The Oklahoma Mesonet … and Thoughts About Soil Moisture Monitoring

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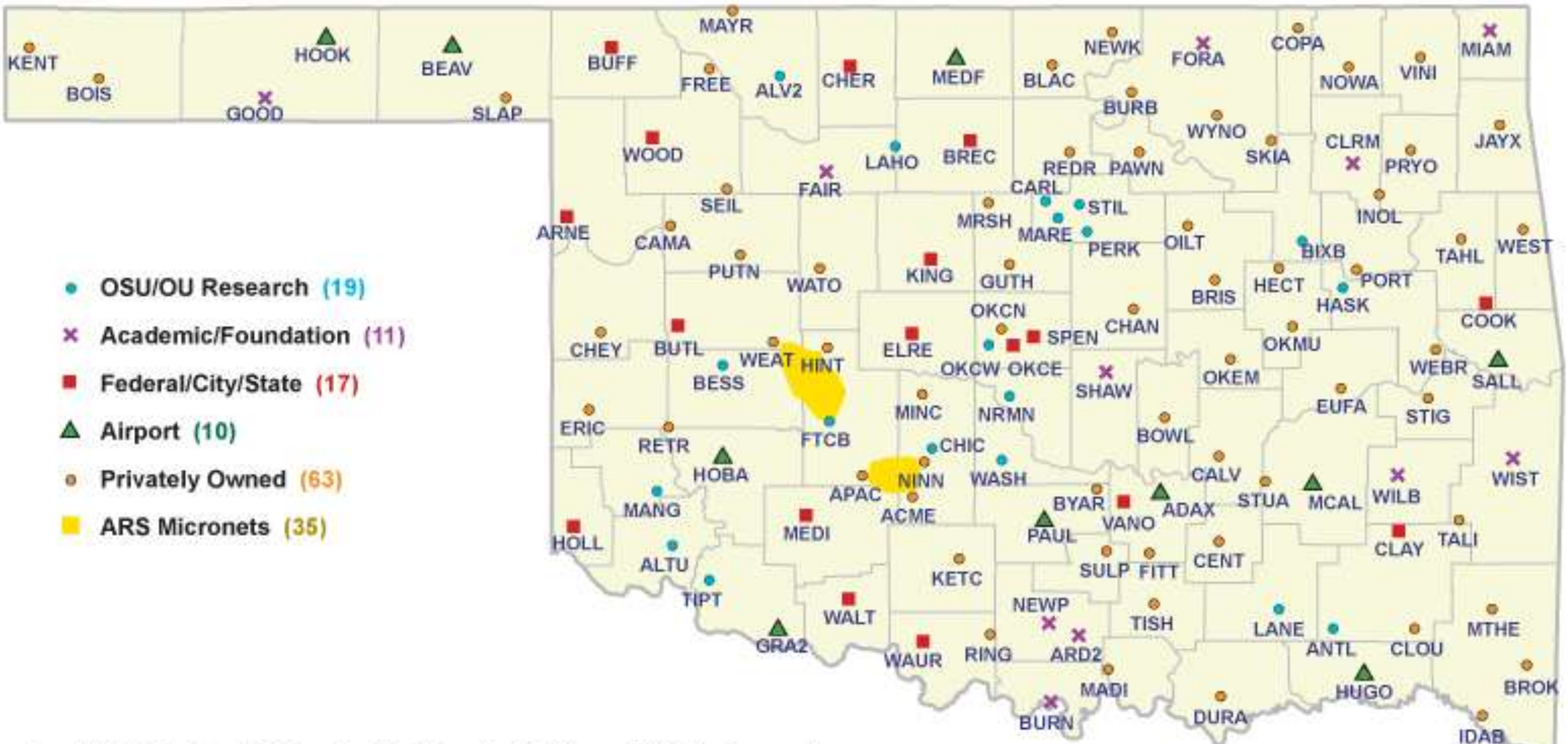
13 November 2013
Developing a Coordinated National Soil Moisture Network
Kansas City, MO

The Oklahoma Mesonet

- Weather and climate network of **120 sites** covering 181,186 km^2
- Commissioned in 1994
- Joint project between the **Oklahoma State University** and the **University of Oklahoma**.
- Extensive quality assurance is applied to the collected observations (real-time and archived ←→ automated and manual)
- Over 5 billion observations archived
- Operational funding supplied by the State of Oklahoma – Research funded mainly by grant awards
- Over 500 peer-reviewed publications, over 100 M.S. theses, and over 40 Ph.D. dissertations have used Oklahoma Mesonet data.

