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Project Title:
Drought monitoring: a system for tracking plant available soil moisture based on the Oklahoma Mesonet

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Principal Investigators:
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Scott, B.L., T.E. Ochsner, J.B. Basara, and B.G. Illston. 2011. Developing a soil physical property database for the Oklahoma mesonet. ASA-CSSA-SSSA International Annual Meetings. San Antonio, TX. Oct. 16-19, 2011.

Scott, B.L., T.E. Ochsner, B.G. Illston, C.A. Fiebrich, J.B. Basara and A.J. Sutherland. in review. New soil property database improves Oklahoma Mesonet soil moisture estimates. J. Atmos. Ocean. Tech.

Problem and Research Objectives:

Real-time drought monitoring is essential for early detection and adaptive management to mitigate the negative impacts of drought on the people, economy, and ecosystems of Oklahoma, and improved drought monitoring is a key need identified in the 1995 Update of the Oklahoma Comprehensive Water Plan. Drought impacts can be severe in Oklahoma. For example, the 2006 drought cost the state's economy over $500 million from lost crop production alone. While drought monitoring is critical to Oklahoma's resource managers, it is hampered by a lack of data on a crucial drought indicator: plant available water. Crop yield losses and, by extension, the economic impacts of drought, are strongly linked to plant available water. Plant available water (PAW) is the amount of soil moisture currently in the profile which is available for plant uptake. Some water is held so strongly by the soil that it is not available to plants.

The *long term goal* of the team of collaborators representing Oklahoma State University, the Oklahoma Mesonet, the Oklahoma Climatological Survey, and the University of Oklahoma is to develop the Mesonet as an innovative tool for understanding and managing the water resources of Oklahoma. The *objective of this proposal* is to bring to completion a first-generation drought monitoring system for Oklahoma based on PAW. The rationale for the proposed research is that providing resource managers with daily data on PAW will enable them to adopt management strategies to mitigate drought impacts. The proposal team is well prepared to succeed with this project due to the extensive expertise and strong achievement records in soil moisture related research, leadership in managing the Oklahoma Mesonet, and experience in the development of online products through the popular websites www.mesonet.org and www.agweather.mesonet.org. The following specific aims are proposed as part of the project:

Specific aim #1: Develop a scientifically-sound procedure for interpolating plant available water between Mesonet sites. Existing meteorological and geostatistical interpolation schemes will be tested for PAW and optimized to create a first-generation method suitable for mapping large-scale patterns in PAW.

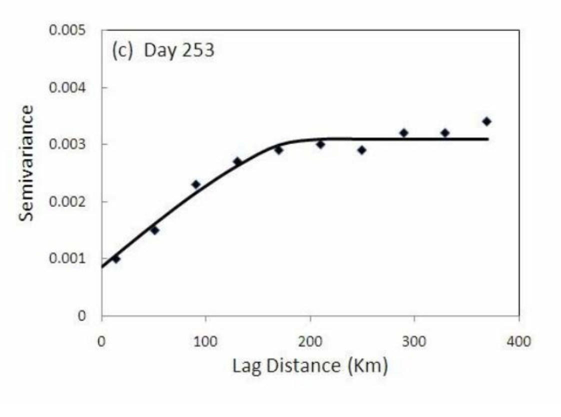
Specific aim #2: Create and release a new daily plant available water map for drought monitoring in Oklahoma. The measured soil properties, the real-time Mesonet sensor data, and the chosen interpolation scheme will be combined to create operational PAW maps on the Mesonet and Agweather websites.

Specific aim #3: Discover the similarities and differences between plant available water and other significant drought indicators (preliminary work only). A statewide PAW database will be created using archived Mesonet data from 1997-2010. Spatial and temporal patterns of PAW will be compared to those of other drought indicators. The goal is to generate preliminary data to leverage future funding opportunities.

Methodology:

Specific aim #1: Develop a scientifically-sound procedure for interpolating plant available water between Mesonet sites. We will develop a scientifically-sound procedure for interpolating PAW between Mesonet sites and for estimating the uncertainty of the interpolation. We will test two candidate methods: the meteorologically-derived Barnes objective analysis and a geostatistical approach called ordinary kriging.

