Design and Framework of Seasonal Prediction Systems

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Outline

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

What is Seasonal Prediction?

- Seasonal mean states can be characterized by the probability density function (PDF). This PDF depends on
  - Season
  - Variable
  - Location
- Seasonal prediction depends our ability to differentiate climatological PDF from the PDF for a particular season (for which prediction is to be made)
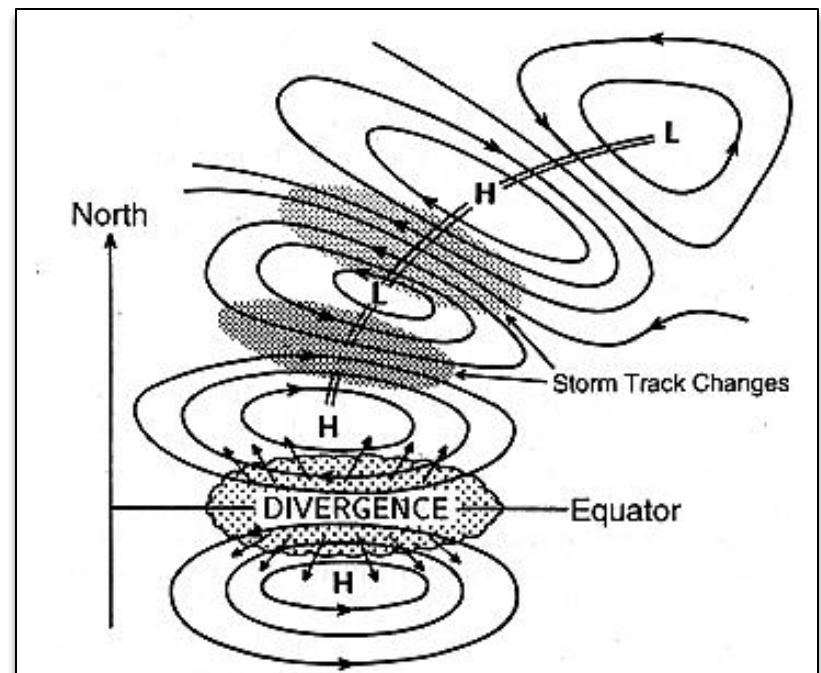
# What is Seasonal Prediction?
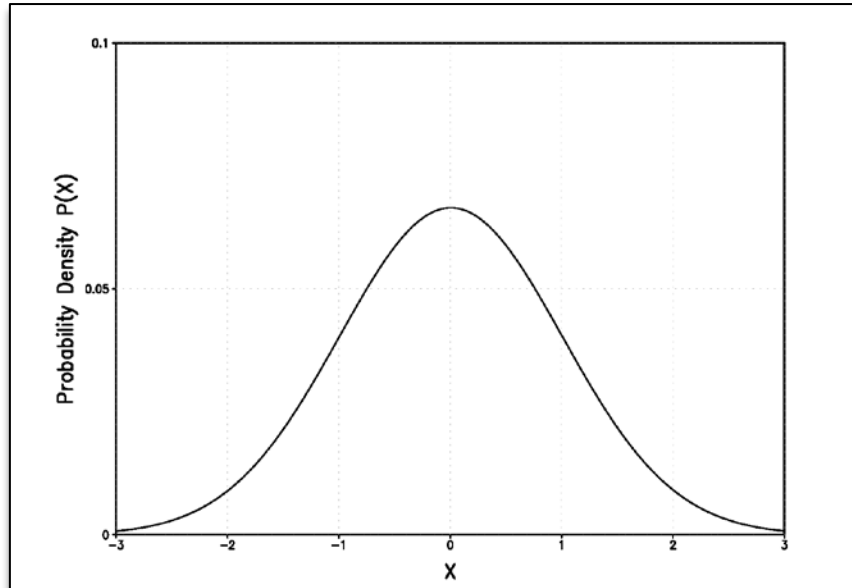
Climatological PDF
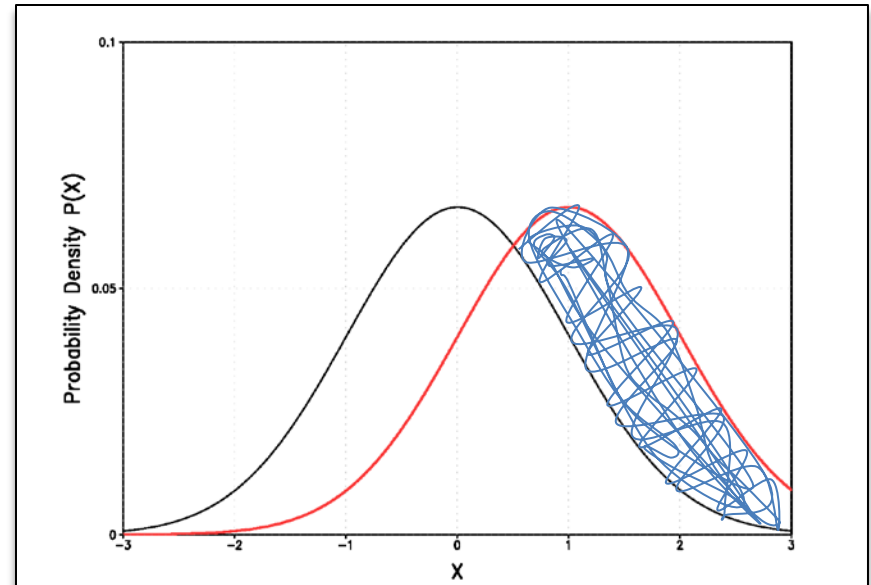
PDF for a Season (Red)

