Physikalisches Institut
Heidelberg University
Germany

GC8-Hydro Napoli
12.6.2023

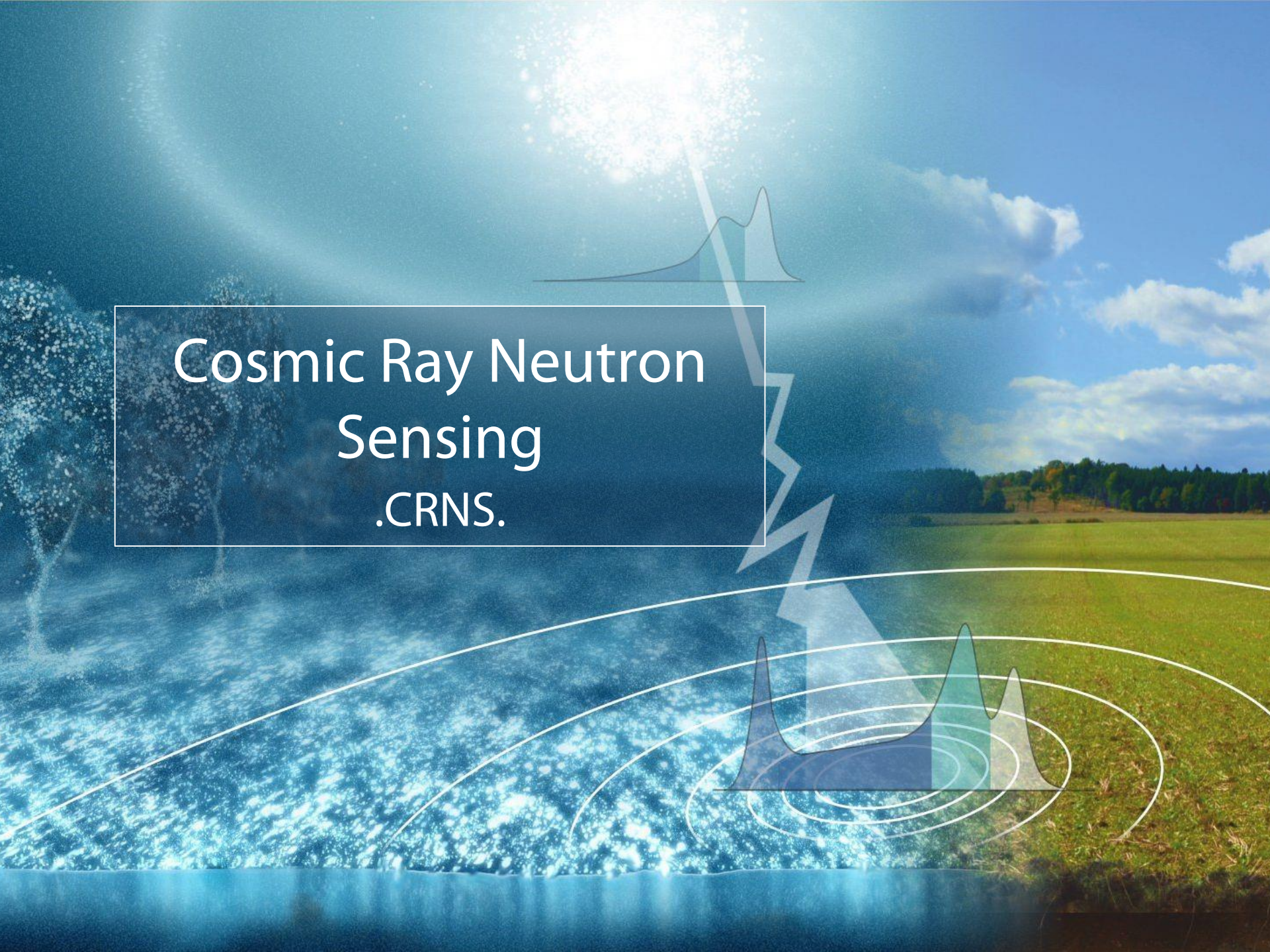
CRNS-based monitoring technologies as solutions for climate-resilient agriculture

Markus Köhli[1,3], P. Stowell[2,*], J. Weimar[1,3], P. Ney[4], F. Nieberding[4], U. Schmidt[1], H. Bogena[4] , K. Görgen[4]

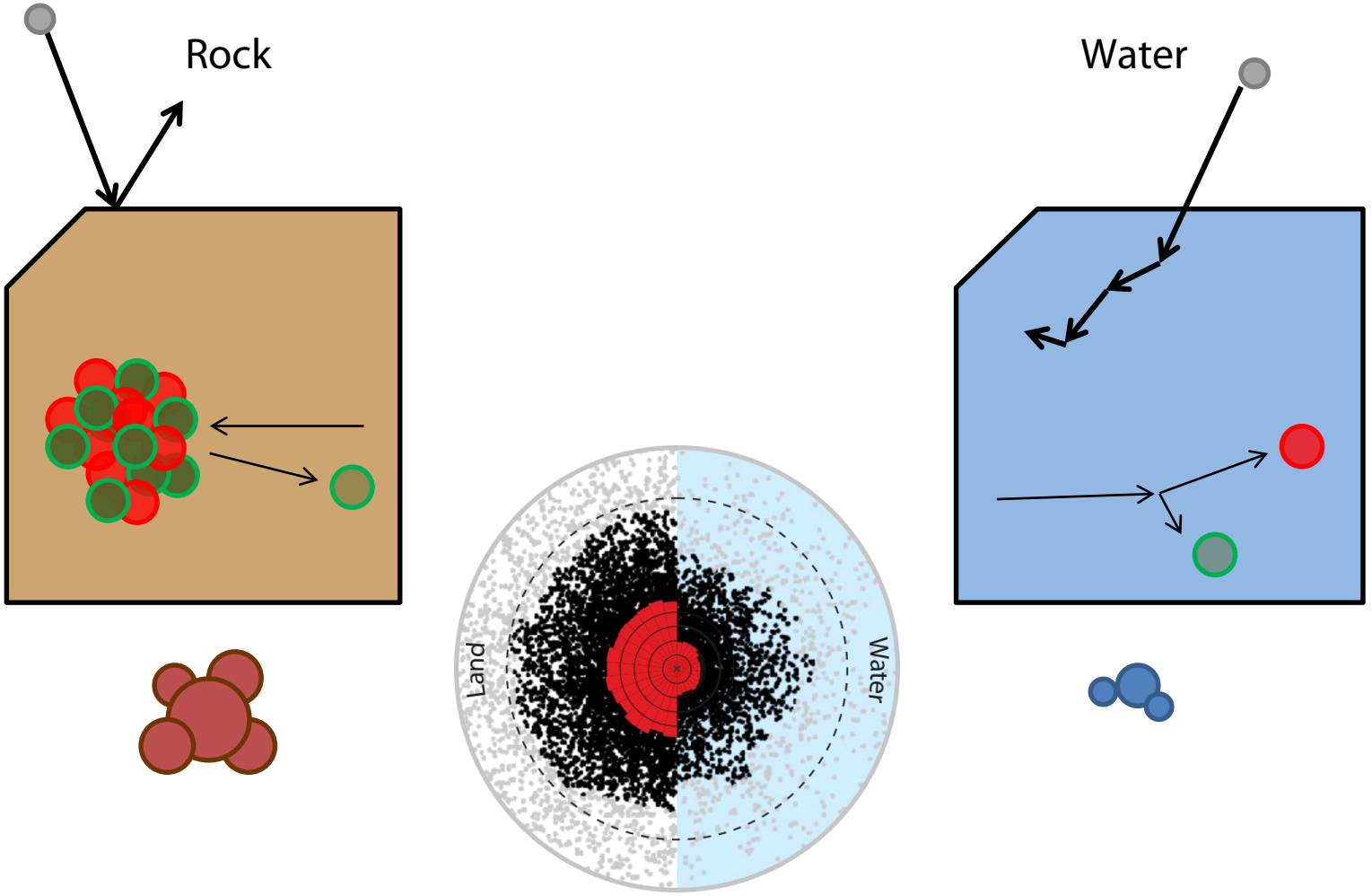
[1] Physikalisches Institut, Heidelberg University, Germany
[2] Centre for Advanced Instrumentation, Durham University, United Kingdom
[*] now: Department of Physics and Astronomy, University of Sheffield, United Kingdom
[3] StyX Neutronica GmbH, Mannheim, Germany
[4] Agrosphere Institute (IBG-3), Forschungszentrum Jülich, Germany

[1]

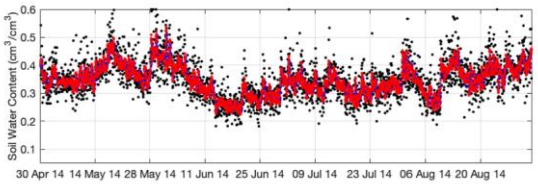
[1] http://www.iso.org/iso/2012_iso-in-action_water_vignette.jpg

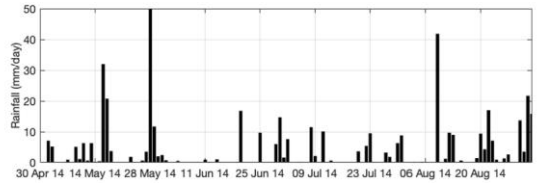

Cosmic Ray Neutron Sensing
.CRNS.

Neutron interaction with water



CRNS Overview





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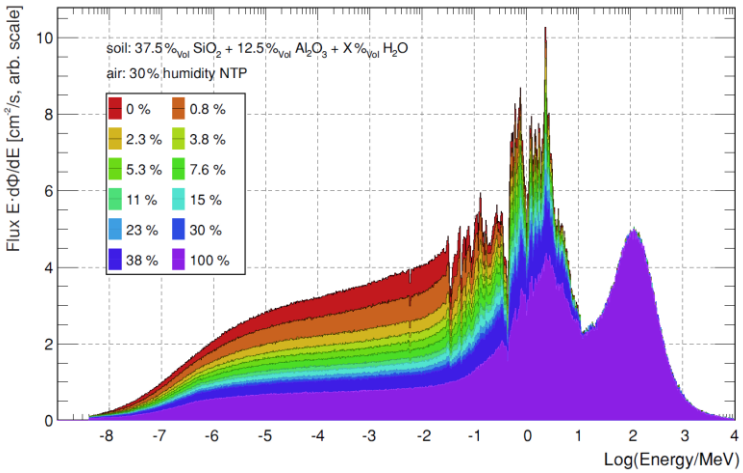
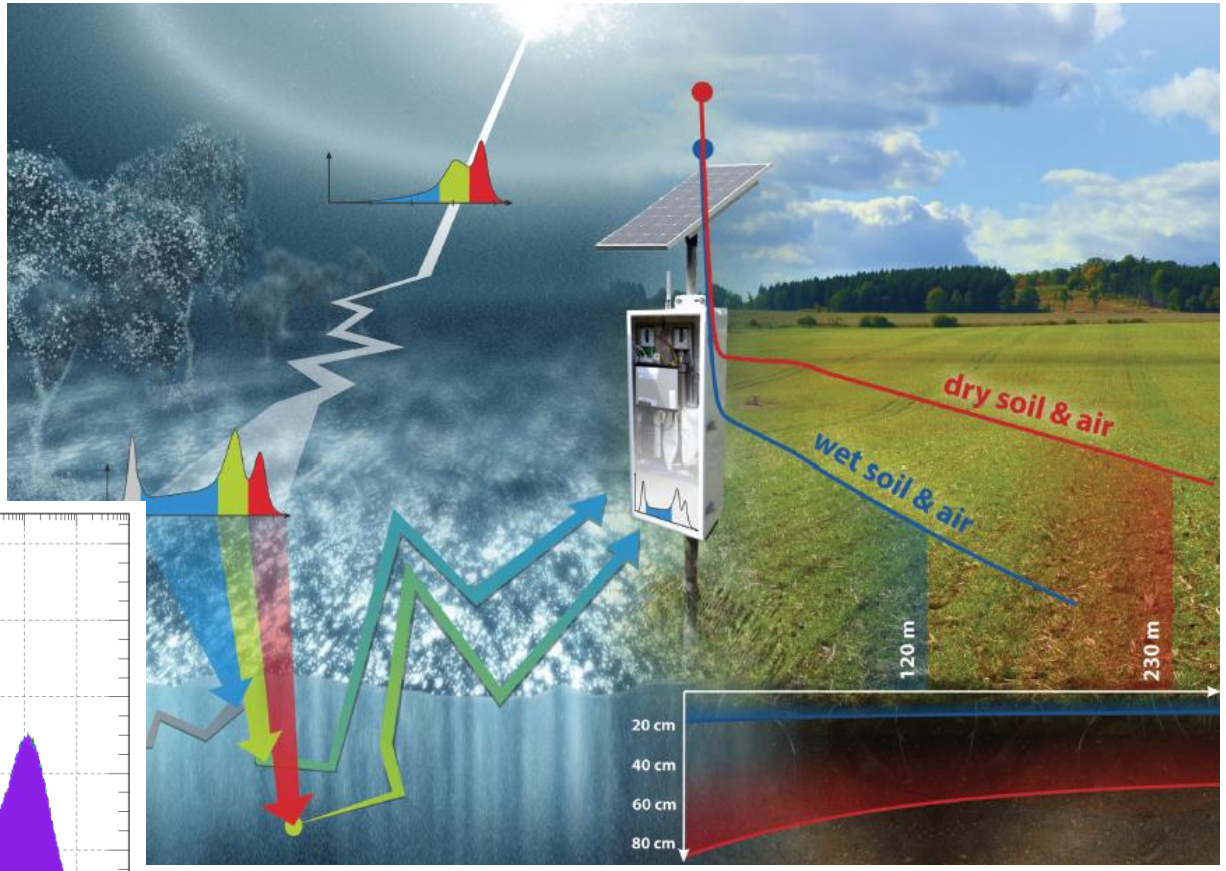
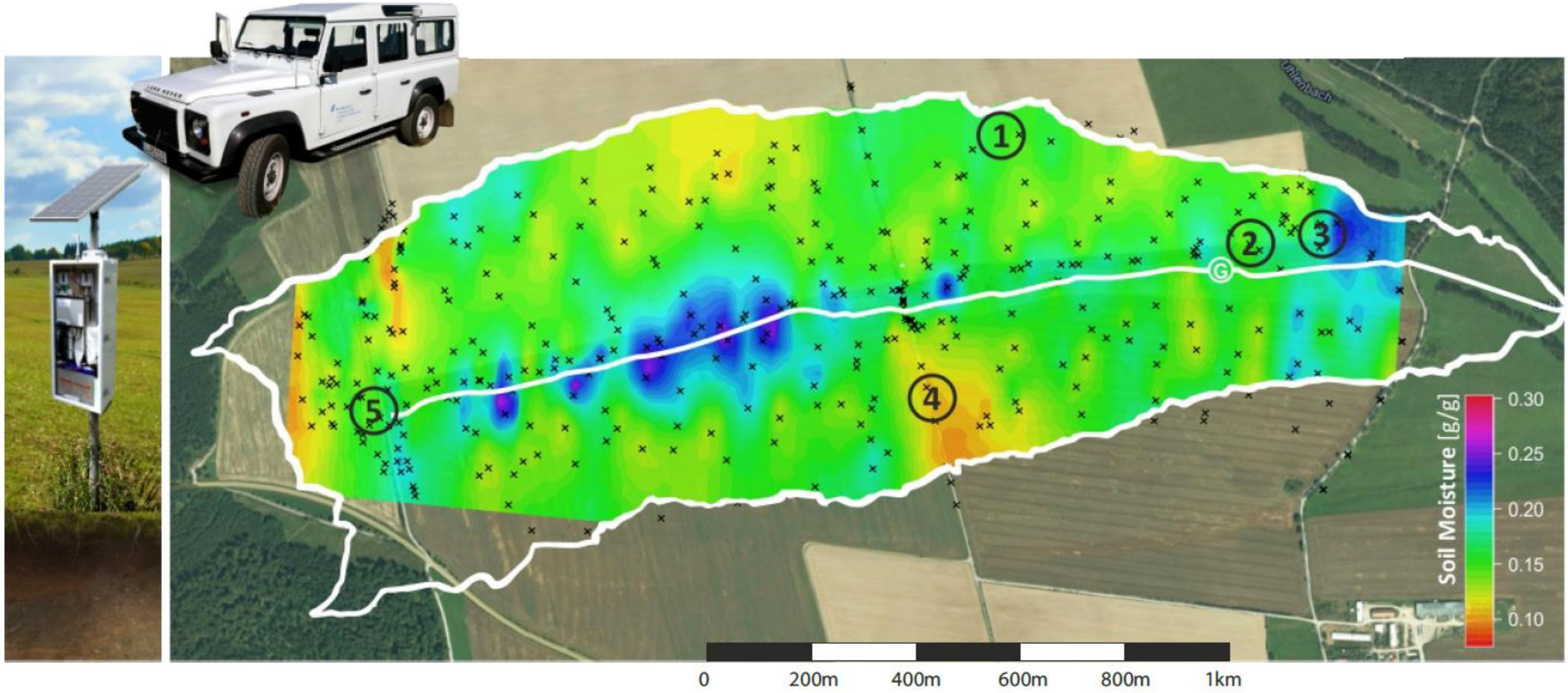




