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

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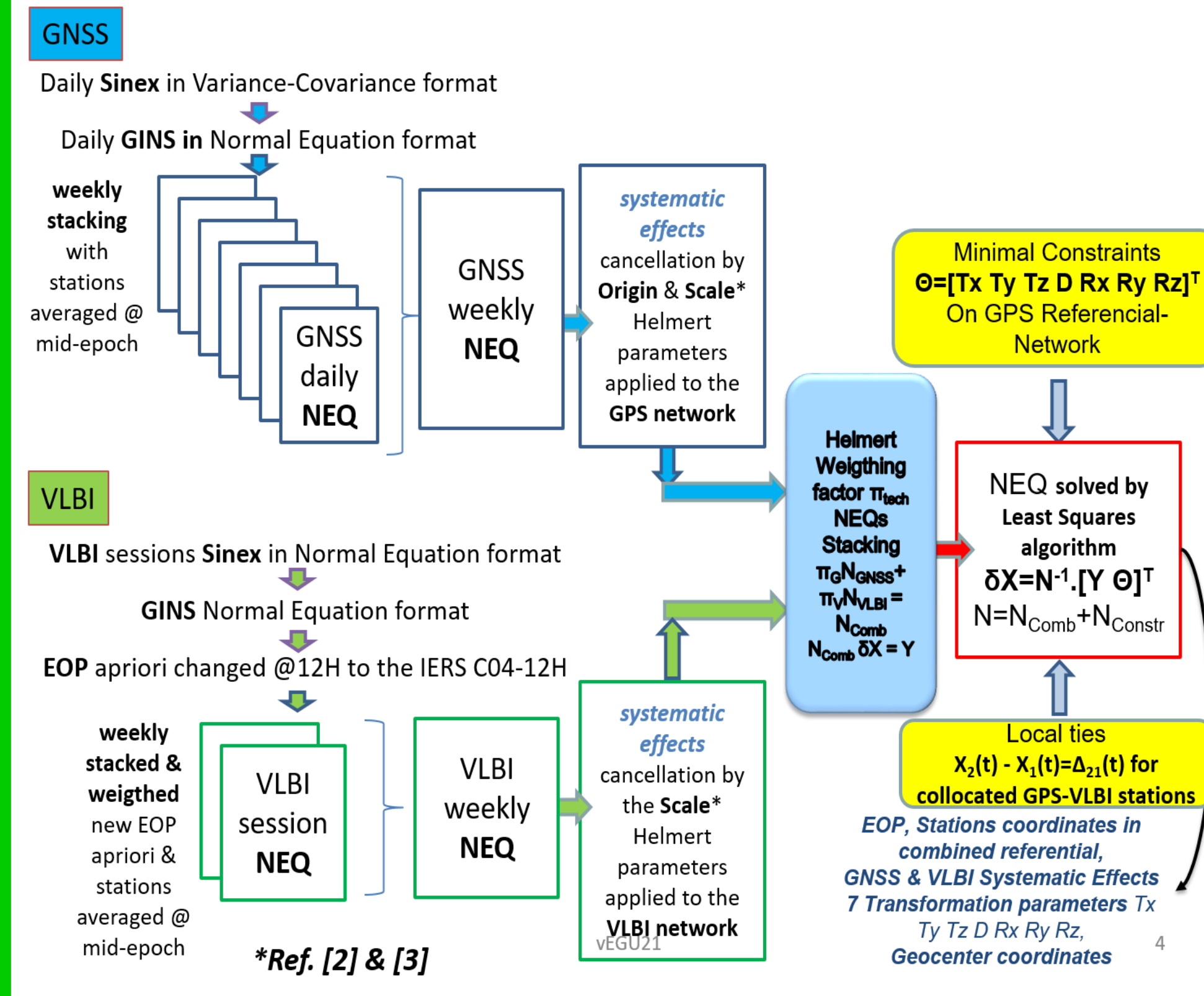
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Summary

