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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Technical Note: A new method for the Lagrangian tracking of pollution plumes from source to receptor using gridded model output" *by* R. C. Owen and R. E. Honrath

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Below, we respond individually to each reviewer's comments.

1 Response to Anonymous Referee #3

We thank the reviewer for their careful review of the paper, positive comments, and editorial suggestions. We have chosen to implement the majority of the suggestions. Below, we comment on some suggestions, including all that are not fully incorporated in the revised manuscript. Please note that all page numbers refer to the revised manuscript, unless otherwise noted.

1.1 Specific comments

page 18844 line 25: The conversion of NO_x to HNO_3 is often considered a permanent removal of nitrogen oxides from the atmosphere because HNO_3 is easily removed from the atmosphere. However, a recent study has shown that if HNO_3 is not removed, it can potentially reform NO_x to participate in O_3 formation (Neuman et al., 2006). We have modified this sentence to remove any reference to O_3 formation and simply state that wet removal of HNO_3 is possible during transport from the BL to the FT (page 2, lines 25-26).

Page 18848 line 2: The reviewer is correct, the source can either be a volume or 2-dimensional surface. We have changed the text here to "particles are released at the source" (page 6, line 2).

Page 18857 line 4: We thank the reviewer for the suggested change in terminology. We have made this change throughout the paper.

Page 18872 line 26: Corrected as suggested. We have also removed "(i.e., α = 0)" since it refers to equations 1-3 in Seibert and Frank (2004), which are not referred to explicitly in our paper (page 29, line 7).

Figure 6: This figure is indeed too small, we will work with the editorial staff to increase its size.

2 Response to Anonymous Referee #1

We thank the reviewer for their careful and insightful consideration of our paper. The reviewer brings up several interesting and important points regarding the method as well as the performance of the model simulations presented. We respond to both the general and specific comments below.

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2.1 General comments

Comment regarding the necessity of using the folded retroplume as opposed to simply using the particle trajectories from one of the model simulations: We agree with the reviewer that particle trajectories are another way to determine the source-to-receptor pathway. In fact, we feel that the particle trajectories represent the ground truth of the source-to-receptor pathway, which is why we use them as the basis for comparison of the folded retroplume pathway. We see four reasons the folded retroplume may be preferred over particle trajectories.

First, there are computational disadvantages to saving particle trajectories. Specifically, as mentioned in the review by P. Seibert, particle dumps require a lot of disk space and slow down the model simulation. We mention these issues on page 3, lines 20-24 of the revised manuscript (page 3, lines 21-24 of the original text). The computing and storage demands are particularly high for forward model simulations, which could use upwards of hundreds of millions of particles during the course of the simulation. It may be reasonable to save particle trajectories for a small number of backward simulations, but this also becomes quite difficult when backward simulations are created regularly for months or years worth of analysis. The reasoning that reducing computation and storage demands is important is supported by Seibert and Frank (2004), who stated that backward simulations offer a better alternative to multiple forward simulations for long-term monitoring stations for these reasons.

Second, we also mention in the text that particle trajectories add a layer of complexity, requiring additional processing, analysis, and interpretation. This is based on our experience as FLEXPART users, that LPDMs are primarily used to calculate gridded fields (concentrations, sensitivities, fluxes, etc.). Our understanding is that FLEXPART users first calculate gridded fields, then later find that they need to determine the source-to-receptor pathway or later determine which periods source-to-receptor pathways are needed for. Their choices are using a product like the folded retroplume or re-running

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simulations with full particle dumps. We are aware of only a few FLEXPART studies that use trajectories for analysis (Stohl et al. (2004); possibly Cooper et al. (2005, 2006); Trainer et al. (2007)).

Third, we feel that there are a number of people who do not run model simulations themselves, but instead obtain the output from a third party and may thus simply not have access to particle trajectories. We do not mention this point in the text because we do not know the size of this population.

The fourth reason relates to the reversibility issue mentioned by the reviewer. The review by P. Seibert suggests that a good folded retroplume, with relatively consistent UMRs, indicates that the transport scenario is reversible. If one only uses the backward simulation or a single set of particle trajectories, there is no good way to determine if the transport simulation is reversible. The folded retroplume allows an easy test to assess the quality of the simulation and thus gives the user the option to ignore periods when there is a poor correlation between the forward and backward model simulations.

In summary, there are situations in which particle trajectories are not a reasonable option, and based on our fourth point, it is possible that the folded retroplume may actually be better than particle trajectories, as it allows for an assessment of the reversibility and the quality of the simulation. In addition, we suggest using LPDM results to sample CTM or other gridded output.

In order to make these reasons more clear in the text, we have added a sentence in the abstract (page 2, lines 14-16), introduction (page 4, lines 28-29) and several sentences in the conclusions (page 33, lines 12-16) that introduce and discuss the to the fourth point presented here. Additionally, we have modified the introduction to more clearly delineate the other three points (page 3, lines 20-24).

Comment regarding the reversibility of the model simulations and the relationship to the well-mixed criterion: As we understand it, there are several reasons for irreversibility. One of these, interpolation errors which produce transport errors, was

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mentioned in the review by P. Seibert. Other reasons are given in Lin et al. (2003), which include the violation of the well-mixed criterion (e.g., the creation and destruction of mass) and failure to maintain a consistent representation of the mass of particles as the air density changes. The issue of irreversibility and transport errors is important and we failed to address these possibilities sufficiently. The UMRs in the method evaluation (section 3) clearly indicate there is SOME problem, though it's not clear to us that it is irreversibility. Based on the good agreement between the forward and backward trajectories and the repeatability of this agreement as well as the repeatability the behavior of the UMRs as the model settings were changed, we conclude that the transport scenario in the evaluation is, for the most part, reversible. Based on the detailed examination of the particle positions, as explained in the text, we instead suggest that the problems with the UMRs in the evaluation appear to stem from errors induced from producing gridded quantities when sub-grid gradients exist. The reviewer suggested that we perform a careful analysis of the disagreements. We have done this (page 17) and expanded the description of the analysis (page 16, lines 11-23) and added a paragraph in the discussion (page 33, lines 3-16) to reflect the these issues.

