The ILRS contribution to ITRF2008

E. Pavlis (GEST/UMBC & NASA Goddard)
V. Luceri (e-GEOS S.p.A., ASI/CGS)
C. Sciarretta (e-GEOS S.p.A., ASI/CGS)
R. Kelm (DGFI/München)

The ILRS contribution to ITRF2008 is a time series of weekly station coordinates and daily Earth Orientation Parameters (X-pole, Y-pole and excess Length-Of-Day (LOD)) estimated over 7-day arcs (15-day arcs for the period 1983-1992) aligned with calendar weeks (Sunday to Saturday), starting from January 1983. Each weekly solution is obtained through the combination of weekly solutions submitted by the official ILRS Analysis Centers (ASI, DGFI, GA, GFZ, GRGS, JCET and NSGF). Both the individual and combined solutions have followed strict standards agreed upon within the ILRS Analysis Working Group to provide products of the highest possible quality.

Individual solutions

SLR observations on LAGEOS 1, LAGEOS 2, and since mid-2002, Etalon 1 and Etalon 2, are analysed to generate the individual EOP and positions solutions; the measurements are retrieved from the CDDIS and/or EDC archive facilities. The observations are processed in intervals of 7 days to generate a loosely-constrained solution for station coordinates and EOP. The EOPs include X_p, Y_p and LOD, all computed as a daily average; daily UT parameters are also solved for, but they are of course considered as weakly-determined parameters by any satellite technique and are not included in the analysis product that is submitted to the combination centers. The station positions, with the midpoint of each 7-day (15-day for the period 1983-1992) interval as reference epoch, refer to the official station markers. Analysis contributors are generally free to follow their own computation model and/or analysis strategy, but a number of constraints must be followed for consistency:

1. The computation models follow the prevalent IERS Conventions as closely as possible.
2. The stations are included (positions estimated) in the weekly analysis if the number of observed LAGEOS 1 plus LAGEOS 2 ranges is greater than 10. Data weighting is applied according to the analyst's preference. However, the AWG has agreed to down-weight “non-core” sites significantly.
3. The tropospheric correction is applied using the IERS Conventions [Mendes-Pavlis, 2004], and there is no modeling of atmospheric pressure loading and no further estimation of tropospheric corrections.
4. The center-of-mass correction for each satellite is according to the ILRS standards. In this analysis a single correction for the two LAGEOS and another one for the two ETALON satellites were used, with the exception of the Herstmonceux station (7840), where for example the applied correction for LAGEOS is 245 mm (instead of the standard 251), to account for its (single-photon detection system) mode of operation.
5. Range corrections were modeled or estimated for a number of sites, based either on engineering reports from these sites or long-term analysis of their systematic behavior. All of the applied corrections are documented in the ILRS database (Data Handling file):

   http://www.dgfi.badw.de/typo3_ilrs/fileadmin/data_handling/ILRS_Data_Handling_File.snx

6. The weekly solutions are loosely constrained with an a priori standard deviation on station coordinates of ~1 meter and the equivalent of at least 1 m for EOPs.

Additional details on the individual AC analysis strategy can be found on the ILRS web page http://ilrs.gsfc.nasa.gov/science_analysis/analysis_centers.html

Intra-technique combination

The combined solution was produced by the primary Combination Center, ASI/CGS, and named ILRSA. The main lines of the combination methodology rely on the direct combination of loose constrained solutions; this straightforward method, "*Methodology for global geodetic time series estimation: A new tool for geodynamics*", [P. Davies and G. Blewitt, JGR, vol. 105, no. B5, pages 11083-11100, May 10, 2000], allows handling input solutions easily, with no inversion problems for the solution variance-covariance matrix and no need to know a priori values for the estimates. The reference frame is defined stochastically and it is undefined; no relative rotation between the reference frames is estimated or removed. The ASI/CGS s/w process, based on these loose combination algorithms, has been implemented in a completely general case, to handle site coordinates, EOP, and EOP-rates.

