GRG AC status

Hugues Capdeville (CLS),
Jean-Michel Lemoine (CNES),
Adrien Mezerette (CLS)

CNES/CLS AC (GRG)

IDS AWG
November 28, 2023

Status of CNES/CLS IDS Analysis Center

❑ Status of the routine DORIS data processing

We processed DORIS data until Sept. 2023 (Serie GRG53) and provided to IDS Combination Center.

- we apply SAA mitigation strategy on Sentinel-6A and HY-2C
- we use cnes_grgs_rl05 gravity model
- we use DPOD2020 as apriori

We provided Sentinel3-A&B and Sentinel-6A orbits to CPOD QWG until Sept 2023.

❑ AC studies

Analyses of the CNES/CLS IDS AC solutions (multi-satellite and single satellites solutions)
Impact of increased solar activity on POD

In progress:

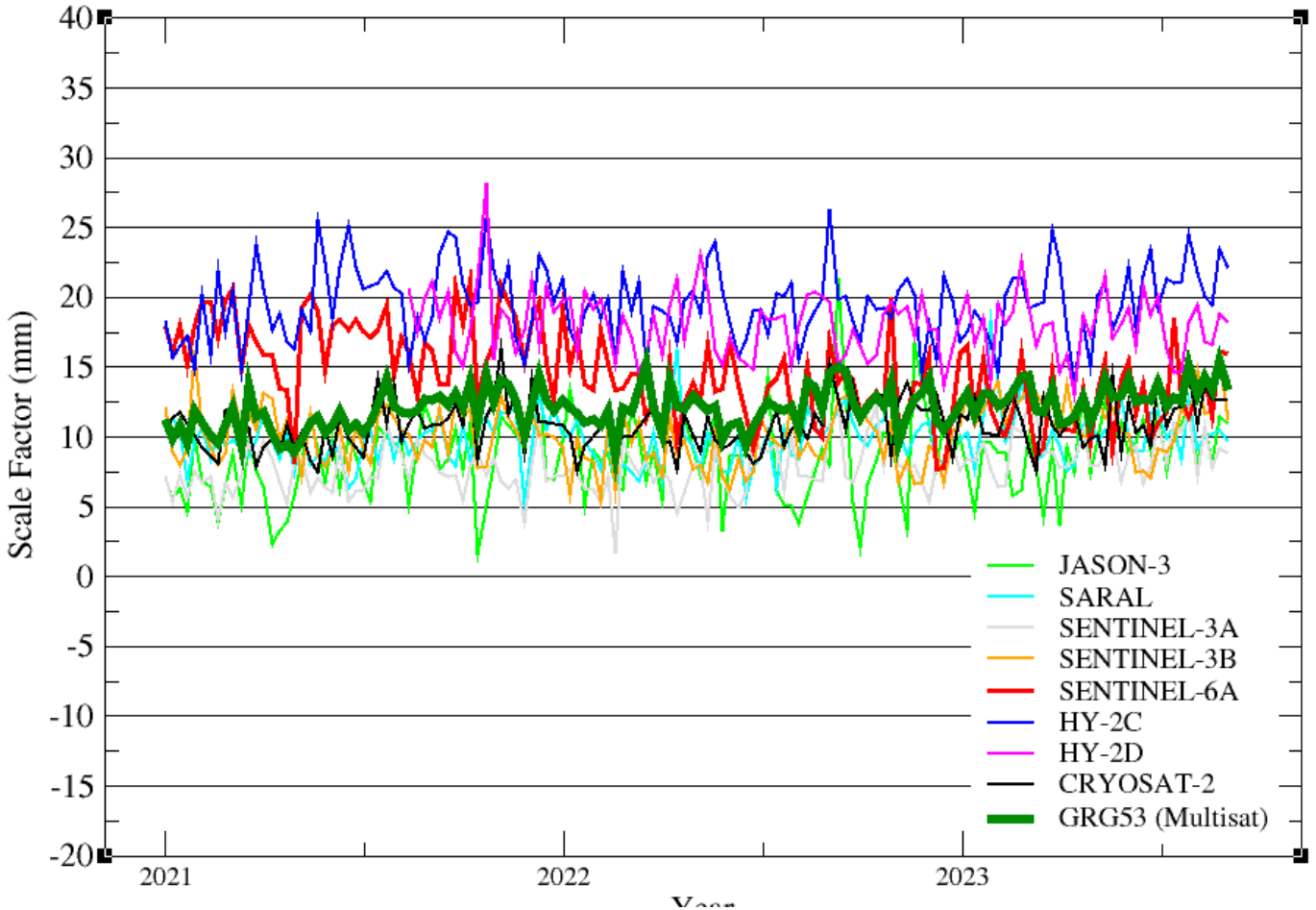
Introduction of the SWOT satellite in our processing chain
Determination of quaternions (BUS+solar panel) files for HY-2C and HY-2D satellites in ORBEX format
Evaluation of DPOD2020 version 2 with annual and semi-annual terms
…

Origin and scale from single satellite solutions

❑ Comparison of each solution to DPOD2020 (computed by CATREF)

SATELLITE	Inclination (degree)	Altitude (km)
Cryosat-2	92	717
Saral	98.65	750
Jason-3	66.04	1336
Sentinel-3A	98.65	814
Sentinel-3B	98.65	814
Sentinel-6	66.04	1336
HY-2C	66	971
HY-2D	66	971

