NEW EARTH ORIENTATION PARAMETERS BY COMBINATION OF GNSS AND VLBI

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ABSTRACT. We present the combined processing of GNSS and VLBI normal equations produced at the IERS technique centers. The DYNAMO sofware allows to obtain the combined solution for EOP and station coordinates, along with the corresponding intra-technique VLBI and GNSS solutions. The combined GNSS/VLBI solution seems to be more robust than the intratechnique ones. First the EOP are better decorrelated, second sub-monthly nutation and UT1 have a better stability.

INTRODUCTION. At SYRTE, thanks to the IERS COL Working Group (Polet, 2011), we have developed a combined treatment of normal equations produced respectively by the International GNSS Service (IGS) and International VLBI Service (IVS). This approach allows to determine the EOP on a daily basis, pole coordinates (x,y) and associated rates (xr,yr), Universal Time UT1 and length of day offset LOD, and nutation offset with respect to IAU2000A/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). The process of such a combination is presented and results over the period 2000-2019 are analyzed.

1. STRATEGY

1.1 Pre-processing Before the combination, we apply a pre-processing to the GNSS and VLBI Sinex files - containing the normal equations - according to the top of Figure **??**. This step rebuilds the GNSS and VLBI normal equations using IGS/IVS combination solution Sinex files. The normal equations are stacked on a weekly basis. For estimating the systematic effects of the GNSS/VLBI networks with respect to the International Terrestrial Reference Frame (ITRF), we introduced the *systematic Helmert parameters*: translation and scale factor for GNSS networks, scale factor for VLBI (Polet, 2011).

1.2 Processing

The weekly normal equations generated by the afore-mentioned pre-processing with the systematics parameters (magenta square for GNSS et green square for VLBI in Figure **??**) are stacked using the Helmert weighting algorithm (Sahin, 1992). The common parameters are the pole coordinates, pole rate and LOD. Moreover minimal constraints are applied on GNSS network: No Net Translation (NNT), Scale (Sc), No Net Rotation (NNR). For VLBI network we apply local ties for colocalized GNSS stations. A least square inversion is performed on the system composed of the normal equations and of the constrain relations on a weekly bases to determine the EOP, the GNSS and VLBI station positions, the Helmert parameters, and the geocenter coordinates. We also perform the mono-technique inversion (without local ties for VLBI) for evaluating the performances of the GNSS/VLBI combination.

Bottom part of the Figure **??** synthesize this combination strategy

2. DATA AND PARAMETERS

The interval of twenty years covers the period from January 2000 until July 2019. The daily GNSS Sinex in the *covariance matrix format* are uploaded from `ftp://igs.ign.fr` (5513 daily

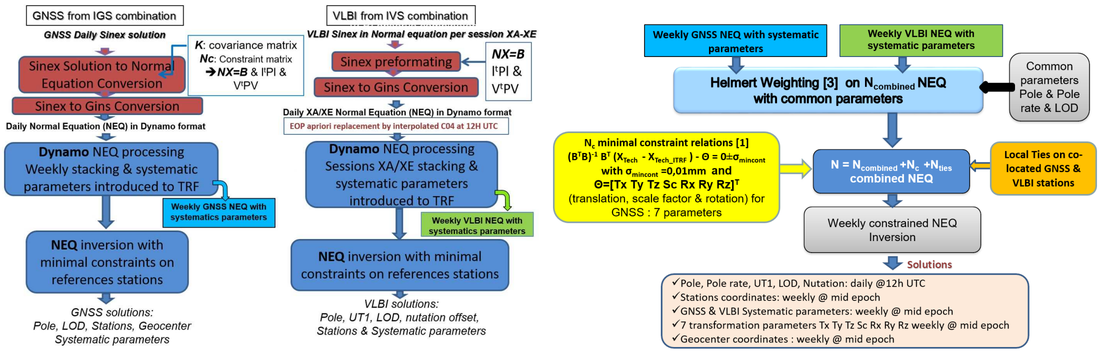

Figure 1: GNSS and VLBI intra and inter technique processing

files). The VLBI Sinex in *normal matrix format* are uploaded from `ftp://cddis.gsfc.nasa.gov` (2585 sessions XA and XE).

In Figure **??** we report the common Earth Orientation Parameters that can be estimated from VLBI and GNSS observations: pole coordinates (XPO, YPO), polar rates (XPOR,YPOR), length of day offset LOD.

