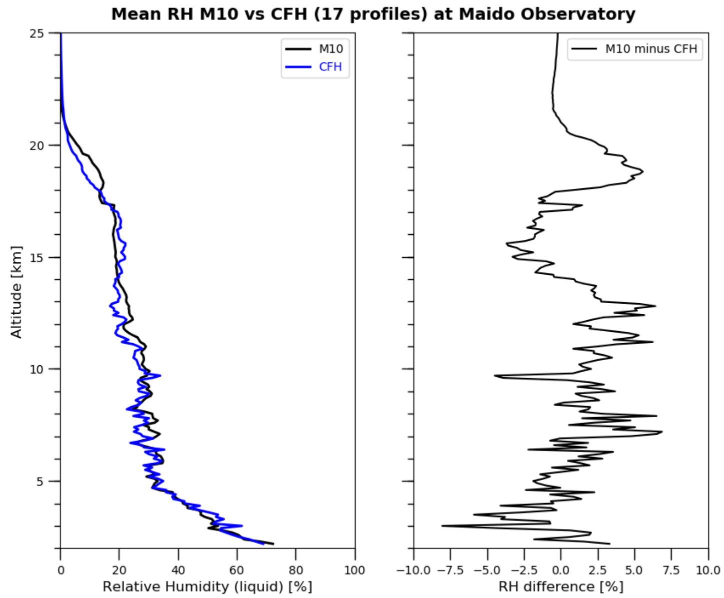
Anonymous Referee #2:

We appreciate the thoughtful and constructive comments from the reviewers. Their helpful suggestions and attention to detail have made this a substantially better paper, and we greatly appreciate the time they put into the manuscript.
Please see below our responses (in bold) to the individual detailed comments. Numerous figures are shown in our response to illustrate our points but some are not included in the revised manuscript.
We have addressed all the reviewers 'comments and modified the manuscript and figures accordingly.

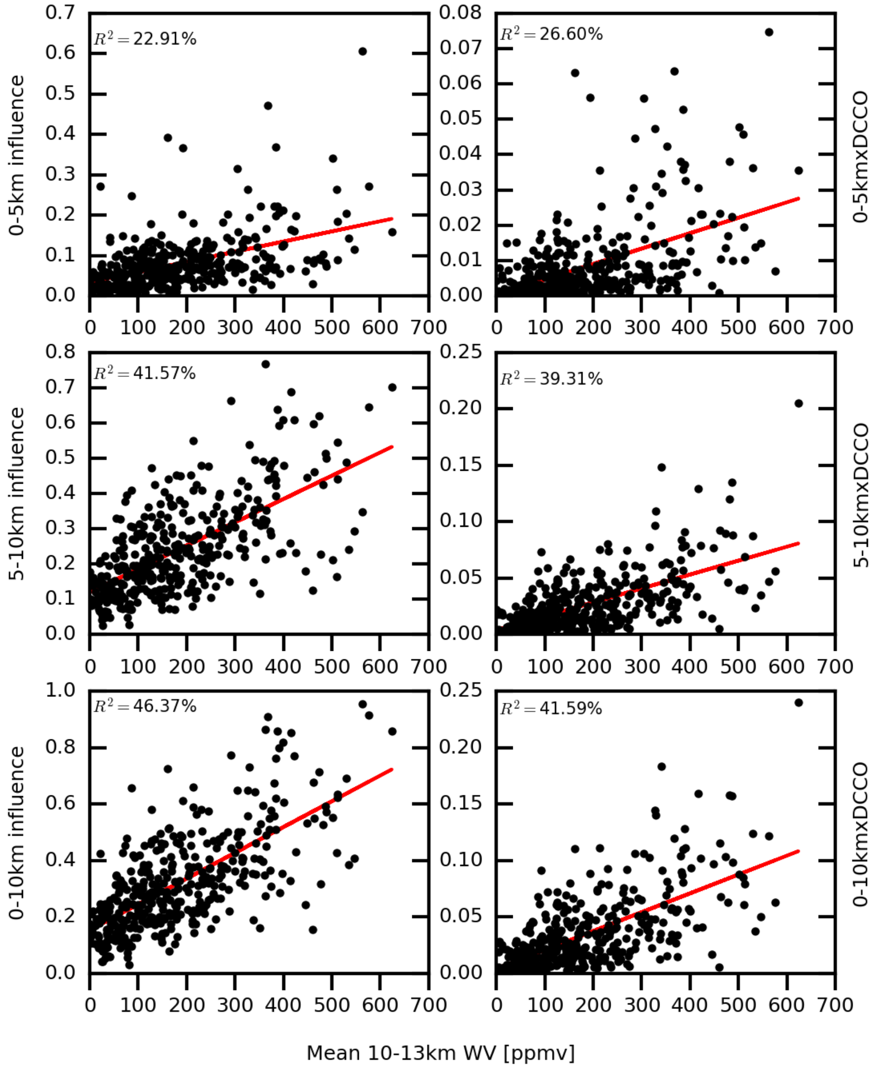
Major Comments:
1. The RH data used comes from daily radiosonde measurements. The standard instruments used in radiosondes have long been known to suffer from significant dry biases in the upper troposphere and stratosphere due to instrument limitations and icing in supercooled liquid clouds (e.g., Miloshevich et al. 2004). No mention is given in the article on the quality of the RH measurements in the radiosonde data used and whether or not a correction has been applied to these data to account for known sources of dry bias. This is an important issue because it impacts much of the analysis presented.

