Response to comments from Reviewer #2

This manuscript presents a comprehensive review of the nocturnal accumulation Radon Tracer Method (RTM) and the considerations involved in applying it under local conditions. The manuscript is well written and structured. It is particularly timely given the expansion of atmospheric observation networks aimed at quantifying greenhouse gas emissions and establishing robust emission baselines. In this context, the RTM provides an alternative top-down approach that can offer an independent constraint on emission estimates.

A particular strength of the manuscript is the detailed discussion of how choices regarding the accumulation window, atmospheric stability, measurement height, contributing fetch, radon flux and instrument performance can vary from site to site. The examples from different locations clearly illustrate how these factors affect the application and interpretation of the method. These examples and clarifications may encourage revisiting previous estimates and help improve the consistency and reproducibility of future applications.

On behalf of all coauthors, I would like to thank the reviewer for their time and effort in reviewing our manuscript. It is encouraging that others share the desire for improved transparency and interpretation of results obtained by the Radon Tracer Method under different scenarios. We are hopeful that the community will test these hypotheses and either verify or improve upon the approach.

Overall, I found no major scientific or technical issues with the manuscript. It provides a well-balanced discussion of previous work, methodological developments and limitations, with sufficient detail to support implementation of the method at new sites. I agree with the other reviewer that it would be useful to briefly consider how some of the insights presented here may apply to RTM implementations at different spatial and temporal scales. I recommend publication following minor revisions/clarifications.

Comments

Lines 70–80 and Conclusions

The Introduction briefly mentions the other three implementations of the radon mass balance approach. It would be useful for the Conclusions to briefly mention whether any of the considerations discussed here may also be transferable to those other approaches.

Thank you for the suggestion. The Conclusions of the revised manuscript have been modified to include a brief discussion of how and if the main suggestions from this study can be applied to other published formulations of the radon tracer method.

Lines 943–950

Given that these eight considerations form the main practical guidance of the manuscript, I wonder whether a short summary table could be useful here. The table could briefly list each factor discussed in Sections 3.1–3.8, the main consideration or recommended criterion, and which aspects should be adapted to local or site-specific conditions. I think this would make the manuscript particularly useful as a reference for researchers implementing the RTM at a new site, without implying a universal method.

We acknowledge the potential value of such a table. Brevity would likely be the most challenging issue. To try to keep this from the main body of the paper, which is already lengthy, we suggest including a summary table as an Appendix (Appendix A in the revised manuscript).

We would value any feedback from the reviewer or Editor as to whether the extent of content in the proposed summary table is appropriate, and as to whether it can be left as an Appendix or included as a Section of the main paper.

Appendix A: Quick reference RTM application overview

To recap, the underlying assumptions for applying the nocturnal accumulation RTM include:

(i) radon and target gas fluxes similarly distributed and relatively homogeneous over the contributing fetch;
(ii) any heterogeneity is small-scale and random, uncorrelated with atmospheric processes on small spatial/temporal scales;
(iii) the target gas has no atmospheric sinks over measurement timescales, or between emission and measurement;
(iv) both species are acted upon by the same transport and mixing processes from the source to the point of measurement (i.e. measured at the same, constant location and height above ground within the SNBL).

The site or application specific considerations discussed in this review include:

Consideration	Comments
Stability classification (optional)	Radon-based stability classification (relative, by season) is most effective for measurement heights always within the SNBL. It groups results by similar weather conditions (improves ability to attribute results to different fetch scales, fetch directions and soil moisture conditions) and can assist with interpretation of findings if point sources exist within the contributing fetch regions.
Nocturnal Window (NW)	The duration and timing of the NW depend on target gas, measurement height, weather conditions, day length (season), and fetch characteristics. Since wind speed and direction change with weather conditions, stability classification can assist with NW definition (fetch can change through the night in consistent ways under different stability conditions). In (or near) complex terrain, flow conditions, fetch and fetch characteristics can change with weather conditions. Stability dependent NW definition can improve consistency and interpretation of findings.
Accumulation thresholds	Defining an appropriate accumulation threshold helps ensure acceptable signal to noise ratios and constrain the fetch extent. The signal to noise ratio is inversely related to the regression uncertainty for RTM flux estimates. The expected accumulation rate within the NW should be ≥3 times the instrument uncertainty. Radon accumulation thresholds should be defined and applied seasonally in regions subject to seasonal soil saturation or freezing / snow cover.
Regression linearity thresholds	Regression linearity is an indication of how similarly distributed and homogeneous the gas source functions are over the fetch (how well the RTM assumptions are being met). A suggested target is $R^2 \geq 0.7$. Since the degree/scale of heterogeneity can change with the size and location of the fetch, R^2 values may change with stability. Isolated instances of heterogeneity (e.g. brief influence of a point source) will present as outliers from the linear trend. If the NW is large enough, 1 or

