The ASI/CGS operational combination for the ILRS Pos+EOP Pilot Project

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Scope

To illustrate ASI/CGS weekly combined solution in terms of

- method selection & implementation (quickly)
- updated results (up to 040410 solution)

within the frame of ILRS Pos+EOP Pilot Project

Our combined solution is based on the implementation of the loose combination method adapted to the operational reqs of the project.

Possible Solution Combination approaches

Basically one can distinguish two distinct approaches that allow the combination of independent geodetic solutions.

- **Fiducial**

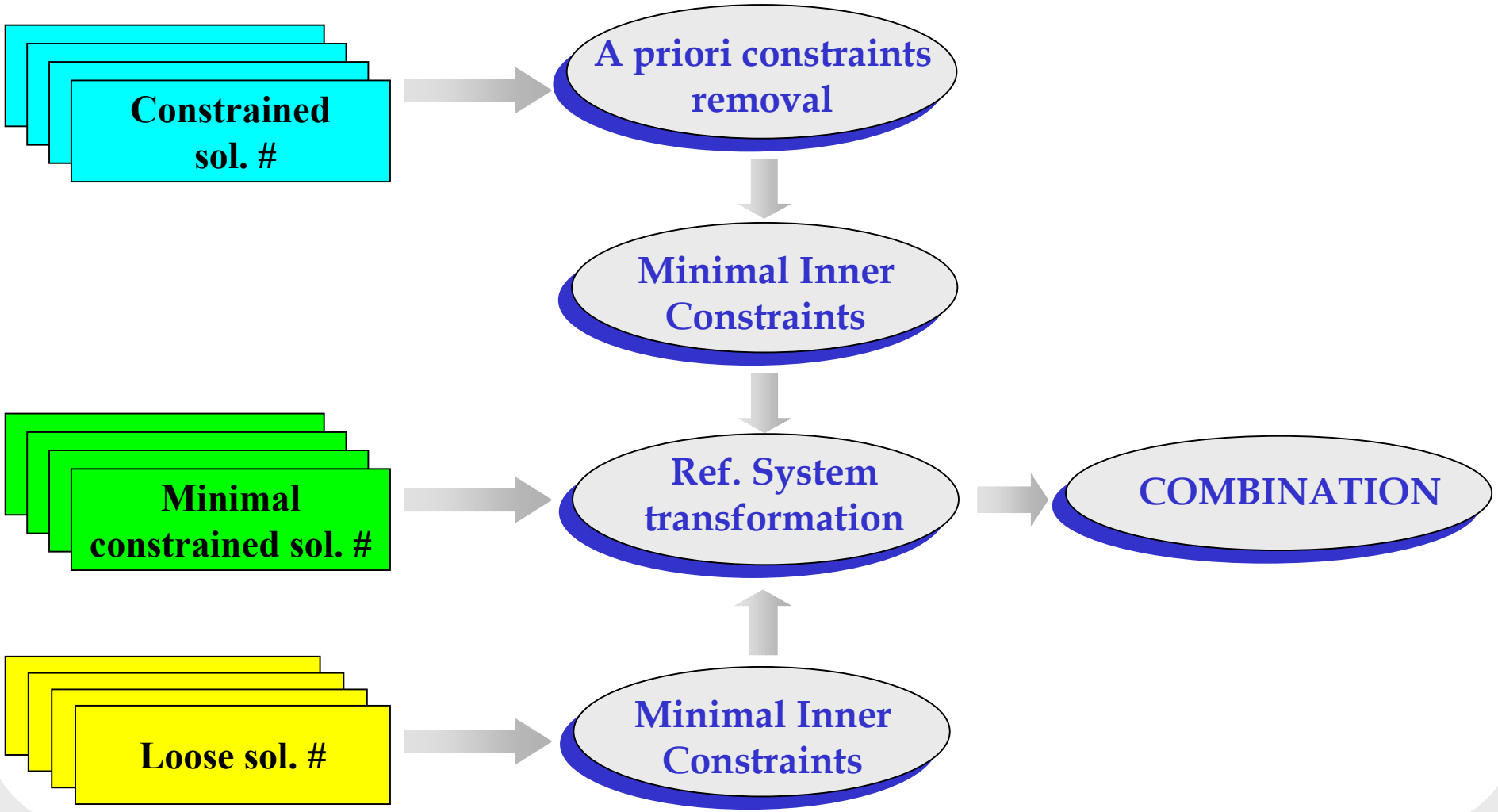
  Each solution is transformed to a conventional reference frame where parameters combination takes place. *The reference frame (datum) is part of the combination scheme, and dictates the applied constraints.*

- **Loose**

  Direct combination of loose constraint solutions. *The reference frame is defined stochastically and is unknown, no constraints are applied.*

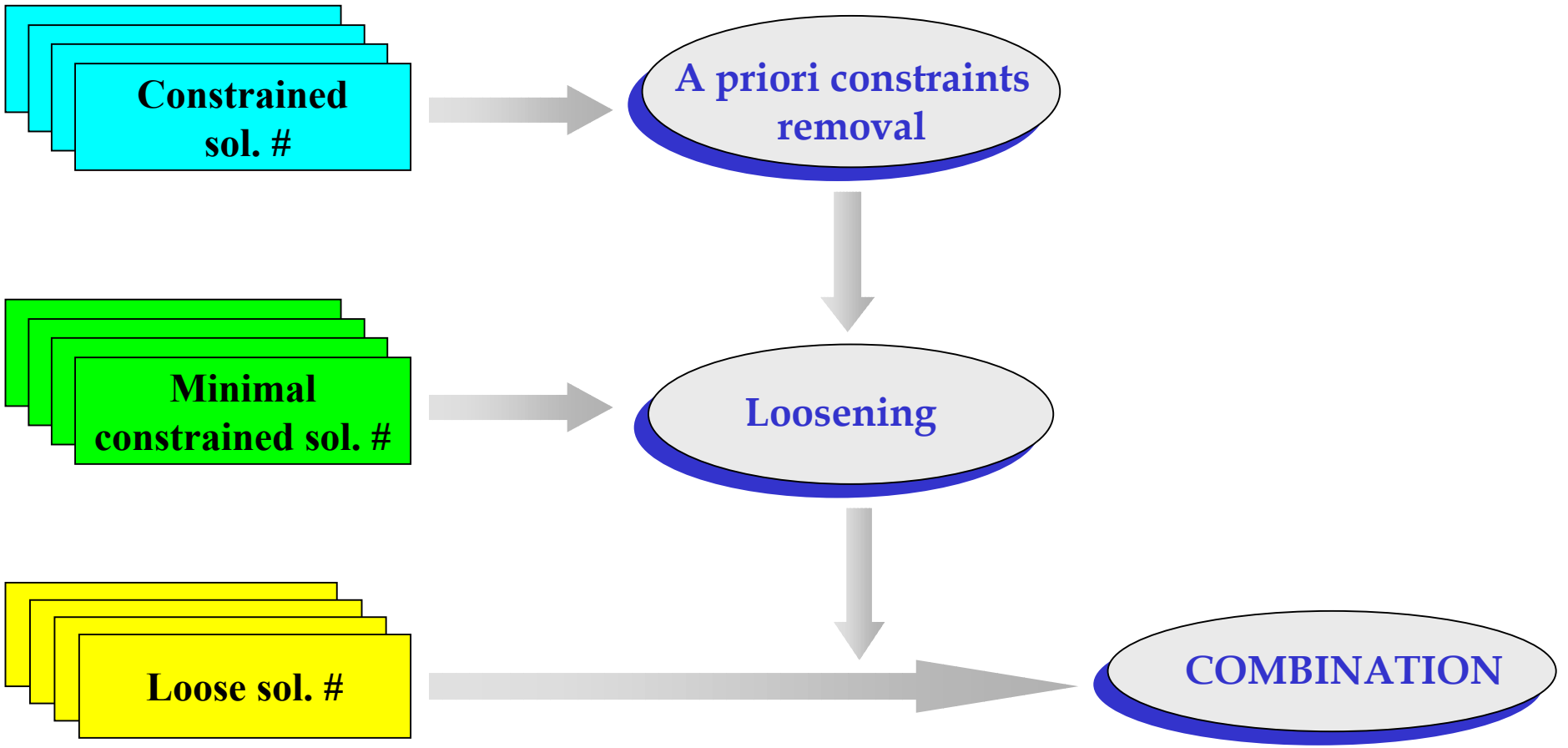
Fiducial approach (1/2)

