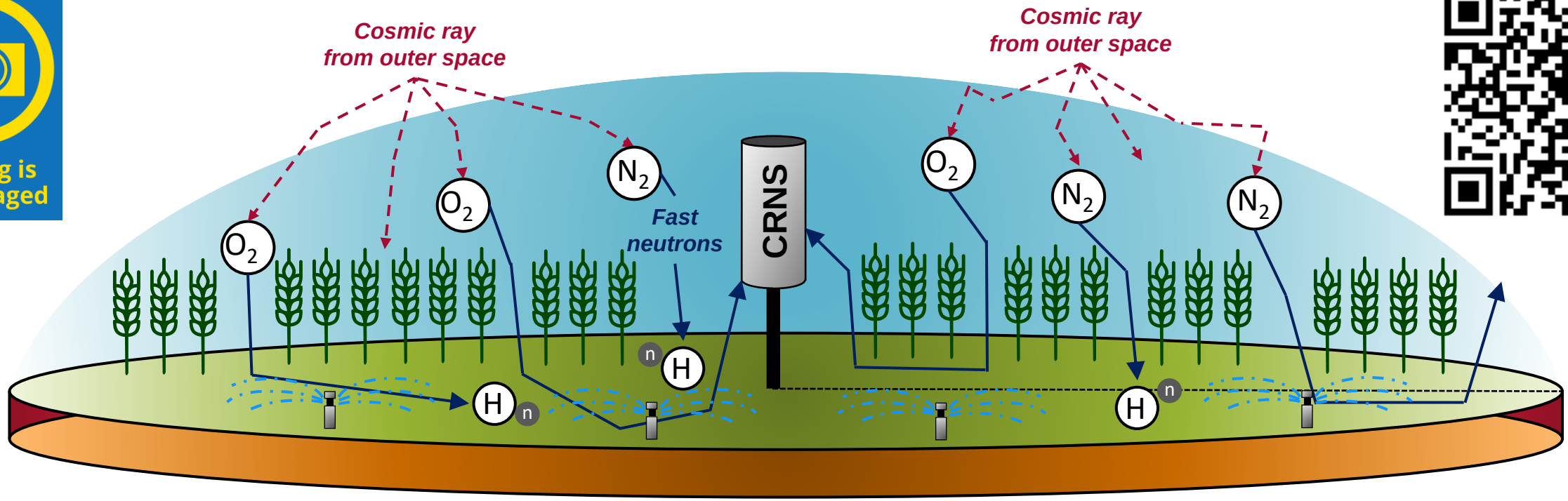
Sharing is encouraged



Challenges and solutions for cosmic-ray neutron sensing in heterogeneous soil moisture situations related to irrigation practices

C. Brogi H. R. Bogena M. Köhli H. J. Hendricks-Franssen O. Dombrowski V. Pisinaras
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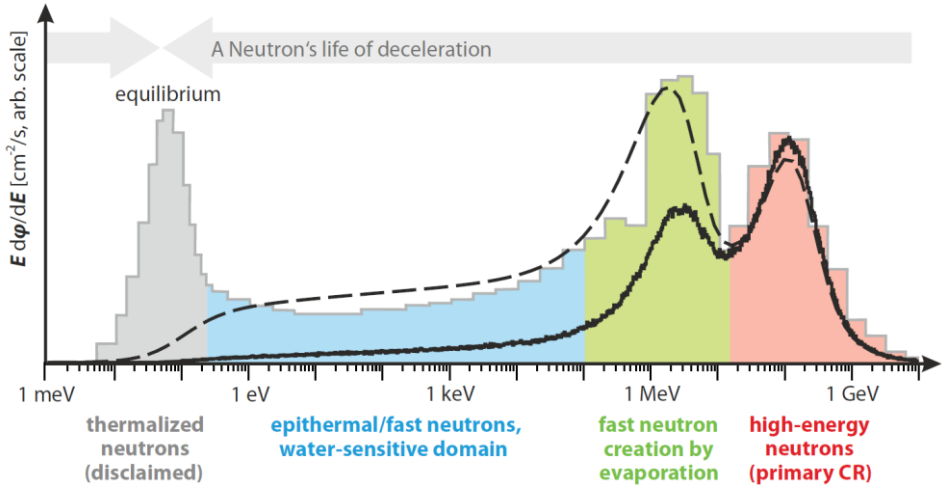
JÜLICH Forschungszentrum
Member of the Helmholtz Association
ATLAS AGRICULTURAL INTEROPERABILITY AND ANALYSIS SYSTEM
SWRI Soil and Water Resources Institute IEYΠ
Cosmic Sense
Horizon 2020 European Union Funding for Research & Innovation

Cosmic ray neutron sensing (CRNS)

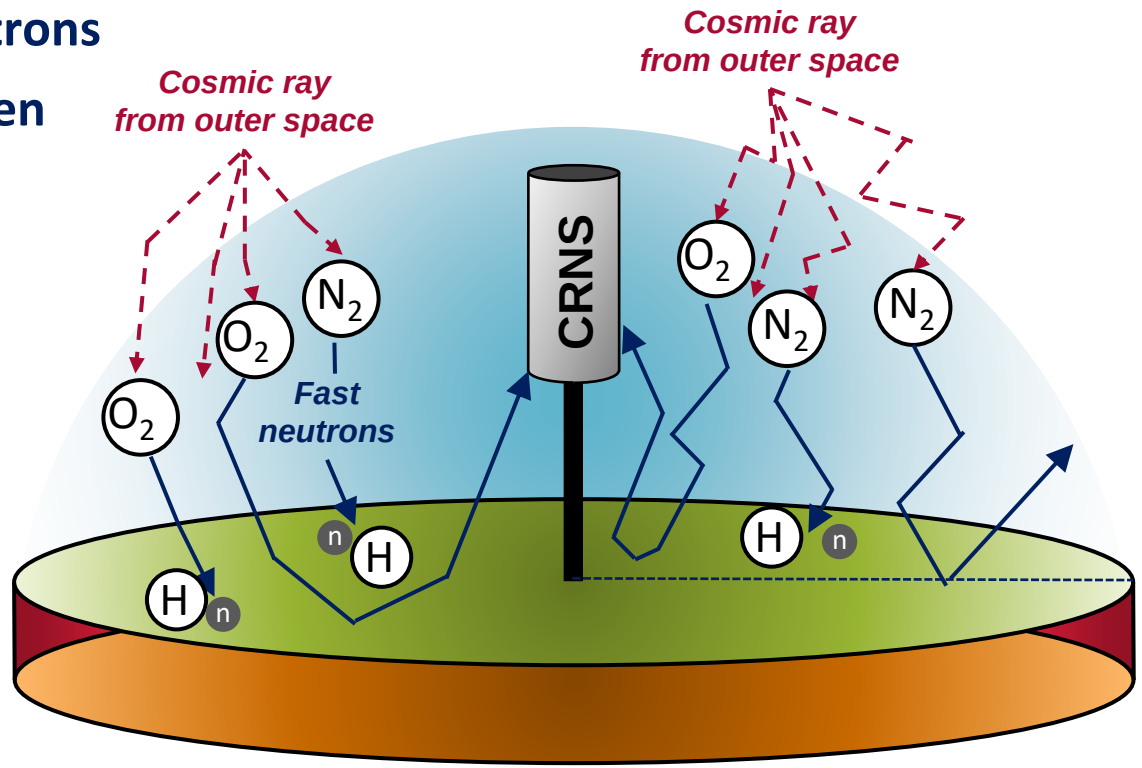
Measure soil moisture (SM) in a 130-240 m radius with a ground penetration of 15-80 cm.

