On the use of water vapour radiometry for assessment of wet delay estimates from space geodetic techniques

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Introduction

During the development of the Mark III VLBI system in the seventies, water vapour radiometers (WVR) were envisaged to provide independent observations of the signal propagation delay due to water vapour along the line of sight. The standard design of the WVR is to measure the atmospheric emission at two frequencies, close to and further away from the centre of the water vapour emission line at 22.2 GHz. These measurements are used to estimate two unknowns, the amount of water vapour, or the wet delay, and the amount of liquid water, along the line of sight.

The main drawback of using a WVR is that the retrieval algorithm requires that any liquid water drops in the sensed volume of air are much smaller than the wavelength observed by the WVR, i.e. ≈ 1 cm (Westwater and Guiraud, 1980). Therefore, the algorithm more or less breaks down during rain, meaning that the WVR cannot be relied on for 100 % of time, unless it never rains on, or close to, the site.

The method generally used is to avoid using WVR data with poor accuracy by ignoring observations obtained during rain and when the inferred liquid water content (LWC) is above a specific threshold. However, there are some difficulties with such procedures:

i. There may be rain drops in the sensed atmospheric volume in spite of the fact that no drops are detected at the ground on the site;

ii. there may still be drops of water on the WVR instrument, such as on the protective covers of the horn antennas and the mirrors many minutes after the rain has stopped;

iii. a low density of large drops may result in a smaller liquid water content than many small drops.

We have studied the retrieval accuracy of the equivalent zenith wet delay (ZWD) from WVR data and its dependence on the estimated liquid water content (LWC) by comparing them to those estimated from data acquired by the GNSS station ONSA. Fig. 1 depicts the ONSA station and the Konrad WVR Konrad.

Data

The WVR data were acquired taking 17 samples of the sky in a 2 min cycle (see Fig. 2) that was repeated continuously. Periods with rain and observations resulting in a equivalent zenith liquid water content (LWC) larger than 0.7 mm were deleted. Thereafter, for each 5 min period, having more than 30 observations, the equivalent zenith wet delay (ZWD) and the linear horizontal gradients were estimated. This resulted in 78,814 data points, corresponding to a time coverage of 75 % of the year. After synchronising with the available GPS data, there are 77,966 data points.

The GNSS data were processed with the GipsyX software, using satellites in the GPS constellation and an elevation cutoff angle of 10 degrees. The ZWD and the east and north horizontal gradients were estimated every 5 min, with constraints equal to 10 mm/√h and 0.3 mm/√h, respectively.

For more details about the WVR specifications and the GPS data processing, see Elgered et al. (2023).

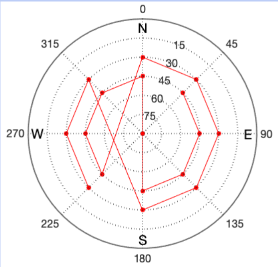

Figure 2. The measurement cycle of the WVR.

Figure 1. The GNSS station ONSA (left) and the Water Vapour Radiometer (WVR) Konrad (in the foreground). The twin telescopes, and the 25 m radio telescope, are seen in the background. A new WVR (to the right), manufactured by RPG, was installed in May 2023, but has not been used in this study.

Results

The ZWD estimates for the ONSA GPS data are shown together with the differences WVR–GPS in Fig. 3.

The ZWD differences shown in Fig. 3 are also shown in Fig. 4 but here vs. the LWC. For large LWC we see a positive bias for the ZWD. Here we also include a small negative LWC (> –0.05 mm) in order to allow for some noise in the sky brightness temperatures. However, this will also introduce a positive bias in the ZWD. In June, July, and August there are a few occasions with large negative differences. Most of these are associated with a large change in the ZWD and a time delay between the WVR and the GPS. We assume that the WVR ZWD are more correct because of the constraint and the Kalman filtering of the GPS data, whereas adjacent values in the WVR time series are independent. On 15 August the large differences are caused by unexplained high sky temperatures observed by the 31.4 GHz channel.

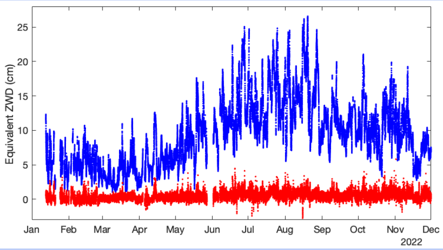

Figure 3. ZWD using GPS data from ONSA (blue dots) and the difference WVR–GPS (red dots).

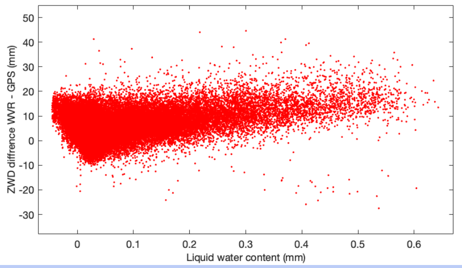

Figure 4. ZWD differences: WVR–GPS.

Results (continued)

We investigate how the bias and the standard deviation (SD) of the ZWD and the gradients depend on the allowed LWC. Fig. 5 illustrates how both are improved by reducing the maximum LWC. The minimum LWC is at –0.05 mm in all cases. The improvement is larger for the ZWD compared to the gradients. This is due to the different sampling of the sky for the WVR and the GPS. The correlation coefficient using all data and –0.05 < LWC < 0.7 mm for the ZWD, the east, and the north gradients are 0.997, 0.61, and 0.52, respectively.

The best agreement (not shown in Fig. 5) is obtained when also the data with a negative LWC are ignored, i.e. 0.00 mm < LWC < 0.05 mm, the ZWD bias and SD are reduced to 3.0 mm and 4.0 mm, respectively.

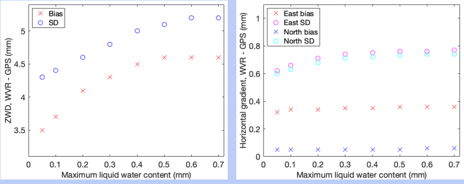

Figure 5. The bias and SD for WVR–GPS differences of the ZWD (left) and the horizontal gradients (right). The number of data points is reduced from 77,966 for LWC < 0.7 mm to 56,176 for LWC < 0.05 mm.

Conclusions and future work

Using WVR data for validation of ZWD estimates in space geodesy means that data must not necessarily be available for all time periods. We can ignore more or less data with high LWC meaning that there is a balance between how much data we want to have available and the data accuracy.

A future application, for time periods when no liquid water is present in the atmosphere, would be to develop a one-frequency radiometer with high stability and accuracy.

References

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