[1] T. Franz et al., Practical Data Products From Cosmic-Ray Neutron Sensing for Hydrological Applications, Front. Water, 2020

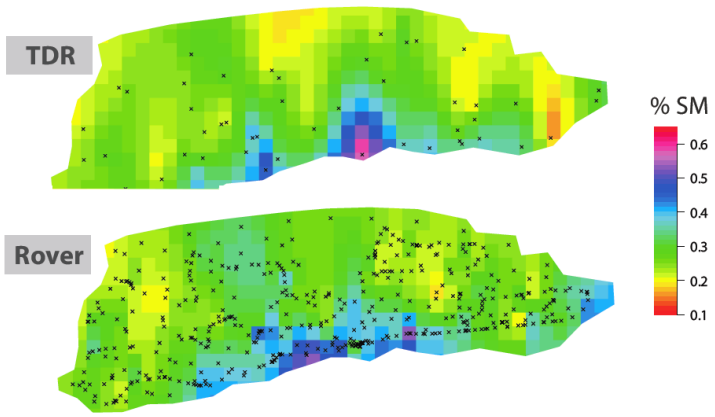
Stationary and Roving

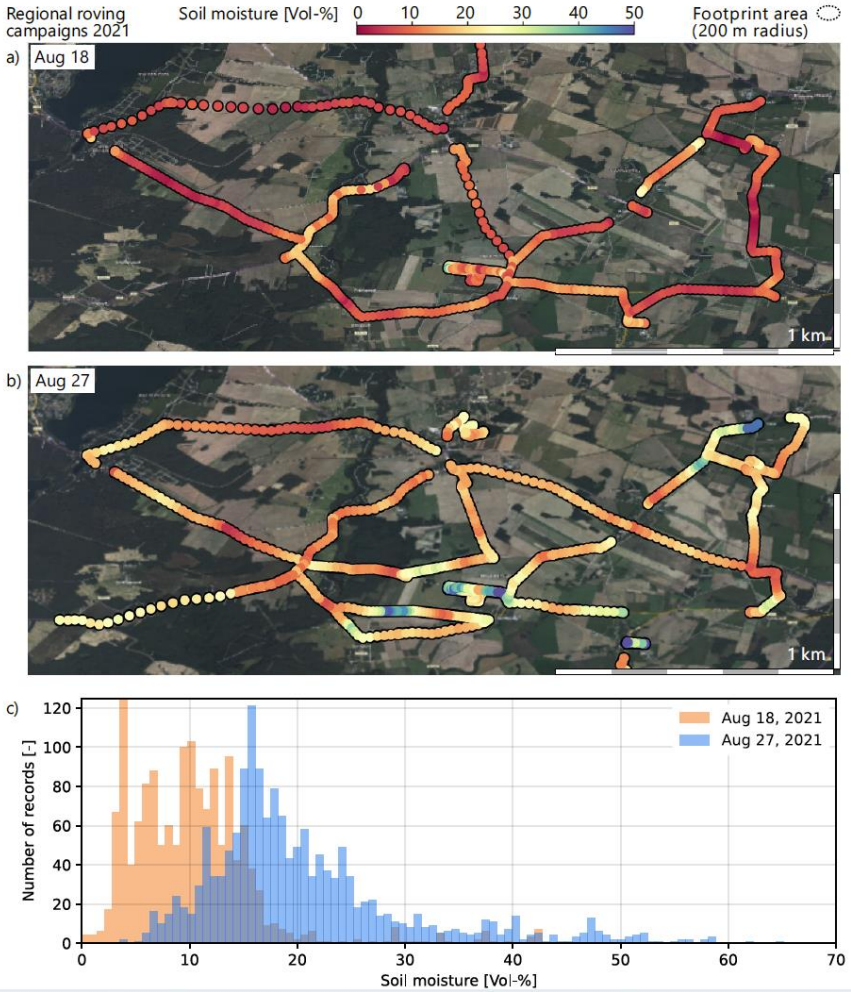
In collaboration with Martin Schrön, UFZ Leipzig



Roving across scales

In collaboration with Martin Schrön, UFZ Leipzig



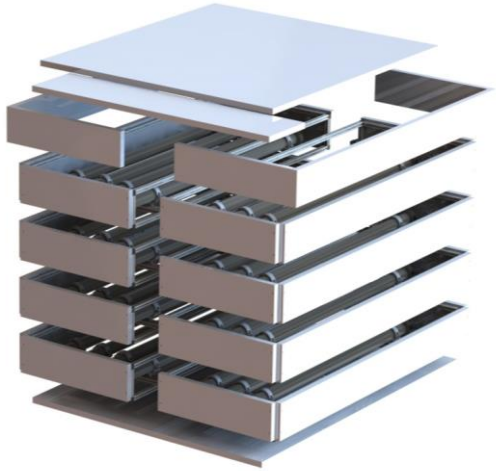


Two-days measurement campaign with the mobile detection system on Aug 18th (a) and Aug 27th (b), 2021. Credit: Martin Schrön, UFZ Leipzig, Germany.

Stationary and Roving Instruments

Stationary - small

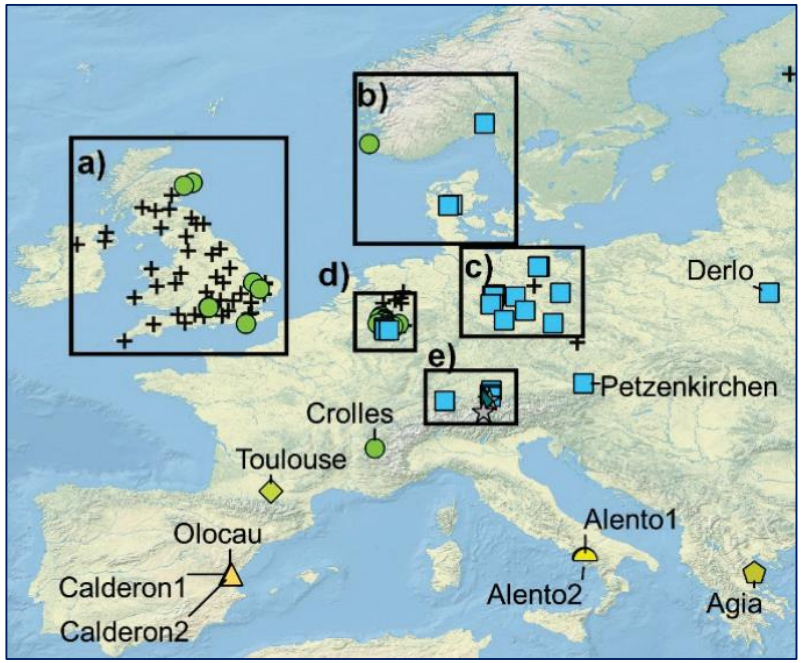
Stationary - large



Roving

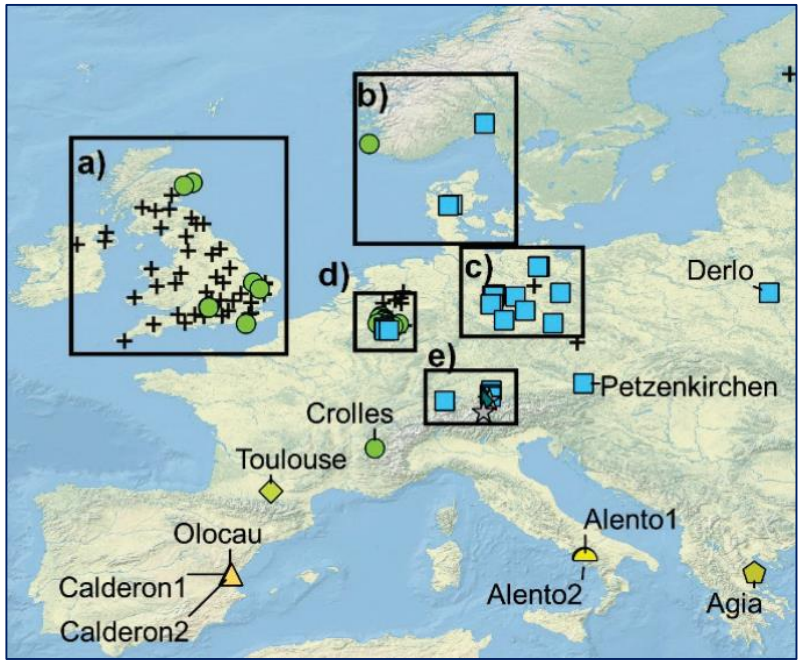
Sty Neutronica

CRNS Networks



COSMOS-Europe sites (Bogena 2021, ESSD)

