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.

[Sources: http://hubblesite.org](http://hubblesite.org)  |  [http://www.marsdaily.com](http://www.marsdaily.com)
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

http://www.aspera-eu.org
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

Pressure, temperature, humidity sensors

Solar panel

Data logger

Small concrete pad

Neutron tube
Neutron collision causes electron cascade
The cosmic-ray probe measurement footprint

HORIZONTAL

600m (~35ha!!!)

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.

![Graph showing soil moisture content vs. neutron counts](image)
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
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**

- Rain
- ET
- Runoff
- Depth = Z*
- Varying soil moisture content
- Saturated soil moisture
- Drainage

**EXAMPLE 2**

- Rain
- ET
- Runoff
- Depth = Z*
- Varying soil moisture content
- Saturated soil moisture
- Drainage
What can OzFlux offer CosmOz?

Fluxes from cosmic-ray probe – early results

SRER ET Comparison, 2011–2012
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

Most of the variability is at small scale

Bogena et al. (2010)
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 (?)**

- 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

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Agricultural Observational Study

- Measured Above-Ground Biological Water
- Measured Above-Ground Biological Water + Fixed Biological Hydrogen
- Neutron-Derived Above and Below-Ground Biomass Water Equivalent

Crop Harvest

Soil Tilled

Franz et al. 2013b
Rover – mobile measurements
Rover – U of A Tucson demonstration

Images courtesy of B. Chrisman and Trenton Franz
Rover – U of A Tucson demonstration

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Rover – U of A Tucson demonstration

Images courtesy of B. Chrisman and Trenton Franz
Time series – Cosmos and ET

Credit: Lindsay Hutley