COL Working Group

Combination at the Observation Level
IERS Working Group

After 4 years of COL activities

Co-chairs: R. Biancale/CNES, D. Gambis/OP, M. Seitz/DGFI

The forerunner: IERS WG3, 2004

Currently the International Terrestrial Reference Frame (ITRF), the International Celestial Reference Frame (ICRF) and the Earth Orientation Parameter (EOP) series, are combined separately… As a result **neither the consistency of the products can be guaranteed rigorously, nor can the different strengths of the individual space geodetic techniques be exploited to provide improved products**.
In view of the challenges that the IERS is facing in support of new satellite missions for gravity, altimetry, and astrometry **it is crucial to proceed towards a fully rigorous combination** of all the parameters common to more than one space geodetic technique.
This IERS WG on Combination will **coordinate the steps towards a very consistent, highly accurate set of IERS products** and will be a forum for the discussion of all relevant combination aspects. The major task of IERS WG will be the coordination of the new **IERS Combination Pilot Project** that is expected to start routine product generation in Spring, 2004. Within the framework of this program, a rigorous combination of "weekly" SINEX files (containing station coordinates, EOPs and eventually quasar coordinates) from all space geodetic techniques is planned. The new products resulting from these combination procedures are expected eventually to replace a considerable part of the current IERS products…

COL WG roadmap (2009)

1) **reviewing the approach of the various groups**
   and their capability to process two or more techniques.
2) **elaborating benchmarks**
   to intercompare results between groups from the same data set.
3) **ensuring SINEX compatibility**
   between techniques and with the international technique services and IERS.
4) **establishing common processing standards**
   for all techniques in order to guarantee homogeneity and consistency.
5) **optimizing and unifying parameterization**
   for instance for tropospheric parameters in order to minimize globally the degree of freedom of the whole inverse system.
6) **studying the appropriate weighting between techniques**
   and the use of local ties or identical satellites tracked by several techniques.
7) **studying stabilization methods**
   and looking for high temporal resolution of parameters.
8) **evaluating and comparing results**
   to search for compatibility between groups.
9) **organizing routine operations**
   for a new TRF realization, either in the framework of the next ITRF or as ITRF assessment.

1) **reviewing the approach of the various groups**

and their capability to process two or more techniques.

COL Analysis Centres (9 groups with 7 different software packages)

groups	*software packages*	*techniques*				*NEq*
• **AIUB/BKG**	BERNESE		GNSS	SLR		X
• **DGFI**	DOGS-OC			SLR		X
	BERNESE/DOGS-RI		G…		V…	
• **ESOC**	NAPEOS	DORIS	GNSS	SLR		X
• **GFZ**	EPOS	D…	GNSS	SLR		X
• **GRGS**	GINS	DORIS	GNSS	SLR	VLBI	X
• **GSFC**	GEODYN	D…	G…	S…		
	CALC-SOLVE				V…	
• **ASI**	BERNESE/GEODYN		G…	SLR		X
• **TUW**	VIEVS				VLBI	X
• **UB**	GEODYN					

2) **elaborating benchmarks**

to intercompare results between groups from the same data set.

Benchmarks

- Two 3-week periods have been chosen encompassing:

  - the VLBI CONT08 campaign (12-26 August 2008)
  - the VLBI CONT11 campaign (15-29 September 2011)

- Data, list of stations, models are provided on the COL forum:
http://grgs.obspm.fr/forum/

- **New set of data** : LEO satellites, in particular Jason-2 with multi-technique (SLR, DORIS, GPS) or GRACE-A/B (SLR, GPS). To be provided by some groups on a volunteer basis

Processing

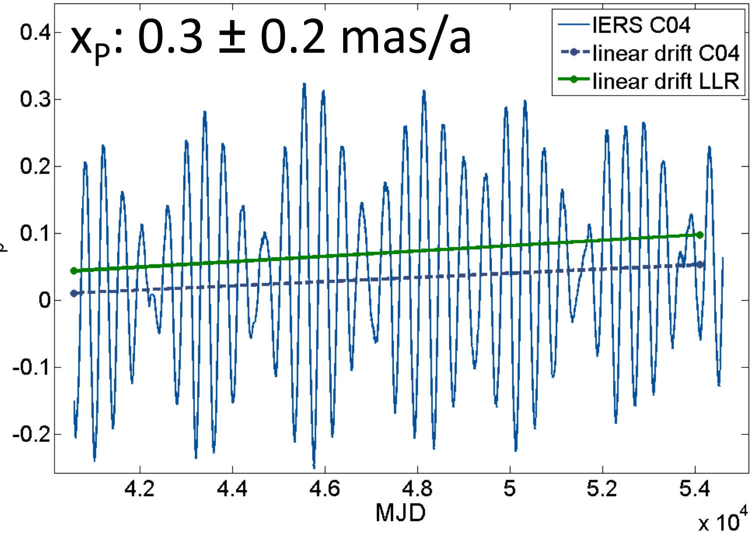
Twice 3 weeks over the VLBI CONT08 & 11 campaigns

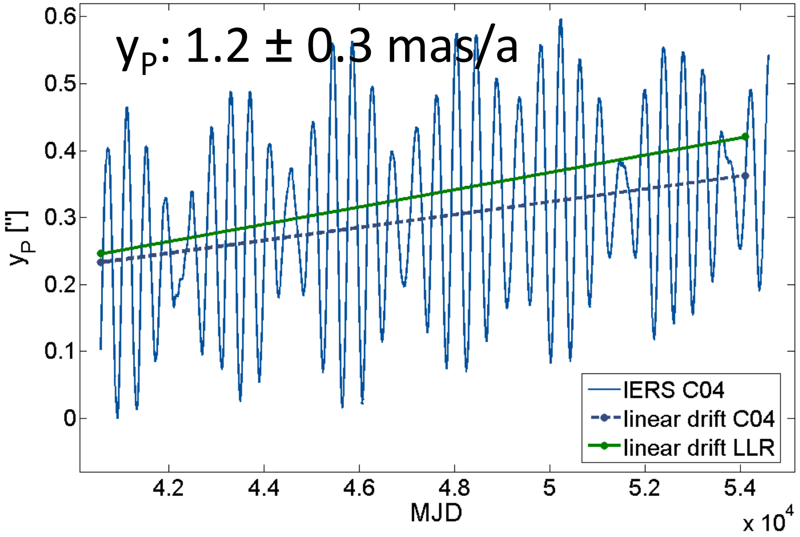
- 2008: 10 August – 30 August
- 2011: 11 September – 1 October

	SLR	DORIS	GPS	VLBI
# measures / week	3 000	300 000	800 000	40 000
# satellites/quasars	2	5	24	80
# stations	25	50	120	11
# residuals	~1 cm	~0.35 mm/s	~8 mm	~1 cm

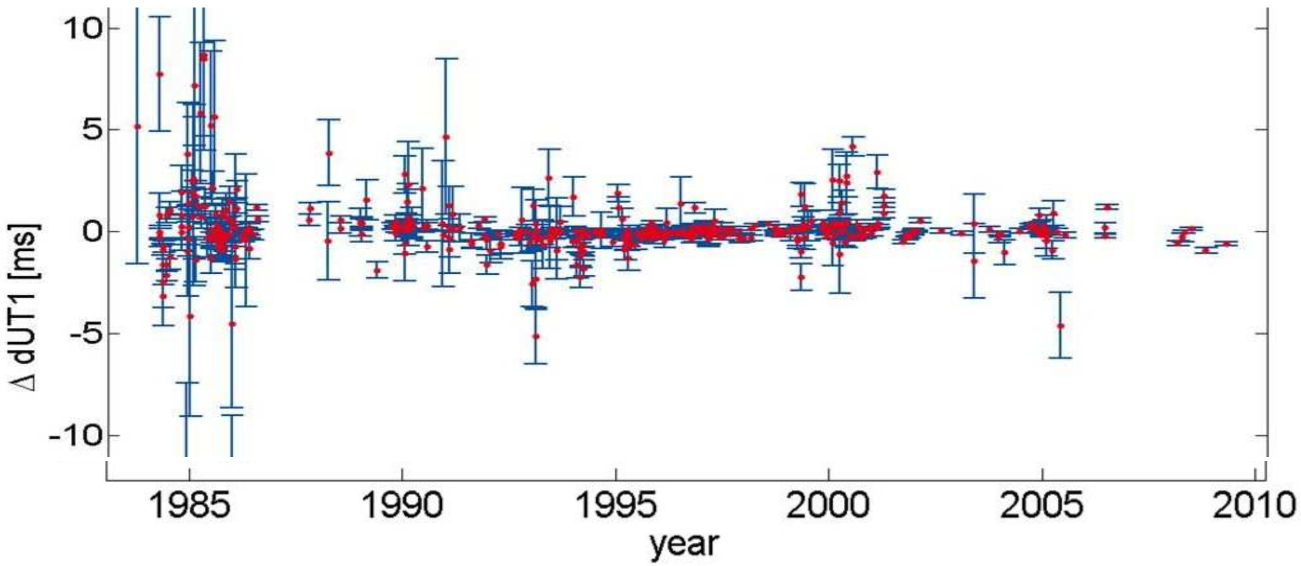
Is there an interest to introduce LLR as well?

