

Soil Moisture measurement  
at the  
hectometer scale  
with  
cosmic-ray neutrons

DPG Frühjahrstagung Bremen

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UP 4.2



HELMHOLTZ  
CENTRE FOR  
ENVIRONMENTAL  
RESEARCH – UFZ



UNIVERSITÄT  
HEIDELBERG  
ZUKUNFT  
SEIT 1386

UP 4.3



# Soil Moisture measurement at the hectometer scale with cosmic-ray neutrons

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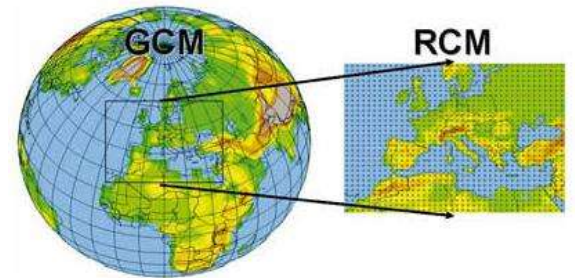
[1]



[3]



[2]



[1]



[1] <http://www.wmo.int/pages/themes/climate/images/figures/ClimateModelnesting.jpg>

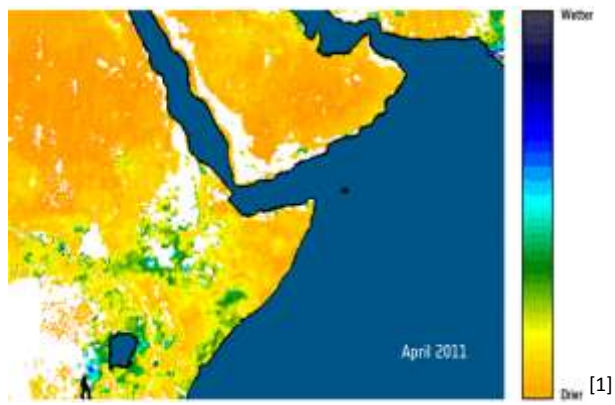
[2] <http://www.livetradingnews.com/wp-content/uploads/2014/04/precisionag.jpg>

[3] [http://upload.wikimedia.org/wikipedia/commons/3/37/Nam\\_steppe.jpg](http://upload.wikimedia.org/wikipedia/commons/3/37/Nam_steppe.jpg)



# The Measurement Gap

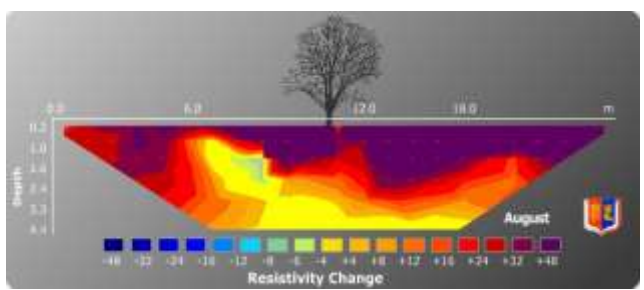
> 1 km



via  
satellite remote sensing  
(optical, microwave)

[1]

< 10 m



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

[2]

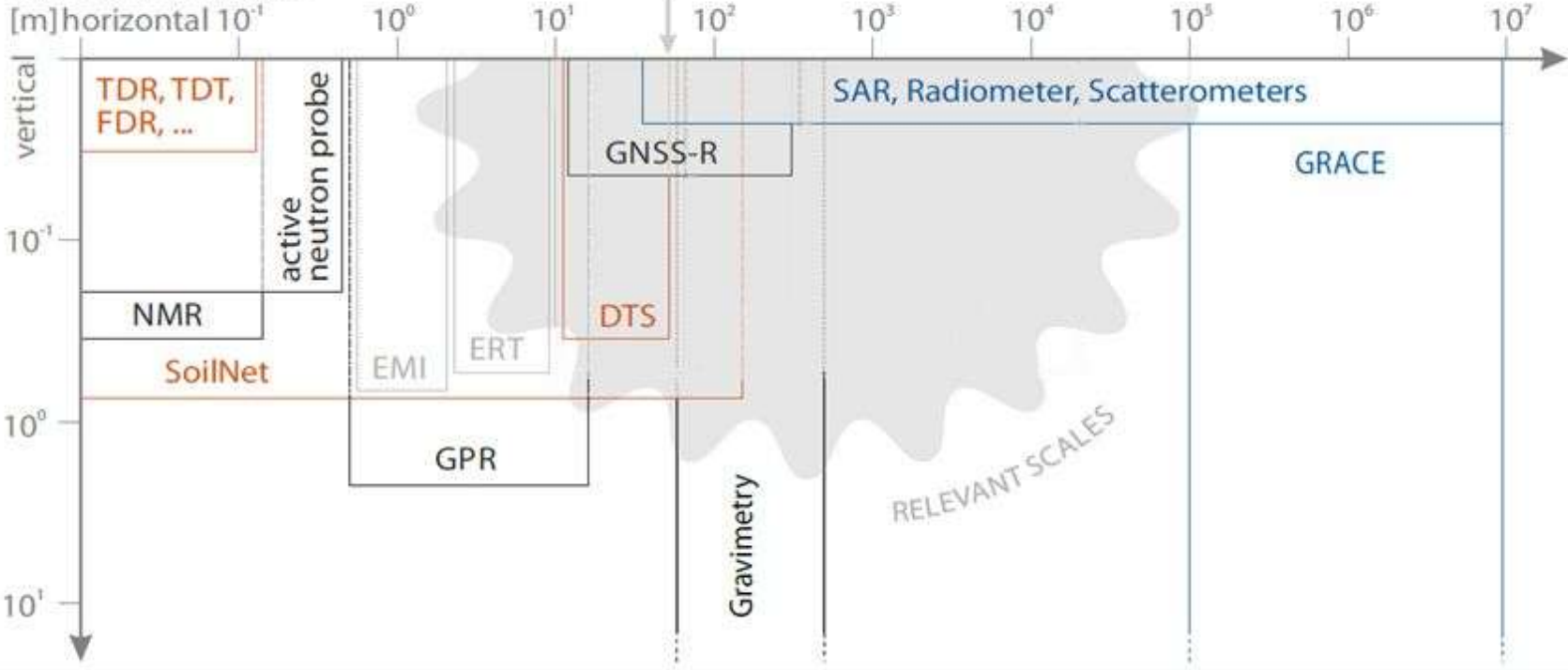
[1] ESA SMOS ([http://www.esa.int/Our\\_Activities/Observing\\_the\\_Earth/SMOS/Horn\\_of\\_Africa\\_drought\\_seen\\_from\\_space](http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS/Horn_of_Africa_drought_seen_from_space))  
[2] The Clay Research Group (<http://www.theclayresearchgroup.org/images/ert.jpg>)

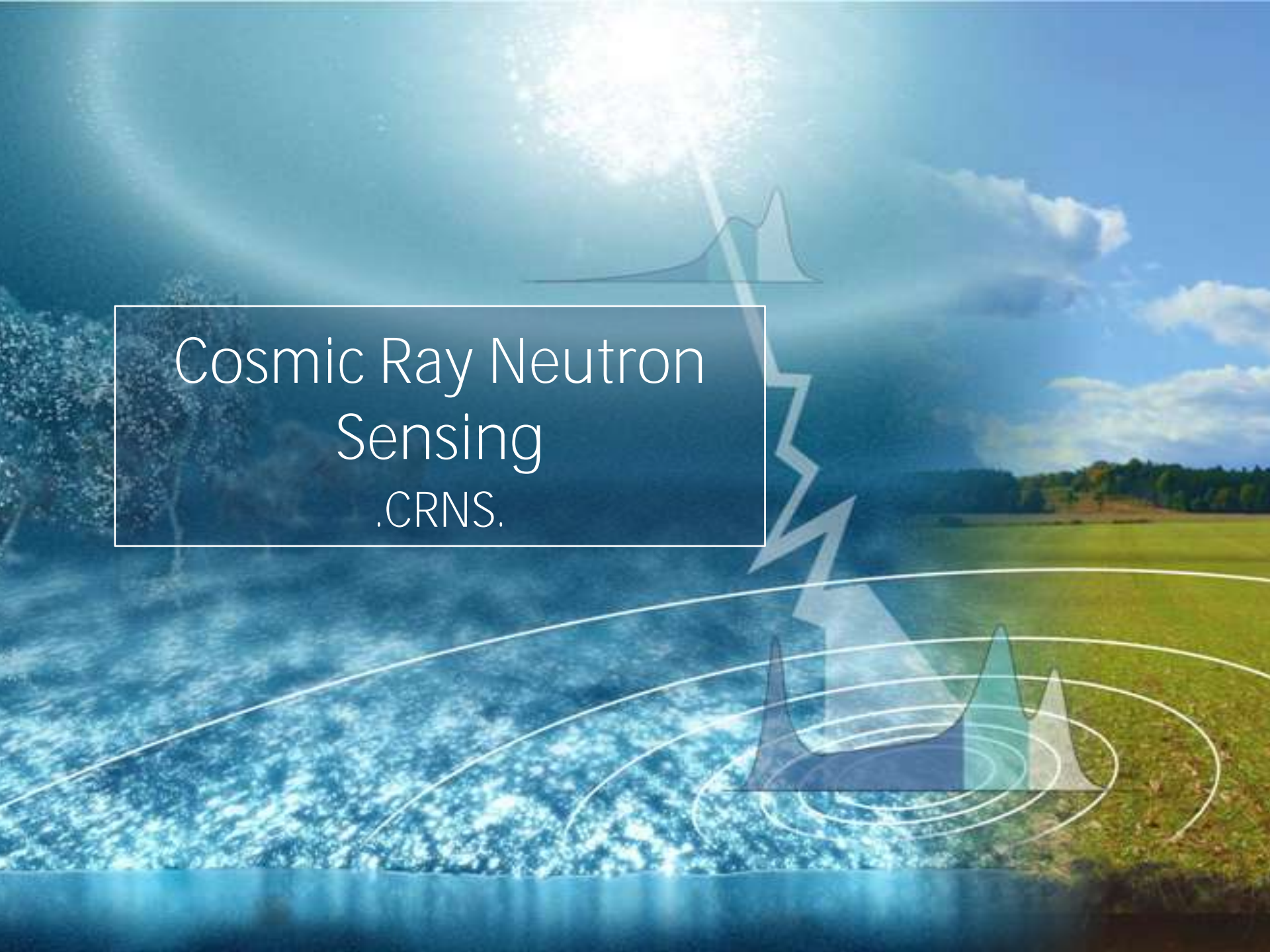


# The Measurement Gap

1

## Scales of soil moisture measurements



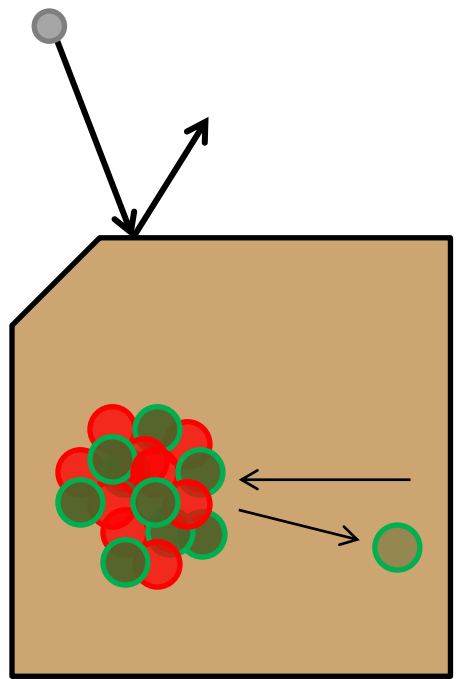


Cosmic Ray Neutron  
Sensing  
.CRNS.

