2 ITRF2014 input data

As for any ITRF solution, the ITRF2014 relies not only on space geodesy solutions (stations positions time series and EOPs), but also on local ties at co-location sites. In the following two sub-sections we describe the two sets of data used in the ITRF2014 construction.

2.1 Space geodesy solutions

We recall that the ITRF input time series solutions are provided on a daily basis for GNSS, session-wise for VLBI, weekly for DORIS and fortnightly and weekly for SLR, by the International Association of Geodesy (IAG) International Services of satellite techniques: International GNSS Service (IGS), International Laser Ranging Service (ILRS), and International DORIS Service (IDS) and on a daily (VLBI session-wise) basis by the International VLBI Service (IVS). Each per-technique time series is already a combination of the individual Analysis Center (AC) solutions of that technique. A typical solution includes notably the positions of a network of stations, EOPs as well as the associated variance-covariance matrix. Table 1 summarizes the submitted solutions by the IAG services, specifying the time span, solution type and the constraints applied by the TCs as well as the estimated Earth Orientation Parameters (EOPs).

The VLBI contribution to the ITRF2014 involves 5789 session-wise solutions [Bachmann et al., 2016], [Nothnagel et al., 2015], with 407 sessions involving 2 stations only which were discarded from the ITRF2014 processing since they are not designed for the TRF determination. The majority (86%) of the VLBI sessions includes a small number of stations, ranging between 3 to 9. 391 sessions involve 10-19 stations, 8 sessions with 20 stations, while two sessions exceptionally include 21 and 32 stations, respectively (see Appendix 6).

The ILRS solution comprises 244 fortnightly solutions, with polar motion and Length of Day (LOD) estimated each three days for the period 1983.0-1993.0, using LAGEOS I satellite data, and 1147 weekly solutions with daily polar motion and LOD estimates afterwards, using data acquired on LAGEOS I and II and ETALON I and II satellites [Luceri and Pavlis, 2016], (see Appendix 5).

The IGS submitted time series comprise 7714 daily solutions, resulting from the second reprocessed campaign, and cover the time period 1994.0 - 2015.1 [Rebischung et al., 2016]. Two IGS Analysis Centers have used available and exploitable GLONASS data in addition to GPS, namely Center for Orbit Determination in Europe (CODE) and European Space Operations Center (ESA). The starting dates of GLONASS ob-

Table 1: Summary of Submitted Solutions to ITRF2014

TC	Data-Span	Sampling	Solution Type	Constraints	EOPs
IVS	1980.0 – 2015.0	Daily	Normal Eq.	None	PM, PMr, LOD[α], UT1–UTC
ILRS	1983.0 – 1993.0	Fortnightly	Var-Cov	Loose	PM, LOD
	1993.0 – 2015.0	Weekly	Var-Cov	Loose	PM, LOD
IGS	1994.0 – 2015.1	Daily	Var-Cov	Minimum	PM, PMr, LOD
IDS	1993.0 – 2015.0	Weekly	Var-Cov	Minimum	PM

[α]PM: Polar Motion, PMr: Polar Motion rate, LOD: Length of Day

servations are 2002 for CODE and 2009 for ESA when the constellation became almost complete (see Appendix 4).

The DORIS contribution is a combined time series involving six ACs, using data from all available satellites with onboard DORIS receiver, and comprises 1140 weekly solutions, spanning the period 1993. – 2015.0 [Moreaux et al., 2016] (see Appendix 3).

More detailed descriptions of the submitted solutions are available in the appendix of this technical note.

Figure 1 illustrates the full ITRF2014 network, comprising 1499 stations located in 975 sites, where about 10% of them are co-located with 2, 3, or 4 distinct space geodetic instruments. Over the entire ITRF2014 observation history, we used local ties available for 91 co-location sites with two or more technique instruments which were or are currently operating. The GNSS network is playing a major role connecting the three other techniques, since 33 SLR, 40 VLBI and 46 DORIS stations were or are currently co-located with GNSS.

