NMME Subseasonal Forecast System Exploratory Workshop Report
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1. Introduction and Motivation

The North American Multi-Model Ensemble (NMME) research initiative has been testing an experimental forecast system aimed at improved sub-seasonal-to-seasonal (S2S) forecasts based on major coupled global models from US and Canadian centers. The NMME-Phase II system has been funded by NOAA, DOE, Environment Canada (EC), NASA and NSF as part of NOAA Climate Test Bed (CTB) and Climate Program Office, MAPP Program research to operation (R2O) transition activities. Although currently in an experimental stage, the NMME system has been providing real-time seasonal forecasts since August 2011. The NMME 30-year reforecast data are archived and available to the community for research and applications. After a positive post-project review in September 2014, NOAA is considering including the experimental NMME-Phase II seasonal forecast system as part of its operational suite starting Summer 2015.

Important decisions in sectors ranging from food and water security and public health, to emergency management and national security, rely on forecast information at S2S timescales (i.e., lead times from 3-4 weeks to as much as 9-13 months), which is beyond traditional weather forecasts, and often at shorter leads or at higher spatial and temporal resolutions than the current seasonal forecasts.

The current NMME-Phase II system has been developed and tested as a seasonal forecast system providing forecasts on a monthly basis, although daily data are provided in order to examine higher order statistics. Preliminary research has been done to test an NMME protocol as applicable to subseasonal probabilistic quantitative prediction. It is a natural next step to explore the potential design, benefits and feasibility of a subseasonal NMME-type prediction system.

This workshop brought together the research community, operational forecasters (e.g. NCEP, EC, Navy, Air Force), and stakeholders to explore opportunities and feasibility to evolve the current seasonal NMME-Phase II system into a system able to meet operational requirements and user needs for shorter lead times of several weeks, and to design the protocol and experiments for a potential NMME subseasonal forecast system. Discussions considered a potential NMME subseasonal system in the broader context of the state-of-the-science and the systems that are being used or developed nationally and internationally to address the needs for S2S forecasts.

The expected outcomes of the meeting were:

- An assessment of the scientific opportunities and issues for an extension of NMME to subseasonal prediction and coordination with the S2S project.
- An assessment of the operational and stakeholder needs for future testing and implementation at CPC.
- A coordinated re-forecast protocol for a potential NMME sub-seasonal forecast system.

The workshop is organized by NOAA Climate Test Bed (CTB) and NOAA Climate Program Office (CPO) Modeling, Analysis, Prediction and Project (MAPP) Program. Workshop program (including all presentation) and participants information is available at:
http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/NMME/NMMEWorkshop.aspx.

2. Scientific Opportunities and Coordination with S2S

The first day of the workshop included overview talks to present current science and community efforts focused on subseasonal prediction, including presentations from forecasting groups describing their modeling systems and experiences. These overview talks were followed by a breakout session consisting of two groups. The groups were asked to discuss key scientific question in subseasonal prediction with the following focus questions:

- What are the most important scientific questions that need to be answered to bridge the gap between current and potential skill for subseasonal timescales?
- Without resource limits, how would you approach answering those questions?
- How would a multi-model ensemble re-forecast contribute to answering those questions?
- Within resource limits, what system improvements (e.g. horizontal resolution, stratospheric vertical resolution, ensemble size, initialization) are most likely to cost-effectively improve sub-seasonal skill?

The overview presentations served to inform the breakout sessions (discussed below) and identified some of the key scientific questions. Here we briefly summarize some of the presentations with particular emphasis on issues that directly relate to the development of a potential subseasonal NMME phase-II effort.

The workshop opened with a presentation of the WCRP/WWRP subseasonal-to-seasonal project (S2S). The S2S project focuses coordinating the sharing of subseasonal forecast data among international operational centers. While this dataset is extremely useful for many multi-model research purposes, it cannot meet real-time multi-model needs. The S2S project also does not include a forecast protocol that is uniform across the operational centers, and the real-time data is embargoed for three weeks.

The presentations also included discussions of some key scientific issues. In particular, the importance of land-atmosphere interactions and stratosphere-troposphere interactions on subseasonal time-scales were themes in the presentations. MJO-NAO coupling as a source of sub-seasonal predictability was described. Several of the presentations discussed various issues related to spatial resolution in the atmosphere including the need for a well-resolved stratosphere and eddy-resolving ocean component models. The question of whether air-sea coupling needs to be included was also discussed in the presentations.