Scale Factor from single satellite solutions



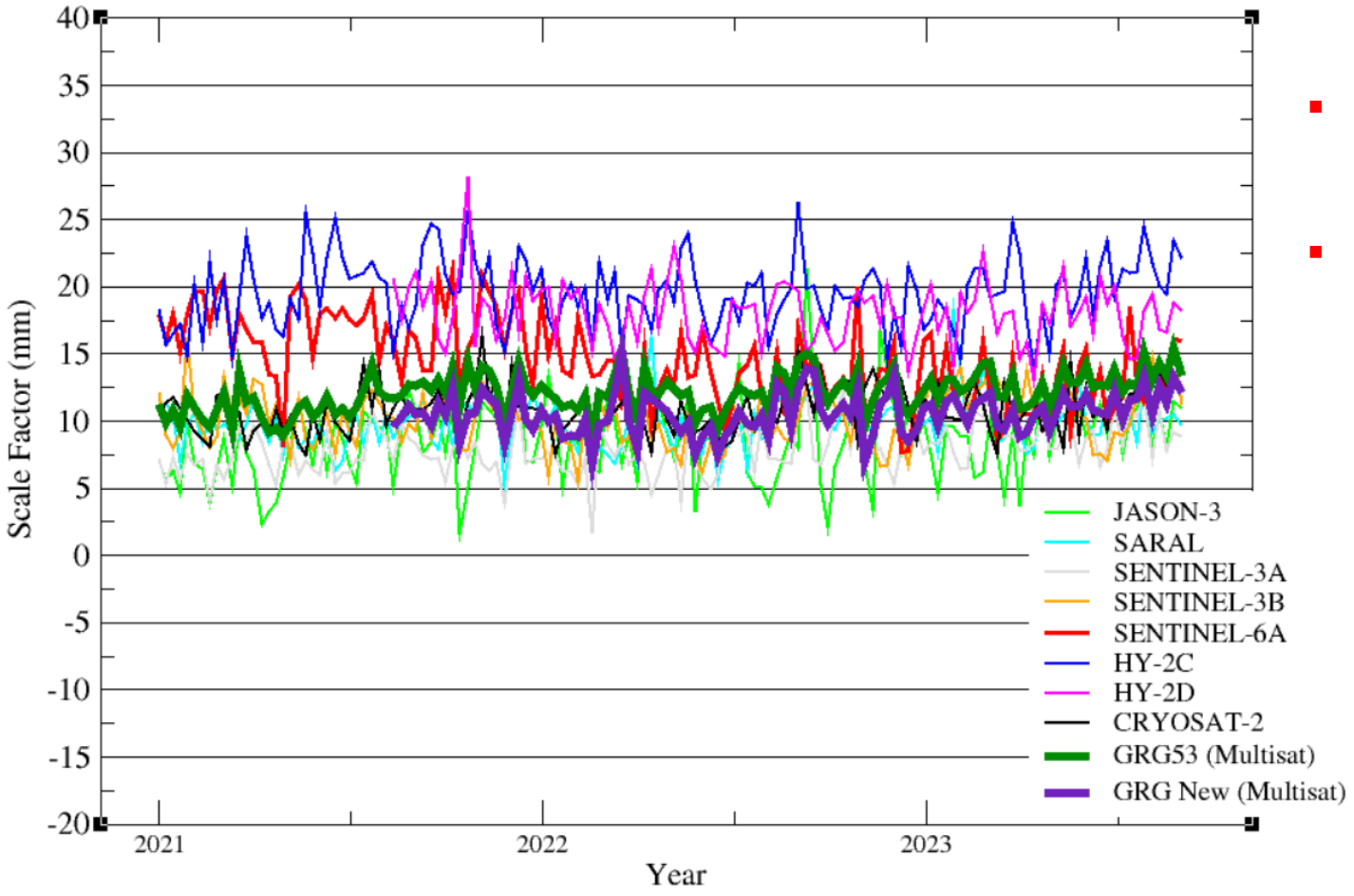
- *HY-2C and HY-2D scales are higher (offset in Z direction of DORIS CoP?).*
- *Multi-satellite solution in dark green.*

Origin and scale from single satellite solutions

❑ Comparison of each solution to DPOD2020 (computed by CATREF)

SATELLITE	Inclination (degree)	Altitude (km)
Cryosat-2	92	717
Saral	98.65	750
Jason-3	66.04	1336
Sentinel-3A	98.65	814
Sentinel-3B	98.65	814
Sentinel-6	66.04	1336
HY-2C	66	971
HY-2D	66	971

Scale Factor from single satellite solutions



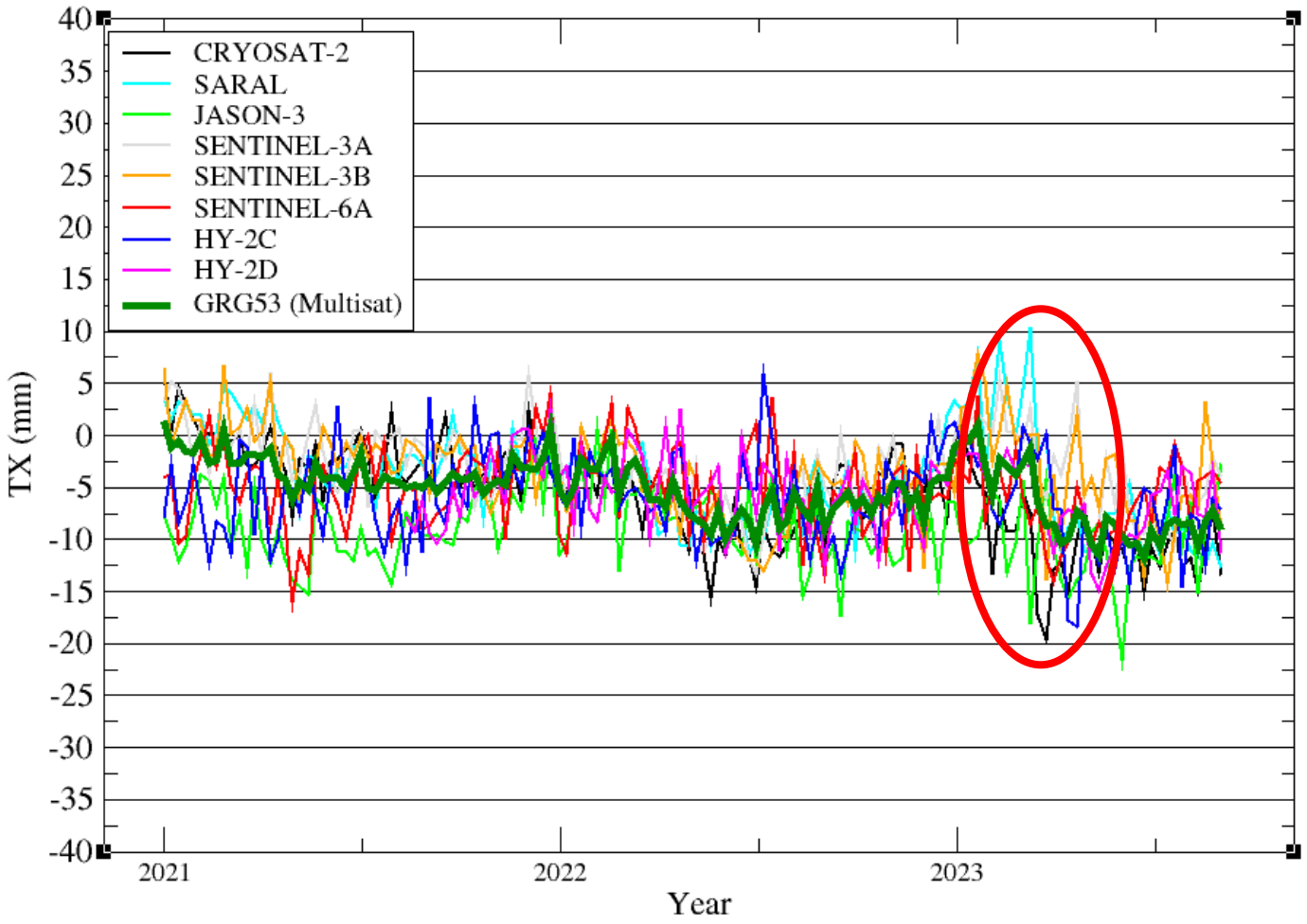
- *Multi-satellite solution in dark green.*
- *In purple: Multi-satellite solution in which HY-2C and HY-2D solution do not contribute to the scale.*

