

Validation potential for Remote Sensing soil moisture products using Cosmic-Ray Neutron Sensing

DPG Frühjahrstagung 2023

22.03.2023

UP 4.6

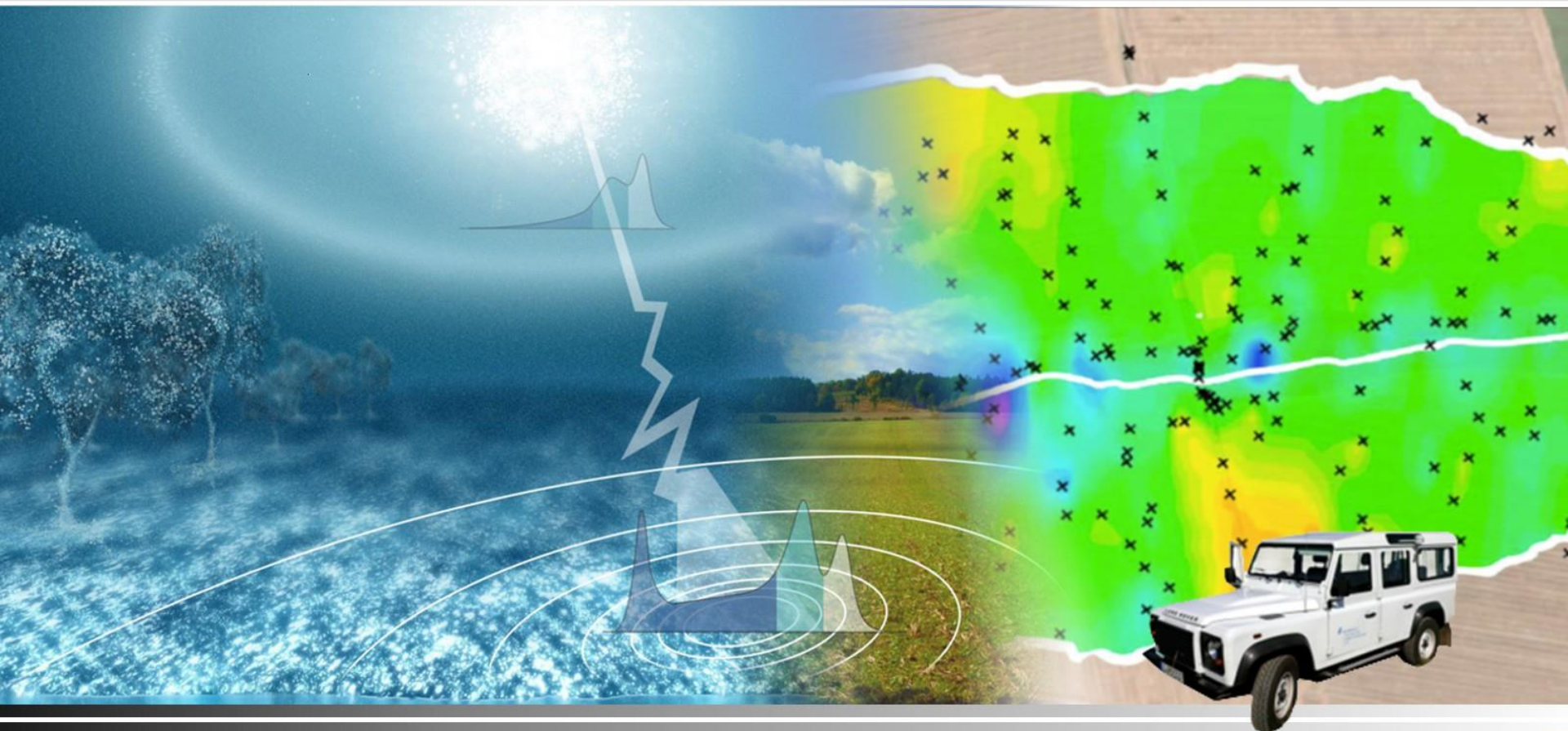


Physikalisches Institut

Ruprecht-Karls-Universität
Heidelberg

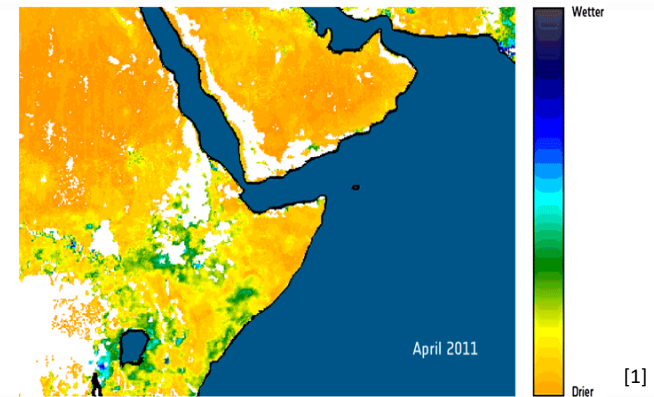
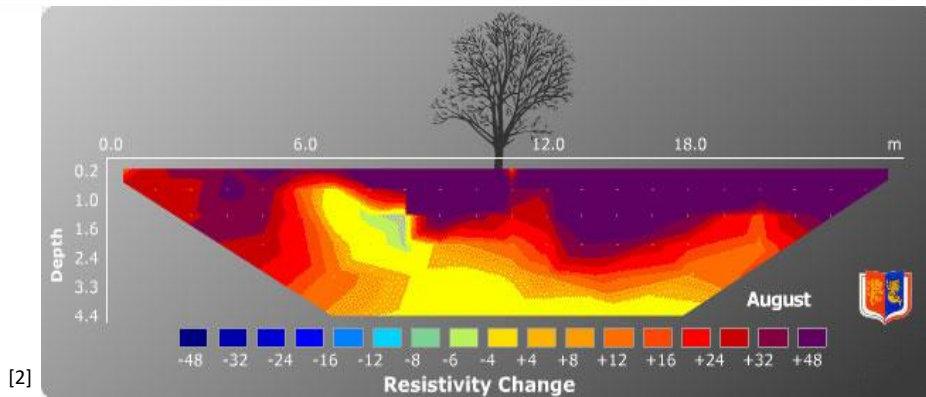
Markus Köhli*, Jannis Weimar, Ulrich Schmidt

ANP-PAT



< 10 m

~ 1 km

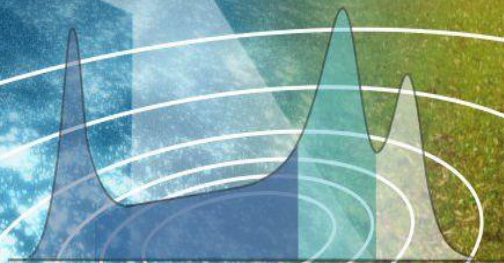
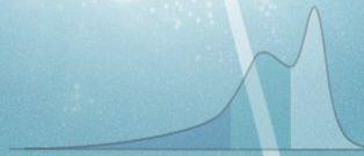


via
local techniques
(electrical resistivity, capacitance, etc)
(even neutrons...)

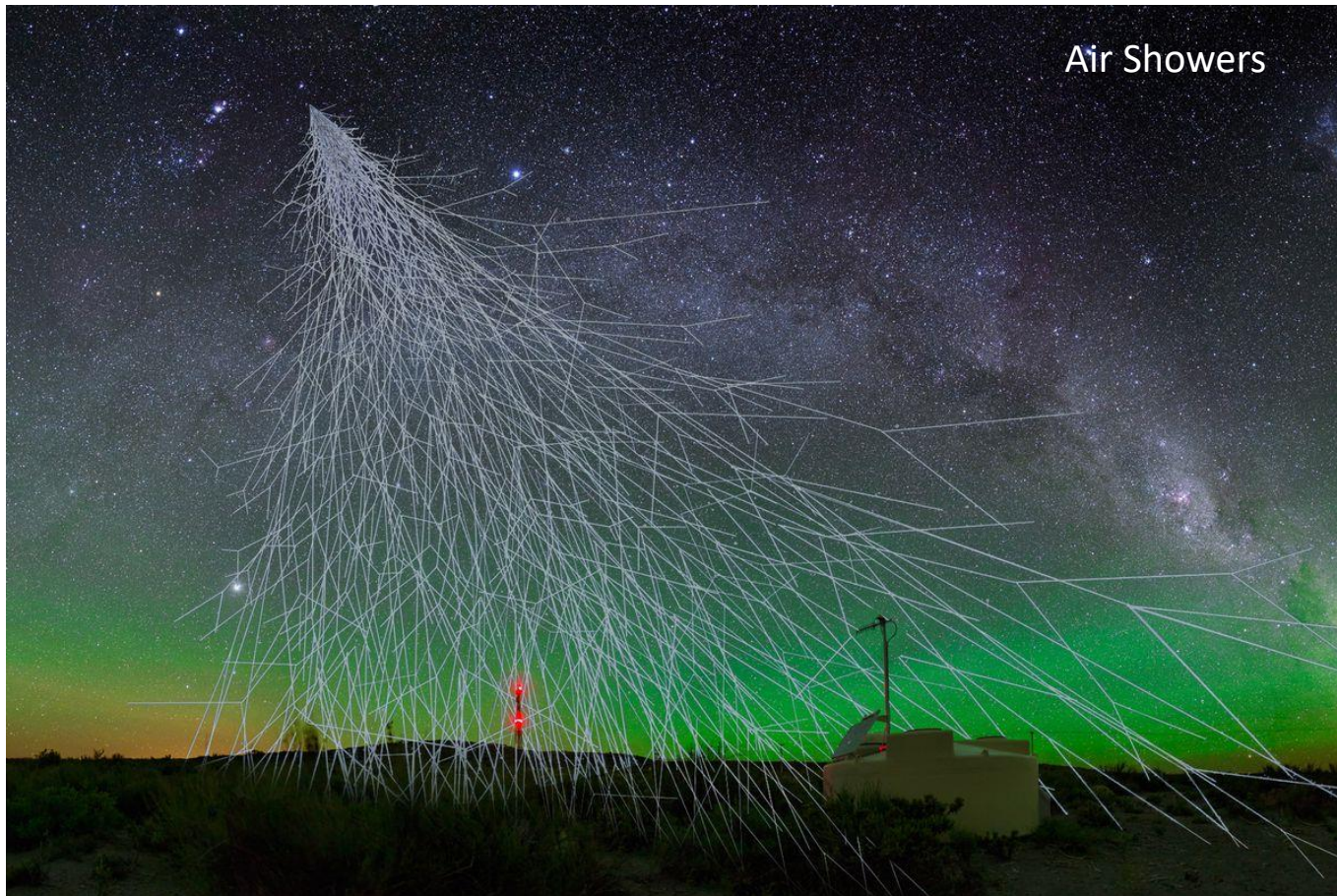
via
satellite remote sensing
(optical, microwave)

[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>)

Cosmic-Ray Neutron Sensing .CRNS.



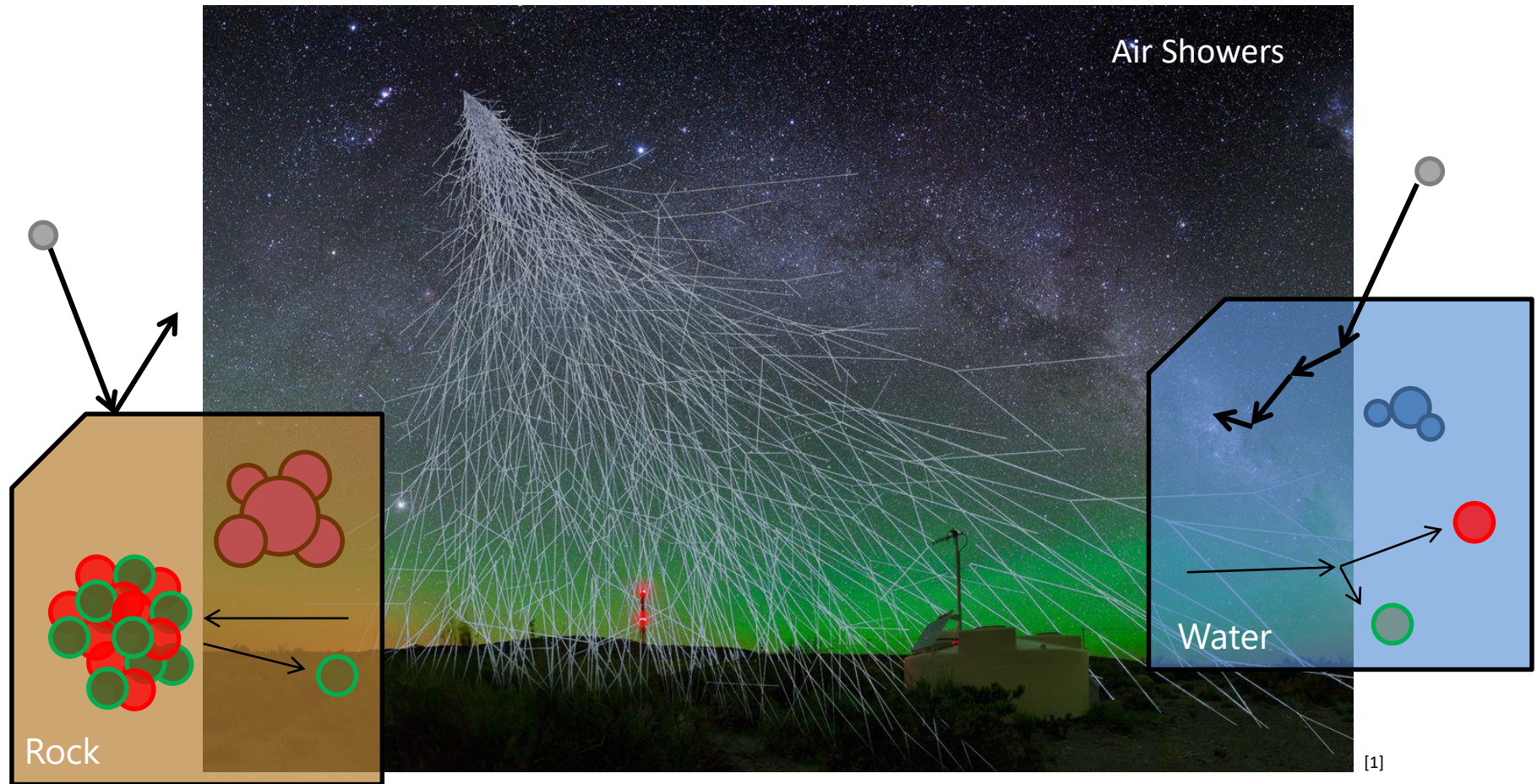
▶ The Cosmic Neutron Basics



[1]

