

Dear reviewer #1,

Thank you for taking time to reply to review our manuscript.

Please, find our response to your comments below.

In order to help you figure out where changes have been made in the paper, we also attach a specific version of the revised paper changes are written in blue (following both reviewers' request).

Best regards,

Review of Influence of atmospheric waves and deep convection on water vapor in the equatorial lower stratosphere seen from long-duration balloon measurements by Carbone et al.

This paper makes use of data from the STRATEOLE 2 campaign to assess the influence of atmospheric waves and deep convection of water vapor in the tropical upper troposphere and lower stratosphere. The authors' method relies on variations in the Pearson correlation coefficient to determine when atmospheric waves are drivers of variations in water vapor concentration. Overall, the dataset and method used here are interesting and novel and will be of interest to ACP readers.

I do have some concerns over the paper which I believe should be addressed before publication. Specifically, the readability of the paper can be greatly improved through reduction of redundancies and careful consideration of which details need to be included for the authors to get their message across. My detailed comments are below.

General Comments:

1. There are several cases throughout the paper where figures are described in detail in both the main text and the figure caption, for example, in Line 121. Removing some of these unnecessary details from the main text may help to improve the flow of the paper.

Authors: Done. We removed unnecessary details in the text.

2. There are some parts of the study which seem secondary (or tertiary) to the main goal of the paper and are perhaps better suited for supplementary material to not overwhelm a reader with details that may be less necessary for their purposes. For instance, section 3.2 and associated figures 4 and 5 do not add anything substantial to the focus of the study and therefore I suggest they be added to supplementary material instead.

Author: The section 3.2 has been moved to the Appendix A1.

3. Throughout the manuscript, the Pearson's r correlation is mentioned many times, but frequently with errors varying from "Pearson's r " to "Pearson's r " to "Pearson's r ", etc. Please review and fix these occurrences.

Authors: Done. We therefore used a consistent terminology, which is Pearson's correlation coefficient.

4. Throughout the paper, there seems to be a lack of “polish” to the writing, specifically when it comes to spelling, misplaced words, and sentence structure. I tried to point out a number of these in my technical corrections below, but I am sure there are quite a few that I missed. I believe the manuscript needs to be reviewed thoroughly by the authors to ensure their message is clear to readers.

Authors: we have proceeded with wording revisions. We hope that the revised version is better.

Specific Comments:

1. Lines 15-16: A bit wordy for first sentence of abstract, especially “intended to fly over the...”

Authors: We reworded the sentence such as : « The Strateole 2 project consists of 3 campaigns of super pressure balloons released from the Seychelles. The balloons have flown in the whole equatorial belt transported by winds during 3 to 4 months. »

2. Line 18: Either include “(H₂O)” for consistency with other gases or get rid of the chemical formulas for the other gases

Authors: We have added « H₂O » to water vapour for consistency with other gases.

3. Line 20: Add “(r)” after Pearson correlation coefficient

Authors: In the whole manuscript, we choose the denomination « Pearson’s correlation coefficient».

4. Lines 35-38: These sentences are quite redundant; suggest combining

Authors: We revised such as : « Observational studies have shown that the global temperature is sensitive to small changes of water vapour in the lower stratosphere (Forster and Shine, 1999; Solomon et al., 2010; Wang et al., 2017). »

5. Line 39: suggest changing to “the observed increase of stratospheric...”

Authors: Done. We included the following citations : (Oman et al., 2008; Noël et al., 2018; Tian and Chipperfield, 2006).

Oman, L., D. W. Waugh, S. Pawson, R. S. Stolarski, and J. E. Nielsen, 2008: Understanding the Changes of Stratospheric Water Vapor in Coupled Chemistry–Climate Model Simulations. *J. Atmos. Sci.*, 65, 3278–3291, <https://doi.org/10.1175/2008JAS2696.1>.

Noël, S., Weigel, K., Bramstedt, K., Rozanov, A., Weber, M., Bovensmann, H., and Burrows, J. P.: Water vapour and methane coupling in the stratosphere observed using SCIAMACHY solar occultation measurements, *Atmos. Chem. Phys.*, 18, 4463–4476, <https://doi.org/10.5194/acp-18-4463-2018>, 2018.

