COL / E-GRASP meeting

19 February 2016 – BKG/Frankfurt

9:00 – 9:30: welcome (D Thaller)

9:30 – 10:30: summarizing final COL activities

- Summarizing COL activities (R. Biancale)
- GRGS (J.-Y. Richard/OP)
- DGFI (D. Angermann/TUM)
- others

10:30 – 11:00: preparing the future of COL

Break

11:15 – 11:30: E-GRASP/Eratosthenes EE9 proposal (R. Biancale)

11:30 – 12:00: mission scenarios

- *orbit simulation (A. Pollet/IGN)*
- *VLBI simulation (S. Glaser/GFZ)*

Lunch

13:30 – 15:00: E-GRASP/Eratosthenes payload

- *GNSS receiver*
- *DORIS receiver (CNES)*
- *VLBI transmitter (JPL)*
- *USO*
- *SLR (GFZ)*
- *μSTAR (ONERA)*
- *T2L2 (OCA)*

15:00 – 16:00: E-GRASP/Eratosthenes proposal organization

16:00 – 16:30: conclusive remarks

COL Working Group

Combination at the Observation Level
IERS Working Group

After 6 years of COL activities…

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

Roadmap (2009)

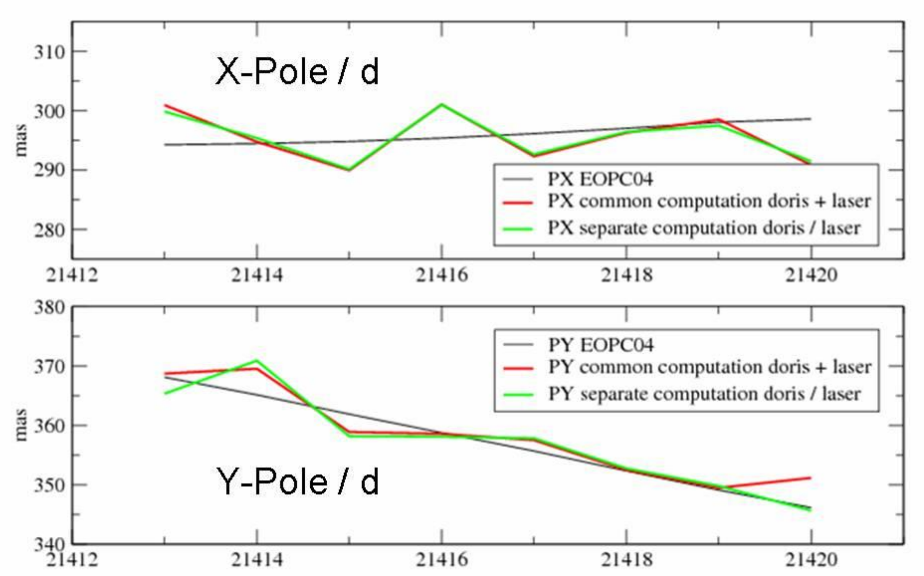
1) **reviewing the approach of the various groups**
   and their capability to process two or more techniques.
2) **elaborating benchmarks**
   to intercompare results between groups from the same data set.
3) **ensuring SINEX compatibility**
   between techniques and with the international technique 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.

COL objectives

COL-WG major tasks will be **to study methods and advantages of combining techniques at the observation level**, searching for an optimal strategy to solve for geodetic parameters.

Demonstration is based on **weekly combined modified SINEX files** (actually containing **unconstrained normal equations** of station coordinates, Earth rotation parameters, nutation parameters and quasar coordinates) from all space geodetic techniques together (SLR/LLR, GNSS, VLBI, DORIS).

Combination at the *observation level* can be considered as equivalent to the *normal equation level* under the condition that **all common parameters must be combined together** (like tropospheric parameters).
At least most of the works have been done at this NEq level.



Adjusted PM from combined DORIS-SLR data on a Jason2 7-day arc in August 2008

Basic principle of Combination

1. Merging all sources of pertinent space information
2. Searching for homogeneity through the same a priori models:
   - Geodetic and geophysical
   - But technique dependent modelling (centre of phase, empirical…)
3. Improving resolution through the same parameterization:
   - Daily or sub-daily EOP (Xp, Yp, UT1); need of LOD?
   - Daily nutation
   - Weekly stations coordinates
   - Quasar coordinates
   - Tropospheric parameters
4. Helping de-correlation through additional constraints between techniques
   - Helmert’s constraints
   - Ties

Tasks (2011)

- **Processing with updated and homogenized standards and parameters** to be finalized over the same 3-weeks period (10-30 August 2008 / CONT08)

- Extension to the **CONT11** campaign (15-29 September 2011)

- Provide on the forum the **list of stations** used (for DORIS, VLBI, SLR, and GNSS)

- **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

- Include LLR for dynamic realization of the celestial reference frame, complementary to kinematic realization of VLBI to contribute to long-term monitoring of nutation as well as pole and UT

- Increase EOP parameterization frequency (from 1d to 3 hrs)

COL Analysis Centres

groups	*software packages*		*techniques*		*NEq*	*product*
• **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					

COL Combination Centres

• **DGFI**	DOGS-CS
• **GRGS**	DYNAMO

Activities in the COL-WG (2014)

• 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 ITRF2014 framework (GRGS, AIUB/BKG, ESOC, GSFC…)

Future of COL

- Very depending on motivation and resources of the ACs and CCs
- Still need of homogenizing technique processing and upgrading several software packages to be really at the observation level
- Demonstrations on VLBI-CONT periods as well as in the ITRF2014 framework are not complete
- COL results must yet be assessed
- Combination at the observation level activities should be updated in the framework of GRASP-like satellite missions

Modelling

IDS, IGS, ILRS, IVS & COL standards to get ready for the GRGS contribution to ITRF2014

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	Set of 50-60 station coordinates & velocities from 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	

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

Combination at the observation level vs. NEq level

Example: Jason2 - 7 day arc over the period: 17/8/2008 – 23/8/2008

Technique	Nb of observ.	Residuals	Orbit # rms
SLR	2216/224	4.1cm	12.1cm
DORIS	109884/52825	.346mm/s	10.6cm
SLR + DORIS	2247/193 109614/53095	4.2cm .352mm/s	

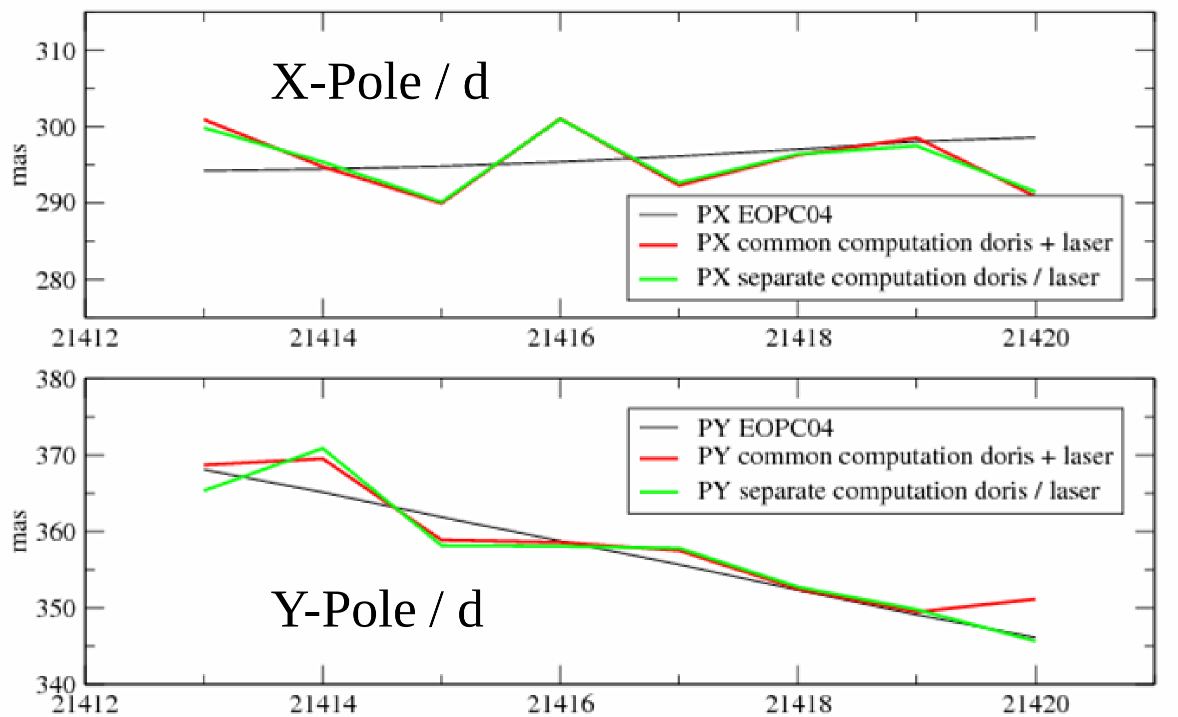
- *difference in data editing*
- *difference in orbits*
- *almost no difference in ERP*

Observation level

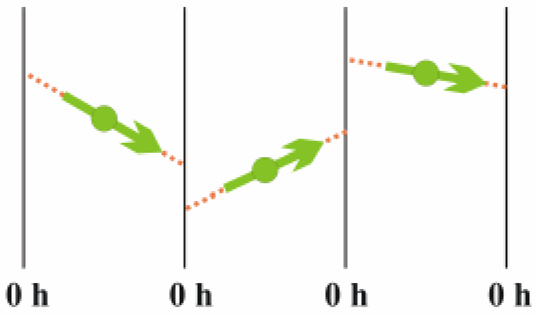
$$\sum_i \frac{\partial Q_i^{calc}}{\partial p_k}\left(\sum_{j=1}^{n}\frac{\partial Q_i^{calc}}{\partial p_j}\Delta p_j - \Delta Q_i\right) = 0$$
$$\forall k = 1,n$$

NEq level

$$\Delta Q_i = Q_i^{obs} - Q_i^{calc} = \sum_{j=1}^{n}\frac{\partial Q_i}{\partial p_j}\Delta p_j$$



Technique of EOP interpolation



ESOC

AIUB/S

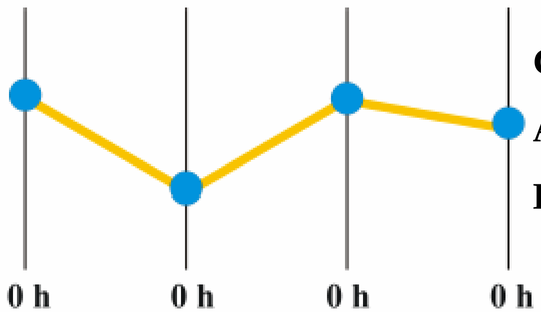
DGFI/V

Piece-wise linear **Offset+Drift**

2*n parameters

no continuity at boundaries

continuity constraints reduce #parameters to ***n+1***



GFZ

AIUB/G

DGFI/S

Piece-wise linear **Polygon**

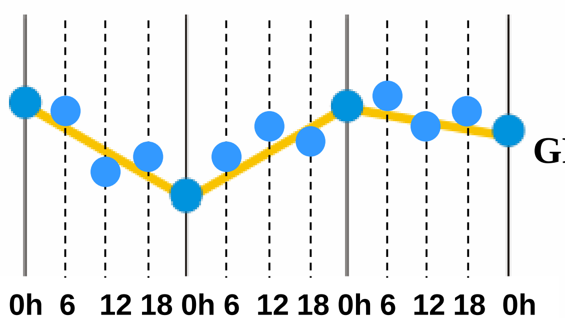
n+1 parameters

"real"continuity at boundaries

no continuity constraints needed

not distinguishable from "offset-only" in SINEX

Seitz, Thaller - Workshop on Combination on Observation Level, 21./22.10.09, Warsaw



GRGS

Densified piece-wise linear **Polygon**

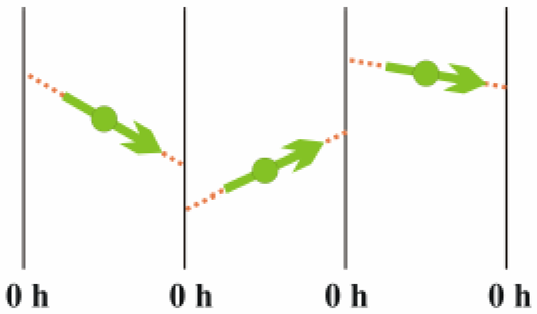
4n+1 parameters

"real"continuity achieved

no continuity constraints needed

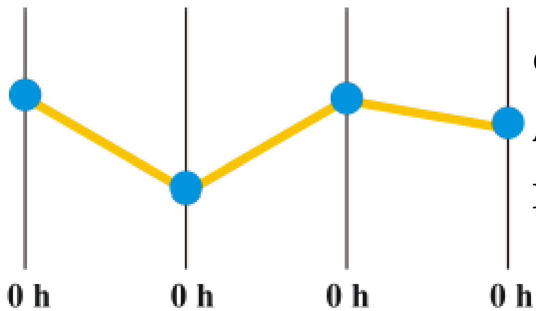
not distinguishable from "offset-only" in SINEX

Technique of EOP interpolation



ESOC
AIUB/S
DGFI/V

Piece-wise linear **Offset+Drift**
2*n parameters
no continuity at boundaries
continuity constraints reduce #parameters to ***n+1***



GFZ
AIUB/G
DGFI/S

Piece-wise linear **Polygon**
n+1 parameters
“real”continuity at boundaries
no continuity constraints needed
not distinguishable from “offset-only” in SINEX

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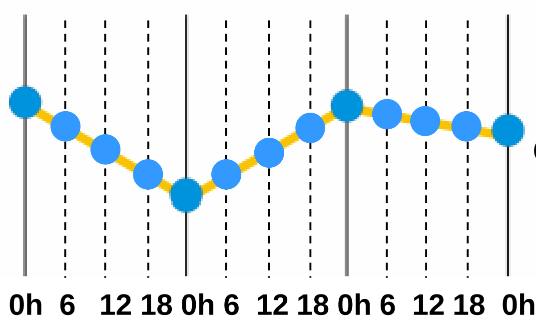


GRGS

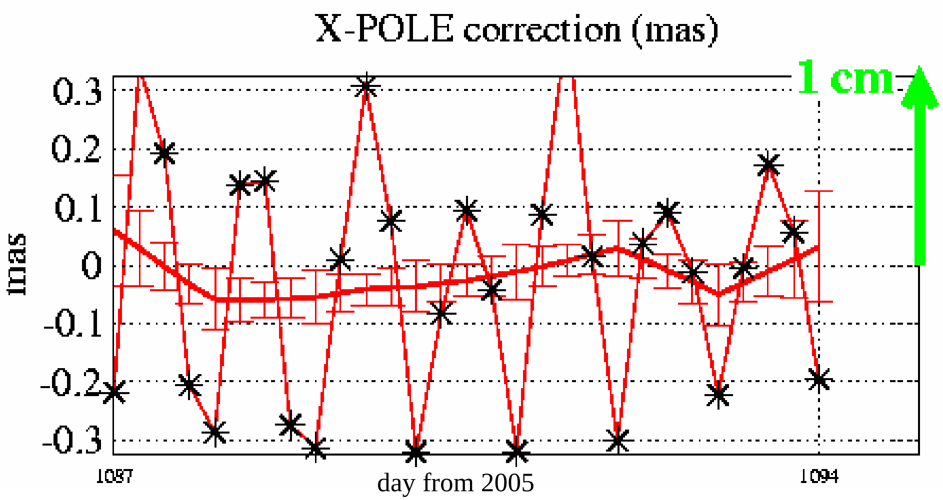
Densified piece-wise linear **Polygon**
4n+1 parameters
“real”continuity achieved
linearity conditions by segment

