3 ITRF2014 data analysis

The general strategy adopted for the ITRF formation involves two-step procedure and described in [Altamimi et al., 2002, 2007, 2011]: (1) stacking the individual time series to estimate a long-term solution per technique comprising station positions at a reference epoch, station 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.

For the first time in the International Terrestrial Reference Frame (ITRF) history, the ITRF2014 is generated with an enhanced modeling of non-linear station motions, including seasonal (annual and semi-annual) signals of station positions and Post-Seismic deformation (PSD) for sites that were subject to major earthquakes.

The seasonal signals were modeled using a sinusoidal function as described below, while the PSDs were accounted for, before the stacking, by applying parametric models that were first fitted to IGS daily station position time series.

3.1 Combination model

The CATREF combination model used for the ITRF combination is extensively described in previous publications, e.g. [Altamimi et al., 2002], [Altamimi et al., 2007]. For the ITRF2014 generation, we followed the same analysis strategy used for the ITRF2008 combination, but enhanced by modeling the nonlinear station motions.

The main two equations of the combination model are given below for completeness. They involve a 14-parameter similarity transformation, station positions and velocities and EOPs and are written as:

$$\begin{cases} X_s^i &= X_c^i + (t_s^i - t_0)\dot{X}_c^i \\ &+ T_k + D_k X_c^i + R_k X_c^i \\ &+ (t_s^i - t_k)\left[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i\right] \\ \\ \dot{X}_s^i &= \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{cases} \tag{3}$$

$$\begin{cases} x_s^p & = & x_c^p + R2_k \\ y_s^p & = & y_c^p + R1_k \\ UT_s & = & UT_c - \frac{1}{f} R3_k \\ \dot{x}_s^p & = & \dot{x}_c^p \\ \dot{y}_s^p & = & \dot{y}_c^p \\ LOD_s & = & LOD_c \end{cases} \tag{4}$$

where for each point i, X_s^i (at epoch t_s^i) and $\dot{X}_s^i$ are positions and velocities of technique solution s and X_c^i (at epoch t_0) and $\dot{X}_c^i$ 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 the rotation matrix. The dotted parameters designate their derivatives with respect to time. The translation vector T_k is composed of three origin components, namely T_x, T_y, T_z, and the rotation matrix of three small rotation angles: R_x, R_y, R_z, following the three axes, respectively X, Y, Z. t_k is a conventionally selected epoch of the 7 transformation parameters. In addition to Eq. (3) involving station positions (and velocities), the EOPs are added by Eq. (4), making use of pole coordinates x_s^p, y_s^p and universal time UT_s as well as their daily rates $\dot{x}_s^p$, $\dot{y}_s^p$ and LOD_s. The link between the combined frame and the EOPs is ensured via the three rotation parameters appearing in the first three lines of Eq. (4).

The first line of Equation (3) and the entire equation (4) are used to estimate long-term solutions for each technique, by accumulating (rigorously stacking) the individual technique time series of station positions and EOPs. In this process, the second line of equation (3) and the rates of the translation, scale and rotation parameters are not included, because station velocities are not available at the weekly (daily) basis. Moreover, a precise definition of the reference frame associated with the resulting long-term solution (comprising station positions at a reference epoch, station velocities and EOPs) has to be clearly specified. As transformation parameters are estimated between each weekly (or session-wise) frame and the long-term frame, it becomes necessary to define the long-term frame origin, scale, orientation and their time evolution, and therefore to complete the rank deficiency of the constructed normal equation. It is essential that the long-term solutions be representative of the mean origin and mean scale information of the space geodesy techniques. The particular type of minimal constraints introduced in Altamimi et al. [2007] have been designed for such pur-

pose and are consequently used here to preserve the long-term solution origin (for SLR and DORIS) and scale (for VLBI, SLR and DORIS).

In addition to station positions and EOPs, described by equations 3 and 4, the combination model includes also the periodic terms modeled as a sinusoidal function. The general equation used for the estimation of the periodic signals embedded in the time series of station positions is written as:

$$\Delta X_f = \sum_{i=1}^{n_f} \mathbf{a}^i \cos(\omega_i t) + \mathbf{b}^i \sin(\omega_i t) \tag{5}$$

where ΔX_f is the total sum of the contributions of all the frequencies considered, n_f is the number of frequencies, $\omega_i = \frac{2\pi}{\tau_i}$, where τ_i is the period of the i^{th} frequency, e.g. annual, semi-annual, etc.

