Global Combination of the Space Geodetic Techniques at the normal equation level

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Summary

- Why combining at the normal equation level?

Currently CRF, TRF and EOP separately computed from the various techniques: VLBI,GNSS,SLR, DORIS

Techniques: Strengths and weaknesses; complementarity and redundancy

A global combination at the level of normal equations benefits from mutual constraints yielded by the various techniques

Geophysical applications: diurnal and sub-diurnal signal in the earth rotation parameters, transient episodic signal

- GRGS Pilot project

- IERS Working Group « COL »
  - Pilot campaign over CONT08

Contribution of the various techniques to IERS

The number of stars matches the relative contribution of techniques

PRODUCTS	LLR	VLBI	SLR	GPS	DORIS
Extragalactic ref. Frame		***			
Tie to solar system	***	*			
Tie to Earth					
Precession-nutation	**	***	*	*	
Universal Time	*	***			
Earth Rotation					
High-frequency UT		**	*	***	
Polar Motion		**	**	***	*
Terrestrial Reference Frame					
Network coverage		*	*	**	***
Long-term geocenter			***	**	*
Tectonic plate motion		***	**	***	***
Densification		*	*	***	**

Global combination: interest of the method

- Towards an optimal consistent combination of:
  - EOP+ station coordinates, troposphere parameters, CRF (in the future)

- Techniques have their own strengths and weaknesses
- Use of same software package (GINS), same conventional models
- Should benefit from mutual constraints of the various techniques
- Densification and complementarity
- UT1 (VLBI) + LOD (GPS)
- Nutation (VLBI) + nutation drift (GPS)

- High frequency resolution of EOP: 6h, 1h ?

- However difficulties !!:
  - Combination strategy to be applied
  - To ensure stability of reference frames (constraints, local ties)
  - Weighting of the various techniques

Constraints applied in the combination procedure

Terrestrial frame: Minimum constraints

Minimum constraints concern transformation parameters: translation, rotation parameters and a scale factor. Their application allows to inverse normal equations matrices suffering from rank deficiencies and therefore are initially not invertible.

