Design and framework of long-range (seasonal) prediction systems

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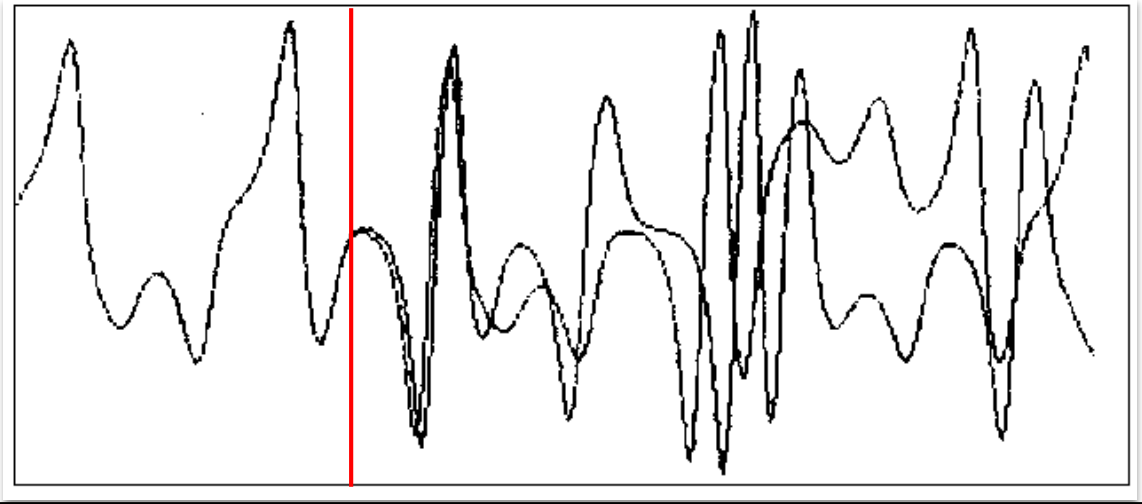
Outline

- What is long-range prediction and what makes long-range (seasonal) prediction possible?
- Methods for making seasonal prediction
- An example of seasonal prediction system: NCEP Climate Forecast System version 2 (CFSv2)
- Summary

There is always a 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

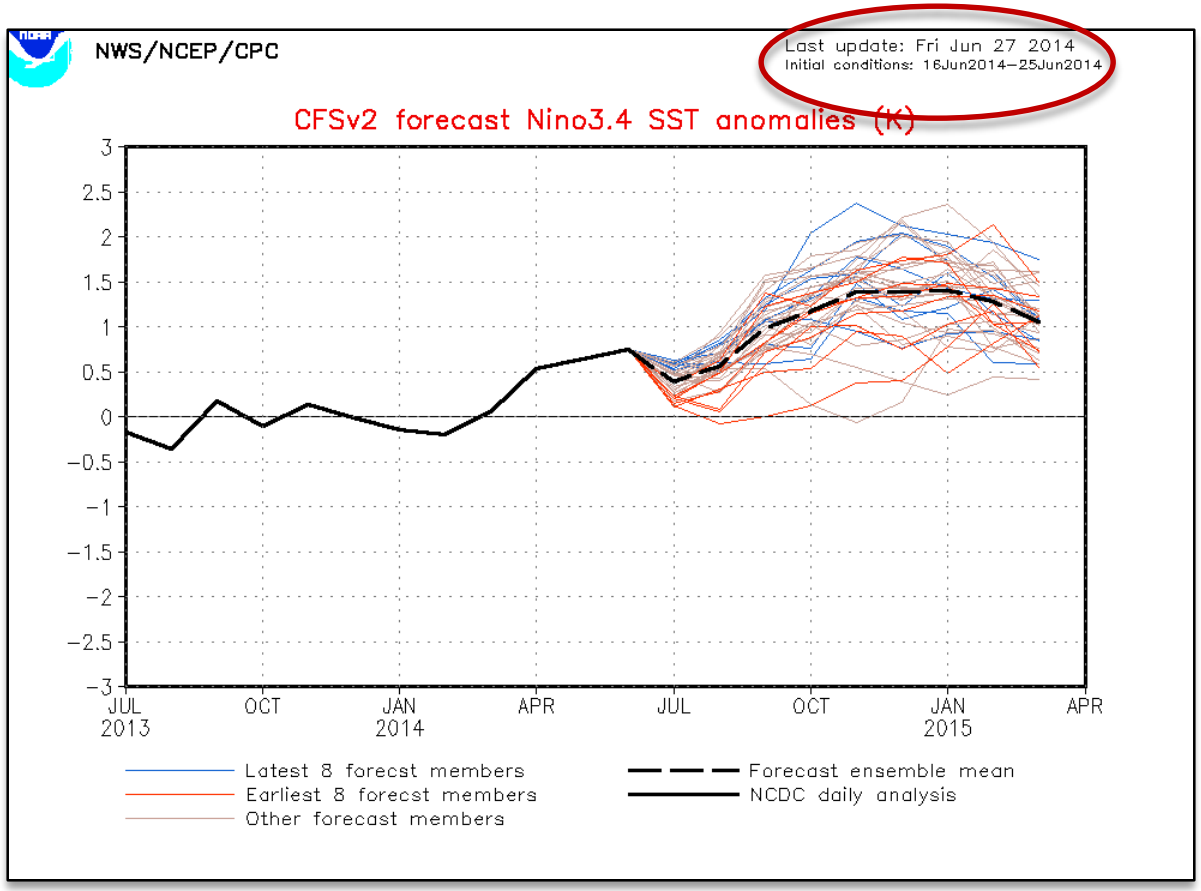


- **$dx/dt = \sigma (y - x)$**
- **$dy/dt = x (\rho - z) - y$**
- **$dz/dt = xy - \beta z$**

