Markus Köhli Jannis Weimar Martin Schrön Ulrich Schmidt

7.3.2018

Soil Moisture measurement at the hectometer scale

using

CRNS

for

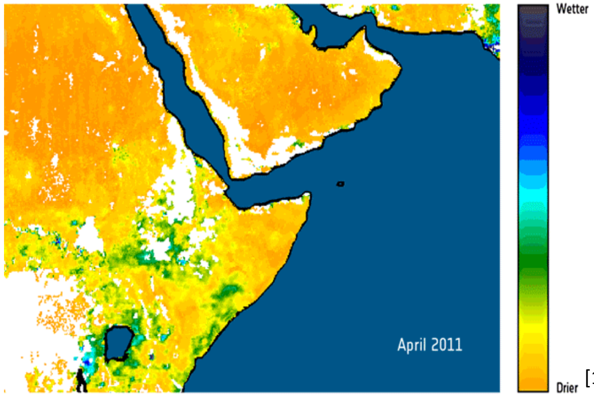
mobile applications

DPG Frühjahrstagung Erlangen

UP 8.2

The Measurement Gap

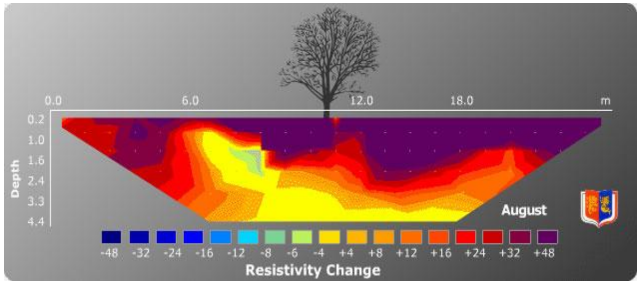
~ 1 km



[1]

via
satellite remote sensing
(optical, microwave)

< 10 m



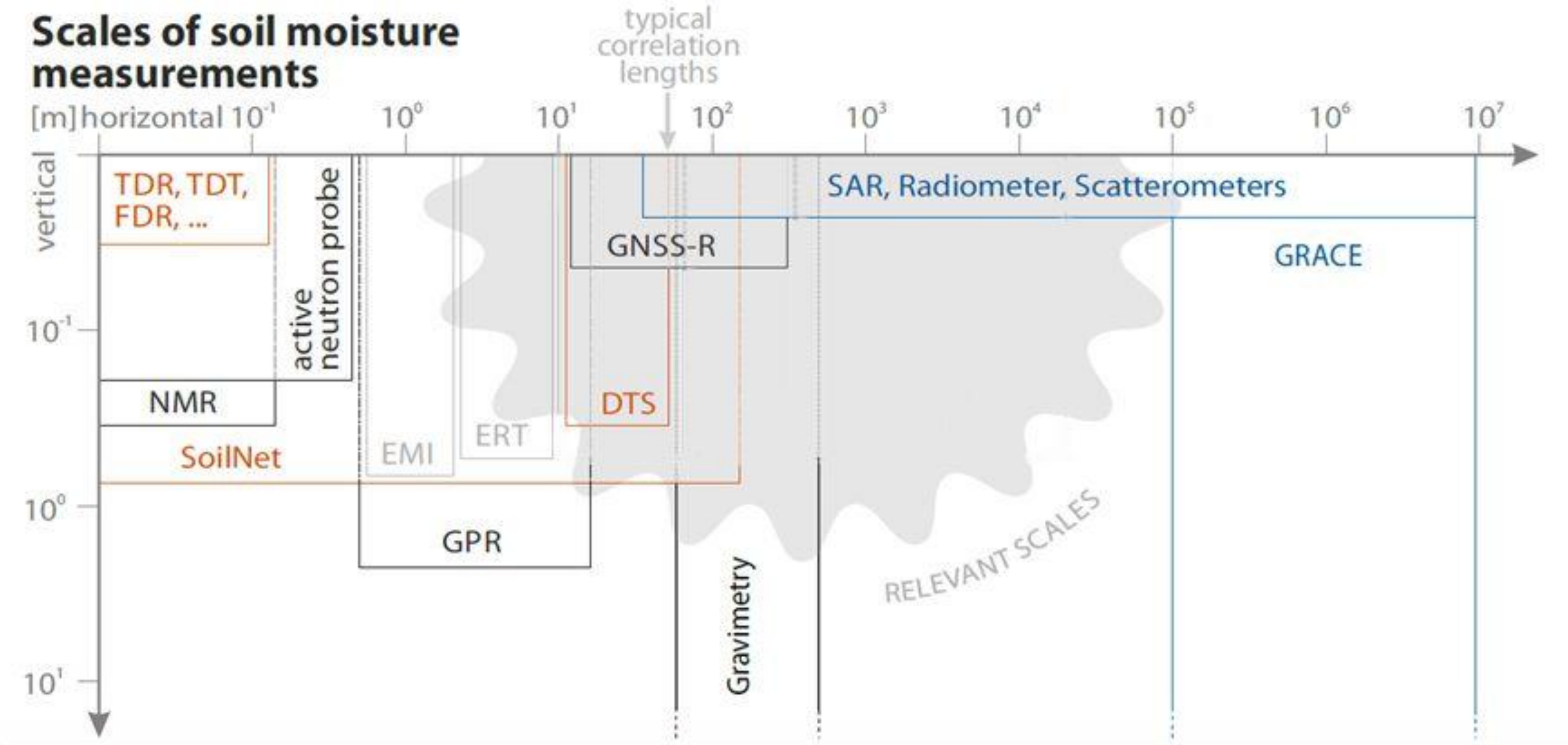
[2]

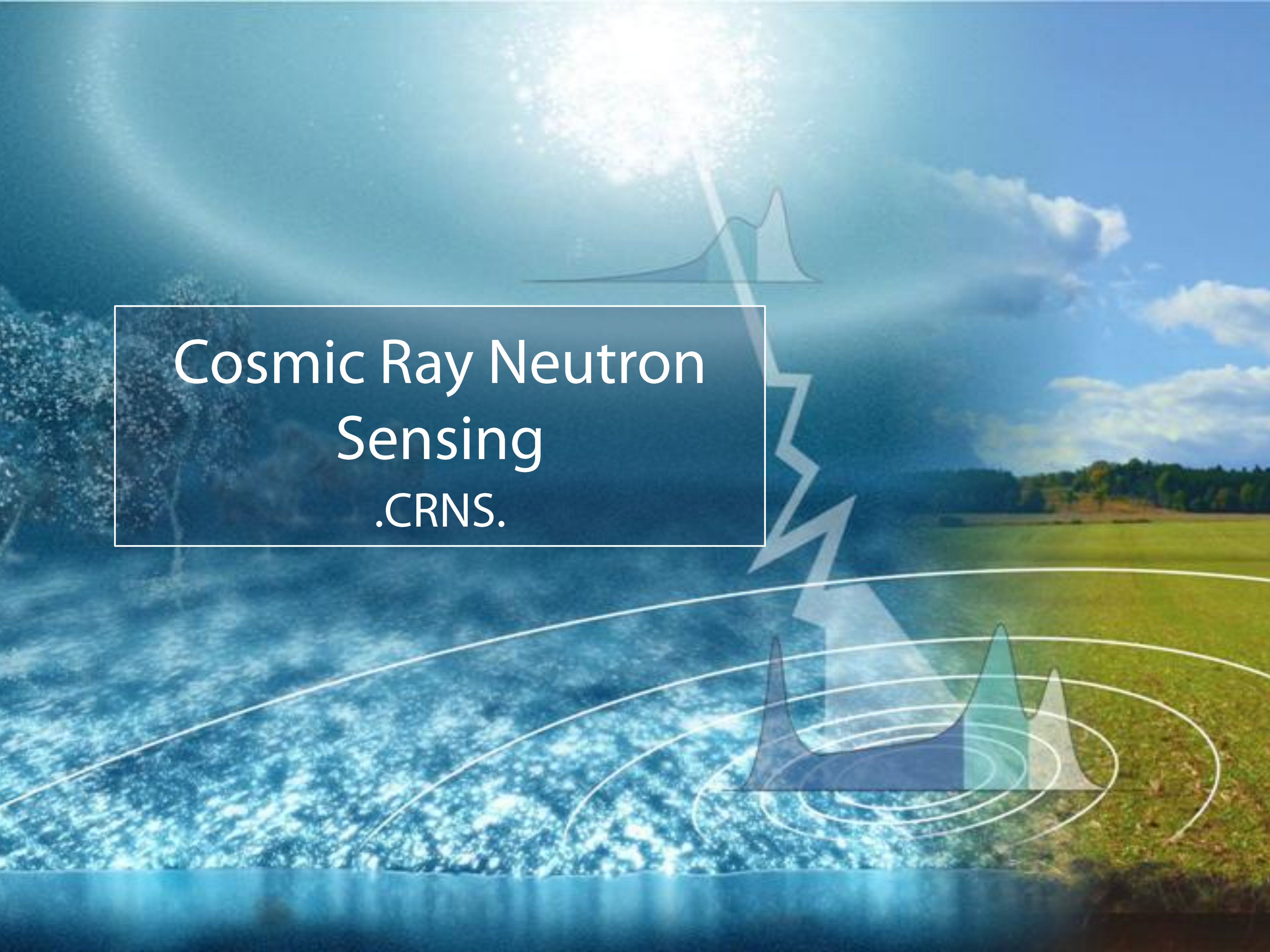
via
local techniques
(electrical resistivity, capacitance, etc)
(even neutrons…)

[1] ESA SMOS (http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS/Horn_of_Africa_drought_seen_from_space)
[2] The Clay Research Group (http://www.theclayresearchgroup.org/images/ert.jpg)

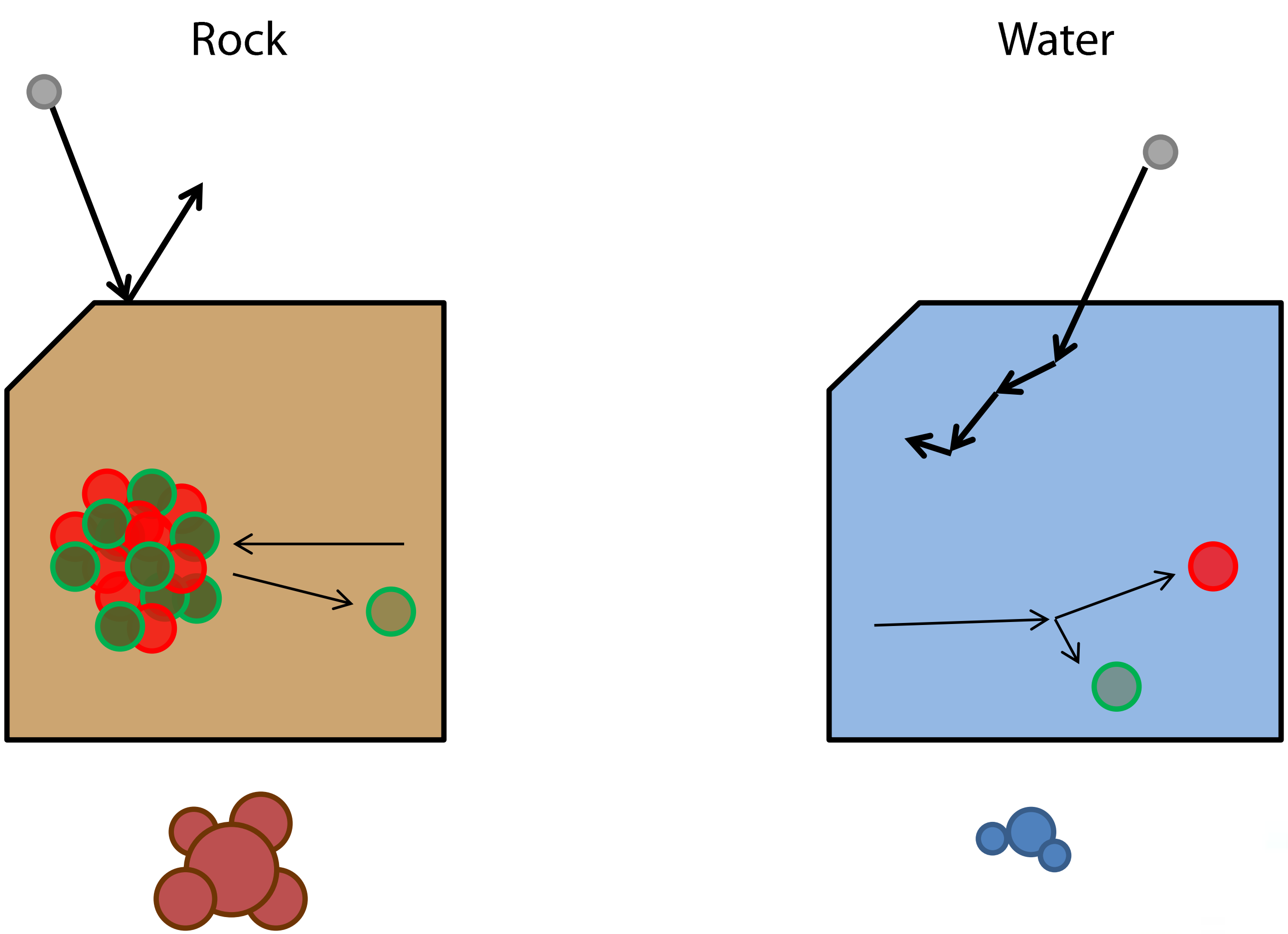
The Measurement Gap

1




Cosmic Ray Neutron
Sensing
.CRNS.

