

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 #2 and #3 for their good and very helpful assessment. Following the advice of reviewer #2 we elaborate the point about the limitations of the backward trajectory analysis, which strengthen the findings of our paper. Our reply to the reviewer comments is listed in detail below. Questions and comments of the referees are shown in italics. In general, all comments of Referee #2 and #3 related to grammar, typos, or confusing sentences will be revised in the updated version.

C6532

General comments Referee #2

1) My principal objection concerns the lack of discussion in the paper regarding the limitations of trajectory analysis. In particular, it is unlikely that this analysis can reliably determine a specific tropical storm as a source 40 days in the past (i.e., due to trajectory dispersion by errors in the wind fields) - particularly with the small sample size used in this study for which only 23 trajectories descend below the 360 K isentrope and only 8 of these reach the surface. In addition, reanalysis data is not capable of resolving the small-scale rapid uplift in convective cores, which makes tracking parcel trajectories through tropical convection problematic.

We agree that the trajectory analysis has limitations due to trajectory dispersion by errors in the wind fields or due the spatial resolution of the starting points of the calculated backward trajectories. Over the timescales in question, also mixing can be relevant. In ERA-Interim reanalysis data changes are implemented to improve deep and mid-level convection (Dee et al., The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Q. J. R. Meteorol. Soc., 2011) compared to previous reanalysis data. To show that the uplift in typhoons as represented in the ERA-Interim reanalysis data is strong enough to transport air parcels from the boundary layer to the Asian monsoon anticyclone, we calculated forward trajectories starting in the boundary layer around the position the typhoon Bolaven on 23 August 2012 (15°N-25°N, 128°E-140°E and below \approx 310 K potential temperature). The trajectories are started at a horizontal grid of $0.5^\circ \times 0.5^\circ$ and a vertical grid of 1 K. Within 48 hours (23 - 25 August 2012 at noon), 10% of these trajectories experience a strong uplift greater than 50 K potential temperature as shown in Fig 1. These calculations demonstrate that trajectories using ERA-Interim reanalysis data show strong uplift and can

C6533

reach the lower stratosphere, in spite of the fact that ERA-Interim reanalysis data do not resolve small-scale rapid uplift in convective cores. This is also valid for other days which is not shown here. The ERA-Interim reanalysis data are therefore well suited for our study with the aim to identify transport pathways from the boundary layer in Asia to the lowermost stratosphere over Northern Europe. We expect that in data sets including in addition the small-scale rapid uplift in convective cores, the strong uplift of air masses in tropical cyclones should be even more pronounced.

To corroborate the finding that trajectories starting in Pacific typhoons can reach the region of interest over Northern Europe during the TACTS measurements on 26 September 2012, we calculated forward trajectories starting within the typhoon Bolaven and Tembin between 22 and 26 August 2012 at noon. These calculations show that starting from these days no trajectories from typhoon Tembin reach the region of interest. However trajectories starting at typhoon Bolaven on 22, 23, 24 and 25 August (12 UTC) reach the region of interest. Fig. 2 shows trajectories started at the typhoon Bolaven on 23 August at noon (as described above). Shown are only trajectories that reach the region of interest during the flight on 26 September 2012 12:00 UTC (at locations between 365K and 385K, between 55°N and 70°N, and between 20°W and 0°W). These calculations confirm that air masses from the typhoon Bolaven have the potential to reach the region of interest within ≈ 5 weeks. Our findings show that trajectories calculated with wind fields from ERA-Interim reanalysis data experience rapid uplift in tropical cyclones and can reach the flightpath of the TACTS flight on 26 September 2012 in the lower stratosphere over Northern Europe. In summary, we can show that first ERA-Interim reanalysis data are a suitable data set for our study and second the coincidence of forward and backward trajectory analysis demonstrate that the transport pathways identified in our study are unaffected by limitations due to trajectory dispersion by errors in the wind fields.

In the revised version of our paper, we added these calculations and the corresponding

C6534

discussion. We believe that this analysis strengthens our findings.

2) Sec. 4.3, which provides a hand-waving discussion of the connection between eddy shedding and tropical cyclone Sanba, introduces a discussion that is beyond the scope of the research in this paper. It would be best if the authors omitted this section and wrote a separate paper that addressed the 'reasons for eastward eddy shedding and intensification of the super typhoon'.

We agree with Referee #2 that the discussion in Sec. 4.3 is a bit short and beyond the scope of the research in our paper. Nevertheless it is an important and interesting point, therefore as suggested by Referee #2 we will prepare a separate paper to discuss this point in detail and removed Sect. 4.3 from our paper.

Specific Comments Referee #2

1) Lines 368-377: It is worth noting in this paragraph that strong uplift in convection over India and Tibet is not well resolved in reanalysis data. Since tropical cyclones are much larger than most convective cells, strong uplift in TCs is better resolved in reanalysis data. This could account for the faster transport by TCs in the trajectories.