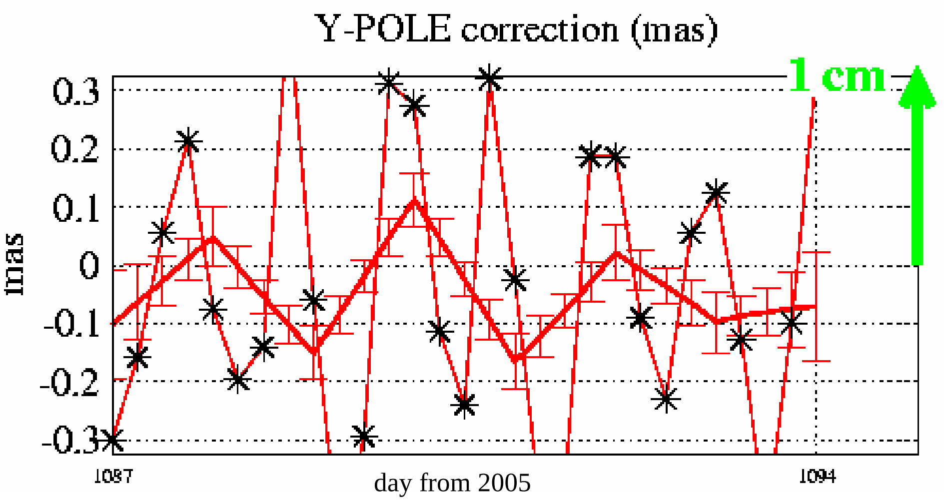
$$\begin{cases} P_j(6h) = \frac{3}{4}P_j(0h) + \frac{1}{4}P_{j+1}(0h) \\ P_j(12h) = \frac{1}{2}P_j(0h) + \frac{1}{2}P_{j+1}(0h) \\ P_j(18h) = \frac{1}{4}P_j(0h) + \frac{3}{4}P_{j+1}(0h) \end{cases}$$

not distinguishable from “offset-only” in SINEX

Example of EOP undersampling

GPS - from 6 hr to 1 day





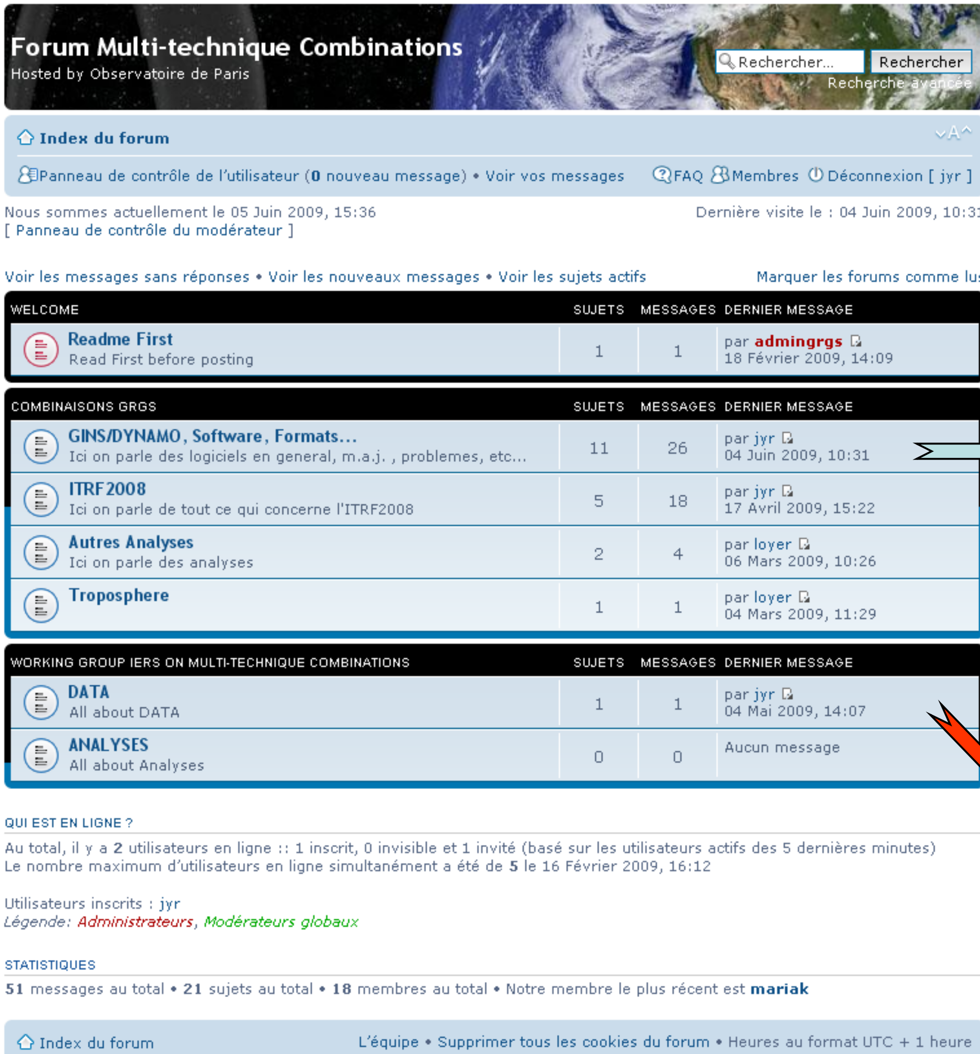
by linearity constraints:

$$\left\{ \begin{array}{l} P_j(6h) = \frac{3}{4}P_j(0h) + \frac{1}{4}P_{j+1}(0h) \\ P_j(12h) = \frac{1}{2}P_j(0h) + \frac{1}{2}P_{j+1}(0h) \\ P_j(18h) = \frac{1}{4}P_j(0h) + \frac{3}{4}P_{j+1}(0h) \end{array} \right.$$

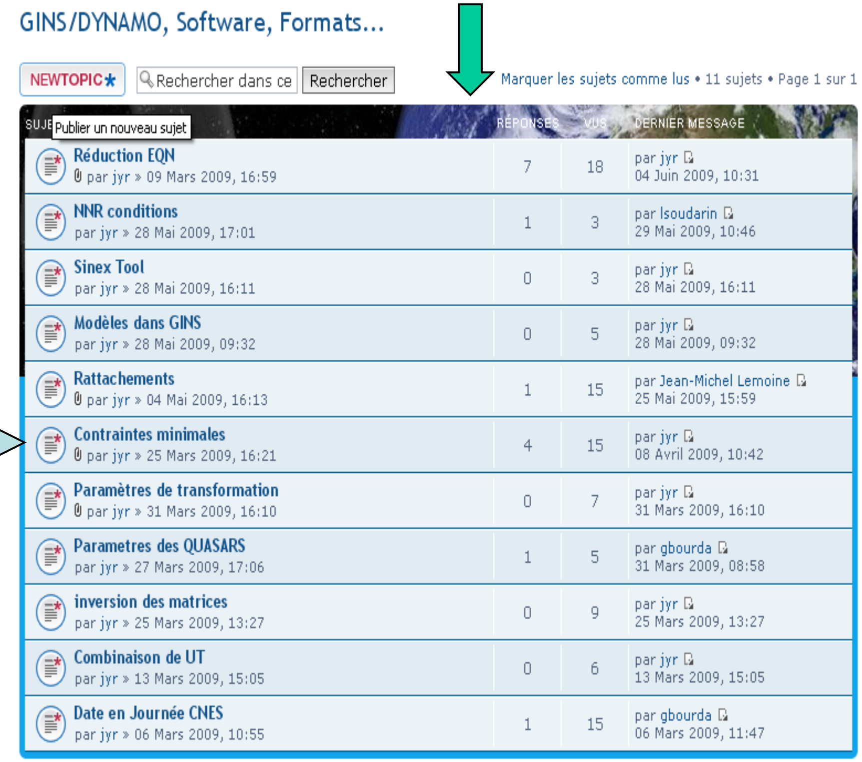
=> One can densify the EOP parameterization (to 3hr for instance) to be closer to the temporal data distribution (mainly for VLBI) and apply linearity constraints afterwards if needed

COL FORUM

http://grgs.obspm.fr/forum/



Discussion for GRGS processing



Exchanges with DGFI,ORB,
Ukrainian Observatory MAO …
For SINEX Matrix

Combinations Series available at
ftp://hpiers.obspm.fr/iers/eop/grgs/

GRGS Solutions EOP, TRF, CRF by multi technique Combination DORIS, GPS, SLR, VLBI at normal equation level, period 2002-2013

Jean-Yves Richard(1) , Daniel Gambis(1), Christian Bizouard(1), Sébastien Lambert(1), Olivier Becker(1), Teddy Carlucci(1)

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(1) Observatoire de Paris - SYRTE – GRGS
(2) CNES / CLS, Toulouse
(3) Observatoire de Bordeaux, LAB
(4) IMCCE – GRGS Paris
(5) IGN – LAREG – GRGS
(7) CNES – OMP – DTP – GRGS Toulouse

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GRGS Normal Equations: 2002-2013 period

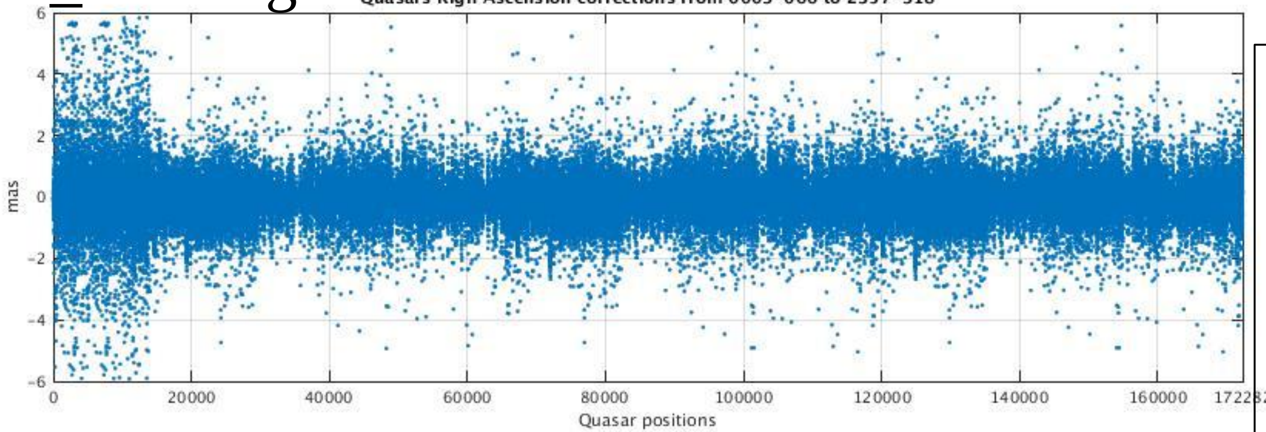
GNSS: CNES-CLS Toulouse	DORIS: CNES-CLS Toulouse	SLR: IMCCE GRGS Paris	VLBI: OB LAB Bordeaux
4372 daily NEQ, Period January 1st 2002 to December 30th 2013 GPS week **1147** to **1773,** GPS – Glonass Constellations, between 23 and 55 GNSS satellites	Weekly NEQ per 3,5d arc length & per satellite: **Doris Doppler**: **288 Topex** 2002-2004, **1077 Envisat** 2002-2012, **1071 Spot-2** 2002-2009, **1228 Spot-4** 2002-2013, **1236 Spot-5** 2002-2013, **386 Jason-1** 2004-2008, **573 Jason-2** 2008-2013, **372 Cryosat2** 2011-2013, **234 Hy2a** 2011-2013 **Doris Laser:** **284 Topex**2002-2004, **1072 Envisat** 2002-2012, **382 Jason-1** 2004-2008, **573 Jason-2** 2008-2013, **371 Cryosat2** 2011-2013, **234 Hy2a** 2011-2013	Weekly NEQ per 9d arc length & satellites **628 LAGEOS-1**, **628 LAGEOS-2**, **628 ETALON-1**, **628 ETALON-2**	Session R1 & R4, **621** NEQ R1 session **621** NEQ R4 session
Pole: PX, PY 1pt/d @12:00 **Pole Rates:** PXR, PYR 1pt/d @12:00 **LOD** 1pt/d @12:00 **Stations** coordinates SX, SY, SZ 1pt/d	**Pole**: PX, PY, **UT1-TAI** 4pt/d @ 00,06,12,18:00 **Nutation** NX, NY 2pt/d @ 00, 12:00 **Stations** SX, SY, SZ 1p/week @ 12:00 **Tropospheric MZB** (Zenith Tropospheric Delay) 12pt/d @ 02h **MGE, MGN** East & North Gradients 1pt/d -- ***CDX,CDY,CDZ** Center of mass correction on satellites 1/sat/week ***Global station bias** SXC, SXS, SXD, SXT, SXB 1pt/arc ***Doppler frequency offset** MFO @ 02h. ***Orbital elements** EX, EY, EZ, EXP, EYP, EZP 1pt /arc ***Atmospheric** drag and lift FD ***Radiation Solar pressure** FS 1pt/arc. ***Orbit Biases** BT, BN ***Radiation forces**, 1 to 8: -specular reflectivity of panel RRS -diffuse reflectivity of panel RRD ***Emissivity of panel** 1 à 8 per arc RE, RF ***Gravity field coefficients** normalized: GCN cosinus, GSN sinus 0 up to 40 degree	**Pole** : PX, PY 4pt/d @ 00,06,12,18h:00 **UT1-TAI** : PT 4pt/d @ 00,06,12,18:00 **Nutation** NX, NY 2pt/d @ 00:00, 12:00 **Stations**: SX, SY, SZ 1pt/week @12:00 **Station range Bias** MRB 1/w/station -------------------------------------- ***Orbital elements** EX, EY, EZ, EXP, EYP, EZP 1pt /arc ***Radiation Solar pressure** 1pt/week/sat ***Orbit Biases** 1pt/week/sat ***Gravity field coefficients** normalized: GCN cosinus, GSN sinus degree 0 to 40 ***Oceanic tides coefficients** normalized OCN, OSN	**Pole** : PX, PY 4pt/d @ 00,06,12,18:00 **UT1-TAI** : PT 4pt/d @ 00,06,12,18:00 **Nutation** : NX, NY 4pt/d @ 00,06,12,18:00 **Stations** : SX,SY,SZ 1pt/week @12:00 **Quasars** : QRA, QDE 1pt/week **Tropospheric zenithal delays MZB** 12pt/d @ 02h (01,03,05,07,09,11,13,15,17,19, 21,23) --- ***Clock error MTB** for VLBI stations @01:00h

* Added parameters for further studies which are reduced or eliminated for this step of development

Radiosources estimation versus ICRF2

~100 quasars estimated at weekly bases

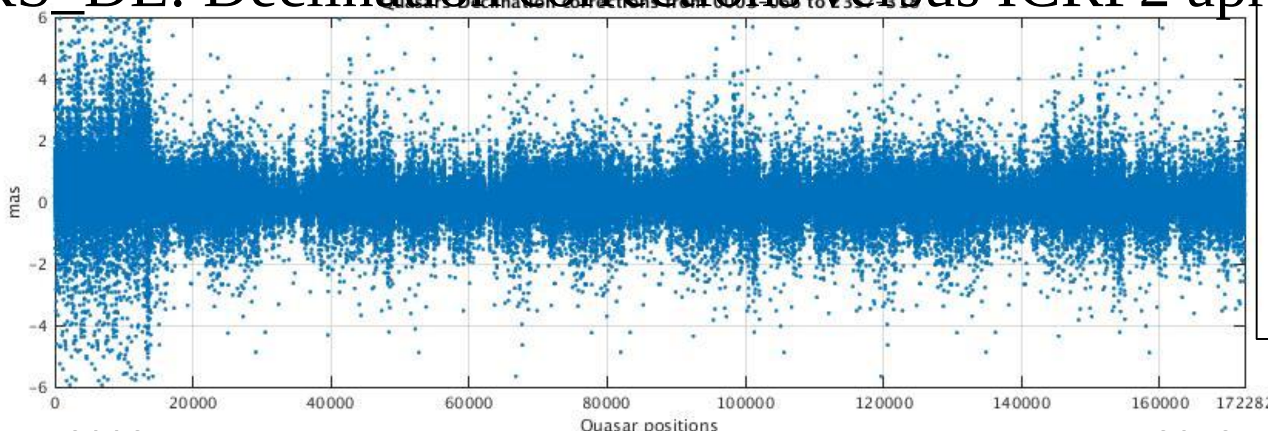
RS_RA: Right Ascension corrections versus ICRF2 apriori



Mean on RS_RA corrections : /mas
-0.0343
Mean on RS_DE corrections : /mas
0.1334
RMS on RS_RA corrections : /mas
0.7221
RMS on RS_DE corrections : /mas
0.7907

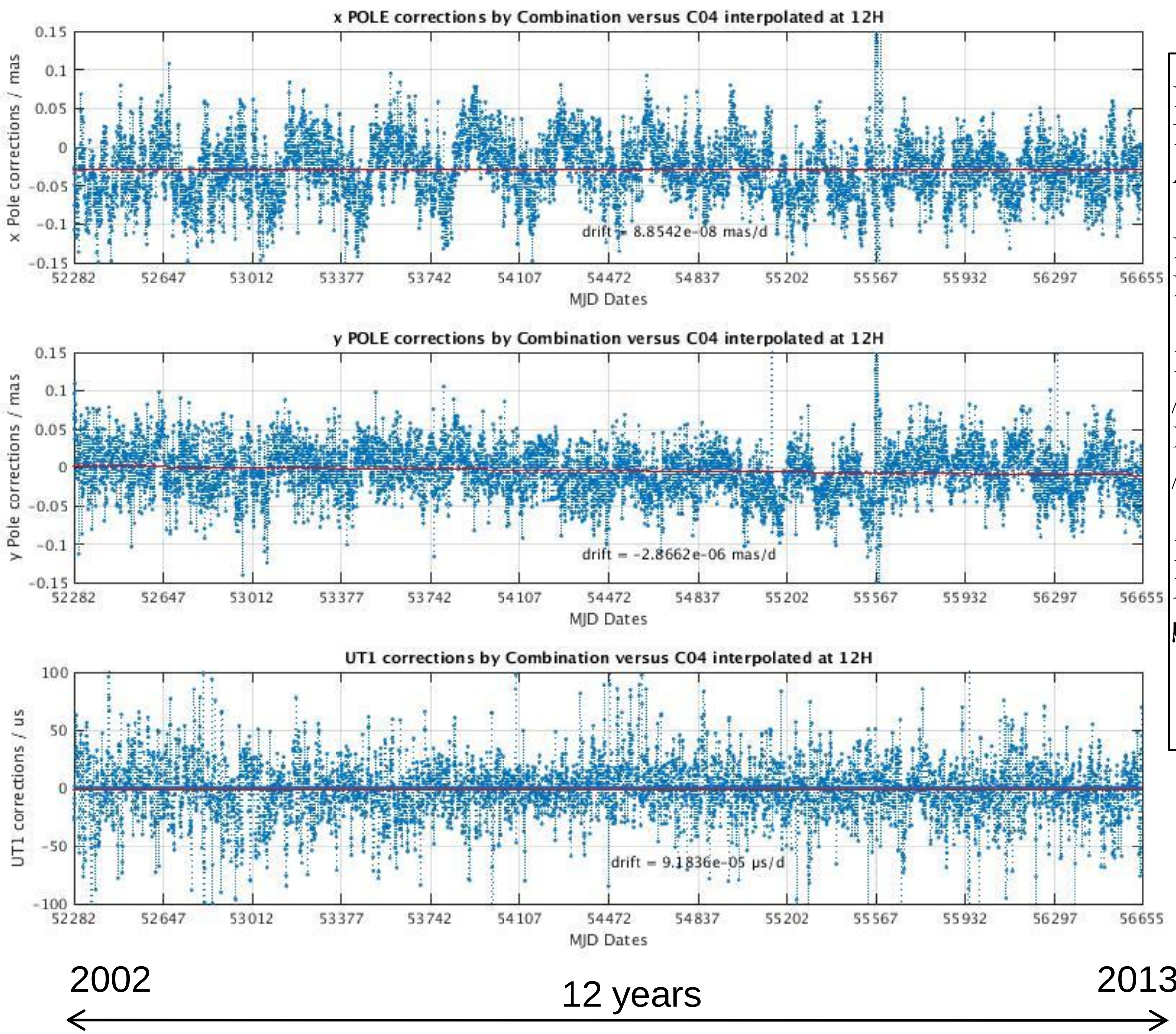
Non Rotation parameters:
R1 : /mas 0.0982
sigma R1 : /mas 212.7201
R2 : /mas 0.0198
sigma R2 : /mas 186.2675
R3 : /mas 0.1537
sigma R3 : /mas 154.2918

