Cosmic ray – new opportunities for subsurface and surface characterization

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Collaborators:
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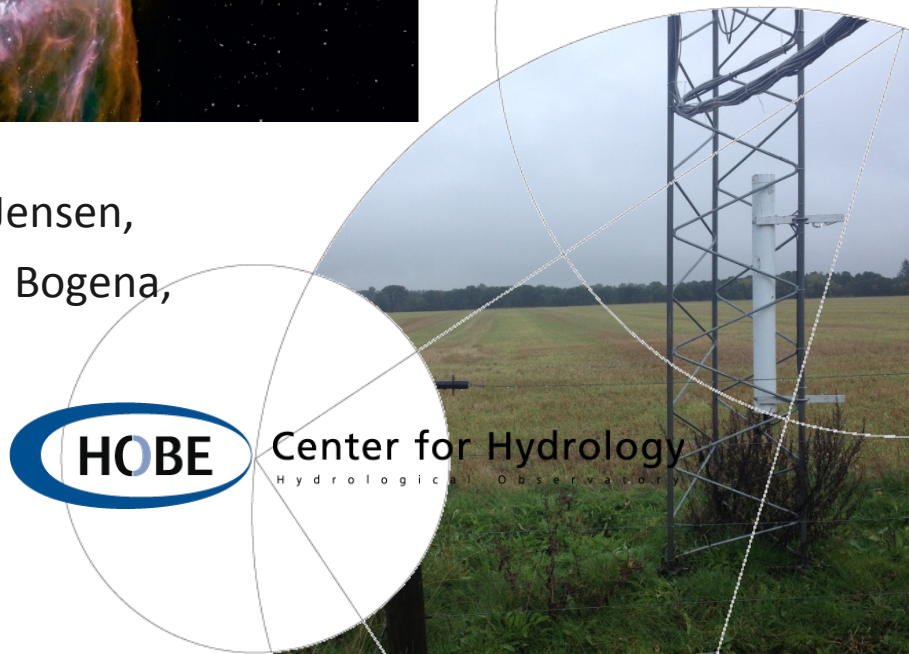
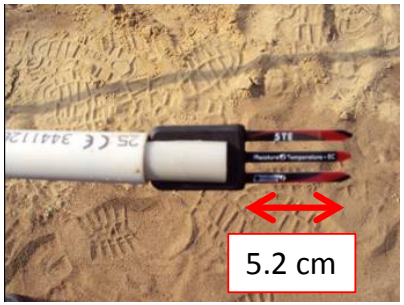
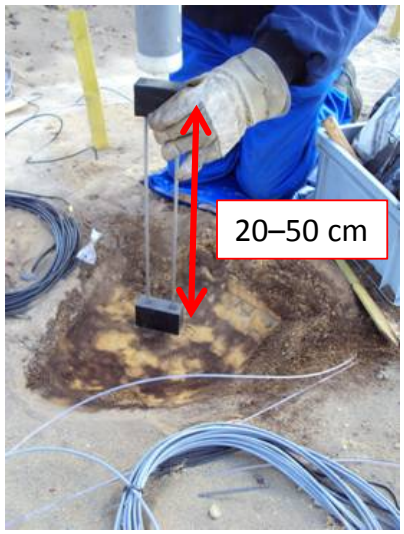


