GEOD-ESIS

A GNSS+Sentinel6A joint processing

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Motivation (1)

Our group (CNES/CLS):

- Holds IDS (DORIS), IGS (GNSS) and ILRS (SLR) Analysis Centers.
- Uses a single POD software (GINS from CNES).
- Contributes to POD of altimetric satellites.
- Is involved in the Copernicus Precise Orbit Determination WG.

In view of the forthcoming ESA GENESIS mission with the four space geodetic techniques onboard, we initiated a multi-technique project with the processing of the Sentinel-6A mission which is equipped with three (DORIS, GNSS, SLR) of the four techniques to:

1) Be prepared to the processing of GENESIS observations.
2) Assess the benefits of a multi-technique space mission (space tie) to TRF realizations.

Motivation (2)

Example of the ITRF contributions:
Measurements from the **four** techniques **are processed separately.**

I. Compute individual technique solutions (DORIS / SLR / GNSS / VLBI)

II. Combine results (ties ensured by local ties, co-velocity constraints and common EOPs)

Example of LEO "altimetric POD" like SENTINEL-6A:
Measurements from **three** techniques **are used separately.**

I. Compute GNSS products (orbits & clocks)

II. Compute LEO orbit from GNSS and/or DORIS observations (**GNSS orbits & clocks fixed, DORIS station positions fixed**)

III. SLR generally used as external validation (**station positions fixed**, e.g., to SLRF2020)

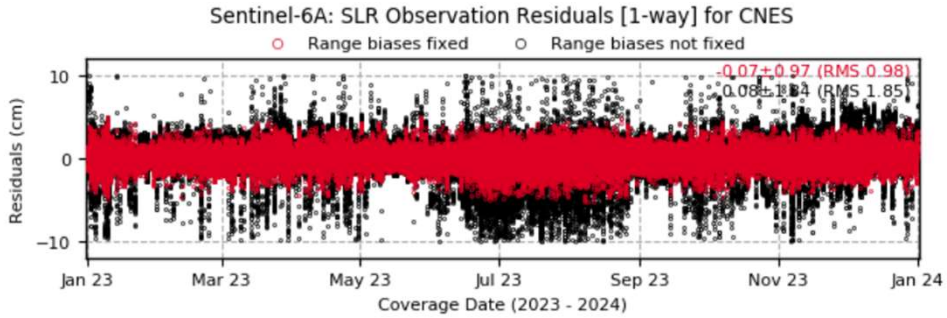


Figure 3-14: SLR observation residuals [1-way; cm] obtained for CNES orbit solution in 2023 (Sentinel-6A)

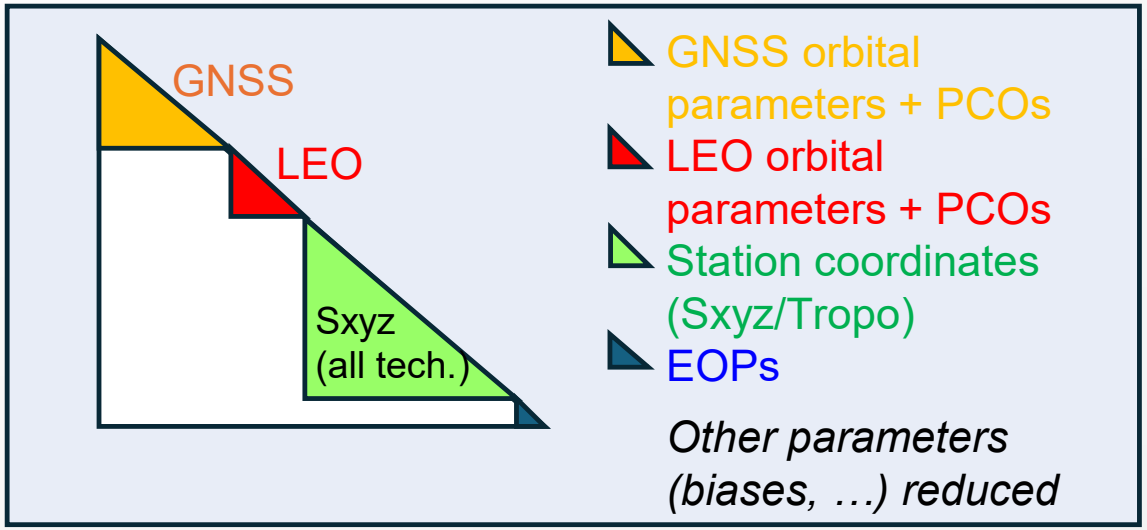
GMV-CPOD-SLR-0008_v1.0_Sentinel-3_and-6_SLR_Yearly_Report-2023, GMV, Sentinel-3 and -6 SLR Yearly Report (nasa.gov) (accessed June 2024)

NEQ Representation: joint processing of LEO obs.

