Project Title: Collaborative Research: Enhancing operational drought monitoring and prediction products through synthesis of N-LDAS and CPPA research results.
Grant: NA10OAR4310246
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2nd Year Progress Report

Project Overview

The overarching goal of the project is: To provide ensemble forecasts of hydrologic variables and products that form the quantitative objective basis for drought assessment, drought forecasting and recovery, and water management, and to test these products in the NIDIS southeastern U.S. pilot study.
The project goal responds to the CTB mission objective "to provide new and improved climate forecast products to the application community for use in planning" as it relates to hydrologic and drought seasonal forecast products.

This is a joint research project between Princeton University and the University of Washington (D Lettenmaier, co-PI) with external collaboration with NCEP Environmental Modeling Center (EMC) and Climate Prediction Center (CPC). Dr. Lifeng Luo (MSU) is a collaborator with the project through Princeton University. This progress report will report only on the activities at Princeton since U Washington is submitting a separate report. The project tasks (and lead institution) are as follows:

Task 1: Transition Bayesian seasonal ensemble forecast system to the CTB (Princeton, primary lead)
This task transitions to the CTB the Princeton Bayesian merging algorithm, and the three forecast sources that have been demonstrated off-line (CFS, ESP, and the ensemble version of the CPC "official" forecasts as implemented in the University of Washington's west-wide forecast system). The existing Princeton system merges multiple seasonal operational forecasts, including ESP (essentially climatology) in a way that optimally weights the seasonal forecasts by their relative skills to create a posterior distribution for each hydroclimate variable that bias corrects and downscales to scales appropriate for hydrologic and drought analysis.

Task 2: Integration of forecast systems to provide objective drought indices (Princeton, primary lead)
The three existing systems (Princeton, University of Washington, and EMC) have slightly different elements; the intent of this task will be to integrate a subset of those elements that is most appropriate for operational purposes. For instance, the existing EMC system uses Noah, Sac, VIC, and Mosaic; the Princeton system uses only VIC, whereas the University of Washington system uses VIC, Noah, Sac, and CLM (Community Land Model).

Task 3: Data set unification (U Washington, primary lead)

Task 4: Generation of drought index hindcasts and forecasts (Princeton, primary lead)
The system as we propose to implement it in the CTB will produce objective measures of drought that include ensemble predictions of drought on-set, severity and recovery, streamflow forecasts (including low flows), and operational CPC indices such as SPI and SRI.

Task 5: Assessment and verification studies (U Washington, primary lead)

Year 2 Princeton Activities and Results

1) Upgrade of realtime drought monitoring system from NLDAS-1forcings to NLDAS-2 forcings
The NLDAS-1 project used to provide the surface meteorological forcing inputs for the realtime drought monitoring system. NLDAS-1 was formally decommissioned in November, 2011, as the successor project

NLDAS-2 has been providing the same forcing fields for land surface models. So we have finished the migration and related upgrades of the monitoring system from NLDAS-1 to NLDAS-2. The realtime drought monitoring system, as forced with the best possible surface meteorological fields, also provides the initial condition for seasonal drought forecast. The drought map is created weekly at Princeton University and the drought condition is presented as the percentiles of daily soil moisture with respect to its climatology. Before the upgrade to NLDAS-2, the climatology was created by the 50-year University Washington daily forcing with the realtime NLDAS extension. As we now have upgraded the drought monitor system to use the new NARR-based NLDAS-2 forcing, the climatology has also been recreated. Figure 1 shows the drought maps for 20120426 using two different climatologies. There are some differences between the two in terms of severity of the drought in several regions. But the overall picture of the drought over the entire CONUS is consistent.

