Understanding the Cosmic-ray Neutron Sensor Calibration Function

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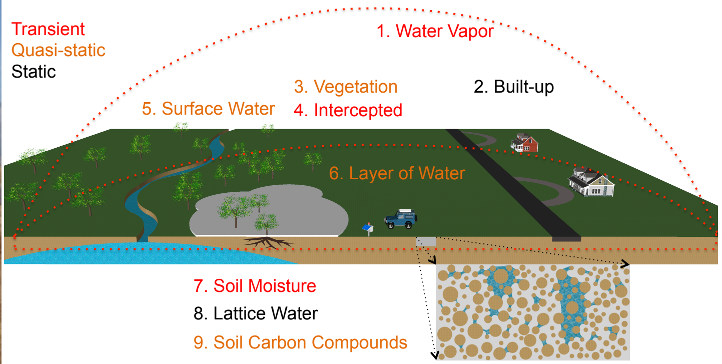
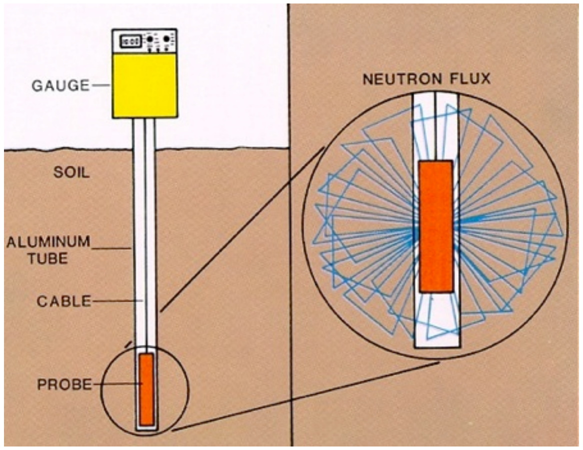
A Comparison of Neutron Probes





- Essentially same detector but with updated electronics and high voltage NPMs
- Same basic physics as in-situ neutron probe
- Passive sensor, uses cosmic-ray neutrons as source
- Relates fast neutrons to water content instead of slow or thermal neutrons
- Footprint is ~1000x larger (density of soil vs. air)
- Probe sees about top 30 cm
- In-situ probe considered gold standard in agronomy and soil physics

http://sanangelo.tamu.edu/agronomy/sorghum/neutron.htm

COSMOS Project

COsmic-ray Soil Moisture Observing System (COSMOS)

Phase I: NSF project 2009-2013, ~50 US Probes

Phase II: Expansion to 500 probes? (NSF, NOAA, sub-networks?????)

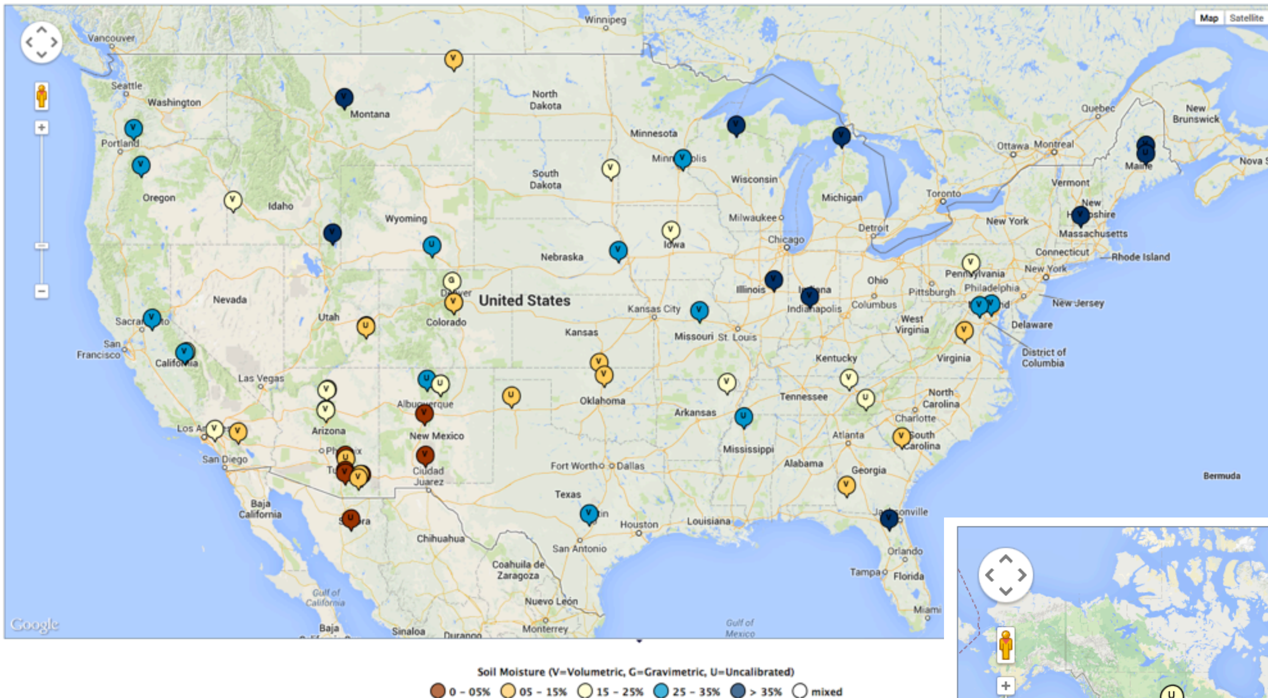
Science Priorities:

- Soil moisture controls:
  - weather and climate models
  - ecological processes and phenomena
  - hydrological flow processes in catchments
- Water storage on/in vegetation canopies
- Frozen precipitation
- Remotely sensed measurements of soil moisture

COSMOS Project Status

- COSMOS data freely available at (http://cosmos.hwr.arizona.edu/) with some quality control, usually co-located with eddy covariance towers, over 90% reliability

- Probes: 60 COSMOS, 100 Independent networks around globe (CosmOz, TERENO, UK, South Africa), with more to come online (Saudi Arabia, Brazil, China?)



