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ENSO Precipitation and Temperature Forecasts in the North American Multi-Model Ensemble: Composite Analysis and Validation

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1. Introduction

The El Niño/Southern Oscillation (ENSO) has a large influence on the seasonal precipitation (P) and temperature (T) patterns over the United States and across the globe (Ropelewski and Halpert 1986, 1987; Trenberth *et al.* 1998; Dai and Wigley 2000). At NOAA Climate Prediction Center (CPC), a large effort is devoted to monitoring and forecasting of Niño-3.4 sea surface temperature (SST) and the tropical Pacific Ocean conditions, in order to provide the most up-to-date information on the phase of the ENSO cycle. Statistical tools have been developed for objective seasonal prediction using Niño-3.4 SST forecasts in conjunction with observed P and T composites keyed to phases of the ENSO cycle (Higgins *et al.* 2004). On the other hand, many studies (*e.g.*, Kumar *et al.* 1996; Mathieu *et al.* 2004) have shown that improved skill of P and T prediction in climate models can be attributed to the known impacts of ENSO signals, especially during the Northern Hemisphere cold season. Recent developments in multi-model ensembles provide a promising way to increase P and T predictive skill using dynamical model forecasts (Graham *et al.* 2000; Kirtman *et al.* 2014).

In this study, we examine P and T forecasts during ENSO events in six models in the North American Multi-Model Ensemble (NMME), including the CFSv2, CanCM3, CanCM4, FLOR, GEOS5, and CCSM4 models, by comparing the model-based ENSO composites to the observed. The composite analysis is conducted using the 1982-2010 hindcasts for each of the six models with selected ENSO episodes based on the seasonal Ocean Niño Index (ONI) just prior to the date the forecasts were initiated. Two types of composites are constructed over the North American continent: one based on mean precipitation and temperature anomalies in physical units, the other based on their probability of occurrence in a three-class forecast system. They are referred as anomaly and probability composites, respectively, hereafter. The composites apply to monthly mean conditions in November, December, January, February, and March, respectively, as well as to the five-month aggregates (NDJFM) representing the winter conditions. For anomaly composites, we use the anomaly correlation coefficient (ACC) and root-mean-square error (RMSE) against the observed composites for evaluation. For probability composites, we develop a probability anomaly correlation (PAC) measure and a root-mean probability score (RMPS) for assessment (Chen *et al.* 2016).

2. ENSO composites

a. Anomaly composites

For each model, monthly ensemble mean P and T forecasts are first obtained by averaging all members. The P and T anomalies for a given start and lead times are then computed as the difference between the ensemble mean P and T forecasts and the lead-specific model climatology derived from the hindcast mean of all members and all years excluding the forecast year. The P and T anomaly composites for the warm ENSO (El Niño) events and cold ENSO (La Niña) events are simply the average of the ensemble P and T anomaly maps of selected years. The years are chosen based on the historical ONI published on the CPC website at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. If the seasonal ONI

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just prior to the date the forecasts were initiated indicates a warm or cold ENSO episode, the forecasts are selected for the composite analysis. The NMME composites are the equally weighted mean of the six models' composites.

