Uncertainties in Prediction - An ENSO Perspective

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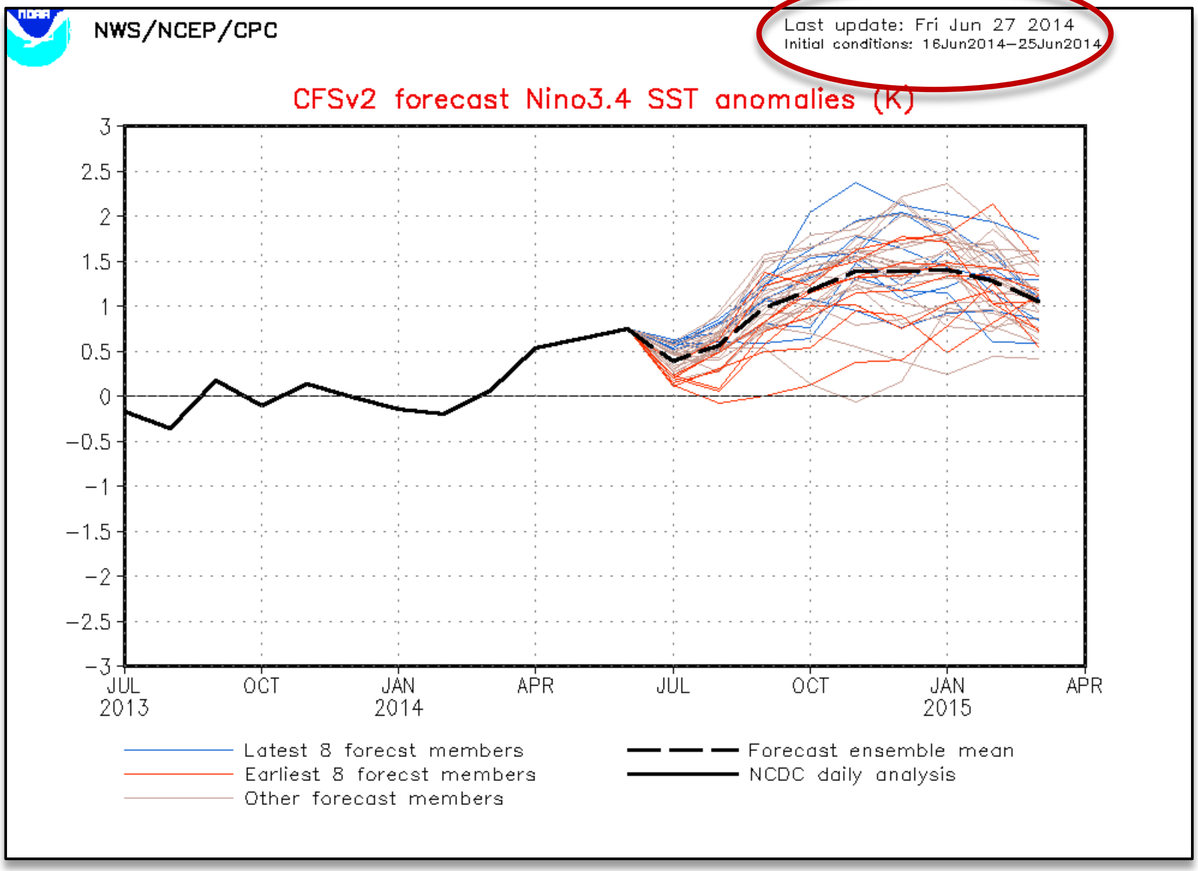
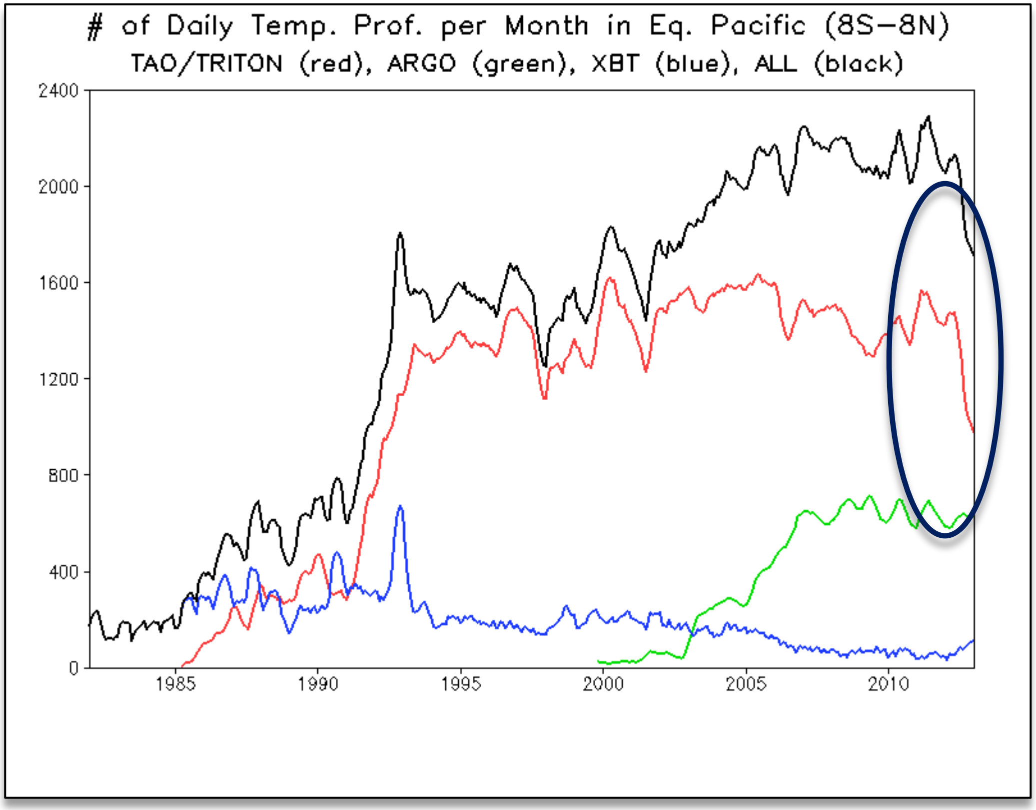
Operational ENSO Prediction: An Example

NCEP/CFS



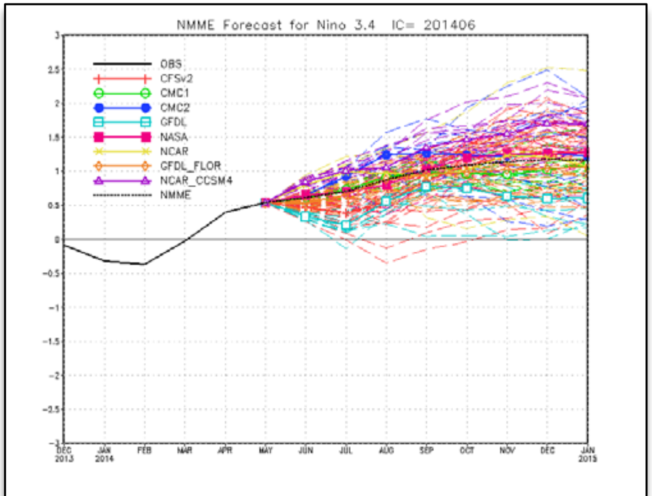
- Is declining status of TAO observations cause for the spread in ENSO forecasts? Or,
- Is there an enhanced level of forecast uncertainty due to a decrease in TAO observations?