RS_DE: Declination corrections versus ICRF2 apriori



2002 12 years 2013

Pole coordinates estimation versus C04 interpolated @12H



Number of daily determination @12H: 4370
Number of redondant dates removed : 413
Any outliers removed

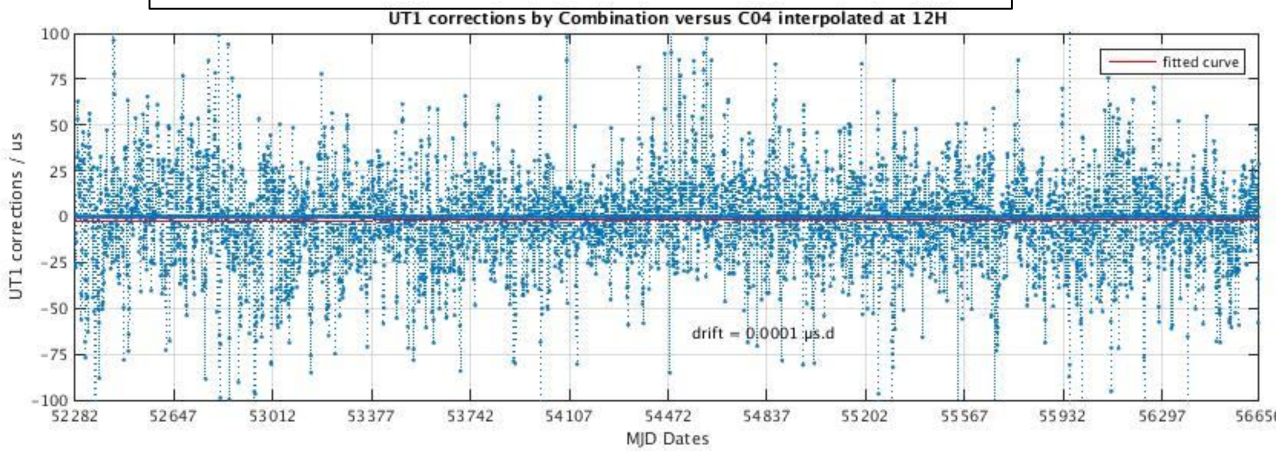
Mean xp C04 - GRGS : /mas -0.0294
Mean yp C04 - GRGS : /mas -0.0042

RMS difference xp C04 - GRGS : /mas 0.0512
RMS difference yp C04 - GRGS : /mas 0.0373

Mean UT1 C04 - GRGS : / µs -1.9881
RMS difference UT1 C04 - GRGS : / µs 26.3918

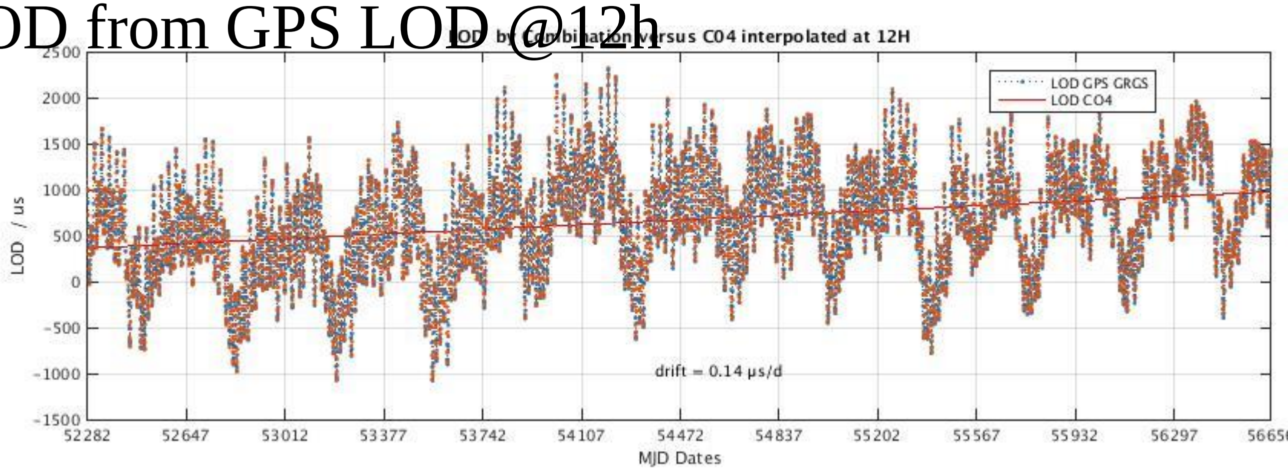
UT1 corrections & LOD compared with C04 interpolated @12h

Number of keeping daily UT1 :	4369
Number of redondant dates removed :	413 , any outliers removed
Mean UT1 C04 - GRGS : / µs	-1.9574
RMS difference UT1 C04 - GRGS: / µs	26.282



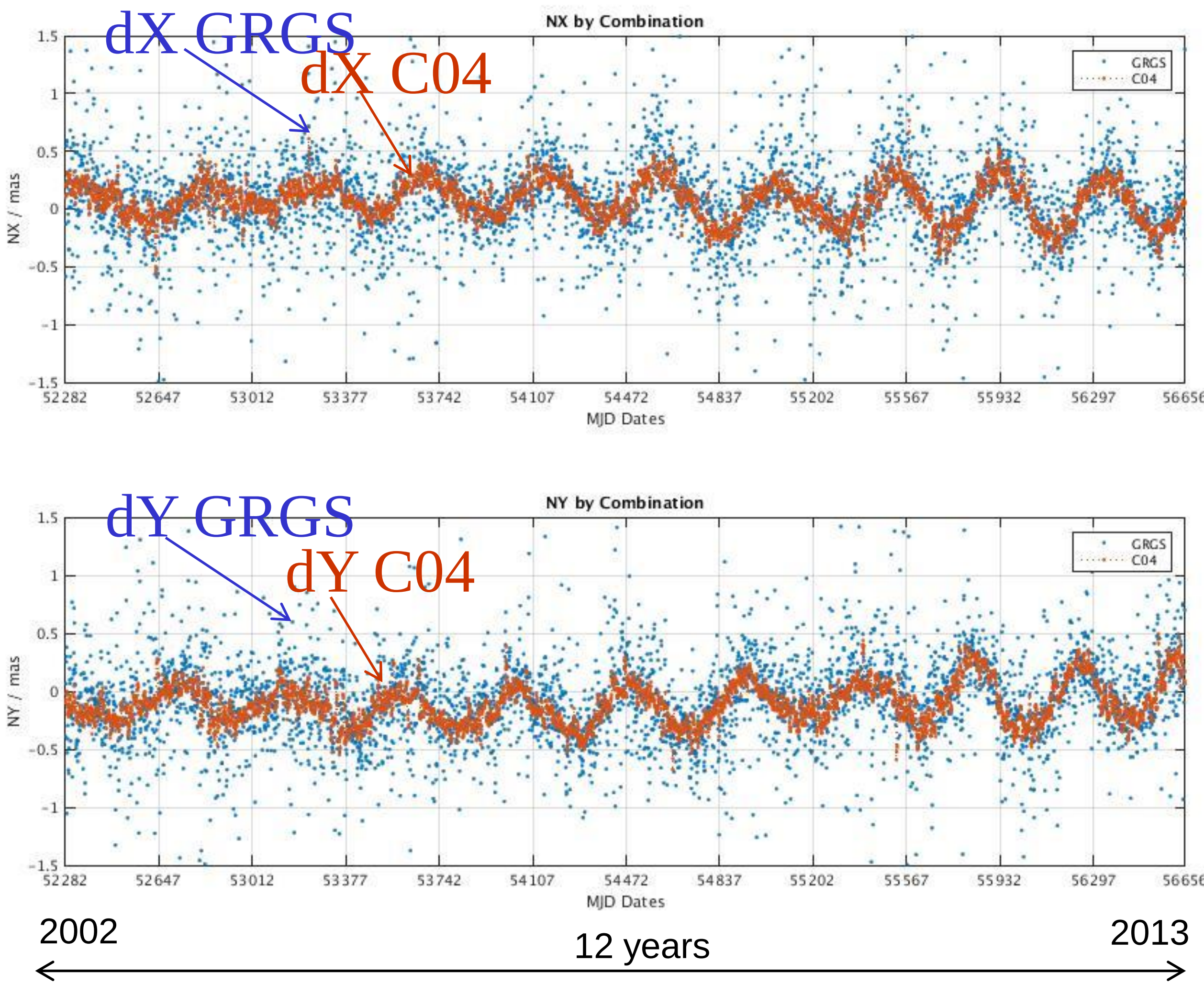
GRGS LOD from GPS LOD @12h

Qualitatively compared with C04 LOD @0h



2002 — 12 years — 2013

Nutation corrections dX, dY versus C04 series interpolated @12h



Nutation
Number of keeping points: 4369
Number of redondante dates removed: 413
Any outliers removed

Mean dX corrections with C04 apriori: /mas 0.0039

Mean dY corrections with C04 apriori : /mas 0.0195

RMS dX corrections with C04 apriori : /mas 0.3670

RMS dY corrections with C04 apriori : /mas 0.3482

Stations for DORIS GPS SLR VLBI techniques

	DORIS	GNSS	SLR	VLBI	Total
Number of Station	50	204	26	14	294
Observation frequency	Weekly	Daily	Weekly	Per session R1 R4, twice per week	~900 parameters per week
Processing		Mean equation over each week	SLR stations measured by DORIS satellites are separated to SLR stations measured by SLR satellites	Mean equation over each week	Systematic effects per technique (17) & minimal constraints per techniques (35)

Supplementary Parameters non used for ITRF2014 comparison		
Zénithal Tropospheric Delay wet component & Horizontal Gradients	**TROWET** @ {01, 03, 05, … 23} Hr: Estimation of wet component versus tropospheric model & **TGETOT**, **TGNTOT** 1 pt/d @ 00Hr	GPT2/GMF1 Model for radioelectric waves & Mendes-Pavlis for SLR/LLR + tropospheric gradient per station North & East directions

COL meeting frankfurt 2016

33 Sites with Collocated Techniques are selected to estimate their tropospheric parameters independently or commonly

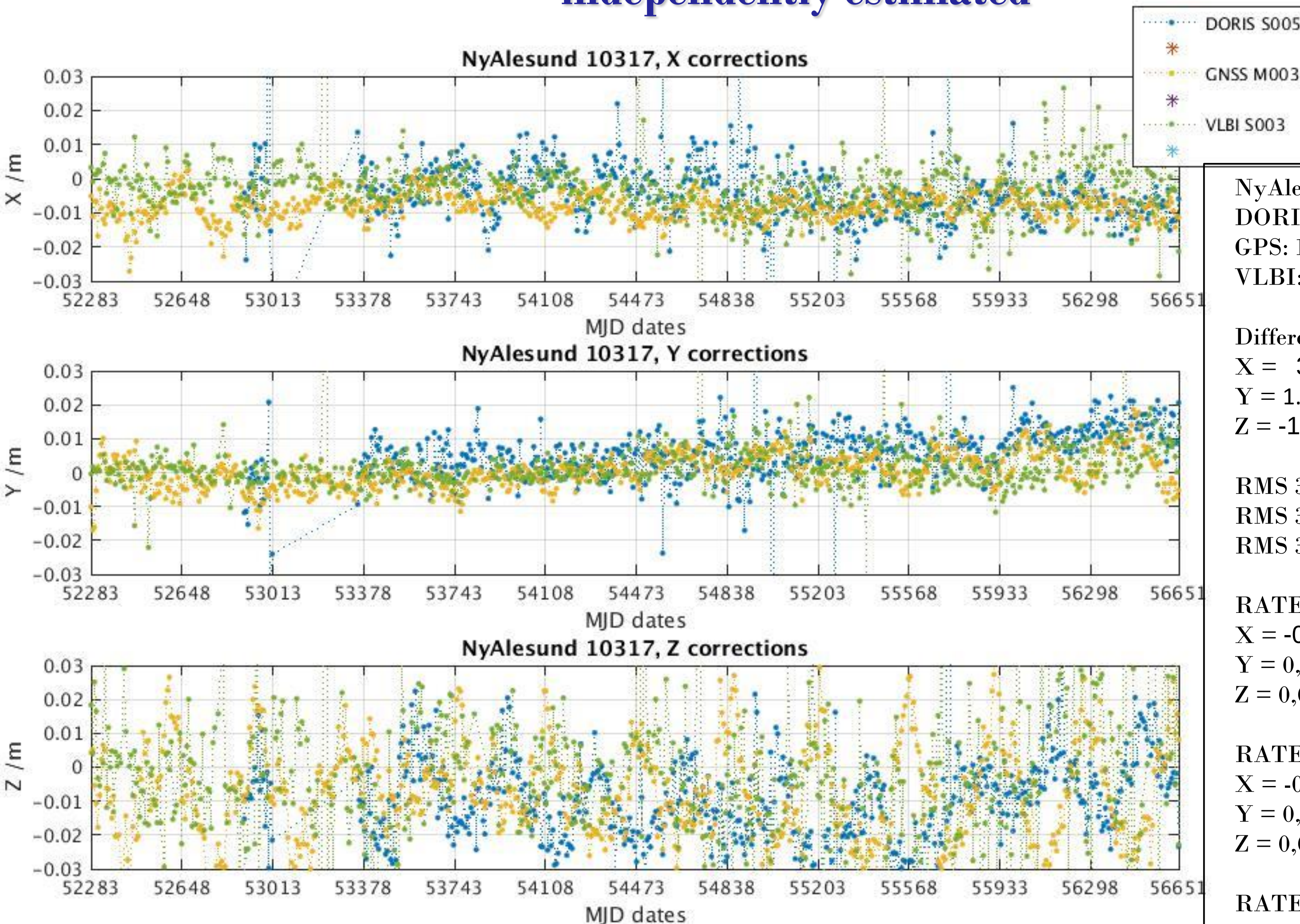
Stations	DORIS Doppler	GNSS	SLR	VLBI
GRASSE, France	10002S018		10002S002	
Toulouse, France	10003S005	10003M009		
Reykjavik, Iceland	10202S003	10202M001		
Ny-Alesund, Norway	**10317S005**	**10317M003**		**10317S003**
Metsahovi, Finland	10503S015	10503M005		
Kitab, Uzbekistan	12334S006	12334M001		
Bad Koetzting, Germany		**14201M010**	14201S018	**14201S004**
Wuhan, P.R. China	21602S005	21602M001		
Libreville, Gabon	32809S004	32809M002		
Algonquin Park, Canada		40104M002		40104S001
Fairbanks, United Stat	40408S005	40408M001		40408S002
Kokee Park, Waimea, USA	**40424S009**	**40424M004**		**40424S007**
Westford, USA		40440S020		40440S003
Greenbelt, United Stat	40451S176	40451M123	40451M105	
Laguna Mountains, USA	40497S009	40497M004	40497M001	
Ensenada, Mexico	41609S002	40508M002		
San Juan, Argentina			41508S003	41508S003
Forteleza, Brazil		41602M002		41602S001
Easter Island, Chile	41703S009	41703M007		
Santiago, Chile	41705S009	41705M003		
Concepcion, Chile		41719M002	41719M001	41719M001
Puerto Ayora, Ecuador	42005S001	42005M002		
Lima II, Peru	42202S007		42202M003	
Thule Airbase, Greenland	43001S005	43001M002		
YARRAGADEE, Australia	50107S011		50107M001	
Canberra, Australia	50119S004	50119M001 50119M002	50119S003	
Waitangi, New Zealand	50207S001	50207M001		
Port aux Francais, Ker TAHITI	91201S005	91201M002	92201M007	
Antarctic base of Dum	91501S003	91501M001		
NOUMEA, FRANCE	92701S003	92701M005		
Kourou, French Guyana	97301S004	97301M210		
Le Tampon, France	97401S002	97401M003		

Selection of 3 stations with commun tropospheric parameters

Sélection of troposphéric parameters to estimate

EXT [MZB 10002 ? ? ? ? ?]
EXT [MZB 10003 ? ? ? ? ?]
EXT [MZB 10202 ? ? ? ? ?]
EXT [MZB 10317 ? ? ? ? ?]
EXT [MZB 10503 ? ? ? ? ?]
EXT [MZB 12334 ? ? ? ? ?]
EXT [MZB 14201 ? ? ? ? ?]
EXT [MZB 21602 ? ? ? ? ?]
EXT [MZB 32809 ? ? ? ? ?]
EXT [MZB 40104 ? ? ? ? ?]
EXT [MZB 40408 ? ? ? ? ?]
EXT [MZB 40424 ? ? ? ? ?]
EXT [MZB 40440 ? ? ? ? ?]
EXT [MZB 40451 ? ? ? ? ?]
EXT [MZB 40497 ? ? ? ? ?]
EXT [MZB 41602 ? ? ? ? ?]
EXT [MZB 41609 ? ? ? ? ?]
EXT [MZB 41703 ? ? ? ? ?]
EXT [MZB 41705 ? ? ? ? ?]
EXT [MZB 41719 ? ? ? ? ?]
EXT [MZB 42005 ? ? ? ? ?]
EXT [MZB 42202 ? ? ? ? ?]
EXT [MZB 43001 ? ? ? ? ?]
EXT [MZB 50107 ? ? ? ? ?]
EXT [MZB 50119 ? ? ? ? ?]
EXT [MZB 50207 ? ? ? ? ?]
EXT [MZB 91201 ? ? ? ? ?]
EXT [MZB 91501 ? ? ? ? ?]
EXT [MZB 92701 ? ? ? ? ?]
EXT [MZB 97301 ? ? ? ? ?]
EXT [MZB 97401 ? ? ? ? ?]