Neutron Response to Water



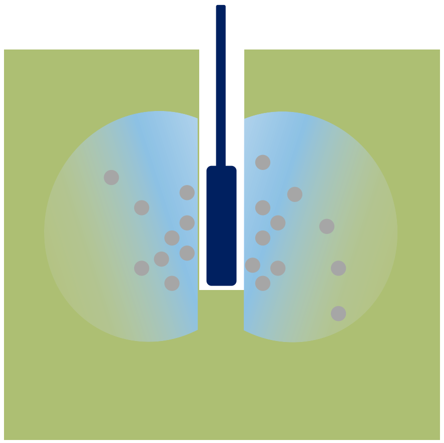
Neutron Response to Water

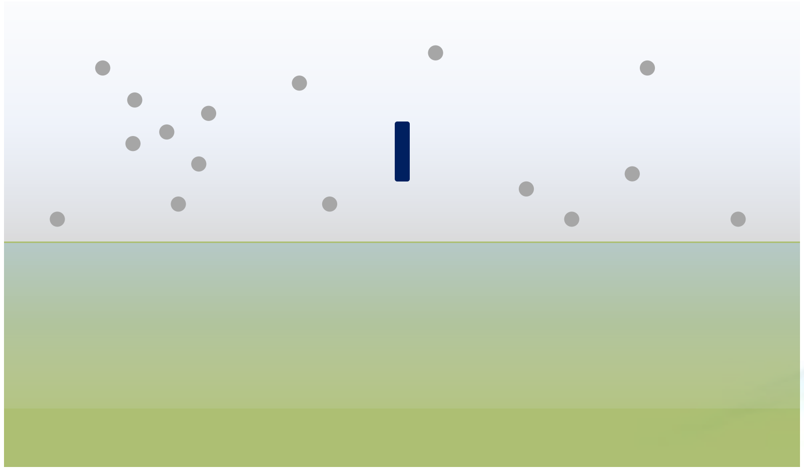
active

small distinct domain
thermalization

passive

large area, diffusive
reflection





Neutron Response to Water

passive

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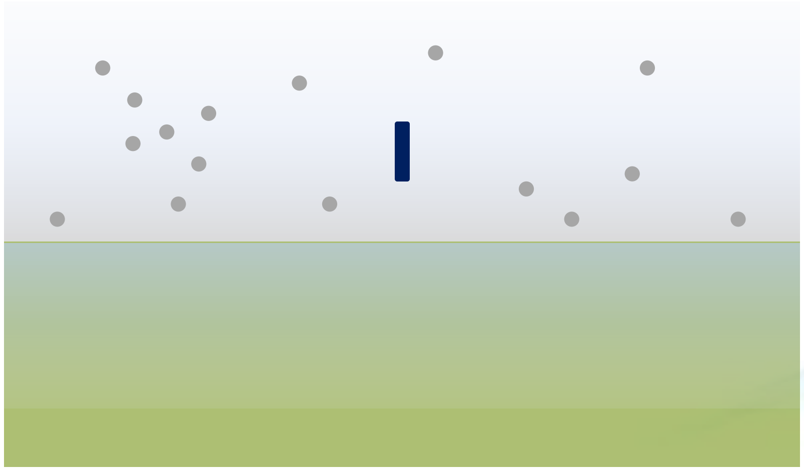
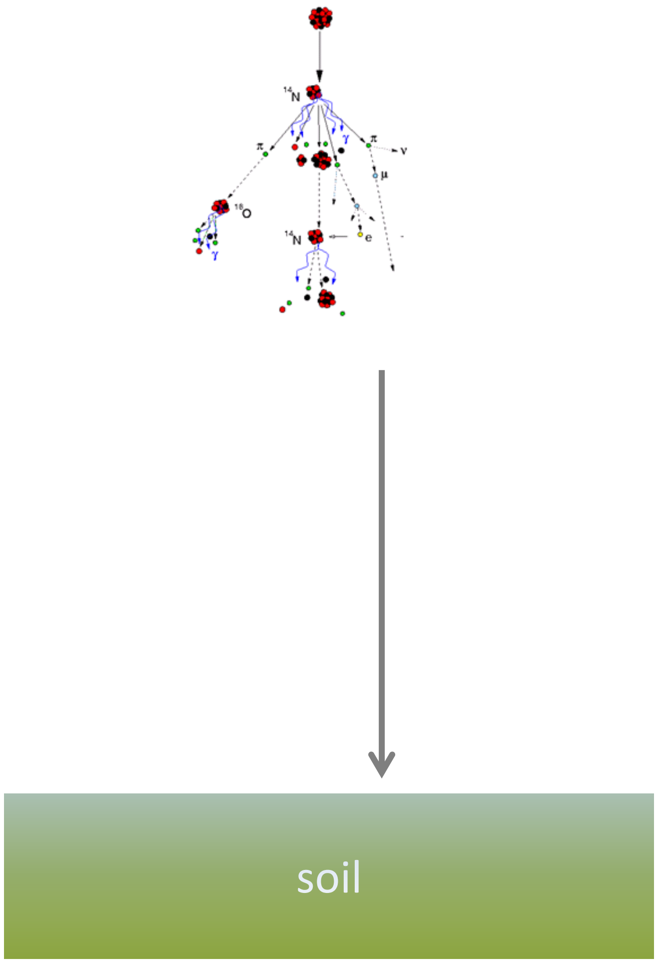
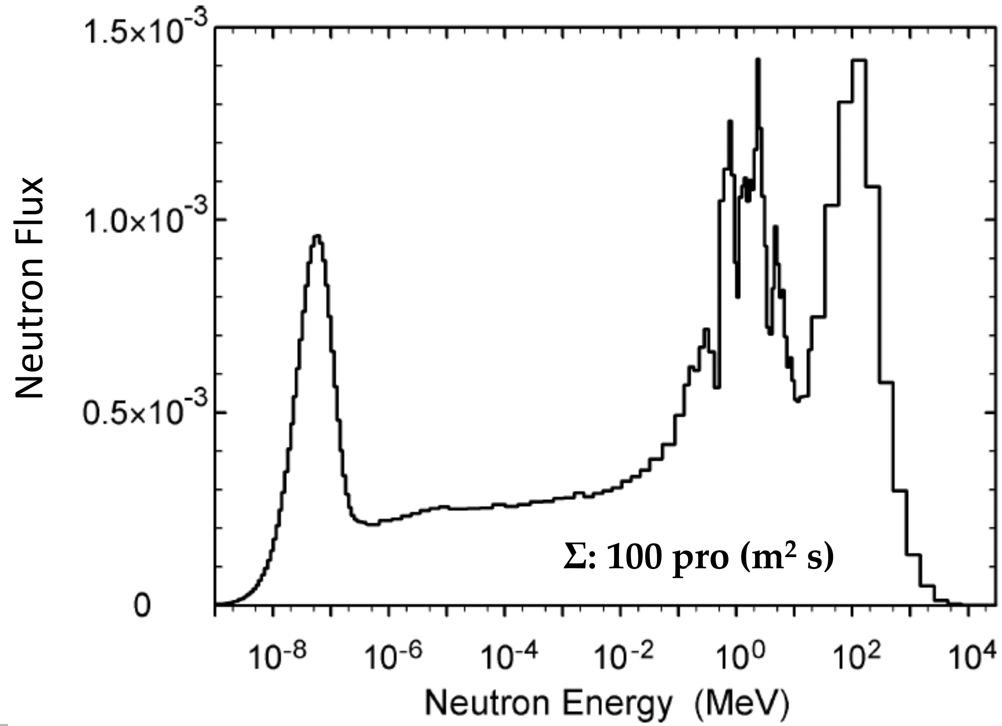
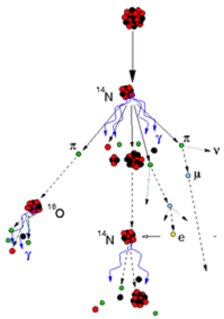


