Design of smart environmental monitoring networks in agricultural landscapes

Trenton Franz

Hydrogeophysicist and Asst. Professor

University of Nebraska-Lincoln

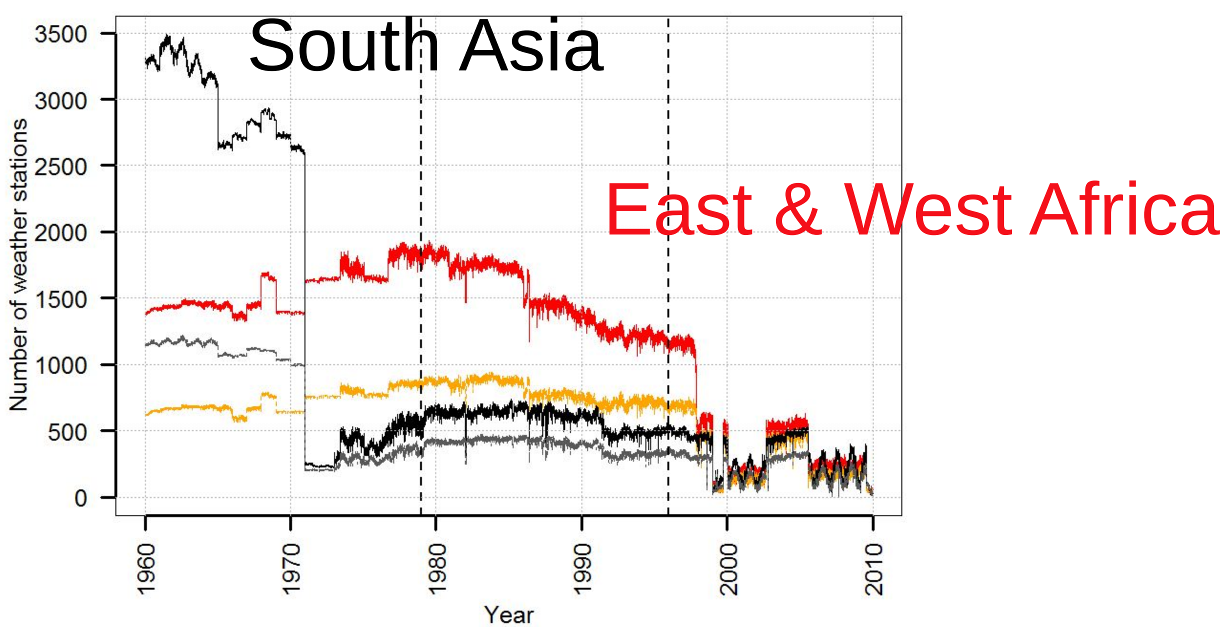
School of Natural Resources

Daugherty Water for Food Institute Faculty Fellow

Acknowledgements: Tiejun Wang (Visiting Scientist), William Avery (MS-2016), Catie Finkenbiner (MS-2017), Justin Gibson (PhD-2019)

Scientific Data Infrastructure

- Collapse of publically available observations
  - Rise of satellite observations- centralized, expensive, indirect, single point of failure
  - Weather data moved to individuals and private companies
- Need for value added products and economic quantification of value to public



Number of available met stations (1960-2010) Ramirez-Villegas & Challinor, 2012

Value Added Products

- Bolster information from existing monitoring networks
- Propose new targeted observations coupled with existing monitoring networks/infrastructure
- Propose new monitoring networks with specific deliverables and objectives

Value Added Products

Existing monitoring networks

- Rainfall and met stations
  - Short and long-term forecasts
- Eddy covariance towers
  - Ecosystem level water, energy, carbon budgets
- Soil moisture monitoring networks?
  - Continuing support of state mesonets, COSMOS, CRN, SCAN networks

Value Added Products

- Combining soil moisture monitoring with numerical modeling to monitor recharge across Nebraska

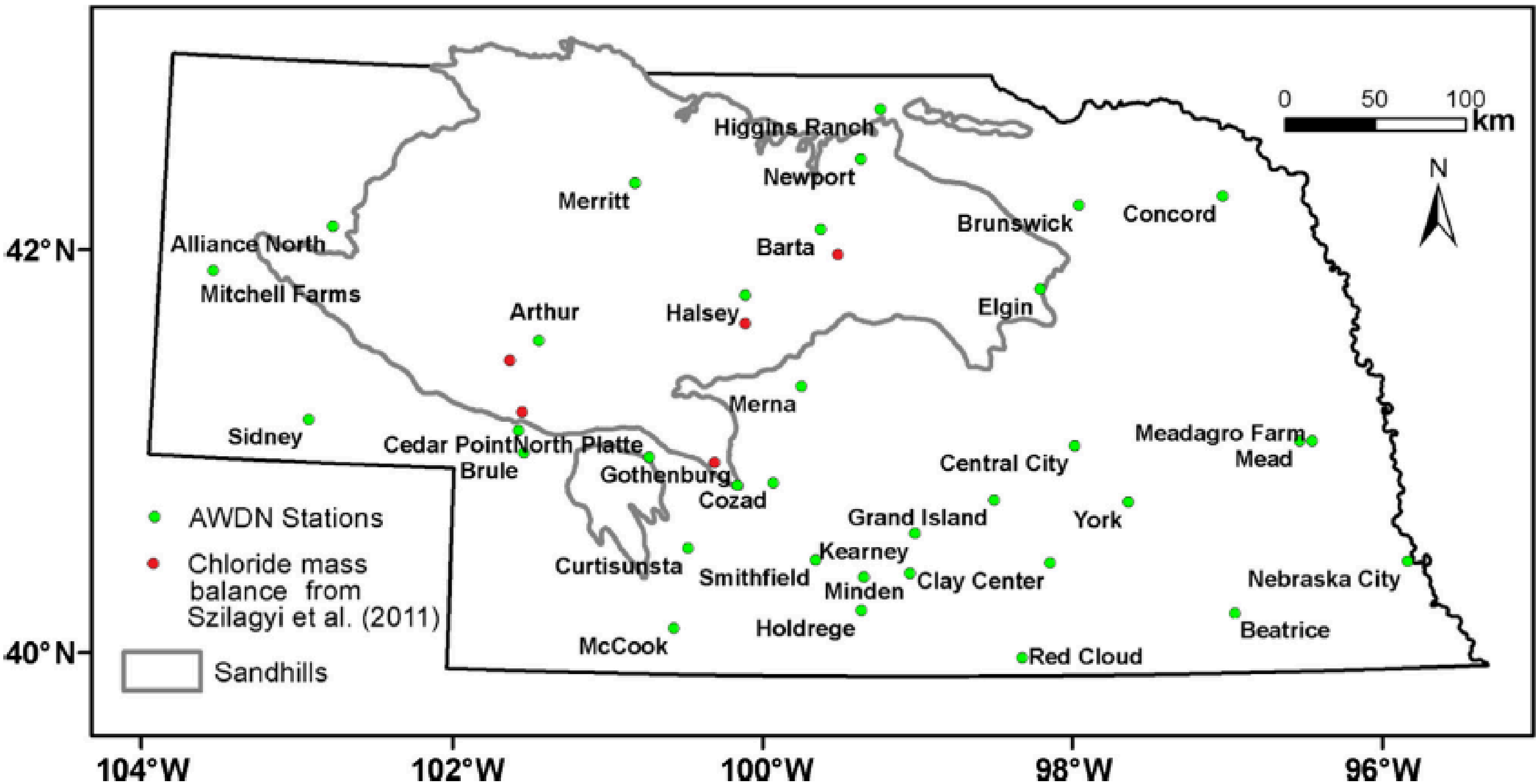
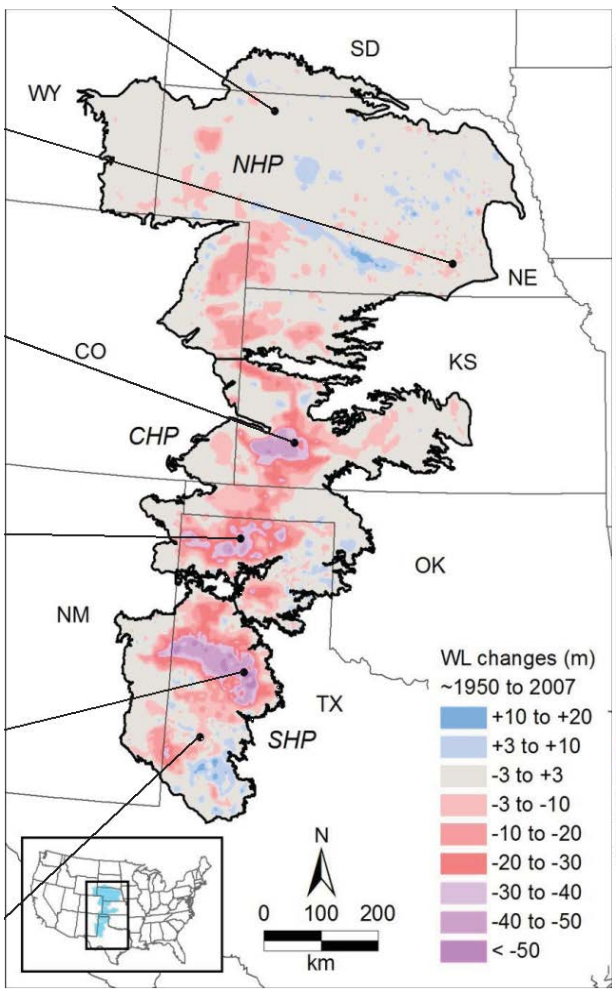


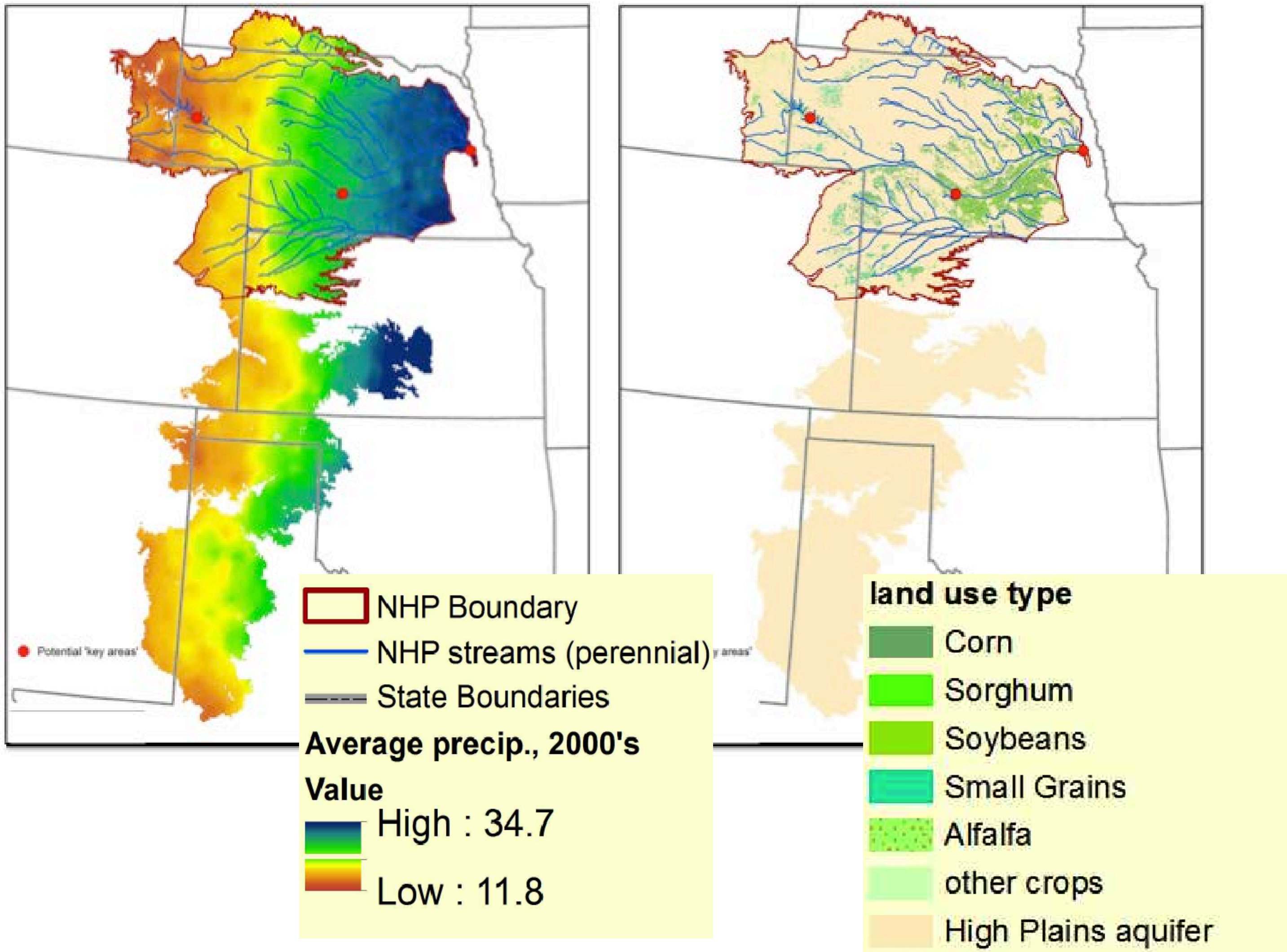
Fig. 1. Location map of soil moisture stations from the Automated Weather Data Network (AWDN) across Nebraska.

