Development of a monitoring and prediction system for flash droughts over the United States

Final Report

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1. Main goals of the project, as outlined in the funded proposal

- To monitor the heat wave and precipitation deficit flash droughts in real time
- To forecast flash droughts on pentad time scales
- To forecast flash droughts on seasonal time scales

2. Results and accomplishments

a) Monitoring flash droughts in real time

In published work (Mo and Lettenmaier, 2015; 2016) we identified two types of flash droughts over the United States: heat wave flash drought and precipitation (P) deficit flash drought. Both flash droughts start to appear in spring and generally last through summer, ending in early fall. Heat wave flash droughts are initialized by high temperature. Intense heat increases evapotranspiration (ET) and reduces soil moisture (SM). P deficit droughts are due to the lack of P; dryness decreases SM and leads to the decrease of ET in the area that ET and SM have a linear relationship. The heat balance requires the increase of sensible heat to compensate the decrease of ET and that leads to intense warm temperatures.

Four variables (T_{2m}, P, SM and ET) are needed for monitoring flash droughts. T_{2m} is based on the CPC surface temperature analysis. P is taken from the CPC unified P analysis. The surface wind speed is obtained from the CDAS. The daily T_{2m} , P and wind speed are used to derive forcing to drive the VIC land surface model (VIC 4.0.6) to get ET and SM. The base period is from 1979-2015. Percentiles and anomalies are derived from data in the base period.

For each pentad, if a) T_{2m} anomaly > 1 standard deviation; b) ET anomaly>0; and c) SMP < 40%, that pentad is flagged as initiating a heat wave flash drought. The corresponding requirements for P deficit flash droughts are a) T_{2m} anomaly >1 standard deviation; b) ET anomaly <0; and c) P<40%.

Because of the temperature dependence, there are no flash droughts in winter so monitoring covers the period from 1 April to 30 September each year. We started real time monitoring at CPC in 2017, and again from 1 April 2018. Flash droughts do not last very long, so we use pentad (5-day mean) data for monitoring. For each pentad, we monitor the standardized T_{2m}, ET anomaly, and P and SM percentiles and mark the locations of flash droughts. The monitoring for pentad 23-28 April 2018 is given in Fig.1 as an example. There were warm temperatures over the West and P deficits over the Southwest including California, Arizona to Nevada and Colorado. There were also P deficits to the west of the Great Lakes. For that pentad, there were no coherent heat wave flash droughts, but there was a P deficit drought occurrence in the Four Corners area. We

display flash drought occurrence from 10 days ago (two prior pentads) to the current pentad on the CPC web site (http://www.cpc.ncep.noaa.gov/products/Drought/), with daily updates.

b. Forecast flash droughts based on MRF forecasts

The purpose of this activity was to examine the ability of the MRF 16 day forecasts to capture the occurrence of heat wave and P deficit flash droughts in advance. The criteria used to select flash droughts were the same as for monitoring. The MRF forecasts were available from 1986-2012. For each year, we evaluated forecasts initialized from 1 April to 30 September with a 5-day interval. During the summer, there are 36 pentads each year. The MRF reforecasts have 11 ensemble members.

The verifying analysis was from gridded daily P and T_{2m} station data. P and T_{2m} daily data with wind speed were also used to drive the VIC model to obtain daily ET and SM. Flash droughts were selected using the same threshold as for monitoring. We labeled this run as analysis.

From the MRF archive, we selected the daily P and T forecasts from day 1 to day 15 (3 pentads). Via cross validation, we corrected systematic errors (biases) using 45 days (9 pentads) prior to the initial forecast date as the training period. From error corrected P, T_{2m} and daily climatological wind speed obtained from CDAS from 1950-1978, we derived forcing to drive the VIC model to obtain daily ET and SM. From the four variables (P, T_{2m}, SM and ET), we forecasted flash drought occurrence using the same criteria as analysis.

There are strong seasonal variations on the occurrence of flash droughts so we verify forecasts for spring (April-May), summer (June-July) and autumn (August-September) separately. The forecasts for heat wave flash drought from spring initial conditions are realistic (Fig.2). They capture the locations of maxima and also magnitudes of FOC. For summer, the forecasts are not realistic. The model overestimates the occurrence over the northern U.S. and does not capture the locations of FOC maxima. For autumn, forecasts capture the locations of flash drought, but not the magnitudes. For P deficit flash droughts, forecasts underestimate the FOC over Texas and overestimate the FOC over the Pacific Northwest (Fig.3). Our assessment is that at present, the forecasts are not realistic enough to use in real-time forecasts.

c. Forecast flash droughts based on the CFSv2 seasonal forecasts

On seasonal time scales, we are not able to forecast individual flash drought events, but similar to seasonal P and T, we can provide categorical forecasts to indicate whether

the occurrence of both types of flash droughts for the coming season will be above, normal or below normal. Overall, the CFSv2 is able to capture the major features of the frequency of occurrence of flash droughts. The model captures the areas where the flash droughts are most likely to occur. For heat wave flash droughts, the areas include the North Central region, and the Pacific Northwest. For P deficit flash droughts, the areas are the southern United States and the Great Plains.

