Prediction of Eastern and Central Pacific ENSO Events and Their Impacts on East Asian Climate by the NCEP Climate Forecast System

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ABSTRACT

The eastern Pacific (EP) El Niño–Southern Oscillation (ENSO) and the central Pacific (CP) ENSO exert different influences on climate. In this study, the authors analyze the hindcasts of the NCEP Climate Forecast System, version 2 (CFSv2), and assess the skills of predicting the two types of ENSO and their impacts on East Asian climate. The possible causes of different prediction skills for different types of ENSO are also discussed. CFSv2 captures the spatial patterns of sea surface temperature (SST) related to the two types of ENSO and their different climate impacts several months in advance. The dynamical prediction of the two types of ENSO by the model, whose skill is season dependent, is better than the prediction based on the persistency of observed ENSO-related SST, especially for summer and fall. CFSv2 performs well in predicting EP ENSO and its impacts on the East Asian winter monsoon and on the Southeast Asian monsoon during its decaying summer. However, for both EP ENSO and CP ENSO, the model overestimates the extent of the anomalous anticyclone over the western North Pacific Ocean from the developing autumn to the next spring but underestimates the magnitude of climate anomalies in general. It fails to simulate the SST pattern and climate impact of CP ENSO during its developing summer. The model’s deficiency in predicting CP ENSO may be linked to a warm bias in the eastern Pacific. However, errors in simulating the climate impacts of the two types of ENSO should not be solely ascribed to the bias in SST simulation.

1. Introduction

El Niño–Southern Oscillation (ENSO) and related teleconnection patterns are important bases for seasonal climate prediction in many regions (Shukla and Paolina 1983; Webster et al. 1998; Jiang et al. 2013b,c). The canonical El Niño is associated with maximum warm sea surface temperature (SST) anomalies in the eastern equatorial Pacific (EP El Niño). In recent years, a new type of tropical Pacific SST warming pattern, with maximum warm anomalies in the central equatorial Pacific, has also been discussed widely (e.g., Fu et al. 1986; Larkin and Harrison 2005; Ashok et al. 2007; Yu and Kao 2007). It is alternatively referred to as date line El Niño (Larkin and Harrison 2005), El Niño Modoki (Ashok et al. 2007; Weng et al. 2007), central Pacific (CP) El Niño (Kao and Yu 2009), and warm-pool El Niño (Kug et al. 2009).

The two types of ENSO exert different climate impacts, from its developing summer to decaying summer (Weng et al. 2007, 2009; Feng et al. 2010; Feng and Li 2011; Zhang et al. 2011, 2012; Yuan and Yang 2012; Yuan et al. 2012). In El Niño developing summer, CP El Niño exerts a stronger influence on East Asian precipitation compared to EP El Niño (Weng et al. 2007; Yuan and Yang 2012). During El Niño decaying summer, however, EP El Niño is more highly correlated with East Asia precipitation anomalies than CP El Niño (Yuan and Yang 2012). The spatial pattern of winter precipitation anomalies related to the two types of El Niño is different, from the eastern Pacific to East Asia (Feng et al. 2010; Yuan and Yang 2012). Feng and Li (2011) reported that CP (EP) El Niño was accompanied by a significant reduction (enhancement) in rainfall over

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southern China. It was also found that CP (EP) El Niño resulted in increased (decreased) rainfall over southern China during its developing autumn (Zhang et al. 2011). Distinct climate responses to the two types of El Niño are found not only over East Asia, but also in other regions (e.g., Weng et al. 2007, 2009; Kim et al. 2009; Zhang et al. 2012). The different surface climate impacts of the two types of El Niño result from their different teleconnection patterns, such as those related to the Walker circulation, the Hadley circulation, Indian Ocean SST, and Asian monsoon circulation (e.g., Weng et al. 2007, 2009; Yuan and Yang 2012).

Prediction of the two types of El Niño and related impacts by state-of-the-art climate models, especially operational climate forecast models, has received limited attention, although interest has been shown in observational analyses (e.g., Weng et al. 2007, 2009; Feng et al. 2010; Feng and Li 2011; Zhang et al. 2011, 2012; Yuan and Yang 2012). Hendon et al. (2009) reported that the lead time for dynamical coupled model seasonal forecast system of the Australian Bureau of Meteorology to predict the major differences in autumn SST anomaly patterns between the two types of El Niño was less than one season. However, the differences in anomalous winter SST patterns of the two types of El Niño can be predicted by the Asia–Pacific Economic Cooperation (APEC) multimodel ensemble seasonal forecast system four months ahead (Jeong et al. 2012). These studies imply that the predictability of anomalous SST patterns of the two types of El Niño is seasonally dependent. The APEC multimodel ensemble seasonal forecast system has also shown different skills in predicting winter climate affected by the two types of El Niño (Jeong et al. 2012).