The Cosmic Neutron Spectrum



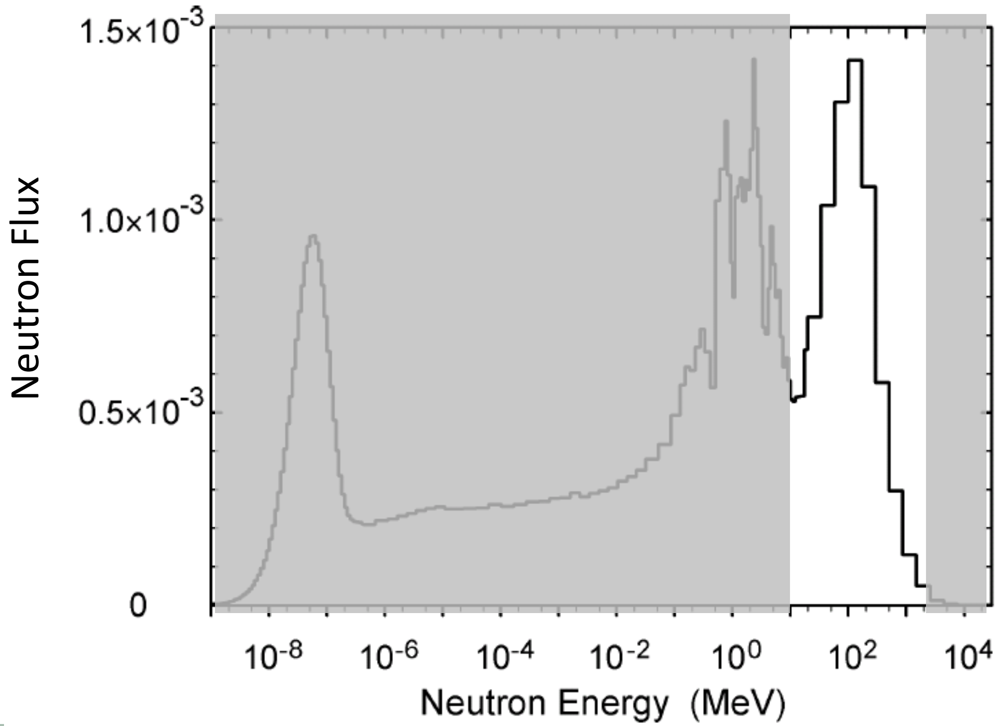


The Cosmic Neutron Spectrum

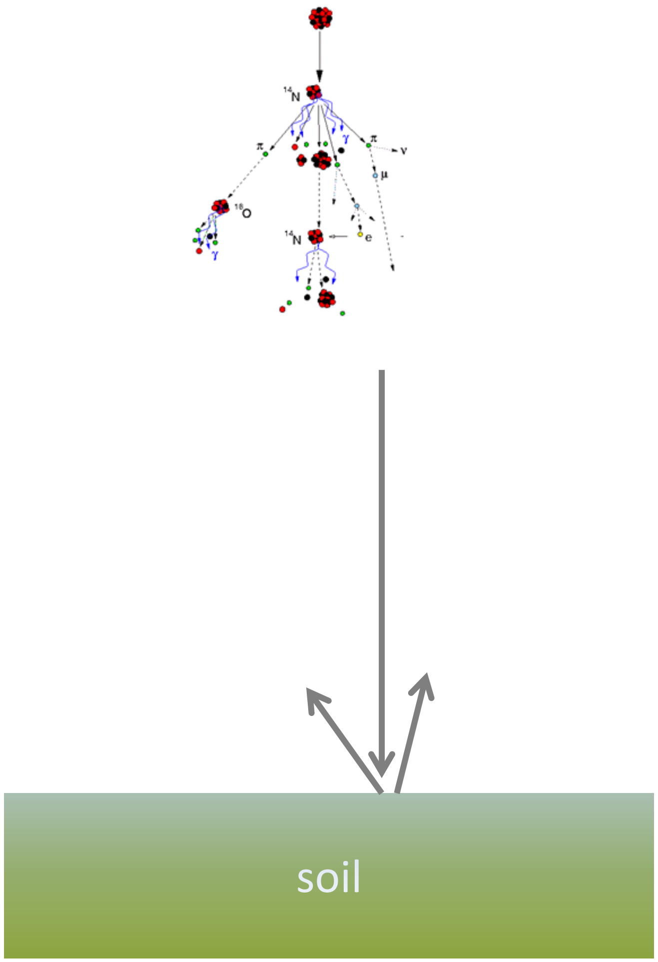


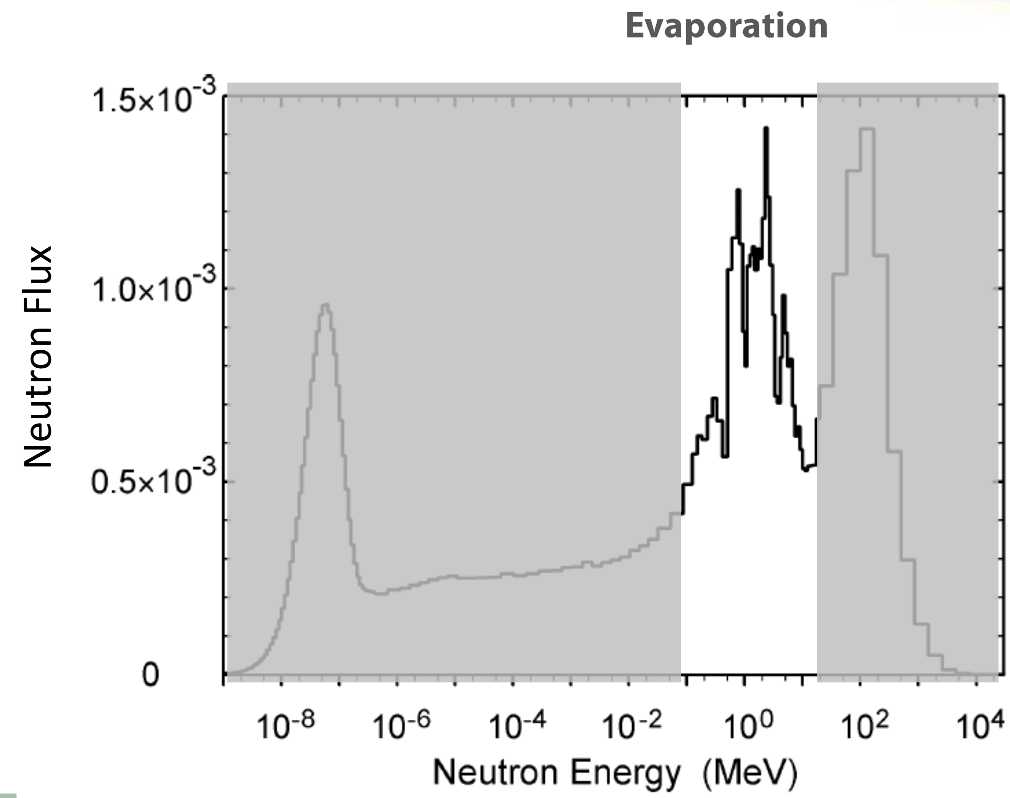
soil

Base Spectrum

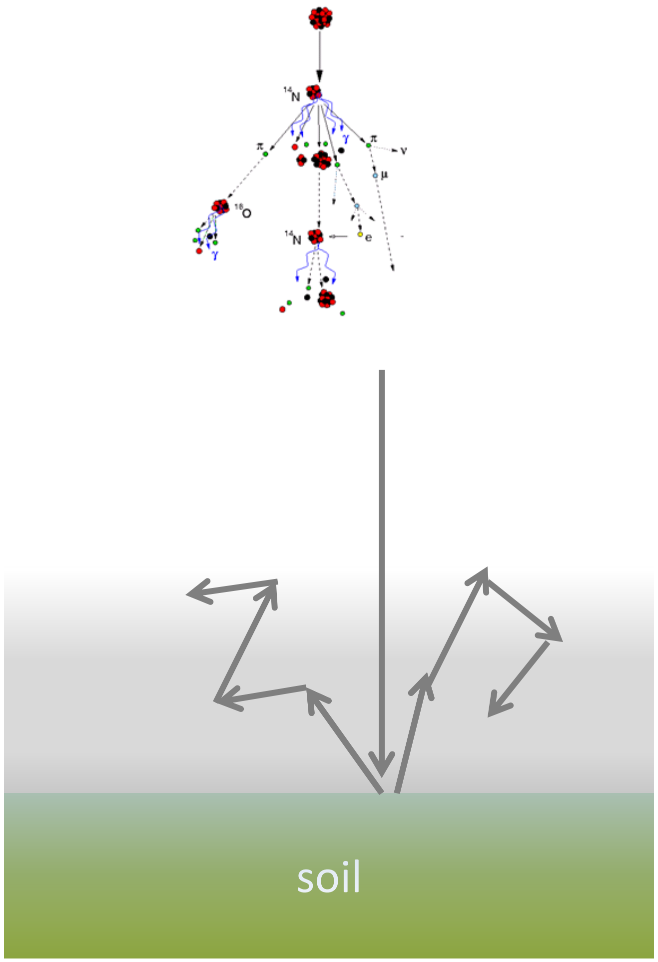


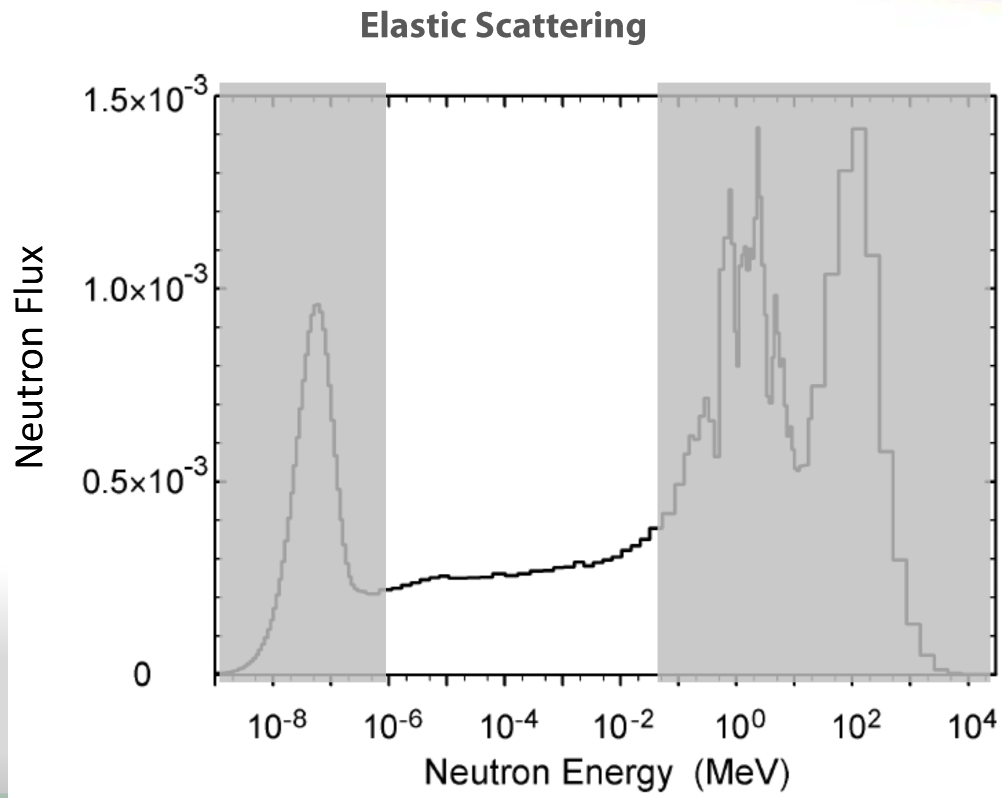
The Cosmic Neutron Spectrum



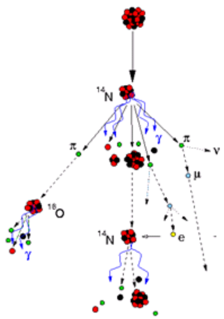


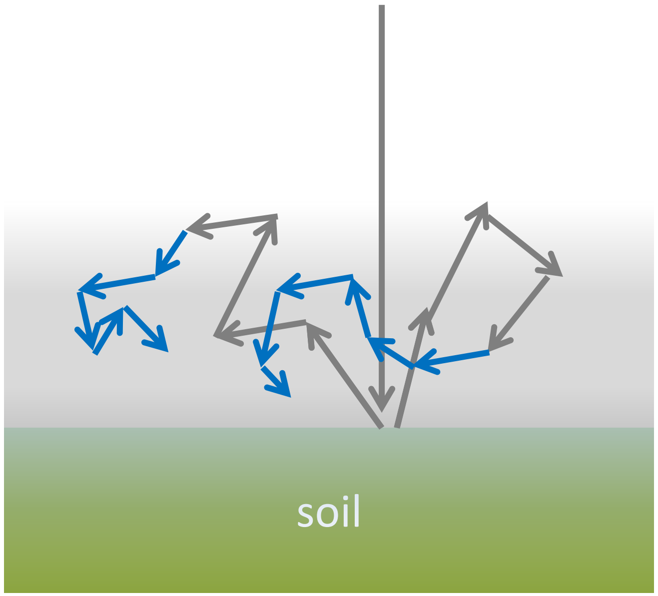
The Cosmic Neutron Spectrum

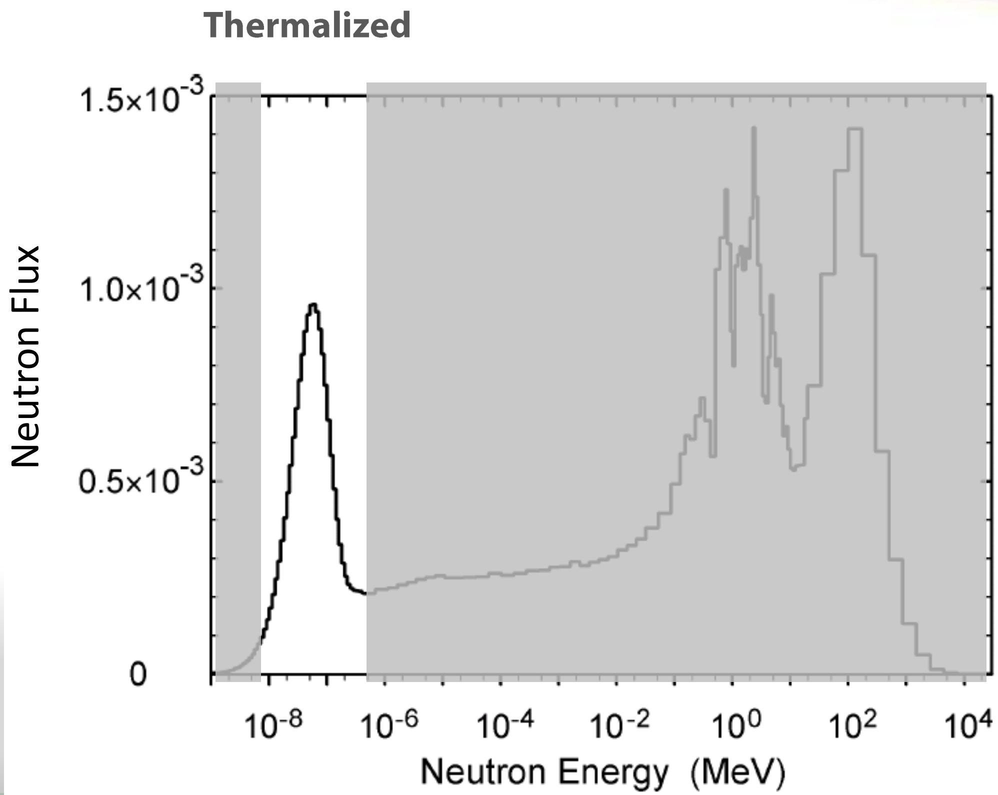




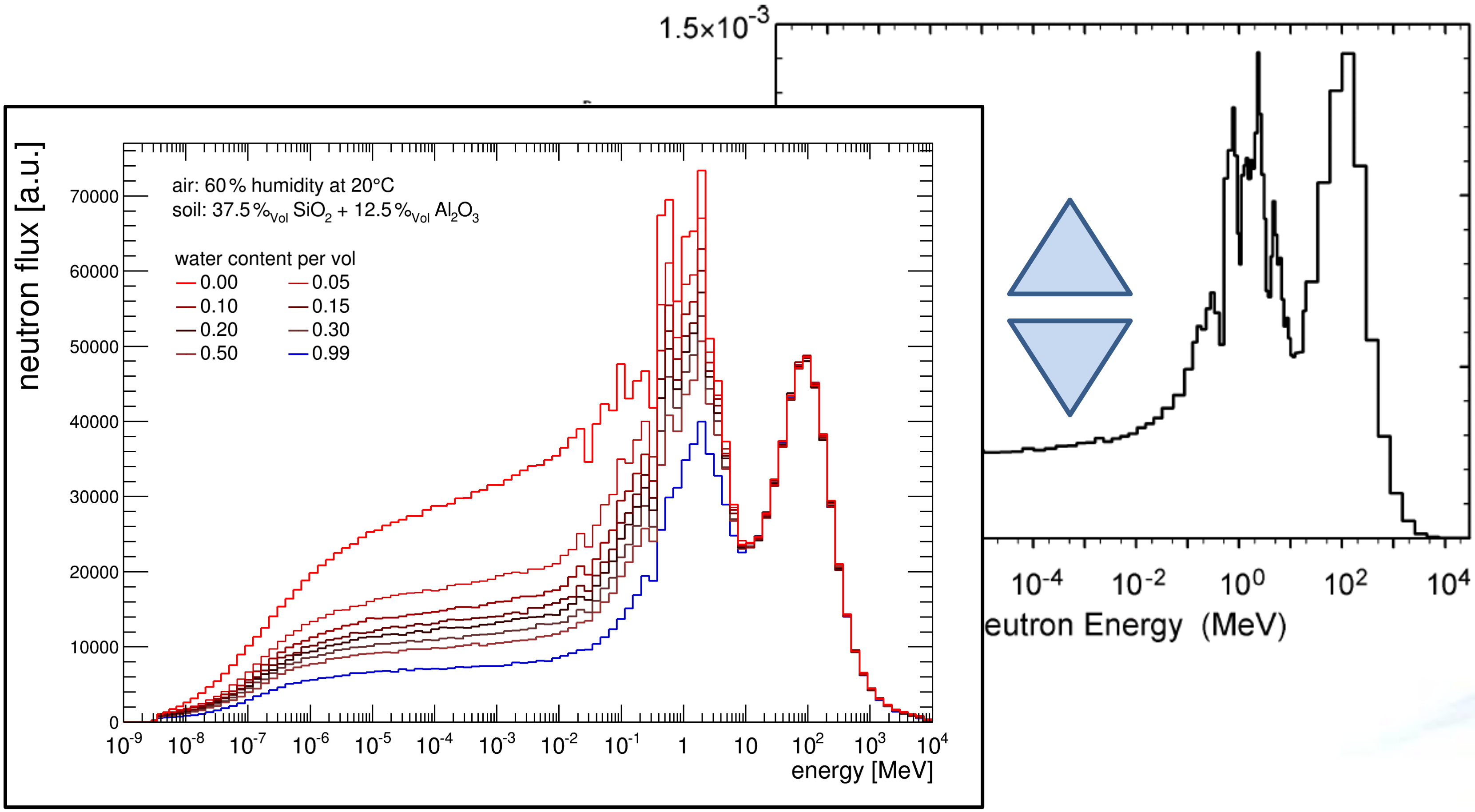
The Cosmic Neutron Spectrum



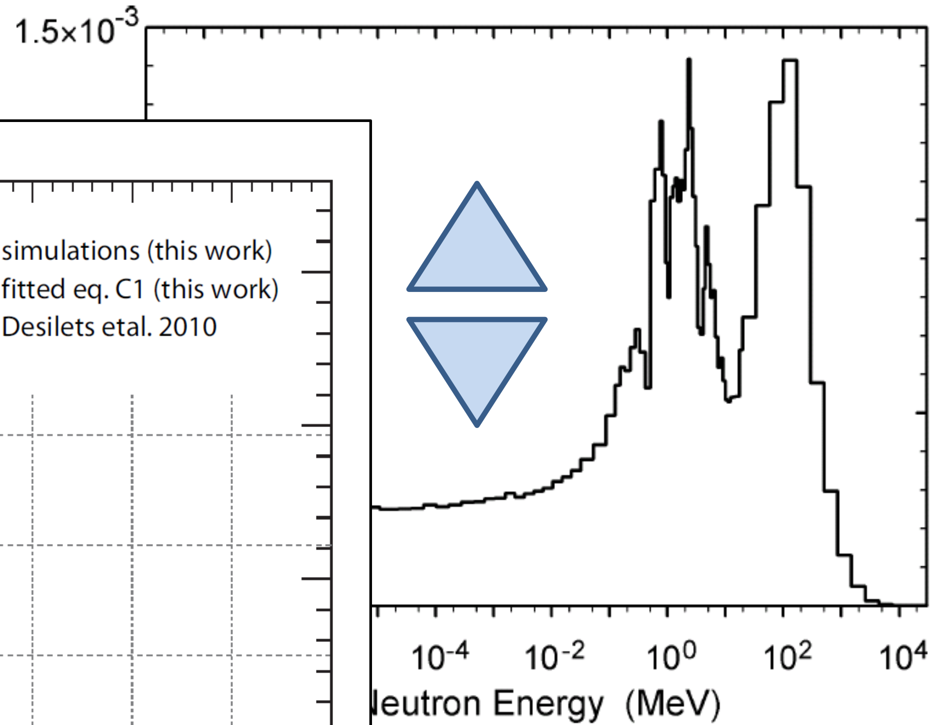


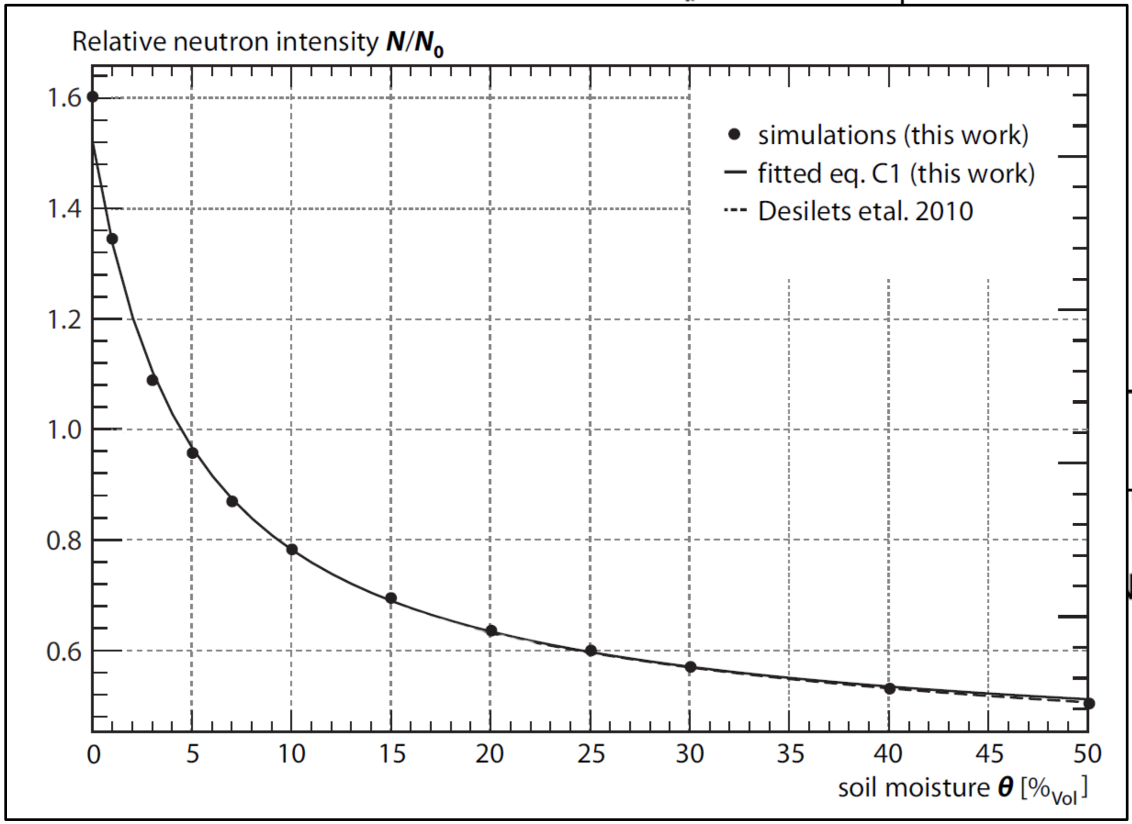


The Cosmic Neutron Spectrum



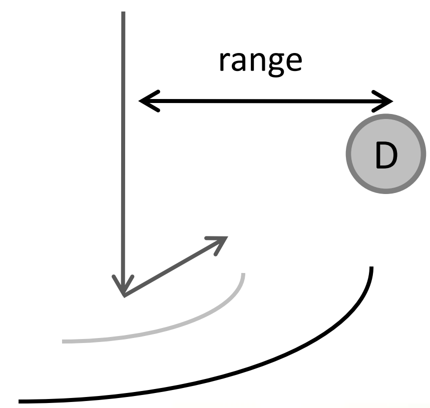
The Cosmic Neutron Spectrum





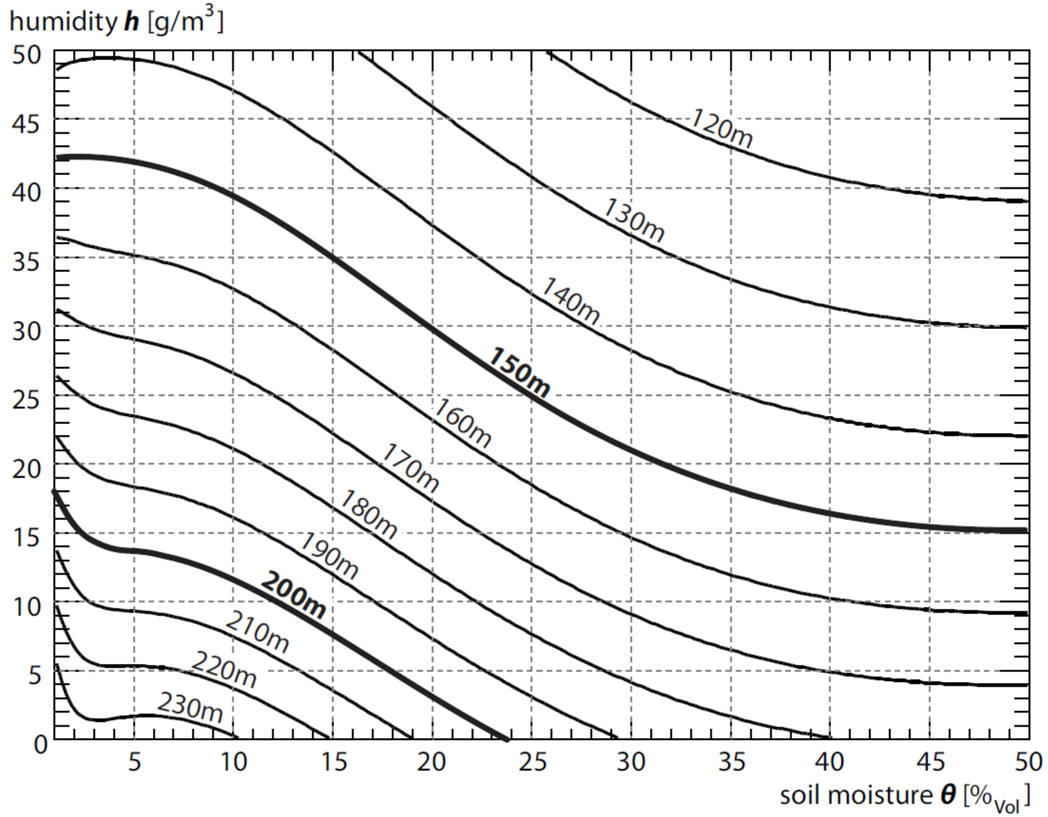
The Footprint

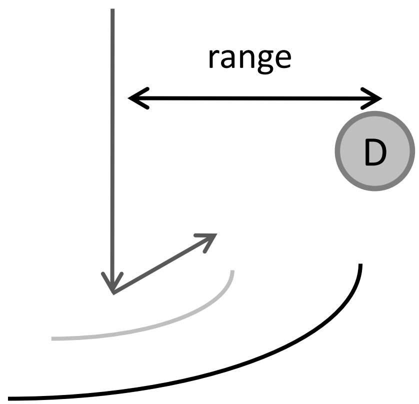
How far do reflected neutrons travel?



