Metrology for multi-scale monitoring of soil moisture

DPG Frühjahrstagung Greifswald 2024
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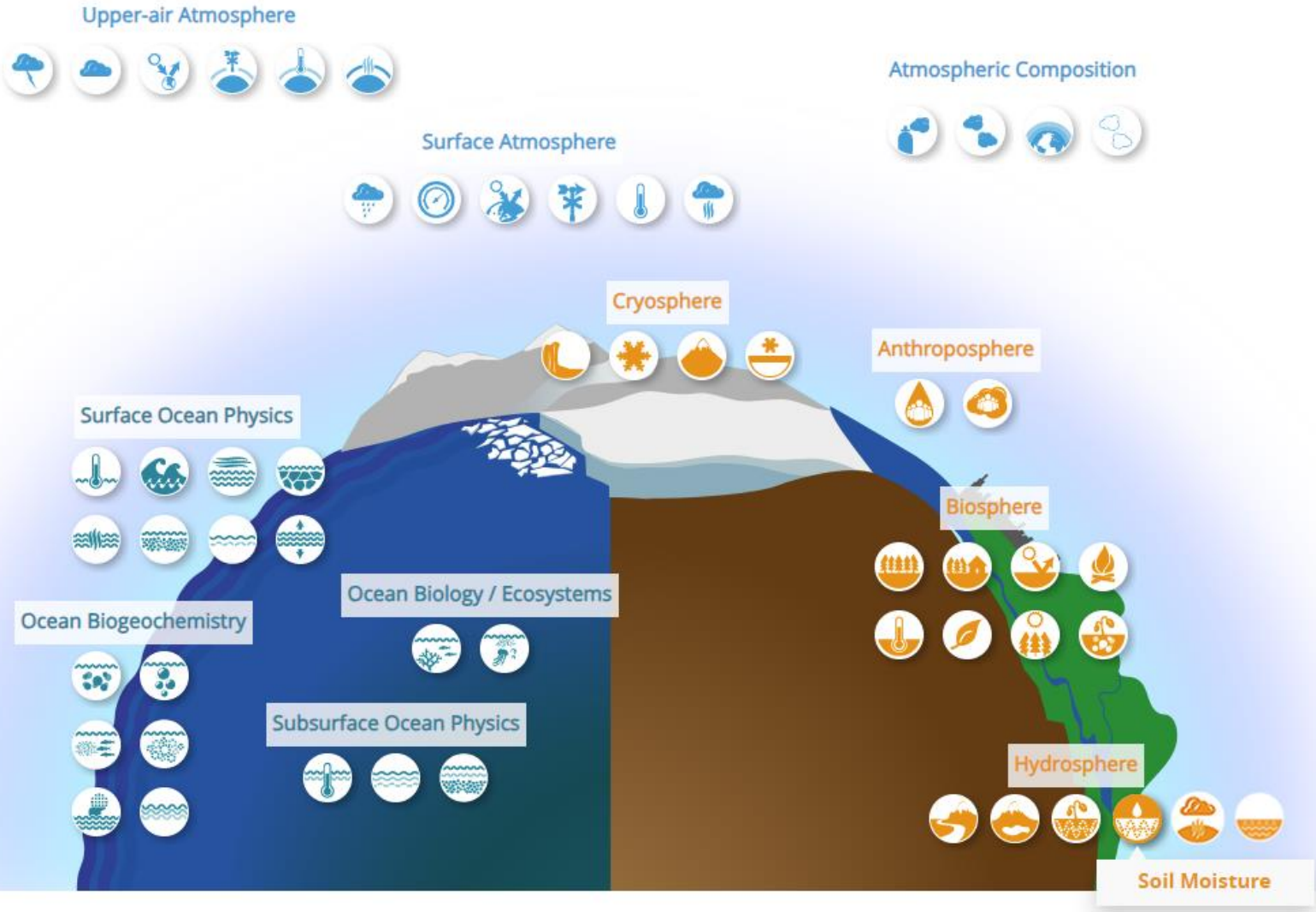
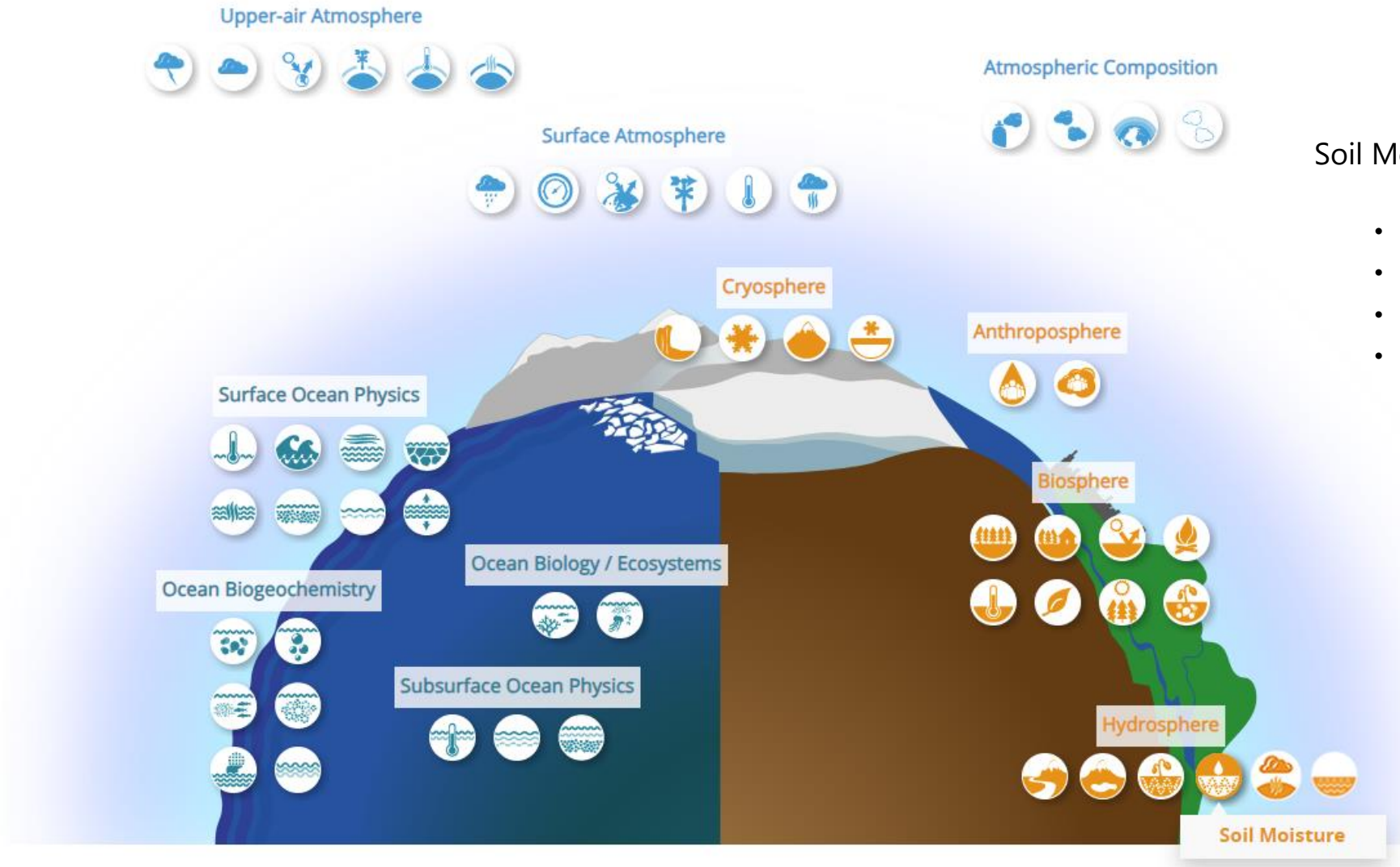
[1] http://www.iso.org/iso/2012_iso-in-action_water_vignette.jpg

World Metrological Organization: Essential Climate Variables



[1] Image by WMO, https://gcos.wmo.int/en/essential-climate-variables/

World Metrological Organization: Essential Climate Variables



Soil Moisture:

- Energy transfer
- Land-atmosphere interactions
- Climate and vegetation
- Agriculture, Forestry, ecosystem Health

[1] Image by WMO, https://gcos.wmo.int/en/essential-climate-variables/

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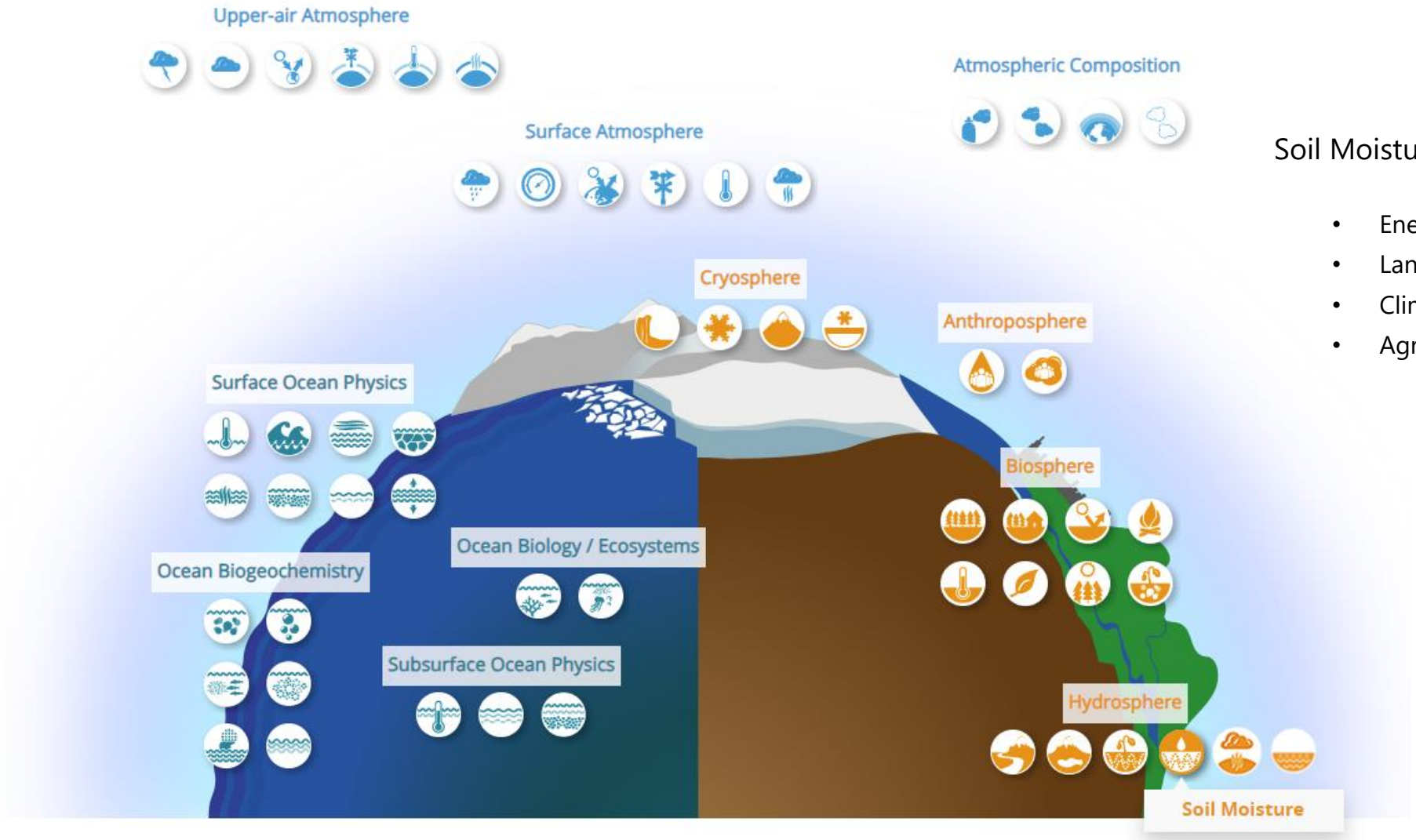