The National Centers for Environmental Prediction (NCEP) Climate Forecast System (CFS), a fully coupled forecast system, provides operational prediction of the world climate (Saha et al. 2006). In March 2011, a new version of the CFS [version 2 (CFSv2)] replaced the previous version of CFS (CFSv1). Compared to CFSv1, CFSv2 incorporates a number of new physical packages for cloud–aerosol radiation, land surface, and ocean and sea ice processes, and a new atmosphere–ocean–land data assimilation system (Saha et al. 2010, 2014). Previous studies (e.g., Yuan et al. 2011; Jiang et al. 2013b) have shown increased skill in predicting the global land precipitation and surface air temperature, as well as large-scale Asian summer monsoon, from CFSv1 to CFSv2. CFSv2 also shows higher skill in predicting the Niño-3.4 index (Jiang et al. 2013c). Xue et al. (2013) reported that CFSv2 had different skill in predicting ENSO onset and decay, and the skill was also different for the periods of 1982–98 and 1999–2010. The climate impacts of ENSO depend not only on the time of ENSO onset or decay, but also on the SST patterns during different phases. Thus, it is also interesting to investigate how well CFSv2 can predict the difference in SST patterns between the two types of ENSO and their climate impacts.

In this study, we focus on the seasonal prediction of the two types of ENSO and related East and Southeast Asian climate by CFSv2, from ENSO developing summer to ENSO decaying summer. In section 2, we describe CFSv2, two different types of model integrations, observations, and analysis methods applied in this study. Prediction of the two types of ENSO from its developing summer to decaying summer by CFSv2 is provided in section 3. In section 4, we investigate the prediction of the climate impact of the two types of ENSO. A summary and further discussion of the results obtained are provided in section 5.

2. Model, experiments, observational data, and analysis methods

The NCEP CFSv2 consists of the NCEP Global Forecast System at T126 spectral resolution, the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model, version 4.0, at 0.25°–0.5° grid spacing coupled with a two-layer sea ice model, and the four-layer Noah land surface model. Output from two types of simulations with CFSv2 is used: hindcasts and Atmospheric Model Intercomparison Project (AMIP)-type simulations, which are referred to as hindcast and AMIP, respectively, for brevity in this study. Output from the CFSv2 9-month hindcast is analyzed over the 28-yr period of 1983–2010. Beginning on 1 January, 9-month hindcast runs were initialized from every fifth day and run from all four cycles of that day. The initial days vary from one month to another. (Details about the initial time can be found at http://cfs.ncep.noaa.gov/cfsv2.info/; see the file link entitled “Retrospective CFSv2 Forecast Data Information”). An ensemble mean of the monthly-mean values of 24 or 28 members is used, with initial dates after the 7th of the particular month used as the ensemble member for the next month. For the June–August 0-month lead forecast, the ensemble mean of the runs initialized from 5 June and 11, 16, 21, 26, and 31 May is used as the forecast. The longest 7-month lead forecast for June–August is an ensemble mean of the runs initialized from 2 and 7 November and 8, 13, 18, 23, and 28 October. The AMIP simulations are an ensemble-mean of 11 integrations by the atmospheric component of CFSv2, which were all initialized from January 1950 with different atmospheric initial conditions. Monthly SST and sea ice from the Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) dataset (Rayner et al. 2003) and
optimally interpolated (OI) SST dataset (Reynolds et al. 2007) are used as the boundary conditions for 1950–2008 and 2009–10, respectively. These runs are forced with observed monthly CO₂ concentration as well.

The observations used in this study for model verification include the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997), the winds and temperature from the NCEP Climate Forecast System Reanalysis (CFSR; Saha et al. 2010), and the SST from the National Oceanic and Atmospheric Administration (NOAA) OI SST analysis (Reynolds et al. 2007). With a first guess from a coupled atmosphere–ocean–sea ice–land forecast system, the CFSR has improved the climatological precipitation distribution over various regions and the interannual precipitation correlation with observations over the Indian Ocean (IO), the Maritime Continent, and the western Pacific Ocean compared to several previous reanalysis (Wang et al. 2011).

Anomalies of all variables are obtained by removing the means of 1983–2010. Seasonal means, which are discussed throughout the paper, are constructed by averaging data for March–May (MAM), June–August (JJA), September–November (SON), and December–February (DJF). Here, DJF 1983 refers to December 1982 and January–February 1983. All these seasons are boreal seasons, and JJA (JJA1) indicates the ENSO developing (decaying) summer, and so on for other seasons.

