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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Evidence of impact of aviation on cirrus cloud formation" *by* C. S. Zerefos et al.

C. S. Zerefos et al.

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Reply to comments of reviewer #1 We would like to thank the reviewer for the helpful and constructive comments.

1. Reviewer #1 commented that there are significant differences in trends in cirrus cloud cover (CCC) east and west of the Rockies and east and west of the west coast of Europe over the middle latitudes of the northern hemisphere, which could have also been caused by differences in trends in dynamics. The reviewerŠs hypothesis is interesting but it is based on the assumption that trends in dynamics are also controlling trends in cirrus clouds. If this was the case, then trends in convective activity should have had opposite signs (e.g. east and west of the Rockies). Using as a proxy index of dynamics in the upper troposphere the vertical velocities at 300 hPa (averaged over the warmer months, JJAS) the observed trends are on both sides of the Rockies negative (the order of Ű1 mPa/s per decade). The difference in dynamics hypothesized for

Europe is also not justified by the observations. Over the European high air traffic region the average cirrus cloud amount is 11.9% statistically insignificantly different when compared to the amount of 10.5% that is observed over the adjacent low air traffic region in Europe. Also the trends in dynamic proxy of vertical velocities at 300 hPa are of the same sign, i.e. the different sign in cirrus cloud trends cannot be attributed to different trends in the vertical velocities at 300 hPa. Moreover, recent studies (Paciorek et al., 2002) have found a tendency for decreases in the frequency of extra tropical storms but increases in the number of intense storms over the last 50 years. Such trends could have an effect on the properties of the mid-latitude cirrus cloud field. However, there is no evidence in those studies that the character of extra tropical storm changes is different between the western and eastern US regions or between western and eastern Europe. Therefore, the difference in cirrus trends between those locales cannot be attributed to different trends in dynamical conditions. The comment of the reviewer was taken under consideration and this point is discussed in Section 3 (Results and Discussion) and in the Conclusions of the revised manuscript. Reference Paciorek, C. J., Risbey, J. S., Ventura, V., and Rosen, R. D.: Multiple indices of Northern Hemisphere cyclone activity, winters 1949-99, J. Climate, 15, 1573-1590, 2002.

2. The second comment of reviewer #1 is also interesting and indeed we have reexamined trends of vertical velocities to understand the difference, i.e. why changes in cirrus cloud cover over middle and high latitudes are as large as those at low latitudes, where air traffic is much reduced. Generally, in tropical latitudes, cirrus clouds are formed primarily from vertical water vapor transport by convective processes. As a result, tropical cirrus amounts are controlled by local temperature conditions and moisture sources and any trend in those conditions would leave a signature on the cirrus cloud field. Therefore, the tropical cirrus trends could reflect trends in the local temperature and moisture field. In the middle latitudes, on the other hand, cirrus formation is controlled by baroclinic processes that are to a great extent independent of local conditions and depend on global wave patterns. Therefore, any localized modulation of mid-latitude cirrus cloud properties would be related more strongly to microphysi-

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cal rather than dynamical condition changes. The results are shown in Fig. 5 of the revised manuscript where it is seen that long-term changes in vertical velocities are significantly correlated over the tropics (-0.4) with corresponding changes in (CCC) but are not significantly correlated (-0.2) over middle latitudes both in wintertime and summertime (not shown here). This comment is also discussed accordingly in Section 3 (Results and Discussion) and in the Conclusions of the revised manuscript.

3. Minor remark: The sentence mentioning ŚItalicsŠ on the caption of Table 3 has been deleted from the paper.

Reply to the comments of reviewer #2

We would like to thank the reviewer for the helpful and constructive comments.

A. SPECIFIC COMMENTS 1. The new Fig. 3 of the revised manuscript shows trends in global cirrus amounts averaged over different latitude zones for the period 1984-1998 (northern extra tropics (30oN-70oN, 180oW-180oE), tropics (30oS-30oN, 180oW-180oE)). The trend over the North Atlantic high air traffic region (40oN-60oN, 35oW-60oW) is also shown.

2. Concerning the question to quantify the so-called spreading factor, this is to be discussed elsewhere and it is outside of the scope of this paper.

3. Fahey and Schumann (1999) summarized trends of cirrus cloud cover (CCC) over areas defined by Sausen et al. (1998) in which contrail coverage either exceeded or was less than 0.5%. In this study, to define regions with high and low contrail coverage we have used the fuel consumption data set. It was assumed that high and low contrail regions are found within areas with high and low air traffic and therefore the cirrus trends were calculated for these regions. More specifically, land contrail regions were assumed to be over the USA (30oN-50oN, 50oW-130oW), Europe (40oN-60oN, 10oW-15oE) while the ocean contrail regions were assumed to be confined over the North Atlantic (35oN-70oN, 70oW-20oE). The remaining regions between 70oS-70oN

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and 180oW-180oE over land and over the ocean were chosen as the low contrail regions. The questions raised for Table 3 have been clarified in Section 4 of the revised manuscript. References Fahey, D. W., and Schumann, U.: Aviation-Produced Aerosols and Cloudiness, Chapter 3 in Aviation and the Global Atmosphere, A Special Report of IPCC (Intergovernmental Panel on Climate Change), eds. Penner, J. E., Lister, D. H., Griggs, D. J., Dokken, D. J., and McFarland, M., Cambridge University Press, Cambridge, UK, p. 65-120, 1999. Sausen, R., Gierens, K., Ponater, M., and Schumann, U.: A diagnostic study of the global distribution of contrails part I: present day climate, Theor. Appl. Climatol., 61, 127-141, 1998.

