Interactive comment on
"Comprehensive assessment of meteorological conditions and airflow connectivity during HCCT-2010"
by A. Tilgner et al. (tilgner@tropos.de)

We would like to thank the Anonymus Reviewer#1 for the careful consideration of the manuscript and for the numerous constructive comments and suggestions made to improve the manuscript. Those are addressed below. In the case we do not concur with the reviewers' comments, adequate reasons are given.

Responses to Anonymous Referee #1

Tilgner et al. evaluate the meteorological conditions and flow connectivity with respect to a Lagrangian-type experimental approach during the Hill Cap Cloud Thuringia 2010 experiment (HCCT-2010). They calculate coefficients of divergence and cross correlation coefficients of ozone and aerosol time series at different sites, the Froude and Richardson numbers from rawinsonde data, and they characterize the overall meteorological conditions using in-situ data, ceilometer data, satellite images, backward trajectories and weather charts. In addition, they present results of four SF6 tracer experiments to validate their procedure of identifying appropriate conditions for a Lagrangian-type approach. Overall, this manuscript will be helpful for researchers investigating the HCCT-2010 data set in further studies. However, I strongly encourage the authors to take into account the following specific comments, and to carefully edit the manuscript for language in a revised version.

According to the reviewer's comments, the authors have further improved the manuscript. The paper in its revised version outlines a very comprehensive approach to figure out fitting conditions for a Lagrangian type hill cap cloud experiment. Suitable flow conditions were evaluated by using three completely different approaches, i.e. (i) a combination of theoretical/statistical parameters, (ii) tracer experiments performed in the field, and (iii) regional scale modelling (newly added to the revised manuscript version). In detail, in the revised abstract and summary, the scientific achievements of the presented work were more strongly emphasized. In the introduction, the description "connected flow condition" concept was extended in order to make this issue more clear to the reader. Furthermore, the use of the paper for other studies for already published and other following studies was further outlined. In section 2, the measurement site description was specified more. Moreover, e.g. the performed statistical approaches were described more precisely according to the reviewer's suggestions. In the main part, among other things, simulations results of additionally performed model simulations were newly included in the revised manuscript in order to improve the flow analysis and later overall assessment of the FCEs. Finally, a native speaker again carefully checked the manuscript for language inaccuracies which resulted in many language changes of the revised manuscript.

Reviewer's comment
(1) When calculating the COD to analyze the relative spatial variability and using a cross correlation analysis to evaluate the time lag between measurement stations, it seems inconsistent not to take into account the time lags for the COD calculation. Even more, this seems mandatory if the desired experimental approach is of a Lagrangian-type, i.e. following an air mass from one site to the next. Also, Equation 1 must be corrected ("+" instead of "-" in the denominator).
Author's response:
We agree with the reviewer that a consideration of the time lag between measurements sites is important in our Lagrange-type experimental approach. This time lag is, however, only valid during time periods where the air flow between the sites can indeed be considered to be "connected". The idea of the COD approach within the present study is, first of all, to identify such time periods (both cloud periods and no-cloud periods) with suitable connected flow conditions in an objective and automated manner. Therefore – for an a priori screening of conditions - it was not possible to include such a time lag. In addition, the time lag may be positive or negative depending on the kind of the incoming flow conditions (e.g. southwest and northeast wind direction).
However, to account for the reviewers' legitimate suggestion, we performed some tests, however, with different aerosol size bins and different time lags applied. The results are shown in Figure 1 (see below). As can be seen, the applied time lag between the time series does not have a significant impact on the obtained COD results (see

Figure 1). This is most likely due to the fact that time lags between the stations are usually rather small (typically 10 – 20 min) as compared to the floating 3 hour time span which was used for the COD calculations.

