Contribution of SLR and LLR to Earth Orientation and Terrestrial Reference Frame monitoring

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Outline of the presentation

I - Past and Present

- Current IERS combined EOP determination, precision and accuracy

- SLR Contribution to Earth Rotation, strengths and weaknesses

II - Future:

- Need for consistent products: EOP, TRF, CRF , tropo.. ➔ Rigourous combinations

Techniques contributing to IERS

Technique	*since*	*EOP*	*Time Res.*	*Present accuracy*	
ASTROMETRY	**1899**	**Pole**	**5 days**	**Pole:**	**20 mas**
		UT1	**“**	**UT1:**	**1 ms**
		Nutation	**“**	**Nutation:**	**40 mas**
DOPPLER	**1972**	**Pole**	**2 days**	**Pole:**	**10 mas**
LLR	**1969**	**UT0**	**1 day**	**UT0:**	**0.1 ms**
SLR	**1976**	**Pole**	**3 days**	**Pole:**	**150 μas**
		LOD	**“**	**LOD:**	**100 μs/d**
VLBI	**1981**	**Pole**	**7 days**	**Pole:**	**100 μas**
		Nutation	**“**	**Nutation:**	**60 μas**
		UT1	**sub-daily - 7 days**	**UT1:**	**6 μs**
GPS	**1993**	**Pole**	**sub-daily**	**Pole:**	**50 μas**
		LOD	**“**	**LOD:**	**25 μs/d**
DORIS	**1995**	**Pole**	**3 days**	**Pole:**	**.5 mas**

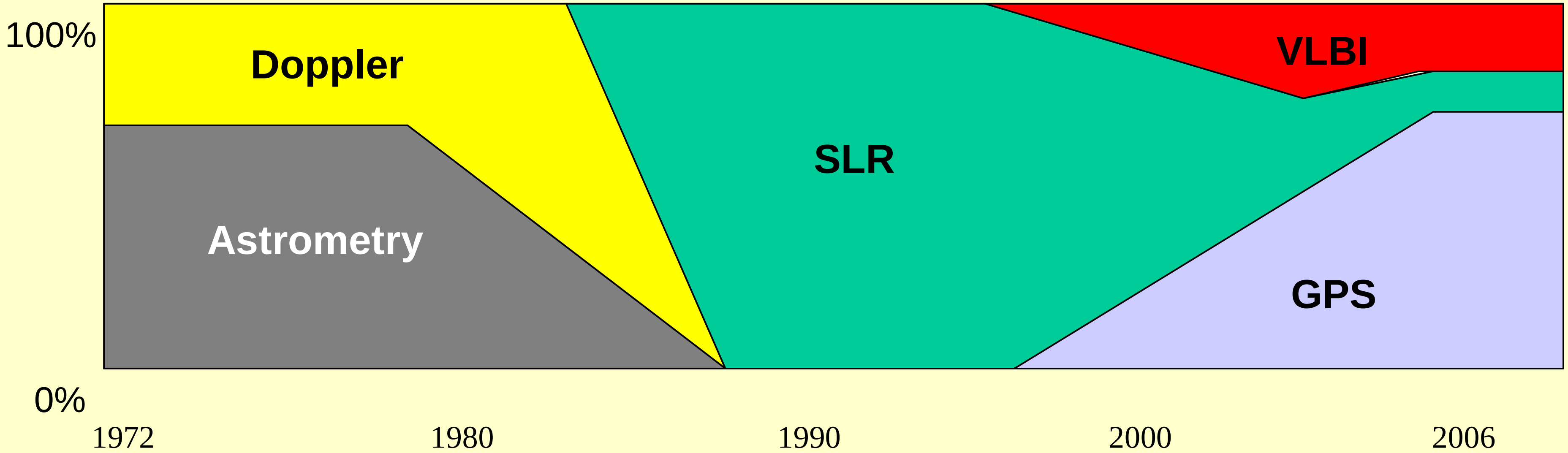
Contribution of the various techniques to IERS

The number of stars matches the relative contributions of techniques

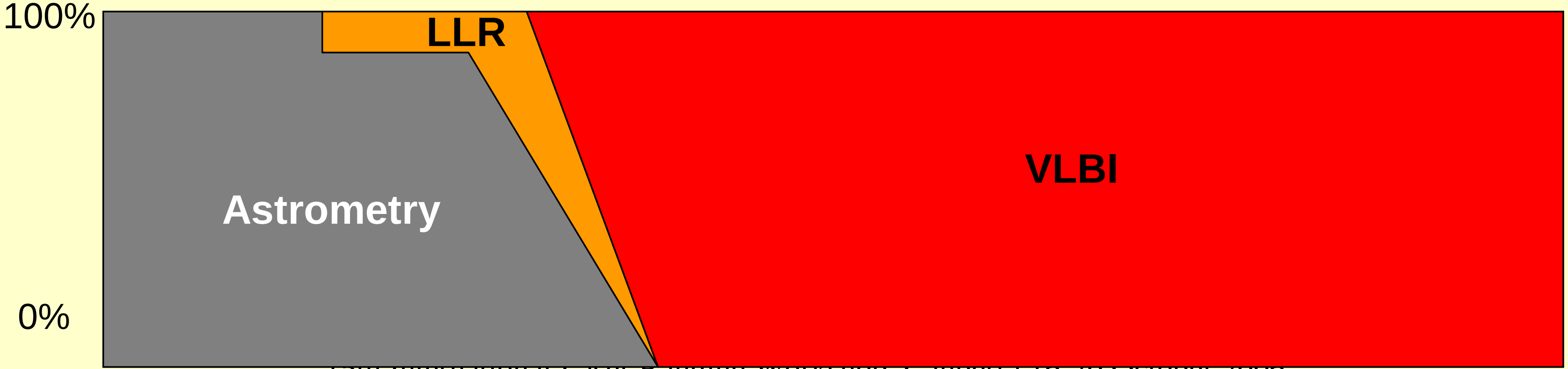
PRODUCTS	LLR	VLBI	SLR	GPS	DORIS
Extragalactic ref. Frame		***			
Tie to solar system	***	*			
Tie to Earth					
Precession-nutation	**	***	*	*	
Universal Time	*	***			
Earth Rotation					
High-frequency UT		***	*	**	
Polar Motion		**	**	***	*
Terrestrial Reference Frame					
Network coverage		*	*	**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

Contributions of techniques to EOP combined solutions

Polar Motion



Universal Time



Current characteristics of EOP estimates

Precision gives an estimation of the agreement of various individual solutions with respect to other combined solutions

- Polar motion : 50 μas
- Universal Time: 4 - 10 μs
- Nutation offsets: 60 μas

Accuracy reflects the real uncertainties of the solutions taking into account the inconsistency of the EOP system with respect to both the terrestrial and celestial frames.