4. The reference cited is the first to describe the method with which these natural oscillations have been accounted for. This method is reproduced here following 3341, 2ff. The reference cannot be deleted because the issue of combined ENSO, QBO and NAO was raised for the first time in that presentation. The method used in this analysis utilizes a simple multiple regression statistical model for the cirrus cloud variations at each individual grid box: CCC(i,j) = S(i,j) + ENSO(i,j) + QBO(i,j) + NAO(i,j) + residuals (1) Where i denotes the month and j is the year of (CCC) and its components, i.e., the seasonal (S), the ENSO, the QBO and the NAO as described by Zerefos et al. (1994). (CCC) data were deseasonalized by subtracting the long-term monthly mean (1984-1998) pertaining to the same calendar month. The QBO and ENSO components were removed by using a phase lag with max correlation. The method is clarified in Section 2 of the revised manuscript. Reference Zerefos, C. S., Tourpali, K., and Bais, A. F.: Further studies on possible volcanic signal to the ozone layer, J. Geophys. Res., 99, 25741-25746, 1994.

5. The tropopause temperature variability on cirrus cloud changes over the regions examined (i.e. high and low air traffic) was removed with simple linear regression analysis applied to the residuals from equation (1). This is clarified in Section 2.

According to the question raised by the reviewer on page 3345, line 5 and Fig. 3 of the initial submitted manuscript, the percentage cirrus changes refer to percentage changes of (CCC) from 1984-1986 to 1994-1996 in the wintertime. These percentage changes were calculated by the formula: Cirrus changes (in %) = [CCC(mean 1994-1996) - CCC(mean 1984-1986)] / CCC(mean 1984-1986) x 100

According to the question raised by the reviewer on page 3345, lines 25-28 of the initial submitted manuscript, this was done so that our results are comparable to those of Minnis et al. (2001). Minnis stated: ŚWe used monthly means averaged over each large region from 7/83Ű5/91 and 7/93Ű8/94. The trends were computed based on monthly mean values, not annual, so we multiplied the monthly trends by 12Š. This is clarified in Section 4 of the revised manuscript.

The comment of the author on page 3346, line 11 of the initial manuscript is correct and the differences in trends in Table 2 should not be mainly attributed to the different data sets. Care was taken to erase this statement from the paper.

According to the question raised by the reviewer on page 3347, lines 10-12 of the initial submitted manuscript, the number of degrees of freedom was different and this was the cause for the difference.

B. TECHNICAL CORRECTIONS

Page 3336, abstract, line 12 of the initial submitted manuscript: The word ŚhoweverŠ has been erased.

Page 3337, line 7 of the initial submitted manuscript: The word ŚsurfaceŠ has been replaced by the word ŚnucleousŠ.

Page 3338, line 1 of the initial submitted manuscript: Care was taken to correct this technical error.

Lines 4 to 21 on page 3338 of the initial submitted manuscript have been reduced considerably. The new lines are ŚContrail occurrence and coverage have been observed using satellite and ground-based observations. The mean coverage of line-shaped contrails is greatest over the USA, over Europe and over the North Atlantic (Fahey and

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Schumann, 1999). Across the continental USA, most contrails prevail in winter and decreasing during the summer reaching a pronounced minimum in September (Minnis et al., 2003). Bakan et al. (1994), using NOAA/AVHRR infrared images, found a mean contrail cover of 0.5% over the eastern Atlantic/western Europe and showed that the highest contrail coverage (>2%) lies along the North Atlantic air routes during the summertime. Sausen et al. (1998) calculated a global contrail cover value of 0.09%, with maximum values exceeding 5% over certain regions in the USA. Comparable estimates of regional and global contrail cover can be found in Meyer et al. (2002) and in Ponater et al. (2002).Š

Page 3339, lines 1-3 of the initial submitted manuscript: Lines 1-3 have been replaced by the lines ŚBoucher (1999) stated that a search for other possible causes of increased cirrus, such as the effects of the El Chichon and Mount Pinatubo volcanic aerosols, or long-term changes in relative humidity and climate variations related to the North Atlantic Oscillation, could not explain solely the observed trend in (CCC) and its regional distributionŠ.

Page 3339, line 10 of the initial submitted manuscript: A footnote has been inserted making clear that ŚFahey and Schumann (1999) included that table based on contributions from unpublished work by Pat. Minnis (the paper cited with that table was submitted but not published until Minnis et al., 2001))Š.

Page 3342, line 7 of the initial submitted manuscript: Yes, we used the number of data points. The independence of data with each other is ensured because the non-random part of the series (seasonal, ENSO and other climatological variations) has been filtered. This has been clarified in Chapter 2.

Page 3341, line 10 and elsewhere of the initial submitted manuscript: Care was taken to correct this spelling error.

Page 3342, line 24 and page 3348, line 10 of the initial submitted manuscript: The reference Minnis et al. (2003) has been erased from the pages.

Page 3349, line 16 of the initial submitted manuscript: Comma has been added after forcing.

Page 3350, lines 31-32 of the initial submitted manuscript: Lower cases in title have been used except for Mt. Pinatubo.

Page 3351, lines 7-15 of the initial submitted manuscript: The reference Minnis et al. (1997) has been erased from the paper.

Page 3351, lines 28-29 of the initial submitted manuscript: ŚKrcherŠ has been replaced by ŚKärcherŠ and ŚfrŠ by ŚfürŠ.

Page 3354 and Table 2 of the initial submitted manuscript: The abbreviations (ASIA, W.EUR, USA, LATR, NA, NP, LATR) have been explained in the table.

In addition different symbols on the various curves in all figures have been used in order to avoid use of colors.

Interactive comment on Atmos. Chem. Phys. Discuss., 3, 3335, 2003.