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TESTING IMPACT OF THE STRATEGY OF VLBI DATA ANALYSIS ON THE ESTIMATION OF EARTH ORIENTATION PARAMETERS AND STATION COORDINATES

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Abstract

Very Long Baseline Interferometry (VLBI) is the only space geodetic technique capable to realise the Celestial Reference Frame and tie it with the Terrestrial Reference Frame. It is also the only technique, which measures all the Earth Orientation Parameters (EOP) on a regular basis, thus the role of VLBI in determination of the universal time, nutation and polar motion and station coordinates is invaluable. Although geodetic VLBI has been providing observations for more than 30 years, there are no clear guidelines how to deal with the stations or baselines having significantly bigger post-fit residuals than the other ones. In our work we compare the common weighting strategy, using squared formal errors, with strategies involving exclusion or down-weighting of stations or baselines. For that purpose we apply the Vienna VLBI Software VieVS with necessary additional procedures. In our analysis we focus on statistical indicators that might be the criterion of excluding or down-weighting the inferior stations or baselines, as well as on the influence of adopted strategy on the EOP and station coordinates estimation. Our analysis shows that in about 99% of 24-hour VLBI sessions there is no need to exclude any data as the down-weighting procedure is sufficiently efficient. Although results presented here do not clearly indicate the best algorithm, they show strengths and weaknesses of the applied methods and point some limitations of automatic analysis of VLBI data. Moreover, it is also shown that the influence of the adopted weighting strategy is not always clearly reflected in the results of analysis.

Keywords: VLBI, weighting strategy, EOP, station coordinates

1. Introduction

The Very Long Baseline Interferometry (VLBI) is a space-based geodetic technique which relies on observations of radio signals from extragalactic radio sources using special radiotelescopes located on the Earth's surface. It plays the key role in modern geodesy, as it is used to define the International Celestial and the International Terrestrial Reference Frames (ICRF and ITRF, respectively) and to monitor their mutual relations, as well as dynamics and orientation of the Earth. VLBI can also be used to create and improve ionosphere models and validate tropospheric parameters derived from other space geodetic techniques (Schuh & Behrend, 2012). It also furnish information about relativistic bending (Sovers et al., 1998), gravitational deflection of radio waves, rudimentary details of radio-source structure, Earth's long term motion in inertial space (galactic rotation) or Love numbers (Krasna, 2013). Therefore it is required to maintain all technical and computational aspects of the technique at the highest possible level (Petrachenko et al., 2013). To fulfil these requirements there is a need for improvement of observing equipment, but also of observing strategies, models or data analysis process, which is the main concern in this work.

Many investigations of the subject have been performed and some improvements of stochastic model have been proposed. For instance, (Schuh & Tesmer, 2000) suggest usage of full variance-covariance matrix with *a priori* correlations between the observables; (Tesmer, 2003), (Tesmer & Kutterer, 2004) and (Zubko et al., 2012) propose to differentiate between stochastic quantities using several variance components (*e.g.* source dependent variance, elevation dependent variance). All of the research mentioned above focus on finding an alternative to the standard Gauss-Markov model with one stochastic property (that is common level of variance). There have been also investigated other problems connected with data analysis like the role of constraints (Kutterer et al., 2003) or methods of the outliers detection (Bachmann et al., 2012). Nevertheless, the process of VLBI data analysis still depends, to a certain extent, on experience of an analyst, especially when incorrect data negatively affect results (e.g. (Nilsson et al., 2014)). In such cases, the analyst has to decide between removing, down-weighting or leaving these data unchanged. Removing data seems to be the least desirable action as it leads to losing information or even to lack of the solution (due to singularity of normal equations). Moreover, excluding any station causes disability to determine coordinates of this site and changes of geometry of the network. On the other hand, if we want to improve the solution, leaving bad data is not an option. The most appropriate solution seems to be down-weighting observations, as it allows saving the required data.

In our work we are attempting to assess when the data should be down-weighted and how the weighting strategy influences the results. We focus here on Earth Orientation Parameters (EOP) and station coordinates. We check four approaches to weighting observations and compare them with the standard approach, all described in section 2. Results of analysis are described in section 3 and conclusions are outlined in section 4.

2. Data and weighting strategies

In this investigation, about 1400 24-hour geodetic VLBI sessions of type R1, R4 and RDV were processed (IVS, 2013). Data sets have been downloaded from the International VLBI Service (IVS) websites and they are in NGS format files. We selected sessions which are appropriate to estimate EOP and station coordinates, so we are able to asses the influence of the weighting strategies on those parameters. Each session was processed separately, using the Vienna VLBI Software - VieVS developed by (Böhm et al., 2012) and applying the same set of parameters and models.

We adopted VTRF2008 (Böckmann et al., 2010) and ICRF2 (Fey et al., 2009) as the terrestrial and celestial reference frames, respectively. Station coordinates were estimated as one offset per session, applying the No Net Rotation and No Net Translation conditions. Conditions were imposed on all stations in a session, except those not contained in the VTRF2008 catalogue or excluded from the catalogue due to *e.g.* an earthquake. Moreover, we introduced station corrections due to the solid Earth tides, ocean tidal loading (FES2004, (Lyard et al., 2006)), atmosphere tidal and non-tidal loading after (Böhm et al., 2006), pole tide, ocean pole tide and thermal antenna deformation. The radio-source coordinates were fixed to their catalogue positions, and source structure corrections were not applied. Regarding troposphere, we estimated zenith wet delays with 1 hour interval, and gradients with 6 hours interval. The *a priori* tropospheric delays were modelled using the Vienna mapping functions (VMF1, (Böhm et al., 2006)) and the Saastamoinen tropospheric model (Saastamoinen, 1972), temperature and pressure were taken from the NGS file (observed at a site). The clock offsets were estimated with 1 hour resolution, as a piece-wise linear offsets with one rate and one quadratic term per clock. Regarding EOP, all parameters were estimated once per day. As an *a priori* values we set the IERS C04 08 time series, including *a priori* celestial pole offsets and high frequency variations due to ocean tides and librations. As a precession-nutation model we used IAU 2006/2000A (Petit & Luzum, 2010). As an additional restriction we chose observations with elevation angle exceeding 5 degrees.