The Barnes objective analysis was selected as a candidate method because it is widely accepted in meteorology and is currently used for interpolating many of the above- and below-ground variables measured by the Mesonet. The Barnes scheme was originally developed for interpolating sea-level pressure across the US. It is an inverse distance weighting approach in which the influence of a given observation drops off exponentially as the distance from the observation increases. Multiple "passes" or iterations of the interpolation are performed and compared to the observation set with the accuracy of the interpolation improving upon each pass. Three or four passes are recommended for optimal performance (Barnes, 1994). Barnes objective analysis requires only about 10% as much computing time as ordinary kriging (Su and Stensland, 1988), and in some cases the Barnes scheme can be as accurate as ordinary kriging (Dirks et al., 1998). We will evaluate the effectiveness of a four pass Barnes scheme for interpolating PAW. In the testing phase, the scheme will be implemented using the "barnes.m" function (Pierce, 2010) in Matlab (Mathworks, Inc. Natick, MA).



The second method evaluated will be ordinary kriging (Matheron, 1971). This method is built on the semivariogram, which shows how the spatial variance increases with the separation distance (lag) between the points. Ordinary kriging was selected as a candidate method in part because it has been successfully applied in a recent study of the Mesonet soil moisture data (Lakhankar et al., 2010). Figure 1 is reproduced from that study and shows an empirical and a fitted theoretical semivariogram of soil moisture in Oklahoma. The lag distance at which the semivariogram approaches the maximum value (or "sill") is called the "range", and that value defines how far spatial dependence extends. In this example, the range is ~175 km. The positive y-intercept in Fig. 1 is called the "nugget" and arises from small-scale spatial variability primarily due to variability in processes and properties at the land surface scale. Based on Fig. 1, these scales and processes accounted for about 33% of the total spatial variance in soil moisture (ratio of nugget to sill).

Fig. 1. Empirical (symbols) and theoretical (line) semivariograms for Mesonet soil moisture, 9/10/03.

Ordinary kriging offers some distinct advantages. In some cases it significantly outperforms inverse distance weighted methods like the Barnes objective analysis (Engel, 1999; Zimmerman et al., 1999). It will also result in semivariogram parameters for PAW which will be of tremendous scientific value for tasks like distributed hydrologic modeling, remote sensing validation, or designing future PAW monitoring networks. And, significantly, ordinary kriging can produce uncertainty maps for the interpolated PAW. Thus, it provides a built in indicator of the interpolation quality. But, as we have mentioned, the ordinary kriging is more complex than the Barnes objective analysis. For our application it is possible that the semivariogram parameters will have to be recalculated for each day of data. And, ordinary kriging assumes that the variable of interest is stationary, i.e. has the same mean value everywhere in the domain. Fortunately, it has been demonstrated that using localized search neighborhoods makes ordinary kriging fairly robust to nonstationary data (Journel and Rossi, 1989; Yost et al., 1982). We will evaluate the effectiveness of ordinary kriging for interpolating PAW. We will use the Geostatistical Analyst extension in ArcGIS (ESRI, Redlands, CA) to accomplish the ordinary kriging during the testing phase.

To evaluate the performance of the two interpolation methods, a set of 15 Mesonet stations will be left out and not used when optimizing the parameters of the interpolation schemes. The 15 omitted stations then provide independent validation data. The value of PAW on selected days as predicted by interpolation at those 15 locations will be compared to the measured values from the Mesonet sensors. Standard statistics such as bias, RMSE, and coefficients of determination will be calculated to determine the accuracy of the interpolation. These validation statistics will be key in quantifying the uncertainty associated with the interpolated PAW values. A similar validation procedure has already been successfully applied for evaluating the interpolation of Mesonet soil moisture data (Lakhankar et al., 2010). We hypothesize that ordinary kriging will lead to greater interpolation accuracy but at the cost of higher computational requirements. We will consider both of these factors in selecting the interpolation method for creating the operational PAW maps.

Specific aim #2: Create and release a new daily plant available water map for drought monitoring in Oklahoma. The measured soil properties, the real-time Mesonet sensor data, and the selected interpolation scheme will be combined to create these first-generation maps.

Operational PAW maps will be added to the Mesonet and Agweather websites and disseminated to a broad range of end users.

Software developers from the Oklahoma Climatological Survey will integrate the formulas for plant available water calculation and interpolation into the C++ based, derived-variable calculation engine for the Mesonet's WeatherScope visualization software. The plant available water formulas will be made available to customers in version 1.9 of WeatherScope. This code will also be incorporated into the WeatherMapper software for server-side generation of map images, and WeatherWriter software for text product generation. Finally, the formulas will be incorporated into PHP-based software that produces vector graphs in HTML for display in web browsers.

