

*Combination at the
Observation Level
IERS Working Group*



IERS COL-WG project GRGS COMBINATION CENTRE

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COL-WG Munich May 2012

COL-WG participants and software packages

Analysis Centres

Techniques

Software

AIUB/BKG
DGFI

SLR, GNSS
SLR

VLBI

Bernese 5.1
DOGS 5.0
OCCAM 6.1 LSM

ESOC

SLR+GNSS, +DORIS

NAPEOS

GFZ

SLR+GNSS

EPOSOC 06.61

GRGS

SLR, GNSS, VLBI, DORIS

GINs/DYNAMO

ASI

SLR

GEODYN/SOLVE

TUW

VLBI

VieVS

GSFC

SLR, GNSS, DORIS

GEODYN/SOLVE

OPA

VLBI

CALC-SOLVE

Combination Centres

DGFI

DOGS-CS

GRGS

DYNAMO

Participating groups & normal equations delivered

	DORIS	GPS	SLR	VLBI	Pre Combined
ASI	expected				
AIUB/BKG		daily	weekly		
DGFI			weekly	daily	
ESOC			Expected		DORIS + SLR weekly GPS + SLR weekly
GSFC	Expected	Expected	Expected	Expected	
GFZ					GPS + SLR daily
GRGS	Weekly	Weekly	Weekly	weekly	
TUW				daily	
OPA				weekly	

Delivered SINEX on ftp site: <ftp://hpiers.obspm.fr/iers/eop/grgs/>

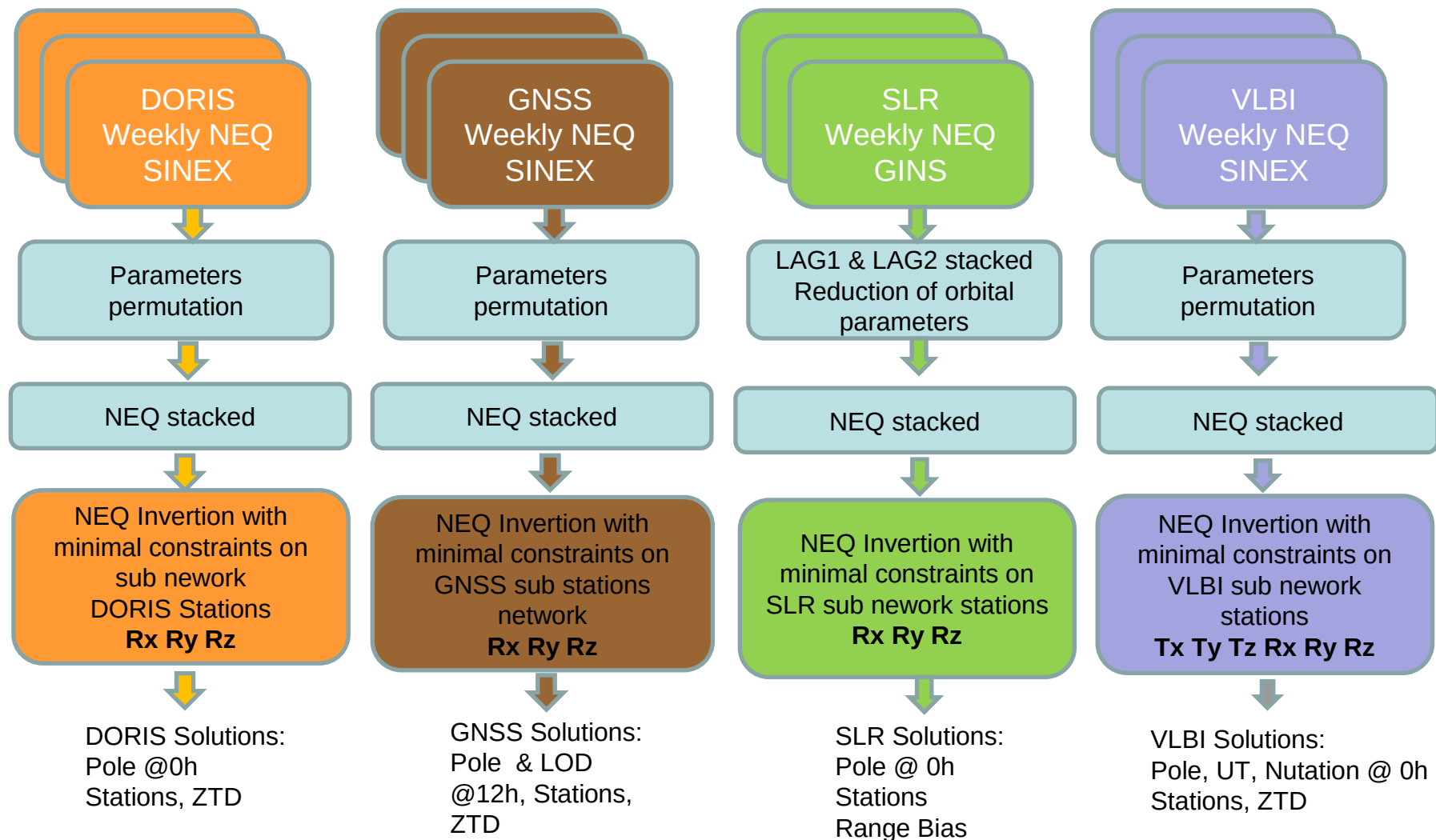
Analysis Center	SLR	GNSS	VLBI	DORIS	Pre combined
AIUB/BKG	Delivered 22-May-2012 SINEX version n3 CONT08 & CONT11	Delivered 14-Nov-2011 SINEX version n3 available			
ASI	Expected				
DGFI	Delivered 11-Oct-2011 SINEX version 02 available		Delivered 07-Jun-2011 SINEX version n2 available		
ESOC	Expected				SLR-GPS expected SLR-DORIS expected
GFZ					SLR-GPS expected Old version n1, October 2010
GRGS	Delivered CONT08-CONT11 10-May-2012 GINS version n4	Delivered CONT08- CONT11 14-May-2012 SINEX version n8 available	Delivered CONT08-CONT11 24-May-2012 SINEX version n5 available	Delivered CONT08- CONT11 16-May-2012 SINEX version n6 available	
GSFC	Expected	Expected	Excepted	Expected	
OPA			Delivered 05-Oct-2011 SINEX version n1 available		
TUW			Delivered CONT08-CONT11 16-May-2012 available		

