Earth Orientation Parameters determination by GNSS & VLBI Combination at Normal Equation Level

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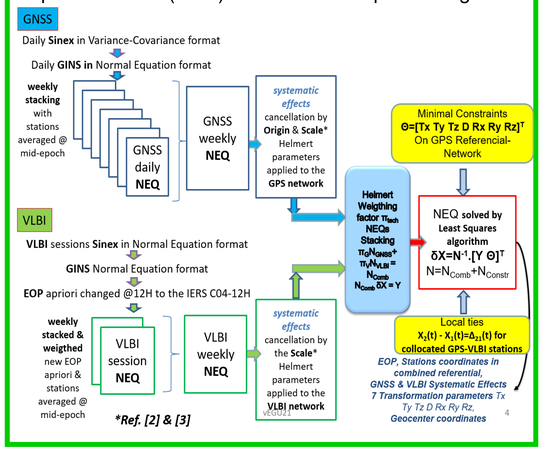
Summary

The Earth orientation parameters (EOP), the regular products of IERS Earth Orientation Centre, are computed at daily bases by combination of EOP solutions using different astro-geodetic techniques. At SYRTE we have developed a strategy of combination of the Global Navigation Satellite Systems (GNSS) and Very Long Baseline Interferometry (VLBI) techniques **at normal equation level** (Ref[1]) using Dynamo software maintained by CNES/GRGS (France). This approach allows to produce the EOP at midday at the daily bases, which contains polar coordinates (x,y) and their rates (x_r,y_r), universal time UT1 and its rate LOD, and corrections from IAU2000A/2006 precession-nutation model (dX,dY), and in the same run station coordinates constituting the terrestrial frame (TRF). The recorded EOP solutions obtained from GNSS and VLBI combination at weekly bases is recently maintained by SYRTE (series **OPAC** (Pole,LOD) and **OPAC2** (UT1,dX,dY) on https://hpiers.obspm.fr/eop-pc/)

Strategy

Consistent weekly combination is applied to the **IGS** and **IVS** solutions provided in Sinex format, over the time period 2000-2021. **IGS** Daily Sinex and **IVS** session Sinex XA/XE are converted in unconstrained normal equation format (NEQ) for combination processing.



Data

Data from IGS (International GNSS Service) ftp://igs.ign.fr/pub/igs/products

7742 GNSS Sinex – January 2000 to March 2021		
repro2	GPS week **1043** January 2-8 **2000** to GPS week **1831** February 8-14 **2015**	**5513** daily GNSS solution Sinex files with variance-covariance Matrix & constraint Matrix
#week	GPS week **1832** February 15-21 **2015** to GPS week **2150** March 21-27 **2021**	**2233** daily GNSS solution Sinex files with variance-covariance Matrix & constraint Matrix

Data from IVS (International VLBI Service) ftp://ivsopar.obspm.fr/vlbi/ivsproducts/daily_sinex/

2540 VLBI solution Sinex files – January 2000 to March 2021	
All sessions **ivs2017a** & **ivs2020a** series: January 2nd 2000 to March 24th 2021	**3111** VLBI sessions in Sinex with Normal Equation Matrix & Normal Equation Vector

Combined Series GNSS+VLBI

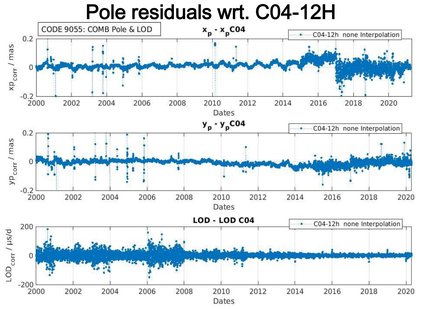
series	Pole & LOD	UT & dX, dY
1108 GPS week from 1043 to 2150 week missing : n°1721	**7742** daily estimate @ midday January 2nd 2000 to March 27th 2021, sampling one day	**3111** daily estimate @ midday January 5th 2000 to March 25th 2021, mean sampling 2 days