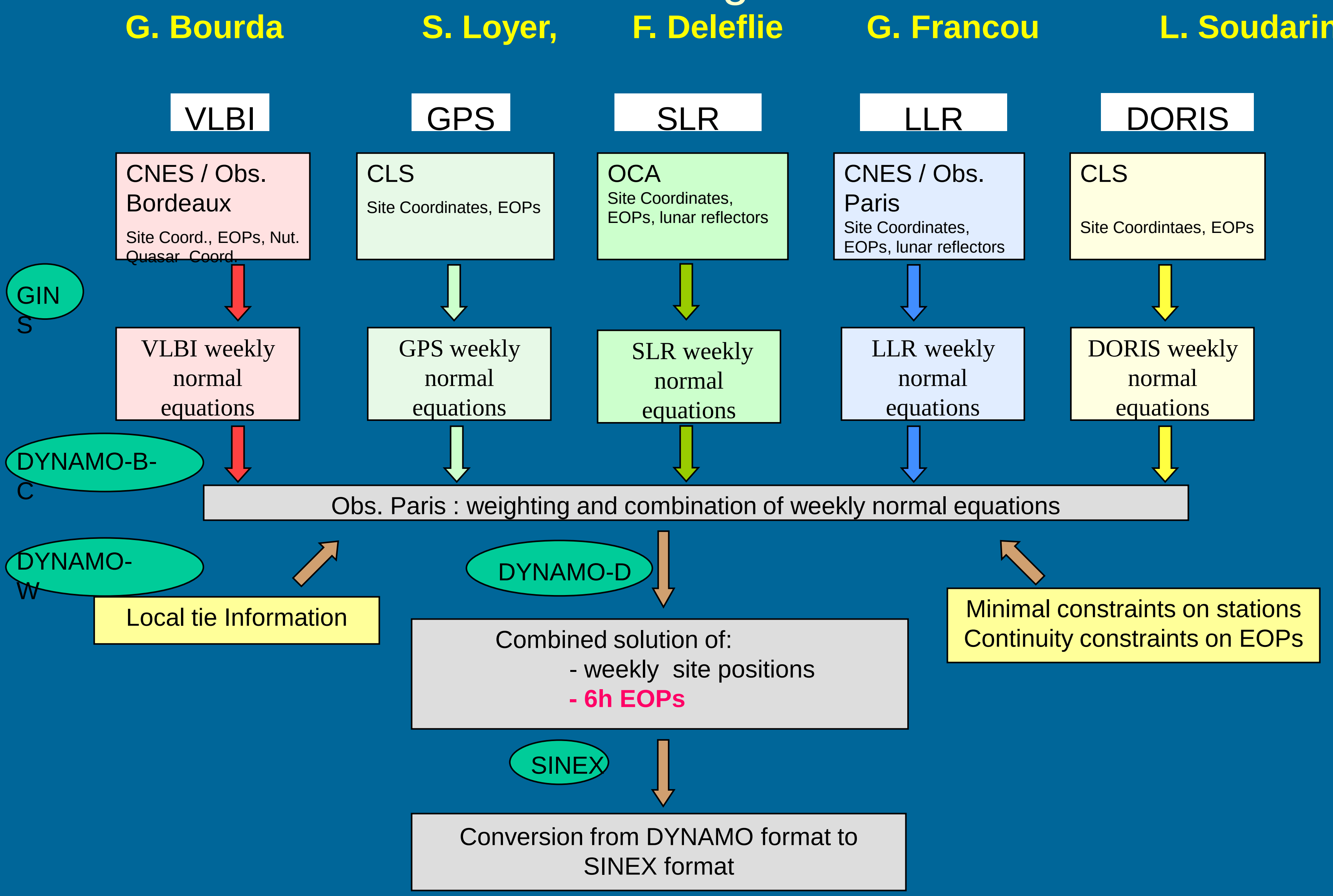
EOP continuity constraints

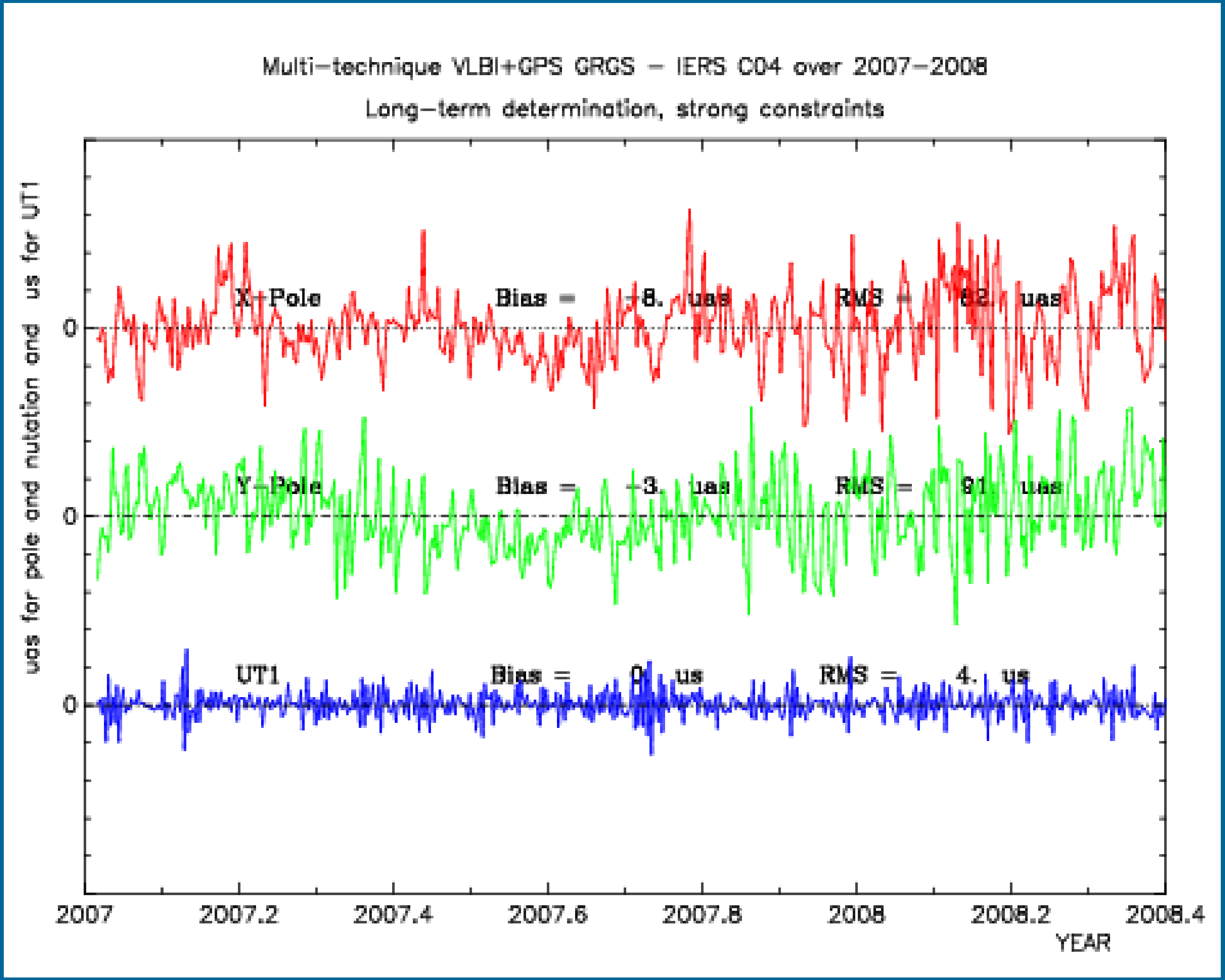
To stabilize the EOP time series and remove the short-term noise, continuity constraints on EOP have to be applied between successive weekly solutions

GINS-DYNAMO software package
GRGS/CNES

- Multi-technique software package, developed in GRGS, initially dedicated to orbit determination and gravity field modeling, extended to VLBI
- *GINS* computes and adjusts orbits around the Earth and planets, generates normal equations
- *DYNAMO* combines, weights (Helmert 's method) , reduces, inverts normal equations and solves for parameters

GRGS Organisation




Multi-technique VLBI+GPS GRGS – IERS C04 over 2007-2008
Long-term determination, strong constraints
uas for pole and nutation and us for UT1
X-Pole
Bias = +8. uas
RMS = 82. uas
Y-Pole
Bias = +3. uas
RMS = 91. uas
UT1
Bias = 0. us
RMS = 4. us
0
0
0
2007
2007.2
2007.4
2007.6
2007.8
2008
2008.2
2008.4
YEAR

