# IERS COL-WG project
# GRGS COMBINATION CENTRE

J-Y. Richard[(1)], D. Gambis[(1)], R. Biancale[(2)], J.M. Lemoine[(2)]

*(1) GRGS, Paris Observatory, SYRTE*
*(2) GRGS, CNES Toulouse*

COL-WG Munich May 2012

## COL-WG participants and software packages

| Analysis Centres | Techniques | Software |
|---|---|---|
| **AIUB/BKG** | SLR, GNSS | Bernese 5.1 |
| **DGFI** | SLR | DOGS 5.0 |
| | VLBI | 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<br>**GPS + SLR** weekly |
| **GSFC** | Expected | Expected | Expected | Expected | |
| **GFZ** | | | | | **GPS + SLR** daily |
| **GRGS** | Weekly | Weekly | Weekly | weekly | |
| **TUW** | | | | daily | |
| **OPA** | | | | weekly | |

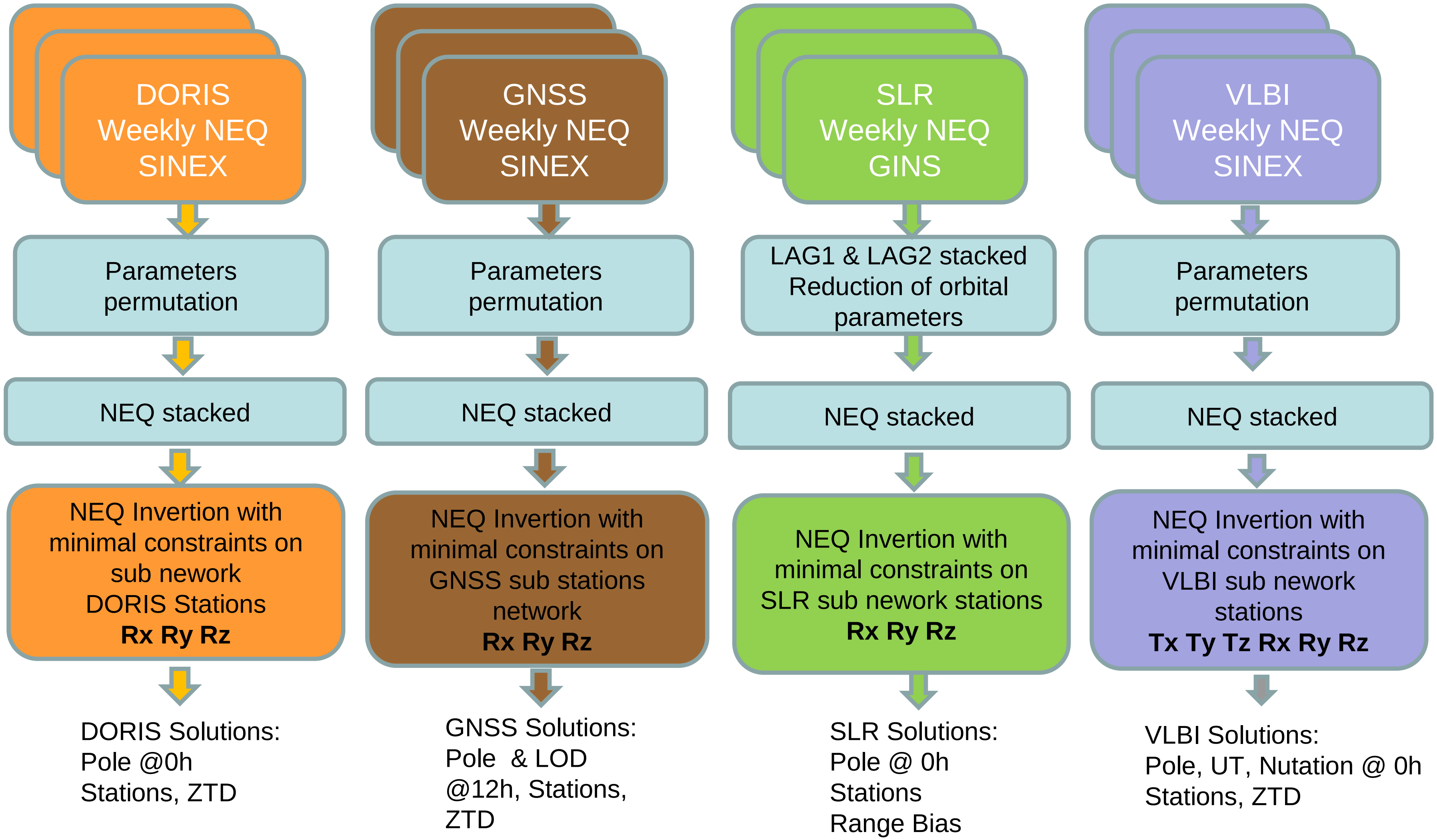
Delivered SINEX on ftp site: ftp://hpiers.obspm.fr/iers/eop/grgs/

