Discriminating irrigation and rainfall with proximal γ-ray spectroscopy

Università degli Studi di Ferrara

INFN

Laboratory for Nuclear Technologies Applied to the Environment

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Summary

» Experimental site and setup

» Field of View of a γ-ray station

» Rationale behind proximal γ-ray spectroscopy

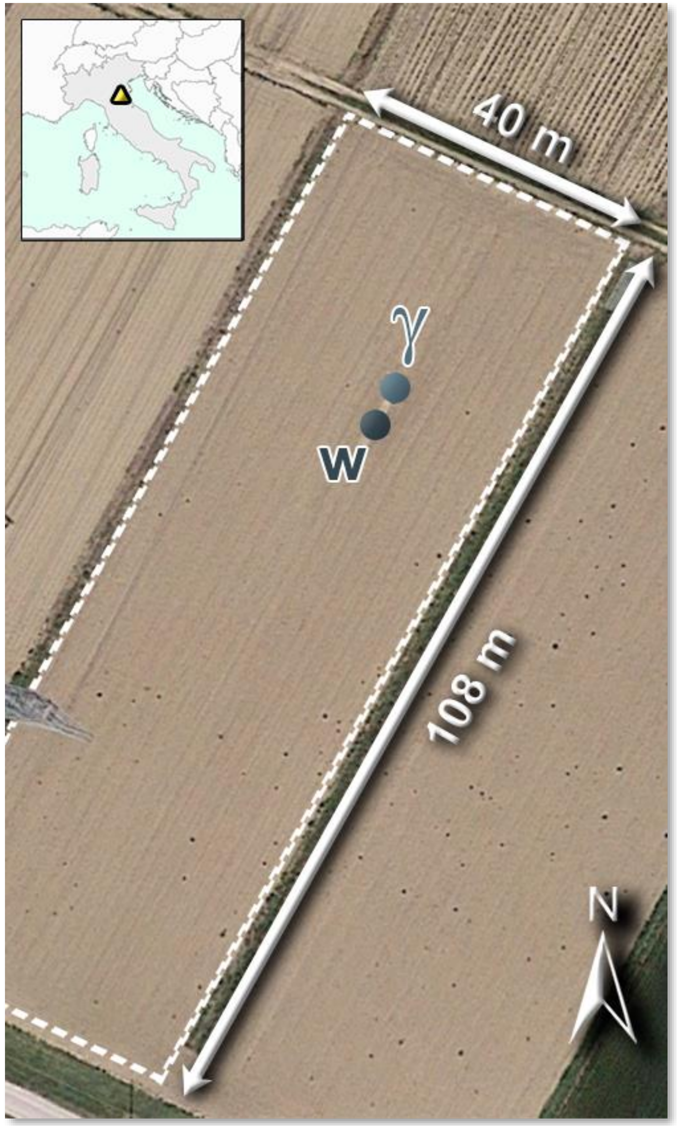
» Sensing rain through γ-ray spectroscopy

   » Genesis of rain-induced γ activity

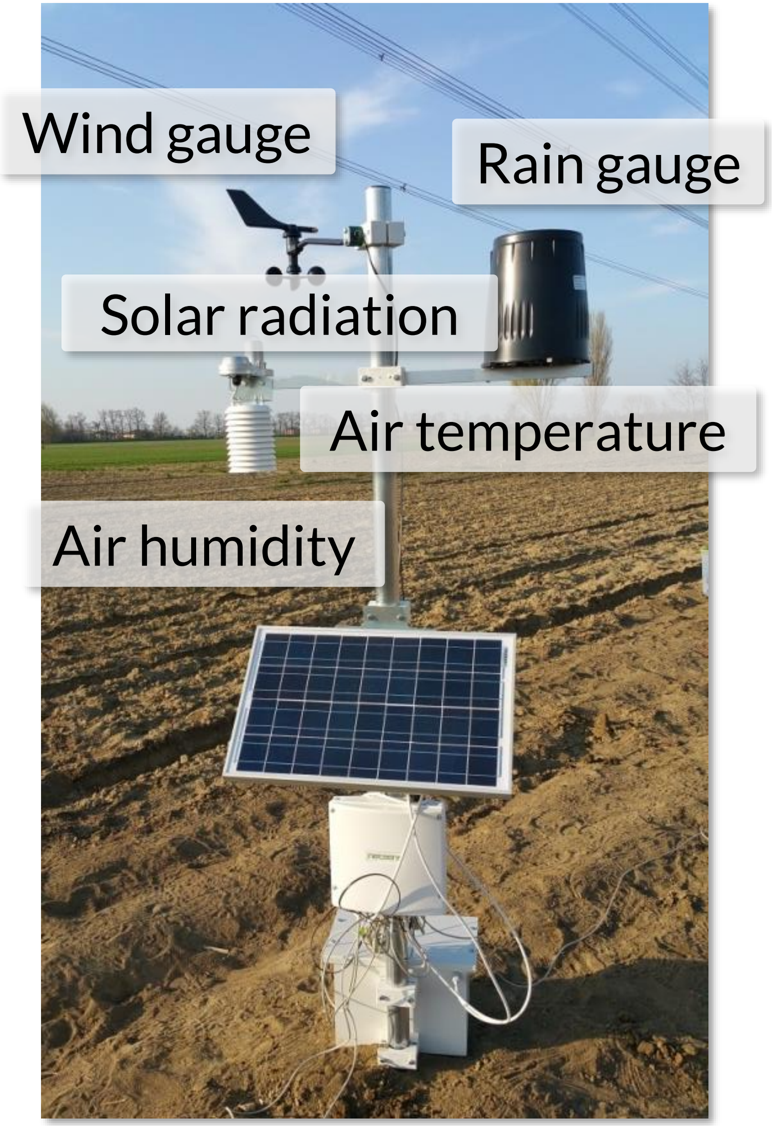
   » Modeling of rain-induced γ activity