Parameters

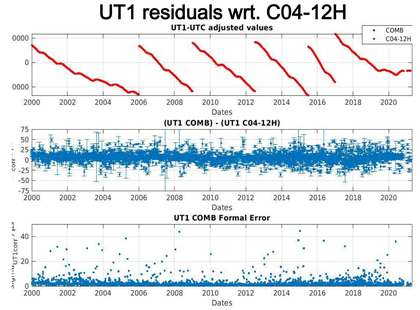
Parameters	GNSS daily		VLBI sessions	
	Sinex parameters	Initial values	Sinex parameters	Initial values
Pole coordinates	**XPO**, **YPO** @12h	IERS EOP 14-C04	**XPO**, **YPO** @~04-06h	IERS EOP 14-C04
Polar motion	**XPOR**, **YPOR** @12h	IERS EOP 14-C04	**XPOR**, **YPOR** @~04-06h	0.0
Delta time UT1-UTC	-		**UT** @~04-06h	IERS EOP 14-C04
Length of Day LOD	**LOD** @12h	IERS EOP 14-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 March 2021	**STAX**, **STAY**, **STAZ** ~**5 stations /session** @~04-06h	ITRF14
Geo-centre	**XGC**, **YGC**, **ZGC** @12h	Set to 0.0	-	

EOP Combined Solution Analyze 2000-2021

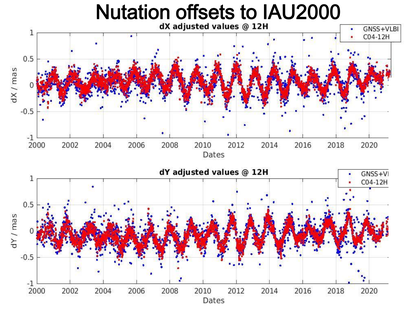
Pole residuals wrt. C04-12H



UT1 residuals wrt. C04-12H



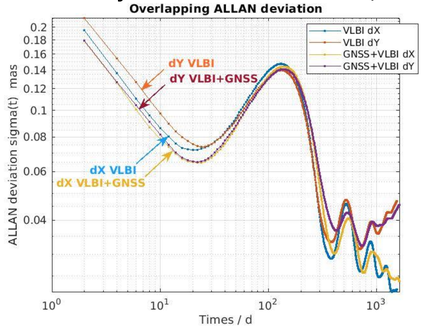
Nutation offsets to IAU2000



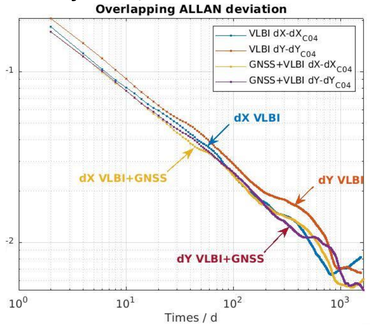
WRMS of differences wrt. C04-12H (µas)	xp	yp	UT1 µs	LOD µs	dX	dY
GNSS	**24.6**	**19.8**	-	**18.8**	-	-
IGS	20.0	15.4	-	18.9	-	-
VLBI	**144.6**	**145.8**	**7.9**	**16.6**	**54.3**	**55.4**
IVS	124.7	137.7	30.4	26.8	41.8	40.7
COMB	**27.0**	**18.6**	**8.9**	**17.1**	**60.0**	**60.8**

Median of errors (µas)	xp	yp	UT1 µs	LOD µs	dX	dY
GNSS	**2.7**	**2.7**		**0.8**		
IGS	3.5	3.6		0.8		
VLBI	**34.8**	**34.6**	**1.4**	**2.7**	**17.8**	**18.2**
IVS					17.2	17.4
C04	30.0	29.0	7.9	13.3	47.0	45.0
COMB	**2.8**	**2.8**	**1.4**	**0.7**	**15.7**	**16.0**