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

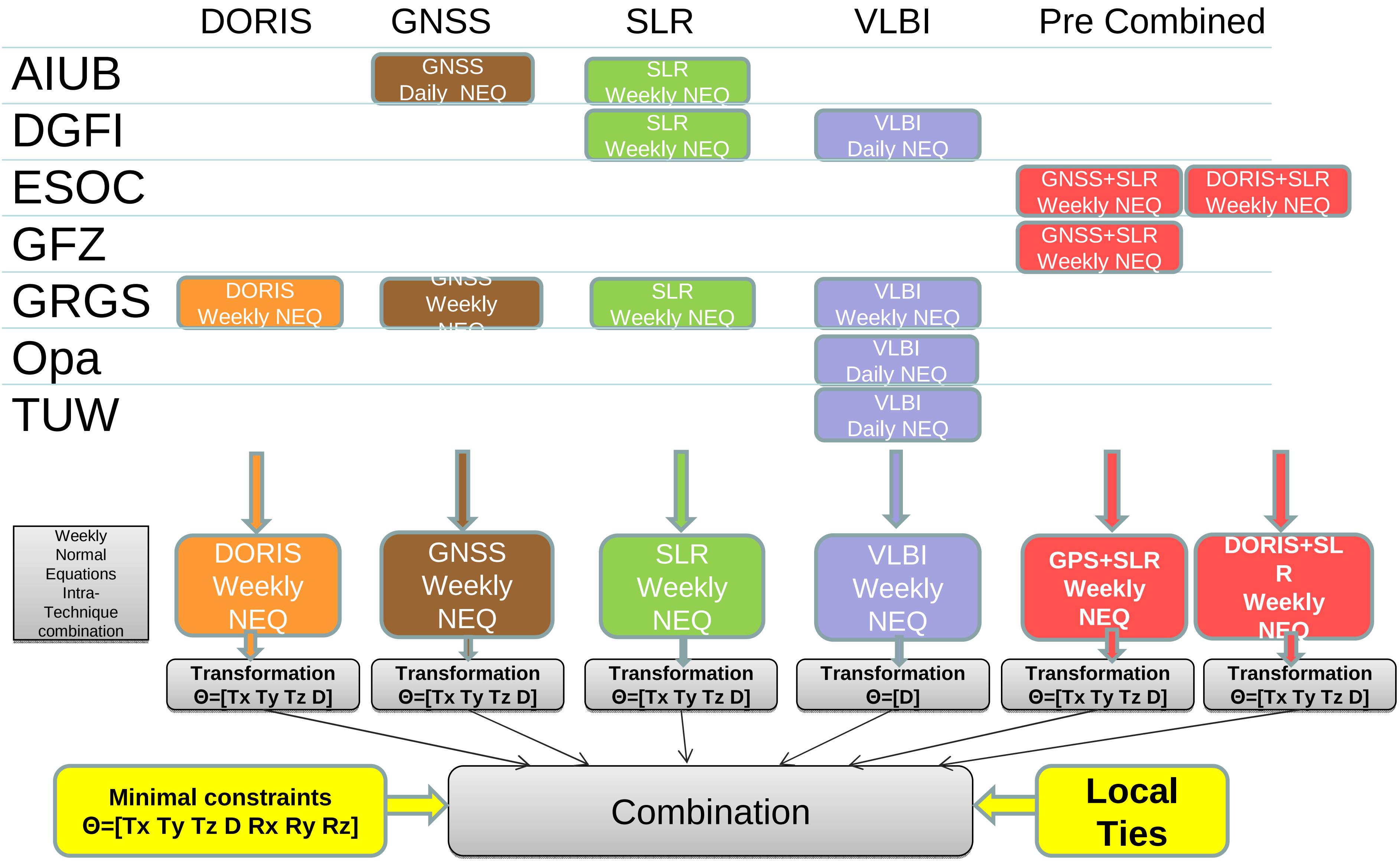
# PARAMETERIZATION for Combination

| *Parameters* | *Implementation into SINEX files* | *Initial values* |
|---|---|---|
| **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:<br><br>TGETOT, TGNTOT daily 00h** | **GPT/GMF model for radio waves & Mendes/Pavlis for optical waves** |