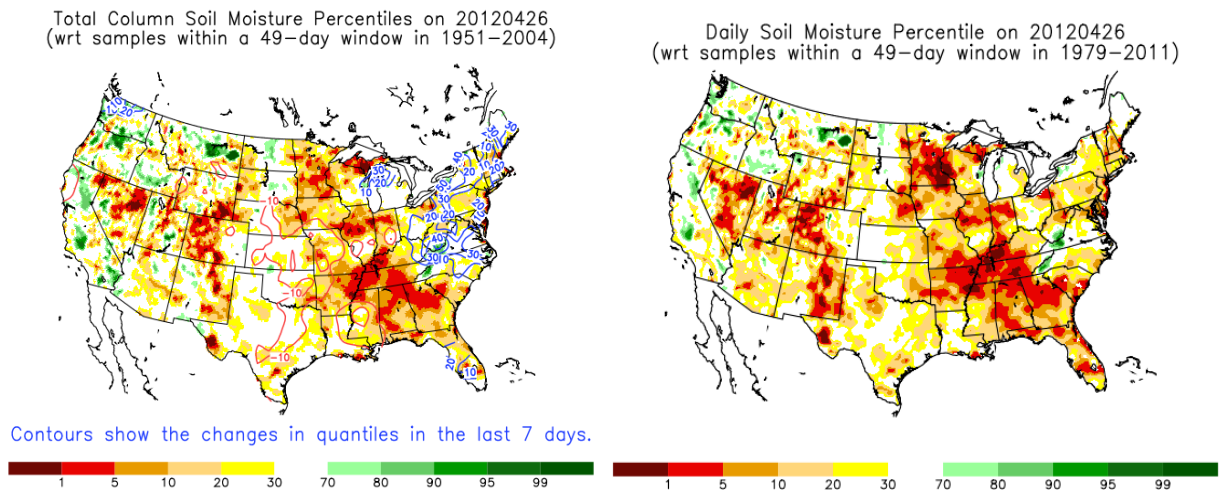

Figure 1: Realtime drought nowcast on 20120426 based on NLDAS-1 reference (left) and NLDAS-2 reference (right).

<u>2) Upgrade of drought prediction system from CFSv1 forecasts to CFSv2 forecasts</u>

On March 30, 2011, the new Climate Forecast System (CFSv2) became operational seasonal forecast system at NCEP. Compared to the previous version of the model, CFSv2 not only has more advanced physics packages but also runs at a higher spatial/temporal resolution, for a longer lead time, and at a more frequent forecast schedule. While NCEP currently runs both versions in an operational mode, they will eventually replace CFSv1 with CFSv2 in operation. CFSv1 is scheduled to discontinue in June 2012.

Our seasonal drought prediction system was originally built with data feeds from CFSv1, so the major task in the second year is to upgrade our forecast system such that it works with CFSv2 output. The following issues need to be resolved in the upgrade:

a) Increase in resolution of CFSv2 from T62 (~1.875 deg) to T126 (~0.9375 deg)
b) Changes in the realtime forecast schedules. CFSv1 forecast was made four times daily from the 00Z initial conditions. The operational configuration for CFSv2 is more complicated. The CFSv2 realtime operation produces four 9-month forecast runs per day from the 00, 06, 12 and 18 UTC cycles of the CFS realtime data assimilation system (CDAS). Additionally, there are three 1-season forecast runs at the 00 UTC cycle, and three 45-day forecast runs at the 06, 12 and 18 UTC cycles. Thus this configuration produces a total of 16 forecast runs each day with various integration lengths, but all of them are at T126 resolution (~0.9375°) with 64 vertical layers in the atmosphere. These forecasts need to be processed to produce monthly precipitation and temperature fields used by seasonal drought prediction system.

c) Changes in model climatology. To support the CFSv2 upgrade, NCEP also finished the new climate forecast system reanalysis (CFSR) and reforecast (CFSRR) with the CFSv2 model. The bias-correction and downscaling method that we developed for the seasonal drought prediction system uses Bayesian merging approach to combine the model forecast with climatological distribution. It thus requires both realtime forecast and hindcast (reforecast). In order to use the realtime CFSv2 forecast, we also need to obtain the CFSRR data and rebuild the likelihood function in the Bayesian merging.

Figure 2 shows an example for CFSv2-VIC based realtime drought forecast result. As predicted by the model, the extremely dry condition over the southeast in May is going to be alleviated in June, while there is persistent moderate drought over Texas. We need to mention that the result is based on an old climatology from VIC. As we will present in the plan for the next year, we are going to use a newly calibrated VIC model, and create new climatology and initial conditions driven by the NLDAS-2 data, and update those in our drought forecast system.

