

Interactive comment on “The diurnal evolution of
²²²Rn and its progeny in the atmospheric boundary
layer during the Wangara experiment” *by*
J.-F. Vinuesa et al.

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Received and published: 24 July 2007

GENERAL COMMENTS

The potential use of radon and its progeny as valuable tracers of vertical mixing processes and entrainment in the atmospheric boundary layer has been recognised for some time. Such information is of particular interest to researchers involved in the development and evaluation of boundary layer mixing schemes in weather and climate models on a range of scales. Good quality datasets at altitudes higher than those reachable from tower-based systems continue to be rare, however, because the development of aircraft-based instrumentation has been hampered by the technical

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difficulties of obtaining sufficiently accurate measurements of the ultra-low radon concentrations found in the middle of the boundary layer and the free atmosphere above. LES models can aid the interpretation of environmental measurements in terms of physical processes, which can in turn suggest improvements in the representations of these processes in the mixing schemes of large-scale models. Contributions such as the paper currently under discussion are therefore extremely useful and topical, and certainly worthy of consideration for publication.

I believe that this is an excellent paper, providing an interesting and valuable insight into the behaviour of radon and its progeny in the boundary layer that will be of use both to experimentalists striving to interpret sparse and problematic datasets, and to modellers seeking to evaluate boundary layer mixing parameterisations. The authors' successful simulation of a realistic diurnal cycle makes the work particularly valuable, and their choice of Wangara Day 33/34 is understandable as it is a common benchmark for inter-comparisons within the modelling community. Furthermore, the manuscript is generally well written (although there are quite a few minor grammatical and technical errors listed below), the presentation is well structured and clear, and the development of arguments is lucid. I recommend that the work be published subject to the implementation of changes as outlined below.

SPECIFIC COMMENTS

1. One thing that immediately strikes the reader, especially if they have an experimental background, is that the authors have simulated an environmental case study for which there are no existing radon measurements for comparison! This seems very strange, especially when the authors assert in the Introduction that "Ground-based measurements and vertical distributions have been extensively studied to characterize the turbulent properties of the ABL" (p8898, lines 6-7). In fact, the reader could be perfectly forgiven for wondering: "Why on Earth did the authors not choose one of the many radon studies for their simulation?". The answer of course is that, contrary to the authors' assertion, there are in fact very few studies that have concentrated on ob-

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taining quality radon measurements throughout the whole depth of the boundary layer, especially over the course of a diurnal cycle. The authors need to discuss this more carefully in their Introduction, as it is crucial to understanding their choice of simulation. One possibility is that the paragraph is split on p8898 line 16 just before "In a recent study, ...", and the following inserted: "Despite many experimental studies in the literature, there have been very few studies that have reported measurements of the vertical variation of radon and its daughters through the whole ABL under a variety of conditions. This has been mainly attributable to the slow development of detection technology of suitable accuracy that can practically be mounted on an aircraft. In the absence of such datasets, LES is an option and [in a recent study...]".

2. It appears that the initial condition used for the whole simulation (i.e. 9:00 LST on Day 33) was a constant distribution of about 20 Bq m⁻³ of radon throughout the full depth of the model domain. Is this correct? (please define the initial profile more clearly in the text). Whereas this may be a reasonable guess up to the top of the previous day's residual layer (actually, it's a bit too big: see below), above this altitude it is unrealistic and should be much smaller. Zero would have been a better approximation, or perhaps a "background" value from the literature (e.g. 0.5 Bq m⁻³ from Zaucker et al. 1996, JGR 101 D22, p29,149-29,164). Having such large values for radon above the ABL top in the simulation means that the beta_0 values you obtain in Figure 12 may be too modest, and should actually be bigger in magnitude! In other words, the effects of entrainment on ABL radon concentrations in your simulation are actually likely to be underestimated! I suggest that you should run the model with an initial profile of 10 Bq m⁻³ within the ABL, stepping down to a small "background" radon concentration (0 or 0.5 Bq m⁻³, as discussed above) above the top of the residual layer from the previous day. The 10 Bq m⁻³ concentration within the ABL is the value generally assumed to be a global average measured close to land surface (UNSCEAR 2000 Report Vol. 1, Sources and effects of Ionizing Radiation, Annex B, page 103).