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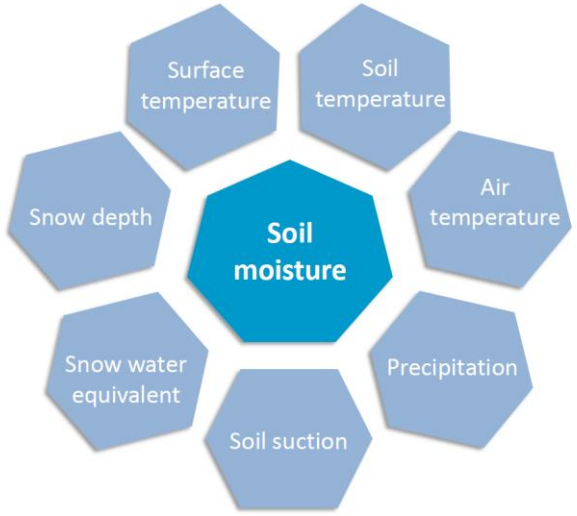

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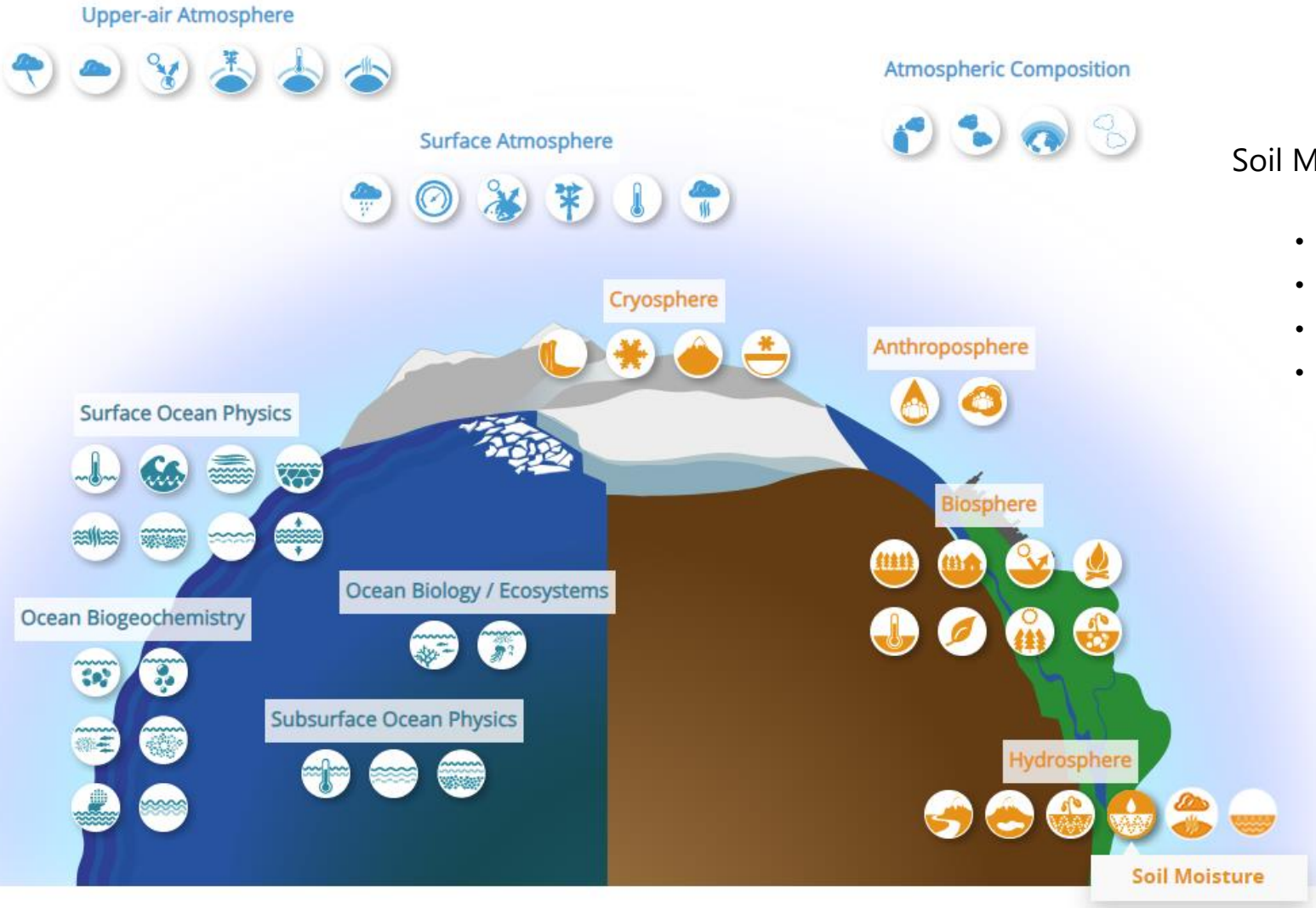


Soil Moisture:

- Energy transfer
- Land-atmosphere interactions
- Climate and vegetation
- Agriculture, Forestry, ecosystem Health

- Progressing climate change
- Extreme events (floods, droughts)
- Water scarcity
- Agriculture: Water management

[1] Image by WMO, https://gcos.wmo.int/en/essential-climate-variables/

Global Hydrological Data

WMO action plan for Hydrology (2020 –2030)

1. No one is surprised by a flood
2. Everyone is prepared for drought
3. Hydro-climate and meteorological data support the food security agenda
4. High-quality data supports science
5. Science provides a sound basis for operational hydrology
6. We have a thorough knowledge of the water resources of our world
7. Sustainable development is supported by information covering the full hydrological cycle
8. Water quality is known

UNESCO IHP IX Priority areas 2022 –2029

1. Scientific Research and Innovation
2. Water Education for the Fourth Industrial Revolution including sustainability
3. Bridging the data and knowledge gaps
4. Integrated and Inclusive Water Resources Management under conditions of global change
5. Water Governance based on science for mitigation, adaptation and resilience

[1] Image by GCOS https://www.gtn-h.info/about-us/

Global Data Management: GCOS

GTN-H

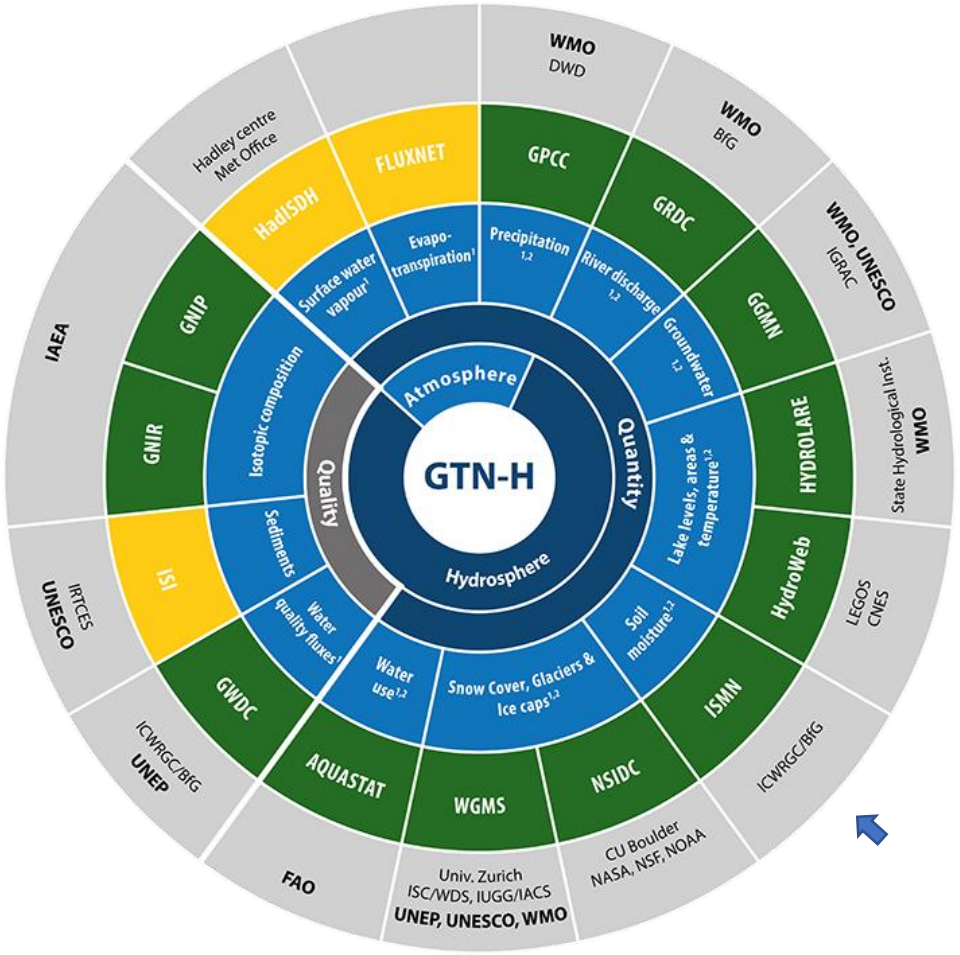
Network of the global water data centres,
In-situ focus

Joint programme of the World Meteorological Organization (WMO) and the Global Climate Observing System (GCOS); implemented in 2001

