Reply to the discussion comment submitted by Prof. Ulrich Schumann

The authors are grateful for the time and thought that Ulrich Schumann put into the comments regarding our paper. Subsequently we show the original comments from Ulrich Schumann in italics and our responses as well as changes in the manuscript in plain text.

We appreciate that Mr. Schumann highlights the occurrence of contrail cirrus as an important point, especially over the European continent, which is subject of strong air traffic. Concerning this aspect, we of course have to admit that the developed data analysis scheme, FLICA, is not intended to separate contrail from natural cirrus. Such a separation would require – according to our understanding – the incorporation of side information from either detailed flight maps or satellite imagery to identify periods of strong contrail formation. Such an analysis was outside the scope of this study. In a possible future follow-up study a separation from natural and contrail cirrus could become an important component.

We decided to mention the topic in the conclusions of the manuscript, highlighting the potential of such long-term datasets for the characterization of anthropogenic effects on cirrus cloud properties. We also incorporated some of the references provided by Prof. Schumann.

This is a nice study of thin cirrus over 3 stations in the Alps and Northern Germany.

1) Which fraction of the thin cirrus originates from contrail cirrus? Liou et al. [1990], e.g., noted a strong increase of thin cirrus over Salt Lake City since about the late 1960's in correlation with increases in jet traffic. The stations are located in regions where line-shaped contrails are ubiquitous [Mannstein et al., 1999; Meyer et al., 2002]. The stations are located near the routes from London to the Near East or the routes from or across Paris to the Far East etc. (see contrail cover results and major traffic routes in Fig. 7 in [Schumann, 2005]). Often aged contrail cirrus might have gotten advected from, e.g., the routes over Lyon to the central Alps. The observed optical depth is fully consistent with optical depth for contrail cirrus from other sources [Immler et al., 2008; Iwabuchi et al., 2012; Vázquez-Navarro et al., 2015]. The computed cover and RF values are consistent with contrail cirrus calculations [Schumann et al., 2015]. Hence, it is very likely that contrails contributed a large fraction to the observed thin cirrus. So far, your nice paper, not even mentions this possibility. I think, at least that needs to be changed.

Response:

We find clear evidence of detected contrails only on one of the days. However, an uncertain number of the detected cirrus clouds may have evolved from contrails. How many is impossible to say without further, elaborate calculations. Especially, aged contrails in a water vapor supersaturated environment are hard to discriminate from natural cirrus clouds when only a stationary lidar is available. Due to turbulent mixing of contrail air with surrounding air masses and further growth of contrail ice crystals their microphysical properties become indistinguishable from those of natural cirrus. We have added a paragraph plus some references about this.

Paragraph added in revised manuscript on page 27, lines 11-20 in blue:

Owing to the central location of the three measurement sites in Europe, a significant fraction of the thin cirrus observed within the present study might actually have originated from contrails. Clear indications for the occurrence of contrails were found on at least one day, given the optically and geometrically very thin cirrus. Liou et al. (1990) noted an increase of thin cirrus with increases in jet traffic. Our measurement sites are located in a region, where line-shaped contrails are ubiquitous (Mannstein et al., 1999; Meyer et al., 2002) as many flight routes cross this area. The observed optical depths are consistent with optical depths of contrail cirrus (Immler et al., 2008; Iwabuchi et al., 2012; Vázquez-Navarro et al., 2015). Furthermore, the cirrus cloud cover determined in the present study is consistent with contrail cirrus calculations by Schumann et al. (2015). Therefore, it is likely that contrails contributed a fraction of the observed cirrus. The determination of the actual contribution of contrails to the cirrus cloud dataset is, however, not subject of this study, considering that the applied data analysis algorithm FLICA cannot distinguish natural and contrail cirrus.

2) How important for longwave radiative forcing (RF) from thin cirrus for otherwise clear sky is the water vapor in the atmosphere below the cirrus? The longwave RF of thin cirrus correlates far better with the brightness temperature of the atmosphere than with surface temperature, see Fig. 15.4 in [Schumann et al., 2012a].The brightness temperature is related to the outgoing longwave radiation (OLR) at top of the atmosphere, as available, e.g., from Numerical Weather Prediction(NWP) data, e.g. from COSMOS. Also: how important is the difference between Earth surface albedo and effective albedo of the Earth-Atmosphere system, e.g. when clouds are nearby the location of observations or when the mountains are snow covered or when there is any dust or haze (derivable from known solar direct radiation and from reflected shortwave radiation, RSR, also available from NWP data), as discussed in these papers? Perhaps you can quantify these effects?

