PROJECT TITLE: Facilitating adaptive management under conditions of rapid drought onset using the GOES-based Evaporative Stress Index

INVESTIGATORS:

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I. PRELIMINARY MATERIALS

A. Research project objective

This project will seek to develop and evaluate an innovative drought early warning toolkit based on satellite-derived maps of evapotranspiration (ET) that will be used to support decision-making and risk characterization for the agricultural and natural resources communities. Recent examples of rapid drought intensification across the U.S. have clearly demonstrated the need for a reliable drought early warning system (DEWS) that would be capable of providing stakeholders additional time to prepare for worsening drought conditions. The study will use the Evaporative Stress Index (ESI) dataset generated with the Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance model using GOES thermal infrared imagery. Focus group studies will be convened in two National Integrated Drought Information System (NIDIS) pilot regions to examine how real-time access to the ESI-based drought toolkit could have assisted stakeholders during recent drought events. The end goal is to provide useful remote sensing tools that can be implemented globally to help mitigate crop losses and other drought-related damages, thereby promoting resilience in a changing climate.

B. Stakeholder and decision maker involvement

- Individual farmers and ranchers
- Farm organization representatives
- Federal and state agency representatives
- County and university extension agents
- Natural resources experts and representatives

C. Approach

In this work, statistical and case study analyses will be used to quantitatively assess the ability of the ESI to accurately identify drought onset and development. The ESI is generated using ET estimates from the ALEXI land surface energy balance model using GOES thermal infrared imagery. The ESI represents standardized anomalies in the ratio of the actual-to-reference ET, and has been shown to agree well with standard precipitation-based drought indices and with classifications in the U.S. Drought Monitor (USDM) archive. Because ALEXI computes ET using remotely sensed land surface temperatures, which respond quickly to changes in soil moisture content, the ESI is often able to detect increasing water stress earlier than other drought metrics, sometimes by several weeks, thereby making it a potentially useful drought early warning tool.

A Rapid Change Index (RCI) product derived from rapid temporal changes in the ESI that is designed to identify areas experiencing rapid stress emergence will be refined though comparisons with various drought monitoring and observational datasets. Focus group studies will be convened to examine how real-time access to ESI and RCI products could have assisted stakeholders during recent drought events by facilitating adaptation to changing climate conditions. User feedback will promote improvements in the analysis and visualization tools developed during this project. The project will focus on the NIDIS Southern Plains and Missouri River Basin pilot regions; however, the analysis and visualization tools will be available for the entire contiguous U.S. and will be applicable to multiple end users. The end goal is to develop an innovative suite of drought early warning tools designed to inform the public about rapidly changing drought conditions over regional scales with high spatial resolution.

D. Matching funds

None.

E. Partners

The project team will work with the National Drought Mitigation Center and the USDM authors to examine the potential for integrating the ESI drought early warning toolkit into the operational USDM mapping process. Additional partners in academia, the private sector, federal agencies, and non-governmental organizations will provide input on the drought early warning toolkit through involvement in the focus group meetings.

II. ACCOMPLISHMENTS

A. Summary of accomplishments and findings

During the past 12 months, two focus group meetings were convened with agricultural stakeholders across the central U.S. to better understand how they could use the drought early warning information provided by the ESI to better prepare for drought development and then improvements were made to the dissemination of the ESI datasets to end users (including USDM authors) based on their feedback. In order to reach a larger audience, we also hosted a 30-minute webinar describing the ESI methodology and its potential use within the agricultural community. In addition, further insight into the role vegetation and soil moisture anomalies play during the onset of flash drought was gained through detailed analyses of in situ observations from the Oklahoma mesonet. Results from these studies were presented at conferences and in peer reviewed publications. Each of these accomplishments is described in greater detail below.