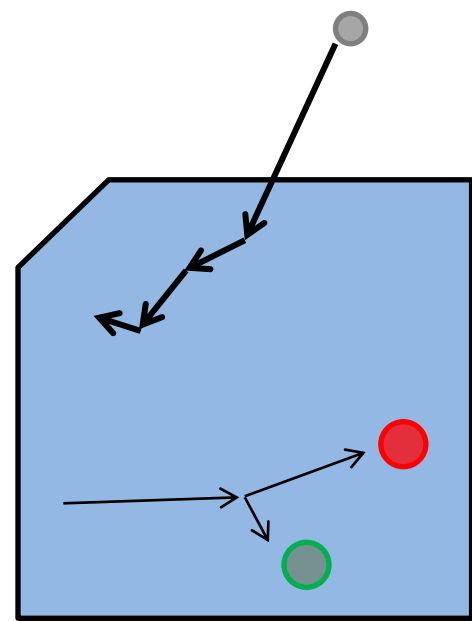
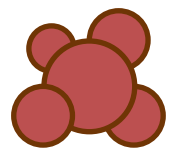


# Neutron Response to Water

2



Rock



Water





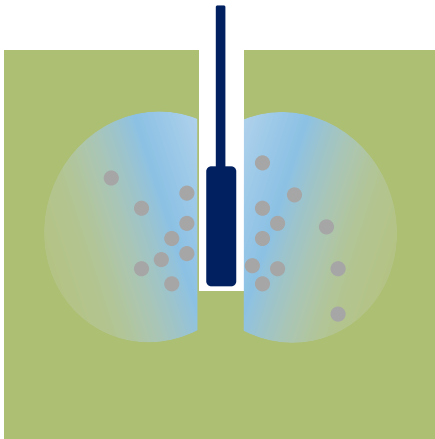


# Neutron Response to Water

3

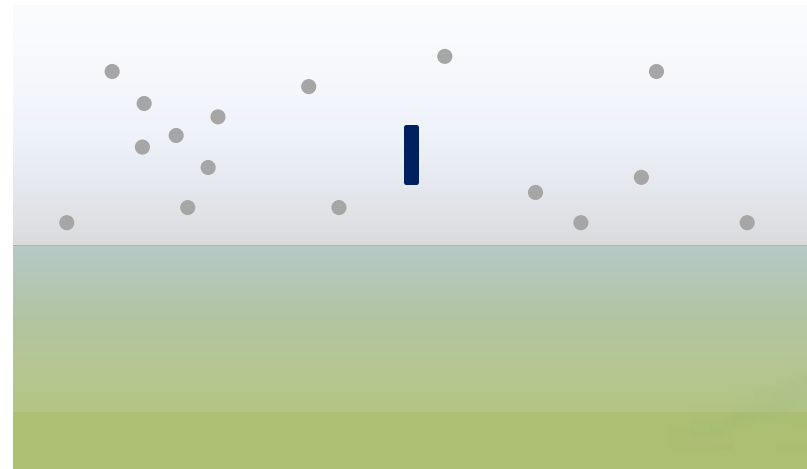
active

small distinct domain  
thermalization



passive

large area, diffusive  
reflection





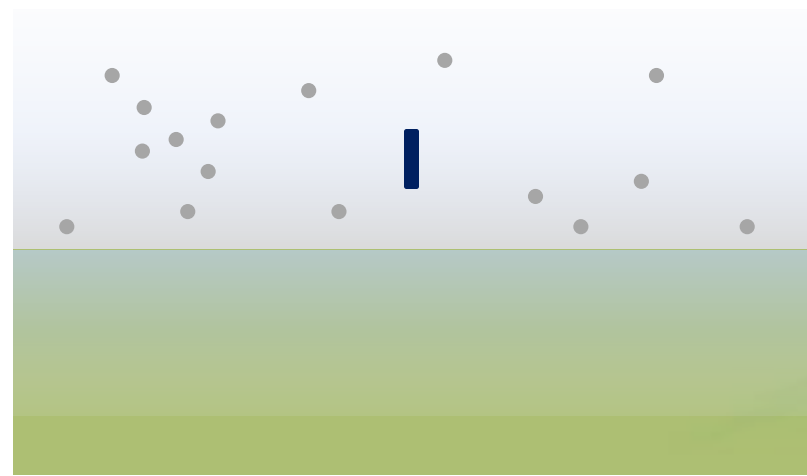
# Neutron Response to Water

3



passive

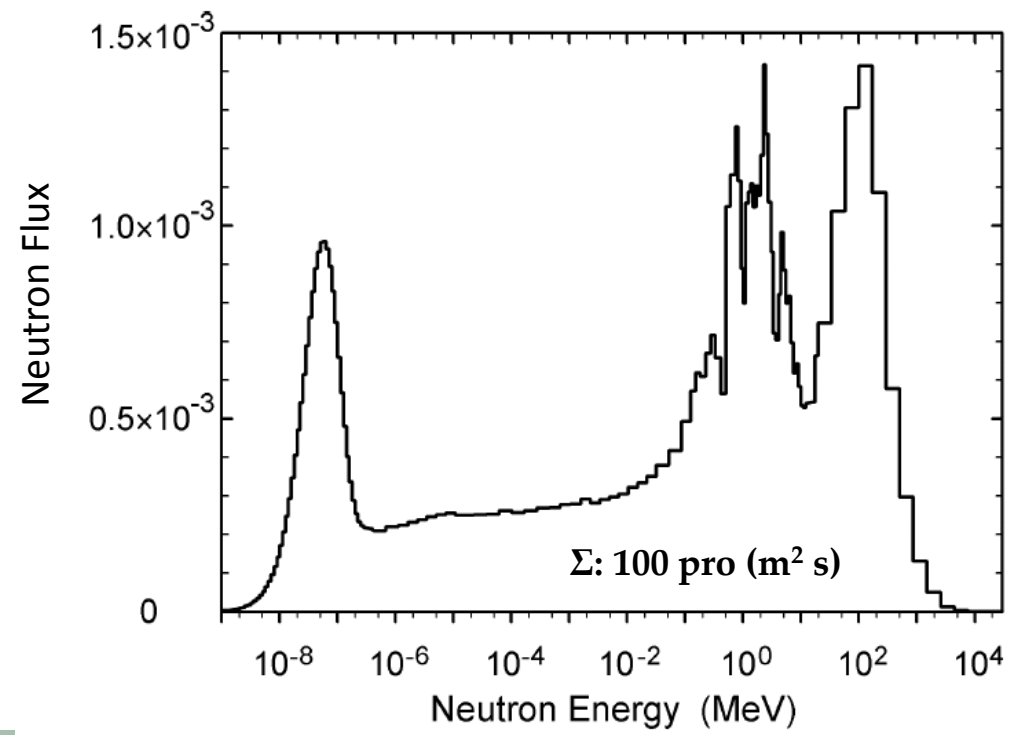
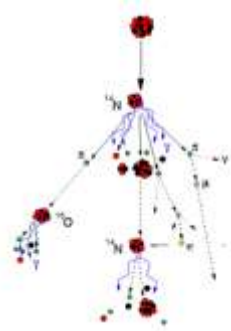
large area, diffusive reflection





# The Cosmic Neutron Spectrum

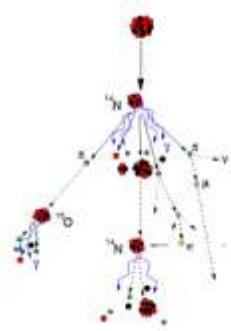
4



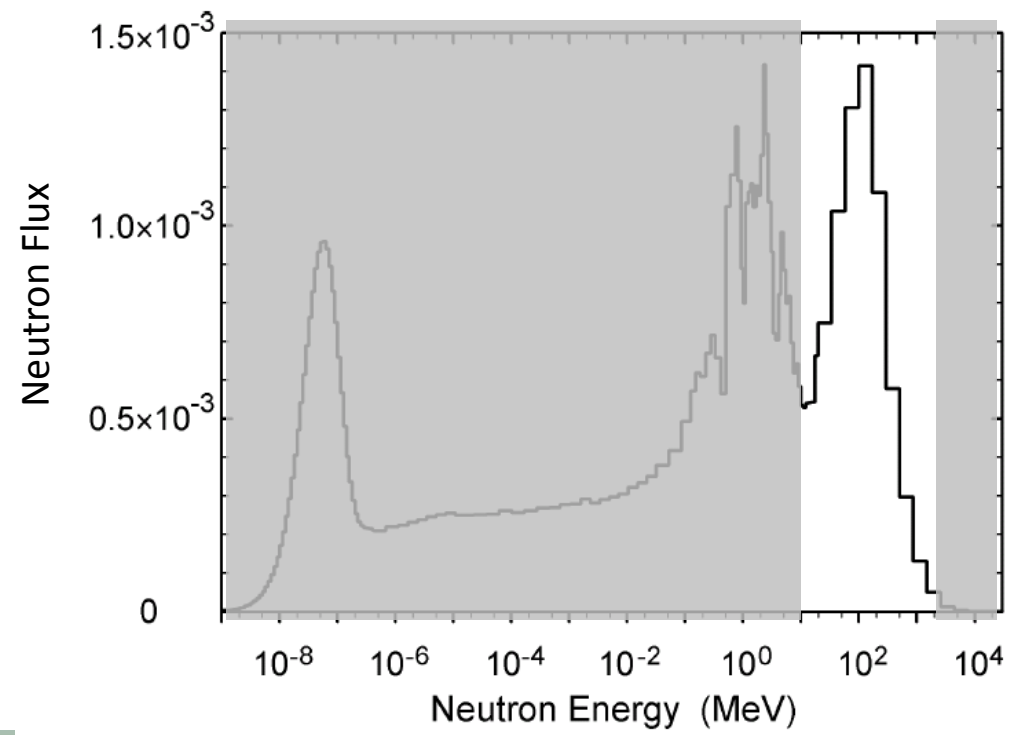


# The Cosmic Neutron Spectrum

4



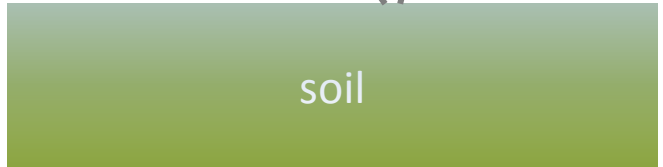
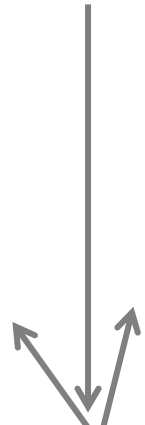
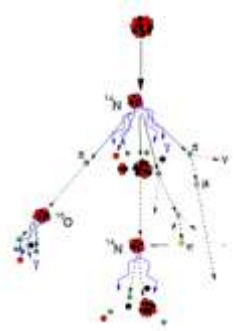
Base Spectrum