2.1. The standard approach

The standard approach (SA) to parameter estimation realized by VieVS is based on the least squares adjustment with the Gauss-Markov model, given by:

$$\mathbf{Ax} = \mathbf{y} + \mathbf{v}, \text{ with } D(\mathbf{y}) = \mathbf{C}_{yy} = \sigma_0^2 \mathbf{Q}_{yy} = \sigma_0^2 \mathbf{P}^{-1} \tag{1}$$

where $\mathbf{y}$ is a vector of the n observations, $\mathbf{v}$ denotes vector of the residuals, $\mathbf{A}$ is a design matrix and $\mathbf{x}$ is a vector of the u unknowns. The stochastic model is described by the dispersion operator $D(\cdot)$, the observation covariance matrix $\mathbf{C}_{yy}$, the corresponding cofactor matrix $\mathbf{Q}_{yy}$, the weight matrix $\mathbf{P}$ and the variance scaling factor σ_0^2, estimated on the basis of post-fit residuals. The vector of unknown parameters $\hat{\mathbf{x}}$ is estimated using the least-squares formula:

$$\hat{\mathbf{x}} = \left(\mathbf{A}^T\mathbf{PA}\right)^{-1} \mathbf{A}^T\mathbf{Py}, \tag{2}$$

and the estimate $\hat{\sigma}_0^2$ of the unitless variance factor is computed based on the post-fit residuals $\hat{\mathbf{v}} = \mathbf{A}\hat{\mathbf{x}} - \mathbf{y}$, by:

$$\hat{\sigma}_0^2 = \frac{\hat{\mathbf{v}}^T\mathbf{P}\hat{\mathbf{v}}}{n-u} \tag{3}$$

As the stochastic dependencies between the observations are unknown, the weight matrix $\mathbf{P}$ does not contain *a priori* information about correlation between observations and it is realized by a diagonal matrix:

$$\mathbf{P} = \begin{bmatrix} \left(\sigma_1^2 + \sigma_{const}^2\right)^{-1} & 0 & \dots & 0 \\ 0 & \left(\sigma_2^2 + \sigma_{const}^2\right)^{-1} & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \left(\sigma_n^2 + \sigma_{const}^2\right)^{-1} \end{bmatrix} = diag\left(\sigma_i^2 + \sigma_{const}^2\right)^{-1} \tag{4}$$

where σ_i is a formal error of a particular observation, derived during the correlation process and given in the NGS file, and $\sigma_{const}^2 = 1$ cm^2 is an arbitrary quantity added to account for model deficiency.

2.2. Baseline-dependent weighting approaches

VieVS offers possibility to apply baseline dependent weights (BDW). In this variant the whole process of parameter estimation is made, the vector $\hat{\mathbf{v}}$ of residuals is computed and the new weights are computed based on it. Then the process of estimation is repeated using the new weight matrix $\mathbf{P}_{BDW}$. The matrix is still diagonal, still contains formal errors σ_i, but instead of constant factor of 1 cm^2 the baseline RMS $\sigma^2_{b_k}$ (where b_k refers to a k-th baseline) is used:

$$\mathbf{P}_{BDW} = diag\left(\sigma_i^2 + \sigma_{b_k}^2\right)^{-1} \tag{5}$$

In this approach all observations of all baselines have different weights. The baseline RMS σ_{b_k} is constant for all n_{b_k} observations of a particular baseline and it is computed based on the residuals $\hat{\mathbf{v}}_{b_k}$ of the baseline:

$$\hat{\sigma}^2_{b_k} = \frac{\hat{\mathbf{v}}^T_{b_k}\hat{\mathbf{v}}_{b_k}}{n_{b_k}} \tag{6}$$

As it was mentioned before, the BDW approach changes weights of all observations. Therefore for our purpose we slightly modify the variant and apply new weights for observations of only one baseline, and we call the approach one baseline dependent weights (OBDW). In this approach the variance estimator (eq. 3) for each baseline is computed first, then it is compared to the critical value σ^2_{max} taken from the χ^2 distribution. If the ratio of those two values exceeds the critical value, the factor $\hat{\sigma}^2_{b_k}$ is computed using eq. 6. The new weights are computed for observations of the baseline with the highest value of $\hat{\sigma}^2_{b_k}$ and 1 cm^2 is added to all observations (even those down-weighted). So the new weight matrix $\mathbf{P}_{OBDW}$ has on its diagonal $\left(\sigma_i^2 + \sigma^2_{const} + \sigma^2_{b_k}\right)^{-1}$ for the least reliable baseline, or $\left(\sigma_i^2 + \sigma^2_{const}\right)^{-1}$ for the rest of observations.

2.3. Station-dependent weighting approaches

VieVS enables also down-weighting observations containing a particular station. This variant is partially manual, as the down-weighting factor σ_{st} is not computed automatically, but is given by a user in the option file (see http://vievswiki.geo.tuwien.ac.at for details). The squared factor is added to the $\sigma_i^2 + \sigma^2_{const}$ of all observations containing the particular station in the weight matrix. We slightly modified this option for our purpose by implementing the following two approaches: Station-Dependent Weighting (SDW) and One-Station-Dependent Weighting (OSDW). In both cases the process of computation is similar to the BDW and OBDW approaches, respectively. Although, instead of using $\hat{\sigma}^2_{b_k}$, the down-weighting factor $\hat{\sigma}_{st}$ (station RMS) is used:

$$\hat{\sigma}^2_{st_i} = \frac{\hat{\mathbf{v}}^T_{st_i}\hat{\mathbf{v}}_{st_i}}{n_{st_i}} \tag{7}$$

where $\hat{\mathbf{v}}_{st_i}$ is a residual vector of observations containing i-th station and n_{st_i} is a number of the observations. In the SDW approach the weights of all observations are changed, using the new weight matrix $P_{SWD} = diag\left(\sigma_i^2 + \sigma^2_{st_a} + \sigma^2_{st_b}\right)^{-1}$ with formal errors and down-weighting factors of both stations constituting the baseline. In this case no changes of the reference frame definition are introduced. In the OSDW approach, the weighting matrix $\mathbf{P}_{OSDW}$ has on its diagonal $\left(\sigma_i^2 + \sigma^2_{const} + \sigma^2_{st_i}\right)^{-1}$ for observations of a baseline with the worst station, or $\left(\sigma_i^2 + \sigma^2_{const}\right)^{-1}$ for the rest of observations. The rule of choosing the weakest station is the same as the way of choosing the weakest baseline in the OBDW approach. Moreover, the down-weighted station is excluded from the NNT/NNR conditions.