Process ground GNSS observations + LEO (GNSS, DORIS & SLR) observations all together
(or sum individual NEQs while keeping common parameters)

Need common LEO orbit between all techniques:
- either single multi-technique processing,
- or technique-specific processings with common models, orbital arc length, etc…

→ same software needed



Advantages:
- Real « space tie »
- Correlations between station positions of different techniques (through LEO observations)

Drawback:
- **Huge processing**: 60 s sampling needed for ground + LEO GNSS observations in order to correctly track the LEO orbit

Like in:
Haines et al. (2015),
Männel et al., (2017, 2020) (geocenter),
Pollet et al. (2023) (GRASP simulations)
…

Possible Experiments

	Experiment	No LEO / classical	Sentinel-6A	Other LEO(s)
1 technique	GNSS (ground-only)	IGS contribution		
	SLR (Lageos-only)	ILRS contribution		
	DORIS (classical)		IDS contribution	
	GNSS + LEO(s)		**See next slides**	To be done
	SLR + LEO(s)		In progress	
2 techniques	SLR + GNSS + LEO(s)		In progress	To be done
	DORIS + GNSS + LEO(s)		In progress	
3 techniques	GNSS+SLR+DORIS+LEO(s)		Just started	

Questions:

- **Impact of LEO data on individual technique solutions?**
  (orbits, EOPs, geocenter, scale, station positions)
- **Reference frame in multi-technique solutions?**
  (Is it common to all techniques, i.e., do space ties work?)

Joint processing of Sentinel-6A observations

	GNSS	DORIS	SLR
Software	GINS (GRGS) + DYNAMO (NEQ manipulations)		
Arc length	1-day arcs		
Data span	560 days from March 2022 to October 2023		
Measurements	GPS+GAL: undifferenced iono-free code+phase observations (60 s rate)	All available Doppler observations	All available observations

Parameters/Models				Comments
Measurement biases / Troposphere	- 1 clock offset per epoch per satellite & station - Fixed ambiguities - GAL/GPS ISB - 1 ZWD every 2 hours - Daily tropo gradients	- Frequency offsets - 1 ZWD per pass - Daily tropo gradients	- Range biases	Reduced BEFORE stacking
Sentinel-6A orbit	- Initial position & velocity (6) - Atmospheric drag factors (6) - Once per rev. accelerations (along-track & cross-track)			Re stacking
PCOs	GNSS & Sentinel-6A (G) (a priori: igs20.atx/ CPOD)	Sentinel-6A (D)	Sentinel-6A (L)	NOT red ed
Ground network	~120 stations	~55 stations	~10 stations	NOT

