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The Variance Component Approach in the IVS Combination

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Abstract. Within the International VLBI Service for Geodesy and Astrometry (IVS) several analysis centers contribute their solutions as input to the official combined products. In order to account for the different levels of variance of the individual solutions, relative weighting factors are determined by means of the variance component estimation method. In this paper, the variance component approach within the IVS combination is explained and the computed variance factors of each contribution are discussed. Furthermore, comparisons are presented showing the benefit of the variance component approach.

1. Introduction

Several IVS Analysis Centers (ACs) analyze geodetic VLBI observations with different software packages and provide their solutions to the official IVS combined VLBI solution as datum-free normal equations in SINEX format containing EOP and station positions. At the moment six ACs contribute to the combination using three different software packages (Tabl. 1).

Table 1. IVS ACs contributing to the combination with the software packages used

AC	Name	Software
BKG	Federal Agency for Cartography and Geodesy	CALC/SOLVE
DGFI	German Geodetic Research Institute	OCCAM
GSFC	Goddard Space Flight Center	CALC/SOLVE
IAA	Institute of Applied Astronomy	QUASAR
OPA	Paris Observatory	CALC/SOLVE
USNO	US Naval Observatory	CALC/SOLVE

From this input, time series of EOP are calculated as the official IVS combined product. Additionally, station position time series are computed for quality assessment. In this study, the variance component estimation is used to determine weighting factors for each contribution. Comparisons are carried out to investigate whether this approach leads to an improvement of the combined time series.

2. Variance Component Estimation

The variance component estimation (VCE), e.g. [1, 3], is used as a tool to determine relative weighting factors for individual solutions. Fig. 1 shows a flowchart of the combination process as performed here for each daily session.

1. All input data are converted from SINEX format into a binary format for the combination software DOGS-CS [2].
2. Every solution is transformed to the same epoch and an identical set of a priori parameters.
3. Station positions of each individual solution are calculated after adding an NNR/NNT datum.

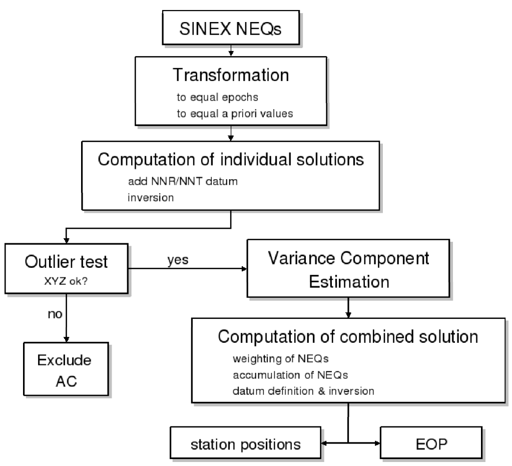

Figure 1. Data flow of the combination

4. As outlier test, the median of each station component over all individual solutions is computed. A contribution is rejected if the individual solution differ from the median by 3σ with a general threshold of 5 cm.
5. Relative weighting factors are determined by VCE.
6. The combined solution is calculated by accumulating the weighted datum-free normal equations and adding a datum definition.

Further details about the combination process can be found in [5].

The basic idea of the VCE is to compute one variance factor for each individual solution instead of one common a posteriori variance factor. The estimated variance factors can thus be used to weigh each solution before the combination. The VCE is performed in an iterative way until convergence is reached, i.e. until the update of the variance components is less than 1%.

In general terms, this should be done for each session independently. However, the redundancy of one single session is too small to estimate stable variance factors. To overcome this problem a sliding window over all sessions of one month (generally 8 sessions) has been used. There are two disadvantages of this approach: the estimated variance factors can only be considered as an approximation and the VCE itself cannot be used as outlier test. Fig. 2 shows the estimated variance components for all R1 and R4 sessions between 2002 and 2008.