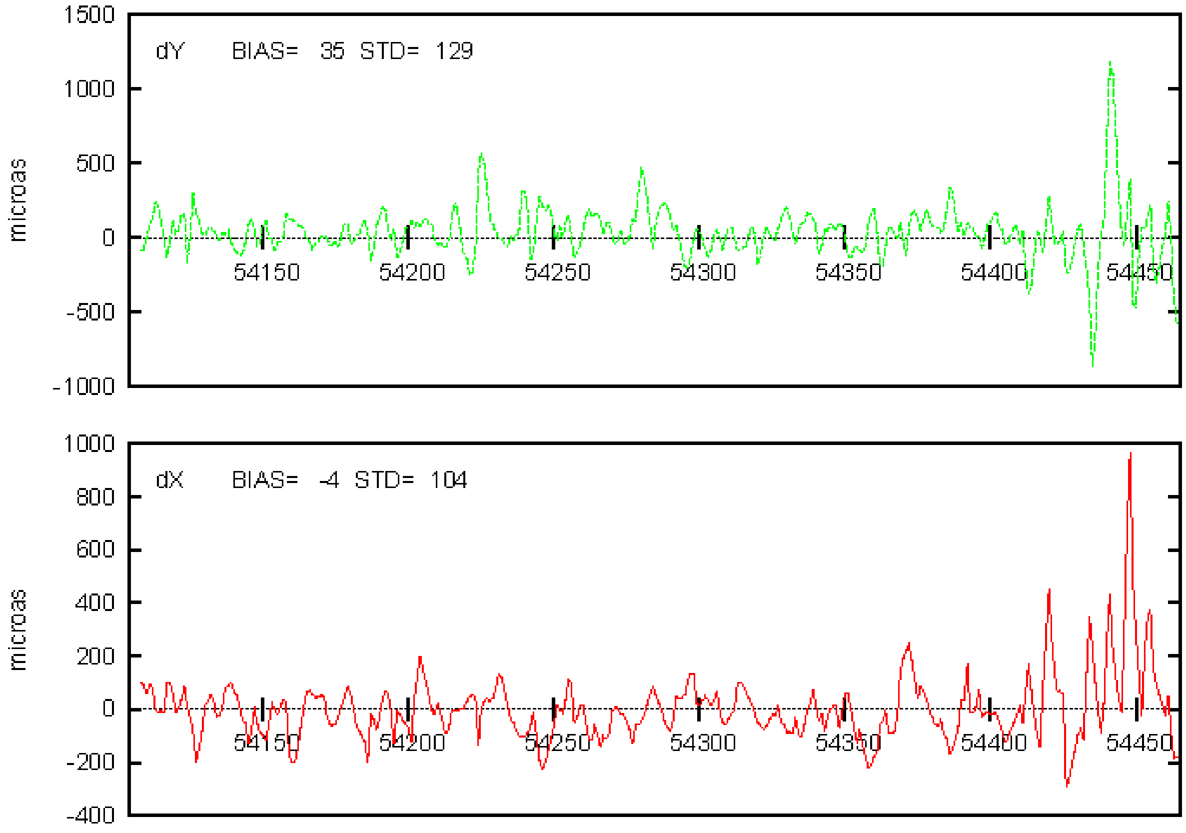
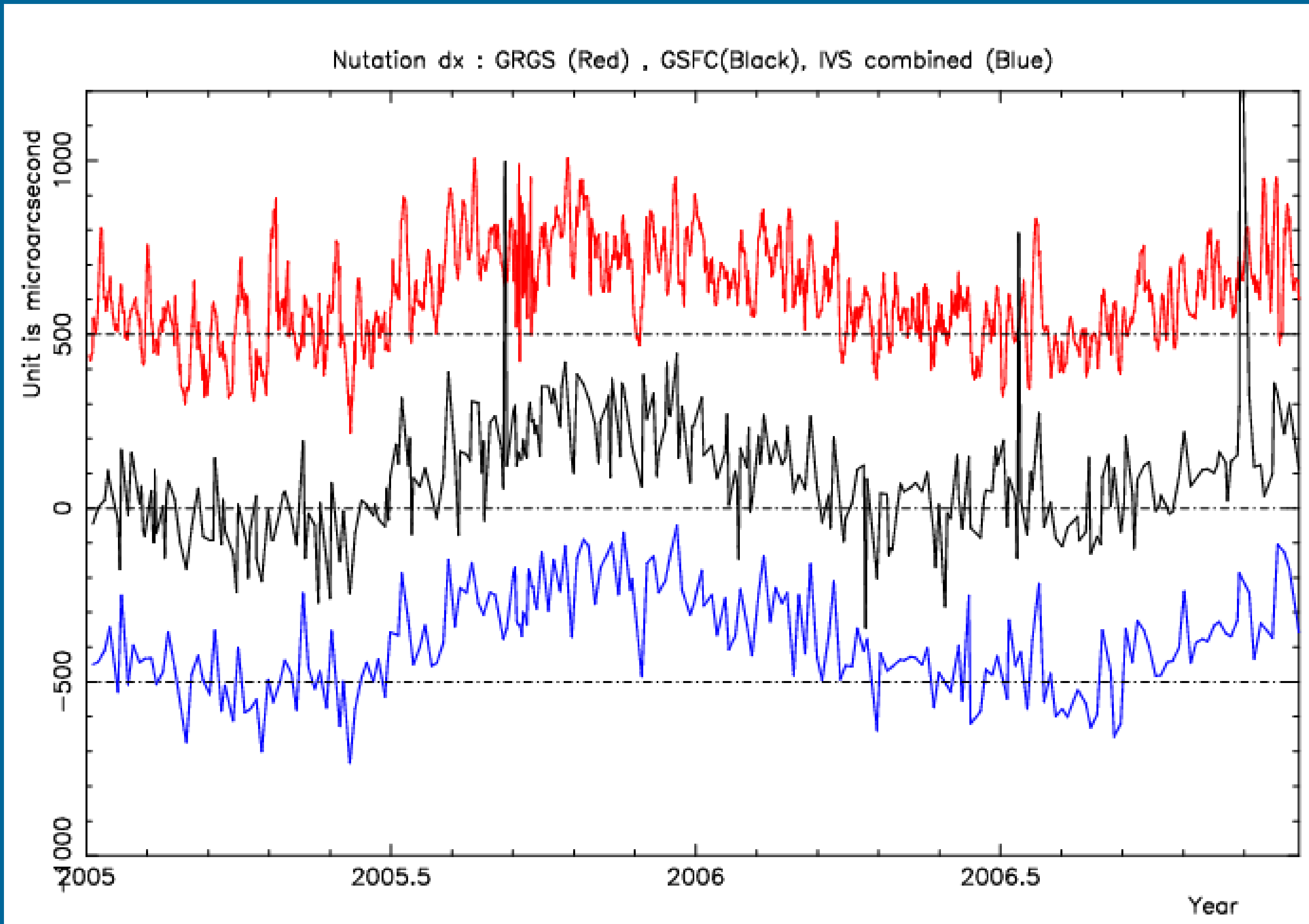
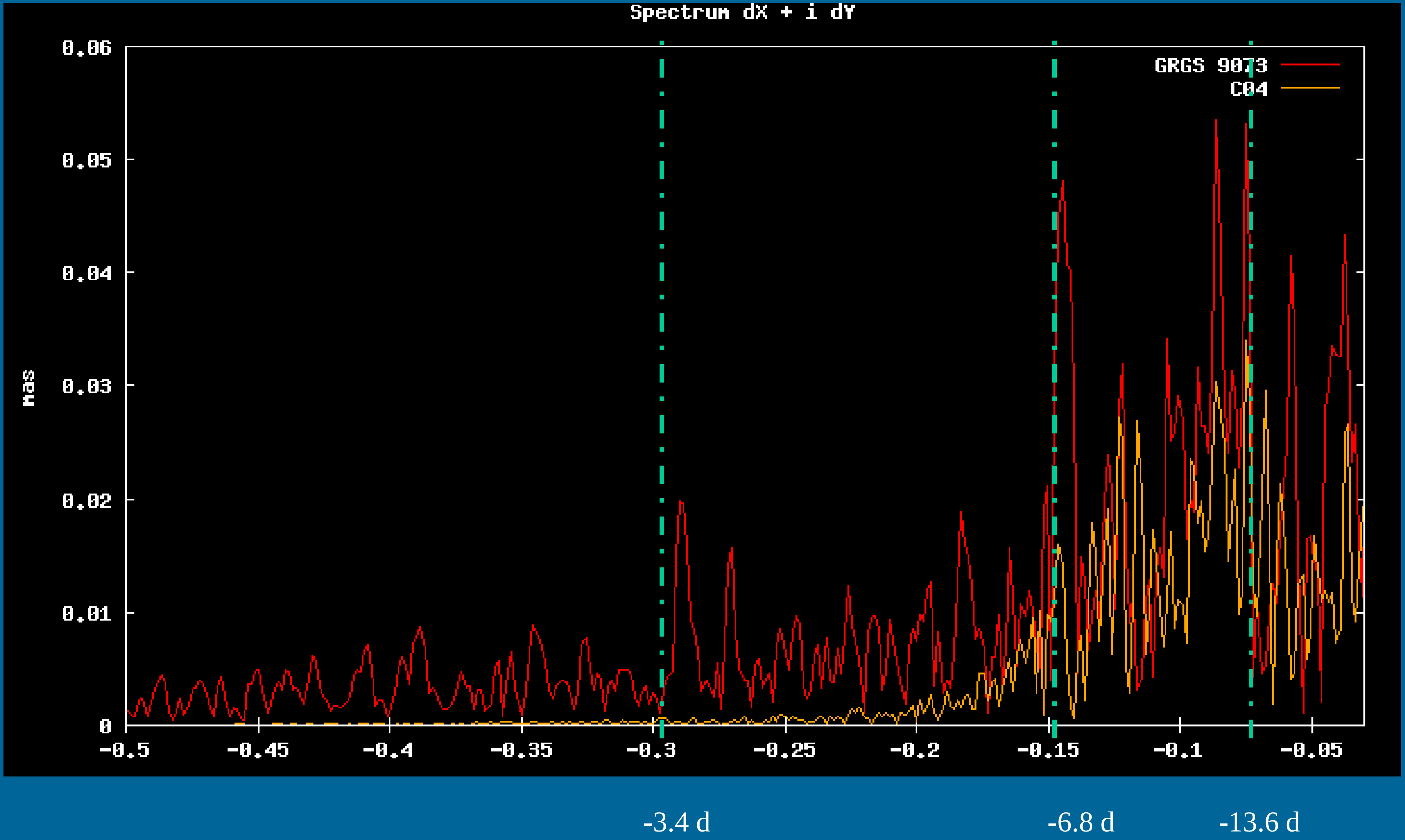