3. In connection with (2) above, your discussion of Figure 12 at the end of Section 7

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would be a lot different if the radon values in the free troposphere were more realistic (i.e. very low). When the CBL top reaches the free troposphere, large β_0 values may actually persist despite the decline in w_e , due to the large gradient encountered. When β_0 values are large, we might expect to see appreciable S_0 gradients within the mixed layer itself, due to the "top-down bottom-up" mixing process. This is evident in Figure 10a at 12:30 (corresponding to the maximum in β_0), and I expect would be a feature of the S_0 profiles whenever β_0 is large in magnitude. These features of radon behaviour in the CBL indicate a strong potential for the use of radon measurements as a delineator of CBL entrainment, and I think they should be emphasised more in your text.

4. The colour contour plots are generally very effective in presenting a large amount of information concisely to the reader in a quickly and easily interpretable form. However, it is sometimes hard to extract by eye certain subtleties (e.g. gradients) and to make comparisons between different plots. I think it would help the clarity of the discussion if the authors were to strategically include some additional graphs of the more conventional altitude-versus-value type, when certain details of the results need to be emphasised. In particular, it would be nice to see the following four graphs, that could perhaps be placed into one additional Figure:

a. Individual profiles of radon at significant times during the 24-hr period (say, 20:00, 03:00, 09:00, 12:30 and 16:00);

b. As (a), but for fluxes;

c. Si profiles for all radionuclides at 08:00; and

d. As (c), but for fluxes.

5. In Figure 4, it would be helpful to show a longer period (maybe the whole period, with the night-time shaded in grey?), and also to present the time-series of friction velocity (u^*) and Obukhov length (L), for completeness of the presentation and for reference

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when studying Figures 14 and 15.

TECHNICAL CORRECTIONS

I also have some technical suggestions for the authors to consider that should improve the clarity of their work:

1. Axes and labels on plots are often faint (hard to read).
2. p8896, line 3. Change "by using a state-of-the-art" to "using a state-of-the-art".
3. p8896, line 5. Change "compounds in a" to "compounds initially in a".
4. p8896, line 7. Change "processes driving the" to "processes driving the behaviour of".
5. p8896, line 7. Change "concentration behaviours. The" to "concentrations. An".
6. p8896, line 8. Change "disequilibrium observed" to "disequilibrium is observed".
7. p8896, line 8. Change "boundary layer is due to" to "boundary layer due to".
8. p8896, line 12. Change "concentration in the unsteady" to "concentrations in the unsteady".
9. p8897, line 20. Change "model (...)" to "models by Kumar et al. (2006) and Basu et al. (2007)".
10. p8898, line 5. Change "since a number of years" to "for a number of years".
11. p8898, line 5. Add " (τ_i) " after "half-life" to define the symbol now.
12. p8898, line 20. Delete "the".
13. p8898, line 24. Change "Not only we" to "Not only do we".
14. p8898, line 27. Change "e.g." to "i.e.".
15. p8899, line 13. After "decay frequencies" add "(related to the half-life by

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$\tau_i = \ln 2 / \lambda$). Not all readers will understand the relationship between τ_i and λ .

16. p8899, line 14. After each λ value, put the half-life in brackets. e.g. " 2.11×10^{-6} ($\tau_i = 3.8$ d)". Not all readers will understand the relationship between τ_i and λ .

17. p8899, line 18. Change "progeny activity (number of atoms) concentrations" to "progeny activity concentrations (measured in Bq, or atomic disintegrations per second)"

18. p8900, line 1. Delete "(at scale DELTA)", as DELTA is not used elsewhere in the text.

19. p8900, lines 13-14. Change "appear (disappear) in (from) specific regions of the ABL as due to the turbulent transport and mixing process" to "accumulate in specific regions of the ABL at different rates, due to turbulent transport and mixing processes".

20. p8900, line 21. To the right of the equation, write ", so that $R_{(i+1)} = 0$ for $i = 0, 1, 2$ ".

21. p8900, line 23. Change "initial condition of" to "initially imposed".

22. p8902, line 28. Change "Thin, very unstable" to "A thin, very unstable".

23. p8903, lines 3-4. Remove "as if ^{222}Rn was emitted" from the title of Section 4 (^{222}Rn was emitted - it just wasn't measured!).

24. p8903, lines 17-21. I suggest you write the two sentences starting "This cooling results ..." in the following way: "This cooling results in a stable temperature stratification and in the formation of a thin boundary layer isolating the surface from the residual layer above where turbulence decays. The nocturnal BL is characterized by very high radon concentrations and significant vertical concentration gradients".

25. p8903, line 26. Change "expand" to "extend".

