

## ***Interactive comment on* “The underestimated role of stratosphere-to-troposphere transport on tropospheric ozone” by Thomas Trickl et al.**

### **Anonymous Referee #1**

Received and published: 6 March 2018

The manuscript “The underestimated role of stratosphere-to-troposphere transport on tropospheric ozone” by Trickl et al. describes an analysis of the effect of stratospheric intrusions over Garmisch-Partenkirchen on ozone values over the full free troposphere. Long-term ozone and water vapor lidar measurements from Garmisch-Partenkirchen, in-situ and radiosonde data from nearby stations, and trajectory analyses combined provide a very good data basis for these kinds of analyses. Different intrusion events are categorized, and possible reasons for changes in event frequencies are mentioned. The structure of the manuscript is somewhat chaotic so that it is difficult to find the storyline in the text. Sometimes the sentence structures are not entirely correct which complicates the understanding of the meaning of phrases and sentences. I believe the applied analyses methods are sound, however, it is hard to tell since there is an

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abundance of information about historical analyses already published, recent analyses, and planned analyses. I think this manuscript needs major restructuring, rewording and general clarifications before the full extent of the presented analyses becomes clear. But I do believe that the study can show some interesting results if they are presented in a precise and detailed manner. I can only recommend the manuscript for publication if major revisions have been done, following the general and detailed suggestions listed below.

General suggestions/comments:

- The manuscript has both too much and not enough information in parts. Very often, much background information about measurements, specific intrusion cases etc. are given that might not be necessary for the storyline (some of these will be pointed out in the specific comment section). And then there are crucial information parts missing to be able to understand which exact intrusion case is actually referred to, or which reference is referred to (some of these will be pointed out in the specific comment section). I strongly recommend checking the whole manuscript for these things to enhance the clarity of the analysis and the storyline. At the moment the storyline (what was exactly done, why was it done, how was it done) is not obvious, which makes reading the manuscript and understanding its message very difficult.

- The manuscript would be easier to read if the authors would refer to specific references, measurement systems or intrusion cases in the same way. For example on page 14, the reference 'Beekmann et al. (1997)' is discussed. However, within this paragraph, this study is also referred to as 'the 1997 analysis' or 'the 1997 results'. Repeating the reference as 'Beekmann et al. (1997)' is not an unnecessary repetition of words, but actually very helpful in understanding what is discussed in the paragraph. Please go through the manuscript and standardize the description of the same reference/results/methods.

- Very often just one or two words are missing to clarify the meaning of a sentence or

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a phrase. For example, on page 14, line 7, 'seasonal cycle peaks' is not unambiguous. 'Season cycle peaks' of what exactly? Some more of the ambiguous descriptions will be provided in the special comments section, but I encourage the authors strongly to check the manuscript independently for these ambiguous descriptions.

- Abstract: The first two sentences are more relevant to an introduction than an abstract. This might be the motivation for the study, but does nothing to explain exactly what has been done in the analysis. Please rewrite the abstract to include all the important parts of information necessary to understand the performed analysis (for example, the exact time period on which the analysis is based), and also state very clearly the main findings of the study.

- The main message of the manuscript is buried in many details and case studies. I think it is necessary to restructure the manuscript that the results of the main analyses become clearer. You present systematic analysis of stratospheric intrusions over the whole troposphere; you discover a change in the annual cycle of intrusion frequencies when you do this; there are many more intrusion layers than previously reported (did I understand this correctly?); some of the changes might be due to a change in climate. If these are the main points of your study, make sure that every reader will understand this and the connections between these points.

- The use of  $7\text{Be}$  as tracer for descending air is explained in detail at the beginning of the manuscript. However, in the discussion section it is mentioned that analyses including  $7\text{Be}$  are only planned for the future and are not done yet. Why the lengthy explanation about this method then earlier in the document?