Figure 1. Celestial pole offsets: GRGS-C04 differences over 2007

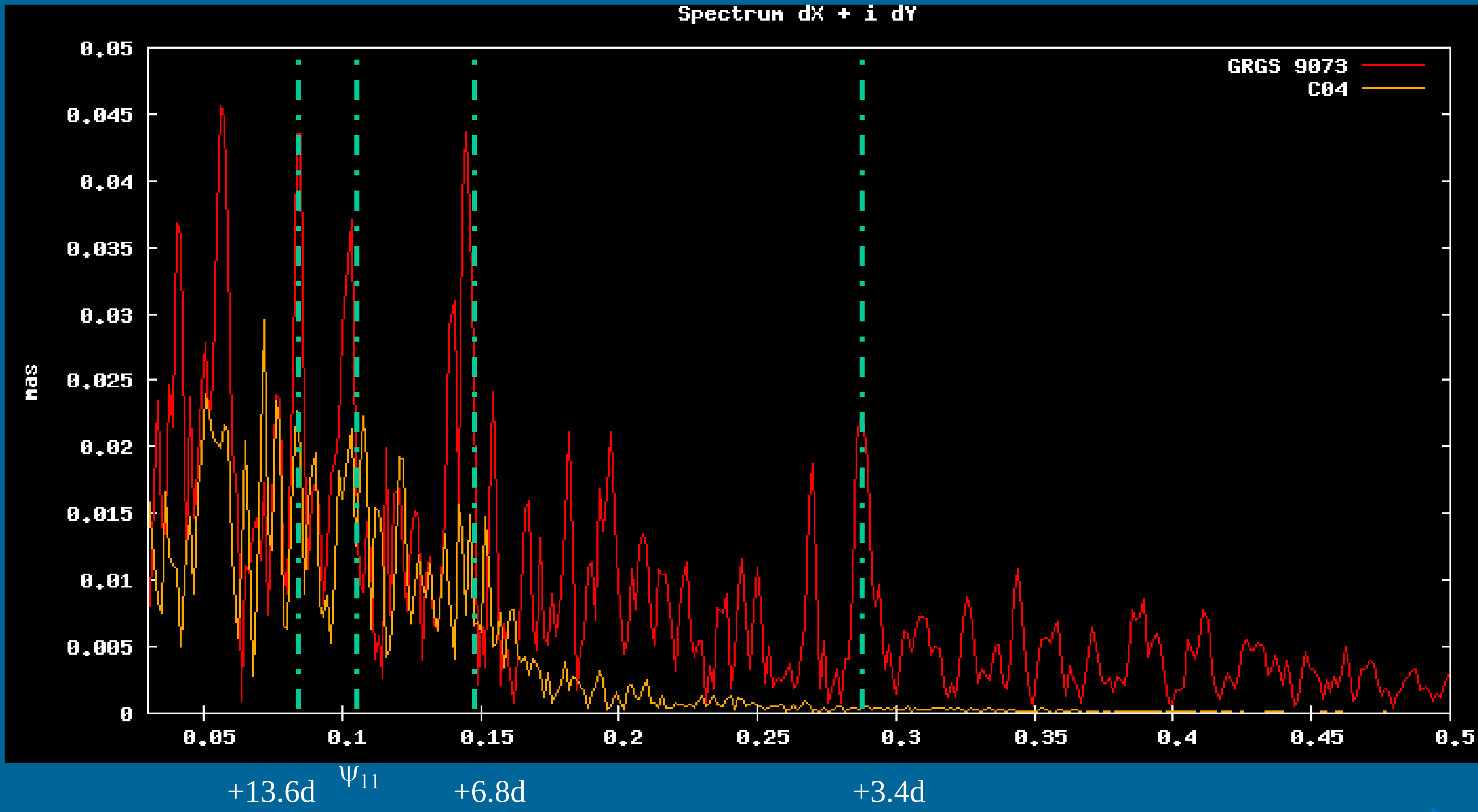
Densification of the nutation series



Nutation offsets dX + i dY : retrograde spectrum



Nutation offsets dX + I dY : prograde spectrum



Results: Celestial pole offsets

- Spectrum: GRGS solution provides a larger spectral power mostly for periods smaller than 50 days.
- We notice a prograde peak at 0.14-0.15 cpd, associated with the -0.85 cpd oscillation in polar motion.
- We compared the spectra of all operational VLBI solution for celestial pole offsets with corresponding C04 values in the domain [+0.1 cpd,0.3 cpd] It appears that C04 present also peak of 20-30 μas at +0.14 cpd
- That harmonic in nutation may be caused by atmospheric normal mode ψ11 (-0.85 cpd in the Earth).
- In the Equatorial Atmospheric Angular Momentum a 7 day oscillation is noticeable and present the same amplitude than in the observed excitation
- In the retrograde band the frequency at -0.1 cpd is amplified and may result from oceanic or atmospheric excitation (Bizouard et al, 2009)

Activity of the IERS COL Working Group
Combination at the Observation Level

Participants

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Maria Kudryashova	ORB

Roadmap of COL

1) review the approach of the various groups

2) elaborating benchmarks *to intercompare results between groups from the same data set.*

3) insuring SINEX compatibility

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4) establishing common processing standards

5) optimizing and unifying parameterization

6) studying the appropriate weighting between techniques *and the use of local ties*

7) studying stabilization methods

8) evaluating and comparing results *to search for compatibility between groups.*

9) organizing routine operations

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First actions of the COL-WG, benchmark campaign

- To intercompare results of different software packages:

  - Defining benchmarks: the period chosen for establishing benchmarks is over the intensive CONT08 VLBI period). Combined SINEX should be delivered per week, separated per technique.

- Reviewing the approach of the various groups: models, standards, methods, parameterization and defining homogeneous processing between groups

- Defining parameters and models:

  a priori models

  products: EOP (piece-wise linear pole, UT1 and nutation parameters per day), station coordinates (per week), troposphere zenith delay ZTD (per hour).

Recommended models for inter-comparison

Gravity field	EIGEN gravity field model computed from a GRACE-GOCE time variable model centered over the 3-week test period (provided by GRGS). This model is completed by mean gravity variations of the atmosphere and of the non-IB oceanic response.
Ocean Tides	FES2004 model.
Other dynamical models	according to IERS conventions 2010
Troposphere delay	**GPT+GMF** is adopted for radio-electric measurements; **Mendes-Pavlis** is used for SLR. Zenithal delays and horizontal gradients are estimated (and included in the SINEX files for co-location sites only)
Elevation cut-off angles	according to processing centers (~10 deg. in principle)

Station Coordinates	ITRF2008
EOP	EOP 08-C04 consistent with ITRF2008
Quasar coordinates	ICRF2
Ocean tide loading	Loading displacement for a few collocated sites is checked between groups at the following triple co-location sites: GPS-VLBI-SLR: Hartebeesthoek (30302), Concepcion (41719), GPS-SLR-DORIS: Washington (40451), Mount Stromlo (50119), Tahiti (92201) GPS-VLBI-DORIS: Kokee Park (40424), NyAlesund (10317))
Atmosphere loading	Not applied

SINEX compatibility

	AC	pole	UT1	nutation
DORIS	GRGS	4d pwl O		
GPS	AIUB	pwl	pwl	pwl
	GRGS	O	O	O
SLR	AIUB	O	D	
	GRGS	O	O (pwl?)	
	ESOC	O+D	D	
	DGFI	pwl stacked	pwl stacked	
VLBI	DGFI	O+D	O+D	O+D
	GRGS	O	O	O
SLR-GPS	ESOC	O+D	D	
	GFZ	O+D	D	
SLR-DORIS	ESOC	O+D	D	

DGFI combination Center

types of EOP parameterization:
O: Offset
D: Drift
O+D: Offset + Drift
pwl: piece-wise linear polygon

Satellites used

	DORIS	LASER	GNSS
AIUB/BKG	-	*Lageos1/2*	*Gps & Glonass*
DGFI	-	*Lageos1/2* *Etalon1/2*	-
ESA/ESOC	*Spot 2-4-5* *Envisat* *Jason2*	*Lageos1/2* *Etalon1/2*	*Gps & Glonass*
GFZ	-	*Grace A/B* *GPS 5/6*	Gps & Grace-AB
GRGS	*Spot 2-4-5* *Envisat* *Jason2*	*Lageos1/2* *Etalon1/2* *Stella / Starlette*	*Gps*

