

# COSMOS – a new way of measuring soil moisture (SM) at the intermediate scale

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With thanks to:

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# Introduction

- Importance of catchment-scale measurements: COSMOS
- SM measurement scales
- Thermal neutrons for measuring soil water content & cosmic rays.
- The COSMOS network in the USA.
- UK trials and future work.



# Clear need for catchment scale SM data

- Accepted need for up-scaled measurements, from plot to catchment – the missing scale.
- Important for hydrological processes (runoff, infiltration etc.), land-surface coupling (latent heat, soil heat flux etc.), biogeochemistry (respiration etc.) and ecohydrology.

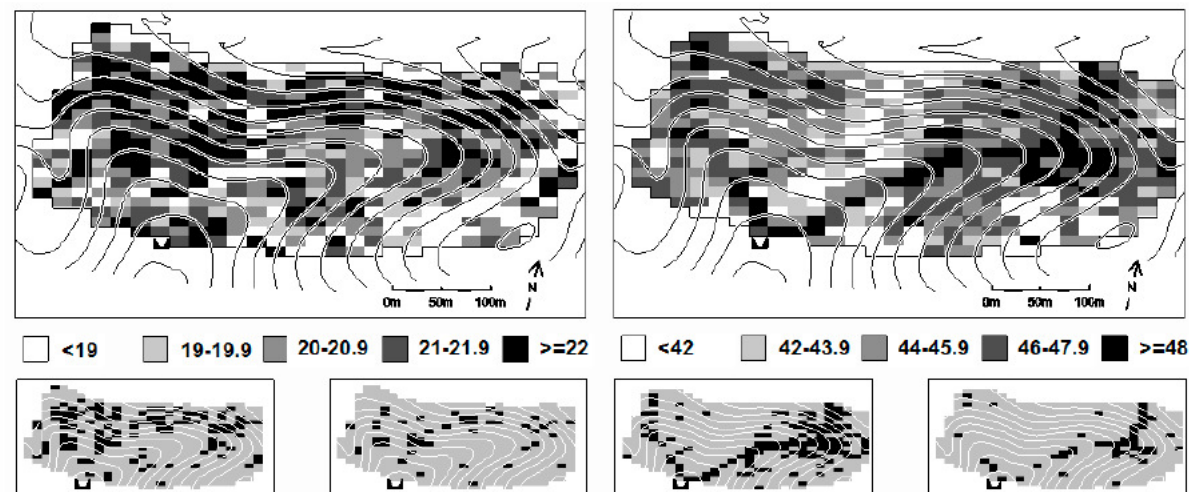


FIG. 4. Adapted from Western et al. (1999), soil moisture in the 10-ha Tarrawarra watershed in Australia when dry (left) and wet (right). Each pixel is one time domain reflectometry point measurement to 30 cm depth. The 75th (left) and 90th (right) percentile indicator plots are shown under each respective figure. During dry periods, the pattern is random, but an organized pattern emerges as the soil becomes wet.

# Point Measurements

- Hitherto small volume 'point' measurements
- .. Or mobile survey systems using point sensors
- ... Or networks of point sensors
- All are expensive to install and/or operate
- Don't give sufficient spatial and/or temporal coverage.



# *In situ* sensors can be difficult to install

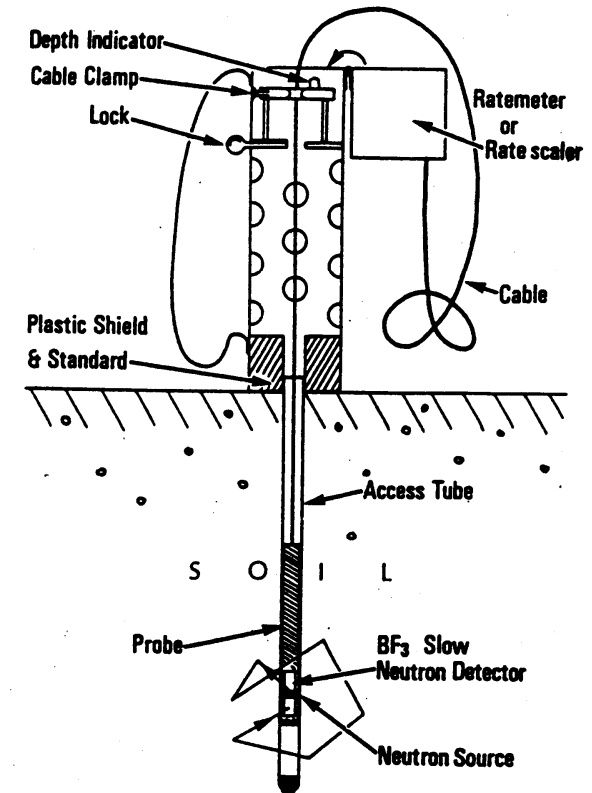
- Many replicates are required to give a large scale average, due to the heterogeneity of soils, vegetation and topography.
- Whereas the COsmic ray Soil Moisture Observing System (COSMOS) gives areal average over a circle about 700 m in diameter using a single non-invasive probe.