1) Focus group meetings with stakeholders across the central United States

Two focus group meetings were convened in August 2014 with stakeholders in the NIDIS Southern Plains and Missouri River Basin regional drought early warning system pilot regions that were impacted by severe droughts in recent years. The first meeting was held in Norman, OK, and the second convened two days later in Lincoln, NE. All attendees were invited based on their prior interest in drought mitigation, with a total of 30 people with diverse backgrounds attending the meetings. A journal article (Otkin et al. 2015) describing results from these meetings has been accepted for publication in the *Bulletin of the American Meteorological Society*.

Each focus group meeting included an interactive discussion on the characteristics of flash drought events and their societal impacts, along with several presentations introducing the attendees to the ESI and associated drought monitoring tools, including ESI “change anomalies” that show how rapidly the ESI is changing with time and the RCI depicting the total moisture stress change occurring over longer time periods. Sub-seasonal probabilistic drought intensification forecasts derived from the RCI were also shown. These datasets along with other commonly-used drought metrics were presented to the attendees either as individual domain maps (e.g. Fig. 1) or as part of a visualization tool referred to as a “plume diagram” (e.g. Fig. 2) that allows a user to quickly evaluate the evolution of multiple datasets over a specific region without the need to examine potentially dozens of domain maps. The attendees were asked to assess the usefulness of these datasets for drought mitigation efforts through group discussions, analysis of recent flash drought events, and a written questionnaire provided at the end of each meeting.

Overall, most attendees had a favorable opinion of the ESI, RCI, and experimental drought intensification forecasts. The attendees generally preferred to use the ESI and RCI variables in map form (Fig. 1) when diagnosing current drought conditions. These variables were considered very helpful when used together because the current conditions could be evaluated with the ESI whereas the RCI provides a longer view of how conditions have been changing. The probabilistic drought intensification forecasts allowed the participants to anticipate which regions were most susceptible to drought development, which also influenced their opinion on current drought conditions. Though some concerns were expressed regarding the potential for false alarms, the consensus was that the probabilistic drought forecasts would be useful when making decisions because most farmers and ranchers are accustomed to dealing with uncertainty.

The attendees had a mixed reaction toward the plume diagrams; however, several people commented that their opinion would likely improve after they gain more experience using them because the visualization method was unfamiliar to them. Many of the attendees appreciated how the columns on the left (ESI, SPI, and soil moisture anomalies) show the current conditions, whereas the columns on the right (ESI change anomalies, RCI, and drought intensification probabilities) provide early warning of drought development. Together, these diagrams provide a concise view of both the current drought status and how things have been changing with time. Overall, the attendee feedback regarding these diagrams was mostly negative at the first meeting, but was mostly positive at the second meeting, with 31% and 80% of the participants expressing a positive opinion in the questionnaire. The higher percentage of positive responses at the second meeting was partially due to the presenters taking more time to explain all of the information included on these complex diagrams because after reading the attendee comments from the first meeting, it was evident that additional time needed to be devoted to explaining how to use them. The more positive comments at the second meeting illustrate the importance of directly engaging stakeholders when developing new tools.