- Polar motion : 150 - 200 μas
- Universal Time: 15 - 20 μs
- Nutation offsets: 60 μas

Inconsistencies and systematic errors, more critical than precision.

Revised version of C04 solution

- Since 2002 reprogramming of the Fortran Code of the C04 solution

- New code operational, solution available on web/ftp

- What is new ? :

  -Implementation of the nutation model IAU 2000

  -Solution can be performed over 20 years in one run

  -New approach for combination of LOD (GPS), compatible with UT1-UTC.

  -Estimation of errors

  -Automatized daily solution

- Aligned to the ITRF2005 solution

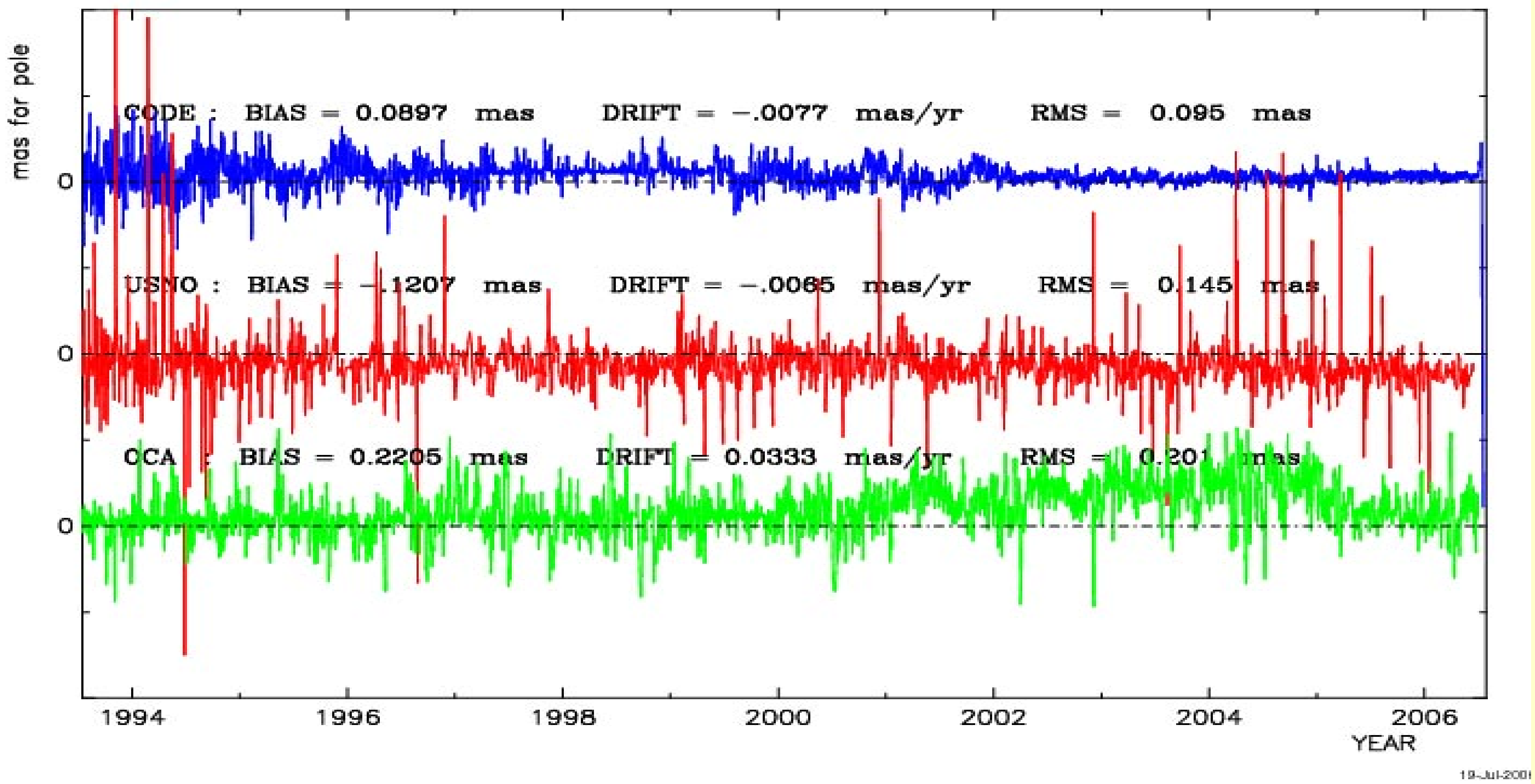
- Will be the reference solution when ITFR2005 from December 2006

