Unified Analysis Workshop 2007
Position Paper Session 4

Combination Strategies and Aspects

Position Paper

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1. ILRS COMBINATION STRATEGIES AND ASPECTS

The current ILRS combination activities include:

- the continuous provision of the official ILRS combined weekly solution to support the IERS EOP computation
- the provision, on request, of the long term combined solution according to the IERS requirements for the establishment of ITRF
- the understanding of the requirements pertaining to new combination products in support of the SLR community (orbits, fast SLR TRF update) and of the whole geodetic community (daily combined solutions for EOP computation) as well as their realization

1.1 CONSOLIDATED ILRS COMBINATION PRODUCTS

ILRS Weekly Solutions

Since 2004, ILRS has been providing routinely the weekly combined SSC/EOP solutions to support IERS Bulletin B and the SLR community for the data reduction.
Each Wednesday, two sets of solutions are provided, ILRSA (ASI CGS) and ILRSB (DGFI), computed along different combination strategies, cross-tested during the past years. Both the solutions share the same timeline: the SLR data acquired during a 7-day period are processed by the ACs and made available within Tuesday; then the CCs produce their version of the combined solution.
For each weekly solution, daily estimated ITRF-framed EOP values (x-pole, y-pole, LOD), a set of loose constrained coordinates for the acquisition network and several quality evaluation indicators are provided.
The weekly solution set is formed by three 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

with the following naming conventions:
ilrs: ilrsa or ilrsb
yymmdd: reference date (the last day of acquired weekly data, Saturday)
nn: version number; nominal (from November 07 onwards) is “10”. The two-digit number has been introduced to track the combination processing changes (first digit) and the updating due to reprocessing of the input AC solutions (second digit).
At present, 8 ACs contribute to the weekly ILRS combined solution: ASI, BKG, DGFI, GA (from April 07), GFZ, GRGS (from October 2007), JCET and NSGF. Each contributing solution is quality evaluated and the relevant indicators (e.g WRMS of the site residuals with respect to the reference ITRF, WRMS of the EOP residuals with respect to the reference EOPs) are reported in the summary file (.sum).

<FIG.>

ILRS contribution to ITRF200X

The role of Satellite Laser Ranging technique in the maintenance of the ITRF is quite critical: in the previous ITRF2000 it realized, alone, its origin and, jointly with VLBI, its scale. The ILRS contribution to ITRF2005, as provided in December 2005, consisted of 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 aligned with the GPS weeks (Sunday to Saturday), starting from January 1993 and ending at December 2005. This ‘backwards’ solution followed the guidelines of the weekly combined solutions and profited of the continuous tuning of that product made during 2004 and 2005.
The contributing ILRS ACs were ASI, DGFI, GFZ, JCET and NSGF, as described in the official ILRS web site.

<FIG.>

1.1.1 COMBINATION STRATEGIES: STATUS

The main lines of the combination methodology used at ASI-CGS (“ilrsa”) rely on the direct combination of loosely constrained solutions; this straightforward method (ref) 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 is unknown;

no relative rotation between the reference frames is estimated and removed. The combination is performed along the lines of the iterative Weighted Least Square technique, wherein each contributing solution (and related variance-covariance matrix) 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, computed at each iteration, fulfilling the conditions that the variance factor of the combination be close to unity and that each solution contribution be equally balanced.
The DGFI combination procedure ("ilrsb") is based on the rigorous variance component estimation (VCE) method. VCE enables an absolute scaling of the contributing solutions wthin 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, this time with minimal constraints defined on the same subset of reference sites (s. below). These solution 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 same subset of reference sites as explained before.

The two combination approaches 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, and the overall agreement assessed.

<FIG.>

It has to be noted that the two approaches must be complemented with

- the implementation of proper outlier editing techniques to remove specific problems within one input solution (e.g. a bad/weak site coordinate estimation, an incorrect system bias,...)
- a preliminary discussion and agreement at the AC level, of common standard and policies in the data analysis; optimal outlier editing alone, in fact, is not able 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.

That means that the major factor impacting the overall quality of the combined solution comes not from the two different combination approaches followed, but from the intrinsic quality of the input AC solutions and the ability of the combination procedures of identifying and removing specific problems.

