Relationship between Precipitable Water Vapor (PWV) and heavy rainfall over Lombardy region in Northern Italy using GNSS and CML sensors network

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Introduction

Nowcasting and understanding of locally evolving severe weather events is a demanding task that requires the combined investigation of different type (both ground- and space-based) of datasets. Atmospheric water vapor (WV) which is the most abundant greenhouse gas (accounting for ~70% of global warming) comprises a significant energy source which generates severe weather and climate phenomena. GNSS (Global Navigation Satellite System) WV has been proved a valuable data source for high-resolution limited area Numerical Weather Prediction (NWP) models. The rapid spatiotemporal variations of WV in the low atmosphere poses one of the main challenges to NWP models forecasting accuracy. **Abrupt increase of WV several hours before extreme rainfall has been temporally correlated with rainfall in various studies, followed by a decrease after the event. Other studies have investigated the joint effect of GNSS-WV and atmospheric pressure on extreme rainfall. Though many studies have evidenced ongoing accumulation of WV before the heavy rainfall, there is still a great difficult to determine a tight relationship between rainfall and WV, that could be reproduced by a plain, physically motivated two-layer nowcasting model.**

Lately, **Commercial Microwave Links (CML), globally used in cellular telecommunication networks of base stations, are exploited as opportunistic sensors to estimate the average rainfall intensity along the radio path and to reconstruct rainfall maps over a region.** Rainfall measured by the CML network has a vast application prospect in both densely populated and remote mountainous regions. Over tropical regions, such as Sri Lanka, the spatial comparison of CMLs with the high-quality satellite product GPM (global precipitation measurement) and with conventional rain gauge data confirmed the potential of CMLs to provide detailed monitoring of heavy rainfall events.

The advantage of both the GNSS and CML opportunistic sensors networks is their high spatial and temporal resolutions.

Objective

In this context, the present **study attempts a first comparison of GNSS tropospheric products (Precipitable Water Vapor, PWV) with the respective CML-derived rainfall measurements with the ultimate aim to investigate the possible correlation between WV and heavy rainfall, during selected extreme precipitation events occurring at the period 20-22 June-2019 (very heavy rainfall event on 22 June)** over the Lombardy region in Northern Italy. To achieve this, we will exploit CML network, owned by Vodafone Italia S.p.A., ground-based GNSS receivers network owned by GReD srl, as well as meteorological observations available through the Lombardy-based Advanced Meteorological Predictions and Observations (LAMPO) project.