Origin and scale from single satellite solutions

❑ Comparison of each solution to DPOD2020 (computed by CATREF)

SATELLITE	Inclination (degree)	Altitude (km)
Cryosat-2	92	717
Saral	98.65	750
Jason-3	66.04	1336
Sentinel-3A	98.65	814
Sentinel-3B	98.65	814
Sentinel-6	66.04	1336
HY-2C	66	971
HY-2D	66	971

Tx from single satellite solutions



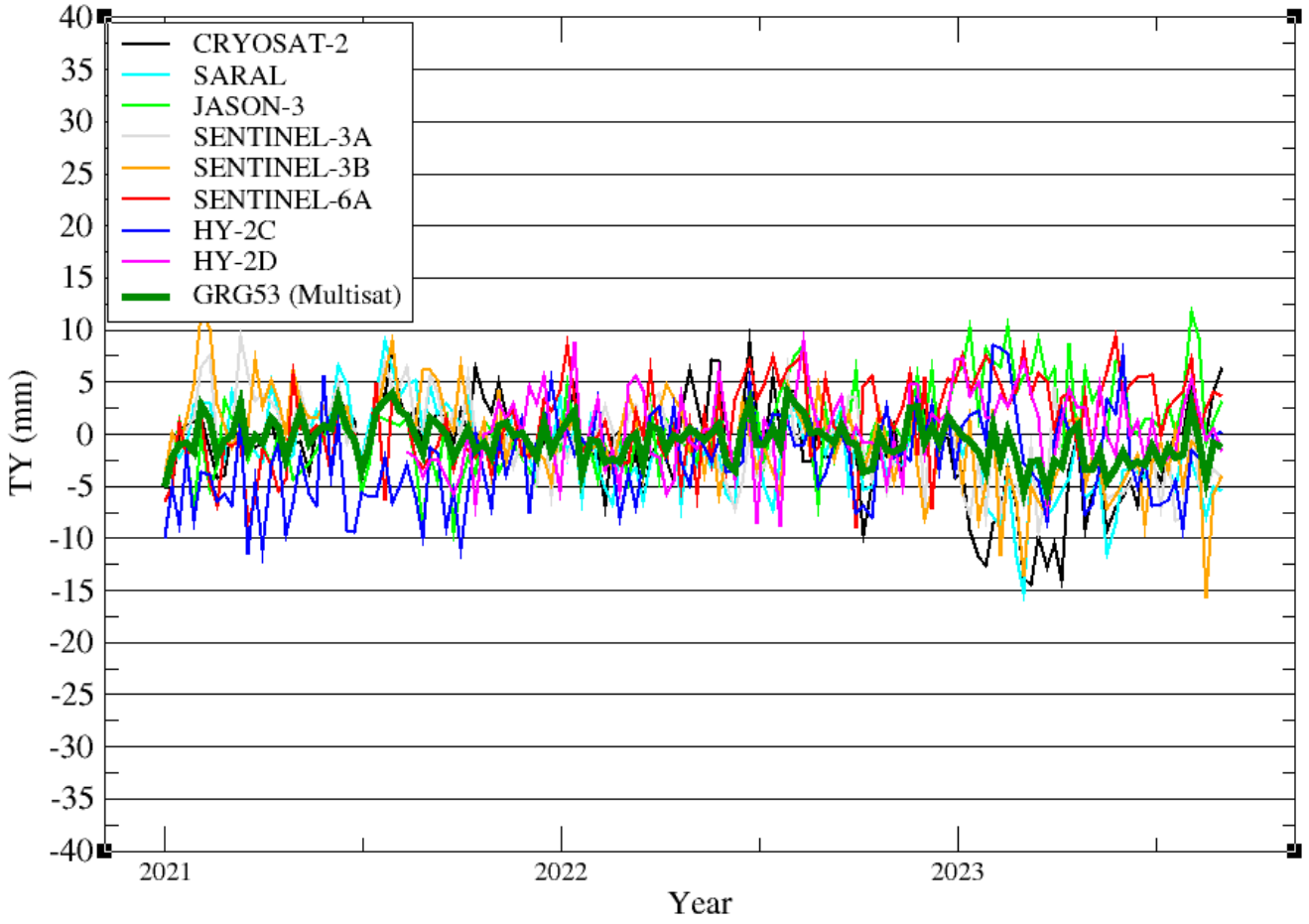
- *There is a good agreement between the single satellite solutions (slightly less good in 2021).*
- *As shown by the IDS CC, there is a jump in March 2023, also present in the single satellite solutions (more or less strong depending on the solution)*