Same Software

Same force models

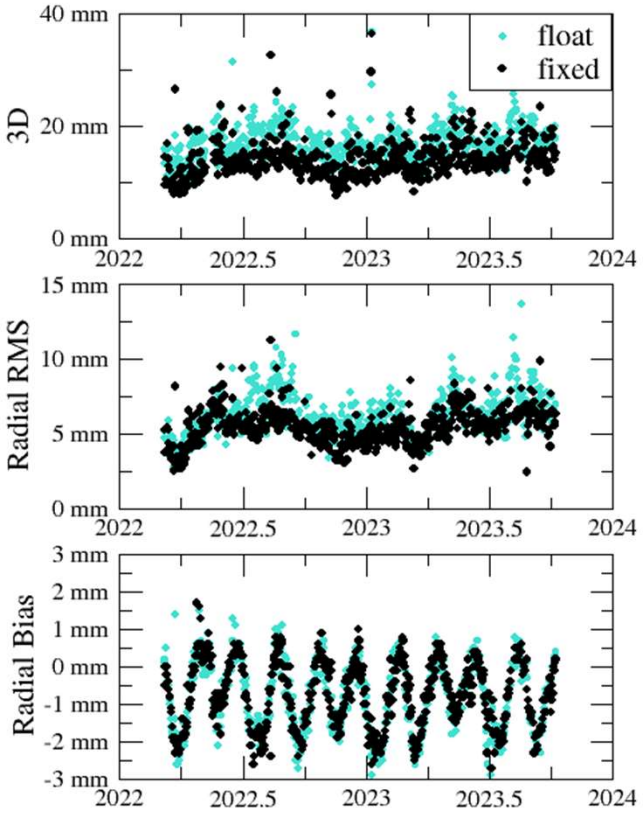
Same displacement models

Artist view of the SENTINEL-6A Satellite from www.esa.int

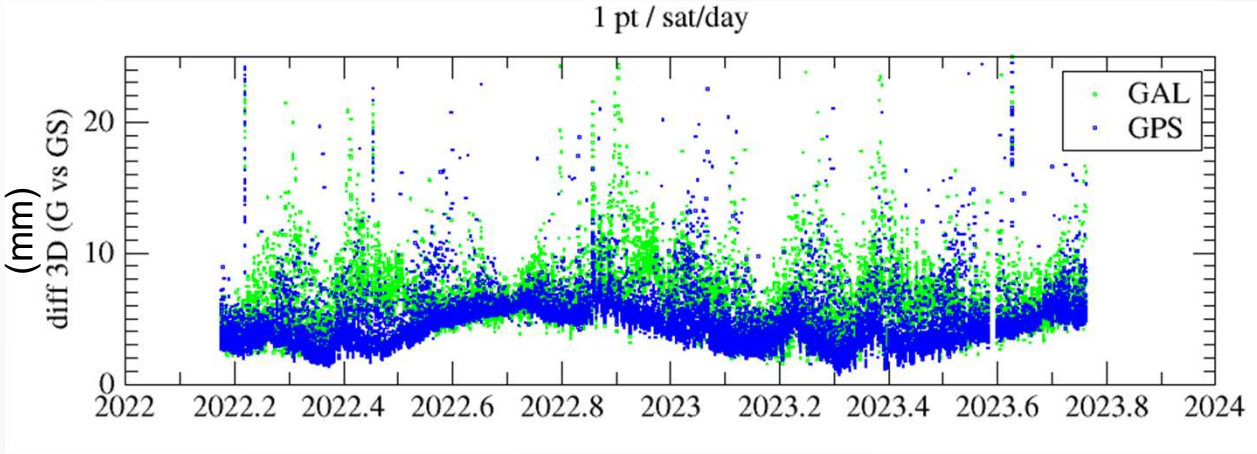
Launch date	2020/11/21
Altitude	1339 km – 1355 km
Orbital period	112.43 minutes
Inclination	66.042°
Eccentricity	0.000098
Tracking systems	DORIS + SLR + GNSS (GPS+GAL)

Orbit quality

Sentinel-6A: *differences wrt CNES POE*



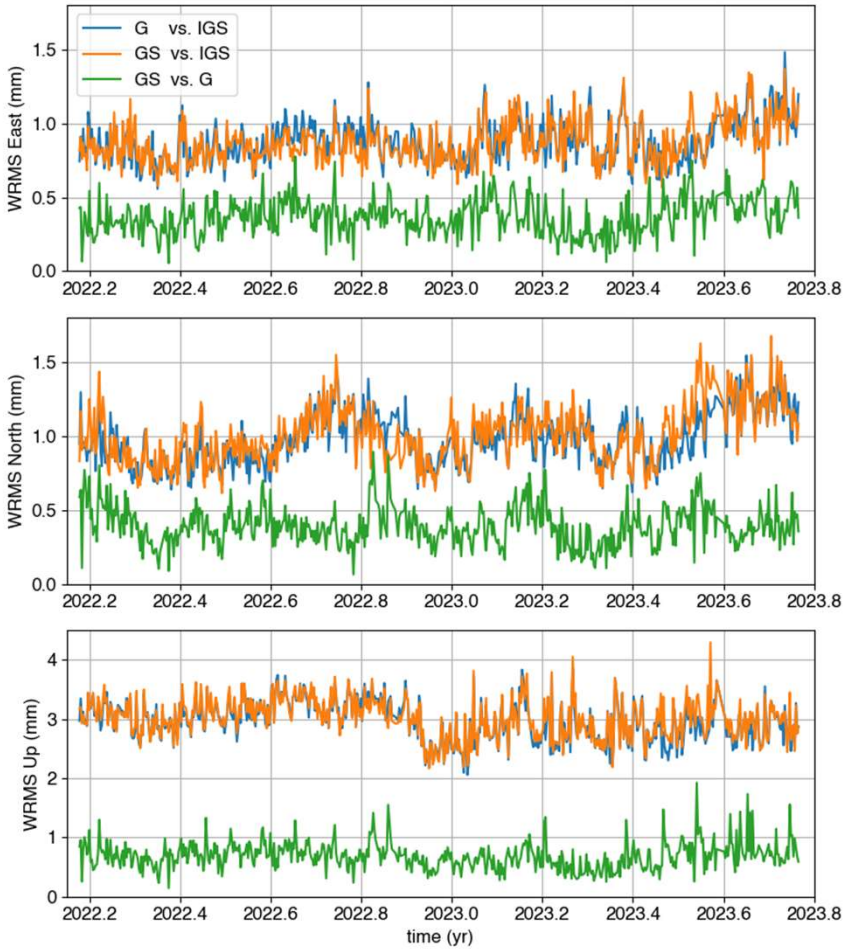
GPS & GAL: *3D orbit differences between G (GNSS-only) and GS (with Sentinel 6A)*



- **Sentinel-6A orbit similar to CPOD QWG(*) solutions**
- **GNSS orbits not significantly affected by Sentinel-6A**

(*) Copernicus Precise Orbit Determination Quality Working group

Station network solutions (All PCOs fixed)