Station Corrections Ny-Alesund versus ITRF2008 – tropospheric parameters independently estimated



2002 12 years 2013

NyAlesund Station 10317
DORIS : 10317S005
GPS: 10317M003
VLBI: 10317S003

Differences DORIS / GNSS
X = 360.6592 m
Y = 1.5310e+03 m
Z = -163.0814 m

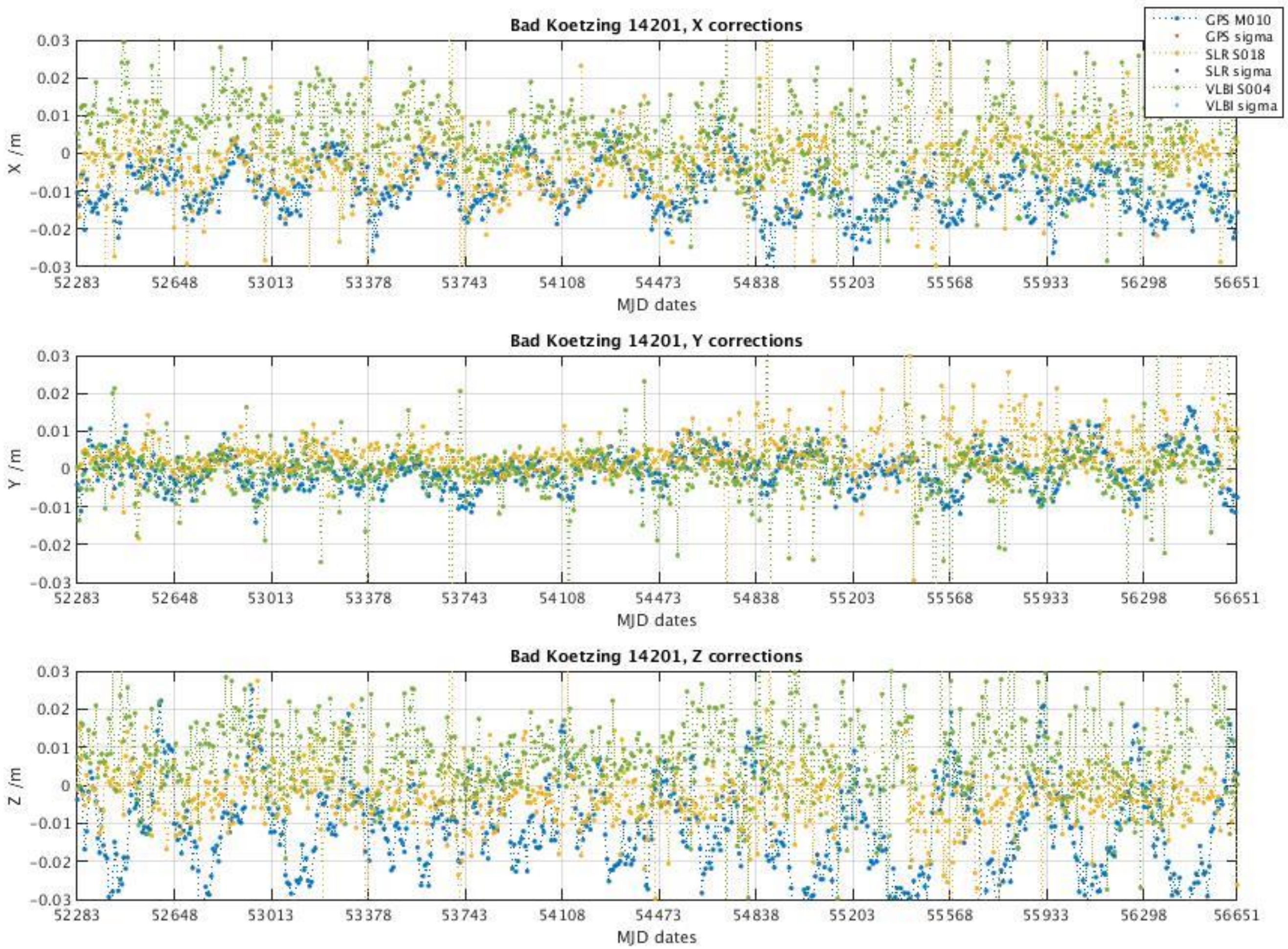
RMS 3D DORIS (m) = 0.4385
RMS 3D GNSS (m) = 0.0161
RMS 3D VLBI (m) = 0.0359

RATE DORIS
X = -0.0156 m/y
Y = 0,0073 m/y
Z = 0,0102 m/y

RATE GPS
X = -0,0143 m/y
Y = 0,0082 m/y
Z = 0,011 m/y

RATE VLBI
X = -0,0148 m/y
Y = 0,008 m/y
Z = 0,0109 m/y

Station corrections Bad-Koetzing versus ITRF2008 – tropospheric parameters independently estimated



2002 12 years 2013

Bad Koetzing Station 14201
GPS: 14201M010
SLR: 14201S018
VLBI: 14201S004

Differences between stations
X GNSS / SLR (m) = 3.805
Y GNSS / SLR (m) = 68.205
Z GNSS / SLR (m) = -15.532
X SLR / VLBI (m) = 36.977
Y SLR / VLBI (m) = 50.191
Z SLR / VLBI (m) = -45.801

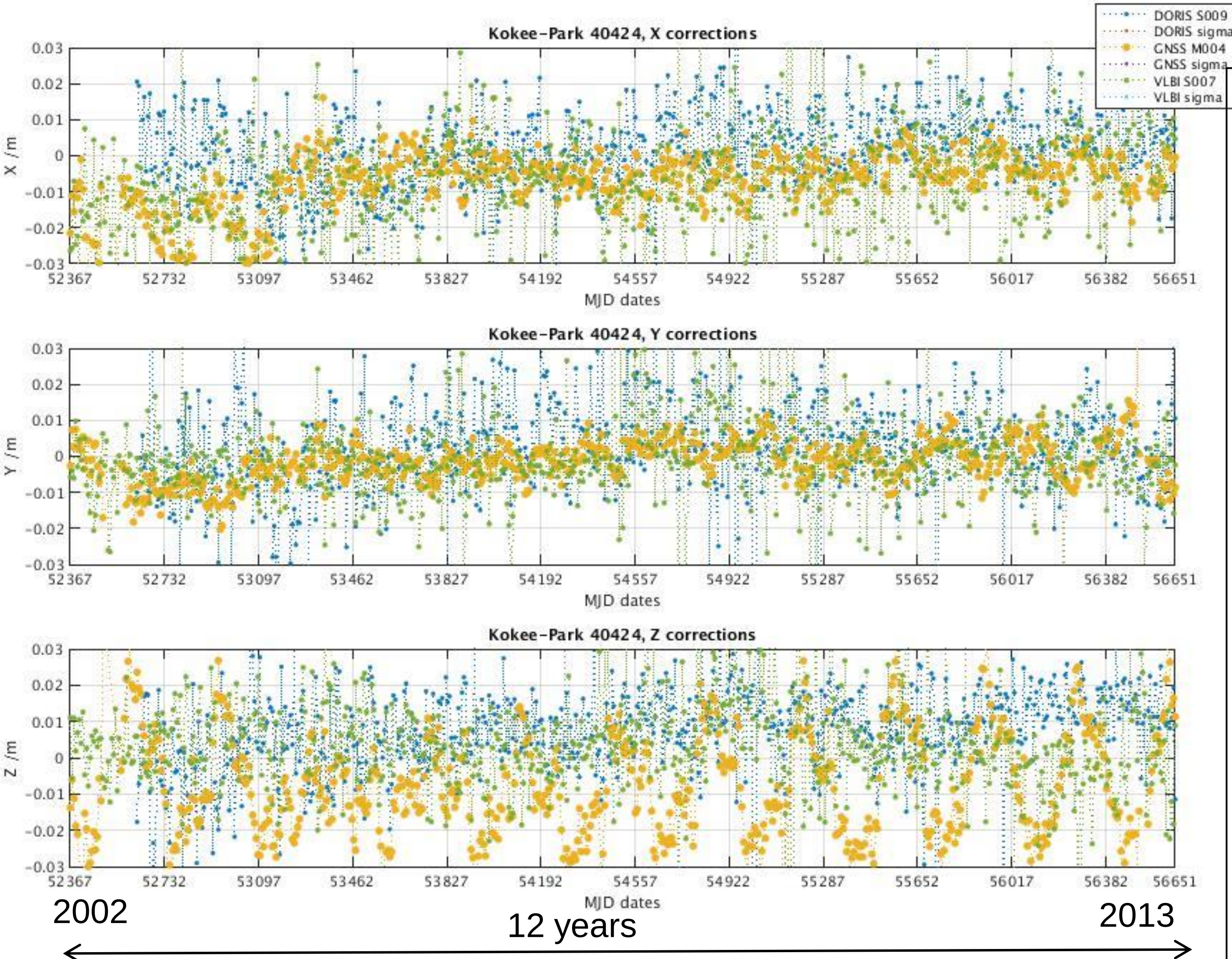
RMS 3D GNSS (m) = 0.0149
RMS 3D SLR (m) = 0.0464
RMS 3D VLBI (m) = 0.0205

RATE GPS
X = -0.0171 m/y
Y = 0.0173 m/y
Z = 0,009 m/y

RATE SLR
X = -0.0148 m/y
Y = 0.0169 m/y
Z = 0.105 m/y

RATE VLBI
X = -0.0167 m/y
Y = 0.0176 m/y
Z = 0.0101 m/y

Station Corrections Kokee-Park versus ITRF2008 – tropospheric parameters independently estimated



Kokee Park Station 40424
Differences between DORIS/GNSS
X (m) = -143.154
Y (m) = 2.627
Z (m) = -328.963

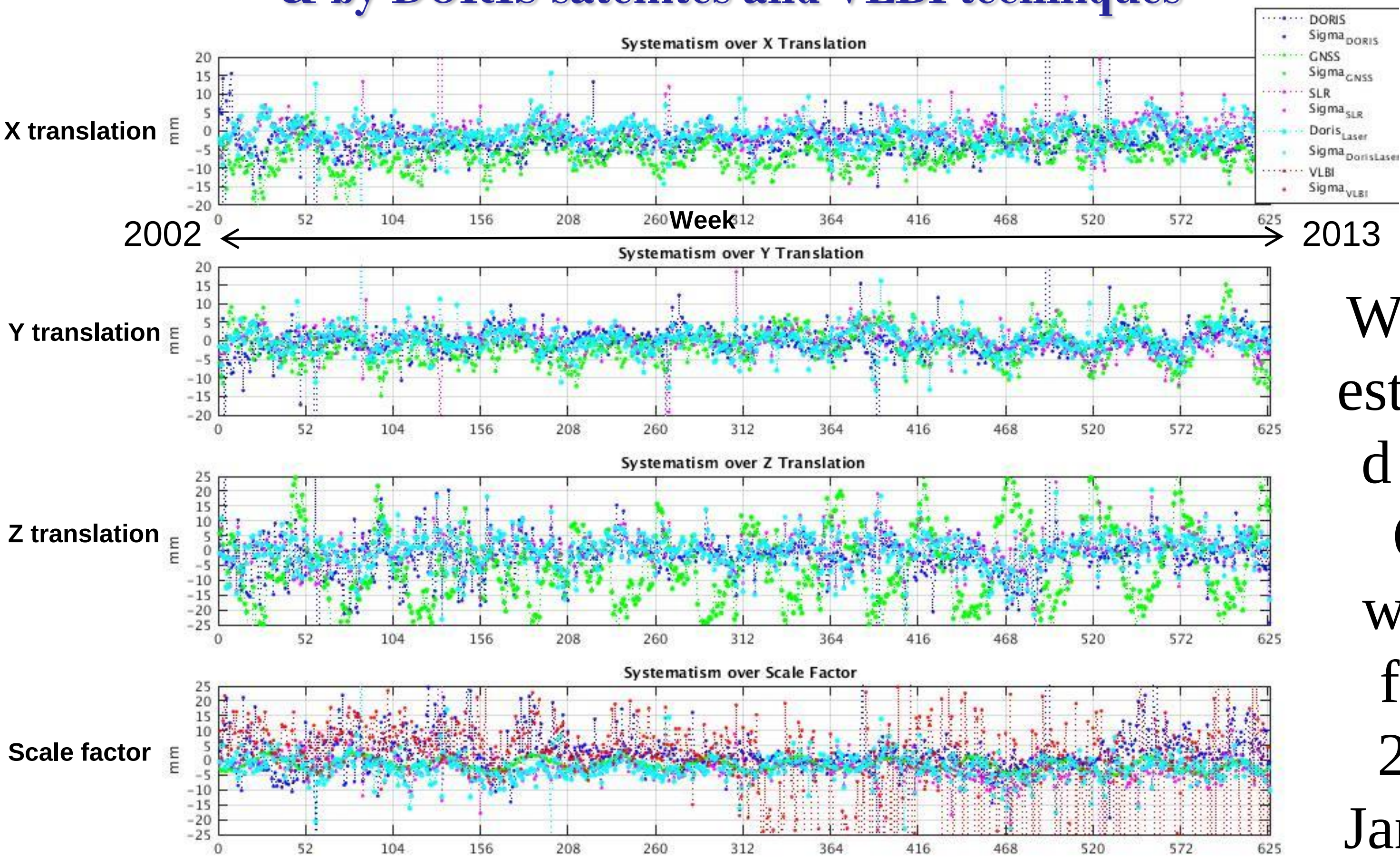
RMS 3D DORIS (m) = 0.3194
RMS 3D GNSS (m) = 0.0181
RMS 3D VLBI (m) = 0.0268

RATE DORIS
X = -0.0082 m/y
Y = 0.0604 m/y
Z = 0.0317 m/y

RATE GPS
X = -0.0069 m/y
Y = 0.063 m/y
Z = 0.0344 m/y

RATE VLBI
X = -0.0081 m/y
Y = 0.0632 m/y
Z = 0.0321 m/y

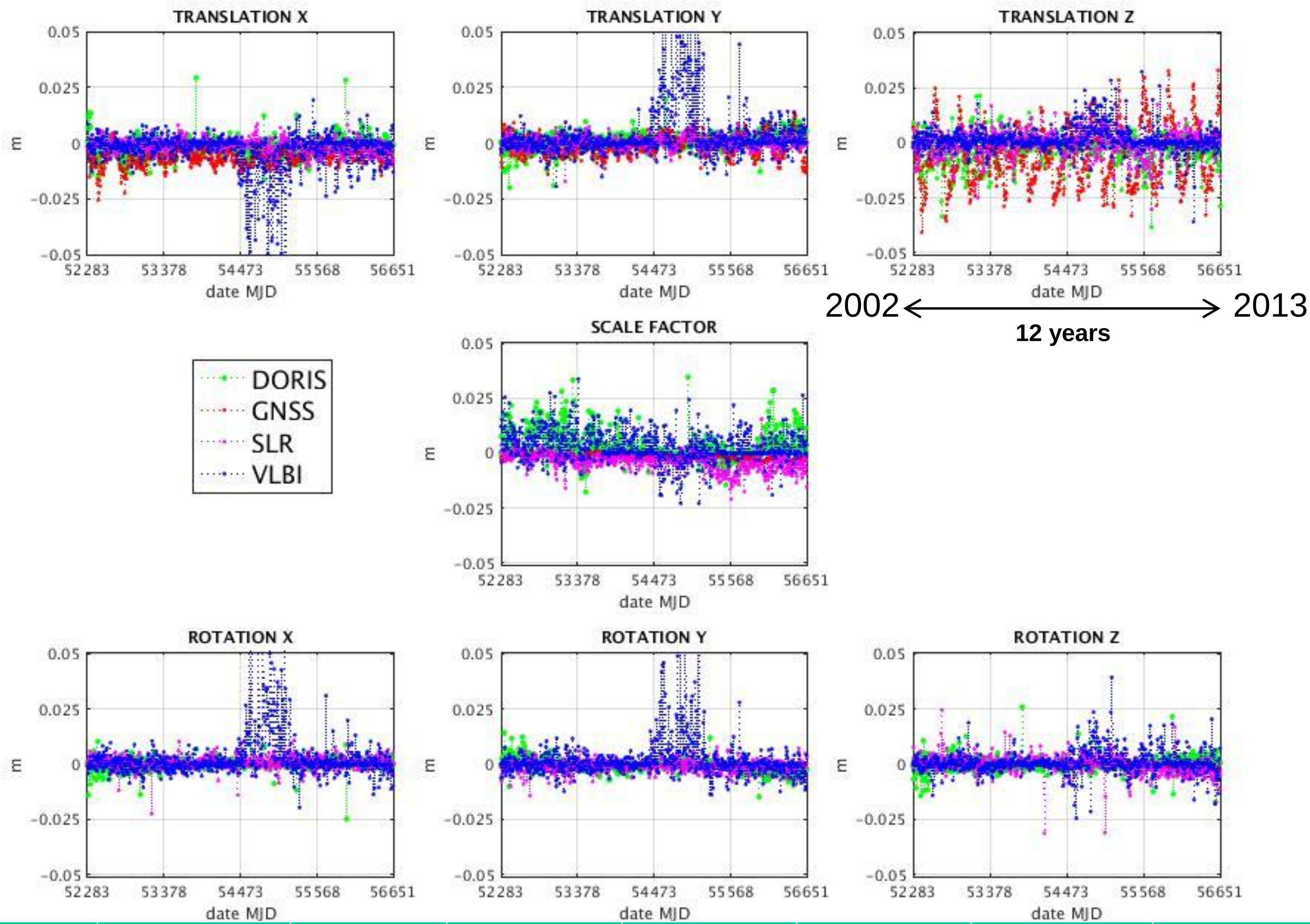
Systematic effects on station networks for DORIS, GNSS, SLR by Laser satellites & by DORIS satellites and VLBI techniques



