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

Anonymous Referee #2

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General comments: The manuscript presents the behavior of GPS-PWV time series during severe precipitation events recorded by an X-band Radar during the CHUVA Vale measurement campaign in 2011. GPS-PWV jumps have been detected between 32 and 64 minutes before the more intense rainfall events. The statistical characterization of this phenomenon has potential for nowcasting. The reasoning of the paper is based on a wavelet analysis of the GPS-PWV times series and on GPS-PWV derivative analysis and distinguishes meteorological events into 3 classes of precipitation. The main value of the article is to focus on the behavior of PWV during intense weather events, expecting to improve their forecasting.

However, the article contains a number of imprecisions that are important to dissipate : too many repetitions, a presentation that deserves to be more rigorous, more structured, more synthetic on the basic methodology and more explicit on the work done: 1. The presentation of GPS data processing is only too partial and often confusing.

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Discussion paper

2. The use of GPS-PPP times series sampled at 1-min intervals is interesting but the manuscript did not present well which specific PPP products were used to get it. 3. The use of wavelet analysis is interesting only for part “3.2 Wavelet cross-correlation analysis” even if shown correlations seem to be weak (figures 5 & 6). Part 3.1 "Wavelet power spectrum analysis” is the effect of the GPS-PWV jumps, a well know wavelet power spectrum of a Dirac function. Part 3 and 4 should be merged : part 3.1 for presenting the GPS-PWV jumps and part 3.2 for presenting time lag correlation. 4. Part 4 is really interesting and could be more developed. However, the criterion on GPS-PWV derivative > +9.5 mm.hˆ(-1) and < -9.5 mm.hˆ(-1) to characterize extreme weather events is not enough analyzed.

About GPS data processing Part "2.2 High temporal resolution GPS-PWV time series" is too confusing and must be structured and clarified: - Orbit and clock data products : what kind of products did you use ? What is the sampling of these products ? Orbit and clock data products from JPL for PPP applications are sampled at 5 minutes (https://gipsy-oasis.jpl.nasa.gov/index.php?page=data). This point determines the rest : I would like to be sure that the final sampling rate of the GPS-PWV values is really 1 minute, as usual. If you made a specific processing, you have to present it and made a comparison with a standard GPS data processing. - Elevation-Dependent Weighting used for GPS observations (constant ?, elevation dependent (aˆ2/sin(elev)ˆ2) ?) - Tropospheric models used : ZHD a priori (Is it GPT ?), ZWD time evolution constraint as a random walk ? Were tropospheric gradients estimated ?

Specific comments are set out below.

Page 1:

1) line 23: "an unconventional solution" This is a usual method to get PWV and it has been validated for some time now.

2) line 24: "delay is associated with the atmospheric density (i.e., temperature, pressure and water vapor)" Explanation too confused: the magnitude of this delay is related

to the integral of the refractivity index of the air as a function of temperature, pressure and water vapor (Bevis et al. 1992) on the optical path followed by the GNSS signal.

3) Explanation line 25-27 is too expeditious. - lines 25-26: "with an error of approximately 5% under all weather conditions (Wolfe and Gutman 2000)" The given reference is outdated using old version of GPS data processing software, relative calibrations of antennas etc. The evaluation of the accuracy of GPS-PWV at around 5% should also be given in millimeter. The accuracy of GPS-PWV estimates remains a active topic of research, especially during severe weather conditions when all other meteorological instruments are down. - lines 26-27 "and in near real time (Rocken et al. 1994)." Outdated reference that could be used to put into perspective the improvements made since. It could be very interesting to emphasize on the methodological improvements made from 2000 and the first utilization of the GPS-PWV estimate until now. (Guerova et al. , 2016) → Guerova G, Jones J, Dousa J, Dick G, De Haan S, Pottiaux E, Bock O, Pacione R, Elgered G, Vedel H, Bender M (2016) Review of the state-of-the-art and future prospects of the ground-based GNSS meteorology in Europe. Atmos Meas Tech Discuss. doi:10.5194/amt-2016-125

4) line 31: "high temporal resolution (∼minutes)." I know it is not easy to present it but this formulation hides many methodological points about the methodology of GPS data processing: zero, single, double difference analysis or PPP, the different ways to model ZWD in analysis... The easiest way to get high temporal resolution (∼minutes) on GPS-PWV estimates is the PPP strategy (Zumberge et al, 1997) → Zumberge, J. F., M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb (1997), Precise point positioning for the efficient and robust analysis of GPS data from large networks, J. Geophys. Res., 102(B3), 5005–5017, doi:10.1029/96JB03860.

