It is now possible to measure soil moisture at sub-kilometer scale using cosmic-ray neutrons

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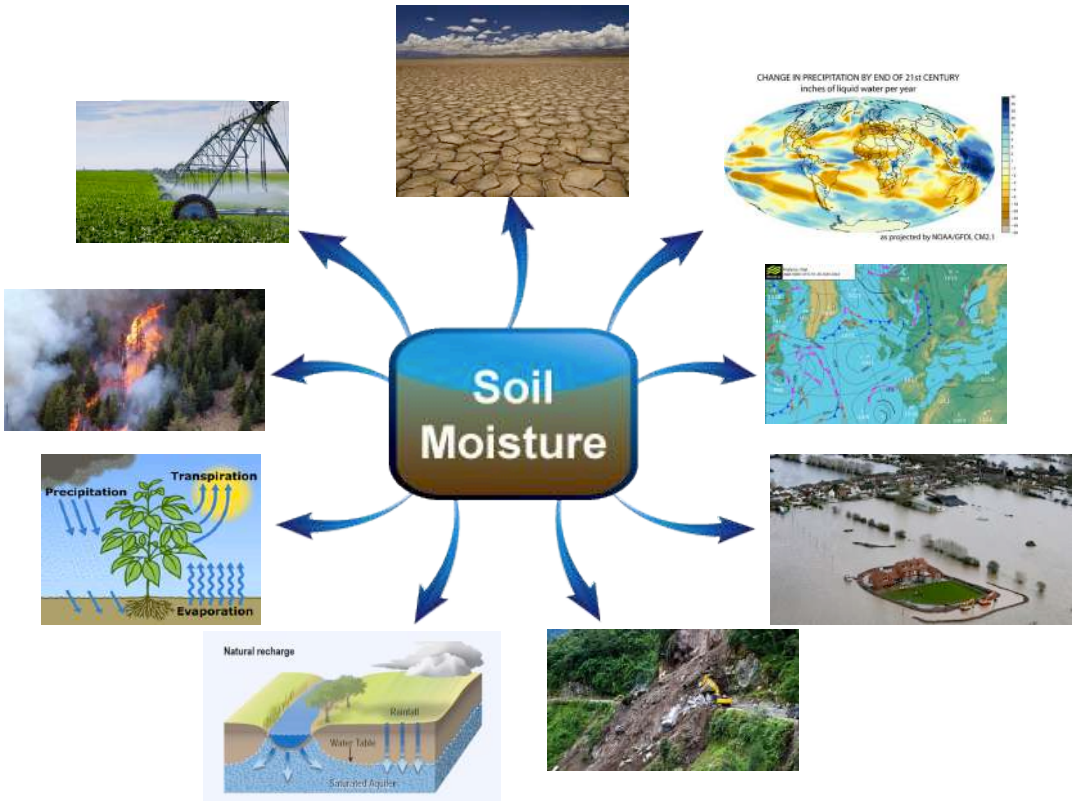
Department of Civil Engineering
University of Bristol

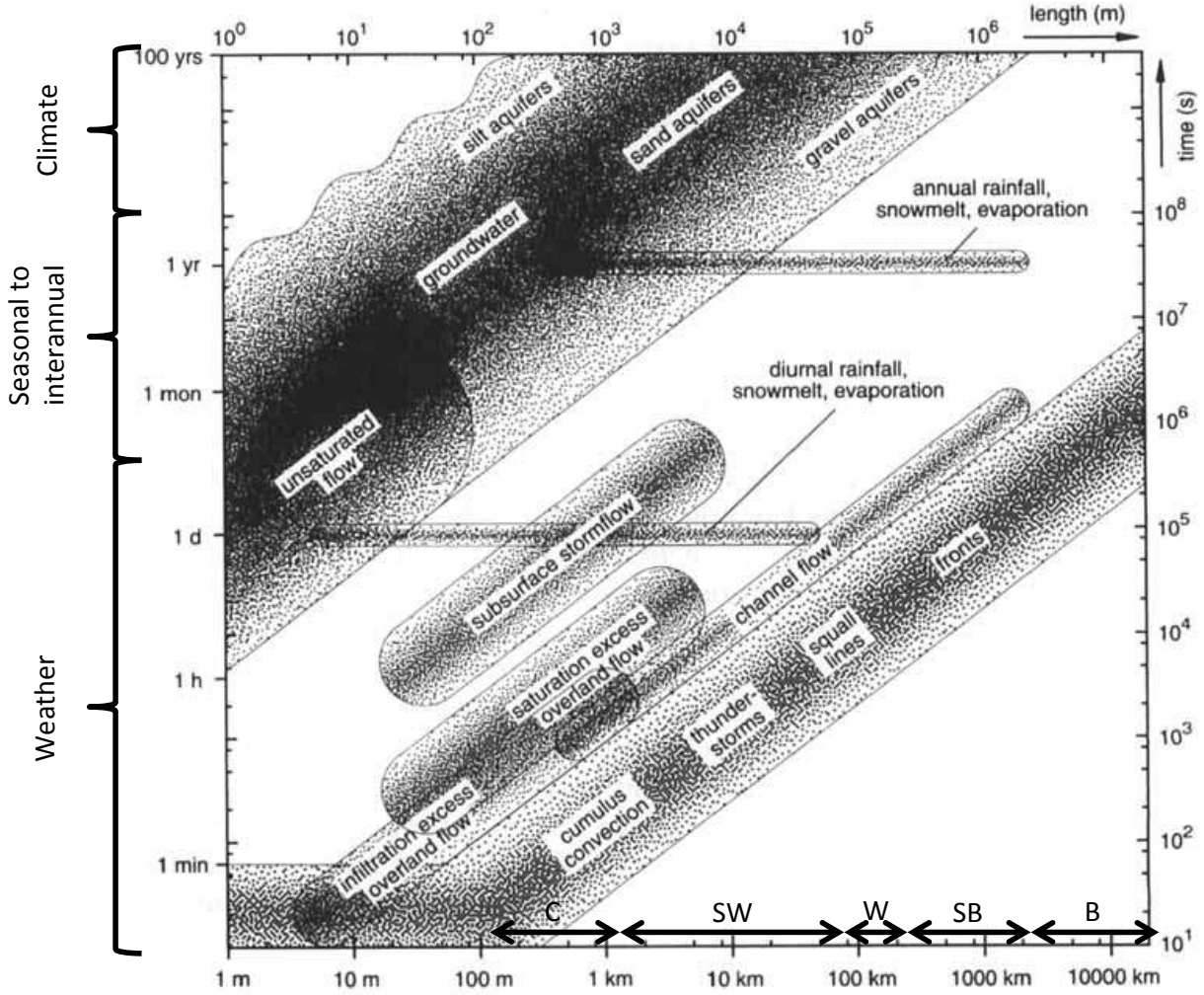


This talk is organized as follows:

- soil moisture and scaling issues
- cosmic-ray soil moisture measurements
- modeling soil moisture – cosmic-ray neutron interactions
- example of applications
  - parameter estimation
  - state estimation
- measurement networks
- summary