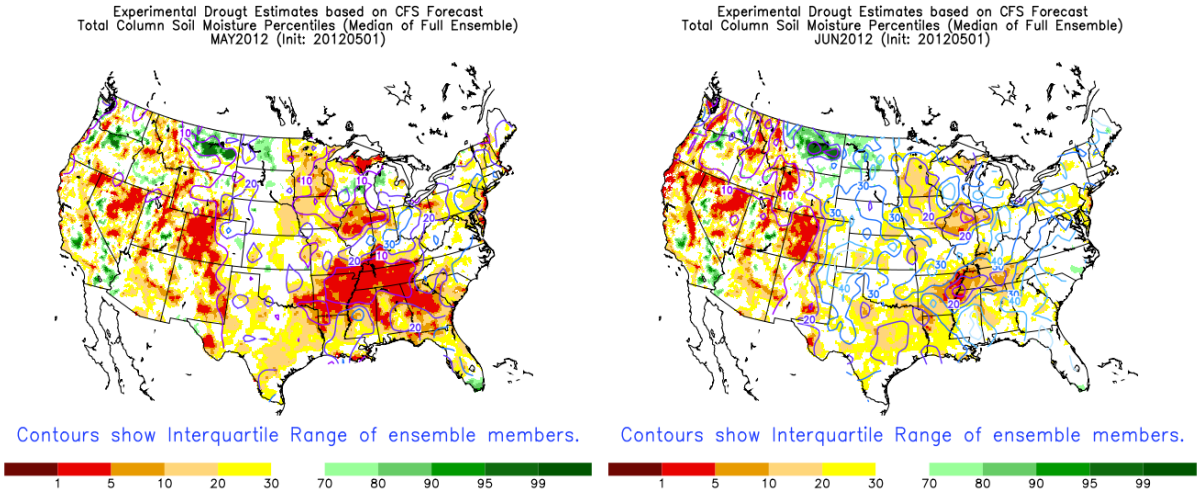

Figure 2: 0.5-month and 1.5-month CFSv2-VIC-based drought forecasts initialized in May, 2012.

3) Case study for CFSv2-VIC-based drought hindcasts

We downscale the precipitation and temperature reforecasts from CFSv1 and CFSv2 to 1/8 degree over conterminous United States using a Bayesian method, conditioned on NLDAS-2 precipitation and temperature. The downscaled fields are then used to force the VIC land surface model to provide 6-month, 20-member ensemble hydrologic reforecasts starting on the 1st of February, May, August and November of each year during 1982-2008, with initial conditions from a 62-year (1949-2010) offline simulation driven by NLDAS-2 forcing data.

To have an overview of soil moisture prediction which is fundamental for agricultural drought analysis, the correlations of interannual variations of month-1 top-layer soil moisture from VIC offline simulation and three forecasting results are calculated and shown in Figure 3. The correlations for ESP prediction are higher over western U.S. than eastern U.S., indicating greater impact from initial conditions for the west part of the country. The best month for ESP prediction is November, where 62% of the grid cells have significant predictive skill, and parts of eastern U.S. have correlations as high as 0.5 (Figure 3d). CFSv1 combines the information from initial conditions and climate forecasts, therefore produces higher correlation than ESP, and increases percentage of skillful forecast by 35%, 32% and 24% for February, May and November, respectively. CFSv2 further improves skillful forecast percentage against CFSv1 by 27% in February and 24% in May. Similar to the geographic distribution of precipitation forecast skill, most of the improvements of soil moisture forecast by CFSv2 are found over eastern coast, central U.S.,

New Mexico and Texas (Figure 3a-b,d). Figure 3 provides a basic feature of the surface soil moisture predictability. As we consider deeper soil, the skill should be higher due to the memory of soil moisture.