[1] Image by A. Chantelauze, S. Staffi, and L. Bret, <https://www.theverge.com/2017/9/21/16335164/pierre-auger-observatory-cosmic-ray-galaxies-air-shower-particles>

The Cosmic Neutron Basics



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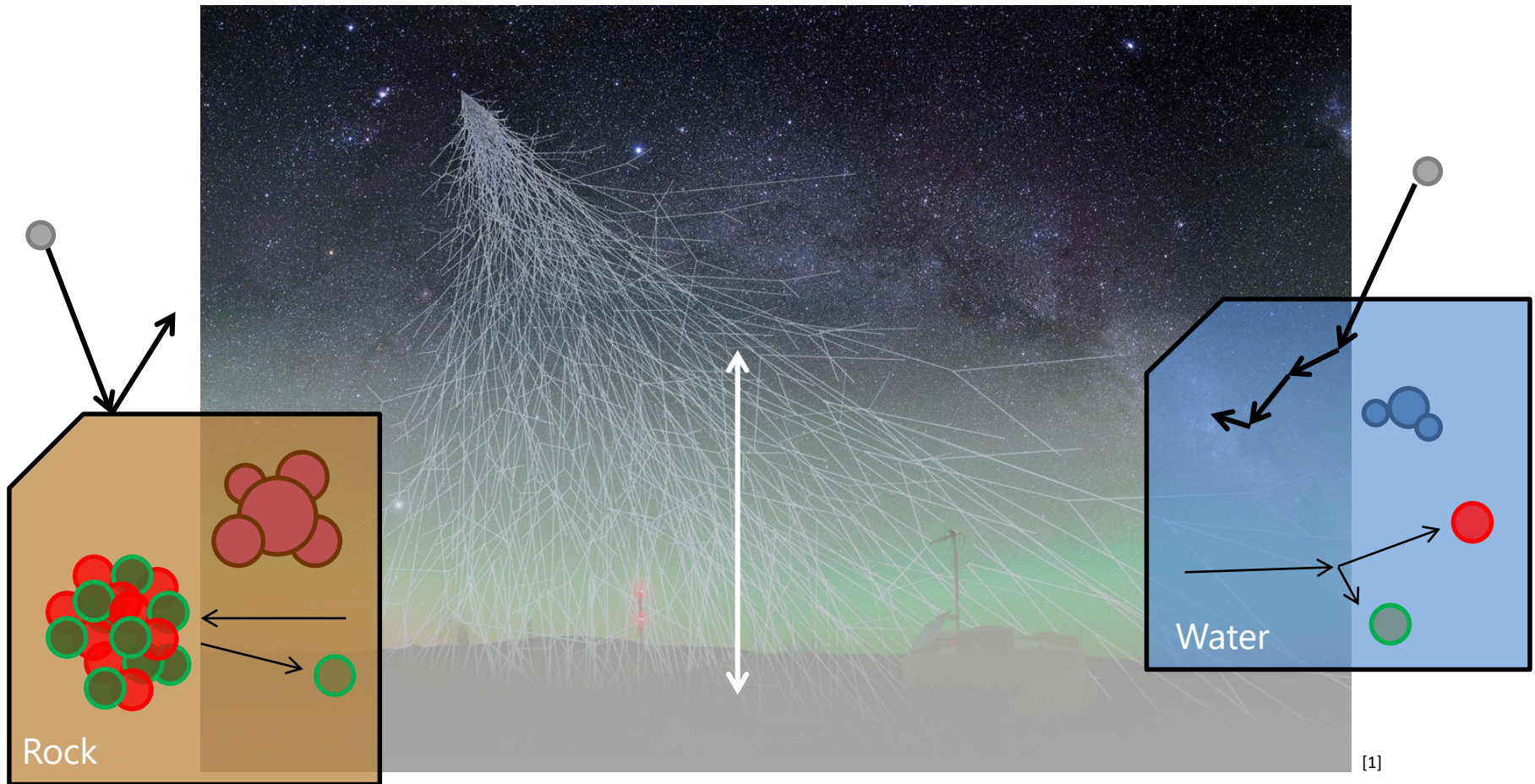
Neutron imaging



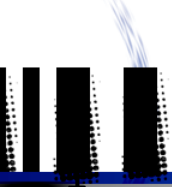
Courtesy: PSI



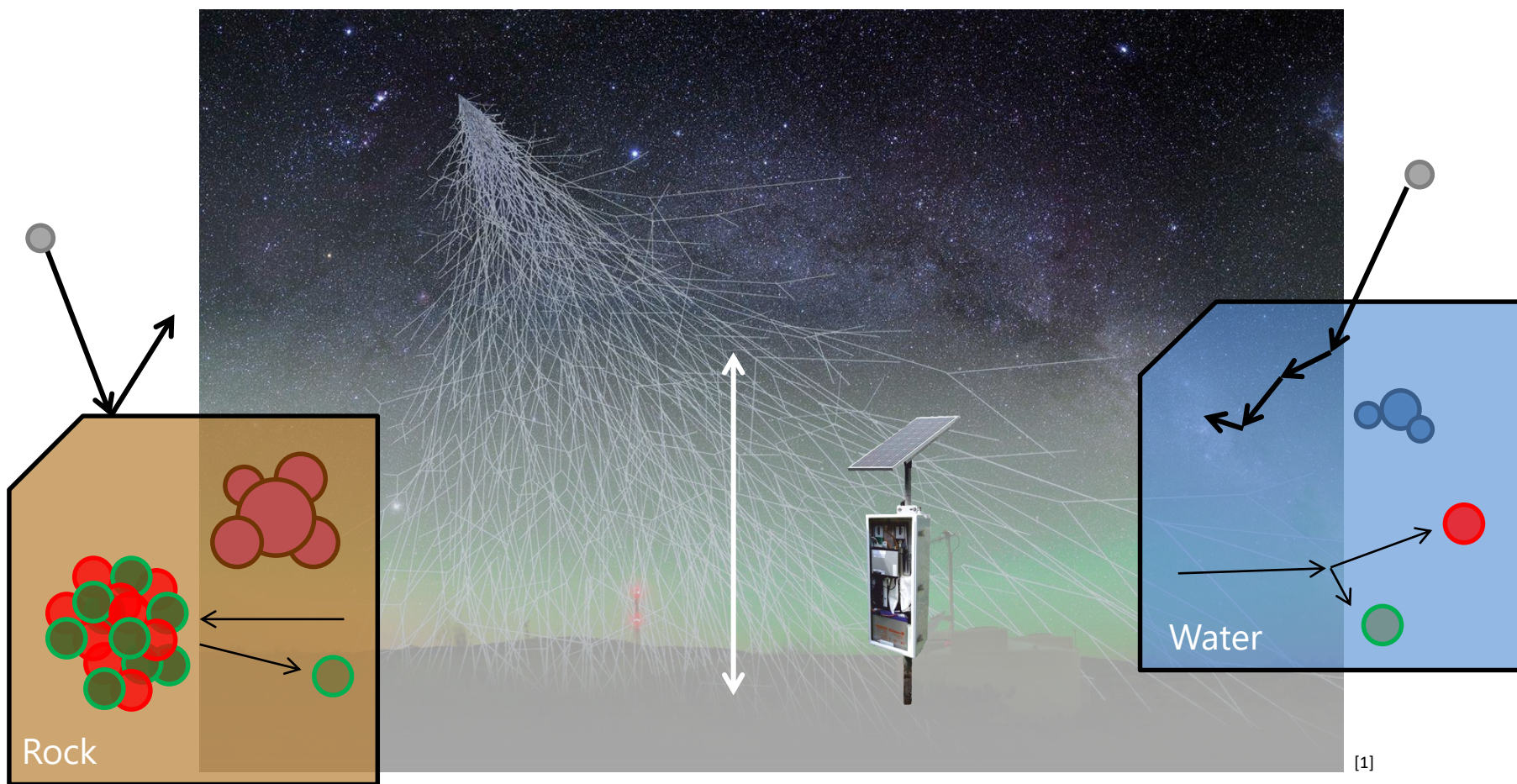
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[1] Image by A. Chantelauze, S. Staffi, and L. Bret, <https://www.theverge.com/2017/9/21/16335164/pierre-auger-observatory-cosmic-ray-galaxies-air-shower-particles>



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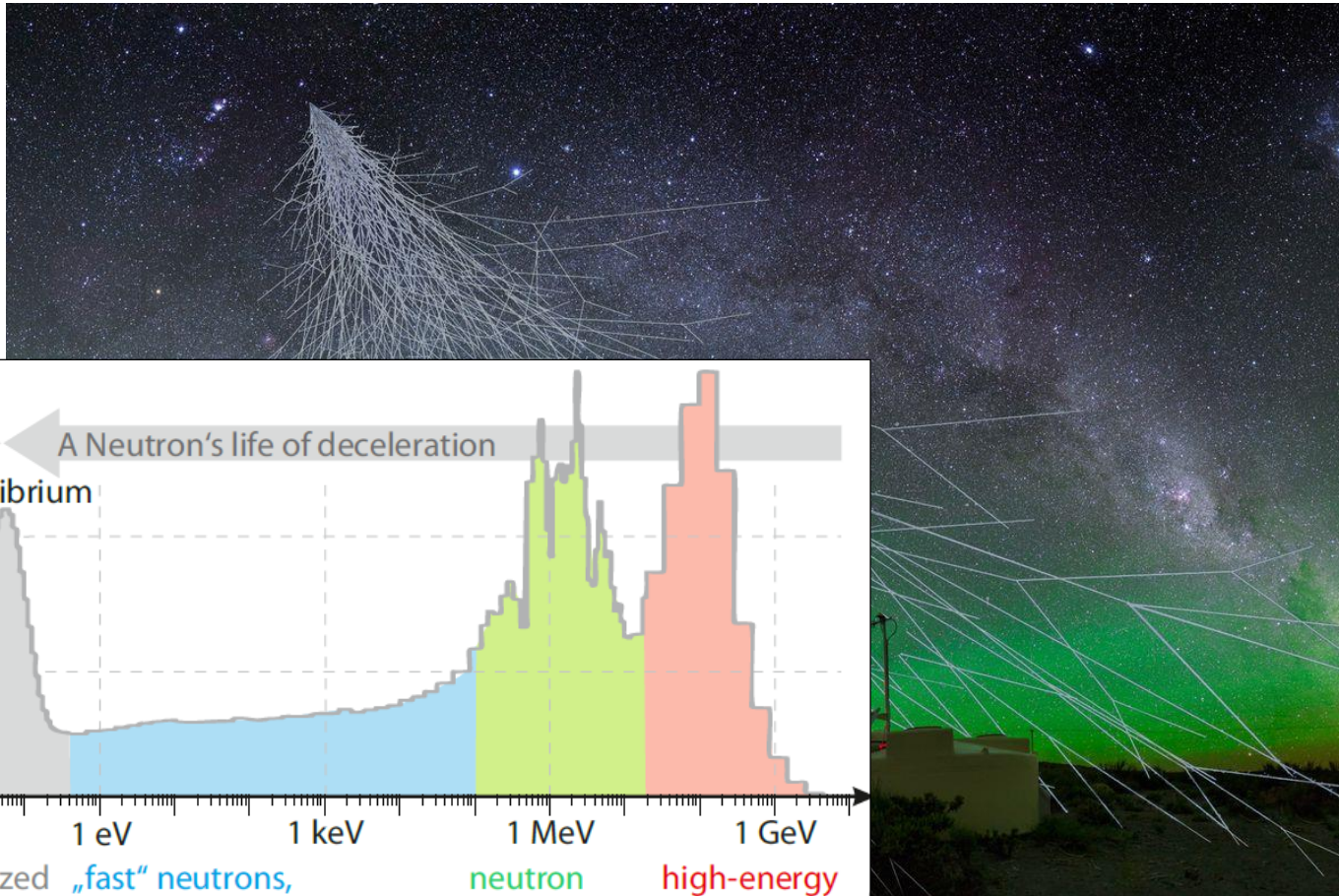


