DOI:10.16555/j.1006-8775.2015.02.006

Article ID: 1006-8775(2015) 02-0153-08

STUDY OF A COMPREHENSIVE MONITORING INDEX FOR TWO TYPES OF ENSO EVENTS

CAO Lu (曹 璐)[1], SUN Cheng-hu (孙丞虎)[2], REN Fu-min (任福民)[2], YUAN Yuan (袁 媛)[2], JIANG Jing (江 静)[3]

(1. Jiangsu Meteorological Observatory, Nanjing 210008 China; 2. National Climate Center, Beijing 100081 China; 3. School of Atmospheric Sciences, Nanjing University, Nanjing 210093 China)

Abstract: Some recent studies presented two existing types of ENSO events, one is the Eastern-Pacific (EP) type and the other the Central-Pacific (CP) type. This study examined the monitoring ability of several current operational ENSO indices. The results indicated that a single index could not distinguish the EP and CP in the historical ENSO events during 1950-2009. The Niño 3 index may only be suitable for monitoring the EP-type ENSO, while the Niño 4 index works only for the CP-type ENSO. In order to capture the occurrence of ENSO events and distinguish the type, we considered a new monitoring index group using Niño 3 and Niño 4 indices. Further analysis confirmed that this index group can monitor different types of historical ENSO events with different spatial distribution of sea surface temperature. It has a good performance in determining the characteristics of the ENSO events, including peak intensity, onset, decay, and mature phase.

Key words: ENSO events; Eastern-Pacific (EP) type; Central-Pacific (CP) type; ENSO index; index group

CLC number: P732 **Document code:** A

1 INTRODUCTION

As the strongest interannual climate signal in the global climate system, El Niño/Southern Oscillation (ENSO) often results in frequent occurrence of climate anomaly and extreme climatic events on the global scale (Christensen et al.[1]). Therefore, monitoring and predicting the ENSO provides reliable information and physical foundation for the prewarning of climate-related disasters (Huang[2]; Cheng et al.[3]; Cai et al.[4]; Wu et al.[5]; Liu et al.[6]; Zhai et al.[7]). In order to conduct operational ENSO monitoring, various institutions at home and abroad use a number of indices developed on the basis of these research results, e.g. the sea surface temperature of Niño 3.4 by Climate Prediction Community, USA (Barnston et al.[8]) or that of Niño 3 by Japan Meteorological Administration (Hanley et al.[9]). In China, the National Climate Center defined a Niño Z index by examining the sea surface temperature (SST) anomaly (SSTA) averaged over extended regions of the central and eastern Pacific (Niño 1+2+3+4) and used it to monitor the ENSO (Li [10]; Li et al.[11]). At the National Oceanological Administration, the conventional Niño 3 index is used. In addition to these indices for ENSO that are based on the variable of SST, an ENSO index (MEI) based on multiple physical variables was designed at the Laboratory for Earth System Studies of USA that combines atmospheric characteristics with the SST ones (Wolter and Timlin [12]). It is clear that there has not been any unified standard for ENSO monitoring indices internationally (Chen et al.[13]). Due to obvious differences among the indices above, large variations exist in determining the onset time and intensity of the same ENSO event (Trenberth[14]). With regard to the fact that there are multiple and inconsistent indices for monitoring the ENSO, the Science Supervision Group of the World Climate Research Program (CLIVAR) especially required its affiliated Working Group for Seasonal and Interannual Prediction (WGSIP) to address the issue with extra effort and solve it at an earliest possible time (WMO[15]).

It can be seen from ENSO's own characteristics that most of its events appeared in the cold tongue of the equatorial eastern Pacific (Niño 3) prior to the 1980s but they began to appear in the equatorial central and eastern Pacific after mid-1980s so that the conventional Niño 3 index could not monitor this type of ENSO efficiently (Wang and An[16]). Furthermore, existing studies have shown that these two types of ENSO differ in nature, evolution, genesis mechanism and climate impact (Kug et al.[17]; Sun et al.[18]), especially the central-Pacific-type of ENSO that often results in anomalously less typhoons (Zhou et al.[19]). As a result, the EMI, Niño 4 and CPI become the indices with which the

Received 2013-09-22; **Revised** 2015-01-21; **Accepted** 2015-04-15

Foundation item: The Definition of El Niño/La Niña Episodes, a National Standard Project; Specialized Project for Public Welfare Industries (GYHY201406018, GYHY200806009); Program 973 (2012CB955901); National Science and Technology Support Program (2009BAC51B05); National Youth Foundation for Natural Science (41005038)

Biography: SUN Cheng-hu, Ph.D., senior engineer, primarily undertaking research on the prediction of short-term climate.

Corresponding author: SUN Cheng-hu, e-mail: sunch@cma.gov.cn

ENSO events happening in the equatorial central Pacific are identified (Trenberth and Stepaniak[20]; Ashok[21]; Kao and Yu[22]). The CPC was the first institution in the world to replace the usual Niño 3 index with Niño 3.4 index, which is for the area joining the equatorial central Pacific (Niño 4) with the equatorial eastern Pacific (Niño 3), as the operational index for monitoring the ENSO. It is an effort to try to monitor all the ENSO events taking place in these areas of the Pacific. The CPC even suggested to the CLIVAR to draw plans to make the Niño 3.4 a standard index for monitoring the ENSO worldwide. However, the Niño 3.4 index alone cannot distinguish the eastern-Pacific type from the central-Pacific type of ENSO (Trenberth et al.[20] and Yu et al.[23]). In view of it, this work, on the basis of comparing main ENSO indices across the globe, sums up the advantages and drawbacks of these indices to determine a proper index that can identify the ENSO event with different distribution pattern accurately and comprehensively.