3. Analysis and results

To assess the influence of adopted strategies we processed over 1400 VLBI 24-hour sessions using standard approach, as well as four alternative weighting strategies. The standard models were applied in computation while changing only the weighting strategy (see Section 2). In order to choose the most appropriate algorithm for particular cases we compared the results and analysed a set of indicators. As a first index of the solution appropriateness we used the variance scaling factor, as it is commonly used in statistic and in VLBI data analysis (eg. (Nilsson et al., 2014)). For each step and for each session the variance scaling factors of session, stations and baselines were computed to indicate the possible source of inappropriateness. In Figure 1 the variance factors of main solution for all sessions in each approach are presented. As it could be seen, the variance factors are smaller for all alternative approaches than for the standard approach which is desirable in most sessions. However, in the BDW and SDW algorithms all observations are down-weighted that significantly decreases the value of the variance factor much below 1. Although we expect a lower variance factor, it should not be much lower than 1, as it means that the a priori errors of observations, which are introduced to the weight matrix, are too high.

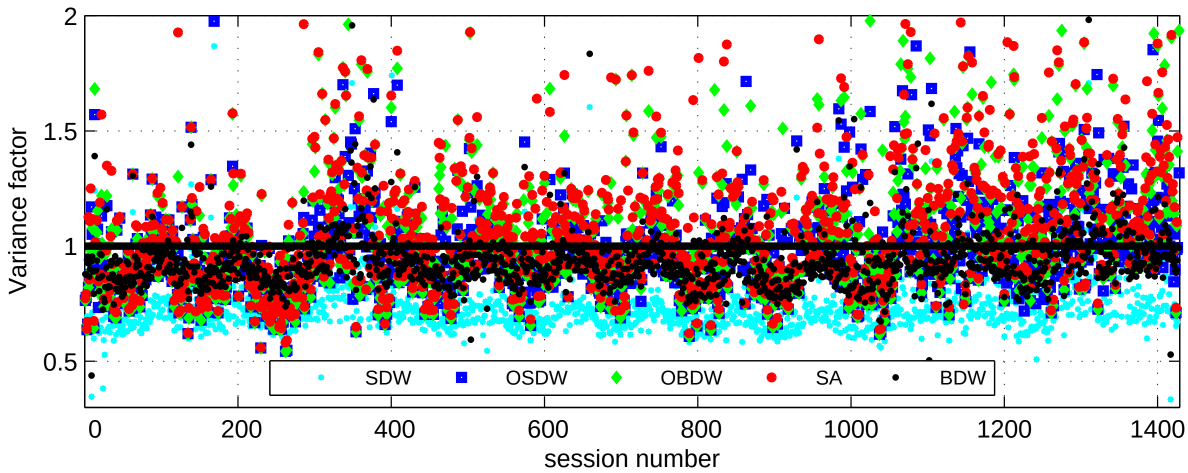

Fig. 1. Estimated variance factors for the analysed sessions and strategies: SA - Standard Approach, SDW - Station-Dependent, OSDW - One-Station-Dependent, OBDW - One-Baseline-Dependent, BDW - Baseline-Dependent

In the standard approach only about 56% of sessions have the variance factor lower than 1, about 34% between 1 and 1.5 and about 10% higher than 1.5. Therefore about 620 out of 1400 sessions require additional analysis to decrease the variance factor below the critical level. For alternative approaches the number of sessions having the variance factor lower than 1 significantly increases: for BDW by $\sim$ 91.5%; SDW $\sim$ 98%; OSDW $\sim$ 78%; OBDW $\sim$ 60.5%. Taking the variance factor as an indicator of correctness of solution we can notice that SDW algorithm reduces the need of manual analysis to 2% of sessions (28 sessions of 1400) while OBDW does not seem efficient in terms of reducing the variance factor.

Apart from the *a posteriori* session variance factors of main solutions we present the station variance factors (Table 1), the baseline variance factors (Figure 2) and residuals for chosen sessions (Figure 3). Session 14MAY29XE (top left) shows results which are typical for about 60-70% of analysed sessions, where change of weighting strategy does not change much the variance factor and value of estimated parameters. As it is shown for

Tab. 1. A posteriori variance factors from different solution strategies for selected sessions

Stat. No	session	SA	BDW	SDW	OSDW	OBDW
	14MAY29	**1.06**	**0.91**	**0.70**	**1.02**	**1.02**
1	MATERA	1.05	0.88	0.67	1.00	1.00
2	NYALES20	0.84	0.79	0.56	0.82	0.82
3	KATH12M	0.90	0.82	0.63	0.90	0.90
4	FORTLEZA	0.94	0.81	0.62	0.90	0.90
5	HOBART12	0.91	0.82	0.61	0.89	0.89
6	WETTZELL	0.95	0.84	0.59	0.89	0.89
7	KOKEE	1.14	0.84	0.71	1.06	1.06
8	TIGOCONC	0.98	0.76	0.63	0.92	0.92
	02AUG29	**5.63**	**1.02**	**0.78**	**2.25**	**4.14**
1	NYALES20	6.26	1.06	0.85	2.43	4.70
2	WETTZELL	7.43	1.01	0.86	1.16	4.98
3	ALGOPARK	4.66	0.97	0.65	2.22	3.47
4	SESHAN25	2.22	0.61	0.37	1.25	1.59
5	KOKEE	3.19	0.92	0.66	2.78	2.93
	09MAY26	**22.83**	**0.85**	**0.65**	**0.86**	**0.90**
1	NYALES20	7.14	0.78	0.55	0.73	0.75
2	ONSALA60	5.87	0.81	0.60	0.82	0.84
3	WESTFORD	35.15	0.79	0.62	0.84	0.89
4	WETTZELL	15.02	0.83	0.60	0.83	0.84
5	ZELENCHK	2.84	0.78	0.57	0.75	0.76
6	FORTLEZA	16.20	0.81	0.62	0.83	0.89
7	TSUKUB32	4.31	0.81	0.63	0.87	0.89
8	TIGOCONC	86.38	0.91	0.84	0.88	1.33
	06MAY11	**30.49**	**0.59**	**0.48**	**1.17**	**10.77**
1	FORTLEZA	3.23	0.74	0.25	1.41	1.99
2	MEDICINA	16.22	0.48	0.20	0.78	4.03
3	ALGOPARK	12.94	0.49	0.23	0.92	4.20
4	SESHAN25	76.53	0.53	1.34	1.54	28.71
5	WETTZELL	18.57	0.51	0.21	0.96	7.08
6	KOKEE	48.20	0.41	0.78	1.37	16.69

this session, the variance factor of standard approach is close to one, significantly lower than the critical value. The same holds for station and baselines (which are not presented here). However, we can see that the use of the alternative weighting strategies decreases the variance factor, although it is not necessary in this case. In case of session 14MAY29 the residuals are at the level of several centimetres for all approaches. The solution for standard approach is good and change of weighting strategy does not influence the size of residuals.