We will incorporate new versions of these software packages into the Mesonet's operational data processing system, and configure that system to produce map and graph products for plant available water. The new products will be incorporated into the Mesonet and Agweather web sites and made available to the public. The maps will include an indication of the uncertainty of the interpolation. If the Barnes method is chosen, then we will provide a single uncertainty value applicable to the entire PAW map, e.g. reported values are accurate to within +/- XX mm. If the kriging method is chosen, we will be able to provide uncertainty values for any point in the State.

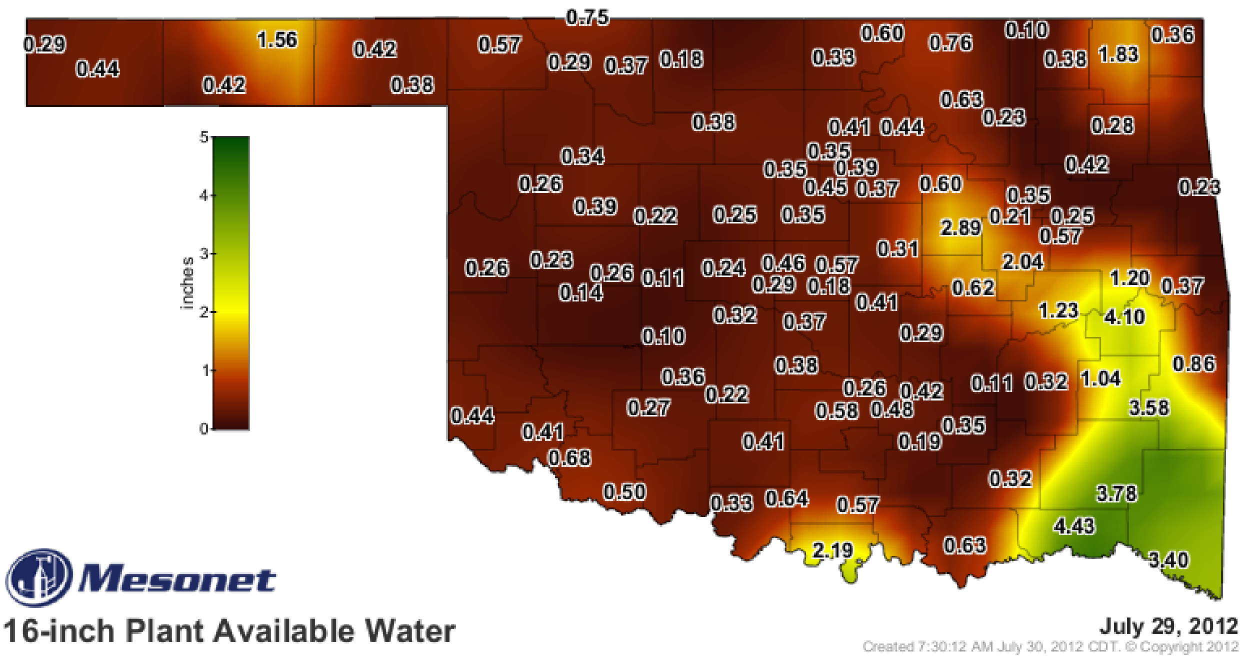
Specific aim #3: Discover the similarities and differences between plant available water and other significant drought indicators (preliminary work only). Multiple techniques have been developed to provide qualitative and quantitative assessments of the magnitude and spatial extent of drought conditions. Quiring (2009) provides a thorough overview of drought monitoring analyses and notes that each methodology has relative strengths and weaknesses. In particular, the use of real-time soil moisture conditions is drastically limited in operational drought monitoring. As noted previously, Illston and Basara (2003) discovered that soil moisture anomalies in Oklahoma were often displaced from regions identified as experiencing drought conditions via the PSDI and the SPI.

Preliminary analysis of PAW estimates utilizing Oklahoma Mesonet data demonstrate that the values provide enhanced insight regarding the spatial and temporal variability of water within the near-surface soil column. In regards to drought monitoring, a great challenge is identifying when meteorological drought conditions impact agricultural and hydrological drought conditions both during the onset and at the conclusion of drought. Because PAW provides an integrated value of soil moisture in the soil column, it captures longer-term trends associated with wetting and drying of the soil useful for monitoring drought. Further, PAW can be monitored in near real-time using Oklahoma Mesonet data.