Above: petrol driven Atlas Copco mechanical hammer being used to drive in an access tube.

# Established method of thermal neutrons

- Well used (e.g. neutron probe) principle of detecting neutrons slowed (thermalised) by hydrogen atoms in soil water.
- Sensitive and selective.
- Easily calibrated through occasional gravimetric sampling.
- ...but the 'neutron probe' configuration requires a radioactive source in the probe, and SM is measured in a small volume.



Above: old technology - the Wallingford 'down-hole' neutron probe.

# The COSMOS Probe

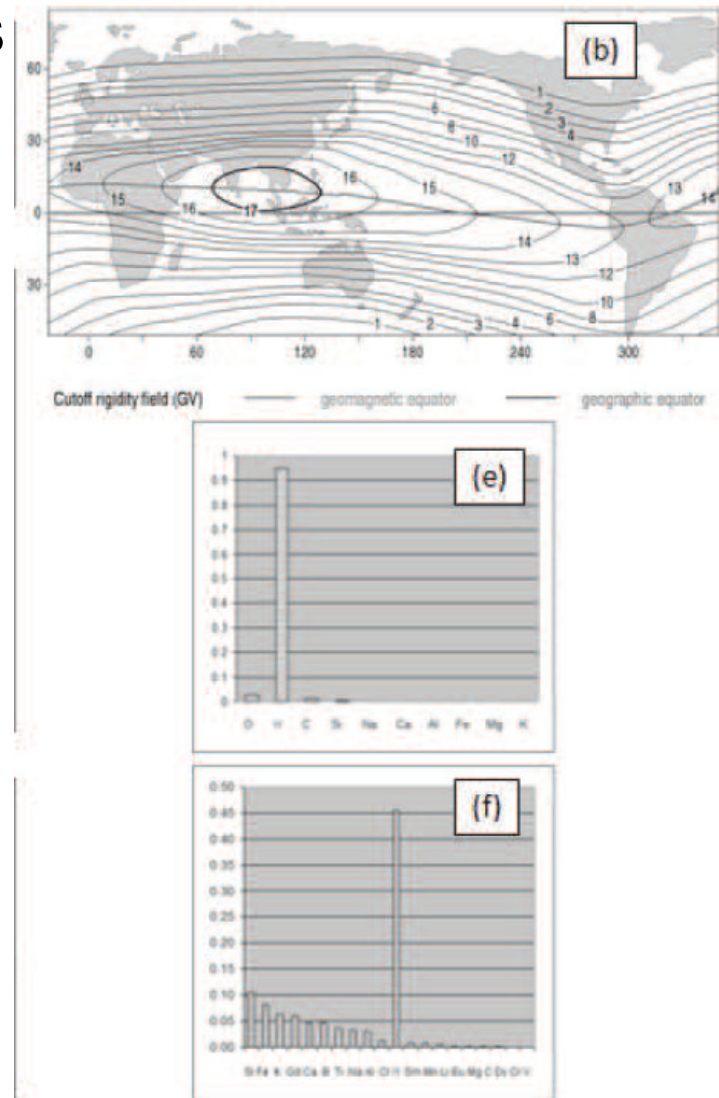
- The new COSMOS probe *does not require a radioactive source* – it is completely *passive*.
- By sensing naturally occurring thermal neutrons – *above the soil* - it has a large footprint of about 350 m radius (86 % of sensitivity).
- The footprint is large as the sensor is above ground (*non-invasive*) – neutrons travel relatively far in air.



Above: Three COSMOS systems on test at CEH Wallingford.