For sessions 02AUG29, 09MAY26 and 06MAY11 we can notice high session's and stations' variance factors for standard approach and considerably lower values for the alternative ones. For sessions 09MAY26 and 06MAY11 we can see very high, reaching even several meters, residuals obtained by the standard approach. When applying the alternative weighting strategies both the size of residuals and the post-fit variances of sessions, stations and baselines became significantly lower. For session 09MAY26 all alternative approaches improve main solution and decrease the variance coefficient for all stations and baselines participating in the observations. Each alternative approach is efficient and gives the variance factor below the critical level. However, for session 06MAY11 the one-baseline-dependent-weighting is not efficient enough. That might suggest that not a baseline is affected but probably a station, which could be deduced from the list of variance factors shown in Table 1 for this session. For the last mentioned session 02AUG29 both the residuals and variance factors are quite large, reaching 40 cm and 5.6, respectively. Here, a change of the weighting strategy gives a positive solution only if we apply the station or

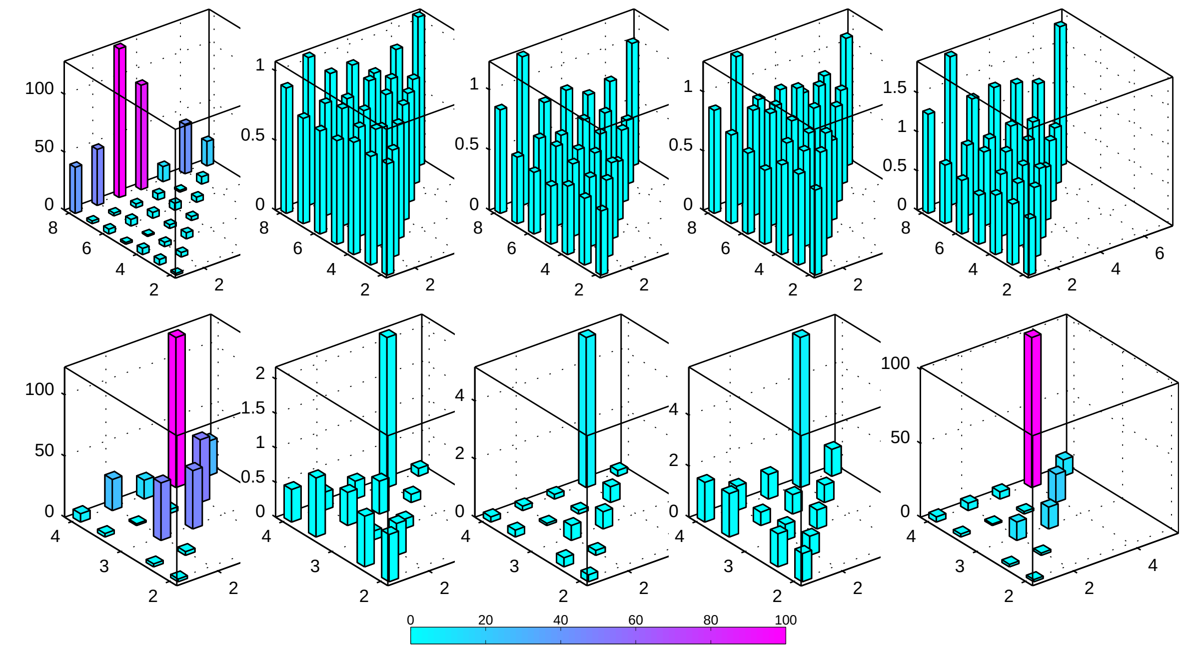

Fig. 2. Baseline variance factors for different approaches (from left: SA, BDW, SDW, OSDW, OBDW) for sessions 09MAY26 (top) and for 06MAY11 (bottom). Stations are identified by the same numbers as in Table 1

baseline-dependent weighting. Changing weights of baselines containing particular station or weights of one particular baseline does not decrease the variance factor and residuals below the critical level, hence we should apply more strict algorithm as BDW or SDW.

Another quality indicator is the baseline length repeatability. Figure 4 illustrates the baseline length repeatability for baselines computed more than 50 times from about 1400 sessions between 1997 and 2014. As it could be seen, change of weighting strategy does not cause big variations in the baseline repeatability. It is also visible that for short baselines (up to 3000 km) there are almost no changes in baseline lengths. In Table 2 we present four baselines with the largest changes of the length repeatability. For the last baseline shown in Table 2, SESHAN25-WESTFORD (representative for most of the baselines), the change in baseline repeatability is very subtle and cannot be treated as an indicator for improvement or deterioration of solution due to the weighting strategy. For problematic baselines applying OSDW or OBDW increases the baseline repeatability factor (*i.e.* standard deviations of baselines from all sessions), which is undesirable. On the other hand, the BDW and SDW algorithm allow us to significantly decrease the repeatability factor.

Tab. 2. Baseline repeatability in [cm] for vectors having the worst baseline repeatability factor and for a typical baseline: SESHAN25-WESTFORD

Baseline	length [km]	SA	BDW	SDW	OSDW	OBDW
TSUKUB32-YARRA12M	7205	34.39	12.87	22.37	42.80	50.49
HOBART12-YARRA12M	3211	23.55	11.39	10.91	10.95	10.92
FORTLEZA-HARTRAO	7025	11.52	6.09	7.75	13.74	15.07
HARTRAO -WETTZELL	7832	11.03	2.62	6.67	11.84	14.83
SESHAN25-WESTFORD	10 157	1.75	1.67	1.70	1.76	1.71