Differences between polar motion linear drift from IERS C04 and LLR (1970-2008)





Determination of UT1-UTC in global LLR adjustment



Credit: J. Müller, Univ. of Hannover

3) **ensuring SINEX compatibility**

between techniques and with the international technique services and IERS.

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

Analysis Center	DORIS	GNSS	SLR	VLBI	Pre combined
AIUB/BKG		Delivered 14-Nov-2011 SINEX **version n3** CONT08	Delivered 22-May-2012 SINEX version **n3** CONT08 & CONT11		
ASI			Delivered 29-April-2013 **SINEX version 2** CONT08 & CONT11		
DGFI			Delivered 09-Nov-2012 **SINEX version 3** CONT08 & CONT11	Delivered 07-Jun-2011 version n2, CONT08	
ESOC			Delivered 18-Mar-2010 version n1, CONT08		**SLR-GPS** CONT08 18-Mar-2010 **SLR-DORIS** CONT08 18-Mar-2010 **GNSS-DORIS-SLR** CONT08 26-Apr-2013
GFZ		**GPS** CONT08-CONT11, 22-Jan-2013, **version n1**			
GRGS	Delivered CONT08-CONT11 22-Nov-2013 **SINEX version n7**	Delivered CONT08-CONT11 20-Nov-2012 **SINEX version n9**	Delivered CONT08-CONT11 10-May-2012 **SINEX version n4**	Delivered CONT08-CONT11 08-Jan-2013 GINS version v4 **SINEX version n6**	
GSFC	Expected	Expected	Expected	Excepted	
OPA				Delivered 05-Oct-2011 SINEX version n1	
TUW				Delivered CONT08-CONT11 31-Oct-2012 **version n3** 29-Apr-2013 **version n4**	

New NEQs with conventional models proposed in May 2012 for the COL project

4) **establishing common processing standards**

for all techniques in order to guarantee homogeneity and consistency.

IDS, IGS, ILRS, IVS & COL standards to get ready for the GRGS contribution to ITRF2013

Gravitational Dynamic	DORIS	GNSS	SLR	VLBI	COL
Geopotential	EIGEN-6S2 up to degree 95 including time variable terms up to degree 50 (bias & drift per yr from 2002 to 2012, periodic 18.6, 1, 0.5 yrs)	EIGEN-6S2 up to degree 12	EIGEN-6S2 up to degree 30 (for LAGEOS)		Static gravity field model is based on EIGEN-GRGS.RL02, tide-free, complete to degree and order 2 up to 160 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Gravity_Field/
Third-body	JPL DE421	JPL DE421	JPL DE421	JPL DE421	JPL DE405
Solid Earth Tides	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards		IERS 2010 standards
Ocean Tides	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 50	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 12	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 20		FES 2004 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Ocean_Tide_Loading/
Atmospheric gravity	3hr ERA-interim / ECMWF up to degree 50	3hr ERA-interim / ECMWF up to degree 12	3hr ERA-interim / ECMWF up to degree 20		none (integrated into the geopotential)
Non tidal oceanic gravity	TUGO R12 up to degree 50	TUGO R12 up to degree 12	TUGO R12 up to degree 20		none (integrated into the geopotential)
Atmospheric tides	none (considered through the ECMWF atmospheric data)	none	none		Ray & Ponte 2003 ftp://hpiers.obspm.fr/iers/eop/grgs/Models/Atmospheric_Tide/
Earth pole tide	IERS2010 standards	IERS2010 standards	IERS2010 standards		IERS2010 standards
Ocean Pole Tide	Desai 2002 up to degree 12	Desai 2002 up to degree 12	Desai 2002 up to degree 12		Desai 2002 up to degree 12

Non gravitational models

Non Gravitational Dynamic	DORIS	GNSS	SLR	VLBI	COL
Atmospheric drag	DTM94 (with Am indices) Spots, Envisat, Cryosat2, HY-2A: one coef/4 hrs (one/1hr in high solar activity periods) ; Topex, Jasons: one coef/half day		None for Lageos		JB2008
Solar radiation pressure	one coef/day strongly constrained (1.e-4) to: 0.98 for Topex; 1.15 for Spot-2; 1.16 for Spot-3/-4; 1.17 for Spot-5; 1.29 for Envisat; 0.97 for Jason-2; 0.85 for Cryosat-2; 0.86 for HY-2A	one coefficient adjusted per day?	one scale coefficient adjusted per arc		applied
Albedo + infra-red	interpolated from grids issued from ECMWF 6hr 4.5° grids	interpolated from grids issued from ECMWF 6hr 9° grids	interpolated from grids issued from ECMWF 6hr 9° grids		applied
Satellite emissivity	none	none	none		none
Relativity	Schwarzschild model + Lense-Thirring + geodetic precession	Schwarzschild model + Lense-Thirring + geodetic precession	Schwarzschild model + Lense-Thirring + geodetic precession	IERS 2010 standards	Schwarzschild model + Lense-Thirring + geodetic precession
Hill/empirical	once/rev along-& cross-track per x day		once/rev along-& cross-track per x day		

Geometrical models

Geometry	DORIS	GNSS	SLR/LLR	VLBI	COL
Earth reference system	DPOD2008	ITRF2008 & IGb08	ITRF2008 (SLRF2008)	VTRF2008	ITRF 2008
Celestial reference system	inertial J2000	inertial J2000	inertial J2000	J2000, ICRF2	J2000, ICRF2
Pole & UT1	daily EOPC04_i08	daily EOPC04_i08	daily EOPC04_i08	daily EOPC04_i08	EOPC04 initial values interpolated (Lagrange polynomial method) with 3hr time intervals
Precession / Nutation	IERS 2010 using NRO origin	IERS 2010 using NRO origin (+ nutation rates)	IERS 2010 using NRO origin	IERS 2010 using NRO origin	IAU2000A - IAU2006 a-priori set to zero
Solid Earth tidal displacement	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards
Ocean loading	FES2012	FES2012	FES2012	FES2012	Ocean tide loading models per stations are obtained from Scherneck's ocean loading site and provided in the BLQ format according to the IERS Standards 2010
Tidal atmospheric loading	S1/S2 Ray & Ponte (2003)	S1/S2 Ray & Ponte (2003)	S1/S2 Ray & Ponte (2003)	S1/S2 Ray & Ponte (2003)	none
Non tidal atmospheric loading	none	none	none	none	none
Solid pole tide displacement	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards	IERS 2010 standards
Ocean pole tide displacement	none	none	none	none	none

Propagation and system models

Propagation & Systems	DORIS	GNSS	SLR/LLR	VLBI	COL
Troposphere	GPT/GMF modelling from Boehm et al. (2006). One zenith delay/pass + one daily tropospheric gradient per station in North & East directions	GPT/GMF modelling from Boehm et al. (2006). One zenith delay/2hr in PWL mode + one daily tropospheric gradient per station in North & East directions	Mendes-Pavlis: (zenith delay & mapping Function)	GPT/GMF modelling from Boehm et al. (2006). One zenith delay/2hr + one daily tropospheric gradient per station in North & East directions	GPT/GMF for radio-electrical waves and Mendes-Pavlis for SLR. One zenith delay/2hr or pass + one daily tropospheric gradient per station in North & East directions
Ionosphere	2nd order corrections using IGS TEC values and igrf2011 magnetic field model	(2nd order corrections using IGS TEC values and igrf2011 magnetic field model) not effective			none
Satellite system	Centre of mass / Phase centre vector from macro model + attitude law No phase law applied	Centre of mass offsets / Phase centre corrections from file: igs08_wwww.atx	Centre of mass corrections from G. Appleby		
Ground system	Phase centre / reference point vector from manufacturer values Phase law applied	Absolute elevation/azimuth dependent phase centre corrections are applied according to igs08_wwww.atx		Antenna thermal expansion: Nothnagel (2008) Antenna axes offset: IVS files	
Elevation cut-off	12 degrees Down weighting law for elevation <= 20 deg; Weight of the observation is multiplied by the factor elevation**2/400 with elevation in degrees)	10 degrees	10 degrees	12 degrees	

5) **optimizing and unifying parameterization**

for instance for tropospheric parameters in order to minimize globally the degree of freedom of the whole inverse system.

