**Dear Referee,**

**Thank you so much for reading the manuscript so carefully and providing so many valuable suggestions. We have learned a lot from your comments! Thanks again! We have carefully read all your question and suggestion, and modifications have been made in the manuscript. My replies are as follows.**

## General Comments

(1) The authors refer to the temperature lapse-rate tropopause as the “thermodynamic” tropopause. It should instead by referred to as the “thermal” tropopause throughout. In addition, there are several alternative instances outlined under the specific comments section below of inappropriate, inaccurate, or unjustified claims in the text.

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 110, 117, 118.

(2) The motivation to carry out the study is principally focused on improving understanding of the microphysical characteristics of overshooting convection. The background bases this motivation on the need to clarify the efficiency of water vapor transported to the lower stratosphere by convective overshooting. However, the detailed analysis of the microphysical characteristics largely ignores characteristics near and within the overshoots. Rather, the focus is on altitudes at and below 12 km, which lie below the lowest tropopause altitudes over the analysis domain. The results presented are largely uninteresting and unsurprising given the modes evaluated (all observations, convection observations, and overshooting convection observations). The overshooting convection observations represent the extremes in convective depths, which (as expected) result in the highest liquid water paths and ice water paths. Conversely, the authors miss an opportunity to evaluate and contrast the characteristics specifically within the overshoots as more directly motivated in the analysis. Thus, I believe a more valuable contribution would be to revise the analysis to focus specifically on characteristics within the overshoot. To do so, it will be important to aggregate the data in a tropopause-relative altitude coordinate.

Answer: Thanks for your comments! ‘the efficiency of water vapor transported to the lower stratosphere by convective overshooting’ is really important and hot topic for ‘improving understanding of the microphysical characteristics of overshooting convection’. However, the motivation of this manuscript is mainly focused on the vertical and microphysical structure of precipitation within the convective overshooting. Driven by this purpose, we use precipitation parameters including particle size, concentration, phase state and other parameters provided by GPM to deeply and comprehensively examine the precipitation structure within the convective overshooting. Therefore, water vapor transported by convective overshooting is not the focus of this manuscript. In the future, we will combine multi-source data and modeling to further conduct detailed research on water vapor characteristics within convective overshooting.

As for ‘the focus is on altitudes at and below 12 km’, on the one hand, that is caused by the limited detection by GPM and detection above 12 km becomes unstable and the credibility of the data decreases. Therefore, we mainly use data below 12 km. On the other hand, for the study of water vapor transported by convective overshooting, study near the tropopause is more meaningful, but for the study of precipitation structure, we can see that the values of precipitation parameters above 12 km are very small, and the high value areas are mostly distributed below 12 km. From this point of view, it’s still meaningful for focus precipitation parameters on altitudes at and below 12 km.

In summary, main purpose of this manuscript is not to study the impact of convective overshooting on water vapor, but to reveal the vertical and microphysical structure of precipitation within the convective overshooting, which is a gap in previous research, and the results of this manuscript can also provide more accurate precipitation microphysical parameters as input for model simulations.

(3) The use of ERA5 to diagnose anomalies in ozone and water vapor concentration for the events seems problematic. For one, ERA5 is not demonstrated to resolve well the overshooting process (detailed comparisons of overshoot occurrence/frequency with the GPM data would be a good way to solve that, but my guess is that it can’t be shown convincingly on the model grid). Moreover, the horizontal and vertical resolution of ERA5 output is a considerable constraint on the degree to which meaningful results toward the study’s goals can be obtained. Beyond convection, resolution impacts the extent to which changes in the environment can be reliably deduced. Finally, it is not clear to what extent ERA5 data are validated against observed composition and demonstrated to be reliable. For example, most reanalyses are far too wet in the upper troposphere and lower stratosphere. Thus, is there really any considerable value about the impacts of overshooting that can be gained from analyzing this output? The use of this data and study design do not provide compelling or convincing evidence to support that.

Answer: Thanks for your comments! As you suggested in specific comments, we have deleted that part. However, comparing ERA5 with other popular data, advantage of ERA5 is obvious, and we still believe that water vapor and temperature from ERA5 can be used in convective overshooting. Focus of this manuscript should be more on the discussion of precipitation structure, and analysis of this part of profiles from ERA5 are rough, so we delete this part.