GCOS
KEEPING WATCH OVER OUR CLIMATE

WMO IOC International Science Council UN environment

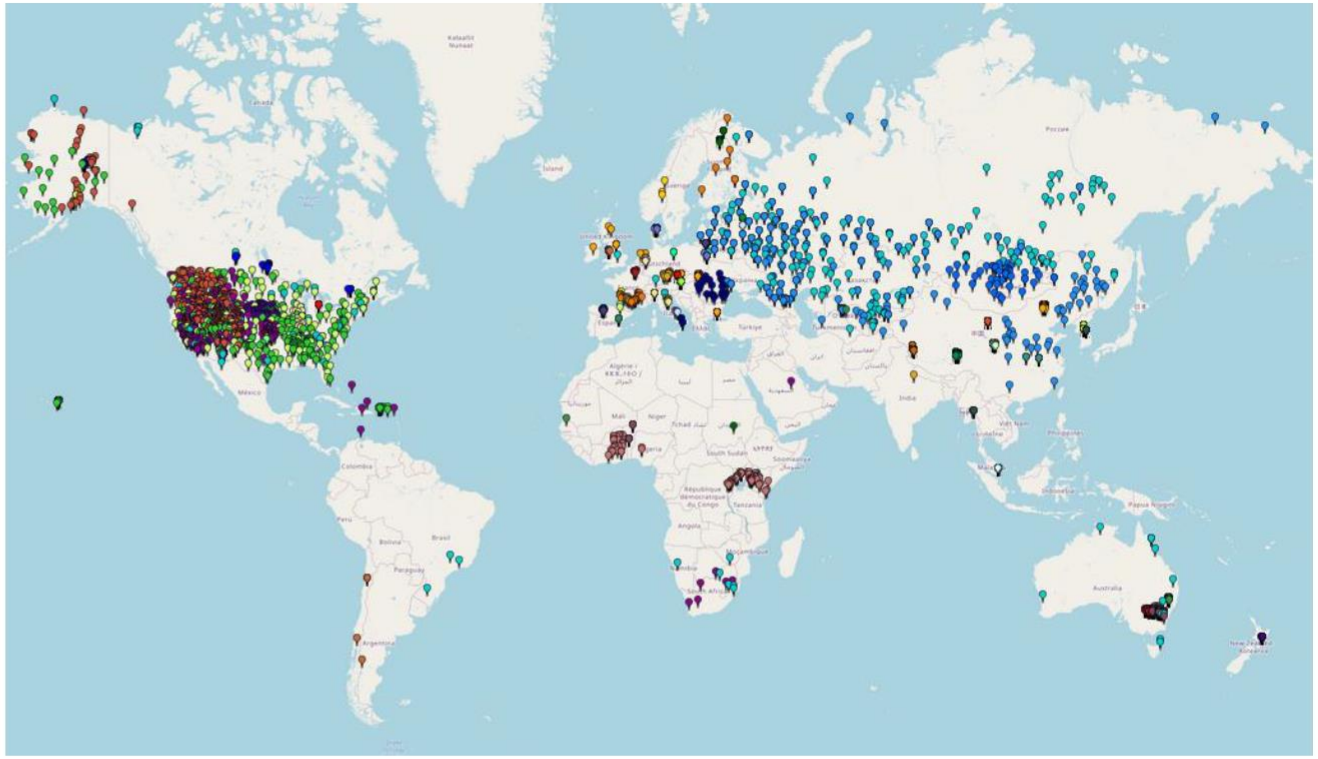
WORLD METEOROLOGICAL ORGANIZATION



[1] Image by GCOS https://www.gtn-h.info/about-us/

Global Data Management: International Soil Moisture Network

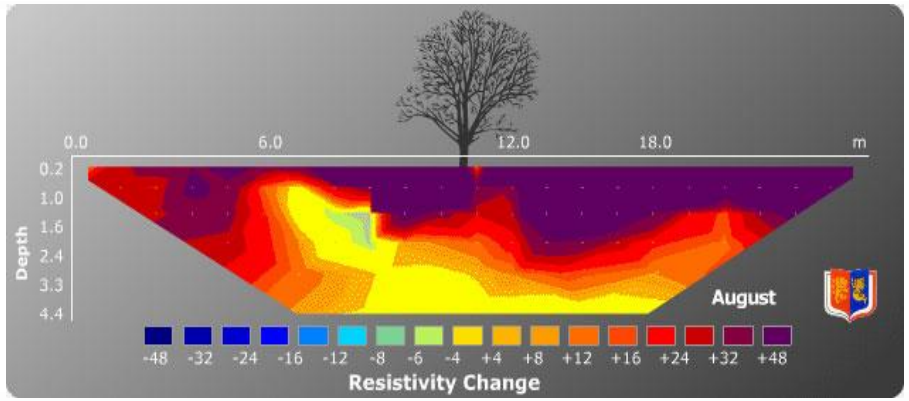
- **In situ data + metadata**
- **Soil moisture + 7 additional variables** integrated in the DB
- **73 networks** participate (June 2022)
- **>2900 stations** with several depths **integrated** (June 2022)
- Time series available from **1952** up **to near real time** (see graph)
- **Daily update** of 6 **NRT networks** → **~1000 stations** (June 2022)



Distribution of the soil moisture stations

The scale gap

< 10 m ~ 1 km



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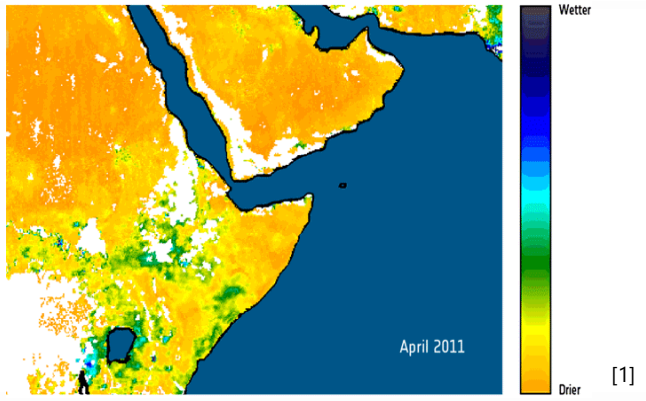


[1]

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)