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
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	-	

Figure 2: GNSS and VLBI common EOP parameters and their a-priori in the GNSS/VLBI Sinex files

3. EOP SOLUTIONS

All EOP are determined at midday. The EOP intra-technique solutions (GNSS and VLBI) and corresponding GNSS/VLBI combined solution (COMB) are compared with the IERS EOP series 14C04 interpolated at midday. Table **??** reports the mean and standard deviations of the paired differences with respect to the 14C04 time series over the period 2000-2019. The nutation

Table 1: EOP Solution Comparison wrt C04

	xp (μas)	yp (μas)	lod (μs)	dX (μas)	dY (μas)	UT1 (μs)
VLBI	-133±126	-15±117	2±18	-3±45	-1±68	8.6±19.3
GNSS	-10±32	16±35	0±20	-	-	-
COMB	-13±32	18±35	0±17	1±60	-6±73	8.9±19.3

offsets (with respecto to the IAU 2000 model) of the GNSS/VLBI combined solution are plotted in Figure **??** along with the reference series C04 for the period 2000-2019. COMB shows larger discrepancies than the intra-technique VLBI solution. It could be due to the limitation of VLBI observations to the XA and XE VLBI sessions. The stability of the nutation offsets for GNSS,

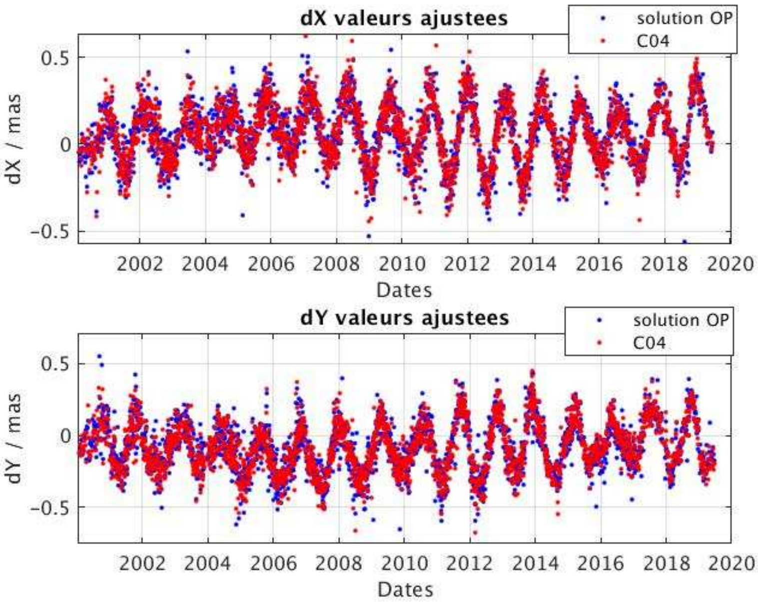

Figure 3: Nutation offsets with respect to IAU2000 model: combined GNSS/VLBI solution (COMB) and reference solution (C04)

VLBI and GNSS/VLBI combination is investigated in light of the overlapping Allan deviation. This one is plotted in the left part of Figure **??**. It shows that the combination nutation corrections have a stronger stability at sub-monthly periods, but this one is downgraded beyond 3 years. For the residuals UT1 wrt C04, the right part of Figure **??** shows that the combination significantly reinforces the stability in regard to the pure VLBI solution. This could results from a stabilization of the VLBI network through local ties. The EOP correlations between EOP are extracted from