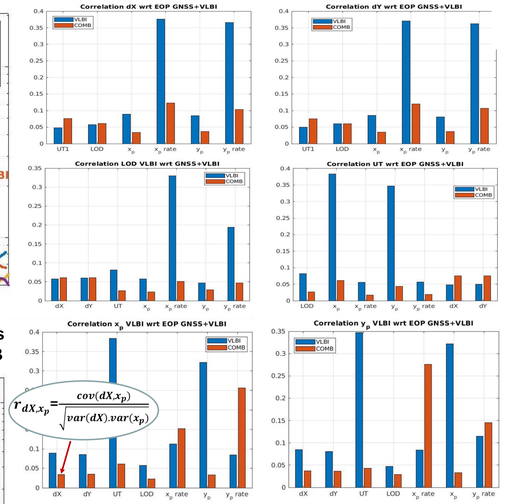
Stability on the nutation offset dX, dY



Stability of dX, dY residuals wrt. C04-12H

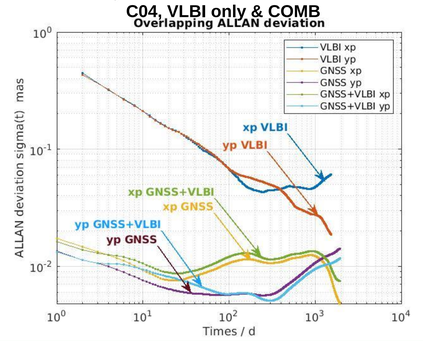


EOP Correlations for VLBI & COMB

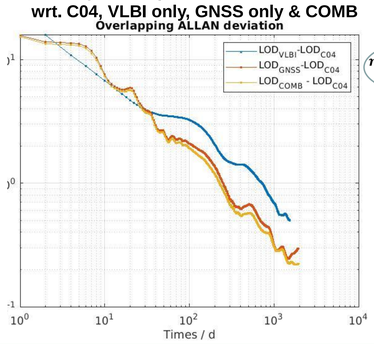


$$r_{dX,x_p} = \frac{cov(dX,x_p)}{\sqrt{var(dX).var(x_p)}}$$

Stability on the UT1-UTC corrections wrt. C04, VLBI only & COMB

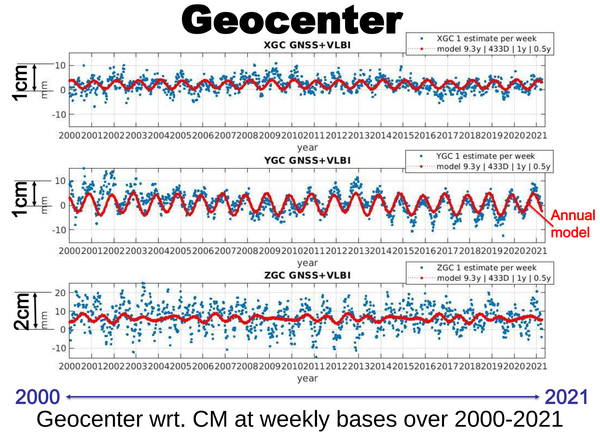


Stability on the polar motion corrections wrt. C04, VLBI only, GNSS only & COMB



Covariance matrices reveal that correlations between dX, dY, LOD, UT1 parameters with other EOP are improved by the combination and neatly with the pole rates. For xp, yp correlations are also improved but increased for pole rates.

Geocenter



2000 ⟵ Geocenter wrt. CM at weekly bases over 2000-2021 ⟶ 2021

Conclusion & Prospects

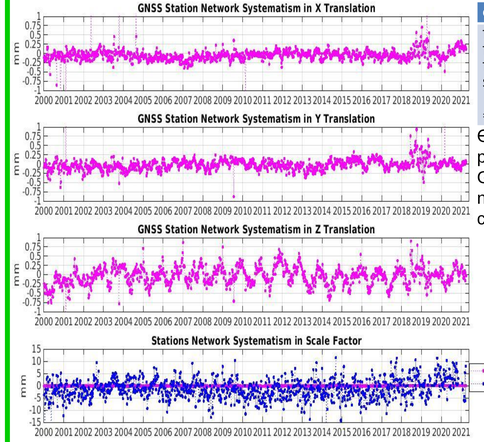
We dispose of an operational chain now available to produce GNSS and VLBI combination from IERS technique centres at the normal equation level, based on the CNES/GRGS DYNAMO software. This combination shows a good consistency with ITRF14 and becomes useful to control the C04 reference series of polar motion in consistency with the official terrestrial frame. Correlations between EOP estimated by VLBI only and by combination are slightly reduced. Comparable accuracy are observed on the EOP wrt. C04-12H. GPS & VLBI Station coordinates are simultaneously estimated in consistency with the ITRF. The long duration series of the geocenter could be useful to analyse the geophysical effect involved. Next steps of our project consist to assess the quality of the celestial reference frame, and to add the Laser technique (SLR, LLR).

