FIRST RESULTS OF S/X AND X/KA-BAND CATALOGUE COMBINATIONS WITH FULL COVARIANCE INFORMATION

A. IDDINK[1], C. JACOBS[2], T. ARTZ[1], A. NOTHNAGEL[1]
[1] Institute of Geodesy and Geoinformation, University of Bonn
Nußallee 17, 53115 Bonn, Germany
e-mail: aiddink@uni-bonn.de, artz@igg.uni-bonn.de, nothnagel@uni-bonn.de
[2] Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr., Pasadena, CA 91109, USA
e-mail: Christopher.S.Jacobs@jpl.nasa.gov

ABSTRACT. The currently existing realizations of the International Celestial Reference System (ICRS), the ICRF1 and ICRF2, are based on solutions estimated by a single VLBI group. All sessions used were dual frequency S/X-band (2.3/8.4 GHz) VLBI sessions. In addition to an improved precision one of the main goals for the upcoming realization of the ICRF3 is an enhanced frequency coverage compared to the ICRF2. By including solutions with full variance-covariance information based on X/Ka-band (8.4/32 GHz) observations in a rigorous VLBI intra-technique combination, an improved frequency coverage can be realized. In this paper, we present a method to mix the combination on the level of datum free normal equation systems (NEQ) and on the solution level with full covariance information. We show preliminary results of a combined S/X- and X/Ka-band catalogue and discuss the prerequisites and the limitations of this approach.

1. INTRODUCTION

The last two versions of the International Celestial Reference Frame (ICRF) had been generated by the VLBI group at the NASA Goddard Space Flight Center (GSFC) with the software package Calc/Solve. Despite the fact that several other catalogues of different analysis centers existed, only comparisons between these solutions had been made (Fey et al. 2009). The primary reason for this procedure was the missing machinery which permits a rigorous combination of radio source position catalogues including a full propagation of the variance-covariance information. To overcome this deficit in the upcoming generation of the ICRF3, a combination procedure for celestial reference frame determinations has been proposed in Iddink et al. (2014a, 2014b). The developed procedure is based on the combination at the level of datum-free normal equations (NEQs), which enables the rigorous transfer of the full variance-covariance information of all parameters and all individual input contributions. In general, these contributions are based on dual frequency S/X-band (2.3/8.4 GHz) sessions, which are being analysed and provided by different analysis centers. Up to now over 5000 sessions were observed and analysed by each of the contributing analysis centers and all information is freely available on the server of the International VLBI Service (IVS) on a session by session basis. The delivery and exchange of these analysis results is performed with the Solution Independent Exchange Format (SINEX).

In addition to this, today a remarkable number of observations at X/Ka-band (8.4/32 GHz) exists, mainly observed on the intercontinental baselines of NASA's Deep Space Network (DSN). The results of these observations are presently realized in a single X/Ka-band catalogue and consist of 631 X/Ka sources (Jacobs et al. 2012). Compared to S/X-band catalogues, X/Ka-band permits access to more compact radio sources. It is important to highlight, that the provided X/Ka contribution is composed of a monolithic X/Ka-band solution vector plus the corresponding full variance-covariance matrix. This contrasts with the S/X-band contributions which are based on session-wise datum-free NEQs. Hence, in order to fulfill the main objectives of the upcoming realization of the ICRF3 (Jacobs et al. 2014), to get an improved frequency coverage and a combined product of multiple VLBI contributions, a suitable methodology and software to combine these different types of contributions need to be focused on.

2. COMBINATION APPROACH

Motivated by the need for a combined multi-frequency CRF, the underlying combination mechanism needs to be structured and divided into several sections. In order to guarantee that the contributions of the combination are not distorted by any constraints before combining them, the combination itself is performed at the level of datum-free NEQs.

In case of the given X/Ka-band solution with full variance-covariance information, the complete datum definition on Earth and in space is already fixed. While the terrestrial reference frame (TRF) is constrained to results from previous solutions, the CRF is aligned to the ICRF2. This is done by an NNR condition based on the positions of a number of selected sources. Hence, in order to be able to include the X/Ka-band solution in the common combination procedure, the datum-free NEQ needs to be reconstructed using information about the applied constraints, illustrated in Fig. 1. The provided X/Ka-band contribution consists of a solution vector x, containing only the source position parameters, and the corresponding full variance-covariance matrix Q_{xx}. All the other system components like the TRF and EOPs have been already removed in previous analysis steps and are not available in the provided dataset. As a consequence, only the applied NNR condition in the context of the CRF can be removed to obtain the datum-free X/Ka-band NEQ system.