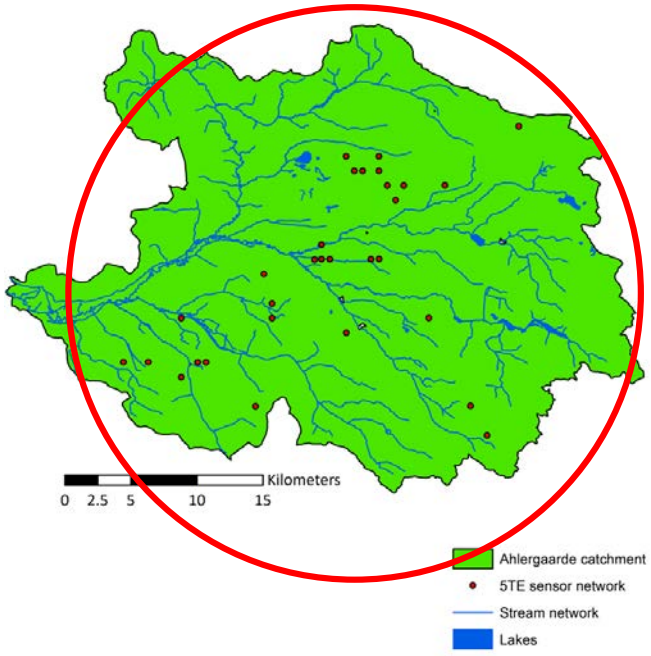
Soil moisture: measurements and scale

Small-scale sensors

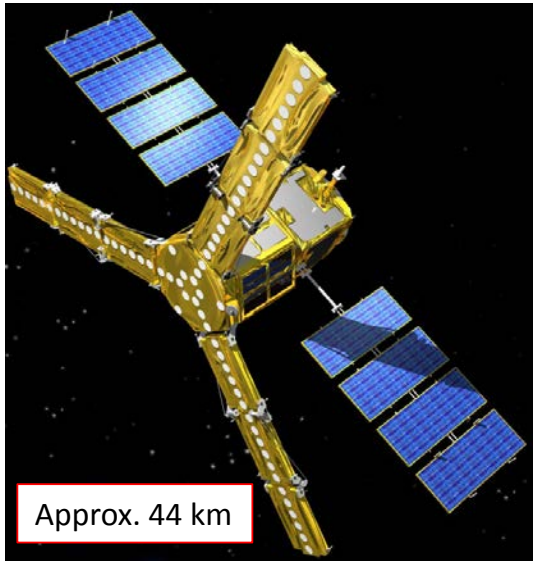




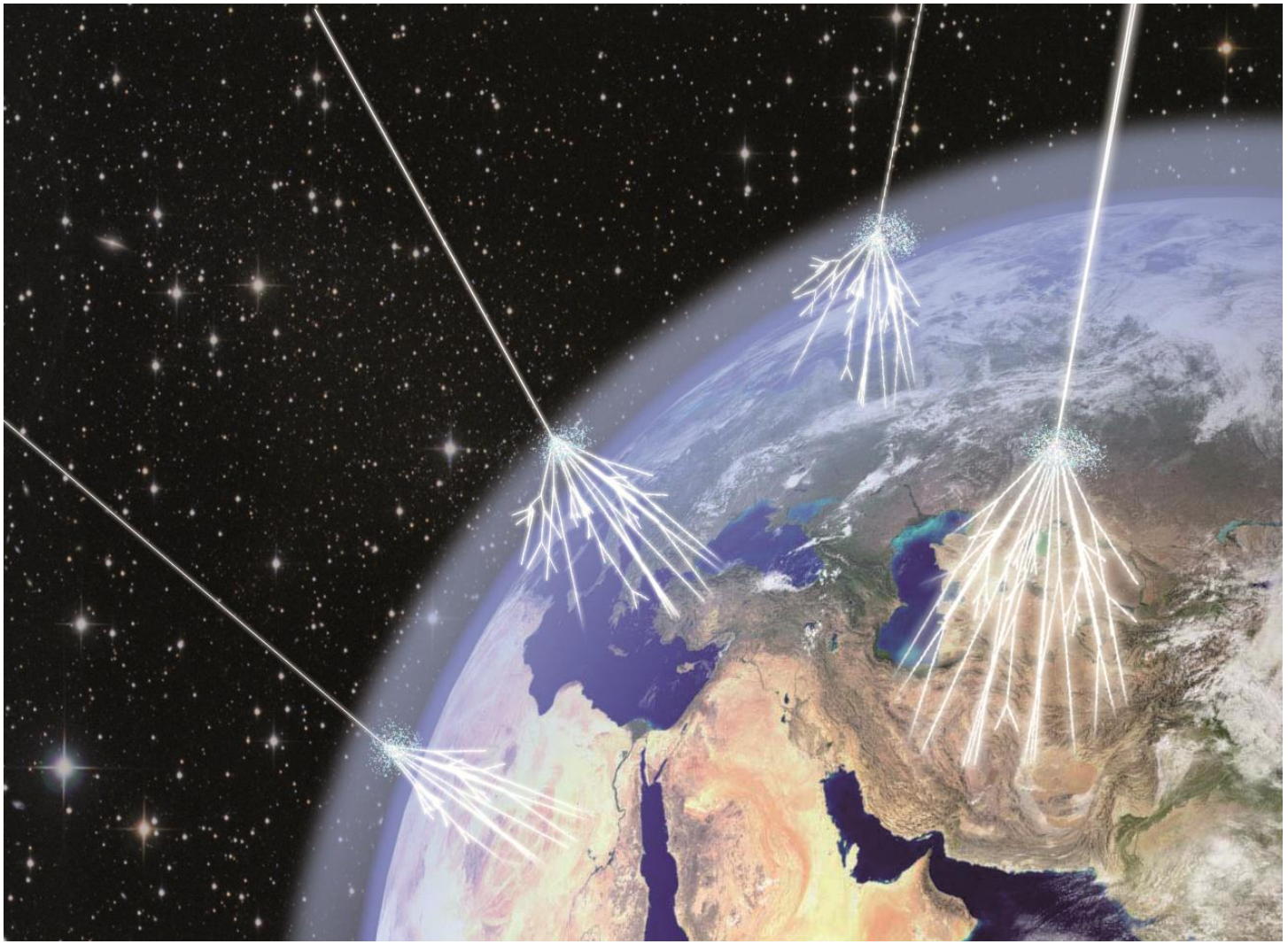
Sensor networks



Large-scale satellite data



Incoming cosmic rays from outer space



Cosmic ray neutrons

From the galaxy/sun

High energy cosmic-ray protons

- *Geomagnetic field and the solar magnetic field*

In the atmosphere

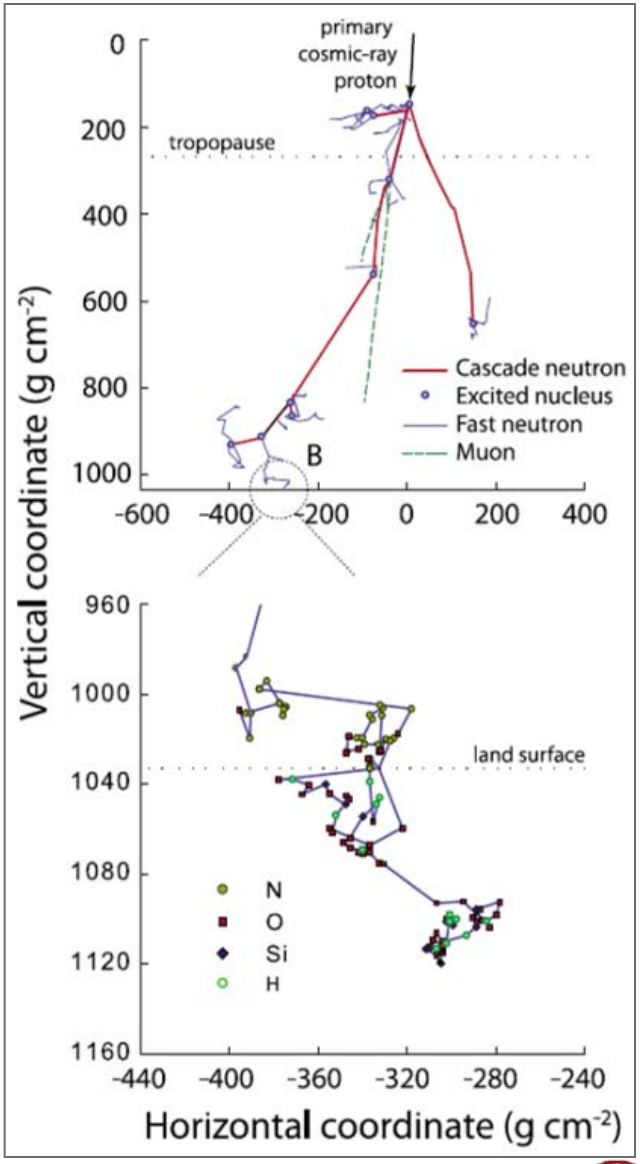
Cascades of secondary cosmic-ray neutrons

- *Elevation and weather conditions (pressure, humidity)*

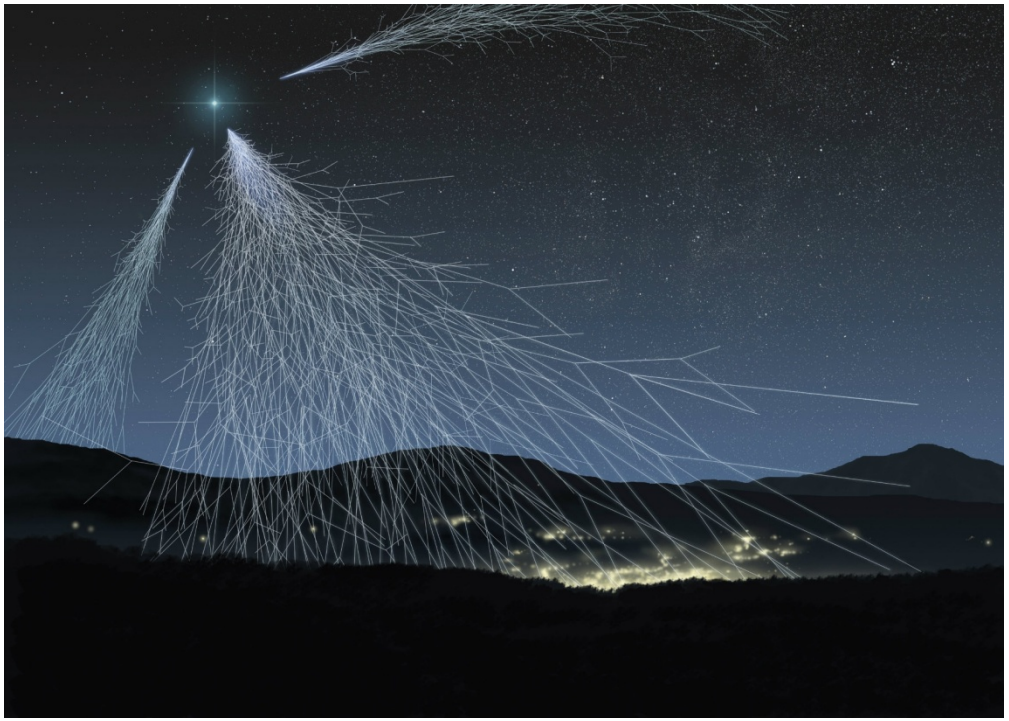
In the soil

Absorption of 'fast' neutrons

- *Soil water content*



Cosmic ray intensity



Sensitive to all hydrogen pools:

- Lattice water
- Soil water
- Surface water
- Atmospheric water
- Biomass water
- Leaf interception

} Water

- Dry biomass
- Soil organic carbon

} Organic matter

Cosmic ray neutrons collisions in the subsurface

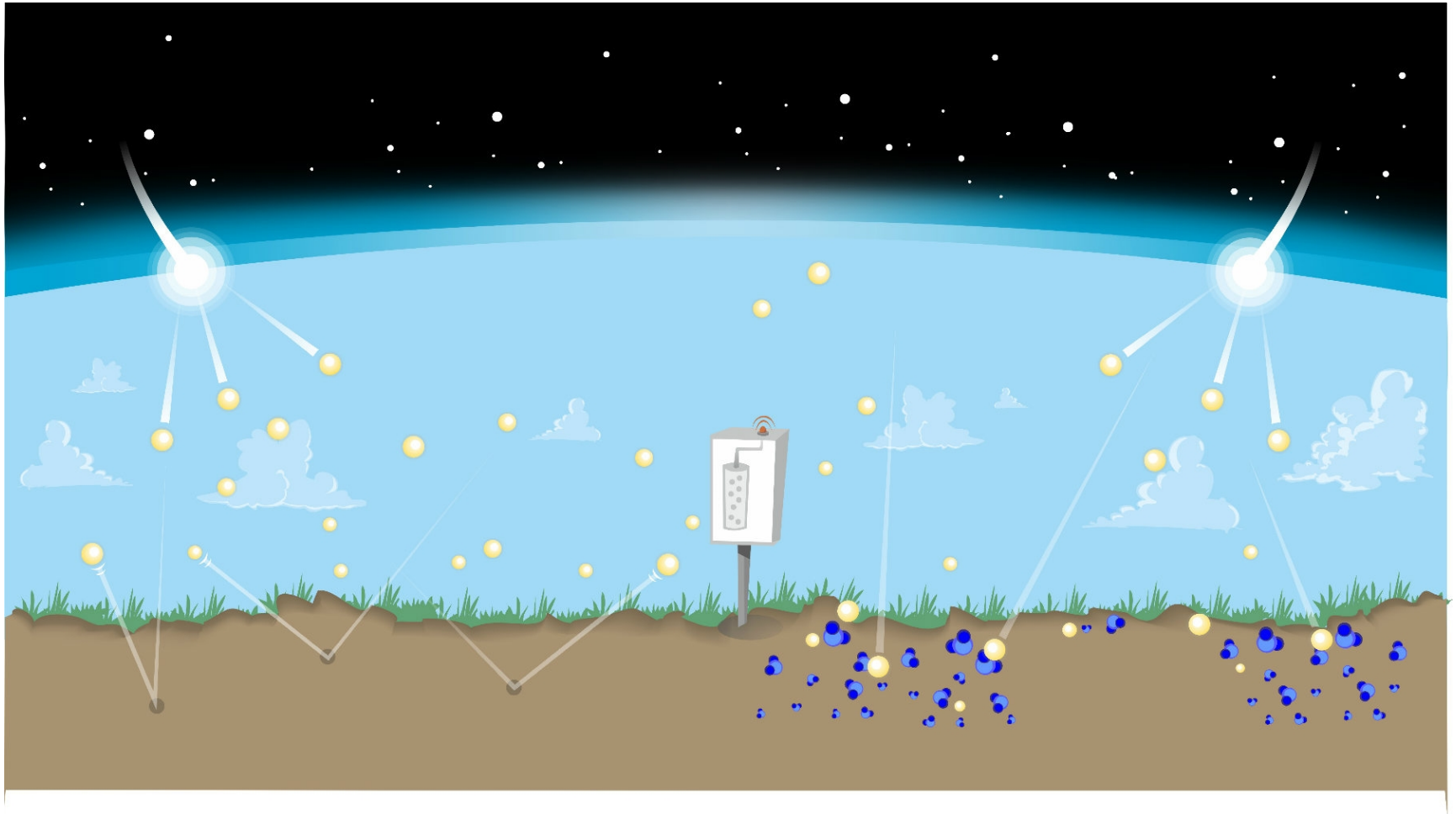
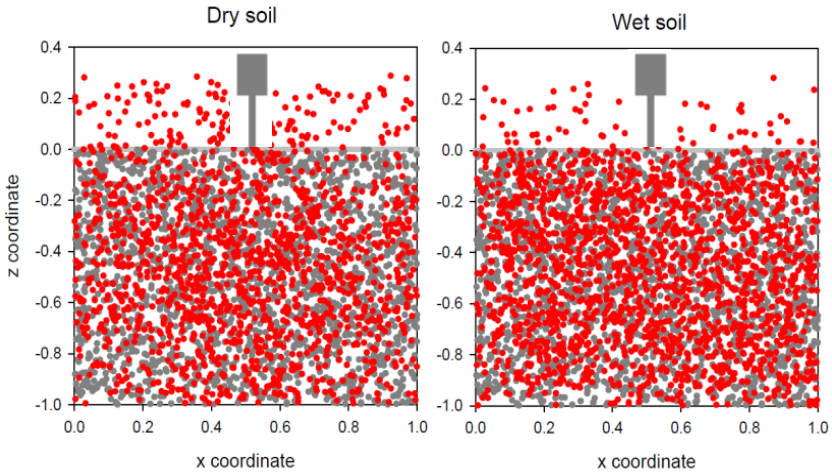
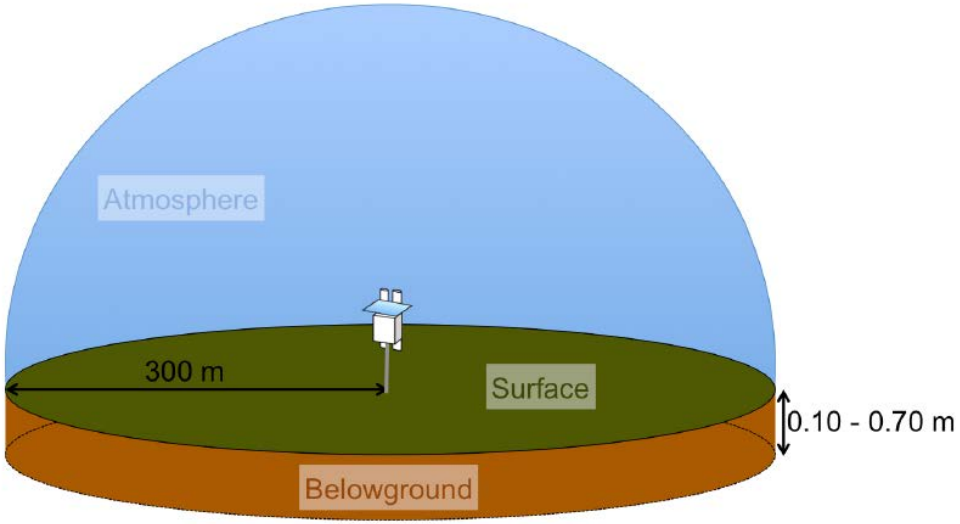