Weekly estimated over 625 weeks from 2002 January 4th to 2013 December 28th

Networks	DORIS		SLR by DORIS satellites		GNSS		SLR by SLR satellites		VLBI	
	Mean	Rms	Mean	Rms	Mean	Rms	Mean	Rms	Mean	Rms
TX (mm)	**-2,8**	**16,0**	**0,0**	**3,9**	**-6,1**	**7,3**	**0,0**	**7,6**		
TY (mm)	**0,0**	**16,5**	**0,0**	**3,9**	**-1,2**	**4,8**	**0,0**	**3,6**		
TZ (mm)	**-1.9**	**12,4**	**0,0**	**6,1**	**-5,7**	**14,3**	**0,0**	**5,9**		
Scale (mm)	**2,5**	**17,0**	**-2,4**	**5,4**	**-1,6**	**2,5**	**-2,5**	**13,0**	**-5,3**	**25,8**

Transformation parameters for DORIS GNSS SLR VLBI networks 2002-2013 period



	TX mm	TY mm	TZ mm	Sc mm	RX µas	RY µas	RZ µas
DORIS	-2,0 ± 4,6	0,0 ± 3,7	-2,8 ± 7,2	-3,2 ± 7,1	0,2 ± 2,4	-1,0 ± 3,0	0,0 ± 3,1
GNSS	-6,3 ± 7,4	-1,1 ± 4,6	**-5,5 ± 14,5**	-1,7 ± 2,1	-0,07 ± 0,3	-0,4 ± 0,6	-0,2 ± 0,9
SLR	-1,1 ± 3,3	0,2 ± 2,7	-0,2 ± 5,5	4,0 ± 5,6	0,7 ± 2,8	-0,9 ± 2,8	-0,3 ± 4,2
VLBI	**-4,0 ± 11,7**	**3,8 ± 12,2**	**1,6 ± 5,9**	**3,1 ± 7,8**	**2,8 ± 10,5**	**1,7 ± 8,6**	**0,8 ± 5,4**

Conclusion

Method
•Algorithms developed to process DORIS GNSS SLR and VLBI techniques are usable to perform combination
•Weekly Normal Equations combined over 2002-2013 are generated in Sinex format and delivery to IGN for analysis and comparison with ITRF2014 realization
•Weekly Normal Equations and solutions files in Sinex format can be downloaded from http://iersweb.obspm.fr/~richard/public_html/

Results
•Quasars positions simultaneously estimated with stations coordinates at the weekly bases shows a discrepancy of about 700 µas versus ICRF2.
•Pole compared to C04: rms(xp_corr)=51µas, rms(yp_corr)=37µas shows an annual periodic term
•UT versus C04: rms(UT_corr)=26µs & LOD is comparable to C04
•Nutation issue meanly from VLBI shows a large discrepancy versus C04 du to nutation format every 12h introduced into GRGS VLBI
•Station coordinates shows annual periodic variations versus ITRF2008 apriori & discrepancies at a cm level have to compare with other realization (IVS, IGS, ILRS, IDS)
•Systematic effects exhibits annual oscillation for all techniques at 1.5 cm level for DORIS, 5mm level for SLR by DORIS satellites, 1.4cm for Z components of GNSS, 1cm level for SLR by SLR satellites and 2.6 cm for scale factor of VLBI network
•Transformation parameters show large discrepancy for VLBI on translations and rotations at 5cm level during the 2008-2010 period, annual oscillation on translations for GNSS network at 6mm level for TX and TZ, 1mm for TY, scale factor for SLR is at a level of 4mm with 6mm of discrepancy

Further investments
•Analysis of EOP, CRF and TRF solutions from GRGS combination has to be more deeply performed to conclude on the quality achieved
•Comparison of EOP and Stations solutions with **ITRF2014**
•Analyses on mutualisation of tropospheric parameters (VLBI, GPS, DORIS) over 2009
•Analyses on mutualisation of orbital parameters for multi-techniques satellites

Communication
•**Paper** on GRGS multi techniques combination at normal equation level is writing to summarize this development

ANNEXES

COL-GRGS communications

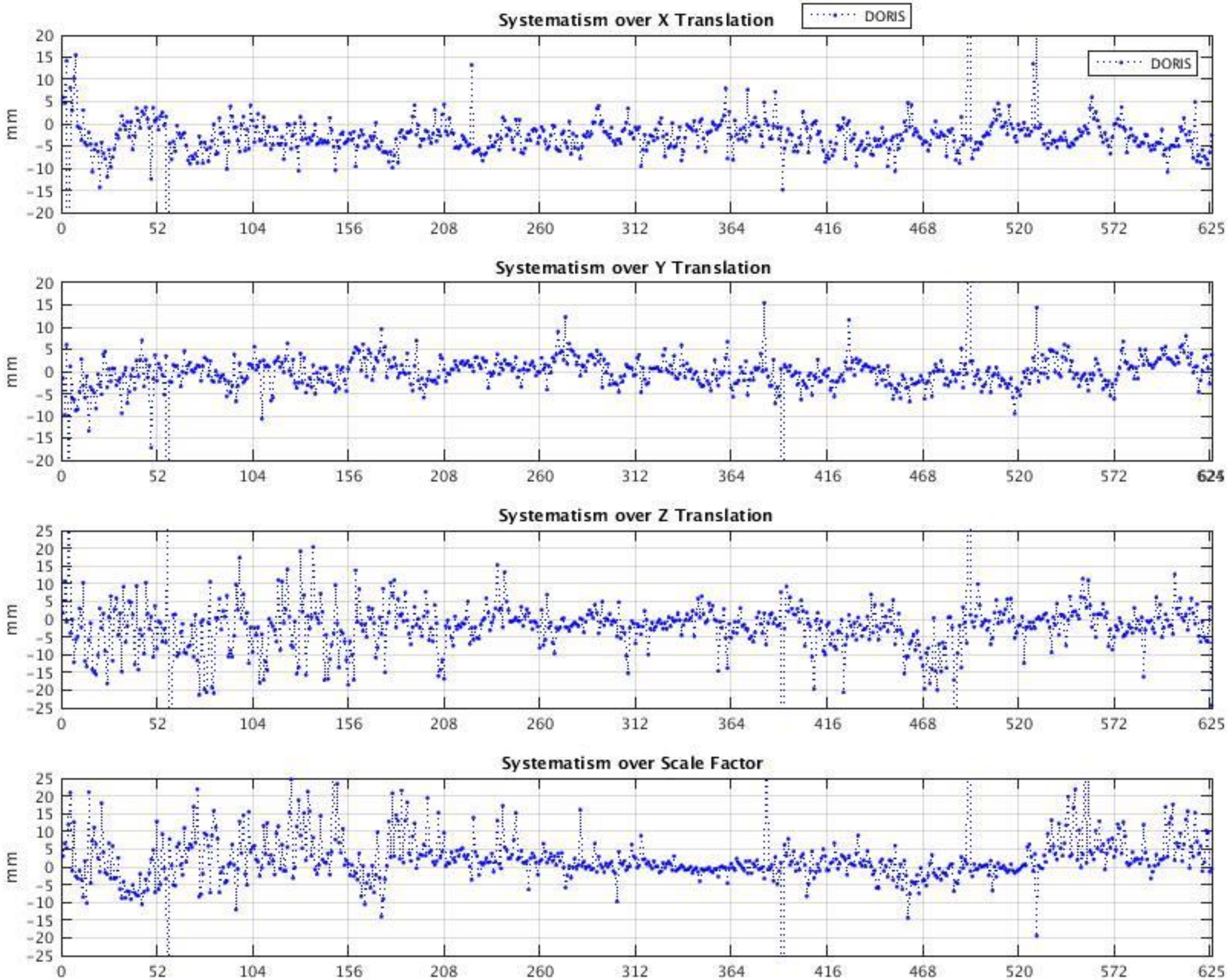
- IERS Workshop, “EOP Combination and Prediction & COL Working Group Kick-off Meeting”, octobre 2009, Varsovie, Pologne
- J.-Y. Richard1, D.Gambis1, G. Bourda, S. Loyer, L. Soudarin, F. Deleflie, “Global combination of astro-geodetic techniques at the normal equations level. Possible contribution to future ITRS realizations”, AGU 2009 14-18 December, Poster, San Francisco
-Richard J.Y., Gambis D., R. Biancale, 2010, Combination of Space Geodetic Techniques at the Normal Equation Level, Geophysical Research Abstracts, Vol. 12, EGU2010-2333
- Richard J.Y., Gambis D., Bizouard Ch, 2011, Earth rotation parameters determined over CONT08 VLBI campaign by the GRGS from the combination of space geodetic techniques, *in Proc. Journées Systèmes de Référence 2010, N. Capitaine (ed.)*, pp219-220
- Richard J-Y., Gambis D., Biancale R., Bizouard C. “**Earth rotation parameters determined over CONT08 VLBI campaign by the GRGS from the combination of space geodetic techniques”.** REFAG 2010, Poster, Marne La Vallée, Octobre 2010
Richard J-Y., Biancale B., Gambis D., Seitz M., Loyer S., Thaller D., Springer T., Koenig R., Sciarretta C., Spicakova H., “**IERS Working group on Combination of Space Geodetic Techniques at the Observation Level (COL)**”, EGU 2011 4-8 April 2011, Poster
- Richard J.Y., Biancale R., Gambis D., Bizouard C., Lemoine J.M., Bourda G., Deleflie F., Loyer S., Soudarin L., “**Multi-technique combination for Earth Orientation & Reference Frames Determination”,** IDS-AWG 2011, May 23-24 2011, Paris, oral.
- Richard J.Y., Seitz M., Biancale R., Gambis D., Loyer L., Soudarin L., Thaller D., Springer T., Koenig R., Sciarretta , C., Spicakova H., Lytvyn M., 2011, IERS Working group on Combination of Space Geodetic Techniques at the Observation Level, IUGG, Earth on the Edge, Science for a sustainable planet, Melbourne, 28 June- 7 July 2011.
-J.-Y. Richard, R. Biancale, C. Bizouard, F. Deleflie, G. Gambis, R. Koenig, S. Loyer, C. Sciaretta, M. Seitz, H. Spicakova, T. Springer, and D. Thaller, IERS Working group on Combination of Space Geodetic Techniques at the Observation Level (COL), EGU2012-1439-2, Vienne, Avril 2012
-Richard J.Y., Gambis D., Multi-Technique Combinations of Geodetic Observations at the level of Normal Equations, IDS Analysis Working Group, Venice, Sept. 2012
-Richard J.Y., Biancale R., Bizouard C., Gambis D., Systematic Effects in Multi-Technique Combination, EGU-2013, Vienne, 7-12 April 2013
--Richard J.Y., Gambis D., Bizouard C., T. Carlucci, Biancale R., Combinaison de Techniques Géodésiques au niveau des Observations, AS GRAM 2014, Bordeaux, Avril 2014
- Richard J.Y., Bellanger A., Biancale R., Bizouard C., Bourda G., Bouquillon S., COULOT D., Deleflie F., Francou G., Gambis D., Lemoine J.M., Loyer S., Pollet A., Soudarin L., Combination at the Observation Level: contribution to ITRF2013, EGU2014, Vienna, 27th April - 2nd May 2014
-Richard J.Y., Bellanger A., Biancale R., Bizouard C., Bourda G., Bouquillon S., COULOT D., Deleflie F., Gambis D., Lemoine J.M., Loyer S., Pollet A., Soudarin L., Multi-Techniques Combination for Earth Orientation Parameters, station and quasar coordinates, EGU2015, Vienna, 12th – 19th April 2015

Article à referee
Gambis D., Richard J-Y., Biancale R., Bizouard C. Why combining at the Observation Level?, REFAG 2010, IAG series 2013

Recommanded Models for GRGS

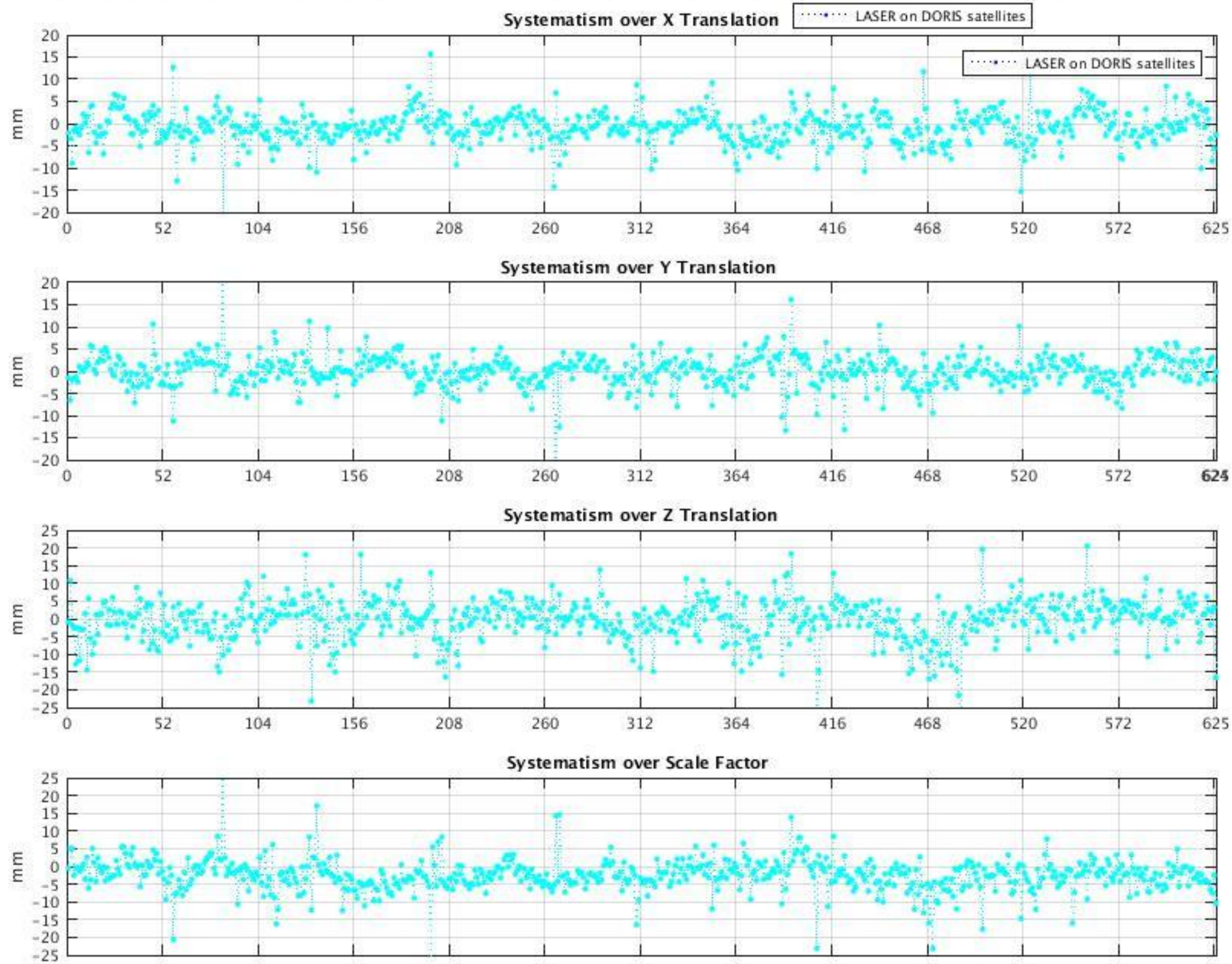
Reference System	
Earth reference system	IGb08 for GNSS & DORIS, ITRF2008 for SLR VTRF2008 for VLBI
Celestial reference system	inertial J2000
Polar motion & UT1	IERS C04 08
Precession/nutation	IERS 2010 using NRO origin
Displacement of reference points	
Solid Earth tidal displacement	IERS2010 Conventions
Tidal ocean loading	FES2012
Tidal atmospheric loading	S1/S2 Ray & Ponte (2003)
Non tidal atmospheric loading	none
Solid pole tide displacement	IERS2010 Conventions
Gravity	
Gravity field (static)	EIGEN-6S2
Gravity field (time varying)	EIGEN-6S2 up to degree 12 including time variable terms up to degree 12 (bias & drift per yr from 2002 to 2012, periodic 18.6, 1, 0.5yrs)
Solid Earth tides	IERS2010 conventions
Ocean tides	FES 2012 (32 principal waves, + 60 admittance waves) up to degree 12
Atmospheric gravity	3hr ERA-interim / ECMWF up to degree 12 for GNSS
Non tidal oceanic gravity	TUGO R12 up to degree 12 for GNSS, 50 for DORIS
Atmospheric tides	none (considered through the ECMWF atmospheric data)
Earth pole tide	IERS2010 conventions
Ocean pole tide	Desai 2002 up to degree 12
Third bodies	Sun, Moon, Mars, Venus, Jupiter, Saturn, Uranus and Neptune ephemeris : DE421 (JPL)
Troposphere	
Troposphere Model	GPT2/VMF1
Troposphere correction	one zenith delay/2hour (wet tropo scale factor adjusted) + one daily tropospheric gradient per station & per day in North & East directions
Ionosphere	Second order corrections using igs final TEC maps / First order corrected using iono free measurements
Atmospheric drag	DTM 94
Relativity	Schwarzschild model + Lense-Thirring + geodetic precession