Tian, W., and M. P. Chipperfield (2006), Stratospheric water vapor trends in a coupled chemistry-climate model, *Geophys. Res. Lett.*, 33, L06819, doi:10.1029/2005GL024675.

6. Line 40: Needs citation

Authors: Done.

7. Line 43-44: consider using the oxford comma here and throughout paper for consistency

8. Paragraph starting at Line 45: Recent literature from William Randel is very relevant and should be included in this paragraph (e.g., <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JD030648>).

Authors: Thank you for suggesting this reference. We have included it to the citations.

9. Line 99: Suggest adding quick general description of location of Seychelles Islands

Authors: We have slightly revised the sentence such as : « Strateole 2 relies on 3 long-duration campaigns where a flotilla of superpressure balloons is launched from the Mahé Island, the Seychelles archipelago, in the Indian Ocean off East Africa ».

10. Line 107: what exactly is the Zephyr gondola?

Authors: We provided additional details in the manuscript :

« The balloons can carry up to 15 kg of scientific instrumentation, allowing to probe several meteorological and chemical variables (wind, pressure, temperature, aerosols, clouds, water vapour, other gases etc.) in situ. The well-functioning of the instruments is ensured by the Zephyr gondola, which is located 2 meters upstream Pico-STRAT Bi Gaz on the flight chain. Zephyr is a gondola which provides power (through solar panels), positioning and timing information (onboard GPS receiver) and communication to the ground control center (using iridium space-borne communication system) to scientific

instruments. Some instrumentations are located inside the Zephyr gondola to protect electronics from the environment cold temperatures (e.g. TSEN). »

11. Line 133: Sentence starting with “This allows...” needs to be reworded, maybe something along the lines of “This allows for the dramatic reduction of the optical path length and thereby enlightens the instruments.”

Authors: We propose the following revision : « The strong line intensities of fundamental bands allow to dramatically reduce the optical path length and thereby enlighten the instruments. »

12. Line 139: Please define HITRAN

Authors: The acronym has been defined.

13. Line 148-149: This sentence is a bit unclear, suggest rewording and using a word other than “deported”, perhaps “transported”?

Authors: the sentence has been reworded : « The optical cell, including the laser diodes and the detectors, is not located in Zephyr but hanging down below the Zephyr gondola, at a 2-m distance. »

14. Line 150-151: This sentence needs to be reworded but I also don't really understand what its trying to say. For instance, what is the compromise that is being discussed?

Authors: Measuring water vapour in the dry TTL requires that the instrument lies in ambient air and not within the Zephyr gondola. The super pressure balloon capacity limits the instrument total weight to 5 kg. To protect the electronics of Pico-STRAT Bi Gaz from frost, it has been installed in Zephyr. The rests of the instrument (the optical cell : sensing area) has to hang down below by 2m. Such distance require to design a feeding cable, weighting already 1.2 kg.

Due to the 5kg limit, the length of the cable had to be limited to 2m, which has some impact on the measurements : daytime contamination from outgassing (from Zephyr and balloon), which could be reduced if the distance between the optical cell and the rest of the flight chain (Zephyr and balloon) was much longer (typically 30 m). Unfortunately, such length could not be implemented due to the overweight it would cause and other technical issues related to CNES certification process.

We revised this paragraph to clarify, such as :

« The optical cell, including the laser diodes and the detectors, is not located in Zephyr but hanging down below the Zephyr gondola, at a 2-m distance, to limit the contamination of water vapour measurements from outgassing Zephyr and balloon surfaces. In this

configuration, the electronics module is connected to the lasers and the detectors using 2.5-m shielded cables. »

15. Line 157: Please include the MLS layer vertical spacing, i.e. X levels per decade of pressure

Authors: Done.

16. Paragraph starting at Line 166: I don't think the few uses of "CTH" warrant using an acronym rather than just spelling out the words

Authors: this is to slightly improve the flow.

17. Figure 3a: I really love the design of this figure and think it's a very interesting way to show the comparisons of the datasets, however, the color range is a bit narrow so it is hard to fully see the differences within each MLS circle. Perhaps look at some alternative possible color tables? And ensure they are colorblind friendly.

Authors: We slightly adjusted the color scale of the anomalies (H₂O) so the contrast between in situ and mean MLS value is more visible. It passes COBLIS tests.