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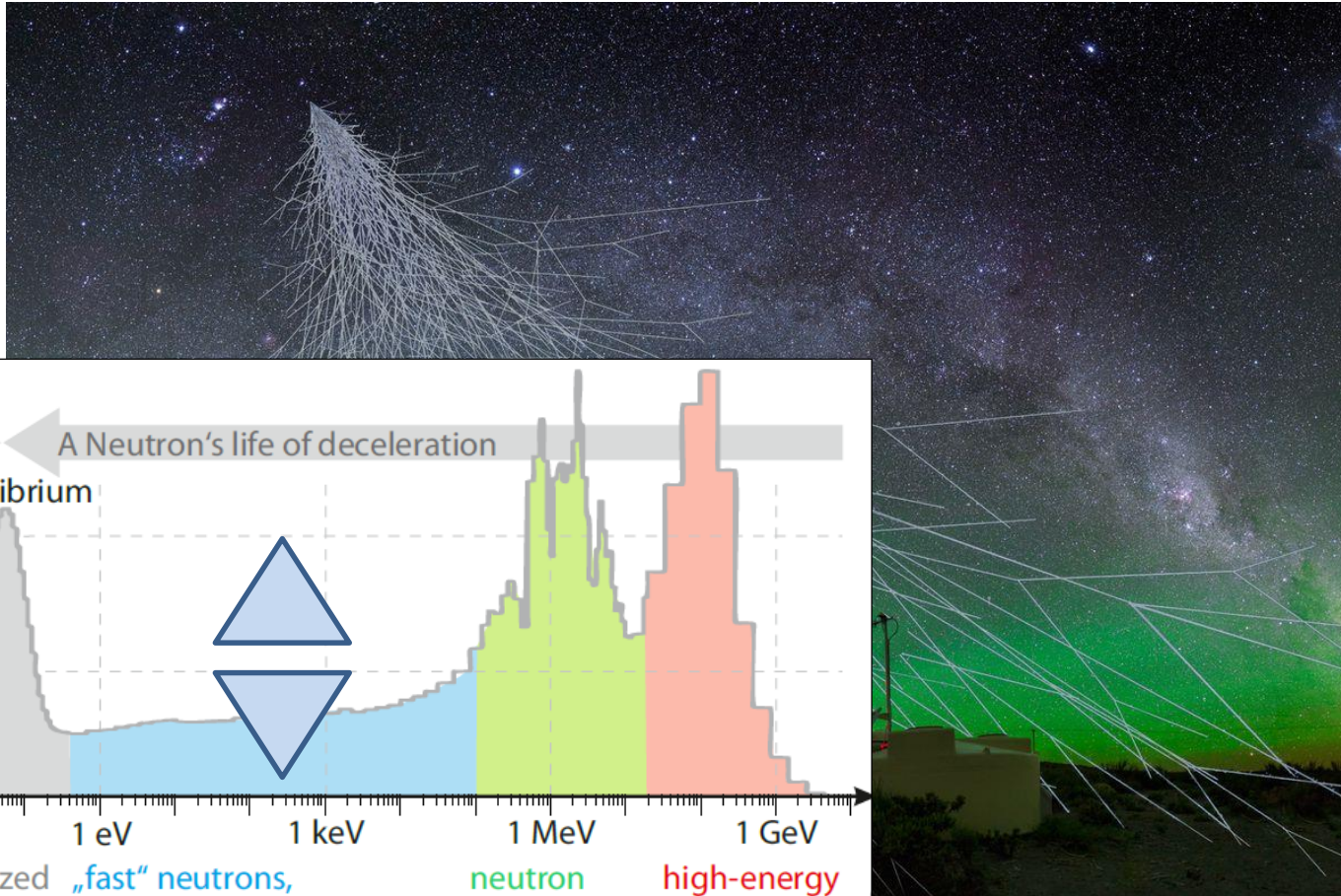
[1] Image by A. Chantelauze, S. Staffi, and L. Bret, <https://www.theverge.com/2017/9/21/16335164/pierre-auger-observatory-cosmic-ray-galaxies-air-shower-particles>



The Cosmic Neutron Basics

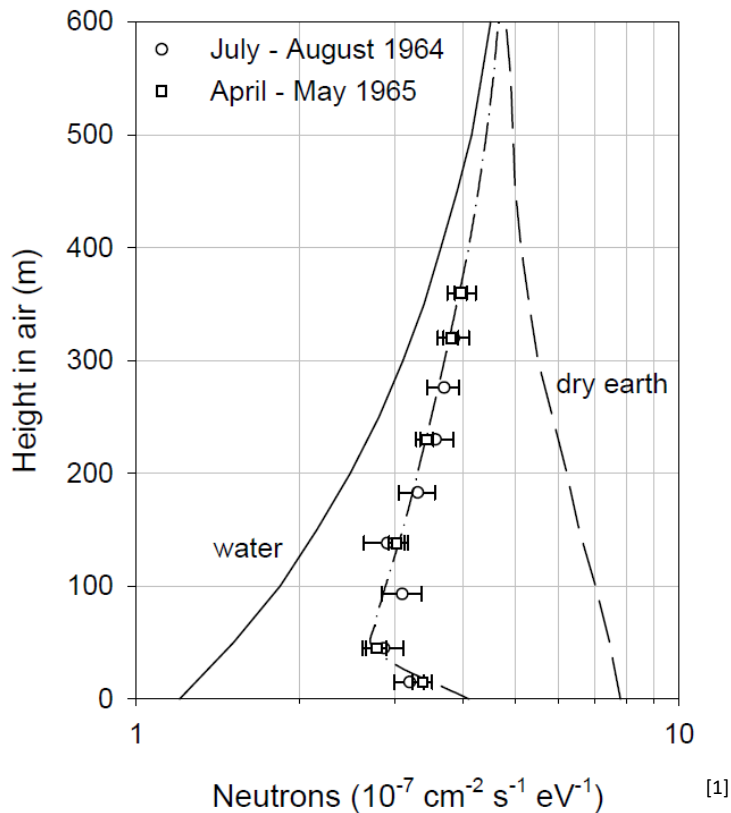


► The Cosmic Neutron Basics



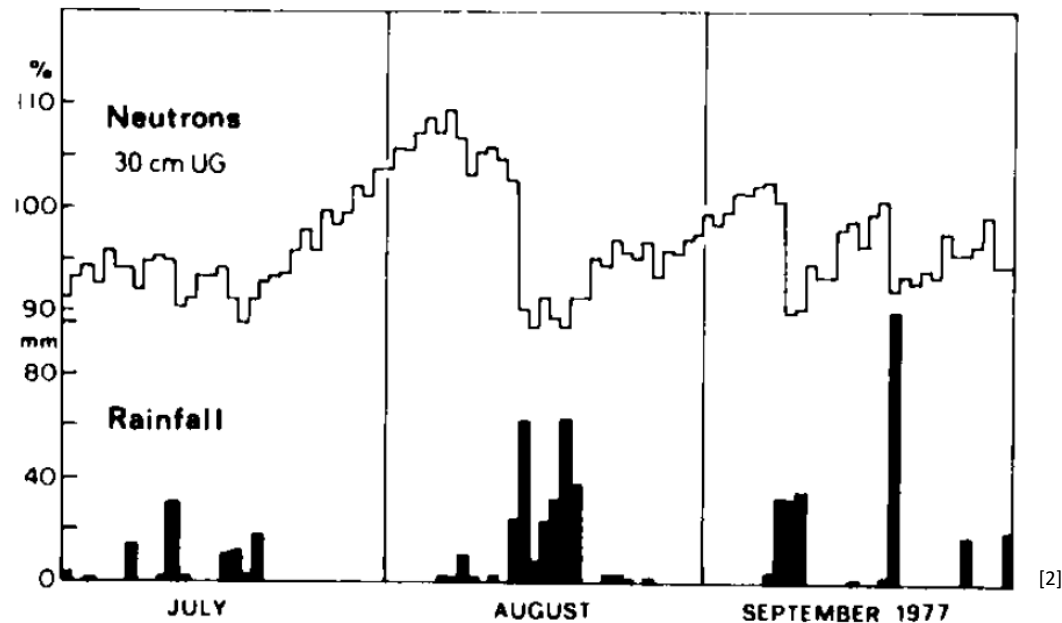
Historical References

1966



[1]

1985



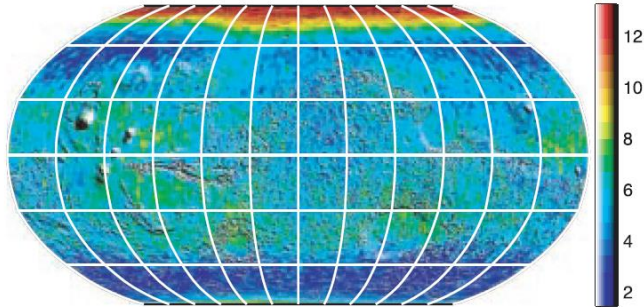
[2]

[1] Hendrick, L. D. and Edge, R. D., "Cosmic-ray neutrons near the Earth", Phys. Rev. Ser. II, 145 (1966)

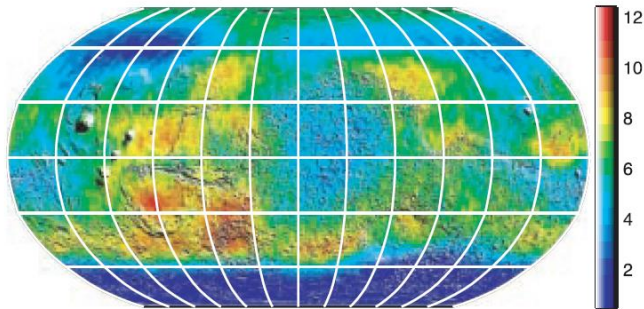
[2] Kodama, M. et al., "Application of atmospheric neutrons to soil moisture measurement", Soil Sci., 140 (1985)

Water on Mars

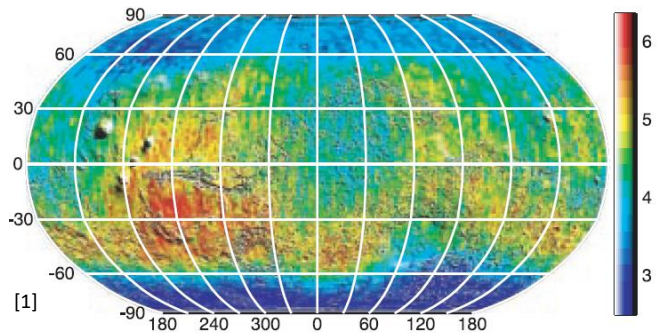
Thermal neutrons



Epithermal neutrons



Fast neutrons

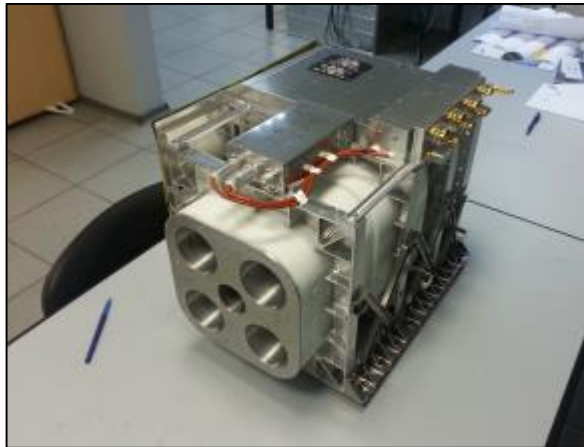


[1]

Curiosity Rover



[2]



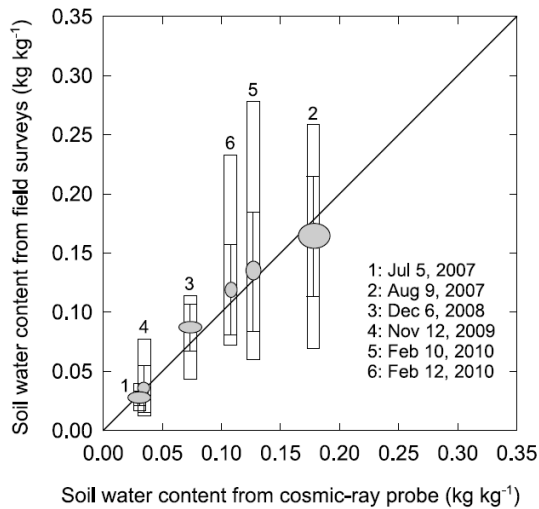
Trace Gas Orbiter

[1] W.C. Feldman, et. al „Global Distribution of Neutrons from Mars: Results from Mars Odyssey“, Science 297 (5578) (2002), 75-78.

[2] <http://exploration.esa.int/mars/48523-trace-gas-orbiter-instruments/?fbclid=2217>

The Birth of CRNS

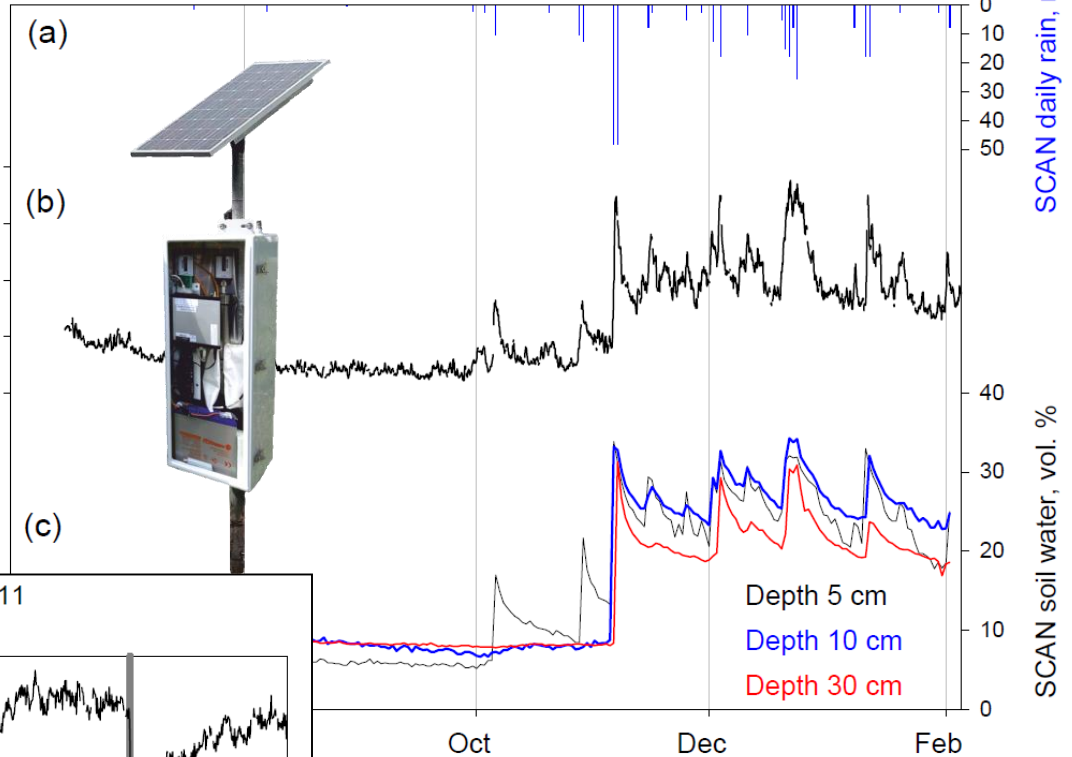
2010



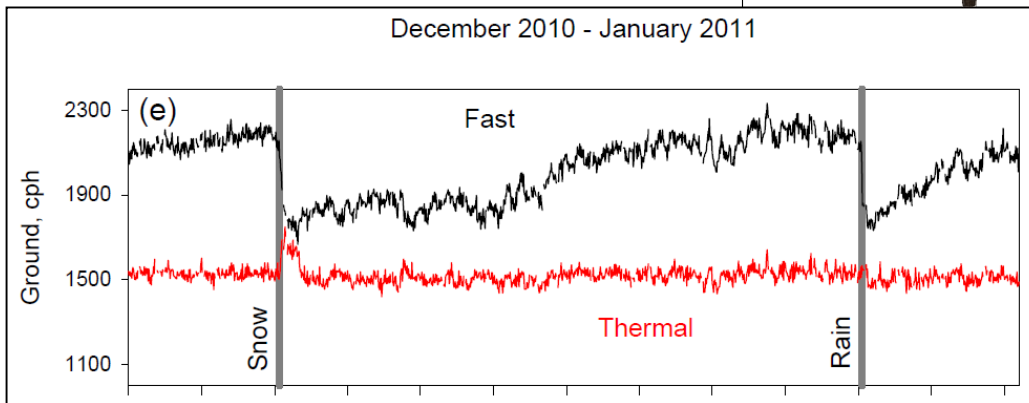
COSMOS soil moisture, $\text{m}^3 \text{m}^{-3}$

