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

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

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

<table>
<thead>
<tr>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
<th>Site D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td>GPS</td>
<td>ASSH-Imko/Trime</td>
<td>GPS</td>
<td>GPS</td>
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<tr>
<td>COSMOS</td>
<td>Passive DTS</td>
<td></td>
<td>CRN</td>
</tr>
<tr>
<td>ASSH-Imko/Trime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDR systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flux System</td>
<td></td>
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</table>
• Installation in May 2010
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.
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.
<table>
<thead>
<tr>
<th>Sensor</th>
<th>Factory Listed Accuracy</th>
<th>Bias w/ factory calibration</th>
<th>RMSE factory calibration</th>
<th>RMSE soil specific calibration</th>
<th>Failure Rate over 3 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theta</td>
<td>0.01</td>
<td>0.014</td>
<td>0.030</td>
<td>0.028</td>
<td>0 out of 20</td>
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<tr>
<td>Hydra</td>
<td>0.01-0.03</td>
<td>0.020</td>
<td>0.040</td>
<td>0.032</td>
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<tr>
<td>ECTM</td>
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<td>0.076</td>
<td>0.081</td>
<td>0.036</td>
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<td>CS-616</td>
<td>0.025</td>
<td>-0.023</td>
<td>0.073</td>
<td>0.063</td>
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<tr>
<td>Trime</td>
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<td>0.074</td>
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<tr>
<td>CS-229</td>
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<td>-</td>
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<tr>
<td>Enviro-</td>
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<td>-</td>
<td>-</td>
<td>4 out 15**</td>
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<tr>
<td>SMART</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
• Monthly Sampling
  o Vegetation Collection
  o Gravimetric Sampling
  o Theta Probe Sampling

• Intensive Observations
  o High Density Sampling
  o Soil Profiles
## SMAP Marena Oklahoma In Situ Sensor Testbed
### Sensor to Sensor Average Comparison

<table>
<thead>
<tr>
<th>Sensor</th>
<th>UnScaled</th>
<th></th>
<th>Scaled</th>
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<tbody>
<tr>
<td></td>
<td>2.5 cm</td>
<td>5 cm</td>
<td>10 cm</td>
<td>Variable Depth</td>
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<tr>
<td>CS-616</td>
<td>0.048</td>
<td>0.062</td>
<td>0.079</td>
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<tr>
<td>Hydra</td>
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<tr>
<td>Theta</td>
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<td>0.178</td>
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<tr>
<td>Acclima</td>
<td>0.047</td>
<td>0.055</td>
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<tr>
<td>Sentek</td>
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</tr>
<tr>
<td>ECTM</td>
<td>0.083</td>
<td>0.085</td>
<td>0.110</td>
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</tr>
<tr>
<td>Trime</td>
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<tr>
<td>CS229</td>
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<td>0.091</td>
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<tr>
<td>GPSR</td>
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<tr>
<td>COSMOS</td>
<td></td>
<td></td>
<td></td>
<td>0.048</td>
</tr>
</tbody>
</table>
SMAP Marena Oklahoma In Situ Sensor Testbed
Uniform conditions in the testbed

@ 5,10 cm
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
Sensor to Sensor Average Comparison

CS616 vs. Hydra

Hydra VSM at 5 cm vs. CS616 VSM at 5 cm
Hydra vs. Sentek at 10 cm
Acclima TDR 315, VWC vs. Acclima TDT, VWC
SMAP Marena Oklahoma In Situ Sensor Testbed
Hydra versus GS1

![Hydra versus GS1 scatter plot](image-url)
Acclima 315 TDR VWC at 5cm

Hydra VWC at 5 cm
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
   \[
   \begin{align*}
   \theta_{1,s}' &= \theta_{1,s} - \overline{\theta_{1,s}} ;
   \theta_{2,s}' &= \theta_{2,s} - \overline{\theta_{2,s}} ;
   \theta_{3,s}' &= \theta_{3,s} - \overline{\theta_{3,s}}
   \end{align*}
   \]

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

*(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 m³/m³)

2. At the 5cm depth, Echo probes produce the smallest random errors (~0.008 m³/m³)

3. At the 10cm depth, Sentek probes display the largest random errors (0.034 m³/m³)

4. At the 10cm depth, Echo probes (again) display the smallest random errors (0.012 m³/m³)

(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.