The Soil Moisture Active Passive Marena Oklahoma In Situ Sensor Testbed (SMAP-MOISST): Design and Initial Results

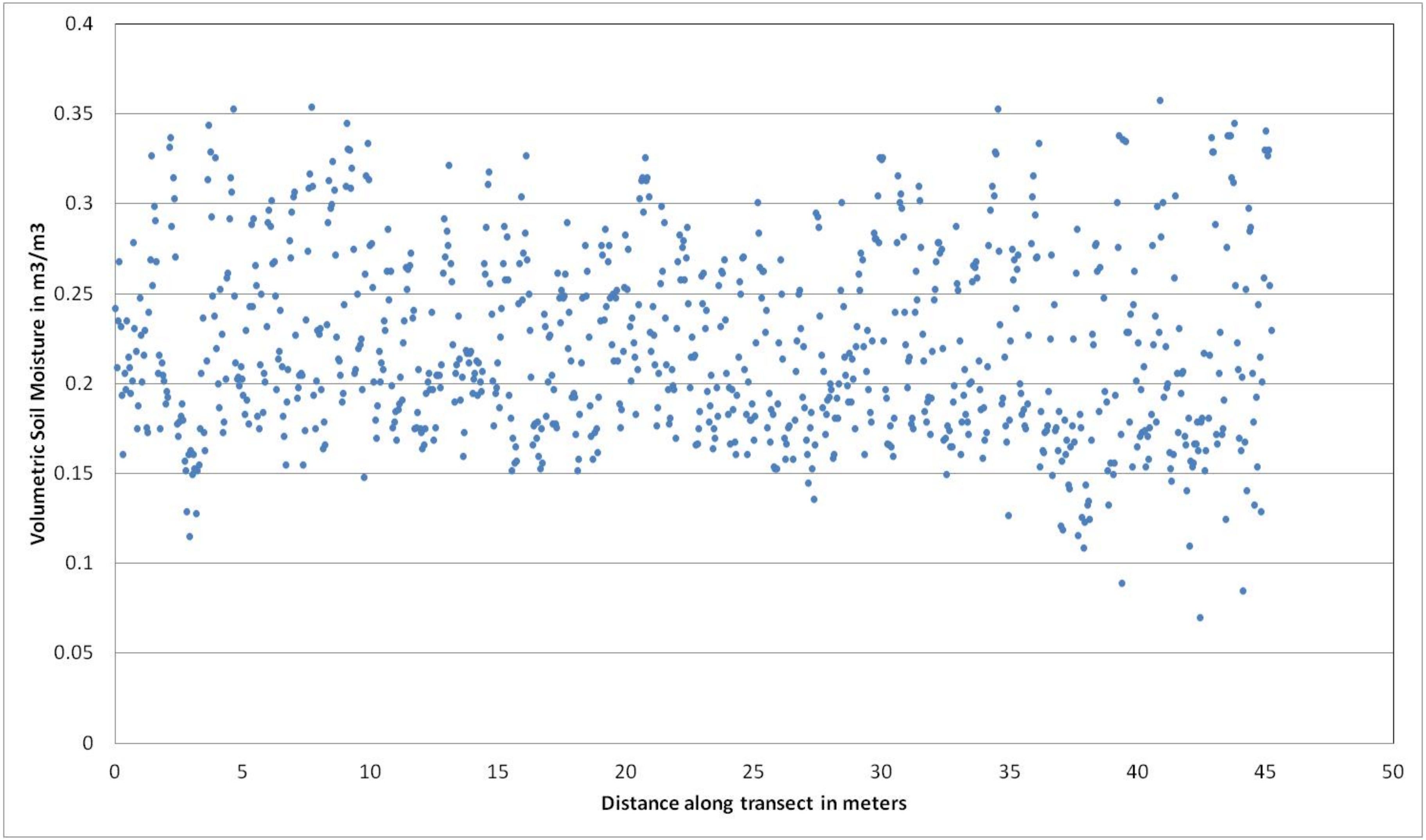
Michael H. Cosh[1], Tyson E. Ochsner[2], Lynn McKee[1], Evan Coopersmith[1], Jingnuo Dong[2], Jeffrey Basara[3], Steven R. Evett[4], Christine Hatch[5], Eric Small[6], Susan Steele-Dunne[7], Chadi Sayde[8], Marek Zreda[9]

[1]USDA-ARS-Hydrology and Remote Sensing Laboratory, Beltsville, MD
[2]Dept. of Plant and Soil Sciences, Oklahoma State University
[3]School of Meteorology, Oklahoma Climatological Survey ,University of Oklahoma
[4]USDA-ARS-Crop Production Research Laboratory
[5]Department of Geosciences, University of Massachusetts-Amherst, Amherst, MA
[6]Department of Geological Sciences, University of Colorado-Boulder
[7]Department of Civil Engineering and Geosciences, Delft University of Technology
[8]North Carolina State University, Greenville, NC
[9]Department of Hydrology and Water Resources, University of Arizona

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

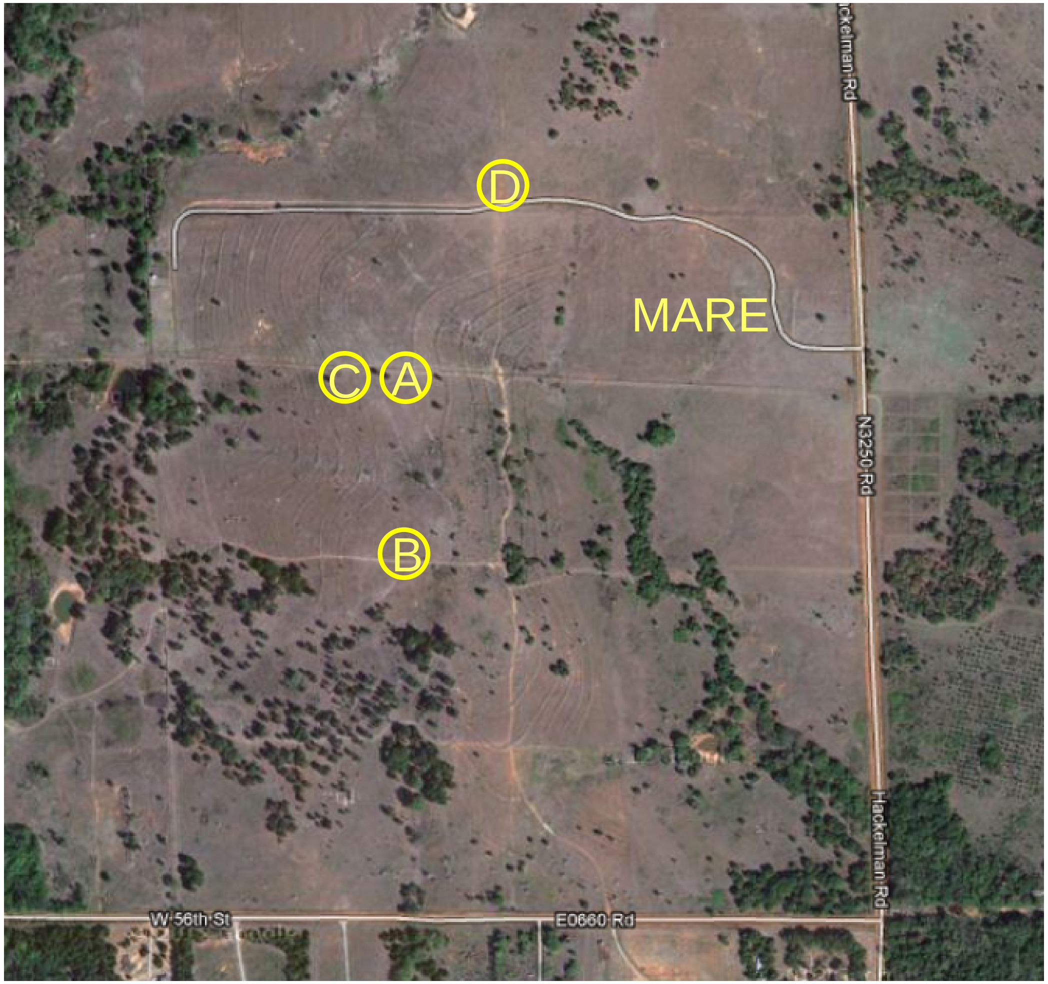
SMAP

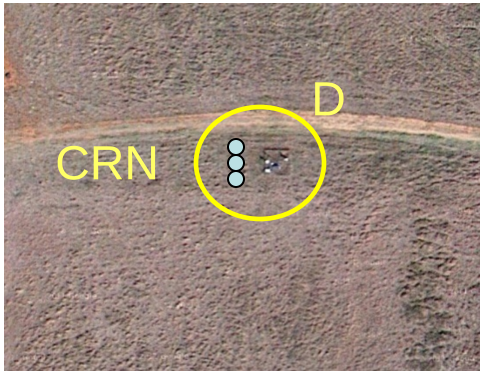
SMAP Marena Oklahoma In Situ Sensor Testbed
Variability at the Surface 0-5 cm