Performance of the new algorithm of combination

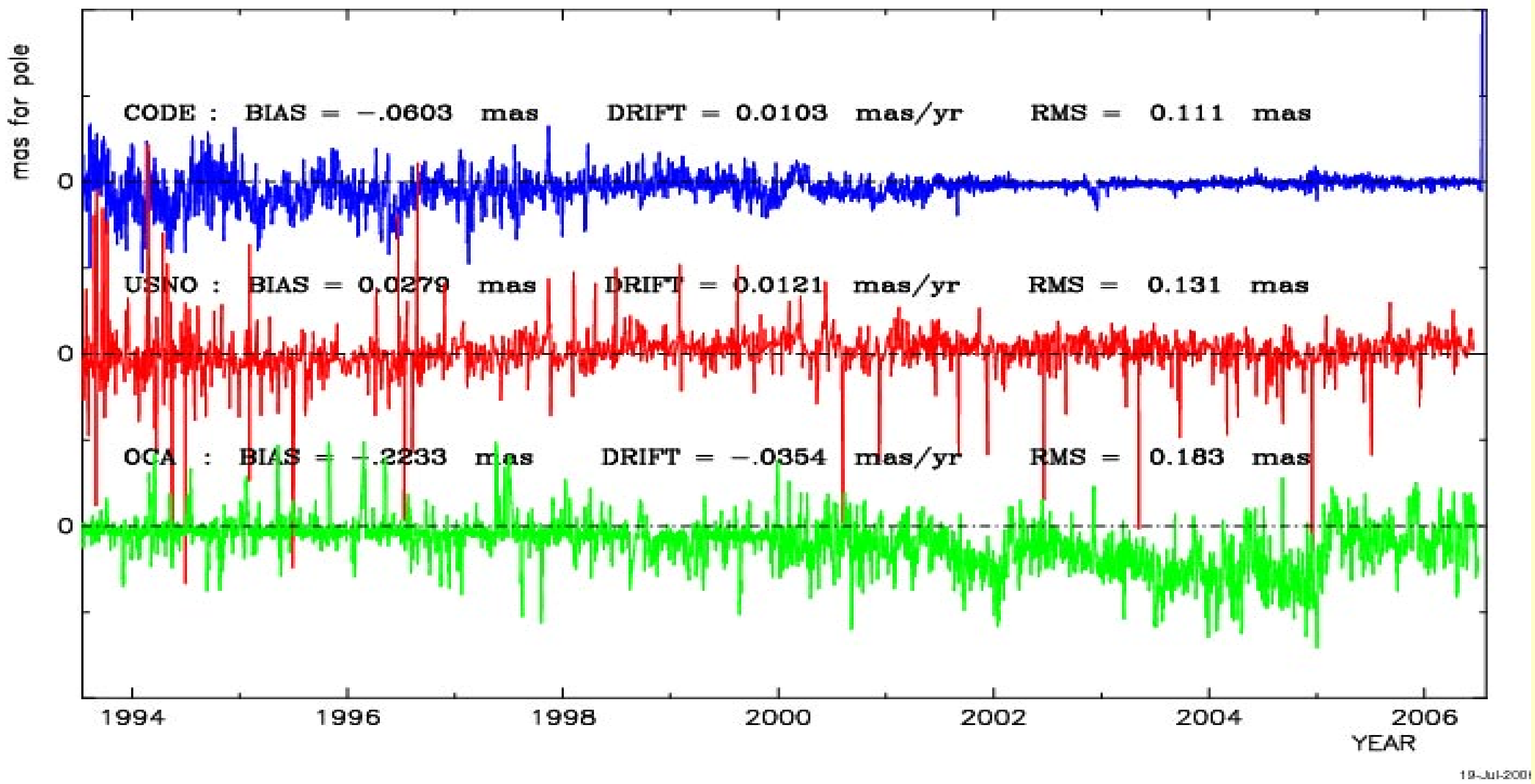
Comparison of RMS agreements of the differences (C04 - GPS/VLBI/SLR) solutions :

- GPS Polar motion : no significative change
- VLBI polar motion : 7-10 μas improvement
- GPS LOD : 6 μs improvement
- UT1 : up to 1-2 μs improvement
- Celestial pole offsets : mean improvement up to 20 μas

X-Pole: long-term stability of GPS, VLBI and SLR
Comparison to IERS current C04

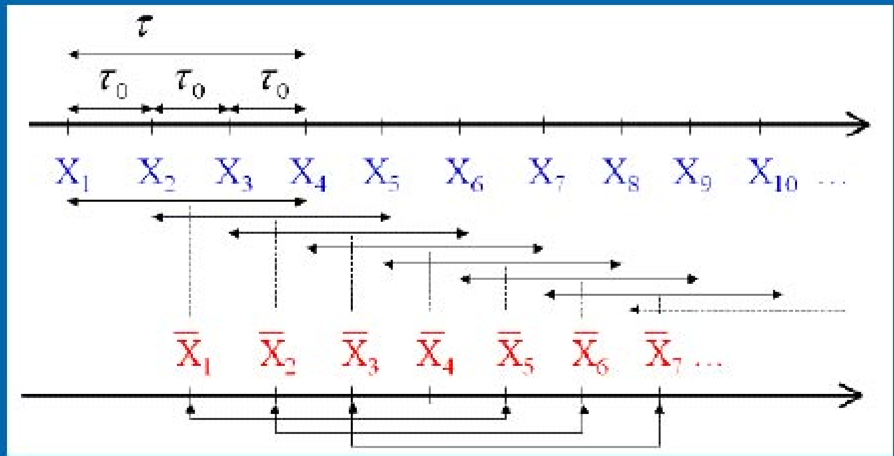


Y-Pole: long-term stability of GPS, VLBI and SLR



Allan Variance

Variance d'Allan



$(X_j)_{j\in I}$ sont les mesures étudiées

τ est le temps d'échantillonnage

- Variance d'Allan : $\sigma_X^2(\tau) = \frac{1}{2} < (\bar{X}_{k+1} - \bar{X}_k)^2 >$

- Sa représentation :

$$\log(\sigma^2(\tau)) = \mu \log(\tau), \; pour \; \tau = \tau_0, 2\tau_0, 4\tau_0, \ldots$$

