New Earth Orientation Parameters by COMBINATION of GNSS & VLBI

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ABSTRACT

At SYRTE, thanks to the IERS COL-WG [1], we have developed a new strategy of combination using the Global Navigation Satellite Systems (GNSS) and Very Long Baseline Interferometry (VLBI) techniques from the recently solution files produced respectively by IGS and IVS international services converted at normal equation level. This approach allows us to produce the EOP at the daily bases, polar coordinates (x,y) and rates (xr,yr), universal time UT1 and rate LOD, and corrections from IAU200A/2006 precession-nutation model (dX,dY), simultaneously with station coordinates constituting the terrestrial frame (TRF) and possibly the quasar coordinates constituting the celestial frame (CRF). This operational process of this combination are presented and results over the period 2000-2019 are analysed.
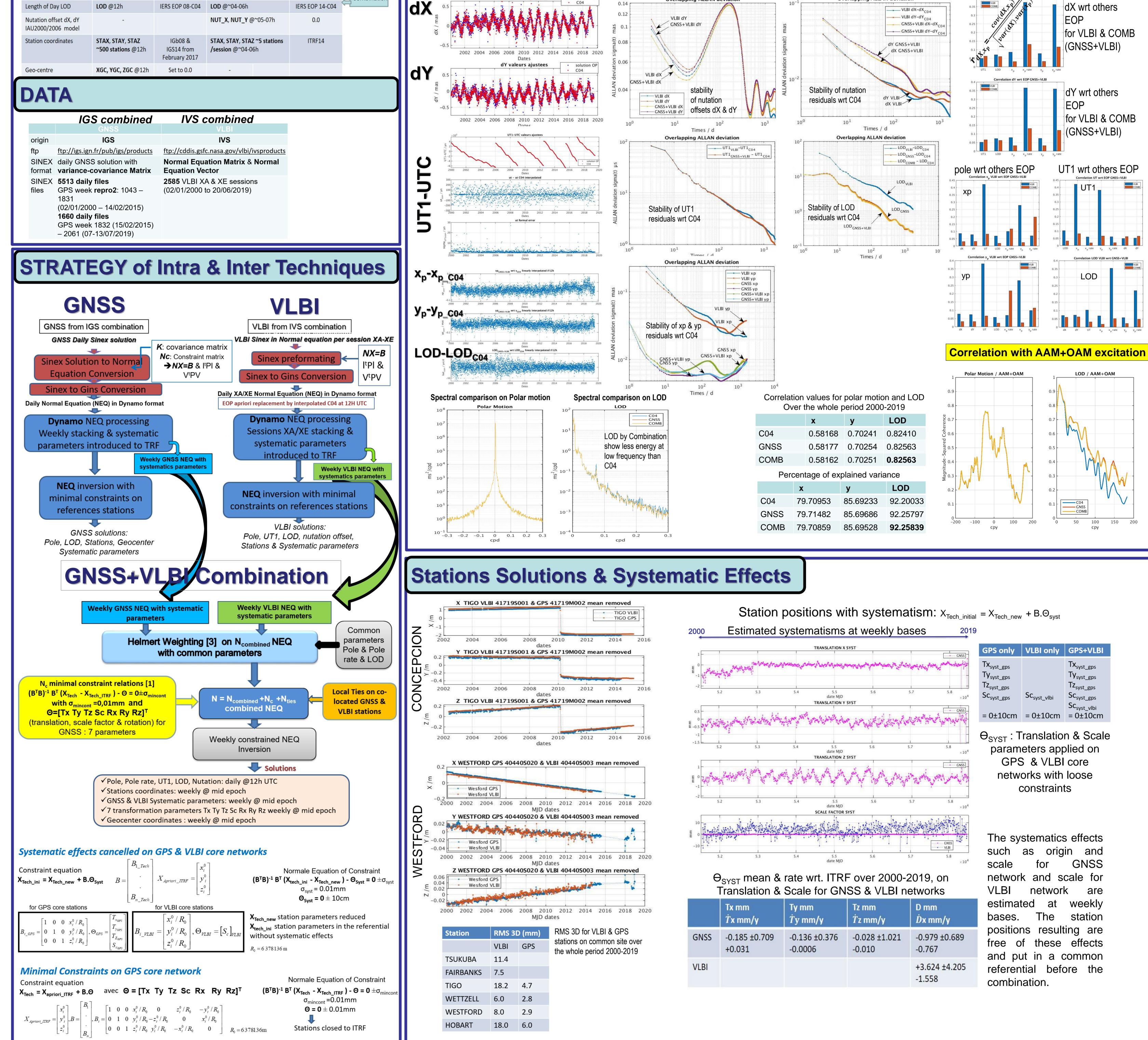
PARAMETERS