Parameterizations for the COL campaign

Parameters	*Parameters to be estimated*	*Initial values*
Pole, UT1-UTC or UT1-TAI	XPO, YPO, UT : PWL @ {00, 03, 06, 09, 12, 15, 18, 21, 24} hr	IERS EOP 08-C04 (tables available on the Forum Multi-technic Combination http://grgs.obspm.fr/forum/)
Pole Rate	XPOR, YPOR 1pt/day @ 12hr	Set to 0
LOD	LOD 1pt/day @ 12hr	Set to 0
Nutation angles	NUT_X, NUT_Y : PWL @ 0hr 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 Tropospheric Delay Wet component & Horizontal gradients	TROWET @ {00, 02, 04, … 24} hr: Adjustment of the wet component to the model TGETOT, TGNTOT daily 00h	GPT/GMF model for radio waves & Mendes/Pavlis for optical waves

6) **studying the appropriate weighting between techniques**

and the use of local ties or identical satellites tracked by several techniques.

Weighting by variance analysis component (Helmert)

$$(w_D N_{Doris} + w_G N_{GNSS} + w_S N_{SLR} + w_V N_{VLBI}).\delta X = N_{Combined}\delta X = Y$$

Variance factor

$$s0 = \frac{(O-C)^T P(O-C)}{N_{obs} - N_{param} - N_{red}}$$

CONT08

	GPS	DORIS	SLR	VLBI
Variance factor **s0**	5,736	1,062	0,2337	35,458
Weight **w**	0,1804	0,9957	7,486	0,0306
s0*w	**1,0347744**	**1,0574334**	**1,7494782**	**1,0850148**
Variance factor **s0**	5,478	1,069	0,2809	31,8319
Weight **w**	0,1889	0,9884	5,492	0,03417
s0*w	**1,0347942**	**1,0565996**	**1,5427028**	**1,08769602**
Variance factor **s0**	5,3362	1,062	0,2187	43,1838
Weight **w**	0,1942	0,9956	7,154	0,0264
s0*w	**1,03629004**	**1,0573272**	**1,5645798**	**1,14005232**

CONT11

	GPS	DORIS	SLR	VLBI
Variance factor **s0**	6,8851	1,061	0,5721	157,292
Weight **w**	0,1501	0,9967	2,353	0,00731
s0*w	**1,03345351**	**1,0574987**	**1,3461513**	**1,14980452**
Variance factor **s0**	6,5659	0,992	0,6723	100,508
Weight **w**	0,1574	1,067	1,669	0,0115
s0*w	**1,03347266**	**1,058464**	**1,1220687**	**1,155842**
Variance factor **s0**	6,6873	1,044	0,4202	147,6499
Weight **w**	0,1546	1,013	2,969	0,0081
s0*w	**1,03385658**	**1,057572**	**1,2475738**	**1,19596419**

7) **studying stabilization methods**

and looking for high temporal resolution of parameters.

Systematic effects associated to the geodetic techniques *

In order to take into account inconsistencies between techniques, we introduce Helmert parameters, translations and scale for satellites and scale factor for VLBI. Station coordinates are transformed into a common reference R_c for each technique by adding the Helmert parameters in the transformation equation:

$$\mathbf{X_{Tech} = X_{Tech\_ITRF} + A.\Theta_{Tech}}$$

$$A = \begin{bmatrix} A_{1_{Tech}} \\ \cdot \\ \cdot \\ A_{n_{Tech}} \end{bmatrix}, A_{i_{Tech}} = \begin{bmatrix} 1 & 0 & 0 & x_i^0 \\ 0 & 1 & 0 & y_i^0 \\ 0 & 0 & 1 & z_i^0 \end{bmatrix}, \Theta_{Tech} = \begin{bmatrix} T_{x_{Tech}} \\ T_{y_{Tech}} \\ T_{Z_{Tech}} \\ S_{c_{Tech}} \end{bmatrix} \qquad A_i = \begin{bmatrix} x_i^0 \\ y_i^0 \\ z_i^0 \end{bmatrix}, \Theta_{Tech} = [S_c]_{Tech}$$

DORIS, GNSS, SLR **VLBI**

Considering all n_{Tech} stations with *Tech: DORIS,GNSS,SLR,VLBI*

$\begin{bmatrix} x_i^0 & y_i^0 & z_i^0 \end{bmatrix}_{Tech}^T$ represents a priori station coordinates in the ITRF reference frame.

Processing of systematic effects estimation

The station parameters X_{Tech} with systematic effects cancelled are expressed in a common reference frame Rc and form the constraints equations added to the unconstraint normal equation for each technique:

$$\mathbf{(A^TA)^{-1} A^T (X_{Tech} - X_{Tech\_ITRF}) - \Theta_{Tech} = 0 \pm\sigma \text{ with } \sigma=10\mu m}$$

The station parameters expressed in the referential ITRF are reduced from the normal equation of each technique and the station parameters X_{Tech} and systematic effect Θ_{Tech} are kept.

*Reference: Arnaud Pollet IGN/LAREG thesis « COMBINAISON DE TECHNIQUES DE GÉODÉSIE SPATIALE », Jan. 2011

Estimation of station coordinates relative to a combined reference frame

Local ties

The technique's link consisting of local ties between stations are considered and form constraints at the epoch between collocated stations 1 and 2: $\mathbf{X_2(t) - X_1(t)=\Delta_{21}(t)}$

Minimal constraints

The weekly normal equations of each technique are stacked and weighted by the Helmert algorithm [Ref. 2] that forms the combined normal equation. Estimation of the station coordinates of each technique relatively to the combined referential frame is realized by adding minimal constraints to the combined normal equation consisting to add 7 transformation parameters for each technique:

$$\mathbf{X_{Tech} = X_{apriori\_ITRF} + B.\Theta}$$

$$B=\begin{bmatrix} B_1 \\ \cdot \\ \cdot \\ B_n \end{bmatrix}, B_i=\begin{bmatrix} 1 & 0 & 0 & x_i^0 & 0 & z_i^0 & -y_i^0 \\ 0 & 1 & 0 & y_i^0 & -z_i^0 & 0 & x_i^0 \\ 0 & 0 & 1 & z_i^0 & y_i^0 & -x_i^0 & 0 \end{bmatrix}, \Theta=\begin{bmatrix} T_x \\ T_y \\ T_Z \\ S_c \\ R_x \\ R_y \\ R_z \end{bmatrix}$$

These minimal constraints form the constraint equation added to the combined normal equation for each technique:

$$\mathbf{(B^T B)^{-1} B^T (X_{Tech} - X_{Tech\_ITRF}) - \Theta = 0} \pm\sigma \text{ with } \sigma=0{,}1\text{mm}$$

No Net Rotation tie of the celestial frame (in VLBI analysis)

In order to orientate the radio sources onto the a-priori catalog (ICRF2) we add transformed parameters between the a-priori and the estimated catalog, imposed to be zero. The 3-parameter transformation is represented by 3 rotations R_1, R_2, R_3 constraining the small angles for the i-th source:

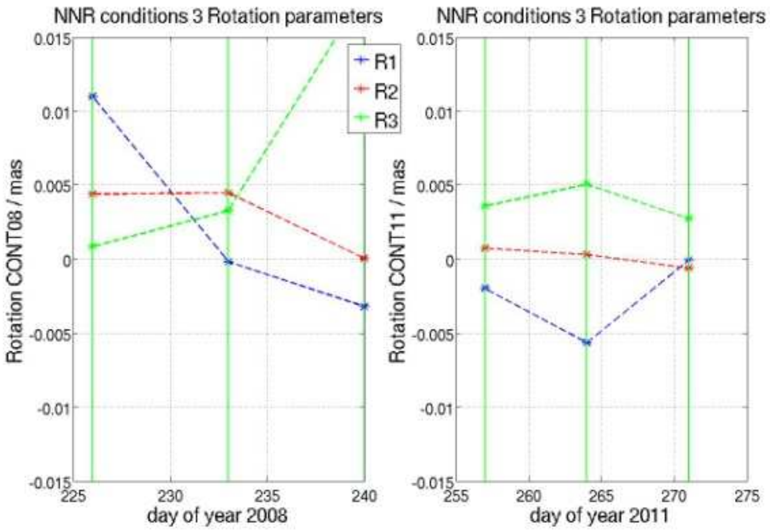
$$\mathbf{\Delta RS\_DA_i = R_1 \cos(RS\_DA_i)\tan(RS\_DE_i) + R_2 \sin(RS\_DA_i)\tan(QDE_i) - R_3}$$

$$\mathbf{\Delta RS\_DE_i = -R_1 \sin(RS\_DA_i) + R_2 \cos(RS\_DA_i)}$$

With **RS_DA** = Right Ascencion & **RS_DE** = Declination

Writing $Q=(\Delta RS\_DA_i , \Delta RS\_DE_i)^T$ & $\mathbf{\Theta = (R_1\ R_2\ R_3)^T}$ The normal equation constraint applied is :

$$\mathbf{(B^TB)^{-1} B^T (\Delta Q) - \Theta = 0 \pm \sigma} \text{ with } \mathbf{\sigma = 1nrd}$$



NNR	CONT08	CONT11
R_1 µas	2,4 ± 6,4	-2,6 ± 3,5
R_2 µas	2,6 ± 3,6	0,1 ± 1,4
R_3 µas	7,6 ± 10,8	1,0 ± 1,0

Mean values over 3 weeks

The 3 Rotation parameters are at the level of 10^{-9} radian that show the good consistency between celestial and terrestrial frame simultaneously estimated

Diurnal retrograde freezing constraint on the polar motion in case of sub-diurnal EOP estimation

Precession-nutation, polar motion and CIP coordinates in the GCRS are correlated due to the Earth rotation. Small (dX, dY) variations of nutation corrections from IAU2006/2000A model result in small (dx_p, dy_p) variations on the polar motion:

$$\begin{cases} dx_p = -dX\cos(ERA) - \mathrm{dY}\sin(ERA) \\ dy_p = -dX\sin(ERA) + \mathrm{dY}\cos(ERA) \end{cases}$$

For the sidereal day period ($ERA \approx 2\pi/T$), a bias on (dX, dY) results in diurnal periodic variations on (dx_p, dy_p). Because the Earth rotation is prograde, the precession-nutation (dX, dY) can be seen as a (dx_p, dy_p) diurnal retrograde component:

$$\begin{cases} dx_p = A\cos\phi\cos(\omega_E t_i) - \mathrm{A}\sin\phi\sin(\omega_E t_i) \\ dy_p = A\cos\phi\sin(\omega_E t_i) + \mathrm{A}\sin\phi\cos(\omega_E t_i) \end{cases} \qquad \omega_E = \frac{2\pi}{T}$$

Or in matrix form:

$$x_p y_p = \begin{pmatrix} x_1 \\ y_1 \\ \vdots \\ x_n \\ y_n \end{pmatrix}, \quad C = \begin{pmatrix} \cos\omega_E t_1 & -\sin\omega_E t_1 \\ \sin\omega_E t_1 & \cos\omega_E t_1 \\ \cdots & \cdots \\ \cos\omega_E t_n & -\sin\omega_E t_n \\ \sin\omega_E t_n & \cos\omega_E t_n \end{pmatrix}, \quad \begin{pmatrix} A\cos\phi \\ A\sin\phi \end{pmatrix} = \begin{pmatrix} A_C \\ A_S \end{pmatrix}, \quad \Longrightarrow \quad x_p y_p = C\begin{pmatrix} A_C \\ A_S \end{pmatrix}$$

The constraint equation on polar coordinates is determined by least squares technique on polar coordinates, considering a diagonal weighting matrix P of component $1/\sqrt{\sigma_i}^2$:

$$(C^T P C)^{-1} C^T P . x_p y_p - \begin{pmatrix} A_C \\ A_S \end{pmatrix} = 0 \pm \sigma_{const}$$

$$\begin{pmatrix} A_C \\ A_S \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \pm \sigma$$

8) **evaluating and comparing results**

to search for compatibility between groups.

COL Combination Centres

groups	*software packages*
• **DGFI**	DOGS-CS
• **GRGS**	DYNAMO

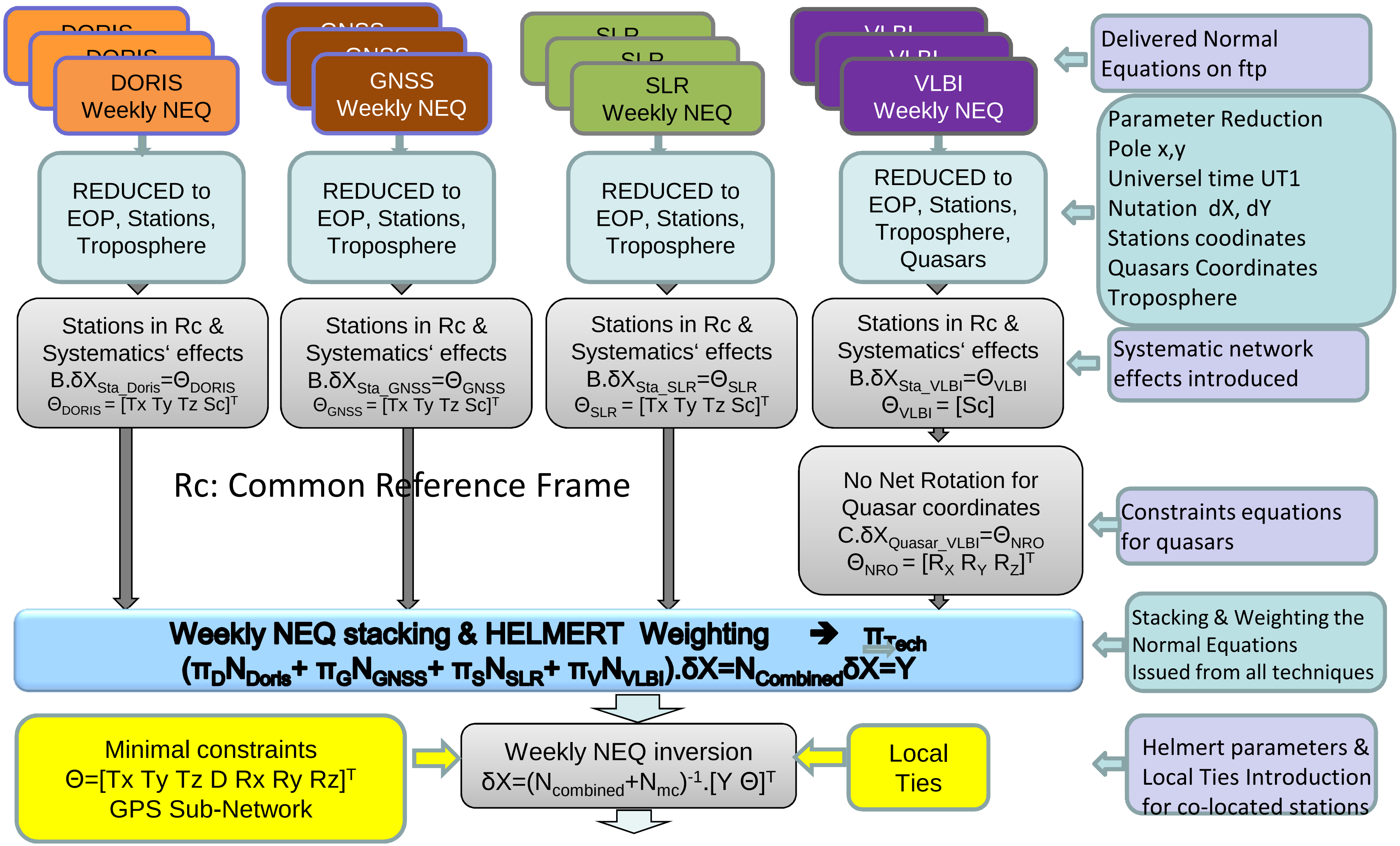
Participating groups & normal equations delivered

	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	

9) **organizing routine operations**

for a new TRF realization, either in the framework of the next ITRF or as ITRF assessment.