Methodology

Radiolink rain vs GNSS PWV over the Lombardy region in Northern Italy

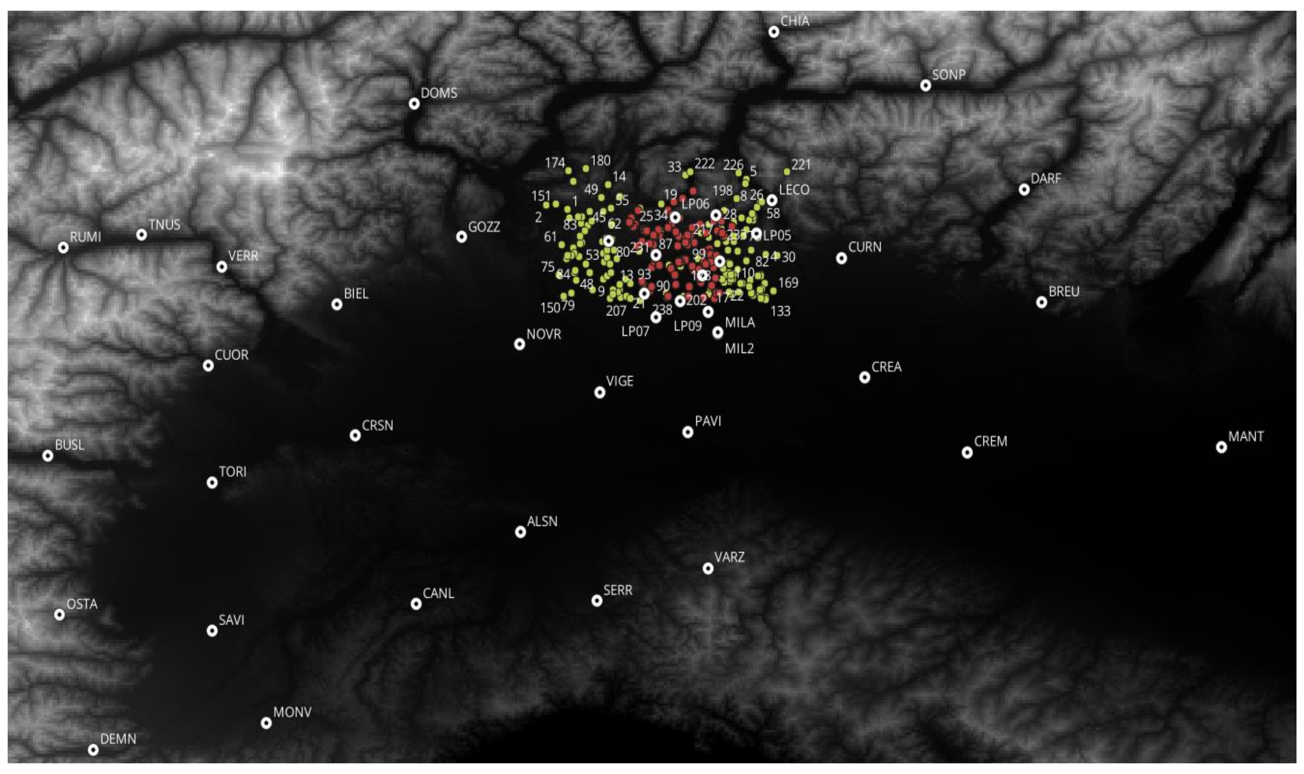


Figure 1. Map showing the spatial distribution of the GNSS stations and the radio link points (the prediction points) over the Lombardy region in Northern Italy. These points are in the middle of the radio link at a height taken from an SRTM DEM (orthometric height).

Red points: radiolinks middle position. We extracted the orthometric heights of these points from SRTM DEM (30 meters spatial resolution, EGM96 model)
Green points are radiolinks not considered here.
White points are GNSS stations, prediction errors range between 5 mm to 30 mm for ZTD and from 1 mm to 6 mm for PWV. These numbers are from leave-one-out daily assement.

The raw CML data are minimum and maximum rainfall intensity (in mm/h) every 15 min. Then we applied a linear combination of them (according to the study of the co-author Dr Roberto Nebuloni: https://www.ursi.org/Publications/RadioScienceLetters/Volume2/RSL20-0062.pdf) and we found the average rainfall intensity in 15 min (in mm/h).

Results

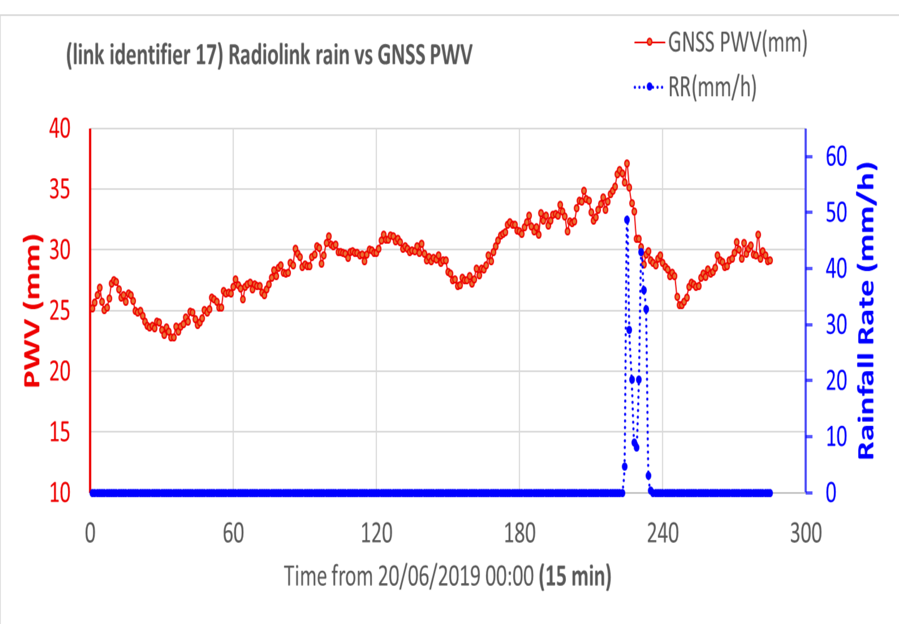
To examine the PWV variation before and during a heavy precipitation event we assigned the PWV/Precipitation time series (240 CML links) in the 8 categories shown at following Table.

