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Interactive Comment

Interactive comment on "Fast transport from Southeast Asia boundary layer sources to Northern Europe: rapid uplift in typhoons and eastward eddy shedding of the Asian monsoon anticyclone" *by* B. Vogel et al.

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We thank Referee #1 for his good and very helpful assessment. Following the reviewers advice we elaborate some specific points, which strengthen the findings of our paper. Our reply to the reviewer comments is listed in detail below. Questions and comments of the referee are shown in italics.

General comments

The paper is focused on a novel rapid transport mechanism from the Southeast Asia boundary layer to the lower stratosphere over Europe. However, only a minor fraction of the computed parcel trajectories follow this pathway (2%, Table I), while another ≈35% of the parcels in the region of interest are likely of near-surface origin but have longer transport times. What is the relative contribution of the 2% parcels to the tropospheric like composition of the measured air masses? The transport mechanism involves the interplay of several factors; how frequently is this pathway expected to take place as compared to other (slower) transports from the tropical troposphere into the extratropical lower stratosphere?

This is an important point. All air parcels measured in the region of interest (except at the very beginning and end) are chemically affected by the troposphere, however only 5% of the backward trajectories originate in the troposphere ($\Theta_{org} < 360K$) and 34% in the Asian monsoon anticyclone or UTLS ($360K < \Theta_{org} < 380K$). The trajectories consider only advective transport, but in the real atmosphere in addition mixing processes occur. Therefore the region of interest is a mixture of air masses from the troposphere and the stratosphere which is reflected in different origins of the backward trajectories. To infer the relative contribution of the 2% air parcels lifted within the typhoon to the composition of the measured air parcels in the region of interest also mixing processes have to be taken into account. That is not possible with a pure trajectory study, here only the relative contributions of the trajectory origins can be calculated.

In the region of interest, a small amount of tropospheric air with high concentrations of CO, CH4, and H2O is mixed with huge amount of unpolluted dry stratospheric air (due to the numbers of trajectories). Filaments or eddy shedding events (Fig 5 in the paper)

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transport polluted tropospheric air from the Asian monsoon to Northern Europe. We assume that within these filaments or small anticyclones the tropospheric amounts of trace gases are frozen in the core and only at the edge of the filaments/anticyclones mixing with stratospheric air occurred, therefore the tropospheric characteristic of these air masses can be transported over a wide range from Asia to Europe before the filaments dissipate. Transport and mixing processes of a tropospheric intrusion from the TTL into the lowermost stratosphere is e.g. described in Vogel et al. 2011 (Transport pathways and signatures of mixing in the extratropical tropopause region derived from Lagrangian model simulations, JGR, 2011, doi: 10.1029/2010JD014876) using the chemistry transport model CLaMS. For the TACTS flight on 26 September we performed also CLaMS simulations with artificial tracers marking different boundary layer sources to take also mixing processes into account, but this is work in progress.

How frequently is this pathway expected to take place as compared to other (slower) transports from the tropical troposphere into the extratropical lower stratosphere?

During the typhoon season 2012[1] 11 typhoons occurred between June and September. But also tropical depressions and tropical storms have the potential for very rapid uplift of boundary layer emissions. The impact of each of theses events in combination with the Asian monsoon anticyclone has to be analyse. We expect that the impact of this pathway is smaller compared to other (slower) transports from the tropical troposphere into the extratropical lower stratosphere, but nevertheless the impact of this rapid transport pathway is evident in the TACTS measurements. The impact of this transport pathway also depends on the particular species considered. The shorter lived the species, the more important the fast transport pathway will be.

[1]see e. g.:http://en.wikipedia.org/wiki/2012_Pacific_typhoon_season; season summary

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In particular, a non-negligible fraction of the parcels in the region of interest (22%) is also transported from the Asian monsoon region towards Northern Europe (green and yellow lines in Fig.6). In order to assess the geographical origin of these air parcels it would be interesting to follow these back trajectories further beyond the 40-days limit, until they reach the boundary layer.