2 DATA AND DEFINITION OF ENSO

In this work, the monthly 1950-2009 ERSST V3 dataset with spatial resolution at 2 longitudes by 2 latitudes is used. The indices studied include Niño 3, Niño 3.4, Niño 4 and Niño Z [10]. To learn about the ability of different indices in distinguishing the CP type or the EP type of ENSO, this work also uses the EP index (EPI) and CP index (CPI) for standard EP and CP type of ENSO developed by Kao et al.[22]. The indices are defined as follows:

(1) Niño 3 anomaly index: SSTA averaged over 150 °W–90 °W, 5 °N–5 °S;

(2) Niño 3.4 anomaly index: SSTA averaged over 170–120 °W, 5 °N–5 °S;

(3) Niño 4 anomaly index: SSTA averaged over 160 °E–150 °W, 5 °N–5 °S;

(4) Niño Z (combining all zones) anomaly index[11]:

$$Z=\sum_{i=1}^{4}(SSTA_i \times S_i)/\sum_{i=1}^{4}S_i$$

i.e. SSTA averaged over Niño 1+2+3+4;

(5) EMI(El Niño/La Niña Modoki) anomaly index[21]: EMI=[SSTA]C-0.5[SSTA]E-0.5[SSTA]W, in which C stands for the central part of the equatorial Pacific (165°E–140 °W, 10 °S–10 °N), E the region of equatorial eastern Pacific (110–70 °W, 15 °S–5 °N), and W the region of equatorial western Pacific (125–145 °E, 10 °S–20 °N);

(6) EPI/CPI anomaly index[22]: For the EPI, first the regression analysis is used to obtain the residue independent of the change in the SST field of the tropical Pacific, and then the residue is analyzed for EOF, and the first primary component and time coefficient are used as the standard EOF mode and index for the EP type of ENSO event. The computation of the CPI is similar to that of the EPI but the effect of the Niño 1+2 SST has to be eliminated.

3 COMPARISONS OF DIFFERENT INDICES FOR ENSO MONITORING

3.1 *Types of spatial distribution of EP and CP types of ENSO*

Figure 1 gives the distribution of the EOF spatial distribution of the EP and CP types of ENSO for the EPI and CPI respectively as well as the evolutions of the time series of standardized EPI/CPI averaged over the winter (November to successive February) for 1950–2008. For the EP type of ENSO (Fig.1a) a main warm (cold) area is over the cold tongue in the equatorial eastern Pacific with the warm (cold) maxima being east of the equatorial 150 °W (inside Niño 3). For the CP type of ENSO (Fig.1b), the warm (cold) area is around the dateline with the warm (cold) maxima being west of the equatorial 150 °W (within Niño 4). It is known from the evolution of the time series of the two indices (Fig. 1c) that they are almost anti-correlated, which indicates that any one ENSO event can be divided into either the EP or CP type according to its pattern of spatial distribution. If the EPI/CPI greater than one standard deviation is taken as the threshold to determine the occurrence of EP-ENSO/CP-ENSO, the background differs

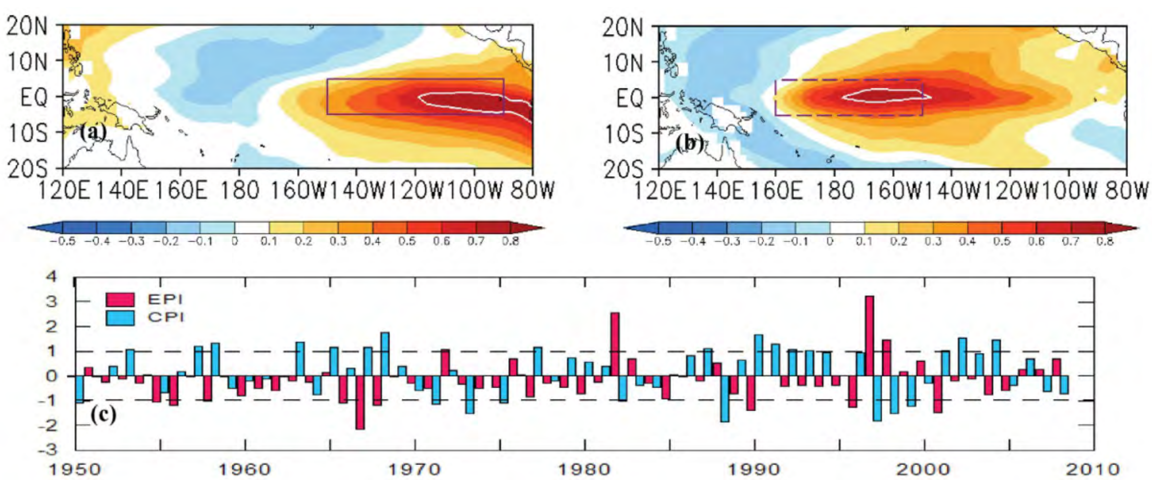

Figure 1. Distribution of EOF spatial modes of the EP-ENSO (a) and CP-ENSO (b) and their time series (c).

much in the time after 1950 and the CP-ENSO event tends to enhance over the past 20 years. It can then be seen that their independence of one another itself is sufficient enough to show that the two indices are highly representative of the type of ENSO each is used to indicate. Because of it, the analysis below will take them as the base of reference to compare them with other indices so as to study their capabilities in monitoring ENSO of different types.