In this study, the Niño-3 index and El Niño Modoki index (EMI) are used to describe EP El Niño and CP El Niño, respectively. The Niño-3 index is defined by the SST anomaly (SSTA) averaged over 5°S–5°N, 170°E–140°W, as marked in Fig. 1a. EMI is defined as [SSTA]C – 0.5[SSTA]E – 0.5[SSTA]W, where [SSTA]C, [SSTA]E, and [SSTA]W stand for the area-mean SSTA over the central (C: 10°S–10°N, 165°E–140°W), eastern (E: 150°S–5°N, 110°–70°W), and western (W: 10°S–20°N, 125°–145°E) Pacific, respectively (see Fig. 1f; Ashok et al. 2007; Weng et al. 2007, 2009).

To investigate the potential impacts of EP ENSO and CP ENSO, lag correlations (mainly from JJA to JJA1) are employed based on normalized DJF Niño-3 index and EMI. The coefficient of correlation between DJF Niño-3 and DJF EMI is 0.42, exceeding the 95% confidence level. Thus, partial correlations are used in this study to exclude the possible influence dominated by either the Niño-3 or the EMI (Sankar-Rao et al. 1996; Behera and Yamagata 2003). The partial correlation coefficient between two variables A1 and A2, after removing the influence of variable A3, is expressed as:

$$r_{12|3} = \frac{r_{12} - r_{13|23}(1 - r_{13}^2)(1 - r_{23}^2)}{\sqrt{1 - r_{13}^2} \sqrt{1 - r_{23}^2}},$$

and

$$r_{12} \text{ is the correlation between } A1 \text{ and } A2.$$}

(3, A3). To reflect the magnitude of the climate impact of the two types of ENSO, partial regression is also used in this study. The partial regression is expressed as

$$Y = b_0 + b_1X_1 + b_2X_2,$$

where the free coefficient $b_0$ represents the predicted value of $Y$ when the other two variables are equal to zero. $b_1$ and $b_2$ are partial regression coefficients. The dependent variables $X_1$ and $X_2$ are normalized Niño-3 index and EMI in this study. The dependent variable $Y$ is zonal wind, longitudinal wind, precipitation, temperature at 2 m, or SST in this study. All statistical significance tests for correlations and regressions are performed using the two-tailed Student’s $t$ test. For a time series having 28 seasons (1983–2010), the correlation coefficients at the confidence levels of 95% and 99% are 0.37 and 0.48, respectively.

3. Prediction of the two types of ENSO

a. The 0-month lead prediction of SST

Figure 1 shows the observed partial correlations of seasonal SSTA with normalized DJF Niño-3 and DJF EMI, respectively. The EP El Niño features a significant warming in the equatorial Pacific Ocean from the developing summer to the decaying spring, although the warming is small and even partly becomes cooling in the decaying summer. On the other hand, negative SSTA emerges from the western Pacific during the developing summer, forming a cold “boomerang” (Trenberth and Stepaniak 2001), reaches a peak in winter, and persists to the decaying summer. Differently, the CP El Niño is characterized by a significant warming over the central Pacific Ocean from the developing summer to the decaying summer, with cold SST to the west and southeast of the warming center.

The cold SST related to El Niño in the western North Pacific (WNP) is important for the maintenance of the anomalous anticyclonic over the WNP from El Niño developing autumn to the following early summer, which exerts a significant impact on East Asian climate (e.g., Wang et al. 2000). The strength and location of SST in the WNP are different between the two types of El Niño, resulting in different impacts on East Asian climate (Weng et al. 2007; Yuan and Yang 2012). It is also noted that the SST patterns in the tropical IO are different between the two types of El Niño. The tropical IO SST shows a dipole pattern in JJA and SON, and a basinwide warming pattern from DJF to JJA1 during EP El Niño. Significant negative SST is found in part of the IO in JJA and SON and positive SST in most of the IO from DJF to JJA1 during CP El Niño. However, the positive correlations over the IO during EP El Niño are larger than those during CP El Niño.
Figure 2 shows the partial correlations of the seasonal SSTA from 0-month lead CFSv2 hindcast with observed normalized DJF Niño-3 and DJF EMI, respectively. Comparison between Figs. 1 and 2 indicates that CFSv2 captures the cycles of SSTA patterns related to two types of El Niño. The model also captures the difference in IO SSTA between the two types of El Niño. However, it predicts weaker-than-observed positive correlation in the central Pacific and negative correlation in the southeastern Pacific during the CP El Niño developing summer. It also predicts weaker-than-observed positive correlation in the equatorial central Pacific during the CP El Niño decaying summer. It is worth noting the weaker-than-observed negative correlation in the southeastern Pacific related to CP El Niño during the entire ENSO life cycle. On the other hand, the negative correlation related to EP El Niño in the WNP is overestimated in DJF, although it is underestimated in JJA1.