- Incoming cosmic ray radiation produces **fast neutrons**
- Fast neutrons are strongly **moderated by hydrogen** (lose energy and decelerate)



Neutron energy spectra from Köhli et al 2015

- Penetrate into the soil
- Scatter back into the atmosphere
- Eventually detected by the CRNS



Most interactions are with water

Higher soil moisture = Fewer neutrons detected

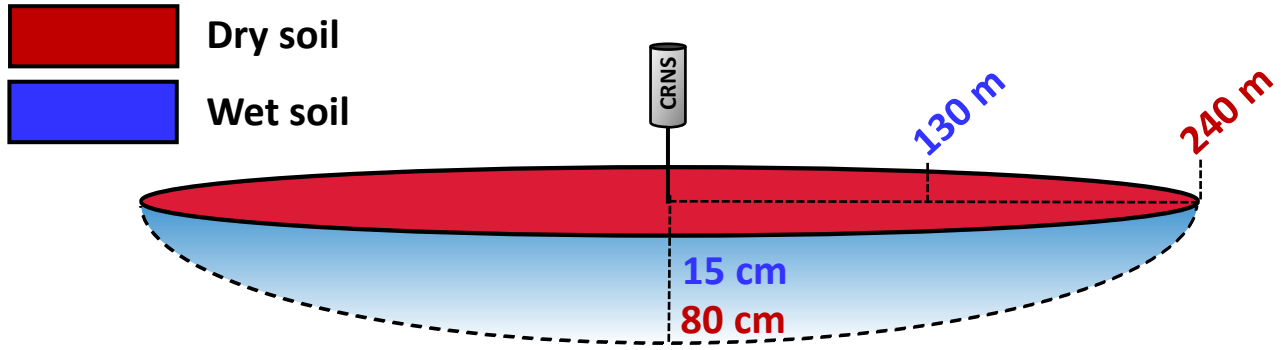
Can CRNS support irrigation?

Measure soil moisture (SM) in a 130-240 m radius with a ground penetration of 15-80 cm.

Higher soil moisture (SM) = Fewer neutrons detected

Advantages of CRNS:

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

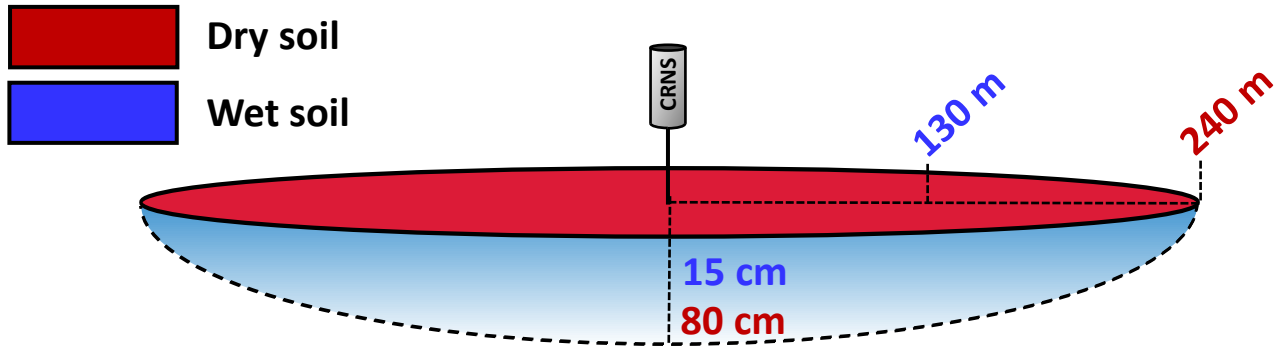


CRNS footprint variation with SM

Challenges in irrigation:

- The footprint varies considerably with soil moisture variations
- Sub-footprint heterogeneities (challenges with drip irrigation, *Li et al 2019*)

Can CRNS support irrigation?



CRNS footprint variation with SM

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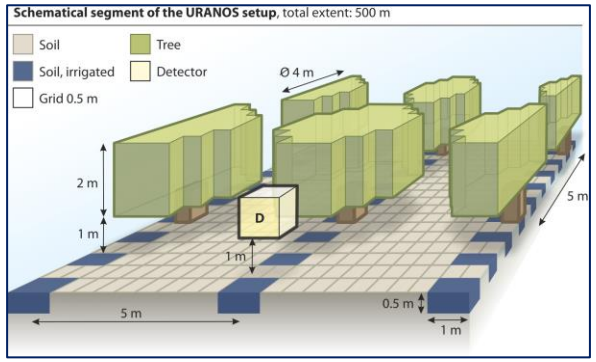
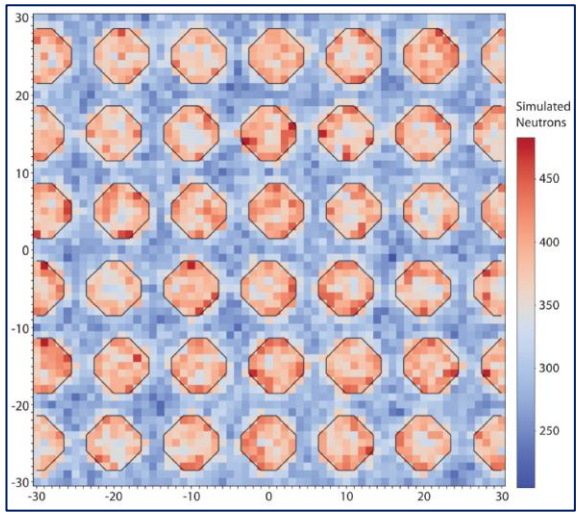


Dazhi Li et al, 2019
CRNS in a drip irrigation scenario



A “patchy” irrigation with local and small SM changes proved challenging for CRNS.

Is it feasible to monitoring larger and less heterogeneous SM changes (sprinkle irrigation)?

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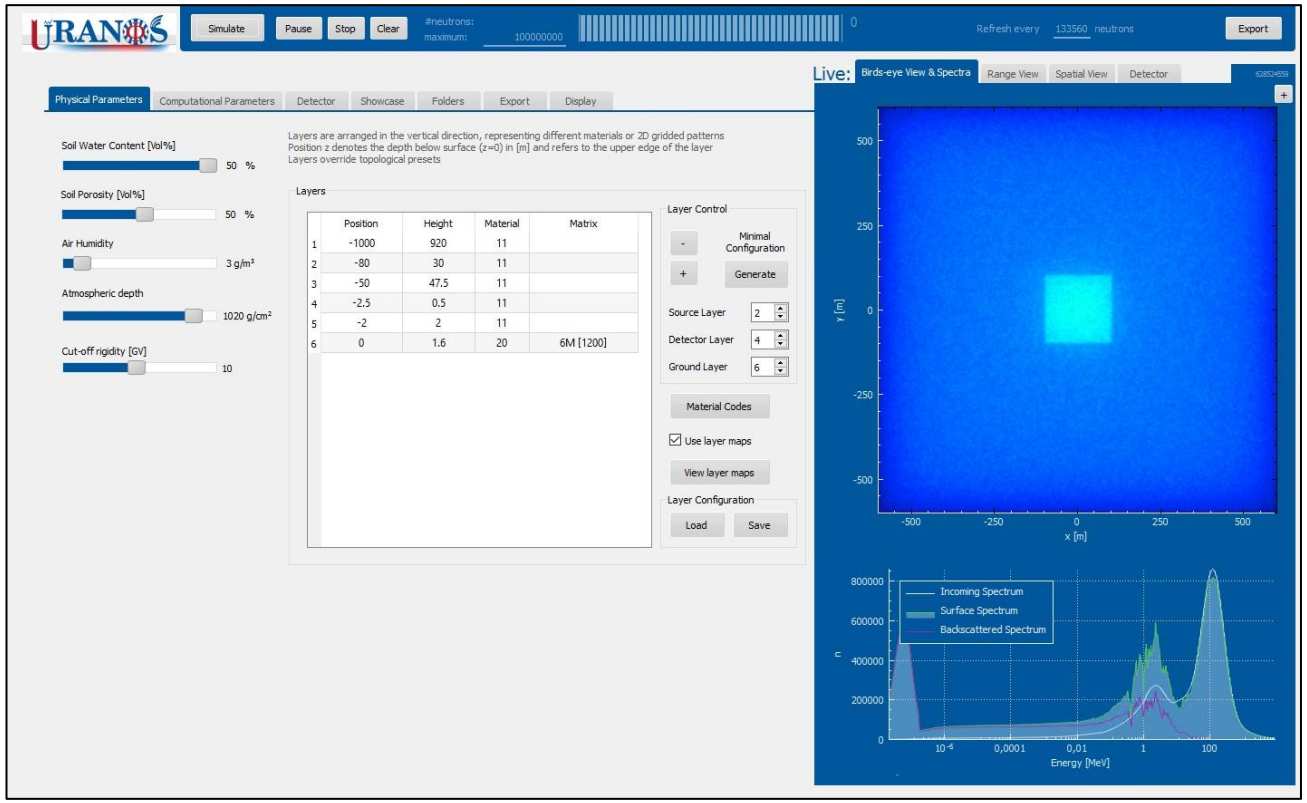
Simulation of neutron transport in irrigation

The Ultra Rapid Adaptable Neutron-Only Simulation (URANOS) model was used to perform simulations of irrigation scenarios.