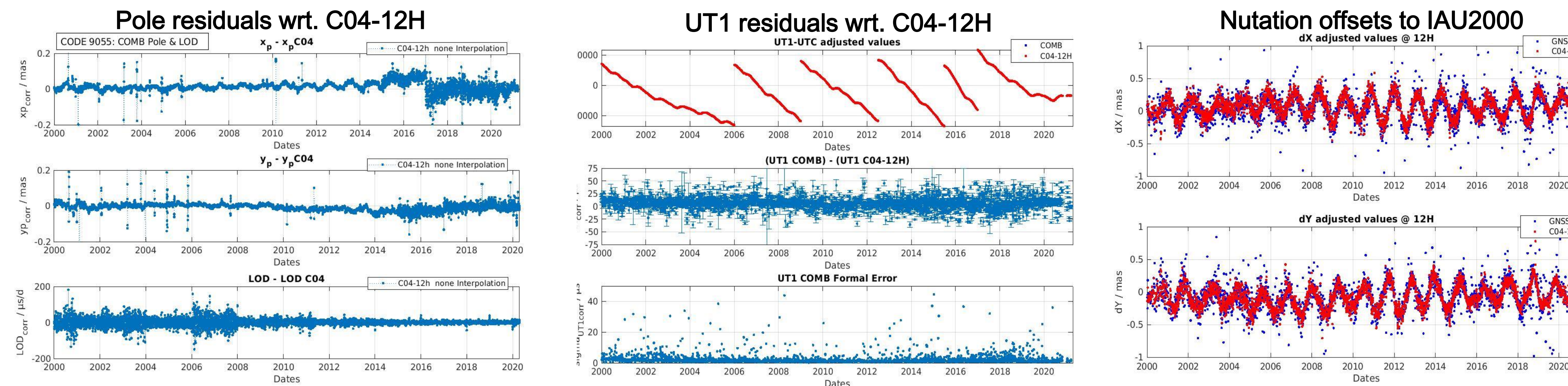
The Earth orientation parameters (EOP), the regular products of IERS Earth Orientation Centre, are computed at daily bases by combination of EOP solutions using different astro-geodetic techniques. At SYRTE we have developed a strategy of combination of the Global Navigation Satellite Systems (GNSS) 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 (xp,yp), 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

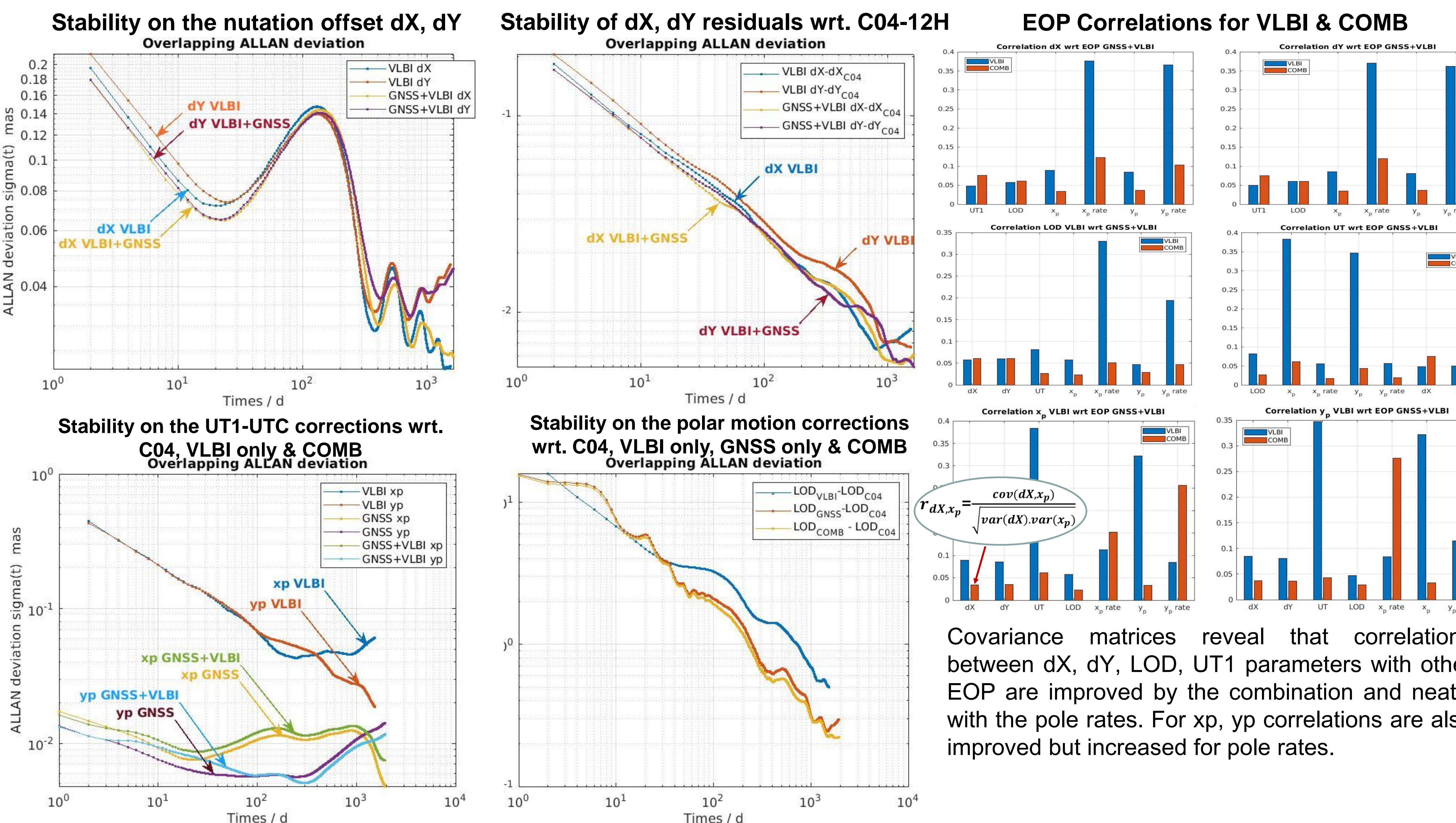
Consistent weekly combination is applied to the IGS and IVS solutions provided in Sinex format, over the time period 2000-2021. IGS Daily Sinex and IVS session Sinex XA/XE are converted in unconstrained normal equation format (NEQ) for combination processing.