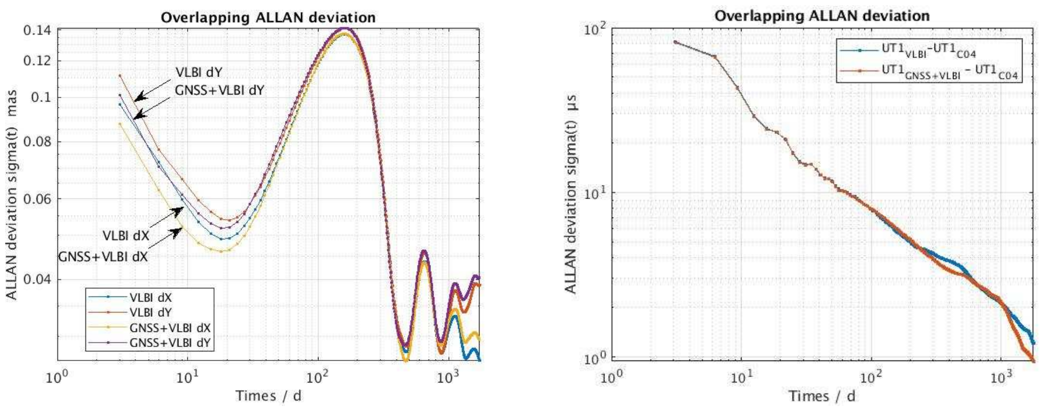

Figure 4: Nutation offsets stability for the VLBI and combined solution (left plot) / UT1 wrt C04 residuals for VLBI and combined solution (right plot)

the covariance matrix of the solutions. For all parameters a significant diminution of correlation is noticed for COMB compared to the VLBI solution. The Figure **??** shows that the correlations of nutation offsets dX and dY with the others EOP decrease for COMB EOP solution.

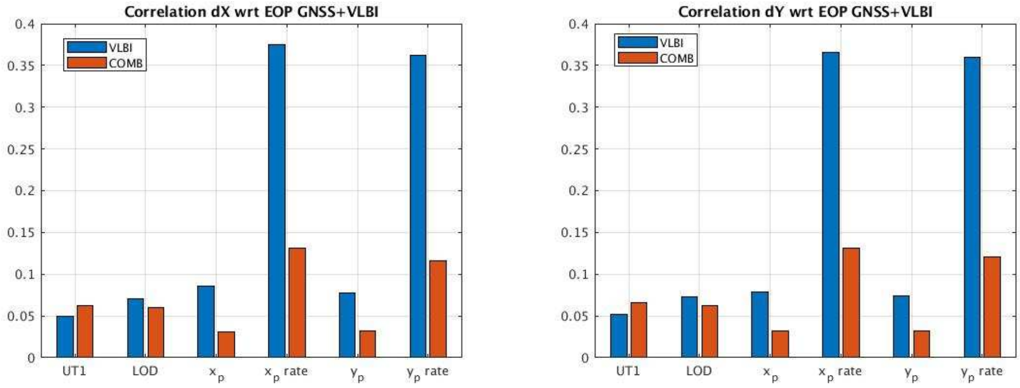

Figure 5: Correlations between nutation offsets dX and dY with the others EOP, VLBI only and combined solution (COMB)

4. STATION SOLUTIONS

The station coordinates are estimated simultaneously with EOP. As an example, the X, Y, Z displacements of the colocated GPS and VLBI stations of TIGO and WESTFORD are shown in Figure **??** and the RMS of the displacement for 6 stations are reported in Table **??**. The positions are estimated at midday on Wednesday for the period 2000-2019.

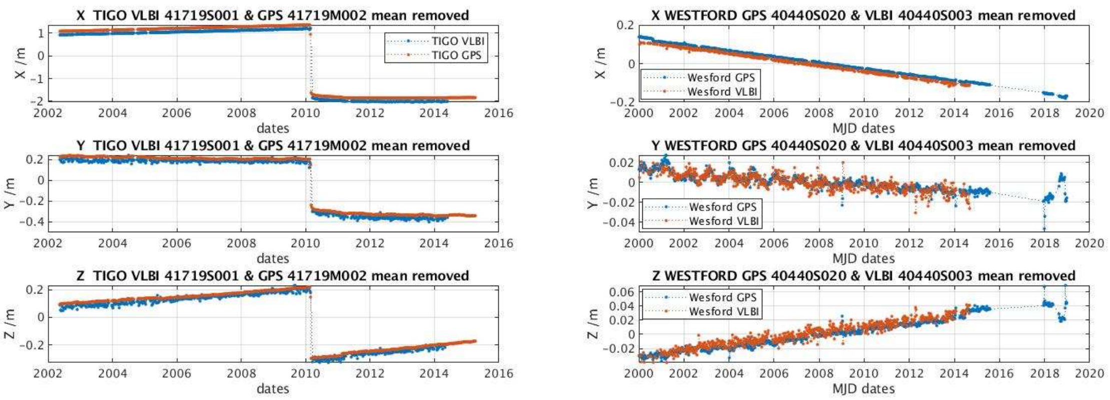

Figure 6: X, Y, Z displacements of GPS/VLBI colocated stations of TIGO and Westford

Table 2: RMS (mm) of the 3D displacment for 6 VLBI/GPS colocated stations, period 2000-2019

Station	TSUKUBA	FAIRBANKS	TIGO	WETTZELL	WESTFORD	HOBART
VLBI	11.4	7.5	18.2	6.0	8.0	18.0
GPS	-	-	4.7	2.8	2.9	6.0

Over the period 2000-2019, the systematic effects of GNSS and VLBI station network are estimated on Wednesday. The Figure **??** shows weekly estimation of these parameters for the GPS (magenta) and VLBI (blue) station networks respectively.