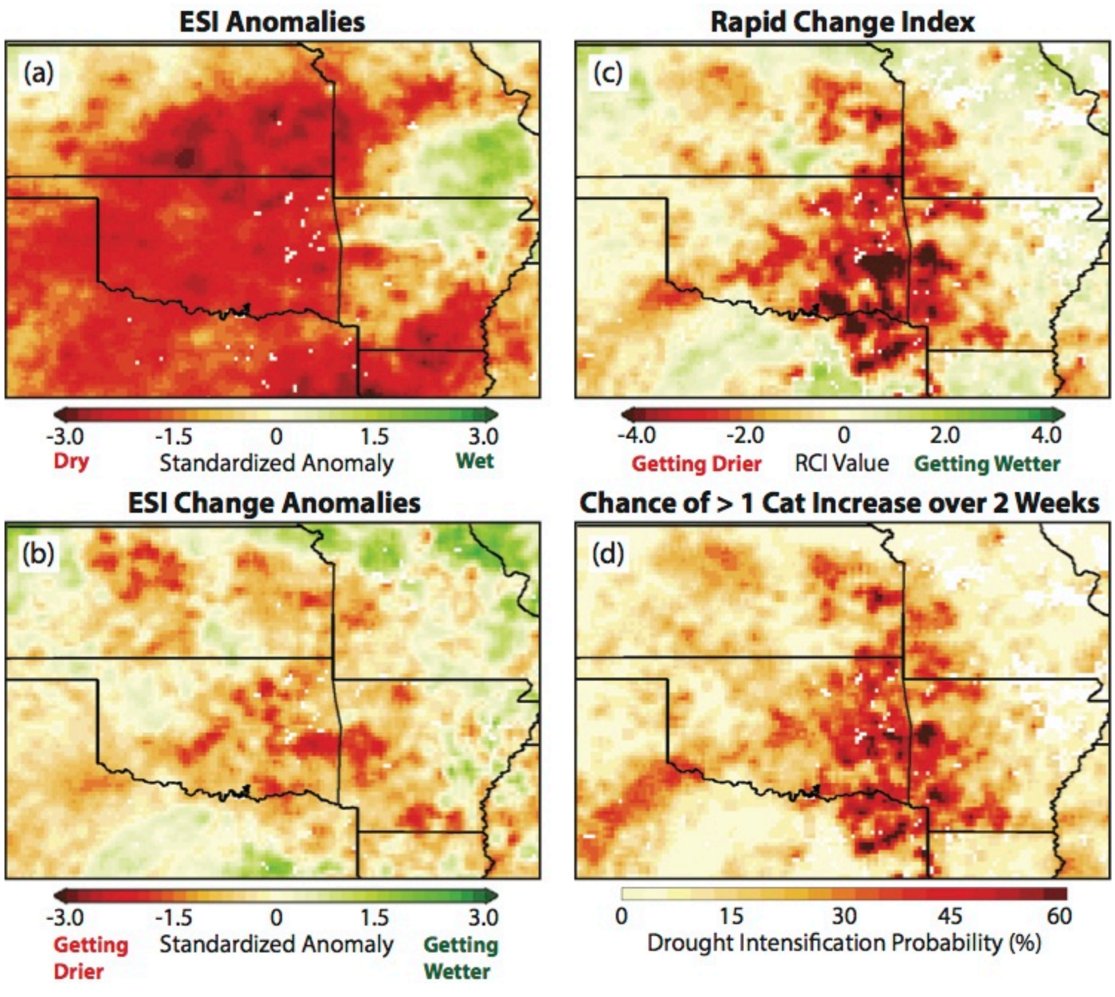

Fig 1. Domain images showing (a) ESI anomalies computed over a 4-week period, (b) standardized ESI change anomalies depicting changes in the ESI during the preceding week, (c) RCI, and (d) the RCI-derived probability of a 1 category increase in the USDM drought severity occurring during the next two weeks. All images are valid on 01 July 2011.

