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Atmospheric
Chemistry
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Discussions

# *Interactive comment on* “Modelling transport and deposition of caesium and iodine from the Chernobyl accident using the DREAM model” *by* J. Brandt et al.

**J. Brandt et al.**

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We would like to thank Dr. Draxler (reviewer 1) for his very useful and constructive comments and recommendations. We shall try to answer them and clarify some important points with regard to our manuscript. The specific concerns are described below.

General comments:

Reviewer: The key findings were that wet deposition dominated the total deposition, being about 10 times greater than dry deposition (no surprise).

Answer: It was not the intention of the paper that this should be the key finding. We agree that it is not surprising that the wet deposition dominated the total deposition in the areas with precipitation during the weeks after the accident.

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Specific Comments

1) Reviewer: The Abstract does not contain a summary of the major results of the paper. It needs to be rewritten. The text on page 847 (15-25) makes an excellent starting point.

Answer: The abstract has been changed according to the suggestion of the reviewer.

2) Reviewer: The dry deposition results are masked by the much greater values of wet deposition. Is it possible to sort the measurement data into those samples where it rained and those where it did not Ű hence creating a subset of the data that are only affected by dry deposition. Are there a sufficient number of "dry-only" and "wet-only" samples for analysis?

Answer: The authors agree that it would have been interesting to sort the measurement data into those samples where it rained and those where it did not, if it were possible. However, most of the measurement data consist of total measured accumulated deposition in the period after the Chernobyl accident. Since it rained in most parts of Europe during the weeks after the accident most of the deposition measurements are also affected by wet deposition.

3) Reviewer: "Wet deposition is one of the key elements of this paper. It is not at all evident that the deposition results tell us anything more than the precipitation fields from MM5 were not as good as the RH field! The authors only devote one sentence (Page 843 line 15) to note that they used MM5 to generate the meteorological fields and a reference to indicated better results with MM5 than ECMWF during ETEX. These meteorological models can be difficult to configure and can generate very different precipitation results depending upon the value of just a few parameters. There should be some discussion about how the MM5 configuration might influence the precipitation prediction. More information is needed on the use of ECMWF data for MM5 initial and boundary conditions. For instance, was MM5 initialized once at the beginning of the simulation and then only the BC were updated? Or were initial conditions applied every

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six hours? Was nudging applied? How were the parameters configured that controlled the precipitation forecast?"

Answer: The authors agree that a description of the configuration of the MM5 model used in the paper is missing. However, a thorough investigation of the different parameterizations of precipitation and validation against measurements in not within the scope of this paper. The following text about MM5 has been added in Chapter 5.1:

"Therefore data obtained from running MM5V1, using ECMWF (1.5° x 1.5°) analysis data with the truncation T106 as input to MM5V1, have been used as meteorologi-cal input data to DREAM in the simulations presented here. Time resolution of input data is 6 hours on 14 standard pressure levels. Assimilation of input data is performed with four dimensional data assimilation (FDDA). The model is run with a forcing term that nudges it towards the next analysis remaining close to a dynamical balance. Furthermore the analysis is initialized after spatial interpolation by using non-linear normal mode initialization. The boundary conditions were updated with the ECMWF data every six hours. Both simple and comprehensive parameterizations are available for parameterization of the planetary boundary layer, moisture schemes, cumulus parameterization and atmospheric radiation schemes [see Chen et al., 1995]. The different schemes chosen in these model simulations, are the most comprehensive schemes, which should give the most accurate results. The high-resolution multi-layer Blackadar planetary boundary layer formulation is applied. A complex explicit moisture scheme is used, including a mixed phase scheme with five prognostic variables (specific humidity, cloudwater, rainwater, cloud ice and snow). In addition the Arakawa-Schubert cumulus parameteriza-tion, which is a multi-cloud scheme suitable for larger scales and allowing for entrainment into updrafts and downdrafts, is applied. An atmospheric cloud-radiation scheme, which is applied in all layers, accounts for longwave and shortwave interactions with cloud and vapor and predicts the surface temperature."

4) Reviewer: Although many readers (including this one) appreciate that all the model details are contained in one paper, the paper is too long for the scope of the results.

Most aspects of the DREAM model have already been published. Differences between the way the model was used in this study and previous versions were not clearly explained. Sections 2, 3, and 4 could be substantially reduced if only the modifications to the model were explained. Most of the deposition equations appear to be right out of the literature (nothing wrong with that) and need not be repeated.