To investigate the performance for drought severity and duration forecasts, Severity-Area-Duration (SAD) plots were shown in Figure 4 for 3-month duration. Severity (S) is defined as $S = (1-\Sigma P/t)*100\%$, where ΣP is the summary of monthly percentile of soil moisture over t months. Given that we were validating drought forecast, the SAD plot was a little different from its traditional way. We defined the drought grid cells based on the offline simulation results, no matter whether they were under drought or not in the forecasts. Therefore, the severity was used to quantify the difference between the models' forecasted droughts and the offline simulation conditioning on drought area. The offline simulated severity values were around 0.9 (Figure 4), which was similar to previous studies for 3-month drought duration. Except for 1988, central U.S. drought forecasts had very low skill (Figure 4b) due to the underestimated drought area. CFSv1 and CFSv2 provided more accurate severity values than ESP (Figure 4a,c-d), indicating the added values from climate forecast besides initial conditions. Unlike monthly drought area analysis where the forecast could produce larger drought areas than the offline simulation, the SAD plot demonstrated that the forecasted severity values were generally lower than offline simulation due to the under-prediction of drought areas and/or intensities. For the 1988 drought, all three forecast approaches under-predicted severity compared to the offline simulation by about 40%. Averaged over the other three droughts, ESP underestimated the severity by 31%, CFSv1 by 24%, and CFSv2 by 15%.

