Reviewer 1

Response to specific comments

1. in Sect. 2.4.1 : the method is for anabatic mountain winds , how are non-anabatic winds recognized? Please clarify it and give more interpretation on Fig. 2

Non-anabatic winds are not directly measured by the method, but we can infer their presence. Our primary measurement is radon concentration, which we assume to be a reliable and quantitative tracer of land-surface influence. This is a robust assumption based on many studies, some of which we cite in the introduction. Next, our method allows us to detect days which are likely to be influenced by anabatic winds – roughly speaking, we look for days which have a sinusoid-like diurnal cycle and call these 'anabatic days'. Although less robust than our previous assumption (that radon is a tracer of land influence) this assumption is still relatively reliable, based on our results and others. All days not classified as anabatic are, by our definition, 'non-anabatic', and sometimes have relatively high radon concentrations despite the absence of anabatic winds. Irrespective of classification, periods of low radon concentration mean that the air being sampled is most likely representative of unperturbed free tropospheric background values, whereas high radon concentrations on non-anabatic days likely correspond to periods where non-anabatic winds are important.

We now augment the present discussion of Fig. 3 with a discussion of this (L331–335).

2. also in Sect. 2.4.1, a run with the steps 5 and 6 could loss an input set for a diurnal composite, which could lead to an inaccurate estimation and the higher radon level in the last period in Fig. 3.

Yes, this may well partly explain the result in Fig. 3. As the main use of the "anabatic radon" diagnostic was to identify a threshold (grey bar in the revised Fig. 3.) we are not so concerned with the behaviour of the anabatic radon diagnostic for the highest ranks, but we have mentioned this point at the end of Sect. 2.4.1. (L346–358)

3. Why are the diurnal changes in radon at Bern so high in Fig. 5? Which impact could the diurnal changes at Bern exert the estimations of anabatic winds?

As an inland site, Bern has land fetch for all wind directions, and radon emissions from the ground are roughly constant. As a result, the main driver of diurnal changes in near-surface radon concentrations is the boundary layer mixing depth, h. Radon increases at a rate $\sim 1/h$ during the night and then drops the next day during the period of boundary layer growth due to the entrainment of comparatively low radon air from the residual layer or free atmosphere. The largest diurnal variations in radon concentrations are observed on days with the largest variation in mixing depth, which typically occur on clear-sky days in summer when daytime convection is strongest and nocturnal cooling the most rapid. Such conditions usually correspond to days with anabatic winds (e.g. days 1–50 in Fig. 5).

The large diurnal changes mean that it is not useful to define a representative radon concentration for “boundary-layer air”. This is the main reason we have not normalised the Jungfraujoch radon concentration by some function, e.g. the daily minimum, of the Bern radon concentration. Instead, we use the Jungfraujoch radon concentration as a direct indicator of the land surface influence function (or footprint) which is equivalent to assuming that radon emissions are constant from land. With the recent improvement in radon emission estimates, it would make sense in a future study to take spatial and temporal variations into account.

A discussion of this appears in the revised Sect 3.1 (L462–).

4. The Sects of 3.4 and 3.5 are a little beyond the topics of manuscript. Please shorten them.

Another reviewer suggested removing Sect 3.5. We have done so, leaving the question of aerosol scavenging to be dealt with in more detail in a future study.

The editorial corrections have been incorporated into the revised version. These were the suggested changes:

P18085, line 15, please delete “to”

1) P18085, line 22, change “The three” to “Three”

2) P18086, line27, change “months they” to “months, they”

3) P18087,line 28, change “towers” to” , towers”

4) P18088,line 4, change “(Zahorowski et al., 2004)” to “Zahorowski et al.(2004)”

5) P18090, line 1, please clarify the “23 pressure levels (6 between 1000–850 hPa)”

6) P18090, line 19, please change “constraints” to “constraint”

7) P18094, line 6, please delete the repeating “direction”

8) P18096, line 4, change “there” to“those”