Answer: The authors do not agree that the paper is too long for the scope of the results. The aspects of the DREAM model in this paper have not been published already. Furthermore, the authors do not agree that the differences between the way the model was used in this study and other studies are not explained. The atmospheric transport and the boundary layer parameterizations in the model were previously tested for the ETEX experiment in the paper: Brandt, J., Bastrup-Birk, A., Christensen, J. H., Mikkelsen, T., Thykier-Nielsen, S. and Zlatev, Z., Testing the importance of accurate meteorological input fields and parameterizations in atmospheric transport modelling, using DREAM - validation against ETEX-1. Atmosphe-ric Environment, Vol. 32, No. 24, pp. 4167-4186, 1998. This paper did not include the various testing of different parameterizations of deposition of the radioactive compounds, since the tracers from the ETEX experiment were non-depositing. This is the reason for the focus of this paper and already explained in the paper Ű namely testing the applicability of different parameterizations of deposition of the three radioactive species. Sections 2, 3 and 4 describe the basic model equations, which are important to explain in a paper like this. The length of the sections is already very small and the authors do not think that the sections can be shortened. The reviewer states that "Most of the deposition equations appear to be right out of the literature (nothing wrong with that) and need not be repeated". The authors do not agree on this for several reasons. First of all it is important to describe in detail the deposition schemes which are tested in the paper. Of course, many of the equations are taken from literature. However, the different equations included in the schemes are not taken from single references and most of them are combined from many different schemes and equations from the literature, papers, books and others. In order for readers to be able to reproduce the work presented in the paper, it is absolutely necessary to present all the details of the different parameterizations tested.

5) Reviewer: The authors results would have a lot more general applicability if they performed the same deposition tests with the original ECMWF data and precipitation fields and observed precipitation. Although the authorŠs mention some of this in the conclusions (Page 849 Lines 22-25) as potential for future investigations, this paper could be substantially enhanced if we knew a just a little more about the measured precipitation compared with the MM5 precipitation. Some simple statistics such as how the MM5 total over the domain compared with the measured totals would help with the data interpretation.

Answer: As already mentioned a thorough investigation of the different parameterizations of precipitation in the MM5 model and validation against measurements in not within the scope of this paper. Comparison of model results based on the ECMWF data used directly in the model and the results based of the MM5 model initialized with the same data has already been published in Brandt et al., 1998a and in Brandt, 1998. The potential for future investigation is especially on assimilation of precipitation measurements in the calculations.

Technical Corrections

Reviewer:

Page 826 (15) - change "worldwide" to "world's" Page 826 (22) - delete "therefore" Page 827 (6-7) - delete "After the Chernobyl accident" Page 827 (19-20) - delete "as input to the models" Page 828 (1) - delete "developed" Page 828 (7) -delete "the treatment of"

Answer: All the suggestions from the reviewer have been included in the manuscript.

Reviewer: Page 829 (4) - Don't Eulerian models also have the same advection errors as Lagrangian models?

Answer: The turbulent transport of air pollutants in the atmosphere can be analyzed

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through either an Eulerian or a Lagrangian approach. In Eulerian models, the time integration is carried out by computing the tendencies of the calculated fields at a set of grid points fixed in space, whereas in Lagrangian models the time integration is performed following a trajectory. The difference between these approaches lies in the way the position within a field is described. The Eulerian and Lagrangian approaches are in principle mathematically equivalent. The two different approaches can, however, give different results when solved numerically, due to both numerical and physical reasons.

Eulerian models are in general adequate to describe long-range transport of air pollutants. The traditional Eulerian models have, however, problems in handling sharp gradients caused by a single and strong source, which results in undesired oscillations, known as Gibbs phenomenon. The use of a finer grid resolution does not solve this problem, because the emissions will be distributed in smaller grid-cells with even sharper gradients as the result. The problem could be solved by smoothing the emissions or by using some kind of filtering (as e.g. a Forester filter, which is used in some Eulerian models), but smoothing or filtering are artificial, non-physical solutions. A solution based on physical arguments, like dispersion, is preferable. Dispersion alone is, however, not sufficient to minimize the un-wanted oscillations in Eulerian models because an unrealistic high dispersion coefficient would be required. Furthermore the K-approach, usually used in Eulerian models, is unsatisfactory in the area close to the source.

Lagrangian models do not have problems with sharp gradients and are able to describe dispersion close to the source reasonably well. Lagrangian models, however, are usually formulated under assumptions of simplified turbulent diffusion, without convergent or divergent flows and without wind shear, and have therefore problems with uncertainties in the trajectory calculations on large scales. Although it is possible in theory to carry out calculations in a Lagrangian framework by following a set of marked fluid parcels, on large scales this is not a practical alternative. Shear and stretching deformations tend to concentrate the particles in a few regions, which gives difficulties

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in maintaining uniform resolution over the domain. Shear and stretching additionally make it very difficult to calculate precise trajectories on large scales. This is especially true near frontal zones where the wind field is divergent or convergent, and in regions of high- and low-pressure systems.

