Quantitative Analysis and Statistics of Land-atmosphere Interactions at Oklahoma Mesonet Sites during Drought Periods

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I. Introduction

Land-atmosphere interactions play an important role in affecting weather and climate on both local and regional scales. Quantifying the variability of evapotranspiration (ET), which is a critical link to land-atmosphere interactions, would contribute to a better understanding of drought development and alleviation during dry periods. As it is difficult to obtain ET across the state due to the limited number of flux towers, a model that estimates ET using *in situ* or remote-sensed climitological and vegetation data would be helpful to monitor ecosystem changes during drought events.

The goal of this study is to estimate ET across Oklahoma from 2000 to 2013 via the Oklahoma Mesonet Model (MEMo) and to investigate ET climatology during this period and its correlation with soil moisture. ET was estimated by combining the Oklahoma Mesonet data (Fig. 1) and MODIS normalized difference vegetation index (NDVI) data. Statewide climatology during the 14 years and spatial distribution of ET for both dry and wet seasons were analyzed. The significant drought event in 2011 was selected as a specific case to conduct the correlation discussion.

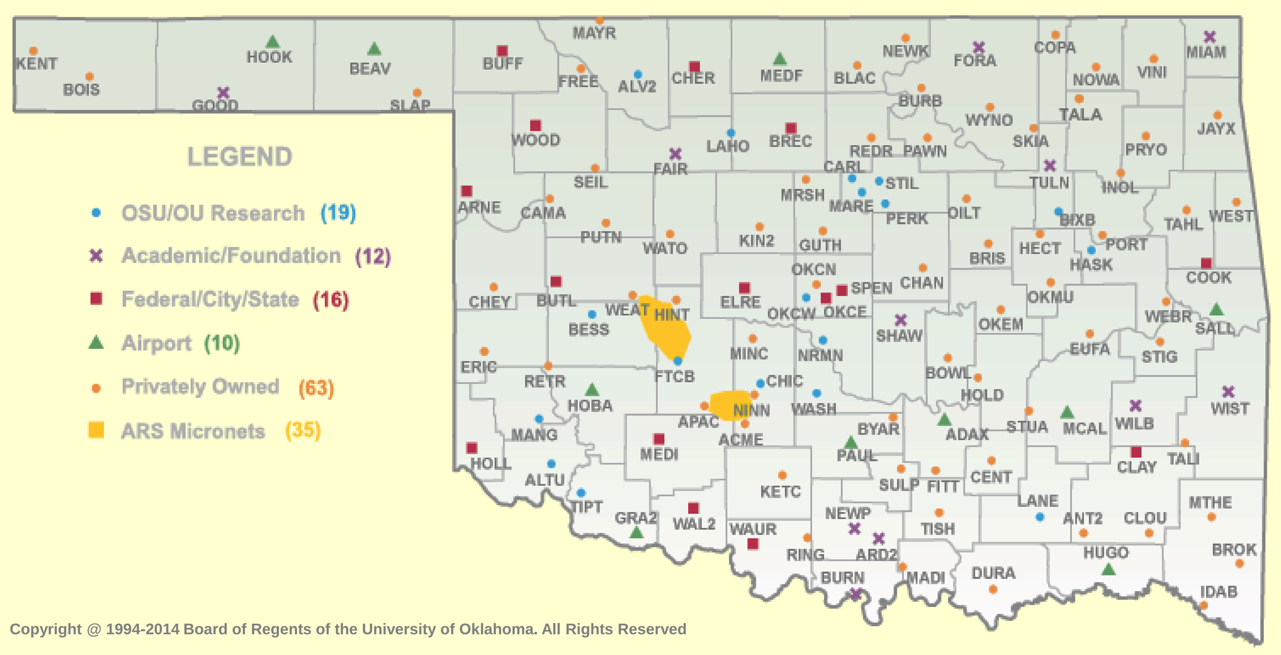

Figure 1. Site Map of the Oklahoma Mesonet

II. The MEMo Model Introduction

The structure of MEMo (Fig. 2) is based on the VegET model developed by Senay (2008), in which the estimated actual ET (ET_a) equals the product of crop coefficient K_{cp}, water stress coefficient K_s, and reference evapotranspiration ET_0. In order to avoid complicated NDVI climatology and crop phenology analysis in VegET, MEMo estimates K_{cp} using a simple linear equation concluded by Allen (2011). K_s is also replaced by the column-depth-weighted average of fractional water index (FWI) measured by Oklahoma Mesonet to minimize soil moisture modeling limitations in VegET. Additionally, MEMo uses Mesonet long-crop potential evapotranspiration (PETL) to delineate the reference evapotranspiration of farming crops and natural vegetation across Oklahoma.