Parameters	GNSS daily		VLBI R1/R4 sessions	
	Sinex parameters	Initial values	Sinex parameters	Initial values	
Polar coordinates	XPO, YPO @12h	IERS EOP 08-C04	XPO, YPO @~04-06h	IERS EOP 14-C04	Stacking these Common Parameters for combination
Polar motion rate	XPOR, YPOR @12h	IERS EOP 08-C04	XPOR, YPOR @~04-06h	0.0	
Delta time UT1-UTC	-		UT @~04-06h	IERS EOP 14-C04	
Length of Day LOD	LOD @12h	IERS EOP 08-C04	LOD @~04-06h	IERS EOP 14-C04	
Nutation offset dX, dY IAU2000/2006 model	-		NUT_X, NUT_Y @~05-07h	0.0	
Station coordinates	STAX, STAY, STAZ ~500 stations @12h	IGb08 & IGS14 from February 2017	STAX, STAY, STAZ ~5 stations /session @~04-06h	ITRF14	
Geo-centre	XGC, YGC, ZGC @12h	Set to 0.0			

DATA

	IGS combined	IVS combined
	GNSS	VLBI
origin	IGS	IVS
ftp	ftp://igs.ign.fr/pub/igs/products	ftp://cddis.gsfc.nasa.gov/vlbi/ivsproducts
SINEX format	daily GNSS solution with variance-covariance Matrix	Normal Equation Matrix & Normal Equation Vector
SINEX files	6513 daily files GPS week repro2: 1043 – 1831 (02/01/2000 – 14/02/2015) 1660 daily files GPS week 1832 (15/02/2015) – 2061 (07-13/07/2019)	2585 VLBI XA & XE sessions (02/01/2000 to 20/06/2019)

STRATEGY of Intra & Inter Techniques

GNSS

GNSS from IGS combination

GNSS Daily Sinex solution

Sinex Solution to Normal Equation Conversion

K: covariance matrix
Nc: Constraint matrix
→NX=B & I'PI &
V'PV

Sinex to Gins Conversion

Daily Normal Equation (NEQ) in Dynamo format

Dynamo NEQ processing Weekly stacking & systematic parameters introduced to TRF

Weekly GNSS NEQ with systematics parameters

NEQ inversion with minimal constraints on references stations

GNSS solutions: Pole, LOD, Stations, Geocenter Systematic parameters

VLBI

VLBI from IVS combination

VLBI Sinex in Normal equation per session XA-XE

Sinex preforming

NX=B
I'PI &
V'PV

Sinex to Gins Conversion

Daily XA/XE Normal Equation (NEQ) in Dynamo format

EOP apriori replacement by interpolated C04 at 12H UTC

Dynamo NEQ processing Sessions XA/XE stacking & systematic parameters introduced to TRF

Weekly VLBI NEQ with systematics parameters

NEQ inversion with minimal constraints on references stations

VLBI solutions: Pole, UT1, LOD, nutation offset, Stations & Systematic parameters

GNSS+VLBI Combination

Weekly GNSS NEQ with systematic parameters

Weekly VLBI NEQ with systematic parameters

Helmert Weighting [3] on $N_{combined}$ NEQ with common parameters

Common parameters Pole & Pole rate & LOD

N_c minimal constraint relations [1]
$(B^TB)^{-1} B^T (X_{tech} - X_{tech\_ITRF}) - \Theta = 0 \pm \sigma_{minconf}$
with $\sigma_{minconf} = 0.01mm$ and
$\Theta = [Tx\ Ty\ Tz\ Sc\ Rx\ Ry\ Rz]^T$
(translation, scale factor & rotation) for GNSS : 7 parameters