We evaluated the 3-category forecasts (above, normal and below) against the corresponding analysis using Heidke skill scores (HSS) for seasons starting from 1April, 1 May, 5 June and 5 July (Fig. 4). For both types of flash droughts, Heidke scores are positive. For heat wave flash drought, events over the Pacific Northwest have the highest skill (HSS > 40). Events over the Northeast has the lowest skill (HSS~ 0.1). For P deficit flash droughts, the skill is higher over the Southwest and the western interior states and is lower over the Gulf Coast and the East Coast. The skill is comparable with the CPC P and T seasonal forecasts.

Based on the evaluation, we started the real time flash drought forecasts at CPC based on CFSv2 during 2017. The 2018 forecasts are available on the CPC web site. (http://www.cpc.ncep.noaa.gov/products/Drought)

3. Highlights of accomplishments

- We developed an experimental real time flash drought monitor on the CPC website;
- We evaluated the skill of flash drought forecasts from lead 1- pentad to 3-pentad based on the MRF forecasts from 1986-2012;
- We implemented experimental real time flash drought forecasts in three categories based on the CFSv2 seasonal forecasts

4. Transition to operations

We transferred the flash drought monitoring and forecast processes from UCLA to CPC, which now produces a flash drought monitor and prediction in real-time.

5. Publications

Mo, K.C., and D. P. Lettenmaier, 2015: Heat wave flash droughts in decline, *Geophysical Research Letters* 42, doi:10.1002/2015GL064018.
Mo, K.C. and D.P. Lettenmaier, 2016: Precipitation deficit flash droughts over the United States *Journal of Hydromet.* doi:10.1175/JHM-D-15-0158.1
Mo, K.C. and D.P. Lettenmaier 2017: Prediction of flash droughts over the United States. To be submitted, *J. Hydromet.*.
Xiao, M., K.C. Mo, and D.P. Lettenmaier, 2017. Global occurrence of flash droughts. To be submitted, *J. Hydromet*.