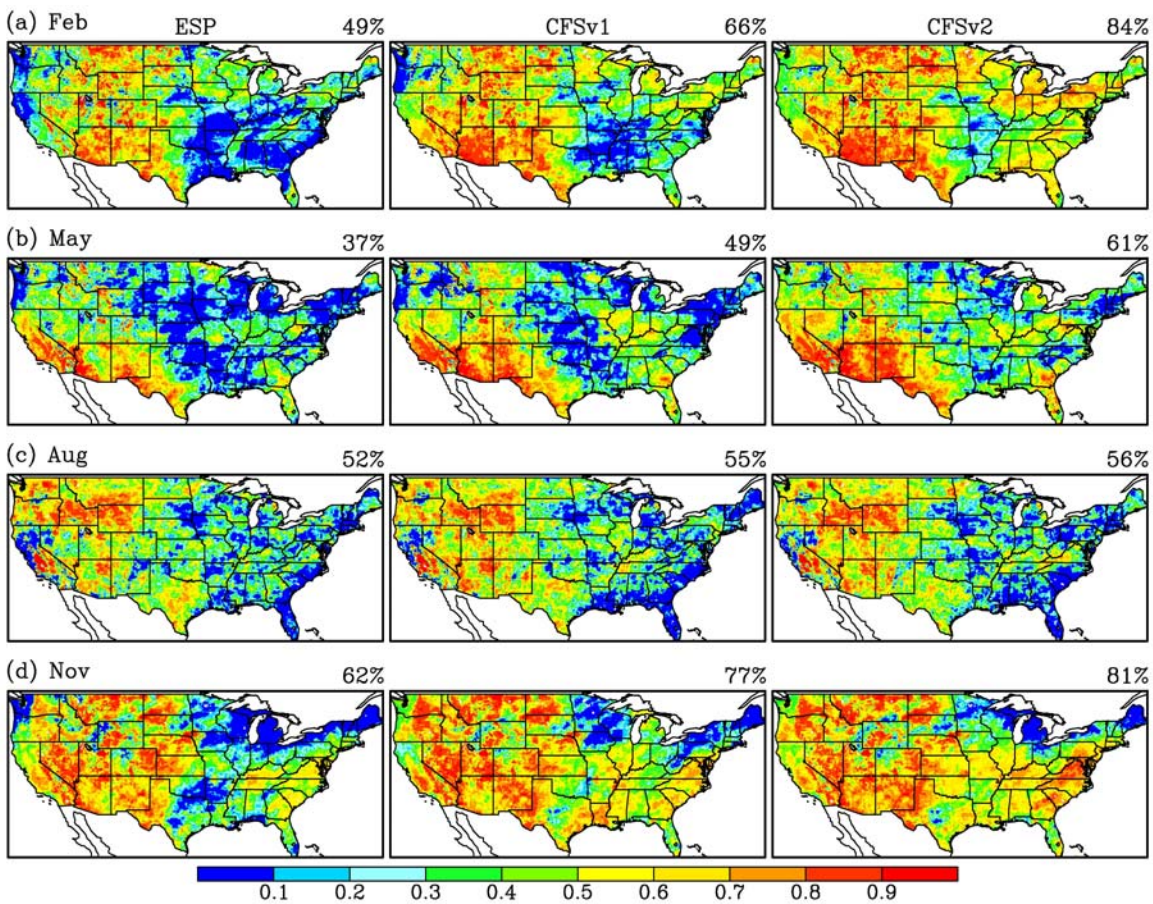

Figure 3. Correlation between offline simulated, ESP, CFSv1 and CFSv2 forecasted month-1 top-layer soil moisture over CONUS during 1982-2008. The percentage of grid cells with significant predictive