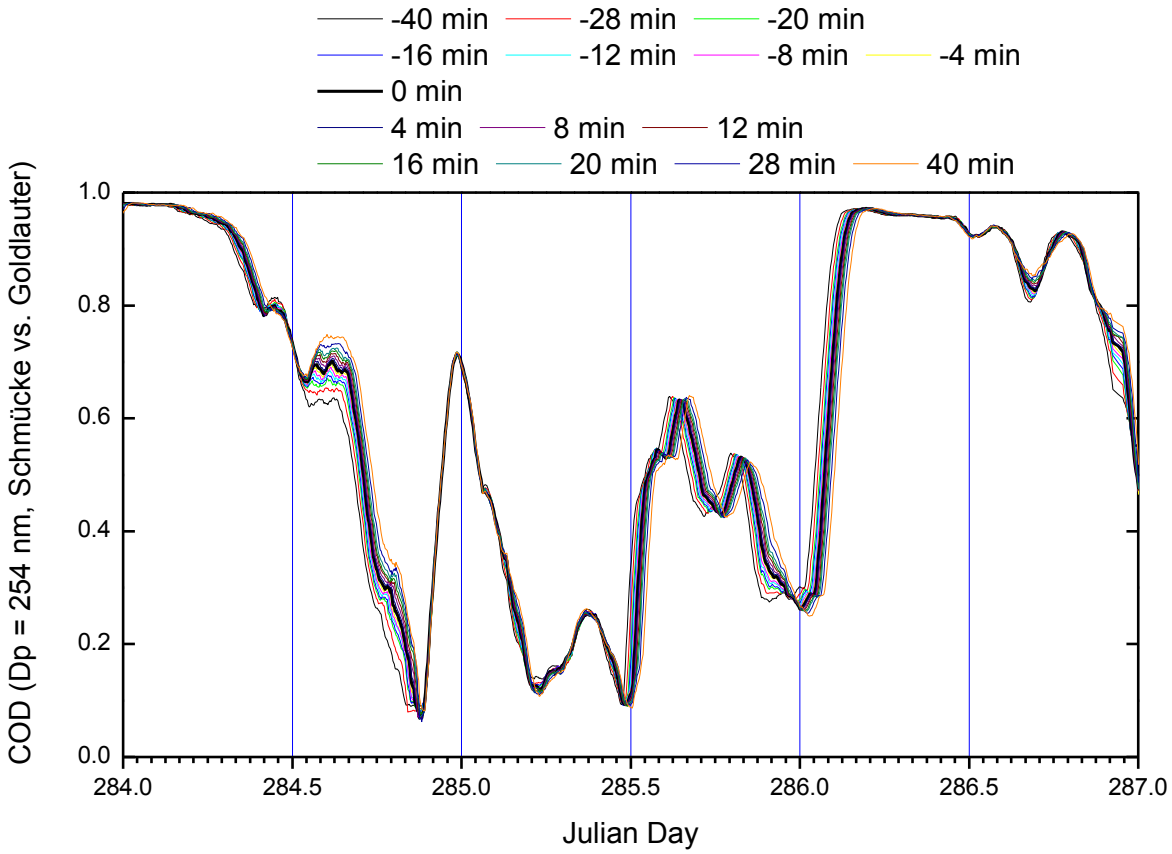

Figure1: Calculated CODs for the particle size bin N_{254nm} (upwind vs. summit site) during 11th and 14th Oct. 2010 assuming different positive and negative time lags (±40 min.).

It should be noted that a similar concentration level between the different sites during the considered time span is more important for the calculated COD than short-term variations. Thus an estimated time lag will not improve the results much or even might lead to less adequate results in some cases. Therefore, we still refrain from applying a time lag between the time series in the revised manuscript. In order to clarify, however, why an estimated time lag between the time series was not applied, an additional paragraph was put at the end of section 2.2., which reads as follows:

"…No time lag between the time series associated with the three measurement sites was applied in these COD calculations. The overall goal of the COD analysis was to identify potentially suitable time periods in an objective and automatic manner. The consideration of predefined assumptions such as a fixed time lag between the different sites contradicts this idea and thus – a priori - it was not possible to include such a time lag. In addition, the magnitude of the time lag varies temporally and, depending on the incoming flow conditions (southwest and northeast wind direction), may be positive or negative. Moreover, the magnitude of the time lags between the sites is typically small compared to the 3-hour time span applied for the COD calculation (see Section 3.2.1). Thus, an applied short-term time lag between the time series (according to the transport time between the sites) do not have a huge impact on the obtained results."

Reviewer's comment

(2) The cross-correlation analysis was only performed for ozone – why not for the well-defined aerosol size bins N_49nm and N_217nm?