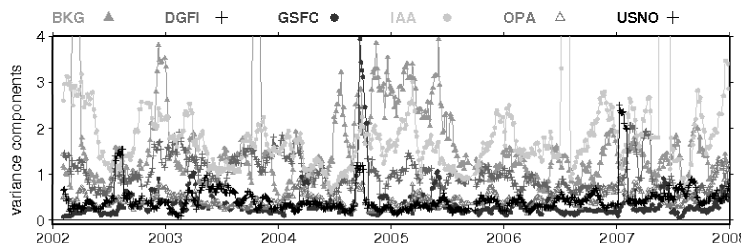

Figure 2. Estimated variance components of all R1 and R4 sessions

3. Validation

The individual and combined station positions of each single observing session are used as input for the VCE. Therefore, to validate the estimated variance components the station position time series of each input series are analyzed. Fig. 3 shows the height component of the station NyAlesund w.r.t ITRF2005 of each single solution. To better visualize the differences only sliding medians are displayed. Especially between 2004 and 2006, the estimated corrections of the BKG solution are bigger than of any other solution. This can directly be connected to the higher variance component estimates of the BKG solution during this time span (Fig. 2).

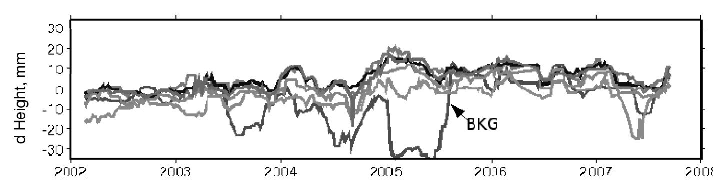

Figure 3. Median smoothed station positions of NyAlesund height component

Another example is displayed in Fig. 4. Here, the median smoothed time series of the height components of the station Algonquin Park is shown. The phase of the yearly signal of the IAA solution is shifted with respect to the yearly signal of all other single solutions. The same effect is visible in the height component of Westford (not shown here). Most probably, this is the reason for the higher variance component values for IAA over the whole time span.

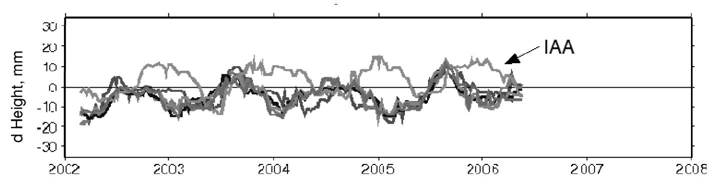

Figure 4. Median smoothed station positions of Algonquin Park height component

Although the station position time series of the DGFI solution does not show any bigger variations than the GSFC, OPA and USNO solutions, the variance factors estimated for the DGFI solutions are considerably higher than for the GSFC, OPA and USNO solutions. Due to the fact that the DGFI solution is the only solution computed with OCCAM, this leads to the assumption that the combined solution could be dominated by the GSFC, OPA and USNO solutions which are all analyzed with the same software (CALC/SOLVE) together with a similar modelling and parametrization.

To verify this assumption, variance components are estimated only for the contributions of 4 ACs. All of them are using either a different software package or a different parametrization and modelling. The results of this test are visualized in Fig. 5. While the estimated variance components of the BKG and IAA solutions remain nearly the same as for the estimation with all six ACs, the levels of variance of the USNO and DGFI solutions are nearly equal. This reflects the general problem of the IVS combination that four of six ACs use the same software package.

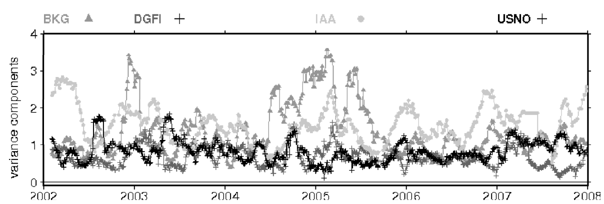

Figure 5. Estimated variance components for the contributions

4. Comparisons

To assess the benefit of the variance component approach, comparisons of station positions and EOP are carried out. For these comparisons three different combined solutions are computed to distinguish between the influence of the outlier test and the VCE. The first combined solution is calculated as described in Sec. 2, but without applying the outlier test and the VCE. The second combined solution is calculated with outlier test but without the VCE while for the third solution both the outlier test and the VCE are applied. In addition, station positions and EOP are estimated from the individual normal equations in a single estimation process applying NNR/NNT conditions on the site coordinates.