The approach foresees the combination of solutions in the same reference frame. Since each solution has its own reference frame, at least a Helmert transformation shall be applied to each solution.



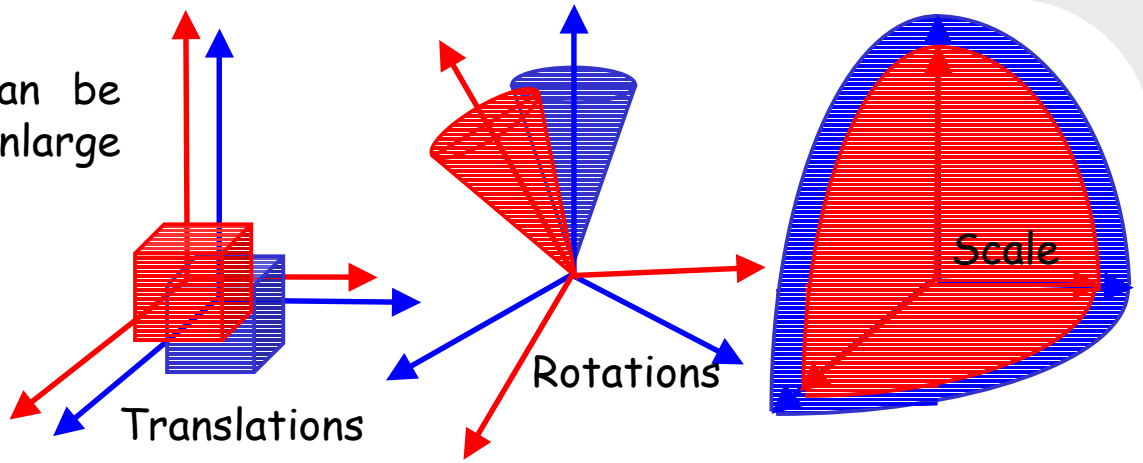
Loose approach (2/2)

The approach foresees an automatic combination of loose solutions without estimating and removing a relative rotation between their reference frames. A preprocessing is necessary in case of constrained solutions.



Combination equations

The solution covariance matrix can be loosened in order to artificially enlarge the reference frame uncertainties.



$$\mathbf{C}' = \mathbf{C} + \mathbf{ALA}^{\mathrm{T}}$$

where:

- $\mathbf{C}'$ is the 'loosened' covariance matrix
- $\mathbf{C}$ is the solution covariance matrix
- $\mathbf{A}$ is the design matrix as defined above
- $\mathbf{L}$ is a diagonal matrix defining the degree of looseness

Under this conditions the reference frame biases are no more estimable and the Helmert transformation parameters could be treated stochastically. The design equations are simple identities between couples of solutions.

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

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

The ASI/CGS combination service for ILRS

Service operational requirements

Frequency: weekly

Issue: within 24:00 UT each Wednesday (CD)

Input: AC solution SINEX files available at 24:00 UT the day before (CD-1)

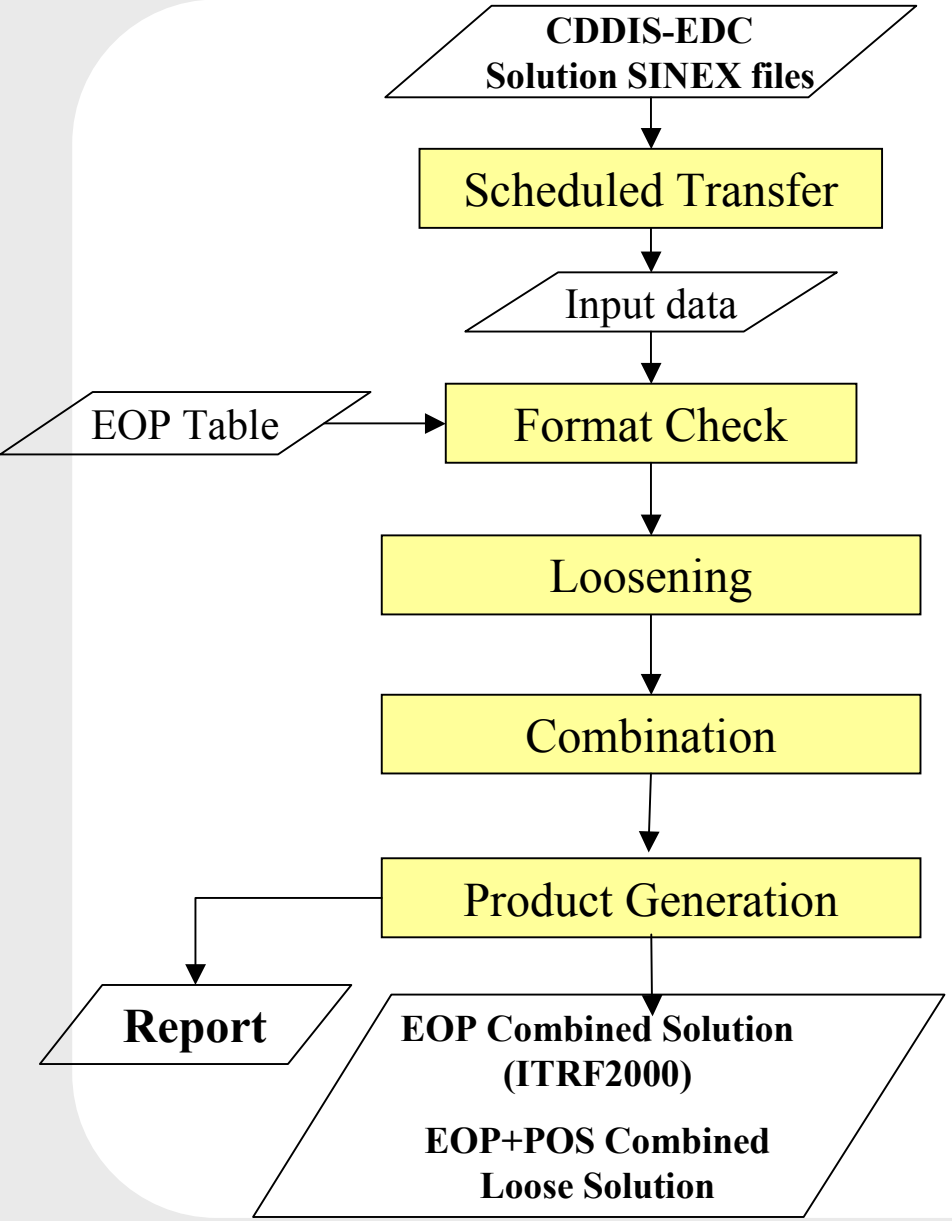
Parameters: Site Coordinates and EOP (x, y, LOD)