The Footprint in 2015

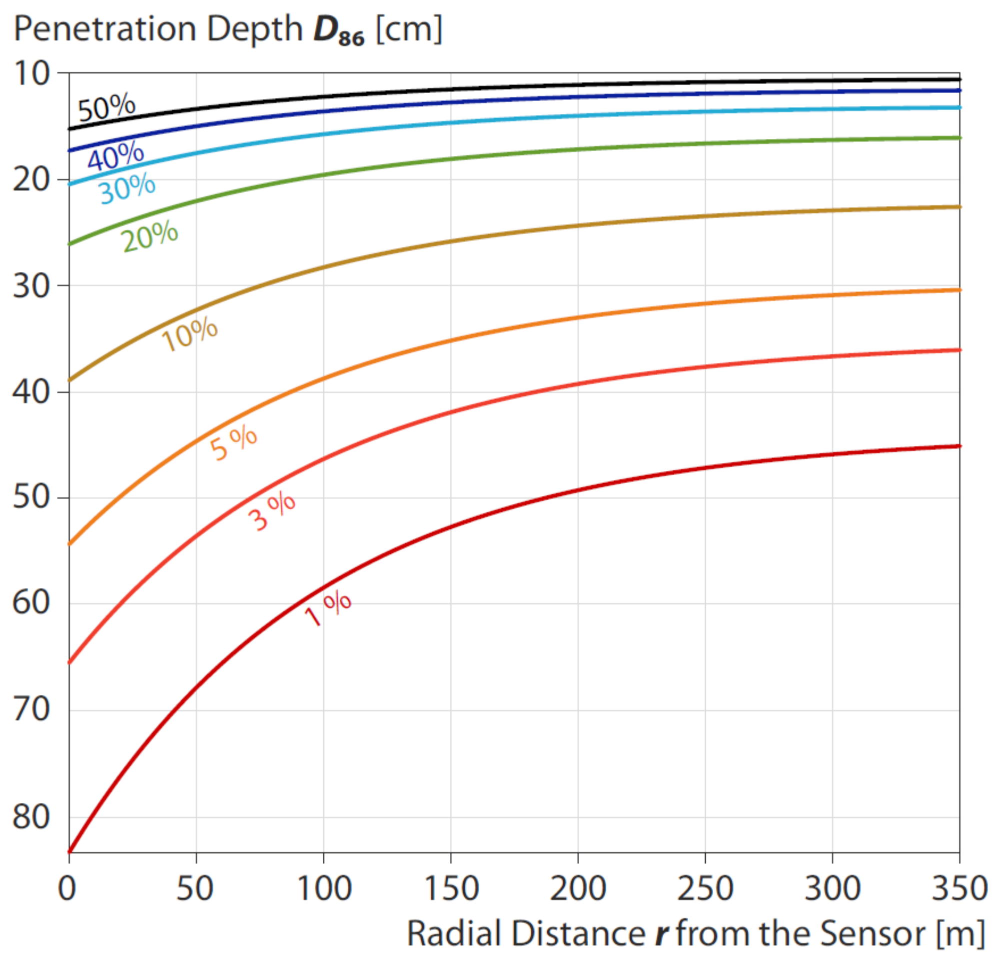
How far do reflected neutrons travel?

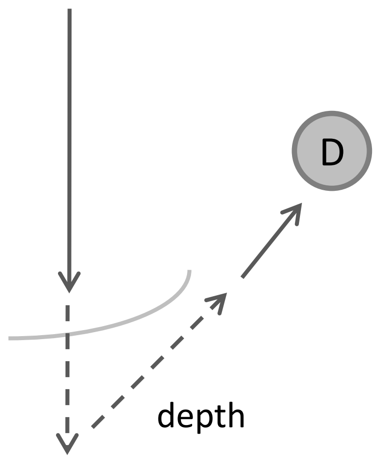




Köhli et Schrön et al.
Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons
Water Resources Research, **51**, 5772-5790

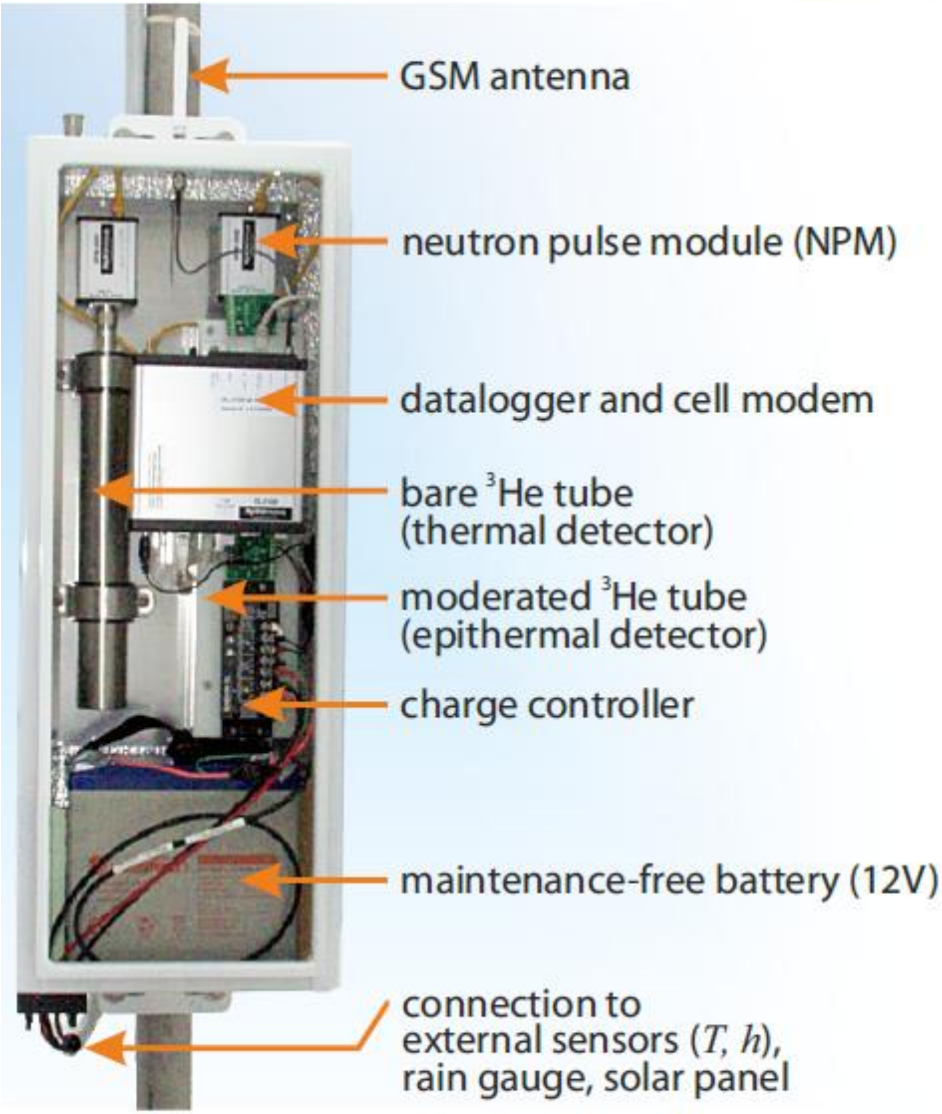
Penetration Depth



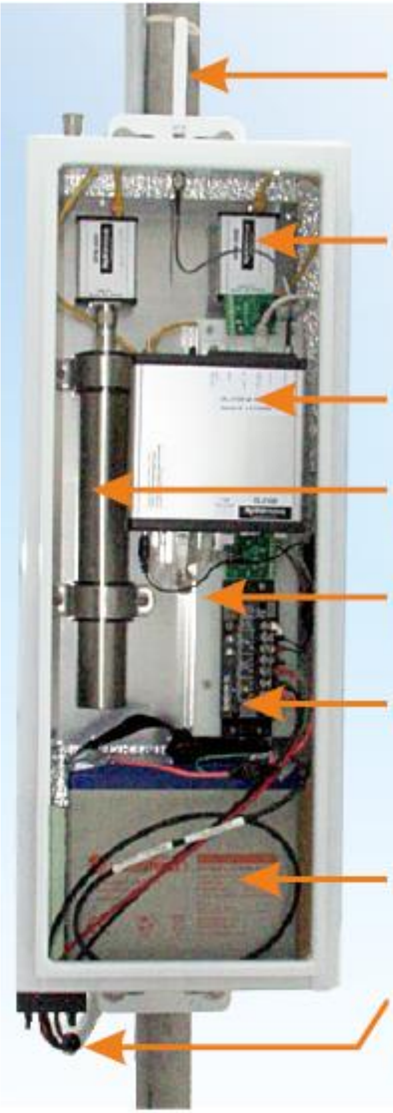


The Equipment

The CRNS Sensor



The CRNS Sensor



M. Zreda et al. (CRNS Website)

URANOS

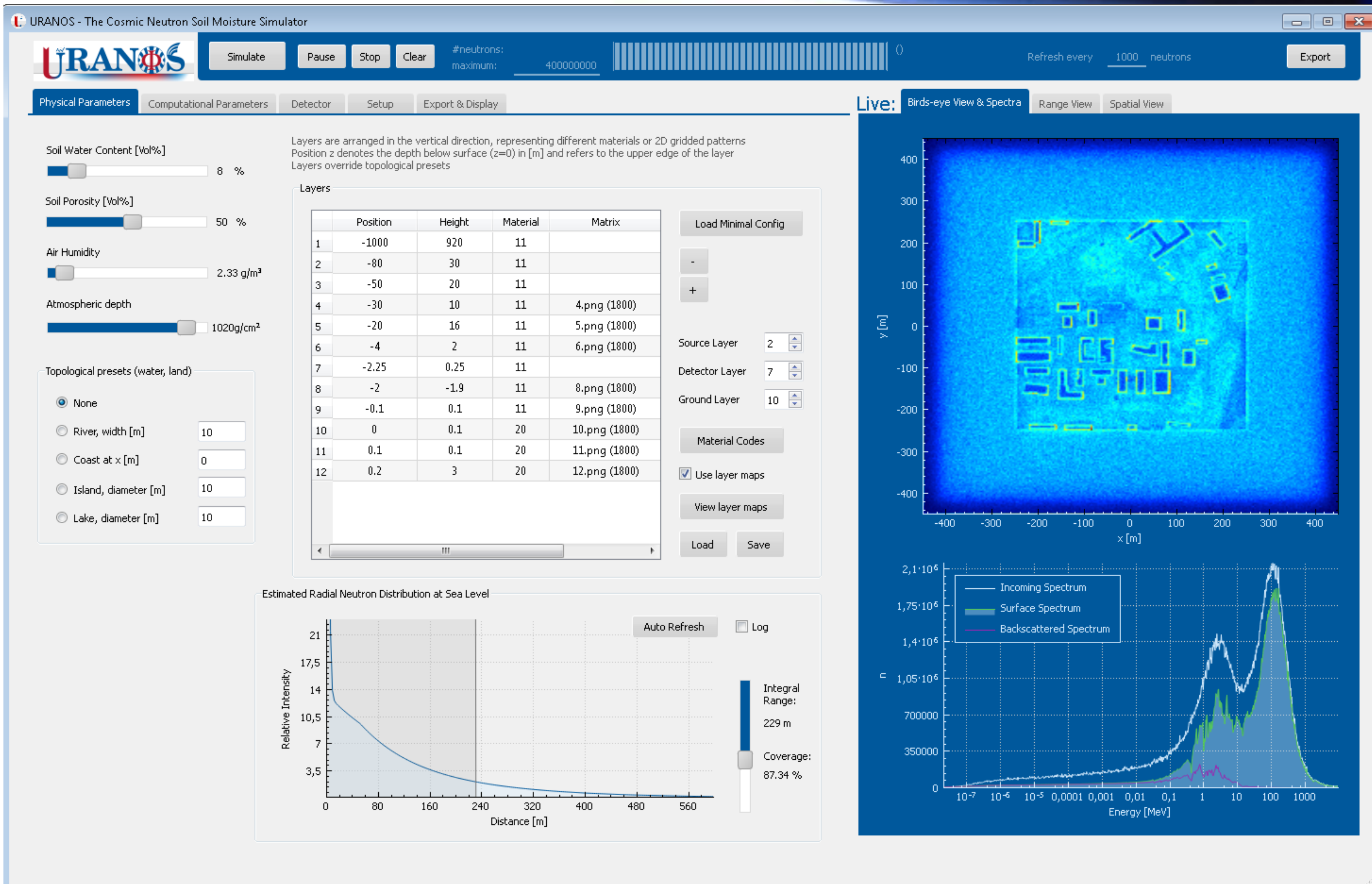
Ultra Rapid Adaptable Neutron-Only Simulation
for Environmental Research

Physikalisches Institut
Heidelberg University

HELMHOLTZ
CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

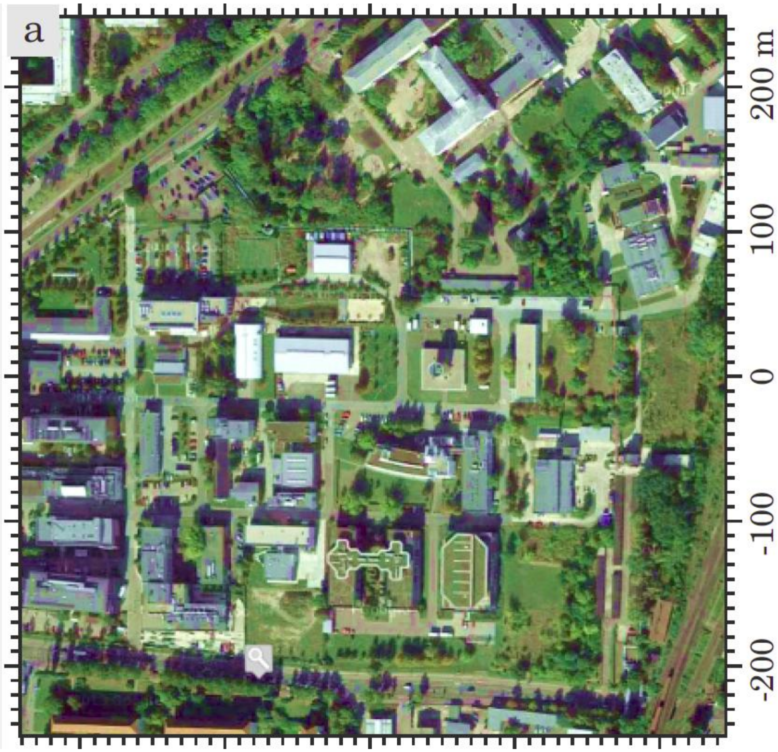
URANOS

9


URANOS - The Cosmic Neutron Soil Moisture Simulator
URANOS
Simulate
Pause
Stop
Clear
#neutrons:
maximum:
400000000
Refresh every
1000
neutrons
Export
Physical Parameters
Computational Parameters
Detector
Setup
Export & Display
Live:
Birds-eye View & Spectra
Range View
Spatial View
Soil Water Content [Vol%]
8 %
Soil Porosity [Vol%]
50 %
Air Humidity
2.33 g/m³
Atmospheric depth
1020g/cm²
Topological presets (water, land)
None
River, width [m]
Coast at x [m]
Island, diameter [m]
Lake, diameter [m]
Layers are arranged in the vertical direction, representing different materials or 2D gridded patterns
Position z denotes the depth below surface (z=0) in [m] and refers to the upper edge of the layer
Layers override topological presets
Layers
Position
Height
Material
Matrix
1 -1000 920 11
2 -80 30 11
3 -50 20 11
4 -30 10 11 4.png (1800)
5 -20 16 11 5.png (1800)
6 -4 2 11 6.png (1800)
7 -2.25 0.25 11
8 -2 -1.9 11 8.png (1800)
9 -0.1 0.1 11 9.png (1800)
10 0 0.1 20 10.png (1800)
11 0.1 0.1 20 11.png (1800)
12 0.2 3 20 12.png (1800)
Load Minimal Config
Source Layer
2
Detector Layer
7
Ground Layer
10
Material Codes
Use layer maps
View layer maps
Load
Save
Estimated Radial Neutron Distribution at Sea Level
Auto Refresh
Log
Relative Intensity
Distance [m]
Integral Range:
229 m
Coverage:
87.34 %
y [m]
x [m]
Incoming Spectrum
Surface Spectrum
Backscattered Spectrum
n
Energy [MeV]

