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Atmospheric Parameters Derived from Simultaneous Observations with Space Geodetic and Remote Sensing Techniques at the Onsala Space Observatory

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Abstract

We compare estimates of zenith wet delay and horizontal delay gradients from 54 days of simultaneous observations with independent collocated space geodetic and remote sensing techniques at the Onsala Space Observatory. The impact of the choice of the constraints for the atmospheric parameters used in the analysis of the space geodetic data on the comparison with water vapour radiometer results is studied. We find estimated weighted RMS differences below the 10 millimetre level and correlation coefficients between 0.73 and 0.87 for the zenith wet delays derived from the different techniques while the agreement for the estimated horizontal delay gradients is less clear.

1. Introduction

Space geodetic techniques using microwave signals as e.g. Very Long Baseline Interferometry (VLBI) or the Global Positioning System (GPS), and microwave radiometry are influenced by water vapour in the Earth's atmosphere. Usually for the space geodetic techniques the atmospheric influence on the radio wave propagation is treated as an error source. Accordingly the atmospheric parameters derived from the analysis of VLBI and GPS data are normally treated as nuisance parameters. This is in contrast to the water vapour radiometer (WVR) which is often used for atmospheric studies.

In recent years the aspect of a possible use of atmospheric parameters derived from space geodetic techniques for atmospheric research and especially weather monitoring and prediction becomes more and more interesting [1]. This is especially due to the ongoing establishment of dense permanent GPS networks in many regions of the world which may be used as multiple-purpose interdisciplinary networks.

One question is whether the atmospheric parameters which are derived from space geodetic techniques can be used for meteorological and climate studies. Comparing these results with independent remote sensing data will also give us information on the impact of the atmospheric parameters in analysis of space geodetic data in terms of the measurement uncertainties. A plausible way to address these questions is to study and to compare the atmospheric parameters derived from simultaneous observations with collocated space geodetic and remote sensing techniques. The Onsala Space Observatory is equipped with collocated space geodetic and remote sensing techniques since many years and an extensive data base to perform such comparison studies is available. We analysed simultaneous observations from VLBI, GPS and WVR and compared the derived atmospheric parameters, i.e. the zenith wet delays and the horizontal gradients. A special focus was on the impact of the choice of constraints for the atmospheric parameters used in the analysis of VLBI and GPS on the agreement of the results with respect to those from the WVR.

2. The Data Set, the Analysis Strategy, and Results

The Onsala Space Observatory (OSO) is active in geodetic VLBI since 1969 [2] and contributes as a network station to the International VLBI Service for Geodesy and Astrometry (IVS). OSO also participates as a network station in the International GPS Service for Geodynamics (IGS) operating a permanent GPS site since 1987. Since 1993 OSO runs a water vapour radiometer (WVR) continuously in sky mapping mode. For more information on these techniques see e.g. [3].

Both, the GPS receiver and the WVR, are acquiring data continuously while 24-hour long VLBI experiments are carried out once or twice a month. In 1999 a total of 18 experiments were performed. Moreover there were also maintenance periods for the WVR and problems at individual days occurred, e.g. not enough useful WVR observations due to unfavourable weather conditions. Finally for the period 1993 to 1998 a data set of 54 days resulted that contains simultaneous observations with all three techniques.

We determined atmospheric parameters from the three techniques averaged over intervals of 90 minutes. The WVR data were analysed applying an in-house software package. In a preprocessing step the wet delay values were derived from the observed sky brightness temperatures. Then the gradient model [4] was fit to the wet delay values in a least squares analysis and the zenith wet delay values and the horizontal north and east gradient components were determined. The VLBI data were analysed using the CALC/SOLVE software package [5], applying the Niell mapping functions [6] and estimating the zenith wet delay and horizontal delay gradients by a least squares analysis. The GPS data were analysed using the Kalman filter software package GIPSY [7]. We used the Precise Point Positioning strategy [8], again applying the Niell mapping functions.

We identified eight out of the 54 days that showed the most variable atmosphere as sensed by the WVR. The VLBI and the GPS data of these eight days were then analysed using all possible combinations of the constraints for zenith wet delay and horizontal delay gradients given in Table 1 which meant that 400 different solutions were processed for each of these days.