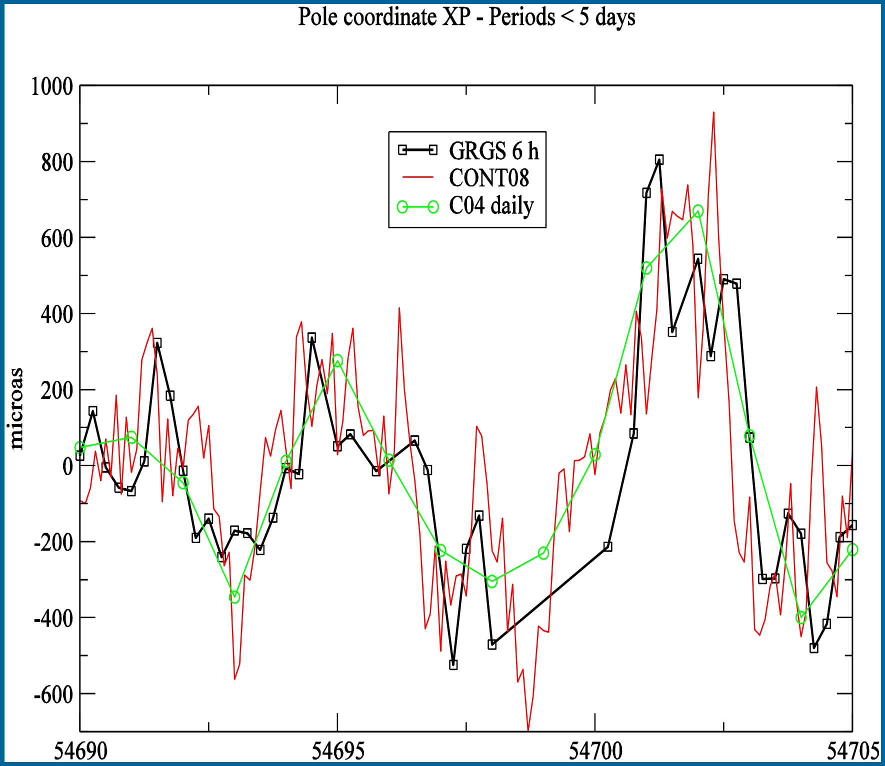
COL-WG participants and software packages

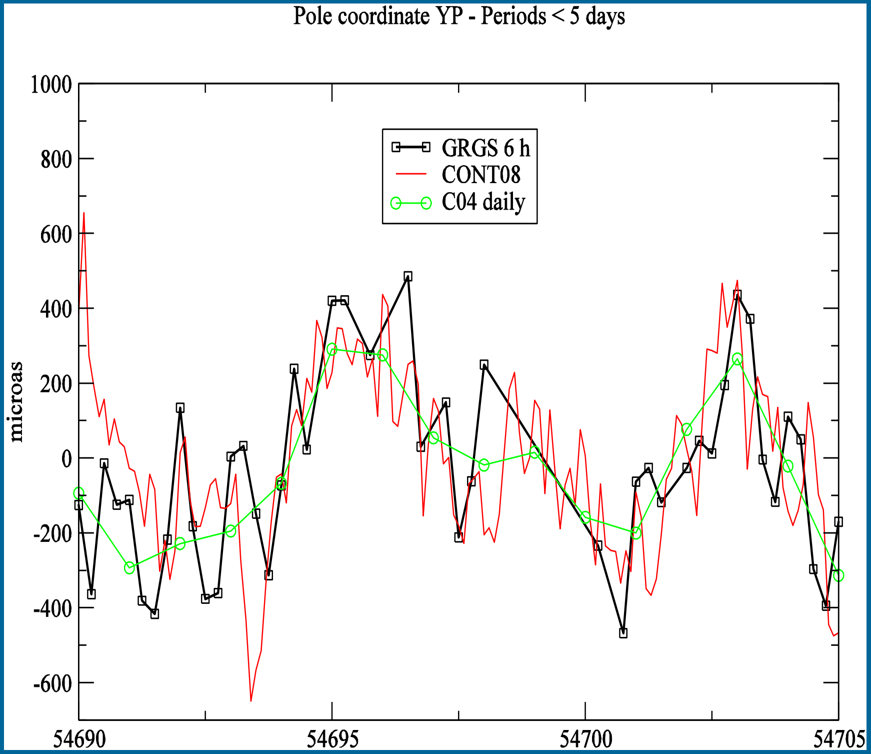
Analysis Centres	Techniques		Software
AIUB/BKG	SLR, GNSS		Bernese 5.1
DGFI	SLR		DOGS 5.0
	VLBI		OCCAM 6.1 LSM
ESOC	SLR+GNSS,	+DORIS	NAPEOS
GFZ	SLR+GNSS		EPOSOC 06.61
GRGS	SLR,GNSS,VLBI,DORIS		GINS/DYNAMO
ASI	SLR		GEODYN/SOLVE
TUW	VLBI		VieVS
GSFC	SLR,GNSS,	DORIS	GEODYN/SOLVE
	VLBI		CALC-SOLVE

Combination Centres

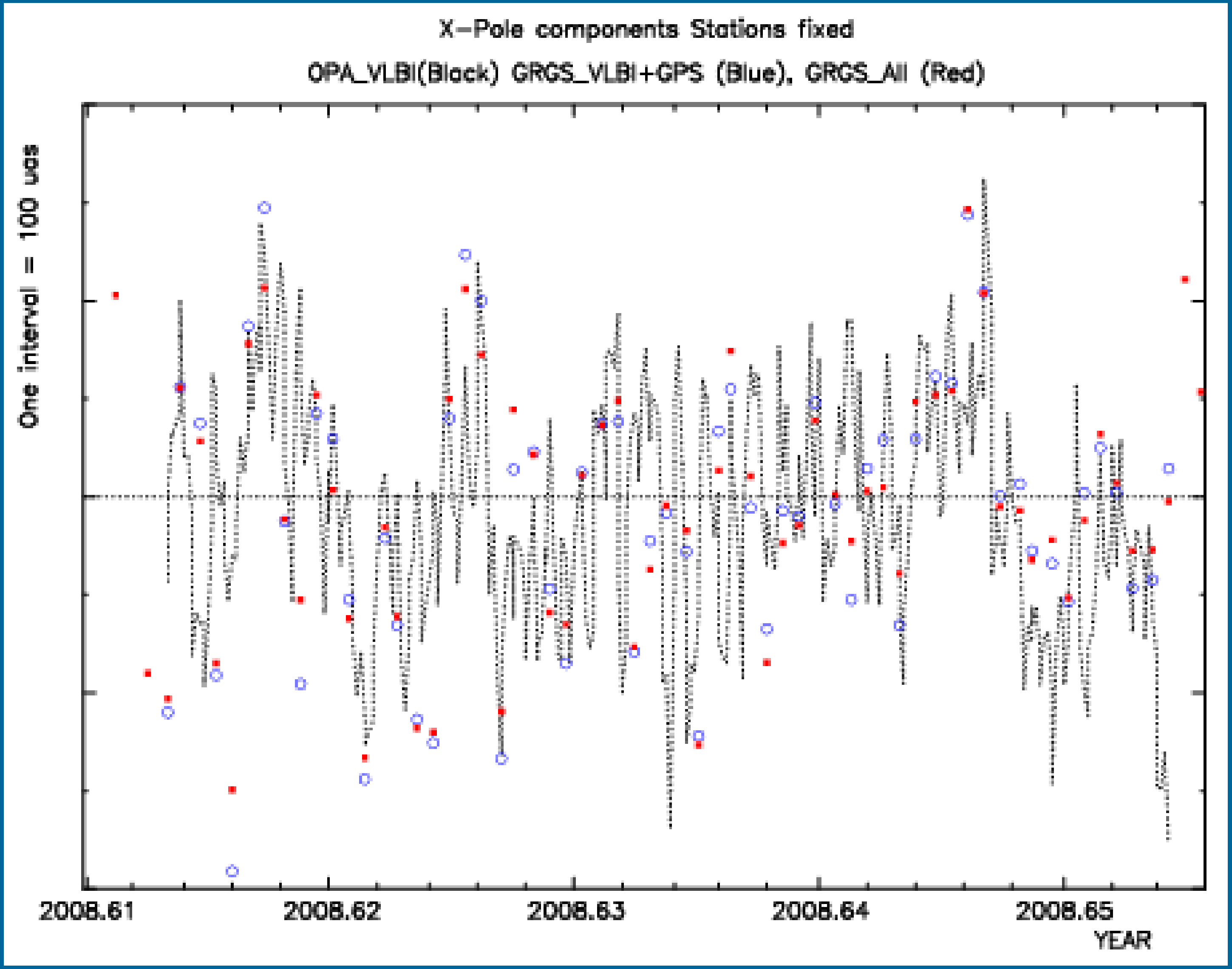
DGFI	DOGS-CS
GRGS/ paris observatory	DYNAMO

