The Spatial and Temporal Variability of the Evaporative Fraction and Soil Moisture During a Period of Historic Precipitation

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1. Introduction

During the summer of 2007, periods of heavy, persistent rainfall resulted in record-breaking precipitation totals across Oklahoma. For example, portions of Oklahoma received over 300 mm of rainfall for the summer, smashing previous climatological records. During this extremely wet summer, the Cloud and Land Surface Interaction Campaign (CLASIC) collected observations of land-atmosphere interactions and a unique surface energy budget data set was collected. The CLASIC data set coupled with a period of historic rainfall and extremely moist soil conditions provided an unmatched opportunity to (1) quantify the impact of soil moisture conditions on the partitioning of the surface energy budget over varying land types and (2) provide understanding of the historical, record-breaking significance of 2007 to other Oklahoma summers. This paper presents a subset of observations from 23 sites installed across central Oklahoma during 2007, including sites in the Atmospheric Radiation Measurement program network, Little Washita and Ft. Cobb ARS micronet, and Oklahoma Mesonet (McPherson et al. 2007).

2. Background of Period of Historic Precipitation

Typically during the summer in Oklahoma, rainfall totals decrease following the climatological peak in precipitation that occurs during the late-spring. When coupled with increased atmospheric demand on evapotranspiration due to increased temperature, soil moisture deceases. In addition to decreasing soil moisture, evapotranspiration increases, due to the growth of vegetation across Oklahoma throughout the early summer.

However during the summer of 2007, statewide precipitation totals yielded the second wettest summer on record, while it was the wettest for two Oklahoma climate divisions (Central and Southwest). In fact most portions of the state received more than 300 mm of rainfall with portions greater than 300 mm above normal. As a result, soil moisture conditions were extremely moist and remained near field capacity for the majority of the summer period.

3. Methodology and Data

The foci of this paper are two sites deployed in the Little Washita watershed and the Norman Oklahoma Mesonet super site during the period of late-April to October 2007. In addition the data from the Norman Oklahoma Mesonet super site was utilized for a comparative analysis to the summers of 2004 and 2006. The sites in the Little Washita watershed were established as part of the CLASIC field experiment with eddy covariance sensors. These sites continually collected surface energy budget observations, including net radiation as well as the latent, sensible and ground heat fluxes. Two of these sites, known as LW3 and LW4, were placed in winter wheat fields and were spaced approximately 3.3 km apart. Following the winter wheat harvest in early June, the vegetation conditions evolved differently through out the remainder of the summer at the two sites.

Located in northern Norman in native vegetation, the Norman Oklahoma Mesonet super site (NRMN) was constructed as part of the OASIS project (Monroe 2007). This particular site, along with the other OASIS sites, continually collected observations of the surface energy budget, soil moisture, and bare and vegetated soil temperature.

The primary analysis of the data set examined soil moisture variability and its impact on the surface energy budget variables. The partitioning of energy received at the surface into latent and sensible heat fluxes is significantly influenced by soil moisture conditions (Entekhabi 1996; Basara and Crawford 2002; McPherson 2007). This study utilizes the evaporative fraction (EF), which can be described as the ratio of the latent heat flux to the available surface energy and ranges from 0 for dry conditions to 1 with maximum evapotranspiration. Specifically, EF is calculated as:

$$EF = LH/(LH+SH) \tag{1}$$

where LH is the latent heat flux and SH is the sensible heat flux. The surface energy budget data were filtered to eliminate erroneous data as well as to eliminate days with excessive precipitation and little downwelling solar radiation due to extensive cloud cover. Once the dataset was thoroughly quality controlled, time series of EF was calculated using the filtered data and then averaged on daily and five day resolutions.

For soil moisture conditions, the fractional water index (FWI) was utilized and ranges from 0 for dry soil conditions to 1 for soils at field capacity (Schneider et al. 2003; Illston et al. 2004; Illston et al. 2008). The FWI values were calculated for the depths of 5, 25, 60, 75 cm below the surface and relevant time-series were generated.