Systematic effects estimated on DORIS station network



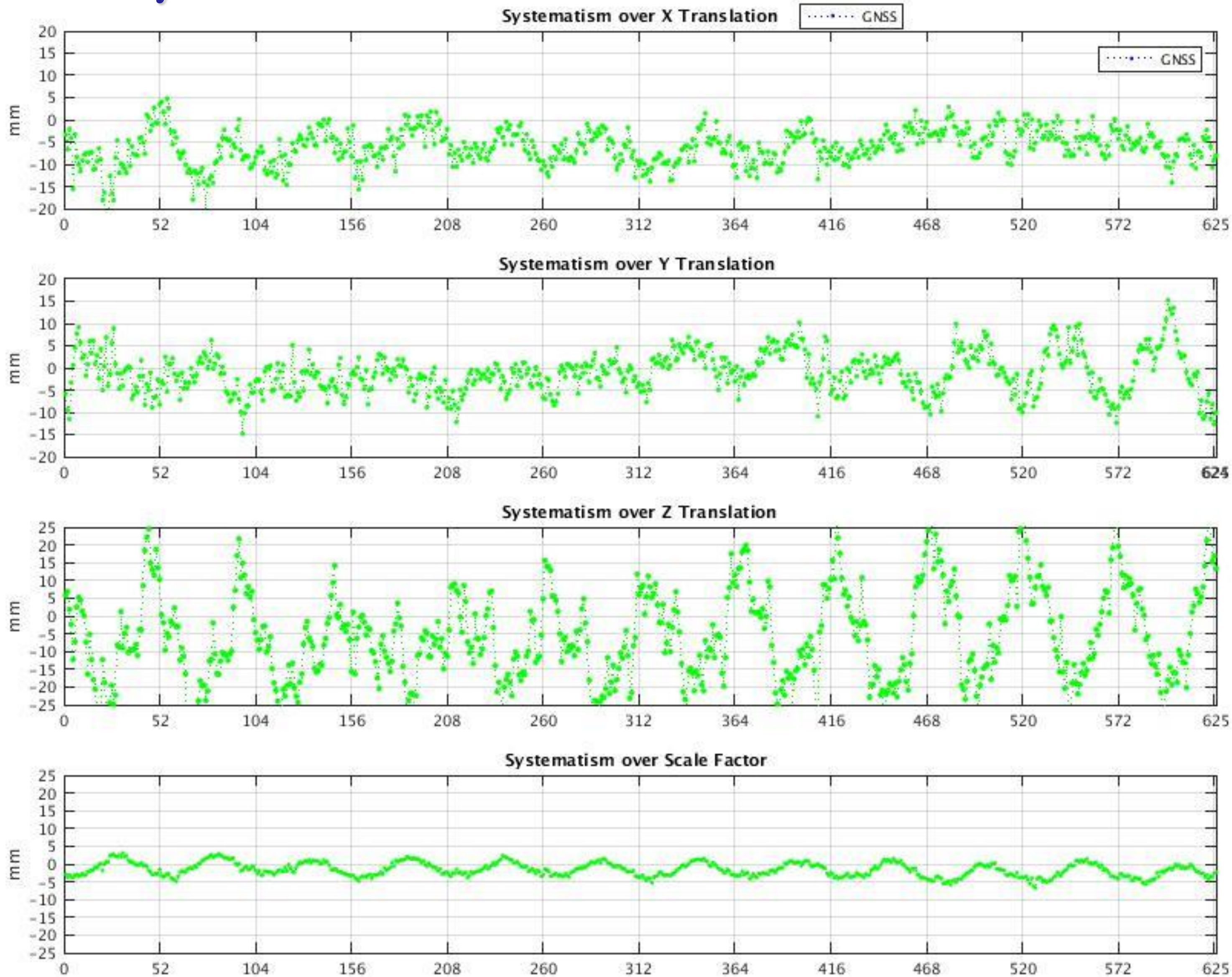
TX (m) mean amplitude & rms : -0.0028 0.0160
TY (m) mean amplitude & rms : -2.5152e-05 0.0165
TZ (m) mean amplitude & rms : -0.0019 0.0124
SC (m) mean amplitude & rms : 0.0025 0.0170

Systematic effects estimated on SLR station network measured over DORIS satellites



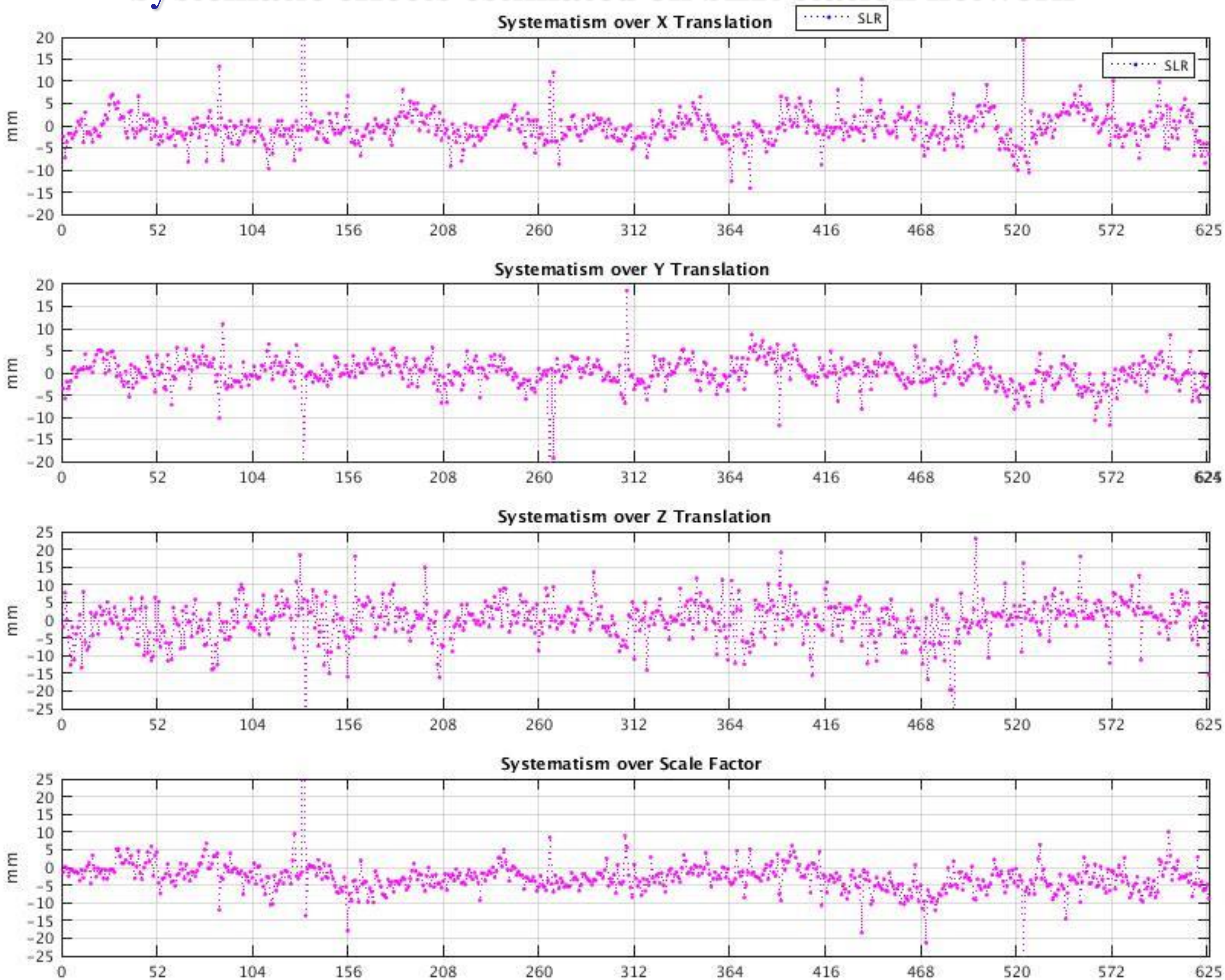
TX (m) mean amplitude & rms : -8.8528e-04 0.0039
TY (m) mean amplitude & rms : 6.6362e-05 0.0039
TZ (m) mean amplitude & rms : -3.2842e-04 0.0061
SC (m) mean amplitude & rms : -0.0024 0.0054

Systematic effects estimated on GNSS station network



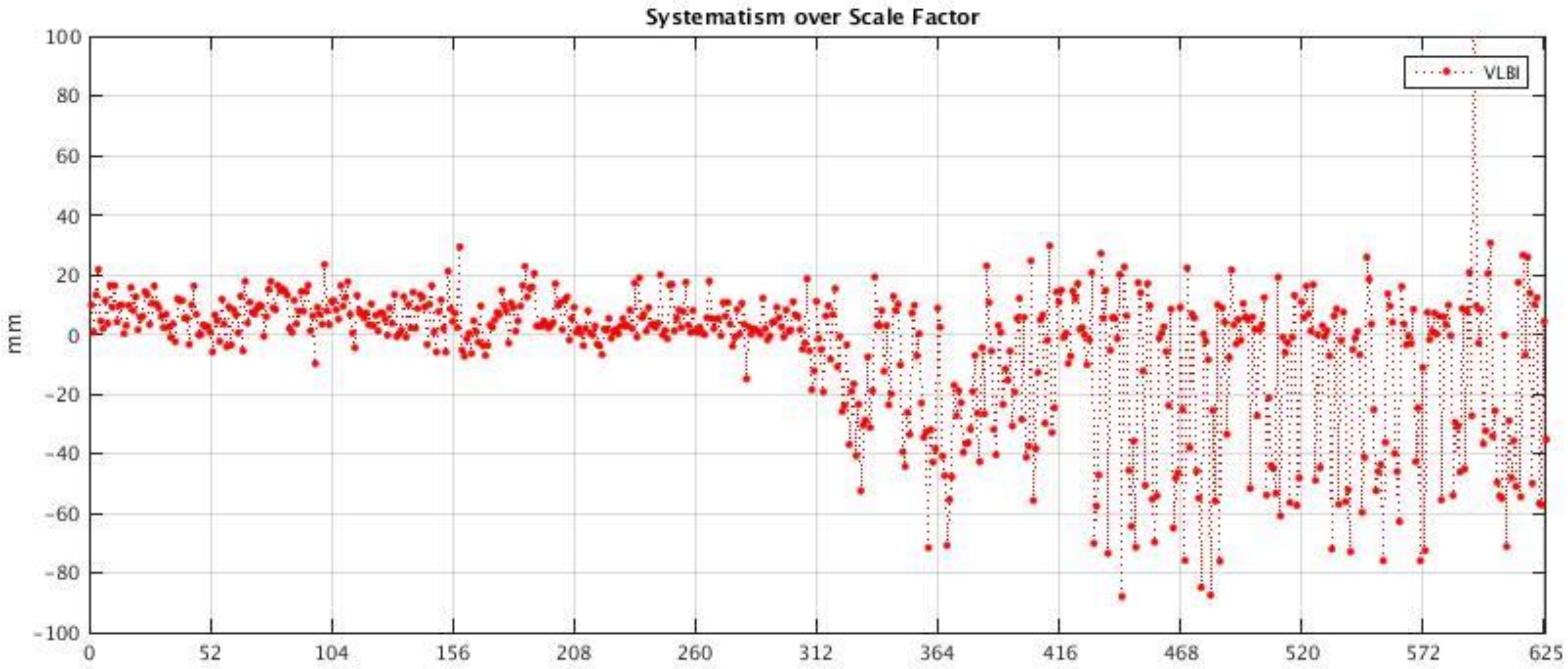
TX (m) mean amplitude & rms : -0.0061 0.0073
TY (m) mean amplitude & rms : -0.0012 0.0048
TZ (m) mean amplitude & rms : -0.0057 0.0143
SC (m) mean amplitude & rms : -0.0016 0.0025

Systematic effects estimated on SLR station network



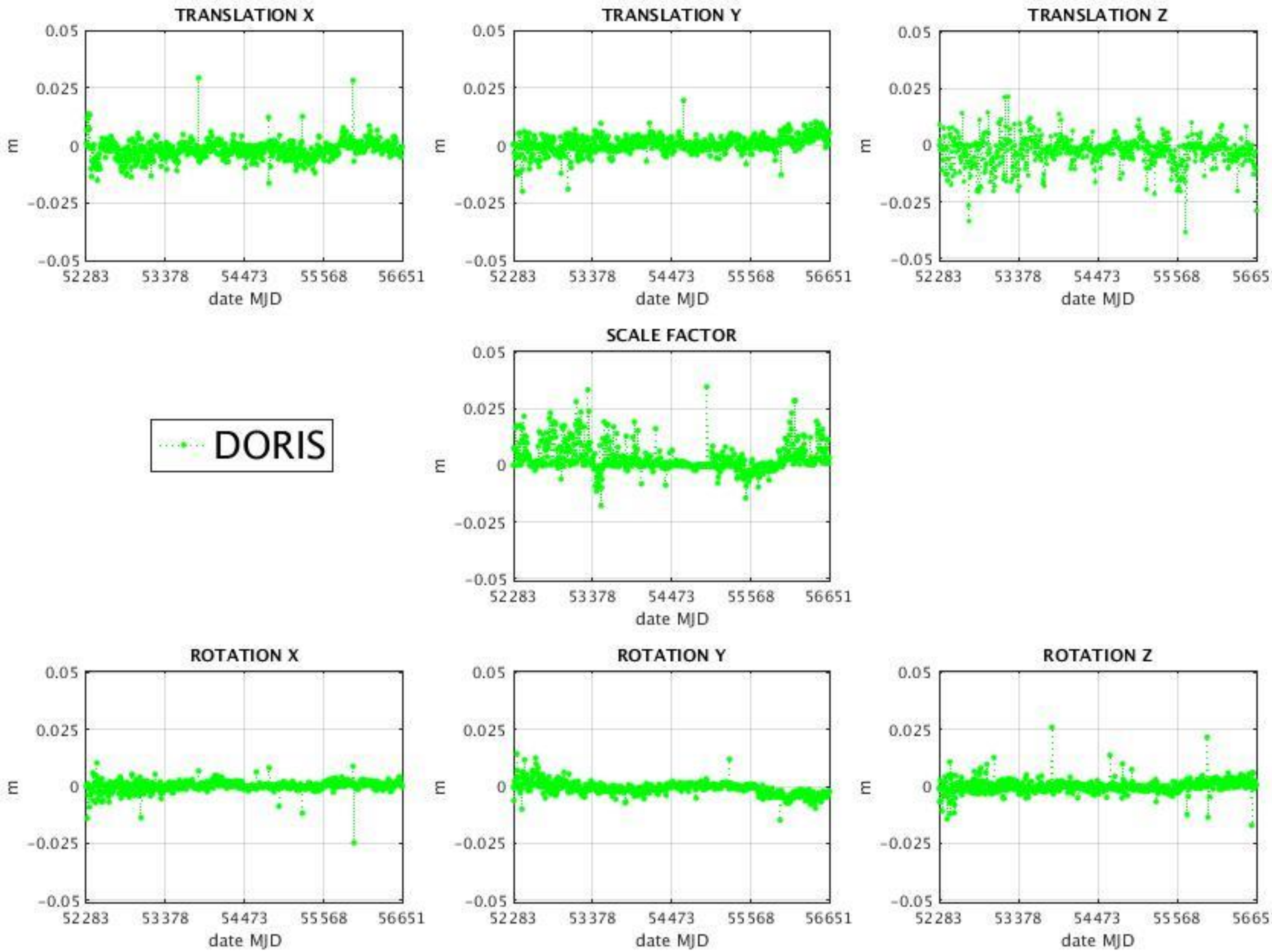
TX (m) mean amplitude & rms : -1.7552e-04 0.0076
TY (m) mean amplitude & rms : -4.8732e-05 0.0036
TZ (m) mean amplitude & rms : 7.7599e-05 0.0059
SC (m) mean amplitude & rms : -0.0025 0.0130

