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.

<u>Responses to Anonymous Referee #1</u>

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.

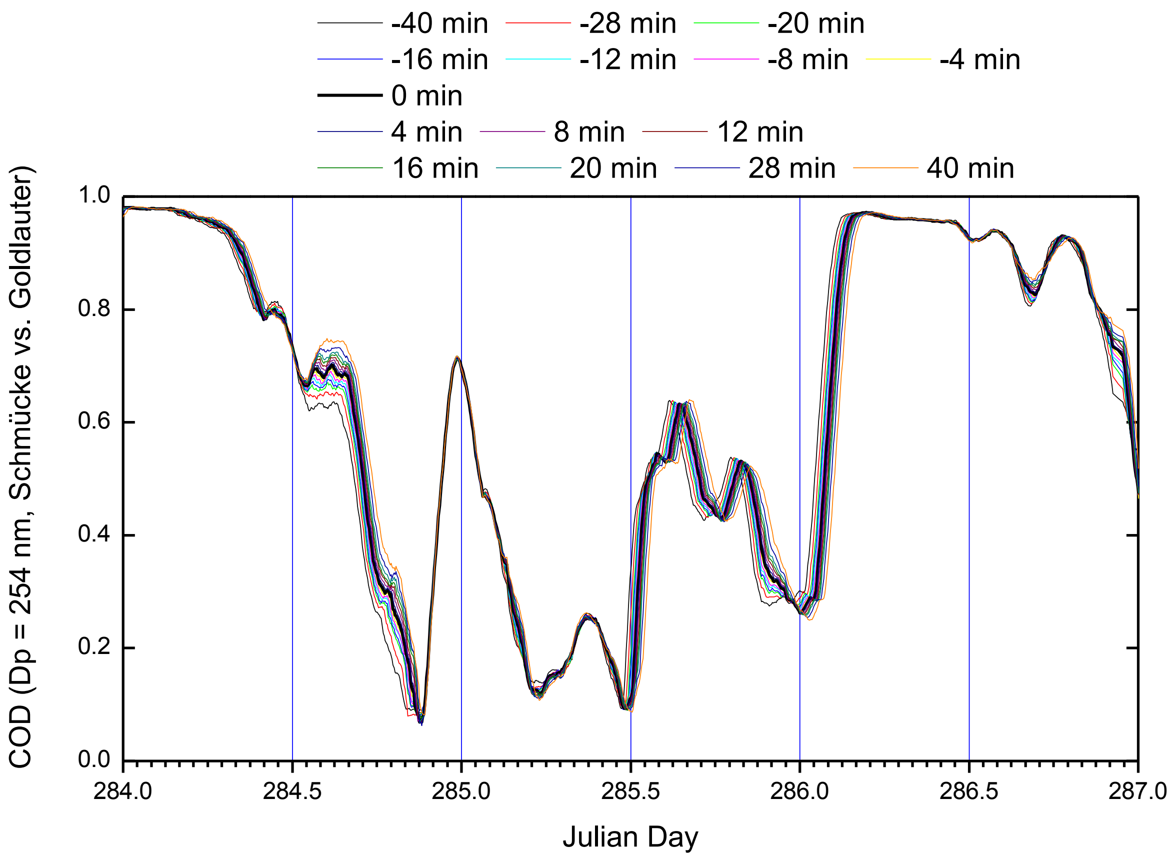

Figure1: Calculated CODs for the particle size bin N_{254nm} (upwind vs. summit site) during 11th and 14th Oct. 2010 assuming different positive and negative time lags (±40 min.).

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.

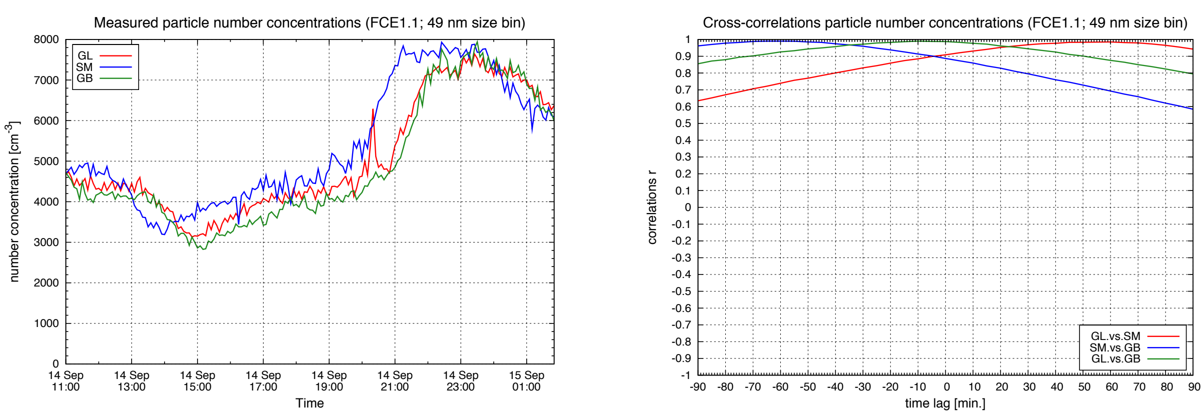

Figure 2: Measured particle number concentrations during FCE1.1 (left) and calculated cross-correlation for the whole event.