- There is always a spread (uncertainty) in forecasts…
- This forecast uncertainty is quantified using ensemble prediction approach where a collection of forecasts is initiated from small perturbations in the initial conditions
- Evolution of individual forecasts in the ensemble results in a collection of future outcomes which can be quantified using a probability density function (PDF)

Example of forecast spread: ENSO Prediction

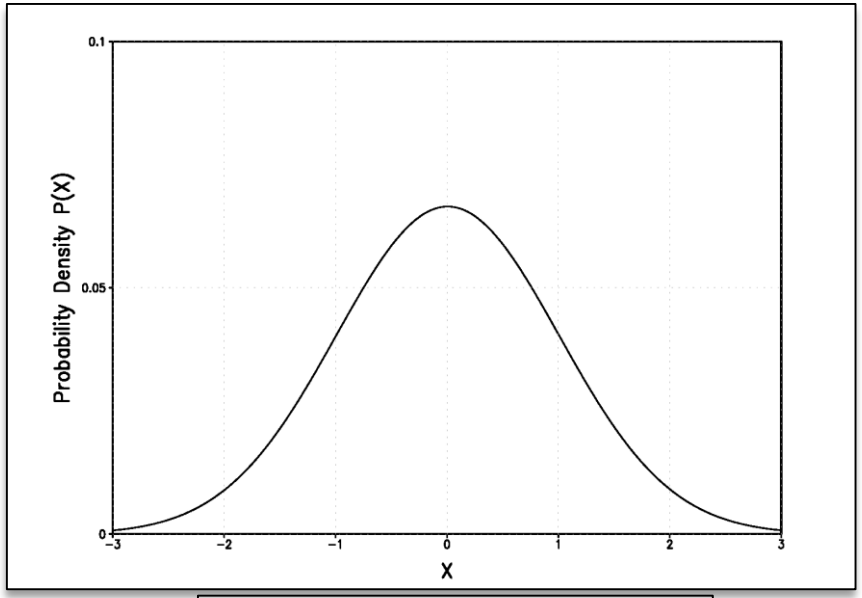
NCEP/CFS
Nino 3.4 SST
Prediction



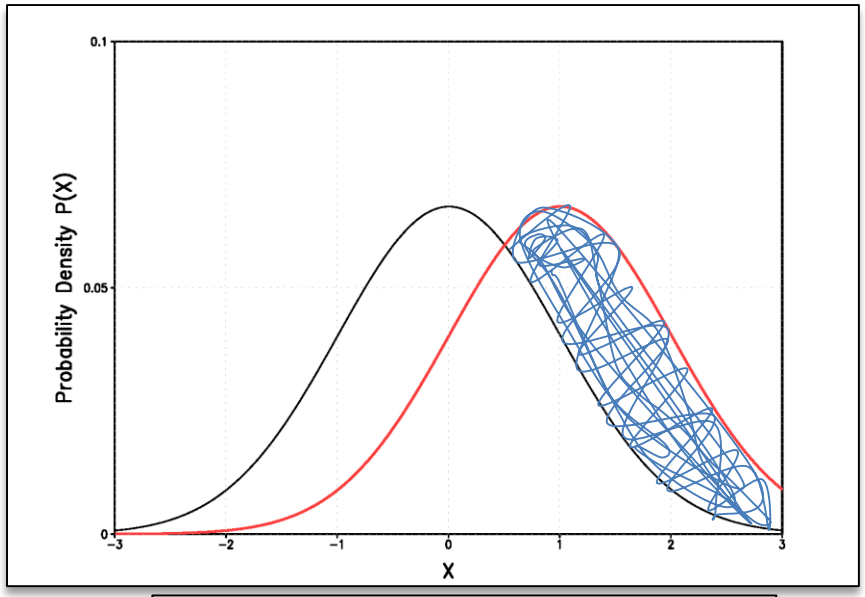
Characterizing seasonal prediction

- There is a forecast PDF of possible outcomes for a specific season (for which we intend to make prediction).
- There is a climatological PDF based on aggregation of all seasons.
- These PDF depend on
  - Season
  - Variable
  - Location
- Seasonal prediction depends our ability to differentiate PDF of forecast PDF from the climatological PDF

Characterizing seasonal prediction



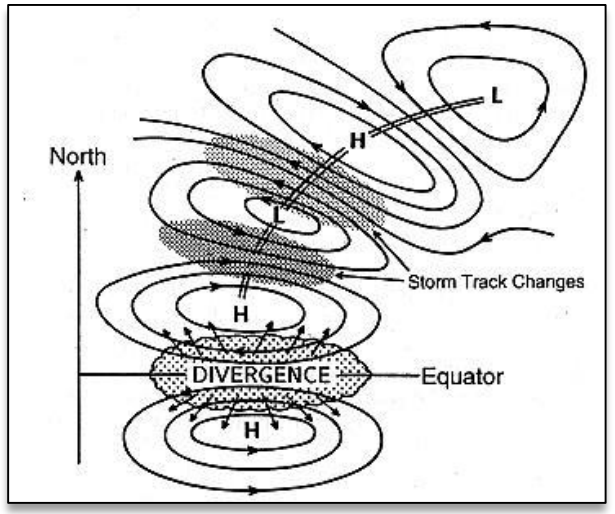
Climatological PDF



PDF for a Season (Red)

What lends predictability in long-range predictions?