Systematic effects estimated on VLBI station network



SC (m) mean amplitude & rms : -0.0053 0.0258

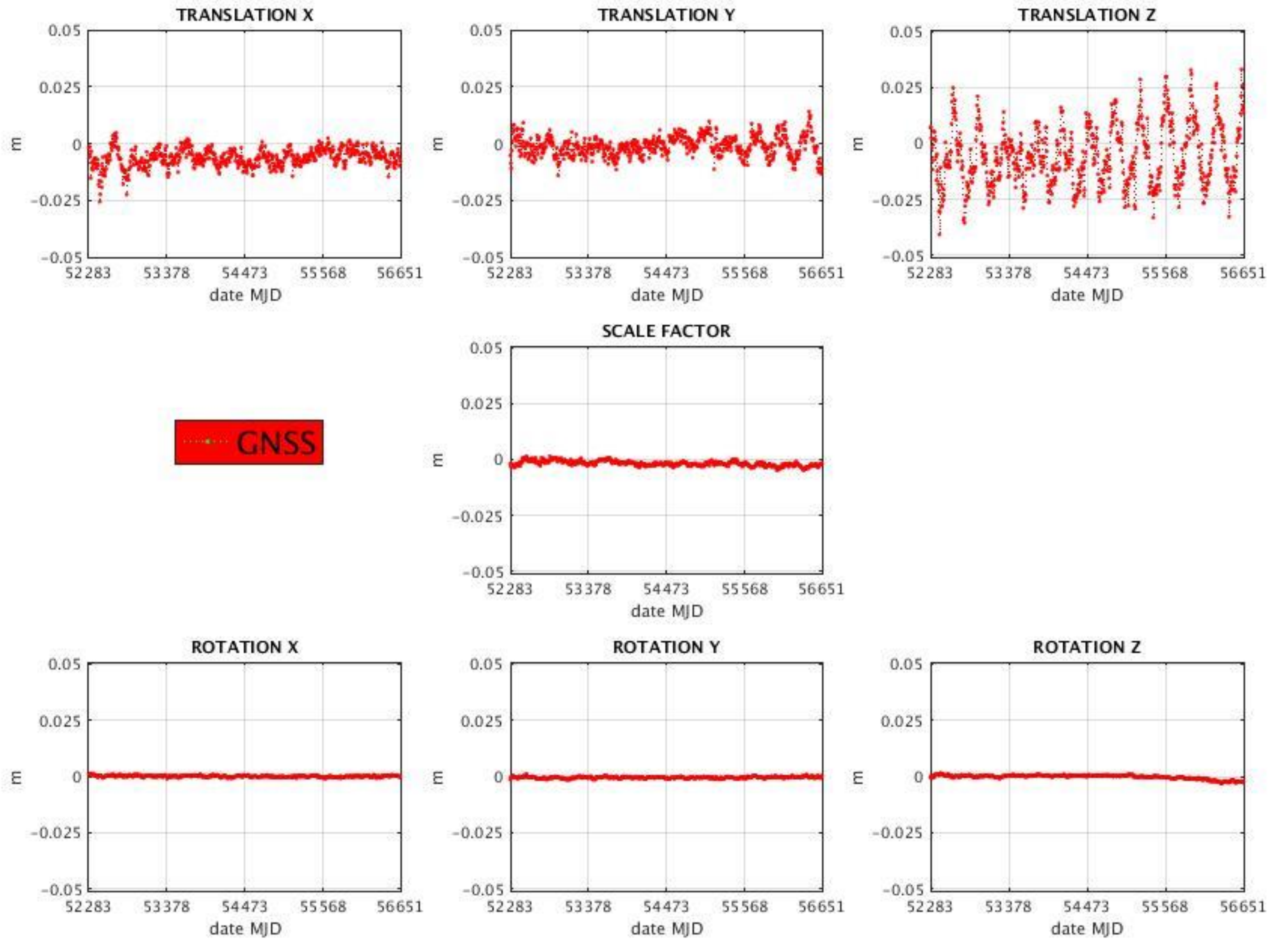
Transformation parameters for DORIS network over 2002-2013



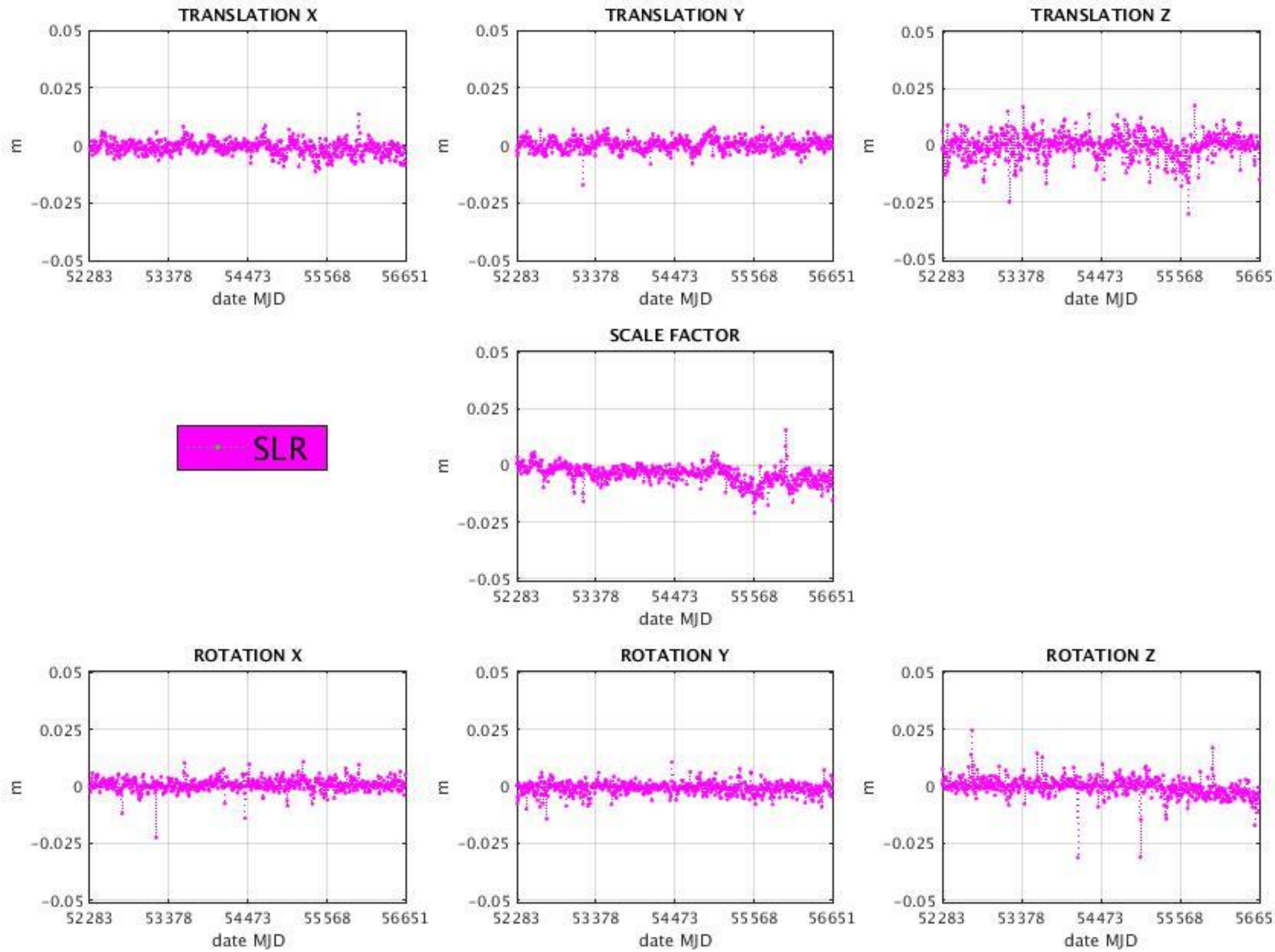
COL Charter

1) *review the approach of the various groups* and their capability to process two or more techniques.
   AUIB, ASI,, BKG, DGFI, ESOC, GFZ, GRGS, GSFC, TUW
2) *establishing common processing standards* for all techniques in order to guarantee homogeneity and consistency.
   List of recommended models established are established
3) *studying the appropriate weighting between techniques* and the use of local ties or identical satellites tracked by several techniques.
   Tests between fixed and Helmert algorithm are applied for NEQ stacking, DORIS satellites performing doppler and laser measurements are used
4) *optimizing and unifying parameterization* for instance for tropospheric parameters in order to minimize globally the degree of freedom of the whole inverse system.
   Tropospheric parameters are included for DORIS, GNSS and VLBI
5) *elaborating benchmarks* to intercompare results between groups from the same data set.
   Tow period are tested for comibination performance evaluation: CONT08 and CON11
6) *insuring SINEX compatibility* between techniques and with the international technique services and IERS.
   File exchanges have been made using the Sinex format 2,1
7) *studying stabilization methods* and looking for high temporal resolution of parameters.
   Earth rotation parameters resolution have been processed every 6h
8) *evaluating and comparing results* to search for compatibility between groups.
   17 meetings
9) *organizing routine operations* for a new TRF realization, either in the framework of the next ITRF or as ITRF assessment.
   Developpment of routines for processing for intra and inter-techniques

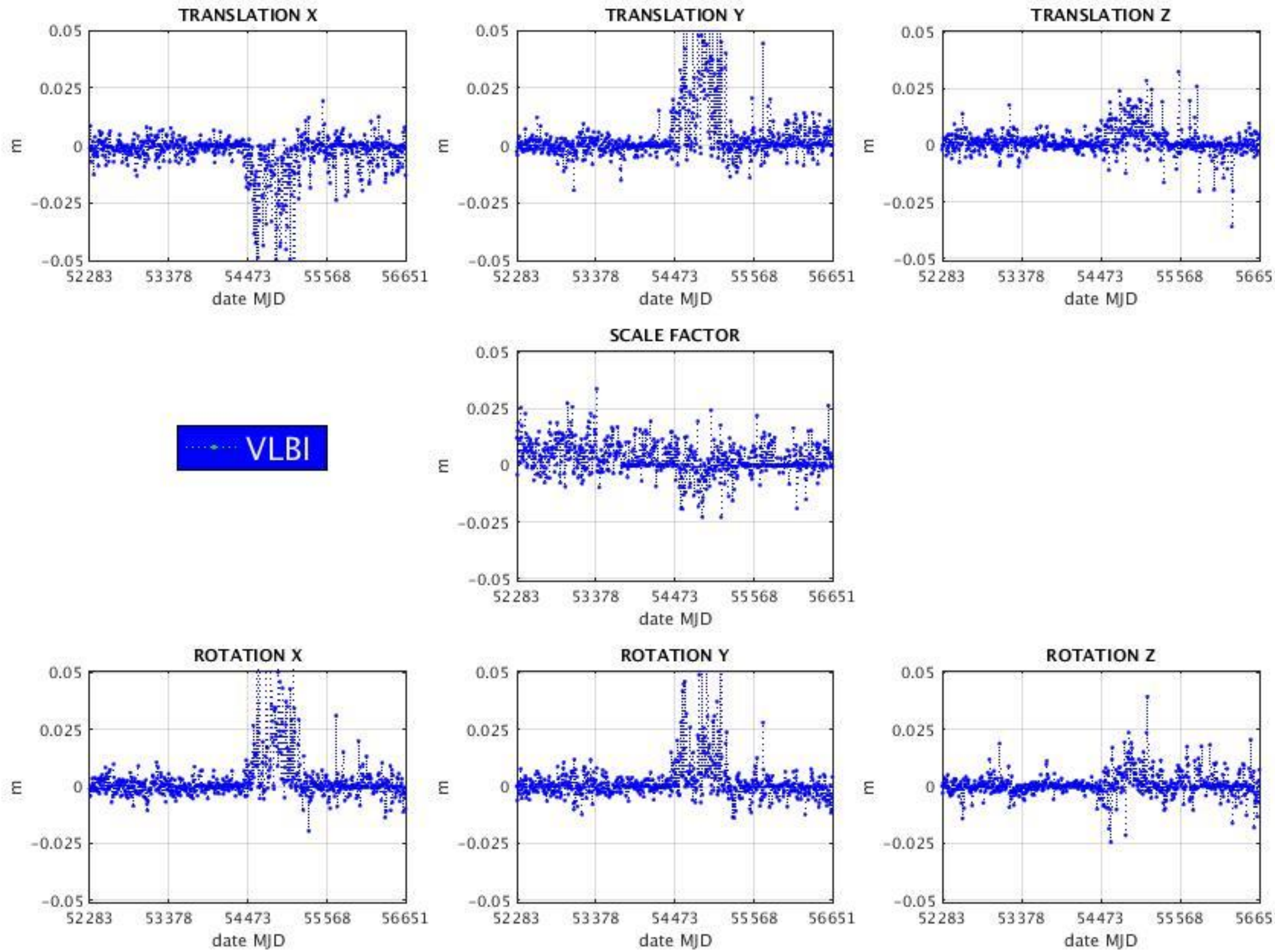
Transformation parameters for GNSS network over 2002-2013



Transformation parameters for SLR network over 2002-2013

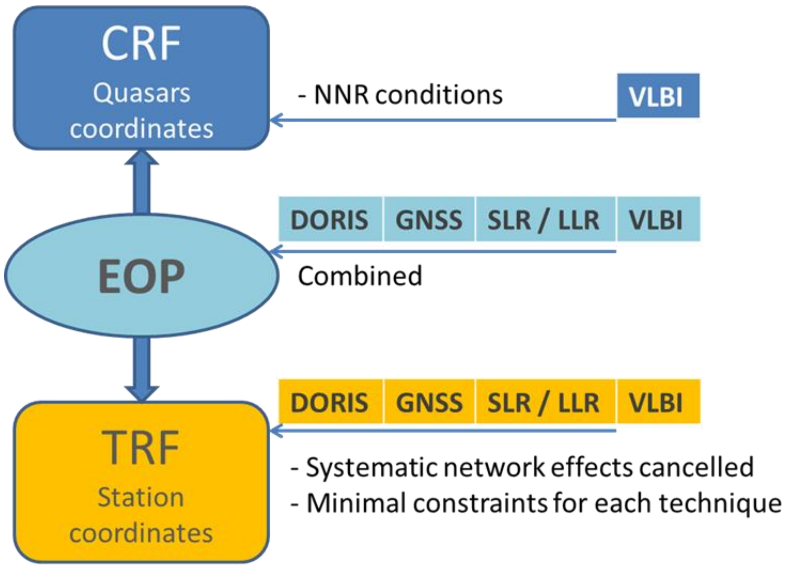


Transformation parameters for VLBI network over 2002-2013



Multi Techniques Combinaison at Normal Equation Level

- Celestial Reference Frame CRF, Terrestrial Reference Frame TRF & Earth Orientation Parameters EOP are estimated by combination of solutions without garanty on the consistency and model between space geodesy technics
- GRGS with the IERS working group on combination « COL » from october 2009, has performed a new approach using inter technique combination at observation level.



- ❑ Allow the consistency and homogeneity between techniques which can be processed using the same sotware with compatible models and similar a priori
- ❑ Allow to cancel systematic effect between techniques
- ❑ Allow to estimate periodicaly and simultaneously the geodetic parameters
  - Quasars coordinates ➔ **CRF** Celestial Reference Frame
  - Terrestrial Station coordinates & rates ➔ **TRF** Terrestrial Reference Frame
  - Polar motion , Rotation and Nutation ➔ **EOP** Earth Orientation Parameters
  - Tropospheric bais & gradients ➔ **ZTD** Zenithal Time Delay
  - Geocentric coordinates andlow degré of gravity filed ➔ **CM, C21, S21** Center of Mass, Stockes Coefficients Order 2

Estimated Parameters to be compared with ITRF2014

Parameters	***Estimated Parameters***	***Initial Values***
Pole, UT1-TAI	**XPO**, **YPO**, **UT** : PWL @ 12Hr (PX, PY into GINS)	IERS EOP 08-C04
Pole Rate	**XPOR**, **YPOR** 1pt/day @ 12Hr (PXR, PYR into GINS)	0.0
LOD	**LOD** 1pt/day @ 12Hr (PTR into GINS)	IERS EOP 08-C04
Precession/Nutation Corrections	**NUT_X**, **NUT_Y** : PWL @ 12Hr IAU2000A/2006 model corrections (dX,dY) (NX, NY dans GINS)	0.0
Station Coordinates	**SX**, **SY**, **SZ** 1 pt/week	ITRF2008
Radio sources Coordinates	**RS_RA**, **RS_DE** 1pt/week (QRA, QDE into GINS)	ICRF2
Supplementary Parameters non used for ITRF2014 comparison		
Zénithal Tropospheric Delay wet component & Horizontal Gradients	**TROWET** @ {01, 03, 05, … 23} Hr: Estimation of wet component versus tropospheric model & **TGETOT**, **TGNTOT** 1 pt/d @ 00Hr	GPT2/GMF1 Model for radioelectric waves & Mendes-Pavlis for SLR/LLR + tropospheric gradient per station North & East directions

Normal Equation Pre-processing per techniques

- **Intra techniques**
- NEQ Reduction: keeping EOP, Stations, Quasars, Tropospheric parameters , orbital elements & non gravitationnal parameters from DORIS satellites
- Stacking of NEQs at weekly bases, synchronous to the GPS week, for DORIS satellites is applied the weighting Helmert algorithm using EOP as common parameters, for SLR satellietes using stations as common parameters, for GNSS satellite constellation stacking is already done at daily bases, for VLBI R1 & R4 session are weekly stacked
- For daily NEQs daily stations parameters are stacked at weekly bases @ mid epoch
- Tropospheric parameters bias & gradients are synchronized every 2h interval (01h, 03h,…, 23h) and selected from a list of stations to test their positions when their tropospheric parameters are mutualized
- For statellite tehniques, at beginning of each week UT parmater is forced to the apriori
- Introduction of stations constraints for systematic technique effects cancellation : transformation parameters (origin & scale for satellite techniques, scale for VLBI technique)
- Introduction of polar motion constraint to cancel the diurnal retrograde oscillation for sub-daily EOP of DORIS, SLR and VLBI techniques

Combination of Normal Equations @ weekly bases

- **Inter techniques**

- Weighted stacking with Helmert algorithm using the common parameters EOP@06:00 for DORIS, Laser from DORIS satellites, SLR and VLBI, Orbital elements, orbital bias and non gravitationnal forces of DORIS satellites are also stacked
- Elimination of EOP outside the GPS week by forcing them with their apriori values
- Whitening technique's identifiers from tropospheric parameters to stack their equations for colocated stations
- Daily Linear constraints on EOP corrections @06:00 are introduced to reduce the NEQ to EOP 1pt/d @ 12:00
- Weighted stacking GPS + (DORIS Doppler, DORIS Laser, SLR and VLBI) by fixed weigthing factor 0,99 for GNSS & 0,01 for (DORIS Doppler, DORIS Laser, SLR and VLBI)
- Whitening blocking the retrograde diurnal oscillation on the pole coordinates to mutualize these parameters
- Application of Non Rotation on the set of quasars (NNR)
- Application of Minimal Constraints on core stations for each technique DORIS, GPS, SLR, VLBI (7 Helmert transformation parameters)