5) Page 1 Line 31 → page 2 line 1: "Other promising applications become viable in dense networks and transects": using dense networks to do tomography is not a "promising application" even if it remains methodological issues (e. g. Champollion et al. (2005); Bastin et al. (2005); Brenot et al. (2014)) → Bastin, S., C.

Champollion, O. Bock, P. Drobinski, and F. Masson (2005), On the use of GPS tomography to investigate water vapor variability during a Mistral/sea breeze event in southeastern France, Geophys. Res. Lett., 32, L05808, doi:10.1029/2004GL021907. → Brenot, H., Walpersdorf, A., Reverdy, M., van Baelen, J., Ducrocq, V., Champollion, C., Masson, F., Doerflinger, E., Collard, P., and Giroux, P.: A GPS network for tropospheric tomography in the framework of the Mediterranean hydrometeorological observatory Cévennes-Vivarais (southeastern France), Atmos. Meas. Tech., 7, 553-578, doi:10.5194/amt-7-553-2014, 2014. → C. Champollion, F. Masson, M.-N. Bouin, A. Walpersdorf, E. Doerflinger, O. Bock, J. Van Baelen, GPS water vapour tomography: preliminary results from the ESCOMPTE field experiment, Atmospheric Research, Volume 74, Issues 1–4, March 2005, Pages 253-274, ISSN 0169-8095, http://dx.doi.org/10.1016/j.atmosres.2004.04.003.

Page 2:

6) line 3: "the diurnal cycle": more discussion about meteorological processes who have been detected according to areas? (For West African Monsoon, Bock et al. (2007)) → Bock, O., F. Guichard, S. Janicot, J. P. Lafore, M.-N. Bouin, and B. Sultan (2007), Multiscale analysis of precipitable water vapor over Africa from GPS data and ECMWF analyses, Geophys. Res. Lett., 34, L09705, doi:10.1029/2006GL028039.

7) About §2 (lines 5-12) and §3 (lines 13-22): Is it possible to merge §2 and §3 to emphasize on links between PWV, deep convective activity and the occurrence of intense rainfall?

8) line 7: "PWV data from a microwave radiometer (MWR) with high temporal resolution" Provide an order of magnitude.

9) Line 8: Wrong reference with Muller et al. (2009) who do not used MWR-PWV data. However, it remains interesting to provide a reference in the article about relationship between the PWV and tropical precipitation.

10) Line 8: Using "Chan 2009" can be useful to discuss about differences between MWR-PWV and GPS-PWV during severe weather events (see in particular the interesting §3.3 Comparison with GPS receivers of the article).

11) Line 9: "useful indications of the accumulation of water vapor" : be more specific, in which these indications are useful ?

12) Line 14: "Mazany et al. (2002) developed a lightning prediction index for Florida based on the GPS-PWV magnitude and its temporal evolution": if this index is interesting, can you write more about it?

13) Line 19: "This study showed that prior to deep convective events in the central Amazon, a 4-hour “ramp up” in the time derivative of GPS-PWV is observed, reaching a maximum approximately one hour before heavy precipitation."ÂăThis sentence should be in the next paragraph to better distinguish results from precedent studies and results of the article. It is a repetition of sentence line 26-27 "The sharp increase in the GPS-PWV values approximately one hour before the occurrence of more intense rainfall events, as found in this study and that of Adams et al. (2013)" and should be merged with it.

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14) line 8: "The CHUVA Vale campaign was carried out in São José dos Campos in São Paulo State in an elevated valley between the Mantiqueira and Serra do Mar mountain ranges." Add the reference of fig.1 given line 23: "Fig. 1 shows the geographic location of the CHUVA Vale campaign, emphasizing the sites at which the instruments were placed."

15) line 11: "During the CHUVA campaigns," Too many repetitions.