18. Tables 1-3: Why are these commas instead of periods?

Authors: Done.

19. Section 3.3: I really like this section! Figure 6 is a very pleasing result in my opinion

Authors: Thank you!

20. Line 203: First usage of ECMWF and ERA5, please define.

Authors: we included the acronym signification of ECMWF and ERA 5 definition.

21. Figure 6 caption: Please indicate what the gray lines are

Authors: After moving the old section 3.3 to the Appendix, figure 6 becomes Figure 4.

The grey lines are the MLS vertical profiles taken ± 2 days around the position of depressurisation events of Pico-STRAT Bi Gaz. This is already stated in the caption.

22. Section 3.4: This section was very hard for me to understand, even after reading it

several times. I suggest reworking and potentially condensing as much as possible.

A couple of things that I feel could benefit from clarification:

- a. What are the plus or minus ranges for all these values? A SD? 95% confidence?
- b. Be extra clear about what specific datasets are being used to calculate each pearson r. I was confused if we were comparing between observations or between one observation (which one?) and ERA 5?
- c. Speaking of ERA5, as this plays a large role in this analysis, this should be discussed/described in the data section, with a citation.
- d. Because of some of my confusion with understanding what datasets are being compared, I also don't fully understand how the Pearson r values are compared with the mean difference values and how that relates to the claimed physical mechanisms? Is it about what can be resolved in ERA5 versus what cannot? What size waves?

Authors: we revised the section, removing extra information which may have caused confusion.

The key elements are that : 1- the ERA5 temperature reproduce well in situ observations, and therefore are reliable for the analysis ; 2- Some larger differences between in situ Pico-STRAT and ERA5 temperatures can be observed in the case of in situ modulations due to waves or to deep convective events which are not resolved by the reanalysis.

23. Lines 297-299: Suggest rewording to “.... Thus limiting the spectrum of atmospheric waves reproduced by the analysis to wavelengths...”

Authors: we revised the sentence such as : « The horizontal resolution of ERA5 temperature fields is of 0.25°x 0.25° (about 28 km), thus limiting the spectrum of atmospheric waves resolved by the analysis to horizontal wavelengths greater than ~ 120 km. »

24. Line 303: The range of latitudes averaged over in ERA 5 should be added to the figure caption instead of this sentence

Authors: we revised this paragraph such as « Figure 5 shows longitude/time quasi-Lagrangian Hovmöller diagrams of temperature anomalies for the 5 flights of Strateole 2 carrying the Pico-STRAT Bi Gaz instrument. The temperature anomalies (ΔT) are calculated such as:

$$\Delta T = T - \bar{T}$$

Where T is the average temperature of ERA 5 over $\pm 5^\circ$ around the mean latitude of the balloon for each night and \bar{T} is the zonal mean temperature over the same latitude band. \bar{T} ».

We also completed the caption of Figure 7 (now Figure 5) such as:

« Figure 5. Longitude/time “quasi-Lagrangian” Hovmöller diagrams in temperature anomalies for each flight with their night-time trajectory color-coded as a function of their water vapour anomalies. The temperature anomalies are calculated hourly as the difference between the ERA5 temperatures averaged over $\pm 5^\circ$ around the mean latitude of the balloon for each night and the zonal mean temperature over the same latitude band. (a) C0_05_TTL2. (b) C1_12_STR4 flight. (c) C1_03_TTL4 flight, (d) C1_07_TTL4 flight, (e) C1_15_TTL4 flight. ».

25. Figure 7: Think black outlines around the circles in this figure could help to make them more visible

Authors: We are not sure to understand what you mean. If you mean that each small circle of the trajectory of the balloon should be surrounded by black lines, it would certainly bring more contrast with respect to the temperature anomalies of the Hovmöller diagrams, but the water vapour anomalies surimposed to the balloon trajectory would then be unreadable. In some cases, the circles can overlap, especially when the balloon is turning around.

We therefore surimposed the balloon trajectory in black dash line to improve visibility on the trajectory location.