Constraints on combined normal équations

❑To inverse the combined normal equation at weekly bases for EOP, station coordinates with their zenithal tropospheric bias or clock bias and quasar coordinates determination, some constraints are applied:

•Stability constraint on

- ➢ pole coordinates ±10mas on corrections (30cm at the Earth surface)
- ➢ UT ±6,47 ms on corrections (3m at the Earth surface)
- ➢ Nutation ±47nrd (±10mas)

•Blocking the diurnal retrograde oscillation parameters AC, AS, Act, Ast with constraint on their corrections ±1frd

•Stations corrections with a loose constraint ±50m for GNSS, DORIS, VLBI and ±20m for SLR

•Minimal constraints on core stations DORIS VLBI SLR et GNSS with constraints on the final values = 0 ±10cm

•Tropospheric Bias with constraint on the corrections ±10m

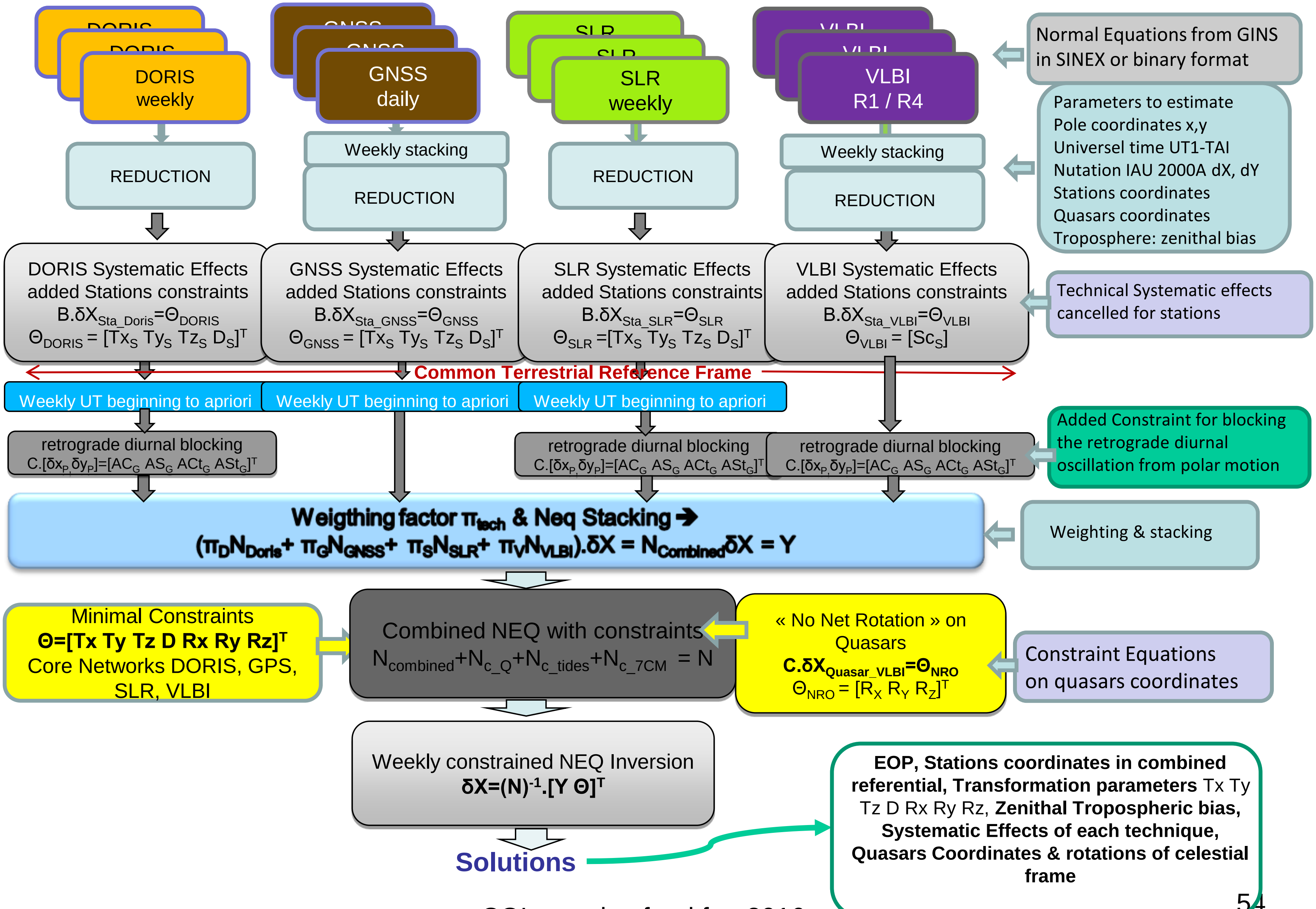
•Clock Bias with constraint on corrections ±100μs

•Quasars coordinates with constraint on corrections ±100nrd

•Non rotating parameters on a quasar set NNR ±100nrd

•Corrections on the Center of Mass for DORIS satellites without constraints

Strategy of Multi-technique Combination



Combination of techniques at CC DGFI

Manuela Seitz, Detlef Angermann,
Mathis Bloßfeld

COL Working Group Meeting
BKG Frankfurt
19. February 2016

Outline

- Intention of the COL WG
- Input data
- CC DGFI combination strategy
- Results intra-technique analysis
- Results of combination
- Summary

Intention of the COL WG

Combination of different techniques on the observation level

Pre-requisites:

- Homogenization of different technique-specific software packages used by the 9 Analysis Centers (AC) with respect to applied models and parameterization
- Normal equations resulting from single-technique and combined analysis provided by the AC in SINEX format
- Normal equations should include all common parameters (station coordinates, EOP, troposphere parameters)

→ Combination of the normal equations by the 2 Combination Centres (CC)

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All items are widely realized by COL

Input data

Data of two time periods (CONT08 and CONT11)

	AIUB	ASI	DGFI	ESOC	GFZ	GRGS	MAO	OPA	TUW
GPS	**n3/08**				**n1**	**n9**			
SLR	**n3**	**n1**	**n3**	**n1/08**		**n4**			
VLBI			**n2**			**n6**	**n1**	**n2**	**n3**
DORIS						**n7**			
SLR-GPS				**n1/08**	**n1/08**				
SLR-DORIS				**n2/08**					
SLR-GPS-DORIS				**n1/08**					

- 18 different data sets
- 4 pre-combined (combined orbit determination)

DGFI

Input data

Data of two time periods (CONT08 and CONT11)

	AIUB	ASI	DGFI	ESOC	GFZ	GRGS	MAO	OPA	TUW
GPS	**n3/08**				**n1**	**n9**			
SLR	**n3**	**n1**	**n3**	n1/08		n4			
VLBI			**n2**			n6	n1	n2	**n3**
DORIS						**n7**			
SLR-GPS				n1/08	n1/08				
SLR-DORIS				n2/08					
SLR-GPS-DORIS				n1/08					

- 18 different data sets / only 9 can be used due incorrect use of SINEX format or problems with statistical values (ITPI)
- Information about new models and parameterization often missed

DGFI

Parameterization

9 parameter types for combination

	Station coord.	Pole	UT1/ LOD	Nuta- tion	Tropo - Off. - Grad.	Geo- cent re	SAO	Bia- ses	Source coord.
GPS (3)	all	2	2	2	2/2	1	1		
SLR (5)	all	all	all	1		1		all	
VLBI (5)	all	all	all	all	2/1				3
DORIS (1)	all	all	all	all	all				
SLR-GPS (2)	all	all	all				1	1	
SLR-DORIS (1)	all	all	all						
SLR-GPS-DORIS (1)	all	all	all				1	1	

Parameterization

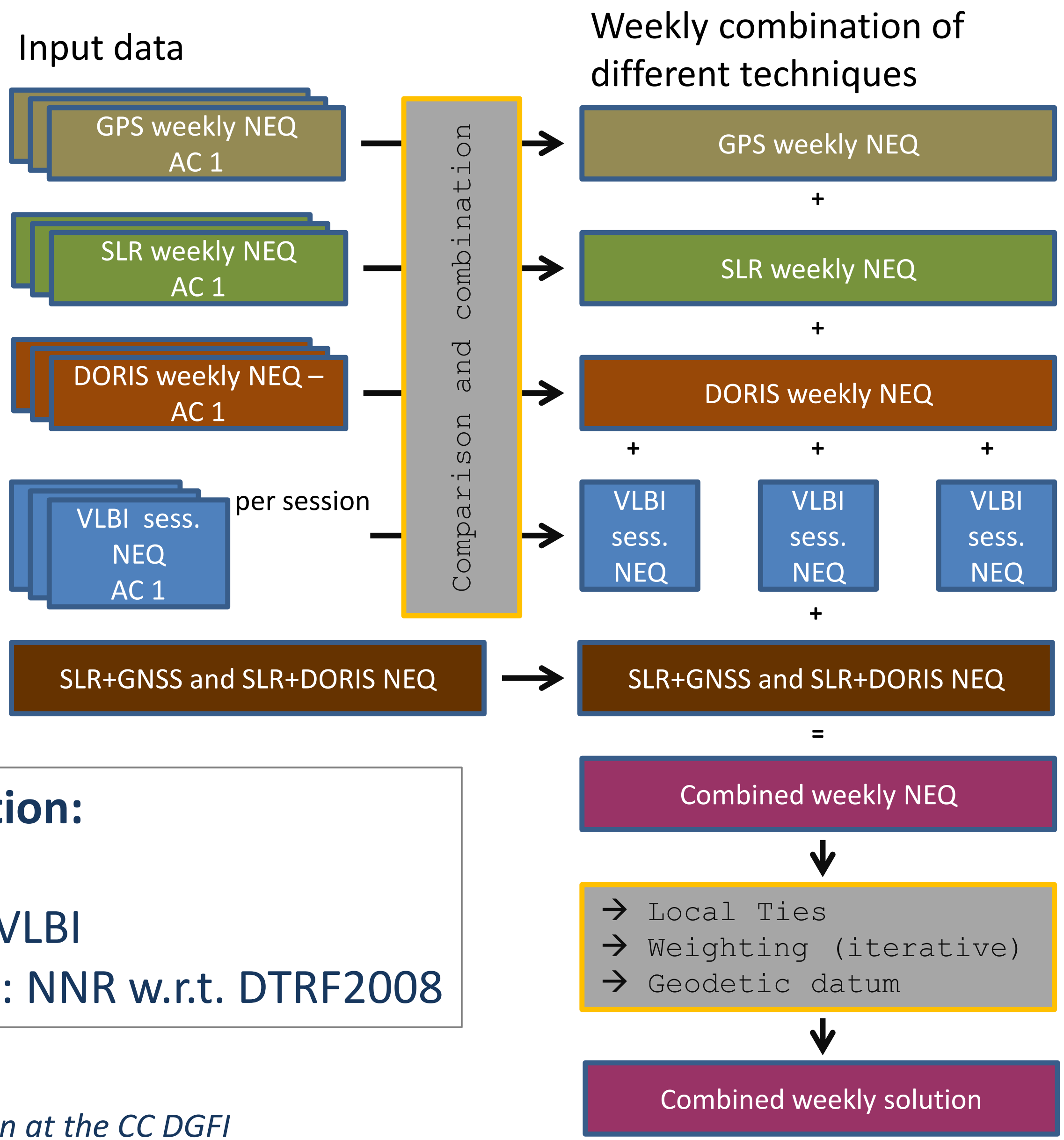
9 parameter types for combination / 3 "basic" parameter types

	Station coord.	Pole	UT1/ LOD	Nuta-tion	Tropo - Off. - Grad.	Geo-centre	SAO	Bia-ses	Source coord.
GPS (3)	all	2	2	2	2/2	1	1		
SLR (5)	all	all	all	1		1		all	
VLBI (5)	all	all	all	all	2/1				3
DORIS (1)	all	all	all	all	all				
SLR-GPS (2)	all	all	all				1	1	
SLR-DORIS (1)	all	all	all						
SLR-GPS-DORIS (1)	all	all	all				1	1	

For some parameter types parameterization not homogeneous

DGFI

Combination procedure at DGFI



Datum realization:

- Origin: SLR
- Scale: SLR+VLBI
- Orientation: NNR w.r.t. DTRF2008

Agreement of technique-specific contributions

GPS: RMS of transformation between AC

	AIUB (250)	GRGS (120)	GFZ (50)
AIUB		5 mm (08)	10-15 mm
GRGS			10-15 mm

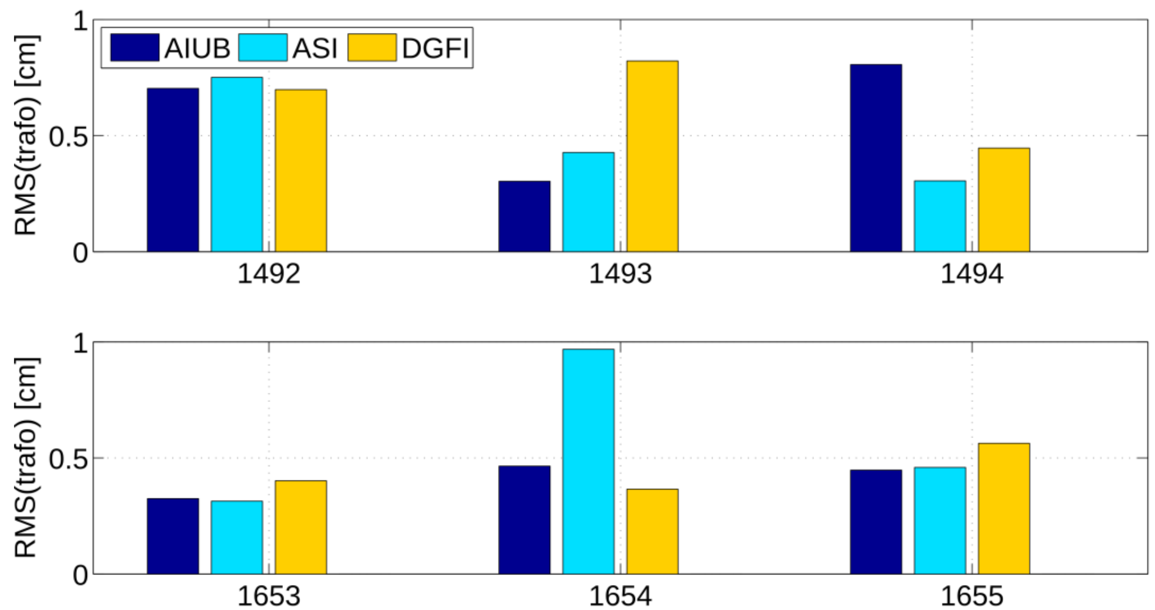
VLBI: RMS and scale differences w.r.t. combined VLBI

	RMS [mm]	Scale [mm]
DGFI	1-2 mm	0-1 mm
TUW	1-3 mm	0-1.4 mm
OPA (does not contribute to combined solution)	4 (08) – 13 (11) mm	0-7 mm

Agreement of technique-specific contributions

SLR: RMS of transformation w.r.t. combined SLR solution

Between
3 and 10 mm



DORIS: RMS w.r.t. DTRF2008

<u>RMS:</u>
2008: 10-12 mm
2011: 15 mm

Combination of all techniques

Internal transformation: Combination w.r.t. single technique

	translation	scale	RMS
GPS			2 mm
DORIS			10 mm
SLR	0-7 mm	0-1.5 mm	6 mm
VLBI		0-1.0 mm	7 mm

- Consistency of scale very high (1.5 mm)
- Realization of origin not better than 7 mm
- RMS (deformation due to combination) between 2mm for GPS and up to 10 mm for DORIS

→ Good agreements. GPS dominates the combination. DORIS slightly worse compared to the other techniques.

Combination of all techniques

External validation of datum realization:
Transformation w.r.t. DTRF2008

	translation	scale	RMS
GPS	0-6 mm	0-3 mm	4 mm
DORIS	0-10 mm	5-11 mm	10-20 mm
SLR	0-10 mm	3 mm	8-17 mm
VLBI	0-10 mm	0-6 mm	3-9 mm

Translation: 0 - 10 mm (also for SLR)
Scale: 0 – 11 mm (0-6 mm for SLR and VLBI)
RMS (difference in network geometry): 3 – 20 mm

→ Good agreement. In case of DORIS model differences w.r.t. DTRF2008 (solar radiation pressure, …)

Summary

Done by COL

– **Combination of 4 different techniques** at the observation level by homogenizing different software packages (common standards)
– **Combined orbit determination** for Jason-2 and some GPS- and GLONASS- Satellites combining SLR, GPS and DORIS observations (done by ESOC and GFZ) → unfortunately not used in final combination by CC due to SINEX format problems
– **Internal agreement** of techniques: 5 – 15 mm
– **External accuracy**: <= 20 mm

Remaining deficiencies

– Homogenization of software packages not fully done
– Changes in software between iterations often not clearly reported
– Parameterization inhomogeneous (EOP, troposphere) and partly unclear (offset or piece-wise linear?)
– SLR range biases not homogeneous (ILRS list or all stations)

→ discrepancies between contributions are hard to analyze

DGFI

Outlook

How to go forward?

- Complete homogenization of software packages
- Integration of contributions resulting from combined orbit-determination
- Investigation: What is the benefit for TRF products from the integration of current and potential future space-based combinations?
- Analysis of longer data series

→ GRASP or E-GRASP/Erathostenes will provide the opportunity for a high-precise space-based combination of all four space geodetic techniques

DGFI

Thank you for your attention!

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