

The prediction on the 2015/16 El Niño event from the perspective of FIO-ESM

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Abstract

Recently atmospheric and oceanic observations indicate the tropical Pacific is at the El Niño condition. However, it's not clear whether this El Niño event of this year is comparable to the very strong one of 1997/98 which brought huge influence on the whole world. In this study, based on the Ensemble Adjusted Kalman Filter (EAKF) assimilation scheme and First Institute of Oceanography-Earth System Model (FIO-ESM), the assimilation system is setup, which can provide reasonable initial conditions for prediction. And the hindcast results suggest the skill of El Niño-Southern Oscillation (ENSO) prediction is comparable to other dynamical coupled models. Then the prediction for 2015/16 El Niño by using FIO-ESM is started from 1 November 2015. The ensemble results indicate that the 2015/16 El Niño will continue to be strong. By the end of 2015, the strongest strength is very like more than 2.0°C and the ensemble mean strength is 2.34°C, which indicates 2015/16 El Niño event will be very strong but slightly less than that of 1997/98 El Niño event (2.40°C) calculated relative a climatology based on the years 1992–2014. The prediction results also suggest 2015/16 El Niño event will be a transition to ENSO-neutral level in the early spring (FMA) 2016, and then may transfer to La Niña in summer 2016.

Key words: El Niño, prediction, FIO-ESM, Ensemble Adjusted Kalman Filter assimilation

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1 Introduction

El Niño-Southern Oscillation (ENSO) phenomenon is the dominant interannual variability in the climate system, which can impact weather and climate across the globe (Alexander et al., 2002; Philander, 1983; Tanaka, 1997; Trenberth et al., 2000; Wang and Picaut, 2004; Wang et al., 2012, 2014; Wang and Wang, 2014). Recently atmospheric and oceanic observations show that weakened trade winds and excess rainfall in the east-central tropical Pacific, and the positive equatorial Sea Surface Temperature (SST) anomalies continue across most of the Pacific Ocean, which indicate the tropical Pacific is at the El Niño level (<http://iri.columbia.edu/our-expertise/climate/forecasts/enso/2015-november-quick-look/>). The multi-model prediction results of CPC/IRI (Climate Prediction Center/International Research Institute for Climate and Society) ENSO predictions plume also suggest continuation of El Niño conditions appears at least 99% likely from the current November–January 2016 season through to the February–April 2015–2016 season, although the strength of El Niño event from each model is much different with others, with most of models predict peak SST anomaly values between 1.8 and 2.8°C. It's not clear whether this El Niño event of this year is comparable to the very strong one of 1997/98 which brought huge influence on the whole world.

Since the pioneer work on establishing the climate model by Manabe and Bryan (1969), it have archived great progress and been widely used in the ENSO prediction (Barnston et al., 2012;

Flato et al., 2013). Now 17 out of 25 models in the IRI ENSO prediction plume are dynamical models, and the skill of dynamical models is exceeding that of statistical models (Barnston et al., 2012). The first climate model with surface gravity waves, namely the First Institute of Oceanography-Earth System Model version 1.0 (hereafter FIO-ESM), was established and employed to conduct the Coupled Model Intercomparison Project Phase 5 (CMIP5) in 2012. The simulation results of CMIP5 experiments show that surface waves can dramatically reduce the tropical biases and improve the ENSO frequency simulation (Qiao et al., 2013). Besides the model simulation ability, the initial condition and ensemble method are also important for ENSO prediction (Luo et al., 2005). The Ensemble Adjusted Kalman Filter (EAKF) assimilation scheme is introduced into FIO-ESM and the results show that the assimilation can effectively improve the simulation of temperature in the upper ocean, atmosphere circulation, and Arctic sea ice (Chen et al., 2015; Shu et al., 2015), which indicate that this EAKF system can provide a reasonable initial condition for ENSO prediction. All of above mentioned studies suggest that FIO-ESM with EAKF scheme should be an effective way to predict ENSO. So, this study aims to give an outlook of 2015/16 El Niño by using FIO-ESM with EAKF assimilation scheme.

