Response to Referees – Valley floor inclination affecting valley winds and transport of passive tracers in idealised simulations

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We thank the reviewers for their constructive comments on our submitted manuscript. We have copied the comments of the reviewers here in black and include our response to each individual comment in blue.

Referee report 1

Abstract - What are the "surface-based down-valley winds"? Is a surface-based wind an anabatic/katabatic wind? Please clarify this concept. We use the term *surface-based* to describe the wind layer in touch with the surface. Down-valley winds refer to winds blowing in the valley towards the plain, i.e, negative y-wind in our simulations. Surface-based down-valley winds can be katabatic, like in the case of inclined valleys in our study. Surface-based down-valley winds do also form in a flat-floored valley (Zardi and Whiteman, 2013; Schmidli and Rotunno, 2010), like in the case FLAT in our study, but then they are not katabatic and driven by the valley volume effect.

L35/36- It is unclear to the reviewer why a steeper slope angle would decrease the mass flux resulting in a weaker flow magnitude. The buoyancy force that drives the anabatic/katabatic winds is proportional to sin(a), where a is the slope angle, increasing as the angle increases. Please clarify. While the buoyancy force increases, the flow depth of the up-slope wind layer decreases with increasing slope angle (Eqn. 10 in Farina and Zardi, 2023). In fact, the mass flux is inverse proportional to the sine of the slope angle (see, e.g., Eqn. 9 in Schmidli 2013). We have added these references in the manuscript.

L41/43- the description of the air volume heating above the valley and plain is not clear to me. Can it be rephrased to be clearer? The explanation of the valley volume effect has been revised: "Due to its confined geometry, a valley exhibits a smaller air volume beneath a horizontal reference surface, e.g., located at crest height, than the volume over the foreland. This smaller air volume is associated with a smaller air mass and, when subjected to the same amount of energy input, experiences a larger heating rate than the larger air mass over the foreland."

L211- "a typical isentropic structure associated with up-valley winds", is the word isentropic correctly used? It seems that an isentropic process is a (idealised) thermodynamic process both anabatic and reversible. One might think that in this real situation, the dynamics are neither anabolic nor reversible, so one wonders whether the term chosen is correct. Please clarify the choice and add references in this field on the use of the term. We agree that using the term "isentropic structure" might be misleading. In this case we don't refer to an isentropic process but to the spacial structure of the potential temperature countours, also referred widely in meteorologic literature as isentropes, i.e. the contour lines plotted in the cross-section figures 3 and 4. We have revised the paragraph to avoid this misunderstanding.

Figure 3a- It seems curious that in the presence of a flat valley and no atmospheric wind, a current is generated entering the valley (see -10km<x<50km). How can this phenomenon be explained? Plain-to-valley winds form even for a flat-floored valley as the valley volume ($y > 0$) heats up more than the CBL_p above the plain ($y < 0$) during the course of the day, which occurs because the volume of air to be heated is smaller in the valley than above the plain (see explanation of valley-volume effect above). The resulting horizontal temperature gradient is associated with a horizontal pressure gradient force that drives the winds from the plain into the valley at the lower levels (Schmidli and Rotunno, 2010).

L209/218- The description of Figure 3 can be made clearer, it is a bit hard to follow. We have revised the terms used related with the potential temperature.

L229- It is not clear to the reviewer by what mechanism the air heats up more in I1, I2 configurations while it is much less hot and the flow seems less intense for I3. This seems contradictory, what explanation do the authors give? On line 229 we describe the daytime up-valley winds and not the heating of the valleys. The valley cases I1 and I2 do not heat up in a notably different way compared to the other cases which can be seen in the Supplementary Figure A6.

L230- The recirculation cells are not visible from the plot display. Please show the cells if you wish to discuss them. We agree that the recirculation cells are not visible in the plotted wind vectors in Figure 3, since they are much weaker than the main circulation cell. However, we think they are clearly visible in Figure 3 in the shaded along-valley wind speed (blue and red colors).

L240- Please specify to which "similar isentrope structure" you are referring, and check if isentrope structure is a good terminology, used in litterature for these types of phenomena. Reference needed. This is revised as "structure of the isentropes", which refers to the spatial structure of the potential temperature.

