

To Editor:

Thanks for Editors/Reviewer' warm work earnestly, the corresponding responses to the reviewer's comments are enclosed below. We hope that the corrections meet with approval. Once again, thank you very much for your comments and suggestions.

The following is a point-to-point response to the reviewer's comments.

Response to Referee #1:

The work described in the manuscript is generally worth publishing however the manuscript itself requires major revisions to be accepted - both on the side of content and the way how are the results presented.

### **General comments**

1. Based on your findings you provide very strong statements about a superiority of your GNSS results however evidences for it are often either very poor or completely missing. Except radiosonde profiles (which seem to have somehow limited vertical resolution) you do not use any reference product which would support the results provided by your GNSS tomography. You also do not describe at all the meteorological situation itself – what type of precipitation occurred (convective, stratiform), how was it developed, etc. Generally, you directly link the increase of water vapour or its vertical movement to a formation of hydrometeors and consequent rainfall. Although this can be potentially correct, there can be situations where an increase of water vapour or its vertical movement will not lead to any precipitation – just because the rainfall life cycle is not related only to water vapour as it is a much more complex process. Have you checked this? I strongly recommend you to discuss your results with somebody who has strong knowledge in meteorology since I miss this knowledge. It would allow you to much better justify your results. And please see my major comment 6 and 7 for more information regarding this general comment.

- ✓ Thanks for the reviewer's comments, some information about the tomographic result has been added in Section 4.2. Additionally, the description of meteorological situation during the experimental period has been added in Section 4.
- ✓ We totally agree with the reviewer's opinion that 'there can be situations where an increase of water vapour or its vertical movement will not lead to any precipitation'. In this manuscript, we analyzed the vertical movement of water vapor during the precipitation period and no-rain period, because we have obtained the hourly precipitation data of 45 rain gauges from the Hong Kong Observatory over the experiment period. We are trying to explain the vertical movement of water vapor during the precipitation period and did not consider the condition that the water vapor increases but without the precipitation.
- ✓ We appreciate for the reviewer's recommendation, and we have discussed with the people who has strong knowledge in meteorology. Some revisions and suggestions have been added in the manuscript.

2. The overall quality of some of your figures is rather poor and it is really not easy to follow and interpret them. Therefore, I recommend you to do edit some of your figures in the below given major comment 5.

- ✓ Thanks for the reviewer's suggestion, some figures have been edited and the specific revisions have been given in the response to comment 5.

3. Although the quality of written English is not bad, some issues occur occasionally. I recommend you to let a native speaker proofread your manuscript before a next submission.

- ✓ Thanks for the reviewer's reminding, the revision manuscript has been proofread by a native English speaker.

### Major comments

1. I have some comments on how you compute your values of SWV (equation 2,P5L121): - Please use the term horizontal tropospheric gradients instead of just gradients and introduce their meaning.

- It would be worthy to at least mention that horizontal tropospheric gradients represent a gradient of ZTD, not just of ZWD. Are you aware of this? Although during the periods you describe in your study the prevailing gradient was probably the gradient of water vapour, it would be possibly worthy to subtract the hydrostatic part from the total gradient.

- Probably you are aware, that you should use gradient mapping function for mapping the gradients to the elevation angle of the observation, not the wet mapping function (mw). Although your formula corresponds to Bar-Sever gradient mapping function, you should explicitly state it, because there are other gradient mapping functions based on different formulas. In the manuscript you don't mention anywhere which mapping function you did use for hydrostatic and wet components.

