

3.6.3 Jet Propulsion Laboratory (JPL)

The activities during 2013 of the ITRS Combination Centre at JPL are summarized here. They consisted mainly in continuing to develop a Kalman filter for realizing terrestrial reference frames and in using the Three-Corner Hat technique to estimate the uncertainties in the observed positions of co-located space-geodetic stations.

KALREF

JPL is developing an approach based on using a Kalman filter to realize terrestrial reference frames (TRFs) from time series of observed VLBI, SLR, GNSS, and DORIS station positions and associated Earth orientation parameters (EOPs) and site ties. This KALman filter for REference frames (KALREF) has been used to produce a number of ITRF2005-like and ITRF2008-like reference frames using updated ITRF2005 and ITRF2008 SINEX files. Comparisons show that these frames agree with ITRF2005 and ITRF2008 at the sub-millimeter and sub-millimeter per year level.

Kalman filters are commonly used for estimating parameters of some system when a stochastic model of the system is available and when the data contain noise. For the purpose of determining a terrestrial reference frame, the system consists of the time-dependent positions and velocities of geodetic observing stations along with their full covariance matrices. The data consist of time series of observed VLBI, SLR, GNSS, and DORIS station positions along with the data measurement covariance matrices, EOPs and site ties.

KALREF includes options for constraining the stations to move linearly or to move linearly and annually. Through the use of stochastic models for the process noise, the station positions can be constrained to exactly follow this linear or linear and annual motion (by setting the process noise to zero), to exactly recover the observed station positions (by setting the process noise to a large value), or to follow a smoothed path (by setting the process noise to some intermediate value).

KALREF has been used to determine four different ITRF2008-like reference frames using three different stochastic models for the process noise: no process noise with linear motion constraint, no process noise with linear plus annual motion constraint, process noise variances based on surface geophysical fluid loading models, and large values of the process noise to exactly recover the observed station positions. Figure 1 shows the comparison of the linear frame and the linear part of the linear and annual frame to ITRF2008. As can be seen, JPL's frames agree quite well with ITRF2008, with differences in translation (T) and rotation (R) being at most 0.7 mm. The difference in scale (D) is larger because the KALREF scale is a weighted average of the SLR and VLBI scales

Transformation Parameters from Secular Combination (ITRF2008) to Weekly Combination (KALREF) Using ITRF2008 Input Data

All Data with No Annual Components

Tx (mm)	Ty (mm)	Tz (mm)	D (mm)	Rx (mm)	Ry (mm)	Rz (mm)
0.1 ± 0.2	-0.3 ± 0.2	0.7 ± 0.2	2.6 ± 0.6	0.2 ± 0.1	0.5 ± 0.1	-0.1 ± 0.1
Vx (mm/yr)	Vy (mm/yr)	Vz (mm/yr)	\dot{D} (mm/yr)	\dot{R}_x (mm/yr)	\dot{R}_y (mm/yr)	\dot{R}_z (mm/yr)
0.02 ± 0.03	-0.1 ± 0.03	0.1 ± 0.04	0.08 ± 0.1	0.0 ± 0.02	0.2 ± 0.01	-0.2 ± 0.02

All Data with Annual Components

Tx (mm)	Ty (mm)	Tz (mm)	D (mm)	Rx (mm)	Ry (mm)	Rz (mm)
-0.1 ± 0.2	-0.2 ± 0.2	0.3 ± 0.2	2.8 ± 0.6	0.2 ± 0.1	0.5 ± 0.1	0.0 ± 0.1
Vx (mm/yr)	Vy (mm/yr)	Vz (mm/yr)	\dot{D} (mm/yr)	\dot{R}_x (mm/yr)	\dot{R}_y (mm/yr)	\dot{R}_z (mm/yr)
0.01 ± 0.03	-0.04 ± 0.03	0.1 ± 0.04	0.07 ± 0.1	0.0 ± 0.02	0.2 ± 0.01	-0.2 ± 0.02

Fig. 1: Comparison to ITRF2008 of JPL's ITRF2008-like frames wherein the stations are constrained to move linearly (top) or to move linearly and annually (bottom).

whereas the ITRF2008 scale is a simple average of the SLR and VLBI scales. Differences in translation rate, rotation rate and scale rate are all quite small, being at most 0.2 mm/yr.

Station Position Uncertainties

The formal uncertainties of station position estimates are oftentimes overly optimistic and do not reflect the true uncertainties of the estimates. The formal uncertainties must therefore be adjusted to obtain more realistic values for the uncertainties. There are many ways of doing this including the analysis of post-fit residuals. At JPL we have explored the possibility of using the Three-Corner Hat technique to estimate the uncertainties of observations of station positions for space-geodetic stations that are co-located with each other.

The Three-Corner Hat technique allows the uncertainty of measurements to be estimated when at least three independent measurements of the same signal are available. If each measurement is modeled as the sum of a common signal and a remaining "noise" term, then forming pair-wise differences of the measurements eliminates the common signal, leaving pair-wise differences of the "noise" terms. Forming a covariance matrix of the differenced "noise" series results in an underdetermined set

of equations for the variances and covariances of the “noise”. Assuming the “noise” terms are uncorrelated with each other reduces the set of unknowns to just the variances, which can be exactly solved if three measurements are available. If more than three independent measurements are available, then the set of equations are overdetermined and can be solved by least-squares.

The Three-Corner Hat technique has been applied to measurements of the positions of GNSS, SLR, VLBI, and DORIS stations that are co-located with each other at the same site. Since the stations are co-located, they should exhibit the same geophysical motion. Pair-wise differences of the station position measurements will eliminate this common geophysical motion, leaving pair-wise differences of the uncommon, or “noise”, terms. This approach was applied to the stations at 16 co-located sites that were used when determining ITRF2008. It was found that GPS, although affected by time-correlated errors, is the most precise of the space-geodetic techniques, with median north, east, and height uncertainties of 1.1, 1.2, and 2.8 mm, respectively. The median uncertainties of the VLBI north, east, and height components were found to be 2.2, 2.0, and 6.2 mm, respectively. And the (SLR, DORIS) median north, east, and height uncertainties were found to be (8.5, 9.2), (7.6, 11.7), and (9.0, 10.6) mm, respectively.

References

- Abbondanza, C., Z. Altamimi, T. M. Chin, R. S. Gross, M. B. Heflin, J. W. Parker and X. Wu, Three-Corner Hat for the assessment of the uncertainty of non linear residuals of space-geodetic time series in the context of terrestrial reference frame analysis, *J. Geodesy*, in press, 2014.
- Wu, X., C. Abbondanza, Z. Altamimi, T. M. Chin, X. Collilieux, R. S. Gross, M. B. Heflin, Y. Jiang, and J. W. Parker, KALREF – A Kalman filter and time series approach to the International Terrestrial Reference Frame realization, *J. Geophys. Res.*, submitted, 2014.

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