Applications of Cosmic Ray Soil Neutron Sensor (CRNS) mapping for precision agriculture

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Why do I care about irrigation and food production?

Green vs. Blue Water & Hot Spots of Social Unrest?

- Global Water Footprint 1996-2005 was 7404 $Gm^3\ yr^{-1}$ (78% Green, 12% Blue, 10% Grey)
- Blue water use relatively small but critical in localized areas

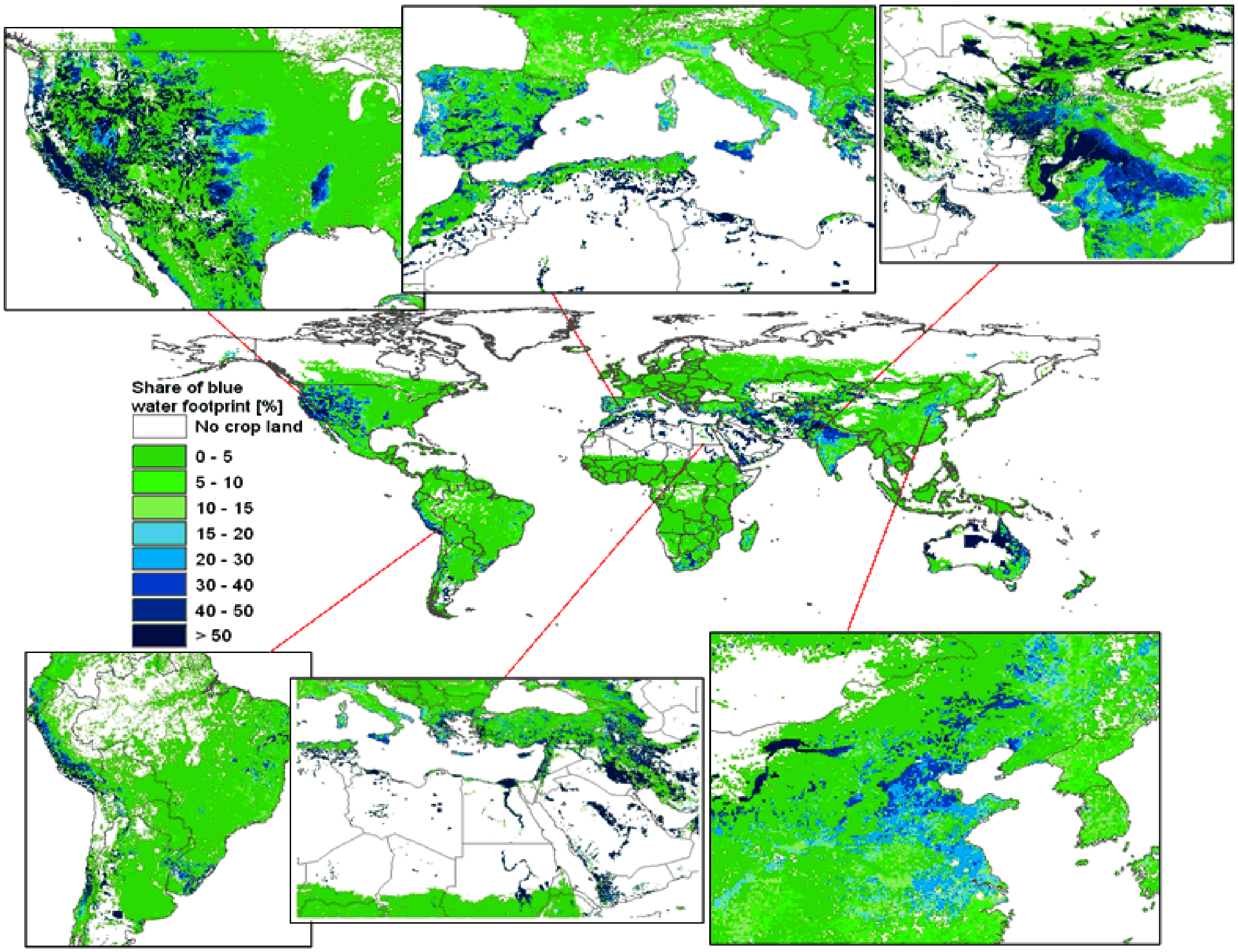


Fig. 3. Contribution of the blue water footprint to the total consumptive (green and blue) water footprint of crop production. Period: 1996–2005.

Mekonnen and Hoekstra 2011

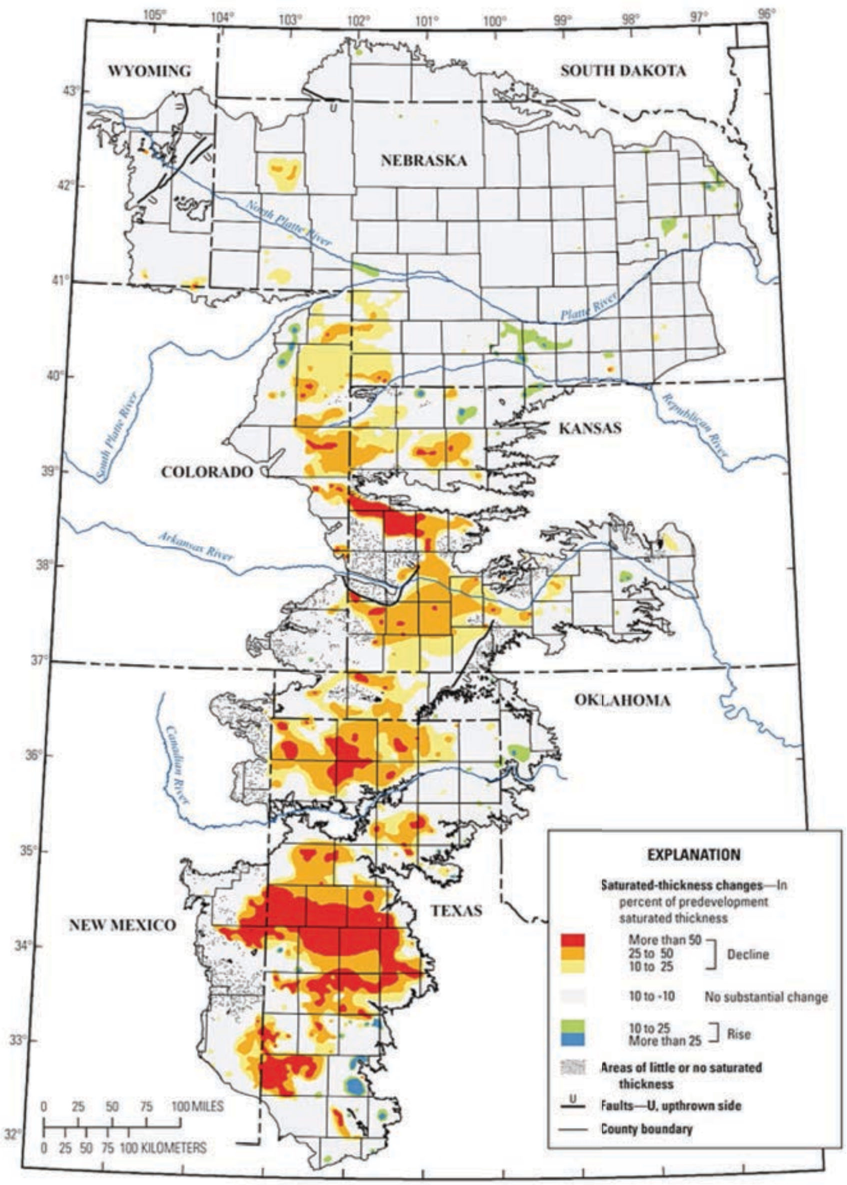
Sustainable Use of High Plains Aquifer?

Depletion as Fraction
of Saturated Thickness
of the Aquifer
(McGuire , 2011)

Depletions in southern High Plains > 50% of saturated thickness

Small area in Nebraska > 25% of saturated thickness

Aquifer Going Dry??



Types of Irrigation

Flood Irrigation

Center pivot Irrigation

Surface Drip Irrigation

Subsurface Drip Irrigation

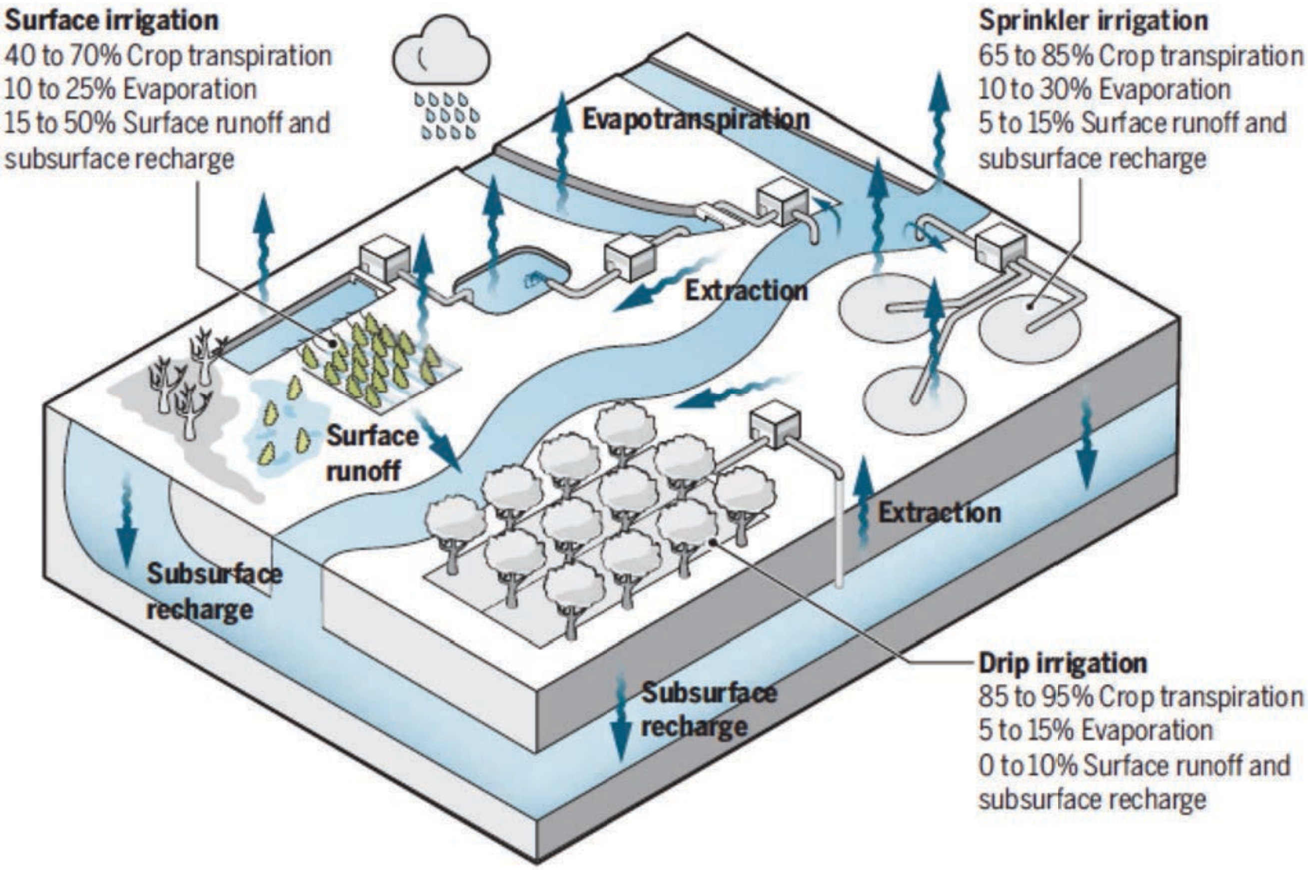
Photo credit: Google search, Valmont Industries

Paradox of Irrigation Efficiency

Many documented cases around the globe where introduction of technology leads to net increase in system water use!

Accounting for water

The paradox of irrigation efficiency (surface, sprinkler, and drip) and the water inflows and outflows can be seen in a watershed example. Ranges of crop transpiration, evaporation, runoff, and recharge are authors' judgment of possible values. These values depend on crop and soil types, weather, and other factors.