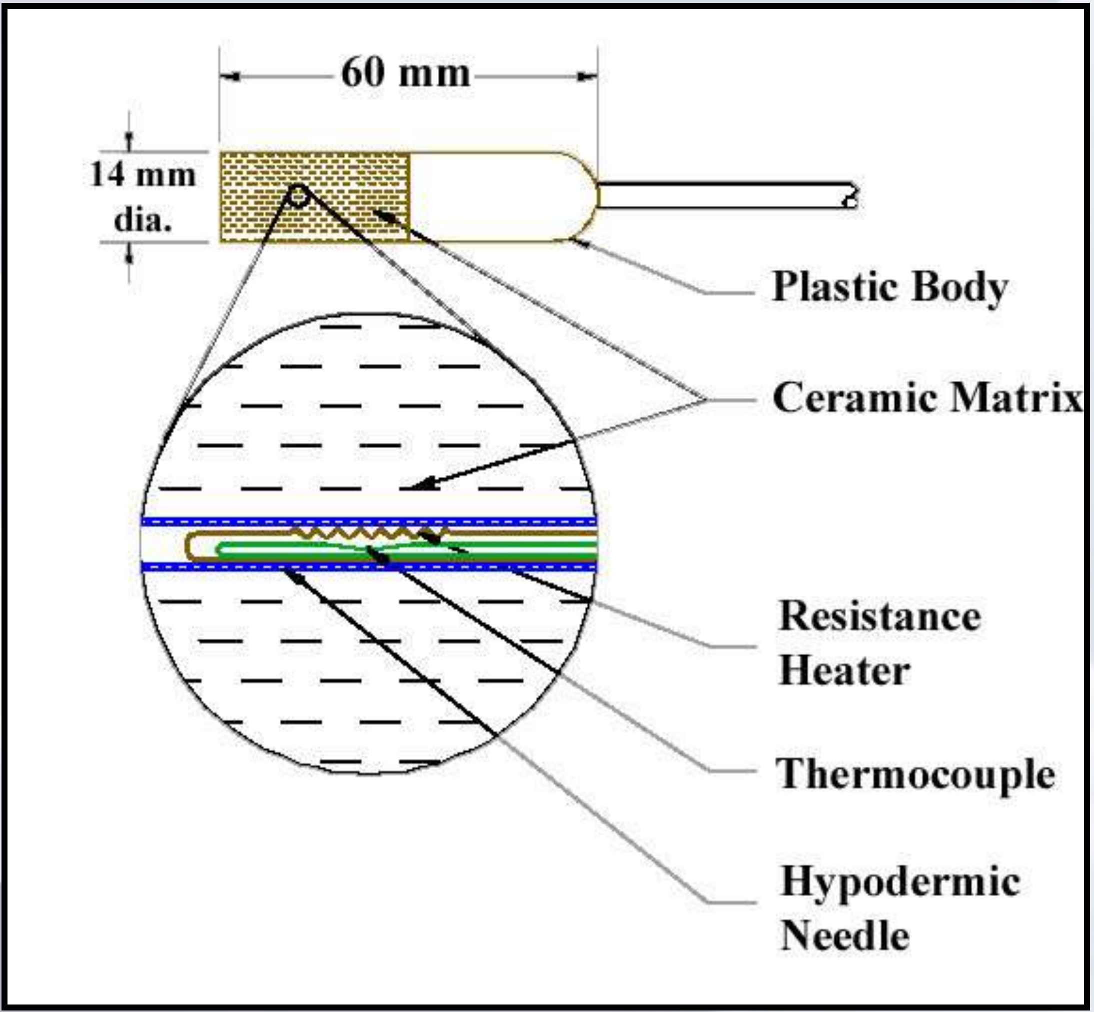
Oklahoma Mesonet

The Oklahoma Mesonet



McPherson, R. A., C. Fiebrich, K. C. Crawford, R. L. Elliott, J. R. Kilby, D. L. Grimsley, J. E. Martinez, J. B. Basara, B. G. Illston, D. A. Morris, K. A. Kloesel, S. J. Stadler, A. D. Melvin, A.J. Sutherland, and H. Shrivastava, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Tech.*, ***24*, *301–321.***

Soil Moisture Instrumentation



- Campbell Scientific 229-L Sensor
- Heat Dissipation Sensor
- Raw measurement is a change in temperature (ΔT) following the introduction of a heat pulse
- Provides relative measures of soil "wetness"
- With soil texture information, soil water content is empirically estimated
- Does not work well in sand

Illston, B.G., J.B. Basara, D.K. Fischer, R.L. Elliott, C. Fiebrich, K.C. Crawford, K. Humes, and E. Hunt, 2008: Mesoscale Monitoring of Soil Moisture Across a Statewide Network. *J. of Atmos. and Oceanic Tech*, ***25, 167-182.***

