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Influence of Elevation-Dependent Weighting on Parameter Estimates: A Case of CONT05

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Abstract. In this paper, results are presented on studies which have been performed to investigate the impact of the cut-off elevation angle and elevation-dependent weighting on the EOP estimates and baseline length repeatability.

1. Introduction

The precision and accuracy of observations made through the Earth's atmosphere grow with increasing elevation due to larger air mass and difficulties in modelling refraction effects at low elevation. From this point of view observations should be made in the near-zenith zone when possible. On the other hand, inclusion in processing of observations made at low elevations is important when highly correlated parameters are estimated simultaneously. In such a case using observations made in a widest range of elevation allows one to mitigate the correlations between unknowns. To meet these mutually exclusive requirements, elevation-dependent weighting (EDW) is used. In a special case of step-like weighting function, one rejects the observations made at the elevation less than the given limit, so-called cut-off elevation angle (CEA).

It is well known that EDW has a significant impact on the results of processing of the space geodesy observations. In particular, several studies on the subject were made in the framework of the IVS VLBI2010 Committee activity (http://ivscc.gsfc.nasa.gov/pipermail/ivs-v2c/). Those results were based on simulation. Gipson in [1] applied elevation dependent additive noise to the measurement error instead of using a weighting factor as it is usually being made. He tested his method with the actual CONT05 observations.

Results of both mentioned and other results are sometimes contradictory. This gave an impulse to the present work where some results are presented about an investigation of the impact of the CEA and EDW on the baseline length repeatability (BLR) and Earth orientation parameters (EOP) estimates.

2. Test Description and Results

For this test, CONT05 observations were processed with the OCCAM software with different EDW functions including CEA, keeping all other options as used during routine processing: Kalman filter mode (KF), random walk model for clocks (PSD=1.5 ps^2/s) and ZTD (PSD=0.25 ps^2/s), one NS and EW troposphere gradient estimate for each 24h session.

For the continuous EDW mode (continuous weighting function), the measurement error is multiplied by a factor

$$W_e = (\sin e_0 \,/\, \sin e)^p \,, \tag{1}$$

where e_0 and p are EDW parameters, e is the source elevation. Such a weighting function provides a smooth stepless change in weight for any e_0. One can see that a case of $e_0 = 90°$, $p = 1$ gives merely $W_e = 1/\sin e$, which is close to actual mapping function used in the last works by MacMillan and Gipson (private communications). EDW mode with $e_0 = 10$, $p = 2$ was implemented in the OCCAM/GROSS software [2] for routine data processing. It will be referred to hereafter as "normal mode". In a case of CEA we have

$$W_e = \begin{cases} 1, & \text{if } e >= e_0 \,, \\ 10^3 & \text{otherwise} \,. \end{cases} \tag{2}$$

The latter line corresponds to the KF realization used in OCCAM. For VLBI delay, the measurement error coming from the correlator is multiplied by two W_e values computed for both stations. In our test, $e_0 = 3(2)25°$ were used for CEA test, and $e_0 = 10, 25, 45, 90°$, $p = 1, 2$ were used for continuous EDW mode.

BLR obtained with different CEA are shown in Fig. 1. The case of $e_0 = 3°$ includes all the observations without weighting, since no CONT05 observations were made at the elevation less than 4°. Tabl. 1 shows EDW test results. Different EDW modes are denoted as 'e_0_p' corresponding to (1). Test results are given for quadratic approximation in percent with respect to the case of CEA with $e_0 = 3°$. One can see that several EDW modes show about the same improvement in the BLR.

Table 1. Baseline length repeatability for different EDW models

EDW	Baseline length, 10^3 km				EDW	Baseline length, 10^3 km			
mode	3	6	9	12	mode	3	6	9	12
10_1	98.0	97.2	97.3	97.6	45_1	101.7	90.0	84.6	81.9
10_2	95.3	95.0	95.5	96.1	45_2	104.0	97.2	101.8	107.6
25_1	102.6	92.8	87.2	83.8	90_1	101.3	90.5	85.4	82.8
25_2	95.7	91.8	91.4	91.9	90_2	109.6	127.3	161.1	191.1

To investigate the change in the baseline length obtained with different CEA and EDW models we compared them (mean of 15 daily estimates) to