Illustration: Martin Schrön

Cosmic ray neutrons

Neutron intensity and soil water content are inversely correlated

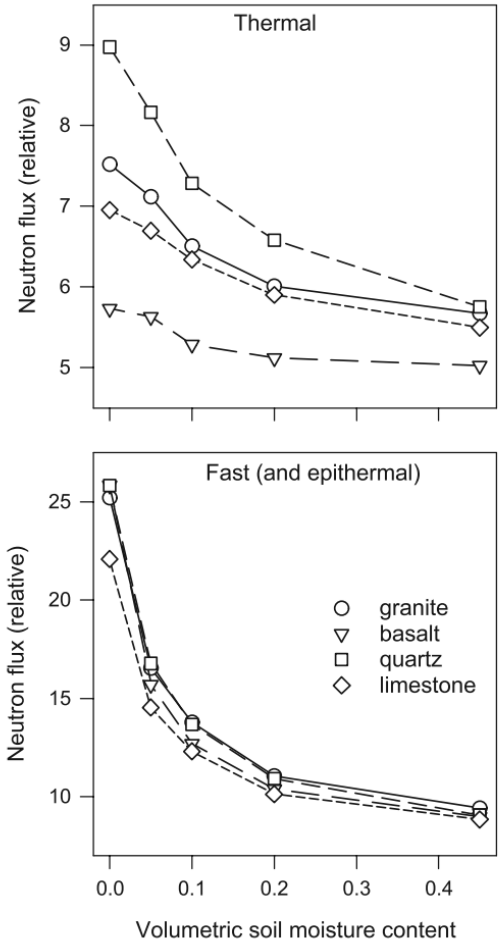


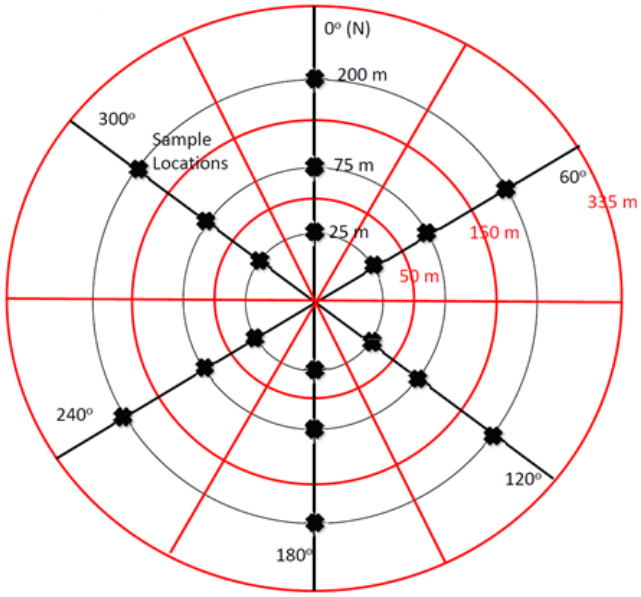


Cosmic ray calibration

Footprint

Gravimetric measurement of soil water: 108 samples

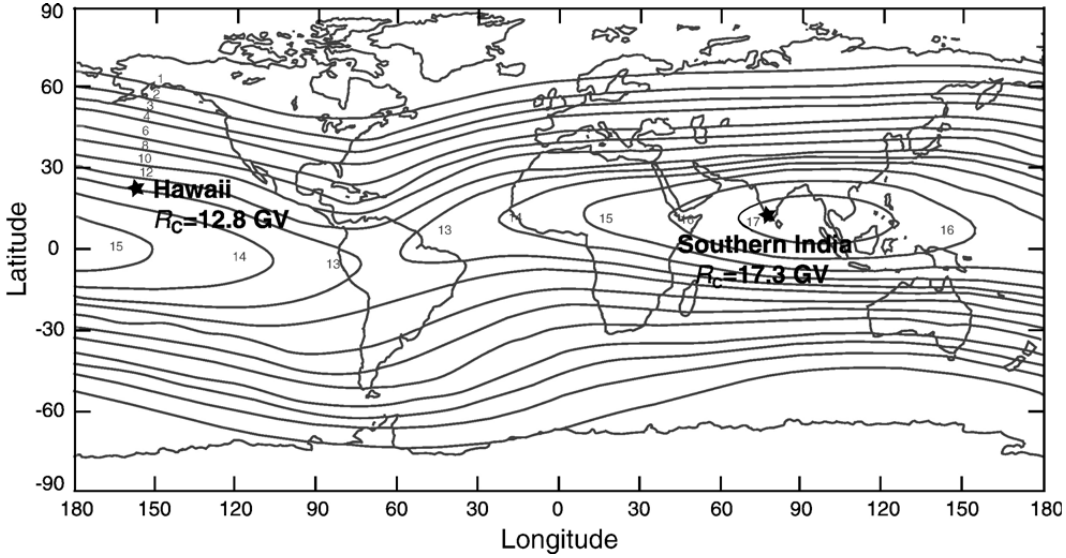




$$\theta(N) = \frac{0.0808}{\left(\frac{N}{N_0}\right) - 0.372} - 0.115$$