- Initial conditions
  - Weather prediction
  - ENSO prediction
- Influence of boundary conditions
  - Anomalous SSTs → Influence on atmospheric variability
- Influence of external forcings
  - Changes in CO_2

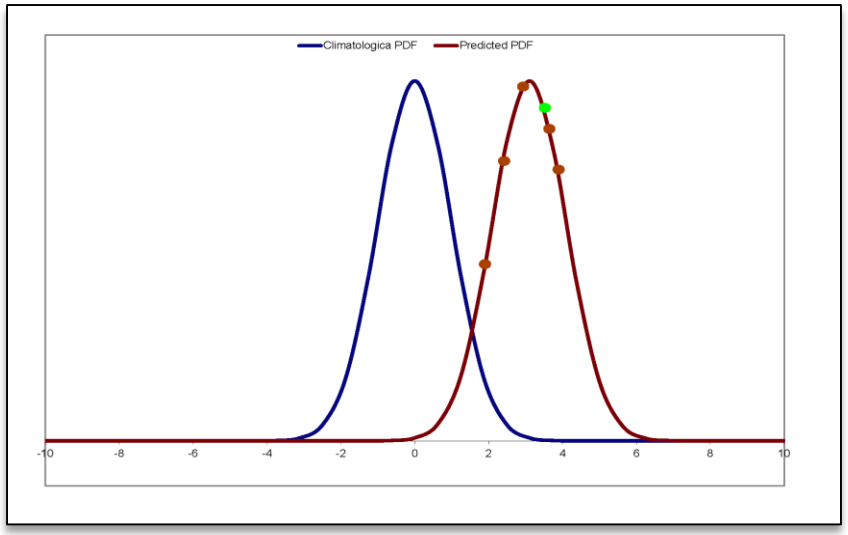


What provides skill in seasonal predictions

- It is our ability to distinguish PDF of outcomes for the season 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

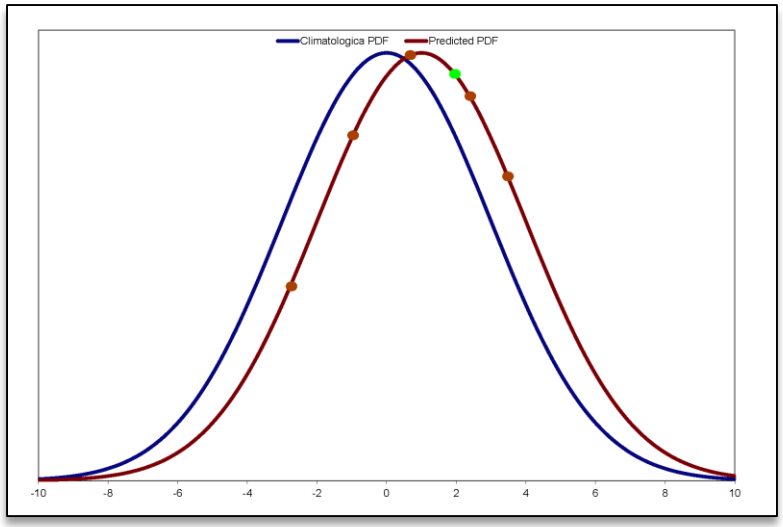
Examples of high/low prediction skill



High Predictability

Climo PDF
FCST PDF

Low Predictability



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Seasonal Prediction Methods

- Empirical prediction tools
  - Advantages
    - Trained based on historical observations
    - Unbiased
    - Simple and computationally efficient
  - Disadvantages
    - Limited by observational data
    - Mostly depend on linear relationships
    - Non-stationarity in climate is hard to include
    - Cannot handle unprecedented situations

Seasonal Prediction Methods

- Dynamical Prediction Tools
  - Advantages
    - Linearity and non-stationarity is not an issue
    - Easier to construct PDF of seasonal mean state
    - Easier to handle unprecedented situations
  - Disadvantages
    - Computationally expensive and require a large infrastructure
    - Forecast systems have biases that requires special attention

- Properties of empirical and dynamical prediction tools are complementary, and in general, and generally both are used in the development of final forecast
- This is the current practice used by several operational centers, e.g., prediction of monsoon rainfall by the IMD

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Components of a Seasonal Forecast System

- Real-time forecasts
  - Initialization
  - Bias correction and calibration of real-time forecasts (uses hindcasts)
  - Forecast dissemination
  - Verification
- Hindcasts
  - Skill assessment of the prediction system
  - Assessment of time-dependent biases

