Accuracy Assessment of the two WVRs, Astrid and Konrad, at the Onsala Space Observatory

P. Forkman, G. Elgered, T. Ning

Abstract Two Water Vapour Radiometers (WVRs), Astrid and Konrad, have been operating at the Onsala Space Observatory during the time period 2013–2016. There are several data gaps due to different types of instrument failures and therefore we also use estimates of the equivalent zenith wet delay (ZWD) from the two GNSS reference stations: ONSA and ONS1. They provide an almost continuous time series during the four years. ZWD root-mean-square differences are 0.38 cm between ONSA and ONS1, 0.92 cm between ONS1 and Astrid, and 0.75 cm between ONS1 and Konrad. For the horizontal linear gradients we see correlation coefficients of the order of 0.9 between ONSA and ONS1 and 0.5 between ONS1 and Konrad.

Keywords Water Vapour Radiometer, Zenith Wet Delay, GNSS, GPS

1 Introduction

Water Vapour Radiometers (WVRs) provide independent information on the signal propagation path delay due to atmospheric water vapour, often referred to as the wet delay.

WVR estimates of the wet delay can be used directly in the VLBI data analysis but also as validation data for delays estimated from the VLBI data themselves.

The two WVRs at the Onsala site have been in operation for a long time. Astrid did the first comparison measurements with radiosondes at the Gothenburg-Landvetter Airport in May 1980. Konrad's first field campaign was in Kiruna, at the Esrange Space Center, in August 2000. We are now considering a new WVR for installation at the Onsala site and have identified a need for an assessment of the accuracy, reproducibility, and repeatability using the existing WVR data from recent years. Here we give an overview of results obtained from the time period 2013–2016.

In Section 2, we describe the instrumentation followed by the data analysis in Section 2. Section 3 present the results and Section 4 the conclusions and plans for a new WVR.

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2 Instrumentation

The two WVRs, Astrid (Fig. 1) and Konrad (Fig. 2), have been used at the observatory since 1980 and 2000, respectively. Both measure the sky brightness temperature approximately 1 GHz below the water vapour line at 22.2 GHz and in the atmospheric window at 31.4 GHz.

The GNSS stations ONSA, first established in the CIGNET network in 1987, and ONS1, established as a back-up station in 2011, are sites in the national reference network SWEPOS®. They also continuously offer the observational data to the open access networks of

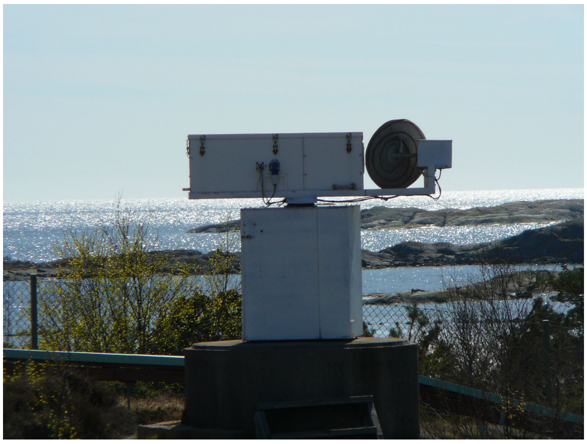

Fig. 1: The WVR Astrid.

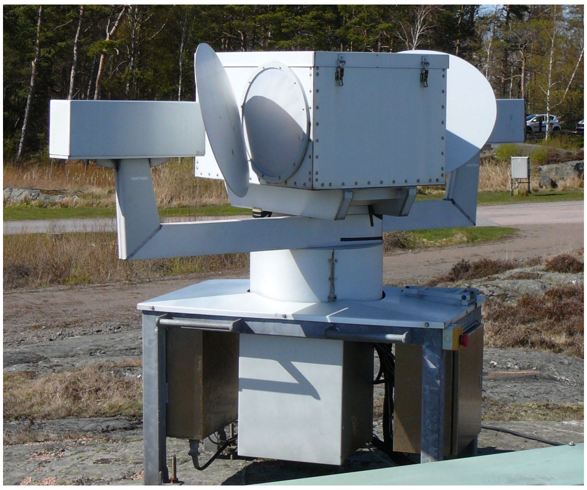

Fig. 2: The WVR Konrad.