- Your results indicate that at 84% of all days when measurements were available, stratospheric intrusions were present. This number is much higher than the previously reported numbers. For me your discussion why your number is so much higher is insufficient. Some of the differences can be explained by the good-weather bias of lidar measurements, some of them can be explained by different stratospheric intrusion de-

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tection criteria, but are these explanations enough to fully explain the huge difference in intrusion percentages? You should make sure that this discussion is focused, detailed, and thorough.

- You speculate a few times throughout the manuscript (for example in the abstract) that the change in stratospheric intrusions might be a result of improved air quality in the most relevant source regions. However, this is never really explained in detail. Please add some more information about this so that this statement is more than pure speculation.

- I would strongly recommend that the authors find a native English speaker to check the manuscript for grammar and structural problems.

Specific comments:

- Page 1, line 23: 'full tour around the northern hemisphere' -> this does not seem like a very scientific description. You might want to change this.

- Page 1, line 31: delete 'as long as'

- Page 1, line 33: delete 'of' in 'estimated of the STT...'

- Page 2, line 2-5: it is not clear what other characteristic than persistence is described with the sentences 'Very strong ozone. . . around the northern hemisphere (Trickl et al., 2011).' Please state them.

- Page 2, line 6: please add more specifics to '...quantify the fraction of stratospheric ozone. . .'. In the troposphere? At alpine sites?

- Page 2, line 8: 'increase' instead of 'rose'?

- Page 2, line 11: reference for 'Scheel' is missing?

- Page 2, line 14: replace 'to the beginning' with 'in 1978 at the beginning'

- Page 2, line 15: delete 'in 1978'

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- Page 2, line 15: start a new sentence with 'The contribution, however, ...'
- Page 2, line 23: state more clearly what positive trend is referred to with 'the positive trend started. ...'. Trend of stratospheric intrusions?
- Page 2, line 24: explain what kind of measurements started in 1992
- Page 2, line 25-27: sentence starting with 'For the lower-lying. ...' needs restructuring. It's meaning is not clear right now.
- Page 2, line 28: 'Scheel's approach. ...' it is not clear what that approach is, nor is it clear which reference it refers to. Please clarify.
- Page 2, line 29: replace 'this isotope' with '<sup>7</sup>Be'
- Page 2, line 29: replace 'cannot be too wrong' with 'seems plausible'
- Page 2, line 32: there is not enough information in this sentence to make its meaning unambiguous. Maybe add rephrase to 'stratospheric contribution to tropospheric ozone the overall positive tropospheric ozone trend disappears.'
- Page 2, line 33: replace 'have even expected' with 'expect'
- Page 2, line 33-34: not enough information given to understand what 'the result' means. Estimate of stratospheric intrusions?
- Page 2, line 35: 'most reasonable explanation' for what? More information needed.
- Page 2, line 35: replace 'has been a reaction of the atmospheric dynamics to the climate. ...' with 'could be a reaction of atmospheric dynamics to climate. ...'
- Page 3, line 2: 'full quantification' of what? Please specify.
- Page 3, line 5: add 'tropospheric' before 'ozone'?
- Page 3, line 6: replace 'By contrast' with 'In contrast'
- Page 3, line 32: replace 'upgrading' with 'upgrade'