The paradox of irrigation efficiency
R. Q. Grafton, J. Williams, C. J. Perry, F. Molle, C. Ringler, P. Steduto, B. Udall, S. A. Wheeler, Y. Wang, D. Garrick and R. G. Allen

Science **361** (6404), 748-750.
DOI: 10.1126/science.aat9314

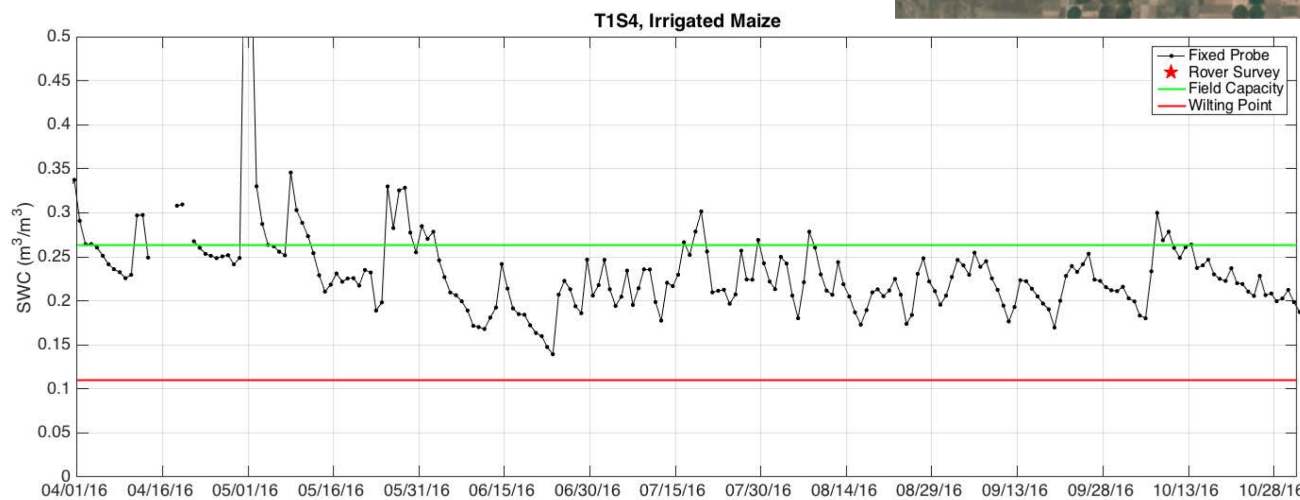
Motivation Summary

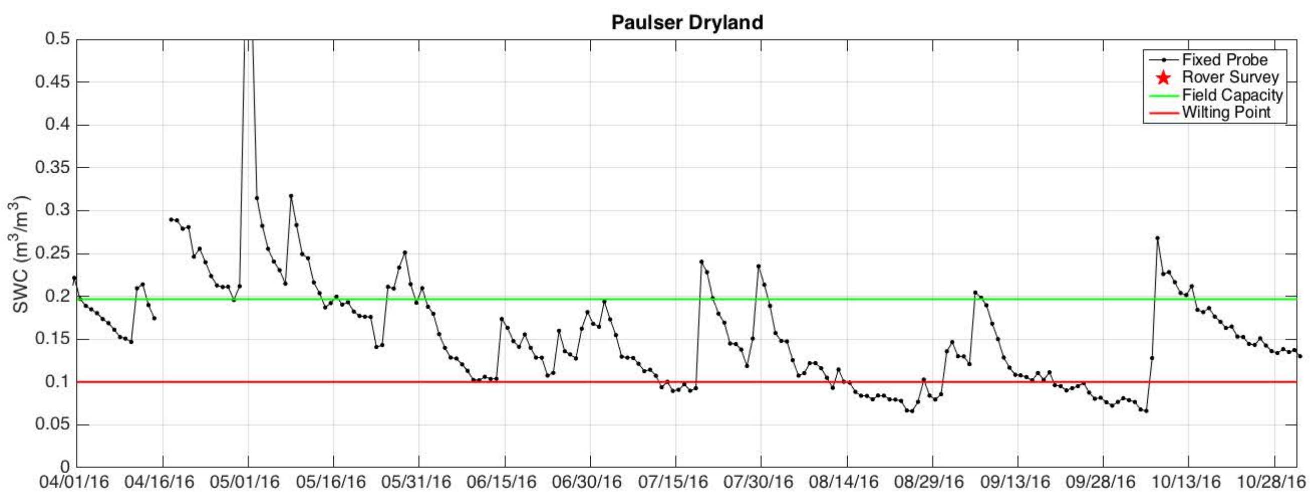
- By 2050 FAO predicts needed increase of 70% in cereal grains to feed 9.5 billion people (FAO 2012)
- 70% of global human water consumptive use for agriculture, 40% of global food production is from irrigation agriculture covering only 20% of land (Molden 2007, Schultz 2005)
- Estimated that 60% of 2,500 trillion liters used for agriculture is wasted for non-productive ET (Clay 2004)
- Investment in advanced technology can lead to “paradox of irrigation efficiency” and net increase in water use for system (Grafton 2018)

How does irrigation scheduling work?

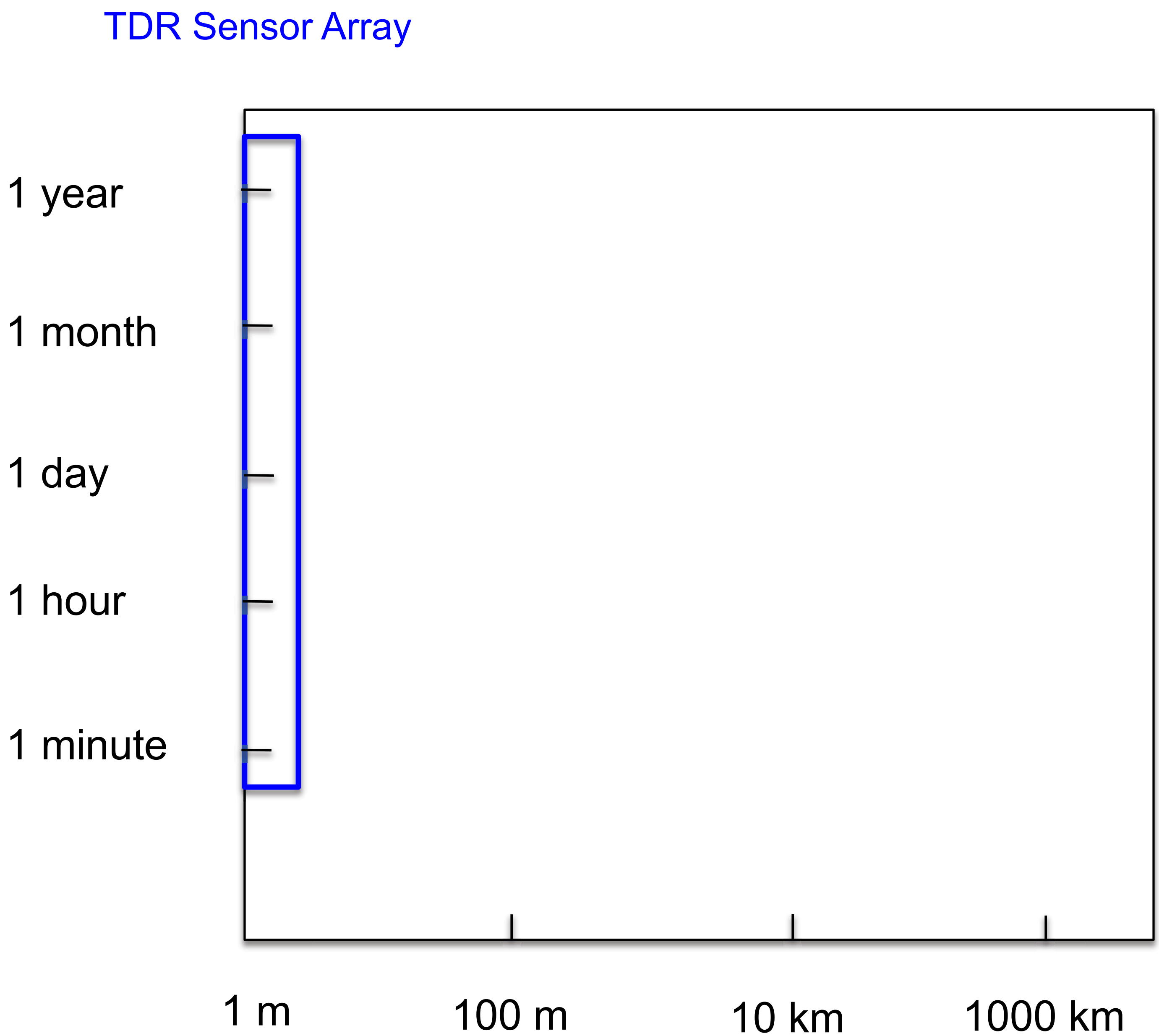
Irrigation Scheduling 101

Need to know size of soil bucket (field capacity and wilting point) and relative soil moisture status through time (trigger irrigation halfway between)





Measurements of Soil Moisture



Adapted from Robinson (2008)

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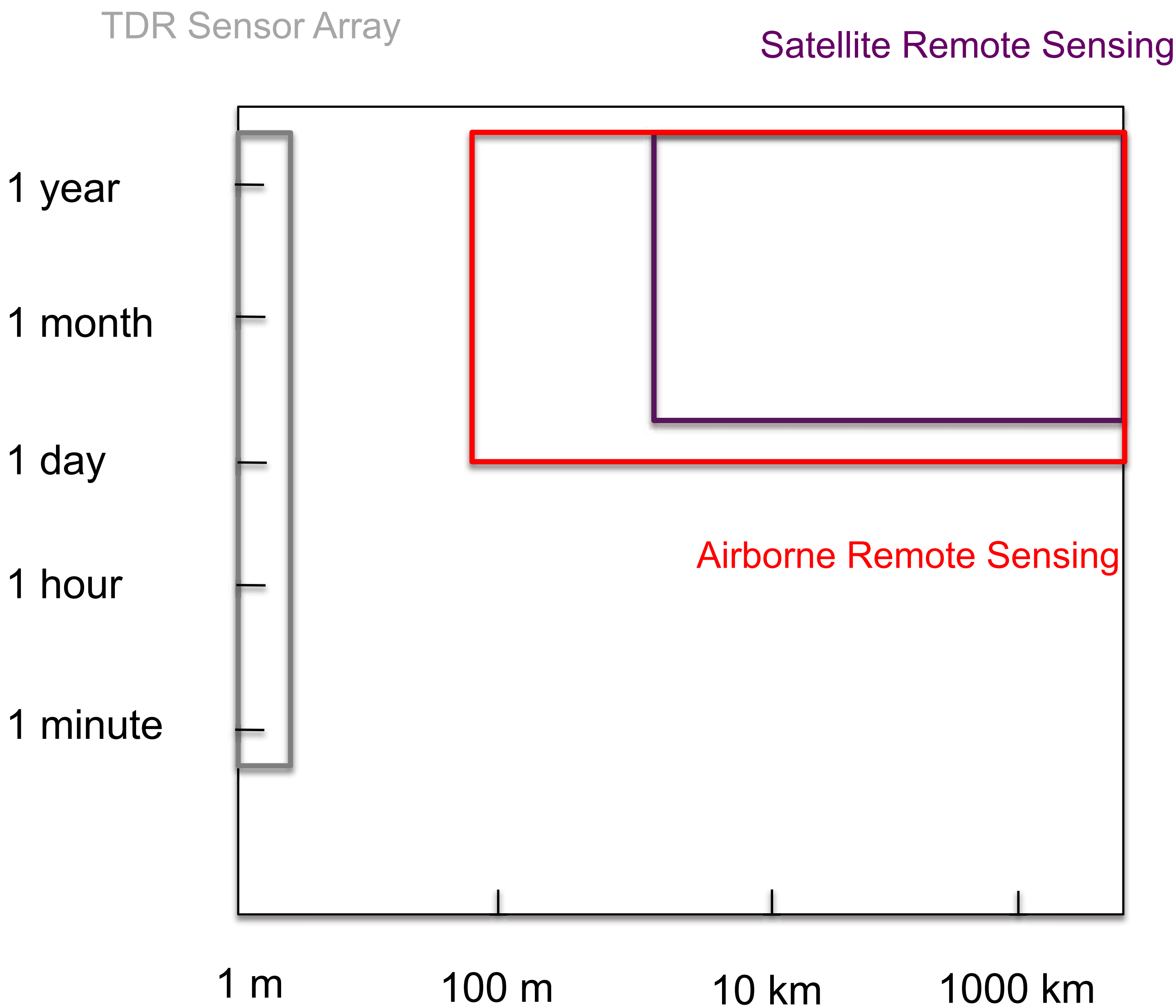