Based on the presentations and summary of breakout sessions, key scientific issues can be categorized into two groups.

a) Questions associated with the design of a subseasonal forecast system

- What is the impact of model bias on subseasonal prediction skill?
- How to initialize appropriately for subseasonal prediction?
- Do we need coupled data assimilation?
- Must system really have their own assimilation system given the critical impact of ICs for this timescales?
- What is best way to generate ensembles?
- Model tuning with resolution changes?
- How large to ensembles need to be?
- What resolution? (horizontal and vertical)
- Model diversity vs. ensemble size?

b) Questions associated with predicting predictors and their impacts

- What is the role of the stratosphere for subseasonal predictability and prediction?
- Tropical-extratropical interactions (two-way interaction—e.g. MJO-NAO-MJO)
- Can we identify flow-dependent forecasts of opportunity and can we combine models in optimal ways based on this?
- What is the role of air-sea coupling and must coupled models be used for subseasonal timescales?
- How much predictability is associated with land-atmosphere interactions?

3. Assessment of Community Needs

The second day of the meeting was focused on understanding community needs for a subseasonal NMME system and overview talks on needs from the operational, research, and applications sectors. Following these talks, a breakout session was held to discuss and define specific needs for the research and operational communities. Participants were asked to self-select their breakout group based on whether they identify more with the operational or research community. The groups were asked to discuss the following focus questions.

- What are the needs for a subseasonal NMME prediction system to be useful to your community (both re-forecast and real-time components)?
- What are the data needs (e.g. format, frequency, flow, access, variables, etc.)?
- What needs are critical vs. negotiable?
- What is your ideal system given no limitations on resources?
- How would you use the system you envision?
- What are the key benchmarks you consider necessary to demonstrate success of such a system?
- What are the feasibilities of deploying a NMME subseasonal forecast system including technical, data, and engineering aspects?

It is noted that the two groups reported back with needs that were similar and consistent with each other. A summary of the needs across both groups is provided below.

Data Frequency
- One time per week minimum
- More than one time per week would be preferred by operational community

Data Variables, Documentation, Codes
- Specific variables: 2m temperature, precipitation, 500-hPa, 200-hPa height, RH, U850, U200, OLR, Tmax, Tmin, 10 m wind, soil moisture, snow related, Sea ice cover, Clouds, Evapotranspiration, Probabilistic extremes, Wind at 80m or 100m
- Variables for downscaling
- Variables for hurricane tracking and analysis
- Variables for severe weather
- Derived quantities: weekly averages, Nino indices, moist static energy budget components; high-demand derived diagnostic variables
- Data Documentation
- Codes – especially data assimilation is hard to get, but all codes optimally
- Captain's log style of model development documentation
- Details of fields
- Most basic data usage documentation.
- Case by case availability for high capacity users

Resolution
- ½ deg or less
- ¼ deg necessary for clouds, "high res" – field level (agric.)

Data transfer
- Need sftp data transfer to NCO

- Needs operational/reliable server for real-time forecasts
- How to handle models that don't deliver

Re-forecast Database

- Same overlap period for all models
- Will they be done on the fly?
- Comprehensive to assess skill
- All models same start dates
- Same number of ensemble members as real-time

Case Studies

- Retrospective for field campaigns that produced high-res observations (e.g. Dynamo) to understand physical processes, sensitivity experiment
- Specific high-impact events
- Climate mode/phase
- Also target for future campaigns (e.g. Maritime continent predictability barrier)
- Designated target periods for comprehensive analysis
- More variables including those sufficient for downscaling
- Higher resolution
- Opportunity to coordinate with other groups (meaning w/S2S or other groups)

Benchmarks

- Operational reliability of component models
- Longevity of commitment from centers
- Forecast skill comparisons with persistence, operational models (evaluation protocol/standard)
- Should there be a set of requirements/benchmark for a model to participate?
- Model re-forecast evaluation

4. Workshop Spin-off: A protocol for experimental sub-seasonal prediction

On Day 2 in the afternoon, potential plans for a subseasonal NMME demonstration project based on the scientific issues and community needs described above were outlined in a presentation that intended to generate community discussion. Given the time constraints and also the fact that workshop discussions had just occurred, only general concepts were presented. These included the need for both a one-year real-time sub-seasonal experiment and a set of reforecasts following a common protocol. Follow-up discussions and work by some of the workshop organizers to meet the workshop goals helped to refine input from the workshop and develop an initial plan for a potential protocol and experiment. Below is a summary of this workshop spin-off plan and protocol for a coordinated re-forecast experiment (Appendix A). This should not be viewed as a consensus result from the workshop but a helpful potential contribution to help guide future experimentation.

The plan is divided into two phases. Phase 1 focuses on building a re-forecast database, developing the capacity for and testing real-time prediction in a limited scoped context. Phase 2 is focused on regular real-time prediction, expansion of the re-forecast data, coordinated case studies, and answering scientific questions regarding predictability and prediction on subseasonal timescales

Phase 1: Building a Reforecast Database and Testing in Real-time

The first phase of the subseasonal NMME project would involve a 6-month spin-up period in which participating modeling groups begin running and evaluating their re-forecasts and develop the technical infrastructure to prepare for real-time forecasts. During this time, the Climate Prediction Center would develop the capability to post-process and calibrate a limited set of variables to inform their products. The re-forecast database would be populated with a limited set of variables and made available to the community. A preliminary protocol for re-forecasts, real-time forecasts, and data requirements can be found in Appendix A and would be expected to evolve based on experiences of modeling groups during Phase 1.