» Discriminating rains and irrigations

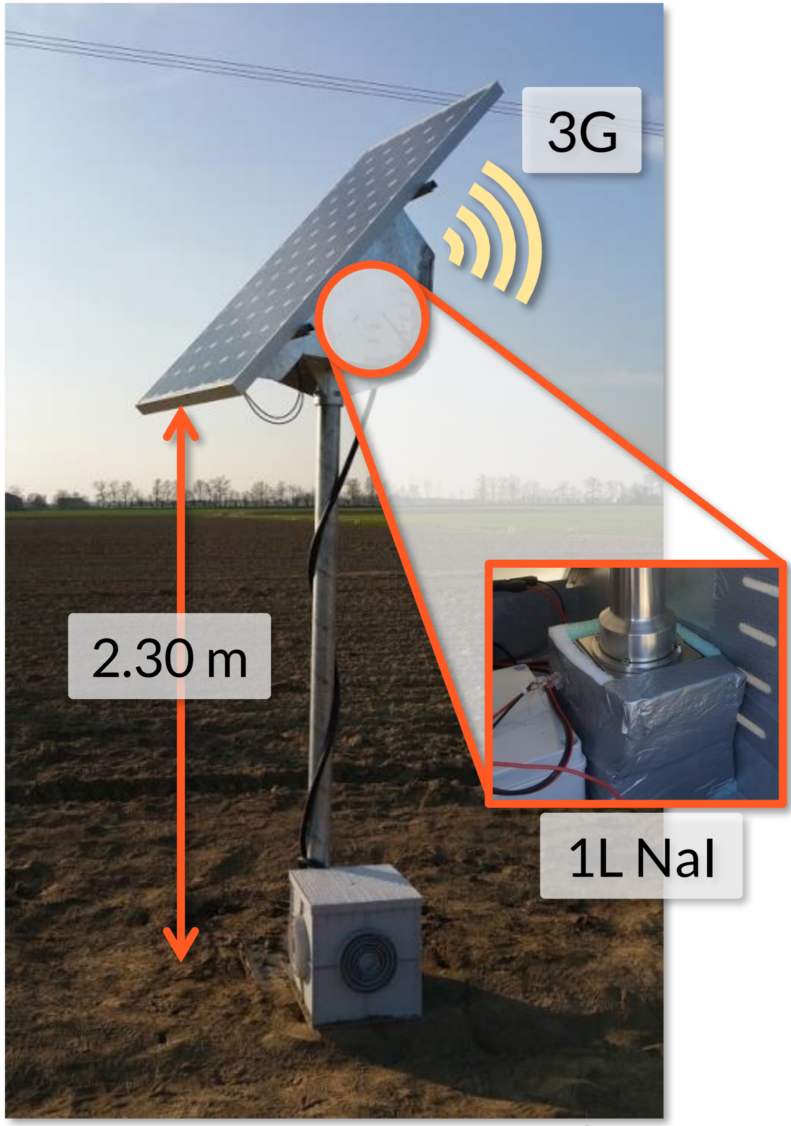
Experimental site



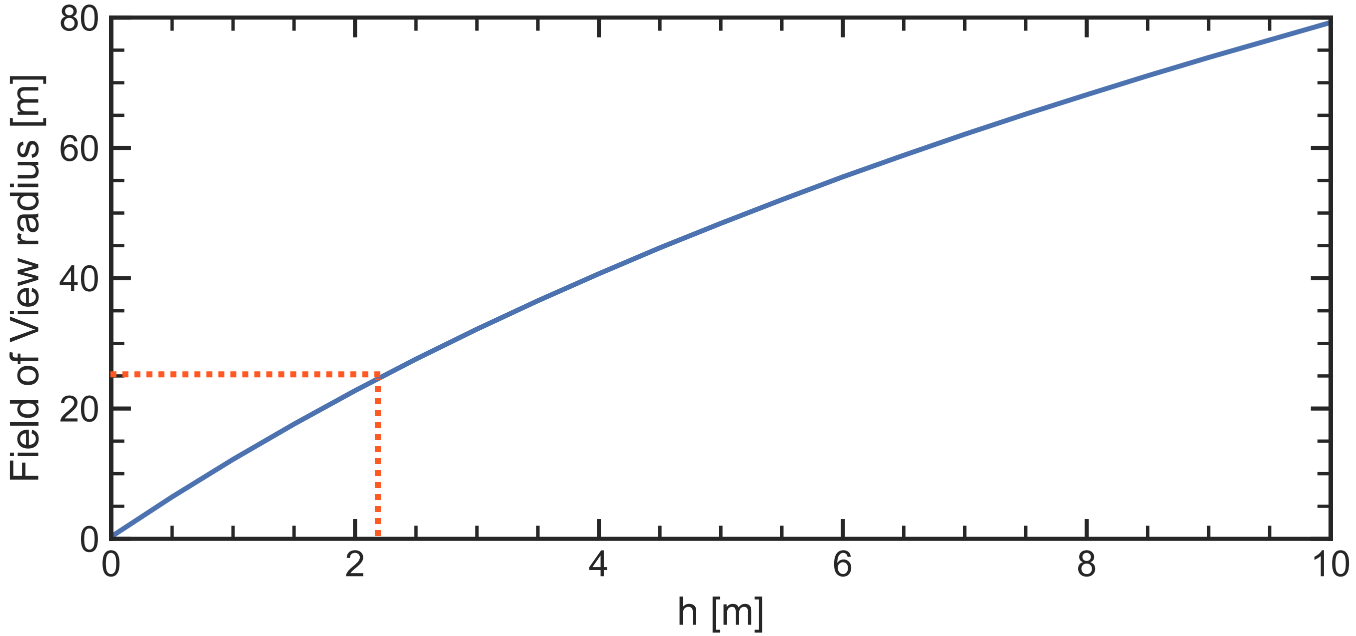
Agrometeorological station (w)



Gamma station (γ)



Field-scale measurements with γ-rays spectroscopy

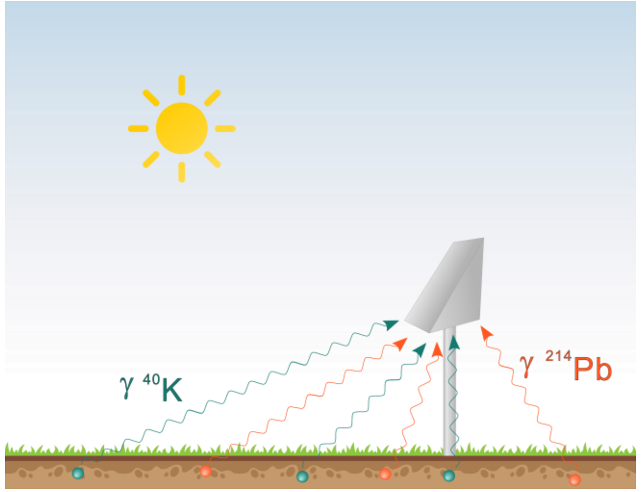


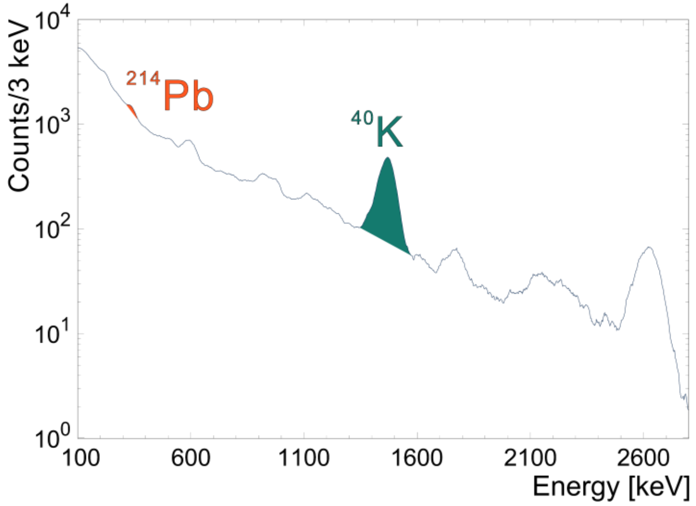
γ-rays are high energy photons which can travel **hundreds of meters** in air.

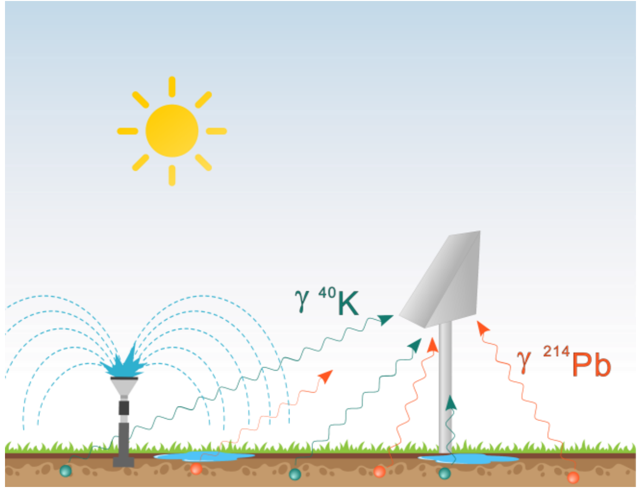
By carefully adjusting the installation **height**, the station can collect γ-rays and **information** coming from **large areas**.

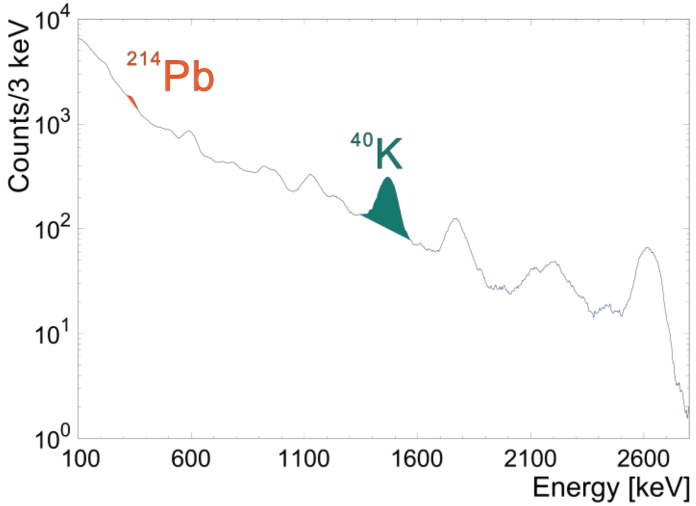
By placing the station at **2.30 m** it is possible to cover a **~25 m radius** footprint area.