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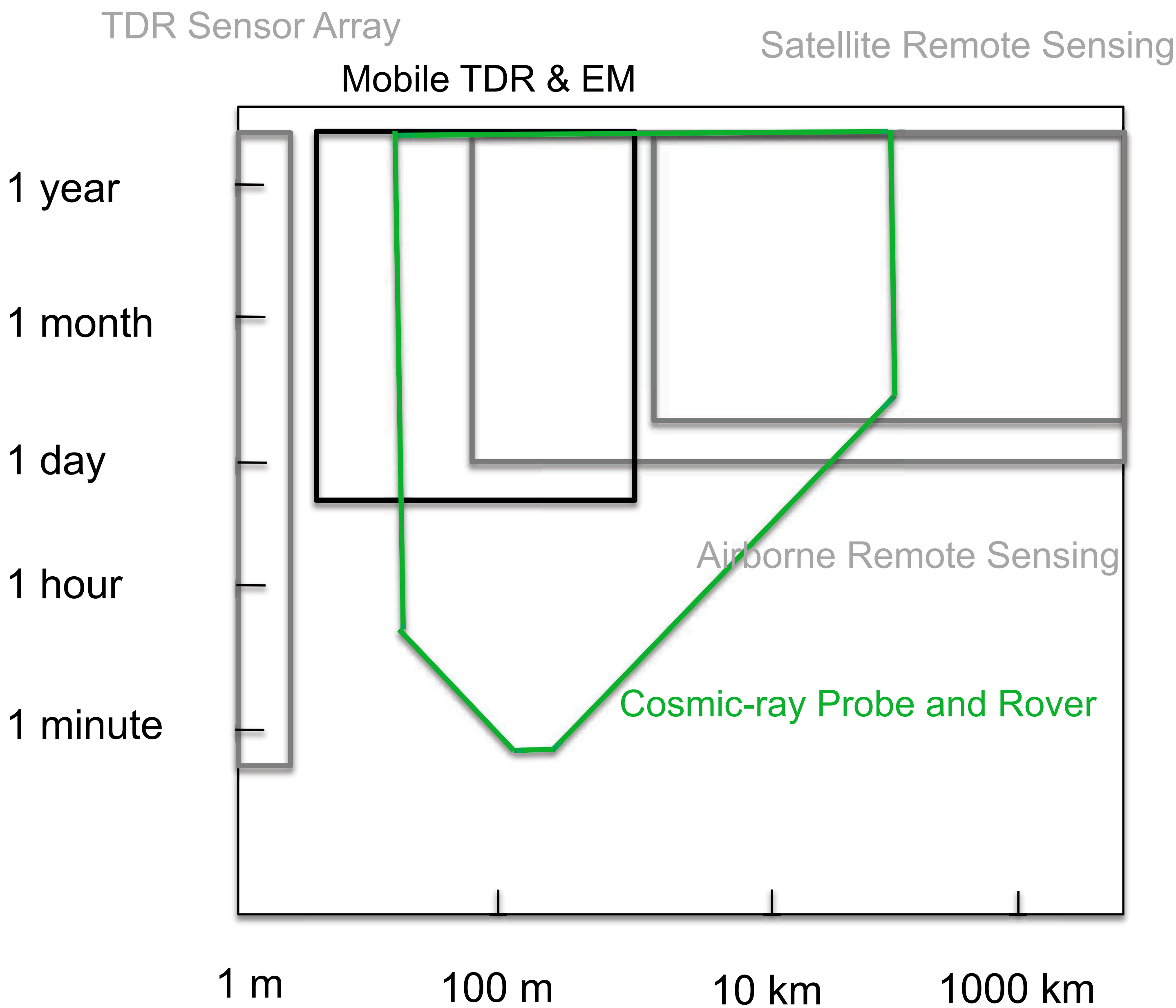
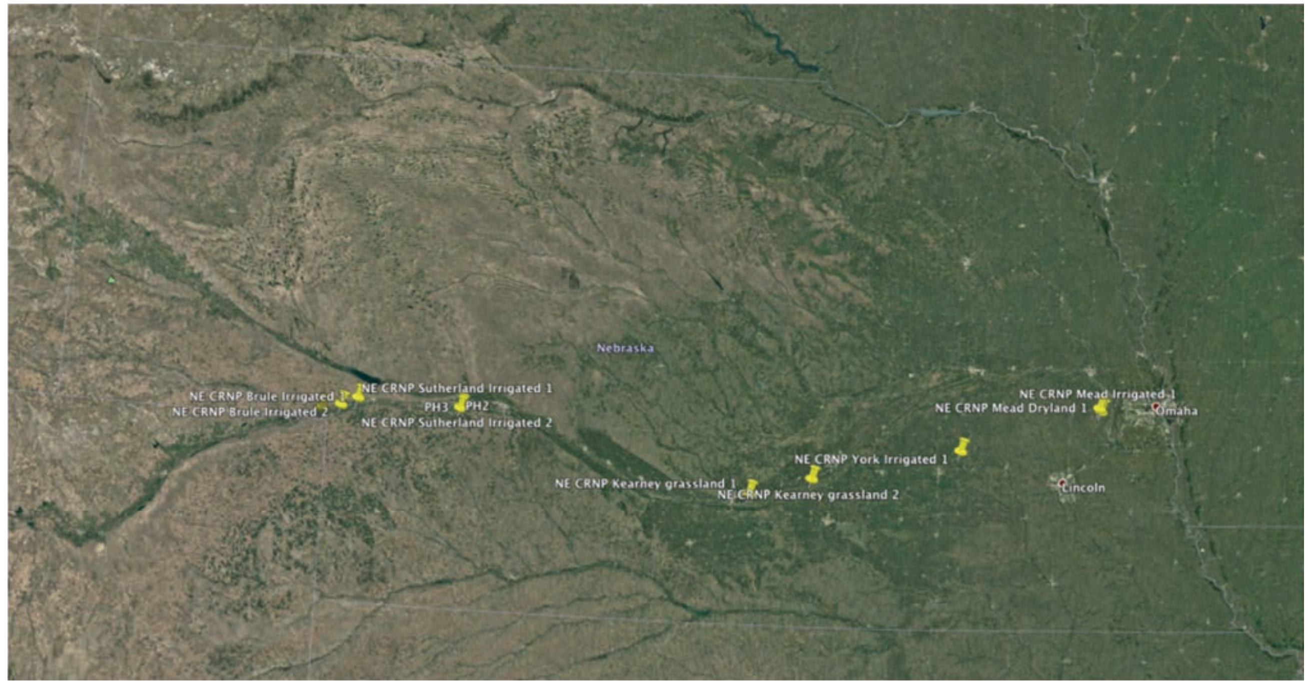


Adapted from Robinson (2008)

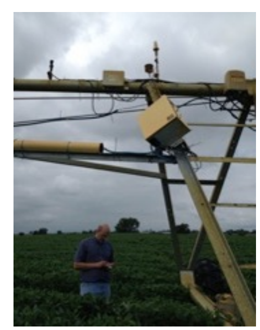
What do I work on in Nebraska?

Platte River Basin Cosmic-ray Monitoring Network

- 10 stationary CRNS from 2014- present
  - 6 irrigated corn/soybean
  - 1 rainfed corn/soybean
  - 3 grassland
- 1 Backpack CRNS
- 2 Vehicle CRNS



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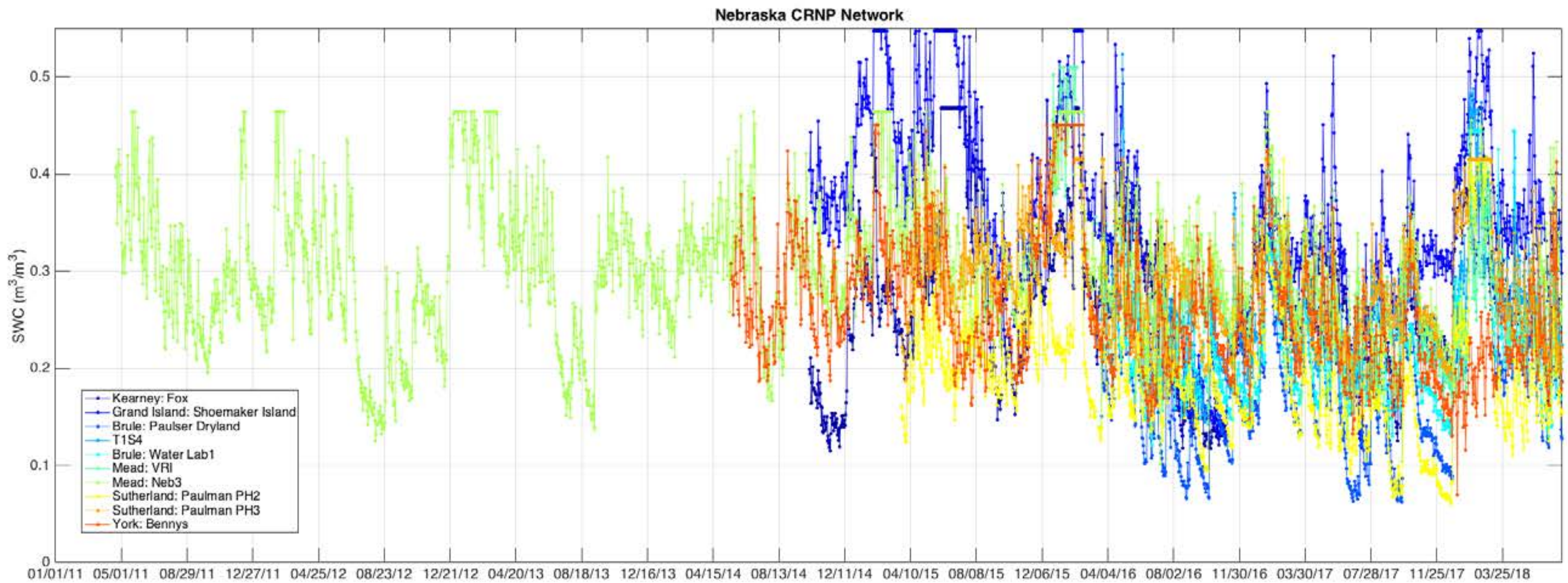
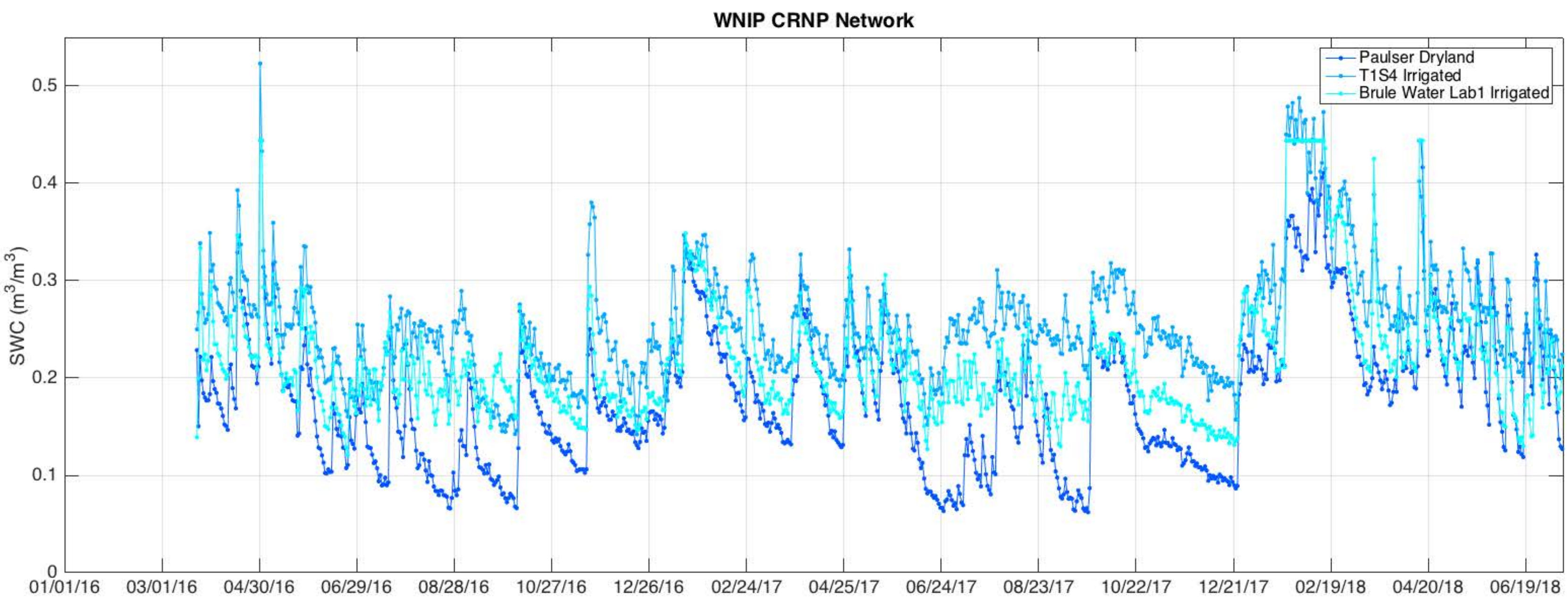
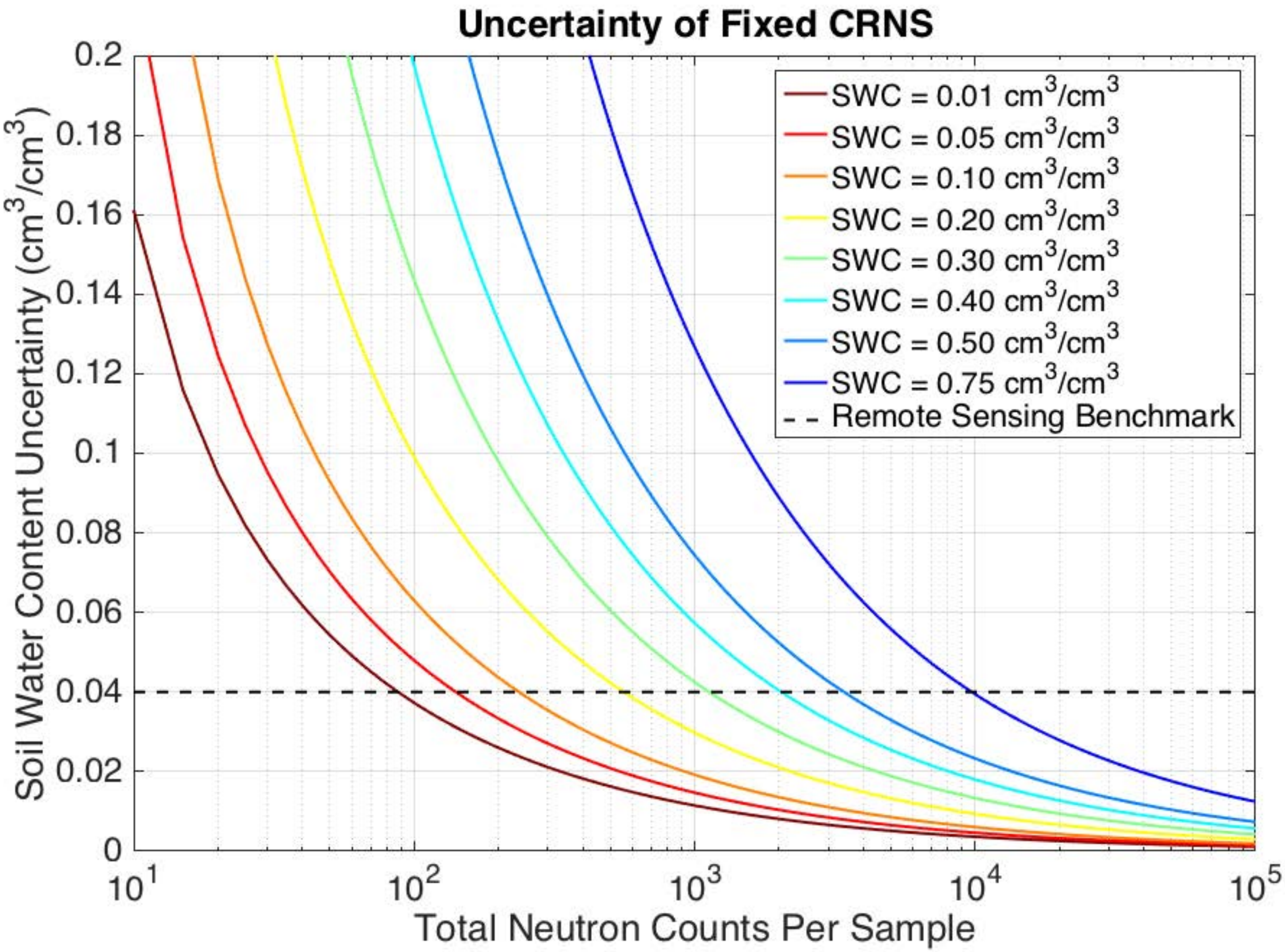