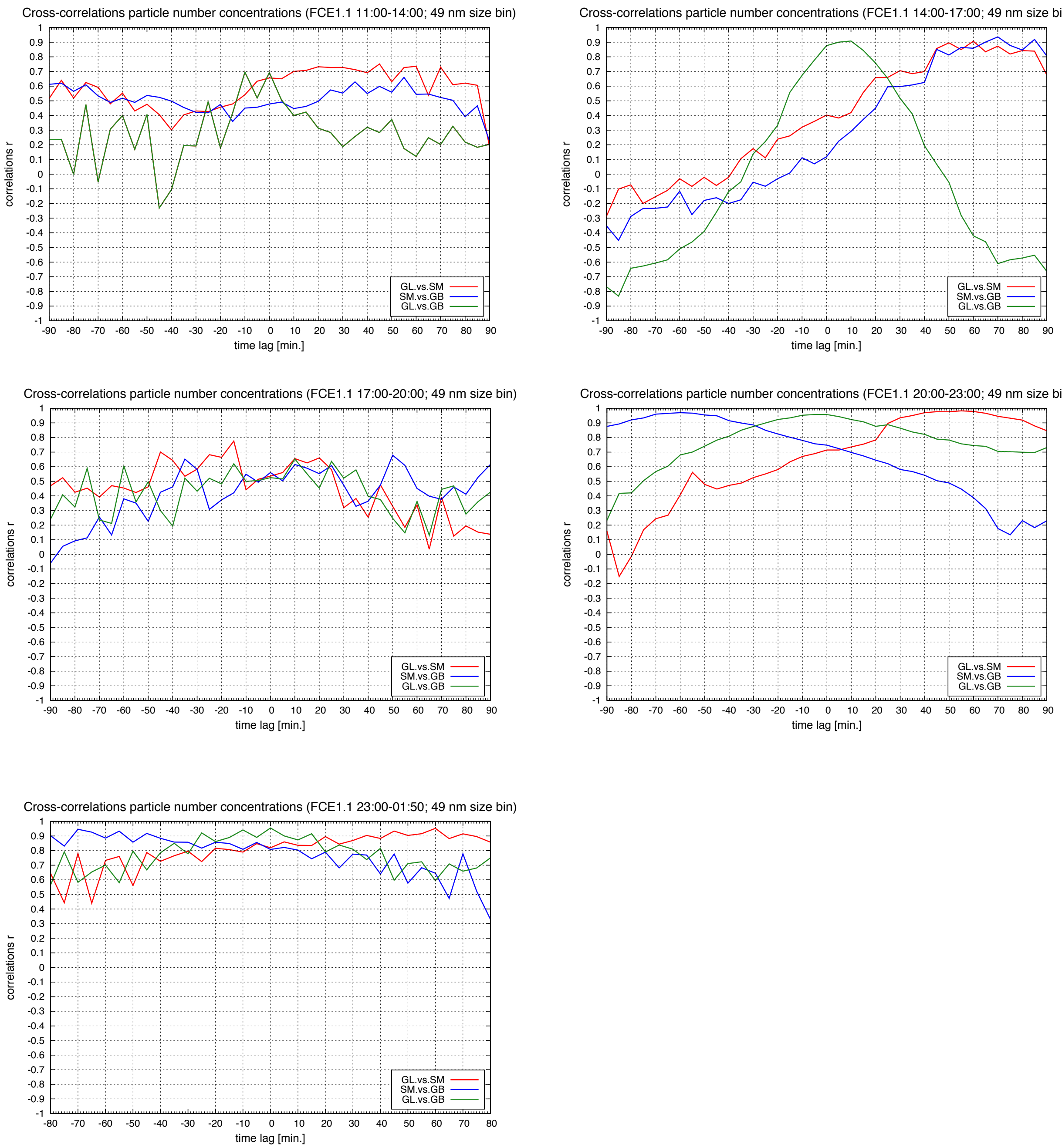

Figure 3: Calculated cross-correlations for 3-hour time intervals of FCE1.1.

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.

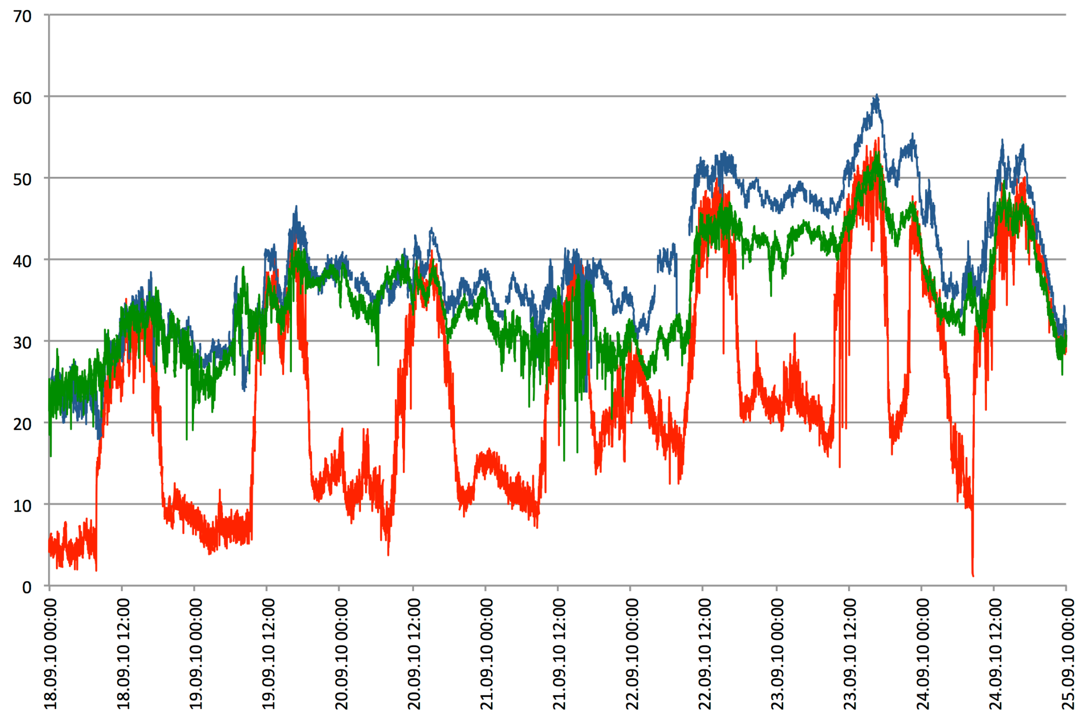

Figure 4: Measured ozone concentrations at the three sites during (18-25)-09-2010.

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.

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 Anonymus Reviewer#2 for reviewing the manuscript and for the constructive comments and suggestions made to improve the manuscript. All comments are addressed below.

