



Background And Framework for Establishing a Seasonal Precipitation Forecast Improvement Project (SPFIP)



Outline



- Vision
- Motivation for establishing the program
- Definitions
- Foundational documents
- State of seasonal forecasting skill including gaps
- Science goals
- Framework for an SPFIP



Vision



Vision: Development of a holistic program to improve seasonal forecast skill through improved understanding of known sources of predictability, exploration of new sources, and improvement of the representation of these processes in our models.

Realizing this vision will require a **substantial and sustained commitment** of resources and need to leverage all members of the short-term climate prediction community including operational centers, federal labs, and academic partners!



Motivation for Improving Seasonal Precipitation Forecasts



The National Climatic Data Center has recorded droughts in the United States having severe economic impacts (more than \$1 billion in damages) during 16 of the 21 years from 1980 to 2011, with an estimated annual average direct drought loss of \$9.5 billion (adjusted to 2011 dollars; Smith and Katz, 2013)).





Definitions



For purpose of this discussion:

1. Seasonal forecast refers to first 3 month season and includes the first month's forecast.
2. Although focus is on precipitation it should be recognized that work to be undertaken will also benefit seasonal temperature forecasts.
3. Predictability is used qualitatively to describe the extent to which the representation of a physical process contribute to prediction skill. Estimates of the lower-bound on predictability are obtained from the skill of current forecasts.



Foundational Documents



Assessment of Intraseasonal to Interannual Climate Prediction and Predictability (NRC, 2010).

Sub-Seasonal to Seasonal Prediction Research Implementation Plan (WMO, 2014)

California Drought Service Assessment (Werner et al., 2015)

Prospects for advancing drought understanding, monitoring, and prediction. (Wood et al., 2015)

Causes and Predictability of the 2011-2014 California Drought. (Seager et al., 2014).

Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts (NRC, 2016)

High-Resolution Coupling and Initialization to Improve Predictability and Predictions in Climate Models Workshop. (Kinter et al., 2016).



State of Seasonal Climate Forecasting



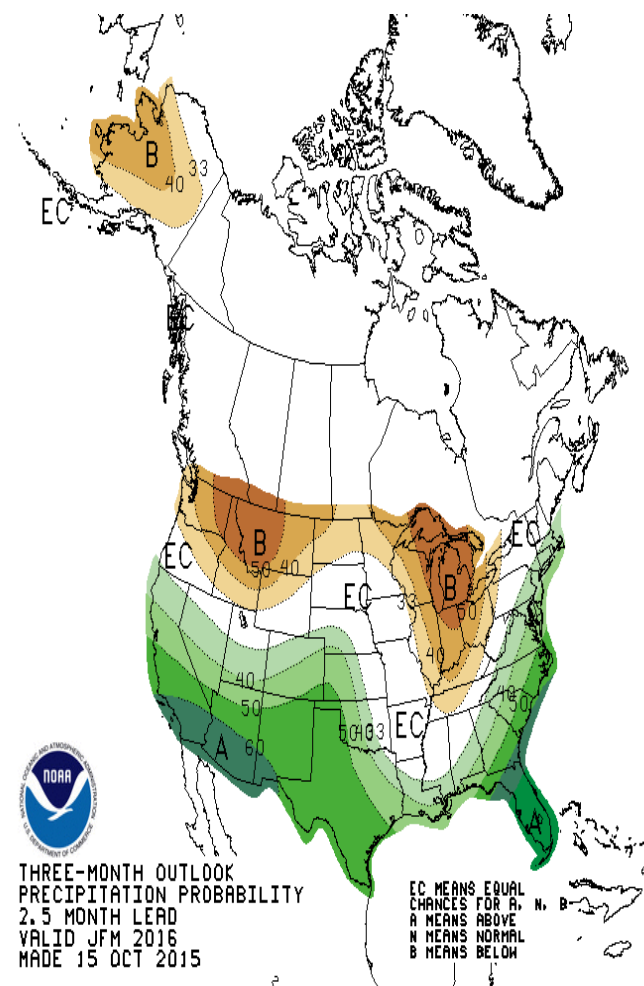
- CPC Seasonal Outlooks
- Skill level of current seasonal forecast tools
- Footnote on ENSO and its role in Seasonal Forecasts for the US
- Examples of where our most skillful tools don't perform well indicating gaps in our knowledge or limited predictability or both
 - 1 Month JFM 2015 NMME forecast
 - Greatly reduced skill of NMME in predicting SST variability outside of central and eastern Tropical Pacific
 - 1 Month January 2016 and JFM 2016 NMME forecasts (Record strength El-Nino)

Human Forecasters Use Various Tools To Develop Seasonal Predictions:

- ☐ Dynamical Models
- ☐ Statistical Models
- ☐ Historical Analogs
- ☐ Historical Composites

Goal is to leverage complementary skill between the tools.

Ultimately, skill of seasonal forecast depends on skill of tools made available to the forecaster.





Multi-Model Ensembles and the North-American Multi-Model Ensemble (NMME) Project



Why do use multi-model ensembles (MME) for forecasts?:

- Allows representation of model uncertainty.
- Possibility of complementary skill between models.
- Skill of MME is frequently higher than that from the most skillful member in the ensemble (though if one model is dominantly better this is not always true).

NMME is frequently our most skillful tool but there is still room for improvement.

Models/Groups Participating in NMME

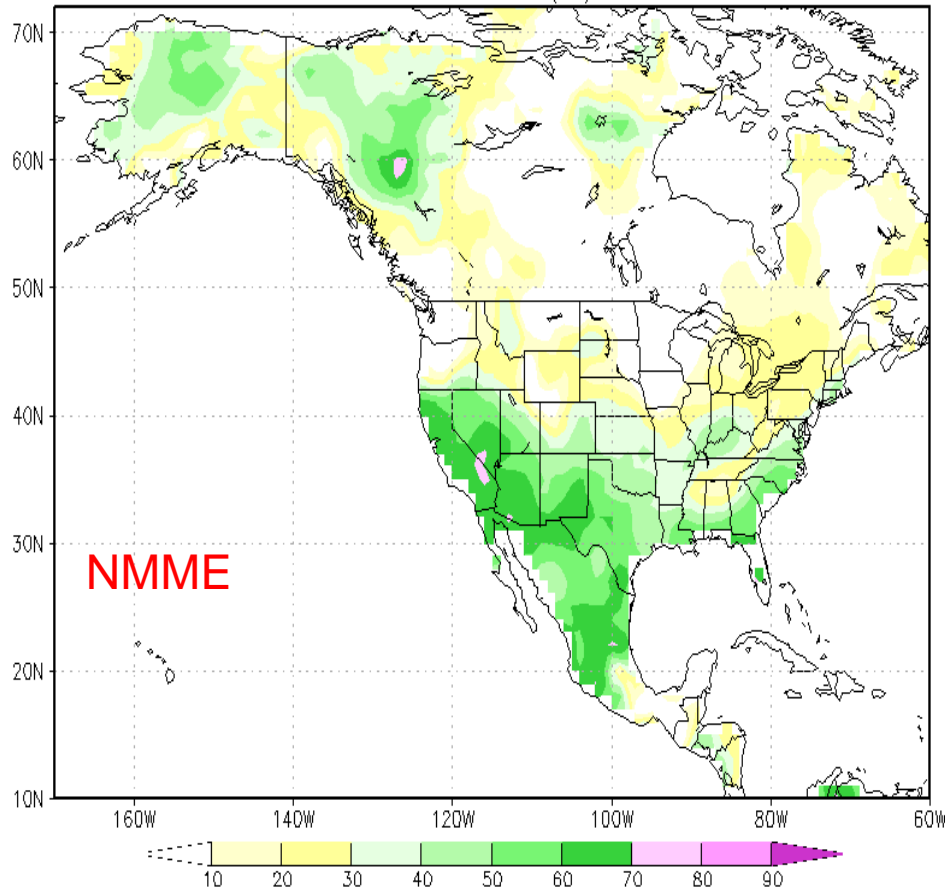
Organizations	Models
NOAA/NCEP	CFSv2
NOAA/GFDL	CM2.1 FLOR (March 2014)
NASA/GMAO	GEOS5
Environment Canada	CMC1-CanCM3 CMC2-CanCM4
NCAR	CCSM3.0 CCSM4.0 (July 2014)
NCAR	CESM1.0 (Mar. 2015)