CRNS Networks



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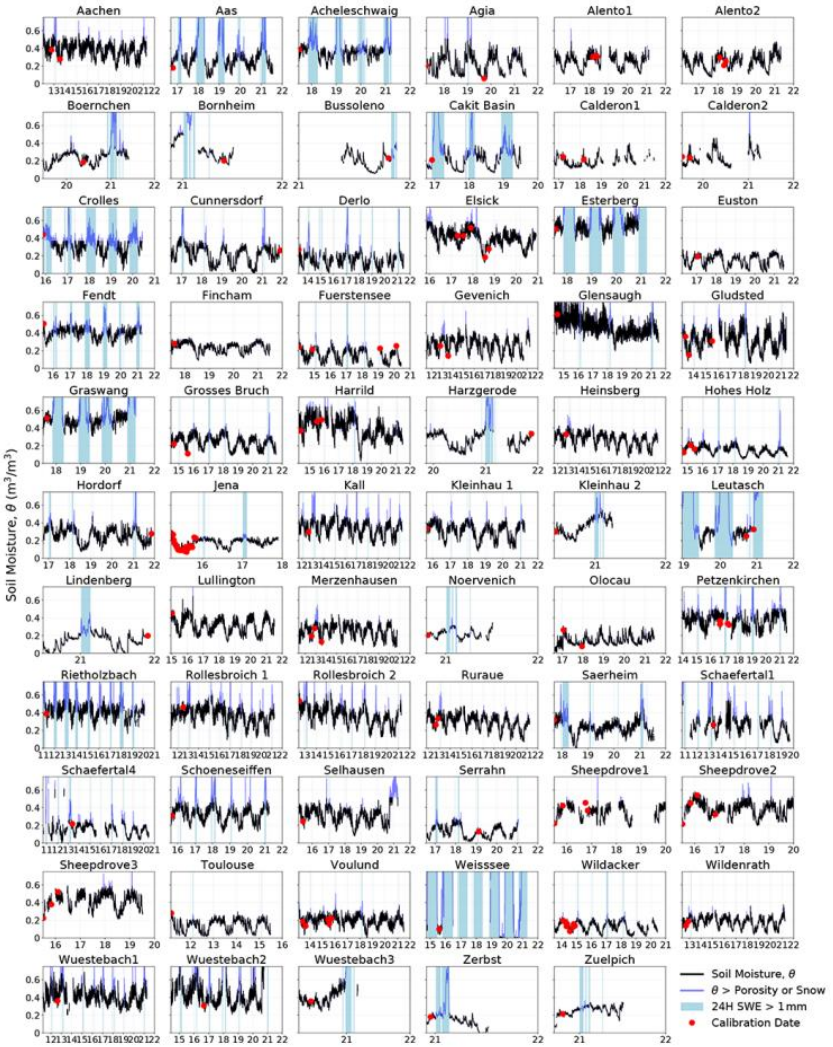
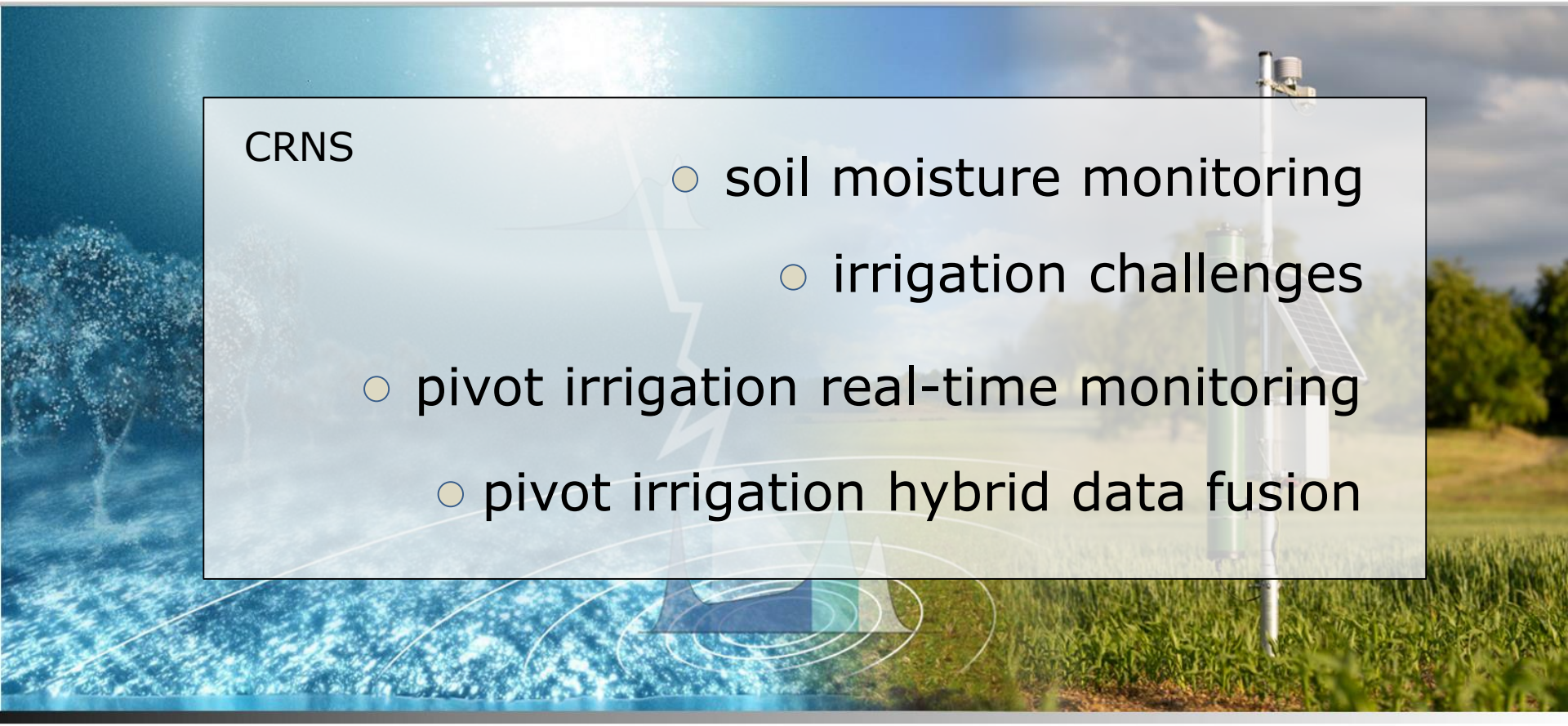


H.R. Bogena et al., COSMOS-Europe: a European network of cosmic-ray neutron soil moisture sensors, Earth Syst. Sci. Data, 14, 1125–1151, 2022

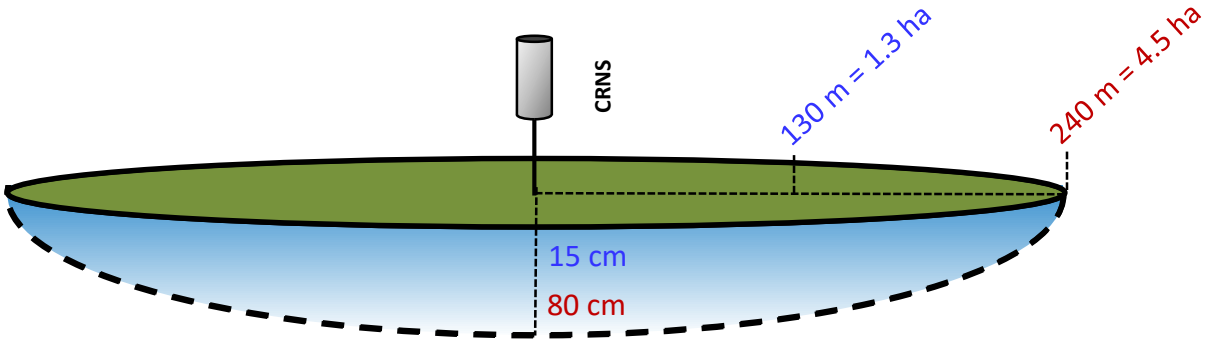
CRNS-based monitoring technologies as solutions for climate-resilient agriculture



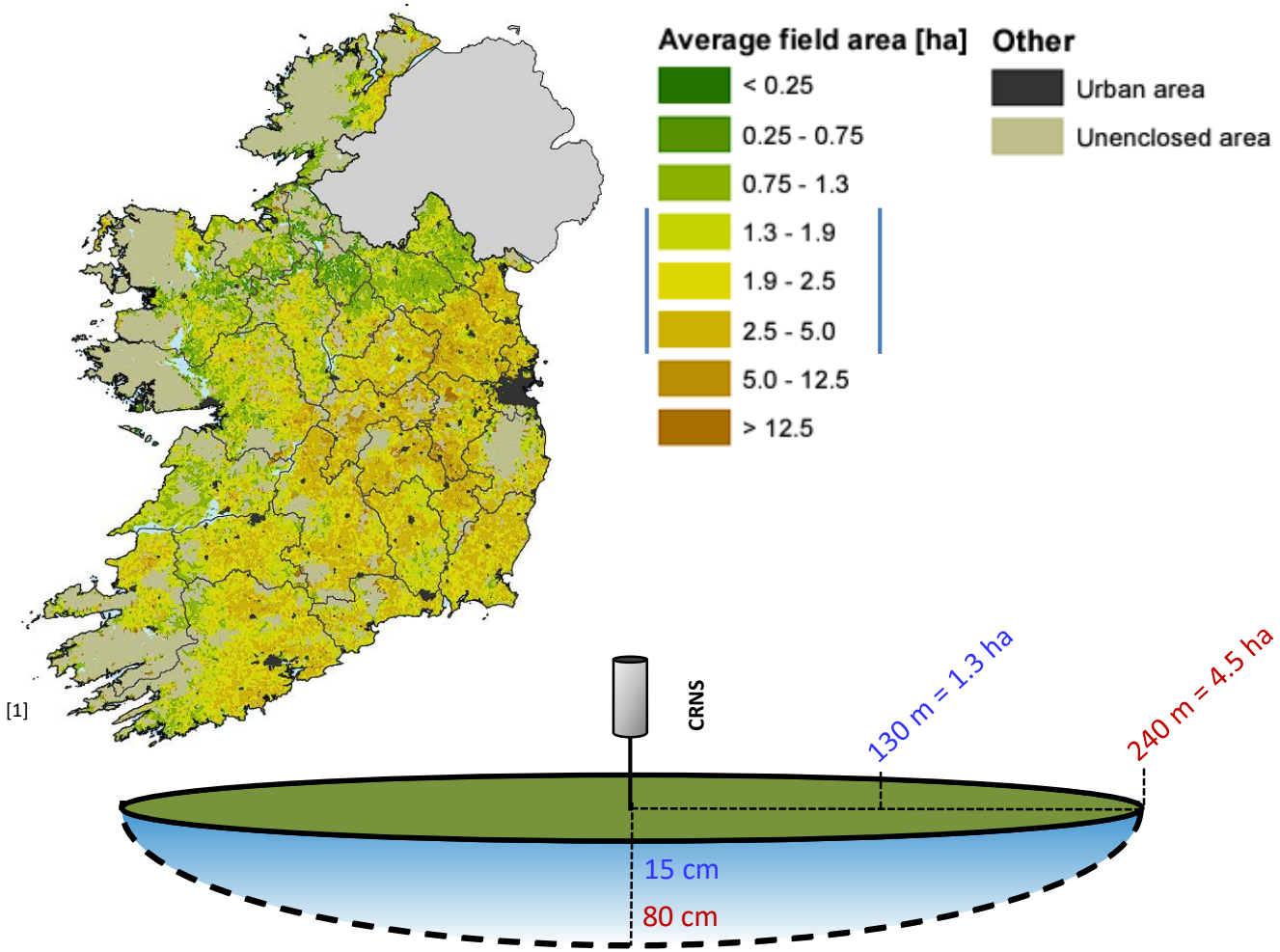
CRNS

- soil moisture monitoring
- irrigation challenges
- pivot irrigation real-time monitoring
- pivot irrigation hybrid data fusion

Motivation for Smart Agriculture

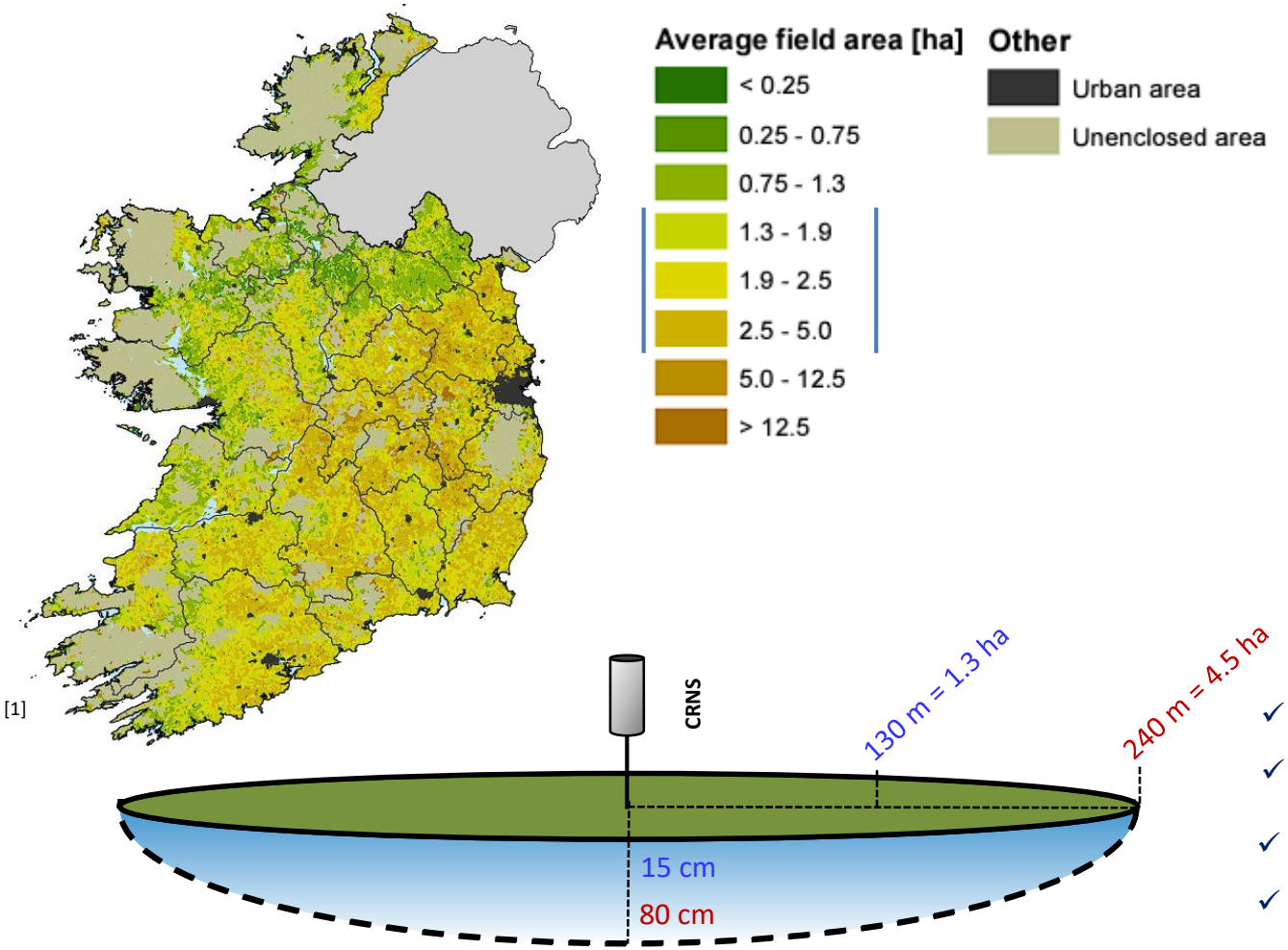


Motivation for Smart Agriculture



[1] J. Zin "Average size of enclosed agricultural fields by townland in the Republic of Ireland", Ordnance Survey Ireland Government of Ireland, 2012

Motivation for Smart Agriculture



- ✓ One sensor per field
- ✓ Large measured volume
- ✓ No removal during management
- ✓ Low maintenance