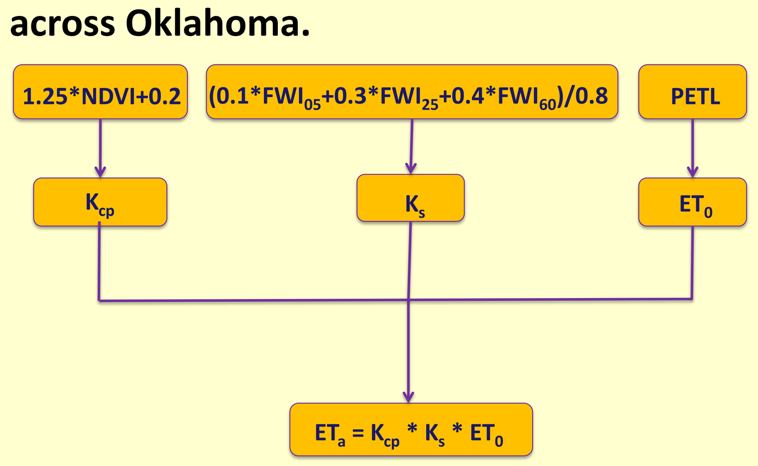

Figure 2. The structure of MEMo based on VegET by Senay (2008)

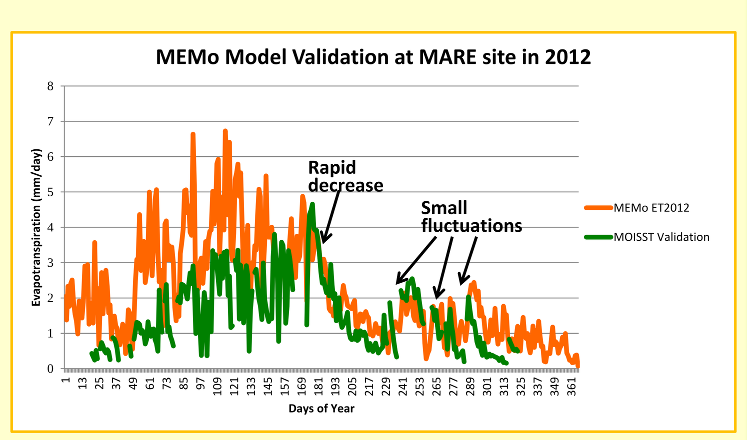

Figure 3. MEMo validation at Marena Mesonet site with MOISST data

MEMo was evaluated at the Marena Mesonet site in 2012 (Fig. 3) by comparing its result with the flux data during the same period at Marena, Oklahoma In Situ Sensor Testbed (MOISST), which locates only a few miles away. MEMo over-estimates ET in the first half year, but shows satisfactory agreement with MOISST flux data during the second half year. It is noted that MEMo captures the rapid decrease of ET in late June accurately, as well as the following fluctuations of ET (pointed out by arrows). This indicates that MEMo has great potential of modeling ET during drought events.

