

**23rd International Conference on
Harmonisation within Atmospheric Dispersion Modelling
for Regulatory Purposes
15-19 September 2025, Hamburg, Germany**

EXTENDED ABSTRACT

Modelling atmospheric transport and deposition of radon-222 and its progeny: impact on environmental dose rates

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Introduction

Radon-222 (^{222}Rn) is a product in the radioactive decay chain of uranium-238, a primordial nuclide present in trace amounts in natural soil. Radon-222 is subsequently exhaled over Earth's land masses by diffusion from soil to the atmosphere (Nazaroff, 1992). Its half-life of 3.8 days allows ^{222}Rn to disperse over continental scales (Arnold et al., 2010). Being a noble gas, radon itself does not deposit on the ground. Its (radioactive) daughter products, however, readily attach to aerosols and are thus subject to deposition processes, such as scavenging by rain. These rain events can trigger alarms in early warning detector networks for nuclear accidents, as the radioactive daughters are deposited on the ground, quickly and significantly increasing the measured dose rates by ground detectors (Fujinami, 1996). To prevent erroneous alarms of such kind, it is important to understand and predict these precipitation-induced dose rate excursions. To this purpose, we simulate the atmospheric transport, dispersion and deposition of ^{222}Rn and its progeny over Europe for the year 2022.

Methods

We use the atmospheric transport model FLEXPART v10.4 (Stohl et al., 2005; Pisso et al., 2019), coupled numerical weather data of ECMWF for the year 2022 and a monthly ^{222}Rn exhalation map covering Europe of the same year (Karstens et al., 2015). The average radon exhaust flux over the whole year is shown in Figure 1.

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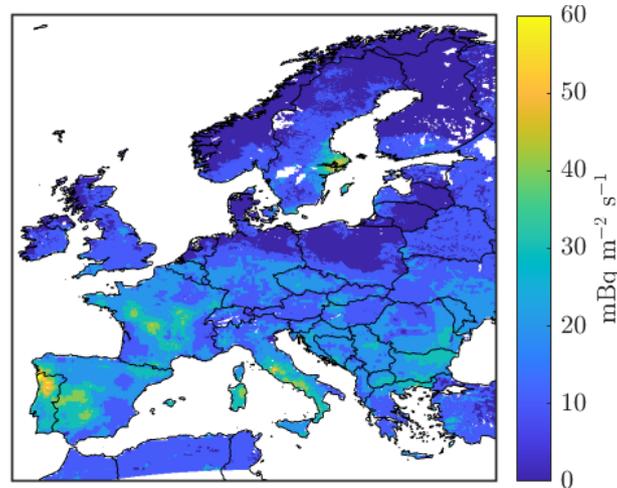


Figure 1. ^{222}Rn exhalation map from Karstens et al. (2015), averaged over the year 2022.

Depletion processes such as deposition impact the radioactive equilibrium of the ^{222}Rn progeny (Jacobi and André, 1963), which FLEXPART is not normally equipped to take into account. Therefore, we have made alterations to the FLEXPART source code by introducing a decay chain, where each nuclide in the chain is a separate species. The time evolution of the activity concentration of each species is based on combining the well-known Bateman equations with species-specific depletion by dry and wet deposition. We use the optimised wet deposition parameters from Van Leuven et al. (2023) for the radon progeny.

We compare the simulation results with both ^{222}Rn air concentration measurements, as a first validation, and subsequently with the dose rate measurements originating from the ^{222}Rn progeny. The air concentration measurements are provided by radon detectors in the TELERAD network of FANC in Belgium, the NMR network of RIVM in the Netherlands and the ICOS network. The dose rate measurements come from gamma detectors in the TELERAD and NMR networks.