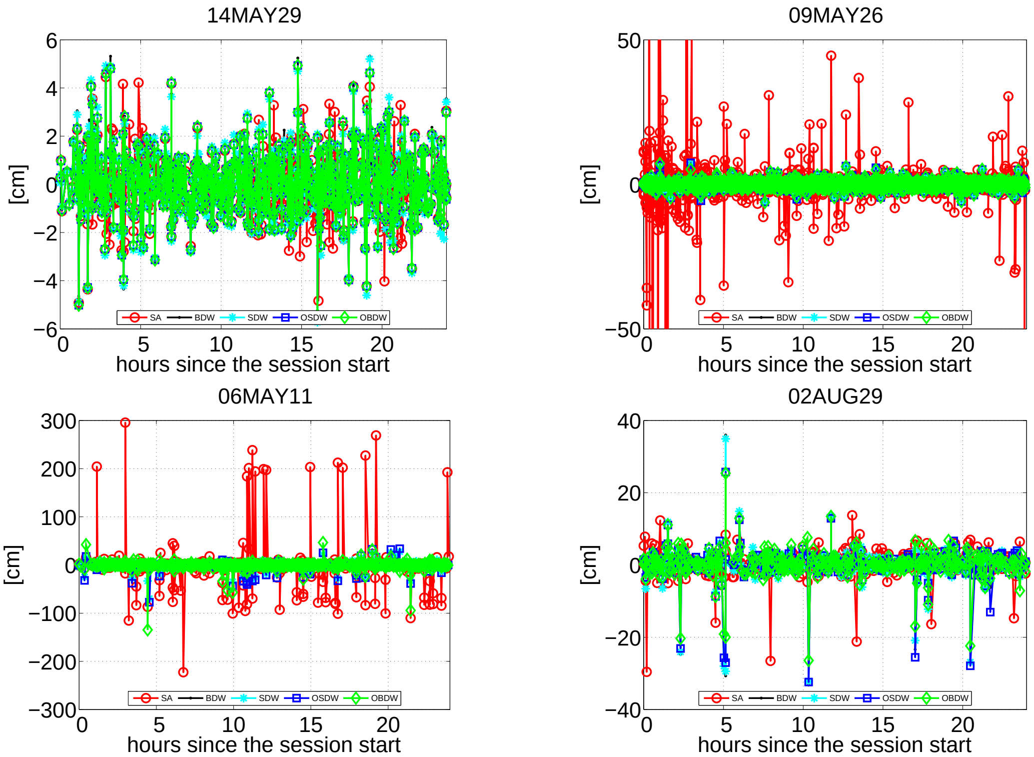

Fig. 3. Post-fit residuals of baseline lengths for sample sessions.

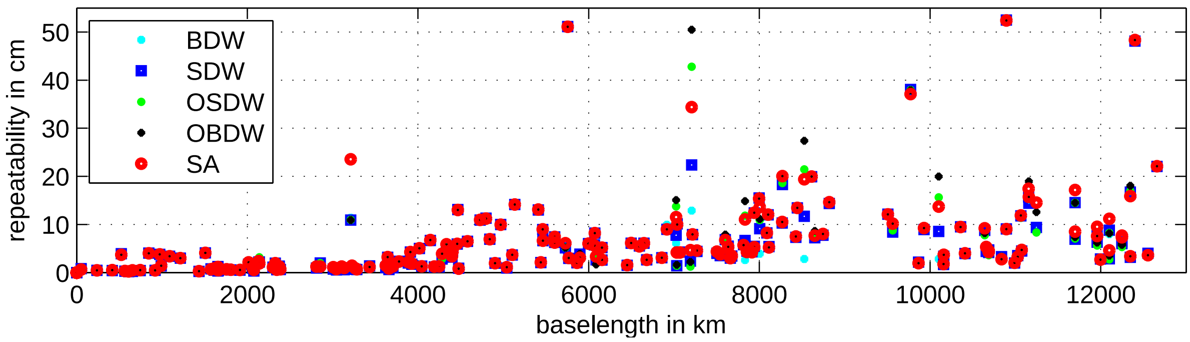

Fig. 4. Baseline repeatability for baselines estimated more than 50 times in about 1400 sessions

The last overall aspect, which we test here, is the correlation coefficient between the estimated parameters. In Figure 5 the correlation matrices for different approaches for sample session 05MAY19, representative for most cases.

What could be seen here is that the correlations between estimated parameters are slightly changed. It shows that introducing the additional weighting in most cases do not increase the correlations between estimated parameters. However, in extreme cases down-weighting observations might cause the singularity in normal equation matrix disabling the least-squares solution. After taking into account all of these indicators it can be concluded that introducing of any alternative weighting strategy is difficult for being automated. Changing the weighting strategy must be carefully analysed and supervised by the user, although some strategies seem to be more effective.

EOP and Station Coordinates

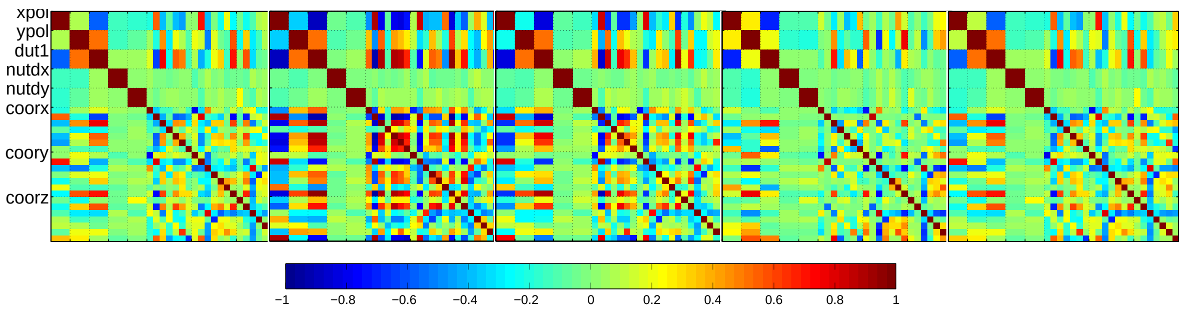

Fig. 5. Correlations coefficients of the estimated parameters for sample session (05MAY19XE) and for the for different weighting strategies: (from left) SA, BDW, SDW, OSDW, OBDW

The overall indicators give an overview of sessions or stations condition and tell whether introducing another weighting strategy improves or deteriorates the solution. We are interested in the influence of the weighting approach on the estimated parameters such as station coordinates and EOP. To assess the impact on EOP, first we compared values obtained in different approaches with respect to the IERS EOP C04 series, which are shown in Figure 6.

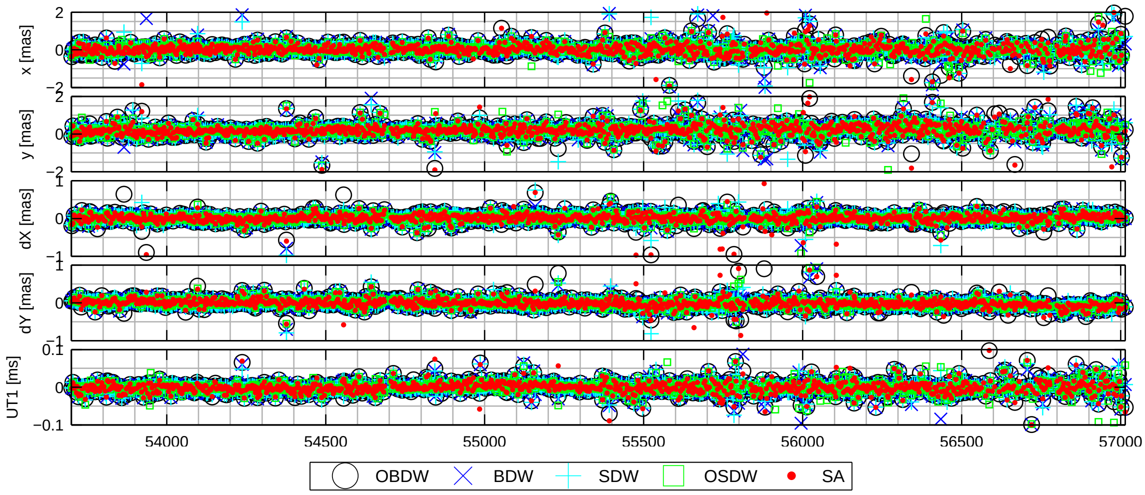

Fig. 6. Corrections to the IERS C04 EOP series estimated from VLBI data basing by using different approaches of weighting strategies

