



Use of Cosmic-ray Neutron Sensing for soil water management

M. Köhli^{1,3}, P. Stowell^{2,*}, J. Weimar^{1,3}, P. Ney⁴, F. Nieberding⁴, A. Torre Neto⁵, K. Görden⁴, H. Bogaen⁴, U. Schmidt¹

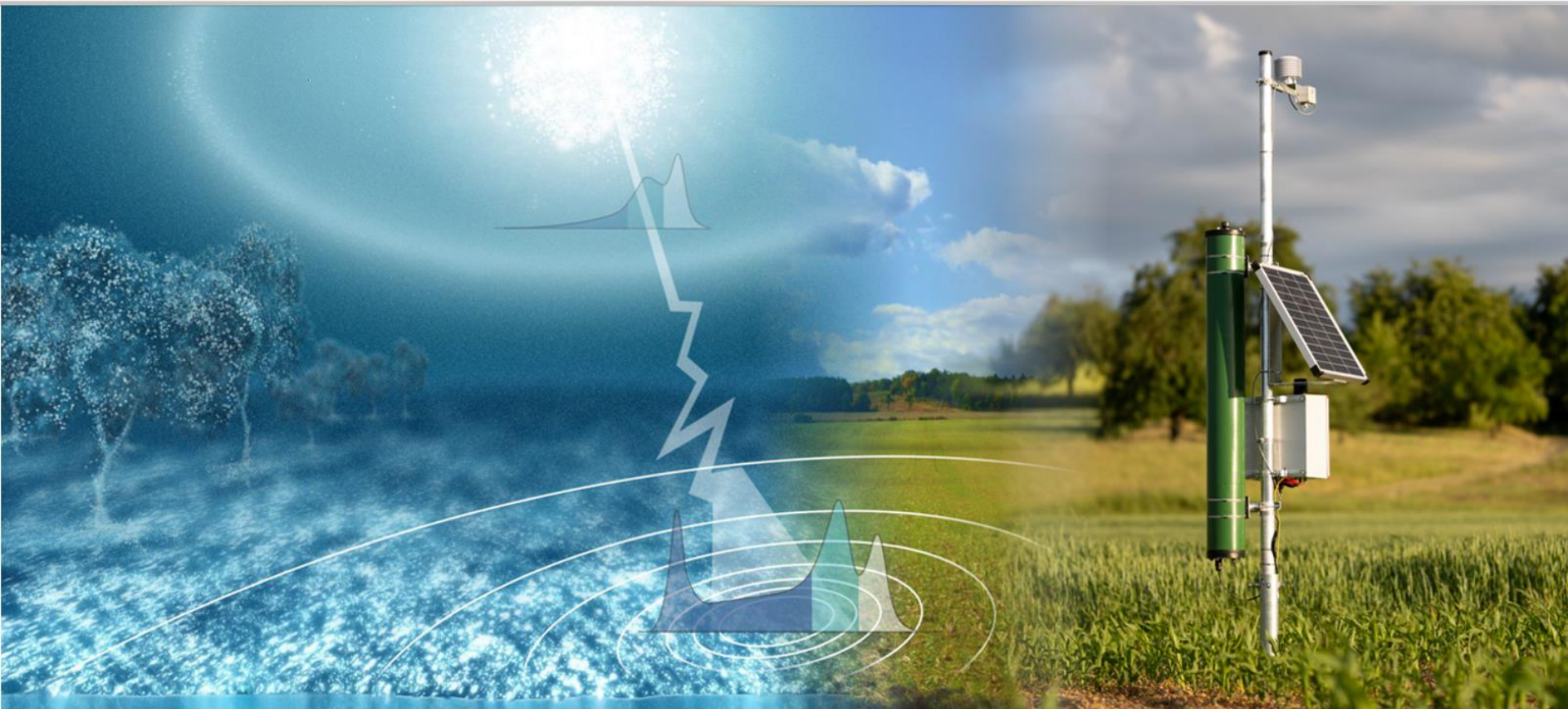
¹ Physikalisches Institut, Heidelberg University, Germany

² Department of Physics and Astronomy, University of Sheffield, United Kingdom

³ StyX Neutronica GmbH, Mannheim, Germany

⁴ Agrosphere Institute (IBG-3), Forschungszentrum Jülich, Germany

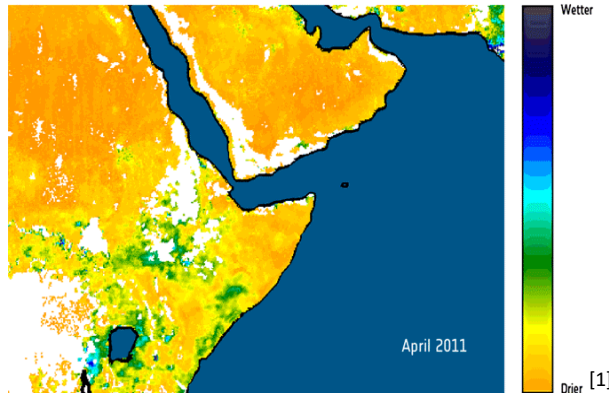
⁵ Embrapa Instrumentação Agropecuária, São Carlos, Brazil





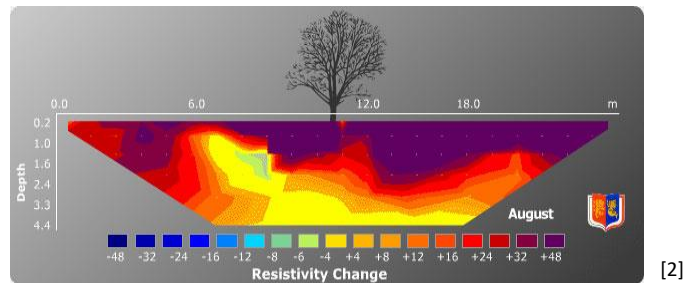
» Soil Moisture Measurement Gap

~ 1 km



via
satellite remote sensing
(optical, microwave)

< 10 m

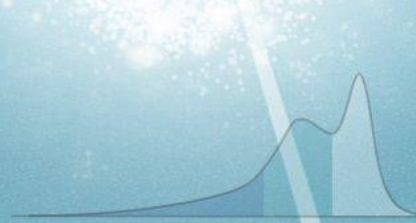


via
local techniques
(electrical resistivity, capacitance, etc)
(even neutrons...)

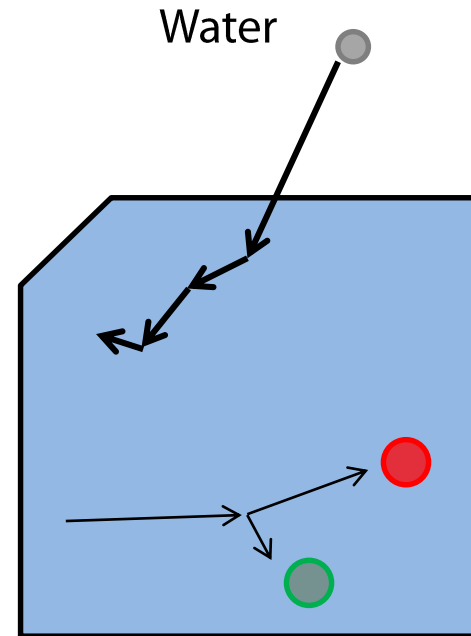
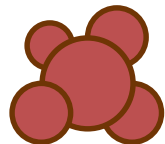
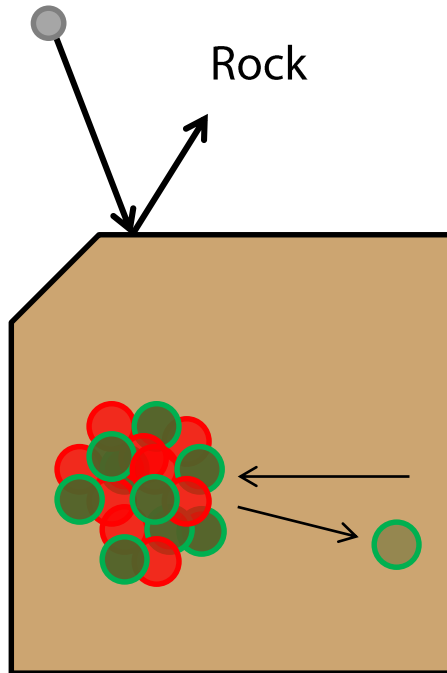
[1] ESA SMOS (http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS/Horn_of_Africa_drought_seen_from_space)

[2] The Clay Research Group (<http://www.theclayresearchgroup.org/images/ert.jpg>)

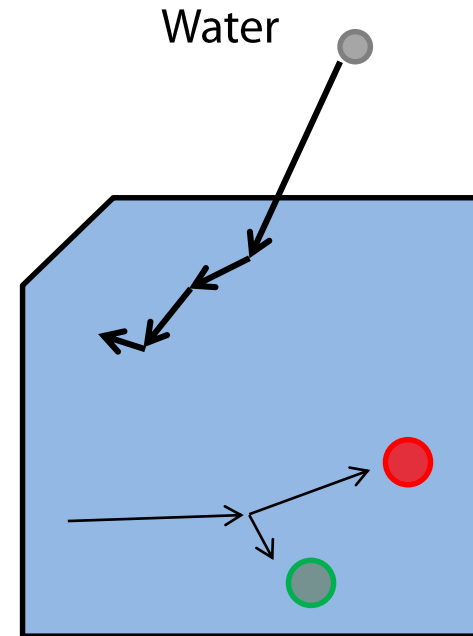
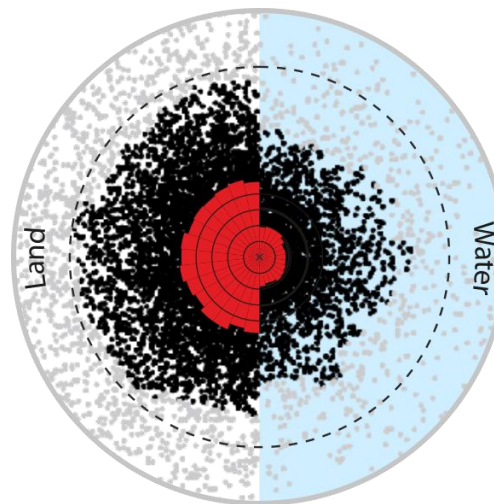
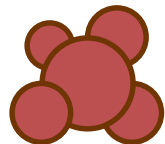
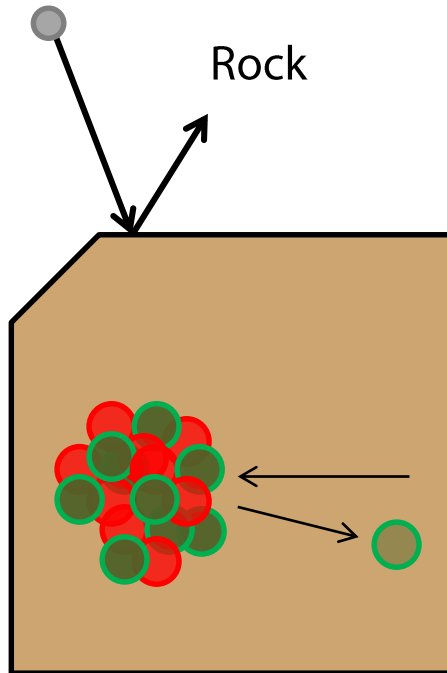
Cosmic Ray Neutron Sensing .CRNS.