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

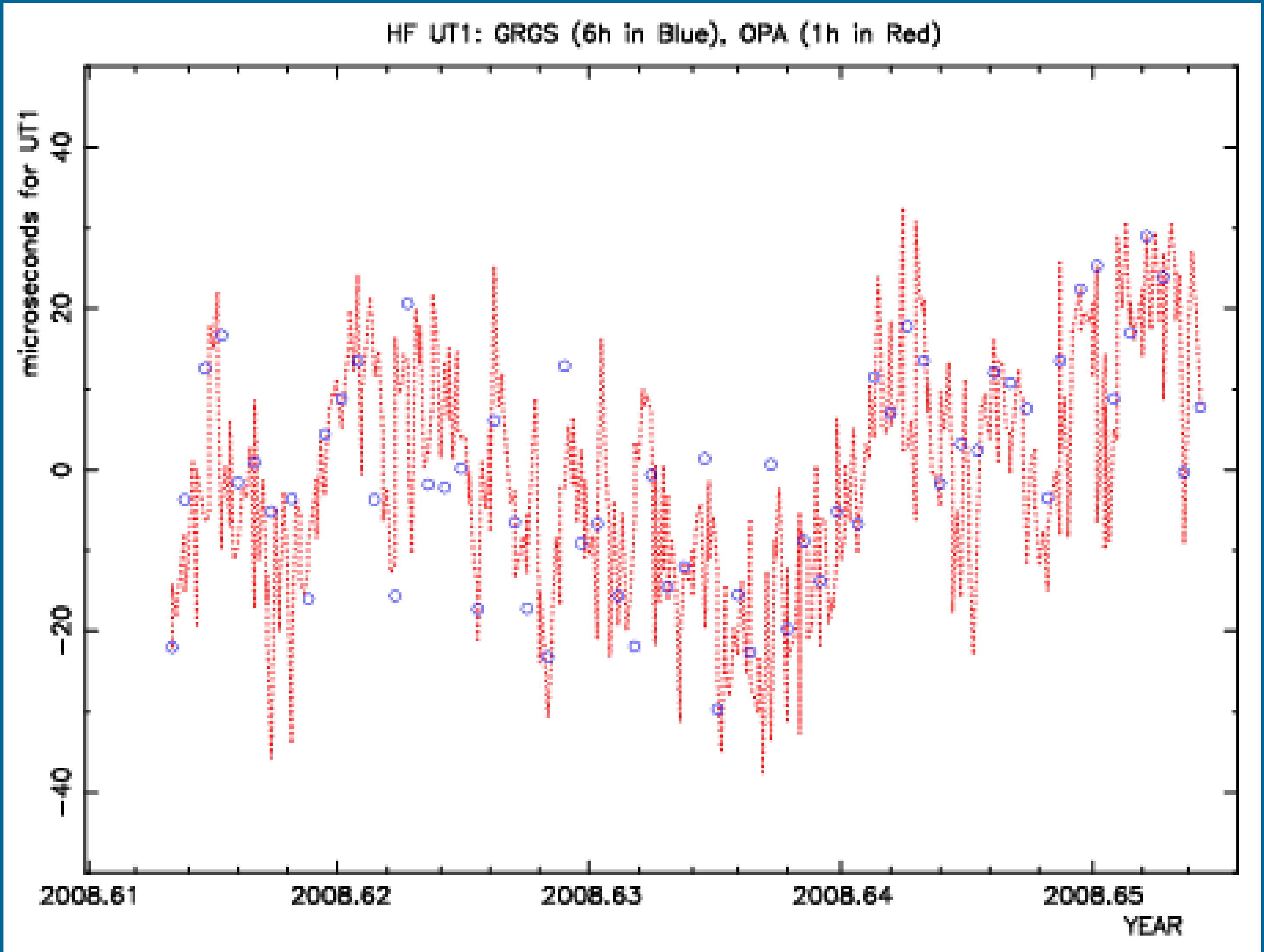




X-pole


X–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

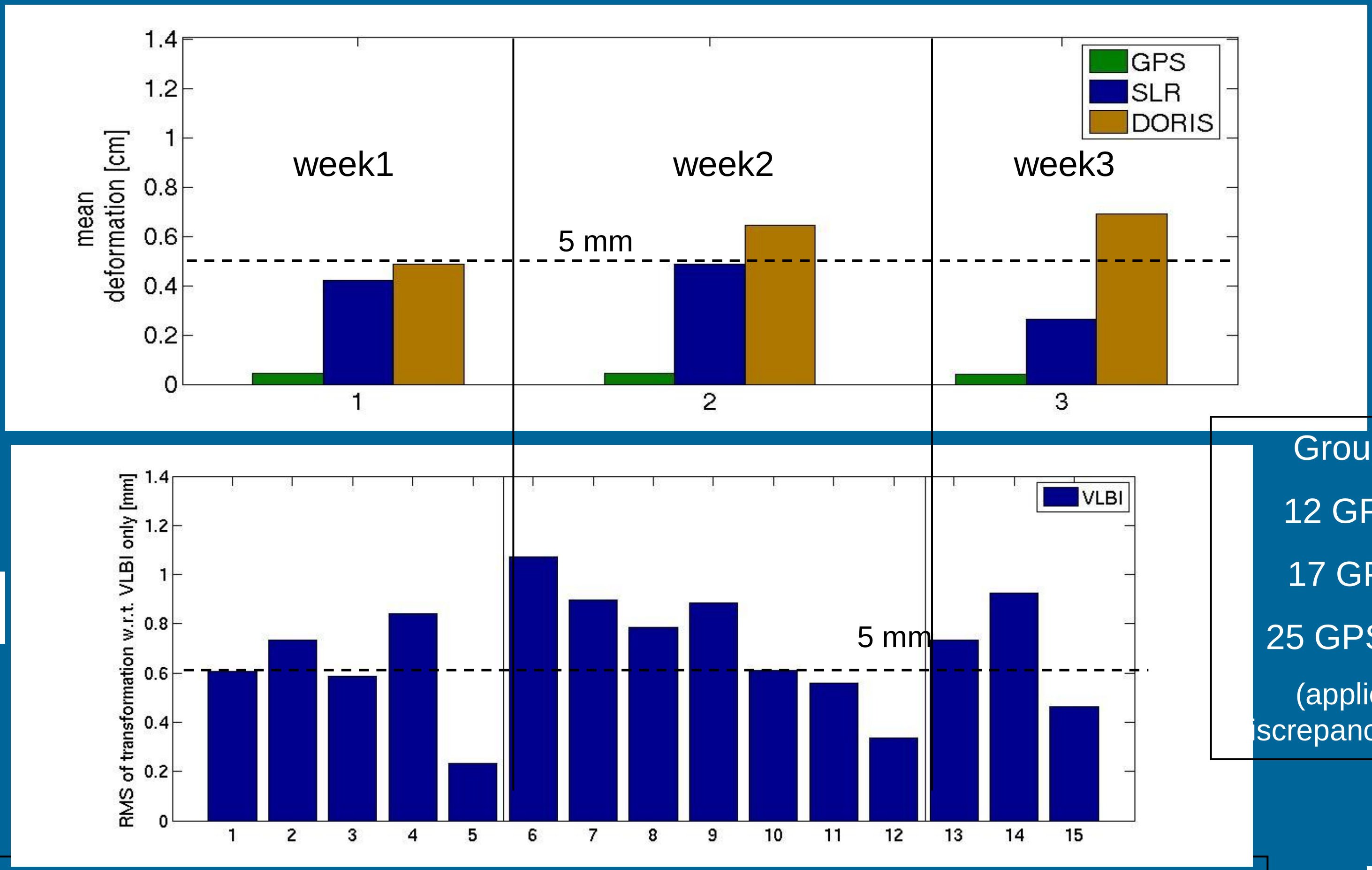
UT1-UTC



HF UT1: GRGS (6h in Blue), OPA (1h in Red)
microseconds for UT1
40
