Measuring large scale soil moisture using cosmic-ray neutrons

Potential synergies between the CosmOz network and OzFlux

David McJannet & Aaron Hawdon

OzFlux Workshop, July 2013

Exploding stars and cosmic rays

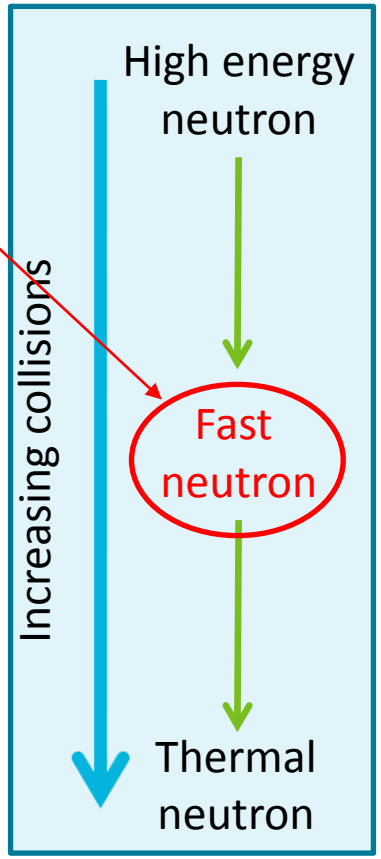
- Cosmic rays are produced by the blast waves from exploding stars (super nova)
- Pieces of atoms are accelerated and energised as they bounce around in the expanding cloud of gas
- Eventually they reach a high enough speed to break away and escape to the galaxy as cosmic rays
- Travelling at close to the speed of light some of these cosmic rays eventually reach the earths atmosphere

Cosmic rays and the earth's atmosphere

- Cosmic rays collide with atmospheric nuclei and initiate a cascade of secondary cosmic rays (spallation)
- Each collision reduces cosmic ray energy
  - High energy neutrons → fast neutrons → thermal neutrons
- Hydrogen is the most effective element in reducing cosmic-ray neutron energy
- Most variable form of hydrogen is usually soil moisture stores

The cosmic-ray probe

- The cosmic-ray probe is a device that measures fast neutrons above the soil surface
- Measurements above the surface represent those in soil as neutrons travel between air and soil very rapidly (10's – 1000's km/s)
- The more hydrogen there is in the soil the less fast neutrons will be measured (inverse relationship)



The cosmic-ray probe

Total cost: ~$18000

Satellite link
~$500 pa

Rain gauge

Solar panel

Pressure, temperature, humidity sensors

Data logger

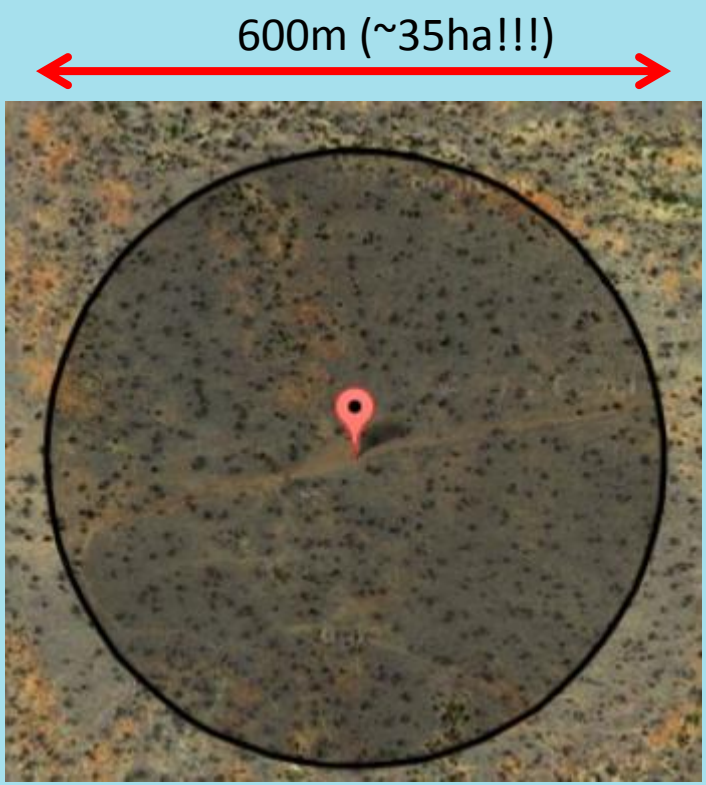
Small concrete pad

Neutron tube

Neutron collision causes electron cascade

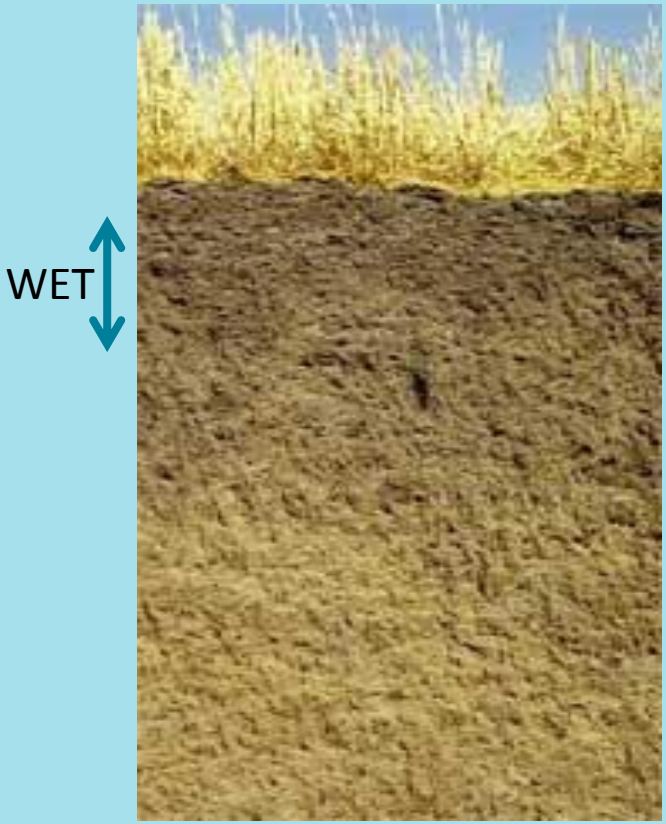
The cosmic-ray probe measurement footprint

