Markus Vennebusch et al.: IVS' Contribution to the IERS Combination Pilot Project and to the ITRF2005 - Status & Results, IVS 2006 General Meeting Proceedings, p.31–35
http://ivscc.gsfc.nasa.gov/publications/gm2006/vennebusch1

IVS' Contribution to the IERS Combination Pilot Project and to the ITRF2005 - Status & Results

Markus Vennebusch, Sarah Böckmann

Geodetic Institute of the University of Bonn

Contact author: Markus Vennebusch, e-mail: vennebusch@uni-bonn.de

Abstract

The VLBI group of the Geodetic Institute of the University of Bonn (GIUB), Germany combined the individual solutions of almost 3600 VLBI sessions on the level of datum free normal equation matrices. These combined sessions form an important basis for the new ITRF2005 and for the new combination strategy within the IERS Combination Pilot Project for the combination of all geodetic space techniques (VLBI, GPS, SLR and DORIS). In this paper the status and some results of this so-called VLBI intra-technique combination will be presented to show the quality of VLBI SINEX data. The results contain comparisons of EOP series derived from IVS SINEX data as well as Helmert parameters of the combined solutions with respect to ITRF2000.

1. IVS' Activities in the Combination Pilot Project

Since about 2002 large efforts have been made by the IVS Analysis Centers in order to contribute their solutions to the IERS CPP.

Most of the software packages used for routine data analysis have been modified to generate SINEX files containing datum-free normal equation matrices. Since CALC/SOLVE and OCCAM (LSM) perform the least squares adjustment by using normal equations, these software packages generate datum-free normal equations in its pure form as it should be provided to the IERS CPP by every technique. Special attention should be paid to SteelBreeze (developed at MAO, Main Astronomical Observatory, Kiev), a software based on Square Root Information Filter technique (SRIF) which is also able to generate SINEX files containing datum-free normal equation matrices.

Currently there are seven IVS Analysis Centers using four different software packages contributing their solutions to the VLBI-intra-technique-combination and to the IERS CPP. Table 1 shows the analysis centers and the software used for regular data analysis.

AC	Name	Software
AUS	Geoscience Australia, Canberra, Australia	OCCAM (Kalman)
BKG	Bundesamt für Kartographie und Geodäsie, Leipzig, Germany	CALC/SOLVE
DGFI	Deutsches Geodätisches Forschungsinstitut, Munich, Germany	OCCAM (LSM)
GSFC	Goddard Space Flight Center, Washington D.C., USA	CALC/SOLVE
MAO	Main Astronomical Observatory, Kiev, Ukraine	SteelBreeze
SHA	Shanghai Astronomical Observatory, China	CALC/SOLVE
USNO	U.S. Naval Observatory, Washington D.C., USA	CALC/SOLVE

Table 1. IVS analysis centers contributing to the CPP

The analysis centers mentioned in Table 1 reprocessed almost all available VLBI data in order to generate SINEX files. About 4100 VLBI sessions (starting in 1979 till 2005) have been analysed by (at most) seven analysis centers. A daily updated website, available at

http://vlbi.geod.uni-bonn.de/sinex_combination/SINEX_statistics.html

lists all sessions available and shows the current status of file submissions to the IVS Data Centers.

2. VLBI – Intra-technique Combination

For the VLBI-intra-technique combination a software called *dogs-cs* (developed at the German Geodetic Research Institute (DGFI), Munich) as well as PERL-scripts (developed at GIUB) are used to combine up to seven individual solutions to an official IVS solution for the IVS CPP.

The VLBI-intra-technique combination consists of the following steps:

2.1. Download of Individual Normal Equations (SINEX Files)

Up to seven SINEX files containing datum-free normal equation matrices of the individual contributions are being downloaded from one of the IVS Data Centers. This process is done automatically at GIUB. As soon as there are enough (usually four to five) individual contributions of a single VLBI session the combination process is started.

2.2. Conversion of SINEX Data into dogs-cs Format

A conversion tool called *snx2dogs* has been developed at GIUB in order to convert all data necessary for the combination into special binary format for *dogs-cs*. If necessary, another tool (from DGFI) generates datum-free normal equation matrices from covariance matrices (contained e.g. in AUS solutions).

2.3. Computation of EOP from the Individual Solutions

The next step consists of the reconstruction of the individual solutions after transformation to the same set of apriori values and to the same reference epoch. After reducing nutation parameters and imposing the same datum definition (usually by fixing all station positions) earth orientation parameters and their rates are estimated and are compared to the combined solution in a later step. These residuals are used to detect outlier solutions which will be excluded from the combination.

The steps are as follows:

- Since every IVS Analysis Center uses different sets of apriori values, the individual normal equations have to be transformed to a common set of apriori values for TRF and EOP. Usually the apriori values of the first contributing normal equations are used as the common set of apriori values.
- The epochs of the results of the individual contributions of one VLBI session may differ by up to 15 minutes. This is caused by the fact that the reference epoch of the parameters is computed as the weighted mean of the epochs of the delay observables. Excluding observations or even entire stations might lead to different mean epochs which have to be accounted for in the combination. This transformation is performed by a *dogs-cs* subroutine.

- Reduction of nutation parameters is necessary because of different nutation models used in the different software packages. Therefore the normal equation system and the vector of unknowns is being partitioned such that only the parameters of interest remain (see e.g. ANGERMANN ET AL., [3]).
- The datum definition is usually performed by fixing all station positions. This step is only necessary for outlier detection, it does not have any impact on the accumulation of datum-free normal equations described below.