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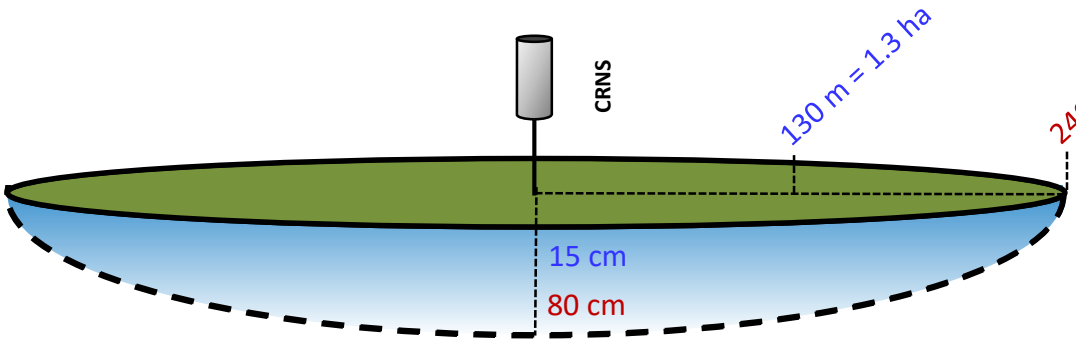
Motivation for Smart Agriculture

M. Köhli et al. "*Soil Moisture and Air Humidity dependence of the above-ground cosmic-ray neutron intensity*", Front. Water, **2**, DOI: 10.3389/frwa.2020.544847



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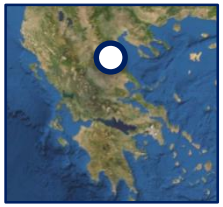
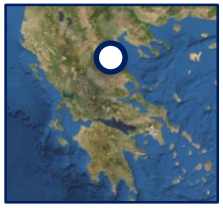
Challenges: Sprinkler Irrigation



See poster by C. Brogi:

Potential and limitations of cosmic-ray neutron sensors for irrigation management in small fields

Challenges: Sprinkler Irrigation



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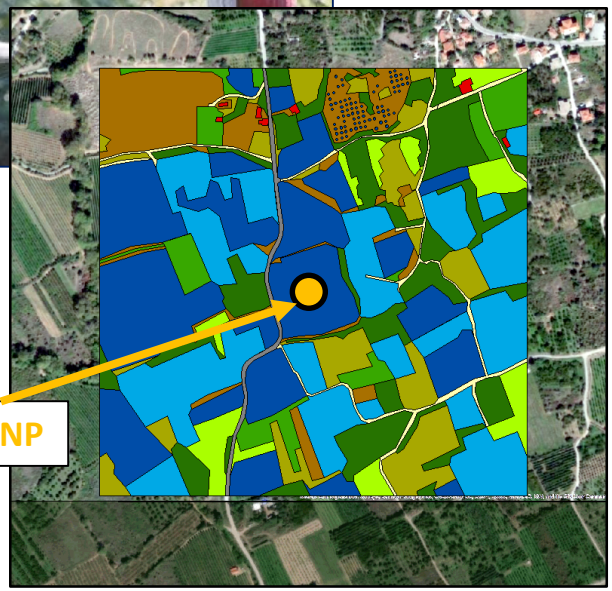
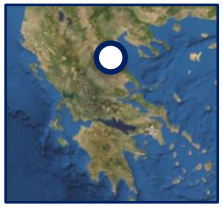
In collaboration with
C. Brogi
FZ Jülich

ATLAS
AGRICULTURAL INTEROPERABILITY AND ANALYSIS SYSTEM

Challenges: Sprinkler Irrigation





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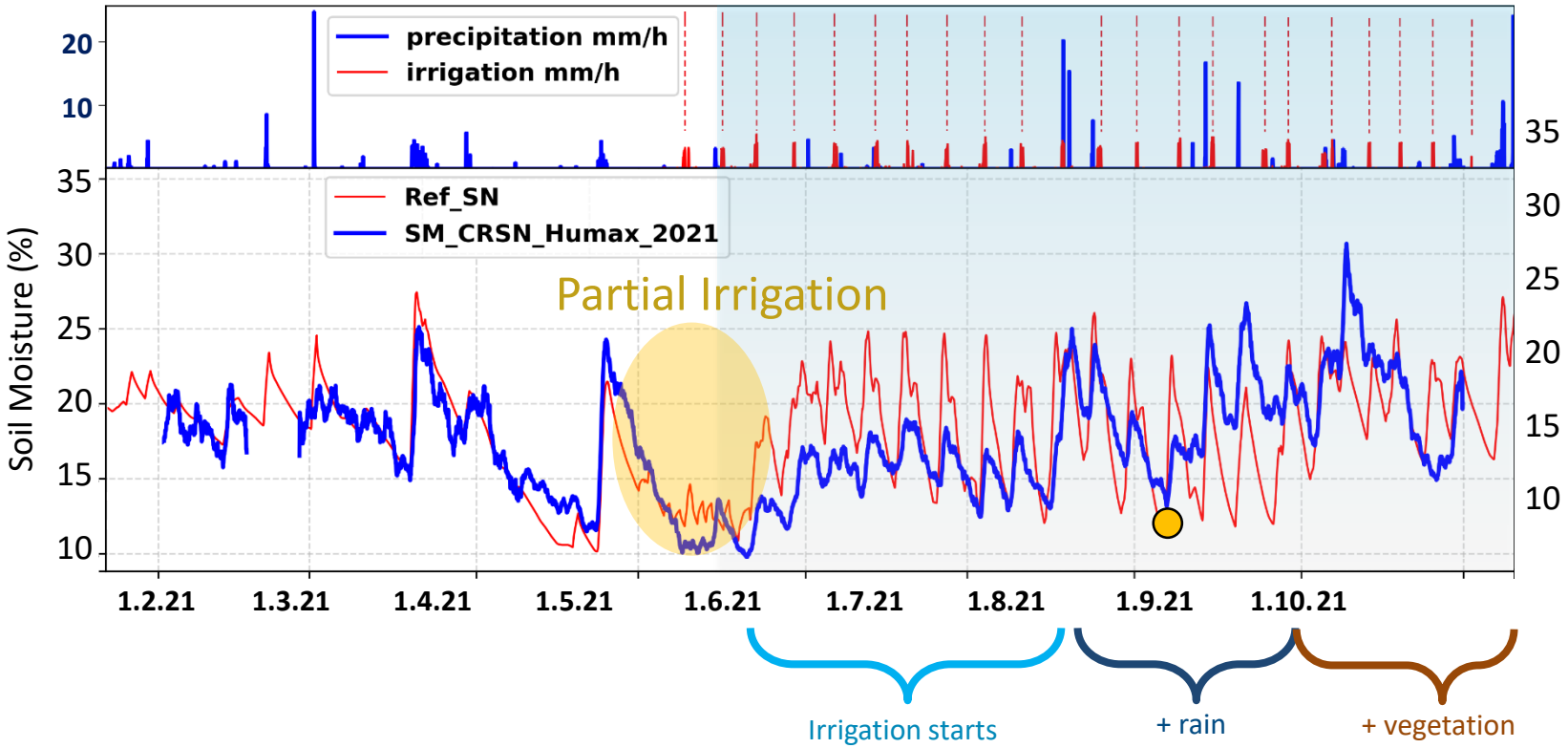
ATLAS
AGRICULTURAL INTEROPERABILITY AND ANALYSIS SYSTEM

Timeseries of irrigation (Agia)

In collaboration with Cosimo Brogi, FZ Jülich

Before irrigation, the CRNS soil moisture match the reference data.
With irrigation, only temporal dynamics are partially represented.

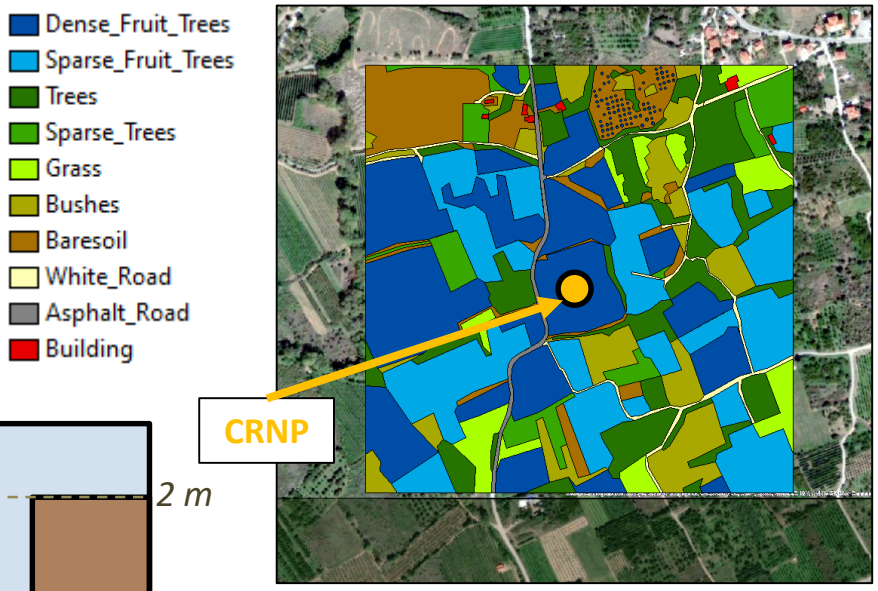


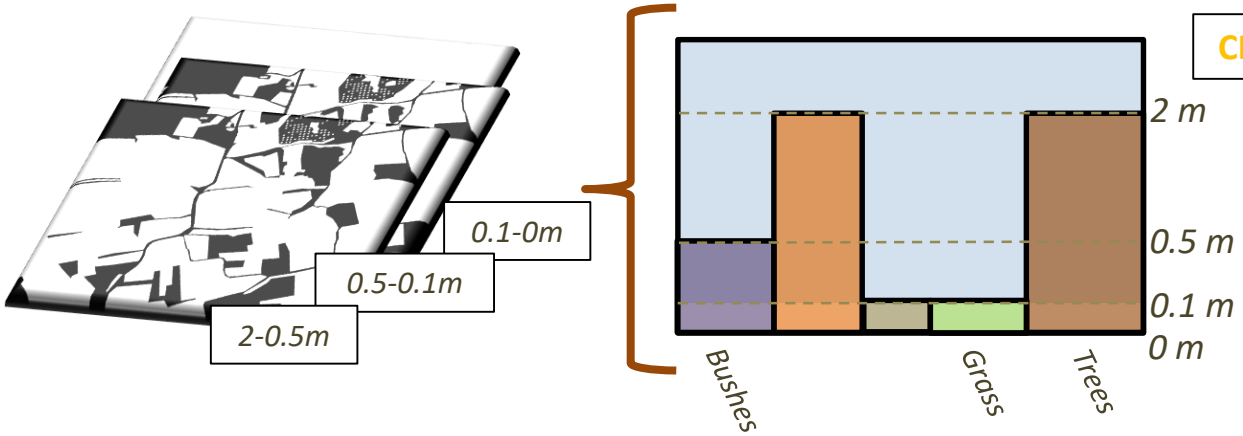
Agia Neutron Simulation

In collaboration with Cosimo Brogi, FZ Jülich

Setup of the actual scenario simulations:

- 600x600 meters domain (center CRNP)
- Irrigation area coincident with field S10
- 8 layers covering 1000 meters of air and 1.6 meters of soil.
  - 4 layers of air (with source/detector)
  - 3 layers of vegetation/air
  - 3 layers of soil (0-0.125, 0.125-0.35, 0.35-1.6)

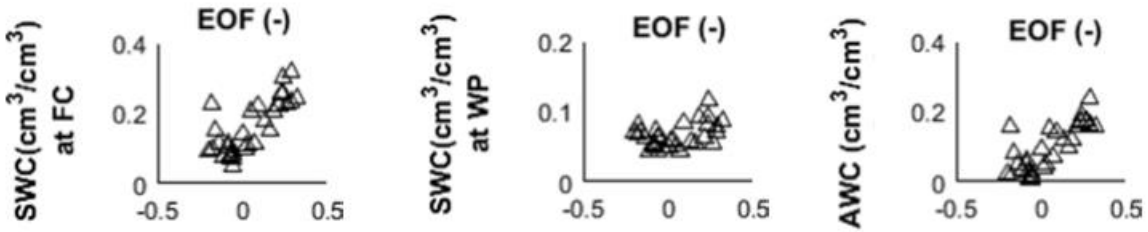


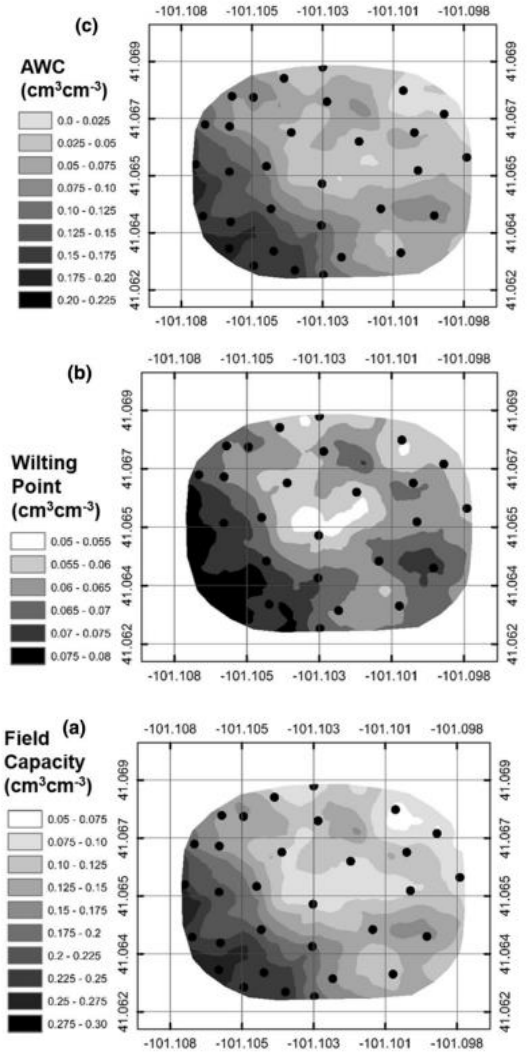


Pivot Irrigation Hybrid CRNS

Soil hydrological properties evaluation by CRNS Roving

(53 ha)





