III.ITRF2008 Results

III.1. ITRF2008 origin and scale

The submitted ILRS SLR solution was used to define the ITRF2008 origin, by fixing to zero (and consequently eliminating from the normal equation) the 6 parameters (translations and rates) of its corresponding long-term cumulative solution. An estimate of the translation components from ITRF2008 to ITRF2005 indicates differences at epoch 2005.0, namely: -0.5, -0.9 and -4.7 mm along X, Y and Z-axis, respectively. The translation rate differences are zero for Y and Z, while we observe an X-translation rate of 0.3 mm/yr (see III.3).

The ITRF2008 scale is specified by the average of VLBI and SLR scales, i.e. ITRF2008 scale is defined to be in the middle of the scales of VLBI and SLR long-term solutions. As results from the final ITRF2008 combination we found that the scale and scale rate differences between VLBI and SLR solutions are 1.05 ($\pm$0.13) ppb at epoch 2005.0 and 0.049 ($\pm$0.010) ppb/yr, respectively. This indicates an improvement compared to the past ITRF2005 results. This improvement is particularly due to the reprocessing effort of both IVS and ILRS. In addition, for some SLR co-located stations, we introduced offsets in the station position time series to account for significant discontinuities (but constraining the velocities to be equal) which improved the agreement of the estimated vertical velocities with GPS and consequently the scale rate agreement with VLBI. Propagating the scale discrepancy between SLR and VLBI at the start and end epochs of the time-span of VLBI data, leads to a maximum discrepancy of 1.2 ppb (8 mm at the equator), which could be considered as the level of the scale accuracy achievable today. Therefore defining the ITRF2008 scale to be in the middle of both technique solutions is the most appropriate choice that minimizes the scale impact for these two techniques when using the ITRF2008 products.

III.2. ITRF2008 adjusted parameters

The ITRF2008 adjusted parameters are:

- Station positions at epoch 2005.0 and velocities. These values are split into four tables corresponding to the four techniques: VLBI, SLR, GPS and DORIS. They are also provided in SINEX files with full variance covariance information. All the corresponding files are available through the ITRF2008 web and ftp sites. See next Chapter for access to these files.

- Transformation parameters between the individual technique solutions and ITRF2008. Note that the parameters defining the ITRF2008 origin, scale and orientation are eliminated from the normal equation.

- Earth orientation parameters. Consistent series of polar motion and its daily rates, universal time (UT1-UTC) and Length of Day (LOD), with the latter being determined by VLBI uniquely. The reason for using LOD values from VLBI only is to avoid contaminating the VLBI estimates by biased determinations from satellite techniques. The EOP series are also available through the ITRF2008 web and ftp sites (see below).

III.3. Transformation Parameters Between ITRF2008 and ITRF2005

For many applications and in order to ensure the link between ITRF2008 and ITRF2005, it is essential to assess consistently the transformation parameters between the two frames. The same 179 stations that were used to ensure the alignment of the ITRF2008 orientation and its rate to the ITRF2005, were also used to estimate the transformation parameters between the two frames. The main criteria for selection of these 179 stations are (1) to have the best possible site distribution; (2) to involve as many as possible VLBI, SLR, GPS and DORIS stations and (3) to have the best agreement between the two frames in terms of post-fit residuals of the 14-parameter transformation. Regarding this third criteria, the WRMS values of the 14-parameter similarity transformation fit are 2.4, 2.9 and 3.9 mm in position (at epoch 2005.0) and 0.4, 0.4, 0.7 mm/yr in velocity, in east, north and vertical components, respectively. Table 4 lists the transformation parameters from ITRF2008 to ITRF2005, to be used with the transformation formula given by equation (III.1).

$$\left\{\begin{array}{l} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i05} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i08} + T + D \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i08} + R \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i08} \\ \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix}_{i05} = \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix}_{i08} + \dot{T} + \dot{D} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i08} + \dot{R} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{i08} \end{array}\right. \quad \text{(III.1)}$$

where $i05$ designates ITRF2005 and $i08$ ITRF2008, T is the translation vector, $T = (T_x, T_y, T_z)^T$, D is the scale factor and R is the matrix containing the rotation angles, given by

$$R = \begin{pmatrix} 0 & -R_z & R_y \\ R_z & 0 & -R_x \\ -R_y & R_x & 0 \end{pmatrix}$$

The dotted parameters designate their time derivatives. The values of the 14 parameters are those listed in Table 4. Note that the inverse transformation from ITRF2005 to ITRF2008 follows by interchanging (i08) with (i05) and changing the sign of the transformation parameters.

