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Discussions

Interactive comment on "Selected topics on interactions between cirrus clouds and embedded contrails" *by* K. Gierens

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1 Reply to Rick Miake-Lye

1.1 Section 2

The variation of water vapour emission indices of fuels is indeed a good measure for comparison, and I will include it in the paper. The IPCC (1999) report gives an allowed range of 1.25 ± 0.03 for EI_{H_2O} or ± 2.4%, which already exceeds the effect of evaporating ambient cloud crystals. Alternative fuels, as they have been tested in the NASA-AAFEX campaign indicate an even larger variation: Table 2 of the report (Anderson et al., 2011) gives a H/C variation of more than 10%, which could translate directly into a variation of EI_{H_2O} and which would dwarf the contribution of evaporating ice even more.

1.2 Section 4

In the paper I wrote that cirrus crystals are too large to react quickly on changing saturation conditions in the vortex and that therefore the sublimation of contrail crystals is hardly halted. Rick Miake-Lye asks whether this could be seen also the other way around, namely: the contrail crystals are small and react quickly to changing saturation conditions in the vortex, thus maintaining nearly saturated conditions, such that the large and relatively inert cirrus crystals do hardly feel subsaturation that would lead to their partly sublimation.

I have the feeling that these two aspects mutually cause each other as long as nearly saturated conditions can be sustained in the vortex. It might be that this is always possible in embedded contrails and then both directions of the above statement are correct. But if for any reason saturation cannot be sustained (for instance if adiabatic heating is too fast), then I believe that my original direction of the argument is the appropriate one. So, I prefer to leave the argument as it is. Note, that the derivation is independent of the relative humidity in the plume, so the argument should be valid in near saturated and subsaturated conditions.

1.3 Section 5

Of course, I made this simplification primarily in order to be able to proceed with the analytic calculation. However, the assumption is probably not too bad although there are sedimenting ice crystals from contrails. A contrail within a cirrus cloud sees an environment that is usually close to ice saturation (plenty of exceptions are admitted). In a near saturated environment the contrail crystals grow slowly or not at all, and

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thus they do not achieve high fall speeds. The cirrus crystals are usually present in much lower concentration than the contrail crystals, and they are much larger, so they fall faster and can collect contrail ice crystals on their way down. Sedimenting contrail crystals are to be expected for non-embedded contrails in supersaturated environment, but also for embedded contrails when they have been formed incidentally in a still supersaturated part of the cirrus. There are many possibilities then that lye outside the reach of analytical calculations.

I shall make a short note on this in section 5 of the revised paper.

1.4 Section 6

“Prooemium” is a greek work with latinized ending. It means something like preface, introduction, prelude. In English as well as in German it is a loanword. For more information, see http://en.wiktionary.org/wiki/prooemium.

The numerical work mentioned (Gierens and Spichtinger) is still in preparation. We are still evaluating our runs. I will change the reference accordingly. This is also the “another paper” mentioned in the end.

2 Reply to reviewer No. 1

2.1 Question about observations

The reviewer asks whether the result of aggregation between cirrus and contrail crystals can be used to explain observations of contrails embedded in cirrus. I would say, in principle: Yes! But unfortunately it seems that the observations we have are not appropriate for this purpose. I know from airborne lidar observations of cirrus clouds with hot spots that might have been embedded contrails (unpublished measurements from colleagues); as these are snap-shots, one cannot see any temporal evolution of these embedded contrails. Their age is unknown. Thus essential pieces of information are missing here. Interpretation in terms of aggregation is only possible when the temporal evolution of the embedded contrail can be followed and when ideally some ice crystals can be collected in situ to see whether or not there are aggregates.

2.2 Minor remark 1)

I have inserted a new paragraph as suggested after the questions and answers in the summary section. Indeed the results shown here justify certain simplifications for numerical work. These simplifications refer to cloud resolving contrail simulations. I do not think that they give a justification for treating contrails and natural cirrus as separate entities in a global model, because at least in the dispersion phase there will be some interaction, as the case of aggregation shows.

2.3 Minor remark 2)

The numerical work which will be described and evaluated in Gierens and Spichtinger (rather 2013 than 2012) is still in preparation, I will change the reference to clarify this.

2.4 Minor remark 3)

$\tau_{\rm jet}$ indeed characterises the mean dilution in the jet and I will mention this (close to eq. 8).