Fig. 3: GPS stations ONSA (left) and ONS1 (right).

IGS and EUREF. Figure 3 shows the two sites. Note that the ONSA site is equipped with a sheet of absorbing material (ECCOSORB®) just below the antenna in order to reduce multipath effects.

3 Data analysis

Unfortunately, there are several data gaps due to different types of instrument failures — both WVRs are becoming old. Therefore, in order to have simultaneous data for comparisons, we also use estimates of the equivalent zenith wet delay (ZWD) and horizontal linear gradients from the two GNSS reference stations: ONSA and ONS1. They offer almost continuous and independent time series for the parameters of interest during the four years. The only GPS data gap is for the ONSA station in the summer of 2015 due to a failing pre-amplifier.

3.1 WVR data analysis

A common method for calibration of the sky brightness temperatures measured by the WVR is the tip curve method, where observations spread over a range of elevation angles are used in order to get an extrapolated sky brightness temperature at zero air mass equal to the cosmic background radiation (Elgered and Jarlemark, 1993). Additionally an elevation pointing offset can be estimated. Here we estimate both so called hot load corrections, low pass filtered with a time constant of ≈ 5 h, and daily elevation offsets. Because of atmospheric inhomogeneities we expect a correlation between the residual offsets of the two channels (see Figure 4). The sky brightness temperatures are finally used to calculate the ZWD (Elgered, 1993).

Subsequently, based on the equivalent ZWDs observed in specific directions, the horizontal linear gradients (east and north) were calculated according to the four-parameter model described by Davis et al. (1993).

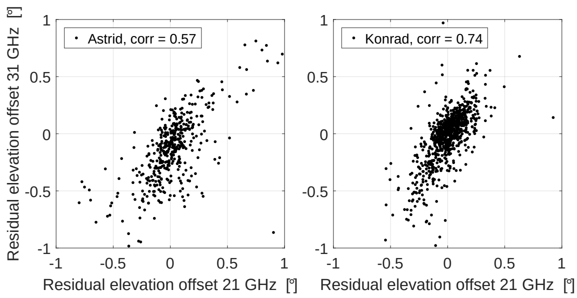

Fig. 4: Estimated daily elevation offsets for the two channels of Astrid (left) and Konrad (right).

3.2 GPS data analysis

The data have been analyzed using the method described by Ning et al. (2013) where the ZWD and the linear east and north gradients are estimated simultaneously in the processing.

4 Results

We first present the results for the equivalent ZWD and then for the gradients. The first comparison is between the two GNSS stations. The estimated ZWD is illustrated in Figure 5. We note that the observed bias between ONS1 and ONSA of 0.36 cm is consistent with earlier results showing the influence of the suppres-

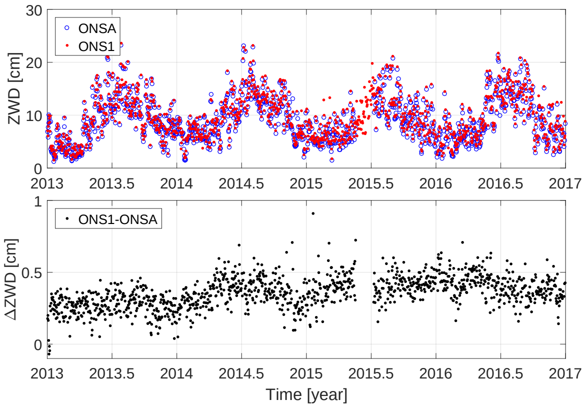

Fig. 5: Time series of estimated ZWD and their differences using GPS data from ONSA and ONS1.