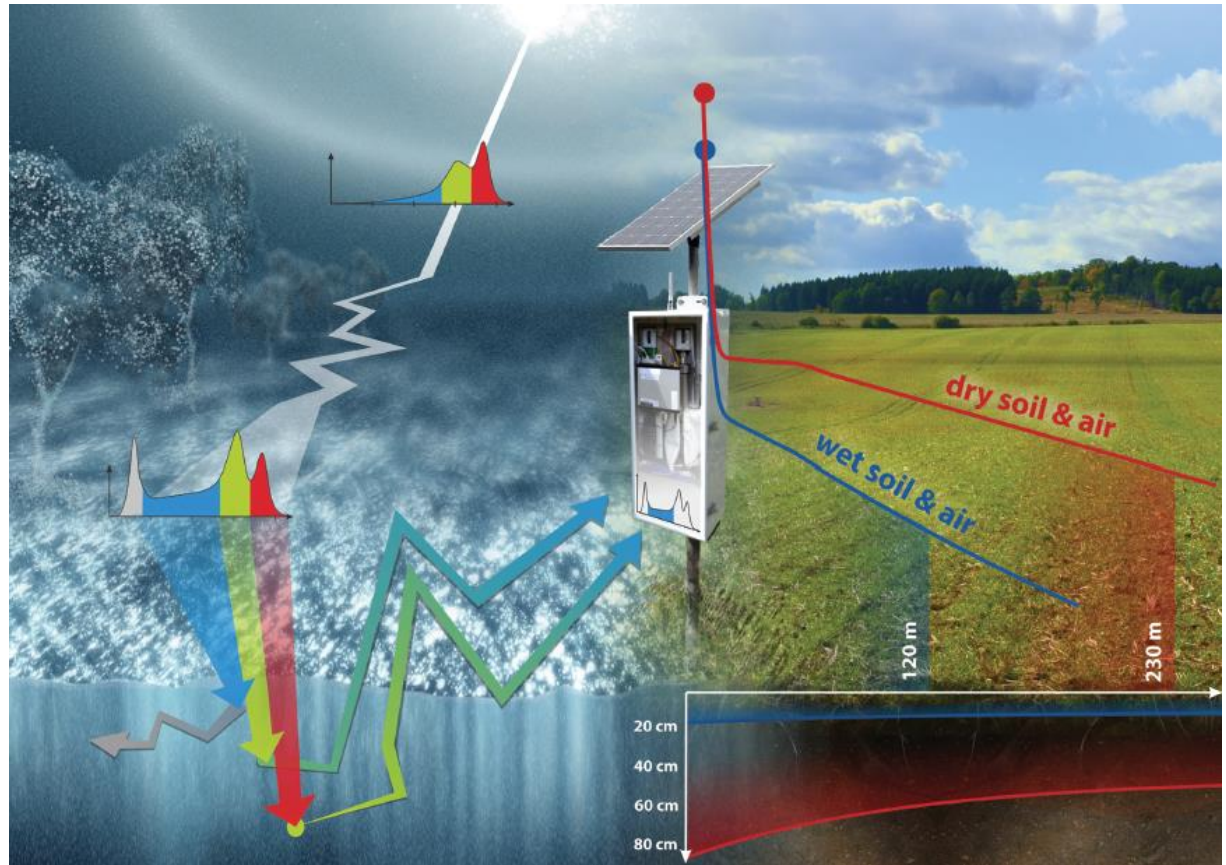
» Neutron interaction with water



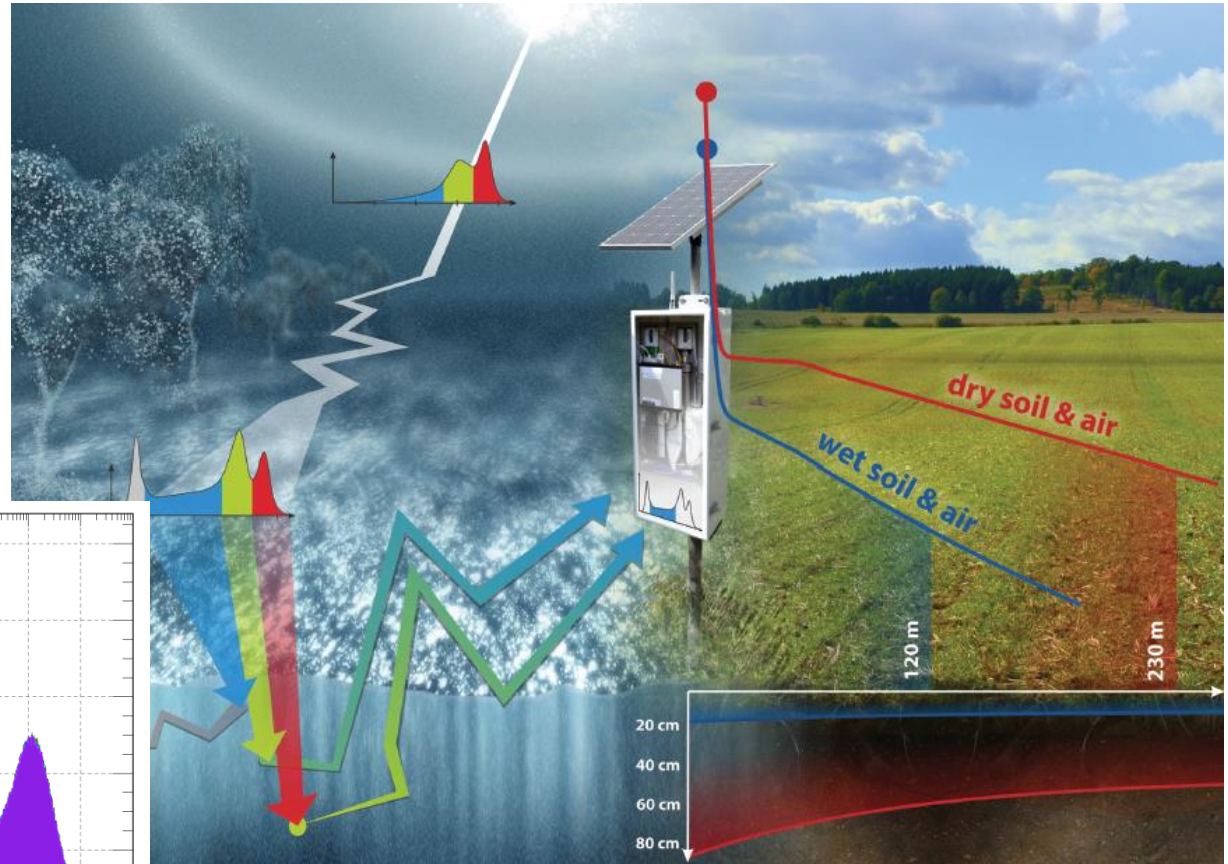
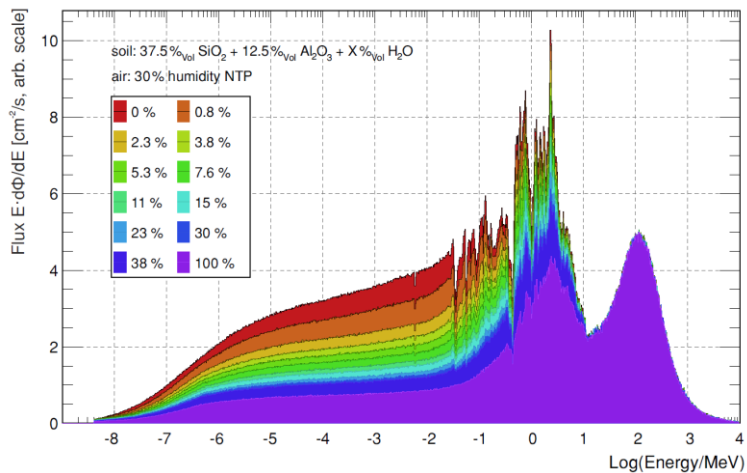
» Neutron interaction with water



