ENSO and ENSO teleconnection

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Abstract: This seminar provides a review of the ENSO and ENSO teleconnection, and the current status of ENSO prediction using retrospective predictions (1982-2010) from the ECMWF System 4 (Sys4) and NCEP CFS version 2 (CFSv2) coupled atmosphere-ocean seasonal climate prediction systems. The simulation ability of long-term mean climatology and the year-to-year variation were assessed for both prediction systems. Both Sys4 and CFSv2 reproduce realistically the observed climatology pattern. In both systems, the standard deviation of winter mean SST anomaly shows similar patterns to observations with maximum variability over the central to eastern Pacific with a stronger magnitude than observed. Although the ENSO SST variability is spatially biased in the models, both models predict the year-to-year ENSO variation accurately. Bias in winter SST trend over the ENSO region in CFSv2 results in relatively low ENSO prediction skill and high RMS error compared to Sys4. Both models capture the main ENSO teleconnection pattern of strong anomalies over the tropics, the North Pacific, the North America.

1 Introduction

El Niño is characterized by unusually warm ocean temperatures in the Equatorial Pacific, as opposed to La Niña, which characterized by unusually cold ocean temperatures in the Equatorial Pacific. ENSO (El Nino Southern Oscillation) is an oscillation of coupled response between ocean and atmosphere circulations over the tropical Pacific and the ocean-atmosphere coupled system in the tropical Pacific having important consequences for weather around the globe. Therefore, ENSO prediction has been an important topic for several decades. Despite the chaotic internal dynamics of the atmosphere, the time average of atmospheric variables is predictable to some degree due to those components that have slow variations on time scales from months to seasons. The socioeconomic importance of accurate seasonal climate prediction has motivated development of better seasonal prediction systems. Recently, the development of coupled ocean-atmosphere dynamical model prediction systems has provided important advances in seasonal predictability (Krishna Kumar et al. 2005, Wang et al. 2005, Kug et al. 2008).

This study focuses on the ECMWF and NCEP CFS seasonal forecasting systems especially for ENSO simulation and prediction based on the recent paper, Kim et al. (2012). Jin et al. (2008) examined the current status of ENSO prediction using retrospective forecasts made with ten different coupled GCMs and found that the ENSO prediction skill in the state-of-the-art dynamical predictions depends on the ENSO phase and amplitude. Generally, dynamical models tend to have better prediction skill when initialized at boreal winter than spring due to the 'spring predictability barrier' (Webster and Yang 1992, Webster 1995, Torrence and Webster 1998, Jin et al. 2008, Kim et al. 2009, Hendon et al. 2010). This study focuses on the boreal winter prediction when the initial condition already contains a strong ENSO signal. The ECMWF forecast model has been found to be better than statistical models at forecasting ENSO events (Van Oldenborgh et al. 2005) and NCEP CFS is shown to be competitive with other statistical models in predicting tropical SST variability (Saha et al. 2006). Here we compare ECMWF System 4 and CFSv2 in terms of winter ENSO prediction based on Kim et al. (2012) results. The ECMWF has upgraded its operational seasonal forecasts from System 3 to System 4 with the later version being operational since late 2011. In the upgrade, it utilizes the use of the most recent atmospheric model version, higher resolution forecasts with a higher top of the atmosphere, more ensemble members and a larger reforecast data set (Molteni et al. 2011). The NCEP CFS has been making coupled ocean-atmosphere forecasts since 2004. Skill of the CFS model has been examined in simulating and predicting ENSO variability (Wang et al. 2005), Asian-Australian/Indian monsoon (Yang et al. 2008, Wang et al. 2008, Pattanaik and Kumar 2011) and climatic variation in the U.S. (Yang et al. 2009). The NCEP CFS version 2 (CFSv2; Saha et al. 2011) represents a substantial change to all aspects of the forecast system including model components, data assimilation system and ensemble configuration.

We compare the ENSO simulation ability and ENSO prediction skill of the two systems using the same validation matrix. The results of this comparison may be useful for the community as a benchmark for future generations of seasonal prediction systems, and may provide valuable information for forecast providers and decision makers that use seasonal forecast products. In this research, we focus on the Northern Hemisphere (NH) winter when the magnitude of ENSO anomalies and teleconnections to the extratropics can be particularly high (Peng et al. 2000).