Author's response:

This is surely a legitimate question and the authors actually did a cross-correlation analysis for selected aerosol size bins as well (see below). However, the results were not as useful as for ozone. The main advantage of the

measured ozone concentration time series is their high time resolution and their high temporal variability. Ozone was measured every 10 seconds. The 6 data points of each minute were averaged. The final dataset with a 1 minute resolution was finally applied for the statistical calculations. Moreover, the ozone time series often show higher temporal variations, which are suitable for cross-correlation analyses and the identification of short-term agreements. For the cross-correlation analysis, where time lags of 10-20 min are expected under suitable conditions, a highly time-resolved dataset is very important to determine short-term agreements between two time-series. Because of the coarser temporal resolution of the particle data (minimal 5 min. resolution), the cross-correlation analysis e.g. for the N_{49nm} bin has shown less suitable results. As an example, the results for FCE1.1 are presented in the Figure 2 and 3 below. It can be seen that the identification of time lags between the stations especially during shorter selected time intervals is rather difficult or impossible (see Figure 2). Furthermore, the statistical method generates partly also unrealistic overflow time lags of more than ±1h (see Figure 2). Moreover, it should be noted that for other events with very similar and stable concentration-time profiles during the FCEs, the cross-correlation analysis shows partly very high correlation values, which, then again, have no statistical significance. The missing temporal variation complicates the identification of short-term agreements and finally the estimation of the time lag between the stations.
In summary, due to the lower time resolution and lower temporal variability of the particle data as compared to ozone data, the cross correlation for N_{49nm} did not yield additional useful information. In view of the already quite long manuscript, we would therefore prefer to present the cross-correlation analysis only for ozone and not for aerosol size bins. To make this issue more clear to the reader, an additional paragraph with some explanations was put at the end of section 2.3 which reads as follows:
"…The cross-correlation analysis presented in this section was also performed for the particle data described in the previous section. However, since the temporal resolution of the particle data was coarser than that of the ozone data, and the magnitude of temporal variation in N_{49nm} was smaller than that observed for measured ozone concentrations, cross-correlation analysis of the N_{49nm} data did not yield additional useful information. For this reason, the results of this analysis are not considered in the present paper.

Regarding the reviewers' suggestion to use the N_{217nm} bin for cross-correlation, we would like to note that because of the droplet activation and the strong impact of cloud processes on this particle size range (they might be depleted by particle growth on activated 217nm particles due to in-cloud mass production or enriched by particle growth of smaller activated particles growing into the 217nm size bin) it would not be appropriate to use this size bin for cross correlation. In the COD evaluation, N_{217nm} size bin was only used as a criterion for cloud appearance, not as a connected flow criteria.

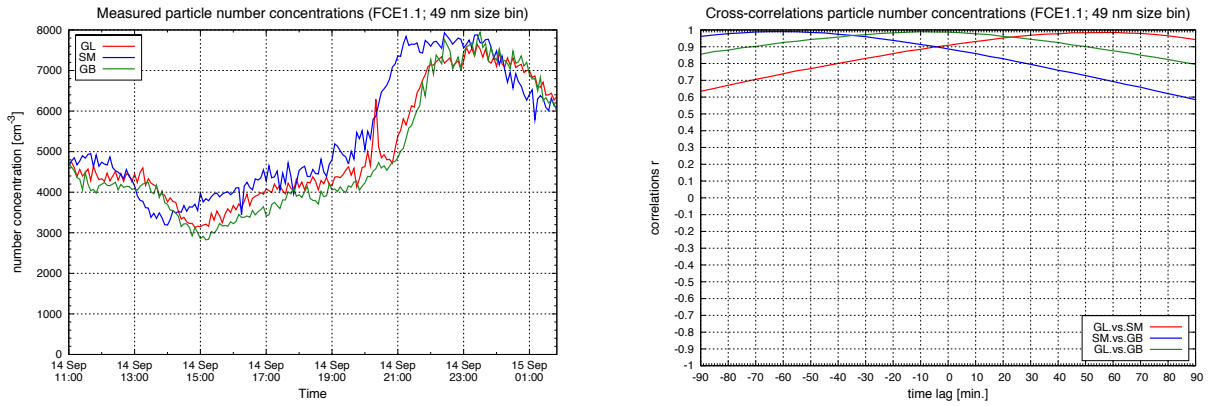

Figure 2: Measured particle number concentrations during FCE1.1 (left) and calculated cross-correlation for the whole event.