- Did you use the conversion factor kappa (which was used to convert ZWD to PWV) also to scale the original values of gradients to "PWV gradients"? I ask because according to your eq. 2 you did not do that and

- Have you considered using post-fit residuals for SWV computation? If not you should at least mention their existence since during severe weather events they can contain important information about tropospheric water vapour distribution which cannot be captured by ZTD or gradients (see i.e. Kacmarik et al., 2017)

- ✓ Thanks for the reviewer's reminding, the term 'gradients' has been replaced by 'horizontal tropospheric gradients', and their meanings have been introduced.
- ✓ We are sorry for our improper expression; the horizontal tropospheric gradients represent a gradient of ZWD in our manuscript. Because the hydrostatic gradient has been removed from the total gradient. The corresponding description has been revised in P5L125-127.
- ✓ Thanks for the reviewer's reminding, the information about which mapping function used in the manuscript has been added in P5L123-124.
- ✓ Thanks for the reviewer's question, we have used the conversion factor, which has been presented in EQ.1.
- ✓ Thanks for the reviewer's reminding, to be honest, we haven't used the post-fit residuals in this experiment. The description of post-fit residual for SWV has been added in P5 L127-129.

2. P6L169: Are you sure that solar radiation data provided by a global model with a  $0.5 \times 0.5^\circ$  horizontal resolution and 6h time interval of outputs is a reasonable source of solar radiation data for the level of local meteorological events you work with? And maybe even more importantly: it is absolutely clear that solar radiation is dependent on day/night change and an occurrence of clouds and that it influences the temperature and relative humidity. Why do you include it in your study, what exactly you want to show using it?

✓ Thanks for the reviewer's question, we cannot obtain other solar radiation data currently, therefore, we used solar radiation derived from the CRU-NCEP Ver. 7 dataset. In our opinion, although the spatio-temporal resolution of this dataset is large, it can reflect the general change of solar radiation in our experiment. That's why we select this dataset. This dataset is selected in order to explain the variations of surface temperature and relative humidity, which are influenced by solar radiation.

3. P7L173: I miss important information about your GNSS data processing:

- Which PPP software did you use? Which mode (I guess post-processing), precise products, mapping function, cut-off elevation angle, etc. did you use?

- Are you sure that you estimated ZTD every 30 s (what was then the observation time interval)? Usually while a deterministic modelling of tropospheric parameters is used, the ZTD is estimated in a 5-minute or longer interval (and on P9L232 you also mention that you used PWV in 5-minute interval). Does the software used for your processing is based on a deterministic or a stochastic modelling of troposphere? Since you state that horizontal tropospheric gradients were estimated in 2-hour interval, I guess that it used deterministic approach. Why have you chosen this type of setting to estimate ZTD every 30 s, but gradients only every 2 h?

- What is meant with the presented "accuracy" of estimated ZTD parameters? Is it standard deviation or root-mean-square error or any other statistical parameter? Although you don't provide the information on what exactly these numbers represent, I don't consider 7 or 8 mm as high quality ZTD estimates. For example, the official IGS ZTD product is stated to have an overall accuracy of 4 mm (Byram et al., 2011). I didn't check the referenced paper of Zhao et al. (2018d), however I would suggest you to provide more information on what these values represent and what kind of solutions using Gamit or Bernese were used for these comparisons.

✓ Thanks for the reviewer's question, the important information about GNSS data processing has been added in P7L180-184. We are sorry for our unclear expression which leads to the reviewer's misunderstanding. The ZTD is estimated in every 5 minutes and the sampling rate of GNSS data is 30s. The gradient is estimated in every 2 hours. Because we think the gradient parameter is changed slowly and 2 hours is also the default setting used in GAMIT software, therefore, we selected this value in our experiment.

✓ Thanks for the reviewer's suggestion, the 'accuracy' has been explained and replaced by 'root-mean-square error'. Additionally, the solution model and the representation of those numbers have been added in P7L186-191.

4. P8L208: Could you please explain what presented values of bias/standard deviation mean? Is it a, a comparison between  $T_m$  from your regional and standard empirical model or b, a comparison between  $T_m$  computed from radiosonde profiles and  $T_m$  from your regional and standard empirical model? I guess the b, is right however it is not fully clear. Anyway, I would be careful with your statement that shown results indicate that “the established regional  $T_m$  model is superior to the empirical formula”. Because if you used radiosonde profiles to correctly establish your regional model, then it MUST be very close to the actual radiosonde profiles. So you only proofed that the established model should provide good results in your area (supposing the radiosonde data are considered to be error-free).

