P1.13 **CLIMATOLOGY OF SOIL MOISTURE VARIABLES USING THE OKLAHOMA MESONET**

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1. INTRODUCTION

Soil moisture is an integral part of the hydrologic cycle. Improved understanding of the spatial and temporal variability of soil moisture will result in a clearer understanding of how the atmosphere is impacted by varying soil moisture conditions. Since 1996, the Oklahoma Mesonet has instrumented nearly 100 sites with soil moisture sensors at four depths (5, 25, 60 and 75 cm). These sites provide observations every 30 minutes across varying soil, vegetation and climate conditions.

While scientists have studied the impact of soil moisture conditions on meteorological variables (Basara 2002), regional, continental, and global climatologies of soil moisture are not available. Thus, a soil moisture climatology is needed as a framework around which other research, such as numerical modeling and drought detection, could be enhanced.

2. INSTRUMENTATION

The Oklahoma Mesonet (Brock et al. 1995) provides real-time data from 114 stations across Oklahoma with at least one station in every county. Data are recorded every 5 minutes and include meteorological variables such as air temperature, wind speed and direction and rainfall.

In 1996, Campbell Scientific 229-L (CSI 229-L) soil moisture sensors were installed at 60 Mesonet sites. These sensors measure a temperature difference (DeltaT), which is a change in the sensor temperature after a heat pulse is introduced (Basara and Crawford 2000).

Over the brief lifetime of the soil moisture sensor network in the Oklahoma Mesonet, two of the original 60 sites no longer collect soil moisture observations because these Mesonet sites were decommissioned. However, during 1999, 229-L sensors were installed at 42 additional sites. The majority of the 100 Mesonet sites which are equipped to measure soil moisture have 229-L sensors at four depths (5 cm, 25 cm, 60 cm, and 75 cm). These depths were strategically placed to enhance agricultural and meteorological modeling and research.

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3. CALCULATED QUANTITIES

From the measured DeltaT values, hydrological variables such as soil water content, soil matric potential, and Fractional Water Index (FWI) (Schneider et al. 2001) can be calculated. Unfortunately, soil water content depends heavily upon soil texture and soil matric potential is exponentially related to soil wetness. Because FWI has no impedance from these factors, it is an ideal variable for analyzing soil drought conditions.

The Fractional Water Index is a normalized version of the 229-L sensor response (Schneider et al. 2001). This unitless value ranges from very dry soil having a value of 0, to soil at field capacity illustrated by a value of 1. It is given by the formula:

$$FWI = \frac{\Delta T_d - \Delta T_{ref}}{\Delta T_d - \Delta T_w} \tag{1}$$

where, ΔT_{ref} represents the sensor response (ºC), ΔT_d represents the response when the sensor is dry (ºC) and ΔT_w represents the response when the sensor is wet (ºC) (Schneider et al. 2001).

4. CLIMATOLOGIES

Because of limited continuous observations of soil moisture, climatological averages of soil moisture values have rarely been calculated. These averages would

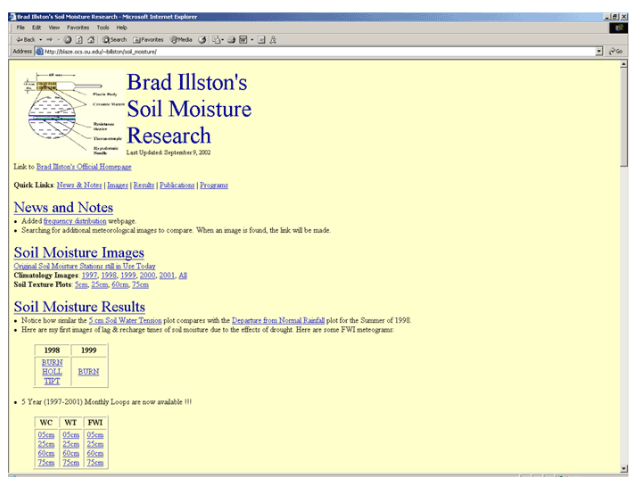

Figure 1 - A screen capture of the website used to display the soil moisture climatology images.