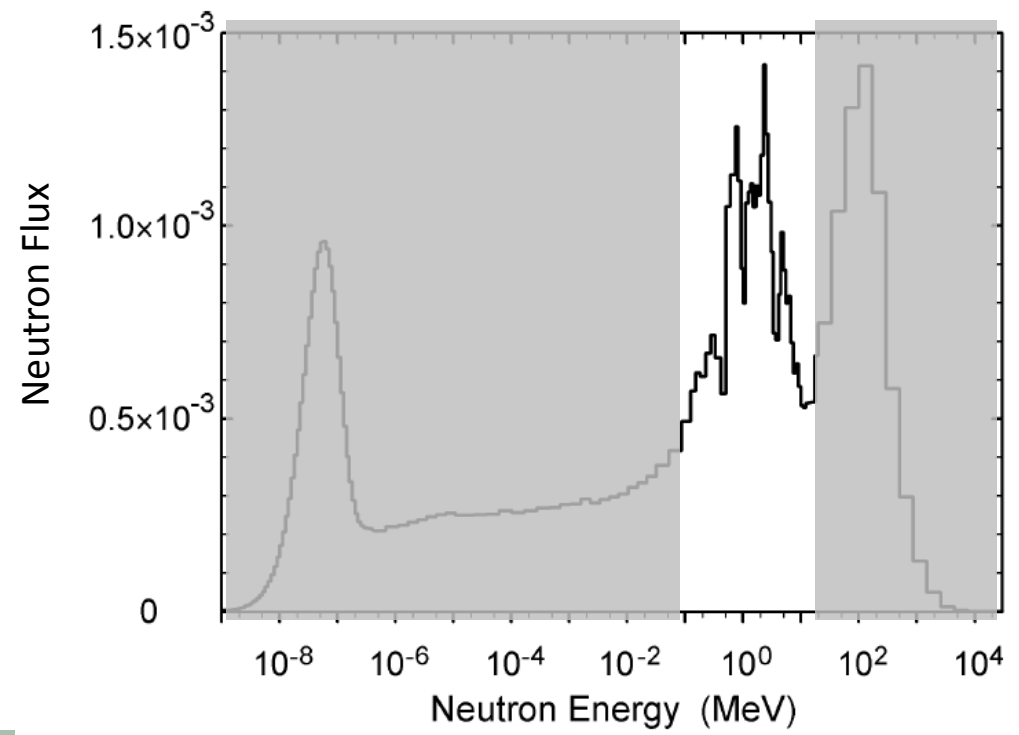


# The Cosmic Neutron Spectrum

4



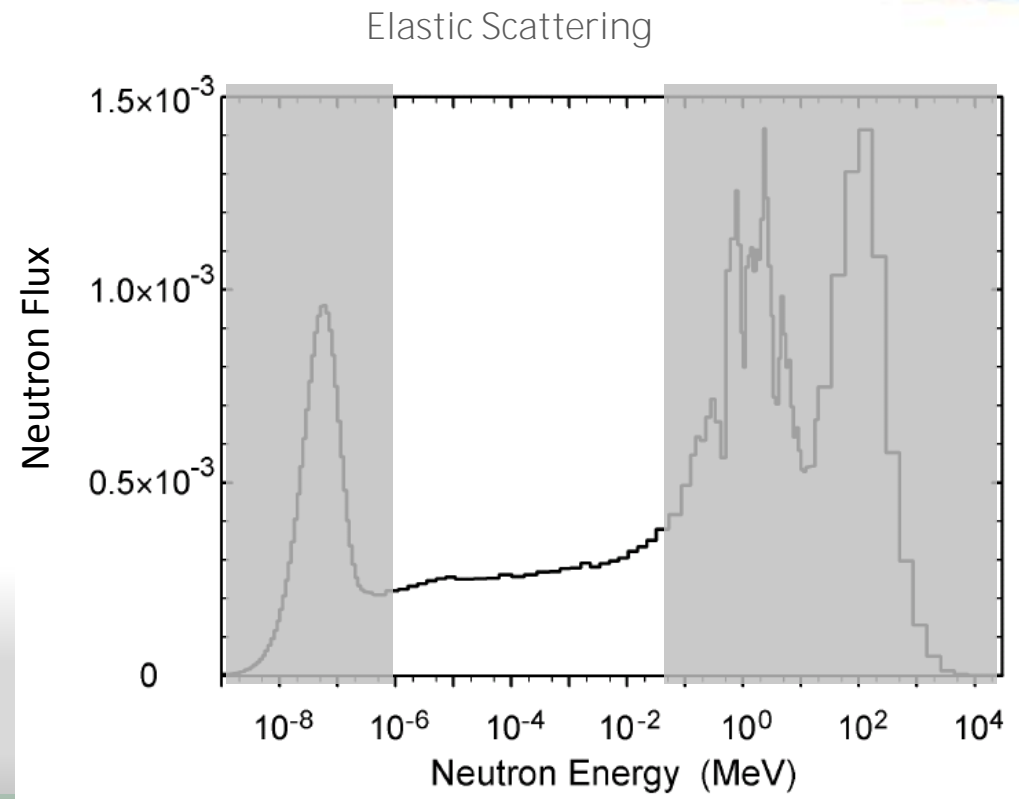
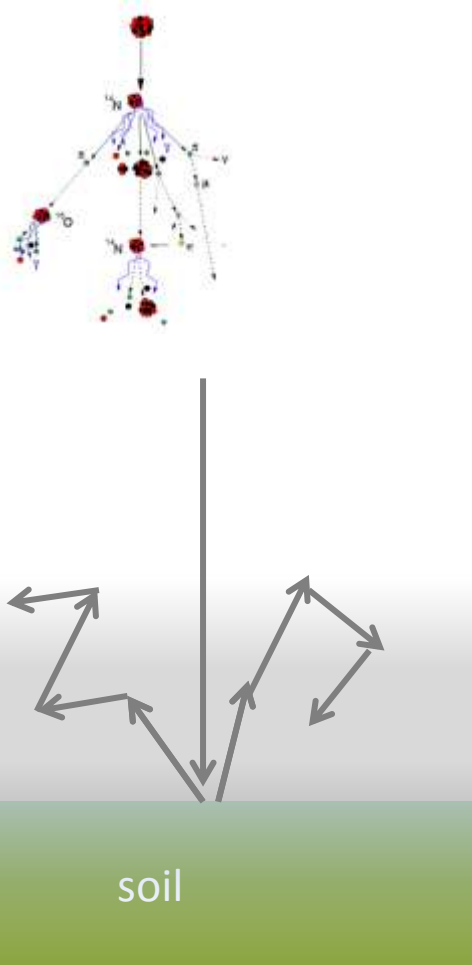
Evaporation





# The Cosmic Neutron Spectrum

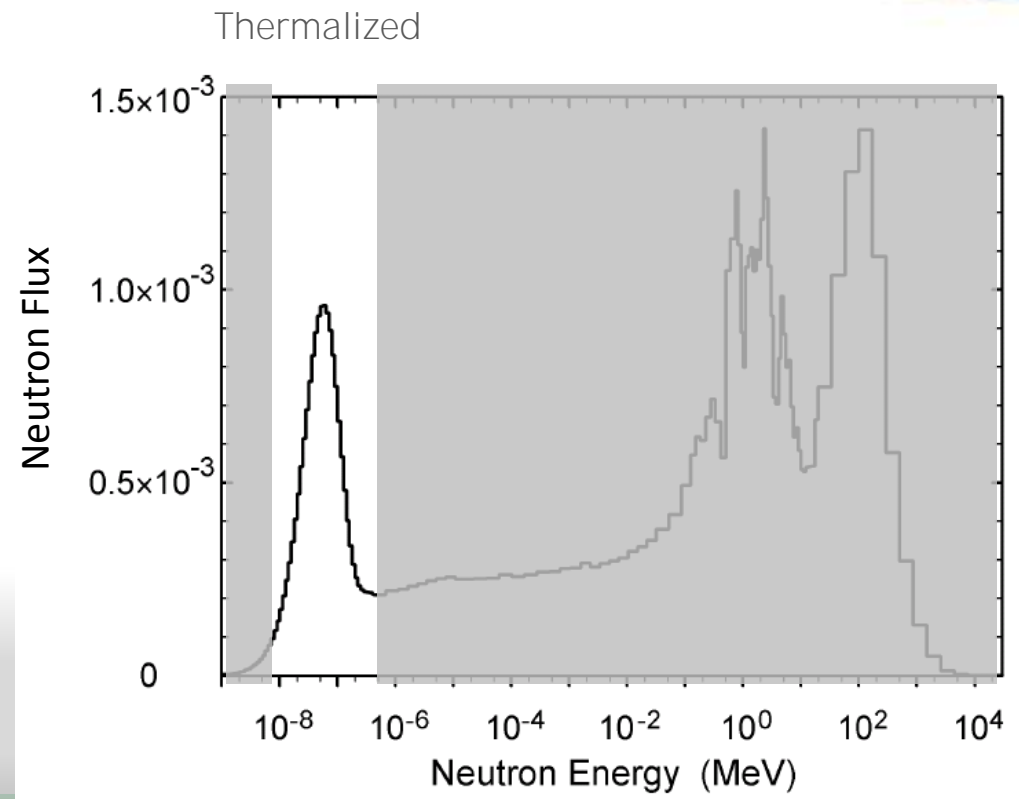
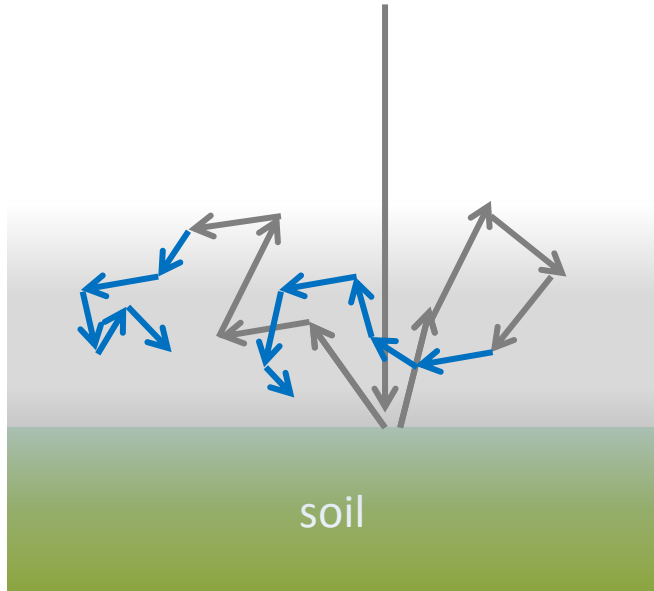
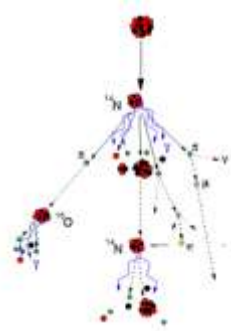
4





