Uncertainties in Prediction - An ENSO Perspective

Arun Kumar
Climate Prediction Center
arun.kumar@noaa.gov
Operational ENSO Prediction: An Example

CFSv2 forecast Nino3.4 SST anomalies (K)

- Latest 8 forecast members
- Earliest 8 forecast members
- Other forecast members
- Forecast ensemble mean
- NCDC daily analysis

Last update: Fri Jun 27, 2014
Initial conditions: 15 Jun 2014–25 Jun 2014
• Is declining status of TAO observations cause for the spread in ENSO forecasts? Or,
• Is there an enhanced level of forecast uncertainty due to a decrease in TAO observations?
Spread (Uncertainty) in Forecasts is a Ubiquitous Feature

NMME - June 2014 ICs

All Models

Model Ensemble Avg.

CMC1

CMC2
Similar Uncertainty Occurs in Outcomes for Atmospheric Forecasts
Why there is Spread (Uncertainty) in Forecasts?

- Non-linear dynamical systems sensitivity to specification of initial conditions
- Deterministic chaos
- Uncertainty could be better quantified, but can never be removed

\[
\begin{align*}
\frac{dx}{dt} &= \sigma (y - x) \\
\frac{dy}{dt} &= x (\rho - z) - y \\
\frac{dz}{dt} &= xy - \beta z
\end{align*}
\]
Consequences of Sensitivity to ICs: Increase in Divergence Among Forecasts with Lead Time
• Spread in ENSO forecasts should not come as a surprise;
• Spread is there in all forecasts and is due to sensitivity to the specification of initial conditions;
• The question is: what is the correct magnitude for spread?
What we want to know is...

- What is the correct estimate of uncertainty (forecast divergence) with different lead time? Or how does the forecast divergence evolves with forecast lead time?
- How can forecast divergence be estimated?
- How does uncertainty changes from event-to-event?
- How can model based estimates of uncertainty be constrained?
• The answers come down to knowing how does the cloud of initial conditions (initial PDF) evolves with forecast lead time

• Uncertainty and concepts of predictability are tightly interconnected
What is Predictability?

- It is our ability to distinguish PDF of outcomes for the event to be predicted from the corresponding climatological PDF
- Differences in the PDF can come from differences in various moments of the PDF
  - Mean
  - Spread
  - Skewness
What Lends Predictability in Long-Range Predictions?

• Influence of boundary conditions
  – Anomalous SSTs → Influence on atmospheric variability
  – Tier-2 predictions

• Initial conditions
  – Weather prediction
  – ENSO prediction
  – Tier -1 predictions
Examples of High/Low Predictability

High Predictability

Climo PDF
FCST PDF

Low Predictability
Analysis Approaches to Estimate Predictability (or Forecast Divergence)

- Observations
  - Analogs: But given the length of historical record, this approach is not feasible for climate predictions

- Models
  - Ensemble of initialized predictions from perturbed initial conditions
  - Lead time dependent evolution of spread can be estimated
  - Estimates, however, can be influenced by model errors
Model based approach

- Evolution of ensemble mean and divergence with forecast lead time
Evolution of Ensemble Mean and Uncertainty

STDV OF ENSEMBLE MEAN (DJF 82–07)

STDV OF ENSEMBLE SPREAD (DJF 82–07)
Evolution of Signal-to-Noise Ratio
Evolution of Signal and Noise

Nino 3.4 SST  Total Variability

Forecast Divergence

Ensemble Mean
What we want to know is...

- What is the correct estimate of uncertainty (forecast divergence) with different lead time? Or how does the forecast divergence evolves?
- How can forecast divergence be estimated?
- How does uncertainty changes from event-to-event?
- How can model based estimates of uncertainty be constrained?
Does Spread Change from Event to Event?

**Graphs:**

1. **CFSv2 Predictions of 3-Month Niño3.4 in 1982–2010**
   - (Red: |Ensemble Mean Niño3.4| > 0.5; Blue: |Ensemble Mean Niño3.4| < 0.5; 24 Member Mean)
   - (a) Standard Deviation of Spread (°C)
   - (b) Standard Deviation of Ensemble Mean (°C)

   **Legend:**
   - **ENSEO Normal**
   - **Forecast Divergence**
   - **Ensemble Mean**
• Indications are that spread in SST (Nino 3.4) prediction, generally, does not vary from one ENSO event to another
• Similar conclusions have been found for the amplitude of seasonal atmospheric variability from one year to another
• Spread in ENSO SST prediction is likely to be the same for normal vs. large ENSO events
What we want to know is...

- What is the correct estimate of uncertainty (forecast divergence) with different lead time? Or how does the forecast divergence evolves?
- How can forecast divergence be estimated?
- How does uncertainty changes from event-to-event?
- How can model based estimates of uncertainty be constrained?
What is the Right Level of Uncertainty?

• What do we know in observations?
  – Observed variance
What is the Right Level of Uncertainty?
What is the Right Level of Uncertainty?

$$RMSE_a = \langle (F_{ej} - O_j)^2 \rangle$$

$$RMSE_p = \langle (F_{ej} - F_{ij})^2 \rangle$$

For an unbiased forecast system:

$$RMSE_a = RMSE_p$$
What is the Right Uncertainty?
ENSO Forecasts are Fairly Reliable

CFSv2 for initial months: Apr, May, Jun
Reasons for Errors in the Estimate of Uncertainty

• Various model biases
  – Simulation of atmospheric noise (MJO; WWB)
  – Mean SST errors
  – Coupling; Atmospheric response to SSTs

• Model initialization and perturbation generation
  – Imbalances and initial shocks
  – Representation of observational errors

• However, RMSE results do indicate that forecast uncertainty in models is approaching a realistic magnitude
Summary

• Uncertainty is a fundamental feature of ENSO (or all) predictions
• RMSE measures indicate that, on average, current generation of coupled models are getting better in quantifying uncertainty
• A related challenge is communicating uncertainty to the users and incorporate that into decision making for individual events
Some Other Things to Remember

• If you believe in a need for ensemble for making forecasts then forecasts will have an uncertainty

• Ensemble size and predictability are complementary variables; Lager (smaller) is the ensemble size, smaller (larger) is predictability

• Predictability is a property of nature; models can realize it as prediction skill, but cannot break through the *glass ceiling* imposed by predictability
Back to this event

- Predicting the right amplitude, which is of considerable importance for impacts, is equally hard for big vs. small events, and this event is no exception
- We just have to wait and see which trajectory observations are going to follow
- Is lack of TAO observations adding to the spread? May be, but are unlikely to be a dominant factor (this is not the first time that we are seeing a large spread among forecasts...with the anticipation of an event, we are just more sensitive about it!)