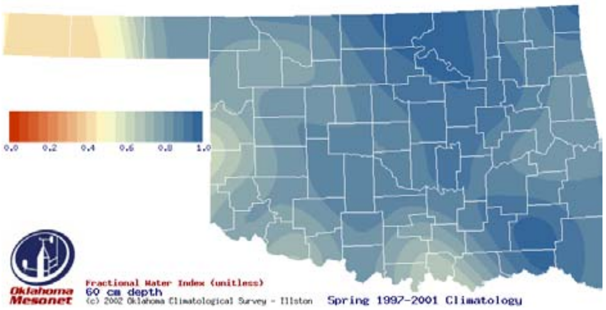

Figure 3 – A plot of the 60 cm Fractional Water Index for Spring 1997-2001.

benefit the meteorological, climatological and agricultural communities. Data from the soil moisture sensors installed at the Oklahoma Mesonet have allowed monthly, seasonal, annual and 5-year averages of soil water content, soil matric potential and FWI to be calculated. Overall, the study used over 20 million observations and generated over 4,000 images.

A website (Fig. 1) was developed to display all of the images created in this study as well as other related works. Additionally, java scripts on the webpage allow animations of the soil moisture climatology images to be shown. While images were created for all 4 depths, greater focus will be given to the 5 and 60 cm depths. They correspond closely to the root zone depths of short grass and crops, respectively. These are the two dominate types of vegetation in the state.

Figures 2 and 3 display the 5 and 60 cm FWI 5-year climatology in the Spring. During this time the soil moisture values across most of the state (excluding the far western portion of the panhandle) transition from moist soil conditions (at or near field capacity) to drier conditions. Frequent precipitation during this period slows this transition, but signs of drying appear in the southern and southwestern parts of the state.

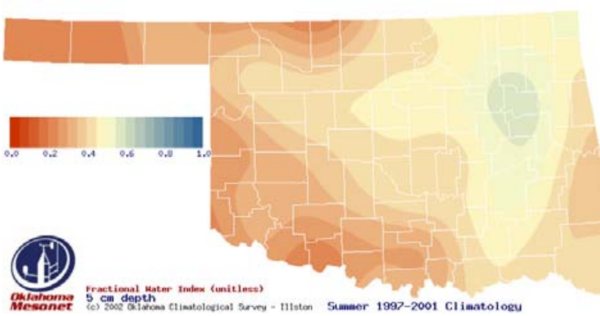

Figure 4 - A plot of the 5 cm Fractional Water Index for Summer 1997-2001.

Figures 4 and 5 display the 5 and 60 cm FWI 5-year climatologies for the summer months. During this period the soil moisture is typically at its driest point of the year.

Further examination of Figure 4 reveals that the near surface soil is more moist in the eastern portion of the state than the west. The western part of Oklahoma typically has lower FWI values due to both the warmer and drier climate as well as reduced vegetation.

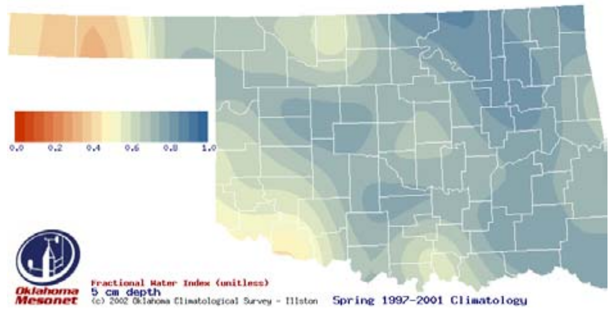

Figure 2 - A plot of the 5 cm Fractional Water Index for Spring 1997-2001.

Figure 5 shows how the deeper depths have FWI values that are not as dry as the near surface. While the warm temperatures and minimal rainfall impact the near surface soil, these conditions do not completely infiltrate to the deeper depths. The soil moisture data demonstrates that it may take over a month for dry conditions similar to those seen at the surface to reach the deeper depths.

While statewide trends are noted in Figures 4 and 5, site specific trends can also be seen. For example, the Altus station in southwestern Oklahoma is adjacent to an irrigated field. The water from irrigation moves laterally in the direction of the non-irrigated Mesonet site. However, only the 60 and 75 cm sensors are affected from this intrusion of water. Thus, the soil moisture sensors yield increased moisture compared with nearby stations. However, since a large portion of the land use is irrigated near Altus, these deeper layer values are representative of the area surrounding the site. This deep layer wet anomaly is termed the "Altus effect." A different wet-biased effect due to sandy soil was found at the Antlers site in southeastern Oklahoma. Both the "Altus effect" and the Antler's wet bias are demonstrated in the 60 cm plot in Figure 5.