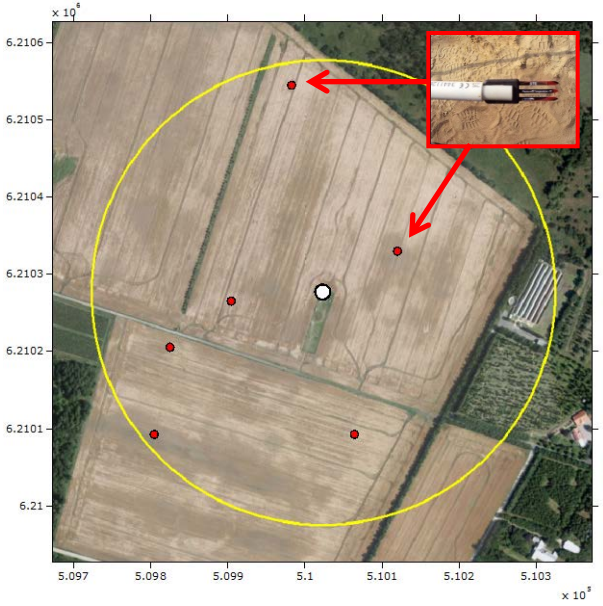
Correction

- Incoming cosmic-ray neutron activity
- Air pressure
- Relative humidity

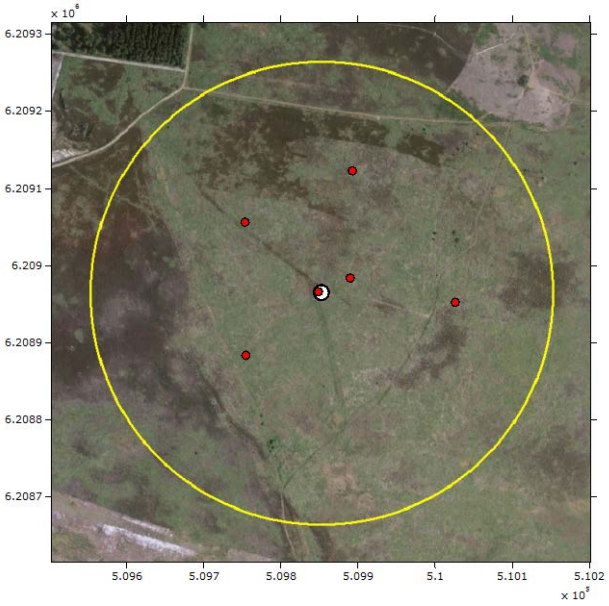


Fieldsites: three land cover types

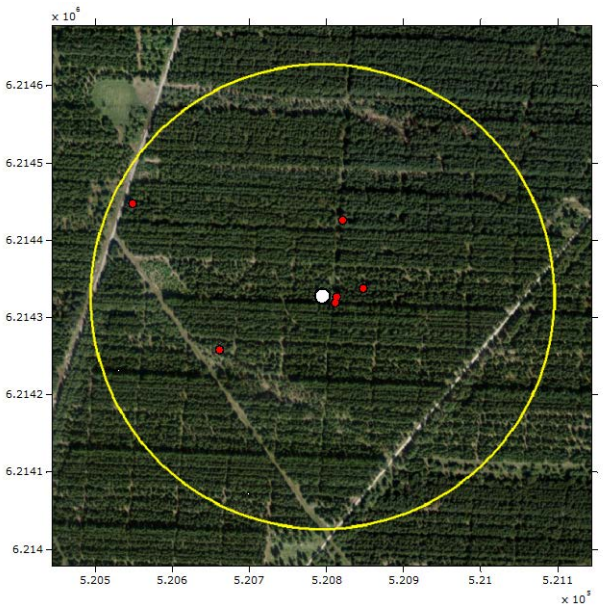
Agriculture



Heathland



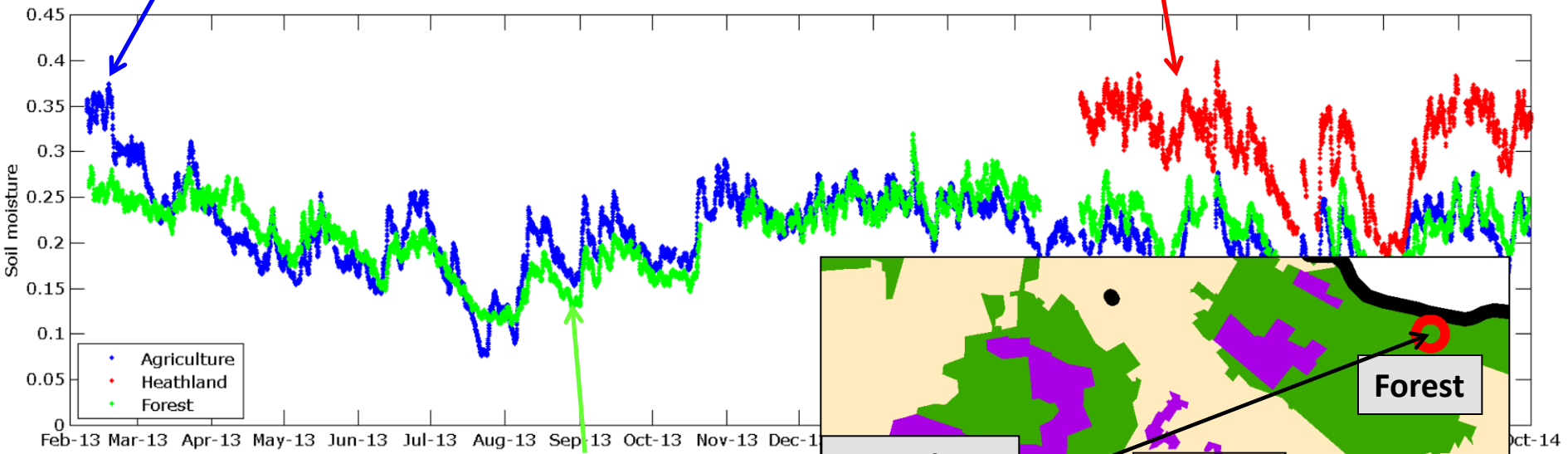
Forest



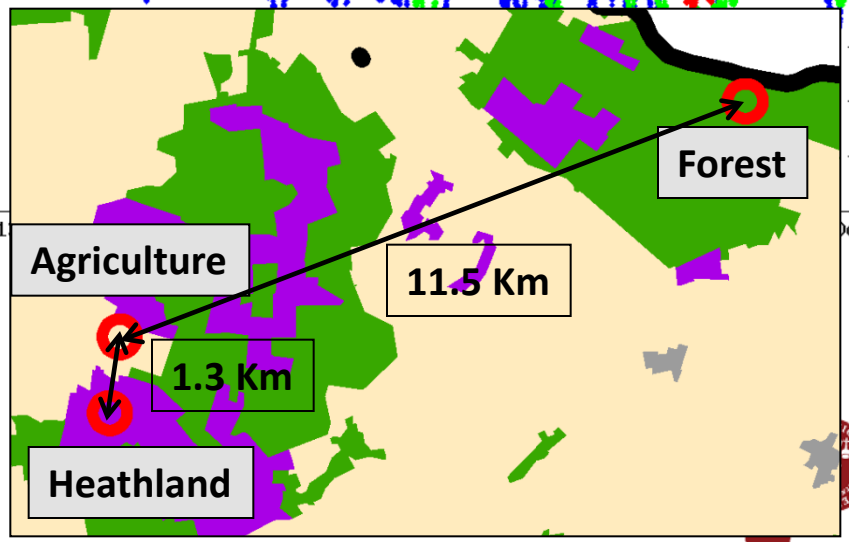