Categories of PWV-RAIN relation	CML Links	Sum of Events
C1. PWV ascending trend before/during rain	ID 10, ID 17, ID 19, ID 21,ID 24,ID 32,ID 34,ID 35,ID 36,ID 37,ID 38,ID 41,ID 57,ID 60,ID 67,ID 70,ID 72,ID 81,ID 87,ID 88,ID 92,ID 93,ID 94,ID 97,ID 98,ID 99,ID 102,ID 104,ID 105,ID 106,ID 107,ID 108,ID 112,ID 113,ID 114,ID 115,ID 116,ID 117,ID 119,ID 120,ID 122,ID 123,ID 127,ID 129,ID 130,ID 134,ID 135,ID 140,ID 144,ID 165	50
C2. PWV peaks within 1h from rain or during rain	ID 10, ID 17,ID 21,ID 24,ID 35,ID 38,ID 40,ID 41,ID 57,ID 60,ID 67,ID 70,ID 72,ID 81,ID 87,ID 88,ID 92,id 93,ID 94,ID 97,ID 99,ID 101,ID 102,ID 104,ID 107,ID 108,ID 112,ID 113,ID 114,ID 115,ID 116,ID 117,ID 119,ID 120,ID 122,ID 123,ID 127,ID 130,ID 134,ID 135,ID 144	41
C3. PWV peaks 1-3h before rain	ID 10, ID 19,ID 25,ID 31,ID 32,ID 34,ID 36,ID 37,ID 39,ID 60,ID 98,ID 105,ID 129,ID 165	14
C4. PWV peaks 3-6h before rain	ID 10, ID 17,ID 21,ID 24,ID 25,ID 32,ID 34,ID 35,ID 36,ID 37,ID 39,ID 40,ID 41,ID 57,ID 67,ID 70,ID 72,ID 81,ID 87,ID 88,ID 92,ID 93,ID 94,ID 97,ID 98,ID 99,ID 101,ID 102,ID 104,ID 105,ID 106,ID 107,ID 108,ID 112,ID 113,ID 114,ID 115,ID 116,ID 117,ID 119,ID 120,ID 122,ID 123,ID 127,ID 129,ID 130,ID 134,ID 135,ID 140,ID 144,ID 165	51
C5. PWV peaks 6-12h before rain	ID 38,ID 57,ID 70,ID 81,ID 88,ID 93,ID 102,ID 106,ID 112,ID 114,ID 116,ID 119,ID 122,ID 123,ID 127,ID 129,ID 130,ID 134	18
C6. PWV peaks occuring more than 12h from rain onset	ID 25,ID 31,ID 32,ID 34,ID 35, ID 36,ID 38,ID 39,ID 40,ID 41,ID 57,ID 67,ID 70,ID 72,ID 87,ID 92,ID 97,ID 98,ID 99,ID 101,ID 104,ID 105,ID 106,ID 112,ID 115,ID 116,ID 119,ID 135	28
C7. Max PWV after max or a high rain peak and before another high rain peak	ID 106,ID 140,ID 188, ID 194	4
C8. PWV descending trend more than 12h from rain onset	ID 25, ID 31,ID 39,ID 101	4