What Lends Predictability in Long-Range Predictions

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

- **Initial conditions**
  - Weather prediction
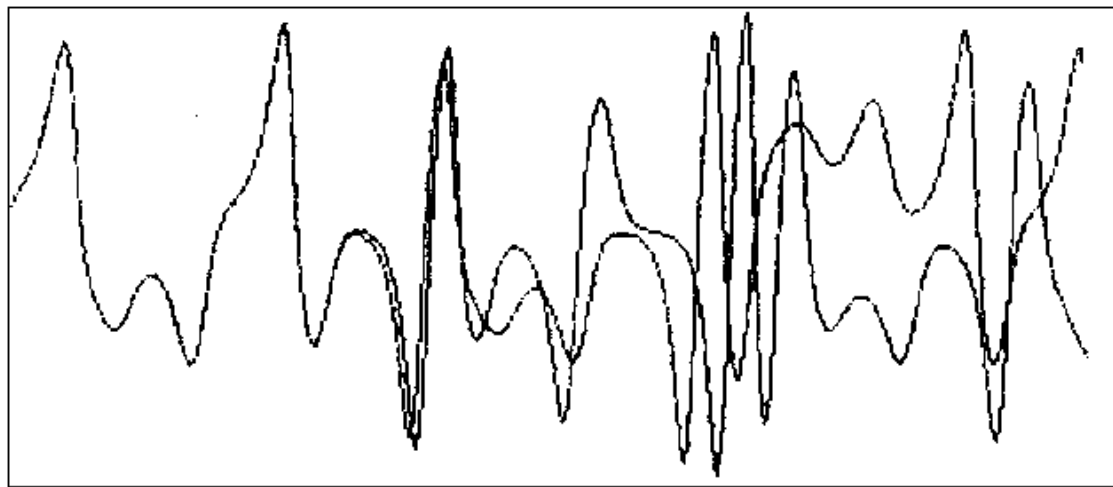 - ENSO prediction
  - *Tier -1 predictions*

What Lends Predictability in Long-Range Predictions?
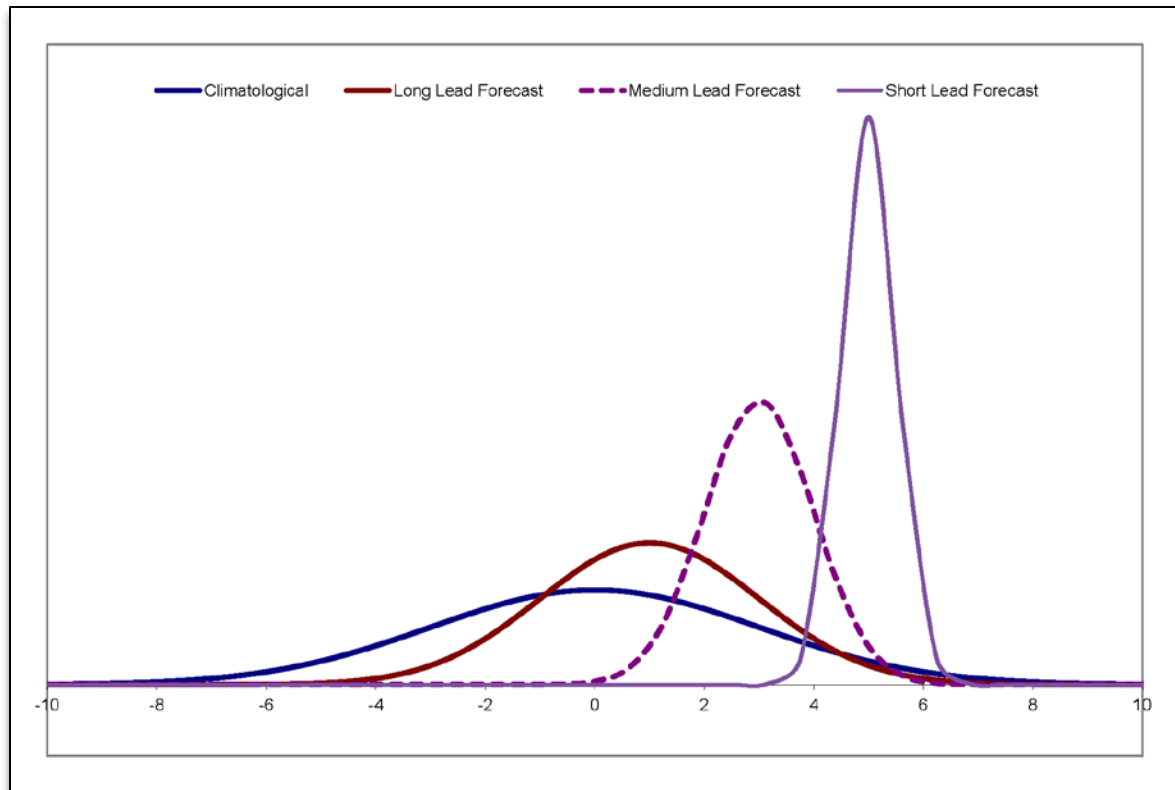
- The spread with lead time increases