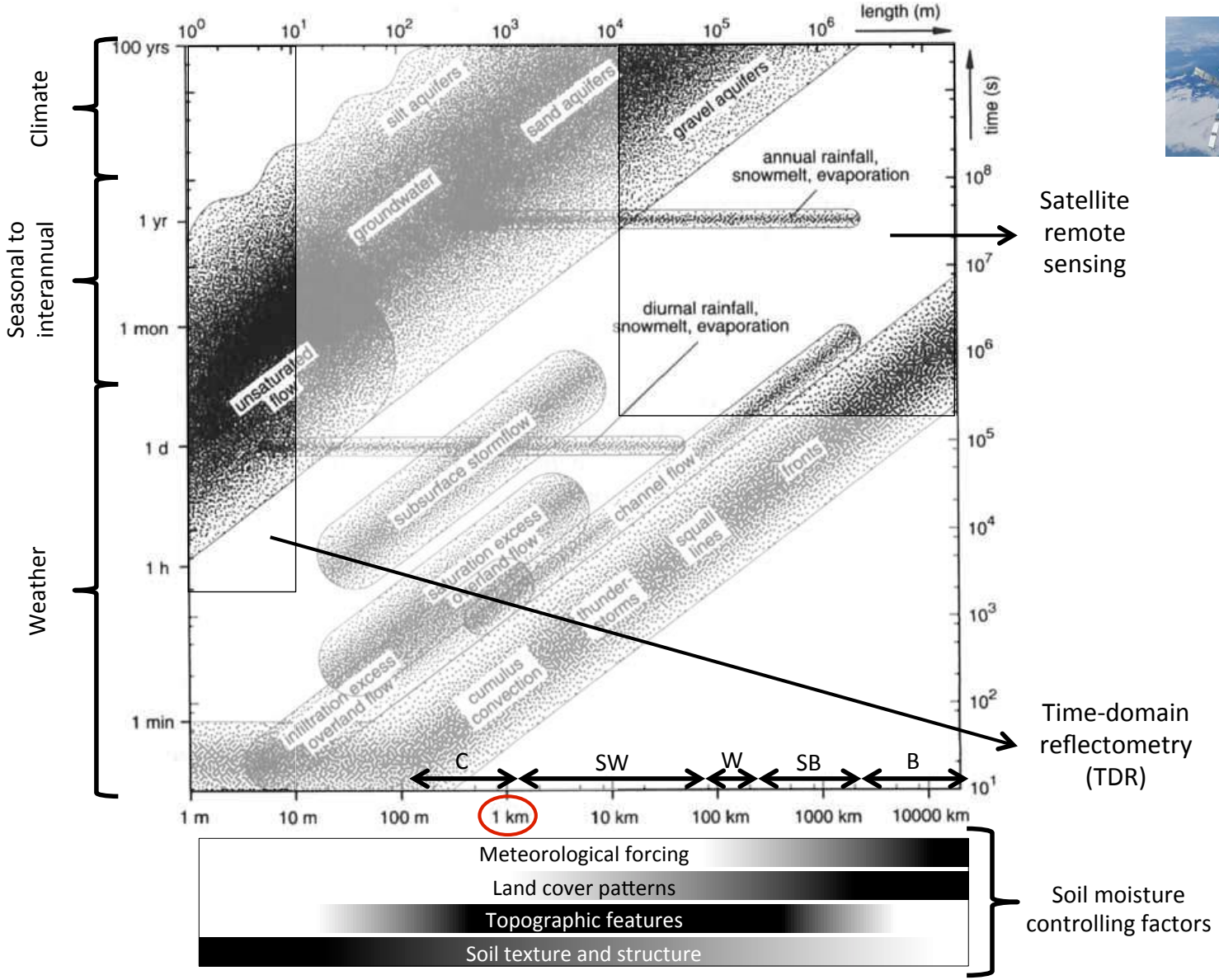
soil moisture and scaling issues

Soil moisture plays a key role in controlling hydrometeorological processes at various spatiotemporal scales…



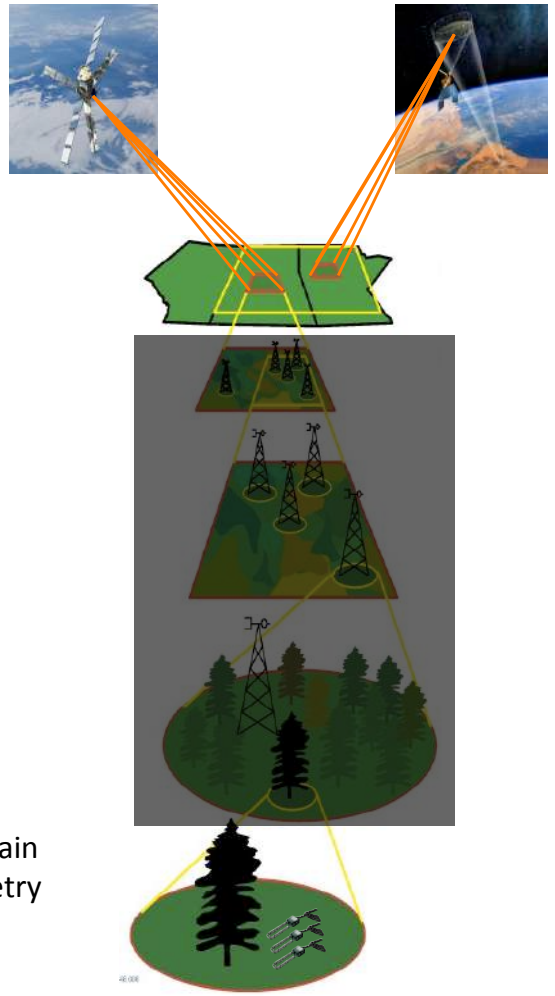
Adapted from Blöschl and Sivapalan (1995; Hydrol. Process.), Robinson et al. (2008; Vadose Zone Journal), and Crow, et al. (2012; Rev. Geophys.)

but we cannot measure soil moisture at all possible scales!!!



Satellite remote sensing

Time-domain reflectometry (TDR)



Soil moisture controlling factors

Adapted from Blöschl and Sivapalan (1995; Hydrol. Process.), Robinson et al. (2008; Vadose Zone Journal), and Crow, et al. (2012; Rev. Geophys.)

cosmic-ray soil moisture measurements

New technology provides an opportunity to estimate soil moisture using cosmic rays

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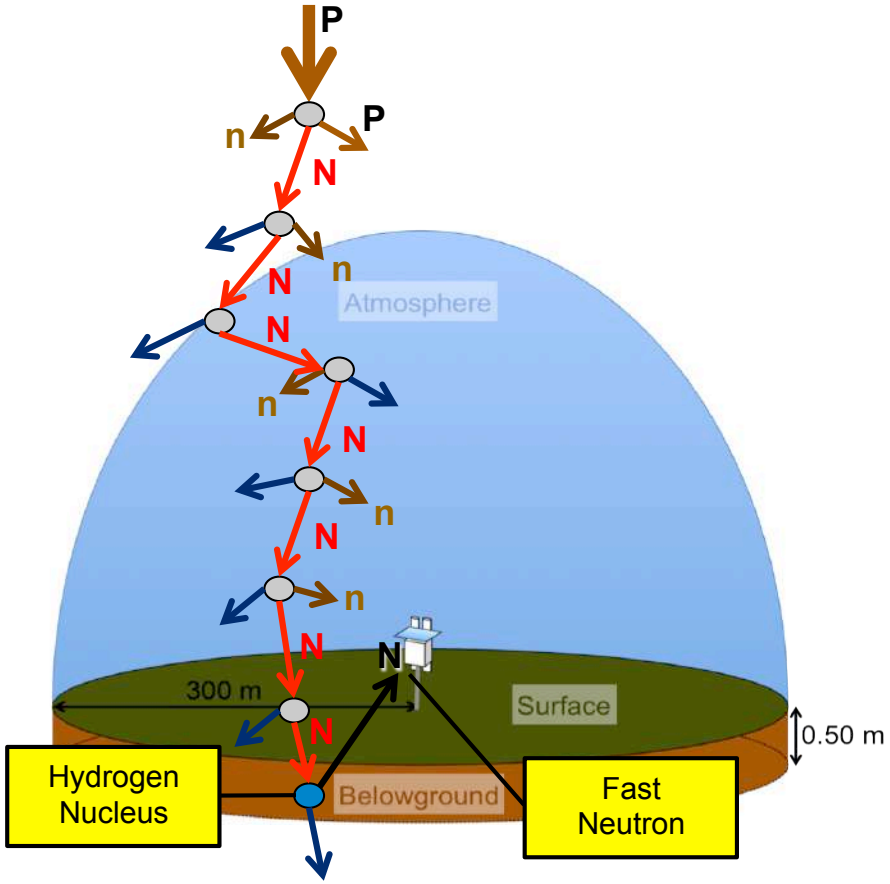
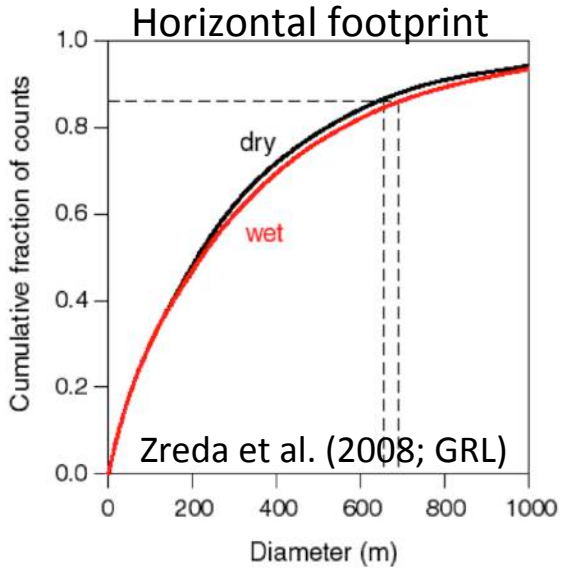
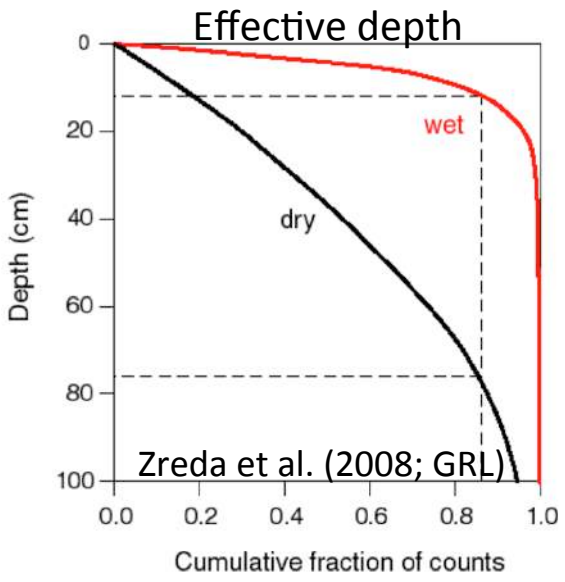
Continuous estimates of soil moisture over an area of ~30 ha and effective depths of tens of cm