	2 outliers may be flagged out of nightly regressions to improve the R^2. Temporal variability of a source function (e.g. photosynthesis/respiration) can impact R^2, and NWs should be adjusted accordingly. For instruments with higher uncertainty the R^2 threshold can be reduced. If so, average over a larger number of events. If the fetch includes a coastline, accumulation becomes a function of wind speed and direction, which can vary over the NW. This complicates NW definition and can impact R^2 values (this situation is best avoided). Instrument response time issues or temporal lags between instruments should be identified and fixed before R^2 values are determined. Check for cases where accumulation and high R^2 values appear to persist several hours after sunrise. This may be the result of a largescale advection event or a persistent temperature inversion.
Measurement height	The scale of contributing fetch increases with measurement height (this can have positive or negative effects depending on scales of heterogeneity). Where measurement height can be selected, consider the intended fetch when installing instruments. Where measurement height is fixed, and stability classification is possible, fetch will increase with decreasing nocturnal stability. The rate and magnitude of accumulation are higher closer to the surface. If using instruments with high uncertainty, plan to measure closer to the surface (e.g. ≤ 20 m agl). The closer measurements are to the surface the smaller the scales of contributing turbulence, and the more important it is for gases to be measured at the same height and location (and vice versa). Measurement height relative to canopy height (whether it is a vegetation canopy or urban canopy) is important, since the vertical distribution of sources/sinks may change. Measurement height will be application specific, depending on sources/sinks being targeted.
Fetch definition	Careful choice of model is important for defining RTM fetch (e.g. optimised high-resolution footprint modelling). Even so, the model's ability to correctly represent fetch will decrease as nocturnal stability increases. If stability classification has been performed, where possible, in situ wind speed and direction at the measurement height should be used to inform contributing fetch estimates under stable nocturnal conditions. In (or near) complex terrain, models seldomly represent nocturnal flow and fetch conditions associated with katabatic drainage accurately. Investigating model-measurement bias in wind speed and direction separately by stability category can help identify potential problem conditions. Representative fetch definition is critical for comparisons with BU emission estimates.
Spatial/Temporal radon flux variability	The RTM assumes radon flux is constant on short timescales (each whole night) and spatially (across the contributing fetch). Contemporary radon flux maps can typically approximate seasonal soil moisture influences on spatially varying radium content and soil characteristics. Individual rainfall events on sub-diurnal to synoptic timescales impact soil moisture variability that, in turn, introduces a poorly constrained variability in radon flux (the spatial and temporal

	nature of which can vary with rainfall type – widespread or convective). Stability classification groups nights with similar weather conditions (regarding wind speed and rainfall). The most stable nights represent the smallest contributing fetch region with the lowest amount of recent rainfall.
Temporal resolution of flux estimates	For sensors with low uncertainty, or sites with moderate to high accumulation rates, the RTM usually provides sufficient data for monthly emission estimates from a representative fetch. Otherwise, seasonal averaging may be required to compensate for higher uncertainty of individual emission estimates.
Requirements of radon monitors	“Typical” nocturnal accumulation rates (estimated from diurnal-composite plots each season) will inform optimum instrument requirements. Accumulation rates (at the chosen temporal resolution) should be at least 3 times larger than instrument uncertainty at that temporal resolution and concentration. Seasonal average nocturnal accumulation rates will decrease with height above the ground, or with degree of soil saturation / freezing typical of the site or season.