Wang, et. al (2016), Journal of Hydrology.

Value Added Products

Regional Groundwater Level Changes, Agriculture and Climate





Scanlon et al (2012)

Source: Steve Peterson, USGS

Climate Variability

Value Added Products

- Inverse solution with physically based unsaturated zone modelling

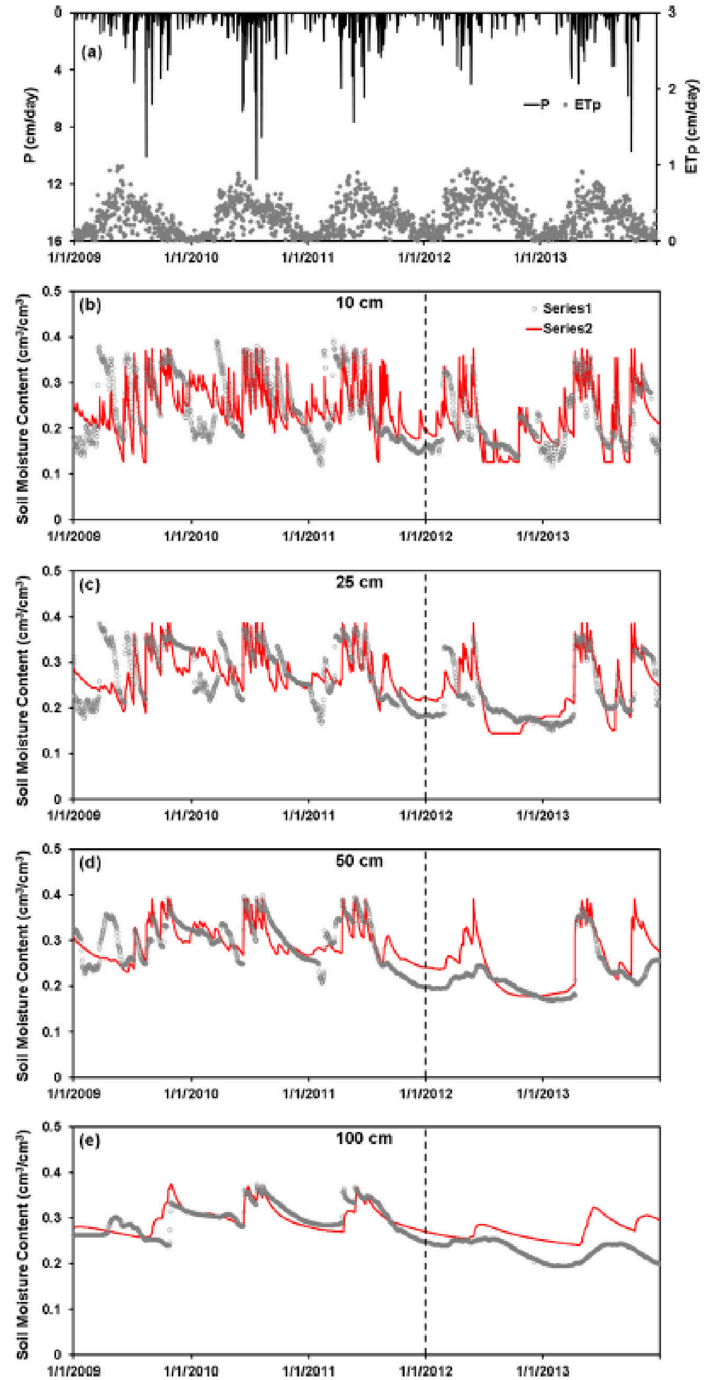
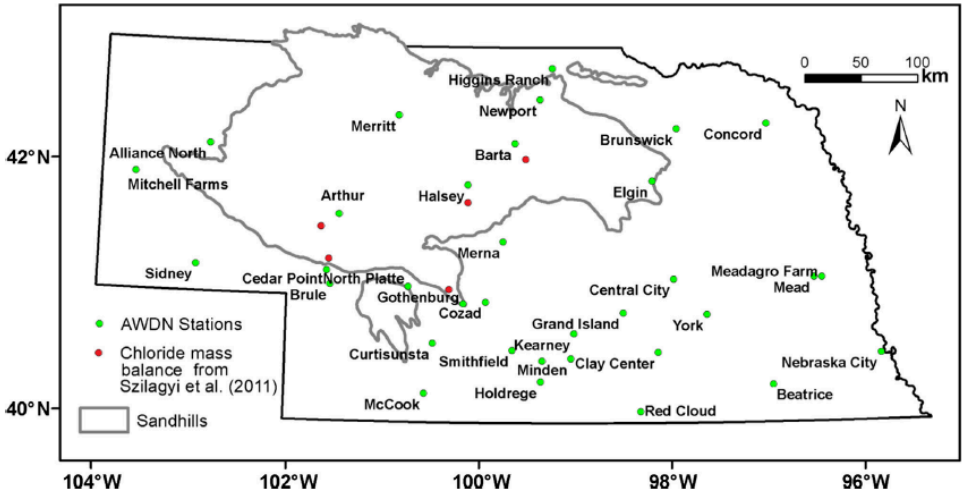


Fig. 6. Daily precipitation (*P*) and potential evapotranspiration (EP_p), and observed and simulated soil moisture contents during the calibration (2009–2011) and validation (2012–2013) periods at Concord.

Wang, et. al (2016), Journal of Hydrology.

Value Added Products



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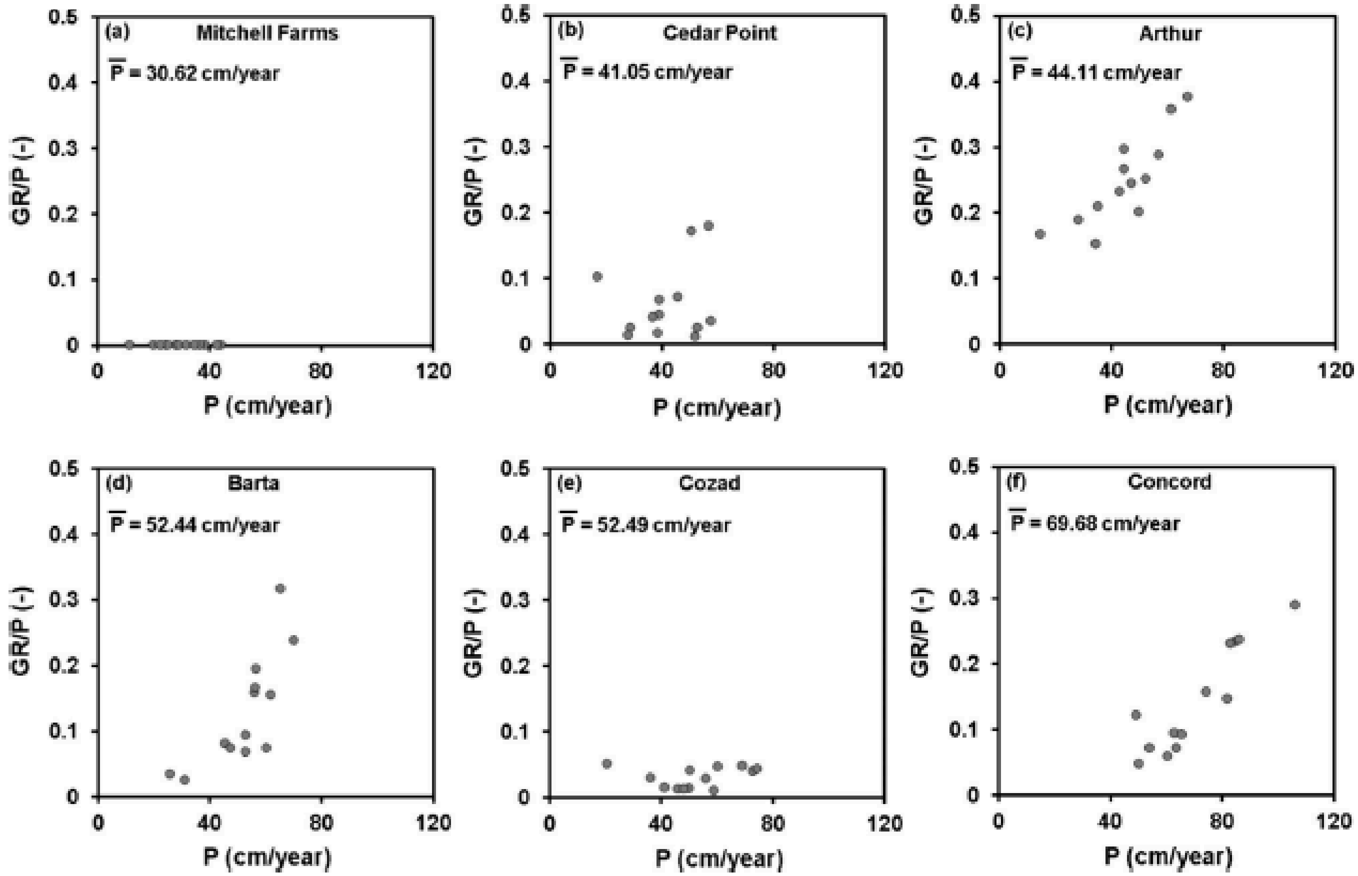


Fig. 10. Examples of the relationships between annual groundwater recharge ratio (*GR*/*P*) with annual precipitation (*P*) at individual AWDN sites.

Wang, et. al (2016)

