

## ***Interactive comment on “A map of radon flux at the Australian land surface” by A. D. Griffiths et al.***

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### **General Comments**

The fact that moisture influences radon flux at the soil surface has been well established in the literature<sup>1</sup>. The physical explanation is that the radon diffuses faster through dry soil than wet soil. In waterlogged conditions, the volume of air space can be reduced sufficiently that radon transport, via diffusion, is effectively blocked.

The expectation of a seasonal cycle in radon flux directly follows from the observed dependence on soil moisture. The presence of a seasonal cycle is not universal, but it is to be expected in areas with a seasonal soil moisture cycle. As examples of where a seasonal cycle is important, the recently-compiled flux map of Europe (Szegvary

<sup>1</sup>For example Nazaroff (1992), Rogers et. al. (1991), Schery et. al. (1984), and Schery et. al. (1989) which are referred to in the manuscript under discussion.

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et. al., 2009) exhibits weekly mean fluxes 2.5 times larger in summer than winter, between 65N and 70N. Direct measurements in the vicinity of Heidelberg (Germany, near 49.4N) are an independent verification of the existence of a strong seasonality, with a summer-to-winter ratio of 1.7<sup>2</sup>.

### **Specific Comments**

[pp C5605 paragraph 3] Radon flux maps can be generated for each month from 1900-present, which is the time period for which soil moisture estimates are available. As 1900 is the beginning of the run of the soil moisture model, it takes several years for the model to spin up. The quality of the soil moisture data also improves with time as more weather stations are added to the Australian network. Averages shown in the ACPD manuscript are over 1900-2008, but will be for the most recent 30 years in the updated version, to take advantage higher quality soil moisture data.

[pp C5605 paragraph 4] Suggestion accepted.

[pp C5605-6 paragraph 5] This is a specific comment regarding seasonal variability, addressed above.

[pp C5606 paragraph 2] 10% is considered to be typical. More importantly, it is a relatively small uncertainty when compared with others.

[pp C5606 paragraph 3] Suggestion accepted.

[pp C5606 paragraph 4] As this reviewer notes, the dependence on soil temperature is secondary to the effect of soil moisture, so we used air temperature as a proxy, specifically the mean of the monthly minimum and monthly maximum temperature, but neglected to state this in the text. The soil temperature is used in Eq. (5) to compute the dependence of the emanation coefficient, and therefore the surface flux, on soil temperature. A description to this effect has been added.

<sup>2</sup>Schmidt, M., H. Glatzel-Mattheier, H. Sartorius, D. E. Worthy, and I. Levin, Western European N<sub>2</sub>O emissions: A top-down approach based on atmospheric observations, *J. Geophys. Res.*, 106, 5507–5516, 2001.

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[pp C5606-7 paragraph 5] Further discussion of the calibration factor has been added. In short, it is introduced to compensate for idealisations in the model and biases in the input data and allows the mean modelled flux to match the mean observed flux. As the model is effectively the product of a number of factors, the calibration factor is also taken to be multiplicative.

[pp C5607 paragraph 2] Suggestion accepted

[pp C5607 paragraph 3] Soil moisture and air temperature (used as a soil temperature proxy) are from AWAP monthly fields from 1900-present, which are updated in near-real-time. Other input data are constant in time.

[pp C5607 paragraph 4] The uncertainty in the input data sets has not been characterised by their authors. As a result, only the uncertainty in mean flux is characterised in our results.

[pp C5607-8 paragraph 5] More information has been added to the chamber results, as requested.

[pp C5608 paragraph 2] Sampling was undertaken at regular intervals, and should therefore capture dry and wet spells equally. No sampling was carried out during rain events, though this would only constitute a small bias, if any.

[pp C5608 paragraph 3] Two estimates of seasonality were given from Tasmanian data: (1) by comparing only locations sampled twice and (2) by comparing the averages from all locations. The reason for including the second comparison was that it increased the sample size, thus reducing the statistical error, but with the disadvantage that the differences in the locations sampled might become important. As the spatial distribution of points was similar during both summer and winter, despite the precise locations differing, it seems that comparison (2) is worth including, as, overall, there is not a large quantity of this kind of data available. As a further note, the original comparison erroneously included some points from the Australian mainland and this has now been

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corrected. Removing the points from the mainland improves the comparison between the model and observations and the model no longer appears to overestimate the seasonal cycle for Tasmania, at least when compared with this small data set.

[pp C5608 paragraph 4] Suggestion accepted, this comparison will now be included.

[pp C5608-9 paragraph 5] The collection of flux chamber measurements, while not strongly constraining the seasonal cycle in the model, show that measured radon fluxes indeed change with time, and therefore we contend that a model of radon flux should also be time-dependent. We can also directly cite other examples, discussed above, which provide further evidence that radon fluxes can exhibit seasonal variation.

[pp C5609 paragraph 2] The clarity of this discussion has been improved.

[pp C5609-10 paragraph 3] All of the model inputs have poorly characterised uncertainties, so it is not practical to determine the uncertainty in the final maps from the uncertainties in inputs. The approach taken, which was to estimate a single "calibration factor", constrains the long term mean flux to observations. The errors in the monthly and seasonal fluxes, or at smaller spatial scales, are larger and not characterised. This is an area for future research.

[pp C5610 paragraph 2] This section has been revised to improve clarity. Regarding specific queries, the flux measurement locations are not known exactly in all of the data sets. The locations from Schery's 1986 survey (the Mainland survey) are taken from textual descriptions similar to "26 km SW of Broome on Great Northern Highway", so we take the location uncertainty to be about  $\pm 1$  km. As a result, the value extracted from the pixel closest to the nominal sample location will have an error associated with the uncertainty of the location. Furthermore, the spacing of aerial survey flight lines is typically 500 m, and soil radium content can have significant variability over tens of meters.

[pp C5610 paragraph 3] The text should have read that modelled fluxes *normalised by*

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*soil radium content* at Cowra and Mary River are similar.

[pp C5610 paragraph 4] Further discussion has been added. Most of the data were indeed obtained in relatively dry conditions, but this is representative of Australia. In order to introduce a bias, the soil moisture at the time of a given flux measurement would need to be consistently higher or lower than the monthly mean flux, and this seems to be unlikely. Conditions of low soil moisture can persist for months at a time, so the low soil moisture observed in the field should be reproduced also in the soil moisture model. The possible exception to this is that no measurements were made during rain.

It is only in exceptional conditions that the soil dry out enough to reduce the emanation factor. This has been discussed in more detail in relation to one of the comments from reviewer #1.

[pp C5611 paragraph 1] “transport” replaced with “diffusive transport”. The conceptual model is that a fraction of radon “emanates” into the pore space and is then “transported” to the surface.

[pp C5611 paragraph 2] This section has been reworked to improve clarity in the updated manuscript.

[pp C5611 paragraph 3] “might improve” replaced with “would improve”

[pp C5612 paragraph 1] It is fair to say that the seasonality of the model is not well constrained by the present data, and may be too strong, but the modelled seasonality has some support from the data and is comparable with other studies. This is an area for future work.

[pp C5612 paragraph 2] This conclusion is based on the discussion, above, that the map underestimates the effect of changing emanation fraction and which has been reworked for improved clarity. Apart from measurement uncertainty, the overall mean flux should be without bias because the free parameter, the “calibration factor” constrains

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the mean to match observations

[pp C5612 paragraph 3] text updated to improve clarity.

Changes have been made in line with suggestions marked as “technical comments”.

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Interactive comment on Atmos. Chem. Phys. Discuss., 10, 14313, 2010.

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