Ground-based measurements of soil water storage in Texas

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Di Long
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Ground-based soil moisture

- Why do we need it?
- How do we modeling it?
- How can we measure it?
  - Current technologies
  - What’s in Texas
- What can we do with it?
Soil Moisture Cycles

Soil moisture is dynamic:

- The very nature of these dynamics sustain our environment
- We need to monitor, observe and predict its behavior

<table>
<thead>
<tr>
<th></th>
<th>WET</th>
<th>DRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood potential</td>
<td>RAINFALL</td>
<td>Drought</td>
</tr>
<tr>
<td>Landslides</td>
<td>EROSION</td>
<td>Dust</td>
</tr>
<tr>
<td>Weak</td>
<td>SOIL STRENGTH</td>
<td>Hard</td>
</tr>
<tr>
<td>Latent heat</td>
<td>SOLAR ENERGY</td>
<td>Sensible heat</td>
</tr>
<tr>
<td>Energy-limited</td>
<td>TRANSPIRATION</td>
<td>Water-limited</td>
</tr>
<tr>
<td>Carbon storage</td>
<td>ECOHYDROLOGY</td>
<td>Stress, mortality, fire</td>
</tr>
<tr>
<td>Oxygen limitations</td>
<td>MICROBIAL ACTIVITY</td>
<td>Nutrient limitations</td>
</tr>
</tbody>
</table>
Variability of Soil Properties

... at the plant level


... at field scale

Young et al. (2009) J. Arid Environ. 73:733-744

... at watershed scale

Young et al. (2004), Vadose Zone J. 3:956-963

Soil Water Storage (NLDAS)
Sensor Technologies and Scale

Scale of Interest ≠ Scale of Observations

Spatial Support

- LSM operate at >km\(^2\)
- Satellite observations are coarse and shallow
- Ground-based measurements are 'points'

Temporal Support

- LSM operate at hourly time scales
- Satellite paths are lower frequency
- Ground-based measurements are cover nearly any range

Effectively merging these scales is a challenge on many levels

Robinson et al., 2008, Vadose Zone J., 7:358-389
Soil depiction in NLDAS-1

**CONUS-SOIL**
- STATSGO (1:250,000)
  - 1 km grid
  - Dominant soil series
- 16 textural classes
  - 12 are actually soil
- 11 layers to 2m depth

**NLDAS**
- ⅛° grid (~14 km)
- %Class over each grid
- Noah, Mosaic, VIC
  - Uniform soil texture from top 5cm layer

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<table>
<thead>
<tr>
<th></th>
<th>Mosaic</th>
<th>Noah</th>
<th>SAC</th>
<th>VIC</th>
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<tbody>
<tr>
<td>Soil Layers</td>
<td>3</td>
<td>4</td>
<td>2 buckets</td>
<td>3</td>
</tr>
<tr>
<td>Depth (cm)</td>
<td>10, 40, 200</td>
<td>10, 40, 100, 200</td>
<td>-</td>
<td>10 + 2 variable</td>
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<tr>
<td>Output</td>
<td>θ (z)</td>
<td>θ (z)</td>
<td>SWS</td>
<td>SWS</td>
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</tbody>
</table>

Economic Geology
Soil hydrology in NLDAS-1

Mosaic and Noah

- Soil hydraulic properties for 12 soil classes
  - Mosaic PTF (Rawls et al., 1982)
  - Noah PTF (Crosby et al., 1984)
- Flux between layers quasi-Richards’ equation
- Uniform soil with depth

TABLE 3. Means and Standard Deviations for the Four Hydraulic Parameters in Each Textural Class

