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Interactive comment on "Long-lived contrails and convective cirrus above the tropical tropopause" *by* Ulrich Schumann et al.

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We thank the Referee for his comments. The comments help us to strengthen the paper.

We repeat the comments after "C:" and add replies after R:

C. This paper presents a convincing case for observations of contrails in the stratosphere from the Geophysica flights over Hector on 16 and 30 November 2005. It covers work already published in previous studies but has enough new material to warrant publication. I have only minor comments on the manuscript.

R. Obviously, we did not make clear enough that this paper deals with two topics. As the title says "Long-lived Contrails AND convective cirrus". We now changed the abstract

and added a roadmap at the end of the Introduction to make these points clearer.

C. The paper is very long, very detailed and difficult to follow because of the complex nature of the dataset (this is not a criticism of the author but it does set a challenge). Peripheral sections should therefore be omitted or moved to the supplementary material. For example, Sections 3.2.5 and 3.2.6 (together with their associated diagrams) add little to the overall argument and could safely be omitted.

R: The paper is long because, because it is complex to distinguish between contrail and convective cirrus. Each of the various observations provides different perspective on the complex situation. The situation would be interpreted differently without having seen all material. The lidars, the AVHRR, radar, and MTP data in combination with previously unavailable and new analyses of the in-situ data (for instance CO2) provide information on the nature of the Hector anvil cloud not available before. Since the cirrus above Hector is at least partially affected by Geophysica exhaust and contrails, the question arises of how valid previous conclusions are about the contribution of deep convection to hydration of the lower stratosphere. Therefore, we do not eliminate sections as suggested, but now stress their importance in the Introduction.

The other comments are of minor nature and are fully taken into account in the revised version as follows:

C: p.7 l.6 - gives the impression that there is always strong turbulence or some similar disturbance. I'm sure that's not the intention so please re-draft the sentence.

R: we omit "strong!

p.7 C: l.33 'a remnant' rather than 'remainders'

R: changed as recommended.

p.8 C: l.27 'This cloud can be found as a narrow line in the 300âŮę direction'

R: we add word "the".

C: l.29 'the remains' rather than 'remainders'

R: changed as recommended.

C: l.18 'between this turn and the Falcon position.' But the Geophysica was always east of the Falcon camera position so how could the white line be between the Geophysica and the Falcon?

R: The answer is: because of drift with wind

C: p.12 l.23 show not shows.

R: The sentence was "The scatterplots show compact correlations. " This needs no change.

C: Also, the tightness of the CO2 scatter plot will be affected by the precision of the measurement. The paper gives a high-frequency noise of 0.05 ppmv which is very small but are there lower-frequency contributions to the random errors?

R. Indeed, the total random error for each of the SCOUT flights used in this study is estimated as 0.18 ppm for CO2 molar mixing ratio (including lower-frequency contributions). We changed the text to make it more precise: The errors given with the data are an estimate for the mean precision during the whole flight, including a calibration bias that is constant for a given flight (but may differ between flights); for absolute accuracy, one has to add 0.1umol mol-1. The total random error within each of the SCOUT-O3 flights is estimated as 0.18 umol mol-1, while the high-frequency noise (relevant for the detection of small CO2 peaks) is about 0.05 umol mol-1.

C. p.14 l.25 '. . ...data; MAL is. .

R: changed as recommended.

p.15 C: l. 33 cause the optical depth to be underestimated

R: changed as recommended.

p.16 C: l.4 has not have; delete 'reaches' from next line

R: changed as recommended.

C: p.22 l.20 either 'during 30 November' or 'during the 30th November' -

R: changed according as suggested in the second version.

C: p.24 l.5 'in this altitude range' - which altitude range?

R: much higher than in the troposphere

C: p.26 l.17 'Effective means,' should read 'By 'effective'; we mean. . .'

R: changed as recommended.

NEW Abstract

Abstract. This study has two objectives; 1) it characterizes contrails at very low temperatures and 2) it discusses convective cirrus in which the contrails occurred. 1) Long-lived contrails and cirrus from overshooting convection are investigated above the tropical tropopause at low temperatures down to -88°C from measurements with the Russian high-altitude research aircraft M-55 "Geophysica" and related observations during the SCOUT-O3 field-experiment near Darwin, Australia, in 2005. A contrail was observed to persist below ice saturation at low temperatures and low turbulence in the stratosphere for nearly one hour. The contrail occurred downwind of the decaying convective system "Hector" of 16 November 2005. The upper part of the contrail formed at 19 km altitude in the tropical lower stratosphere at ïĄ¿60 % relative humidity over ice at -82°C. The ïĄ¿1-h lifetime is explained by engine water emissions, slightly enhanced humidity from Hector, low temperature, low turbulence, and possibly nitric-acid hydrate formation. The long persistence suggests large contrail coverage in case of a potential future increase of air traffic in the lower stratosphere. 2) Cirrus observed above the strongly convective Hector cloud on 30 November 2005 was previously interpreted as cirrus from overshooting convection. Here we show that parts of the cirrus were

caused by contrails or are mixtures of convective and contrail cirrus. The in situ data together with data from an upward-looking lidar on the German research aircraft “Falcon”, the CPOL radar near Darwin, and NOAA-AVHRR satellites provide a sufficiently complete picture to distinguish between contrail and convective cirrus parts. Plume positions are estimated based on measured or analyzed wind and parameterized wake vortex descent. Most of the non-volatile aerosol measured over Hector is traceable to aircraft emissions. Exhaust emission indices are derived from a self-match experiment of the Geophysica in the polar stratosphere in 2010. The number of ice particles in the contrails is less than 1 % of the number of non-volatile aerosol particles, possibly because of sublimation losses and undetected very small ice particles. The radar data show that the ice water content in convective overshoots is far higher than measured along the flight path. These findings add insight into overshooting convection and are of relevance with respect to hydration of the lower stratosphere.

Road-Map, to be introduced at the end of the Introduction:

This study started with the objective to characterize contrails at very low temperatures based on previous airborne measurements above the tropical tropopause. For this purpose we developed a method to identify encounters of exhaust plumes or contrails along the flight track of the aircraft with a trajectory analysis and subsequent discussion of the measured plume properties in respect to exhaust and contrail signatures. Since some contrails were found mixed with convective cirrus, we had to extend this study considerably to characterize also the convective clouds. Section 2 describes the measurements and the data available for analysis. It also describes a method to identify contrails based on plume trajectories. The analysis uses emission indices of the Geophysica as determined in the appendix. Section 3 describes the measurement and analysis results. Section 3.1 analyses the properties of the contrail seen in Figure 1 in the aged outflow of the decaying Hector cloud of 16 November 2005. Section 3.2 describes the measurements inside Hector under strongly convective conditions during 30 November 2005. The results provide indications for potential contrail penetrations

and insight into convective and anvil cirrus. The results are discussed in Section 4. Section 4.1 tries to explain the long live time of the contrail observed in the photo using various simplified ice mixing and sublimation models. Section 4.2 and 4.3 discuss the results of Section 3.2 and show that the measured cirrus samples were partially caused by contrails. Section 4.4 discusses the number of ice particles in contrails at low temperatures. Section 5 provides the conclusions.

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