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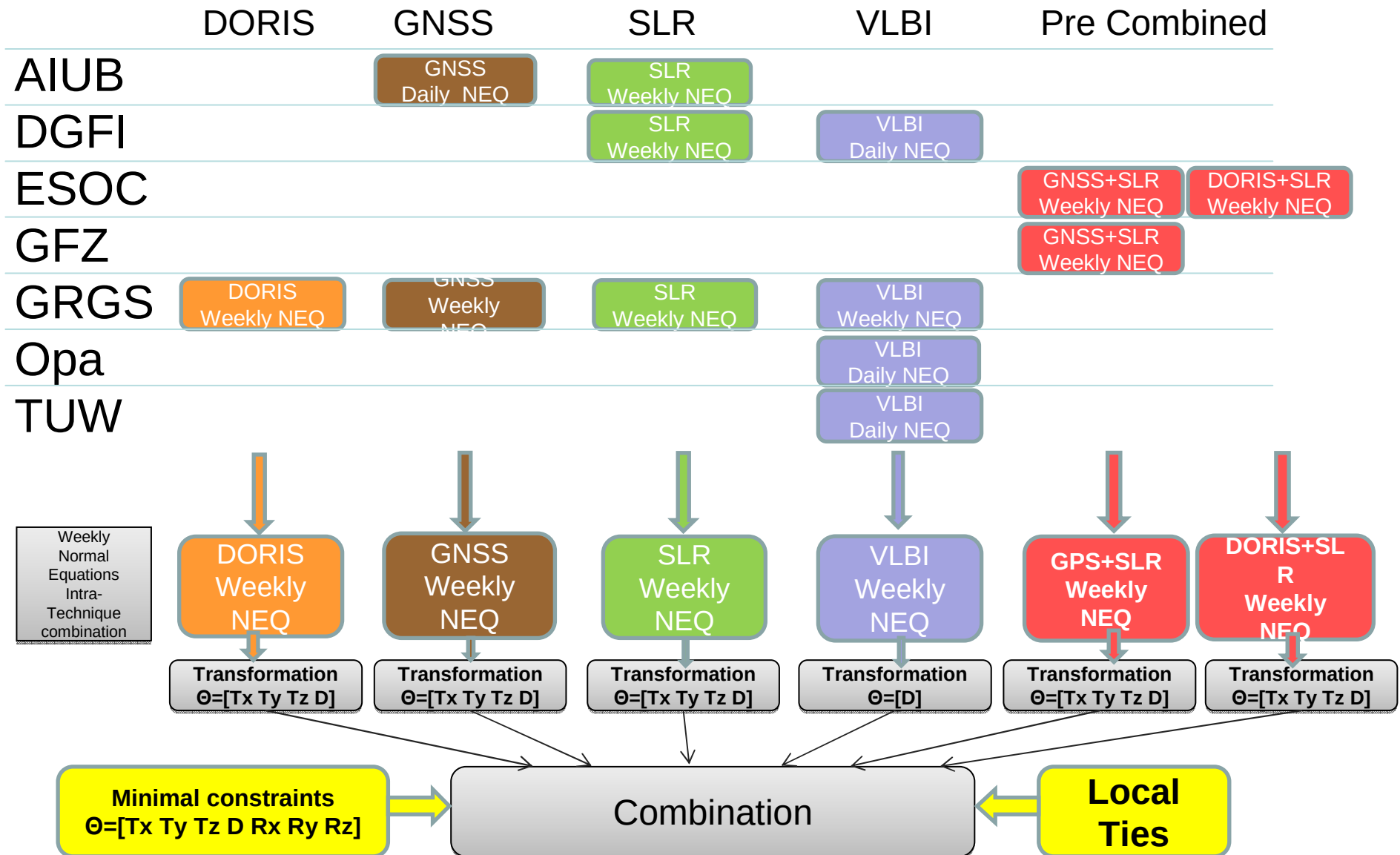
PARAMETERIZATION for Combination