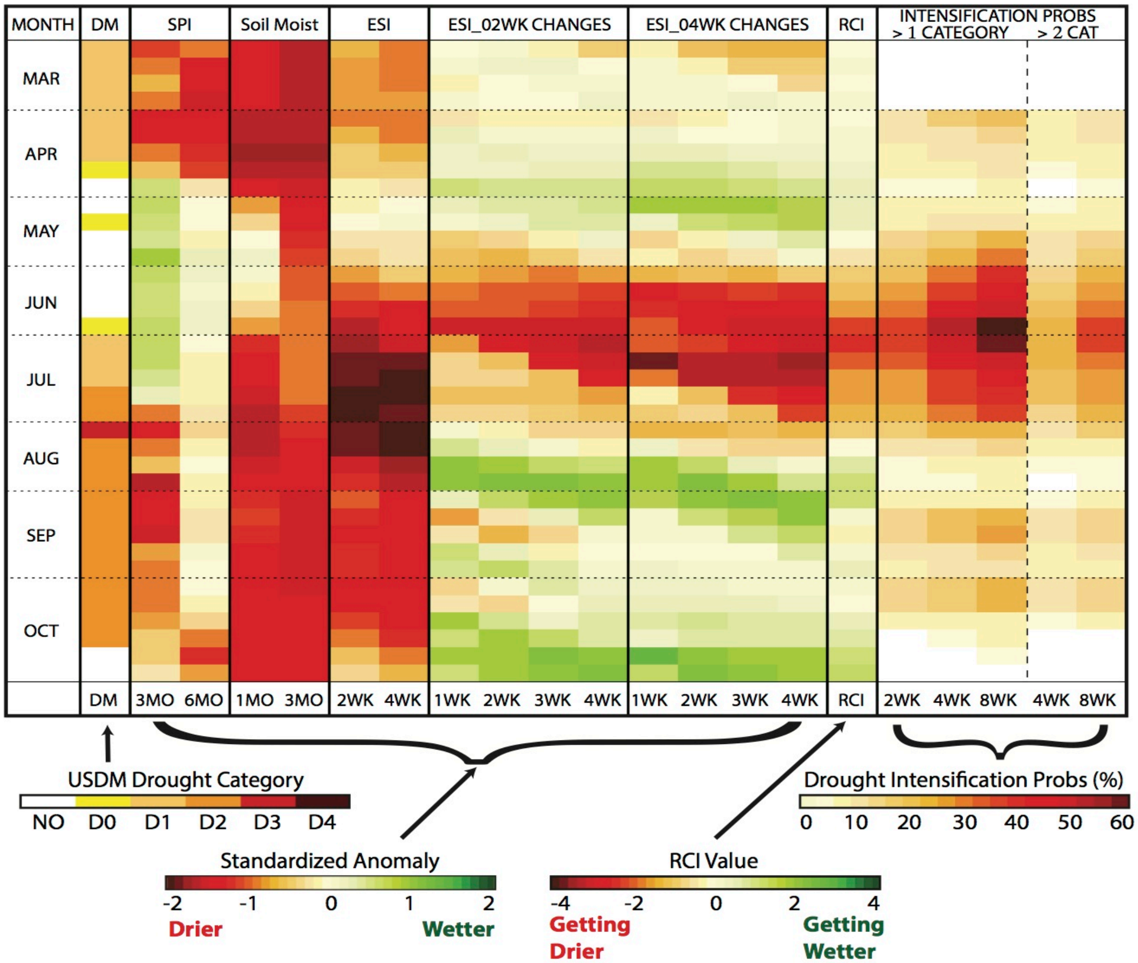

Fig 2. Example "plume diagram" depicting the evolution of the 2012 flash drought event across eastern Oklahoma. The weekly USDM drought analysis is shown in column 1. The Standardized Precipitation Index computed over 3- and 6-month periods is shown in columns 2 and 3, with total column soil moisture anomalies from the North American Land Data Assimilation system computed over 1- and 3- month periods shown in columns 4 and 5. ESI anomalies computed over 2- and 4-week periods are shown in columns 6 and 7. Standardized ESI change anomalies computed by differencing the 2- and 4-week ESI fields over 1, 2, 3, and 4 week time periods are shown in columns 8-15. The Rapid Change Index is shown in column 16, with various drought intensification probabilities computed from the RCI shown in columns 17-21.

The attendees were also asked to describe how access to drought early warning information would potentially affect their decisions. For ranchers, early warning of worsening conditions would allow them to pre-emptively move livestock to different pastures less susceptible to drought or to purchase supplemental feed. Several people noted that forage management is more dynamic than farming, thus, ranchers may realize larger benefits from improved drought early warning. Even so, farmers indicated that they would still benefit from early warning. For example, knowledge of an increased risk for drought development either locally or across other important farming areas may influence their marketing decisions. It may also help farmers determine if it would be beneficial to plant a cover crop after harvest and which one is most appropriate for the anticipated conditions.

