

Improving Environmental Radioactivity Measurements for Sustainable Energy Use

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Abstract

Energy and environmental radioactivity are closely interconnected. The production of energy by nuclear power plants, currently considered a way to meet greenhouse gas emission targets and reduce dependency on fossil fuels, generates radioactive waste, which has to be adequately handled in order to prevent environmental contamination. Furthermore, non-renewable energy production from coal and other fossil fuels increases the release of radionuclides, such as radium (Ra-226), uranium, thorium, and radon, into the environment, potentially causing adverse effects on human health and ecosystems. Thus monitoring of radioactivity levels in the environment is fundamental to assess environmental risks from energy production activities and protect populations from potential adverse health effects, as well as balancing health against energy saving efforts. Project NuClim (Nuclear observations to improve Climate research and GHG emission estimates) aims to increase the capability to assess radioactivity levels in the natural environment and improve radiation protection by a detailed field campaign in the Graciosa Island (Azores archipelago) that combines very detailed meteorological information from the Eastern North Atlantic (ENA) Atmospheric Radiation Measurement (ARM) facility and accurate measurements of atmospheric radon activity concentration and ambient gamma dose rate, down to very low levels/activities. The new measurements will enable improvements in radiation protection, including the distinction between natural and anthropogenic sources of radioactivity, thus contributing to more environmentally responsible and sustainable energy production.

Motivation

The production of energy involves the release of radioactive substances into the natural environment (Figure 1).