[2]

2012



December 2010 - January 2011

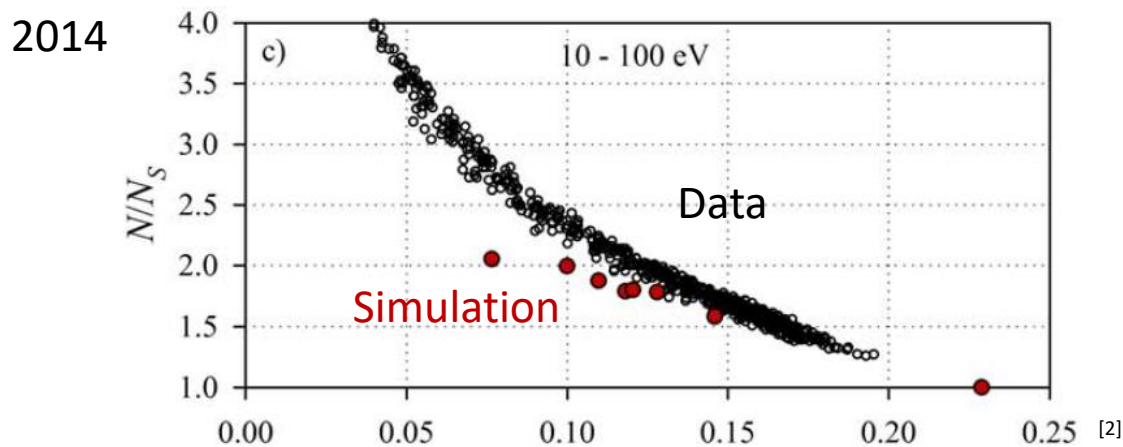
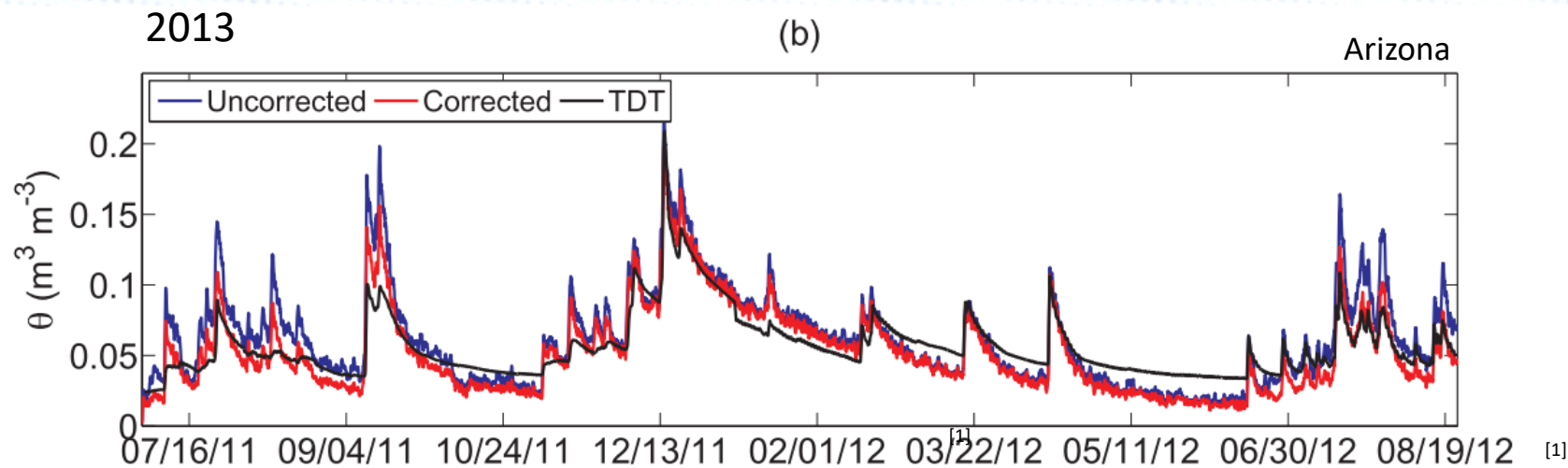


2010 - 2011

[1] Zreda, M. et al., "COSMOS: The COsmic-ray Soil Moisture Observing System." Hydrology and Earth System Sciences 16(11) (2012)

[2] Desilets, D. et al., "Nature's neutron probe: Land surface hydrology at an elusive scale with cosmic rays.", Water Resources Research 46(11) (2010)

The Birth of CRNS



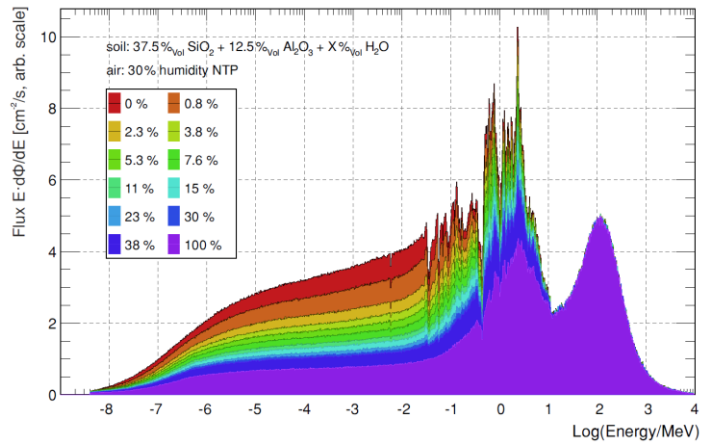
[1] Rosolem, R. et al. "The Effect of Atmospheric Water Vapor on Neutron Count in the Cosmic-Ray Soil Moisture Observing System." J. of Hydrometeorology 14(5) (2013)

[2] McJannet, D. et al., "Field testing of the universal calibration function for determination of soil moisture with cosmic-ray neutrons." Water Resources Res. 50(6) (2014)



The Birth of CRNS

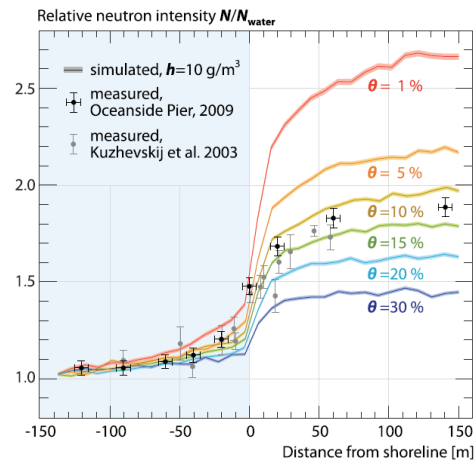
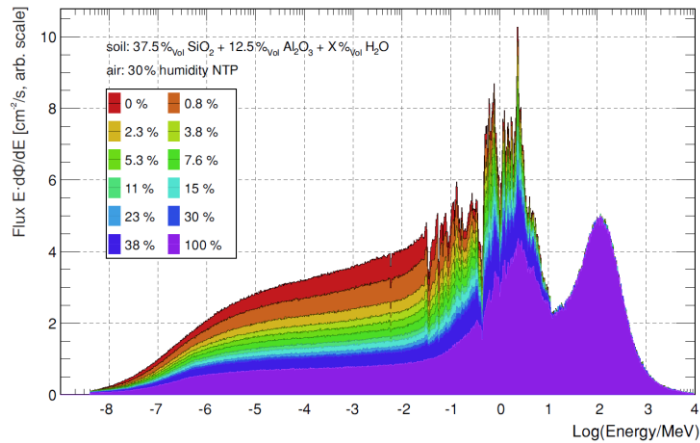
2015





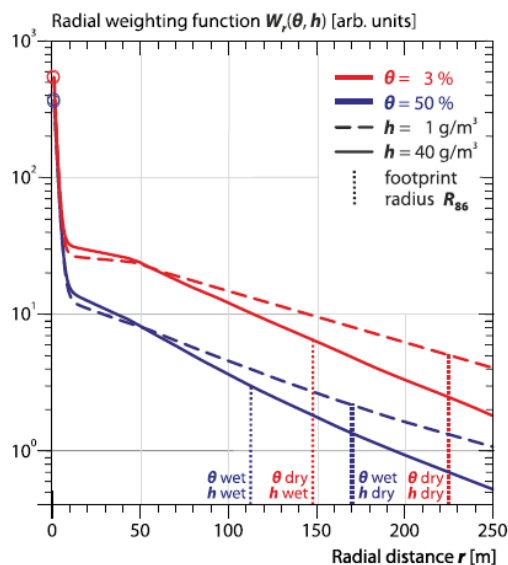
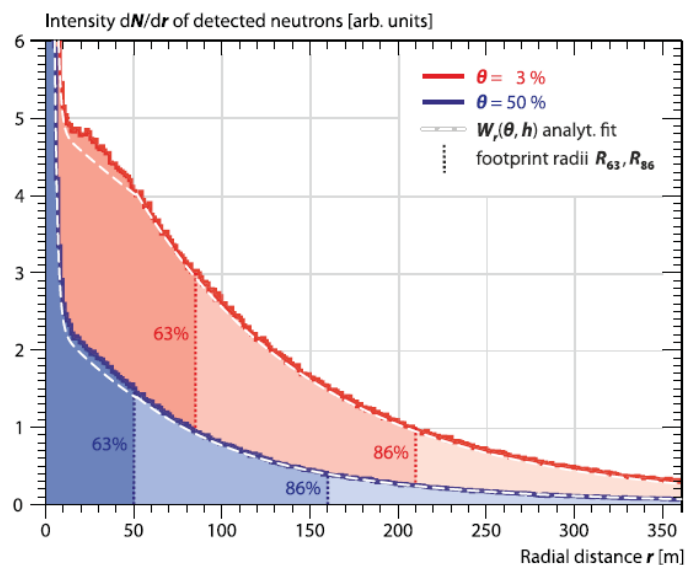
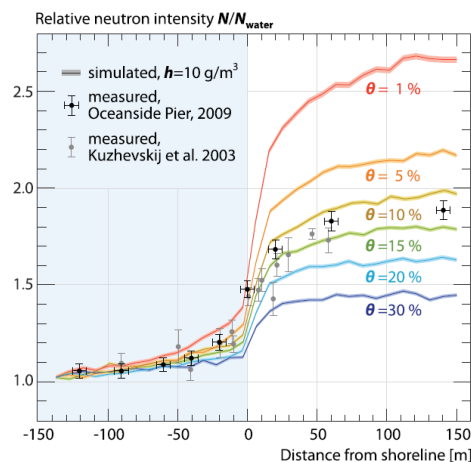
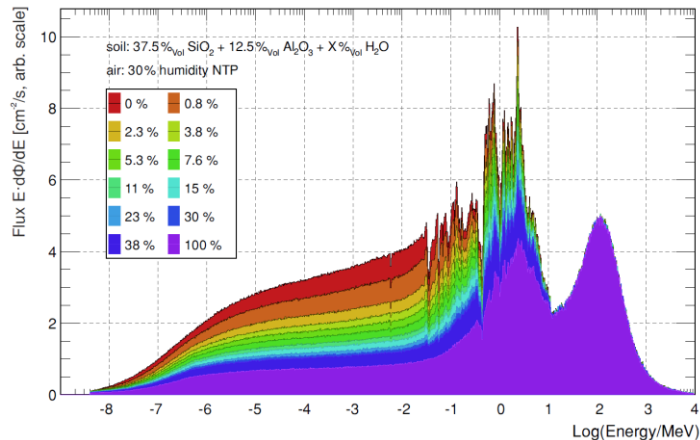
The Birth of CRNS