We agree and revised the paragraph in response to the comment as follows:

Our trajectory calculations suggest that air masses from altitudes, which are potentially strongly affected by boundary emissions from Southeast Asia and the West Pacific are rapidly uplifted and are transported within approximately 5 weeks to Northern Europe. The air mass origins are not found in surface regions located close to the core of the Asian monsoon such as North India, South India or East China. This suggests that

C6535

boundary emissions from these regions may need a longer time period for upward transport within the Asian monsoon anticyclone to reach the lowermost stratosphere over Northern Europe. However, we cannot rule out that a strong uplift in convection over India and Tibet is not well enough resolved in ERA-Interim reanalysis data in contrast to convection in tropical cyclones that are much larger than most convective cells. This might lead to a certain underestimation of upward transport in smaller scale convective systems compared to upward transport in typhoons.

2) Lines 516-521: *It seems that the trajectories in Fig. 3 are in the eddy shedding region ≈ 12 days before observation - approximately Sep. 14. This is too early to be affected by the Sep. 20 shedding event. Can you explain better why you think the departure is of the trajectories from the anticyclone is on Sep. 20 and not Sep. 14?*

For clarification we revised this paragraph as follows:

The general behaviour of 40 day backward trajectories shown in Fig. 1 of the supplementary material and and Fig. 3 (here in the paper) can be explained by the temporal evolution of the Asian monsoon anticyclone. The period between 10 and 20 September 2012 is very active in terms of release of filaments and eddy shedding events with two pronounced events on 14 and 20 September on the northeast flank of the Asian monsoon anticyclone (see Fig. 5) causing the separation of the trajectories from the flow around the core of the anticyclone. Nearly all trajectories below a Θ_{org} of 380 K show this separation between 10 and 20 September 2012.

3) Lines 635-637: *Wind fields from ERA interim might not resolve the convective cores that provide rapid transport from the boundary layer into the anticyclone over India and Tibet.*

C6536

As discussed above, in the revised version we discuss that in ERA-Interim reanalysis data the strong uplift in convective systems over India and Tibet could be not well enough resolved.

Minor Comments Referee #3

1) Page 18467, lines 6-7: *Reproducibility in what sense? Can you explain in more detail why this is important?*

TRIHOP is in-situ calibrated by secondary standards of compressed air during flight typically every 20 minutes to check for the drift of the instrument, which can occur mostly due to temperature induced effects (e.g. temperature changes of the optical alignment or detector sensitivity). During post-processing of the data we account for the drift by using a linear interpolation between two subsequent calibrations. The reported value is based on the standard deviation of the calibration values before applying the drift correction procedure. Therefore it does not account for the linear correction of the data and can thus be regarded as upper limit for the drift of the data between the calibrations. For clarification we added in the revised version:

From the standard deviation of the in-situ calibrations, which were performed every 20 minutes, we estimate a reproducibility of the calibrations of 2.3 ppbv for CO and 15 ppbv for CH₄. The reproducibility can be regarded as an upper limit for the drift of the measurements between the calibrations.

2) *Figures: It is not clear where the PV, wind, potential temperature, and geopotential heights come from in each graph since both CLaMS and ERA-Interim are discussed*

C6537

in the text. Please provide more information in the captions were applicable

PV, wind, potential temperature, and geopotential heights shown in the Figures are taken from ERA-Interim reanalysis data as noted in Sect. 3 and 4. CLaMS trajectories are driven by wind fields from ERA-Interim reanalysis data. In the revised version of the paper we will add the information about the source of these quantities in the individual figure captions.

3) Figures 3-5: The font size in these figures is quite small. Please increase to a readable size.

Yes, we agree and will increase the font size of these figures in the revised version.

4) Figure 3, bottom: In the caption the description of this time axis says '(in UTC)', but I am not familiar with the value form in the figure. What do these numbers represent? Wouldn't it be clearer to label the axis by trajectory day number (as colored in the middle panels)?

UTC is the Universal Time Coordinated (UTC), in the past also referred to as Greenwich Mean Time (GMT). We prefer to use UTC in Figure 3, because UTC is a usual definition for dates. See for example:

<http://www.nhc.noaa.gov/aboututc.shtml>

For clarification we wrote out 'UTC' in the revised version as 'Universal Time Coordinated'.

5) Figure 4: Please show the position of the cross-section on the map.

C6538

Ok, the suggestion will be implemented.

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

C6539

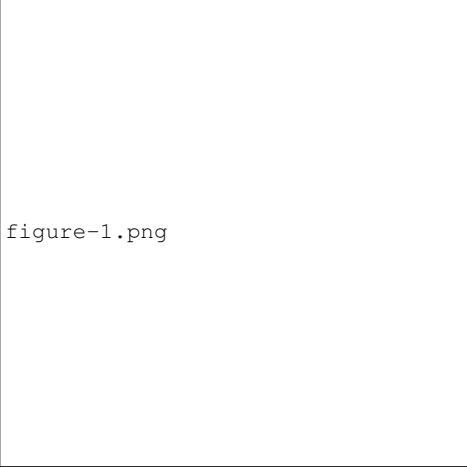


figure-1.png

Fig. 1. Selected forward trajectories starting in the boundary layer around the position of the typhoon Bolaven on 23 August 2012 (15°N - 25°N , 128°E - 140°E and below $\approx 310\text{ K}$ potential temperature). The trajectories are started at a horizontal grid of $0.5^{\circ} \times 0.5^{\circ}$ and a vertical grid of 1 K . Shown are only trajectories that experience a strong uplift greater than 50 K within the first 48 hours caused by typhoon Bolaven. For simplification only a subset of the trajectories is shown (every 100th trajectory).