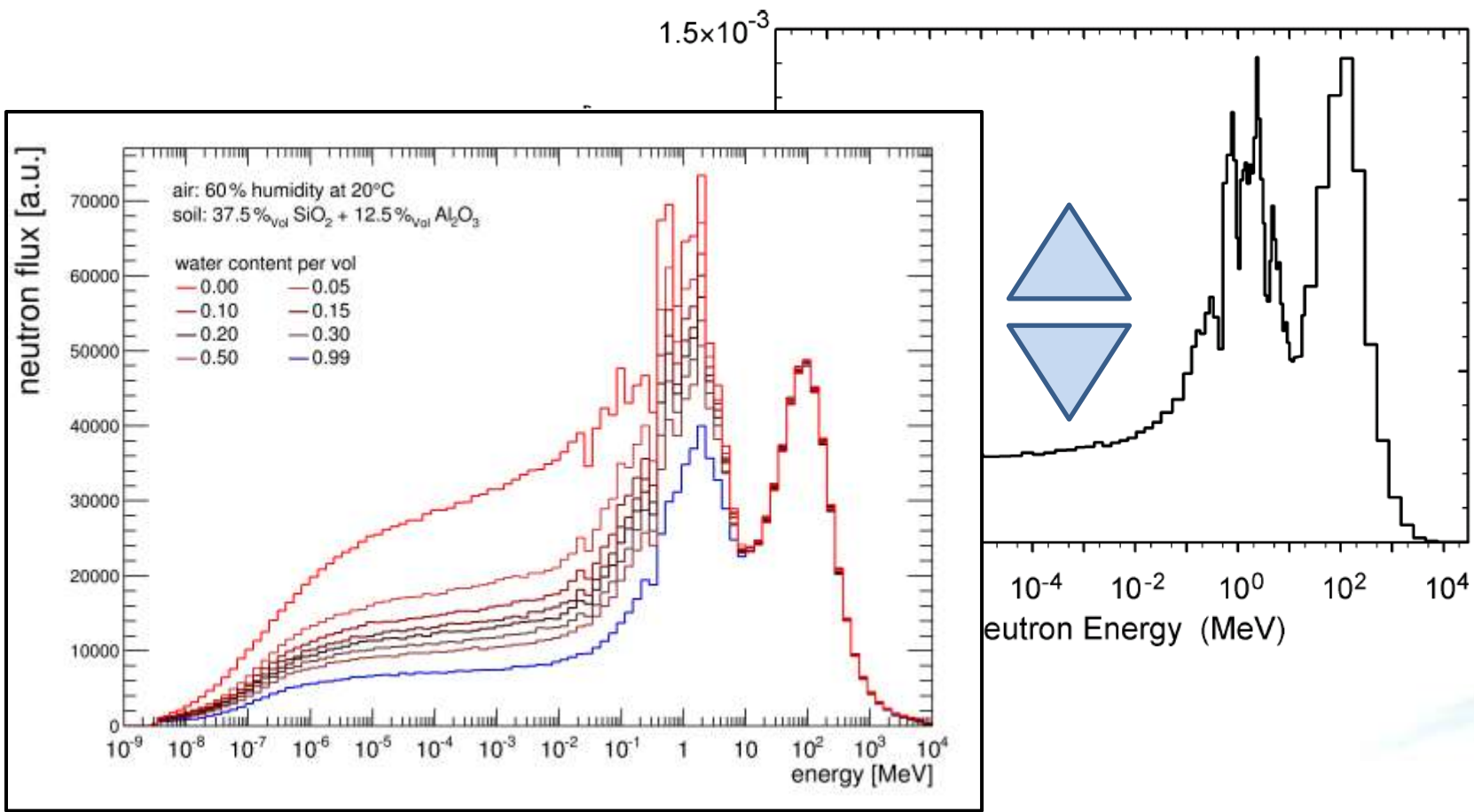
# The Cosmic Neutron Spectrum

4





# The Cosmic Neutron Spectrum

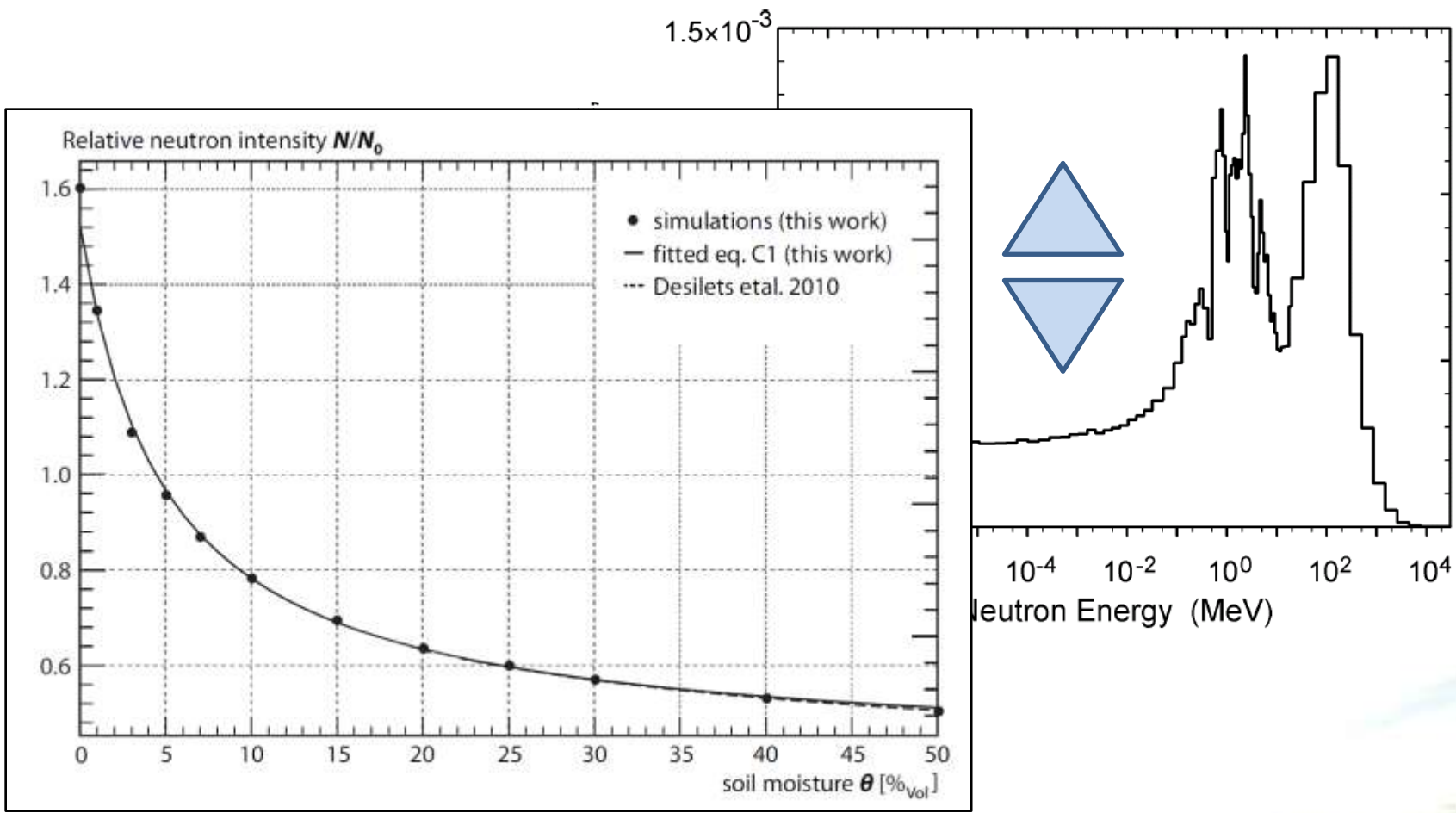






# The Cosmic Neutron Spectrum

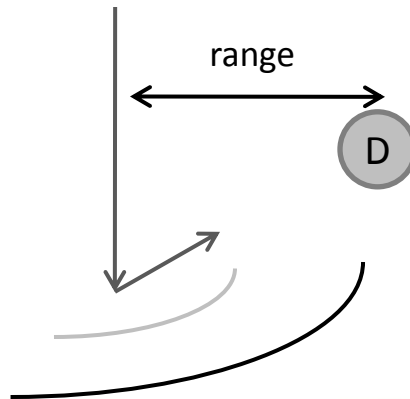
5





How far do reflected neutrons travel?

- Movie removed -

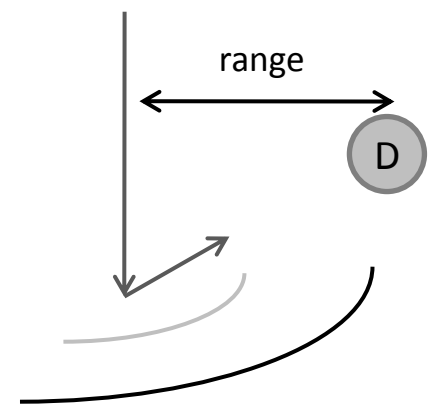
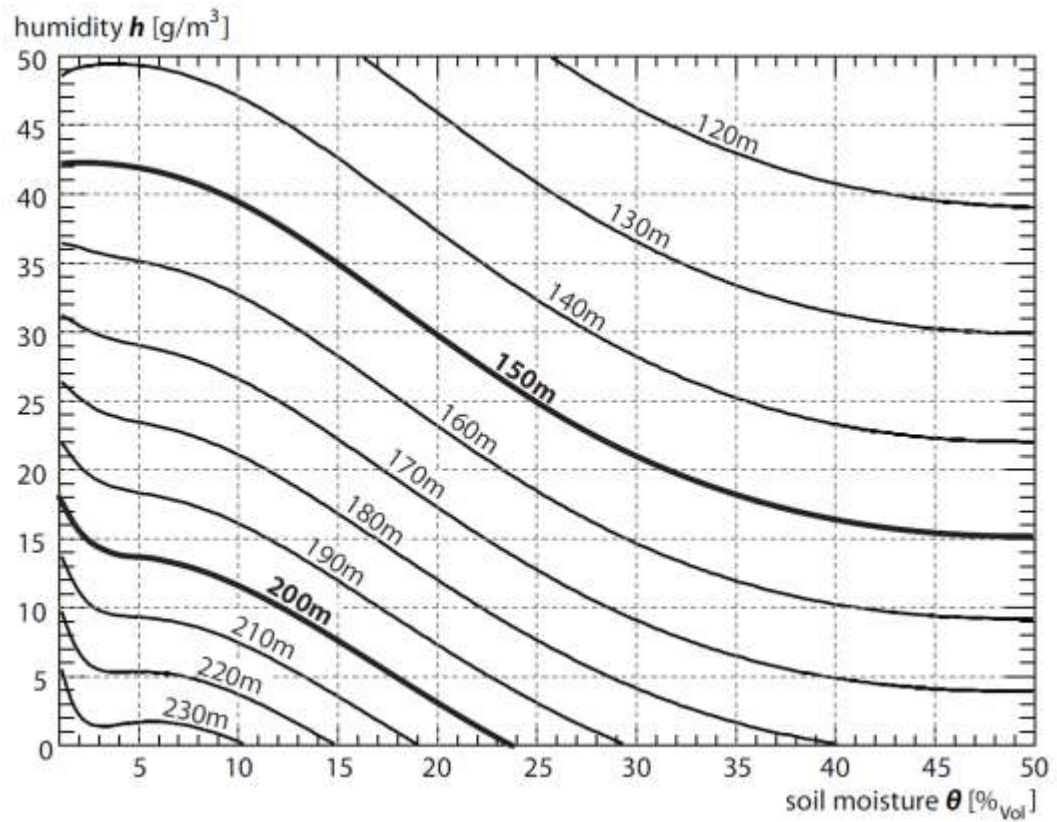




# The Footprint in 2015

6

How far do reflected neutrons travel?



Köhli et Schrön et al.

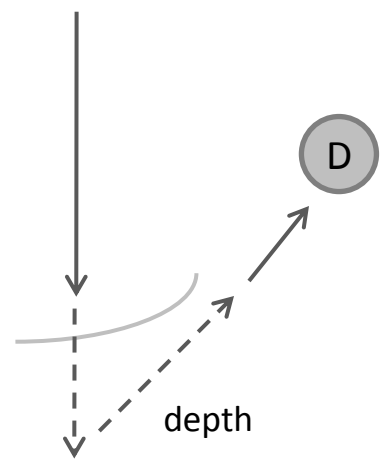
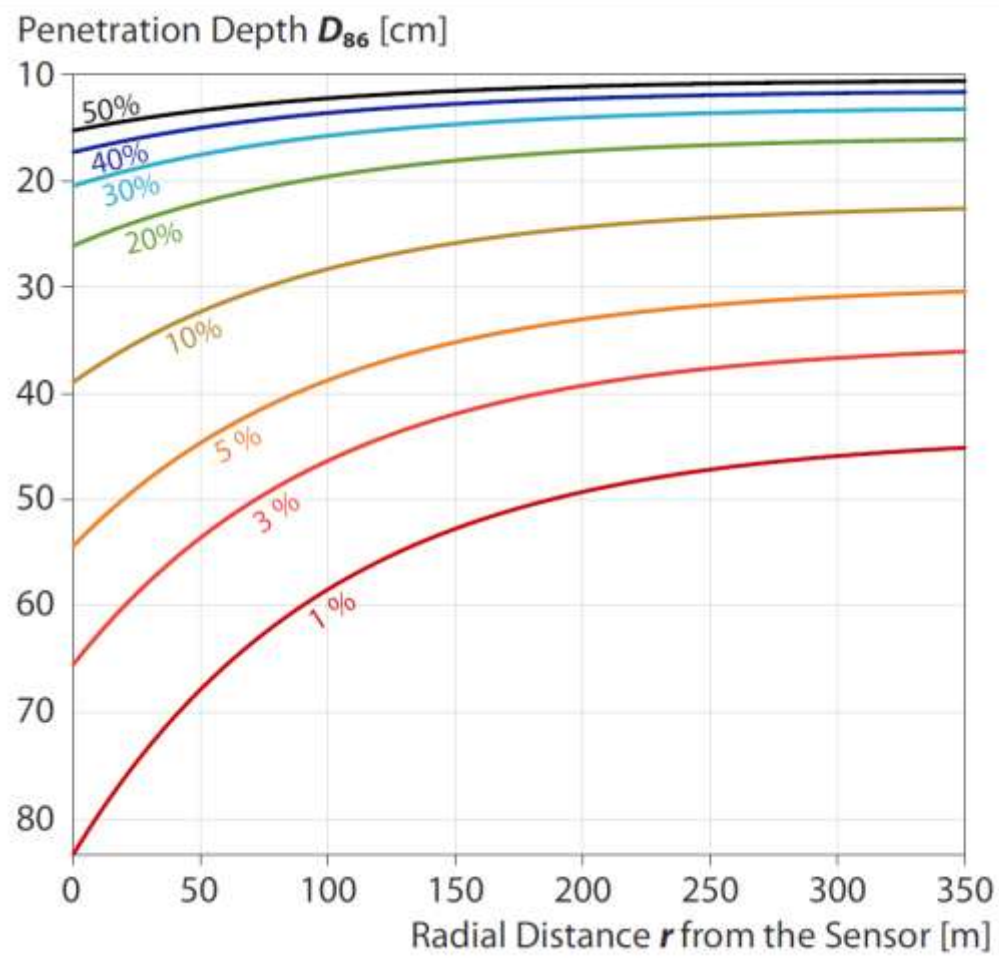
*Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons*