3.2 *Application of different ENSO indices in the monitoring of the two types of ENSO*

3.2.1 OVERALL DIFFERENCES BETWEEN THE NIñO INDICES AND EPI/CPI

To study the difference of capabilities between the Niño indices and EPI/CPI, this work computes the correlation coefficient between these indices and EPI and CPI (Table 1). The results show that when the EP-ENSO appears, the Niño 3 index is best correlated with the EPI that represents the EP-ENSO at a coefficient of 0.62, followed by Niño Z and Niño 3.4, and Niño 4 is uncorrelated with an EPI of 0.0. On the other hand, the Niño 4 index is best correlated with the CP-ENSO index of 0.82, followed by the EMI and Niño 3.4. To further study the difference between the Niño indices and the EPI/CPI, the former indices are standardized and computed for their root mean square error (RMSE, see Table 1). As shown in the result, Niño 3 has the smallest difference from the EPI with a RMSE of 0.84 while Niño 4 has the smallest difference from the CPI with a RMSE of 0.67.

Table 1. Correlation coefficients and RMSEs (indicated by the numerals inside the brackets) for various Niño indices and the EPI/CPI.

Niño index	EPI	CPI
Niño 3	0.62(0.84)	0.46(1.06)
Niño 3.4	0.35(1.08)	0.68(0.82)
Niño 4	0.00(1.21)	0.82(0.67)
Niño Z	0.47(0.93)	0.58(0.9)
EMI	-0.59(1.35)	0.78(0.8)

3.2.2 COMPARISONS BETWEEN THE TWO TYPES OF ENSO IN SEASONAL PHASE-LOCKED NIñO INDICES

As shown in Yu et al.[23], both the EP and CP types of ENSO have good seasonal phase lock with the peak appearing from the end of autumn to winter. Then, can the existing Niño indices represent this characteristic well? For the strong EP-ENSO and CP-ENSO (Fig.1), the individual Niño indices in the phase-lock season (from November to the successive February) are further computed (Fig.2). As shown in the result, the Niño 3 index is the closest to the EPI, followed by the Niño Z index; the EMI is the closest to the CP-El Niño, followed by the Niño 4 index; the Niño 4 index is the closest to the CP-La Niña, followed by the EMI.

As shown in the analysis above, the widely used Niño 3 index has the best ability of monitoring the EP-ENSO while the Niño 4 index works best in monitoring the CP-ENSO. The Niño Z index is advantageous in monitoring the EP-ENSO while the Niño 3.4 index works with desirable ability in monitoring the CP-ENSO. It is then known that the main operational indices, either at home or abroad, are not able to monitor both types of ENSO.

3.3 *Description of the two types of ENSO by the Niño indices*

To have more knowledge about the difference in various Niño indices in monitoring the evolution and decay of both the EP-ENSO and CP-ENSO, this work follows Kuo's definition [22] and chooses from the cases in the winters of 1950-2009 the EP-ENSO and CP-ENSO with the EPI and CPI larger than one standard deviation (Fig.1) and uses the composite method to study the evolution of various Niño indices during the evolution and decay periods of ENSO.

It is clearly shown in Fig.3 that the EP type is much stronger for the El Niño event than the CP type

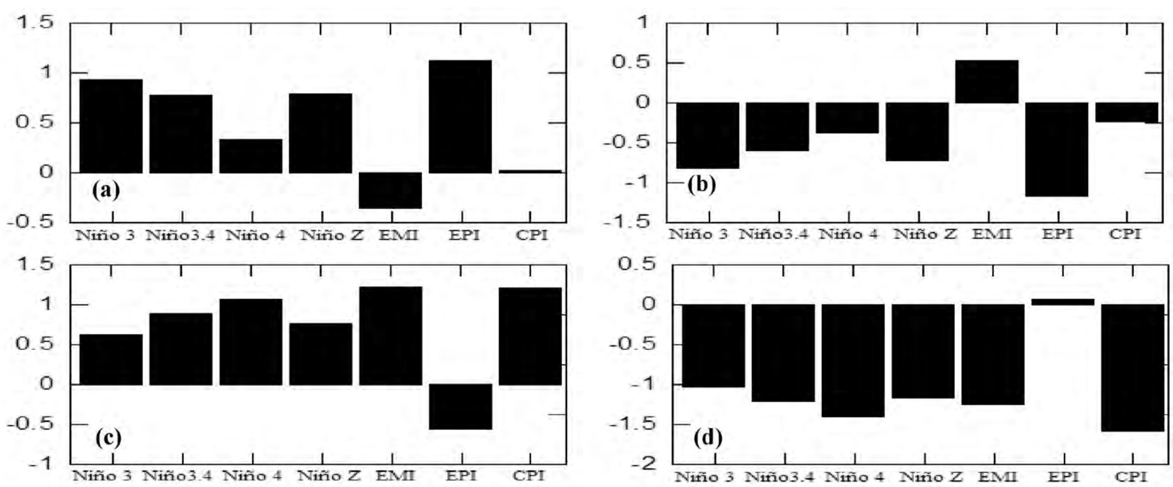

Figure 2. Composite mean of the indices for the winters (November to successive February) of 1950-2009. (a): EP-El Niño; (b): EP-La Niña; (c): CP-El Niño ; (d): CP-La Niña.