Five irrigated areas were simulated (0.5, 1, 2, 4, and 8 ha) with variable SM (500 sims in total).



Example of the URANOS modelling GUI set for a 8 ha irrigated area.

Simulation of neutron transport in irrigation

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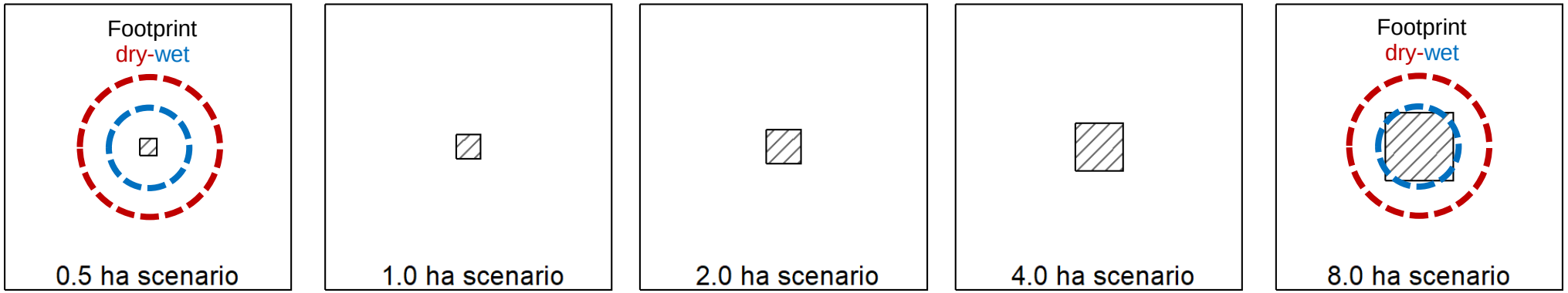
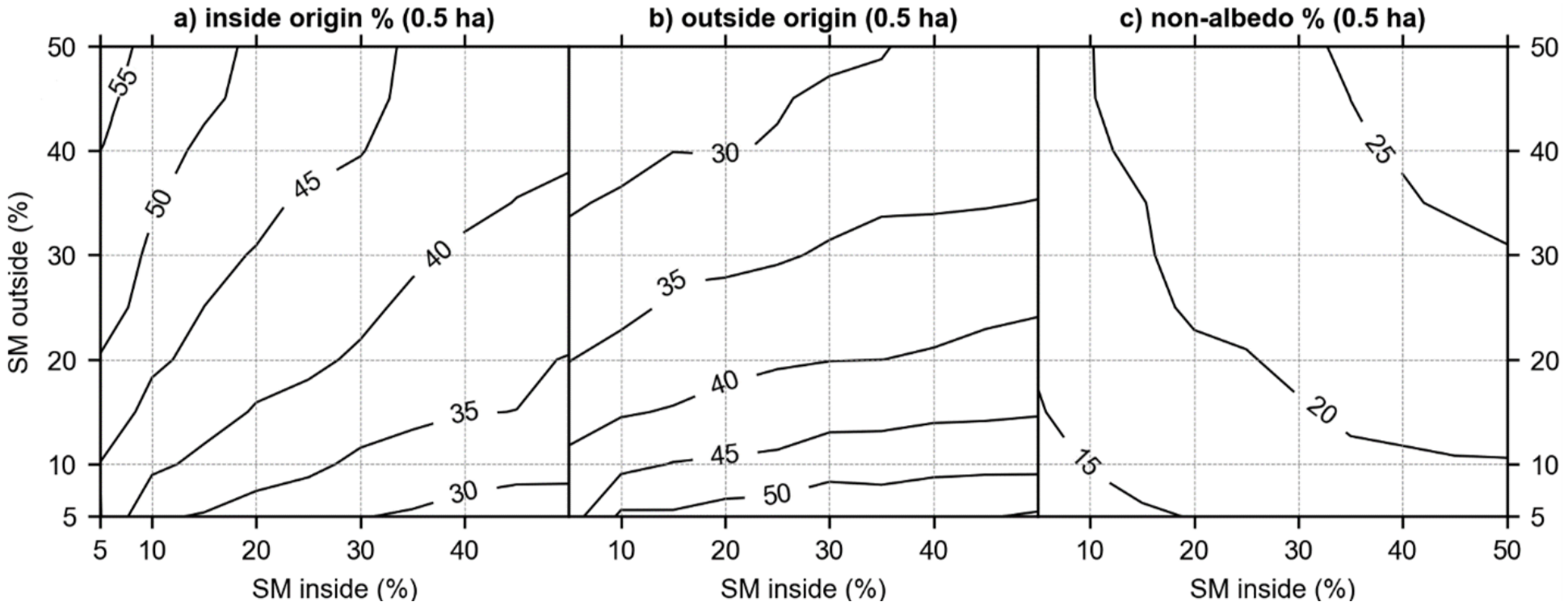


Setup of the five irrigated areas within the model domain with indication of the CRNS footprint.

Strong influence of the surrounding area

- The detected neutrons that originate within a small irrigated field can be less than half of the total detected neutrons

Simulation of neutron transport in irrigation



Origin of detected neutrons for a 0.5 ha field in dependence of SM variations. Albedo neutrons can originate:

- *Inside (a)*
- *Outside (b)*

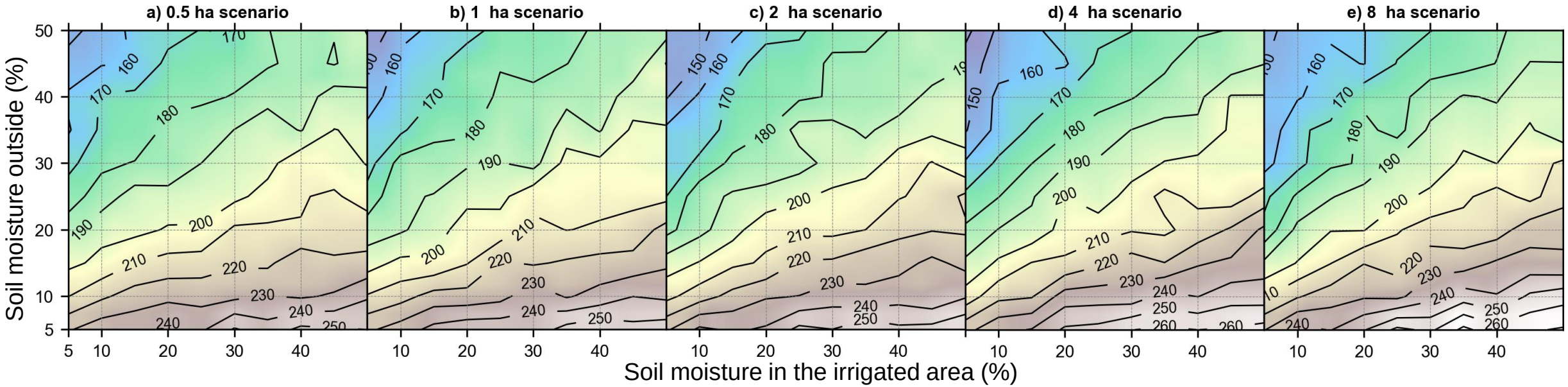
And the rest is non-albedo neutrons with no soil contact (c)

Strong influence of the surrounding area

➢ The detected neutrons that originate within a small irrigated field can be less than half of the total detected neutrons

Variation of CRNS footprint (86%) in irrigated scenarios

- The instrument footprint (86%) varies considerably with heterogeneous SM
- The footprint (86%) is generally larger than an 8 ha irrigated field