2 Retrospective forecasts and observation data

The ECMWF System 4 (hereafter Sys4) and the NCEP CFSv2 (hereafter CFSv2) are fully coupled general circulation models (GCMs) that provide operational seasonal predictions. Both systems provide reforecast simulations for the purpose of evaluating and calibrating the model simulations. The ECMWF System 4 seasonal reforecasts, commencing in 1981, include 15 member ensembles consist of 7 month simulations initialized on the 1st day of every month. The atmospheric initial conditions come from ERA Interim reanalysis for the period 1981 to 2010. Details for the ECMWF System 4 can be found in www.ecmwf.int/products/forecasts/seasonal/documentation/system4. The NCEP CFSv2 (Saha et al. 2011) is an upgraded version of CFSv1 (Saha et al. 2006). CFSv2 produces a set of 9-month reforecast initiated from every 5th day with four ensemble members for the period 1982-2010. Initial conditions for the atmosphere and ocean come from NCEP Climate Forecast System Reanalysis (CFSR, Saha et al. 2010). Details of the system can be found in Saha et al. (2011). As prediction skill depends strongly on the ensemble size (Kumar and Hoerling, 2000), we match the ensemble size, as well as lead-time for the comparison of the Sys4 and CFSv2 forecasts. The Sys4 reforecast consists of 15 ensembles initialized on November 1st and for CFSv2 16 member ensembles initialized from October 23rd to November 7th from the target variables and those from December to February (DJF), which we define as the

NH winter. For example, 1997 winter is an average of December 1997 and January and February of 1998. A total of 28 boreal winters from 1982/83 to 2009/2010 are examined in this study. For the forecast evaluation, SST data is obtained from monthly NOAA Optimum Interpolation (OI) SST V2 (Reynolds et al. 2002). The air temperature at 2 meter (2mT), mean sea level pressure (SLP), and geopotential height at 500 hPa data are obtained from the CFS reanalysis and ERA-Interim reanalysis products (Berrisford et al. 2009) from 1981. The CFSR is a major improvement over the first generation NCEP reanalyses (NCEP R1 and R2) as it is the product of a coupled ocean–atmosphere–land system at higher spatial resolution (Higgins et al. 2010, Saha et al. 2010). Global Precipitation Climatology Project (GPCP) version 2.1 combined precipitation dataset (Alder et al. 2003) is used as the validation dataset.

3 ENSO simulation and prediction

Here, we examine the capability of the systems in simulating the spatial patterns of seasonal climatology and the predictive skill of seasonal anomalies including ENSO variability. The prediction skill is calculated as an anomaly correlation based on the ensemble mean of each seasonal prediction and the target observations. To examine seasonal prediction skill, the correlation coefficients between reanalysis and reforecast anomalies are calculated for the ensemble mean determined from 28 winter seasons. Figure 1 shows the correlation coefficients for 2 meter temperature (2mT) and precipitation (PRCP) anomaly for each modeling system compared to ERA and GPCP. In both systems, the prediction skill for 2mT and PRCP is greater over the tropics than over the extra-tropics and greater over ocean than over land (Peng et al. 2000, Peng et al. 2011). 2mT has its greatest prediction skill in the tropical belt, especially in the ENSO region. The South Indian Ocean, the North Pacific and the equatorial North Atlantic also show high skill in both systems. There is almost no skill near the east coast of North America, a common problem in both systems (Figure 1a, b). Prediction skill of precipitation in both reforecasts is generally lower than 2mT, but it also shows greatest skill over the equatorial Pacific which is influenced by ENSO (Figure 1c, d).

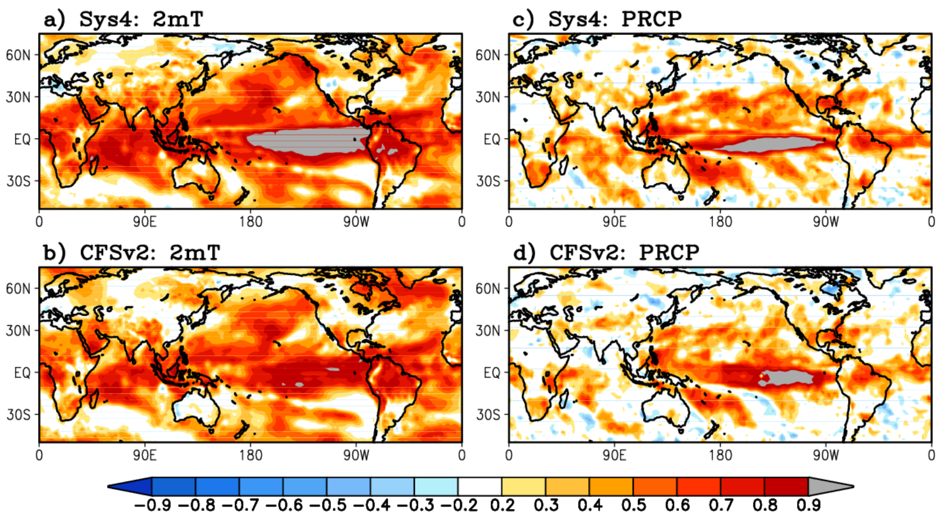

Figure 1. Correlation coefficients of (left) 2 meter temperature and (right) precipitation for (top) Sys4 and (bottom) CFSv2 for the period of 28 years from 1982 to 2009 winter.