- PDF shifts towards the climatological PDF

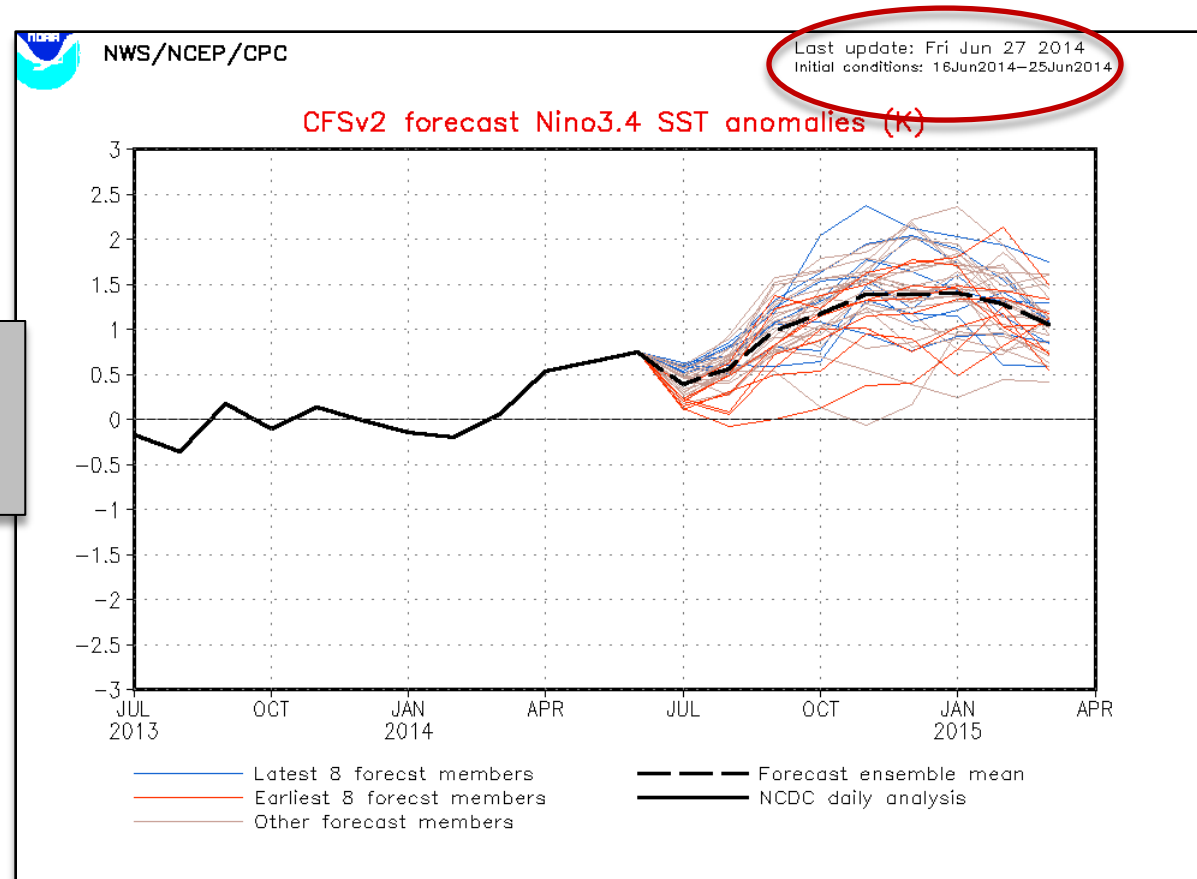# Why there is Spread (Uncertainty) in Forecasts?

- Non-linear dynamical systems sensitivity to specification of initial conditions

- Deterministic chaos

- Uncertainty could be better quantified, but can never be removed

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

# Examples of Spread: ENSO Prediction

NCEP/CFS
Nino 3.4 SST
Prediction

What Provides <u>Skill</u> in Seasonal Predictions

- 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
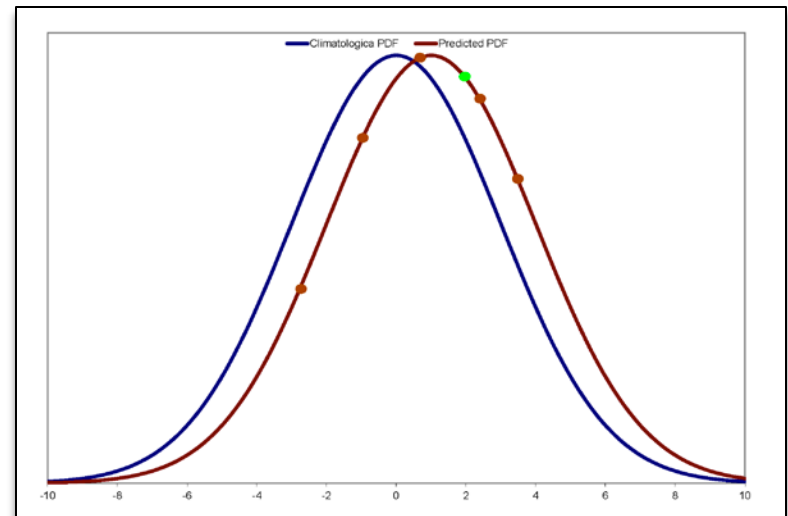 - Mean
  - Spread
  - Skewness

Examples of High/Low Prediction Skill
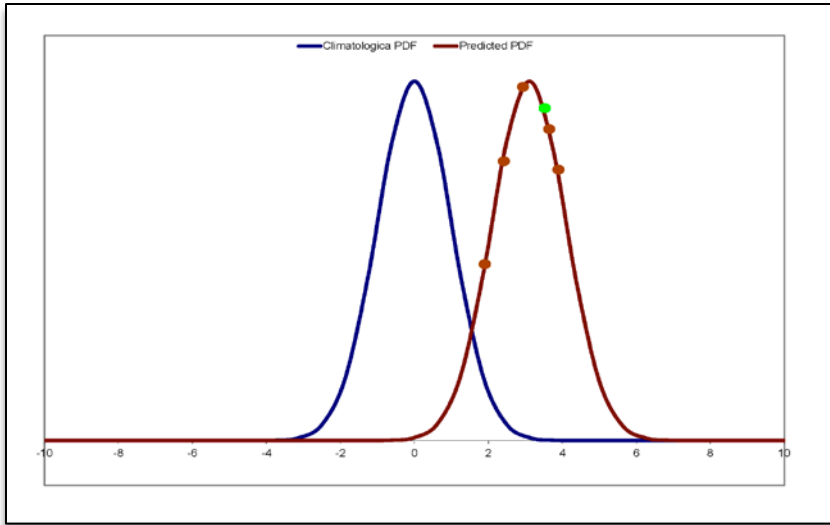
High Predictability

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 in nature, and in general, and generally both are used in the development of final forecast

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Components of a Seasonal Forecast System

- Forecast system components
  - Initialization
  - Hindcasts
  - Real-time forecasts
  - Skill assessment
  - Bias correction and calibration
  - Forecast dissemination

Initialization

- Various components of the forecast system need to be initialized with 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