Value Added Products

New observations with existing networks

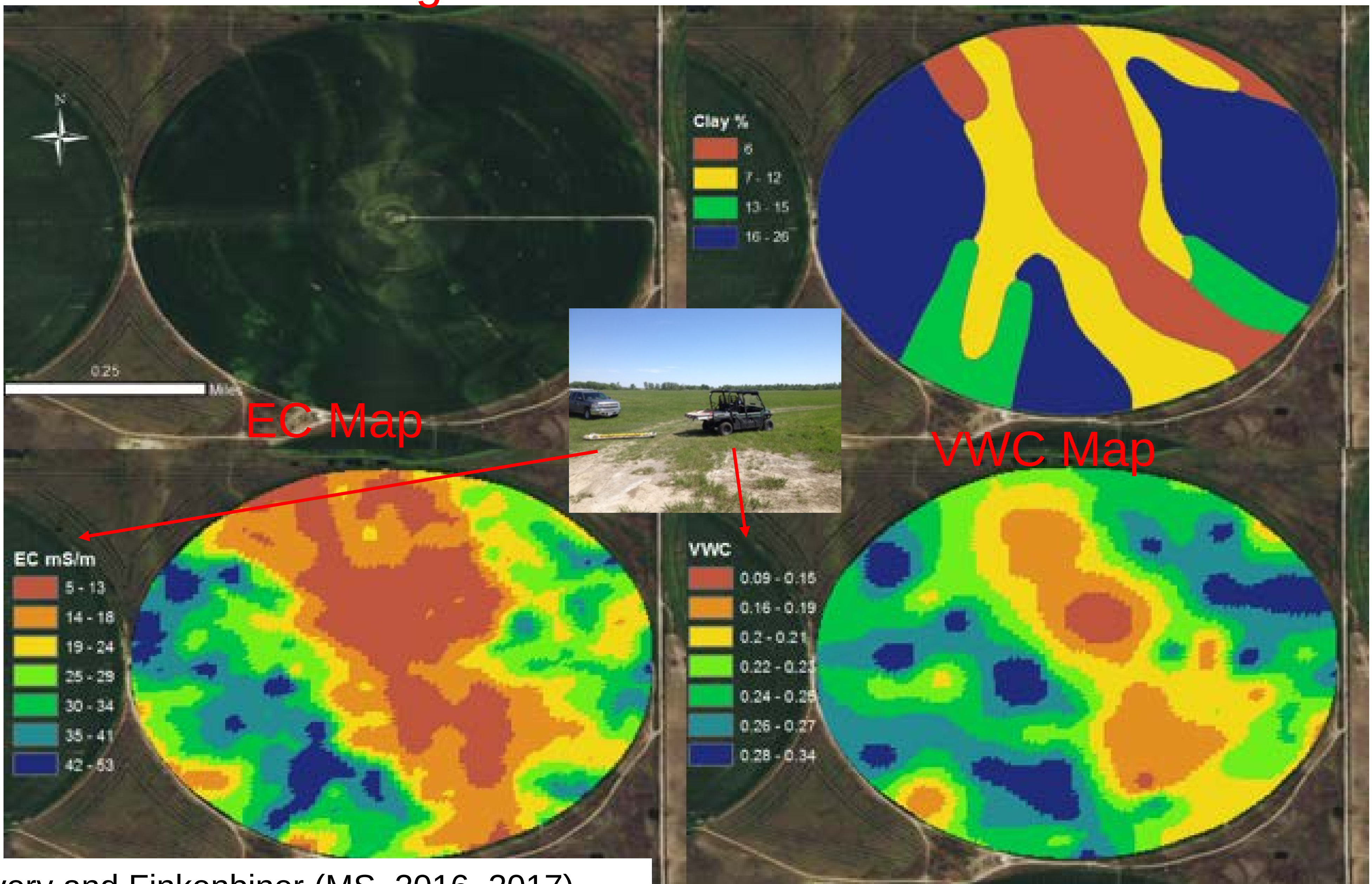
- Precision agriculture
  - Zone delineation of soil texture zones for precision planting, fertilizer, seeding, water
  - Couple hydrogeophysics with SSURGO database and lab analyses
  - Better rainfall for producers
  - Scientific evaluation of irrigation water savings technology

Precision Agriculture

Mapping done in 2 hours for both EC and VWC on 3/10/16, Brule Water Lab 1

Aerial Image

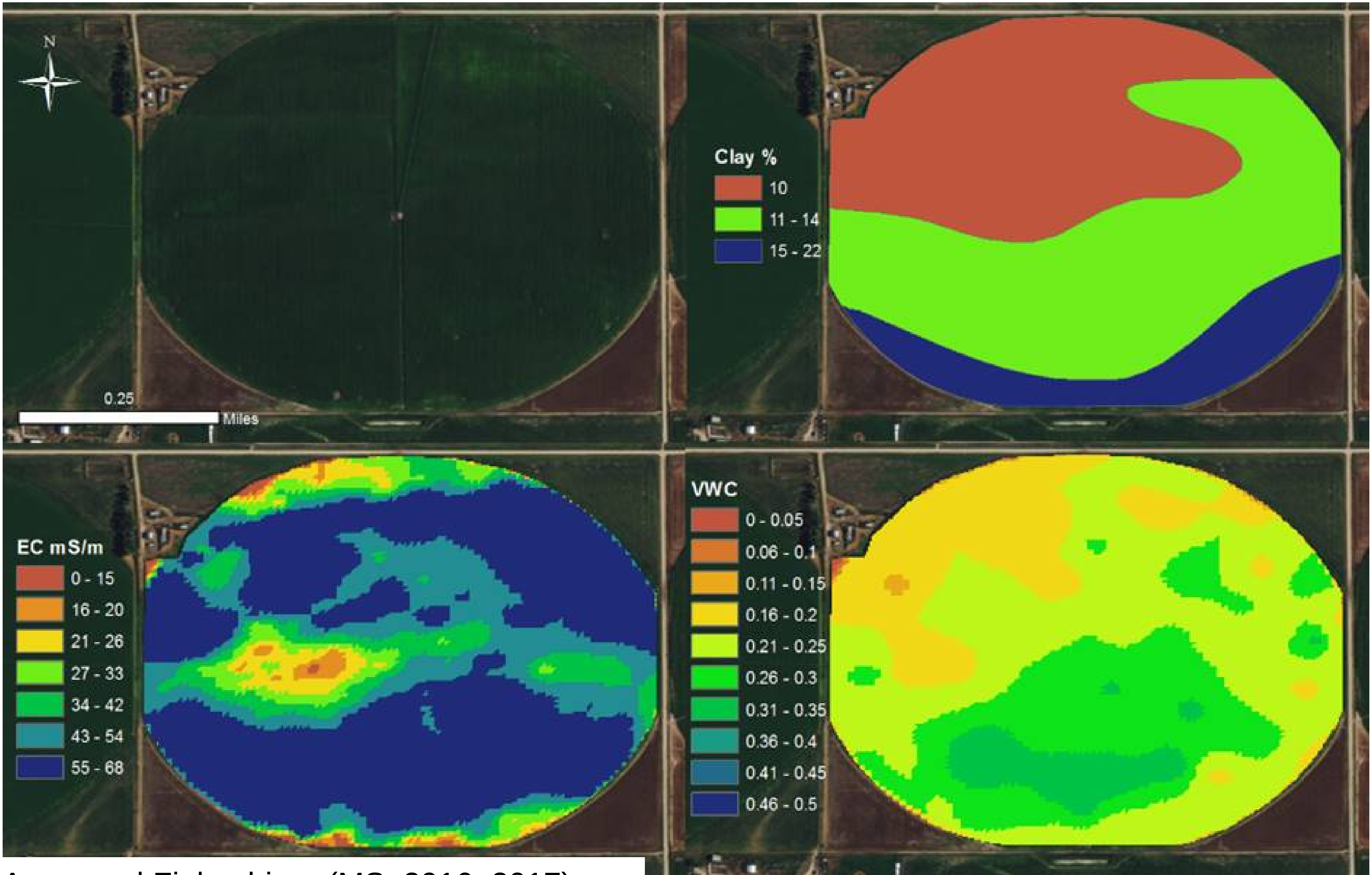
SSURGO Database



Avery and Finkenbiner (MS, 2016, 2017)

Precision Agriculture

Mapping done in 2 hours on 3/11/16, T3



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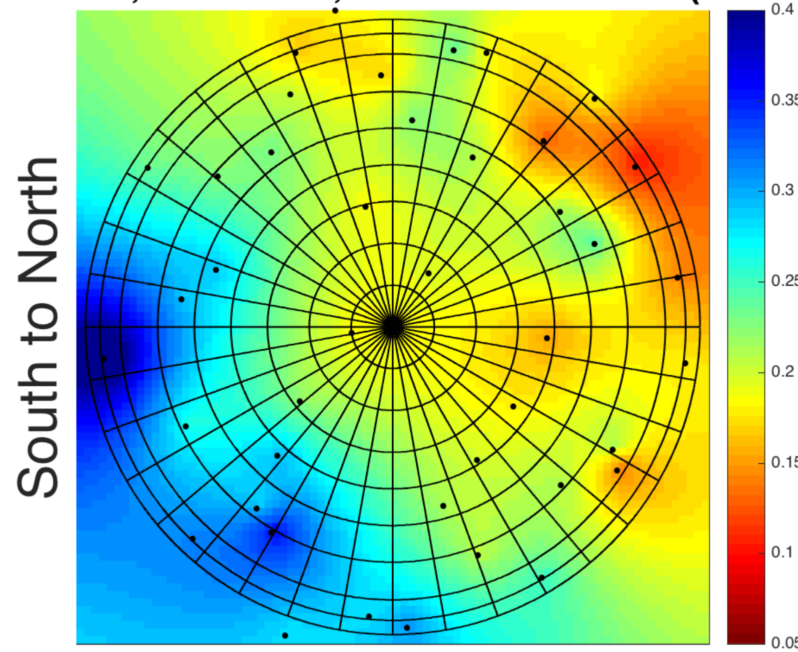
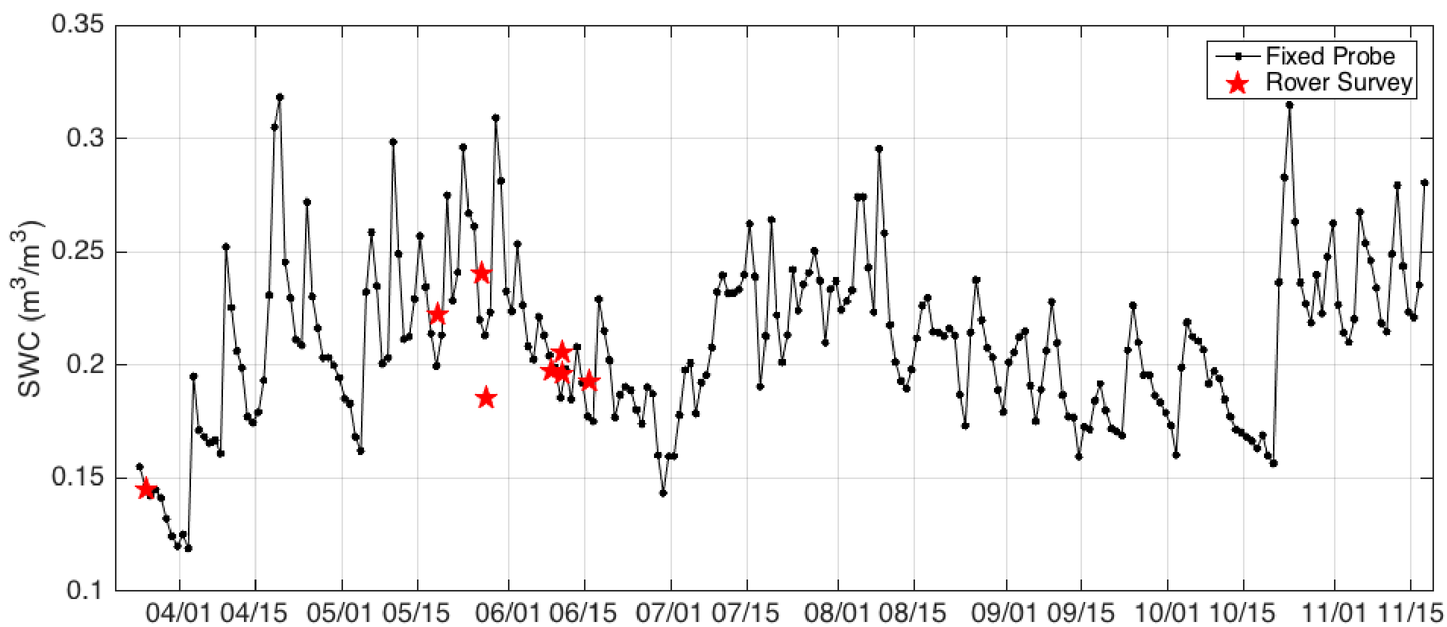
Precision Agriculture

Paulman P2, 06/15/2015, Soil Water Content (cm^3/cm^3)