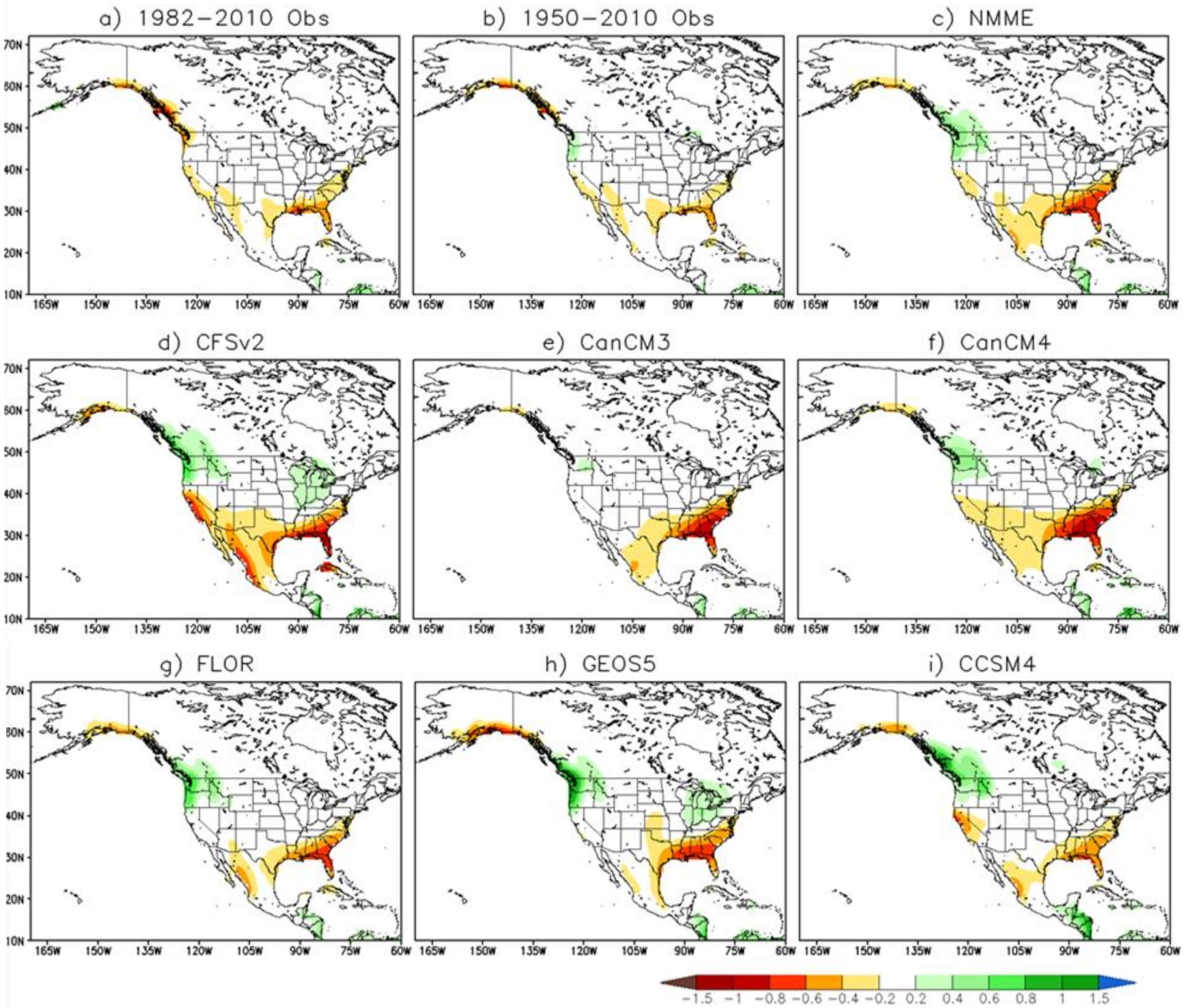

Fig. 1 La Niña precipitation anomaly composites for NDJFM based on (a) 1982-2010 observations, (b) 1950-2010 observations, (c) NMME, (d) CFSv2, (e) CanCM3, (f) CanCM4, (g) FLOR, (h) GEOS5, and (i) CCSM4 forecasts over the North American continent. The anomaly unit is mm/day.

b. Probability composites

For each model, P and T forecasts for a given start and lead times are classified into three categories (above, near, and below normal) based on the terciles derived from the hindcasts of all members excluding the forecast year. For P forecasts, the tercile thresholds are the 33th and 67th percentiles determined by fitting a gamma distribution to the hindcasts. For T forecasts, the tercile thresholds are set as mean plus/minus 0.431×standard deviation by assuming a Gaussian distribution. The classification applies to each individual member forecast, and the number of ensemble members that fell into the three categories under the El Niño and La Niña events are counted for the selected ENSO years. At each grid point, the probability of occurrence for each category under the El Niño (or La Niña) condition is then calculated by dividing the total number of counts by the product of the number of the selected ENSO years and the number of ensemble members for each model. The ENSO probability composites for NDJFM are the combination of all five winter months, that is, the probability of occurrence for each category is calculated by summing all counts in each of the five months (all at Lead 1) divided by the total number of events from all five months. Similarly, the NMME probability composites are the combination of all six models by adding all counts in each category from the six models together, but note that the classification of each model is determined separately in respect to model's own hindcast distribution for a particular month.

