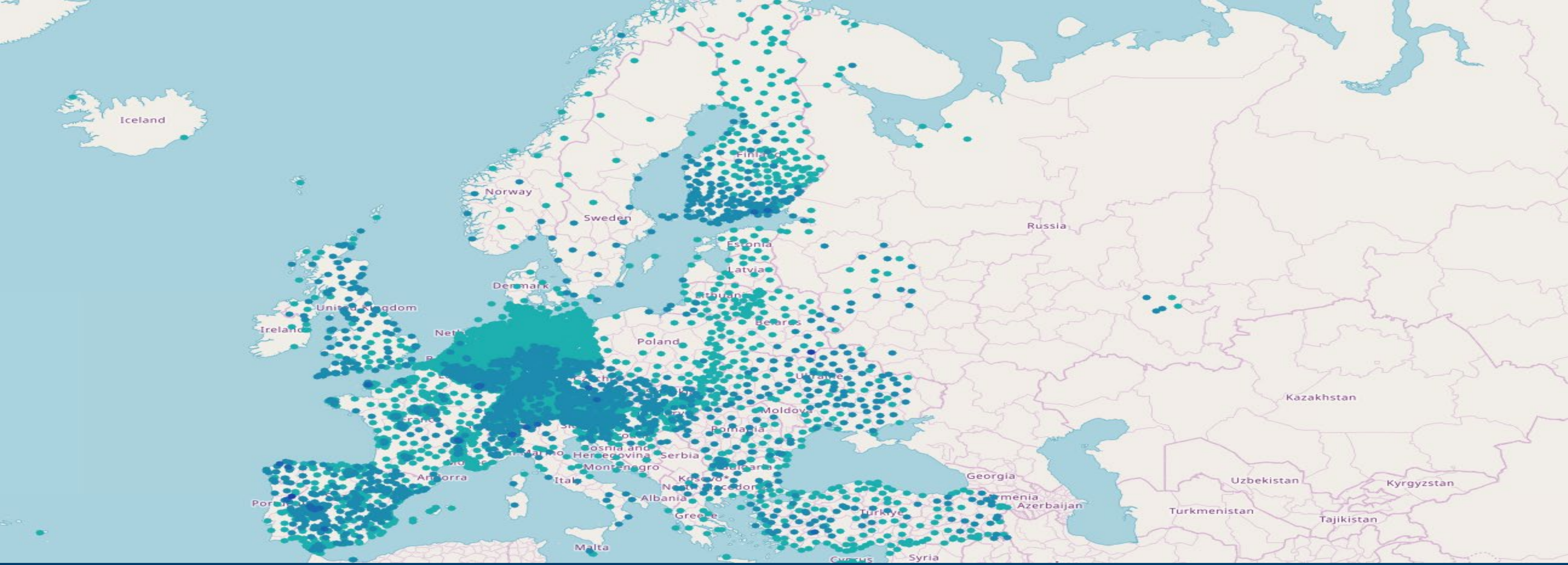

ACCURACY OF ROOT-ZONE SOIL MOISTURE ESTIMATES FROM GAMMA RADIATION MONITORING DATA

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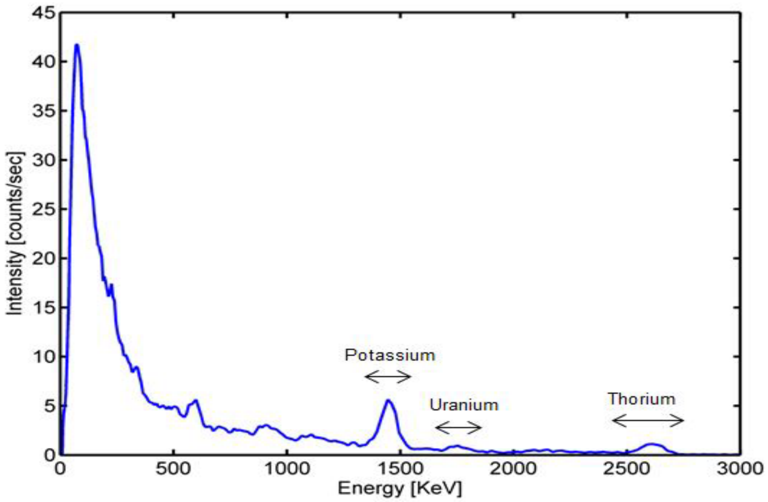
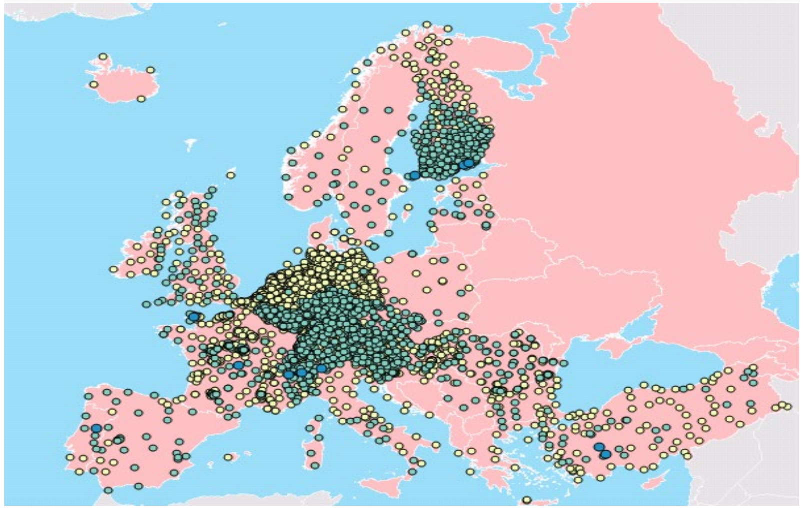
Gamma radiation as a proxy of soil moisture



Gamma ray spectrum

- The terrestrial component of the gamma radiation provides information on soil moisture in the root zone
- Gamma radiation is more attenuated in wet soil compared to the dry soil