Sensing an irrigation through γ-rays







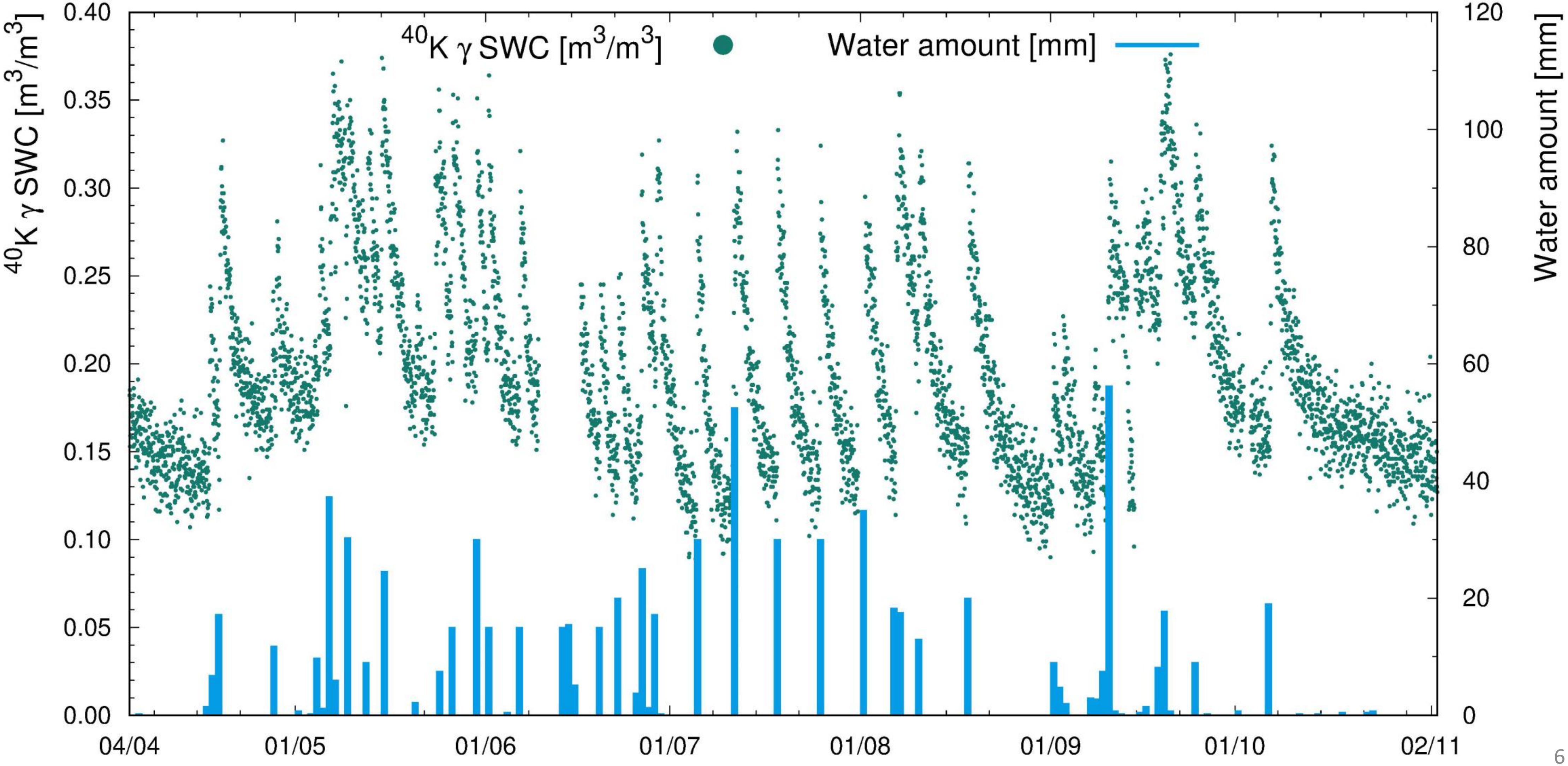


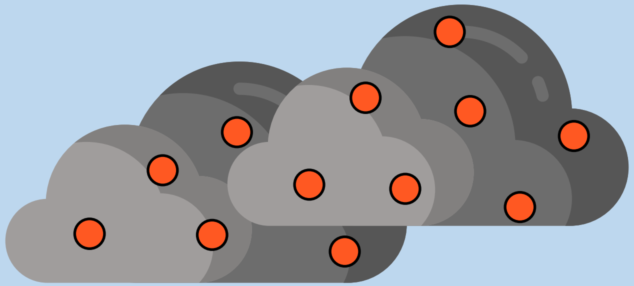
After an irrigation, the γ signal is **attenuated** by the **water deposited** between the emitters (i.e. the **soil**) and the detector.

The soil water content w (V_{water}/V_{soil}) is **inversely proportional** to the signal S_K produced by the ^{40}K decay measured by the detector:

$$w(t) = \frac{A}{S_K(t)} - B$$

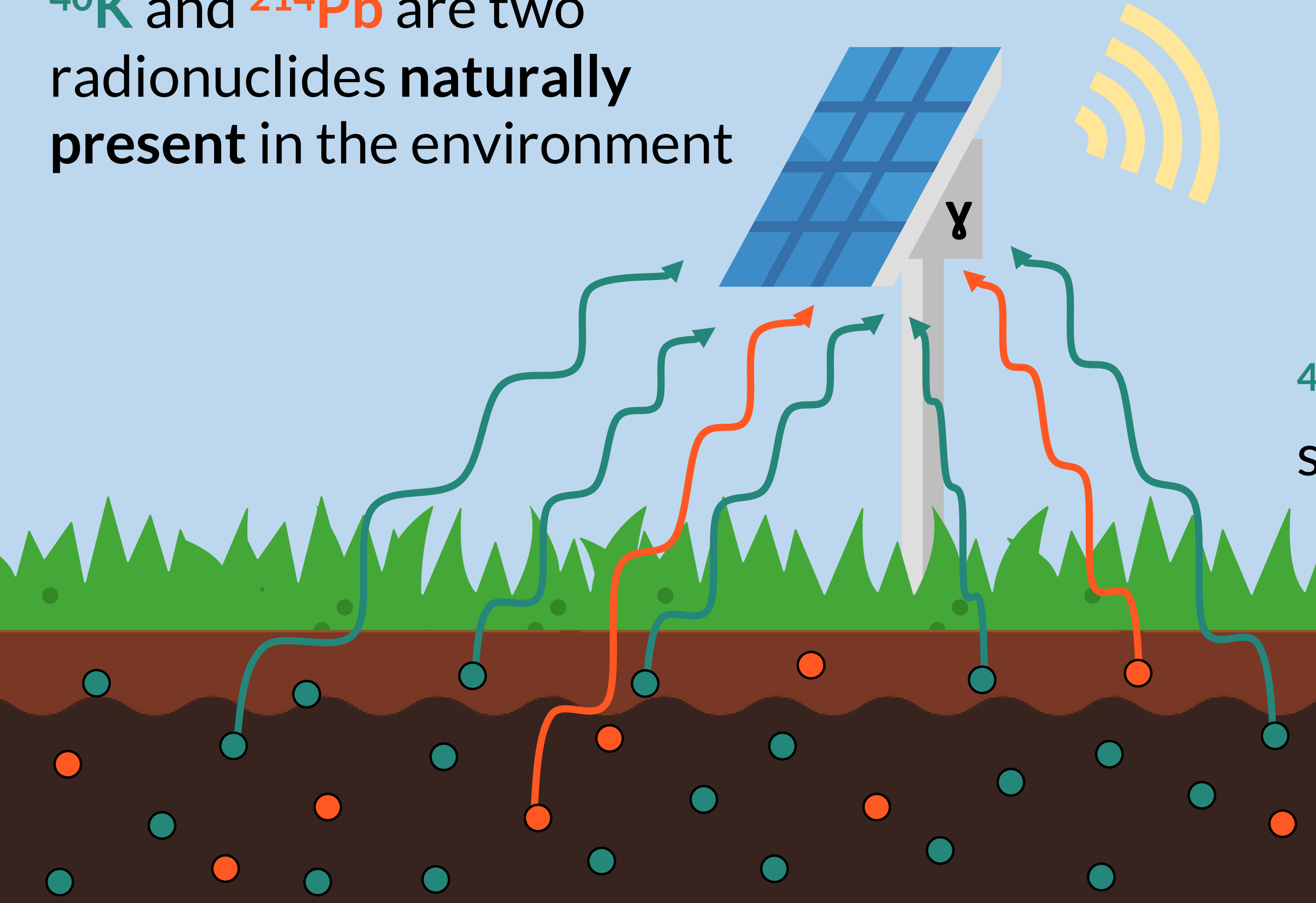
Time series of the estimated soil water content

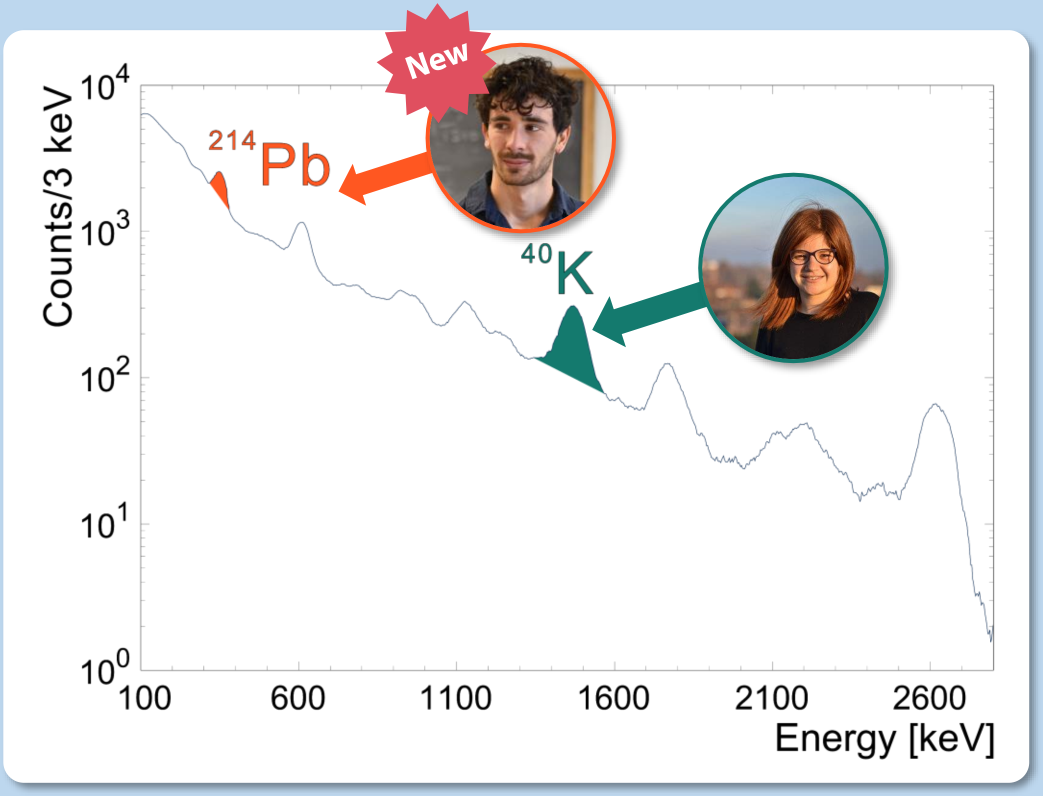




^{214}Pb is a decay product of **radon**, which is present in the atmosphere

^{40}K and ^{214}Pb are two radionuclides **naturally present** in the environment