Responses to Anonymous Referee #2

Review on:
Critical assessment of meteorological conditions and flow connectivity during HCCT-2010, by A. Tilgner et al.
The present paper gives an extensive description of the meteorological conditions prevailing during a field experiment performed at Mount Schmucke, Germany during September and October 2010. Also a larger scale analysis of the air mass origin prevailing at the observational sites by means of back-trajectories is given.
In addition the paper wants to document the flow connectivity between upwind, summit and downwind sites of the experimental place as the field experiments aim probably at further studies on atmospheric chemistry and physics in capped clouds. The study on flow connectivity uses non-dimensional numbers for atmospheric stability, gas and aerosol observations as well as tracer experiments.
Thus, a main focus of the paper is to provide information on the periods when so-called full cloud events with connected flow conditions occurred.
The volume of the paper, with about 50 pages and the on - line material of 100 pages, is very important and reflects a considerable work. However, real scientific findings or conclusions cannot be identified.
Author's response:

Given that the reviewer was unable to identify real scientific findings or conclusions in the manuscript, we made an attempt to emphasize the scientific achievements of this work more strongly in the revised version. In our view, there are several of such achievements:

1. The paper outlines a very comprehensive approach to figure out fitting conditions for a Lagrangian type approach, which has never been done so far in that detail in the context of a hill cap cloud experiment. Suitable conditions were evaluated by three completely different approaches, i.e. (i) the flow conditions are characterised by a combination of theoretical/statistical parameters, (ii) tracer experiments were performed in the field, and (iii) regional scale modelling was applied to characterise local flow conditions (newly added in the i manuscript version, see below). Tracer experiments are of the best measure, however it is impossible to perform these experiments throughout the whole campaign. Thus, other measures have to be used. The present paper has shown that also theoretical/statistical parameters fit very well to the findings of the tracer experiments and the performed regional modelling. The consistency between the statistical approach and the experimental and modelling approach is certainly a significant achievement as it allows for using these tools (cross-correlation and COD analysis) in similar Lagrange-type studies with much greater confidence than before.
2. The results of the present paper demonstrate in a very comprehensive way that under appropriate meteorological conditions a Lagrangian-type approach is valid for a hill cap cloud experiment such as HCCT-2010. This assumption has often been questioned in similar experiments in the past and has now been supported in an unequalled level of detail. This is an important result not only within the HCCT project, but also for past and especially future studies, as it shows the principal feasibility of a Lagrange-type approach, if flow conditions are carefully evaluated.
3. The identification of FCEs and NCEs is – as the reviewer correctly assumes – a crucial prerequisite for any further data evaluation in HCCT-2010 and thus a major achievement within the project. Given the complexity of the different approaches applied and the level of detail necessary for a critical assessment of the flow conditions, the authors do not see how this could be added in a convincing way to future papers dealing with data interpretation in the Lagrange-type approach.

To make these points clearer, we have modified the manuscript in sections 1, 3 and 4. Overall, the paper in it's revised version now contains - to the authors' opinion – all of the elements for a stand alone paper and represents an important work both for other studies on the HCCT-2010 field campaign and also any other future hill cap cloud experiments, where the approved methods and tools applied and developed in the present study may find further application for identifying suitable meteorological and connected airflow conditions.

- In the largely revised Abstract, the results of the comprehensive study are much better outlined as well as implications and prospects for other HCCT-2010 works and future hill cap cloud experiments are now given. The revised Abstract reads as follows:
  "This study presents a comprehensive assessment of the meteorological conditions and atmospheric flow during the Lagrangian-type "Hill Cap Cloud Thuringia 2010" experiment (HCCT-2010), which was performed in September and October 2010 at Mt. Schmücke in the Thuringian Forest, Germany and which used observations at three measurement sites (upwind, in-cloud, and downwind) to study physical and chemical aerosol–cloud interactions. A Lagrangian-type hill cap cloud experiment requires not only suitable cloud conditions but also connected airflow conditions (*i.e.* representative air masses at the different measurement sites). The primary goal of the present study was to identify time periods during the 6-week duration of the experiment in which these conditions were fulfilled and therefore which are suitable for use in further data examinations. The following topics were studied in detail: i) the general synoptic weather situations, including the mesoscale flow conditions ii) local meteorological conditions and iii) local flow conditions. The latter were investigated by means of statistical analyses using best-available quasi-inert tracers, SF_6 tracer experiments in the experiment area, and regional modelling. This study represents the first application of comprehensive analyses using statistical measures such as the coefficient of divergence (COD) and the cross-correlation in the context of a Lagrangian-type hill cap cloud experiment. This comprehensive examination of local flow connectivity yielded a total of 14 full-cloud events (FCEs), which are defined as periods during which all connected flow and cloud criteria for a suitable Lagrangian-type experiment were fulfilled, and 15 non-cloud events (NCEs), which are defined as periods with connected flow but no cloud at the summit site, and which can be used as reference cases. The overall evaluation of the identified FCEs provides the basis for subsequent investigations of the measured chemical and physical data during HCCT-2010 (see http://www.atmos-chem-phys.net/special_issue287.html).
  Results obtained from the statistical flow analyses and regional-scale modelling performed in this study indicate the existence of a strong link between the three measurement sites during the FCE and NCE events, particularly under conditions of constant south-westerly flow, high wind speeds and slightly stable stratification. COD analyses performed using continuous measurements of ozone and particle (49 nm diameter size bin) concentrations at the three sites revealed, particularly for COD values < 0.1, very consistent time series (*i.e.* close links between air masses at the different sites). The regional scale model simulations provided support for the findings of the other flow condition analyses. Cross-correlation analyses revealed typical overflow times of ~15–30 min between the upwind and downwind valley sites under connected flow conditions. The results described here, together with those obtained from the SF_6 tracer experiments performed during the experiment, clearly demonstrate that a) under appropriate meteorological conditions a Lagrangian-type approach is valid and b) the connected flow validation procedure developed in this work is suitable for identifying such conditions. Overall, it is anticipated that the methods and tools developed and applied in the present study will prove useful in the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."
- In the introduction the following sentences/paragraphs were added:
  "However, the use and quality of Lagrangian-type hill cap cloud field campaigns strongly depends on meteorological conditions: without a connected flow, comparisons of the physical and chemical properties of aerosol upwind and downwind of a cloud are meaningless."
  "In the present study, so-called "connected flow conditions" are defined as conditions where the incoming flow passes the upwind area and subsequently the mountain ridge before finally reaching the downwind area. It is explicitly noted here that "connected flow conditions" do not necessarily require an air parcel trajectory to connect all three sampling sites, as these sites were designed to measure representative aerosol compositions in the upwind, summit and downwind areas."
  "Since fulfilment of these conditions is a prerequisite for meaningful comparisons of the physical and chemical aerosol properties measured in the upwind (before the cloud interaction), summit (inside the cloud), and downwind (after the cloud interaction) regions, the comprehensive analysis presented here is of major

importance both for previously published works and for additional further studies performed using data obtained during HCCT-2010 *(e.g.* those contained in the HCCT-2010 Special Issue, http://www.atmos-chem-phys.net/special_issue287.html). Moreover, the methodology used and applied here is of a wider scientific interest for the design and interpretation of Lagrange-type hill-cap cloud experiments."