It is essential to know, which sources and which weights were used for the applied NNR condition. Based on this information, the constraint matrix C can be generated and subtracted from the inverted full covariance matrix Q_{xx}^{-1}. Assuming that all information about the applied NNR constraints is given entirely, a fully datum-free NEQ should be obtained. Due to remaining datum-defining impacts like troposphere and the tidal effects which are sensitive to absolute orientation of the catalogue, the resulting NEQ N_{free} is not strictly rank 3 deficient. For our first initial combination approach in context of a multi-frequency band CRF, we neglect this less than ideal situation.

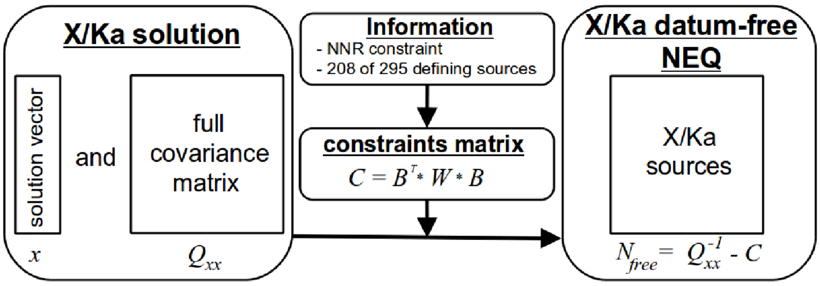

Figure 1: Reconstruction of datum-free NEQ based on given X/Ka-band solution.

In contrast to the monolithic X/Ka-band solution, the S/X-band contribution relies on several thousand datum-free single session NEQs. Based on these NEQs, we are able to generate one monolithic datum-free NEQ, containing all CRF, Earth orientation parameters (EOPs) and TRF components with respect to S/X-band observing sessions, as shown in Fig. 2. Due to the fact that the X/Ka-band contribution only contains the CRF component, only the sources can be used to link the contributions to each other within the combination. Fortunately, a significant number of sources in the X/Ka-band catalogue corresponds to those of S/X-band. These sources can be used as link sources for the datum transfer. Applying an NNR condition to a number of selected linking sources, automatically aligns the remaining non-corresponding sources to eachother and defines their positions. Consequently this leads to a combined S/X and X/Ka catalogue. It needs to be mentioned that combining source positions of different observing frequencies may lead to systematic effects and should not be performed with every possible link source. Hence, in upcoming studies it needs to be investigated if different emitting cores, respectively core shifts, need to be considered in the CRF combination. Due to the physics of quasars a parameterization of some kind of source tie might become indispensable when trying to combine source position parameters of different frequency bands.

Furthermore, even if the TRF component would be existent in the provided X/Ka-band dataset, no direct combination of the station coordinates would be possible. This is due to the fact that the observing sites are completely different to the ones which are used in the regular IVS S/X-band observing sessions. Because we focus on the multi-frequency combination mechanism, we currently simplify the combination by using S/X-band analysis results provided by only one analysis centers (GSFC).

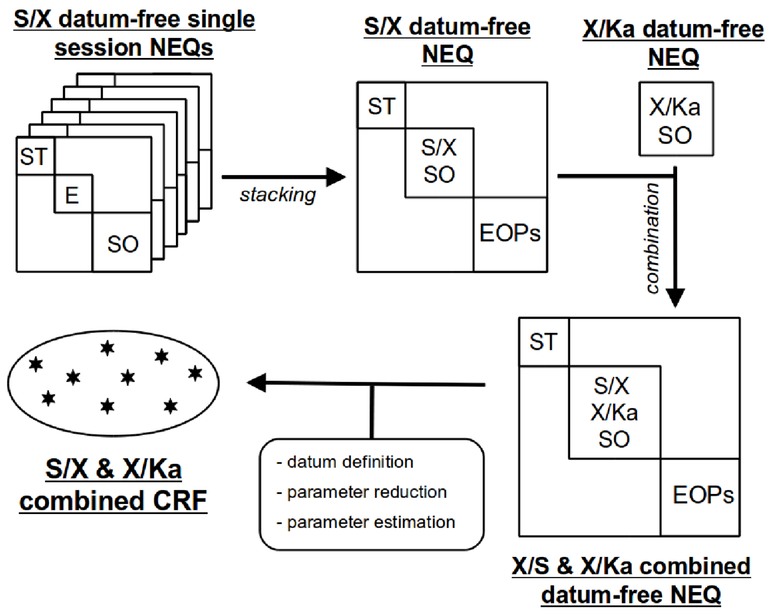

Figure 2: General combination approach after reconstruction at the level of datum-free NEQs for a multi-frequency band CRF. ST = station coordinates, E/EOPs = Earth orientation parameters, SO = source positions.