2) Webinar and online drought impacts questionnaire

As part of the Southern Climate Impacts Planning Program's (SCIPP) *Managing Drought in the Southern Plains* webinar series, we hosted a 30-minute webinar in April 2015 that described the methodology used to compute the ESI and associated datasets, discussed their potential use as drought early warning tools within government and the agricultural and natural resources communities, and presented results from the focus group meetings. An online questionnaire soliciting feedback concerning the characteristics of flash drought events and their societal impacts and seeking ways to improve the visualization and dissemination of the ESI was also prepared. The webinar can be accessed at https://www.youtube.com/watch?v=PeLew-DFAuc&feature=youtube_gdata and the questionnaire can be accessed at https://www.surveymonkey.com/r/ESI_Comments.

3) Webpage and data dissemination modifications

Modifications were made to the ESI webpage (http://hrsl.ba.ars.usda.gov/drought/) based on feedback from the focus group meeting participants, USDM authors, and other people interested in using the ESI as a drought early warning tool or to assess vegetation health conditions. Most of the changes focused on enhancing the utility of the webpage for non-scientists by adding more detailed descriptions that can be used to interpret each image, improving the color bars used to plot the data, and streamlining the webpage by reducing the number of variables displayed on it. Modifications were also made to the ftp server so that USDM authors can directly access geotiff files corresponding to the current date in addition to being able to search for a specific prior date. In response to USDM author questions, we are also exploring ways to improve the representation of the ESI during periods of drought recovery.

4) Analysis of flash drought development at the Marena, OK In Situ Sensor Testbed

This study was performed by an M.S. student at the University of Oklahoma under the supervision of Co-PI Jeffrey Basara. The goal of the project was to provide insight into how physical relationships within the soil-vegetation-atmosphere continuum impact the intensity and development of flash drought events using observations from the Marena Oklahoma In Situ Sensor Testbed (MOISST) during the 2012 flash drought event.

The warmest year on record for the state of Oklahoma occurred during 2012. In response to exceptional warmth during the spring, the growing season began approximately three weeks earlier than normal, with vegetation flourishing due to the availability of sufficient precipitation and soil moisture. Inspection of Gross Primary Production (GPP) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) revealed large positive anomalies in vegetation biomass (200-400% of normal GPP) during March-May 2012. However, rapid drying of the soil column occurred during May (Fig. 3) as the vegetation extracted water from the soil to maintain overall health and precipitation was below normal. Beneficial rainfall during June 2012 moistened the topsoil, but the soil moisture at deeper depths (e.g., the 60 cm level) was not replenished. As such, when precipitation ceased in July during a time of greatly increasing atmospheric demand, the soil column rapidly dried due to increased evaporation and water extraction by the vegetation. As a result, ET rates rapidly diminished as the vegetation reached the wilting point, with the overall ecosystem collapsing by mid-August. With the reduction in green vegetation and soil moisture, the impacts of a long-term heat wave were accentuated and contributed to flash drought development. These results demonstrate that the soil and vegetation both played a critical role in driving the 2012 flash drought event at this location.