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26. p8905, line 8. Change "the amount ..." to "the proportion of freshly created daughters to radon is smaller than in upper regions".
27. p8905, line 10. After "equilibrium" insert "(see also Figure 13, discussed in Section 8)". This change, and the change above, are important because the departure from secular equilibrium discussed is not clear from Figure 5.
28. p8905, line 12. Change "slower and delayed" to "slower and delayed, as seen in Figure 5".
29. p8905, line 14. Break paragraph just before "The important temporal ..".
30. p8905, lines 15-25. The discussion here is very confused. I suggest the following rewrite: "One can note that while the maximum vertical fluxes of radon are located close to the surface, the location of the maximum flux for its daughters moves upwards with increasing rank. These flux maxima correspond to the altitudes where the vertical concentration gradients are strongest. In contrast, the radioactive decay contributions to the short-lived daughter concentrations show maxima very close to the surface, and Figure 7 reveals strong vertical gradients away from the surface for all the daughters. These gradients are related to...".
31. p8906, lines 2-4. Change sentence to "The same process occurs for R2 and R3, although, due to the slower decaying ... not as strong as for R1".
32. p8906, line 6. Change "time" to "daytime".
33. p8906, line 10. Change "The same boundary layer" to "In the CBL, similar".
34. p8906, line 11. Insert a colon (":") after "daughters".
35. p8906, line 12. Insert "at the surface" after "emission of radon".
36. p8906, lines 13-16. Change sentence to "As mentioned previously, this behaviour is the result of an imbalance between production by surface emissions and the decaying chain on one hand, and dilution by boundary layer deepening and ventilation on the

other".

37. p8906, line 17. Change "which process is responsible for" to "the processes dominating".

38. p8906, line 24. Change "radionuclide ... layer" to "radionuclides from within the CBL towards its upper boundary (Figure 9)".

39. p8906, lines 26-27. Change sentence to "As a result we found important detrainment fluxes, i.e. positive flux values at the entrainment interface, that were even larger than the emission flux for S0 at the surface".

40. p8907, lines 3-4. Rewrite as: "... the boundary layer depth, and therefore also the entrainment velocity we, shows a maximum (see Fig. 11, discussed in Section 7)."

41. p8907, line 6. Rewrite as: "... decay term (Fig. 10) acts...".

42. p8907, lines 7-10. Rewrite as: "... close to the surface, but with different vertical gradients: the gradient of R1 is extreme compared to those of R2 and R3, which show almost well-mixed profiles in the lower CBL and a maximum at the bottom of the entrainment layer".

43. p8908, line 16. Should it be "From 09:30 to 11:00 LST"?

44. p8908, line 21. Should it be "From 11:00 to 12:30 LST"?

45. p8909, line 2. Should it be "From 12:30 LST"?

46. p8909, line 4. Insert "interface" after "entrainment".

47. p8909, line 13. Change "one" to "1.0", to improve the clarity of the text.

48. p8909, line 16. Change "In this layer" to "In the stable layer".

49. p8910, line 2. After "disequilibrium activity ratio", insert references to the studies mentioned.

50. p8910, lines 4-5. Change "should be considered" to "are also influential".
51. p8910, line 10. Change "radon is increasing" to "radon trapped in the stable boundary layer tends to increase".
52. p8910, line 13. Change "restored" to "fully established".
53. p8910, line 25. Break the paragraph just before "In this figure".
54. p8910, lines 25-26. Replace sentence with: "In Figure 14, one can notice important differences ... at dusk between the ratios for different daughters".
55. p8910, lines 28-29. Change sentence "One may wonder..." to "It is of interest to consider whether the driving process of these differences is mixing by nocturnal turbulence or aging of the radionuclide mixture".
56. p8911, lines 2-5. Change to "number (Vinueza and Galmarini, 2007), Dat , defined as the ratio between ... time-scale (τ_c). In Fig. 15, the Damkohler numbers ... are plotted against Obukov length. Here,".
57. p8911, lines 9-12. Change sentences to "Therefore, S1 and S2 are the daughters most and least (respectively) affected by turbulence in Fig. 15. However, the ... is found for S3 in Fig. 14. This clearly shows that nocturnal turbulence does not have the dominant impact on the departure...".
58. p8911, line 24. Break paragraph just before "Near the surface".
59. p8912, lines 6-10. Change sentence to: "Both turbulent transport and transport asymmetry of the ^{222}Rn daily evolution are important consequence of the entrainment of "clean" air from the reservoir layers above into the boundary layer during its unsteady morning growth period".
60. p8912, lines 11-13. Change to: "... mixed layer radon concentrations. Our analysis reveals that the spatial and temporal evolution of the concentrations of radon and its daughters is directly related...".

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 8895, 2007.

ACPD

7, S3325–S3334, 2007

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