

## ***Interactive comment on “Effect of tropical cyclones on the Stratosphere-Troposphere Exchange observed using satellite observations over north Indian Ocean” by M. Venkat Ratnam et al.***

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Received and published: 12 April 2016

The paper presents the impact of cyclones that occurred over the North Indian Ocean during 2007-2013 on stratosphere-troposphere exchange using satellite measurements. Changes in ozone and water vapour distribution in the upper troposphere and lower stratosphere were analyzed. The cross-tropopause mass flux was estimated. The manuscript has some significant shortcomings. Therefore, I recommend some important revisions to address the comments listed below before publication by ACP.

Reply: First of all we wish to thank the reviewer for going through the manuscript

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carefully and offering potential solutions to improve the manuscript content further.

General comments:

1) Scientific significance The paper presents new interesting results, however the results need to be better developed.

Reply: Thanks for appreciating actual content of the manuscript. We have revised the manuscript while considering both the reviewers comments/suggestions.

2) Scientific quality One important questions is whether the MLS measurements have sufficient spatial and temporal resolution to apply the used methodology? This has to be demonstrated. The explanation how the cross tropopause mass flux is calculated and which data are used is confusing. The method is explained in Sect. 2 and the used data are introduced in Sect. 3.1. I recommend to combine this in one Section. Further, the method of Ravindra Babu et al., 2015 is used (e.g. Fig. 2). However, the reader cannot understand this method without reading Babu et al., 2015. I recommend to provide more information about this method in Sect. 2. Many general statements have not been established with references (e.g. within the introduction, see below specific comments).

Reply: More details are provided in the revised manuscript with related to MLS data resolution, tropopause mass flux calculation and the methodology that is adapted from Ravindra Babu et al. (2015). We have not provided these details earlier to avoid repetition and/or plagiarism report. For MLS data resolution, first we separated MLS overpasses with respect to cyclone centre for each day of cyclone period and we made it cyclone-centre composite of corresponding ozone and water vapor, respectively. For tropopause mass flux, we considered whatever available tropopause temperature and pressure within 500km from the cyclone centre taken from Ravindra Babu et al. (2015) and winds within 500 km from the cyclone centre are taken from ERA-Interim data sets.

3) Presentation quality The presentation quality needs some improvements. There are

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number of language and grammar issues. Further a lot of blank characters are missing, in particular after mathematical symbols or brackets. In the manuscript, abbreviations are still used that are not introduced. In some figures, the legend is missing.

Reply: We are sorry for the grammatical mistakes which have been reduced to the maximum possible extent in the revised manuscript. Missing of blank characters is mainly due to software problem loaded in one of our computers which is rectified now. We have elaborated all the abbreviations used in the manuscript when they appear for the first time in the manuscript. Specific comments:

1. Introduction: p. 3, line 51: 'Tropical cyclones with deep convective synoptic scale systems persisting for a few days to weeks play an important role on the mass exchange between troposphere and stratosphere and vice versa.' Please add some references.

Reply: Added.

p. 3, line 52: 'They transport large amount of water vapor, energy and momentum to the upper troposphere and lower stratosphere (UTLS) region.' Please add some references.

Reply: Added.

p. 3, line 60: 'The transport of water vapour and ozone around the tropopause caused by the cyclones can affect the radiation balance of the atmosphere.' Please add some references.'

Reply: Added.

p. 3, line 62: 'Increase of water vapor in the LS region will leads to a warming and ozone loss in this atmospheric region (Stenke and Grewe, 2005).' An increase of stratospheric water vapor contributes to tropospheric warming and stratospheric cooling, see e.g.: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed.

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S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M. M. B. Tignor, H. L. Miller and Z. Chen, Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2007, pp. 1-996. D. Rind and P. Lonergan, *J. Geophys. Res.*, 1995, 100, 7381-7396 P. Forster and K. P. Shine, *Geophys. Res. Lett.*, 1999, 26, 3309-3312 V. L. Dvortsov and S. Solomon, *J. Geophys. Res.*, 2001, 106, 7505-7514. D. T. Shindell, *Geophys. Res. Lett.*, 2001, 28, 1551-1554. P. Forster and K. P. Shine, *Geophys. Res. Lett.*, 2002, 29, 1086-1089. G. Myhre, S. J. Nilsen, L. Gulstad, K. P. Shine, B. Rognerud and I. S. A. Isaksen, *Geophys. Res. Lett.*, 2007, 34, L01807. However, small changes of water vapor in the lower stratosphere have an impact on surface climate, see e.g: Riese et al., *Impact of uncertainties in atmospheric mixing on simulated UTLS composition and related radiative effects*, *J. Geophys. Res.*, 117, D16305, doi:10.1029/2012JD017751, 2012. Solomon et al., *Contributions of stratospheric water vapor to decadal changes in the rate of global warming*, *Science*, 327, 1219-1223, 2010.