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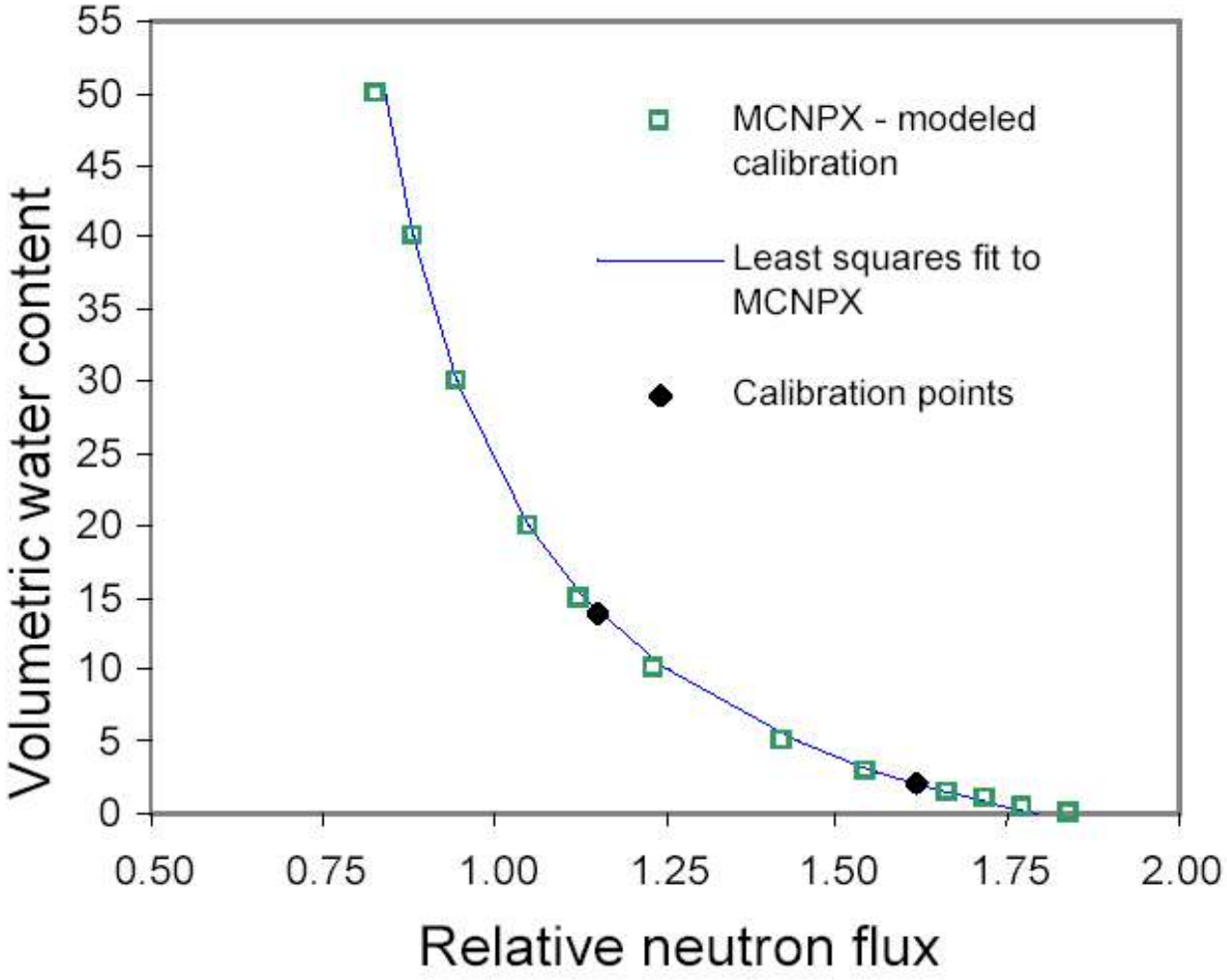
Fast neutrons produced from cosmic rays are predominantly moderated by water molecules in the soil



