# *Combination approaches at ILRS CCs, products and issues*


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# *Current ILRS combination activities*

At present, the **ILRS** activities at the CCs (**ASI-CGS** *primary CC*; **DGFI** *backup CC*) are focussed on

- the provision and updating of the consolidated products
  - combined SSC/EOP weekly solution
  - long term solutions as contribution to ITRF realization

- the definition and realization of new combination products for the SLR and overall geodetic community

# *ILRS consolidated products*

## ILRS Weekly Solution

Since **2004**, ILRS has been providing, routinely, the weekly combined *SSC/EOP* solutions to support IERS for the EOP computation and the SLR community for the data reduction.

Each *Wednesday*, CCs generate two sets of combined solutions, ILRSA (ASI CGS) and ILRSB (DGFI), computed along different combination strategies. Both the solutions share the same **timeline**: the SLR data acquired (Lageos1/2, Etalon1/2) during a **7-day** period (*Sunday-Saturday*) are processed by the ACs and made available to the CCs within *Tuesday*.

## ILRS contribution to ITRF realization

The ILRS contributes to the realization of ITRF according to the IERS requests.

The contribution to **ITRF2005** is a long time series of weekly combined *SSC/EOP* solutions covering the period **1993-2005** aligned with the GPS weeks, provided to IERS at the **end of 2005**.

# *ILRS consolidated products*

For each weekly solution

- daily estimated ITRF-framed and loose constrained EOP values (x-pole, y-pole, LOD)
- a set of loose constrained coordinates for the acquisition network
- several quality evaluation indicators

are provided in 3 different files available at **CDDIS** and **EDC**:

***ilrs***.pos+eop.***yymmdd***.v***nn***.snx

***ilrs***.pos+eop.***yymmdd***.v***nn***.sum

***ilrs***.eop.***yymmdd***.v***nn***.snx

At present, **8 ACs** contribute to the weekly ILRS combined solution:

**ASI BKG DGFI GA GFZ GRGS JCET NSGF**

**Apr 07** **Oct 07**

while **5 ACs** contributed to the ILRS combined solution for ITRF2005

**ASI DGFI GFZ JCET NSGF**

# *ILRSA combination approach*

The ASI-CGS combination procedure is based on the direct combination of loose constrained solutions (*"Methodology for global geodetic time series estimation: A new tool for geodynamics*", Davies and Blewitt, 2000).

no inversion problems for the solution covariance matrix
no need to know apriori values for the estimates
no relative rotation between the reference frames is estimated

Site Coordinates
Site Velocities
E.O.P.
E.O.P. Rates

$$\begin{pmatrix} \mathbf{X}_1(t_1) \\ \mathbf{X}_{1\mathrm{dot}}(t_1) \\ \mathbf{Y}_1(t_{1i}) \\ \mathbf{Y}_{1\mathrm{dot}}(t_{1j}) \end{pmatrix} = \mathbf{P} \begin{pmatrix} \mathbf{X}_0(t_0) \\ \mathbf{X}_{0\mathrm{dot}}(t_0) \\ \mathbf{Y}_0(t_{0j}) \\ \mathbf{Y}_{0\mathrm{dot}}(t_{0j}) \end{pmatrix} = \begin{pmatrix} \mathbf{I} & (t_1 - t_0)\mathbf{I} & 0 & 0 \\ 0 & \mathbf{I} & 0 & 0 \\ 0 & 0 & \mathbf{I} & (t_{1j} - t_{0j})\mathbf{I} \\ 0 & 0 & 0 & \mathbf{I} \end{pmatrix} \begin{pmatrix} \mathbf{X}_0(t_0) \\ \mathbf{X}_{0\mathrm{dot}}(t_0) \\ \mathbf{Y}_0(t_{0j}) \\ \mathbf{Y}_{0\mathrm{dot}}(t_{0j}) \end{pmatrix}$$

# *ILRSA combination approach*

The combination is performed along the lines of the iterative Weighted Least Square technique: each contributing solution plays the role of an 'observation' whose residuals with respect to the combined solution must be minimized; each solution is stacked using its full covariance matrix rescaled by a factor by imposing

$$\chi^2 = R_1^T C_1^{-1} R_1 + \ldots + R_i^T C_i^{-1} R_i = 1$$

$$R_1^T \left(f_1 C_1\right)^{-1} R_1 = \ldots = R_i^T \left(f_i C_i\right)^{-1} R_i$$

The first guess for the combination is obtained with $f_i=1$ for each solution.