16) Lines 11-14: "GPS meteorology was used to monitor the horizontal and temporal variations in the PWV associated with the wide variety of convection-producing mechanisms for the 6 geographic regions. For example, Adams et al. (2015) described the

temporal and spatial evolution of tropical sea-breeze convection with GPS meteorological transects during the CHUVA-Belem field campaign." Of topics in this part : be more concise. You can eventually add this point in your introduction part. You speak about " 6 geographic regions" without using it after.

17) line 23: "Fig. 1 shows the geographic location of the CHUVA Vale campaign, emphasizing the sites at which the instruments were placed." See comments about line 11.

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18) subsection "2.2 High temporal resolution GPS-PWV time series" is too confusing and must be structured and clarified.: - GPS data of receiver sampled at one-second frequencies → under-sampling ? - Orbit and clock data products : what kind of products did you use ? What is the sampling of these products ? Orbit and clock data products from JPL for PPP applications are sampled at 5 minutes (https://gipsy-oasis.jpl.nasa.gov/index.php?page=data). This point determines the rest : I would like to be sure that the final sampling rate of the GPS-PWV values is really 1 minute and not 5 minutes, as usual. If you made a specific processing, you have to present it. In addition, you have to ensure that this kind of estimation is appropriated for your purposes and your estimation doesn't suffer the effect of an artifact. - elevation weight function used for GPS observations (constant ?, elevation dependent (a/sin(elev)ˆ2) ?) - Cut-off (OK line 5) - Tropospheric models used : mapping function (OK line 5), ZHD a priori (Is it GPT ?), ZWD time evolution constraint as a random walk ? Tropospheric gradients have been estimated ?

19) Line 6: "To ensure the quality of the PWV time series with high temporal resolution required in this study, a rigorous data-processing strategy was adopted with possible noise sources taken into consideration." What does it mean? Give a reference if you used a validated data-processing strategy else explicit it please.

20) Line 8: " recommended by the International Global Navigation Satel-

lite System Service" : use IERS conventions that are authoritative in the field. → IERS Conventions (2010). Gérard Petit and Brian Luzum (eds.). (IERS Technical Note ; 36) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2010. 179 pp., ISBN 3-89888-989-6 https://www.iers.org/IERS/EN/DataProducts/Conventions/conventions.html

21) lines 9-10: "absolute calibration was performed to ensure the correct phase center variation, as reported by Görres (2006)" : It would be clearer to distinguish ÂńÂăabsolute calibration (Schmidt et al., 2009)ÂăÂż and the specific absolute calibration of your antenna (Görres, 2006) if you have done it. → Schmid, R., P. Steigenberger, G. Gendt, M. Ge and M. Rothacher (2007), Generation of a consistent absolute phase-center correction model for GPS receiver and satellite antennas, Journal of Geodesy, Volume 81, Number 12, 781-798, doi :10.1007/s00190-007-0148-y.

22) Line 10: New paragraph to explain the conversion ZTD → PWV?

Line 13-14: Which TM and Pressure data have been used, and with which time resolution? How are they computed at 1 minute sampling?

23) Line 15: "The sampling rate of the GPS-PWV values was 1 minute." Again, if the sampling rate is 1 minute, that implies PPP products cannot be sampled at 5 minutes. Have you done a specific GPS data processing to compute your own PPP products to obtain a sampling rate of the GPS-PWV values at 1 minute?

24) Line 16: "problems with the satellite ephemerides" Can you explicit these problems? I don't understand why you got a problem with it.

25) Lines 16-17: "unavailable pressure measurements" Is it possible to complete it with a meteorological modelÂăor the problem was not so important to solve it?

26) Lines 17: "other unknown causes": If we consider GPS data from receiver, orbit/clock products for PPP processing and pressure measurements, I don't see which other unknown causes can be possible.

Subsection "2.3 Precipitation time series from disdrometer and XPol radar data" should be clarified:

27) Line 23: "very small spatial scale": Provide an order of magnitude.