2015



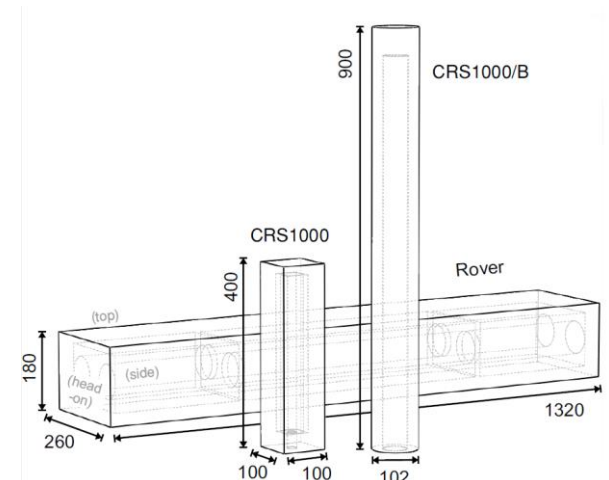
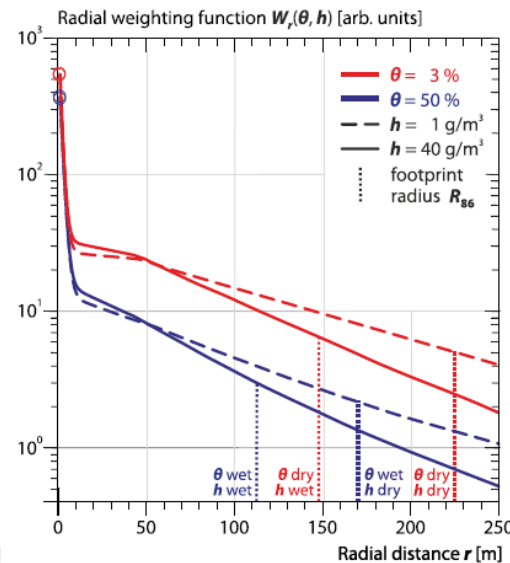
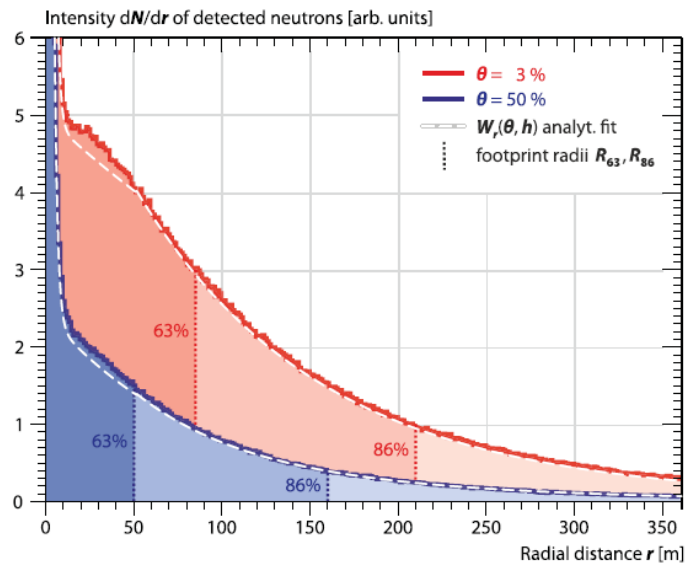
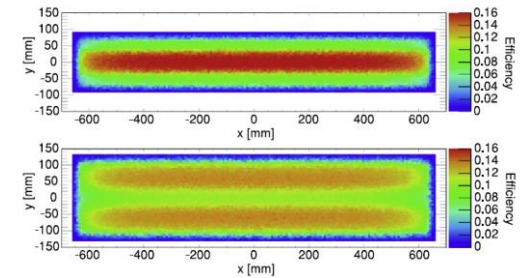
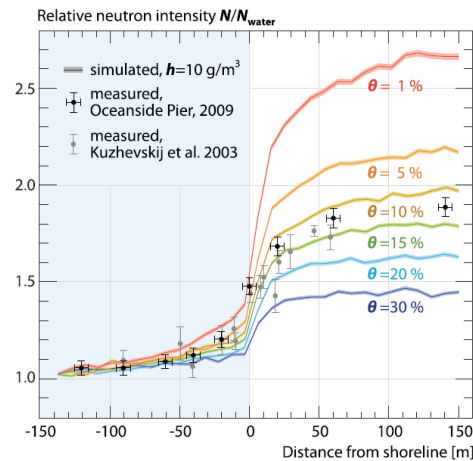
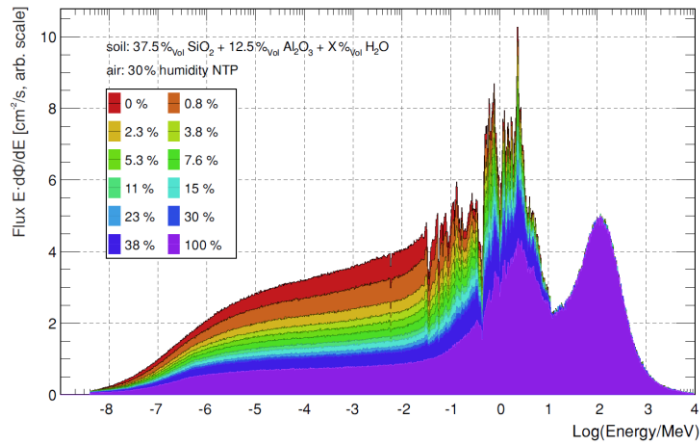
The Birth of CRNS