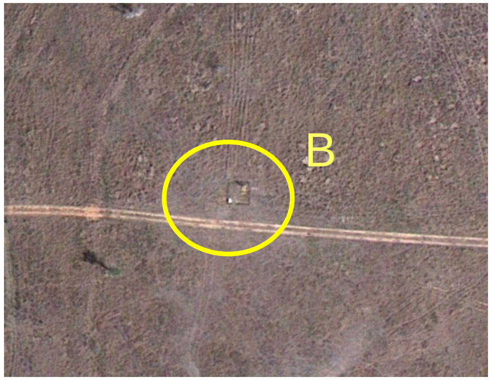


*BEAREX08 Transect Data
Cosh et al., 2012

SMAP Marena Oklahoma In Situ Sensor Testbed
Site Design







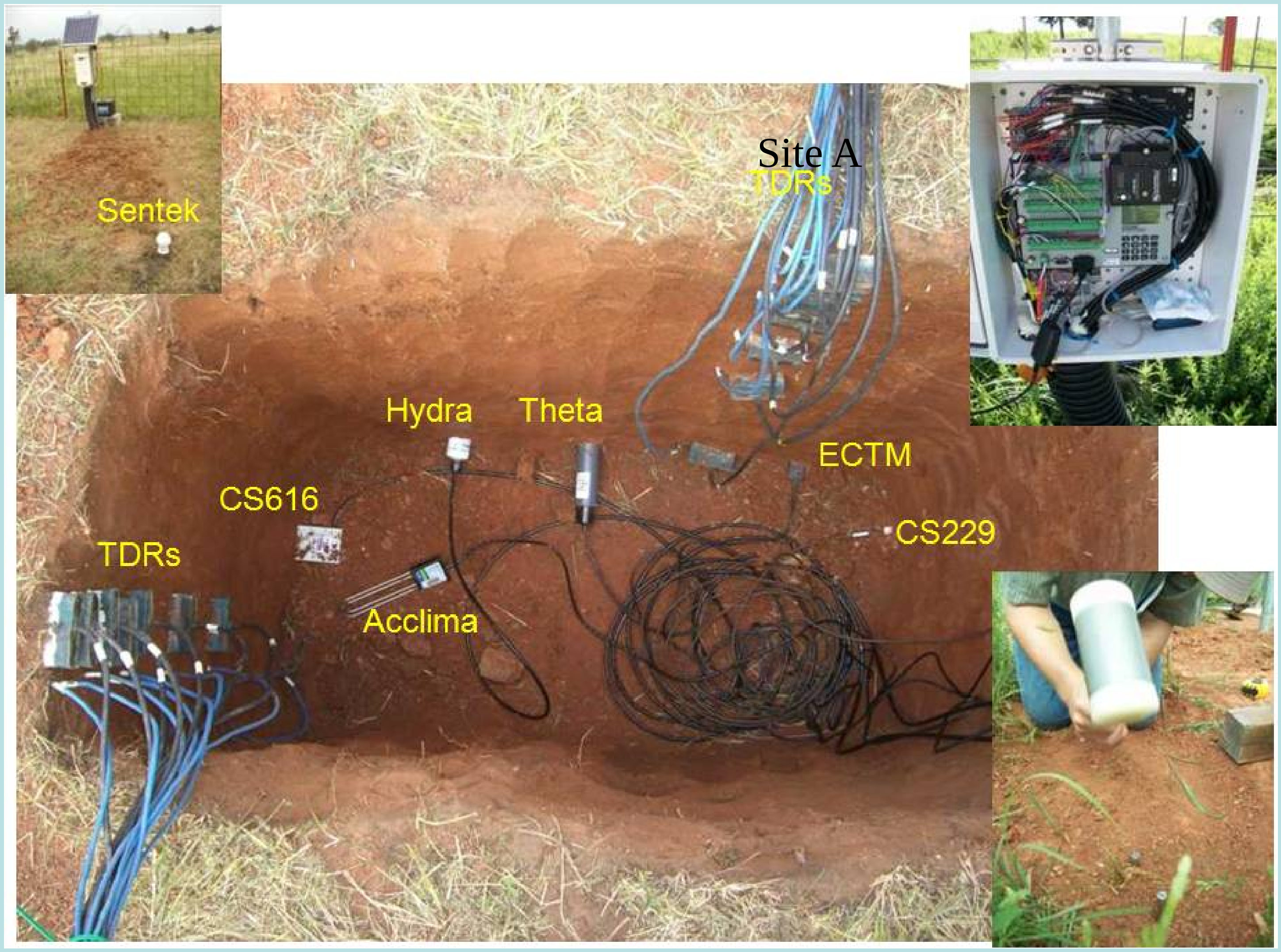
SMAP Marena Oklahoma In Situ Sensor Testbed
Marena Site Design

- Four Base Installations
- Common depths of 5, 10, 20, 50, 100 cm, with some sampling at 2.5 cm with Hydra.
- Base station sensors
    - Stevens Water Hydra Probes (6)
    - Delta-T Theta Probes (5)
    - Decagon EC-TM probes (5)
    - Sentek EnviroSMART Capacitance Probes (4)
    - Campbell CS615/CS616 TDRs (5)
    - CS 229-L heat dissipation sensors (OK Mesonet) (5)
    - Acclima TDT (5)

  In 2016
    - Acclima 315(4)
    - GS-1 (4)
    - Acclima TDT (4)
    - CS655 (4)

Site A	Site B	Site C	Site D
Base	Base	Base	Base
GPS	ASSH-Imko/Trime	GPS	GPS
COSMOS	Passive DTS		CRN
ASSH-Imko/Trime			
TDR systems			
Flux System			

- Installation in May 2010



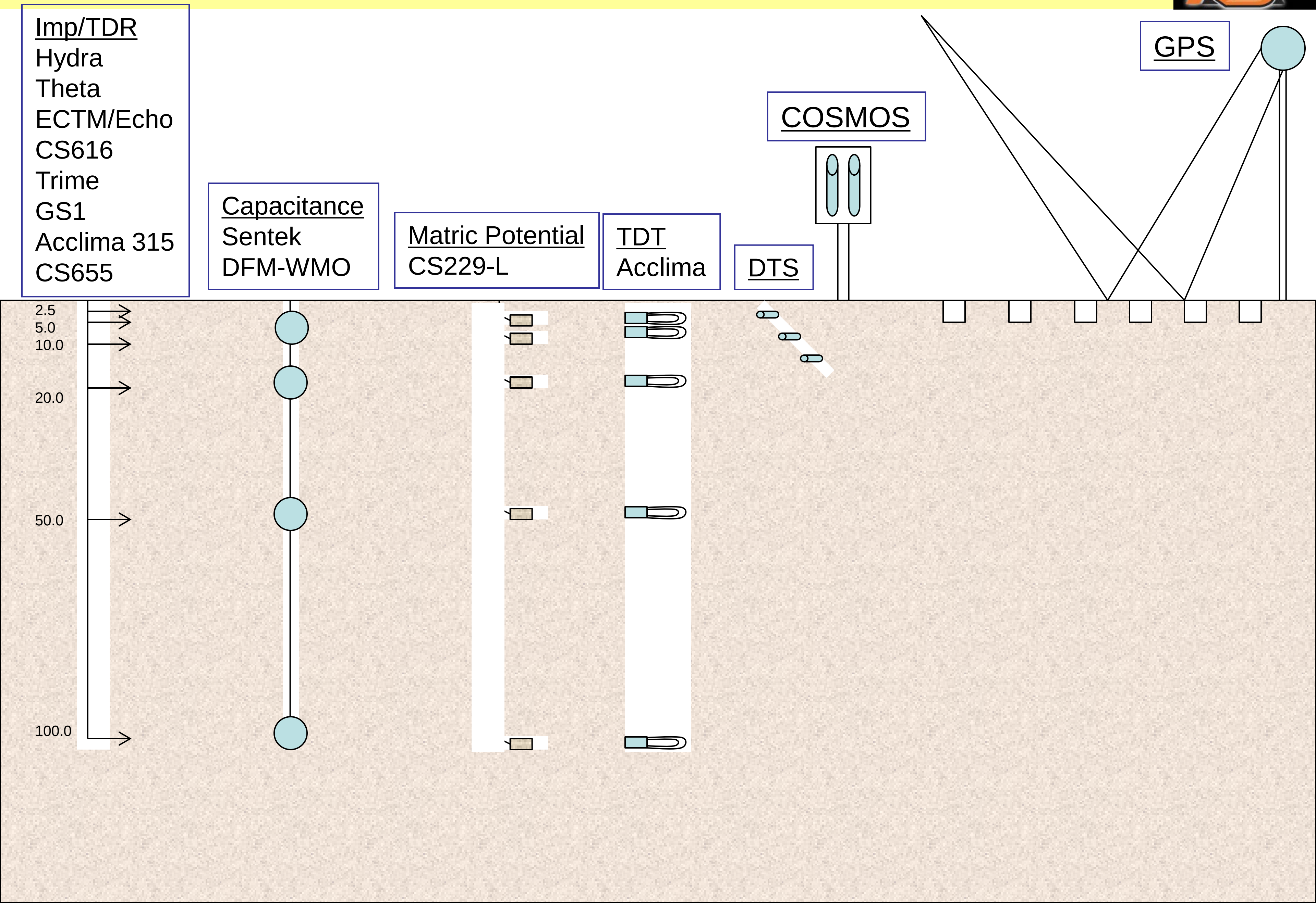
New Sensors/Networks

COSMOS – COsmic ray Soil Moisture Observing System uses a neutron counting system to measure broken down water molecules as a proxy for moisture at the surface and root zone (~30 cm).

GPS Reflectometry - Using full GPS stations which measure tectonic movement and taking the reflections at the horizon to estimate soil moisture in the foreground.

Passive Distributed Temperature Sensor Systems (PDTS) – Long buried cabling at various depths can estimate on a high spatial scale, the moisture content immediately surrounding the wire.

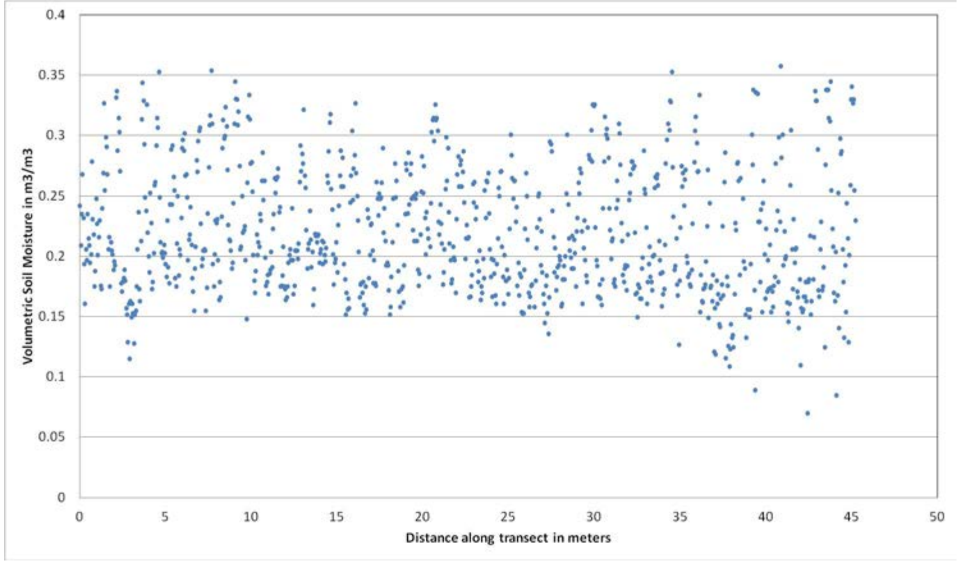
SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor Methods



Soil Calibration

Every sensor can be calibrated to each specific soil to be installed in.

- Soil specific Calibration, in field or in lab with replication of soil bulk density
- Variety of soil moisture conditions necessary for accurate calibration.