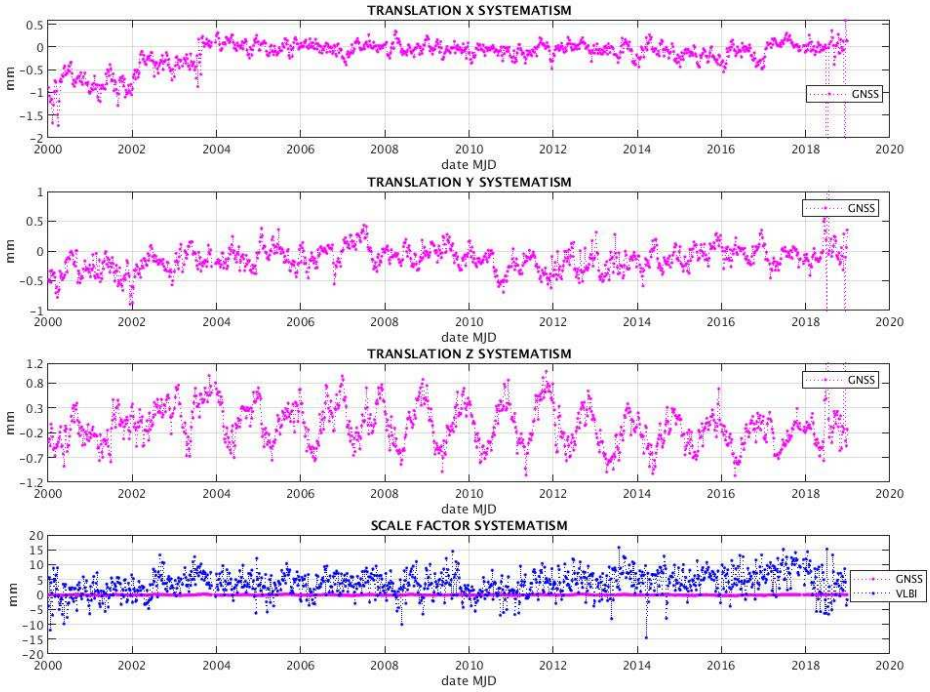

Figure 7: Systematic effects for GPS and VLBI station networks

The Table 3 brings together the means and rates of these weekly systematic parameters, translation and scale for GPS station network and scale factor for VLBI station network.

Table 3: Systematic effects for GPS and VLBI station networks, means and rates wrt ITRF for the period 2000-2019

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

5. CONCLUSION

At SYRTE, an operational chain, based on the CNES/GRGS DYNAMO software, allows to combine GNSS and VLBI observations at the normal equation level (SINEX files from IERS technique centers). The results show a good consistency with ITRF14 and could be useful to control the consistency of the IERS C04 series with respect to the ITRF. Nutation offsets stability is improved for sub-monthly periods and UT1 stability is slightly better than C04 beyond a few year. Correlations between EOP are significantly reduced, suggesting that such a combined treatment is more robust. Obtained EOP are consistency with the ITRF, and freed of network effects. For densifying the EOP, all VLBI sessions have to be included. In the near future, this process will be extended to the SLR technique, and the quasars coordinates (CRF) will be simultaneously estimated with the

EOP and station coordinates.

6. REFERENCES

Pollet, A., 2011, "Combinaison des techniques de geodesie spatiale", Thèse de doctorat en Astronomie et astrophysique.

Ray, J., Kouba, J., Altamimi, Z., 2005, "Is there utility in rigorous combination of VLBI and GPS Earth orientation parameters", J. Geodesy 79, pp. 505–511, doi: 10.1007/s00190-005-0007.

Sahin, M., 1992, "Variance composent estimation applied to satellite laser ranging", Bulletin Geodesique Springer-Verlag 1992, pp. 284–295.