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IMPACTS OF TWO DIFFERENT TYPES OF EL NIÑO ON THE THERMAL VARIABILITY IN THE SOUTH CHINA SEA

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Key words: EP El Niño, CP El Niño, South China Sea, thermal variability

ABSTRACT

The El Niño-Southern Oscillation (ENSO) has been classified into two types: the Central-Pacific (CP) type and the Eastern-Pacific (EP) type. To further understand the impacts of the two types of ENSO upon the thermal variability in the South China Sea (SCS), the reanalysis dataset dealing with the parameters of sea surface temperature (SST), surface air temperature, sea surface wind, precipitation, and sea-level pressure are analyzed herein via the regression-empirical orthogonal function. In addition, the Western Pacific Warm Pool (WPWP), the largest warm water mass in the world's oceans, is known to have a strong impact upon the climate of its surrounding areas, including the SCS. Hence, the thermal variability and atmosphere-ocean interactions between the SCS and the WPWP during the CP and EP El Niño periods are also inspected in the present study. The results indicate that the SST anomalies significantly increase during the EP El Niño, but slightly decrease during the CP El Niño. In detail, a positive sea level pressure anomaly coupled with weaker northeasterly winds during the EP El Niño contribute to wet conditions, whereas a negative sea level pressure anomaly coupled with stronger northeasterly winds during the CP El Niño contribute to dry conditions. When multiple variables are compared, the EP El Niño is seen to have a more significant impact upon thermal variability than does the CP El Niño.

I. INTRODUCTION

The El Niño-Southern Oscillation (ENSO) is a principal mode of thermal variability in the tropical oceans characterized by co-variability in the sea surface wind and the sea surface temperature (SST). The Western Pacific Warm Pool (WPWP) in the tropical Pacific Ocean has the highest SST and the largest volume of warm water of all the world's oceans. The South China Sea (SCS) is the largest marginal sea at the western side of the tropical Pacific Ocean. The thermal variability in the SCS over longer periods is the result of varying ecosystems, climate, wind variability and changes in ocean circulation (Ho et al., 2004; Rong et al., 2007; Lin et al., 2011; Mohan and Vethamony 2018; Yu et al., 2019; Liu et al., 2020). Numerous studies have shown that the surrounding areas of the tropical Pacific Ocean, including the SCS, are strongly influenced by the ENSO (Lin et al., 2011; Yuan and Yang, 2012; Wang et al., 2013; Liu et al., 2014). Although several early studies examined the influence of the ENSO upon the SCS, their results were mostly based on one type of ENSO (e.g. Lau, 1997; Elsner and Liu, 2003; Qu et al., 2004; Wang et al., 2006; Wang et al., 2007; Lin et al., 2008). More recently, two types of ENSO were proposed, namely the Central-Pacific (CP) ENSO and the Eastern-Pacific (EP) ENSO), and these have subsequently been paid more attention (e.g. Ashok et al., 2007; Yeh et al., 2009; Kao and Yu, 2009; Yu and Kim, 2010; Yu et al., 2012; Wang and Wang 2013). Consequently, an investigation into the various differences in the SCS under each type of ENSO is necessary.

Whereas the conventional EP El Niño is characterized by warm SST anomalies in the eastern Pacific, the maximum SST anomalies are confined to the central equatorial Pacific during the CP type of El Niño. Investigations have indicated that different ENSO episodes having different influences upon weather and climate on both the regional and global scales (Larkin and Harrison, 2005; Ashok et al., 2007; Kug et al., 2009; Kao and Yu, 2009; Yeh et al., 2009; Yu et al., 2012; Liu et al 2014; Liang et al., 2015; Lin et al., 2015a; Lin et al., 2015b). Although Liu et al. (2014) suggested that double warm peaks can occur in the SCS during both types of El Niño, the patterns and climate impacts of the EP El Niño are generally different from those of the CP El Niño. For instance, a significant warm basin mode can only develop in the EP El Niño, whereas the warm semi-basin mode exists only during the CP El Niño. During the EP El Niño, an anomalous in