We agree that standard instruments used in radiosondes have long been known to suffer from significant dry biases in the upper troposphere and stratosphere. We compared the M10 measurements of RH (with respect to water) with Cryogenic Frospoint Hygrometer (CFH) water vapor sondes at the Maïdo Observatory (21.08°S, 55.38°E on the west coast of the island, 20 km away from the airport). Balloon-borne measurements of water vapor and temperature started in 2014 at the Maïdo Observatory on a campaign basis within the framework of the Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN) network (Bodeker et al., 2015). The balloon sonde payload consists of the CFH and the Intermet iMet-1-RSB radiosonde for data transmission. The iMet-1-RSB radiosonde provides measurements of pressure, temperature, Relative Humidity (RH) and wind data (speed and direction from which zonal and meridional winds are derived). The CFH was developed to provide highly accurate water vapor measurements in the Tropical Tropopause Layer (TTL) and stratosphere where the water vapor mixing ratios are extremely low (~2 ppmv). CFH mixing ratio measurement uncertainty ranges from 5% in the tropical lower troposphere to less than 10% in the stratosphere (Vömel et al., 2007b); a recent study shows that the uncertainty in the stratosphere can be as low as 2-3% (Vömel et al., 2016). The CFH instrument is often launched in tandem with the Modem M10 sonde. The CFH RH data were calculated with the CFH water vapor mixing ratio and the Intermet iMet-1-RSB temperature using the water vapor pressure equation by Hyland and Wexler (1983) and interpolated to the same 200-m vertical grid as the M10 data. A total of 17 multiple-payload (CFH+M10) soundings is used for the comparison shown on Figure 1. The RH profiles from the CFH and Modem M10 show good agreement with differences of less than 10% mostly from the surface to the stratosphere. In the lower troposphere, below 5km, the mean RH difference is -1%. In the middle (5-10km) and upper troposphere (10-15km) the mean RH differences are 1.5 and 2.2% respectively. Near 15km, the M10 RH shows dry biases with a peak difference of -3.7% at 15.6km (the mean RH at this level ranges from 18.5 for the M10 sonde to 22.2% for the CFH sonde). Figure 1 is not shown in the revised manuscript but we have included some text on the comparison between the M10 and CFH sondes in section 2.1.



<u>Figure 1: Vertical profiles of mean RH obtained from 17 multiple-payload sounding of CFH&M10 radiosondes (blue and black curves respectively on the left panel) at the Maïdo Observatory over 5 years (2014-2019). The mean profile of differences in RH is shown on the right panel.</u>