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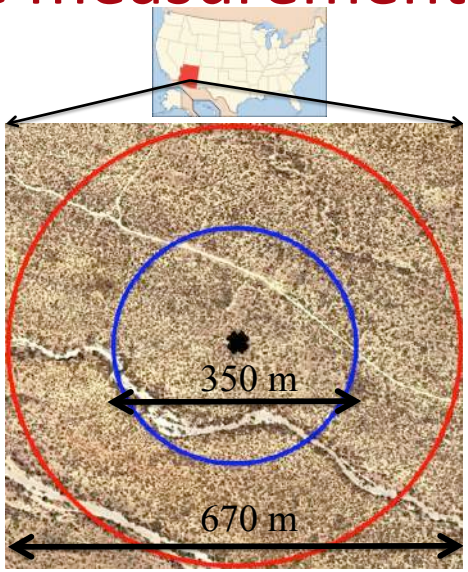
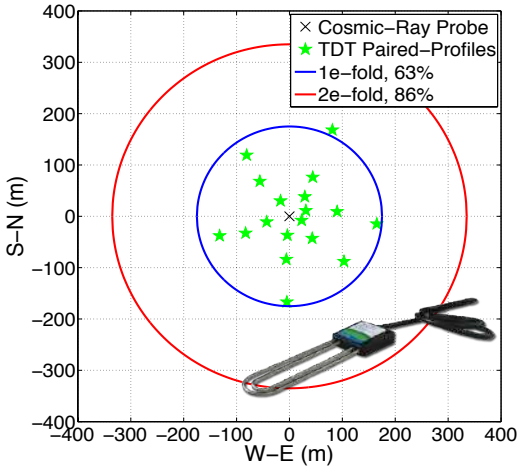
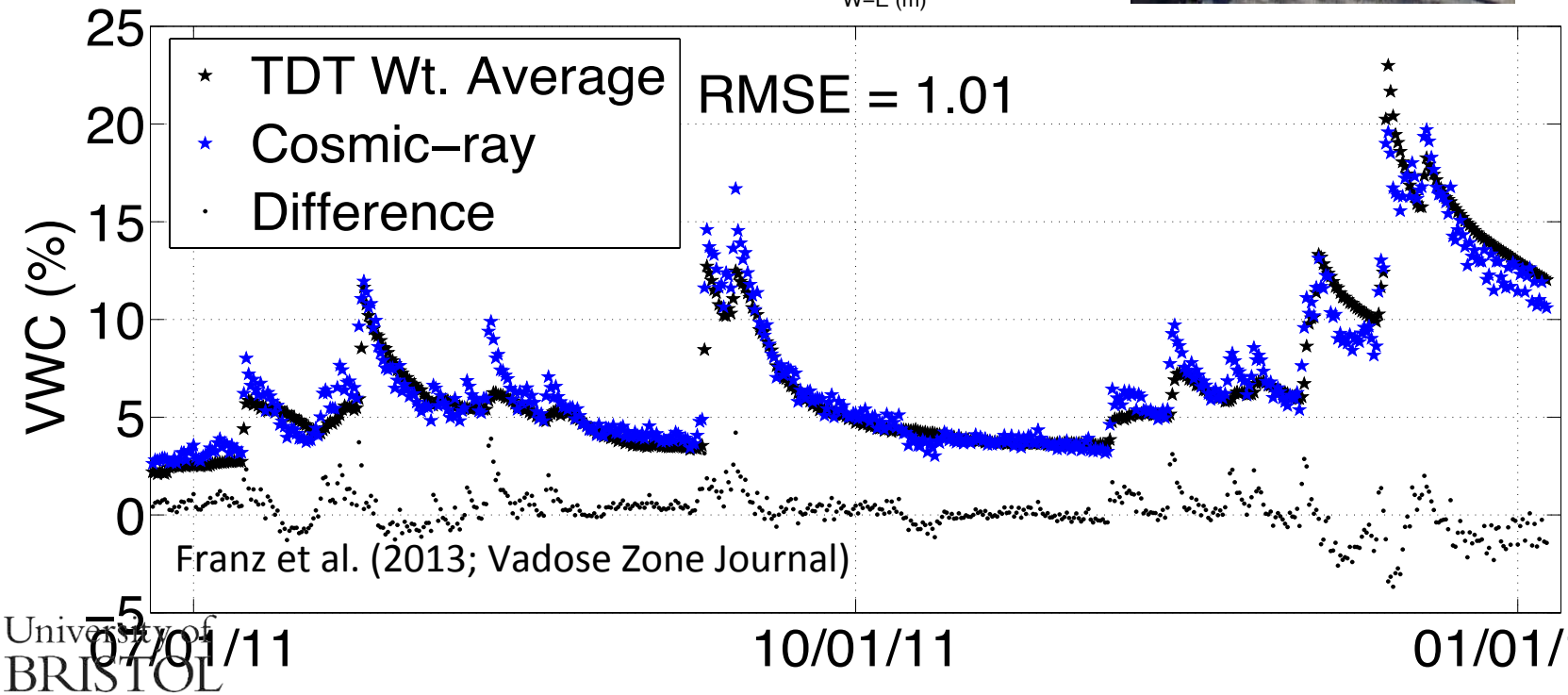
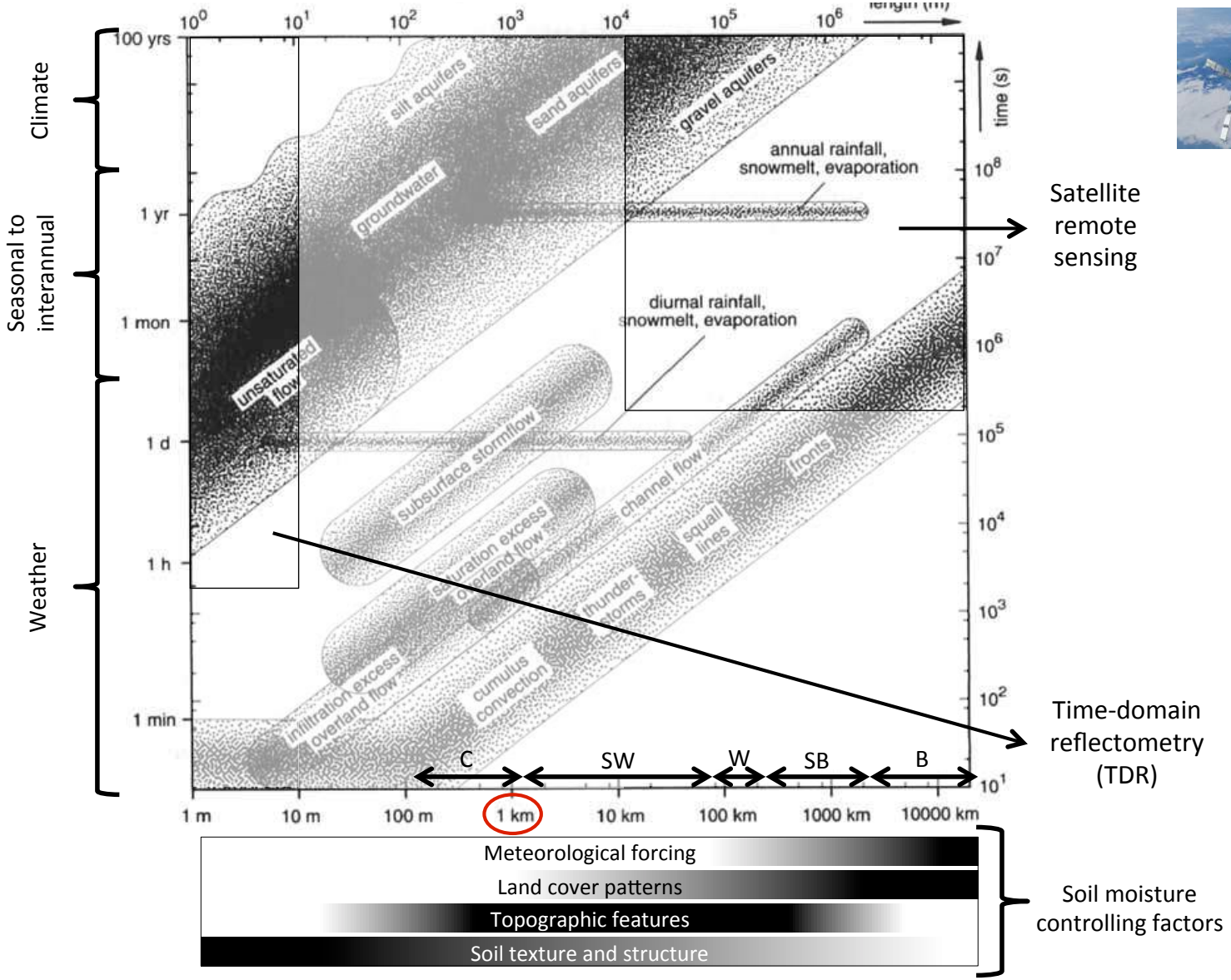
CRS soil moisture compares very well with network of point-scale measurements within same horizontal footprint





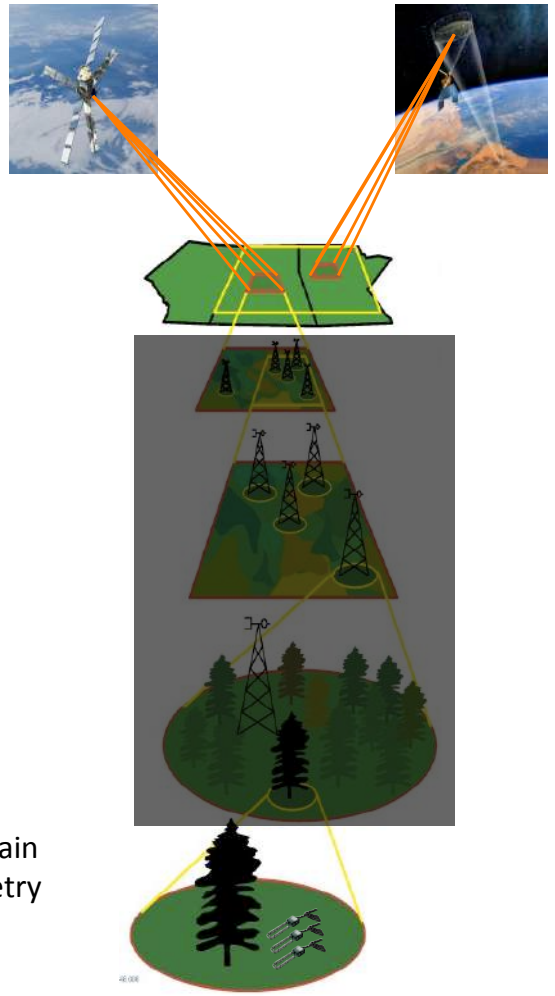


CRS provides an opportunity to measure soil moisture at unprecedented spatial scales in hydrometeorology!



Satellite remote sensing

Time-domain reflectometry (TDR)



Soil moisture controlling factors

Adapted from Blöschl and Sivapalan (1995; Hydrol. Process.), Robinson et al. (2008; Vadose Zone Journal), and Crow, et al. (2012; Rev. Geophys.)