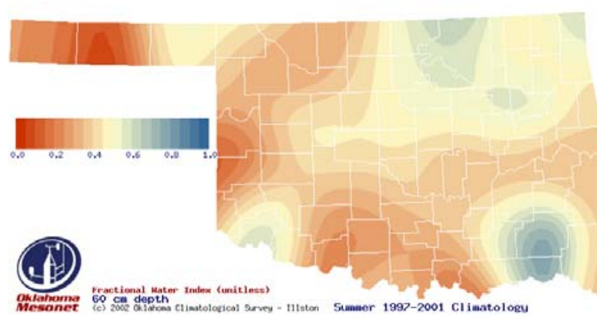

Figure 5 - A plot of the 60 cm Fractional Water Index for Summer 1997-2001.

5. DEVIATIONS

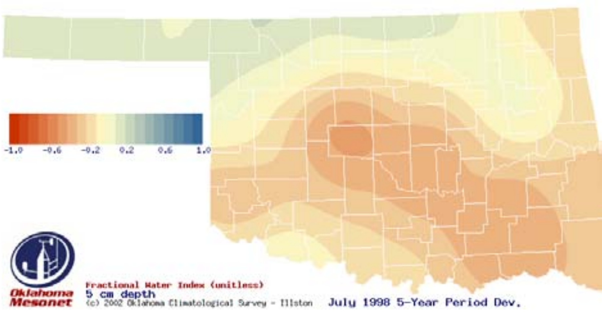

Figure 6 - A plot of the 5 cm Fractional Water Index 1998 July deviation from the 1997-2001 July 5cm mean.

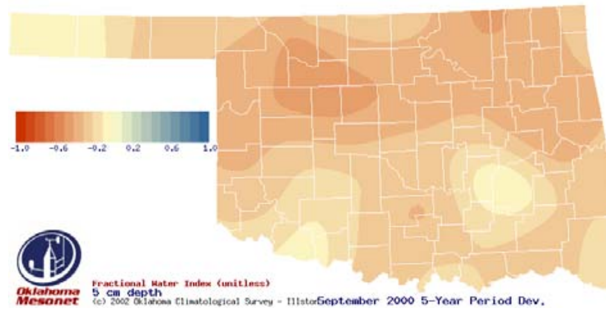

Figure 7 - A plot of the 5 cm Fractional Water Index 2000 September deviation from the 1997-2001 September 5 cm mean.

Once five year mean values were determined, deviations from the mean were calculated to determine variations of the soil moisture conditions in Oklahoma at each given time period. Climatological anomalies, such as the Altus and Antlers effects, are removed through the deviation process. Since FWI resides on a linear scale, linear deviations were calculated. Two types of deviations were calculated: overall deviations and period deviations.

An overall deviation is the difference between a given time period (i.e. January 1997) from the total five year mean (i.e. All data). These deviations reveal when the soil moisture is above or below average for the five year period. However, these plots show limited, but useful results. One may expect August to be a month which conditions are drier than the five year period and that a plot is not necessary. However, these plots are useful in other ways, such as climate and agricultural model verification and research of past events.

A period deviation is the difference between a given time period (i.e. January 1997) and the five year mean for that time period (i.e. All January data). These deviations are more useful in climatological analysis, such as drought analysis. While August is know to be a dry month on average, period deviations reveal whether if a particular August is wetter or drier than an average August.

Figures 6 and 7 display the FWI period deviations from the five year mean at the 5 cm depth for July of 1998 and September of 2000. These months correspond to the peak intensity of two droughts that occurred for their respective years. These droughts resulted in significant economic loss to the state from lower crop yields and lost livestock.

In 1998, the central portion of the state deviated farther towards the dry end than other parts of the state. The majority of the state had FWI deviations in excess of -0.20 to -0.50. In some locations the deviation of FWI reached over -0.60. The northwest part of the state was wetter than normal due to a stalled front, which is reflected in Figure 6.

In 2000, almost no rain fell statewide resulting in below average soil moisture conditions statewide. Similar to 1998, the majority of the sites had FWI deviations in excess of -0.20 to -0.50, while in some locations the deviation of FWI reached over -0.60. However, in 2000 the driest conditions covered a larger area of the state when compared to 1998.

6. DATA DISTRIBUTION

Understanding the distribution of the data for the five year climatology provides further insight into the dataset. For every year and every sensor depth in this study, point distribution and cumulative percentage plots were generated. Sensor depth plots provide insight into the temporal variations of the environment (i.e. short-term climatological signals), while yearly plots can give

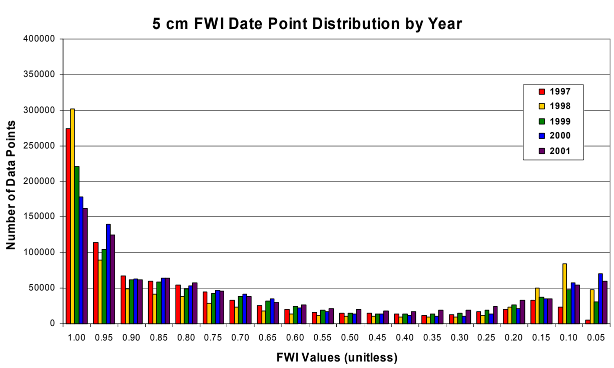

Figure 8 - A point distribution per year for FWI values at 5 cm.