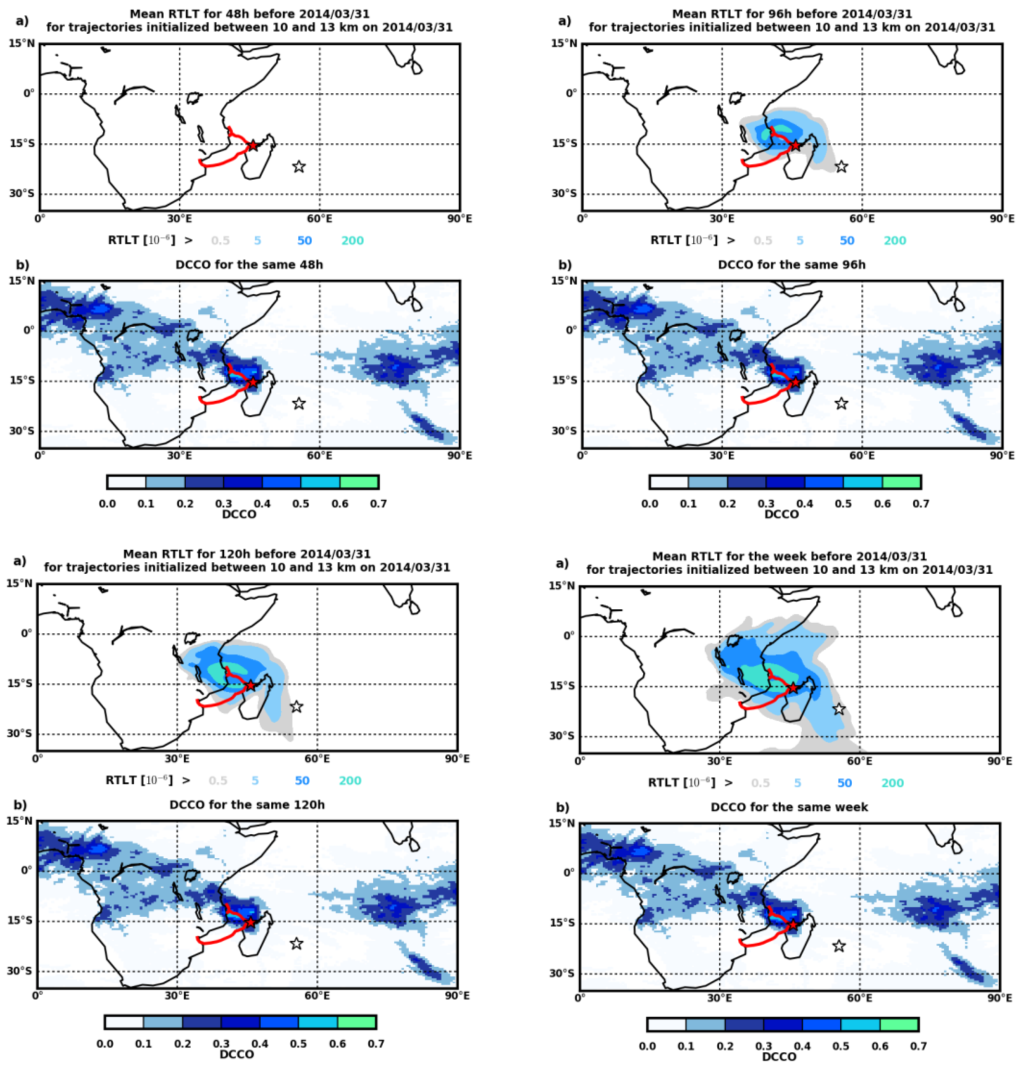
2. The use of a trajectory model to track air mass history and identify boundary layer sources of air associated with convection is a good approach to analysis, but the accuracy of the parameterized subgrid-scale motions along the trajectories is not well demonstrated. How well does the parameterized convection match actual convection in this region? The reliability of this approach is fundamental to the analysis and arguments presented in the paper and an assessment should be provided. The lack of agreement in RTLT and DCCO for the case study included in the paper (i.e., Figure 8) is particularly concerning as it suggests the parameterized convection fails to represent much of that observed (at least for the week shown). The only element of the paper acknowledging this potential issue (lines 299-305) is, in my opinion, insufficient.