Procedure strategy

- Pre-processing (format check, loosening)
- Combination (normals, editing, iterations)
- Quality check and delivery

The whole processing chain is completely automated

Procedure overview



1) Reads sequentially the SINEX solution files and verify data integrity

2) First rough outlier detection (and loosening) of each input solution

3) Combination of the loosened solutions:

- Data editing
- Scale factor computation
- Solve normal equations

4) Construction of the combined products and issue of the quick look report:

- ITRF2000 frame transformation & delivery
- Summary Report
- Archiving

Procedure remarks

- The implemented SW procedure has been realized in the Matlab environment (Matlab functions + F90 subroutines).
- At present, the procedure runs on a PC; we plan to move it to HP WS.
- The procedure is completely automated and can be activated without human intervention.

Scale factor estimation

The solution scale factor f_i is such that the **reduced** χ^2 of the combination is close to unity and that each solution contribution to the total χ^2 is equally balanced. The first guess for the combination is obtained with f_i =1 for each solution:

Condition 1:

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

Condition 2:

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

$$\Rightarrow \quad f_i = \frac{N}{DoF} R_i^T (C_i)^{-1} R_i$$

Where R_i and C_i are respectively the solution residuals and covariance matrix, N the number of contributing solutions, and DoF the solution degrees of freedom.

Example of estimated variance-covariance scale factor

Solution week	ASI-	DGFI	GFZ-	NERC	JCET
031008	7	15	11	32	-
031015	12	25	10	29	-
031022	11	30	10	39	-
031029	25	-	6	-	-
...					
040310	5	5	6	4	2
040317	4	6	2	2	5
040324	4	8	5	5	3
040331	6	4	4	2	3

Contributing input solutions

ASI, DGFI, GFZ, NERC and JCET 28-d and 7-d weekly solutions have been combined. Solutions contain SSC and EOP according to the ILRS Pos+EOP Pilot Projects requirements, and have different characteristics listed below.

Contributing Solutions	ILRS contribution start	ASI combination start	SINEX Solution Covariance Information	LOOSENESS (7-day weekly solutions)				
				Translations mm		Rotations mas		Scale ppb
				Tx,Ty	Tz	Rx, Ry	Rz	
				"order of"				
ASI	030630	030714	U COVA	1	2	8	15	0.10
DGFI	030707	030714	L COVA	1	2	4	8	0.10
GFZ	030630	030922	L INFO	1	2	10	10	0.10
NERC	031006	031006	L COVA	2	5	3	5	0.20
JCET	040221	040221	U COVA	2	5	5	10	0.10

Input solutions features vs SW procedure

Several features of the contributing solutions (e.g. the covariance issue), the new requirement on arc length, SINEX format imprecisions have contributed to the evolution of the SW procedure from an initial, prototype version to a more refined and operationally robust version.

Issued products

- **EOP-only SINEX file (ITRF2000-framed solution)**

  Header, File/Reference, Input/History, Solution/Statistics, Solution/Estimate, Solution/Matrix_Estimate L Cova

- **Pos+EOP SINEX file (loose solution)**

  Header, File/Reference, Input/History, Solution/Statistics, Solution/Epochs, Site/Id, Site/Eccentricity, Solution/Estimate, Solution/Matrix_Estimate L Cova

- **Summary Report**

Summary Report

Centro Geodesia Spaziale, Agenzia Spaziale Italiana, Matera, ITALY
Report on the combination of ILRS solutions.
File: asi.pos+eop.yymmdd.sum
Software: CoGeoS/Matlab
Hardware: PC PentiumIII
Contact: cecilia.sciarretta@asi.it

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|========================|
| CONTRIBUTING SOLUTIONS |
|========================|
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Legend:
Core Sites are labeled with a 'C' after the site ID.
Edited Sites are labeled with an asterisk '*' before the site ID
Edited EOP values are labeled with an asterisk '*' after the epoch

CHECKING SINEX FILES

--
sol1.yymmdd.snx, - passed (or diagnostics).
...
soln.yymmdd.snx, - passed (or diagnostics).

Summary Report (cont'd)

for each contributing solution

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sol1.yymmdd.snx

ITRF2000 TRANSFORMATION:
estimated Helmert parameters [mm, mas, ppm]

Tx	Ty	Tz	Scale	Rx	Ry	Rz

Site coordinate residuals with respect to ITRF2000 [mm]

Sigma's scaled by the factor: sqrt(chi2) = x.xx

Dome Num.	Site	X	Y	Z	sigX	sigY	sigZ	3-DWRMS
.....								

Global WRMS of 3-D residuals: xx.xx mm

EOP residuals with respect to Bull.A (daily), after ITRF2000 transformation [µas, µs]

EPOCH	X-pole	Y-pole	LOD	sig-X	sig-Y	sigLOD
mjd	(µas)	(µas)	(µs)	(µas)	(µas)	(µs)
...						
W-MEAN (µas)	xxx.x	xxx.x	xxx.x			
STD (µas)	xxx.x	xxx.x	xxx.x			

Preliminary editing factor: 10.0
Number of manually edited parameters: N

Summary Report (cont'd)

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|======================|
| COMBINED ASI SOLUTION |
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SUMMARY OF COMBINATION PROCESS

INPUT SINEX FILES:

#	Agency	Filenames	Sites	EOP	EOPr	Edit Pars	Scale	ChiSquare

GLOBAL RESULTS:

Number of iterations, ChiSquare, RedChiSq, Estimated parameters, DoF, Editing Factor, No. of edited parameters

RESIDUALS WITH RESPECT TO THE COMBINED SOLUTION

Coordinate residuals (WRMS) [mm]:

X	Y	Z	Up	East	North	Global	Edited

...