1.1.2 WEIGHTING OF THE OBSERVATIONS AND OUTLIERS EDITING CRITERIA

In the combination process, the 'observations' are the single contributing solutions. These are in turn formed by a set of parameters and the related covariance matrix. A key point is the rigorous editing of single parameters within the solutions. If no technique to remove a single 'bad' parameter from a solution is applied, if huge may cause the complete elimination of that solution.
About the weighting of the solutions, the "ilrsa" combination strategy aims at generating a final product uniformly balanced: as first step, a preliminary combination is computed by a weighted average of each input solution, each one weighted by its input covariance matrix. Then, the residuals of each solution with respect to the combined one are evaluated with respect to the given input covariance: a scaling factor is computed to allow each one of the "n" solutions to give a "1/n" contribution to the final overall post-fit variance factor. The scale factor computation is iterative and affected by the editing criteria applied: in the consolidated ILRS products, generated following the "ilrsa" approach, the following editing criteria are followed:

- **Before combination**
  - any estimated parameter in the incoming solutions being nor site coordinates neither EOPs (e.g. range bias) are removed
  - core sites/EOPs in the incoming solutions 5σ far from the reference values are removed
- **During combination**
  - estimated parameters 5σ far from the combined ones are classified as outliers and are removed.
- **After combination**
  - if requested by the final user (e.g. as in the case of ITRF2005), bad/weak parameters can be removed

The outlier editing is performed in a rigorous way (ref, E. Brockmann), i.e. taking into account the effect of the parameter to be removed on the other ones, by means of its covariances.
This 'fine' approach for outlier identification and removal allow to keep within the combination process all the contributing solution, with eventual modification if needed.

1.1.3 CONSTRAINING OF PARAMETERS, RANK DEFICIENCIES, DATUM DEFINITION STRATEGIES

The ILRS ACs solutions are provided as loose constrained solutions; that allows their direct combination (linear model, no apriori needed) to a final loose constrained solutions, with no (or at least minimal) distorsion of the network.
The ilrs combination product series are provided as 'loose' solutions (SSC/EOP) and as fixed solutions (EOP only). The two series share a common definition of the reference Core Sites, (discussed and agreed at the AWG meetings) reflected in the summary report assessing the quality of the solutions with respect to a reference frame and in the EOP provided to the IERS as ITRF-framed.

- The selection of the Core Sites, in the SLR analysis context, relies upon the robustness and reliability of sites in terms of data history and quality, as well as their proper modelization availability.

1.1.4 TIME RESOLUTION OF PARAMETERS; EPOCHS OF PARAMETERS

Each geodetic technique has its characteristic time resolution for the solve-for-parameters, due to the sensitivity of the technique to the force field and to the acquisition features. The SLR solutions, even the combined (more precise) ones, can provide daily EOP estimates (x-, y-pole <0.3 mas, LOD<0.1 ms accuracy) and weekly SSC estimates (<10 mm overall accuracy) with the present acquisition network.

1.1.5 PRODUCTS EVOLUTION

ILRS Weekly Solutions

- In 2007, two ACs joined the weekly production (GA, GRGS) after the ILRS evaluation (benchmark process).
- The ILRS weekly solution has included the quality assessment in the ITRF2005 frame since November 2007, according to the new apriory 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.
- It has to be noted that, being the combination a sort of average of the contributing solutions, their intrinsic quality is the major factor affecting the overall quality of the final product. In particular, different treatment of station biases may cause incorrect and not physically interpretable coordinates estimation in the combined solution.
- Formal correctness (sinex files) of the contributing solutions also increased, allowing the derivation of more complete auxiliary information (e.g. correctness of the EPOCHS section) reported in the summary file.
- It is under study the possibility of providing the weekly solution at daily frequency (each day one day shift): that requires full, robust automated combination procedures

ITRF Contribution

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.

1.2 NEW ILRS COMBINATION PRODUCTS

The ILRS AWG is studying new combined products for the geodetic community (in particular SLR).
These products are the following:

- Combined weekly Orbit solution (Lageos1, Lageos2, Etalon1, Etalon2)
- SLR-tailored, continuous updating of ITRF2005

Combined weekly Orbit solution

ILRS AWG plans to issue also a combined orbit solution, relevant to the satellites whose data are used in the weekly SSC/EOP solution, i.e. Lageos1&2, Etalon1&2 to be provided as SP3 orbit files.