Origin and scale from single satellite solutions

❑ Comparison of each solution to DPOD2020 (computed by CATREF)

SATELLITE	Inclination (degree)	Altitude (km)
Cryosat-2	92	717
Saral	98.65	750
Jason-3	66.04	1336
Sentinel-3A	98.65	814
Sentinel-3B	98.65	814
Sentinel-6	66.04	1336
HY-2C	66	971
HY-2D	66	971

Ty from single satellite solutions



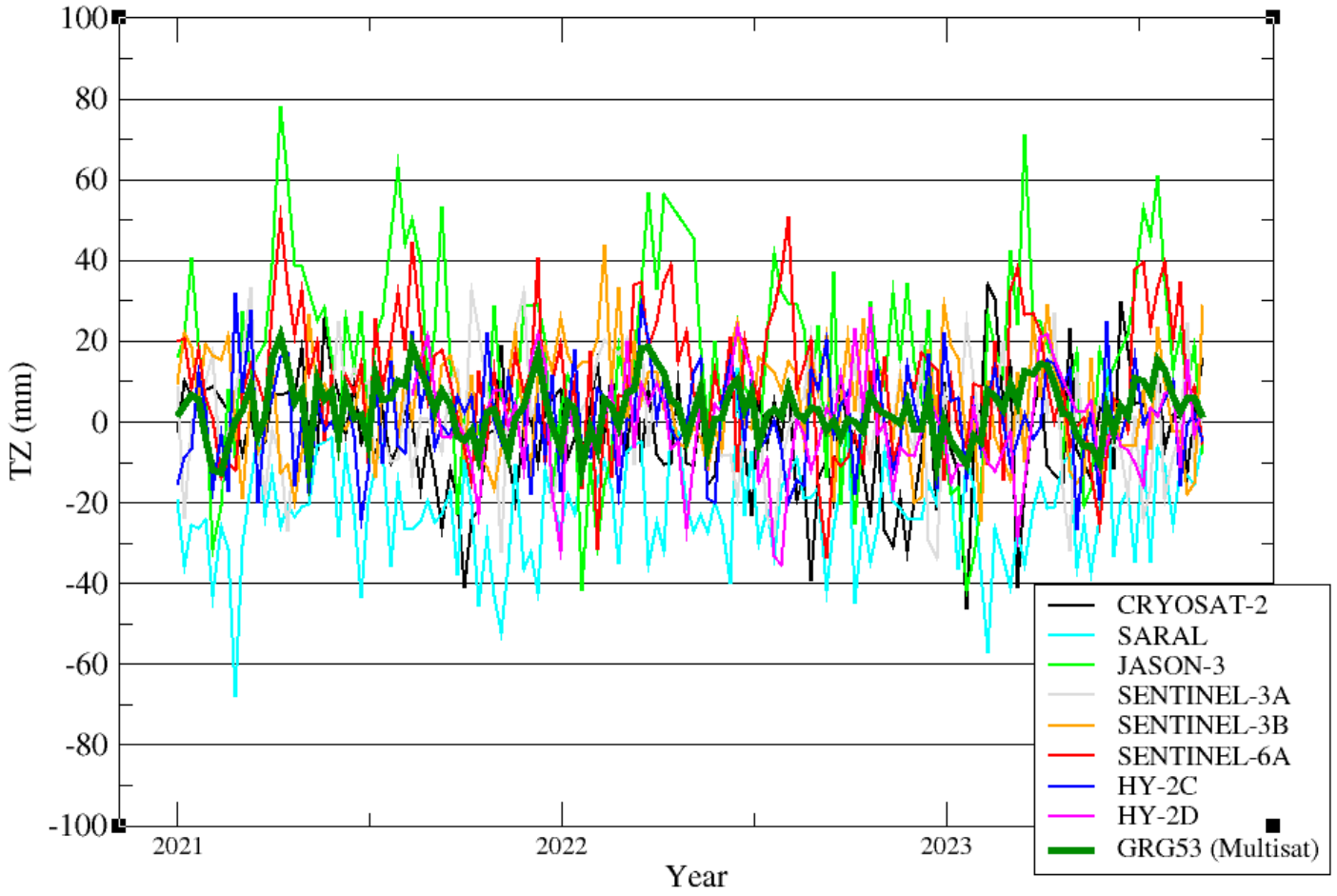
- *The multi-satellite TY is stable.*
- *There is a good agreement between the single satellite solutions. Less since the beginning of the year 2023?*

Origin and scale from single satellite solutions

❑ Comparison of each solution to DPOD2020 (computed by CATREF)

SATELLITE	Inclination (degree)	Altitude (km)
Cryosat-2	92	717
Saral	98.65	750
Jason-3	66.04	1336
Sentinel-3A	98.65	814
Sentinel-3B	98.65	814
Sentinel-6	66.04	1336
HY-2C	66	971
HY-2D	66	971