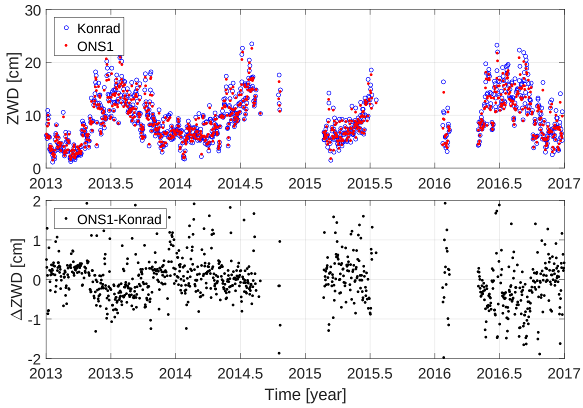

Fig. 7: Time series of estimated ZWD and their differences using Konrad data and GPS data from ONS1.

sion of multipath using a microwave absorber at ONSA, which is not the case for ONS1 (Ning et al., 2011).

We chose to use ONS1 data for the WVR comparison because of the slightly better data coverage over the four years. In Figures 6 and 7 we calculate daily averages of the ZWD based on hourly averages where the data coverage is at least 75 % of the default observation schedule for each instrument.

Table 1 summarizes the results (depicted in Figures 6 and 7) in terms of bias, standard deviation (SD) and root-mean square (RMS) of the differences, ΔZWD.

Table 1: Instrument comparison results for the ZWD.

Instruments compared	Bias (cm)	SD (cm)	RMS (cm)
ONS1−ONSA	0.35	0.14	0.38
ONS1−Astrid	0.44	0.81	0.92
ONS1−Konrad	0.06	0.75	0.75

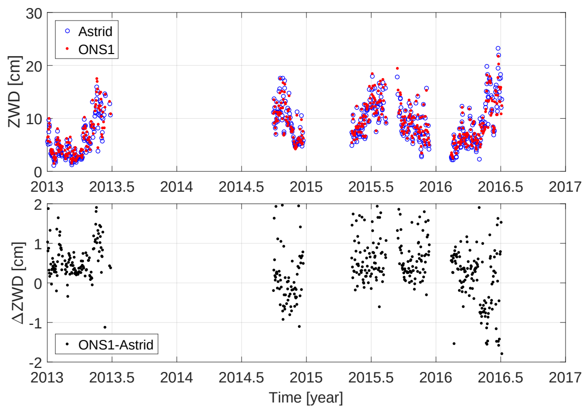

Fig. 6: Time series of estimated ZWD and their differences using Astrid data and GPS data from ONS1.

When comparing gradients estimated from WVR and GPS data it is noted that the WVR measures gradients in the water vapour whereas the GPS measure gradients in the refractive index (determined by both the wet and the dry atmosphere). Unfortunately the Astrid WVR was affected by an unstable pointing in the azimuth coordinate during the period. In principle we can estimate a pointing offset for subsets of the data over the period by fitting the data in order to have an agreement in the horizontal gradients with the other instruments. This was, however, not the aim of this study and we chose to focus on a comparison using Konrad data and GPS data only. All estimated gradients are shown in Figure 8. We note that the size and variability of the WVR gradients are significantly larger compared to the GPS gradients. This is consistent with earlier results (Gradinarsky and Elgered, 2000).

Figure 9 depicts the correlations for the gradients over the whole four year period. The upper graphs illustrates that even though the GPS observations see the same atmosphere and observes the same satellites the agreement is not ideal. Furthermore, when using GPS as ground truth, we must add an additional uncertainty due to the fact that the hydrostatic delay is also included whereas the WVRs are only inferring the gradients due to the water vapour. The lower graphs show the correlation between ONS1 and Konrad. The observed correlations do not differ by more than 5 % for the individual years and a value around 0.5 is also a typical value reported for comparisons between gradients estimated from WVR data and different GNSS data (Lu et al., 2016).