HORIZONTAL



Not sensitive to soil moisture content

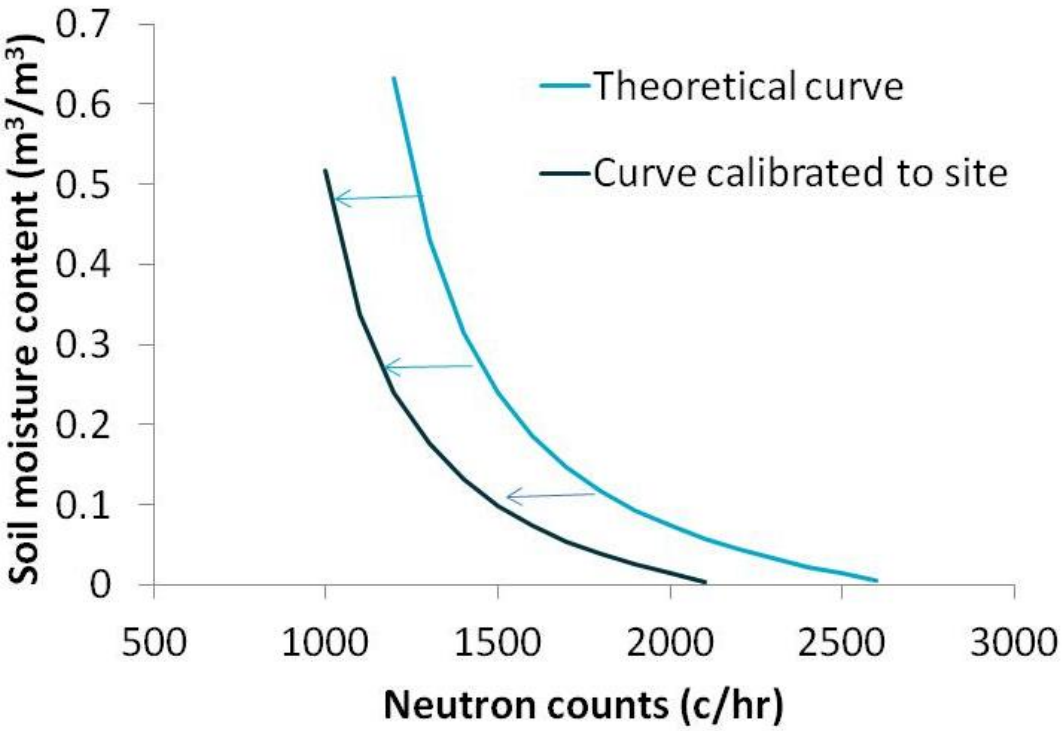
VERTICAL

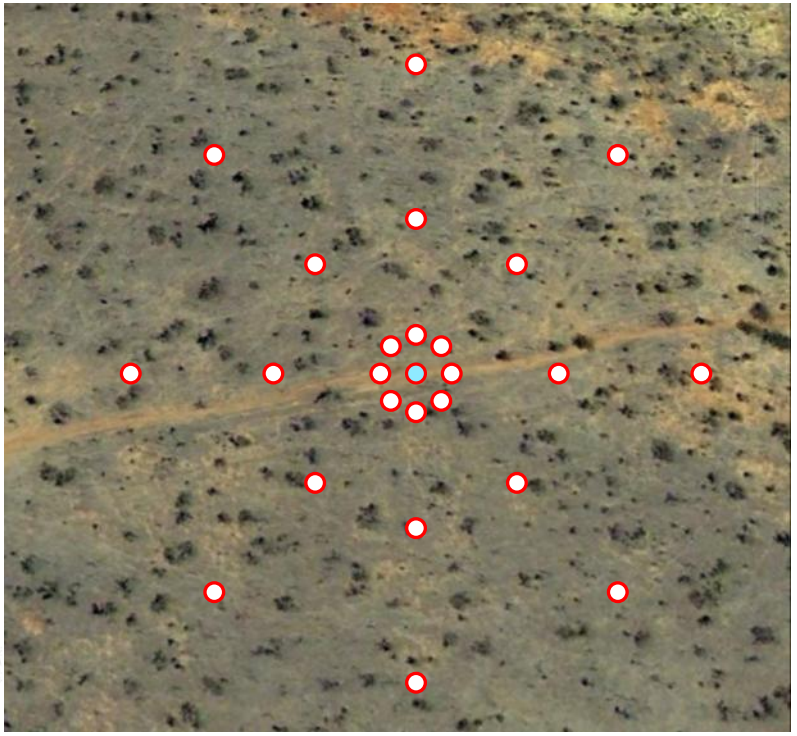


Measurement depth ~10 cm in wet soil, ~70 cm in dry soil

Calibration of the cosmic-ray probe

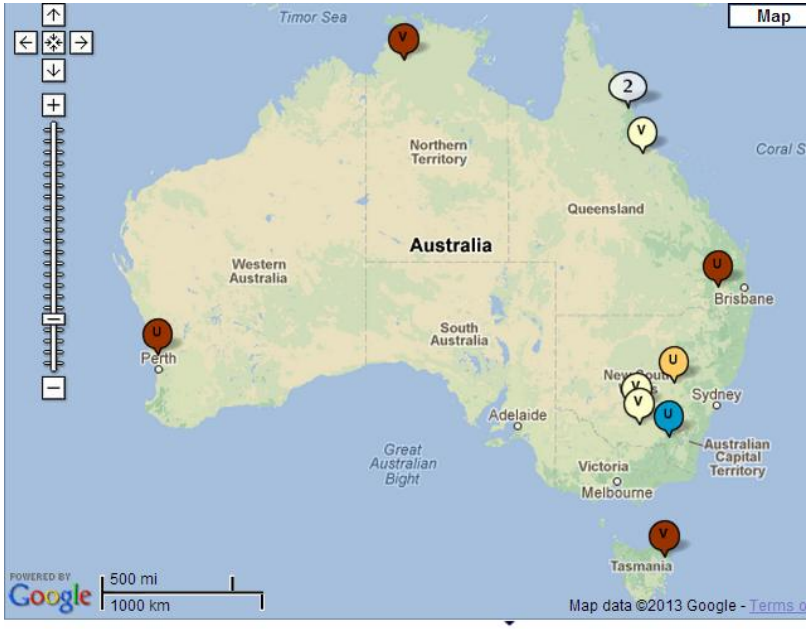
- A universal calibration function has been developed which is shifted to match site data

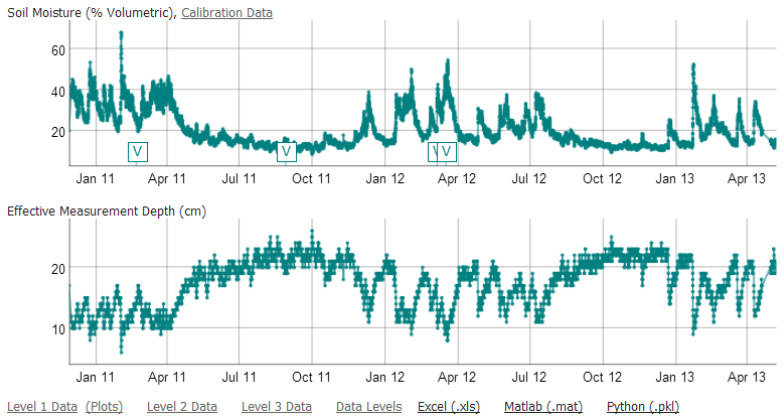




The CosmOz network

- 2010 CLW funded 11 probes
- Developed collaborative network with 4 CSIRO divisions and 5 Universities
- Co-located with other measurements e.g. flux towers (4), water balance, CalVal, crop growth
- Looking for more members/uptake





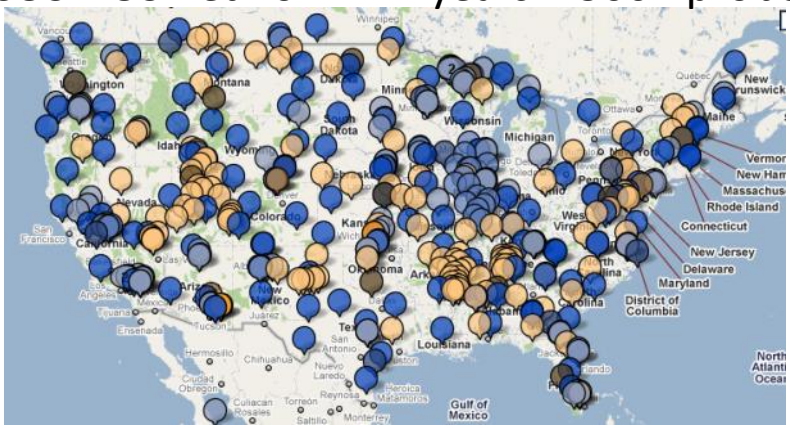
The COSMOS network : USA

- COSMOS run out of University of Arizona
- Nearly all with AmeriFlux sites!

- Other networks:
  - Germany - 70 Probes
  - Smaller networks of instruments in UK, France, Switzerland, Brazil and Kenya

Existing COSMOS network – 60 probes

COSMOS network in 2 years – 500+ probes



What can OzFlux offer CosmOz?

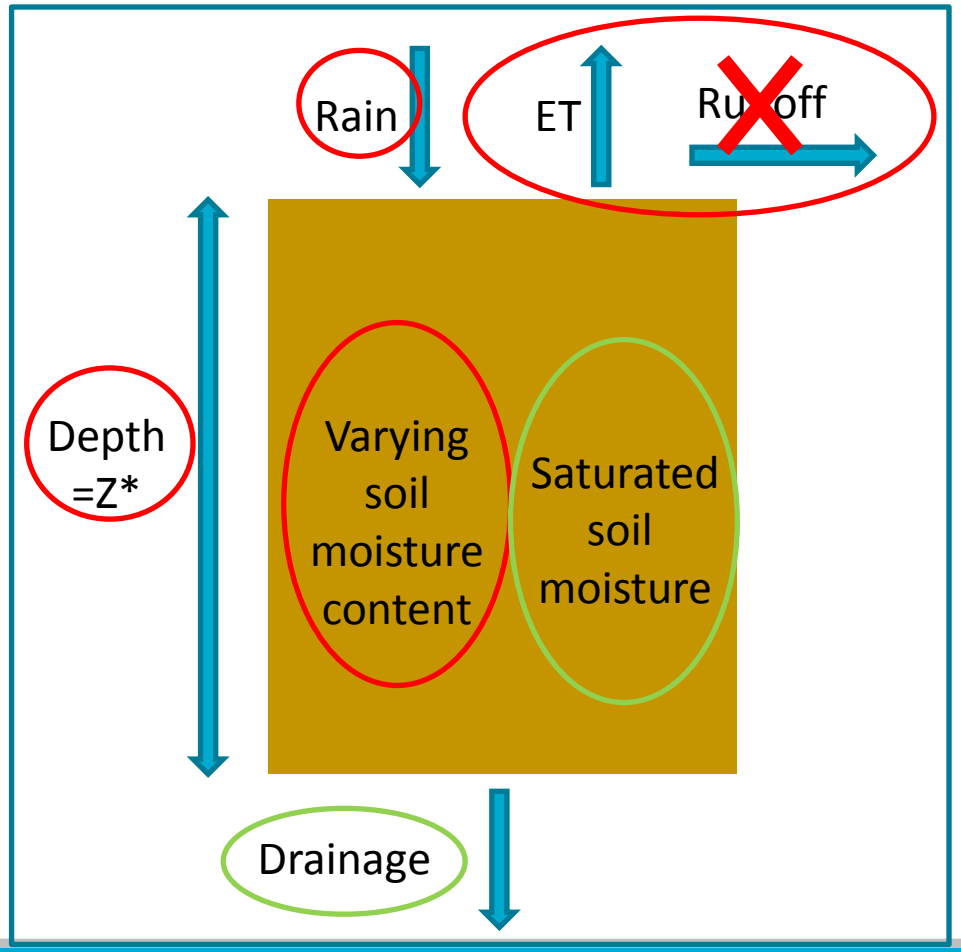
Complementary measurements to explain process!!!