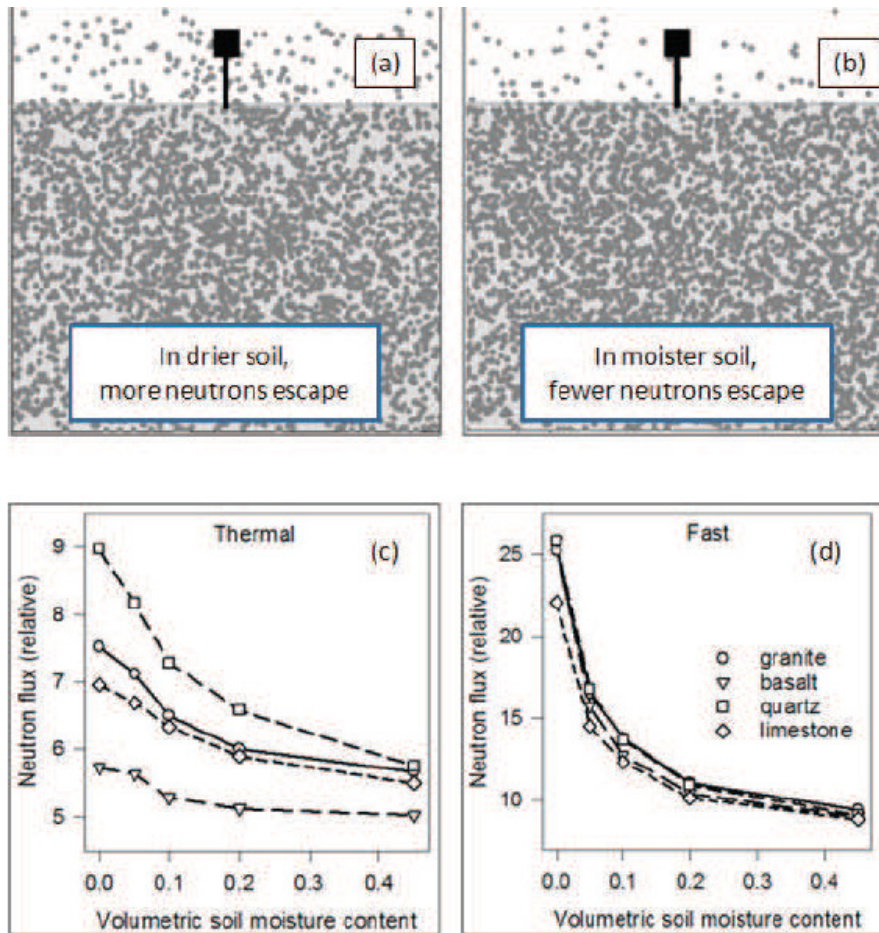
# COSMIC rays as a fast neutron source

- COSMIC rays are captured by Earth's known magnetic field (b)
- Cosmic particles are produced at top of the atmosphere, at a rate determined by the pressure and temperature.
- ... this cosmic shower enters the soil, generating neutrons with a spectrum of energies.
- Hydrogen atoms are most effective at thermalisation - slowing (e) and absorbing (f), these 'fast' neutrons.
- Some neutrons leak back to the atmosphere → SM measurement.





# Monte Carlo simulations of neutrons



The Cosmic Ray soil moisture probe (COSMOS) was developed by:

**Dr. Marek**

**Zreda** (University of

Arizona) and **Dr. Darin**

**Desilets** (Sandia National Laboratory, USA)

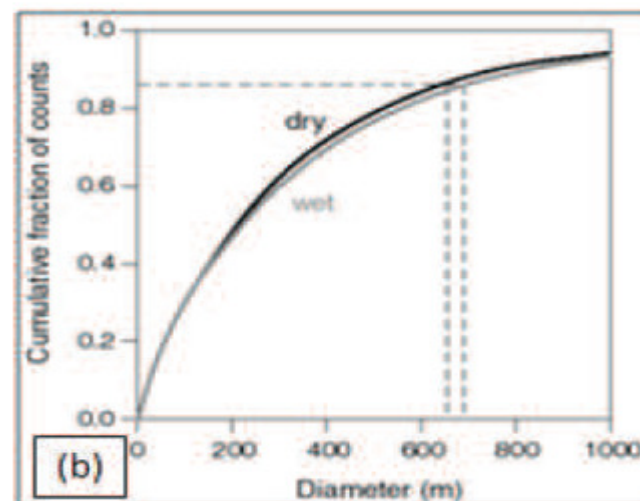
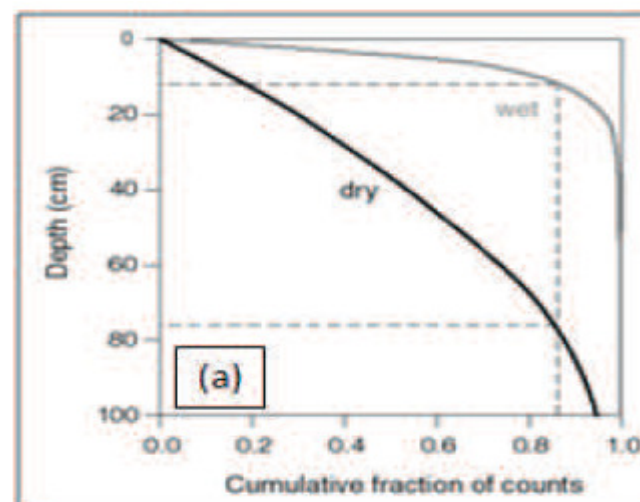
*Figure 3* (a) and (b) representations of a Monte Carlo simulation of neutron density made for dry and moist area-average soil moisture conditions, respectively. (c) and (d) the relationships between the intensity of neutrons measured above the ground for "thermal" and "fast" neutrons, respectively, as determined by Monte Carlo calculations for a range of soil types and for different soil moisture content.

# Depth of COSMOS measurement

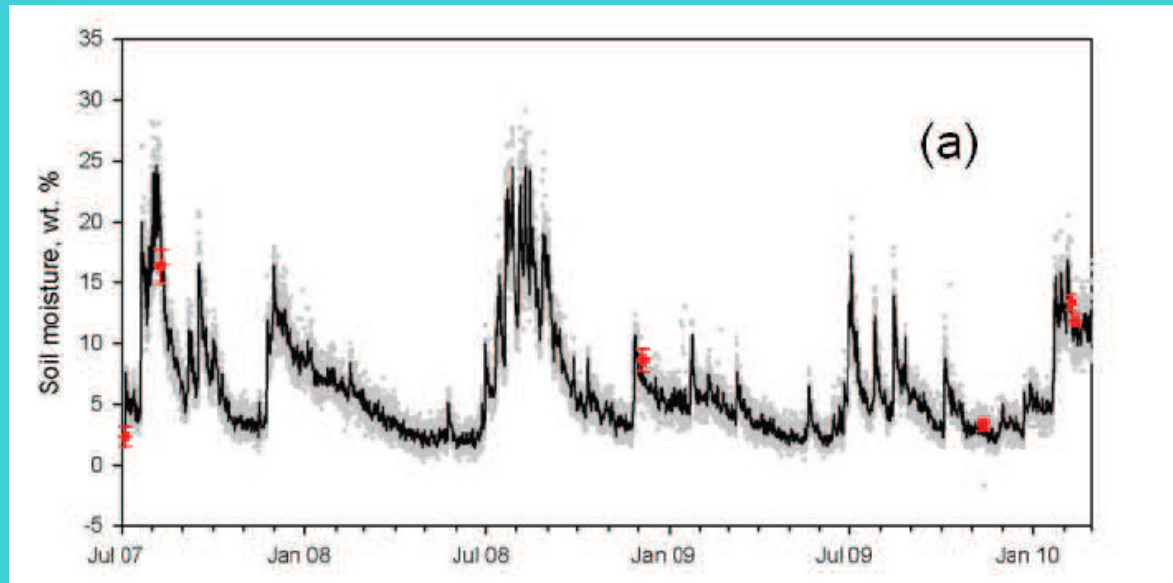
(a) Because neutrons are captured more effectively by wet soil, the source depth of the measurement is reduced.

i.e. it is more likely that detected neutrons have come from closer to the surface when the soil is wet.

(b) Measurement radius is much less sensitive to SM



# COSMOS calibration example



COSMOS time series (hourly data in grey, black line is 7-hour running mean) from San Pedro river valley, Arizona, compared with gravimetric samples (red points).

- Statistically a minimum of 30 – 40 gravimetric spatial point samples are required to give 2 % error, for typical heterogeneity.
- Here 72 samples were used – along 8 directions, 3 radii & 3 depths.