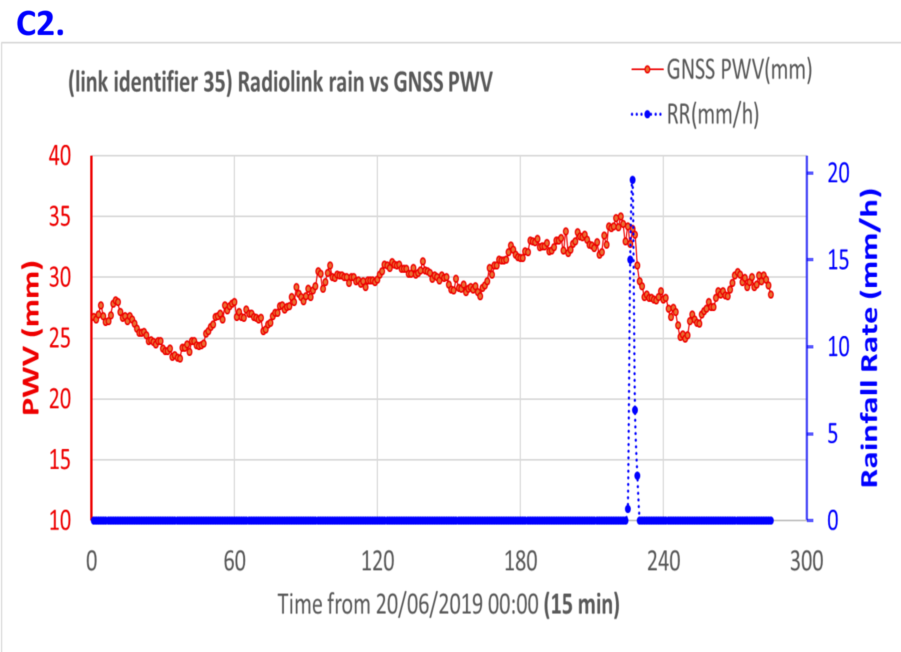
Results

Graphs of PWV and CML links time series during a very heavy rainfall event, on 20-22 June 2019 over the Lombardy region in Northern Italy. In total, for the 240 links were produced. Representative graphs are shown here for each of the 8 categories.

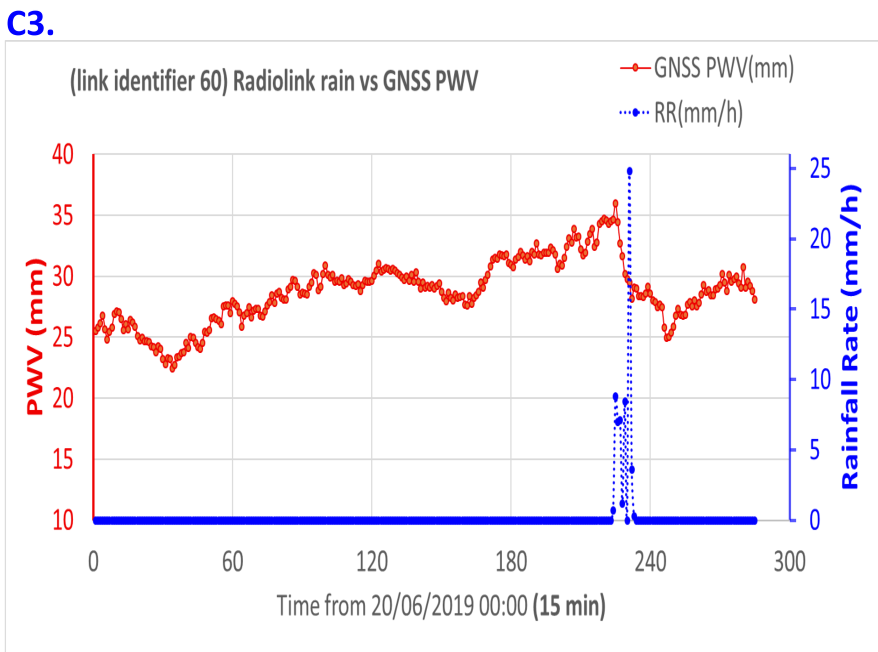
C1.



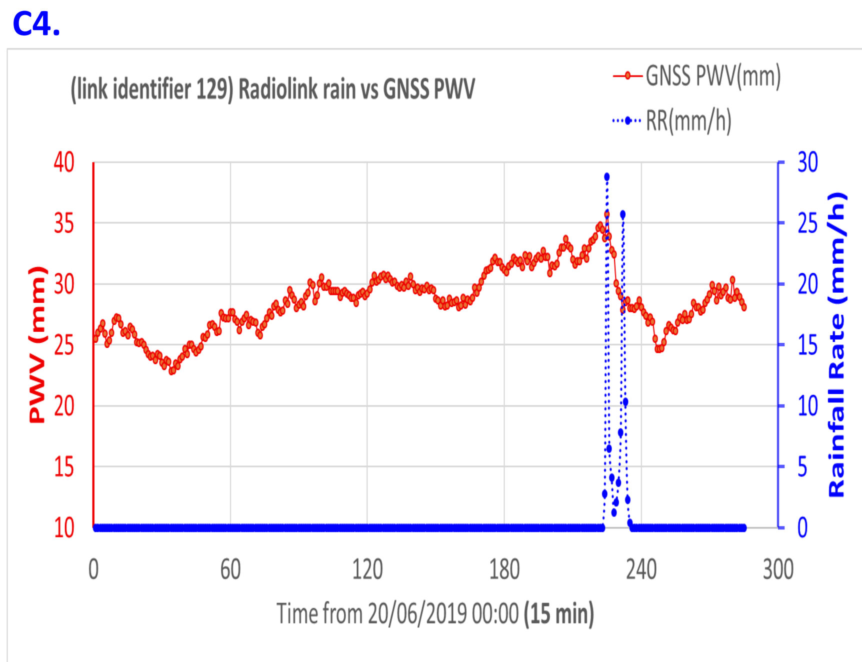
C2.