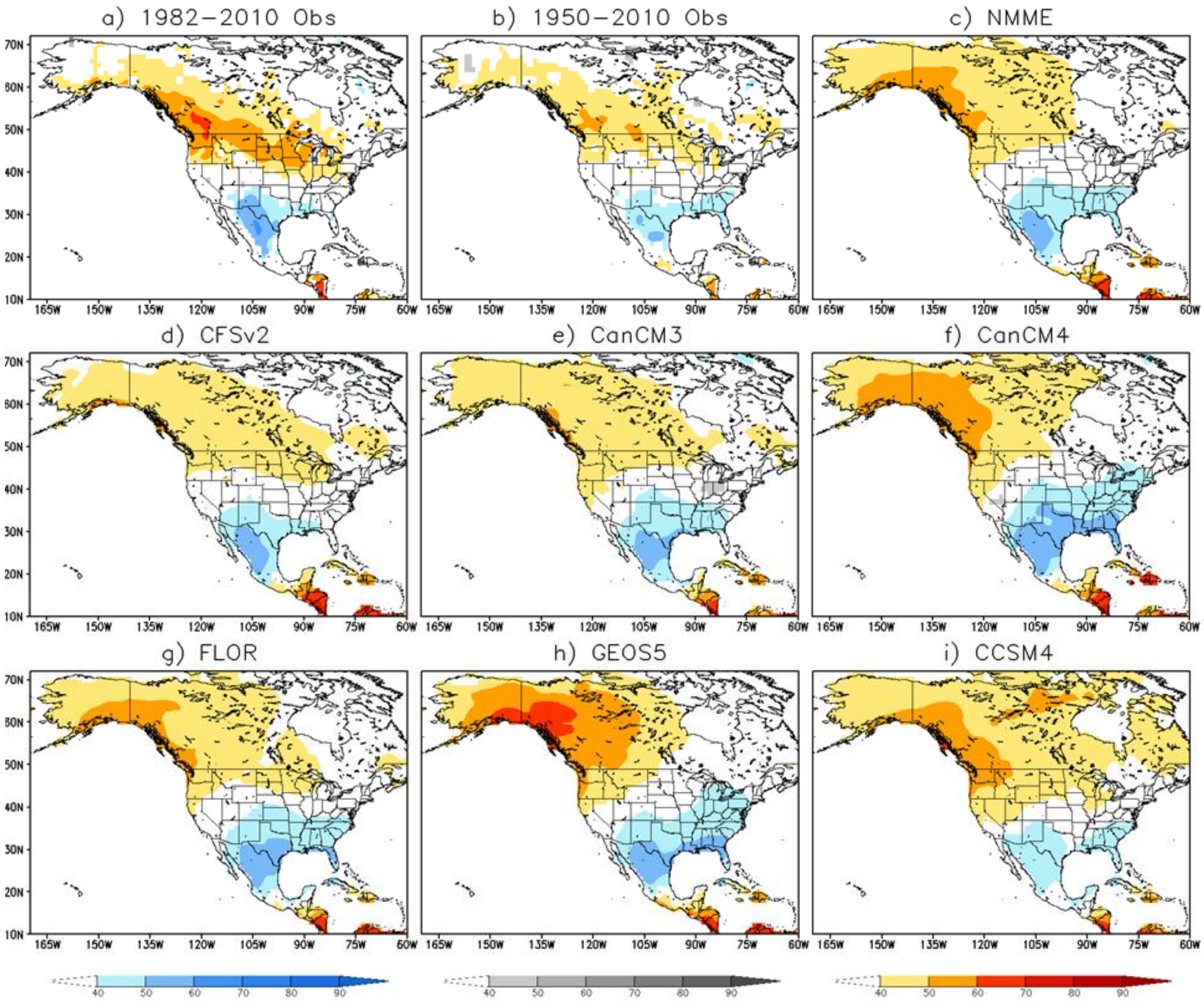

Fig. 2 El Niño temperature probability composites for NDJFM based on (a) 1982-2010 observations, (b) 1950-2010 observations, (c) NMME, (d) CFSv2, (e) CanCM3, (f) CanCM4, (g) FLOR, (h) GEOS5, and (i) CCSM4 forecasts over the North American continent.