Following the 6-month spin-up period, 1-year of real-time forecasts would be run on the Climate Prediction Center operational schedule. During this 1-year period, the set of variables specified by the protocol (Appendix A) would continue to be archived to the re-forecast database for research use and made available in real-time. A smaller set of variables will be ingested by CPC, post-processed and contribute to their subseasonal products.

The re-forecasts would also be vetted against a set of metrics to provide documentation of basic skill of the multi-model ensemble. This evaluation would be performed throughout the development phase.

Phase 2: Revising and mining the re-forecast database, regular real-time forecasts, and case studies

The lessons learned from phase 1 would inform how to adapt the re-forecast database and real-time forecasting for phase 2. Goals in this phase would be to fill out the re-forecast database with a larger suite of variables, extend the minimum capabilities in terms of ensemble members, reforecast period and forecast length, incorporate new and/or upgraded models, and finalize initialization strategies based on these lessons. This phase would also aim to move from testing of real-time forecasts to regular real-time forecasting, consistent quality control, pushing output to NOAA Central Operations (NCO) and expansion of variables provided. Further, research enabled by the reforecast dataset would aim to investigate the scientific questions that are important to understanding predictability and improving prediction on subseasonal timescales (e.g. Section 2) using the re-forecast database and a set of coordinated case studies.

Appendix A

Protocol for A Subseasonal Re-forecast and Real-time Forecast Experiment

A. General Requirements

1. The model used for real-time forecasts must be the same as that used for reforecasts. Model resolution, physics, and numerics are left to the forecast provider. Models can be coupled ocean-atmosphere-land models or atmosphere-land models.
2. Reforecasts must be performed over the period of 1999-2015. Additional years are encouraged.
3. A minimum of four ensemble members is required. Additional members are encouraged.
4. Ensemble generation procedure is left to the forecast provider.
5. Forecasts should be a minimum of 32 days in length. Forecasts of 45 days are preferred and strongly encouraged.
6. One-year of real-time forecasts is required.

B. Initialization Requirements

1. Initialization frequency is once per week.
2. All procedures for generating reforecasts and real-time forecasts, including initialization time, should be the same.
3. It should be noted that skill will strongly depend on initialization time, and forecast providers are encouraged to use the most recent observations to initialize real-time forecasts.
4. Initialization of the atmosphere is required. Procedures are left to forecast provider.
5. Initialization of the ocean is required for coupled ocean-atmosphere models. Procedures are left to forecast provider. For models that do not include an ocean, the time evolving predicted (and/or persisted) ocean state should be used.
6. Initialization of the land surface is required. Procedures are left to the forecast provider.

C. Requirements Specific to Real-time

1. All forecasts (and corresponding reforecasts) must be available by 5pm Eastern time on every Wednesday of every month. All real-time forecasts and corresponding reforecasts (listed in C3) must be sent to NCEP via NCEP Central Operation (NCO) data lines. *Note: Any exceptions will need to be reflected in a special agreement between NCEP and the contributing modeling center or institute"*
2. If a forecast (and corresponding reforecast) is not available on time, it will not be included in the experimental forecast production. If a forecast has been made available on time, but a problem is discovered subsequently, NCEP Climate Prediction Center (CPC) is under no obligation to reproduce the forecast.

3. To test potential CPC real-time products, a subset of the full list of output data variables (listed in D) is required in real-time including 2m temperature, precipitation, 500 hPa height, 200 hPa height, sea surface temperature, soil moisture.

D. Output Data Requirements

1. Data will be output on a 1x1 grid
2. Total fields, not anomalies, must be provided.
3. All ensemble members, not the ensemble mean, must be provided.
4. The land-sea mask must be provided on the same 1x1 degree grid as the data output. All missing values must be specified consistently as '-9999'.
5. Daily means of the following variables should be output:
    - 2m temperature
    - precipitation
    - 500 hPa geopotential height
    - 200 hPa geopotential height
    - 2m dewpoint
    - zonal and meridional winds at 850 hPa
    - zonal and meridional wind at 200 hPa
    - outgoing longwave radiation
    - wind at 10m
    - vertically integrated soil moisture
    - runoff
    - sea surface temperature
    - snow depth
    - snow cover
    - sea ice concentration
    - latent heat flux (W m^{-2})
    - wave heights (if available)
    - zonal and meridional wind stress
    - sea level pressure
6. The following additional variables should be output
    - maximum 2m temperature (every 24 hours)
    - minimum 2m temperature (every 24 hours)

Note: The above variables are the full list to be archived for the reforecasts and forecasts for research purposes.