Point-to-point response to Reviewer 2:

Thank you very much for your careful review and critical comments and corrections! We performed a moderate revision and took advantage of your expertise.

Your points are in bold face, *our response is in italic font style*, the changed text is in a normal font style.

1) As a general comment I suggest that the manuscript be improved through major revisions that strengthen the results. In particular I notice some weaknesses such as lack of error bars in the figures, lack of significance test on the trend analysis and need for more discussion on the significance of the trend vs. the natural water vapor variability at the site.

We added an explanation how the error bar is connected to the confidence level and that a climatic trend actually has to exceed the 2σ *uncertainty (95% confidence level). Later, in the text, we explain why we do not show the monthly and annual standard deviations. The standard deviations are strongly influenced by the seasonal variation of IWV and have only a weak relation to the measurement error.*

The error bars show the 1σ uncertainty which corresponds to the 68.3% confidence level. The 2σ uncertainty (not shown) corresponds to the 95% confidence level. Figure 5 shows that the seasonal trends exceed the 95% confidence level from June to September. In the rest of the year, the confidence of a positive IWV trend is below 95% but mostly beyond 68.3% (exceptions are ERA5 values in March, May and October). According to the criterium, that a climatic trend has to exceed the 95% confidence level, we cannot say that there is a trend in the months from January to May and from October to December. However, if one considers the error of the mean, it is significant that the trend values are in each month positive and in its majority above the 68.3% confidence level.

1a) more discussion on the significance of the trend vs. the natural water vapor variability at the site.

Yes, interannual variability of IWV really plays a role. The trend would be smaller if we compute it for 1995 to 2021. Figure 4 shows a local minimum of IWV in the year 2021.

The interannual variability of IWV can enhance or reduce the absolute trend by about 10 to 20%. For example, if our trend study would end in 2021 instead of 2025, the trend would be smaller since there is a local minimum of IWV in 2021 (Figure 4). For 1995 to 2021, TROWARA's IWV trend is only 0.7mm/decade (instead of 0.8mm/decade for 1995 to 2025). The ERA5 IWV trend for 1995 to

2021 is 0.5mm/decade (instead of 0.6mm/decade for the complete series). However, in both cases the positive trend would still has a 95% confidence. This means, the interannual variability of IWV cannot mask the positive IWV trend at Bern.

2) Multiple times in the manuscript the Clausius-Clapeyron is mentioned to explain the observed positive water vapor trend at the site and link it to the observed positive 2-m temperature trend from reanalysis. Although it is true that, globally, the increase in temperature can determine an increase in the water vapor, locally and seasonally there are many factors that can influence the rate at which vapor changes. The 7% increase of water vapor per 1oC warming is true over the Ocean where you have enough water at the surface to sustain that change. In Bern, it is possible that the extra source of moisture comes from large scale circulation at higher altitudes in the troposphere. For example, synoptic patterns that transport moist or dry airmasses over the site and especially more or less clouds can contribute to water vapor trends and feedback that are distinct from the pure temperature effect. I think there should be more discussion on this.

We agree. We added a sentence that Bern has an Atlantic west coast climate. Further, we added a reference with observational results.

According to Clausius-Clapeyron, we expect an IWV increase of 7% per 1K increase of temperature. [1] found values from 6%/1K to 8%/1K for the IWV to temperature sensitivity at northern latitudes from 15 to 55° N. Since the location of Bern (575m a.s.l.) has an Atlantic west coast climate, we further expect a sensitivity value of about 7%/1K.

3) Line 7 in Abstract: "The relative IWV increase is 5.1%/decade" Please provide the absolute trend in mm/decade for both radiometer and ERA5

We agree and added the trends in mm/decade

The IWV increase is 5.1%/decade (or 0.8mm/decade). Evaluation of coincident IWV data from ERA5 (reanalysis of European Centre for Medium-Range Weather Forecasts) gives a trend of 3.7%/decade (or 0.6mm/decade).

4) Line 12 in Abstract: "This strong increase of water vapour certainly has an impact on weather, climate, and hydrology." I suggest removing this sentence from the abstract as this is not something that is evaluated in this work.