To examine the SST variability over the ENSO region, Figure 2 compares the predicted SST with OISSTv2 variability over the tropical Pacific for each forecast system. The SST variability is calculated by the standard deviation of NH winter SST anomalies over the 28 year period. Both modeling systems show similar patterns to the observations with maximum variability over the central to eastern Pacific, but with stronger magnitudes (Figure 2). It has been previously noted that NCEP CFSv1 and v2 consistently tends to forecast larger ENSO amplitude (Wang et al. 2010). Sys4 overestimates the amplitude of SST variability over the entire Tropics and CFSv2 overestimates the amplitude especially from 150°W to the eastern Pacific and underestimates it in the western Pacific.

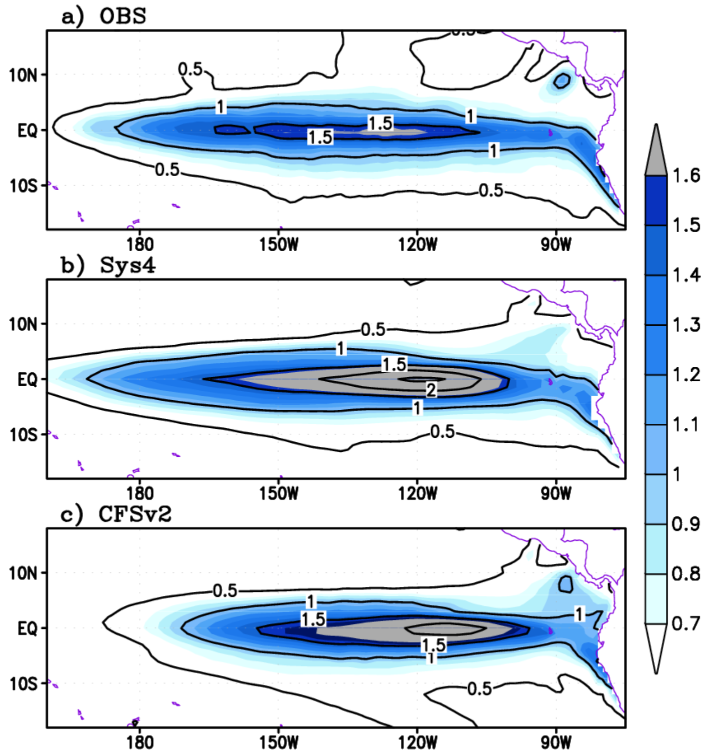

Figure 2. Standard deviation of winter mean SST anomalies for (a) observation, (b) Sys4 and (c) CFSv2.

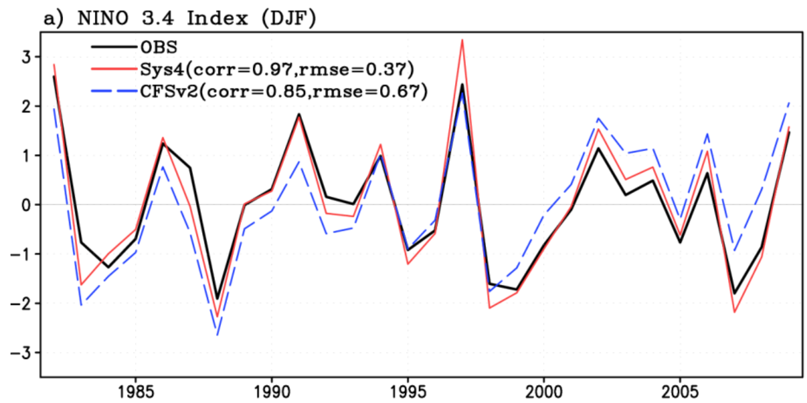

Figure 3. Nino 3.4 index for observation (black), Sys4 (red) and CFSv2 (blue) from 1982 to 2009. Correlation coefficient and root-mean-square error between observation and hindcasts are indicated together.

