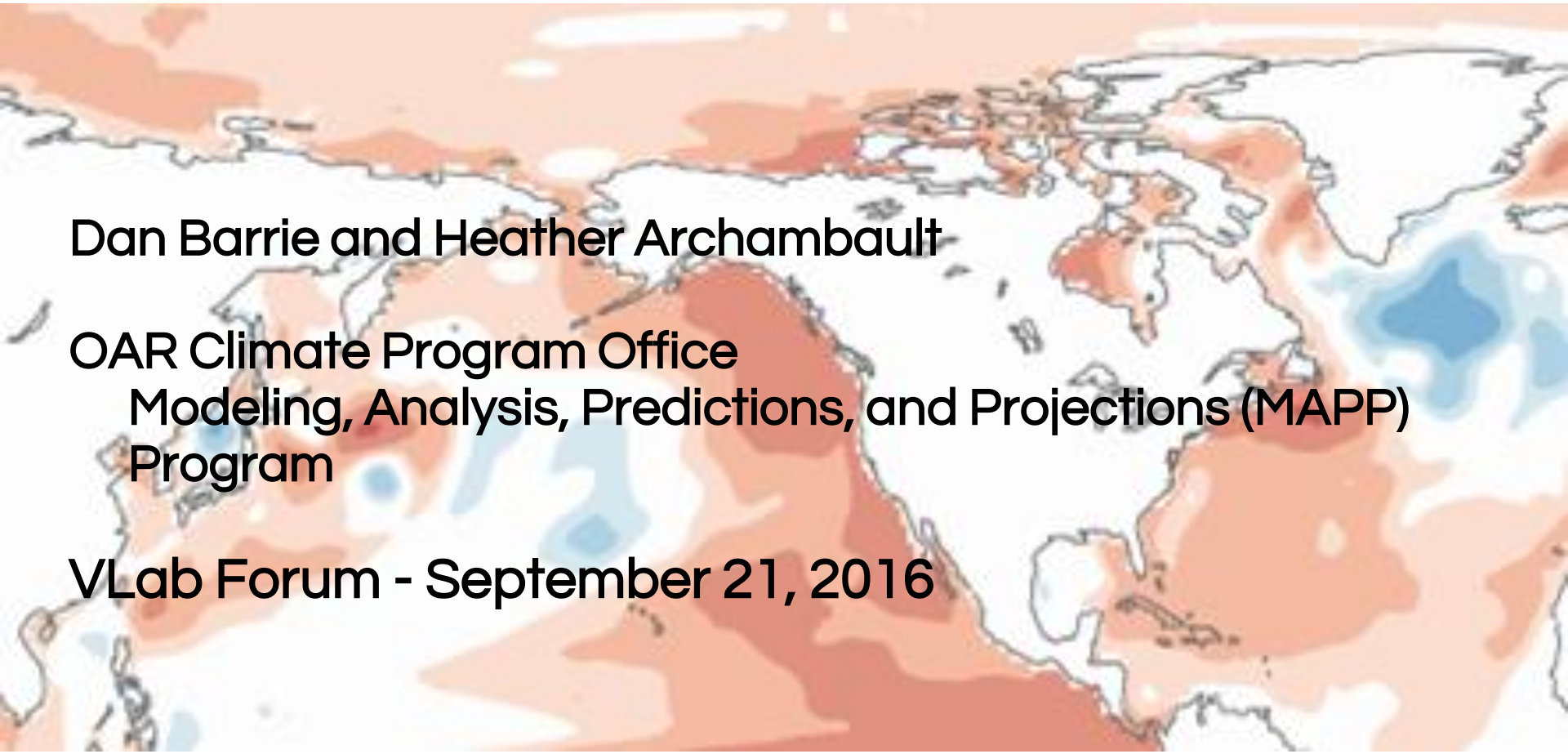
Testing Multi-Model Ensemble Systems for Prediction on Weeks to Seasons



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OAR Climate Program Office
Modeling, Analysis, Predictions, and Projections (MAPP) Program

VLab Forum - September 21, 2016

Introduction

- Part of MAPP's portfolio is dedicated to *developing*, *testing*, and *transitioning* dynamical and statistical prediction tools for Week 3 and beyond

- These efforts support NOAA's aim to build a national capability for predictions to meet a range of stakeholder needs (e.g., water management decisions)

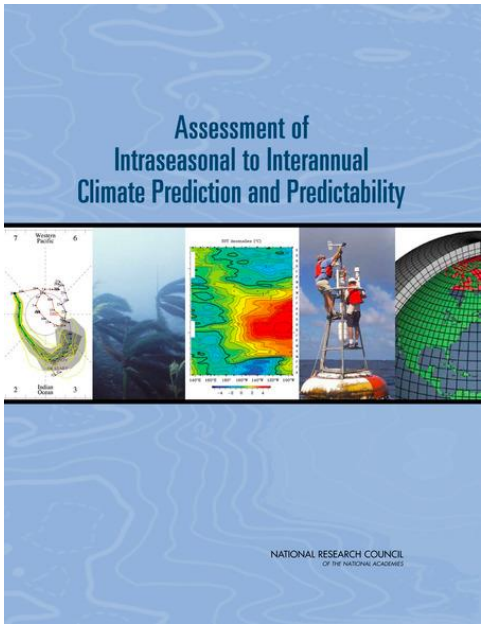
- MAPP's activities support the National Earth System Prediction Capability (ESPC), a multi-agency initiative to improve predictions and products across timescales