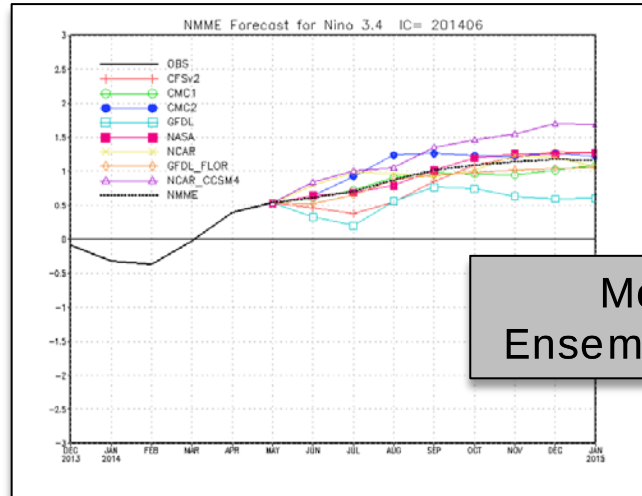


Spread (Uncertainty) in Forecasts is a Ubiquitous Feature

NMME - June 2014 ICs

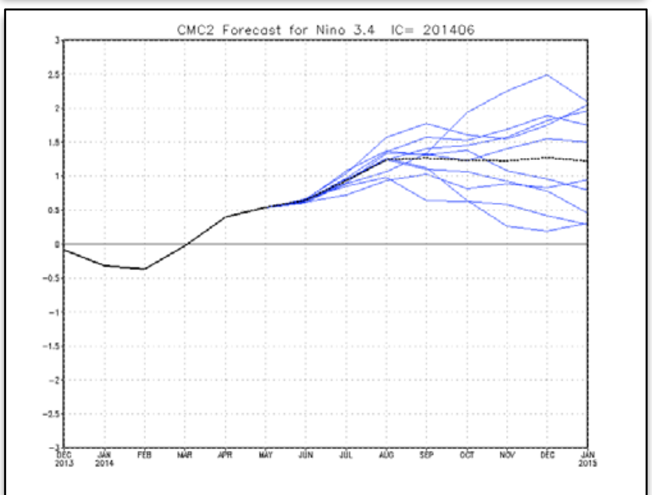
All Models

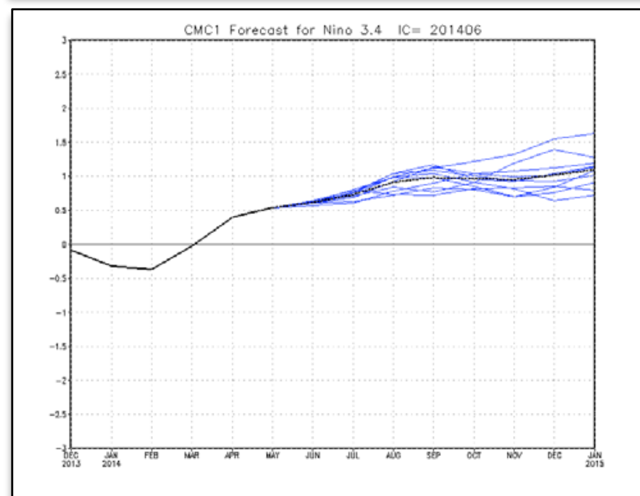




Model Ensemble Avg.

