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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Tracing troposphere-to-stratosphere transport above a mid-latitude deep convective system" *by* M. I. Heggin et al.

Anonymous Referee #2

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Review of paper ACPD, 2003-149 by Hegglin et al.

General comments

In this paper airborne trace gas data collected during one of the SPURT campaigns during November 2001 are analysed in respect of isentropic and diabatic troposphere-to-stratosphere transport. Multifaceted auxiliary information in particular provided by meteorological analyses (ECMWF, CHRM) and RDF calculations are considered.

The paper is very well written. The analysis is straightforward, goes in an unusual depth, and contains ample new information on tracer transport across the extratropical tropopause. Well done!

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Interactive Discussion

Discussion Paper

However, there is one major problem I have with the interpretation of the data. This problem should be solved before the paper is accepted for publication.

As previously demonstrated by co-authors of the present paper (Fischer et al., GRL, 2000; Hoor et al., JGR, 2002), mixing lines in the lowermost stratosphere (LMS) are formed by mixing of a tropospheric reservoir and a stratospheric reservoir. Most simple to explain is flight segment III (as correctly done in the paper) where the slope of the NOy/O3 mixing line well agrees with the slope known from former observations in the lower stratosphere (Fig. 3).

In contrast thereto, the NOy/O3 relationships in the flight segments I and II are unusual. The authors explain them with the in-mixing of NOy-rich tropospheric air. This statement itself is most likely correct. My concern however is: what process actually caused this in-mixing and how the initial trace gas compositions have looked like in order to result in the NOy/O3 relationship as observed.

Starting with flight segment I. A compact linear mixing line was found. This basically tells us that a tropospheric reservoir mixed with a stratospheric reservoir. If, as suggested in the paper, the tropospheric air mass was strongly enriched in NOy (e.g. 3-4 ppbv, at modest O3 m.r. of below 100 ppb) a mixing line should result, which 1. starts well above the observed intercept point of the two black lines in Fig. 3 and 2. shows a small, maybe even negative slope in order to meet the well-known stratospheric correlation line. This has not been observed.

My suggested explanation is slightly different and should also be considered for the interpretation of flight segment II. If mixing of tropospheric air and stratospheric air has effectively formed the observed NOy-O3 co-variation line (otherwise it would be difficult to account for the linear relationship), not the tropospheric but the stratospheric reservoir is the untypical one, with high NOy m.r. of ˜4 ppbv and modest O3 m.r. of ˜300 ppb. The flight took place in November, that is a season during which the LMS is strongly influenced by tropospheric air that primarily crossed the tropopause in summer and autumn along isentropic surfaces (eg. Ray et al., JGR, 1999). This means 1. O3 is low in the entire LMS (see eg. the two J. Logans' papers in JGR, 1999) and 2. in extensive areas of the LMS, NOy could be much higher than suggested by the stratospheric NOy/O3 relationship. In summary, the NOy/O3 relationship in flight segment I could also be explained by mixing of a (typical) upper tropospheric reservoir with O3 = 80 ppbv and NOy = 1 ppbv and a (unusual) LMS reservoir with O3 = 300 ppbv and NOy = 4 ppbv. This (unusual) LMS reservoir might be due to previous in-mixing of tropospheric air.

Maybe the authors can rebut this hypothesis, but in this case they should try to explain the strange linear NOy/O3 relationship in flight segment I. That is, they should answer the questions: What reservoirs mixed with each other? Can it be that the linear NOy/O3 relationship in flight segment I is not a mixing line, at all? But then, how it can happen that sporadic and small-scale (diabatic) injections of NOy-rich tropospheric air are dispersed in such a way that a couple of days later a linear NOy/O3 relationship is present?

The same applies for flight segment II. If we understand the line with a slope of 0.013 as representative for the isentropic level of 345-350 K, and the line with a slope of 0.003 as representative for an higher isentropic level of ˜365 K (as suggested in Fig. 3), flight segment II could simply be interpreted as a continuous transition from one to the other isentropic level or from one to the other NOy/O3 relationship, respectively. My question is: For explaining the NOy/O3 relationship observed in flight segment II, does we indeed need relatively fresh injection of NOy-rich tropospheric air, as suggested in the paper?

In fact, I also assume that some diabatic injection of polluted tropospheric has occurred hours or days before the flight. But I question, if these convective events 1. actually formed the observed NOy/O3 relationships, and 2. are essential for the formation of these relationships.

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Specific comments:

Albeit the paper is quite long, some additional information (literature) about the NOy-O3 slope in the background LS and LMS should be given. To my knowledge, the NOy-O3 slope undergoes some latitudinal and seasonal variation in the lower stratosphere. For instance, in mid- and high latitudes often steeper slopes of up to 0.01 have been observed, also outside the polar vortex (Bregman et al., JGR, 1995; Fischer et al.; JGR, 1997, Singh et al., GRL, 1997; Ziereis et al., JGR, 2000). As I wrote above, in late summer and autumn, the NOy-O3 relationship should more or less be decoupled from the stratospheric NOy-O3 relationship that is formed in the overworld. It should strongly be influenced by isentropic in-mixing of tropospheric air near the subtropical jet. Are there experimental or theoretical studies about that topic?

Fig. 10. The wind speed around flight segment II most likely was quite high. If I assume a typical wind speed near such tropopause folds of 50 m/s, air is advected by 2160 km in 24 hours. The mean wind angle during flight segment II is 60-70° (Fig. 11). Assuming these numbers, can flight segment II actually be influenced by the convective events occurred on 9 November?

Technical comments:

Fig. 11. Please use hours instead of seconds.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 169, 2004.

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