# STRATEGY Intra-Technique Combination



# STRATEGY Inter-Technique Combination

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# TRANSFORMATION for each Technique before combination

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

$\delta X^{RC}{}_{Tech}$ station coordinate corrections
CP common parameters for combination (EOP, Tropo …)
$\alpha_{Tech}$ specific technical parameters (orbital parameters, bias …)
$\theta_{Tech}$ transformation parameters $[T_x\ T_y\ T_z\ \mathrm{D}]_{\text{Tech for satellite}}$ , $[\mathrm{D}]_{\text{Tech for VLBI}}$

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

$$N_{new} = C^T.N.C$$
$$B_{new} = C^T.B$$

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

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

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:

$B.X=B.X_D \pm \Sigma_\theta$ (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:

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

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

$\theta=(T_X,T_Y,T_Z,k,\varepsilon,\psi,\omega)$ three translations, one scale factor, three rotations

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

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

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 $\Sigma_\theta$ relative to the 7 (or 14) parameters of transformation.

While the unconstrained system is written N.X=S, the constrained system is:

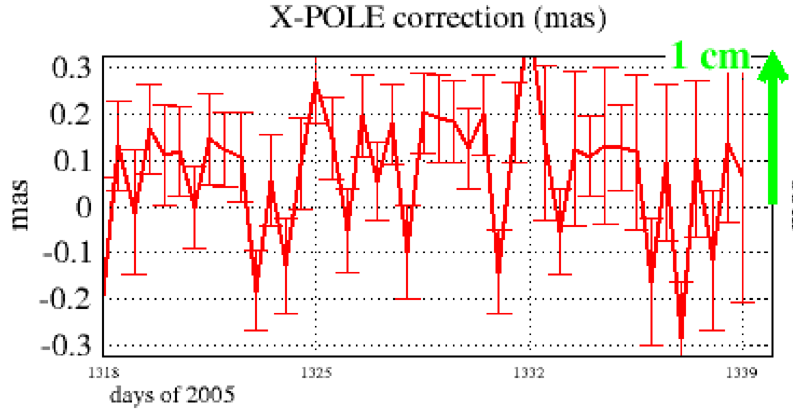
$(N+B^T\Sigma_\theta B).X=S+B^T\Sigma_\theta BX_D$

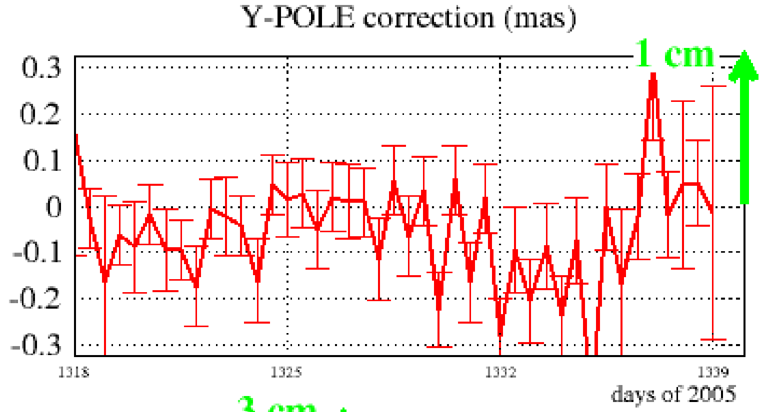
# preliminary POLE & UT solutions with GRGS multi-technique combination

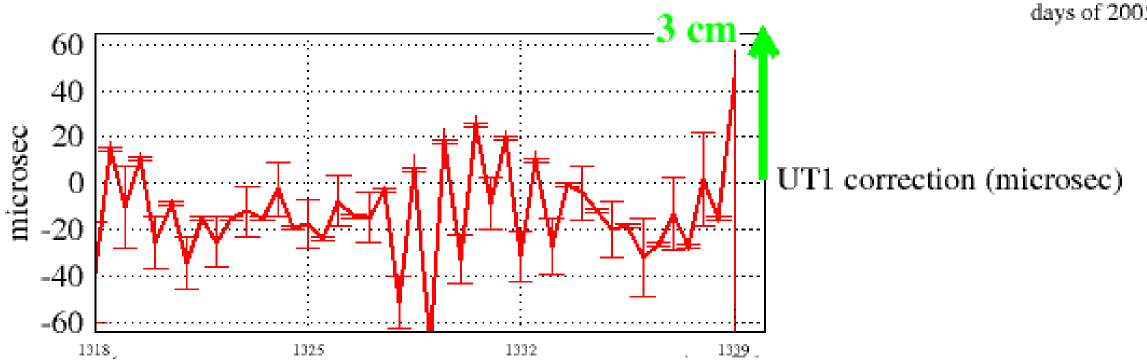
| techniques | weighting |
|---|---|
| GPS | 0.1532E+00 |
| VLBI | 0.2937E-01 |
| DORIS | 0.9935E+00 |
| SLR | 0.4137E+01 |