C3.



C4.



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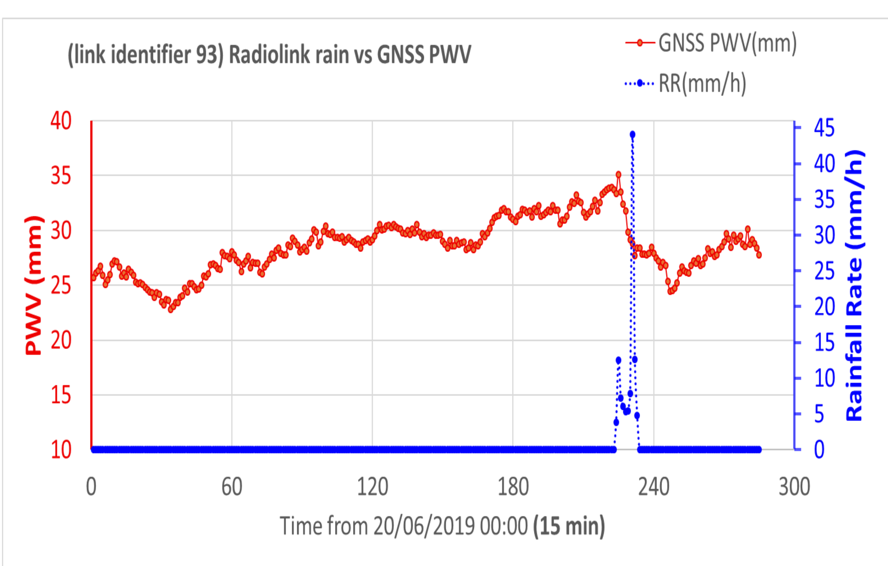
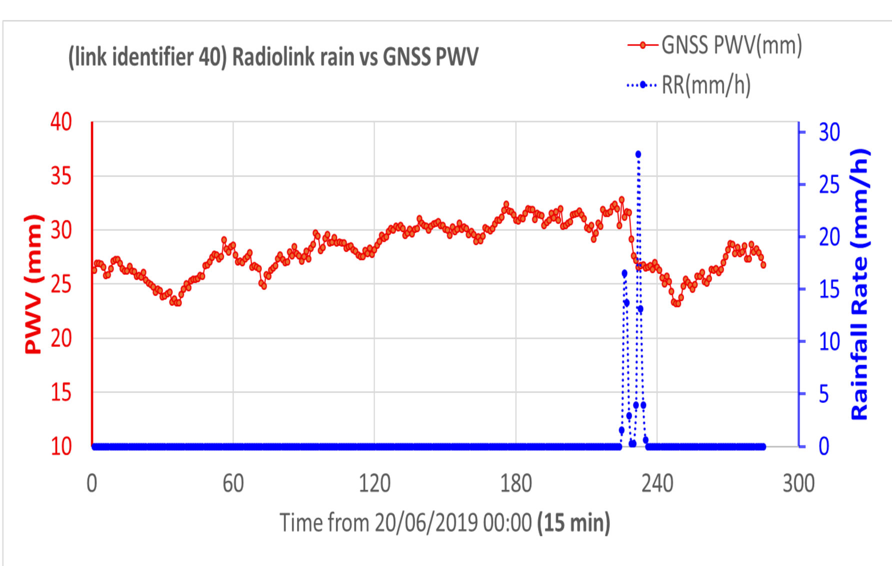
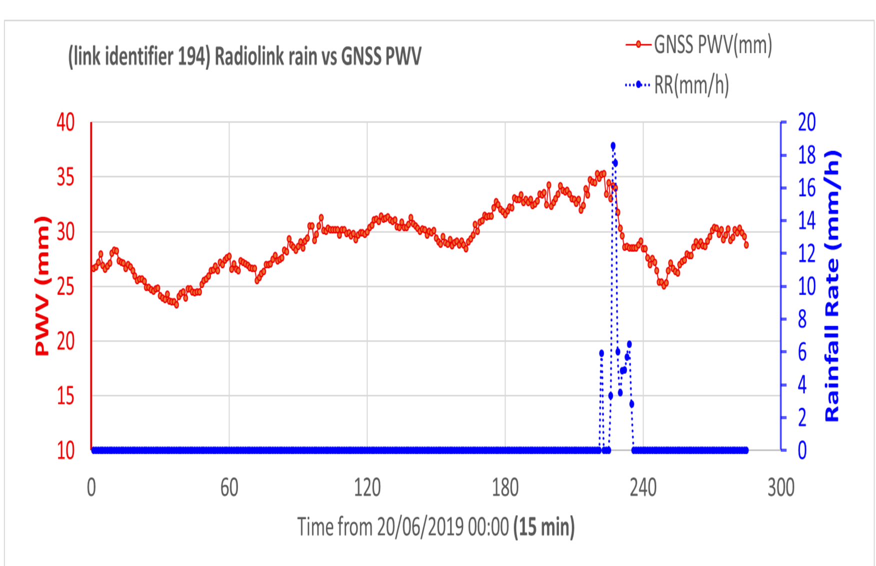