Tz from single satellite solutions

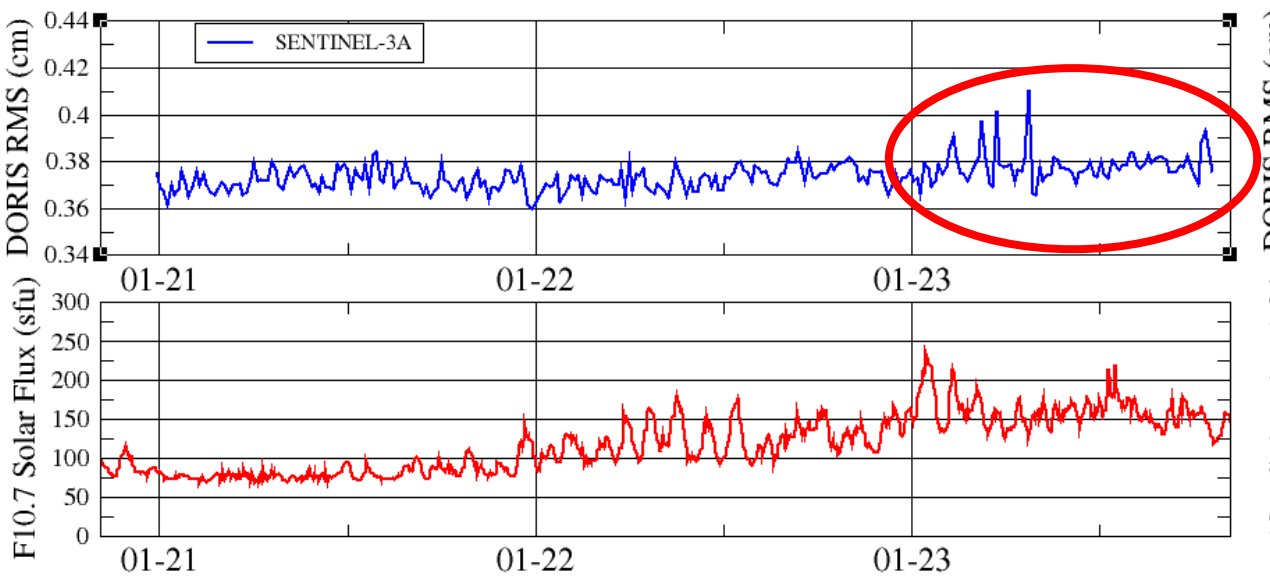


- *Saral has a small bias (offset in normal direction of DORIS CoP?).*
- *There is 118 days signature for Jason-3 and for Sentinel-6A (stronger on Jason-3).*

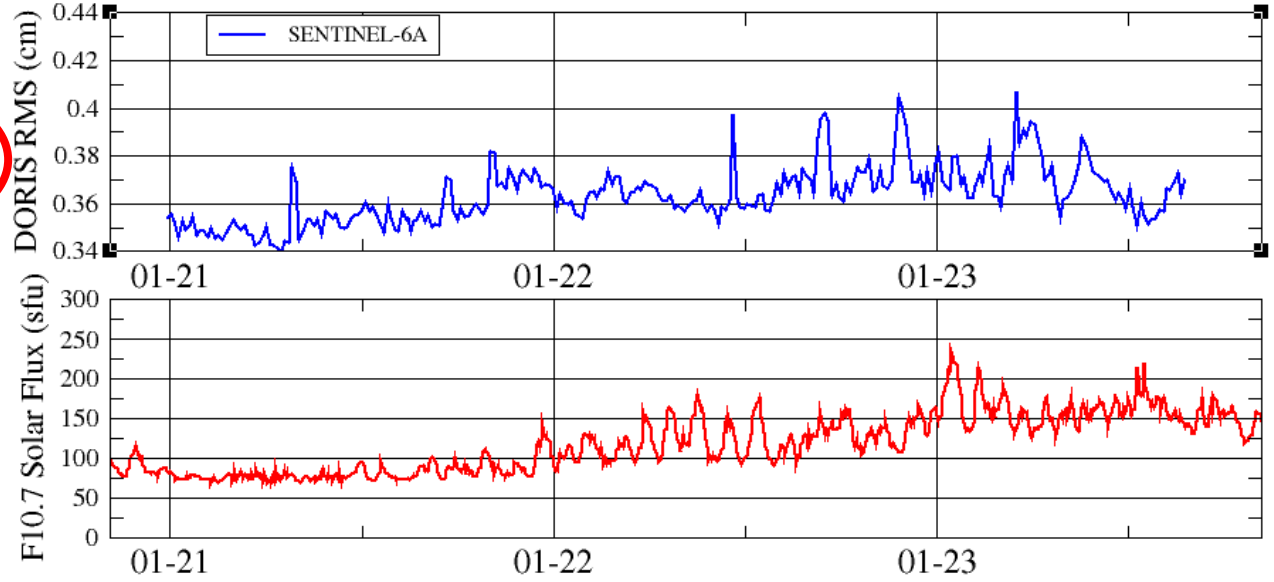
Impact of increased solar activity on POD

❑ DORIS RMS of fit

- **Sentinel-3A** (from Jan. 2021 to Sept. 2023)



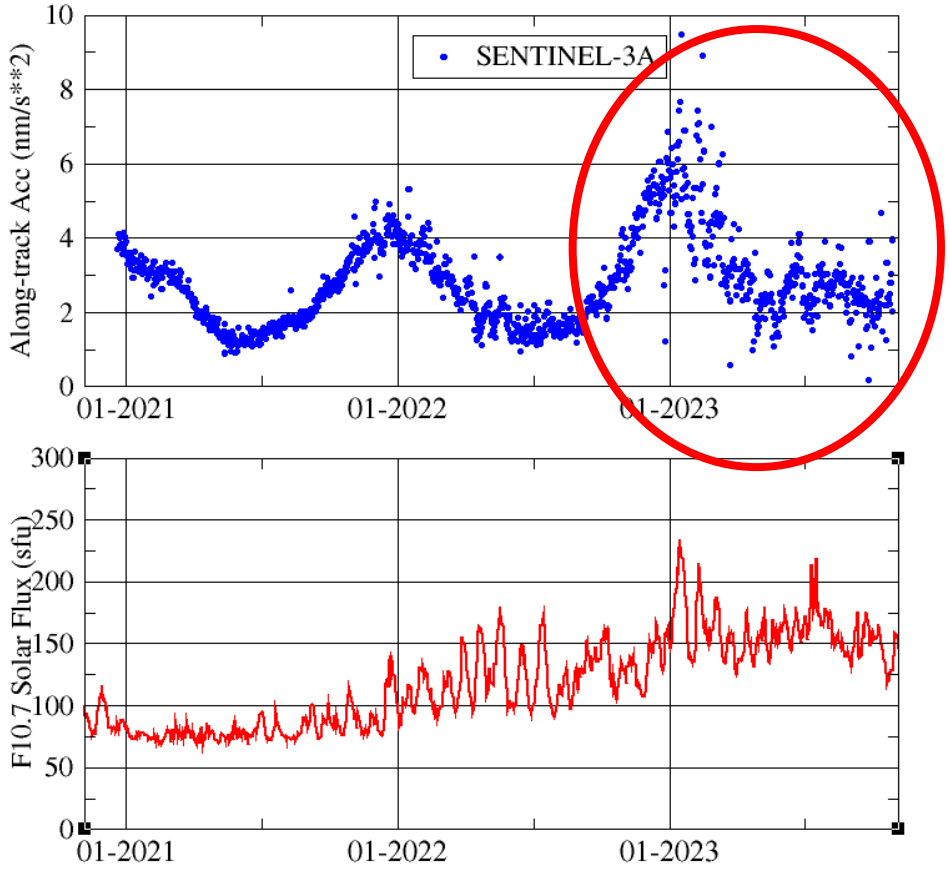
- **Sentinel-6A** (from Jan. 2021 to Sept. 2023)