GRGS Multi-Techniques Combination Strategy at the weekly bases



Global Solutions: EOP, Stations coordinates in the combined frame, Troposphere, Systematic effects, Quasars coordinates, Transformation parameters, rotations parameters of celestial frame

Solutions are available on
ftp://hpiers.obspm.fr/iers/eop/grgs/

In summary

COL meetings

2008 – proposal for creating a WG on Combination at observation level

2009 (21-22 October) – kickoff meeting of the COL-WG / Warsaw

2010 (3 June) – intermediate meeting / Vienna

2010 (9-10 December) – 2nd COL meeting / Munich

2011 (5 April) – intermediate meeting / Vienna

2011 (21-22 November) – 3rd COL meeting / Paris

2012 (29 May) – 4th COL meeting / Munich

2013 (24 January) – GRGS-COL meeting / Toulouse

2013 (5 April) – intermediate meeting / Vienna

2013 (3 May) – 5th COL meeting / Munich

2014 (27 May) – 6th COL meeting / Paris

Goals of the COL-WG

• to improve precision, resolution and consistency of products (EOP, TRF, CRF) by combining GNSS, SLR/LLR, VLBI, DORIS techniques at the level of observation

• to extend this combination approach to several research groups in a planned IERS action (8 ACs presently, 2 CCs)

• to unify parameterization (e.g. troposphere…) and to discriminate technique systematisms

• to progress in combination methods and strategies (inter-technique weighting, stabilization procedure, space ties…)

• to establish the gain of this approach vs. actual realizations (C04, ITRF…)

• to prepare future of IERS…

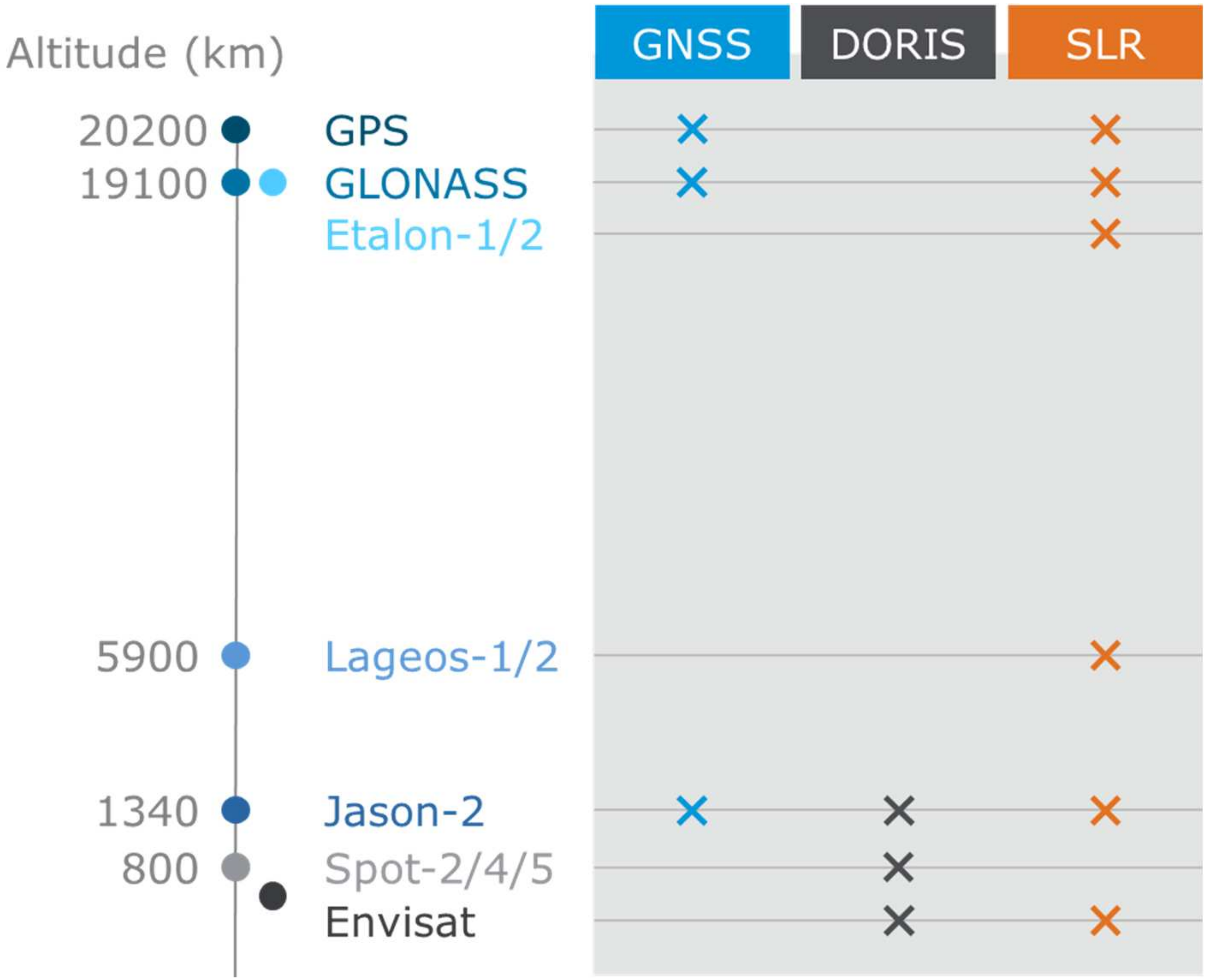
Activities in the COL-WG

- to continue to homogenize processing in the COL ACs over CONT08 and CONT11 3-week periods
- to look at high resolution ERP (3hrs)
- to unify all common parameters (e.g. troposphere) solving for EOP, TRF, CRF
- to check different kinds of constraints in global treatments (TRF/CRF nnr, retrograde diurnal pole, Helmert's systematisms…)
- to study the impact of ground and space ties (Jason2, GRACE…)
- to progress in multi-technique processing directly at the level of observation (ESOC, GRGS…)
- to maintain a forum site (at OP) for data exchange and discussion: http://grgs.obspm.fr/forum/
- to submit long term combinations in the ITRF2013 framework (GRGS, AIUB/BKG, ESOC, GSFC…)

Future of COL (to be discuss at the next IERS-DB)

- very depending on motivation and resources of the ACs and CCs
- still need of homogenizing technique processing and upgrading software packages to be really at the observation level
- demonstrations on VLBI-CONT periods as well as in the ITRF2013 framework are still in progress but not effective
- activities were redefined at the last COL meeting May 27,2014)
- besides their effort in producing a combined TRF in parallel to ITRF2013, GRGS, GSFC, BKG, DGFI have expressed their interest to pursue combination activities within the COL-WG
- it is proposed to simplify combination works to only satellite data (DORIS, GNSS, SLR) and to check the impact of multi-technique platforms such as Jason1/2, Envisat, Cryosat-2, when processing them directly at the level of observations, in addition to Lageos and GPS data as already defined.
- next milestone: mid 2015