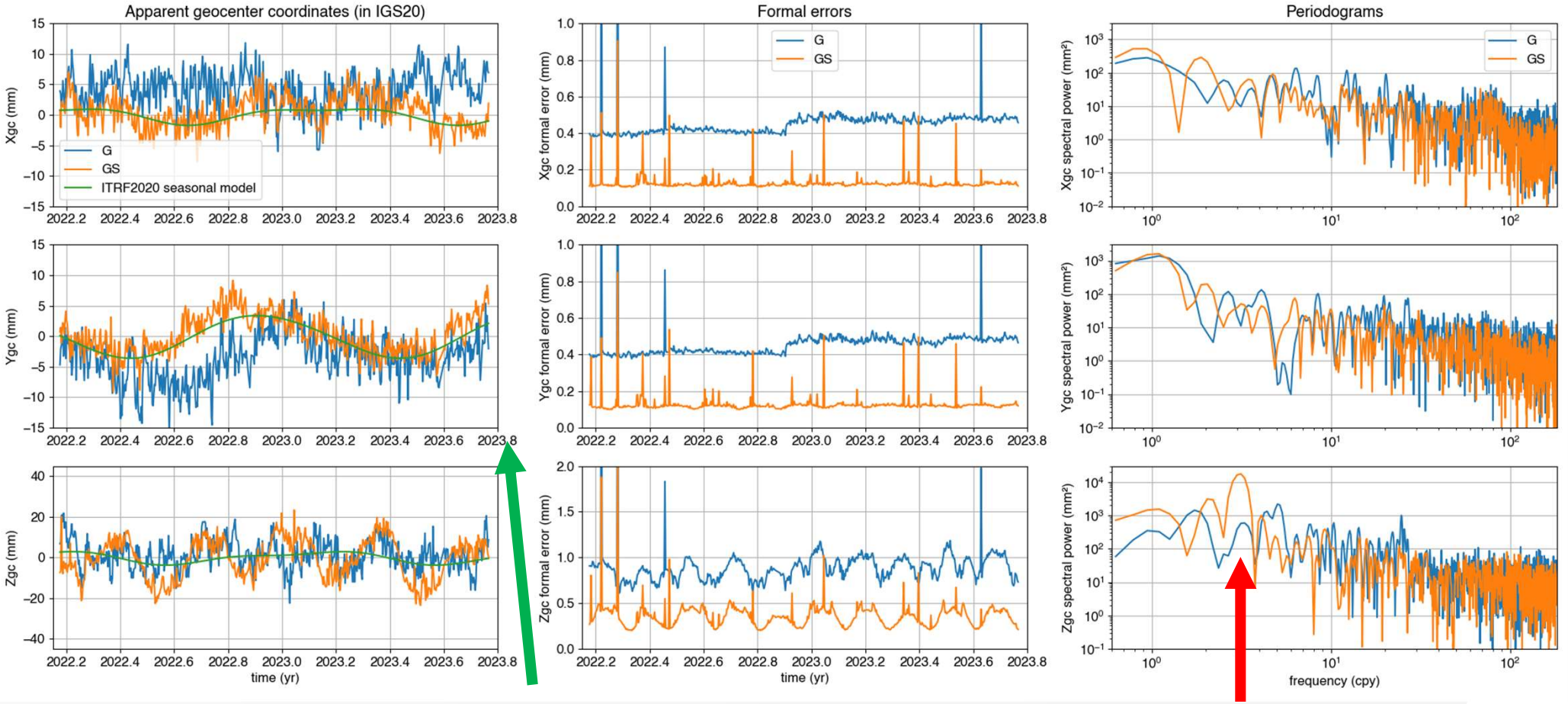


G : GNSS-only
GS: with Sentinel-6A

Inclusion of Sentinel-6A does not significantly affect station network geometry (relatively to IGS solutions)

Geocenter coordinates (all PCOs fixed)

G : GNSS only
GS : with Sentinel-6A



Sentinel-6A improves agreement with ITRF2020 seasonal model in X & Y

Sentinel-6A draconitic period (118 days)

Conclusions

We started to investigate space ties using unique software for all techniques:

- Processing line allows computing daily single & multi-technique solutions
- Daily solutions provided in SINEX format to allow collaboration with other teams

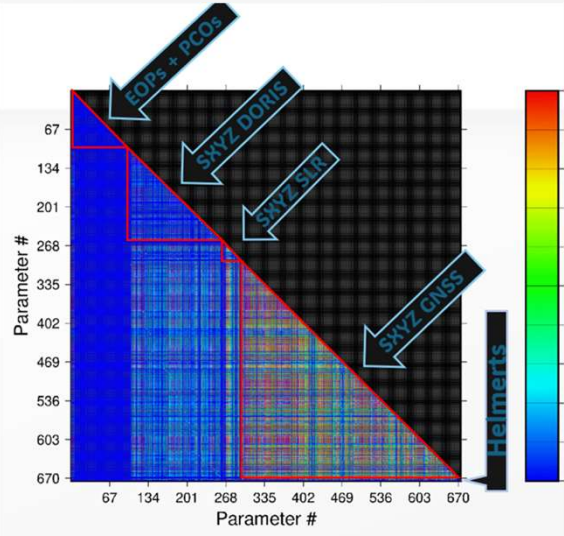
First results show that the inclusion of Sentinel-6A in GNSS solutions:

- Does not significantly affect the geometry of the GNSS ground network
- Reduces geocenter formal errors by factors of ~2 (in Z) / ~4 (in X & Y)
- Improves the agreement with the ITRF2020 seasonal geocenter motion model in X & Y
- But introduces cm-level Sentinel-6A draconitics in the Z component of the geocenter

Future IGS/ITRF products should benefit from the use of *LEO GNSS observations*.