» CRNS Overview

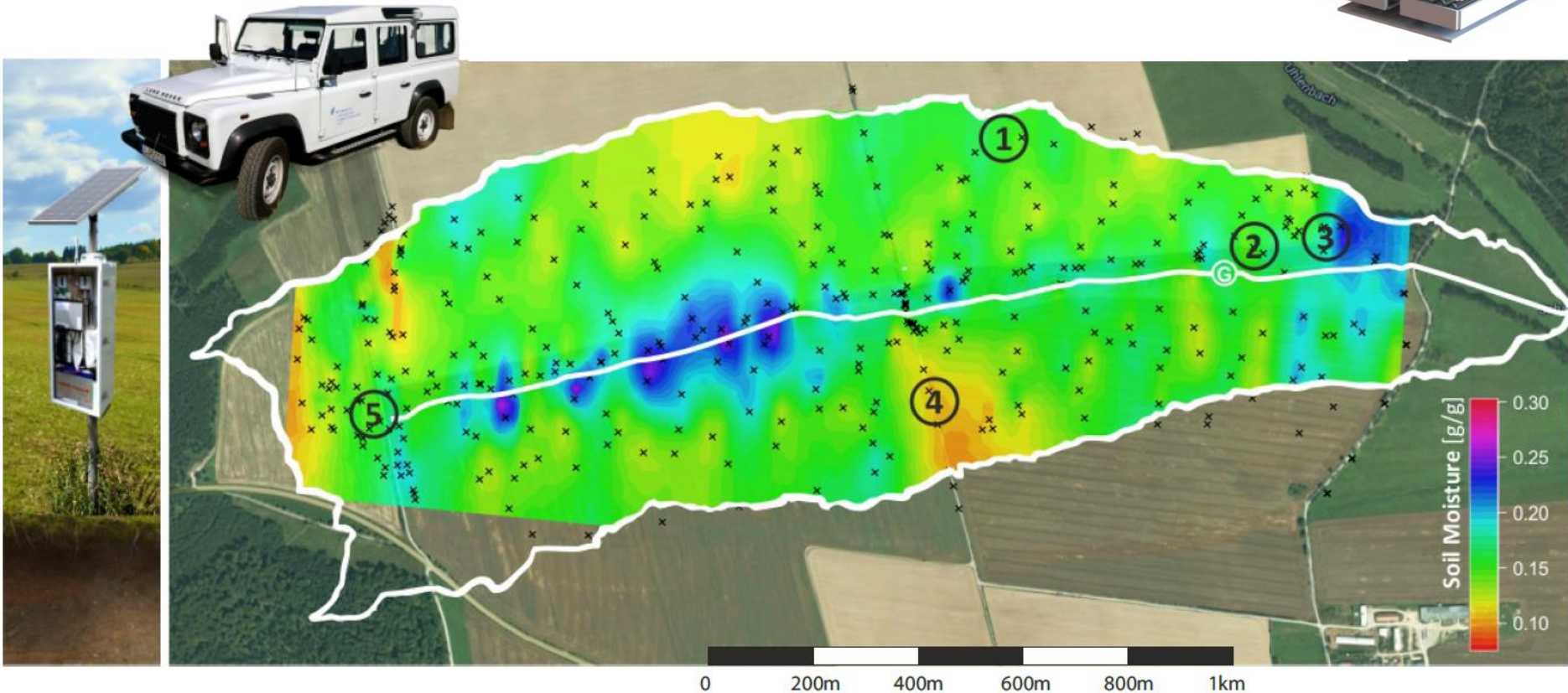
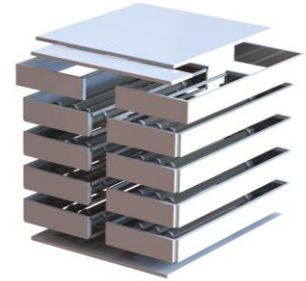


» CRNS Overview



» Stationary and Roving

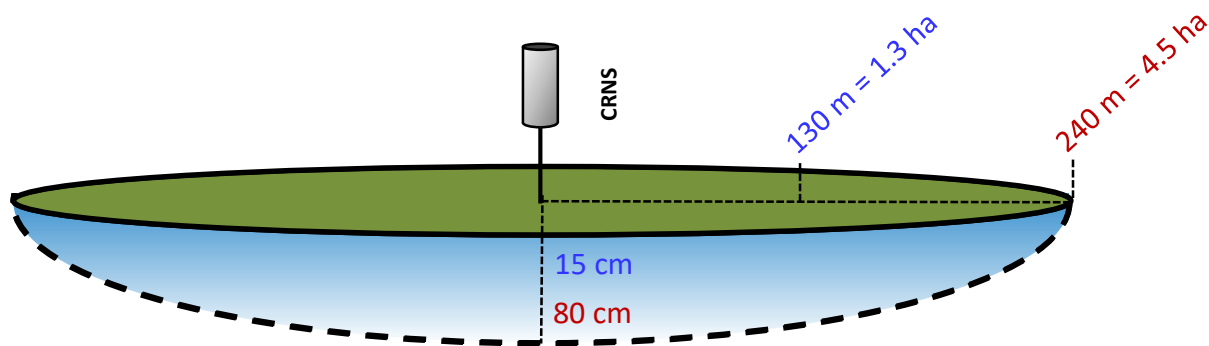
In collaboration with Martin Schrön, UFZ Leipzig