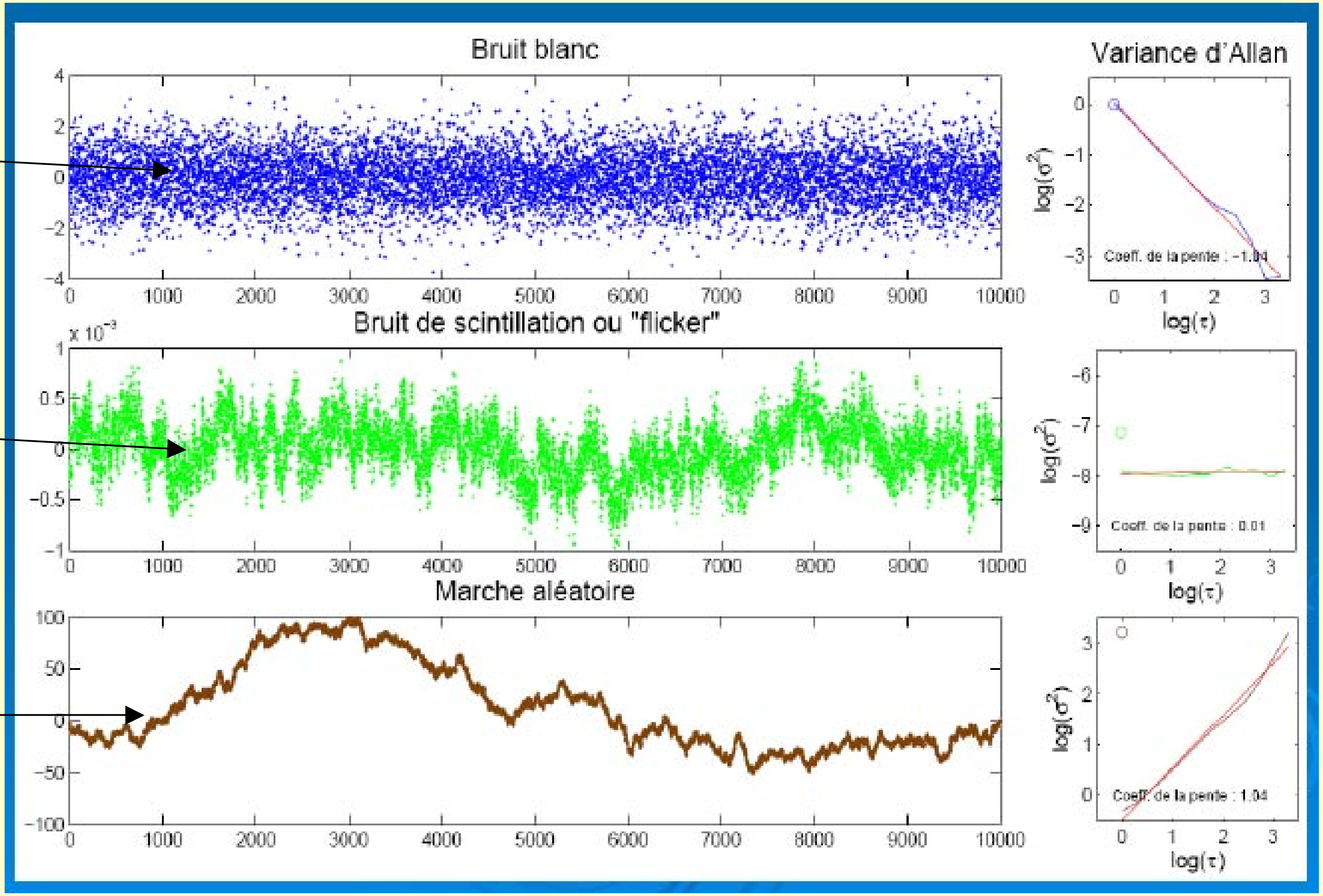
Different types of noise in time series

White

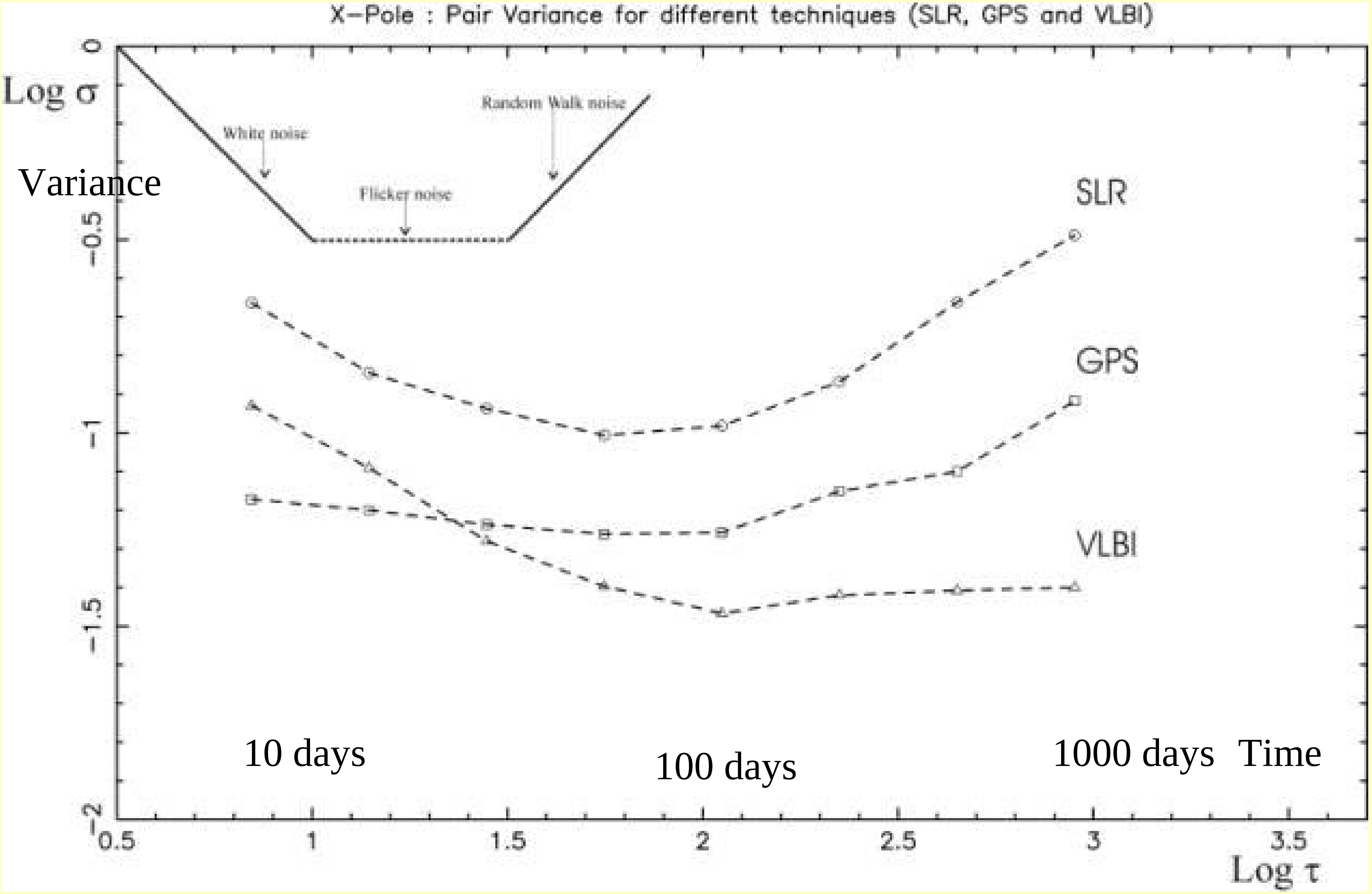
Flicker

Random

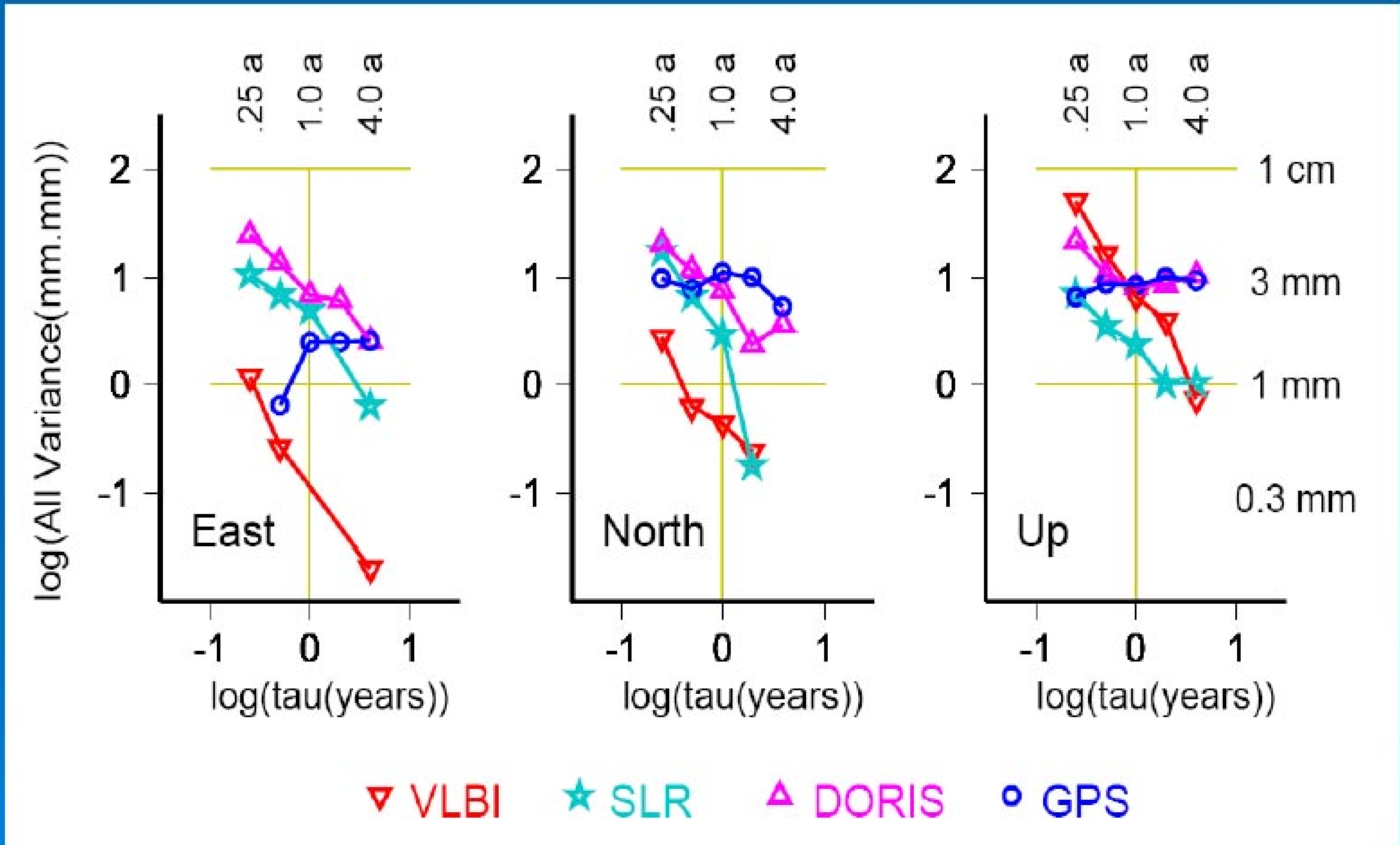
walk



Allan variance analysis for SLR, GPS and VLBI