We changed the sentence according to reviewer 1 who also did not like the *word "impact"*

This strong increase of water vapour has implications for weather, climate, and hydrology.

5) Line 14 in Introduction: "The ERA5 reanalysis data of the 2m air temperature at Bern..." Does Bern have measurements of 2-m temperature?

The ERA5 data user interface provides the 2m air temperature at a user-selected latitude and longitude. We selected the coordinates of Bern. However, the ERA5 surface model level height is at 706m a.s.l. while Bern is at 575m a.s.l. We are sure that this difference in height has no big influence on the temperature trend value. The reader is informed about the lowest ERA5 model level in section 2.2

6) Line 17 in Introduction: "...increase of man-made emissions of CO2 and CH4 (IPCC, 2013)." Perhaps cite a more recent IPCC report (IPCC, 2023) that reflects the latest models and observations.

Thank you. We refer now to the IPCC report of 2021 (The Physical Science Basis).

Climate models proved that global warming is caused by the increase of human-caused emissions of CO_2 and CH_4 [2].

7) Line 57 in Introduction: "20116". Replace with 2016?

Thank you. Yes , it is the trend until 2016. We corrected it.

8) Line 83 in Section 2.1: "the antenna elevation angle is 40deg". I think this point deserves more discussion. Essentially the radiometer is measuring the PWV along a slant path through the atmosphere in one specific direction. How does this geometry affect what the radiometer is really measuring? Given the fact that the radiometer can see through tens of kilometers, the observations may be affected by water vapor that is not above the site. Additionally, could looking in one direction expose the measurements to biases due, for example, to prevailing wind patterns?

This effect is negligible for a long-term trend study of IWV. The lower troposphere contributes the major part to IWV. The monthly mean of IWV above Bern is not different from the monthly mean of IWV in 5-10 km distance to Bern. Through the IWV measurements at Payerne we know that IWV behaves very similar to IWV at Bern though Payerne is 40km away from Bern (but still on the Swiss Plateau). We added more details in the revised manuscript.

The antenna points to the southeast direction. The main part of the observed IWV originates from lower tropospheric water vapour within a horizontal range from 0 to 5km.

9) Line 90-103 in Section 2.1: Please specify the PWV retrieval uncertainty from the TROWARA instrument.

Thank you, we added the retrieval uncertainty of IWV.

The retrieval uncertainty of IWV during rain-free periods is 0.28mm [3].

10) Line 118 in Section 2.2: "The grid resolution is 0.25deg". It is useful to specify that this corresponds to approximately 25 square km at the latitude of the radiometer. This would place the radiosondes outside of the ERA5 grid?

Yes, in this study, we compared the radiosondes launched at Payerne with the ERA5 IWV values at Bern. So the locations are not at the same grid point. Differences between radiosondes and ERA5 are partly due to the lack of coincidence. However, monthly means of IWV over the Swiss Plateau should be quite similar because of the relatively flat topography of this region.

11) Figure 2: In my opinion this figure would be more useful if it showed the monthly averages of the entire 30 years with standard deviation. As it is, the figure raises more questions than it answers. For example, it shows that TROWARA has on average 1 mm more PWV compared to radiosondes although later on is stated that TROWARA is lower 0.25 mm (on average over the 30 years).

At first, we also thought that the standard deviation of the monthly mean of IWV would be useful for the error estimation. However, the standard deviation strongly depends on the seasonal gradient of IWV, for example, the standard deviation is large in the month May when IWV increases from 10 to 20mm. Thus, the standard deviation of the monthly mean cannot represent the measurement error. Figure 2 is useful to show the close agreement between ERA5 and TROWARA in the year 2025. It shows that the 31 year-old TROWARA instrument is still in a good form. Later in Figure 4 , we see that TROWARA has possibly a small dry bias in the years before 2011.

12) Figure 2 caption: It would be useful to specify "Monthly means of IWV at Bern (TROWARA and ERA5) and Payerne (radiosondes and GNSS)" in the caption.

Thank you, we changed it.

Monthly means of IWV at Bern (TROWARA and ERA5) and Payerne (radiosondes and GNSS) in 2025.