EOP RESIDUALS [µas, µs]:

Weighted Mean			Weighted RMS (about the mean)			Edited
X (µas)	Y (µas)	LOD (µs)	X (µas)	Y (µas)	LOD (µs)	

Summary Report (cont'd)

TRANSFORMATION PARAMETERS WITH RESPECT TO THE COMBINED SOLUTION

Estimated Helmert parameters [mm, mas, ppm]:

Tx	Ty	Tz	Scale	Rx	Ry	Rz

TRANSFORMATION ON ITRF2000

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estimated Helmert parameters [mm, mas, ppm]

Tx	Ty	Tz	Scale	Rx	Ry	Rz

Site coordinate residuals with respect to ITRF2000 [mm]

Sigma's scaled by the factor: sqrt(chi2) =

Dome Num.	Site	X	Y	Z	sigX	sigY	sigZ	3-DWRMS

Global WRMS of 3-D residuals: xx.xx mm

EPOCH	X-pole	Y-pole	LOD	sig-X	sig-Y	sigLOD
mjd	(µas)	(µas)	(µs)	(µas)	(µas)	(µs)

W-MEAN (µas)

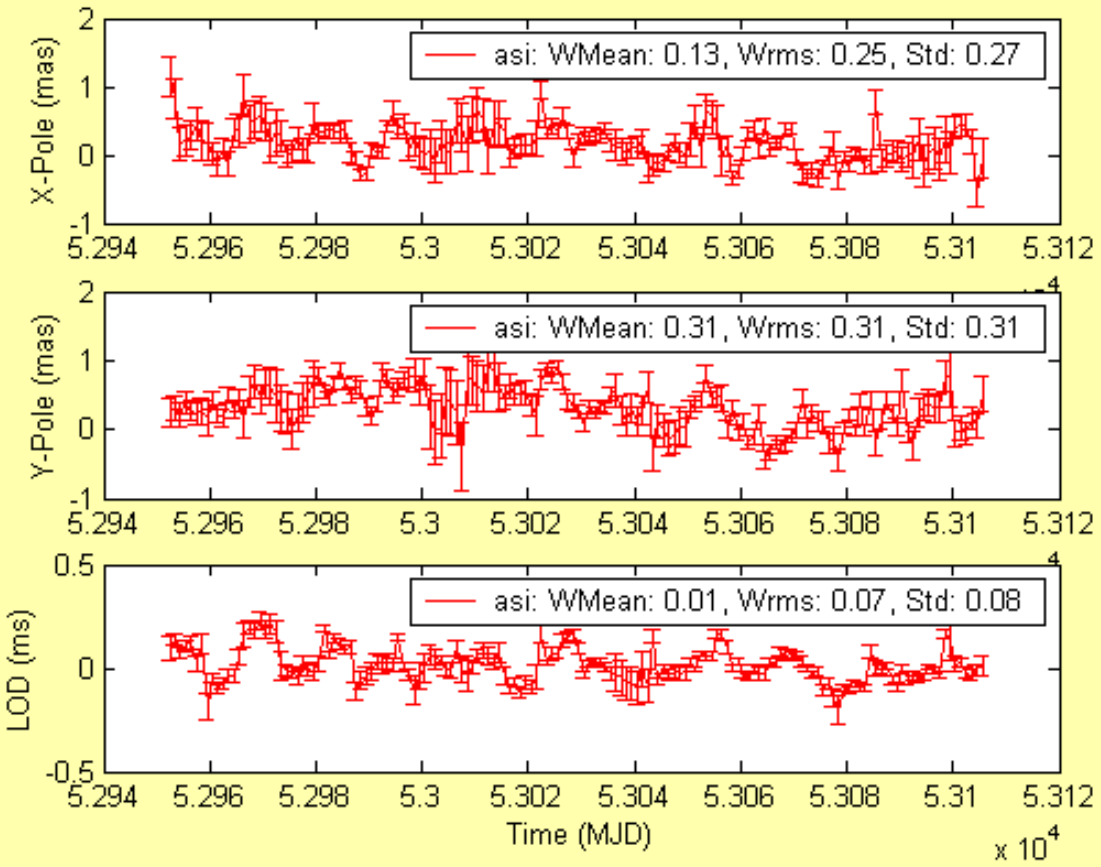
STD (µas)

Analysis results

In the following slides several results of the combined solution time series are presented.

EOP are the main objective of the solution, to contribute to the IERS operational products; combined site coordinates, anyway, are useful to verify the quality of the solution, in terms of comparison w.r.t. ITRF2000 and w.r.t other combined solutions.