Cosmic-rays on Earth

- Primary - mostly protons and alphas
- Interact with magnetic field

  - intensity depends on geomagnetic latitude

- Interact with atmospheric nuclei
- Produce secondary particles - cascade

  - intensity depends on barometric pressure

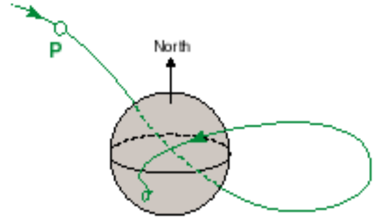
- Produce fast neutrons

  - slowing down by elastic collisions

  - leads to thermalization

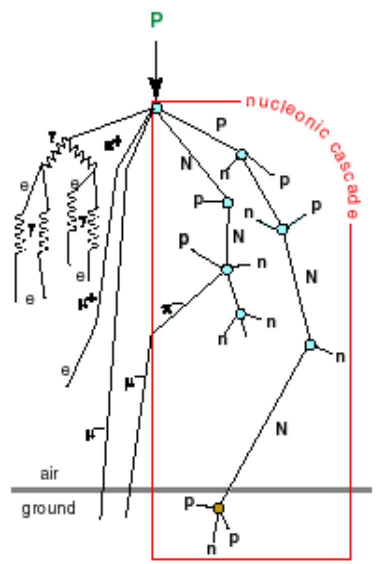
  - and then absorption

The last three processes depend on the chemical composition of the medium, in particular on its hydrogen content



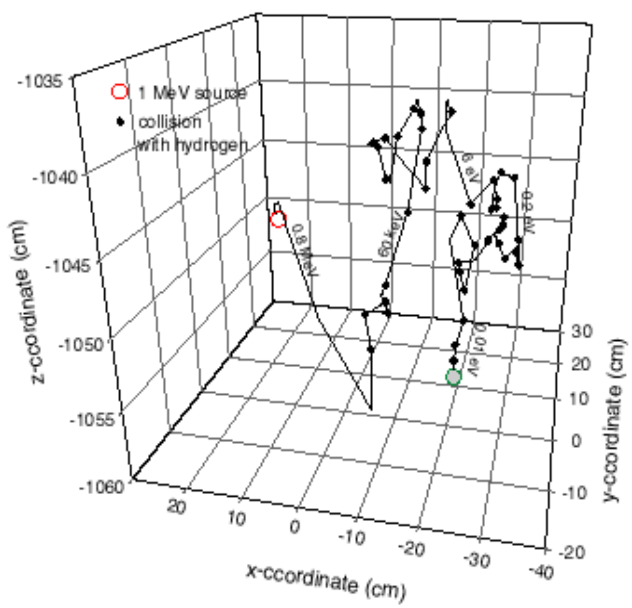
Space:

incoming high-energy cosmic-ray proton



Atmosphere:

generation of secondary cosmic rays

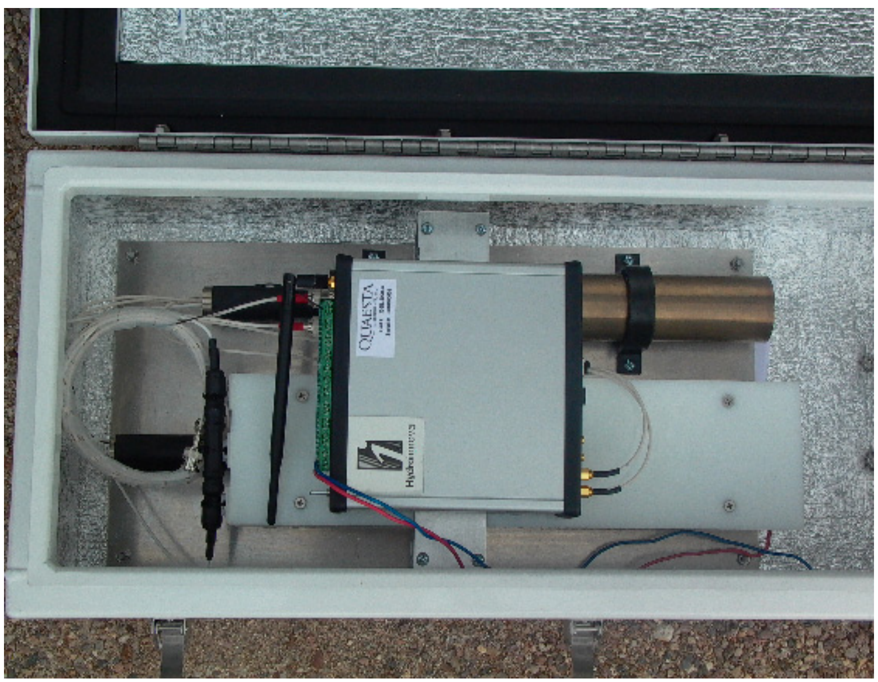


Ground:

scattering thermalization absorption

Summarized in Zreda et al., 2012

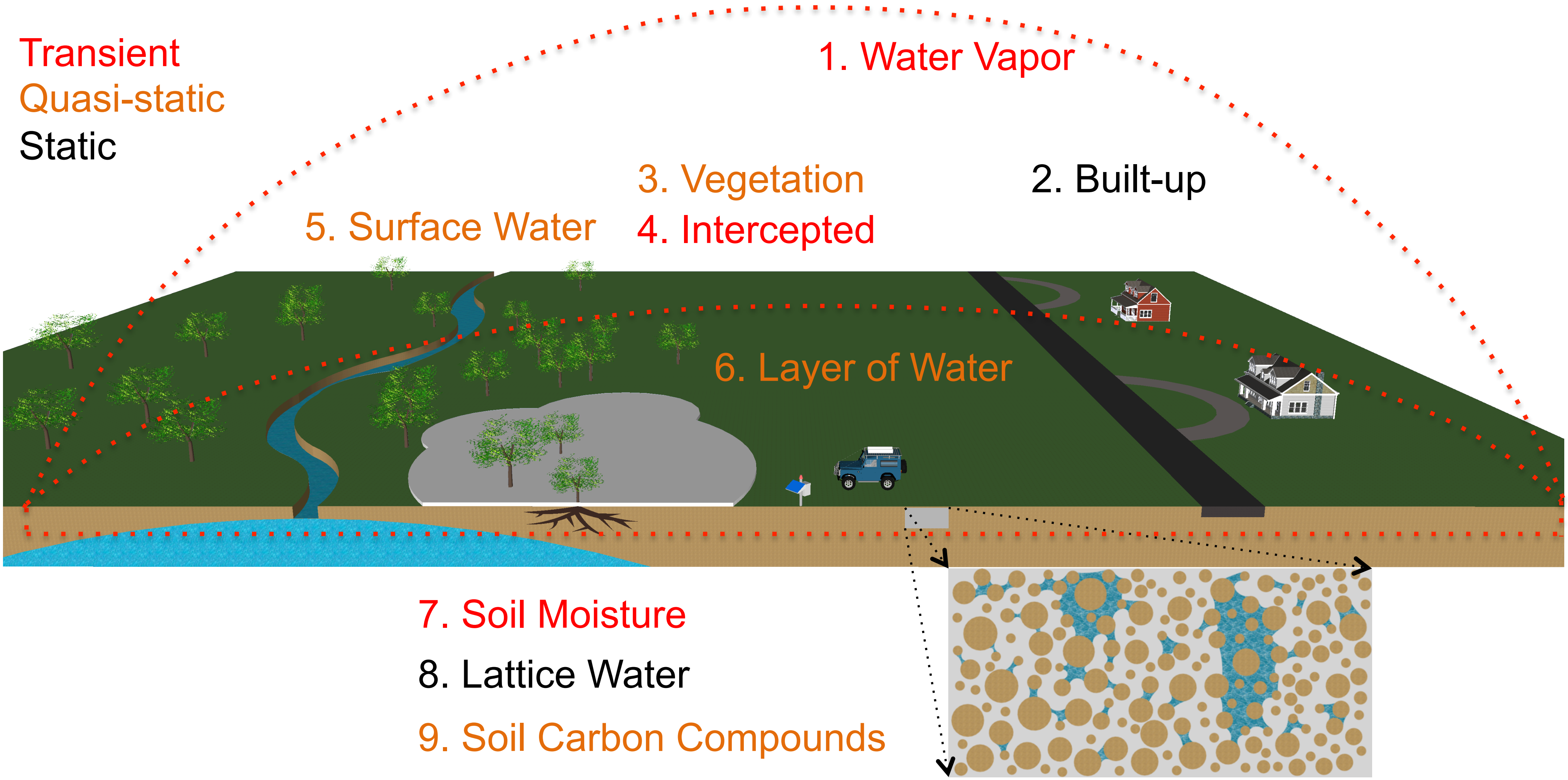
Cosmic-ray Probe in the Field



Marshall Lake, CO, Oct 2009, D. Desilets of Hydroinnova LLC (http://hydroinnova.com/main.html)