Reviewer 2

1. The method description was not detailed enough to be implemented by another researcher

In addition to elaborating upon our methodology description we have added an overview of what the algorithm is trying to achieve. We have noted that, "In overview, the procedure involves computing the diurnal composite of the set of all observed days and then removing days from the set in the order which most quickly reduces the amplitude of the set's composite diurnal cycle." Following from this is a more detailed description of the sorting method. (L289–)

2. "In summary, the method section lacks detailed scientific understanding [of] the impact of anabatic wind on mountaintop Rn concentrations"

From the context of this remark, we understand this to mean that the reviewer would like to see more discussion of what motivated the choice of methodology. Presently we say, "the central feature of our method is the recognition that anabatic mountain winds are associated with a diurnal cycle in tracer concentrations near mountain tops, peaking in the afternoon." but can understand how a longer discussion would be useful. In the revised version we add more discussion of how anabatic winds lead to the sinusoidal pattern in trace gas concentrations, also citing Whiteman (2000) and Brooks et al. (2012) as suggested, but have chosen to include this in the Introduction rather than the Methods section. (L102–118)

3. The results/discussion section "should discuss the relationship between low/high [rank] days with the observed radon gradient (Bern and JFJ) in the daytime. How does that relationship relate to the gradient values reported in the literature?"

This is an interesting point and warrants discussion in the revised version. In this context, the radon gradient means the difference in radon concentration between Bern and Jungfraujoch, $\Delta\mathrm{Rn} = \mathrm{Rn}_B - \mathrm{Rn}_{JFJ}$. As we (and the reviewer) mention, the radon difference become small on days with active anabatic winds and we use this fact as evidence of coupling between the Bern and Jungfraujoch airmasses on anabatic days. However when $\Delta\mathrm{Rn}$ is not close to zero we are unconvinced that it is a useful parameter for characterising the strength of vertical mixing between Bern and Jungfraujoch. This is because the two measurements are far enough from each other (60 km horizontally, 3 km vertically) for first-order influences on $\Delta\mathrm{Rn}$ to be factors other than vertical mixing unless mixing is particularly active. Assuming the air masses are decoupled, which is likely when Jungfraujoch is sampling free tropospheric air, the first-order influences on $\Delta\mathrm{Rn}$ are factors which control Rn_B, such as the boundary layer mixing depth at Bern, because $\mathrm{Rn}_B \gg \mathrm{Rn}_{JFJ}$ and therefore $\Delta\mathrm{Rn} \sim \mathrm{Rn}_B$. The radon concentration measured at Jungfraujoch, on the other hand, *is* primarily influenced by the history of airmass mixing so it is preferable to use Rn_{JFJ} as an indicator of vertical mixing rather than $\Delta\mathrm{Rn}$ (comments added in Sect 3.1, L462–483).

Details of changes

Method

Authors should elaborate their methodology

We have described the method in more detail in the revised text (see point 1 above).

first discuss the general pattern of trace gas concentration variability and how is it affected by slope flows so that "sinusoidal" curve is often observed

Added to the introduction: "For tracer measurements at stations near mountain peaks the thermally driven winds result in a characteristic diurnal cycle which is approximately sinusoidal in shape. . . " (L289–)

07:00 UTC to be the time when minimum radon concentration in the JFJ diurnal composite is observed. I wonder if this time is season-independent

The time of minimum diurnal radon concentration varies with season and fetch direction, as shown in Fig. 4. However, since the variation is small, we considered it appropriate to use a fixed time year-round in order to keep the method as simple as possible. A comment to this effect has been added to the revised description of the method. (L299)

they should discuss in detail how does the interaction between anabatic wind and mountaintop measurements affect the representivity of JFJ measurements to be considered as background (baseline) measurements

This issue is presently discussed in Sect. 3.4. This section has been edited to emphasise this important issue. (L749–)

In many past papers, using other tracers like CO, O3, aerosols, etc. have been found. Which kind of new information you get using radon