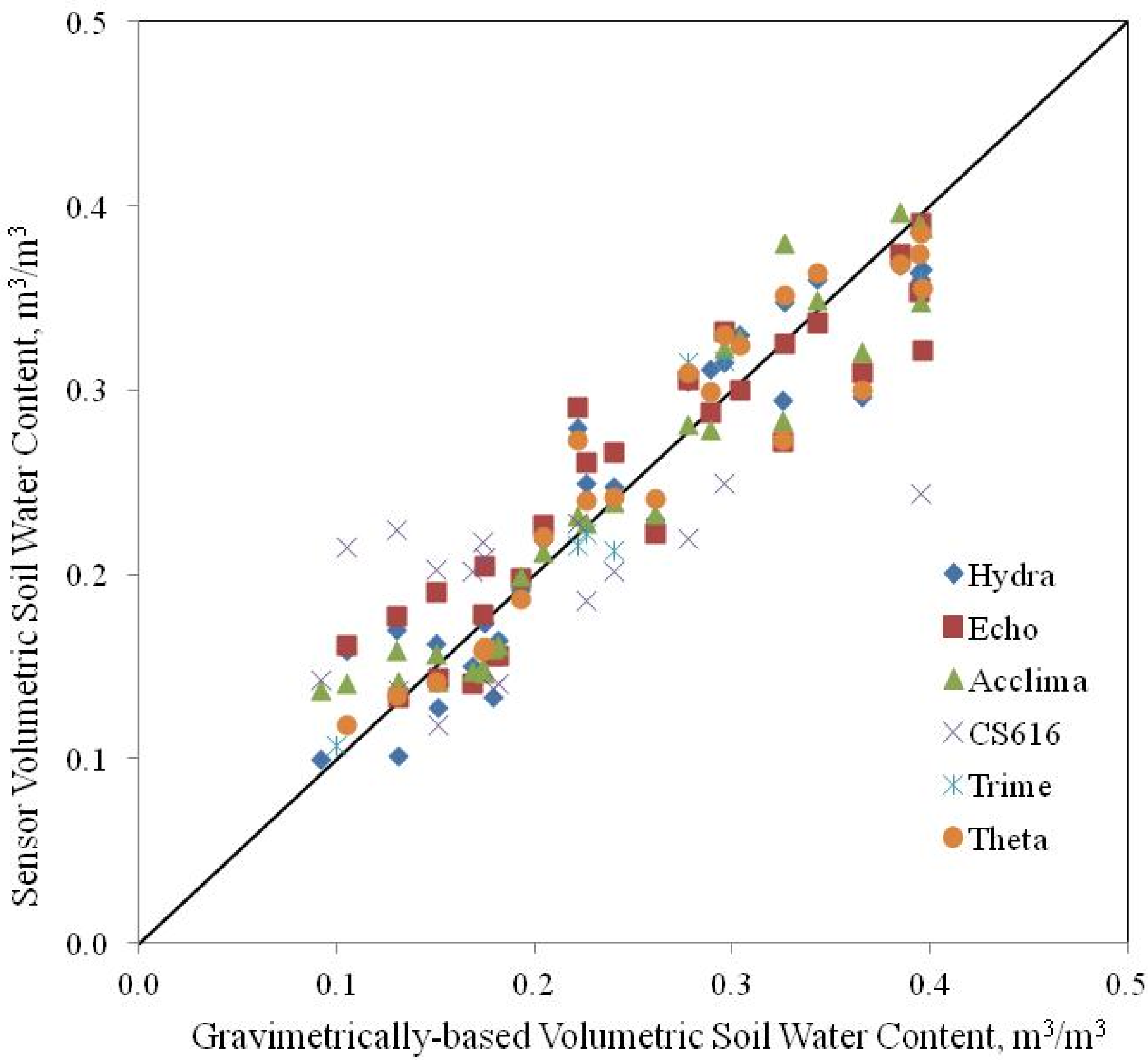


Installation Scaling

Each installation should be scaled to determine how it represents the domain in which it is installed.

- Each installation or set of installations is one data series to be calibrated
- Scaling is against the satellite metric, 0-5 cm gravimetrically based volumetric soil moisture.

SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor Calibration

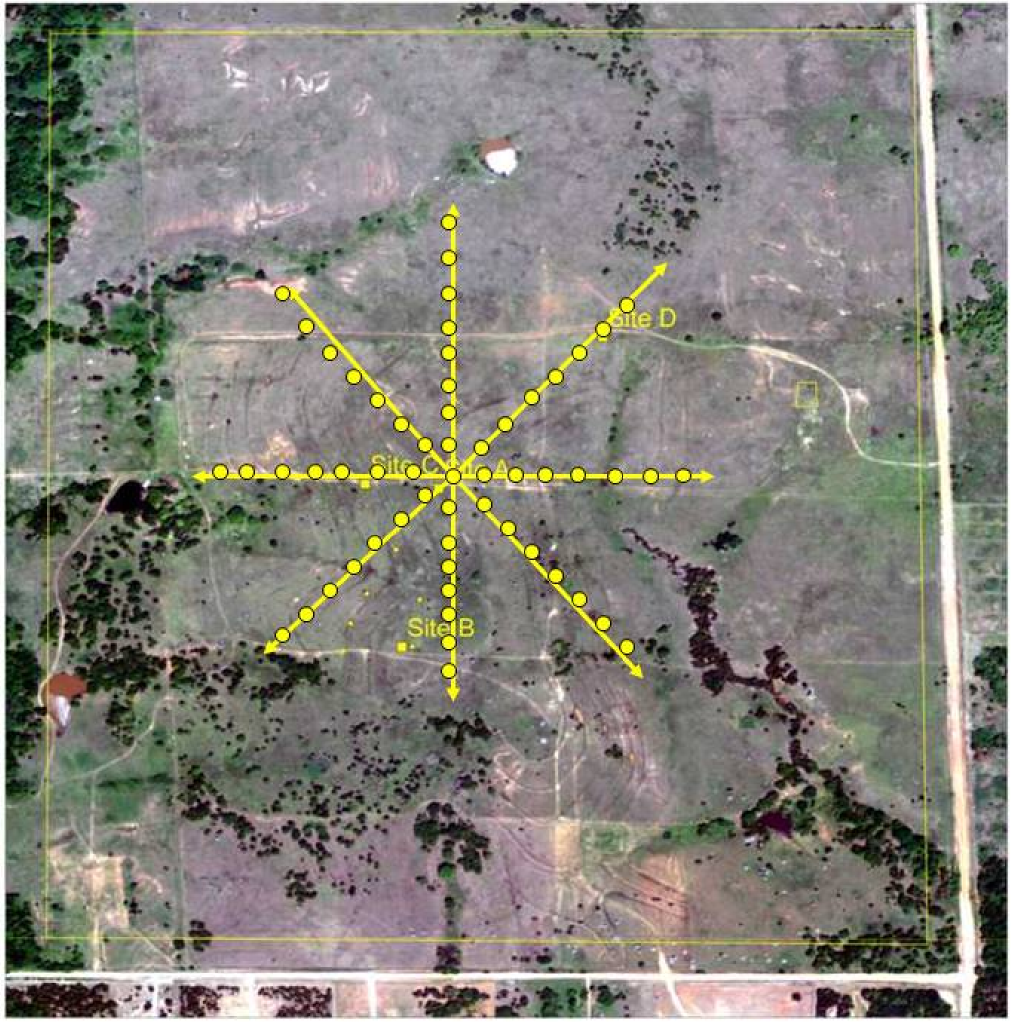


SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor Calibration

Sensor	Factory Listed Accuracy	Bias w/ factory calibratio n	RMSE factory calibration	RMSE soil specific calibration	Failure Rate over 3 years
Theta	0.01	0.014	0.030	0.028	0 out of 20
Hydra	0.01-0.03	0.020	0.040	0.032	0 out of 24
ECTM	0.03	0.076	0.081	0.036	8 out of 20
CS-616	0.025	-0.023	0.073	0.063	1 out of 20
Trime	0.01-0.03	0.005	0.042	0.023	0 out of 6
Acclima	0.01	0.074	0.080	0.025	9 out of 20
CS-229	N/A	-	-	-	2 out of 20*
Enviro-SMART	N/A	-	-	-	4 out 15**

SMAP Marena Oklahoma In Situ Sensor Testbed
Validation Sampling Campaigns

- Monthly Sampling
  - Vegetation Collection
  - Gravimetric Sampling
  - Theta Probe Sampling
- Intensive Observations
  - High Density Sampling
  - Soil Profiles

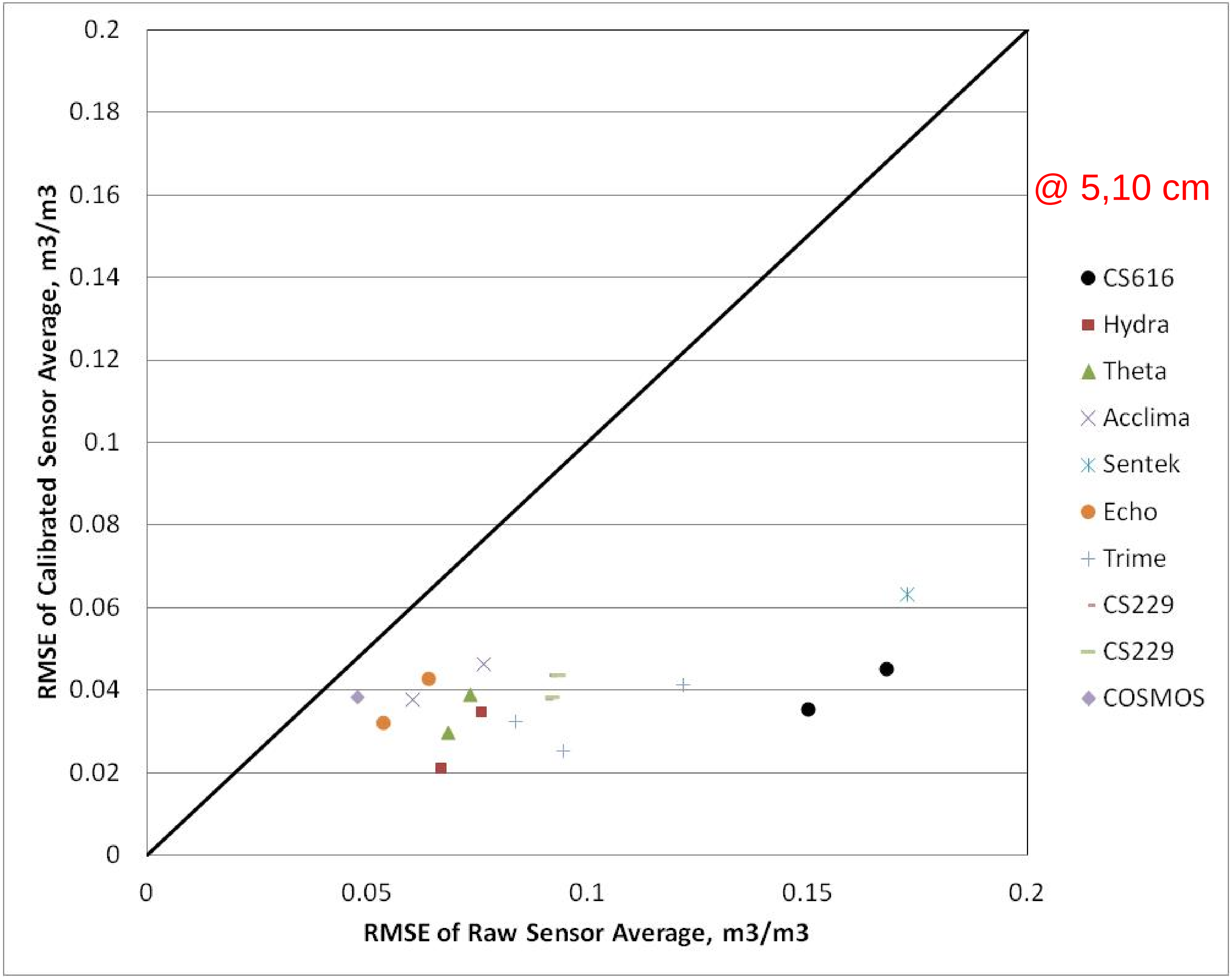


SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor to Sensor Average Comparison