The rest of this paper is organized as follows. A brief description of the FIO-ESM, EAKF assimilation scheme and experiments is introduced in Section 2. Section 3 presents the hindcast and prediction results of FIO-ESM, and Section 4 provides the conclusions and discussion.

2 Model description and numerical experiments design

2.1 FIO-ESM

FIO-ESM is developed by Qiao et al. (2013) and then employed to conduct the CMIP5 experiments. It's the first climate model including the surface wave model through including the non-breaking wave-induced vertical mixing into the ocean circulation model. It's the earth system model and composed of a coupled physical climate model and a coupled carbon cycle model. In this study, only the coupled physical climate model is employed. The components are the Community Atmosphere Model Version 3 (CAM3) (Collins et al., 2006), the Community Land Model Version 3.5 (CLM3.5) (Dickinson et al., 2006), the Los Alamos National Laboratory sea ice model Version 4 (CICE4) (Hunke and Lipscomb, 2008), the Parallel Ocean Program Version 2.0 (POP2.0) (Smith et al., 2010), and the MASNUM surface wave model (Yang et al., 2005). The horizontal resolutions of the CAM3 (with 26 vertical layers) and CLM3.5 are T42 spectral truncation (about 2.875°), a nominal 1° (about 1.1° in longitude and 0.3° – 0.5° in latitude, with the North Pole displaced to the Greenland) for POP2.0 (with 40 vertical layers) and CICE4, and 2° for the MASNUM surface wave model (with a resolution of 30° for wave direction). The detail of FIO-ESM can be found in Qiao et al. (2013).

2.2 EAKF assimilation system

Ensemble Adjustment Kalman Filter scheme (Anderson, 2001) based on Ensemble Kalman Filter (Evensen, 1994) has been used to establish an EAKF data assimilation system for FIO-ESM (Chen et al., 2015; Yin, 2015). Satellite SST and SLA (Sea Level Anomaly) are assimilated into FIO-ESM using this assimilation system. This assimilation system consists of five components: Data Pre-processing Module (including SLA data preprocessing and SST data preprocessing in this study), EAKF module, initial condition (IC) perturbing module for FIO-ESM, ensemble models of FIO-ESM and ocean surface data EAKF assimilation for FIO-ESM (Fig. 1). More detail about this EAKF assimilation system and these components can be found in Chen et al. (2015) and Yin (2015).

Satellite SST used in this assimilation system is the daily-averaged data provided by the Climate Data Center of NOAA (National Oceanic and Atmospheric Administration). This dataset is from satellites of NOAA-AVHRR (Advanced Very High Resolution Radiometer) and AMSR (Advanced Microwave Scanning Radiometer), with the horizontal resolution of $(1/4)^\circ \times (1/4)^\circ$ (Reynolds et al., 2007). The daily-averaged SLA data for data assimilation is from AVISO (Archiving, Validation and Interpretation of Satellite Data in Oceanography). The SLA data covers the globe ocean with the horizontal resolution of $(1/3)^\circ \times (1/3)^\circ$ (Ducet et al., 2000).

2.3 Numerical experiments

Three numerical experiments are designed (Table 1) in this study. Experiment ASSI is a long-term data assimilation experiment. Satellite SST and SLA during 1 January 1992 to 31 October 2015 are assimilated into FIO-ESM using this EAKF assimilation system with 10 ensemble members. Experiment HIND contains a series of 6-month hindcast tests. The start date of each test is the 1st day of each month from January 1992 to December 2013. The hindcast initial conditions are from the assimilation results in Experiment ASSI. Experiment PRED is a prediction experiment for the 2015/16 El Niño event. The start date of prediction is 1

November 2015 and the prediction length is 6-month. The prediction initial conditions are also from the assimilation results in Experiment ASSI with 10 ensemble members.