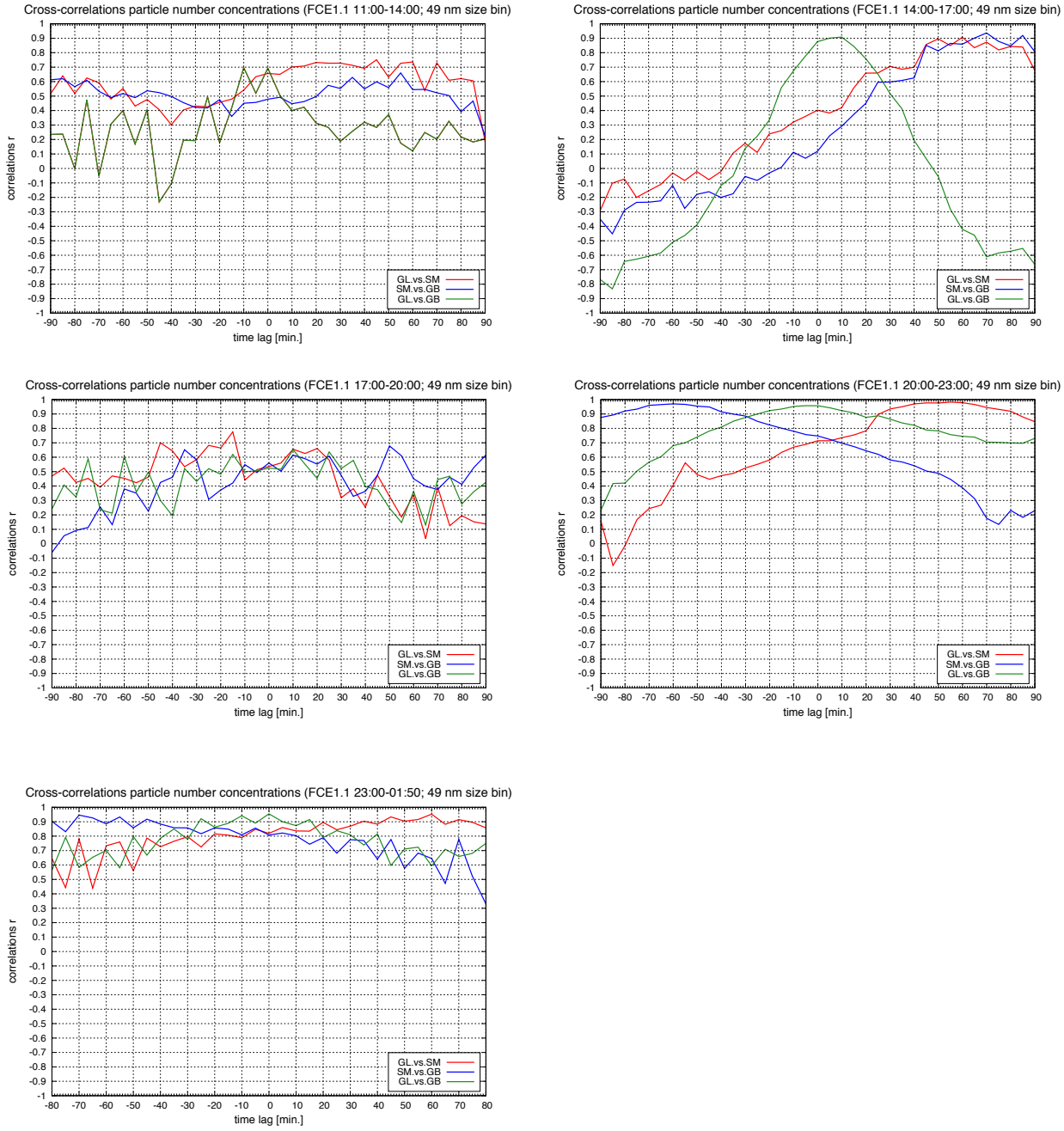

Figure 3: Calculated cross-correlations for 3-hour time intervals of FCE1.1.

Reviewer's comment

(3) Ozone measurements by UV absorption, e.g. using a TE49C analyzer, were shown to be influenced by potentially large water vapor interferences (cf. Wilson, K.L. and Birks, J.W. (2006) Mechanism and elimination of a water vapor interference in the measurement of ozone by UV absorbance. Environmental Science & Technology, 40, 6361-6367). Did you dry the sample air before measuring ozone at the three stations?

Author's response:

We appreciate the reviewers' well-taken comment on this technical issue. In the updated manuscript, it is now outlined that the air was not dried before measuring ozone concentrations with the gas monitors. Moreover, it is mentioned that ozone measurements by UV absorption, e.g. using a TE49C analyser can be influenced by potentially large water vapour interferences. The paper of Wilson, K.L. and Birks, J.W. (2006) has revealed a negative offset of 13 ppb for the TE49C analyser between dry and wet conditions (90%rH) at 23°C.