C6540




figure-2.png

Fig. 2. Forward trajectories starting at the position of the typhoon Bolaven (15°N - 25°N , 128°E - 140°E and below $\approx 310\text{ K}$ potential temperature) on 23 August 2012 marked as grey box. Shown are only trajectories that reach the region of interest during the flight on 26 September 2012 12:00 UTC (at locations between 365 K and 385 K , between 55°N and 70°N , and between 20°W and 0°W). The flightpath shown in black is transformed to synoptic 12:00 UTC locations.

C6541

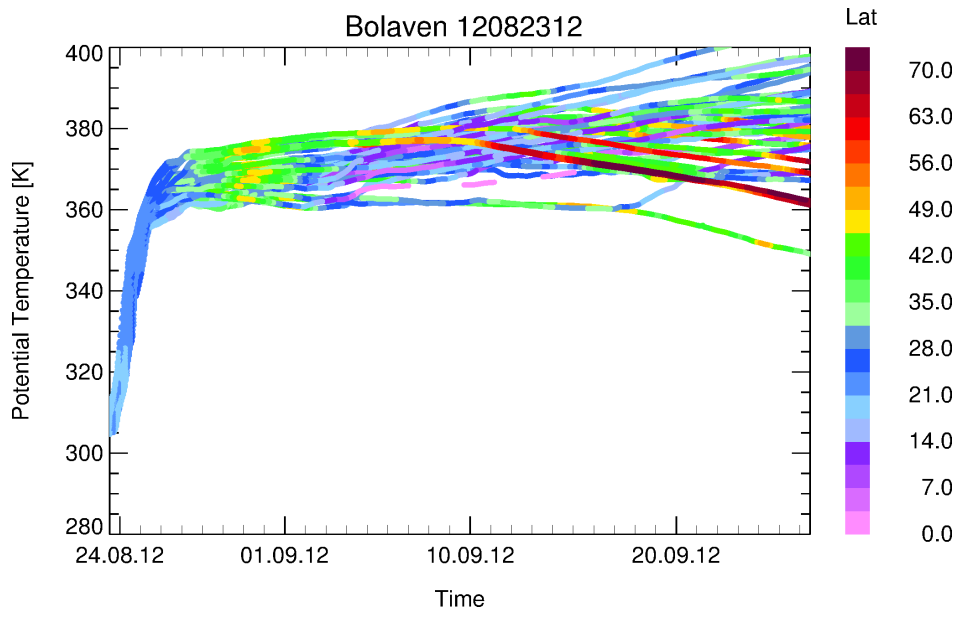


Fig. 3. Caption see Fig. 1

C6542

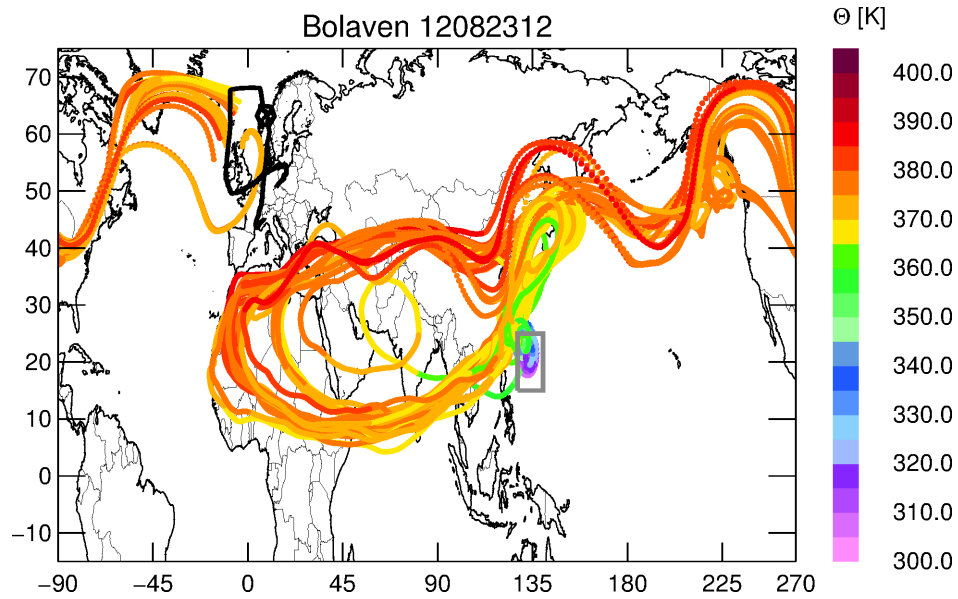


Fig. 4. Caption see Fig. 2

C6543