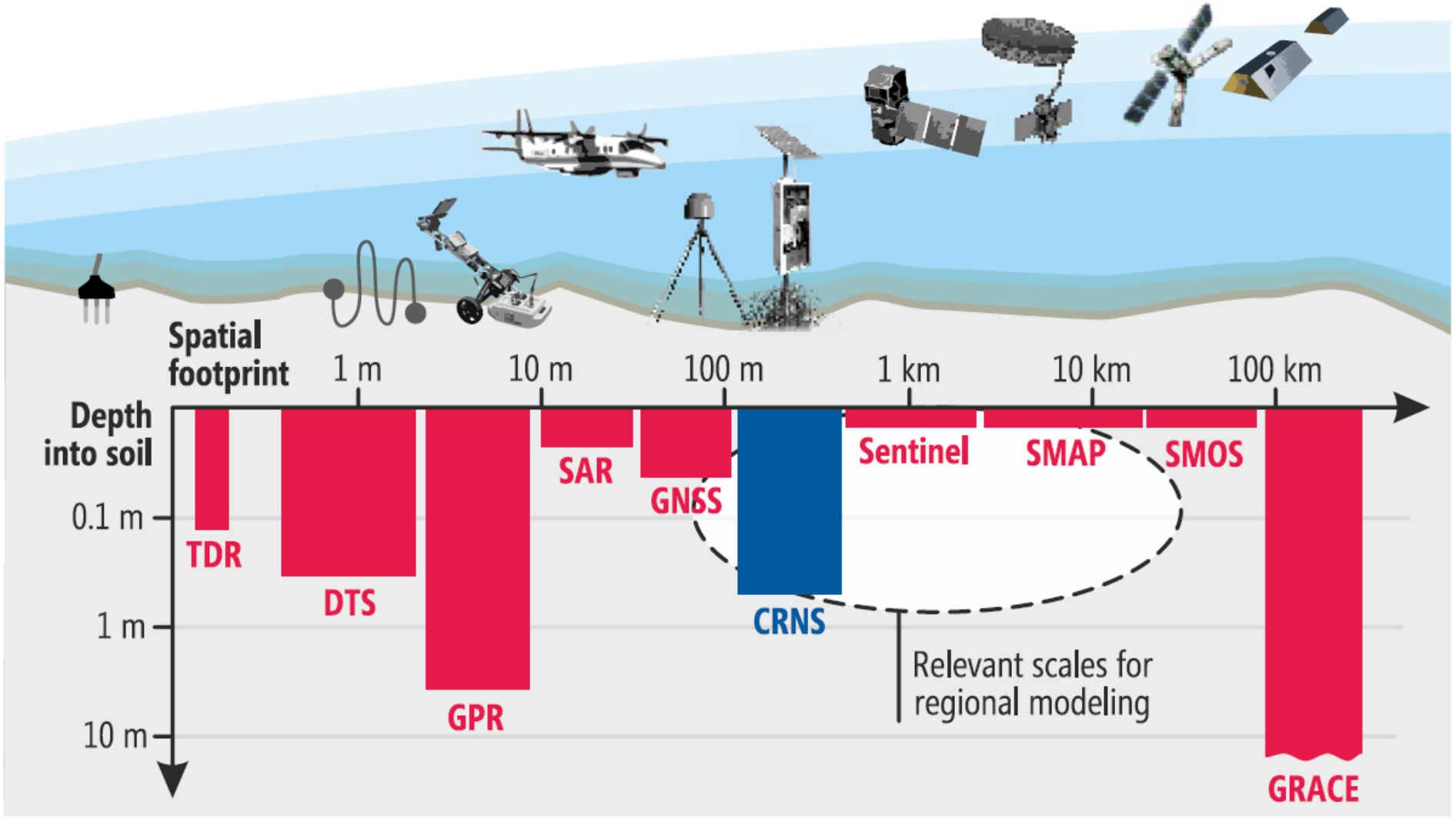
Remote Sensing Upscaling

250 m upscaled | 100 m upscaled | Difference between both

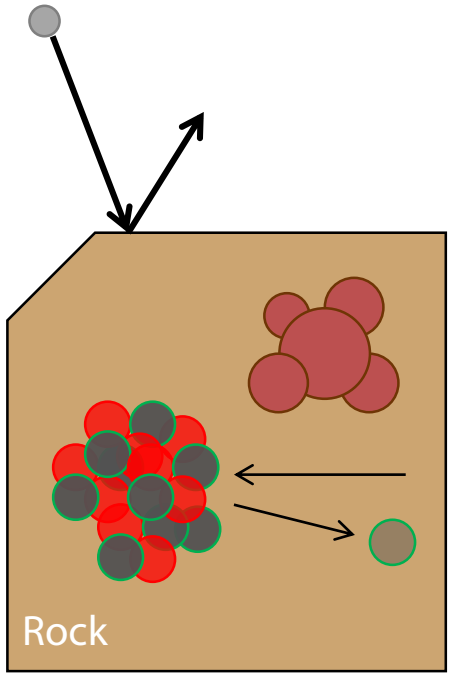
Wisconsin, USA

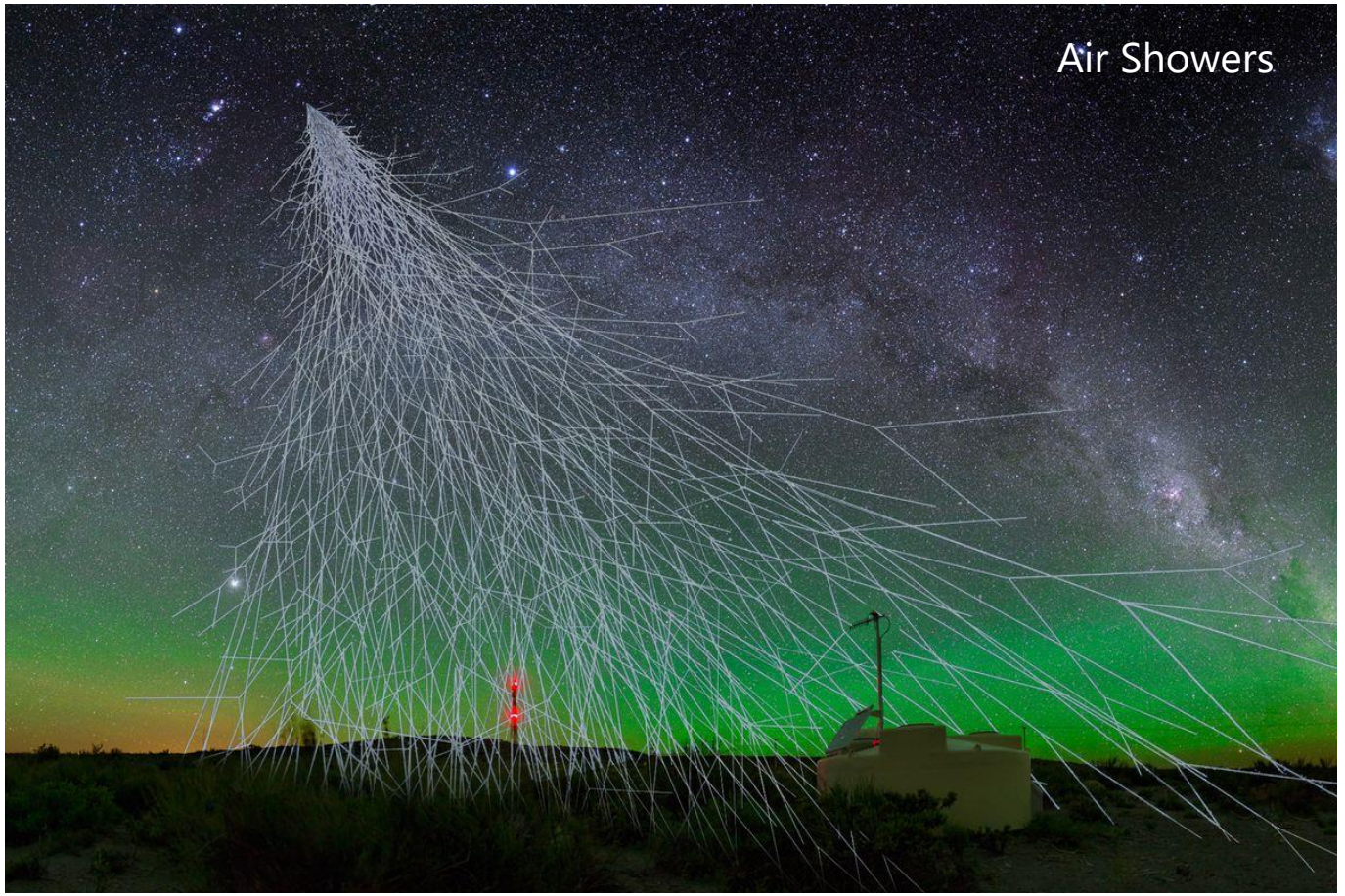
[1] J. Huang, et al. „Retrieving Heterogeneous Surface Soil Moisture at 100 m Across the Globe via Fusion of Remote Sensing and Land Surface Parameters", Front. Water 28(2) (2020)

Soil moisture measurement methods



CRNS Method





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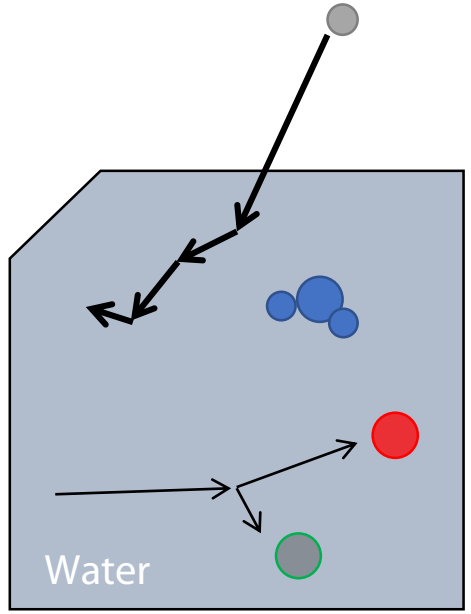

[1] Image by A. Chantelauze, S. Staffi, and L. Bret, https://www.theverge.com/2017/9/21/16335164/pierre-auger-observatory-cosmic-ray-galaxies-air-shower-particles

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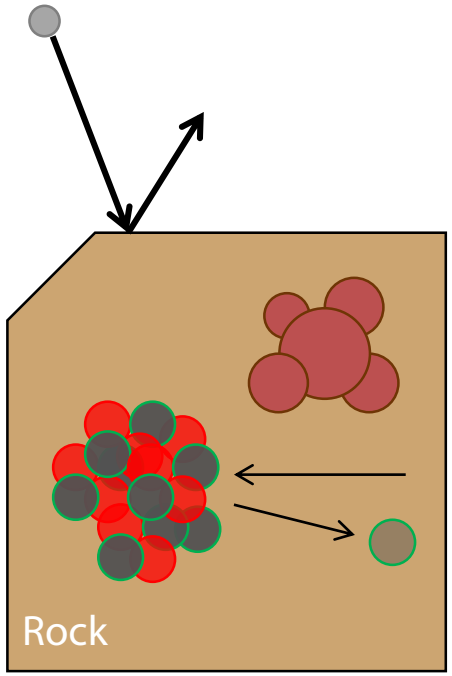

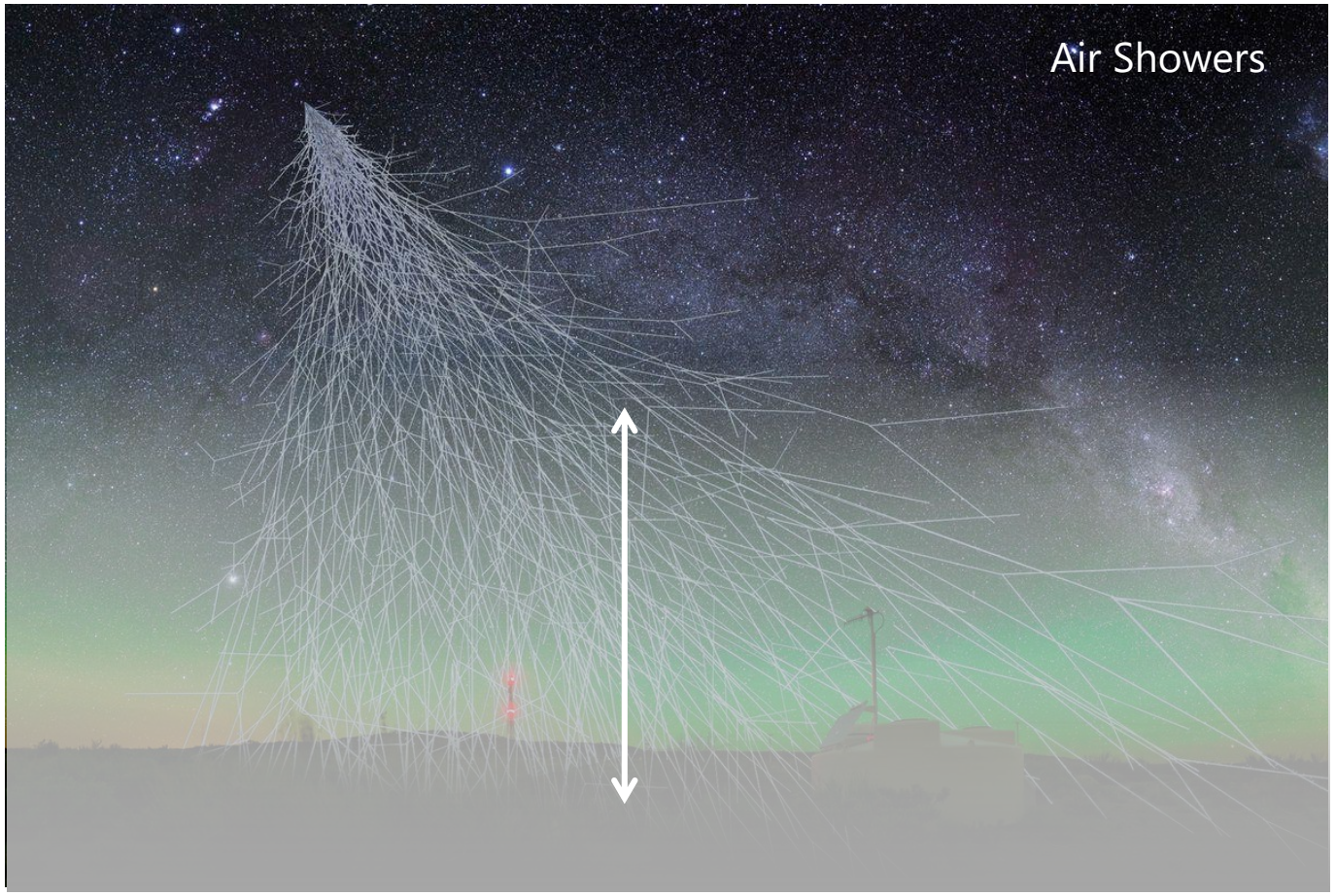

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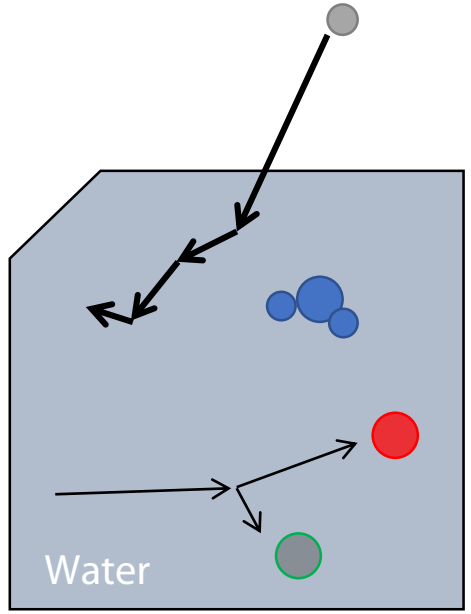