Inhomogeneous Terrain

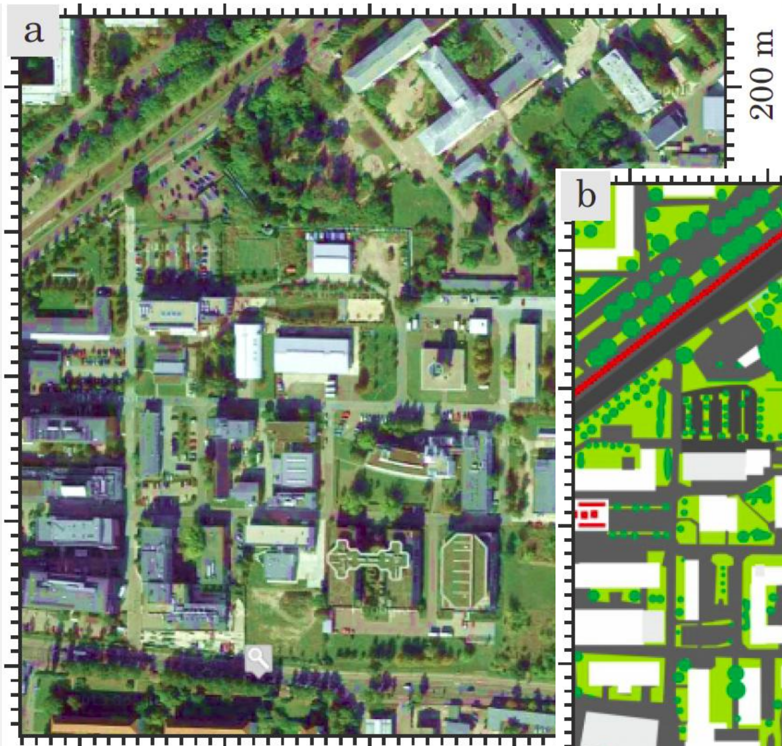
9



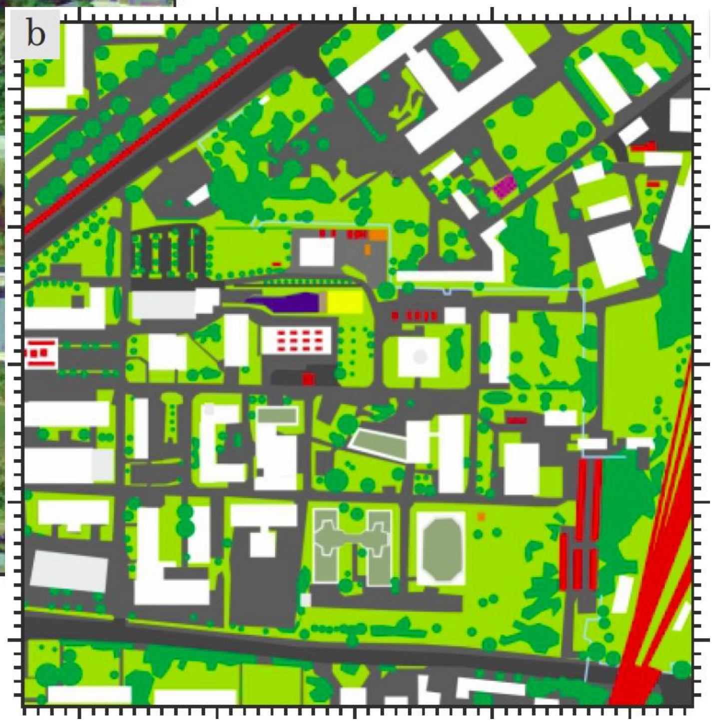
topography

Inhomogeneous Terrain

9

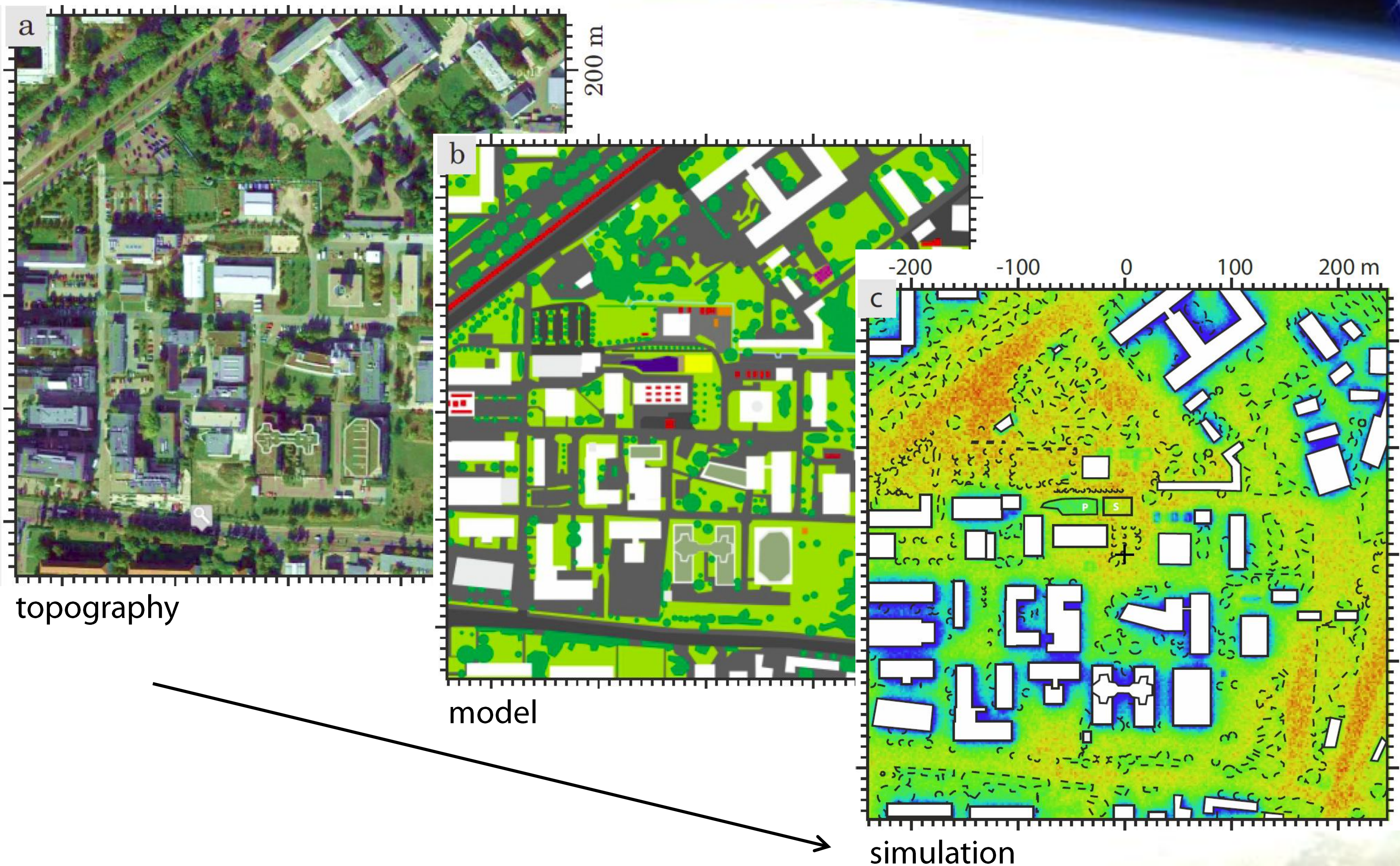


topography



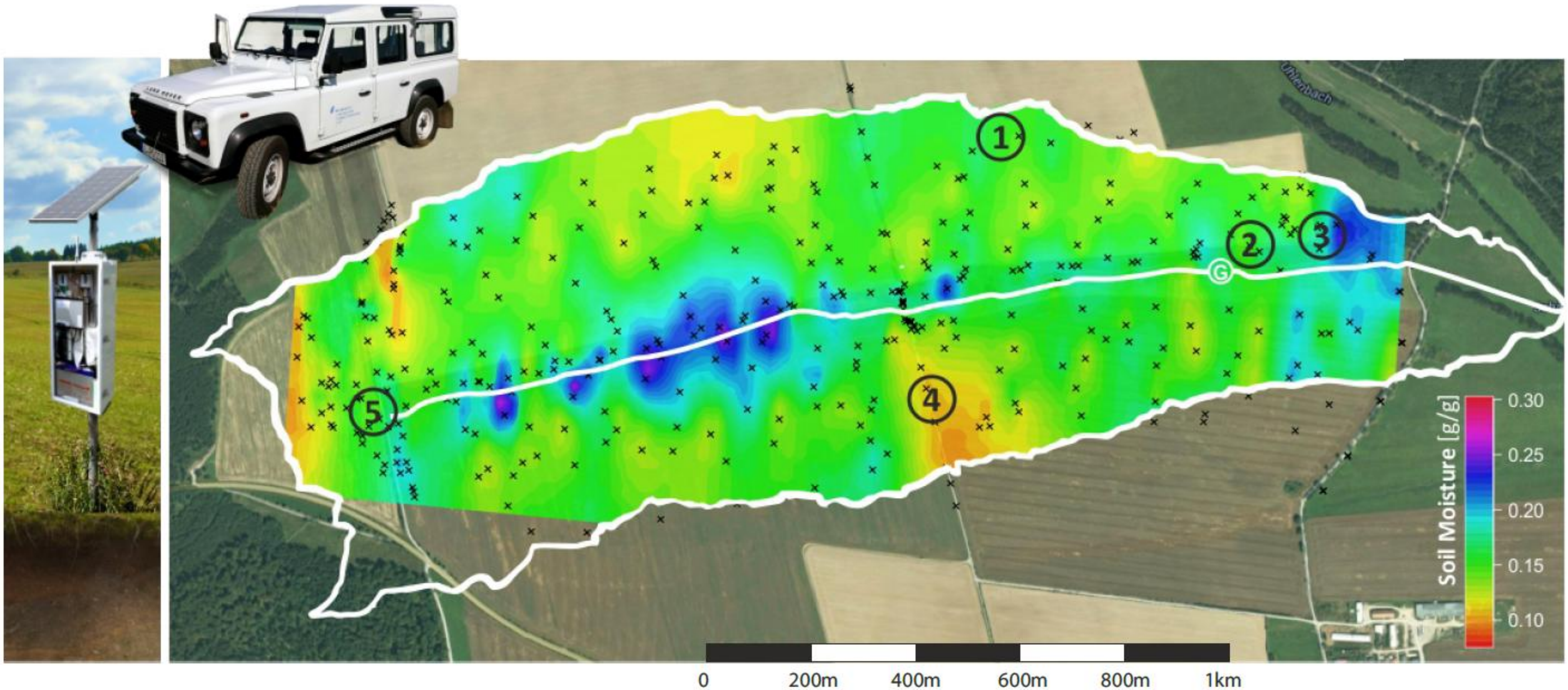
model

Inhomogeneous Terrain



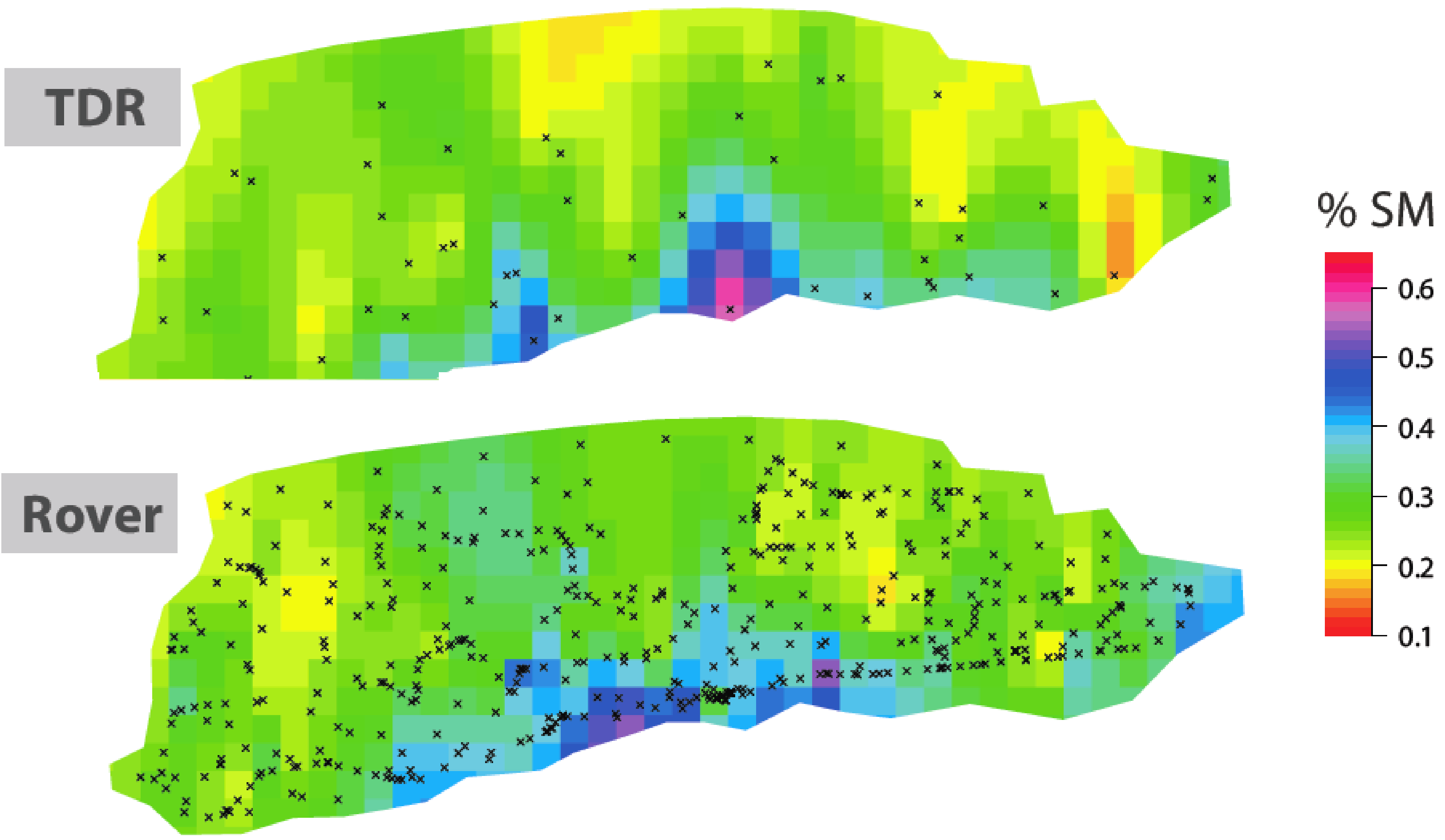
Mobile CRNS

Mobile CRNS



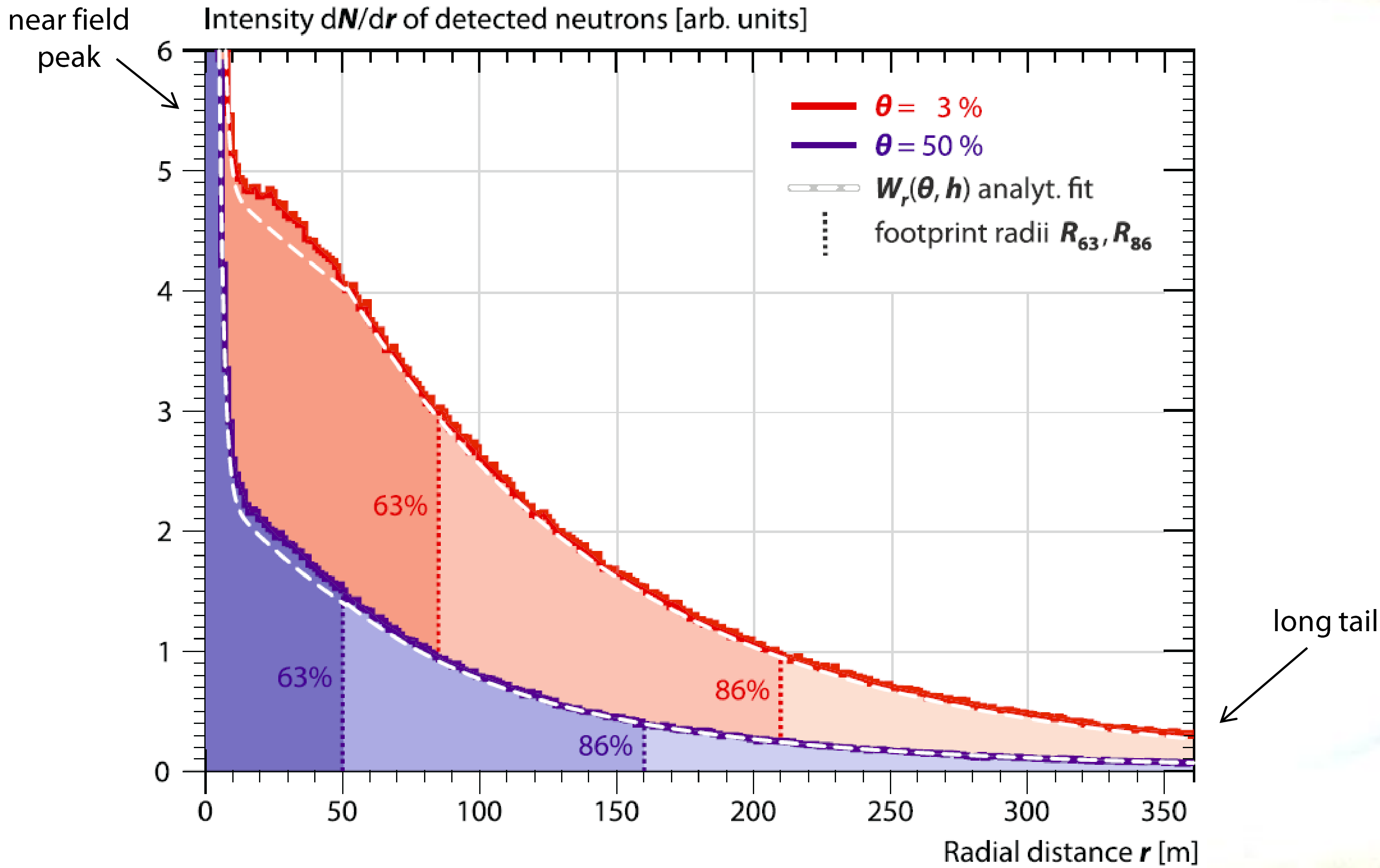
UFZ Site Schäfertal

Mobile CRNS



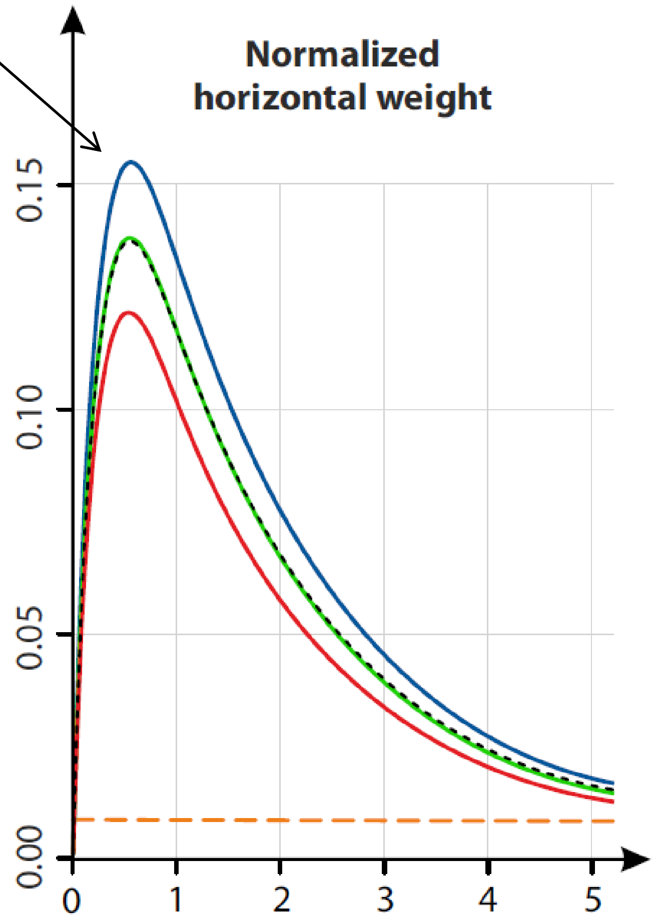
Local Effects

Local Effects



Local Effects