Finkenbiner et al. „Integration of hydrogeophysical datasets and empirical orthogonal functions for improved irrigation water management", Precision Agric (2019) 20:78–100

Cosmic SWAMP

In collaboration with Patrick Stowell, University of Sheffield

Weather Data

Neutron Probes

Capacitive Probes

Use of hybrid sensor networks to optimise irrigation **(SWAMP)**

Adding CRNP to capacitive probe networks for monitoring large centre pivots **(COSMIC-SWAMP)**

PCSE Simulations for automated yield optimisation

University of Bristol

Universidade Federal do ABC

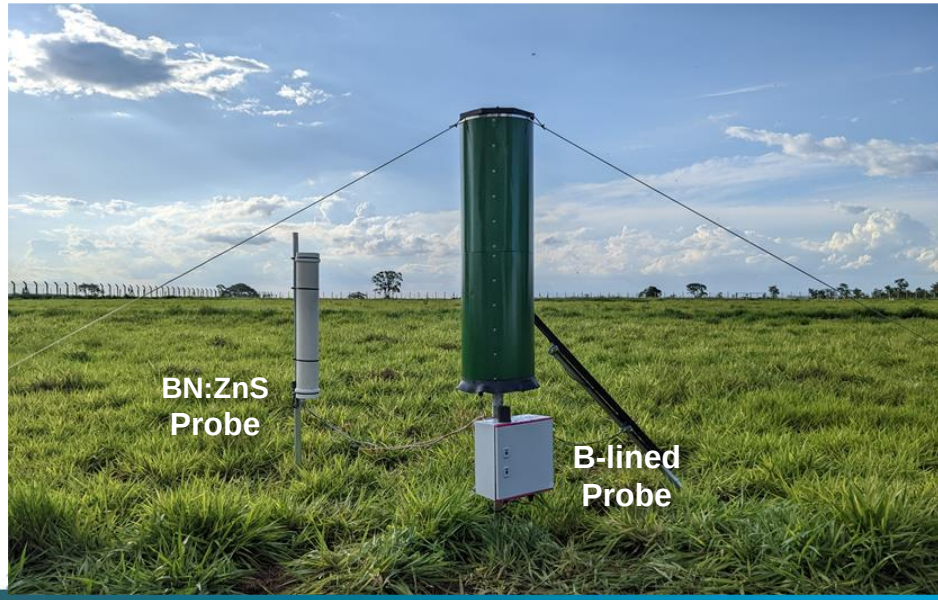
Embrapa

USP Universidade de São Paulo

Universität Heidelberg Zukunft seit 1386

STYX NEUTRONICA

UKRI Natural Environment Research Council



Cosmic SWAMP

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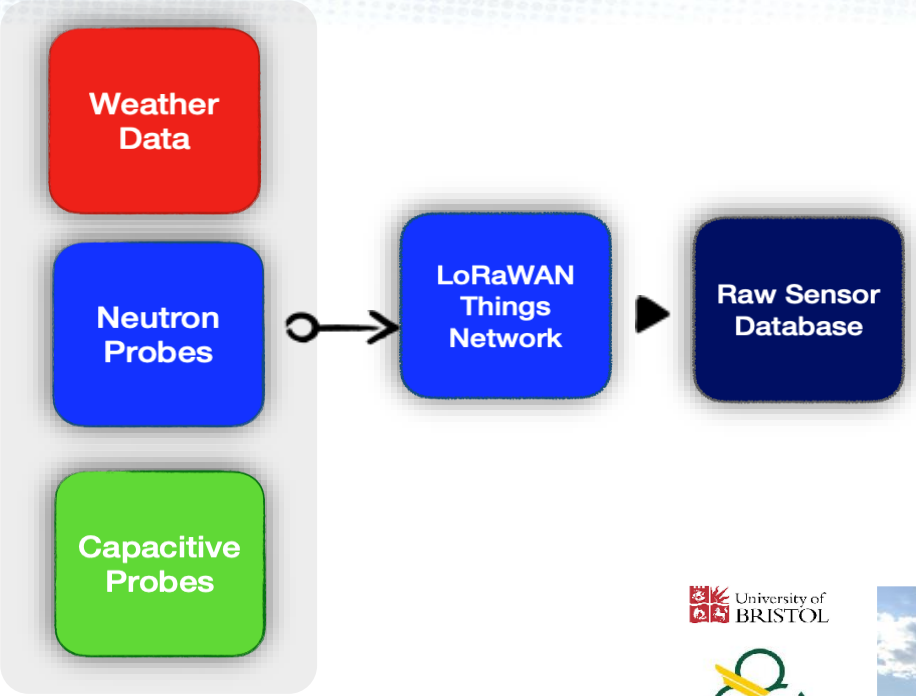

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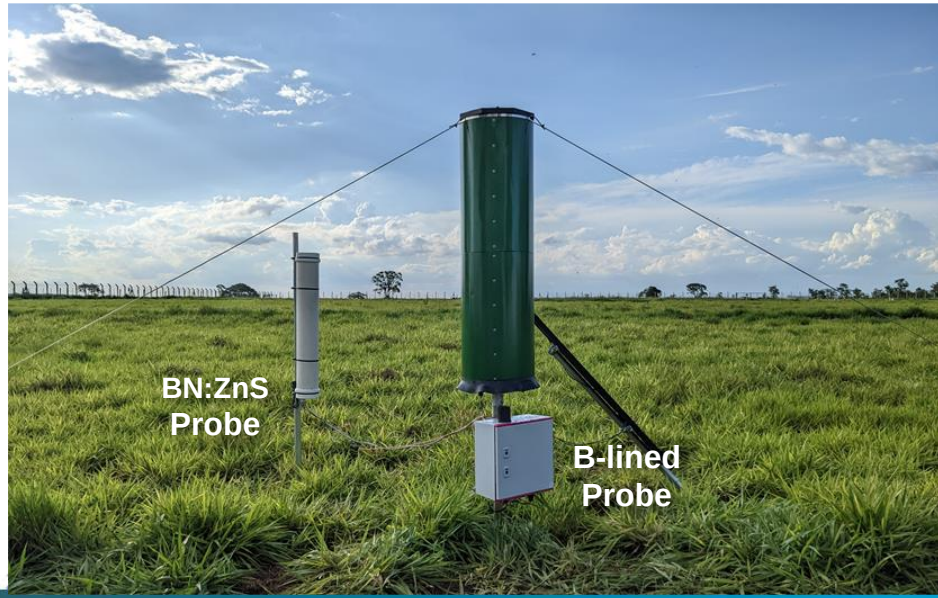

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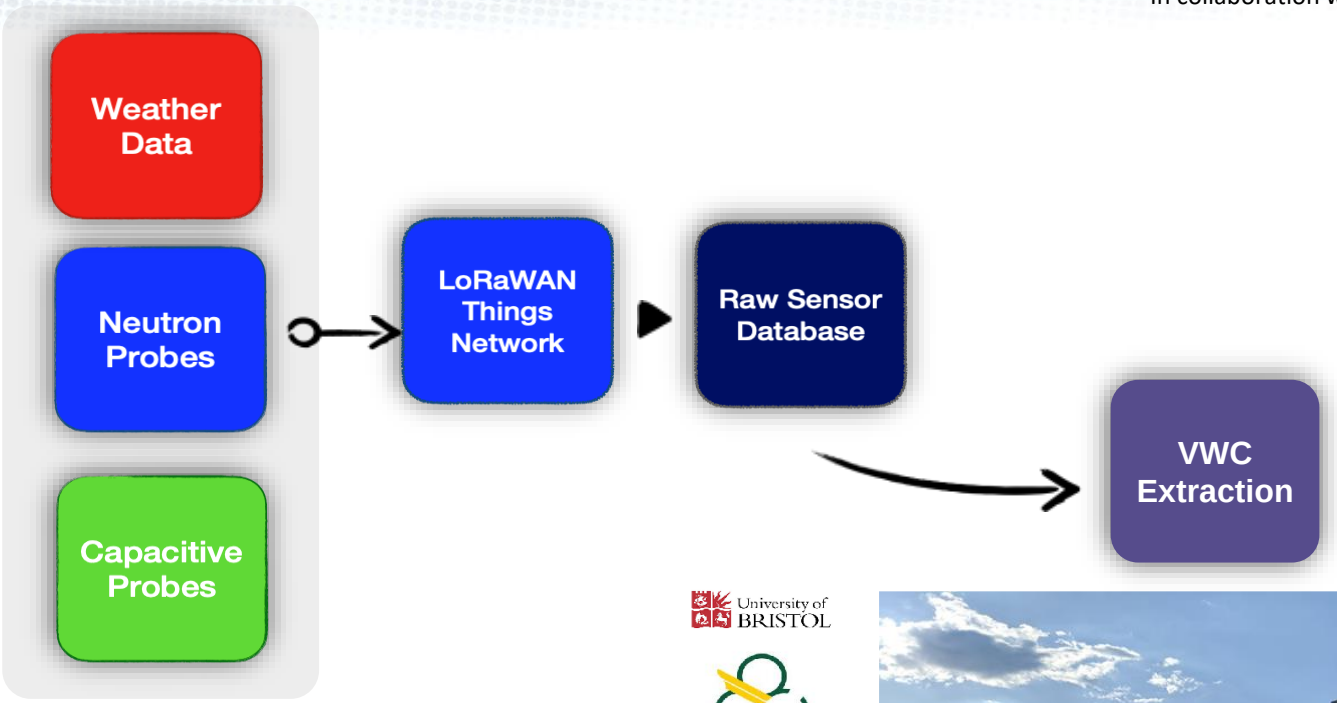

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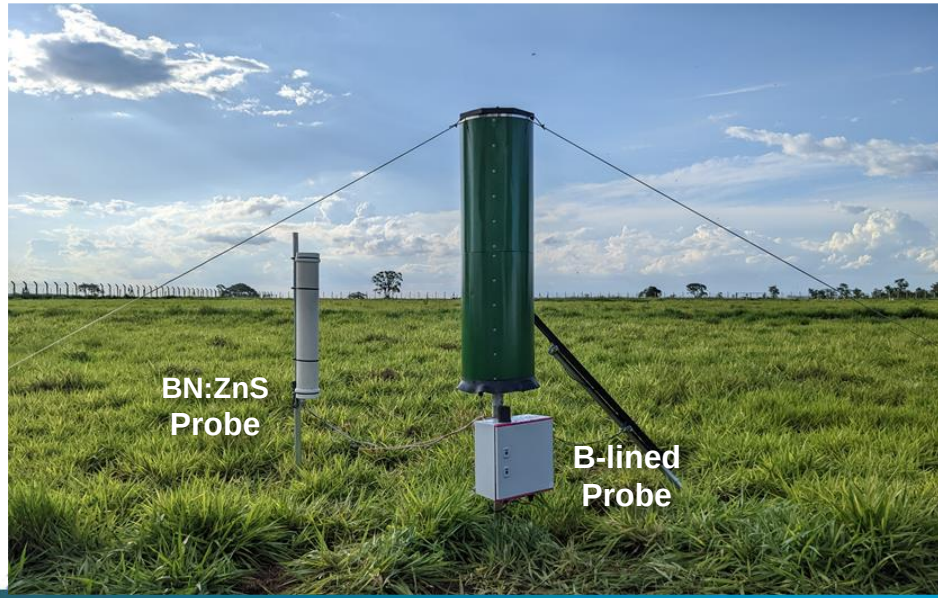

Cosmic SWAMP

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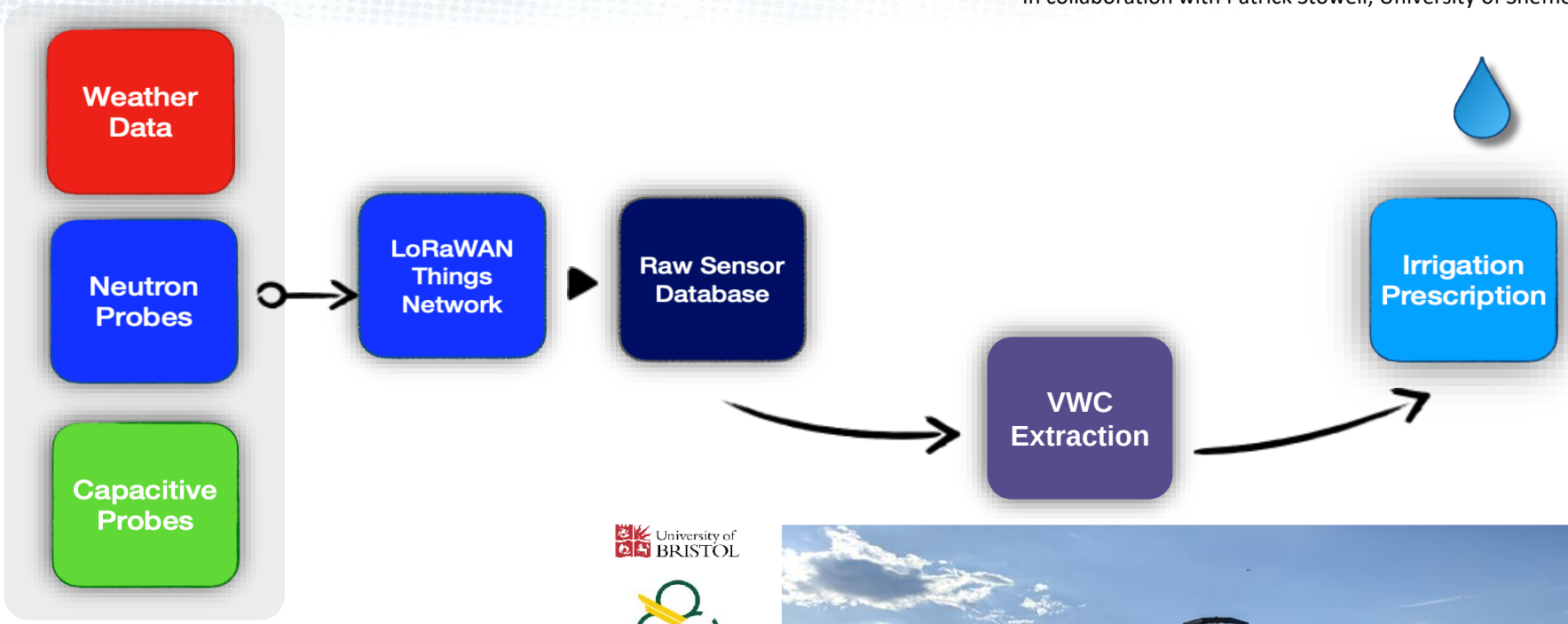