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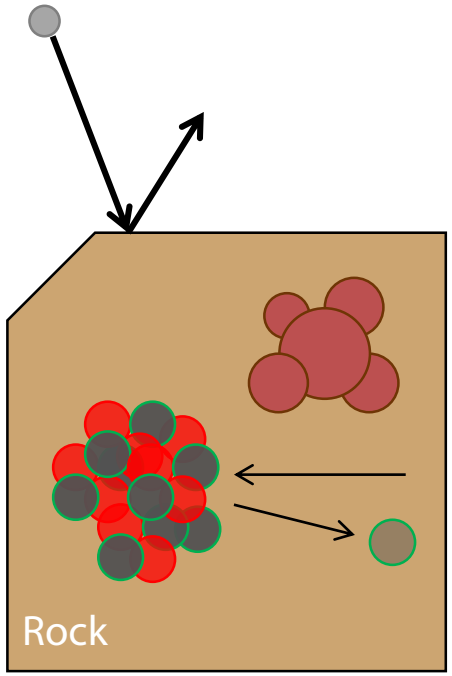

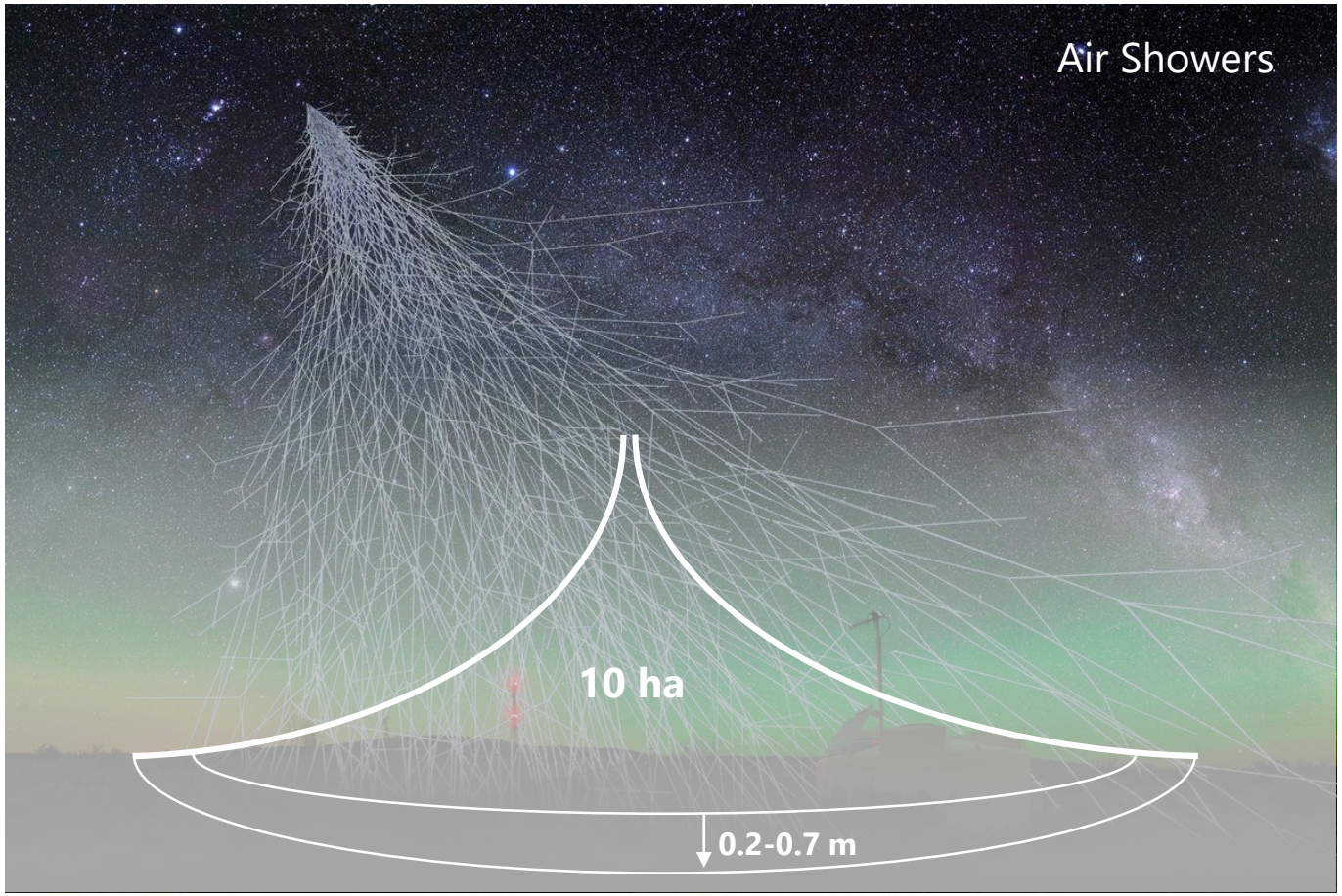

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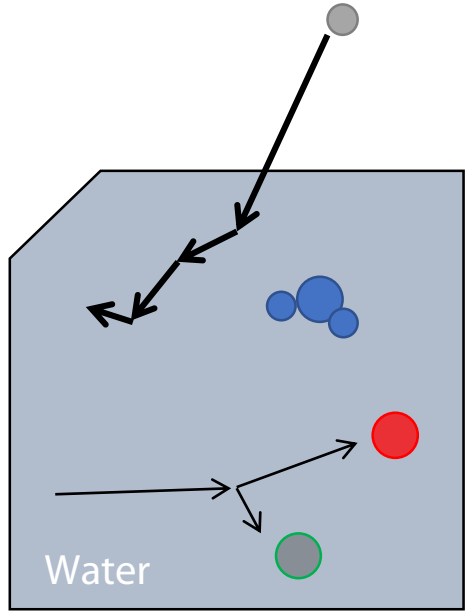

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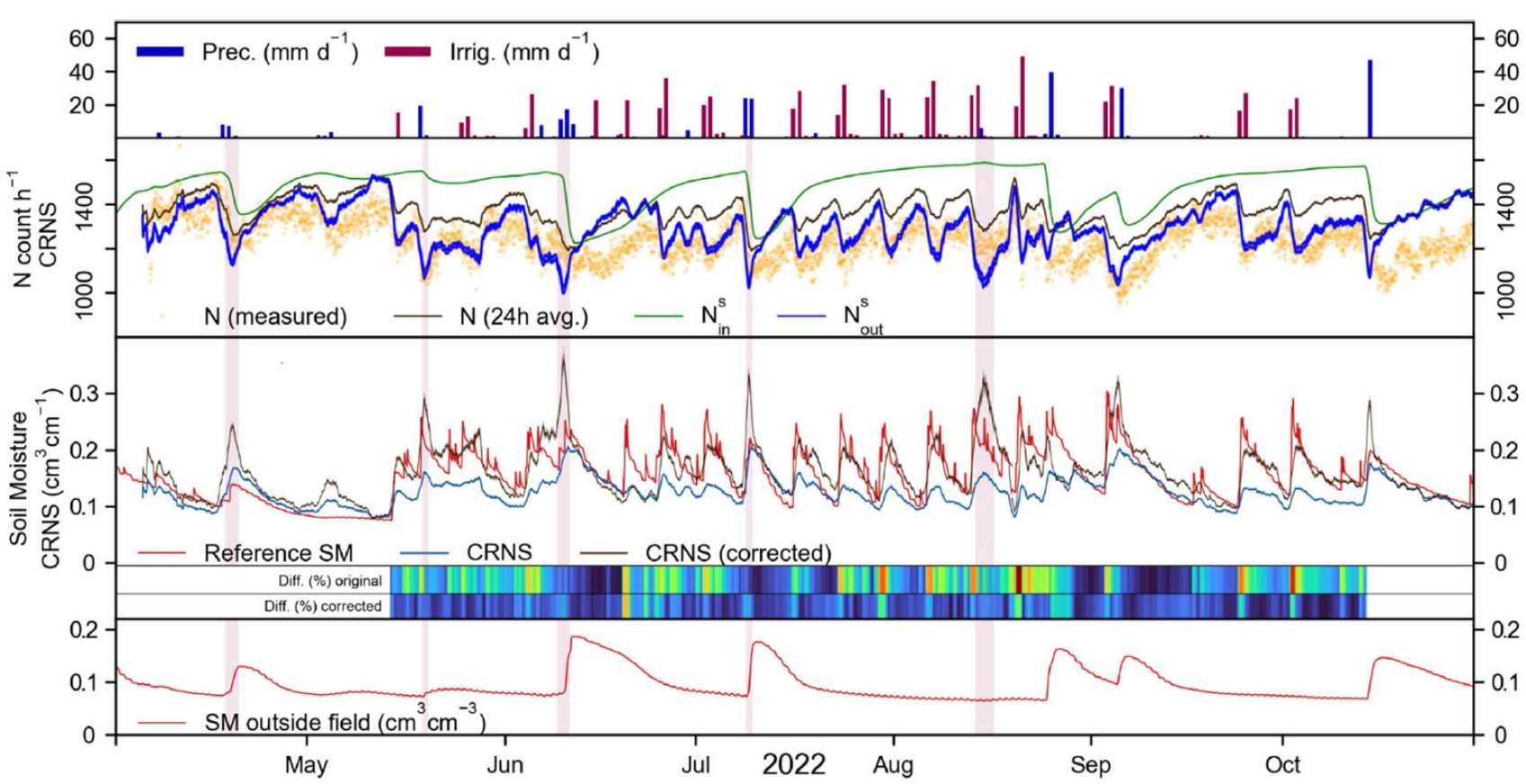
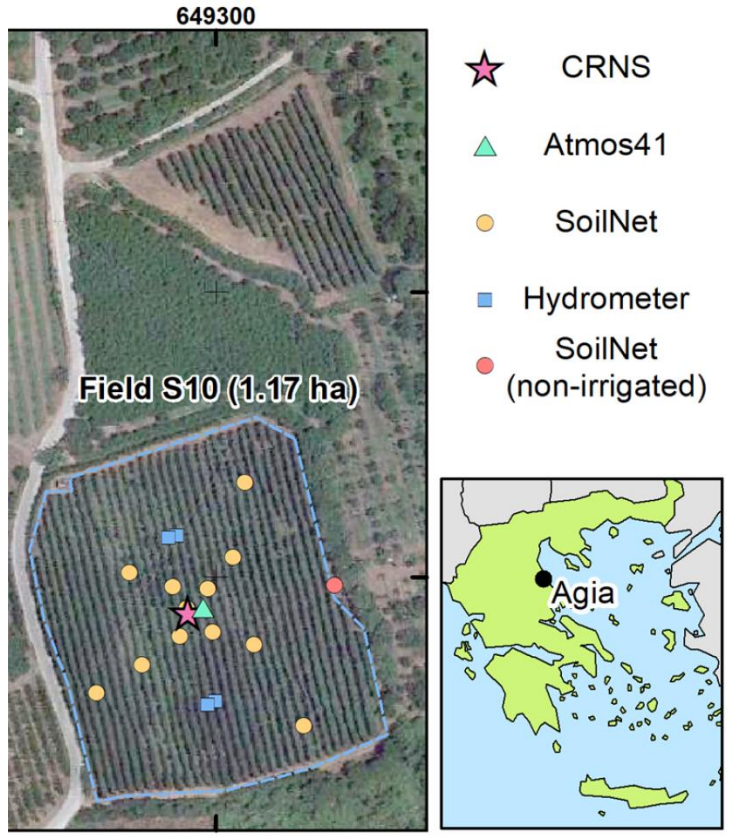
CRNS Sensors