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

Hindcasts

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

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!
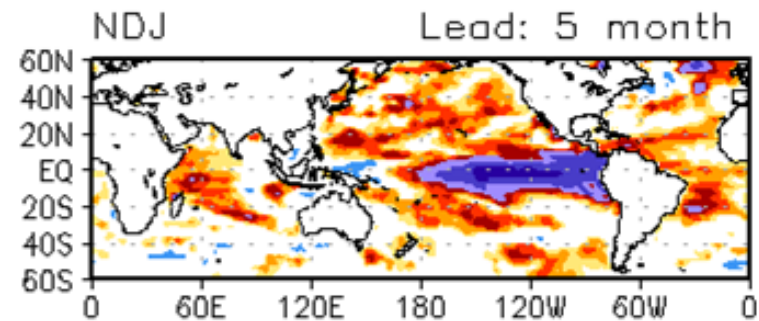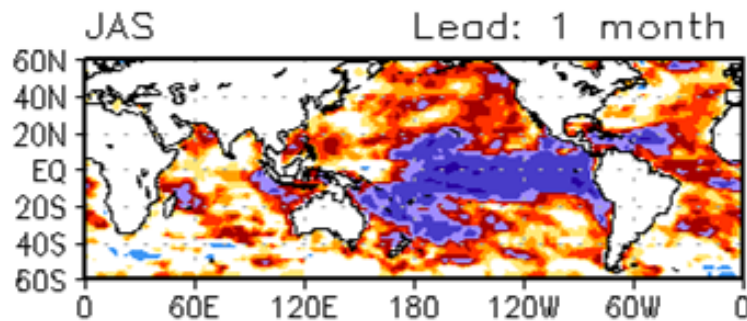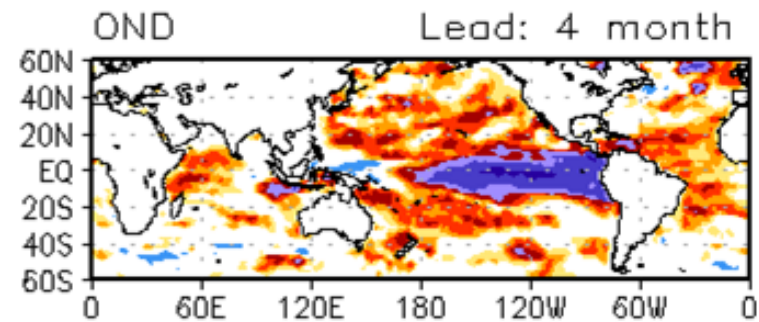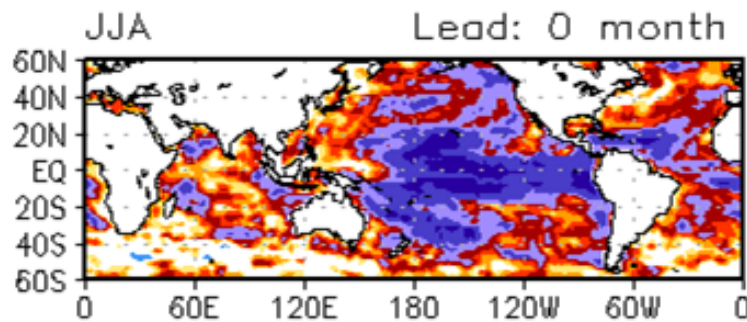
Skill Assessments

- 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
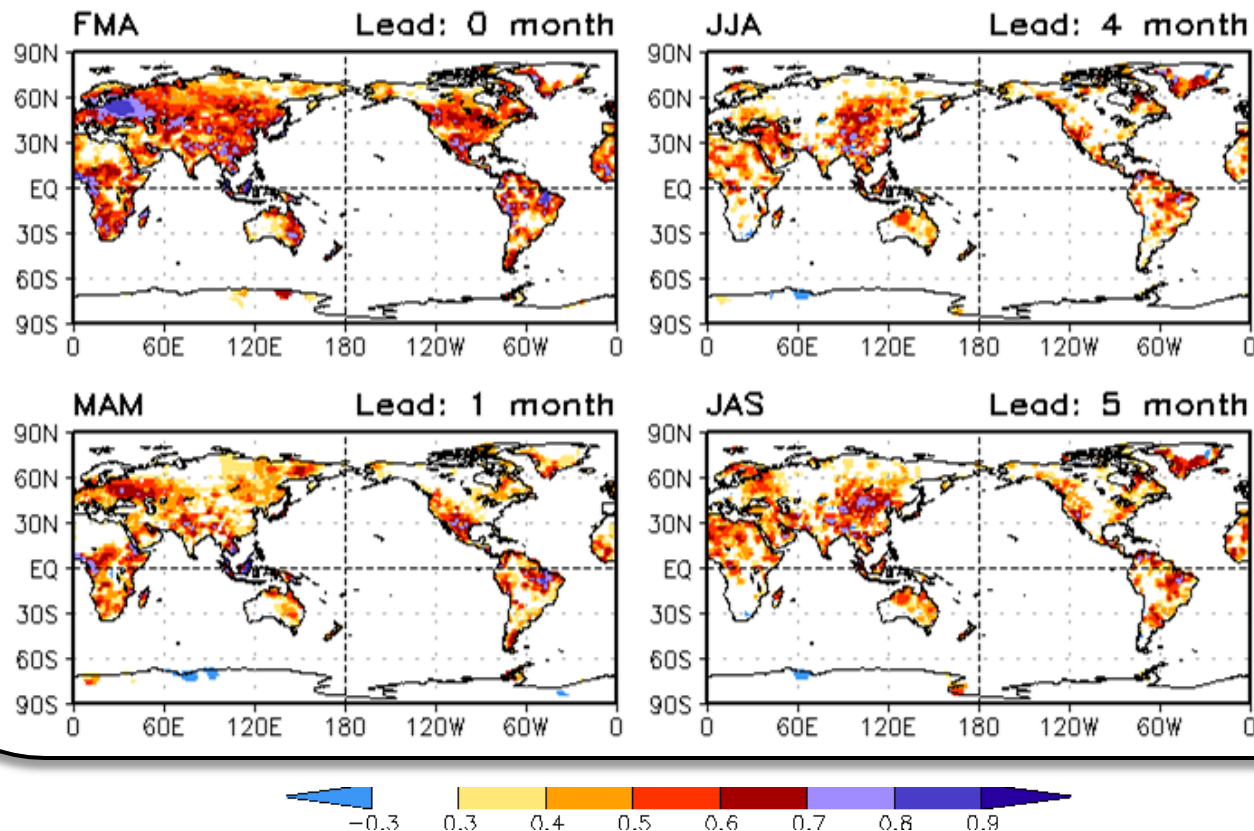
Skill Assessment: SST