Under the colder meteorological conditions during HCCT and the smaller water vapour pressures, the deviations should be smaller. Moreover, to the author's opinion, the impact on the obtained concentrations should be similar for all three sites and thus the temporal behaviour of the measured time series should be not much affected. Finally, a corresponding offset in the dataset would not much affect the cross-correlation values as the concentration pattern will be hardly affected and just the absolute concentration level will be changed. However for other studies, the influence on the measured ozone concentrations should be considered. An additional paragraph was added to the manuscript (see section 2.3, page 10) addressing this issue.

"…Previous studies have shown (*e.g.* Wilson and Birks, 2006) that ozone measurements by UV absorption*, i.e.* those obtained using a TE49C analyser, can be influenced by potentially large water vapour interferences. In the present studies, the air was not dried before measuring ozone concentrations with the gas monitors. Since the impact on the obtained concentrations should be quite similar for all three sites (similar high relative humidity at all three sites), the temporal behaviour of the measured time series should be not much affected by this artifact. However, for other studies, the influence of water vapour on measured ozone concentrations should be considered."

Reviewer's comment

(4) The ozone time series at the Goldlauter station (red line in Fig. 4) obviously exhibits a strong diurnal cycle during extended periods (e.g. 18 – 25 September). This may indicate a local impact on ozone measurements, e.g. NOx from nearby traffic, which makes a direct comparison of the ozone measurements at the Goldlauter station and the other stations difficult. Thus, the corresponding COD values are not necessarily indicative of local flow connectivity. Please discuss in a revised manuscript!

Author's response:

The authors agree to the reviewer's observation and that local nearby sources might affect the ozone concentration levels. However, meteorological conditions such as local inversions (no overflow conditions) will be much more important to explain very large ozone differences. Within a quite homogeneous air mass, the ozone concentrations should show at least on a quite similar level (cp. ozone concentrations levels at the summit and downwind site). Local NO point sources can modify the O_3 level but will not change it dramatically (NO concentration in Goldlauter mostly < 1ppb). Furthermore, it is known that ozone concentrations decrease usually during the evening and night because of the lowered production and the deposition.

During the period 18 – 25 September, the ozone concentrations at the upwind site are often during the night between 15 and 30 ppb lower compared to the two other stations (see Figure 4 below). Such a huge difference cannot be explained by short-term interactions with local emissions, lowered productions and deposition only.

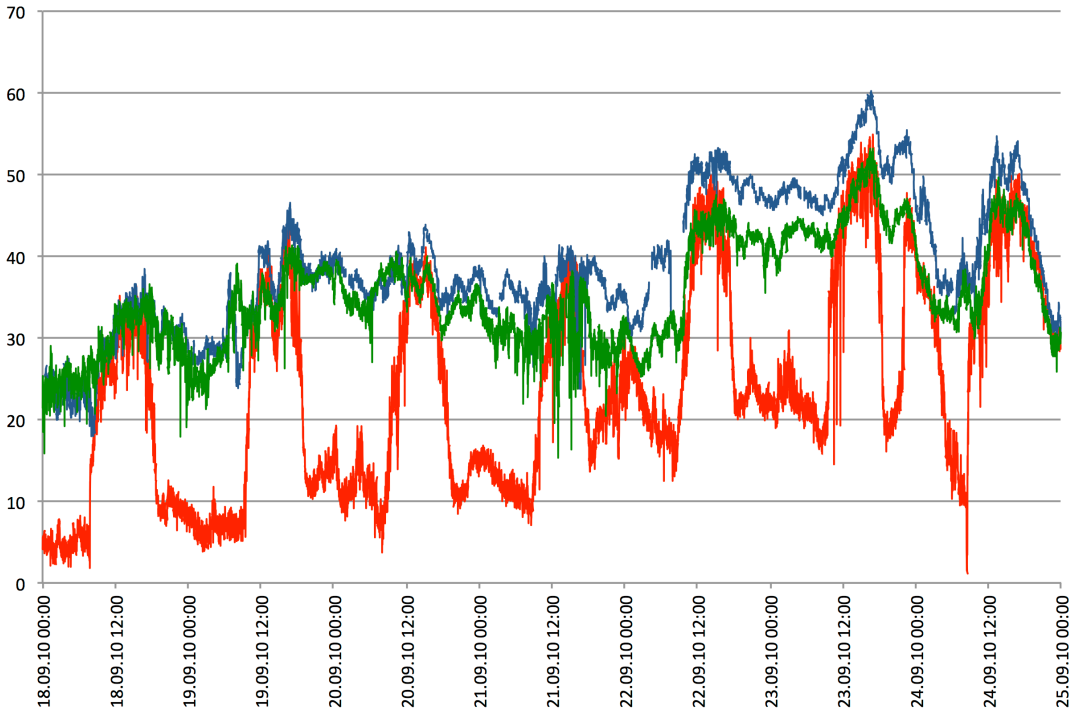

Figure 4: Measured ozone concentrations at the three sites during (18-25)-09-2010.