✓ Thanks for the reviewer’s reminding, yes, the  $T_m$  computed from radiosonde profiles are compared with that from our regional and standard empirical model in the experiment, respectively. This expression has been rewritten in P9L220-223.

5. Comments regarding selected figures:

- Figure 2: since the differences in PWV estimated using different  $T_m$  are very small, it is practically impossible to see anything in the figure. Therefore, I propose not to include the figure at all and only optionally provide some statistical information about the variation of PWV based on various  $T_m$  values.

- Figure 3, 4, 5, 6: It is really hard to a, see something in detail in these figures, b, compare results in figures 3, 4 with results in figures 5 and 6. In different words, it is really complicated to confirm your written description and interpretation of these figures. Therefore, I strongly recommend you to 1, increase the size of these figures, 2, provide detailed looks on interesting periods (i.e. these with the highest rainfall), 3, try to put all the shown parameters into one figure per station (I mean combine information from figures 3 and 5 and from figures 4 and 6, for example show temperature and Rh together with PWV and rainfall in just one figure – the individual curves can be shifted using a constant offset to increase the readability). I also recommend you to use the same scale in axis y in all figures to make their mutual comparison fair (i.e. in figure 3 you use for PWV interval from 20 to 80 mm, but in figure 4 an interval from 30 to 66 mm).

- Figures 8, 9, 10: I recommend you to provide all these figures as ONE figure with ONE caption. I also recommend you to somehow mark time of a beginning of the precipitation in these figures to increase their readability

✓ Thanks for the reviewer’s suggestion, Figure 2 has been removed in the manuscript and some statistical information about the variations of PWV have been given in P9L226-229.

✓ Thanks for the reviewer’s suggestion, the size of these figures (3, 4, 5 and 6) has been increased. The scale of axis y in all figures has been unified. We are sorry that we cannot put all parameters into one figure per station because we compare the variables of PWV, RH, and temperature with rainfall separately. If all parameters are presented into one figure, we think this may become more complicated and harder to explain.

- ✓ Thanks for the reviewer's suggestion, Figures 8, 9 and 10 have been put as one figure with one caption. Additionally, the beginnings of the precipitation in these figures (8, 9 and 10) have been marked with the blue line.

6. Section 4.1 – I miss a reasonable discussion of your results together with their short summary. I can see only a description of your figures together with some generally valid information (like that the solar radiation is connected with day/night cycle or cloud coverage or that the IWV time series can exhibit an increase of values before the beginning of rainfall). What is your interpretation of whole shown time series? Is there any clear relation between PWV and any other meteorological parameter? Are your results in agreement with other researches who studied this topic? Can PWV time series help us to predict rainfall? You should deal with questions like these. Please see also my minor comments related to individual sentences in section 4.1.

- ✓ Thanks for the reviewer's comments, we are sorry for our unclear expression which leads to the reviewer's confusion. Here, we want to analyze the variations of PWV time series during the rainfall period and no-rainfall period. Additionally, we also analyzed the changes of three meteorological parameter (temperature, relative humidity and solar radiation) during the rainfall period and no-rainfall period. In this section, we did not analyze the relation between PWV and other meteorological parameters. The corresponding content has been rewritten in Section 4.1.
- ✓ Yes, the PWV time series is capable of forecasting rainfall and the corresponding information has been added in P10L254-255. In fact, we have done some works in this area, the related references are as follows.