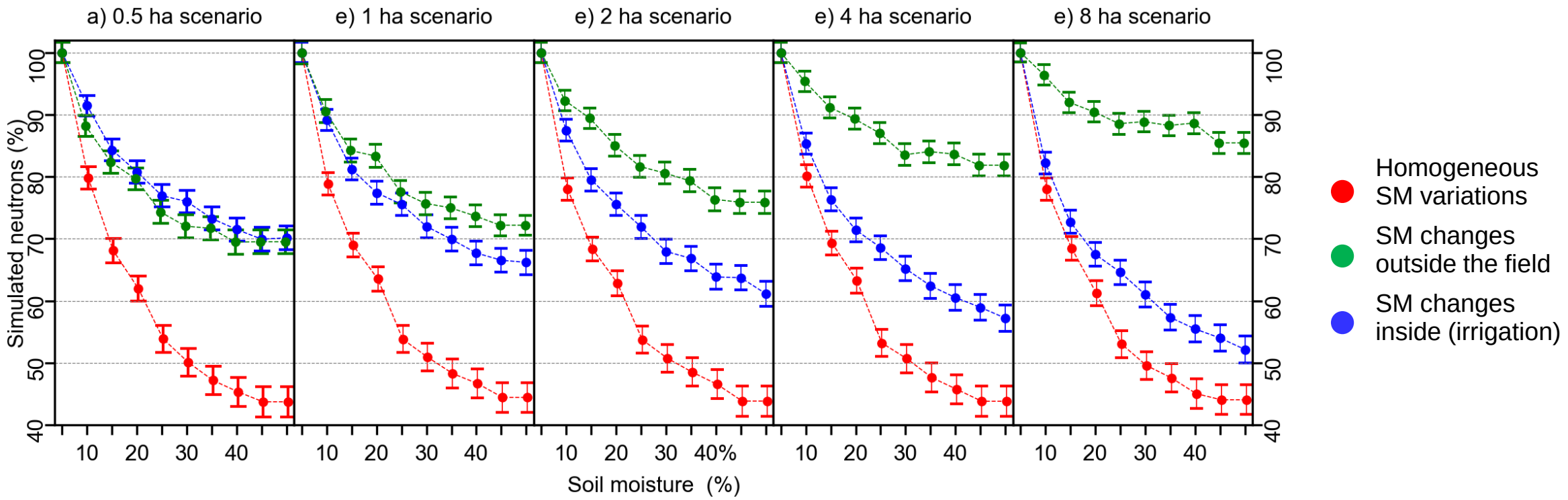


Footprint variations with SM of the irrigated and non irrigated area (upper plot).
Footprint compared to irrigated areas of 0.5 and 8 ha (right plots).

The footprint can increase by more than 30% when irrigation water is added. The exact value depends on both SM variation due to irrigation and on the SM of the surroundings.

Influence of the dimension of the irrigated area

- A small irrigated field might contribute to CRNS signal less than its surroundings
- Future research should focus on irrigated fields of 1 ha or more



Simulated neutron count variations with SM changes for a CRNS with 25 mm HDPE moderator and additional Gadolinium shielding. Higher variations are beneficial.

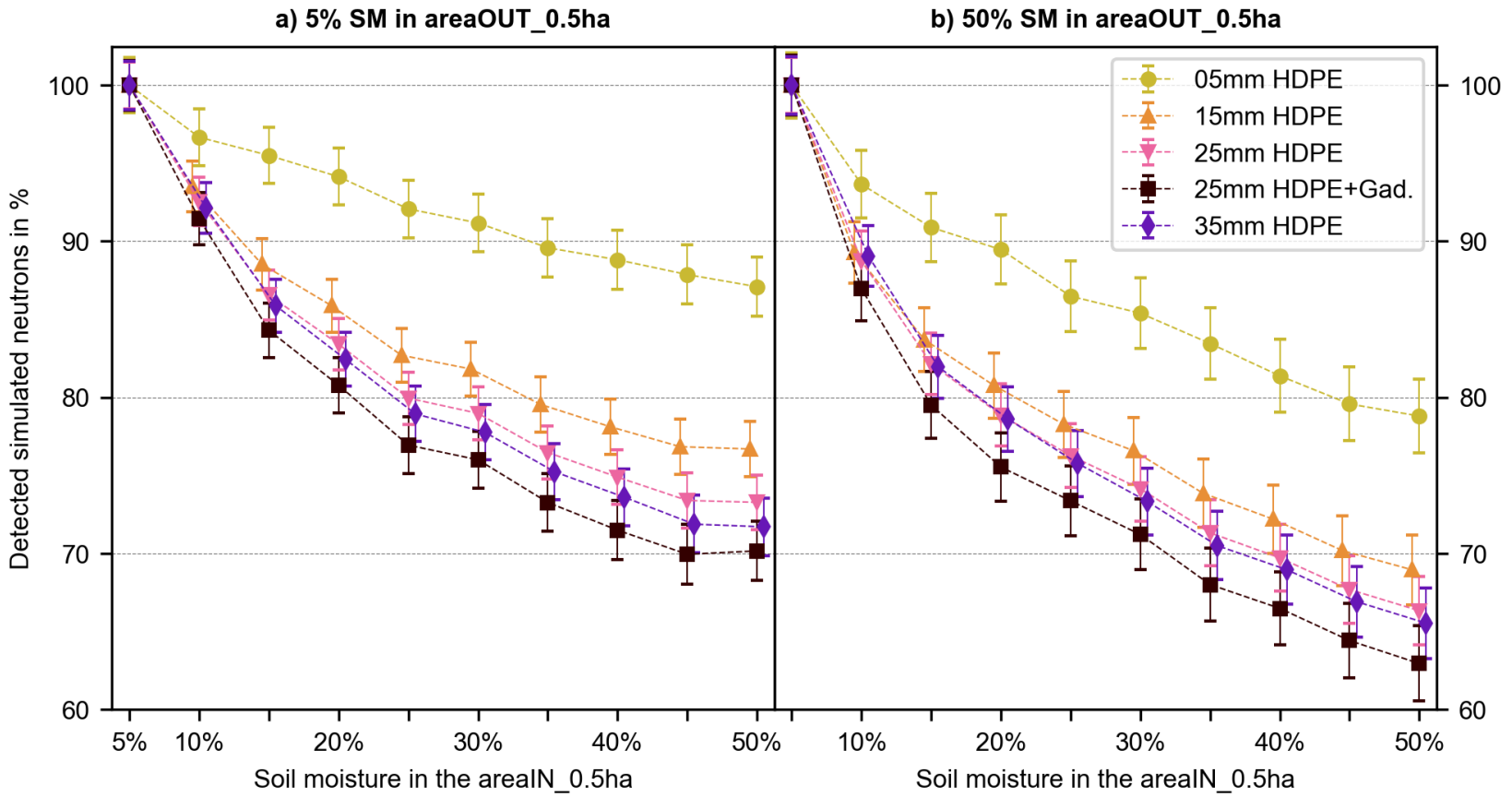
Optimize CRNS detector design for irrigation monitoring

Improved monitoring using:

- Thick HDPE moderators (non-linear improvements)
- Thermal shielding (Gadolinium)

Additionally:

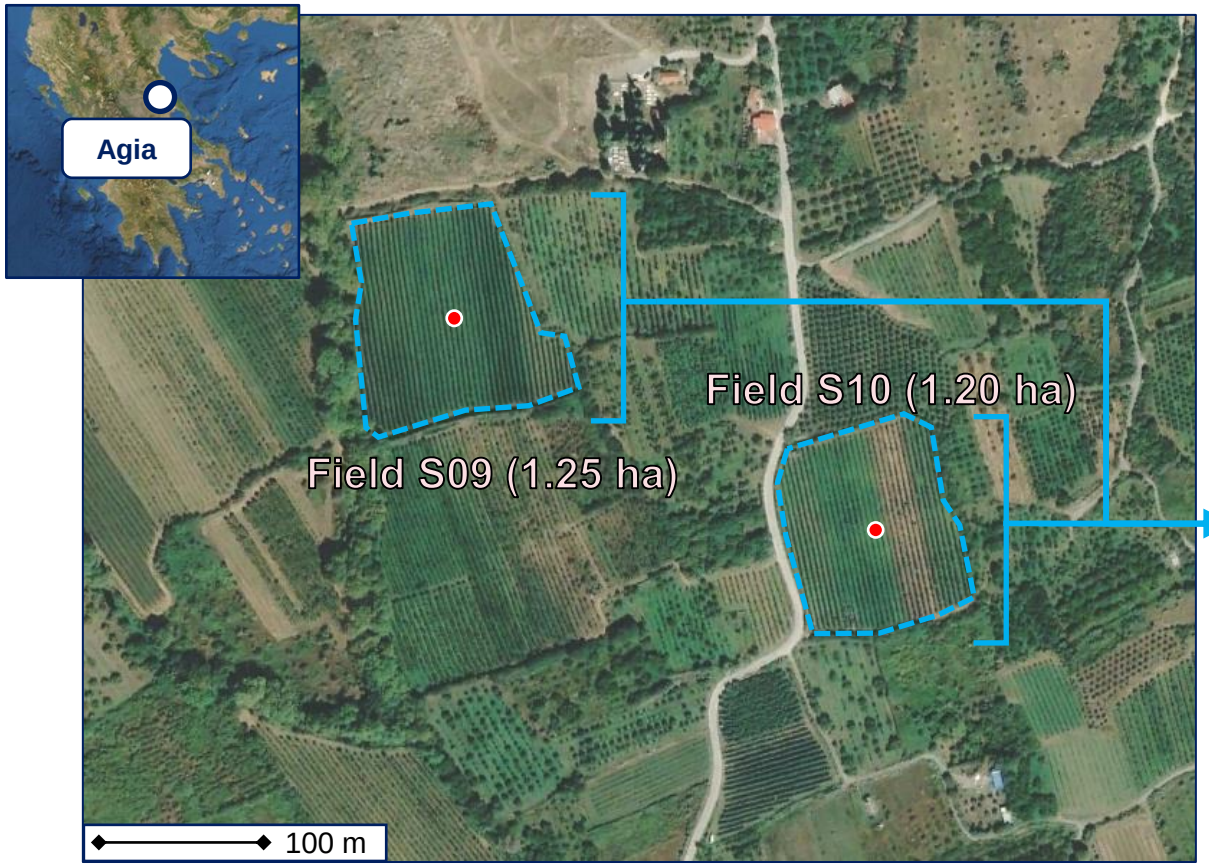
- High SM outside the irrigated area improves results