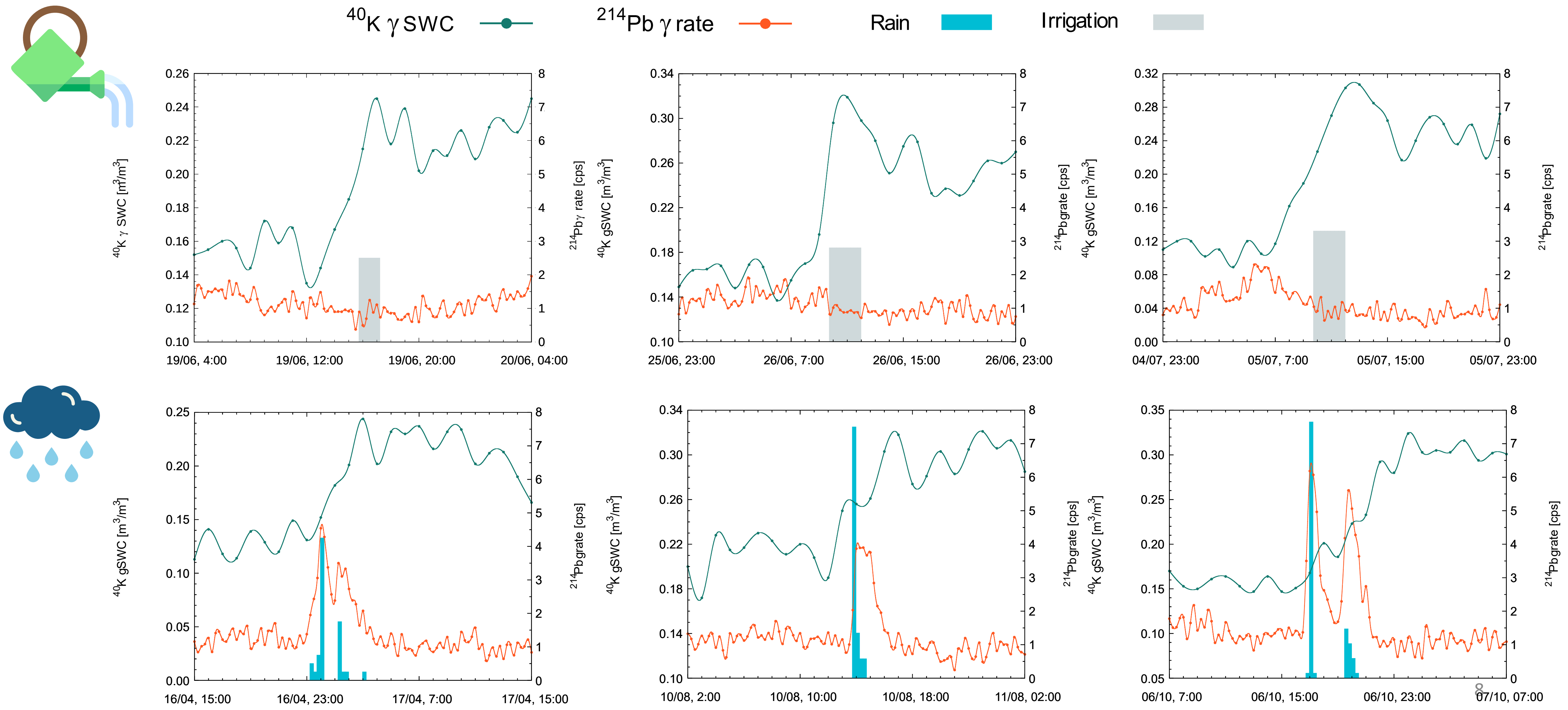




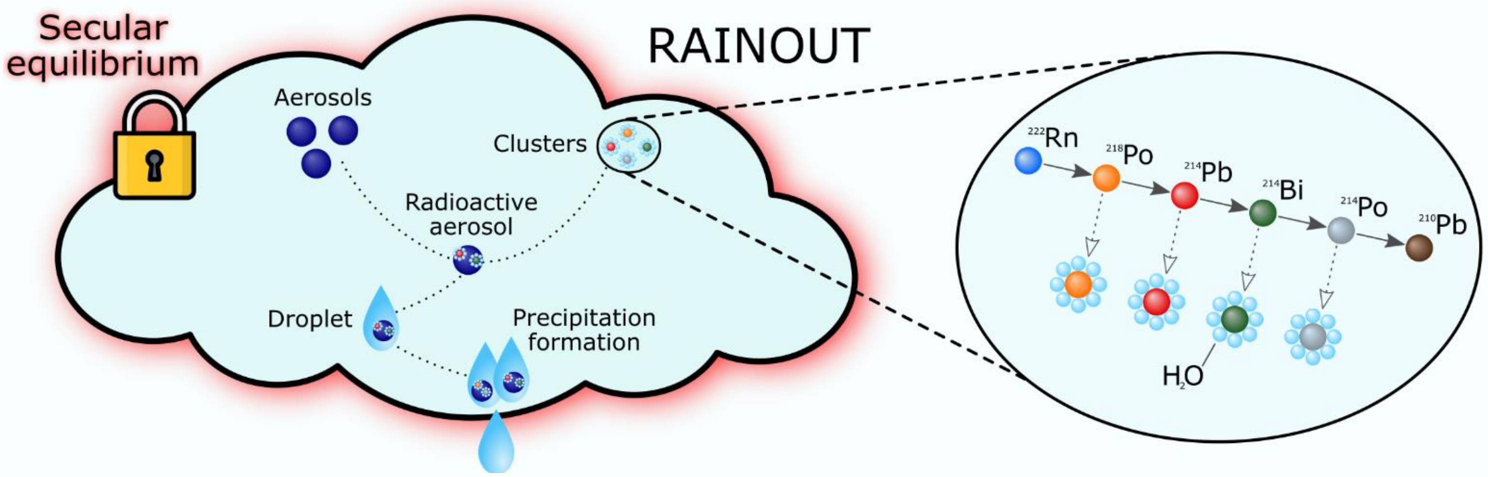
^{40}K and ^{214}Pb emit **ɣ-rays** that can be sensed by spectroscopic stations

^{40}K and ^{214}Pb are **homogeneously** distributed in **soils.**
Their abundance is **constant in time.**

An experimental observation…



Genesis of rain-induced γ activity



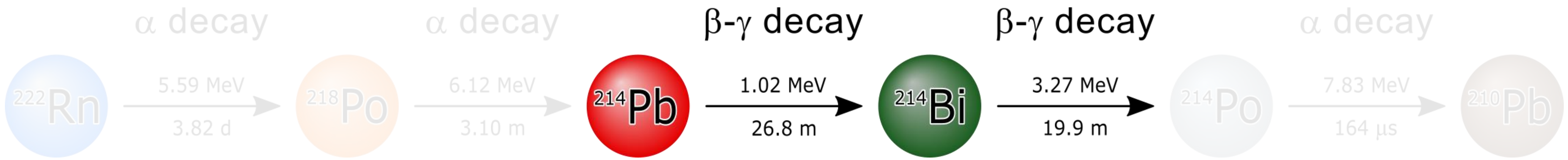
1

RAINOUT (in-cloud process): radon daughters attach to aerosols which are scavenged by rain droplets.

2

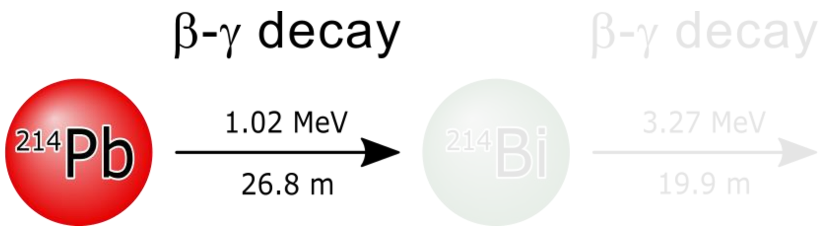
WASHOUT (below cloud p.): raindrops, falling, collect radon daughters' nuclei present in the atmosphere.