Combined TRF

Systematic effects w.r.t ITRF : Helmert parameters

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

2000 ⟵ Estimated systematic effects at weekly bases ⟶ 2021



Θ_{SYST} vector constraint

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_vlbi}	Sc_{syst_gps}
		Sc_{syst_vlbi}
= 0±10cm	= 0±10cm	= 0±10cm

Θ_{SYST} : Translation & Scale parameters applied on GPS and VLBI core networks with loose constraints of 10cm.

These systematics effects on GNSS and VLBI networks are estimated at weekly bases in combination processing and show their amplitude at sub-millimeter level. The station positions in the common referential resulting are free of these effects.

Θ_{SYST} Mean & RMS over 2000-2021, for Translation & Scale for GNSS & VLBI networks

	Tx mm	Ty mm	Tz mm	Scale mm
GNSS	-0.051 ±0.201	-0.019 ±0.196	-0.045 ±0.271	-0.585 ±0.516
VLBI				-1.298 ±4.084

Minimal constraints: 7 GNSS Transformation Parameters w.r.t. ITRF

Station positions at weekly bases

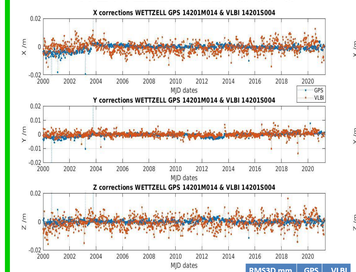
$X_{Tech} = X_{Tech\_new} + B.\Theta$ with $\Theta=[Tx\ Ty\ Tz\ D\ Rx\ Ry\ Rz]^T$

Minimal Constraints 'Θ' on GPS core stations 2000-2021: Mean & RMS

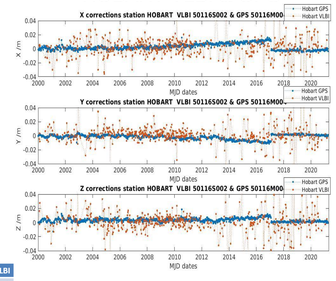
	Tx mm	Ty mm	Tz mm	Scale mm	Rx mm	Ry mm	Rz mm
GNSS	-0.013 ±0.037	-0.007 ±0.037	0.002 ±0.038	-0.669 ±0.539	-0.053 ±0.243	0.096 ±0.190	0.020 ±0.200

Station coordinates estimation

WETTZELL VLBI & GPS

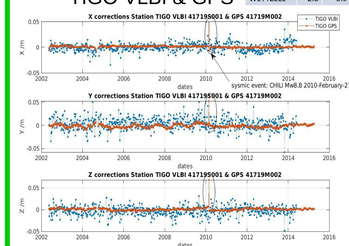


HOBART VLBI & GPS

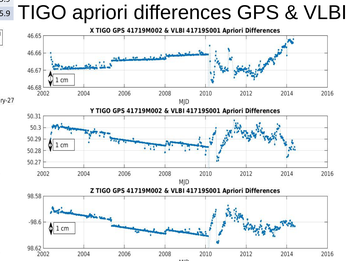


RMS3D mm	GPS	VLBI
HOBART	6.1	24.1
TIGO	12.5	5.9
WETTZELL	2.8	5.9

TIGO VLBI & GPS



TIGO apriori differences GPS & VLBI



References: **[1]** Gambis D., Richard J-Y., Bizouard C., "Why combining at the Observation Level?" REFAG 2010, IAG series 138, Reference Frames for Applications in Geosciences, 111-117

[2] Sahin M., Variance component estimation applied to satellite laser ranging, Bul Geo Springer-Verlag 1992

[3] Arnaud Pollet IGN/LAREG thesis « COMBINAISON DE TECHNIQUES DE GÉODÉSIE SPATIALE », January 2011