EURDEP gamma radiation monitoring network

Source: https://essd.copernicus.org/articles/12/109/2020/

- Possibility to obtain Europe-wide soil moisture
- Lack of information on the radiation energies of the radionuclides present in the soil
- Additional sources of uncertainty may affect the measurement accuracy

Objective of this study

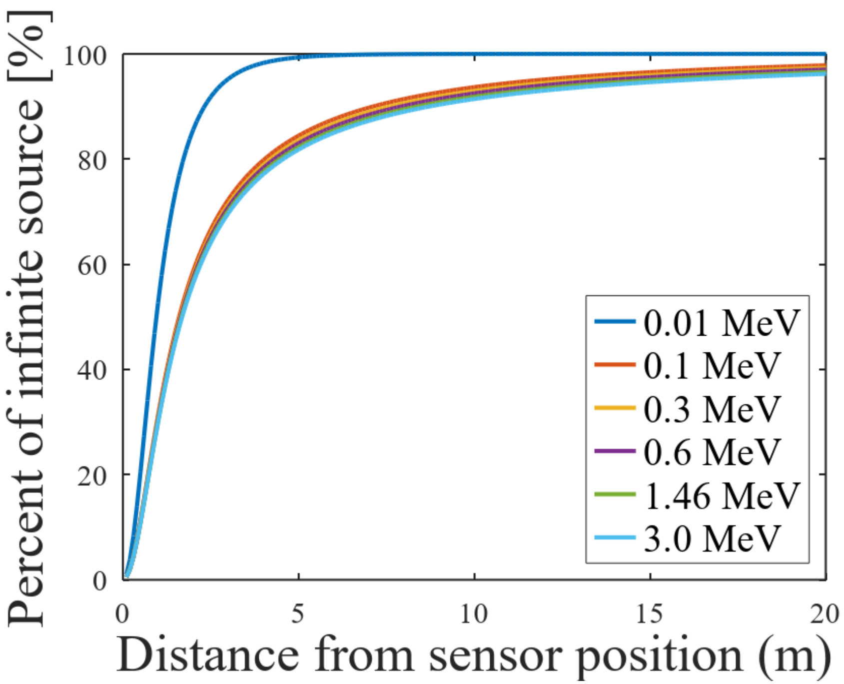
Assess accuracy of soil moisture derived from standard gamma radiation monitoring detectors

Footprint and Sensing depth

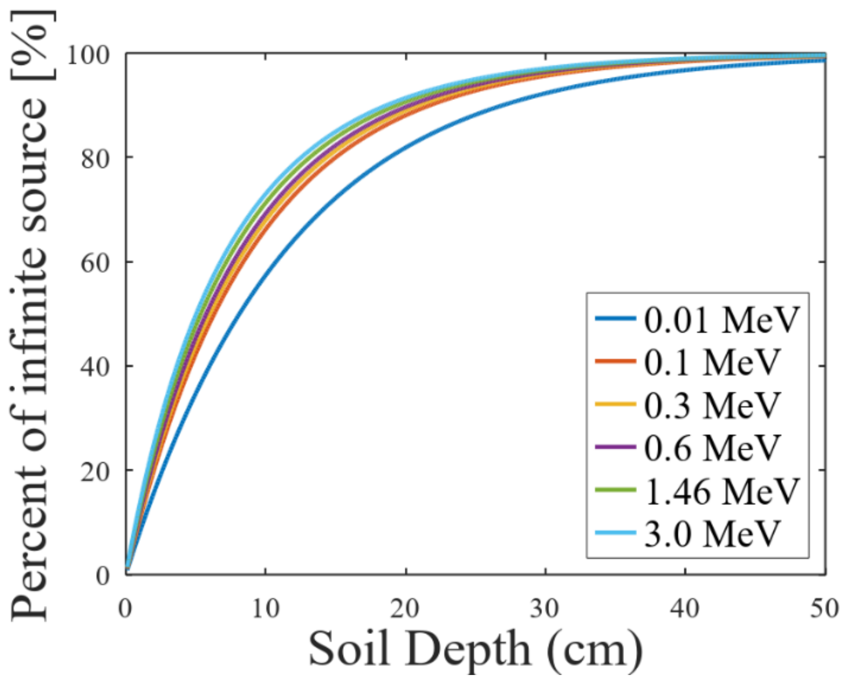
- Straight-ray propagation model assuming mono-energetic attenuation

$$dI = \frac{A\varepsilon}{4\pi R^2} \exp - (\mu_e r_e + \mu_a r_a) dV$$

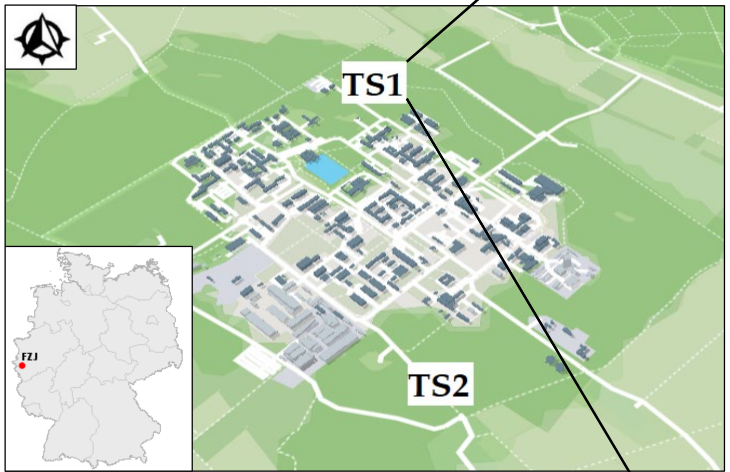
- **Radial footprint**: 5–10 m, independent of soil properties (0.1–3 MeV)



- **Sensing depth**: ~20 cm, depends on water content and porosity (0.1–3 MeV)