Water Resources Research, 51, 5772-5790



# Penetration Depth

6





# Precipitation Events

7



raw data from T. Franz, Santa Rita Site, refined by URANOS



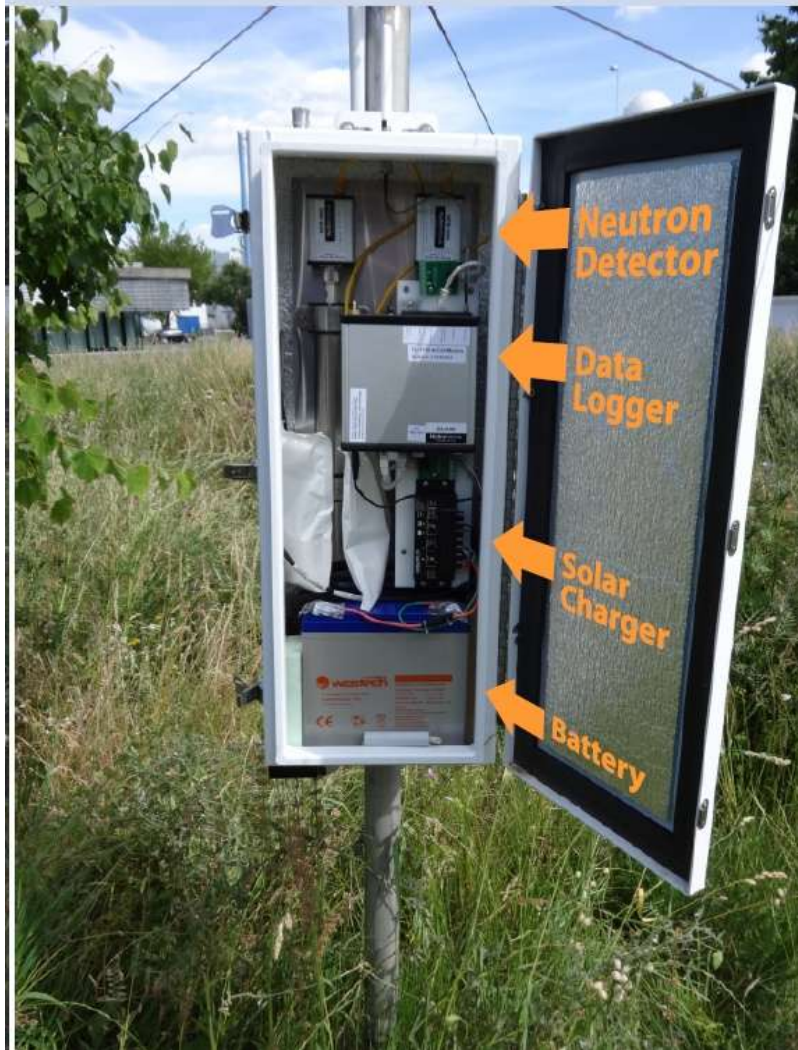
# The Equipment

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# The CRNS Sensor

8





# The CRNS Sensor

8



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: 40000000

Refresh every: 1000 neutrons

Export

Physical Parameters Computational Parameters Detector Setup Export & Display

Soil Water Content [vol%] 8 %

Soil Porosity [vol%] 50 %

Air Humidity 2.33 g/m<sup>3</sup>

Atmospheric depth 1020 g/cm<sup>2</sup>

Topological presets (water, land)

- None
- Rives, width [m] 10
- Coast at x [m] 0
- Island, diameter [m] 10
- Lake, diameter [m] 10

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	-1800	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	-8.1	0.1	11	8.png (1800)
10	0	0.1	20	18.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

Integral Range: 229 m

Coverage: 87.34 %

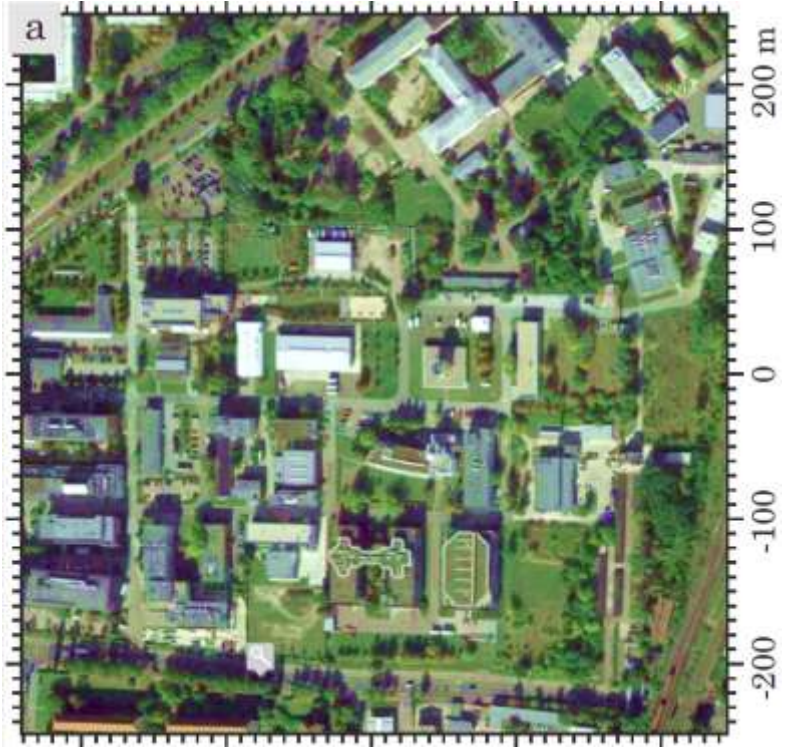
Live: Bird-eye View & Spectra Range View Spatial View