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 µs, bias -5.3µs*

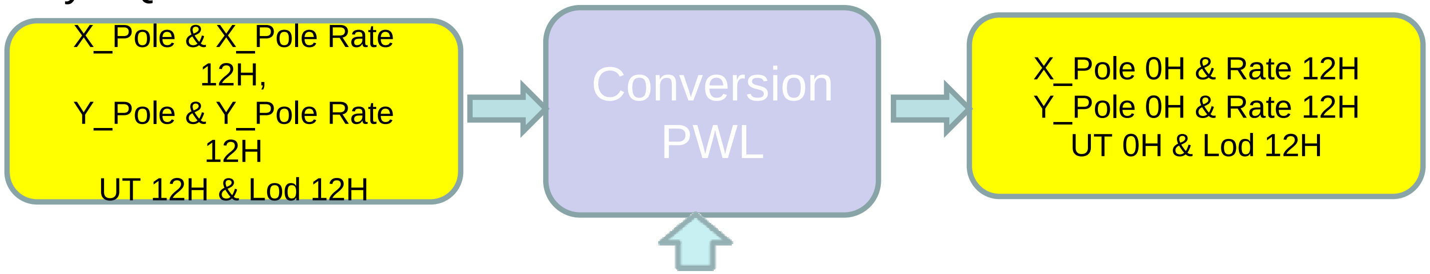


# TRANSFORMATION  EOP O+D 12H to Biais at 0H

Weekly EQNs GPS from GRGS

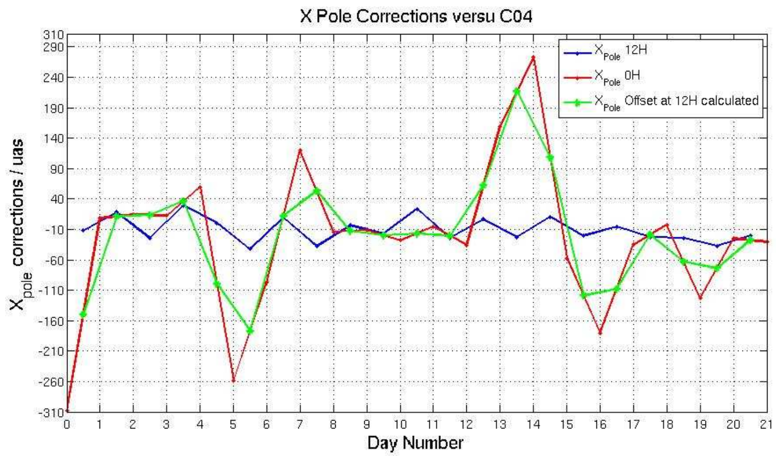


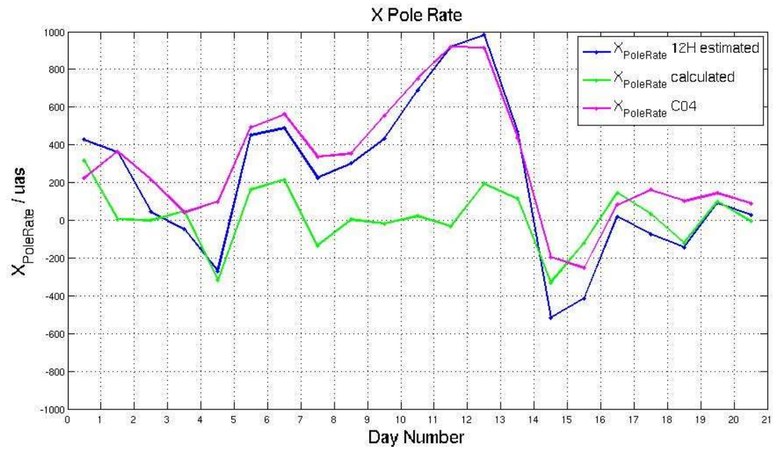