At present, the most common methods for detecting water vapor include sounding detection, occultation detection and reanalysis data. Sounding detection is the most accurate method as it involves on-site exploration. We have compared water vapor from ERA5, sounding detection (IGRA) and occultation detection (COSMIC), and results show that water vapor from ERA5 is relatively reliable (Sun et al., 2022), sho wn as Fig. 1. IGRA is the sounding detection, which can be used as a benchmark. Both case study and statistical results show that difference of water vapor between ERA5 and IGRA is small in the upper troposphere, indicating the credibility of water vapor from ERA5. Due to the lack of observation of IGRA near tropopause and lower stratosphere, we can only compare ERA5 with COSMIC. At this point, we can also see that although sounding data is more correct, it has obvious limitations in terms of detection height. Previous study has shown that water vapor from COSMIC is biased towards humidity (Kursinski et al., 1997). We can see that water vapor of ERA5 is generally lower than that of COSMIC near tropopause and lower stratosphere, indicating that ERA5 is relatively accurate compared to COSMIC. In addition, ERA5 has the highest spatiotemporal resolution, compared with other popular reanalysis data, such as JRA55 and MERRA2. In general, using ERA5 to study the impact of convective overshooting on temperature and water vapor is not a bad choice. In the future, we will refer to your suggestions and combine model simulation to conduct more detailed and in-depth research specifically on water vapor in the UTLS region.

Kursinski, E. R., Hajj, G. A., Schofield, J. T., Linfield, R. P., and Hardy, K. R.: Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System. Journal of Geophysical Research: Atmospheres, 102(D19), 23429-23465, https://doi.org/10.1029/97JD01569, 1997.

Sun, N., Zhong, L., Zhao, C., Ma, M., and Fu, Y.: Temperature, water vapor and tropopause characteristics over the Tibetan Plateau in summer based on the COSMIC, ERA-5 and IGRA datasets, Atmospheric Research, 266, 105955, https://doi.org/10.1016/j.atmosres.2021.105955, 2022.

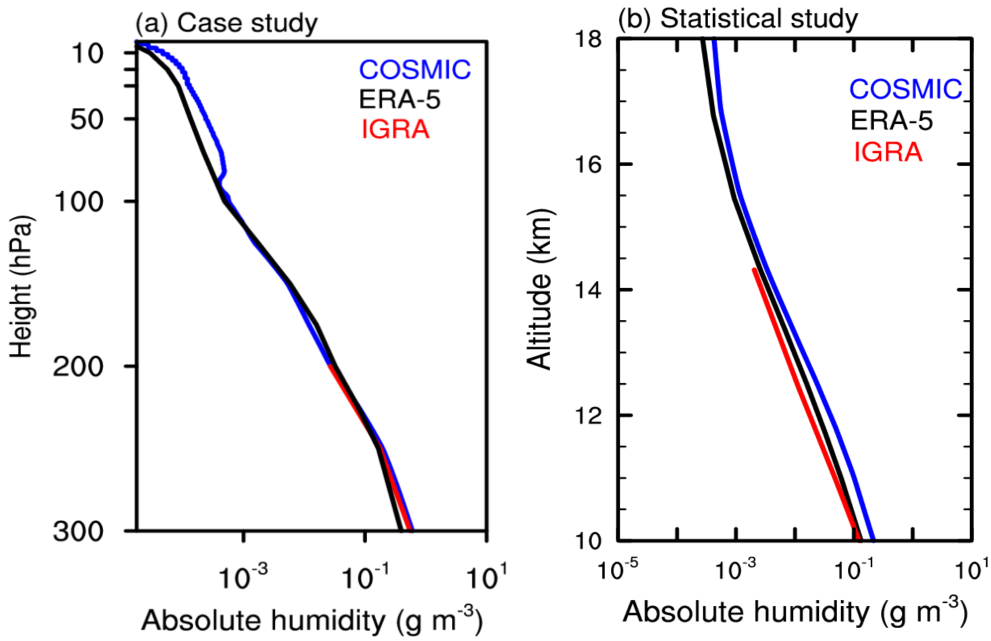


Figure 1 Case study and statistical study of water vapor profiles from COSMIC, ERA5, and IGRA

**Specific Comments**

(4) Lines 32-34: previous studies do not show that overshooting has a net dehydrating effect on the stratosphere. Several studies do show that convection and dehydrate the upper troposphere in the tropics, but otherwise convection has been universally shown to hydrate the stratosphere.