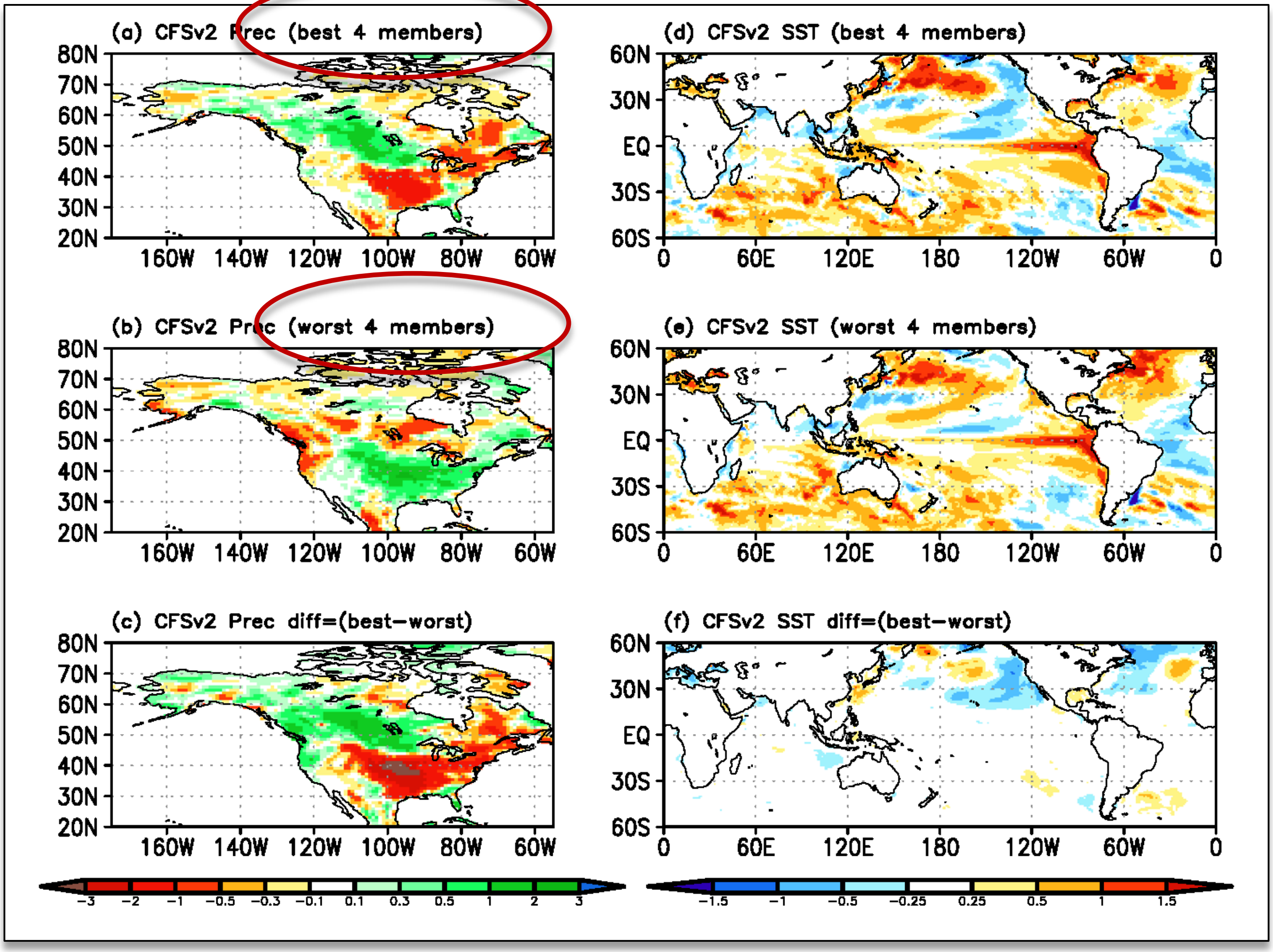
CMC1





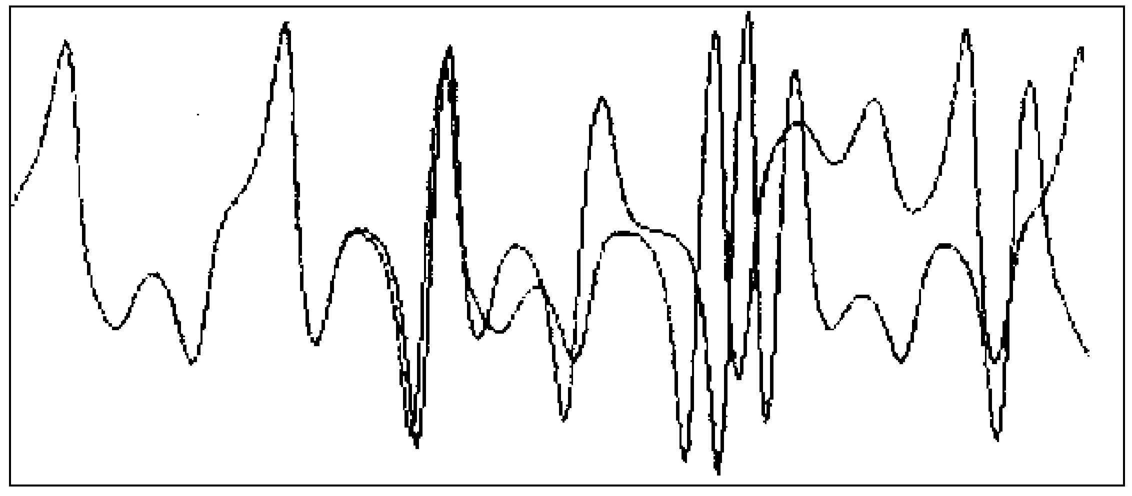
CMC2

Similar Uncertainty Occurs in Outcomes for Atmospheric Forecasts



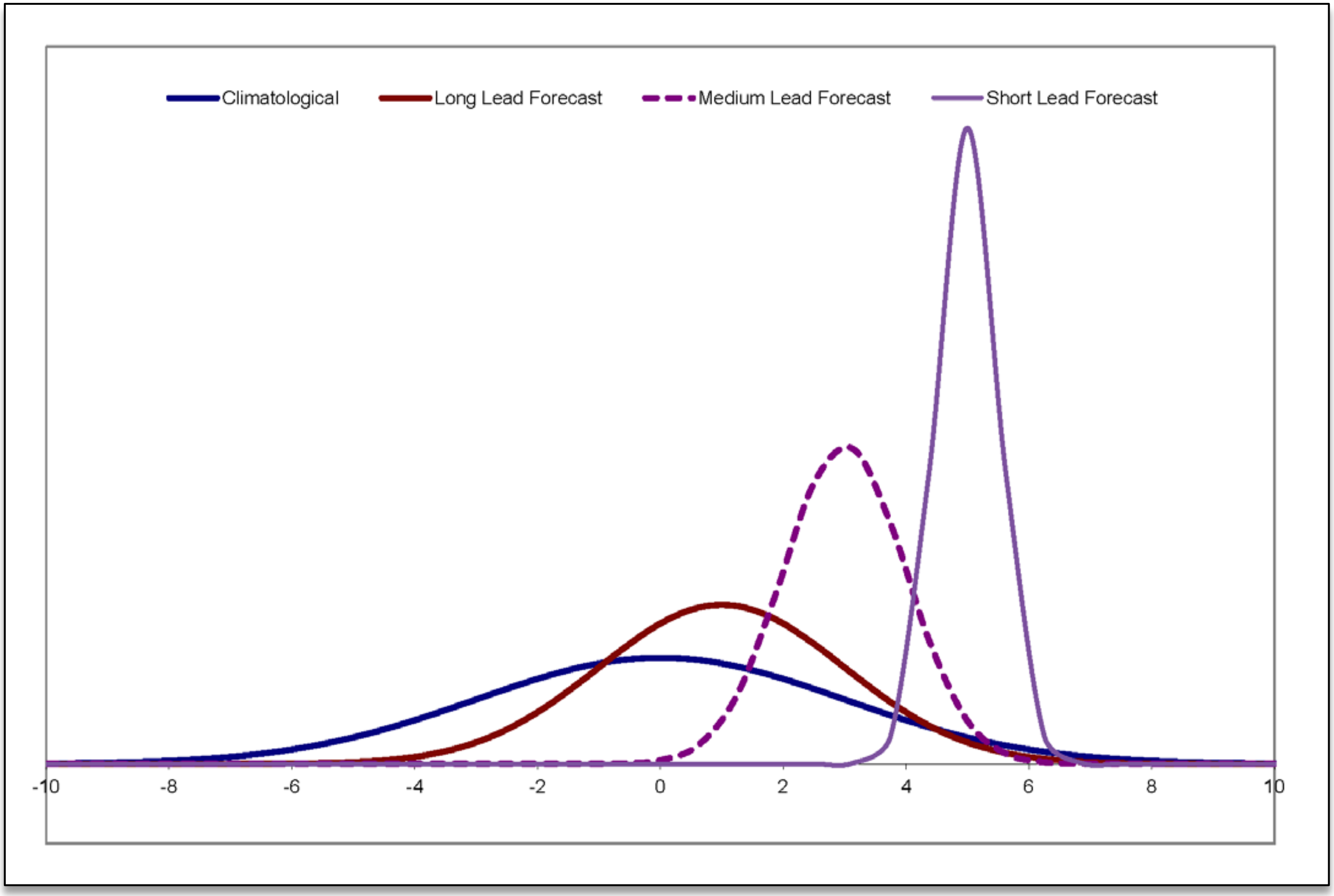
Why there is Spread (Uncertainty) in Forecasts?

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



- **$dx/dt = \sigma (y - x)$**
- **$dy/dt = x (\rho - z) - y$**
- **$dz/dt = xy - \beta z$**

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 comes down to knowing how does the cloud of initial conditions (initial PDF) evolves with forecast lead time

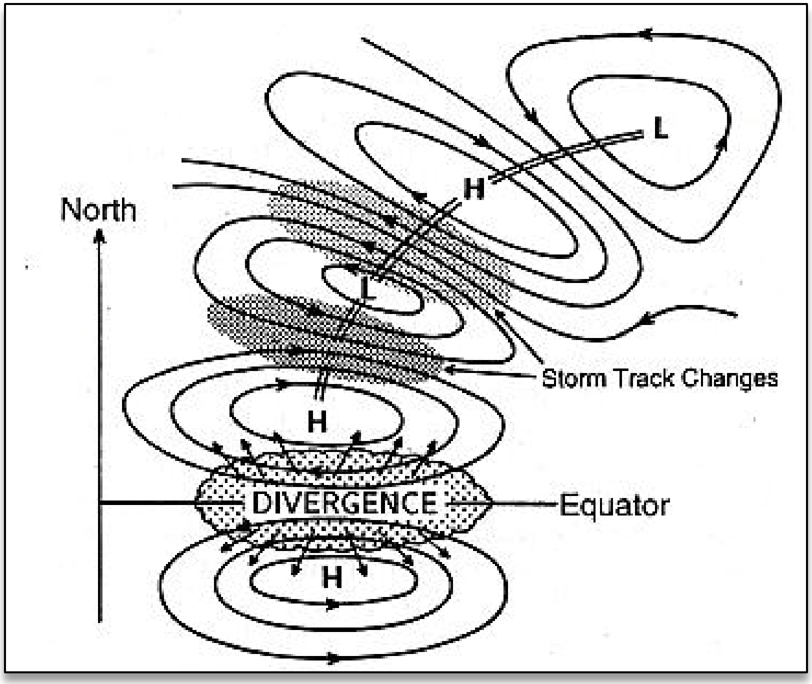
- Uncertainty and concepts of predictability are tightly interconnected

What is Predictability?

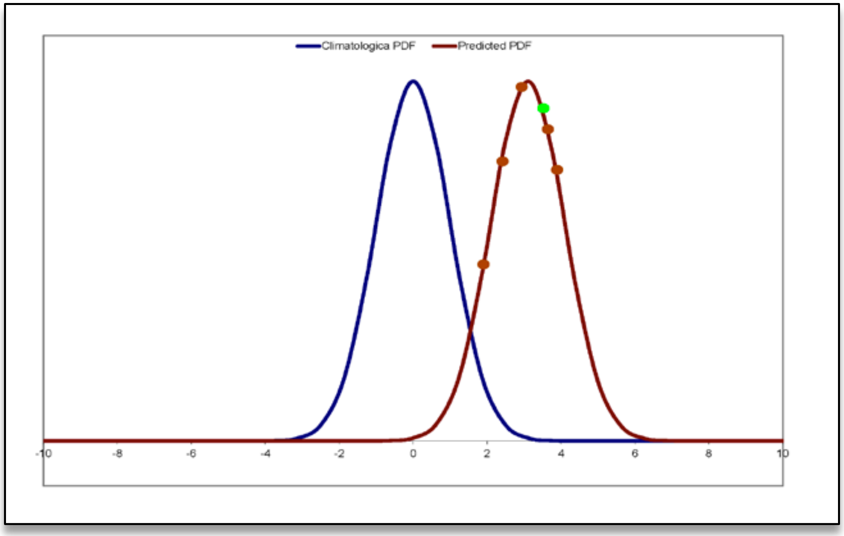
- It is our ability to distinguish PDF of outcomes for the event to be predicted from the corresponding climatological PDF
- Differences in the PDF can come from differences in various moments of the PDF
  - Mean
  - Spread
  - Skewness