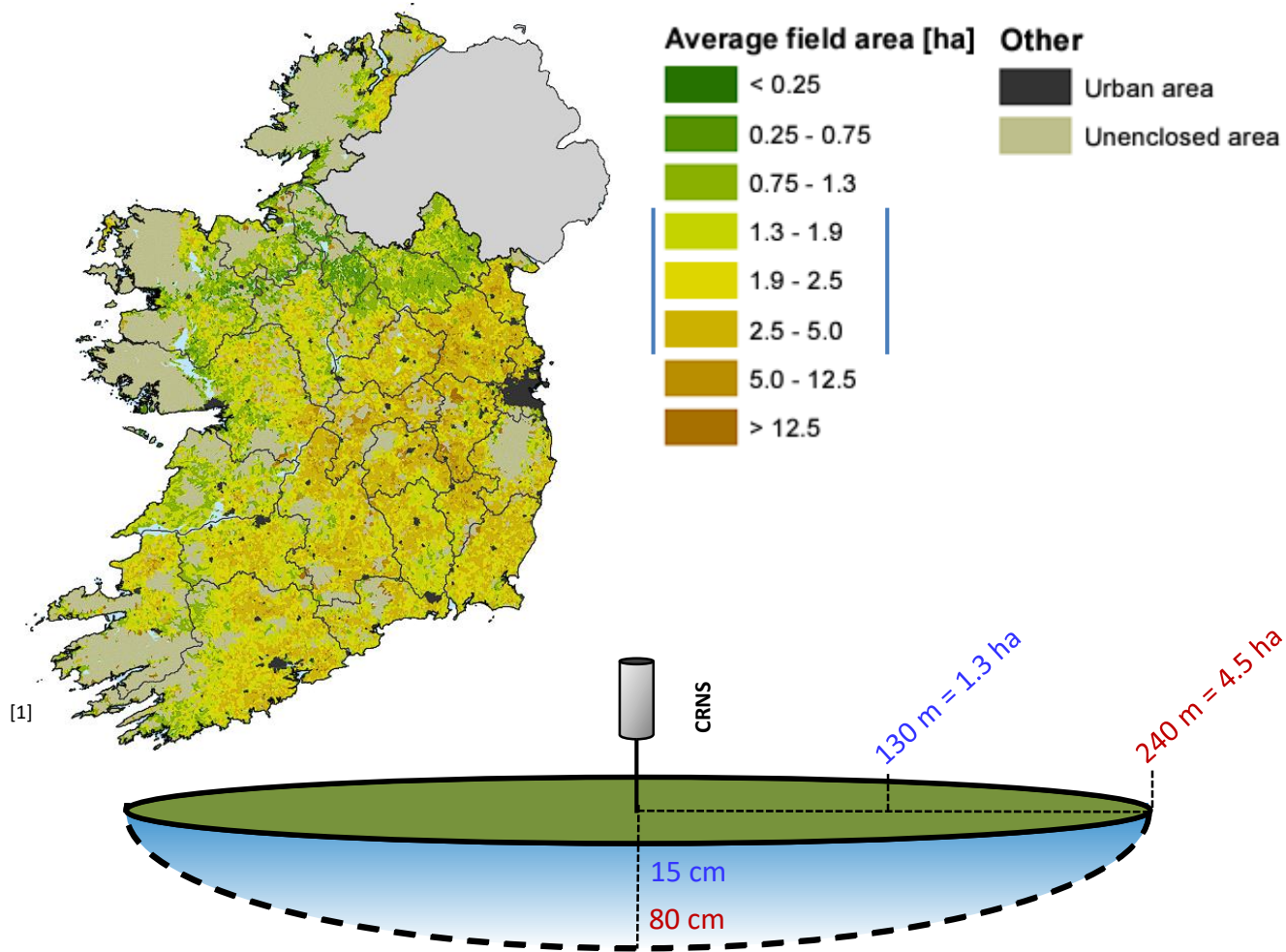
» Stationary Instruments



» Motivation for Smart Agriculture

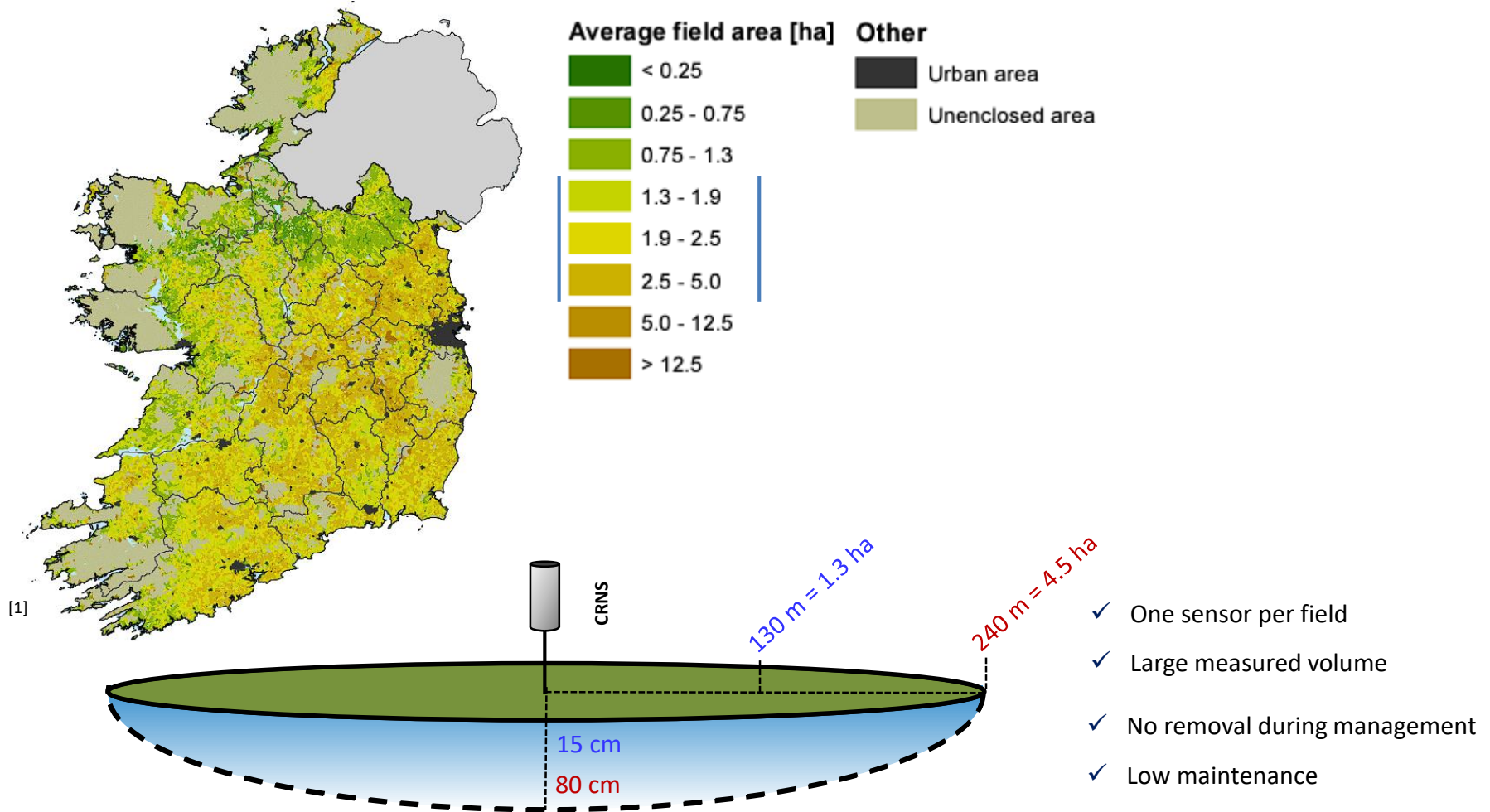


» Motivation for Smart Agriculture



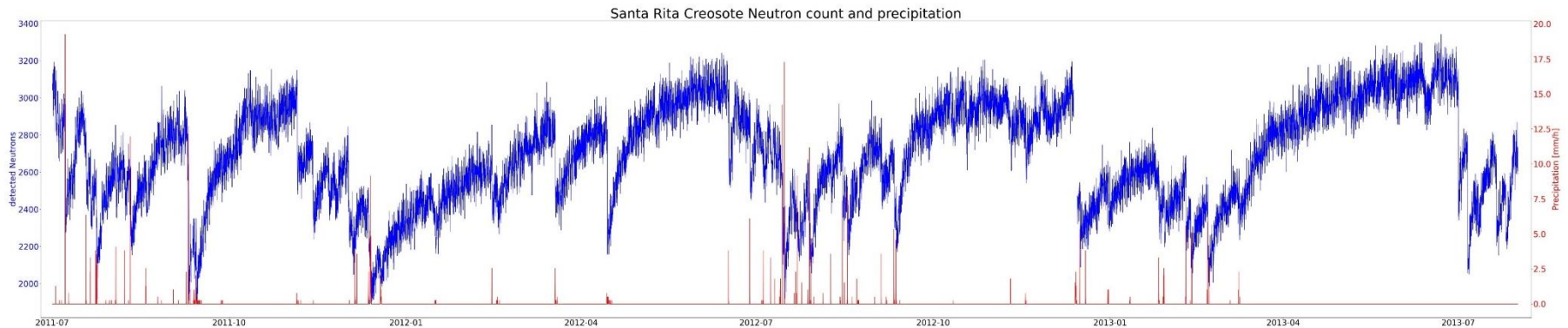
[1] J. Zin "Average size of enclosed agricultural fields by townland in the Republic of Ireland", Ordnance Survey Ireland Government of Ireland, 2012

» Motivation for Smart Agriculture

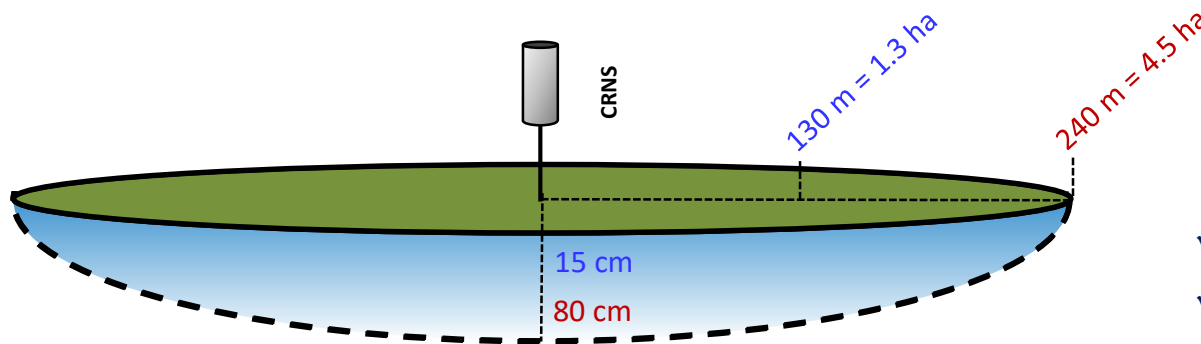


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» Motivation for Smart Agriculture



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



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



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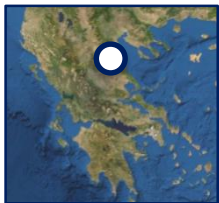
⁴ Agrosphere Institute (IBG-3), Forschungszentrum Jülich, Germany

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CRNS

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

» Challenges: Sprinkler Irrigation

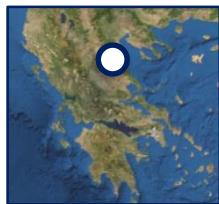


See also C. Brogi:

**Novel assessment and development
of land surface modelling for
irrigation schemes in Mediterranean
apple orchards**



» Challenges: Sprinkler Irrigation



See also C. Brogi:

Novel assessment and development of land surface modelling for irrigation schemes in Mediterranean apple orchards



In collaboration with
C. Brogi
FZ Jülich



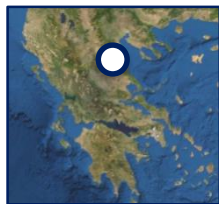
ATLAS
AGRICULTURAL INTEROPERABILITY
AND ANALYSIS SYSTEM



Challenges: Sprinkler Irrigation

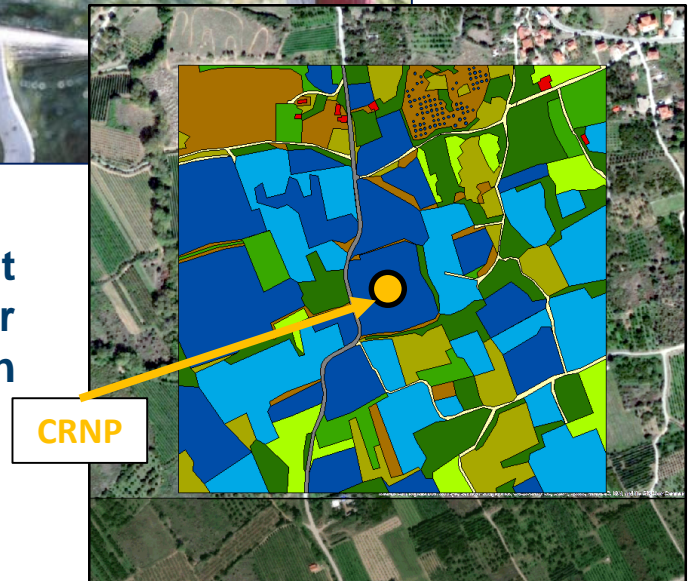


- Dense_Fruit_Trees
- Sparse_Fruit_Trees
- Trees
- Sparse_Trees
- Grass
- Bushes
- Baresoil
- White_Road
- Asphalt_Road
- Building



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Novel assessment and development of land surface modelling for irrigation schemes in Mediterranean apple orchards