L241/242- "This suggests that the buoyancy-driven anabatic winds are contributing in the daytime to the up-valley winds near the surface." If the reviewer has correctly understood, the convection is the only force triggering the flow as the horizontal wind components are set to zero. If not, this point can made clearer. The simulations are initialised with wind components set to zero. However, thermally driven winds, such as valley and slope winds, may form due the topography induced horizontal temperature gradients.

Section 3.1.2- It seems that these results do not add anything to the discussion. This section can be removed or the authors can highlight the information added to the discussion in this section. The valley-volume-averaged up-valley winds are notably stronger on the second day which is discussed later in Section 3.1.4 with Figure 5. This difference between the days would anyway arise when discussing Figure 5, so we find it logical to explain shortly here. Therefore, we decided to keep this text.

L302/303- Also here, it seems very strange that the down-slope flow develops where no slope is present. How this can be justified? Here we describe the night-time down-valley winds which form also for flat-floored valleys (Zardi and Whiteman, 2013). Due the aforementioned valley volume effect, horizontal temperature gradient forms with reversed sign when compared to the daytime. This causes valley-to-plain winds during the night.

L303- What is the accuracy of the WRF model? The error in temperature can be around 0.5K, what about the velocity magnitude? is it possible that a velocity of 0.5m/s is within the numerical error of the simulation? We have revised this sentence and exclude the exact value for the weak wind speeds.

Section 3.1.1- Authors may consider shortening this section and making it more concise, as done for section 3.1.3. The focus of the study is more on the daytime up-valley winds, which are discussed in more detail than the night-time winds. We think all the paragraphs in this section are necessary and have not excluded any of the discussed topics.

L356- The formula for computing this quantity can be reported for clarity. Is this quantity made non-dimensional with respect to the total volume? It seems strange that the FLAT case exhibits the largest values. Equations for the Figure 5 are added in the Appendix A1.1 in the revised manuscript. The valley averaged along-valley wind speed shown in Fig 5a is average of the y-wind component over the whole valley volume. The valley averaged up-valley wind shown in Fig. 5b is averaged over all grid points or vertical levels with positive along-valley wind hence up-valley wind. All the valleys have the same valley volume since the cross-valley shape remains the same despite the inclination.

Figure 6- what is the formula used to compute this quantity' Please report it for completeness. The derivation of the variable shown in this figure was reported in Appendix A and it was referred to in the text right after introducing Figure 6.

L402/following- This is a very interesting finding that can be expanded. I think that authors can report Eq. 5 and show some more analyses to gain a deeper knowledge of this mechanism, which is a bit counterintuitive. This result is highlighted and discussed in details in section 4.

Figure 7,8,9- Please add the expression of the formulas used to compute the quantity plotted. Equations have been added as Appendix A2 in the revised manuscript. The Appendix is referred in the first paragraph of Section 3.2 Tracer transport.

Figure 10- Percentages are not all readable. We have fixed this problem.

Section 4- The reviewer believes that the manuscript is very long and prolix in some parts. The analyses are extensively discussed and, in this section, information that has already been read previously in the text is reported again, adding a further very long and verbose discussion. It is recommended that the manuscript be shortened by making it more concise and focused on points of interest. With this aim, this section can be integrated into the previous section 3, or it should be greatly shortened by eliminating all previously reported information. Section 3 describes the results of our simulations with minimal discussion or speculation. In Section 4 we compare our results to previous studies and provide explanation for the results, which we are tempted to keep separated from the results section.

L653- As already mentioned, this is a very interesting point that deserves some more analysis and a dedicated point in the conclusion, in the opinion of the reviewer. Thank you for the interest on our results. We keep the conclusions related on the winds to two bullet points, one for the daytime and one for the night-time winds.

L16- "Diurnal valley and slope winds" is a bit confusing, did you mean "diurnal and slop winds". Both the valley (along-valley directed i.e. y-wind in our simulations) and slope winds (cross-valley directed i.e. x-wind) are thermally driven and exhibit a diurnal cycle in mountain valleys (Zardi and Whiteman, 2013).