"All selected reference periods (i.e., FCEs see below) of HCCT-2010 are further evaluated with respect to the question of flow connectivity and cloud conditions. Both calculations of non-dimensional flow parameters (*e.g.* the Froude number (Fr)) and simulations performed using the COSMO meteorological forecast model (COnsortium for Small-scale MOdelling (Baldauf et al., 2011; Schättler et al., 2012)) were used to characterise the regional flow regime in the mountainous terrain."

- In section 3, a new subsection (3.5) was added (the subsection is outlined further down in this paper)
- In the section 4 the following sentences/paragraphs were added/modified:

"The main goal of the present study was to provide a comprehensive evaluation of the meteorological and connected flow conditions present during the ground-based Lagrangian-type experiment HCCT-2010, in order to provide a set of suitable measurement time periods for detailed investigations (see e.g., Harris et al. 2013, 2014, Spiegel et al. 2012)."

"In addition, the local meteorological conditions during the identified FCEs were studied in detail. Simulations performed using the weather forecast model COSMO were used to further investigate the regional and local flow conditions. These simulations enabled the characterisation of the regional wind pattern and the identification of decelerated or blocked flow conditions at the upwind site and downdrafts at the downwind site."

"The findings of the COD and cross-correlation analysis in particular were supported by results obtained from regional modelling. The overall evaluation of the HCCT-2010 measurement period with respect to meteorological and connected flow conditions resulted in the identification of 14 FCEs useful for further studies (see http://www.atmos-chem-phys.net/special_issue287.html).

In conclusion, the present study used an unprecedentedly comprehensive variety of tools, including tracer experiments, statistical measures, non-dimensional flow parameters and regional modelling, to provide a comprehensive analysis of connected flow conditions crucial for a Lagrangian-type hill cap cloud experiment. Results obtained using the statistical approach and those obtained using the experimental and modelling approach exhibited a high degree of consistency. This is a significant result suggesting that statistical tools such as cross-correlation and COD analysis can be applied in future Lagrangian-type studies with greater confidence than before. Overall, the results of the present paper demonstrate that, under appropriate meteorological conditions, a Lagrangian-type approach is valid for hill cap cloud experiments. Finally, the methods and tools developed and applied in the present study can be used for the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."

The paper doesn't explain its utility or importance for other following studies of HCCT - 2010 or give references to papers already accepted or at least submitted which use or will use the presented results and analyses.

Author's response:

In the paper, the importance particularly for other works is mentioned several times throughout the manuscript (please see e.g. p1863/12-14, p1896/25, etc. in the original manuscript). However, according to the reviewer comment, the authors added further details regarding the utility or importance of the present paper to the manuscript in order to strengthen the relevance of the paper for already published works and upcoming works (please see e.g. the abstract, section 1 and summary in the revised manuscript). In addition, links to the HCCT-2010 Special Issue and already published papers have been added to the text (see below for details).

In detail the following text was added/revised in the

1) Abstract:

"The overall evaluation of the identified FCEs provides the basis for subsequent investigations of the measured chemical and physical data during HCCT-2010 (see http://www.atmos-chem-phys.net/special_issue287.html)"

"The results described here, together with those obtained from the SF_6 tracer experiments performed during the experiment, clearly demonstrate that a) under appropriate meteorological conditions a Lagrangian-type approach is valid and b) the connected flow validation procedure developed in this work is suitable for identifying such conditions. Overall, it is anticipated that the methods and tools developed and applied in the present study will prove useful in the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."

2) Introduction:
"Since fulfilment of these conditions is a prerequisite for meaningful comparisons of the physical and chemical aerosol properties measured in the upwind (before the cloud interaction), summit (inside the cloud), and downwind (after the cloud interaction) regions, the comprehensive analysis presented here is of major importance both for previously published works and for additional further studies performed using data obtained during HCCT-2010 *(e.g.* those contained in the HCCT-2010 Special Issue, http://www.atmos-chem-phys.net/special_issue287.html). Moreover, the methodology used and applied here is of a wider scientific interest for the design and interpretation of Lagrange-type hill-cap cloud experiments."

3) Summary:
"The main goal of the present study was to provide a comprehensive evaluation of the meteorological and connected flow conditions present during the ground-based Lagrangian-type experiment HCCT-2010, in order to provide a set of suitable measurement time periods for detailed investigations (see e.g., Harris et al. 2013, 2014, Spiegel et al. 2012)."
"The overall evaluation of the HCCT-2010 measurement period with respect to meteorological and connected flow conditions resulted in the identification of 14 FCEs useful for further studies (see http://www.atmos-chem-phys.net/special_issue287.html)."
"Overall, the results of the present paper demonstrate that, under appropriate meteorological conditions, a Lagrangian-type approach is valid for hill cap cloud experiments. Finally, the methods and tools developed and applied in the present study can be used for the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."

It is obvious that the paper wants to confirm the "Lagrangian type approach" of the hill cloud experiment. But is flow connectivity (as discussed in this paper) a sufficient criterion to justify that the same air parcel travels along the 3 observational sites? For such applications a quantitative analysis of flow connectivity is needed but not a qualitative evaluation as it is done in the paper.

Author's response:

Based on the reviewers' comment we realize we should have better explained our idea of a connected air flow to avoid misunderstandings. Our definition of a connected flow does not necessarily mean that an air parcel is starting directly from the upwind site passing the summit site and later the downwind site. Under ideal conditions, this would be of course the optimal case (even though it has to be noted that something like an "air parcel" with a definite volume does not really exist in the atmosphere due to continuous deformation processes during the air flow (diffusion, turbulence, convection, …)). Instead, our general idea is that the upwind/summit/downwind sites are representative stations to characterise (chemically and physically) the air and aerosol before (i.e., in the LUV), on top, and after the passage of the mountain ridge (i.e., in the LEE). Therefore, it is not absolutely necessary that the air parcel - or better the trajectory - is directly connecting all sites. If the incoming flow is fulfilling the concept of a flow from the upwind area passing the mountain ridge and finally reaching the downwind area, then so-called "connected flow conditions" are present, which are useful for a hill cap cloud experiment. In order to clarify this issue, an extended explanation of the "so-called" connected flow conditions is given in the updated manuscript (please see section 1 in the revised manuscript), which reads as follows:

"In the present study, so-called "connected flow conditions" are defined as conditions where the incoming flow passes the upwind area and subsequently the mountain ridge before finally reaching the downwind area. It is explicitly noted here that "connected flow conditions" do not necessarily require an air parcel trajectory to connect all three sampling sites, as these sites were designed to measure representative aerosol compositions in the upwind, summit and downwind areas."

