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REAL-TIME SOIL MOISTURE INFORMATION FOR DROUGHT MONITORING AND ASSESSMENT

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1. INTRODUCTION

Soil moisture is an important parameter in many hydrologic and land-atmosphere interactions (Brubaker and Entekhabi, 1996). Anomalous soil moisture conditions on a large-scale can lead to droughts or floods, while regional variations can enhance dryline formation, convective initiation, and precipitation recycling. Furthermore, the relative partitioning between latent and sensible heat fluxes at all spatial and temporal scales is controlled largely by variations in soil moisture conditions. Thus, understanding the spatial and temporal nature of soil moisture is vital to determine the influence that land surface processes have upon the atmosphere.

The need for soil moisture observations has been addressed in recent articles such as Emanuel et al. (1995), who emphasized that improved observations of soil moisture conditions may lead to dramatic forecasting improvements related to the location and timing of the onset of deep convection over land, quantitative precipitation forecasting, and seasonal climate prediction. Furthermore, Entekhabi et al. (1999) noted that existing surface networks could be instrumented with sensors to measure soil water as well as atmospheric processes. The information gathered by these co-located sensors could be used to evaluate new hydrological theories, modeling and remote sensing techniques.

Recognizing the need for improved in situ measurements, the Oklahoma Mesonet (Brock et al., 1995), an automated network of 115 remote, meteorological stations across Oklahoma, installed sensing devices to measure soil moisture conditions. A new suite of products were recently developed to display the soil moisture observations within an interactive, web-based infrastructure. This paper provides background information on the soil moisture measurements, highlights the new capabilities of the web-based display system, and discusses the utility of such observations in monitoring subterranean conditions during extended wet and dry periods.

2. NETWORK OVERVIEW

The Oklahoma Mesonet (Brock et al. 1995) provides real-time meteorological data from 115 stations across Oklahoma with at least one station in every county (Figure 1). The Mesonet sites measure variables including air temperature and relative humidity at 1.5 m, wind speed and direction at 10 m, pressure, solar radiation, rainfall, and bare and vegetated soil temperatures at intervals between 5 and 30 minutes. The co-located nature of each of the individual sensors provides an excellent opportunity to directly compare atmospheric and hydrologic observations.

Since 1996, Campbell Scientific 229-L (CSI 229-L) soil moisture sensors were installed at 101 Mesonet sites. These heat dissipation sensors measure the temperature change (DeltaT), of sensor before and after a heat pulse is introduced (Basara and Crawford 2000). The majority of the 101 Mesonet sites are equipped to measure soil moisture at four depths (5 cm, 25 cm, 60 cm, and 75 cm). These depths were strategically placed to enhance agricultural and meteorological modeling, aid in drought monitoring, and generate research quality datasets. From the measured DeltaT values, hydrological variables such as soil water content, soil matric potential, and Fractional Water Index (FWI; Schneider et al. 2003) can be calculated.

3. SOIL MOISTURE QA PROCEDURES

Careful calibration of the 229-L sensor is critical in providing quality soil moisture observations. Thus, careful laboratory measurements were collected to calibrate the sensors. First, to replicate dry soil conditions, each sensor was placed in desiccant for 3 days. The largest DeltaT measured during that time was recorded as DeltaT$_{max}$. Next, each sensor was placed in a water bath for three days to replicate saturated soil conditions. As a result, the smallest DeltaT values were measured (DeltaT$_{min}$) because the specific heat of water is larger than air. Finally, the laboratory analyses were used to calculate the sensor-specific calibration coefficients.

Once the soil moisture sensor was installed, the data was flagged as erroneous for a period of 21 days to allows time for the soil to heal around the sensor.

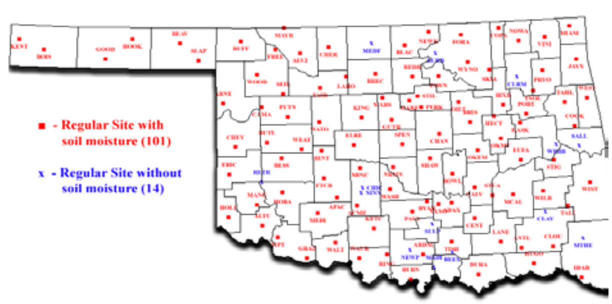

Figure 1. A map of the Oklahoma Mesonet indicating stations with and without soil moisture sensors.