<i>Parameters</i>	<i>Implementation into SINEX files</i>	<i>Initial values</i>
Pole, UT1-UTC or UT1-TAI	XPO, YPO, UT : Offset + Drift at 12h or PWL at 0h	IERS EOP 08-C04
Pole Rate	XPOR, YPOR 1pt/day at 12h	Set to 0
LOD	LOD 1pt/day at 12h	IERS EOP 08-C04
Nutation angles	NUT_X, NUT_Y corrections to the model IAU2000	IERS EOP 08-C04
Station coordinates	SX, SY, SZ at mid epoch	ITRF2008
Radio sources coordinates	RS_RA, RS_DE 1pt/week	ICRF2
Zenithal Trop. Delay Wet comp. (TROWET) and horiz. gradients (TGETOT,TGNTOT) limited to 7 stations	TROWET: Adjustment of the wet component to the model Every 2-hours or Every 1 hour: TGETOT, TGNTOT daily 00h	GPT/GMF model for radio waves & Mendes/Pavlis for optical waves

STRATEGY Intra-Technique Combination



STRATEGY Inter-Technique Combination



TRANSFORMATION for each Technique before combination

Normal equation per technique: $N \cdot \begin{bmatrix} \delta X^{RT}_{Tech} \\ CP \\ \alpha_{Tech} \\ \theta_{Tech} \end{bmatrix} = B \Rightarrow N_{new} \cdot \begin{bmatrix} \delta X^{RC}_{Tech} \\ CP \\ \alpha_{Tech} \\ \theta_{Tech} \end{bmatrix} = B_{new}$

δX^{RC}_{Tech} station coordinate corrections

CP common parameters for combination (EOP, Tropo ...)

α_{Tech} specific technical parameters (orbital parameters, bias ...)

θ_{Tech} transformation parameters $[T_x \ T_y \ T_z \ D]_{Tech}$ for satellite , $[D]_{Tech}$ for VLBI

RT: reference frame
of the Technique
RC: reference frame
of the combined
technique

$$N_{new} = C^T \cdot N \cdot C$$

$$B_{new} = C^T \cdot B$$

$$C = \begin{bmatrix} I & 0 & 0 & B_{Tech} \\ 0 & I & 0 & 0 \\ 0 & 0 & I & 0 \end{bmatrix}$$

For each stations $i=[1,n]$ with apriori $\begin{bmatrix} x^0_i \\ y^0_i \\ z^0_i \end{bmatrix} \Rightarrow B_{Tech} = \begin{bmatrix} B_{1_Tech} \\ \dots \\ B_{n_Tech} \end{bmatrix}$

For satellite technique

$$B_{i_Tech} = \begin{bmatrix} 1 & 0 & 0 & x^0_i \\ 0 & 1 & 0 & y^0_i \\ 0 & 0 & 1 & z^0_i \end{bmatrix}$$

For VLBI technique

$$B_{Tech} = \begin{bmatrix} x^0_i \\ y^0_i \\ z^0_i \end{bmatrix}$$

Implementation of the minimal constraints equations in DYNAMO

The minimal constraints condition is implemented in DYNAMO according to the paper of Sillard et al. (1991, Journal of Geodesy) “A review of algebraic constraints in terrestrial reference frame datum definition”. We have chosen version c) (page 69) of the proposed algorithms. In this version, the constraints added to the unconstrained normal equations system $N.X=S$ are:

$$B.X=B.X_D \pm \Sigma_{\theta} \quad (1)$$

where X_D are the coordinates of the stations in the target datum.

X_D can be X_0 , the initial value of the coordinates, or can be any realization of the terrestrial reference frame.

B is obtained from:

$$B=(D^TW D)^{-1}D^TW \quad (2)$$

And D is constructed from the similarity transformation of each set of station coordinates (or velocities), involving 7 (or 14) parameters noted θ .

