GROUND-BASED GPS RECEIVER AND MICROWAVE RADIOMETER TO CHARACTERISE WATER VAPOUR OF PRECIPITATION EVENTS

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ABSTRACT

This work considers the use of a ground-based GPS receiver and a a dual-channel microwave water vapour radiometer located at the same site for monitoring integrated precipitable water vapour with the purpose of analysing the behaviour of such parameter during precipitation events. Measurements of the temporal evolution of the water vapour content before the beginning of the rainfall and during the event have been performed at the site of Perugia (Italy) for two years, taking into account that WVR measurements are affected by rainfall whilst GPS is an all-weather system.

INTRODUCTION

Water vapour, the most variable of the major constituents of the atmosphere, plays a key role in atmospheric processes and also it has a significant impact on radio propagation at millimeter wavelengths. Therefore, it is important that the amount of water vapour in the atmosphere is experimentally quantified accurately, with frequent sampling and under all weather conditions. For instance, the knowledge of water vapour field comes usually from radiosoundings and ground or space based water vapour radiometers (WVR). Radiosonde observations (RAOB's) produce accurate measurements of the water vapour profile, but the availability of data two or four times per day does not meet the requirements of frequent sampling of such parameter, taking into account the high degree of variability. Ground-based microwave radiometers are able to work continuously for the retrieval of integrated precipitable water vapour (*IPWV*) with a high temporal resolution, but providing measurements not reliable during rainfall.

Considering the growing employment of Global Positioning System (GPS) ground-based receivers as a microwave (L-Band) remote sensing tool for the estimation of integrated precipitable water vapour, time series of *IPWV* become available with high temporal and spatial resolution, taking into account that GPS estimates are not affected by rainfall, and GPS can therefore be considered an all-weather system [1], [2].

This work considers the use of a ground-based GPS receiver and a dual-channel microwave water vapour radiometer positioned at the same location for monitoring *IPWV* with the purpose of analysing the behaviour of water vapour time series during precipitation events.

On the basis of previous experimental assessments of *IPWV* retrieval by GPS and WVR [3] for clear sky conditions, showing a good agreement between the two remote sensors, a characterisation of atmospheric water vapour content has been attempted to improve the knowledge of water vapour field of precipitation systems [4]. Since GPS and WVR are able to work automatically and continuously as well as with high temporal resolution, on the basis of estimations from GPS the use of WVR measurements in the presence of rain has been attempted for monitoring water vapour.

For this purpose, a statistical characterisation of *IPWV* has been carried out selecting the precipitation events during two years of measurements at the site of Perugia (Italy). In this study we focus on the measurement of the amount and temporal evolution of atmospheric water vapour content starting just before the beginning of the rainfall and during the event at Perugia, where the mentioned microwave sensors and a meteorological weather station with rainfall measurement system are positioned at the same location and are working continuously in unattended mode since 2000.

MEASUREMENTS OF *IPWV* USING GPS AND WVR

By processing GPS observations with specific geodetic softwares, it is possible to estimate the zenith total delay (*ZTD*) due to the neutral atmosphere and therefore to infer the zenith wet delay (*ZWD*) by subtracting the zenith hydrostatic delay (*ZHD*). The atmospheric total zenith path delay *ZTD* is defined as:

$$ZTD = ZHD + ZWD = 10^{-6}\int_h^\infty N(z)dz = 10^{-6}\left(\int_h^\infty N_D(z)dz + \int_h^\infty N_W(z)dz\right) \tag{1}$$

where $N_D(z)$ and $N_W(z)$ represent respectively the dry and wet atmospheric refractivity, h is the height of GPS receiver antenna and z is the vertical coordinate. The refractivity is given by:

$$N = 77.6\,(P/T) + 3.73\text{x}10^5(e/T^2) \tag{2}$$

where P is the air pressure (mb), T is the air temperature (K) and e is the partial pressure of water vapour (mb). If surface measurements of P and T are known, *ZHD* can be estimated through simple models [5] to better than 1 mm and removed from the GPS solution: then *ZWD* is computed by subtracting *ZHD* from *ZTD* and it can be directly transformed into an estimate of the *IPWV* using the relationship:

$$IPWV = \pi\, ZWD \tag{3}$$

where the constant of proportionality π is a function of various physical constants and of the mean temperature of the water vapour in the atmosphere [6]. The transformation described in (3) assumes that the wet path delay is entirely due to water vapour and that liquid water and ice do not contribute significantly to the wet delay.
Concerning the ground-based microwave radiometer, for a non-scattering atmosphere in local thermodynamic equilibrium, the emission can be quantified through brightness temperature T_B. The brightness temperature observed at zenith, assuming z=0 at the antenna position, is given by:

$$T_B(\nu) = T_c e^{-\tau_\nu(0,\infty)} + \int_0^\infty k_\nu(z) T(z) e^{-\tau_\nu(0,z)} dz \tag{4}$$

where T_C is the cosmic background temperature (2.75 K), ν is the operating frequency, $\tau_\nu(0,\infty)$ is the atmospheric opacity, $k_\nu(z)$ is the atmospheric absorption coefficient (m^{-1}), $T(z)$ is the physical temperature (K) of the medium, and $\tau_\nu(0,z)$ is the optical depth of the layer between 0 and z. The T_B is commonly converted in terms of atmospheric opacities $\tau(\nu)$ by using the definition of the mean radiative temperature $T_m(\nu)$ [7]:

$$\tau(\nu) = \ln((T_m(\nu) - T_c)/(T_m(\nu) - T_B(\nu)) \tag{5}$$

The $\tau(\nu)$ is the key parameter for retrieving *IPWV*. Neglecting scattering and ice contributions and considering a dual-channel instrument with one frequency mainly sensitive to water vapour (subscript 1) and the other to the liquid (subscript 2), then [8]:

$$IPWV = a_0 + a_1\tau_1 + a_2\tau_2 \tag{6}$$

where the retrieval coefficients a_i convert atmospheric opacities τ_1 and τ_2 (Np) to *IPWV* (cm) [9].
The values of retrieval linear statistical inversion coefficients a_i in (6), of coefficient π in (3), and of mean radiating temperature T_m in (5) have been estimated on the base of simulations performed by applying radiative transfer models [10] to a large set of fifteen years of RAOB profiles collected at Italian stations from 1980 to 1999.

EXPERIMENTAL RESULTS FOR PRECIPITATION EVENTS.

The work focuses on the estimations of *IPWV* around precipitation events at the site of Perugia exploiting two years (2000 and 2001) of measurements using a GPS receiver and a dual-channel ground-based radiometer (WVR-1100), operating at 23.8 and 31.6 GHz. The permanent GPS stations of Perugia belongs to the Italian GPS Network managed by ASI and the processing of GPS data was performed by using GIPSY-OASIS II software, with a time resolution of 15 minutes. The WVR-1100 provides brightness temperatures regularly calibrated with a time resolution of about 1 minute observing at 5 elevation angles (39, 30, 25, 21 e 90 degrees) along each North, South, East and West azimuthal direction. In this analysis only zenithal observations have been processed.
On the basis of time duration and cumulated rain measured by the rain gauge, a two-step classification of precipitation events has been performed: first, the events have been classified into few classes of different duration, then each of the previous classes has been further subdivided, considering different levels of cumulated rain. For these classes *IPWV* time series have been computed, starting one hour and half before the beginning of the rainfall.
Table 1 synthesises the classification of the precipitation events statistically significant for Perugia in terms of duration, reporting also the cumulated rain recorded by the rain gauge.

Fig.1 shows the *IPWV* time series from one hour and half before until two hours after the beginning of the rainfall for the classified events, where precipitation events of the same class (i.e. of the same time duration) with different cumulated rain are assembled together. A general increase of *IPWV* field just before the rainfall can be noted, while during the precipitation the averaged *IPWV* evolution reaches a plateau.

Concerning the *IPWV* retrieval using the WVR-1100, taking into account that the instrument provides measurements not reliable during rainfall due to the wet antenna effects, we have considered the atmospheric opacities $\tau_{23.8}$ and $\tau_{31.6}$ provided just before the beginning of rainfall and corrected with the rain specific attenuation γ (attenuation per unit distance) given by:

$$\gamma = k \cdot R^{\alpha} \tag{7}$$

where R is the rain rate in mm/h, and k and α are the Laws and Parsons power-law parameters, which depend on frequency, raindrop size distribution, rain temperature and polarization [11].

As preliminary results, Fig. 2 refers to events of duration greater then three hours but with different levels of cumulated rain. Such figure shows *IPWV* time series estimated from GPS and WVR-1100 starting again one hour and half before the beginning of the rainfall until two hours after. Table 2 reports the characteristics of four selected events and the comparison between GPS and WVR-1000 estimates, that shows a good agreement between the two sensors considering events with no heavy rain.