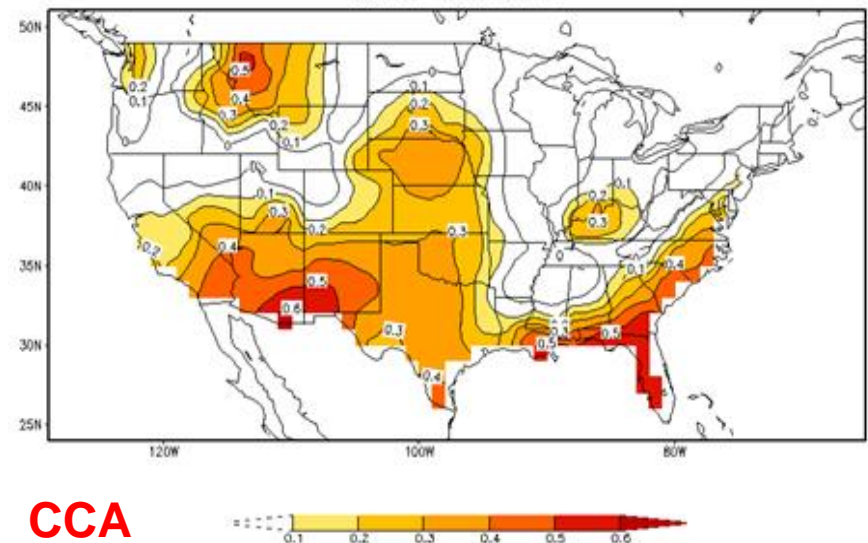
Lead 1 Precipitation Forecast Skill for JFM from Two State of the Art Forecasting Tools: NMME and CCA



NMME Forecast of Prate Skill (AC) IC=12 for JFM



USA PRECIPITATION FOR JFM (0.5 month lead)
CCA CV ACC SKILL



Users perspective on the skill level of these forecast tools and hence their utility will vary.



Footnote on ENSO and Seasonal Prediction Over the US

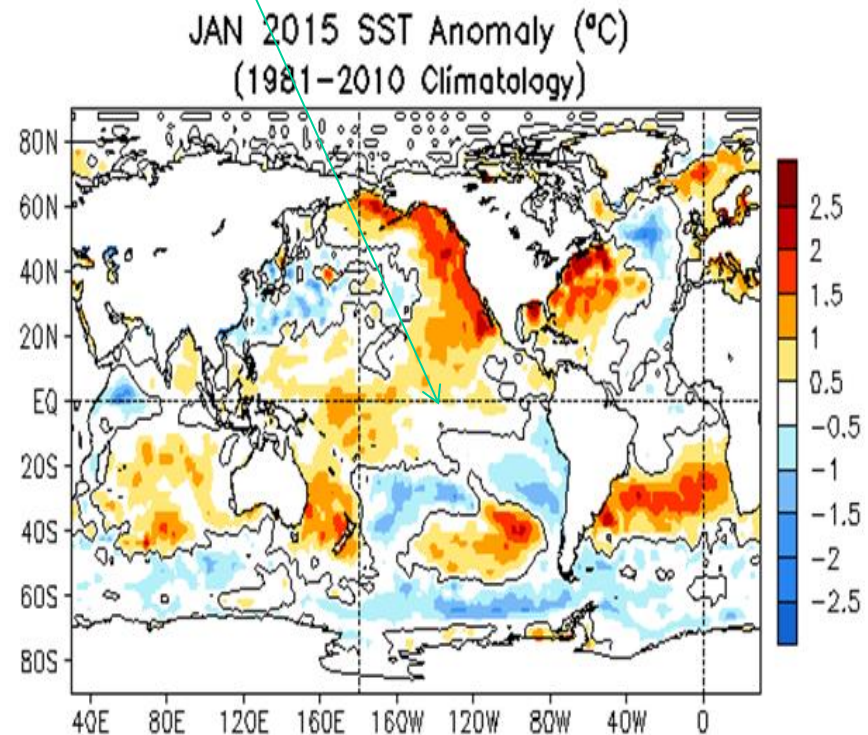
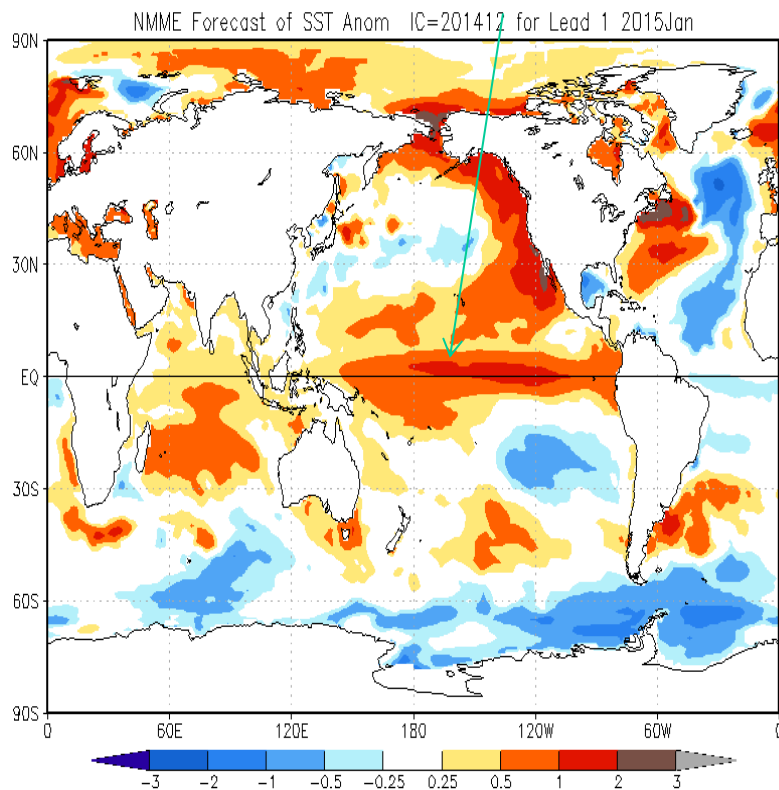


ENSO isn't the only factor controlling the seasonal distribution of precipitation over the US.

However, it is commonly accepted that accurate forecasts of ENSO and its associated teleconnections are a necessary but not sufficient condition for accurate seasonal precipitation forecasts.