References:

Zhao Qingzhi, Yao Yibin and Yao Wanqiang, GPS-based PWV for precipitation forecasting and its application to a typhoon event, *Journal of Atmospheric and Solar-Terrestrial Physics*, 2018,167:124-133, DOI:10.1016/j.jastp.2017.11.013

Yao Yibin, Shan Lulu and Zhao Qingzhi. Establishing a method of short-term rainfall forecasting based on GNSS-derived PWV and its application, *Scientific Reports*, 2017,8:12465, DOI:10.1038/s41598-017-12593-z

## 7. Section 4.2

- P14L306: I would really correct your statement in sentence "In addition, it also can be observed that more sophisticated water vapour variations detected vertically (with 29 layers) can be provided by the GNSS tomographic technique than by radiosonde data." Firstly, looking on figure 7 I consider your radiosonde profiles not to have a full vertical resolution which is standardly accessible by this instrument (standardly you should get one measurement per approximately 30 m). Could you please explain you're your radiosonde profiles are so coarse? Secondly, even if your GNSS tomography could reach a better vertical resolution than a radiosonde (what is not possible with just 29 vertical layers), you could not call your tomography profiles to be "more sophisticated" – because you are not able to proof that variation in your profiles is related to real meteorological conditions and not only to errors of tomographic reconstruction.

- P18L382: I don't agree with you that "delays to the satellite signals induced by liquid water and icy species : : : are unavailable in the case of GNSS observations". The GNSS signals ARE influenced by them (see Solheim et al., 1999 and Kacmařík et al., 2017) and therefore the estimated ZTD/SWD/SIWV contain these effects. However, it is not possible to separate them from the estimated parameters. This also means that your GNSS tomography profiles should be influenced by these hydrometeors.
- I don't see any trustworthy quality evaluation either for your SWV values or for the vertical profiles from GNSS tomography reconstruction. How you can justify that described changes in presented vertical profiles of WV are related to real weather conditions and not only to mismodelling deficiency of your GNSS tomography solution? You should at least discuss this topic.
- Please see also my minor comments related to individual sentences in section 4.2.
- ✓ We appreciate for the reviewer's comments, the expression in P14L306 has been deleted according to the reviewer's suggestion. We have analyzed and removed the data of some layers because of the errors in pressure, water vapor pressure or temperature following some principles (Wang et al., 2008; Wang et al., 2016). Therefore, the radiosonde profiles are relatively coarse. Additionally, we agree with the reviewer's opinion that we cannot call the tomographic profiles to be 'more sophisticated', therefore, this expression has been removed from the manuscript. We don't know where we can download the radiosonde data with the vertical resolution of about 30 m. We have checked the radiosonde files carefully, which downloaded from <ftp://ftp.ncdc.noaa.gov/pub/data/igra/> and found that the vertical resolution is non-uniformed with the value ranges from several hundred meters to more than one kilometer.
- ✓ Thanks for the reviewer's opinion. We are sorry for our unclear expression which leads to the reviewer's misunderstanding. In our opinion, the GNSS tomography profiles are influenced by these hydrometeors, but not evident like the delays induced by atmospheric water vapor. In other words, the satellite signals induced by liquid water and icy species are very small (Brenot et al., 2014), which cannot be reflected by GNSS observation evidently. This improper expression has been rewritten in P18L387-389.
- ✓ Thanks for the reviewer's suggestion, the comparison experiment of tomographic result with radiosonde data has been performed and presented in the first paragraph of Section 4.2. Due to this paper is mainly focus on the analysis of 2-d-/4-d water vapour variation during the heavy rainfall events and the quality evaluations of vertical profiles from GNSS tomography reconstruction have been carried out in this research area in the previously studies (Yao and Zhao, 2016, 2017; Zhao et al., 2017; Zhao et al., 2018). Therefore, we didn't give much information in this aspect. Some information corresponding the quality evaluation of tomographic result have been added in P13L317-321.

#### References:

Wang, J., & Zhang, L. (2008). Systematic errors in global radiosonde precipitable water data from comparisons with ground-based gps measurements. *J Clim*, 21(10), 2218-2238.