URANOS  
Community  
Version

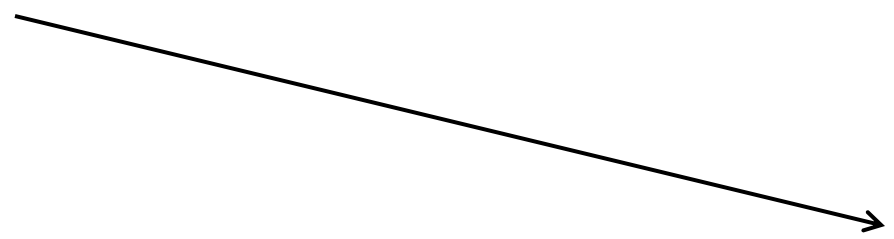


# Inhomogeneous Terrain

9



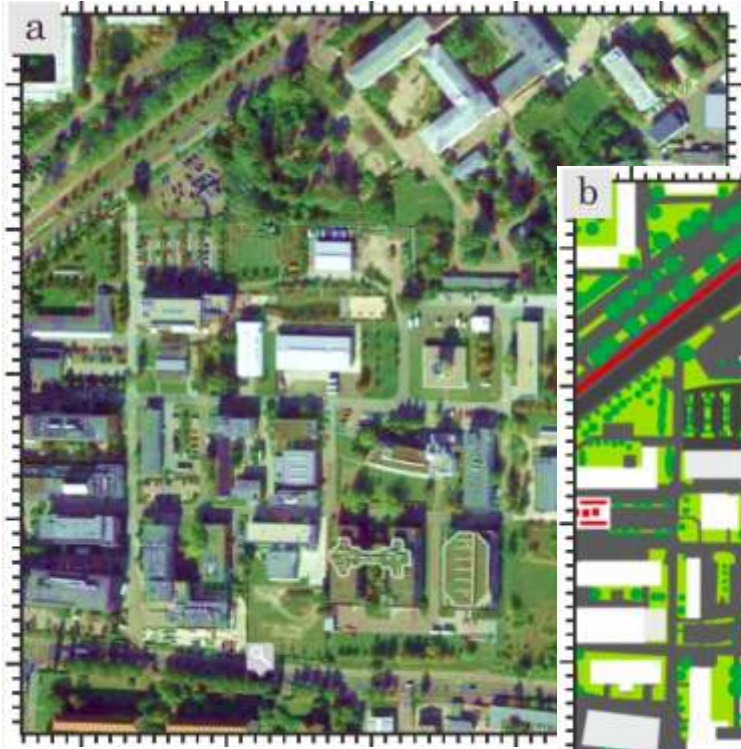
topography



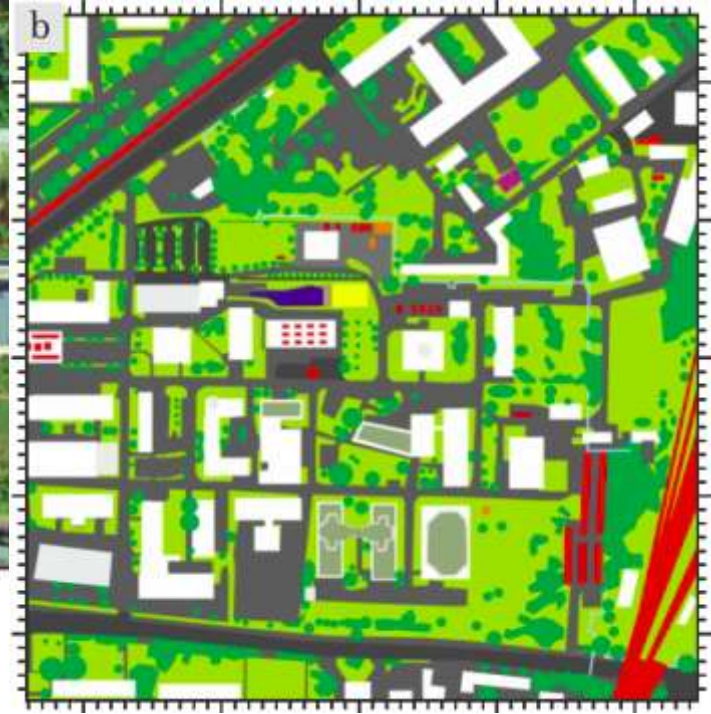


# Inhomogeneous Terrain

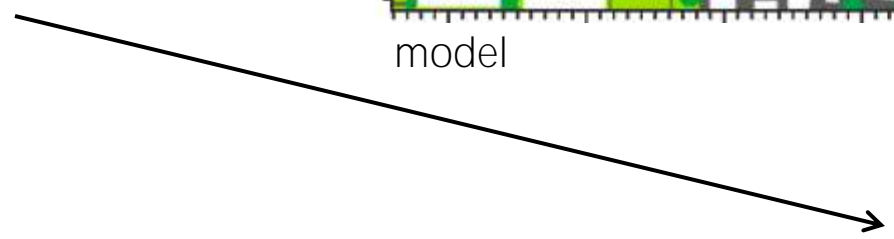
9



topography



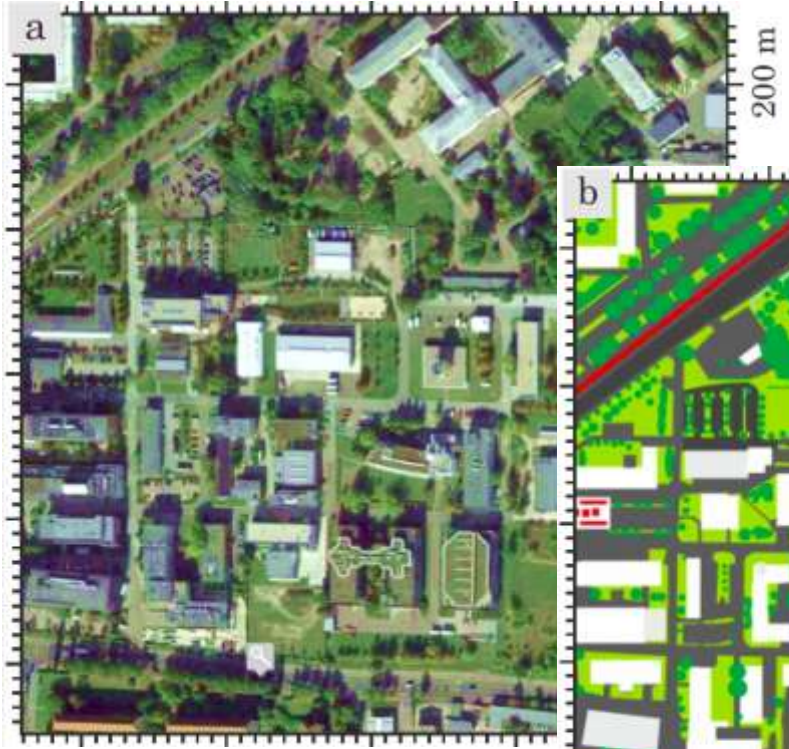
model



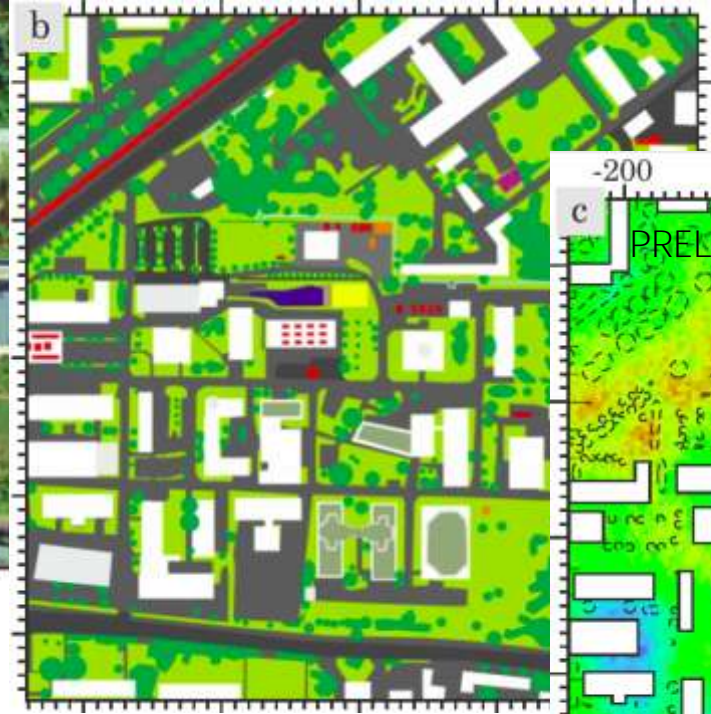


# Inhomogeneous Terrain

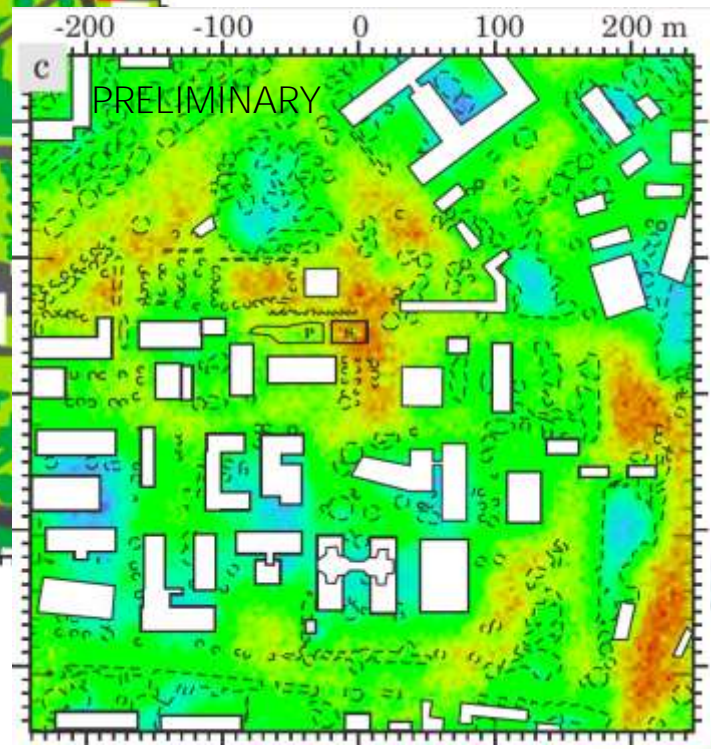
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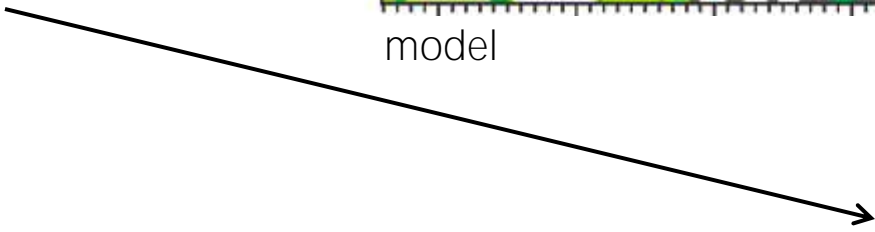
topography



model



simulation





# Local Effects

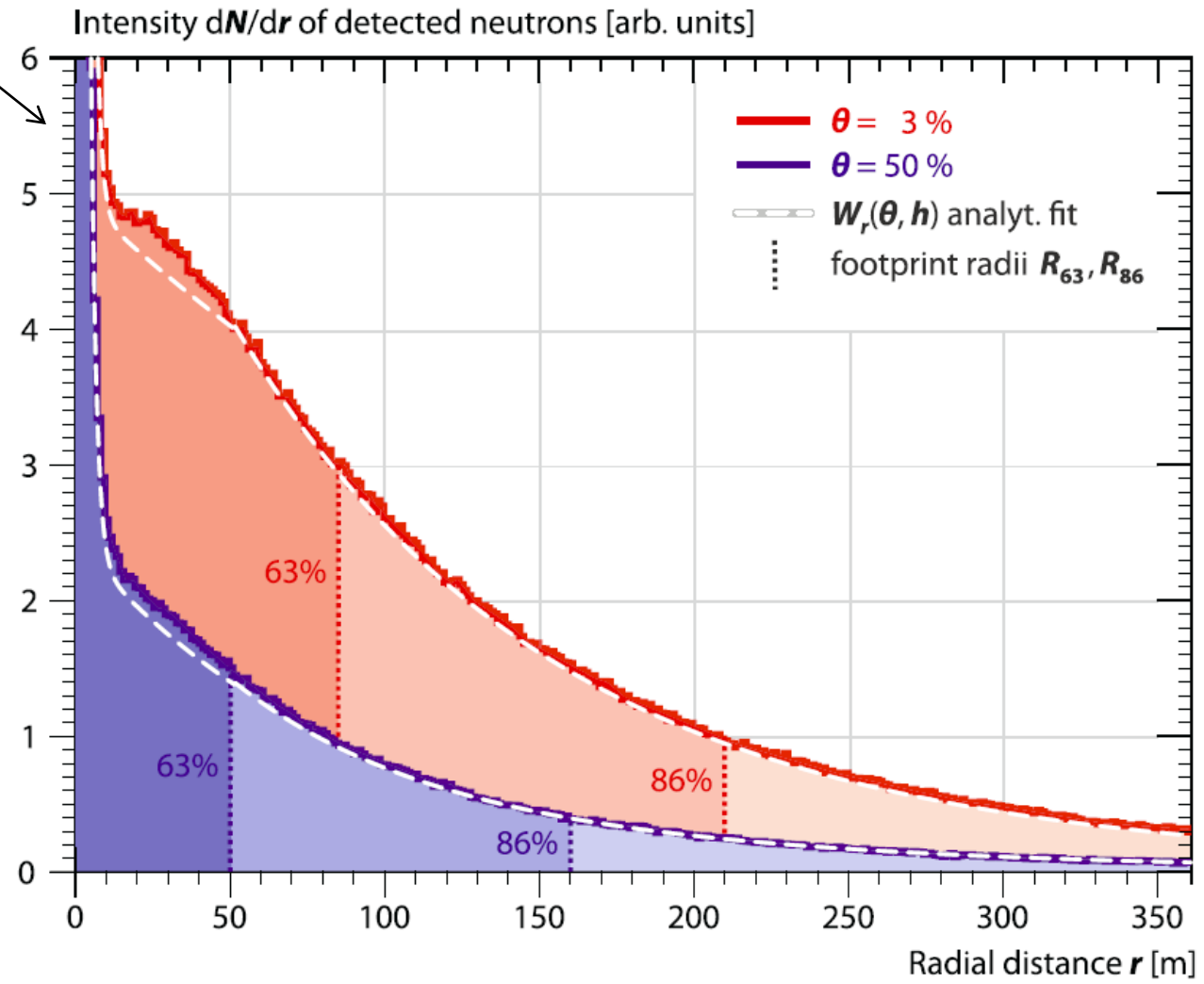
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# Local Effects

10

near field peak



long tail



# Buoy on a lake

11

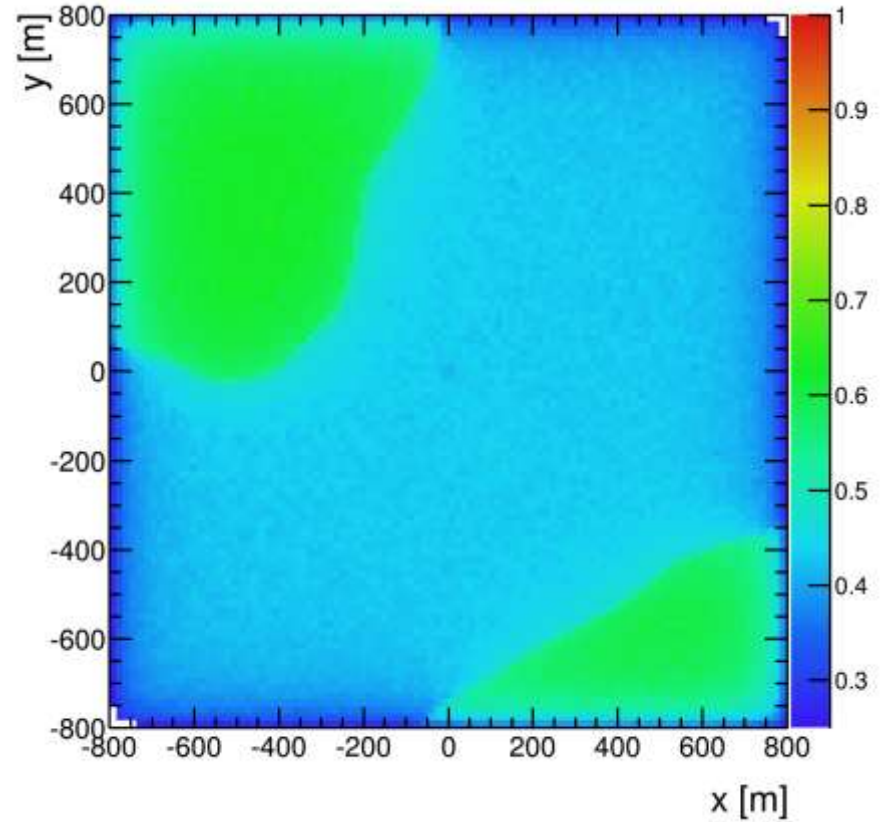
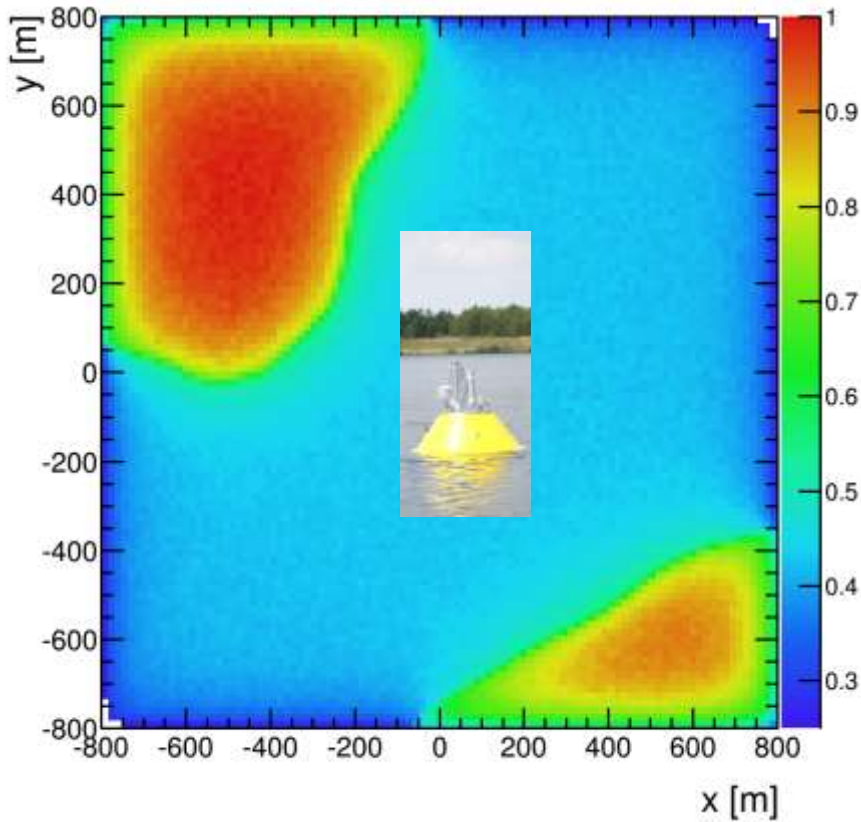