The year-to-year ENSO prediction skill is assessed by using the Nino 3.4 index, defined as a mean SST anomaly averaged over the region from 190°E to 240°E and from 5°S to 5°N. The index possesses a strong interannual variability (Figure 3) and both prediction systems capture the year-to-year ENSO variability very well. The correlation coefficient between the reforecasts and observations for Sys4 is 0.97 with root-mean-square error (RMSE) of 0.37, and for CFSv2 is 0.85 with RMSE of 0.67. Although the ENSO phase is well predicted in CFSv2, the magnitude of ENSO is overestimated in the system as noted earlier. Relatively low prediction skill and large RMSE in CFSv2 result from larger SST variability over the tropics. For example, the observed Nino 3.4 index in 1988 winter is around -2 K while CFSv2 predicts a value almost 1 K lower than the observation. Before 1993, CFSv2 underestimates the Nino 3.4 values, but after 1998 CFSv2 overestimates the Nino 3.4 continuously, about 0.5 K higher than the observation (Figure 3). A clear upward trend in the predicted winter Nino 3.4 index is found in CFSv2 (Xue et al. 2010). The large warming trend in the eastern Pacific SST is primarily associated with changes in satellite observing system that occurred in 1998/99 period that were assimilated in the CFSR (Xue et al. 2010, Wang et al. 2011).

4 ENSO teleconnection patterns

We now examine how the models predict winter teleconnection patterns in relation to the ENSO phase. Clearly, the NH winter is strongly influenced by the warm and cold phases of ENSO, especially the North Pacific and North America. Figure 4 and 5 shows the composite map of the ERA 2mT, the 500 hPa geopotential height and the PRCP anomaly in four strong El Nino (1982, 1991, 1997 and 2009) and La Nina (1988, 1998, 1999 and 2007) winters.

The composite patterns in CFSR are similar to the ERA analyses (not shown). The conventional El Nino pattern is apparent, with warm/wet anomaly across the equatorial central to eastern Pacific produced by the shifting pattern of the Walker circulation (Figure 4-5). A boomerang pattern of cold and dry anomaly appears to the north and south of the equatorial western Pacific. Although the La Nina pattern is not exactly the mirror image of El Nino (Hoerling et al. 1997), it is almost the opposite from El Nino in the extratropics. Both prediction systems simulate well the general pattern of ENSO response over the tropics, although the boomerang pattern in the western Pacific is not well simulated by either system. The magnitude of the SST anomaly in both prediction systems is larger than the observed anomaly. The warm anomaly over the South Indian Ocean during El Nino and the warm/cold anomaly over the northern part of Australia in El Nino/La Nina are well captured in Sys4 (Figure 4b, e).

The ENSO forcing of the Polar Jet over the North Pacific and North America is known to be responsible for ENSO teleconnections such as Pacific North America (PNA) (Wallace and Gutzler 1981). The southern part of North America experiences a cold and wet winter during El Nino and a warm and dry winter during La Nina (Figure 4-5). The northwestern part of North America experiences milder winter during the El Nino and colder winter during the La Nina phase. Both modeling systems capture the gross

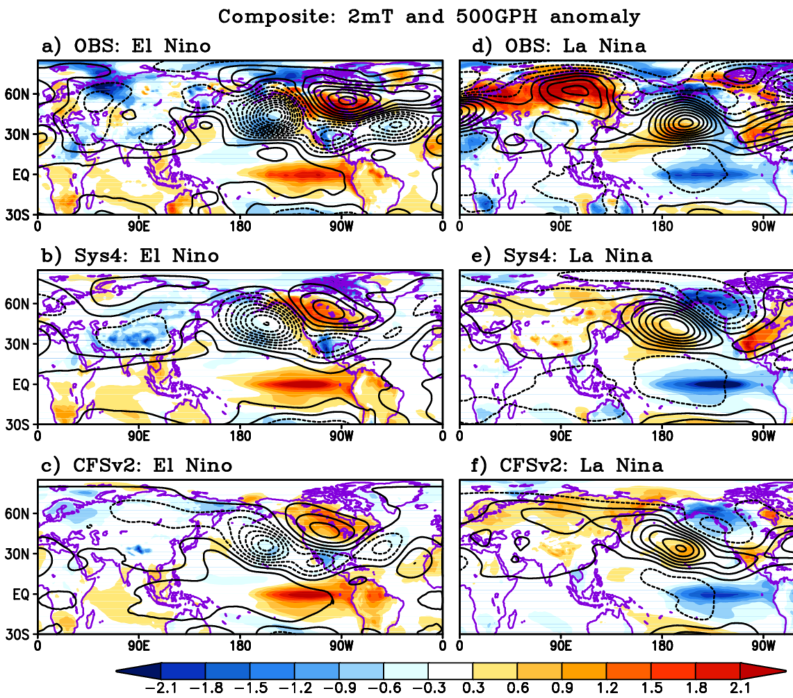

Figure 4. Composite map of 2 meter temperature (K, shading) and 500 hPa geopotential height anomaly (m, countour) for (top) ERA interim, (middle) Sys4 and (bottom) CFSv2 for (left) El Nino and (right) La Nina winter.