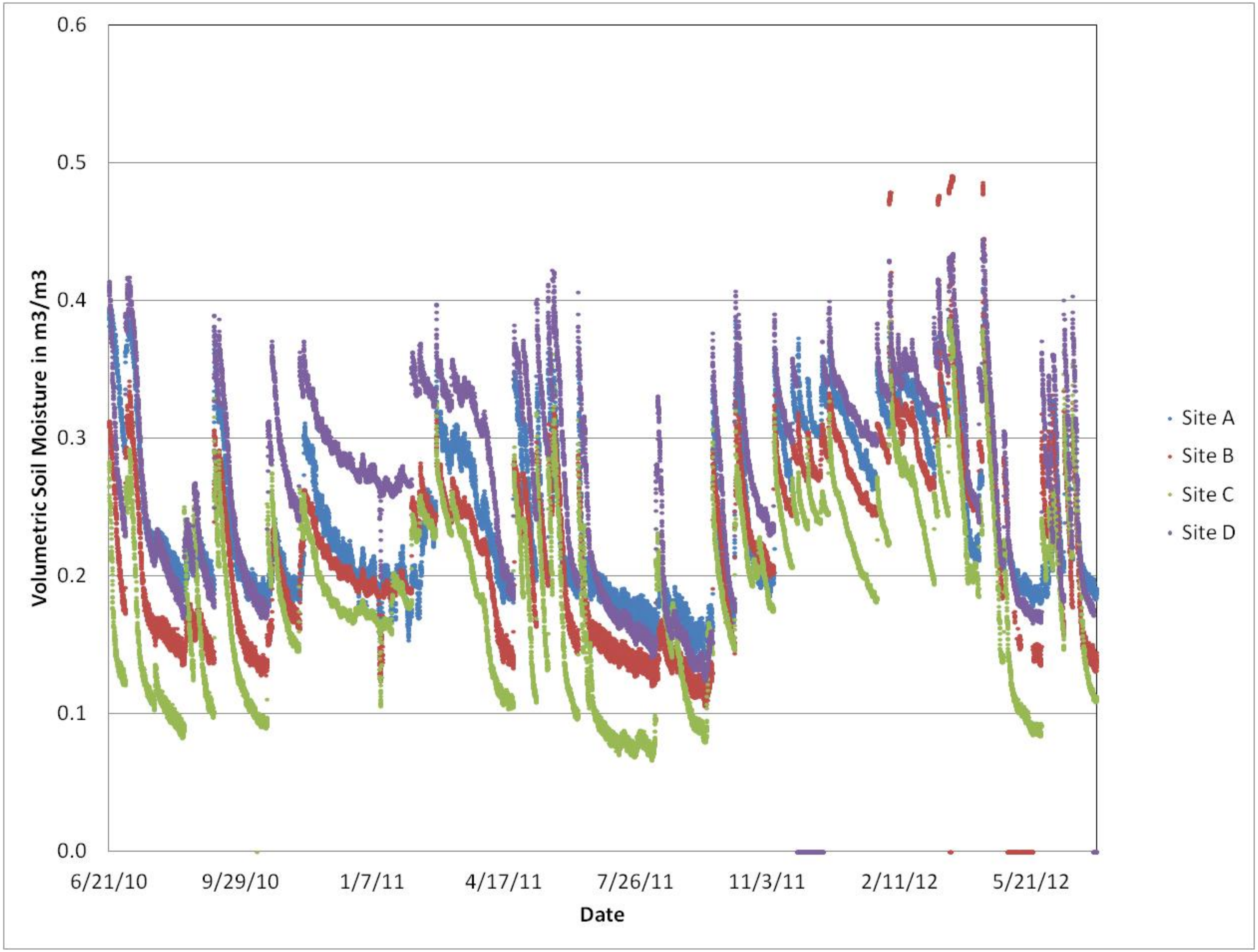
Sensor	UnScaled				Scaled			
	2.5 cm	5 cm	10 cm	Variable Depth	2.5 cm	5 cm	10 cm	Variable Depth
CS-616		0.110	0.140			0.036	0.046	
Hydra	0.048	0.062	0.079		0.021	0.035	0.047	
Theta		0.058	0.063			0.030	0.039	
Acclima		0.027	0.053			0.030	0.047	
Sentek			0.178				0.064	
ECTM		0.047	0.055			0.032	0.043	
Trime	0.083	0.085	0.110		0.026	0.032	0.042	
CS229		0.089	0.091			0.038	0.044	
GPSR				0.050				0.036
COSMOS				0.048				0.035

SMAP Marena Oklahoma In Situ Sensor Testbed

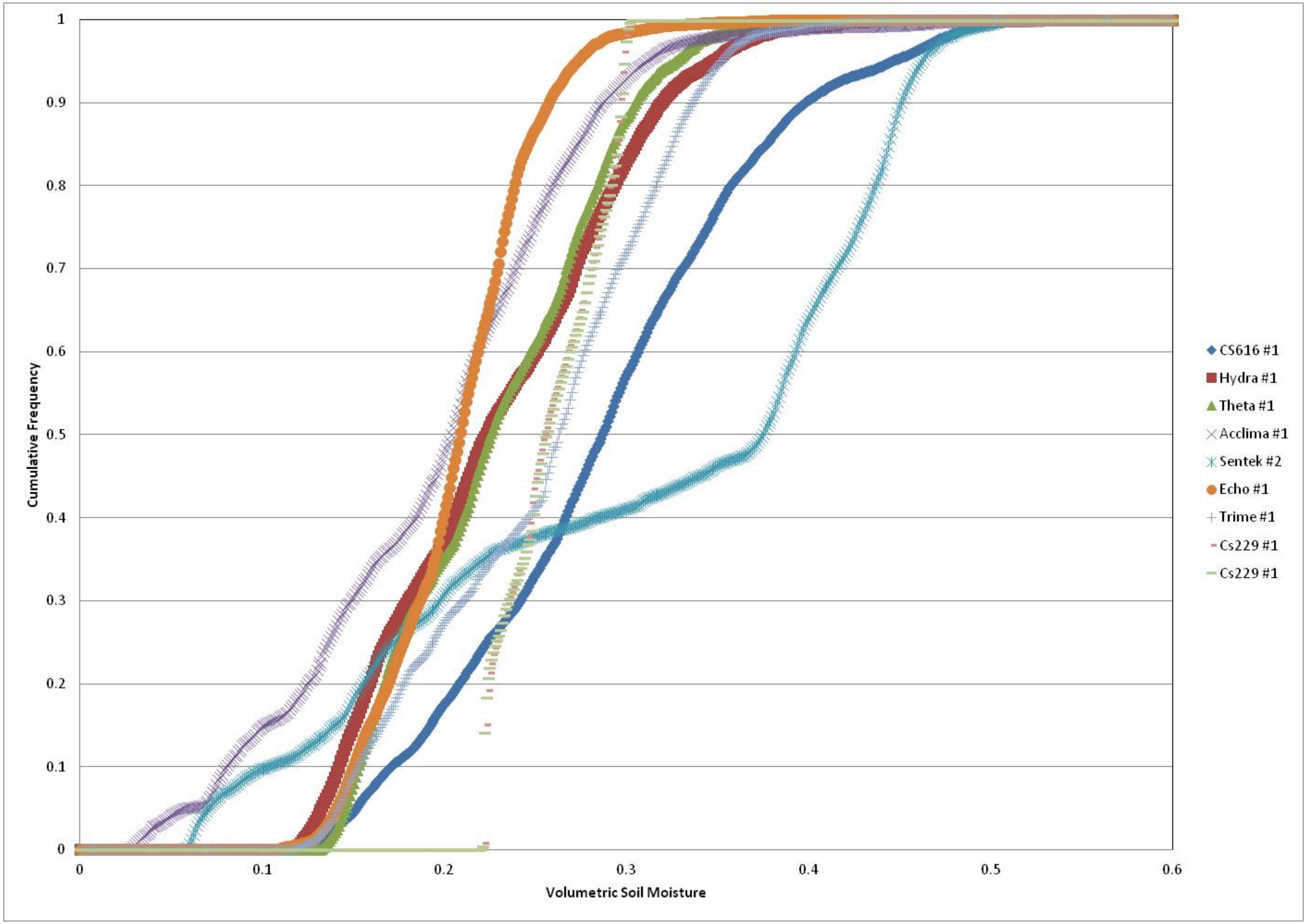
Uniform conditions in the testbed



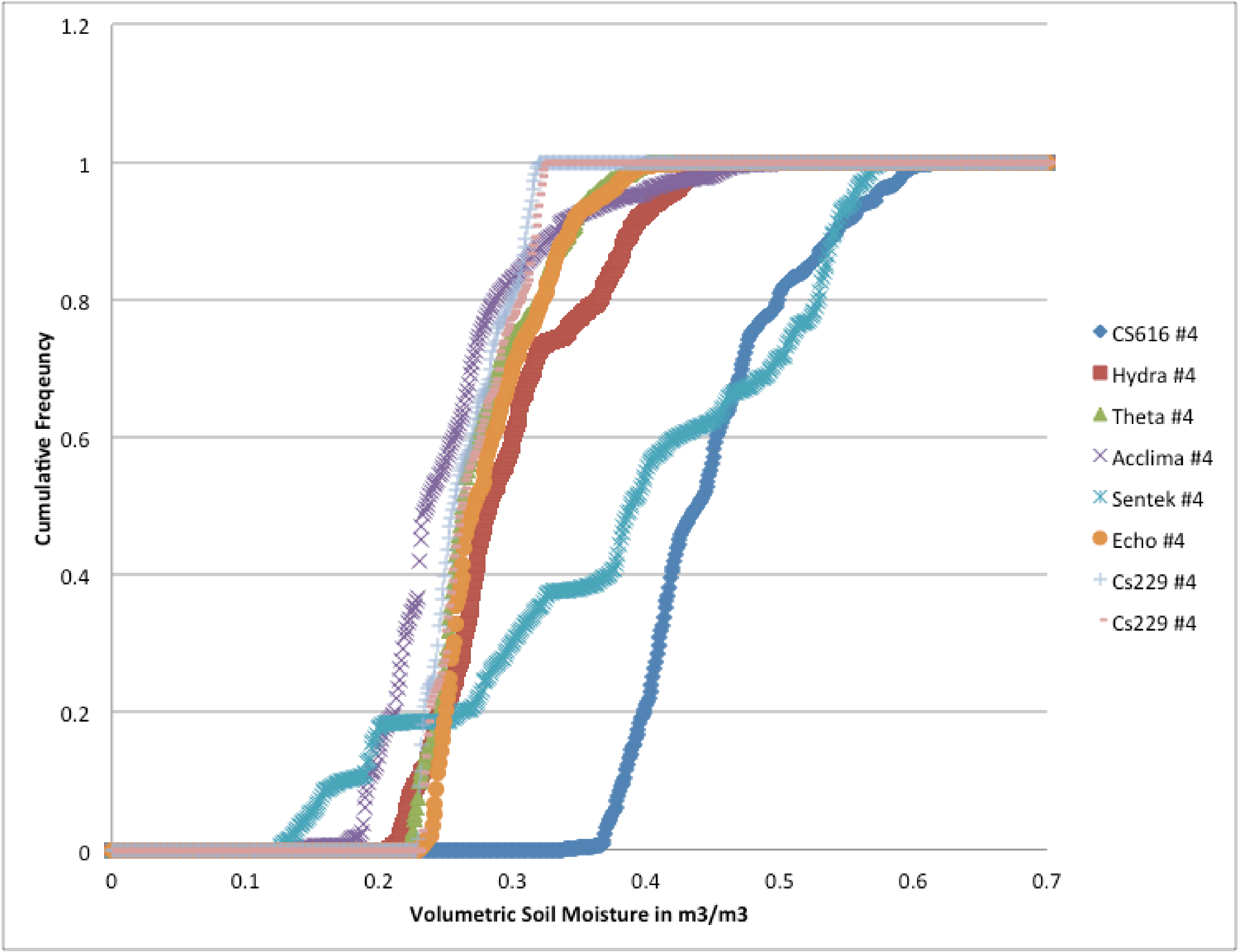
SMAP Marena Oklahoma In Situ Sensor Testbed
Sites A-D Hydras at 5 cm depth