This is presently addressed in Sect. 3.2 "Comparison with other indicators of upslope winds". Radon is preferred to other tracers in principle because it is chemically inert, decays at a known rate, and has a source function which is well known and homogeneous compared with alternatives. These features make it a quantitative tracer of land-surface influence. An exhaustive comparison with all other tracers would be lengthy and is unwarranted, given the scope of this investigation, but we now explain in Sect. 3.2 why we compare radon only with the vapour mixing ratio, a good example of a generic tracer. (L585)

they should clearly discuss how does the rank-based approach differentiate anabatic component and advected component since JFJ measurements are oftentimes influenced by transported contribution

This has been clarified in the revised text. Briefly, the rank-based approach identifies the anabatic component. The advected component is inferred from the measured radon concentration minus the anabatic component with the important caveat that the method is unable to tell the difference between air which has been ejected from the boundary layer upstream and air which has been lifted by synoptic winds interacting with the mountain range. The following text has been added to the results section: "On these days, vertical transport is most likely the result of synoptic-scale winds interacting with the terrain." (L510)

P18092, L5: "intra-day variability combined with the method's inability..." What makes the method imperfect?

We referred to the method as being imperfect because the only requirement for a day to be classified as an anabatic wind day is for the diurnal cycle of radon concentration to match our expectations. Although this works well on average, there are occasions when the radon concentration varies diurnally in the expected way purely by chance (L354).

Results and Discussion

P18093, L10: "allowing 77 %" what explains the remaining 23% of days to be non-adiabatic. Are these days affected by dynamically driven winds and/or synoptic scale advection? Please also explain the role of convective boundary layer along with overshooting thermals which oftentimes reach mountaintops although the CBL top height remains below the ridge height.

The "77%" was referring to the number of days that had enough data for us to run our detection algorithm. We would like to take this opportunity to remind readers that we exclude entire days if they include a data gap of 3 h or more. (L399)

P18093, L13-15: "Mean radon concentration" Do you mean daily average values?

This means composite-mean radon values (the dots in Fig. 4). Changed "Mean" to "Composite mean". (L403)

P18093, L13-15: "Strength of the diurnal cycle": Do you mean peak to trough amplitude?

Changed to Strength to "Peak to peak amplitude" (L409)

P18094, L13: "different time-scales" what do you mean by different? Please clarify.

Paragraph deleted in revision.

P18094, L15: "diurnal cycles of similar strength" What do you mean here? Unclear to me.

Changed to "... composites are generated according to the anabatic rank, which results in grouping together days with similar diurnal cycles." (L447)

An important discussion about the results presented in Fig. 5 is missing...

This was addressed above as major discussion point 3.

Section 3.4

... I suggest dropping the entire section...

Section removed from revision.

Figures

Most problems raised here will be resolved when the figures are printed full-size in the ACP layout, as we scaled the figures down for the ACPD format but neglected to consider the effect on font sizes. Other suggestions have been used to improve the figures.

Other comments

1. About the references...

The suggested references have been added. (L104)

2. P 18086, L12: "a factor of three". Please mention that this factor is site specific.

Change made as suggested. (L85)

3. P18086, L19: CO: VOC?

Changed to VOC; added comment that Forrer et al. (2000) used CO (L124)

4. P18087, L4: Syntax

Change made as suggested. Now "Yet another approach is..." (L134)

5. P18095, L5, "with little dilution": What do you mean by "little". This is an awkward phrase for a scientific paper.

Changed to "radon concentrations at Jungfraujoch as high as those in the boundary-layer at Bern" (L507)

6. P18095, L5-6: "not by solar forcing". Is it related to advection?

Processes 2. and 3. in the list on P18085 are all candidates, but the highest radon concentrations are indicative of direct transport rather than the advection of an elevated layer to Jungfraujoch. Added the text "On these days, vertical transport is most likely the result of synoptic-scale winds interacting with the terrain." (L510)

7. P18098, L24: "abatic"

The discussion paper had confusing hyphenation at the end of a line (an-abatic), no change made.