Constraint equations introduced

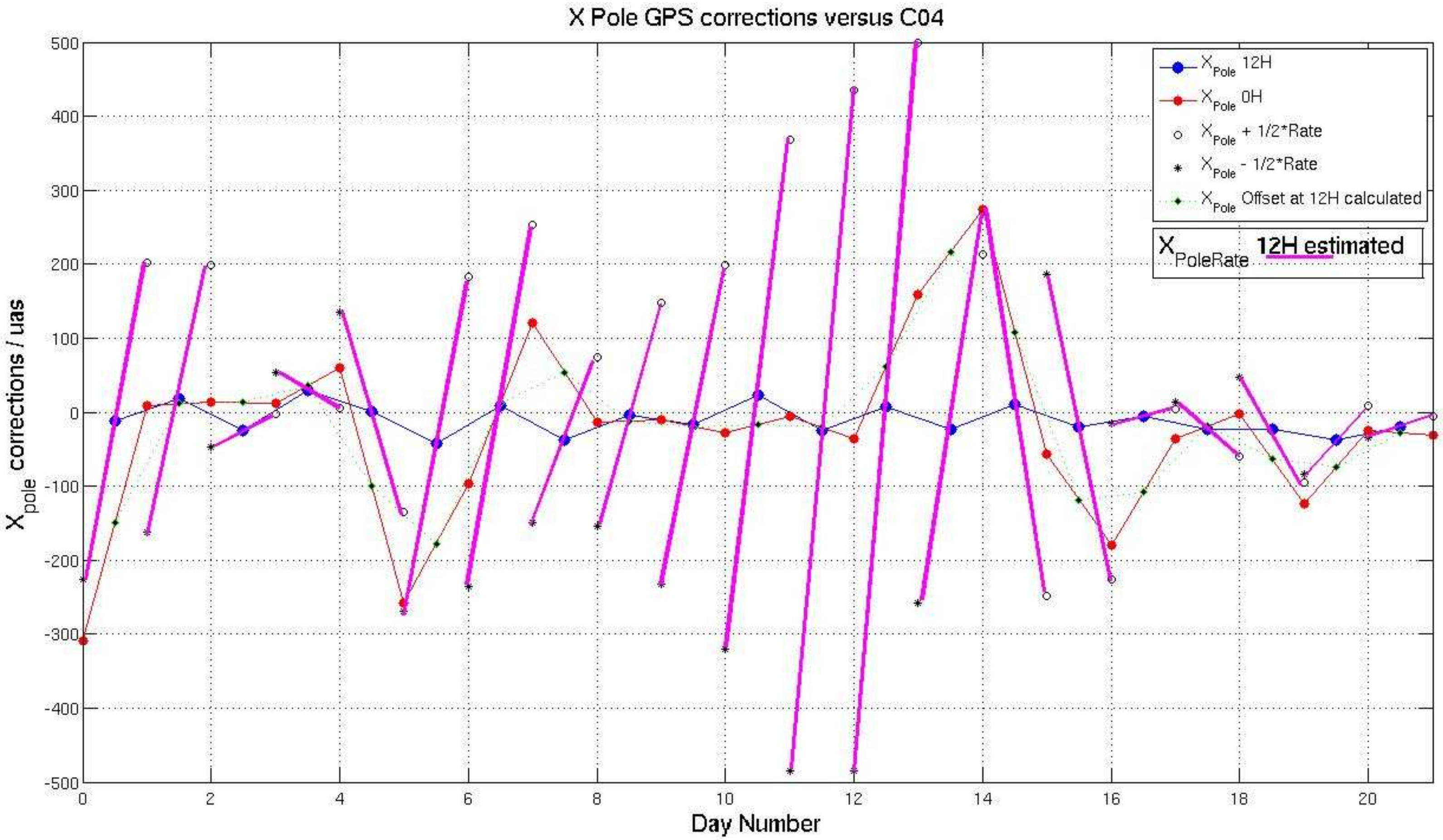
$$\begin{cases} 0{,}5 * \delta P_{j,0H} + 0{,}5 * \delta P_{j+1,0H} = \delta P_{j,12H} \pm \sigma_{\delta P} \\ \delta P_{j+1,0H} - \delta P_{j,0H} = \delta \dot{P}_{j,12H} \pm \sigma_{\delta \dot{P}} \end{cases}$$