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 based on (TBC, under study)

- SP3 files transformation to the ITRF of reference, by using the Helmert parameters estimated in the SSC/EOP combination and reported in the 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)

SLR continuous update of reference ITRF

From the SLR analysis point of view, the availability of an SLR-tailored TRF, aligned with the current ITRF but continuously updated to include young stations poorly modeled is required.

ILRS AWG plans to issue such a product and rigorous techniques for that fast combination are under study, as well as the frequency update of the product.

R. Ferland, RFWG coordinator

2. IGS COMBINATION STRATEGY

2.1 BACKGROUND

~ 1995 - Original version Development with the following objectives:

- Extract station coordinates and erp's from emr's GIPSY daily solution files.
- Analyse and combine the daily emr solutions to generate the emr weekly sinex files,
- ~30 stations.

1996 Start SINEX contribution.

Mid-1998 started investigations to combine ACs weekly SINEX files.

March 1999 (Wk 0999) start of Pilot Project

February 2000 (Wk 1050) – Start official products.

Now ~275-300 stations in weekly combination.

2.2 PROCEDURE

The combination is done using a standard least-squares adjustment.

Eight analysis centres are providing weekly SINEX files containing estimates for:

- Station coordinates
- ERPs (daily)
- Implicit geocenter at the origin.

The AC's and GNAACs products are retrieved from CDDIS or SIO or IGN (in that order).

The main inputs to the combination include:

- AC solutions (cod + emr + esa + gfz + jpl + mit + ngs + sio),
- GNAAC combinations (mit + ncl),
- Apriori information:
    - Previous week weekly and cumulative solutions,
    - IGS realization of ITRF2005,
- Other sources:
    - Coordinates and residuals time series,
    - Station logs,
    - IGS mail,
    - Discontinuity table.

The combination strategy can be subdivided as follow:

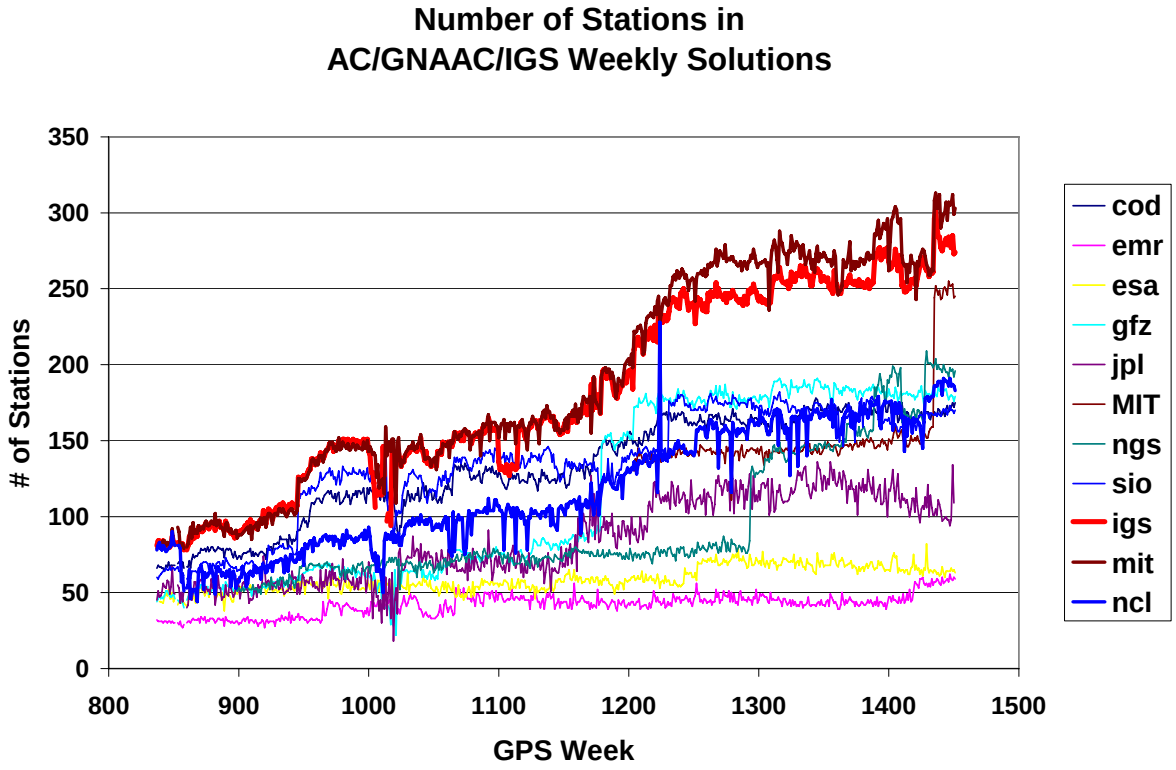
- Pre-processing (as needed):
    - Conversion to a consistent “flavour” of SINEX.
    - Apply Variance factor
    - Unconstrain
    - Explicit extraction of the Apparent Geocenter.
- Alignment to the Reference Frame
    - Include Outlier detection/rejection
- Pair wise comparison:
    - ACs,
    - GNAACs,
    - IGS weekly (previous week),
    - IGS Cumulative (previous week).
- Weekly Combination:
    - Includes station coordinates + ERP’s + Apparent Geocenter.
    - Apply inner constraints
    - Aligned to the most recent realization of ITRF. (IGS05)
    - Stations without dome# excluded.
- Cumulative Combination:
    - Include station coordinates and velocity
    - Apply inner constraints (no condition imposed on velocity)
    - Aligned to the most recent realization of ITRF. (IGS05)
    - Exclude stations:
        - Without Dome#
        - Poor velocity estimates
- Quality Assurance checks:
    - Outliers
    - Velocity estimates
    - Review statistics before submitting the solutions.