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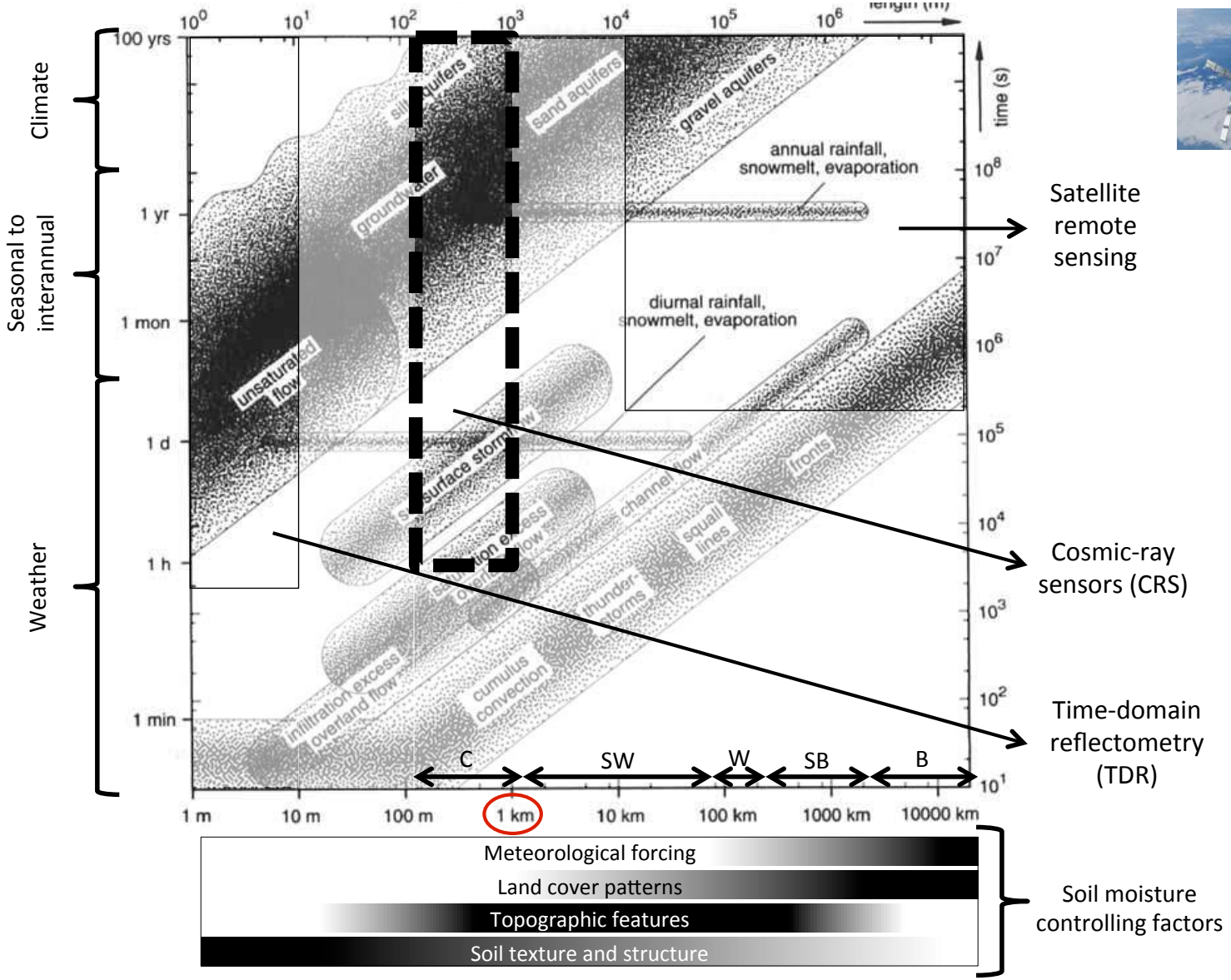
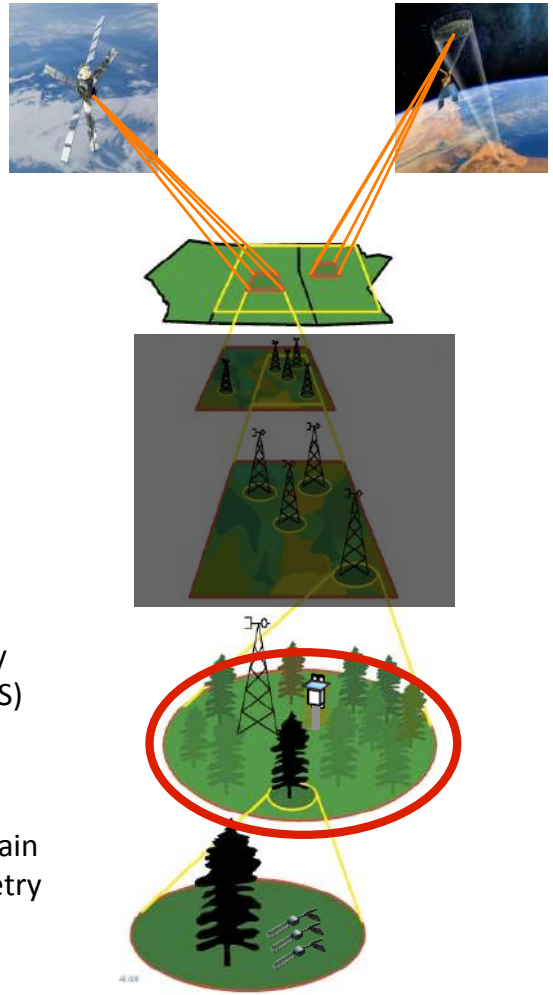


Satellite remote sensing

Cosmic-ray sensors (CRS)

Time-domain reflectometry (TDR)

Soil moisture controlling factors



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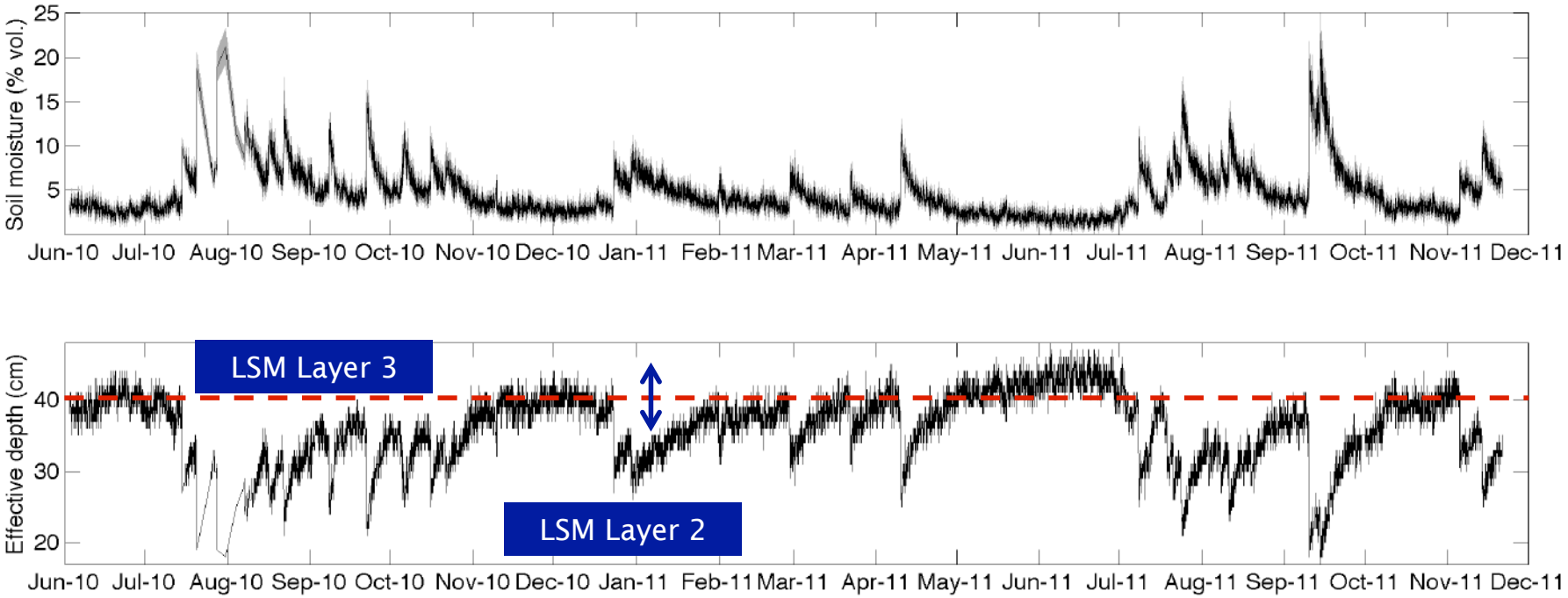
modeling soil moisture & cosmic-ray neutron interactions