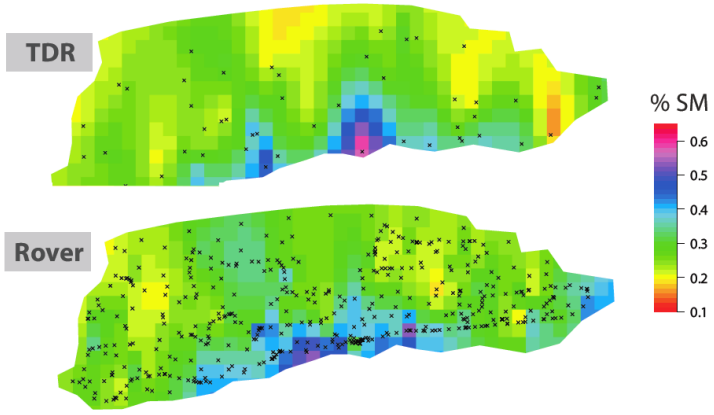


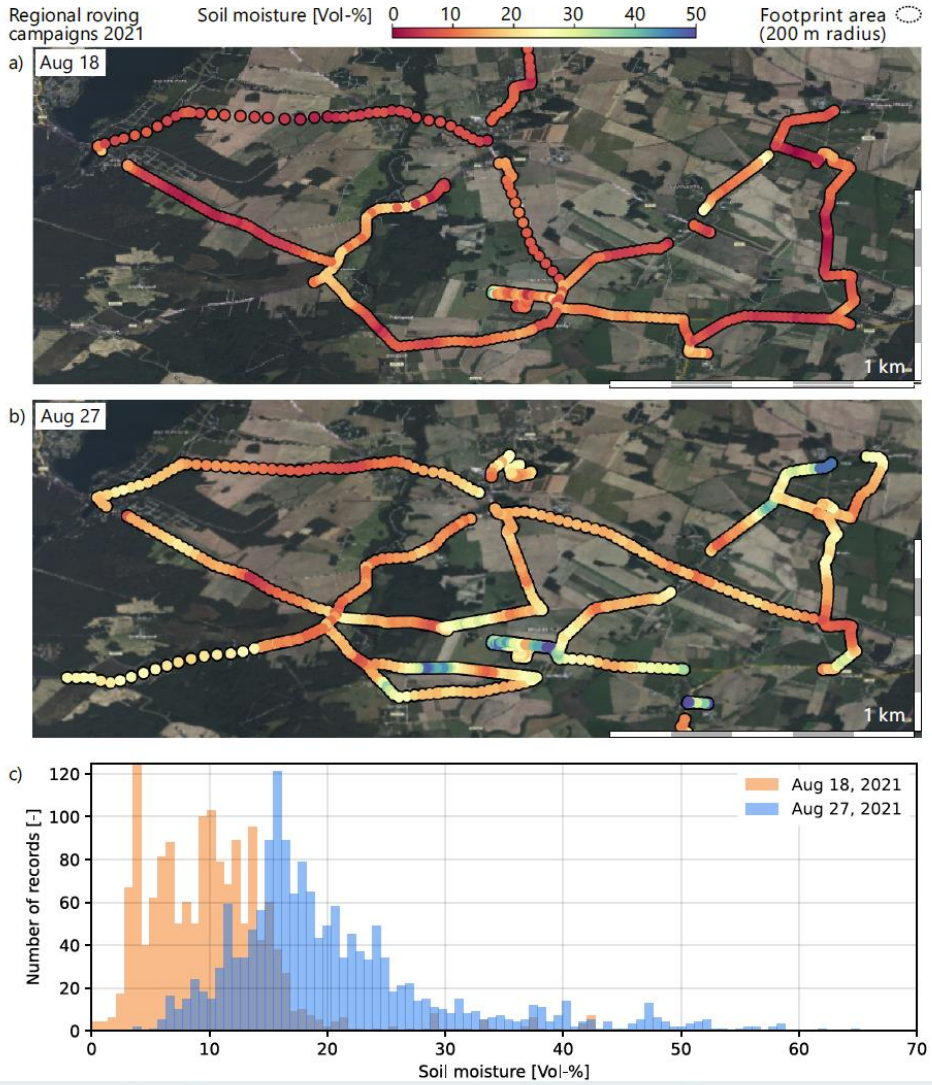

CRNS Example: Irrigation





CRNS Example: 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.

PROJECT PARTNERS:

PTB — Coordination, Lead WP6

Ciemat — Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

CMI — Czech Metrology Institute

Danish Technological Institute — Lead WP1

INRiM — Istituto Nazionale di Ricerca Metrologica — Lead WP5

IRSN — Institut de Radioprotection et de Sûreté Nucléaire

SMU

Justervesenet

TÜBİTAK

Universität Potsdam — Lead WP2

CTU — Czech Technical University in Prague

Alma Mater Studiorum Università di Bologna — Lead WP3

Politecnico Milano 1863

IIA — Istituto per il rilevamento elettromagnetico dell'ambiente — Lead WP4

UK Centre for Ecology & Hydrology

UFZ — Helmholtz Zentrum für Umweltforschung

Institute of Agrophysics PAS

IMPACT & SUPPORT:

esa

ASI — Agenzia Spaziale Italiana

UNESCO — United Nations Educational, Scientific and Cultural Organization

International Centre for Water Resources and Global Change under the auspices of UNESCO

WMO

eLTER

Deutscher Wetterdienst — Wetter und Klima aus einer Hand

ECMWF

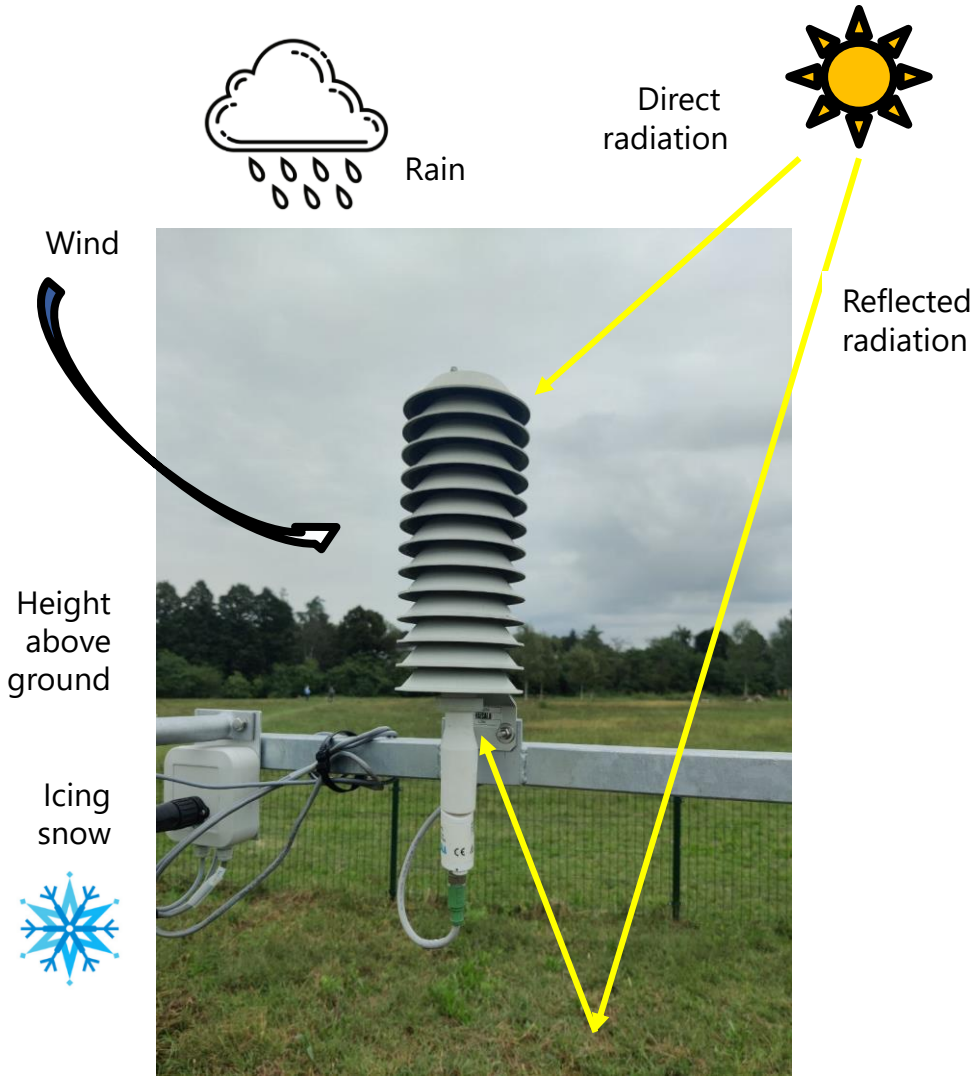
The University of Arizona

Landbrug Fødevarer

AHDB — Agriculture & Horticulture Development Board

NMBU — Norwegian University of Life Sciences

SI-tracable measurement on the point scale



WP1: **Traceability** WP3: Harmonization
WP2: Validation WP4: Data fusion

Measurement Quality Classification Scheme *(system)*

Measurement System & Calibration *(Annex 1A)* + Instrument(s) Coupling + Maintenance & Verification + Environment Effects

- Construction quality,
- Resolution,
- Instrument calibration,
- Linearity,
- Hysteresis,
- Time constant,
- Drift with temperature,
- Sampling method,
- Sampling frequency,
- Processing algorithm,
- Digitization and rounding,
- Response time.