Combined DORIS/GNSS & SLR/GNSS results to be presented at:

- ESA ICSFAG (September 2024)
- ILRS workshop (October 2024)

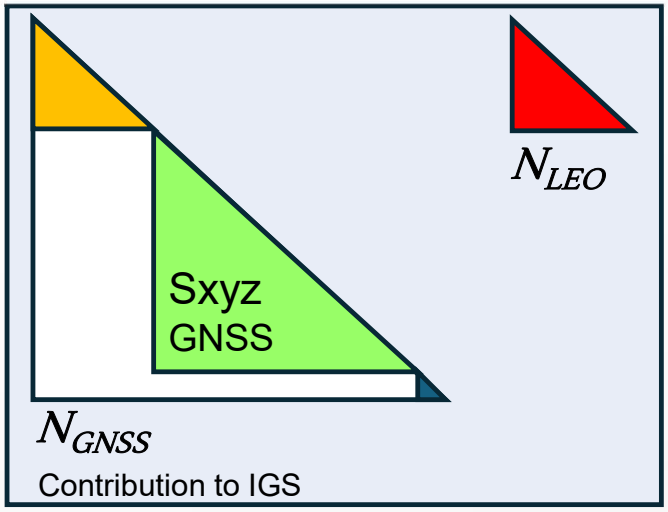


Extra

NEQ representation: LEO observations with fixed GNSS products

Daily batches of Normal Equations : $N_{n,n} \cdot \overrightarrow{dx_n} = \overrightarrow{b_n}$ with a priori $\overrightarrow{x_{0n}}$

(SINEX notations with a total of n parameters)



- GNSS orbital parameters + PCOs
- LEO orbital parameters + PCOs
- Station coordinates (Sxyz/Tropo)
- EOPs

Other parameters reduced

Drawbacks:

- LEO observations (geometrically interesting) do not contribute to GNSS products
- Space tie between GNSS & other techniques (DORIS/SLR) is impossible
- No correlations between station positions of different techniques

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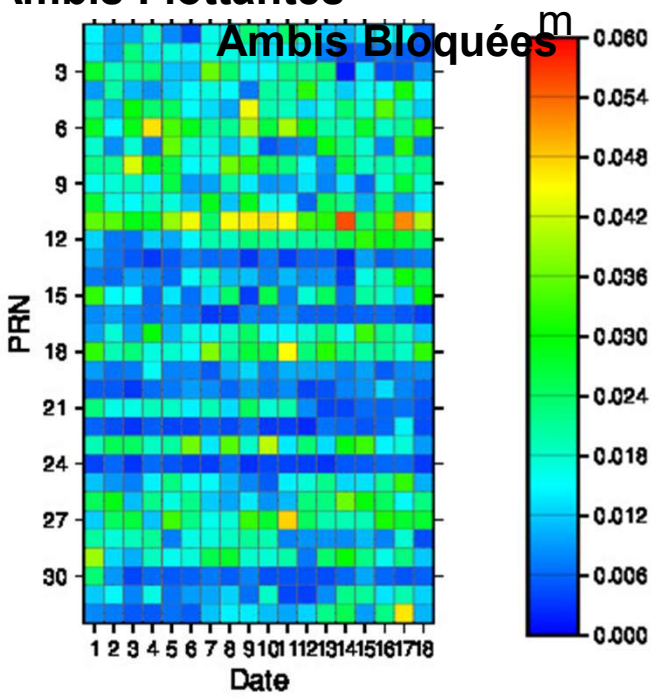
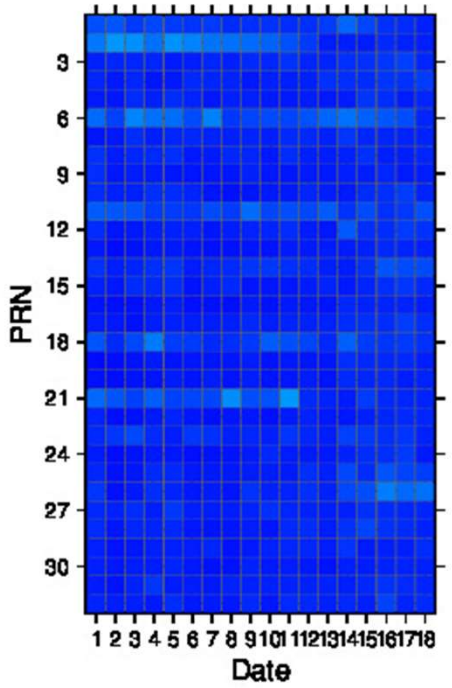
Différences 3D des orbites GNSS avec/sans SE6A