The various hydrogen pools

Transient
Quasi-static
Static



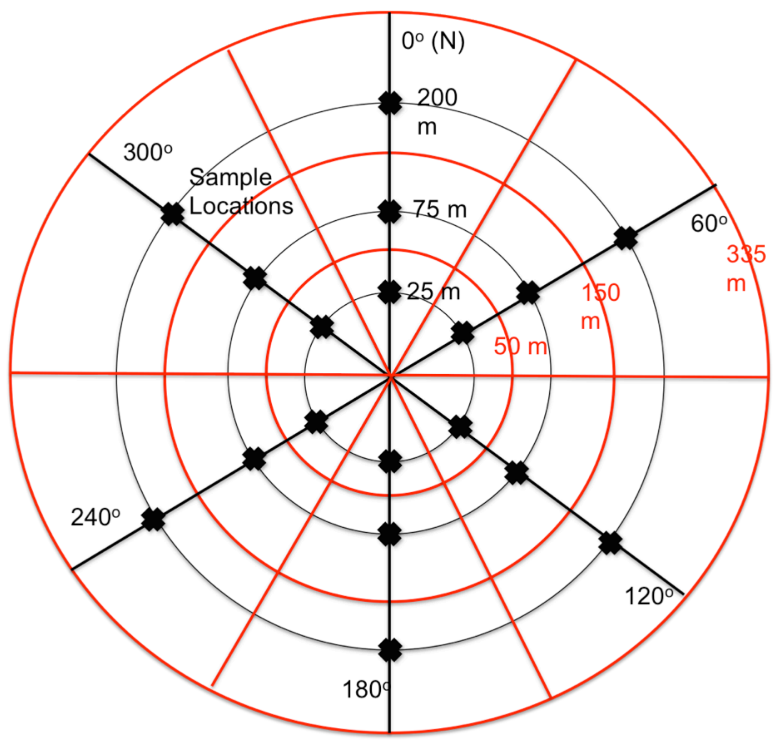
Modified Desilets (2010) Calibration Function

1. Apply pressure, incoming high neutron intensity correction (Zreda et al. 2012), and water vapor correction factors to neutron counts (Rosolem et al. 2013), need local measurements of surface air temperature, pressure, and relative humidity (not currently implemented in COSMOS database!)

$$N = N * CP * CI * CWV \begin{cases} CP = \exp\left(\dfrac{P_i - P_0}{130}\right) \\ CI = \dfrac{N_H^i}{N_H^0} \\ CWV = 1 + 0.0054\left(\rho_v^0 - \rho_v^{ref}\right) \end{cases}$$

2. Where θ are all in units of g/g and $\theta_{SOC_{eq}}$ = (TC-12/44*CO_2)*0.5556

$$\left(\theta_p + \theta_{LW} + \theta_{SOC_{eq}}\right)\rho_{bd} = \frac{0.0808}{\dfrac{N}{N_0} - 0.372} - 0.115$$



Desilets et al. (2010), Bogena et al. (2013)

However, N_0 f(Dry Biomass, Fresh Biomass)

Data from IVS COSMOS site (Irvin 2013, MS Thesis)

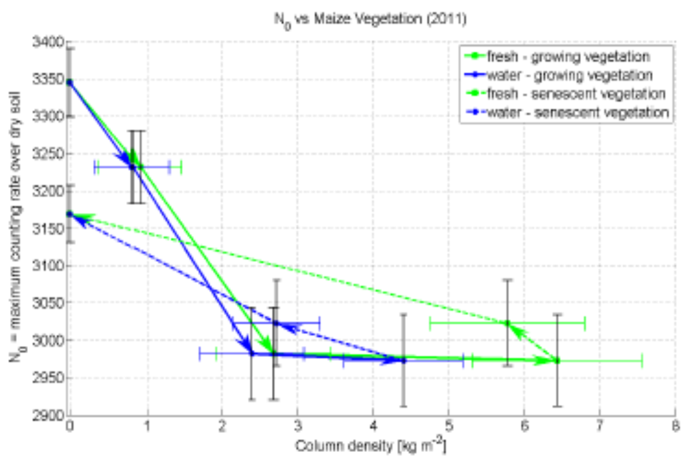
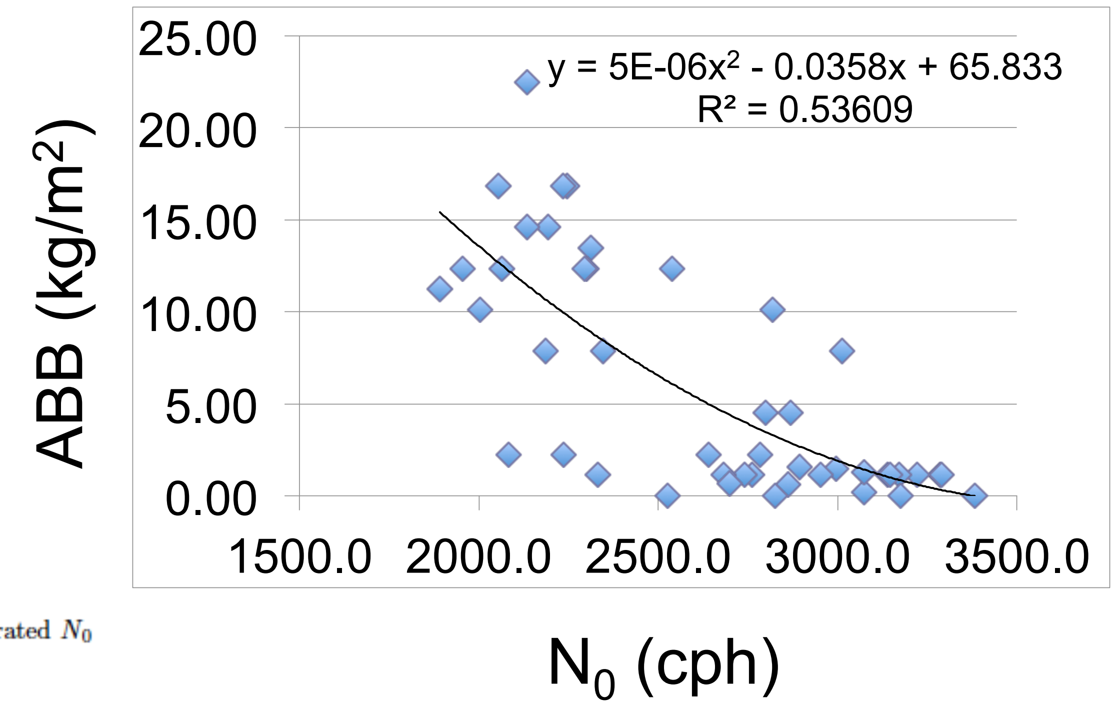


Figure 3.3 Fresh matter and water column densities of maize plants versus recalibrated N_0 values for 2011.