Initialization

- Various components of the forecast system need to be initialized from their observed state
  - Atmosphere (temperature; humidity; winds)
  - Ocean (temperature; salinity; ocean currents)
  - Land (soil moisture; snow)
  - Sea ice (extent; thickness)
- Initialization is done from the Climate Forecast System Reanalysis (CFSR) that provides a consistent 3-dimensional analysis of various components of the Earth System
- After initialization, forecast system is run to nine months into the future

Real-time forecasts: CFSv2

- Four nine month forecasts every day
- 120 seasonal forecasts in a month
- Real-time forecasts are constructed based on forecasts from latest 10 days of initial conditions, i.e., an ensemble of 40 forecasts is used for developing real-time seasonal predictions
- Lagged ensemble provides an estimate of PDF of seasonal mean states

Real-time forecasts

- Configuration of real-time forecasts generally differs from their hindcast counterpart
  - More frequent
  - Larger ensembles

- Consistency in the analysis of initial conditions, particularly for slowly varying components of the Earth System (SST, soil moisture) is crucial!

Hindcasts

- Hindcasts – Run the real-time forecast system over historical cases
- Run the forecast system over last thirty years (1981-2010)
- Four nine months forecast every 5th day of the calendar
- 72 forecasts every year

Hindcasts

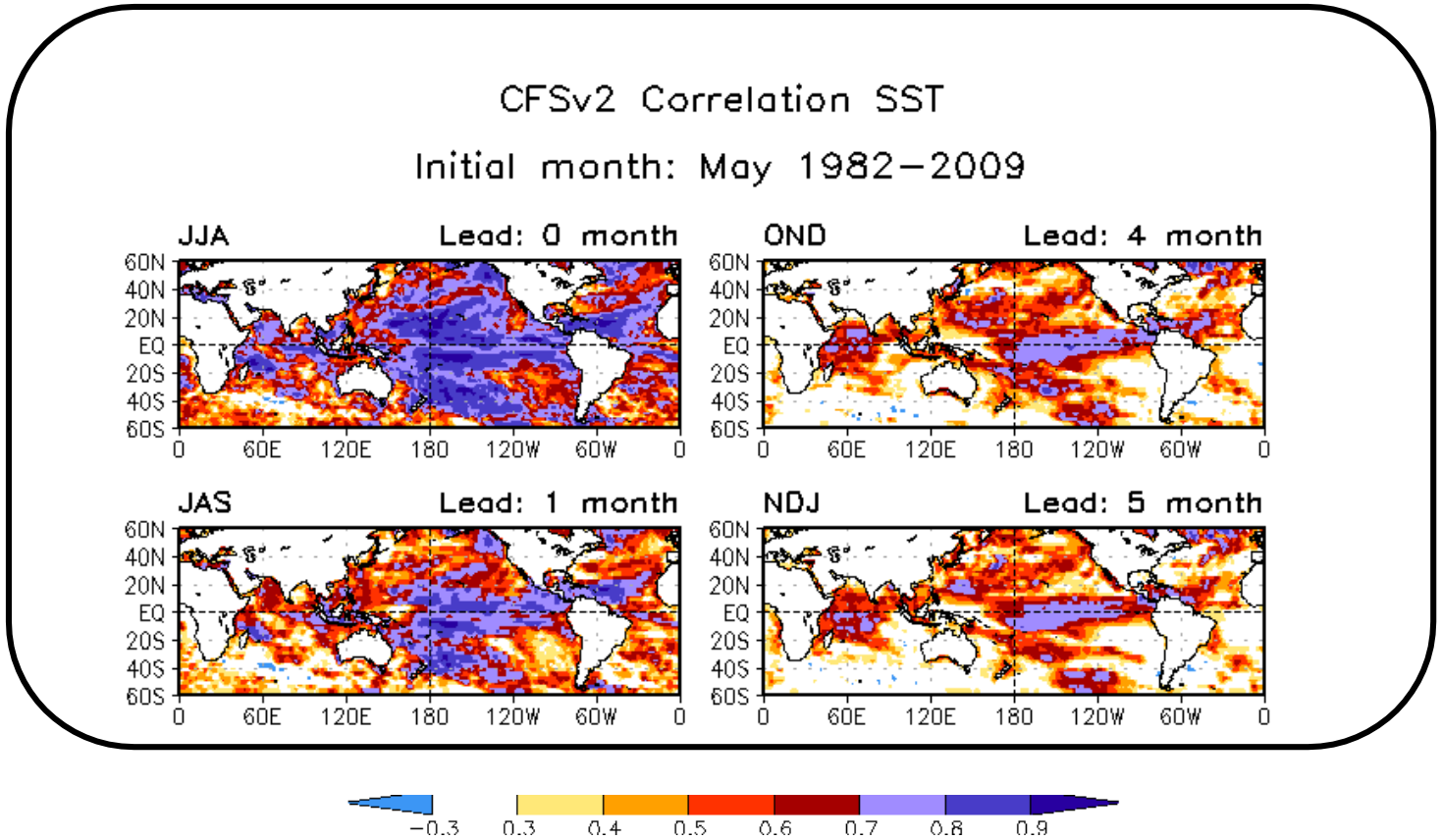
- What is the purpose of hindcasts?
  - Provides an assessment of the skill of the seasonal forecast system
  - Because of model biases
    - Real-time forecasts have to be bias corrected
    - Hindcasts provide the data set for bias correction
    - Hindcasts are used to develop initial month, and lead-time dependent model climatology
  - Calibration of real-time forecasts