2015

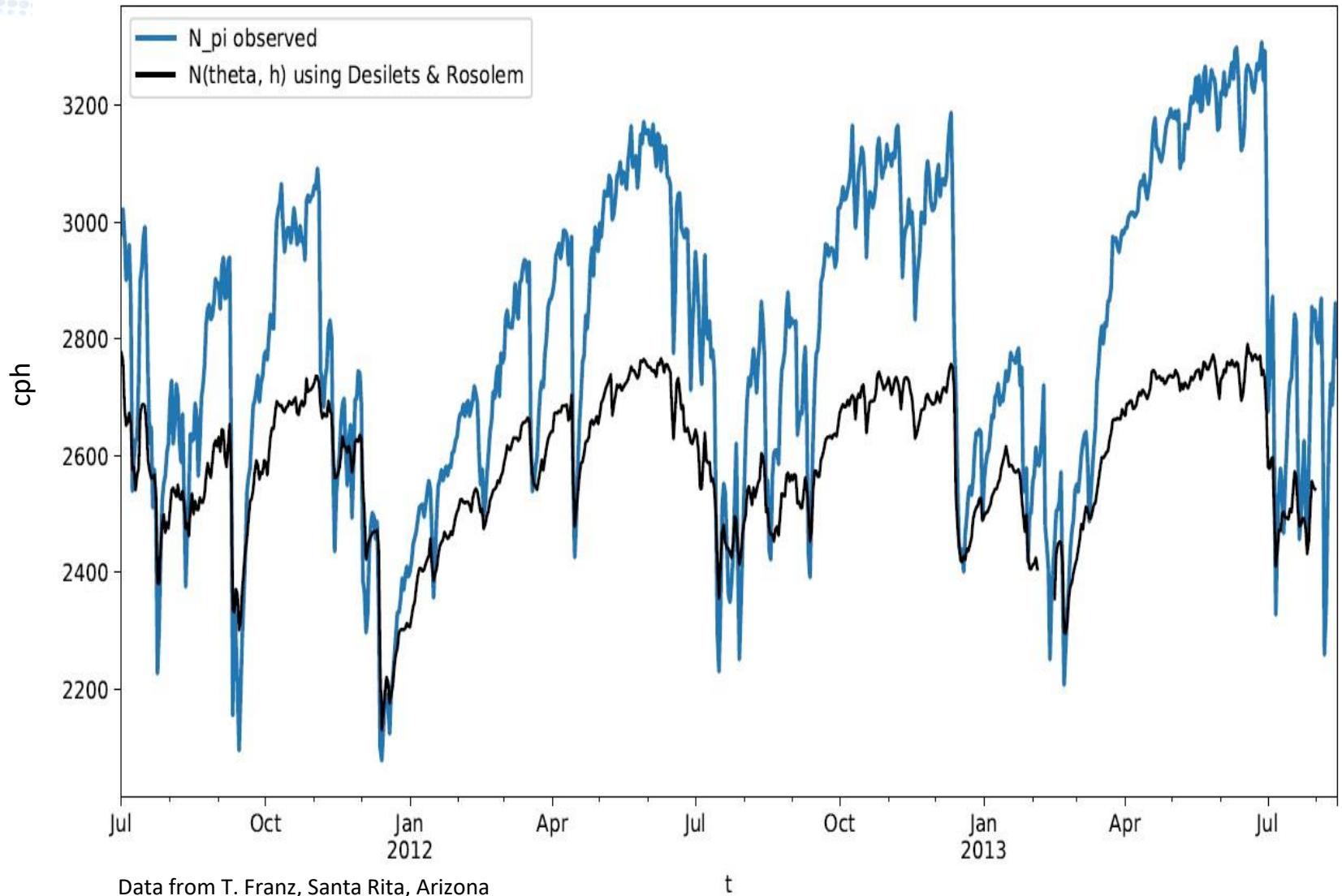


The Birth of CRNS

2015

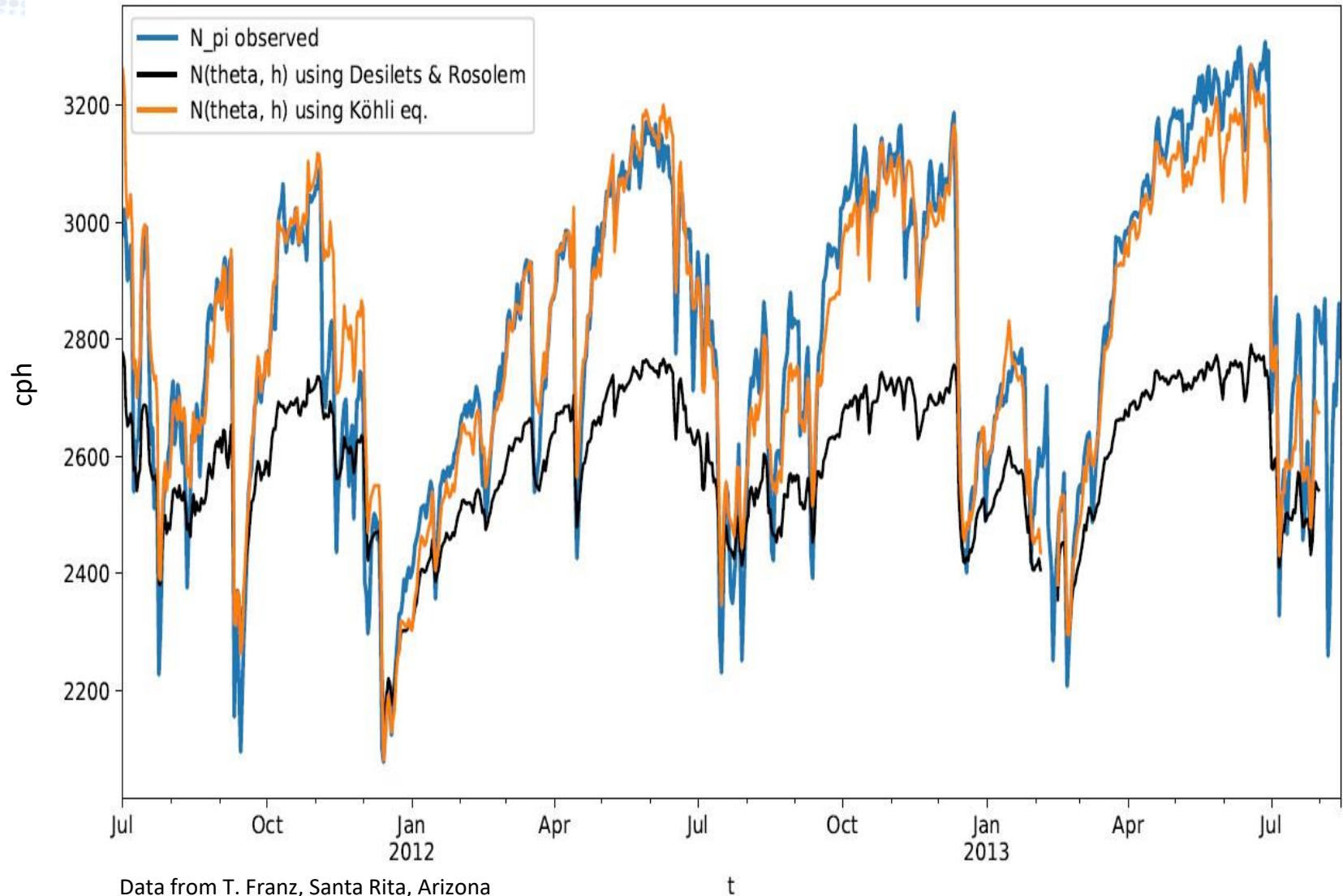


Intensity Function



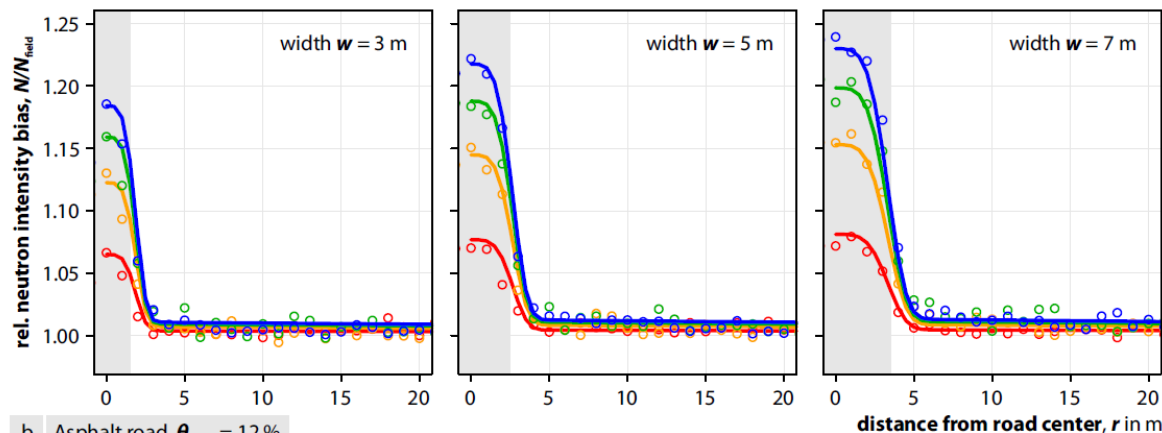


Intensity Function Revised

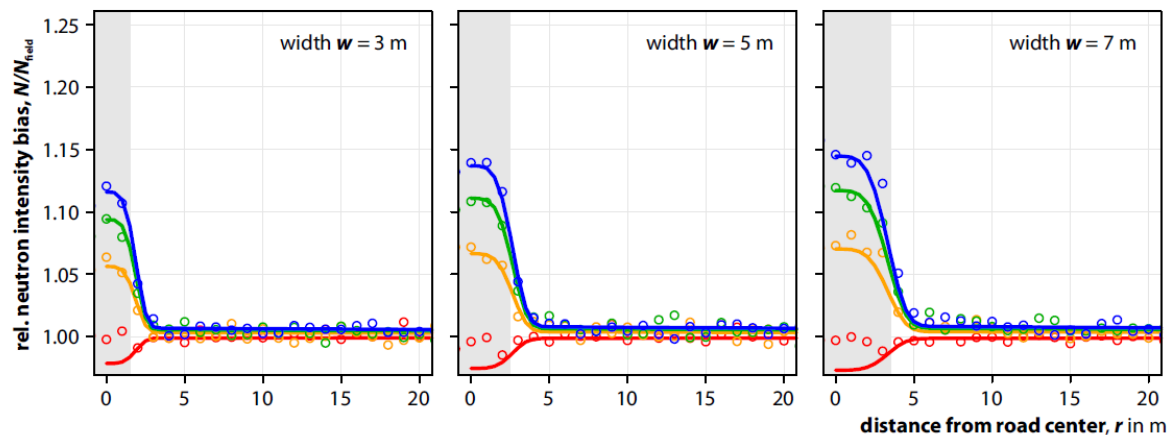


The Road Effect

a Stone road, $\theta_{\text{road}} = 3\%$

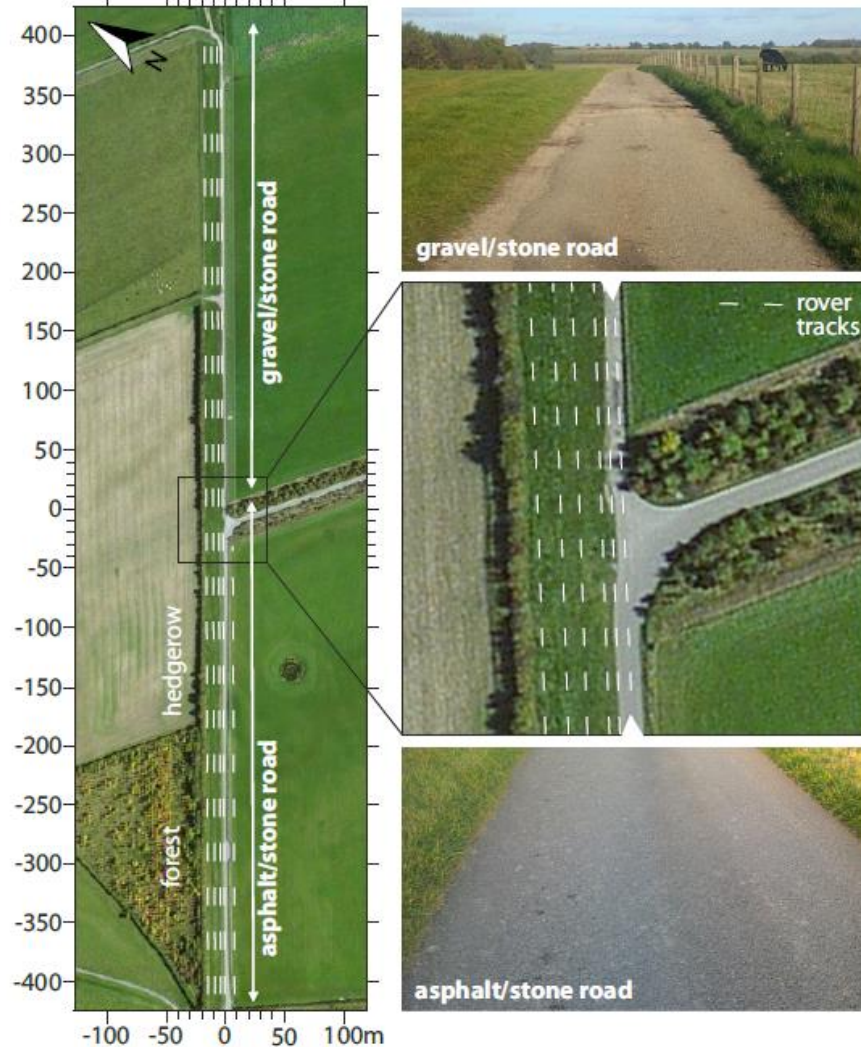


b Asphalt road, $\theta_{\text{road}} = 12\%$



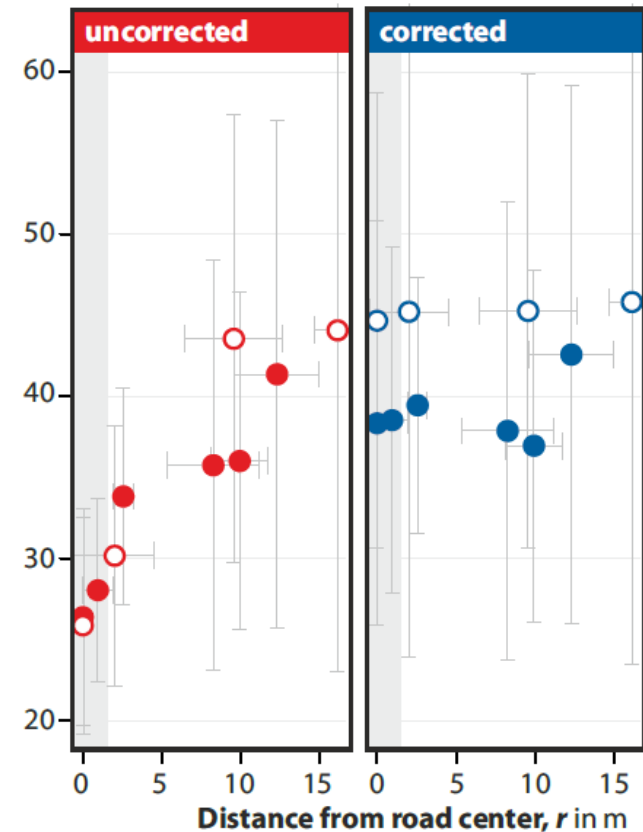
The Road Effect

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

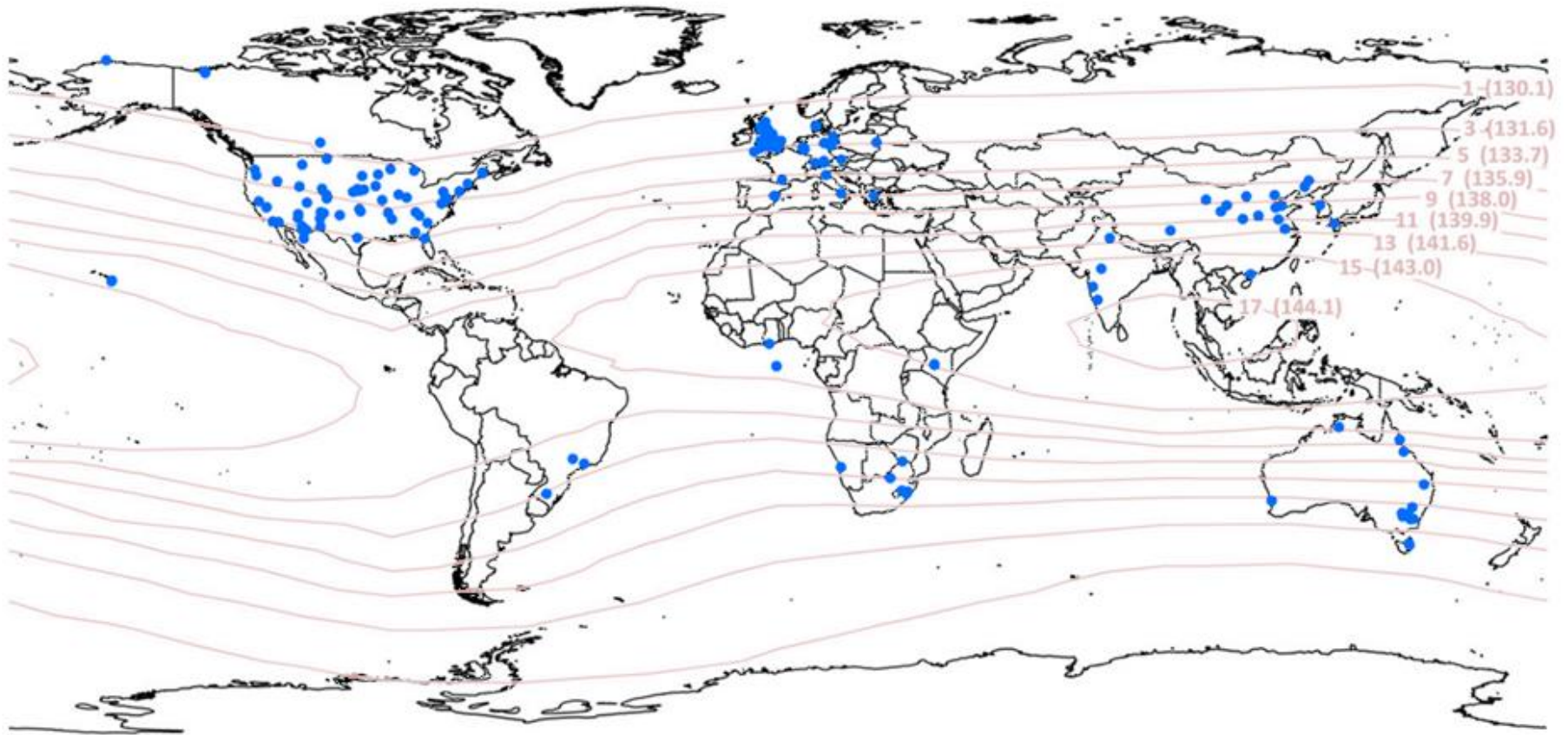


b **Ex B: Observed vol. soil moisture in %**

○ gravel/stone road ● asphalt/stone road
 ┘ variability along each track (400 m)



COSMOS Probe Deployment



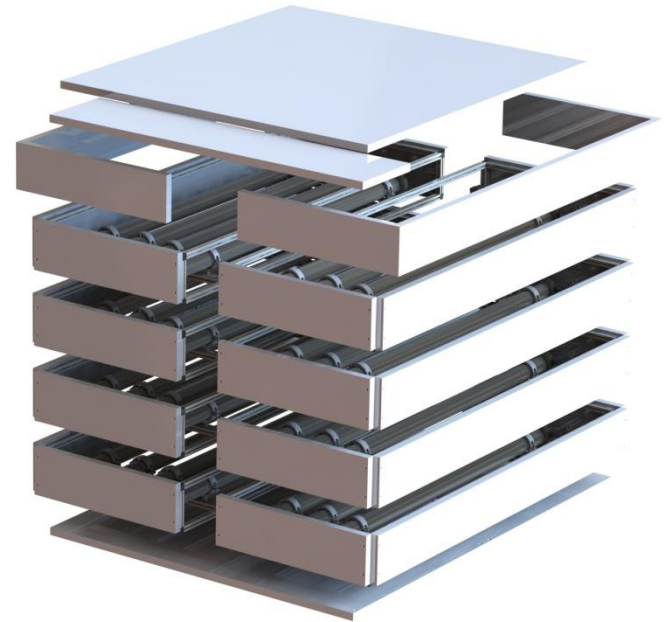
[5] Andreasen, M. et al. "Status and Perspectives on the Cosmic-Ray Neutron Method for Soil Moisture Estimation and Other Environmental Science Applications." *Vadose Zone Journal* 16(8) (2017)

Large CRNS Detectors

Standard Sensor:



Heidelberg Rover:





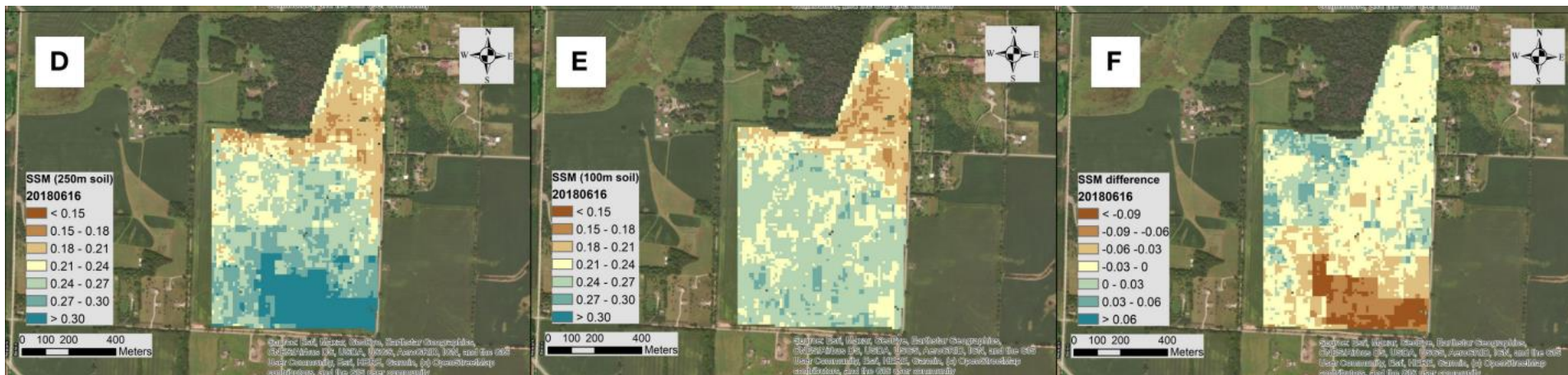
Examples and Recent Studies

RS upscaling

250 m upscaled

100 m upscaled

Difference between both

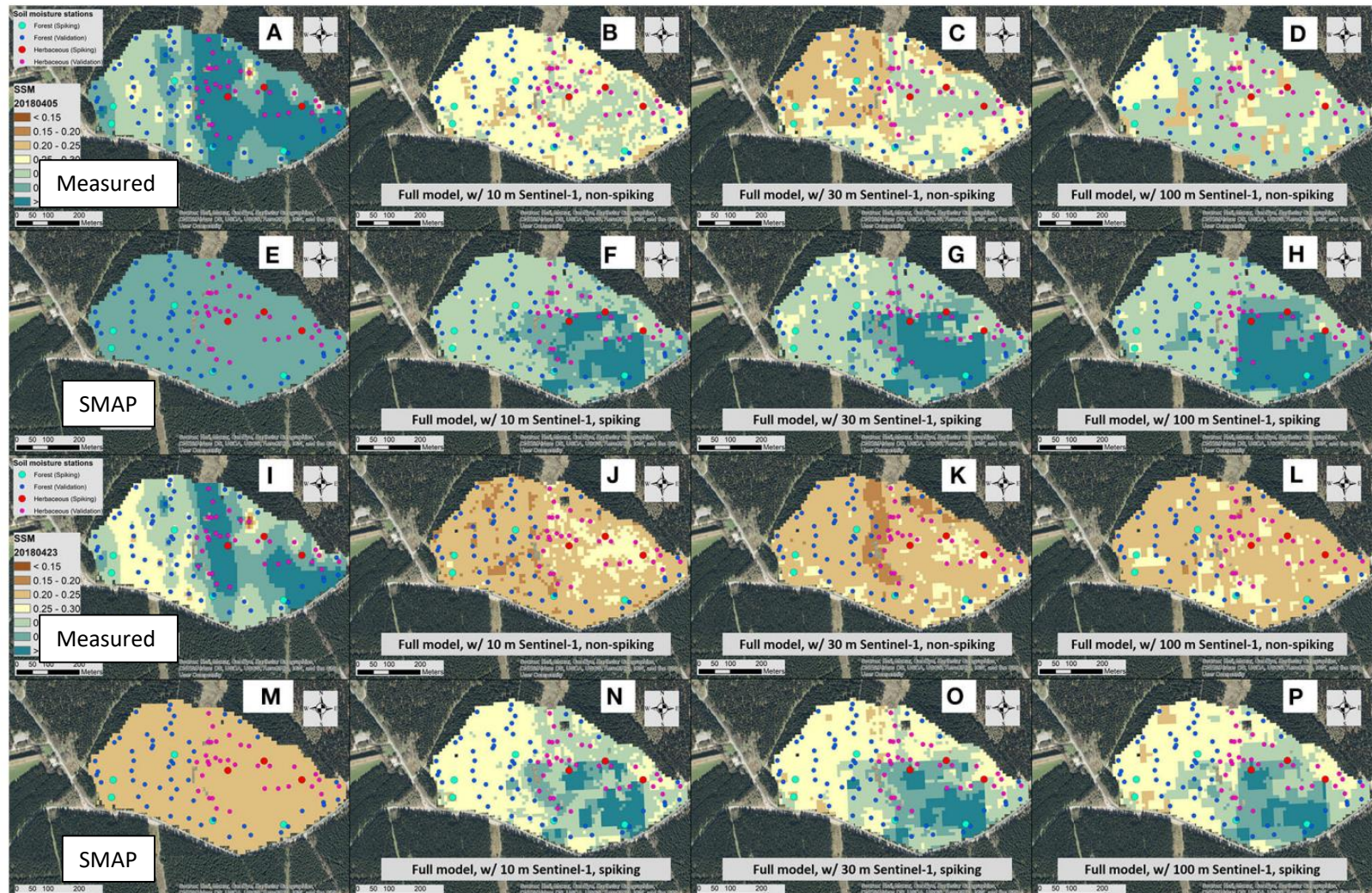


Wisconsin, USA

[1] J. Huang, et al. „Retrieving Heterogeneous Surface Soil Moisture at 100 m Across the Globe via Fusion of Remote Sensing and Land Surface Parameters”, Front. Water 28(2) (2020)

