(SubX) Sub-Seasonal Prediction with CCSM4

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1. Introduction

There is a growing interest in a wide swath of user communities for forecast information on time scales beyond 10 days but less than a season. Moreover, there is compelling evidence that leveraging multiple modeling groups and centers to produce a multi-model ensemble is a practical approach to both increase the overall ensemble size and to represent at least some aspects of the forecast uncertainty due to model uncertainty. This proposal seeks to participate in a coordinated multi-model sub-seasonal effort. Specifically, the proposed work described here leverages the existing *seasonal* North American Multi-Model (NMME) effort at the University of Miami:

I. To produce retrospective CCSM4 sub-seasonal forecasts following an already agreed upon uniform protocol;
II. To participate in a 1-year experimental multi-model real-time CCSM4 prediction effort including the on-time delivery of real-time forecasts and the retrospective forecasts for calibration;
III. To participate in the coordination of research and rapid data sharing to support both research and real-time prediction needs.

In addition to the production of the retrospective and real-time forecasts, we will demonstrate the skill of CCSM4 in predicting sub-seasonal phenomena as sources of predictability, including MJO, blocking, NAO, sub-seasonal variability of ENSO and their impact on various hazards (e.g. precipitation, tropical cyclones, heat waves/cold spells). We will develop tools for performing quality control checks on CCSM4 forecasts based on the re-forecasts and apply them to the real-time predictions. We will also document the relative contributions of land surface vs. atmospheric initialization in forecast quality, diagnose how well the forecasts capture the interactions of the MJO and NAO, and how this impacts forecast quality of rainfall variability over the US. Moreover, we will examine how strong sub-seasonal drying events during spring along with land surface-cloud-precipitation feedback serve to initiate droughts in the US Great Plains. This later effort will leverage existing collaborations with Texas water managers to improve the use of sub-seasonal forecast information in decision support.

2. Results and accomplishments

Four main activities to report here:

I. Retrospective sub-seasonal predictions with CCSM4 following the SubX protocol have been completed and all priority I variables have provided to the IRI data library and CPC. Priority II variable are in process.
II. Real-time forecasts began in July 2017, and the CCSM4 forecasts have been delivered on-time every Wednesday of every week since that time.
III. Analysis of sub-seasonal variability, predictability and prediction quality using the NMME CCSM4 retrospective and real-time forecasts.

2a. Results of Real-Time Forecasts with CCSM4

Below we report on three aspects of III. Specifically, we describe an analysis of (i) air-sea feedbacks, (ii) how well the forecasts perform with respect to the Great Plains Low Level Jet (GPLLJ) and associated precipitation, and (iii) We also show some of our forecast quality assessment results.

2b. Air-Sea Feedbacks

One of the overarching goals of the SubX project is to assess the role of air-sea feedbacks on predictability – essentially asking is a coupled model necessary. As a first step in this analysis we show briefly how the local correlation between turbulent heat-flux (sensible+latent) evolves as a function of lead-time. This local correlation suggests that the ocean locally forces the atmosphere when this correlation is positive. We assert that the first week the model largely captures the observed relationship, but this seriously degrades as a function of lead-time. For comparison, we also show this simple diagnostic using forecasts from a high-resolution model. We note that the correlation does not degrade in the high-resolution model. The results are shown in Fig. 1 below.

