

Anonymous Referee #2

Received and published: 2 October 2015

Review of 'On the inclusion of GPS precipitable water vapour in the nowcasting of rainfall' by Benevides et al.

The manuscript is of interest and worthy of publication after a major revision. The data sources, methods and the results are well presented; my main concerns are that the conclusions drawn from the evaluation are hardly scientifically discussed and – from technical point of view - I found the quality of writing very poor. There were many instances of awkwardly worded sentences, bad grammar, and missing punctuation. I realize that English is likely not the author's native language, so I recommend to have someone carefully review the revised manuscript.

General comments:

1. The introduction gives a clear overview about GNSS/GPS data and its applications, especially with respect to water vapour. As the paper focuses on the application of rainfall nowcasting, the authors should also provide more information about the state-of-the art on the use of GPS data for NWP and/or nowcasting (i.e. assimilation issues).

The following text has been included in P.3863 L.18:

'Some studies revealed the potential of the GNSS meteorology to analyse the water vapour distribution at near real time and its applicability for weather nowcasting (Haase et al., 2003; Brenot et al., 2006; Yan et al., 2009; Karabatic et al., 2011). Assimilation of GPS derived water vapour data into weather forecast models has already been studied, resulting in better forecast of severe rain events (Vedel et al., 2004; Cucurull et al., 2004), even at the convective scale (Yan et al., 2009). The technique allows to estimate water vapour measurements with high sampling rate with less than 1 hour of temporal delay. However a major drawback is the estimation of the near real time satellite orbit with high accuracy, which has an impact on the GPS atmospheric measurements (Karabatic et al., 2011). Nevertheless recent developments have improved the GPS PWV precision through near real time orbit, clock and phase delay corrections, using a large network of stations and multi-GNSS processing techniques (Li et al., 2014; Li et al., 2015a).'

2. In chapter 3, last sentence, the authors mention the influence of westerly flow, occasionally leading to torrential rainfall. Could you be more precise, what do you mean with 'fast transformation in various temporal and spatial scales'?

The sentence was not clear and therefore it was modified to:

'The geographical setup favours the penetration of westerly marine air masses into the coastal areas often characterized by complex topographic relief, occasionally leading to torrential rainfall...'

3. Chapter 4 'Methods': Generally, the method is well described, but the strategy to reduce the ZTD discrepancy between daily estimates is not fully clear. Maybe a graphical example could help here.

Text modified to:

'The time overlap window strategy consists in performing on each day 4 processing sessions with a 12 h duration, (e.g. 21:00–09:00, 03:00–15:00, 09:00–21:00, 15:00–03:00 UTC) and use only the central 6 h on each time window, therefore resulting in a complete 24 h set of a day. To avoid the orbit adjustment starting from the final hours of the previous day, orbits adjusted in the first daily processing step are used.'

4. Chapter 5: The evaluation focuses on heavy precipitation events rather than medium or weak precipitation for one station. Could you provide an estimate of applicability of the method for non-extreme events and other locations at different climate regions?

The main achievement of this paper is the possibility of heavy rain forecast based on a positive correlation between the fast increase of the PWV (more than 1.5 mm /hour) and a subsequent (in time) heavy precipitation event. The method must complement other operational forecast methods. We believe that the method should be applied to other locations or different climate regions as long as all precipitation events are preceded by an increase of the water vapour in the atmosphere irrespectively the location. However it was not possible to define a clear cause and effect between the PWV and the precipitation in view of the huge number of false positives.

5. In the discussion it is stated that some of the mismatch between PWV and precip is due to the sparse rain gauge network. Did the author take radar data also into account? A radar – rain gauge merging method which combines both data source would help to overcome this problem (at least in areas where radar problems with beam blockage etc. are not that relevant).

We agree with your observation. However the goal of this paper was to analyse the behaviour of the PWV from the GPS signal with a continuously hourly meteorological measurement, which is hardly achieved by other than local surface stations. Radar data has a high spatial resolution making very hard to manage or arrange a long hourly temporal series to analyse with the GPS PWV. While such data was not available for the present study, its analysis remains a goal for future studies.

Technical comments:

1. P. 3862, line 8: it should read: 'It is found that most severe rainfall events occur . . .'

Corrected.

2. P. 3862, line 19: ' . . . and one that is notoriously difficult to monitor' sounds odd.

Corrected to '...being difficult to monitor'.

3. P. 3862, line 19: ' . . . are unable to do a sufficient time and space sampling of its distribution': please rewrite.

Entire sentence modified to: 'Direct observations of that variable by synoptic meteorological stations provide only local surface measurements, while radiosondes provide a continuous vertical profile although at poor temporal resolution due to its expensive operational cost.'

4. P. 3863: line 3-9: split up into 2 sentences

Lines corrected to: 'The rapid increase in the density of such networks in some regions, has been motivating the exploration of GNSS data for other meteorological applications. Some examples are including three-dimensional water vapour tomography from short term field experiments (Champollion et al., 2005), or from the analysis of country-wide networks (Bender et al., 2011), and even the deployment of high-density GNSS systems specifically designed for the monitoring of atmospheric convection (Adams et al., 2011).'

5. P. 3863: line 26/27: with cloud and precipitation patterning: what do you mean exactly? Please reformulate.

Corrected to: '...with large horizontal gradients in the cloud and precipitation fields.'