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- Page 4, line 8-9: wrong parenthesis for the reference, should be 'Trickl et al., (2015)'?
- Page 4, line 31: remove 'were' before 'started'
- Page 4, line 38: wrong parenthesis for references 'see also (Vogelmann...)'
- Page 5, line 13: It is not clear which measurements were discontinued in January 2013. RH or ozone as well? Please be clearer.
- Page 5, line 25: replace 'routine' with 'routinely'
- Page 5, line 26: remove 'the' before ozone
- Page 5, line 27-28: replace 'in view' with 'regarding'?
- Page 5, line 31: 'to the north' not specific enough. To the north of where?
- Page 6, line 1: '1%' not specific enough. 1% of what? RH?
- Page 6, line 9: replace 'with 1°x1° horizontal resolution' with 'a 1°x1° grid'
- Page 6, line 10: 'starting in the entire region' it is not clear if that region is indeed based on the 1x1 grid?
- Page 6, line 11: how many levels are there between 250mbar and 600mbar?
- Page 6, line 19: change 'daily distributed' to 'distributed daily'
- Page 6, line 23-24: change '1x1 horizontal resolution' to '1°x1° grid'
- Page 7, line 4: add 'trajectory' before 'calculations'
- Page 7, line 24: replace 'soundings' with 'measurements'. 'Soundings' sound like they were done with ozone sondes which is not the case here, right?
- Page 7, line 26: add 'per day' after 'at least one measurement' to clarify the meaning here
- Page 7, line 32-33: the meaning of 'had gradually grown before' is not clear. Please

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rephrase.

- Page 7, line 34: replace 'either for the existence of' with 'if there was'
- Page 7, line 36: replace 'looked for' with 'applied as search criteria'
- Page 7, line 37: 'had been found to be sufficient' -> sufficient for what?
- Page 7, line 38 to page 8, line 1: The sentence 'With decreasing...' does not make sense. Please rephrase.
- Page 8, line 1-2: the sentence 'At the same time...' does not make sense. Please rephrase.
- Page 8, line 2: '8-10% RH being the exception'. The meaning is not clear, please rephrase.
- Page 8, line 4: move 'in the sonde data' to after '1-2%'
- Page 8, line 5: the different types of intrusions are mentioned here, and later in the manuscript (especially Type 6). However, it is only stated that more information about the different types can be found in Trickl et al. (2010). You might want to think about explaining these different types a little more, so that readers understand what they refer to.
- Page 8, line 14: change 'Range of ozone values in intrusion layers was...' to 'Ozone values in intrusion layer ranged...'
- Page 8, line 16: remove one 'not' at the end of this line
- Page 8, line 17: replace 'looked for' with 'searched for'
- Page 8, line 26-36: It is not entirely clear why this paragraph is placed here. Does it contribute to the main message? Is it just an additional interesting case study? If it is not necessary for the main message of the manuscript, I would suggest deleting it.
- Page 9, line 5: the phrase 'the period described here' is not unambiguous. Many

different time periods have been mentioned, and at that point the reader is lost as to which this phrase refers to. Please clarify, and check the rest of the manuscript to correct the ambiguous time period references.

- Page 9, line 5: remove 'case' after 'intrusion'
- Page 9, line 6-7: combine the two sentences to 'The peak ozone mixing ratio on that day was 235 ppb, which dropped rapidly to less than 100ppb'.
- Page 9, line 9: Stop the sentence after '5ppb'. Then start a new sentence with 'Given the normally good agreement between UFS and lidar, this bias is ascribed...'
- Page 9, line 17: replace 'bundles' with 'calculations'?
- Page 9, line 18: 'later plots' is not specific enough. Please clarify which plots you mean.
- Page 9, line 18: replace 'South' with 'Southern'?
- Page 9, line 19: please be more specific which observations you refer to here with 'confirm the observations'
- Page 9, line 19: replace 'clearness' with 'clarity'
- Page, 9, line 20: 'separate in time and altitude' -> not clear what is meant by this
- Page 9, line 23-24: are the mentioned measurements examples for very thin layers? This is not clear from the text as it is written at the moment.
- Page 9, line 31: the mentioned example (26-27 December 2008) is not the example that is shown in Figure 4. If this is on purpose, then why not discuss the example that is shown in Figure 4 here in the text rather than discussing the 26-27 December 2008 example?
- Page 9, line 37: remove '(definition: Trickl et al., 2010)'
- Page 9, line 38: 'A source...' -> a source of what?