2.2 Local ties in co-location sites

The ITRF combination fundamentally depends on the availability of co-location sites where (1) two or more geodetic instruments of different techniques are operated and (2) local surveys between instrument measuring points are available. Local surveys are usually conducted using terrestrial measurements (direction angles, distances, and spirit leveling) or the GPS technique. Least Squares adjustments of local surveys are performed by national agencies operating ITRF co-location sites to provide differential coordinates (local ties) connecting the instrument reference points.

The local ties (mainly old ones) which are not available in SINEX format were converted into a complete set of positions for each site, provided in SINEX format. This has been achieved by solving for the following system of observation equations (1):

$$\begin{pmatrix} \Delta x_s^{i,j} \\ \Delta y_s^{i,j} \\ \Delta z_s^{i,j} \end{pmatrix} = \begin{pmatrix} x^j - x^i \\ y^j - y^i \\ z^j - z^i \end{pmatrix} \quad (1)$$

Where ($\Delta x_s^{i,j}$, $\Delta y_s^{i,j}$, $\Delta z_s^{i,j}$) are the geocentric components of the tie vector linking two points i and j, of a given data set s. The standard deviations (SD) ($\sigma\Delta x_s^{i,j}$, $\sigma\Delta y_s^{i,j}$, $\sigma\Delta z_s^{i,j}$) for each local tie vector are used to compute a diagonal variance matrix. If these SD are not available, they are computed by :

$$\sigma_{computed} = \sqrt{\sigma_1^2 + \sigma_2^2} \quad (2)$$

where,

σ_1 = 3 mm and $\sigma_2 = 10^{-6} \times \sqrt{(\Delta x_s^{i,j})^2 + (\Delta y_s^{i,j})^2 + (\Delta z_s^{i,j})^2}$

The equation system (1) needs of course initial coordinates for one point per tie vector set s, which are taken from existing ITRF solutions with 1 meter as standard deviation.

In addition to the local ties used in the ITRF2008 computation, a certain number of local ties used in the ITRF2014 computations are new, either resulting from new co-location sites, or from new surveys. 36 new surveys were conducted since the release of ITRF2008 and their determined local tie SINEX files, together with the old ones, were used in the ITRF2014 computation. In total, 139 local tie SINEX files were used in the ITRF2014, versus 104 for ITRF2008. Over the entire ITRF2014 observation history, we used local ties available for 91 co-location sites with two or more technique instruments which were or are currently operating.

The agencies that provided new local tie SINEX files are: Geoscience Australia, Istituto Nazionale di Astrofisica, Bologna, Italy, USA National Geodetic Survey, Onsala Space Observatory, Sweden, Geodetic Observatory Wettzell/Bundesamts für Kartographie und Geodäsie, Germany, Geographical Survey Institute (GSI), Japan. All the DORIS co-location

sites were re-adjusted by the IGN survey department in order to generate full SINEX files, including the most recent surveys operated at these sites. All the local tie SINEX files used in the ITRF2014 combination are available at http://itrf.ign.fr/local_surveys.php.

Similar to past ITRF solutions, the local ties used in the ITRF2014 combination are provided in SINEX (Solution INdependent EXchange) format with known measurement epochs (with the exception of a few old ties), and 80% of them are available with full variance-covariance information.

Counting the number of co-locations between VLBI, SLR and DORIS, taken by pairs, we find 11 VLBI-SLR, 12 VLBI-DORIS and 11 SLR-DORIS. These are very small numbers of co-locations to allow a reliable combination of these three techniques alone. Therefore, the GNSS network is playing a major role in the ITRF combination, by linking together the three other techniques. We count in total 212 tie vectors between GNSS and the three other technique reference points: 62 for VLBI, 50 for SLR and 67 for DORIS. Additional 14 ties were also used between old and current DORIS beacon reference points in DORIS-only sites.