National ESPC
EARTH SYSTEM PREDICTION CAPABILITY

Background: Multi-Model Ensembles

Multi-model ensemble prediction systems (EPSs) offer an immediate route to improved skill for both weather and climate prediction:

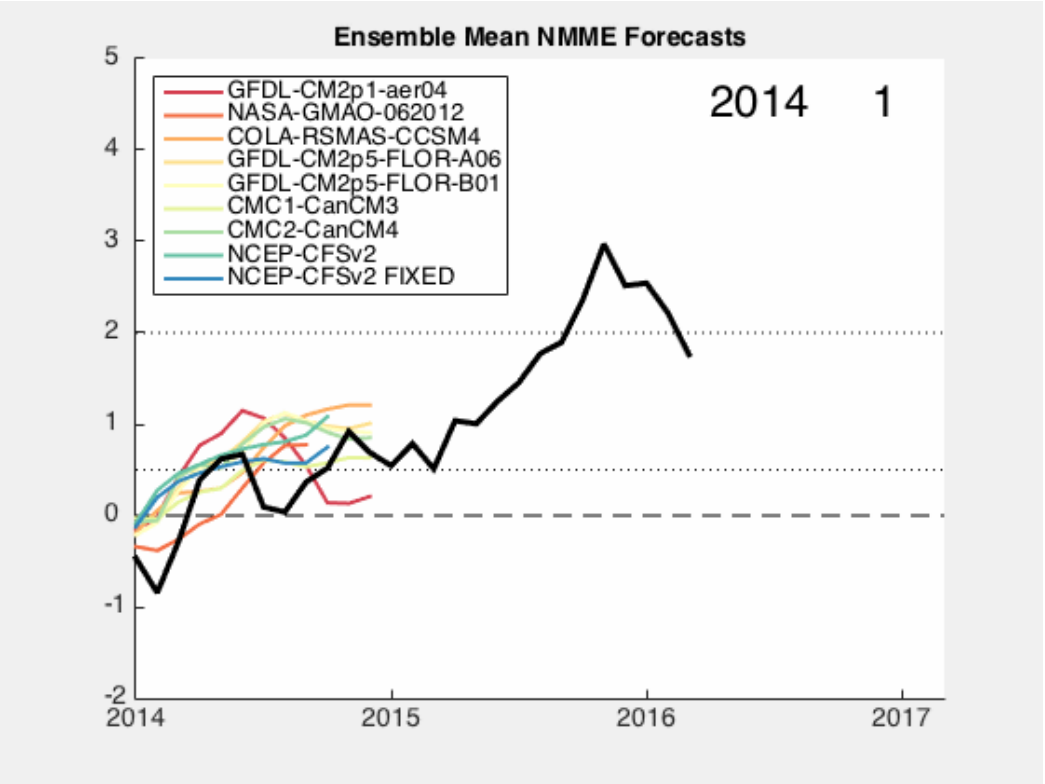
- Owing to model diversity, a multi-model EPS gives more reliable predictions than a single EPS
- Averaging predictions across models improves skill because model biases tend to be canceled out, whereas more predictable parts are preserved
- Recommendation in 2010 NAS report on ISI Prediction: "MME forecast strategies should be pursued…"

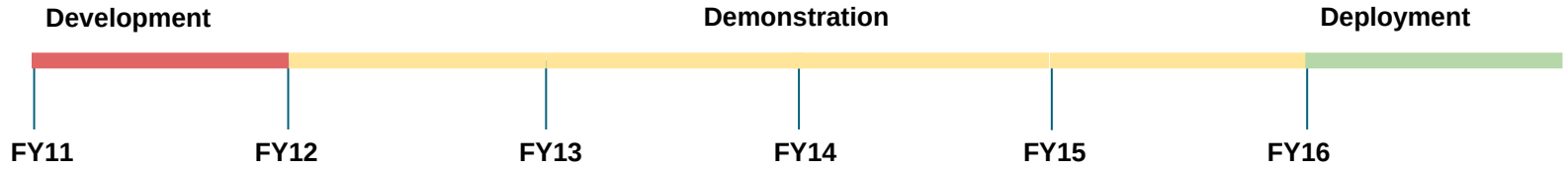


What is the North American Multi-Model Ensemble (NMME)?

→ A multi-model EPS comprised of operational and research climate models developed and demonstrated via NOAA Climate Test Bed (CTB)

→ Transitioned to NWS Climate Prediction Center as an operational seasonal prediction tool





NMME – Phase 1

In 2011, MAPP and NOAA CTB jointly organized workshops that established scope of NMME initiative ("NMME Phase I")
→ subsequently funded as a MAPP–CTB project in FY 2011