skill is annotated at the upper right corner of each panel.

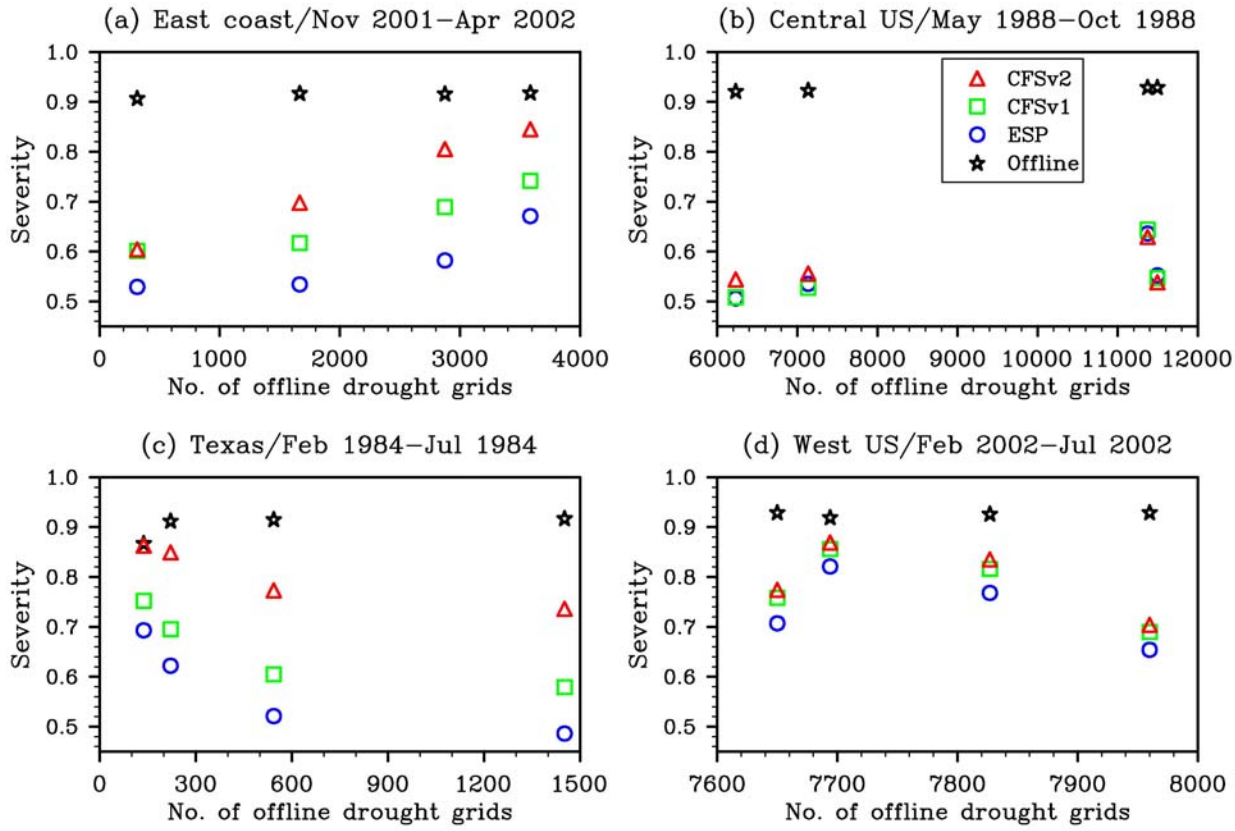

Figure 4. Severity-Area-Duration (SAD) plots for 3-month duration. The 3-month drought grid cells are identified from offline simulation.