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- Page 10, line 11: 'of' missing at the end of the line after 'upstream'?
- Page 10, line 13-20: The paragraph starting with 'Another dust case...' seems to be another example for 'intrusion layers arriving via North Africa'. Is it really necessary here for the storyline?
- Page 10, line 29: 'origin of the moisture', it is not clear what the authors mean by this. Please clarify.
- Page 10, line 30: maybe add 'during the days shown in Figure 9' after 'was reduced' for clarity
- Page 10, line 35-36: wrong parenthesis for the reference Trickl et al. (2016)
- Page 11, line 6-7: add 'e.g.' before 'Fig.8' and remove 'or more complex cases'
- Page 11, line 8: 'ones' is not unambiguous. Should this be 'intrusions' or 'trajectories' instead?
- Page 11, line 11: remove 'planetary boundary layer' and use only 'PBL' since it was already defined before
- Page 11, line 20: remove 'one to quantify easily the' with 'the easy quantification of a'
- Page 11, line 21: it is not clear what is meant with 'layer boundaries'
- Page 11, line 25: please explain how you actually calculate the measurement days with intrusion layers, if the method is only similar to the method used in Beekmann et al. (1997).
- Page 11, line 29: please add the error bars for the fraction of intrusion days to Figure 10. (this is what is referred to as 'standard deviation of 0.12', right?)
- Page 11, line 32: 'The variability is obviously much higher...' -> this is not obvious from Figure 10! Please add the error bars so that this is clear.
- Page 11, line 33: what is 'the principal seasonal cycle'? Please clarify and explain.

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- Page 12, line 1: 'summer minima' of what? Stratospheric intrusions?
- Page 12, line 4: 'strong difference in seasonal cycle'. It is not clear what is meant by this. Which seasonal cycles?
- Page 12, line 5-7: please explain somewhere in this sentence what 'TT2010' means (see Figure 10).
- Page 12, line 1-15: please add the reference to the color of the bars from Figure 10 whenever they are discussed here in this section (e.g. line 8: 'lidar-based fractions', would those be the green bars?)
- Page 12, line 9: add 'to' after 'due'
- Page 12, line 23: 'the separating layer' -> it is not clear what you mean with this
- Page 12, line 24: 'initial layer thickness' -> it is not clear what you mean with this
- Page 12, line 26: add 'of weather' after 'the influence'
- Page 12, line 26: replace 'year with full coverage of all months' with 'year with measurements taken in all months'
- Page 12, line 28: 'the same high fraction', what does the 'same' refer to?
- Page 12, line 32: change 'stratosphere' to 'stratospheric'
- Page 12, line 33: did you mean 'value' instead of 'structure'? If not, it is not clear what 'structure' refers to.
- Page 12, line 36-37: change 'give rise to' to 'result in'
- Page 12, line 37: the meaning of 'discernible structure' is not clear
- Page 12, line 39: 'first years' -> which years are meant exactly by this?
- Page 13, line 2: add 'and' before 'are, thus. . .'

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- Page 13, line 5: what do you mean with 'observational period'?
- Page 13, line 7: why are the results from the 'observational period' compared to the period 1996-2003? Is that period analyzed in a study? If yes, please cite which study you mean, if no, please explain why comparing the results to this period.
- Page 13, line 10-11: The two sentences starting with 'In our current effort...' do not make sense. Please rephrase or add more details for clarity.
- Page 13, line 12: 'step-like ozone rise' -> is that step like ozone rise within a profile, or on the same level with changing time? Please be more specific.
- Page 13, line 12-13: Sentence not complete? '...typically above 5km and contain dry layers'
- Page 13, line 15: it is not clear why the described episode is so spectacular. Please add an explanation, or avoid the very strong word spectacular.
- Page 13, line 15-25: in these two paragraphs add references to the color of the profiles that are discussed.
- Page 13, line 33: 'deviations' -> it is not clear which deviations are referred to here. Between which results?
- Page 13, line 34-36: the meaning of the sentence 'This result is in...' is not clear. Please rephrase.
- Page 14, line: the meaning of 'temporal coverage' here is not clear. Please explain or rephrase.
- Page 14, line 7: 'seasonal cycle peaks' -> be more specific. Seasonal cycle peaks of what?
- Page 14, line 9: which data set did Sprenger et al. (2003) analyze? Please discuss with more details!

