IGS contribution to the ITRF

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Abstract We examine the contribution of the International GNSS Service (IGS) to the International Terrestrial Reference Frame (ITRF) by evaluating the quality of the incorporated solutions as well as their major role in the ITRF formation. Starting with the ITRF2005, the ITRF is constructed with input data in the form of time series of station positions (weekly for satellite techniques and daily for VLBI) and daily Earth Orientation Parameters. Analysis of time series of station positions is a fundamental first step in the ITRF elaboration, allowing to assess not only the stations behavior, but also the frame parameters and in particular the physical ones, namely the origin and the scale. As it will be seen, given the poor number and distribution of SLR and VLBI co-location sites, the IGS GPS network plays a major role by connecting these two techniques together, given their relevance for the definition of the origin and the scale of the ITRF. Time series analysis of the IGS weekly combined and other individual Analysis Center solutions indicates an internal precision (or repeatability) <2 mm in the horizontal component and <5 mm in the vertical component. Analysis of three AC weekly solutions shows generally poor agreement in origin and scale, with some indication of better agreement when the IGS started to use the absolute model of antenna phase center variations after the GPS week 1400 (November 2006).

Keywords Reference systems · Reference frames · ITRF · GPS · Earth rotation · IGS

1 Introduction

Station positions derived from observations of the Global Positioning System (GPS) were first included in the formation of the International Terrestrial Reference Frame (ITRF) in 1992, starting with the ITRF91 (Boucher et al. 1992). The International GNSS Service (IGS), formerly the International GPS Service, is a voluntary federation of more than 200 worldwide agencies aiming at providing the highest quality of GPS and GLONASS products, mainly precise orbits, clock corrections, station positions and Earth rotation parameters. In parallel, all the IGS products are expressed directly or indirectly in the ITRF frames. At the inception of its activities, the IGS used directly the ITRF frames to be the underlying frame of its products (Kouba 1995, 1998, 2003). Following the methodology of Kouba et al. (1998), the IGS started in 2000 to form its own, internally more consistent GPS-only frame, but still inheriting the ITRF datum in terms of origin, scale and orientation and their rates of change (Ferland 2004). A more detailed history of IGS reference frame realizations can be found in Ray (2004); Ray et al. (2004). Starting with GPS week 1400, the IGS has switched from relative to absolute model corrections to account for antenna phase center variations (PCV). In the same time, the IGS has adopted the ITRF2005 (Altamimi et al. 2007) to form its specific frame called IGS05, composed of about 100 sites whose ITRF2005 coordinates were corrected to account for relative to absolute PCV differences. In order to preserve the ITRF2005 datum (origin, scale and orientation) the IGS05 was aligned to the ITRF2005 using a 14-parameter similarity transformation (Ferland 2006). In reality, among the 14 parameters, only the scale factor was significant, representing the mean height difference of IGS05 station positions estimated with relative and absolute PCVs.
Since almost 10 years, initiated first by the IGS, analysis centers of three other IERS techniques (VLBI, SLR, DORIS) started to make available time series of station positions and Earth Orientation Parameters (EOPs) provided in SINEX format. The power of time series of station positions, allowing to control not only the station behavior and in particular to monitor non-linear motion, but also the frame physical parameters (origin and scale) led the ITRF Product Center to consider them as input for the ITRF generation, starting with the ITRF2005. In addition to station positions and velocities, ITRF2005 integrates also consistent daily EOPs. The latter was already used by the IERS EOP Product center in order to improve the consistency of the IERS operational series of EOPs with the ITRF (Altamimi et al. 2008). The ITRF input time series solutions are provided on a weekly basis by the IAG International Services of satellite techniques: the IGS, (Dow et al. 2005), the International Laser Ranging Service (ILRS), (Pearlman et al. 2002) and the International DORIS Service (IDS), (Tavernier et al. 2005), and in a daily (VLBI session-wise) basis by the International VLBI Service (IVS), (Schlueter et al. 2002). Each per-technique time series is already a combination of the individual Analysis Center solutions of that technique.