4) Evaluation of CFSv2 realtime forecast for heat wave

An important work that will ultimately benefit the seasonal drought prediction is to evaluate the skill of CFSv2 forecast in its temperature and precipitation forecast at subseasonal to seasonal time scale. So in collaboration with Princeton University, we are carrying out multiple analyses using both realtime CFSv2 forecast and its companion reforecast CFSRR. One of the studies is to investigate the operational capability of the CFSv2 model in predicting the 2011 summer heat wave using both the realtime CFSv2 data stream and the CFSRR hindcast dataset. The question we would like to address is whether the state-of-the-art seasonal forecast system provided any clear indication of forthcoming the summer heat wave in an operational setting. If the event was successfully predicted with sufficient lead time, it will demonstrate the usefulness of the new system, and provides added confidence to end users for incorporating climate forecast information in their decision making process.

Figure 5 shows the predicted percentage of days when predicted daily temperature is above the 90th, 95th and 99th percentile of the corresponding temperature climatology. Figure 5 only shows the predicted field from one single realtime CFSv2 run made from the 06 UTC cycle on April 30, 2011. This individual forecast was able to predict the summer heatwave that took place in the central plains during the second half of July 2011.

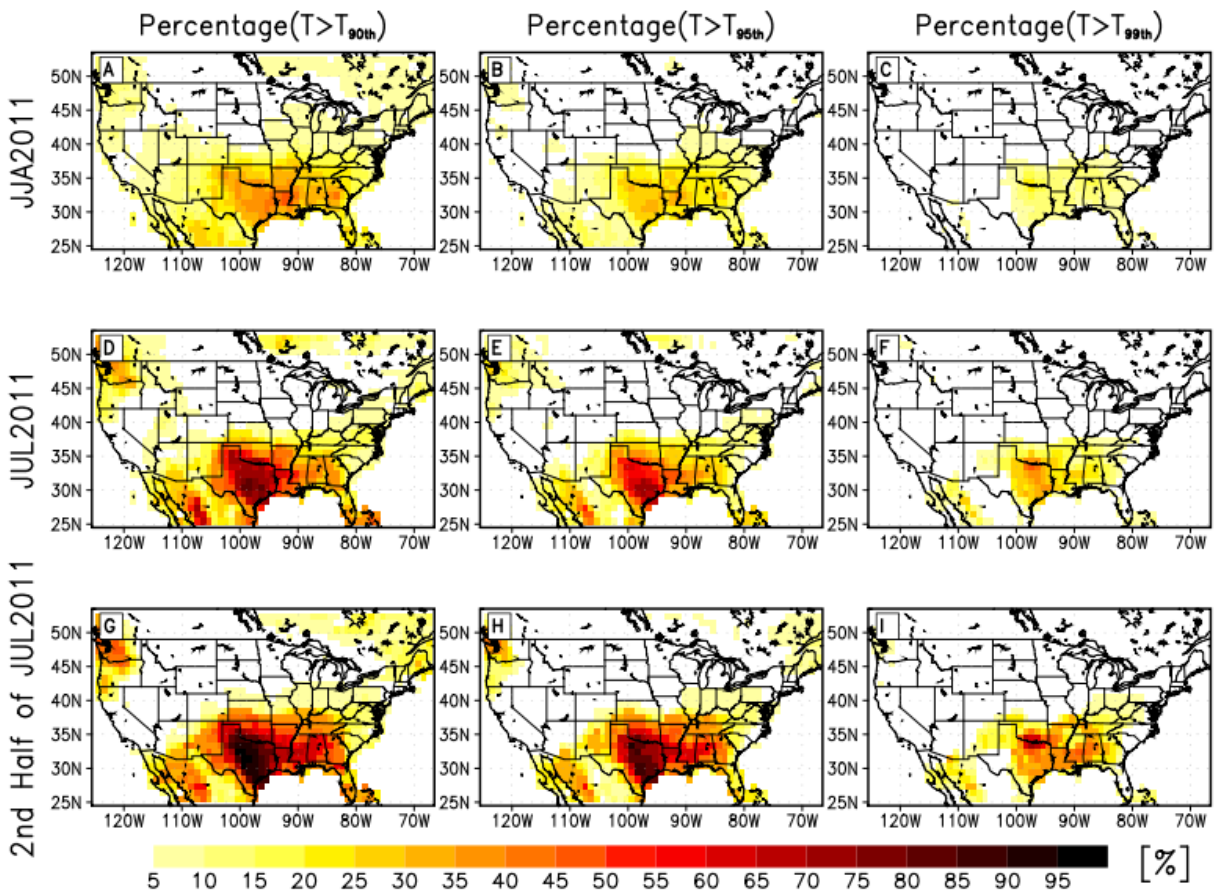

Figure 5: The predicted percentage of days [%] with daily air temperature higher than the 90th, 95th, and 99th percentiles of the climatological distributions for the three periods. This is for the single 9-month CFSv2 forecast run from the 06 UTC cycle on April 30, 2011.

Combing all results from 424 CFSv2 forecast runs, Figure 6 shows the predicted average percentage of days with daily temperature above the thresholds over the Central Plains. It is evident that almost all of the 424 forecast runs showed increased percentage of days with temperature higher than the thresholds for all three periods (solid lines vs. long-dashed lines), which means that the model consistently suggested a warmer than normal summer with many hot days over the region. It also shows that the predicted percentage increased more quickly as the initial time of forecast approaches the target period. As the initial time of forecast approached the summer, forecasts became more certain about the summer heat wave in the intensity, geographic locations, and timing. The results not only demonstrate the ability of the CFSv2 model in capturing the extreme event, but also demonstrate climate extremes like the summer heat wave have predictability at seasonal time scale.

Planned activities for Year 3

The following activities are planned for the third year of the project.

<u>Transition of CFSv2-based Princeton drought prediction system to NCEP EMC</u>

We have ported our nowcast and forecast system to NCEP mainframe computer but have not been able to make successful runs due to issues with data storage and data feeds. Additionally, NCEP has recently moved everything from Haze to Zeus as part of their facility upgrade. We will continue working with EMC/NCEP people to finish this transition.