Besides a few sessions, the weighting strategy does not change significantly the estimated values of polar motion, nutation or universal time. The differences between the estimates based on particular strategies, in most cases, are not larger than the uncertainties of the estimated parameters. However, in some cases quite big discrepancies can be noticed. Nevertheless they usually refer to sessions with high variance factors, which can be also seen from the comparison in Figure 7, where the estimated corrections to the EOP C04 series are presented for sample sessions from Table 1. Detailed description of this comparison is presented below.

Subsequently, we compared mean values of each parameter (Table 3), to check if a bias occurs in any approach. Then we subtracted mean value from the respective time series and computed standard deviation (Table 3) of each parameter. Many values and standard deviations are at the same level in each approach, so we can conclude that no bias occurs in our results and a chosen strategy has no substantial influence on EOP estimates.

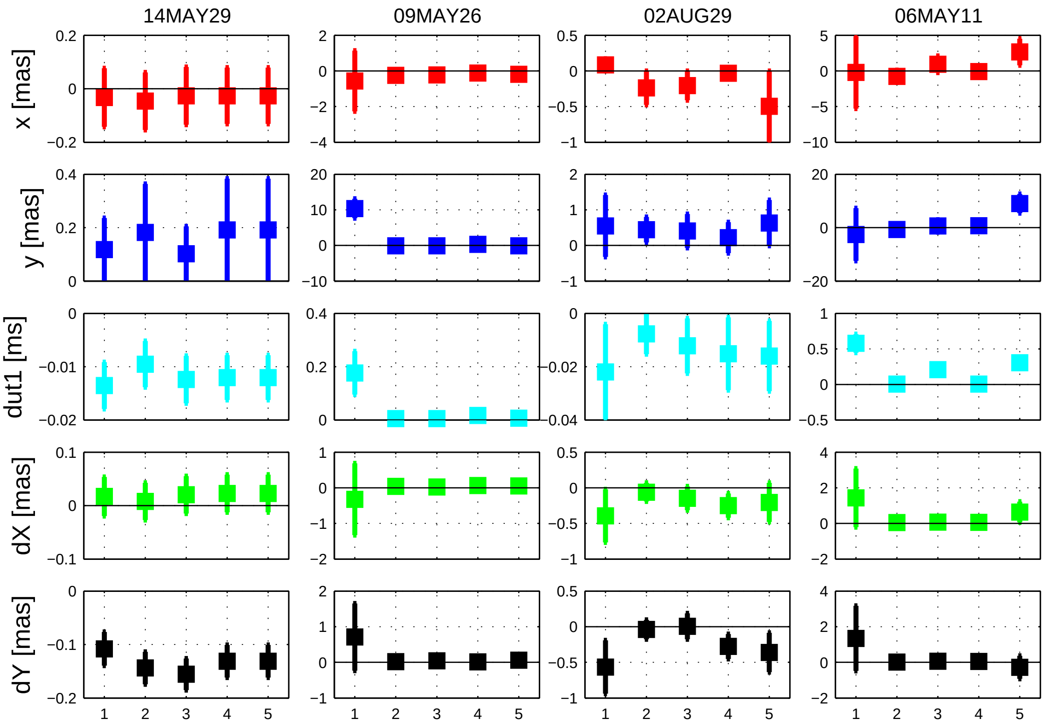

Fig. 7. Corrections to the IERS C04 EOP series for sample sessions and uncertainties of estimated parameters for different approaches: 1 - SA, 2 - BDW, 3 - SDW, 4 - OSDW, 5 - OBDW

Tab. 3. Mean differences with respect to the IERS-08-C04 series and standard deviations of EOP (UT1 in [ms], Polar motion and nutation in [mas])

	Mean values					Standard deviations				
Approach	x_{pol}	y_{pol}	UT1	dX	dY	x_{pol}	y_{pol}	UT1	dX	dY
SA	0.0141	0.1518	-0.0013	0.0028	-0.0044	0.2461	0.2806	0.0147	0.0961	0.1055
BDW	0.0119	0.1453	-0.0018	0.0023	-0.0031	0.2361	0.2745	0.0138	0.0868	0.0933
SDW	0.0140	0.1502	-0.0015	0.0051	-0.0047	0.2475	0.2797	0.0135	0.0929	0.0987
OSDW	0.0155	0.1518	-0.0015	0.0033	-0.0033	0.2410	0.2705	0.0140	0.0884	0.0942
OBDW	0.0114	0.1520	-0.0014	0.0032	-0.0048	0.2443	0.2766	0.0140	0.0951	0.1049

Nevertheless, we checked also percentage of outliers in the time series of every EOP derived from each approach (Table 4). For polar motion we discarded values higher than 1 mas, for nutation corrections higher than 0.5 mas and for dUT1 higher than 100μs. Despite the similar level of standard deviations, all alternative approaches have a lower percentage of outliers than the standard approach. It is visible especially for nutation corrections. In this comparison, the BDW approach seems to be the most effective.

Regarding station coordinates, we compared corrections obtained with different approaches for all stations, which took part in more than 20 sessions. We analysed not only corrections as such, but also differences between corrections obtained with alternative approaches and the standard one. In Figure 8 the time series of XYZ corrections to the coordinates for station Wettzell are shown. This station was chosen as its time series covers the whole time span and it participated in most sessions, *i.e.* 1296.

There are no big discrepancies between values based on different weighting strategies. Typical difference between coordinates from alternative approaches and the SA does not exceed 0.5 centimeter and the Wettzell station is representative for most of stations. In general, mean differences between coordinates corrections from alternative approaches and the standard one do not exceed (or slightly exceed) the level of 0.5 cm in 80% of stations.