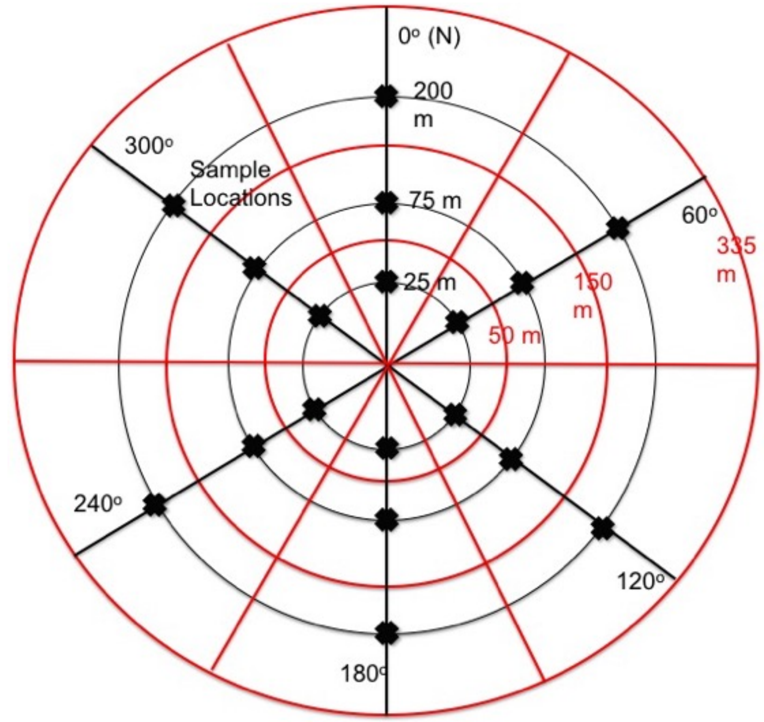


CRNSs in the real world

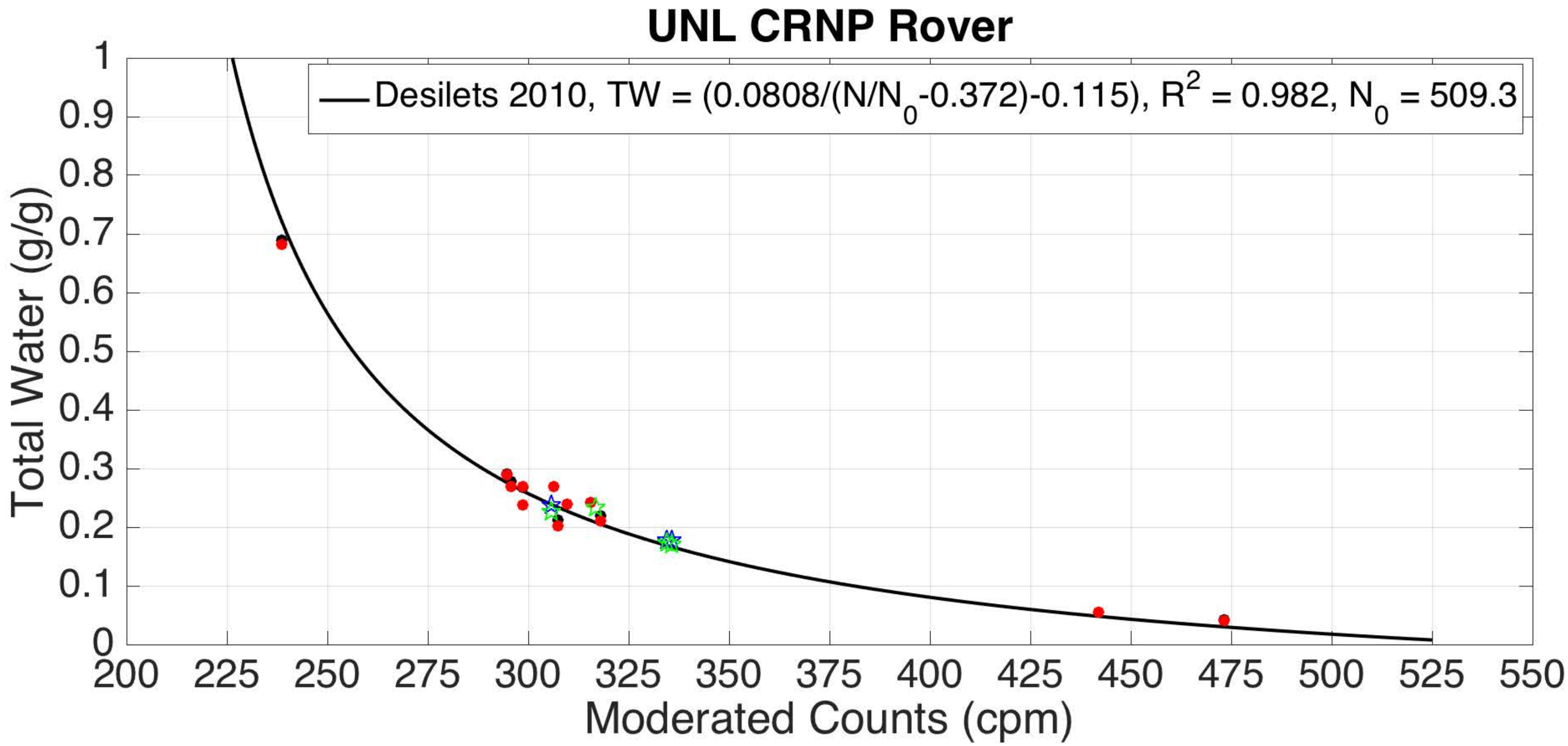
Design of Detectors and Experiments



Calibration in the USA and Austria



Rover Calibration Across Nebraska, USA



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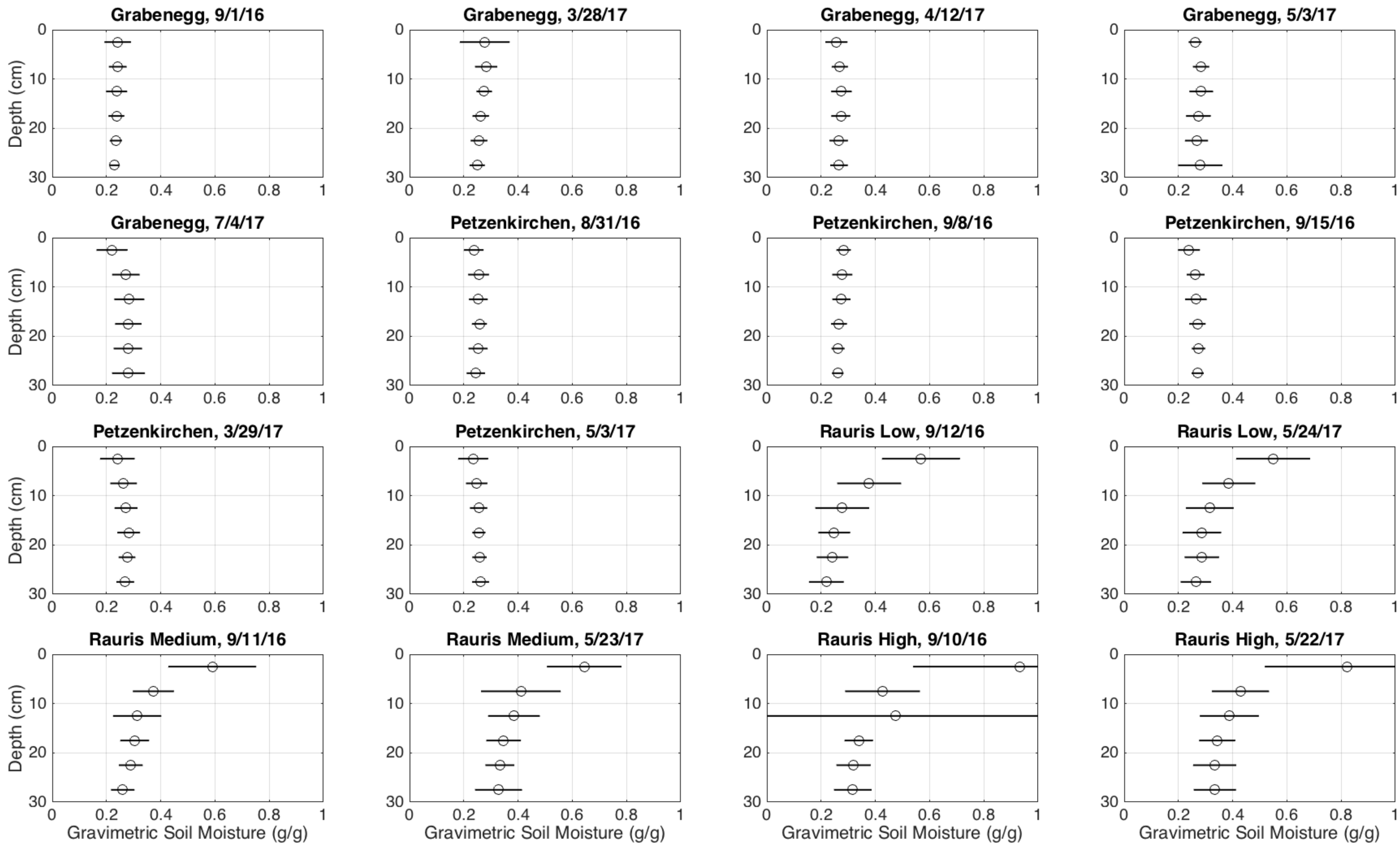
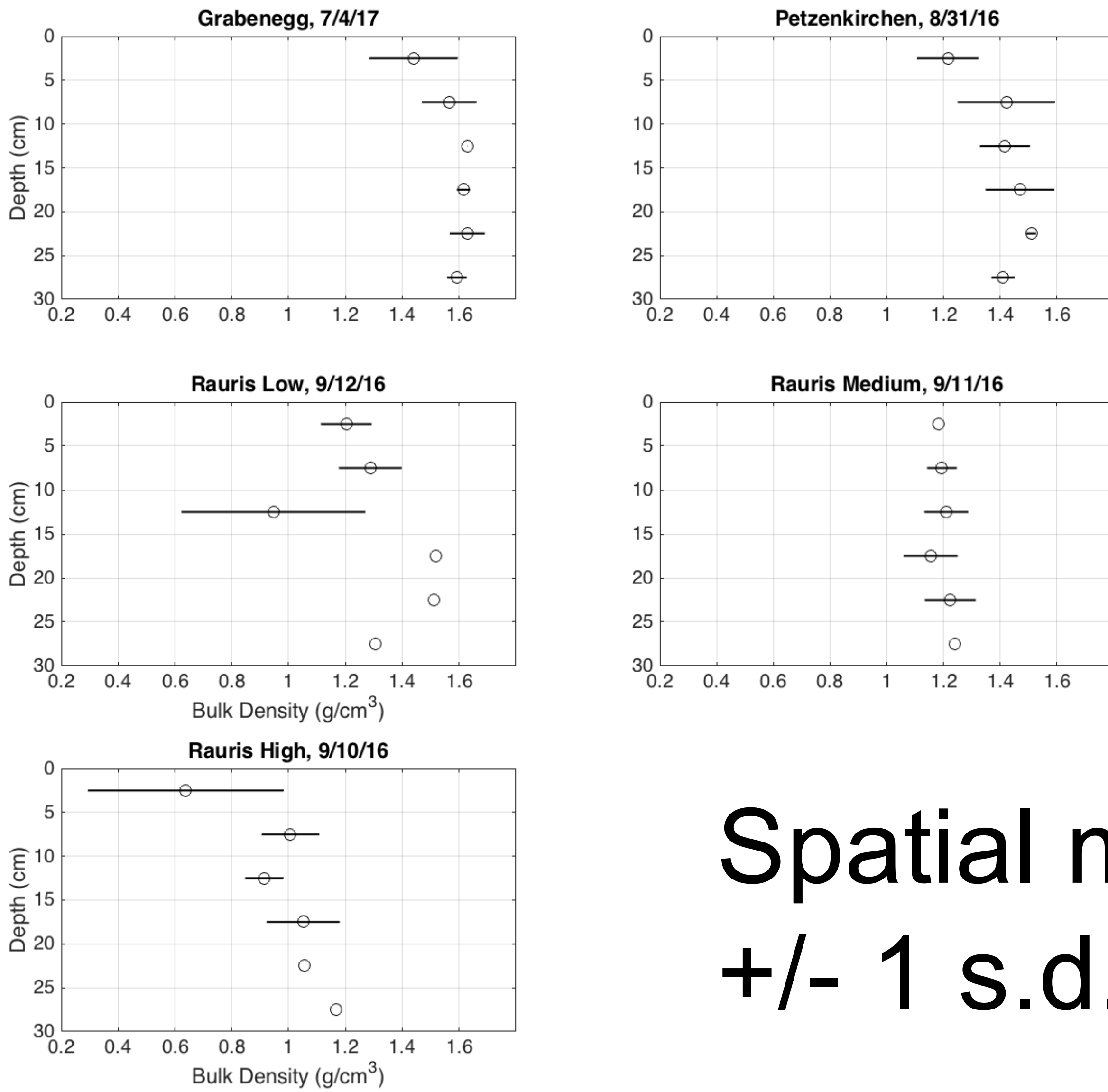


Spatial mean +/- 1 s.d.