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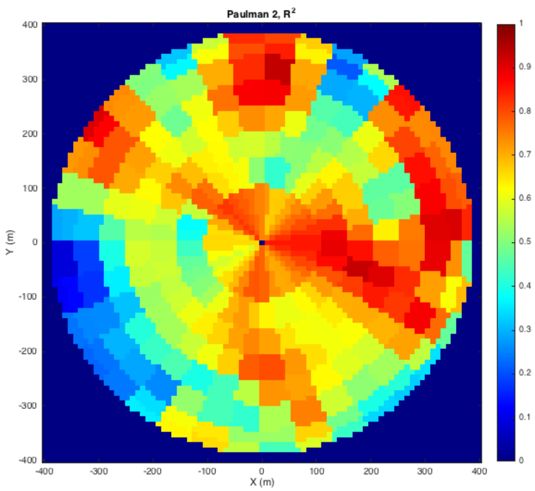
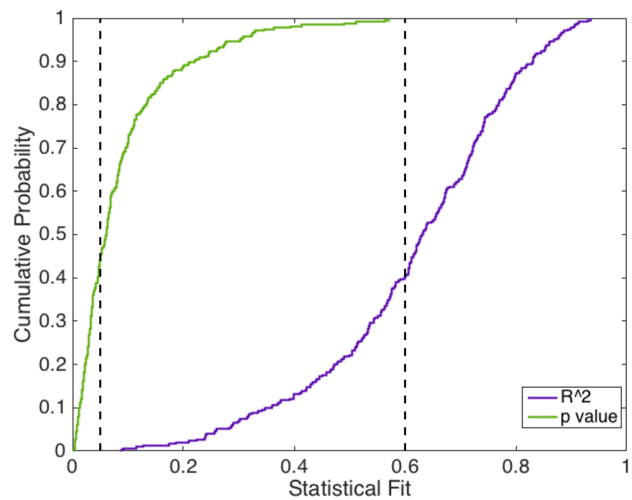
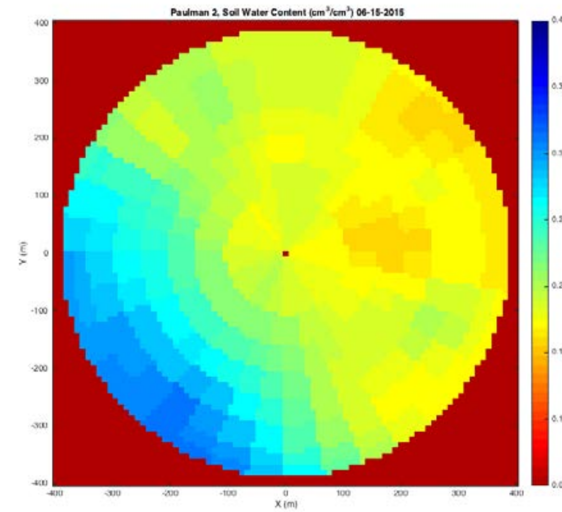
Precision Agriculture

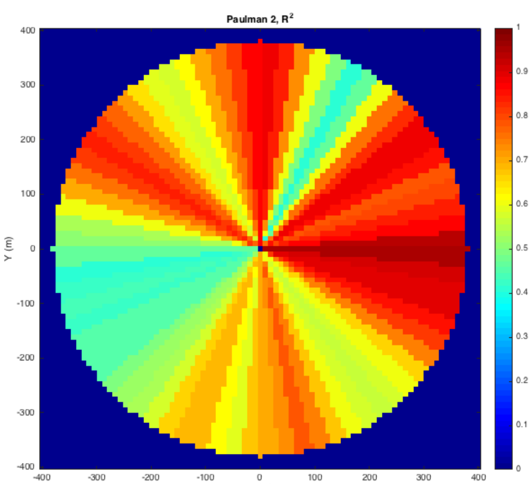
Combine data statistically so that the geometry is arbitrary

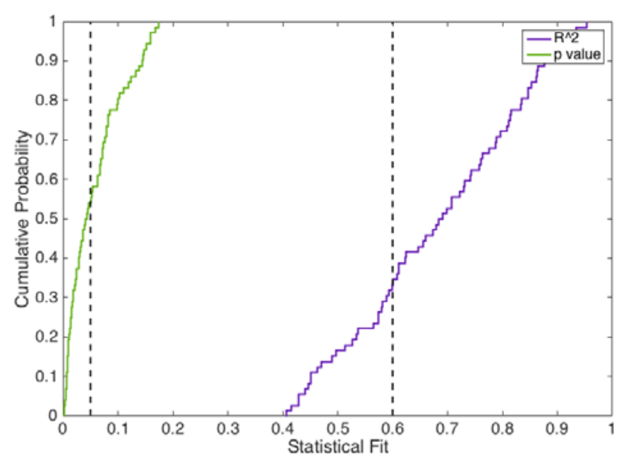
Applied to irregular shaped management zones or numerical modelling grids

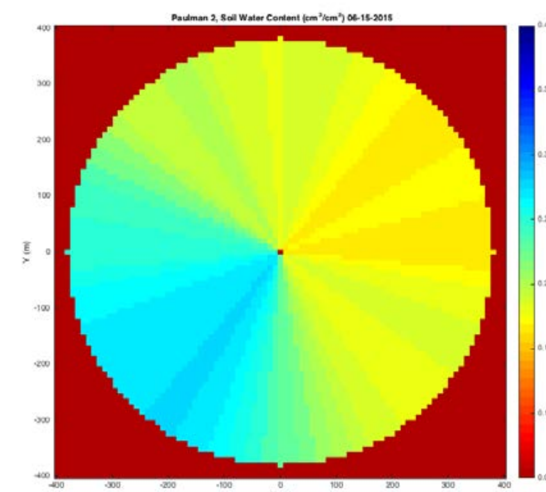










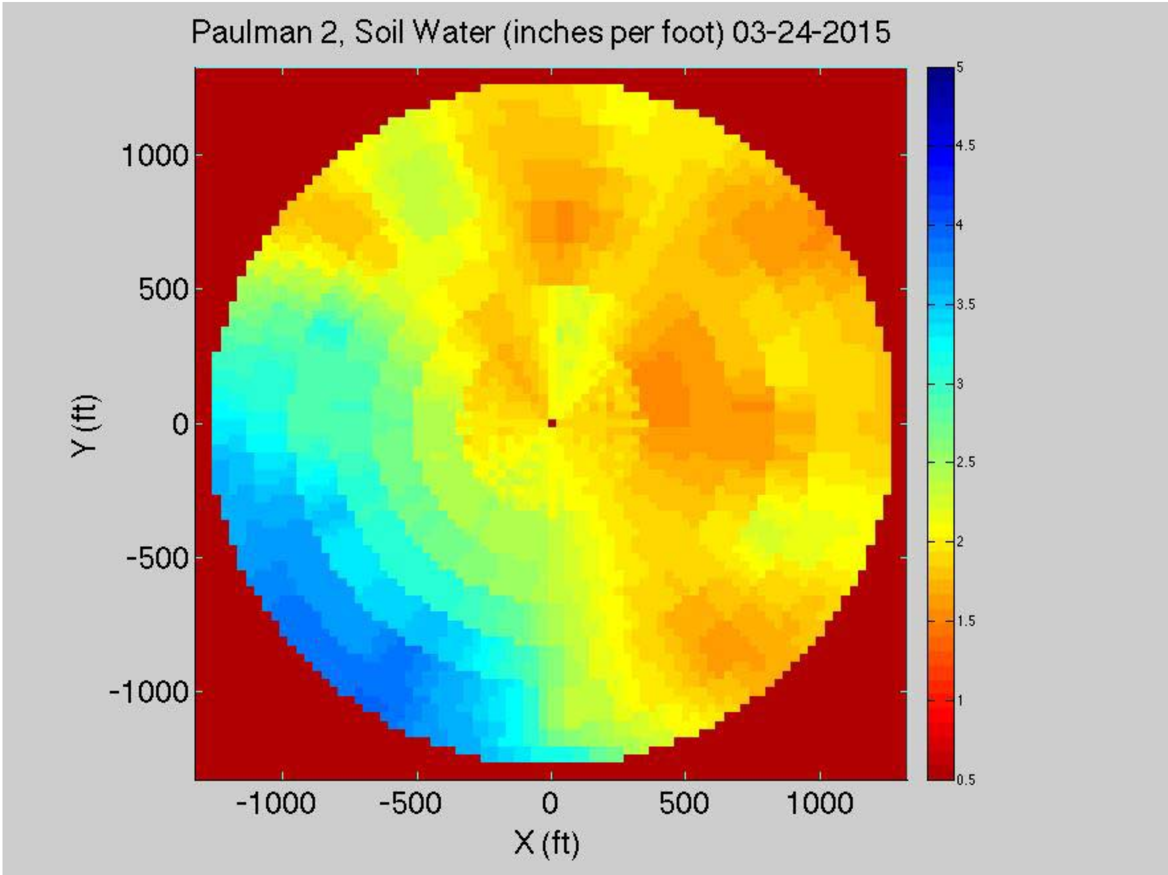


Avery and Finkenbiner (MS, 2016, 2017), Franz et al. (2015 GRL)

Precision Agriculture

- Scientifically accurate generation of static and dynamic water prescription maps by a crop consultant (~$10-15/acre)

- Continuous estimates of field average or zone average soil water storage for variable rate or speed irrigation ($?)



Avery and Finkenbiner (MS, 2016, 2017)

What about Rainfall, ET, kc?

Next generation of met. and crop water demand sensors?

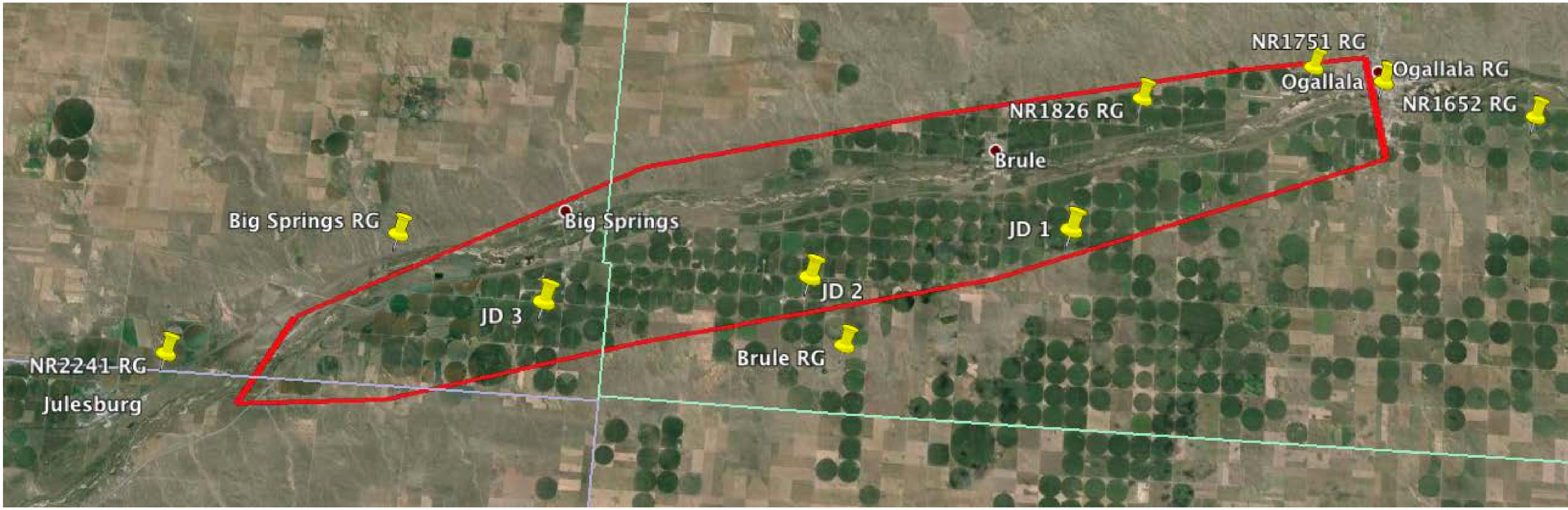
Available Summer 2016?