Soil moisture time series

Agriculture

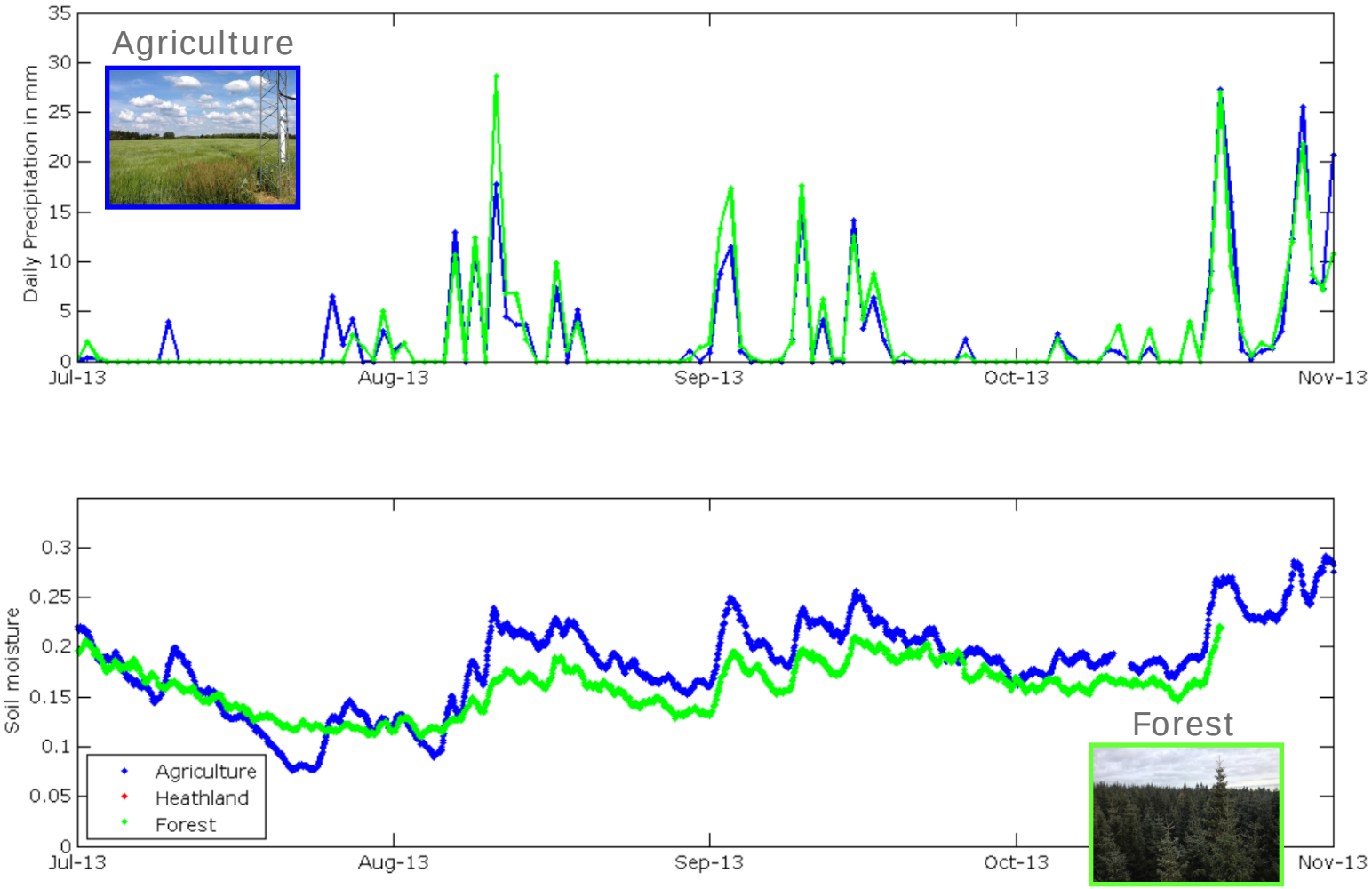
Heathland



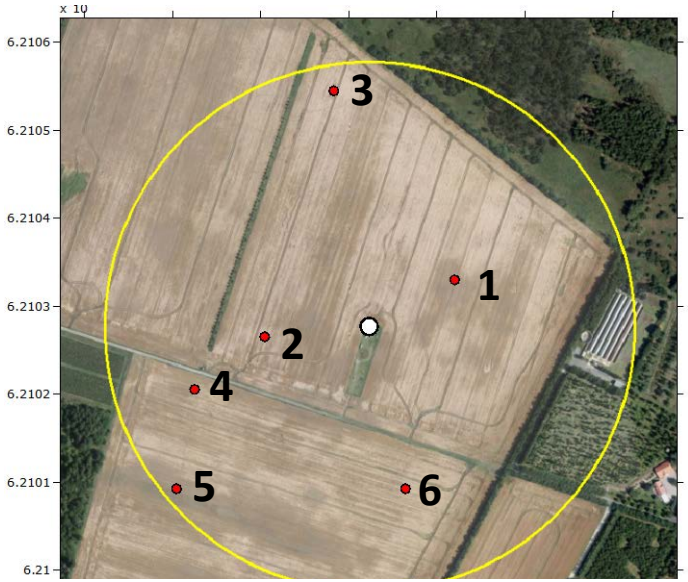
Forest

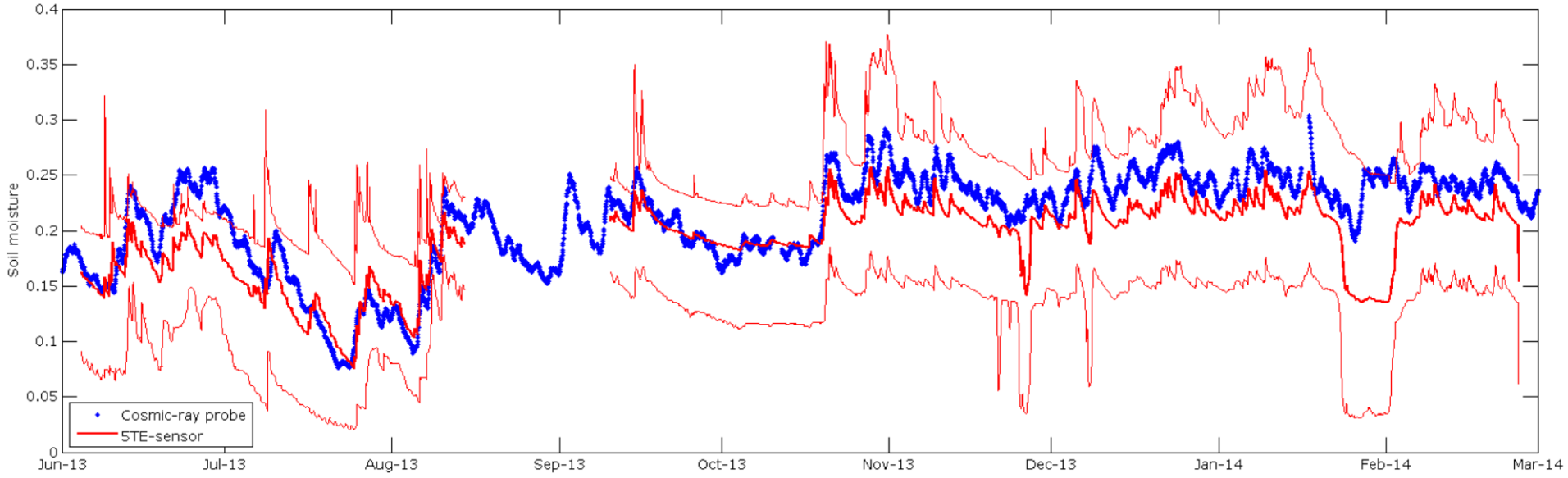


Effect of precipitation



Comparison to local measurements





Cosmic ray sensoring

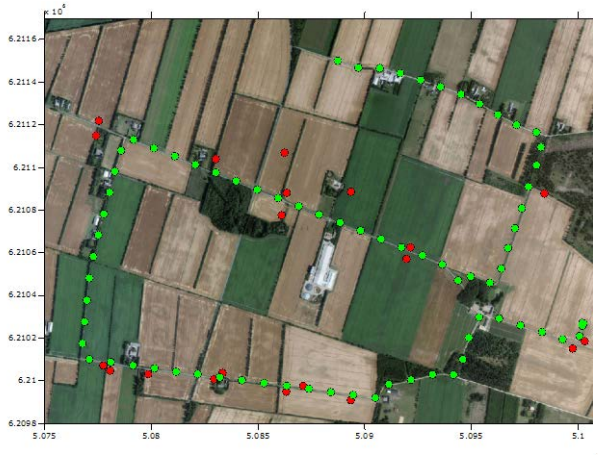
Stationary sensor

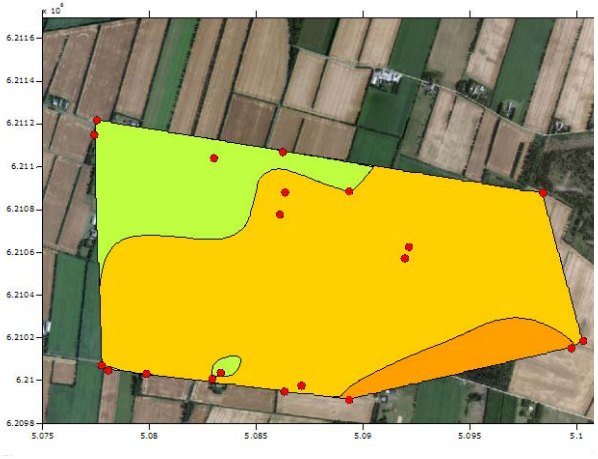
Movable sensor “Rover”