The rawinsonde data show distinct low-level inversions during the night. This means that there probably was no air exchange occurring during this time. Under such conditions, local emission e.g. of NO into the near ground inversion layer and depositions might have led to strongly decreasing ozone concentrations. On the other hand, during the day when the inversion is not present anymore, the ozone concentrations switches mostly back to the level of the two other sites. Such a behaviour, can be sometimes also observed during nighttime and is thus not restricted to daytime conditions. For example between the 23-09-2010 and 24-09-2010, the upwind station is not disconnected for the whole time. In the evening of the 23rd and in the early morning hours of the 24th, the ozone concentration of the upwind site is substantially different as the other two stations. However, around midnight the concentrations at the upwind site are similar. Most likely the inversion was not present at this time.
In conclusion, the disconnection of the valley site Goldlauter, due to a nighttime inversion, is reflected in the strongly dissimilar ozone concentration time series. This dissimilarity is also reflected in high COD values, which in turn indicate that connected air flow cannot be assumed during these time intervals. Thus, in our opinion, the COD values and the ozone concentration time series do very well indicate local flow connectivity (in a positive or negative way).
To make this point more clear to the reader, the discussion of the ozone concentrations and the calculated CODs was extended in the revised manuscript (section 3.2.1).
The following paragraph was added to the manuscript:
"High COD values arise not only during periods of low wind speed but also during periods of high vertical thermal stratification. During one such period, which was observed from September 18–25, nighttime ozone concentrations at the upwind valley site Goldlauter were often 15–30 ppb lower than those measured at the other two stations (see Fig. 4). A difference of this magnitude cannot be explained by short-term interactions with local emissions, lowered production, and deposition only. Analysis of rawinsonde data during this time period shows distinct low-level nighttime inversions, which suggests that air exchange did not occur during this time. Under such conditions, local emission *(e.g.* of NO into the near-ground inversion layer) and deposition processes could result in strongly lowered ozone concentrations. Support for this interpretation is provided by the fact that ozone concentrations at the upwind site largely paralleled those at the other two measurement sites during daytime, when inversions were not present. Disconnected flow was not always observed under nighttime conditions, however: on the night of September 23–24, for example, the ozone concentration measured at the upwind site was substantially different from those measured at the other two stations in the evening of September 23 and the early morning hours of September 24; at midnight, however, the three concentrations were

similar. It is likely that the inversion was not present at this time. In summary, nighttime inversion conditions led to the disconnection of the upwind valley site from the two downwind sites, and this disconnection is reflected in differences in the ozone concentration time series measured at this site. These differences are also reflected in the high COD values observed for this site under these conditions, which in turn indicate that connected airflow did not occur during inversion periods. Taken together, therefore, the COD values and the ozone concentration time series provide an excellent indication of the extent of local flow connectivity."

Reviewer's comment

(5) When calculating the Froude number, how representative is an effective mountain height of 484 m, which is apparently the change in altitude between the Meiningen station and the Mt. Schmücke station?

Author's response:

In our opinion, the applied height is quite representative for the mountain ridge level of the Thuringian Forest in this area. This height was also used in former studies (see Heinold et al., 2005) and showed rather good agreements with results of meteorological modelling. The manuscript was updated accordingly. At the end of section 2.4 the following text was added:

"An effective mountain height of 484 m was used for the Fr and Ri calculations, since this height is broadly representative of the mountain ridge level in this region."

Reviewer's comment

(6) Figure 4 clearly shows that wind speed and direction at the Goldlauter station deviate from the summit and Gehlberg stations. I found a brief hint in section 3.4 that the Goldlauter station is located in a rather narrow valley. This should already be mentioned and discussed in the corresponding text of Figure 4.

Author's response:

Thanks for the comment. Due to the reviewer comment, an additional comment on the data quality and carful use of the wind data measured in Goldlauter was attached to section 3.2.1.