Experiment ASSI is designed to evaluate the performance of FIO-ESM using the EAKF assimilation system and provide initial condition for Experiment HIND and Experiment PRED. Experiment HIND is designed to evaluate the prediction ability of FIO-ESM. Experiment PRED is designed to predict the evolution of 2015/16 El Niño event in the next 6 months.

3 Results and analysis

3.1 Assimilation results

Previous studies (Chen et al., 2015; Shu et al., 2015; Yin, 2015) show that the simulation abilities of FIO-ESM for SST, ocean temperature and salinity profiles, surface wind, precipitation and Arctic sea ice can be significantly improved by using the EAKF data assimilation system. Here we mainly focus on the 3-month running mean Niño 3.4 (5°N – 5°S , 170° – 120°W) anomalies for El Niño criteria which is the same to it using in CPC/IRI. Observed and simulated 3-month running mean Niño 3.4 anomalies during January 1992 to October 2015 are shown in Fig. 2. In this paper, all the Niño 3.4 anomalies are calculated relative to a climatology based on the years 1992–2014. The observed Niño 3.4 anomaly (black line) is calculated from the daily-averaged satellite SST used in this assimilation system data, and the simulations (red line) are from Experiment ASSI results. Figure 2 shows that the Experiment ASSI ensemble mean Niño 3.4 index fits the ob-

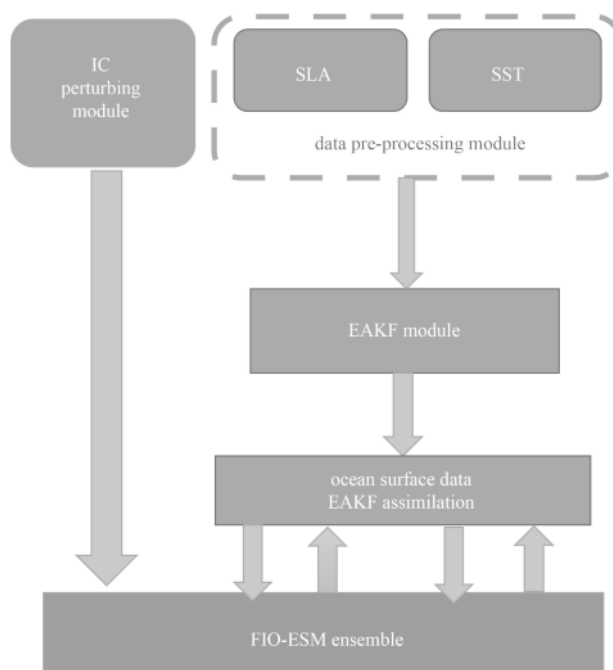


Fig. 1. Schematic view of the EAKF system.

Table 1. Numerical experiment design

| Experiment | Data assimilation | Period | Note |
|------------|-------------------|-----------------|--------------|
| ASSI | yes | 1992.01–2015.10 | assimilation |
| HIND | no | 1993.01–2013.12 | hindcast |
| PRED | no | 2015.11–2016.04 | prediction |

servations well. The correlation coefficient between simulation and observation is 0.98 while the root mean square error (RMSE) is 0.16°C. Simulated Niño 3.4 anomaly shows that there is a strong El Niño event during 1997/98, two moderate El Niño events in the years of 2002/03 and 2009/10, four moderate La Niña events in the years of 1998/99, 1999/00, 2007/08, and 2010/11, which are very consistent with observations. This illustrates that FIO-ESM with this kind of EAKF data assimilation can reproduce ENSO events well. All above suggest the assimilation results from Experiment ASSI should be reasonable to provide the initial conditions for prediction.