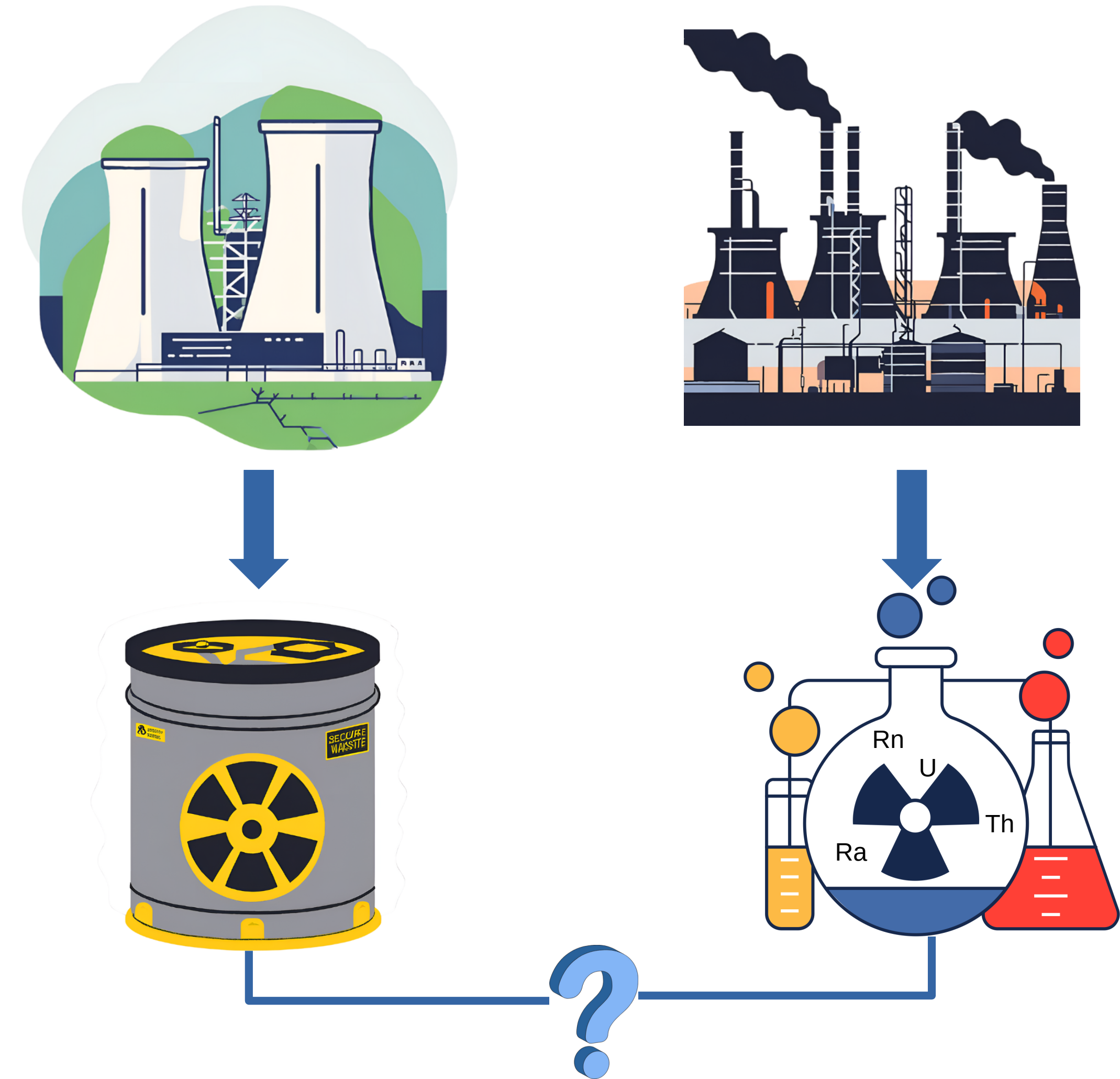


Figure 1: Energy production and release of radioactive substances (source: individual images generated by AI).

Metrology for radon at the environmental level

Accurate measurements of low-level radon activity concentrations, such as those found in the environment ($<20 \text{ Bq}\cdot\text{m}^{-3}$), are fundamental to assess environmental risks from energy production activities, as well as for radio-protection in general and climate change applications. New metrological capabilities developed in the EMPIR project 19ENV01 traceRadon (Röttger et al, 2021; 2025) enable the reliable and traceable measurement of environmental low-level radon activity concentrations, supporting novel climate applications.

Project NuClim "Nuclear observations to improve Climate research and GHG emission estimates" (NuClim), funded by the EURATOM programme, started in September 2024 with the aim of using high-quality measurements of low-level atmospheric radon activity concentration and ambient radioactivity to advance climate science and improve radiation protection and nuclear surveillance capabilities.

Field measurements

Field measurements in the framework of project NuClim will improve Europe's capability regarding accurate, continuous atmospheric radon activity concentration measurements in the North Atlantic.

Reliable low-level radon activity concentration measurements will be performed at two key sites (Figure 2):

- Eastern North Atlantic (ENA) site, Graciosa Island, Azores (Portugal)
- Mace Head atmospheric station (Ireland)