Referee report 2

General note: I find Introduction, Results, and Discussion to be too lengthy. However, this may be influenced by my bias towards terse writing and shorter texts, so keep that in mind! I understand that it might be necessary for the potential readers. That is why I tried to point out how to simplify the sentences. Thank you for the suggestions. We have examined the manuscript with this point-of-view.

Abstract
3: We explore a range of the valley inclinations...

3-4: We explore a range of valley inclinations from 0 to 2.28 degrees. Revised as suggested.

5: the sentence could be written better. A suggestion:
We find that during daytime in the inclined valleys, up-valley winds penetrate deeper [into the valleys] and become stronger, up to a critical inclination [angle] beyond which the winds weaken.

- The text within [ ] is implied and I think the sentence works without it as well.
- additional comma after inclined valleys adds to readability
- "inclination" instead of "angle" - angle might be a bit ambigious since it might refer to the angle of the wind. Changing the word to "inclination" more clearly refers to the valley inclination. The sentence also works without "angle", but it can be added.
- "daytime" without "the" - you are not referring to the specific daytime that was mentioned before or that awaits the reader in the paper.

Thank you for the suggestions, we have applied most of them in the text. We left the "into the valley" in this sentence for clarity.

7-9: Flat-floored valleys exhibit the strongest night-time down-valley winds overall, but surface-based down-valley winds are more prominent in inclined valleys. - ? In the flat-floored valley (case FLAT) the night-time valley-volume-averaged along-valley winds have the smallest values (=strongest down-valley winds, see Fig. 5a in the manuscript). However, most of these down-valley winds consist of the return flow related with the residual night-time up-valley winds. The katabatic down-valley winds are prominent in the inclined valleys but in the case FLAT the surface-based down-valley winds are only a couple of tens of meters deep and very weak in magnitude.

9: flat-floored valleys - consistency with the previous. This is revised here and elsewhere in the manuscript.

11: at ventilating tracers Revised as suggested.

11: which would, for example, lead to... - “for example” is parenthetical Commas added.

Introduction

25-36 (second paragraph): is the explanation of valley winds necessary? Vergeiner and Dreiseitl (1987) is cited 4 times. Line 34-36 is fine, but before it, it seems too lenghtly. Of course, if this kind of explanation is required for the readers of this paper, discard this comment. Our main result of the wind comparison is focused heavily on the combination of the slope and valley wind mechanisms which we find necessary to be explained in the introduction.

36:"hence result as weaker flow magnitude and flow depth." - suggestion: “resulting in a weaker flow magnitude and shallower flow depth.” Changed to the suggested sentence.

97: “... ends up”. Revised as suggested.

Methods

Generally, I find no objections to the Methods section, except a few suggestions below.

115: provide a reference for the local time (LT = UTC + ?). Also, write that, e.g. 18:00, refers to LT. We have removed the LT / Local time reference here, as it was not used else where in the manuscript.

165-167: instead of 0 km < y < 10 km, etc., just: 0-10 km, 20-30 km, 40-50 km? Or $y in<0,10>. Same for x. Just a suggestion. We tried various options but find the original to be the clearest.

193: inclination, meaning they... Comma added.

195-196: Unclear sentence, missing 2 commas. Suggestion: For the case SLOPE, the flux components are the same as those shown by F1-F3, but they account for the entire domain in the x-direction due to the homogenity of the slope. We replaced the sentence with this suggestion.

Results

Most of the results clear, with occassional dips in clarity. I find it a bit lenghty though, like the introduction.

3.1.1: inconsistent use of CBLv and CBL_v (same for p). Please correct. We have revised the text to be consistent and now use CBL_{V} and CLB_{P}

256: Here, the term \textit{main cell circulation} refers to... English guidelines for submissions in ACP do not allow the use of italics for this case: `https://www.atmospheric-chemistry-and-physics.net/submission.html#:~:text=Italicization`

293: surface-based Revised as suggested.

Section 3.1.4. - I have comments and suggestions.