Lead 1 NMME SST Forecast for January 2015

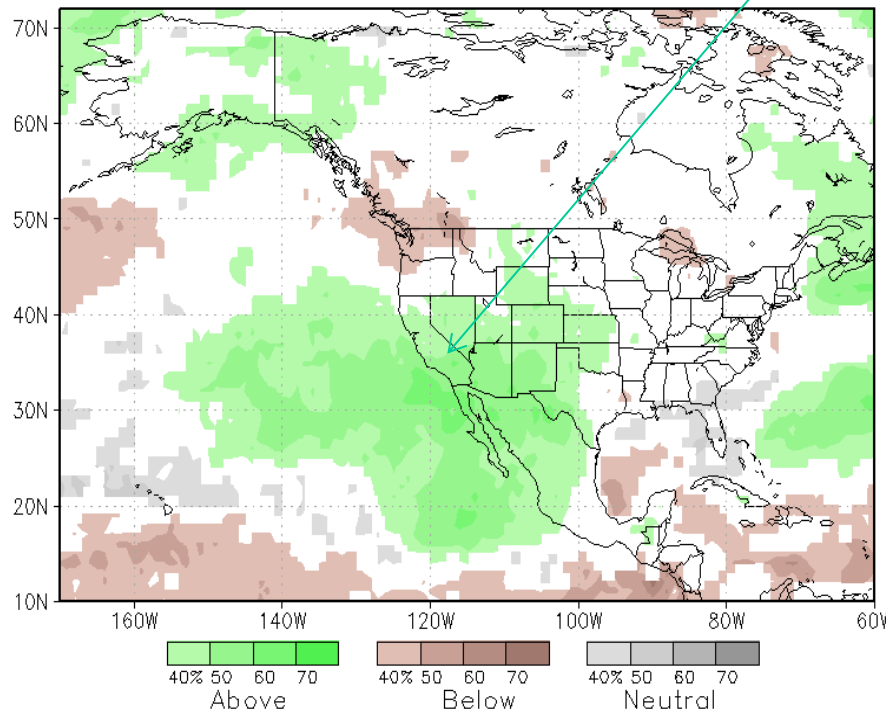
1 month lead NMME forecast calls for moderate canonical El-Nino while observed anomalies were confined to western Pacific



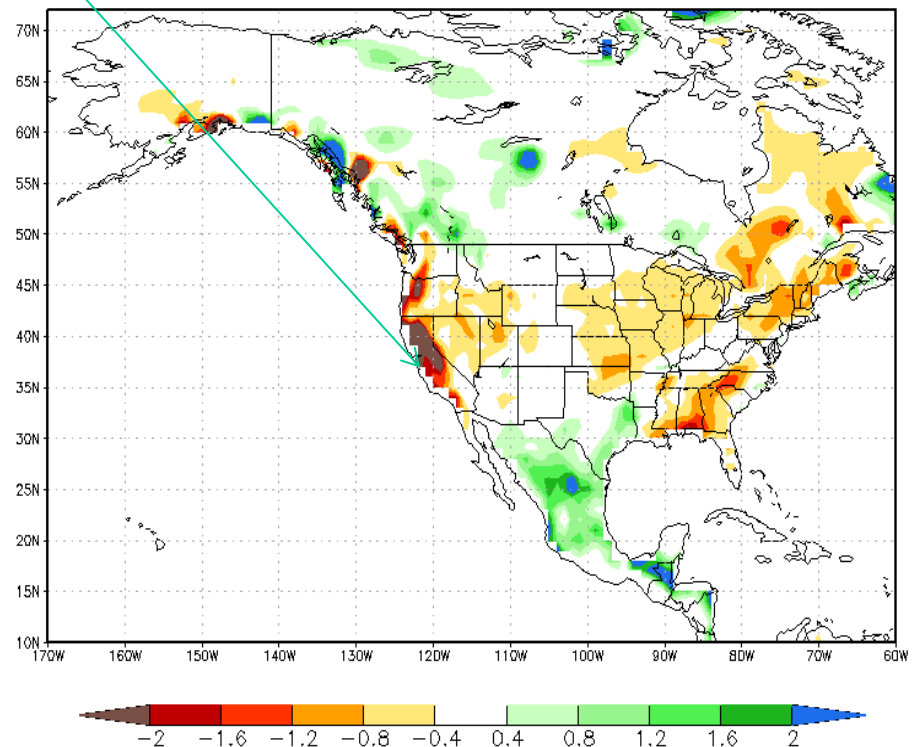
Lead 1 NMME Precipitation Forecast for JFM 2015

Associated precipitation forecast calls for modest probability of above normal precipitation, while record breaking drought was observed.

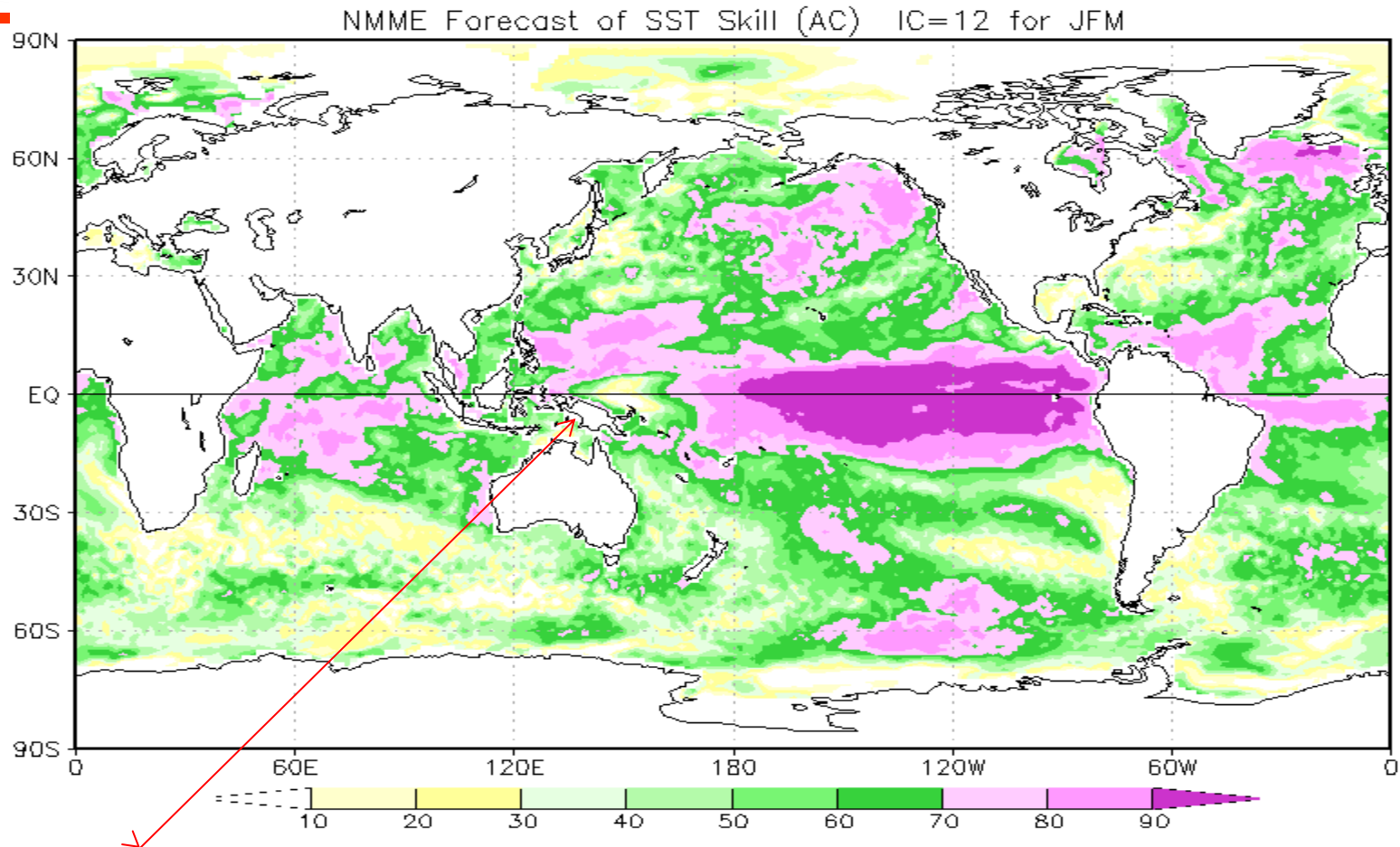
NMME prob fcst Prate IC=201412 for lead 1 2015 JFM



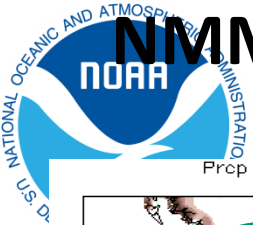
Observed Prate anom JFM 2015



Retrospective Forecast Skill of Lead 1 NMME SST Forecast for JFM from NMME



State of the Art MME Dynamical Forecast System has Low Skill in Predicting Near-Equatorial Western Pacific SST. If SST in this region drove the large-scale pattern in 2014-2015 there is an issue.

