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Comment

## ***Interactive comment on “Winter greenhouse gas emissions (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) from a sub-alpine grassland” by L. Merbold et al.***

### **Anonymous Referee #1**

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This manuscript presents an impressive dataset of gas flux measurements from a snow-covered site in Switzerland. The presentation of the data is generally appropriate, but in some cases there is a lack of transparency on how the data analysis was performed. While the introduction provides a good overview of the importance of measuring gas fluxes from snow covered sites, there is very little in the discussion or conclusions that puts the results of this study in a broader context. There are some comparisons of these data compared to other sites, but there is very little interpretation of what it means when the results either are similar or differ from other sites. Further, there is almost no discussion of the spatial component of this study. Finally, the writing would benefit from careful editing. In many cases, the authors have interesting ideas, but there are too many crammed into a single sentence, or paragraphs contain sentences that don't provide a consistent narrative, and in some cases there are En-

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English usage errors. I have identified some examples of this in the specific comments below, but the authors would benefit from careful editing to make sure that individual sentences and the sentences within paragraphs tell a clear narrative throughout the manuscript.

**Introduction** There is useful information in this section, but the current structure needs some editing at both the paragraph and the sentence level. Why is the sentence starting on P403L8 a whole paragraph? Why is the general paragraph on N<sub>2</sub>O and CH<sub>4</sub> emissions starting on P404L5 included? Why does the paragraph starting on P403L12 jump back and forth between what we know about GHG emissions generally and what we know about GHG in winter more specifically. One possible way to clarify the narrative of the introduction would be to first put GHG fluxes from ecosystems were put into a context of total GHG emissions (based on the data from the existing networks), followed by a discussion of GHG in snow covered ecosystems more specifically, including the methodological approaches and difficulties and what is known already about the magnitude of fluxes and the controls on the fluxes.

Furthermore, the authors should be clear about the results of this work will contribute to our understanding the global significance of GHG fluxes in seasonally snow-covered systems or just subalpine/alpine grasslands. If it is the latter, they need to make a case for the broader significance of understanding GHG emissions there.

P402 L25- P403L2 This sentence is awkward

P403L12-P404L4 This paragraph is particularly confusing. Is the discussion specific to snow-covered ecosystems? What are the “complex processes” that we need to understand better? How come the first sentence suggests that “a profound understanding of such processes exists only for CO<sub>2</sub>” when two sentences later it is suggested that “knowledge of fluxes for all three gases remains sparse?”

P404 L12-P405L2 This paragraph switches back and forth between CO<sub>2</sub> and N<sub>2</sub>O/CH<sub>4</sub>. Why not complete the discussion of our limited knowledge of CO<sub>2</sub> and

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then discuss what we know about total GHG balance based on the even fewer measurements of CH<sub>4</sub>/N<sub>2</sub>O

P405L5-7 It might be useful to have a table showing the studies that have compared methods including the means and some estimate of variability as well as the location of the study, snow depth, duration of study, frequency of measurements, etc. Or this could be included in the discussion.

P405L7-9. This sentence doesn't make sense. Are you trying to say something about the hourly/daily/seasonal variability with a particular methodology compared to the difference among methodologies for a particular hour/day/season?

P405L9-10 Another comparison between chambers and the gradient method is McDowell et al. (2000), which found no difference between techniques.

McDowell N.G., Marshall J.D., Hooker T.D. and Musselman R. 2000. Estimating CO<sub>2</sub> flux from snowpacks at three sites in the Rocky Mountains. *Tree Physiol.* 20: 745–753.

P405L20 Where do the authors attempt to “identify the variables driving GHG emissions from different land-use type in a subalpine valley?” It seems like they looked at the variables related to the fluxes near the EC tower and they mapped the spatial pattern of fluxes, but there is nothing in the results suggesting what is driving differences in fluxes related to land use?

P406L18 Delete “greenhouse gas”

P406L20 Delete “majorly”

P407L9-12 What is the frequency of the data used for the calculations (e.g. presented in figure 4 or compared to the physical data)?

P408L14 fix the spelling of “tortuosity.”

P409L1-14 More details about the sampling and analysis are needed here. How is the air collected with the ski pole. Is there a pump? How much air is pulled from the

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snowpack and over what period of time? How many depths were sampled? Was CO<sub>2</sub> always measured with the IRGA in the field or was it also measured on the GC? In Lines 10-13, you should be specific about which detector was used to measure which gas.

P409L15 The data from the automated system would provide an interesting comparison. However, since the method was not successful, there is not a compelling reason to include the description of the methodology or the short results section (3.5).

P410L15-22 There needs to be more description of what was actually done here. Was the same gas sampling and analysis used here as in the weekly samples? What depths were sampled for the CO<sub>2</sub> measurements? It seems like there were two sampling strategies to look for spatial variability: first, two perpendicular transects were established in the grassland and CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O were measured and second, just CO<sub>2</sub> was sampled across a transect that spanned multiple vegetation types. It would help to have a map of the sampling design as part of Figure 1. Were there gradients in some environmental variables that would be expected to contribute to variability?

P411L24-25 What does “continuous snowfall” mean?

P412L11 What does “followed a seasonal course” mean?

P412L15-17 The mention of CO<sub>2</sub> concentrations doesn’t fit here. More broadly, it would be helpful to make clear what time period is included in the flux values. That is, are they averages for all the samples during that month?

P412L17-24 It would be a useful comparison to calculate the EC values for the times that the gradient measurements were done to see how similar they are at the same time and not just over the whole season.

P413L16-20 How was this model selected? Were the calculations done for every day of the snow-covered season? There needs to be a description in the methods of what this was done.