3. RESULTS AND OUTLOOK

In a first step, a datum-free monolithic NEQ system based on daily sessions data from GSFC was generated. About 4000 single SINEX files were used and stacked together. The resulting monolithic NEQ system contained 1682 global source positions including all 295 ICRF2 defining sources. The small number of sources is owed to the fact that only sources with at least 3 good observations in each session were set up. Furthermore, to facilitate our intial combination investigations, the special handling sources had been parameterized as global parameters as well. In a next step the properties of the reconstructed monolithic X/Ka-band NEQ was analysed. The contribution is composed of 631 sources including 208 of 295 defining sources. Consequently, all 208 defining sources can be used as link sources. All in all, 443 of the 631 X/Ka-band sources are existent in the generated S/X-band contribution and can be used as link sources. Approximately 65% of the 188 sources which are only existing in the X/Ka-band contribution are located in the southern celestial hemisphere. For our initial combination results we fixed the S/X-band station coordinates and applied an NNR condition to all 208 linking defining sources. Finally we obtained a combined S/X and X/Ka catalogue with 1870 sources and calculated the residuals by subtracting the combined catalogue minus the original X/Ka catalogue. In Fig. 3 the residuals of the 208 linking defining sources are illustrated. The results should only demonstrate the proper function of our initial multi-frequency CRF combination. The variations of the residuals match the expectations with no significant systematics recognizable except for the far southern sources. Here we can see some slightly bigger residuals pointing in similar directions.

Summarizing, a combination approach for a S/X and X/Ka dual frequency CRF generation has been presented in this paper. The underlying combination mechanism and the most important steps have been described and illustrated. Based on the gained achievements further investigations need to be focused on. For example, the non-ITRF observing sites, the core shift and the parameterization of special handling sources as arc parameters need to be looked at.

4. REFERENCES

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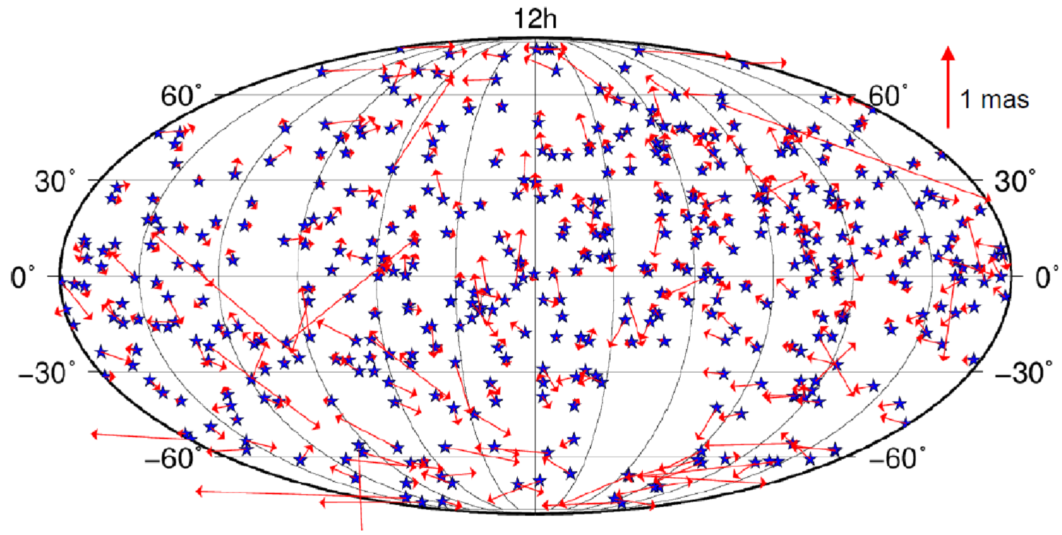

Figure 3: Initial results of a combined S/X and X/Ka catalogue. Residuals of the combined catalogue minus the original X/Ka catalogue of all linking defining sources.

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