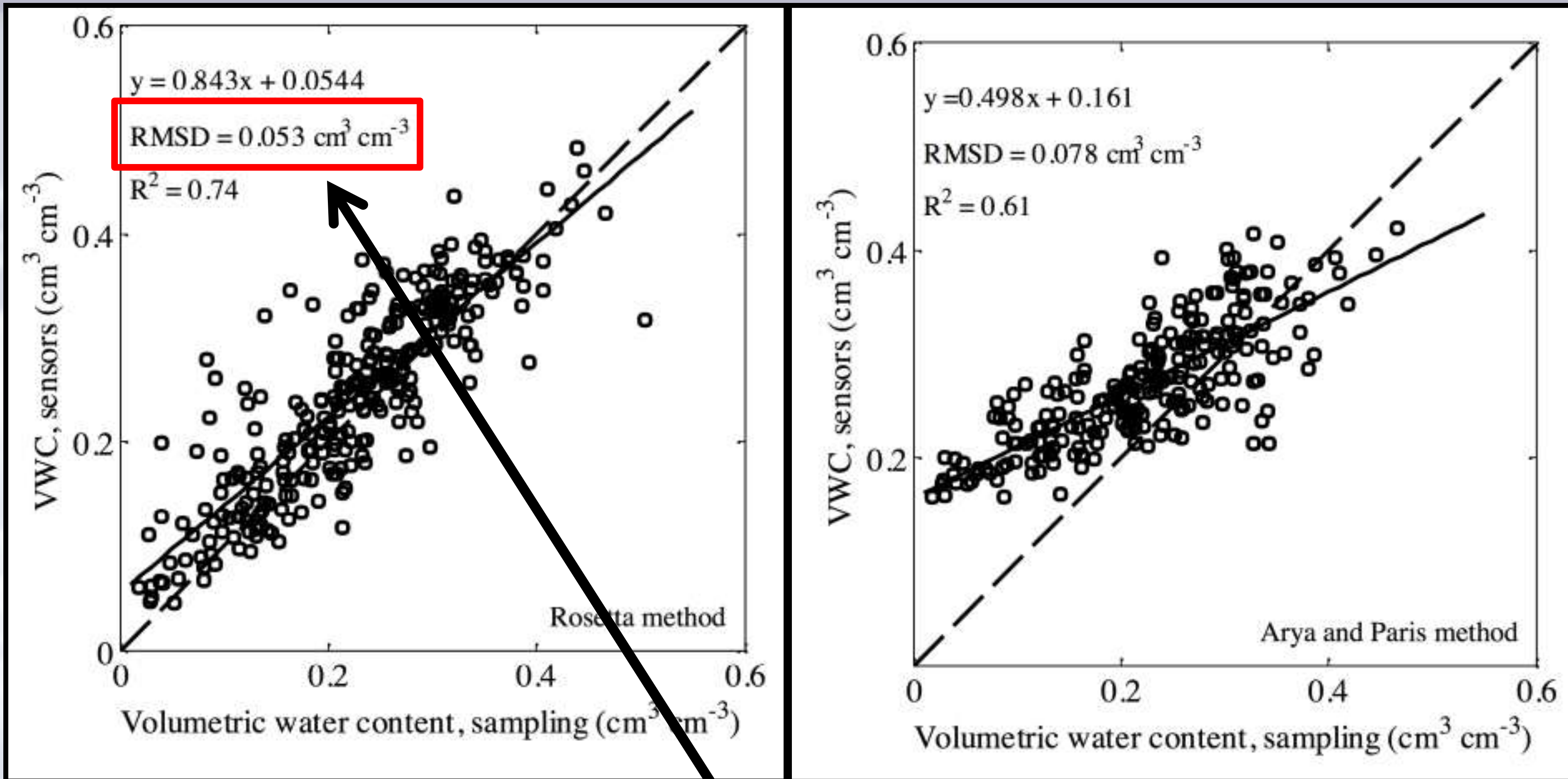
Oklahoma Mesonet Soil Moisture

- **Core Measurement** of the Oklahoma Mesonet at 5, 25, and 60 cm – i.e. fully supported both now and into the future.
- Current technology does not measure **Water Content** directly – empirical relationships exist and have been improved via collaborative efforts at Oklahoma State University.
- Over **15 years** of soil moisture data collected thus far – data available in near real time or via archived datasets.
- Coincident metadata available (soil texture, vegetation, bulk density, etc.).

Mesonet Water Content Calibration

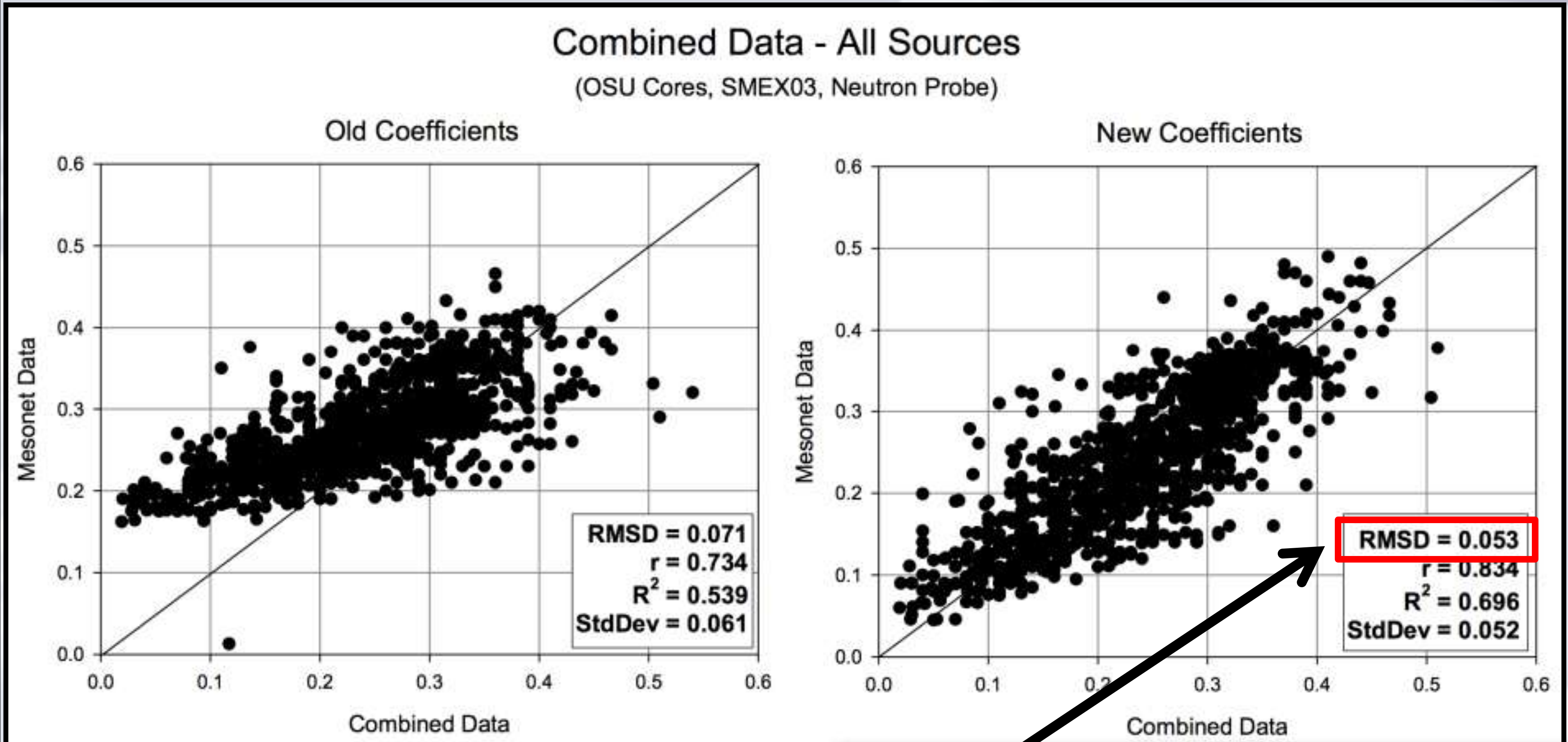
- New empirical technique applied to 229-L sensor response (Rosetta) to estimate VWC and compared with original Mesonet method (Arya-Paris).

- Compared with gravimetric samples (OSU soil cores) collected during the empirical analysis as well as gravimetric samples collected at Mesonet site during SMEX03 as well as neutron probe measurements collected at the sites.