Integrated soil moisture from CRS can reach multiple soil layers in land models



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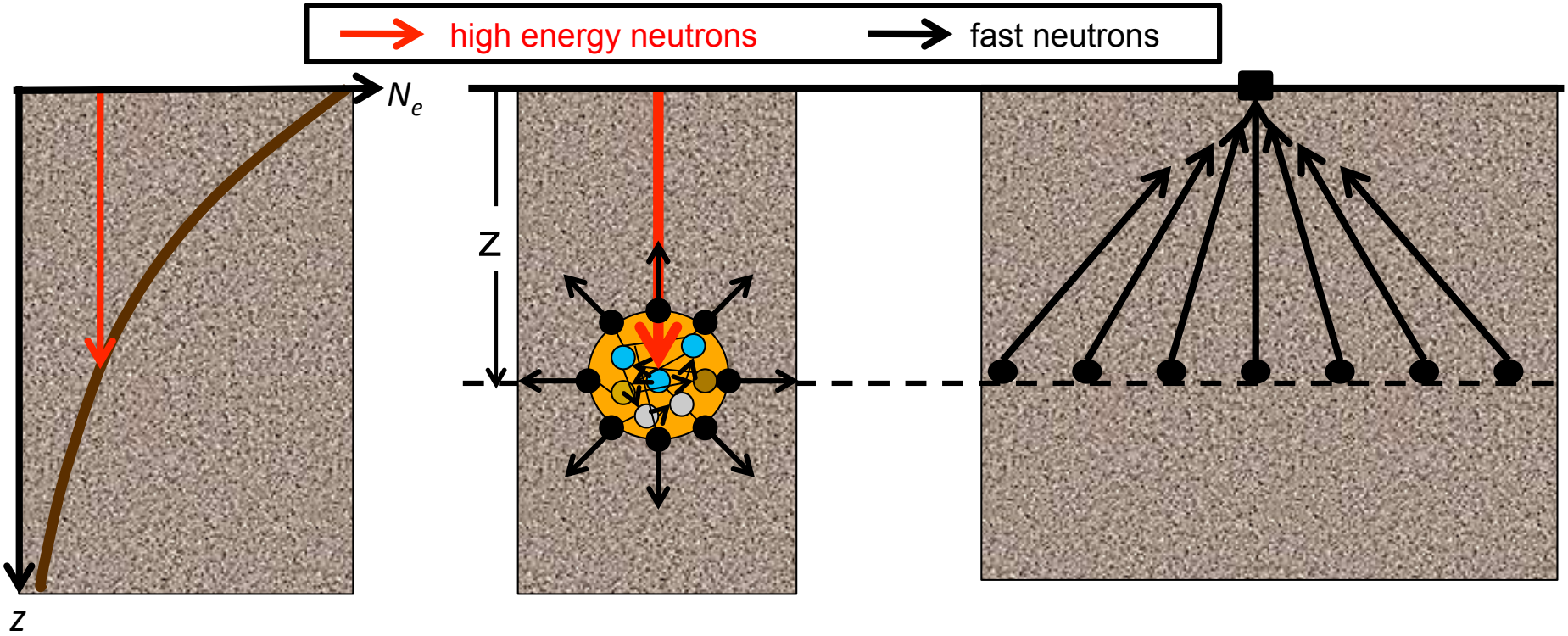
COsmic-ray Soil Moisture Interaction Code (COSMIC)

captures essential below-ground physics in parametric form



Exponential reduction in the number of high energy neutrons with depth

Isotropic creation of fast neutrons from high energy neutrons at level "z"

Exponential reduction in the number of the fast neutrons created at level "z" before their surface measurement

$$N_{COSMOS} = N \int_0^{\infty} \left[\exp\left(-\left[\frac{m_s(z)}{L_1} + \frac{m_w(z)}{L_2} \right] \right) \cdot \left[\alpha\, \rho_s(z) + \rho_w(z) \right] \cdot \left(\frac{2}{\pi} \right) \int_0^{\pi/2} \exp\left(\frac{-1}{\cos(\theta)} \left[\frac{m_s(z)}{L_3} + \frac{m_w(z)}{L_4} \right] \right) .d\theta \right] .dz$$

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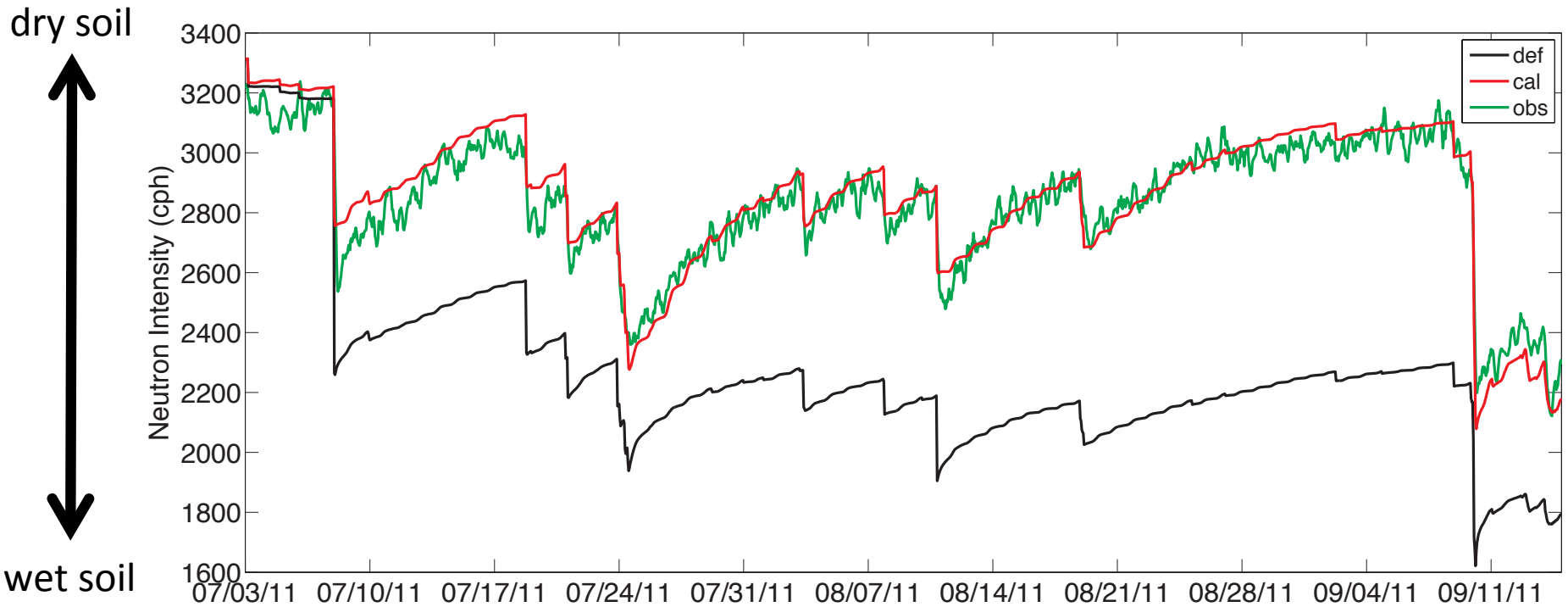
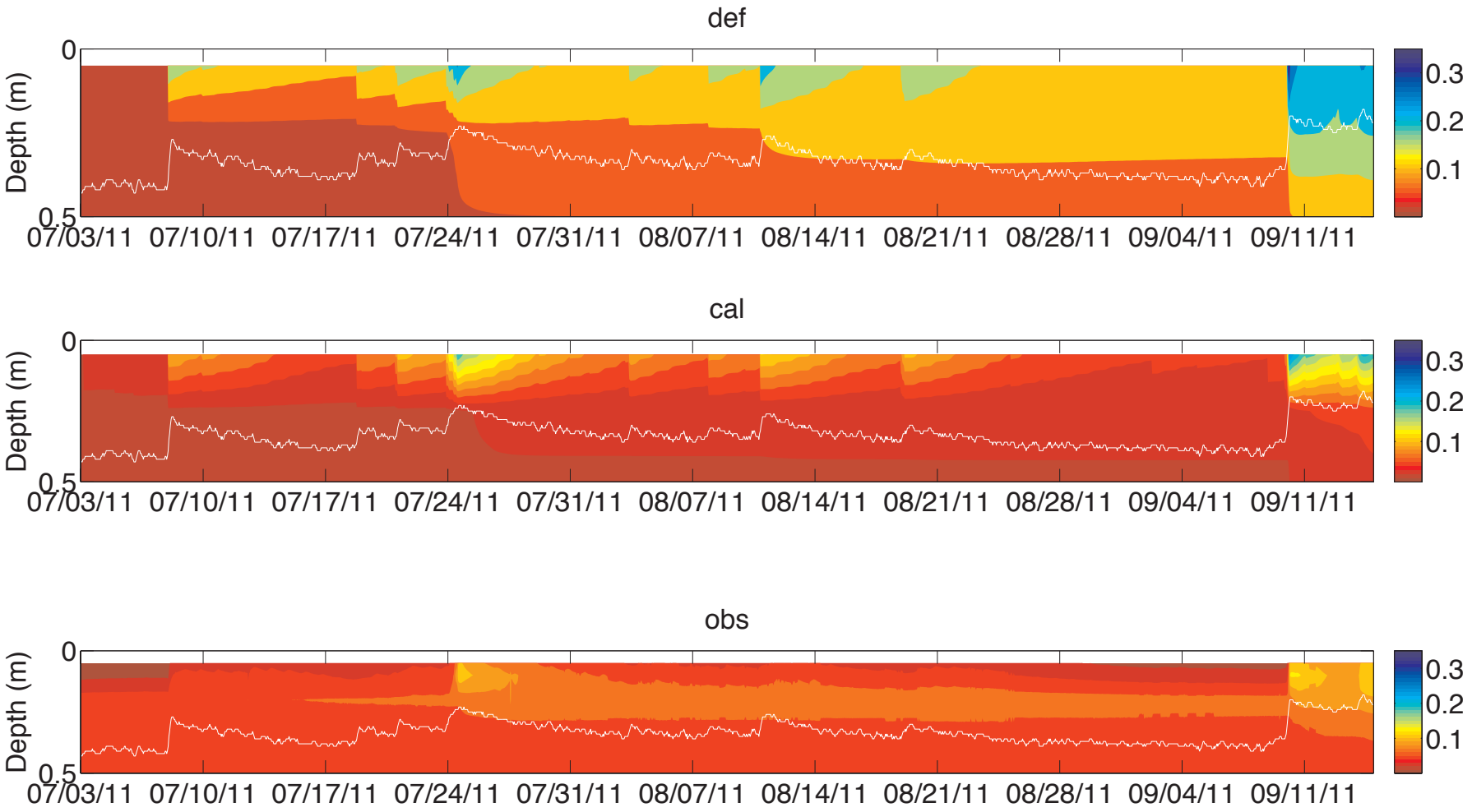
Shuttleworth et al. (2013)

example of applications: parameter estimation

Calibration of soil properties in land models using cosmic-ray neutron counts as target variable