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ATLAS
AGRICULTURAL INTEROPERABILITY
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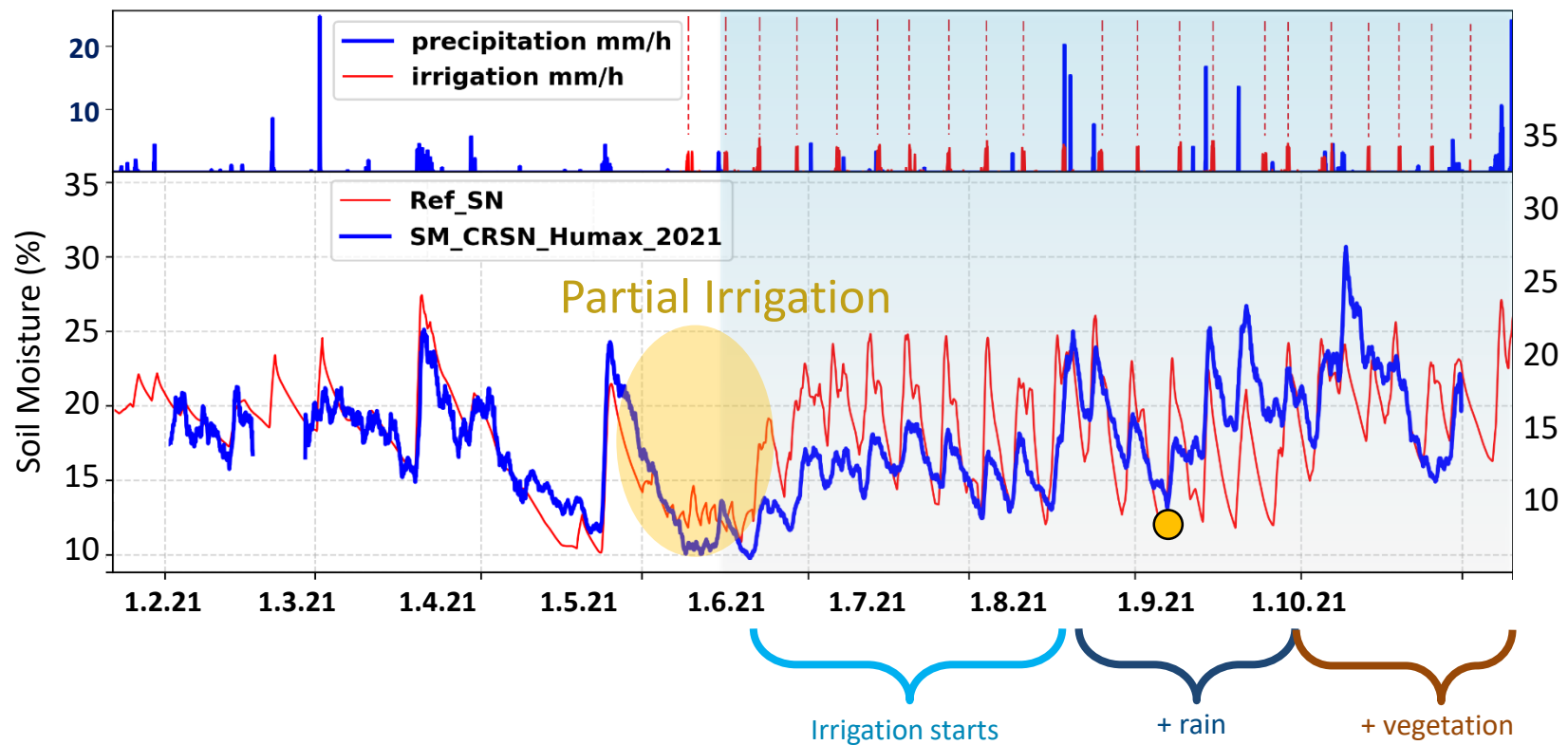


Timeseries of irrigation (Agia)



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.



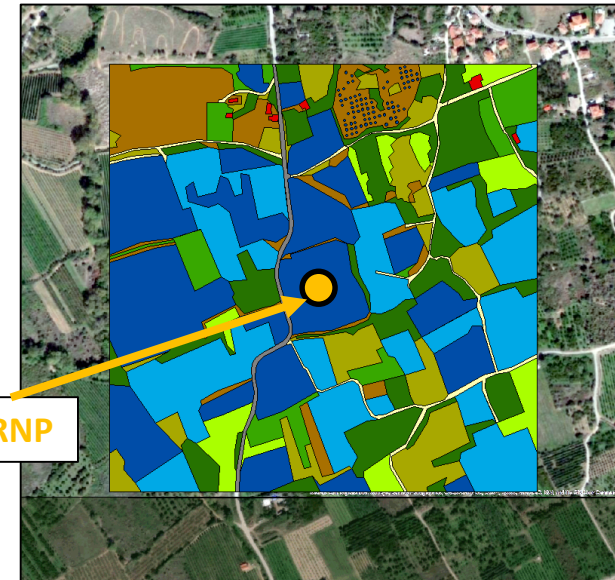
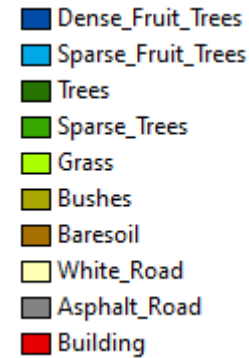
» Agia Neutron Simulation



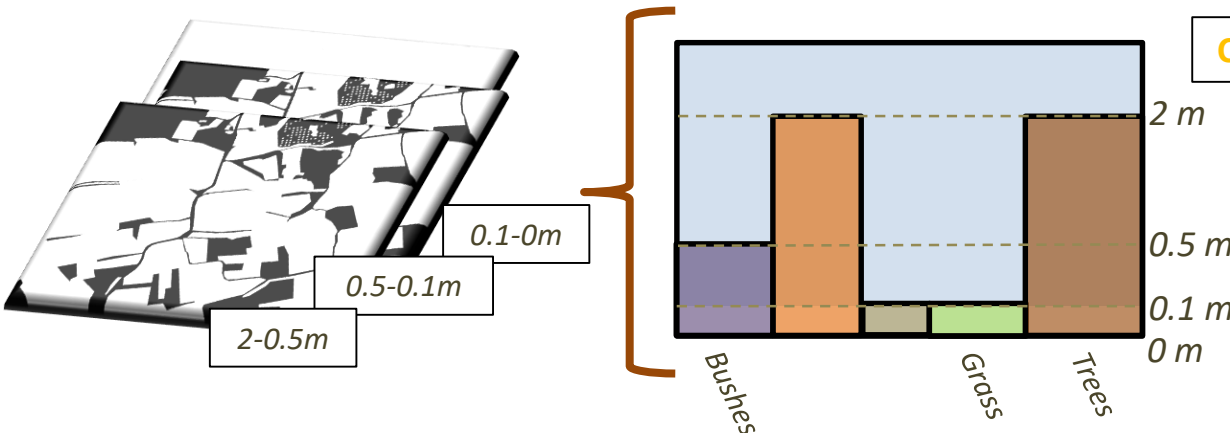
In collaboration with Cosimo Brogi, FZ Jülich

Setup of the actual scenario simulations:

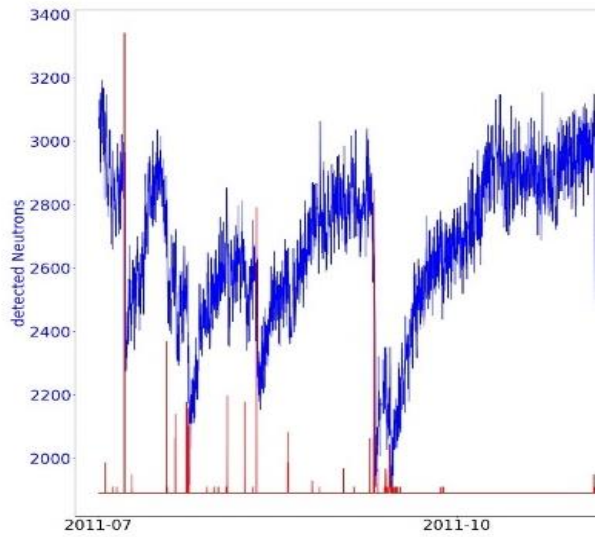
- 600x600 meters domain (center CRNP)
- Irrigation area coincident with field S10
- 8 layers covering 1000 meters of air and 1.6 meters of soil.
 - 4 layers of air (with source/detector)
 - 3 layers of vegetation/air
 - 3 layers of soil (0-0.125, 0.125-0.35, 0.35-1.6)