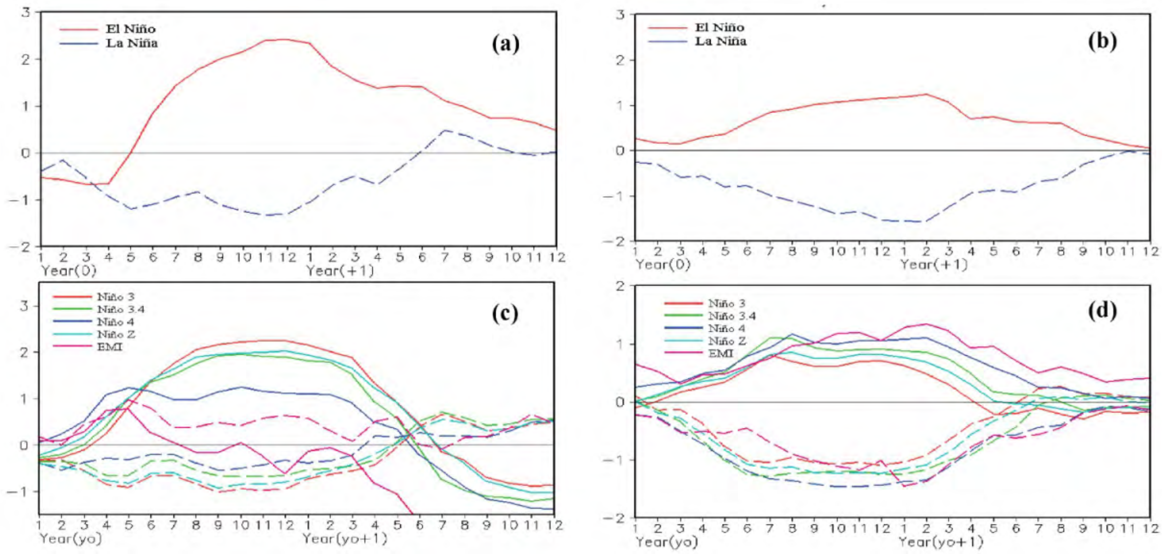

Figure 3. Evolution of different standardized ENSO monitoring indices for the EP-ENSO (a, c) and CP-ENSO (b, d) events. Solid curve: El Niño event; dashed curve: La Niña event. (a): Year of EP-ENSO occurrence and 24-month composite mean of standardized EPI; (b): Year of CP-ENSO occurrence and 24-month composite mean of standardized CPI; (c): Year of EP-ENSO occurrence and 24-month composite mean of standardized Niño indices; (d): Year of CP-ENSO occurrence and 24-month composite mean of standardized Niño indices.

with the largest index being up to 2 standard deviation while the CP type is much stronger for the La Niña event than the EP type, a characteristic consistent with the finding of Yu et al.[23]. It is also known from the evolution of the EP-ENSO that the Niño 3 index is always much warmer (cooler) than any other indices, suggesting that the main area of warming (cooling) for the EP-ENSO is located over a cold tongue of the equatorial eastern Pacific, a feature that reflects its nature.

Among various indices, the EMI is the index that reflects best the El Niño evolution for the CP-ENSO but works much worse for the La Niña, which may be attributed to its main function of being mainly used to reveal the El Niño Modoki (a western CP-El Niño). Further study indicates that the Niño 4 index is the best among the remaining indices in capturing the evolution of CP-El Niño and CP-La Niña and is able to represent all the periods from the genesis, evolution, maturing and decay of the CP-ENSO. It is therefore concluded that this is the right index for monitoring the CP-ENSO.

4 A GROUP OF INDICES COMBINING CP AND EP TYPES OF ENSO

As shown in the analysis above, the Niño 3 index has the best ability, among the current Niño indices in use, to monitor the EP-ENSO while the Niño 4 index is the best monitor for the CP-ENSO. No one single index can do well in identifying different types of ENSO. Then, can they be combined into a group to do the job? Before specific definition is given, the time-longitude distribution of equatorial SSTA smoothed for three months since 1950 and the evolution of corresponding Niño 3 index larger than 0.5℃ and Niño 4 index smaller than -0.5℃ that maintain for more than five months (Fig.4) are first presented here. Over the past 60 years, a total of 36 ENSO events have taken place by the Niño 3 index but the number is only 29 by the Niño 4 index. In contrast, the index group can cover all of the ENSO events. It is also found from Fig.4 that some relatively long ENSO events are with multiple peaks. For instance, for the strong La Niña events in 1954/1956 and 1999/2000, the Niño 3 index reported as two discontinuous events while the Niño 4 index showed it as one single event with dual peaks.