Simulated neutron count variations with SM changes. Larger variations are beneficial.

Study site in Agia (Greece)

ATLAS test sites in Agia (Greece)



Both fields are equipped with:

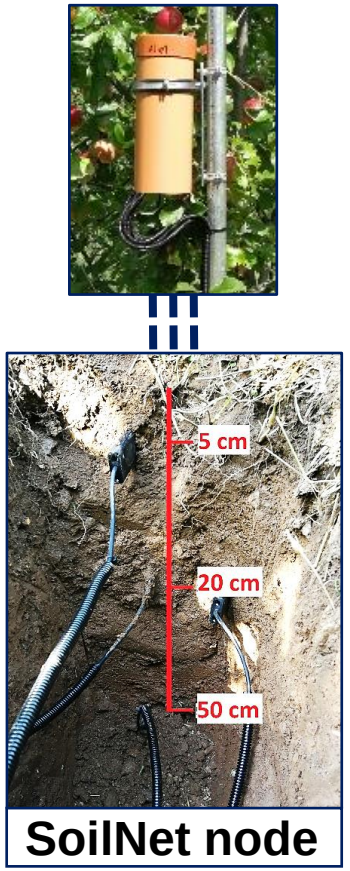
x1 Cosmic Ray Neutron Sensor

x12 SoilNet (soil Moisture at three depths)

x1 Climate station

Cosmic Ray neutrons sensor from Styx Neutronica GmbH (Heidelberg, Germany)

Atmos41



SoilNet node

- Two apple orchards with sprinkler irrigation
- 204 instruments with near-real time NB-IoT connection

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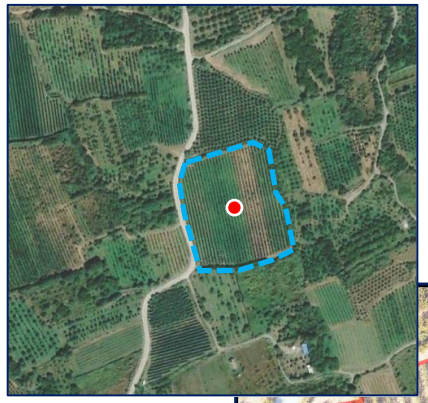
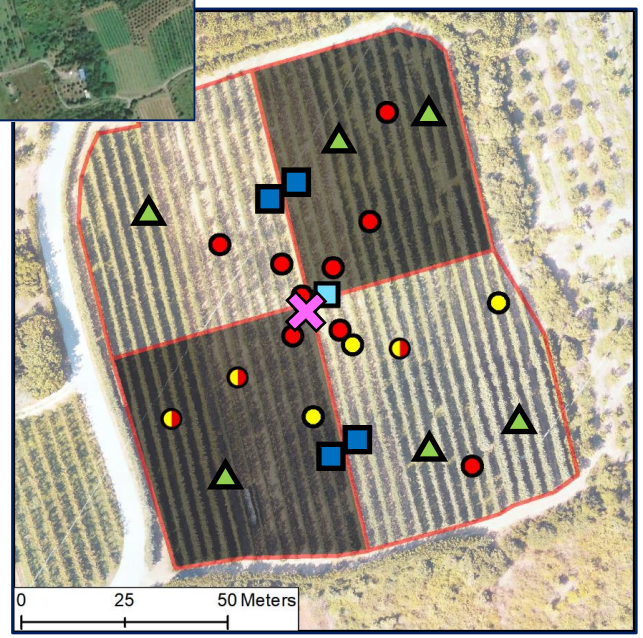
Additional details on the installed instrumentation





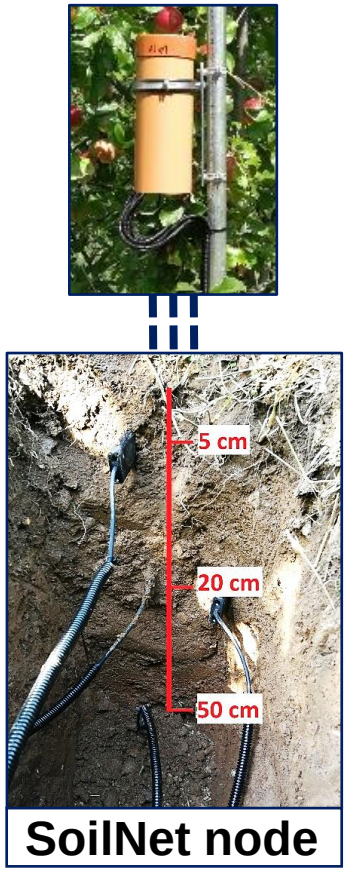
Test site S10 in Agia (Greece)

Position of instruments installed at Field S10

- **Cosmic Ray Neutron Sensor**
- **SoilNet** (soil moisture, *h*, and temperature)
- **Atmos41** (climate station)
- **Water Meters** (irrigation in m^3)
- **Sap-Flow**
- **Monitoring Camera**
- **Irrigation Plots**

Cosmic Ray neutrons sensor from Styx Neutronica GmbH (Heidelberg, Germany)

Atmos41



SoilNet node

- Each field is intensively monitored, and additional data will be available for the 2022 irrigation season (stay tuned!)

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Near-Real Time Measurements

The **Atmos41** is a compact meteorological station and measures:

- Precipitation
- Air temperature
- Air humidity
- Air pressure
- Solar radiation
- Wind speed/direction

Atmos41

Above Ground

The **Cosmic Ray Neutron Sensor CRNS** measures field-scale soil moisture.

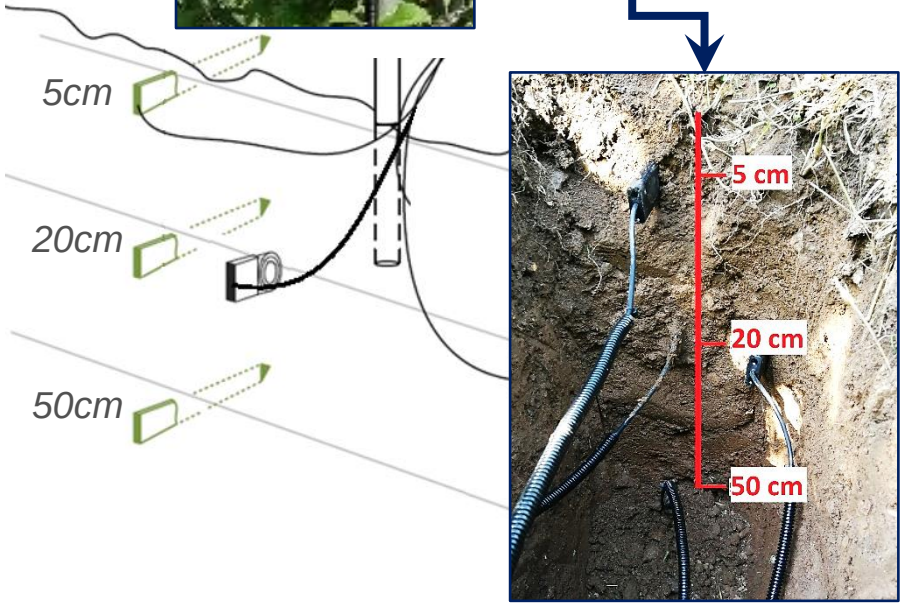
Cosmic Ray Neutron Probe

Below Ground

SoilNet node with 8 sensors:

6x SMT100 (*SM and temperature*)

2x Theros21 (*water potential*)



Soil profile with three SMT100 and one Theros21

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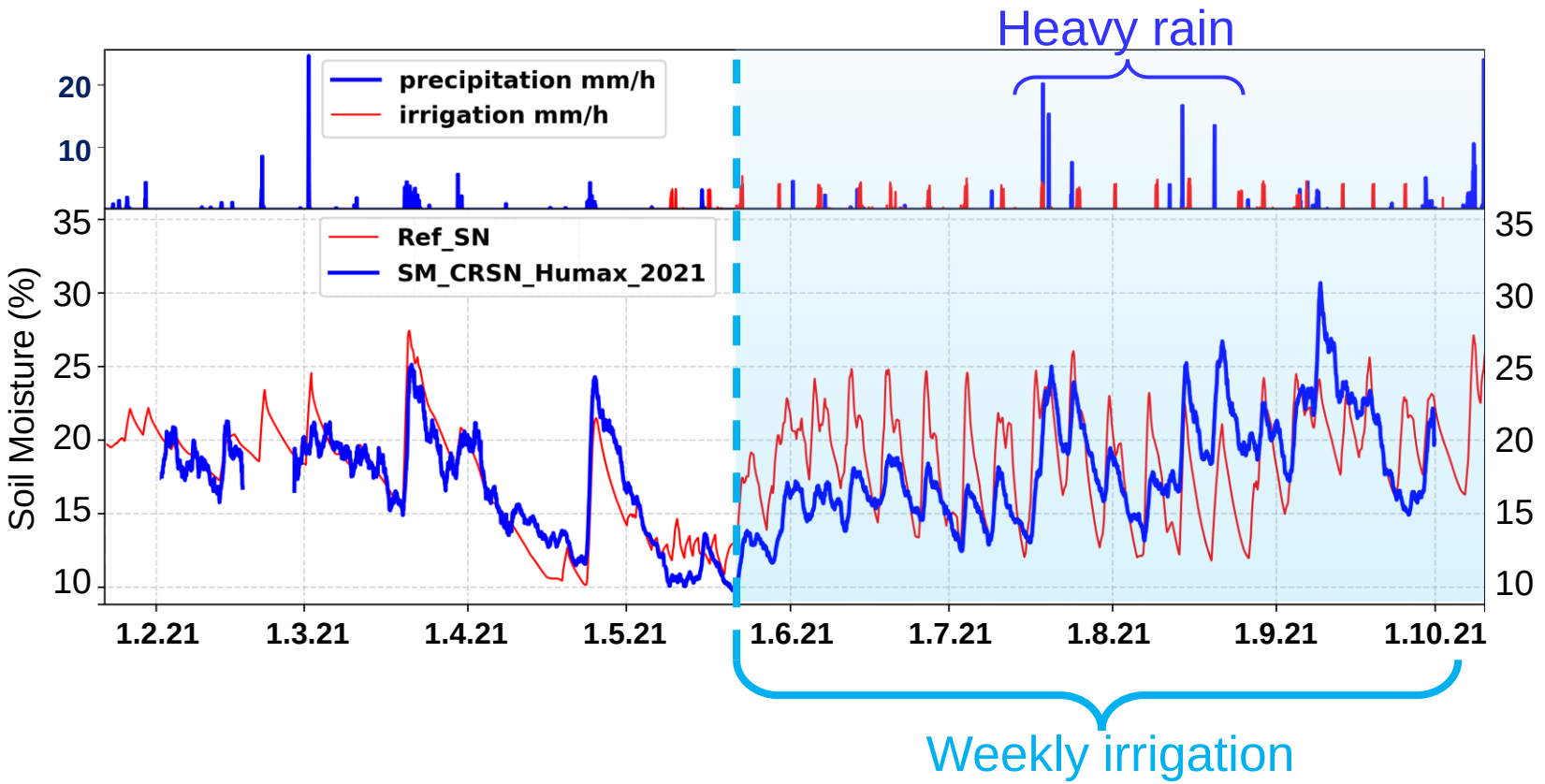
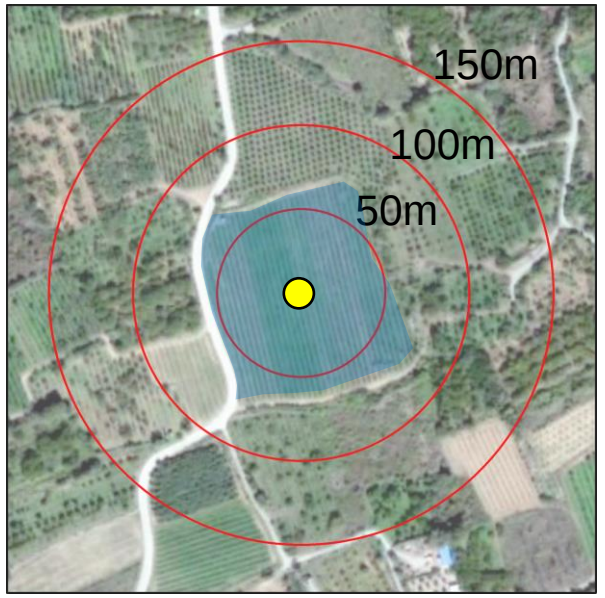
First results from Agia = mixed feelings

- Soil moisture obtained with the CRNS well match the reference data before irrigation starts
- With irrigation, only the temporal dynamics are partially represented
- Environmental conditions affecting neutron detection?





Agia study site with distances from the CRNS (footprint = 130-240 m)

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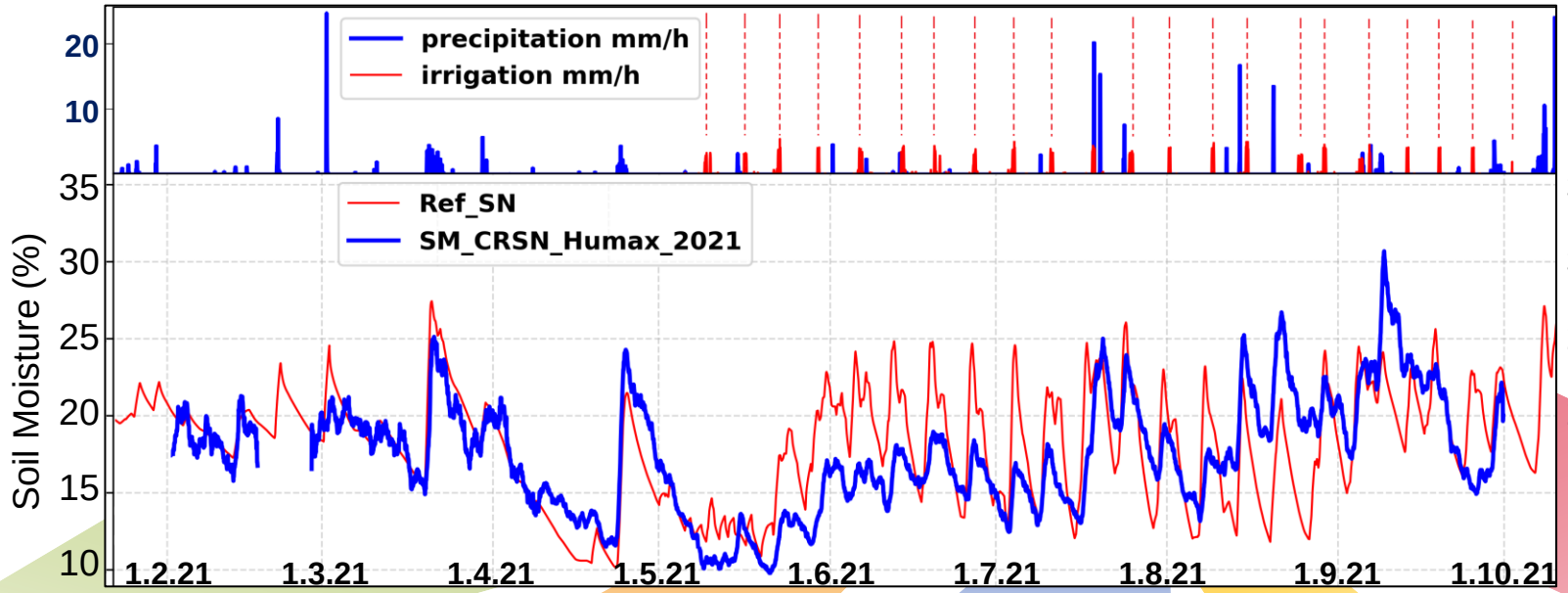
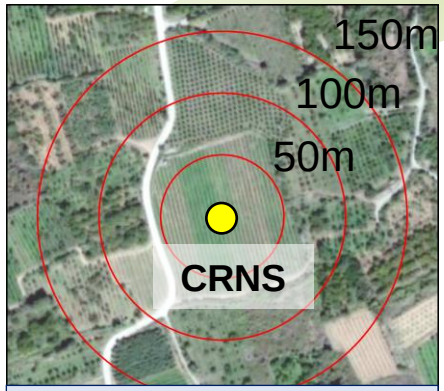
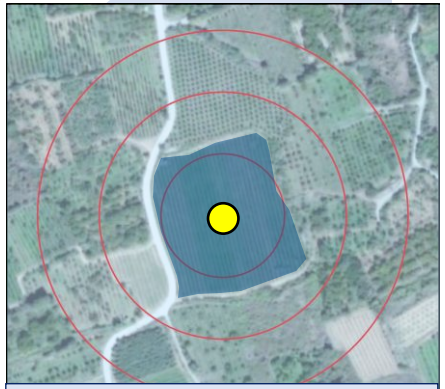
Environmental conditions affect the quality of CRNS-based SM