2 Current procedure for ITRF construction

In order to give the reader the necessary information regarding the current procedure adopted for the ITRF formation, we recall here that this procedure involves two steps: (1) stacking the individual time series to estimate a long-term solution per technique comprising station positions at a reference epoch and velocities and daily EOPs; and (2) combining the resulting long-term solutions of the four techniques together with the local ties at co-location sites. In addition, the combination model incorporates station positions and EOPs using the following two sets of equations, involving the 14-parameter similarity transformation:

\[
\begin{align*}
X_i^c &= X_i^c + (t_i^c - t_0^c)\dot{X}_c^c + T_k + D_kX_i^c + R_kX_i^c \\
\dot{X}_i^c &= \dot{X}_i^c + \dot{T}_k + \dot{D}_kX_i^c + \dot{R}_kX_i^c
\end{align*}
\]

where for each point \(i\), \(X_i^c\) (at epoch \(t_i^c\)) and \(\dot{X}_i^c\) are positions and velocities of technique solution \(s\) and \(X_i^c\) (at epoch \(t_0^c\)) and \(\dot{X}_i^c\) are those of the combined solution \(c\). For each individual frame \(k\), as implicitly defined by solution \(s\), \(D_k\) is the scale factor, \(T_k\) the translation vector and \(R_k\) rotation matrix. The dotted parameters designate their derivatives with respect to time. The translation vector \(T_k\) is composed of three origin components, namely \(T1\), \(T2\), \(T3\), and the rotation matrix of three small rotation parameters: \(R1\), \(R2\), \(R3\), according to the three axes, respectively \(X\), \(Y\), \(Z\). \(t_k\) is a conventionally selected epoch of the seven transformation parameters, which is, in case of time series stacking, the epoch of the week.

In addition to Eq. 1 involving station positions (and velocities), the EOPs are added by the following equations, making use of pole coordinates \(x_p^s\), \(y_p^s\) and universal time \(UT_c\) as well as their daily rates \(\dot{x}_p^s\), \(\dot{y}_p^s\) and LODs:

\[
\begin{align*}
x_i^p &= x_i^p + R2_k \\
y_i^p &= y_i^p + R1_k \\
UT_s &= UT_c - \frac{1}{f}R3_k \\
\dot{x}_i^p &= \dot{x}_i^p + \dot{R}2_k \\
\dot{y}_i^p &= \dot{y}_i^p + \dot{R}1_k \\
\dot{LOD}_s &= \text{LOD}_c + \frac{\Delta\theta}{f^2}\dot{R}3_k
\end{align*}
\]

where \(f = 1.002737909350795\) is the conversion factor from UT into sidereal time. The last line of Eq. 2 is derived from the relation between LOD and UT, that is \(LOD_c = \int_{t_0}^{t+\Lambda_0}dUT\). Given the assumption that \(\frac{dUT}{dt}\) is constant in the interval \([t, t + \Lambda_0]\), then \(LOD_c = -\Lambda_0\frac{dUT}{dt}\). \(\Lambda_0\) is homogeneous to time difference, so that \(\Lambda_0 = 1\) day in time unit.

Note that the link between EOP and the Terrestrial Reference Frame (TRF) is ensured upon the three rotation angles \(R1\), \(R2\), \(R3\), and their time derivatives \(\dot{R}1\), \(\dot{R}2\), \(\dot{R}3\). Therefore, the EOP values follow faithfully the defined combined frame.

The combination consists of estimating:

- Positions \(X_i^c\) at a given epoch \(t_0\) and velocities \(\dot{X}_i^c\) in the combined frame \(c\).
- Transformation parameters \((T_k, D_k\) and \(R_k)\) at an epoch \(t_k\) and their rates \((\dot{T}_k, \dot{D}_k, \dot{R}_k)\), from the combined frame to each individual frame \(k\).
- Daily EOPs.

The normal equation system constructed upon the above combination model is singular and has a rank deficiency of 14 corresponding to the number of the parameters that are necessary to define the combined frame in origin, scale and orientation. There are several ways to add additional constraints to define the combined frame, two of which are based on minimum conditions involving the 14 degrees of freedom (and not more): the classical method of minimum constraints (Sillard and Boucher 2001; Altamimi et al. 2002a, 2004) and a method imposing internal conditions in case of time series stacking (Altamimi et al. 2007).