"Error" = 0.053 cm^3 cm^{-3}

Scott, B., T. Ochsner, B. Illston, C. Fiebrich, J. Basara, and A. Sutherland, 2013: New Soil Database Improves Oklahoma Mesonet Soil Moisture Estimate. *J. of Atmos. and Oceanic Tech*, ***in press.***



"Error" = 0.053 $cm^3\ cm^{-3}$

Mesonet Water Content Data – 5 cm observations represents the 0-5 cm SMAP Product

Mesonet | 16-inch Plant Available Water

www.mesonet.org/index.php/weather/map/16_inch_plant_available_water/soil_moisture_temperature

16-inch Plant Available Water

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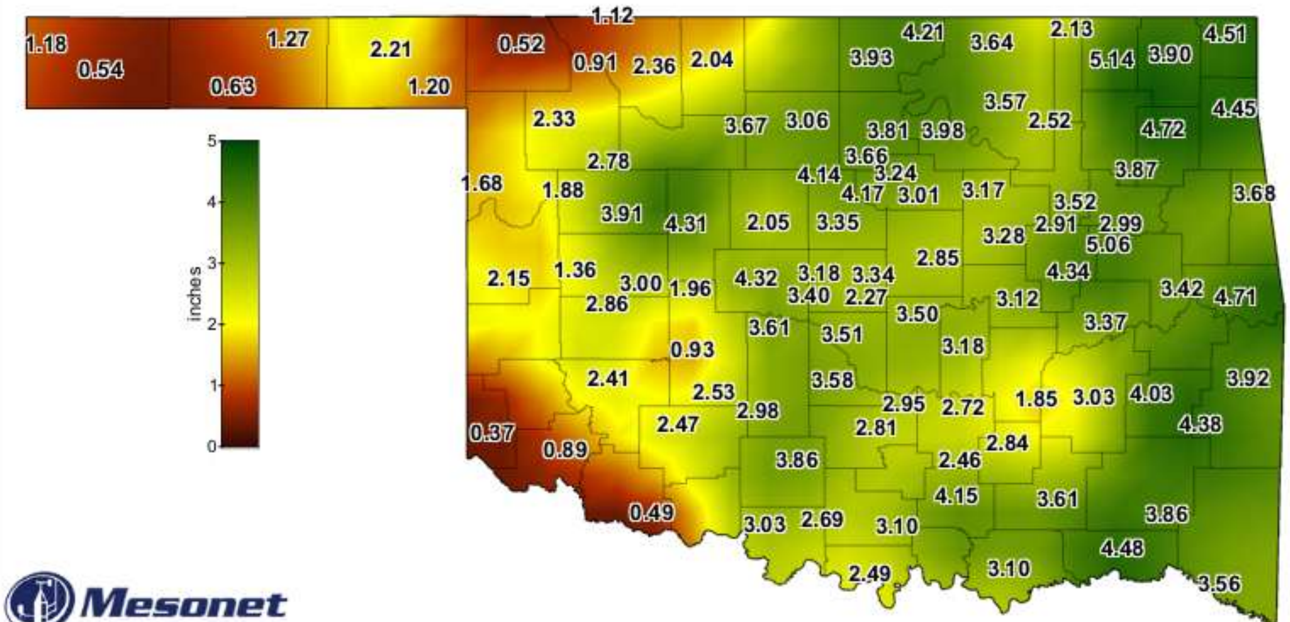
- Radar
- Solar Radiation & Satellite
- Advisories
- Upper Air



Mesonet

16-inch Plant Available Water

November 11, 2013

Created 6:30:06 AM November 12, 2013 CST. © Copyright 2013

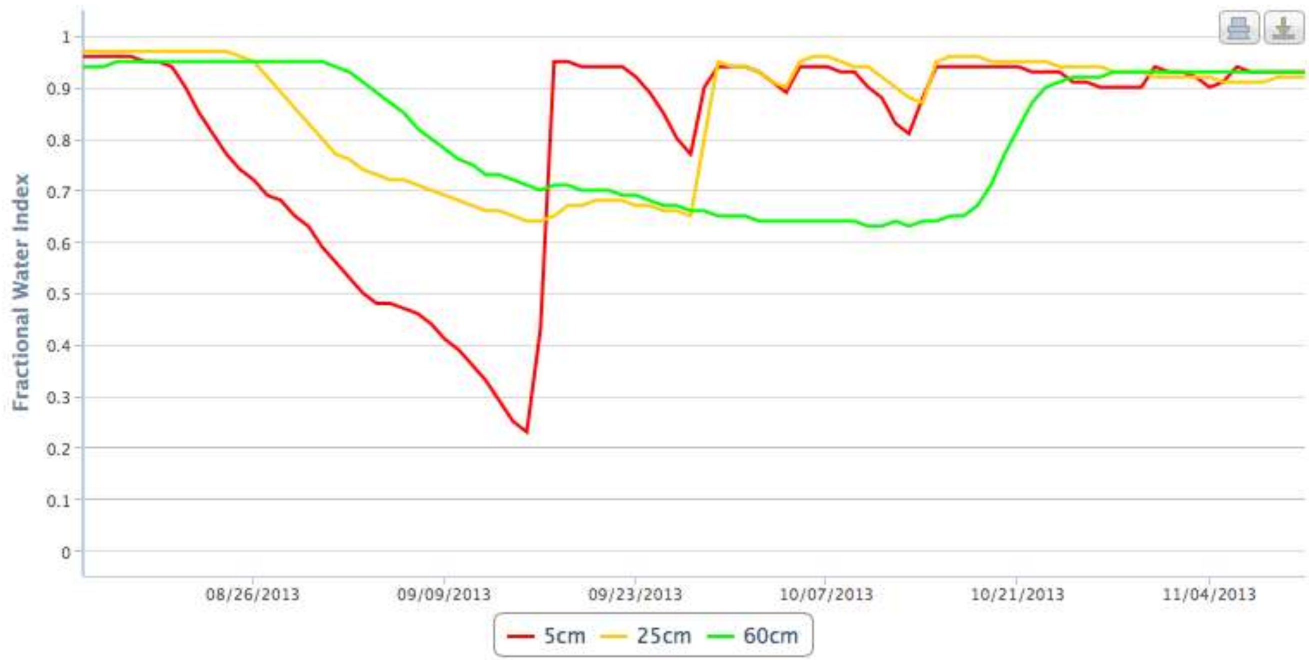
The 16-inch Plant Available Water map is based on the 24-hour-averaged plant available water for the top 16 inches (40 cm) of soil under the existing vegetation at each Mesonet site for the previous day. Plant available water under other vegetation types may differ. Plant available water is the amount of water in the soil that is potentially available for plant uptake. Technically, it is calculated as the amount of soil water at matric potentials above -1500 kPa. The maximum possible plant available water varies between sites due to soil differences. Most plants experience water stress when less than 50% of the maximum plant available water remains in the active root zone. This map is updated once each day between 7 and 8 AM.