4.1 *Index group for comprehensive monitoring*

4.1.1 DEFINITION OF ENSO EVENT

An index group, which has been treated with moving average, is set up using the SSTA of the Niño 3 and Niño 4 from the climatological field in 1971-2000. When either of the indices reaches the threshold (±0.5℃) and remains in this state for at least five months, an El Niño (La Niña) event is defined to take place. When both of the indices pick up such an event but with different time of beginning and ending, the event is defined to begin at the earlier time and end at the later time.

4.1.2 DEFINITION OF ENSO TYPE

The indices of Niño 3 and Niño 4 are used to define the intensity of the ENSO event and the intensity at the peak of the ENSO is compared between Niño 3 and Niño 4 to decide on the type. When the peak intensity appears in Niño 3 (Niño 4), the event is defined as an EP type (CP type).

4.1.3 DEFINITION OF ENSO INTENSITY

With the Niño 3 and Niño 4 indices that are based on the 1971-2000 standard deviation, the peak intensity

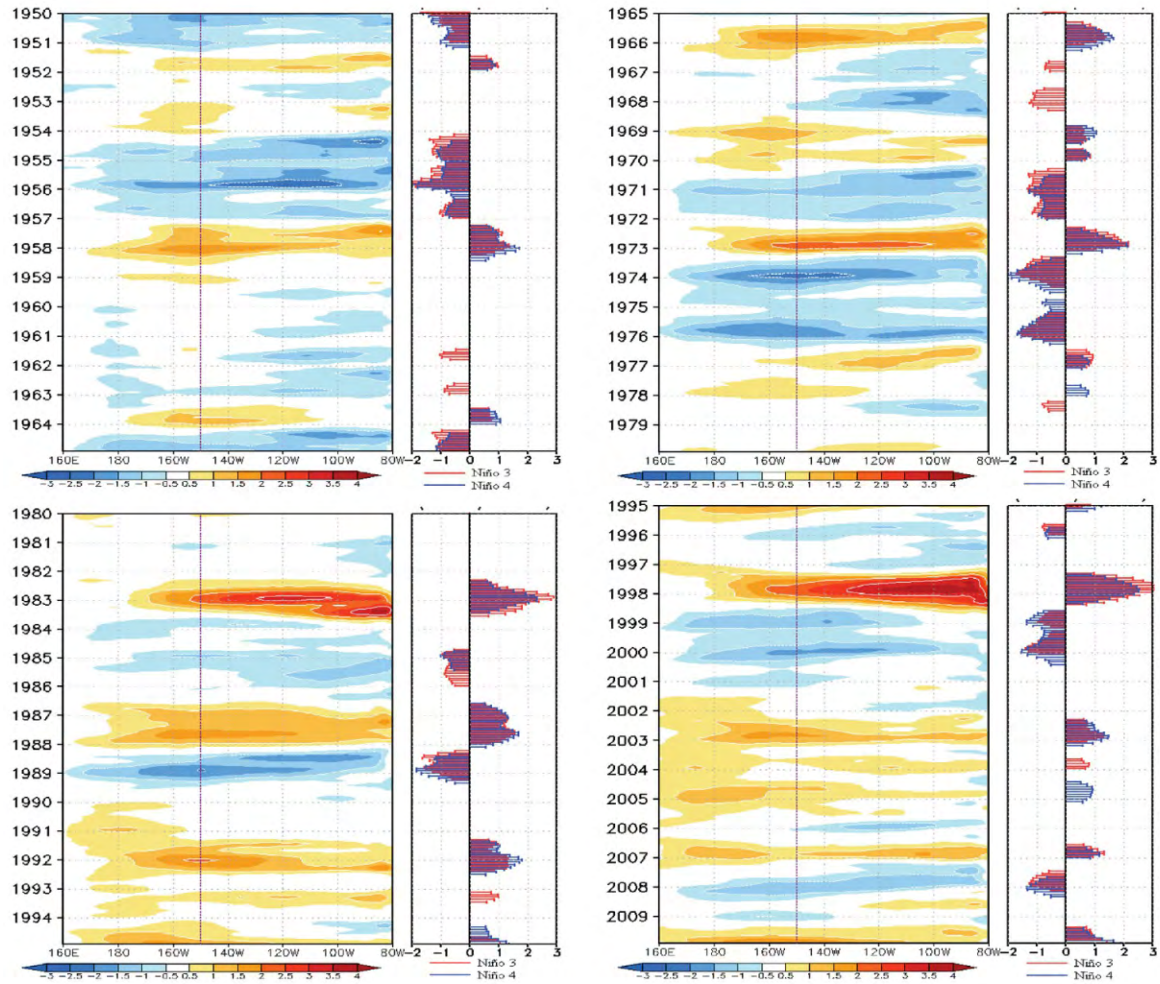

Figure 4. Time-longitude cross sections of three-month-smoothed SSTA evolution for 1950-2009 and evolution of corresponding Niño 3 and Niño 4 indices. The indices are plotted if they are larger (smaller) then 0.5℃ (-0.5℃) for five months.

of EP-El Niño and CP-La Niña events, which is defined with the index group, is statistically determined and five levels of intensity, namely very weak, weak, moderate, strong, very strong, are divided against four values within $\pm 0.5\sigma$ and $\pm\sigma$.