Genesis of rain-induced γ activity

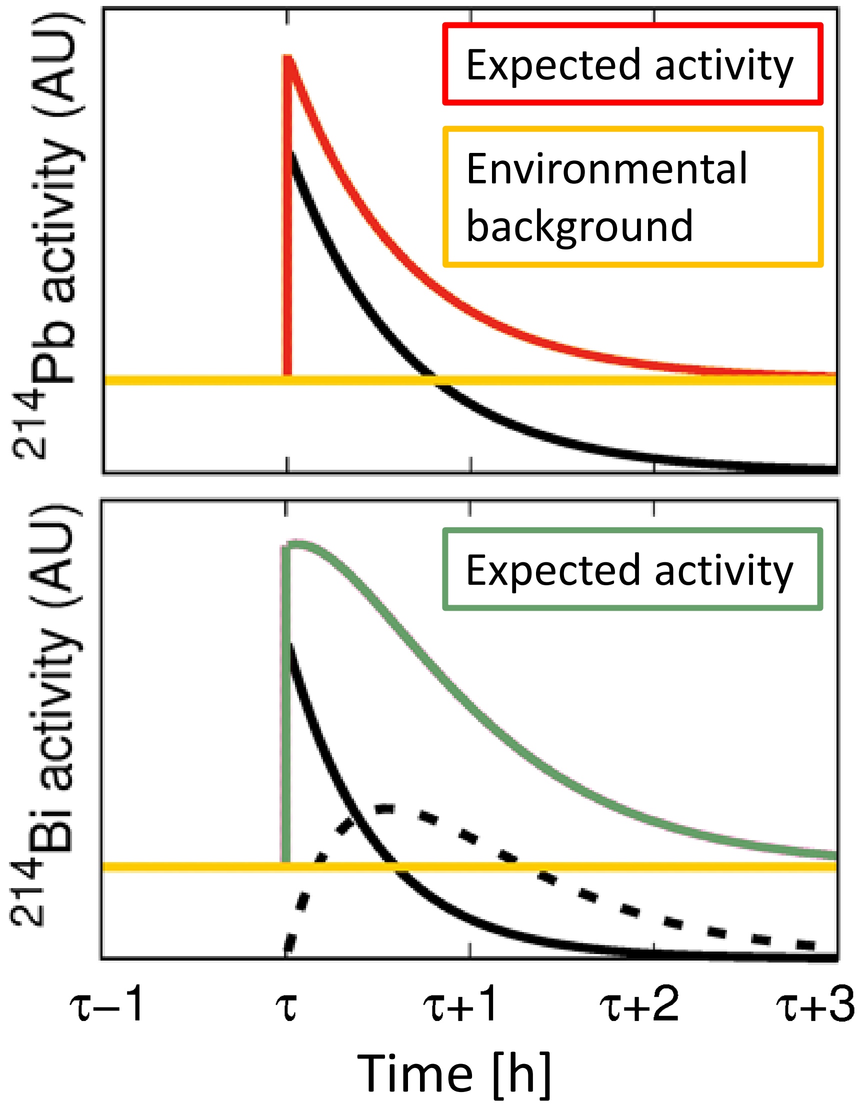


- The enhancement in activity is induced by the atmospheric ^{214}**Pb** and ^{214}**Bi**, gamma emitters **daughters of** ^{222}**Rn**.
- These radon daughters fall from the clouds **to the ground with a precipitation**, leading to an increase in the activity beyond the terrestrial background.
- Such an activity augmentation is measurable using **gamma-ray spectroscopy** techniques.
- ^{214}**Pb** (half-life = 26.8 min) can be observed through its gamma line at E_γ = 351 keV;
  ^{214}**Bi** (half-life = 19.9 min) can be observed through its gamma line at E_γ = 609 keV.