Wang, X., Zhang, K., Wu, S., Fan, S., & Cheng, Y. (2016). Water vapor - weighted mean temperature and its impact on the determination of precipitable water vapor and its linear trend. *Journal of Geophysical Research Atmospheres*, 121(2).

Brenot, H., Wautelet, G., Warnant, R., Neméghaire, J., & Roozendaal, M. V. (2014). GNSS meteorology and impact on NRT position. *Enc-Gnss*.

Yao Y.; Zhao Q. Maximally Using GPS Observation for Water Vapor Tomography. *IEEE Transactions on Geoscience and Remote Sensing*, 2016, 54(12), 7185-7196.

Yao Y.; Zhao Q. A novel, optimized approach of voxel division for water vapor tomography[J]. *Meteorology and Atmospheric Physics*, 2017, 129(1), 57-70.

Zhao Q.; Yao Y.; Yao W. A troposphere tomography method considering the weighting of input information[C]//*Annales Geophysicae*. Copernicus GmbH, 2017, 35(6), 1327-1340.

Zhao Q., Yao Y., Cao X., Zhou F. and Xia P. An Optimal Tropospheric Tomography Method Based on the Multi-GNSS Observations. *Remote Sensing*, 2018, 10(2), 234.

### Minor comments

1. P2L42: you write about using GNSS PWV for severe weather and climate studies, however you provide only two references. Since there are many studies related to GNSS meteorology and (a) severe weather monitoring (i.e. Japanese team around Y. Shoji); (b) climate (i.e. Gradinarsky et al., 2002, Vey et al., 2010, Ning a Elgered 2012, Bock et al., 2014), I recommend you to cite at least the most important ones and cite them separately for (a) and (b).

✓ Thanks for the reviewer's reminding, this expression has been revised and the corresponding references have been added separately in P2L43-45.

### References:

Shoji, Y. (2009). Assimilation of nationwide and global gps pwv data for a heavy rain event on 28 July 2008 in hokuriku and kinki, Japan. *SOLA - Scientific Online Letters on the Atmosphere*, 5(1), 45-48.

Shoji, Y. (2013). Retrieval of water vapor inhomogeneity using the Japanese nationwide GPS array and its potential for prediction of convective precipitation. *Journal of the Meteorological Society of Japan*, 91(1), 43-62.

Gradinarsky, L. P., Johansson, J., Bouma, H. R., Scherneck, H. G., Elgered, G. Climate monitoring using GPS, *Physics and Chemistry of the Earth*, 27, 335–340, doi:10.1016/S1474-7065(02)00009-8, 2002.

Vey, S., Dietrich, R., Rülke, A., Fritsche, M., Steigenberger, P., Rothacher, M.: Validation of precipitable water vapour within the NCEP/DOE reanalysis using global GPS observations from one decade, *Journal of Climate*, 23, 1675–1695, doi:10.1175/2009JCLI2787.1, 2010.

Ning, T. a Elgered, G. Trends in the atmospheric water vapour content from ground-based GPS: the impact of the elevation cutoff angle, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 5, 744–751, doi:10.1109/JSTARS.2012.2191392, 2012.

Bock, O., Willis, P., WaDng, J., Mears, C. A high-quality, homogenized, global,



long-term (1993–2008) DORIS precipitable water data set for climate monitoring and model verification, *Journal of Geophysical Research*, 119, 7209–7230, doi:10.1002/2013JD021124, 2014

2. P2L44: what do you mean with “traditional sounding stations” – radiosondes? It should be explicitly given. Are you aware of WV observations from remote sensing satellites or of other instruments as WVR or Raman Lidar?

✓ Thanks for the reviewer’s reminding, “traditional sounding stations” refers to radiosondes. This expression has been revised in P2L44. Yes, the atmospheric water vapor information also can be obtained based on the remote sensing technique or Raman Lidar.