Table 4. Transformation Parameters at epoch 2005.0 and their rates from ITRF2008 to ITRF2005, to be used with equation (III.1)

	Tx	Ty	Tz	D	Rx	Ry	Rz
	mm	mm	mm	ppb	mas	mas	mas
	$\dot{T}x$	$\dot{T}y$	$\dot{T}z$	$\dot{D}$	$\dot{R}x$	$\dot{R}y$	$\dot{R}z$
	mm/y	mm/y	mm/y	ppb/y	mas/y	mas/y	mas/y
	-0.5	-0.9	-4.7	0.94	0.00	0.00	0.00
±	0.2	0.2	0.2	0.03	0.08	0.08	0.08
	0.3	0.0	0.0	0.00	0.00	0.00	0.00
±	0.2	0.2	0.2	0.03	0.08	0.08	0.08

III.4. Consistency between local ties and space geodesy estimates

One of the most important by-products of the ITRF2008 combination is the assessment of the level of agreement between local ties and space geodesy estimates, through the availability of the post-fit residuals at co-location sites. In case of large discrepancies, discriminating between local ties and space geodesy estimates is a very delicate exercise, because the reasons for these discrepancies could be due to errors in local ties, in space geodesy estimates or in both. However quantifying the level of agreement between the two ensembles is very critical for further investigation and hopefully for identifying the error sources. At co-location sites, not only station position residuals are computed, but also velocity residuals. Therefore in order to take into account velocity disagreements between the technique solutions, it is more effective to compute the tie discrepancies at their measurement epochs. In order to identify the most performing co-location sites, we list in Table 2 the tie vectors where the discrepancies are less than 6 mm (corresponding to the level of scale consistency between VLBI and SLR solutions) in all three components: North, East and Up. As the GPS is playing the major role of connecting the three techniques together, the vectors listed in Table 2 are from GPS to other technique reference markers. With some exceptions, the geodetic instruments at the co-location sites listed in this table are still in operation in 2010. If we count the percentage of these sites listed in Table 2 over the total currently operating co-locations, we find approximately: 47%, 43% and 34% for GPS-VLBI, GPS-SLR and GPS-DORIS, respectively. However, using this sub-set of local ties only, would result in a non-optimal combination. Indeed a test combination was performed involving these co-location sites only yielded an increase of the uncertainties of the estimated parameters by a factor of 3.4, compared to the results of the ITRF2008 combination. In particular the obtained scale factor between VLBI and SLR would be 0.83 ppb, but with an increase of its uncertainty: ± 0.44 versus ± 0.13 ppb. In addition, we found the following percentages of co-location sites where tie discrepancies are larger than 10 mm: 29%, 28% and 54% for GPS-VLBI, GPS-SLR and GPS-DORIS, respectively. Rejecting these co-location sites from the ITRF2008 combination increases the uncertainties of the estimated parameters by a factor of 2. Table 3 summarizes the tie discrepancy percentages following three categories: less than 6 mm, between 6 and 10 mm and larger than 10 mm.

The full list of discrepancies between ITRF2008 local tie and space geodesy estimates, as results from the ITRF2008 global adjustment is available in the appendix.

Table 2. ITRF2008 tie discrepancies less than 6 mm at tie epochs in (E)ast, (N)orth and (U)p : Residuals = Space Geodesy - Terrestrial Tie (in mm). The tie vectors are listed from GPS to other technique reference markers.

