Texas Soil Observation Network: TxSON
Linking Soil Moisture to Water Resources in the Texas Hill Country

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Soil Moisture and the Drought in Texas

I. How is drought linked to water resources?

II. Where does soil moisture fit into the picture?

III. At what scale is soil moisture operational?

IV. How are we validate these products?

V. How can stakeholders use soil moisture?

We cannot have drought without socio-economic impact. Otherwise, it’s just desert.

2011: ~$8 billion in losses from the agricultural sector
Droughts are defined differently by impact

- **Meteorological drought**
  - Significant negative departure from normal precipitation
  - Shortage of precipitation (or moisture supply) over some period of time (weekly, monthly, seasonal, or annual time scales).

- **Agricultural drought**
  - Period of moisture deficiency that is sufficient to have a lasting and adverse impact on plant growth or crop yield

- **Hydrologic drought**
  - Prolonged precipitation deficiencies on water supply from surface or subsurface sources

- There is an inherent time-lag between meteorological, agricultural and hydrological drought
Obvious impacts to our surface water reservoirs
Obvious impacts to our surface water reservoirs

Reservoir Storage
- 18 maf 2010
- 22 maf 2060

Rebounded
Brazos, Red, Trinity

Continuous decline
Rio Grande, Colorado, Nueces

http://waterdatafortexas.org
Obvious impacts to our surface water reservoirs

Colorado River Basin Reservoirs

Monitored Water Supply Reservoirs are 25.8% full on 2014-09-09

http://waterdatafortexas.org
PROBLEM: The perplexity of drought beyond 2012

How much precipitation do we need to get out of drought? Despite near-normal rainfall, why are reservoir levels NOT recovering?

How much water can we release for ag?

- How much water do we have?

“Soil moisture is of modest value to everyone but critical value to none”

- State (withheld) Climatologist
How can we account for all the water in Texas?

\[ \sum \text{IN} - \sum \text{OUT} = \Delta \text{STORAGE} \]

\[ \text{WATER}_{\text{IN}} \quad - \quad \text{WATER}_{\text{OUT}} \quad = \quad \Delta \text{STORAGE} \]

- Precipitation*
- Snowpack
- Streamflow
- Groundwater
- Consumption*
- ET*
- Streamflow*
- Groundwater*
- Reservoirs*
- Groundwater*
- Soil Moisture*

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Storage components

\[ PPT - (Q + C + ET) = \Delta R + \Delta GW + \Delta \theta \]

How about those storage terms?

- Reservoir Storage (\(\Delta R\)): observable
- Groundwater storage (\(\Delta GW\)): somewhat observable
- Soil moisture storage (\(\Delta \theta\)): ???

We have uncertainty in our inputs (PPT)

Unknowns in our outputs: crop consumption & ET

Unknowns in our storage: soil moisture
What is soil moisture storage?

- Gravity
- Drainage
- Field Capacity
- Wilting Point

Soil Water Component:
- Gravitational H$_2$O
- Plant Available H$_2$O
- Hygroscopic H$_2$O

Fine sandy soils:
- 0.6 - 1.25 inch H$_2$O per ft. soil depth

Loam soils:
- 1.2 - 1.9 inch H$_2$O per ft. soil depth

Clay loam soils:
- 1.5 - 2.3 inch H$_2$O per ft. soil depth

Map of soil moisture storage in Texas, showing different regions colored according to moisture content.
Using GRACE to estimate total water storage

\[ \Delta \text{Total Water Storage} = \Delta \text{Reservoir} + \Delta \text{Soil Moisture} + \Delta \text{Groundwater} \]

\[ \Delta \text{TWS} = \Delta R + \Delta \text{SMS} + \Delta \text{GW} \]

50 maf = 6 maf + 70-80% TWS + 4-8 maf

Majority of depletion appears to be in soil moisture storage

Source: Long et al., 2013
Changes in Total Water Storage: GRACE 1° Grid
Texas Drought: Soil moisture deficit in Texas

Soil moisture from multiple LSM indicate that depletion in 2011 could range from 20% to 100% of TWS from GRACE – the soil reservoir is BIG

Uncertainty in soil moisture storage between models is high

Source: Long et al., 2013
NLDAS-2: Noah output and forcings

**Primary Forcing Data at Hourly Time Steps (NARR)**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (PRISM)</td>
<td>Solar Rad</td>
</tr>
<tr>
<td>Convective Available PE</td>
<td>PET</td>
</tr>
<tr>
<td>Air T and RH (2m)</td>
<td>Wind Speed (10m)</td>
</tr>
</tbody>
</table>

**Noah Output**

- GRIB outputs at hourly and monthly values (1/8°)
- 52 fields of parameters
- Soil Moisture Storage (4):
  - 0-0.1 m  0.1-0.4 m
  - 0.4-1.0 m  1.0-2.0 m

http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings
Changes in Total Water Storage: Statewide

\[ \text{Residual} = dTWS - dRes - dSWS \]
Cross-correlation from monthly anomalies: 2003-2013
What have we done to communicate our results?