near field peak



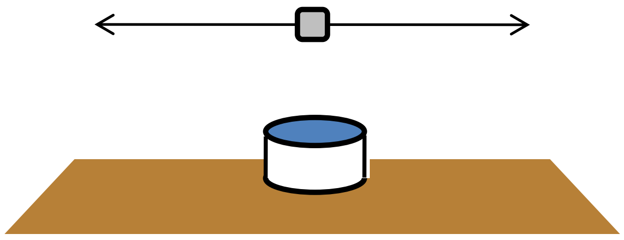
Conventional, W^{conv}

Revised, $W_r\,(h,\theta)$

Condition	Humidity	Soil moisture
Dry	h = 5 g m^{-3}	θ_v = 10 %
Humid	h = 10 g m^{-3}	θ_v = 20 %
Wet	h = 15 g m^{-3}	θ_v = 40 %

W_r^* average approximation (eq. B1)

Pool Transect



Local Effects

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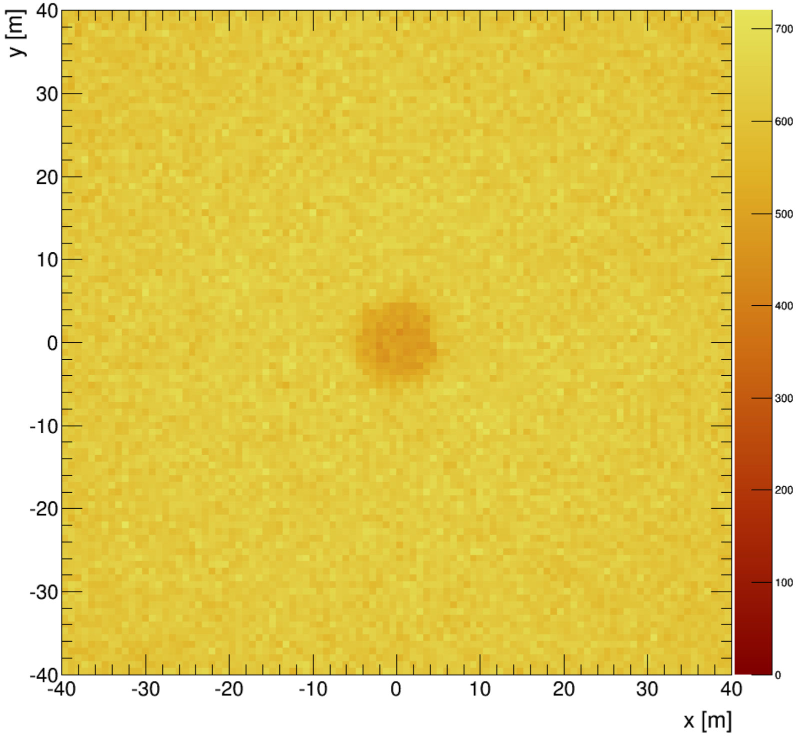
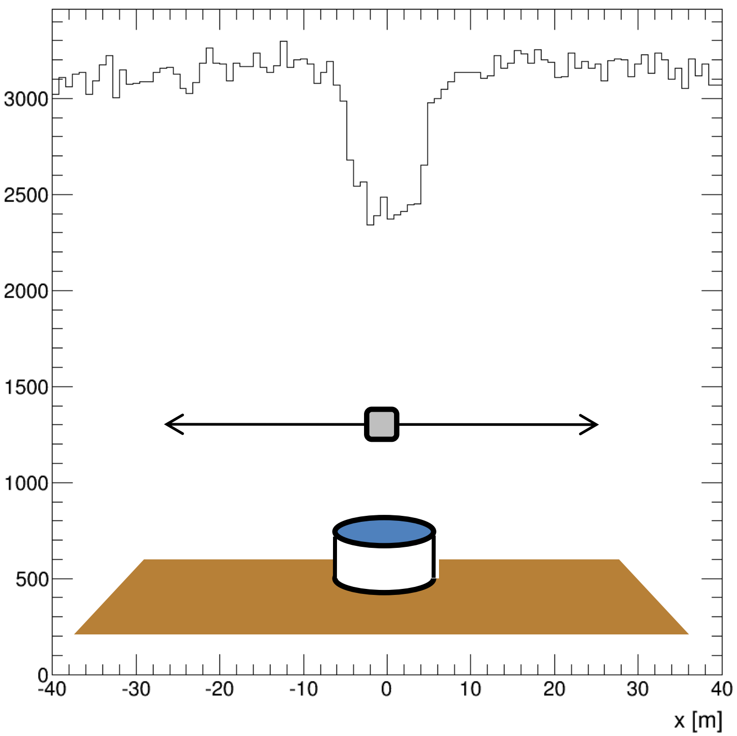
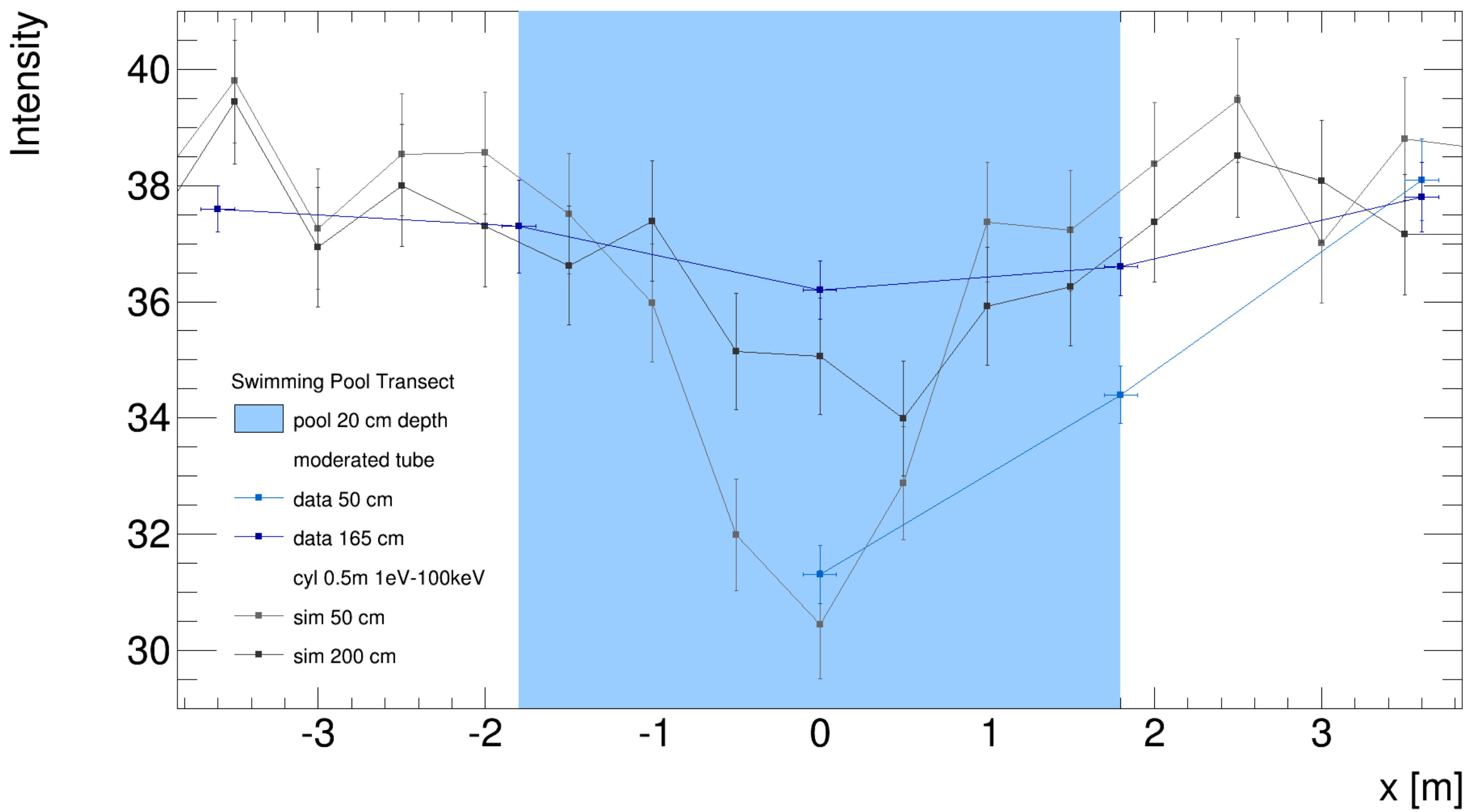
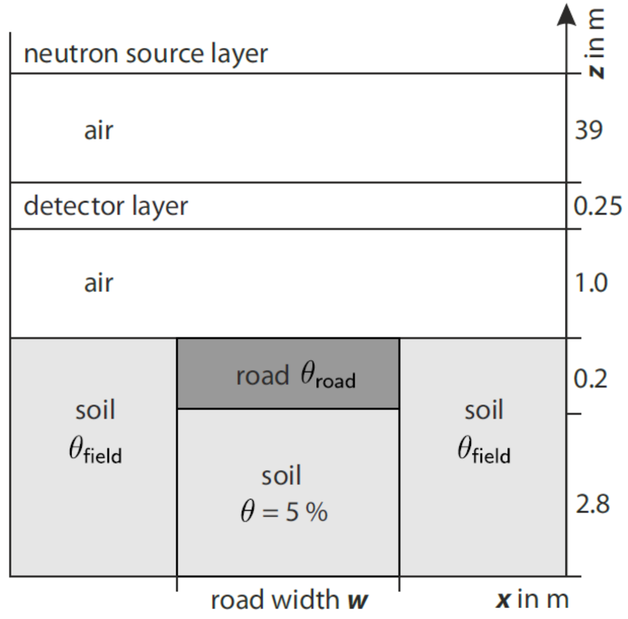