A good example of full combination at observation level with Napeos



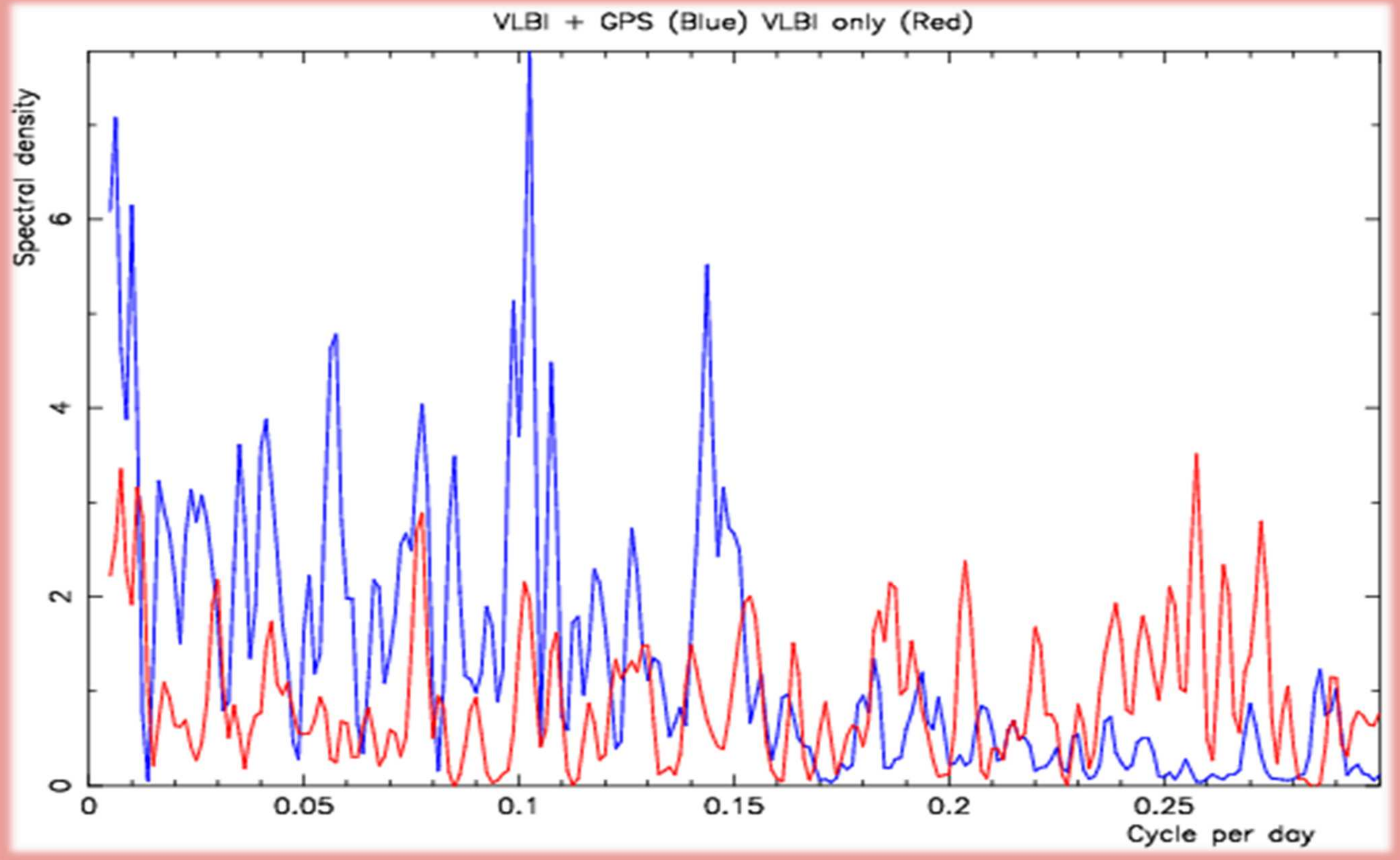
Michiel Otten, Claudia Flohrer, Tim Springer, Werner Enderle

Results

Interest of the combination at the observation level for

- EOP densification
- EOP diurnal and sub-diurnal variations

Nutation densification . All other parameters are maintained fixed in the combination.

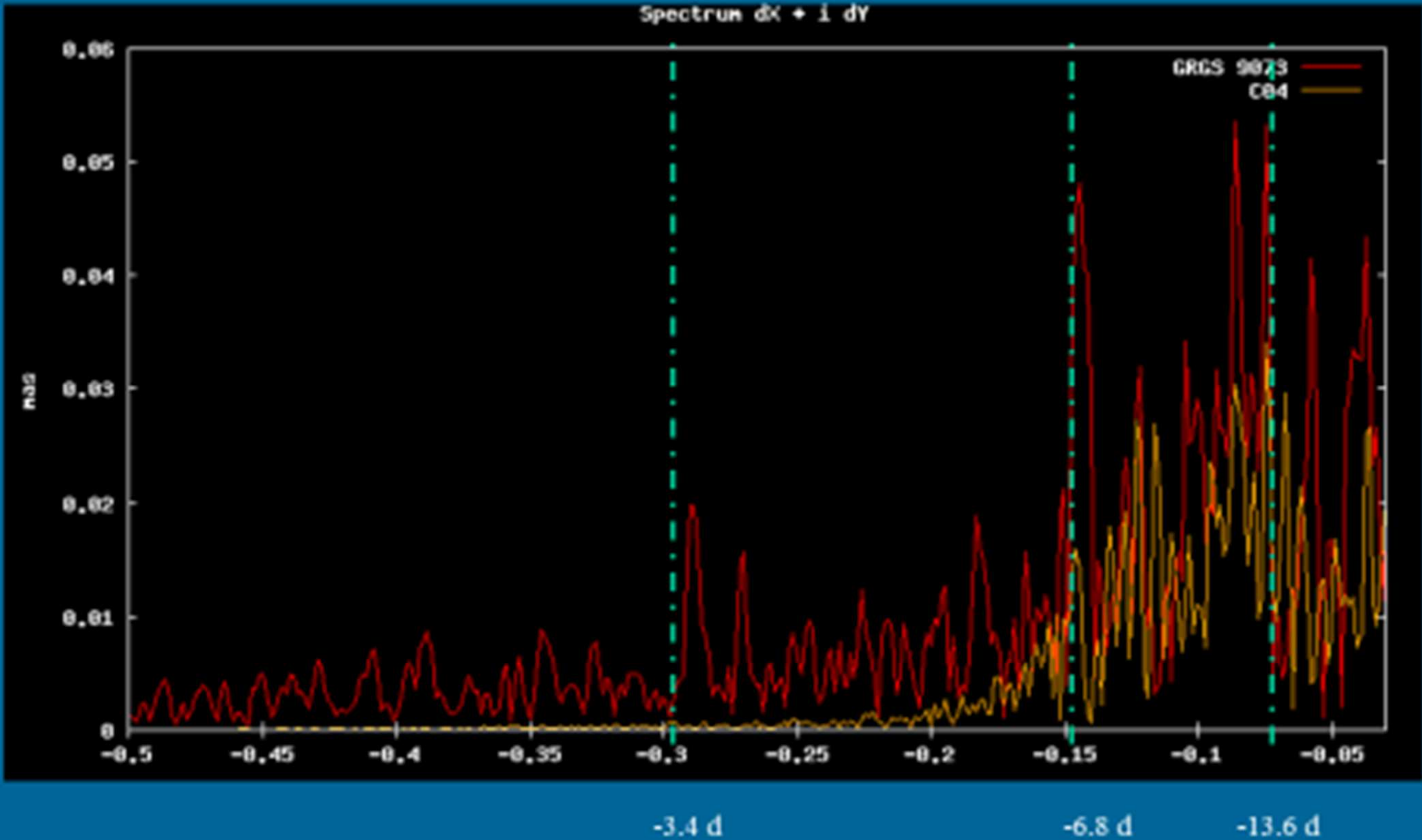


Fourier spectrum of the differences between the combined nutation series "dY" (relatively to IAU2000) with the current C04, for VLBI only (Red) and VLBI+GPS (Blue).

