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First Results of SINEX Combinations

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Abstract

Up to now combinations of VLBI sessions have been performed on the level of results, i.e. different analysis centers generate series of earth orientation parameters and compute terrestrial reference frames. These series are collected and combined by computing weighted means. This kind of combination is done routinely and the results are official IVS products. A new approach uses datum-free normal equation matrices of VLBI sessions which are provided as SINEX files. Using this kind of strategy a common reference frame is introduced. The lack of a common reference frame has been the likely reason for offsets in current EOP series. Within this paper first results of EOP combinations will be presented.

1. Purpose of SINEX Combination

A new approach of combining all the advantages of the different geodetic space techniques is the IERS Combination Pilot Project. In order to provide a unique VLBI solution to this combination project the Bonn VLBI group is developing ways to combine different solutions of VLBI sessions computed by different Analysis Centers.

2. Current Method of Combining VLBI Sessions

Combination of VLBI sessions can be performed by at least two different methods. On the one hand sessions can be combined on the level of results i.e. analysis centers create time series and send them to a combination center where the different solutions are combined by computing weighted means. On the other hand different VLBI sessions can be combined at an earlier step of analysis i.e. on the level of normal equation matrices.

Advantages of the first approach are the capability of an easy outlier detection and error estimation. This is a widely accepted and established approach which the official combined EOP time series provided by the IVS is based on. However, using this way of combination offsets of up to 300 microarcseconds for the pole coordinates and 7 microseconds for dUT1 were detected (Steinforth, personal communication). It is assumed that a possible cause of these offsets may be seen in the underlying TRFs.

3. New Approach of Combining VLBI Sessions

A new approach of combining VLBI solutions is based on the principle of addition of normal equation matrices and thus begins in an earlier step of analysis. This approach is also known as "Adjustment of groups of observations" (see Strang, Borre, 1997, Mikhail 1976) and reads as follows:

$$\sum_{i=1}^{n}(A_i' P_i A_i)\hat{x} \;=\; \sum_{i=1}^{n} A_i' P_i y_i \qquad (n = \text{nr. of ACs})$$

with
- A_i Jacobian matrix of solution of the ith analysis center
- P_i matrix of weights of solution of the ith analysis center
- y_i vectors of observations of solution of the ith analysis center
- $\hat{x}$ common vector of unknowns

An advantage of this approach is that all relations/correlations between parameters are correctly considered. Since this approach can only be used when all data is based on the same apriori values a transformation of the individual normal equation matrices to common apriori values must be performed. This approach can be used to analyse the aforementioned offsets in the EOP time series. The advantages of this method are costly in a way that much more data (i.e. entire normal equation matrices, right hand sides of normal equation matrices, weighted square sum of observations, number of observations etc.) is needed and the actual process of combination is quite sophisticated.

In order to be able to perform this alternative way of combination various data of single sessions have to be provided. As an appropriate data format the IERS recommends SINEX V 2.0 (=Solution Independent Exchange format). These standardised files contain information about the type of session, about apriori values, the (decomposed) normal equation matrix and its right hand side, information about constraints and further statistical information.

So far only the CALC/SOLVE software is able to create SINEX files which contain decomposed normal matrices (see Ma, Petrov 2003).

4. Datum Free (Singular) Normal Equation Matrices

The process of combination is divided into the addition of normal equation matrices and the definition of the geodetic datum: in the first step so-called datum free or singular normal equation matrices are added. These matrices are created by estimating coordinate components of all participating stations, all earth orientation parameters and their rates as well as nutation parameters. Since datum free normal equation matrices are singular they can not be inverted and therefore no solution can be computed without defining a geodetic datum.

The geodetic datum can be defined by imposing constraints which is analogous to adding a "constraint matrix" or it can be defined by simply eliminating a specific number of unknowns.

5. Software

The new approach of SINEX combination is performed by using two different kinds of softwares. On the one hand there is an already established composition of scripts for adding normal equations, eliminating unknowns, inverting matrices and other tasks concerning the combination on the basis of normal equation matrices. This software package is called DOGS-CS (abbreviation for DGFI Orbit- und Geodätische Parameterbestimmungs-Software - Combination & Solution) which has been developed by the German Geodetic Research Institute (DGFI), Munich (see e.g. IERS Annual Report 2002).

On the other hand a second software called combine_sinex is used which consists of different FORTRAN programs and PERL scripts in order to control DOGS-CS. The module combine_sinex

performs quality checks of the (singular) normal equation matrices like verification of rank deficiency and apriori values and transforms all input normal equation matrices to equal epochs.

6. Results

At present only those Analysis Centers which use CALC/SOLVE can create SINEX V 2.0 files regularly, so data from only three analysis centers (BKG, GSFC and USNO) can be used for the new combination approach. So far GSFC and BKG have already produced SINEX files of previous sessions and are creating them regularly. Several selected SINEX files from USNO were used for test purposes so that soon USNO will also create this type of files regularly.

So far combine_sinex only combines different solutions of equal sessions. As it can be seen in the left part of figure 1 a reasonable result can be obtained by fixing all coordinate components. Then differences between the estimated parameters are normally below 0.1 mas for the pole coordinates and below 2 microsec for dUT1. The standard deviation of the combined pole coordinates of single sessions is usually less than 0.1 mas and about 2.0 microsec for dUT1. These results are quite similar to the results of the routine analyses.