20
0
−20
−40
2008.61
2008.62
2008.63
2008.64
2008.65
YEAR

Deformation of the network due to combination

Comparison to single technique solutions



[cm]

Ground ties:

12 GPS-VLBI

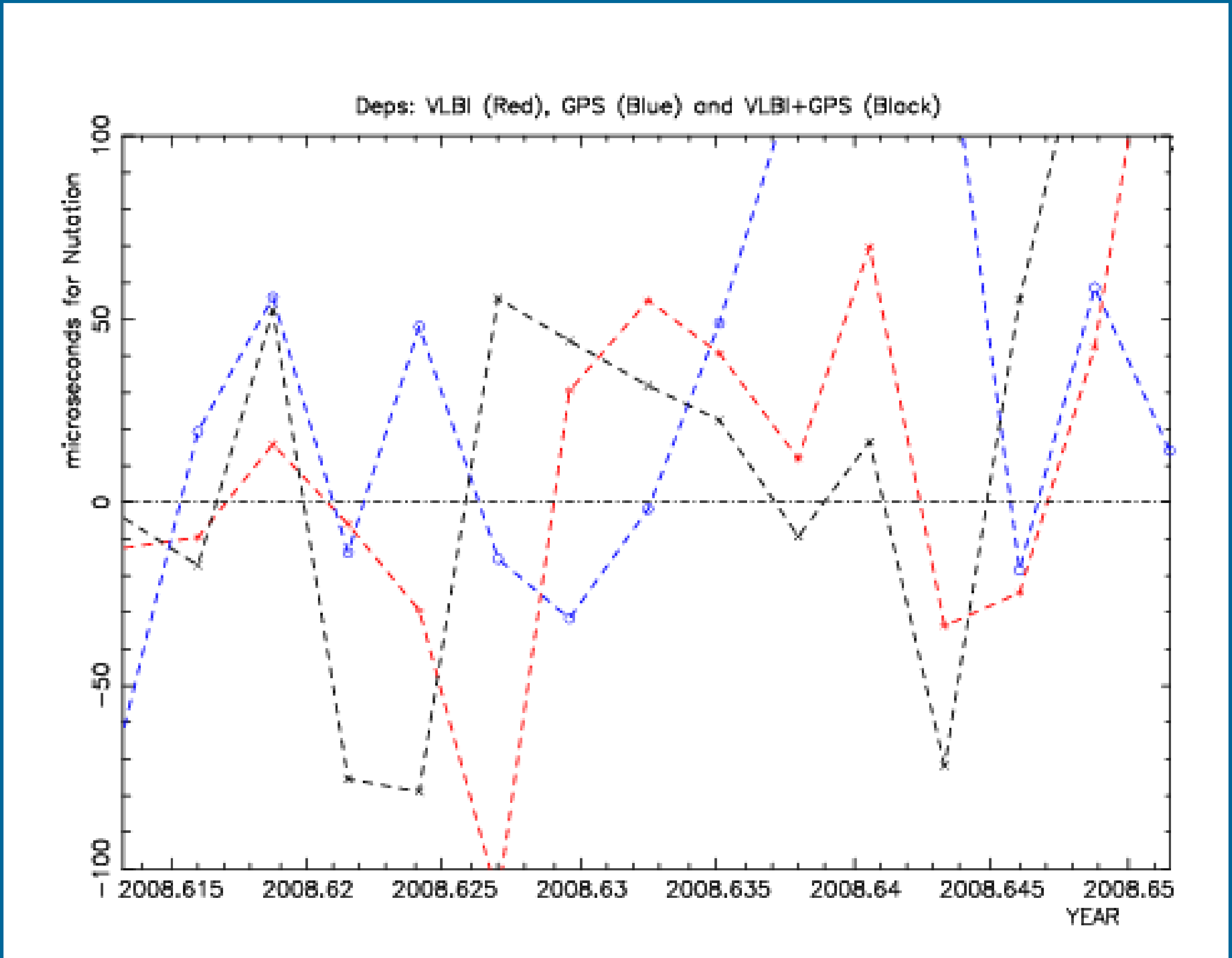
17 GPS-SLR

25 GPS-DORIS

(applied when discrepancies < 25mm)