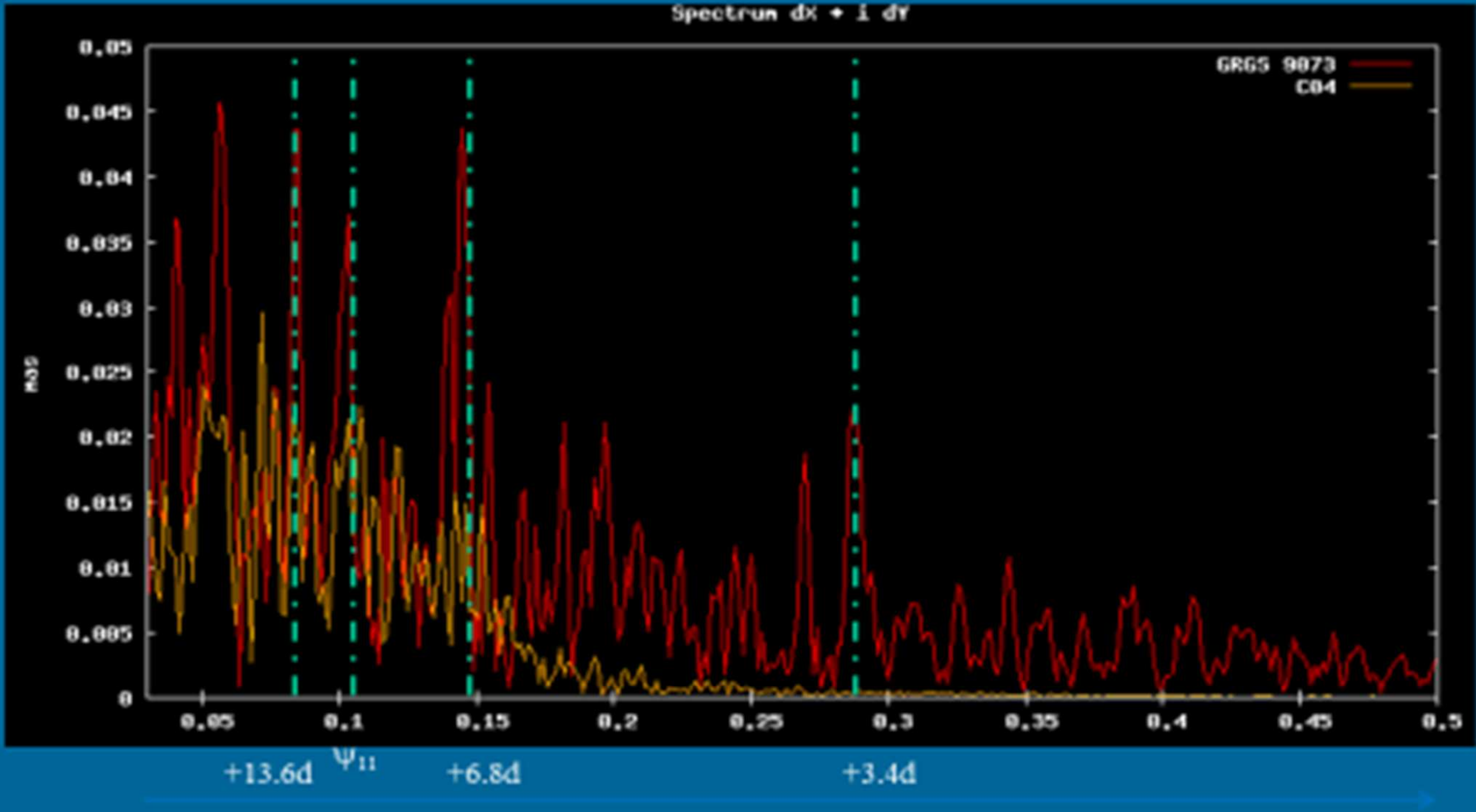
We notice the emergence of several peaks in the combined series which do not appear in the VLBI series sampled at 3-4 days in particular at 6.8 days with amplitude of 40 μas (about 0.14 cy/d associated with the -0.85 cy/d oscillation in polar motion).

Other peaks appear at about 18 days. The 6.8 day peak might be due to some atmospheric normal mode.

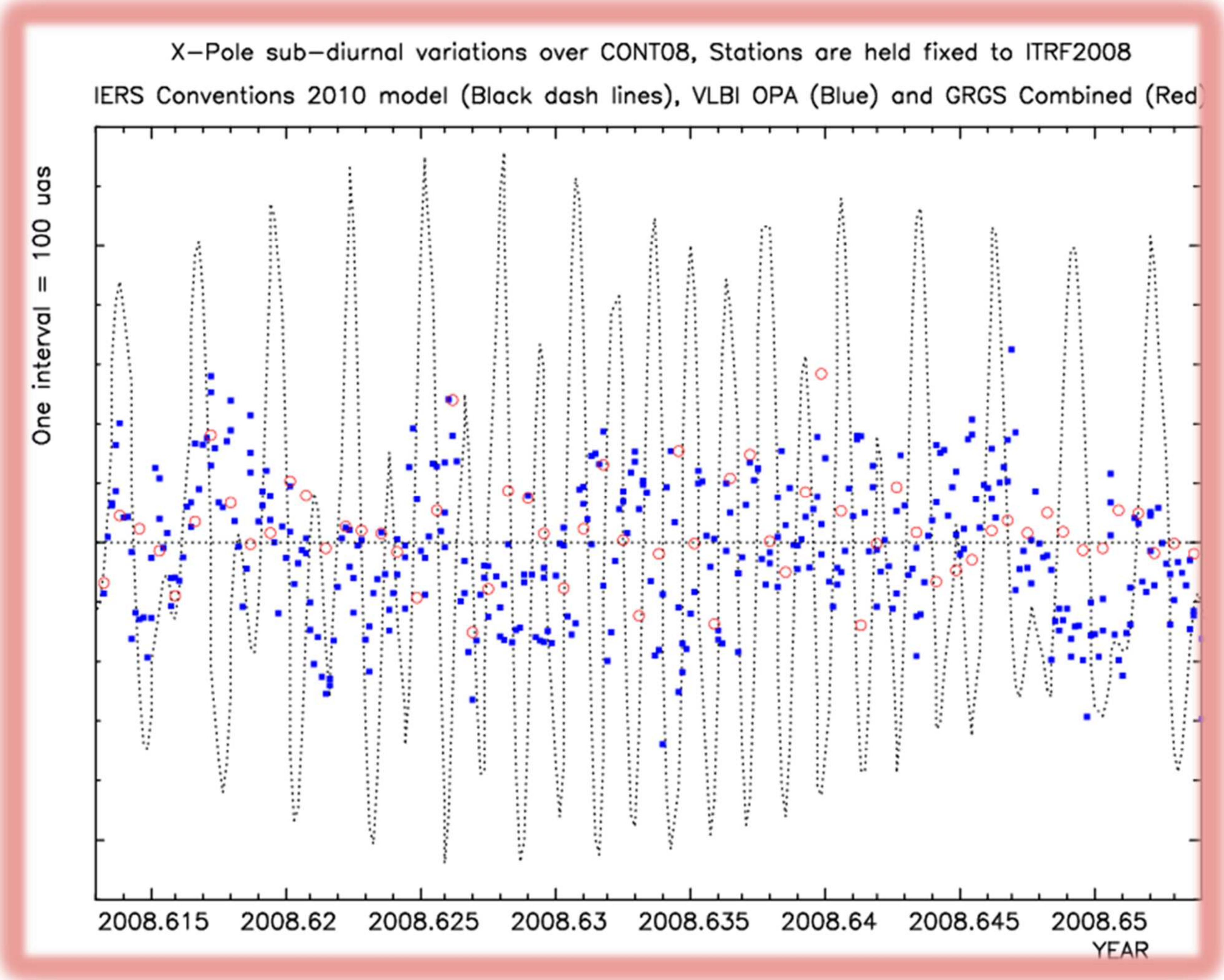
Nutation offsets dX + i dY : retrograde spectrum



Nutation offsets dX + I dY : prograde spectrum



Diurnal and Sub-diurnal variations

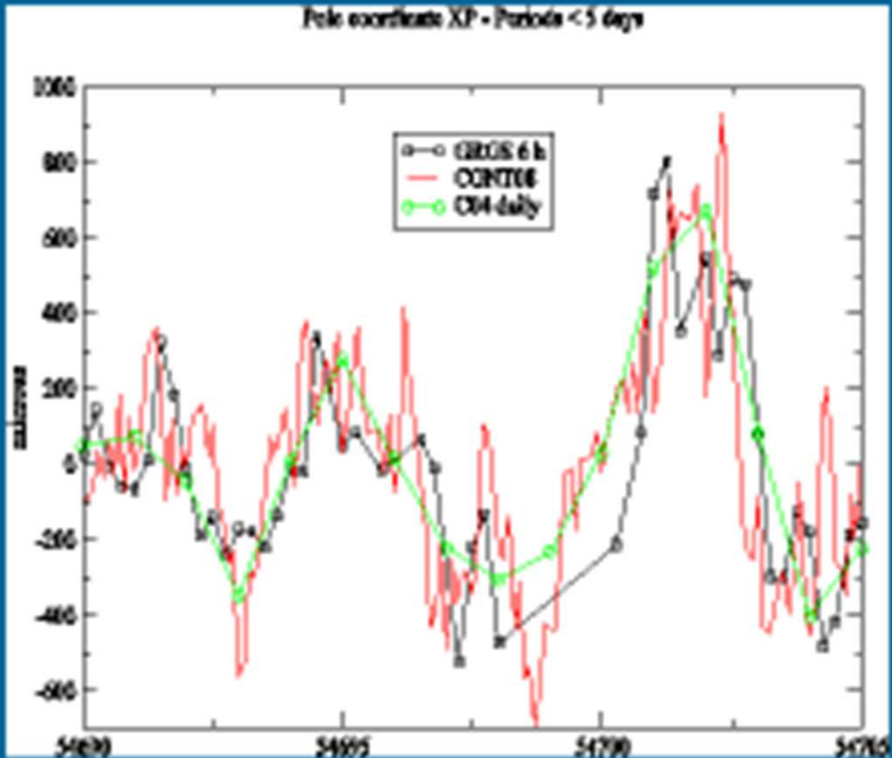

X–Pole sub–diurnal variations over CONT08, Stations are held fixed to ITRF2008
IERS Conventions 2010 model (Black dash lines), VLBI OPA (Blue) and GRGS Combined (Red)
One interval = 100 uas
2008.615
2008.62
2008.625
2008.63
2008.635
2008.64
2008.645
2008.65
YEAR