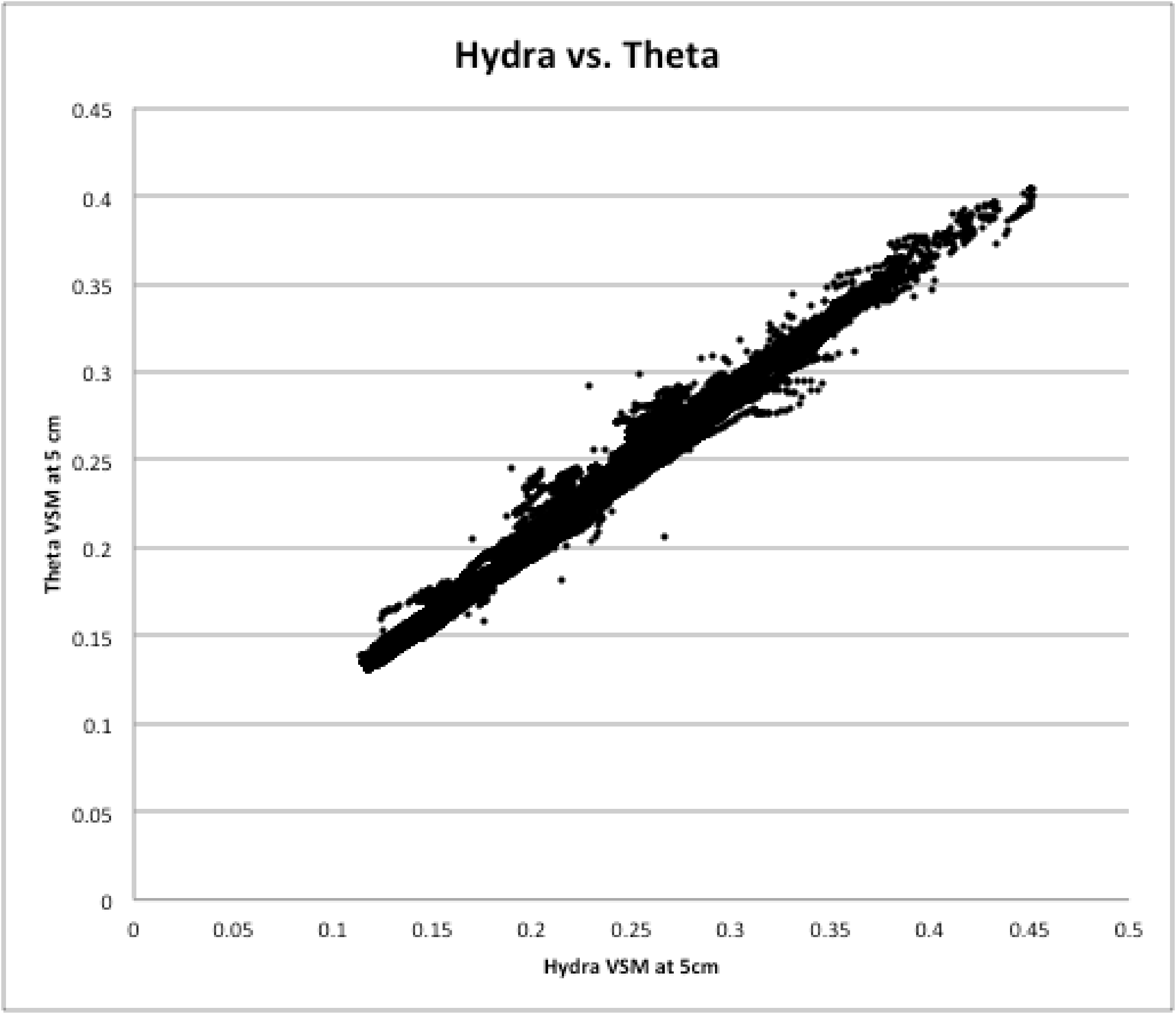
SMAP Marena Oklahoma In Situ Sensor Testbed
CDFs of Site Averages by Sensor at 5 cm



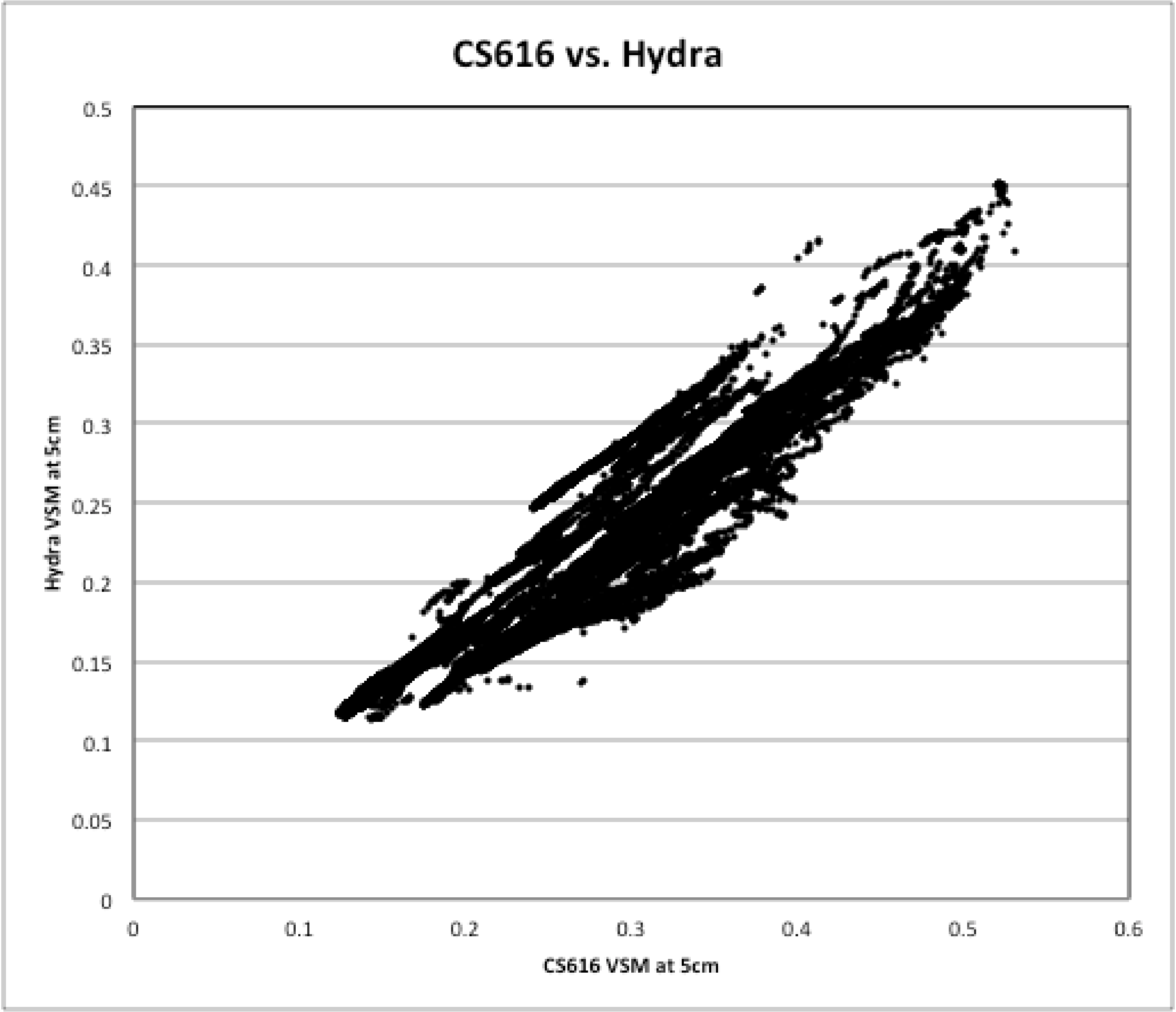
SMAP Marena Oklahoma In Situ Sensor Testbed
CDFs of Site Averages by Sensor at 50 cm



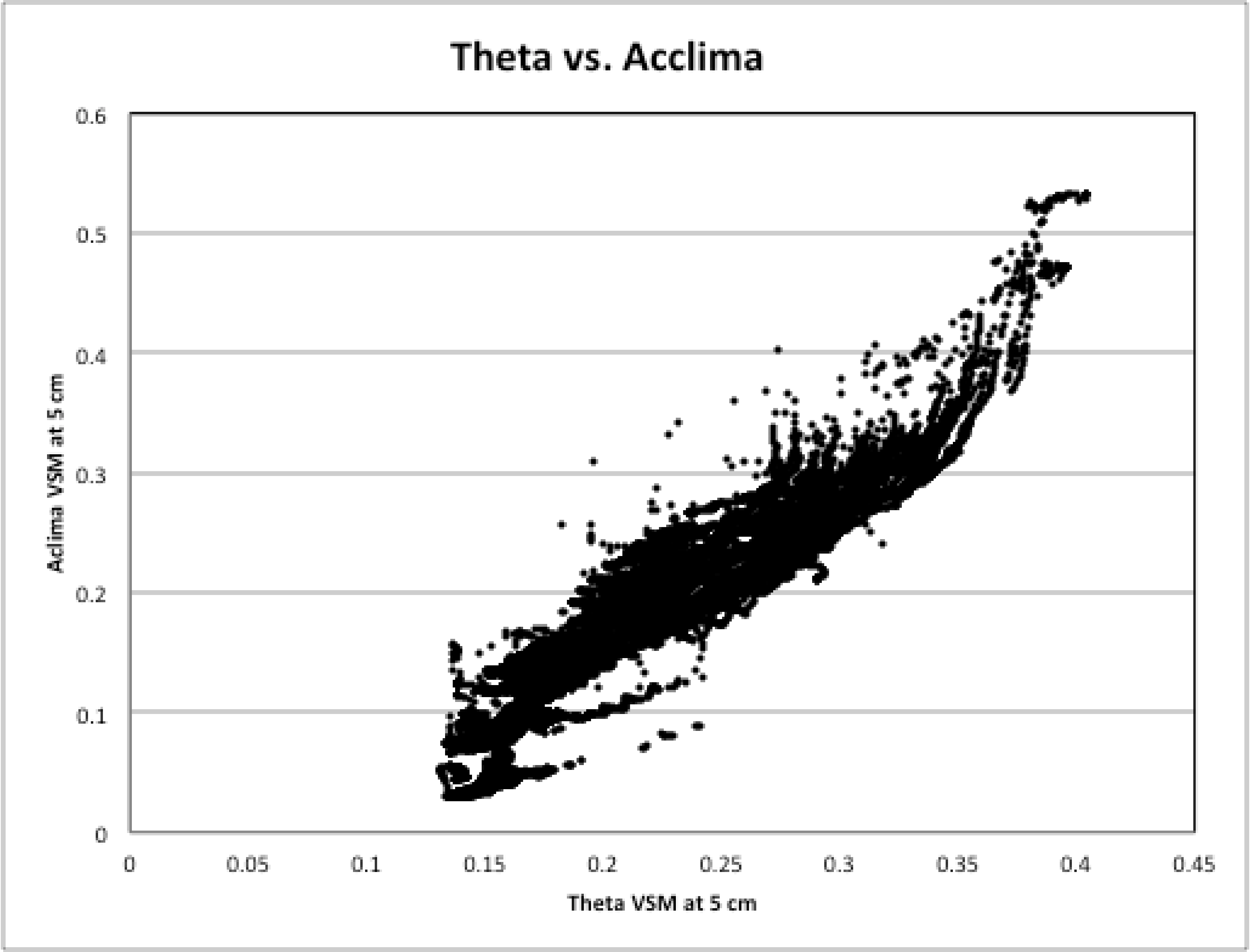
SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor to Sensor Average Comparison



SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor to Sensor Average Comparison

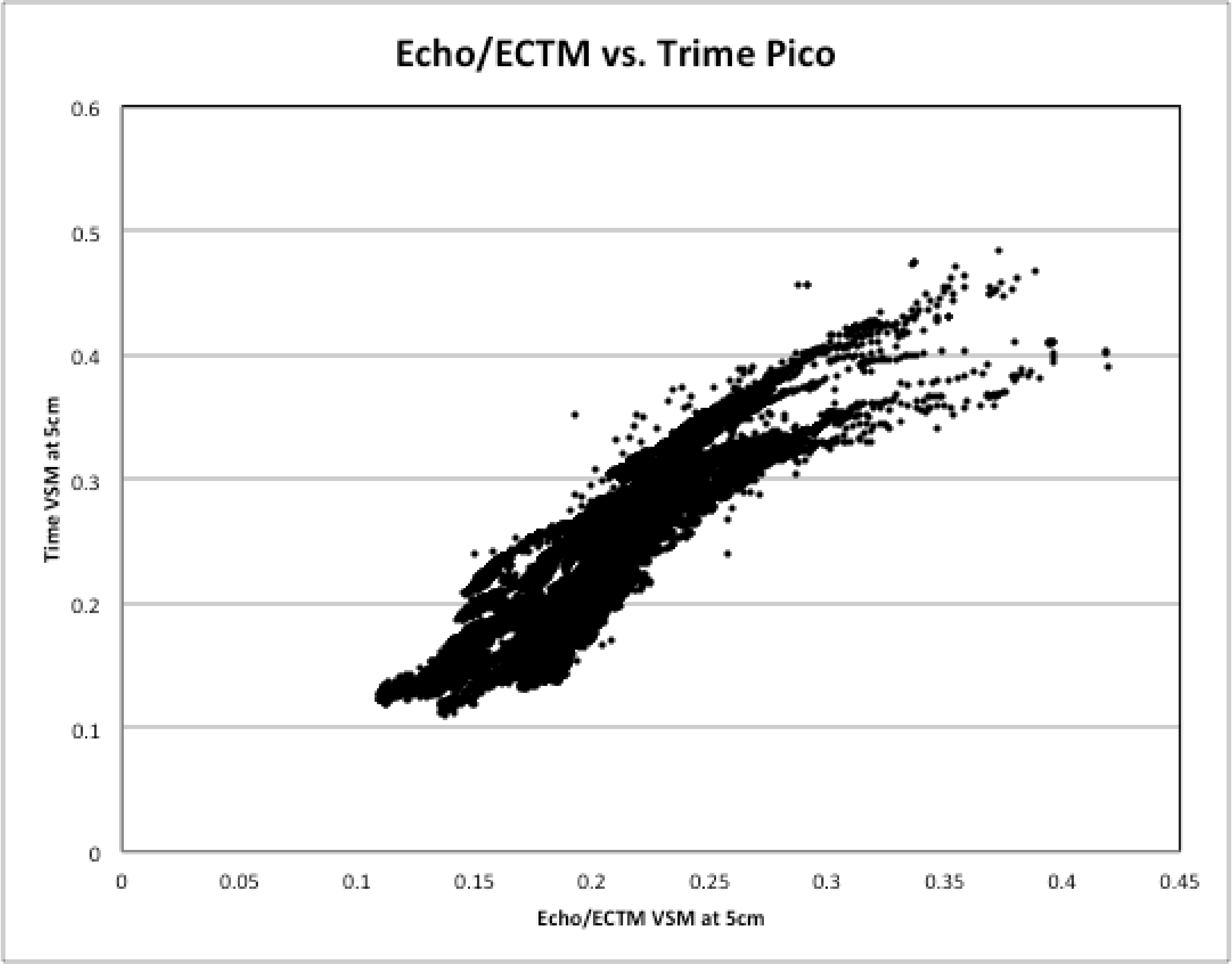


SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor to Sensor Average Comparison