III. ET climatology & distribution estimated by MEMo

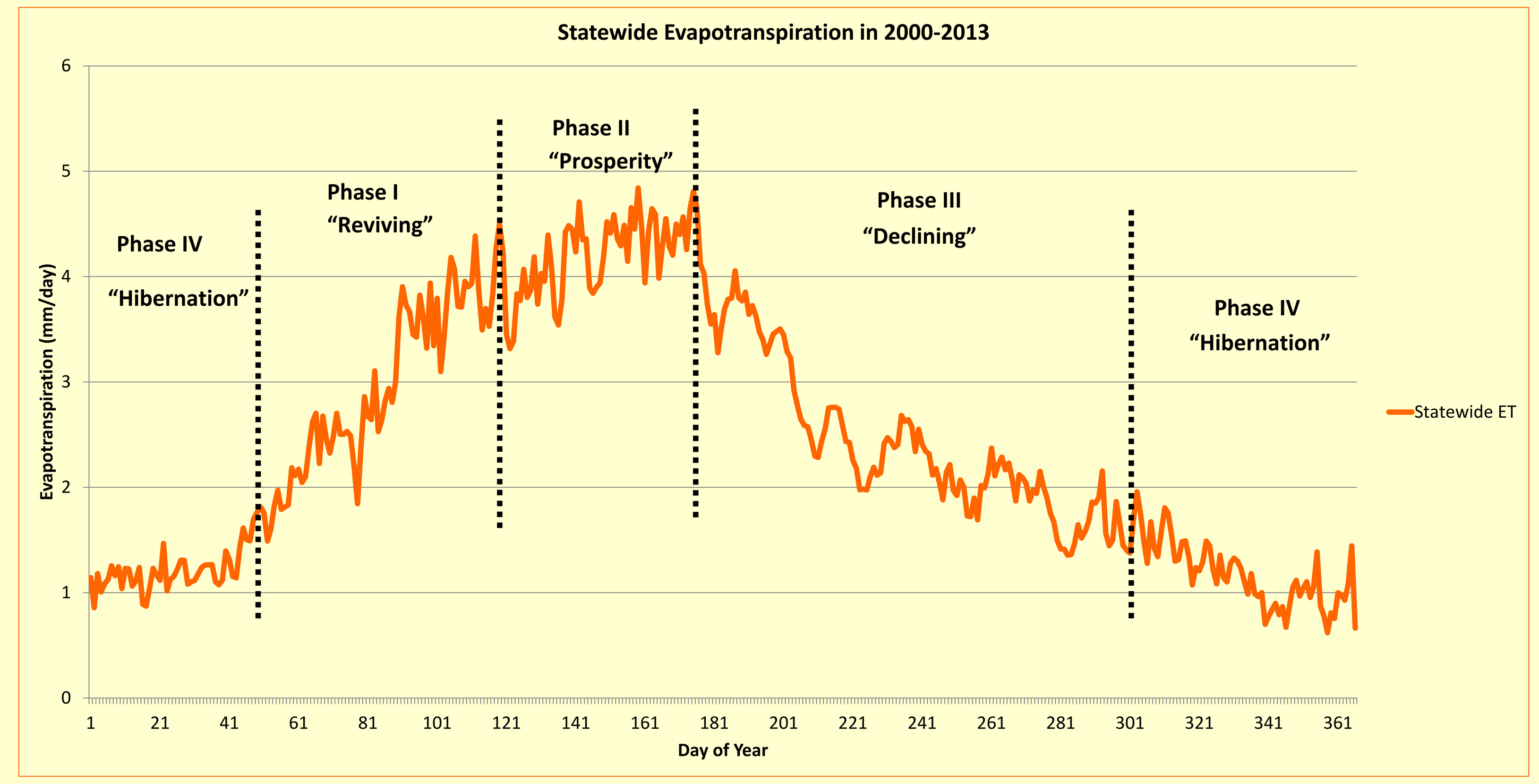

Figure 4. The yearly climatology of statewide evapotranspiration estimated by MEMo averaged over 14-year study period and all sites across the state

Fig. 4 shows the yearly climatology of statewide evapotranspiration (ET) estimated by MEMo averaged over the 14-year study period. ET is low at the beginning of the year due to low precipitation and low vegetation activity, and then increases as the vegetation starts to grow. It reaches its maximum at the end of June and then decreases gradually as time approaches the end of the year, in accordance with the dry climate in summer and the following senescence and withering of plants.

The climatology of ET can be divided into 4 phases (dash line in Fig. 4). The Phase I "Reviving " is in the early spring when precipitation starts to increase and plants begin to grow. The Phase II "Prosperity" is in late spring and early summer when precipitation is abundant and vegetation is lush. The Phase III "Declining" lies in late summer due to dry climate and thus the low evaporation from soil and low transpiration by plants, and this phase lasts for the whole period of fall as plants senesce. The Phase IV "Hibernation" is in the winter time when low temperature, little precipitation, and inactive vegetation lead to low evapotranspiration.

The spatial distribution of average ET over the 14-year period was also investigated (Fig. 5). June is selected as a representative month in the "prosperity phase" with active vegetation and abundant precipitation. The east part of the state generally has higher ET than the west part in June. The maximum ET lies in the northeast part of the state which has vast forest and wetter climate, and the lowest ET appears in the dryer panhandle area. In December, the winter "hibernation phase", ET is low across the state, due to low or no vegetation activity and low precipitation.