<table>
<thead>
<tr>
<th>Class</th>
<th>$n$</th>
<th>$b$</th>
<th>S.D.</th>
<th>$\log \Psi_{s}$</th>
<th>Mean</th>
<th>S.D.</th>
<th>$\log K_{s}$</th>
<th>Mean</th>
<th>S.D.</th>
<th>$\Theta_{s}$</th>
<th>Mean</th>
<th>S.D.</th>
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</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>124</td>
<td>4.74</td>
<td>1.40</td>
<td>1.15</td>
<td>0.73</td>
<td>-0.13</td>
<td>0.67</td>
<td>43.4</td>
<td>8.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sand</td>
<td>14</td>
<td>2.79</td>
<td>1.38</td>
<td>0.84</td>
<td>0.56</td>
<td>0.82</td>
<td>0.39</td>
<td>33.9</td>
<td>7.3</td>
<td></td>
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<tr>
<td>Loamy sand</td>
<td>30</td>
<td>4.26</td>
<td>1.95</td>
<td>0.56</td>
<td>0.73</td>
<td>0.30</td>
<td>0.51</td>
<td>42.1</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Loam</td>
<td>103</td>
<td>5.25</td>
<td>1.66</td>
<td>1.55</td>
<td>0.66</td>
<td>-0.32</td>
<td>0.63</td>
<td>43.9</td>
<td>7.4</td>
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<td></td>
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<tr>
<td>Silty loam</td>
<td>394</td>
<td>5.33</td>
<td>1.72</td>
<td>1.88</td>
<td>0.38</td>
<td>-0.40</td>
<td>0.55</td>
<td>47.6</td>
<td>5.4</td>
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<tr>
<td>Sandy clay loam</td>
<td>104</td>
<td>6.77</td>
<td>3.39</td>
<td>1.13</td>
<td>1.04</td>
<td>-0.20</td>
<td>0.54</td>
<td>40.4</td>
<td>4.8</td>
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<tr>
<td>Clay loam</td>
<td>147</td>
<td>8.17</td>
<td>3.74</td>
<td>1.42</td>
<td>0.72</td>
<td>-0.46</td>
<td>0.59</td>
<td>46.5</td>
<td>5.4</td>
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<tr>
<td>Silty clay loam</td>
<td>325</td>
<td>8.72</td>
<td>4.33</td>
<td>1.79</td>
<td>0.58</td>
<td>-0.54</td>
<td>0.61</td>
<td>46.4</td>
<td>4.6</td>
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<tr>
<td>Sandy clay</td>
<td>16</td>
<td>10.73</td>
<td>1.54</td>
<td>0.99</td>
<td>0.56</td>
<td>0.01</td>
<td>0.33</td>
<td>40.6</td>
<td>3.2</td>
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<tr>
<td>Silty clay</td>
<td>43</td>
<td>10.39</td>
<td>4.27</td>
<td>1.51</td>
<td>0.84</td>
<td>-0.72</td>
<td>0.69</td>
<td>46.8</td>
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<tr>
<td>Light clay</td>
<td>148</td>
<td>11.55</td>
<td>3.93</td>
<td>1.67</td>
<td>0.59</td>
<td>-0.86</td>
<td>0.62</td>
<td>46.8</td>
<td>3.5</td>
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<tr>
<td>All classes</td>
<td>1448</td>
<td>7.22</td>
<td>3.86</td>
<td>1.39</td>
<td>0.70</td>
<td>-0.42</td>
<td>0.64</td>
<td>45.7</td>
<td>6.1</td>
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</table>

Parameters: $b$ is the slope of $\log \Psi$ versus $\log (\Theta/\Theta_s)$ regression, $\Psi$ in centimeters $H_2O$; $\log \Psi_s$ is the intercept of $\log \Psi$ versus $\log (\Theta/\Theta_s)$ regression, $\Psi$ in centimeters $H_2O$; $\log K_s$ is the log of the saturated hydraulic conductivity in inches per hour; $\Theta_s$ is the saturated water content in percent (volume/volume).
Soil Moisture Sensors

Soil Monitoring
Water content (TDR, DPHP)
Matric potential (HDS)
Soil temperature (HDS)
Permittivity/EC (TDR)
Thermal diffusivity & conductivity (DPHP)
Additional DIELECTRIC Sensors

ADVANTAGES

- There is NO standard for soil moisture measurements
- No single probe can function across all environments
- All electrical sensors indirectly infer soil moisture

DISADVANTAGES

- Calibration requirements
- Smaller volume
- Less robust

Decagon 5TE
- Soil $T$, $\theta$, and $EC_{\text{actual}}$

Stevens’ HydraProbe
- Soil $T$, $\theta$, and $EC_{\text{apparent}}$
# Ground-based soil moisture networks

