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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Parameterization of subgrid aircraft emission plumes for use in large-scale atmospheric simulations" *by* A. D. Naiman et al.

Anonymous Referee #1

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This discussion paper presents a subgrid plume model (SPM) that is intended to be included in large-scale atmospheric models in order to study aircraft effects on a global scale. The SPM treats individual aircraft plumes and captures the basic processes affecting their cross-sectional areas (advection by the mean wind, deformation by vertical wind shear and expansion by turbulence). The validity of their approach is demonstrated by detailed comparison with two existing dispersion models of PASSIVE tracers.
However, the applicability and adaptation to active tracers (active chemical species or contrail ice crystals) is not convincing. Especially I doubt that the presented contrail SPM is adequate for its intended use as will be outlined below in detail. In the

present form the manuscript cannot be accepted for publication in ACP. I suggest to first improve the contrail parameterisation. A future manuscript should be tailored to the presentation of the subgrid contrail model as this would better reflect the obvious purpose of the paper, i.e. to support the study of Jacobsen et al., *submitted*, 2009

GENERAL comments:

POINT 1:
The purpose of the paper is not clearly outlined.
Purpose 1: The title of the paper and some text passages (first line of abstract, section 2.1) hint that the introduced plume model has been devised in a way that it is flexible enough to treat all kinds of aircraft emissions.
Purpose 2: On the other hand, many text passages (introduction, references to GATOR-GCMOM model) indicate that the main purpose is the introduction of a new subgrid contrail model.
I believe that neither purpose is met satisfactorily. None of the difficulties and subtleties are addressed which arise when treating active tracers.
Considering Purpose 1, one obvious possible usage of a Lagrangian subgrid model is the treatment of nonlinear chemical reactions of aircraft species (as an alternative to the approach of effective emissions in a GCM framework, for an overview see e.g. introduction of Cariolle et al., 2009). How could chemical reactions be accounted for in the SPM? How would the plume area, the tracer concentration and its distribution evolve within one individual plume? Can your model be easily adopted to solve these questions? Since no plume species but contrail ice crystals are treated in detail in this paper, the title of the paper is misleading.
Considering Purpose 2, the subgrid contrail model is introduced in sect 4.1. The apparent deficiencies of this model approach are discussed in a subsequent section of this review.

POINT 2:
The present contrail-SPM is integrated in the global model GATOR-GCMOM. It should be described in more detail which contrail-related questions are to be addressed on the global scale (contrail coverage only, microphysical properties, radiative forcing, life times, vertical redistribution of water vapour). This is crucial to deciding which contrail processes have to be considered in the contrail-SPM.

Specific Comments:

p.24756, l.3/4: Aircraft emissions do not only form condensation trails. Aircraft emit many chemical species.

p.24756, l.5: Which processes do you mean? Please name them.

p.24757, l.3: "due to them"
Unclear to what it refers.

p.24757, l6/7:
This sentence could be misunderstood. Please make clear that potential contrail coverage is not a function of air traffic density.

p.24758, l.7: The evolution and dispersion of plumes are subgrid scale processes, only if coarse resolution models for global/regional scale simulations are used. This should be mentionned.

p.24761, l.7-9: The references (Chlond, Lewellen & Lewellen, Huebsch & Lewellen) study contrails up to 30 minutes age. As the life time of contrails can be of orders of

hours, it should not be stated that these studies include contrails at late times.
You use a time step of 60 minutes in the global model which implies that initial contrails are 30 minutes old on average, if not introduced at intermediate points of time in the subgrid model. This implies that the latter studies can be used for the validation of your contrail initialisation only.
Studies with longer simulation periods are rare, but do exist, e.g. Jensen et al., JGR, 1998. Does this study support your assumption of an ellipsoidal cross-section?