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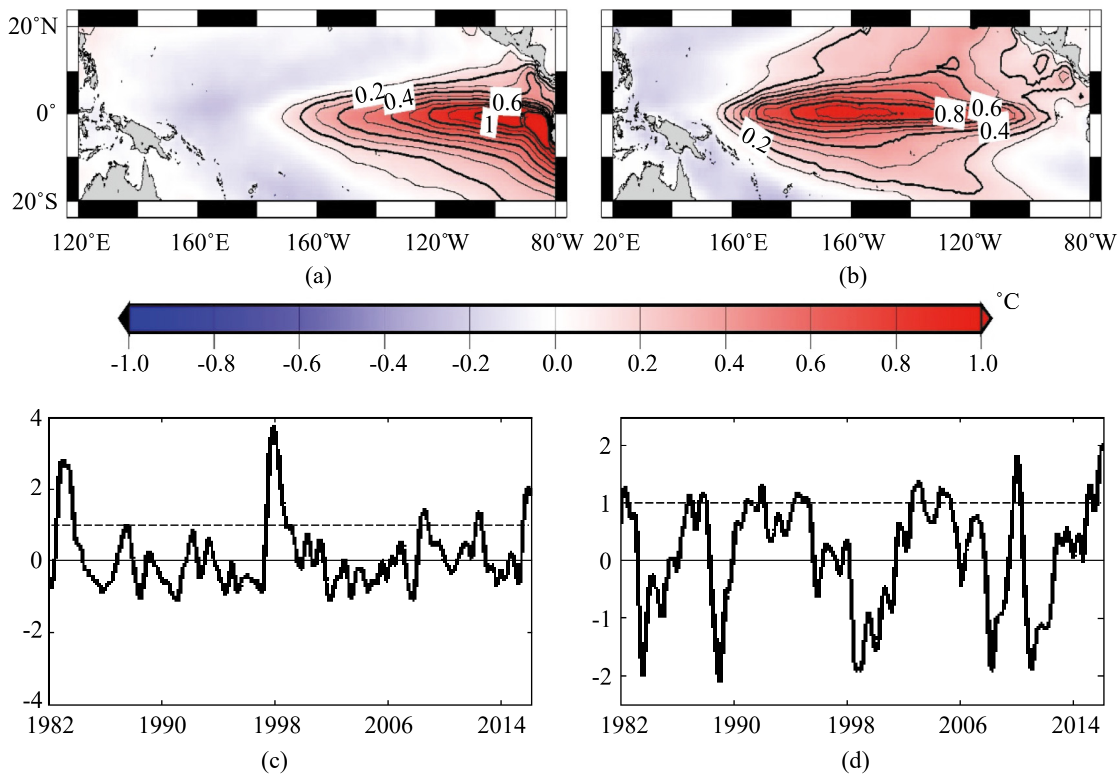


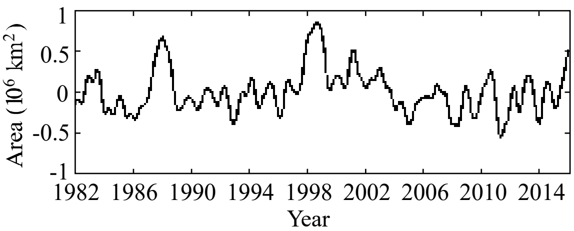
Fig. 1. The spatial structures for the first mode of the empirical orthogonal function (EOF) (a, b) and the corresponding time functions (c, d) obtained via EOF-regression analysis for the EP El Niño (b and d) and for the CP El Niño (a and c) calculated from the sea surface temperature (SST) anomalies. The dashed line shows one standard deviation value from the principal components. The units are defined so that the product of the spatial pattern and the corresponding time function denotes the temperature in degrees Celsius.

crease in the net surface heat flux coupled with a shallower thermocline and weaker northeasterly wind anomalies leads to warmer SST anomalies. By contrast, during the CP El Niño, an anomalous decrease in the net surface heat flux coupled with a steeper thermocline and stronger northeasterly wind anomalies leads to cooler SST anomalies. Yuan and Yang (2012) analyzed sea surface winds associated with the East Asian monsoon during the CP El Niño to find that the western North Pacific summer monsoon is enhanced, while the East Asian summer monsoon is weakened. Moreover, the impact of the CP El Niño upon the East Asian climate is stronger than that of the EP El Niño during the developing summer. For instance, Weng et al. (2009) suggested that the decreased level of precipitation in Southeast Asia affects more northerly areas during the CP El Niño than that affected during the EP El Niño. In addition, the temperature anomalies and summer precipitation levels in Japan and China during the developing phase of the CP El Niño are distinct from those during the EP El Niño. The impacts of both types of El Niño upon typhoons have also been pointed out in numerous studies (Elsner and Liu, 2003; Wang et al., 2007; Wang et al., 2013; Wang and Wang 2013).