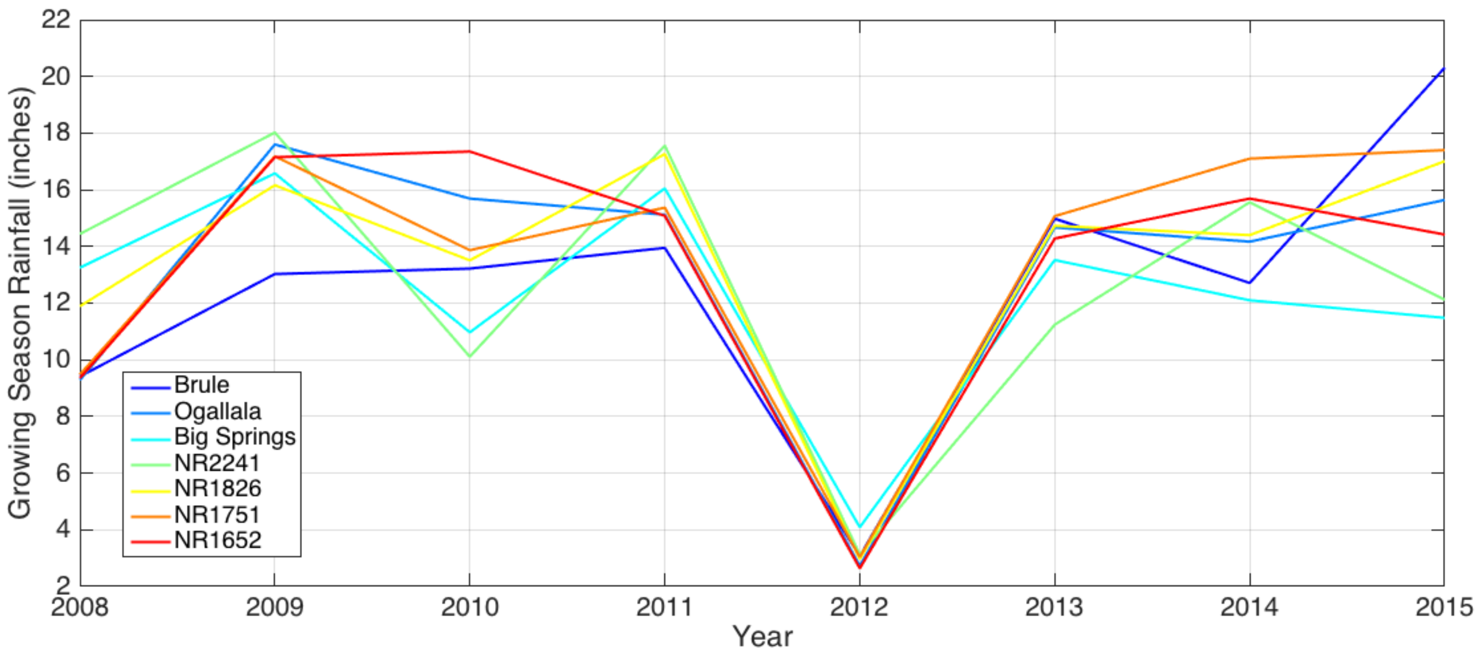
Integrated sensor package with 1 year data plan (~$1k):

- rain gauge (disdrometer)
- leaf wetness
- shortwave and longwave up and down
- 6-band spectrometer
- air temp
- humidity
- pressure
- GPS
- digital level and compass
- plug for peripherals, i.e. camera and soil moisture
- Telemetry: Cell, Wifi, or Bluetooth

PulsePod by Arable (www.arable.com)

How good do we measure rainfall?





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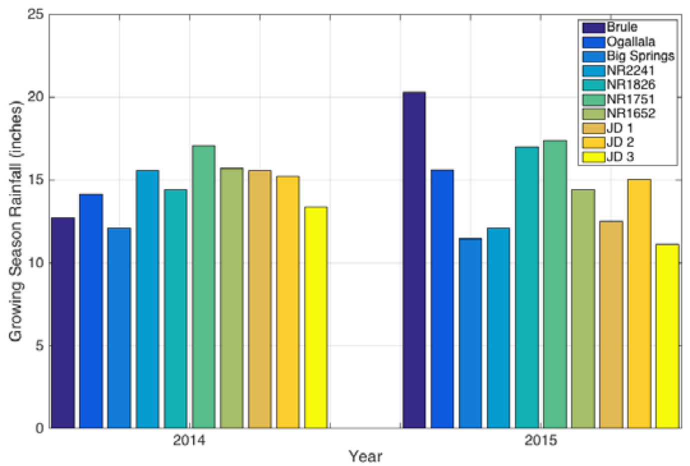
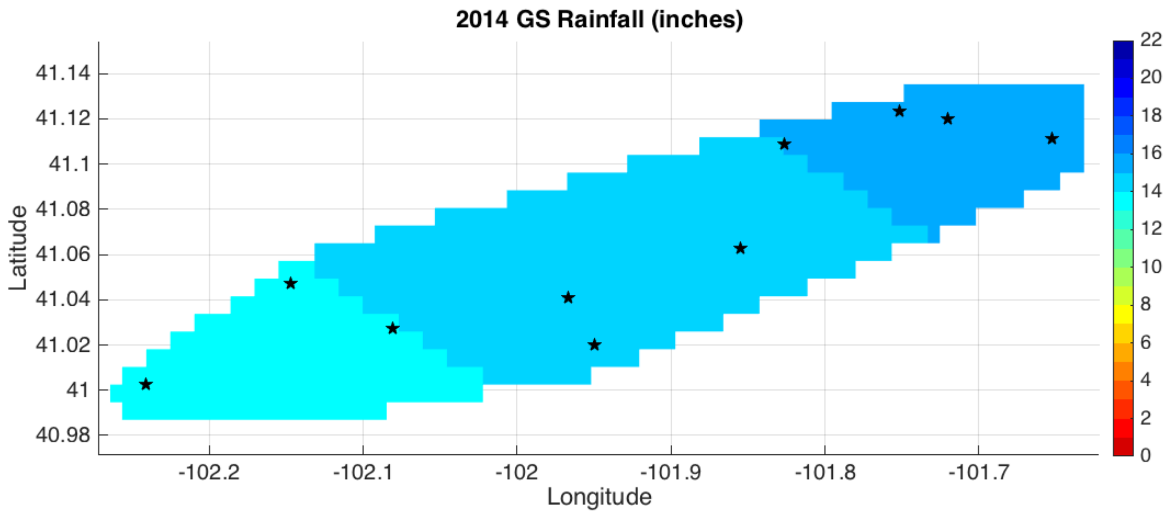
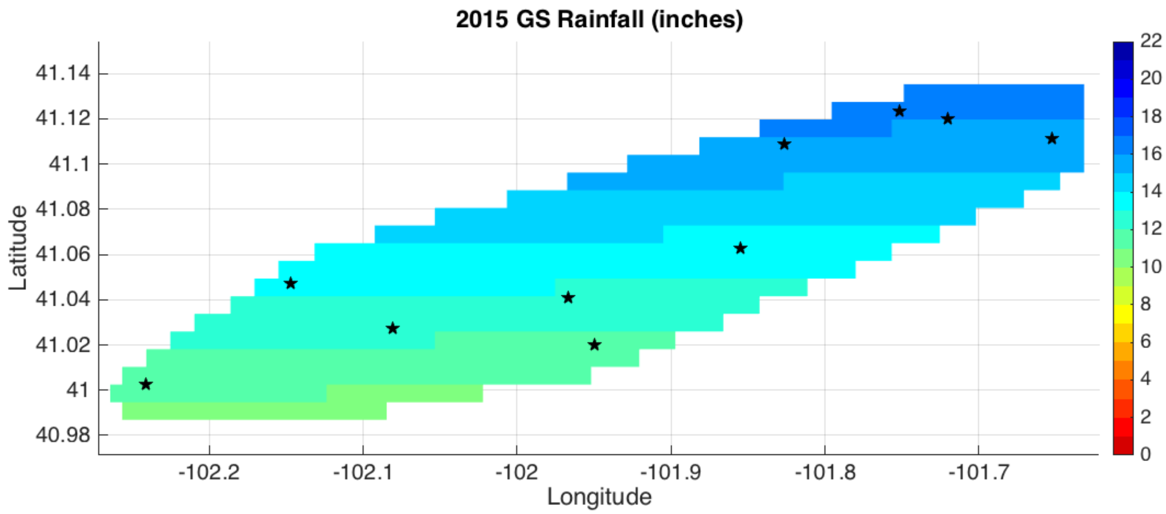


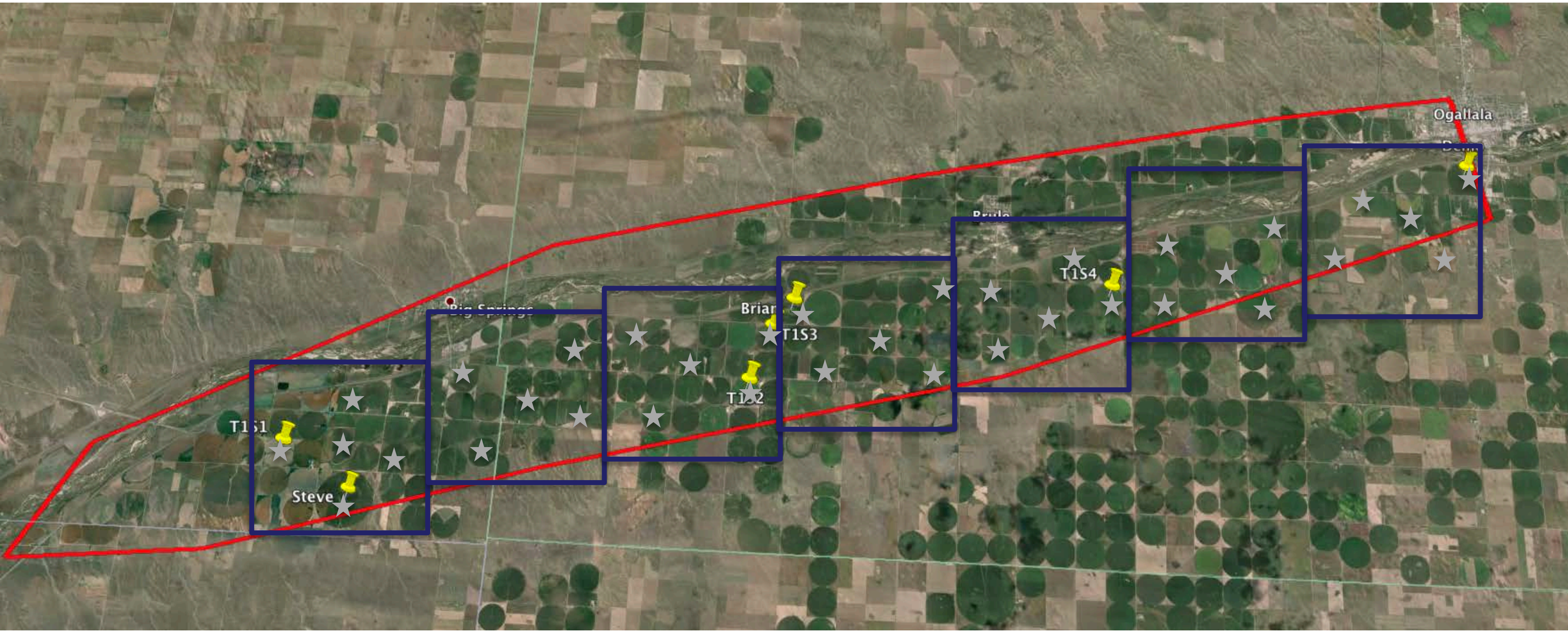




Design of Smart Rainfall Network

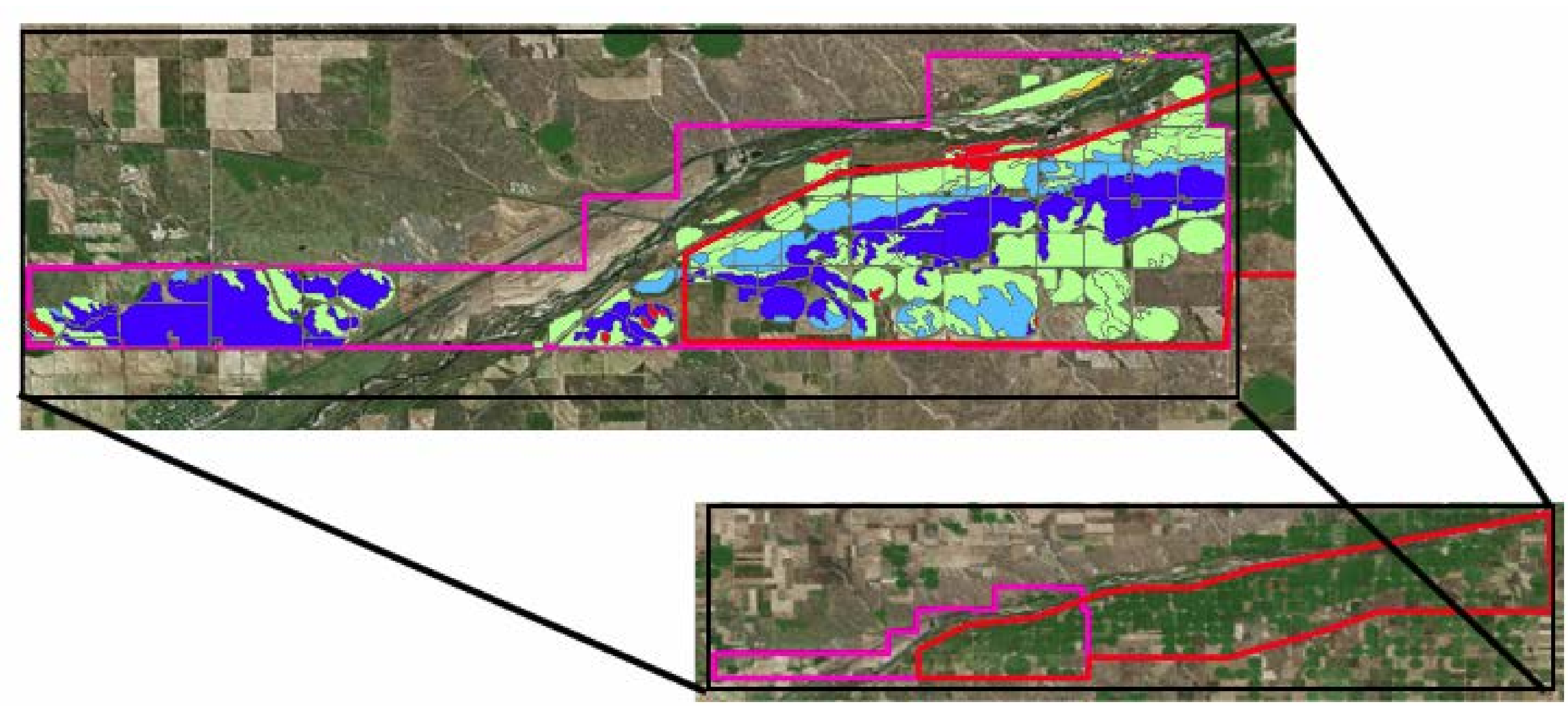
Goal: Determine hourly mean rainfall averaged over 3x3 mile boxes. Report to producers via text in that box when 24 hour cumulative value exceeds 1/4 inch.