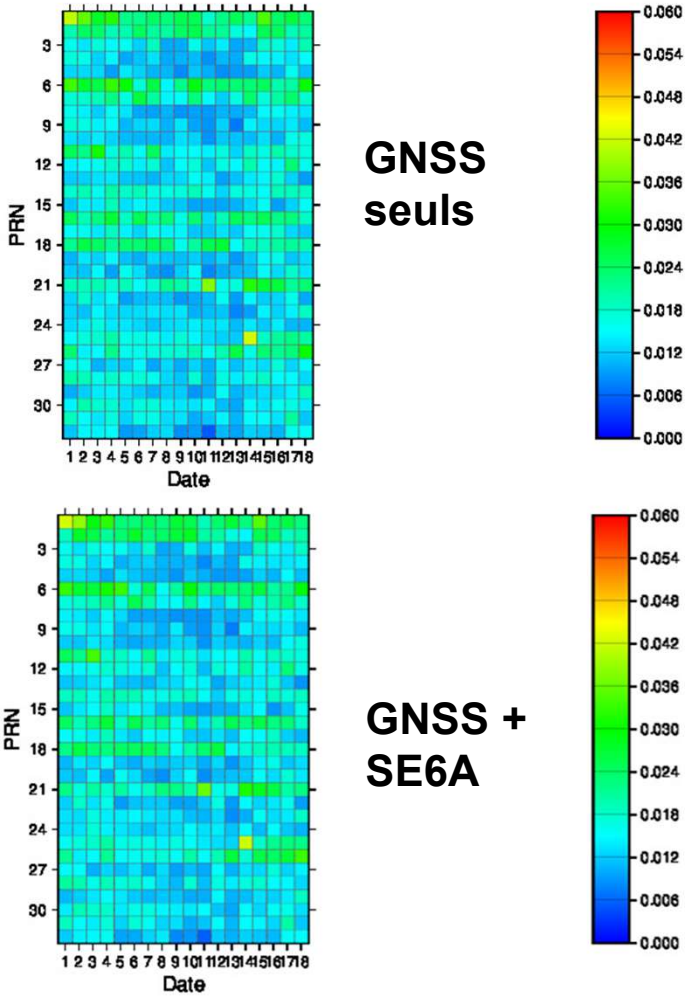
Ambis Flottantes

Ambis Bloquées





Différences 3D GNSS vs IGS



GNSS seuls

GNSS + SE6A

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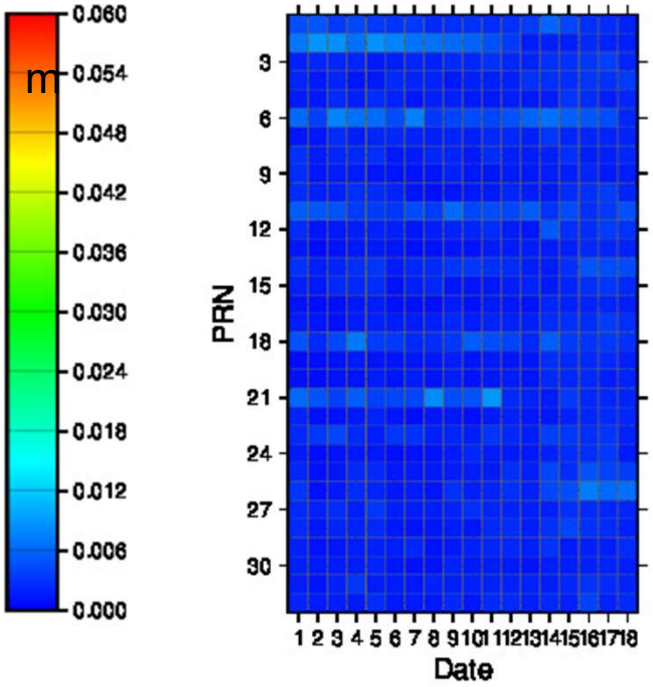
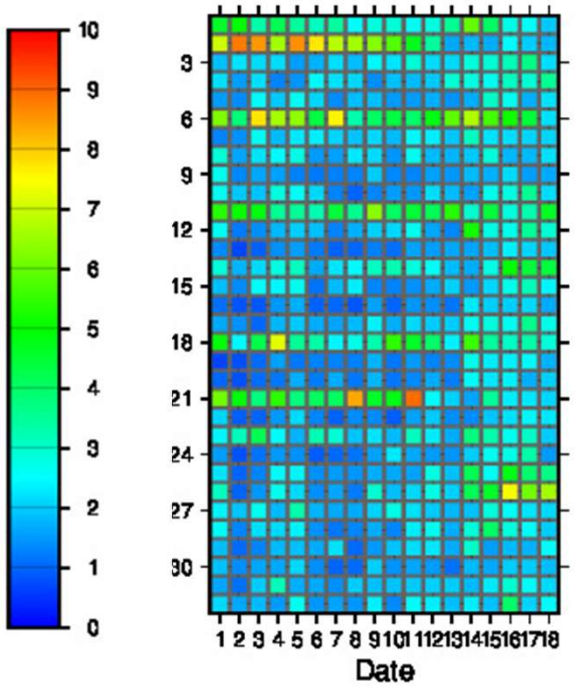
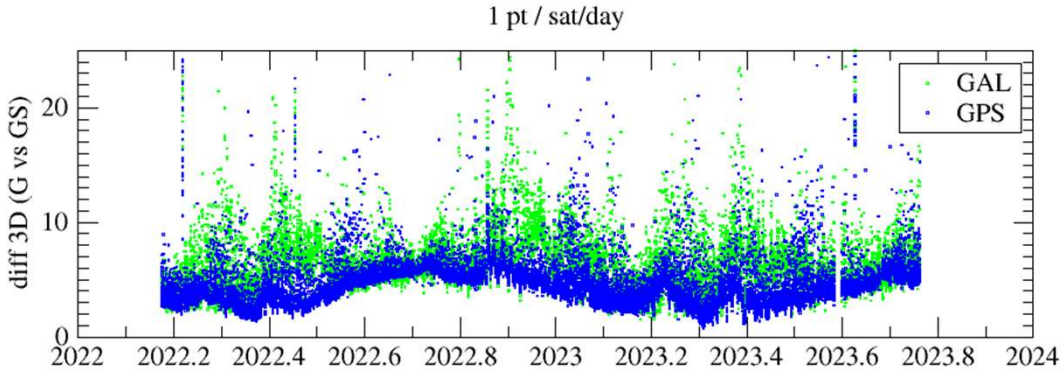