Comment regarding the length of the paper: The review by P. Seibert also suggested the paper is too long, but also found value in the extension of the method to sample CTMs. Thus, we have kept section 5, but condensed 5.2 and 5.3 into a single section. We have also removed the illustrative potential applications presented in the conclusions (page 36 line 8 – page 37 line 4 of the original text). The revised text is thus three pages shorter.

2.2 Specific comments

Page 18858, line 4: These two particles likely represent the small portion of the transport that was irreversible, as evidenced by the lack of backward particles in this region. As the reviewer points out, this region is a relatively minor part of the transport pathway.

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Accordingly, we have changed the text here to “this region is not part of the primary source-to-receptor transport pathway” (adding “primary”, page 15, line 13). Additionally, we note in our discussion of the UMRs that these particles may indicate that a small portion of the transport is irreversible so that the issue is clearly identified in the text.

Page 18858, line 24: We expect that the UMR should be constant during this transport leg, though we do not expect any particular value. Since we view the folded retroplume as the backward simulation sampling the forward, we chose the UMR closest to the receptor for our normalization factor, since it is the sample of the forward simulation with least amount of transport in backward simulation. We have added “(i.e., a non-constant UMR)” to this sentence to clarify this point (page 15, line 28).

Page 18869, 2nd paragraph: As noted above, we feel that the transport is correct, but errors induced from the use of gridded data are the cause of the significant variations in the UMRs. We would like to emphasize, as we do in the text (page 32, lines 17-19), that the transport scenario provided a very strict test of the method - the forward and backward plumes were often on a few grid cells thick and traveled over 3000 km! Given this test, we feel that FLEXPART actually did a good job producing agreement between the forward and backward trajectories. The results showed that the UMR can be sensitive in these situations (large gradients), but the agreement between the particle trajectories and the folded retroplume pathway shows that pathway is more robust. As noted above, however, we have expanded our discussion to include the possibility of irreversible transport.

Page 18871, line 6: The tracer would be dropped from the forward model because its age exceeded the 20 day limit we imposed on the ages of particles in the simulation. This is a common practice with FLEXPART simulations that use continuous emissions from the source region, such as in our sample analysis, where CO had a maximum age of 20 days. Particles in the forward mode are only carried for 20 days, then dropped from the simulation. We have added “(i.e., the particles will reach the maximum age al-

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lowed and will thus be dropped from the forward simulation)" to the end of this sentence to clarify (page 27, lines 25-27).

3 Response to the review by P. Seibert

We thank Dr. Seibert for her comments and suggestions our the paper. We respond to her general and specific comments below.

3.1 General comments

Comment regarding the necessity of using the folded retroplume as opposed to simply using the particle trajectories from one of the model simulations: Dr. Seibert provided three good reasons to use the folded retroplume over particle trajectories. As described in our first response to a similar comment by Anonymous Referee #1 above, we have modified the text to make the justification for use of the new product (over trajectories) clearer. Additionally, we have used the suggestion that the folded retroplume provides a means to determine when the simulated transport is good as support for the use of the folded retroplume over trajectories.

Comment regarding reversibility: Please refer to our response to Anonymous Referee #1. We thank Dr. Seibert for her excellent suggestion to use the folded retroplume as a means to determine when the simulation is good. We have incorporated this idea into the abstract (page 2, lines 14-16), introduction (page 4, lines 28-29) and several sentences in the conclusions (page 33, lines 12-16).

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3.2 Specific comments

Comment regarding the accuracy of the folded retroplume as compared to standard LPDM products: By standard LPDM products, we refer to gridded concentrations, sensitivities, fluxes, etc (i.e., not particle trajectories), as these are the most often used in the literature. For the purpose of determining the source-to-receptor pathway, we feel that the folded retroplume is more accurate than attempting to use the forward and backward output individually (e.g., superimposing contours). We have modified the abstract to clarify this point (lines 11-13).

Comment regarding the output units for backward simulations: We acknowledge that the backward simulation can provide a number of types of output. Our comment in the abstract is an example of one such output and we discuss the different output possibilities in section 6.2 and refer the reader to Seibert and Frank (2004) for more information. The use of "i.e." in "i.e., residence time" was an error. We have corrected this to be "e.g., residence time."

Comment regarding the terminology ”tracer” versus “substance”: We have modified the text to use the term “trace substance”.

Comment regarding instantaneous output: If the folded retroplume is to be used to calculate UMRs, either from an LPDM+LPDM combination or an LPDM+CTM combination, then instantaneous output would be useful. It seems that earlier versions of FLEXPART allowed instantaneous output (I believe at one point the time average of output could be set to 0), but this option was removed from more recent versions. I think it is worthwhile to include this option in future versions, particularly if it is easy to do. With respect to the text, we have added a sentence (page 20, lines 20-21) to point out the impact of increased stochastic uncertainties when using instantaneous output.

Comment regarding the length of the paper: Please see the second response to Anonymous Referee #1.

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