- Soil moisture data on its own is pretty dull
- Combining with other process measurements (ET & CO2 fluxes, crop growth, satellite data) brings out the true value

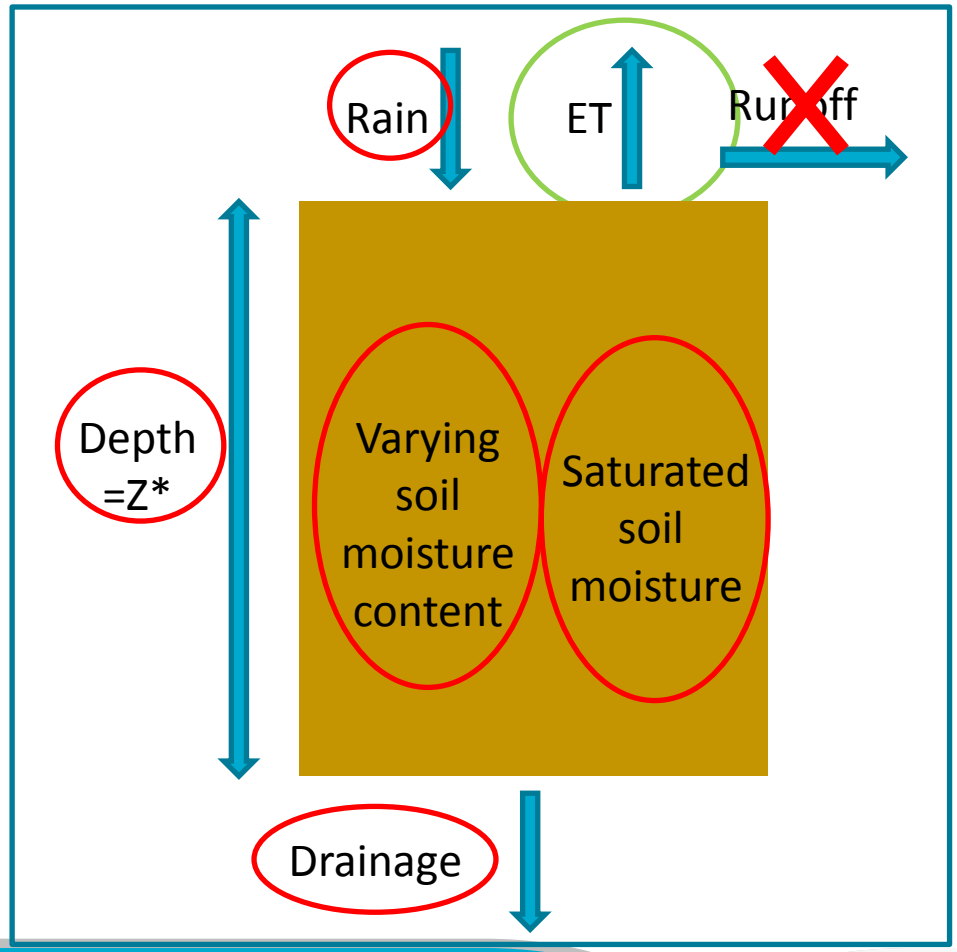
What can OzFlux offer CosmOz?

Complementary measurements

EXAMPLE 1

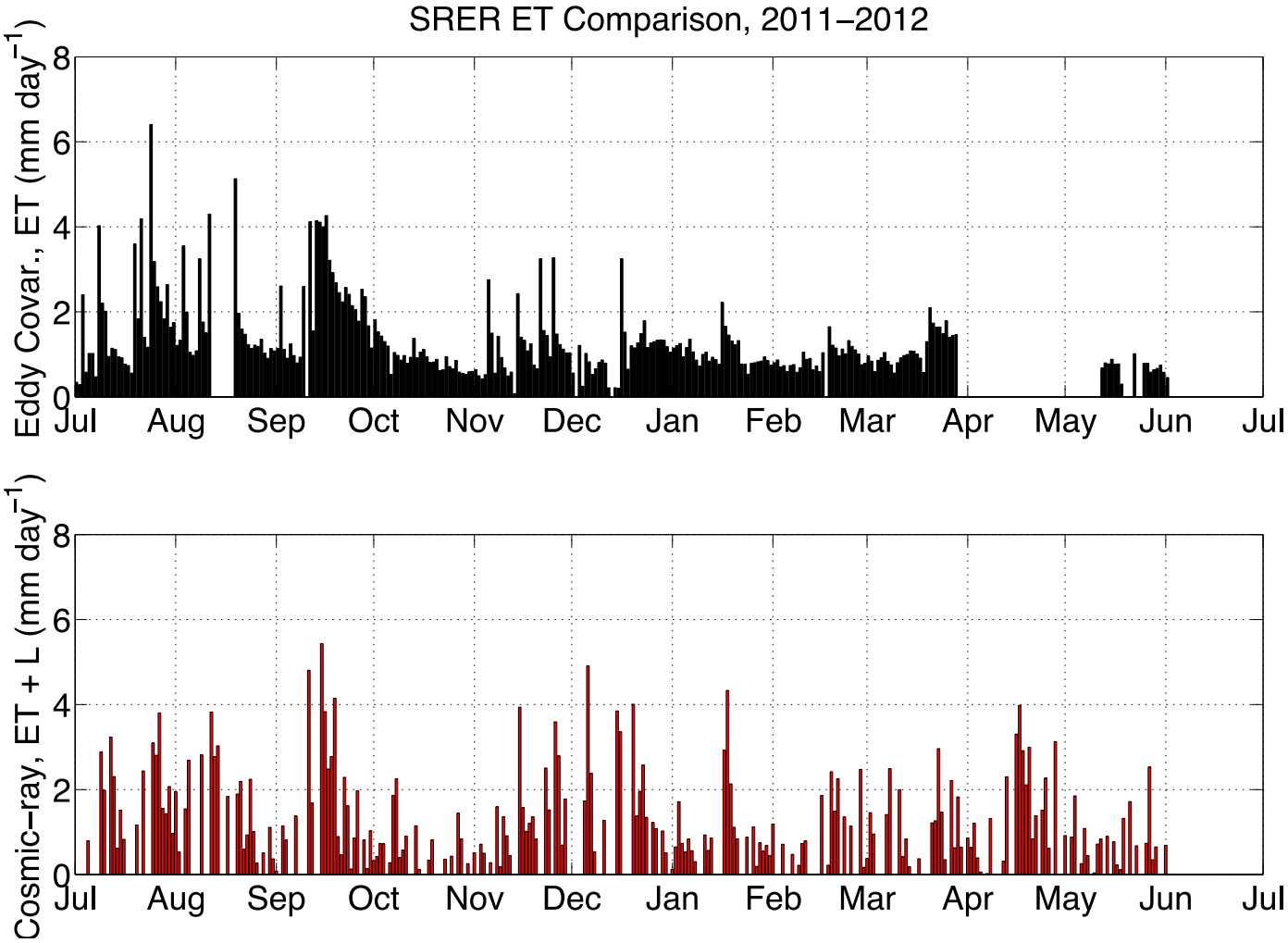


EXAMPLE 2



What can OzFlux offer CosmOz?

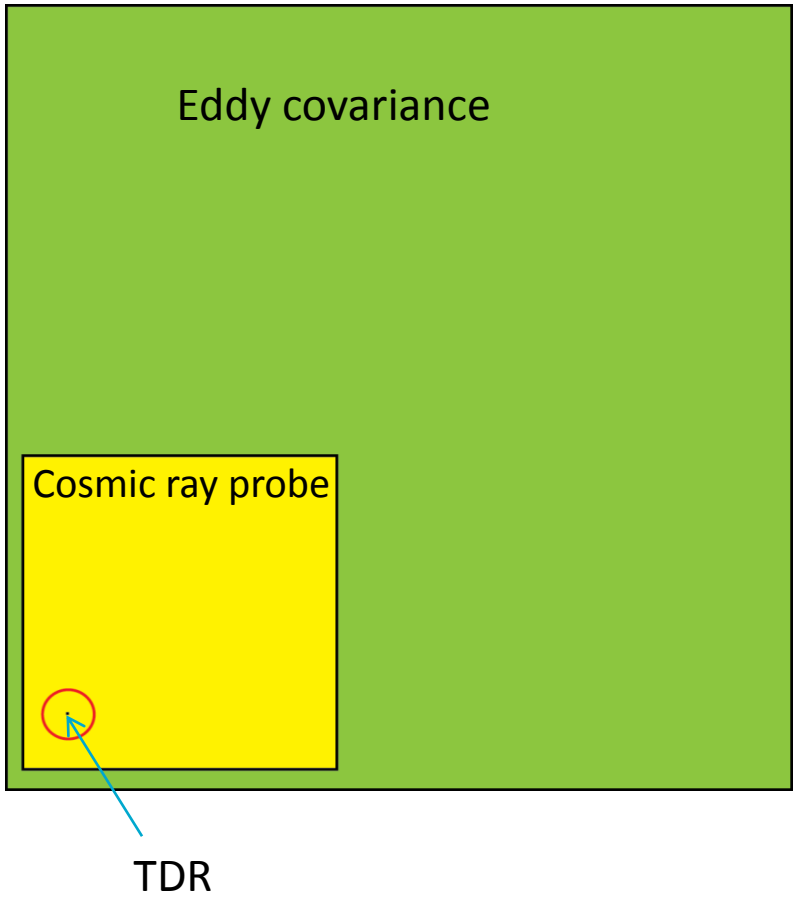
Fluxes from cosmic-ray probe – early results



What can CosmOz offer OzFlux?