3. P2L50: I would rather write that GNSS PWV can be used to provide information about water vapour distribution, which is related to form of precipitation and not only to severe weather events. In this regard – how do you define a severe weather event in your perspective?

✓ Thanks for the reviewer’s suggestion, this expression has been revised in P2L53-54.

✓ In our opinion, the severe weather event mentioned in this manuscript mainly refer to the severe precipitation or some events related to this.

4. P2L52: I would rather write that GNSS PWV is operationally used for their assimilation into numerical weather prediction models (NWM) than just for operational meteorology. Italy doesn’t use GNSS PWV operationally, work presented in Barindelli et al. (2018) was just a case study to promote an operational deployment.

✓ We appreciate for the reviewer’s comments earnestly and we are sorry for our improper expression about the work presented in Barindelli et al. (2018). This expression has been revised according to the reviewer’s suggestion in P2L55-57.

5. P2L56: I would rather say that ZTD or PWV can be used for early warnings than that it is used. I recommend you here to cite the work of Brenot et al. (2013) at least.

✓ Thanks for the reviewer’s suggestion, this sentence has been revised and the work of Brenot et al. (2013) has been added P1L59-60.

6. P3L65: there are much more (recent) studies that used radiosonde profiles for GNSS tomography validations, i.e. Shanguan et al. (2013).

✓ Thanks for the reviewer’s reminding, the corresponding reference has been added in P2 L69.

7. P3L68: COSMIC is not an instrument for water vapour sensing, it is whole program designed for various purposes – in this regard I would rather write GNSS Radio occultation technique to be consistent.

✓ Thanks for the reviewer’s reminding, the improper expression has been revised in P2 L71.

8. P3L75: I would not say that iterative reconstruction techniques deal with resolution of tomography models or division of tomography areas.

✓ Thanks for the reviewer's reminding, this expression has been removed in the manuscript.

9. P4L91: please correct your statement that ionosphere causes signal delay – since ionosphere causes a delay for code measurements, but an advance for phase measurements (see i.e. Hofmann-Wellenhof et al. 2008). Also you cannot fully eliminate ionosphere with just the IF linear combination – this eliminates only the first order effect but not effects of higher order.

✓ Thanks for the reviewer's suggestion, this expression has been rewritten in P4L93-94.

10. P4L95: I would firstly introduce the hydrostatic and non-hydrostatic part of the delay and then call the non-hydrostatic the wet delay. Also please use zenith direction all the time (instead of a vertical direction).

✓ Thanks for the reviewer's suggestion, this expression has been rewritten according to the reviewer's suggestion in P4L95-97. Additionally, the 'vertical direction' has been replaced by 'zenith direction' throughout the manuscript.

11. P4L101: replace the word measurements with a more appropriate signal.

✓ Thanks for the reviewer's suggestion, this word has been replaced by 'observations'.

12. P4L102: provide references for given processing software.

✓ Thanks for the reviewer's reminding, the corresponding references have been added.

13. P4L103: you should rather mention that in the GNSS data processing the ZHD is usually taken from an a priori model and later precisely computed from i.e. real meteorological observations to subtract ZWD from ZTD. Because strictly speaking in the GNSS data processing you do not estimate a ZWD, but a correction to a priori modelled ZHD.

✓ Thanks for the reviewer's suggestion, this expression has been added in P4L101-103.

14. P4L107: use rather base SI units for all the given coefficients. It would be also worthy to mention that different sets of refractivity constants exist (see Rueger, 2002).

✓ Thanks for the reviewer's suggestion and reminding, the SI units for all given coefficients have been given in P4L108.

15. P5L117: I recommend replacing the term SWV with SIWV (Slant integrated water vapour).

- ✓ Thanks for the reviewer's suggestion, the SWV has been replaced by SIWV throughout the manuscript.

16. P5L142: Rohm (2013) developed a GNSS tomography solution using no constraints, so please correct your sentence according to that.