Following the definition presented above, Tables 2 and 3 introduce the type, intensity, onset and ending time of all the ENSO events in 1950-2009. How do the two types of ENSO exhibit their type, outbreak and ending time and intensity with the new definition of the index group? It will be studied in detail in the sections that follow.

4.2 *Variations of the two types of ENSO*

Figure 5 presents the 36 ENSO events taking place in the 60 years from 1950 to 2009 with 20 of them being the El Niño event and 16 being the La Niña event. The CP-El Niño (11 times) is in the majority in the El Niño event while the EP-La Niña (10 times) is much more in the La Niña event. It is attributed to the fact that Niño 4 is the area where warm water of the equatorial central Pacific piles up to lead to high SST, likely to cause El Niño events, while Niño 3 is relatively cool, making the La Niña event likely to occur. Besides, the interdecadal distribution of these events also reveal that there were more EP-ENSO events prior to the 1980s but there were more CP-ENSO events after it (Table 4).

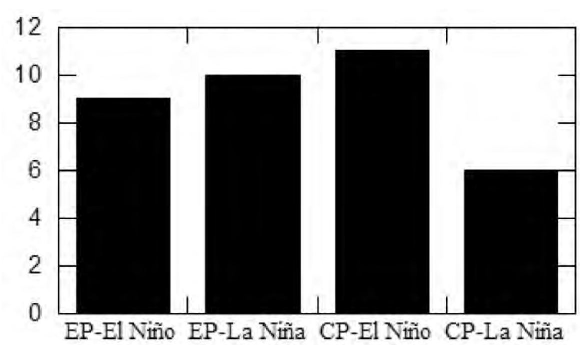

Figure 5. Statistics of the times of El Niño/La Niña events of different types.

4.3 *Comparisons of the time of outbreak, ending and getting matured*

To further study the temporal characteristics of ENSO events of different types, this work studies the

Table 2. Type and intensity of the El Niño event as defined by the group of Niño 3 and Niño 4 indices.

Times	beginning year	Month	ending year	Month	duration	peak year	Month	peak type	peak intensity
1	1951	6	1952	1	8	1951	11	EP	Strong
2	1957	3	1958	7	17	1958	1	CP	Moderate
3	1963	6	1964	2	9	1963	11	CP	Moderate
4	1965	4	1966	5	14	1965	11	CP	Moderate
5	1968	10	1969	7	10	1969	1	CP	Moderate
6	1969	8	1970	2	7	1969	11	EP	weak
7	1972	4	1973	4	13	1972	11	EP	Very strong
8	1976	6	1977	3	10	1976	10	EP	Weak
9	1977	8	1978	2	7	1977	12	CP	Weak
10	1982	4	1983	9	18	1982	12	EP	Very strong
11	1986	7	1988	3	21	1987	9	CP	Moderate
12	1991	4	1992	8	17	1992	1	CP	Strong
13	1993	2	1993	8	7	1993	5	EP	Weak
14	1994	4	1995	4	13	1994	12	CP	Moderate
15	1997	4	1998	7	16	1997	11	EP	Very strong
16	2002	4	2003	4	13	2002	11	CP	Moderate
17	2003	8	2004	2	7	2003	11	EP	Weak
18	2004	5	2005	3	11	2004	9	CP	Weak
19	2006	7	2007	2	8	2006	12	EP	Moderate
20	2009	5	2009	12	8	2009	12	CP	Strong

Table 3. Same as Table 2 but for the La Niña event.

times	Beginning year	month	Ending year	month	duration	Peak year	month	Peak type	Peak intensity
1	1950	1	1951	4	16	1950	1	EP	Strong
2	1954	2	1957	2	37	1955	11	EP	Very strong
3	1961	6	1961	12	7	1961	9	EP	Moderate
4	1962	8	1963	2	7	1962	11	EP	Weak
5	1964	3	1965	2	12	1964	5	EP	Moderate
6	1966	8	1967	2	7	1966	12	EP	Very weak
7	1967	7	1968	6	12	1968	2	EP	Moderate
8	1970	4	1972	2	23	1971	1	EP	Moderate
9	1973	4	1974	8	17	1973	12	CP	Very strong
10	1974	9	1976	5	8	1975	12	CP	Strong
11	1978	3	1978	9	7	1978	5	EP	Weak
12	1984	9	1986	2	18	1984	12	CP	Moderate
13	1988	3	1989	6	16	1988	12	CP	Very strong
14	1995	8	1996	3	8	1995	10	EP	Weak
15	1998	7	2000	7	25	2000	1	CP	Strong
16	2007	6	2008	6	13	2008	1	CP	Moderate

Table 4. Interdecadal distribution of the ENSO event types in 1950-2009.

year	EP type	CP type
1950-1964	6	2
1965-1979	7	5
1980-1994	2	5
1995-2009	4	5

time of outbreak, ending and maturing on the seasonal time scale, i.e. the month in which the ENSO events reach their peaks (Fig.6). The EP-ENSO mostly breaks out in summer and ends in winter, the EP-El Niño mostly gets matured in autumn, and the EP-La Niña evolves to its mature stage in autumn and winter. The CP-El Niño mostly starts in spring, ends in the successive spring and summer and becomes matured in autumn and winter, and the CP-La Niña mostly initiates in the first half of the year and ends in the successive summer with maturing coming in winter. Comparisons show that the CP-ENSO has early onsets but late endings, persisting relatively long, while the EP-ENSO has late onsets but early endings, lasting relatively short. Besides, the EP-ENSO matures a little earlier than the CP-ENSO, which is consistent with Kao et al.[2].