First, the clarity of the following lines should be improved:

- 336: "valley-volume-averaged" would clarify it as a compound-adjective Changed here and elsewhere in the manuscript.
- 338: valley-averaged Changed here and elsewhere in the manuscript.
- 342: A diurnal cylce? Revised as suggested.
- 342: down-valley wind at night... Revised as suggested.
- 345: up-valley winds occur in case I1... Revised as suggested.
- 345: I3 which aligns with Fig.3 Revised as suggested.
- 348: values in Fig 5., it would appear that the case FLAT clearly has the strongest... Revised as suggested.
- 349-351: This difference is due to the down-valley-directed return flow, which is mostly outside the valley volume in case FLAT (Section 3.1.1) and, therefore, does not affect the valley volume average as much as in the inclined cases. Revised as suggested.
- 370: on the second day (Fig 5b).Revised as suggested.

Thank you for these suggestions. We have applied them in the text.

Then, Figure 5 could use a bolder horizontal line at 0. Also, what about making the y-limits identical: -1.0 to 3.0.? It would make the figures a pair. It was hard to read the figure as presented due to the y-limits that kept mixing in my head. Additionally, section 3.1.4 jumps between 5a and 5b, so this different y-limits really get annoying. Consider making the captions at least 1 fontsize larger. Thank you for the suggestions. We added bold horizontal zero-lines, adjusted the y-limits from -1 to 3 m s^{-1} for both panels and increased the font size.

Finally, when I, as a reader, am first introduced to fig 5, you make me guess: why is only the upslope component shown in b? I expect to analyse the 5a, since it is a more conventional average, and then for you to lead me into 5b and reveal the reason behind this choice. However, I am not able to comprehend the message of this section without reading it VERY carefully and multiple times. If you spent more time with 5a, and then wrote: "(...) values in Fig 5., it would appear that the case FLAT clearly has the strongest (...)", you would naturally lead me, the reader, to the reasoning and make your case better and my reading easier. I have made suggestions for clarity, but consider restructuring this paragraph and modyfing figure 5. Thank you for the suggestions. We have revised the Section 3.1.4 based on these suggestions.

375-380: could use a more clearer phrasing. Instead of commenting everything, I rewrote it:

""""

In the volume-averaged along-slope wind, case SLOPE shows much weaker winds compared to case I2 (Fig. 5a). This is because its return flow is entirely located within the analysis volume (Section 3.1.1), which significantly reduces the volume-averaged up-slope wind. The 2-km-deep analysis volume in case SLOPE was chosen to correspond to the ridge height in the valley simulations. However, when averaging only the positive along-slope winds, the flow strength in case SLOPE is comparable to that in case I2 (Fig. 5b). In the morning, the winds in case SLOPE are slightly stronger than those in the valley simulations.

""""

We have replaced the original paragraph by the suggested text with minor changes.

387: For a detailed explanation of how the plotted variable in Fig 6 is derived, refer to Appendix A. Changed in the text.

Figure 6: again, confused me a bit due to the unequal y-ranges. How about minusing the 6c and then making an equal y-range? In the revised manuscript the panel c has an inverted y-axis and the range of values within the panel a is now equal to panels b and c.

484: In the second day, the ventilation… Comma added.

494-500: simplify the phrases and remove unnecessary words (In case SLOPE, nearly all the transport), brake up the sentence about the first and second days, change “drastic” to “significant” Paragraph revised based on the suggestions. To avoid potential misunderstanding, we use the word ”significant” only in the case of statistical significance.

515: are weak, so the… Comma added.

Discussion

562: In Wagner et al (2015a), the ridges… Comma added.

591: inclination, and … Comma added.

598: ,but Comma added.

Conclusions

651: allows Revised as suggested.

657-660: Use "Steeper valley floors" OR "inclined valleys" instead of "steeper valleys"? Sure, it is implied, but if someone just reads the conclusion, it might be ambigious since you are using 2 terms. Changed to "Inclined valleys".

All in all, I find the paper interesting, particularly in the way it presents the tracer export/outflow as an interplay between the cross-valley winds, valley volume effect, and buoyancy forcing due to heating. Thank you for the extensive suggestions and comments which improve the manuscript.

References

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