$\theta=(T_x, T_y, T_z, k, \epsilon, \psi, \omega)$ three translations, one scale factor, three rotations

For each station i , we write 3 lines of matrix $D=(\Delta_1 \Delta_2 \dots \Delta_i \dots)^T$:

$$\Delta = \begin{pmatrix} 1 & 0 & 0 & x_i^0 & 0 & z_i^0 & -y_i^0 \\ 0 & 1 & 0 & y_i^0 & -z_i^0 & 0 & x_i^0 \\ 0 & 0 & 1 & z_i^0 & y_i^0 & -x_i^0 & 0 \end{pmatrix}$$

If less than 7 transformation parameters have to be constrained (for instance only the rotation parameters for SLR, GPS and Doris), then the corresponding columns of matrix D can be omitted.

In the formulation we have chosen, we can introduce a distinct weight for each station through the weighting matrix W acting on the sets of station coordinates ; we can also modulate the compliance of the solution to the selected datum through the weighting matrix Σ_θ relative to the 7 (or 14) parameters of transformation.

While the unconstrained system is written $N.X=S$, the constrained system is:
 $(N+B^T\Sigma_\theta B).X=S+B^T\Sigma_\theta BX_D$

preliminary POLE & UT solutions with GRGS multi-technique combination

techniques	weighting
GPS	0.1532E+00
VLBI	0.2937E-01
DORIS	0.9935E+00
SLR	0.4137E+01

Pole UT LOD (12H), Stations coordinates & troposphere
GPS+VLBI+DORIS+SLR CONT08 period