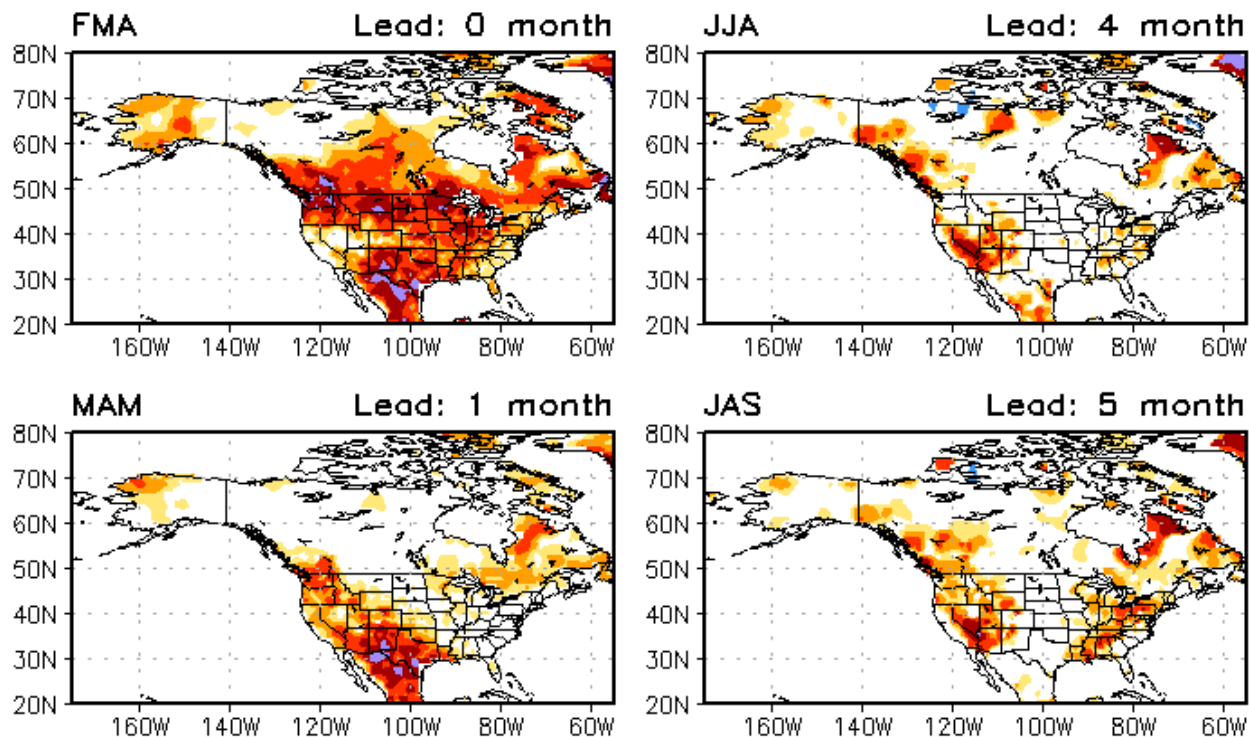# Skill Assessment: Surface Temperature

Skill Assessment: Surface Temperature

Anomaly Correlation

CFSv2 Correlation T2m
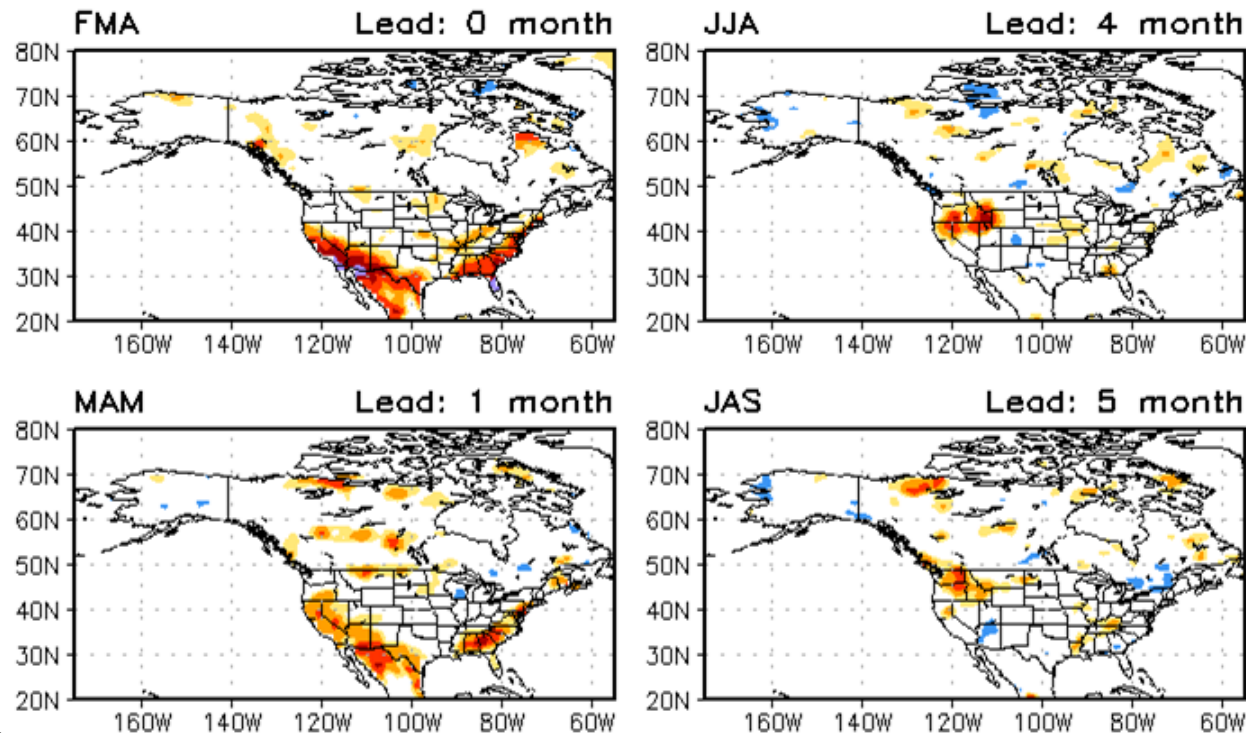
Initial month: Jan 1982−2009