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28) line 5-6 "The dimensions of the precipitation area that influences the GPS-PWV is a key factor in the development of this study": If it is the case, you should explicit what you have really done and not summarize quickly your tests to directly provide the area of 22x22 1. "Different areas were tested": explicit 2. "found to be more representative of the observed area by GPS": what criteria have been used? 3. "better for exploring the correlation between the precipitation occurrence and GPS-PWV": Could you please provide quantified results?

29) Line 14: "around" Can you specify?

30) Line 22-24: "the statistical measurements calculated from the radar data were in the 95th percentile of the intensity of the precipitation observed in the area of 4.4 km per 4.4 km around the GPS antenna" OK it is a statistical way in order to examine the intensity of the precipitation.

Figure 2:Âă

1 Lack of data DOY 319Âăfrom Xpol radar?

2 b and c should be at the same scale.

3 On 3 rainfall events, precipitation intensities are above 125 mm/h according to Disdrometer (Fig. 2 b) whereas the 95th percentile of the intensity of the precipitation observed by Xpol radar radar are below 100 mm/h (Fig. 2c): It seems strange that the disdrometer measures a statistical anomaly 3 times on 20 (>95th).

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“3 Wavelet analysis”

31) Lines 15-16: “In this study, both continuous and discrete wavelets are investigated to achieve intra- and interrelation analysis, respectively.” Distinguish what wavelet decomposition should be used to answer to what scientific questions.

Page 7

32) Lines 6-7: “The methodology employed to process the GPS data in one-minute intervals did not provide any additional information. Fig. 3 shows that the GPS-PWV energy variability begins to be significant only for time scales longer than 16 minutes.” The influence of stochastic constrains applied on temporal evolution of ZWD during the GPS data processing must be taken into account. If you have used a too small random walk parameter, that could explain what you have observed.

33) line 8: “Therefore, the one-minute time series representativeness is not a limitation, and if there is noise, it is white noise.” Can you explicit and prove it?

34) It is obvious that a jump in a time series will produce what is described lines 13-15: “there are expressive changes in the power between different time scales in those cases in which an increase in the power of the oscillation from low to high frequency is observed.” It is the well known example of the Wavelet power spectrum of a Dirac signal.

35) Figure 3: GPS-PWV presents a jump DOY 358 with a strong signal in the Wavelet Power Spectrum but Xpol radar did not detect any precipitation : have you any comment on it?

36) lines 31-32: “The results show that the wavelet correlation between the PWV and precipitation intensity is more evident and significant for the time scale between 32 and 64 minutes”. Again it would be clearer to speak about PWV jump before speaking about the lag between GPS-PWV jump and rainfall and introduce wavelet to determine the lag precisely.

37) lines 31-32: Correlations shown figure 5 do not exceed 0.15 and do not look significant: it seems clear there is a lag between GPS-PWV and rainfall and the evaluation of this lag seems good but the correlations of figures 5 and 6 diminish the strength of the demonstration.

page 8

38) “4 Behavior of PWV time series before precipitation events: the GPS-PWV jumps”: I appreciate the meteorological interpretation of GPS-PWV jump during severe weather events but this interpretation seems to be founded only on a single reference (Adams et al., 2013): Is there any other references on these meteorological processes during severe weather events?

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39) line 3-5 “This result corroborates the pattern observed in Fig. 7, showing the GPS-PWV maximum before the precipitation event and its minimum after the maximum precipitation” It would be clearer if the zoom of figure 7 has shown precipitation.

40) “4.2 GPS-PWV derivative analysis” Line 20-21: “Fig. 9 clearly shows an expressive change in the pattern of the derivative distribution as a function of the different precipitation intensity terciles.” : I suppose you did it but did you check that for each severe weather event of upper tercile you got around 7.8% of GPS-PWV derivative > +9.5 mm.hˆ(-1) and around 5.47% of GPS-PWV derivative < -9.5 mm.hˆ(-1) because if I have well understand, you proposed section 4.3 to use this criterion to detect severe weather events for nowcasting application.

Page 11 - Conclusions

41) line 28-30: “The wavelet analysis for the GPS-PWV time series was explored, and it clearly shows that during precipitation events, there are expressive changes in the power spectrum between different time scales, in which an increase of the power of the oscillation from low to high frequency is observed.” It is a logical result due to the fact

there is a jump in GPS-PWV time series during severe weather events (see comment 34) .

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