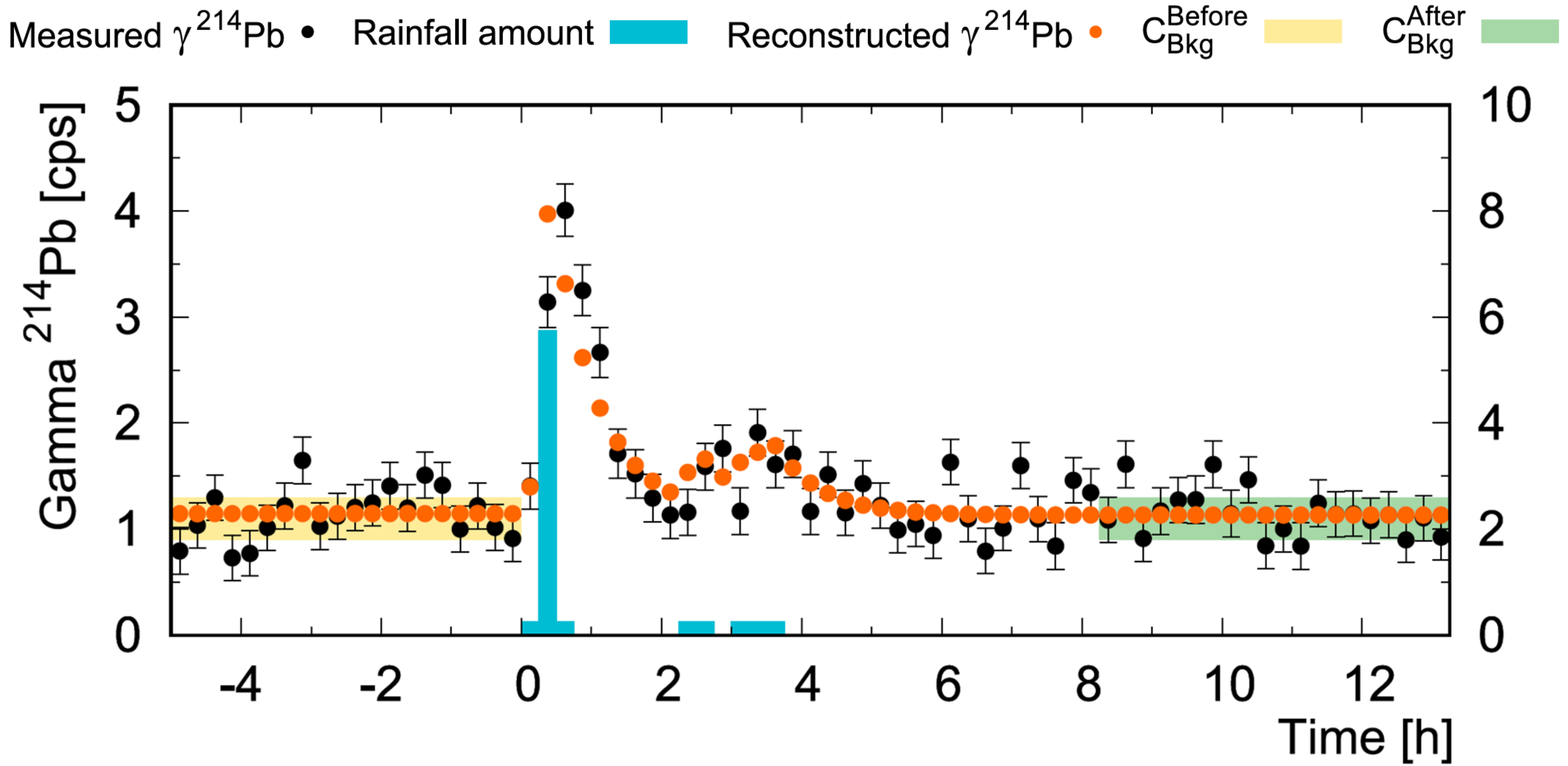
Modeling rain-induced γ activity



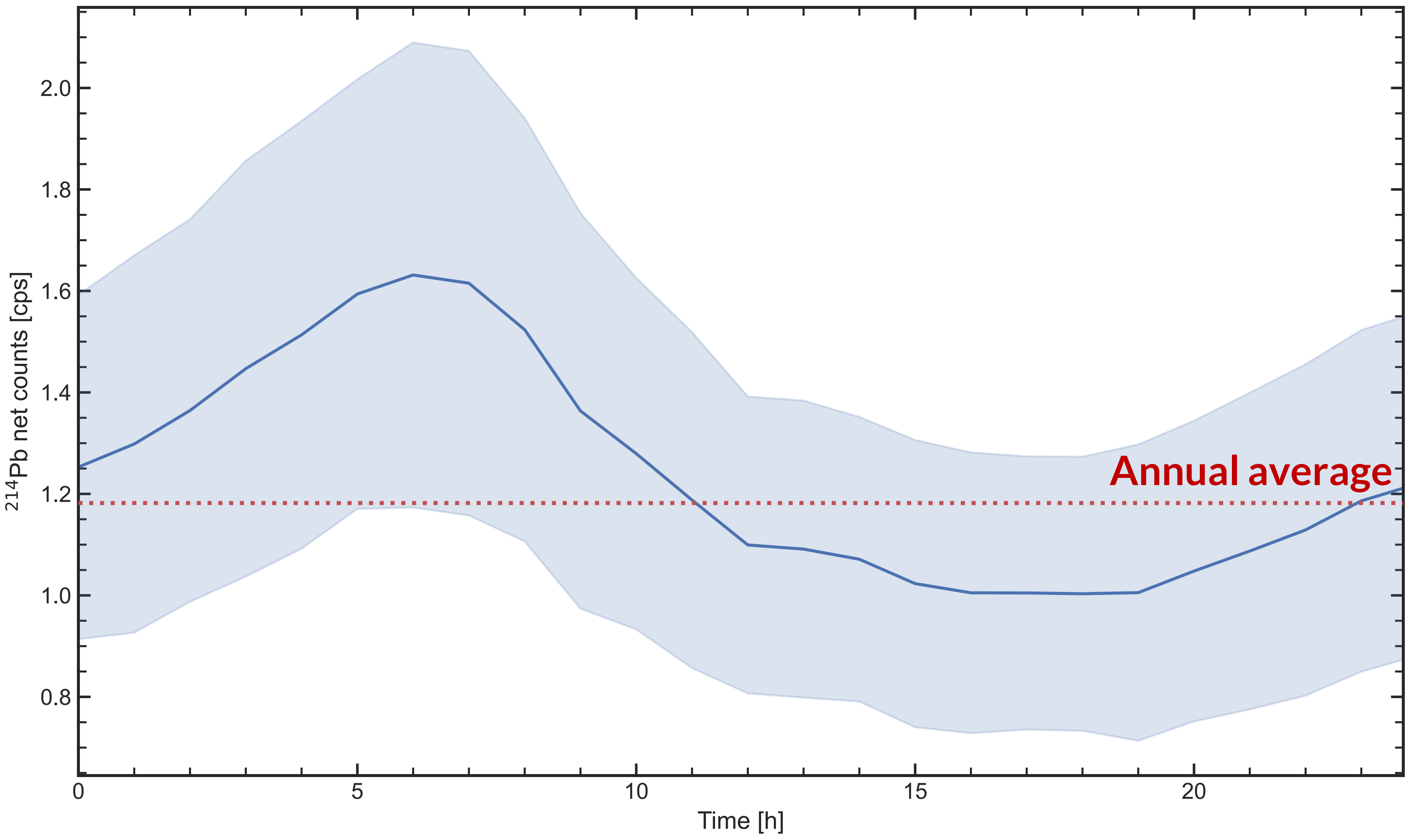
- The **additional ^{214}Pb** nuclei deposited by rain cause a sudden increase in the γ activity over the **environmental background**.
- This additional γ activity vanishes following an **exponential** law as ^{214}Pb nuclei **decay to ^{214}Bi.**
- As in ^{214}Pb case, **rain deposits additional ^{214}Bi nuclei** to the ground, increasing the γ activity over the **background**.
- ^{214}Bi nuclei created by the **decays of ^{214}Pb** create an **additional source term**, which **fights against ^{214}Bi exponential decay.**
- Present work considers the activity of **^{214}Pb** ($E_γ$ = 351 keV, half-life = 26.8 min), being the first ^{222}Rn daughter to undergo γ decay.



Experimental data and model fit



Backgrounds: daily ^{214}Pb oscillations

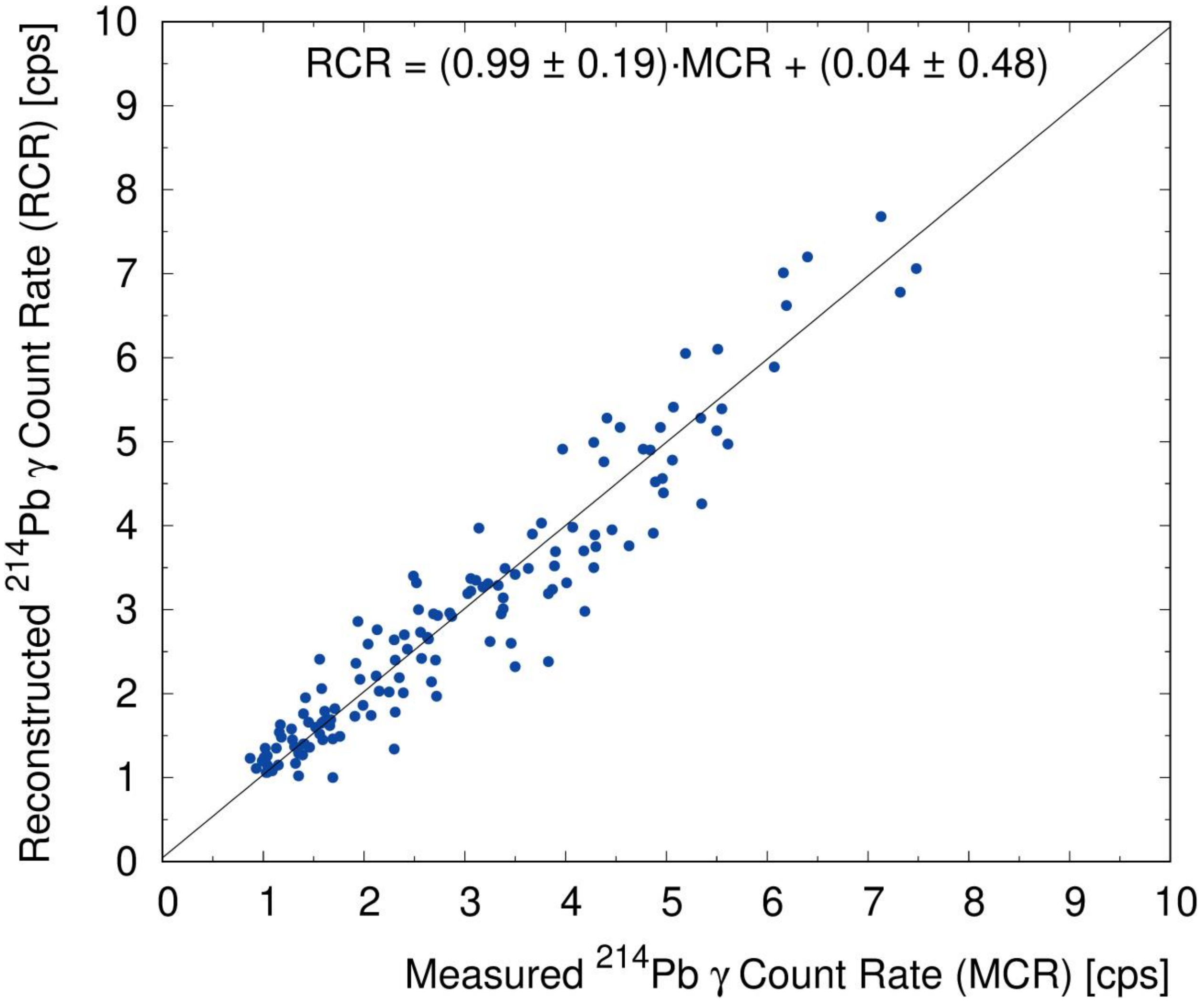


Changes due to daily **"radon oscillations"** are **slow**.

Typically, Pb net counts oscillate in a **30%** range around the mean value.

Instead, **during rains** the Pb count rate **suddenly** increase of a factor **x5**.

How well do we reconstruct the ^{214}Pb signal?



The reliability of the model is demonstrated by the **good linear relation** observed between **measured** and **reconstructed ^{214}Pb** net count rate during the rain time.

The **slope** and **intercept** best fit values of **(0.99 ± 0.19)** and **(0.04 ± 0.48)** compatible respectively with 1 and 0 at 1σ level, allowing to **exclude** statistically significant **systematic effects**.

A relation between rain rate and γ-activity

$$\Delta C = \Delta T \cdot A \cdot R^{d}$$

ΔC **[cps]** = impulsive count rate parameter.

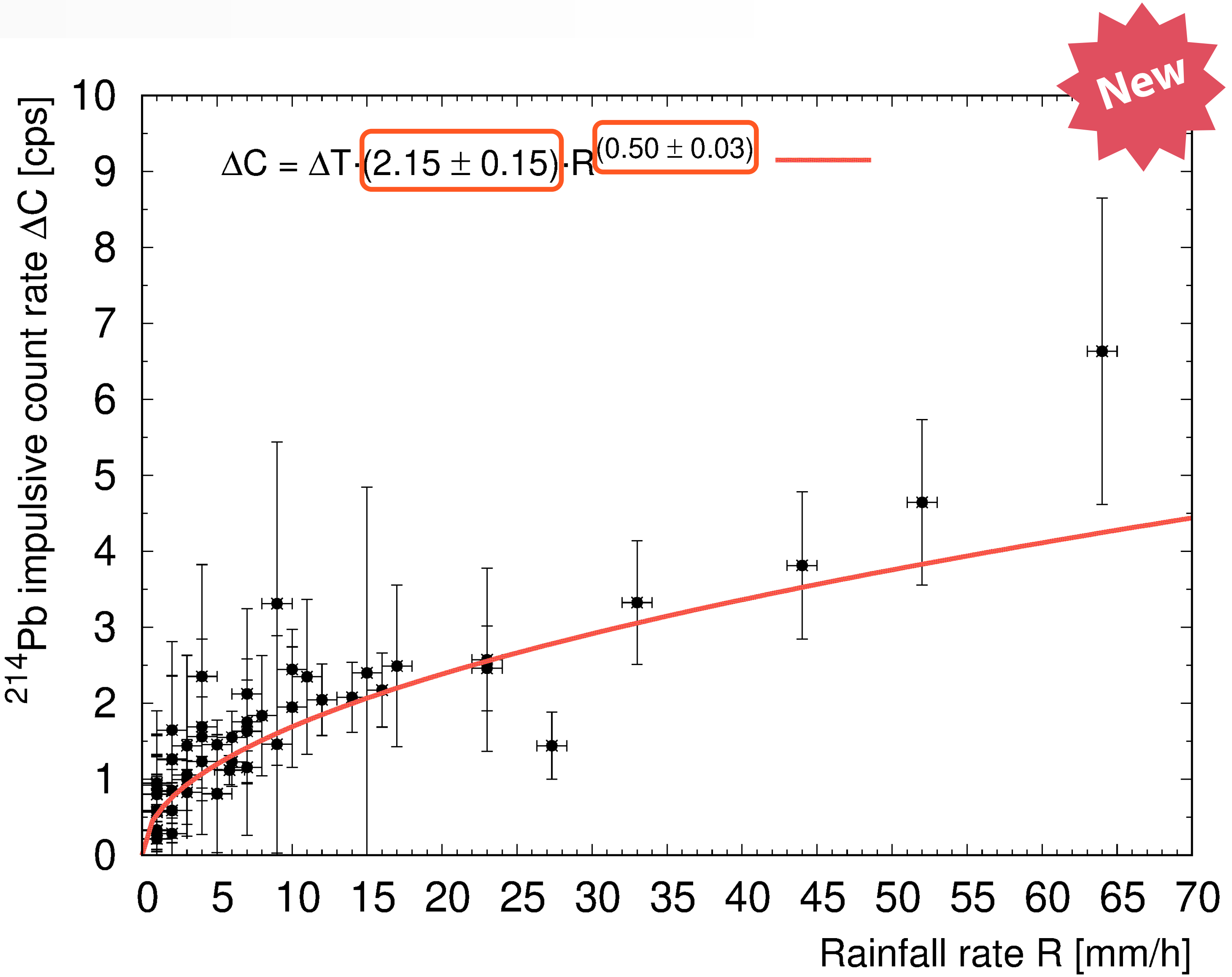
ΔT **[h]** = time resolution = 0.25 h.