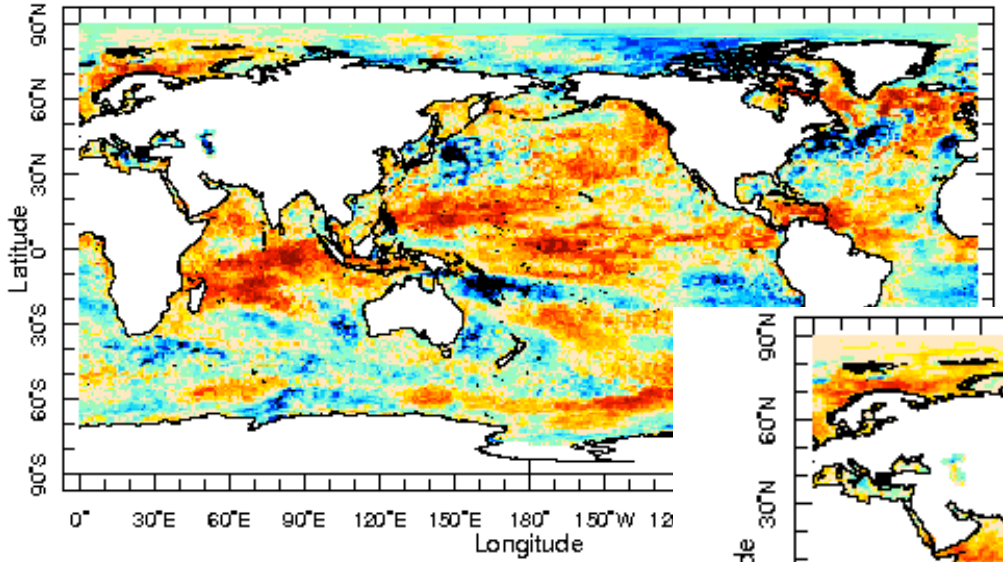
<u>Goal of NMME Phase I:</u>

- Test, optimize design of system for seasonal prediction
- Attempt to demonstrate that system could improve predictions compared to then-current operational prediction systems on which NMME was based

NWS Climate Prediction Center began producing NMME-based predictions on a real-time schedule in September 2011