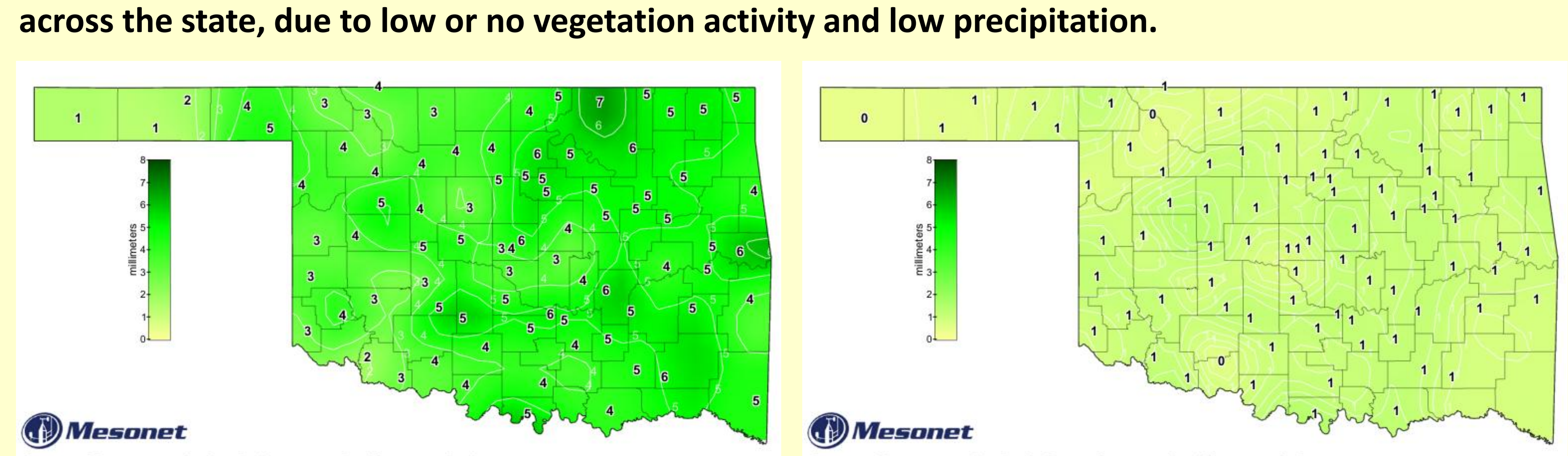

Figure 5. Spatial distribution of average ET over 14-year period in June (left) and December (right)

IV. ET dynamics in a specific drought event

The climatology of ET as well as its correlation with the moisture in soil columns was specifically studied in the significant drought in 2011. The statewide average fractional water index (FWI) at 5 cm, 25 cm, and 60 cm depths are plotted daily in the same figure (Fig. 6) as statewide average ET in order to understand how ET changes as drought develops. Statewide average precipitation is also plotted for reference (Fig. 7).

With the soil moisture storage from the winter of 2010 and a few precipitation events in the spring of 2011, FWI was high at all three depths at the beginning of 2011, and ET was increasing as a result of plant growth. However, as precipitation was far below average in the following early summer months, soil moisture reduced rapidly when the plants extracted a large amount of water from the soil column.

After a few rainfall events in August, there were significant fluctuations in the upper soil column (5 cm), but ET only bounced slightly as the vegetation did not recover. Soil moisture gradually returned to its original level when winter came, but ET remained low as the dominant part of ET, which is transpiration by vegetation, was low when plants were inactive.

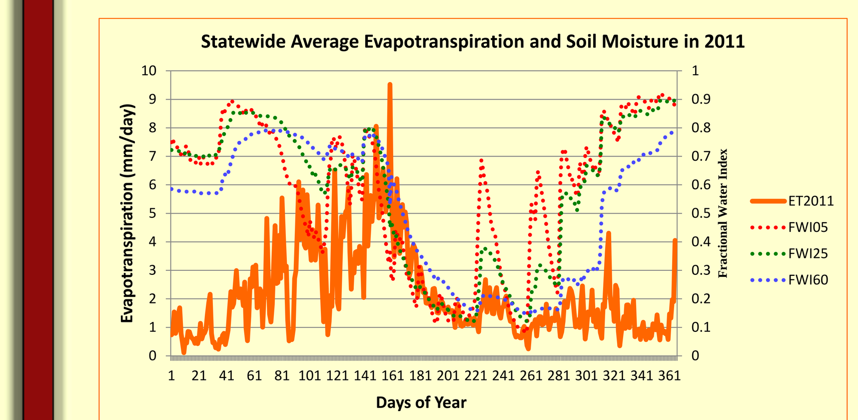

Figure 6. Statewide average ET climatology together with fractional water index climatology at 5 cm, 25 cm, and 60 cm