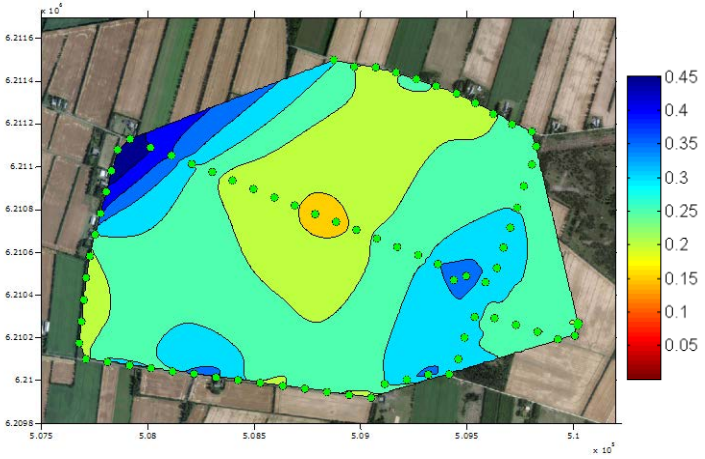
Agricultural site

Core samples 

Rover data 



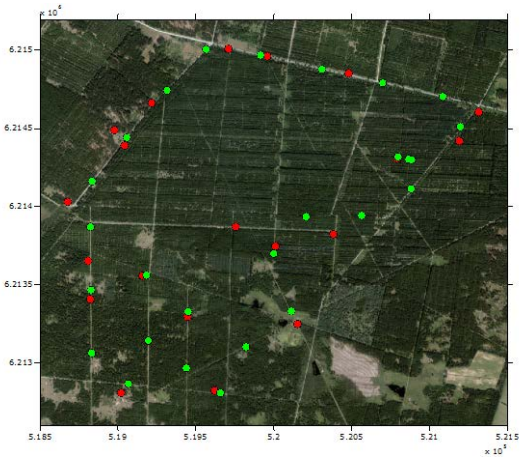


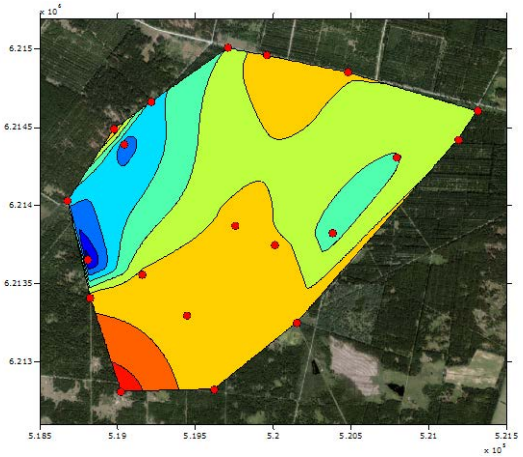


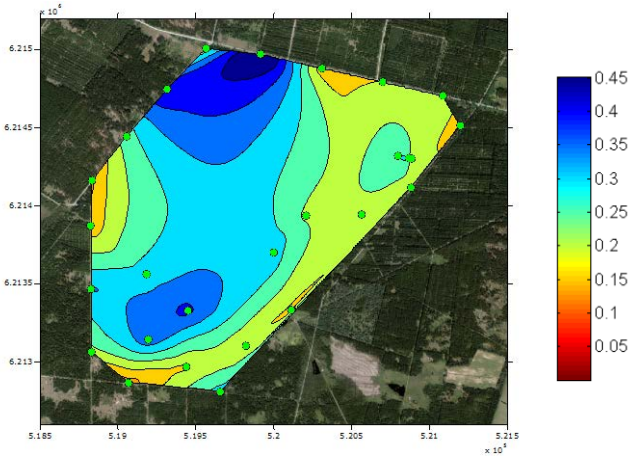
Forest site

Core samples 

Rover data 



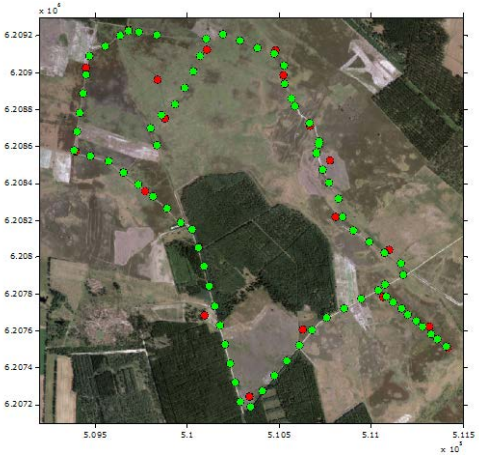


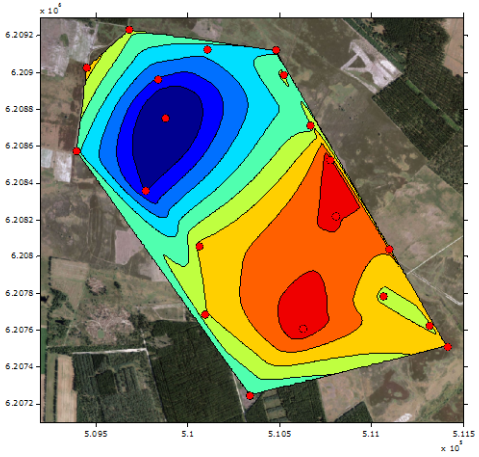


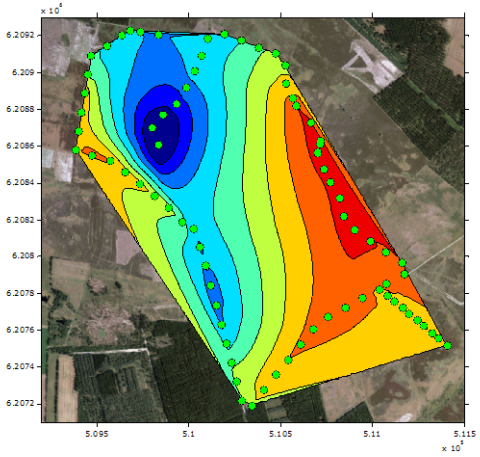
Heathland site

Core samples 

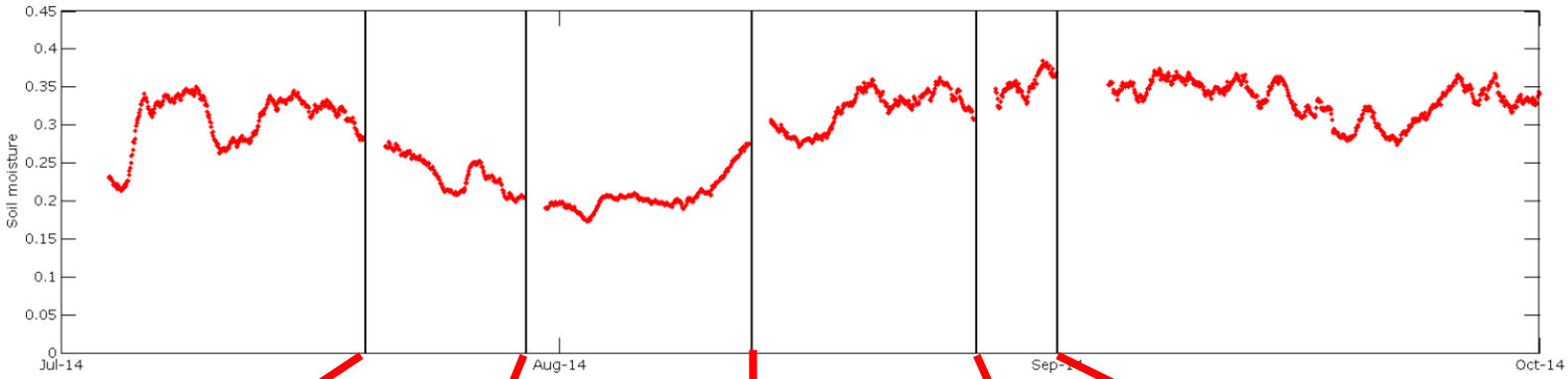
Rover data 



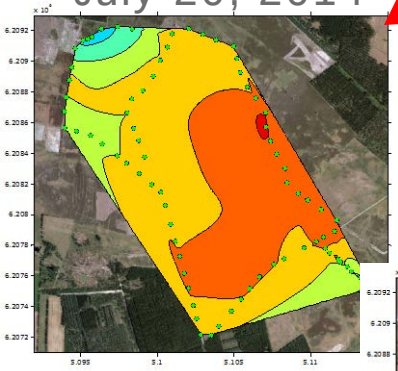




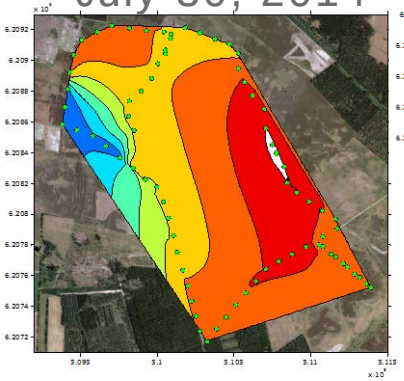
Heathland site