The following text was added in the first paragraph of section 3.2.1:

"Briefly, it is noted that the meteorological measurements at the upwind site Goldlauter were performed in a rather narrow valley, *i.e.* under less suitable wind measurement conditions, and for this reason the wind data obtained at this site should be used with great care only."

Reviewer's comment

(7) Figure 5 (right) is discussed as an example of a cloud period but I cannot identify a cloud event on 14/15 October in Figure 4. Please clarify!

Author's response:

Unfortunately, there was a typo in the Figure caption. The plot shows data of a cloud event on 14/15 September and not October. The Figure caption has been revised.

Reviewer's comment

(8) Please indicate the source of the land use data shown in Figure 7!

Author's response:

Land cover data was obtained from the Global Land Cover 2000 project of the European Commision Joint Research Centre (GLC2000 database, http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php). Further details on this dataset are given in van Pinxteren et al. (2010). Information on the source of the land use data is now given in the updated manuscript (see ESM).

Reviewer's comment

(9) It is difficult to find the location of the measuring site in Figures 8 and 9. Please clearly indicate the measuring location and add more information about the show satellite images (e.g. IR or VIS?) to the figure captions.

Author's response:

The authors agree with the reviewer that the measurement area should be marked in the corresponding Figures. Therefore, the revised Figures now includes a square to mark the measurement site.

Reviewer's technical comments:

Please carefully edit the text for language. I found many parts of the manuscript cumbersome to read. The following list of technical corrections is not complete:

Author's response:

Thank you for the comment and the numerous corrections given below. The manuscript was again carefully checked for language inaccuracies by a native speaker and some parts of the manuscript were placed into the supporting information to improve the manuscript with regards to clarity and readability.

p.1862/19: "Comprehensive analyses" instead of "A comprehensive analyses"
Author's response: The text has been revised as suggested.
p.1863/1: "approximately" instead of "approx."
Author's response: The text has been revised as suggested.
p.1867/4-7: I don't understand this sentence, please rephrase!
Author's response: The sentence was rephrased.
p.1867/7: Remove "aimed" twice!
Author's response: The text has been revised as suggested.
p.1868/5: "slope of the Thuringian Forest"
Author's response: The text has been revised as suggested.
p.1868/15-16: Rephrase the last sentence of this section!
Author's response: The sentence was rephrased.
p.1869/7: Correct Eq. 1!
Author's response: Equation 1 was corrected.
p.1869/25: What do you mean by "floating 3h time span"?
Author's response: Floating 3-hour time span means that an interval of 3 hours centred around the time point of interest is used for the calculation of the COD. For the COD of next time point, the time span is floated or shifted accordingly. According to the reviewer comment, an additional explanation was added to the text in section 2.2. ("In the present study, a floating 3-hour time span of the measured aerosol number concentrations (*i.e.* an interval of 3 hours centred around the time point of interest) was used for the calculation of the COD at a given time.")
p.1870/18-19: What do you mean by "trace gas concentration profile analyses"?
Author's response: The sentence was rephrased.
p.1871/18: What do you mean by "concentration profiles"?
Author's response: The sentence was rephrased.
p.1871/19: "was" instead of "were
Author's response: The text has been revised as suggested.
p.1868/5: "slope of the Thuringian Forest"
Author's response: The text has been revised as suggested.
p.1872/24: Delete "Performed"!
Author's response: The text has been revised as suggested.
p.1873/1: What do you mean by "gravity waves initiate to amplify"?
Author's response: The sentence has been slightly changed to clarify the issue.
p.1873/16: Explain all variables used in Eq. 4!
Author's response: All variables are now explained.
p.1874/17: "in Heinold et al. (2005)" instead of "in (Heinold et al., 2005)
Author's response: The text has been revised as suggested.
p.1874/19: Delete "ca."!
Author's response: The text has been revised as suggested.
p.1875/7: "presence of orographic" instead of "presence orographic"
Author's response: The text has been revised as suggested.
p.1875/8: Delete "occurred"!
Author's response: The text has been revised as suggested.

