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Integrating Analysis Goals for EOP, CRF and TRF

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Abstract

In a simplified, idealized way the TRF can be considered a set of positions at epoch and corresponding linear rates of change while the CRF is a set of fixed directions in space. VLBI analysis can be optimized for CRF and TRF separately while handling some of the complexity of geodetic and astrometric reality. For EOP time series both CRF and TRF should be accurate at the epoch of interest and well defined over time. The optimal integration of EOP, TRF and CRF in a single VLBI solution configuration requires a detailed consideration of the data set and the possibly conflicting nature of the reference frames. A possible approach for an integrated analysis is described.

1. Introduction

VLBI has features that give it unique capability in the area of fundamental reference frames and Earth orientation. These are summarized in Table 1.

Table 1. Features of VLBI

Sensitivity to all Earth orientation parameters: x-pole, y-pole, UT1, $\Delta\varepsilon$, $\Delta\psi$
Direct access to a quasi-inertial reference frame
Direct access to the terrestrial reference frame
Direct tie between celestial and terrestrial frames

In contrast, satellite space geodesy techniques lack direct access to a quasi-inertial reference frame and rely on VLBI measurements to make this connection. Routine generation of VLBI results for EOP and TRF implicitly assumes that the VLBI frames and EOP are derived from the same analysis. However for historical reasons and to achieve different optimization goals the analysis strategies for CRF, TRF, and EOP have been different in practice. In particular, the analysis strategy for the ICRF dispenses with the TRF. Consequently the various results are incompatible at some level. As even better accuracy and consistency are desired for scientific and operational uses the need for an integrated analysis optimized as well as possible for all these types of results has grown. The paper first describes ideal frames and data. Some problems of real data and possible analysis treatments are highlighted. Finally one possible strategy for an integrated analysis is given.

2. Ideal Frames and Data

The ideal TRF and CRF conditions along with the VLBI data required are summarized in parallel in Table 2.

Table 2. Ideal Frames

TRF	CRF
set of positions and linear velocities	set of positions
all stations rigidly connected by overlapping networks	all sources rigidly connected by overlapping source sets
sufficient time and data for velocity estimates	
all stations permanent	all sources permanent
even distribution of data over stations and time	even distribution of data over sources and time
even distribution over globe	even distribution over sky

From such data it would be straightforward to estimate a TRF from which a position and error for each station could be calculated at any past or future time. Since an ideal source has an unchanging position, its error would be constant in time. As new data were included in the analysis, the station positions at the reference epoch and the velocities would change only according to their statistical errors, and the statistical errors would decrease. A similar situation would apply for the CRF and EOP. Even with ideal VLBI data and station/source behavior, however, the real errors would need to take into account the imperfections of the geophysical modeling and of the estimation of non-TRF/CRF/EOP parameters, notably the troposphere and short-term station motions.

3. Some Real Data Conditions and Possible Analysis Options

Of course none of the actual stations and sources behaves exactly ideally, and the VLBI data set fails to meet the ideal conditions except for the rigid connection of sources. These shortcomings arise for historical and practical reasons. There has been a slow and continuing evolution of instrumentation, and the earlier data were limited by sensitivity, particularly in the choice of sources. The list of stations and sources used for the EOP monitoring programs, the dominant type of observing in terms of session count, is only a small part of the complete list of stations and sources. Stations and sources have been used and discontinued, some after only a few appearances but others after years. The quality of observing schedules has improved with experience and instrumentation. Certain conditions cannot be easily changed: the paucity of stations in the Southern Hemisphere and the number of stations that can be routinely correlated at the facilities supporting the geodetic observing programs. The deployment of TIGO in Chile will ameliorate the first problem in the near future, and the use of the VLBA correlator allows some large networks to be used occasionally.

Some non-ideal conditions affecting TRF, CRF and EOP results are listed in Table **??** along with ways to extract some useful information or to prevent undesirable distortion of the particular parameters.

Table 3. Real data and analysis options

	condition	**analysis**
TRF	nonlinear station motion	piecewise-linear continuous position parameters
	“loose” station	a priori EOP for session(s)
	short time span	a priori velocity error from model
	episodic motion	tie of velocity before and after event
CRF	unstable source	arc position parameters
	position drift	proper motion parameters
EOP	single baseline network	a priori EOP errors
	small network	exclude from time series after generation
	distorted CRF at epoch	arc position parameters
	distorted TRF at epoch	piecewise-linear continuous position parameters

A “loose” station is one that has only been observed with networks that do not overlap sufficiently with the rigidly connected stations. This situation occurs when the loose station’s networks do not have at least three, well-spaced stations in common with the set of rigidly connected stations. Some mobile VLBI stations (because of poor network design) and parts of the Japanese domestic network (because of incompatible equipment) fall into this category. A priori EOP information must be used to orient the poorly connected sessions. Episodic motion can be caused by seismic events or by major antenna repairs that move the VLBI reference point.