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- Page 14, line 10: 'that observational site' is not specific enough, please be more specific.
- Page 14, line 12: remove the 'the' before 'transport'
- Page 14, line 13: move 'derived' before 'seasonal cycle'
- Page 14, line 14: Change 'These pathways... ' to 'However, these pathways do not always... '
- Page 14, line 15: wrong parenthesis for reference 'Forster et al., (2001)'
- Page 14, line 18: change 'call for' to 'point to'
- Page 14, line 18: what meteorological explanation would this be? Please explain.
- Page 14, line 19: 'about 15 days', is that time period different to the  $\sim 315$ h of HYSPLIT? Or does this sentence just mean that you should recalculate the earlier analyses with this  $\sim 315$ h version of HYSPLIT?
- Page 14, line 25: delete 'by the observational groups in that effort'
- Page 14, line 27: replace 'asked' with 'required'
- Page 14, line 31: adjust the spelling of 'Type-6' to the spelling that is used in the rest of the manuscript 'Type 6'
- Page 14, line 33: it is not clear why the sentence starts with 'On the other hand...'. What is it the opposite to?
- Page 14, line 34-35: the sentence 'In addition, ...' is incomplete.
- Page 15, line 2: delete 'was made that'
- Page 15, line 3: meaning of the sentence 'On the other hand, just the directly detected intrusions can be used' is not clear. Please clarify.
- Page 15, line 11: 'calculated rise' -> rise of what?

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- Page 15, line 21-22: change the sentence 'The tropopause region...' to 'The tropopause region is a mixture of about 50% stratospheric and tropospheric air each...'
- Page 15, line 23: it is not clear what you mean by 'stratospheric nature'. Please specify.
- Page 15, line 26-27: The meaning of the two sentences starting with 'Sometimes air masses...' is not clear. Please clarify.
- Figure 1, line 3: do you mean '2004' instead of '2003'?
- Figure 1, line 5: 'The stratospheric influence remarkably grew during that period' -> this is a strong statement that I cannot see very clearly in the figure. Please rephrase or explain in more detail!
- Figure 1, line 6: is the '1981' part of the sentence, or is it wrong here?
- Figures 2, 7, 9 and 12: please explain what the error bars (?) indicate in these figures! Also please add a reference to the profile of question to the figure caption or the text whenever you refer to a specific profile out of the bundle (for example: Fig 12. Intrusion layers at 3.1km (pink profile)...)
- Figure 2, line 5: one '.' too much at the end of the line.
- Figure 2, line 7: 'measurement at...' instead of 'measurements next to...'?
- Figure 3: please add a label to the color bar
- Figure 3: please add a description of what the red dot in the figure represents to the figure caption.
- Figure 4: it is not clear why this example is shown here. It is not mentioned in the text.
- Figure 10: please change the color for either 'Zugspitze fraction' or 'Zugspitze fraction (TT2010)' to something else than green. It is not clear which green bar is representing what in the figure.

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- Figure 10: please explain the abbreviation 'TT2010' in the figure caption and the text
- Figure 10, line 4-5: reference 'Trickl et al., 2010' should not be fully in parenthesis.
- Figure 10 and 11: as far as I understand fractions, they cannot be greater than 1.0. Please adjust the y-axes of those two figures, since their maximum values are misleading.
- Figure 11, (first line of figure caption): you might want to add 'ozone' before 'peaks'
- Figure 12, line 3: there might be 'cycle' missing after 'diurnal'
- Figure 12: please add references to the different colored profiles to the figure caption to clarify which profile is meant when different ozone peaks are discussed.
- Figure 13: it seems like the whole figure caption is copied from Figure 8. Please provide the correct figure caption for this figure.

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