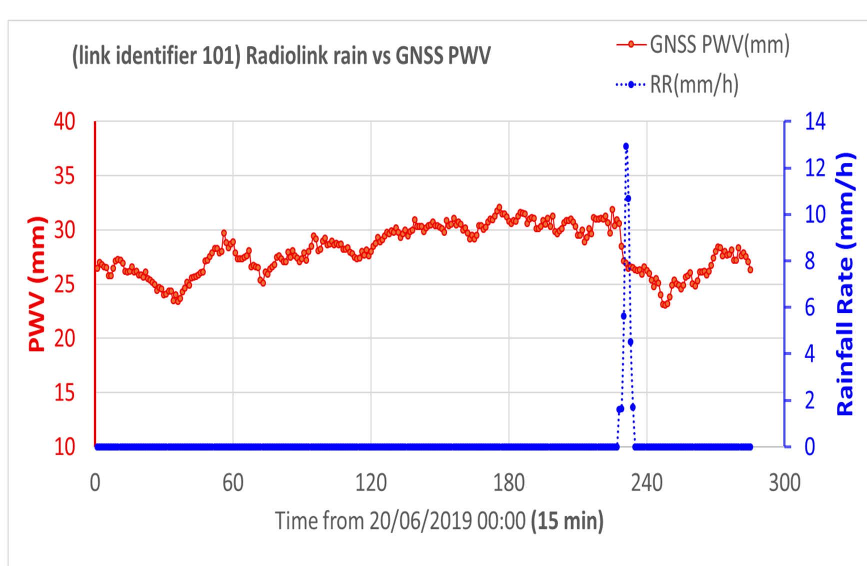
C6.



C7.



C8.



References

1. R. Nebuloni, M. D'Amico, G. Cazzaniga, and C. De Michele (2020). On the Use of Minimum and Maximum Attenuation for Retrieving Rainfall Intensity Through Commercial Microwave Links, DOI: 10.46620/20-0062.
2. Barindelli, S., Realini, E., Venuti, G. et al. Detection of water vapor time variations associated with heavy rain in northern Italy by geodetic and low-cost GNSS receivers. Earth Planets Space 70, 28 (2018). https://doi.org/10.1186/s40623-018-0795-7

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Concluding remarks

In most of the analyzed events, GNSS PWV increase before heavy rainfall starts, with clear PWV peaks related to rain peaks occurring from several hours before the onset of heavy rain to right before or during the heavy rain peaks. When rainfall begins to weaken, the PWV is expected to drop sharply. We do not always observe a sharp decrease in the studied events, as we can also see a smother decrease in some cases. In the majority of these events, PWV peaks within 1h or 1-3h before the precipitation onset.