<u>Figure 2: Correlations between mean upper-tropospheric water vapor mixing ratio (WV), residence times in the troposphere (0-5km RTLT, 5-10km RTMT and 0-10km RTLT+RTMT) and tropospheric residence times multiplied by DCCO. Backtrajectories over one-week were computed with the FLEXPART Lagrangian model.</u>

The location, intensity and vertical extent of deep convection in the FLEXPART model is determined by the calculation of a CAPE and the atmospheric thermodynamic profile using the meteorological fields from ECMWF. The trajectories are then redistributed vertically by a displacement matrix. Hence, the accuracy of the convective cells' location will be driven by the convective cells' locations within the ECMWF model output. An analysis on the correlations between WV mixing ratio and residence time calculated with 168h FLEXPART backtrajectories found at different altitude range in the troposphere is shown on figure 2. The first row shows the correlation between WV and RTLT (0-5km, left) or the product of RTLTxDCCO (right). According to the correlation calculations, 23% to 27% of the WV variability is explained byRTLT or RTLTxDCCO. Different phenomena can influence the upper tropospheric water vapor variabilty, such as deep convection, gravity waves or large-scale uplift of air masses. The low value of the R² factor is therefore difficult to interpret.
The second row on Figure 2 shows the correlation between WV mixing ratio and the rate of residence time in the middle troposphere (RTMT) between 5-10km altitude. The R-squared coefficient between RTMT and WV is 41.46%. The study of Schumacher et al. (2015) has shown that stratiform clouds have a vertical speed up to 10m s^{-1} below 7km and then a slow ascent (<0.5 m s^{-1}) up to 10km. It suggests that a higher correlation between WV and in RTMT than in RTLT can be expected for these kinds of clouds.

To conclude, the RTLTxDCCO product can represent only the influence of deep convective clouds, while higher R-squared coefficient with RTMT with WV shows that stratiform clouds can contribute to enhance the WV mixing ratio in the 10-13km range. We added comments in section 2.3 and 3.4.2.



<u>Figure 3: Panel of RTLT (rows 1,3) and DCCO (rows 2,4) calculated using different duration of backtrajectories, initialized on 31 March 2014, during the passage of Tropical cyclone Hellen cyclone. Upper panel: backtrajectories over 48h (left) and 96h (right). Bottom panel: backtrajectories over 120h (left) and 168h (right).</u>

Figure 3 presents the residence time in the lower troposphere for the case study of the Tropical cyclone Hellen calculated with 48h, 96h, 120h, and 168h FLEXPART backtrajectories. After 48h, no contribution in RTLT is found. After 96h, the RTLT is located north of the storm track, with an anti-clockwise dispersion toward Africa, outside the convective cells. It represents the fraction of air masses in the lower troposphere that was advected toward the convective clouds before reaching the 10-13km altitude range. The dispersion outside the convective cells increases with the 120h and 168h backtrajectories. Hence, it is clear that the colocation of RTLT with DCCO depends on the duration of the backtrajectories, and a poor value on RTLTxDCCO does not necessary mean that the trajectories were not lifted by deep convective clouds. The section 3.4.2 has been revised.

3. There is a missed opportunity to put the case study of tropical cyclones into broader context. Previous work on the impact of tropical cyclones on upper troposphere and lower stratosphere water vapor and ozone is not acknowledged and would help in the authors' interpretation and argumentation here (e.g., Ray & Rosenlof, 2007; Zhan &Wang, 2012). Moreover, I do not find the impact of tropical cyclones on upper troposphere RH to be convincing in the paper, likely related to my concerns outlined in #2 above.