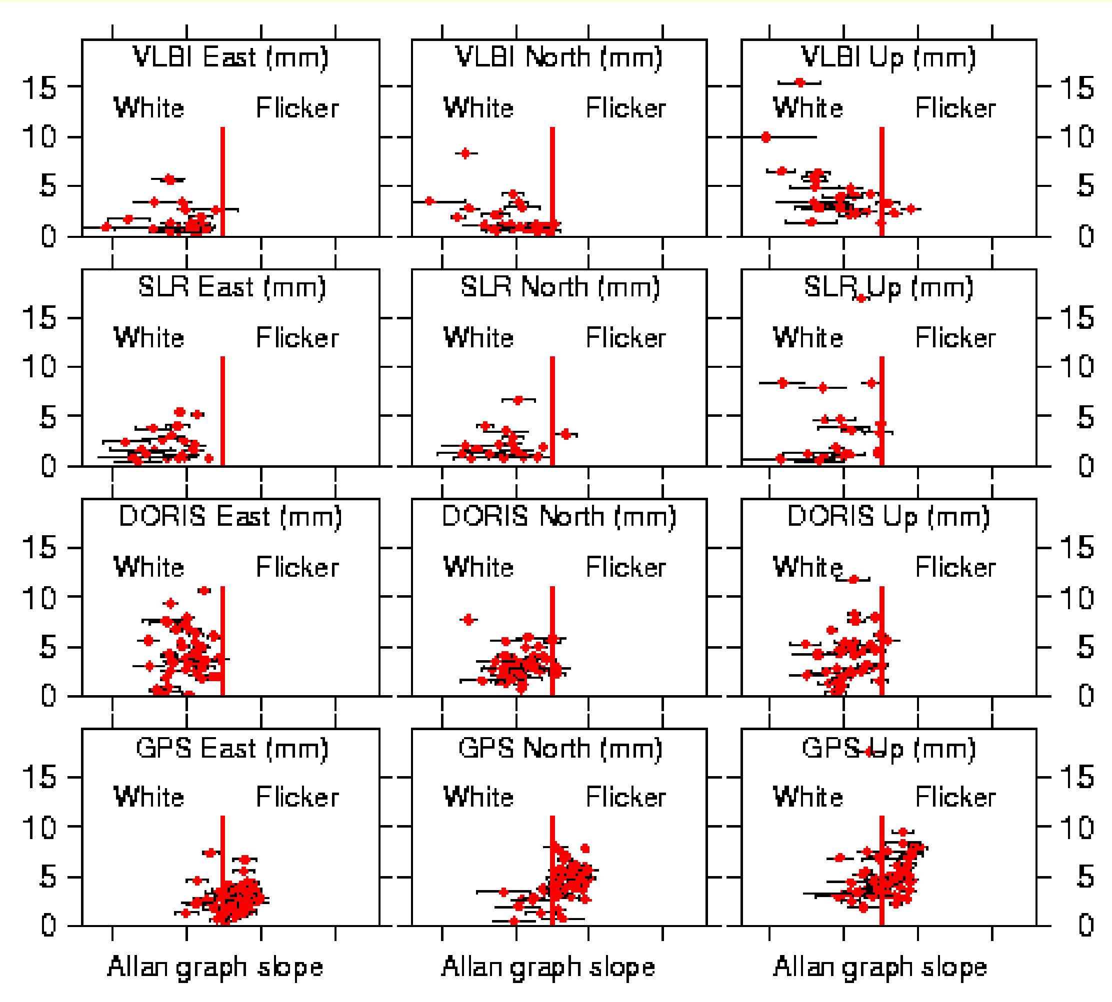


Station coordinates: Noise characterizing the various techniques



Source: K. Le Bail

Station noise for the varous techniques



Source Feissel et al.