6. P. 3863, line 29: an advection cannot be 'large', please rewrite

Corrected to: '...are driven by the advection of high humidity air masses from the ocean'

7. P. 3863, first paragraph: split into 2 sentences

Maybe you were referring to P.3864. Sentence was modified to:

'If this warm and moist air encounters cold polar air transported southward in the mid and high troposphere, as frequently occurs in that region in the autumn, these are conditions that favour static instability. This will likely lead to convection, especially in places with topographic forcing, initiating deep convective storms (Champollion et al., 2004).'

8. P. 3867, line 12: should read '...can be related to a more ...'

Corrected.

9. P. 3867, line 22: 'by a sufficient set' is strange. I guess, the set should be large enough.

Corrected to 'by a large set'

10. P. 3869, line 1: '... favours the penetration ...' is odd, should read '... favors the advection of ...'

Corrected

11. P. 3870, line 25: 'Outside 2012 the analysis looked ...': what do you mean? Please rewrite.

Sentence corrected to: 'For the remaining 2010 and 2011 years the analysis was performed...'

12. P. 3871, line 26: '...bringing maritime ...' sounds odd, please rewrite.

Corrected to: '...flows carrying maritime tropical...'

13. P. 3873-3874, line 26-2: Split into 2 sentences.

Entire sentence corrected to:

'The case studies previously analysed indicated that one often observes a pattern of heavy rain occurring after a peak in PWV, leading to a subsequent sharp decrease of the latter variable. Despite the observation of this simple characteristic, the relationship between variations of PWV and precipitation may be rather complex, as one would expect due to the heterogeneous distribution of precipitation in both space and time, and especially during severe weather events.'

14. P. 3874, line 3: 'the relation is not one-to-one' sounds odd. Please rewrite.

Sentence was modified to: 'The cause effect of this relation is not reversible, meaning that large variations of PWV often occur without a rainfall registered event. However these large variations could indicate cases where...'

15. P. 3874, line 13-16: Please rewrite the sentence, it reads very clumsily.

Entire sentence from the beginning of line 13 was modified to:

'In this method, the evolution of the hourly PWV retrieved from the GPS signal is analysed by linear fitting of the PWV signal to a broken line. PWV temporal evolution at a station is continuously verified, grouping the hourly increments or decrements in line segments. Linear least-squares fitting of the previous 6 hours of PWV is performed to evaluate the trend signal. If the signal is reversed, the line is terminated resulting in a broken line segment with increase or decrease trend.'

16. P. 3875, line 16: 'a raining probability' is wrong. Should read 'rain probability'

Corrected.

17. P. 3875, line 27: 'In the other extreme' is awkward, please rewrite.

Sentence corrected to: 'In contrast, class A shows values corresponding...'

18. P. 3876, line 12: 'occur' instead of 'occurs'. This is only an example of bad grammar which I do not comment all of them.

Corrected.

19. P. 3877, line 16: '... and most events are forecasted with 1 to 2h of anticipation'. What do you mean?

Sentence corrected to: '...most rain events are forecasted up to 2 h or less before.'

20. P. 3877, line 17: 'unforecasted' should be replaced by something like 'non-forecasted'

Corrected.

21. P. 3878, line 1: what do you mean with 'recovers'??

Corrected to: 'detects'. Line 2 also corrected.

22. P. 3879, line 2: 'until it is out of range' sounds odd, please rewrite.

Corrected to 'fading away in the following hours'.

23. P. 3880, line 12: 'Seco et al. looked at' is odd. Such phrase is repeated several times in the manuscript.

Sentence modified to:

'A much larger amount of continuous data of 9 years in NE Spain was evaluated, being developed a neural network system to forecast rain from GPS PWV data and observed surface pressure, in a single point, concluding for the existence of some predictability in a range beyond two days (Seco et al., 2012).'

Sentence from line 4, P. 3880 modified:

'Such result is consistent with Inoue and Inoue (2007) study, where data from "summer thunderstorm active days" in a five year period was analysed, indicating that ...'

Sentence from line 7, P.3880 was modified to:

'A study evaluating one month of data in Japan (Shoji, 2013) verified, as in this work, that the precipitation frequency...'

Other improvements on the manuscript.

Paragraph in P.3863, L10 to L18 has been removed due to redundancy of its content in the “Introduction” section.

Paragraph in P.3864, L9 to L24 has been removed from the “Introduction” and some of its content included in the “GPS atmospheric processing” section (details are below).

The following text was introduced in P.3866, L1:

‘Its pathway departs from the satellites to the station receivers at the speed of light, but alterations are induced in its course because of density differences in the medium causing refraction. Clouds, moisture, temperature and pressure gradients, mainly caused by the water vapour, provoke delay and bending in the signal path travel.’

Paragraph from L25 P.3864 to L7 P.3865 has been removed from the “Introduction” and some of its content included in the “GPS atmospheric processing” section (details are below).

The following text was introduced in P.3867, L24, creating a new paragraph:

‘Several studies have shown that PWV estimates obtained from GPS are typically achieved with an accuracy of the order of 1 to 2 kg m⁻² (mm), when comparing with classical measurements like radiosonde, radiometer, lidar or radar (Rocken et al., 1995; Baker et al., 2001; Niell, 2001; Haase et al., 2003; Brenot et al., 2006; Snajdrova et al., 2006; Bastin et al., 2007; Jin et al., 2007; Byun and Bar-Sever, 2009; Champollion et al., 2009; Li et al., 2014), although some studies reach a bias of 3 kg m⁻² or more (Tregoning et al., 1998; Bock et al., 2007; Boniface et al., 2012).’

Figure 5 was modified to make the caption coherent with the text reference.

Other smaller corrections were also performed throughout the whole document.