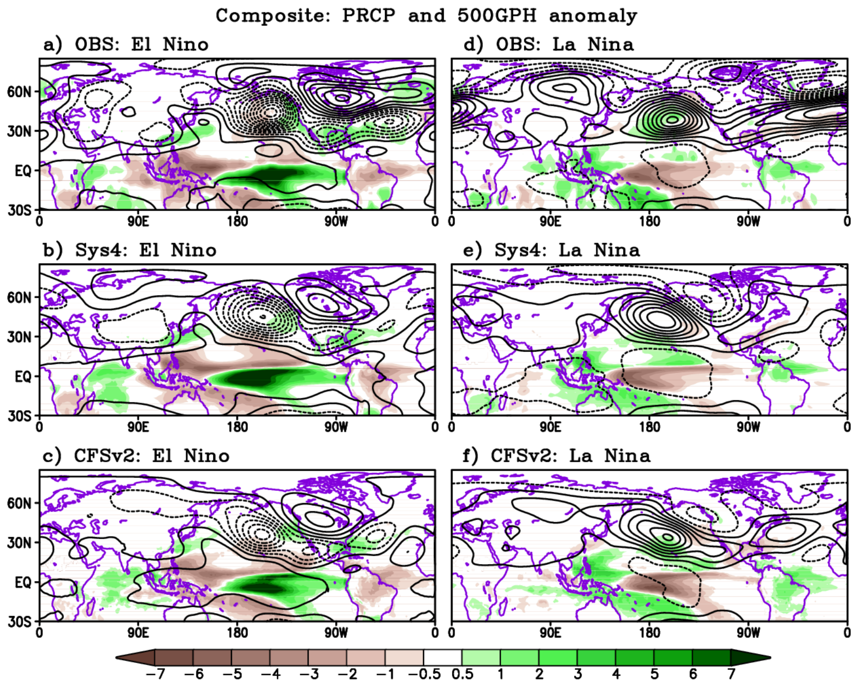

Figure 5. As in Figure 4, but for the precipitation anomaly (mm/day, shading).

global patterns in strong ENSO winters. The 500 hPa high pressure area over the North America in El Nino winter is well captured in Sys4 but with weaker magnitude, and it is shifted to the west in CFSv2. The strong low pressure area in the North Pacific is well captured in both models, but slightly shifted to the south in CFSv2 (Figure 4-5). The other low pressure area in the southern part of U.S. and the Atlantic Ocean is not well simulated in Sys4. In La Nina winters, the models have a tendency that is similar but slightly asymmetric to El Nino winters (Figure 4-5).

5 Summary

This study has examined the ENSO simulation ability and prediction skill for NH winter using retrospective predictions (reforecasts) by the ECMWF System 4 and NCEP CFSv2. The simulation ability of long-term mean climatology and the year-to-year variation were assessed. Both Sys4 and CFSv2 reproduce realistically the observed climatology pattern. For both the Sys4 and CFSv2 systems, the mean prediction skill of 2mT and precipitation is higher over the tropics than the extra-tropics and higher over ocean than land. The 2mT over the South Indian Ocean, the North Pacific and equatorial North Atlantic shows high predictive skill in both reforecasts. The 2mT and precipitation show the greatest skill in the tropical belt, especially in ENSO region. In both modeling systems, the prediction skill of both tropical 2mT and precipitation is higher during strong ENSO winters than during weak ENSO winters. In both systems, the standard deviation of winter mean SST anomaly shows similar patterns to observations with maximum variability over the central to eastern Pacific with a stronger magnitude than observed. Although the ENSO SST variability is spatially biased in the models, both models predict the year-to-year ENSO variation accurately. Bias in winter SST trend over the ENSO region in CFSv2 results in relatively low ENSO prediction skill and high RMS error compared to Sys4. Both models capture the main ENSO teleconnection pattern of strong anomalies over the tropics, the North Pacific, the North America.

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