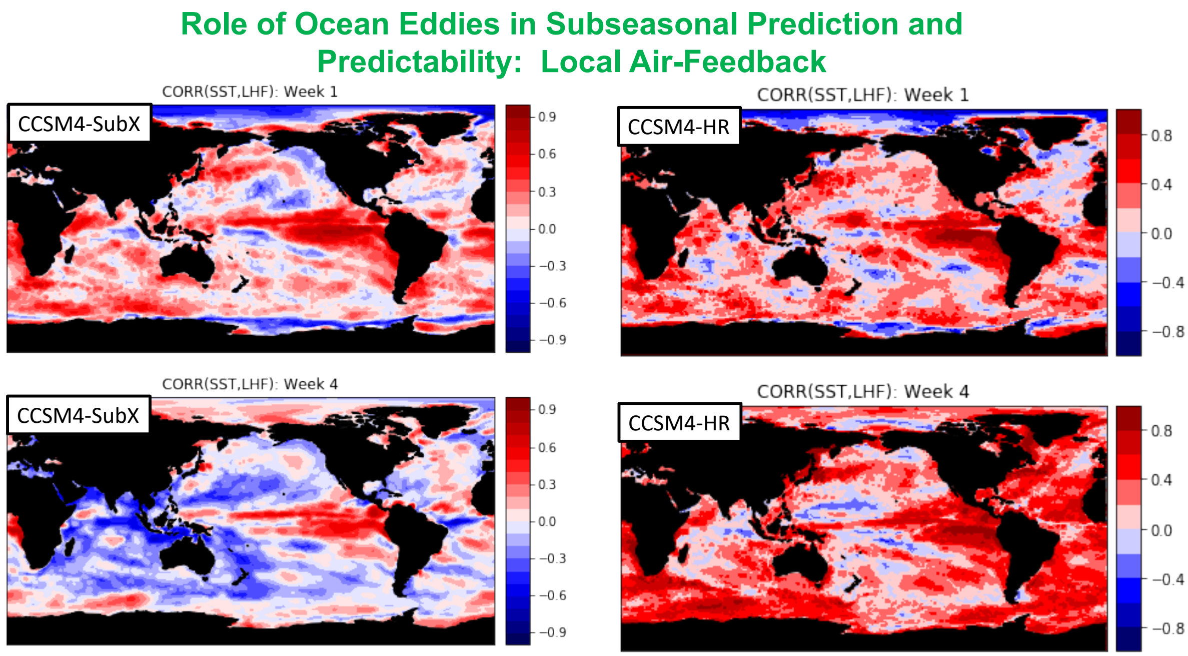


Figure 1: Local correlation between turbulent heat-flux and SST for CCSM4 SubX forecasts for week 1 (top left) and week 4 (bottom left). The right two panels shows the results from a parallel set of forecasts using a much higher resolution model. All forecasts are initialized at the beginning of January 1999-present.

2c. Predictability of mid-summer Great Plains low level jet and associated precipitation

Warm-season extreme precipitation in the north-central Great Plains has significant socioeconomic implications, ranging from agricultural production to human and property loss from associated flooding. For this reason, there has been an increasing effort to understand Great Plains hydroclimate variability and improve both seasonal and subseasonal prediction of heavy rainfall events as well as lack of such events that might lead to drought.

The primary objective in this study is to analyze large-scale, low-frequency variability modes in a predictive framework by employing an ensemble approach. Here we use the Community Climate System Model, version 4 (CCSM4) forecasts to assess the skill in predicting extreme GPLLJ events. There are three main research questions that arise:

(i) Are the CCSM4 forecasts able to reproduce the interannual variability of the GPLLJ and its associated extreme mid-summer GP and Midwest precipitation?
(ii) Are there relatively consistent large-scale sources of predictability for mid-summer forecasts out to a month?

(i) Are these large-scale drivers from (ii) able to provide a “forecast of opportunity”, i.e. confidence in forecast increases when large-scale driver exhibits its expected signal for an event?

The CCSM4 produces a July climatological low-level jet that resembles the jet in MERRA-2, though the difference between the two reveals immediate biases. Figure 1 shows the V900 climatology for MERRA-2, CCSM4 free-running model (no July 1st initialization), and CCSM4 forecast model, and it outlines the domain for the LLJ index. At first glance, the CCSM4 forecast climatological jet looks realistic and comparable to observation. However, the CCSM4 forecast minus MERRA-2 panel reveals that the model GPLLJ is too strong and extends too far east. However, the forecast shows slight improvement over the free-running model, supporting that initialization does improve prediction. The figure shows the climatological precipitation for July and the GPP index domain. Once again, the forecast model is improved from the free-running model. CCSM4 forecast climatology exposes the several challenges in precipitation prediction, but most important to this study is that the GP/Midwest is too dry. It is also noted that the southeast US is extraordinarily too wet, which is a separate limitation of the CCSM4 and will remain excluded from this paper’s research focus.