How much energy and water savings from hourly shutoff capability? Pay for network with 1-2 reduced irrigation event? ~$500 in energy costs per irrigation event.



Historical Data

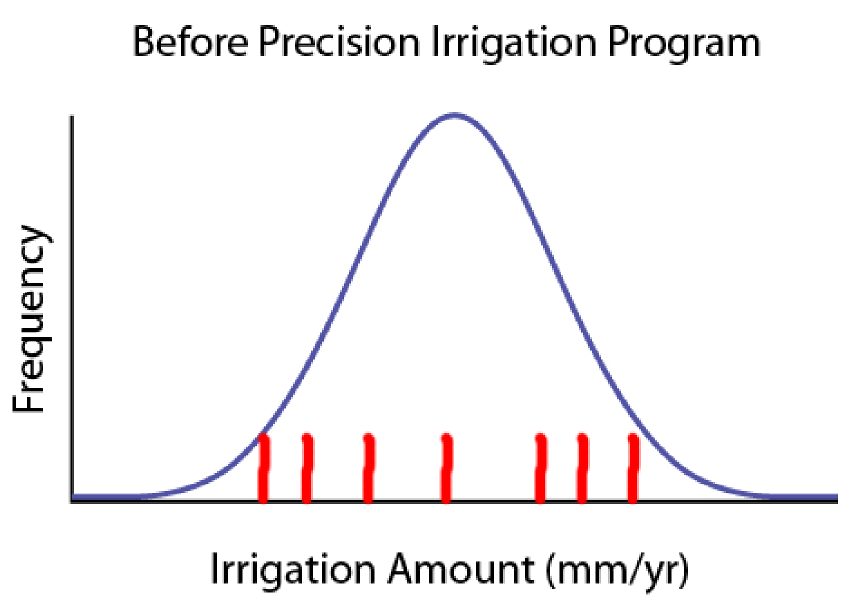
- Historical land use data is available for 80 fields in the study area from 1998-2015. This field-specific data includes: irrigation amount, yield, crop type, applied nitrogen, and nitrogen in irrigation water.

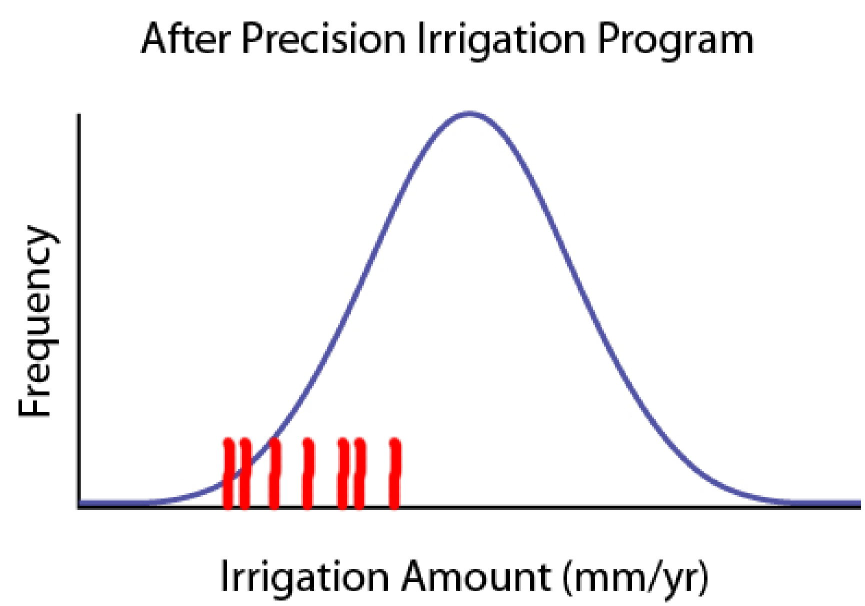


Data courtesy of SPNRD. Gibson (PhD, 2019)

Impact of Precision Irrigation

- Compare difference in irrigation amounts between precision irrigators and the rest of the basin in 2014-2016.
  - Split groups into soil texture, crop rotation, others…
- Where did active precision irrigation producers fall within the **distribution** of irrigation amounts **before** and **after** new irrigation techniques?



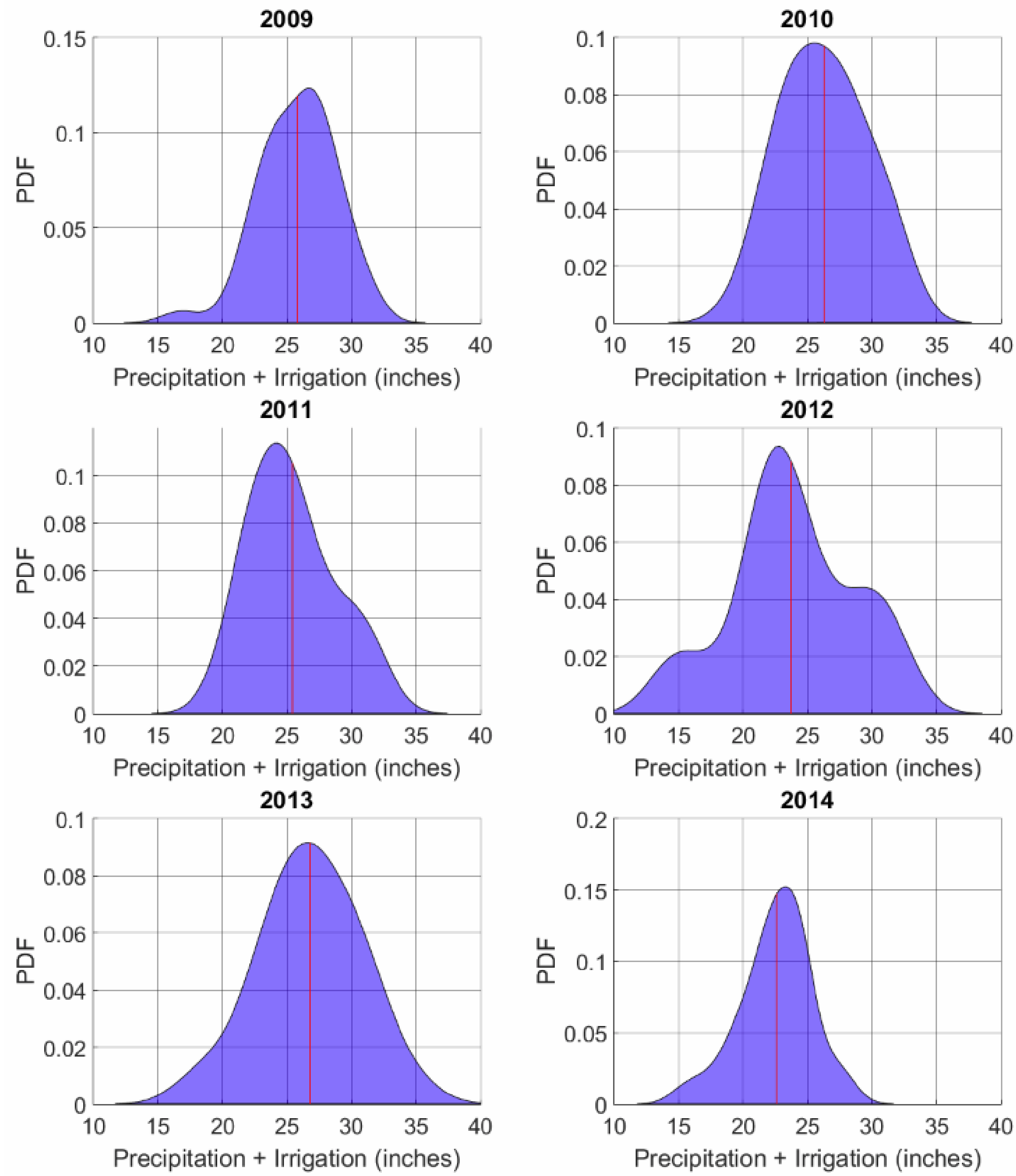


Gibson (PhD, 2019)

Irrigation and Precipitation

"When the question "Should I water one more time?" comes up, the answer can be decided by a calculation rather than a guess. **For example, corn requires approximately 25.5 inches (650 mm) of water before reaching maturity.** Knowing the water requirements for a crop from a growth stage to maturity will enable you to determine an irrigation rate to most efficiently achieve profitable yields and avoid costly over-watering."

-South Platte NRD



Precipitation amount from May 1st to physical maturity (~Sep. 30th)

Gibson (PhD, 2019)

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National Soil Moisture Network

Water for Food

- Combine COSMOS(+) networks with multi institutional rover platforms (UNL, KSU, OSU, Texas AM, …?)
- Use EOF framework to design and implement data analysis
  - Spatial grid can be matched to key modelling, remote sensing and management zones

Journal of Hydrology (2007) 334, 388–404

available at www.sciencedirect.com

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Journal of Hydrology

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

Mark A. Perry, Jeffrey D. Niemann *

$$V*E = L*E$$

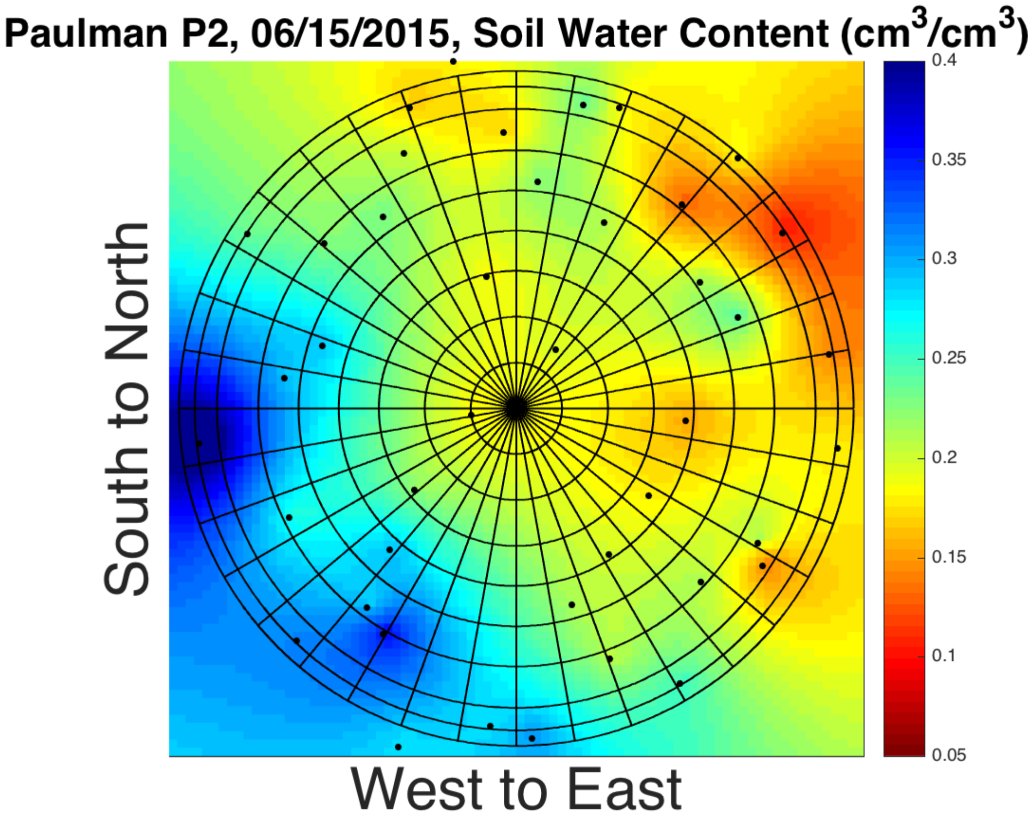
- Use calibrated rover(s) to determine time stable but spatially varying EOFs

