

## ***Interactive comment on “GPS-PWV jumps before intense rain events” by Luiz F. Sapucci et al.***

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### **Response letter for Referee1**

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### **General comments from Referee#1**

The manuscript presents a combined analysis of time series of precipitable water (PW) derived from GPS (Global Positioning System) observations and surface precipitation estimated from an X-band Radar. Both datasets were obtained in 2011 during the CHUVA Vale measurement campaign. The study mainly focusses on a statistical analysis of the relationships between precipitable water fluctuations and precipitation inten-

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sity (with wavelets in particular). The results suggest a potential of high-frequency PW for nowcasting.

A major originality of the manuscript lies in the particularly high frequency of the PW dataset: one minute. I had never seen GPS time series of PW provided with such a small temporal sampling, and I think that this is very interesting. I also think that this specificity of the study is not emphasized enough, for instance the abstract does not mention the 1-min sampling of precipitable water.

My main comments for now concern the presentation of the results

A) In my opinion, the authors jump too quickly to statistical results. The results will be much more convincing with the addition of the time series centred on rain events, because I think that they must first present, and in much more details, these results (see specific comments).

B) This goes with some reorganization of the manuscript, with section 4 placed before section 3.

C) The datasets, methods and results are not all clearly separated. It would have been easier for the reader if the datasets, data processing and methods (wavelets...) had been presented before the results. In addition, such a structure would have prevented repetitions. In case you choose to stick to the present organization (apart from the one indicated in B), please make sure to remove unnecessary repetitions (I noted some in the specific comments below).

**Response:** All the comments and suggestion presented by referee were taken into consideration in this revised version of the manuscript, which generated strong and important improvement in the presentation of the ideas associated with this conceptual study and obtained results. It was necessary a substantial restructure of the paper and more figures with additional results had to be produced and they are included. About the general comments:

- It is true that PWV-GPS with high temporal resolution has not been explored for now-casting activities, we agree that this aspect was not emphasized enough in previous version of the manuscript, which was corrected in the new one. Information about the high temporal resolution in GPS-PWV time series was included in abstract and the objective of this work, it was suitably emphasized. Motivated by this suggestion and comments from other referee, in the revised version of the manuscript we have better explored the results to study rapid oscillations of PWV time series (time scale of 8-16 and 16-32) before precipitation, which we associated with PWV jumps. This was done using Wavelet Cross-correlation analysis with lead-lag (new figure included) in the section 4, now titled "High temporal resolution GPS-PWV time series analysis".

- The discussion about the GPS-PWV Jump was moved to before of the statistical analysis of the GPS-PWV time series, as suggested. We agree that the GPS-PWV jumps it the most important subject of this work and deserve special treatment. In this new strategy used to present the PWV-Jump, many parts of manuscript had to be changed, such as: abstract, introduction, the new section 3 dedicated to discuss the GPS-PWV jumps. The other analyzes, such as wavelet and time-lag, are presented in new section 4. The methodology applied wavelet analysis was better detailed, as suggested by other referee. We moved it to introduction of the sub-section 4.1.

- Two new figures was included in the manuscript. The new Fig. 4 shows other GPS-PWV jumps observed before different extension rain events, one of each tercile. GPS-PWV time series before of the 18 events were efficiently organized in the composite presented in the new Fig.5.

Following the recommendations presented in the specific comments, several parts of the manuscript were rewritten, correcting repetitions, some not appropriated terms were excluded and several phrases were rewritten. The two recommended paper were included in the bibliographic revision. Some information about the comparison of time series were clarified and information about the statistical significance of the results presented are discussed. Specific comments point-by-point are presented below. The

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numbers (in the new version of the manuscript) of the changed lines and respective page in each point are listed and highlighted in green. The numbers of figure in the response refer to 13 figures of the new version of the manuscript.

## Specific comments

1) **Referee#1:** Page 2, introduction, "PWV data from a microwave radiometer (MWR) with high temporal resolution have been used to describe the observed relationship between the PWV and precipitation in the tropics (Muller et al. 2009). Muller et al. (2009) do not use any microwave radiometer (MWR), they use a purely model-based approach. On the other hand, Holloway and Neelin (2010) is a proper reference.

**P2L17: Response:** This phrase was rewritten, the mistake about the MRW-PWV data was removed, and the reference was maintained to provide a reference about relationship between the PWV and tropical precipitation, as suggested by reviser 2. The information about the MWR data applied to analyse and better understand the temporal relations of column water vapor and tropical precipitation was referenced by Holloway and Neelin (2010), as suggested.