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



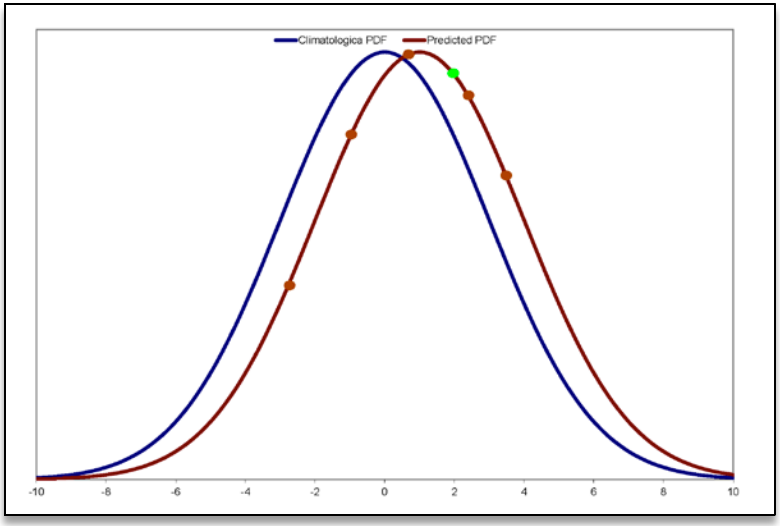
Examples of High/Low Predictability



High Predictability

Climo PDF
FCST PDF

Low Predictability

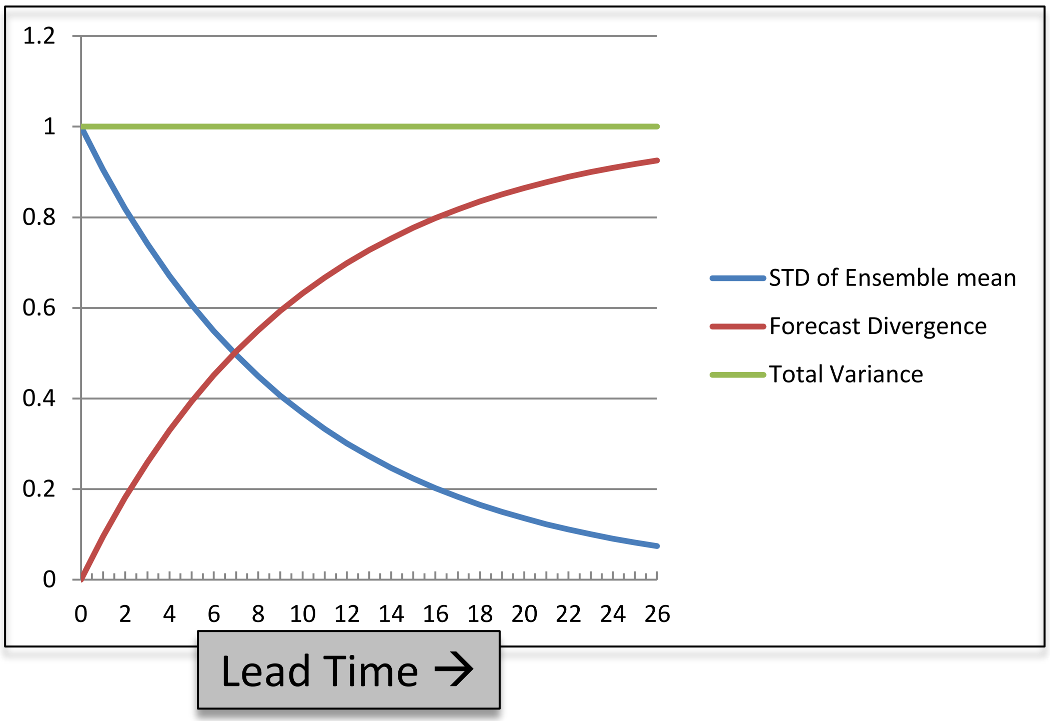


Analysis Approaches to Estimate Predictability (or Forecast Divergence)

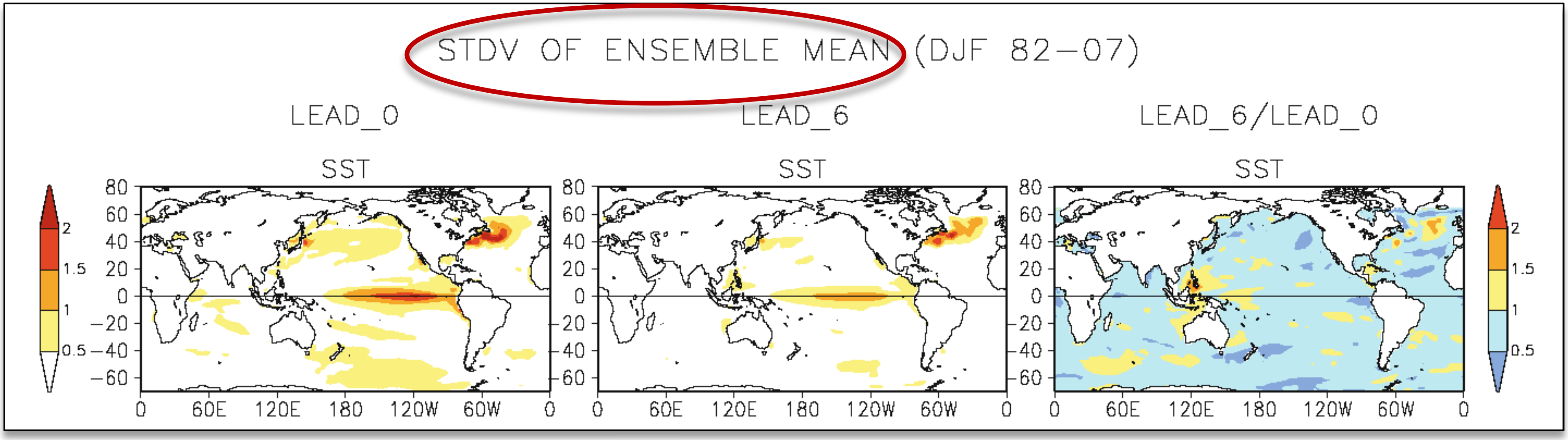
- Observations
  - Analogs: But given the length of historical record, this approach is not feasible for climate predictions
- Models
  - Ensemble of initialized predictions from perturbed initial conditions
  - Lead time dependent evolution of spread can be estimated
  - Estimates, however, can be influenced by model errors