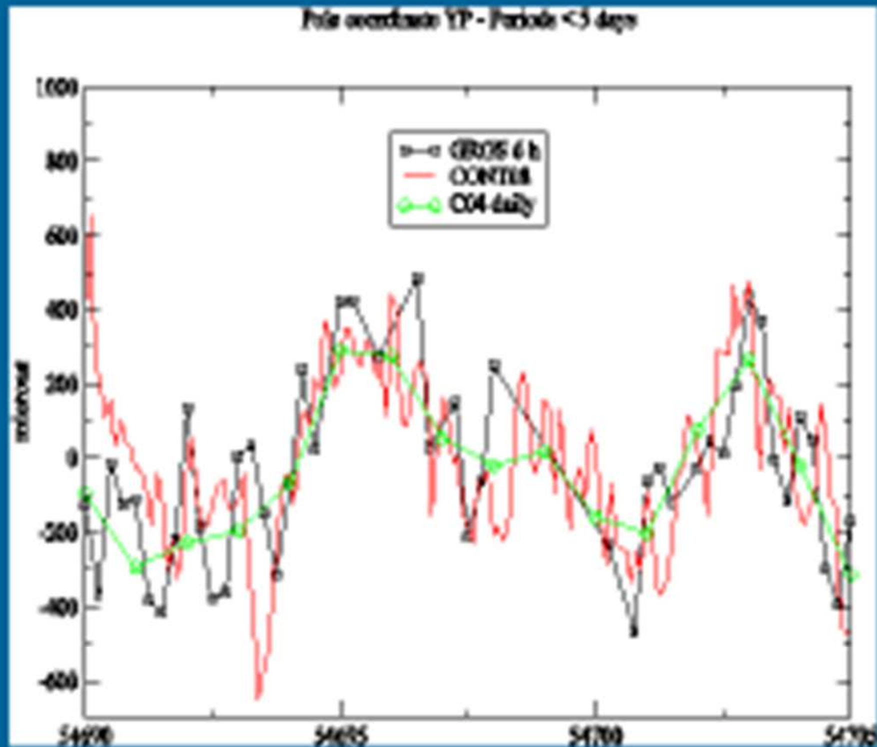
Diurnal/sub-diurnal variations for X-Pole

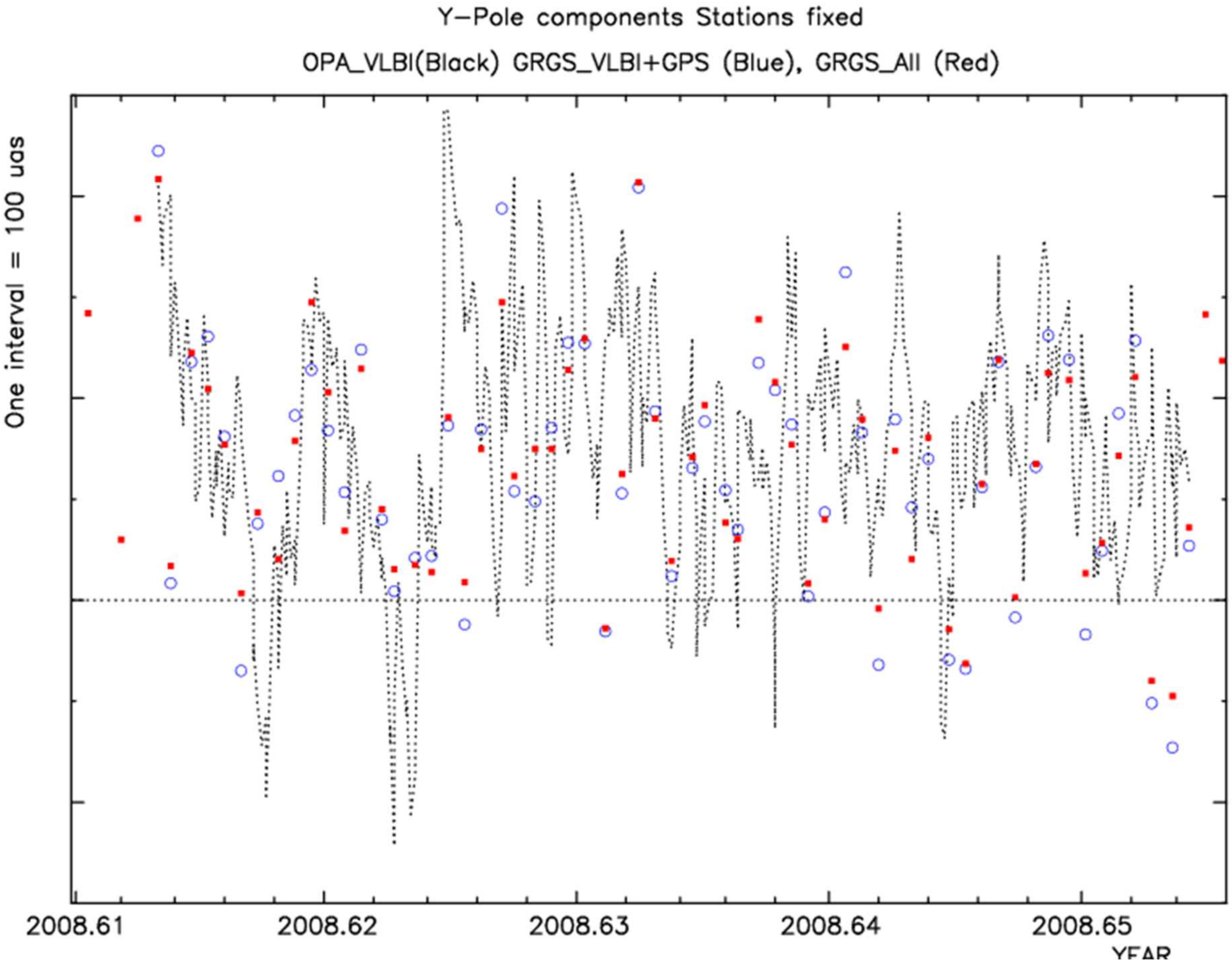
Comparisons of three series
Black: Oceanic diurnal/ sub-diurnal IERS 2010 model
Red: GRGS Combined solution (6 hour time resolution)
Blue: Solution derived from VLBI intensive CONT08 campaign (OPA, 1_hour resolution, courtesy S. Lambert)

It is remarkable to see the fair agreement between the two independant series based on observations (OPA and GRGS).
Large differences exist between these two series and on the other hand with the IERS Conventions 2010 model. They may point out the deficiency of this model.

High frequency Polar motion derived from the weekly combination of GPS + VLBI during CONT08 campaign






Y-Pole components Stations fixed
OPA_VLBI(Black) GRGS_VLBI+GPS (Blue), GRGS_All (Red)
One interval = 100 uas
2008.61
2008.62
2008.63
2008.64
2008.65
YEAR

Sub-diurnal and diurnal variations of LODR (in which zonal tides were removed) over the VLBI intensive CONT08 campaign. Red: 6-hour series was derived from the series of Universal Time UT1 obtained from the combination at the normal level by GRGS. Blue: Atmospheric data derived from NCEP + Oceanic model (IERS Conventions 2010) A good agreement appears between both series.
High-frequency variations that appear (Red) can be attributed in part to inaccuracy in the oceanic model. In addition they can be due in part to the atmosphere, with variations on the order of 30 to 40 μs.