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Assessing the Quality of Water Vapor Radiometer Data from Onsala during the CONT11 Geodetic VLBI Campaign

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Abstract

Two water vapor radiometers (WVRs), called Astrid and Konrad, were operated during the CONT11 campaign at the Onsala Space Observatory. A well known feature of WVRs is that their algorithm breaks down when there are large drops of water, affecting the observations. Without any independent information one has to rely on the WVR data themselves to detect rain and remove the corresponding low quality results. In order to assess this technique we operated different types of rain sensors during CONT11: a zenith looking Doppler rain radar, three optical sensors, and three capacitive sensors. The first 8.25 days had frequent rain events whereas the last 7.75 days were significantly drier. We summarized the data set acquired by the WVRs and the rain detectors. The inferred time series of the equivalent zenith wet delay (ZWD) and linear horizontal gradients are compared to the corresponding estimates from GPS data (acquired at the IGS station ONSA) and the VLBI data themselves.

1. Introduction — the Role of WVRs in Geodetic VLBI

The propagation delay caused by water vapor in the atmosphere has been identified as one of the most important error sources in geodetic VLBI since the introduction of the Mark III System in the late seventies. The concept during the eighties was that the WVRs were to be used at every geodetic VLBI station in order to provide independent estimates of the wet delay, in the appropriate direction, for correction of the VLBI observables. For such a scenario there would be no need for observations at low elevation angles. However, it turned out that it was a major difficulty to keep WVRs operational at all VLBI sites at all times. Another problem is that the WVR algorithm for inferring the wet delay breaks down during rain, and therefore there were significantly long periods of time that lacked good quality WVR data at the stations. Therefore, there was also a requirement to include (very) low elevation observations in order to be able to estimate the wet delay from the VLBI data themselves [1][2].

The WVR data acquired were often used to assess the quality of wet delays estimated for the VLBI data and to study the occurrence of horizontal gradients, often associated with the passage of weather fronts. A model developed by Davis et al. [3] was later applied to the VLBI data analysis by MacMillan [4].

For the last couple of decades the role of WVRs in geodetic VLBI experiments has focused on the assessment of the quality of the model for the wet delay variability used in the VLBI data analysis. For example both WVR data and GPS data have been used to estimate the strength parameter describing the atmospheric turbulence, e.g., during earlier CONT experiments [5].

2. Instrumentation during CONT11

The two WVRs used at Onsala during CONT11 are shown in Figures 1 and 2. Astrid was running during the whole experiment but suffered from a data loss of a few hours on Sep. 25, when the azimuth drive failed. During the remaining part of the experiment it was carrying out elevation scans between the East and the West in a continuous mode. The Konrad WVR acquired data from Sep. 20 in a sky-mapping mode, meaning that observations were carried out, evenly spread over the sky at elevation angles above 20° until the end of the campaign.

Figure 1. The WVR Astrid.

Figure 2. The WVR Konrad.

Of specific interest for the editing and assessment of the WVR data is the consistency of the results from the rain sensors. Figures 3 and 4 depict the sensors. A zenith looking rain radar was operated together with both capacitive and optical sensors. The rain radar uses frequency modulated Doppler observations, and the data processing infers a height profile of the rain intensity.

The first two time series in Figure 5 show 1 minute averages of the inferred rain intensity at a height of 100 m above the radar. The first includes all data whereas the second zooms in on the scale at 0–10 mm/h. We note that there are some detections, especially during the second half where the campaign is of very low rain rates. Some of these are possibly false, and a detection limit of 0.1 mm/h may be reasonable. This is supported by the output signal from the capacitive (third time series from the top) and optical (fourth from the top) sensors. Also these time series

Figure 3. The Doppler rain radar.

Figure 4. The capacitive and optical rain sensors.

are 1 minute averages. The three capacitive sensors are identical and give +5 V when water is detected on the surface of the sensor, otherwise zero. The three optical sensors can be tuned to different sensitivities. For this data set the red, green, and blue symbols denote condensation, rain, and heavy rain, respectively.

We note that there is a consistency between the output from the different types of sensors. For our application of using rain data to edit WVR data, it is important to note that the radar only measures in the zenith direction and the other sensors measure rain and condensation at the site and at the ground level only. Therefore, WVR observations acquired at elevation angles other than in the zenith direction may still be affected by large drops in the antenna beams even if there is no detection made by any of the rain sensors.