Moreover it should be noted that due to the reviewer suggestion of more quantitative analysis, additional model simulations were performed to complement and thus improve the analysis of the flow conditions. Further details on the model simulations are given in the answer to the third reviewer comment following from here (please see page 5).

The given tracer experiments of this study are an excellent quantitative measure. TE3 (Fig.10b) is evaluated as one of 14 Full Cloud Events with connected flow conditions (Tab. 5). But the absent tracer concentrations at the downhill site contradict the statement that air parcels travel from the summit to the downhill location. Thus Lagrangian conditions are not met although the selected criteria of airflow connectivity are fulfilled.

Author's response:

Here it should be kept in mind that for the tracer experiments a point source at the upwind site was used, which increases the probability of a plume missing the exact location of the downwind site. However, as can be seen from the Figure, the plume does pass the second downwind site "Am Brand" which is quite close to the actual measurement downwind site (see map). Together with our above given understanding of connected flow as measuring representative air masses at the sites, this finding does indeed indicate airflow connectivity during TE3. If SF_6 was advected in a spatially more homogeneous way to the upwind site (as real air masses during FCEs do), it would certainly have been measured at both downwind sites during TE3 as well. This has already been explained in the original manuscript and now been strengthened in the revised version by emphasizing the fact that the SF_6 plume during TE3 did pass the near downwind site "Am Brand".

The title informs that the paper deals with the "critical" assessment of the atmospheric conditions, but nowhere in the paper a critical discussion or conclusion can be detected; it is just a lengthy listing of observational results and of meteorological conditions prevailing during the field campaign.

Author's response:

"Critical assessment" in our understanding means that several parameters are evaluated and various approaches are applied in order to test the hypothesis of connected airflow during certain time interval. A non-critical assessment would e.g. rely on wind direction only, neglecting all possible disturbances of the airflow that can occur. Such a critical assessment of meteorological and flow conditions during HCCT-2010 was made in section 3.5. In the corresponding Table 5, all advantages and disadvantages of the selected FCE are given and a critical/concluding remarks for each FCE is given. In the revised manuscript, the assessment of the different events was further extended with the results of the regional modelling (please see updated Table 5 and the corresponding text in section 3.6). Moreover, for reasons of clarity and readability, the revised manuscript is now more condensed and according to the reviewer comment the manuscript title has been modified ("Comprehensive assessment of …" instead of "Critical assessment of").

More detailed remarks:

The presentation of the flow analysis is inaccurate and not very profound.

Author's response:

The authors agree with the reviewer that the flow investigations were not as comprehensive as possible. Thus, additional model simulations have been performed in order to improve the flow analysis. The simulations represent a very useful tool in combination with the other analyses. The model simulations enable a much better characterisation of the regional wind pattern (flow over/around the Thuringian Forest) and supported thus the flow analysis significantly. Moreover, the comparison of the model results with the outcome of the statistical investigations provided also the possibility to assess the quality of the performed statistical investigations. Overall, the model results assisted also the characterisation of decelerated/blocked flow conditions and provided also indications for downward mixing of air from higher levels for some of the FCEs. The obtained results of the model application are outlined in the new section 3.5 and assessed individually for each event in Table 5 in section 3.6. Furthermore, graphical material for each of the FCEs was included into the supporting material and two examples (see Figure below) are presented and discussed in the text of section 3.5. Thus, the presentation of flow analyses is now more profound.

- For the description of the applied model and the performed simulations, the following paragraph was added into the new section 2.7:

  "**Characterisation of the regional flow conditions using COSMO**

  For the model-based investigation of the flow conditions, simulations with the meteorological forecast model COSMO (Baldauf et al., 2011; Schättler et al., 2012) were conducted for the whole measurement period. In brief, COSMO is based on the primitive hydro-thermodynamical equations that describe compressible nonhydrostatic flow in a moist atmosphere. It uses a staggered Arakawa C-grid on a rotated geographical coordinate system and a hybrid terrain-following vertical coordinate. The COSMO model includes the dynamic kernel for the atmosphere and the required parameterisation schemes for numerous meteorological processes, boundary conditions and surface exchange relations. COSMO can describe not only the atmospheric flow but also phenomena occurring between the meso- and micro-scales, including near-surface processes, convection, clouds, precipitation, orographic and thermal wind systems. Further details on the model and its implementation can be found elsewhere in the literature (see *e.g*. Baldauf et al. (2011)). In the present study, the COSMO model was applied for a domain spanning between 50°N, 9.5°W and 51°N, 11.5°W with a horizontal resolution of ~1.4 km (100 × 80 grid cells). For the investigation of the regional-scale flow conditions, the wind field predicted by COSMO was used. The model output is presented in the ESM for each of the FCEs identified during the measurement period."

- The newly introduced section 3.5 with the model results reads as follows:
  "Model-based characterisation of the flow conditions during FCEs
  The extent to which the identified FCEs met the required overflow conditions was also characterized using the wind field predictions of the COSMO model. Figures showing the horizontal wind conditions predicted by the COSMO model in the Mt. Schmücke area for each of the selected FCEs are presented in the ESM.
  A nearly constant wind field, with wind arrows of approximately the same orientation (SW) and length *(i.e*. the same wind speed and direction) is a good indication for mountain overflow conditions without a deceleration/blocking of the flow, without significant downward mixing of air from higher levels, and without a circulation around the Thuringian Forest. This condition was fulfilled for all FCEs during September and for FCE26.1/FCE26.2 in October, in which very constant SW flow conditions were predicted by COSMO. For example, as illustrated in Fig. 7, FCE7.1 showed a very homogeneous regional wind field with similar wind directions and wind speeds before, on top and behind the mountain ridge, which indicates an adequate flow over the mountain (*i.e.* without an upwind deceleration of the incoming flow and almost no entrainment of higher-level air).
  The other FCEs (11.2, 11.3, 13.3 (in part), 22.0 (in part), 22.1, and 24.0), by contrast, showed less congruent wind directions and wind speeds before, on top and behind the mountain ridge—for these FCEs, the COSMO model predicted an upwind blocking, at least in part. For example, as shown in Fig. 7, the model predicted decelerated flow conditions in the upwind area and stronger winds in the downwind area during FCE 24.0. The latter prediction indicates the presence of downdrafts in the lee of the mountain ridge and, thus, entrainment of air from higher altitudes.
  The COSMO-predicted wind conditions during each of the identified FCEs are presented in Table 5. In general, these modelled results are quite consistent with the results obtained from the COD and cross-correlation analyses discussed previously. Therefore, the connected flow validation scheme developed in this work is approved to be applicable for identifying suitable flow conditions for a hill cap cloud experiment."