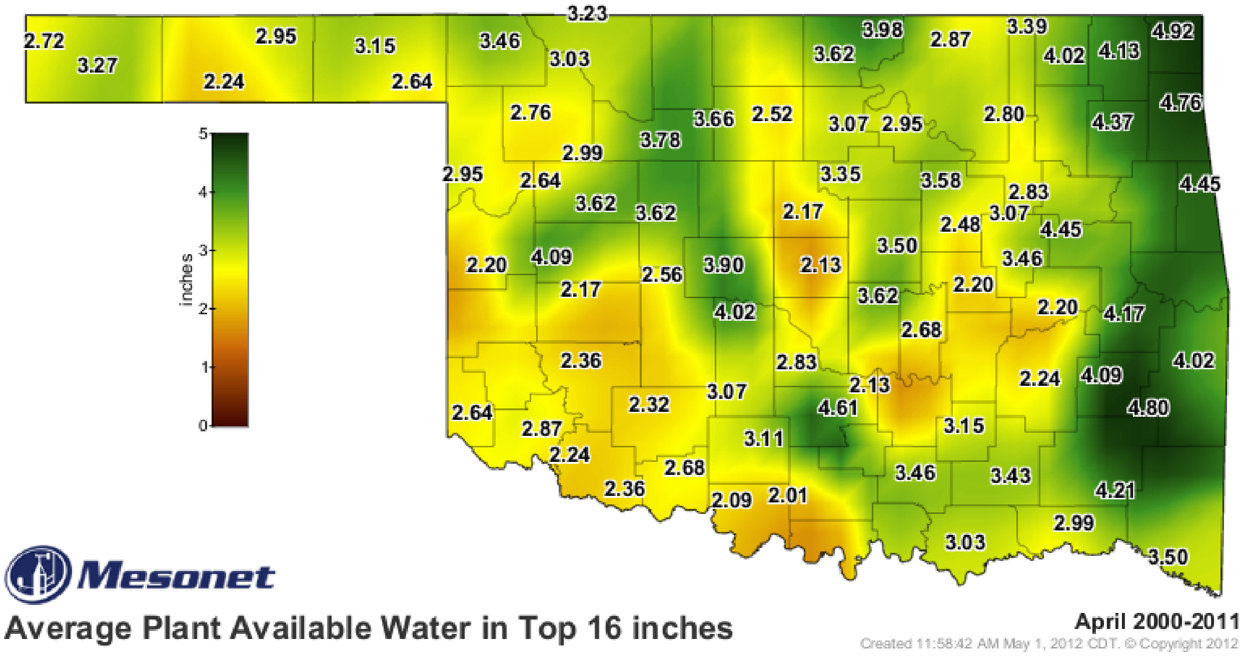
To quantify the utility of PAW as a drought monitoring tool, a 14-year, statewide, PAW database will be created using archived Mesonet data from 1997-2010. Spatial and temporal analyses of PAW will be compared to other drought indicators including PSDI, SPI, the effective drought index (Byun and Wilhite, 1999), percent normal values, and deciles/percentiles (Gibbs and Maher, 1967). In addition, analyses from the U. S. Drought Monitor (http://drought.unl.edu/dm/monitor.html), available beginning in 2000, will also be compared with PAW. This work will enable us to begin to discover and document the connections between PAW and other accepted indicators of drought. The goal is to generate quantifiable results demonstrating the utility of real-time drought monitoring in Oklahoma using PAW that can be used to leverage future funding opportunities.

Principal Findings and Significance:

We completed the development of a system for tracking PAW based on mesoscale observations from the Oklahoma Mesonet. We have developed and released to the public statewide daily PAW maps for the 0-4 inch, 0-16 inch, and 0-32 inch soil layers as described in specific aims #1 and #2 (Fig. 2). We have opted to use the Barnes objective analysis for interpolation of PAW data at present because we have no evidence yet that ordinary kriging will produce more accurate maps and the Barnes approach is simpler. This is an area that needs further research.



We have also created and released publicly via www.mesonet.org user-selectable, historical maps of statewide PAW as described in specific aim #3 (Fig. 3).



Student Status	Number	Disciplines
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M.S.	1	Plant and Soil Sciences
Total	3	