Table 1. Constraints of a random walk model for zenith wet delay and horizontal gradients used in the VLBI and GPS data analysis. Characters are used as combination identifiers.

zenith wet delay constraint $[mm/\sqrt{h}]$										horizontal delay gradient constraint $[mm/\sqrt{h}]$									
A	2	E	6	I	12	M	23	Q	40	a	0.2	e	0.6	i	1.2	m	2.3	q	4.0
B	3	F	7	J	14	N	27	R	45	b	0.3	f	0.7	j	1.4	n	2.7	r	4.5
C	4	G	8	K	17	O	31	S	50	c	0.4	g	0.8	k	1.7	o	3.1	s	5.0
D	5	H	10	L	20	P	35	T	56	d	0.5	h	1.0	l	2.0	p	3.5	t	5.6

Figure 1 shows the time series for the atmospheric parameters for one out of the eight days studied in detail. For VLBI and GPS we only show the four "corner-solutions" Aa, At, Ta and Tt with the tightest and weakest constraints since all other results lie in-between. We calculated and compared the weighted RMS differences (WRMSD) of the atmospheric parameters derived from VLBI and GPS to those obtained from the WVR, depending on the constraints used. As an example Figure 2 shows the average of the WRMSD for the zenith wet delay results for all eight days. We found relative minima of the WRMSD for zenith wet delay constraints of 5–15 mm/$\sqrt{h}$ and horizontal delay gradient constraints of 0.5–2.0 mm/$\sqrt{h}$. Using a combination of constraints in this range we processed the data of all 54 days again. The results are shown in Figure 3.