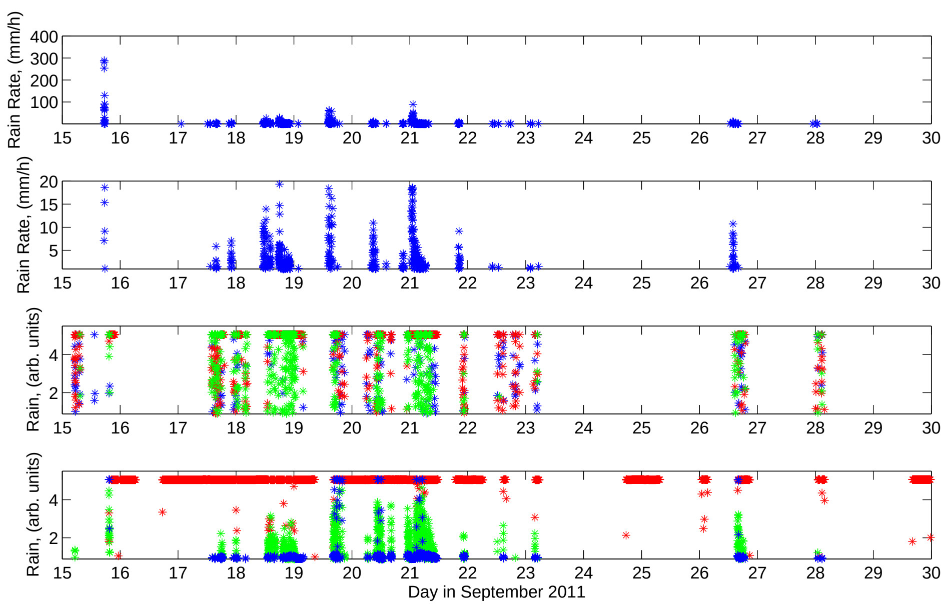

Figure 5. The output data from the rain sensors are shown for the whole CONT11 campaign (see text).

3. Preliminary Results

Figure 6 shows all time series of the equivalent zenith wet delay (ZWD). The WVR data shown have used the estimated amount of liquid water in order to decide which data are affected by rain and therefore ignored [6]. Figure 7 depicts the period when all sensors were fully functional. The problems caused by rain are obvious. The wet delays from the two WVRs have a positive bias compared to the estimated time series from VLBI and GPS data. We note that in contrast to the WVRs, the VLBI and the GPS estimates of the wet delay are based on the experienced time delay, rather than the emission, and liquid water has a very small influence on the time delay. The absolute calibration of the WVRs is maintained through the use of continuous tip curves, and if the atmosphere is inhomogeneous for many hours the absolute calibration will be affected.

An example of a passage of a cold front is presented in Figure 8. We show the ZWD and the horizontal linear gradients estimated from Astrid, Konrad, VLBI, and GPS data. We note that the gradients from VLBI and GPS are smoothed, whereas the WVR estimates provide a higher temporal resolution. This means that we can study the short lived horizontal gradients in much

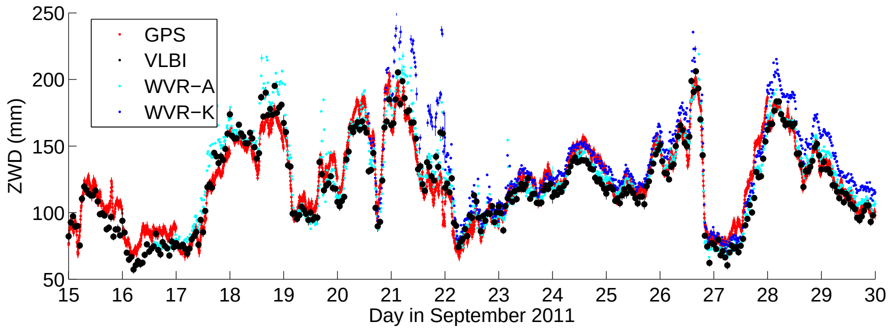

Figure 6. Time series of the equivalent zenith wet delay (ZWD) measured at Onsala using VLBI, GPS, and the two WVRs Astrid (WVR-A) and Konrad (WVR-K).