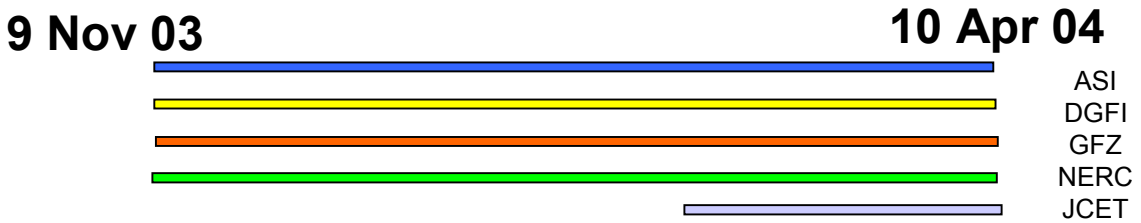
ASI combined solution vs IERS EOP



IERS EOP "finals.data" as reference

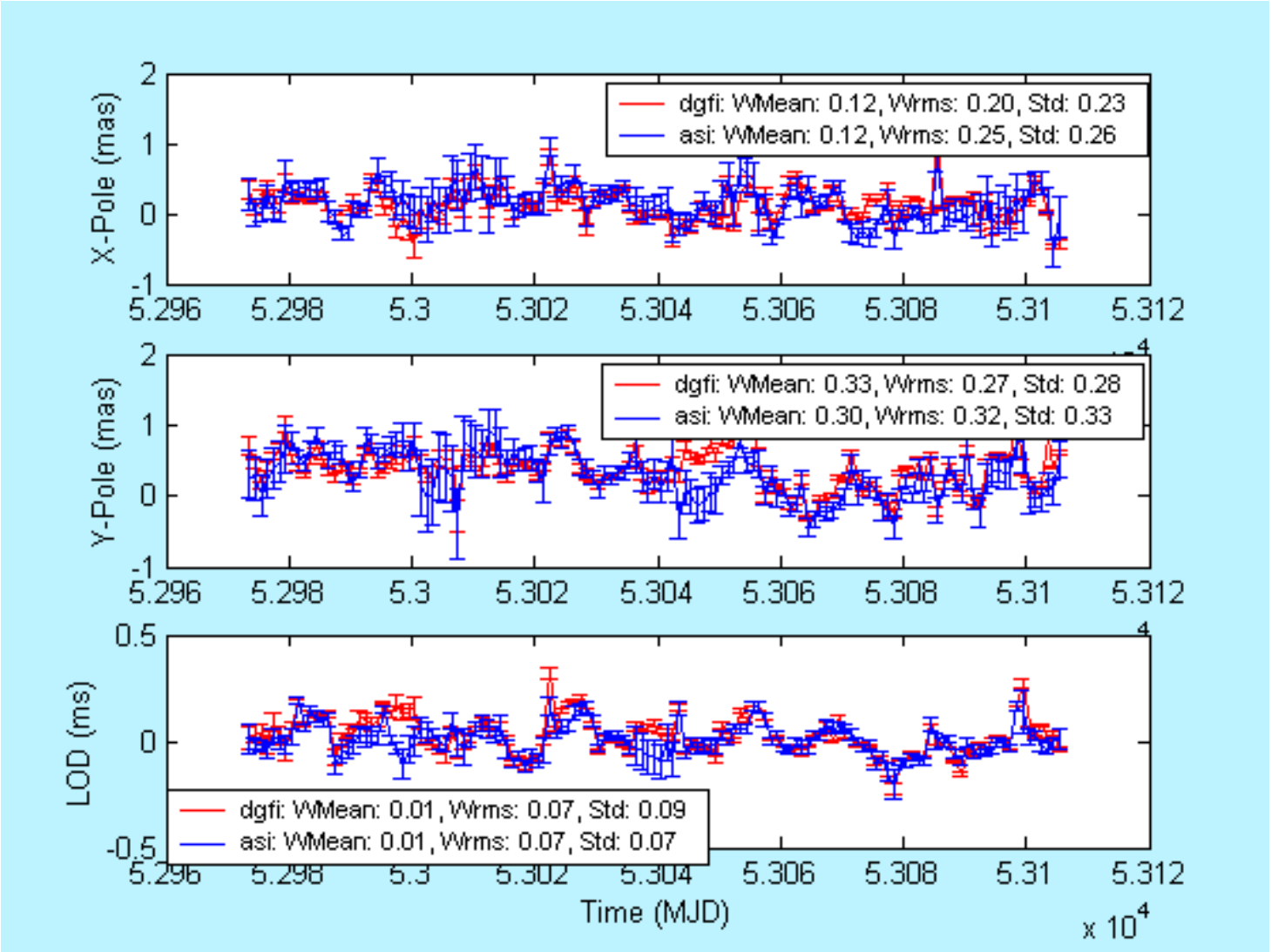
ASI 7-day weekly combined solutions only

ASI combined solutions 040117 and 040131 have been recomputed!