Tab. 4. Percentage of outliers in time series of each EOP [%]

Approach	x_{pol}	y_{pol}	UT1	dX	dY
SA	4.94	6.35	2.60	1.62	1.27
BDW	4.02	5.57	2.19	0.28	0.35
SBDW	4.02	5.85	2.54	0.63	0.63
OSDW	3.39	4.87	2.19	0.42	0.63
OBDW	4.37	6.00	2.47	0.99	0.56

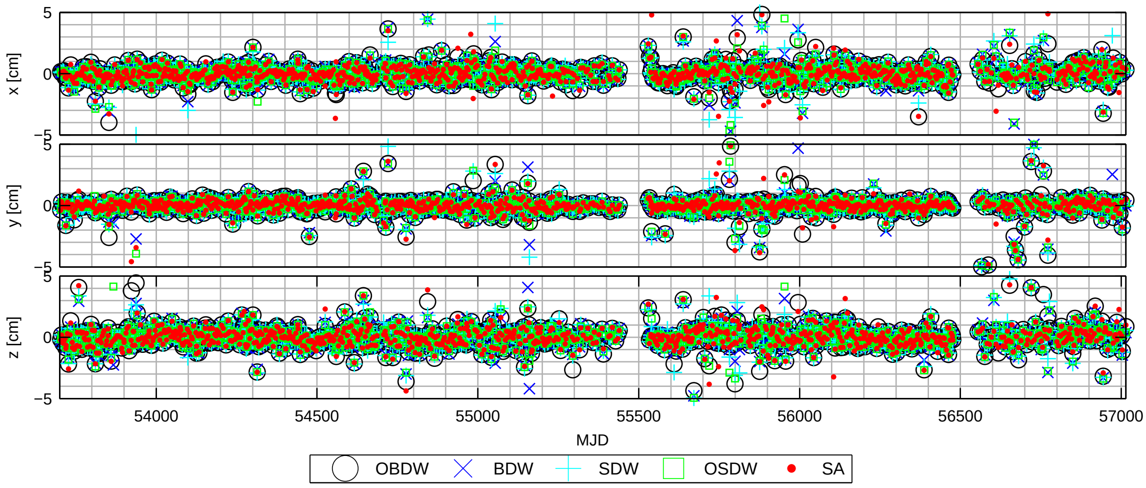

Fig. 8. Estimated corrections to the station coordinates using different approaches; case of station WETTZELL

In fact, depending on approach about 72 to almost 86% differences between corrections are not bigger than 0.25 cm, 85 to almost 92 % not bigger than 0.50 cm, 92 to over 95% not bigger than 1.00 cm and only 5.0 to 8% is higher than 1.0 cm. Those few percent cases with considerable discrepancies could be simply divided into two groups. First, where the change of weighting strategy gave actual improvement (*e.g.* session 09MAY26, see second row of Figure 9) and second, where discrepancies in coordinates are high, but there was no improvement, or there was a deterioration.

Nevertheless, looking at Figure 10 the RMSs of coordinates obtained with different method are at the same level and the maximum differences are not higher than 0.3 cm, so it seems that the change of the strategy does not have much influence on corrections to station coordinates.

Finally, we compared station coordinates and EOP from sessions 14MAY29, 09MAY26, 02AUG29 and 06MAY11 (Figures 9 and 7, respectively) with results from Table 1. Regarding sessions 14MAY29 and 09MAY26, results from Table 1 and Figures 9 and 7 are consistent. The former one is a good representation of most sessions and in this example it is visible that differences between corrections (from all approaches) to both station coordinates and EOP, are small and there is no clear indication which strategy might be more efficient or better than the standard one. Therefore, when a session seems to contain a good-quality data, changing of weighting strategy does not influence results and simply might be unnecessary. On the other hand, the latter session is a good example of sessions having some bad quality data. Regarding this example it is clear that the standard approach does not deliver good quality solution. It results in a high variance factor and very high corrections to station coordinates

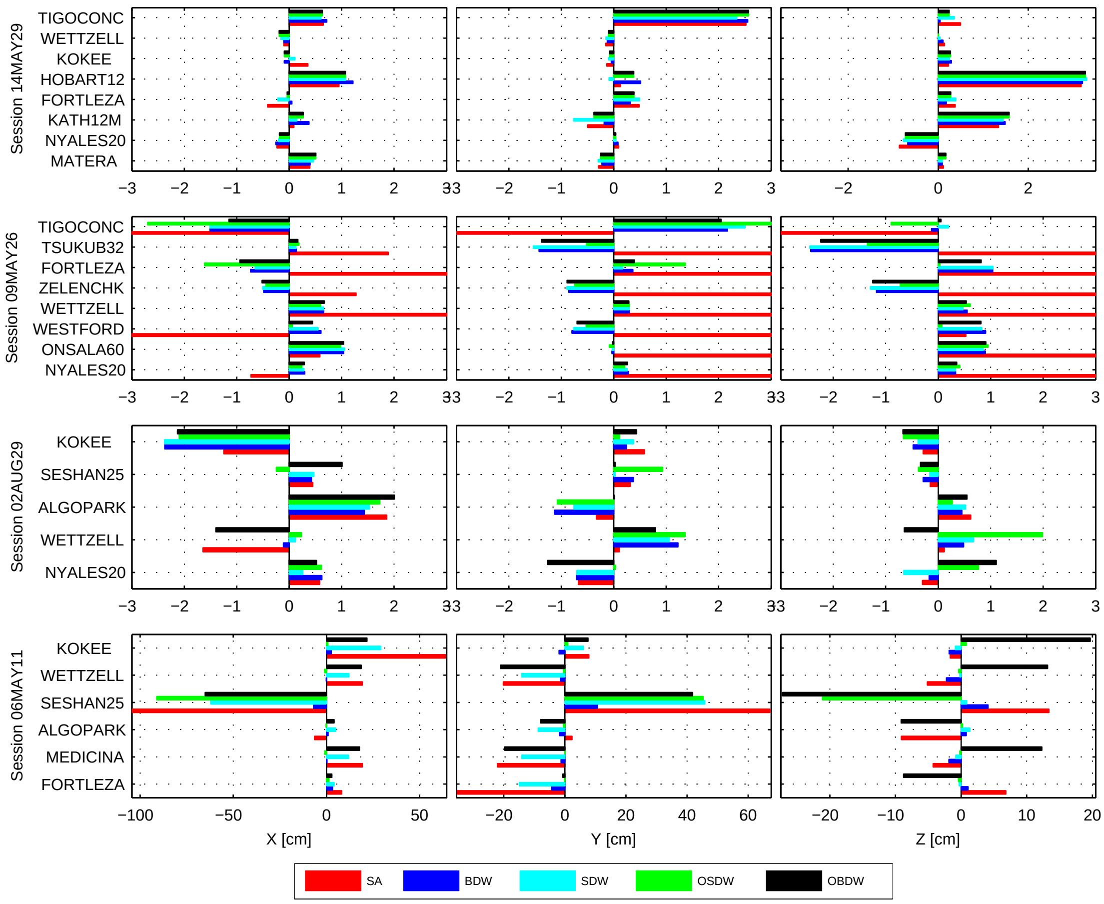

Fig. 9. Corrections to the coordinates estimated using different approaches for sample sessions