4. Results

a. Little Washita watershed (LW3 and LW4)

In early May 2007, the winter wheat crops were lush and green at both sites. By late May, the senescence of the winter wheat occurred and harvest occurred in early June. Following the wheat harvest, significance differences in the trend of the evaporative fraction were evident between the two Little Washita sites. Wheat stubble remained at after the harvest, but the vegetation conditions at LW3 and LW4 developed differently throughout the remainder of the summer. For example, vegetation consistent with native rangeland developed over the wheat stubble surrounding LW3. However, the area surrounding LW4 remained as stubble with extensive bare soil. Consequently, these differences in land surface conditions were evident in the evaporative fraction time series for both sites.

During the summer of 2007, soil moisture below 25 cm measured at the Apache Mesonet site (midway between LW3 and LW4) remained at or near field capacity from late spring to early August (DOY 200 -205). Near the surface (i.e., 5 cm) the soil remained near field capacity while fluctuating due to rainfall received at the surface and

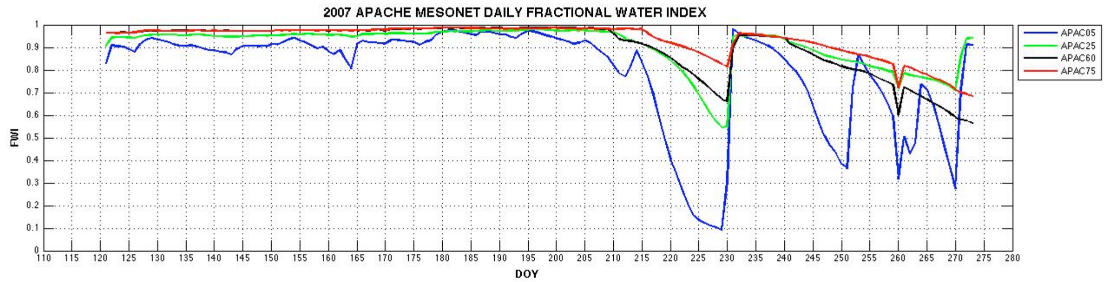

Figure 1: FWI for the apache Mesonet site from 1 May to 30 September 2007.

limited evaporation. However, during a lull in summer precipitation (DOY 205-230), soil moisture content declined, but quickly saturated with the passing of the remnants of tropical storm Erin in mid-August (DOY 230; Ardnt et al. 2009) before declining again throughout the remainder of the summer.

During early May, near saturated soils coupled with healthy, green vegetation allowed for more than 70% of available energy at the surface to be partitioned into latent heat flux (Fig. 2). However, as the wheat crop senesced and was subsequently harvested, the EF values declined in late-May and early June (DOY 135-155). From the second

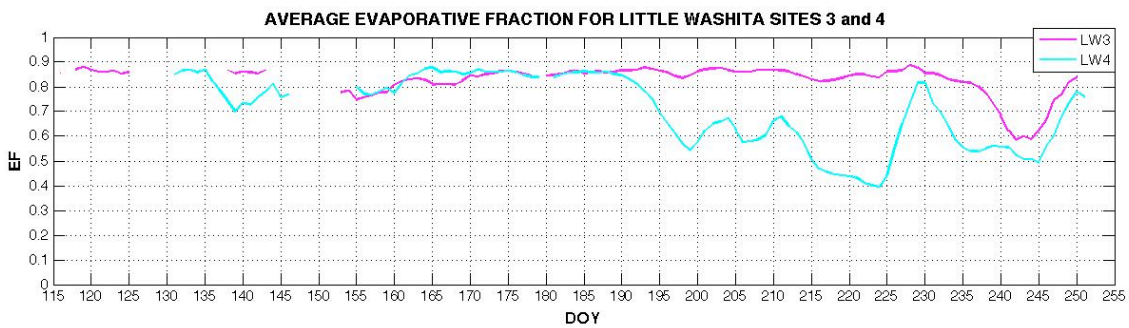

Figure 2: Average Evaporative Fraction for LW3 and LW4 from 25 April to 12 September 2007

week of June through early July (DOY 155-190) values of the evaporative fraction increased due to increasing soil moisture and remained greater than 0.7, suggesting that a large part of available energy at the surface was used for evaporation due to saturated soils. By the second week in July (DOY 190) the EF values decreased at LW4 as the amount of the available energy at the surface was increasingly partitioned into the sensible heat flux due the absence of vegetation and transition to bare soil conditions. Conversely, due to the transition to native rangeland vegetation at LW3, EF values remained greater than 0.8 until late-August when EF values declined in response to drying soils. The passing of the remnants of tropical storm Erin (DOY 230) was evident at LW3 and soil moisture (Fig. 1), where both values of EF and FWI quickly increased before declining afterwards. Finally, the EF values at both sites increased to values greater than 0.7 in response to the recharge of soil moisture in early Fall 2007.