Skill Assessments

- Based on 30-year hindcast, skill of the CFSv2 can be assessed for
  - Predicting sea surface temperature anomalies
  - Predicting various SST indices that are important for seasonal predictions, e.g., Nino 3.4 SST index
  - Surface quantities over land, e.g., precipitation and surface temperatures
  - Other variables
    - Soil moisture
    - Sea ice

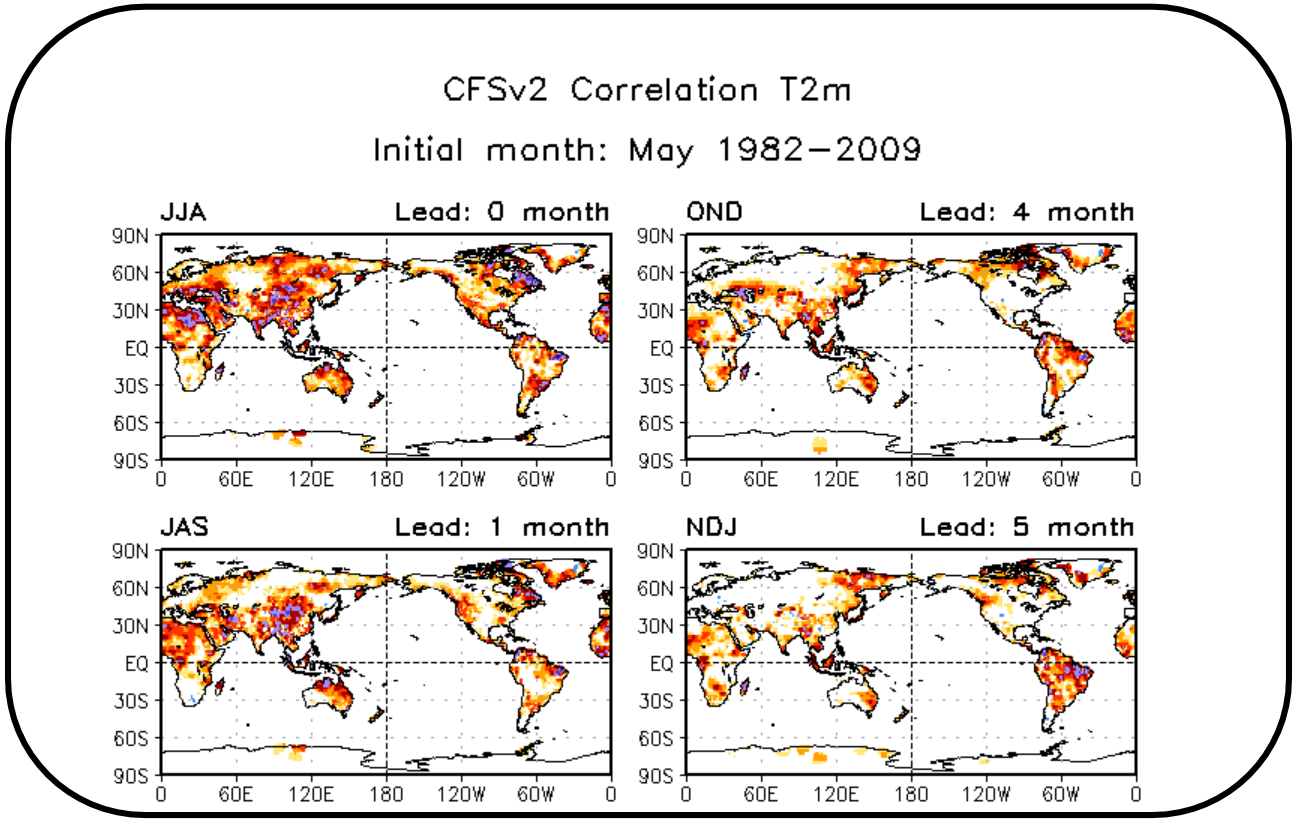
Skill Assessment: SST

Anomaly Correlation



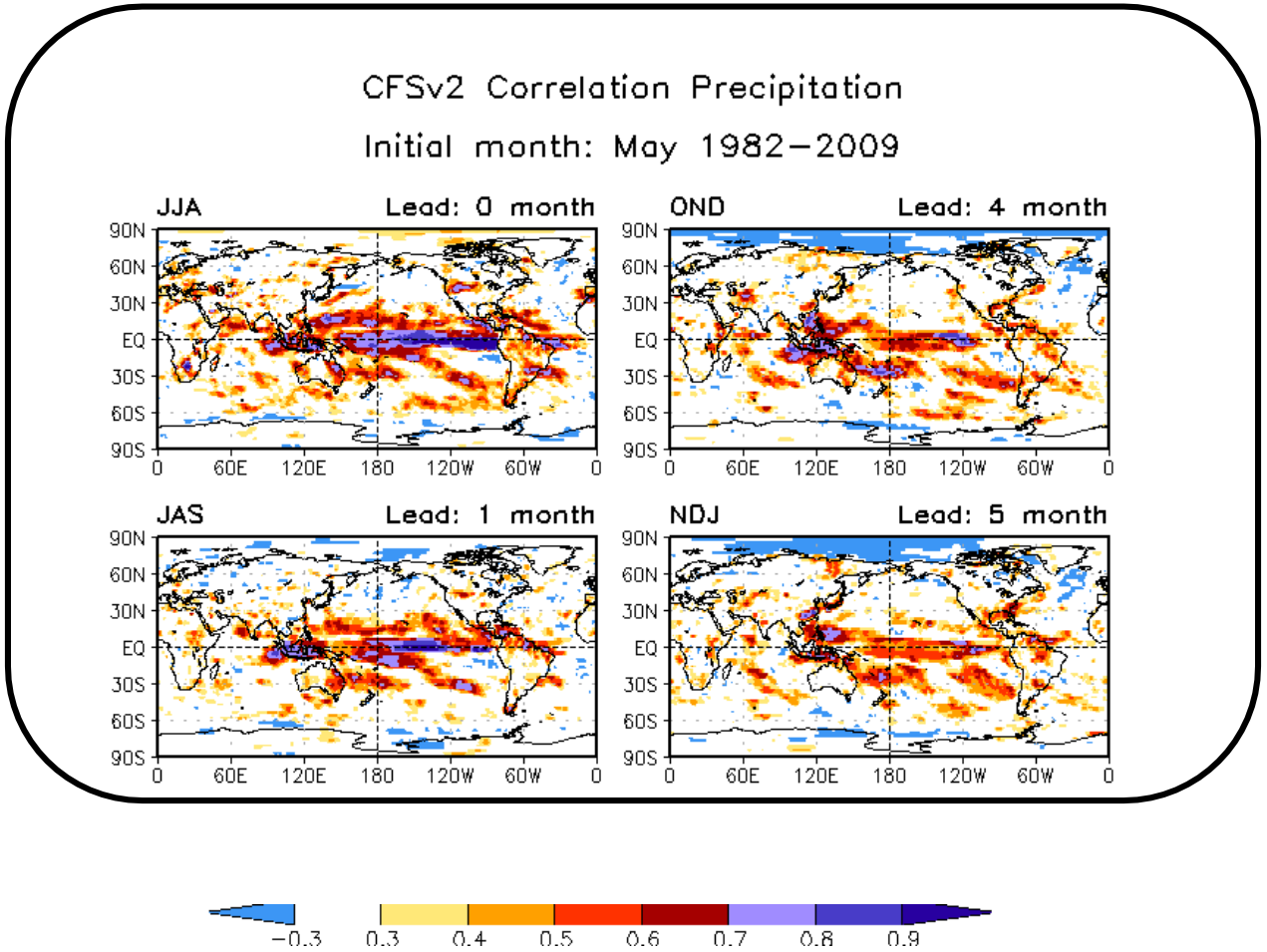
Skill Assessment: Surface Temperature