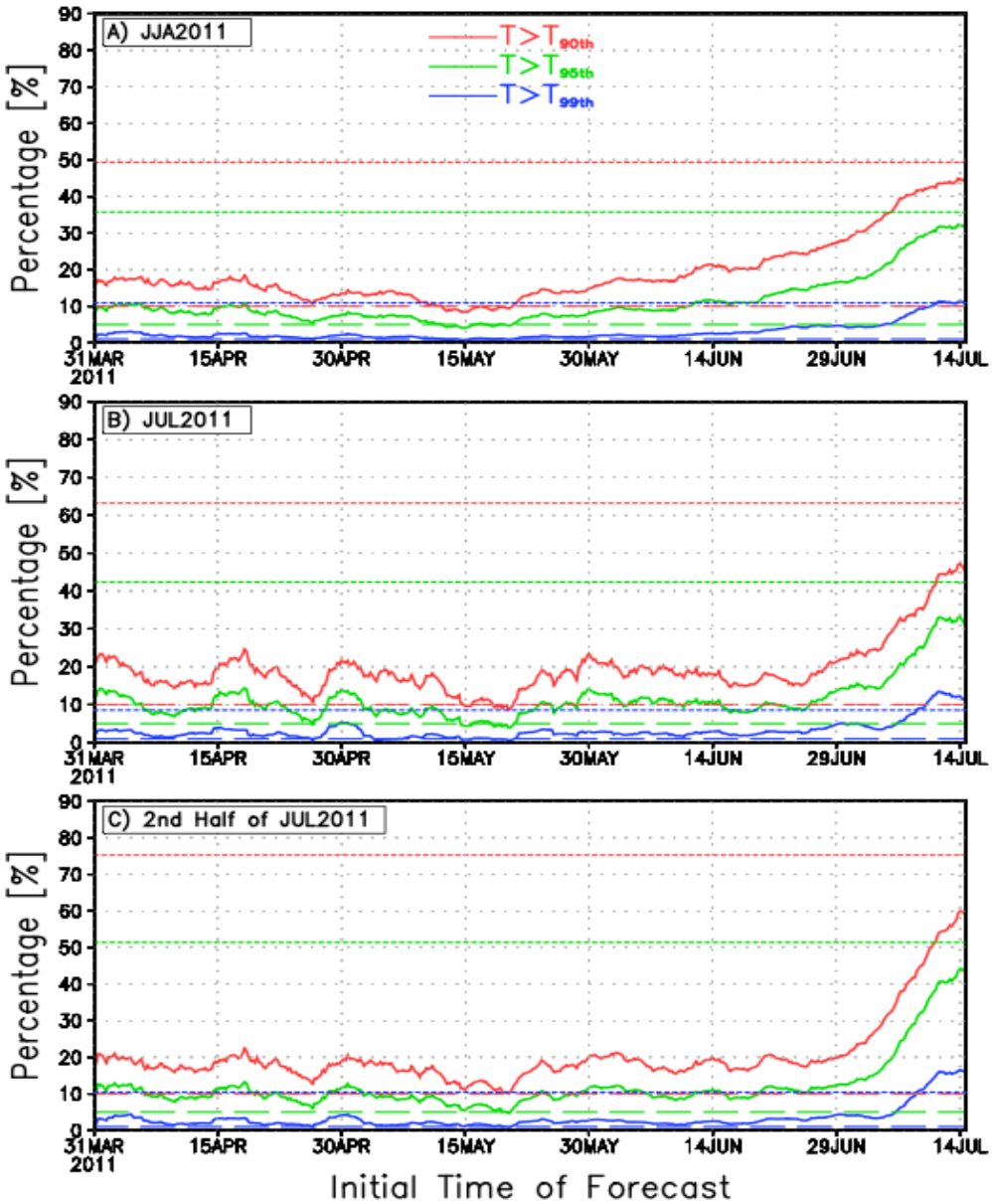

Figure 6: The predicted average percentage of days with daily temperature higher than the 90th (red), 95th (green) and 99th (blue) percentile of the climatological distributions over the Central Plains for A) JJA of 2011, B) July of 2011, and C) second half of July 2011. The dotted horizontal lines represent the observed percentage based on NLDAS2 data. The dashed horizontal lines represent the expected percentage from a climatological forecast.

<u>Facilitate the implementation of the current UW multiple (land) model nowcast system at NCEP/EMC or CPC as update to existing NLDAS-based system</u>

University of Washington has developed and implemented a drought nowcast system that utilizes multiple land surface models. This system will be implemented at NCEP/EMC to provide operational guidance on drought nowcast. MSU group will provide help to facilitate this process in the second year.

<u>Evaluate, analyze and document the forecast skills of CFSv2 and seasonal drought prediction system.</u>

We will continue the ongoing evaluation and analyses of CFSv2 using both its realtime component and reforecast data. This includes a comprehensive evaluation of CFSv2-base seasonal hydrological

prediction over CONUS, comprehensive evaluation of predictions of temperature and precipitation extremes.

Project publications

Luo, L. and Y. Zhang, 2012: Did we see the 2011 summer heat wave coming?, *Geophys. Res. Lett.*, 39, L09708, doi:10.1029/2012GL051383.

Wood, E.F., X. Yuan, and J.K. Roundy, 2011: Enhancing Hydrological Seasonal Forecast by Downscaling CFSv2. *NWS Science & Technology Infusion Climate Bulletin*, 110-115.

Yuan, X., E. F. Wood, L. Luo, and M. Pan, 2011: A first look at Climate Forecast System version 2 (CFSv2) for hydrological seasonal prediction. *Geophys. Res. Lett.*, 38, L13402, doi:10.1029/2011GL047792.

Yuan, X., X.-Z. Liang, and E.F. Wood, 2011: WRF ensemble downscaling seasonal forecasts of China winter precipitation during 1982-2008. *Clim. Dyn.*, doi:10.1007/s00382-011-1241-8, in press.

Yuan, X., and E. F. Wood, 2012: Downscaling precipitation or bias-correcting streamflow? Some implications for CGCM-based ensemble seasonal hydrologic forecast. *Water Resour. Res.* (submitted)