NMME vs. CFSv2 Skill: An Example

CFSv2 forecast skill

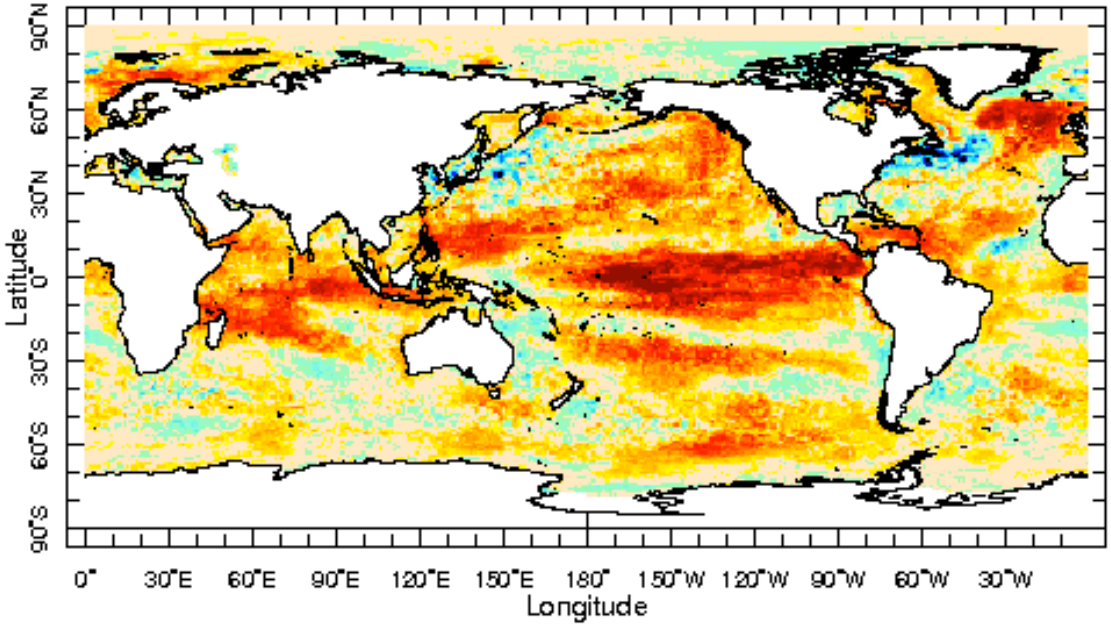


lead 6.5 months S2 Jul

Warmer colors = greater skill

Ranked probability skill scores of 6.5-month sea surface temperature forecasts

NMME forecast skill



lead 6.5 months S2 Jul

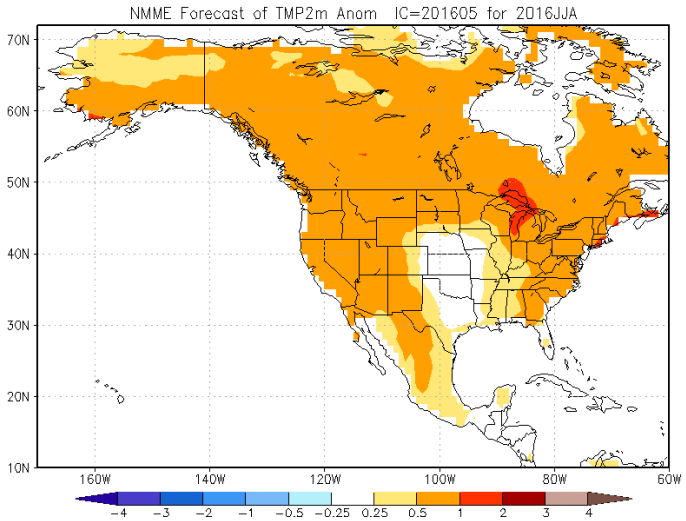
NMME – Phase 2

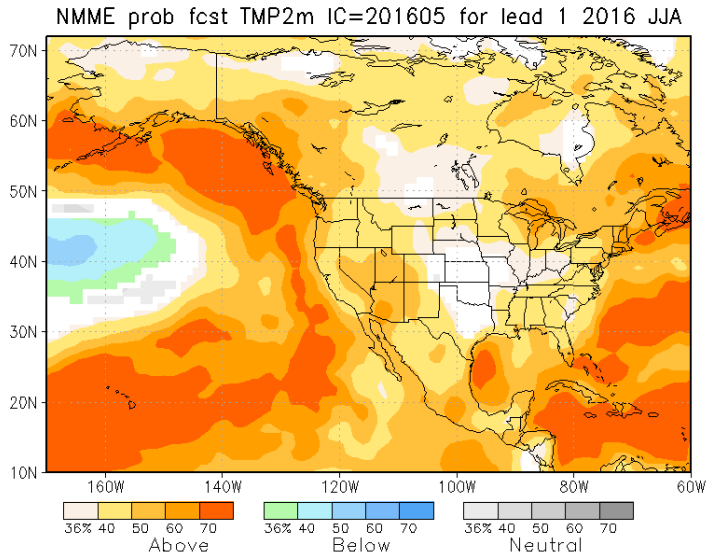
- Upon completing development phase, project entered a two-year demonstration phase (FY 2012, 2013)
- Multi-agency support
- During NMME development, Phase 1 and 2 data served as basis for a variety of prediction and predictability research projects

NMME – Operations

- In 2014, as part of NOAA CTB process, an expert panel reviewed NMME research project and found that system was ready for transition to operations
- Following review, NMME real-time predictions were incorporated into NWS operational production suite, with transition completed in May 2016

http://www.cpc.ncep.noaa.gov/products/NMME





Visit cpo.noaa.gov/MAPP/webinar to view or download presentations from our June 2016 webinar on research, operations, and applications for NMME

Dual Purposes of Operational NMME

Transition to operational mode serves dual purposes:

- Improves operational seasonal predictions at NCEP and Environment Canada
- Enables research on prediction and modeling based on NMME data

Operational NMME allows:

- Operational centers to receive improved forecast data
- Research centers involved to have their models tested in an operational environment to inform future model development

Contributing Prediction Systems (NMME Phase 2, v1)

Organizations	Models
NOAA NCEP	CFSv2 (operational)
NOAA Geophysical Fluid Dynamics Laboratory	FLOR (research)
NASA Global Modeling and Assimilation Office	GEOS5 (research)
Environment Canada	CMC1-CanCM3 (operational) CMC2-CanCM4 (operational)
National Center for Atmospheric Research	CESM1 (research) CCSM4 operated by U. Miami (research)

Cooperative Arrangement: Signatories

- NOAA NWS/NCEP)
- NOAA OAR/Climate Program Office
- NOAA OAR/Geophysical Fluid Dynamics Laboratory
- Environment Canada
- NASA Goddard Space Flight Center
- UCAR (on behalf of NCAR)
- University of Miami

Terms of NMME Operation

Cooperative arrangement establishes terms of operation with the dual purpose to:

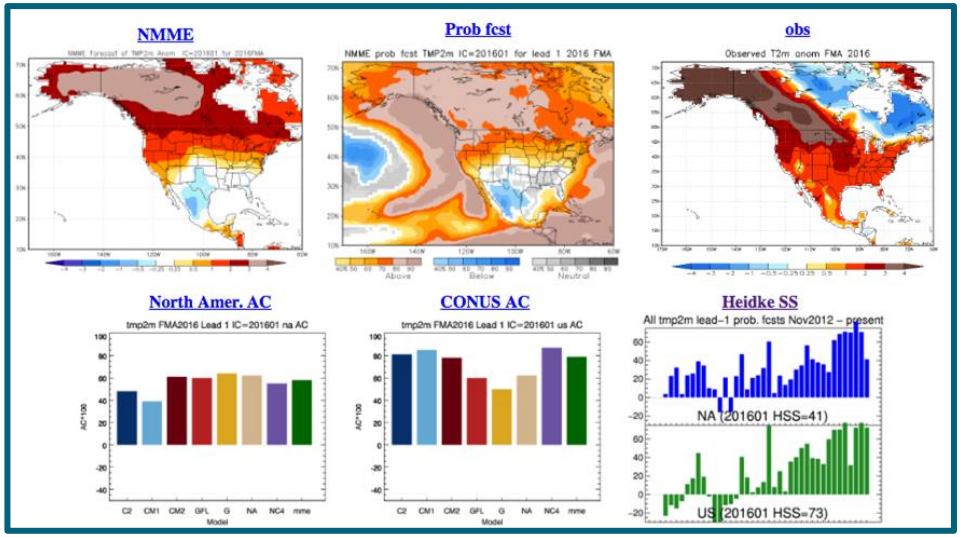
1) Enhance operational seasonal forecasts at NCEP and EC

2) Enable research on prediction and modeling based on NMME data

- Covers the period August 1, 2015 through July 31, 2018
- Co-sponsored by operational and research institutions
- Includes metrics to ensure both operational and research needs are met

Terms of NMME Operation

CPC evaluates whether NMME system is meeting its operational service requirements by assessing:

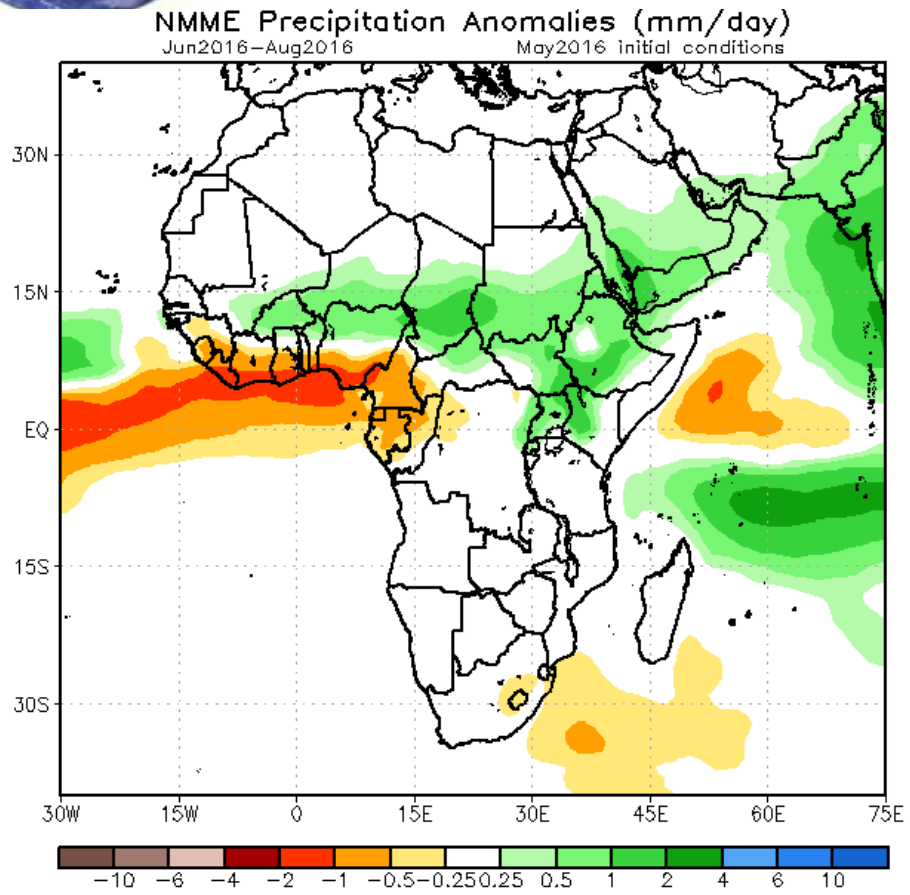


Courtesy of Emily Becker, NWS CPC

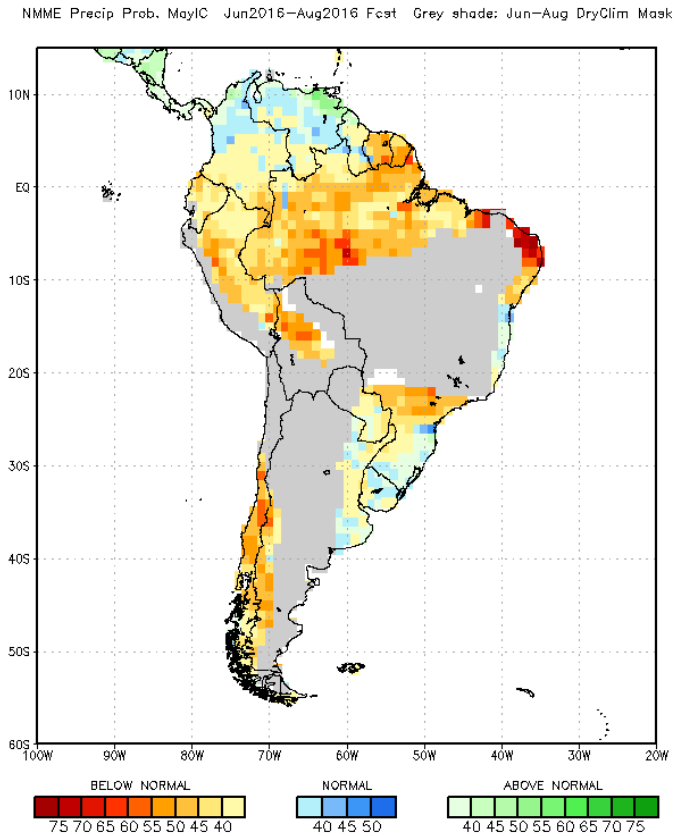
- Timeliness: Baseline is NWS's 99% on-time product delivery requirement
  - Forecasts are due at CPC by 5pm Eastern time on the 6th of the month
  - Forecasts are processed overnight on the 6th
  - Graphics and data are posted on the 7th / 8th

- Skill of NMME-derived products, physical variables (e.g., SST), and major climate phenomena (e.g., ENSO) is evaluated based on standard NCEP skill metrics

Example NMME activities at CPC: International Desk



Slide courtesy of Emily Becker, NWS CPC



http://www.cpc.ncep.noaa.gov/products/international/nmme/nmme.shtml

Created and maintained by V. Kumar, NWS CPC

Terms of Agreement: Data Archive

Real-time data archive:

8 real-time monthly fields available at CPC, with supporting monthly hindcasts available at IRI

- ftp://ftp.cpc.ncep.noaa.gov/NMME/realtime_anom/
- http://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME/

Real-time NMME forecast and verification products for SST, 2-m temperature, and precipitation available at CPC NMME website:

- http://www.cpc.ncep.noaa.gov/products/NMME/

Terms of Agreement: Data Archive

Hindcast data archive:

- 22 daily surface fields (atmospheric and land)
- 5 daily atmospheric fields provided at 850, 500, 200, 100, and 50 hPa (i.e., geopotential, temperature, zonal and meridional winds, specific humidity)
- 2 monthly sea-ice fields (i.e., sea-ice concentration and thickness)
- 7 monthly ocean fields at 13 depth levels
- 6-hourly data from CFSv2 during 1999-2012

http://www.cpc.ncep.noaa.gov/products/ctb/nmme/NMME-PhaseII-DataPlan-27May.pdf

https://www.earthsystemgrid.org/search.html?Project=NMME

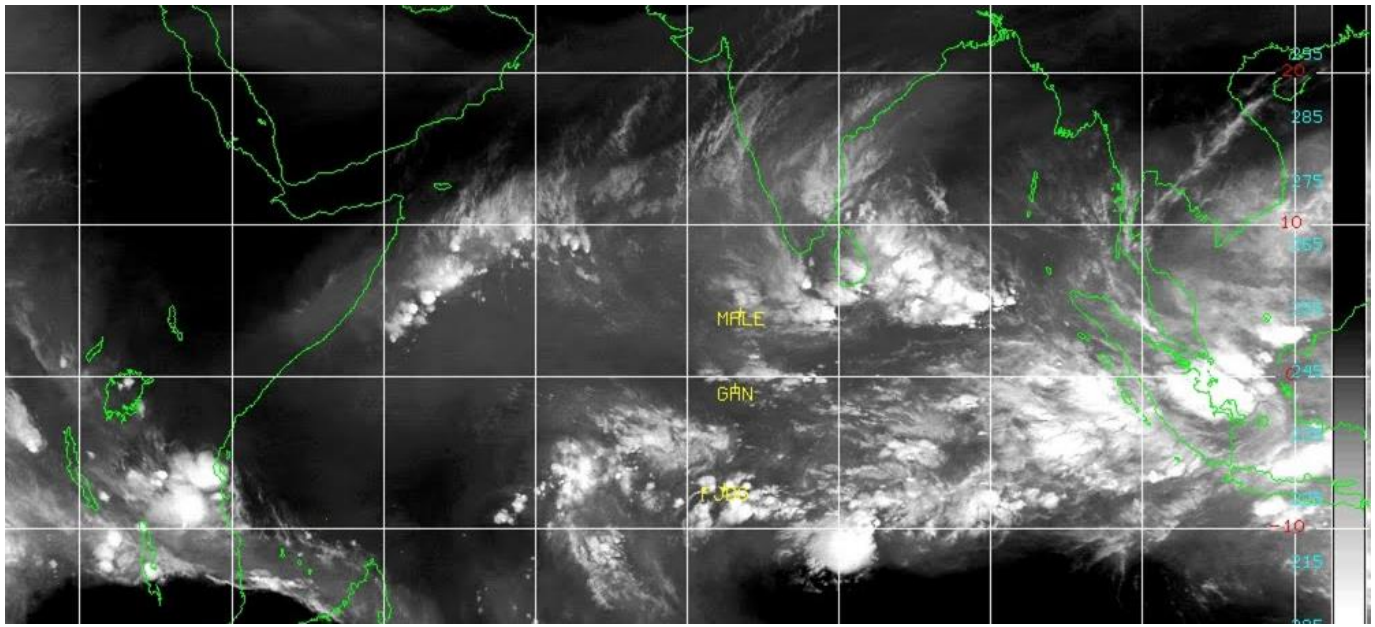
Research Applications

NMME real-time and hindcast forecasts (1.5+ PB database) support research at participating centers, as well as in the larger science community

Research is ongoing with support from NOAA and other agencies:

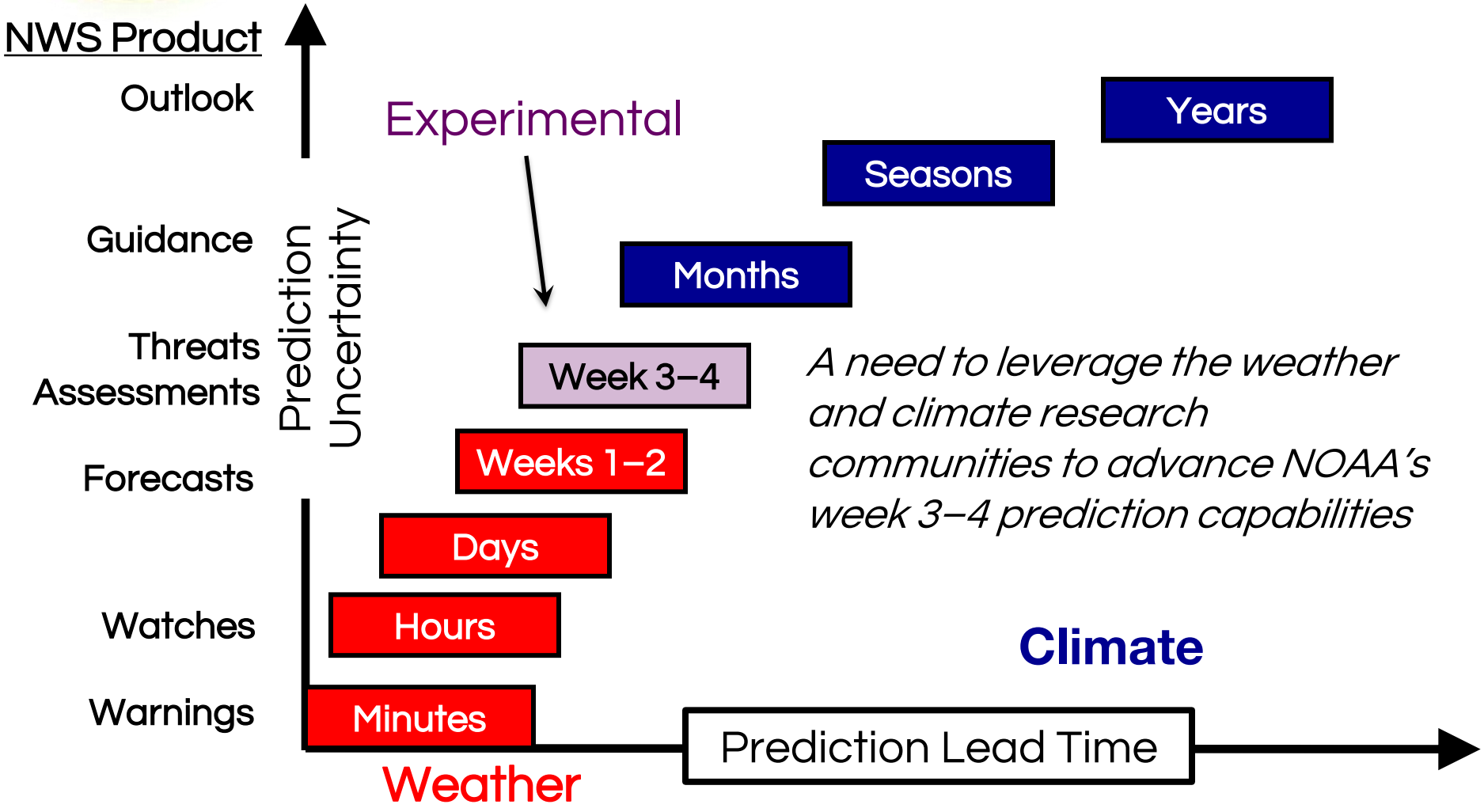
- Within NWS NMME Team (e.g. sea-ice prediction evaluations)
- As part of 9 one-year NMME evaluation/application projects sponsored by MAPP, DOE, and ONR on
  - sudden stratospheric warmings
  - atmospheric rivers
  - excessive heat
  - tools for water resources
  - exploring optimal multi-model combinations

The Subseasonal Multi-Model Prediction Experiment (SubX)



In FY16, MAPP solicited projects for SubX, an experimental multi-model EPS focused specifically on advancing prediction for subseasonal timescale, as a Climate Test Bed initiative.

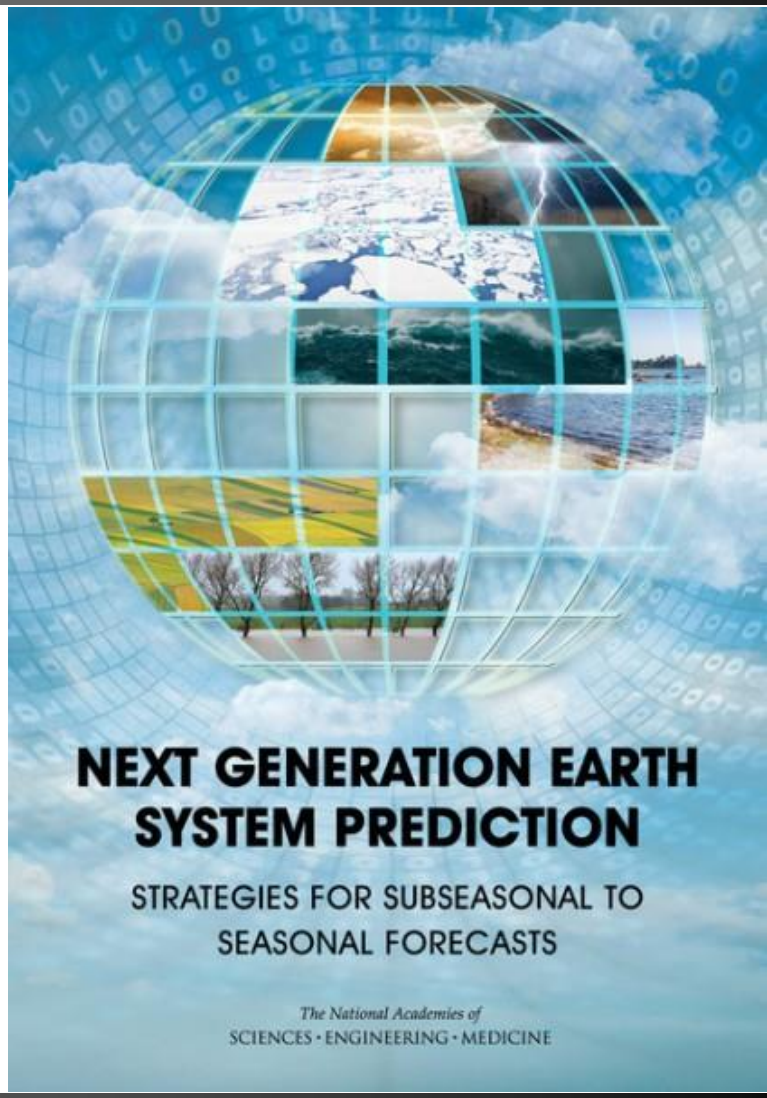
Closing the Gap in NOAA's Prediction Products