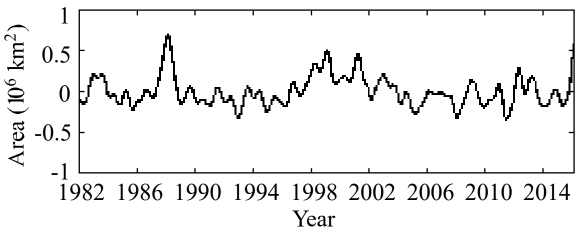
II. DATA AND METHODS

The role of multiple variables in the SCS thermal fluctuation was investigated via a re-analysis dataset of the National Center for Atmospheric Research/National Centers for Environmental Prediction (NCEP/NCAR) on SST, sea surface wind, surface air temperature, sea-level pressure, and precipitation. The key aspect of this work is the use of a frozen state-of-the-art analysis/forecast system to assimilate data covering the period of time from 1957 to the present day (Kalnay et al., 1996). The temporal resolution of the NCEP re-analysis is one month and the spatial resolution is about 1.8° in latitude and longitude. To understand the thermal fluctuations in high SST areas, estimates of the numerous variables are needed. All datasets are calculated from the 1-month gridded product in the SCS region (5°N to 28°N, 105°E to 122°E) for the time period from 1982 to 2015. In the present study, anomalies relating to all the variables are obtained by removing the mean values for 1982-2015.

Following the recent recognition of two distinct types of ENSO, the importance of thermal variability in the development of this phenomenon has been emphasized (Larkin and Harrison, 2005; Ashok et al., 2007; Kao and Yu 2009; Kug et al., 2009; Yeh et al., 2009; Wang and Wang 2013; Liang et al., 2015). There are various methods to decompose the CP and EP El Niño from the traditional ENSO, including (1) the EP/CP-index method (Kao and Yu, 2009), (2) the Niño method (Yeh et al., 2009), (3) the El Niño Modoki index (EMI)



(a)



(b)

Fig. 2. Time series of (a) the SST anomalies in the SCS and (b) areas of SCSWP anomalies in the SCS from 1982 to 2015

method (Ashok et al., 2007), and (4) the consensus method (Yu et al., 2012).

In the present study, monthly SST anomalies are applied in order to identify the EP and CP types of ENSO via the significant EP/CP-index method in combination with the consensus method calculated using a regression-empirical orthogonal function (EOF) analysis (Kao and Yu, 2009; Yu and Kim, 2010; Yu et al., 2012). To obtain the SST anomaly patterns of the CP and EP El Niño events, the monthly anomalies from observations and model simulations are calculated by removing the respective monthly mean climatological trend. In this method, the tropical Pacific SST anomalies regressed with the Niño 1+2 (0° to 10°S, 80°W to 90°W) SST index were first subtracted, then the EOF analysis was applied to the remaining SST anomalies to obtain the SST anomaly pattern for the CP El Niño (Kao and Yu, 2009; Yu and Kim, 2010). Similarly, the SST anomalies regressed with the Niño 4 (5°S to 5°N, 160°E to 150°W) SST index were subtracted from the original SST anomalies prior to application of the EOF analysis to identify the leading structure of the EP El Niño.

III. RESULTS AND DISCUSSIONS

1. Two types of ENSO and their influence on the SCS

As shown in Fig. 1, the SST anomalies of the EP El Niño are located off the South American Coast, whereas those of the CP El Niño are located close to 180° longitude, with a branch extending towards the subtropical Pacific. The analysis is applied only to strong EP or CP El Niño events, i.e. those whose seasonally averaged EP or CP index (from September to the following February) has a magnitude larger than one standard deviation (Kao and Yu, 2009; Yu and Kim, 2010). Based on this selection criterion and the consensus method (Yu et al., 2012), SST observations collected in the tropical Pacific between 1982 and 2015 are used to compare five EP El Niño events (i.e. 1982-1983, 1986-1987, 1997-1998, 2006-2007, and 2011-2012) and seven CP El Niño events (1987-1988, 1991-1992, 1994-1995, 2002-2003, 2004-2005, 2009-2010, and 2015).

The patterns of EP El Niño and its climate changes are distinguished from those of the CP El Niño. Previous studies investigated the influences of ENSO on the SCS SST mostly based on one type of ENSO. Since the ENSO has been classified into the CP and EP types of El Niño that the differences of influence on the SCS thermal variability during the two types of ENSO need to further study.