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Results & Discussion

Firstly, the model's radon air concentrations are validated against measurements. The detectors of the TELERAD and NMR networks are (assumed to be) located near the surface, labelled at 0m height above the surface for simplicity. The radon detectors of the ICOS network are located on towers at three locations: 15m, 120m, and 180m. Figure 1 shows the bias (mod/obs) against height of the radon detector. The radon concentrations from the TELERAD and NMR networks result in an median under-estimation of the model by a factor 2-3. Comparing with the ICOS measurements at greater heights suggests a trend of better model-observation correspondence with increasing height. The reason the model preforms worse near the surface is unclear. One hypothesis is that FLEXPART does not handle convection near the surface well enough for this application. Another aspect is that wind speed near the surface is not included in the numerical weather data, with the lowest model layer at 10m. A decreasing wind speed is expected near the surface, which would increase the air concentration.

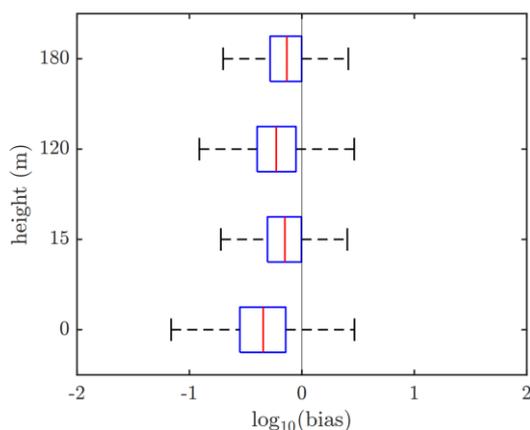


Figure 2. Bias of model-observation radon concentration at different heights in the datasets used (TELERAD, NMR, ICOS).

Wet deposition originates from scavenging across the entire precipitating vertical. Since the model performs better at altitude, the resulting error of the air concentration under-estimation on the wet deposition is expected to be minimal. Therefore we consider the air concentration to be sufficiently validated.

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Figure 2 shows the model-observation bias of the wet deposition measurements over the entire simulated year. There is a significant under-estimation visible all throughout. The under-estimation around the winter period is most significant, where the model under-estimates with a bias of around 10^{-2} . Around the summer season, the model fares much better, with a bias around 10^{-1} . Since such large seasonal swings in bias are not seen in the radon air concentration results, the main remaining physical parameters that could be the culprits for the seasonal bias swings in the deposition results are the precipitation intensity and the scavenging coefficients. The bias of the precipitation from the numerical weather data has been checked using rain gauge data that accompanies almost all dose rate measurements. The precipitation bias is very close to zero (not shown). Therefore, the remaining hypothesis to explain the significant under-estimations lies in an under-estimation of the scavenging coefficients.

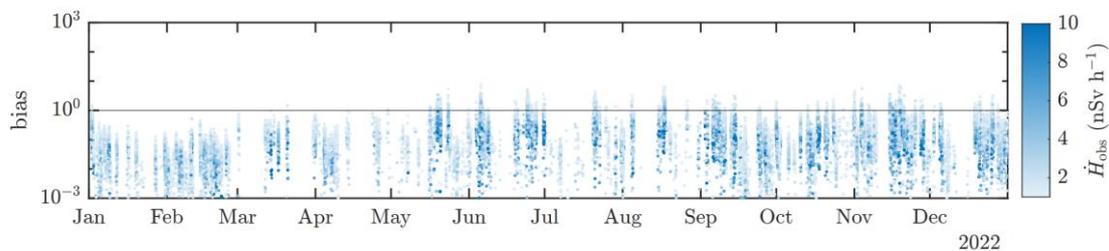


Figure 3. Time series of the model-observation bias for all (dose rate) wet deposition measurements (TELERAD and NMR). Each measurement is color-coded according to the observed deposition signal.

Conclusions

In this work we coupled the long-range atmospheric transport model FLEXPART to a radon exhalation model to simulate the radon air concentration and wet deposition of radon progeny across continental Europe. This was achieved by implementing a decay chain in FLEXPART. The model gives reasonable results for the radon air concentrations. The wet deposition, however, is severely under-estimated despite already being increased by a factor ~ 2 by Van Leuven et al. (2023). By validation of the air concentration and precipitation intensity, the wet deposition scheme is a likely culprit of the under-estimation. As part of future work we will test a different deposition scheme in FLEXPART, and evaluate if this improves the model-observation bias.

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