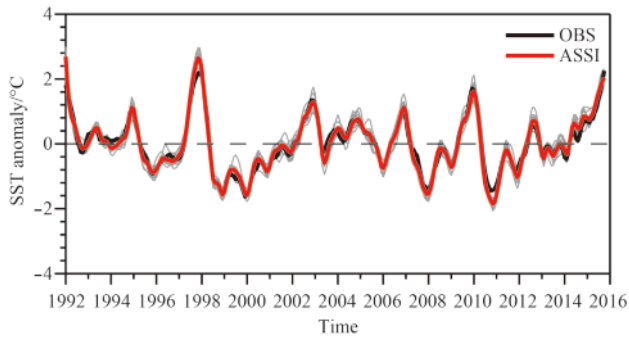


Fig. 2. Time series of 3-month running mean SST anomalies with respect to the 1992–2014 climatology for Niño 3.4 region (5°N–5°S, 170°W–120°W). Black and red lines are the SST anomalies from observation (OBS) and assimilation experiment (ASSI) respectively. Thin gray lines are the SST anomalies of each ensemble members in the assimilation experiments (ASSI).

3.2 Hindcast results

Time series of 3-month running mean ensemble mean Niño 3.4 anomalies, their RMSEs and correlation coefficients from Experiment HIND tests are shown in Fig. 3. The colored lines are the predictions Niño 3.4 anomalies for same 3-month period from earlier start times at 1- (red), 2- (blue), 3- (brown), 4- (green), 5- (cyan), and 6-month (purple) leads respectively. It can be seen that FIO-ESM has a high predictability for ENSO events during the period of 1992–2014. The RMSEs of Niño 3.4 anomaly are 0.23, 0.46, and 0.60°C at the 1-, 3-, and 6-month lead time respectively (Fig. 3b). The correlation coefficients between hindcast results and observations are 0.96, 0.87 and 0.77 at the 1-, 3- and 6-month lead time respectively (Fig. 3c), which is comparable to other dynamical coupled models (Barnston et al., 2012). Almost all the past strong or moderate El Niño and La Niña events can be reasonable predicted by FIO-ESM. These results of Experiment HIND tests give us confidence to try to predict the evolution of 2015/16 El Niño event.

3.3 Prediction results

The 3-month running mean Niño 3.4 anomaly in ASO (August–September–October) and October 2015 is more than 2.0°C, and near real-time observations show that Niño 3.4 anomaly in the second week of November 2015 has been reached 3.0°C (<http://iri.columbia.edu/our-expertise/climate/forecasts/enso/2015-november-quick-look/>). These mean that the tropical Pacific SST is at a strong El Niño level. The 3-month running Niño 3.4 anomaly predicted by Experiment PRED is shown in Fig. 4. The predicted ensemble mean Niño 3.4 anomaly will continue increase and likely peak a little more than 2°C in OND (October–November–December) and NDJ (November–December–January) 2015, which means that this El Niño will continue