Soil Moisture for El Reno

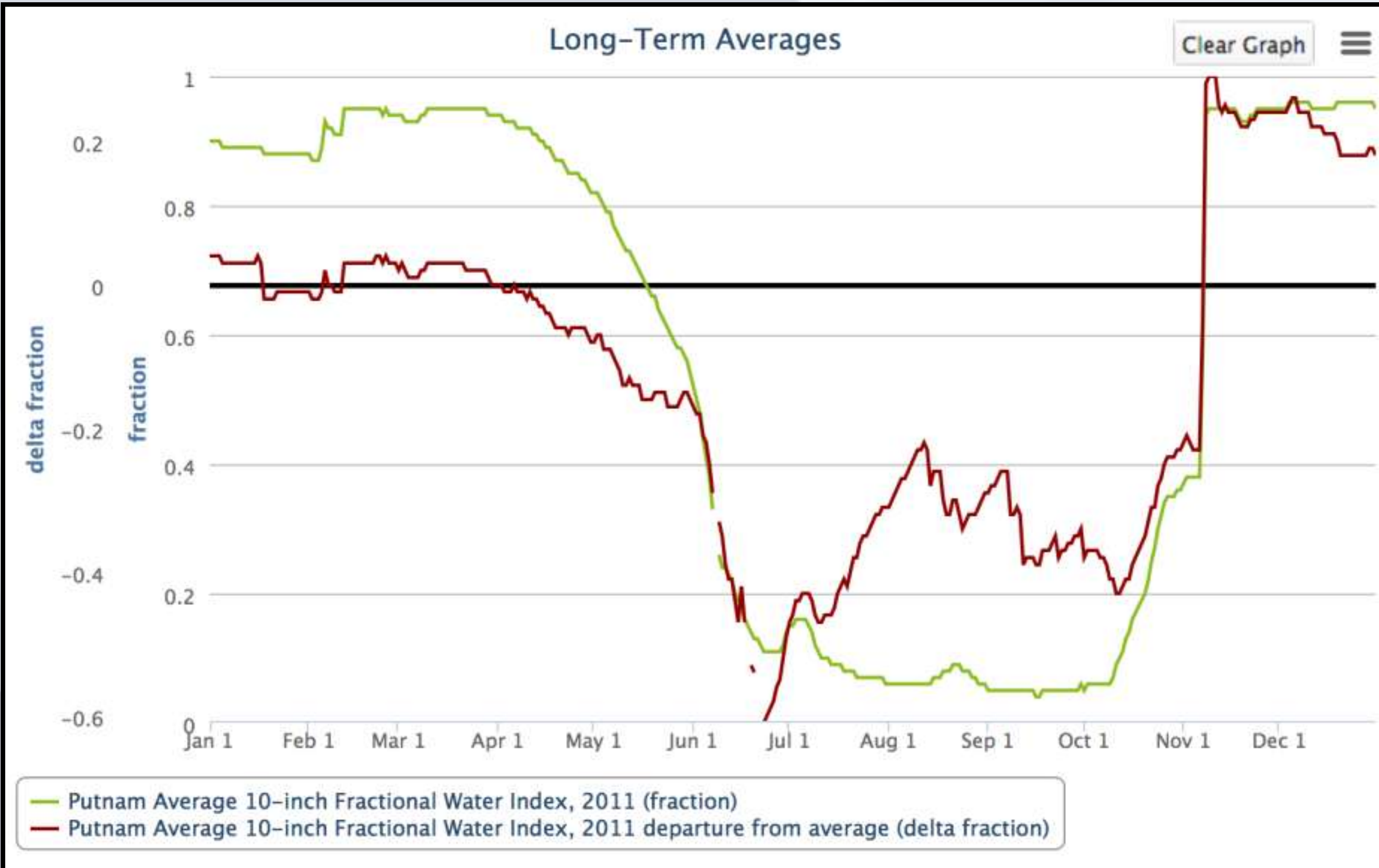
Duration: 90 Days

Change Mesonet Site Share Tweet

Local Weather
Current Conditions
Air Temperature
Rainfall
Wind
Dewpoint & Humidity
Soil Moisture/Temperature
Pressure
Ground Water
Station Meteograms
Past Data & Files
Radar
Solar Radiation & Satellite
Advisories
Upper Air



The Soil Moisture Graph plots the Fractional Water Index for a station through time. The user can pick either a 7, 15, 30, 60, or 90 day period. Fractional Water Index varies from 0 (wilting point) to 1 (saturation).


Long-Term Averages
Clear Graph
delta fraction
fraction
1
0.8
0.6
0.4
0.2
0
0.2
0
-0.2
-0.4
-0.6
Jan 1
Feb 1
Mar 1
Apr 1
May 1
Jun 1
Jul 1
Aug 1
Sep 1
Oct 1
Nov 1
Dec 1
Putnam Average 10-inch Fractional Water Index, 2011 (fraction)
Putnam Average 10-inch Fractional Water Index, 2011 departure from average (delta fraction)

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **24**: 1883–1896 (2004)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/joc.1077

SEASONAL TO INTERANNUAL VARIATIONS OF SOIL MOISTURE MEASURED IN OKLAHOMA

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ABSTRACT

Agriculture is a $2 billion component of the state economy in Oklahoma. As a result, meteorological, climatological, and agricultural communities should benefit from an improved understanding of soil moisture conditions and how those conditions vary spatially and temporally. The Oklahoma Mesonet is an automated observing network that provides real-time hydrometeorological observations at 115 stations across Oklahoma. In 1996, sensors were installed at 60 Mesonet sites to provide near-real-time observations of soil moisture.