- We have shown that soil moisture storage is a huge ‘reservoir’ in Texas
- We have shown the merit of both remote sensing products and land surface models
- We have shown the associated error in remote sensing and uncertainty in LSM
- We have explained soil moisture to Stakeholders
- Now, we can increase monitoring networks:
  - Texas Soil Observation Network (TxSON)
Validating Noah/SMAP – in situ soil moisture

**Buried sensors**
- SCAN/USCRN sites
- Neutron access tubes (HPWD)
- Small sampling area, calibration

**Above-ground sensors**
- Cosmic ray attenuation (COSMOS)
- Big footprint (300’), mobile platform

**Remote sensing**
- Passive/active microwaves (AMSR-E/SMAP)
- Gravity (GRACE)
- Big footprint (30-100 km)
- Shallow penetration (<5cm)
- Infrequent visits

- TDR moisture sensors
- COSMOS at Freeman Ranch, TX
- COSMOS Rover System
How can we measure soil moisture from space?

- NASA Soil Moisture Active/Passive (SMAP) Mission
  - *First dedicated θ-satellite*
  - Global coverage at 3, 9, 36 km resolution
  - November 5, 2014 launch date
- 1000 km swath provides data ~50 hours globally to 5 cm depth
- JSG is partnering with NASA Jet Propulsion Laboratory, to improve on-ground data collection

Together, we’re building TxSON!
SMAP EASE-2 Grid: Middle Colorado Basin, TX

Ideal Core Cal/Val Site:
- **36 km footprint** (yellow)
  - 7 stations (existing LCRA)
- **9 km footprint**
  - 2 cells each with 7 stations
- **3 km footprint**
  - 3 cells each with 7 stations
- Nested design: 37 total stations
- Sensors at 5, 10, 20 and 50 cm
- Minimal variability in:
  - Vegetation
  - Topography
  - Soils/geology
  - Non-urban
- **Stakeholder interests**
- **Educational outreach**
Core Cal/Val: Mean relative difference (SWS)

MRD using NLDAS for each HUC 8
- Cool = wet (+ 25%)
- Hot = drier (- 25%)
- Neutral = within HUC8 mean and temporally stable
Noah SWS: Pedernales River Basin

- HUC8 12090106
- Gray = all nodes within HUC
- Blue = MRD ~ 0
Texas Soil Observation Network: TxSON
Fredericksburg 36 km Footprint (LCRA)
Grid 11 at 9km

- 9km
- SW 3km
SW 3km cell in Grid 11 (3 cells in all)
TxSON in action

- Deal and console landowner
- 12” auger to ~3’
- Sample and describe soil
- CS-655 Sensor
  - 12 cm rods
  - High EC (<8 dS/m)
  - θ, EC, and T (SDI-12)
TxSON in action

- Insert CS-655 sensors at 5, 10, 20, and 50 cm
- Add precip gage, cell modem, etc.
TxSON in action: 9km Grid 11
TxSON in action: 15 stations completed

- 7 of 7 LCRA Hydromet stations (36km cell)
- 5 of 7 micro-stations in Grid 11 (9km cell)
- 3 of 6 micro-stations in Grid 11 (3km cell)
TxSON in action: next month

- 2 full meteorological stations in Grid 11 (9km cell)
  - 3 stations in 3km cell
  - 6 in the other
- 2 full meteorological stations in Grid 2 (9km cell)
  - 6 more microstations
Soil Moisture & Water Resources

- Soil moisture (model) and TWS (RS) both x-corr to reservoir storage
- Partitioning TWS is tricky
  - LSM show wide variability
  - Residual is compounded errors, groundwater, moho
- We need *in situ* data
- We need to **communicate** the importance of soil water storage

Texas Soil Observation Network (TxSON)

- Operational by November
- Land leases for 2, 9km grids
- Sensors are calibrated - paid by JSG donors
- Working on LSM at 0.04km²
- Field campaigns planned for early Fall-Spring.
- Expansion throughout TX
http://www.beg.utexas.edu/soilmoisture/