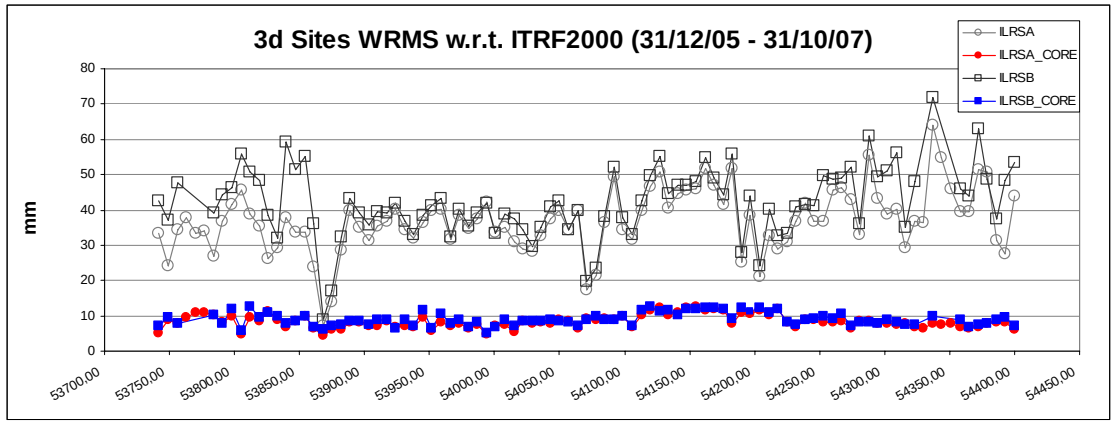
# *ILRSB combination approach*

The DGFI combination procedure is based on the rigorous variance component estimation (VCE) method *("Estimations of variance components and applications",* e.g. Rao and Kleffe, 1988). VCE enables an absolute scaling of the contributing solutions within the iterative combination process.

At first, unconstrained normal equation systems (NEQs) are reconstructed from the loose-constrained input solutions and are analyzed with respect to eigen-values and rank type. The NEQs are then used to re-compute input solutions with minimal constraints defined on the same subset of reference sites. These solutions are the basis for the following VCE which produces variance components for the scaling of the input NEQs. Finally, the scaled NEQs are added and solved for with minimal constraints with the subset of reference sites.

# *ILRSA – ILRSB intercomparison*

ILRSA and ILRSB have demonstrated to provide equivalent results in terms of global parameters (e.g. Helmert parameters) and overall quality indicators. Extended comparisons of the two analysis strategies has been performed during time, and the overall agreement assessed




Statistics on the 1983-2005 solutions time series

| | ILRSA mm | ILRSB mm |
|---|---|---|
| All Sites | 21.5 | 26.0 |
| Core Sites | 8.0 | 10.1 |

| | Tx mm | Ty mm | Tz mm | Scale mm |
|---|---|---|---|---|
| Wmean | 1.14 | -0.24 | -0.10 | 0.05 |
| WRMS | 3.14 | 2.27 | 4.03 | 3.13 |