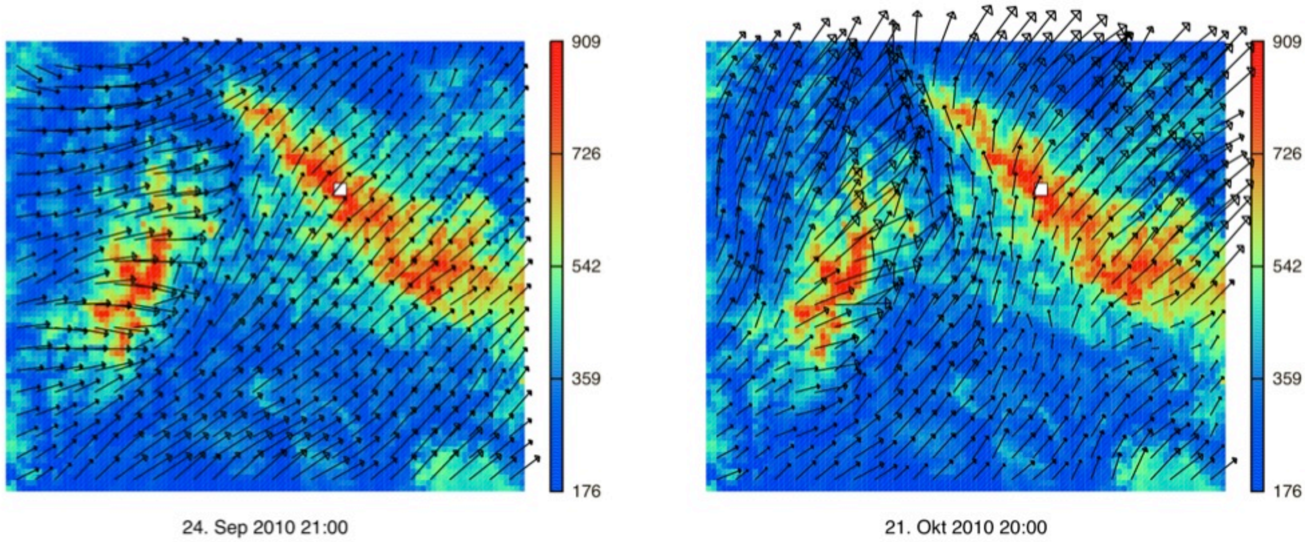

Figure 7: Depiction of the horizontal cross-section of the topography and the wind conditions (black arrows) above the ground for the COSMO-MUSCAT model domain at 24-09-2010 (21 UTC, left) and at 21-10-2010 (20 UTC, right). The white square marks the Mt. Schmücke area.

Richardson and Froude number are calculated from soundings 30 km southwest from the experiment location. The terrain is quite complex as illustrated by my attached Fig.1. Why should wind speed, wind shear and stratification all be conserved during the flow from Meiningen (located in center of Fig.1) to Goldlauter and Schmucke?

Author's response:

The author's agree with the reviewer that the terrain is complex and the vertical stratification and properties could be different 30 km upwind of Mt. Schmücke. However, inside of a quite homogeneous air mass and under quite stable thermal/flow conditions, the thermal stratification and the wind field should not be substantially different 30 km upwind of the measurement site. The authors agree that rawinsonde measurements performed directly at the measurement site would be much better but, unfortunately, there are no rawinsonde data available However, we have used the data for the characterisation in addition to other parameters and newly model simulations only. Furthermore, in former studies (see Heinold et al., 2005), the results from the Richardson and Froude number calculations agreed rather well with other results e.g. from small scale modelling. Therefore, the two parameters were calculated in order to support the identification of suitable overflow periods and to present a comprehensive study investigating all possible issues/measures.

In the manuscript it is already mentioned that "…the evaluation of flow connectivity can be complicated by non-homogeneous terrain, such as a variable crest line and changeable surface roughness. Therefore, other local parameters also need to be used to assess the likelihood of an air parcel passing over a mountain ridge.".

However, due to the reviewer comment, we have included some sentences addressing the above-mentioned issues of the reviewer in the revised manuscript (see end of section 2.4).

"Finally, it should be noted that since the calculation of Fr and Ri numbers is based in part on data taken ~30 km upwind of Mt. Schmücke, it therefore assumes that both the wind conditions and the thermal stratification were conserved during transport to the measurement site. Since this assumption may not always be valid, the calculated values of Fr and Ri should be used with caution."

Fig. 2 of the paper shows a 'geographical map' with the different observational sites but gives no idea on the real topographical conditions for the airflow. NASA SRTM data with a 90 m resolution allow today for all (as free access) to reconstruct a 3D image of topography (see my Fig.2 attached). This figure illustrates the complexity of the terrain up and downwind of Schmucke. Surprisingly, downwind of the summit two valleys begin uphill of the Gehlberg station what suggests that dominant parts of the downhill flow will escape along these two valleys.

Author's response:

The author's thank the reviewer for the additional material. In order to improve the measurement site characterisation, a more profound description of the terrain was put into the revised manuscript (see section 2) together with the graphical material (see updated Figure 1).

In the measurement site description (section 2.1) the following text was added:

"The topography in the measurement area is quite complex (see Figure 1). The terrain is characterised by a rather narrow valley, wherein the upwind site Goldlauter is located, and two downwind valleys, which begin uphill of the downwind site Gehlberg. Since they permit diverging flow, these valleys can complicate the connected flow conditions. However, previous tracer experiments (Heinold et al., 2005) have shown that, under suitable flow conditions, representative air masses from the upwind area are able to reach the downwind site."