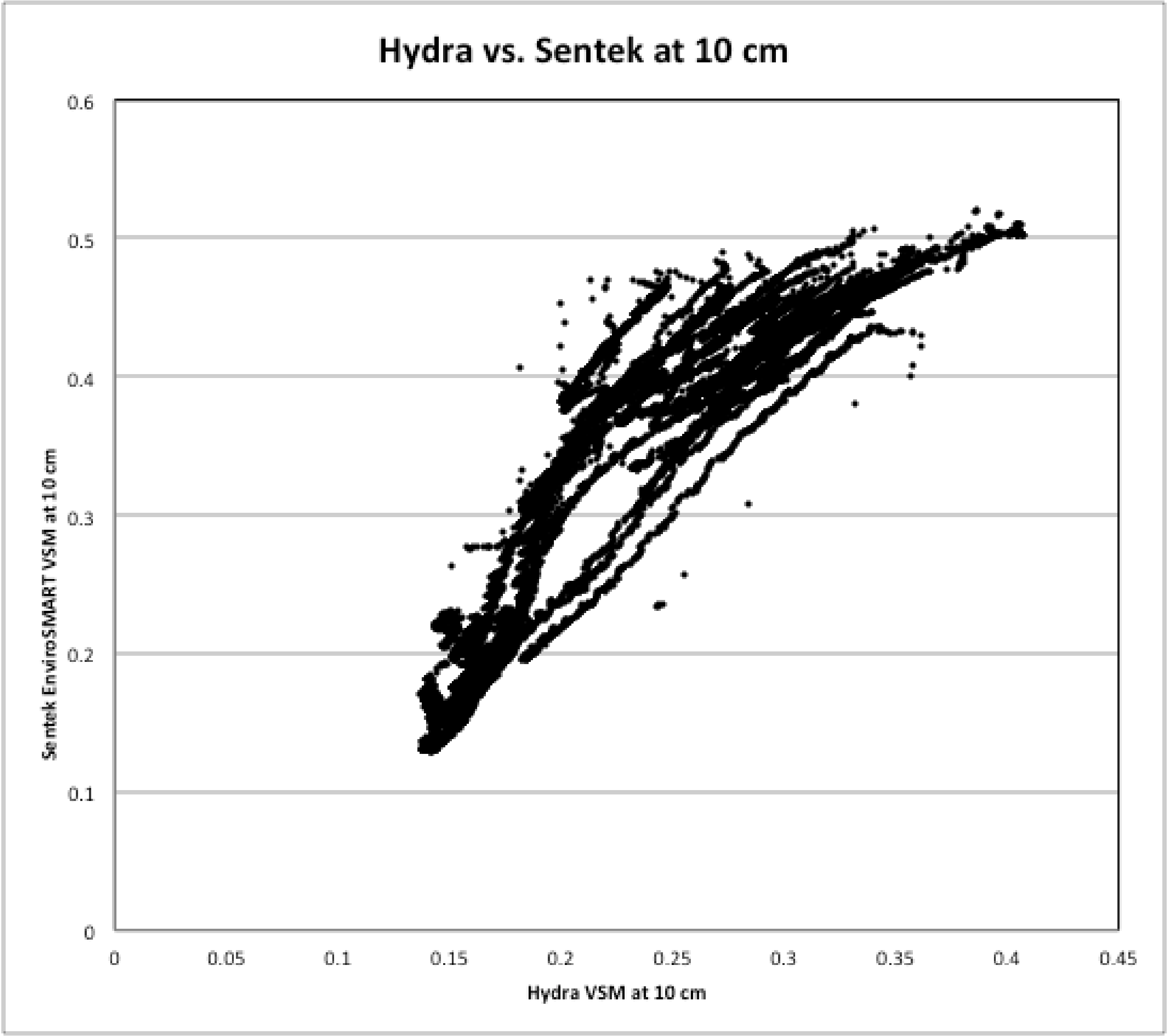


SMAP Marena Oklahoma In Situ Sensor Testbed

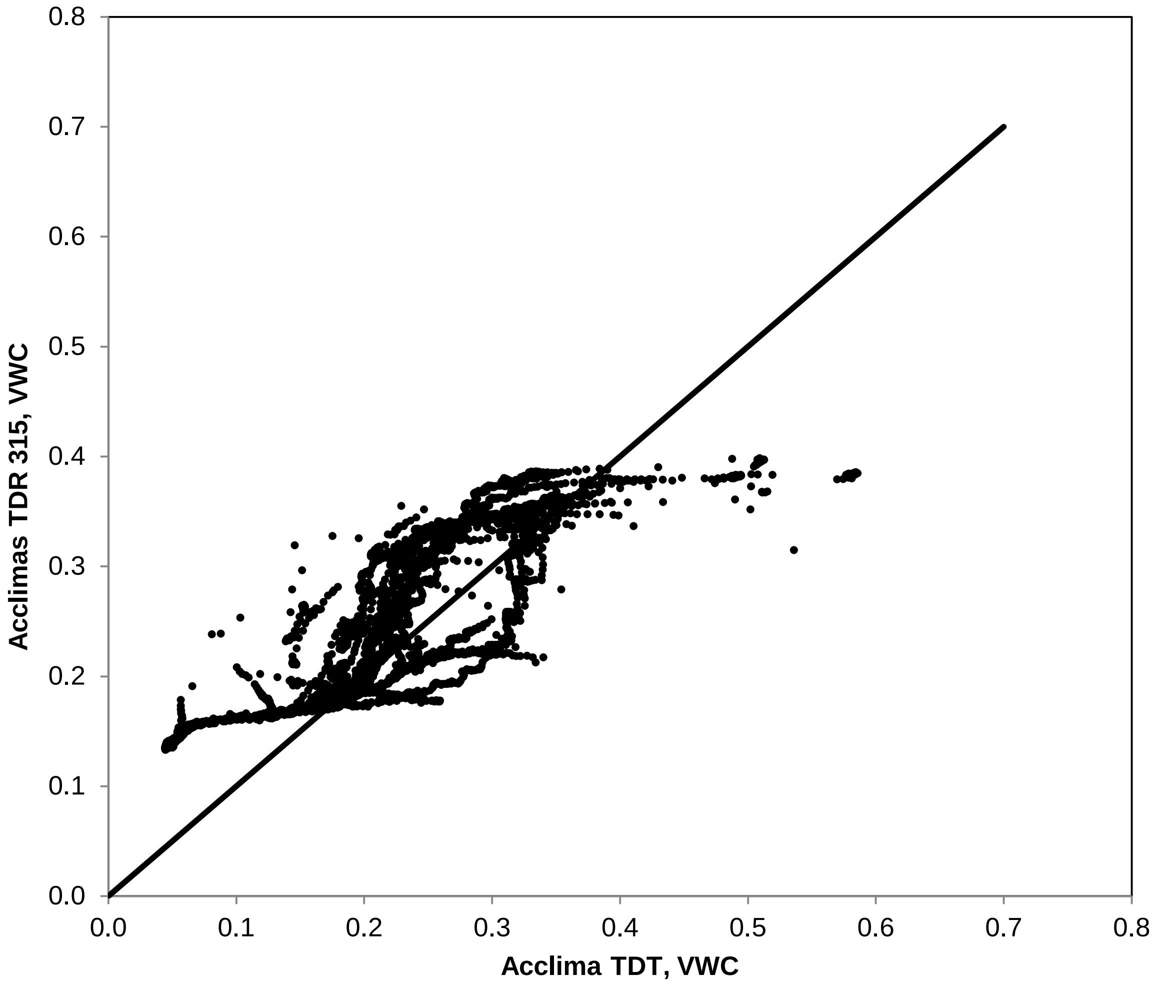
Sensor to Sensor Average Comparison



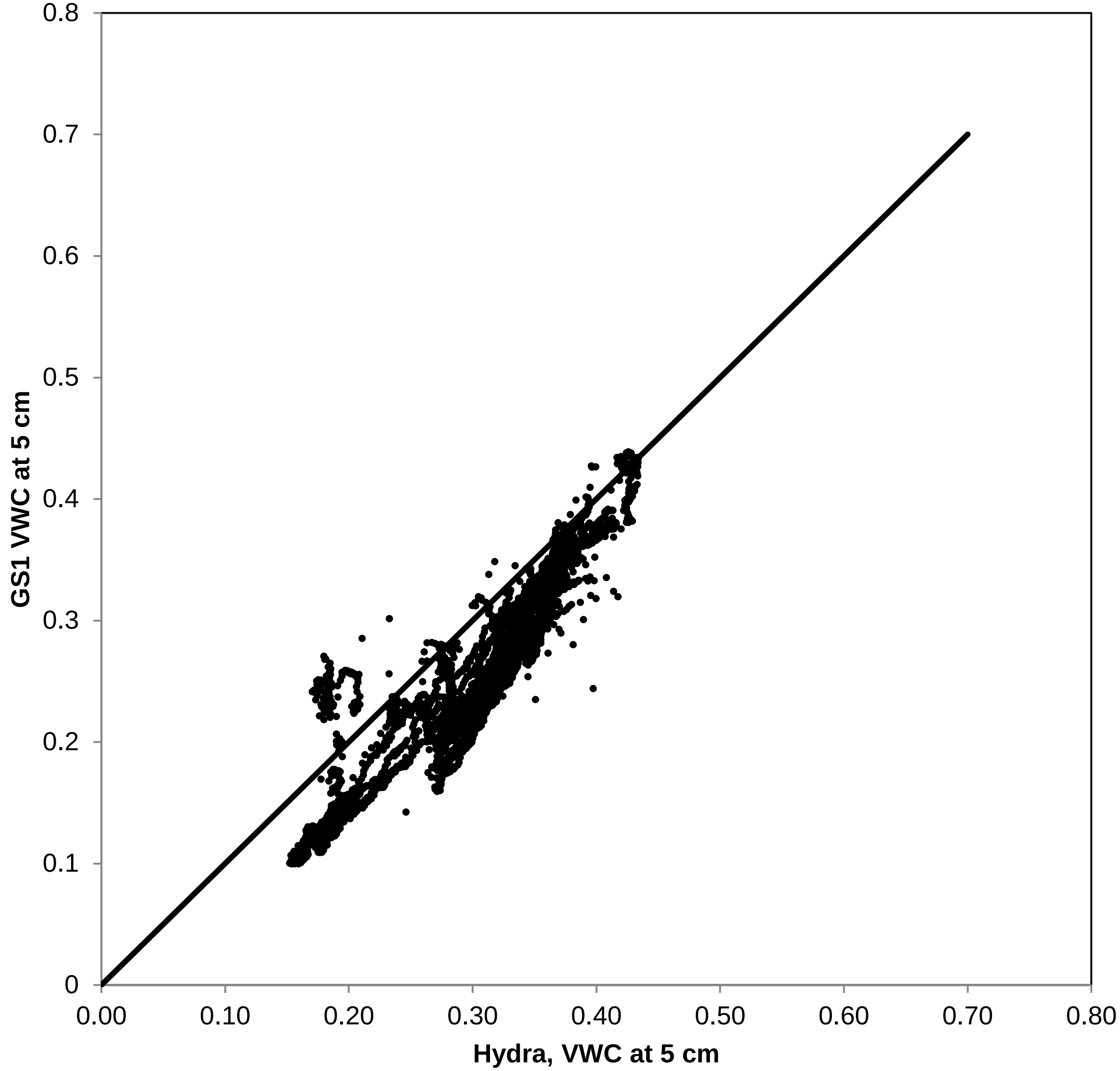
SMAP Marena Oklahoma In Situ Sensor Testbed
Sensor to Sensor Average Comparison



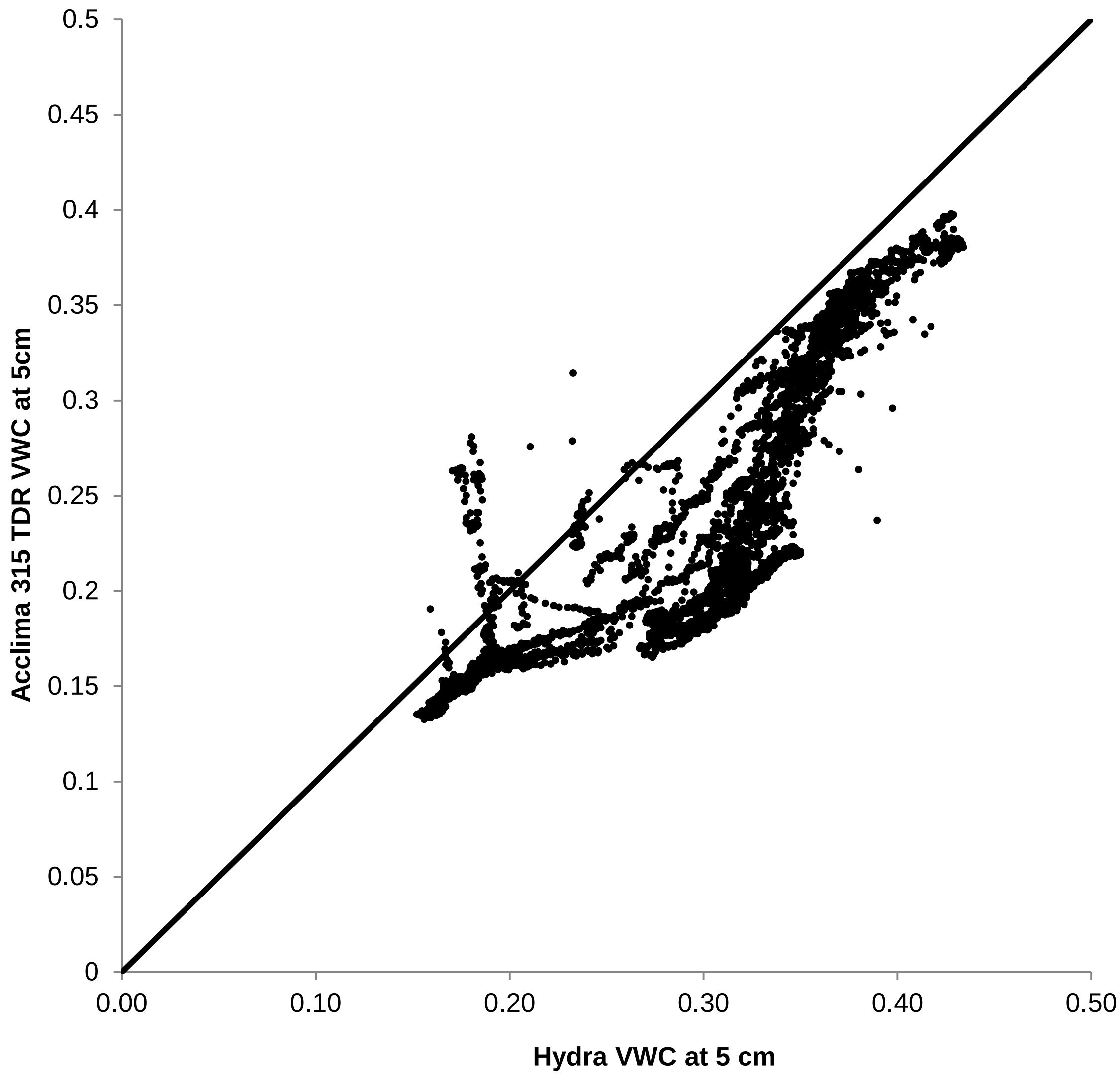
SMAP Marena Oklahoma In Situ Sensor Testbed
Acclima versus Acclima



SMAP Marena Oklahoma In Situ Sensor Testbed
Hydra versus GS1



SMAP Marena Oklahoma In Situ Sensor Testbed
Hydra versus Acclima 315



Not all measurements are created equal
(Some are more equal than others)

All sensors are "wrong…"
However, consistency matters a great deal.

The one-slide lecture on triple-collocation

1. Consider three ‘independent’ soil moisture estimates $(\theta_1, \theta_2, \theta_3)$

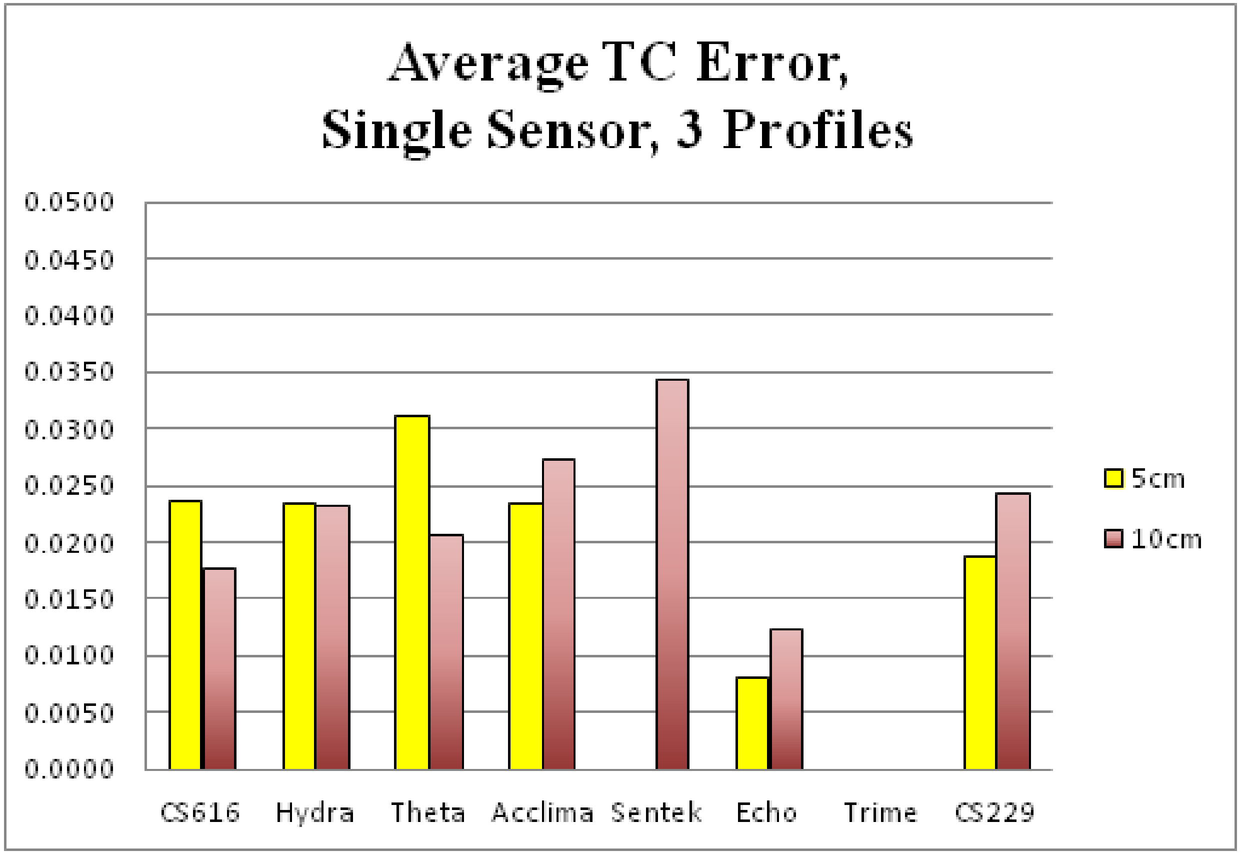
2. Subtract their means, ensuring the same numerical scale

$$\theta_{1,s}{}' = \theta_{1,s} - \overline{\theta_{1,s}} \; ; \theta_{2,s}{}' = \theta_{2,s} - \overline{\theta_{2,s}} \; ; \theta_{3,s}{}' = \theta_{3,s} - \overline{\theta_{3,s}}$$