Soil moisture profile compares well with network of point-scale measurements within same effective area



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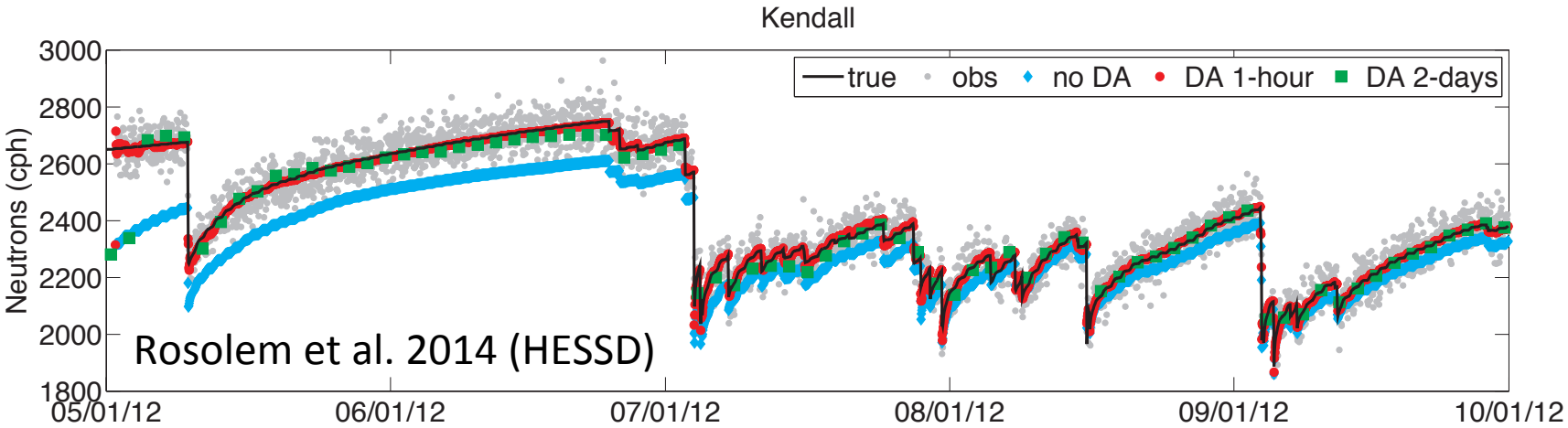
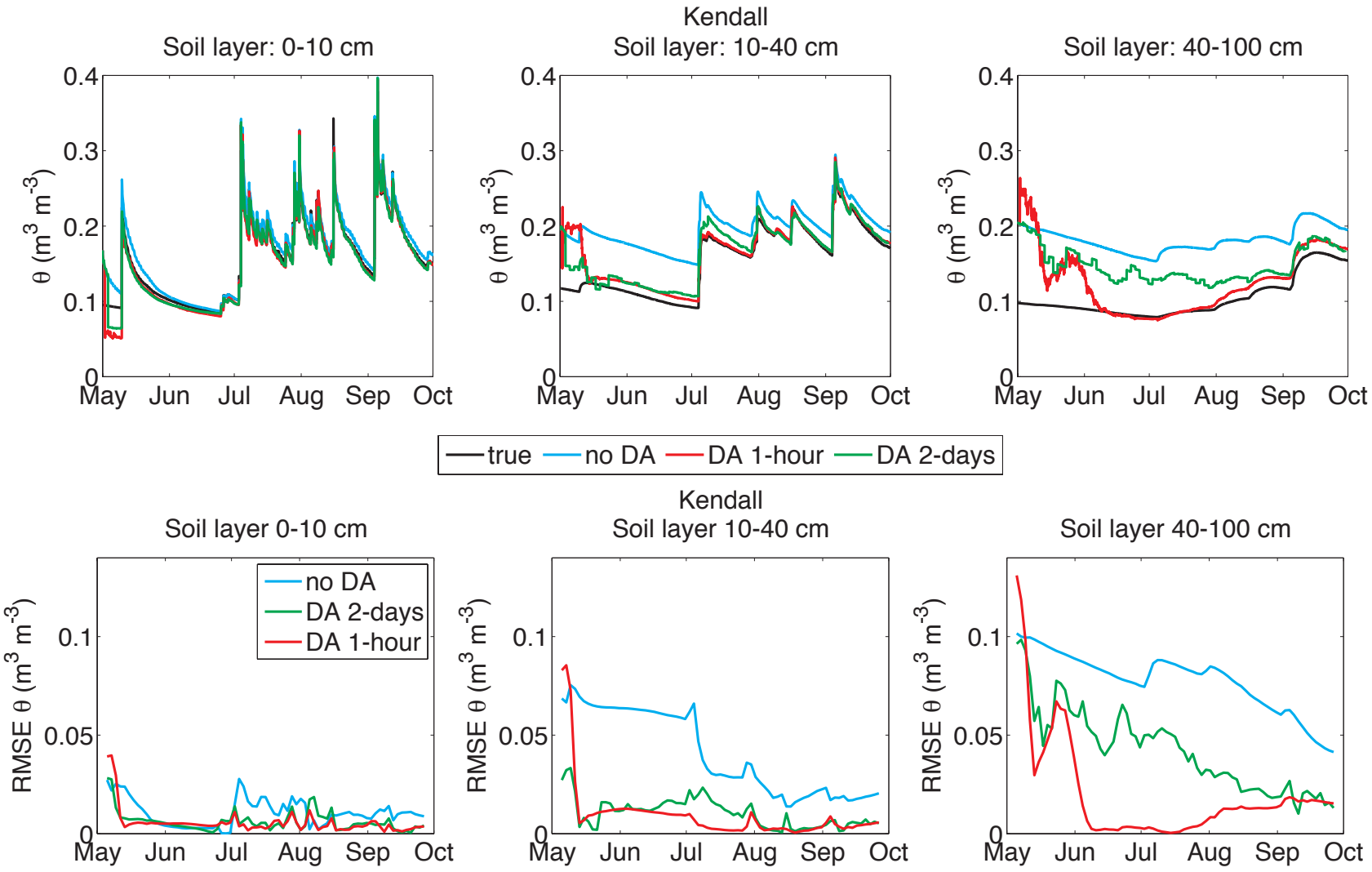
example of applications: state estimation

Assimilation of neutron observations improves the dynamics relative to the true neutron count!



Simulated soil moisture profile is improved remarkably even beyond the sensor effective depth!



Rosolem et al. 2014 (HESSD)

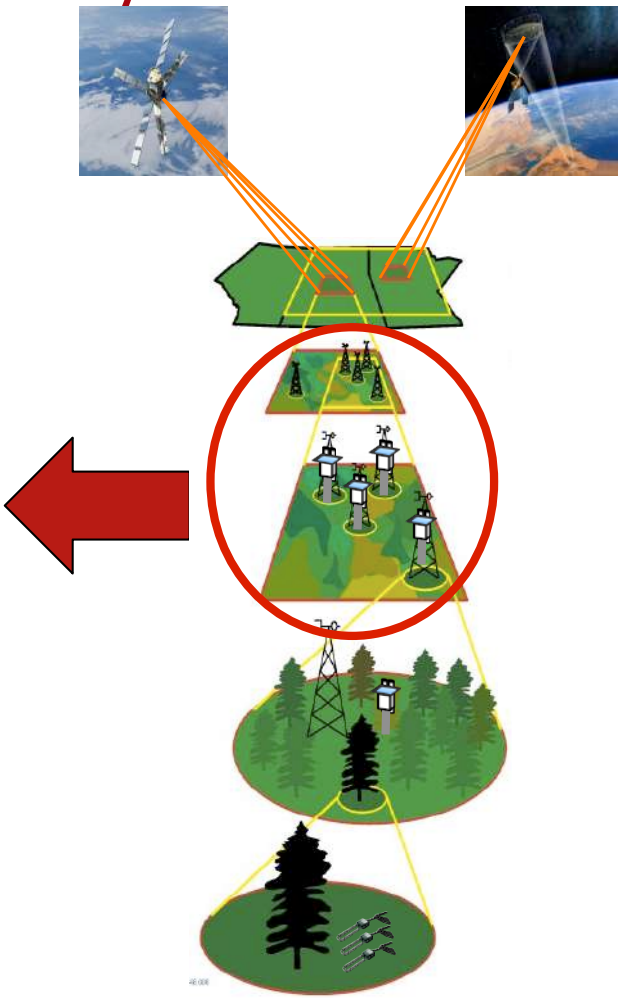
cosmic-ray soil moisture networks

The use of CRS has been rapidly growing within the hydrometeorological community!