Data from 35 COSMOS sites in continental USA (Franz et al. 2013 HESS)



Local Calibration

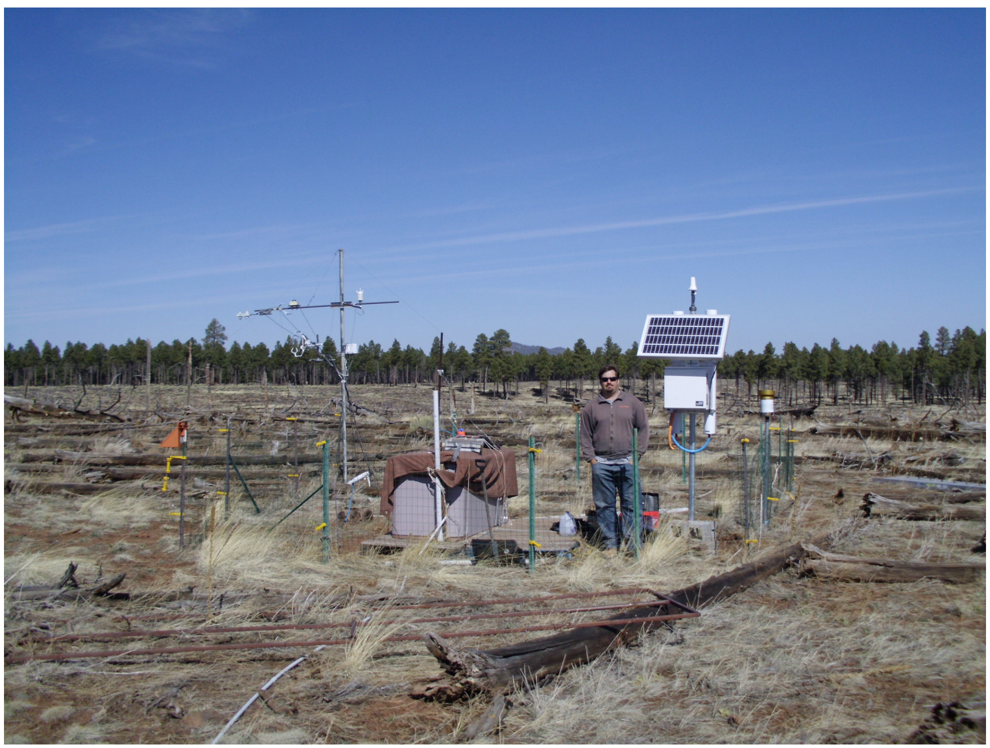
Established methods with local soil sampling (~0.5 day+lab), vegetation sampling (~0.5 day +lab), and chemistry analysis (~1 month)
(see Zreda 2012 HESS, Franz 2013 GRL)



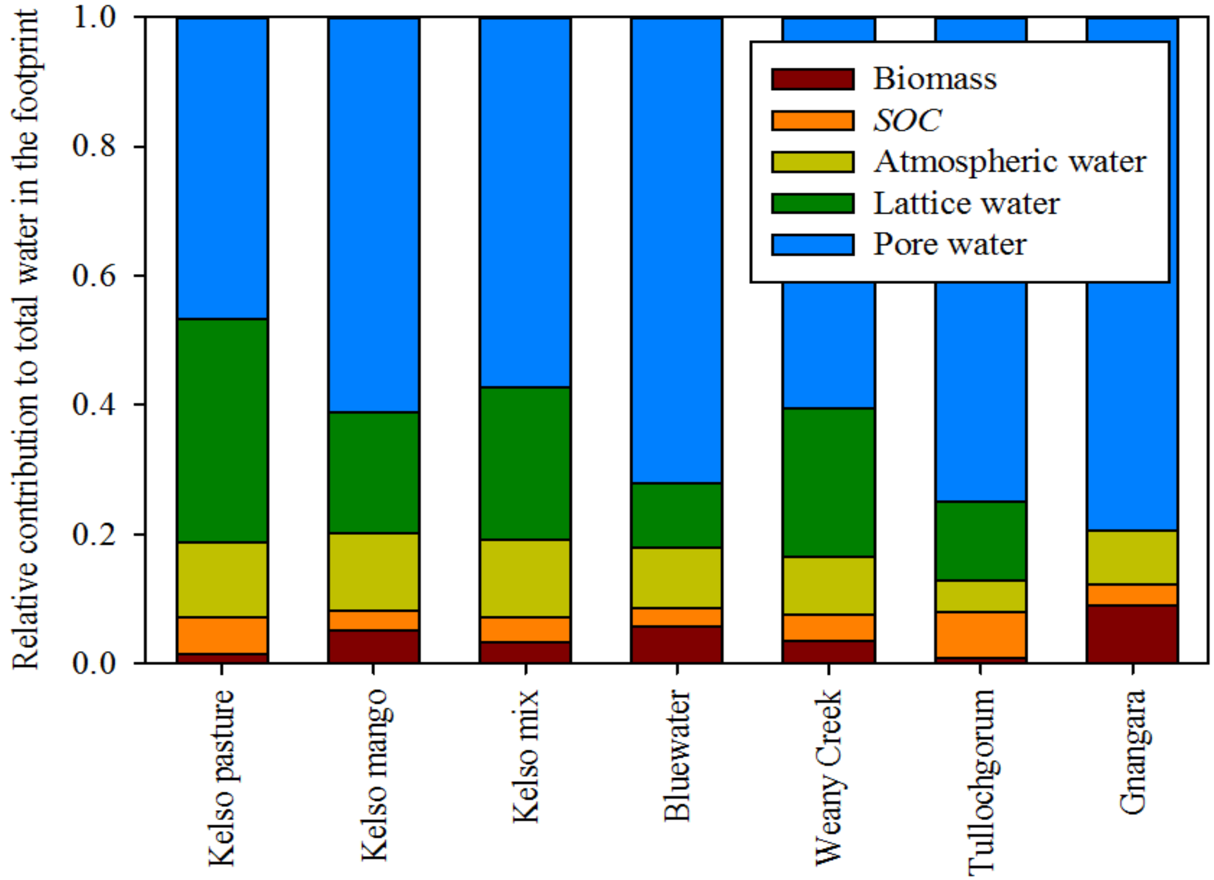

Iowa St. Univ. S. Irvin

Alternative Method

- Need alternative method (UCF Franz 2013 HESS) for sites that are difficult to calibrate (rocky soils, urban areas, hard to access, conflict zones, etc.)
- Or for mobile surveys, especially if they cross significant biomass or landuse gradients