Experimental setup of the pilot study



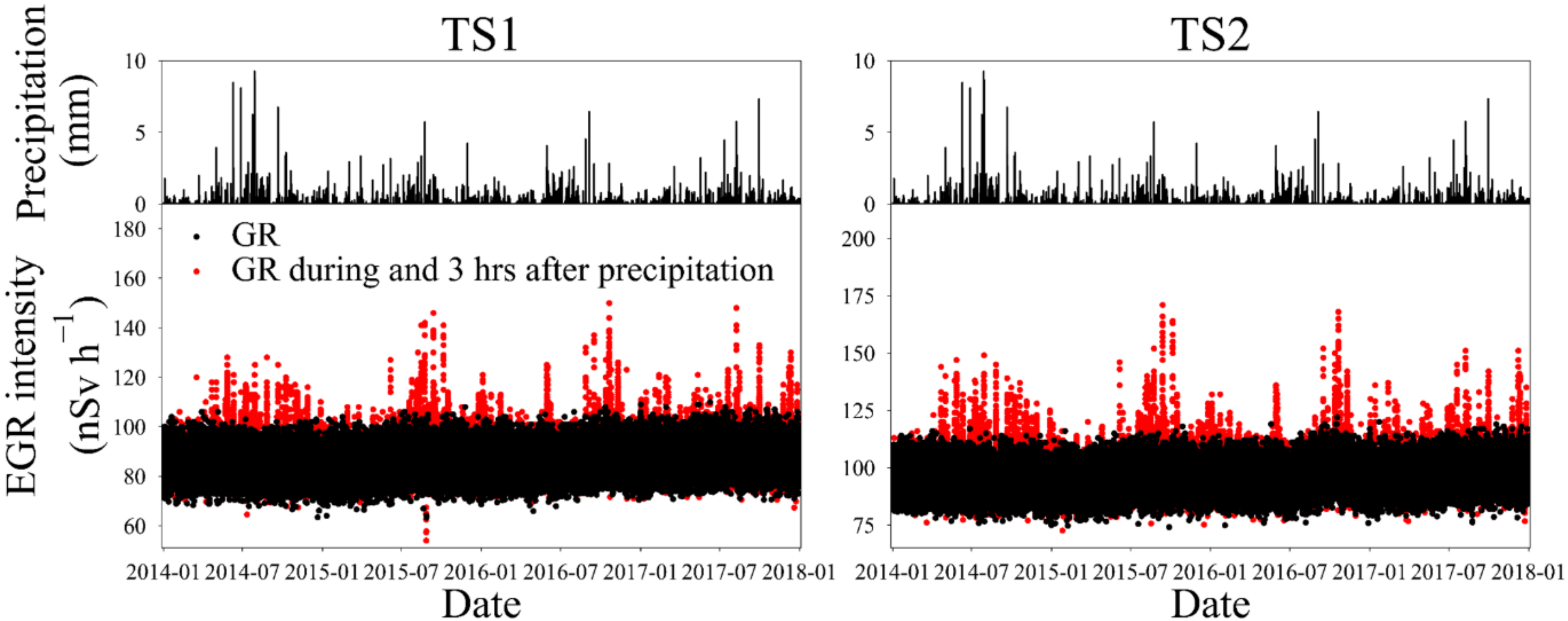
Gamma radiation detectors

SoilNet reference stations:
Eight soil moisture sensors per site distributed in the footprint

- Long-term monitoring data of gamma radiation at two sites available
- Reference in-situ soil moisture and meteorological data

Gamma radiation correction

- Atmospheric radon progenies washed out by precipitation are responsible for short-term increases in gamma radiation
- Using a filter, these GR peaks can be removed:

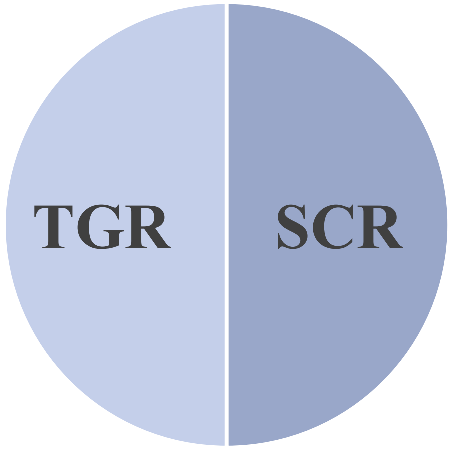


Extracting terrestrial radiation component

- The measured gamma radiation (R) is composed of:

$$R = R_{TGR} + R_{SCR} + R_{AR}$$

R_{TGR}	R_{SCR}	R_{AR}
Terrestrial gamma radiation	Secondary cosmic radiation	Artificial radiation
Radionuclides present in soil	Generated from cosmic rays	e.g. Nuclear tests and accidents



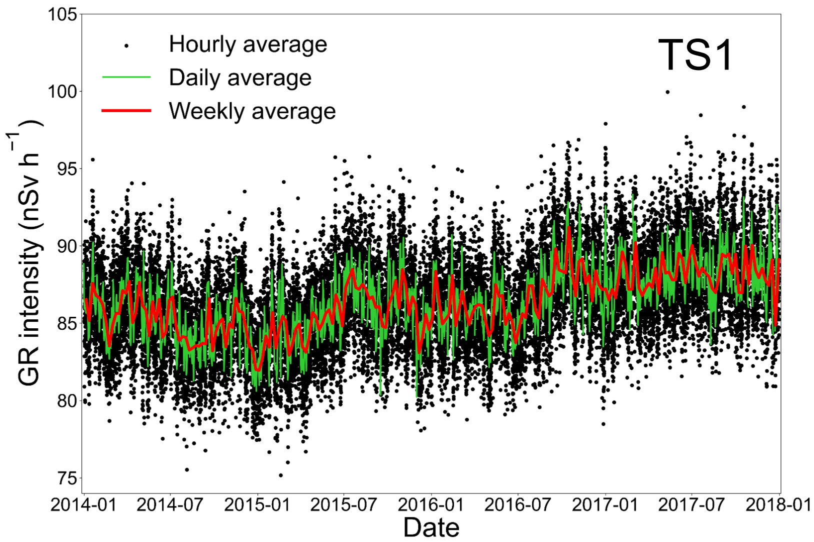
- Simplified equation:

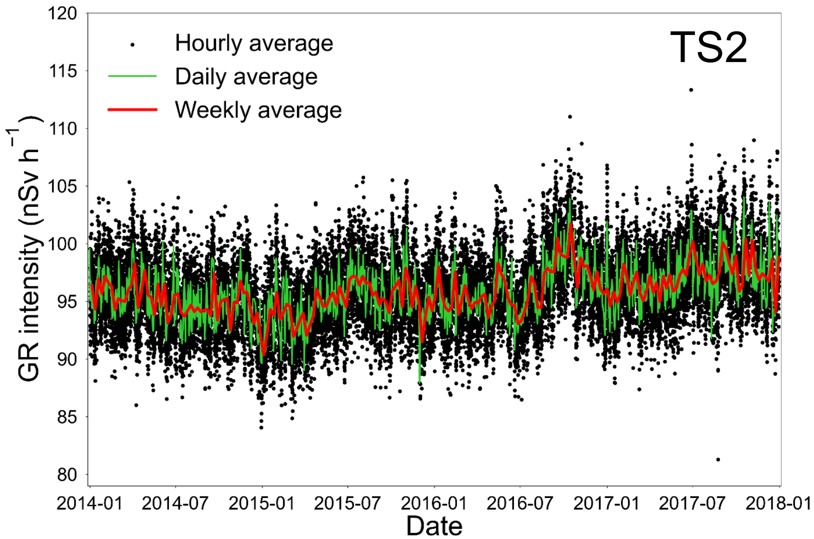
$$R_{TGR} = R - R'_{SCR}$$

- Long-term average fraction of SCR is assumed to be 50 %
- Correction for short-term variations due to air pressure and incoming neutron intensity

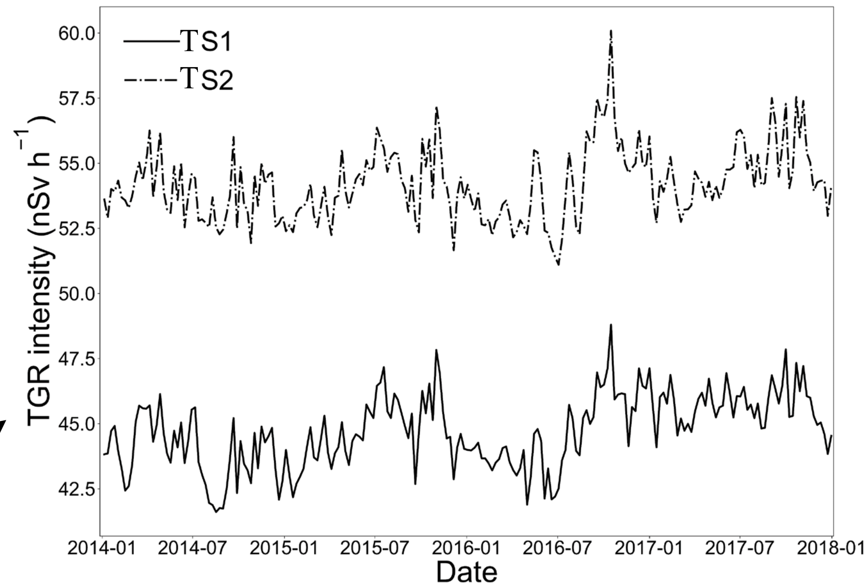
Extraction of the terrestrial component

Measured gamma radiation





Terrestrial gamma radiation



Test site	Correlation coefficient, r	
	Atmospheric pressure	Incoming neutron count
1	-0.37→0.14	0.58 →0.33
2	-0.43→0.03	0.47→0.20

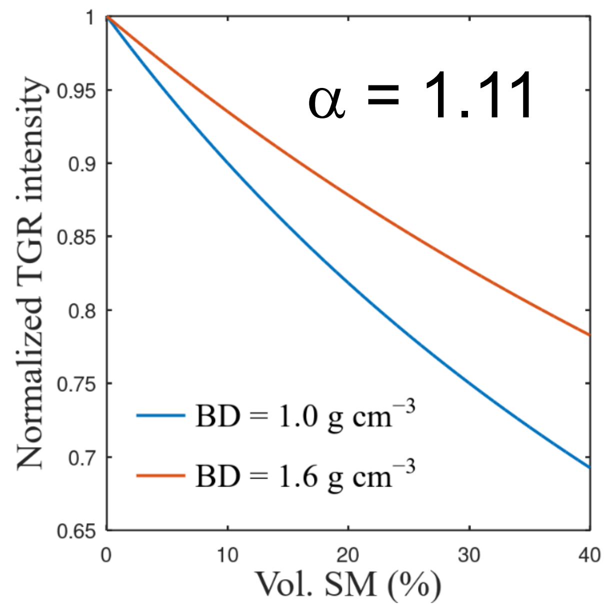
Conversion of TGR intensity to soil moisture

- Normalized TGR as a function of the vol. water content:

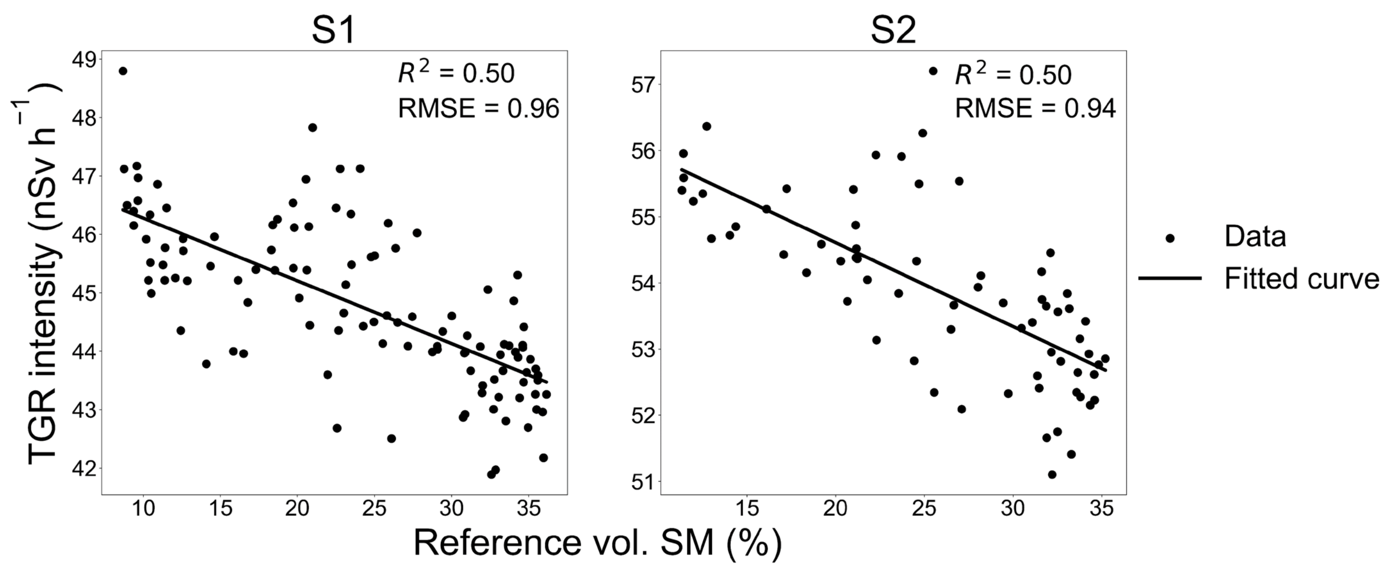
$$\frac{R_{TGR}}{R_{TGR,dry}} = \frac{1}{1 + \alpha \frac{\theta \rho_w}{\rho_b}}$$

α: Ratio of TGR mass attenuation coefficients for water and solid phases

- For homogenous sources and energies >0.4 MeV



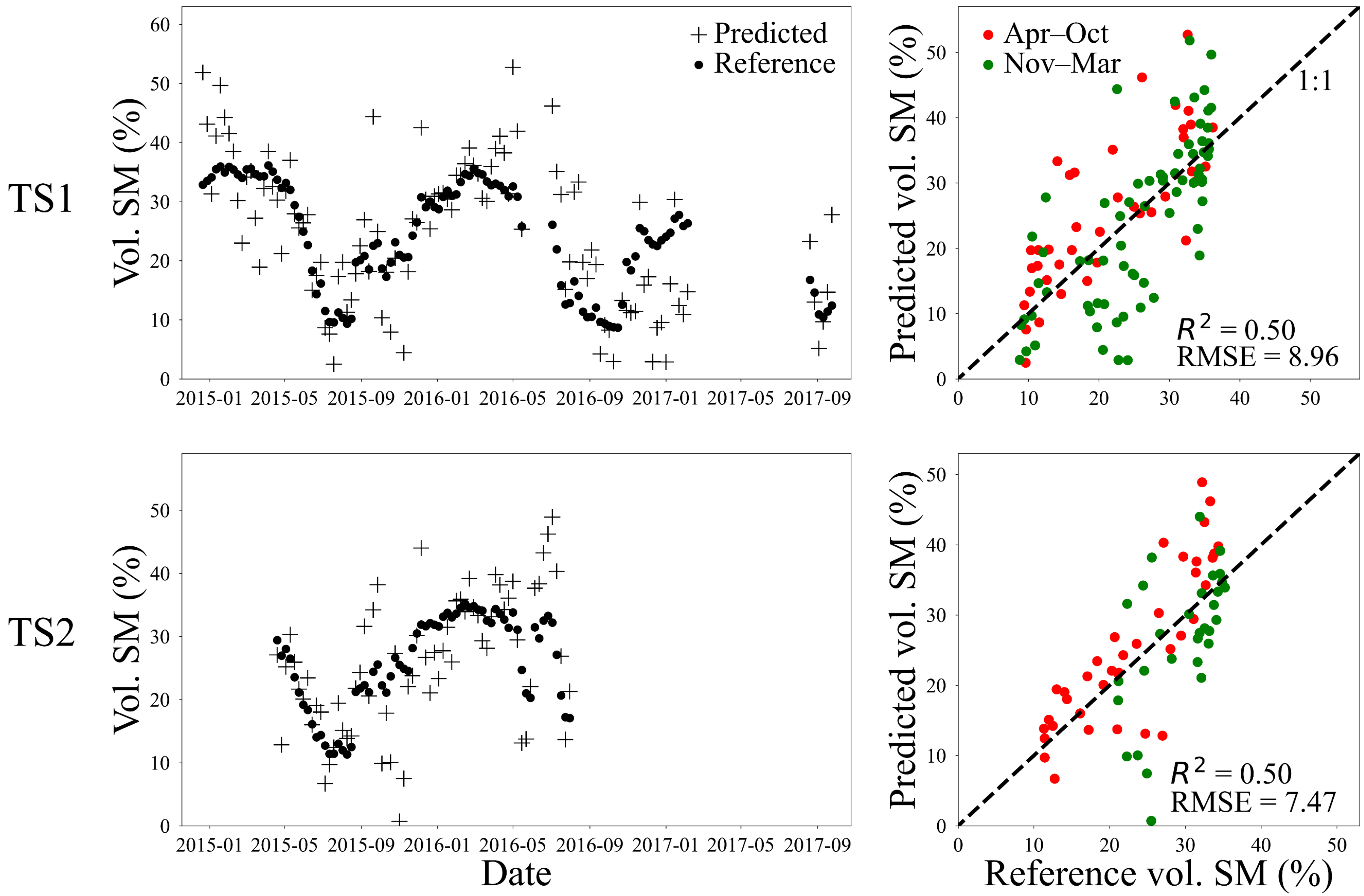
Calibration results:



Test site	$R_{TGR,dry}$	α
1	47.47	0.404
2	57.31	0.397

→ $\alpha \sim 0.4$ suggests a high contribution of low-energy gamma-rays

Accuracy of soil moisture predictions



- The seasonal variation of soil moisture was reasonably well predicted
- Uncertainty in weekly soil moisture estimates ranges from 7 to 9 vol.%