26. Lines 312 – 336 and figure 8: This detail may be better suited for the methods section or supplementary materials, as it feels more like a methodology than results and distracts from the results you are trying to describe in this section

Authors: We do understand your point. However, we prefer to keep this section because it directly illustrate the interpretation of the results and provides clue to the reader to understand the approach (correlation or anti-correlation between the temperature anomalies due to waves and the water vapour anomalies).

27. Line 360: What exactly are the “unfavorable” tape recorder dynamics?

Authors: Unfavourable tape recorder dynamics is when the balloon evolves at a level close to vertical gradient reversal or in an altitude range where the vertical gradient of water vapor is small.

We revised the text such as : « Modulations of this Pearson’s correlation can occur when, on some portion of the flight, the balloon evolves at a level close to a vertical gradient reversal or in an altitude range where the vertical gradient of water vapour is small (leading to null correlations). Additional contributions from other short time or local processes like overshooting deep convection can also be a cause. »

28. Line 406: a brief discussion/description of Typhoon Rai could be helpful here for context

Authors: we have added elements of information about Rai : « Rai is one of the most intense typhoons of the 2021 season. It started to develop on December 8, 2021, in the Northeast of New Guinea, in the Pacific Ocean. It reached the Category 1 of the Saffir-Simpson scale on December 14, 2021. On December 15-16, 2021, it reached the Category 5 and hit the Philippines. »

29. Line 463: Reword “none of them shows undoubtedly a signature of deep convection”

Authors: we have rephrased the paragraph so the meaning is more clear, such as :

« On the opposite, several nights with depressurization events are associated with wet anomalies, C0_05_TTL2 December 23, 2019, and January 28, 2020; C1_07_TTL4 November 8, 2021, December 8 and 14, 2022; C1_15_TTL4 December 12 and 13 2021. For these cases, satellite observations of HIMAWARI show that the balloons were overpassing deep convective systems while no direct signature of direct injection has been observed. Instead, the signatures which are observed depict a quasi-linear trend with potential temperature, suggesting isentropic displacements, but the amplitude of the anomalies cannot be explained only considering those displacements. These cases represent the limit of our methodology and are not easily interpreted.»

30. Line 523: Reword “Not seen in Fig. 11 but seen in Fig. 10b”

Authors: Done. We rephrased such as « On November 25, 2021, a significant hydration (higher than 0.65 ppmv) at about 420 K is observed (though not during a depressurization night) during the C1_07_TTL4 flight (see Fig. 8b). »

31. Line 526: By “vicinity of the decreasing phase”, do you mean the dissipating phase of the tropical storm?

Authors: Yes. We therefore rephrased « The balloon has flown in the vicinity of the Paddie tropical storm Northeast of Australia, while the storm was dissipating. The back trajectories calculation did not undoubtedly prove the overpass of a severe convective cell from Paddie. »

32. Line 526: Some context about tropical storm Paddie could be helpful here

Authors: We have included a short description of Paddy (misspelled in the original version of the article) :

« The balloon has flown in the vicinity of the Paddy tropical storm Northeast of Australia, while the storm was dissipating. Paddy was a relatively short-lived storm that

formed North-West of Australia. It did not reach the typhoon category but impacted Micronesia. »

33. Figure 11: I am having a very hard time reading this figure. The combination lower resolution and higher resolution cloud tops within each panels is very confusing. Why are there seemingly multiple resolutions from one product? Perhaps smoothing could help to make this figure more digestible. Additionally, I suggest making the balloon observations a bit larger so they can stand out against the background.

Authors: To plot this figure, we are using the CTHH product made available for the scientific community. We are not able to justify why, in some specific locations and dates, the resolution of the product is degraded. So there is nothing we can do get rid of this combination of different resolutions within each pannels. We have carried out different tests of smoothing, but it didnt make any improvement. So here, we decided keep the same resolution as it was previously. However, answering to your second point, we have made the ballon observations a bit larger in each panels.

34. Line 545: Specify tropical cyclones, not just cyclones in general

Authors: Done.

Technical Corrections:

Authors: We have applied all the below-listed technical revisions and, in general, revised the wording of all the manuscript.