7. PI Contact Information

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Figure 1

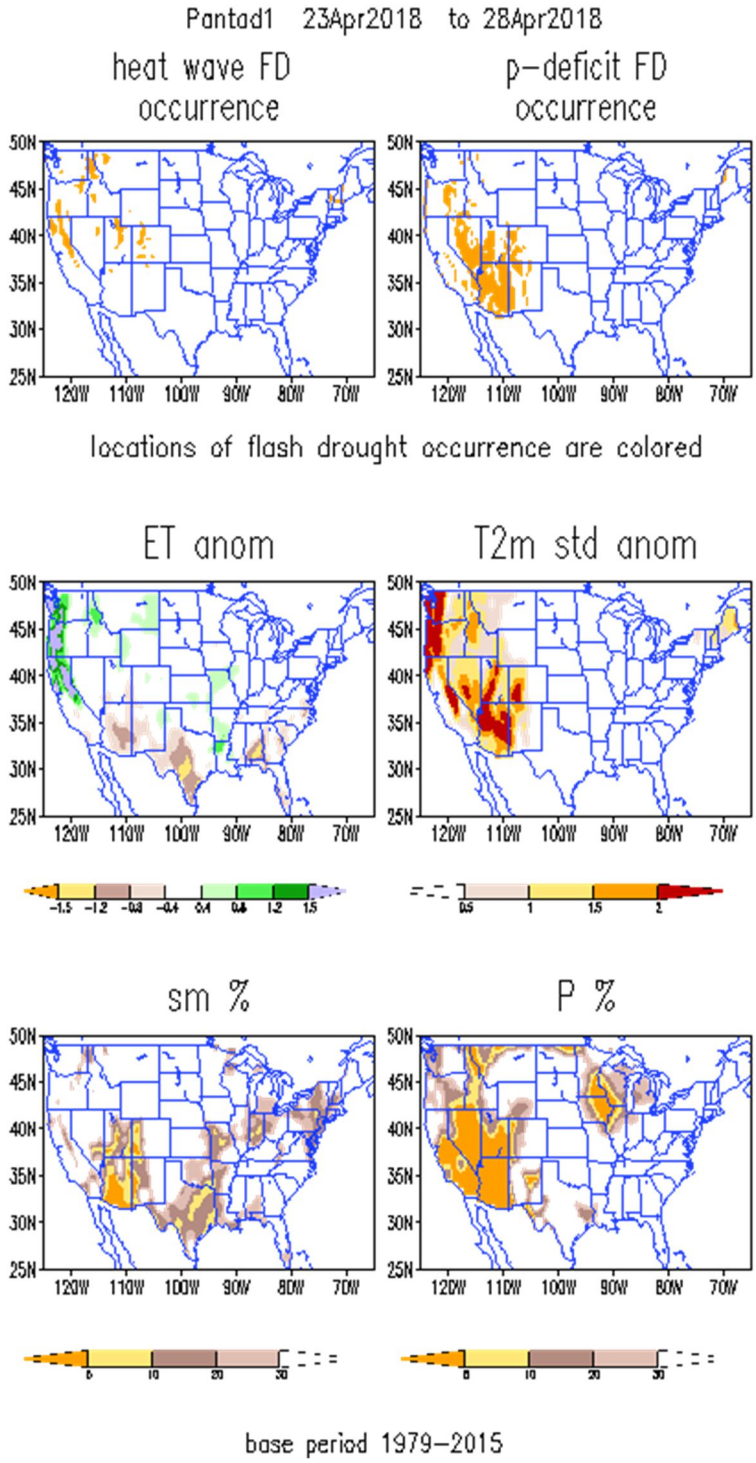

Fig.1: (a) Occurrence of heat wave flash drought, locations of drought are marked, (b) ET anomalies unit mm day^{-1}, (c) SM percentile and (d)-(f) same as (a)-(c) but for P deficit flash droughts for pentad 23-28 April 2018.