EOP Combined Solution Analyze 2000-2021



WRMS of differences wrt. C04-12H (µas)		xp	yp	UT1 µs	LOD µs	dX	dY	Median of errors (µas)
		GNSS	VLBI	COMB				
	GNSS	24.6	19.8	-	18.8	-	-	2.7
	IGS	20.0	15.4	-	18.9	-	-	3.5
	VLBI	144.6	145.8	7.9	16.6	54.3	55.4	34.8
	IVS	124.7	137.7	30.4	26.8	41.8	40.7	3.6
	COMB	27.0	18.6	8.9	17.1	60.0	60.8	2.8

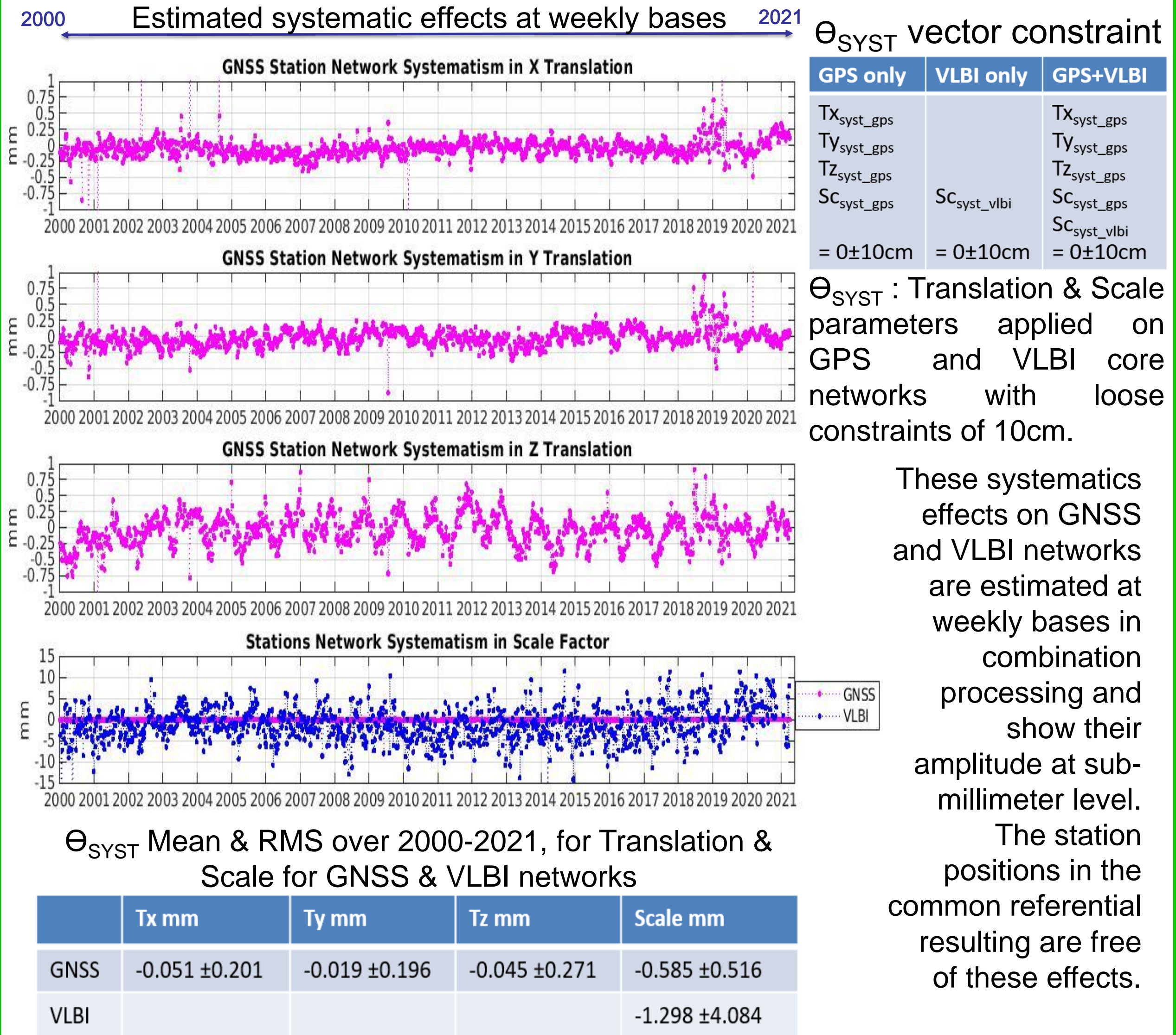


$$r_{dX, xp} = \frac{cov(dX, xp)}{\sqrt{var(dX) \cdot var(xp)}}$$

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.

Combined TRF

Systematic effects w.r.t ITRF : Helmert parameters
Station positions with constraints: $X_{Tech_initial} = X_{Tech_new} + B \cdot \Theta_{syst}$