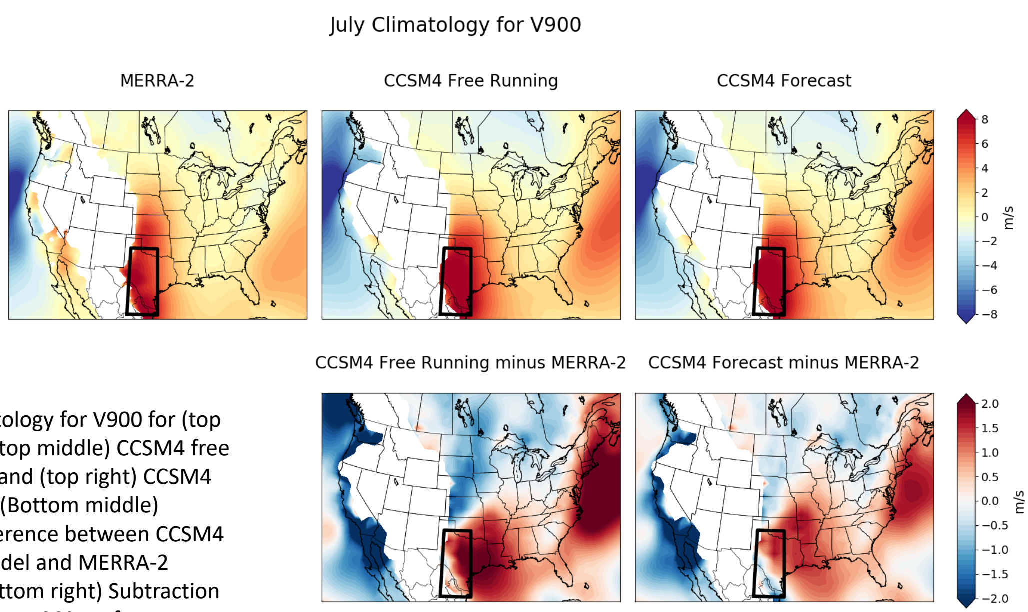


Fig 1: July climatology for V900 for (top left) MERRA-2, (top middle) CCSM4 free running model, and (top right) CCSM4 forecast model. (Bottom middle) Subtraction difference between CCSM4 free running model and MERRA-2 climatology. (Bottom right) Subtraction difference between CCSM4 forecast model and MERRA-2 climatology. Boxes indicate LLJ index domain.

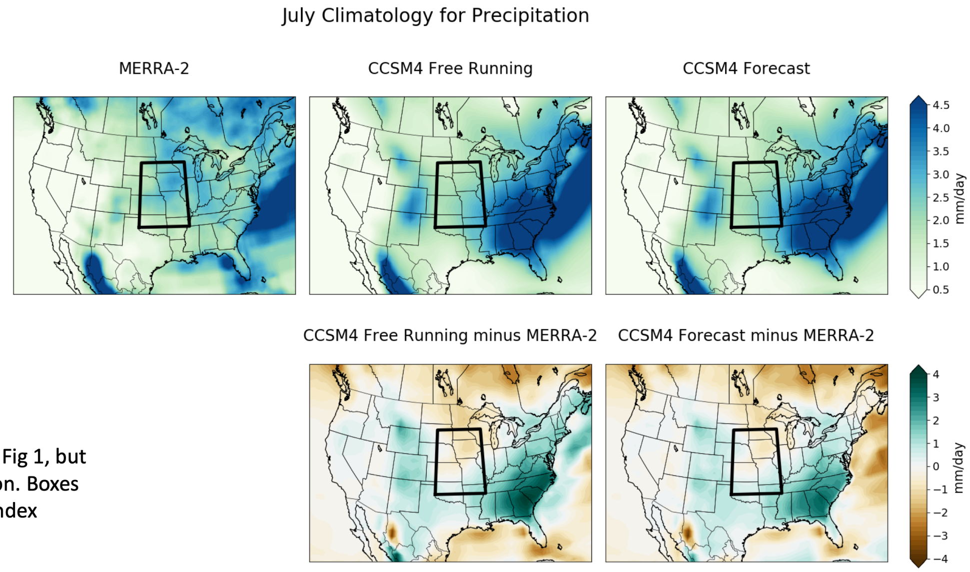
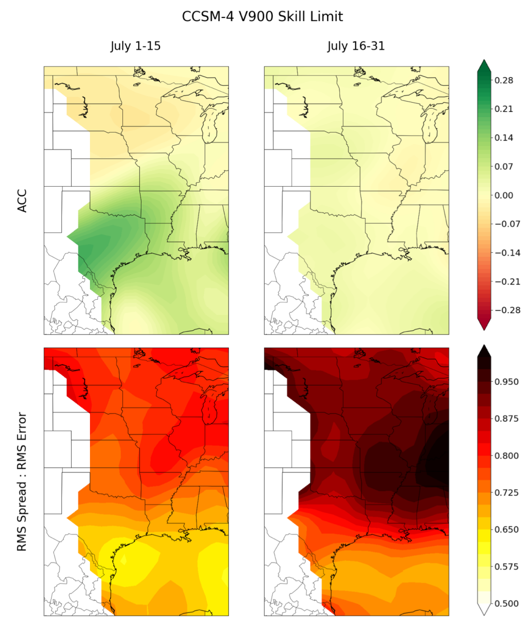