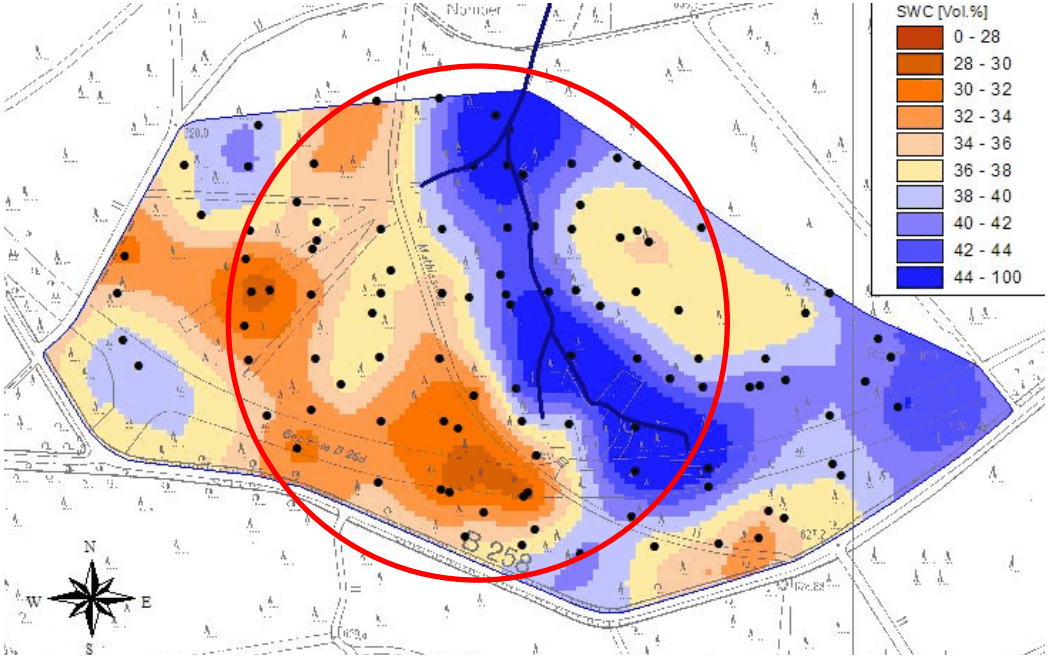
Soil moisture at a meaningful scale

- Spatially commensurate with eddy covariance method
- Most variation in soil moisture is at the small scale
- Cosmic-ray probe operates at scales above this



What can CosmOz offer OzFlux?

Soil moisture at a meaningful scale



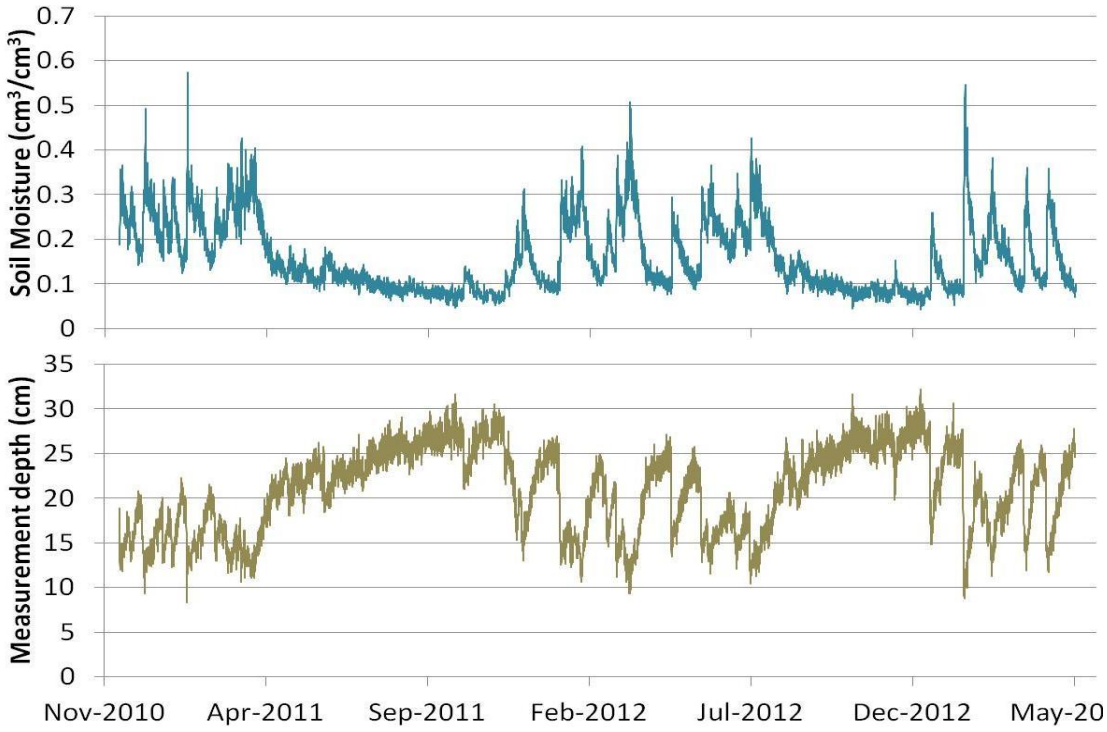
Bogena et al. (2010)

Most of the variability is at small scale

What can CosmOz offer OzFlux?

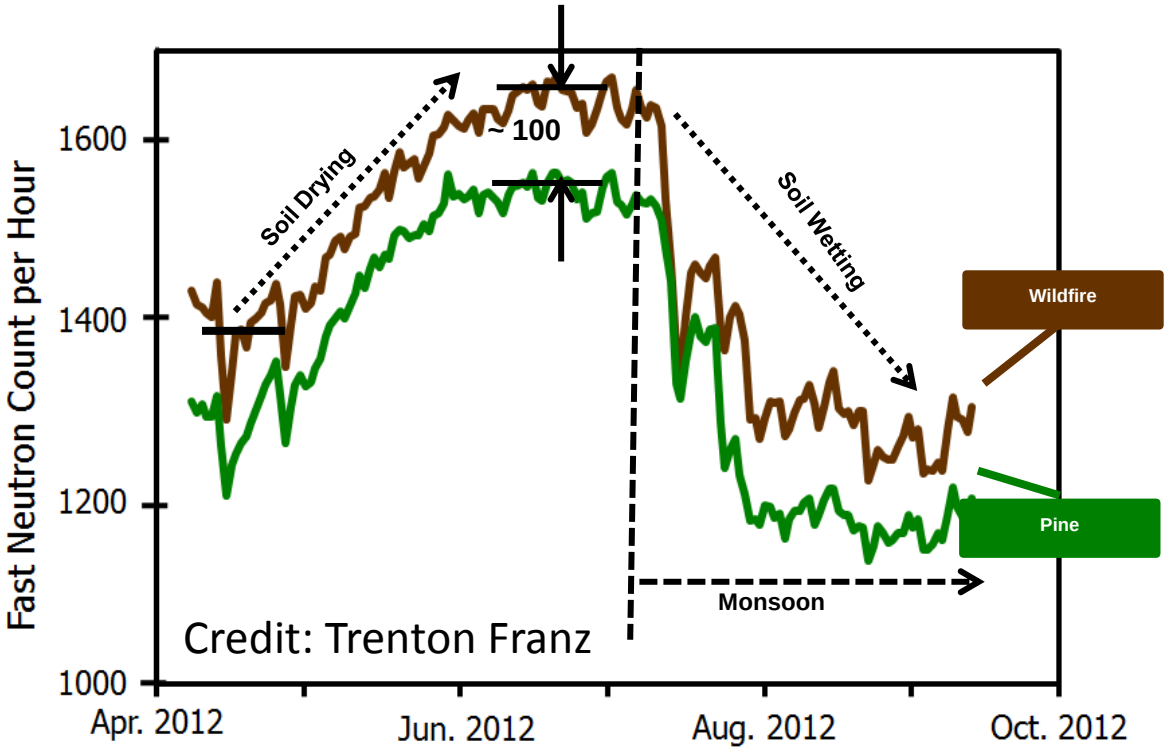
High quality, low maintenance soil moisture