Conclusions from the pilot study

- Weekly soil moisture estimation from GR monitoring is feasible

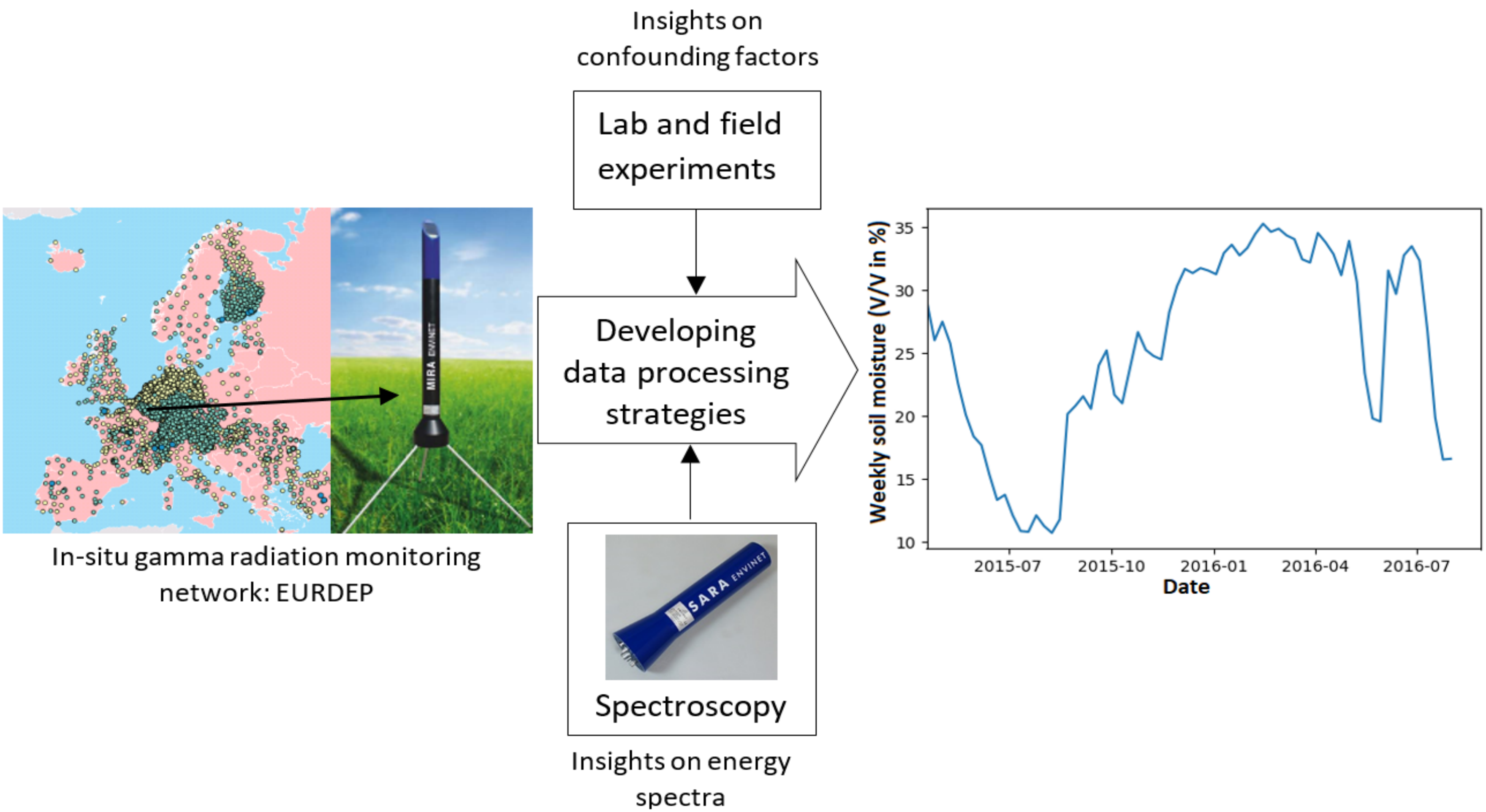
  Submitted in Vadose Zone Journal

- Possible sources of error:
  - Observed GR mainly originated at low energy associated with more noise
  - Variable influence of cosmic radiation
  - Unconsidered influences, e.g. radon emissions from the soil

→ More investigations are needed to understand those confounding factors

Next step

- Using additional measurements and experiments to enhance data processing:

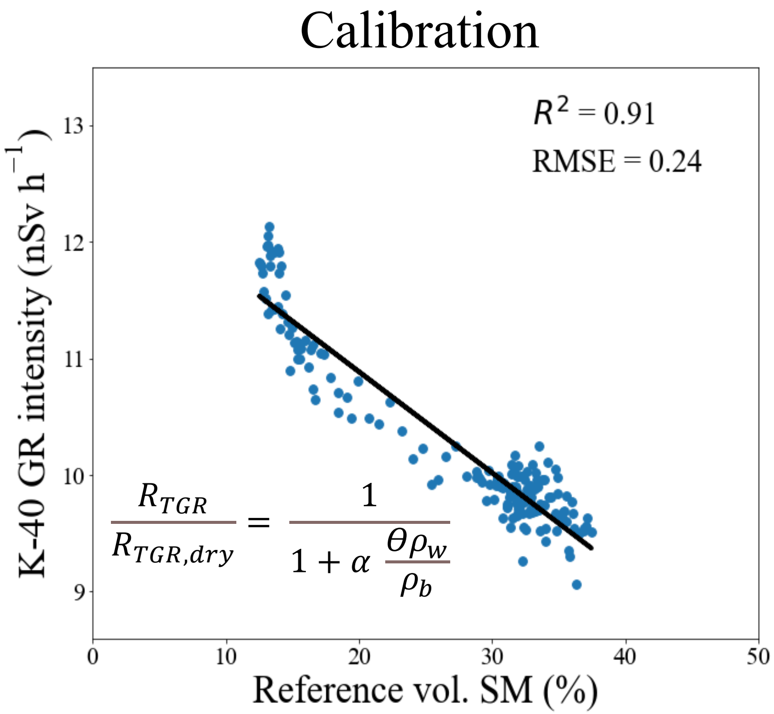


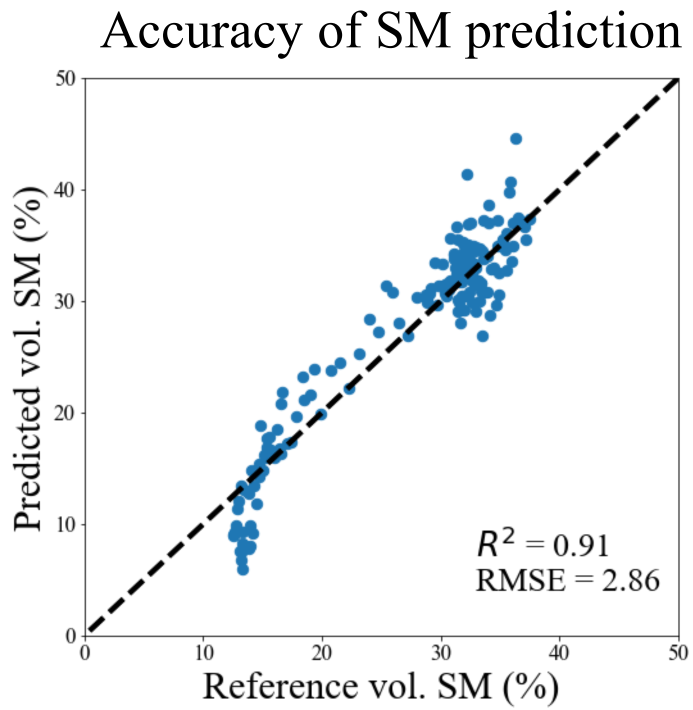
Ongoing measurements: SARA and MIRA sensors

- Improve the interpretation of the integrated gamma radiation measurements by combining measurements at different sites:
  - Agricultural test site Selhausen
  - Grassland test site Rollesbroich
  - Forest test site Wüstebach

TERENO/ICOS site Selhausen

First results: Soil moisture from Potassium-40 radiation





Parameters	Values
ρ_b	1.2
$R_{TGR,dry}$	**12.80**
α	1.11

- Higher accuracy of soil moisture prediction from gamma radiation originating at a specific single energy compared to bulk gamma radiation measurements

Thanks for your attention

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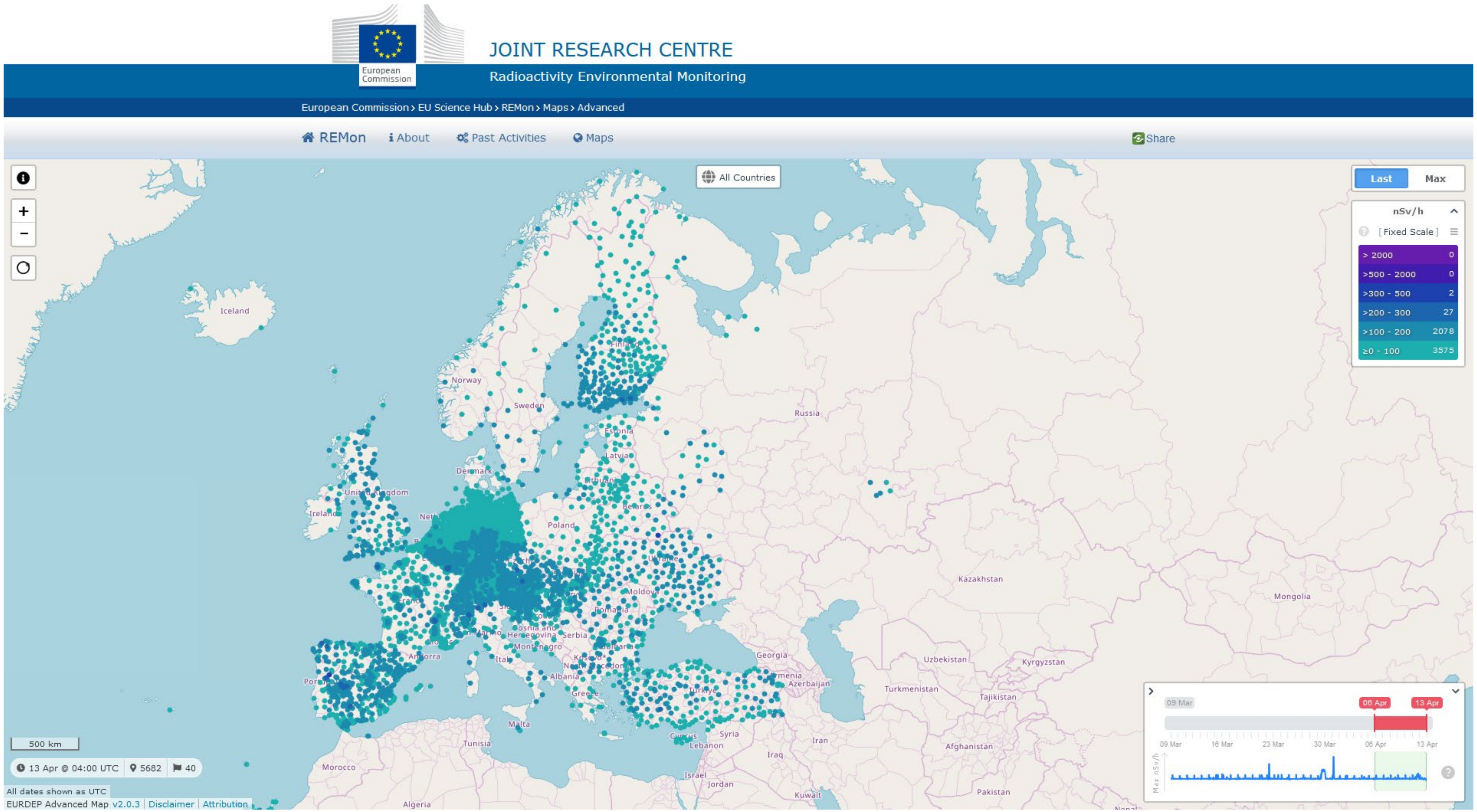
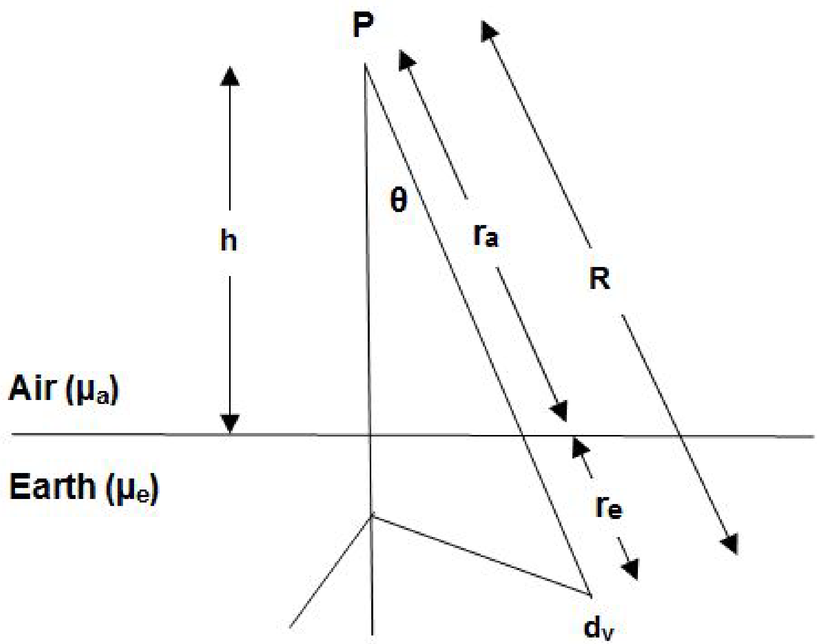
Additional information