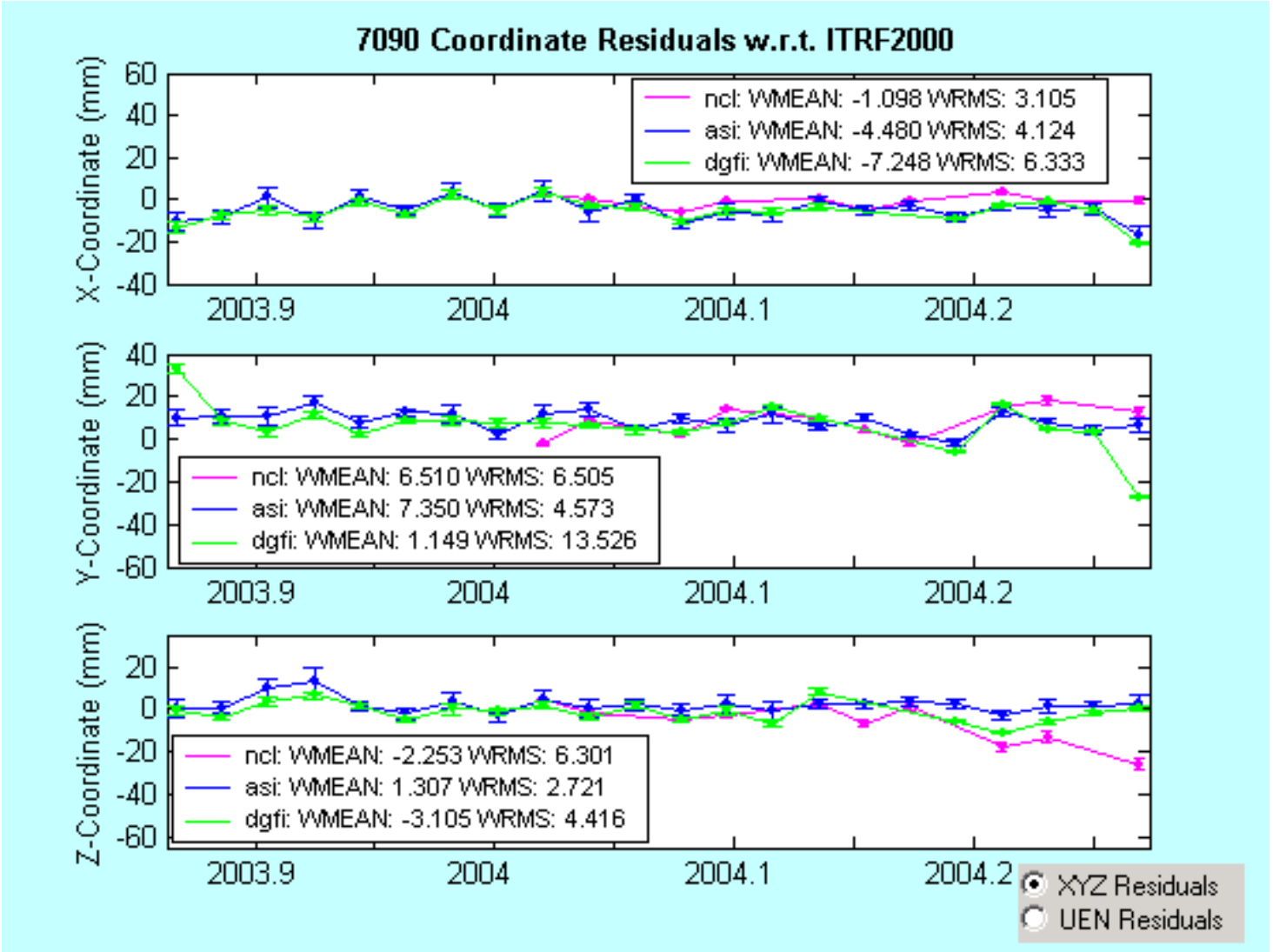
EOP Comparison ASI/DGFI

031206 - 040410



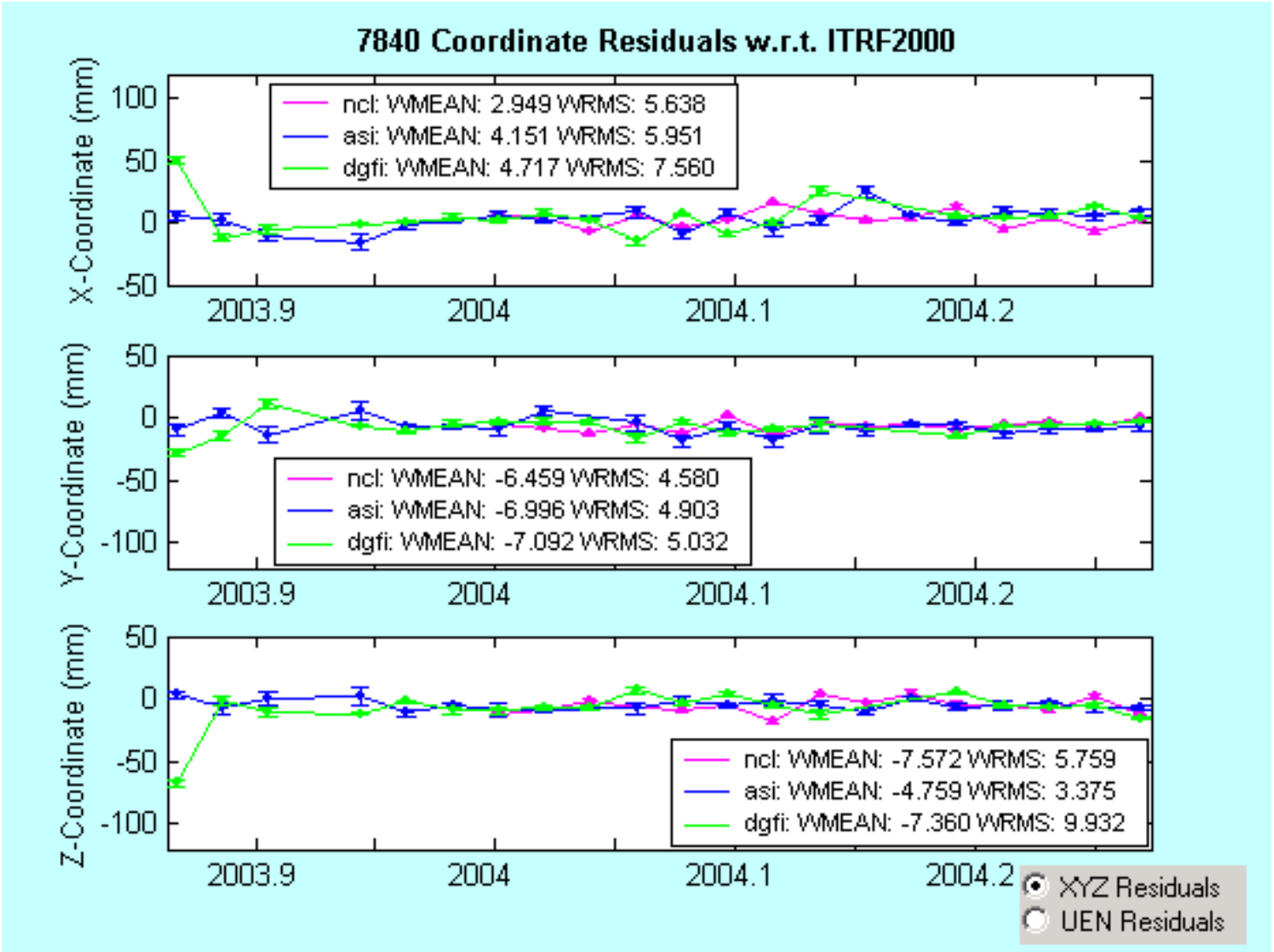
Site Position Comparison ASI/DGFI/NCL

examples



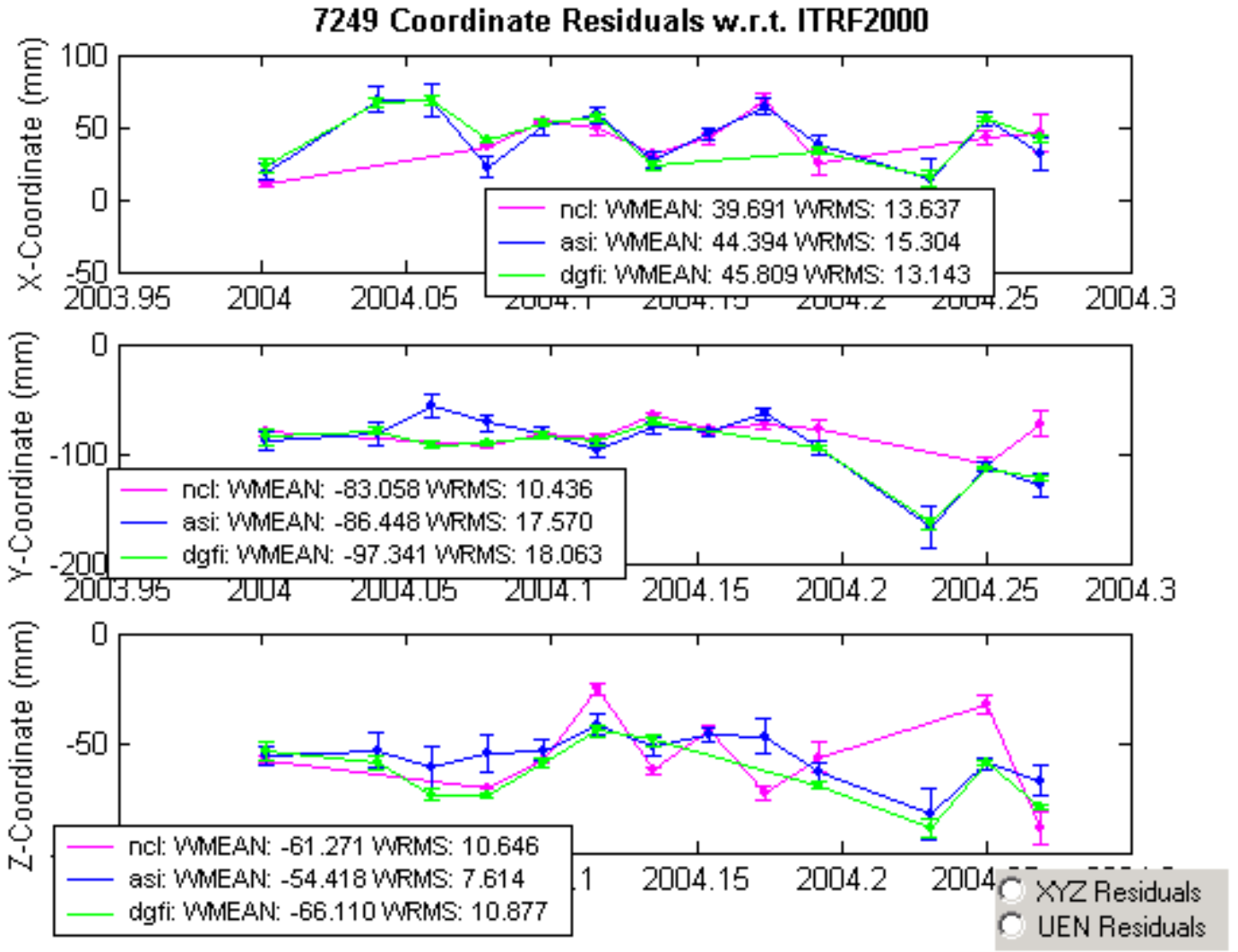
Site Position Comparison ASI/DGFI/NCL

examples



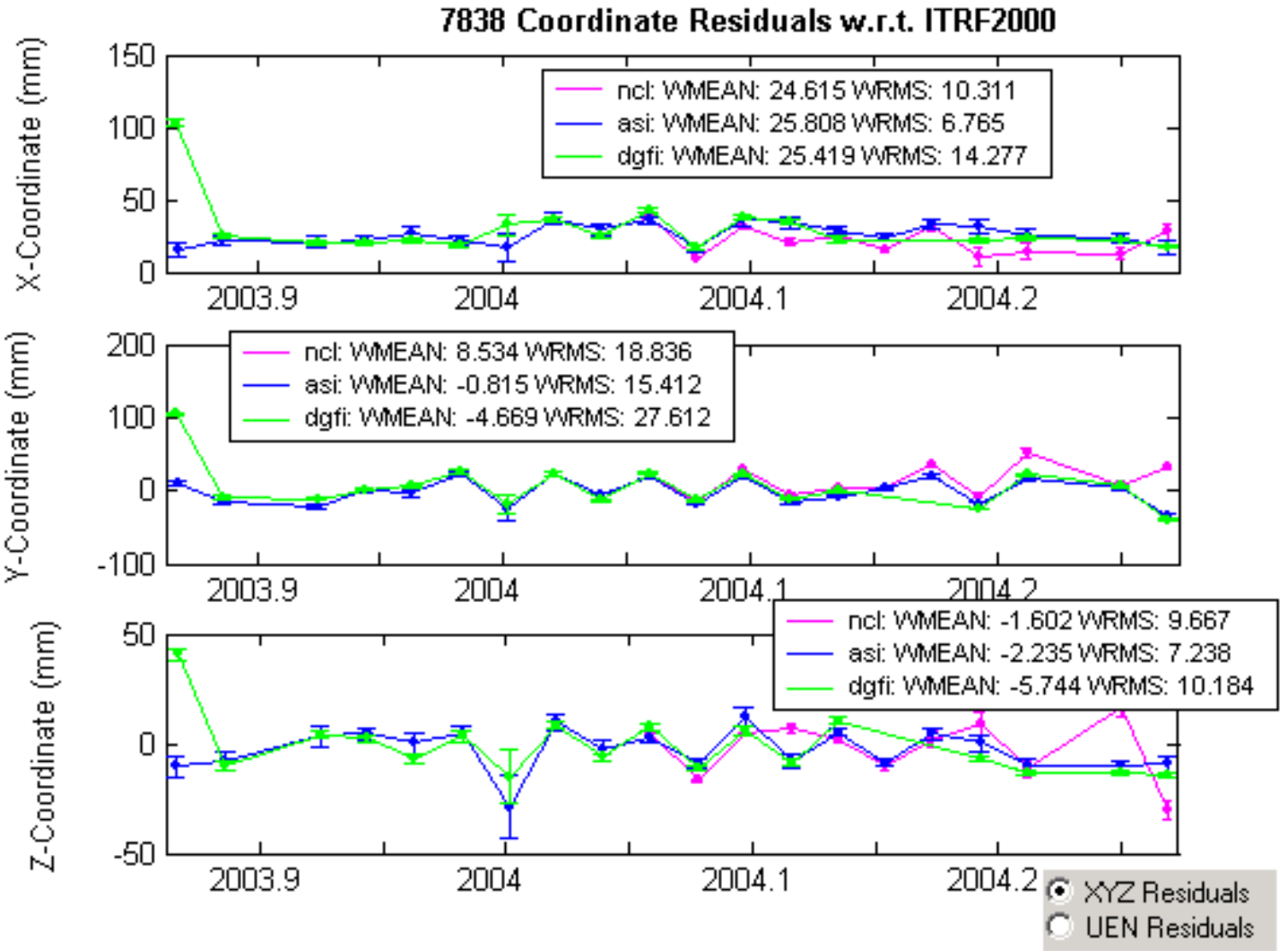
Site Position Comparison ASI/DGFI/NCL

examples



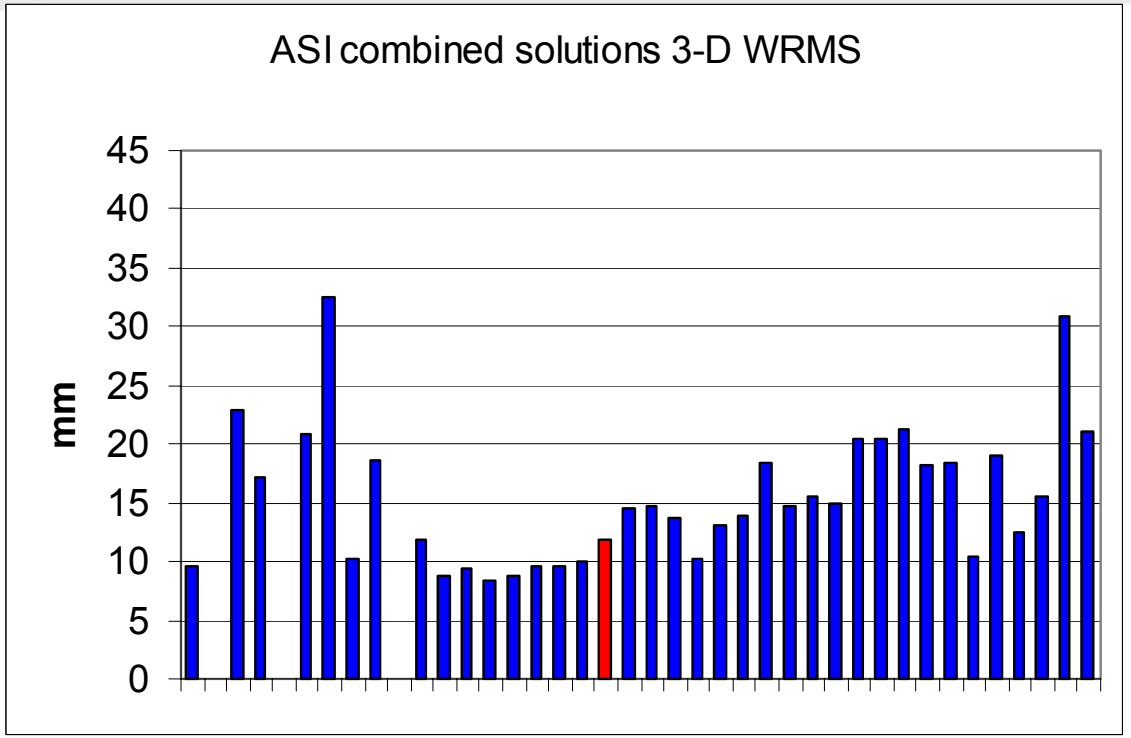
Site Position Comparison ASI/DGFI/NCL

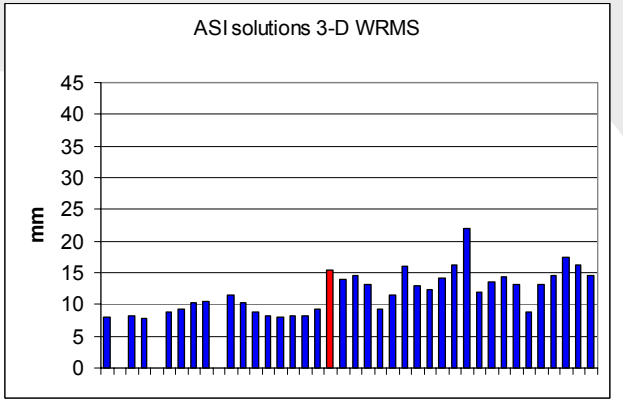
examples

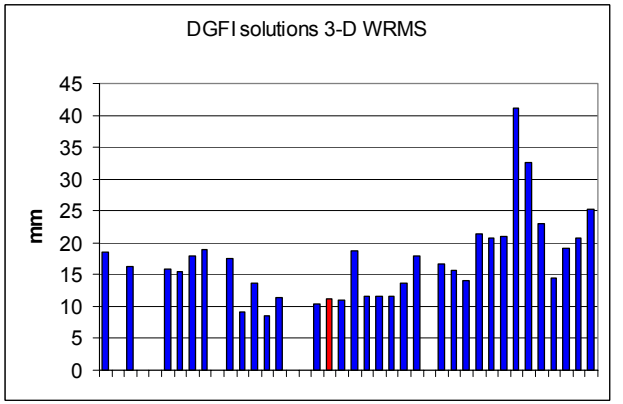


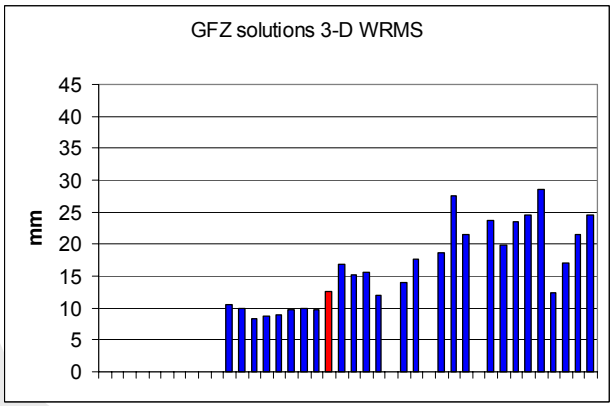
Global WRMS of 3-D position residuals vs time

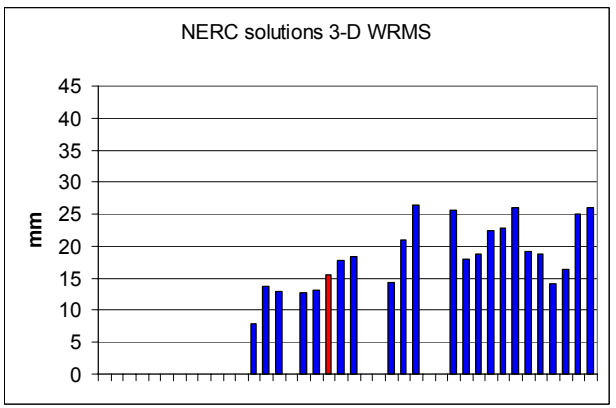