1. Line 31: In the light of à in light of
2. Line 40: and to the à as a result of
3. Line 45: in tropical tropopause layer à in the tropical tropopause layer
4. Line 94: accent should be removed from STRATÉOLE
5. Line 103: It is a bit hard to tell in this formatting, but there are some off occurrences of new paragraphs that should be double checked
6. Line 114: Add comma – altitude of 20.5 km thus above à altitude of 20.5 km, thus above
7. Line 127: an heritage à a heritage

8. Line 152: allows to demonstrate à demonstrates
9. Line 158: In the frame of the present study à In the present study
10. Line 271: ZEPHYR à Zephyr for consistency with the rest of the paper
11. Line 278: 8K à 8 K
12. Line 278: present are large à present large

Authors: This comment do not apply anymore following revisions of this subsection.

13. Line 300: No need to mention (a,b,c,d,e) for figure 7.
14. Line 301: Strateole should be in all caps for consistency with the rest of the paper.
15. Line 395: here you stated typhoon Raï but later just say Rai, please select the correct one and use consistently throughout
16. Line 404: has been à was
17. Line 417: isentropic level à isentropic levels
18. Line 425: to a fast à with a fast
19. Line 449: week à weak
20. Line 461: “on the opposite” needs to be reworded

Authors: we used « On the other side »

21. Line 503: besides à outside of
 22. Line 509: to à too
 23. Line 520: hours à hour
 24. Line 527: Autralia à Australia
 25. Line 553: Suggest changing “exposes” to a different word
 26. Line 568: could à can
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Dear reviewer #2,

Thank you for taking time to reply to review our manuscript.

Please, find our response to your comments below.

Also attached a new version of the paper with changes provided in blue, according to both referees' request

Best regards,

Carbone et al. provide a study where they relate water vapor distribution with wave activity and deep convection. They employ super pressure balloons observations to give unique insights on the influence of tropical waves and deep convection on stratospheric water vapor. In their study they identify one flight with clear indication of water vapor modulation of waves, while the influence of deep convection is analyzed on the example of typhoon Rai. The paper is well organized, and the science is novel and after a few clarifications worthy of publication. I thoroughly enjoyed reading the manuscript and mostly have technical comments to improve readability.

Main comments:

Line 76f: The sentence does not make sense at the moment. Please rephrase.

Authors: Done

Line 85: "Water vapor anomalies..." this sentence needs to be moved to the methods section

Authors: we have removed this sentence since it is redundant with the introductive paragraph of section 3. Methodology.

Line 103f: I would suggest rephrasing the sentence to: once at float level, the balloons drift with the wind either east- or westward depending on the QBO phase.

Authors: thank you for this suggestion. Done.

Line 111: what does "has evolved in the wet phase" mean?

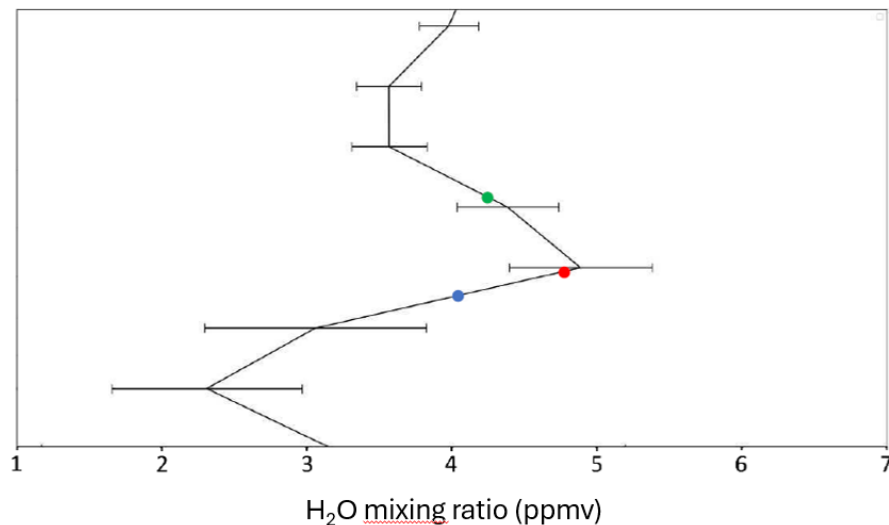
Authors: We wanted to emphasize that the flight occurred within the wet phase of the tape recorder, but this was not well written. Instead, we replaced the sentence by : « It flew for 79 days within the wet phase of the tape recorder ».

