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Interactive Comment

Interactive comment on "Probing ETEX-II data set with inverse modelling" *by* M. Krysta et al.

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Answer to referee #3

We would like to thank referee #3 for an instructive review as far as the meteorological situation is concerned. Firstly, as the inverse modelling of ETEX-II is the first aim of the paper, we comment on inverse modelling performance in presence of errors. Secondly, we tackle the problem of the influence of the meteorological situation on modelling error. Since some of the issues raised by referee #3 are similar to those addressed to us by referee #1, the ideas present in both responses are similar.

1. Issues raised by referee#3 (loosely quoting):
A model executed in the adjoint mode will likely suffer from the same numerical dispersion errors as forward in time model. How do the errors of the advection scheme affect the result of the inversion? In the case of Eulerian models it was evident that they

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represent neither the complex spatial patterns nor intermittent character of the time dependence of the tracer concentration. One can anticipate similar difficulties when solving the inverse tracer transport model in order to calculate the influence function and subsequently the matrix $\boldsymbol{H}$. The difficulties with correct calculation of the influence function can be additionally compounded by the inadequate spatial distribution of detectors. The influence function obtained in such a case [i.e. detectors are placed at the ground level whereas the transport takes place aloft] will not lead to a very accurate evaluation of the source term. The entire inversion is also dependent on the vertical distribution of the forcing term in the equations calculating influence function. What was the specific form of this function used in calculations?

Authors' answer:
Inverse modelling is limited by the performance of a direct model (perfect inversion being only possible with a perfect model and a sufficient quantity of perfect measurements). The procedure employs influence functions and there is a full 4D influence function linked to each measurement. The influence function arises as a solution to the adjoint equation with a forcing term representing the corresponding measurement. For an Eulerian model the measurement is modelled so as to represent a temporal mean (3h) of an entire spatial grid cell containing a measurement station. It is a source of inaccuracy (representativity), especially in the vicinity of the release point (before the tracer has been properly mixed). Please note, however, that a Lagrangian model does not seem to perform significantly better than an Eulerian model if (as it is usually the case) they are driven by the same meteorological fields and similar vertical diffusion schemes. In particular, we wouldn't expect that, given one set of meteorological fields at a fixed resolution, the suppression of a numerical diffusion in the advection scheme would make a very significant difference in the forecast of observations.

The adjoint model, and the subsequent adjoint solutions (or influence functions), are subject to modelling error. Consequently, these errors are present in inverse mod-

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elling. The inverse modelling formalism that we have developed, however, accounts explicitly for a joint modelling and observation error (in the same manner as advocated in geophysical data assimilation), via ε in

$$\boldsymbol{\mu} = \boldsymbol{H}\boldsymbol{\sigma} + \boldsymbol{\varepsilon} \,.$$

No supplementary errors, that are not already present in the model, are added to the problem, except for the adjoining-discretising issue which is controlled here (Fig.2 in the manuscript).

The form of the observation equation given above implies that, in addition to the source, the errors are also inverted in our inverse modelling procedure. Hence, the method allows to improve the consistency between the modelled measurements and the observed ones. The prior modelling of errors ε being crude (Gaussian), it enables the analysis to cope with the localised errors, consequently even with local vertical motions, as long as their impact is localised (typically far from the source). However, it may not be able to accommodate the highly correlated errors like the one induced by a front close to the source.

2. Issues raised by referee#3 (loosely quoting):
It is, however, worthwhile to mention that the meteorological situation during this experiment was very difficult for both the forecast tracer models and for the models calculating the influence function which is essential for the application of the Maximum Entropy method. Quite likely, both temporal and spatial resolutions were not adequate to address the nonstationarity and fragmented tracer cloud. It is quite likely that ETEX-II plume had a complicated three-dimensional fractal structure as opposed to a relatively smooth distribution observed during the ETEX-I experiment. When looking at the particular details of the ETEX-II case, we can certainly suspect the strong layering of the tracer and the subsequent decoupling of the low and high level transport. Quite likely, both temporal and spatial resolutions where not adequate to address the nonstationar-

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ity and fragmented tracer cloud.