Calibration in the Alps



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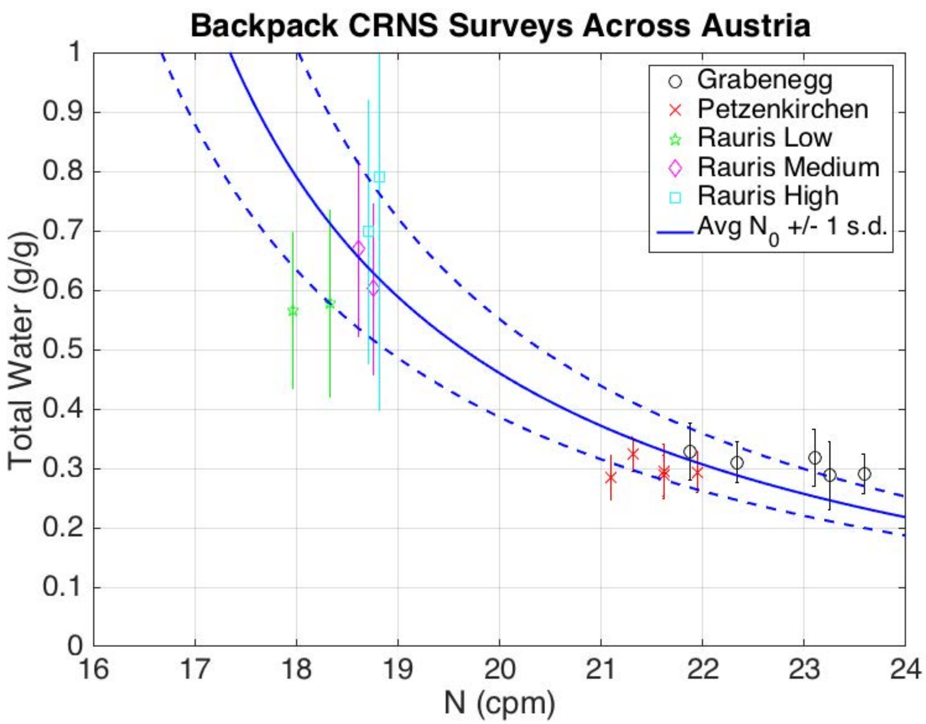
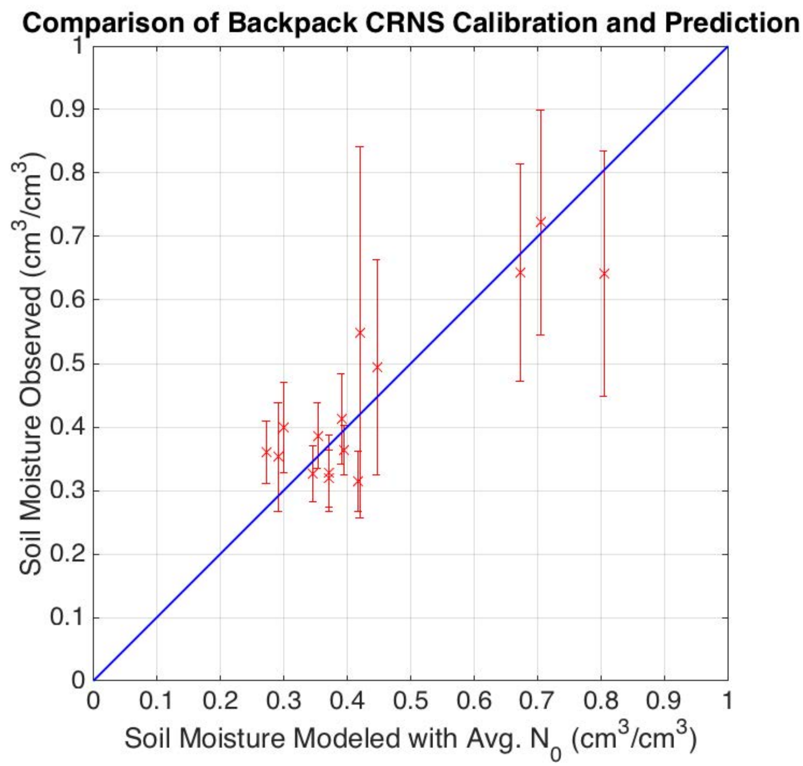
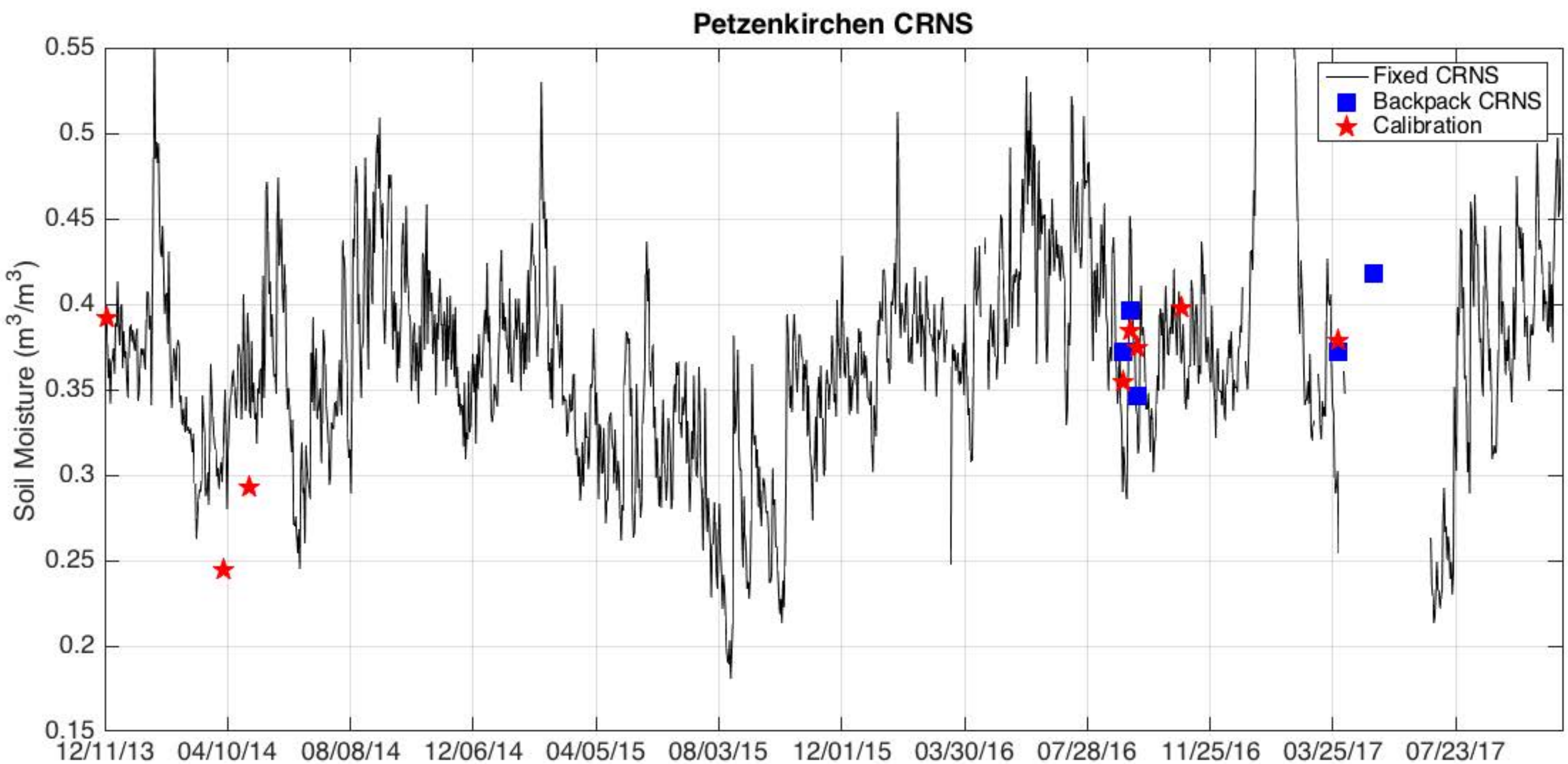
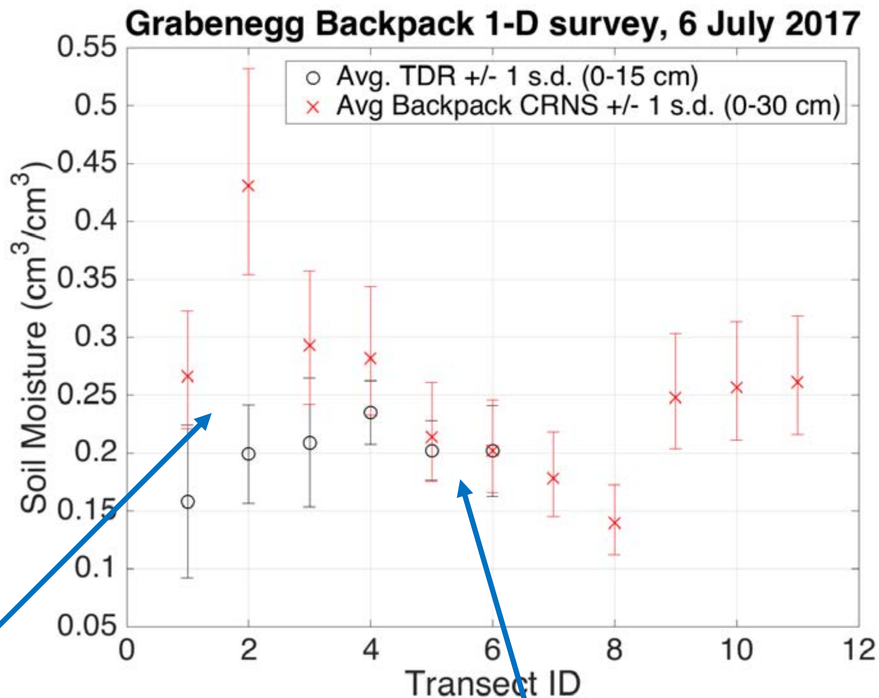




Cross Calibration

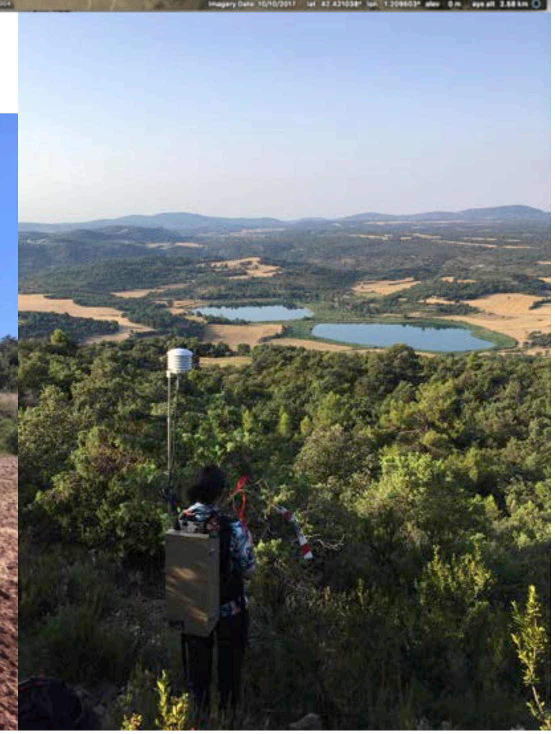


1-D Surveys in Austria



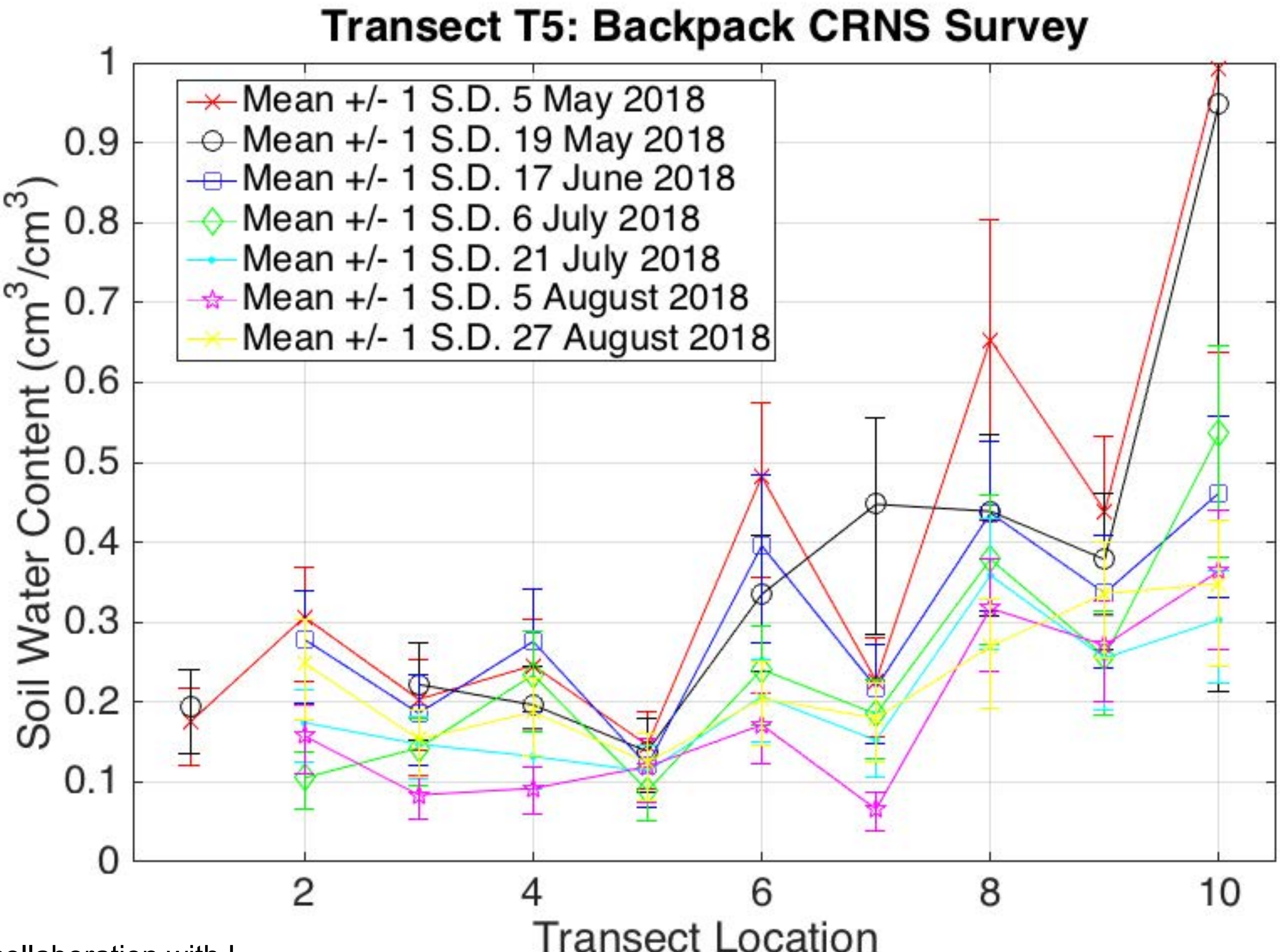
Repeat 1-D Surveys in Spain

3 Study sites in Eastern Spain (T5, TC, TS) with 7, 6, and 5 surveys in wet and dry conditions, ~15 minutes at each location