2. Interannual variability in the SCS

The SST anomalies and warm pool size anomalies from 1982 to 2015 are shown in Fig. 2. A warm pool is usually defined as an area where the SST is at least 28°C. As part of the WPWP, the SCS has a warm water temperature above 28 °C during most of the year. Moreover, since the SCS is predominantly influenced by the Southeast Asian monsoon system, the warm pool area and changes in the SST are governed by the annual cycle (Lau, 1997; Lin et al., 2011). To reveal the interannual signals, the mean seasonal cycle was subtracted from the SST and the warm pool area in the SCS prior to application of a low-pass filter to remove any anomalies shorter than 12 months. The SST anomaly time series shows a strong interannual cycle with evident relative maxima in 1982, 1987, 1997, and 2015. The warm pool area in the SCS (designated hereafter as the SCSWP) is defined in the same way as the WPWP, but for the box from 105°E to 120 °E and 5°N to 20°N (Lin et al., 2011).

In the SCS, the SCSWP fluctuates in sync with the changes in the SST, and a broader SCSWP is accompanied by a higher SST with a correlation coefficient of 0.87. The time series of SCSWP anomalies demonstrate a strong interannual cycle (Fig. 2a), and relative SCSWP maxima can be observed in the 1982, 1988, 1997, 2002, and 2015 ENSO events (Fig. 2b). Notably, most of the relative maximum periods are associated with the EP El Niño. Although the warming patterns during the EP El Niño are more significant than those during the CP El Niño, the monsoon forcing is a dominant factor controlling the SCS climate (Lau, 1997; Yuan and Yang, 2012; Liu et al., 2014). Some common air-sea interaction features and differences are discussed in more detail in the following section.

3. Thermal variability during different types of El Niño

Some parameters associated with thermal variability during EP and CP El Niño events are analyzed and discussed in this section.

3.1 Variability of SST anomalies

The mean climatological SST patterns in the SCS for the years 1982-2015, along with the composite EP and CP El Niño

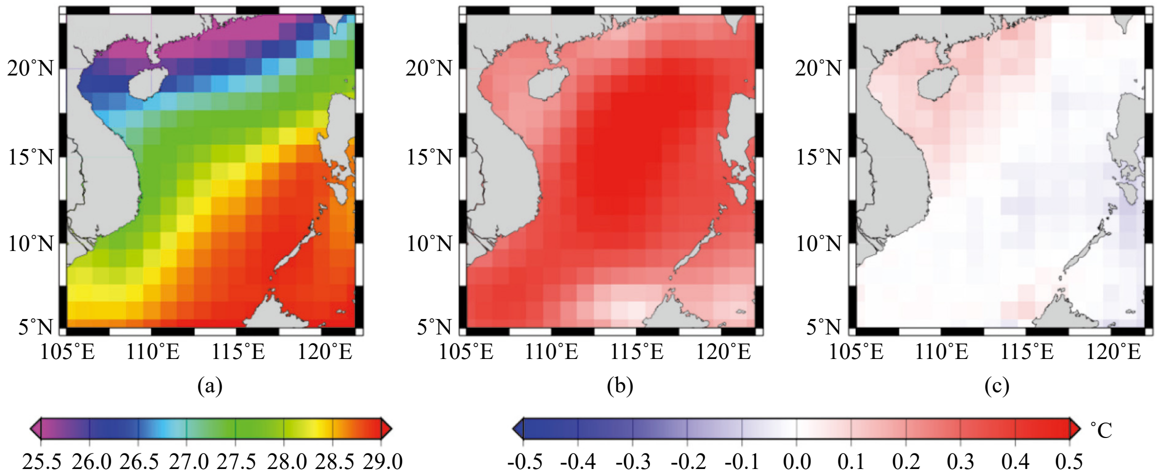


Fig. 3. The SST patterns in the SCS: (a) the climatological mean (1982-2015); (b) composite of anomalies during the EP El Niño events, and (c) composite of anomalies during the CP El Niño events.