# *The quality of the final product*

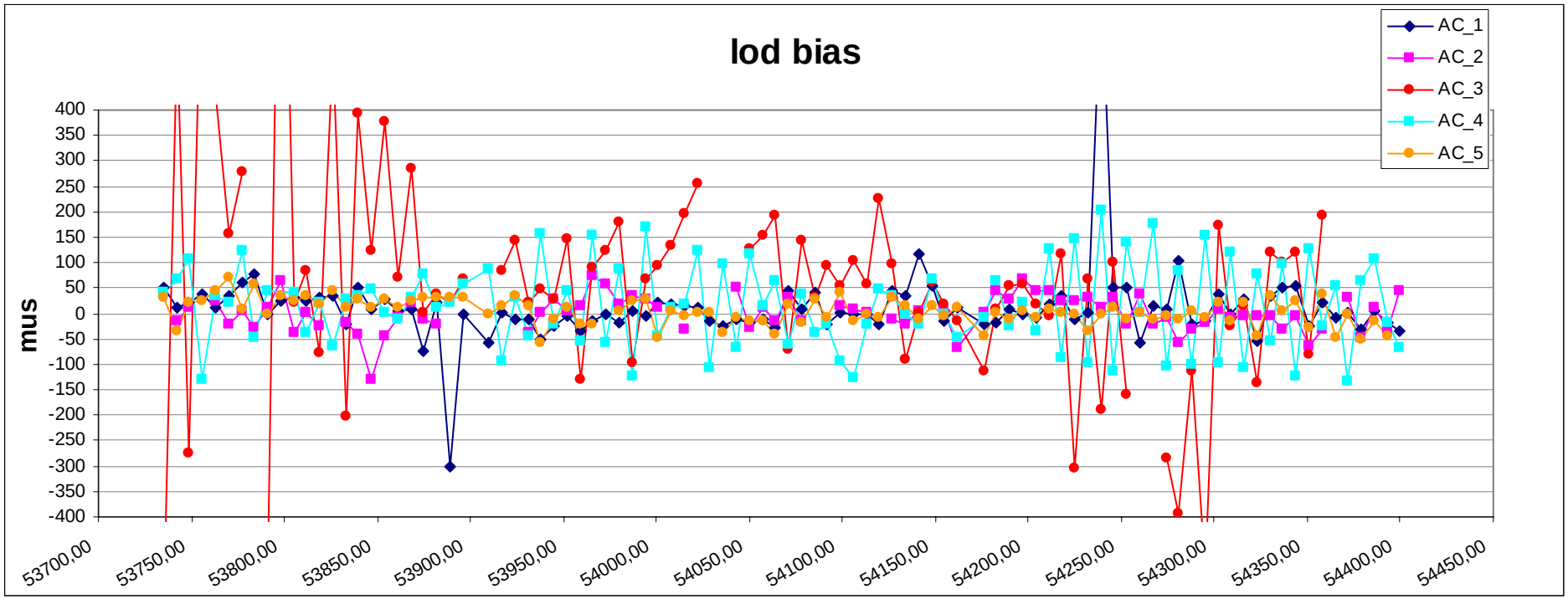
The two combination approaches must be complemented with

- the implementation of proper **outlier editing techniques** to remove specific problems within one input solution
- a preliminary discussion and agreement at the **AC** level, of **common standard and policies in the data analysis**; optimal outlier editing alone, in fact, might not to be effective: a specific problem in one of the input solution, if not too exaggerated, may be only 'smoothed' by the combination and not removed.

The **"coherence"** of the input solutions is thus a critical factor impacting the quality of the final combined products as the inconsistencies (different application/estimation of system bias, existence of hidden constraints not traceable in the SINEX file, different conventions applied,...) might not be removed in the combination step. In particular, different treatment of station biases may cause incorrect and not physically interpretable coordinates estimation in the combined solution.

# The quality of the final product: an example

A typical example comes from the LOD combination; for this parameter contributing solutions show a remarkable different behavior, often impacting on the quality of the final estimation, both for ILRSA and ILRSB. It is likely due to hidden constraints (UT1) not present in the SINEX file and thus not removable. The 'pointwise' outlier removal may not be enough: a long term monitoring is needed.



# *Outlier detection and editing*

In the ILRSA combination procedure a rigorous editing has been included: any estimated parameter in the incoming solutions being not SSC nor 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:

1. too weak sites (<10 NP) erroneously present in the contributing solutions
2. outliers with respect to combined solution following a 5$\sigma$ criterion

**for the ITRF2005 contribution only**

3. too bad estimates in the contributing solutions, with discrepancy greater than 0.3m w.r.t. ITRF2000 in at least one coordinate for the set of Core Sites, 0.5m for the other sites (Arequipa excluded)
4. too weak site estimations in the contributing solutions, with uncertainties greater than 0.8m, in at least one component, after transformation to ITRF2000

# *Outlier detection and editing*

- The fine approach for outlier identification and removal allows to keep within the combination process all the contributing solution. If no technique to remove a single ‘bad’ parameter from a solution is applied, if discrepancy is huge, it may cause the complete elimination of that solution from the combination process.

- The outlier editing affects the iterative computation of the solution scaling factors in the combination process.