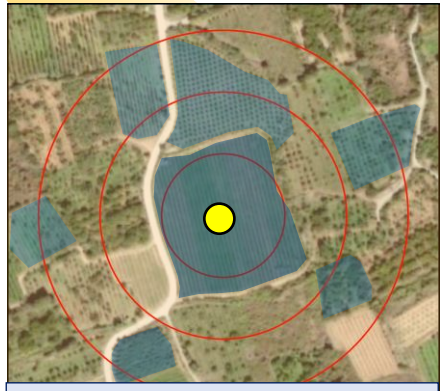


Standard conditions

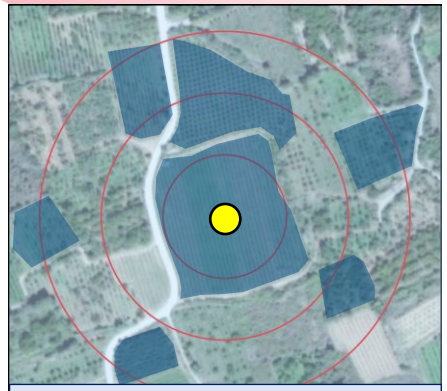
Irrigated field



Irrigation + rain



Multiple irrigations

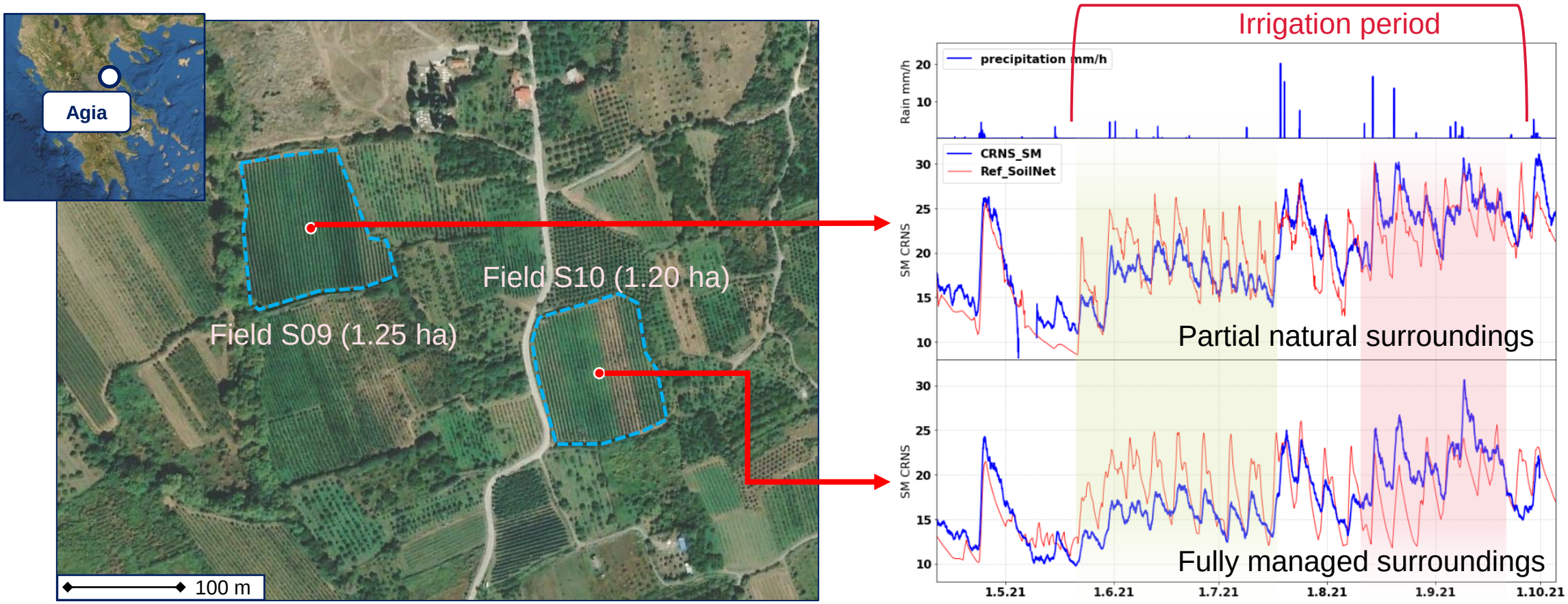


Nightmare!

Satellite (GeoEye) view showing 50, 100, and 150m radius from the CRNS and areas with wet (blue) or dry soil (orange)

Study site in Agia (Greece)

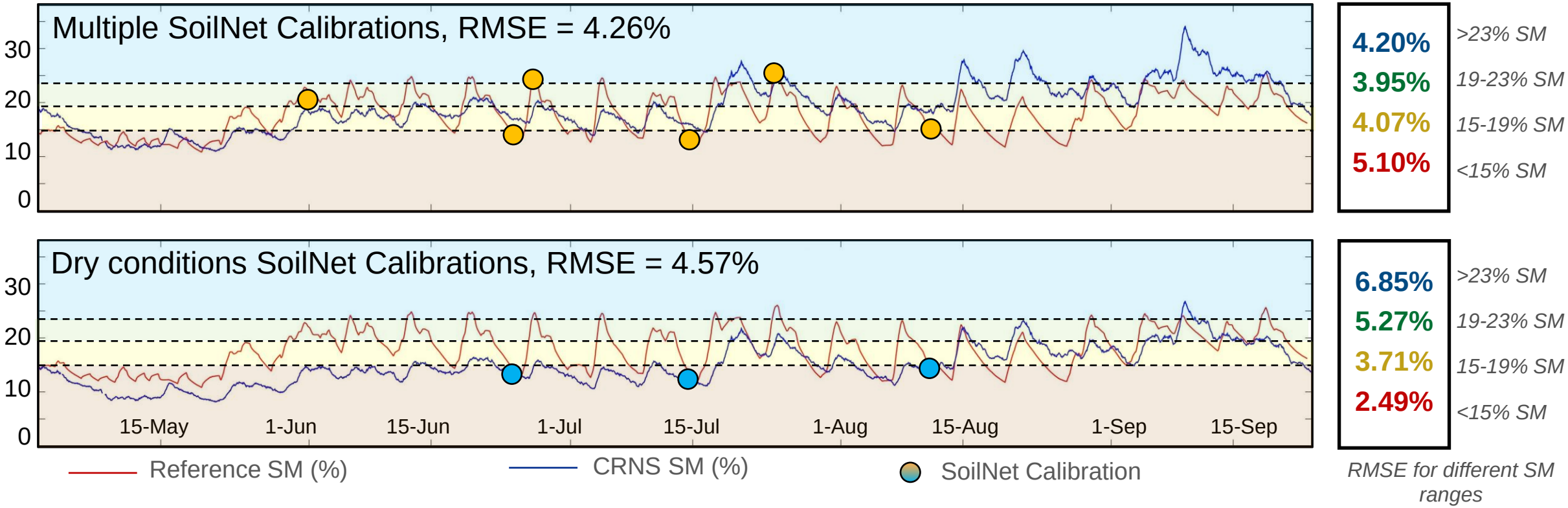
Large deviations between **CRNS** and **reference data** During irrigation.