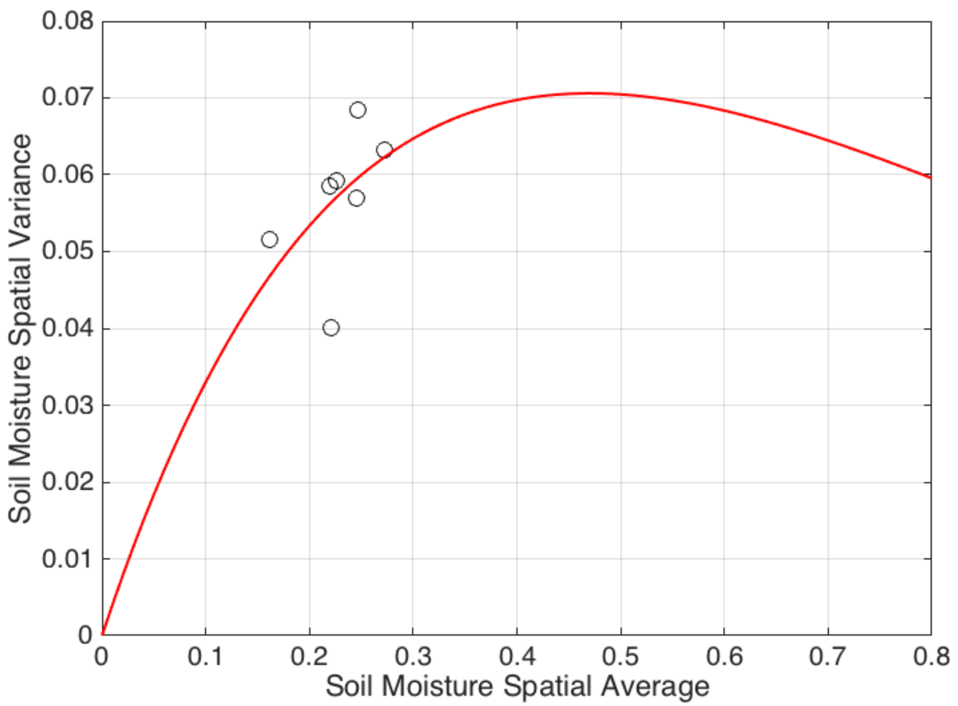
- Use calibrated fixed probe(s) or remote sensing to measure spatial average time varying component (EC)

- Questions?
- How many rover surveys per study area do you need?
- How many fixed probes per area do you need?

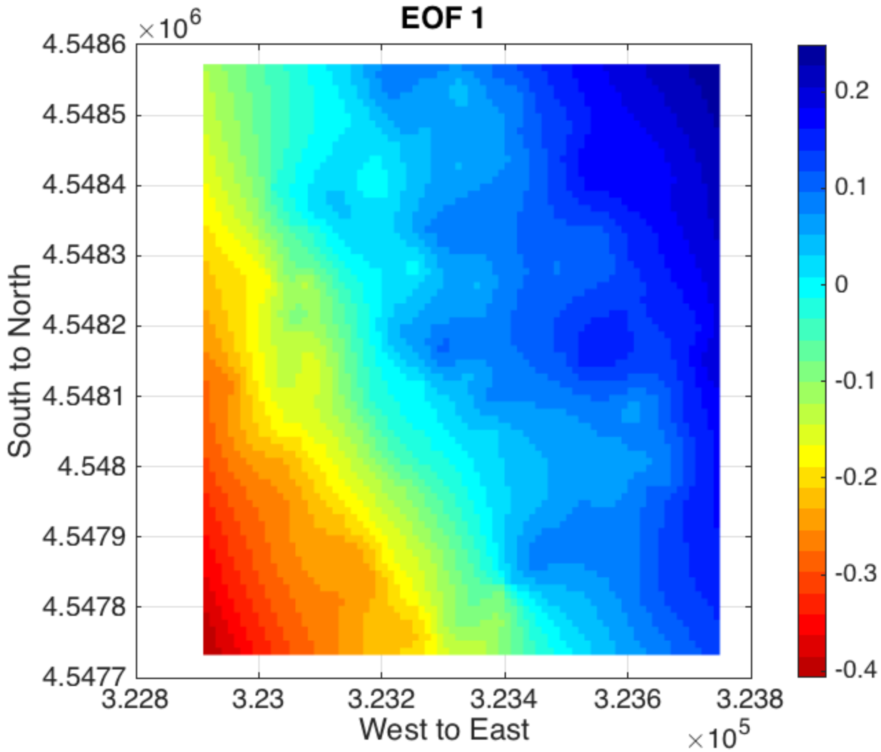
- It depends of course, no fun if we had all the answers already ☺

PH2: 7 rover maps 3/2015 to 2/2016





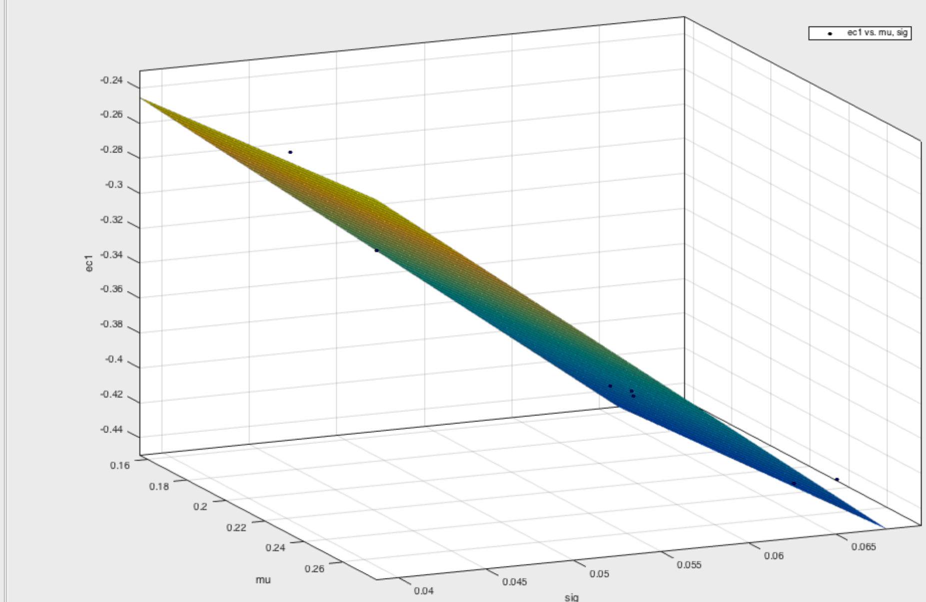
National Soil Moisture Network



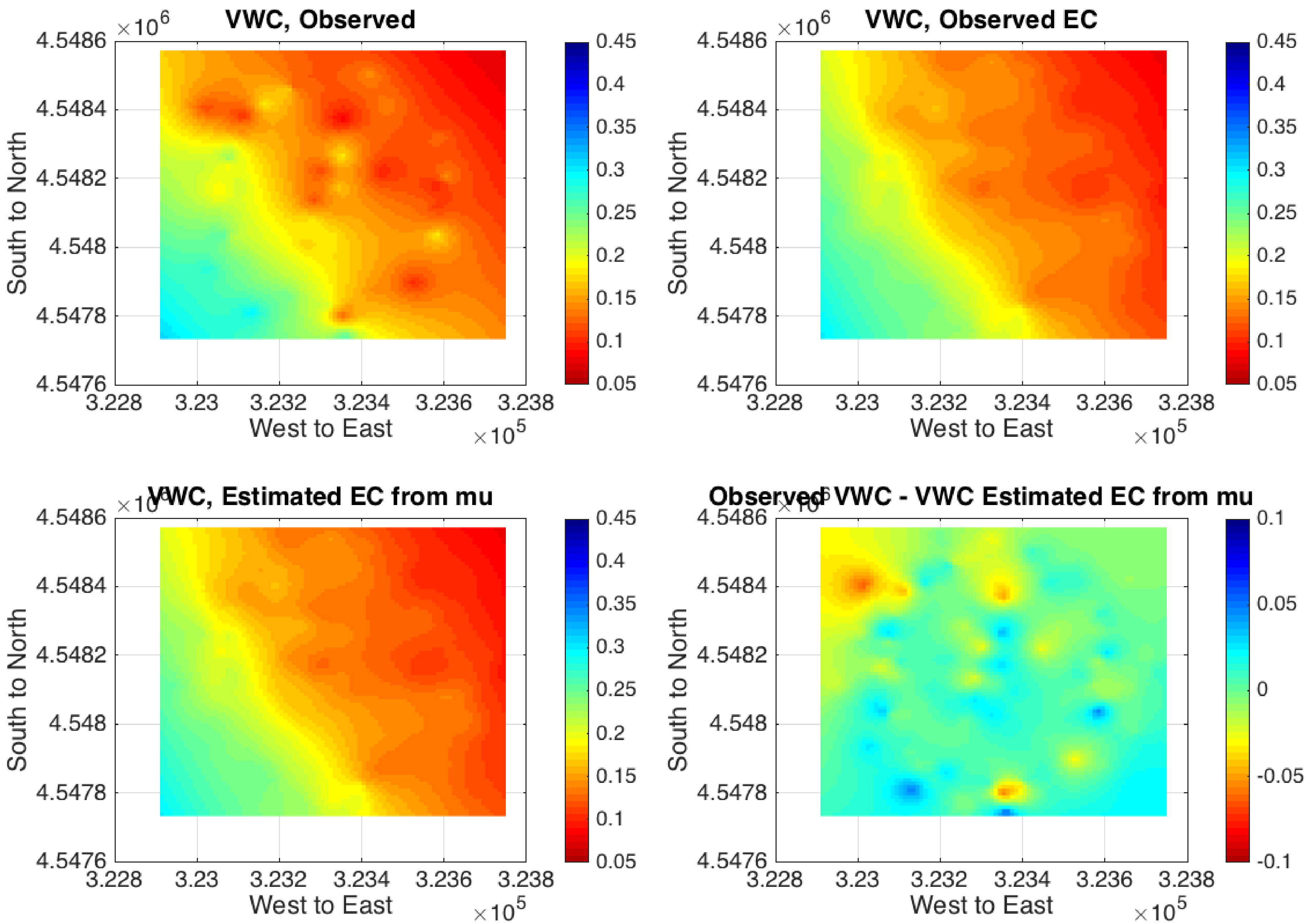
EV	Explained Variance
1	90.5%
2	4.3%
3	1.6%
4	1.2%
5	1.0%
6	0.8%
7	0.6%