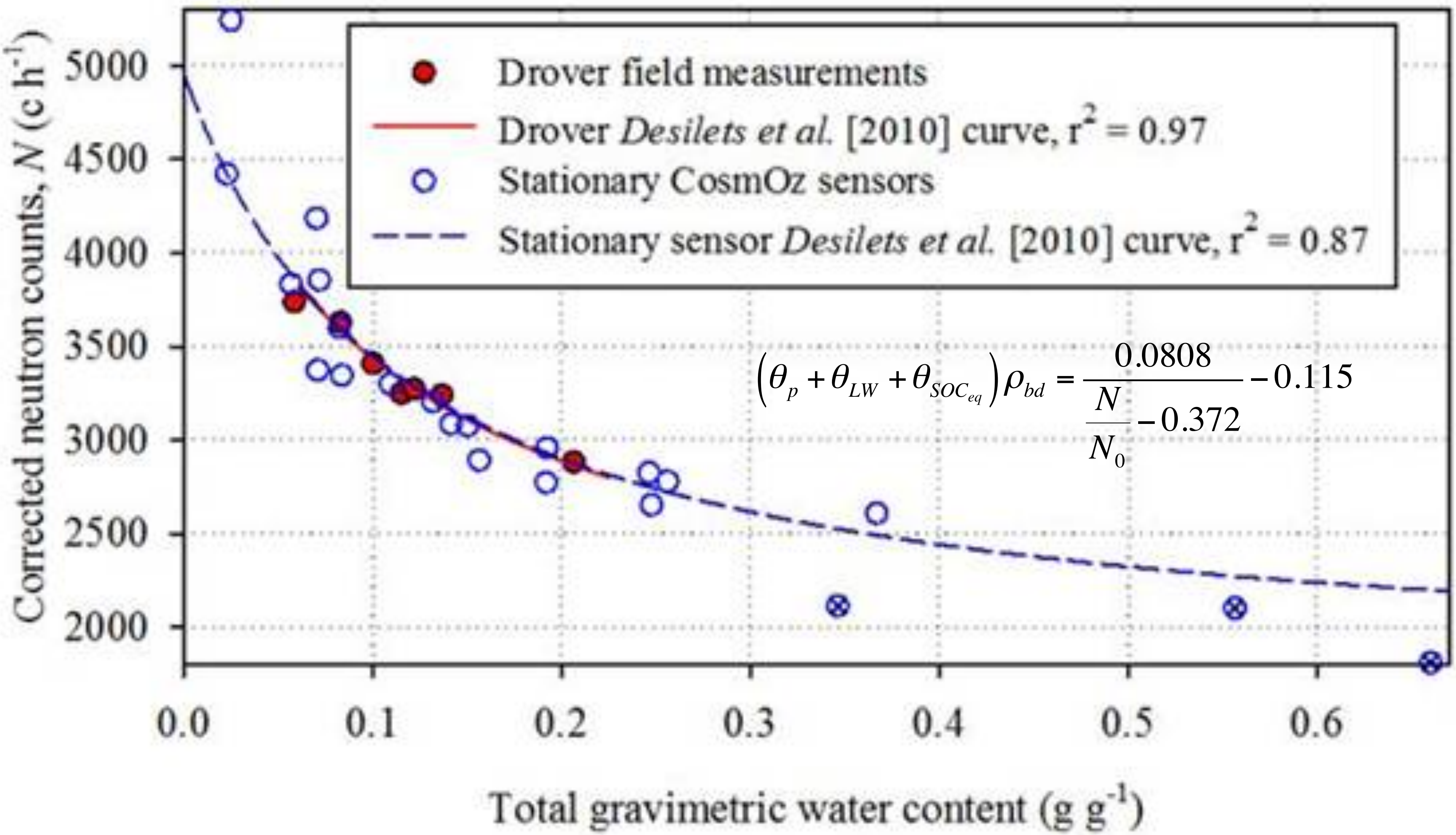
The Drover Experiment Down Under



Paper currently in review at WRR

Validation of A Simple Function

Sample sites with biomass >~20 kg/m² diverge from line



$$\left(\theta_p + \theta_{LW} + \theta_{SOC_{eq}}\right)\rho_{bd} = \frac{0.0808}{\frac{N}{N_0} - 0.372} - 0.115$$

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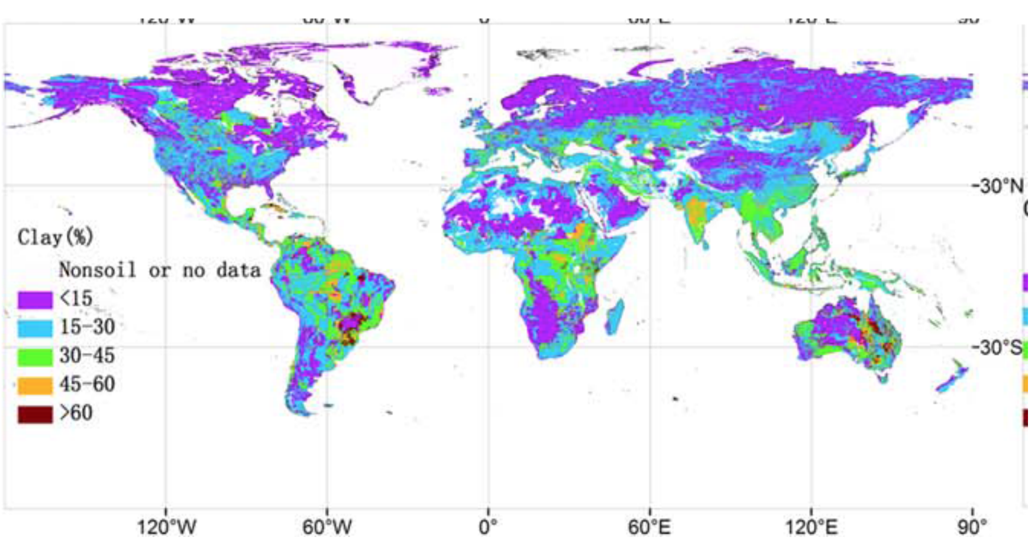
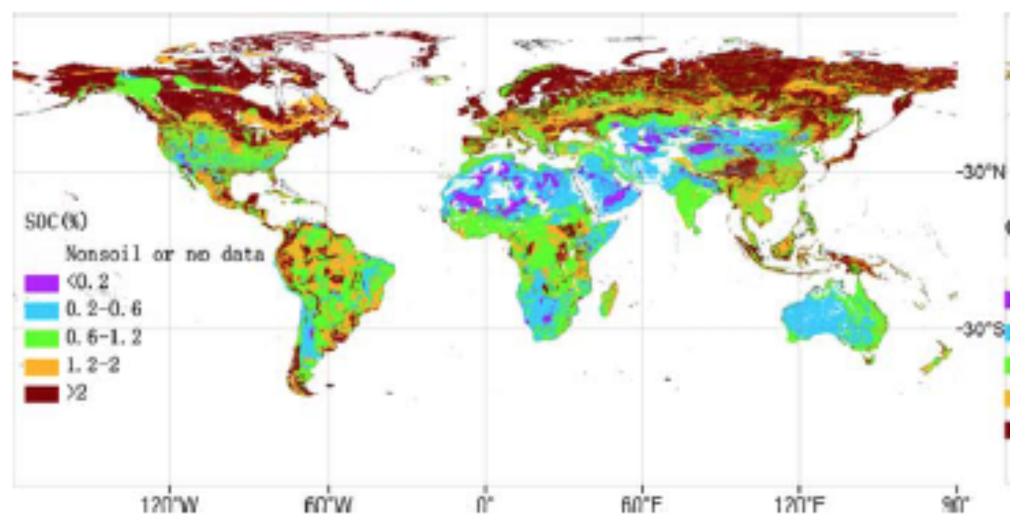
Global Soil Data Products