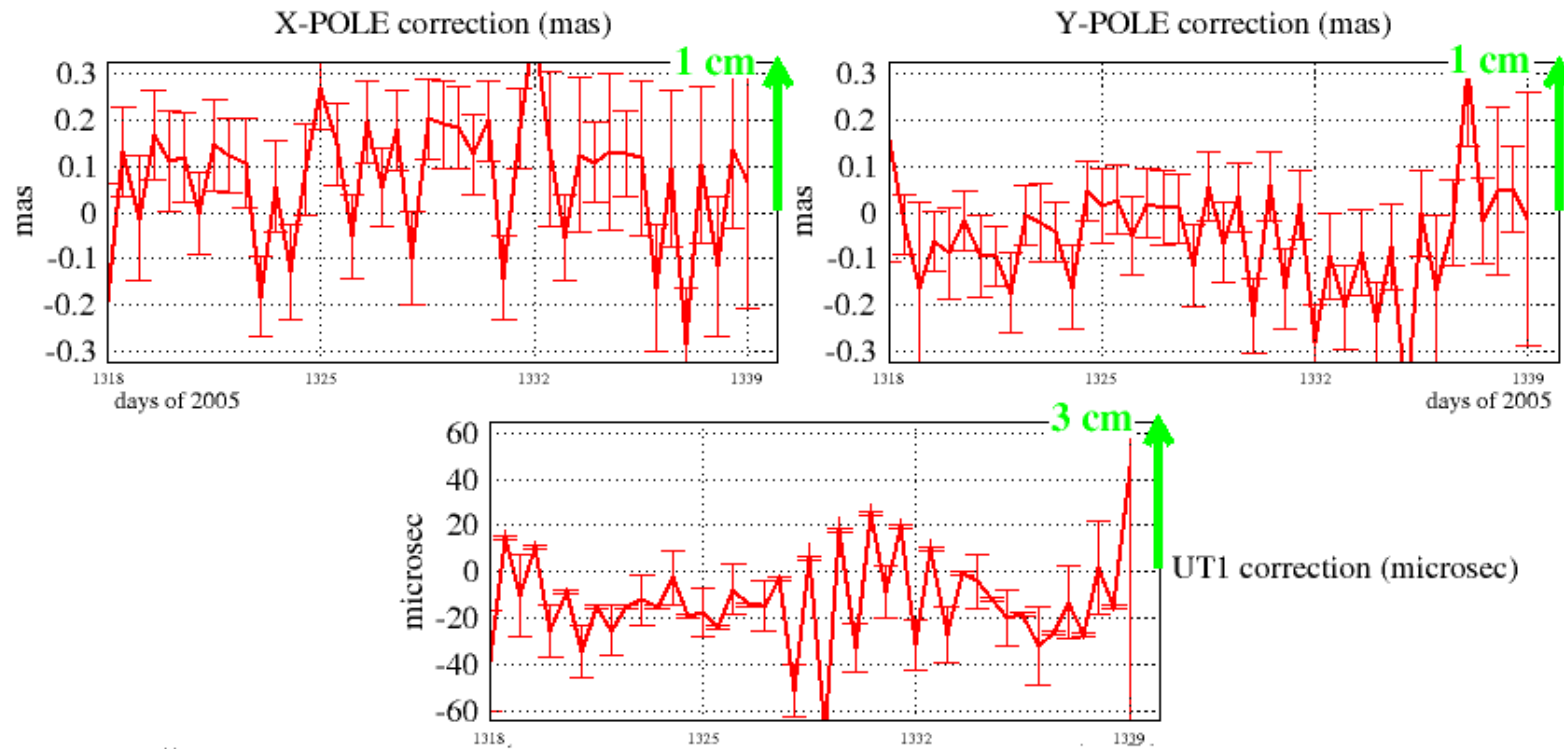
Nutation fixed, Pole rate fixed

Minimal Constraints on the 7 transformation parameters

X_pole corrections (std_dev): 0.136 mas

Y_pole corrections (std_dev): 0.102 mas

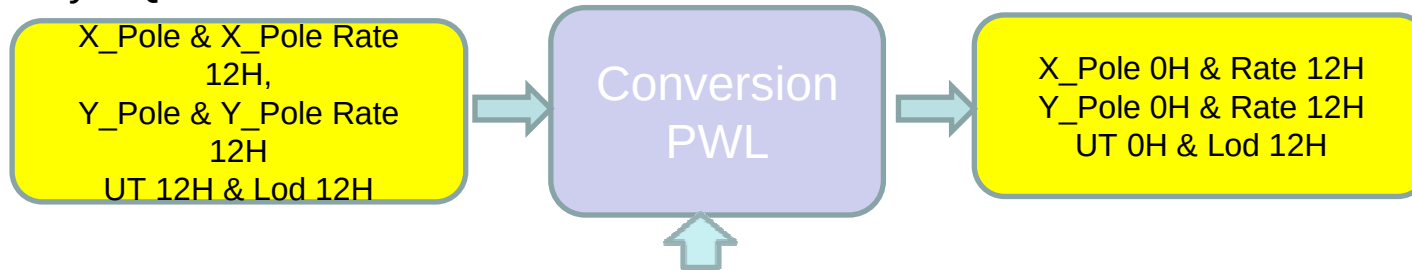
UT corrections (std_dev): 15.9 μ s, bias -5.3 μ s



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TRANSFORMATION EOP O+D 12H to BiaIs at 0H

Weekly EQNs GPS from GRGS

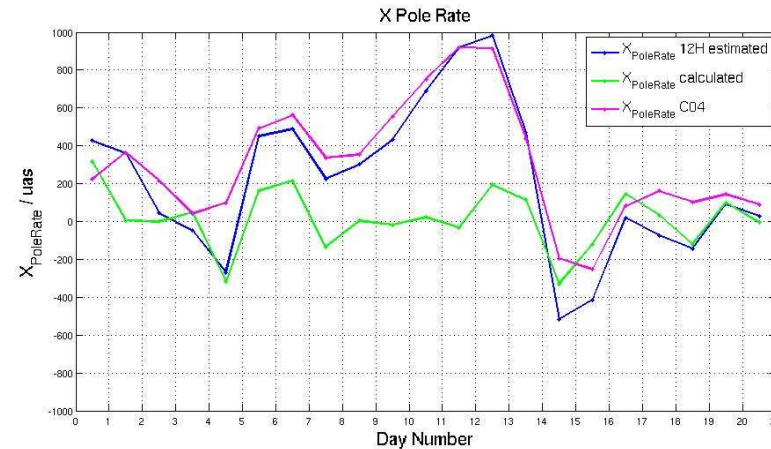
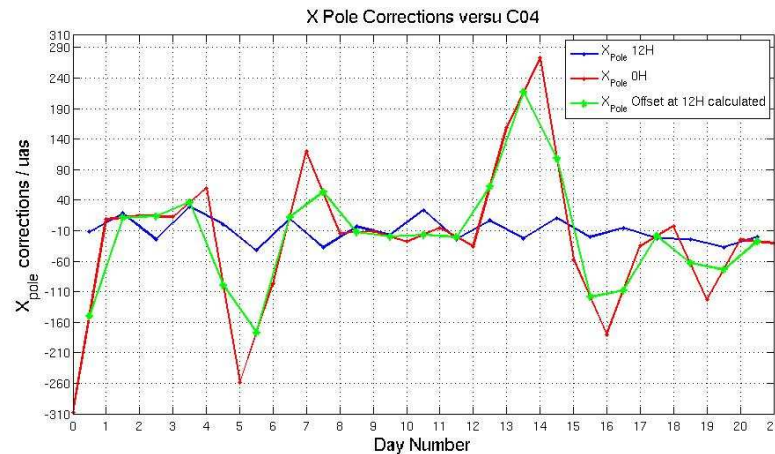