Future: rigorous combinations

To ensure the overall consistency of products TRF, EOP and CRF rigorous multi-technique combinations are needed

2 approaches:

- Combination of IGS, ILRS, IVS weekly SINEX files (IGN, DGFI)

- Combination at the level of observations (GRGS)

Rigorous combinations

Simultaneously determine a terrestrial reference frame (TRF) and Earth Orientation Parameters (EOP) is now currently applied on a routine basis

Coordinated project involving different institutes within the Groupe de Recherches de Géodésie Spatiale (GRGS)

Data of each individual technique are processed by expert groups:

GPS at NOVELTIS, DORIS at CLS,

SLR at OCA,

VLBI at the Observatoire de Bordeaux

LLR at CNES and Paris Observatory.

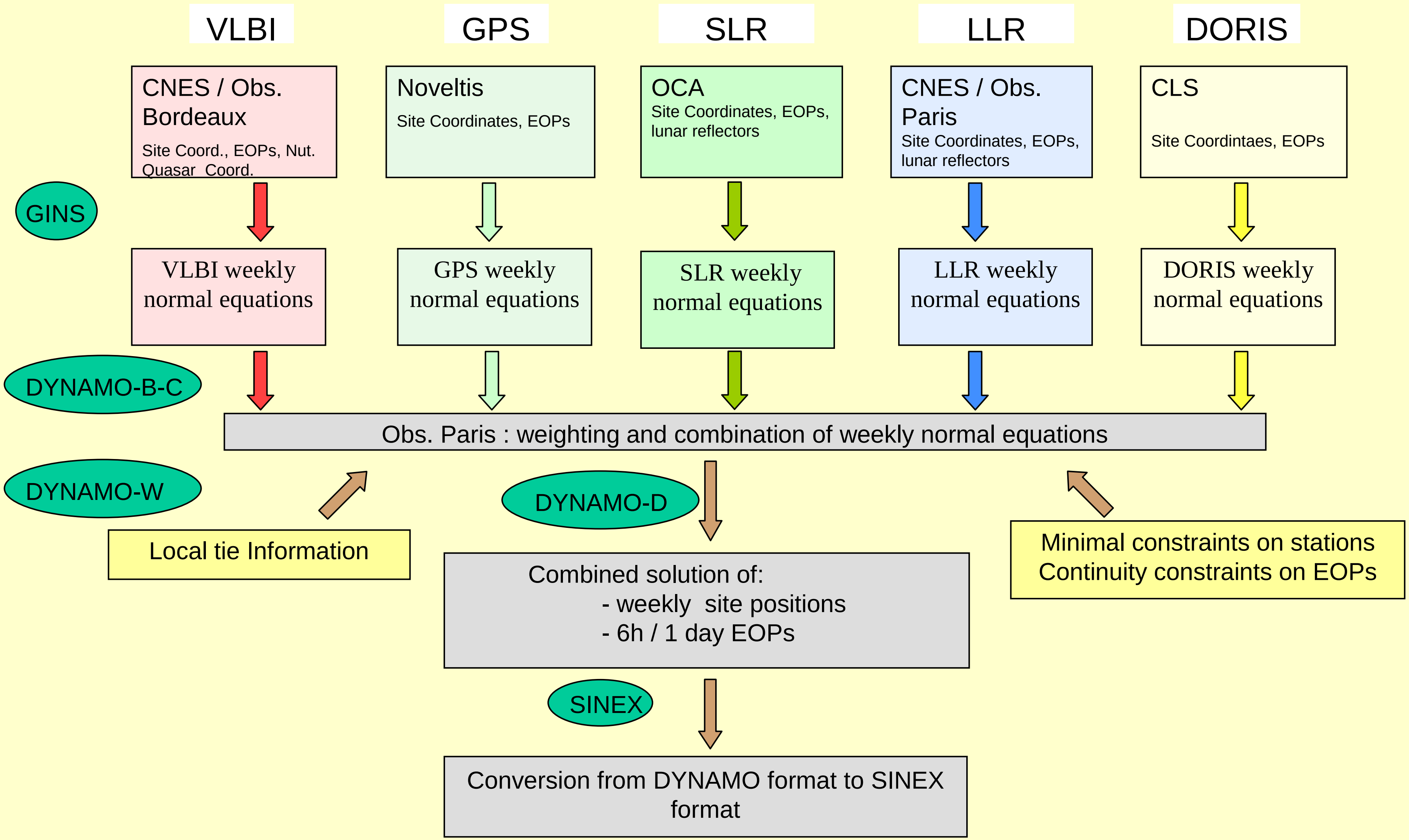
Global combinations and validations are performed at the Observatoire de Paris.

Normal equations matrices are stacked to derive a global solution solutions of TRF+EOP.

The resulting combined products available on http://www.iers.org

So far, the period 2005-2006.4 was processed.

GRGS Organization



GRGS Coordinated Project

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OCA/ GEMINI - Grasse
Noveltis - Toulouse
CLS – Toulouse
Observatoire de Bordeaux
IGN/LAREG - Marne-la-Vallée

GINS-DYNAMO software package

- Multi-technique software package, developed in GRGS, initially dedicated to orbitography and gravity field modeling
- ***GINS*** computes and adjusts orbits around the Earth and planets, generates normal equations and in addition processes VLBI, LLR data
- ***DYNAMO*** is a “ Matrices handling” software package:
  - reduces, inverts normal equations, weights (Helmert ’s method), combines and solves for parameters; EOP, TRF, CRF, tropo..