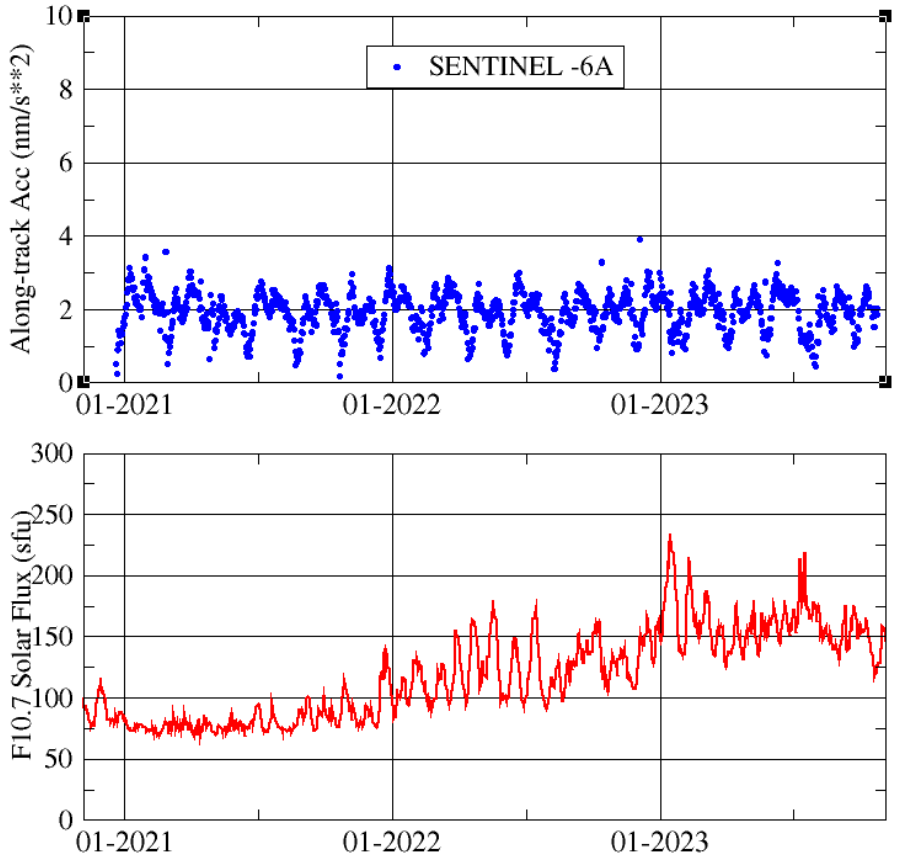


- *The DORIS RMS residuals for Sentinel-3A increase significantly from early 2023 like the solar flux.*
- *For Sentinel-6A, the correlation is less clear.*

Impact of increased solar activity on POD

❑ OPR Acceleration Amplitude (along-track)





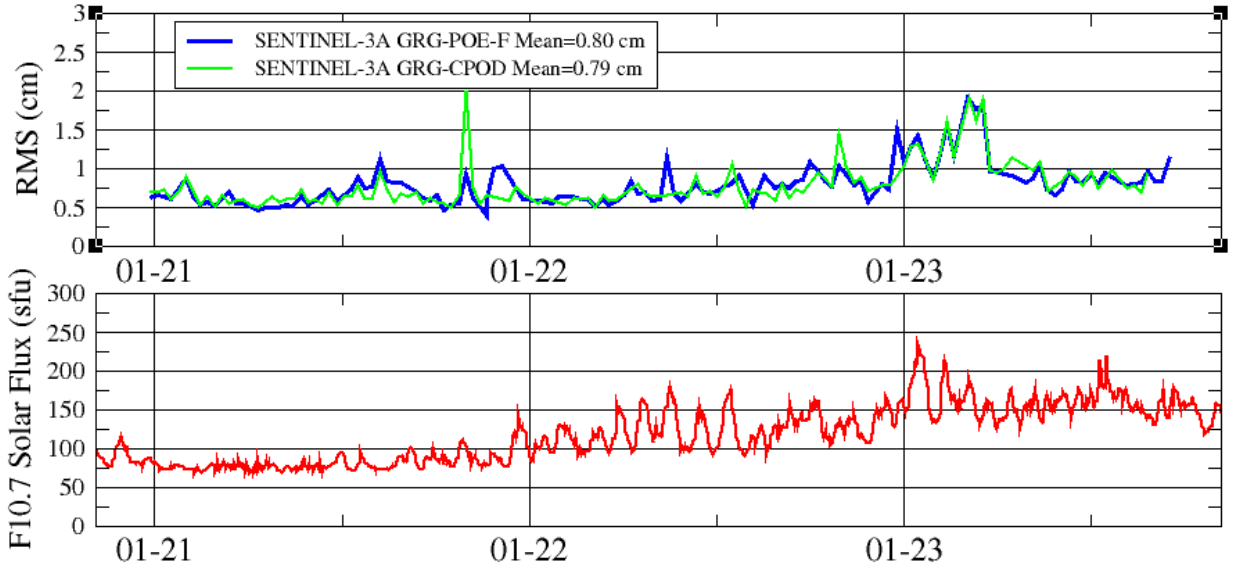
- *For Sentinel-3A, there is a degradation in the along-track amplitude from early 2023 as the solar flux increases.*
- *We see no impact for Sentinel-6A which has a higher amplitude.*