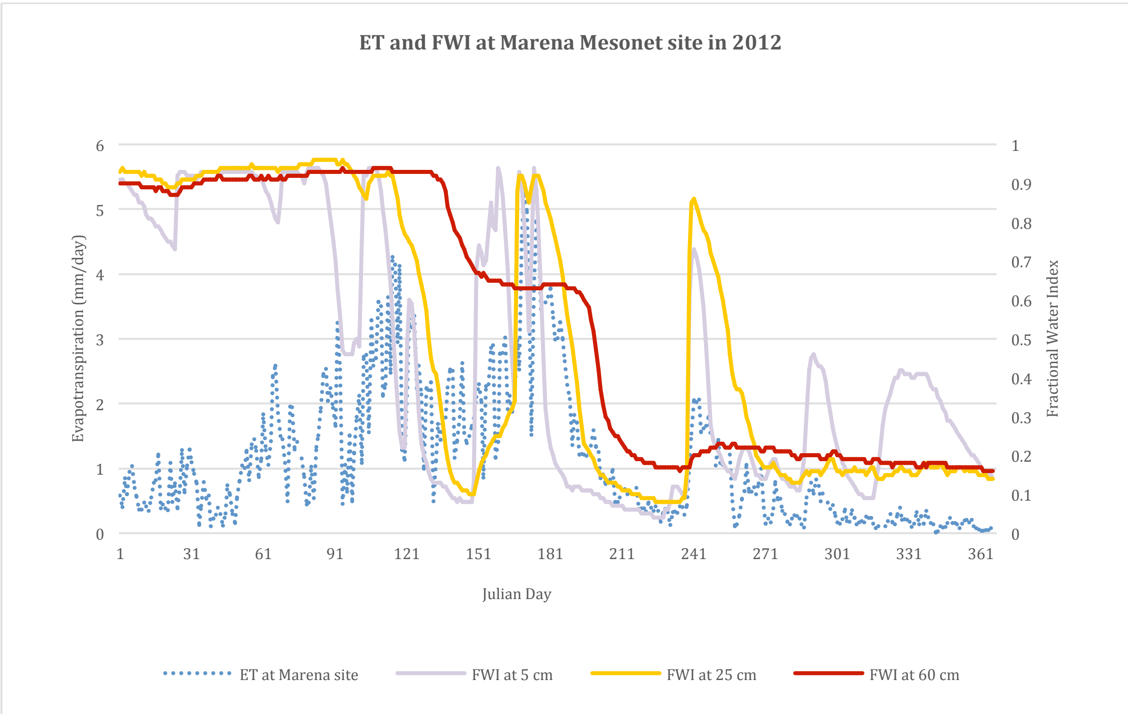

Fig. 3. Time series of evapotranspiration (blue line) and Fractional Water Index (FWI) at the 5, 25, and 60 cm levels (gray, yellow, and red lines) during 2012 at the Marena, OK site.

5) Exploring the relationship between drought and the dry line over Oklahoma

This study was performed by an M.S. student at the University of Oklahoma under the supervision of Co-PI Jeffrey Basara. The goal of this project was to explore potential relationships between drought, the location of the dry line, and convective precipitation during the 2011 flash drought using data from the Oklahoma mesonet. During the early stages of the drought (April-May), the USDM showed that severe drought conditions were present across southwestern Oklahoma, with the remainder of the state experiencing abnormally dry to moderate drought conditions. Significant precipitation fell across eastern Oklahoma during April and May, which relieved drought conditions across that part of the state and helped create a strong west-to-east gradient in soil moisture. Land-atmosphere coupling resulted in the anomalous eastward propagation of the dry line to where the soil moisture gradient was strongest, which impacted convective initiation and precipitation across Oklahoma. Very hot temperatures and abnormally strong surface winds during June resulted in rapid drying of the wet soil over central and eastern Oklahoma. Soil moisture analyses showed that significant drying moved from west to east and initiated along the western edge of the soil moisture gradient. As a result, while drought was present throughout the period across western Oklahoma, flash drought conditions developed over eastern Oklahoma in only a few weeks from the end of June to early July. Furthermore, by the end of the study period most of the state was in exceptional drought and soil moisture conditions were anomalously dry throughout the vertical profile.

B. Application of your findings to inform decision-making

Results from this project were shown in numerous conference presentations and as part of the focus group meetings and webinar.

Presentations:

Otkin, J. A., M. Shafer, M. Svoboda, B. Wardlow, and M. C. Anderson, 2015: Facilitating the use of drought early warning information through interactions with stakeholders. *13th Annual Climate Prediction Applications Science Workshop (CPASW)*, Las Cruces, NM.

Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, 2015: Temporal changes in drought indices used to provide early warning of drought development over sub-seasonal time scales. *29th Conference on Hydrology*, Phoenix, AZ.

Basara, J. B., J. A. Otkin, H. R. Mahan, M. C. Anderson, C. Hain, P. Wagle, and X. Xiao, 2015: Local Contributors and Predictability of Flash Drought at the Marena Oklahoma In Situ Sensor Testbed (MOISST) During 2012. *29th Conf. on Hydrology*, Phoenix, AZ.

Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, 2014: Temporal changes in drought indices provide early warning of drought development over sub-seasonal time scales. *2014 American Geophysical Union Fall Meeting*, San Francisco, CA.

Basara, J. B., J. A. Otkin, H. R. Mahan, M. C. Anderson, and C. Hain, 2014: Local contributors and predictability of flash drought at the Marena Oklahoma In Situ Sensor Testbed (MOISST) during 2012. *2014 American Geophysical Union Fall Meeting*, San Francisco, CA.

Otkin, J. A., 2014: Monitoring drought conditions using the satellite-derived Evaporative Stress Index. *United States Geological Survey*, Madison, WI. (Invited talk)

Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, 2014: Using temporal changes in drought indices to provide early warning of drought development over sub-seasonal time scales. *NOAA's 39th Climate Diagnostics and Prediction Workshop*, St. Louis, MO.

Otkin, J. A., 2014: Monitoring Drought Conditions using the Evaporative Stress Index. Nelson Institute for Environmental Studies Climate, People, and the Environment Program seminar, Madison, WI. (Invited talk)

Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, 2014: Using temporal changes in drought indices to provide drought early warning over sub-seasonal time scales. *World Weather Open Science Conference*, Montreal, Canada.

C. Planned methods to transfer information and lessons learned from this project

Information concerning the drought early warning capabilities of the ESI was shared with members of the agricultural community via the focus group meetings and through an ongoing dialogue with the participants after the meetings. In addition, the ESI is being generated and delivered weekly to the USDM authors in a format that enables overlay with the USDM, facilitating real-time assessment and evaluation. The ESI will be exposed to the larger USDM list server group of ~350+ experts for their feedback concerning the accuracy and responsiveness of the indicator. Finally, we will work with the USDM authors to investigate the potential for the ESI to be part of a new suite of gridded objective blend products, particularly the short-term blend, as a means of helping the USDM detect and depict rapid onset drought events.

D. Significant deviations from proposed work plan

None.

E. Publications, white papers, and reports during past 12 months

Otkin, J. A., M. C. Anderson, C. Hain, and M. Svoboda, 2015: Using temporal changes in drought indices to generate probabilistic drought intensification forecasts. *J. Hydrometeor.*, **16**, 88-105.

Otkin, J. A., M. Shafer, M. Svoboda, B. Wardlow, M. C. Anderson, C. Hain, and J. Basara, 2015: Facilitating the use of drought early warning information through interactions with agricultural stakeholders. *Bull. Am. Meteorol. Soc.*, in press.

Basara, J. B., J. A. Otkin, and co-authors, 2015: Soil, Atmosphere, and Ecosystem Contributors to Flash Drought Development. To be submitted to *Proceedings of the National Academy of Sciences*.

Flanagan, P. F., J. B. Basara, J. A. Otkin, 2015: Soil Moisture and Near-Surface Atmospheric Evolution Across Oklahoma During the 2011 Drought. To be submitted to *Advances in Meteorology*.

III. WEBSITE ADDRESS FOR FURTHER INFORMATION

ESI Webpage: http://hrsl.ba.ars.usda.gov/drought/

Webinar: https://www.youtube.com/watch?v=PeLew-DFAuc&feature=youtube_gdata

Online drought questionnaire: https://www.surveymonkey.com/r/ESI_Comments