A data weakness for EOP time series is that some older sessions have only one baseline observing, so polar motion and UT1 cannot be separated. Values for these three parameters can be estimated if large a priori EOP errors are included, and the two orthogonal axes with real information can be obtained from the EOP covariance matrix. Another situation is that the networks for a few sessions are very small to provide relative positions of antennas at one or nearby sites. These sessions are valuable for the TRF but cannot generate useful EOP or source position results. A more pernicious situation is that for a particular session a station or source may not be located at the position projected from the TRF and CRF. The estimated EOP values will be affected at some level by using incorrect geometry.

What to do in any particular case is a matter of judgment or could be decided on the basis of objective criteria.

4. A Possible Approach for Integrated Analysis

Table 4 shows a set of goals for the reference frames to be determined by an integrated solution and one important condition for each area. These conditions, and other reasonable choices, can conflict when optimizing an analysis for a single area. For example, using all the available data to maximize time span for TRF velocities would include data on non-ideal sources, which would affect the CRF. If only the sessions of the EOP observing programs were used, both the TRF and CRF would be very sparse since only a small portion of the total number of stations and sources

Table 4. Reference Frame Goals and Conditions

TRF	**CRF**	**EOP**
maximum number of site positions and velocities	highest accuracy for positions of best sources	accurate TRF/CRF at observing epoch
long time span for precise velocities	minimal effects from network geometry and unstable sources	subset of TRF/CRF used at each epoch

is used, in each session and in aggregate, in the EOP sessions.

Table 5 lists the steps in one possible strategy for an integrated analysis.

Table 5. Steps for an Integrated Analysis

1. Identify non-ideal stations and sources.
2. In a TRF-optimized solution, estimate TRF positions and velocities for ideal stations, treating non-ideal stations and sources as arc parameters.
3. In a CRF-optimized solution, estimate CRF positions for ideal sources, treating non-ideal sources as arc parameters.
4. Compute average positions and velocities of non-ideal stations from time series.
5. Compute average positions of non-ideal sources from time series.
6. Using the information from steps 2, 3, 4, and 5 examine each session to determine which station(s) and/or source(s) are not at their correct position at that epoch and flag these as arc parameters.
7. In a single solution, estimate TRF positions and velocities for all stations, CRF positions for all sources, and for each session five EOP values and the arc parameters found in step 6.
8. Discard EOP time series points derived from small networks.

The identification of non-ideal stations and sources in step 1 could be done from preliminary time series of station and source positions. The criteria for classifying as ideal or non-ideal would be developed from the actual range of behavior. In step 3, the station positions would be arc parameters. Steps 2 and 3 would generate time series for steps 4 and 5, respectively, and the process might be iterated. For all solutions the geophysical modeling and the estimation of non-TRF/CRF/EOP parameters would be identical, and the entire VLBI data set would be used. In step 6 the threshold for a station or source to be classified as "out of position" and therefore requiring arc parameters would be related to the criteria used in step 1. Step 8 recognizes the fact that some sessions have minuscule networks that are important for the TRF in locating nearby stations but provide no useful information for EOP.

The rationale for this type of approach is that data contribute to the TRF and CRF when the conditions of linear motion and constant source position are met. For ideal stations and sources, all their data would be included. For non-ideal stations and sources, only data agreeing with their average velocity and position would contribute to the TRF and CRF, and the statistical errors would reflect only these points. For each session the subset of the TRF and CRF observed would be undistorted since the stations and sources with non-ideal behavior during that day would be treated as arc parameters. EOP values are thus determined from only the well-behaved elements of the TRF and CRF. Since no data points are eliminated, each observation can still provide information for non-TRF/CRF/EOP parameters. This approach is only suggestive, and the implementation of step 6 would be difficult.

5. Conclusion

To reach the full potential of VLBI in integrating CRF, EOP, and TRF the non-ideal nature of the sources and stations must be considered as well as limitations imposed by the heterogeneous nature of the VLBI data set. While one analysis strategy is described, others are conceivable. The choice of optimal strategy will depend on comparison of actual studies and the emphasis given to various desired outcomes.