Answer: Thanks for your reminder, and modifications have been made in the introduction , shown as line 37-40.

(5) Line 39: The studies cited in this paragraph are almost entirely focused on tropical overshooting convection. Equal consideration/discussion related to prior work on midlatitude overshooting convection should be given here.

Answer: Thanks for your advice, and modifications have been made in the introduction, shown as line 45-50. And analysis of following references about midlatitude overshooting convection have been added in the introduction.

Smith, J. B., Wilmouth, D. M., and Bedka, K. M. et al.: A case study of convectively sourced water vapor observed in the overworld stratosphere over the United States, Journal of Geophysical Research: Atmospheres, 122(17), 9529-9554, https://doi.org/10.1002/2017JD026831, 2017.

Werner, F., Schwartz, M. J., and Livesey, N. J. et al.: Extreme outliers in lower stratospheric water vapor over North America observed by MLS: Relation to overshooting convection diagnosed from colocated Aqua - MODIS data, Geophysical Research Letters, 47(24), e2020GL090131, https://doi.org/10.1029/2020GL090131, 2020.

Wang, X., Huang, Y., and Qu, Z. et al.: Convectively Transported Water Vapor Plumes in the Midlatitude Lower Stratosphere, Journal of Geophysical Research: Atmospheres, 128(4), e2022JD037699, https://doi.org/10.1029/2022JD037699, 2023.

Liu, N. and Liu, C.: Global distribution of deep convection reaching tropopause in 1 year GPM observations, Journal of Geophysical Research: Atmospheres, 121, 3824-3842, https://doi.org/10.1002/2015JD024430, 2016.

Liu, N., Liu, C. and Hayden, L.: Climatology and detection of overshooting convection from 4 years of GPM precipitation radar and passive microwave observations, Journal of Geophysical Research: Atmospheres, 125, e2019JD032003, https://doi.org/10.1029/2019JD032003, 2020.

(6) Lines 52-54: it is not clear what the authors mean here. What is the difference between convective overshooting and deep convection?

Answer: Thanks for your question, and Modifications have been made in the manuscript, shown as line 66-67. Rain top heights of more than 10 km are defined as deep convection, whose rain top heights are more than 14 km are defined as convective overshooting. Deep convection includes convective overshooting, but overall it's not as strong as convective overshooting.

(7) Lines 55-56: "of the polarimetric radar" should be "of polarimetric radar observations"

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 70.

(8) Line 62: revise “ways for detecting convective overshooting is to find pixels” to“way for detecting convective overshooting from satellite is to find pixels in infrared imagery”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 76.

(9) Lines 66-68: Also, overshoots mix with relatively warm stratosphere air such that cold pixels are often diminish and not a reliable means to identify overshooting.

Answer: Thanks for your advice! We have added this to the manuscript, shown as line 83-84.

(10) Lines 83-84: because of what? This claim seems unsubstantiated to me. Synoptic evolution is typically slow and tropopause altitudes do not change rapidly (i.e., in periods <6 hr) in most circumstances. The varying latitude of the tropopause break, which is responsible for the band of high tropopause altitude deviation in Figure 1c, is a case where the tropopause could change rapidly, but it is also poorly constrained at such an abrupt transition.

Answer: Thanks for your reminder! We delete that sentence, shown as line 100-102.

(11) Line 88: “cold tropopause” should be “cold point tropopause”. Also, as mentioned above, here and after “thermodynamic tropopause” should be “thermal tropopause”.

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 106, 110, 117, 118.

(12) Lines 117-118: why choose June, July, and August only? Is it based on Liu et al. KuPR results?

Answer: Thanks for your question! On the one hand, observations and model simulations show that deep convection over land more frequently overshoot the tropopause during summer (June, July and August) and inject ice and water vapor into the lowermost stratosphere in midlatitude (Wang et al., 2023). On the other hand, due to limited space, only one season can be selected for in-depth research. In the future, we will specialize in the seasonal variation characteristics of convective overshooting.

Wang, X., Huang, Y., and Qu, Z. et al.: Convectively Transported Water Vapor Plumes in the Midlatitude Lower Stratosphere, Journal of Geophysical Research: Atmospheres, 128(4), e2022JD037699, https://doi.org/10.1029/2022JD037699, 2023.