The revised Figure 1 looks as follows:

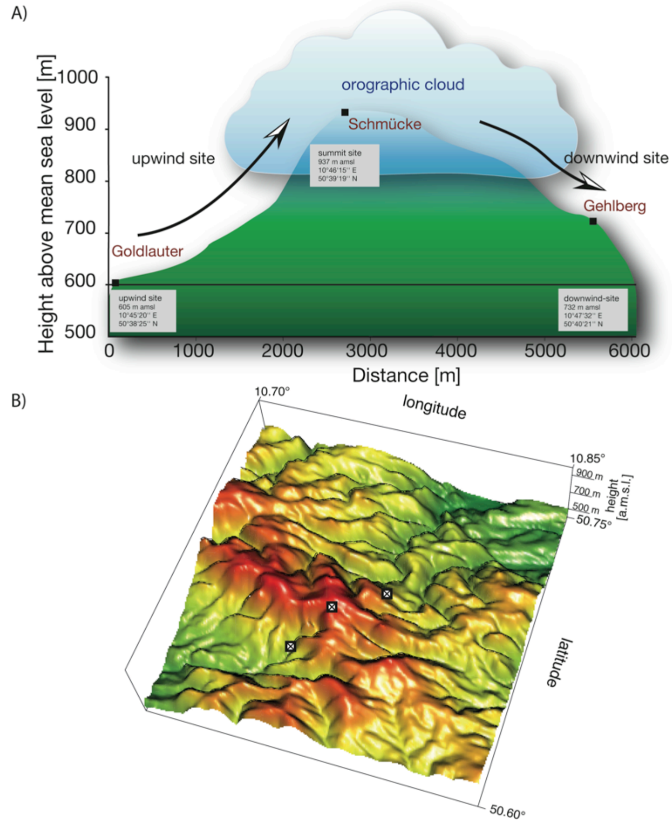

Figure 1: A) Schematic depiction of the HCCT-2010 measurement area and the three sampling sites, including the upwind site Goldlauter, the summit/in-cloud site Mt. Schmücke, and the downwind site Gehlberg. B) Depiction of the terrain of the measurement area (based on SRTM data (Shuttle Radar Topography Mission) available from the CGIAR-CSI SRTM 90m Database v4.1 (http://srtm.csi.cgiar.org/; Jarvis et al., 2014)).

Moreover, the authors agree with the reviewer that the place of the downwind site is surely not ideal. It is noted that the sampling site was placed at their location because of topographical/infrastructural reasons and based on tracer experiments which were performed beforehand and during the hill cap cloud experiment FEBUKO in 2001. The trace experiments have shown that under suitable conditions an advection of air from the upwind area to the downwind is possible and that released SF_6 can be detected the downwind site after reasonable transport times. Thus, the idea of representative air masses passing all three sites can be present under suitable flow conditions. Additionally, it should be mentioned that the Schmücke area is part of the UNESCO Biosphere Reserve „Vessertal-Thuringian Forest" and thus a sampling at a possibly more suitable site from the flow condition point of view is difficult. Due to the above-mentioned issues regarding the connected flow, the authors think that under atmospheric conditions, which allow an overflow of the mountain ridge, air masses from the upwind area have to reach the downwind site.

As the FCE events are typically coupled with strong winds on the summit it is also most likely that a downdraft occurs behind the summit or mountain ridge causing the mixing with air from higher levels (from 300-400 m above the summit). Thus, it is not surprising that SF6 was not or only slightly detectable on the downslope station.

Author's response:

The authors agree with the reviewer that downdrafts can occur behind the summit or mountain ridge leading to an increased mixing with air from higher levels (see e.g. Pierrehumbert and Wyman (1985)). However, the occurrence of downdrafts in the back of a mountain ridge depends also on the thermal stratification. In case of downdrafts, increased wind speeds should be observable at the downwind site connected with lower wind speeds upwind of the mountain ridge (blocking effects). Such behaviour can be sometimes seen in the output of the newly performed model simulations. (see for example the wind field on the 19th Oct. at 00:00 UTC in the revised supplementary material). However, for many of the FCEs we see if at all only slightly increased wind speed in the Lee of the mountain ridge compared to the luv. That means, a continuous low-level flow over the mountain is predicted with small downdraft effects only. According to the reviewer comment, downdraft and the caused mixing (entrainment) are outlined in the revised manuscript in section 2.4 and discussed in section 3.5 (see above):

The added text in section 2.4 reads as follows: "Under these conditions (*i.e.* under decelerated or blocked upwind low-level flow conditions), stronger downdrafts behind the mountain ridge can occur. These downwind site downdrafts lead to a mixing of low-level air with air from higher altitudes (see Pierrehumbert and Wyman, 1985)."

Regarding the mixing of the SF_6, both vertical and horizontal mixing will happen after the release from a point source. Under the most likely present stable thermal stratification conditions, the vertical mixing should be less important compared to the horizontal dilution and distribution. Thus, much lower SF_6 concentrations measured at the other sites are not really surprising.

Very high resolved numerical modeling would be basically needed to understand the local transport phenomena and their consequences for the different measuring sites.

Author's response:

The authors agree with the reviewer that the application of a numerical model is a helpful tool to better characterise the local flow conditions. Thus, the weather forecast model COSMO was applied to simulate the local flow conditions. Model simulations were performed with a horizontal resolution of 1.4 km, which allows an adequate simulation of the local wind field. It has to be noted that model simulations with an even higher resolution has not been performed yet. Form former studies (Heinold et al., 2005), it is known that that further model runs using a higher resolution will provided not so much more details on the overflow.

The results of the modelling are included in the revised version of the manuscript (see the new section 3.5 (see above), Table 5 in section 3.6, and the supplementary Figures in the supporting information) and improved the outcome of the study (please see the summary). Moreover, in most of the cases the model agrees very well with the other findings in the study.

In the revised Table 5, the COSMO results are outlined for each FCE including indications on upwind flow blocking and downwind site downdrafts. For example, the following text was added to Table 5 for the FCE22.1: "… stable SW winds with a small blocking of the upwind flow predicted by the COSMO model, …"

In the revised summary the following text was added:

"Simulations performed using the weather forecast model COSMO were used to further investigate the regional and local flow conditions. These simulations enabled the characterisation of the regional wind pattern and the identification of decelerated or blocked flow conditions at the upwind site and downdrafts at the downwind site."

and

"The findings of the COD and, cross-correlation analysis were supported by results obtained from regional modelling."

Another method for flow analysis in this paper is the comparison of the concentration of O3 or $N_{aerosol}$ (49nm) between upwind, summit and downwind site. Non-connected air masses are identified when the concentrations between the three sites deviate and thus COD values are elevated. But no explanation is given on physical or chemical processes causing differences in O_3 or $N_{aerosol}$ concentration on scales of 3 km, which would clarify why the airflow does not cross the mountain ridge! Low CODs certainly support the idea of overflowing air but do not prove the connectivity of the observational sites.