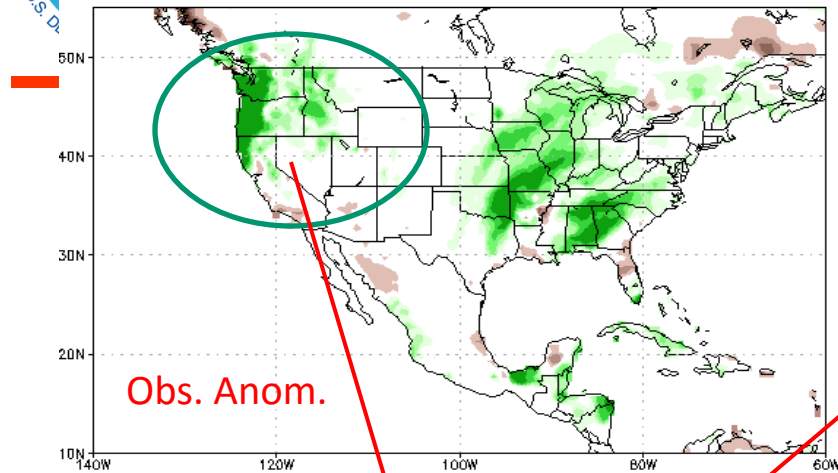


NMME Precipitation Forecast for December 2015 at One Month Lead Despite Strong El-Nino

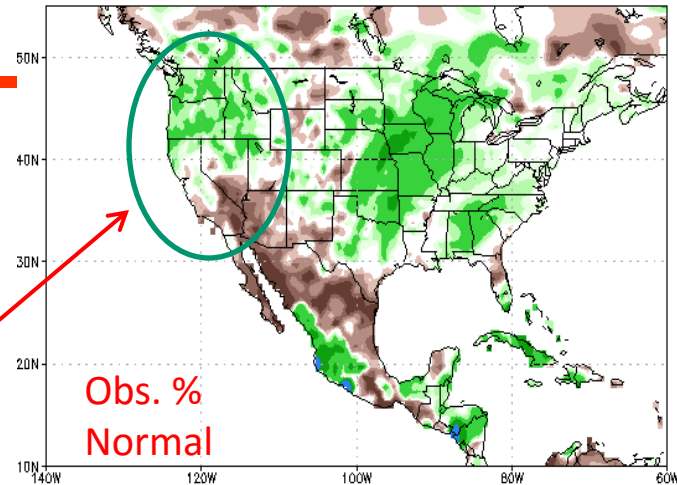


Prp Anomalies (mm) 01DEC2015-30DEC2015

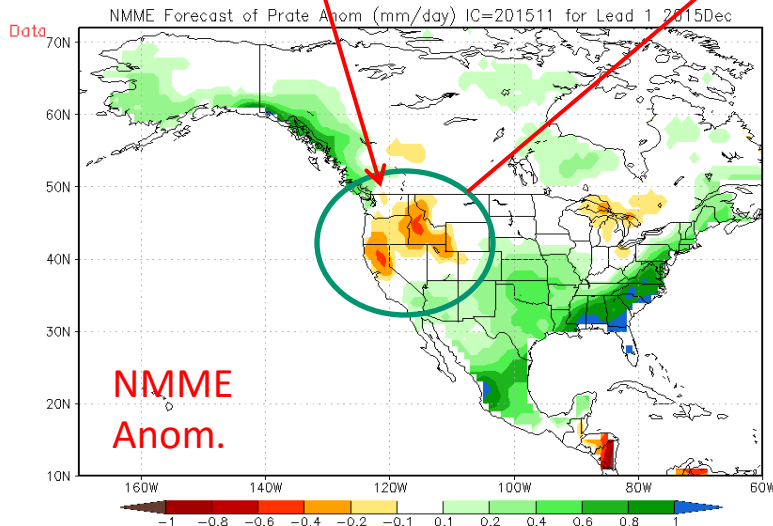
30-day Accumulated Prp % of Normal 01DEC2015-30DEC2015



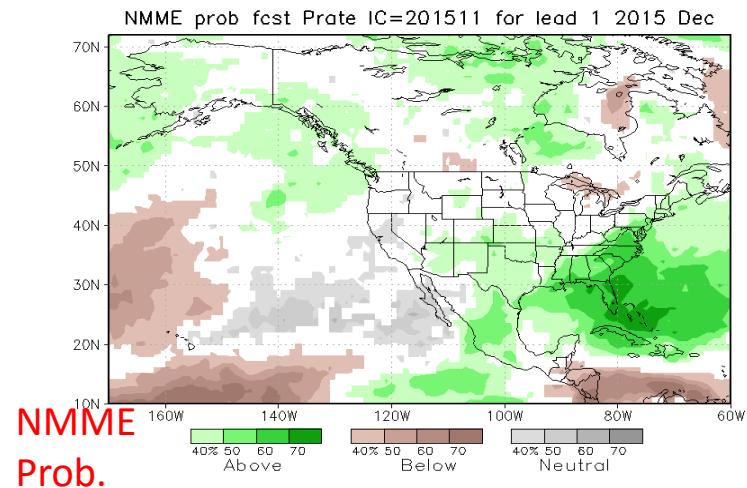
Obs. Anom.