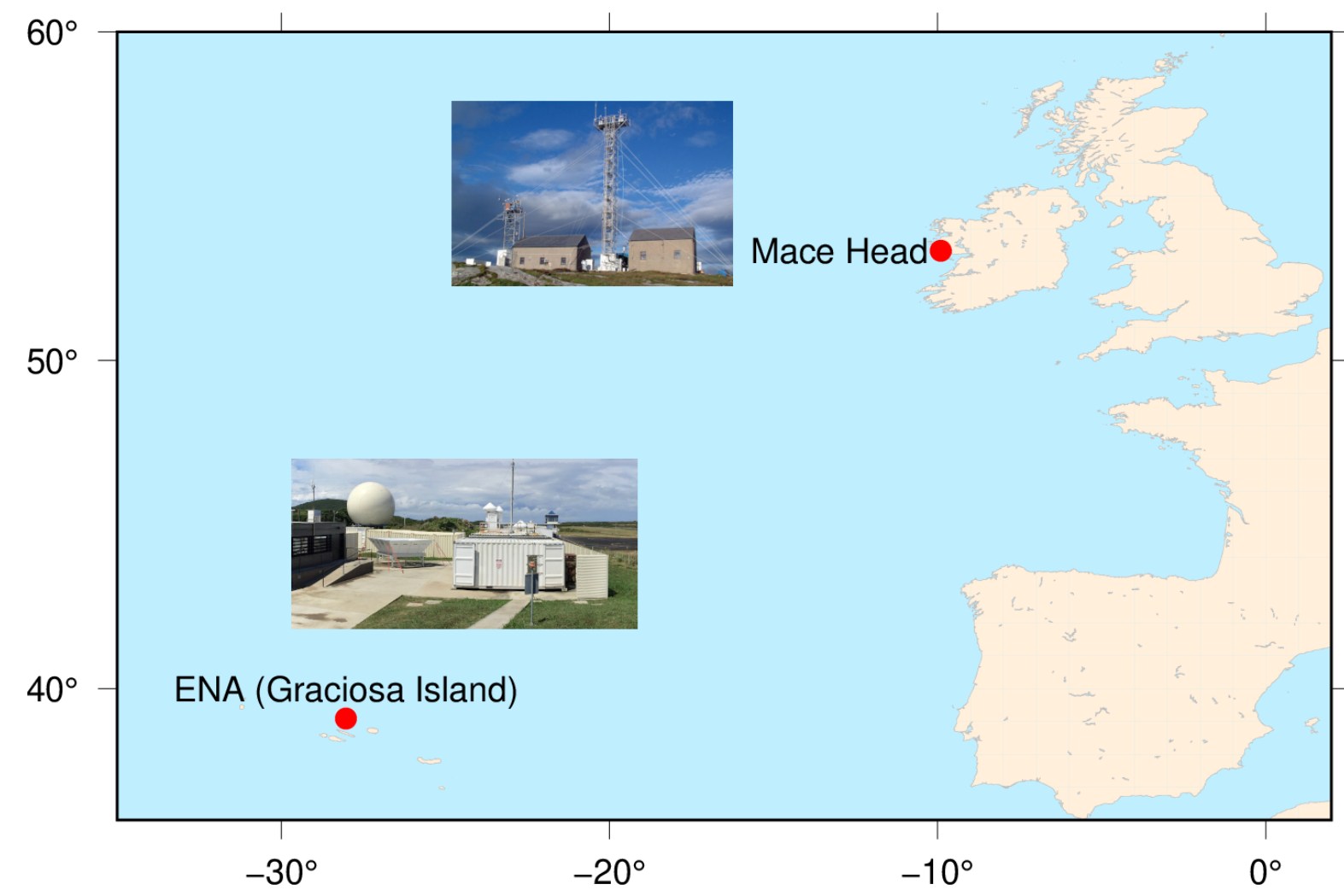


Figure 2: Map showing the location of the stations measuring atmospheric radon activity concentration in the scope of project NuClim.

The measurements being implemented at the Graciosa ENA station include:

- ✓ Trace gases (CO_2 , CH_4) and cluster ions;
- ✓ Radon activity concentration (ANSTO detector);
- ✓ Total and spectral (NaI(Tl) and LaBr_2) gamma radiation;
- ✓ Filter-based measurements of Be-7 and Pb-210

At the renowned Mace Head station its atmospheric radon monitoring capability is being enhanced by upgrading from indirect (by progeny) to direct radon activity concentration measurements.

Modelling

The distinction between natural and anthropogenic sources of radioactivity is critical to assess environmental risks from energy production activities and protect populations from potential adverse health effects, as well as balancing health against energy saving efforts. Enhancements in ambient gamma dose due to meteorological conditions (rain, snow, dust events and strong atmospheric stability) need to be distinguished from other causes (e.g. malfunction of a nuclear facility, or a radioactive event) in order to improve the capability of European surveillance networks monitoring continuously ambient gamma dose for nuclear security and safety purposes.

Modelling efforts enable to improve the quantification of the background variability in ambient gamma dose, in particular the identification of false positive peaks due to meteorological factors. Figure 3 exemplifies the typical variability in gamma radiation time series. Enhancements in gamma radiation occur both due to rain events and, in some cases, in the absence of rain due to atmospheric stability conditions. Furthermore, some rain events do not cause any increase in gamma radiation (Fig. 3, bottom). Machine learning techniques will be implemented in the NuClim project to enable the automatic identification and classification of enhancements in gamma radiation, contributing to improve the identification of both natural and non-natural sources of radioactivity in the environment.