The combination is performed along the lines of the iterative Weighted Least Square technique, in which each contributing solution (and related variance-covariance matrix) plays the role of an 'observation' whose misclosure with respect to the combined solution must be minimized; each solution is stacked using its full covariance matrix rescaled by an estimated factor. A scaling of the covariance matrix of the *i*-th solution is required because the relative weights of the contributing solutions are arbitrary. Imposing $\chi^2=1$ for the combination residuals and requiring that each contribution to the total χ^2 is appropriately balanced, the relative scaling factors (σ_i) are estimated iteratively together with the combined solution. If R_i represents the solution residuals (with respect to the combined product) and Σ_i the solution covariance matrix, the imposed conditions are:

$$R_1^T(\sigma_1\Sigma_1)^{-1}R_1 = \ldots = R_i^T(\sigma_i\Sigma_i)^{-1}R_i \quad \text{and} \quad \chi^2 = R_1^T\Sigma_1^{-1}R_1 + \ldots + R_i^T\Sigma_i^{-1}R_i = 1$$

The first guess for the combination is obtained with $\sigma_i=1$ for each solution. Table 1 shows the mean value and its standard deviation, over the period 1983-2009, of the scale factors for each contributing agency.

Table 1. Mean scaling factors

	ASI	DGFI	GA	GFZ	GRGS	JCET	NSGF
Mean	5,6	16,7	3,9	11,8	6,0	8,3	7,5
Standard deviation	13,1	35,8	14,8	18,3	11,0	14,2	4,1

In ILRSA a rigorous editing has been introduced: any estimated parameter in the incoming solutions that is **not** site coordinates or EOP (e.g. range bias, ...) has been rigorously pre-eliminated ["Combination of solutions for geodetic and geodynamic applications....", E. Brockmann, PhD thesis, AIUB].

The same technique has been used to eliminate outliers with respect to the combined solution following a 5σ criterion for:

1. too weak sites (<10 NP) erroneously present in the contributing solutions
2. too weak site estimations in the contributing solutions, with uncertainties greater than 0.8m, in at least one component, after transformation to the *a priori* (SLRF2005)

3. too poor estimates in the contributing solutions, with discrepancy greater than 0.3m with respect to the *a priori* in at least one coordinate for the set of "Core Sites" (see below), 0.5m for the other sites (Arequipa excluded during the post-earthquake relaxation period).

The list of core sites has been officially defined, within the Analysis Working Group, considering the quality and stability of the entire set of network sites over several decades. This list was proposed by ASI at the AWG meeting in Grasse, France (September 2007) and accepted by the ILRS/AWG for the generation of the ILRS official products for contribution to ITRF2008.

List of core sites to be used for EOP referencing (June2009):

Site No.	dome	Wav	from	to (year included)	Notes
7080	40442M006	G	1988	--	
7090	50107M001	G	1979	--	
7105	40451M105	G	1981	--	
7109	40433M002	G	1981	1997	
7110	40497M001	G	1981	--	
7210	40445M001	G	feb 1994	2004	subset
7403	42202M003	G	1990	dec 2000	subset
7501	30302M003	G	2000	--	
7810	14001S007	B	1998	--	
7825	50119S003	G	2004	--	
7832	20101S001	G	2001	--	
7834	14201S002	G	1976	1991	
7835	10002S001	G	oct 1988	2005	subset
7836	14106S009	G	1993	2004	
7837	21605S001	G	1997	2005	subset
7839	11001S002	G	1983	--	
7840	13212S001	G	1983	--	
7849	50119S001	G	1998	2003	
7907	42202S001	G	1976	1992	
7939	12734S001	G	1983	2000	
7941	12734S008	G	2001	--	
8834	14201S018	G	may 1996	--	subset

The note "subset" identifies those sites tracking over a data span longer than the period they perform as core sites. In Fig. 1 below, the periods with low performance are indicated in yellow.