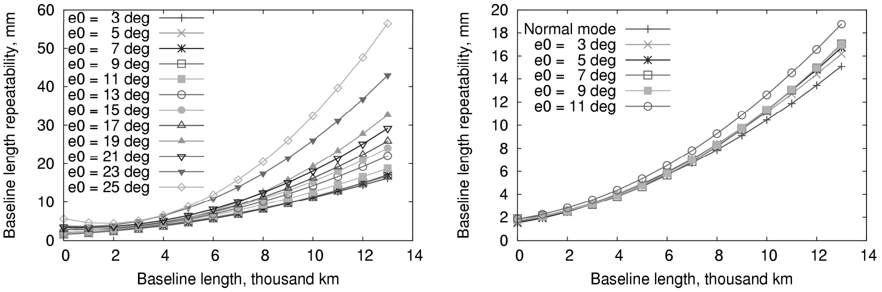

Figure 1. Baseline length repeatability for different CEA (quadratic regression)

the length value obtained with $e_0 = 3°$ (all the observations included). The comparison shows that change in the baseline length essentially depends on stations involved in the baseline under consideration. For stations located among others, for which observation sky coverage is close to uniform, change in baseline length may reach several millimeters with increasing of CEA. For outside stations, HARTRAO and especially TIGOCONC for CONT05, one can see very asymmetric sky coverage, and change in baseline length may reach 3 cm as CEA grows from 3° to 25°. EDW mode shows much less change in the baseline length, and in this case increasing e_0 leads to greater change in the baseline length too up to 1 cm for TIGOCONC and HARTRAO.

Fig. 2 shows EOP statistics for different CEA. Notation used is the following: Xp, Yp – terrestrial pole coordinates, Xc, Yc – celestial pole coordinates. Results of comparison of CONT05 EOP with the IGS time series are presented in Fig. 3. Xp and Yp wrms with respect to IGS EOP series are computed after removing the bias. Tabl. 2 shows the main EDW test results. Notation of the EDW modes is the same as used in Tabl. 1. The column labelled "All" corresponds to inclusion of all observations without weighting. One can see again that several EDW modes show about the same EOP precision and accuracy.

3. Conclusions

The preliminary conclusions from this test are the following.

The BLR steadily grows with the CEA increasing, remaining practically the same up to 9°. The same can be said for the bias in the baseline length. Maximal impact of the CEA on the baseline length bias is seen for the outside network stations with the most asymmetric observations sky coverage.

The Xp, Yp and UT1 uncertainties grow with the increasing CEA after about 10°. Most probably, this reflects the fact that only about 6% of the total number of CONT05 observations were made at the elevations below 10°. The Xc and Yc uncertainties and scatter depend on the CEA much less. Xp bias w.r.t. IGS slightly depends on the CEA, except the maximum tested CEA values, evidently unrealistic. In contrast, Yp bias substantially changes