and EOP. Nevertheless, again it is hard to say which alternative approach is more efficient, as all of them give similar results. Looking at results from sessions 02AUG29 and 06MAY11, we can see that the corrections to EOP and station coordinates are not exactly consistent with the variance factors. Considering the session 02AUG29 the SA and OBDW seem to not deliver a good solution (Table 1), but it does not reflect in corrections to station coordinates and EOP. Although in many cases corrections from both solutions assume the largest values, they often do not exceed the assumed limit of outliers. Another situation is in the session 06MAY11. According to Table 1, the BDW, SDW and OSDW approaches seem to improve the solution, nevertheless it is not explicitly reflected in the rest of results, especially station coordinates. In this case, only the BDW approach seems to actually improve the solution.

Summarizing, we can conclude that for about 70% sessions the standard approach gives an appropriate solution and the change of the weighting strategy does not influence significantly the results. For 29% of sessions using the alternative algorithms improve solution in terms of the variance factor. Nevertheless estimated corrections to station coordinates and EOP seem to not always reflect those improvements. However, there were also sessions, wherein none of the approaches could improve the solution and further manual analysis (including station exclusion) was necessary. Nonetheless, they constitute only about 1% of all sessions.

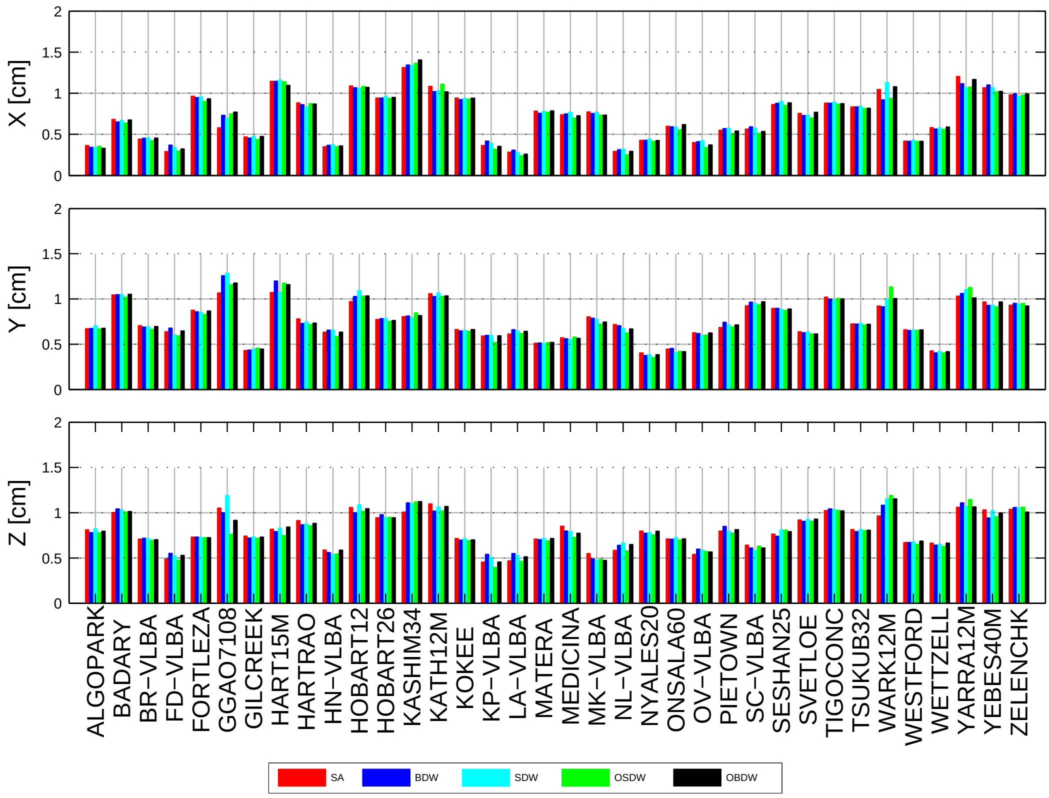

Fig. 10. RMS of VLBI station coordinates for different weighting strategies

4. Conclusions and remarks

In this experiment different weighting strategies of VLBI observations were tested. We assumed the difference between the estimated variance coefficient and its nominal unit value as an indicator of appropriateness of the solutions. We also analysed residuals, baseline repeatability and correlation between the estimated parameters. Finally, we compared the EOP and station coordinates derived on the basis of five different approaches. We automate the process of introducing alternative weighting strategy, as well. After taking into account all of aforementioned issues we can point out that:

- not every session requires an alternative weighting strategy; therefore any possible automation of the process should take into account some selected indicators, e.g. the variance factor, in order to asses whether any change is advisable;
- all alternative approaches change the main solution of the session, however, the BDW and SDW solutions decrease values of weights too much. Therefore they might not reflect properly the influence of particular observations. Moreover, the OBDW strategy is not effective and in most cases does not improve the solution sufficiently;
- promising alternative seems to be the OSDW algorithm, which does not change weights of a good-quality sessions and stations. Application of this strategy allows down-weighting baselines with a problematic station. Nonetheless, it increases correlations between estimated parameters and sometimes it does not fully compensate the impact of other badly behaving stations and should be done in an iterative way for one or more stations per session;
- it seems that the least effective is the OBDW approach, which gives results most consistent with the standard approach and in most of analyses do not introduce any improvement.

- the estimation of EOP and station coordinates does not strongly depend on a weighting strategy. The differences between the five solutions are generally not larger than their uncertainties. Nevertheless it could be expected that the weighting algorithm affects other estimated parameters;
- there were some sessions for which no alternative approach was efficient and the exclusion of a station or a baseline was necessary. Nonetheless, the problem concerns only about 20 sessions out of over 1400.

Summarizing, we can claim that down-weighting observation is in most cases an efficient way to improve the solution. Nevertheless it is difficult to completely automate the VLBI data analysis. Hence the analysis process still requires an user's attention.

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