Anomaly Correlation



Skill Assessment: Precipitation

Anomaly Correlation



Bias Correction and Calibration

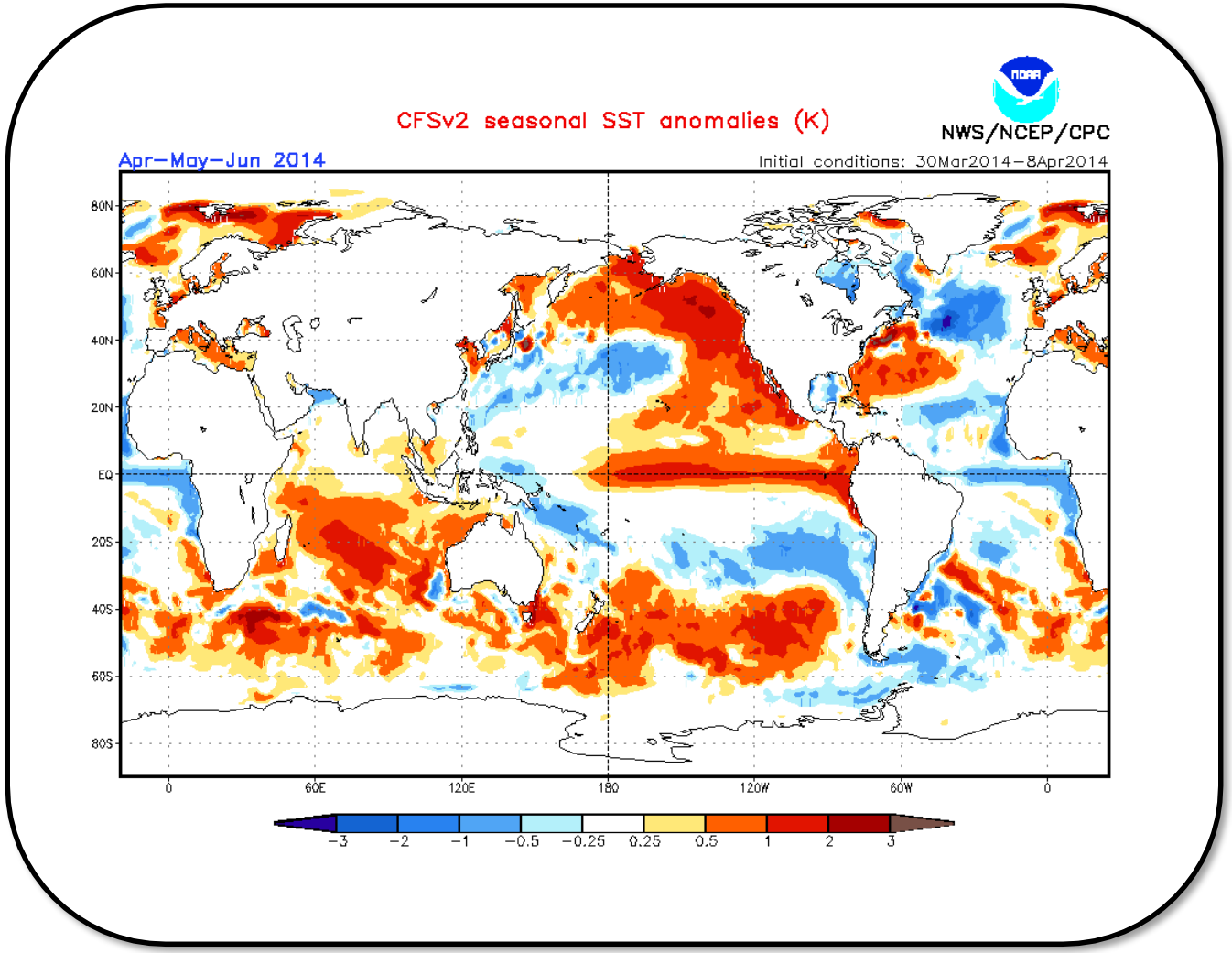
- Bias correction
  - Correct for differences in observed and predicted mean state
  - Adjust if variability between observations and predictions differs
- Calibration
  - Adjust predicted anomaly based on assessment of past skill (e.g., from hindcast data set)
  - If past skill is close to zero, make the forecast PDF same as the climatological PDF