3. Composite analysis and validation

Figure 1 shows the La Niña P anomaly composites for NDJFM based on 1982-2010 and 1950-2010 observations, NMME, and the six models. All model and the 1950-2010 observed composites present drier than normal conditions over the southern U.S. and enhanced rainfall over the Pacific Northwest, consistent with the pattern suggested by Ropelewski and Halpert (1986, 1987). The 1982-2010 observed NDJFM P anomaly composite also displays similar La Niña pattern to the 1950-2010 observed. In contrast to the NMME and 1950-2010 observed composites, the 1982-2010 observed has below-normal rainfall over the Pacific Northwest, likely a sampling error due to small sample size. There are some variations among the six models but all models are reasonably good. CFSv2 has the biggest North-South contrast in the anomalies and its dry area is spread farther into central Mexico, while both CanCM models produce large negative deviation over the southeastern U.S. Despite the subtle differences, the remarkable similarity between the NMME and observed P anomaly composites under both El Niño (not shown) and La Niña conditions demonstrates the significant progress in ENSO-precipitation relationships from seasonal dynamical models since Smith and Ropelewski (1997).

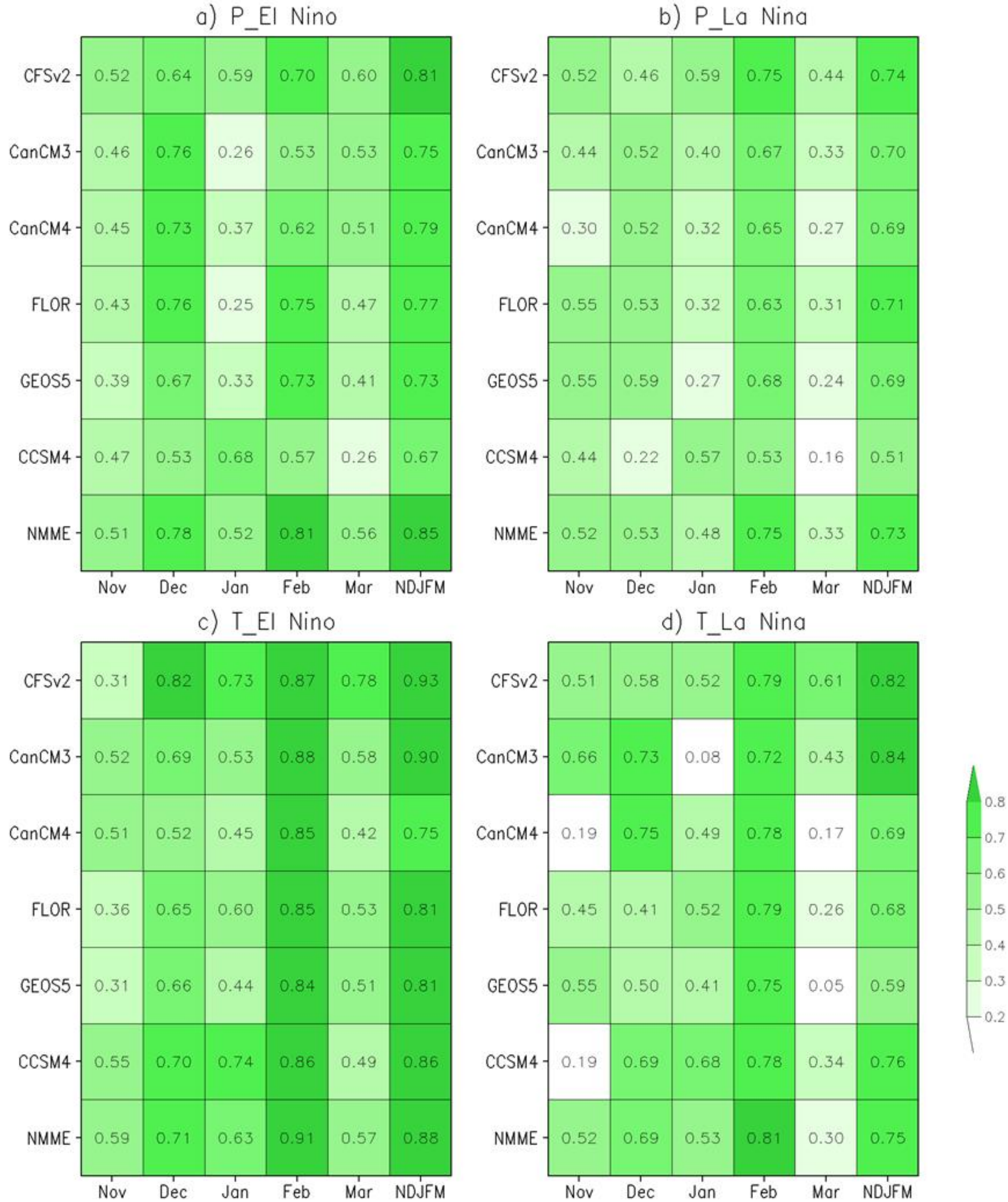

Fig. 3 ACC of all models and months for (a) El Niño precipitation anomaly composites, (b) La Niña precipitation anomaly composites, (c) El Niño temperature anomaly composites, and (d) La Niña temperature anomaly composites, validated with 1950-2010 observations.

Figure 2 presents the El Niño T probability composites for NDJFM based on 1982-2010 and 1950-2010 observations, NMME, and the six models. Unlike the observed P composites, there are larger differences between the 1982-2010 and 1950-2010 observed T probability composites. The 1982-2010 observed composite has bigger warm-cold (North-South) contrast, and its below-normal area is centered over Texas and northern Mexico and does not cover the southeast U.S. Similar to the findings from the T anomaly composites (not shown), T probability composites vary greatly with model. GEOS5, CanCM4, and FLOR models have the largest deviations and are the main contributors to the difference between the NMME and observed probability composites.

In order to present a quantitative evaluation of how well NMME models predict P and T patterns under ENSO conditions, we compute the ACC and RMSE for P and T anomaly composites, and PAC and RMPS for P and T probability composites (Chen et al. 2016). Figure 3 shows the matrix charts of ACC for all models and months, including NMME and NDJFM, using the 1950-2010 observations for validation. Several features are worth highlighting in Figure 3. First, the fidelity is generally higher for NMME composites, as well as NDJFM composites, though a given model at a given month may have slightly larger ACC score. Second, predictive skill varies with