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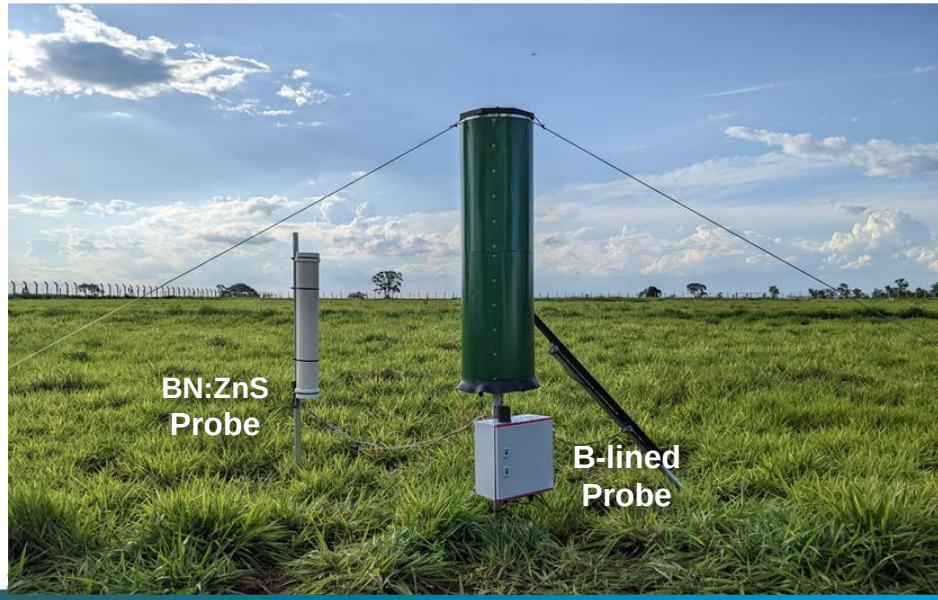

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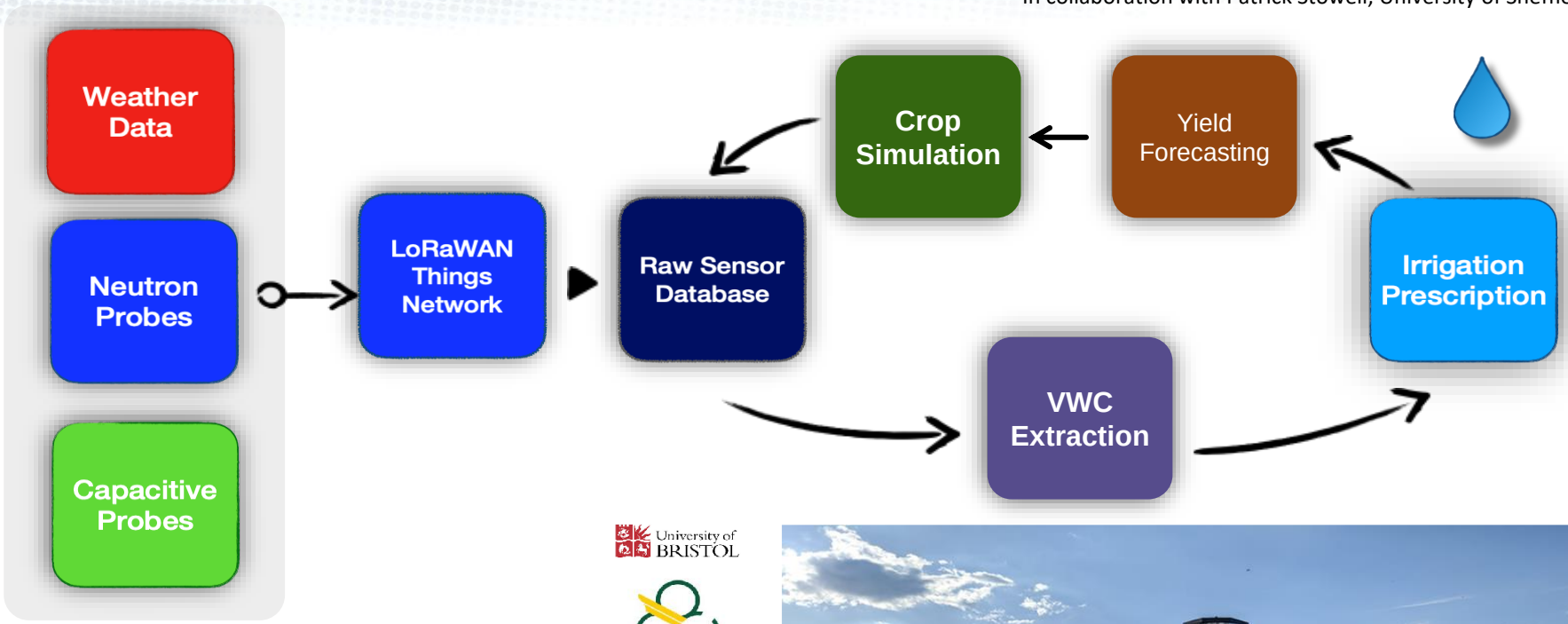

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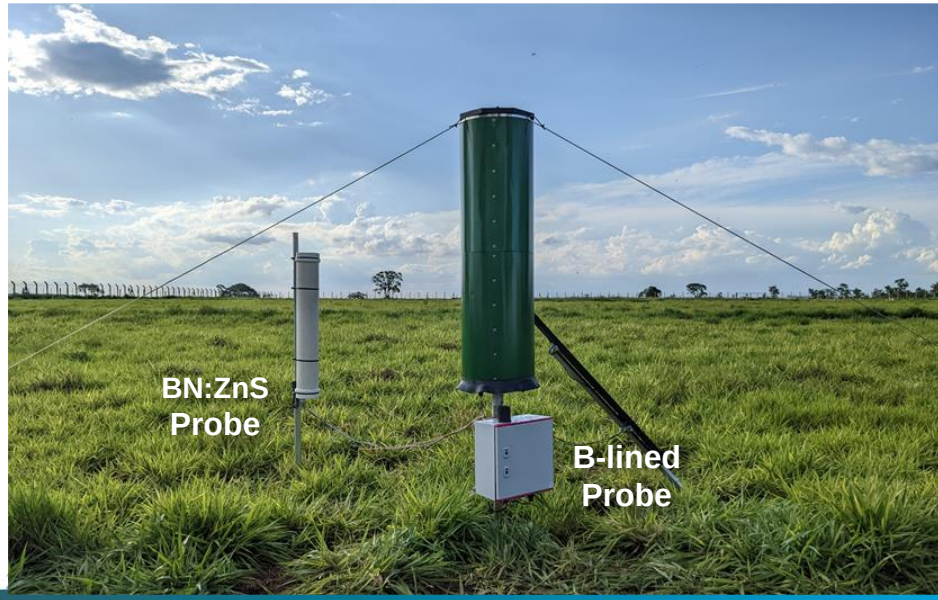

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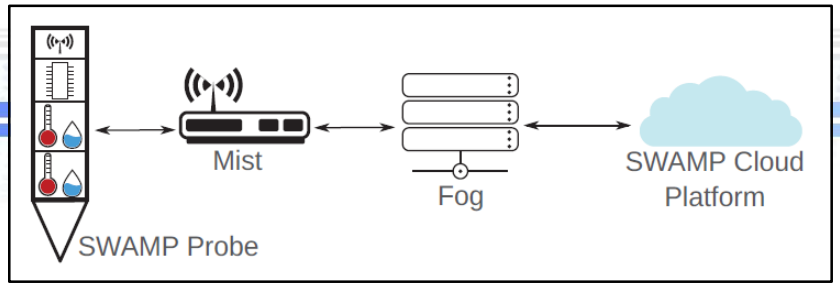
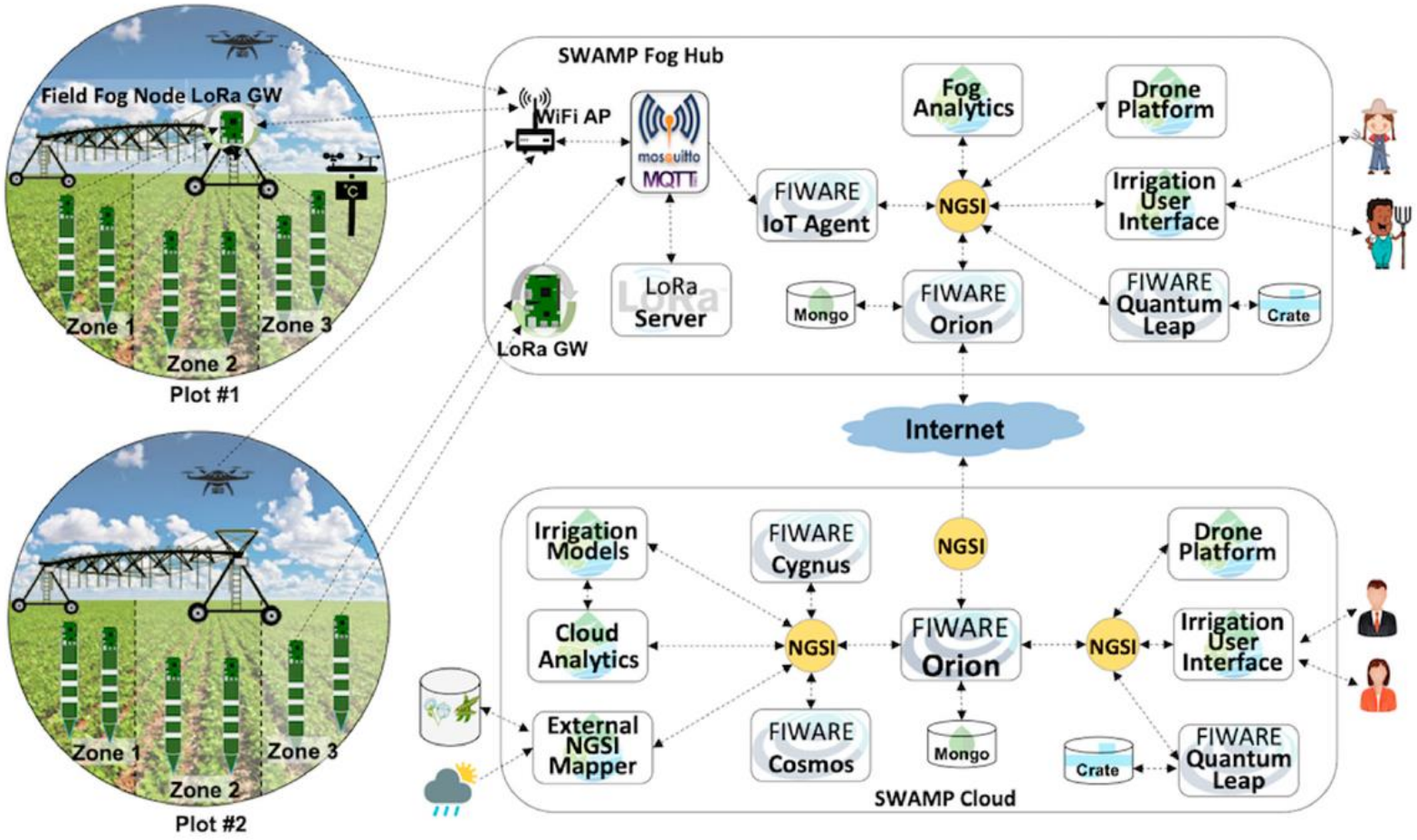
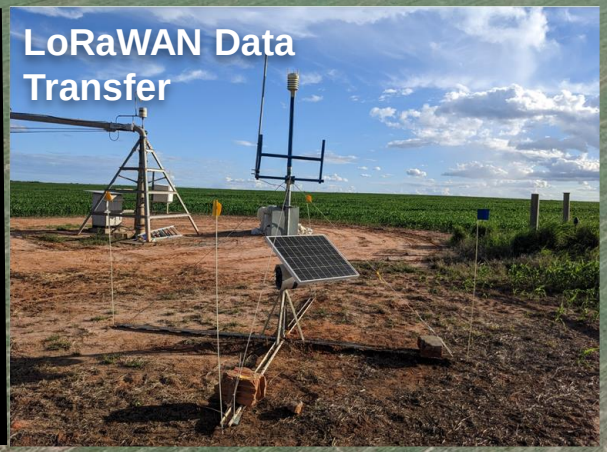




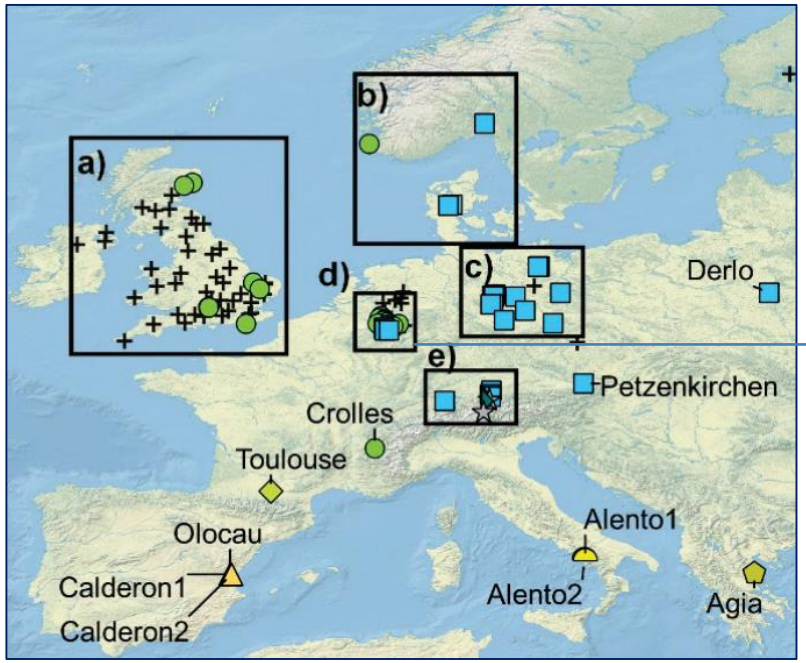
C. Kamienski et al., „Smart Water Management Platform: IoT-Based Precision Irrigation for Agriculture”, *Sensors* **2019**, *19*(2), 276