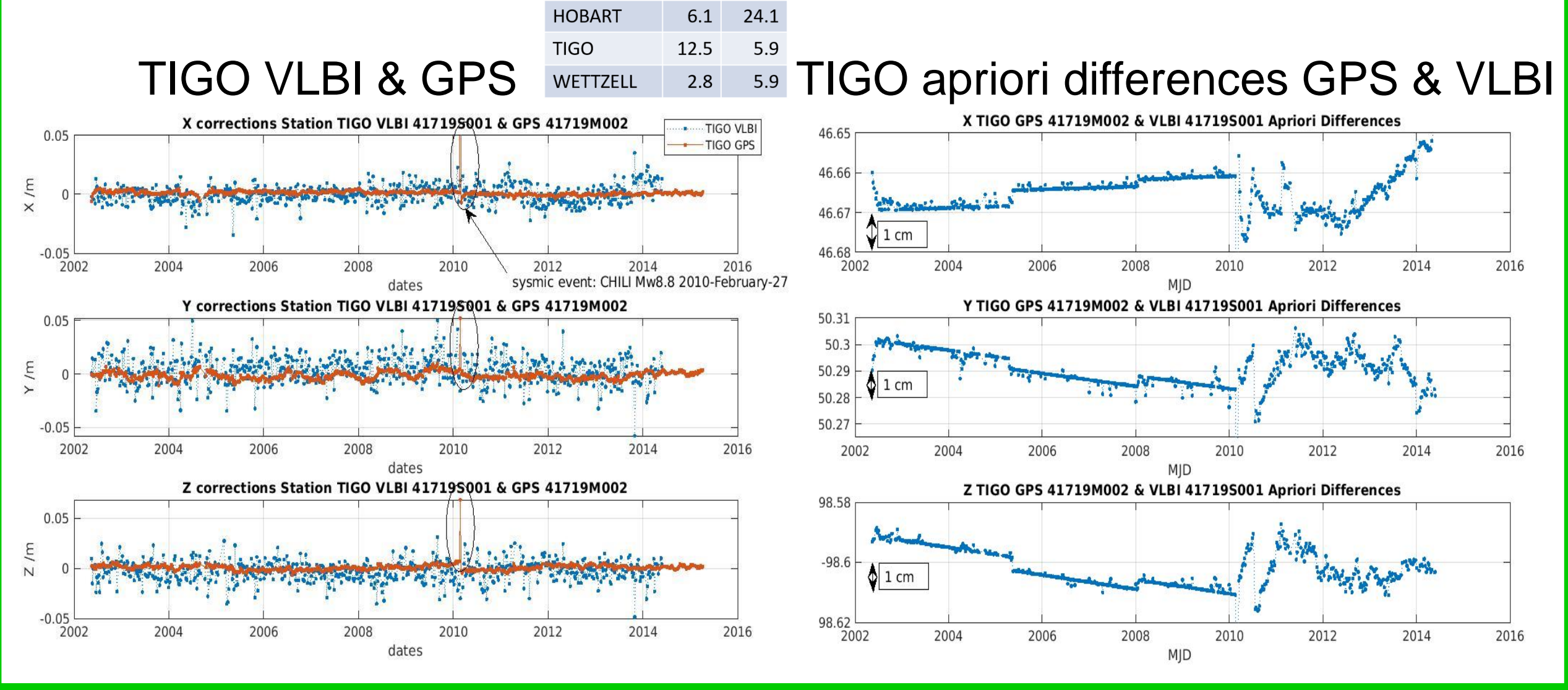
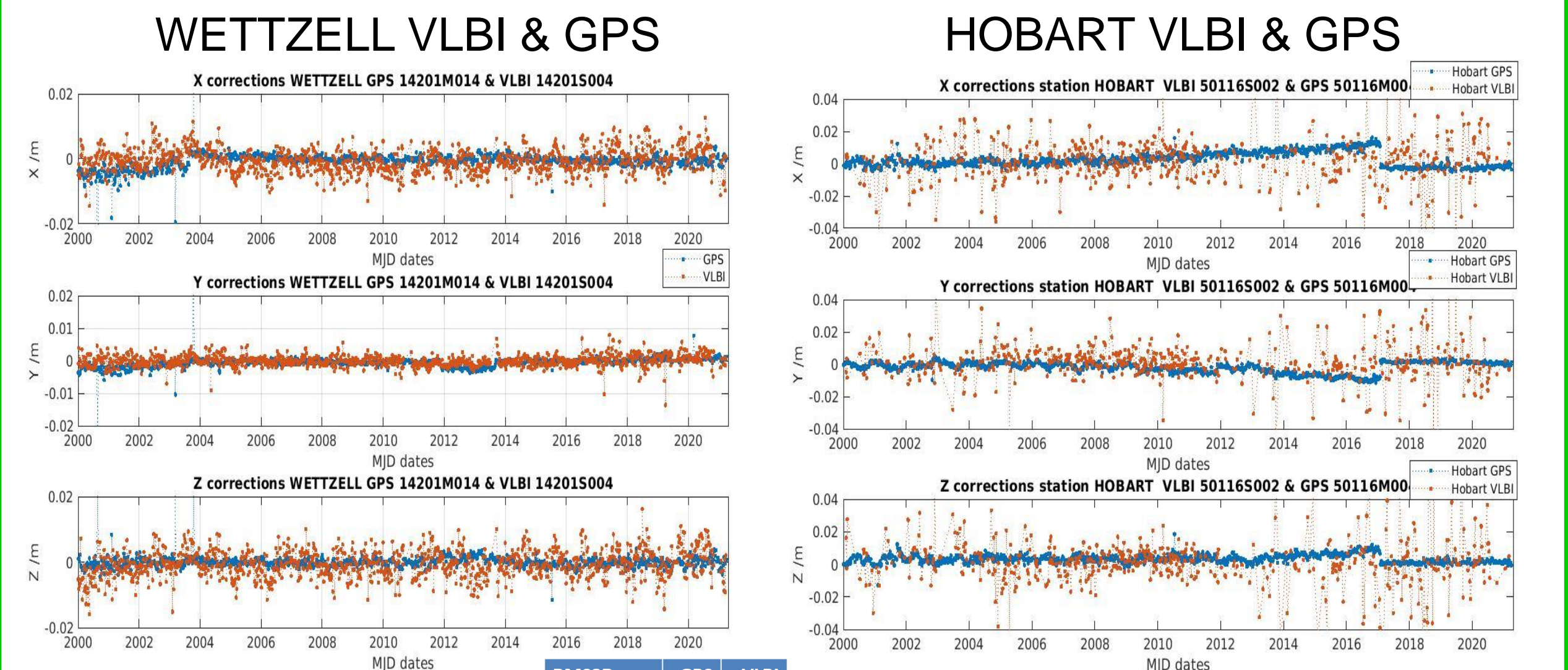


Minimal constraints: 7 GNSS Transformation Parameters w.r.t. ITRF

Station positions at weekly bases
 $X_{Tech} = X_{Tech_new} + B \cdot \Theta$ 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



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

Data

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

repro2	GNSS 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	GNSS 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