Figure 2

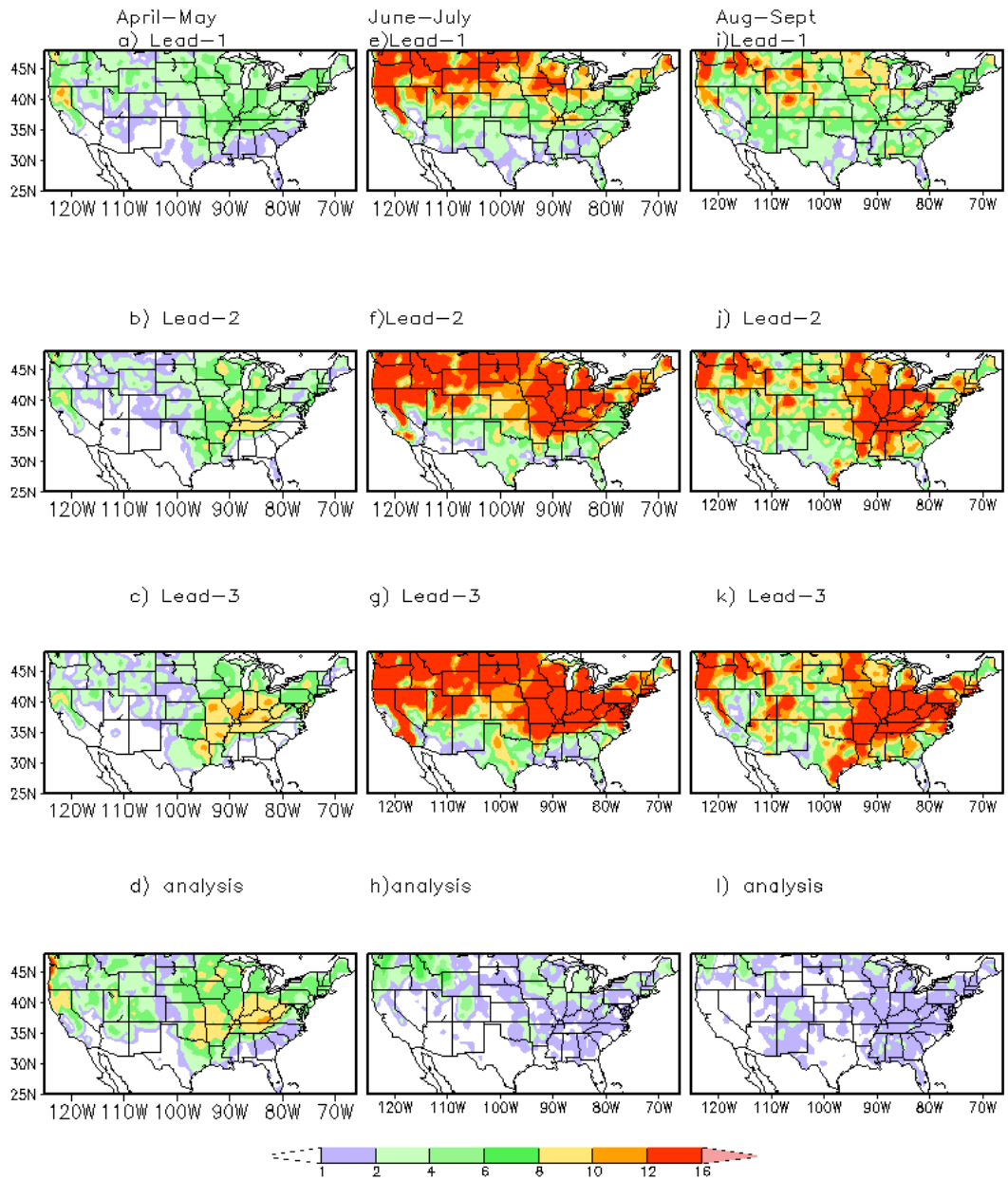

Figure 2 Locations of heat wave flash droughts in spring for (a) lead 1 pentad, (b) lead 2 pentad, (c) lead 3 pentad and (d) analysis. Contours are given by the color bar. (e)-(h) same as (a)-(d) but for summer and (i)-(l) same as (a)-(d) but for autumn.