2) **Referee#1:** Page 2, Introduction, references to studies using GPS PW: several references are given, they mainly concern American areas. Similar studies were carried out by Bock and colleagues in Africa (e.g. Bock et al. J. Geophys. Res. 2008) and in Europe, and very likely by others elsewhere.

**P2L33 Response:** We agree that the mentioned reference (Bock et al. 2008) has an important contribution for the evolution of this research and was included in the manuscript, as suggested.

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3) **Referee#1:** Page 2, Introduction, paragraph "The motivation ...": the authors should clearly state at this point that they will use very high frequency datasets.

**P3L10 Response:** This phrase was changed. The information about the high frequency of PWV-GPS data used in this work was evidenced, as suggested.

4) **Referee#1:** Page 3, section 2, first paragraph: the three last sentences ("During the CHUVA... and precipitation." are unnecessary.

**P3L27 Response:** We agree that these phrases can be excluded from manuscript, because the information presented are not relevant by the work's focus.

5) **Referee#1:** Page 3, section 2: the same information is given twice, lines 7,8: "The CHUVA Vale campaign was carried out in São José dos Campos" line 16: "The CHUVA Vale experiment performed in São José dos Campos City" Please correct, be more concise

**P4L02 Response:** Both phrases were rewritten to make the manuscript more concise. The localization (with geographic coordinates) of the CHUVA Vale experiment was organized in the first phrase and excluded from the second one.

6) **Referee#1:** Page 5, "The time series of the precipitation fractional area around the GPS receiver observed by radar were calculated by determining the position of the GPS antenna in the gridded precipitation points and taking into consideration the area formed by points in the longitudinal direction for the same number of points in the latitudinal direction where the nearest point of the GPS antenna is located in the center of these areas": this sentence is unclear.

**P5L28-P5L31 Response:** This sentence was rewritten in more direct way to be clearer.

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7) **Referee#1:** Page 5, "representative" in "Different areas were tested, and an area of 22x22 (longitudinal per latitudinal direction grid point values of rainfall intensity (mm h<sup>-1</sup>)) was found to be more representative of the observed area by GPS'. Can you precise what you mean with "representative" here? This is too vague.

**P6L6-P6L8 Response:** The term "representative" in this phrase we mean that the area of precipitation observed by Radar more adequate to associate with observed area by GPS. This phrase was rewritten to make clear the idea and more information about the tested areas were included.

8) **Referee#1:** Page 6, "The disdrometer time series has a good correlation with the 95 th percentile time series": how did you do precisely? The time samplings of these variables are 1 min and 6 min. Did you regrid the disdrometer time series, please precise. The same apply to the legend of Fig. 2.

**P6L29-P6L32 Response:** In fact, the term "correlation" is not appropriated metric in this case. This sentence was totally rewritten in function of your comment and one other from reviser 2 (specific comment number 30). The new version of this phrase is: "The figure show that the disdrometer time series is consistent with the 95th percentile time series, although differences are expected due to different areas covered by each instrument and besides total precipitation from disdrometer is always larger than the one measured by radar and rain gauge, due to problems with the large droplet concentration (Giangrande et al, 2016)."

9) **Referee#1:** Page 6, 1st paragraph of section 3, "As argued by Adams... in this region". These sentences are not so much about the methodology. They would be better placed in the introduction or discussion.

**P9L28 to P3L12 Response:** The reviser is right. The first phrase was changed to introduction section and the second was rewritten.

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10) **Referee#1:** Page 7, section 3.1: I found that the paragraph was not always very clear. For instance, the authors write "The methodology employed to process the GPS data in one-minute intervals did not provide any additional information." (line 6) and a few lines below "For this reason, it is necessary to take into consideration ... a short time step, e.g., the one-minute interval used in this study."

**P10L15 P10L17 Response:** This first mentioned phrase was excluded from manuscript because was misunderstanding of the results showed by color scale used in the wavelet power spectrum. This color scale was selected to make clear the information in this plot. Other scales were tested, but the presentation of the results were not so good. Information about the color scale used were included. The second mentioned phrases were separated in different paragraph, which now treat of the difference between temporal frequency of rainfall events and PWV-GPS jumps and the consequent difficulties in the results analyses.

11) **Referee#1:** "expressive": this word is frequently used in the manuscript but I am not sure that is is appropriate (note that I am not a native English speaker).