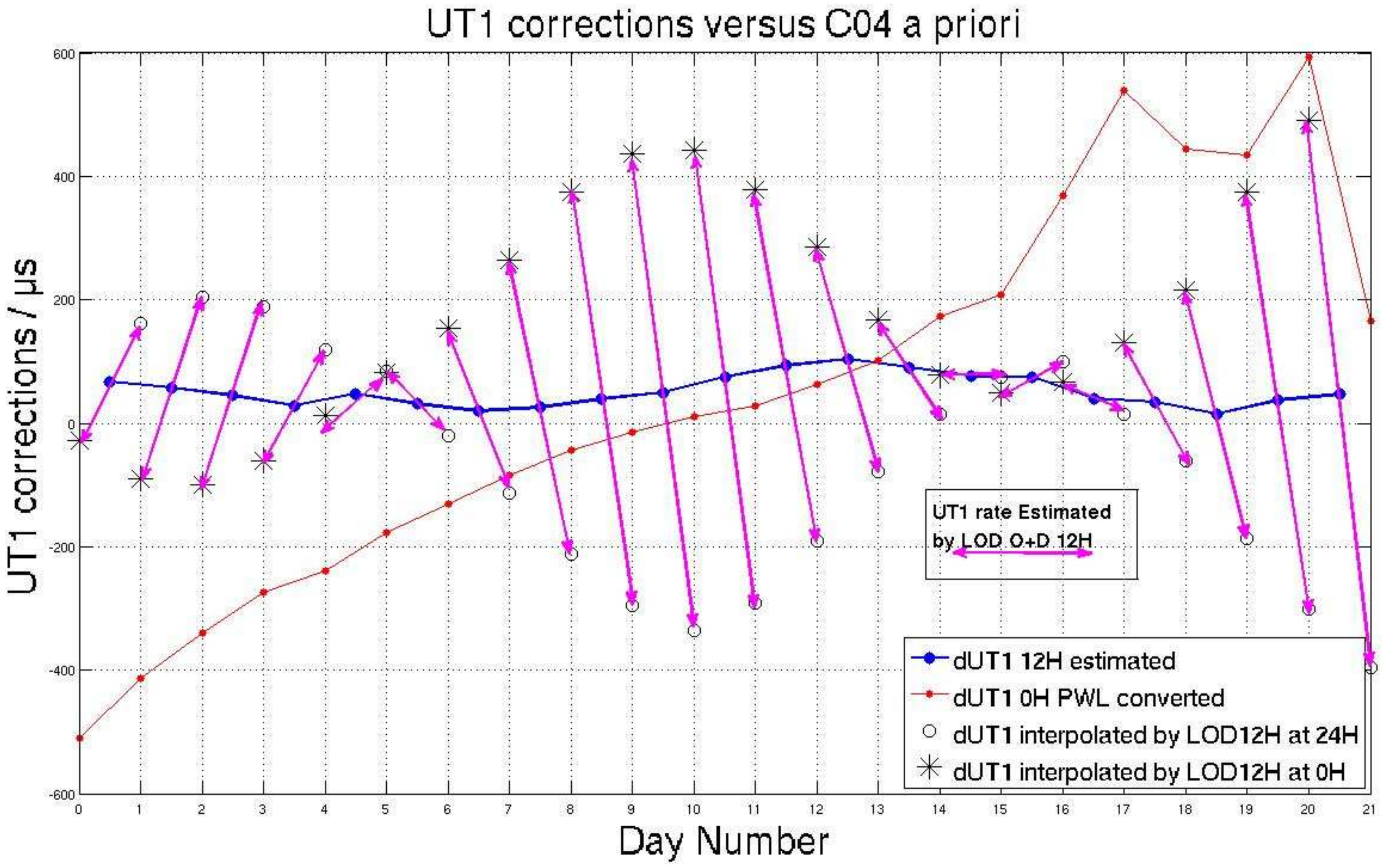
| | Pole | Lod |
|---|---|---|
| $\sigma_{\delta P}$ | 0,2µas | 0,09µs |
| $\sigma_{\delta \dot{P}}$ | 0,3µas/d | 0,13µs/d |