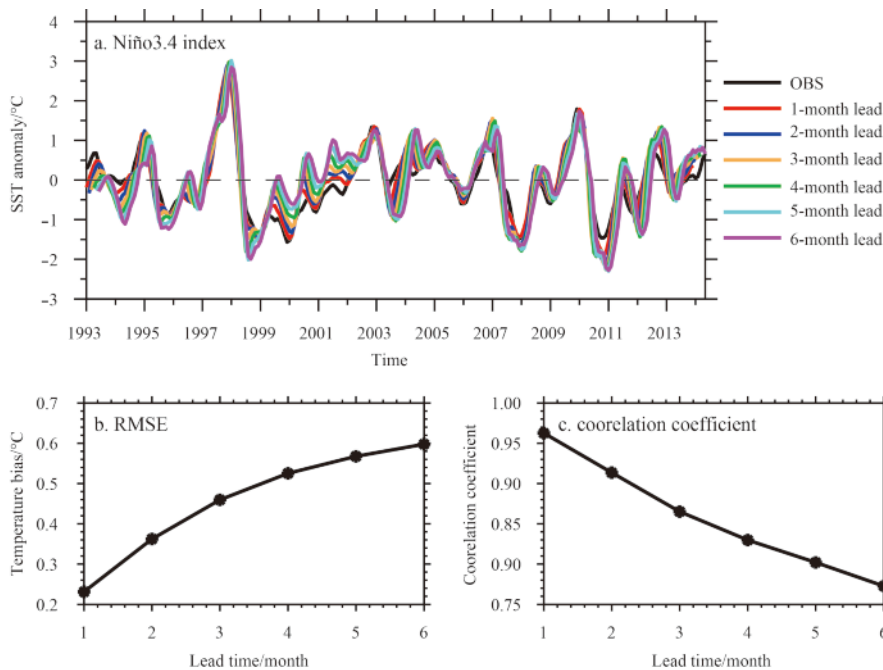


Fig. 3. Hindcast of 3-month running mean SST anomalies with respect to the 1992–2014 climatology for Niño 3.4 region (5°N–5°S, 170–120°W). a. Hindcast time series. Black line is the SST anomaly from observation, other color lines are the predictions for same 3-month period from earlier start times at 1- (red), 2- (blue), 3- (brown), 4- (green), 5- (cyan), and 6-month (purple) leads respectively; b. RMSE between model hindcast and observation as a function of lead time; and c. correlation between model hindcast and observation as a function of lead time.

strengthening and can reach the very strong level. However, the strength of 2015/16 El Niño event (2.34°C in OND and 2.22°C in NDJ) is slightly less than 1997/98 El Niño event with 2.40°C. One point should be noted, the Niño 3.4 anomalies are calculated relative to a climatology based on the years 1992–2014 in this paper, so here the strength of 1997/98 El Niño event is slight larger than it climatology based on the years 1981–2010 defined by CPC (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enstouff/ONI_change.shtml).

Based on FIO-ESM prediction, the 3-month running mean

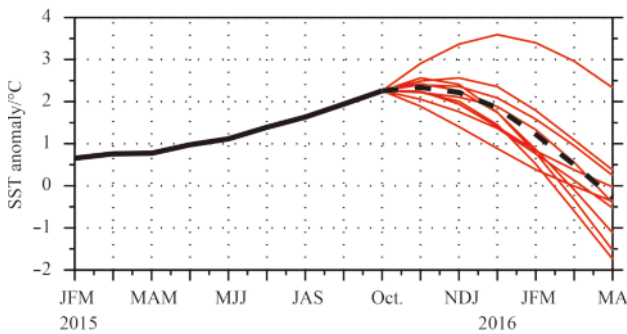


Fig. 4. Forecast of 3-month running mean SST anomalies with respect to the 1992–2014 climatology for Niño 3.4 region (5°N–5°S, 170°–120°W) started from 1 November 2015. Black solid and dashed lines are the SST anomalies of observation and ensemble mean respectively. Each ensemble member is shown with the red thin line.

Niño 3.4 anomaly will decrease to 0.5°C in FMA (February–March–April) 2016 after the peak at the end of 2015, and this suggests that this El Niño will likely transit to ENSO-neutral during the early spring 2016. The 3-month running mean SST anomalies in the tropic Pacific predicted by FIO-ESM are shown in Fig. 5. It can be seen that OND 2015 has the warmest tropic SST anomalies among the predicting 6 months. Then the positive SST anomalies will decrease in the following months, but the positive SST anomalies will extend to the west equatorial Pacific gradually. It is worth mentioning that negative SST anomalies will appear in the east equatorial Pacific in FMA 2016 and then propagate to west, it seems to indicate that will be a La Niña event following the strong 2015/16 El Niño event.