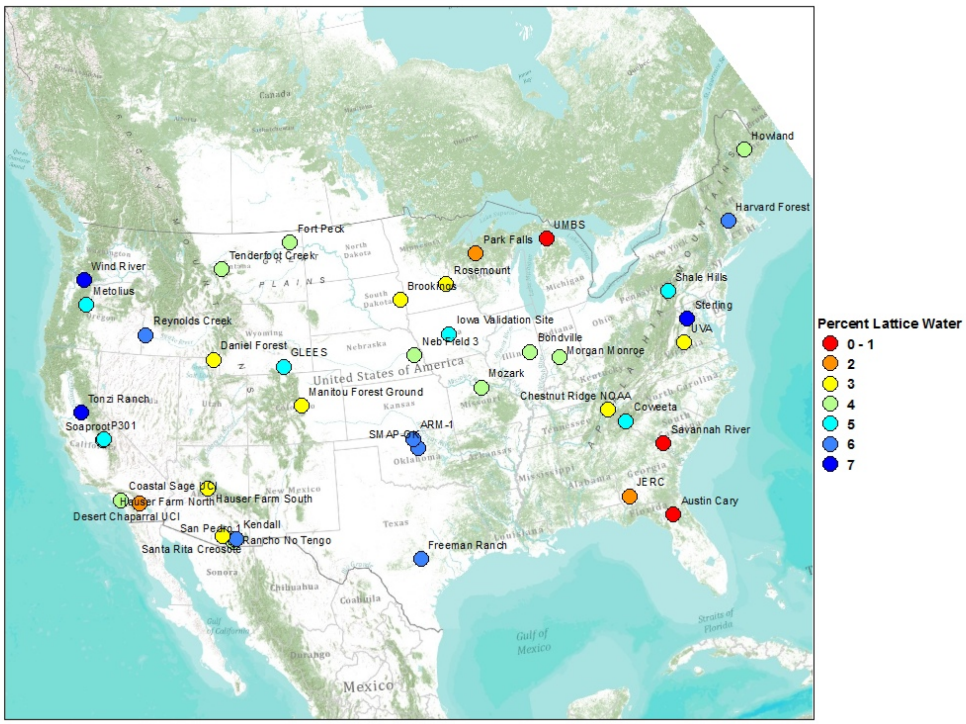
Shangguan et al. (2014) compiled 1 km resolution global dataset of 34 soil variables in 8 layers over the top 2 m including:

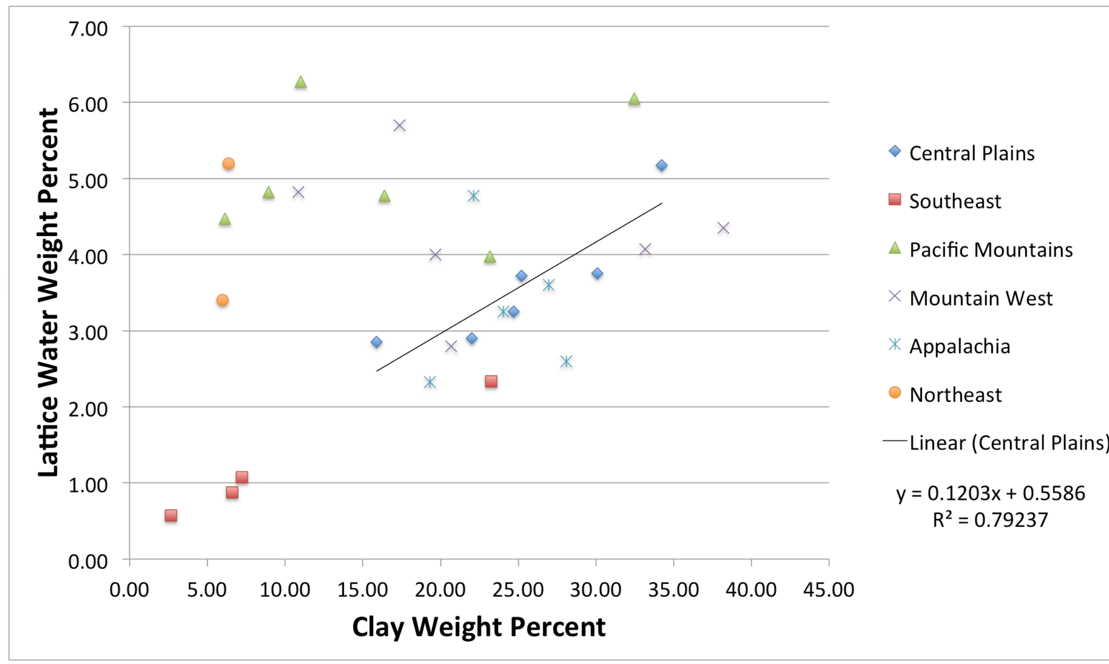
SOC, bulk density, and clay percent





Gracean 1981 notes linear relationship with clay percent in Australia. Some geologic zones follow linear trends others not.