Each frequency adds six parameters per station, i.e $(a_x^i, a_y^i, a_z^i, b_x^i, b_y^i, b_z^i)^T$, in addition to the six position and velocity parameters.

For more details, the reader may refer to the full ITRF2014 article [Altamimi et al., 2016] appended to this technical note.

3.2 ITRF2014 frame definition

The second step of the ITRF2014 analysis consists in combining the long-term solutions of the four technique solutions together with local ties at co-location sites. The ITRF2014 is specified by the following frame parameters:

1. Origin: The ITRF2014 origin is defined in such a way that there are zero translation parameters at epoch 2010.0 and zero translation rates with respect to the mean origin of the ILRS SLR time series;
2. Scale: The scale of the ITRF2014 is defined in such a way that there is zero scale factor at epoch 2010.0 and zero scale rate with respect to the average of the implicit scales and scale rates of VLBI and SLR time series.
3. Orientation: The ITRF2014 orientation is defined in such a way that there are zero rotation parameters at epoch 2010.0 and zero rotation rates between ITRF2014 and ITRF2008. These two conditions were applied over a set of 127 reference stations located at 125 sites as illustrated by Figure 2.

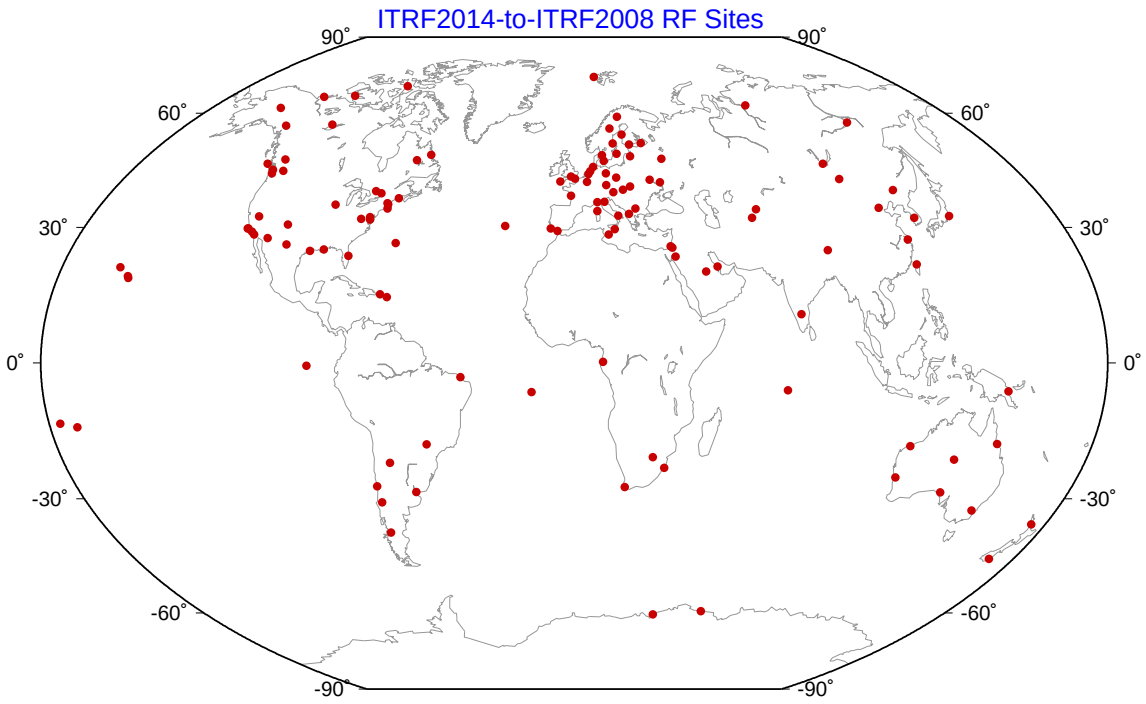

Fig. 2: Location of the reference frame sites used in the estimation of the 14 transformation parameters between ITRF2014 and ITRF2008 and their orientation alignment