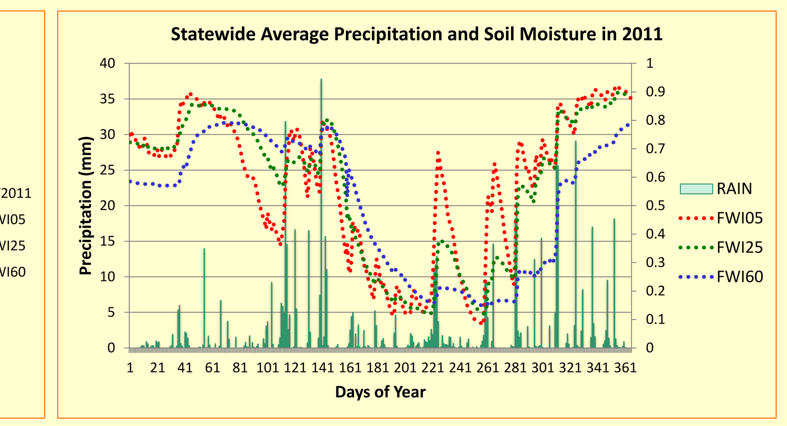

Figure 7. Precipitation together with fractional water index climatology at 5 cm, 25 cm, and 60 cm

The change of ET across the state in the drought event in 2011 was studied by looking into the spatial distribution of ET in the early summer months. The ET map of May, June, and July were plotted to demonstrate how the vegetation responded to the drought during the drying-out period. In May, ET was above 4 mm/day for most of the state, indicating healthy vegetation and relatively wet condition across the state. When it came to June, the west, northwest, and southwest parts of the state started to dry out, representing by the reduction of ET at these areas. The central part of the state received some precipitation and thus ET increased slightly in this month. After entering July, ET had significant reduction across the whole state after low or no precipitation for several months, as the plants dried out after depleting the water in the soil.

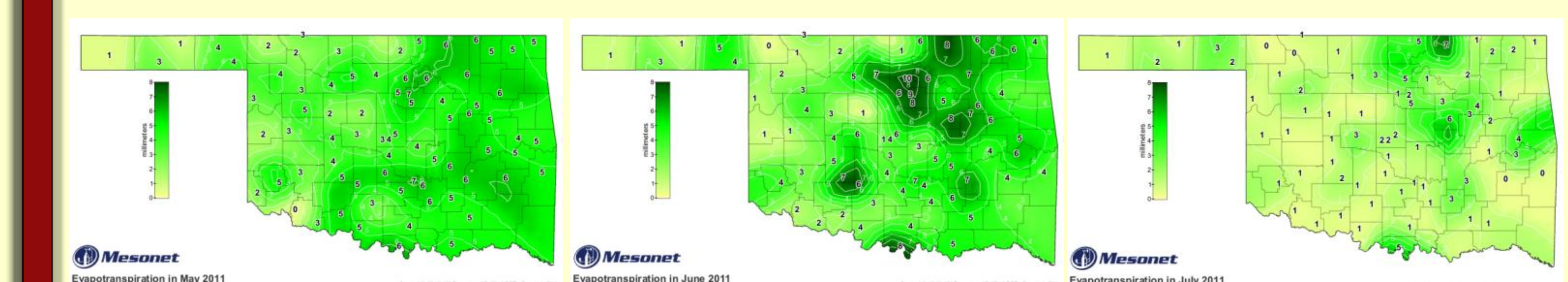

Figure 8. Spatial distribution of ET in 2011 in May (left), June (middle) and July (right)

V. Future Plans

- Examine and modify the equation of each factor in MEMo to improve the accuracy in ET estimation during early spring.
- Conduct the research on ET climatology respectively in the 9 different climate divisions of Oklahoma to compare.
- More cases will be studied to have a better understanding in different types of droughts.

VI. Acknowledgments and References

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