# *Updating of/comments on the consolidated products*

## ILRS Weekly Solutions

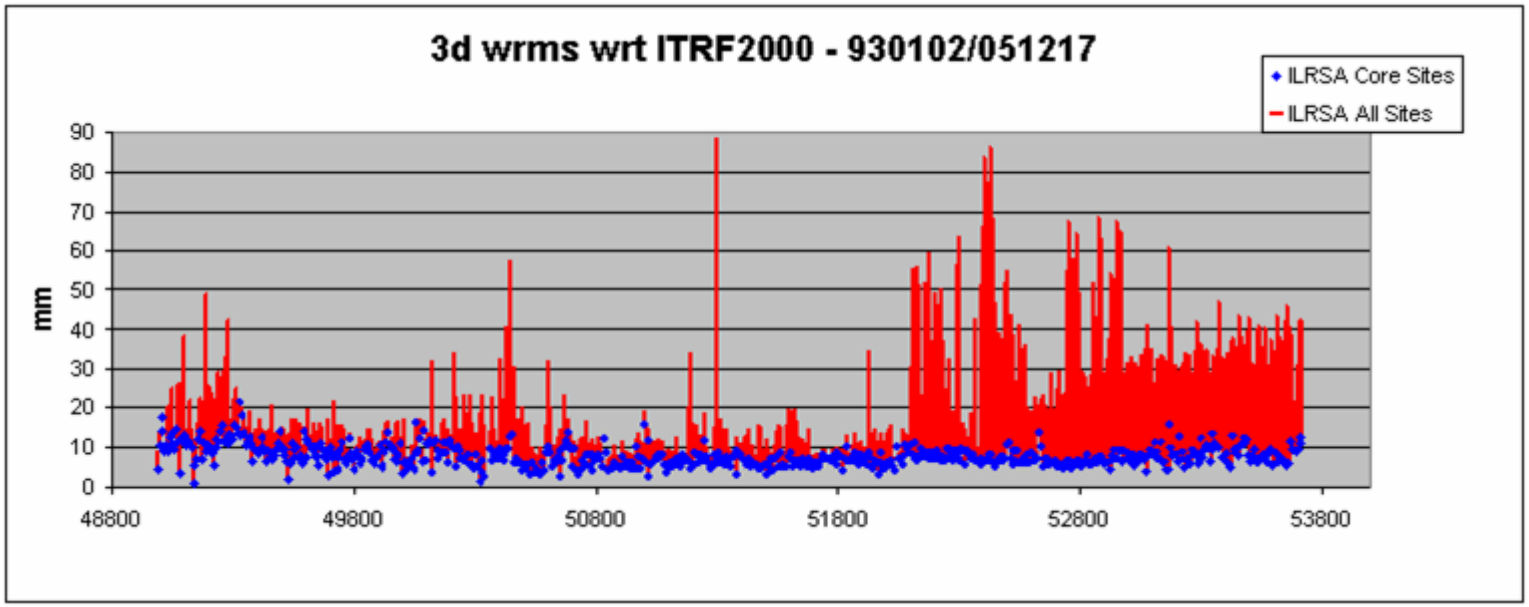
- In 2007, two ACs joined the weekly production (**GA, GRGS**) after the ILRS benchmark process.
- The quality assessment in the **ITRF2005** frame has been included since **November 2007**, according to the new apriori standard adopted by the ACs in their solution preparation.
- Since the start of the product generation (2004), the contributions from ACs are more homogeneous and robust, with few outliers and discrepancies.

## ILRS Contribution to ITRF realization

- The long series **1983-2007** of ILRS weekly solution for the updating of ITRF2005 is planned. ACs are producing their individual solutions according to the decisions at the most recent AWGs following the recommended standard and agreed processing policies with respect to the system biases. The combined solution is expected in the next pair of months.