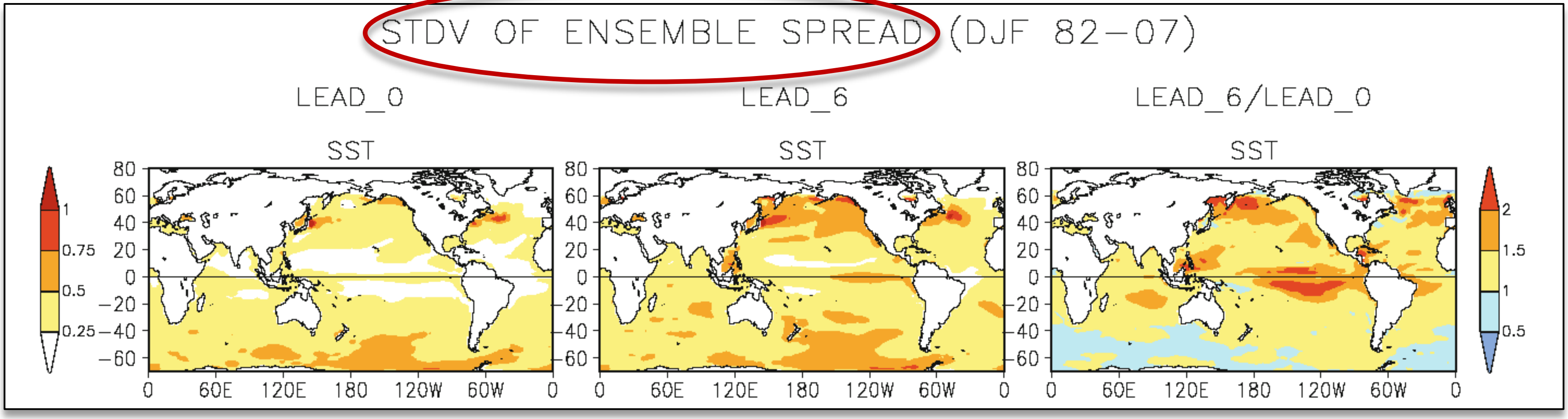
Model based approach

- Evolution of ensemble mean and divergence with forecast lead time

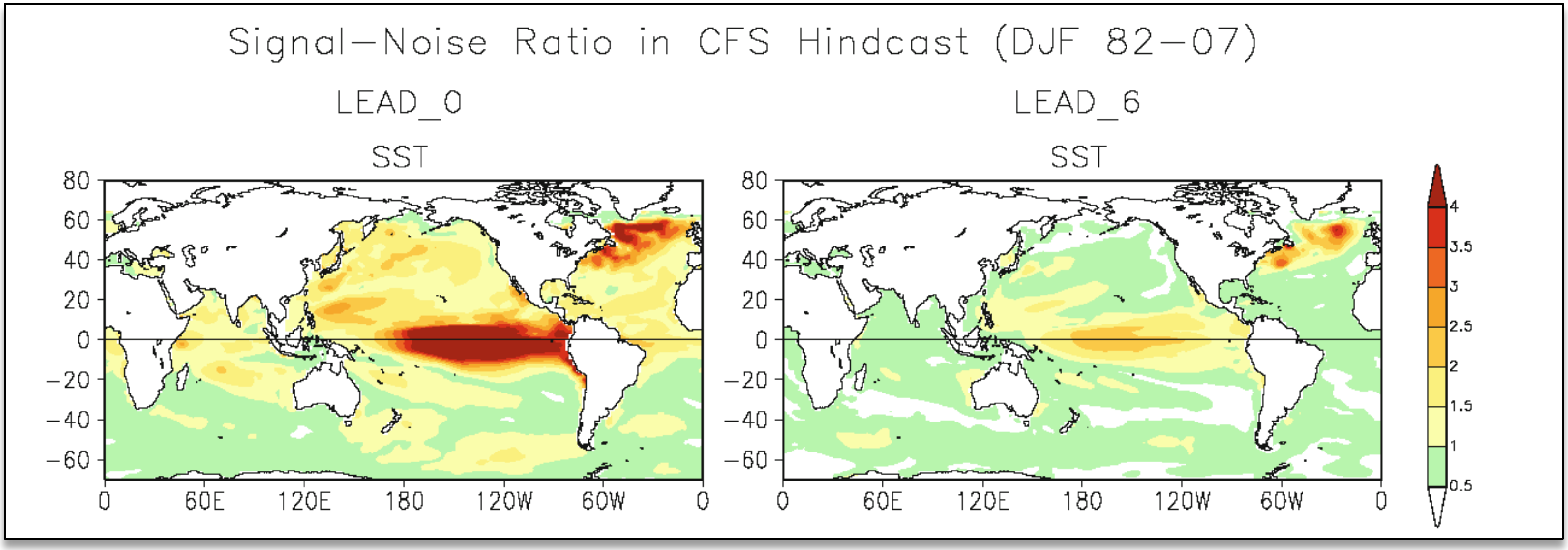


Evolution of Ensemble Mean and Uncertainty





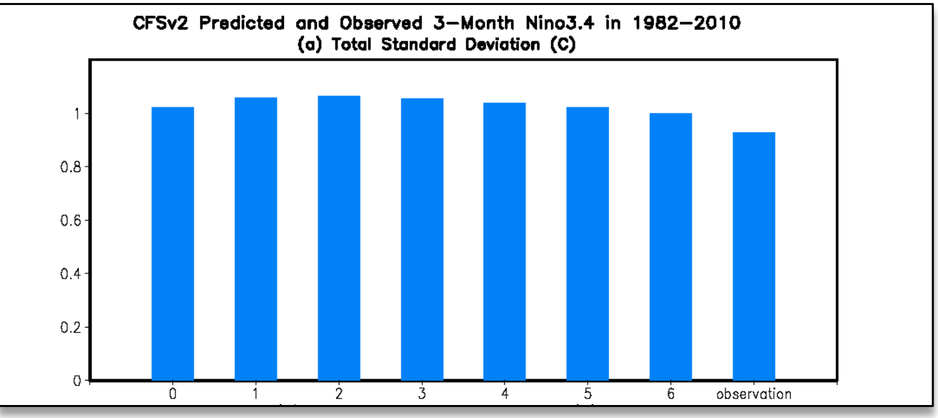
Evolution of Signal-to-Noise Ratio

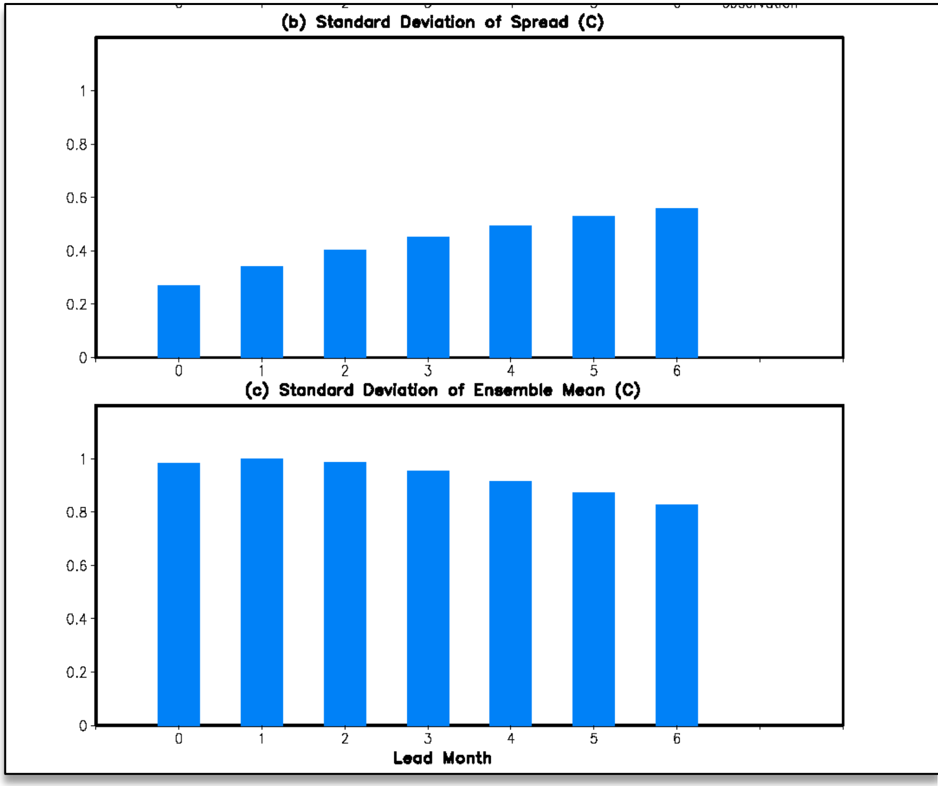


Evolution of Signal and Noise

Forecast Divergence

Nino 3.4 SST   Total Variability





Ensemble Mean

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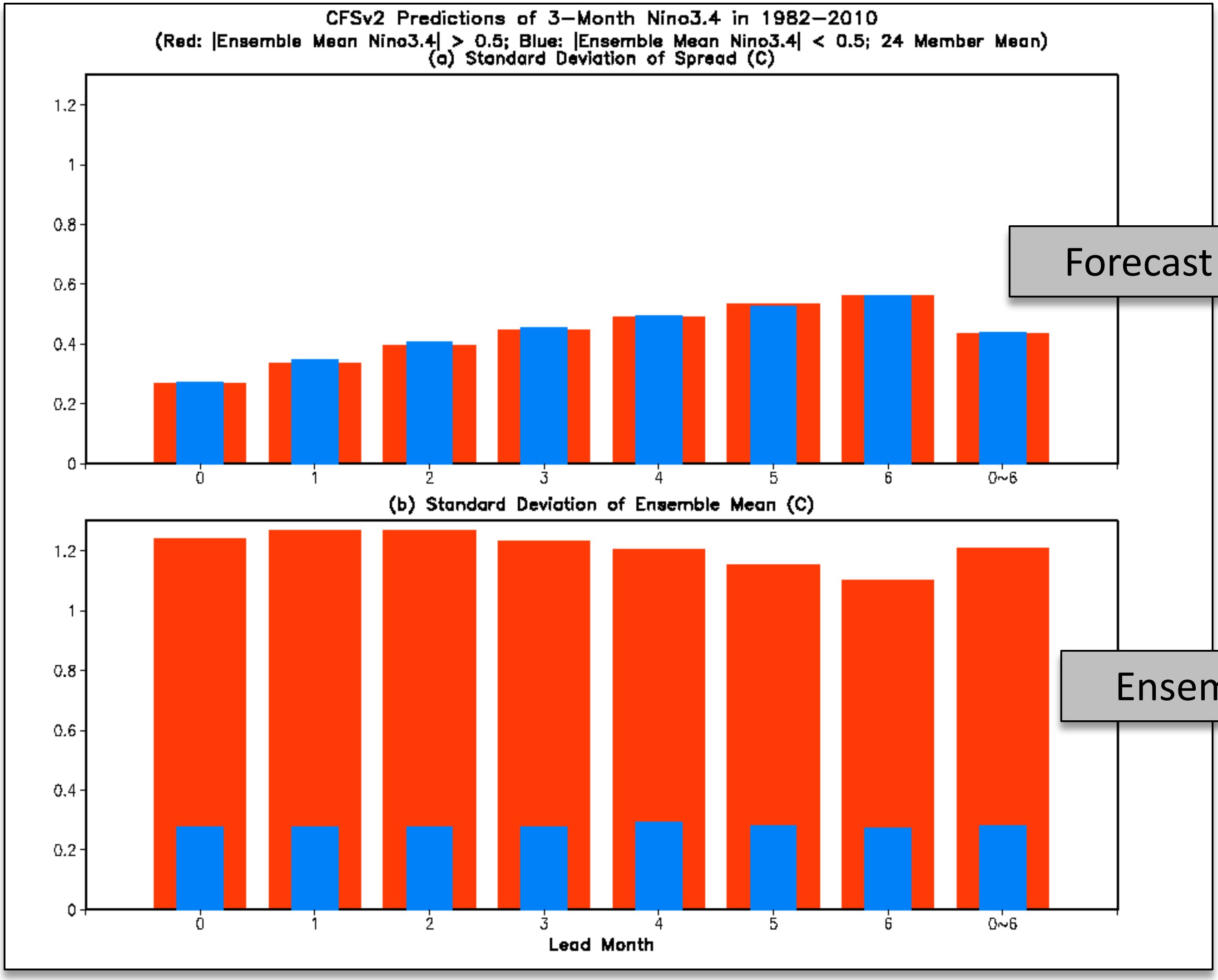
Does Spread Change from Event to Event?

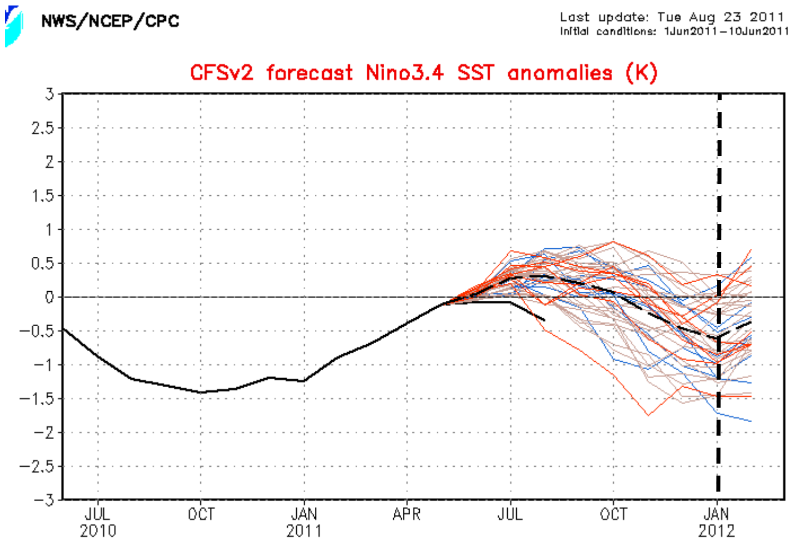
ENSO

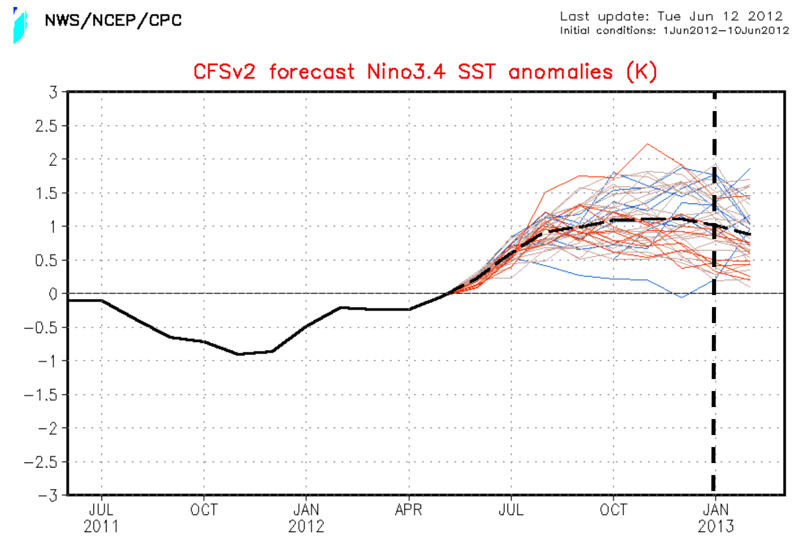
Normal



Forecast Divergence

Ensemble Mean