# Buoy on a lake

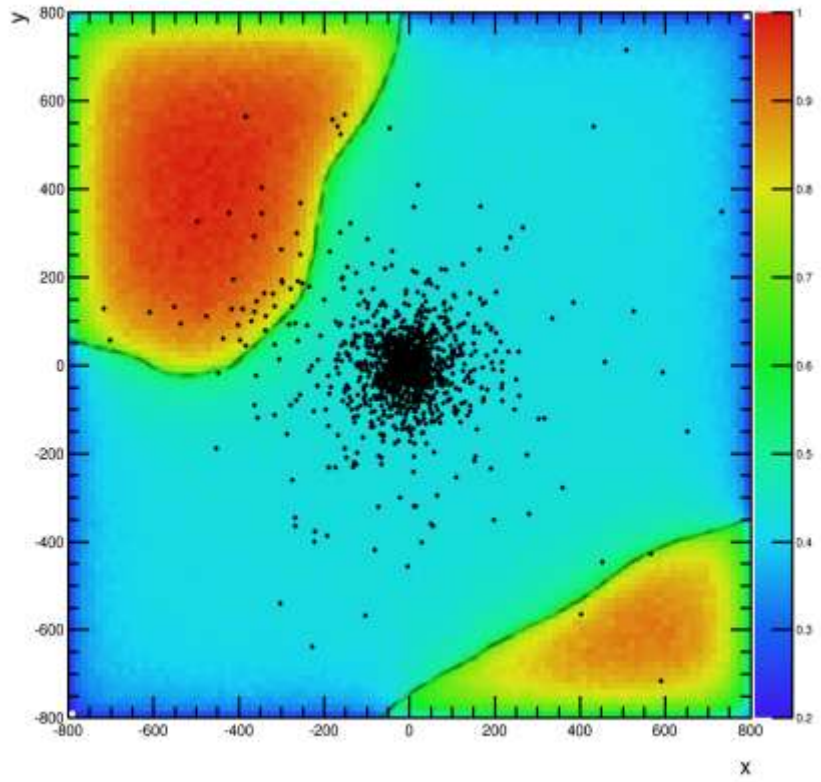
11



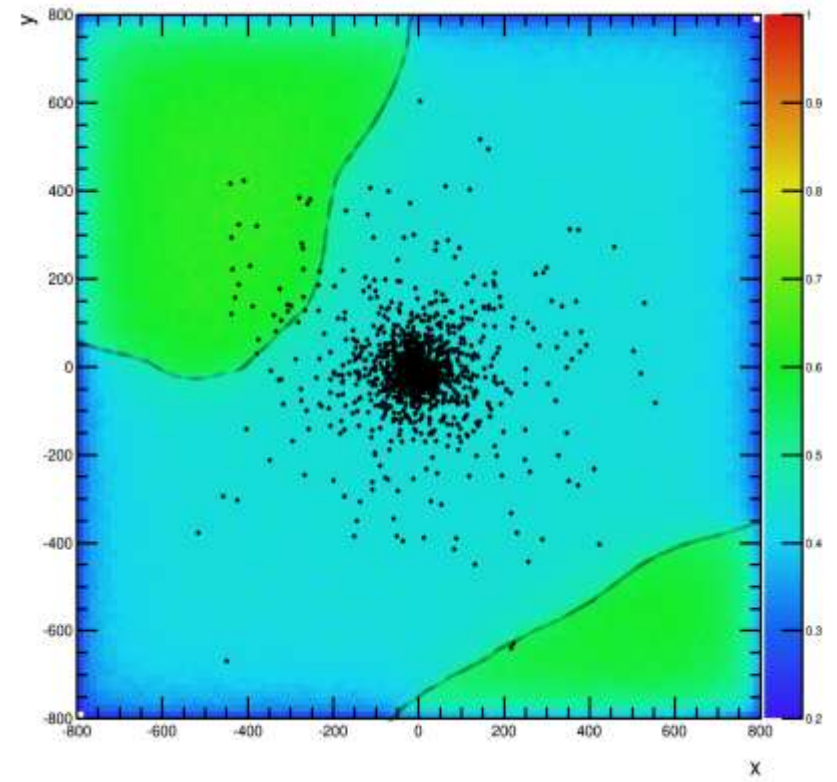


# Buoy on a lake

11



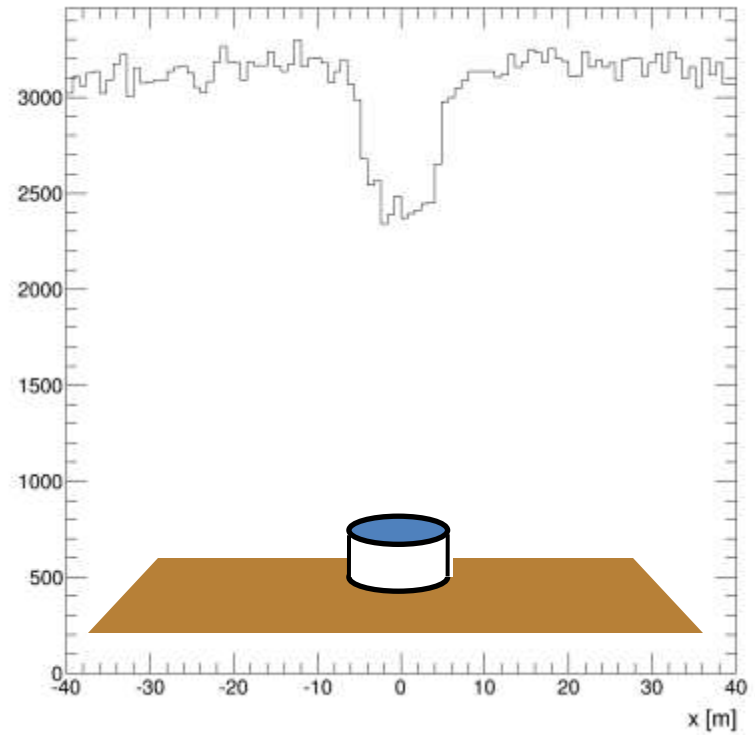
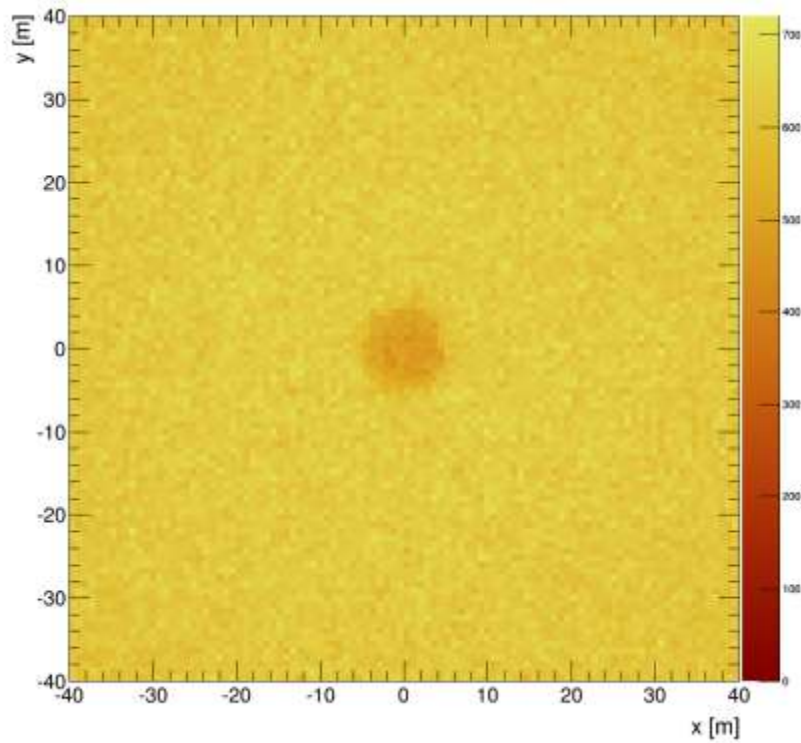
dry coast