month. All models, as well as NMME, have greater ACC for February prediction, and this is seen for both P and T anomaly composites under either El Niño or La Niña condition. Third, most models perform marginally better in predicting El Niño P and T anomaly patterns than La Niña patterns. Fourth and last, CFSv2 is the overall best individual model in predicting ENSO P and T patterns during wintertime. The findings from the RMSE for anomaly composites and PAC and RMPS for probability composites are similar to the ACC results. However, PAC is able to discriminate the performance between the P and T prediction more and shows larger scores for P probability composites than T probability composites under both El Niño and La Niña conditions.

4. Summary and conclusions

We have compared and validated precipitation and temperature forecasts under ENSO conditions in six NMME models with long-term climate observations. Our aim is to understand whether coupled seasonal dynamical models can adequately predict ENSO's impacts on North American precipitation and temperature patterns while an El Niño or La Niña event is in progress. We focus on the overall model performance, and provide a comprehensive analysis and validation of both the anomaly and probability composites constructed from selected warm or cold ENSO episodes based on the tropical Pacific Ocean conditions during the Northern Hemisphere winter season. The key findings from the study are summarized below.

- NMME predicts ENSO precipitation patterns well during wintertime. All models are reasonably good. CFSv2 performs particularly well. This result gives us confidence in NMME precipitation forecasts during an ENSO episode and models' ability in simulating teleconnections.
- There are some discrepancies between the NMME and observed composites for temperature forecasts, in terms of both magnitude and spatial distribution. The differences are mainly contributed by the GEOS5, CanCM4, and FLOR models, and thus the NMME aggregates have difficulties in reproducing the ENSO-temperature relationships.
- For all ENSO precipitation and temperature composites, the fidelity is greater for the multi-model ensemble, as well as the five-month aggregates. February tends to have higher performance score than other winter months.
- For anomaly composites, most models perform slightly better in predicting El Niño patterns than La Niña patterns.
- For probability composites, all models have superior performance in predicting ENSO precipitation patterns than temperature patterns.

A full-length technical paper (Chen *et al.* 2016) documenting details of this study has been submitted to Journal of Climate for publication. The complete set of ENSO composites for all models and months (including all the figures not shown in this abstract), along with global composites, are available on CPC NMME website at http://www.cpc.ncep.noaa.gov/products/NMME/enso/.

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