b. Norman Oklahoma Mesonet super site

During 2007, soil at the 60 cm depth remained at field capacity for the substantial part of the summer with a decline in soil moisture towards the end of the study period. Figure 3 revels that soils near the surface at 5 and 25 cm remained saturated

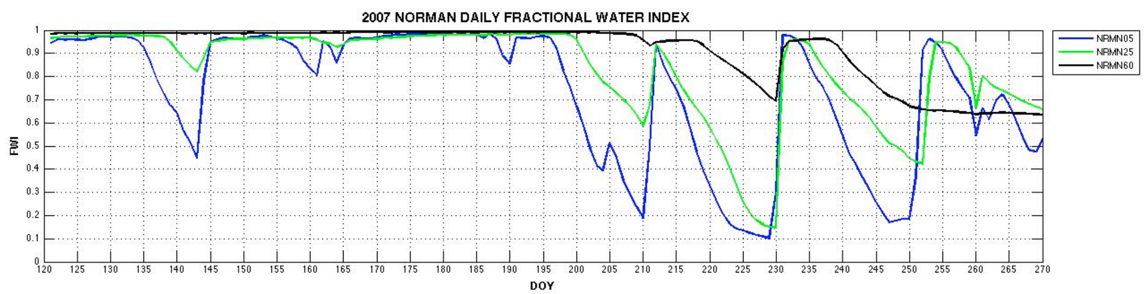

Figure 3: FWI for Norman from 1 May to 30 September 2007

with fluctuations in soil moisture content through early July (DOY 195). Through the remainder of the study period, the soil moisture content at 5, 25, and 60 cm below the surface fluctuated in response to rainfall, especially to tropical storm Erin in mid-August (DOY 230). Unlike 2007, the soil moisture conditions were quite dry and variable throughout the summer of 2004. For example, soil moisture declined rapidly in late-April at all measured depths and remained dry through early June (DOY 150; Fig. 4).

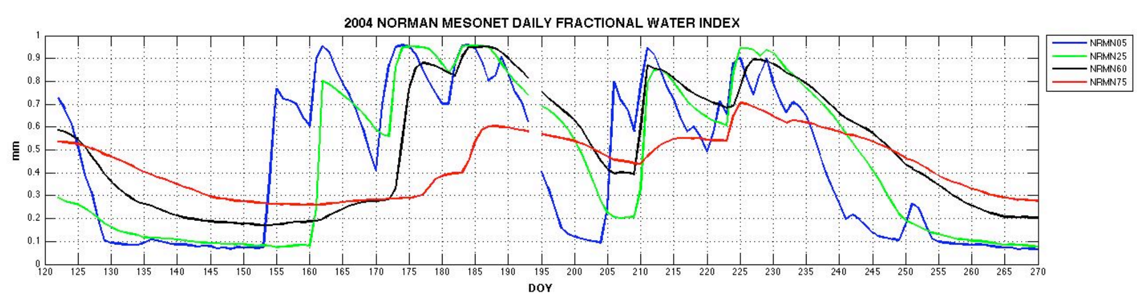

Figure 4: FWI for Norman from 1 May to 30 September 2004

In addition soil moisture fluctuated for the majority of the summer and finally declined in mid-August (DOY 230) to extremely dry conditions. Figure 5, demonstrates a declining trend in soil moisture at the depths of 25, 60, and 75 cm from early May through mid-July (DOY 121-195). For the remainder of the summer and in the early fall