Above we have examined the SSTA patterns that are related to the EMI and the Niño-3. What is the relationship between the two indices and how well can it be predicted? The two indices vary relatively independently in JJA and MAM, with insignificant correlation coefficients of 0.02 and -0.03, respectively. However, they vary in phase for SON and DJF, with correlation coefficients of 0.47 and 0.42, respectively. The correlations between the

FIG. 1. Partial correlations of observed seasonal SSTA with observed normalized (left) DJF Niño-3 and (right) DJF EMI: (a),(f) summer, (b),(g) autumn, (c),(h) winter, (d),(i) following spring, and (e),(j) following summer. Shadings indicate the significant correlations above the 95% and 99% confidence levels. The domains used to defined the Niño-3 and EMI are outlined in (a) and (f), respectively.
EMI and Niño-3 in CFSv2 for all time leads indicate that CFSv2 generally captures the independent variations of the two indices in JJA and MAM, but the correlation between the two indices is overestimated in SON and underestimated in DJF (not shown).

**b. Predictions of SST as a function of lead time**

Figure 3 presents the partial correlations of JJA SSTA from the CFSv2 hindcast of different leads of time with observed normalized DJF Niño-3 and DJF EMI, respectively. For 1-month lead, CFSv2 predicts the EP El Niño related JJA warm SSTA over the eastern Pacific and cold SSTA over the WNP, but not the warm SSTA over the northern tropical IO. CFSv2 cannot predict the observed SSTA pattern when lead time is beyond one month, although the model SSTA over the eastern Pacific is positively correlated with the observed DJF Niño-3. The model also fails to predict the JJA SSTA pattern related to CP El Niño for all time leads. For SON, however, CFSv2 can predict the EP El Niño–related SSTA pattern when lead time is less than 5 months, although the correlation between predicted SST and observed DJF Niño-3 decreases as lead time increases (not shown). As for JJA, CFSv2 shows low skill in predicting SON CP El Niño, and the related SSTA pattern can only be predicted one month in advance (not shown). As seen from Fig. 4, which presents the partial correlation of DJF SSTA from the CFSv2 hindcast of different leads with observed normalized DJF Niño-3 and DJF EMI, CFSv2 captures the EP El Niño–related SSTA pattern over the tropical Pacific for all time leads, although the correlation is underestimated over the

![Figure 2](http://journals.ametsoc.org/jcli/article-pdf/27/12/4451/4018031/jcli-d-13-00471_1.pdf)
southeastern Pacific and overestimated over the WNP as lead time increases. The model captures EP El Niño–related warming over the IO, but fails to depict the observed maximum positive correlation over the southwestern IO for lead time longer than one month. For CP El Niño, CFSv2 captures the related SSTA over the WNP and the central Pacific, but not over the southeastern Pacific. There is an obvious decrease in the positive correlation between predicted SSTA and observed DJF EMI over the central Pacific with increase in lead time. However, the negative correlation between the WNP SSTA and the DJF EMI is well predicted for all time leads. For MAM1, CFSv2 shows higher skill in predicting the SSTA related to EP El Niño, compared with CP El Niño (not shown).

We now analyze the partial correlation of JJA1 SSTA from the CFSv2 hindcast of different time leads with observed normalized DJF Niño-3 and DJF EMI, respectively (Fig. 5). CFSv2 captures the general patterns of anomalous JJA1 SSTA related to the two types of El Niño. The correlation between predicted SSTA and observed DJF Niño-3 increases over the Pacific and the eastern IO and decreases over the western IO with lead time. The model underestimates the correlation between predicted SSTA and observed DJF EMI in the equatorial central Pacific for 1- and 3-month leads. Interestingly, the deficiency is smaller in the predictions of 5- and 7-month leads, even though the position of positive correlation shifts westward. CFSv2 also has a bias in predicting the CP El Niño–related SSTA over the IO, with a positive correlation between predicted SSTA and observed DJF EMI for all time leads.

c. Persistency skill and CFSv2 skill in predictions of El Niño indices

Here we analyze the Niño-3 and EMI indices in both observations and CFSv2 to discuss the skill of predictions for the two types of El Niño quantitatively. Figure 6 shows the observed persistency skill and CFSv2’s skill in predictions of Niño-3 and EMI indices. The persistency skill for DJF Niño-3 features a spring predictability barrier, and it is apparently lower than
that for DJF EMI when lead time is longer than 4 months. CFSv2 predicts the two DJF indices very well, and shows higher skill for long lead predictions compared to the persistency prediction, especially for the DJF Niño-3 index. CFSv2 does not have any apparent advantage in predicting the MAM El Niño indices, which have high persistency in observation. Persistency prediction shows some skill in predicting the JJA EMI, but little skill for the JJA Niño-3 index. However, CFSv2 has better skills in predicting the two indices, with a higher skill for the JJA EMI. The persistency skill in predicting the SON El Niño indices decreases rapidly, especially for the Niño-3 index. The lead time for significantly predicting the SON Niño-3 index (EMI) is 2 (3) months. CFSv2 even better predicts the SON El Niño indices, beating the persistency prediction skill.