As, suggested, we calculated also longer trajectories (60 days backward). The origin of these air parcels for the region of interest is shown in Figure 1. Trajectories from the Θ_{org} interval 295 K–320 K originate mainly in Southeast Asia, Pacific Ocean, Bay of Bengal, and the Arabian Sea. Trajectories from the Θ_{org} interval 320 K–360 K originate mainly at the Tibetan Plateau, East China, Southeast Asia, and the Pacific Ocean. These longer trajectories confirm that the origin of the air masses with tropospheric signatures in the region of interest are mainly from boundary source emissions in Asia. We propose to add these results and discussion into the revised version of the paper.

Specific points

Referee #1 specified a few points where some further discussion is highly recommended:

(1) Fig. 3 misleading

In the lower right panel in Fig. 3, the location of the 'origin' of the parcels is shown, although these do not correspond to surface locations as in the corresponding left panel (this could be misleading).

We agree that this could be misleading. We propose to replace this figure by a figure where the 'origin' of the air parcels is colour-coded by potential temperature (as in the

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supplement, Figure 1, 3rd row) to avoid any misunderstanding.

(2) The event observed about one hour before the region of interest

The event observed about one hour before the region of interest (Fig. 2), which is of similar magnitude but shorter duration than the main event: what are the geographical sources for these parcels?

We stated in the paper that this event is not present in 40 day backward trajectories, but in 50 day backward trajectories to a small extent. We calculated in addition 60 day backward trajectories as shown in Fig. 2. After 60 day also air parcels similar as in the 'region of interest' are found originating between 295 and 320 K potential temperature.

Fig. 3 shows that these air parcels are also from Southeast Asia and experience rapid uplift on 2-3 August 2012 southeast of the Philippines. The reason for the strong upward transport is also a typhoon (here typhoon 'Haikui'[2]). We propose to include these results into the paper to strengthen our findings that fast transport from Southeast Asia boundary layer sources to Northern Europe occurs by rapid uplift in typhoons.

(3) Air parcels originating near the Tibetan Plateau

Finally, parcels originating near the Tibetan Plateau could reach the boundary layer at higher potential temperatures than 300 K, is this the case for any of the trajectories considered?

Yes, in 60 days backward trajectories, air parcels originating near the Tibetan Plateau

[2] see e.g., http://www.nasa.gov/mission_pages/hurricanes/archives/ 2012/h2012_Damrey.html

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are found at potential temperatures around ≈ 340 K (see Fig. 1). We will include this piece of information into the revised version of the paper.

Specific comments

All comments related to grammar, typos, or confusing sentences will be revised in the updated version.

Why use ERA-Interim data and not operational data with higher resolution? What is the temporal resolution of the heating rates used for the trajectories (e.g. do you consider daily cycles?

As stated in the paper we use for trajectory calculations the diabatic approach using diabatic heating rate (with contributions from radiative heating including the effects of clouds, latent heat release, mixing and diffusion) as vertical velocity. To include all these effects we need to use ERA-Interim data because not all of these terms are included in the operational data with higher resolution. Further, we use the same vertical velocities in the chemistry transport model CLaMS and have therefore the possibility to compare pure trajectory calculations with CLaMS simulations including in addition mixing processes (this work is in progress). Finally, it is remarkable that also in meteorological data with coarser resolution the rapid transport in typhoons is apparently included.

Temporal resolution of the heating rates used for the trajectories and daily cycles:

The procedure to calculate the heating rates is described in Ploeger et al, 2010 (Im-

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pact of the vertical velocity scheme on modeling transport in the tropical tropopause layer, JGR, doi:10.1029/2009JD012023): As heating rates are not stored in standard ECMWF operational analysis data, the ERA-Interim data set of meteorological reanalysis and forecasts is used. The heating rate information is taken from ERA-Interim forecast data. To be more precise, the 6 h forecasts at 0000/1200 UTC provide heating rates for the 0600/1800 UTC reanalyses, while the 12 h forecasts the heating rates for the 1200/0000 UTC reanalyses. The temporal resolution of the heating rates is also 6 hours and include therefore the daily cycles. We will add this information into the revised version of the paper.