Reply: Thanks for updating us while providing above references. Most of the above mentioned references are included in the revised manuscript at appropriate places.

p. 3, line 65: troposphere air ! tropospheric air Reply: Corrected.

p. 4, line 82: 'TC event': abbreviation is not explained p. 4, line 86: 'MST Radar observations': abbreviation is not explained p. 4, line 87: 'BoB': abbreviation is not explained

Reply: These are explained in the revised manuscript.

p. 4, line 87: 'More literature related to influence of cyclones on the UTLS structure and composition is presented in Cairo et al. (2008).' Unspecific statement: please add some details or remove Cairo et al. 2008.

Reply: We have added major findings of Cairo et al. (2008) in the revised manuscript.

p. 5, line 105: 'COSMIC' is not explained Reply: Explained in the revised manuscript.

2. Data and Methodology p. 5, line 116: How many MLS profiles or measurements

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(spatial and temporal resolution, horizontal distance between tracks) contribute to one typhoon event. Please add here some information and demonstrate that the data density is sufficient.

Reply: We have included details in the revised manuscript in the form of table (table 2).

p. 5, line 120: Which definition is used for the tropopause?

Reply: We used cold point and lapse rate tropopause definitions in this present study. For calculating tropopause mass flux, we used lapse rate tropopause definition only.

p. 6, line 135: Please add the precise time period for pre- and post-monsoon season and explain why you exclude the monsoon season.

Reply: Added in the revised manuscript. We also included monsoon season.

p. 7, line 149: 'tropopause parameters': Which parameters? Please combine this paragraph with details from Sect. 3.1'.

Reply: We combine and explained clearly this aspect in the revised manuscript.

3. Results and discussion p.7, line 162: How are the climatological mean values calculated? Is the monsoon season in the climatological mean excluded? During the Asian monsoon season the tropopause above the Asian monsoon anticyclone is elevated. Therefore, during this time period the lapse rate tropopause altitude differs from the altitude during the rest of the year. Is this considered in your analysis?

Reply: We have not considered this in the calculation. There could be day-to-day to the inter-annual variability in the observed climatological tropopause parameters. Since large data (14 years) have gone through climatology, we assume that variability less than the solar cycle is nullified, if not removed completely. Further Asian monsoon anticyclone aspect is related to the latitudes greater than 25oN, thus, do not affect our study in a significant manner. However, upper level anti-cyclonic circulation over the cyclones is reflected very well in our observations.

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p. 7, line 169: How many measurements (tracks) do you have within 1000 km radius for one cyclone?

Reply: The total available RO measurements are not fixed for each cyclone; the RO measurements will change one cyclone to another. For example, the total RO measurements in the case of Nargis cyclone are 73. These details are provided in the revised manuscript.

p. 7, line 175: How is the cyclone intensity considered in the methodology of Ravindra Babu et. al, 2015? Please give a short summary about the method of Ravindra Babu et al., 2015 used for Fig. 2. How is vertical uplift at different flanks of the cyclone and difference between individual cyclones considered?

Reply: In Ravindra Babu et al. (2015), we did tropopause analysis based on different intensities of the cyclones such as depression (D), deep depression (DD), cyclonic storm(CS), severe cyclonic storm (SCS) and very severe cyclonic storm (VSCS). After detailed analysis we found that there is no major variation between D and DD, SC and SCS. So we combined the results of D and DD as one category and CS and SCS as another category and VSCS as one category. From each cyclone we separated the RO measurements based on the intensity and we combined.

p. 12, line 280-284: '...higher ozone mixing ratios are observed in the western and northwest side and more water vapor is located at the eastern side of the cyclonic center...'. Why do you have this preference for the western and eastern side, respectively? In the schematic diagram Fig. 6 upward and downward transport of water vapor and ozone is shown. The diagram implies rotational symmetry around the center of the cyclone. How fits the rotational symmetry together with the preference at the western and eastern side?