2.4. Scaling of the Individual Normal Equation Matrices

In order to equalize the impact of the individual contributions **in the inter-technique combination** it is necessary to scale every matrix by the factor "1 / *number of contributions for the particular session* = 1 / *number of analysis centers used in the combination*".

2.5. Weighting of the Individual Normal Equation Matrices

In order to account for the different qualities of the individual contributions, some kind of quality criterium must be found. Using the statistical information from the SINEX file (as e.g. WEIGHTED SQUARE SUM OF O-C) the residuals of the individual solutions concerning the combined solution can be computed (see e.g. ANGERMANN ET AL., [3]) and can be used to estimate variance components (see e.g. KOCH, [1]). The reciprocal variance factors are then used as weights for the following step of accumulation.

This step is still under development. Investigations of different methods for variance component estimation are currently being carried out.

2.6. Accumulation and Combination

This part forms the actual combination step of the datum-free normal equation matrices. Based on the accumulation theorem for pre-reduced normal equation matrices (see e.g. MIKHAIL, [2]) the normal equations are added by a *dogs-cs* subroutine.

2.7. Imposing Datum Definition and Inversion of the Combined Normal Equation Matrix

Using the same datum definition as for the individual contributions for the accumulated normal equations, combined EOP and their rates are being estimated.

2.8. Analysis of Individual EOP and Their Rates w.r.t. Combined EOP (Residuals)

As a first quality check the EOP results of the individual contributions are being compared with the combined results. If the residuals exceed a certain threshold (usually $2 \cdot \sigma_{Combination}$) the solution containing the outlier will be excluded and the combination will be repeated without this particular solution.

2.9. Determination of Helmert Parameters w.r.t. to ITRF2000

In the next step an NNT/NNR condition is imposed on the combined datum-free normal equation matrix in order to generate an (undeformed) TRF solution. Then Helmert parameters of the resulting coordinates w.r.t. ITRF2000 are computed in order to check the quality of the polyhedron formed by the combined solution and to detect outlier stations or other station anomalies.

2.10. Generation of SINEX File Containing Accumulated Normal Equations

If there are no station anomalies, the accumulated datum-free normal equation matrix is being written into a new SINEX file containing all station components, polar motion, dUT as well as their rates.

2.11. Submission of Combined Normal Equations

At last, the combined SINEX file is send to one of the IVS Data Centers where it is automatically downloaded to the IERS CPP data center.

3. Current Investigations

Using the strategy described above, more than 3600 VLBI sessions have been combined sessionwise on the level of datum-free normal equation matrices (the remaining 500 sessions are either too small for reasonable parameter estimation or they were designed for special purposes and are therefore not suitable for the combination). Each combined session can be used as contribution to the IERS CPP as well as for internal VLBI investigations. The results of the internal investigations (e.g. determination of EOP or site positions) are also being used as quality checks and validation of the contributions to the IERS CPP.

3.1. Earth Orientation Parameters

VLBI SINEX data containing data of sessions from 1979 to 2005 have been used to generate EOP series. In order to obtain EOP usually all station positions have been fixed to their a priori positions and only EOP and their rates have been estimated.

EOP series resulting from this method have been compared to EOP series generated from other techniques (e.g. GPS, SLR, etc.) as well as to IERS C04.

3.2. Station Components

Each individual VLBI session can also be used to estimate site positions of each station participating in the particular session. Using all available data from 1984 till now, time series of site positions can be generated and can be compared to time series derived by other techniques.

A comparison of time series of the coordinates of about 40 VLBI stations with co-located GPS stations shows a good agreement in the particular trends. This shows the suitability of VLBI data for the ITRF2005.

3.3. Helmert Parameters

Another quality check is the computation of Helmert parameters for the individual combined solutions with respect to ITRF2000. The agreement of the combined site positions with the ITRF (in terms of scale and residuals) shows the quality of the individual VLBI polyhedron and its suitability for the ITRF2005 combination.

4. Outlook and Future Tasks

The generation of consistent VLBI time series of EOP and station coordinates requires independency from a single VLBI software package alone. Only the combination of the results of different VLBI software packages can produce a reliable basis for a further combination with other space geodetic techniques.

In addition, the VLBI-Intra-technique combined products not only serve as contribution to the inter-technique combination, but these time series can also be used as an independent validation of the inter-technique solution as well as for further VLBI investigations.

The VLBI time series generated in form of pre-reduced normal equation matrices show the capability of VLBI SINEX data as a promising contribution to the ITRF2005. So far, both the comparisons with station components of GPS and the Helmert parameters show good agreement. The final results will be presented in another paper soon.

Nevertheless, the following problems or tasks still have to be solved:

- Transformation of the reference epoch towards 12 UTC
- Introducing correlations between different analysis centers
- Transformation of nutation parameters based on different nutation models into one common set for a uniform modelling of the movement of the rotation axis in space.
- Investigations for a consistent estimation of atmosphere parameters at fixed epochs taking into account horizontal gradients.

References

[1] Koch, Karl-Rudolf: *Parameter Estimation and Hypothesis Testing in Linear Models*, Springer, New York, 1999.

[2] Mikhail, E., F. Ackermann: *Observations and Least Squares*, IEP, New York, 1976.

[3] Angermann et al.: *ITRS Combination Center at DGFI: A Terrestrial Reference Frame Realization*, Deutsche Geodätische Kommission, München, 2004.