This study focuses on 6 years of soil moisture data collected between 1997 and 2002 to analyse the annual cycle and temporal characteristics of soil moisture across Oklahoma. The statewide analysis of the annual cycle of soil moisture revealed four distinct soil moisture phases. In addition, the four statewide phases were also observed in each of the nine climate divisions across Oklahoma, although the temporal characteristics of each phase were unique for each division. Further analysis demonstrated that, at shallow soil depths (5 and 25 cm), the spatial variability of soil moisture across Oklahoma was most homogeneous during the winter and spring periods and most heterogeneous during the summer and autumn periods. Conversely, at greater depths (60 and 75 cm), soil moisture was most heterogeneous during the winter period and the most homogeneous during the late spring. Copyright © 2004 Royal Meteorological Society.

KEY WORDS: soil moisture; Oklahoma Mesonet; phases; annual cycle; climatology

1. INTRODUCTION

Soil moisture is a critical component of a feedback system that conveys meteorological memory to the climate system over land surfaces (Delworth and Manabe, 1988, 1993). On the local scale, soil moisture controls the partitioning of mass and energy between the land surface and the atmosphere through surface fluxes of latent and sensible heat; it also mitigates the soil heat flux (Brubaker and Entekhabi, 1996).

Soil moisture conditions also contribute to the natural and agricultural productivity of a region by defining the root water that is available for uptake into the vegetation canopy (Hillel, 1998). In turn, water is transpired from the vegetated surface to the atmosphere during photosynthesis, thus increasing low-level atmospheric moisture on both a local and regional basis.

The spatial and temporal variability of soil moisture conditions (specifically the total amount of water contained within a given soil mass or volume) are influenced by a number of competing factors. The factors include soil properties and organic material (Reynolds, 1970a,b; Henninger *et al.*, 1976; Miller, 1977; Dingman, 1994; Hillel, 1998), topography (Hills and Reynolds, 1969; Reid, 1973; Moore *et al.*, 1988; Nyberg, 1996; Famigletti *et al.*, 1998), mean soil moisture content (Hills and Reynolds, 1969; Bell *et al.*, 1980; Hawley *et al.*, 1983; Laogue, 1992; Nyberg, 1996; Famigletti *et al.*, 1998, 1999), depth of the water table, vegetation

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GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L22401, doi:10.1029/2008GL035772, 2008

Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data

Yingxin Gu,[1] Eric Hunt,[2] Brian Wardlow,[2] Jeffrey B. Basara,[3] Jesslyn F. Brown,[4] and James P. Verdin[4]

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[1] The evaluation of the relationship between satellite-derived vegetation indices (normalized difference vegetation index and normalized difference water index) and soil moisture improves our understanding of how these indices respond to soil moisture fluctuations. Soil moisture deficits are ultimately tied to drought stress on plants. The diverse terrain and climate of Oklahoma, the extensive soil moisture network of the Oklahoma Mesonet, and satellite-derived indices from the Moderate Resolution Imaging Spectroradiometer (MODIS) provided an opportunity to study correlations between soil moisture and vegetation indices over the 2002–2006 growing seasons. Results showed that the correlation between both indices and the fractional water index (FWI) was highly dependent on land cover heterogeneity and soil type. Sites surrounded by relatively homogeneous vegetation cover with silt loam soils had the highest correlation between the FWI and both vegetation-related indices (r~0.73), while sites with heterogeneous vegetation cover and loam soils had the lowest correlation (r~0.22). **Citation:** Gu, Y., E. Hunt, B. Wardlow, J. B. Basara, J. F. Brown, and J. P. Verdin (2008), Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data, *Geophys. Res. Lett.*, *35*, L22401, doi:10.1029/2008GL035772.

1. Introduction

[2] Drought is one of the most costly natural disasters in the United States. Satellite observations potentially provide much greater spatial and temporal coverage of drought conditions than from site measurements of soil moisture and precipitation, and any relationships identified between these indicators might greatly enhance future drought monitoring efforts around the world. Currently, satellite-derived normalized difference vegetation index (NDVI) data has played an important role for vegetation drought monitoring [e.g., *Kogan*, 1995; *Gu et al.*, 2007; *Brown et al.*, 2008]. Another remote sensing measure, the normalized difference water index (NDWI) has also recently been used to monitor moisture conditions of vegetation canopies over large areas [*Jackson et al.*, 2004; *Chen et al.*, 2005]. Accurately monitoring and assessing near-real time vegetation drought conditions within the United States may provide decision makers accurate, synoptic, and timely information for effective drought planning and mitigation and should reduce economic losses. For that reason, continued evaluation of satellite-derived NDVI and NDWI for vegetation drought monitoring using ground observations (e.g., soil moisture) is required to better understand how these indices respond to soil moisture fluctuations, which are ultimately tied to drought stress on plants.

[3] NDVI, which is the normalized difference between the near infrared (NIR) and visible red reflectance [*Rouse et al.*, 1974; *Tucker*, 1979], is responsive to changes in both the chlorophyll content and the intracellular spaces in spongy mesophyll of plant leaves. Higher NDVI values reflect greater vigor and photosynthetic capacity (or greenness) of vegetation canopy, whereas lower NDVI values for the same time period are reflective of vegetative stress resulting in chlorophyll reductions and changes in the leaves' internal structure due to wilting. NDWI, derived from the NIR and shortwave infrared (SWIR) channels, responds to changes in both the water content (absorption of SWIR radiation) and spongy mesophyll (reflectance of NIR radiation) in vegetation canopies, respectively [*Gao*, 1996].