We would like to point out that the study of Zhan & Wang in 2012 analyzed water vapor at a higher altitude range (Tropical Tropopause Layer between 14km and 20km) than our study.
However, the study of Ray and Rosenlof (2007) is relevant to our study and we thank you for pointing out this paper. A description of this study was added to the manuscript. Using AIRS and MLS satellite data, Ray and Rosenlof (2007) estimated the enhancement of water vapor within a 500 km radius of the center of 32 typhoons (Western Pacific) and 9 hurricanes (Northern Atlantic) at 223 hPa (~11km). They found an enhancement of up to 60 to 70 ppmv, within a 500 km radius north of the tropical storm centers, where the highest water vapor enhancement was found.
In the revised manuscript, we have included a list of tropical cyclones that have enhanced the WV in the upper-troposphere above Réunion Island. In 2014 summers the RTLT is influenced by tropical cyclones Hellen and Guito in the Mozambique Channel, Bejisa and Deliwe in the North East of Madagascar. In 2015, Bansi and to a lower degree Fundi in the Mozambique Channel, Chedza in the Northeastern part of Madagascar and in the eastern part of the basin, Haliba in the vinicity of Réunion Island have influenced the RTLT calculation.
The convective outflow of tropical cyclones that impacted the upper troposphere over Réunion Island was located south of the cyclone centers, the most hydrated part of the tropical cyclones in the Southern Hemisphere according to Ray and Rosenlof (2007).
Figure 4 presents the RTLT and DCCO for WV profiles that have been influenced by tropical cyclones in the South-West of the Indian Ocean in the previous 48h (row 1), 96h (row 2), 120h (row 3) and 168h (row 4). It is clear that the RTLT calculated with 48 and 96h backtrajectoires is collocated with DCCO of tropical cyclones. For longer backtrajectories (120h, 168h), RTLT covers a larger area in the lower troposphere, due to the advection of air masses in the lower troposphere.

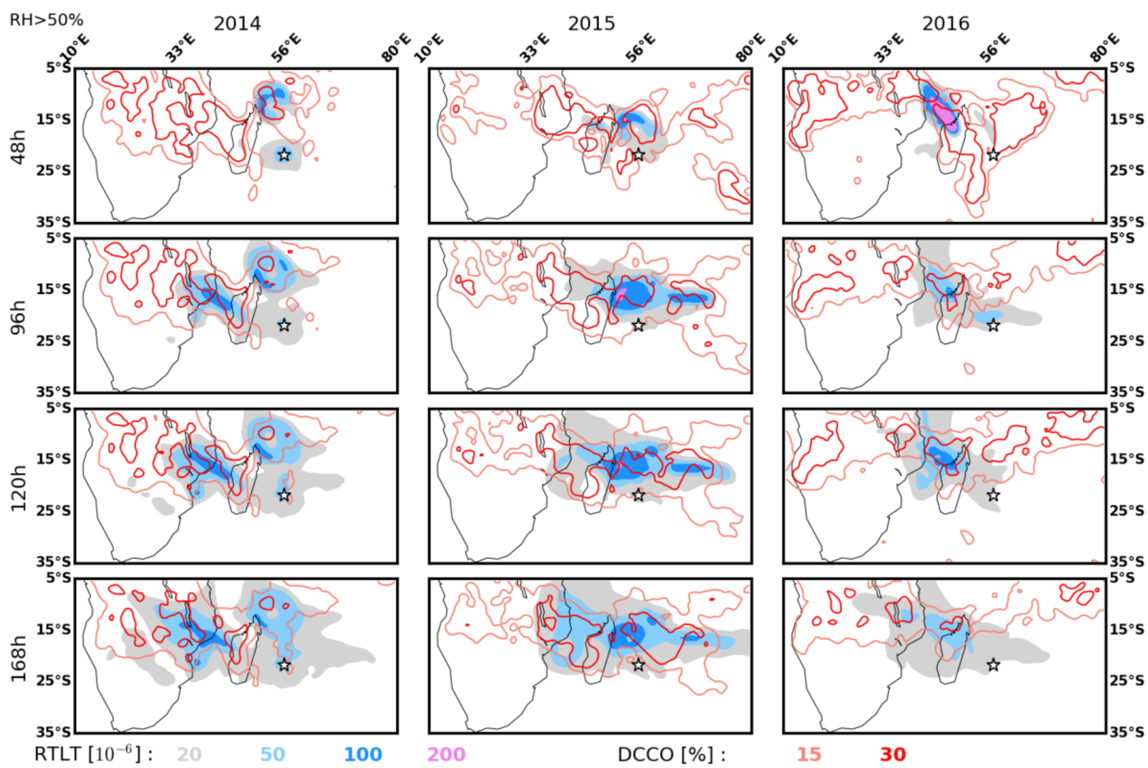


Figure 4: RTLT (filled contours) and DCCO (contours) calculated in the previous 48h (row 1), 96h (row 2), 120h (row 3) and 168h (row 4) for sounding associated with a tropical cyclone over the basin. Only the day with mean upper-tropospheric (10-13km) RH>50% have been selected.