NWS/NCEP/CPC
Last update: Tue Aug 23 2011
Initial conditions: 1Jun2011–10Jun2011
CFSv2 forecast Nino3.4 SST anomalies (K)
JUL 2010
OCT
JAN 2011
APR
JUL
OCT
JAN 2012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Last update: Tue Jun 12 2012
Initial conditions: 1Jun2012–10Jun2012
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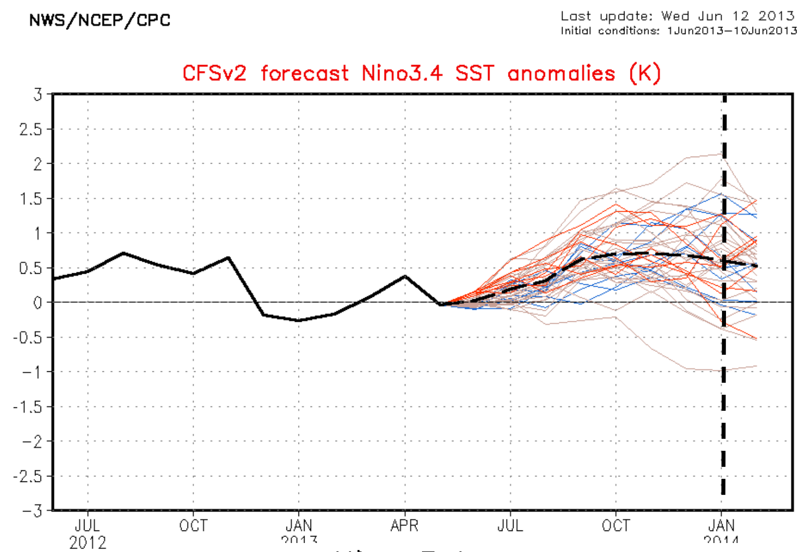
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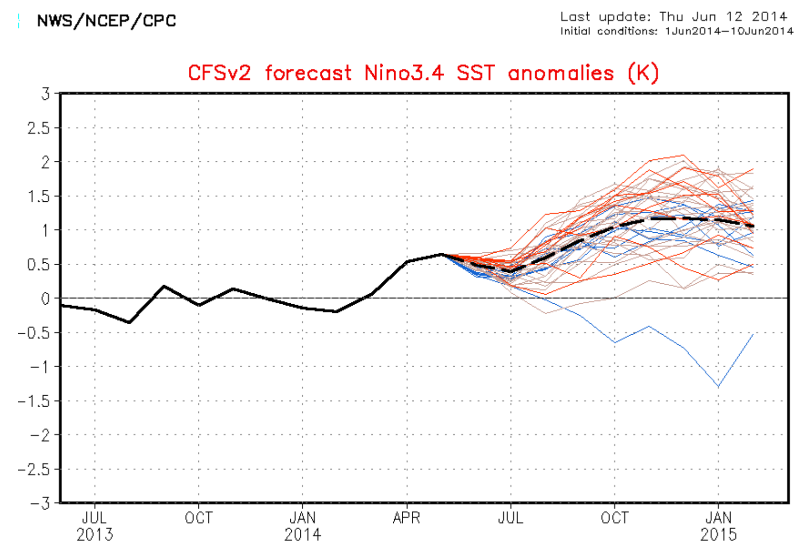
NWS/NCEP/CPC
Last update: Thu Jun 12 2014
Initial conditions: 1Jun2014–10Jun2014
CFSv2 forecast Nino3.4 SST anomalies (K)
JUL 2013
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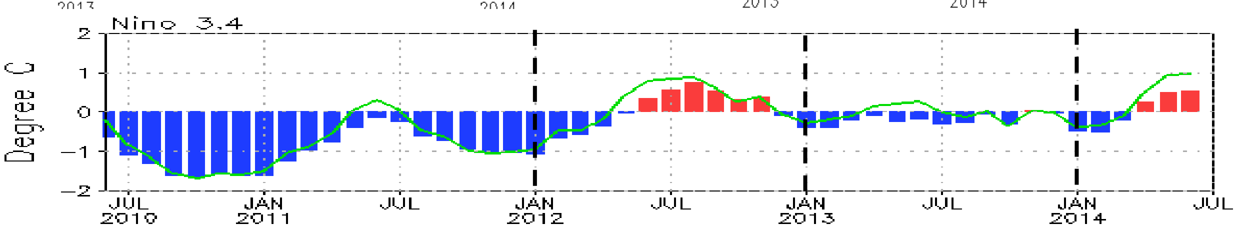
JUL
OCT
JAN 2015