[4] Soil moisture is a critical component in land surface-atmospheric processes [*Brubaker and Entekhabi*, 1996], and prolonged soil moisture deficits often lead to drought-induced vegetation stress. Over the past decade, soil moisture observations in near-real time from the Oklahoma Mesonet have been collected and used for monitoring and assessing the spatial and temporal variability of soil moisture [*Illston et al.*, 2004] and drought conditions across Oklahoma [*Basara et al.*, 1998]. The Oklahoma Mesonet is an extensive network of over 110 environmental monitoring stations [http://www.mesonet.org/] that provide an excellent data source for thoroughly evaluating satellite-based indices in relation to soil moisture status and vegetation drought conditions. One of the most useful variables for estimating soil moisture is the fractional water index (FWI) [*Schneider et al.*, 2003; *Illston et al.*, 2004, 2008], which is a relative measure of the soil wetness and does not directly reveal the soil water content. The FWI is a calculation specific to heat dissipation sensors, such as the Campbell 229-L used by the Oklahoma Mesonet, and FWI values range from 1 (purely saturated soil) to 0 (very dry soil). Because FWI is not limited by soil texture variation, the soil water condition of each site is easily comparable across the state.

[5] A limited number of investigations examining the relationships between NDVI and soil moisture have been done over the U.S. Corn Belt [*Adegoke and Carleton*, 2001], semiarid New Mexico and Arizona regions, and

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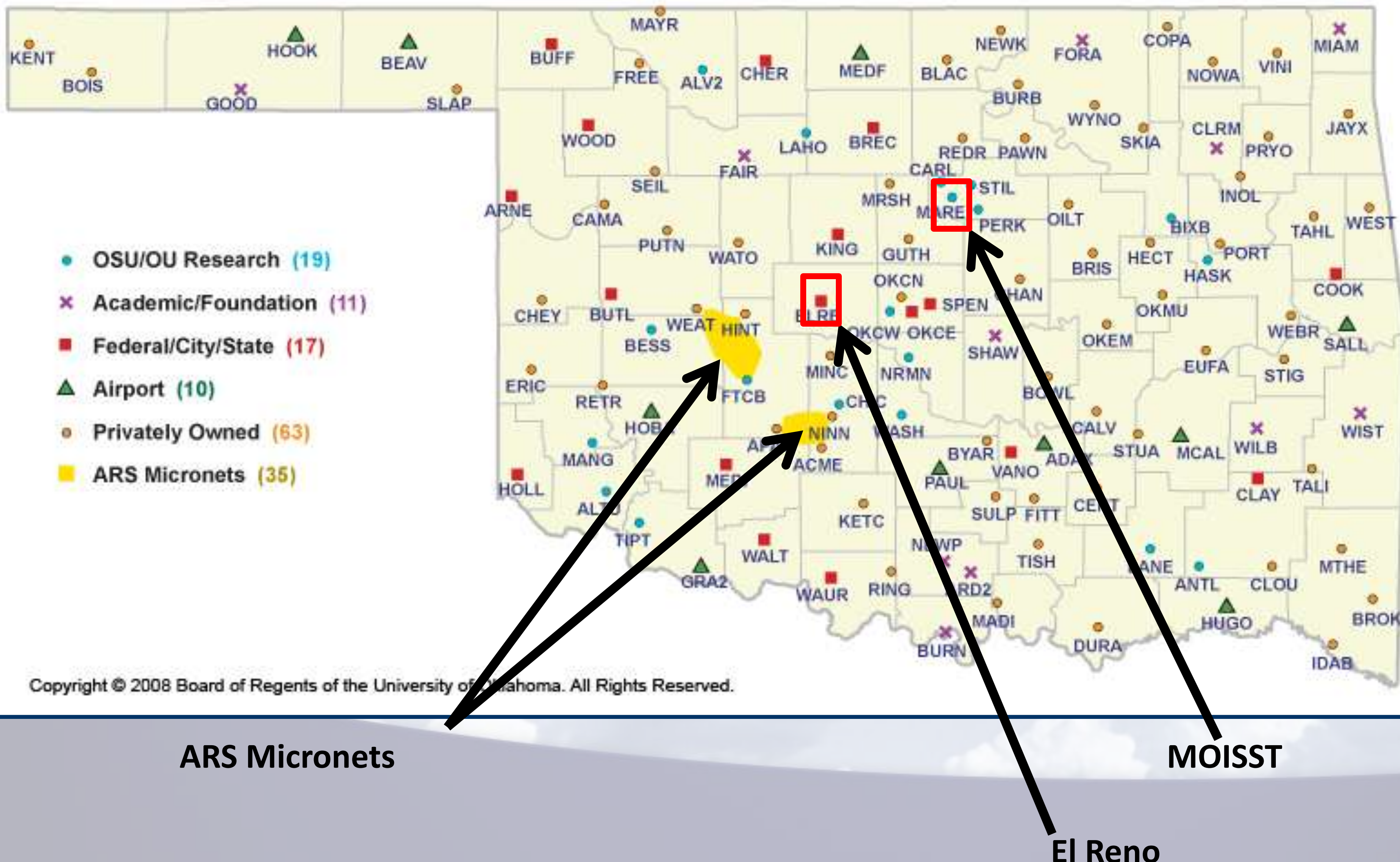
[3]Oklahoma Climatological Survey, University of Oklahoma, Norman, Oklahoma, USA.
[4]USGS Earth Resources Observation and Science Center, Sioux Falls, South Dakota, USA.

0094-8276/08/2008GL035772$05.00

Cooperative Validation Sites in the Region



SMAP-MOISST
Soil Moisture Active Passive
Marena, Oklahoma In Situ Sensor Testbed

MOISST PI: Michael Cosh, USDA-ARS
OSU Co-I: Tyson Ochsner, OSU

A cooperative project to compare in situ soil moisture sensors for use in satellite calibration and validation programs. Located near Marena, Oklahoma, this testbed hosts multiple partners featuring current and emerging measurement technologies for sensing soil water content at the surface and in profile.