Cosmic SWAMP (Bahia Pilot)



Variable Rate
Irrigation Arm [500 m]

CRNS Networks



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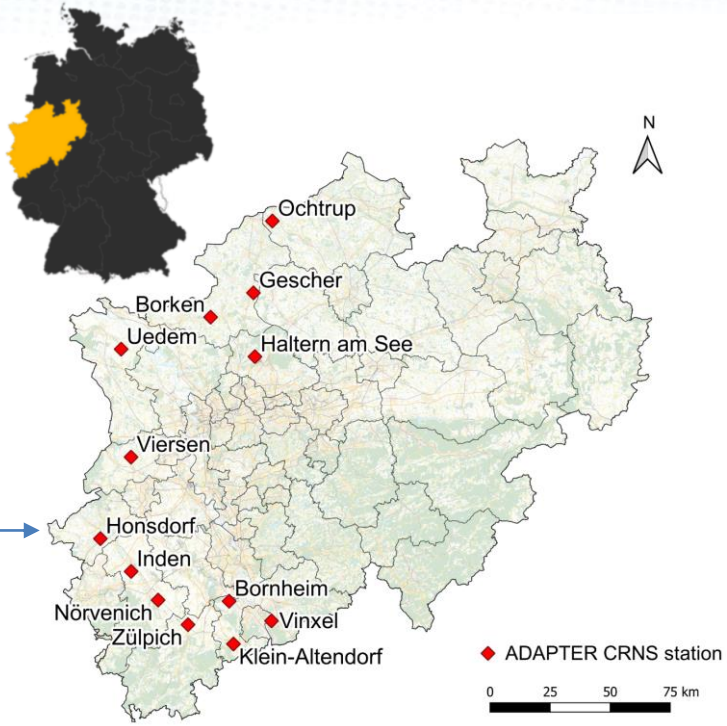


ADAPTER sites (Ney 2021, MetroAgriFor)

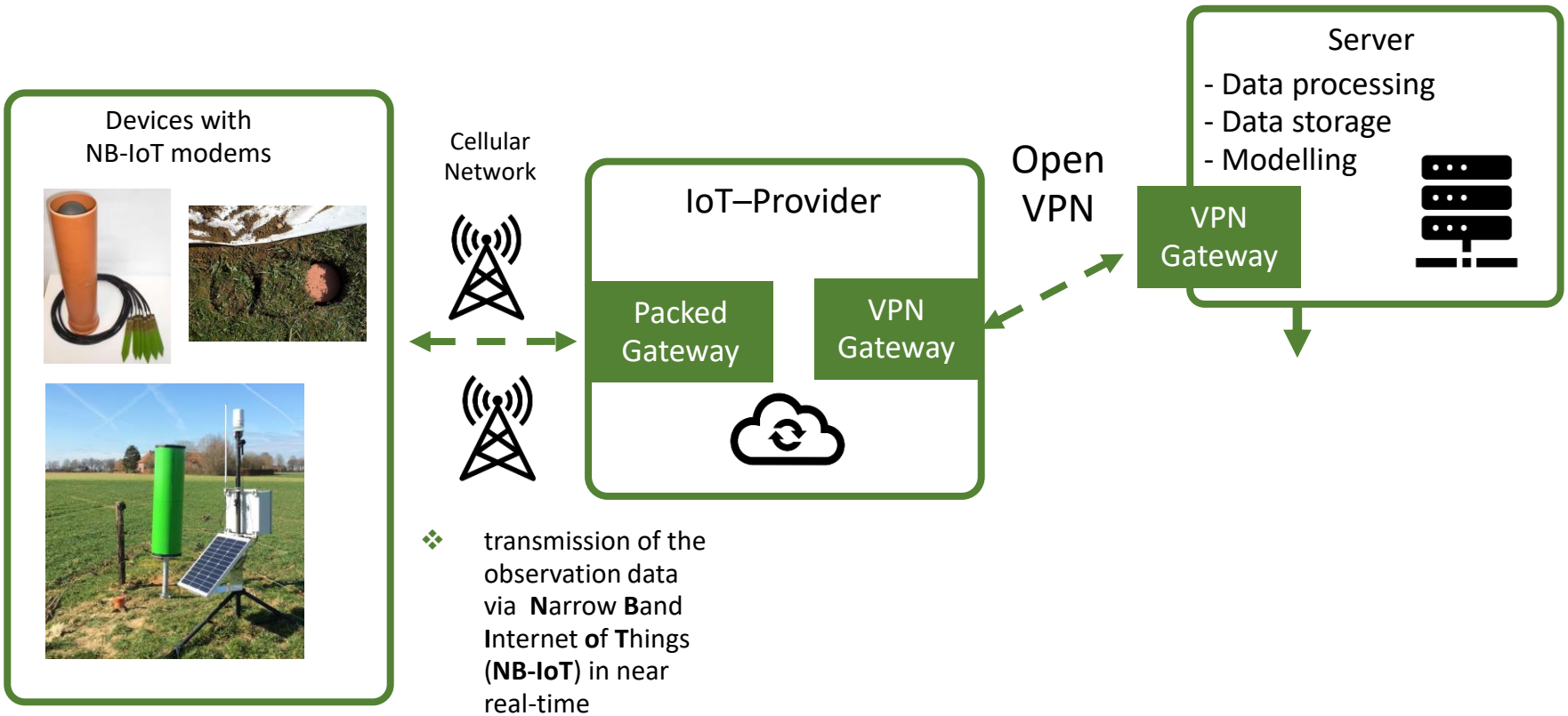
The ADAPTER Network

Devices with
NB-IoT modems

- transmission of the observation data via **N**arrow **B**and **I**nternet **o**f **T**hings (**NB-IoT**) in near real-time

In collaboration with
Patrizia Ney
FZ Jülich

The ADAPTER Network



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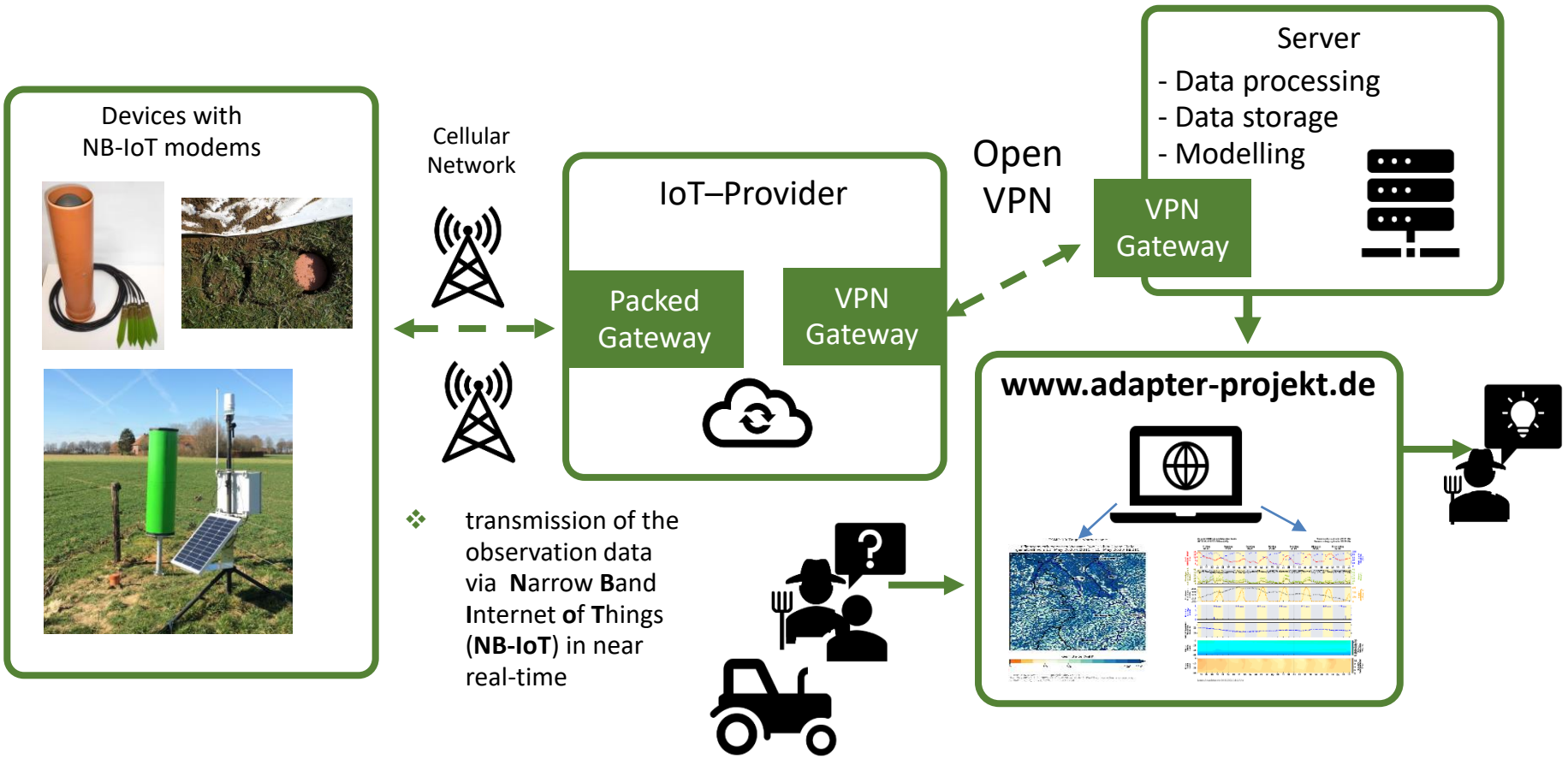

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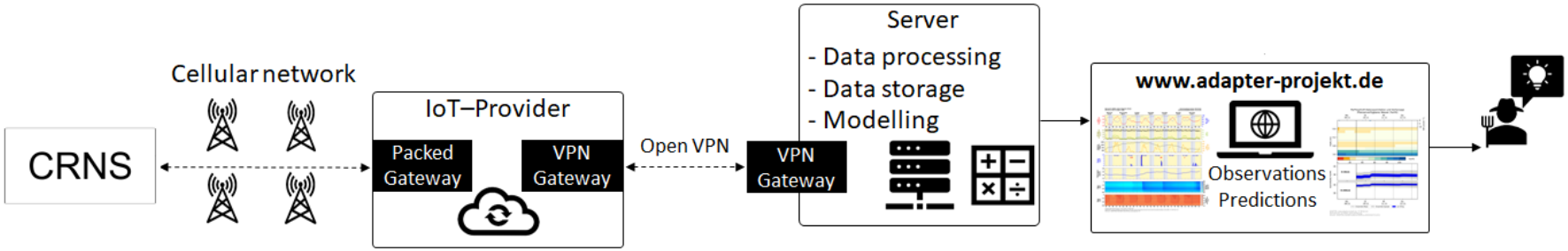
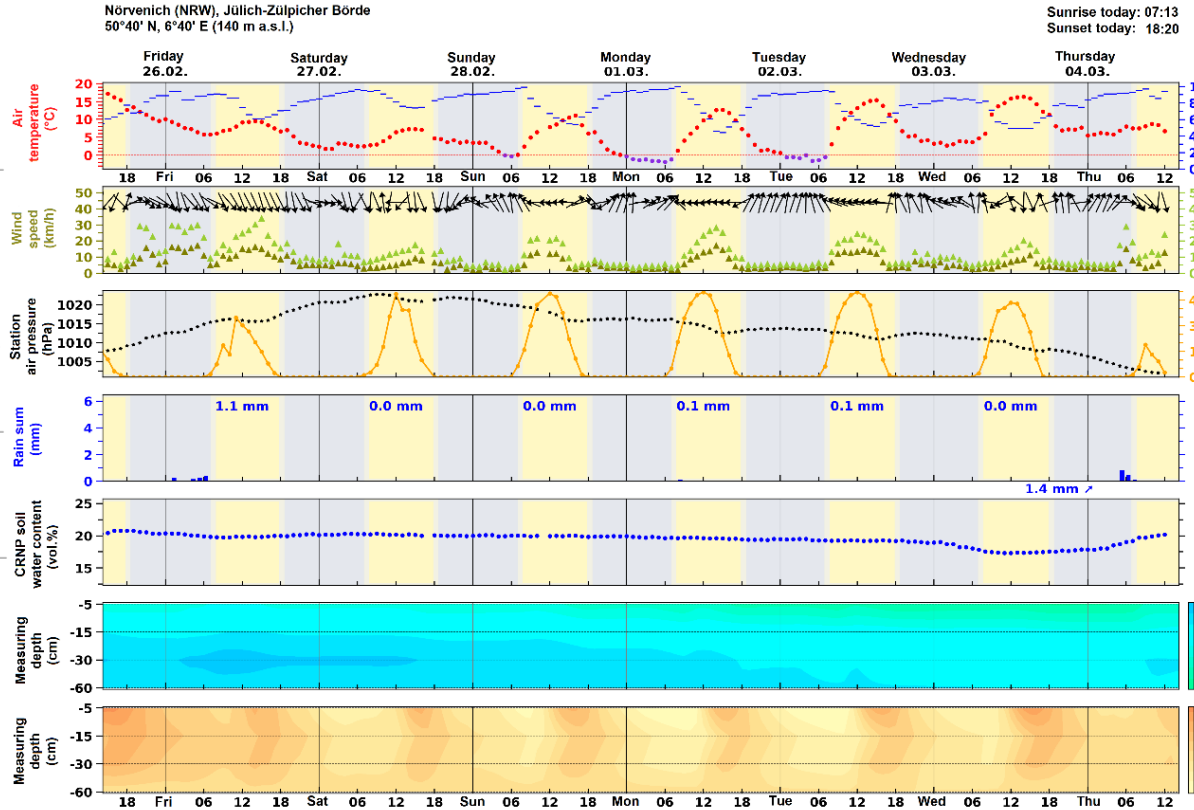
Telemetry Integration