CODE DOMES #	CODE DOMES #	East	North	Up	Epoch	Technique
GRAS 10002M006	7835 10002S001	1.3	-3.6	-5.6	99:284	SLR
GRAS 10002M006	7845 10002S002	-1.1	-1.2	-0.6	99:284	SLR
TLSE 10003M009	TLSA 10003S001	-1.2	0.7	2.3	4: 34	DORIS
NYA1 10317M003	SPIB 10317S004	-1.2	5.7	2.2	3:228	DORIS
NYA1 10317M003	SPJB 10317S005	-1.9	-0.8	-0.9	3:228	DORIS
NYA1 10317M003	7331 10317S003	2.9	-2.7	1.2	3:228	VLBI
ONSA 10402M004	7213 10402S002	5.4	-0.6	-5.2	2:193	VLBI
GRAZ 11001M002	7839 11001S002	1.4	-0.6	-5.9	92:319	SLR
BOR1 12205M002	7811 12205S001	0.5	1.7	-2.9	94: 10	SLR
YSSK 12329M003	SAKA 12329S001	-0.4	-2.3	-2.9	4:231	DORIS
YSSK 12329M003	SAKB 12329S002	2.3	-5.0	-2.3	4:231	DORIS
MATE 12734M008	7941 12734S008	-3.7	-4.7	-1.6	4:300	SLR
HERS 13212M007	7840 13212S001	-1.2	-3.1	-2.4	8:177	SLR
ZIMM 14001M004	7810 14001S007	-1.9	-2.2	-5.2	96: 95	SLR
WTZZ 14201M014	7224 14201S004	-1.4	-4.1	-0.3	2:266	VLBI
BJFS 21601M001	7249 21601S004	0.6	2.2	5.9	3:171	SLR
TSKB 21730S005	7345 21730S007	-2.9	-0.8	-3.0	8: 16	VLBI
HRAO 30302M004	7232 30302S001	-1.6	3.2	2.0	3:214	VLBI
HRAO 30302M004	7501 30302M003	-2.2	2.6	3.5	3:214	SLR
HRAO 30302M004	HBKB 30302S006	5.4	-1.0	-4.2	3:214	DORIS
NKLG 32809M002	LIBB 32809S003	2.9	0.2	2.7	99: 36	DORIS
STJO 40101M001	7625 40101M003	0.3	0.1	1.6	99:269	VLBI
YELL 40127M003	7285 40127M001	-3.9	-3.9	-1.0	1:285	VLBI
PIE1 40456M001	7234 40456S001	-3.1	-2.8	-0.3	92:336	VLBI
NLIB 40465M001	7612 40465S001	-3.4	-2.0	-5.2	93: 64	VLBI
MKEA 40477M001	7617 40477S001	-3.7	-1.1	0.8	96:221	VLBI
MONP 40497M004	MONB 40497S008	3.1	-4.7	-0.8	5:335	DORIS
MONP 40497M004	7110 40497M001	3.2	-2.5	5.7	99:280	SLR
FORT 41602M001	7297 41602S001	-0.6	-4.0	2.3	93:264	VLBI
GLPS 42005M002	SCRB 42005S001	-2.8	-1.0	-1.1	5: 92	DORIS
CRO1 43201M001	7615 43201S001	-1.5	2.2	1.6	94: 16	VLBI
HOB2 50116M004	7242 50116S002	4.7	-3.0	-2.0	2: 81	VLBI
STR1 50119M002	7849 50119S001	4.1	0.1	4.0	1:209	SLR
CHAT 50207M001	CHAB 50207S001	0.1	0.6	-3.3	99: 56	DORIS
SYOG 66006S002	7342 66006S004	0.8	3.8	0.6	0: 1	VLBI
KERG 91201M002	KERB 91201S003	-3.2	-2.2	2.0	7:101	DORIS
DUM1 91501M001	ADEB 91501S002	-0.2	-0.2	1.3	8: 39	DORIS
DUM1 91501M001	ADFB 91501S003	-5.0	-3.0	3.3	8: 39	DORIS
THTI 92201M009	PAPB 92201S007	-1.3	1.7	4.4	7:278	DORIS
NOUM 92701M003	NOUB 92701S002	0.5	5.8	2.2	5:236	DORIS
REUN 97401M003	REUB 97401S002	0.4	2.5	-1.0	3:335	DORIS

Table 3. Tie discrepancy percentage

Discrepancy	GPS-VLBI	GPS-SLR	GPS-DORIS
$<$ 6 mm	47	43	34
6-10 mm	24	29	12
$>$ 10 mm	29	28	54