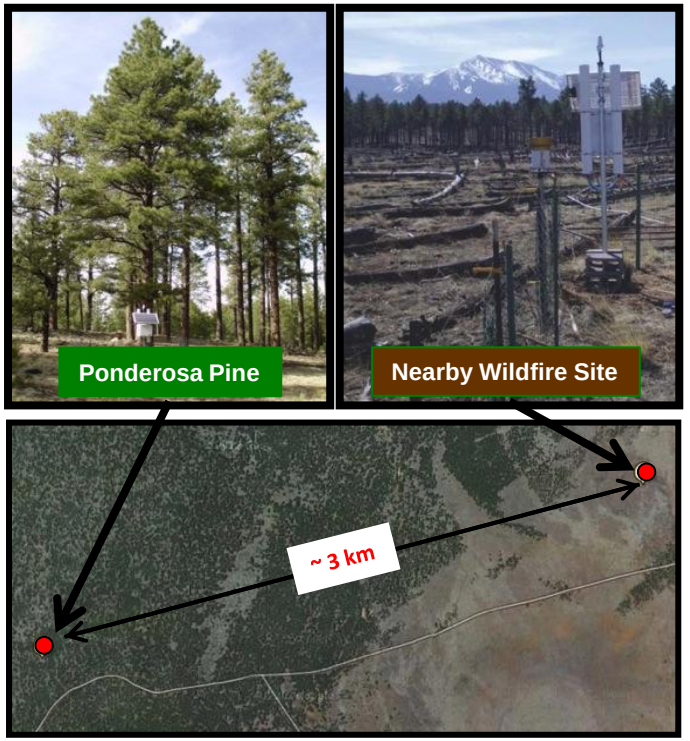
- 90%+ high quality data from CosmOz network
- Site visits 1-2/year
- Not a big investment of resources for good return



What can CosmOz offer OzFlux?

Biomass estimates (?)



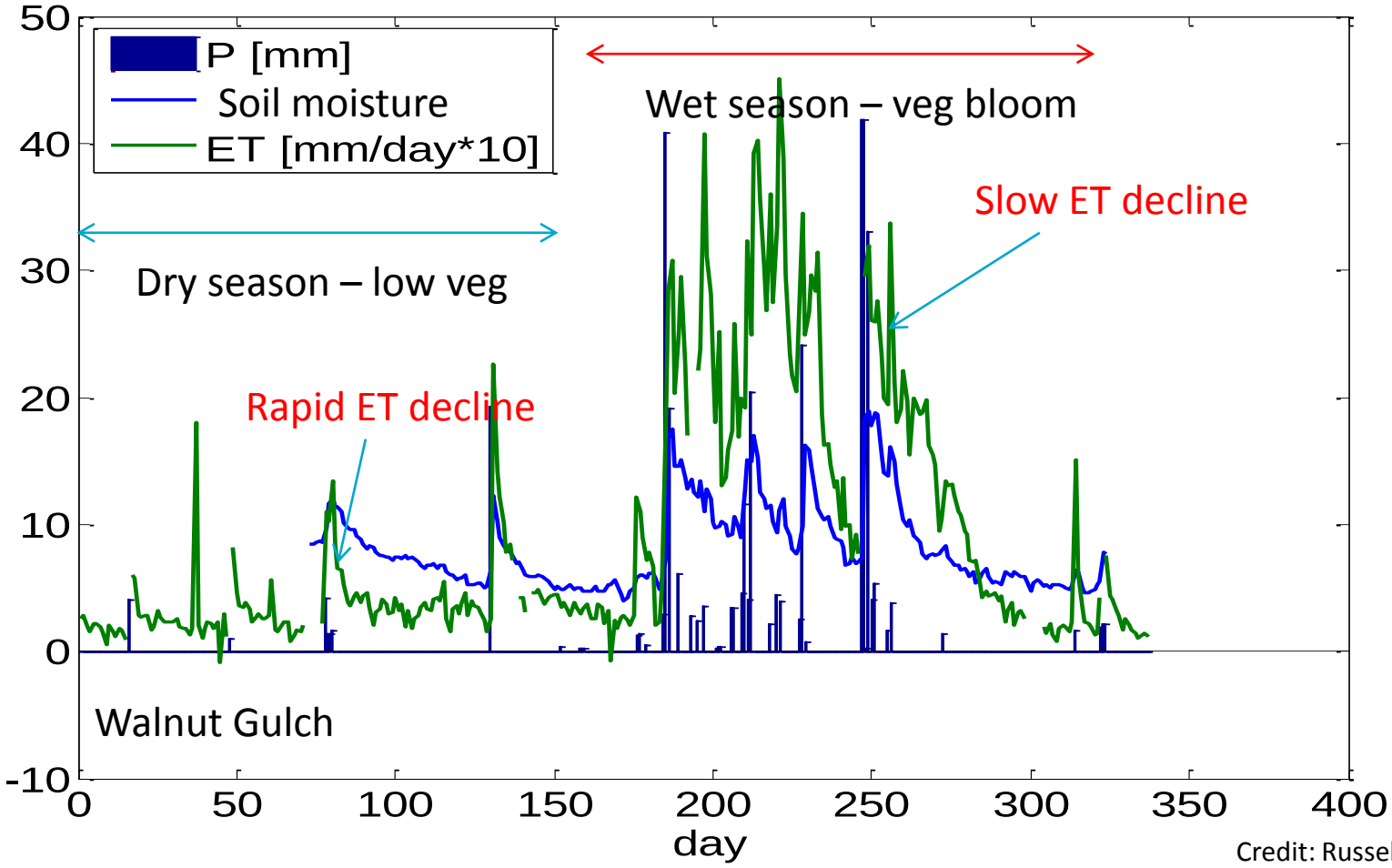


H. Adams Los Alamos, T. Kolb NAU

- count difference is due to canopy biomass water (27.6 $\pm$ 0.8 mm)
- allometric estimates give biomass water in the range 22-32 mm

What can CosmOz offer OzFlux?

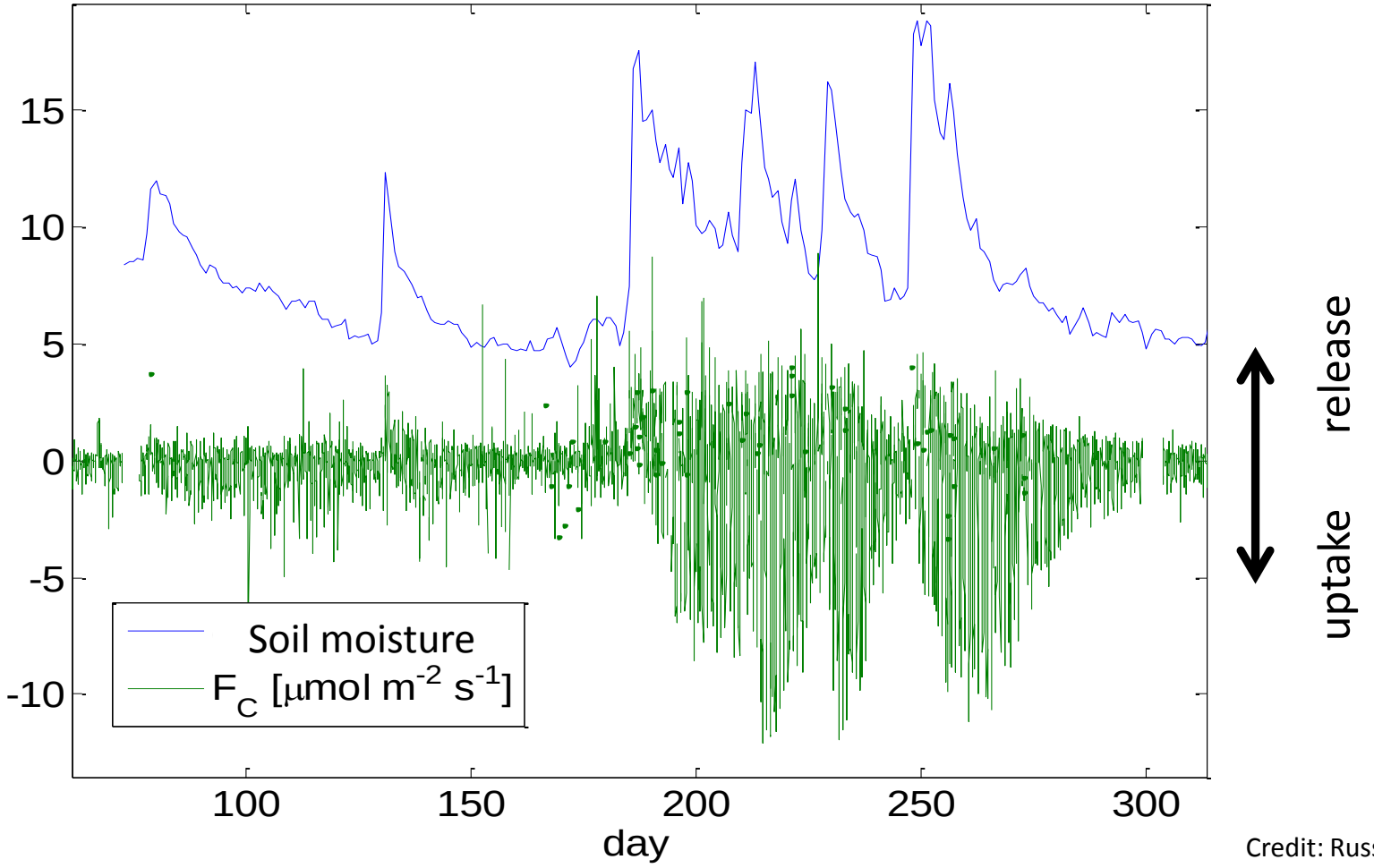
Links between ecosystem processes and soil moisture



Credit: Russell Scott, USDA

What can CosmOz offer OzFlux?