Model bias

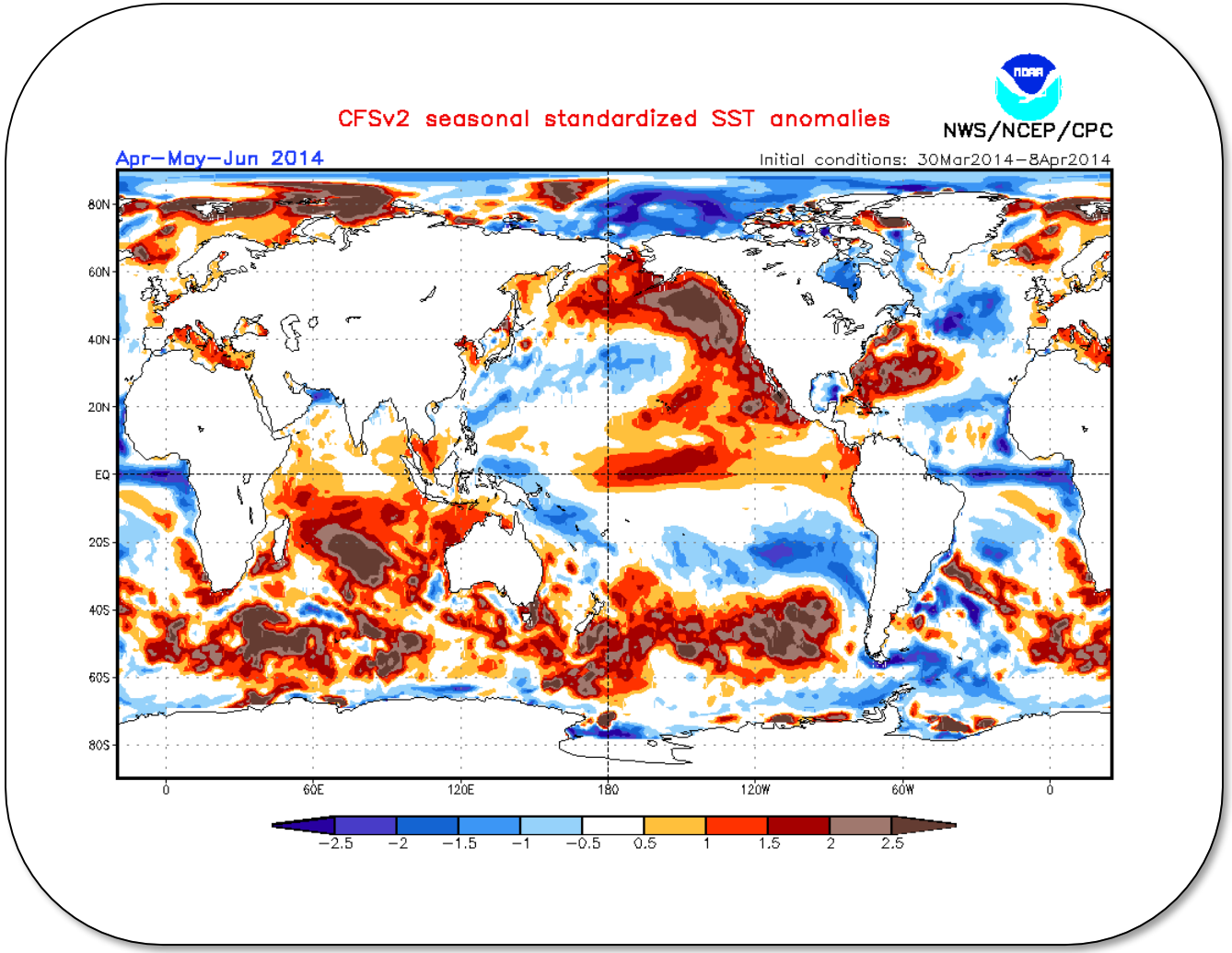
Forecast Dissemination

- Graphical products
  - Bias corrected seasonal mean anomalies
  - Normalized anomalies
  - Bias corrected anomalies with skill mask
- Forecast and hindcast gridded data
  - Real-time forecasts
  - Hindcast data available via several outlets
  - Data could be used for statistical downscaling

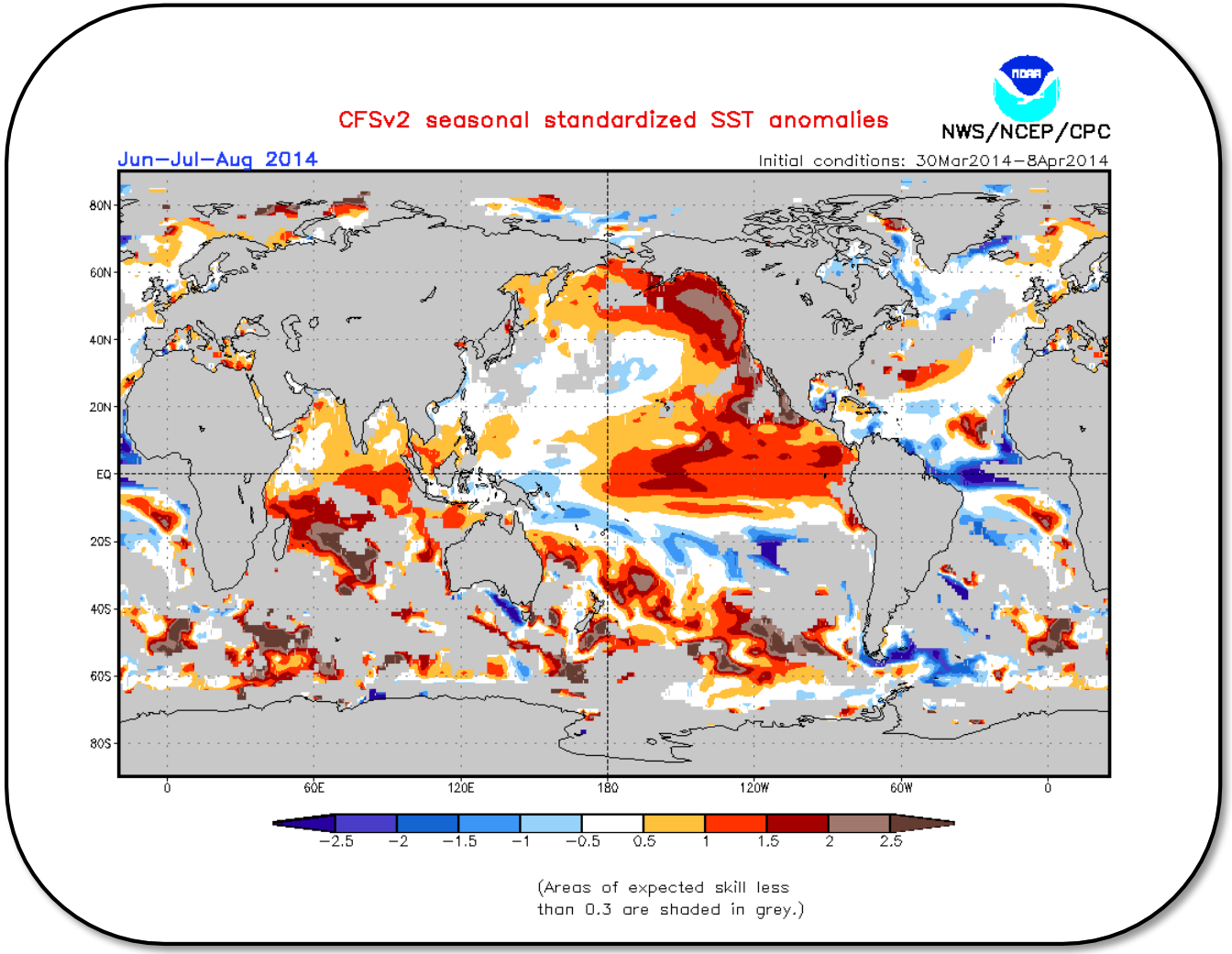
Graphical Products: SST Anomaly



Graphical Products: Standardized SST Anomalies



Graphical Products: SST Anomalies with Skill Mask



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- Seasonal prediction system are fairly mature
- Skill of prediction is limited, but it is better than a random guess
- Hindcast and real-time forecast data is a huge data base that can be used for various research and analyses purposes, for example,
  - Analysis and predictability of extremes
  - Influence of various climatic factors on extremes