Response:

We have added some remarks about the brightness temperature and its relation to the longwave radiative forcing to the manuscript and added the suggested reference.

As also mentioned in our response to reviewer 2, we chose a value of 0.3 for the underlying albedo to demonstrate, which radiative effect the detected cirrus would have, if they were located above the "mean" of the planet. Jungfraujoch is located on top of a glacier and is all year covered by snow. We have made calculations using albedos of snow (0.65) for Jungfraujoch. In that case, the radiative effect of the cirrus clouds disappears as all radiation is scattered back by the snow surface.

Changes in revised manuscript on page 19, lines 18-20 in blue:

The CRF_{LW} further correlates well with the brightness temperature of the atmosphere, which is related to the outgoing longwave radiation at top of atmosphere (Schumann et al., 2012a). This correlation has not been considered in the model of Corti and Peter (2009).

3) Why not to test the differences between the nice and simple Corti&Peter parametrization and that which we developed in parallel (see my comment of May2009 on the ACPD paper by Corti and Peter and [Schumann et al., 2012b])? The input needed (OLR and RSR) is available form COSMO and other NWP models. The model could be used to test the influence of various assumptions on particle habits and particle sizes [Markowicz and Witek, 2011]. The quantitative results may well change by50 %, and hence change your conclusions.

Response:

Thank you for this interesting remark. We have added a remark on this in the manuscript and provided the suggested references, but refrain from performing additional computations at this stage of the paper and leave this to potential follow-up projects.

Changes in revised manuscript on page 27, lines 33-35 and page 28, line 1 in blue:

Besides the radiation model of Corti and Peter (2009) used for this study, other approaches exist that can be used to investigate the effect of other cloud properties besides optical depth on the cirrus radiative forcing. For instance, the radiation model of Schumann et al. (2012b) could be used to test the influence of various assumptions on particle habits and particle sizes (Markowicz and Witek, 2011).

4) Does the Lidar signal (e,g., depolarization) allow to discriminate, perhaps together with other data, contrails from cirrus? Perhaps there are some ideas which could fit into your outlook?

Response:

We have not examined this so far. We think that it might be possible to distinguish fresh contrails from cirrus clouds as the contrails have a large number of small particles that are rather round due to the rapid cooling they were exposed to (Jensen, 1998). This would result in different depolarization values than for natural cirrus clouds. In a supersaturated environment, contrails can stay persistent for a long time and are more similar to natural cirrus clouds after growth. In a subsaturated environment the contrails will evaporate very quickly.

Changes in revised manuscript:

No changes have been made in the manuscript.

References implemented in the revised version of the paper:

Immler, F., R. Treffeisen, D. Engelbart, K. Krüger, and O. Schrems (2008), Cirrus, contrails, and ice supersaturated regions in high pressure systems at northern mid latitudes, Atmos. Chem. Phys., 8, 1689–1699, doi:10.5194/acp-8-1689-2008.

Iwabuchi, H., P. Yang, K. N. Liou, and P. Minnis (2012), Physical and optical properties of persistent contrails: Climatology and interpretation, J. Geophys. Res., 117, D06215, doi:10.1029/2011JD017020.

Liou, K. N., S. C. Ou, and G. Koenig (1990), An investigation of the climatic effect of contrail cirrus. In: Air Traffic and the Environment – Background, Tendencies and Potential Global Atmospheric Effects. U. Schumann (Ed.), Lecture Notes in Engineering, Springer Berlin, 154-169.

Mannstein, H., R. Meyer, and P. Wendling (1999), Operational detection of contrails from NOAA-AVHRR data, Int. J. Remote Sensing, 20, 1641-1660, doi: 10.1080/014311699212650.

Markowicz, K. M., and M. Witek (2011), Sensitivity study of global contrail radiative forcing due to particle shape, J. Geophys. Res., 116, D23203, doi:10.1029/2011JD016345.

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Schumann, U., K. Graf, H. Mannstein, and B. Mayer (2012a), Contrails: Visible aviation induced climate impact, in Atmospheric Physics – Background - Methods - Trends, edited by U. Schumann, pp. 239-257, Springer, Berlin, Heidelberg, DOI: 10.1007/978-

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Vázquez-Navarro, M., H. Mannstein, and S. Kox (2015), Contrail life cycle and properties from 1 year of MSG/SEVIRI rapid-scan images, Atmos. Chem. Phys., 15, 8739-8749, doi:10.5194/acp-15-8739-2015.