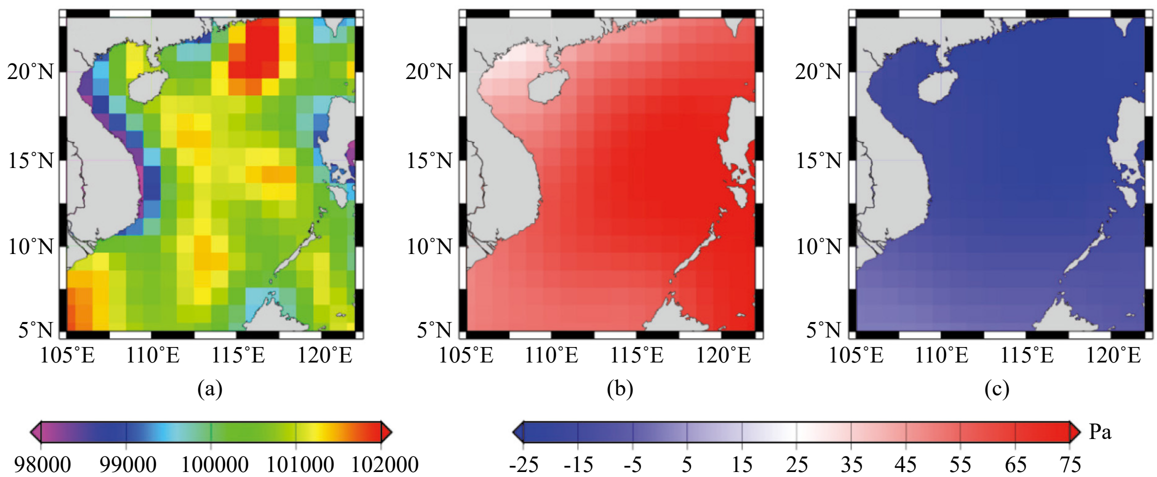


Fig. 4. The sea level pressure patterns in the SCS: (a) the climatological mean (1982-2015); (b) composite of values during the EP El Niño events, and (c) composite of values during the CP El Niño events.

anomalies, are presented in Fig. 3. In Fig. 3a, the southeastern SCS displays a particularly prominent area of high SST which decreases in magnitude toward the north. The composite data for the EP El Niño events (Fig. 3b) indicate an increase in the SST anomaly over the SCS region. This increase is particularly extensive over the central portion of the SCS basin. During the EP El Niño, the strength of the SST anomalies increase by as much as 0.45 °C, which is about 3% of the climatological value. By contrast, the SST anomaly during the CP El Niño (Fig. 3c) indicates a decrease in the SST over the entire SCS basin, except for the surrounding areas near Hainan Island. The strength of the cooling patterns weakens by about −0.25°C in the eastern part of the SCS. Thus, distinct and contrary influences are observed for the EP and CP El Niño events. The observed evolution in the SST changes of the SCS during the EP and CP El Niño is consistent with the previously reported results of Wang et al. (2006) and Liu et al. (2014).

3.2 Variability of sea level pressure anomalies

To understand why the two types of El Niño produce opposite effects on the strength of the thermal variability, the atmosphere-ocean interactions in the SCS are discussed. The climatological sea level pressure and the anomalies therein during the EP and CP El Niño events are shown in Fig. 4. The climatological mean sea level pressure is about 998 hPa, with maxima in the northern SCS and minima in the eastern areas around Vietnam. Significant positive sea level pressure anomalies over the SCS basin are observed in association with the EP El Niño (Fig. 4b), whereas completely opposite sea level pressure anomalies are observed for the CP El Niño (Fig. 4c).

Wang et al. (2006) and Yuan and Yang (2012) showed that the central Pacific and East Asia can be linked by an anomalous Philippine Sea anticyclone during the strong phases of the ENSO cycles, which can have a warming effect in East Asia

Table 1. The variations in SST, surface wind speed, sea-level pressure, and precipitation anomalies are compared during the EP and CP El Niño periods from 1982 to 2015.