R **[mm h^{-1}]** = rain rate.

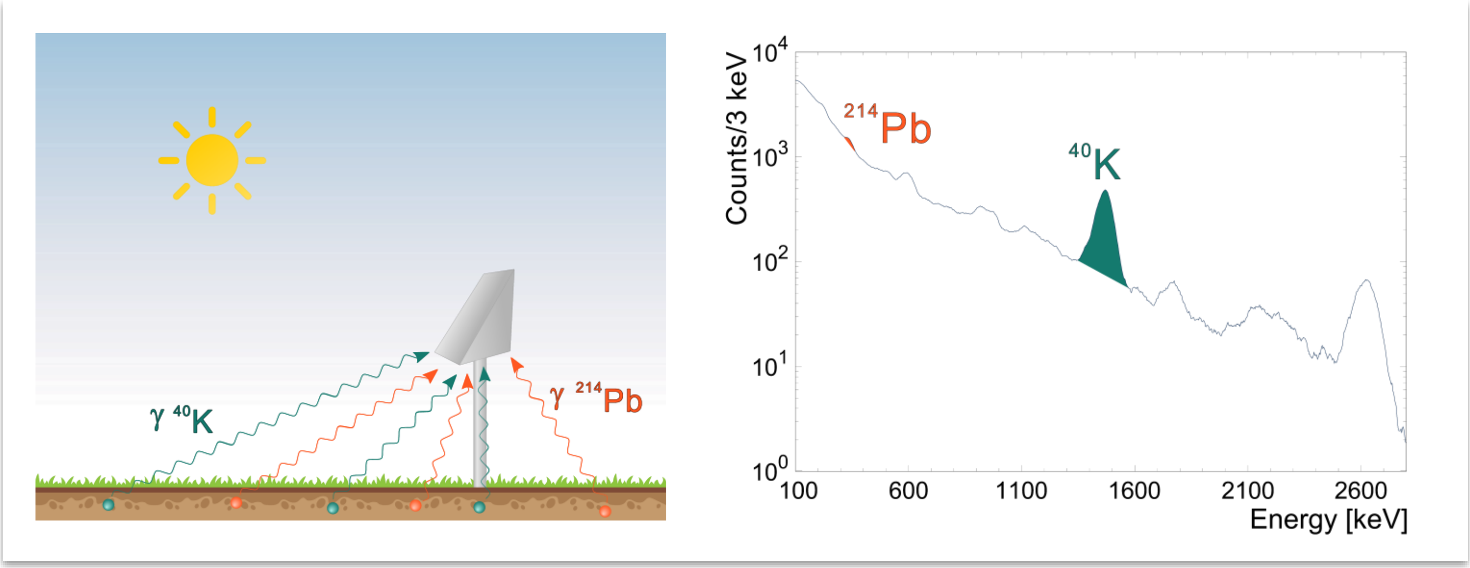
A **[cps mm^{-d} h^{d-1}]** = proportional constant.

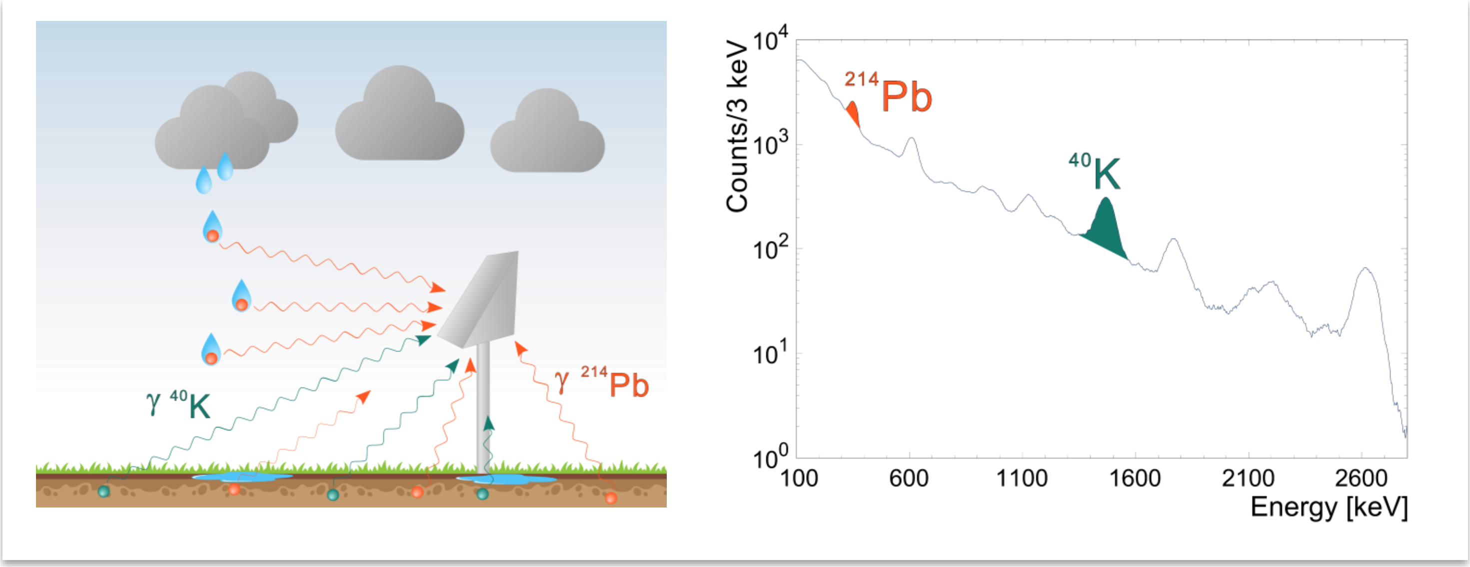
d **[adim.]** = power of R.

- The 82 0.25 h impulses of rain of the selected episodes were reported in figure.
- This allows to determine the A and d parameters that describe the ΔC dependence on the rain rate R for the mean rain episode.
- The d value agrees with values reported in literature.