Table 1. Perugia site: classification of precipitation events during 2000 and 2001

Duration (hours)	MIN cumulated rain (mm)	MAX cumulated rain (mm)	Averaged cumulated rain (mm)	Number of events
>3	4.8 mm	25.8 mm	11.6 mm	15
>1 and <3	1.0 mm	38.2 mm	5.18 mm	65
<1	0.4 mm	20.2 mm	2.23 mm	172

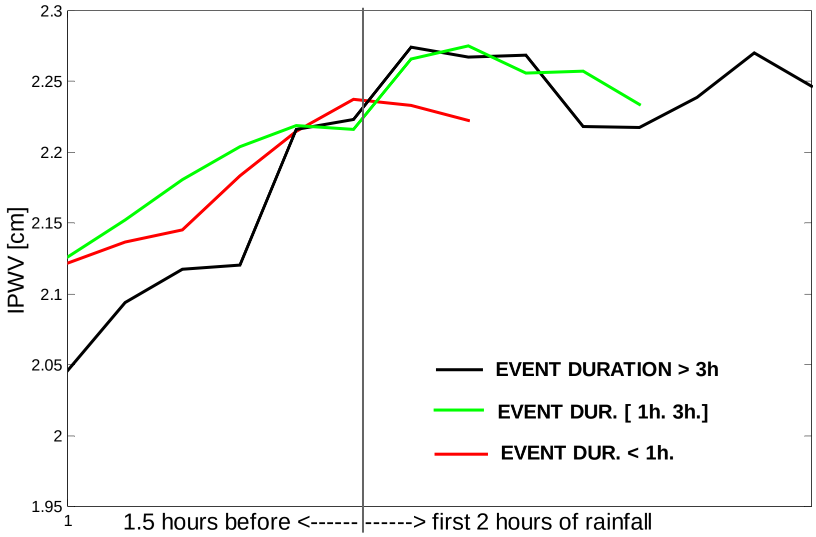

Fig. 1. Perugia (2000 - 2001): averaged *IPWV* values for rainy events classified in terms of duration. The vertical line marks the beginning of the rainfall

Table 2. Perugia site: comparison of IPWV retrieval using GPS and WVR-1000 for the selected rainy events.

Event	Length	Cumulated rain	Bias (cm) GPS – WVR	Std. Dev. (cm) GPS – WVR
15 October 2000	6 hours	18.6 mm	0.028	0.099
26 December 2000	4.30 hours	11.20 mm	0.055	0.217
30 January 2001	5.30 hours	9.6 mm	0.064	0.062
25 February 2001	3.30 hours	4.6 mm	0.020	0.117

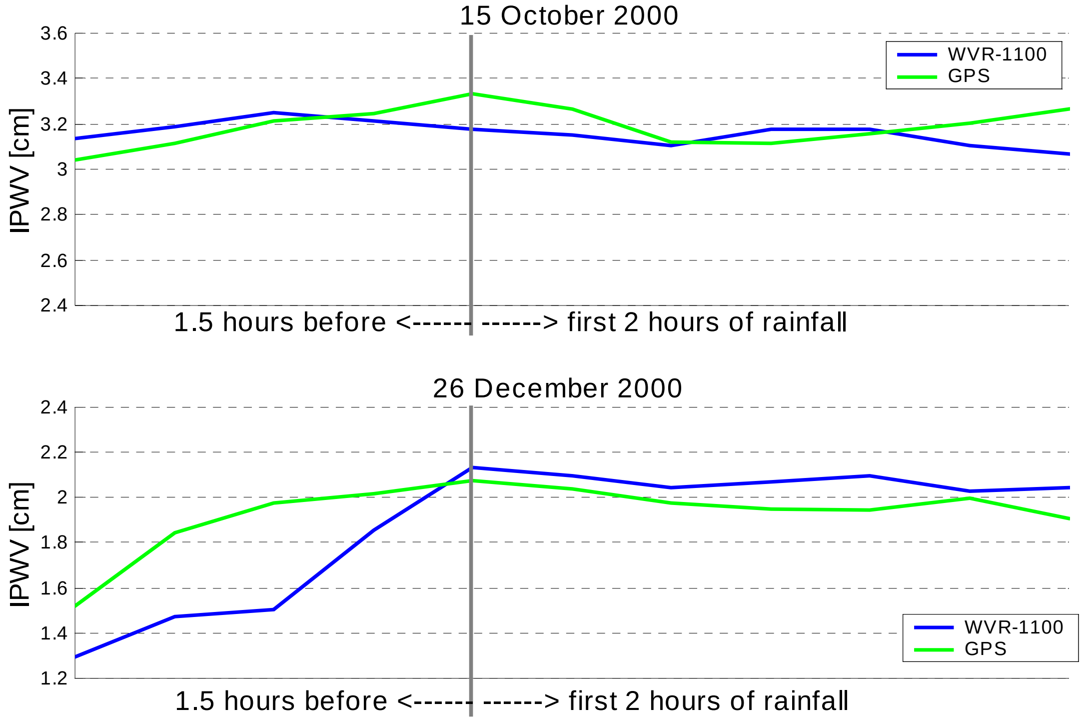

Fig. 2. *IPWV* time series estimated from GPS and WVR-1100 for the first two events reported in Table 2. The vertical line marks the beginning of the rainfall.

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