13) Figure 3: It is difficult to understand what this figure is telling us. Judging from figure 5 (shown later) it seems that the annual trend is essentially driven by 4 summer months and there is no trend in the other seasons. It is better to show the trend of the seasonal means for example (the mean DJF each year and show it with standard deviation). A significance test should also provide to what degree the seasonal trend is significant once the variability of the data is considered. A seasonal aggregation of the data would also help isolate the seasonal variability of the dataset. It will probably show that there is no trend except in summer.

We add sentences where we further explain the purpose of Figure 3 and why we do not show the standard deviation

The standard deviations of the monthly means of IWV are not shown since the standard deviation mainly depends on the seasonal gradient of IWV and does not represent the measurement uncertainty. Figure 3 gives a nice overview of the strong seasonal variation of IWV at Bern, changing over the decades. Figure 3 shows that the minima and maxima of IWV observed by TROWARA are often lower or higher than those of ERA5. We cannot explain why there is a bias between TROWARA and ERA5 during some winters and some summers. Particularly, in the years before 2011, TROWARA seems to have a dry bias compared to ERA5 in several winters.

14) Figure 4: Please add standard deviation or even better box plots of the distributions. It may be good to add the Payerne radiosondes as well. It may help understand the trend better.

The standard deviation of the annual means would be too large. I guess the standard deviation is about 10mm due to the large seasonal variation. We have not an harmonized radiosonde series from Payerne. Figure 4 nicely shows the linear trend and the interannual variability of IWV. Further it shows a dry bias of TROWARA in the years before 2011.

15) Lines 178-182 in Section 4: Although ERA5 reanalysis is strongly anchored in radiosondes observations it doesn't reproduce them 100%. Especially in the low boundary layer and in regions of complex topography the ERA5 profiles (especially humidity) can have their own biases compared to radiosondes. Generally, I would expect ERA5 PWV to have less diurnal variability compared to the TROWARA observations.

We mention now that ERA5 also assimilates data from satellites and surface *stations.*

Also, the ERA5 reanalysis can have a bias since ERA5's IWV trend significantly depends on the homogeneity of the assimilated humidity profiles from radiosondes, satellites, and presumably also surface station humidity which also displayed a change from manual to automated sensors. In Switzerland, the radiosonde humidity sensors changed several times during the past three decades. A tiny systematic change in the radiosonde measurement already can increase or decrease the IWV trend value.

16) Lines 193-195 in Section 4: "We are not aware..commercial outdoor radiometers". Perhaps not from the HATPRO, but a recent publication of Lubin et al., acp, 26, 295-311, 2026, https://doi.org/10.5194/acp-26-295-2026 examines 25-year trends of PWV (among other things) at the North Slope of Alaska from commercial radiometers.

Thank you for this interesting reference. We will mention it in the revised manuscript.

We are only aware of one IWV trend study based on data from a commercial outdoor radiometer [4].

17) Figs 5 and 6: These 2 figures appear partially repetitive. The red line is the same (ERA5 IWV). I suggest they are shown in 1 figure with 3 lines.

We think that showing the error bars of three curves in one plot would be confusing . And the error bars are important for assessment of the confidence level of the trends.

Thank you for your review which improved the manuscript.

References

[1] Wan, N.; Lin, X.; Pielke Sr., R.A.; Zeng, X.; Nelson, A.M. Global total precipitable water variations and trends over the period 1958–2021. *Hydrology and Earth System Sciences* **2024**, *28*, 2123–2137. https://doi.org/10.5194/hess-28-2123-2024.

[2] IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK and New York, NY, USA, 2021; p. 2391. https://doi.org/10.1017/9781009157896.

[3] Mätzler, C.; Morland, J. Refined physical retrieval of integrated water vapor and cloud liquid for microwave radiometer data. *IEEE Transactions on Geoscience and Remote Sensing* **2009**, *47*, 1585–1594. https://doi.org/10.1109/TGRS.2008.2006984.

[4] Lubin, D.; Zou, X.; Mülmenstädt, J.; Vogelmann, A.; Cadeddu, M.; Zhang, D. Surface radiation trends at North Slope of Alaska influenced by large-scale circulation and atmospheric rivers. *Atmospheric Chemistry and Physics* **2026**, *26*, 295–311. https://doi.org/10.5194/acp-26-295-2026.