**Response:** We agree that this term can generate misunderstanding and it was replaced by other more appropriated. All six occurrences in the text was rewritten and the term "expressive" was avoided. P7L14 "more expressive" was changed to "stronger"

P10L22 changed to "strong"

P10L28 "more expressive" was changed to "stronger"

P11L27 "an expressive" the phrase was excluded

P13L22 "the differences... are not expressive" was changed to " the differences are small between..."

P15L08 "expressive" was changed to "strong"

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12) **Referee#1:** Page 7, section 3.1, replace "A vertical line was put at the peak of the maximum precipitation in each event to simplify the analysis" by "For clarity, a vertical line was drawn for each precipitation maximum". This information is missing in the legend, where it would possibly be more appropriately introduced.

**P10L27 Fig.7 Response:** The phrase was replaced as suggested. In the caption of the Fig. 7 this information was included also.

13) **Referee#1:** Page 7, section 3.2: did you need to re-sample the GPS PW dataset on the 6 min time step of radar precipitation here? And if so, how? e.g. via sub-sampling, time averaging?

**P11L10 Response:** Actually, the radar data were re-sampled to match the higher temporal resolution of PWV-GPS estimates. A linear interpolation function was used in the precipitation time series from radar. This was done for applying the method in the higher resolution without loss of information from GPS. This information has been forgotten in the previous version of the manuscript. The following phrase was included "In this analysis, the precipitation data from Radar, originally with sampling rate of 6 minutes, were linearly interpolated to one-minute rate."

14) **Referee#1:** Section 3.5, Figures 5 and 6: correlations are not very high. You need to comment their magnitude. Also, the caption does not indicate the error bars nor how they were drawn.

**P11L15 Fig.8 Fig.9 Response:** Although the correlations are not very high, it was possible to identify statistical significance in these results. This comment was included in the manuscript. Information about the bars was included in the Caption: "The 95% Confidence Interval for each WCC is estimated considering a Gaussian Distribution after applying the Fisher's Z Transformation (Whitcher et al 2000)".

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15) **Referee#1:** Page 8. You recall the same information several times. For instance, below, an information that was already given before. lines 10-11: "...the results reported by Adams et al. (2013), who showed that the strongest water vapor convergence is typically 1 hour before heavy precipitation." Page 7, lines 23-24: "... the water vapor may increase through low-level moisture convergence, as suggested by Adams et al. (2013)on the time scale of 32-64 minutes" Please reorganize and avoid repetitions.

**P15L14 Response:** We agree that this information was repeated in the manuscript. This information was removed in this analysis and maintained in the conclusion section, in which is more appropriated for it. The phrase "as suggested by Adams et al. (2013)" was removed by simplification, because this idea and reference was well discussed in the introduction section, as suggested by reviser in the specific comment (9).

16) **Referee#1:** Raymond (1987) is missing in the list of references.

**P19L12 Response:** This reference is in the reference list of the new version of manuscript.

17) **Referee#1:** Section 4, inset in Figure 7: this is the first and only time that the fluctuations of high-frequency GPS PW are presented. I think that this is late in the manuscript, and that this is not enough. I think that you have to present several of the cases presented in table 1, in the form of graphs jointly showing time series of radar precipitation (either fraction above 50 mm/h or another rainfall diagnostic) and GPS PW. I would prefer to see the 18 cases, organized by terciles, or at least 3 of them per tercile. I further strongly suggest to move section 4 before section 3 (see main comment B).

**P7L1-P8L30 Fig.4 Fig.5 Response:** We agree that the discussion about the GPS-PWV Jump before a high temporal resolution GPS-PWV time series is more appropriated. It was done in this new version of the manuscript. In this new strategy

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used to present the PWV-Jump, many parts of the manuscript had to be changed, such as: abstract, introduction in the content of the sections, the section 3 (denominated now "3. Behavior of PWV time series before precipitation events: the GPS-PWV jumps"). The sections 3 and 4, from previous version of the manuscript, were merged (as suggested by reviser 2) denominated now as "4. High temporal resolution GPS-PWV time series analysis". In the conclusions section was changed the sequence of presentation of the results obtained in this work, as consequence of this restructure. Based on this comment was included two new figures in the manuscript. The new Fig. 4 shows other GPS-PWV jumps observed before different extension rain events, one of each tercile. It is important highlight that the there are many precipitation events of lower intensity (lower tercile) which the GPS-PWV jump are not observed. Instead of present the GPS-PWV before of the 18 events, this information were efficiently organized and presented in the new Fig. 5.

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Please also note the supplement to this comment:

<http://www.atmos-meas-tech-discuss.net/amt-2016-378/amt-2016-378-AC1-supplement.pdf>

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