(13) Section 2.2: what ERA5 products do you use. Specifically, what grid spacing (horizontal and vertical)? Those are important details to note regardless of how it is used.

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 145-146, 148-151.

(14) Lines 154-166: I don't find much value in this analysis.

Answer: Thanks for your advice! We rewrote this paragraph, shown as line 208-225.

(15) Line 159: "else region" should be "otherwise"

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 214.

(15) Line 195: "allow" should be ", which allows"

Answer: Thanks for your advice! Another referee also pointed out this issue. Combining your two suggestions, modifications have been made in the manuscript, shown as line 256.

(16) Lines 196 & 198: "penetrate *the* troposphere" should be "reach the stratosphere"

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 257.

(17) Lines 199-201: unnecessary - recommend deleting

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 261-263.

(18) Line 204: "with regionally different" should be "varying regionally (Table 1)"

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 266.

(19) Lines 204-206: no need to repeat numbers from the table here. Just describe the differences.

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 266-269.

(20) Section 3.2.2. The diagrams referred to here as DPDH would be more appropriately referred to the community standard of CFADs (contoured frequency by altitude diagrams). Also, there are many instances of "the zero level". What is meant

by this? Do you mean the altitude where the temperature is 0 ℃? If so, that is not evidenced by any of the analysis that you show!

Answer: Thanks for your advice! “DPDH” have been modified to “CFADs”, shown as line 276, 279, 280, 286, 428, 430, 786-791. And we have added the explanation of “the zero level” in the manuscript, shown as line 289-290.

(21) Line 217: delete “obviously”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 280-281.

(22) Line 219: “peak 47” should be “peak near 47”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 282.

(23) Line 222: “feature are” should be “character is”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 286.

(24) Line 227: rather than more ice crystals, this could alternatively imply they are larger.

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 292.

(25) Line 231: “very” should be “much”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 296.

(26) Line 233: “precipitation” should be “production”

Answer: Thanks for your advice! Another referee also pointed out this issue. Combining your two suggestions, modifications have been made in the manuscript, shown as line 298.

(27) Lines 304-345: This should all be removed based on the comment provided above.

Answer: Thanks for your advice! We remove that, shown as line 370-411.

(28) Line 350: “a more accurate algorithm”. Based on what evidence?

Answer: Thanks for your question! After thinking about the question, we have changed this sentence to “a reliable algorithm”. Here’s and explanation of why this algorithm is reliable. First of all, the algorithm design is strictly based on the principle of the definition of convective overshooting (Rain top height higher than tropopause height), which ensures the accuracy of the algorithm in principle.

From the perspective of the data input of the algorithm, tropopause height calculated from ERA5 and rain top height from GPM DPR are reliable. We have compared tropopause height calculated from ERA5 with sounding observation (IGRA), occultation detection (COSMIC) and reanalysis data (JRA55 and MERRA2) (Sun et al., 2021). Results show that tropopause calculated from ERA5 is reliable. Rain top height data here we use mainly relies on GPM KuPR’s echo top height and KuPR is good at detecting intense precipitation like convective overshooting (Kojima et al., 2012), which guarantee the accuracy of the detection of rain top height. Based on the principle of the algorithm and the input data, the detecting method in this manuscript is reliable.

Sun, N., Fu, Y., Zhong, L., Zhao, C. and Li, R.: The Impact of Convective Overshooting on the Thermal Structure over the Tibetan Plateau in Summer Based on TRMM, COSMIC, Radiosonde, and Reanalysis Data, Journal of Climate, 34, 8047-8063, https://doi.org/10.1175/JCLI-D-20-0849.1, 2021.

Kojima, M., and Coauthors: Dual-frequency precipitation radar (DPR) development on the global precipitation measurement (GPM) core observatory, Earth Observing Missions and Sensors: Development, Implementation, and Characterization II, H. Shimoda et al., Eds., International Society for Optics and Photonics (SPIE Proceedings, Vol. 8528), 85281A, https://doi.org/10.1117/12.976823,2012.

(29) Line 356: delete “obviously”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 422.

(30) Lines 359-360: “differences. And” should be “differences, and”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 426.

(31) Line 364: “And the” should be “The” & “obviously” should be “obvious”

Answer: Thanks for your advice! Modifications have been made in the manuscript, shown as line 430.

(32) Lines 384-397: remove

Answer: Thanks for your advice! We remove that, shown as line 451-464.