4 Conclusions and discussion

In this study, based on the Ensemble Adjusted Kalman Filter assimilation scheme, the first earth system model with surface waves, FIO-ESM was employed to predict the 2015/16 El Niño event started from 1 November 2015. The model prediction results show that the strength of 2015/16 El Niño event will reach 2.34°C at the end of 2015. It indicates the 2015/16 El Niño event will be at the very strong level but a little weaker than 1997/98 El Niño event with 2.40°C. The forecast results also suggest 2015/16 El Niño event will fade to ENSO-neutral level in the early Spring (February–March–April) 2016.

One point should be noted that the above conclusion is analyzed from the ensemble mean results. For each ensemble member prediction for 2015/16 El Niño event, 8 out of 10 is consistent with the ensemble mean results, although 1 out of 10 is stronger than 1997/98 and 1 out of 10 is the moderate El Niño event (Fig.

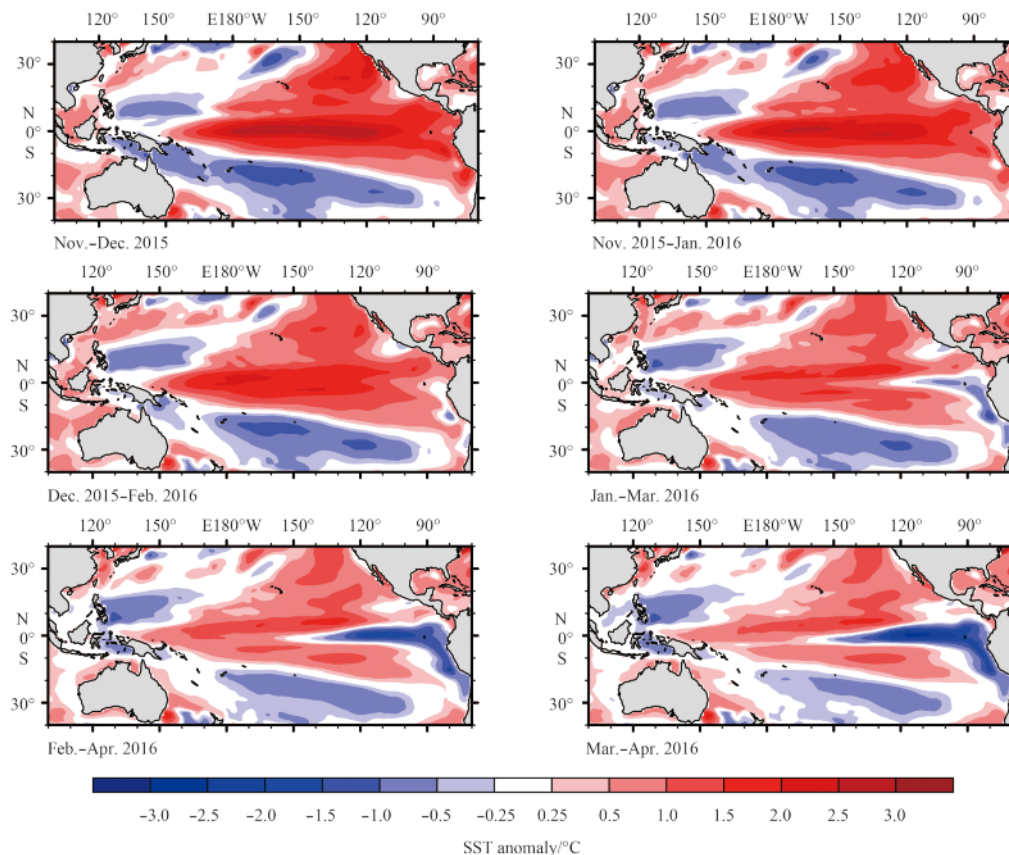


Fig. 5. Prediction of SST anomalies with respect to the 1992–2014 climatology started from 1 November 2015.

4). In summary, the 2015/16 El Niño strength will continue to be strong. And in the end of 2015 the probabilistic of becoming the very strong El Niño event is more than 90%, but at least 80% the strength is less than that of the 1997/98.

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