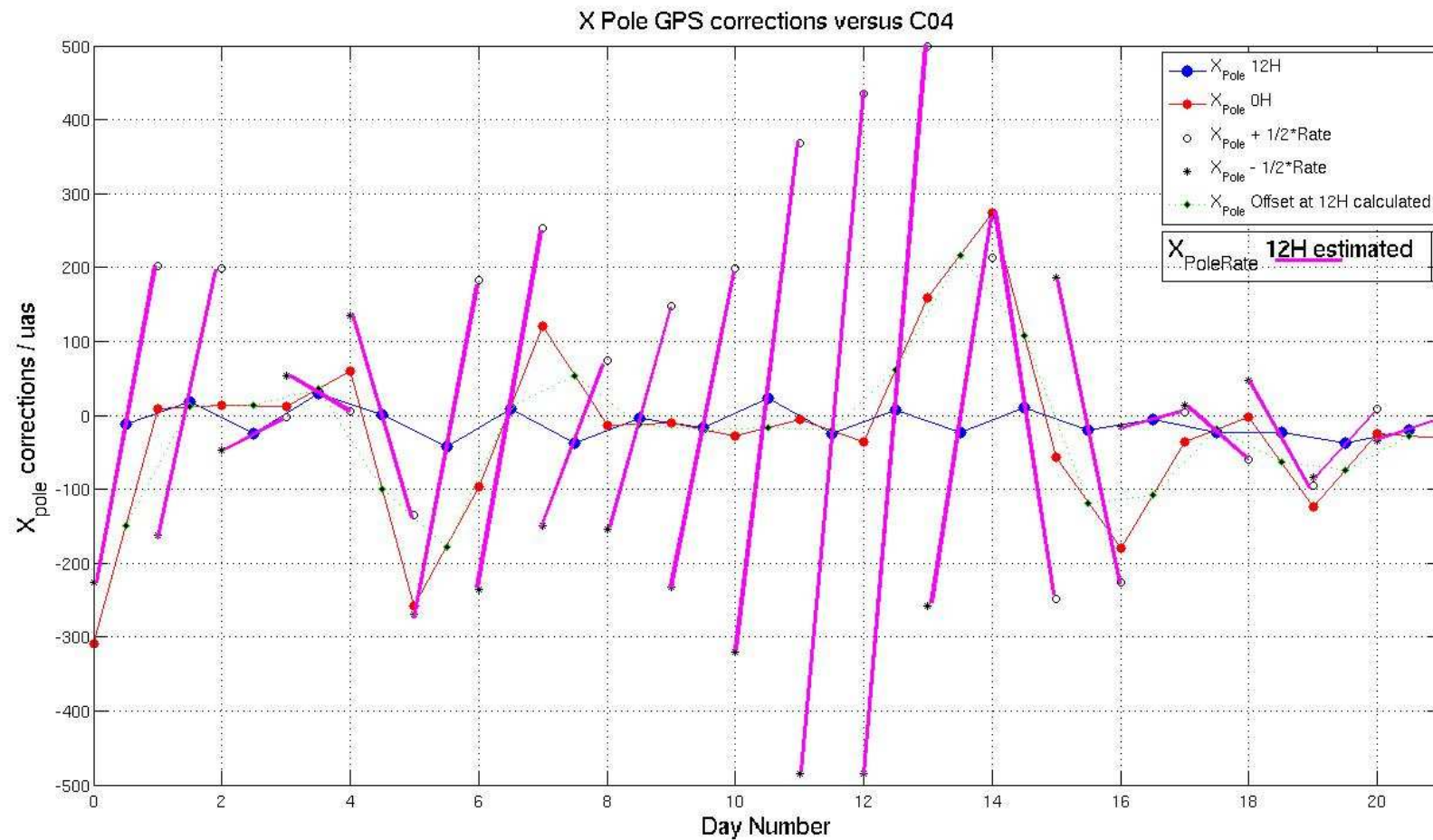
Constraint equations introduced

$$\begin{cases} 0,5 * \delta P_{j,0H} + 0,5 * \delta P_{j+1,0H} = \delta P_{j,12H} \pm \sigma_{\delta P} \\ \delta P_{j+1,0H} - \delta P_{j,0H} = \delta P'_{j,12H} \pm \sigma_{\delta P} \end{cases}$$