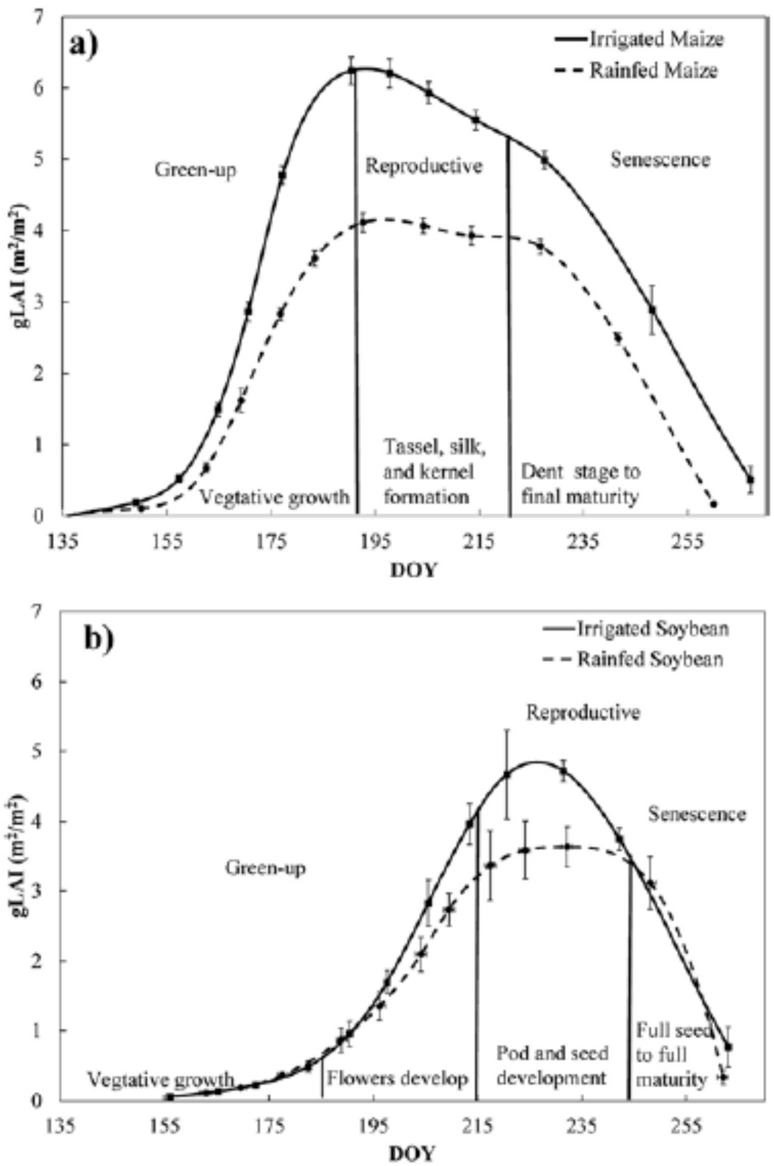


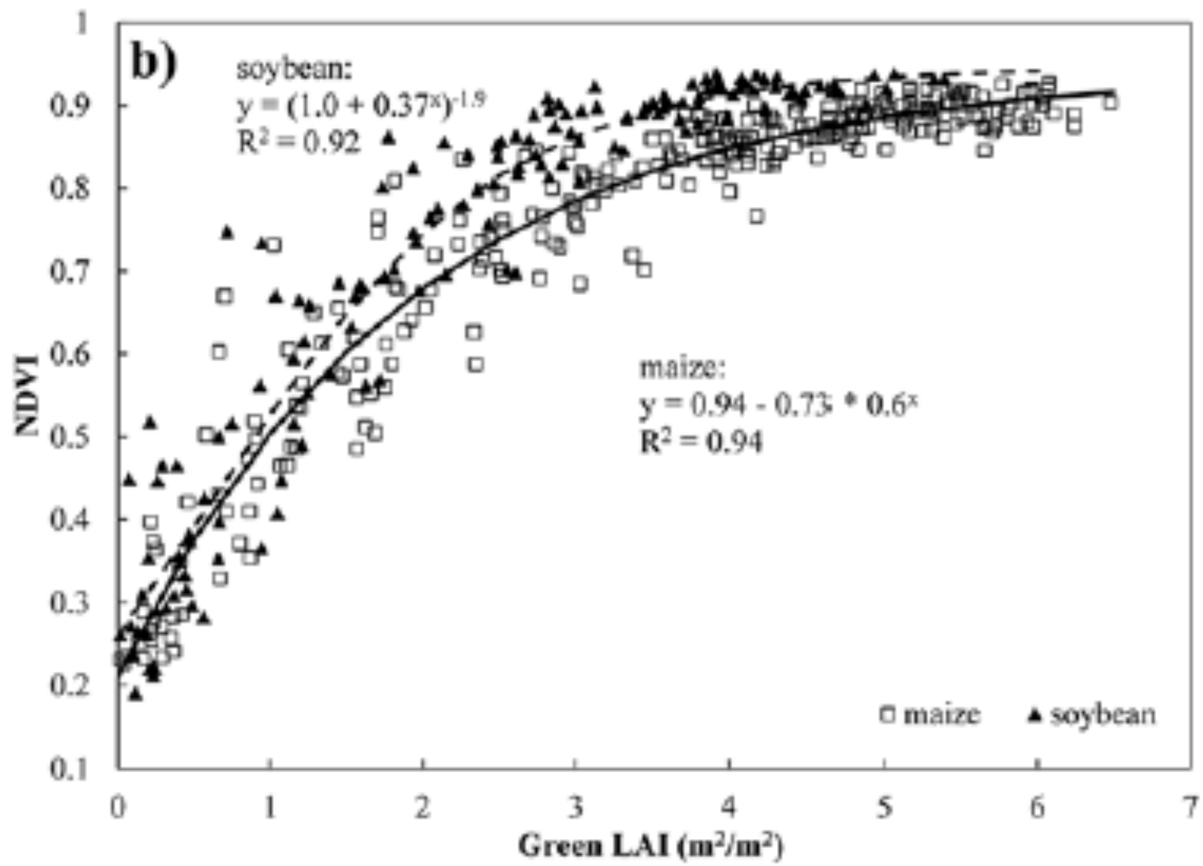


Data compiled from COSMOS project

Non-Woody Biomass

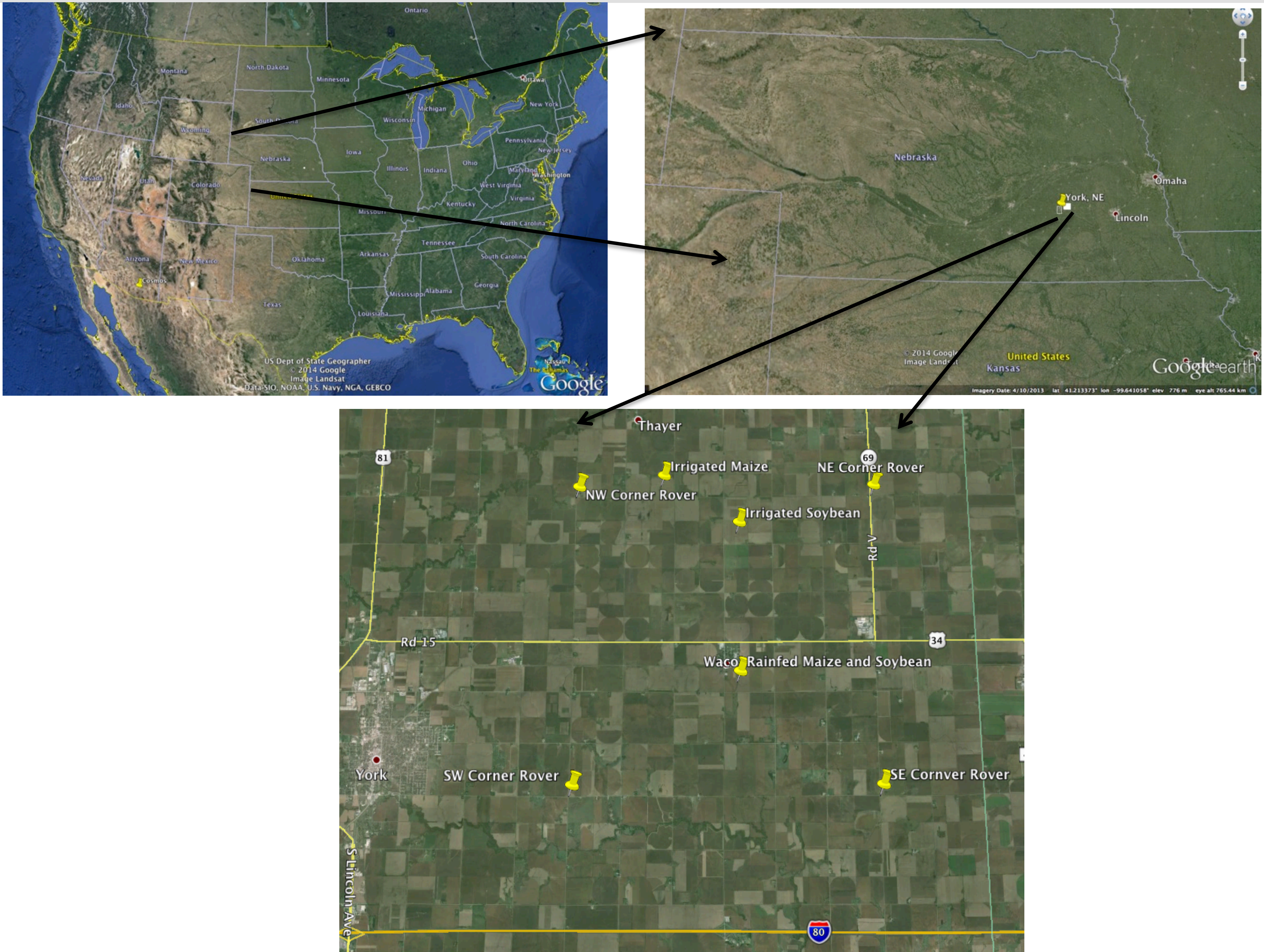
Use Vegetation Indices from a variety of global remote sensing products (MODIS) at various scales



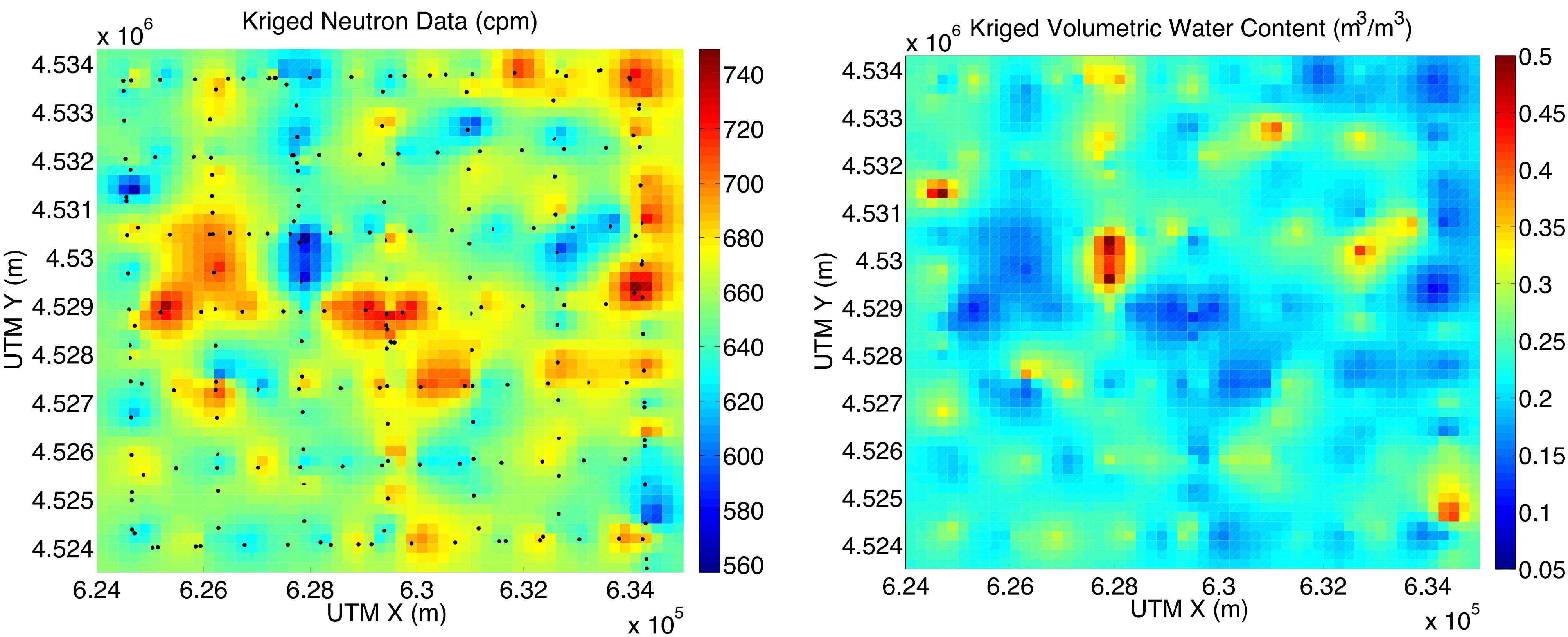


Nguy-Robertson et al. 2012

Study Area: 3.6 mill. irrigated ha in Nebraska



20 May 2014


Kriged Neutron Data (cpm)
x 10^6
4.534
4.533
4.532
4.531
4.53
4.529
4.528
4.527
4.526
4.525
4.524
UTM Y (m)
6.24
6.26
6.28
6.3
6.32
6.34
UTM X (m)
x 10^5
740
720
700
680
660
640
620
600
580
560
Kriged Volumetric Water Content (m^3/m^3)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05

Discussion Questions

Use Shangguan et al. (2014) as baseline data for rover surveys? Need to perform uncertainty and bias analysis of dataset vs. local sampling (COSMOS datasets + other users)?

Use gLAI and MODIS data to estimate dry and fresh biomass for non-woody biomass?

Community establishment of lattice water layer, function of percent clay and parent material (need repository of additional chemistry samples, currently ~40 from COSMOS stations USA, ~12 from Australia, Germany, UK to come)

Need for rover processing algorithm and spatial interpolation. Right now using Kriging but perhaps should use co-Kriging or other method? Need correction for roads, small differences between paved and gravel roads.

Questions?