The main outputs are:

- igsYYPWWWW.snx Combined weekly solution
- igsYYPWWWW.erp Daily Earth Rotation Parameters
- igs00p03.erp Daily Earth Rotation Parameters since GPS week 860
- IGSYYPww.snx Cumulative Combined solution
- igsYYPWWWW.sum Summary report,
- igsYYPWWWW.itr Residuals between the AC and the IGS05 for the RF stations
- igsYYPWWWW.res Residuals between the AC and the Combined Weekly solution
- IGSYYPww.res Residuals between the AC and the Cumulative Combined solution

The ACs inputs are available within 10 days after the end of each week (Tuesday). Some are even ready within 5-6 days. The GNAACs combinations require the ACs solutions and are ready 10.5 days after the end of the week. The combined IGS products are ready 11 days after the end of each week. The products are sent to CDDIS and SIO. A copy of the products is also available locally for at least a few days to further ensure of the products availability. Time series tables and plots of the coordinates, residuals, summary files are also available via ftp.

The following figure shows the evolution of the number of stations in the ACs, GNAACs and IGS weekly solutions.



2.3 SOME TECHNICAL ISSUES

2.3.1 CONSTRAINTS

The ACs generally keeps them to a minimum. If they are explicit, they are simply removed. When un-removable (not in apriori) constraints are found, they are reported to the ACs. The affected parameters affected have been removed, until the problem could be resolved.

2.3.2 MODELING

Modeling issues have been handled on a case by case.
Some AC's have reported in the past LODR. Corrections were applied locally (LODR > LOD).
Inconsistent models such as relative vs. absolute antenna phase center. Inconsistent AC excluded from the combination.

2.3.3 CONSISTENCY WITH OTHER IGS PRODUCTS

All AC SINEX solutions are treated such that the original files (with constraints) are consistent with the AC other products (E.g. Orbits, Clocks, Tropo).

2.3.4 NUMERICAL

Numerical issues do occur from time to time. For singular cases, the matrices are "tweaked" to allow proper inversion. ~ppm tweak may be sufficient.
In the case where significant matrices change would be required, the problem is reported to the AC. The action taken depends on the situation.

Potentially more concerning, are “hypothetical” cases where the adjustment may not fail, but may affect the results.

2.3.5 DISCONTINUITIES

Large discontinuities are easy to detect with high level of certainty. However, smaller ones are more problematic, and the level of uncertainty increases very significantly. The reprocessing will certainly affect in a very significant way the current list.

2.3.6 OPTIMIZED SOLUTIONS

For various reasons, the official solutions may often be improved. Background optimization of the combined solutions is often needed. The updated solutions are currently not publicly available. They are updated as needed. For example, weekly AC solutions that may have missed a deadline are added when available. Small discontinuities may need a few weeks to be detected. Combinations are then redone to properly reflect this type of change.

2.3.7 SOFTWARE UPGRADE

On the “To Do List” for some time:

- SINEX Version 2 +
- More stations
- More solutions
- Extended modelling
- ...

3. SUMMARY – MAIN COMBINATION ISSUES

TBW

End of Document