EURDEP map



The EURDEP network of gamma radiation intensity monitoring (https://remap.jrc.ec.europa.eu/Advanced.aspx accessed on 13.04.2023 04:00 UTC).

Model for gamma radiation measurements



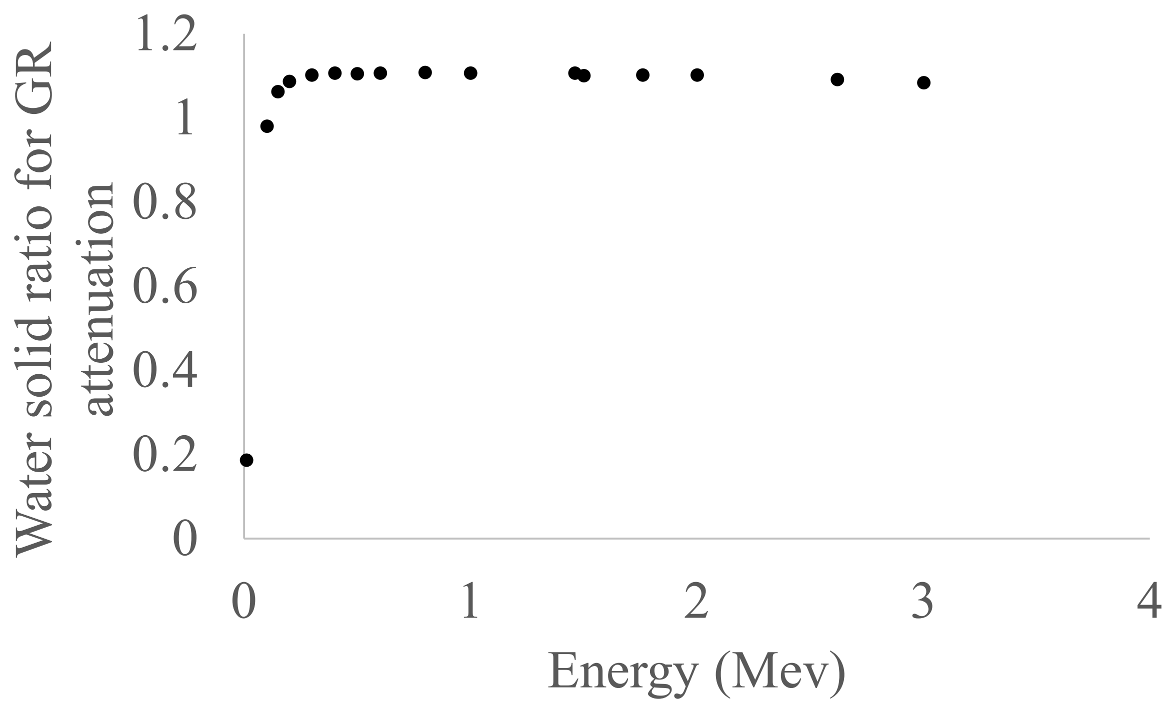
$$dI = \frac{A\varepsilon}{4\pi R^2} \exp -(\mu_e r_e + \mu_a r_a) dV$$

- Model assumes straight-ray propagation and mono-energetic attenuation.
- Equation can be integrated over different geometries to obtain estimates of:
  - Sensing depth
  - Measurement footprint
  - Relationship between gamma radiation and volumetric water content

Gamma-ray attenuation

- Attenuation coefficients strongly depend on the gamma radiation energy

Energy	μ_{mw}	μ_{ms}	μ_{ma}
100 keV	0.168	0.171	0.151
1.46 MeV	0.058	0.053	0.053



Removing contribution of cosmic radiation

$$R'_{SCR} = (R_{\mu,mean} - 0.051\,(P - P_{ref})(1 + 0.52 \times \Delta N_m)) + (R_{n,mean} - 0.076\,(P - P_{ref})(1 + \Delta N_m))$$

R'_{SCR} : corrected secondary cosmic radiation (SCR) contribution

$R_{\mu,mean}$: 32.7 nSv h^{-1} is the average muon intensity at sea level

$R_{n,mean}$: 8 nSv h^{-1} is the average neutron intensity at sea level

P_{ref} : 1013.25 is the standard atmosphere pressure at sea level

P : atmospheric pressure at the test site

ΔN_m : relative deviation of incoming neutron count from the average