Impact of increased solar activity on POD

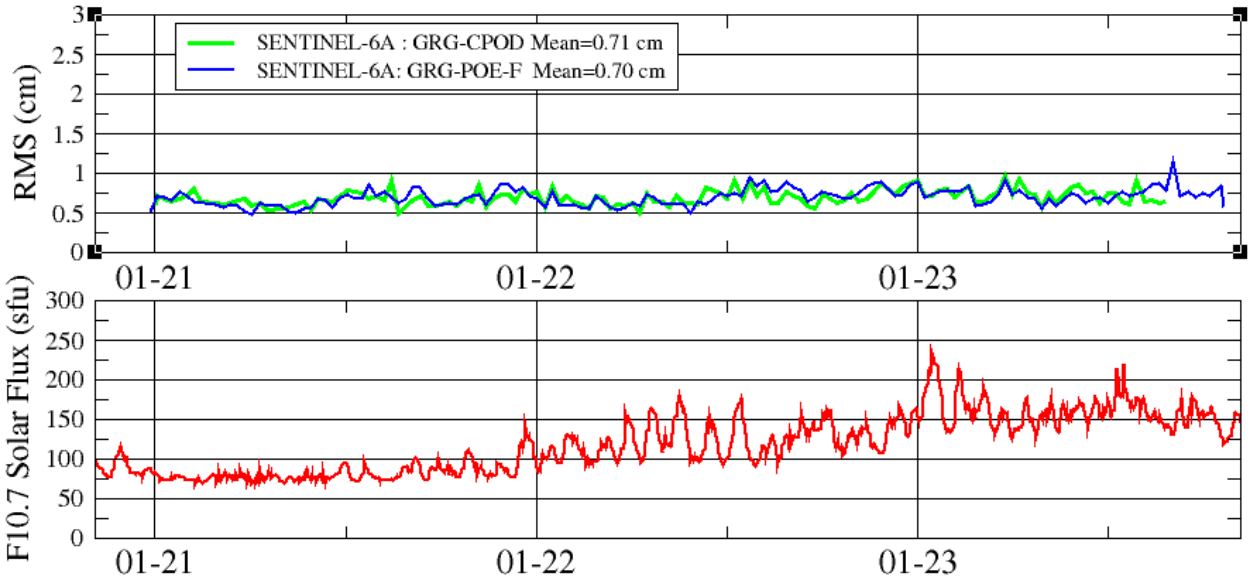
❑ Comparison to external orbit

Weekly RMS orbit differences (in cm)

- **Sentinel-3A** (from Jan. 2021 to Sept. 2023)



- **Sentinel-6A** (from Jan. 2021 to Sept. 2023)