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Test Name	Description
Range	a) If Start Temp or Final Temp are outside of the range –30 °C to 50 °C, flag observation as “failure” b) If Calibrated Delta-T is outside of the range 1.0 °C to 4.1 °C, flag the observation as “failure” c) If Reference Temperature is outside of the range –30 °C to 55 °C, flag the observation as “failure”
Suspect Calibration	If Calibrated Delta-T passes the Range test, but is outside of the range 1.38 °C to 3.96 °C, flag the observation as “suspect” and investigate whether new field coefficients are needed
Step	a) If Calibrated Delta-T at 5 cm increases by more than 0.75 °C in 30 minutes, flag the observation as “warning” b) If Calibrated Delta-T at 25, 60 or 75 cm increases by more than 0.50 °C in 30 minutes, flag the observation as “warning” c) If Calibrated Delta-T at 5 cm decreases by more than 2.58 °C in 30 minutes, flag the observation as “warning” d) If Calibrated Delta-T at 25 cm decreases by more than 2.5 °C in 30 minutes, flag the observation as “warning” e) If Calibrated Delta-T at 60 cm decreases by more than 2.0 °C in 30 minutes, flag the observation as “warning” f) If Calibrated Delta-T at 75 cm decreases by more than 1.5 °C in 30 minutes, flag the observation as “warning” g) If Start Temp or Final Temp at 5 cm change by more than 5 °C in 30 minutes, flag the observation as “warning” h) If Start Temp or Final Temp at 25, 60, or 75 cm change by more than 3 °C in 30 minutes, flag the observation as “warning”
Freeze	If Start Temp or Final Temp are less than 1.25 °C, flag the observation as “suspect”

Table 1. Automated quality assurance algorithms test for soil moisture data collected by the Oklahoma Mesonet.

A number of automated quality assurance (QA) algorithms test the soil moisture data throughout the day (Table 1). In general, the algorithms check to ensure that: 1) the data are reporting in appropriate ranges, 2) the calibration coefficients are correct, 3) the data are not behaving erratically, and 4) the soil is not frozen. The QA Meteorologist investigates each problem detected by the automated tests. Information on the problems verified by the QA Meteorologist is communicated to field technicians so that problematic sensors can be replaced. In some cases, the problem can be resolved by updating the sensor coefficients using field data.

4. SOIL MOISTURE PRODUCTS

From the measured DeltaT values, hydrological variables such as soil water content, soil matric potential, and Fractional Water Index (FWI: Schneider et al. 2003) can be calculated. Soil matric potential is the capillary force needed to retain water in the soil and volumetric water content is defined as the total percent of water that a particular soil holds at any given time (Dingman 1994). Because soil matric potential is exponentially related to soil wetness, the Oklahoma Mesonet categorizes the values into 4 categories (1-4) for easier viewing of the data. Soil water content is the total percent of water that a particular soil holds at any given time (Dingman 1994). As such, soil type at each sensor location is needed to calculate soil water content. Finally, fractional Water Index is a normalized version of the 229-L sensor response (Schneider et al. 2003 and ranges from very dry soil having a value of 0, to soil at field capacity illustrated by a value of 1. FWI , which is unitless, is not impacted by exponential valuess like matric potential or soil type like soil water content.

5. WEB INTERFACE

OCS provides soil moisture data from the Oklahoma Mesonet to the public via the web. The Oklahoma Mesonet Public Products Sites

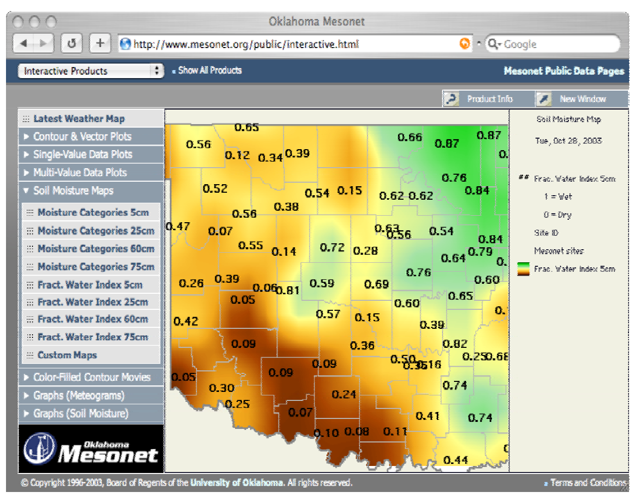

Figure 2. The web display of a Fractional Water Index map on the Oklahoma Mesonet website.

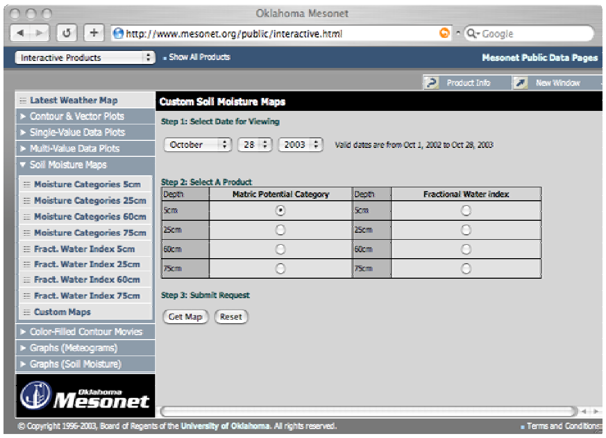

Figure 3. The web interface for creating custom soil moisture maps on the Oklahoma Mesonet website.

