Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-181-RC2, 2020

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effect of contrail overlap on radiative impact attributable to aviation contrails" *by* Inés Sanz-Morère et al.

Anonymous Referee #2

Received and published: 29 June 2020

The paper investigates the impact of cloud-contrail and contrail-contrail overlap on the radiative forcing due to contrail cirrus. The authors use a radiative transfer model of Corti and Peter that they modify in order to study the impact of cloud overlap on contrail radiative forcing. They consider two options no overlap and maximum overlap and study the difference when using those two assumptions. Cloud and contrail properties are varied systematically and the impact on LW and SW RF is analyzed. Cloud properties are prescribed using observed natural clouds (from Satellite) and CERM simulated contrails. Whereas, in principal the impact of cloud overlap is an interesting topic, the authors' extreme assumptions (no or maximum overlap) limit the relevance of the paper. They wrongly claim that other studies assume no or maximum overlap between contrails and clouds and contrails and contrails and claim that the sensitivity that they

see is a measure for the bias of contrail cirrus RF published in the literature. Relevant literature that discusses the impact of overlap on RF in detail has not been discussed and comparisons with the results in the literature only partly made.

I suggest presenting the work as a sensitivity study, including a detailed comparison with the many results in the literature and removing text stating that the present work improves contrail RF estimates and estimates the uncertainty in contrail RF in the literature or that the results help to inform policymakers and similar claims.

Major comments:

1. The sensitivity of contrail RF on the overlap analyzed in this paper is not a measure for the uncertainty in contrail RF in the literature. Both assumptions used in this paper, no or maximum overlap, are very extreme whereas in the literature mostly maximum-random overlap for contrail-cloud and contrail-contrail overlap has been used. The statements that in the literature mainly maximum overlap has been used (e.g. line 346-348) or that random overlap has been used for contrail-contrail overlap (line 350) the authors partly contradict their own table 1.

2. The estimate for contrail RF is not an improved estimate relative to the estimates in the literature

a. Neither maximum nor no overlap are good assumptions. Maximum overlap is certainly an upper bound for the overlap but far away from the truth.

b. Using only cloud data with 3 hourly temporal resolution does not allow for a realistic representation of contrail-cloud overlap or a realistic estimation of overlap frequencies. The low temporal resolution cannot resolve the correlation between cloud and contrail frequency.

c. Overlap assumptions have been shown to be dependent on vertical resolution. Even if vertically extended clouds are assumed the vertical overlap decreases strongly with layer depth. When levels are separated by more than 4km the overlap is essentially random (Hogan and Illingworth, 2000). At a low vertical resolution random overlap is a good assumption while maximum overlap is realistic (for vertically extended clouds) at high vertical resolution. At lower horizontal resolution the arguments must include a discussion of synoptic situations and the resulting vertical and horizontal statistics of the moisture field. Using observed cloud statistics aggregated in only 4 atmospheric layers and calculating the overlap with contrails the assumption of maximum overlap is far from realistic.

d. Assuming maximum overlap between contrails and contrails is not realistic. Even if planes would follow each other on the same flight track advection would mean that contrails don't maximally overlap. But this topic does not seem to be very promising as contrails have a low optical depth and the overlap between contrails does not impact the radiative forcing strongly.

e. As the authors say whether a contrail cools or warms depends on the height of the clouds that may be vertically overlapping this contrail. The cloud height cannot be properly represented using cloud observations aggregated on only 4 levels.

3. Comparison of the results to the previous publications should be improved.

a. The publications of Markowicz and Witek (2011 a,b) have not be cited. They discuss the impact of contrail cloud overlap in great detail e.g. the dependence on particle habit. They also show that contrail RF turns negative for all considered ice crystal shapes at much higher optical depth (at zenith angle 30°) then shown in fig. 3a. As a zenith angle of 30° is often used in the literature it would be good to supply results for that angle in order to allow for comparison.

b. The results in Fig. 7 should be compared with results of e.g. Schumann et al. 2012 and Myhre et al 2009 in detail. Why are absolute values of contrail RF so different from previous results?

4. The result that cloud-contrail overlap is responsible for 93% of the net radiative

forcing attributable to contrails in 2015 relies on the assumption that the authors have simulated the 'true' overlap between contrails and natural clouds which is not the case. Instead they should say that overlapping contrails maximally with clouds instead of prescribing no overlap leads to an increase in radiative forcing by xx%. The same is true for the statements about the importance of contrail-contrail overlap. Note also that those values will be resolution dependent so that their significance is very limited and should not appear in the abstract!

5. Line 891-892: How do you suggest avoiding cloud contrail overlap? Contrails mostly form close to natural clouds which means that they often overlap with other clouds. Cloud-free areas are mostly dry and therefore persistent contrails cannot exist.

Minor comments:

1. Table 1 is incomplete, contains mistakes and is misleading: The table serves to show the great scatter in the contrail RF estimates but it omits to say

- that the Marquart et al and the Frömming et al estimates are for line-shaped contrails only whereas the other estimates are for contrail cirrus.