How many trajectories are run?

In the region of interest: 432 trajectories
Along the whole flight path: 3582 trajectories

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 18461, 2014.

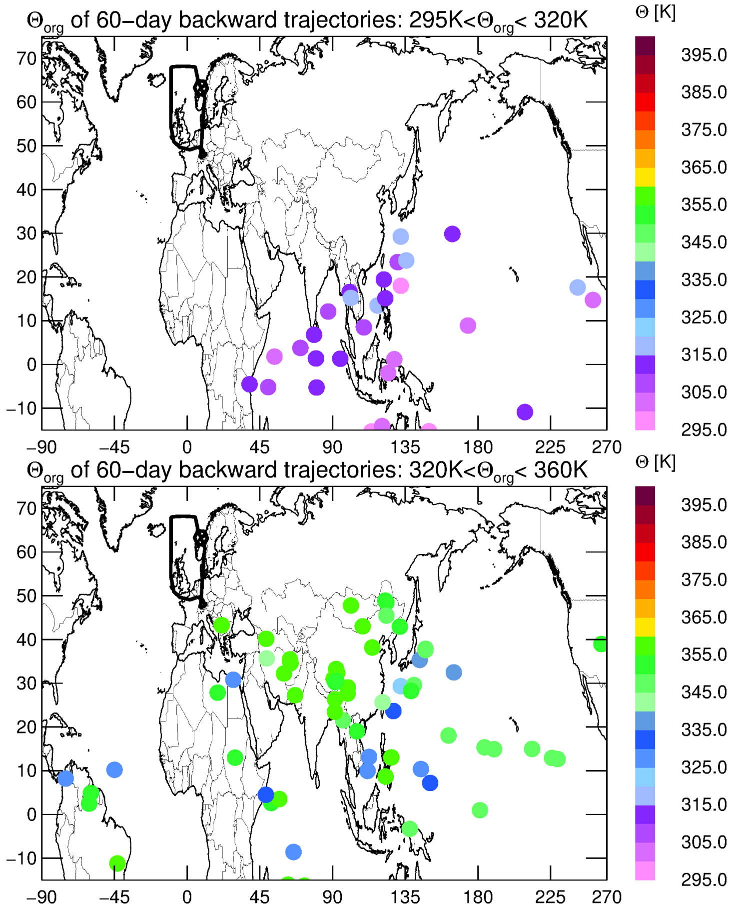

Fig. 1. Origin of 60 day backward trajectories originating in intervals 295K-320K (top) and 320K-360K (bottom) potential temperature.