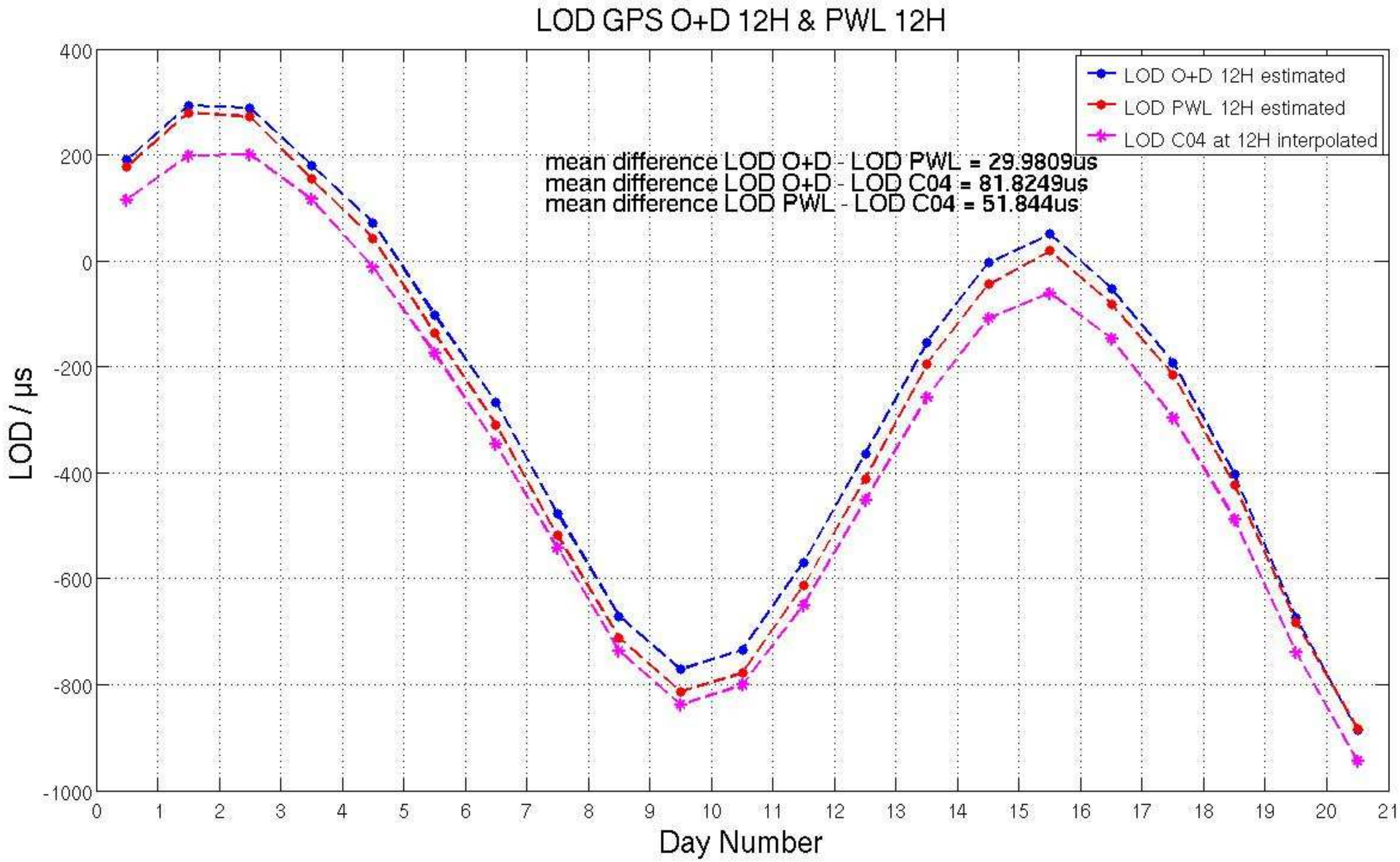
Weighting: 99% from constraint & 1% from EQN




X Pole GPS corrections versus C04
$X_{Pole}$ 12H
$X_{Pole}$ 0H
$X_{Pole}$ + 1/2*Rate
$X_{Pole}$ - 1/2*Rate
$X_{Pole}$ Offset at 12H calculated
$X_{PoleRate}$ 12H estimated
$X_{pole}$ corrections / uas
Day Number
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
2
4
6
8
10
12
14
16
18
20


UT1 corrections versus C04 a priori
600
400
200
0
-200
-400
-600
UT1 corrections / µs
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Day Number
UT1 rate Estimated
by LOD O+D 12H
dUT1 12H estimated
dUT1 0H PWL converted
dUT1 interpolated by LOD12H at 24H
dUT1 interpolated by LOD12H at 0H



LOD GPS O+D 12H & PWL 12H
LOD O+D 12H estimated
LOD PWL 12H estimated
LOD C04 at 12H interpolated
mean difference LOD O+D - LOD PWL = 29.9809us
mean difference LOD O+D - LOD C04 = 81.8249us
mean difference LOD PWL - LOD C04 = 51.844us
LOD / µs
Day Number