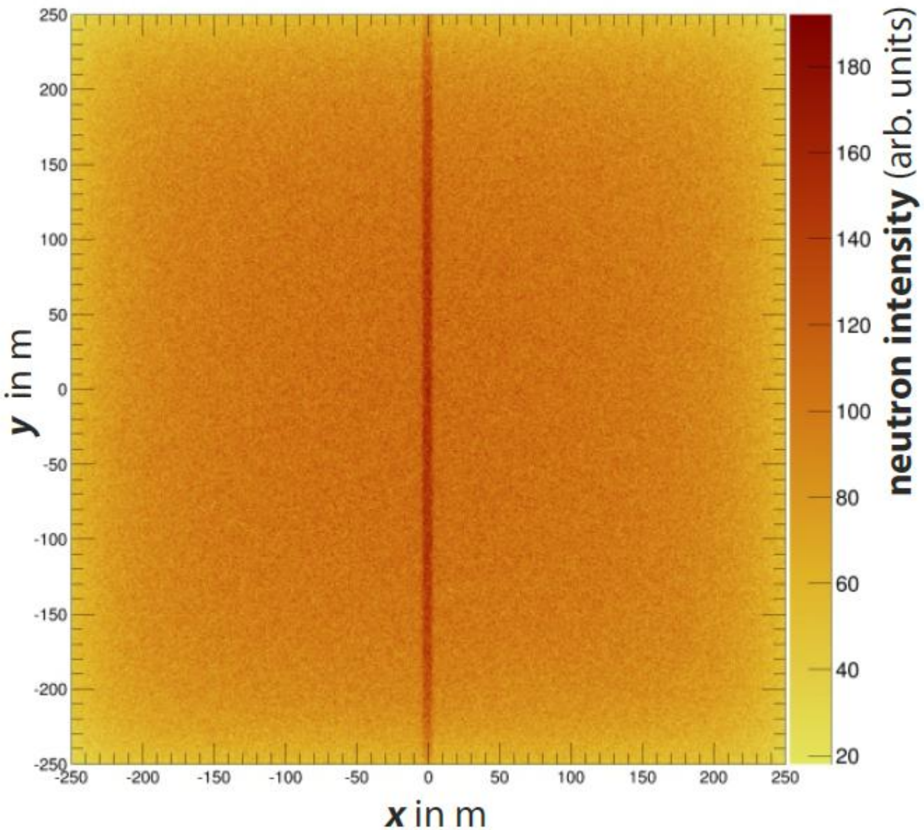
Local Swimming Pool Effects

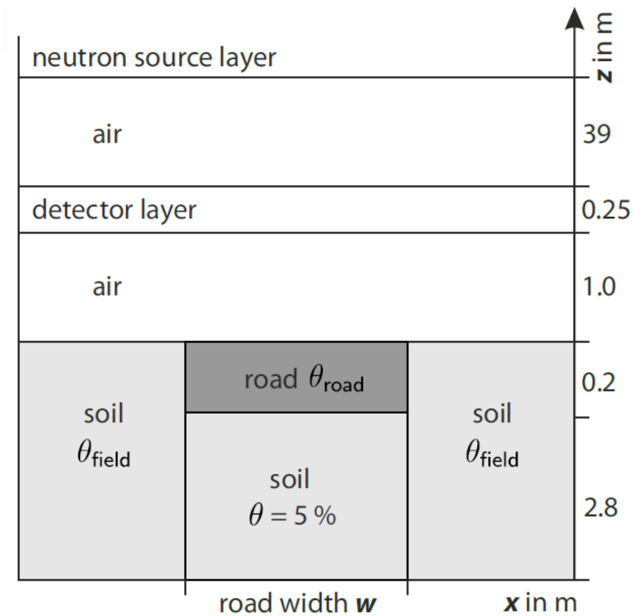


Road Simulations



Road Simulations





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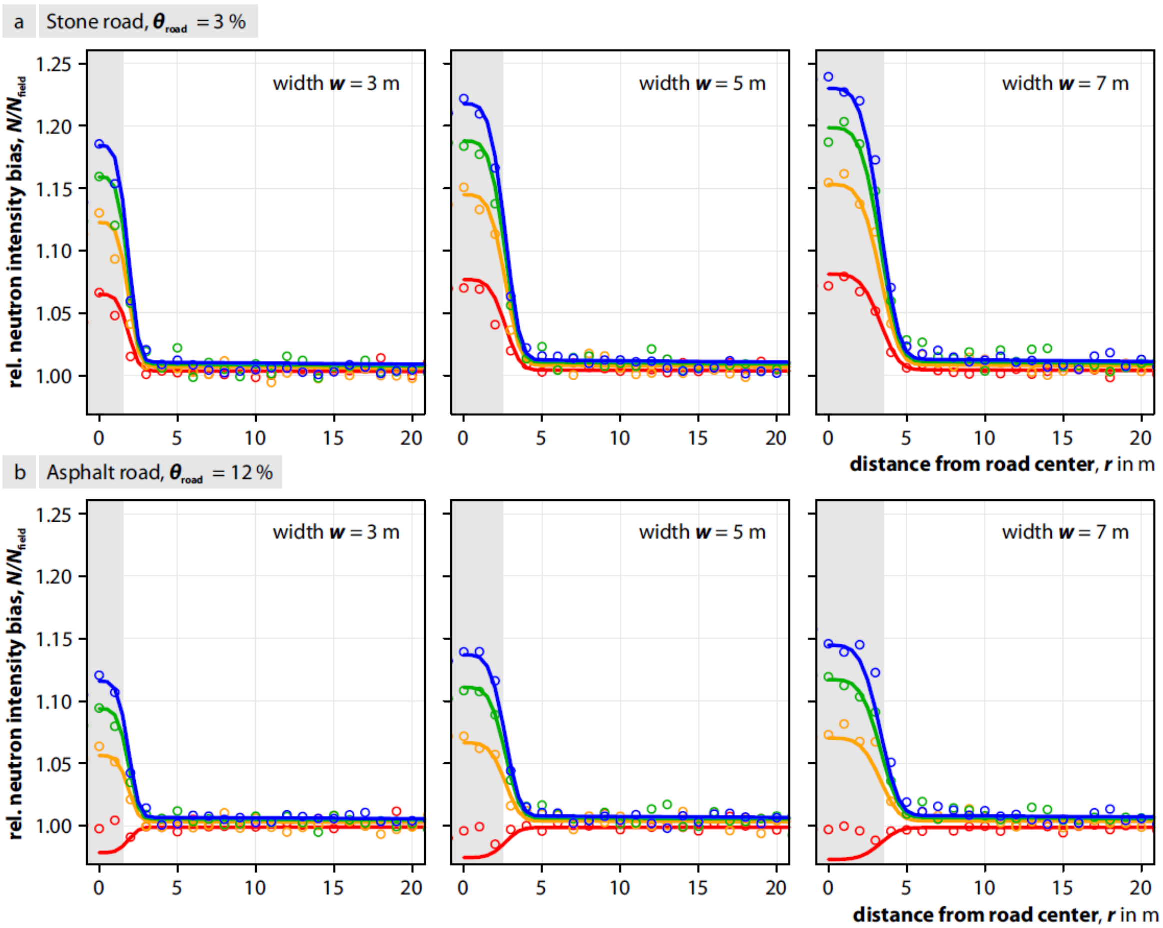
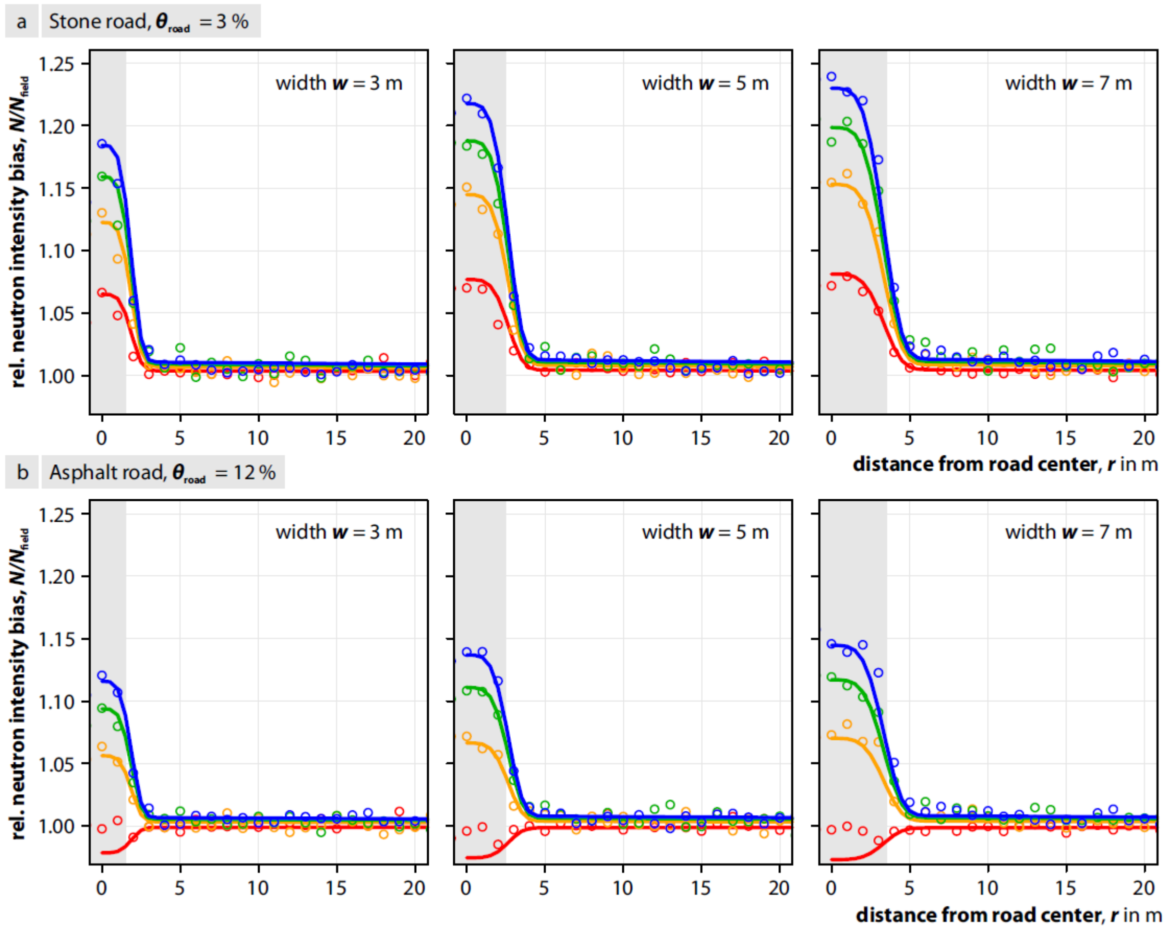


[1]

[2]

[1] https://www.meinromulus.de/ratgeber-community-rom/meilensteine/die-via-appia-eine-wichtige-handelsstrasse
[2] http://chregu.veloblog.ch/post/94/2145

Road Simulations

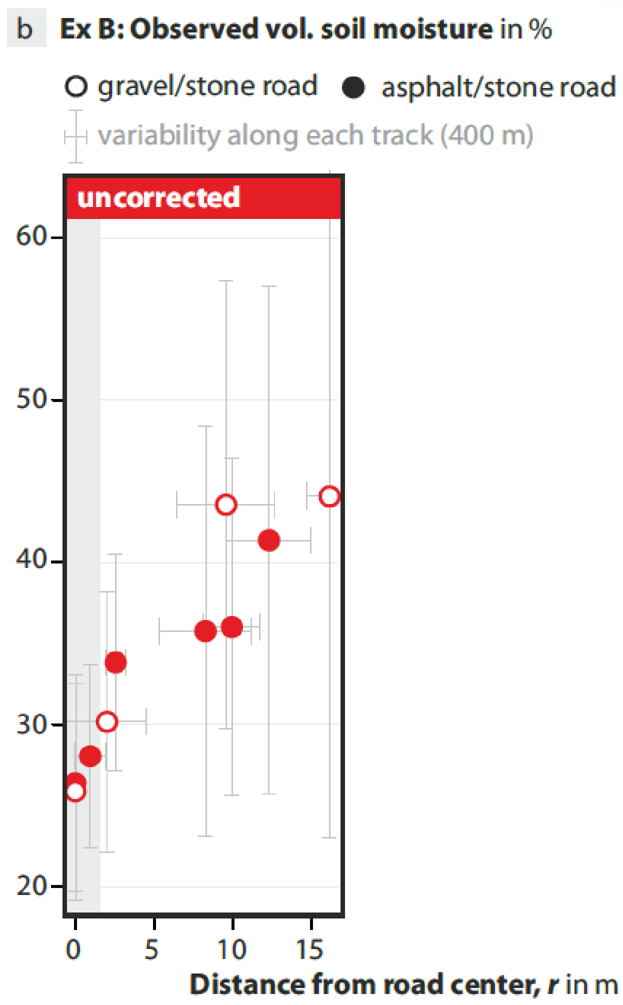


Road Experiments

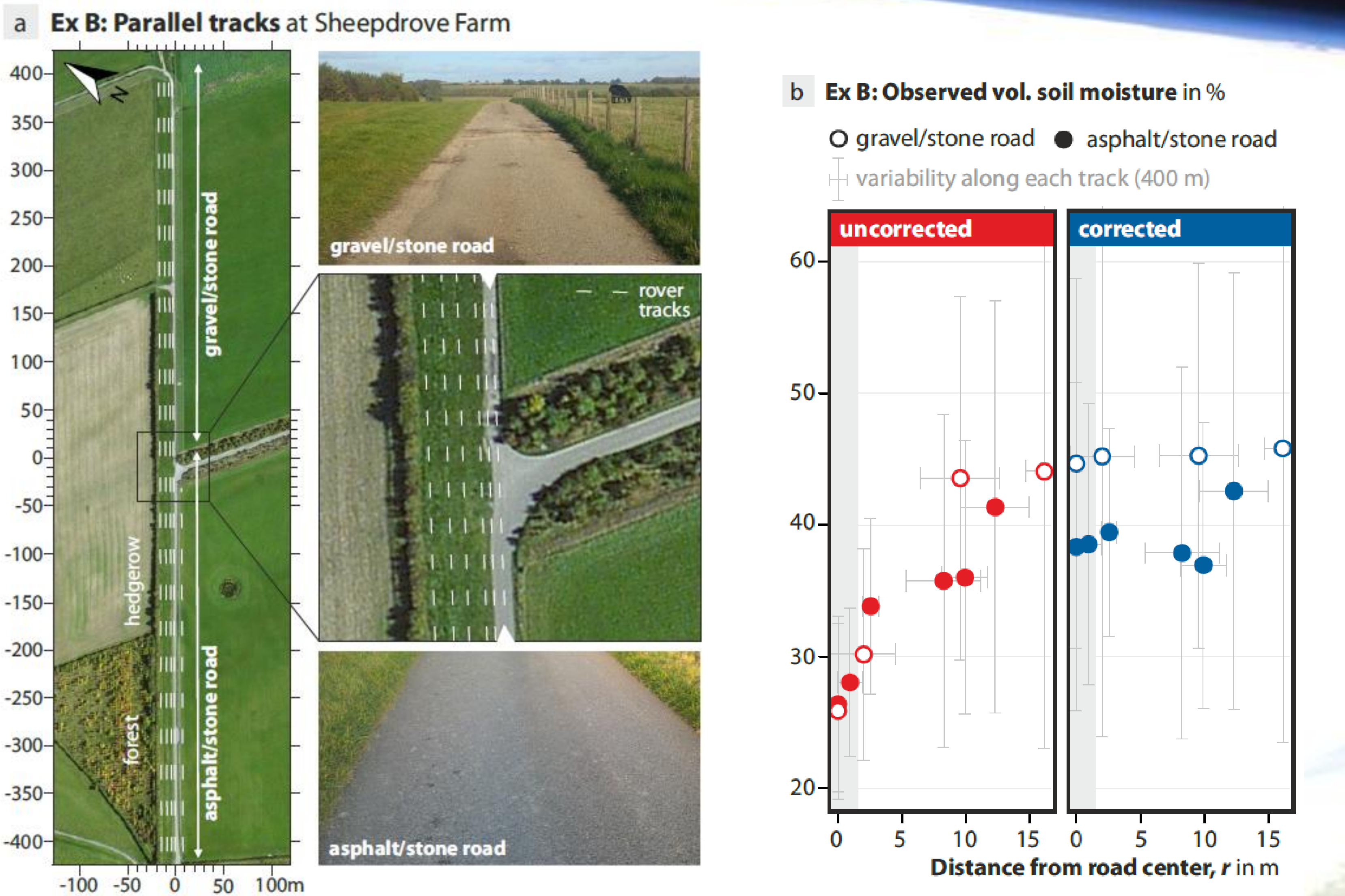
a **Ex B: Parallel tracks** at Sheepdrove Farm