4.4 *Determination of intensity level*

From the statistical results of intensity levels of EP-ENSO and CP-ENSO events (Fig.7), it is known that they are not in normal distribution. For the El Niño event, the CP type all concentrates in the moderate level

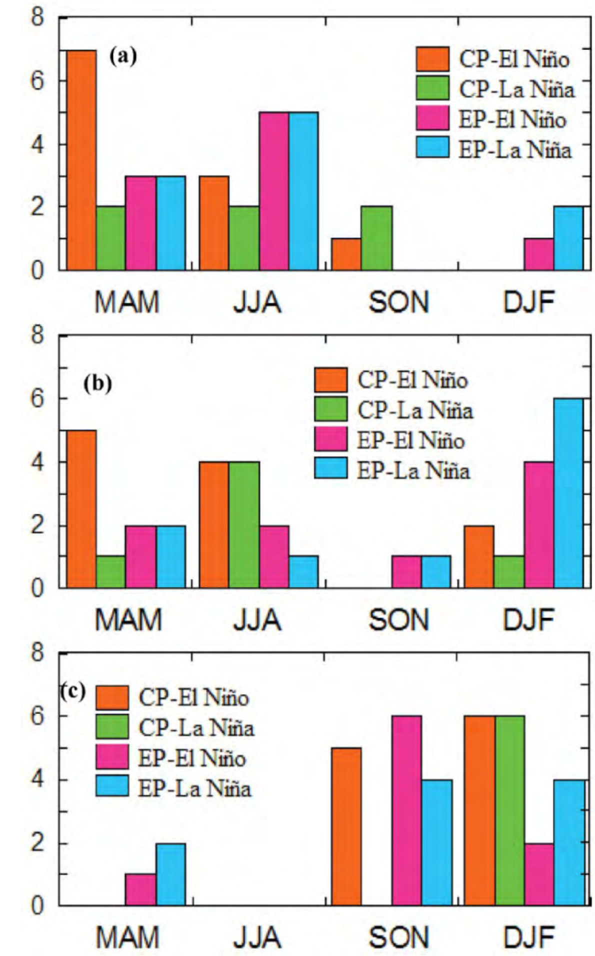

Figure 6. Seasonal distribution of the time of onset (a), ending (b) and peak (c) of ENSO events of different types.

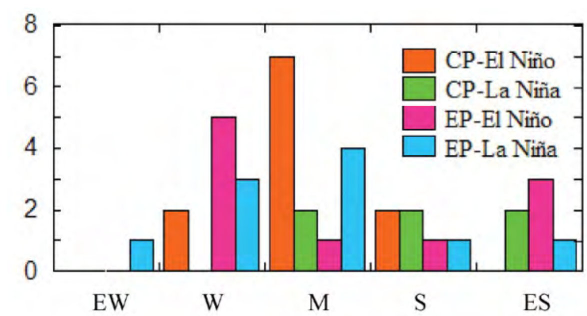

Figure 7. Statistics of intensity levels for the EP-ENSO and CP-ENSO events. EW for extremely weak; W for weak; M for moderate; S for strong; ES for extremely strong.

while the EP type is either very weak or very strong. For the La Niña event, the CP type is relatively strong while the EP type is relatively weak.

In summary, the intensity of EP-El Niño and CP-La Niña is relatively high while that of the CP-El Niño and EP-La Niña is relatively moderate.

5 CONCLUSIONS

The ENSO indices currently used at home and abroad are studied in this work for their ability to monitor the ENSO events of the EP and CP type from 1950 to 2009. As shown in the result, no single index is able to distinguish which type of distribution they belong to; the Niño 3 index is good at identifying the EP-ENSO event while the Niño 4 index works well in capturing the CP-ENSO event. In view of the finding, the two indices are suggested to be combined into a new group of indices to monitor different types of ENSO events.

(1) The index group can monitor different types of ENSO events ever taking place in history while no one single index can decide on the type all on its own. The group of indices is also able to have accurate determination of the peak value, starting and ending time and maturing period.

(2) In the 60 years spanning from 1950 to 2009, a total of 36 ENSO events have taken place, 20 of which are El Niño events while only 16 are La Niña events. The CP-El Niño (11 times) is in the majority in the El Nivo event while the EP-La Niña (10 times) is much more in the La Niña event. Besides, the interdecadal distribution of these events also reveal that there were more EP-ENSO events prior to the 1980s but there were more CP-ENSO events after it.

(3) From the statistical results of intensity levels of EP-ENSO and CP-ENSO events, it is known that they are not in normal distribution. For the El Niño event, the CP type all concentrates in the moderate level while the EP type is either very weak or very strong. For the La Niña event, the CP type is relatively strong while the EP type is relatively weak.