030716 - 040410

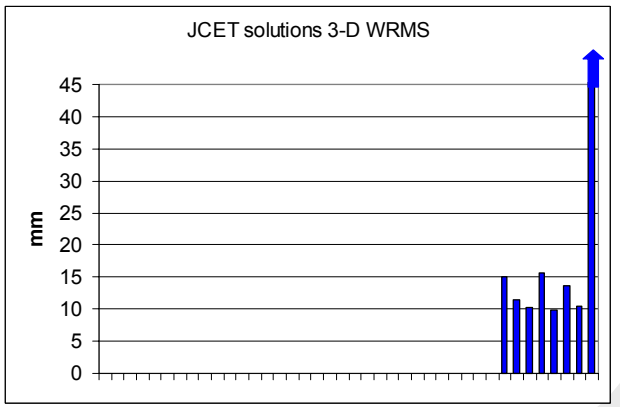












Conclusive remarks

- ASI combined solution for ILRS Pos+EOP Pilot Project has been submitted since 030716, regularly (in terms of frequency and of contributing solutions handled) since 030924. It is compliant with the Pilot Project reqs after 031115 (7-day arc solutions).

- ASI combined solution implements a 'loose' approach within a fully automated procedure.

- The implemented 'loose' approach has provided consistent results with respect to the apriori reference values (IERS Bulletin A, ITRF2000) and with respect to the other combined solutions.

Conclusive remarks (cont'd)

- The 3-D WRMS of the coordinate residuals (w.r.t. ITRF2000) of the ASI 7-day combined weekly solutions, is about 15 mm (10 mm for the 28-day combined weekly solution).
- The 3 combined solutions (ASI, DGFI, NCL) show similar behavior for site coordinates time series.
- EOP & EOP-rate residuals (w.r.t. IERS Bulletin A):
  - -the Wmean of the ASI combined X and Y pole residuals are about 0.1 an 0.3 mas respectively, with a scatter about 0.3 mas;
  - -LOD residuals are on the order of 0.01 ms with a scatter of 0.07 ms;
  - -similar patterns are visible in the residual time series of different combined solutions (ASI, DGFI)