Reply: Our results from Ravindra babu et al. (2015) shows the integrated RH is more in the east and south east side within 500 km from the cyclone centre and the COH, TTL thickness also shows high in the north and north west side within 500 km from

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the cyclone centre. From these we assume that different sides within 500 km from the centre there may be different variations in the ozone and water vapour as well as cross tropopause flux. That's why we calculated the flux with respect to sector wise from the cyclone centre. The diagram shown in the figure 6 it is just assumption of the cyclone structure only. Our main aim of the figure 6 is to show the variation of tropopause parameters in the schematic way i.e., ozone coming down from the lower stratosphere due to subsidence at the centre and water vapour entering in to the lower stratosphere due to anti-cyclonic circulation above the cyclone. The higher ozone mixing ratios are observed in the western and northwest side and more water vapour is located at the eastern side of the cyclone centre because of the upper level anti-cyclonic circulation over the cyclones. This will push the water vapour towards the south and east side of the cyclone centre. In the other side of the cyclone, the detrainment of the lower stratospheric air may occur along with strong subsidence in the cyclone centre. This might be the region for higher ozone in the west and northwest side and more water vapour in the east and southeast side of the cyclone centre. Note that Ray and Rosenlof (2007) also reported higher water vapour mixing ratios in the east side of the cyclone centre for Atlantic and Pacific oceans. Further, very recently Reutter et al. (2015) reported that the more stratosphere- troposphere transport takes place in the west side of the cyclone centre due to west ward tilt of the cyclone with height.

p. 12, line 294: 'by assuming change in the tropopause pressure by 0.5 hPa' Why 0.5 hPa is used?

Reply: Since we do not have pressure variation with time we have assumed different pressures while considering minimum to maximum possible pressure variations.

p. 13, line 299: Please explain why different cross-tropopause flux occurs in different sectors.

Reply: As we found different variations in the water vapour and ozone transport in

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different sectors, we have estimated cross-tropopause flux for these different sectors. Please see reply for above comment (p. 12, line 280-284) for more details.

4. Summary and conclusions p. 14, line 335: 'The main findings of the present communication are summarized below.' ! Our main findings are summarized below.'

Reply: Modified.

p. 14, line 336-339: 'Lowering of CPH (0.6 km) and LRH (0.4 km) values with coldest CPT and LRT (2-3K) within a 500 km radius from the cyclone centre is noticed. Higher (2 km) COH leading to the lowering of TTL thickness ( 3 km) is clearly observed (Ravindra Babu et al., 2015).' That is a result from Ravindra Babu et al, 2015 and not from the present paper Ratman et al.. That should be clearly recognizable in the text.

Reply: We have already provided reference when it is mentioned.

p. 15, line 346-347: 'Interestingly significant enhancement in the lower stratosphere (82 hPa) water vapor is noticed in the east and SE side from the cyclone centre.' Again, why only at the east and SE side?

Reply: Please see explanation provided for the comment p. 12, line 280-284.

p. 15, line 355-357: 'Strong convective towers with strong updrafts extending up to the tropopause altitude in the form of spiral bands extending from 500 to 1000 km are present.' In Fig. 6, three bands of downward transport of ozone and three bands for upward transport of water vapor are drawn which are not visible in Fig. 3 and 4. Please explain this discrepancy or adapt Fig. 6. To confirm the spiral bands of upward and downward transport illustrated in Fig. 6 trajectory calculations would be very helpful.

Reply: Note that figure 3 and 4 are cyclone-centre composite of ozone and water vapour obtained from all 16 cyclones and the figure 6 is the only schematic picture of a cyclone. Our main aim in figure 6 is to show the variation of tropopause parameters in the form of schematic way i.e., ozone coming down at the centre from the lower stratosphere due to subsidence and water vapour entering in to the lower stratosphere

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due to anti-cyclonic circulation above the cyclone above the spiral bands.

Figures: Fig. 1: 'strom' ! 'storm' Fig. 3: Legend from a-d is missing. Fig. 4: Legend from a-d is missing.

Reply: Corrected in the revised manuscript.

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Interactive comment on Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2015-988, 2016.