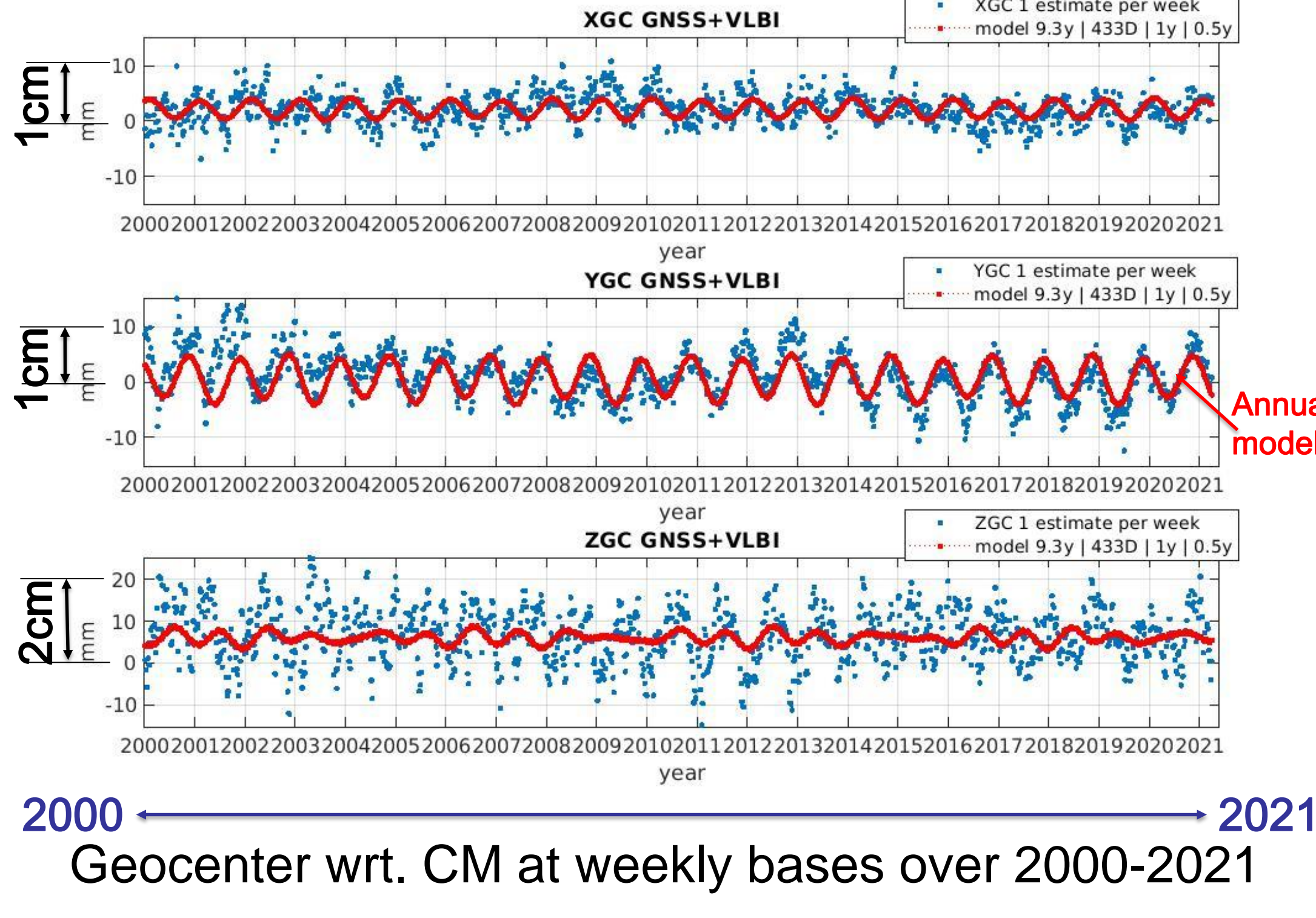
Data from IVS (International VLBI Service) http://ivsopar.obspm.fr/vlbi/ivsproducts/daily_sinex/

series	Pole & LOD	UT & dX, dY
1108 GPS week from 1043 to 2150 week missing : n°1721	7742 daily estimate @ midday January 2 nd 2000 to March 27 th 2021, sampling one day	3111 daily estimate @ midday January 5 th 2000 to March 25 th 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	UT @*04-06h	0.0
Delta time UT1-UTC	LOD @12h	IERS EOP 14-C04	LOD @*04-06h	IERS EOP 14-C04
Length of Day LOD				
Nutation offset dX, dY IAU2000/2006 model				
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		

Geocenter



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).