Specific Comments:

Lines 134-135: "lower upper-tropospheric ozone values observed" is a bit confusing phrasing. Suggest rephrasing to "lower observed ozone values in the upper troposphere"

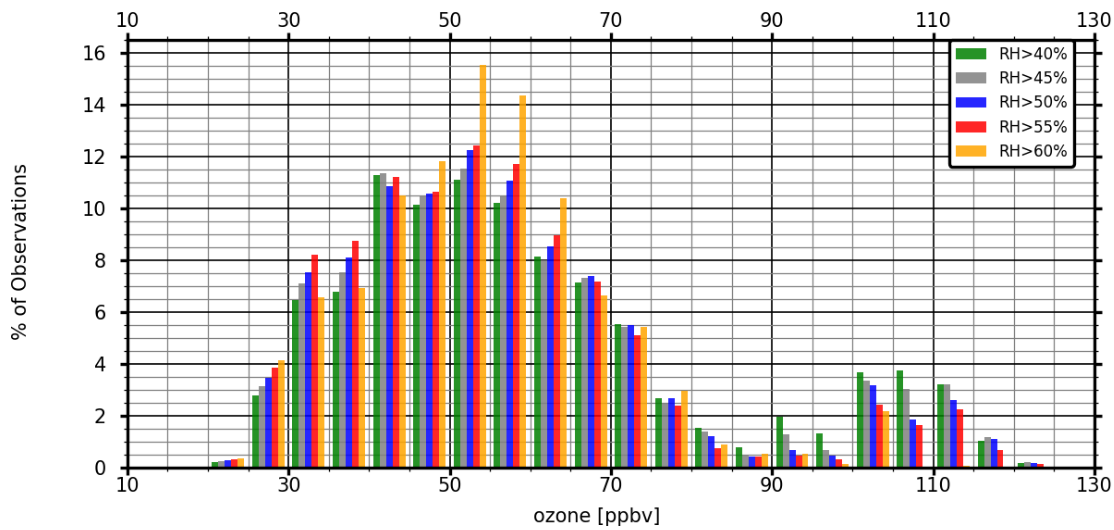
Added in the revised manuscript.

Line 144: suggest revising "the day" and "the latitude" to "day" and "latitude"Line 183: "affected by several three tropical cyclone events" Which is it several or three?

We meant "three", it has been corrected

Lines 194-195: Why is a threshold of 50% chosen? What is the sensitivity to this choice?

A threshold on RH had to be chosen to isolate the ozone profiles that most likely were impacted by convection. The average WV mixing ratio between 10 and 13 km in austral summer (182ppmv) is larger than in austral winter (65ppmv), certainly due to the effect of deep convection and associated moister transport/cloudiness. The average RH of air masses with a WV higher than 182ppmv is 48.8%. Hence, we decided to use a threshold of 50% to isolate the profiles with anomalously high WV mixing ratio. The sensitivity to the value of this threshold is rather limited. Figure 5 shows the sensitivity of the ozone distribution to the RH threshold. The ozone distribution is very similar for RH thresholds ranging between 40% to 55%.



<u>Figure 5: Upper tropospheric ozone distributions for RH>40% (green), RH>45% (grey), RH>50%(blue), RH>55% (red), RH>60% (orange).</u>

Lines 219-221: This statement doesn't seem appropriate. What if the responsible convection is land-based? One should expect a higher ozone mixing ratio in the boundary layer in that case. It seems reasonable that many/most convective sources for air in the upper troposphere at Reunion island would be land-based (e.g., look at Figure 3!).

Thank you for the comment, we have modified our statement as follow:
"Another explanation would be that land-based convection (from Madagascar or the African continent) lifted air masses enriched in ozone from the boundary layer." The comment has been added in section 3.2.

Line 221: comma should be a period
Corrected

Lines 343-346: as presented, this seems anecdotal and based on a single case. It Would be more convincing to show a map of the FLEXPART convective sources (i.e.,locations of most recent position in the lower troposphere) for matches with the RH profiles. It would help to better answer the question of importance of differences in boundary layer sources and mixing to impacting the upper troposphere ozone observed.

Figure 4 of my previous comment and our answer to the major comment or referee #1 should address your comment.

References

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