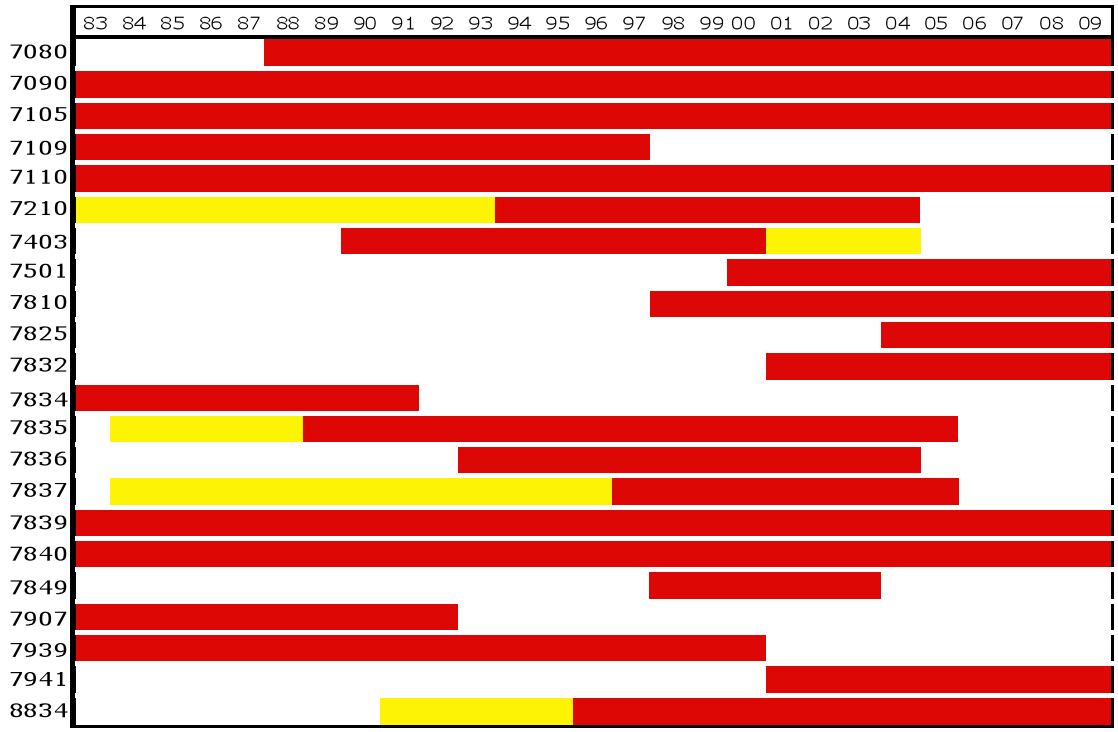

Figure 1. The selected "Core Sites" and their period of performance (yellow indicates operational period when the site is underperforming and remains excluded from the "Core Sites" list).

The mean values of the 3-dimensional weighted root mean square (WRMS) error of the site coordinate residuals with respect to the combined solution, obtained considering all the stations of the network and the entire time span 1983-2009, are shown in Table 2.

Table 2. 3D WRMS with respect to ILRSA

	ASI	DGFI	GA	GFZ	GRGS	JCET	NSGF
3D WRMS (mm)	10,7	19,8	11,8	13,0	9,2	11,9	20,2

The official ILRSA weekly solution is routinely compared with the backup combined solution ILRSB that is produced by DGFI (the official ILRS backup combination center) following a completely independent approach. The two solution series show an overall good agreement; eventual discrepancies are investigated to identify problems left. This comparison step has been performed also to check the results of the official ILRS contribution to ITRF2008.
The ILRSA solution has been extensively compared to SLRF2005; the two tables below show a limited comparison in terms of:

1) mean of the 3D WRMS of the site coordinates residuals w.r.t. SLRF2005 (see also Fig. 2)
2) translation and scale parameters of ILRSA w.r.t. SLRF2005

The evaluation of the results should take into consideration the different strength of the solution before and after 1993. The initial decade of the solution (1983-1992) consists of less precise estimates, based on 15-day arc data reduction. The weakness of the estimates is clearly visible both in the coordinate evaluation (Figure 2) and in the Helmert parameter time series (Figure 3). However, the old portion of the series is a valuable, unique contribution of the SLR to the long-term Terrestrial Reference Frame definition, contributing a number of sites from the early stages of space geodetic networks and strengthening the velocity estimates for sites that span both periods.