wet coast



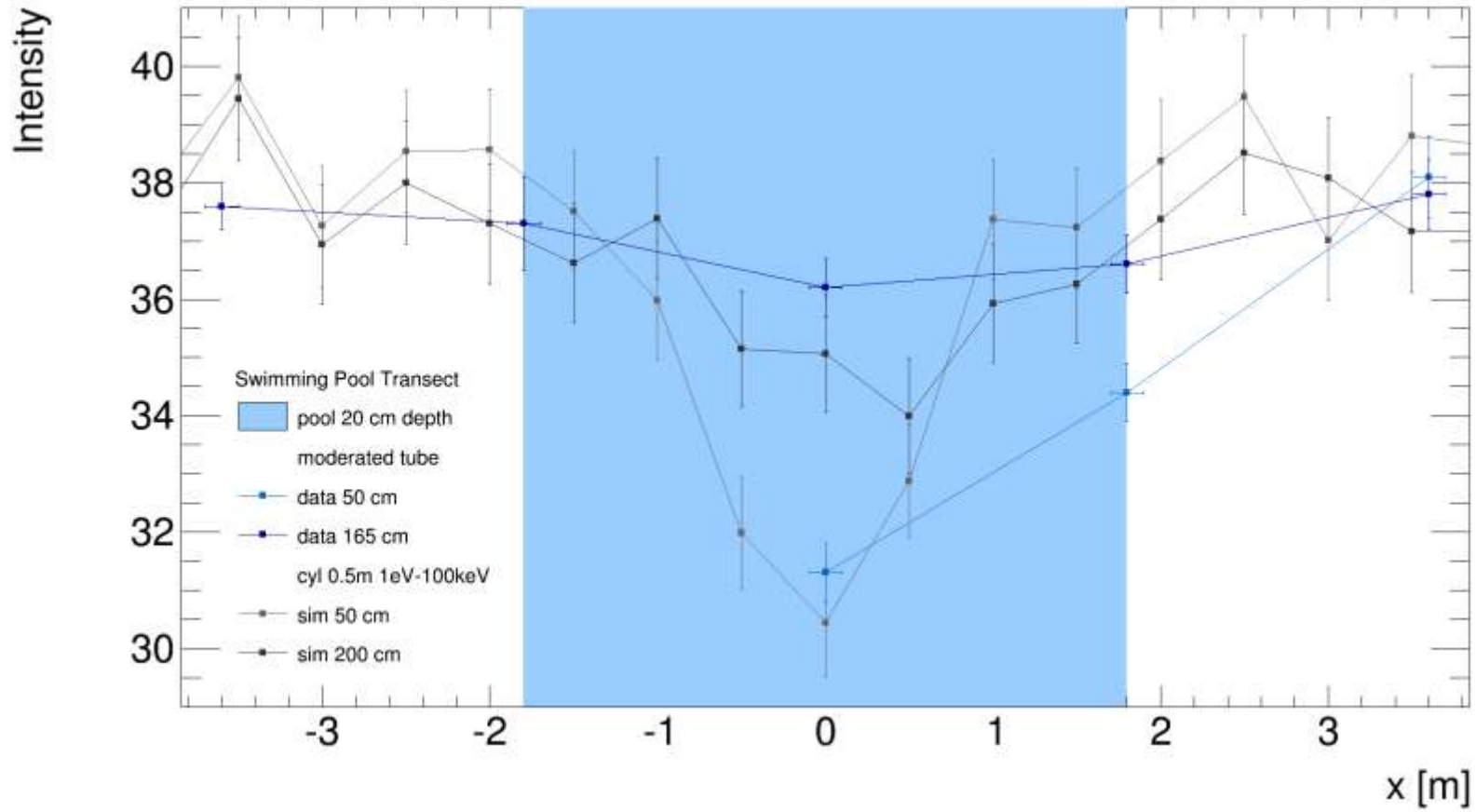
## Pool Transect





# Local Swimming Pool Effects

12





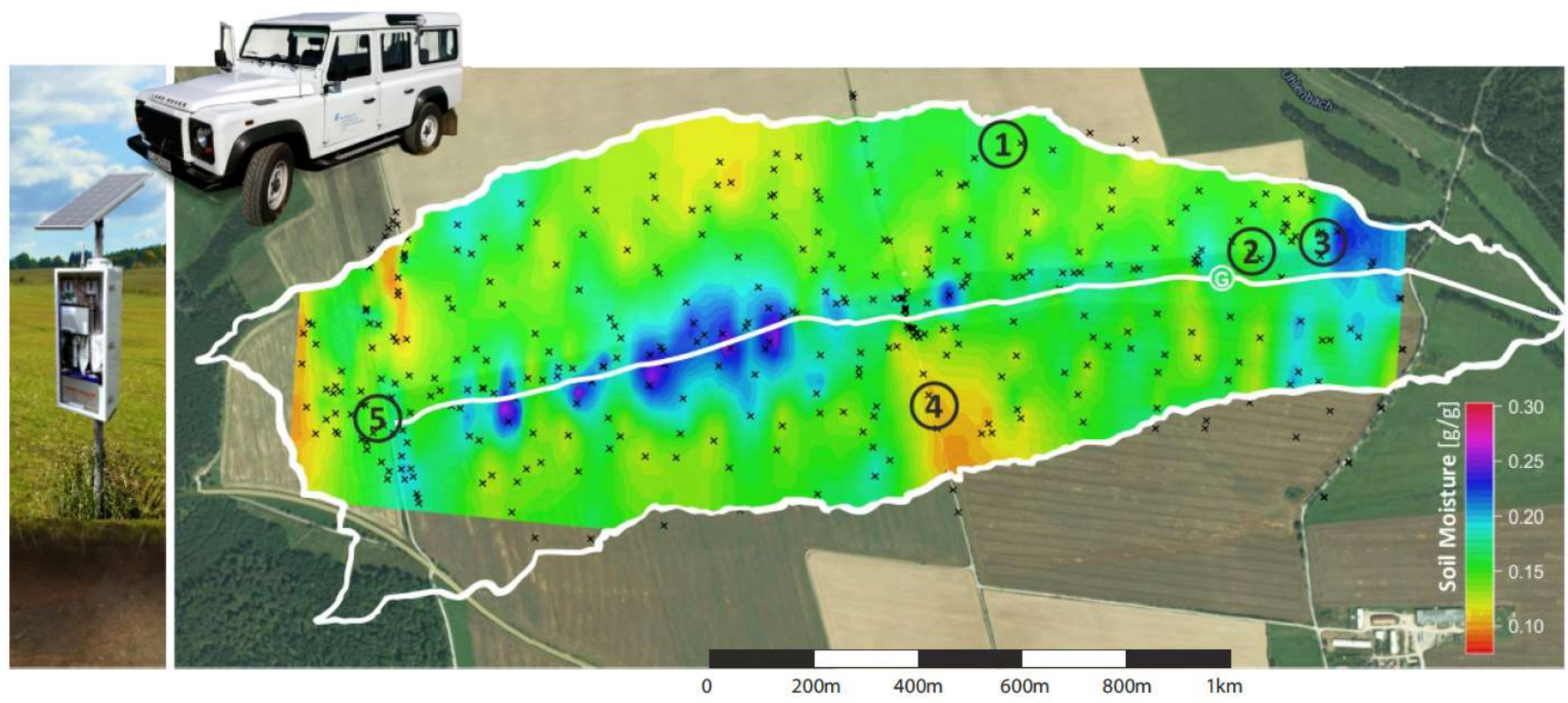
# Mobile CRNS

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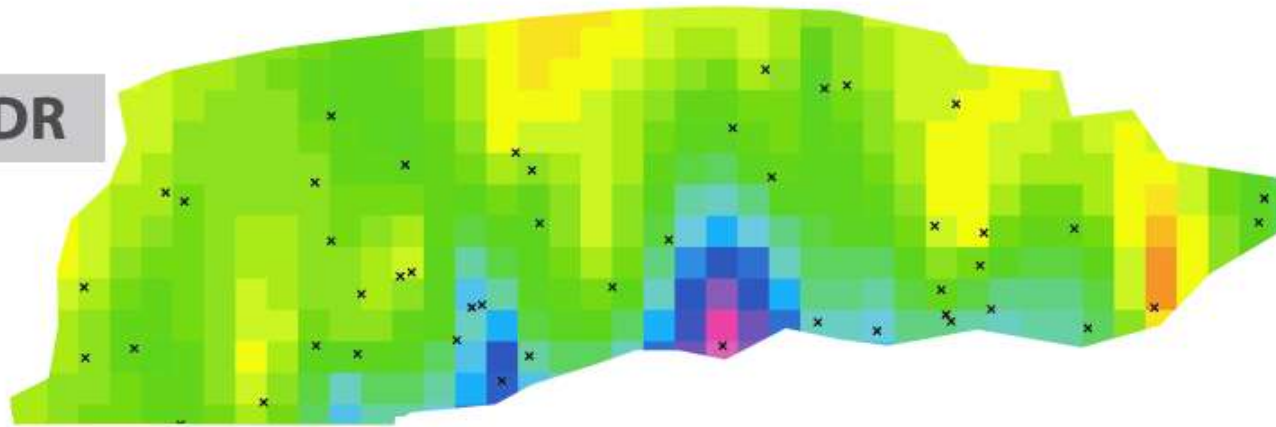
# Mobile CRNS

13

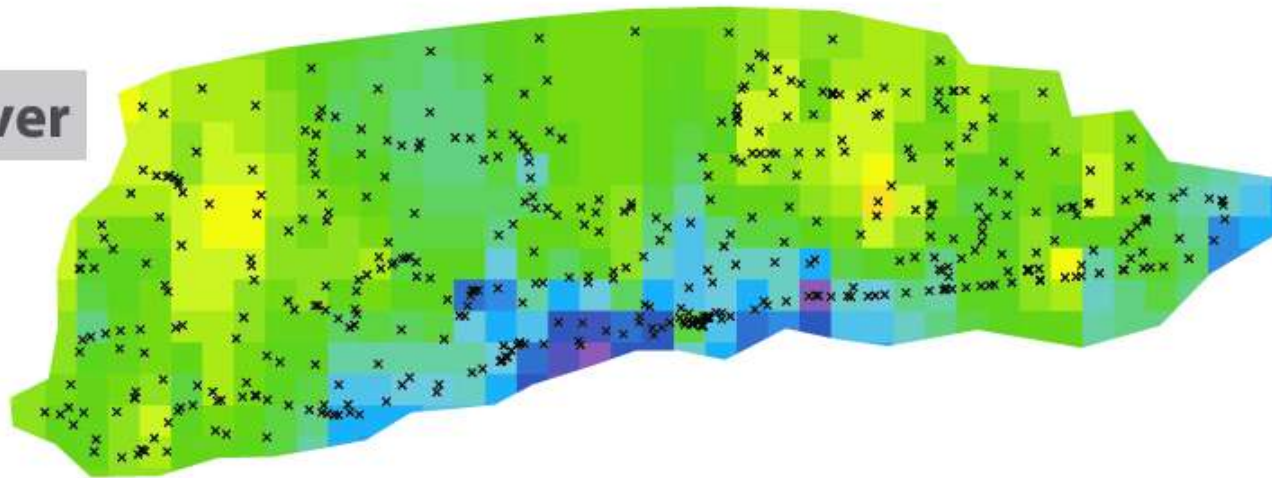




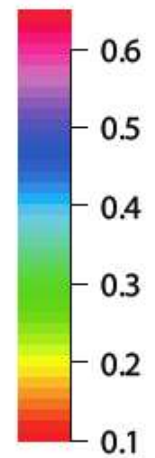
**TDR**



**Rover**



% SM

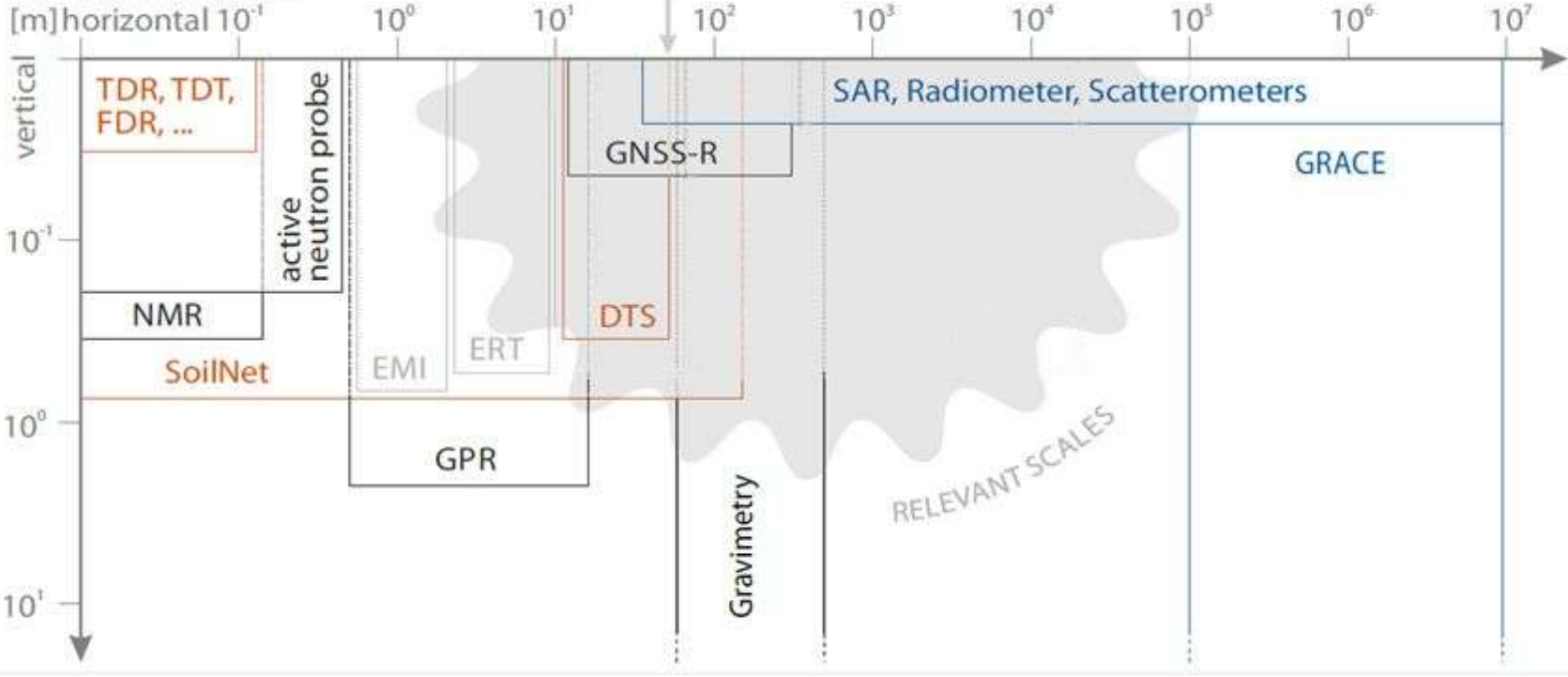




# The Measurement Gap

15

## Scales of soil moisture measurements



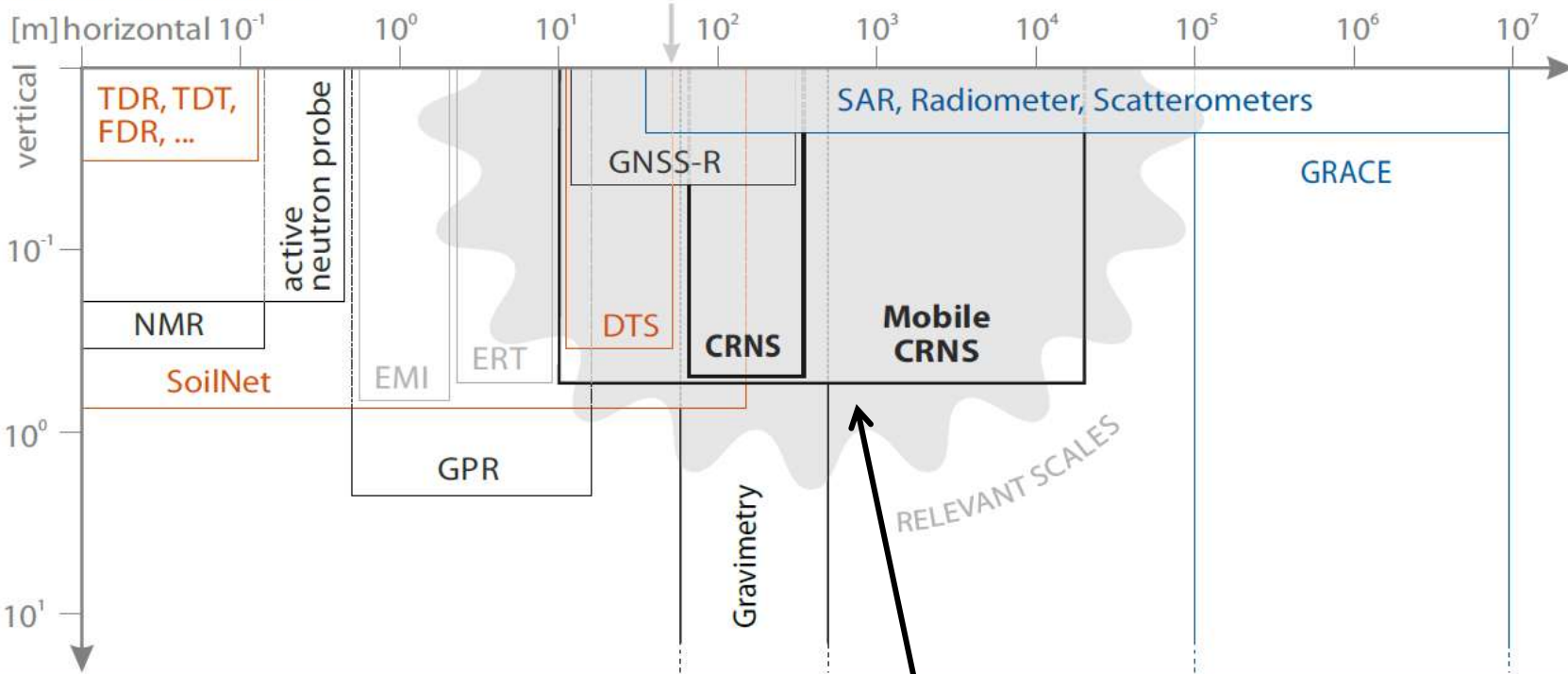




# The Measurement Gap

15

## Scales of soil moisture measurements



And now here



## ■ Cosmic-Ray Neutron Detection

## ■ Outlook:



## □ Cosmic-Ray Neutron Detection

- 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 explained

## □ Outlook:



## □ Cosmic-Ray Neutron Detection

- 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 explained

## □ Outlook: Development of mobile technologies