Obs. %
Normal

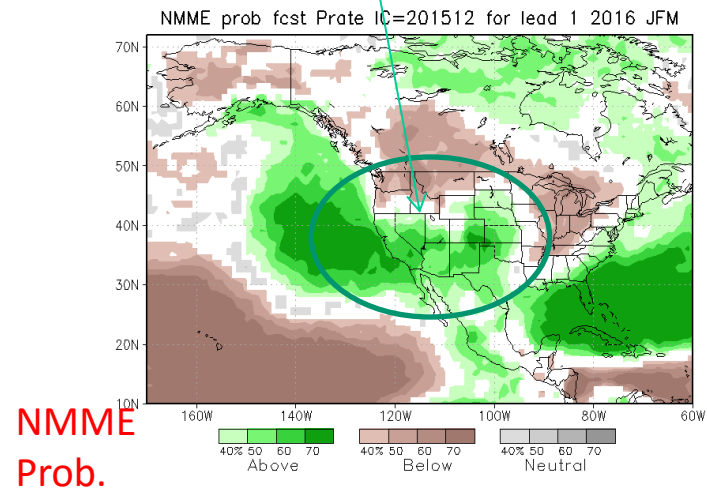
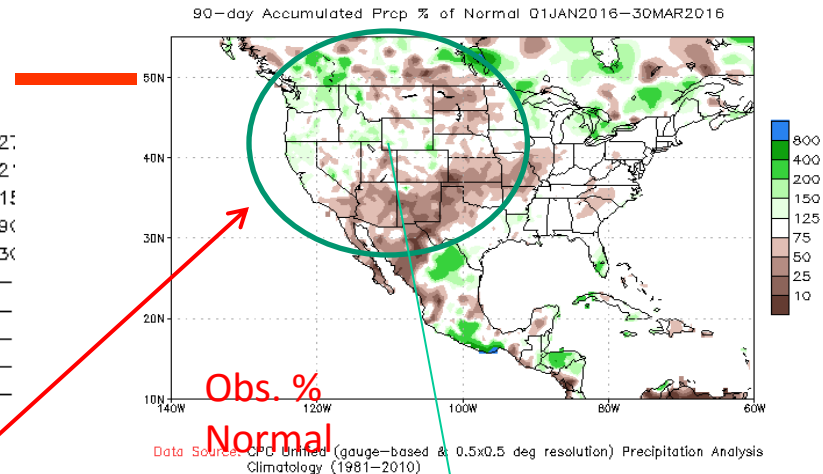
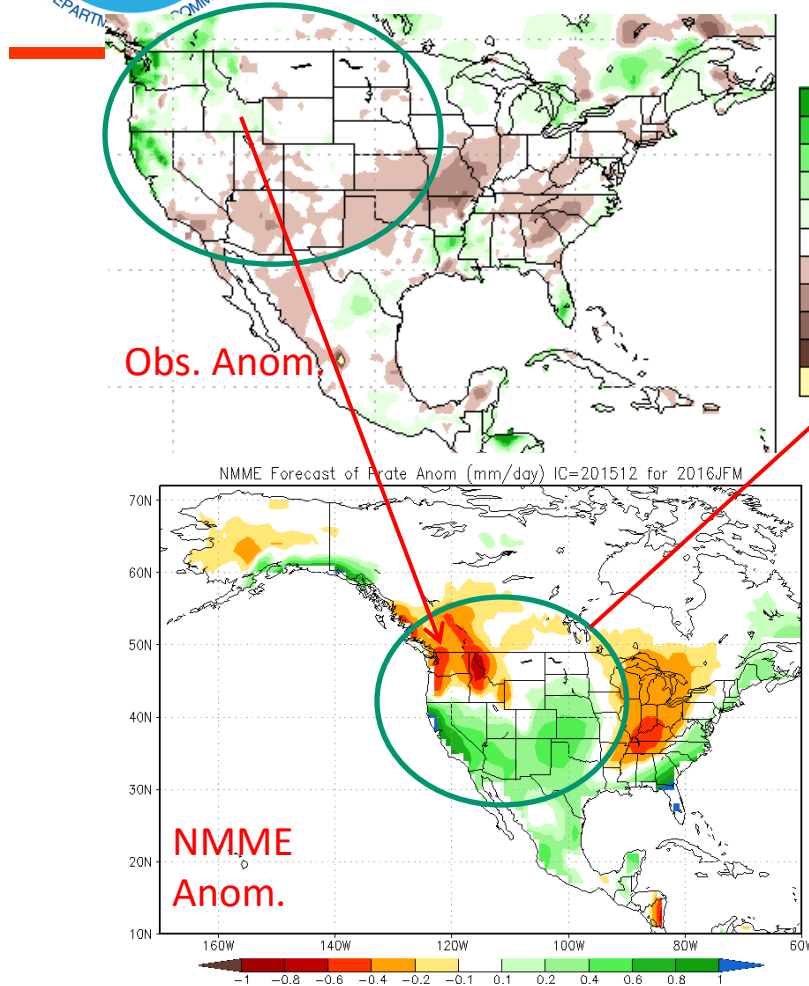


NMME
Anom.



NMME
Prob.

State of the art NMME misses major precipitation anomalies in Western US despite Strong El-Nino.



State of the art NMME misses major precipitation anomalies in Western/Central US despite record El-Nino.



Key Science Issues that Need to Be Addressed to Improve Seasonal Forecast Skill



Borrowing heavily from the collective recommendations made in the foundational documents especially the NRC Report on Intraseasonal to Interannual Prediction and Predictability (but also very consistent with NRC 2016 and Kinter et al., 2016)



National Academy Assessment of State of Interseasonal to Interannual Climate Prediction and Predictability (2010)



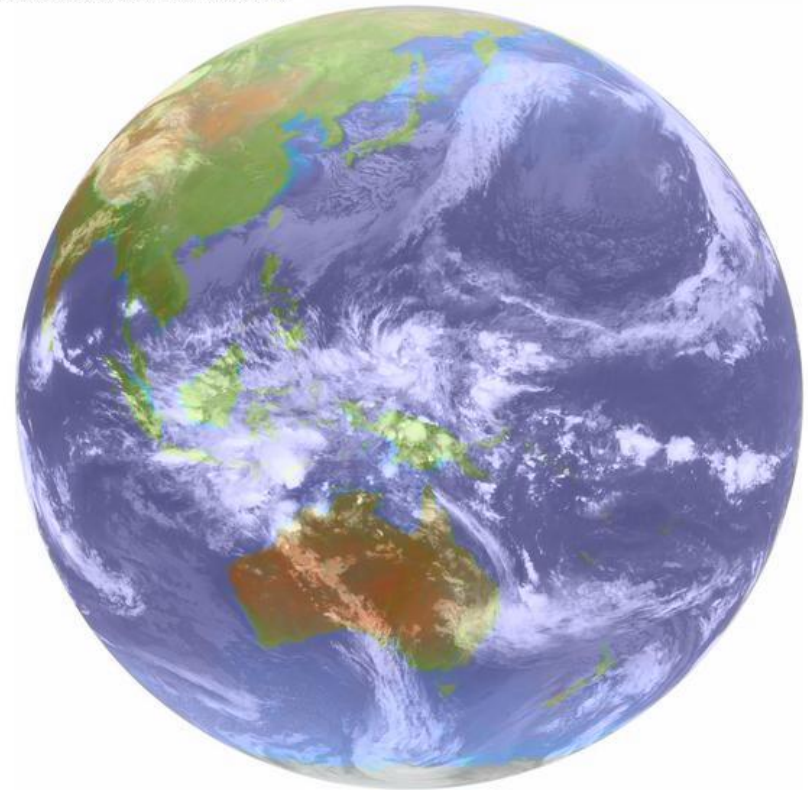
Main Conclusions:

- There are no “silver bullets;” there is no single action that will lead to a revolutionary leap forward in ISI predictions.
- Incremental increases in ISI forecasting quality are to be expected as the building blocks of ISI forecasts are improved and we increase knowledge of sources of predictability.

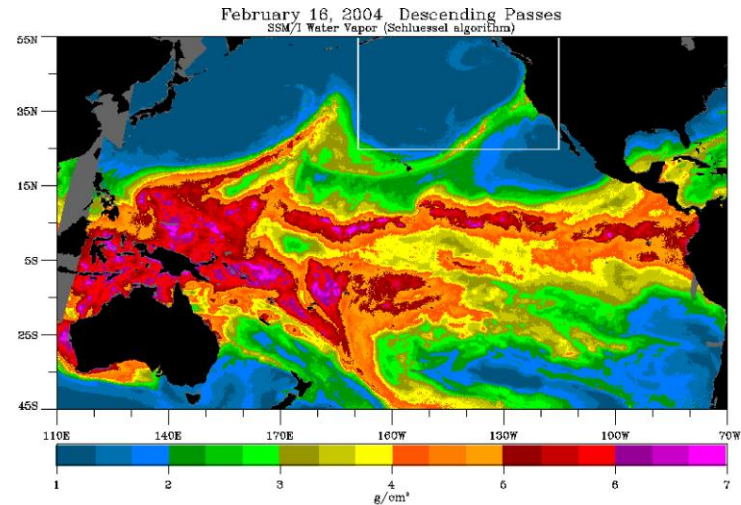
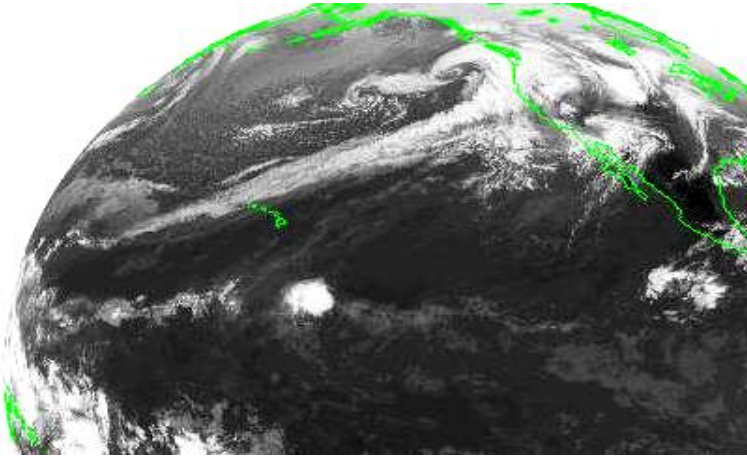
Challenge 1: Understanding Processes Controlling Organization of Tropical Convection

- A pervasive weakness of weather and climate models.
- Studies suggest that beyond 10 days, variations in tropical heating are a (the) major source of predictability, including weather events.
- Tropical climate biases often appear very early in model integrations.