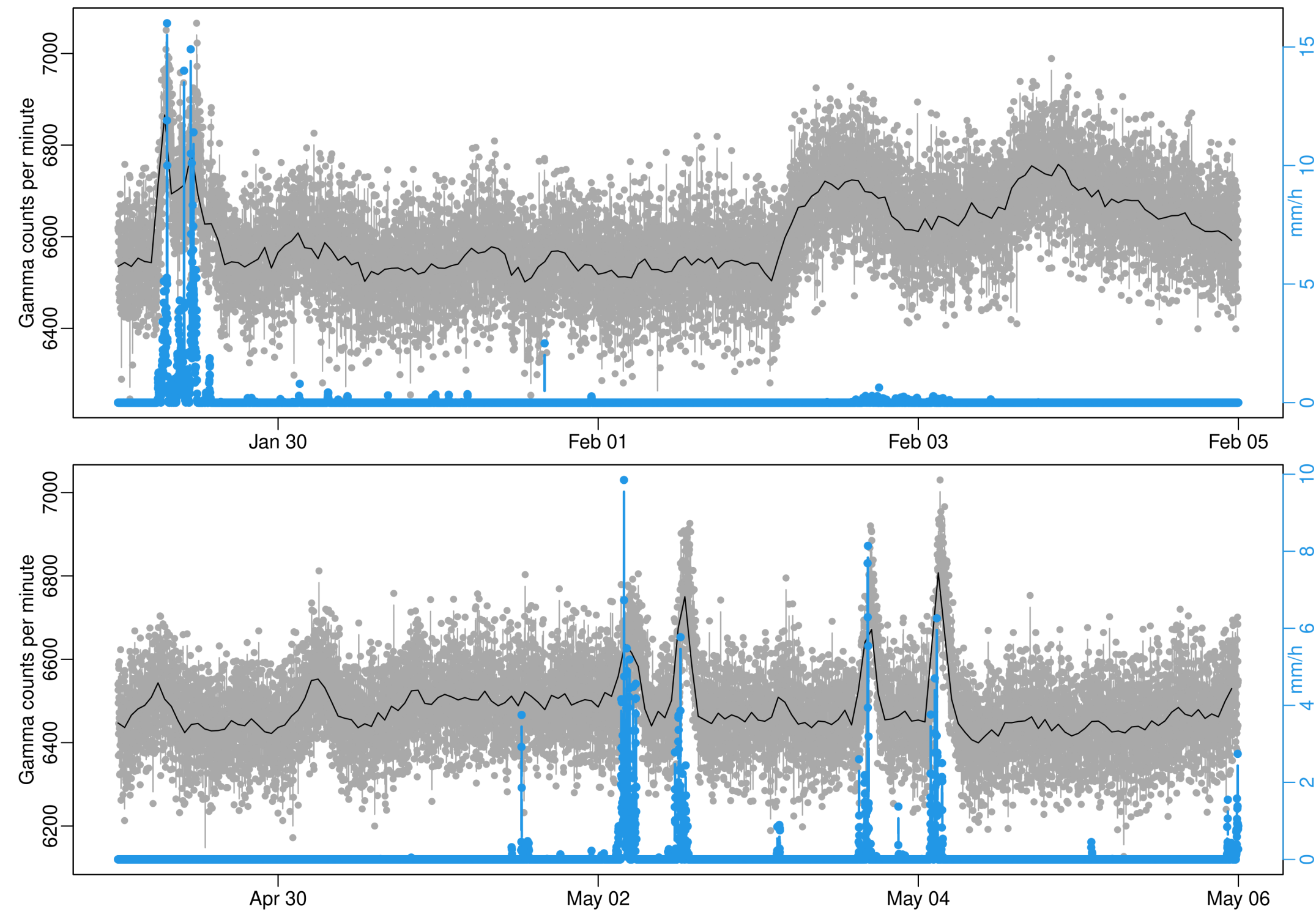


Figure 3: Weekly time series of total gamma counts recorded at the ENA station every 1 minute (grey points), 1 hour-averaged (black line), and 1 minute precipitation (blue points): week from 2024-01-29 to 2024-02-04 (top) and from 2024-04-29 to 2024-05-05 (bottom).

References

- Röttger, A. et al., New metrology for radon at the environmental level Meas. Sci. Technol., 32 (2021), 124008, 10.1088/1361-6501/ac298d.
- Röttger, S., et al., Traceable low activity concentration calibration of radon detectors for climate change observation networks. Measurement: Sensors 101708 (2025).

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