Small scale atmospheric variations sensed with very short baseline interferometry (VSBI) and microwave radiometry

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Introduction

Three telescopes at the Onsala Space Observatory are regularly used in geodetic VLBI experiments: the 20 m radome enclosed telescope (ON) and the twin telescopes (OE and OW). The distance between the twin telescopes is approximately 75 m and they are in turn approximately 500 m southwest of the 20 m telescope, see Figure 1. The location of the Onsala telescopes close to the coast line suggests that there may occasionally be significant local horizontal gradients in the atmospheric water vapour content. Horizontal gradients estimated by collocated GNSS stations and a Water Vapour Radiometer (WVR) frequently reach a size of several millimetres (Elgered et al. 2019). In this study we address if it is reasonable to estimate the differential equivalent zenith wet delay (ΔZWD) between the 20 m telescope and the OTT telescopes. A series of 25 local interferometer experiments has been carried out with these three telescopes in 2019 and 2020 (Varenius et al., 2020).

The ΔZWD relates to the horizontal linear gradient via the scale height of the wet refractivity. Elósegui et al. (1997) and Zus et al. (2019) have estimated it to be roughly in the range from 1 to 3 km.
A gradient observed by the WVR of 6 mm, when mapped to the OTT-ON baseline, then corresponds to a ΔZWD of 1–3 mm over the 500 m baseline.
With this in mind we compare the horizontal gradients from the WVR with the ΔZWD estimated in the VLBI analysis using the 20 m and the OTT telescopes.

Input data

The VSBI data analysis is carried out using the *ASCOT* software (Artz et al., 2016) as follows:

- A group delay analysis was carried out.
- Station coordinates were fixed for ON on VTRF2020b, but estimated for OW and OE.
- The reference clock was ON. Clock parameters for OE and OW were estimated every hour.
- ZWD was fixed at OE and OW, based on the ground pressure referred to the reference points, and estimated for ON as a continuous piece-wise linear function updated every 5 min. We tested with different constraints (see Table 1). All observations down to an elevation angle of 5º were used.
- EOP and radio sources were fixed according to IERS C04 and ICRF3.

The WVR data were analysed with our in house software as described by Elgered et al. (2019) but now with the difference that during 2019–2020 the WVR was operated according to a 5 min long cycle, over which 52 observations were distributed over the sky at elevation angles above 25º. A drawback of the WVR is that data acquired during rain, and when the liquid water content is larger than 0.7 mm, are inaccurate and therefore ignored. There were also several periods during the VLBI experiments when the WVR was unstable and these data were therefore deleted. Gradients were estimated for each 5 min cycle when there were more than 40 observations available.

Out of the original 6125 ΔZWD estimates, we had 2526 matching gradients from the WVR for a comparison.

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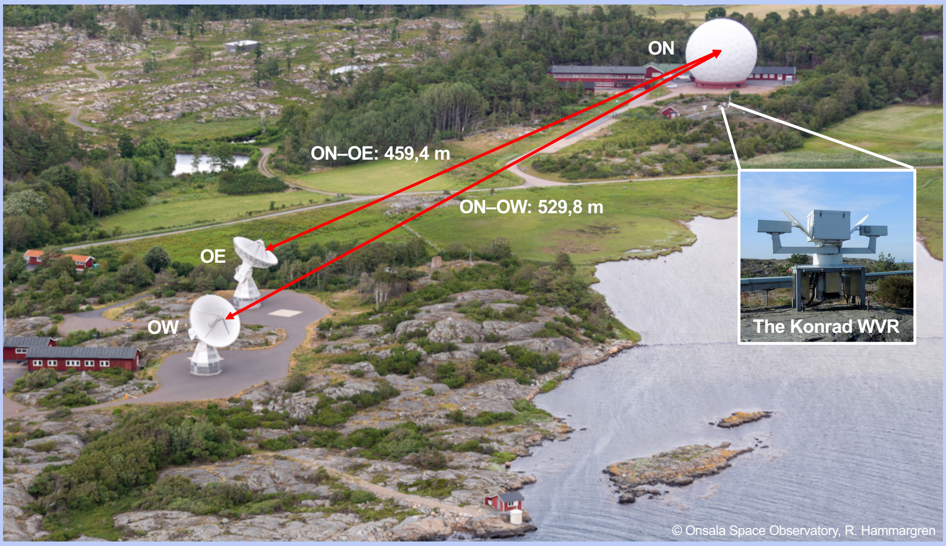

Figure 1. The three telescopes used for geodetic VLBI at Onsala: the 20 m radome enclosed telescope and the twin telescopes. The WVR is located close to the 20 m telescope.