air temperature

wind speed

air pressure

precipitation rate

CRNP
soil water content

relative humidity

wind gust

solar radiation

SoilNet
soil water content

soil temperature

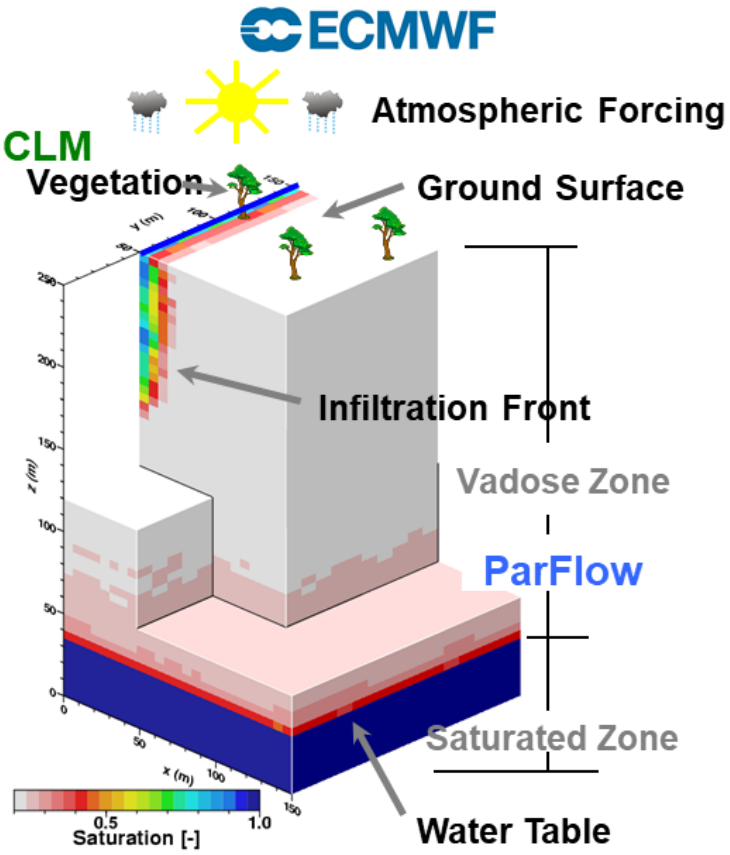
In collaboration with
Patrizia Ney
FZ Jülich

Forecast Model

High-resolution soil moisture forecast

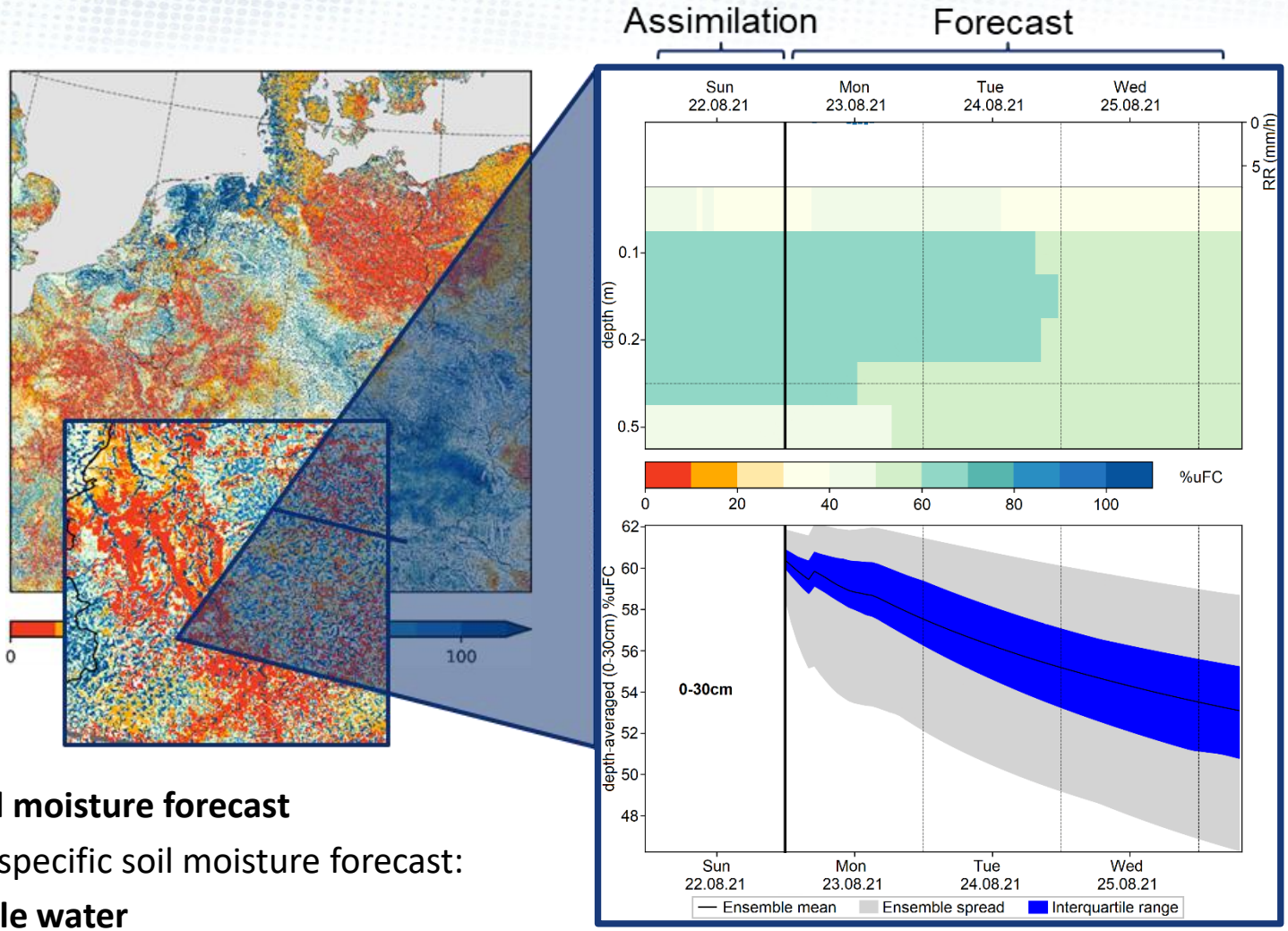
- Focus on **soil water states** and **fluxes**
- **ParFlow** hydrological model for the complete dynamical representation of the subsurface and surface hydrological processes, coupled with
- **CLM** (**C**ommon **L**and **M**odel) for the interactions at the surface
- Atmospheric forcing: forecasts from ECMWF
- Assimilation of observed soil moisture

→ **Initialization closest to reality**



Parflow

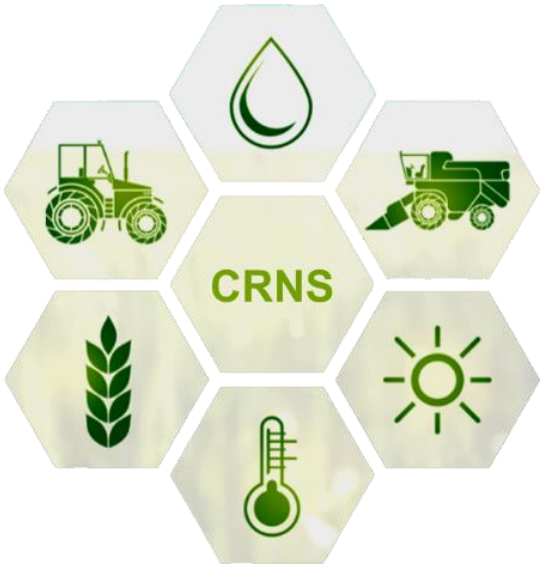
Model: ParFlow/CLM
Forcing: ECMWF HRES



High-resolution soil moisture forecast

- Prototype: site specific soil moisture forecast:
  e.g., **plant available water**
- Ensemble accounts for **uncertainty** due to heterogeneity of soil hydraulic properties

CRNS-based monitoring technologies as solutions for climate-resilient agriculture



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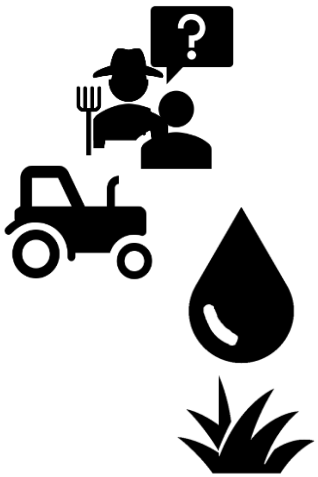

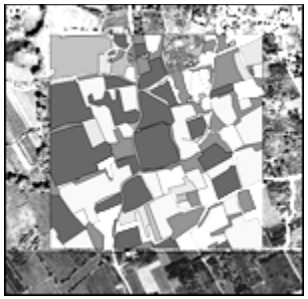

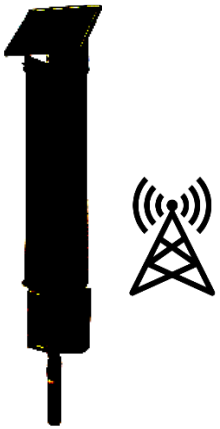

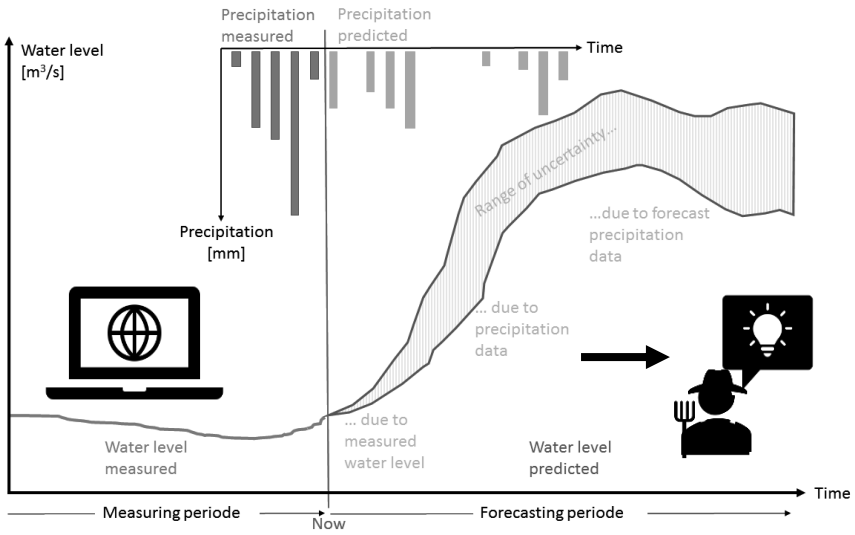

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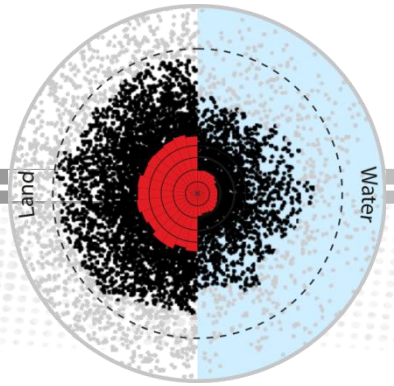
CRNS-based monitoring technologies as solutions for climate-resilient agriculture

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



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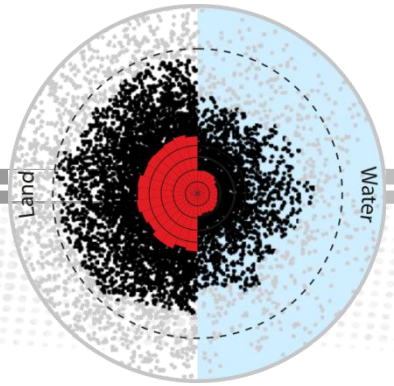

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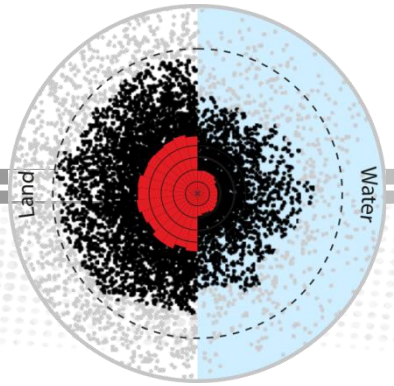

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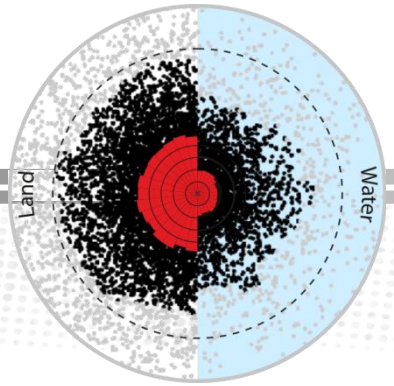

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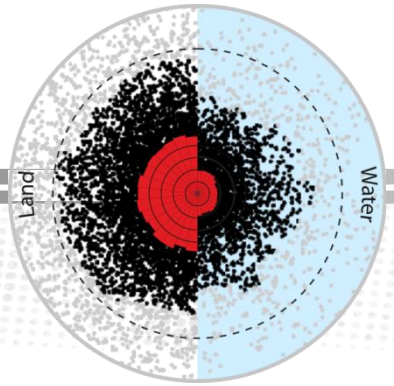
- **Forecast models** based on weather station data in development, possible combination with **scheduled irrigation**



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