Sensors in MOISST profiles

- Stevens Water Hydra probes
- Delta-T Theta probes
- Acclima sensors
- Campbell Sci 229-L probes
- Campbell Sci 616 TDRs
- Decagon EC-TMs
- Imko TDRs
- Sentek Capacitance Probes

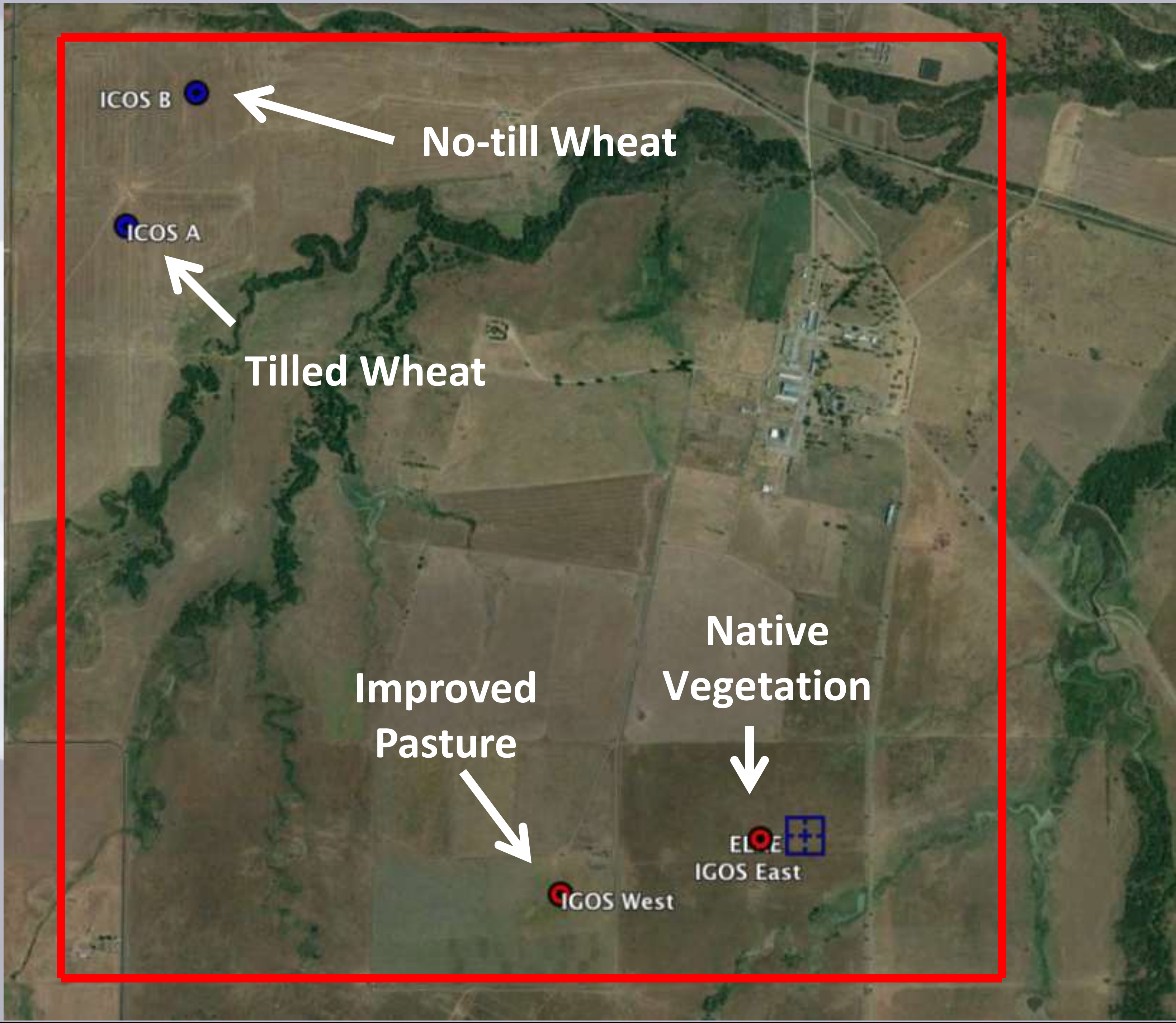
Partners included in MOISST

- COSMOS
- GPS Reflectometers
- Passive/Active DTS
- NOAA CRN System
- Oklahoma Mesonet

Cooperative Research sponsored by

USDA OSU NASA

Integrated Grassland/Crop Observing Systems at El Reno – To be completed in 2014


ICOS B
No-till Wheat
ICOS A
Tilled Wheat
Native
Vegetation
Improved
Pasture
IGOS East
IGOS West


marena - NetCam SC - Mon May 27 2013 16:00:05 CST
Temperature: 50.5
Exposure: 24

What Governs the State of Soil Moisture?

"Soil is a wetting body. For this reason capillary moisture in the soil has a concave surface and is invariably under supplementary negative pressure [or suction]. Its magnitude is governed by the surface tension of the water and the radii of the curves, which depend on size and shape of the interstices, i.e., in the final analysis on the dispersion of the soil." Razumova (1965)

Simply put, soil moisture is most directly influenced by a number of microscale physical properties which determine soil composition. These factors include **soil texture** (size, shape, and mineral composition of the soil particles), **soil water potential** (the energy state of soil water), **organic matter** and the **magnitude of water** contained in any given soil parcel

Thoughts Concerning Soil Moisture Monitoring

- Volumetric Water Content is **NOT** Sufficient to Understand the full, true state of “Soil Moisture” without additional, on-site, site-specific, scaled metadata:
  - Soil Texture
  - Vegetation Type and Conditions
  - Hydraulic Conductivity
  - Organic Matter
  - Bulk Density
- Every monitoring network should have detailed descriptions of the calibration and validation procedures for the soil moisture measurements. **Know the strengths and limitations of the data!!!!**
- Standards are needed for soil moisture monitoring – What are the acceptable error ranges? Installation procedures? Quality assurance?
- Soil moisture monitoring in not an easy undertaking – in many ways, it is more complicated than atmospheric measure sand requires sufficient resources.
- Often, users want information about soil wetness which is inherently different than VWC.

Questions?