Author's response:

The authors do not fully agree with the reviewer in the above-mention issues. In the manuscript, there are physical or chemical processes mentioned with can affect e.g. the N49nm particles. Proper explanations for the use of this size bin are given ("The particle number density in the 49 nm diameter bin (N_{49nm}) was selected because this represents the upper range of the aerosol particles that tend to be unaffected by cloud activation. Meanwhile, these particles tend to be substantially less affected by coagulation and diffusion processes than smaller particles."). Furthermore, it is outlined why and under which conditions ozone can be used as a tracer ("…Ozone is only secondarily produced in the troposphere and has no primary direct emission sources. Moreover, ozone is characterised by low water solubility with a Henry's Law constant of about $1.0 \cdot 10^{-2}$ M atm^{-1}

(see Sander, 1999 and references therein) and is consumed only ineffectively in acidic continental clouds. Overall, the suitable properties of ozone allow the applicability of ozone as a quasi-inert tracer for the connected flow analysis….").
In order to further improve the manuscript, we have included further potential reasons in the text, which might cause for example additional differences in the $N_{aerosol}$ concentrations during the overflow (dry and wet depositions, collision/coalescence, etc.). Regarding the last comment ("…not prove the connectivity…"), it has to be kept in mind that we are not interested in a trajectory, which is directly connecting all sites. For the hill cap cloud experiment just an overflow connecting all sampling areas and representative air masses at all sites are required.
The following text was added to the revised manuscript:
"It should be noted here that the measured N_{217nm} values could be slightly affected during the overflow by processes including dry/wet deposition, collision/coagulation, chemical in-cloud mass production and entrainment processes."

In summary, the flow analysis is definitely not comprehensive as emphasized in the paper. It restricts to wind and temperature conditions in the mesoscale environment, and to O_3 and 50 nm particle concentrations on the very local scale. Discussion of flow characteristics prevailing over the experimental site, appropriate to the topographical conditions with varying mesoscale conditions are entirely missing. I considered this paper as an extended documentation of observations but their interpretation is left in most parts up to the reader, or to other (further) studies focusing on the same experiment. Actually this study has not the elements for a stand alone paper. Its individual results could be better incorporated into papers dealing with the same field experiment but with well identified objectives and results.
Author's response: In order to improve the paper, additional results form regional scale modelling were included in the updated manuscript (please see the new sections 2.7 and 3.5). Moreover, the manuscript was shorted for reasons of clarity and readability (see section 3.3). However, the authors cannot follow the reviewers' opinion that interpretation would be left up to the reader. The events of the campaign are discussed individually and finally assessed in Table 5. The presented work represents an important element for the whole Special Issue of the HCCT-2010 campaign as it documents and assesses the overflow conditions, which are crucial for further data interpretations in the context of a Lagrange-type experiment. Including all these evaluations into other papers would in the author's opinion heavily overload these. Moreover, as outlined in the first Author's response**,** the outlines a very comprehensive approach to figure out fitting conditions for a Lagrangian type approach, which has never been done so far in that detail in the context of an hill cap cloud experiment. The paper summarises different tools (theoretical/statistical parameters, tracer experiments, regional scale modelling) to perform a comprehensive flow analysis. The different approaches were compared regarding their consistency. The present paper revealed that theoretical/statistical parameters fit relatively well to the findings of the tracer experiments and additionally performed regional modelling. Overall, the present paper clearly demonstrate feasibility of a hill cap cloud experiment and approved that under appropriate meteorological conditions a Lagrangian-type approach is valid. The approved methods and tools applied and developed in the present study a provide tool for future Lagrangian-type experiments identifying suitable meteorological and connected airflow conditions. Overall, the present paper now, to the authors' opinion, fulfils the stand-alone paper status because of the included results of the comprehensive study as well as the given implications and prospects for other HCCT-2010 works and future hill cap cloud experiments.
In order to present the results, implications and prospects more clearly, we have much improved the text, e.g., in the abstract and the summary.
1) Abstract:

"… The overall evaluation of the identified FCEs provides the basis for subsequent investigations of the measured chemical and physical data during HCCT-2010 (see http://www.atmos-chem-phys.net/special_issue287.html).;

… The regional scale model simulations provided support for the findings of the other flow condition analyses.;

… The results described here, together with those obtained from the SF_6 tracer experiments performed during the experiment, clearly demonstrate that a) under appropriate meteorological conditions a Lagrangian-type approach is valid and b) the connected flow validation procedure developed in this work is suitable for identifying such conditions. Overall, it is anticipated that the methods and tools developed and applied in the present study will prove useful in the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."

2) Summary:

"The main goal of the present study was to provide a comprehensive evaluation of the meteorological and connected flow conditions present during the ground-based Lagrangian-type experiment HCCT-2010, in order to provide a set of suitable measurement time periods for detailed investigations (see e.g., Harris et al. 2013, 2014, Spiegel et al. 2012).;

… In addition, the local meteorological conditions during the identified FCEs were studied in detail. Simulations performed using the weather forecast model COSMO were used to further investigate the regional and local flow conditions. These simulations enabled the characterisation of the regional wind pattern and the identification of decelerated or blocked flow conditions at the upwind site and downdrafts at the downwind site.,

... The findings of the COD and cross-correlation analysis in particular were supported by results obtained from regional modelling. The overall evaluation of the HCCT-2010 measurement period with respect to meteorological and connected flow conditions resulted in the identification of 14 FCEs useful for further studies (see http://www.atmos-chem-phys.net/special_issue287.html).

In conclusion, the present study used an unprecedentedly comprehensive variety of tools, including tracer experiments, statistical measures, non-dimensional flow parameters and regional modelling, to provide a comprehensive analysis of connected flow conditions crucial for a Lagrangian-type hill cap cloud experiment. Results obtained using the statistical approach and those obtained using the experimental and modelling approach exhibited a high degree of consistency. This is a significant result suggesting that statistical tools such as cross-correlation and COD analysis can be applied in future Lagrangian-type studies with greater confidence than before. Overall, the results of the present paper demonstrate that, under appropriate meteorological conditions, a Lagrangian-type approach is valid for hill cap cloud experiments. Finally, the methods and tools developed and applied in the present study can be used for the identification of suitable meteorological and connected airflow conditions during future Lagrangian-type hill cap cloud experiments."