2.5 Minor remark 4)

Figure will be made larger.

3 Reply to reviewer No. 2

3.1 Specific comments and questions

3.1.1 title

The title will be changed according to the first recommendation.

3.1.2 p. 25240

The Schmidt-Appleman criterion indeed requires water saturation to be reached in the expanding plume. At first, this is admittedly an assumption (because the additional effects listed by the reviewer cannot be excluded a priori). But it is a tested assumption and the tests were positive, see e.g. Figure 3-4 in the IPCC report, or equivalently, Kärcher et al., 1998, J. Geophys Res., 103, 17129-17148. Because of coatings etc. contrail formation might commence at slightly subsaturated (wrt liquid water) conditions that cannot be distinguished from saturation with current instruments (within the error bar). As long as there is sufficient soot in the plume, these soot particles, being much larger than volatile aerosol particles in the plume, lead to condensation and freezing first, and only a very minor part of the volatile aerosol contributes to ice formation, see Kärcher and Yu, Geophys. Res. Lett., 36, L01804, doi:10.1029/2008GL036649, 2009.

3.1.3 p. 25242

ϵ is defined together with all other variables in the nomenclature section, and the presence of the latter is mentioned in the last sentence of the introduction. The value of $EI_{\mathrm{H_2O}}$ is given in the nomenclature section as well.

The formal definition of τ_{jet} $(= e^*/(GC(t)))$ is now given in the text preceeding eq. 5, where timescales are mentioned and also directly in equation 8. For equation 8 I put together equations 3 and 7. Redoing the calculation I also spotted an error in eq. 7 which is now corrected (equation 8 was correct, anyway).

3.1.4 p. 25243

This is correct, and there is indeed a dependence on a size distribution parameter in the expression for the growth time scale, τ_{g}. This dependence is hidden in equation 9 and thus not visible. The derivation of this quite complicated formula is given in the quoted paper (Gierens, 2003) in equations 7, 17, and 18 (which is the result). The required size parameter is r_0 in that paper which is “Assuming that the initial supersaturation s_0 is transferred completely into N spherical ice crystals of equal size, their radius would be” r_0.

3.1.5 p. 25244

The Koenig parameterisation of crystal growth is for a single ice crystal of the form $dm/dt = am^b$ where m is the mass of the single crystal. In a bulk microphysics formulation we have an ice mass concentration instead of single crystals. Thus we want to know how the summed-up ice mass changes, that is, we integrate $dm/dt = am^b$ over the ice crystal mass distribution function (mass probability density function, pdf: $f(m)$). On the lhs of the equation this yields $\frac{\mathrm{d}\mathcal{M}}{\mathrm{d}t}$ while on the rhs we get an integral of the form $\int m^b f(m)\mathrm{d}m$ wich is the moment of order b of the mass pdf, μ_b. The total ice concentration is of course the mean mass (proportional to the first moment, μ_1) times the number concentration, thus we have $\mathcal{M} \propto \mu_1$.

Some explanation is now given in the text before equation 11.

3.2 Minor points and technical corrections

3.2.1 p. 25239

Some commas added here and there.

3.2.2 p. 25240, l. 3

I added “(water mass divided by air mass)”. Schiller et al. do not say whether “air mass” is dry or moist air, but this is anyway a very small difference.

3.2.3 p. 25239, l. 9-11

I have rephrased the 1st sentence and deleted the second one, because this is now said at the end of a new paragraph.

3.2.4 p. 25241

Abbreviation expanded.

3.2.5 p. 25243

“To halt” replaced by “to reduce”.

3.2.6 p. 25244

Changed as suggested.

3.2.7 p. 25248

No. Look at eq. 18: τ_{aggr} is the time scale decreasing the number concentration of contrail crystals by aggregation with cirrus crystals. It is quasi an e-folding time (after τ_{aggr} the number of contrail crystals is diminished by a factor $1/e$), and thus it is a bulk quantity. For a single crystal the interpretation is slightly different: $1/\tau_{\mathrm{aggr}}$ is the probability that a given contrail crystal will be collected by an cirrus crystal in the next second (if τ_{aggr} is measured in seconds). These considerations are analogous to the case of radioactive decay.

3.2.8 Figure 1

Figure will be made larger.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 25237, 2012.