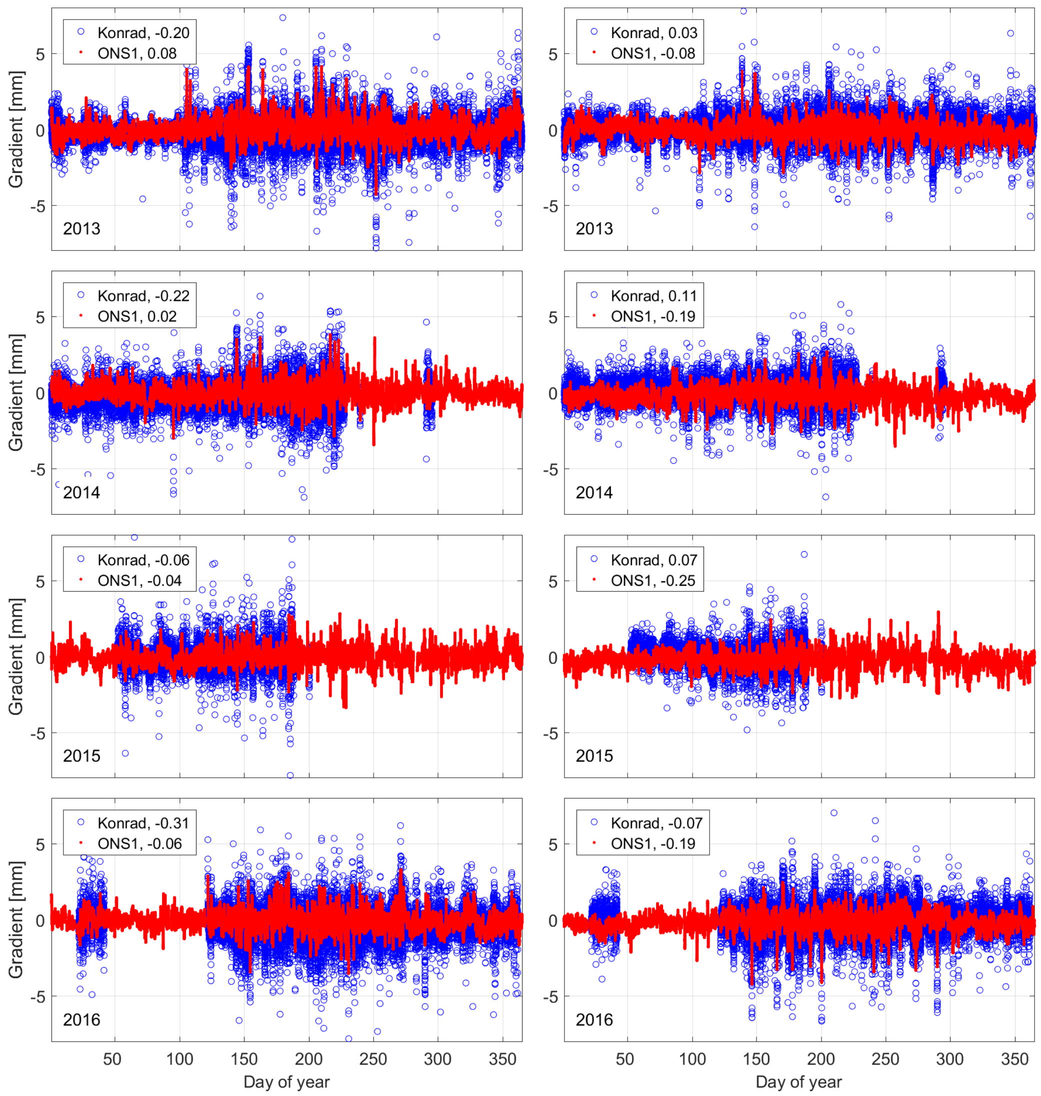

Fig. 8: Time series of estimated gradients using Konrad data and GPS data from ONS1. East and north gradients are displayed in the left and right columns, respectively. Average gradients are shown in the upper left corners. The average north gradient due to an increasing ground pressure with decreasing latitude, is seen in the GPS results, typically of the order of −0.2 mm.