# United States COSMOS deployments

Top: funded  
COSMOS network

Bottom: possible, if  
funded, 4 years  
hence

Data available – Use  
it to demonstrate  
value & achieve next-  
stage funding.

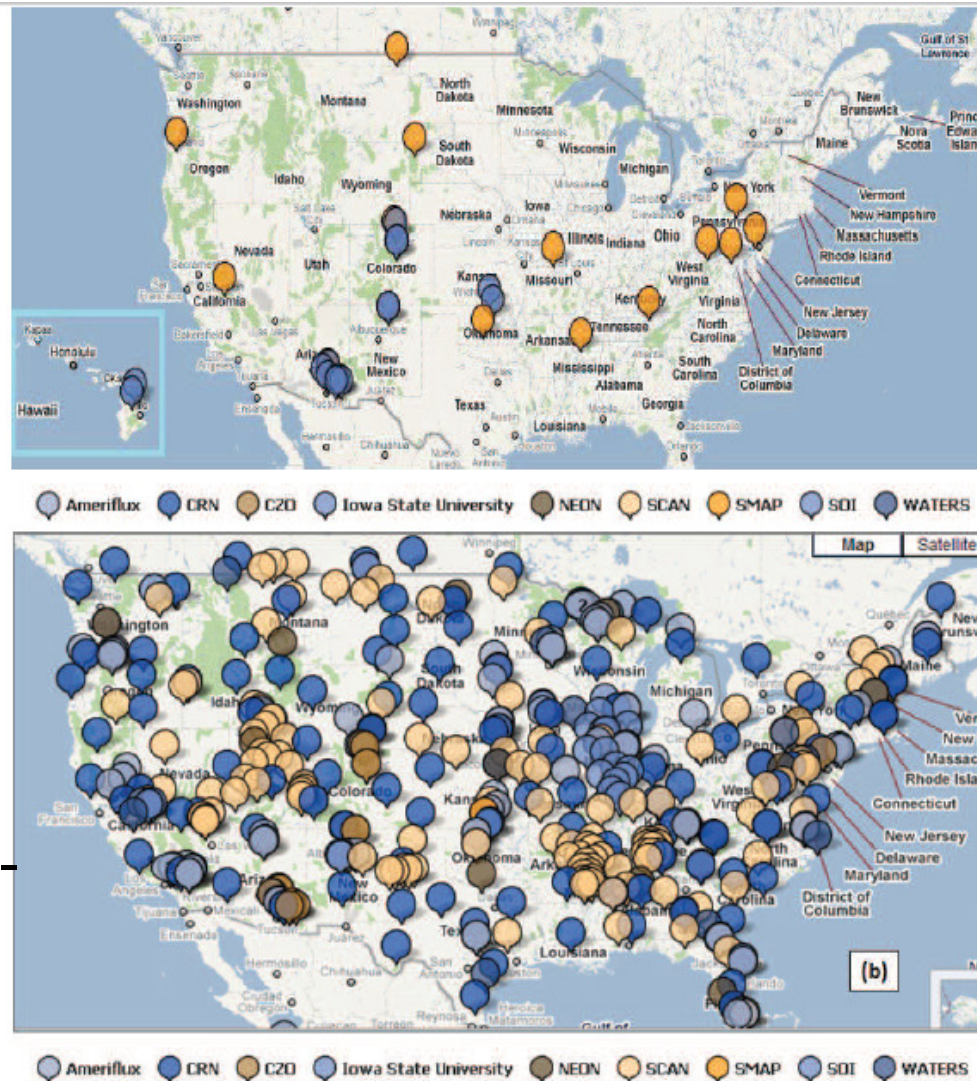


Figure 6 (a) Currently planned COSMOS deployment sites during 2010 (provisional). (b) a potential US COSMOS deployment network if COSMOS sites are collated with existing monitoring networks during a subsequent large scale deployment starting in four years time.

# Summary

- COSMOS is a powerful, well understood, 'technology ready' tool for small catchment scale SM measurement.
- Integrated SM over about 0.4 km<sup>2</sup> comparable with JULES, satellite LST etc.  
... and surface observations of H & LE by scintillometry and eddy covariance.
- Need UK/EU funded network to provide COSMOS spatial coverage and develop online soil moisture maps.

# Thank you

## Any questions?