CRNP

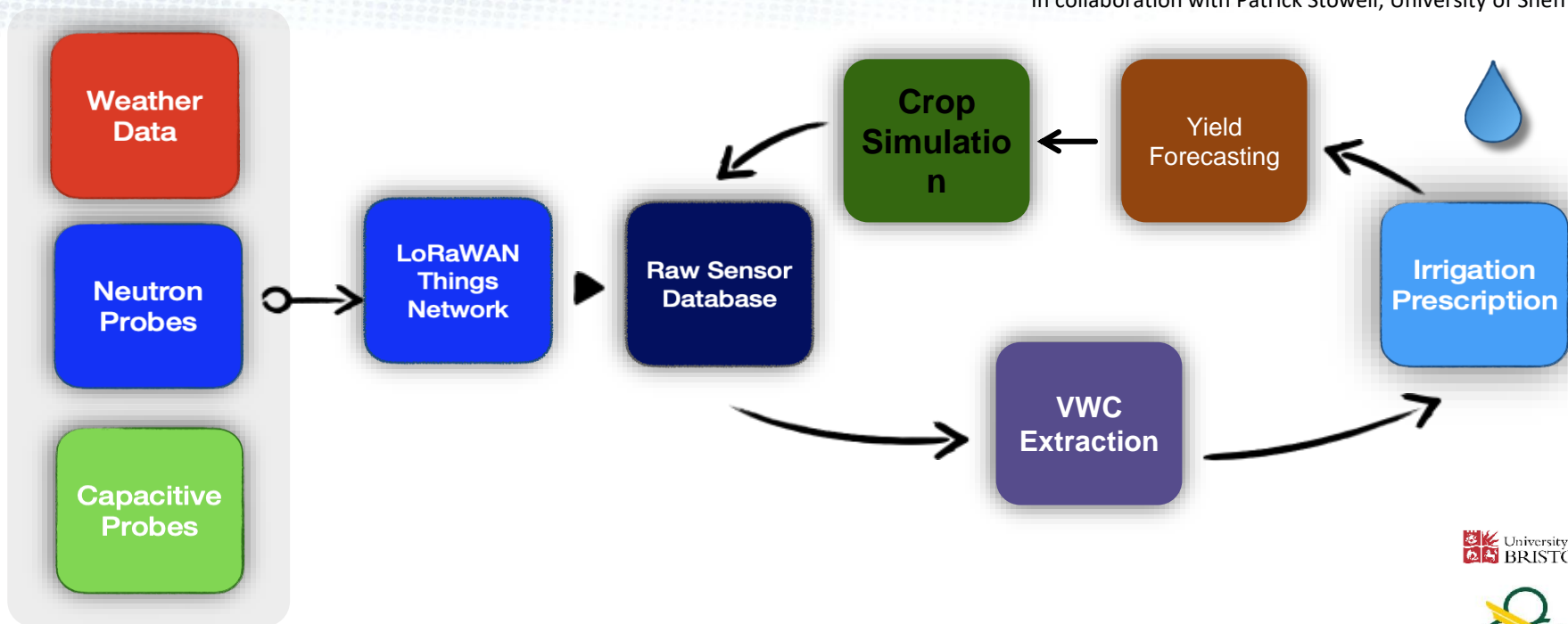


» Interfaces



» Cosmic SWAMP

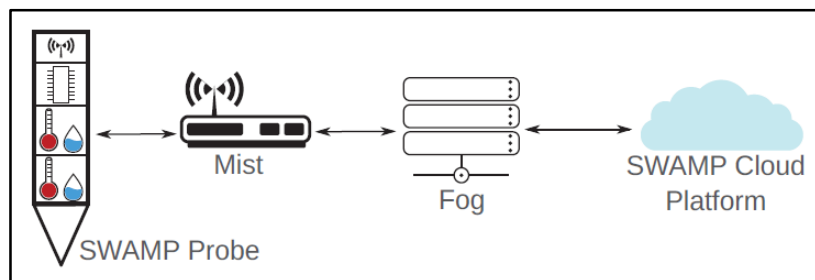
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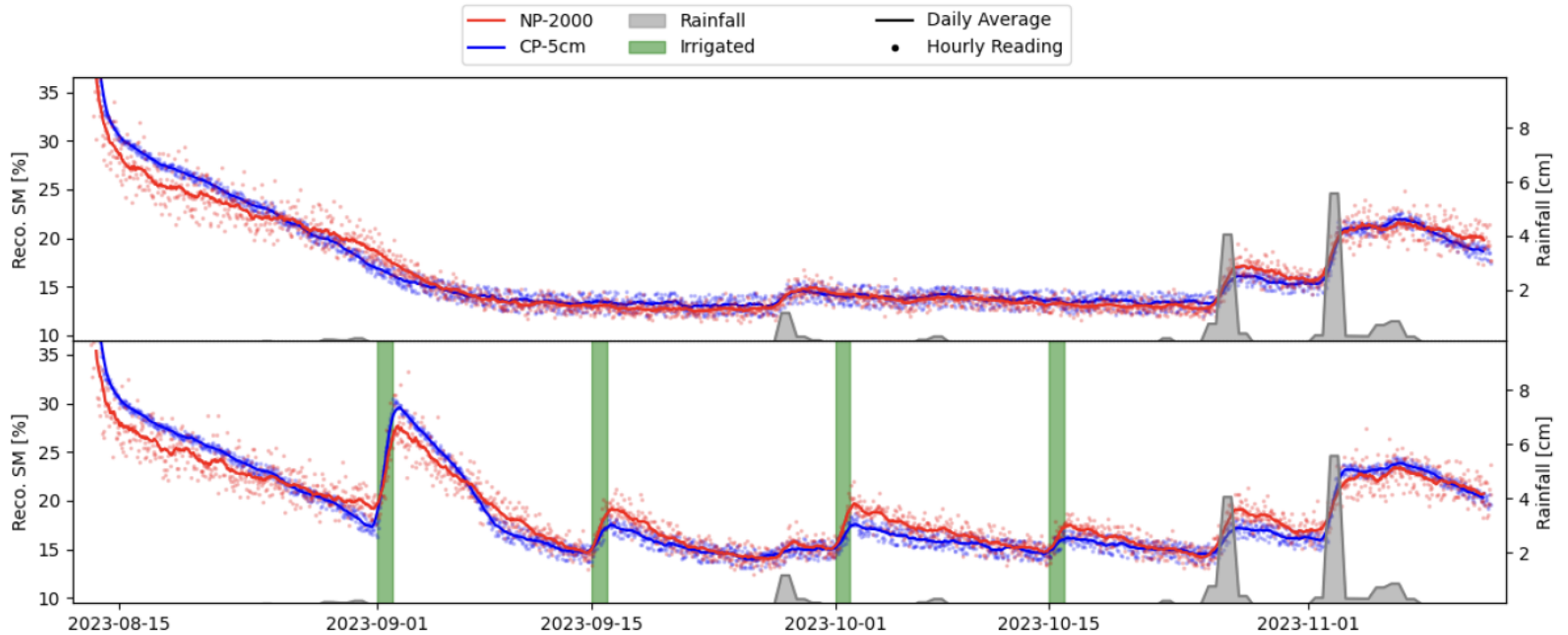
Use of hybrid sensor networks to optimise irrigation (**SWAMP**)

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

PCSE Simulations for automated yield optimisation



» Cosmic SWAMP Simulator

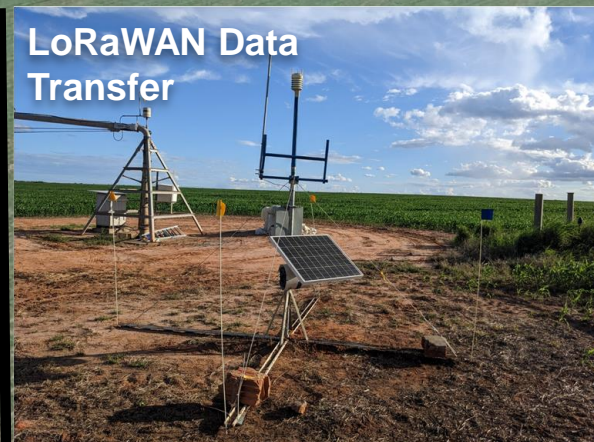


» Cosmic SWAMP (Bahia Pilot)

1 Roving CRP
3 Static CRP



LoRaWAN Data
Transfer



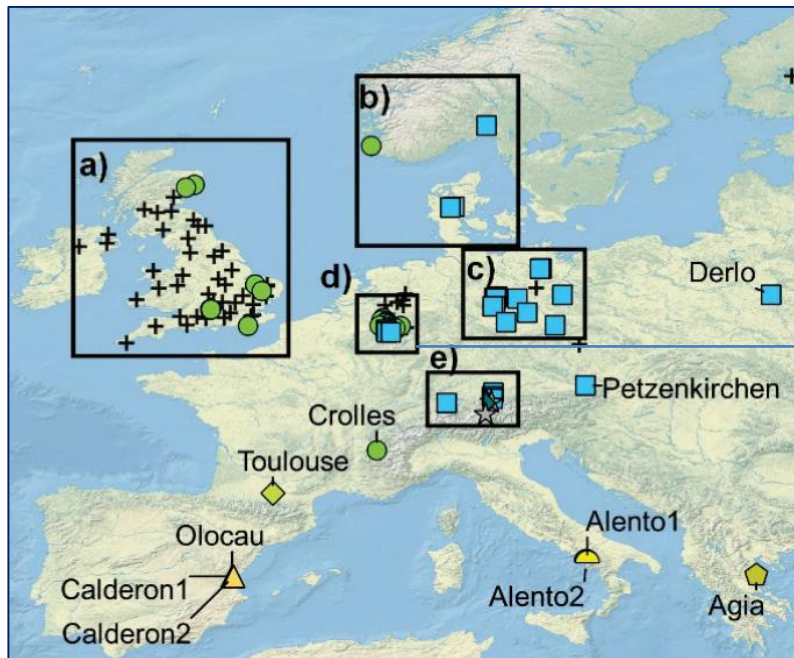
Variable Rate
Irrigation Arm [500m]