	SST	Surface wind speed	Sea-level pressure	Precipitation
EP El Niño	increase	decrease	increase	increase
CP El Niño	decrease	increase	decrease	decrease

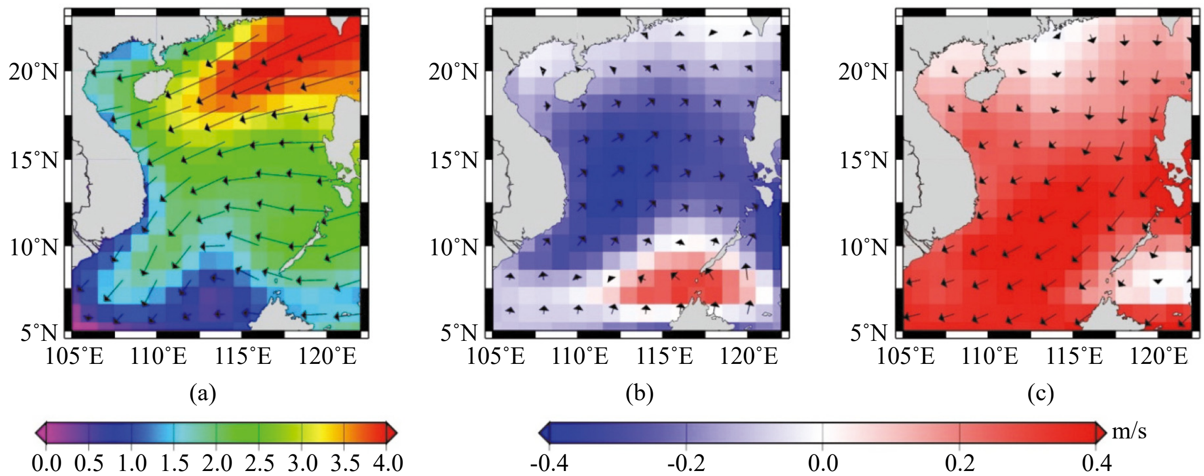


Fig. 5. The sea surface wind patterns in the SCS: (a) the climatological mean (1982-2015); (b) composite values for the EP El Niño events, and (c) composite values for the CP El Niño events. The color indicates wind speed in (a) and wind speed anomalies in (b) and (c).

and weaken the winter monsoon. However, the negative sea level pressure anomaly over the SCS during the CP El Niño seems to result from an anomalous low-level anticyclone over the SCS at a more westward location than the afore-mentioned Philippine Sea anticyclone during EP El Niño (Yuan and Yang, 2012; Liu et al., 2014). In view of this westward shift in the anomalous low-level anticyclone during the CP El Niño, the variations in surface wind and precipitation between the two types of El Niño are an important area of study and are examined in the following subsections.

3.3 Variability of sea surface wind anomalies

The monsoon forcing is a dominant factor controlling the SCS climatology (Lau, 1997; Yuan and Yang, 2012; Liu et al., 2014). The patterns of sea surface wind anomalies during the two types of El Niño events are presented in Fig. 5, and can be compared with the SST patterns of Fig. 3 and the sea level pressure patterns of Fig. 4. Whereas the climatological wind field is characterized by an easterly wind over the SCS (Fig. 5), the composite SST and sea surface wind fields reveal different interactions during the different types of El Niño event.

As shown in Figs. 3 and 4, both the SST and the sea level pressure increase during EP El Niño events and decrease during CP events. However, the patterns in the sea surface wind anomalies during the EP and CP El Niño events are not similar. During the EP El Niño, the sea surface wind anomalies over most of the SCS are characterized by westerly winds, with the negative wind velocity anomalies being found in the central SCS. Meanwhile, the weaker north-easterly wind results in a decrease in the net surface heat flux released by the ocean into the atmosphere from the north down to ~13°N, whereas the net surface heat flux gained by the ocean from the atmosphere is increased from the south up to ~13°N. Finally, the SST begins to warm over the entire SCS (Liu et al., 2014). By contrast, during the CP El Niño, an anomalous northeasterly wind results from the dominance of an anomalous low-level anticyclone over the SCS. In association with this stronger northeasterly wind, the net surface heat flux released from the SCS is increased, and the SCS shows a cooling pattern (Liu et al., 2014).

3.4 Variability of precipitation anomalies

The mean climatological pattern of precipitation in the SCS is presented in Fig 6, along with the precipitation anomalies during the two types of El Niño event. The precipitation patterns each shows a poleward decrease, with maximum values in the southern part of the SCS and minimum values in the northern part. However, the developing precipitation anomaly during the EP El Niño is different from that during the CP El Niño. During the EP El Niño (Fig. 6b), the most significant anomalous precipitation features are the wet conditions over the SCS with heavy precipitation in the eastern areas of Vietnam. By contrast, the CP El Niño displays the completely opposite precipitation anomaly (Fig. 6c), with dry conditions in the SCS and strong decreasing patterns in the central and northern SCS. Thus, the precipitation is generally lower than average during CP El Niño years and higher than average during EP El Niño years. During CP El Niño years, an anomalous