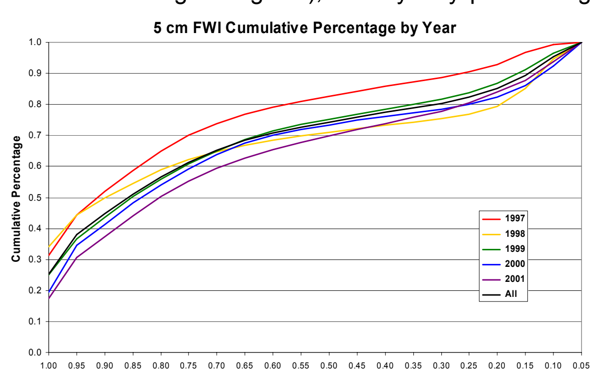

Figure 9 - A cumulative percentage per year for FWI values at 5 cm.

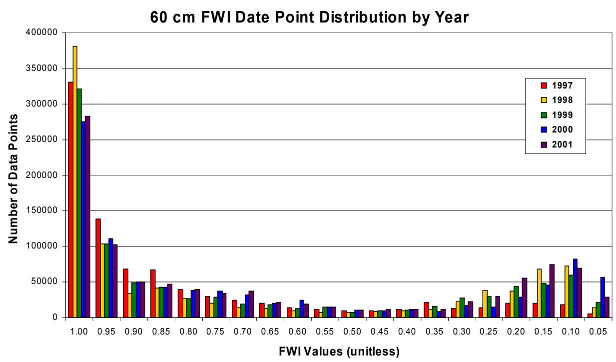

Figure 10 - A point distribution per year for FWI values at 60 cm.

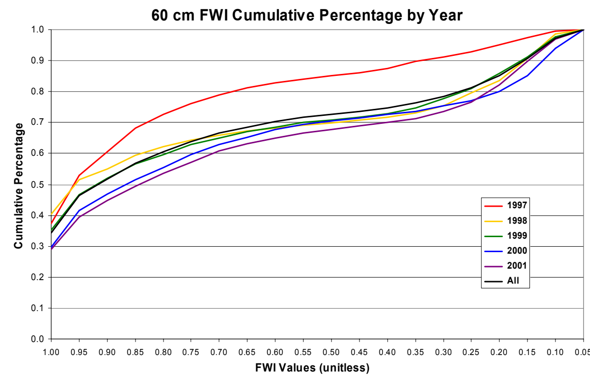

Figure 11 - A cumulative percentage per year for FWI values at 60 cm.

further understanding to the temporal variations of the sensors (i.e. sensor drift or long-term climatological signals).

Plots of point distribution and cumulative percentages at 5 cm are shown in Figures 8 and 9. The majority of the data in the point distribution resides on the wet and dry ends. This shows that the soil conditions transition fairly quickly from wet to dry and dry to wet. The cumulative percentage plots reveal that over the years, the overall soil conditions have progressively become drier. For the most part, each year's curve is drier than the previous year. Because quality assurance procedures remove, and the fractional water index formula does not result in sensor drift, this is likely a sign of long-term climatological change in the soil moisture across Oklahoma.

Plots of point distribution and cumulative percentages at 60 cm are shown in Figures 10 and 11, respectively. The results at 60 cm are almost identical as those at the 5 cm depth. The exception is that the magnitude of the of the point distribution at the wet and dry ends are a little stronger than those at the near surface. This quicker transition period at the 60 cm depth is likely due to the buffer from lighter precipitation events that only affect the near surface.

7. CONCLUSION

The creation of a soil moisture climatology was successful. A five year library of climatologies and deviations serve as a first step in better understanding the subterranean hydrological aspects of Oklahoma. With the continued monitoring of soil moisture conditions by the Oklahoma Mesonet, this climatology can be expanded and grow each year. Results from this study, such as plots of soil moisture deviations, are very important in areas such as climate modeling, agricultural modeling, drought analysis, and other meteorological and hydrological applications.

8. REFERENCES

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