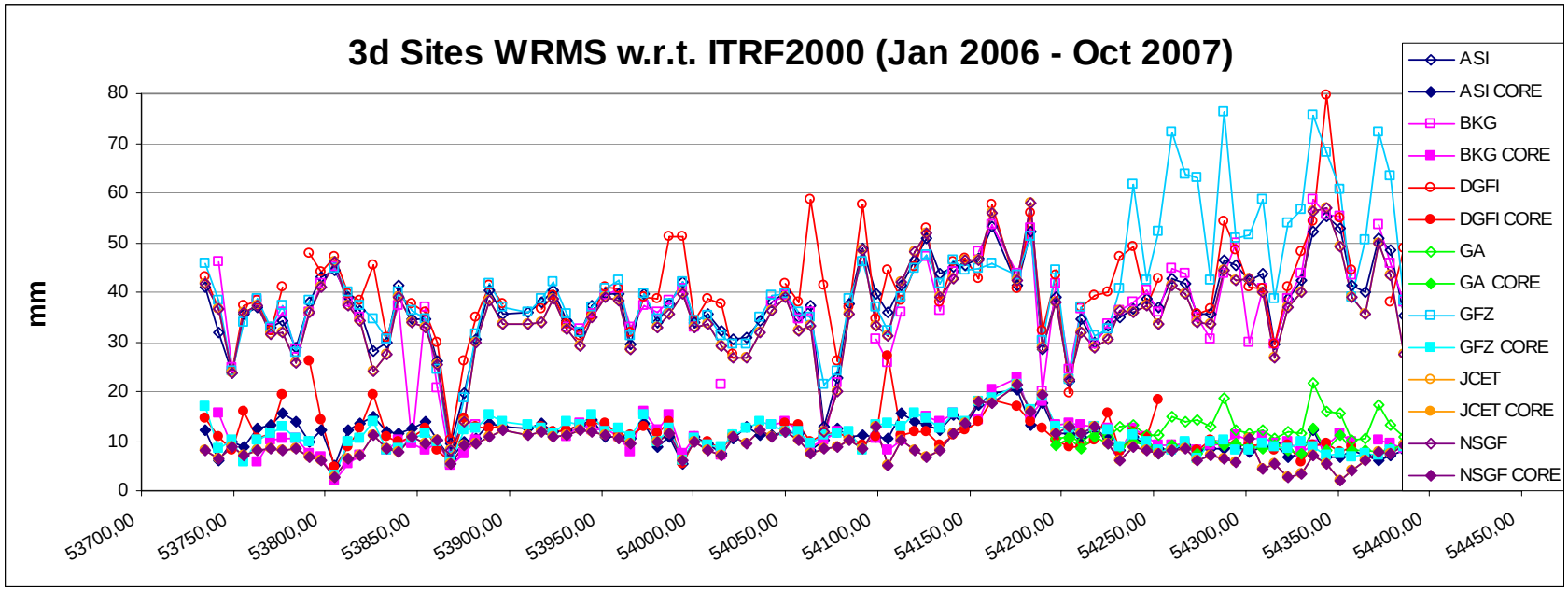
# *Impact of/contribution to ITRF*

The need of the new ITRF2005 for SLR data analysis is evident from the plot below. After 2000, many new SLR systems joined the network and at that date many systems were young, thus not properly modeled. Core Sites have been selected on the basis of the robustness and reliability in terms of data history and quality, as well as their proper modelization availability.



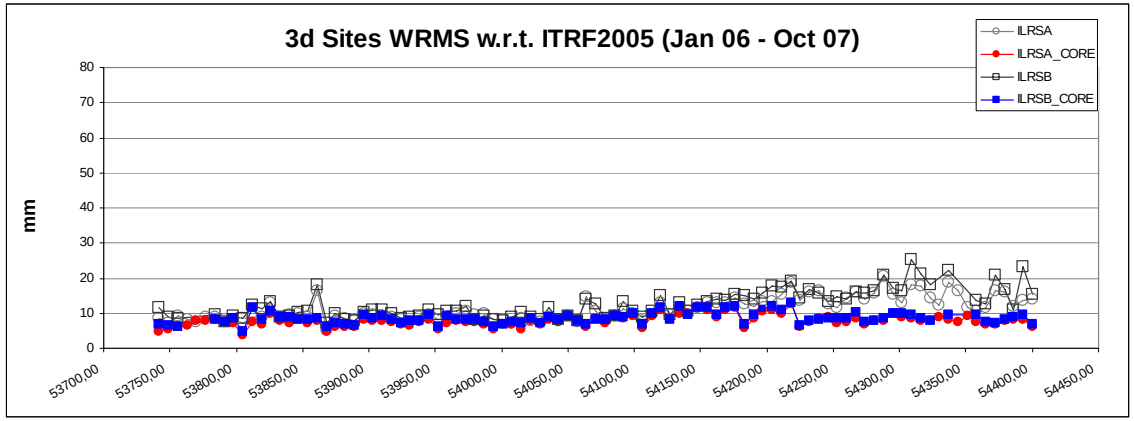
# *Impact of/contribution to ITRF*

Assessing the quality of the routinely weekly solution wrt ITRF2000 for 2006-2007, as expected, the Core Sites are stable and the mismodeled sites go worst with time. The planned 1983-2007 ILRS combination will give a further contribution.