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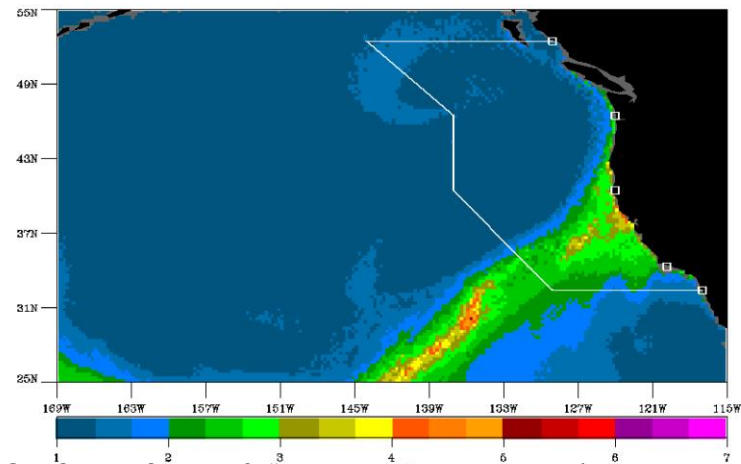


Challenge 2: Improve Understanding and Prediction Tropical – Extratropical Interactions



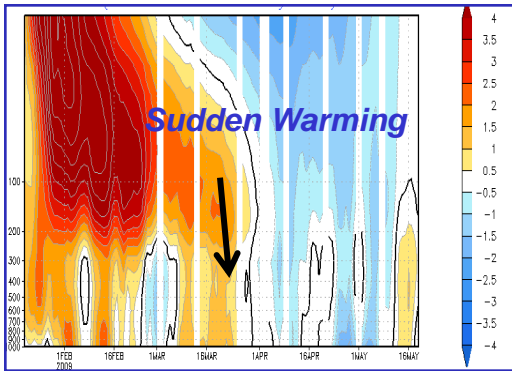
Improve understanding and prediction of:

- Madden-Julian Oscillation
- “Atmospheric Rivers”
- “Pineapple Express” events
- Blocking and Storm Tracks
- Impacts: West Coast floods



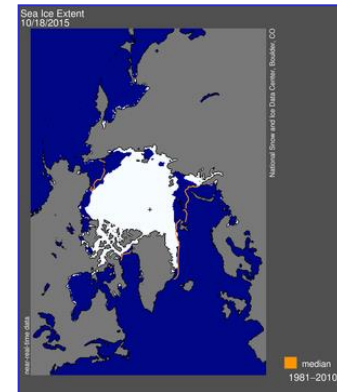
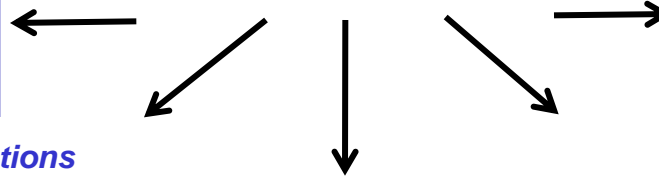
California floods & “Atmospheric Rivers” (Bao et al 06)

Challenge 3: Increase Understanding and Exploit Sources of Predictability

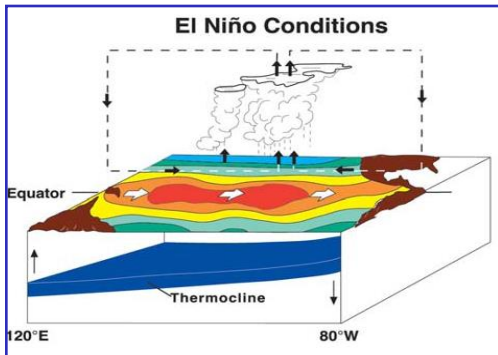


Stratosphere – Troposphere Interactions

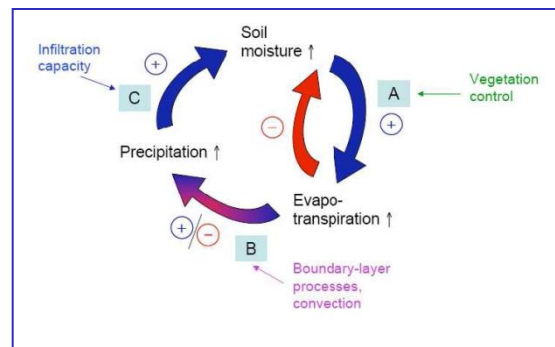
Key sources that link
climate to weather:



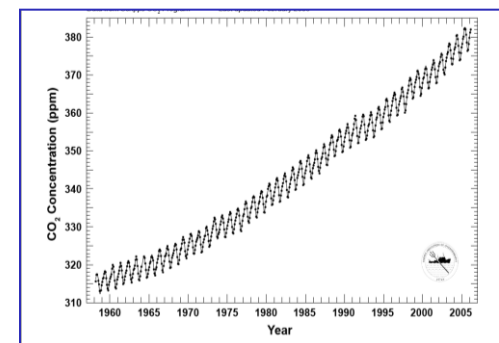
Arctic Sea ice



*Ocean-Atmosphere Interactions;
Role of sea-surface temperature*



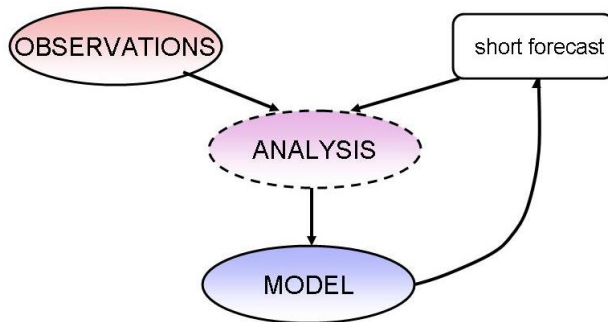
*Land -Atmosphere Interactions;
Role of soil moisture & land processes*



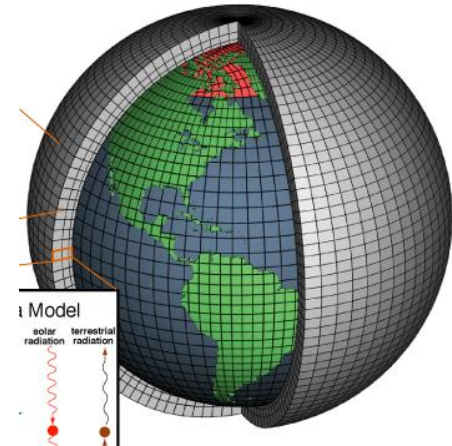
*Long-term Trends and
Climate Variability*

Challenge 4: Improve the “Building Blocks”

Upgrade Data Assimilation Systems



Identify / correct model errors



Enhance Observational Networks



Improvements in models, observational networks, and data assimilation systems lead to improved understanding and more realistic prediction over time.