Skill Assessment: Precipitation

Anomaly Correlation

CFSv2 Correlation Precipitation

Initial month: Jan 1982−2009

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
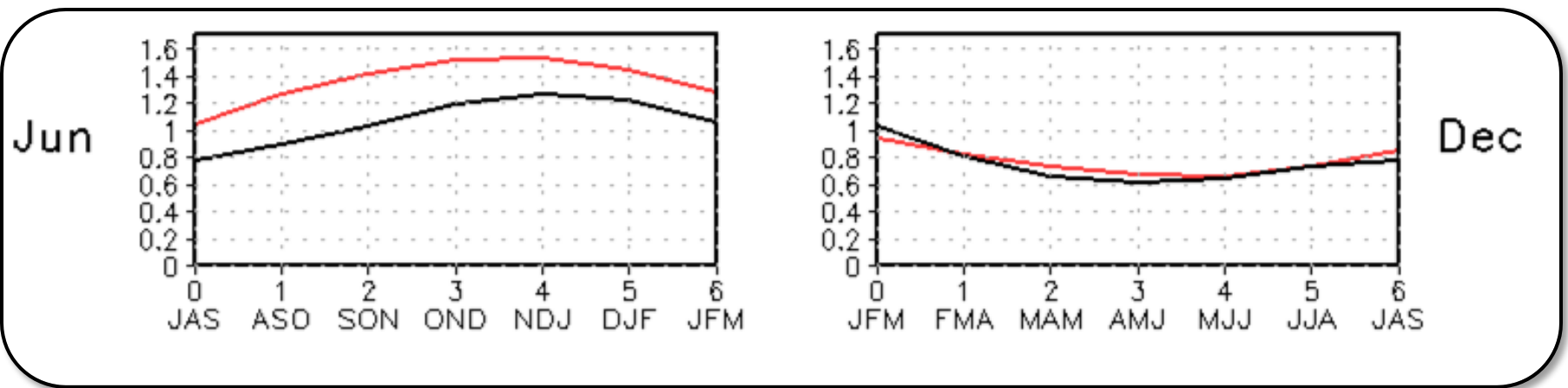
Differences in Mean State

CFSv2 Bias(Fcst−Ghcn) T2m (K)