Authors' answer:
According to Fig.12 in (Gryning et al., 1998), during the majority of the release interval, the direction of the horizontal wind component at the release point seems quite stable. Its magnitude decreases slowly but remains higher than $5\,\mathrm{m\,s^{-1}}$. Should one limit oneself to the conditions at the release site, one would expect the ETEX-II plume to be narrow and elongated, and moving rapidly towards north-east. As the corresponding indicators (horizontal wind speed and direction) seem (wind speed vertical scales are different in Figs. 6 and 12 in (Gryning et al., 1998)) less stable for ETEX-I than for ETEX-II, one could almost expect a plume to be more confined than for the first ETEX release.

The overview of the measurements taken at the release site for ETEX-II clearly proves the passage of a cold front over it, which contrasts indeed with the first experiment. However, according to the figure illustrating SODAR measurements (Gryning et al., 1998) the passage of the front took place at 0200, less than an hour before the end of the release. Should the passage have been accompanied by convection uplifting the tracer to the higher layers of the atmosphere, some of the tracer should be missing in the measurements. However, there seems to be little support for such a phenomenon in the heat flux profile, Fig.12 in (Gryning et al., 1998), which (with a short-lasting exception) remains roughly constant with the values slightly below zero. Obviously, some tracer uplift is not to be excluded right before the passage of the front, as indicated by non-zero vertical components of wind velocity in Fig.11 (nor is it for the first ETEX release by a similar argument). As pointed to us by referee #3 and stated in (Ryall and Maryon, 1998) "the second release exhibiting an area of cloud (in particular the older parts) above the capping inversion and effectively decoupled from the surface". It might be linked (Ryall and Maryon, 1998) to a pre-frontal uplift. Yet, possibly hindered by an important modelling error, this phenomenon seems to be present in modelling and the model-data comparison is still very bad.

If one moves now from the release site with the advected plume, one realises indeed that on 15 November at 1200 the front moving towards south-east, Fig.9 in (Gryning et al., 1998), have most likely crossed the plume advected towards north-east. According to (Stohl and Koffi, 1998) the ECMWF meteorological fields were of excellent quality for the second ETEX release which implies that there should be no important error in plume advection. The tracer missing in the measurements could, however, have resulted from some process that blew it up and “there was enough time for most of the tracer material to be lifted into the free troposphere by organized rising motion ahead of the front or by convective processes behind the front” (Stohl and Koffi, 1998).

But there seems to be little evidence, either for or against such a situation provided by meteorological measurements. Indeed, as stated in (Stohl and Koffi, 1998), “These small scale flow features were not resolved by the ECMWF data.“ Moreover, there are indirect indications against it (Ryall and Maryon, 1998), “The observations of mainly light rain and drizzle in the general area do not support the presence of either frontal ascent or convective updraught contributing to the removal of the tracer from the boundary layer, but the dynamics were indeed vigorous, and it seems likely that, at least in part, frontal uplift may have accounted for the dilution”.

Hence, the fractal structure of the plume and a large part of the emitted tracer missing from the measurements, seem to be solely supported by the chopped structure of the measurements which leaves the question of the quality of the measurements open.

3. Issues raised by referee#3 (loosely quoting):
It will be quite helpful to add a few sentences discussing these problems in order to emphasize what are the potential limitations of the method used in the manuscript.

In the revised manuscript, we have extended the discussion and devoted a full section

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to the pivotal question: how much does inverse modelling add and why it is still limited although it is supposed to perform better in the data analysis than the model alone.

We also agree that meteorological conditions should be mentioned in the manuscript as possibly responsible for inconsistency of the measurements - the manuscript has been modified accordingly and the citations to the papers which the referee #3 kindly pointed to us have been added. Nevertheless, we would be doubtful about ascribing the entire blame to the meteorological situation. Indeed, the errors that it implies should be localised and uncorrelated. At the same time the inverse modelling procedure using such a hypothesis with respect to the errors ε produces very bad results. This implies, in turn, the presence of large scale correlated errors. The errors of such nature are excluded by the meteorological conditions (with the exception of the frontal passage at the release site, unable, however, to account for more than 85% of the mass missing in the measurements) which casts doubt on the quality of the measurements.

References :

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3. A. Stohl and N.E. Koffi: Evaluation of trajectories calculated from ECMWF data against constant volume balloon flights during ETEX. Atmospheric Environment, Vol 32, No. 24, pp. 4151-4156, 1998

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