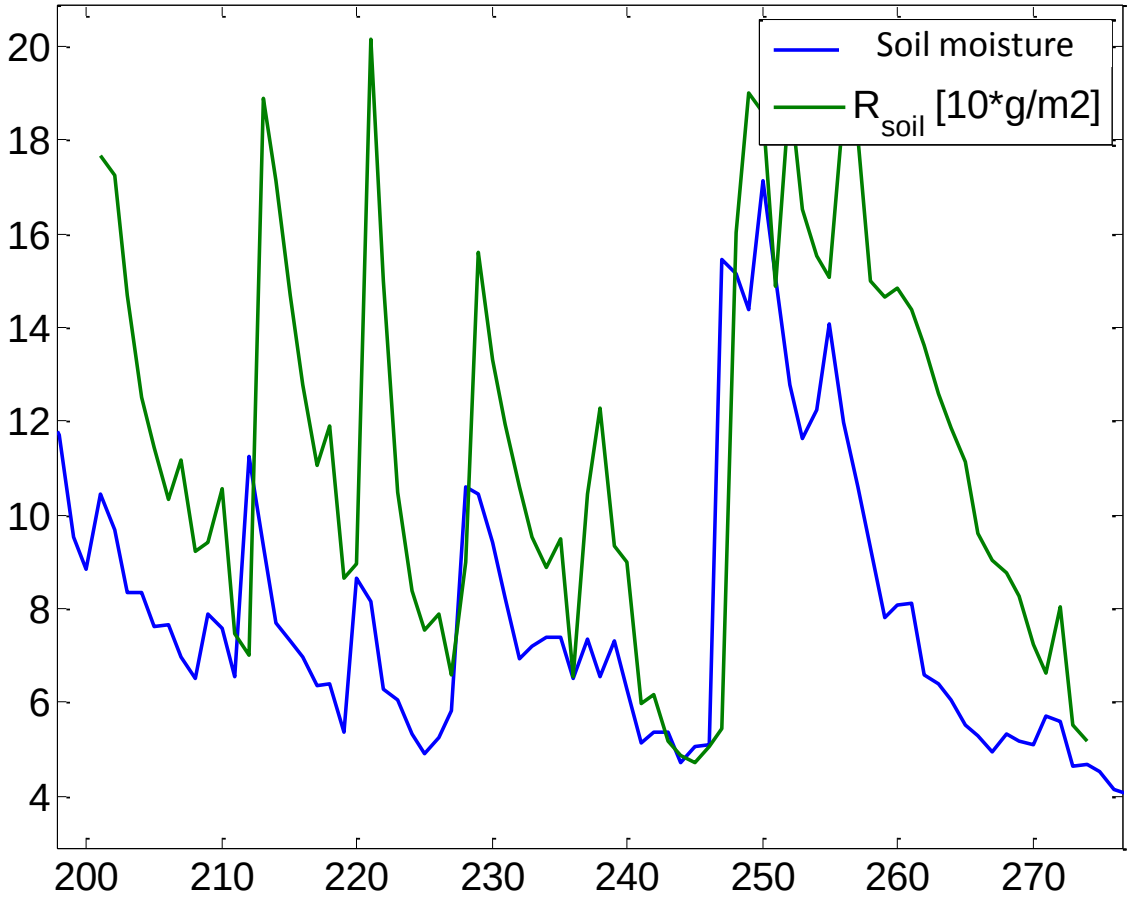
Links between ecosystem carbon fluxes and soil moisture



Credit: Russell Scott, USDA

What can CosmOz offer OzFlux?

Links between soil respiration and soil moisture



Credit: Russell Scott, USDA

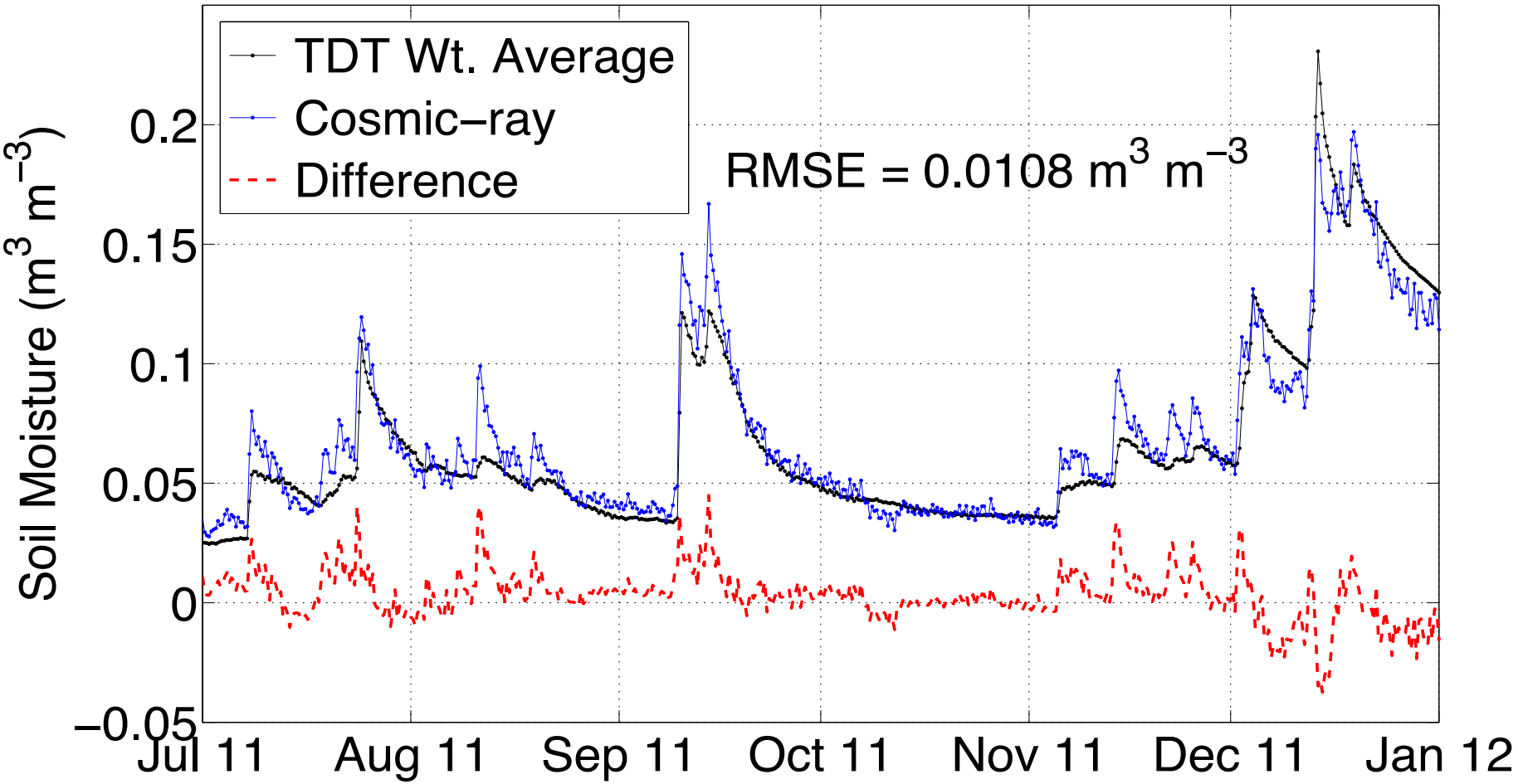
Advantages of the cosmic-ray method

- Continuous measurements
- Established calibration & correction approaches
- Similar measurement scale to fluxes
- Easy above-ground installation
- Low power consumption and maintenance
- Excellent data sets

CosmOz – community of practice

- People involved because they want to be
- Standardised analysis approaches
- Data portal
- Exchange of ideas