In brief, CFSv2 has higher skill in predicting the two types of ENSO indices compared to the persistency prediction for JJA and SON. The model has even higher skill for DJF in long-lead predictions. The persistency of the EMI is generally higher than that of the Niño-3 index in JJA and SON.

d. Prediction of the magnitude of two types of ENSO

The patterns of partial regression of observed SSTA on observed normalized DJF Niño-3 and EMI are presented in Fig. 7. The patterns clearly show that EP ENSO is stronger than CP ENSO from the developing summer to the decaying MAM. The CP ENSO exhibits significant SST warming in the central Pacific during its decaying summer, when the EP ENSO does not show obvious SST in the equatorial Pacific.

Compared with the observed patterns (Fig. 7), the predicted SSTA patterns related to the two types of ENSO (Fig. 8) present that the magnitude of warm SSTA in the eastern Pacific related to EP ENSO is generally captured by CFSv2, although the cold SSTA in the WNP is overestimated during SON and DJF. However, the model predicts weaker-than-observed warm SST in the central Pacific and cold SST in the southeastern Pacific for CP ENSO. The standard deviations of Niño-3 and EMI in observations and predictions (Table 1) also indicate that CFSv2 generally captures the magnitude of Niño-3. On the other hand,
the model produces a weaker-than-observed EMI, especially for long lead predictions.

Comparison among Figs. 1–4 indicates that CFSv2 predicts a weak (strong) correlation between SSTA and ENSO indices and underestimates (overestimates) the magnitude of SSTA related to ENSO. The predictions from 1- to 7-month lead also indicate that CFSv2 has almost same skill in predicting the phase and the magnitude of ENSO (not shown). For example, the magnitude of predicted DJF SSTA over the eastern Pacific related to Niño-3 decreases as lead time increases, consistent with the feature in correlation analysis (Fig. 4).

4. Prediction of climate impacts of the two types of El Niño

a. The 0-month lead prediction

1) PRECIPITATION

Figure 9 shows the patterns of partial regression of observed precipitation on observed normalized DJF Niño-3 and DJF EMI, respectively. CP El Niño is associated with above-normal JJA precipitation over the southeastern South China Sea and the eastern Philippine Sea, and below-normal JJA precipitation over the central Maritime Continent, which moves to the western Maritime Continent in JJA1. For EP El Niño, precipitation decreases over the Maritime Continent in JJA, but anomalous precipitation occurs over most of East Asia in JJA1, with increased precipitation over the Maritime Continent and from the Yangtze River to the south of Japan, and decreased precipitation over the WNP. For SON, EP El Niño is accompanied by decreased precipitation over the Maritime Continent, the South China Sea, and the Philippine Sea, whereas CP El Niño is accompanied by decreased precipitation over the southeastern Maritime Continent and the central South China Sea and increased precipitation to the west of the date line. For DJF, EP El Niño is accompanied by reduced precipitation over the Maritime Continent, the southern South China Sea, and the southern Philippine Sea, and enhanced precipitation from southern China to the south of Japan. Precipitation related to DJF CP El Niño only shows a decrease in the
vicinity of the Philippines. During EP El Niño decaying spring, precipitation decreases over the southern South China Sea, the southern Philippine Sea, and the southern Indochinese peninsula, but increases in northern China and southern Japan. On the other hand, reduced precipitation dominates the southeastern Indochinese peninsula, the South China Sea, the Philippines, the eastern Maritime Continent, and south of Japan during the CP El Niño decaying spring.

As seen from Fig. 10, which shows the patterns of partial regression of CFSv2 0-month lead precipitation on observed normalized DJF Niño-3 and DJF EMI, respectively, CFSv2 captures the general features of precipitation anomalies related to the two types of El Niño. However, the model overestimates the response of precipitation to EP El Niño, but underestimates the response to CP El Niño except for DJF and MAM1. CFSv2 also apparently underestimates the magnitude of anomalous precipitation for the two types of ENSO. Specifically, CFSv2 has a bias in simulating the enhanced precipitation from southern China to southern Japan during EP El Niño SON and MAM1, and enhanced precipitation over the western Maritime Continent during EP El Niño DJF and MAM1. It cannot simulate the above-normal precipitation over the WNP during the CP El Niño JJA, and it underestimates the above-normal precipitation to the west of the date line and the below-normal precipitation over the northern South China Sea and the East China Sea during the CP El Niño MAM. The model also has a bias in simulating the enhanced precipitation over central-southern China from SON to MAM1 during CP El Niño.