$N = N_{combined} + N_c + N_{ties}$ combined NEQ

Local Ties on co-located GNSS & VLBI stations

Weekly constrained NEQ Inversion

Solutions
✓ Pole, Pole rate, UT1, LOD, Nutation: daily @12h UTC
✓ Stations coordinates: weekly @ mid epoch
✓ GNSS & VLBI Systematic parameters: weekly @ mid epoch
✓ 7 transformation parameters Tx Ty Tz Sc Rx Ry Rz weekly @ mid epoch
✓ Geocenter coordinates : weekly @ mid epoch

Systematic effects cancelled on GPS & VLBI core networks

Constraint equation
$X_{Tech\_ini} = X_{Tech\_new} + B.\Theta_{Syst}$

Normale Equation of Constraint
$(B^TB)^{-1} B^T (X_{tech\_ini} - X_{tech\_new}) - \Theta_{Syst} = 0 \pm \sigma_{syst}$
$\sigma_{syst} = 0.01mm$
$\Theta_{syst} = 0 \pm 10cm$

X_{Tech_new} station parameters reduced X_{Tech_new} station parameters in the referential without systematic effects

$R_e = 6378136m$

Minimal Constraints on GPS core network

Constraint equation
$X_{Tech} = X_{apriori\_ITRF} + B.\Theta$ avec $\Theta = [Tx\ Ty\ Tz\ Sc\ Rx\ Ry\ Rz]^T$

Normale Equation of Constraint
$(B^TB)^{-1} B^T (X_{tech} - X_{tech\_ITRF}) - \Theta = 0 \pm \sigma_{minconf}$
$\sigma_{minconf} = 0.01mm$
$\Theta = 0 \pm 0.01mm$

$R_e = 6378136m$

Stations closed to ITRF

EOP solutions for GNSS+VBI Combination over the period 2000-2019

Comparison of EOP series wrt 14C04 linearly interpolated @12h (outliers > 7*Mad removed)

	GNSS_GRGS series 9050		VLBI_IVS series 9052		VLBI_GRGS series 9051		COMB GNSS_GRGS VLBI_GRGS pole & LOD series 9055		COMB GNSS_GRGS VLBI_GRGS UT1 & Nutation series 9056	
Number of dates	7035		2545		2307		6958		2289	
Number of outliers > 7*MAD	xp:7 / yp:4 / LOD:30		xp:40 / yp:43 / UT1:32		xp:32 / yp:45 / LOD:26		xp:10 / yp:7 / LOD:30		dX:23 / dY:26 / UT1:20	
	Median	WRMS	Median	WRMS	Median	WRMS	Median	WRMS	Median	WRMS
$x_{p\_GRGS} - x_{p\_C04}$ (μas)	14.7	36.2	-7.2	119.3	-14.1	178.0	17.4	35.2		
$y_{p\_GRGS} - y_{p\_C04}$ (μas)	-8.9	32.4	-15.5	118.5	-13.2	136.0	-13.3	32.4		
$LOD_{GRGS} - LOD_{C04}$ (μs)	0.49	16.0	0.49	25.5	1.9	36.9	0.52	15.0		
$(UT1_{-UTC})_{GRGS} - (UT1_{-UTC})_{C04}$ (μas)			0.6	37.7	9.3	67.0			1.1	67.1
$dX_{GRGS} - dX_{C04}$ (μas)			2.7	33.0	3.6	30.9			0.6	47.1
$dY_{GRGS} - dY_{C04}$ (μas)			-1.3	32.9	-1.2	31.7			1.2	49.0