- the main difference between the contrail cirrus modeling studies are the different ways of treating contrails, keeping them separate from natural clouds or treating them with the cloud scheme, and the contrail initialization. The Chen and Gettelman study follows a very different approach from the others.

- That there is another estimate for contrail cirrus RF (Bock and Burkhardt, 2016 – which is already in the literature list) that lies in between the Schumann et al. and the Burkhardt and Kärcher estimate. This means that 3 of 4 estimates lie close together.

- Chen and Gettelman include contrail-contrail overlap since overlap is dealt with in the cloud scheme. The model assumes maximum random overlap for clouds. Only at the initialization stage contrails (age of up to ∼30 min.) do not overlap but that is not the same as no overlap between contrails in general.

That means that the scatter between contrail cirrus RF estimates is much smaller than suggested by the current table 1 and that the scatter is not due to the overlap scheme. Even though the uncertainty in the overlap between clouds and contrails leads to an uncertainty in contrail cirrus RF, the results from the literature do not demonstrate this fact as they tend to use the same overlap scheme. The range of net RF due to contrail cirrus encompasses the estimate of this study only because estimates for line-shaped contrails are included here.

2. Biofuels have little impact on contrail formation likelihood but instead on soot number emissions, ice nucleation and contrail life times and optical depth (Moore et al. 2017, Kärcher et al. 2018, Burkhardt et al. 2018)

3. Marquart et al (2003) and Frömming et al. (2011) both use the contrail parameterization of Ponater et al. (2002) and simulate line-shaped contrails of varying optical depth including those with an optical depth smaller than 0.02. They both calculate the fractional increase in cloudiness due to contrails. Only the overlap was calculated differently.

4. Chen and Gettelman do not assume zero overlap between linear contrails when calculating radiation. Instead they use the overlap scheme of CAM (maximum random) in order to take care of overlap between different clouds.

5. Page 6: You cite papers that determine if cloud-contrail overlap reduces or enhances contrail RF and conclude that this is a major uncertainty instead of mentioning the known fact that the effect depends on the contrail and cloud properties and temperature/height.

6. On page 7 you talk about contrail-contrail interaction. Please note that interaction can happen due to a number of processes and does not necessarily have to do with radiation.

7. On page 11 the error of the model compared to FL96 is determined. In that context

the systematic bias, the underestimation of the dependency on the zenith angle, should be discussed and its impact on the results of this paper.

8. Line 341-344: All 3 sentences are unclear. It is not clear what it means to aggregate single contrails into one layer! Are coverages due to single contrails added up or not? 'Overlap between . . . is therefore not explicitly resolved': What does that mean – minimum overlap? 'the same approach . . ... as if clouds were centered in the grid cell'. What does that have to do with overlap. Equations would make this text easier to understand.

9. Line 349: what does '(linear in most cases)' refer to?

10. Line 349: I assume you mean to say that contrail area 'overlaps' and not 'interacts'

11. Line 353: what is 'potential maximum overlap'

12. Line 355-357: even more useful would be a higher temporal and vertical resolution. The lower the resolution the larger the overlap.

13. In order to correct for errors in the model the authors use for the clear-sky estimates CERES data. Without any discussion where the errors are coming from it is difficult to understand if this approach is acceptable. The radiation emitted from the cloud could still be affected by this error which would mean that the estimated contrail RF would include this model error.

14. The term 'independent overlap' needs to be defined.

15. Line 434: The asymmetry parameter in Schumann et al is 0.787 (and not 0.77) for older contrails and 0.827 for younger contrails.

16. Line 503: Figure 3b is the upper right panel

17. Line 854: You probably meant to cite Kärcher et al., 2009 and not 2002.

18. Line 886 – 888: Those conclusions depend very much on the type of clouds you

prescribed. In the tropics many very thick clouds can be found and differences between cloud and contrail top temperature can be very large as well.

Markowicz, K. M., and M. L. Witek (2011), Simulations of contrail optical properties and radiative forcing for various crystal shapes, J. Appl. Meteorol. Climatol., 50(8), 1740–1755, doi:10.1175/2011JAMC2618.1.

Markowicz and Witek Sensitivity study of global contrail radiative forcing due to particle shape. JGR, 116, doi:10.1029/2011JD016345 (2011)

Moore, R. H. et al. Biofuel blending reduces particle emissions from aircraft engines at cruise conditions. Nature 543, 411–415 (2017).

Kärcher, B. Formation and radiative forcing of contrail cirrus. Nature Comm.Communications 9, :1824, DOI: https://doi.org/10.1038/s41467-018-04068-0 (2018).

Burkhardt, U., L. Bock, A. Bier, Mitigating the contrail cirrus climate impact by reducing aircraft soot number emissions. npj Climate and Atmospheric Science 1:37, https://doi.org/10.1038/s41612-018-0046-4 (2018).

Kärcher B, Burkhardt U, Unterstrasser S, Minnis P (2009) Factors controlling contrail cirrus optical depth. Atmos Chem Phys 9:6229–6254

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