SPFIP Science Goal 1: Improved Understanding and Modeling Sources of Seasonal Predictability



- Madden-Julian Oscillation
- Stratosphere-Troposphere Interactions
- Ocean-atmosphere coupling (including ENSO)
- North Atlantic Oscillation (NAO)/Arctic Oscillation (AO)
- Land-atmosphere feedback
- Polar Sea-Ice
- Atmospheric Rivers
- Pacific Decadal Oscillation
- Role of SST forcing versus internal variability?



SPFIP Science Goal 2: Improved Seasonal Prediction Tools



Identify cause reduce systematic errors in coupled atmosphere-ocean general circulation models (CGCMS):

- Double intertropical convergence zone
- Excessively strong equatorial cold tongue
- Weak or incoherent intraseasonal variability and associated teleconnection
- Failure to represent multi-scale organization of tropical convection
- Poorly represented cloud processes, especially low-level clouds

Increase model resolution to better resolve physical processes and orographic variations



SPFIP Science Goal 2: Improved Seasonal Prediction Tools



Improved Representation of physical process in CGCMS:

- Deep and shallow convection
- Planetary boundary layer in the atmosphere and the ocean
- Sea ice
- Soil moisture
- Snow cover

Exploration of new statistical techniques and hybrid dynamical-statistical techniques

- Need to ensure rigorous cross-validation to estimate true forecast skill



SPFIP Science Goal 2: Improved Seasonal Prediction Tools



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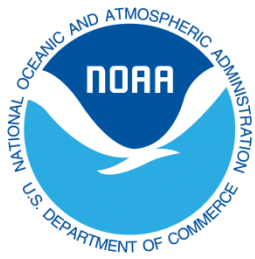
SPFIP Science Goal 2: Improved Seasonal Prediction Tools



Dramatic failure of state of the art dynamical models (including NMME) in predicting the precipitation anomalies in the western and central US during the record 2015-2016 El-Nino suggests that:

1. Either there is less predictability in the system than we previously believed **or**
 - The current generation of models misrepresent or don't represent at all key processes

Tremendous opportunity for the short-term climate community to conduct targeted experiments to try to determine which of these is true.



Framework for an SPFIP



1. Need to recognize the difficulty of the problem and ensure sufficient and stable resources are obtained. Uncertain funding levels make it difficult to plan and make progress.
2. Essential components:
 - Grants program supporting mission-driven research on understanding sources of predictability
 - Support to modeling centers for model improvements
 - Grants program on tailoring products for end users
 - Support infrastructure for testing new tools and transitioning to operations
 - High-performance computing augmentation
3. Key partners:
 - Academic community
 - Within NOAA: NWS (NCEP, NWC), OAR (GFDL, ESRL, CPO); NESDIS (NCEI)
 - Other willing federal agencies



How to Measure Success for an SPFIP



1. (Somewhat) arbitrarily chosen metric of 20% improvement over year 1 baseline at 5 years and 40% improvement over year 1 baseline at 10 years.

This engenders two very distinct replies:

- a. You are nuts: We can't achieve that.
- b. That doesn't seem very ambitious

2. We need to define some baseline metric(s) and set goals for improving on those metrics.

Given that the motivation for this project is to inform water resource decisions the best approach may be to let water resources experts propose some initial metrics and then iterate with climate scientists to refine these.

Experimental Week 3-4 Outlooks
And
NWS Week3-4 Prediction Initiative

Challenge of Filling the Week 3-4 Gap

The Week 3-4 outlook period is within a time range that:

- (1) Primarily no longer benefits from predictability due to atmospheric initial conditions (i.e., Week-2) and
 - (2) Is at times in a range too short to reliably benefit from slowly evolving parts of the climate system (ocean, land, etc.) known to aid longer time scale prediction (monthly to seasonal outlooks)
- Consequently, the Week 3-4 time range often suffers from low predictability
 - Important to understand this limitation to manage expectations

Product Description

- The experimental product is 2-class (above or below-average) temperature and precipitation outlook maps for the favored category of ***two-week*** mean temperature and ***two-week*** total accumulated precipitation
- The target is a combined two week outlook for Weeks 3-4 in the future
- Outlook maps depict probabilities for the favored category
- The experimental product is released once per week every Friday at approximately 3 PM ET
- First experimental outlook was released on September 18, 2015

Scientific Basis of Outlook

The following factors/tools are considered in preparing the experimental outlooks:

- ✓ El Nino-Southern Oscillation (ENSO)
- ✓ Madden-Julian Oscillation (MJO)
- ✓ Atmospheric blocking (NAO and AO)
- ✓ Bias corrected dynamical model guidance
- ✓ Empirical and statistical tools targeting above climate variability
- ✓ Soil moisture and snow cover anomalies
- ✓ Local sea surface temperature (SST) anomalies

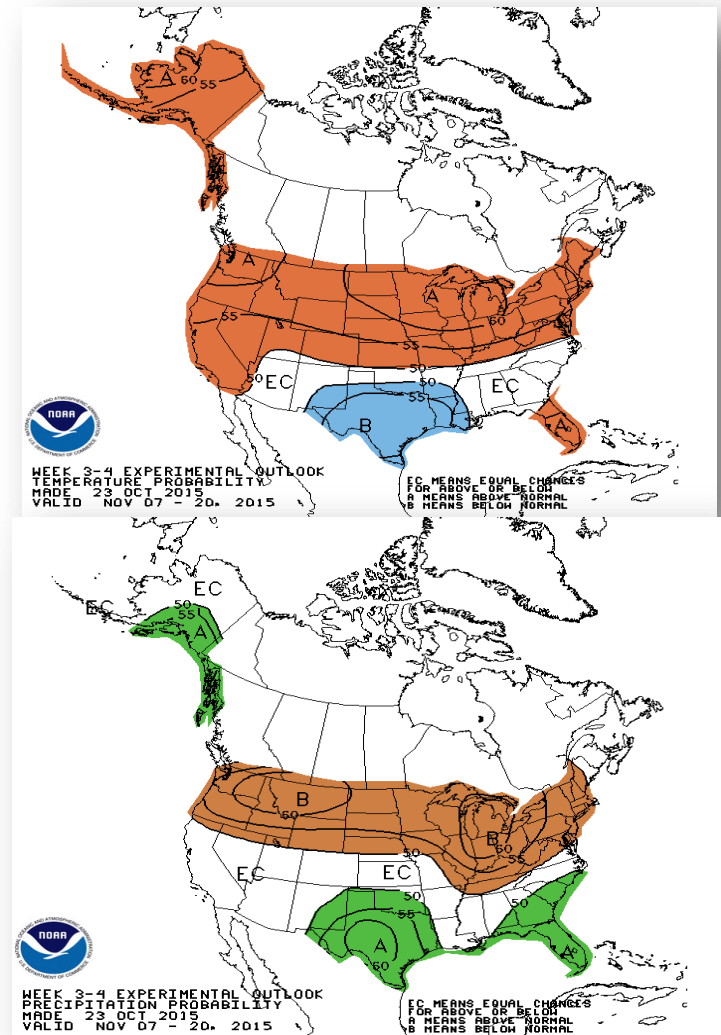
Strategic Product Development Leveraging Partnerships:

Experimental Week3-4 Temperature and Precipitation Outlooks

CPC started issuing Experimental combined Weeks 3-4 Temperature and Precipitation Outlooks on September 18, 2015.