5 Conclusions and future work

We find that in spite of their old age the two WVRs give biases in the ZWD comparable to historical results. The standard deviations are slightly worse. Ning et al. (2012) report typical standard deviations around 0.7 cm between ONSA and Astrid for ZWD averages over 1.5 h. Also when comparing horizontal gradients we find consistent results to those reported earlier. The main problem with the WVRs is the frequent hardware failures causing a significant data loss.

We plan for a new installation of a WVR. Presently Omnisys Instruments in Gothenburg is developing a prototype WVR for the European Space Agency. When this instrument is completed a field campaign will be carried out at Onsala. Thereafter a copy will operate at the site for a long term. The prototype instrument is shown in Figure 10.

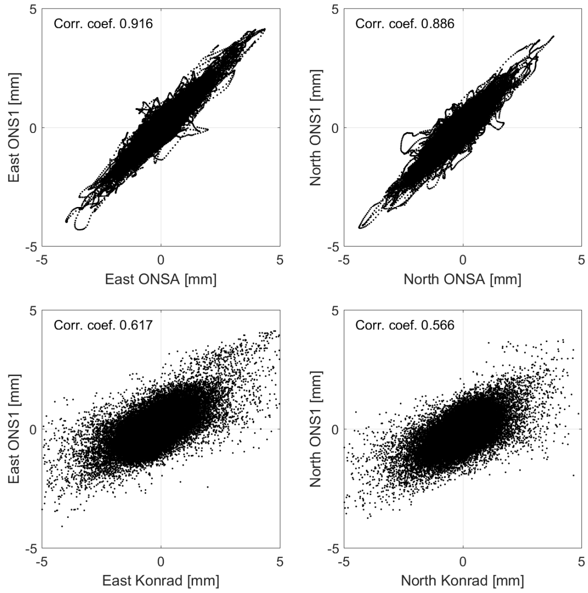

Fig. 9: Correlations between estimated east (left) and north (right) gradients. Upper graphs show the correlation between the two GPS stations and the lower graphs between the GPS station ONS1 and the Konrad WVR.

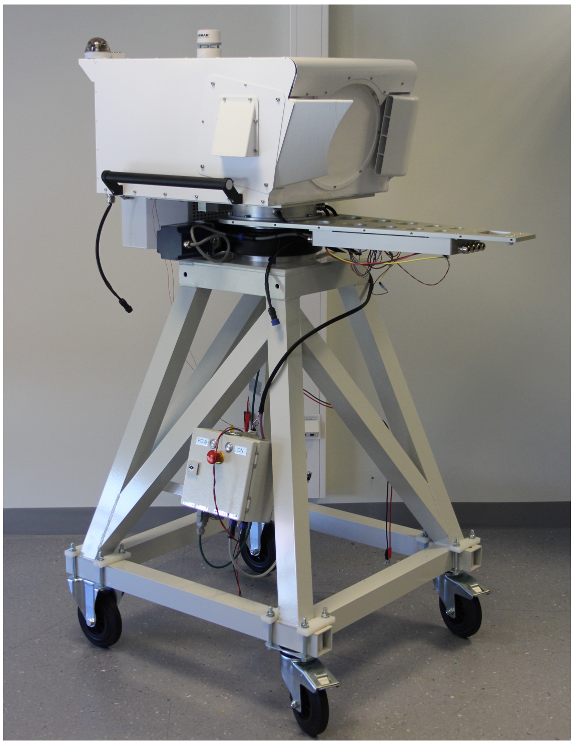

Fig. 10: The WVR under development at Omnisys Inc.

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