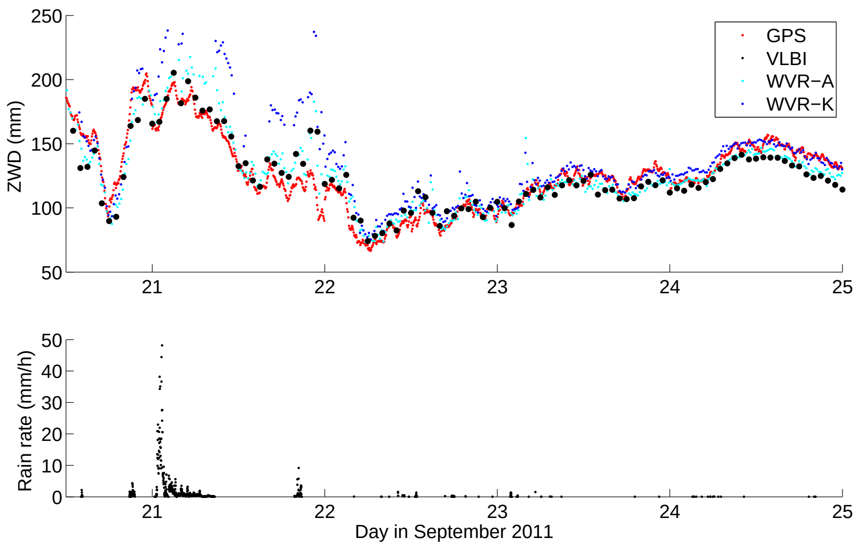

Figure 7. A subset of the ZWD from the WVR, VLBI, and GPS data when all instruments were fully operational (top). The rain rate measured by the Doppler radar (bottom) shows that the two WVRs have problems with the calibration of the absolute level during rainy periods, and especially Konrad, which we attribute to the fact that its more narrow antenna beams ($\approx 3°$ compared to $6°$ for Astrid) are more affected by the less homogeneous atmosphere which is likely to be present during rainy weather.

more detail. Although horizontal gradients in the hydrostatic delay are typically a magnitude smaller over time scales of hours, we note that they are included in the VLBI and GPS estimates.

4. Conclusions and Future Work

A data set with different types of observations of water vapor in the atmosphere at the Onsala Space Observatory, covering the period of the CONT11 geodetic VLBI campaign, has been produced for further studies of variations in the propagation delay. Specifically, it will be interesting to evaluate different criteria and algorithms using the output signals from the rain sensors to edit the WVR data. Here one can even foresee different editing algorithms depending on if the WVR data shall be used in the fundamental tip-curve calibration or used for other applications.

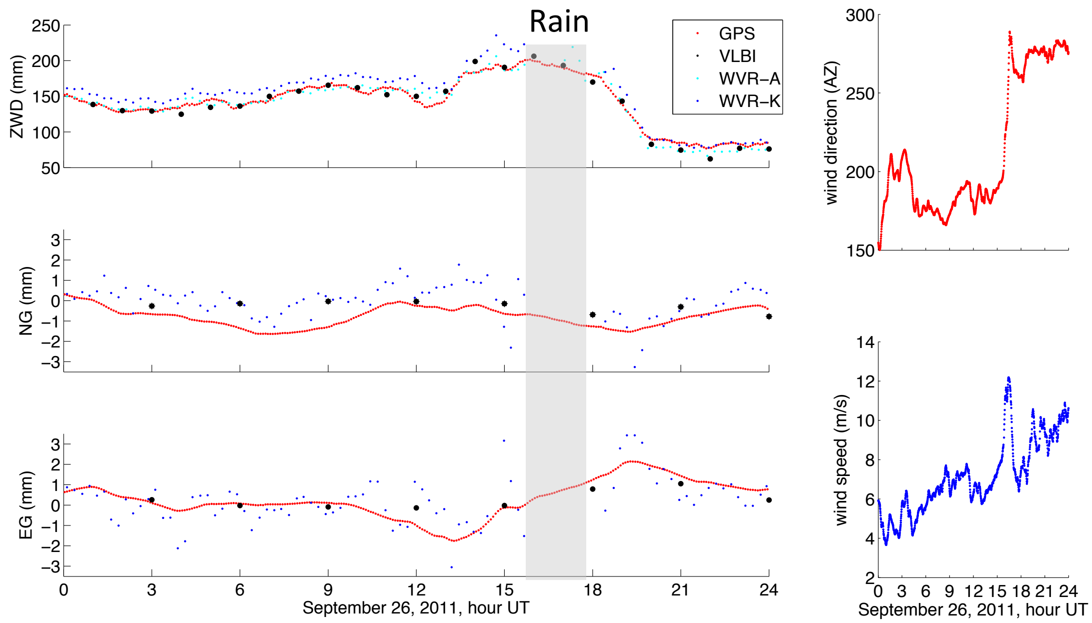

Figure 8. During the afternoon of Sep. 26 a warm air mass was replaced by a cooler and drier air mass. Time series of the ZWD and the East (EG) and North (NG) gradients are shown (left). During the passage the wind speed increased (lower right) and the direction of the wind changed from southerly to westerly in just about one hour (upper right). Note that there are no gradients estimated from the Astrid WVR data, since it was not running in a sky-mapping mode.

Acknowledgements

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