Initial month: Jan 1982−2009
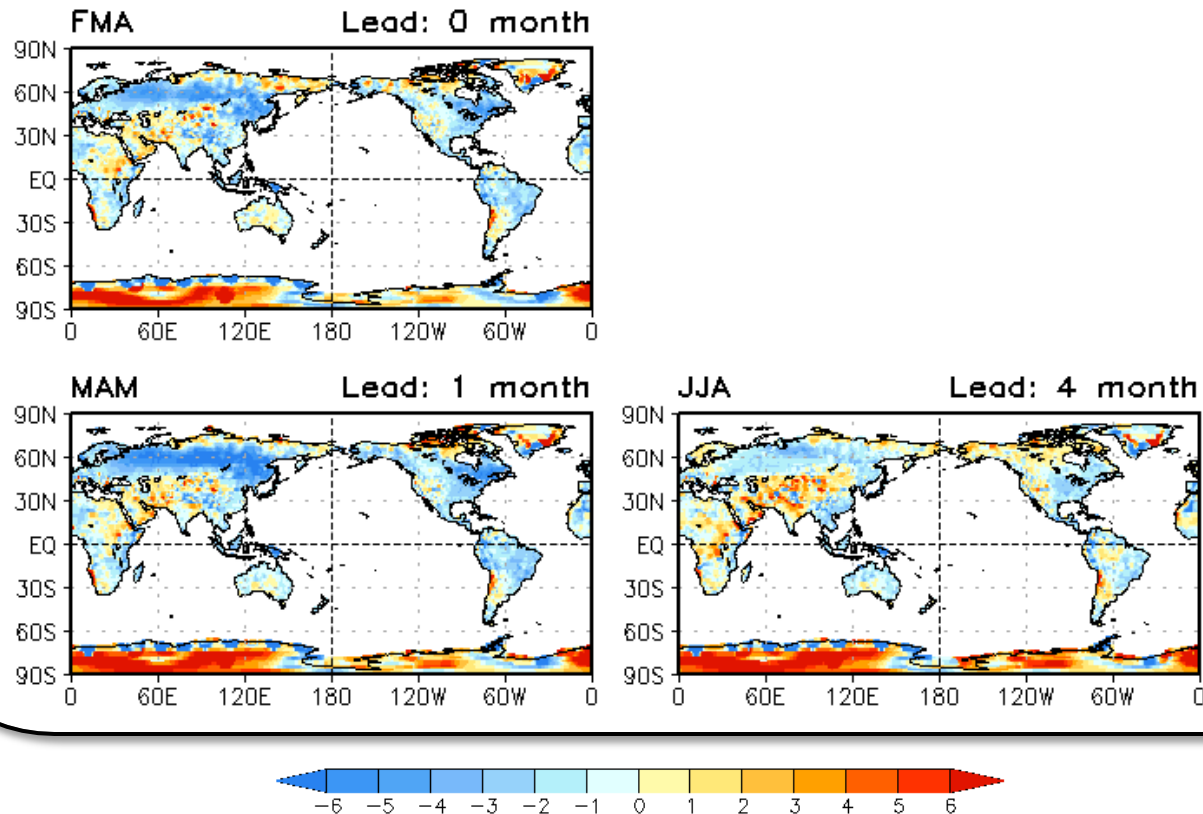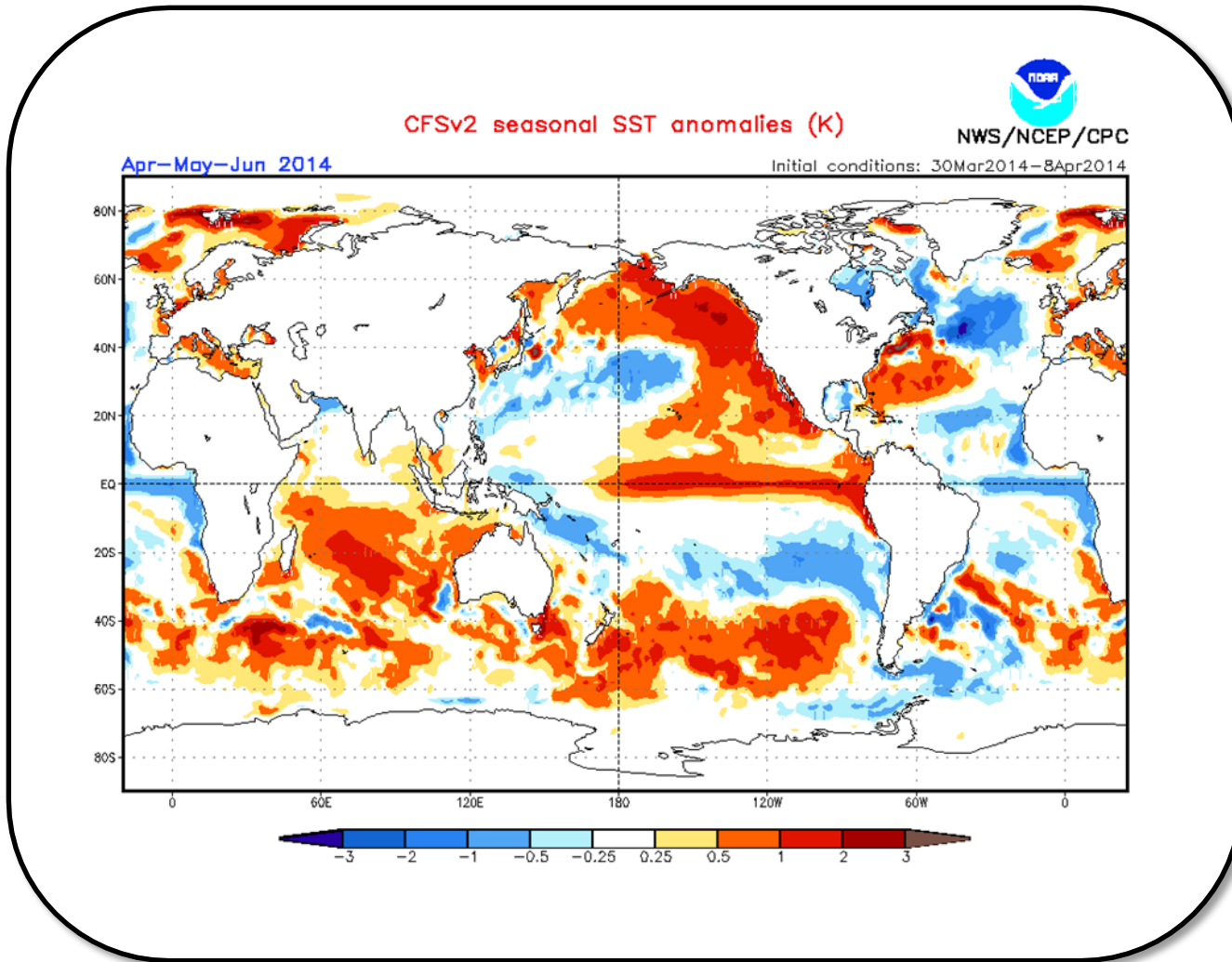
Differences in Variability
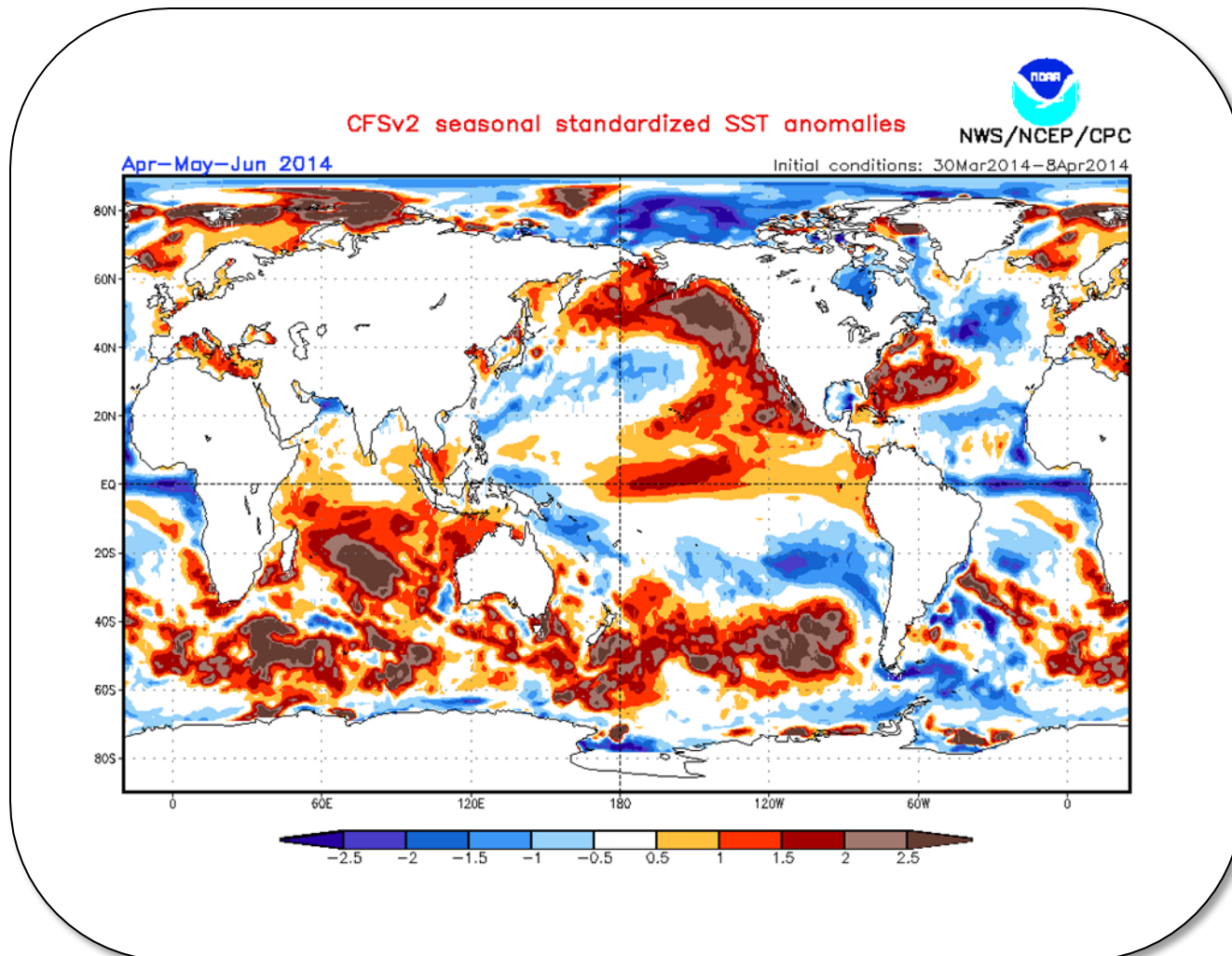