3. Calculate random error associated with the triad of measurements $\epsilon_s = TC\left(\theta_{1,s}{}', \theta_{2,s}{}', \theta_{s,3}{}'\right)$

(A paper discussing USCRN triple-collocation estimates is currently under review in VSJ)

Comparing Sensors:
What is the random error associated with each technology?



1. At the 5cm depth, Theta probes produce the largest random errors (~0.030 m^3/m^3)

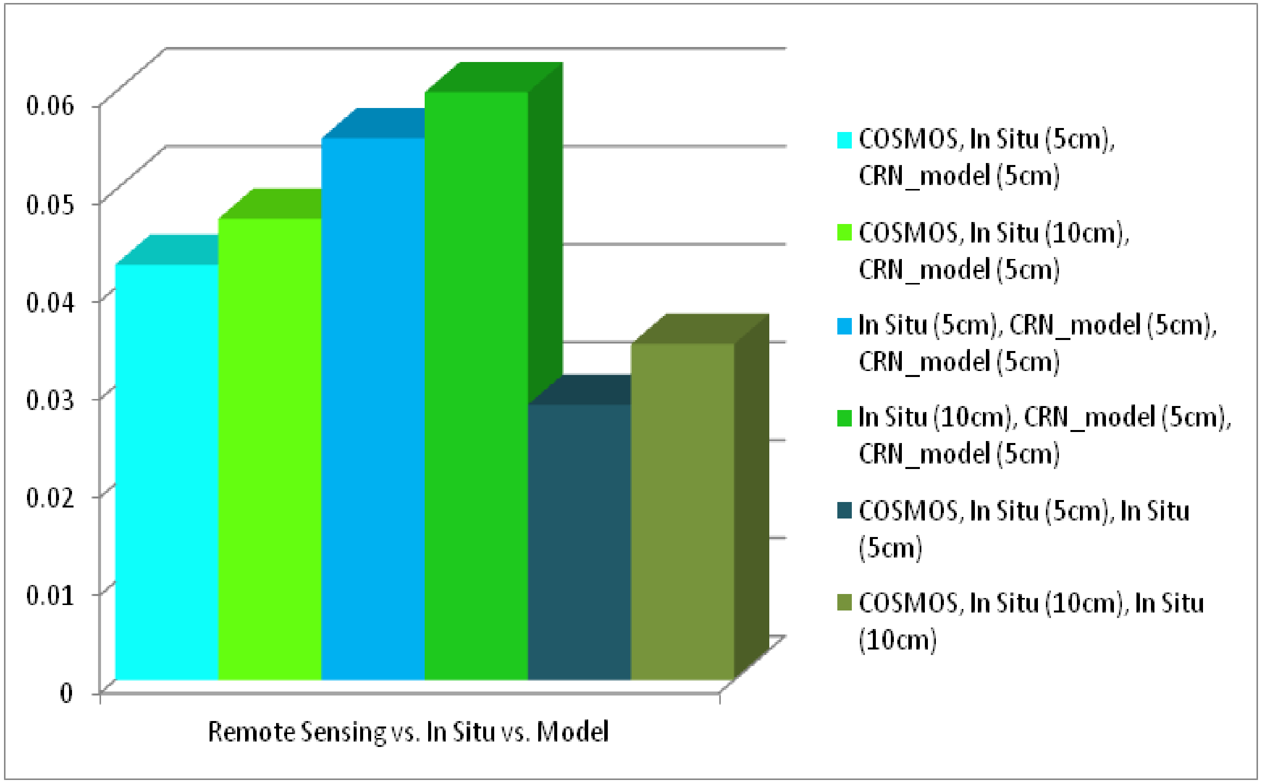
2. At the 5cm depth, Echo probes produce the smallest random errors (~0.008 m^3/m^3)

3. At the 10cm depth, Sentek probes display the largest random errors (0.034 m^3/m^3)

4. At the 10cm depth, Echo probes (again) display the smallest random errors (0.012 m^3/m^3)

(Trime sensors are only available in two locations, Sentek readings are unavailable for the 5cm depth)

Comparing Remotely-Sensed Estimates and Models: How do the errors grow as the *type* of product changes?

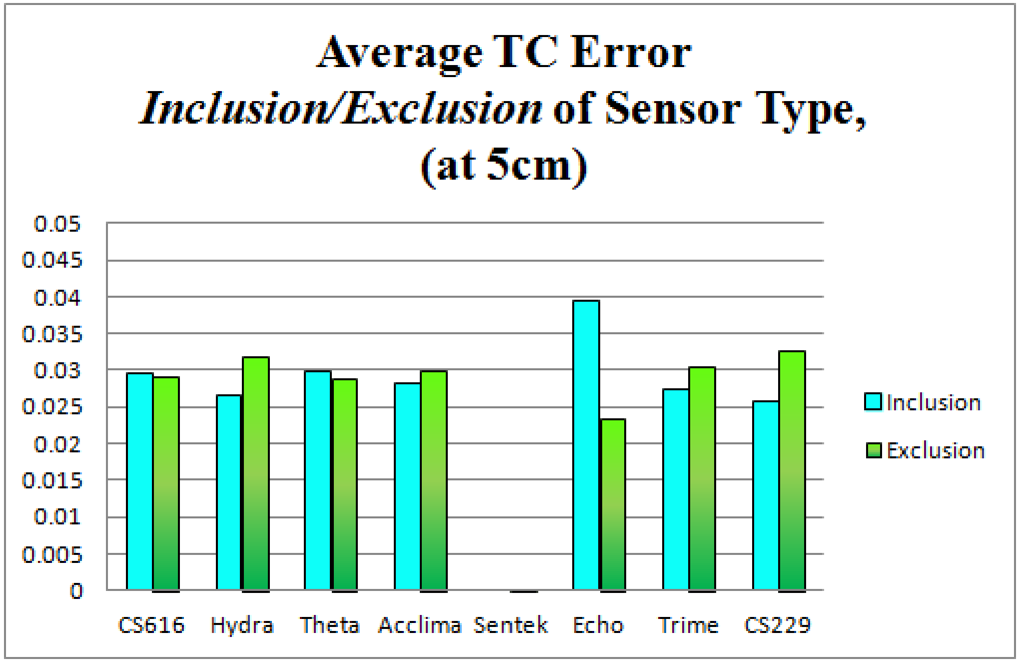


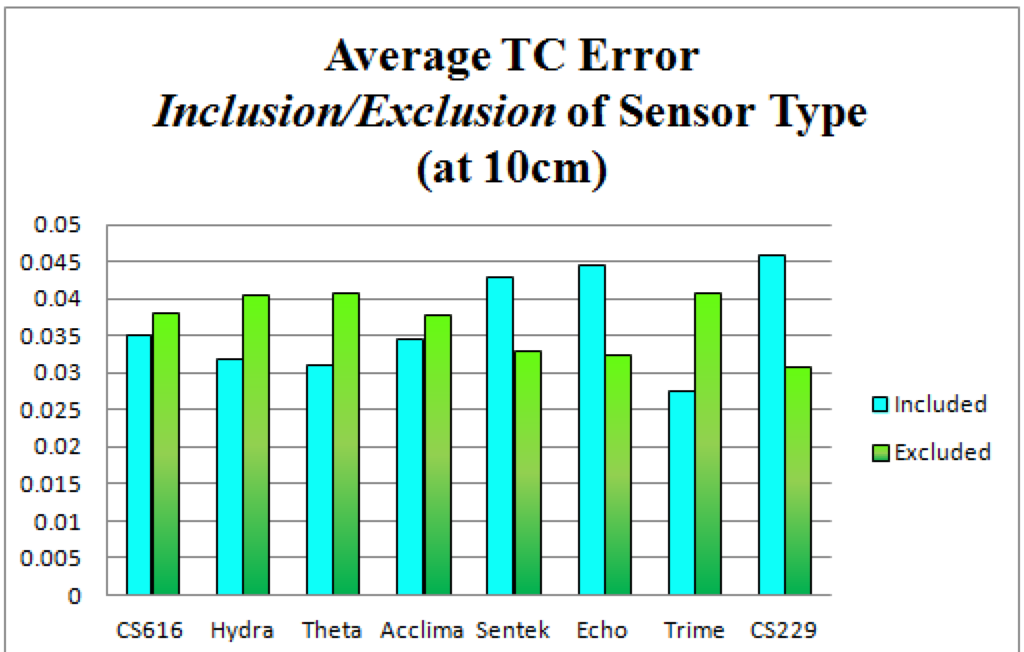
Analysis of combinations of three soil moisture products. at a single location: *in situ*, remotely-sensed (COSMOS), and model.

1. The CRN model introduces smaller errors against 5cm *in situ* sensors
2. Largest errors are obtained when model products are compared with *in situ* sensors.
3. COSMOS and *in situ* triads produce comparable errors to three *in situ* sensors. (Even though COSMOS's effective depth is larger)

(COSMOS readings are available the MOISST test bed, CRN model estimates were calibrated using each of the paired USCRN soil moisture and precipitation gauges)

Comparing Mixed Networks:





Analysis of combinations of three sensor types at a *single location* that include or exclude a specific technology.

1. At the 5cm depth, inclusion of Echo probes produces significantly larger errors. (And excluding Echo probes helps)

2. At the 10cm depth, Sentek Echo, and CS229 sensors produce much larger random errors when included.

3. Networks including Hydra, Theta, and Trime probes outperform those without

Conclusions: What do we know?
(or what do we think we know?)

1. Calibration is important, scaling is more important
2. Not all probes are equal.

---

1. Though Echo probes are extremely consistent (small random errors), their presence increases errors in mixed networks.
2. Sentek sensors produce the largest errors in homogeneous and heterogeneous networks.
3. Integrating COSMOS sensors with *in situ* technologies presents comparable errors to all-in-situ networks.
4. Hydra, Theta, and Trime sensors offer the greatest benefit to mixed networks.