Road Experiments

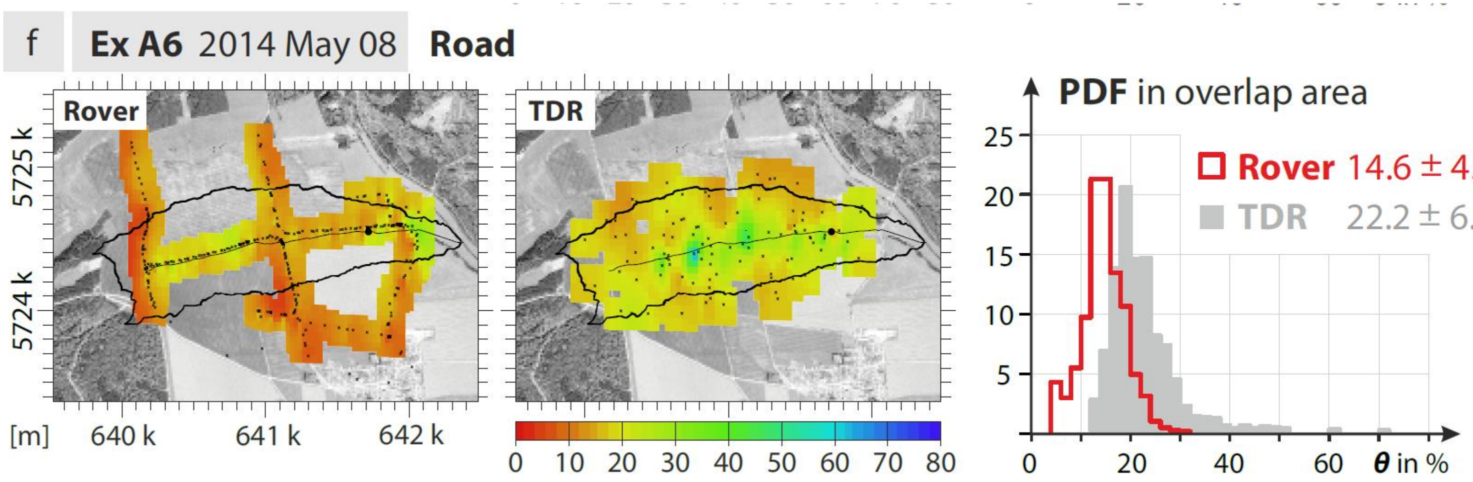
15



Road Experiments

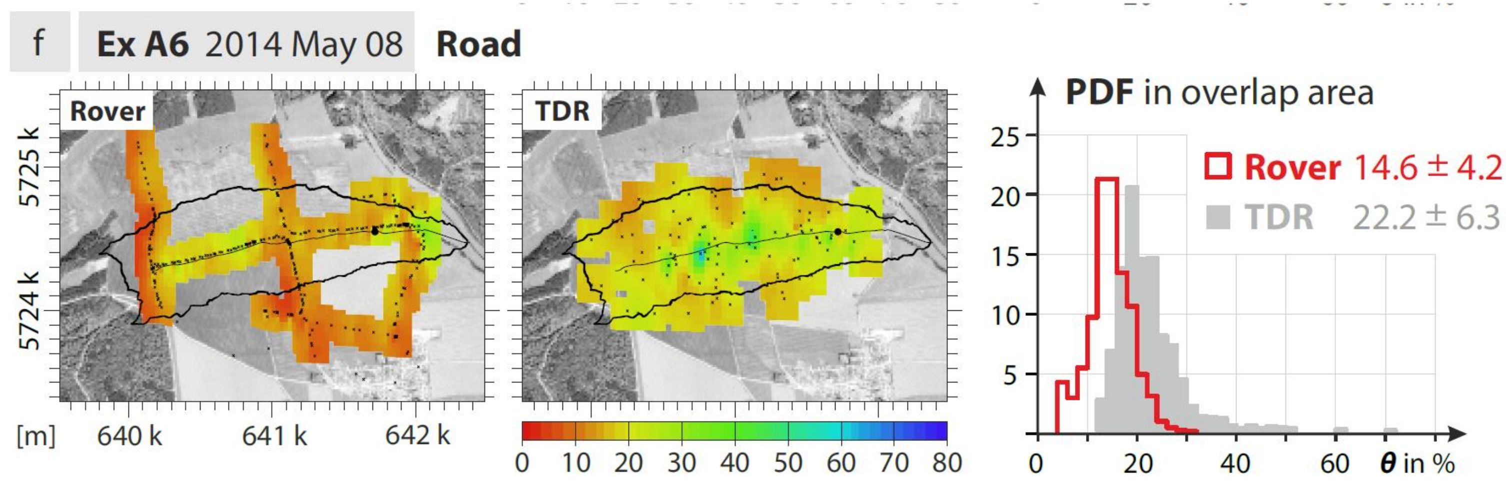


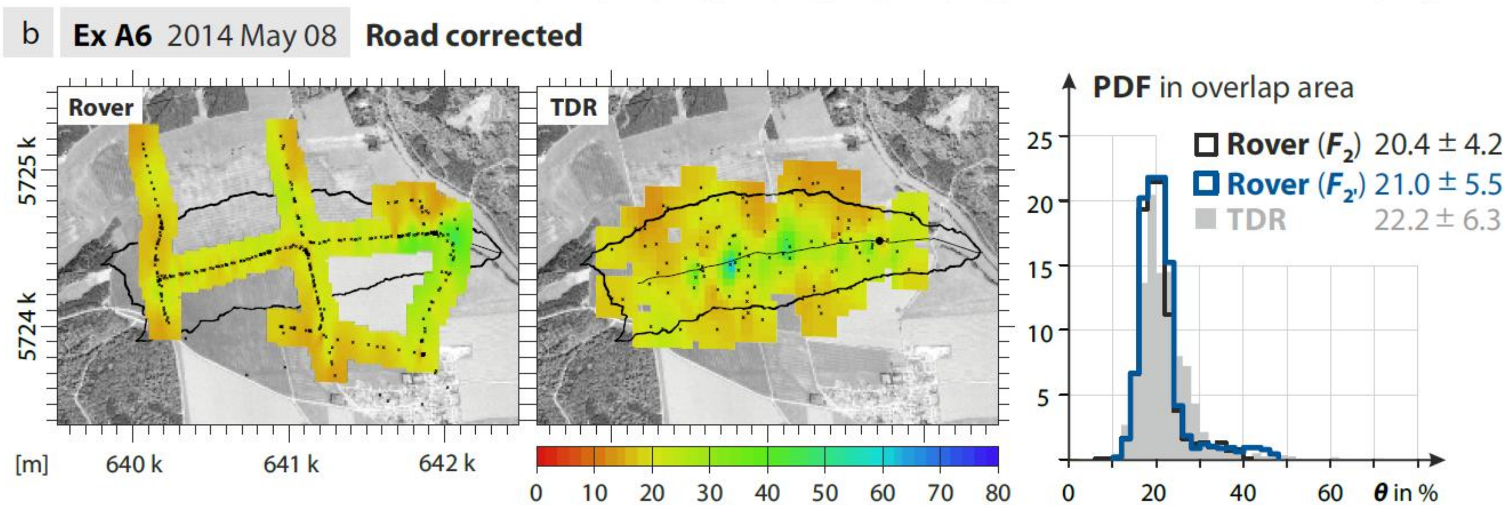
Mobile CRNS



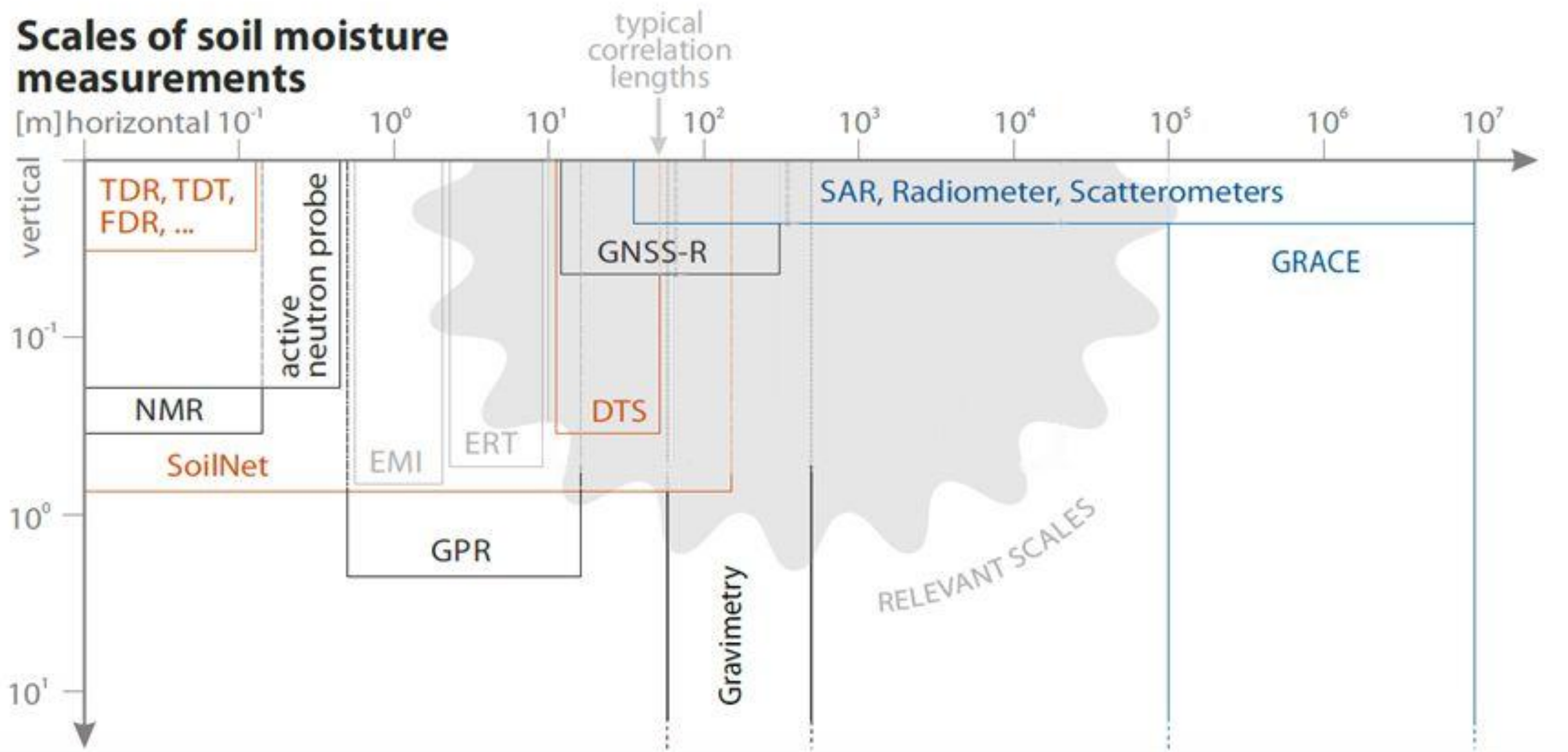
f
Ex A6 2014 May 08
Road
Rover
TDR
5725 k
5724 k
[m]
640 k
641 k
642 k
0 10 20 30 40 50 60 70 80
PDF in overlap area
Rover 14.6 ± 4.2
TDR 22.2 ± 6.3
25
20
15
10
5
0
20
40
60
θ in %

Mobile CRNS

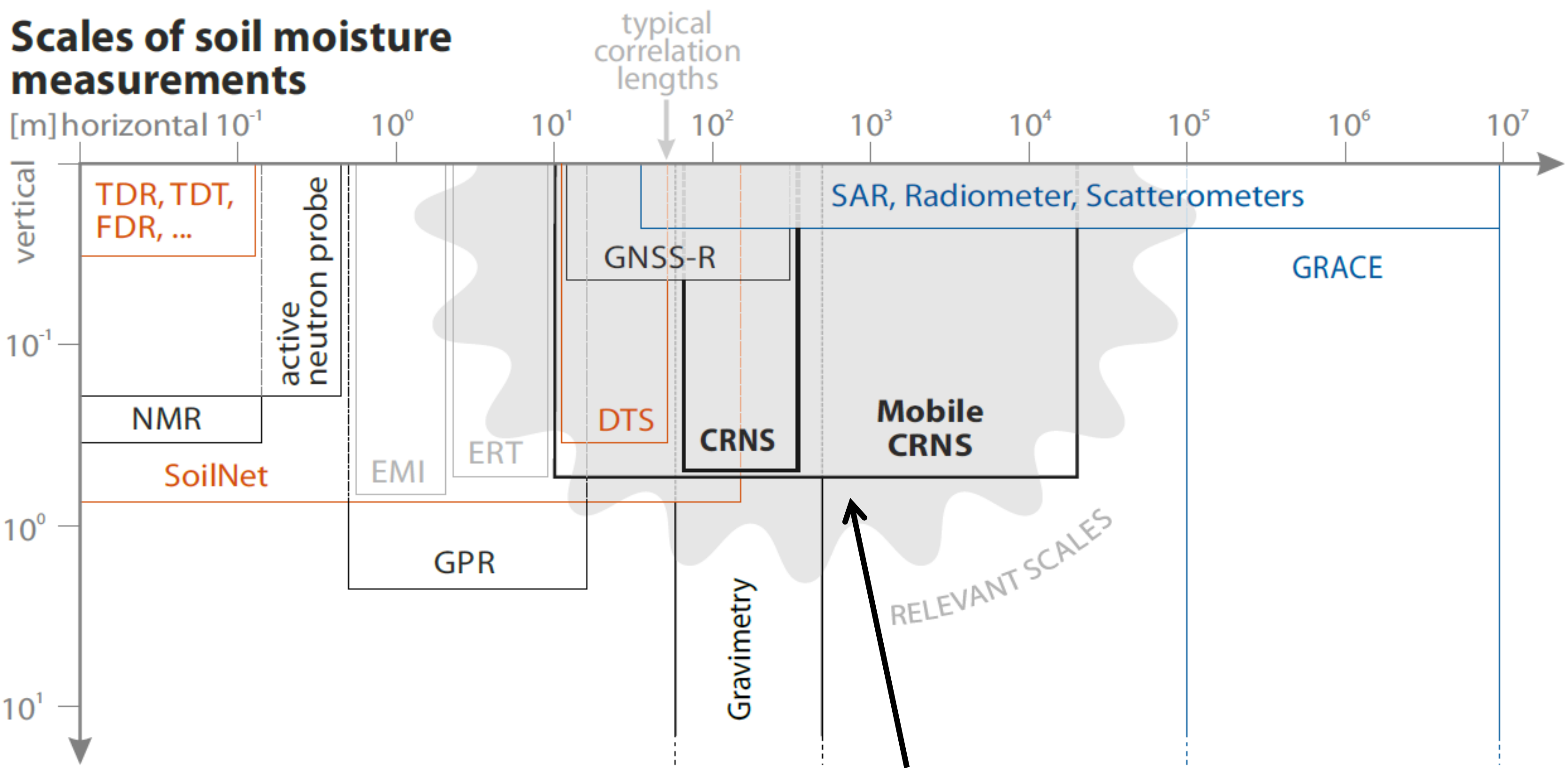

f
Ex A6 2014 May 08
Road
Rover
TDR
5725 k
5724 k
[m]
640 k
641 k
642 k
0 10 20 30 40 50 60 70 80
PDF in overlap area
Rover 14.6 ± 4.2
TDR 22.2 ± 6.3
θ in %


b
Ex A6 2014 May 08
Road corrected
Rover
TDR
5725 k
5724 k
[m]
640 k
641 k
642 k
0 10 20 30 40 50 60 70 80
PDF in overlap area
Rover (F2) 20.4 ± 4.2
Rover (F2') 21.0 ± 5.5
TDR 22.2 ± 6.3
θ in %

The Measurement Gap



The Measurement Gap



And now here

Summary

- Cosmic-Ray Neutron Sensing

- Outlook:

Summary

Cosmic-Ray Neutron Sensing

- provides an average soil moisture measurement over **several hectares** and **0.5 m in depth**
- can be understood by Monte-Carlo transport modelling
- road effect, small scale variations, inhomogeneous soil moisture patterns can now be **corrected**

Outlook:

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- can be understood by Monte-Carlo transport modelling
- road effect, small scale variations, inhomogeneous soil moisture patterns can now be **corrected**

Outlook

- development of **larger detectors** for mobile sensing
- application in **heterogeneous** environments
- snowpack monitoring