As a main result of these tests, station position repeatabilities w.r.t. ITRF2005 are computed from single session position estimates of all R1 and R4 sessions between 2002 and 2008. WRMS and RMS are calculated after offsets, rates and annual signals are removed with a least squares fit.

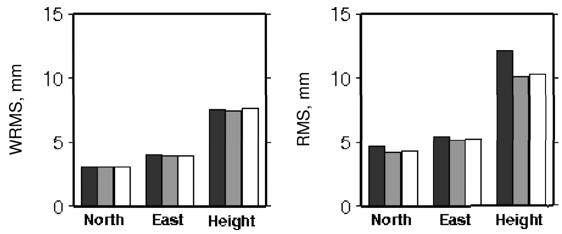

Figure 6. Station position repeatabilities w.r.t ITRF2005 of the three combined solutions, (black: without outlier test and VCE, gray: with outlier test, without VCE, white: with outlier test and VCE)

The common WRMS and RMS of all 17 stations of the three combined solutions are shown in Fig. 6. While no significant changes are visible neither for the WRMS of the horizontal components nor for the height, the unweighted RMS values show an improvement of 2.5 mm in the height component due to the outlier test. This simply indicates, that the detected outliers exhibit big formal errors.

Although no significant improvement of the station position repeatabilities is reached due to the outlier test and the VCE, the combined solution (outlier test and VCE applied) shows smaller WRMS values than any individual input series. For the horizontal components the WRMS is about 1 mm smaller than the smallest WRMS of all single solutions, the height WRMS about 2 mm.

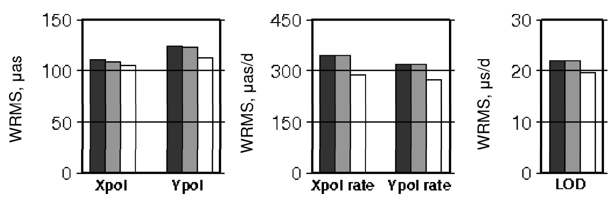

Figure 7. WRMS of the differences between the three VLBI combined EOP time series and the IGS EOP series (black: without outlier test and VCE, gray: with outlier test, without VCE, white: with outlier test and VCE)

In the same way as for the station coordinates, EOP series from 2002 till 2008 have been computed and compared to the IGS EOP series (igs00p03.erp, ftp://cddis.gsfc.nasa.gov/pub/gps/products). Offsets and rates are removed before computing the WRMS of these differences. Fig. 7 summarizes the results of the three combined solutions. The achieved improvement due to applying the outlier test only is rather small, but the VCE leads to improvements of about 10 % for the polar motion offsets, of 20 % and 15 % for the polar motion rates and more than 10 % for LOD.

Comparing the VLBI EOP series of the six individual solutions and the combined solution (outlier test and VCE applied) with the IGS EOP series, the combined solution fits better to IGS than any individual solution in all components.

5. Summary and Outlook

The comparisons of the station positions have shown that a small improvement of the combined solution due to the outlier test was reached but no additional improvement due to the VCE. Nevertheless, in the comparison with the all input solutions, the combined solution shows smaller station position repeatabilities w.r.t. ITRF2005 than any single solution.

Concerning the EOP, improvements of up to 20 % were obtained by applying the outlier test and the VCE in the combination process. Furthermore, the combined series agrees better with the IGS EOP in all components than any individual solution.

At the moment these investigations were only carried out for the R1 and R4 session. In the future this promising approach will be applied to the quarterly solution including all daily VLBI sessions from 1984 till now. Moreover, we are working on stabilizing the estimation of the variance components, so that these components can be estimated for one session individually. We expect that this leads to more realistic variance factors for individual observing session and not only to an approximate level of variance over 8 sessions.

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