COSMOS-UK
UK Soil Moisture Monitoring Network

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES



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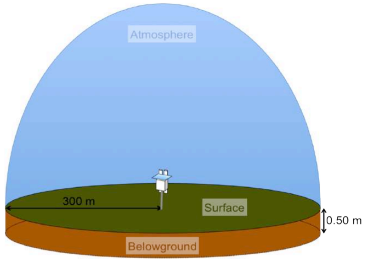
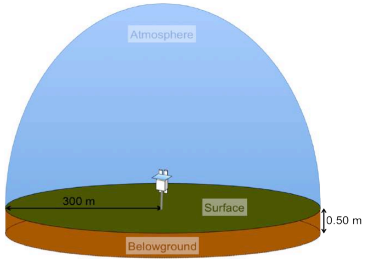
to summarize…

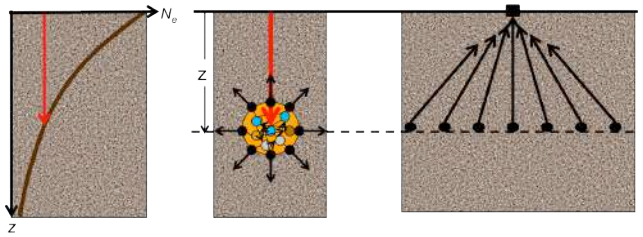
- Integrated soil moisture at intermediate scales through cosmic-ray neutron interactions



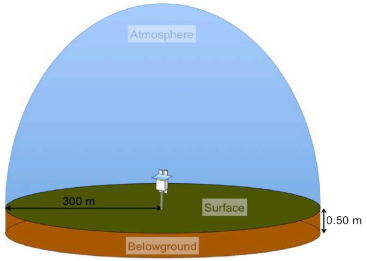
- Integrated soil moisture at intermediate scales through cosmic-ray neutron interactions

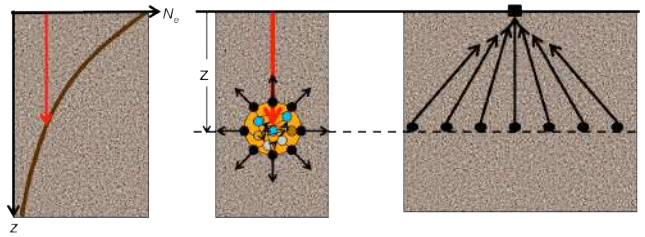
- Simple and robust model for soil moisture – neutrons interactions (COSMIC)

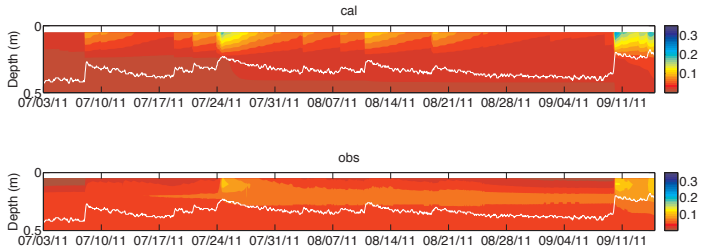




- Integrated soil moisture at intermediate scales through cosmic-ray neutron interactions
- Simple and robust model for soil moisture – neutrons interactions (COSMIC)
- Neutron signal used successfully to constrain model parameters







- Integrated soil moisture at intermediate scales through cosmic-ray neutron interactions
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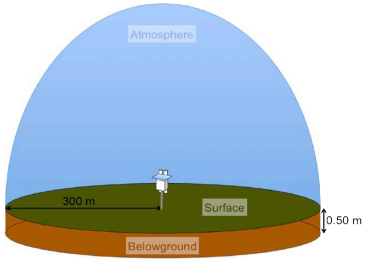
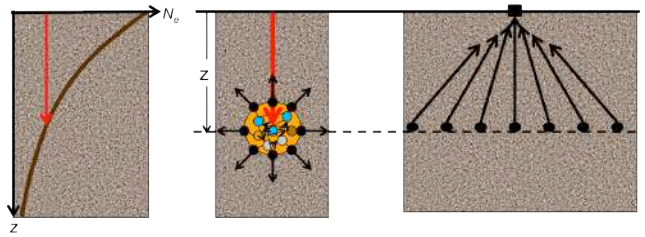
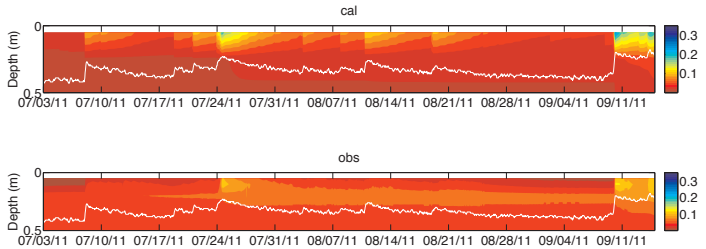
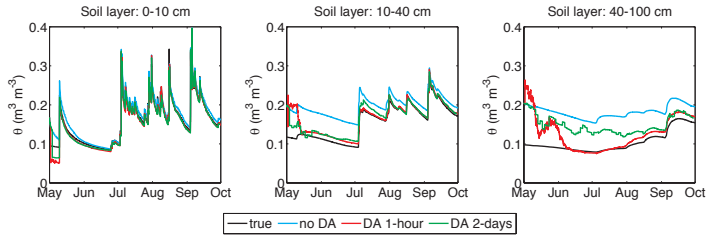
- Assimilation of neutron counts improves simulated soil moisture even at deeper soil layers









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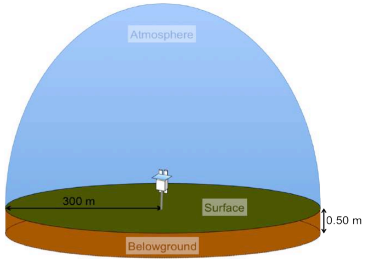

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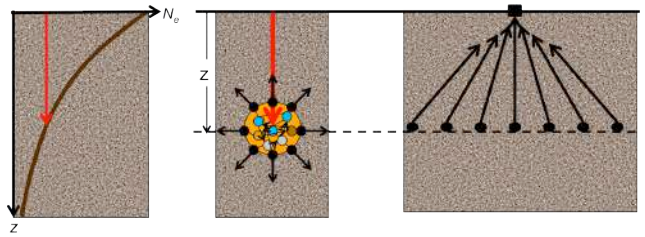

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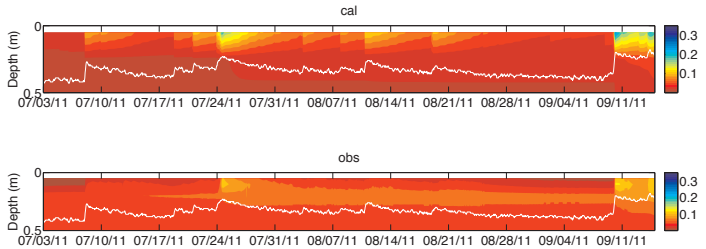

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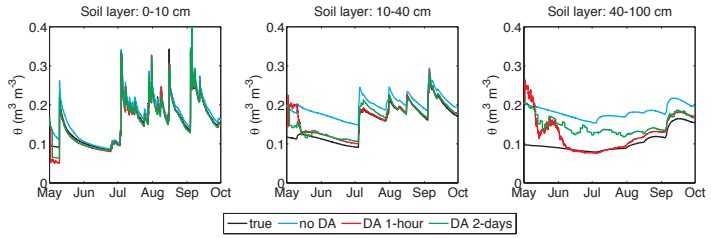

Would like to test those with JULES in the very near future!!!

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