Results

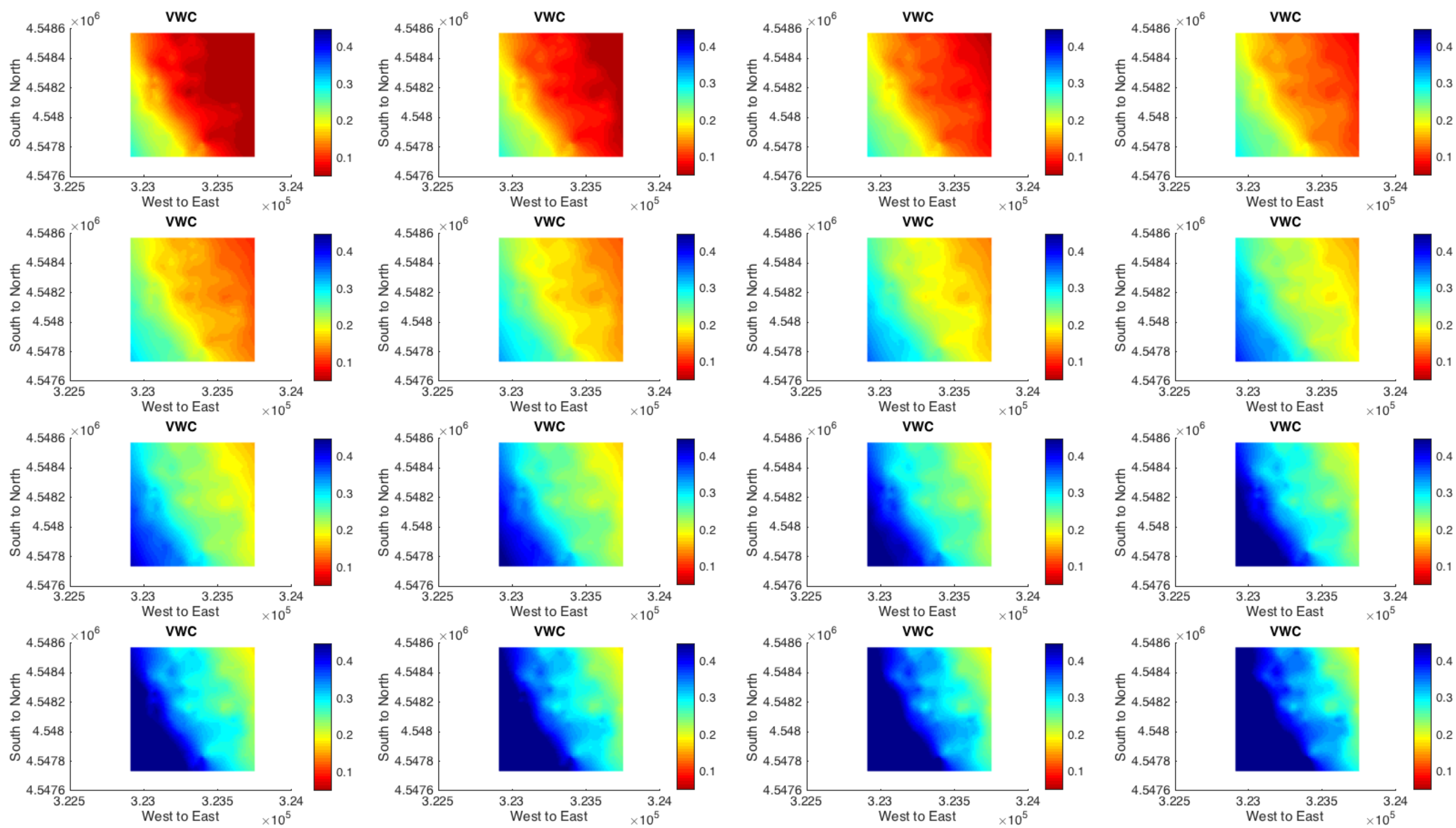
```
Linear model Poly11:
    f(x,y) = p00 + p10*x + p01*y
Coefficients (with 95% confidence bounds):
    p00 =     0.02701  (-0.07269, 0.1267)
    p10 =       0.108  (-0.3399, 0.5559)
    p01 =      -7.466  (-9.182, -5.75)

Goodness of fit:
  SSE: 0.0005545
  R-square: 0.979
  Adjusted R-square: 0.9685
  RMSE: 0.01177
```



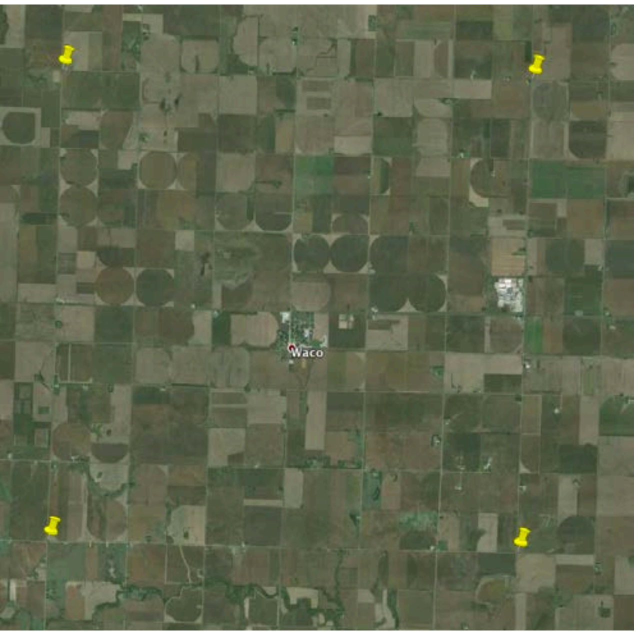
National Soil Moisture Network

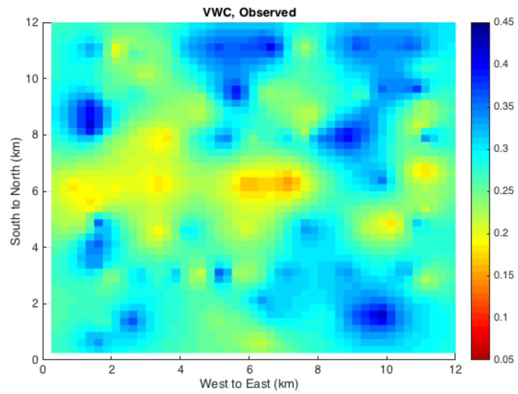


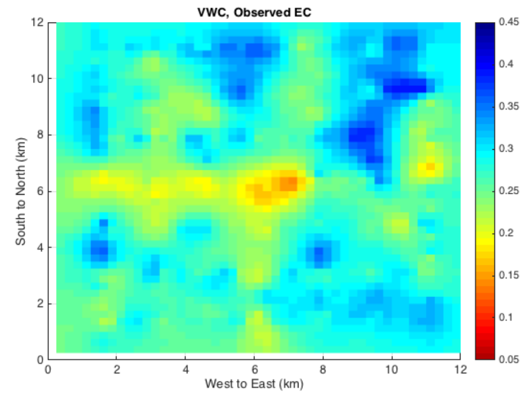
For increasing spatial mean VWC

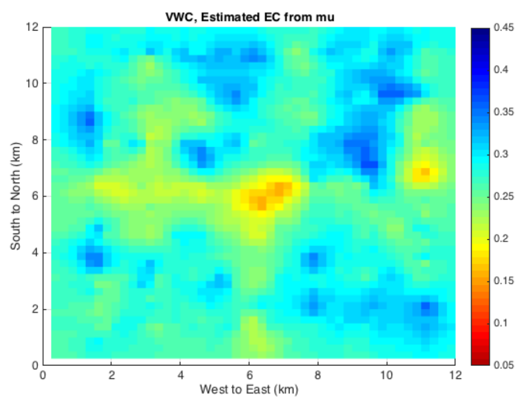


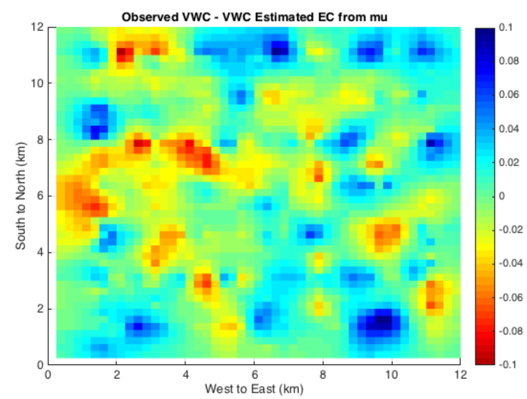
Waco: 22 rover maps 5/2014 to 10/2014











EV	Explained Variance
1	34.4%
2	8.7%
3	6.4%
4	5.9%
5	4.4%
6	4.2%
7	4.1%
8	3.8%
9	3.5%
10	3.1%
11	2.7%
12	2.4%
13	2.2%
14	2.0%
15	1.9%
16	1.8%
17	1.7%
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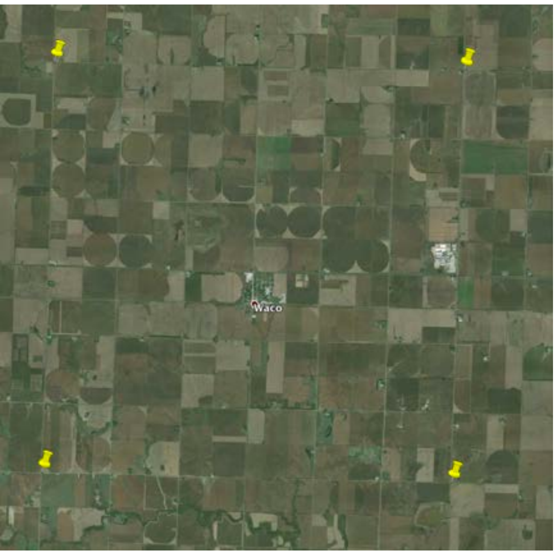

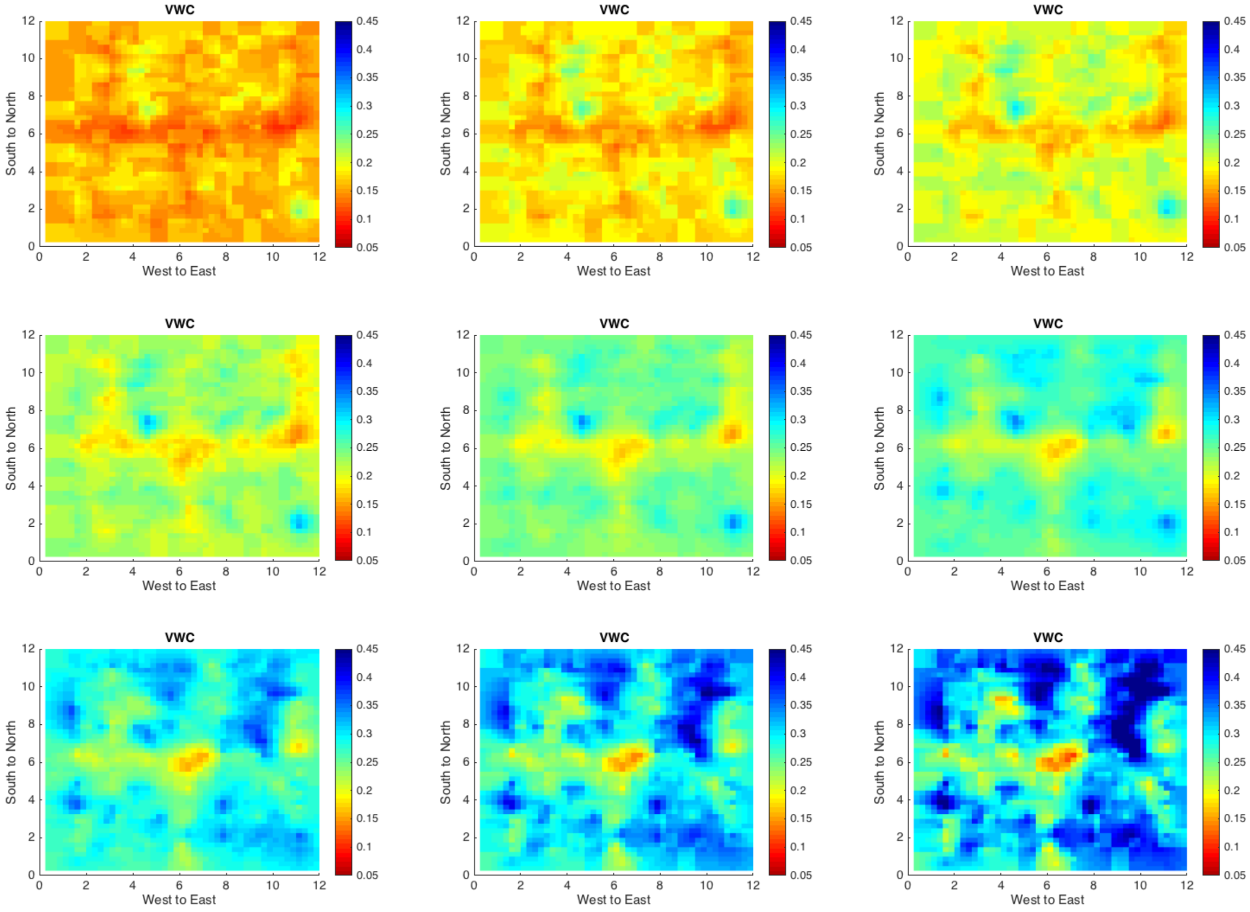

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Summary

- Maturation of the CRNP technology to some “value added” products for various stakeholders
  - Will we learn lessons from other networks successes and failures

- Proven and robust framework (EOFs) for combining fixed and rover CRNP technology?
  - Flexible geometry of products

- Building momentum and organization of various networks/infrastructure to propose a national or global monitoring network for soil moisture???

Cosmic rays gone wild