2) TEMPERATURE

Figure 11 shows the patterns of partial regression of observed 2-m surface air temperature (T2m) on observed normalized DJF Niño-3 and DJF EMI, respectively. During EP El Niño, significant increases in T2m are found over northern China in JJA, the southeastern Indochinese peninsula in DJF, the entire Indochinese peninsula in MAM, and parts of the Maritime Continent from DJF to JJA1. Significant decreases
in temperature are observed over the Tibetan Plateau during DJF and MAM1, especially the latter. On the other hand, during CP El Niño, a significant cold T2m anomaly can be seen over northeastern China and the central Indochinese peninsula in JJA, around the Philippines from SON to MAM1, and over northern China in MAM1. Unlike the cold anomalies over the Tibetan Plateau during EP El Niño, T2m increases in part of the Tibetan Plateau during the CP El Niño DJF and MAM1.

Patterns of partial regression of CFSv2 T2m from 0-month lead on observed normalized DJF Niño-3 and DJF EMI are shown in Fig. 12. CFSv2 simulates the T2m anomalies related to the two types of El Niño over most of the ocean and parts of land. However, it tends to predict a stronger-than-observed response of T2m to DJF Niño-3 and a weaker-than-observed response of T2m to DJF EMI except for SON and DJF. As for precipitation, CFSv2 fails to produce the magnitude of T2m anomalies. The model cannot predict the T2m anomalies over China for the two types of El Niño, with an exception for the cold T2m over the Tibetan Plateau during the EP Niño MAM. The model produces an unrealistic positive T2m anomaly over the Indochinese peninsula in SON and most of the Indochinese peninsula in DJF during EP Niño.

3) ATMOSPHERIC CIRCULATION

Previous studies have reported that the teleconnection patterns such as those related to the Walker
and Hadley circulations between the two types of El Niño are different (Weng et al. 2007, 2009; Yuan and Yang 2012). Here we analyze the 850- and 200-hPa winds over East Asia to understand the differences in surface climate between the two types of El Niño in both observations and CFSv2 predictions.

Figure 9 presents the patterns of partial regression of observed 850-hPa winds on observed normalized DJF Niño-3 and DJF EMI. It can be seen that EP El Niño features equatorial westerly anomaly over the western and central Pacific from the developing summer to the next spring. The intensity and center location of the anomalous anticyclone around the Philippines vary from EP El Niño developing SON to decaying summer, resulting in different impacts on East Asian climate. At 200 hPa, EP El Niño is accompanied by anomalous easterlies over most of the equatorial Pacific, but by anomalous westerlies over the tropical IO from the developing summer to the next spring (not shown). The circulation anomalies over the equator in the lower and upper troposphere suggest a single anomalous Walker cell over the Pacific, with anomalous rising motion over the western Pacific and sinking motion over the eastern Pacific (Weng et al. 2007; Yuan and Yang 2012).

Anomalous cyclonic circulation at 200 hPa is found over East Asia from the EP El Niño developing autumn to the next spring (Fig. 11), which weakens the East Asian jet stream and in turn the East Asian winter monsoon (Jiang et al. 2013c).

Unlike EP El Niño, there exists an anomalous cyclone around the Philippines in the CP El Niño developing summer, which moves eastward to the Philippine Sea in
The East Asian Monsoon

Previous studies have also reported that the anomalies of East Asian monsoon are different between the two types of El Niño (Weng et al. 2007; Yuan and Yang 2012; Yuan et al. 2012), a feature partly seen in the above analysis. To illustrate the ENSO-related difference in monsoon more directly, we analyze two East Asian monsoon indices. One index is the East Asian summer monsoon (EASM) index defined as the difference in 850-hPa zonal wind between a northern region (22.5°–32.5°N, 110°–140°E) and a southern region (5°–15°N, 90°–130°E) (Wang et al. 2008). The other is the East Asian winter monsoon (EAWM) index defined by Li and Yang (2010) as the mean horizontal shear of 200-hPa zonal wind (U200):

\[
\text{EAWM} = \frac{(U1 - U2 + U1 - U3)/2}{U200(5^\circ - 35^\circ N, 90^\circ - 160^\circ E)},
\]

where
\[
U1 = U200(30^\circ - 35^\circ N, 90^\circ - 160^\circ E),
\]
\[
U2 = U200(50^\circ - 60^\circ N, 70^\circ - 170^\circ E),
\]
and
\[
U3 = U200(5^\circ S - 10^\circ N, 90^\circ - 160^\circ E).
\]

As shown in Table 2, the anomalies of the EASM are out of phase between ENSO developing summer and decaying summer, and are related to different types of ENSO. The observed EASM is significantly and negatively correlated with the EMI during the CP El Niño developing phase, but significantly and positively correlated with the Niño-3 during the EP El Niño decaying phase. The 0-month lead hindcast captures the correlation between Niño-3 and EASM during the CP El Niño decaying summer, but fails to simulate the correlation between EMI and EASM during the CP El Niño developing summer. The EAWM is negatively and significantly correlated with the Niño-3 in observations, which is well captured by CFSv2.