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P413L21-25 Once again, there needs to be a description in the methods for how this analysis was done. For example, was a daily mean flux used to test the model? It is confusing that the seasonal values are so similar for the EC and gradient methods, but on shorter time scales the drivers of fluxes are not the same.

P413L25-26 Can you compare month by month instead of using vague terms like “beginning and the end of the season?” Is there any statistical analysis here?

P414L12-14 What was the point of extrapolation for N<sub>2</sub>O fluxes? Is it just for calculating the total seasonal emissions? I don’t understand exactly how the running mean was calculated, but why not just do a linear interpolation between the days that were sampled?

P415L1-10 Delete

P415L13-15 How is the variability “stronger?”

P416 L6-11 Based on figure 8, it seems like a statistical test was actually used to compare among ecosystems. This should be included in the results section as well as in the methods section.

P416L24 Do you know what the footprint is?

P416L25-P417L4 I don’t understand what is being compared? Is it the value along both transects, is it the transects compared to the weekly sampling, is it the transects compared to EC?

P417L8-9 Pressure pumping doesn’t necessarily increase the CO<sub>2</sub> efflux, but it means that gradient measurements are underestimating the CO<sub>2</sub> efflux

P417L21 “bares” is not the right word. Maybe contributes the most to the uncertainty? There is also some debate in the literature on how to calculate tortuosity (see discussion in Seok et al. (2009))

P418L5 NO and NO<sub>2</sub> are not inert in the snowpack

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P418L6-11 Is this discussion of liquid water apply all winter long or just when the snowpack is at zero during melt events?

P418L12-21 I can understand why liquid water might increase dissolved CO<sub>2</sub> and prevent emission to the atmosphere, but I don't understand why this would affect the methods differently. That is, I can believe that CO<sub>2</sub> fluxes would be lower during snowmelt, but why would meltwater lead to the large discrepancy in the two methods?

P418L22-P19L13 This section should be condensed to make the point that tracers could be used. IS SF<sub>6</sub> injected into the snowpack to be used as a tracer? This is different than using radon. It seems like you have to know what the flux of radon is at the soil surface in order to validate the flux calculated with the gradient method?

P419;L14-25 This paragraph doesn't belong in the discussion. It seems like the necessary portions are already included in the methods section.

P420L2-8. It is true that the pattern in this study doesn't match the data for the sub-alpine site in Liptzin et al. 2009 (Fillipa et al 2009 and Seok et al 2009 are not appropriate references here). However, it is similar to the conceptual zone II in Liptzin et al. (2009). There are many other studies in the Rocky Mountains report a mid winter (Jan or Feb) minimum compared to higher rates in late fall or spring. This is the pattern reported by Sommerfeld et al (1996) cited here as well as the Monson 2006a reference below as well as Brooks et al. 1997.

P420L19-25. This sentence is awkward because it has too many ideas combined.

P420L19-P421L7 This discussion is confusing. What would the mechanism be for SWE affecting CO<sub>2</sub> flux? Sommerfeld et al (2006) reports a similar correlation, but also does not provide a mechanism. The authors should provide some explanation for why this correlation is meaningful. The relationship for Monson et al. (2006b) does not seem appropriate here as it is a comparison of CO<sub>2</sub> flux and maximum snow depth among years and not in a given year.

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P421L26-29 How does the soil moisture at this site compare to the others cited in the text. That might help evaluate if the lack of variability

P422L4-9 Are you suggesting that land management affects N<sub>2</sub>O emissions? Or is the beginning of this paragraph is just a summary of N<sub>2</sub>O emisisions?

P422L11 What does the reactivity of NO, N<sub>2</sub>O and NO<sub>2</sub> have to do with the seasonal patterns of N<sub>2</sub>O fluxes?

P422L18-20 Why not estimate porosity based on the bulk density?

P423L10-17 It would be helpful to have more discussion of the spatial variation. Otherwise why include them? For example, there is no mention in the discussion of why the different land uses differ in CO<sub>2</sub> fluxes.

P423L25-P424L4 Are the author's suggesting that there would be lower gas emissions during a shorter snow-covered season because the snow-covered season itself is shorter? It would be more useful to have a discussion of whether a shorter snow-covered season would affect soil temperatures which seem to be highly related to at least CO<sub>2</sub> and CH<sub>4</sub> emissions. If snow cover started later or snow depths were lower, what would the consequences for gas fluxes be.

Table 2. Why is April included when there are so few manual samples taken? Wasn't snowcover assumed to be gone on April 4th? How were the modeled values calculated for the EC measurements?

Table 3. It is confusing that the EC technique is used in this table since the CH<sub>4</sub> and N<sub>2</sub>O measurements are only for the gradient technique.

Figure 1. The intermediate scale is not needed, but it would be helpful to see where the various transects were.

Figure 2. The changes in soil temperature during the snow covered season are difficult to see in panel b because the scale has to go up to 30 degrees. Can you just show the

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temperature during the snow covered season? The useful information is the variability between -0.5 and +0.5 degrees

Figure 3. What are the error bars on this graph?

Figure 4. I don't understand the gray polygon.

Figure 5. What do the plots look like for daily CO<sub>2</sub> flux from the EC method vs temperature on the days when the gradient method was done? Is the lack of relationship between temperature and CO<sub>2</sub> flux a function of the high variability in flux as seen in Figure 4 at some times scales whereas the longer term trends are clearer. Is this a signal to noise problem depending on the time scale of averaging?

Figure 6. Not needed

Figure 7. It is confusing to have the two transects connected to each other in a different orientation than on the ground. Even if there is a point of overlap between the two transects, the graphs would be easier to interpret as separate panels for the two transects. How was the interpolation done? Was it done first along the vertical profile of each gradient and then the horizontal interpolation between sampling locations?

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