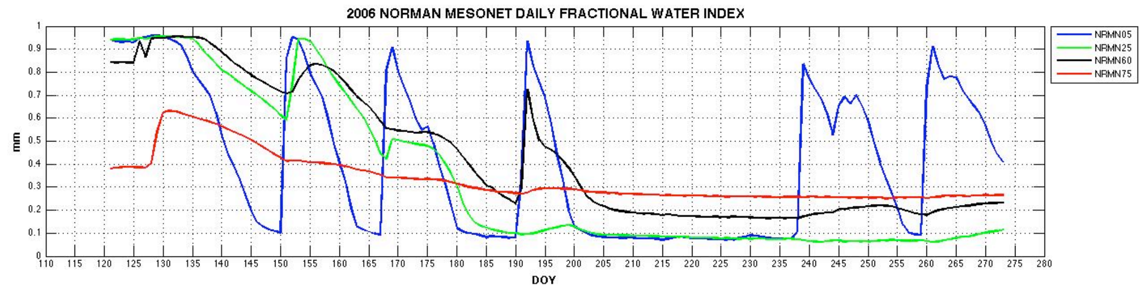

Figure 5: FWI for Norman from 1 May to 30 September 2006

(DOY 195-273), soil at the depths of 25, 60, and 75 remained extremely dry. While the period was quite dry, the soil moisture conditions near the surface (5 cm) oscillated with periods of rainfall for majority of the summer while during late-July to late-August (DOY 200-237) near surface soil was extremely dry.

During the summer of 2007 Norman, the values of EF remained at or above 0.7 as abundant moisture influenced the partitioning of available energy near the surface toward increased latent heat flux. Meanwhile, the values of EF for 2004 and

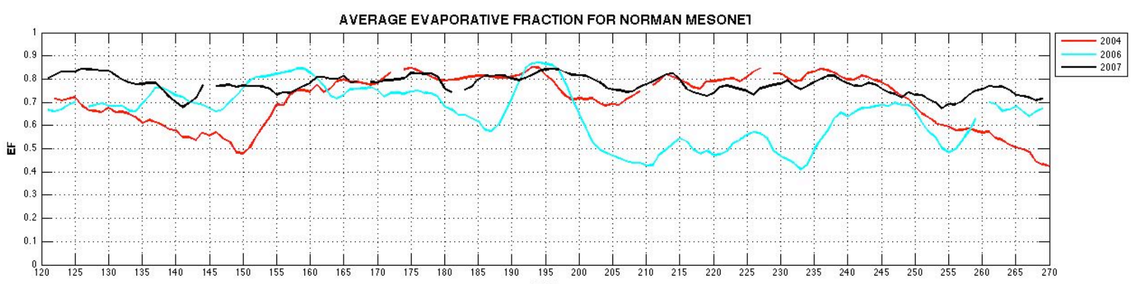

Figure 6: Average Evaporative Fraction for Norman from 1 May to 30 September 2004, 2006, and 2007.

2006 mimicked the pattern of the soil moisture. As such, EF values decreased with decreasing soil moisture and increased as soil moisture increased. For periods during the summer of 2004, the relative partitioning of available energy at the surface utilized for evaporation was actually greater than during the summer of 2007. For the majority of the summer of 2006, values of evaporative fraction were lower than 2004 and 2007. Unlike 2004 and 2007, the sensible heat flux dominated due to a deficiency of moisture from soil and vegetation.

5. Conclusions

During the summer of 2007, the state of Oklahoma received periods of heavy, persistent rains, which resulted in record-breaking rainfall totals and extremely moist soil moisture conditions across most of Oklahoma. At the Little Washita sites, near saturated soils coupled with healthy, green vegetation allowed for more than 70% of available energy at the surface to be partitioned into latent heat for evaporation. However, at LW4 due to lack of vegetation after wheat harvest, EF values decreased below 0.7 as sensible heat flux became a larger component of the surface energy budget. The summer of 2007 may have broken records in regard to rainfall totals, but for sites classified as native rangeland values of EF were equal to or near values for 2004. For the summer of 2006, much of Oklahoma was in a severe to extreme drought. As such, the EF and FWI values reflected the severity drought where values were lower to those for both 2004 and 2007.

6. Acknowledgements

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