EOP Solutions

dX, dY, UT1-UTC, x_p-x_{p_C04}, y_p-y_{p_C04}, LOD-LOD$_{C04}$

Spectral comparison on Polar motion

Spectral comparison on LOD

LOD by Combination show less energy at low frequency than C04

EOP Stability

Overlapping ALLAN deviation

stability of nutation offsets dX & dY

Stability of nutation residuals wrt C04

Stability of UT1 residuals wrt C04

Stability of LOD residuals wrt C04

Stability of xp & yp residuals wrt C04

Correlation values for polar motion and LOD Over the whole period 2000-2019

	x	y	LOD
C04	0.58168	0.70241	0.82410
GNSS	0.58177	0.70254	0.82563
COMB	0.58162	0.70251	0.82563

Percentage of explained variance

	x	y	LOD
C04	79.70953	85.69233	92.20033
GNSS	79.71482	85.69686	92.25797
COMB	79.70859	85.69528	92.25839

EOP Correlations

dX wrt others EOP for VLBI & COMB (GNSS+VLBI)

dY wrt others EOP for VLBI & COMB (GNSS+VLBI)

pole wrt others EOP   UT1 wrt others EOP

xp   UT1
yp   LOD

Correlation with AAM+OAM excitation

Polar Motion / AAM+OAM   LOD / AAM+OAM

Stations Solutions & Systematic Effects

Station positions with systematism: $X_{Tech\_initial} = X_{Tech\_new} + B.\Theta_{syst}$

Estimated systematisms at weekly bases

X TIGO VLBI 417195001 & GPS 41719M002 mean removed
Y TIGO VLBI 417195001 & GPS 41719M002 mean removed
Z TIGO VLBI 417195001 & GPS 41719M002 mean removed

X WESTFORD GPS 40440S020 & VLBI 40440S003 mean removed
Y WESTFORD GPS 40440S020 & VLBI 40440S003 mean removed
Z WESTFORD GPS 40440S020 & VLBI 40440S003 mean removed

	GPS only	VLBI only	GPS+VLBI
	Tx_syst_gps		Tx_syst_gps
	Ty_syst_gps		Ty_syst_gps
	Tz_syst_gps		Tz_syst_gps
	Sc_syst_gps	Sc_syst_vibi	Sc_syst_gps Sc_syst_vibi
	= 0±10cm	= 0±10cm	= 0±10cm

Θ_{SYST} : Translation & Scale parameters applied on GPS & VLBI core networks with loose constraints

The systematics effects such as origin and scale for GNSS network and scale for VLBI network are estimated at weekly bases. The station positions resulting are free of these effects and put in a common referential before the combination.

Θ_{SYST} mean & rate wrt ITRF over 2000-2019, on Translation & Scale for GNSS & VLBI networks

	Tx mm Tx mm/y	Ty mm Ty mm/y	Tz mm Tz mm/y	D mm Dx mm/y
GNSS	-0.185 ±0.709 +0.031	-0.136 ±0.376 -0.0006	-0.028 ±1.021 -0.010	-0.979 ±0.689 -0.767
VLBI				+3.624 ±4.205 -1.558

Station	RMS 3D (mm)	
	VLBI	GPS
TSUKUBA	11.4	
FAIRBANKS	7.5	
TIGO	18.2	4.7
WETTZELL	6.0	2.8
WESTFORD	8.0	2.9
HOBART	18.0	6.0

RMS 3D for VLBI & GPS stations on common site over the whole period 2000-2019

CONCLUSION & PROSPECTS

We dispose of an operational chain now available to produce GNSS and VLBI combination from IERS technique centres at the normal equation level based on the CNES/GRGS DYNAMO software. This combination shows a good consistency with ITRF14 and becomes useful to control the C04 reference series of polar motion in consistency with the official terrestrial frame. Nutation offsets stability is improved in short periods and UT1 stability is better than C04 in long periods. Correlations between EOP estimated by VLBI only and by combination GNSS & VLBI are slightly reduced. LOD shows an improvement in correlation with the AAM+OAM excitation wrt C04 and less energy in low frequency than C04 LOD. Station coordinates are simultaneously estimated in consistency with the ITRF. Next step is to process SLR & DORIS NEQ and to estimate the quasars coordinates (CRF) simultaneously with the EOP and TRF.

REFERENCES

[1] Richard J-Y. & al. Systematic effects in multi-technique combination, EGU-2013, Session Geodesy G2.1
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[3] Variance component estimation applied to satellite laser ranging, Sahin M., Bul Geo Springer-Verlag 1992