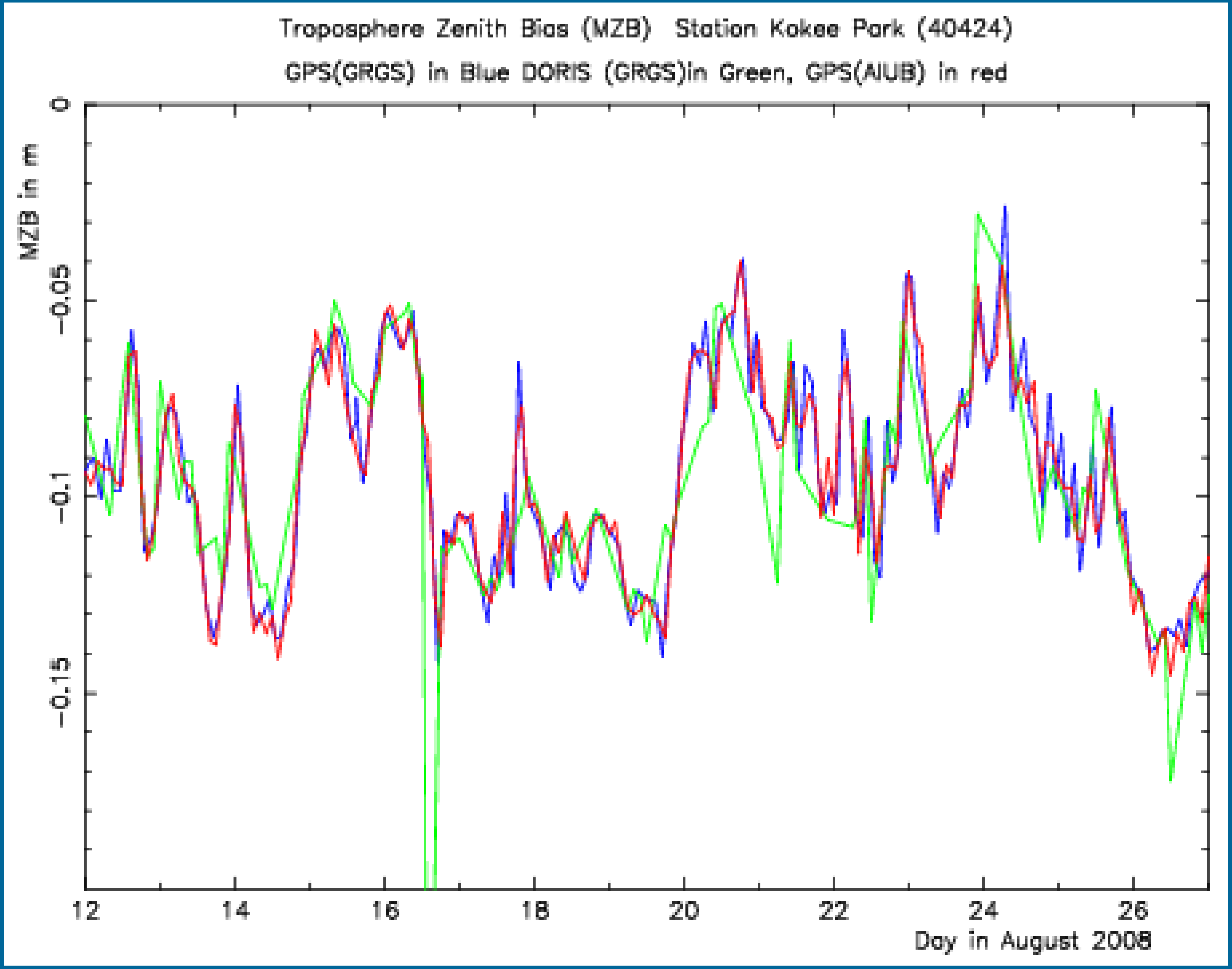
Conservation of datum: Origin: SLR (< 3mm)
Scale: SLR (< 1mm) + VLBI (~0)
Orientation: NNR

Nutation

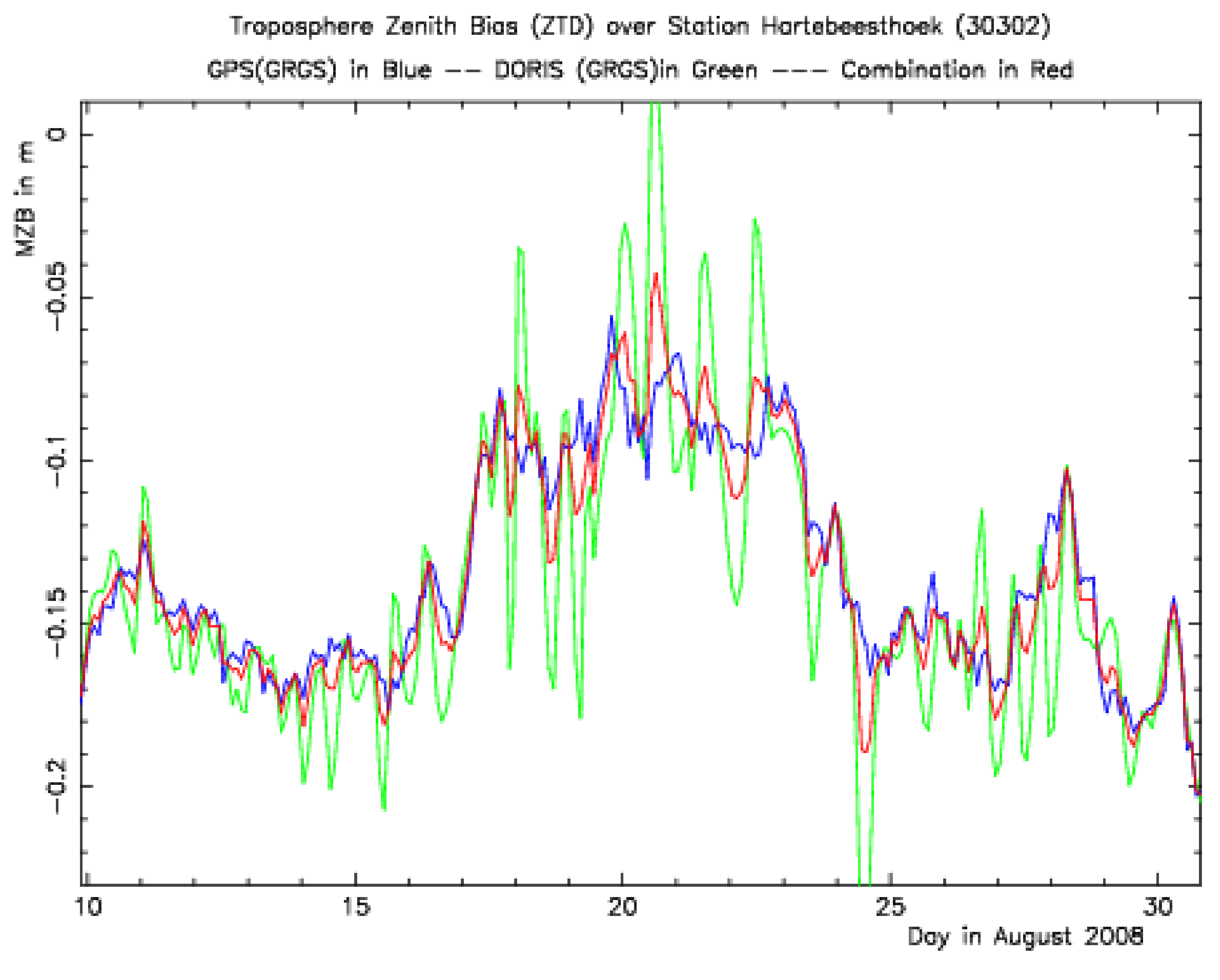


Deps: VLBI (Red), GPS (Blue) and VLBI+GPS (Black)
microseconds for Nutation
100
50
0
-50
-100
2008.615
2008.62
2008.625
2008.63
2008.635
2008.64
2008.645
2008.65
YEAR

Troposphere delay



Effect of combination



Summary

- Towards an optimal combination of:
  - EOP+ station coordinates, tropospheric parameters, CRF (in the future)
- Techniques have their own strengths and weaknesses
- Benefit potentially from mutual constraints of the various techniques
- Densification and complementarity

  UT1 (VLBI) + LOD (GPS)

  Nutation (VLBI) + nutation drift (GPS)
- Higher frequency resolution of EOP (1 h) to check the diurnal/sub diurnal model and to study rapid fluctuations

COL objectives

- bringing together the expertise of groups able to process and to combine several space techniques (SLR/LLR, GNSS, VLBI, DORIS)

- evaluating software homogeneity (in terms of models, standards, parameterization, weighting…) for multi-technique processing

- defining some common parameterization between techniques: EOP (x-hourly sampling), nutation (model) parameters, stations and quasars coordinates, troposphere delay parameters…

- discussing and testing combination and weighting strategies of different techniques involving ground and space ties (Jason 2 and GRACE-A/B)

- Next pilot campaign: intercomparison and combination of techniques over CON11 period (EOP every 1 hour)