Table 3. 3D WRMS of the site coordinate residuals w.r.t. SLRF2005

Units are millimeters (mm)	ILRSA
All sites (mean)	12.3
Core sites (mean)	8.2
All sites (mean) 1993-2008	9.9
Core sites (mean) 1993-2008	6.5

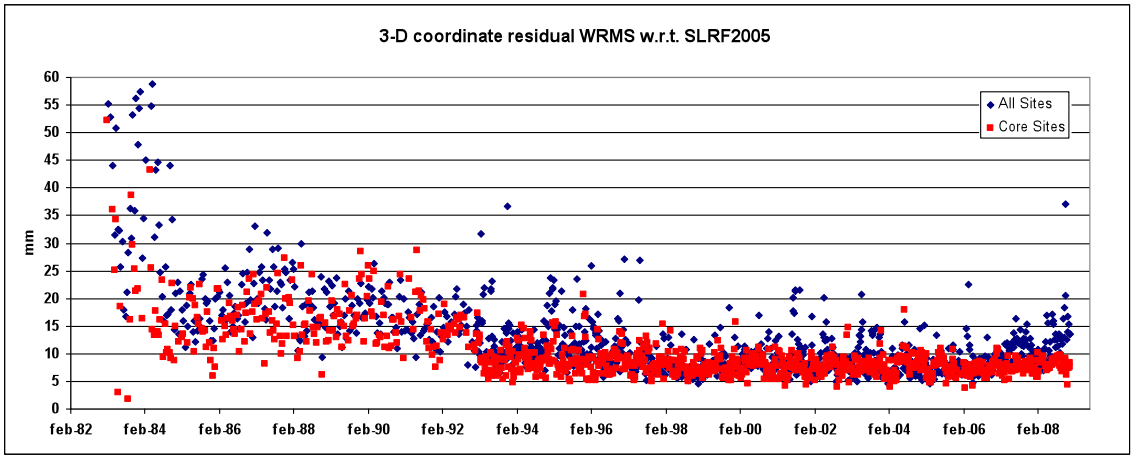

Figure 2. 3D WRMS of the core site coordinate residuals w.r.t. SLRF2005

Table 4. Translation and scale (w.r.t. SLRF2005)

	T_X	T_Y	T_Z	SCALE
Slope (mm/y)	-0.29±0.02	0.06±0.02	0.38±0.03	-0.30±0.01
Residual WRMS (mm)	4.16	3.82	7.45	3.15

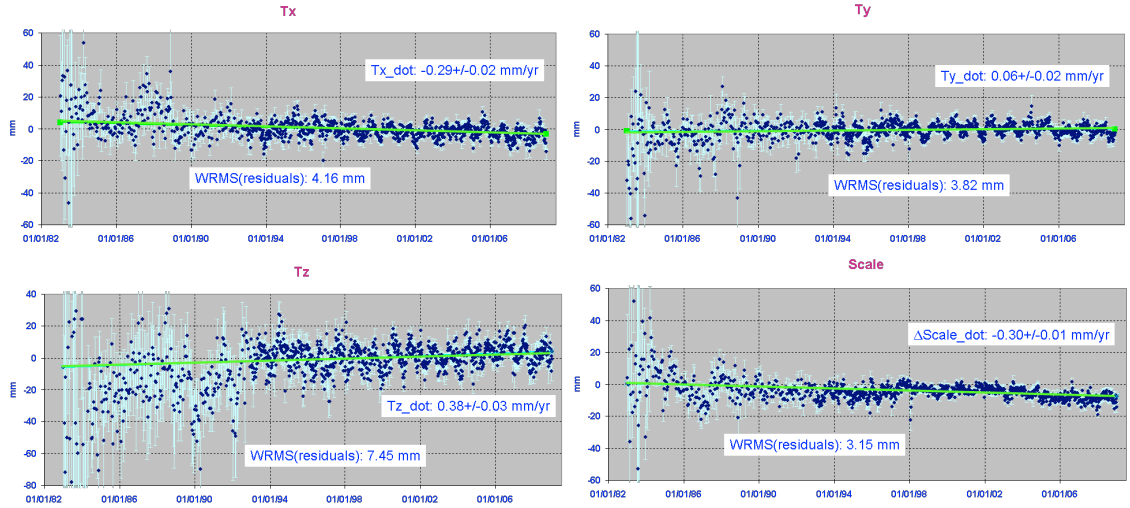

Figure 3. Helmert translation and scale w.r.t. SLRF2005

Additional information can be found on the ILRS web pages
http://ilrs.gsfc.nasa.gov/science_analysis/analysis_products.html