In collaboration with L. Gapsar and A. Navas

T5 Results



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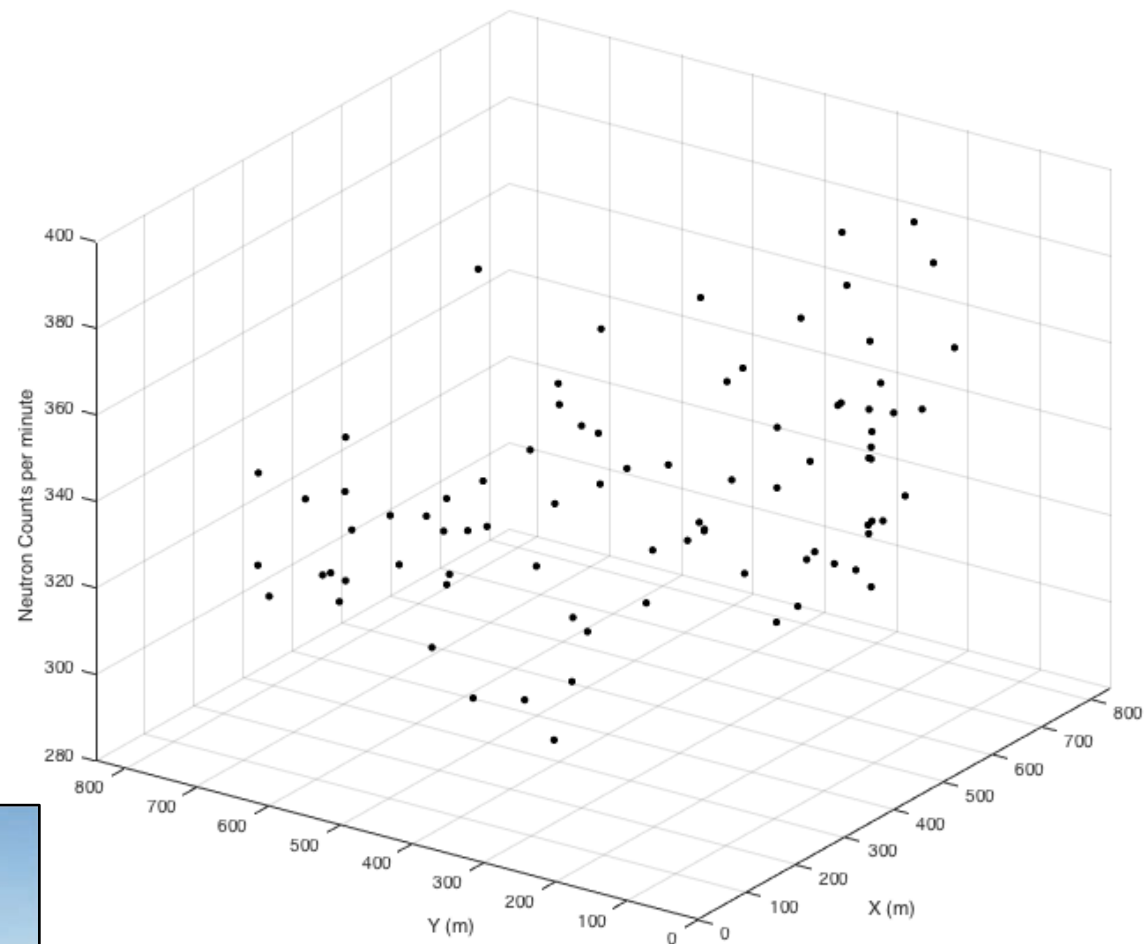
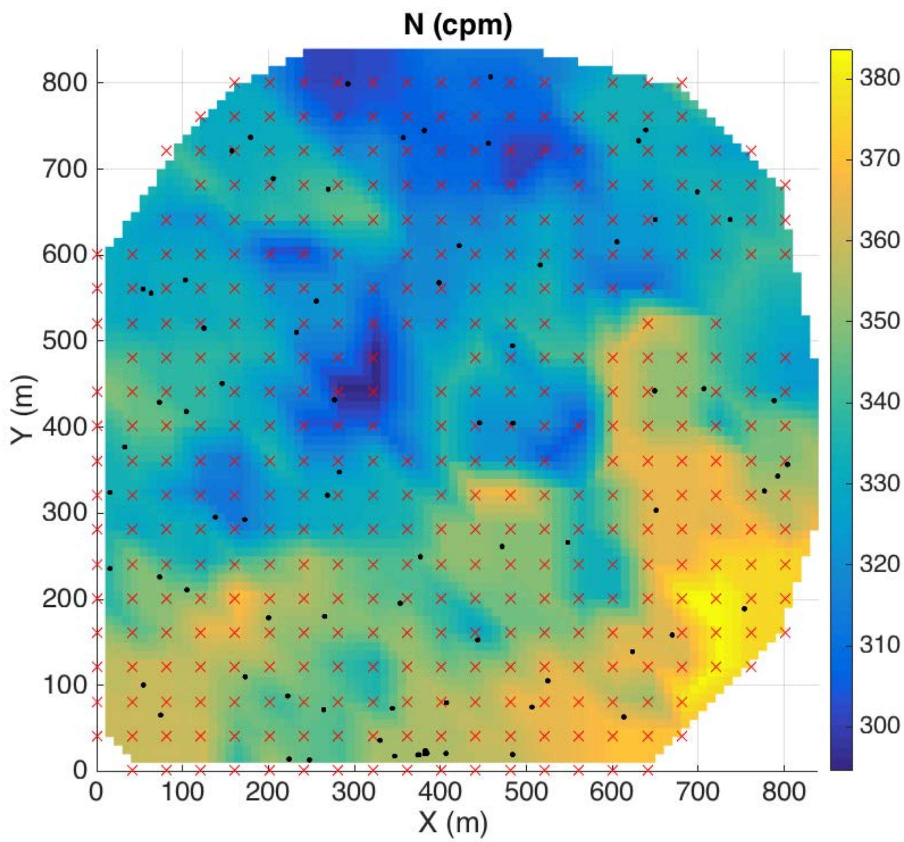
2-D Surveys in NE, USA



~driving at 10 kph, ~75 minutes for a 65 ha field

2-D Surveys in NE, USA



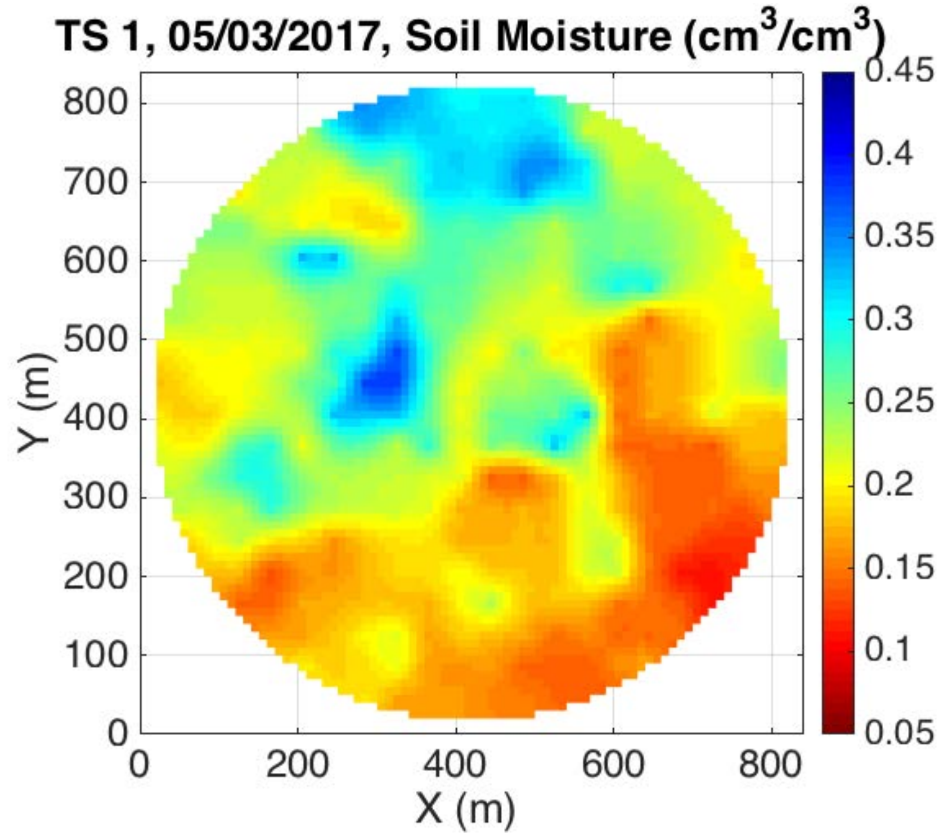


Image sharpening technique with drop-in-the-bucket inverse distance weighted algorithm used by NASA SMAP team

Hypothesis

- Difficult to accurately measure water availability in the soil at the measurement scale of water application (individual nozzle and center-pivot) with existing point based technology. That uncertainty leads to overwatering as to not adversely affect yield.

Images courtesy of Valmont Inc.

Study Site

- Paulman Farms located near Sutherland, NE
- Center-pivot irrigated corn

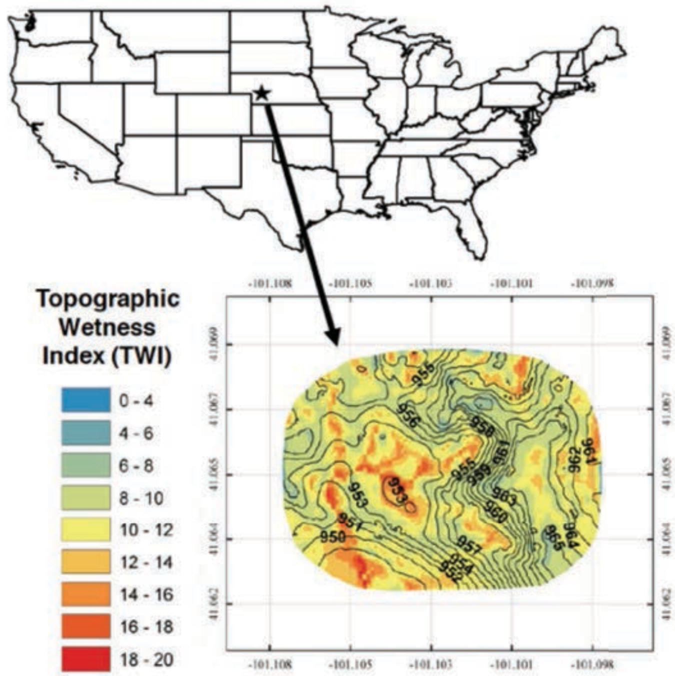
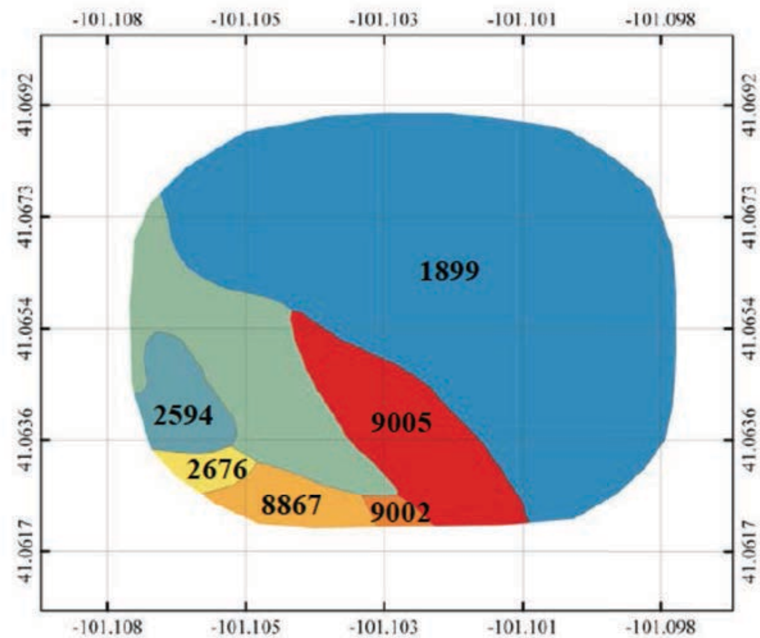


Figure 2.2: Field site located near Sutherland, NE (field center: 41.065393°, -101.102663°), illustrating latitude, longitude, soil core sampling locations (black dots), 1m elevation contours and the calculated topographic wetness index (TWI).