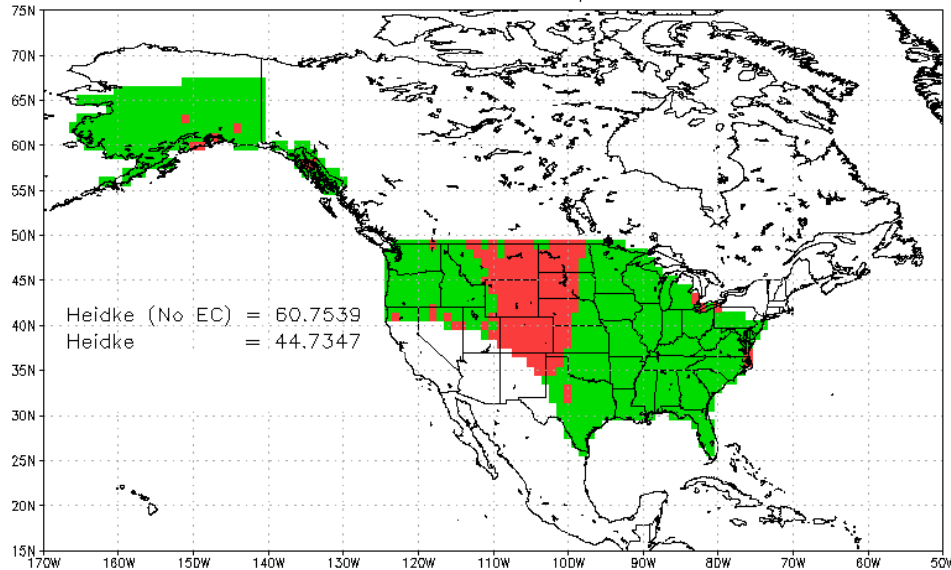
- Cross-branch activity within CPC with contributions from **Scripps/GFDL, ESSIC, and ESRL PSD.**
- Utilizes dynamical model output from CFS, ECMWF, and JMA.
- Utilizes **statistical tools** including:
 - MJO-ENSO Phase Model (**CTB project.**)
 - Coupled Linear-Inverse Model (CLIM).
 - Constructed Analog
- Issued once per week on Friday afternoon
- Forecasts are 2-class (above/below) as opposed to traditional 3-class tercile probabilities.
- Users can provide feedback on product via web
- Forecasts of opportunity depending on presence of large-scale climate drivers

Forecasts Valid for Nov. 7-20, 2015



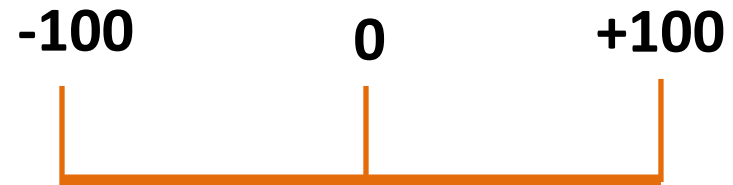
Skill Score Description

Weeks 3/4 Temperature Hit/Miss
Forecast Issued 01Apr2016



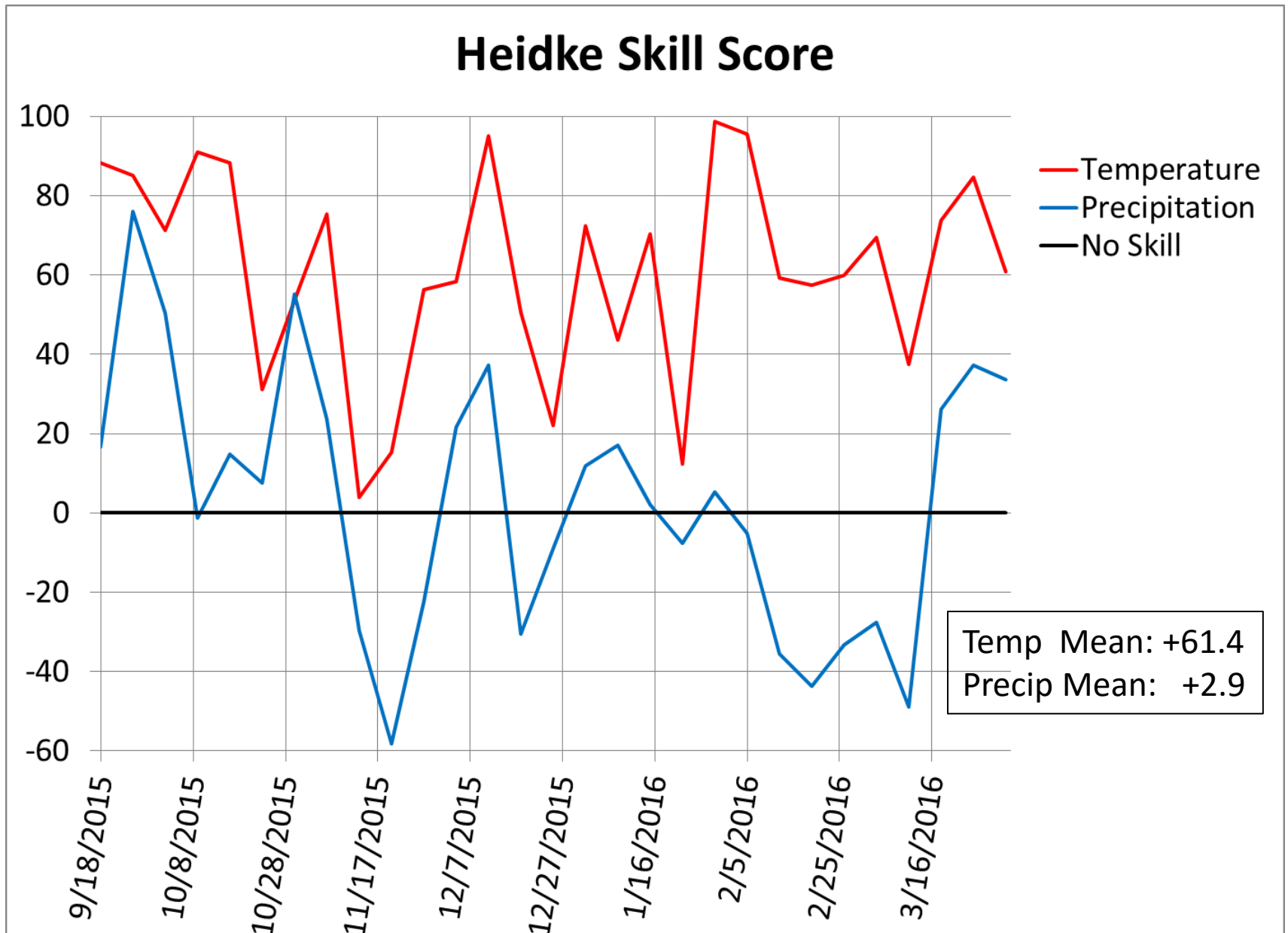
- Heidke Skill Score – Hit/miss based skill metric

$$HSS = \frac{C - \epsilon}{T - \epsilon} * (100)$$



- Positive values indicate forecast skill over that expected by chance
- Zero or negative values demonstrates no forecast skill

Verification to Date



Recent OSTP Budget Initiative

- Initiative focuses on prediction on the week 3-4 time scale. Champion of the initiative was OSTP. Initially promotion of initiative was by DOD.
- \$5M (minus taxes) planned for each of the next 5 years (FY16, FY17, FY18, FY19 and FY20) managed by NWS.
- NWS money split between NCEP EMC (extend GEFS to 30 days), competitive grant research (including NWS FFO, co-funding of grants at OAR CPO), and NCEP CPC (targeted projects described on next slide).

OSTP Initiative CPC Proposed Projects

7 Proposed Projects:

(a) 6 physical science projects that:

- ➔ Build on existing CPC products (*T/P, monthly drought outlooks*)
- ➔ Engage in operationally-oriented state of the science research to explore development of new products (*excessive heat*, sea ice*, tropical cyclone activity*, week-2 severe weather**)

(b) 1 social science project that will:

- ➔ Engage stakeholders to better understand how they use CPC products to inform decision making
- ➔ Tailor representation of products for most effective communication to stakeholders