Différences 3D des orbites GNSS avec/sans SE6A (ambis FIX)

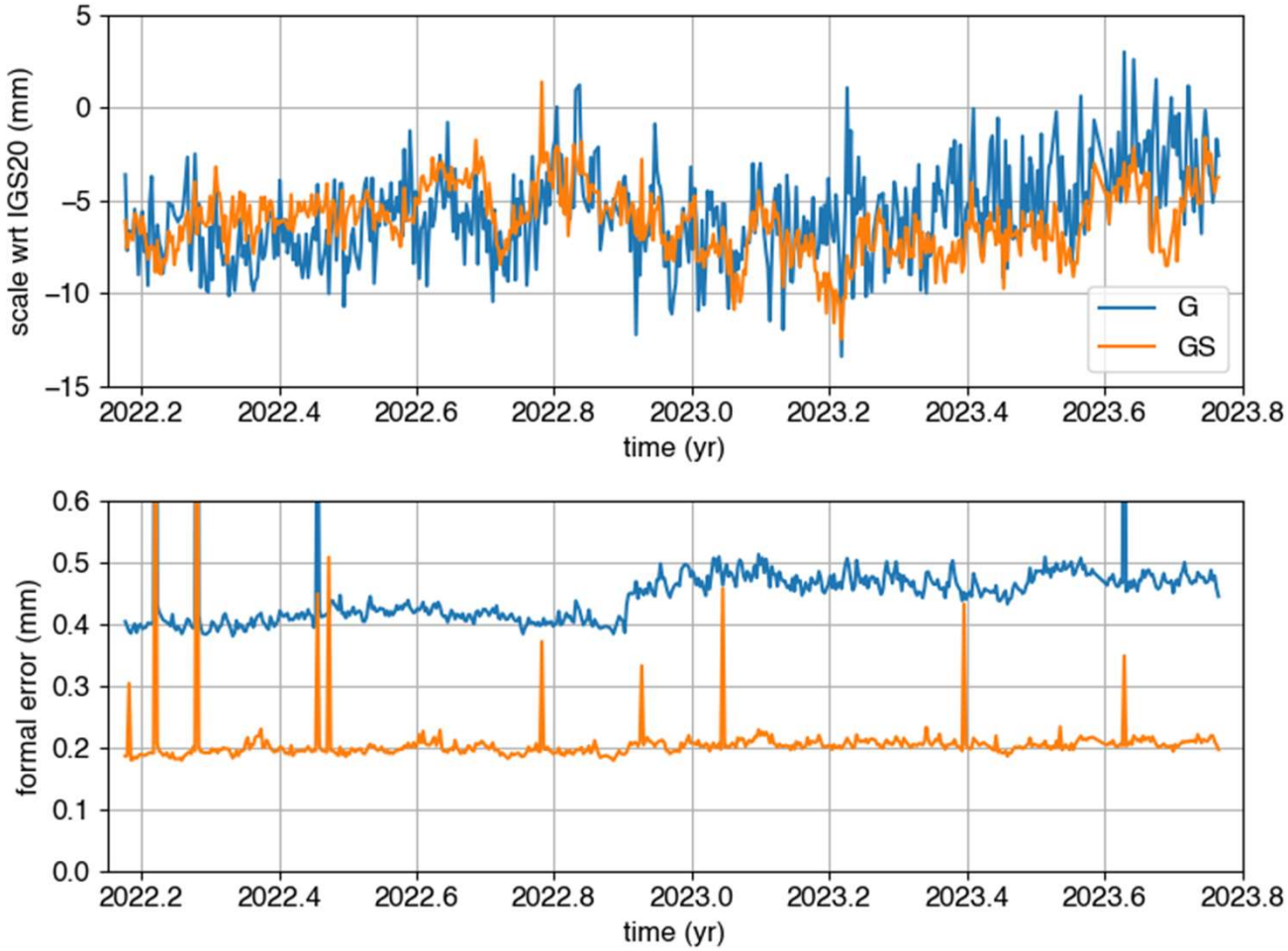
m
m



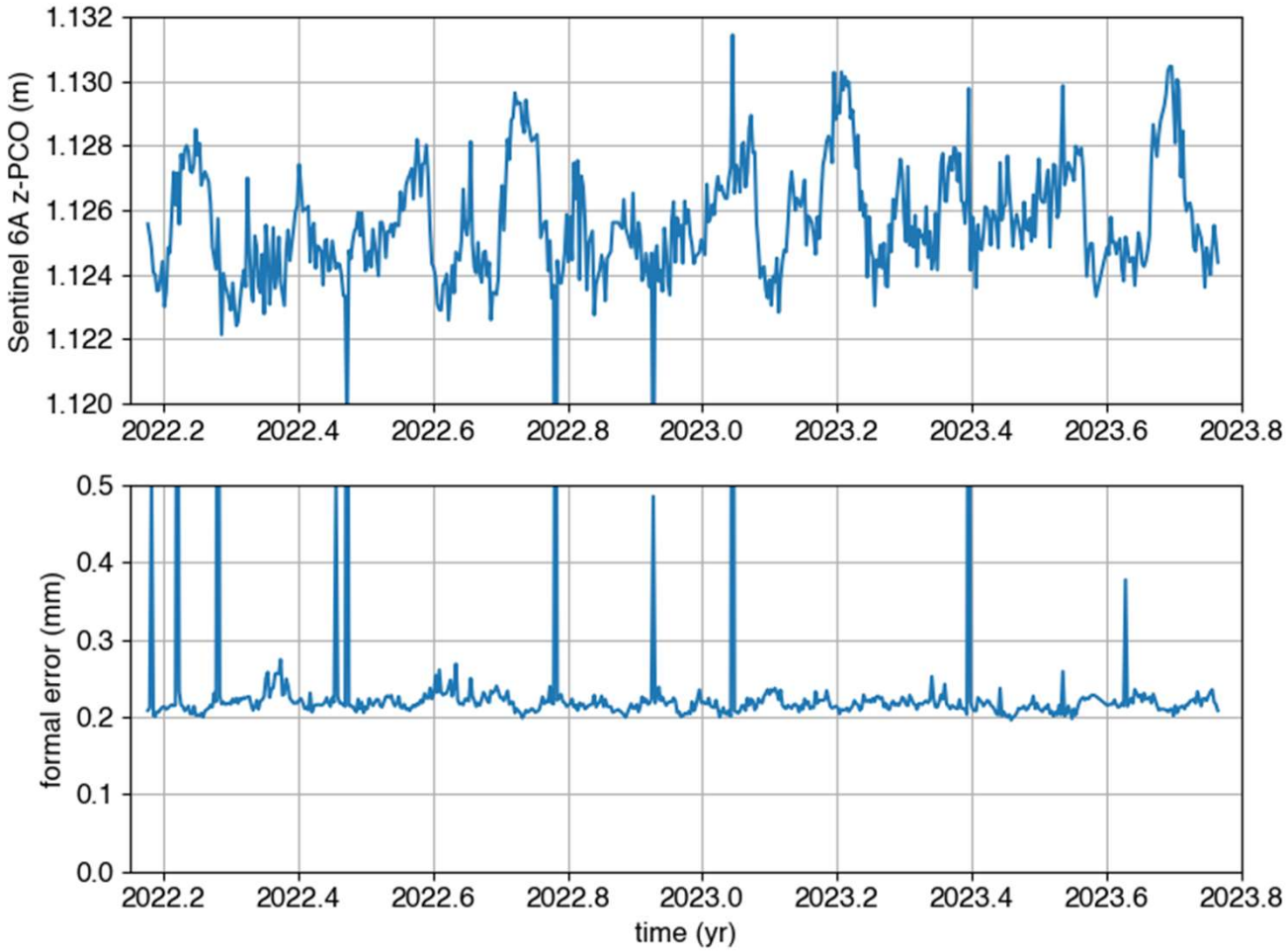


GNSS + SE6A : Z-PCO GNSS free / GNSS PCO of SE6A fixed

Less noise in GNSS network scale (les formal errors) – No real impact on mean scale.



GNSS + SE6A : Z-PCO GNSS fixed / GNSS PCO of SE6A free



+9 mm from starting value = 1.117 m

» from *Montenbruck, O., Hackel, S., Wermuth, M. et al. Sentinel-6A precise orbit determination using a combined GPS/Galileo receiver. J Geod* ***95****, 109 (2021). https://doi.org/10.1007/s00190-021-01563-z*