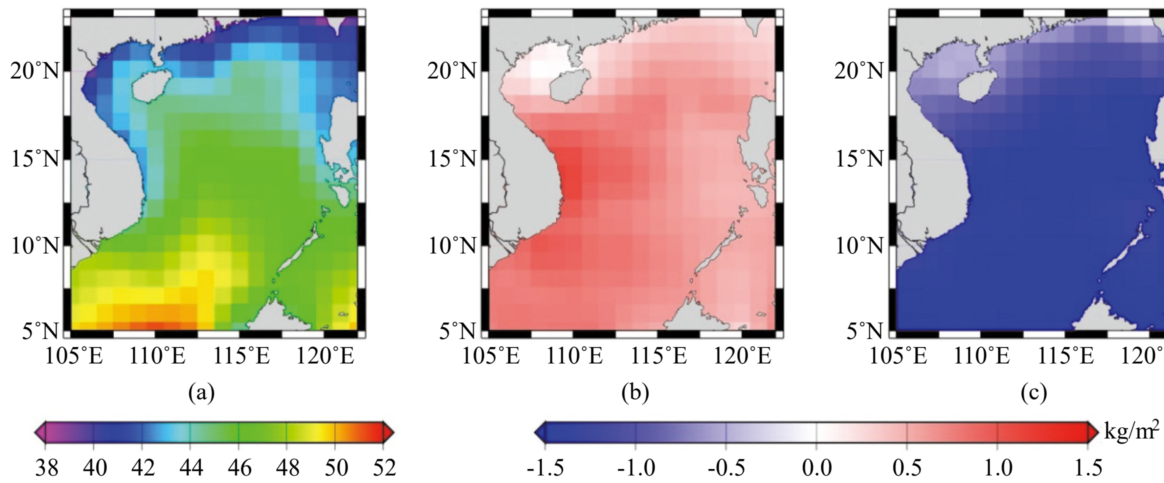


Fig. 6. The precipitation patterns in the SCS: (a) the climatological mean (1982-2015); (b) composite values for the EP El Niño events, and (c) composite values for the CP El Niño events.

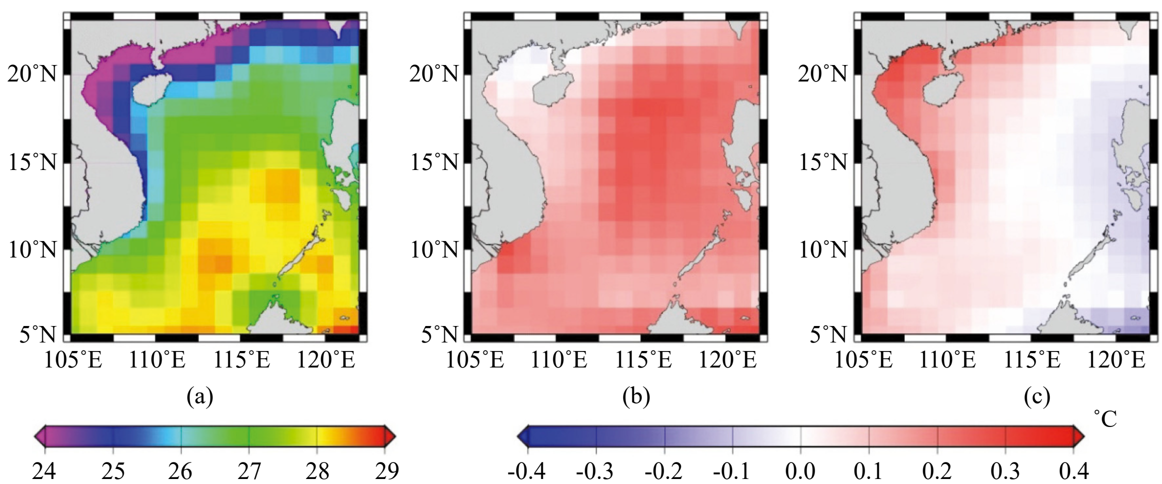


Fig. 7. The surface air temperature patterns in the SCS: (a) the climatological mean (1982-2015); (b) composite anomalies for the EP El Niño events, and (c) composite anomalies for the CP El Niño events.

sinking of the Walker circulation over the western equatorial Pacific leads to decreased convection. This, in turn, reduces the cloud cover and, hence, diminishes the level of precipitation. The circulation is reversed during EP El Niño years, such that convection is reinforced over the western equatorial Pacific, leading to high levels of precipitation over the SCS (Singh et al., 2011; Yuan and Yang, 2012; Wang and Wang, 2013). It is important to note that the interannual variation of precipitation is principally influenced by the interannual changes in sea level pressure and the SST associated with two types of El Niño.