- ✓ Thanks for the reviewer's reminding, this expression has been corrected in P5L147-148.

17. P6L169: could you provide a reference for given CRU-NCEP solar radiation data sets you used in your study?

- ✓ Thanks for the reviewer's suggestion, the corresponding reference has been added in P6L176.

18. P7L191: with the "layered parameters" you mean that information about vertical profile of some meteorological parameters as water vapour pressure or air temperature is not available? I recommend you rewriting this sentence to make better understandable what you mean.

- ✓ Thanks for the reviewer's suggestion, this expression has been rewritten to make it better understandable in P8L204-205.

19. P8L209: I recommend you to see the paper of Ning et al. (2016) providing a rigorous evaluation of uncertainty in GNSS IWV estimation including impact of  $T_m$  uncertainty. I would also like to put you into perspective with the number of overall achievable accuracy of IWV estimates from GNSS which is meant to be around 0.4  
– 0.6 mm (see Guerova et al., 2016) – it would be possible good to mention it in the paper.

- ✓ We appreciate for the reviewer's suggestion and comments, we have learned the paper and cited the result obtained by Guerova et al. (2016) in the manuscript in P9L232-233.

20. P9L227: 300 mm is a value for one day and one station? Or for whole studied period from July 19 till July 25? It is not clear from your sentence.

- ✓ Thanks for the reviewer's reminding, this expression has been rewritten in P9L237-239 to make it clear.

21. P9L240: with the sentence "Additionally, the PWV time series data present a downward trend at four stations during this period" you mean the whole processed period from June 19 till July 25 or anything else? If yes, why do you state it? It is from whatever reason important for your study?

- ✓ Thanks for the reviewer's question, yes, the variation of PWV time series shows a downward trend during the experimental period. This expression is not important for our study; therefore, we delete this expression in the manuscript.

22. P10L244: please add information at which stations these values of cumulative rainfall occurred.

- ✓ Thanks for the reviewer's reminding, the name of stations have been added in the manuscript.

23. P10L249: what do you want to say with your sentence that "the PWV values during rainfall are much larger than that of no rainfall time" You just want to state the fact, that this situation occurred in your selected time periods or you want to state it as a general fact which is valid every time? Because I would not agree with the second option.

- ✓ Here, we want to express that the PWV values during rainfall are much larger than that of no rainfall time at the situation occurred in the selected time period. This expression has been revised according to the reviewer's comments.
- ✓ Additionally, we totally agree with the reviewer's opinion that the PWV values are not often larger during rainfall period than that of no rainfall period.

24. P14L314: The sentence starting "For the SPP rain gauge" is not understandable for me.

- ✓ Thanks for the reviewer's reminding, this sentence has been revised to make it understandable.

25. P14L325: I would consider rewriting the sentence starting "The above phenomenon indicates". The heavy rainfall could be induced by vertical motion of water vapour, but the opposite (variation of water vapour induced by heavy rainfall) is not so logical.

- ✓ Thanks for the reviewer's suggestion, this expression has been revised in P14L339-340.

26. Table 1 and Table 2: could you provide a more detailed look on the precipitation? I mean provide the rainfall information not only in 1-hour interval, but for example in 5-minutes or 10-minutes time interval. You don't need to provide it in a table, in can be in a figure (optionally in the figures 8, 9, 10 themselves or in figure 11). It would provide the reader a much better idea how was the rain spread out in time.

- ✓ Thanks for the reviewer's suggestion, we are sorry that we cannot provide the rainfall information with a higher temporal resolution. Currently, we only bought the hourly rainfall data of 45 rain gauges from the Hong Kong Observatory for the experimental period.

We appreciate for Reviewer's warm work earnestly, which has a significant improvement for our manuscript. And we hope that our corrections meet with the reviewer's requirement. Once again, thank you very much for your comments and suggestions.