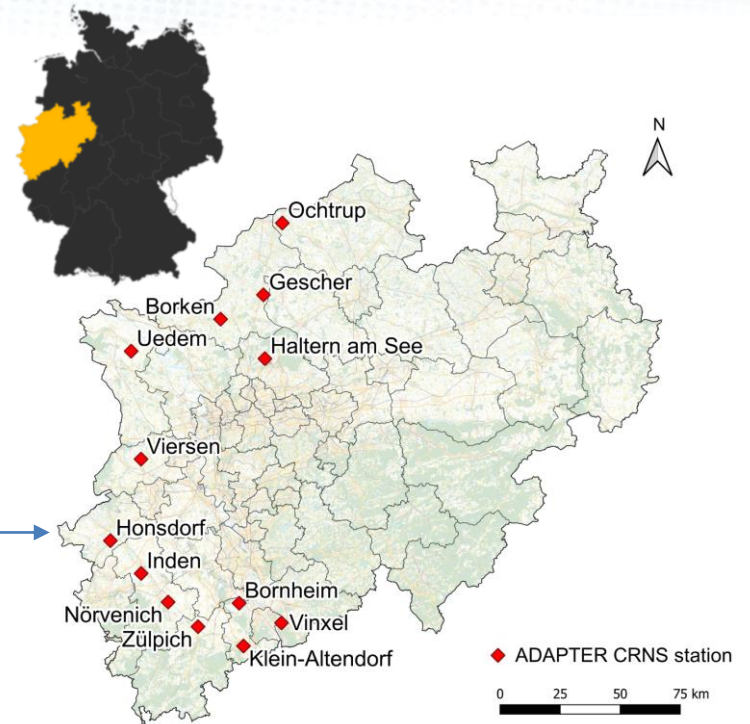
12 Root Zone
Moisture Probes



» CRNS Networks

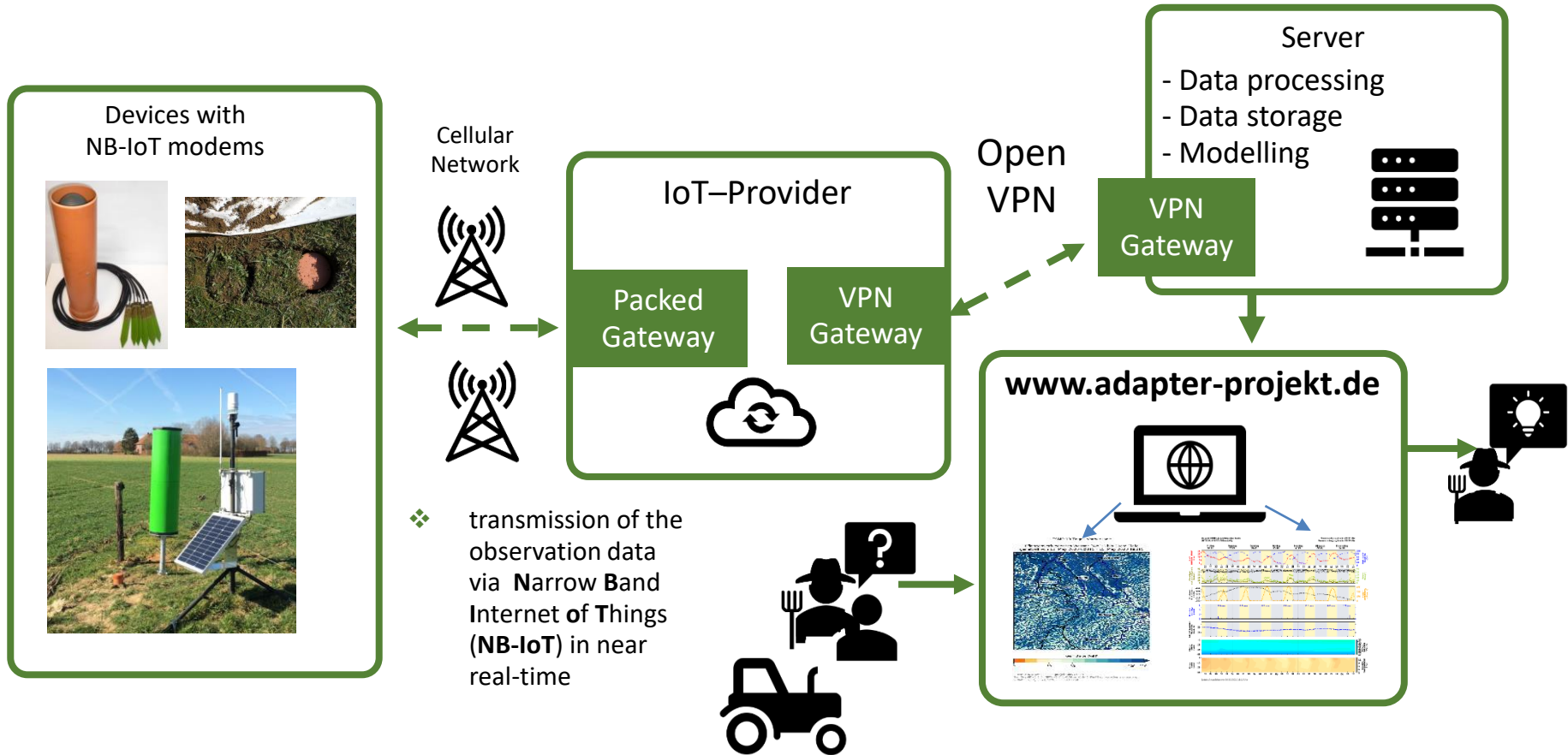


COSMOS-Europe sites (Bogena 2021, ESSD)



ADAPTER sites (Ney 2021, MetroAgriFor)

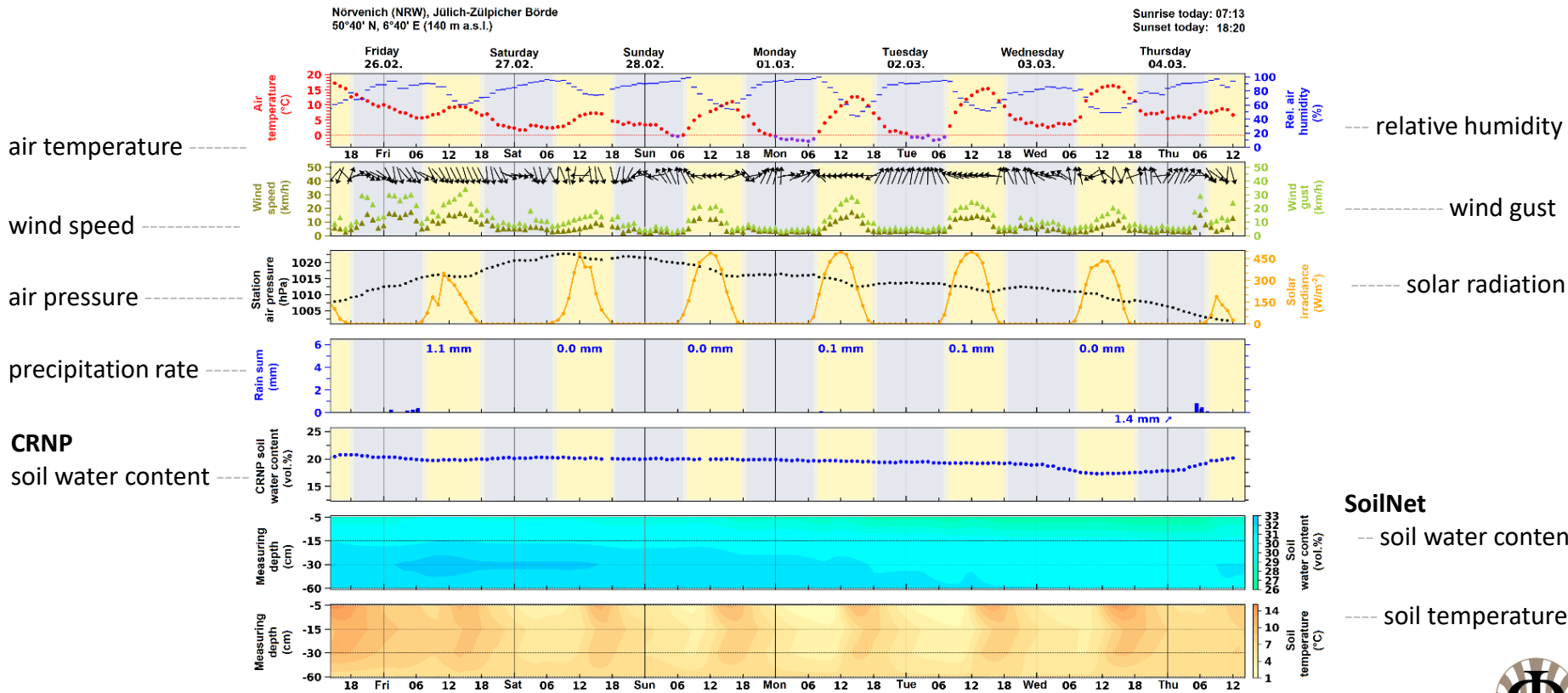
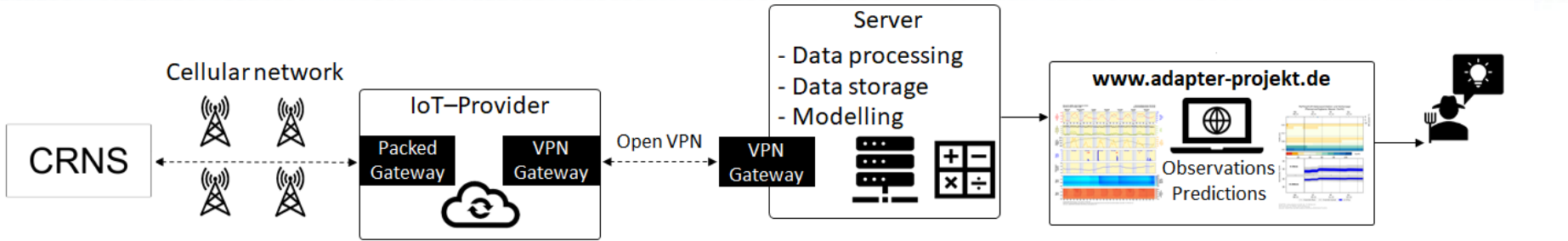
» The ADAPTER Network