Results

We find, as expected, that both the differential ZWD between the 20 m telescope and the OTT telescopes and the gradients estimated from the WVR are slightly larger during the warmer season when there is a higher water vapour content in the atmosphere.

The estimated values and their formal uncertainties are summarised in Table 1. The formal uncertainties of the ΔZWD, from the VLBI analysis, are larger than the estimated values and the effect of course increase when the constraint is looser.

The overall correlations for the 25 experiments between the ΔZWD and the WVR gradient mapped on to the OTT–ON averaged baseline are 0.21, 0,18, and 0.15, for the applied constraints of 50 ps/h, 200 ps/h, and 350 ps/h, respectively. The effect of using different constraints is illustrated in Figure 2. A tighter constraint reduce the noise, but at the same time the possibility to catch and follow rapid changes are decreased. An overall result for all the experiments studied is that loosening the constraint results in larger ΔZWD values and more noise. Also in all cases the correlation decreases at the same time.

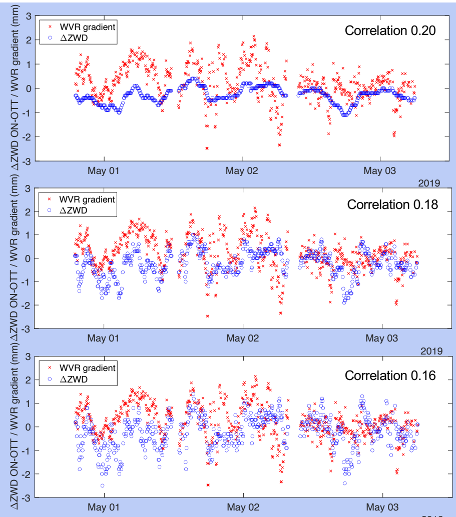

Figure 2. An example of estimated ΔZWD (ON–OTT) and WVR gradients mapped on to the ON–OTT baseline for two contiguous experiments. Constraints used are 50 ps/h (top), 200 ps/h (middle), and 350 ps/h (bottom).

Table 1. Statistics of ΔZWD and the WVR gradients mapped on to the OTT–ON averaged baseline.

	ΔZWD from VLBI for 3 different constraints			WVR gradient
Constraint	50 ps/h	200 ps/h	350 ps/h	No constraint
Mean absolute value (mm)	0.34	0.48	0.57	0.73
Maximum absolute value (mm)	1.70	3.10	3.90	5.86
Mean formal error (mm)	0.35	0.61	0.75	0.08
Maximum formal error (mm)	0.98	1.59	2.01	0.69

Discussion and future work

Given the lack of clear agreements, also when the WVR observes strong gradients of several millimetres we may question if it is reasonable to estimate the ΔZWD between the 20 m telescope and the OTT telescopes. Related to this issue is which temporal resolution shall be used if the ΔZWD is estimated? These estimates may also absorb other errors in the observations and thereby hiding the possibility to identify their origin. Therefore, when large differences occur between the WVR gradient and the ΔZWD this calls for detailed studies in order to identify and eliminate problems that are not necessarily caused by the atmosphere.

We also note that a linear model for horizontal gradients is also a source of error. Especially in this case when the WVR observes a smaller part of the sky (elevation angles > 25º) is likely to result in larger gradients compared to a gradient averaged over the sky down to an elevation angle of 5º. For the turbulent atmosphere there is an equivalent argument when carrying out temporal averaging.

In this study we focused on the highest possible temporal resolution, defined by the gradients inferred from the WVR data, since the primary goal was to assess if it would be possible to detect gradients with the VLBI telescopes. However, from a geodetic point of view, i.e. in terms of the accuracy of the estimated geodetic parameters, a lower temporal resolution may be desired. We have not addressed this question yet.

Future work in order to assess the modelling of the wet atmosphere is proposed to also analyse experiments where the Onsala telescopes are included in long baseline experiments, allowing estimates of the ZWD for each telescope, or for a combination of telescopes.

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