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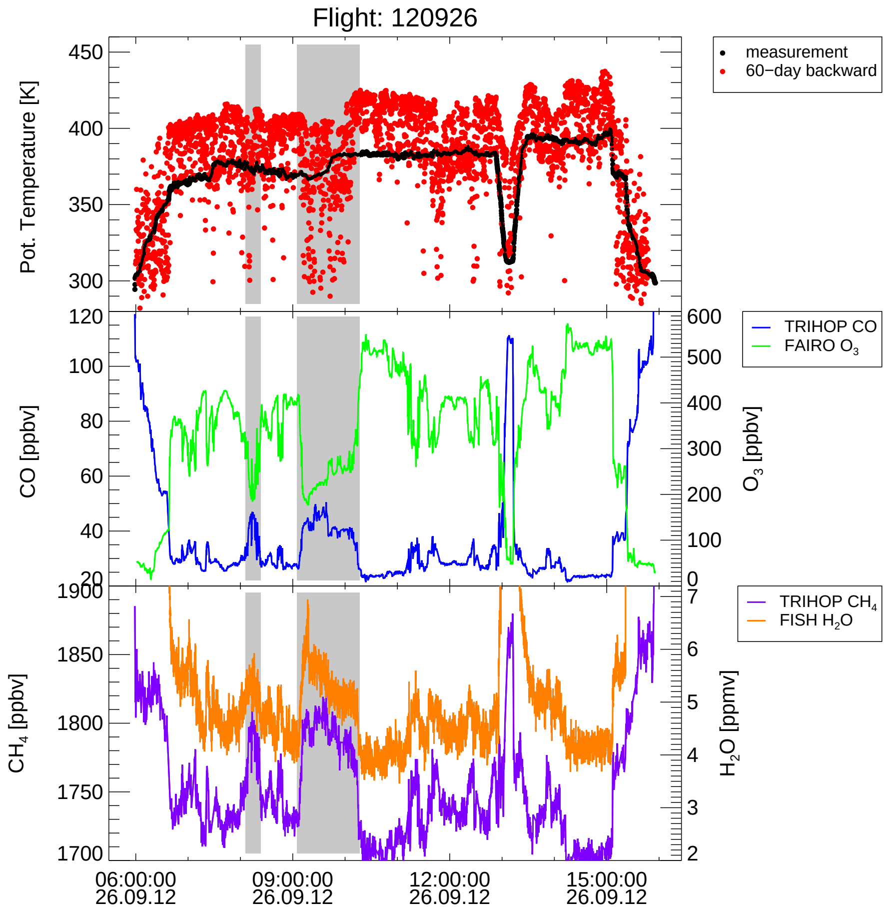

Fig. 2. As Figure 2 in the paper, but for 60 day backward trajectories

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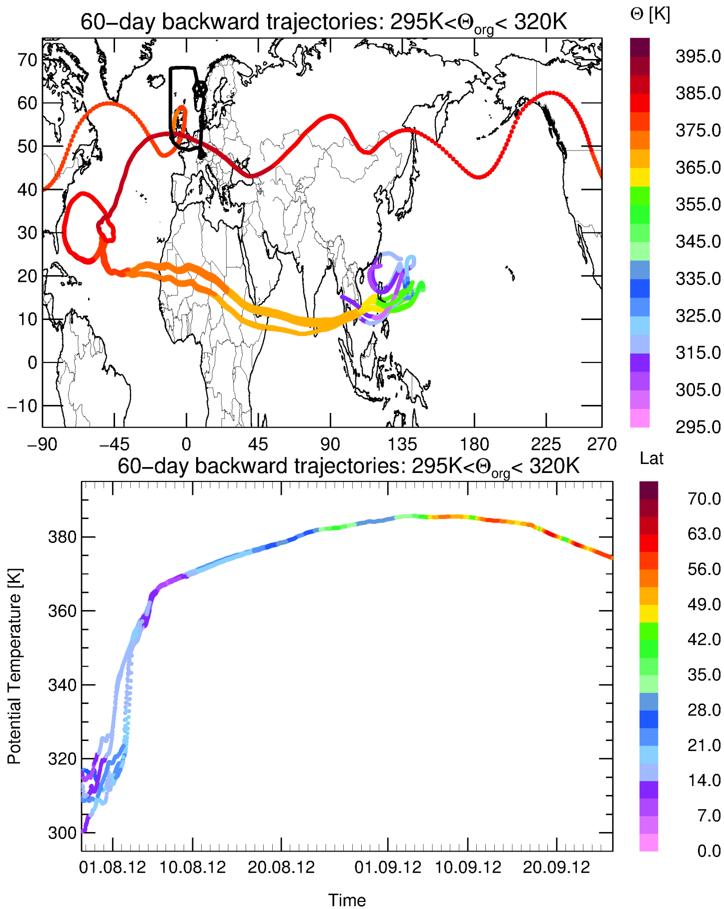

Fig. 3. 60 day backward trajectories (event observed around 8:15)) originating in intervals 295K-320K (top). Potential temperature versus time (in UTC) along 60 day backward trajectories (bottom).

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