As shown in Table 3, CFSv2 underestimates the magnitude of variations of the summer and winter monsoon indices related to the two types of ENSO. It is also interesting to see from the table that the EAWM in the 0-month lead hindcast during CP ENSO is even stronger than that during EP ENSO, consistent with the exaggerated correlation between the EMI and the EAWM.

b. Predictions of precipitation and atmospheric circulation as a function of lead time

For JJA, the features of precipitation and 850-hPa atmospheric circulation related to EP El Niño can be predicted by CFSv2 by one lead month only, consistent
FIG. 9. Patterns of partial regression of observed seasonal precipitation (shading) and 850-hPa winds (vectors) respectively on observed normalized (left) DJF Niño-3 and (right) DJF EMI: (a),(f) summer, (b),(g) autumn, (c),(h) winter, (d),(i) following spring, and (e),(j) following summer. Only values (either zonal wind or meridional wind) exceeding the 95% confidence level are plotted.
FIG. 10. As in Fig. 9, but for precipitation and 850-hPa winds from CFSv2 0-month lead hindcast.
FIG. 11. As in Fig. 9, but for observed 2-m surface air temperature and 200-hPa winds.
Fig. 12. As in Fig. 9, but for 2-m surface air temperature and 200-hPa winds from CFSv2 0-month lead hindcast.
with the skill in SST prediction. The features of precipitation and atmospheric circulation related to CP El Niño, as well as the relationships between EMI and EASM index (Tables 2 and 3), cannot be well predicted. However, for SON, the patterns of precipitation and atmospheric circulation related to EP El Niño can be predicted when lead time is less than 5 months and the predicted patterns are similar to the pattern of 0-month lead. For CP El Niño, the features of precipitation and atmospheric circulation can be predicted partially when lead time is less than 3 months (not shown). The magnitude of the predicted precipitation and wind anomalies decreases as lead time increases.

The predicted patterns of DJF precipitation and 850-hPa precipitation and atmospheric circulation related to the observed DJF Niño-3 from 1- to 7-month lead are similar to the pattern of 0-month lead, although the areas with significant anomalies decrease slightly as lead time increases (Figs. 13a–d). CFSv2 also captures the patterns of DJF precipitation and 850-hPa winds related to the DJF EMI over the western Pacific for all time leads, although the area and magnitude of predicted precipitation and winds decreases with increase in lead time, consistent with SST prediction (Figs. 13e–h). CFSv2 overestimates the response of EAWM to CP ENSO and cannot well capture the different relationships of EAWM with Niño-3 and EMI (Tables 2 and 3). The skill of predicting precipitation and 850-hPa atmospheric circulation for MAM1 is similar to that for DJF (not shown).

The patterns of predicted JJA1 precipitation and 850-hPa atmospheric circulation related to DJF Niño-3 from 1- to 7-month lead are similar to the pattern of 0-month lead, but the response of precipitation and winds tends to become stronger with lead time (Figs. 14a–d). The correlation between EASM and Niño-3 during the decaying summer also shows an increasing tendency with lead time (Tables 2 and 3). The enhanced response may be related to the increase in the correlation between predicted JJA1 SST and DJF Niño-3 in the eastern Pacific (Figs. 5a–d). Jiang et al. (2013b) speculated that there may be a positive feedback air–sea bias in the tropical Pacific, which causes the bias amplification as lead time increases. For CP ENSO, CFSv2 has a bias in producing the anticyclone around the Philippine Sea in 1- and 3-month lead predictions.

To conclude, the skill of CFSv2 in predicting the climate impact of the two types of El Niño as a function of lead time is consistent with the skill in predicting SST. A well-predicted SST is accompanied by a well-predicted climate impact. Because of its deficiency in predicting the phase and magnitude of SSTA related to CP ENSO, CFSv2 faces great challenges in capturing the impact of CP ENSO on East Asian climate.

5. Summary and discussion

ENSO and its teleconnection patterns are the important bases for seasonal climate prediction. The NCEP CFSv2, which became operational in March 2011, provides an important source of information for seasonal climate prediction over many regions of the world. In this study, we have provided a comprehensive assessment of the predictability of the two types of ENSO and their impacts on East Asian climate by the state-of-the-art climate forecast system. CFSv2 captures the spatial patterns of SST related to EP ENSO and CP ENSO as well as their differences several months in advance. Prediction skills are different for the different phases of ENSO cycle. The model has advantages in predicting the two types of ENSO compared to SST persistency predictions based on the Niño-3 and EMI indices in JJA and SON, as well as in DJF for long lead predictions. However, the magnitude of SST anomalies related to the DJF EMI is generally underestimated by CFSv2.