MUSYM	Soil Description	SWC (cm^3cm^{-3}) at -33kPa	SWC (cm^3cm^{-3}) at -1500kPa
1899	Valent sand, rolling	0.090	0.027
2594	Hersh and Valentine (fine sand) soils, 6-11% slopes	0.168	0.068
2601	Hersh soils (well drained sandy loam), 3-6% slopes	0.193	0.100
2676	Holdrege silt loam, 3-7% slopes, eroded, plains and breaks	0.307	0.164
8867	Hord fine sandy loam, 1-3% slopes	0.225	0.125
9002	Anselmo fine sandy loam, 1-3% slopes	0.204	0.112
9005	Anselmo fine sandy loam, 6-9% slopes	0.206	0.112

Figure 2.3: The USDA SSURGO soil descriptions and their respective SWC at field capacity and wilting point.

Hydrogeophysical Mapping

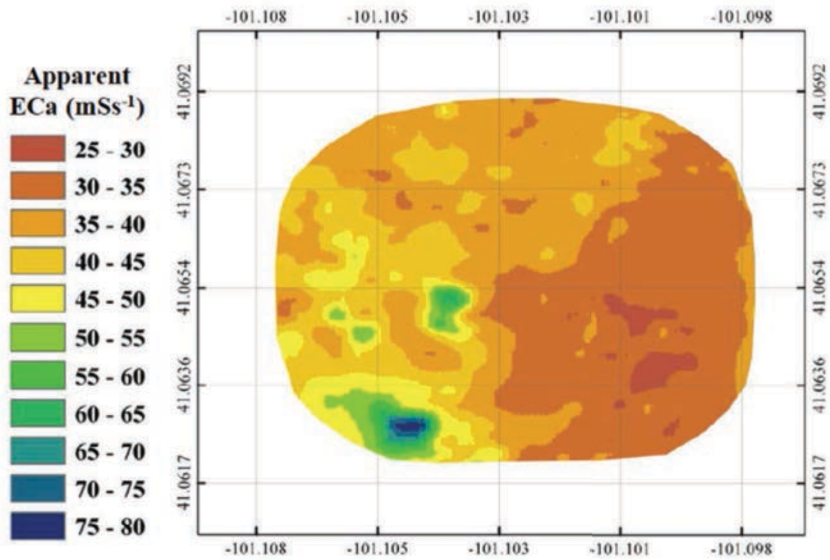
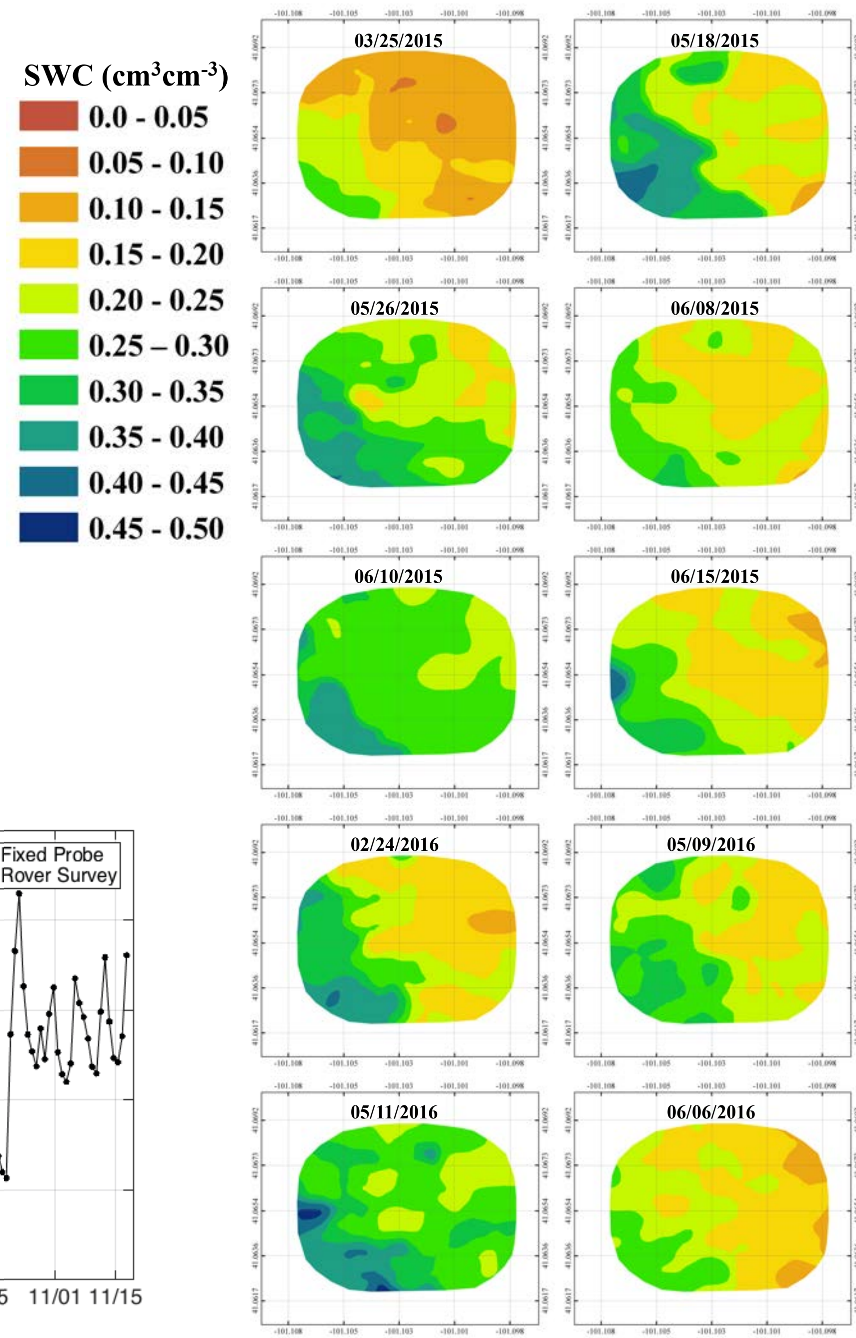
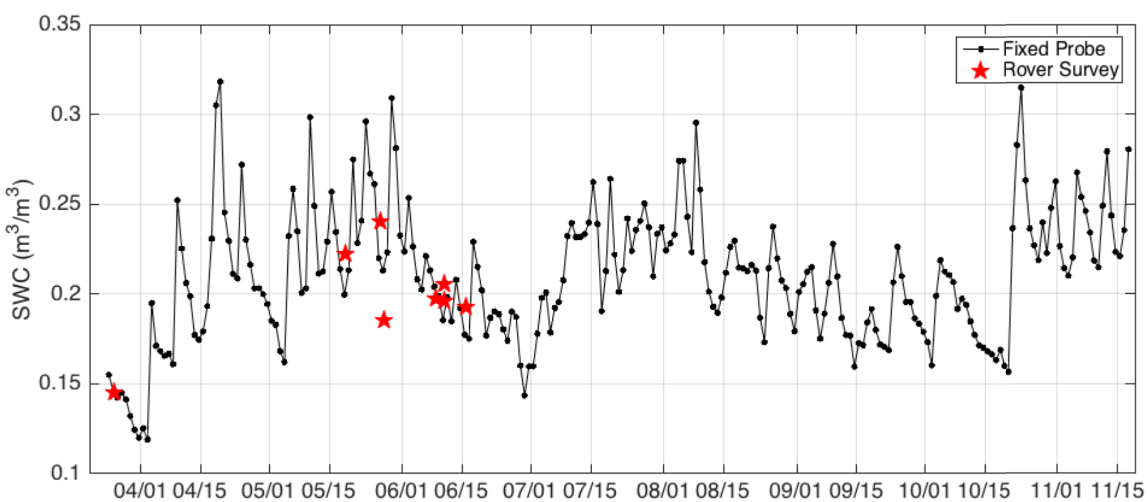


Figure 2.4: Apparent electrical conductivity map (ECa) collected on 24 February 2016 using a Dualem-21S sensor.





Finkenbiner 2018

Use EOF framework to seperate spatial and temporal soil moisture anomalies

- Spatial loadings map (EOFs) can be used to group sites of “like” soil moisture states
- Spatial moments of point sensors can be used to describe temporal varying component (ECs)
- Combine reduced number of spatial (EOFs) and time varying loadings (EC) to reconstruct spatial patterns across space and time

Journal of Hydrology (2007) 334, 388–404

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available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol

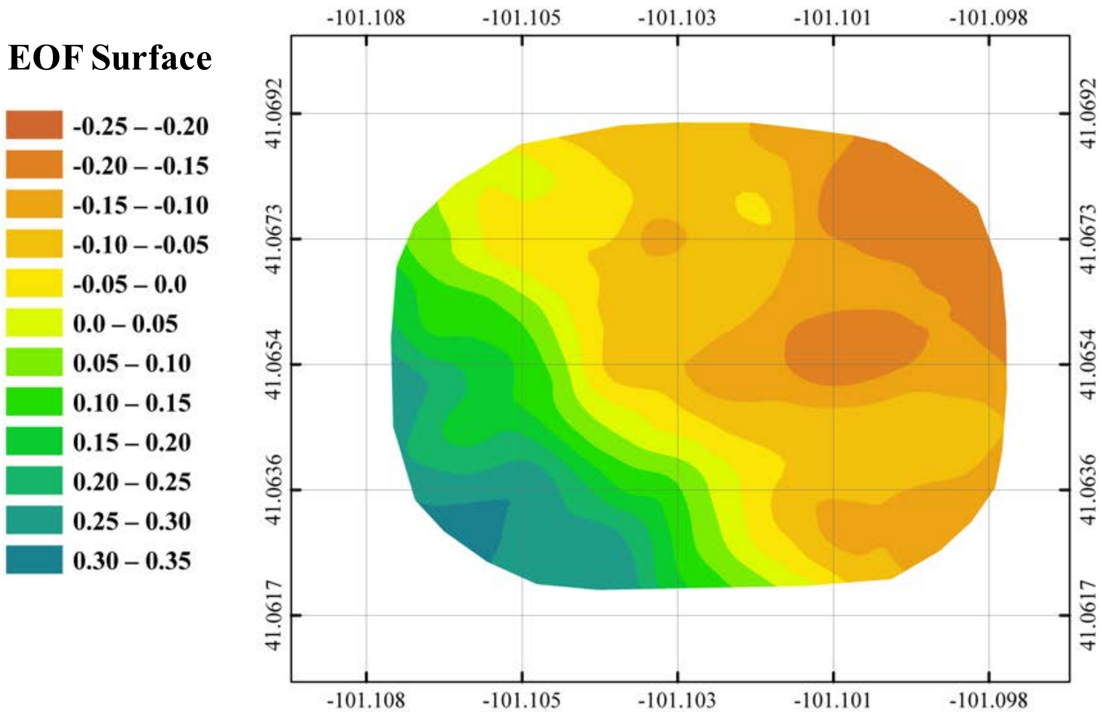
Analysis and estimation of soil moisture at the catchment scale using EOFs

Mark A. Perry, Jeffrey D. Niemann *

$$V*E = L*E$$

EOF Example

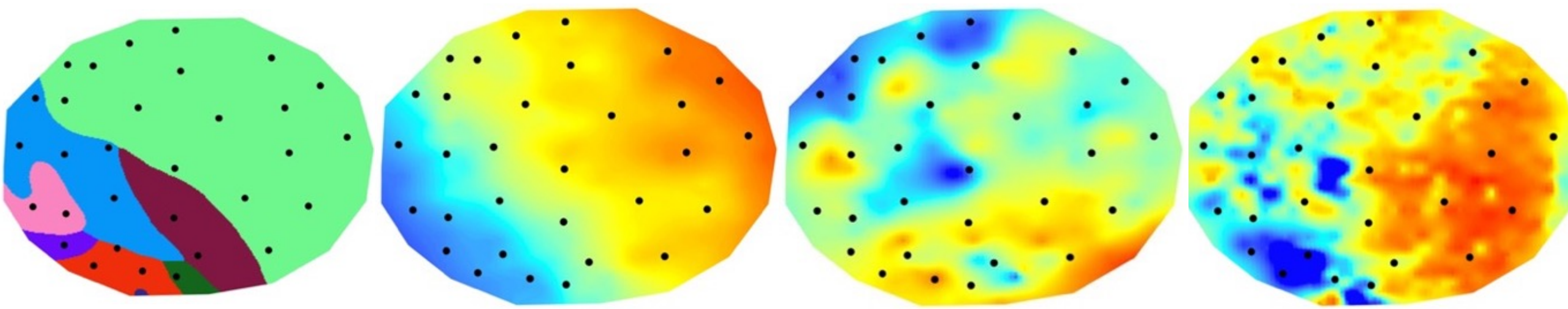
Spatial Loadings



EV	Explained Spatial Variance
1	90.5%
2	4.3%
3	1.6%
4	1.2%
5	1.0%
6	0.8%
7	0.6%

Soil Sampling

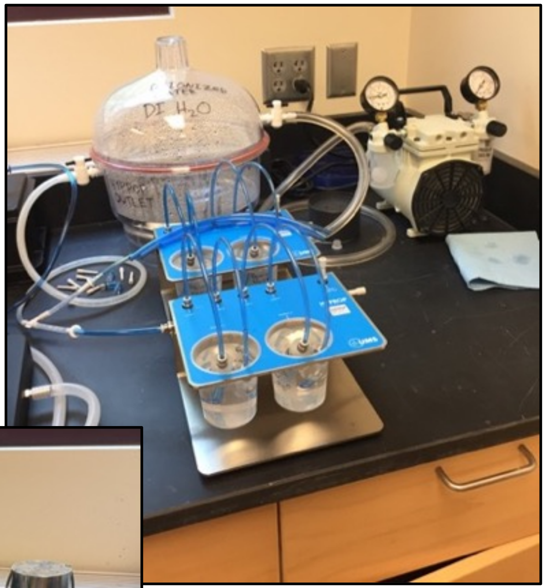
- Collected 31 undisturbed soil cores at 20cm depth
- Sample locations chosen based on SSURGO soil boundaries, EOFs, and EM surveys
- Samples were placed in a cooler in the field and then stored in a freezer at the lab