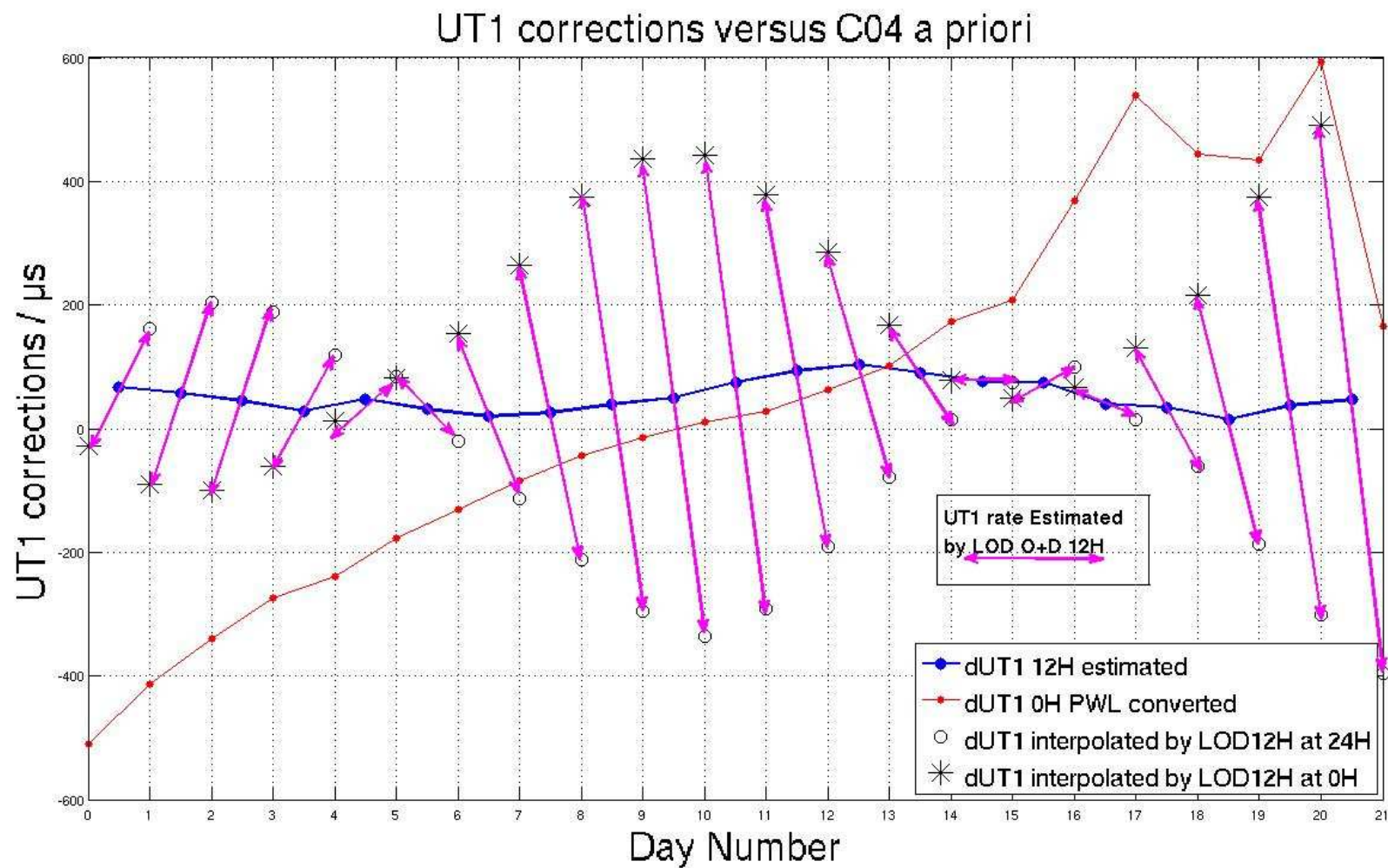
	Pole	Lod
$\sigma_{\delta P}$	0,2 μ as	0,09 μ s
$\sigma_{\delta P}$	0,3 μ as/d	0,13 μ s/d