Fig 2 Same as Fig 1, but for precipitation. Boxes indicate GPP index domain.

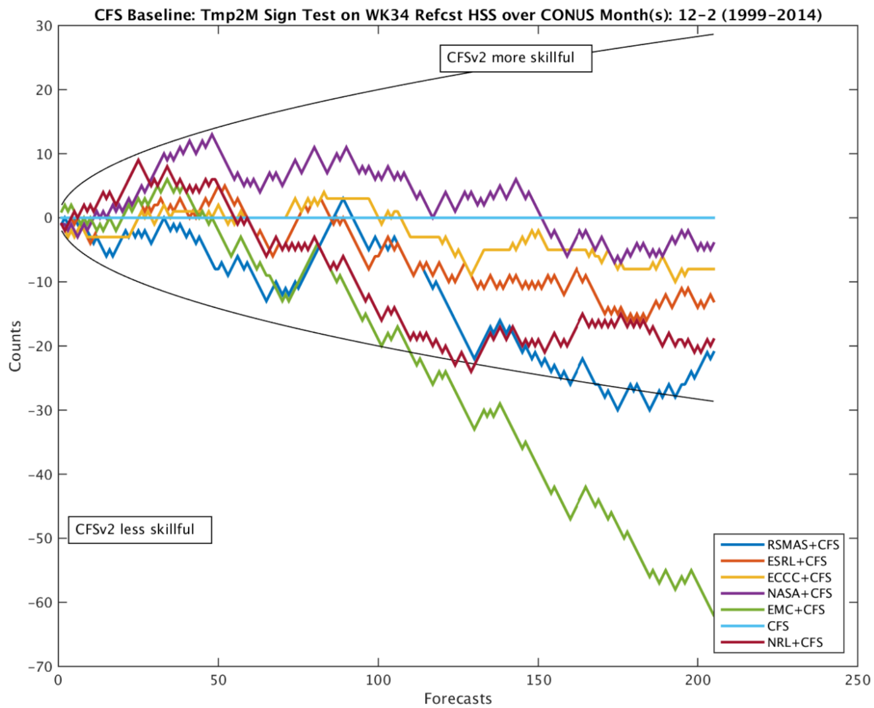
Figure 3 shows the ACC and ratio of RMS Spread to RMS Error. During the first two weeks, the ACC in the jet core is fair (~0.3), though surprisingly slightly negative above the jet. The ACC plummets during the last couple weeks of the month. In addition, the ratio of RMS Spread to RMS Error gets closer to 1:1, signaling the ensemble spread is growing to be as large as the error itself. The attribution of skill within the first two weeks is most likely due to initialization. Erroneous jet events may result from poor simulations of changing circulation responses after the first week or two as the CCSM4 ensembles diverge. This further motivates the need for additional large-scale predictors of V900, or at least to build confidence in certain forecasts of jet events. These results have been submitted for publication (Malloy and Kirtman, 2019).