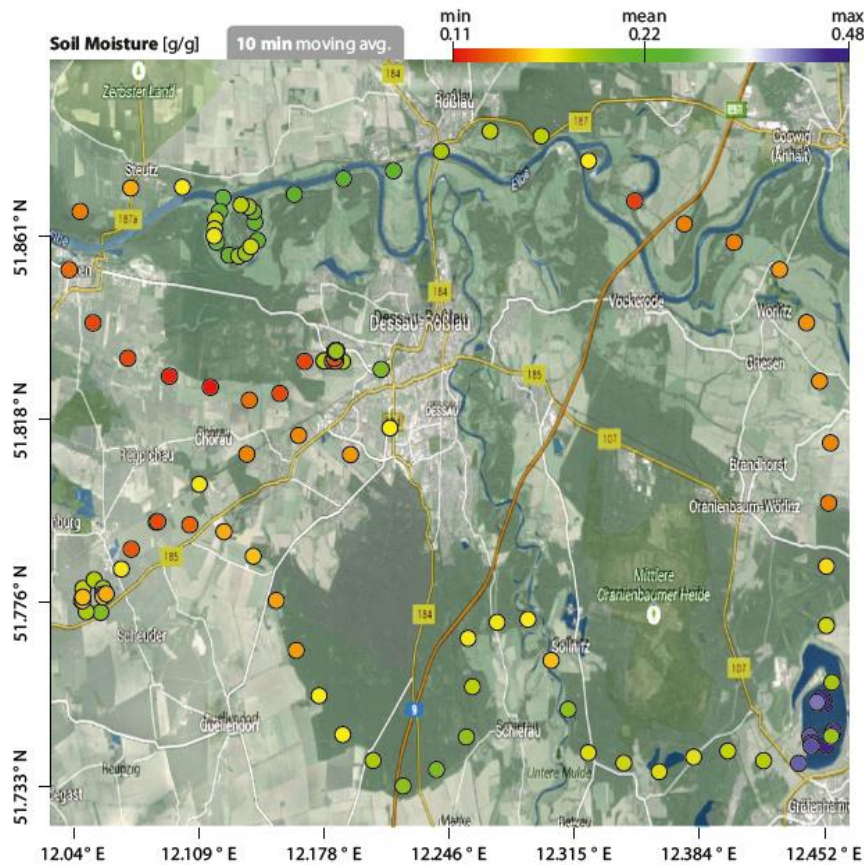
RS upscaling

Models ->

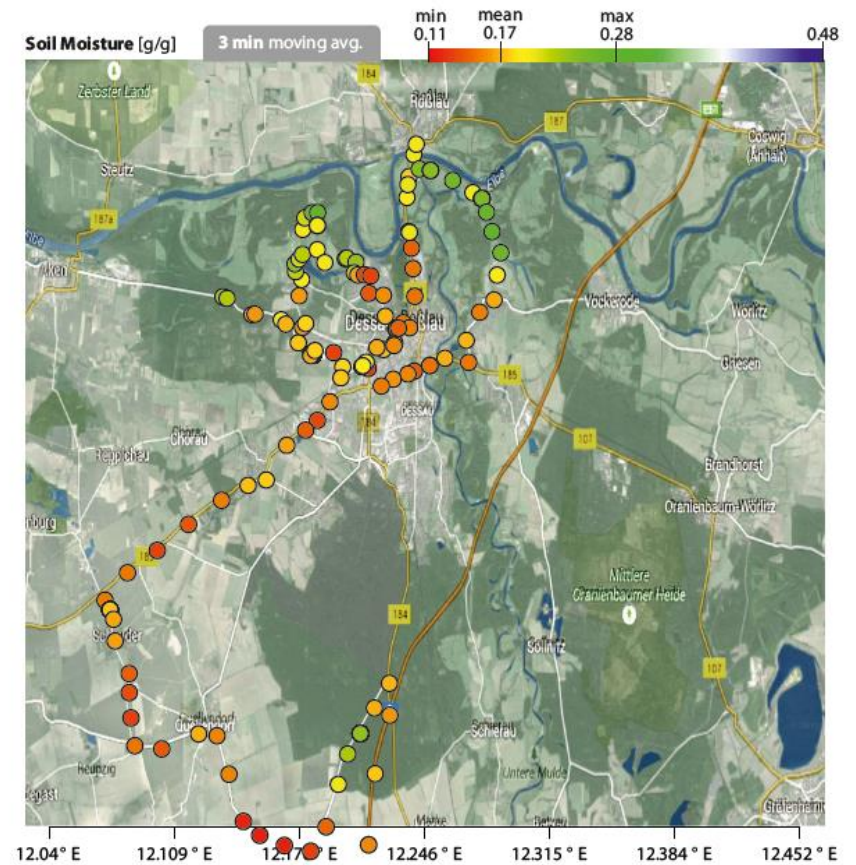


[1] J. Huang, et al. „Retrieving Heterogeneous Surface Soil Moisture at 100 m Across the Globe via Fusion of Remote Sensing and Land Surface Parameters”, Front. Water 28(2) (2020)

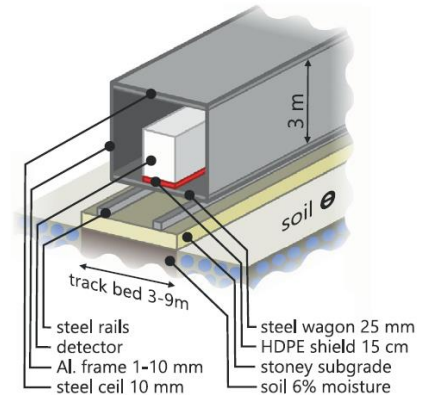
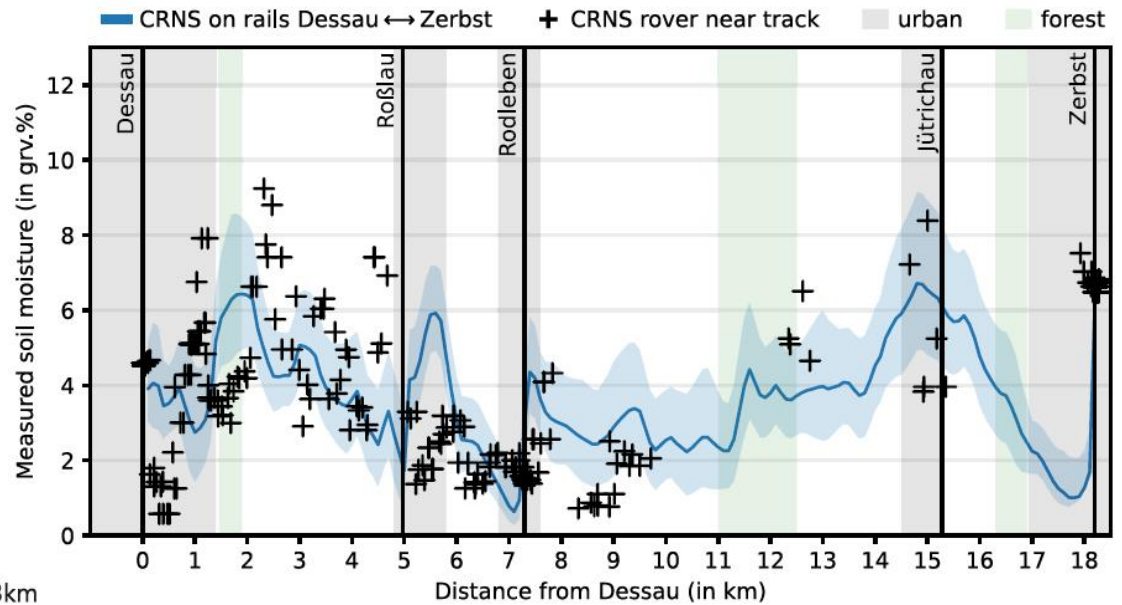
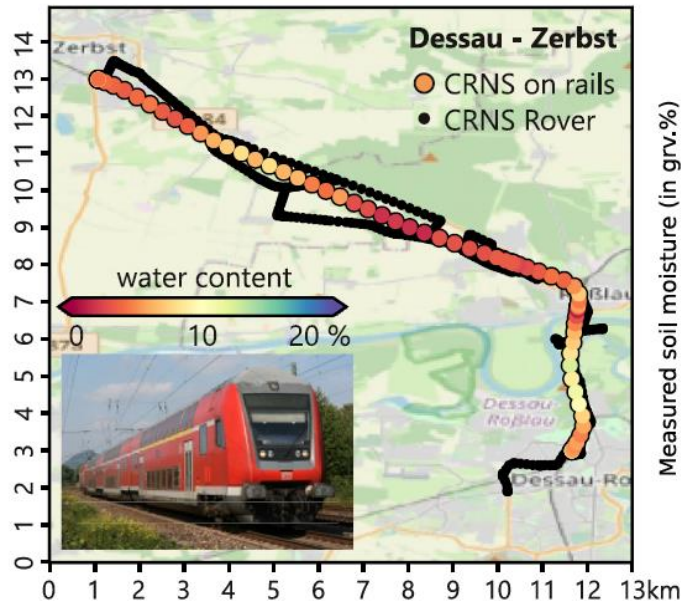
Gyrocopter



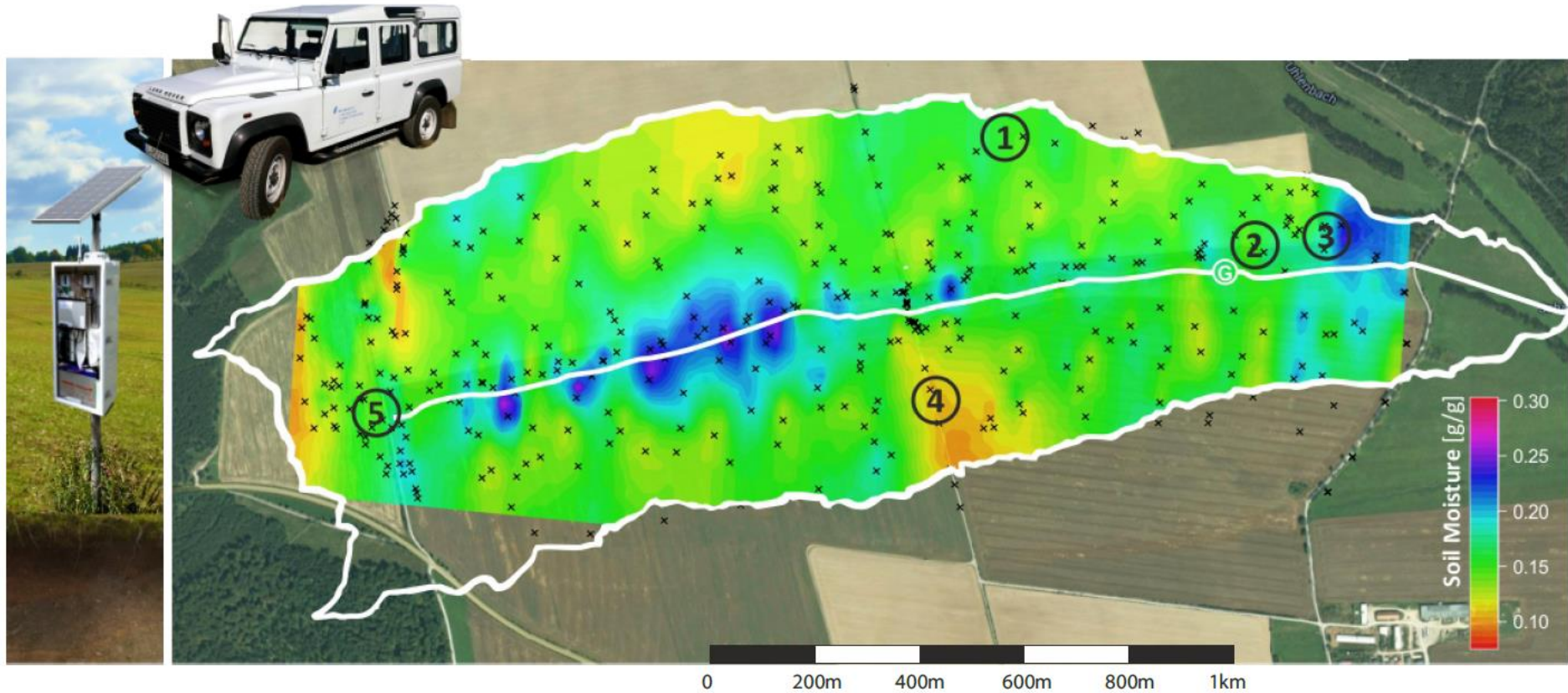
Rover (car)