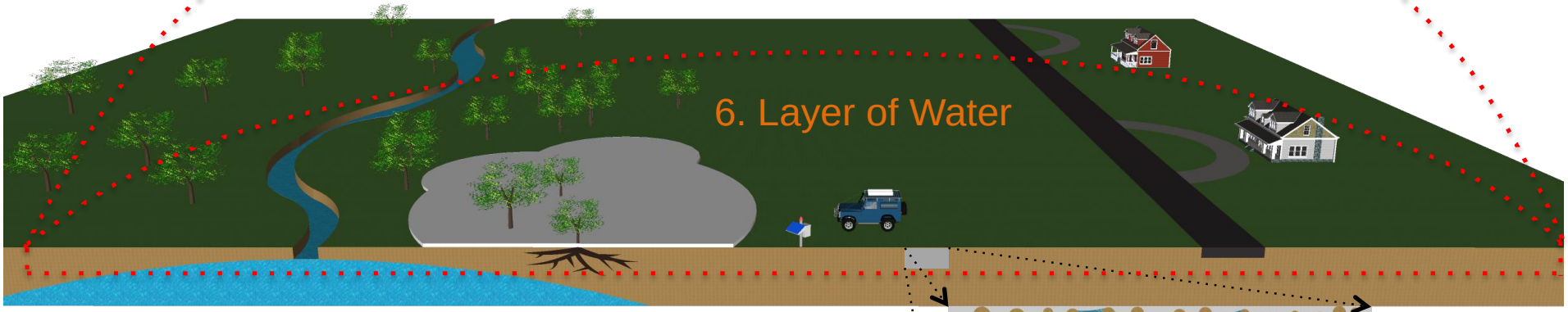
Email David.McJannet@csiro.au

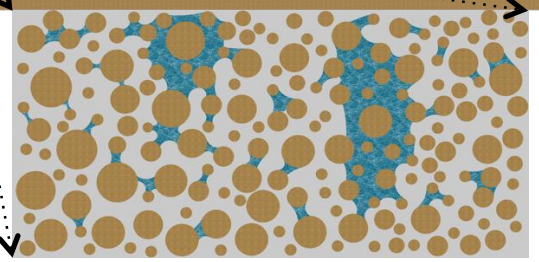


Franz et al., 2012b

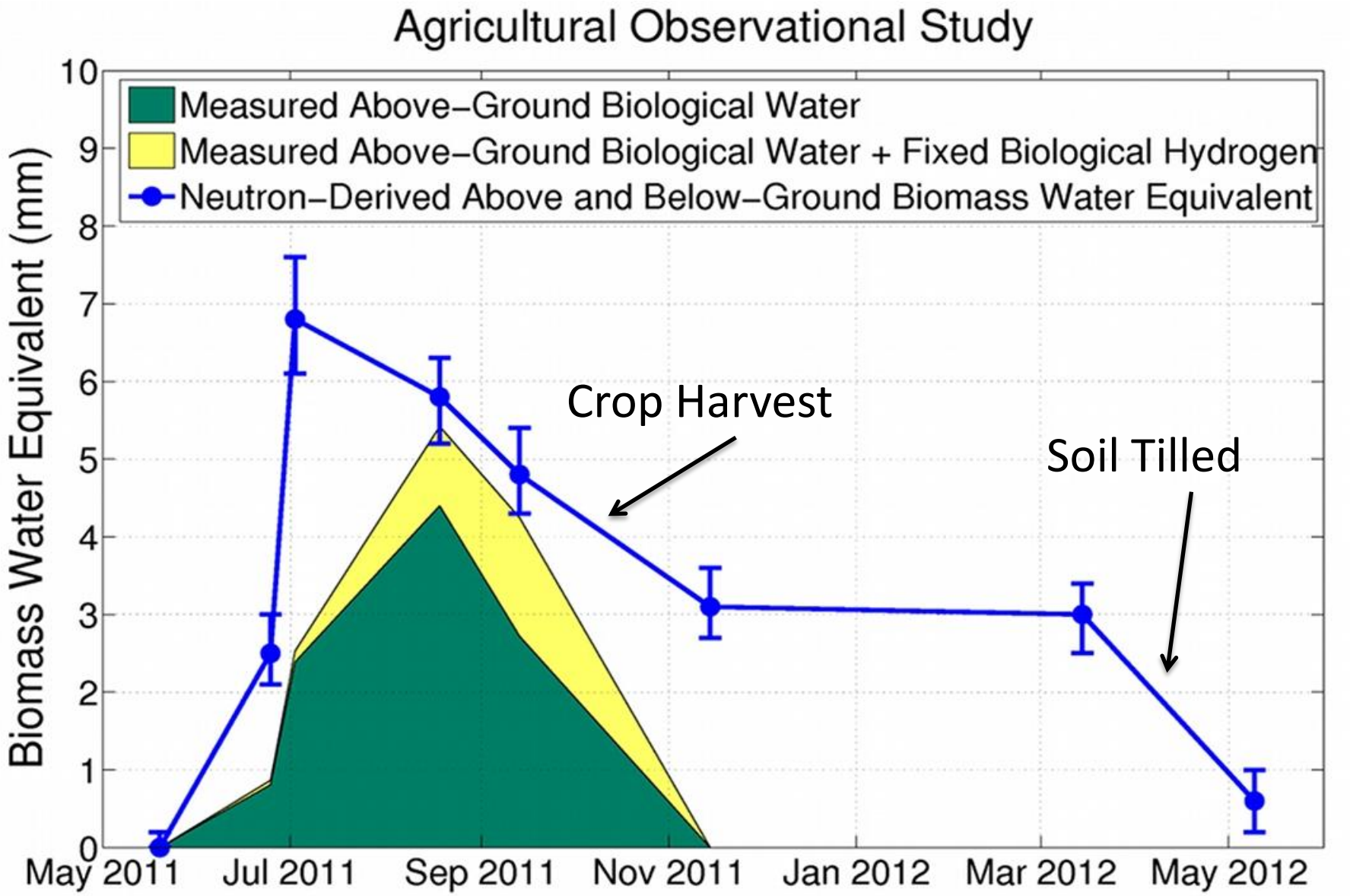
Transient
Quasi-static
Static

1. Water Vapor
2. Built-up
3. Vegetation
4. Intercepted
5. Surface Water
6. Layer of Water





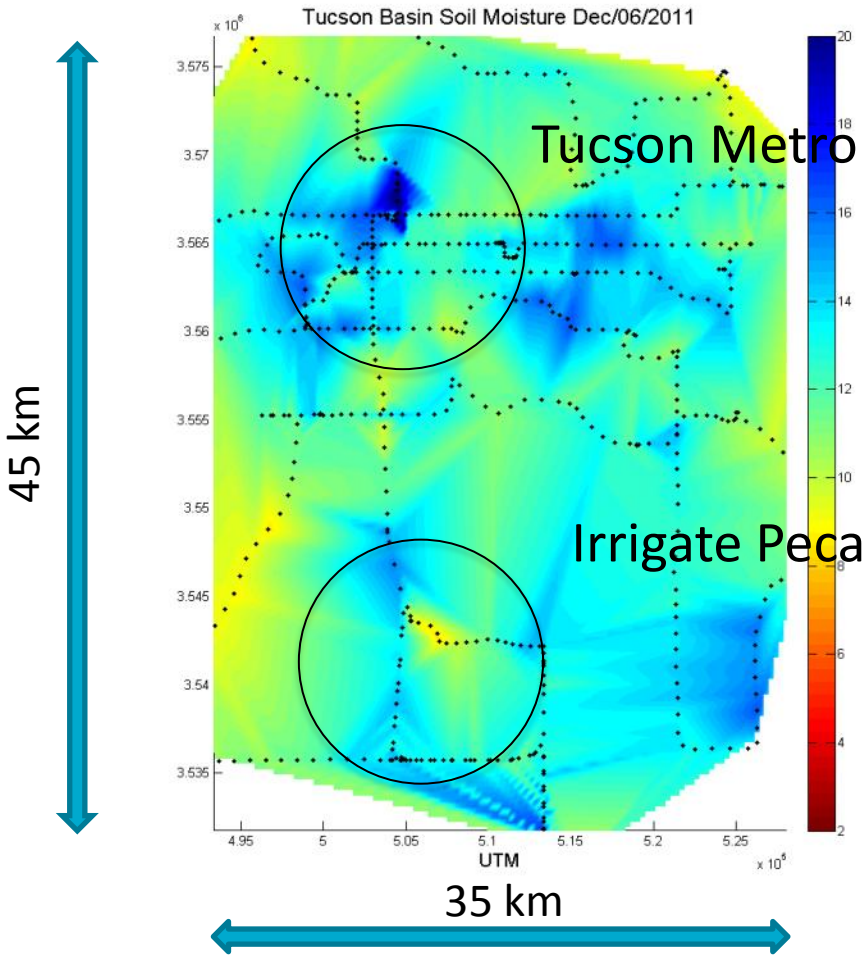
7. Soil Moisture
8. Lattice Water
9. Soil Carbon Compounds

