution patterns.

4. Summary and Discussion

[13] In this study, we identified three distinct evolution patterns of the CP type of El Niño based on an analysis of the nine strongest CP events since 1958. Our major finding is that the equatorial thermocline structure can determine whether a CP El Niño event will undergo a prolonged, abrupt, or symmetric decay. This finding does not contradict the previous suggestion that the CP type of El Niño/La Niña does not rely on the subsurface ocean processes for their

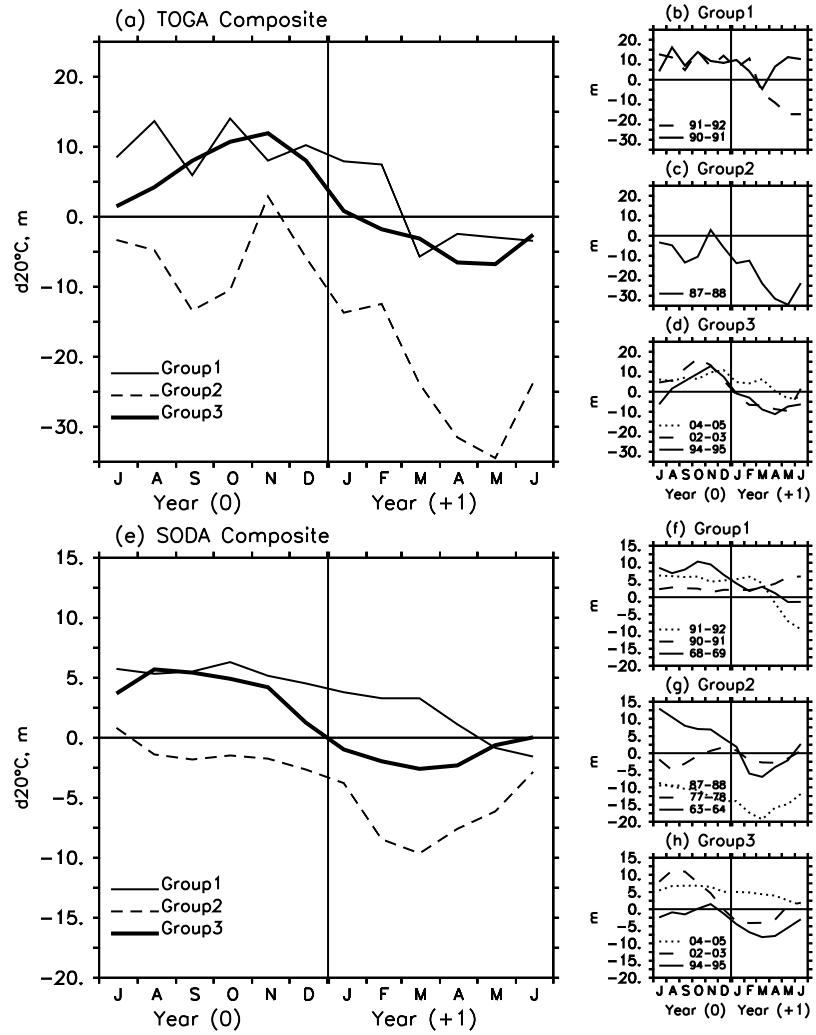

Figure 4. Evolution of the depth anomalies of the zonal-mean 20°C isotherm (D20°C) at the equator (5°S–5°N) calculated from the (a–d) TAO/TRITON observations and (e–h) SODA reanalysis data. A composite for each group (Figures 4a and 4e) and individual events of each group (Figures 4b–4d and 4f–4h) are displayed. The zonal mean is averaged between 120°E and 80°W. The evolution is shown from July of El Niño year (0) to June of the following year (+1).

generation. Rather, our results confirm that thermocline variations control only the generation of the EP type of SST variability but not the CP type of SST variability. CP El Niño events can occur in the presence of a deeper-than-normal (i.e., recharged state), shallow-than-normal (i.e., discharged state), or near-normal (i.e., neutral state) thermocline depth. However, these different thermocline structures do affect whether a warming, cooling, or neutral event may occur in the eastern Pacific as the CP event decays. Depending on the thermocline structure, the eastern Pacific warming, cooling, or neutral event may interfere with the SST evolution of the CP event and give rise to the three distinct CP El Niño SST decay patterns.

[14] Results in this study suggest that although thermocline variations are not crucial to the generation and the dynamics of the CP type of El Niño, the information on the thermocline depth at the peak phase of a CP event can potentially be used to predict when and how the CP event will terminate. It is the interplay between the dynamics of the CP and EP types of tropical SST variability that makes the thermocline information useful for the prediction of both types of SST variations. Although the results obtained from this exploratory study are interesting and possibly important for climate prediction, it should be cautioned that the results can only be considered as suggestive due to the limited number of CP events and limited duration of observed tropical ocean thermocline information available.

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S. T. Kim and J.-Y. Yu, Department of Earth System Science, University of California, Irvine, CA 92697-3100, USA. (jyyu@uci.edu)