

Interactive comment on “Impact of the Asian monsoon on the extratropical lower stratosphere: trace gas observations during TACTS over Europe 2012” by S. Mueller et al.

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We thank the reviewers for their careful reading and suggestions for improvements. We also thank all three reviewers for constructive suggestions and clarifications, which will help to improve the paper. We think the manuscript provides new scientific insight, since no other study has identified the monsoon region as significant contributor to the “flushing” of the extratropical lower stratosphere (Hegglin and Shepherd, 2007, Boenisch et al., 2009). This is the first time that in-situ observations beyond single case studies revealed a significant impact of the Asian summer monsoon as a source region for the rapid change of the chemical composition of the lower stratospheric

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background during TACTS 2012. It is well known that the upper tropospheric monsoon region is a region where tropospheric tracers and pollutants accumulate (e.g. ACE-FTS, MLS, MIPAS) and which act as a potential pathway to the stratosphere. To our best knowledge no other in-situ study (beyond case studies) quantifies the change of the background composition in the extratropical stratosphere above $\Theta=370$ K far away from Asia and links it to the impact from the monsoon region. For water vapour this has been shown by Randel and Jensen (2013) on the basis of satellite observations. The reviewers highlighted a number of points which we will address in a revised version and in more detailed replies:

1. As noted by all reviewers, the use of the terminology appeared not always clear and partly fuzzy. This is partly due to the fact that beyond the term ‘lowermost stratosphere’ other terms are not clearly defined in literature (e.g. UTLS, ExTL, Ex-UTLS, lower stratosphere,...). As requested particularly by reviewer 2 and also by reviewer 3, we therefore will include a scheme to facilitate the readers to follow our conclusions and try to sharpen the use of the acronyms.
2. This also includes a more concise definition of the terms monsoon region in the upper troposphere, which we mostly linked to the upper tropospheric Asian summer monsoon anticyclone. The geographical thresholds, which we used for the selection of trajectories are relatively large. They correspond to regions of enhanced probability to find air parcels initialized within the anticyclone after 30 days as e.g. shown in Garny and Randel, (2015, their Fig.5). As shown e.g. in Ploeger et al., (2015), the day by day variability leads to excursions of the anticyclone at $\Theta = 380$ K extending from 50N, 40E to 10N120E (their Fig.10). Since our trajectories are driven by daily fields, they reflect the daily variability of the monsoon location thereby extending the central mean location of the anticyclone core as shown in Bergman et al., (2013). We will test the sensitivity of our results in Fig. 11. We will also include a meteorological analysis of the upper tropospheric situation 30-50 days prior to the measurements as suggested by the reviewer 3.
3. We will extend the discussion of the relevance and chemical implications for this transport pathway. Part of the chemical implication is demonstrated by the increased CO, which shows,

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that the lower stratospheric mixing ratios of relatively short-lived species with lifetimes of weeks to months can in principle increase by transport from the monsoon region. The full chemical implications are still an open question and stimulate current research activities and other measurement campaigns (e.g. the Stratoclim-project with the Geophysica aircraft, the international ACAM initiative, which partly focuses on air quality aspects and pollution transport in the monsoon region). Comprehensive global and regional modeling is beyond the scope of this paper, but our data will clearly contribute to evaluate such models and to e.g. differentiate between transport from the tropics and the monsoon region. 4. As further suggested by reviewer 2 we will improve the quantitative aspect by calculating the relative changes and absolute changes of the composition, although a reader can derive quantitative information on e.g. transport time, amount of composition change for ozone, CO and N₂O from the figures in their present form. 5. We are certainly aware, that we are not the first ones measuring in this region, but to our knowledge there are very few studies which identified ongoing mixing on the basis of CO-O₃ mixing lines above Theta=380 K in the extratropics. We agree, that the work of Volk et al.,(1996), Waugh et al., (1997), Plumb et al., (2000) is relevant to identify and quantify aspects of transport and mixing within the stratosphere (e.g. between the tropical pipe and mid-latitudes, vortex). However, an extensive use of stratospheric correlations between long-lived tracers as suggested by reviewer 2 is difficult to apply to our study since we largely deal with transport times from the tropopause on the order of 50 days or less. The slopes of stratospheric correlations of long-lived tracers are much stronger affected by deep stratospheric processes on time scales of months or years while our study focus on transport of recent tropospheric air on time scales < 50 days. This also results in a small dynamical range of variability of stratospheric tracers (e.g. N₂O lowest minimum values are 25 ppbv below tropospheric values during TACTS, compared to e.g > 100 ppbv N₂O in the aforementioned studies). The special use of the N₂O-O₃ correlation in the manuscript is related to the aforementioned work and we will rework this section for the revised version. However, the CO-based correlations, which are affected by transport from the troposphere are

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a centerpiece of our analyses. Since all reviewers claimed the discussion and use of the N₂O-O₃ correlation as critical we will rewrite this section. In addition we will take the suggestion of reviewer 2 to derive more quantitative measures to characterize the different regions which we focus on (e.g. the ExTL apart from the lower stratosphere beyond the ExTL). We think that these revisions along with the detailed comments will further improve the paper along with the specific points raised by the reviewers.

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