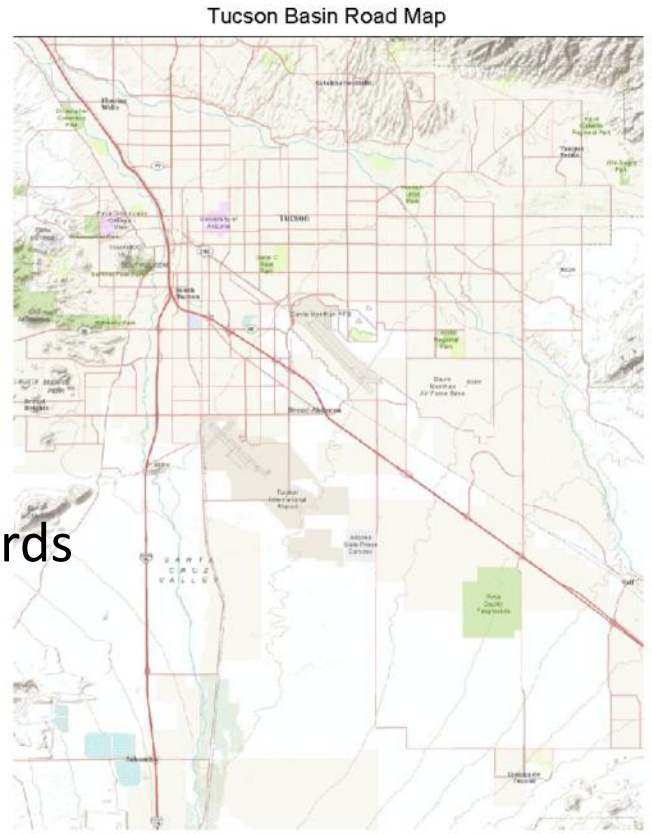


Franz et al. 2013b

Rover – mobile measurements

Rover – U of A Tucson demonstration





Images courtesy of B. Chrisman and Trenton Franz

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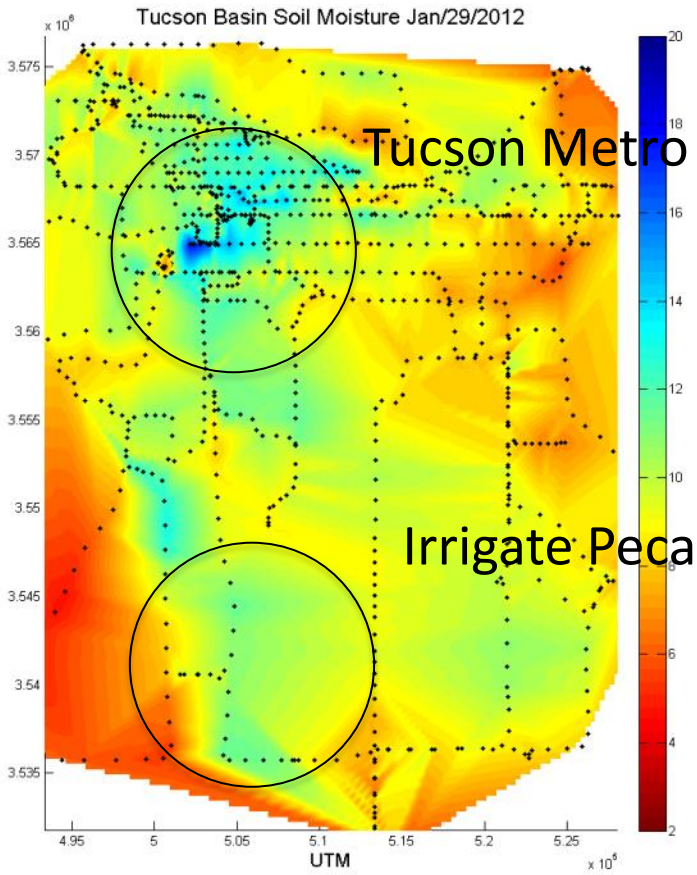
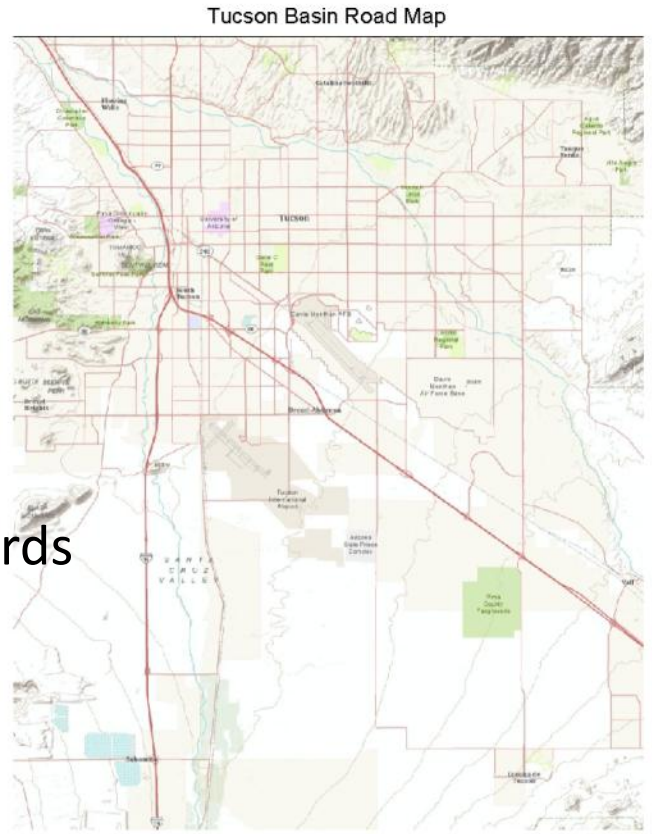
Rover – U of A Tucson demonstration



Tucson Metro Area

Irrigate Pecan Orchards



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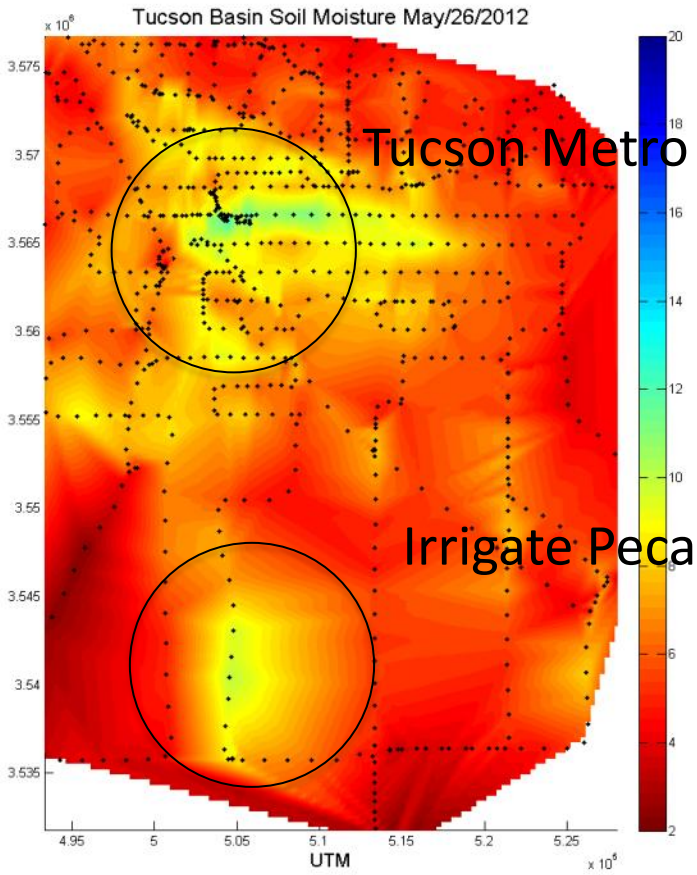

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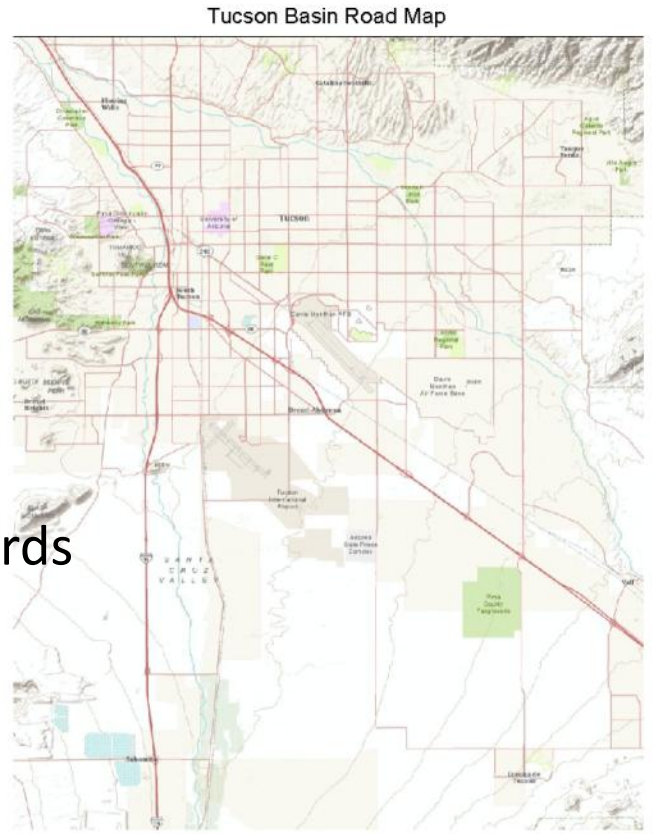

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Time series – Cosmos and ET