GINS a priori model evolution

a priori dynamical models (GRACE Standards):

EIGEN-GL04C gravity field model

3rd body point mass attraction from Sun, Moon (+ J2 Earth's indirect effect), other planets

Earth tide model according to IERS Conventions 2003

FES-2004 ocean tide model

6h-ECMWF atmospheric pressure fields + MOG2D barotropic ocean model

DTM94bis thermospheric model

Albedo and Infra-Red grids from ECMWF (resolution of 4.5 degrees)

a priori geometrical models :

a priori station coordinates from ITRF 2000

a priori EOP from IERS EOP C04 series

Earth tide model according to IERS Conventions 2003

oceanic loading effect from FES-2004 ocean tide model

atmospheric loading from 6h-ECMWF atmospheric pressure fields over continents

Procedure

• Routine production started at GRGS at the beginning of 2005 (new server)

• Five geodetic techniques are processed with a single software (GINS)

• Combination : Earth Orientation Parameters (Pole-X, Pole-Y, UT1, Nutation-ψ, Nutation-ε) every 6 hours and weekly station coordinates (DYNAMO)

• EOP are converted in daily series in SINEX format and delivered to IERS in the framework of the Combination Pilot Project

Combined techniques :

✓ **GPS** : all GPS satellites, stations subset (~60 stations)

✓ **SLR** : Lageos & Lageos2 (~30 stations)

✓ **DORIS** : SPOT-2, -4, -5 and ENVISAT since Mai (~50 stations)

✓ **VLBI** : only A and E sessions used (~15 stations)

✓ **LLR** : 2 stations (Grasse & Mc Donald), now NO data

Analyses

Two approaches

1) Weekly multi-technique combined matrices derived
   - Contribution of minimal constraints on stations
   - Contribution of local ties

2) In the first step intra-technique solution is performed over the full interval
   - Contribution of minimal constraints on stations
   - Contribution of local ties
   - Contribution of EOP continuity constraints

Analyses done over the period 2005.0 – 2006.4

SLR

Strategy:

Orbit determination of LAGEOS-1 and -2 (9 days-arc)

RMSLA1=1.06cm RMSLA2=0.99cm

NPs per week 1504/1338 for LAGEOS-1/-2

Normal matrices for LAGEOS-1 and LAGEOS-2 (1 range bias per week, per station and per satellite, 3 station coordinates per week, EOPs each 6 hours)

30 SLR stations (more than 20 normal points per week)

SLR network

Advantages of the method

•Optimal combination TRF + EOP

and in future CRF and tropospheric parameters..

•Mutual constraints of the various techniqsues

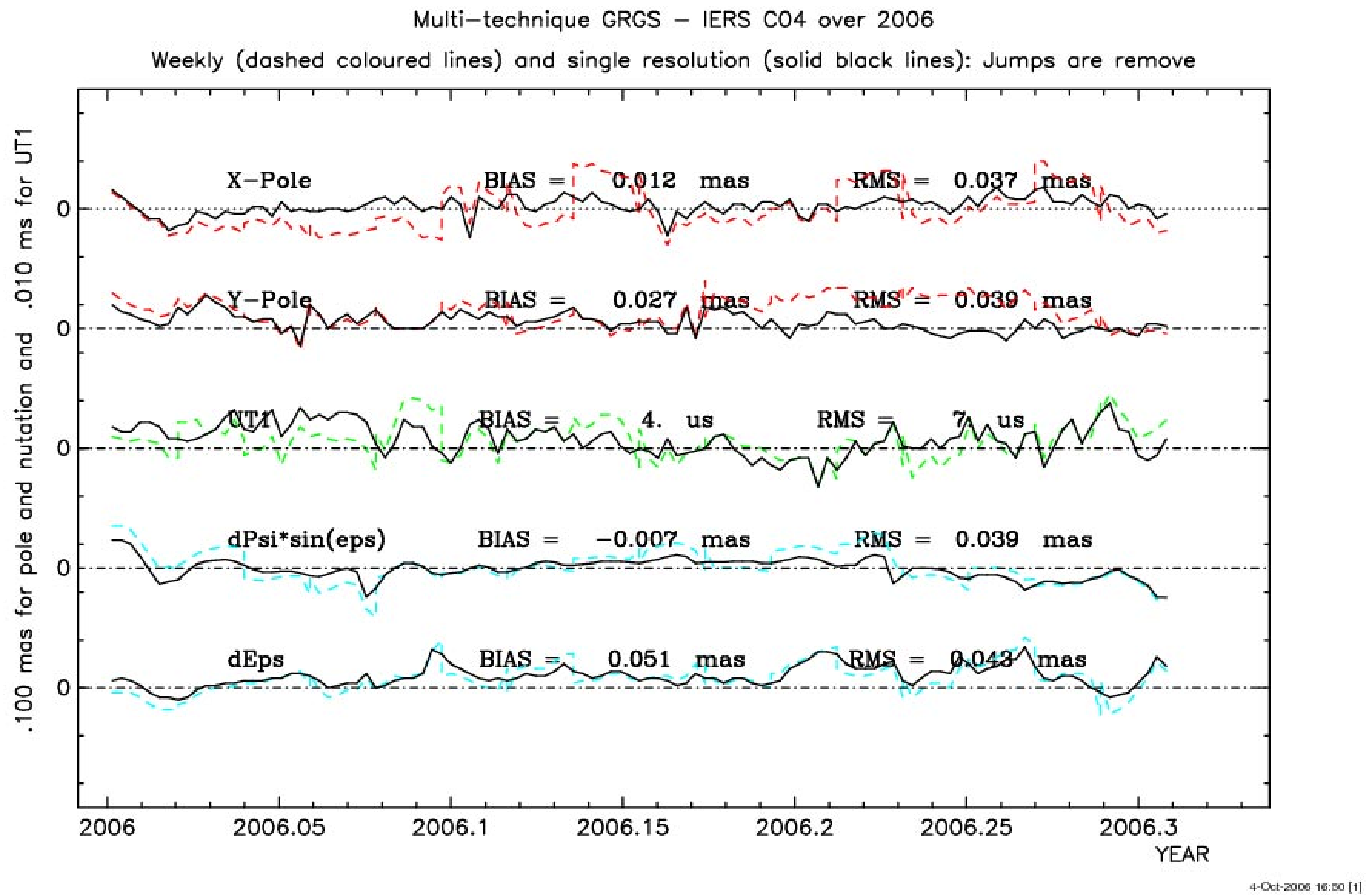
•Densification

UT1 (VLBI) + LOD (GPS)

Nutation (VLBI) + nutation rates (GPS)

•Contribution of intensive VLBI session

•Reference system constrained through local co-location ties



Multi–technique GRGS – IERS C04 over 2006
Weekly (dashed coloured lines) and single resolution (solid black lines): Jumps are remove
.100 mas for pole and nutation and .010 ms for UT1
X–Pole BIAS = 0.012 mas RMS = 0.037 mas
Y–Pole BIAS = 0.027 mas RMS = 0.039 mas
UT1 BIAS = 4. us RMS = 7. us
dPsi*sin(eps) BIAS = –0.007 mas RMS = 0.039 mas
dEps BIAS = 0.051 mas RMS = 0.043 mas
2006
2006.05
2006.1
2006.15
2006.2
2006.25
2006.3
YEAR
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RMS of the difference between individual techniques and Global with IERS C04 over 2006