The two types of ENSO have different impacts on East Asian climate from the developing summer to the
FIG. 13. Patterns of partial regression of DJF precipitation (shading) and 850-hPa winds (vectors) from CFSv2 hindcast on observed normalized (left) DJF Niño-3 and (right) DJF EMI: (a),(e) 1-, (b),(f) 3-, (c),(g) 5-, and (d),(h) 7-month leads. Only values (either zonal wind or meridional wind) exceeding the 95% confidence level are plotted.
FIG. 14. As in Fig. 13, but for precipitation and winds during ENSO decaying JJA (JJA1).
FIG. 15. As in Fig. 9, but for precipitation and 850-hPa winds from AMIP simulations.
decaying summer. CFSv2 captures the anomalous climate patterns related to the two types of ENSO and their differences, consistent with its skill in predicting SST. However, it overestimates the areas where the climate is affected by ENSO, but underestimates the magnitude of climate anomalies related to ENSO. CFSv2 also shows low skill in predicting the climate impact of CP ENSO, consistent with the prediction of SST.

The prediction of Niño-3 and EMI indicates that the EMI is better predicted by CFSv2 in JJA and SON. However, the anomalous SST patterns related to DJF Niño-3 and EMI show that CFSv2 has better skill in predicting EP ENSO. What are the possible causes of this discrepancy? One of the possible reasons is that the prediction of the indices does not separate the different skills of CFSv2 for different phases of ENSO evolution. As shown in Fig. 6, EMI has higher persistency compared to Niño-3. Weng et al. (2007) reported that EMI did not clearly exhibit a phase locking with the seasonal cycle and EMI values were positively large in either late summer or late winter while Niño-3 was phase locked. The anomalous SST patterns discussed in this study are all related to DJF Niño-3 and EMI, which may lead to lower skill of CFSv2 in predicting CP ENSO. To better understand this issue, we have also examined the anomalous SST patterns related to Niño-3 and EMI simultaneously. Results indicate that CFSv2’s deficiency in predicting CP ENSO is not apparently different from that discussed in this paper, in spite of some changes in anomalous SST pattern (not shown).

CFSv2’s skill in predicting the climate impact of El Niño depends partly on its skill in simulating El Niño-related SST. If CFSv2 is forced by realistic SST, how well can the climate impact of ENSO be predicted? Figure 15 shows the patterns of regressed precipitation and 850-hPa winds from the CFSv2 AMIP on observed normalized DJF Niño-3 and EMI, respectively. In the AMIP experiments, the general features of the climate impacts and their differences between the two types of ENSO are captured, although the spatial extent affected is overestimated. It is interesting to note that the magnitude of precipitation and atmospheric circulation predicted by the AMIP is compared to that in observations. The AMIP also simulates an anomalous cyclone over East Asia during the CP El Niño developing summer, which is more northeastward compared to observation. These features imply that a better simulation of SST pattern by CFSv2 for CP El Niño potentially improves the prediction of its climate impact. However, the prediction of the anomalous anticyclone over the WNP during the EP El Niño decaying summer simulated by the AMIP is not as good as that in the hindcast. This difference may be partly ascribed to the exclusion of air–sea interaction in the AMIP, since air–sea interaction may be important for the maintenance of the anomalous anticyclone, especially in July and August (Jiang et al. 2013a).

Why does CFSv2 predict a weaker-than-observed ENSO? This bias was also found in CFSv1 and ascribed to a warm bias in the eastern Pacific caused probably by the model’s deficiency in simulating the amount of stratus clouds off the North American coast (Kim et al. 2012). The climatological annual mean SST simulated by CFSv2 also has a warm bias over the eastern Pacific, especially the southeastern Pacific where CP ENSO has a warm bias. Thus, the deficiency of CFSv1 in simulating CP ENSO, reported by Kim et al. (2012), may also exist in CFSv2. To understand how the warm bias affects the simulations of the two types of ENSO in CFSv2 requires further studies. In addition, previous studies based on observations and model simulations have indicated that the generation of CP El Niño can be linked to extratropical forcing associated with the North Pacific Oscillation while the evolution of EP El Niño is associated with basinwide thermocline variations (Kao and Yu 2009; Yu et al. 2010; Kim et al. 2012). CFSv2 has low skill in predicting the extratropical atmospheric circulation (Jiang et al. 2013c), which may result in low skill in predicting the generation of CP El Niño.

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