Nino 3.4
Degree C
JUL 2010
JAN 2011
JUL
JAN 2012
JUL
JAN 2013
JUL
JAN 2014
JUL

- 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?
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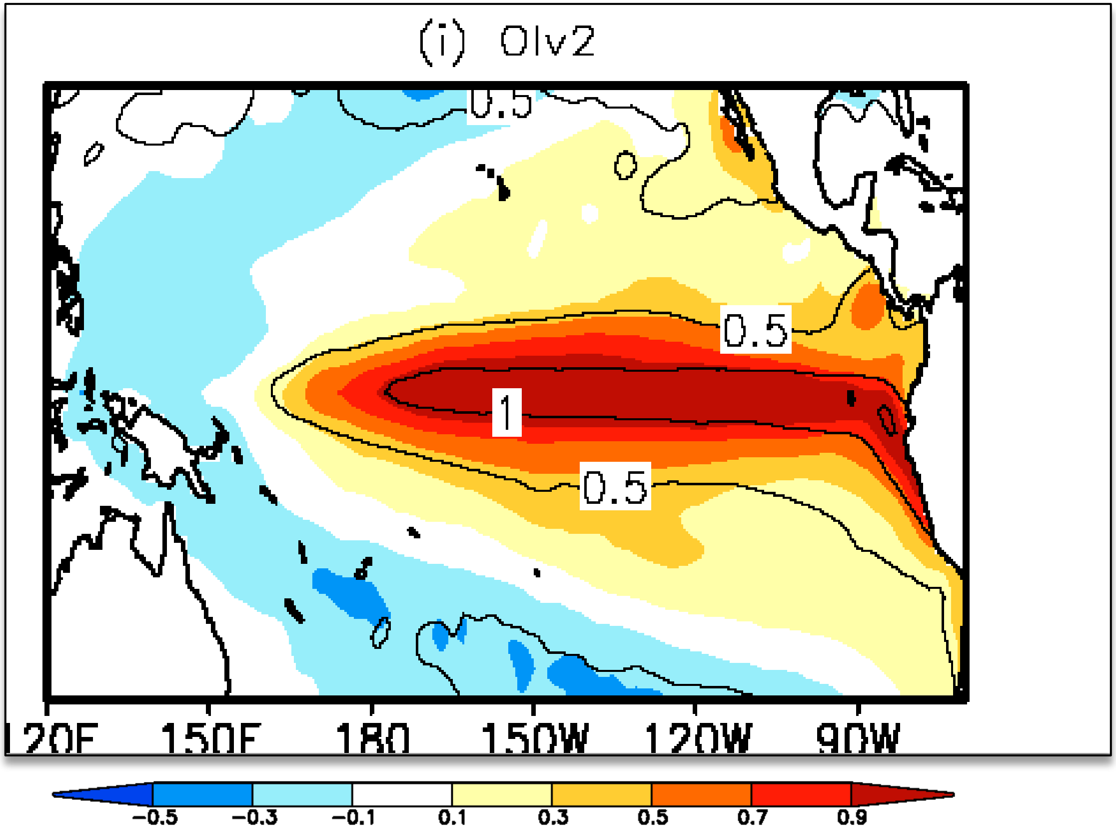
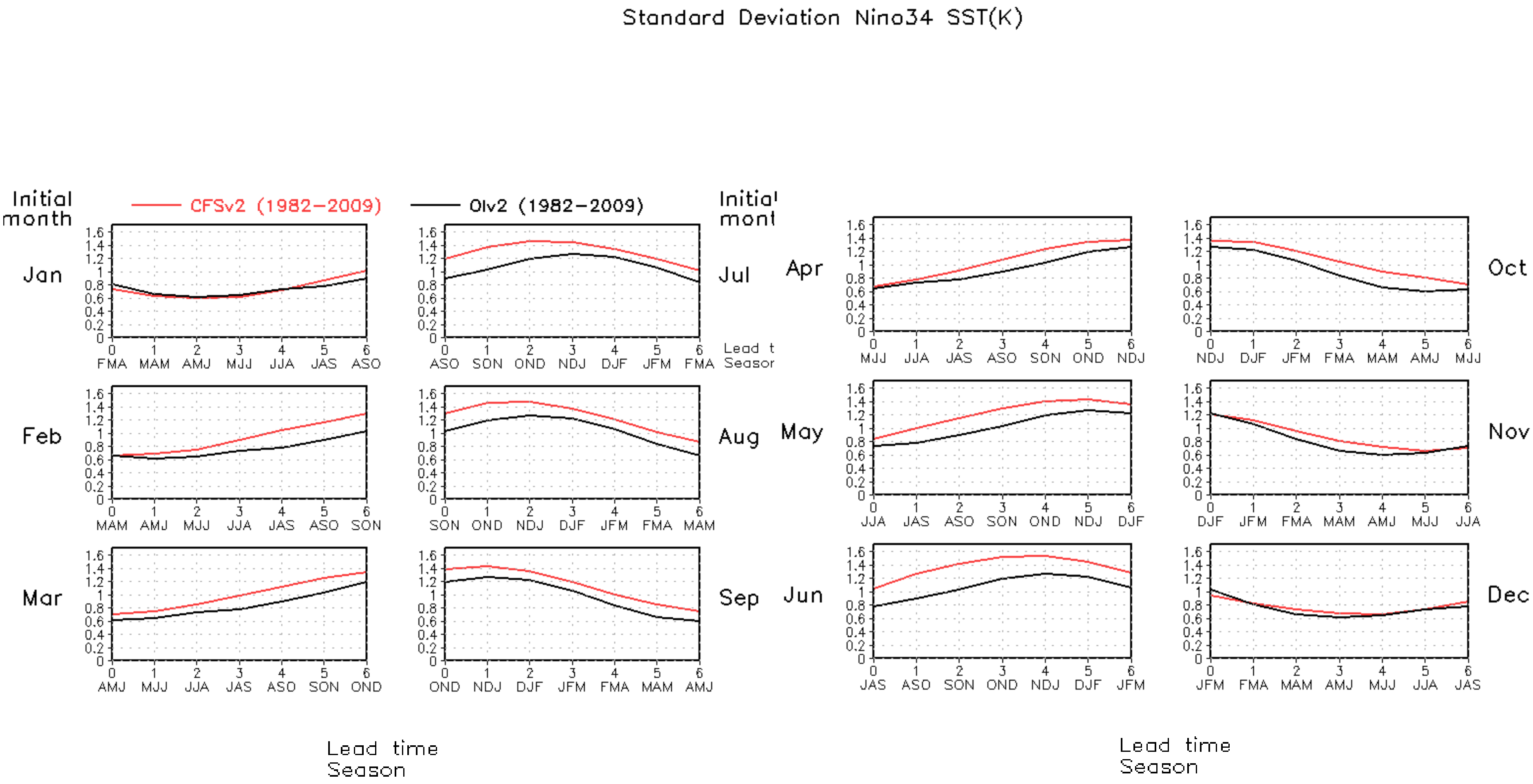
What is the Right Level of Uncertainty?