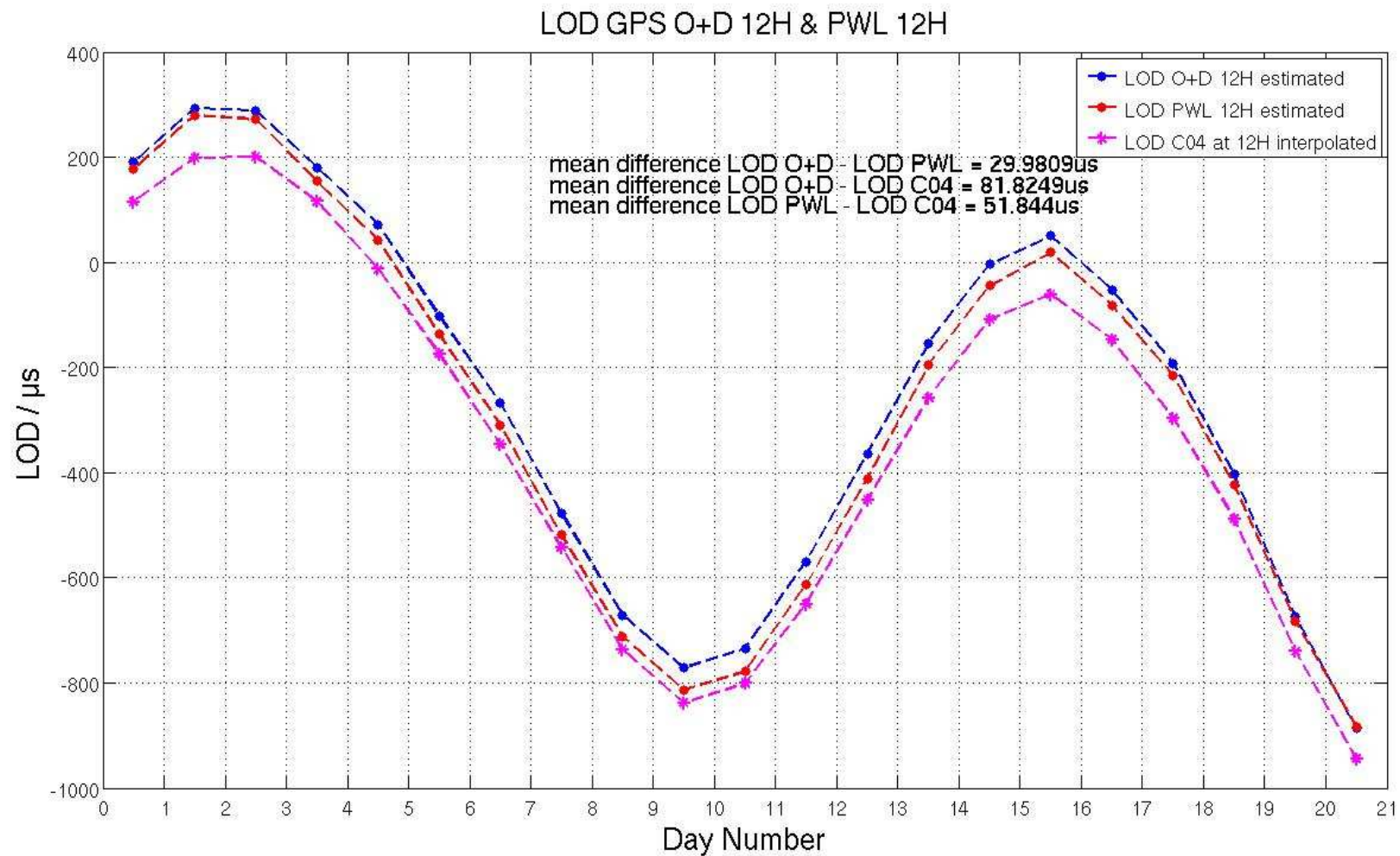
Weighting: 99% from constraint & 1% from EQN





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INTRODUCTION No Net Rotation Constraint for Celestial Frame

Estimation of a set of N radio sources through VLBI normal equation consists to impose transformation parameters (3 rotations) between the a priori and the estimated catalog to be zero: $\Theta = C.\Delta X$ where $\Theta = (A1, A2, A3)^T$ and ΔX the sources' coordinate offset to a priori values.

C is the matrix formed by:

$$C = (B^T.W.B)^{-1}.(B^T.W)$$

With the B matrix $(B_1, B_2, \dots, B_n)^T$ where B_i :

$$B_i = \begin{pmatrix} \cos(\alpha_i) \tan(\delta_i) & \sin(\alpha_i) \tan(\delta_i) & -1 \\ -\sin(\alpha_i) & \cos(\alpha_i) & 0 \end{pmatrix} \quad \begin{array}{l} \alpha_i \text{ is the right ascension} \\ \delta_i \text{ is the declination} \end{array}$$

We can introduce a distinct weight for each quasar coordinates through the weighting matrix W.

The constraint matrix to add to the unconstrained matrix is for Non Rotation condition:

$$N_c = W.C^T.C$$

<http://hpiers.obspm.fr/combinaison/>

Combinaison at the Observation Level

HOME

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FTP EOP C04

FORUM Combinaison

FTP COMBINED

The objective of the Working Group is to study methods and advantages of combining techniques at the observation level, searching for an optimal strategy to determine geodetic parameters such as Earth orientation Parameters (EOP) and both Terrestrial and celestial reference frames. One main goal is to bring together groups capable to do combinations at the observation level and to improve the homogeneity, precision and time resolution of the products. Further details can be found in the [Working group charter](#)

Tuesday, 22 May 2012

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Thanks to José Araujo, Olivier Becker & Teddy Carlucci

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Conclusion & Prospects

- EOP Offset+Drift at 12H to PWL at 0H conversion is to be re-considered (interpolated methods)
- Multi-technique combination processing is to pursue
- NNR condition have to be implemented for the celestial frame determination
- GINS to SINEX format is to upgraded
- Combination of Nutation parameters and troposphere parameters not consistent in GRGS normal equations
- Local tides to considered for the combination process
- Upgraded the combination web site