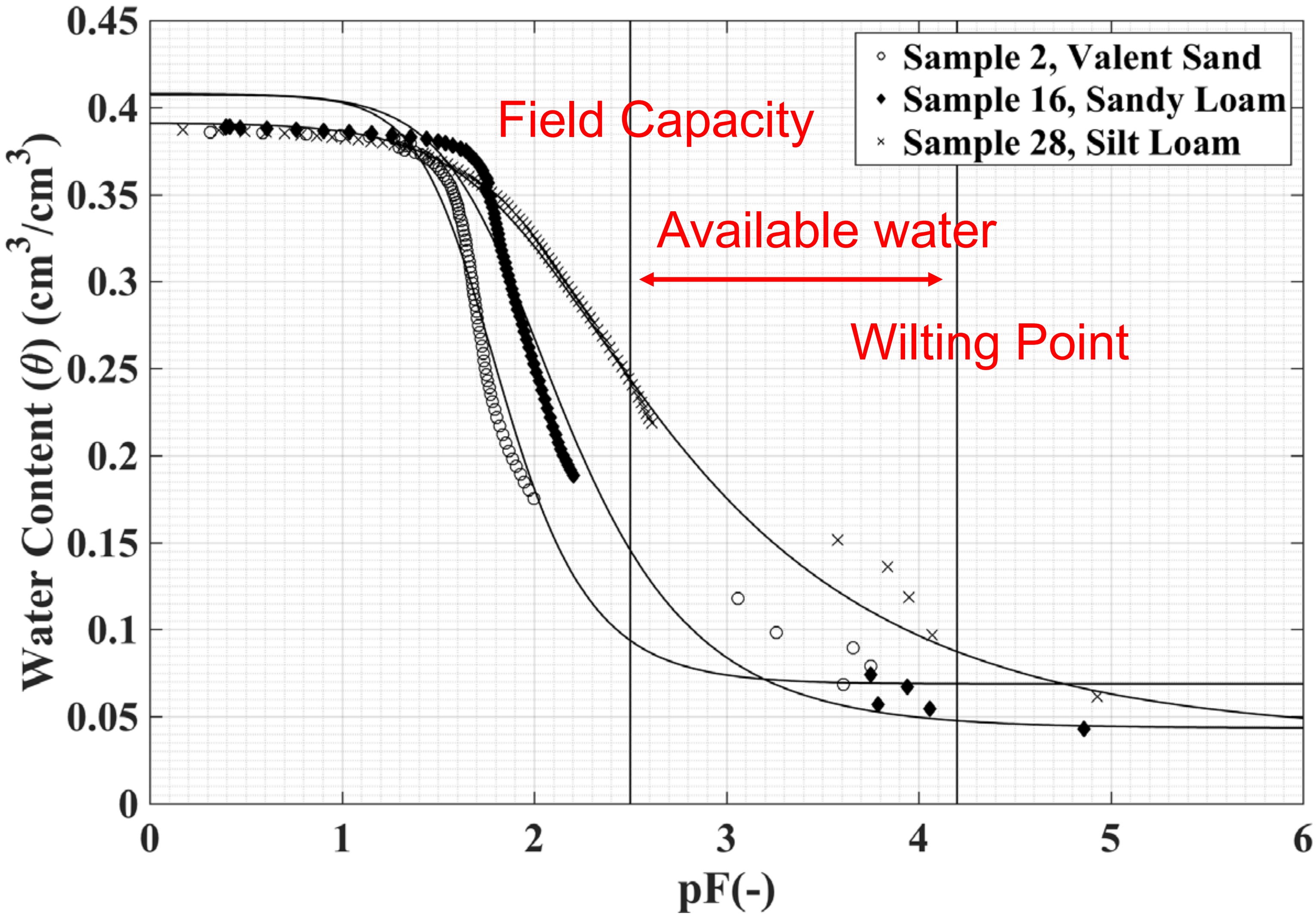
SSURGO **EOF1** **EOF2** **ECa**

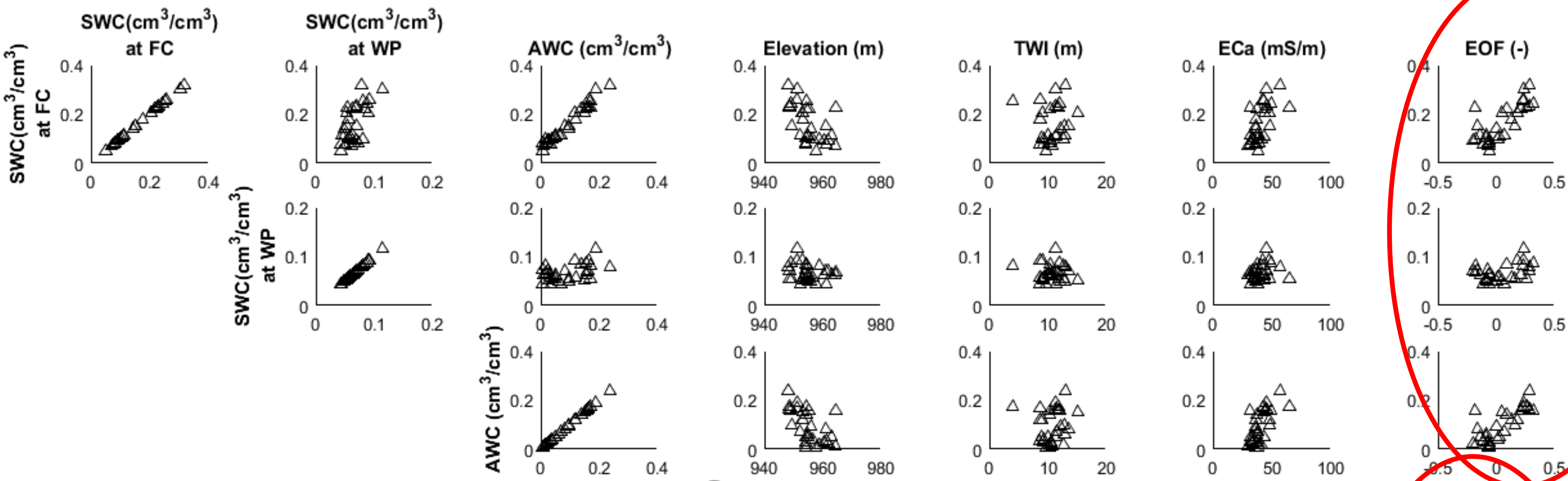
Calculating Field Capacity/ Wilting Point

Decagon HYPROP
- Records mass change and change in tension



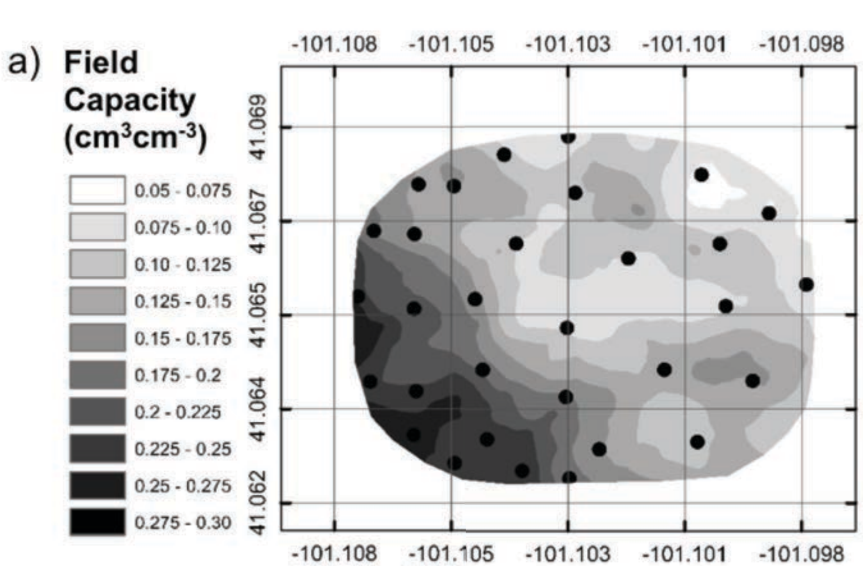
Soil Water Retention Curve Generated by HYPROP Software

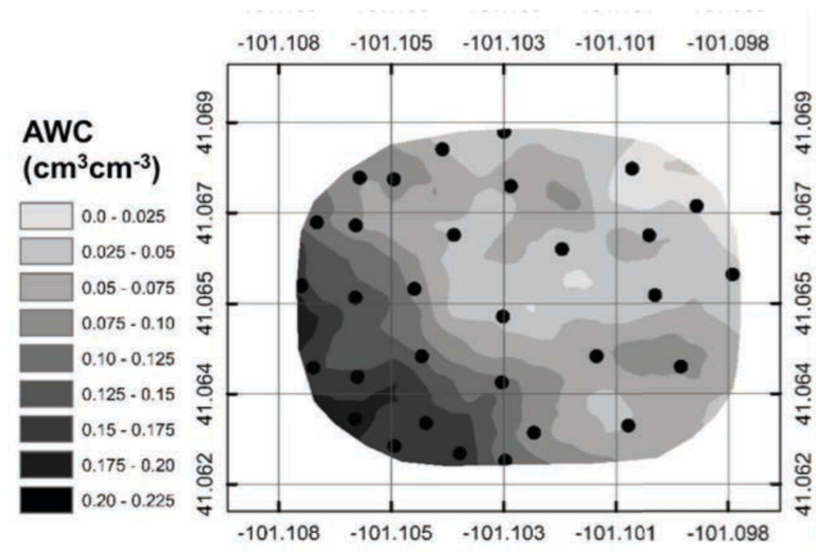


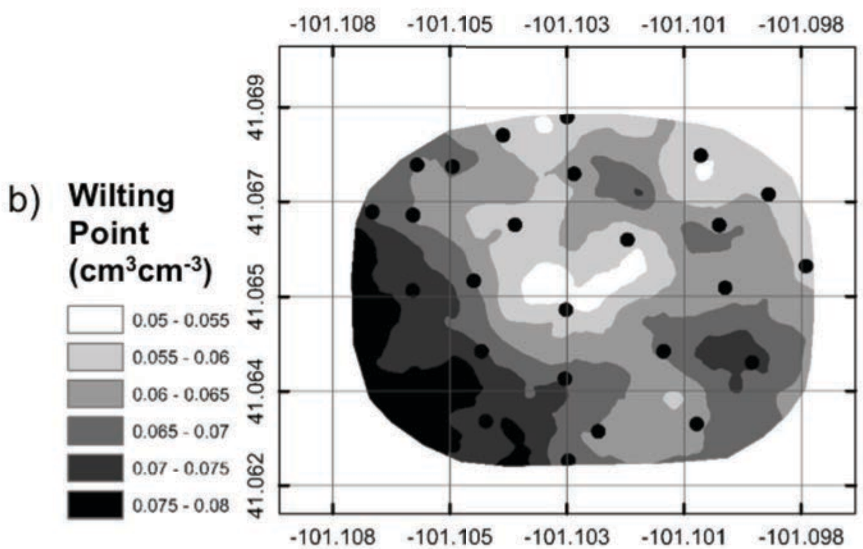


	Elevation (m)	TWI (m)	ECa (mSm^{-1})	EOF (-)	ECa (mSm^{-1}) + Elevation (m)	EOF (-) + Elevation (m)
SWC at Field Capacity (cm^3/cm^3)	$r^2 = 0.297$, RMSE = 0.064	$r^2 = 0.005$, RMSE = 0.076	$r^2 = 0.385$, RMSE = 0.060	$r^2 = 0.603$, RMSE = 0.048	$r^2 = 0.393$, RMSE = 0.061	$r^2 = 0.630$, RMSE = 0.047
SWC at Wilting Point (cm^3/cm^3)	$r^2 = 0.047$, RMSE = 0.016	$r^2 = 0.011$, RMSE = 0.017	$r^2 = 0.070$, RMSE = 0.016	$r^2 = 0.166$, RMSE = 0.015	$r^2 = 0.070$, RMSE = 0.017	$r^2 = 0.210$, RMSE = 0.015
AWC (cm^3/cm^3)	$r^2 = 0.321$, RMSE = 0.055	$r^2 = 0.012$, RMSE = 0.067	$r^2 = 0.411$, RMSE = 0.051	$r^2 = 0.613$, RMSE = 0.042	$r^2 = 0.422$, RMSE = 0.052	$r^2 = 0.632$, RMSE = 0.041

Spatial Products Useful for Irrigators







Precision Agric
https://doi.org/10.1007/s11119-018-9582-5

Integration of hydrogeophysical datasets and empirical orthogonal functions for improved irrigation water management

Catherine E. Finkenbiner[1,3] · Trenton E. Franz[1] · Justin Gibson[1] · Derek M. Heeren[2] · Joe Luck[2]

Strategies Moving Forward

- Collect 4+ hydrogeophysical maps at different SWC (medium to dry conditions)
  - Use self driving car, existing farm equipment to reduce costs?

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  - EOF additional spatial dataset uncorrelated to satellite imagery (CRNP=10^{-12} m and EMI=10^{5} m vs. 10^{-7} to 10^{-5} m for visible, NIR, IR)
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- Combine hydrogeophysics at medium to dry field conditions with hyperspectral data (UAS, aircraft, satellites) during wet to very wet field conditions to complete soil hydraulic picture
  - The light will show you the way

Summary

- CRNS technique has advanced over the last decade to provide useful information about agronomic decision making in time and space
  - Cost is challenging compared to market and competition (Use CRNS to cross calibrate and locate lower cost sensors?)
  - Complexity of CRNS calculations need be addressed and streamlined for stakeholder use (Addressed in this CRP)
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- Lots of opportunities to work with agricultural scientists from various disciplines
  - Design/evaluation of yield trials, placement of sensors, sampling strategy

Questions?