p.1875/14-15: Revise sentence!
Author's response: The sentence has been revised.
p.1876/10-14: Verb is missing in sentence!
Author's response: The text has been revised.
p.1876/16: “with both a” instead of “with a both”
Author's response: The text has been revised as suggested.
p.1877/7-8: For clarity, I suggest “...by frontal passages and variable weather conditions.”
Author's response: The text has been revised as suggested.
p.1877/24-28: Please rephrase!
Author's response: The text has been rephrased.
p.1878/16: “caused” instead of “cause”
Author's response: The text has been revised as suggested.
p.1878/24: “Wind direction changed” instead of “Wind direction has changed”
Author's response: The text has been revised as suggested.
p.1879/13: Remove “good”!
Author's response: The text has been revised as suggested.
p.1879/15 and afterwards: Replace “congruencies” by “agreement”!
Author's response: The text has been revised as suggested.
p.1880/4: Rephrase “period is with about 0.11 smaller than”!
Author's response: The text has been rephrased.
p.1880/22: Remove “hence”!
Author's response: The text has been revised as suggested.
p.1880/24: Replace “than” by “as”!
Author's response: The text has been revised as suggested.
p.1882/1: Replace “differ” by “distinguish”!
Author's response: The text has been revised as suggested.
p.1882/4-5: Rephrase sentence!
Author's response: The sentence has been rephrased.
p.1883, section 3.2.3: Carefully revise language of section 3.2.3!
Author's response: In section 3.2.3, the language has been carefully revised.
p.1885/20: Rephrase “between the upwind and the two seems...”!
Author's response: The text has been revised.
p.1886/3: Remove “on”!
Author's response: The text has been revised as suggested.
p.1886/27: Remove “to”!
Author's response: The text has been revised as suggested.
p.1887/4-5: Rephrase sentence!
Author's response: The text has been revised.
p.1888/13: “Arctic circle” instead of “Arctic cycle”
Author's response: The text has been revised as suggested.
p.1888/13 and afterwards: “unstable” instead of “labile”
Author's response: The text has been revised as suggested.
p.1890/13: What do you mean by “overall adequate conditions”?
Author's response: Due to the reviewers comment, the text has been slightly changed.
p.1891/13 and afterwards: “lay” instead of “lied”
Author's response: The text has been revised as suggested.
p.1892/10: Remove “by both”!
Author's response: The text has been revised as suggested.
p.1893/1: Remove “by both”!
Author's response: The text has been revised as suggested.
p.1893/26: Remove “cannot”!
Author's response: The text has been revised as suggested.
p.1893/28: “was” instead of “were”

Author's response: The text has been revised as suggested.
p.1894/24: I cannot find a site 31 in Figure 10; please correct!
Author's response: The site number in the text was corrected (site 30 is correct).
p.1895/1: "that this was" instead of "that is was"
Author's response: The text has been revised as suggested.
p.1895/8: Remove "official"!
Author's response: The text has been revised as suggested.
p.1896/14 and afterwards: "pros and cons" is colloquial language.
Author's response: "pros and cons" has been changed to "advantages and dis advantages"
p.1896/18: Revise sentence!
Author's response: The sentence was revised.
p.1896/22-23: I don't understand the part starting from "...it is noted that the disadvantages...".
Author's response: The sentences were revised according to the reviewers comment.
p.1896/24: Remove "aimed"!
Author's response: "aimed" has been removed.
p.1897/15: "in an objective" instead of "in a objective"
Author's response: The text has been revised as suggested.
p.1897/17: "was" instead of "were"
Author's response: The text has been revised as suggested.
p.1897/23-24: Remove sentence "An overall evaluation..."!
Author's response: The sentence has been removed.
p.1897/27: "approximately" instead of "approx."
Author's response: The text has been revised as suggested.
p.1897/28: "about two thirds by clouds associated to" instead of "about two third by clouds occurring associated to"
Author's response: The text has been revised as suggested.
p.1898/6: Remove "required"!
Author's response: The text has been revised as suggested.
p.1898/7: Remove "relatively"!
Author's response: The text has been revised as suggested.
p.1902/Table 1: Add "(TE)" at end of table caption!
Author's response: TE has been added to the caption.
p.1904/Table 3: Please clarify in table caption if RR is total precipitation amount or mean precipitation during indicated period!
Author's response: Additional information was added to the Table caption.
p.1905/Table 4: "unstable" instead of "labile"
Author's response: The text has been revised as suggested.
p.1910/Figure 3: For clarity, label top and bottom panels as Fig. 3a and 3b!
Author's response: Additional labels (A, B) for the top and bottom panel were added to the Figure.
p.1912/Figure 5: For clarity, label left and right panels as Fig. 5a and 5b!
Author's response: Additional labels (A, B) for the left and right panel were added to the Figure.