- Environmental factors affect measurement quality (e.g., irrigation in nearby fields and precipitation)
- Smaller deviations are found in fields with lower agricultural management in nearby fields

Customize CRNS measurements for the end user

Focus the calibration on the occurrence of low soil moisture that can motivate irrigation.



- Different calibration strategies can improve/degrade performance for specific SM intervals

Achievements and Conclusions

- ✓ Improved understanding of neutron transport and CRNS signal in irrigated scenarios
- ✓ Identification of major challenges and of key aspects that can improve/degrade measurement quality, e.g.,:
  - Dimension of the irrigated field
  - Type of moderator
- The large footprint of a CRNS results in influences from surrounding managements
- Calibration strategies can help mitigate such influences for irrigation applications

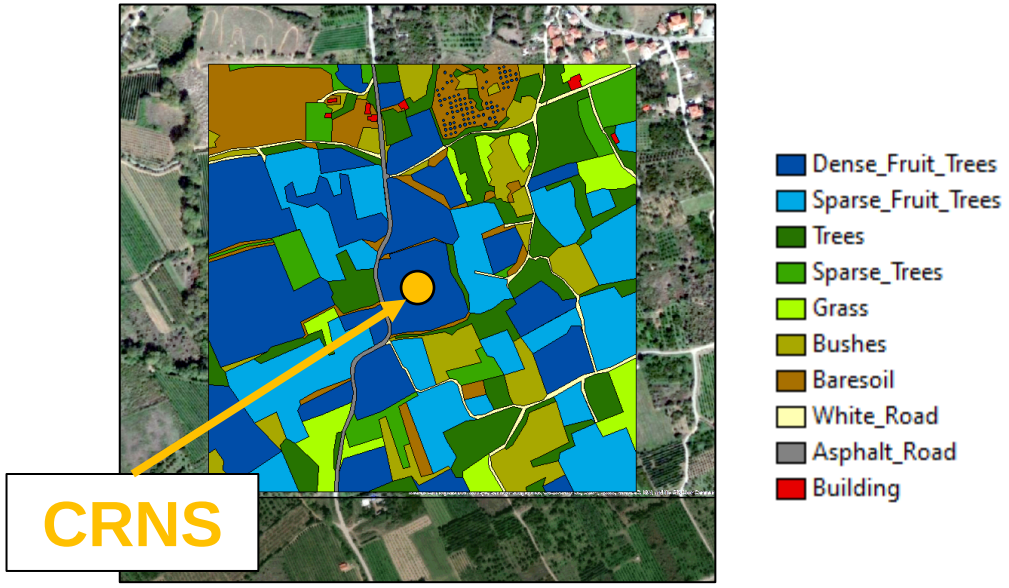
Outlook

- ➢ Evaluation of costs/benefits of CRNS irrigation monitoring prior to installation
- ➢ Correction of CRNS with SM measurements of nearby fields (Summer 2022)
- ➢ Study the influence of biomass growth (e.g., vegetation, apples, and harvest)

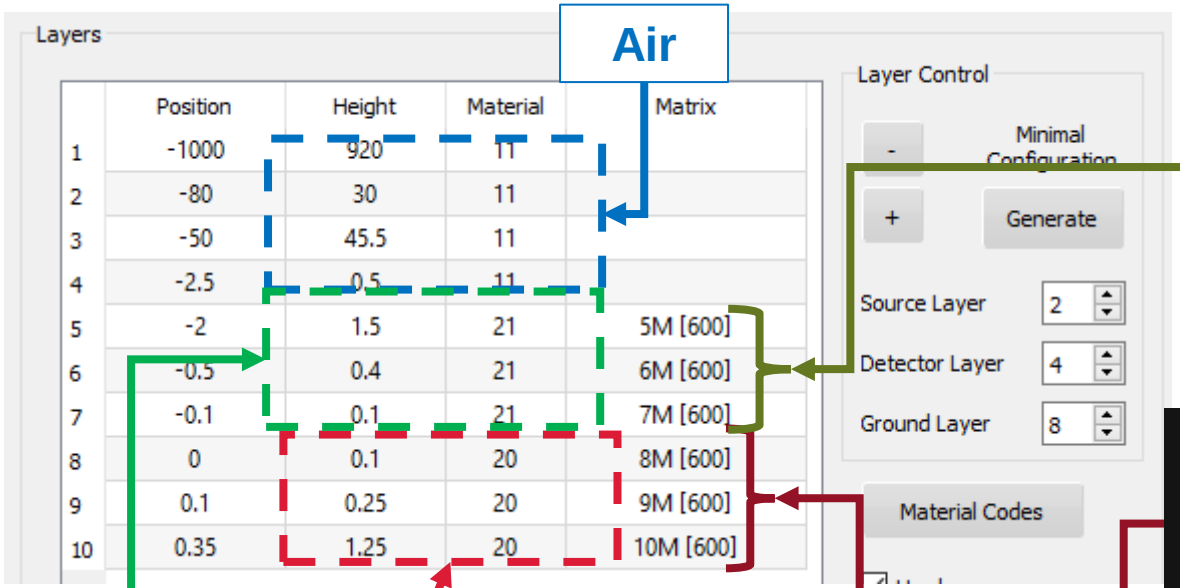
Outlook: URANOS Simulations

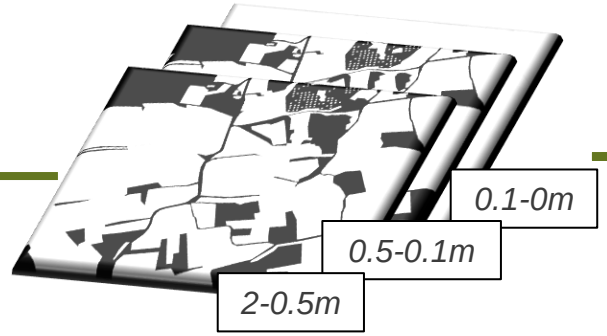
Setup of the actual scenario simulations:

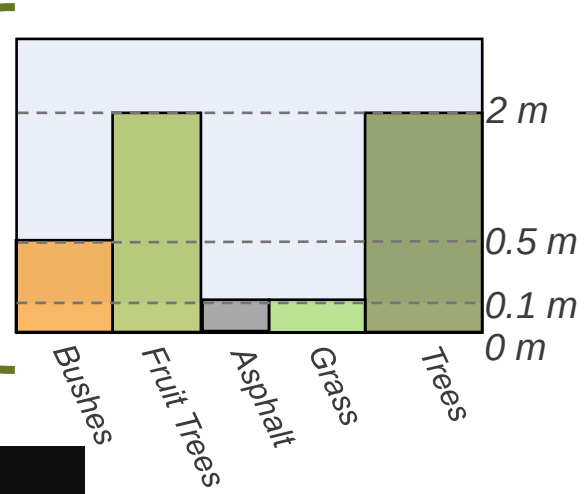
- Irrigation area coincident with actual field
- 8 layers covering 1000 meters of air and 1.6 meters of soil.
  - 4 layers of air (with source/detector)
  - 3 layers of vegetation/air
  - 3 layers of soil (0-0.125, 0.125-0.35, 0.35-1.6)

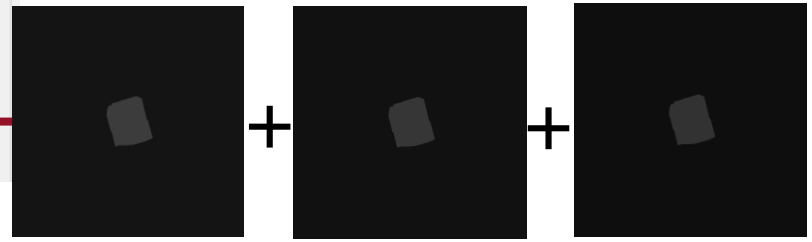


LUSE of the 600x600m domain (satellite image)









Synthetic domain 600x600 meters with irrigated patch

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Horizon 2020
European Union Funding
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ATLAS
AGRICULTURAL INTEROPERABILITY AND ANALYSIS SYSTEM

SWRI
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Cosmic Sense

Thank you for the attention

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