(http://www.mesonet.org/public) includes near-real-time and historical soil moisture products in the form of interactive maps and graphs. These products are found under the "Interactive Products" section of the site. OCS's WxScope Plugin software (Wolfinbarger, et al., 1998) is used to view web-based soil moisture products.

The web site includes maps that display daily averages of categorized matric potential and fractional water index at 5, 25, 60, and 75 cm. Maps displaying the most recent data are available via direct links on the web site. Figure 2 shows the web site displaying a Fractional Water Index map. In addition, custom maps can be created from historical data dating back to October 1, 2002. Figure 3 shows the interface for creating custom soil moisture maps.

Time series graphs of soil moisture products are also available on the web site. The standard graph displays Fractional Water Index and volumetric water content at all depths from a single site over the past 30 days. An example of this product is shown in Figure 4. Custom graphs can also be created from the historical archive back to October 1, 2002. These products can display up to 90 days of data from a single site. Figure 5 shows the interface for creating custom soil moisture graphs.

6. APPLICATIONS

Soil moisture observations from the Oklahoma Mesonet show a promising contribution to drought monitoring. Visualization of soil moisture conditions at several depths of soil provides a valuable verification tool that is measured independently of other drought variables. It has proven to be particularly effective during drought recovery, by helping to provide guidance on whether precipitation events have provided relief to the deeper soil depths or are simply impacting the soil just a few inches below the surface.

The soil moisture dataset also offers tremendous opportunities for drought-related research. Decomposing long-term events into individual episodes of precipitation and drying will isolate the building blocks of drought and recovery. Analyzing soil moisture behavior during episodes of drought and recovery will

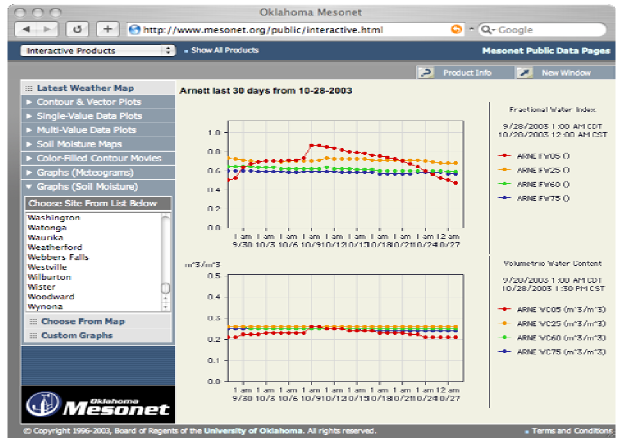

Figure 4. The web display of a time series plot of Fractional Water Index and Volumetric Water Content on the Oklahoma Mesonet website.

provide a greater understanding of the response of soil moisture to precipitation of varying intensity, duration and frequency across varying soil, vegetation, and climate conditions.

7. CONCLUSIONS

Soil moisture has become an integral variable in the understanding of meteorological, hydrological, and atmospheric process. Through the Oklahoma Mesonet, quality assured soil moisture observations are displayed in near real time to the public. Drought applications and studies, as well as other research, continues to rely on quality soil moisture observations. The Oklahoma Mesonet will continue to be an integral part of this process. More products will be released to the public in order to better address the soil moisture needs and more data sets will continue to be produced for researchers.. New studies are sure to improve current theories and applications as well as to help society in general.

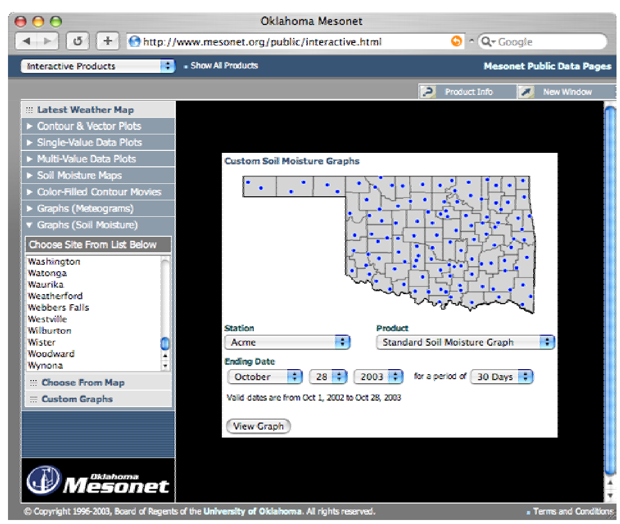

Figure 5. The web interface for creating custom soil moisture time series plots on the Oklahoma Mesonet website.

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