- What do we know in observations?
  - Observed variance



What is the Right Level of Uncertainty?



What is the Right Level of Uncertainty?

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

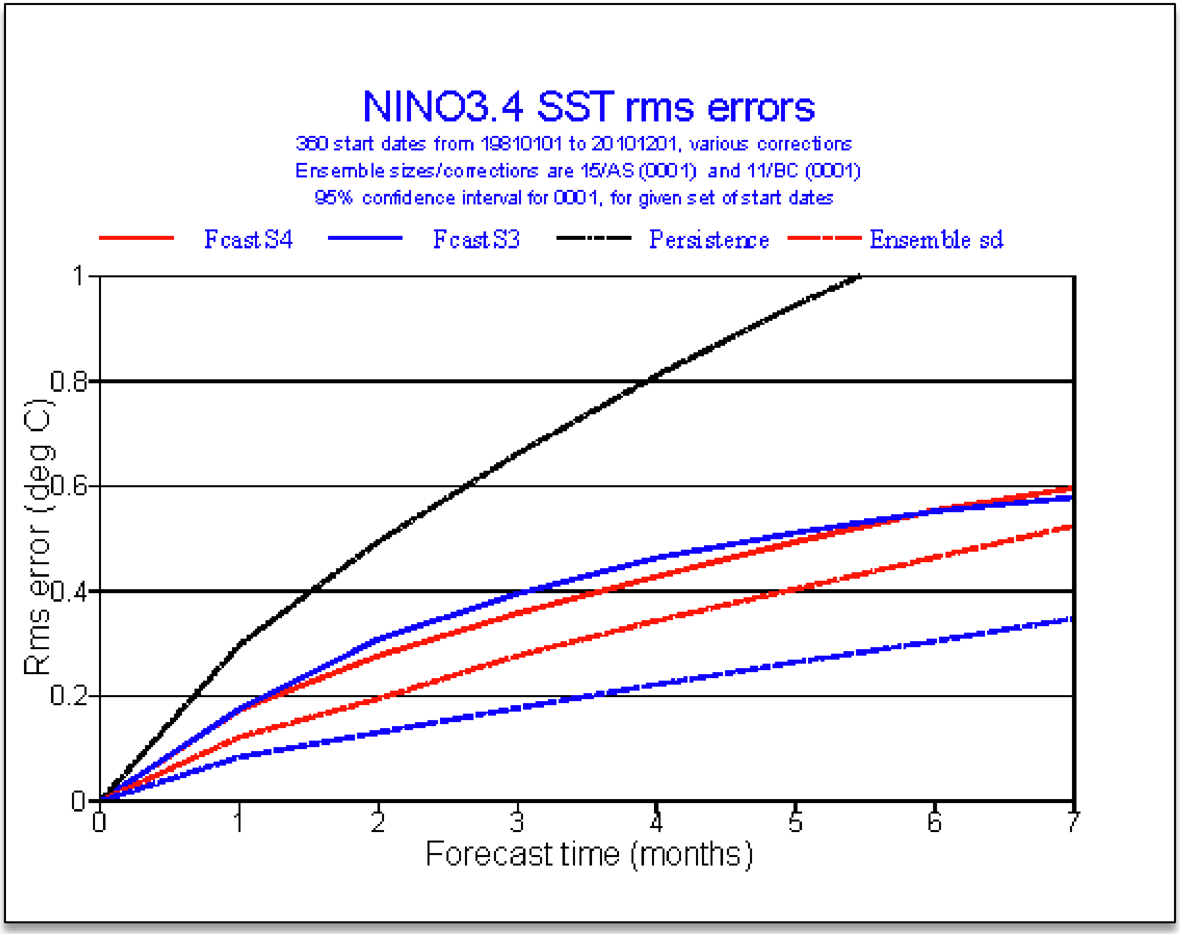
$$\boxed{RMSE_p = \left\langle \left(F_{ej} - F_{ij}\right)^2 \right\rangle}$$

For an unbiased forecast system:

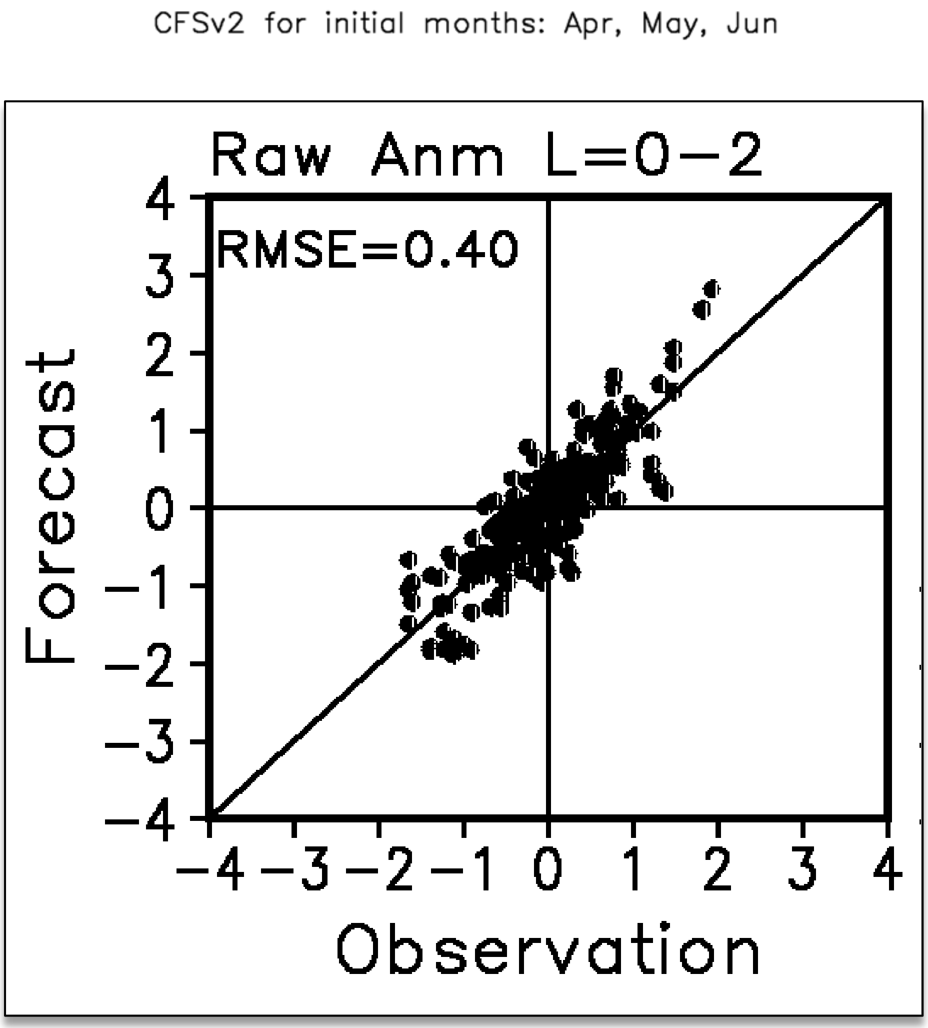
$RMSE_a = RMSE_p$

→

What is the Right Uncertainty?



ENSO Forecasts are Fairly Reliable



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

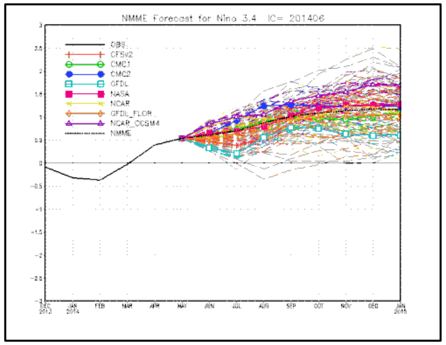
Summary

- 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!)