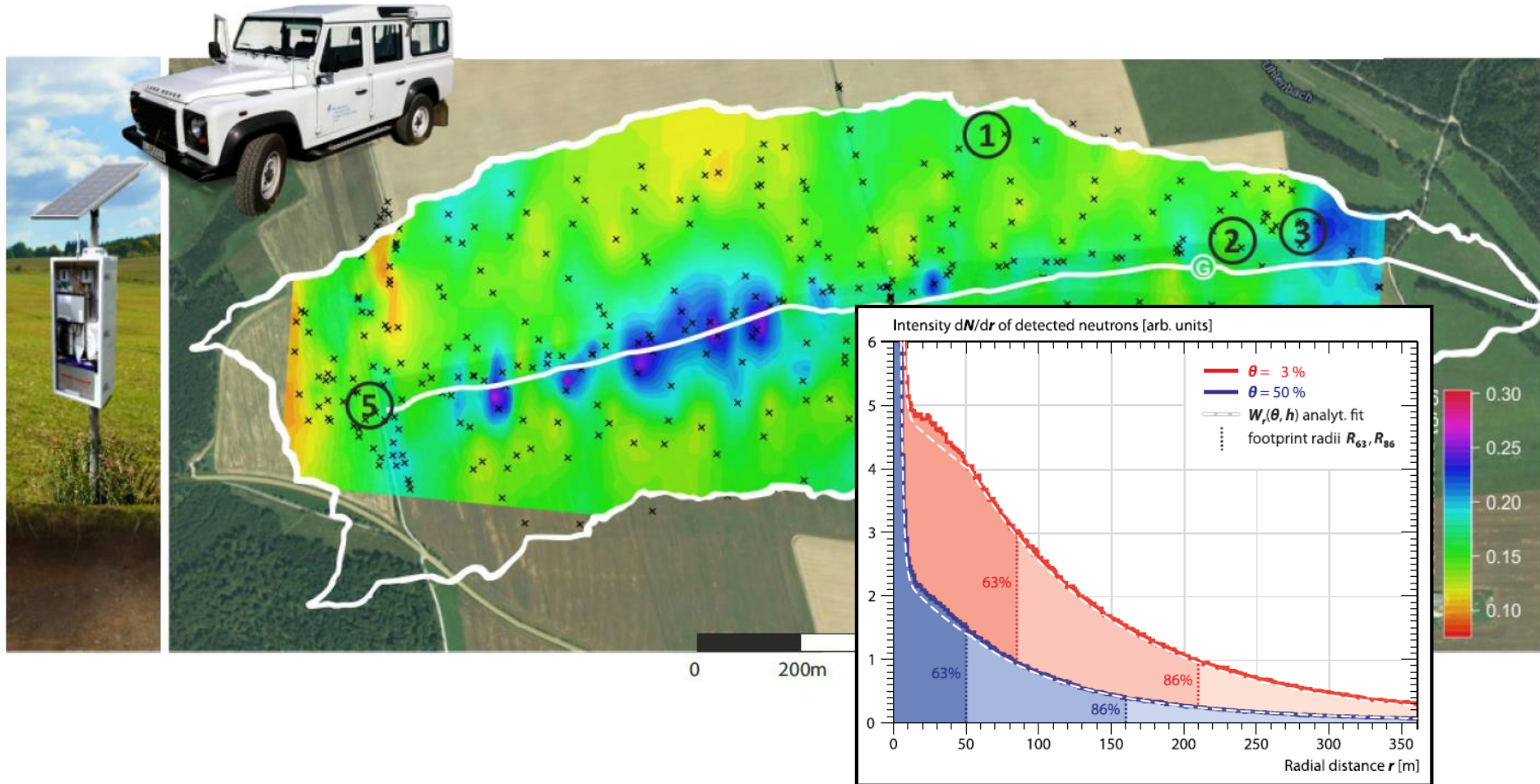
Roving on Rails



▶ Roving

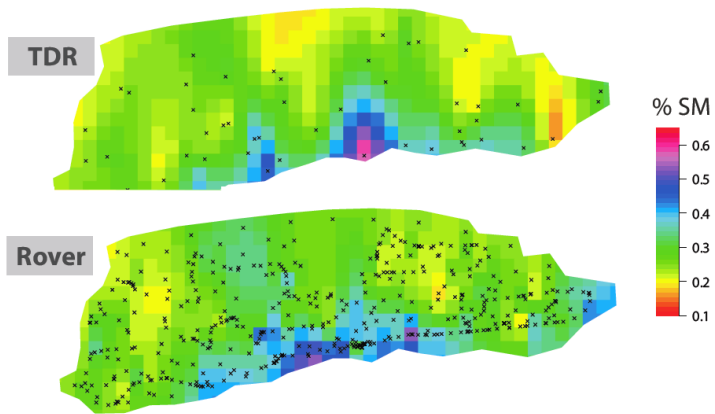


Roving

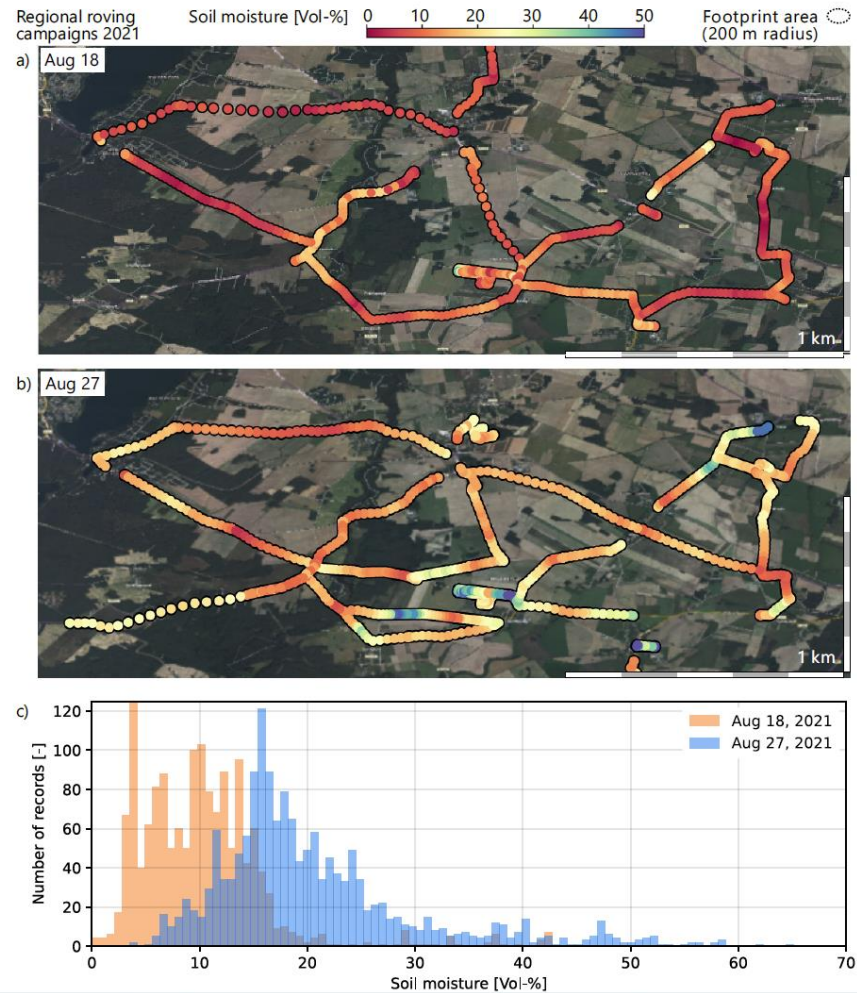
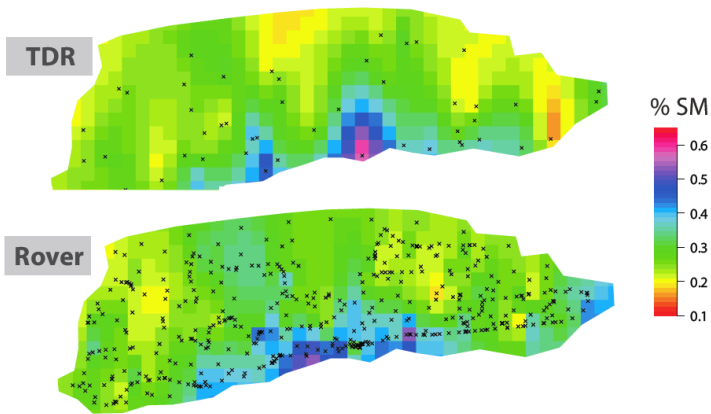




Roving

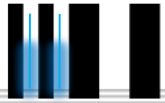


Roving



Two-days measurement campaign with the mobile detection system on Aug 18th (a) and Aug 27th (b), 2021. Credit: Martin Schrön, UFZ Leipzig, Germany.



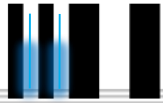


Validation potential for Remote Sensing soil moisture products using Cosmic-Ray Neutron Sensing

CRNS is an emerging technology

- **Bridges the scale** between remote sensing and local probes



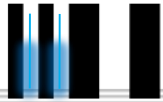


Validation potential for Remote Sensing soil moisture products using Cosmic-Ray Neutron Sensing

CRNS is an emerging technology

- **Bridges the scale** between remote sensing and local probes
- Provides an **area-averaged soil moisture** estimate on **10 ha** and around 50 cm depth



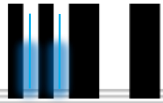


Validation potential for Remote Sensing soil moisture products using Cosmic-Ray Neutron Sensing

CRNS is an emerging technology

- **Bridges the scale** between remote sensing and local probes
- Provides an **area-averaged soil moisture** estimate on **10 ha** and around 50 cm depth
- **Stationary: real-time data**
- **Roving: snapshot of km² scale**





Validation potential for Remote Sensing soil moisture products using Cosmic-Ray Neutron Sensing

CRNS is an emerging technology

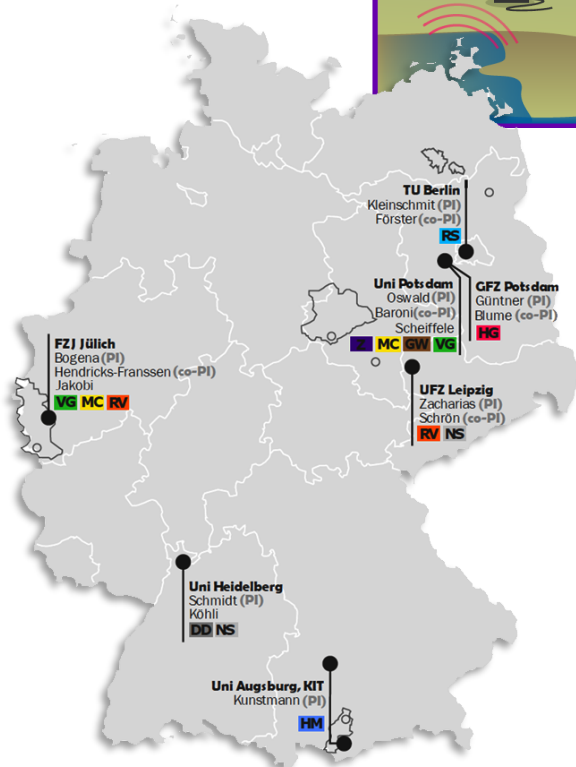
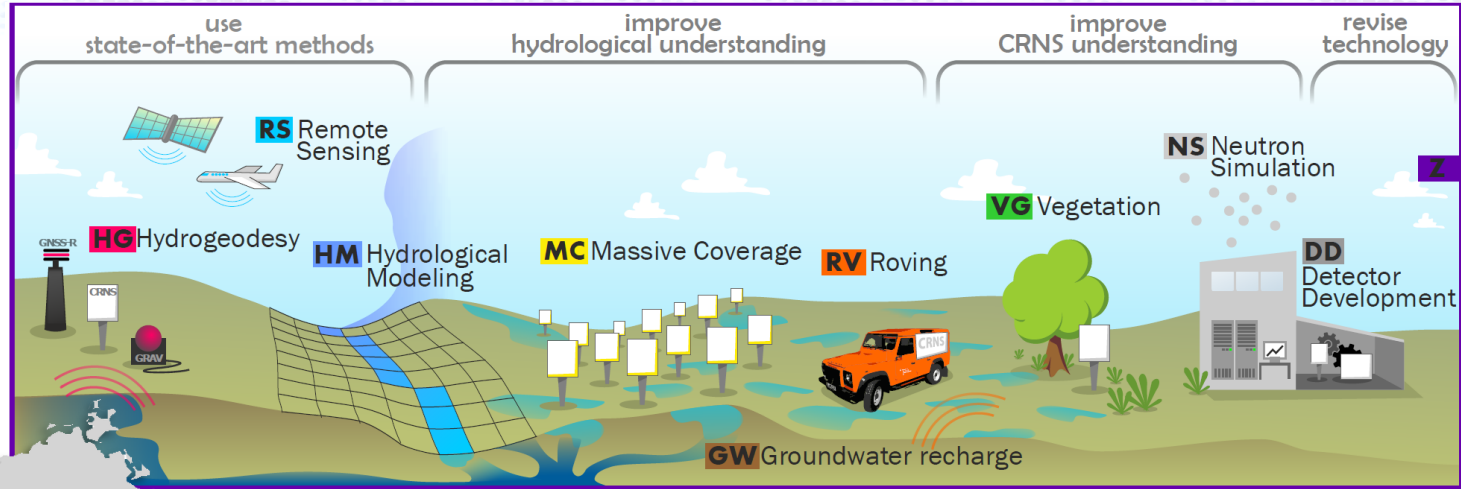
- **Bridges the scale** between remote sensing and local probes
- Provides an **area-averaged soil moisture** estimate on **10 ha** and around 50 cm depth
- **Stationary: real-time data**
- **Roving: snapshot of km² scale**

Mobile CRNS campaigns can provide high quality data sets
for RS data assimilation and ground truthing



An interdisciplinary Collaboration

DFG
FOR 2694



DFG Research Group



<https://www.uni-potsdam.de/de/cosmicsense.html>