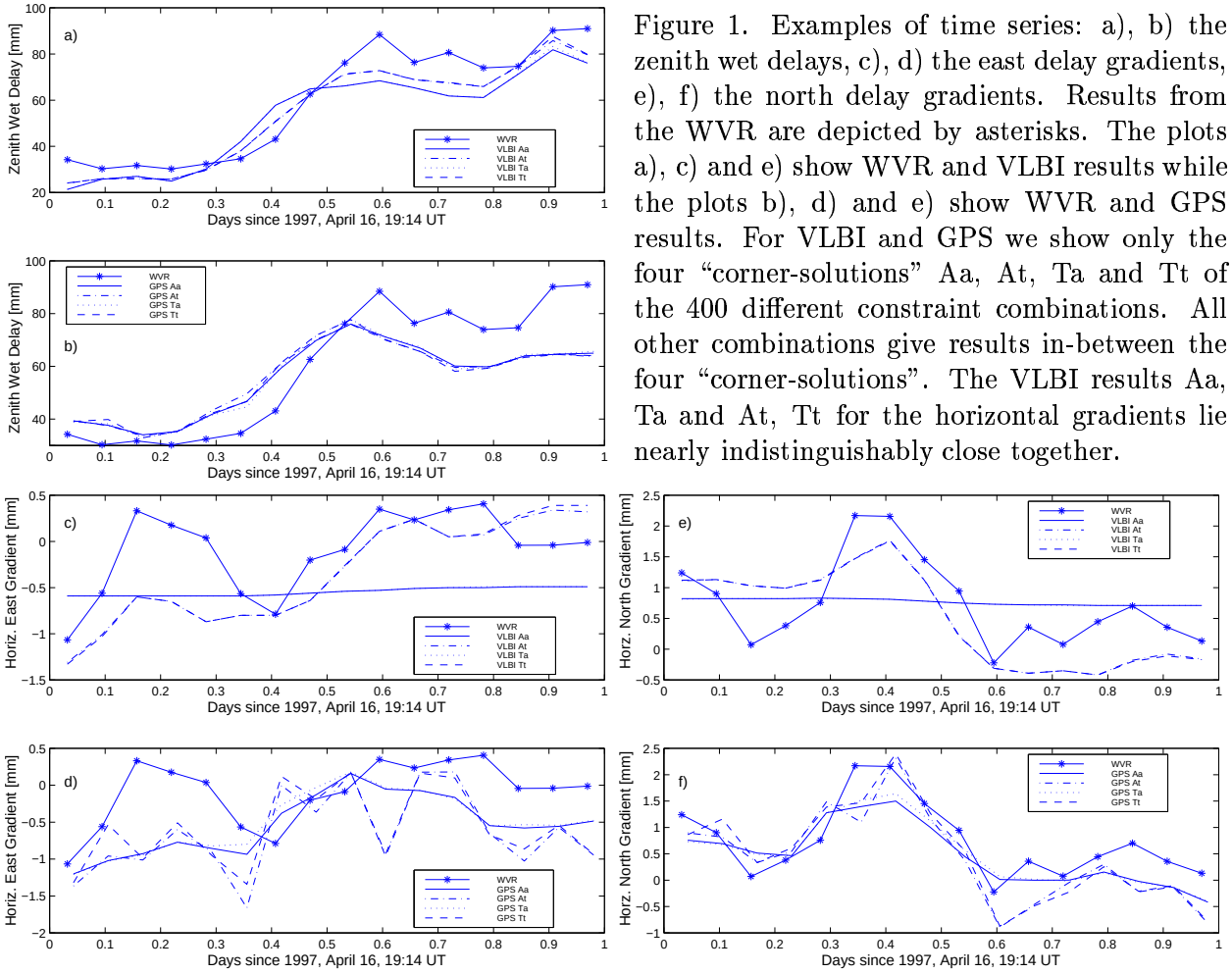

Figure 1. Examples of time series: a), b) the zenith wet delays, c), d) the east delay gradients, e), f) the north delay gradients. Results from the WVR are depicted by asterisks. The plots a), c) and e) show WVR and VLBI results while the plots b), d) and e) show WVR and GPS results. For VLBI and GPS we show only the four "corner-solutions" Aa, At, Ta and Tt of the 400 different constraint combinations. All other combinations give results in-between the four "corner-solutions". The VLBI results Aa, Ta and At, Tt for the horizontal gradients lie nearly indistinguishably close together.

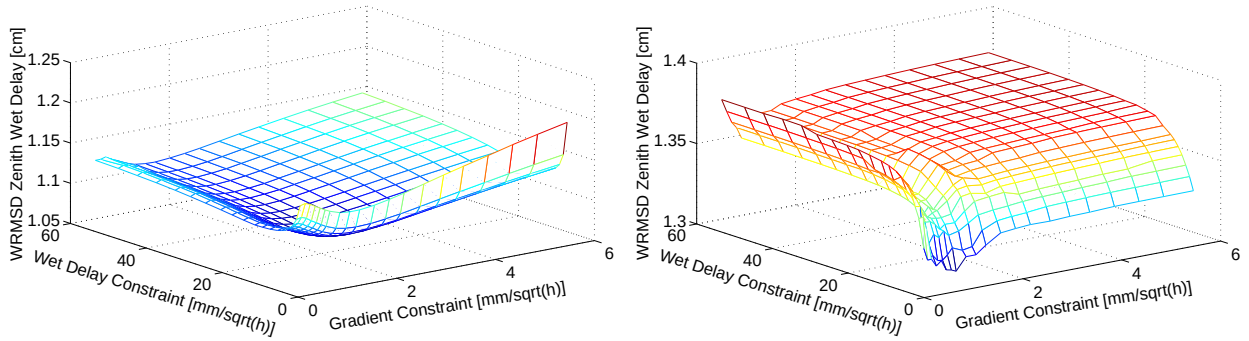

Figure 2. Average weighted RMS differences for zenith wet delay vs. the constraints used for the zenith wet delay and the horizontal gradients: left plot WVR-VLBI, right plot WVR-GPS.