This is a fundamental nature of transport in the atmosphere: a small change in the initial conditions (e.g. starting position) results in major differences with time. Even though the equations describing the transport in Lagrangian and Eulerian models are mathematically linear they exhibit chaotic behavior. The distance D(t) (which can be considered as a measure for the uncertainty of the trajectory calculations) as a function of time between two trajectories with slightly different initial starting positions, D(0), is exponentially increasing with time t (taken as an ensemble average of many trajectories)

D(t)=D(0) exp(lambda t)

where lambda is the Lyaponov exponent. If lambda=0 then the motion is laminar. If the system, on the other hand, has at least one positive Lyaponov exponent, then the whole system will exhibit chaotic behavior. Examples of this chaotic behaviour are shown in e.g. Kahl et al. (1989) or Baumann and Stohl (1997) where different trajectory calculations have been made with nearly the same initial positions. After a few days the trajectories are separated by more than 1000 km in these calculations. On shorter scales, an exponential increase can, in fact, be approximated by a linear increase. Therefore Lagrangian models can be used for calculations on short scale.

The basic difference is the discretization of the transport equation and of the meteorological fields. The two kinds of models will converge to the same (true) solution as the grid resolution goes to zero. The difference between the two kinds of models is the way they handle the discretization problem. Eulerian models have artificial dispersion (smoothing) of the con-centrations, because the concentrations are distributed in the grid-cells and thus representing a grid-cell average. This is in contrast to Lagrangian models where the transport is described along "one-dimensional" trajectories, even though the trajectories are located in a three-dimensional space. The smoothing has the effect that Eulerian models contain a greater part of the ’true’ solution, compared to the Lagrangian approach, especially on large scales. In order to obtain the same effect and to diminish the uncertainties in trajectory calculations, heavy computations on large scale (many puffs/particles) and huge trajectory calculations with some kind of stochastic element included, as e.g. random walk, are needed.

Coupling of a Lagrangian model with an Eulerian model, where the Lagrangian model is used to calculate the initial transport and dispersion of the plume in an area close to the source and the Eulerian model is used to calculate transport and dispersion on long range is therefore desirable. By coup-ling a Lagrangian model with an Eulerian model in this work, the idea is to employ the advantages of both kind of models.

Baumann, K. and A. Stohl, 1997: Validation of a long-range trajectory model using gas balloon tracks from the Gordon Bennett Cup 95. Journal of Applied Meteorology, Vol. 36, 1997, pp. 711-720.

Kahl, J. D., J. M. Harris, G. A. Herbert & M. P. Olson, 1989: Intercomparison of long-range trajectory models applied to arctic haze. Air pollution modelling and its application VII, edited by Han van Dop, 1989, pp. 175-185.

Reviewer: Page 829 (15) - What is the depth of the lowest layer?

Answer: The depth of the lowest layer is approximately 80 meters. This information has been now included in the text.

Reviewer: Page 834 (Eq. 5) - Suggests that mass is removed from the entire vertical extent of the puff when the lowest part of the puff is within the lowest layer. Would this not over-estimate dry deposition?

Answer: It is correct that the mass is removed from the entire vertical extent of the puff during the dry deposition process. One can say that in a puff model, the sizes of the individual puffs represent the spatial resolution in the area where the puff model is operated. Every puff in the Lagrangian model has only one mass attributed, so it is not possible to remove mass from the lowest layer only. However, close to the source, the initial vertical extent of the individual puffs is small, and typically has the same size as the depth of the lowest model layer. Eventually, when the puff sizes are increasing, the puffs are incorporated in the Eulerian model.

Reviewer: Page 837 (Eq 11) - The Hanna and Maryon references seem too recent to credit them for this equation. It looks a lot like (the inverse) of PanofskyŠs 1963 paper (QJRM, pp 85-94) on the diabatic correction to the neutral momentum profiles. Same with Voldner and Eq. 12.

Answer: The original reference to equations (11) and (12) has been included in the manuscript.

Reviewer: Page 843 (2-3) - delete "Especially" and "of areas" Page 843 (4) - delete "therefore" Page 843 (8) - replace "all the" with "our" and delete "that are included here," Page 843 (12) - delete "used in this study" Page 843 (19-20) - "shows the situation at two day intervals,"

Answer: All the suggestions from the reviewer have been included in the manuscript.

Reviewer: Page 844 (7) - The usual convention is to reference illustrations in sequence.

Answer: Yes - but not always convenient as is the case here.

Reviewer: Page 845 (2) - Regardless of the statistical test results, very few readers will believe that the deposition results shown in Fig 3 have a "significant correlation coefficient."

Answer: Well - there are 67 points in the scatter plot. If one removes just a few of the outliers, the scatter will decrease visually. The test statistics of 4.35, results in a significance within a significance level of less than 0.1% - meaning that there is a risk of less than 1 to 1000 that the correlation coefficient is not significant.

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Reviewer: Page 850 (References) - About half the references are internal reports, commission publications, or conferences. Many of these are almost impossible to find in non-European libraries.

Answer: Five of the total of 54 references are institutional reports that can be received from the respective institutions upon request. The rest of the references are reviewed journal papers and conference proceedings, which are normal to include as references.

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