Standard Deviation Nino34 SST(K)

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 channels
  - Procedures could be developed for statistical downscaling

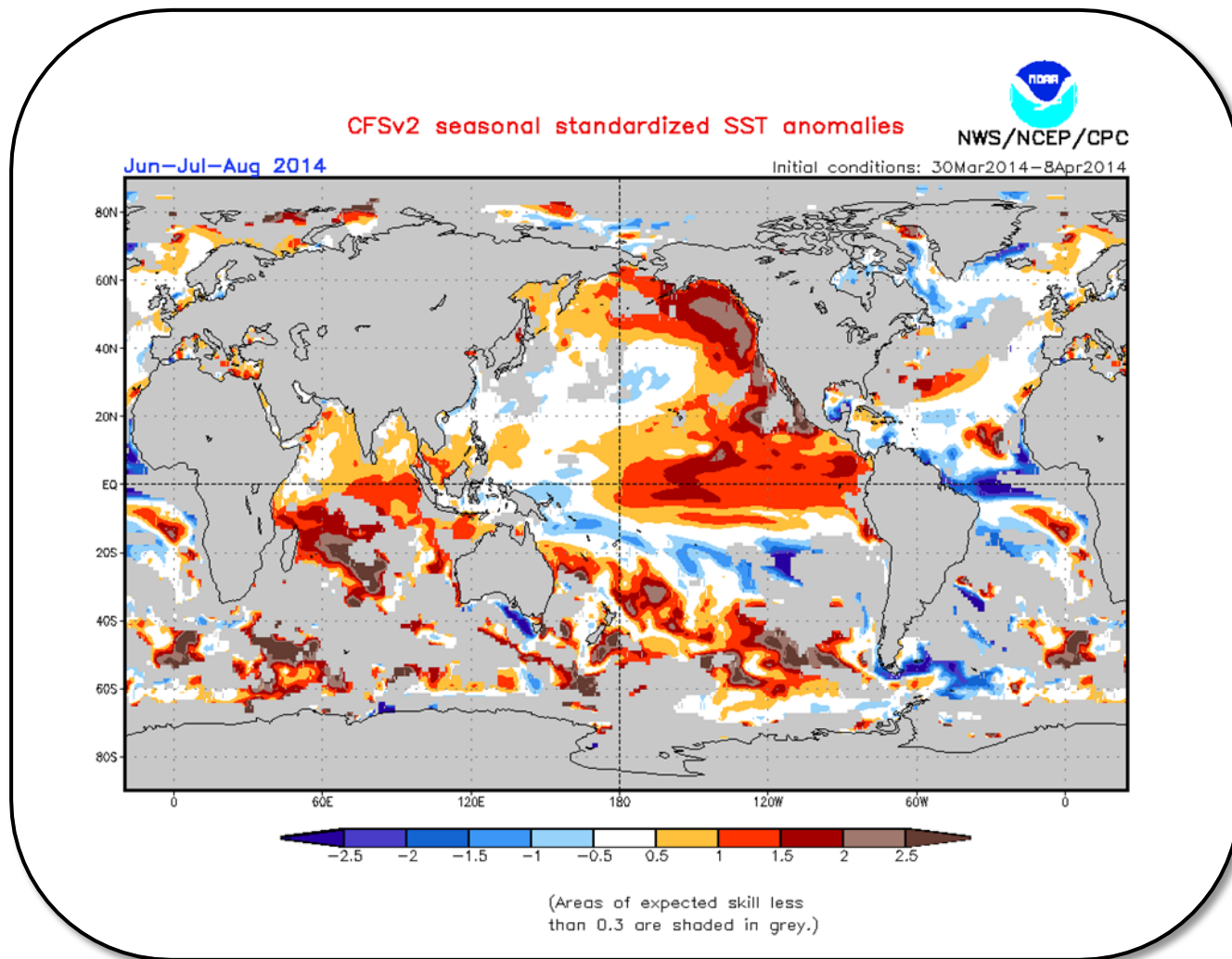# Graphical Products: SST Anomaly

CFSv2 seasonal SST anomalies (K)

NWS/NCEP/CPC

Apr—May—Jun 2014   Initial conditions: 30Mar2014—8Apr2014

Graphical Products: Standardized SST Anomalies

Graphical Products: SST Anomalies with Skill Mask

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Current Status of Seasonal Prediction Systems

- WMO (World Meteorological Organization) Global Producing Centers (GPCs) for seasonal Predictions
  - 12 in all
  - To be designated as a GPC, a seasonal prediction center has to conform with some designation criterion
  - All GPCs generate seasonal predictions on a monthly basis
  - https://www.wmolc.org/

Summary

- Seasonal prediction system are fairly mature
- Hindcast and real-time forecast data is a huge data base that can be used for various research and analyses purposes
  - Analysis and predictability of extremes
  - Influence of various climatic factors on extremes (attribution and prediction)