Fig 3 ACC Scores for CCSM4 for (top left) July 1-15 and (top right) July 16-31. Ratios of RMS Spread to RMS Error for (bottom left) July 1-15 and (bottom right) July 16-31. Data has been spatially smoothed using Gaussian filter.



2d. Forecast Quality Assessment

As a snapshot of the overall assessment of forecast quality we show the week 3-4 mean hindcast, the Heidke Skill Score (HSS) with respect to observations over U.S. and Canada. The random walk score is a function of time that starts at zero and, for each hindcast, goes up one unit if the multi-model mean (i.e., the combination of CFSv2 and one other SubX model) has a larger HSS compared to CFSv2 along, otherwise the score goes down one unit. The score is tallied for each SubX model separately.   The resulting random walk scores for week 3-4 2m-temperature and precipitation are shown in Figure 4. For the 2m-temperature and most of the SubX models improve the HSS over CFSv2 along, but it is only statistically significant (at the 95% level) for EMC+CFSv2. On the other hand, for precipitation all the SubX multi-model combinations (i.e., SubX model + CFSv2) improves the skill over CFSv2 alone.



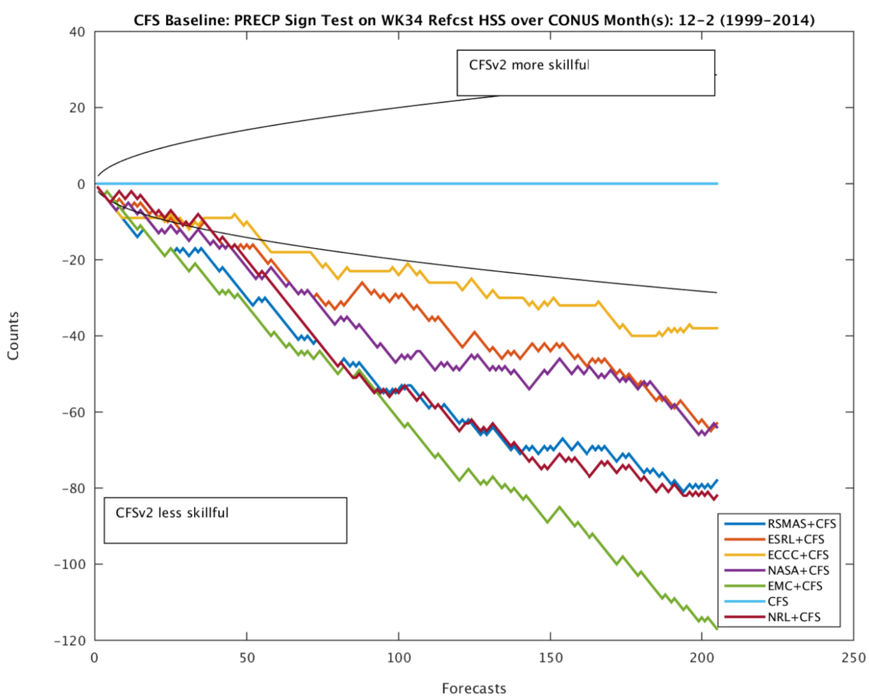


Figure 4: Multi-model (SubX model + CFSv2) random walk HSS skill scores for US plus Canada for (top) 2m-temperature and (bottom) precipitation. The black curves correspond to 95% significance.

3. Highlights of Accomplishments

- Real-time forecasts began in July 2017 and have been on-time all the time since (even during hurricane Irma).
- All priority I and II variables from all the hindcasts have been provided to the IRI.

4. Transitions to Applications

Retrospective subseasonal forecasts with CCSM4 are in production, and in collaboration with NCEP have established protocols for transferring both the real-time and the retrospective forecast data.

5. Publications from the Project

Molloy, K., and B. P. Kirtman, 2019: Predictability of mid-summer Great Plains low-level jet and associated precipitation. JGR-atmospheres (submitted).

6. PI Contact Information

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7. Budget for Coming Year

Project is scheduled to end.

8. Future Work

Future work will primarily focus on: assessing the forecast quality and predictability from CCSM4 and continuing the real-time forecasts.