In collaboration with
Patrizia Ney
FZ Jülich



Telemetry Integration

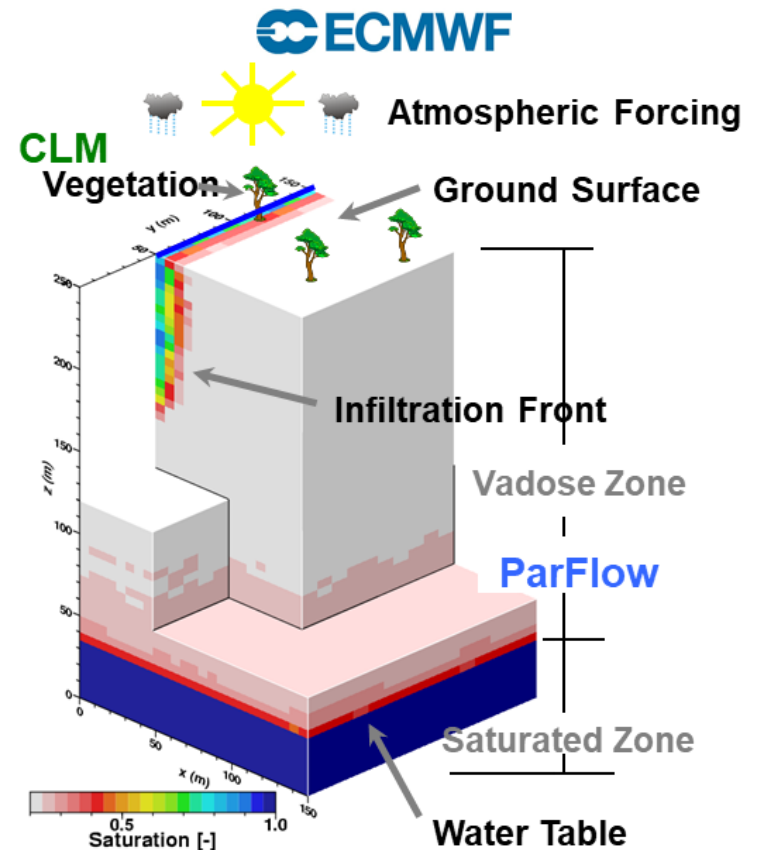


» Forecast Model

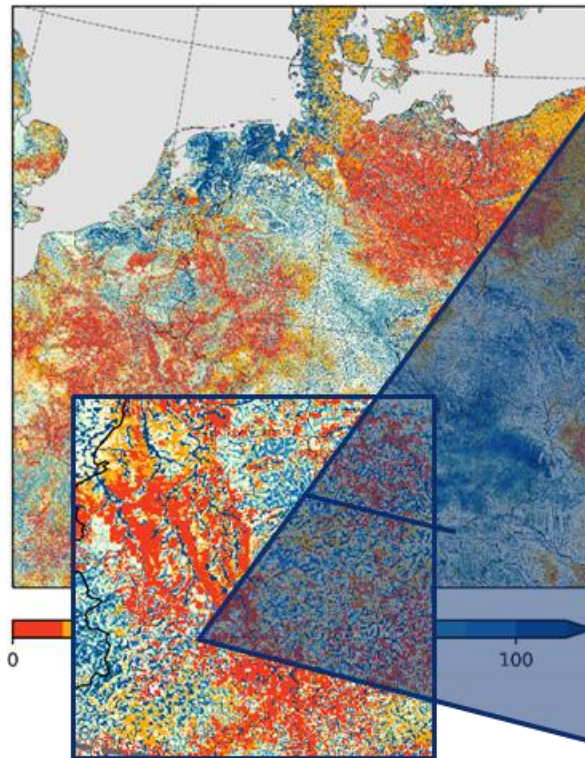


High-resolution soil moisture forecast

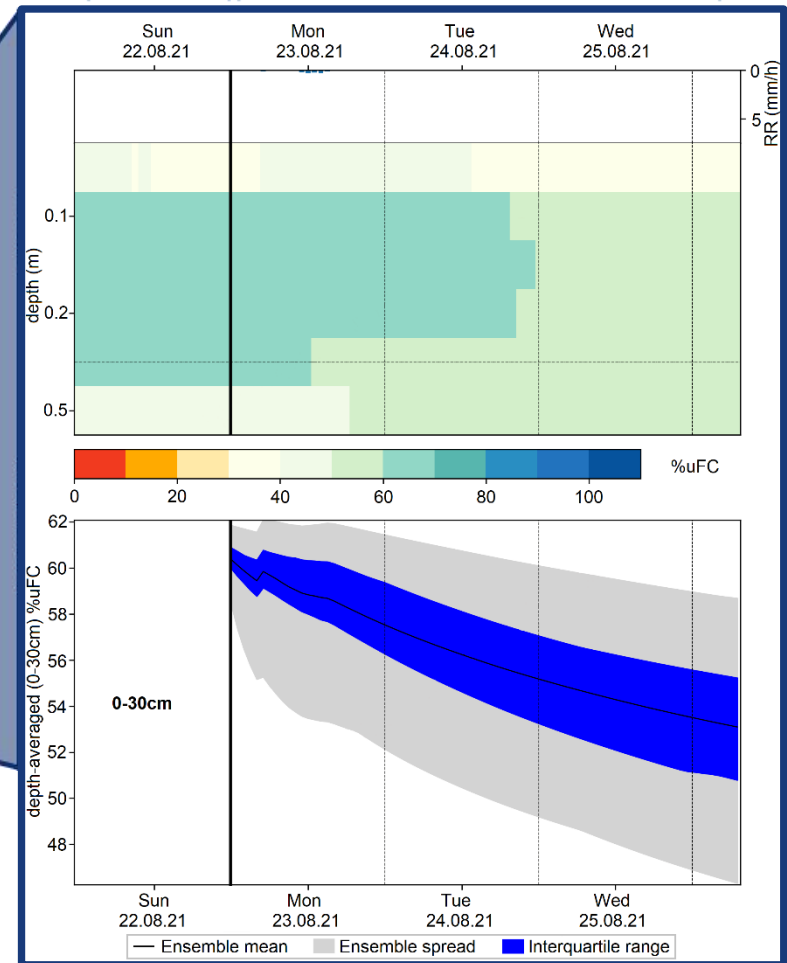
- Focus on **soil water states** and **fluxes**
 - **ParFlow** hydrological model for the complete dynamical representation of the subsurface and surface hydrological processes, coupled with
 - **CLM (Common Land Model)** for the interactions at the surface
 - Atmospheric forcing: forecasts from ECMWF
 - Assimilation of observed soil moisture
- **Initialization closest to reality**



Model: ParFlow/CLM
Forcing: ECMWF HRES



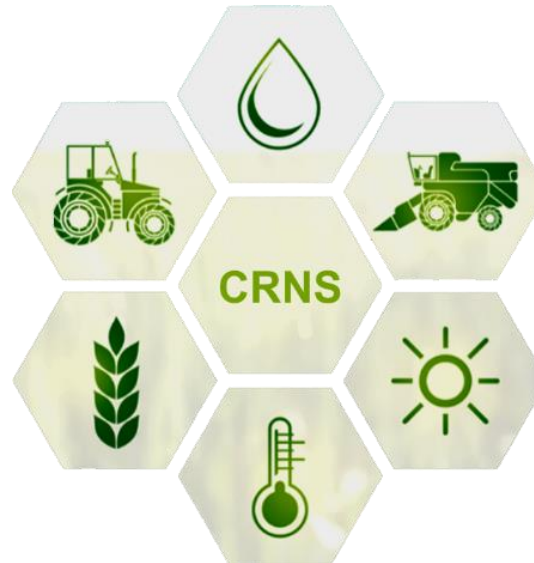
Assimilation Forecast



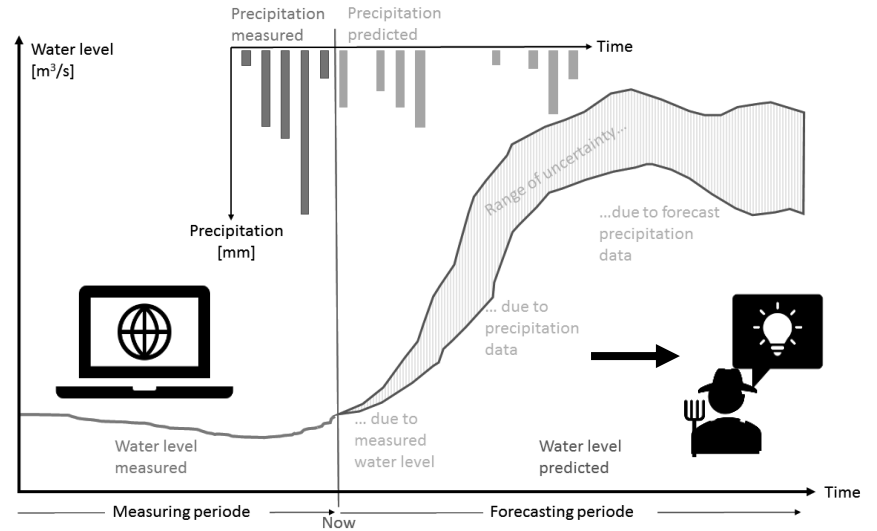
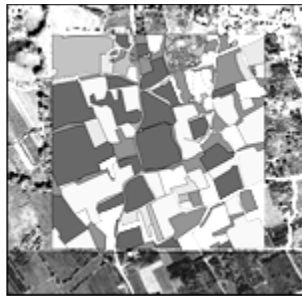
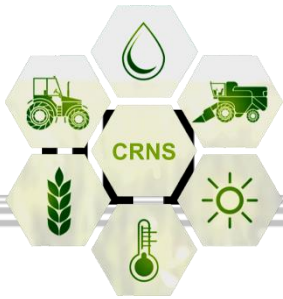
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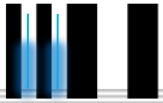
- Prototype: site specific soil moisture forecast:
e.g., **plant available water**
- Ensemble accounts for **uncertainty** due to heterogeneity of soil hydraulic properties

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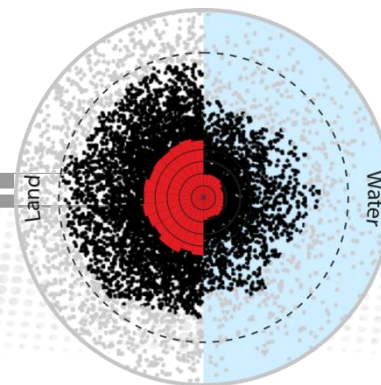


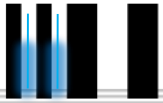


Use of Cosmic-ray Neutron Sensing for soil water management

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 max. 50 cm depth

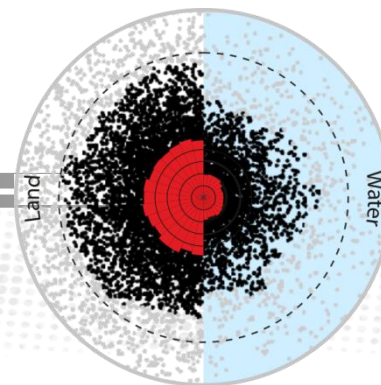


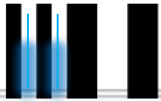


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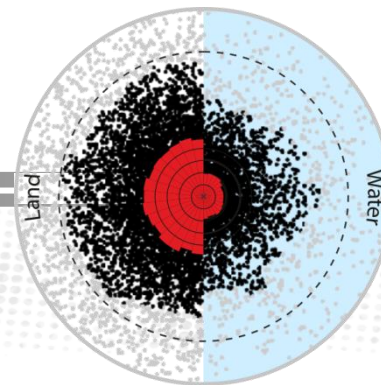


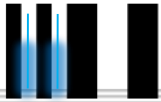


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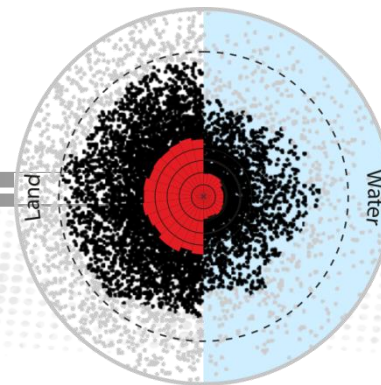




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- IoT-Integration for precision farming facilitated by
 - Independent, non-invasive sensor operation and low maintenance



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