A need to leverage the weather and climate research communities to advance NOAA's week 3–4 prediction capabilities

Motivation for Experiment

- Building on WWRP/WCRP Subseasonal to Seasonal (S2S) Prediction Project
- Increasing focus on subseasonal timescales by seasonal prediction research community
- New subseasonal product requirements at CPC
- Increasing agency focus on the subseasonal timescale
- Inadequacy of NMME real time and hindcast datasets for subseasonal prediction research and operations
- (Post hoc) Supports conclusions of NRC "Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts"
    - *"Accelerate efforts to carefully design and create robust operational multi-model ensemble S2S forecast systems."*
    - *"...deliberate design of an operational MME system (and one that is not based solely on expediency)."*
    - *"critical that the broader research community be engaged in this effort"*
    - *"...NOAA Climate Test Bed activity provides the potential for such a connection"*



Draft Experiment Protocol

- Outcome from "Sub-Seasonal Forecast System Exploratory Workshop" March 30-31, 2015
- Protocol available at http://www.cpc.ncep.noaa.gov/products/ctb/Protocol_Subseasonal_NMME.pdf

Protocol Elements

- 1999-2015 reforecast period
- > 4 ensemble members
- Forecasts > 32 days in length (45 days encouraged)
- Initialization once per week
- Initialization of atmosphere, ocean, land is required (if participating model contains those systems)
- Forecasts and reforecasts sent to NCEP CO
- 1x1 output
- Specifies daily mean output variables

CPO MAPP FY16 Competition

SubX solicited through MAPP-NOAA CTB Competition

Two types of proposals:

- Individual modeling systems
  - Documented skill for phenomena and predictability drivers on subseasonal timescales
  - Extended-lead skill from initialization
- Core team to coordinate experiment
  - Develop and evaluate MM predictions
  - Ensembling techniques and post-processing
  - Developing products
  - Supporting timely sharing of data

Proposals required a clear plan, demonstrated potential to transition to operations

CTB Competition Results

- **"Developing a Real-Time Multi-Model Sub-Seasonal Predictive Capacity,"** PI: Ben Kirtman (University of Miami - RSMAS); co-PIs: Kathy Pegion (George Mason University), Andy Robertson (Columbia University IRI), Robert Burgman (Florida International University), Hai Lin (Environment Canada), Jon Gottschalck (NCEP CPC), Dan Collins (NCEP CPC)
- **"An NCEP Global Ensemble Forecast System for Monthly Forecasts,"** PI: Yuejian Zhu (NCEP EMC), co-PIs: Malaquias Pena, Wei Li, Hong Guan, and Xiaqiong Zhou (NCEP EMC)
- **"Estimating the Subseasonal Forecast Skill in the NASA GEOS-5 System with a Focus on the Madden Julian Oscillation and the Land Surface Memory Feedback Processes,"** PI: Deepthi Achuthavarier (NASA Goddard Space Flight Center/Universities Space Research Program), co-PIs: Randal Koster and Jelena Marshak (NASA Goddard Space Flight Center)
- **"Sub-seasonal Prediction with CCSM4,"** PI: Ben Kirtman (University of Miami - RSMAS); co-PIs: Kathy Pegion (George Mason University), Rong Fu (University of Texas, Austin)
- **"The Inclusion of Sub-seasonal to Seasonal Predictions of the Navy's Earth System Model in the North American Multi-Model Ensemble (NMME),"** PI: Neil Barton (Naval Research Laboratory Monterey); co-PI: Joseph Metzger (Naval Research Laboratory Stennis)

SubX - Subseasonal Experiment

Modeling systems: CCSM4, CFSv2, EC, GEFS, GEOS5, Navy ESM

Co-supported by ONR, NASA/MAP, and NWS/STI Global Modeling Program

CTB Competition Results

- Models include a diversity of approaches to subseasonal timescales (coupled, weather, research, operational, various resolutions)
- Cross-participation with the new MAPP Subseasonal to Seasonal Prediction Task Force (NOAA point of contact: Heather Archambault)
- Hindcast dataset (after year 1) and real-time dataset (during year 2) available to the broad research community
- Individual modeling system and overall experimental results considered for transition to operations after second year

SubX is not an extension of NMME.

Summary

- Via NOAA Climate Test Bed, MAPP initiated, organized, and funded the NMME, an experimental prediction system that officially completed transition to NWS CPC operations in May 2016

- Today, NMME features an extensive, growing hindcast/ forecast database that is used for a wealth of predictability, prediction, and applications research

- Via the NOAA Climate Test Bed, in FY16 MAPP initiated an interagency experiment - **SubX** - to test multi-model subseasonal EPSs for potential transition to NWS operations in support of Week 3-4 products