REFERENCES:

[1] CHRISTENSEN N S, WOOD A W, VOISIN N, et al. The effects of climate change on the hydrology and water resources of the Colorado River basin [J]. Clim Change, 2004, 62(1): 337-363.

[2] HUANG Rong-hui. Latest advances in the research on dynamics of ENSO and tropical air-sea interactions [J]. Sci Atmos Sinica, 1990, 14(2): 234-242 (in Chinese).

[3] CHENG Zheng-quan, LIANG Jian-yin, DING Yu-guo. Relationship of interannual oscillation between global temperature and ENSO [J]. J Trop Meteorol, 2006, 22 (2): 169-175 (in Chinese).

[4] CAI Xue-zhan, WEN Zhen-zhi, WU Bin. Relationship between west Pacific subtropical high and ENSO and its influence on rainfall distribution of rainy season in Fujian [J]. J Trop Meteorol, 2003, 19(1): 36-42 (in Chinese).

[5] WU Shang-sen, HUANG Cheng-chang, XUE Hui-xian. Relationship of ENSO to temperature variation in South China [J]. J Trop Meteorol, 1990, 6(1): 57-64 (in Chinese).

[6] LIU Shi, WANG Ning. The impacts of antecedent ENSO episode on air temperature over Northeast China in summer [J]. J Trop Meteorol, 2001, 17(3): 314-319 (in Chinese).

[7] ZHAI Pan-mao, GUO Yan-jun, LI Xiao-yan. A diagnostic analysis of 1997/1998 ENSO episode and role of intra-seasonal oscillation in tropical atmosphere [J]. J Trop Meteorol, 2001, 7(2): 113-121.

[8] BARNSTON A G, CHELLIAH M, GOLDENBERG S B.

Documentation of a highly ENSO-related SST region in the equatorial Pacific [J]. Atmos -Ocean, 1997, 35 (3): 367-383.
[9] HANLEY D E, BOURASSA M A, O'BRIEN J J, et al. A quantitative evaluation of ENSO indices [J]. J Climate, 2003, 16(8): 1 249-1 258.
[10] LI Xiao-yan. On indices and indicators of ENSO episodes [J]. Acta Meteorol Sinica, 2000, 58(1): 102-109.
[11] LI Xiao-yan, ZHAI Pan-mao, REN Fu-min, et al. redefining ENSO episodes based on changed climate references [J]. J Trop Meteorol, 2005, 11(1): 97-103.
[12] WOLTER K, TIMLIN M S. Monitoring ENSO in COADS with a seasonally adjusted principal component index [C]//Proceedings of the 17th Climate Diagnostics Workshop, Norman: CIMMS and the School of Meteor, Univ of Oklahoma, 1993: 52-57.
[13] CHEN Yi-dem, ZHANG Ren, JIANG Guo-rong. Summary of Chinese research on ENSO in recent years [J]. J Trop Meteorol, 2005, 21(6): 634-641 (in Chinese).
[14] TRENBERTH K E. The Definition of El Niño [J]. Bulletin of the American Meteorological Society, 1997, 78 (12): 2 771-2 777.
[15] World Meteorological Organization. Strategic Framework for World Climate Research Program 2005—2015: Coordinated Observation and Forecasting of the Earth System [M]. Beijing: China Meteorological Press, 2006.
[16] WANG B, AN S, IL. Why the properties of El Niño changed during the late 1970s [J]. Geophys Res Lett, 2001, 28(19): 3 709-3 712.
[17] KUG J S, JIN F F, AN S I. Two types of El Niño episodes: Cold tongue El Niño and warm pool El Niño [J]. J Climate, 2009, 22(6): 1 499-1 515.
[18] SUN Mi-na, GUAN Zhao-yong, ZHANG Peng-bo, et al. Principal modes of the South Pacific SSTA in June, July and August and their relations to ENSO and SAM [J]. J Trop Meteorol, 2013, 19(2): 154-161.
[19] ZHOU Xue-ming, WEI Ying-zhi, WU Chen-feng. Relation between summer typhoon frequency anomalies in West Pacific and ENSO events and the anomalous atmospheric circulation characteristics [J]. J Trop Meteorol, 2006, 12(1): 16-23.
[20] TRENBERTH K E, STEPANIAK D P. Indices of El Niño evolution [J]. J Climate, 2001, 14(8): 1 697-1 701.
[21] ASHOK K. El Niño Modoki and its possible teleconnection [J]. J Geophys Res, 2007, 112, C11007, doi: 10.1029/2006JC003798.
[22] KAO H Y, YU J Y. Contrasting Eastern-Pacific and Central-Pacific Types of ENSO [J]. J Climate, 2009, 22(3): 615-632.
[23] YU J Y, KAO H Y, LEE T, et al. Subsurface ocean temperature indices for Central-Pacific and Eastern-Pacific types of El Niño and La Niña episodes [J]. Theor Appl Climatol, 2011, 103(3): 337-344.

Citation: CAO Lu, SUN Cheng-hu, REN Fu-min, et al. Study of a comprehensive monitoring index for two types of ENSO events [J]. J Trop Meteorol, 2015, 21(2): 153-160.