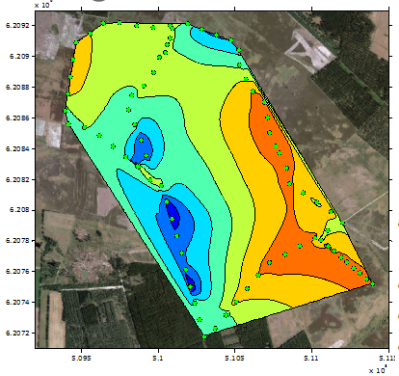
July 20, 2014



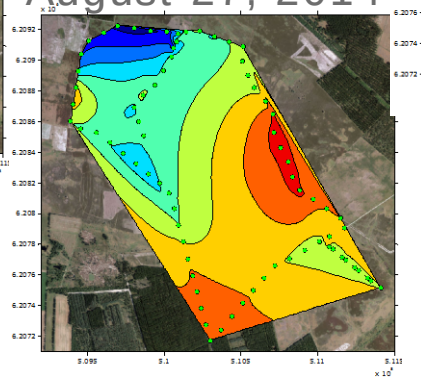
July 30, 2014



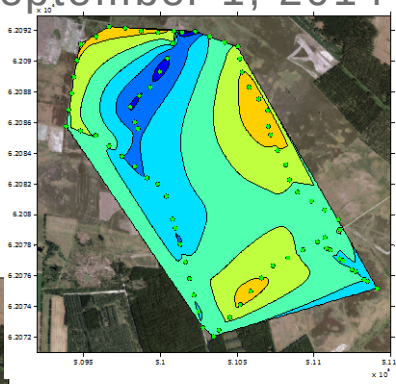
August 13, 2014



August 27, 2014



September 1, 2014



Gludsted Forest

Cosmic-ray neutron probes:

MOD and BARE probes are installed at the:

-ground surface (1.5 m; “Ground”)

-canopy surface (27.6 m; “Tower”)

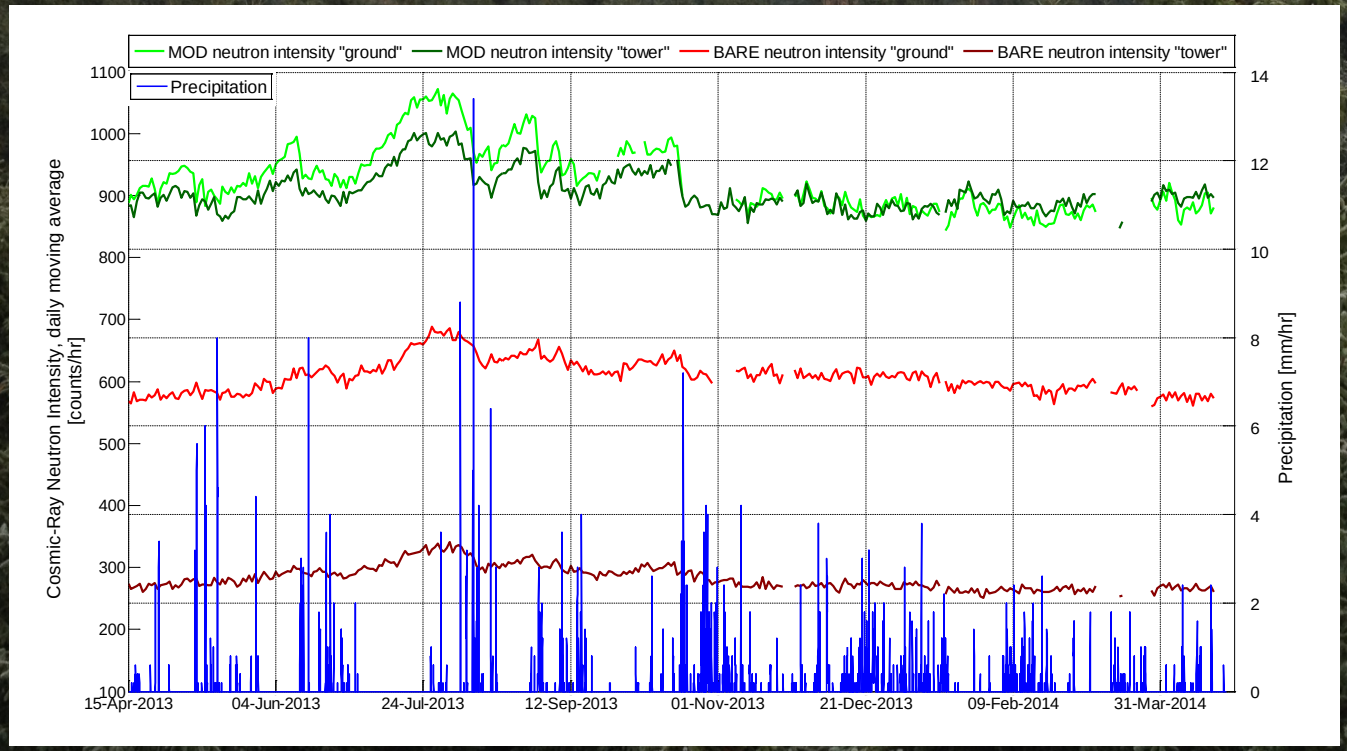
”Tower” probes

”Ground” probes

Stationary Cosmic-ray neutron intensity measurements

April 2013 – April 2014

Data is daily moving average



"Tower" probes

"Ground" probes