## 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 estmated catalog to be zero: $\Theta = C.\Delta X$ where $\Theta = (A1, A2, A3)^T$ and $\Delta X$ 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 $(B_1, B_2, \ldots, B_n)^T$ where $B_i$:

$$B_i = \begin{pmatrix} \cos(\alpha_i)\tan(\delta_i) & \sin(\alpha_i)\tan(\delta_i) & -1 \\ -\sin(\alpha_i) & \cos(\alpha_i) & 0 \end{pmatrix}$$

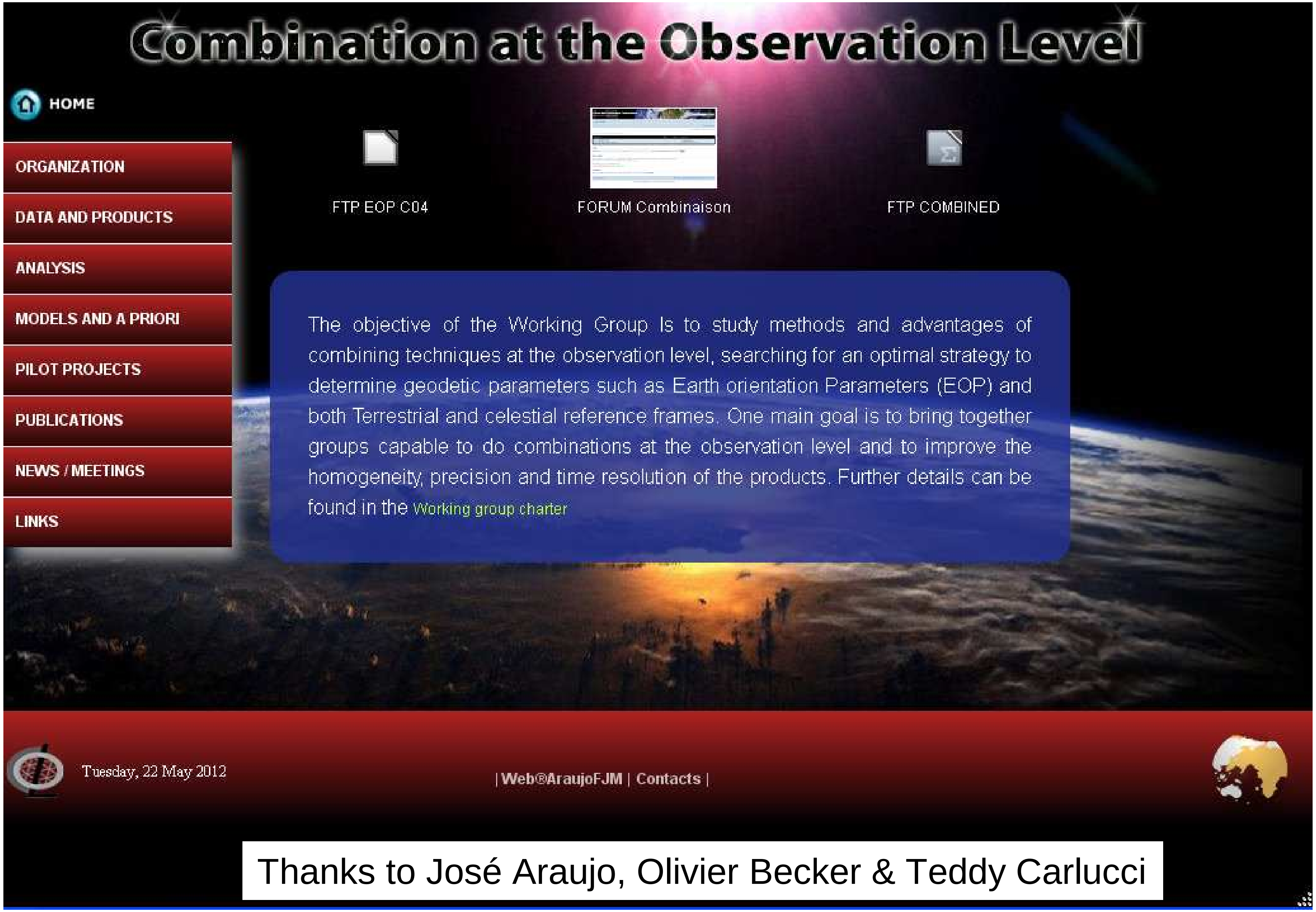
$\alpha_i$ is the rigth ascension
$\delta_i$ is the declination

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/




Thanks to José Araujo, Olivier Becker & Teddy Carlucci

# Conclusion & Prospects

- EOP 0ffset+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