Class A | Class B | Class C | Class D

+

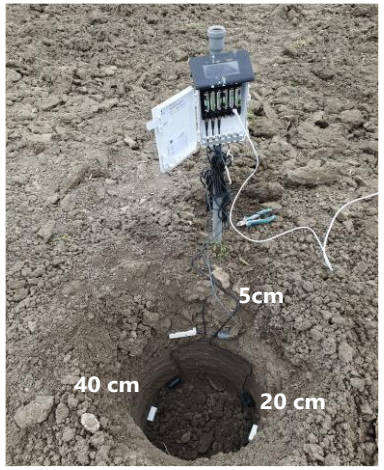
Siting Classification Scheme *(measurement exposure)*

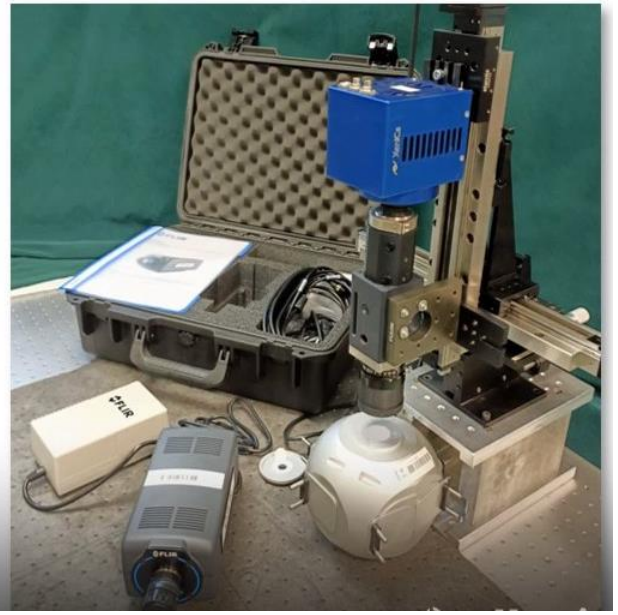
Class 1 | Class 2 | Class 3 | Class 4 | Class 5

SI-tracable measurement on the point scale

WP1: **Traceability** WP3: Harmonization
WP2: Validation WP4: Data fusion

- Calibration facilities for point scale sensors
  - Primary measurement methods and transfer standards
    - Provide a tracability scheme to CRNS





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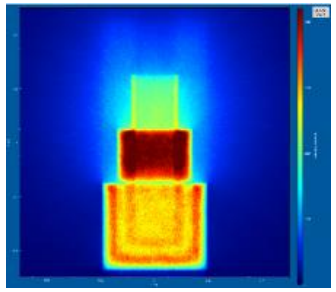
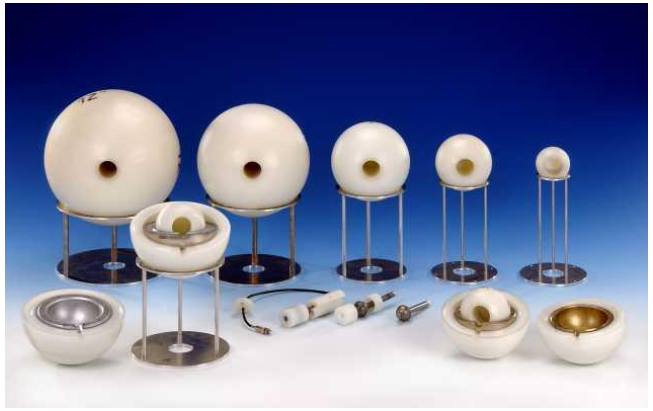
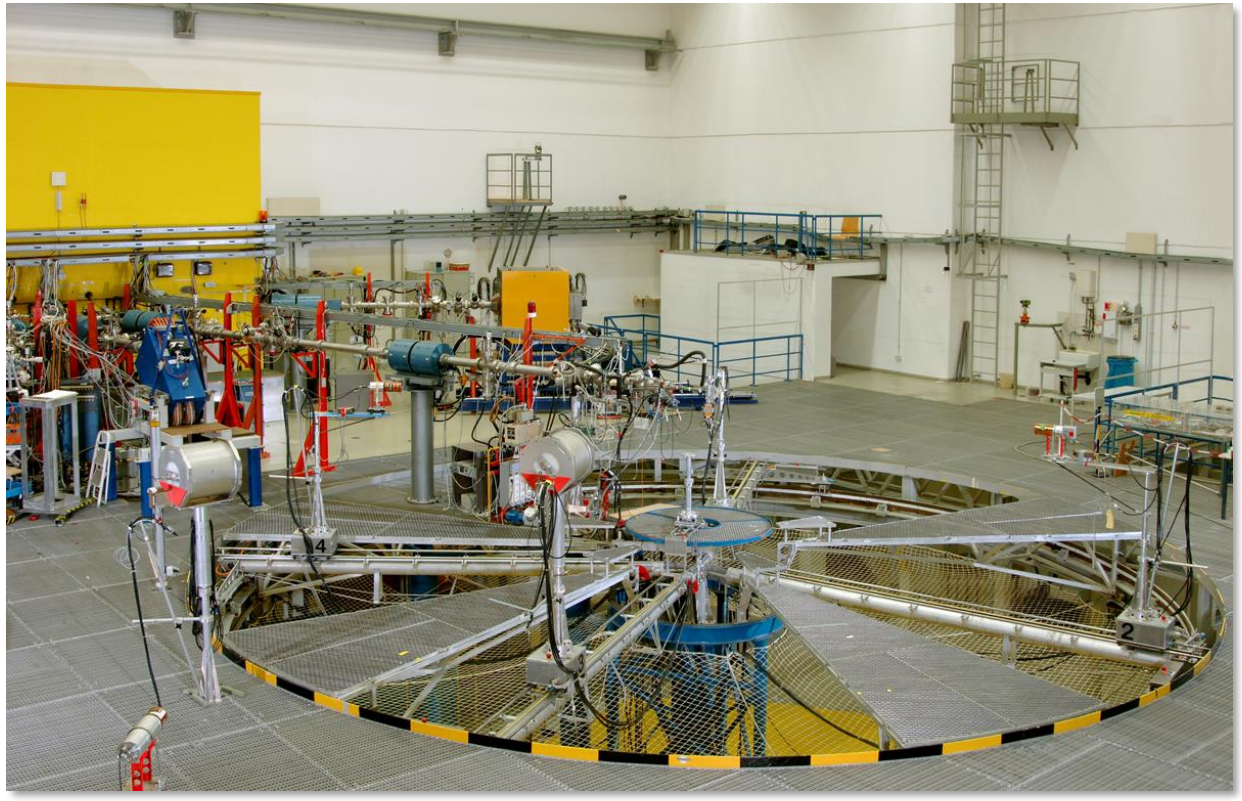




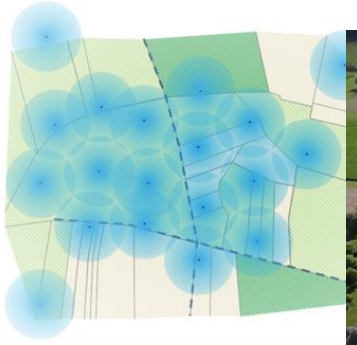


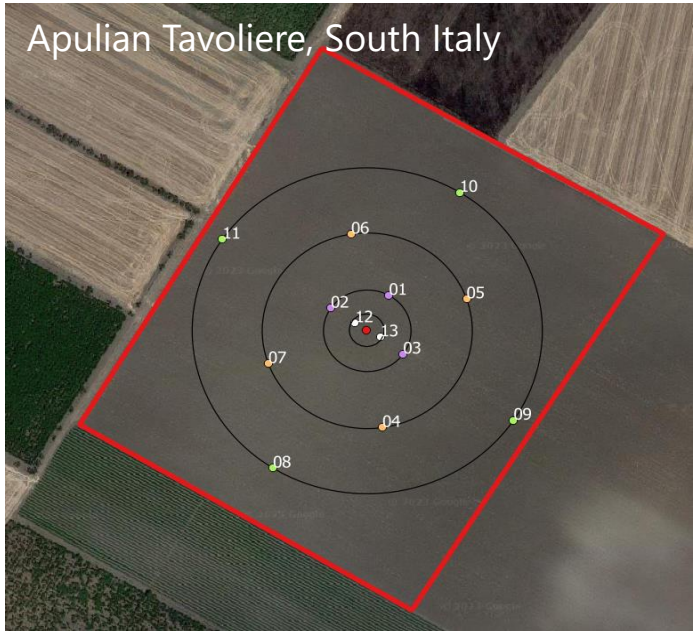
[1] https://www.ptb.de/cms/ptb/fachabteilungen/abt6/fb-64/642-neutronenmetrologie/neutronenreferenzfelder.html, https://www.ptb.de/cms/ptb/fachabteilungen/abt6/fb-64/643-neutronenspektrometrie/nemus/neutronen-spektrometer-nemus-neutron-multisphere-spectrometer.html