On the right hand side of figure 1 the impact of fixing different numbers of station coordinate components can be seen. There, only a minimum number of station components has been fixed which results in much larger standard deviations of the single solutions. In these cases the combination process obviously fails.

Both results have been obtained by transforming each solution to apriori values of the BKG solution and by transforming them to equal epochs.

7. Outlook

- For a regular combination of VLBI sessions in future a regular generation of SINEX files by all IVS Analysis Centers is required. Therefore not only the CALC/SOLVE software should be able to create SINEX files.
- General investigations of all VLBI sessions can be performed when all Analysis Centers have processed their databases again for the creation of SINEX files for all sessions since 1980.
- In order to provide a unique VLBI solution to the IERS Combination Pilot Project the combined solution has to be provided again as a SINEX file. Therefore the output of the combined solution in SINEX format has to be accomplished.
- Since this approach neglects correlations between solutions of different Analysis Centers (of essentially the same data) the standard deviations of the results might be too optimistic.

References

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[3] Strang, Borre, Linear Algebra, Geodesy and GPS, Wellesley-Cambridge Press, 1997

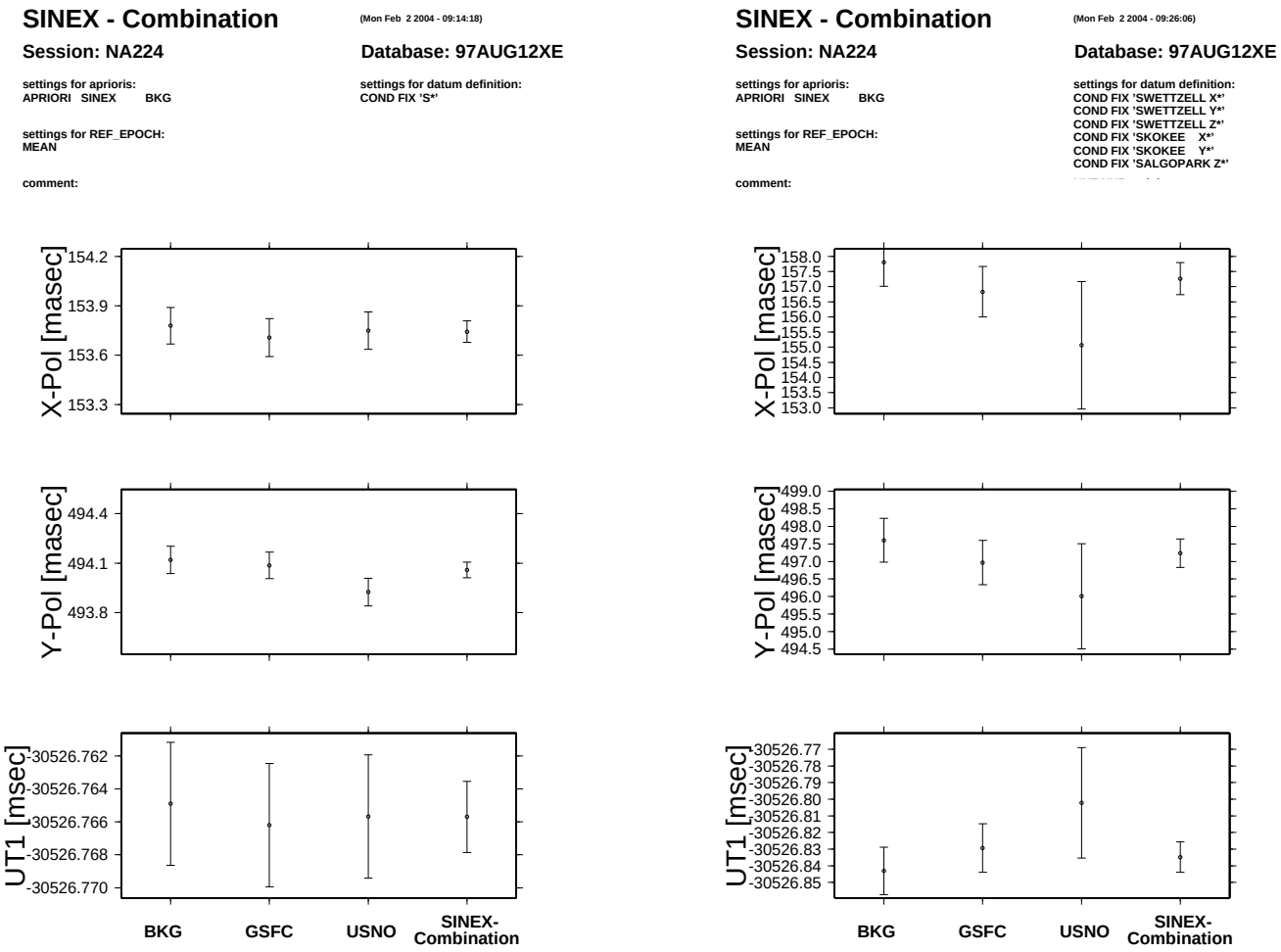

Figure 1. Example for combine_sinex results.