	DORIS	SLR	GPS	VLBI	COMBINED Weekly	COMBINED One run	Best current solution
X-Pole in µas	37	60	36	98	**88**	**37**	**34 (IGS)**
Y-Pole in µas	49	77	36	133	**61**	**39**	**30 (IGS)**
UT1 in µs				9	**7.4**	**6.6**	**5 (IVS)**
Dψsinε **in µas**				55	61	39	**30 (IVS)**
Dε **in µas**				60	59	43	**30 (IVS)**

Comparison of the mean solution to ITRF2000
For VLBI the initial reference frame is VTRF2005

	SLR	DORIS	GPS	VLBI	Multi-technique GRGS
3-D differences with ITRF2000	4.0 cm	2.5 cm	2.7 cm	2.8 cm	2.8 cm

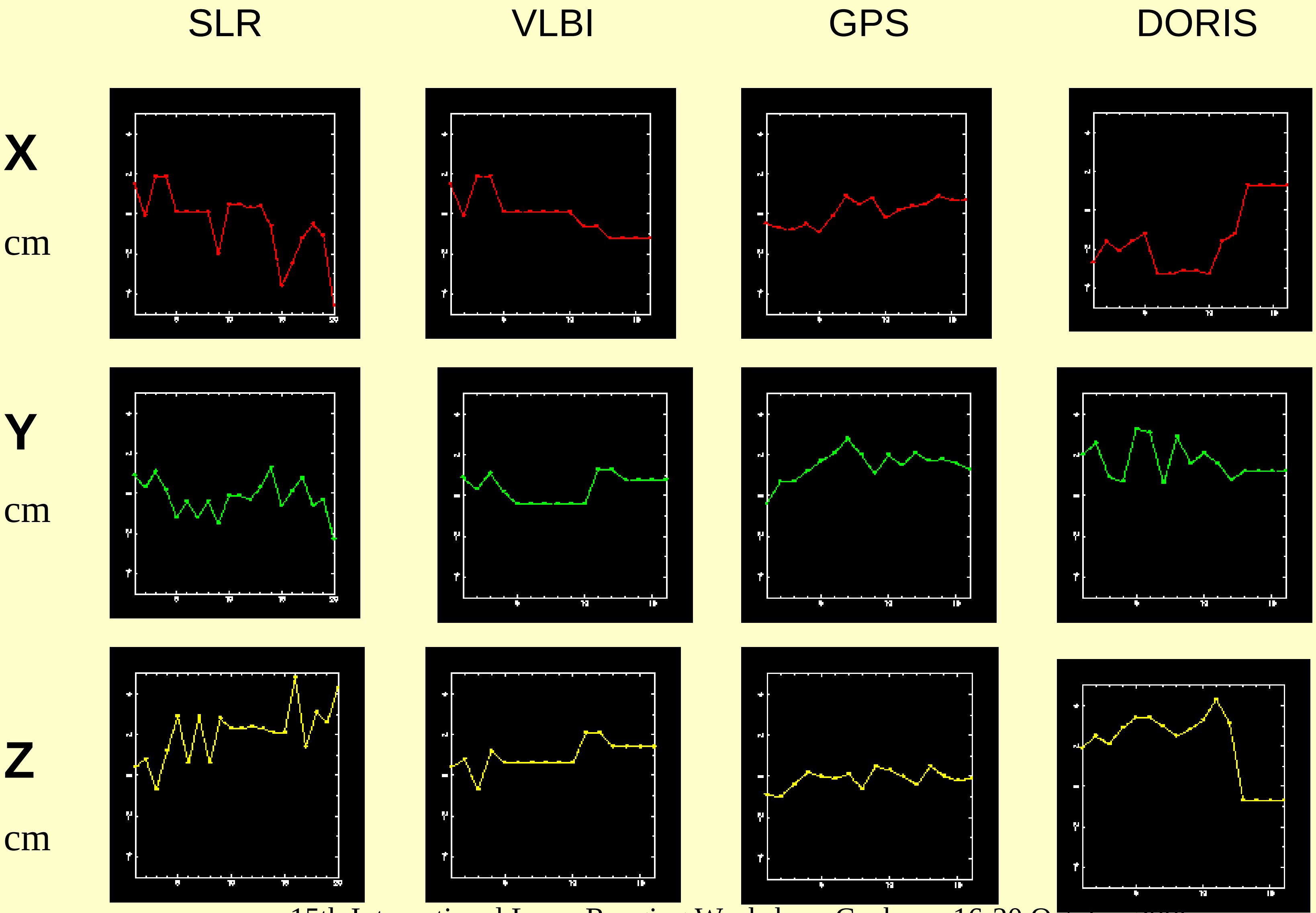
Correction to local ties over 2006

Raw RMS	Weighted RMS
2.0 cm	1.8 cm

Reference frame solution 7-parameter transformation with respect to ITRF2000 over 2006

	Tx cm	Ty cm	Tz cm	Scale cm	Rx cm	Ry cm	Rz cm
DORIS	1.9	.0	-1.6	-1.1	.0	.0	.0
GPS	2.5	-.8	-.7	-1.2	.0	.0	.0
SLR	2.4	-1.7	-2.7	1.2	0	0	0
VLBI	1.5	-2.1	-1.0	.6	.0	.0	.0
GLOBAL	2.5	-.9	-.9	-1.0	.0	.0	.0

Hartebeesthoek, Coordinates stability wrt ITRF2000,



Conclusion

- SLR plays a significant role in EOP (long-term stability) and TRF (geocenter realization)

- Global combinations benefit of contributions and mutual constraints of the various techniques VLBI, SLR , GPS, LLR and DORIS

  Densification

  UT1 (VLBI) + LOD (GPS)

  Nutation (VLBI) + nutation drift (GPS)

- Quality is improving in parallel to individual techniques processing upgrade

- « Tuning » still critical in the combination (constraints)

  ➔ Propagation of errors due to subsets of local ties to be investigated

  ➔ Necessity to improve weighting procedure (stations)

- Combination TRF + EOP is routinely performed and we plan to realize in addition in the future:
  - CRF and multi-technique tropospheric parameters