Line 365-369: I don't fully understand the reasoning here. Why are the VGWV variations reflected in the correlation coefficients? The VGWV for C1_03_TTL4 and C1_07_TTL4 are similar, however the correlations are very different (from no correlation at all to 0.39).

Authors: We agree. This paragraph has been removed.

Also I would be interested in why there is no correlation for C1_07_TTL4 balloon? How far apart were these balloons? In other words, why does one balloon show a correlation signal and the other does not? Are they geographically far apart? Where they flying through different convective systems?

Authors: The calculation of a mean H₂O MLS profile nearby the balloon position and location depicts the vertical structure of H₂O. We can see an oscillation of the water vapour mixing ratio with altitude. (see figure below the mean MLS vertical profile).



Our analysis shows that the flight C1_07_TTL4 took place during a phase of tape recorder where the balloon was flying close to the altitude of H₂O vertical gradient inversion (red dot on the figure above). This implies that during isentropic vertical displacement (of few hundreds meters or less) the mixing ratio does not vary significantly, while the temperature changes. This leads to the poor correlation coefficient. This configuration is similar for flight C1_03_TTL4.

The flights C0_05_TTL2 and C1_15_TTL4 are in the configuration of the blue dot on the figure above.

In the manuscript, we added a short paragraph which explains the flights' configurations.

Line 395: Please rephrase the sentences: what does "... flight has evolved almost half the time for each phase..." mean?

Authors: We rephrased : « Indeed, the C1_15_TTL4 flight has evolved half of time within each phase of the tape recorder (moistening/drying) while the C0_05_TTL2 flight has evolved more than 75% of the time in the same phase (drying), leading to a strong change in the Pearson's r correlation. »

Line 398ff: I'm surprised. C1_15_TTL4 has a lower correlation coefficient in Table 2 and yet almost half the time influenced by waves if I understand correctly. So I would expect the same if not more for C1_03_TTL4. Do you have an explanation for that difference?

Authors: this is in line with our previous reply. The Pearson's r coefficient on its own is not sufficient to conclude on the importance of atmospheric waves on our H₂O time series.

It could be sufficient if a given flight had evolved during the same phase of the tape recorder and that the balloon was flying at a favorable altitude (not too close of the altitude where the vertical gradient reverses).

One has to consider both coefficients and large-scale dynamics (the tape recorder-induced vertical variability of H₂O). The statistics of the number of nights influenced by waves is determined by comparing the sign of the water vapour anomalies and the sign of the theoretical vertical gradient of H₂O. The correlation coefficient between H₂O anomalies and temperature can decrease if a sufficient number of nights occur in a configuration where the balloon is influenced by vertical displacements in a negative vertical gradient. In this case the correlation coefficient decreases but still the H₂O anomalies are coherent with the vertical gradient (and then are considered as influenced by waves).

The flight C1_03_TTL4 occurred in a steady phase of the tape recorder where the vertical gradient of H₂O nearby the balloon is small. Additionally, the calculated vertical displacement are the smallest.

Line 510: I did not understand the last half of the sentence. Please rephrase. What does "... system anvil is compatible with overshoot within it" mean?

Authors: We rephrased the sentence : « The resolution of Himawari (2 km x 2 km) is too coarse to detect all the overshooting tops reaching the stratosphere which are typically at a km² scale. »

Figure 6: I would suggest to zoom into this plot and have the top at 50hPa that way it is easier to see the variation of Pico-STRAT Bi Gaz observations. Also the inversion is an important feature and therefore I would suggest to highlight it in the figure.

Authors: We have replotted the figure having the top at 40 hPa (and not 50 hPa) : it allows to see the inversion altitude.

Figure 7: Some of the circles are difficult to see, I would suggest to make them bigger.

Authors: Making the circles bigger would increase the overlap between consecutive circles, especially in cases where the balloon operated a turn around and when the winds are weak (slow motion). We therefore surimposed the balloon trajectory in black dash line to improve visibility on the trajectory location.

Figure 10: It's impossible to follow the discussion of this figure as you can only see black dots. Maybe work with different transparencies? Description of black dots is missing in the figure caption.

Authors: The figure caption has been clarified. We added the following sentence : « Black dots are for any other dates »