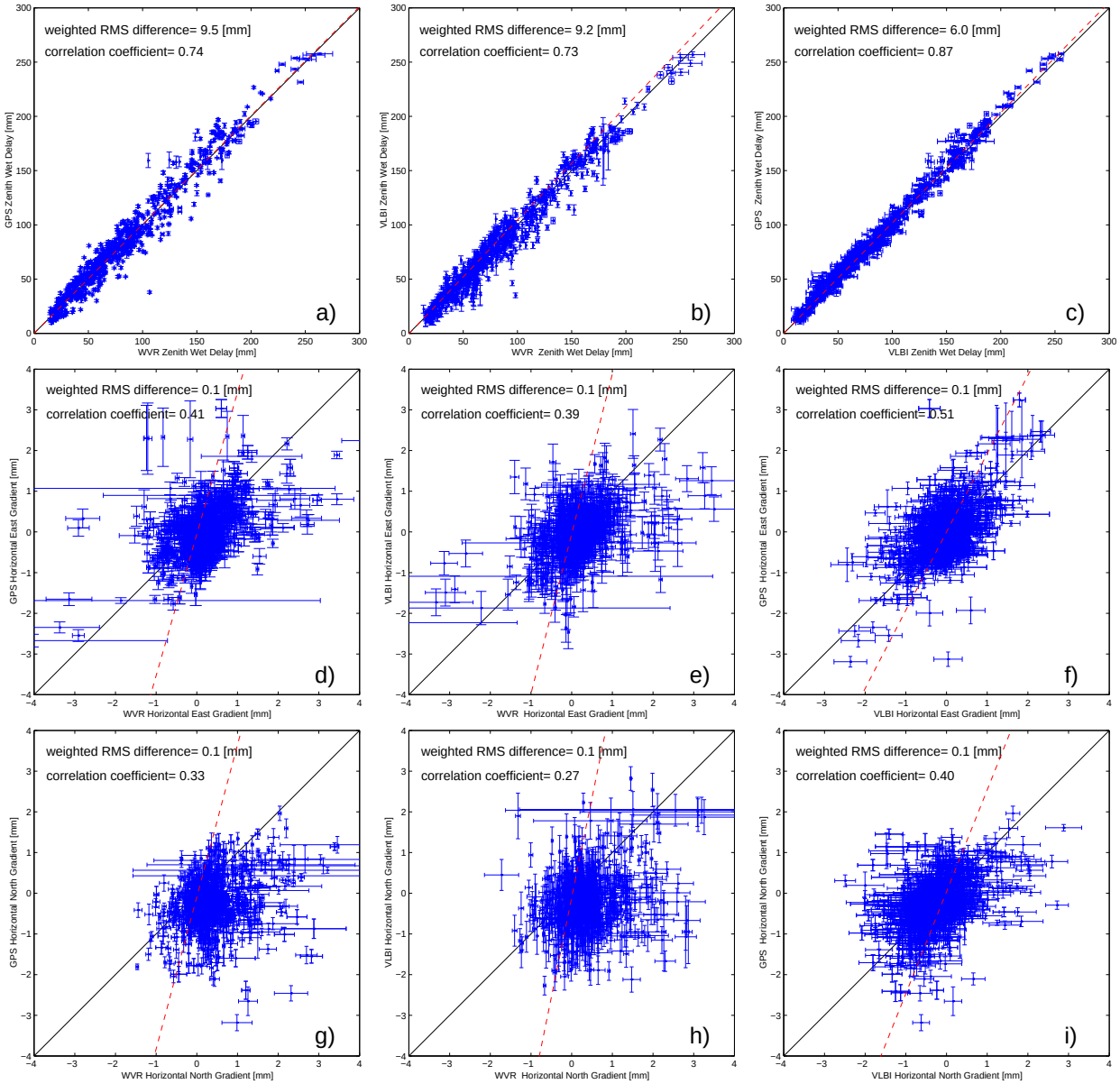

Figure 3. Scatter plots for the atmospheric parameters: The upper, middle and bottom row shows the zenith wet delay, east gradient and north gradients, respectively. The left, middle and right column shows GPS vs. WVR, VLBI vs. WVR, and GPS vs. VLBI, respectively.

3. Conclusions and Outlook

We find that the choice of the constraints for the atmospheric parameters used in the analysis of the space geodetic data does not drastically influence the agreement of the results with respect to the ones from WVR. The minimum average weighted RMS differences have relative minima for

constraints in the range of 5–15 mm/$\sqrt{h}$ and 0.5–2.0 mm/$\sqrt{h}$ for random walk models for the zenith wet delay and the horizontal delay gradients, respectively. This conclusion is based on the detailed analysis of eight out of the 54 days only and for the future we plan to analyse more data and search for a possible seasonal dependence.

Using constraints for the atmospheric parameters in these ranges for the space geodetic data analysis we obtain good agreement for the zenith wet delay results from the three techniques. The correlation coefficients are in the range of 0.73 to 0.87, where the higher correlation is obtained for the two space geodetic techniques. This can be partly explained by the fact that both techniques share some common error sources, e.g. the same mapping functions are used, and they do not suffer from rain effects as does the WVR.

The agreement of the results for the horizontal delay gradients is less pronounced. Here the correlation coefficients are between 0.27 and 0.51, where again the best agreement is found between the two space geodetic techniques. We do see a systematic behaviour for the north gradients where the WVR results would appear to indicate a positive contribution while the space geodetic techniques sense a negative contribution. This cannot be explained alone by the inclusion of the pressure term in the refractivity gradients which is of course not sensed by the WVR. An average positive north delay gradient has also been found from the analysis of a larger WVR data set [9].

Given that the Onsala site is on the coast further investigations especially with respect to pressure and local temperature gradients are necessary. The acquisition of more data and further comparisons are planned.

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