3.5 Variability of air temperature anomalies

The average monthly climatological surface air temperature pattern in the SCS is presented Fig. 7, along with the anomalous patterns during the EP and CP El Niño events. In Fig. 7a, the surface air temperature is particularly high in the southern SCS and decreases in magnitude towards the north. Whereas the SCS generally experiences significant warming during the EP El Niño (Fig. 7b), the CP El Niño (Fig. 7c) is characterized by air temperature cooling anomalies in the eastern SCS. One possible mechanism for this is the weakened East Asian winter monsoon, along with the shallower pressure anomalies in the East Asian trough during the EP El Niño, as opposed to the increased winter monsoon and deeper East Asian trough during the CP El Niño (Yuan and Yang, 2012; Liu et al., 2014). The patterns observed in Fig. 7 are strikingly similar to the SST patterns observed in Fig. 3, and to the wind patterns in Fig. 5, because changes in the SST provide a source of thermodynamic forcing for the atmospheric circulation.

4. Individual interannual variability in the El Niño events

In terms of the air-sea interaction in the SCS, the changes in the SST play an important role in influencing the climate variability. The EP El Niño induces high SST anomalies and positive sea level pressure anomalies over the SCS, thus leading to anomalous westerly winds and greatly increased precipitation (Table 1). By contrast, the CP El Niño generates low sea-level pressure anomalies and positive sea surface wind anomalies that lead to anomalous easterly winds and dry conditions over the SCS. Thus, an examination of the climatic variations for each of the ten El Niño events since 1982 has demonstrated a number of opposite influences due to the CP and EP types of El Niño.

IV. SUMMARY AND CONCLUSIONS

In the present study, the thermal variability during two different types of El Niño were examined and possible mechanisms were discussed. The variations in the SST, sea surface wind, surface air temperature, sea-level pressure, and precipitation anomalies were examined via the re-analysis of observational datasets. In terms of the air-sea interaction in the SCS, it was noted that the changes in the SST play an important role in influencing the climate variability. Whereas the EP El Niño events induced high SST anomalies and positive sea level pressure anomalies over the SCS, leading to anomalous westerly winds and increased precipitation, the CP El Niño was associated with positive sea surface wind anomalies and low-level sea level pressure anomalies, leading to anomalous easterly winds and dry conditions over the SCS. When multiple variables were considered, the thermal variability was seen to be more significantly affected by the EP El Niño than by the CP El Niño.

The CP and EP El Niño events were distinguished in the present study by application of the significant the EP/CP-index method in combination with the consensus method from monthly SST anomalies (Kao and Yu, 2009; Yu and Kim, 2010; Yu et al., 2012). Based on these selection criteria, the SST observations made during 1982-2015 in the tropical Pacific were used to contrast the five EP El Niño events (1982-1983, 1986-1987, 1997-1998, 2006-2007, and 2011-2012) and the seven CP El Niño events (1987-1988, 1991-1992, 1994-1995, 2002-2003, 2004-2005, 2009-2010, and 2015). However the distinction between the CP and EP types of El Niño is not always clear-cut. For example, the 1991-1992 El Niño has been previously categorized as an EP El Niño according to the EMI and EP/CP-index methods, but as a CP El Niño by the Niño method (Yeh et al., 2009). Some studies have even classified this example as a mixed El Niño event (Kug et al., 2009; Yuan and Yang, 2012). Consequently, the present study makes significant use of the consensus method and it is recognized that further observation and analyses are needed in order to address this problem.

It has been previously suggested that the ENSO is a prominent factor in the year-to-year variability in the East Asian monsoon (Lau, 1997; Yuan and Yang, 2012; Liu et al., 2014). In the present study, the impact of the CP El Niño upon the East Asian monsoon was seen to be more significant than that of the EP El Niño. Since the thermal variability of the SCS is known to interact with the Asian monsoon system and the climate of China (and possibly even that of the whole of East Asia) (Lau, 1997), the thermal variability in the SCS may strongly impact upon the hydrography and climatology of the surrounding areas.

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