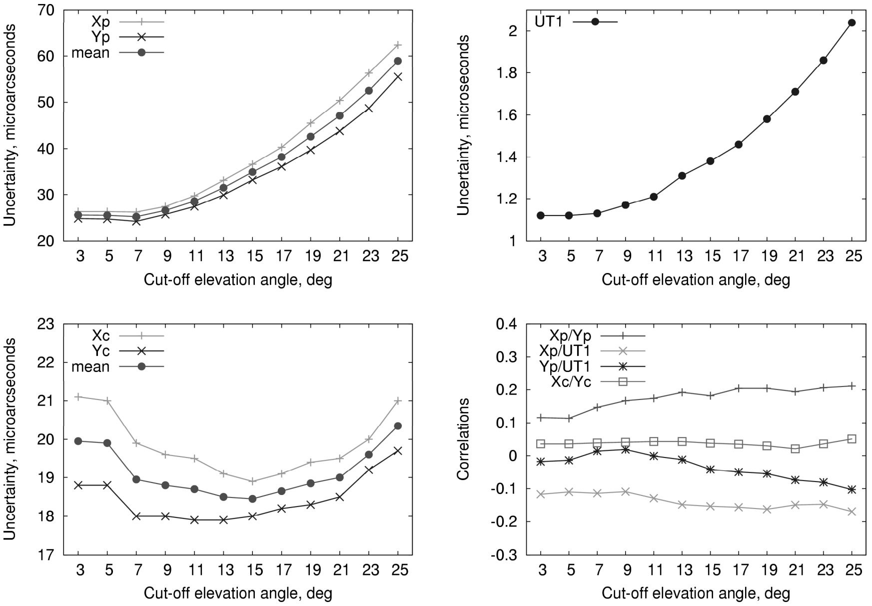

Figure 2. Statistics of EOP obtained from CONT05

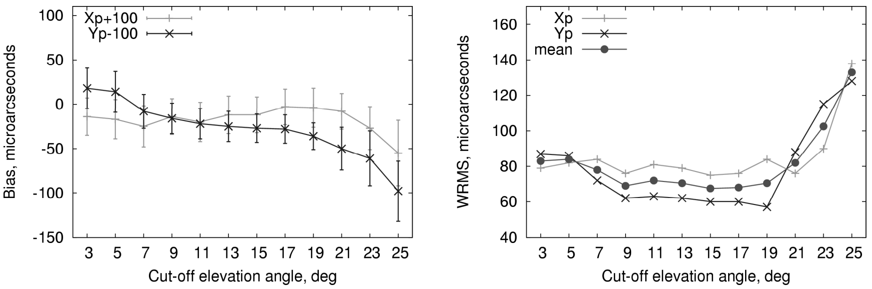

Figure 3. Comparison of EOP obtained from CONT05 with the IGS EOP series

with increasing CEA. Most probably, this can be explained by the CONT05 network orientation, for which the longitude of the central meridian $\lambda_0 = 265°$ just corresponds to the Yp direction. Some statistics, such as the uncertainty and the scatter of the Xc and Yc, as well as the WRMS of Xp and Yp w.r.t. IGS have the minimum at the CEA around 15°, which is interesting and deserves a supplement investigation. As one can expect, the correlations between EOP comprising Xp and Yp grow with increasing CEA, but remain small due to good CONT05 network geometry. The same can be expected for the IVS2010 network. The correlation between Xc and Yc remain practically the same for

Table 2. EOP statistics for different EDW models

Statistics	Unit	All	EDW mode							
			10_1	10_2	25_1	25_2	45_1	45_2	90_1	90_2
Xp uncertainty	μas	26	26	25	26	28	27	37	30	51
Yp uncertainty	μas	25	24	24	24	26	25	32	26	43
UT1 uncertainty	μs	1.1	1.1	1.1	1.1	1.1	1.0	1.3	1.1	1.6
Xc uncertainty	μas	21	21	20	20	19	20	22	22	27
Yc uncertainty	μas	19	18	18	18	18	18	21	20	27
Xp bias w.r.t. IGS	μas	–79	–75	–79	–77	–73	–80	–86	–81	–123
Yp bias w.r.t. IGS	μas	+135	+135	+128	+132	+129	+134	+127	+129	+92
Xp wrms w.r.t. IGS	μas	77	72	76	69	65	68	69	64	86
Yp wrms w.r.t. IGS	μas	73	74	72	69	61	68	63	71	83

all tested CEA, except the maximum tested CEA value, evidently unrealistic.

For most of the tests performed, the best result was obtained with EDW applied to the low-elevation observations. However, the test results are not always unambiguous. Further adjustment of the weighting method may be fruitful.

Finally, we can conclude that inclusion of the low-elevation observations, properly weighted, improves the baseline length and EOP estimates. On the contrary, filtering the observations using the CEA method may lead to degradation of geodetic results. However, it should be mentioned that the conclusions drawn from the result obtained in this paper has been proven with standard geodetic VLBI observations, where rather few observations were made at low elevations, as mentioned above. Perhaps, special R&D sessions with more uniform distribution of observations over the sky, including observations at very low elevations, may be useful for more detailed study on optimal scheduling and processing of the space geodesy observations.

It ought be mentioned that all the EDW modes considered in this paper in fact modify only diagonal elements of the corresponding covariance matrix. According to Gipson's work [1] best results can be achieved when correlations between observations are also accounted for. It seems to be interesting to investigate how this approach will work for the KF estimator.

References

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[2] Malkin, Z., E. Skurikhina. OCCAM/GROSS Software Used at the IAA EOP Service for processing of VLBI Observations. IAA RAS Transactions, v. 12. "Nauka", St. Petersburg, 2005, 54–67 (in Russian).