Sensing a rainfall through γ-rays





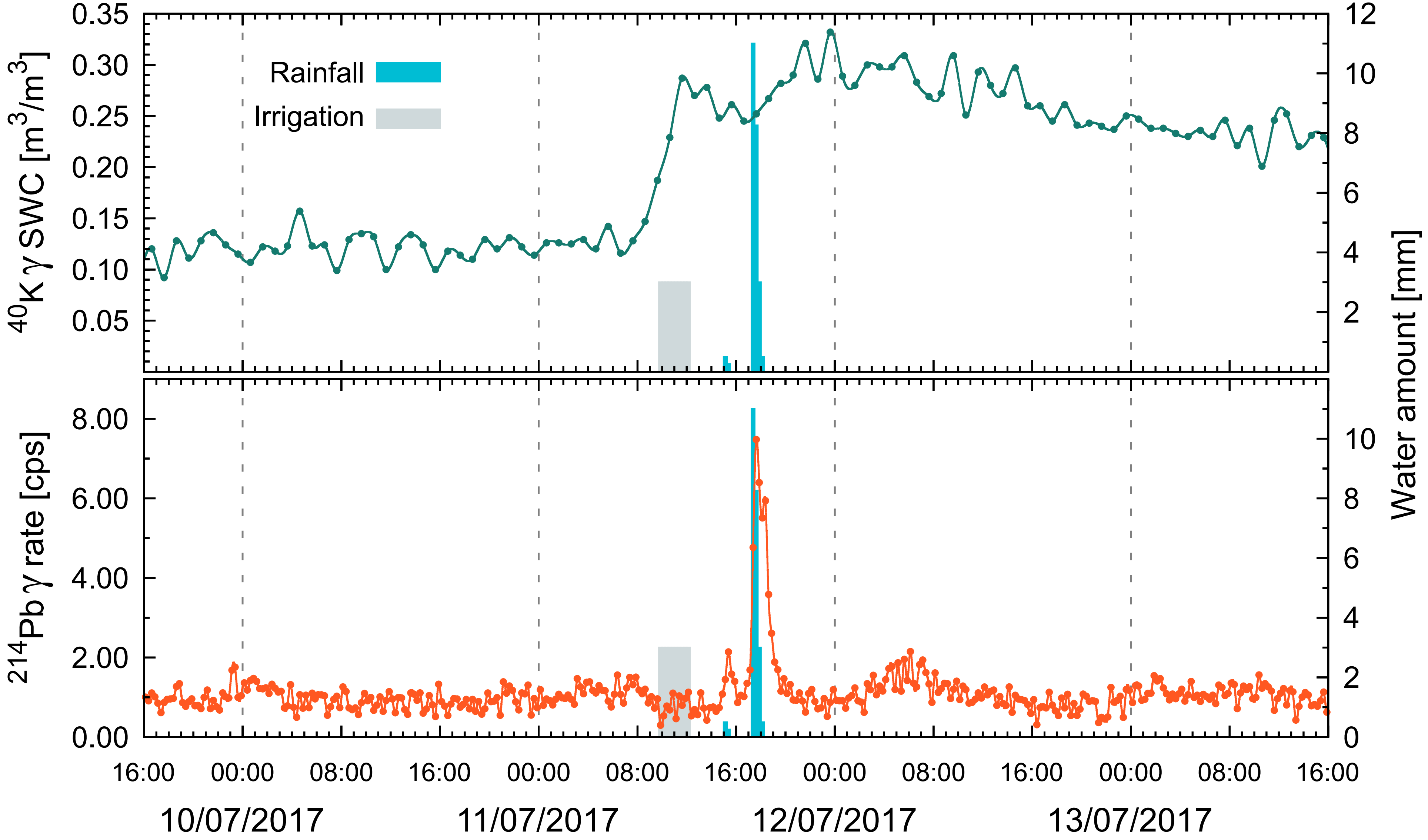
During a rainfall, the **soil water content** $\boldsymbol{w}$ can still be estimated by the attenuated $\boldsymbol{S_K}$ signal.

The signal $\boldsymbol{S_{Pb}}$ is instead enhanced by the **additional ^{214}Pb** atoms collected in the cloud and **brought to ground by rain.**

The rainfall rate $\boldsymbol{R}$ is **proportional** to the **square** of the of ^{214}Pb signal increase $\boldsymbol{\Delta S_{Pb}}$:

$$R = C \cdot \Delta S_{Pb}^2$$

Discriminating irrigation and rainfall through γ-rays

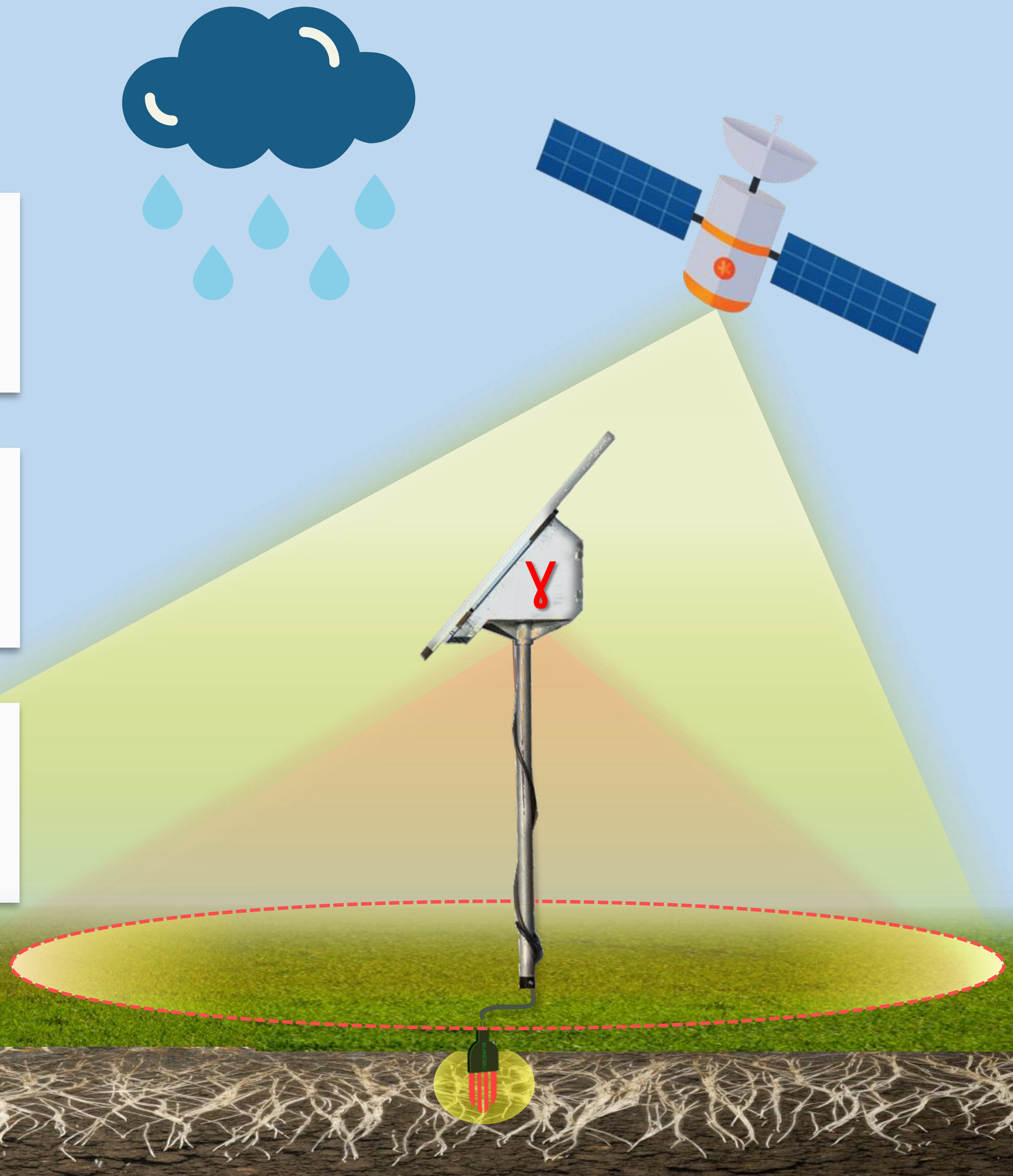


Take away messages

Proximal ɣ-ray spectroscopy is an effective tool for estimating **soil water content** at **field-scales.** It is a promising technique in view of **satellite data calibration**.

A sudden **increase** in the **^{214}Pb gamma signal** is an unequivocal smoking gun for a **rainfall**.
This signal does not increase in the case of irrigation.

The sudden **increase in ɣ-ray** signal S **during rain** shows a **relation with the rain rate**. The relation is found to be $\Delta S = k \cdot \sqrt{R}$, in accordance with literature.



If you're still curious...

Laboratory for Nuclear Technologies
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Modelling Soil Water Content in a Tomato Field: Proximal Gamma Ray Spectroscopy and Soil–Crop System Models

Strati V., Albéri M., Anconelli S., Baldoncini M., Bittelli M., Bottardi C., Chiarelli E., Fabbri B., Guidi V., Raptis K.G.C., Solimando D., Tomei F., Villani G. and Mantovani F.
Agriculture, 8(4), 60 (2018)

Biomass water content effect on soil moisture assessment via proximal gamma-ray spectroscopy

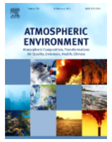
Baldoncini M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani.
Geoderma, 335, 69-77 (2019)

Investigating the potentialities of Monte Carlo simulation for assessing soil water content via proximal gamma-ray spectroscopy

Baldoncini, M., M. Albéri, C. Bottardi, E. Chiarelli, K. G. C. Raptis, V. Strati, and F. Mantovani
Journal of Environmental Radioactivity, 192, 105-116 (2018)

Soil moisture as a potential variable for tracking and quantifying irrigation: a case study with proximal γ-ray spectroscopy data

Filippucci, P., A. Tarpanelli, C. Massari, A. Serafini, V. Strati, M. Alberi, K. G. C. Raptis, F. Mantovani and L. Brocca (2020).
Advances in Water Resources 136, 103502 (2020)



Rain rate and radon daughters' activity.

Bottardi, C., M., Baldoncini, M. Albéri, E. Chiarelli, M. Montuschi, K. G. C. Raptis, A. Serafini, V. Strati, and F. Mantovani
Atmospheric Environment, 238, 117728 (2020)

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Serafini, A., Albéri, M., Chiarelli, E., Montuschi, M., Raptis, K. G. C., Strati, V., & Mantovani, F.
2020 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), 191-195 (2020)

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