Figure 3

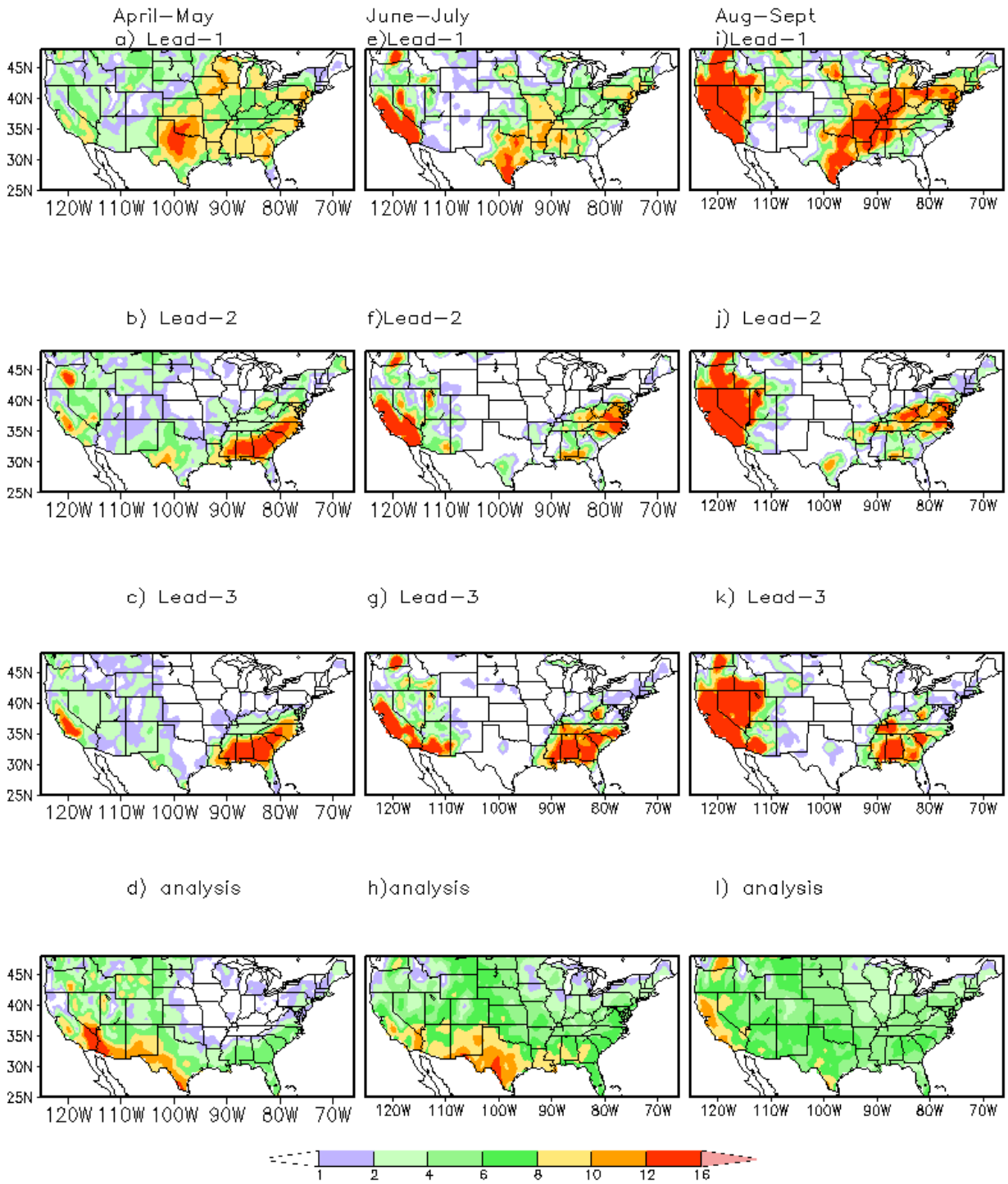

Fig 3: same as Fig.2, but for the P deficit flash drought.

Figure 4

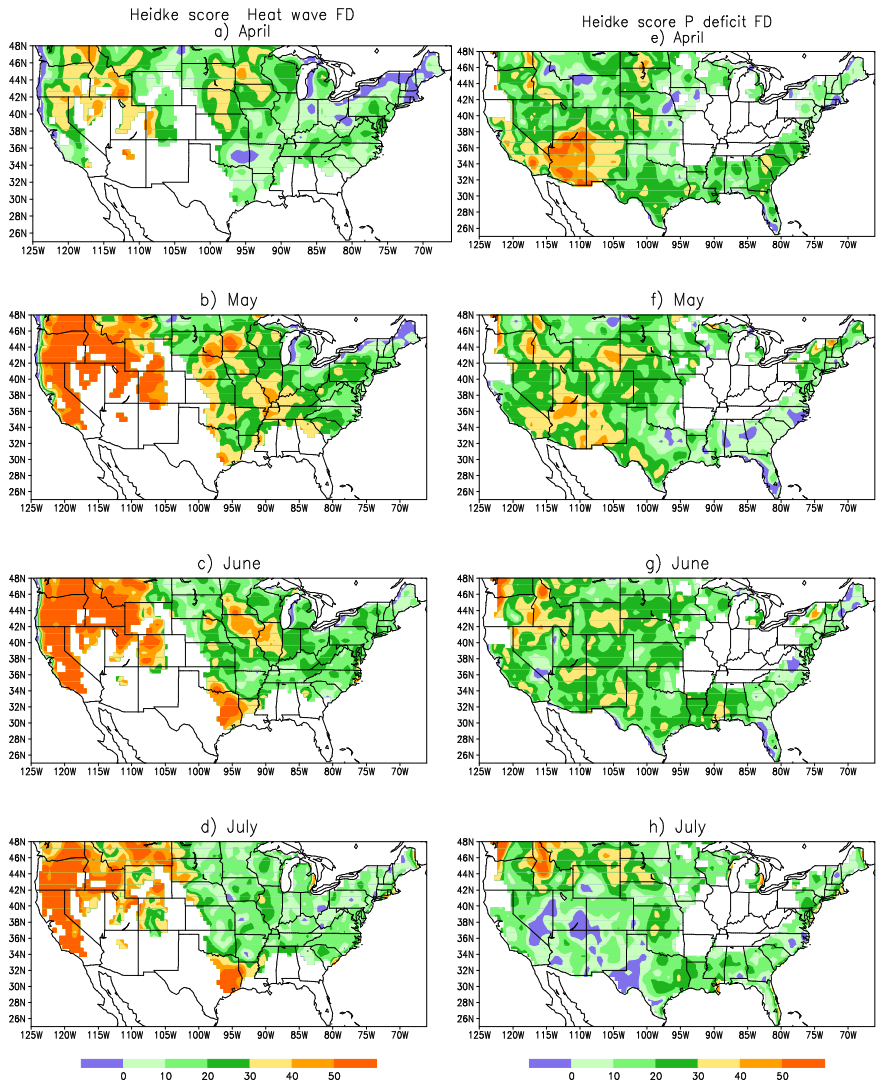

Fig.4: Heidke skill score for heat wave forecasts for the season starting from (a) 1 April, (b) 1 May , (c) 5 June and (d) 5 July and (e)-(h) same as (a)- (d), but for P deficit flash drought. Contours are given by the color bar.