# *Impact of/contribution to ITRF*

When ITRF2005 is assumed as reference for the same period, besides the overall good behavior of all the sites, again, higher values of the site coordinate residuals begin to be evident in time.




After the production of the whole 1983-2007 set of combined weekly solutions, ILRS plans to generate an **SLR-only, ITRF2005-framed SSC/SSV solution** and update it systematically at a reasonable frequency by including the SSC weekly solutions being produced on.

This **living SSC/SSV product** has a very important operational impact, as it allows to have the best SLR coordinates at epoch for any site, while the official ITRF is frozen.

# ILRS combined SSC/SSV solution

ASI-CGS is approaching the modeling of the mixed position/velocity problem in a recursive way:

$$(A_n{}'W_nA_n)\,k^0{}_n = A_n{}'W_n y_n$$

$$A_n = \begin{pmatrix} 1 & t_1 \\ . & . \\ . & . \\ . & . \\ 1 & t_n \end{pmatrix} = \begin{pmatrix} A_{n-1} \\ 1 \quad t_n \end{pmatrix}; \quad k^0{}_n = \begin{pmatrix} x^0{}_n \\ \dot{x}^0{}_n \end{pmatrix}; \quad y_n = \begin{pmatrix} Y_1 \\ . \\ . \\ . \\ Y_n \end{pmatrix}$$

$$(A_{n-1}{}'W_{n-1}A_{n-1} + B_n)k^0{}_n = A_{n-1}{}'W_{n-1}y_{n-1} + z_n$$

$$B_n = \begin{pmatrix} w_n & w_n t_n \\ w_n t_n & w_n t_n{}^2 \end{pmatrix}$$

$$z_n = \begin{pmatrix} w_n \\ w_n Y_n \end{pmatrix}$$

update at step n

to be estimated

$$(A_{n-1}{}'W_{n-1}A_{n-1} + B_n)k^0{}_n = (A_{n-1}{}'W_{n-1}A_{n-1})k^0{}_{n-1} + z_n$$

from step n-1

# *ILRS combined Orbit product*

The purpose is to issue a new ILRS product providing a combined set of SVs for **Lageos I/II**, **Etalon I/II** aligned with the EOP/SSC weekly product

ACs are requested to provide their orbital solution as **SP3** files, in the same ECEF they provide the 'loose' SSC/EOP solutions, with state vectors every **2' (Lageos)** and every **15' (Etalon)**, covering the whole week.

The combination procedure is under design; as a basis, it will include

- SP3 files transformation to the ITRF of reference, by using the Helmert parameters estimated in the SSC/EOP combination and reported in the weekly summary report
- a weighted average of the state vectors, based on a unique weekly weight for each AC solution reflecting the agreement of each solution to the reference ITRF (3d WRMS of SSC residuals)

# ILRS combined Orbit product

At present, only ASI and DGFI SP3 test files are available; comparison tests go on and show a **5-cm level** position agreement (see table and plots) in the Lageos1 orbit after the proper similarity transformation.

| SAT | X mean std | Y mean std | Z mean std | VX mean std | VY mean std | VZ mean std |
|---|---|---|---|---|---|---|
| **LAGEOS 1** | **m** | **m** | **m** | **mm/s** | **mm/s** | **mm/s** |
| **6 days** | **0,001** | **0,004** | **-0,010** | **-0,001** | **0,001** | **0,001** |
| | **0,053** | **0,060** | **0,055** | **0,062** | **0,061** | **0,034** |
| **1 day** | **-0,003** | **0,006** | **-0,012** | **0,001** | **0,001** | **-0,001** |
| | **0,035** | **0,037** | **0,044** | **0,058** | **0,054** | **0,026** |