Deficiencies or unclear issues of the contrail model

As I wrote in the beginning of the review, I do not doubt the SPM capabilities for passive tracers. However, I do not believe your model is adequate for active tracers, especially for contrail ice crystal mass/number. The following paragraphs give several reasons for this assessment:

p.24758, l.9/10:
Do I understand correctly that the Lagrangian treatment of individual plumes stops when a single contrail extends over the total gridbox or the contrail crystal ice mass/number concentration have decreased below a certain background concentration? What thresholds do you use for the background concentrations?
How is the contrail ice transferred/included in the global model (or is it removed from the system)?
What prognostic equations for the contrail ice mass/number are used in the SPM? Are there prognostic equations for contrail ice mass/number in the global model? How often does it happen that a contrail covers the whole gridbox?

Deposition growth

- How do you include depositional growth in the SPM? What relative humidity with respect to ice do you assume inside the contrail or how fast is it reduced/relaexed to a certain value? Is all excessive water vapour converted to contrail ice? What happens if several contrail partially overlap? How is the water vapour distributed then?

- Is supersaturation generally allowed in the global model? How is the grid mean value of relative humidity interpreted in the subgrid model? Are subgrid variations assumed?

Sedimentation, p.24767, l.1-24
I disagree with your arguments to justify the omission of sedimentation in the subgrid model for the following reasons:

- The vertical extent of a initial contrail is 120m. On the one hand, your Fig. 6 shows a slow vertical expansion due to turbulence, mainly caused by the fact that the vertical diffusivity is much smaller than the horizontal diffusivity. Within 10 hours the vertical plume extent has not yet doubled. On the other hand, you give a crude approximation that 30μm-diameter contrail particles descend approximately 500m which is much larger than the initial contrail depth of 120m. Contrary to your reasoning my conclusion is that the sedimentation process may strongly increase the vertical extent of the contrail and cannot be neglected in the SPM since it has the potential to considerably increase the horizontal spread due to vertical wind shear.

- For the above estimate you used the diameter of an average-sized contrail particles. So generally the descent can be even larger for those contrail crystals that are larger.

- As the vertical grid size of the global model is $500m$, a contrail with an average $500m$-descent would completely move to the next gridbox below. The typical

thickness of ice-supersaturated air layers (ISSR) ranges roughly from 500m to 1.5km (for an overview see Kärcher et al., 2009, section 2.2.1). If the thickness of the ISSR is small, contrails may fall into a subsaturated layer and finally sublimate. If the thickness of the ISSR is large, a contrail may extend over several grid layers (formation of fall streaks) and can take up much more water vapour than contrails in the SPM restricted to one grid layer. Hence, the contrail evolution may be considerably affected by the inclusion of the sedimentation process.

- p.24767, l.14-18: Reading the explanation of Fig.1 of Unterstrasser & Gierens they state that at $t = 17000s$ the sedimentation impact is evident in the plot. Although the radiative impact of the sedimenting particles itself is small (as stated there), this does not imply that sedimentation has no impact on the radiative impact of the total contrail. The IWC in the upper part of the contrail is reduced due to sedimentation, as stated. Moreover the study concludes that sedimentation is a second effect besides subsidence that limits the contrail life time (see their conclusions). Thus, neglecting sedimentation may overestimate the lifetime and radiative impact of contrails.

- Independently of the implementation of sedimentation:
  If a contrail extends over two grid layers, how are the values passed from the global to subgrid scale determined or averaged? Analogeous question for the horizontal direction.

- p.24767, l.20-25:
  Are the contrail ice crystals added to the grid box mean ice water content?

Technical corrections:

p.24766, l.25/26:
contains significant ice particle **density**.

Is this correct English?

Fig. 3 , third row
I would prefer to reduce the image size on the left in order to approximately use the same scale for both images.

References:

Cariolle, D., D. Caro, R. Paoli, D. A. Hauglustaine, B. Cuenot, A. Cozic, and R. Paugam (2009), Parameterization of plume chemistry into large-scale atmospheric models: Application to aircraft NOx emissions, J. Geophys. Res., 114, D19302, doi:10.1029/2009JD011873.

Kärcher, B., Burkhardt, U., Unterstrasser, S., and Minnis, P.: Factors controlling contrail cirrus optical depth, Atmospheric Chemistry and Physics, 9, 6229-6254, http://www.atmos-chem-phys. net/9/6229/2009/, 2009.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 24755, 2009.