<table>
<thead>
<tr>
<th>Network</th>
<th>Sensor</th>
<th>US Sites</th>
<th>TX Sites</th>
<th>Year</th>
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<tbody>
<tr>
<td>SCAN</td>
<td>HydraProbe</td>
<td>140</td>
<td>5</td>
<td>~2005</td>
</tr>
<tr>
<td>USCRN</td>
<td>HydraProbe</td>
<td>144</td>
<td>7</td>
<td>~2008</td>
</tr>
<tr>
<td>COSMOS</td>
<td>Neutron scatter</td>
<td>50</td>
<td>2</td>
<td>2010</td>
</tr>
<tr>
<td>AmeriFlux</td>
<td>Dielectric</td>
<td>215</td>
<td>1</td>
<td>2005</td>
</tr>
<tr>
<td>NEON</td>
<td>??</td>
<td>20</td>
<td>1</td>
<td>~2011</td>
</tr>
</tbody>
</table>

- Oklahoma Mesonet: 127 sites, heat dissipation sensors
- Illinois Climate Network: 19 sites, neutron probe and sensors
- High Plains Regional Climate Center: 14 sites (NE), Theta probe
- Critical Zone Observatories: 6 sites, miscellaneous sensors
Soil Climate Analysis Network (SCAN)

- Evolution of SNOTEL (USDA/NRCS)
- Technique
  - Frequency domain dielectric sensor
  - Vertical footprint: 5, 10, 20, 50, 100 cm depths
  - Horizontal footprint: < 2 m²
- Plus/minus
  - Soil characterization (+)
  - Supplemental MET data (+)
  - Discrete depths(+/−)

Reese Center, TX

http://www.wcc.nrcs.usda.gov/scan/
US Climate Reference Network (USCRN)

- NOAA project to monitor long-term temperature/PPT

Technique (from SCAN)
- Frequency domain dielectric sensor
- Vertical footprint: 5, 10, 20, 50, 100 cm depths
- Horizontal footprint: < 2 m

Plus/minus
- Discrete depths (+)
- Supplemental Met data (+)
- Most stations have just 5 and 10-cm sensor (-)
- Soil disturbance (-)
- Indirect measurement (-)
- USCRN plans 538 (130 km grid) across the US – may include SM

http://www.ncdc.noaa.gov/crn/
AmeriFlux Network

- DOE project to monitor net ecosystem carbon and water flux

- Technique
  - Primarily Eddy covariance
  - Soil moisture is hit/miss
  - Vertical footprint: 2 cm depth
  - Horizontal footprint: < 2 m²

- Plus/minus
  - Water vapor, carbon and energy flux is measured (+)
  - Discrete depth (+/-)
  - Complicated system (-)

Gamboa, Panama

http://ameriflux.ornl.gov
COsmic-ray Soil Moisture Observing System (COSMOS)

- Technique
  - Monitor cosmic-ray neutrons above soil surface
  - Vertical footprint: 15-70 cm
  - Horizontal footprint: ~350 m

- Plus/minus
  - Largest footprint (+)
  - No soil disturbance (+)
  - Direct measurement (+)
  - Variable and shallow depth (-)

Freeman Ranch, TX

http://cosmos.hwr.arizona.edu
Current of Soil Moisture and Climate Observatories in the State of Texas

- **USDA SCAN Sites**
  - 140 nationally
  - 5 (4%) in Texas, ~9 planned

- **NOAA USCRN Sites**
  - 144 nationally, 538 planned
  - 7 (5%) in Texas

- **NSF COSMOS Sites**
  - 50 nationally, 450 planned
  - 2 (4%) in Texas

- **AmeriFlux Sites**
  - 212 nationally
  - 3 (1%) in Texas, ? planned

Freeman Ranch, TX
Recommendations for Texas

- Diversity of temperature and precipitation across Texas implies diverse soil moisture

- Ground-based networks exist in the US as do methods to scale their data.
  - SCAN/COSMO – below ground
  - USCRN/AmeriFlux – above ground

- The scientific community (us) need to:
  - Push heavily for more stations in Texas
  - Make this data available to the agencies and scientific groups using TNRIS

- We now have the unique opportunity to partner the university and stakeholders for both the good of Texas and the scientific community
Questions for discussion

1. Do we need more **observational** data to validate our models and predictions?

2. Would more refined maps of soils and their properties aid our predictive abilities?