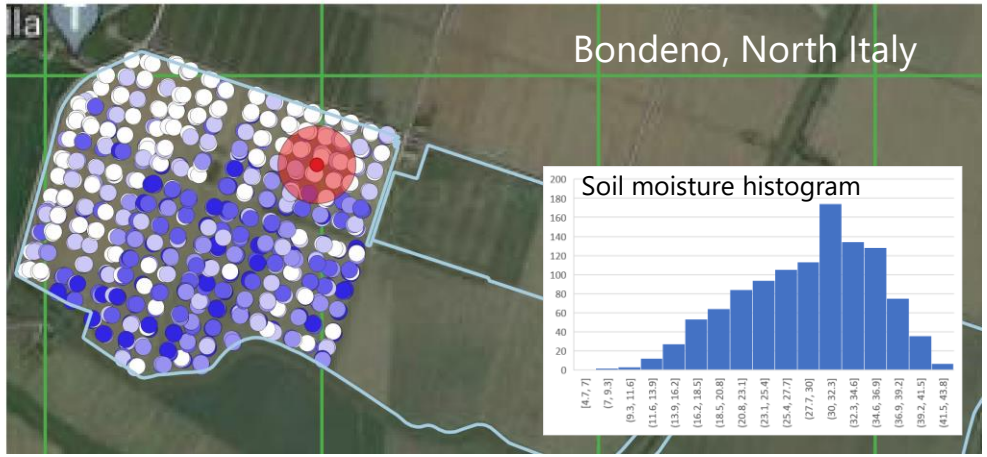
Development of CRNS validation practices

WP1: Traceability
WP2: **Validation**
WP3: Harmonization
WP4: Data fusion

- Three ‚high level' test sites selected
  - Characterized, equipped with in-situ sensors
    - Validation of neutron transport models
      - Uncertainty evaluation under environmental conditions (heterogenity, changing vegetation, irrigation)





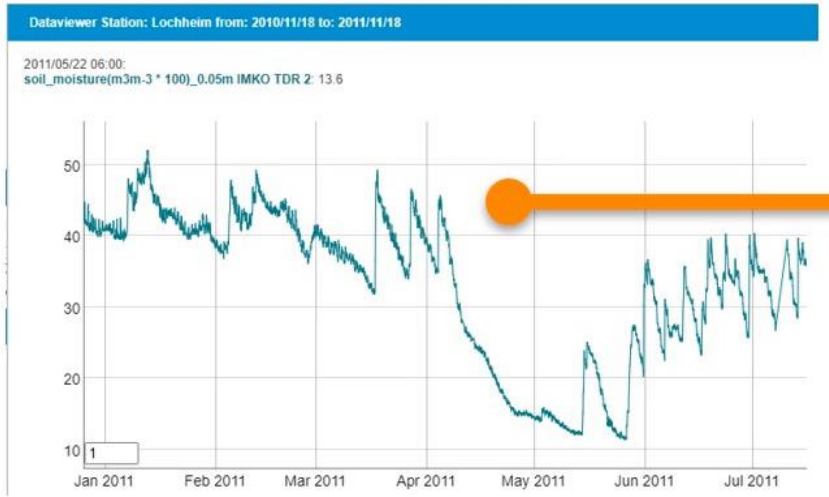


Comparison and harmonization of soil moisture measurement methods at multiple spatial and temporal scales

WP1: Traceability
WP2: Validation
WP3: **Harmonization**
WP4: Data fusion

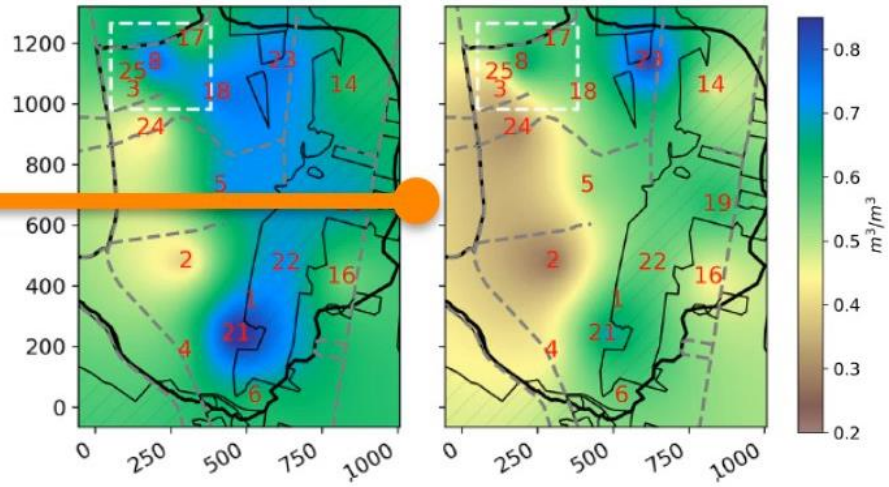
- Comparison of methods, their constraints and different spatial and temporal characteristics
  - Development of an approach to harmonize point scale, field scale and remote sensing

Point-scale *in situ* measurements
Example: Time series of a single sensor



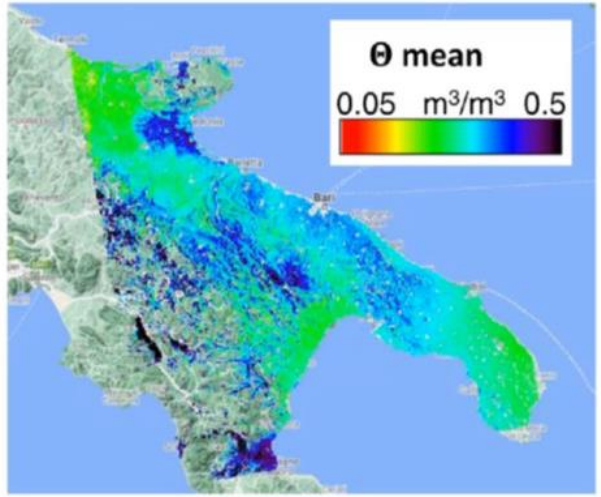
[International Soil Moisture Network]

Cosmic-ray neutron sensing
Example: Daily average soil moisture at catchment scale



[Heistermann, HESS 25 (2021) 4807]

Satellite remote sensing
Example: Sentinel-1 surface soil volumetric water content product



[Balenzano *et al.*, Data in Brief 38 (2021) 107345]

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Multi-scale and multi-disciplinary data fusion

WP1: Traceability
WP2: Validation
WP3: Harmonization
WP4: **Data fusion**

- Comparison of methods, their constraints and different spatial and temporal characteristics
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Point-scale *in situ* measurements
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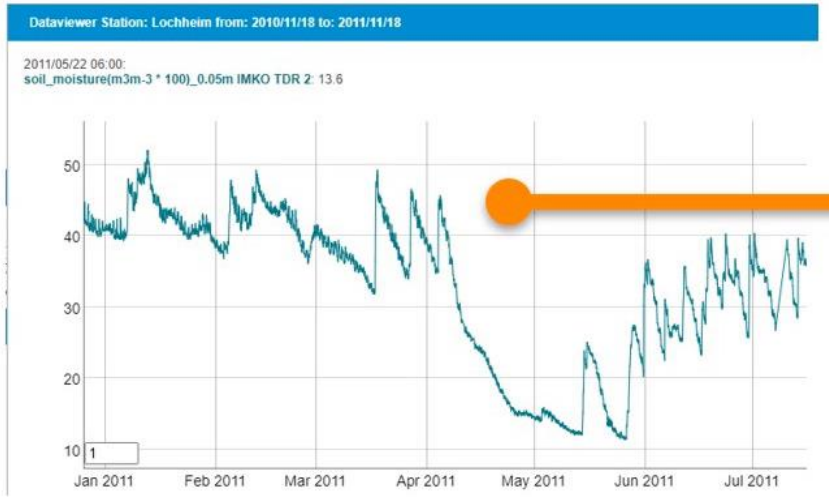

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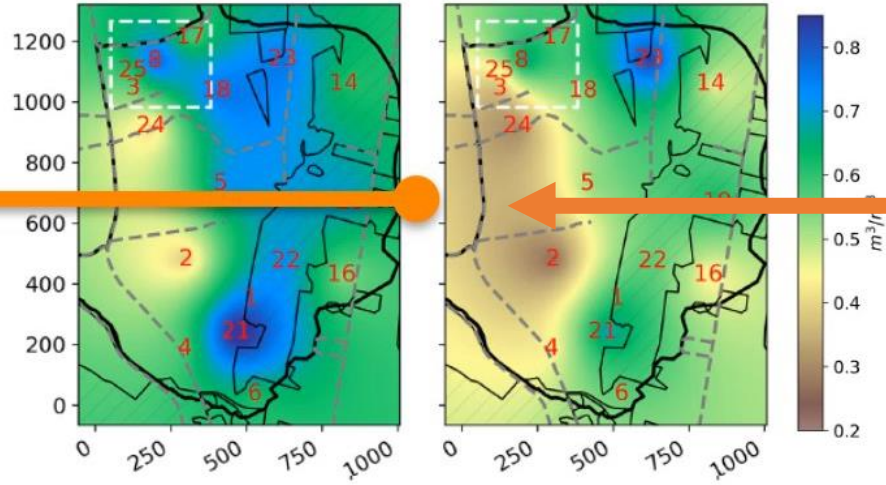

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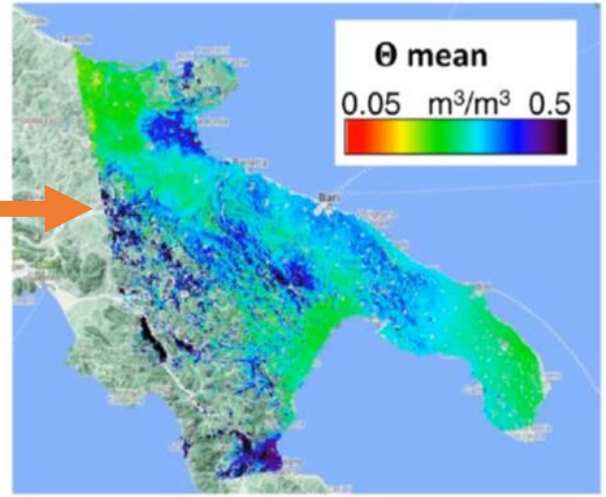

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Metrology for multi-scale monitoring of soil moisture

'Soil Moisture Metrology' (SoMMet) – a project within framework of the European Partnership on Metrology

Co-funded by the European Union
European Partnership
METROLOGY PARTNERSHIP
EURAMET

The project 21GRD08 SoMMet has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

Gefördert durch DFG Deutsche Forschungsgemeinschaft
FOR 2394

Markus Köhli for the SoMMet collaboration:

Metrology for multi-scale monitoring of soil moisture

'Soil Moisture Metrology' (SoMMet) – a project within framework of the European Partnership on Metrology

- Consortium: 9 National Metrology Institutes and 9 research institutions in Europe

Co-funded by the European Union
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Traceability – Validation - Harmonization - Data fusion

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- On the point scale (10^{-1} m - 10^{1} m): primary and secondary standards of measurements, specifically for soil samples
- On the intermediate range (10^{2} m - 10^{3} m): establish the metrological basis of the CRNS in laboratory and outdoors
- On the large scale (10^{3} m - 10^{4} m): utilize satellite-based remote sensing products

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