Usefulness of ensemble forecasts from NCEP Climate Forecast System in sub-seasonal to intra-annual forecasting

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Overview

- Motivation and Objective
- Anomaly Calculation/Bias Correction
- Hypothesis Testing
- Results
- Conclusions
- Interpretation for the operational forecast
Motivation: 2014 ENSO Forecast

SST Outlook: NCEP CFS.v2 Forecast
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The CFS.v2 ensemble mean (black dashed line) predicts ENSO-neutral conditions into early 2014.
24-member SST anomaly forecast in Nino3.4 region using **May initial conditions** in 2006

Forecasts are referred by their month of initialization.
Objective 1: Quantify departure of ensemble mean from observation

Two Month Lead (July, 2006) Temperature Forecast in the Midwestern United States using May 2006 initial condition
Perfect Model Framework

• Observations => CFSv2 Reanalysis data

• Issues of observational uncertainties and deficiency in model parameterization are mitigated to some extent

• Likely to provide an upper bound of predictability in the climate system
Anomaly Calculation/Bias Correction

1. Absolute Anomaly Departure (AAD)

\[
\text{AAD}_{m,l,y} = \frac{\text{abs}\left[\left(\frac{1}{n} \sum_{i=1}^{n} fA_{i,m,l,y}\right) - OA_{m,l,y}\right]}{s_{m,l,y}}
\]

\[
fA_{i,m,l,y} = f_{i,m,l,y} - \frac{1}{p} \sum_{y=1}^{p} \left(\frac{1}{n} \sum_{i=1}^{n} f_{i,m,l,y}\right)
\]

\[
OA_{m,l,y} = O_{m,l,y} - \frac{1}{p} \sum_{y=1}^{p} (O_{m,l,y})
\]

Forecast anomaly relative to forecast climatology from the corresponding month initialization month (m) and lead time (l)

Observation anomaly relative to observation climatology

Two different climatology were used for anomaly calculations one for forecast anomaly and another for observation anomaly

\(s_{m,l,y}\) is the standard deviation calculated across 24-member ensemble reforecasts
1. AT A GIVEN LEAD TIME (e.g. 2°C at 4 month lead, and 0.8°C at 9 month lead) FORECAST BIASES ARE TIED TO THEIR INITIALIZATION MONTH (e.g. JUNE IC (2°C) or DEC. IC (0.6°C)).

2. FORECAST BIASES DO NOT NECESSARILY GROW WITH LEAD TIME (e.g. 2°C at 4 month lead, and 0.8°C at 9 month lead) [EFFECT OF SEASONALITY].
2. Traditional Absolute Anomaly Departure (TAAD)

\[
TAAD_{m,l,y} = \frac{\text{abs} \left\{ \left( \frac{1}{n} \sum_{i=1}^{n} f_{i,m,l,y} \right) - \left( \frac{1}{p} \sum_{y=1}^{p} O_{m,l,y} \right) \right\} - OA_{m,l,y}}{S_{m,l,y}}
\]

Observation climatology is used to calculate forecast anomaly as well as the observation anomaly.

Two types of anomaly calculation /bias correction methodologies (AAD and TAAD) are compared to their forecast skills.
AAD versus TAAD type ENSO Forecast

24-member SST anomaly forecast in Nino3.4 region using May (m) initial conditions in 2006 (y)
Hypothesis Testing

Null Hypothesis (H0): Observations (anomaly) are randomly distributed about the ensemble mean forecasts (anomaly forecasts)

- White noise hypothesis
- Mean = 0, Standard deviation = ensemble forecast (anomaly) standard deviation

Alternative Hypothesis (H1): Part I - Observations (anomaly) and ensemble mean forecasts (anomaly forecasts) are statistically indistinguishable i.e. absolute departure ~ 0. Part II - the ensemble mean forecast is too far away from the observation that may fall outside the forecast ensemble 95% range

- The hypothesis testing was designed using the property of half normal distribution
- If $x$ has a white noise Gaussian distribution (mean = 0, and standard deviation = 1) and $u = \text{abs}(x)$, then $u$ has a half-normal distribution
- See Kumar et al. (2014) for details
For a large sample size (~ 30)
- Using re-forecast data from 1982 to 2008

* Provided forecast also mentions about ensemble spread in addition to ensemble mean (a two parameter model)
Result of Hypothesis Testing

- Test statistics (mean AAD or mean TAAD) are calculated for each month initialized forecast and at each lead time (0 to 9 month lead forecasts [MLF])
- Average values for the forecasts initialized in JJA is shown here

## Average AAD (JJA, 1982 to 2008) [a]

## Average TAAD (JJA, 1982 to 2008) [b]

Color shading are shown only when $H_0$ is rejected

Blue color – H1 Part I; Red color – H1 Part II
Similar results for JJA and DJF Initialized Forecasts

**AAD Type**
(H0 not rejected)

**TAAD Type**
(H0 rejected, H1 Part II)

[c]
[d]
[e]
[f]
Hypothesis Testing in NINO3.4 region

**AAD Type**
*(H0 not rejected)*

**TAAD Type**
*(H0 rejected, H1 Part II)*

Effects of smaller sample size (data with ensemble spread < 0.25°C not considered)
Is ensemble mean forecast is a reliable ENSO forecast?

Answer: YES for 60% times, and NO for 40% times for long lead (5 to 9 month lead) forecasts. But the observations are always contained within 95% ensemble spread range for all leads (broken lines in the figure)
Is the forecast ensemble spread smaller than inter-annual variability?

Average of Variance Ratio (forecast/inter-annual)

Answer: YES in NINO3.4 region
What about other regions’ forecast ensemble spread


X MLF- x Month Lead Forecast

Average of Variance Ratio (forecast/inter-annual)
Conclusions

1. Forecast ensemble spread – a required component of the forecast (condition 1)

2. Removal of systematic Biases – a function of forecast initialization month and lead time (condition 2)

3. CFSv2 provides useful ensemble forecast even at longer-lead in several regions including NINO3.4 (provided conditions 1 and 2 are met)
Interpretation for the operational forecast

Reforecast Configuration

24-members forecast ensemble initialized 4-times daily every 5th day over the last 30 days

Operational Forecast Configuration

28-members forecast ensembles initialized 4-times daily in the last 7 days

We need same re-forecast and operational forecast configurations to correctly remove biases
Thank You