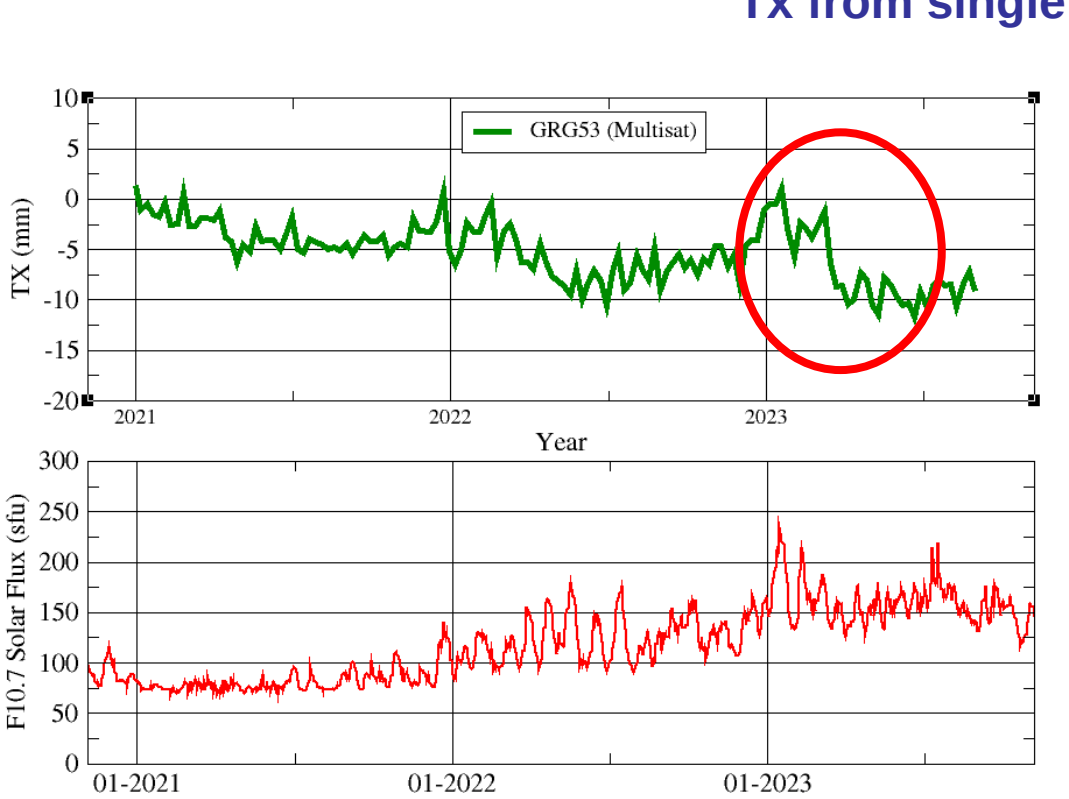


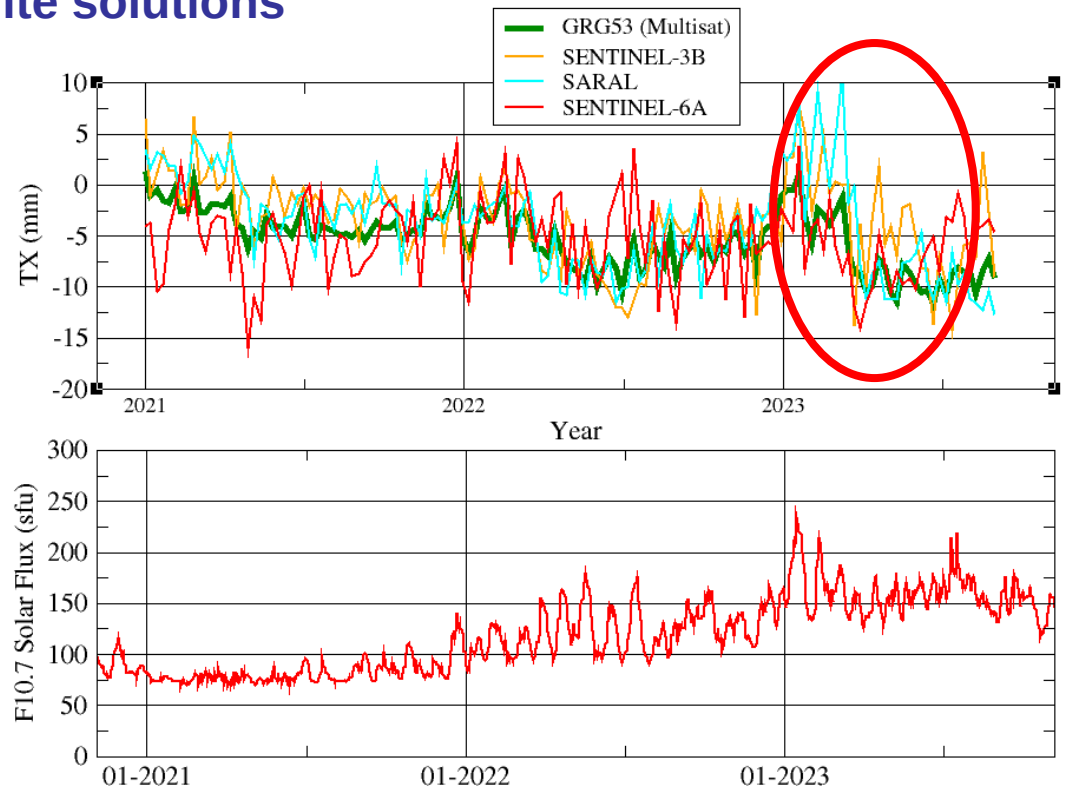
- *For Sentinel-3A, the agreement between GRG orbit and external orbits deteriorates as the solar flux increases.*
- *For Sentinel-6A, the agreement between GRG orbit and external orbits is similar over the entire period (~0.7 cm RMS), even when the solar flux is higher.*

Impact of increased solar activity on Tx ?

- **Comparison of each solution to DPOD2020 (computed by CATREF)**

Tx from single satellite solutions





- *As shown by the IDS CC, there is a jump in March 2023, also present in the single satellite solutions (more or less strong depending on the solution). The jump is more obvious for lower satellites (like Saral and Sentinel-3B).*
- *This could be due to the impact of increased solar activity.*

Introduction of SWOT in GRG processing chain

- **Latest additions:**

Macromodel available at: https://ids-doris.org/documents/BC/satellites/DORISSatelliteModels.pdf
Attitude: Quaternions
Nominal attitude law not yet implemented

- **Preliminary results:**

Few results, due to the lack of quaternions.

The level of DORIS residuals, and the OPR amplitudes are good.

The agreement with POEF is also good, around 8.5 mm RMS for radial orbit difference.

SATELLITE	DORIS RMS (mm/s)	OPR amplitude average (10^{-9} m/s^2)		Radial orbit RMS difference (mm) with POE-F
		Along-track	Cross-track	
Sentinel-3A	0.382	3.5	2.8	11
Sentinel-3B	0.401	3.4	2.6	11
Sentinel-6MF	0.371	1.9	2.7	6.5
HY-2D	0.370	2.6	2.1	7.3
SWOT	0.380	2.9	3.8	8.5

Attitude exchange using ORBEX

- ORBEX provides information on the satellite orientation
- Orientation given using the quaternion representation
- Widely used in the GNSS domain

```
%=ORBEX  0.09
%%
+FILE/DESCRIPTION
 DESCRIPTION          Attitude quaternions for grg/grm products
 CREATED_BY           CNES-CLS IGS-AC
 CREATION_DATE        2022 03 01 13 15 10
 INPUT_DATA           u+U
 CONTACT              igs-ac@cls.fr
 TIME_SYSTEM          GPS
 START_TIME           2022 02 24 00 00  0.000000000000
 END_TIME             2022 02 24 23 55  0.000000000000
 EPOCH_INTERVAL         300.000
 COORD_SYSTEM         IGS14
 FRAME_TYPE           ECEF
 ORBIT_TYPE           FIT
 LIST_OF_REC_TYPES    ATT
-FILE/DESCRIPTION
```

- Meta data in header:
  - EPOCH_INTERVAL : the spacing between each epoch
  - TIME_SYSTEM: TAI, UTC, GPS
  - FRAME_TYPE: INE (inertial), ECEF (Earth-Centered, Earth-Fixed)

- Key/value pairs for each epoch:
  - ATT: gives the attitude quaternions in the reference frame

```
+EPHEMERIS/DATA
*ATT RECORDS: TRANSFORMATION FROM TERRESTRIAL FRAME COORDINATES (T) TO SAT. BODY FRAME ONES (B) SUCH AS
*                              (0,B) = q.(0,T).trans(q)
*REC ID              N ___q0_(scalar)_____ ____q1__x_________ ____q2__y_________ ____q3__z_________
## 2022 02 24 00 00  0.000000000000  50
 ATT E01             4  0.0818006698101173 -0.2149178684197441  0.6372632756423002  0.7355368636378298
 ATT E02             4  0.2135123129484599  0.0811600232538931 -0.7337406813437488  0.6398829231867637
 ATT E03             4  0.2488197825386463  0.0564189412555211 -0.9121903687621332  0.3206467683021779
 ATT E04             4 -0.0592402382002847  0.1147267377193328  0.2895012946222156  0.9484288957229813
```

Format description available online http://acc.igs.org/misc/ORBEX009.pdf

Attitude exchange using ORBEX

- ORBEX format was developed to describe GNSS satellites
- solar panels orientations are not part of the original format which are useful when dealing with LEO satellites

- Format extension for LEO satellites, 2 additional keys :
  - SP1/SP2: gives the orientation of the solar panels in the satellite frame

```
%=ORBEX  0.09
%%
+FILE/DESCRIPTION
 DESCRIPTION          Attitude quaternions
 CREATED_BY           CNES-CLS IGS-AC
 CREATION_DATE        2023 06 13 12 13 29
 CONTACT              igs-ac@cls.fr
 TIME_SYSTEM          TAI
 START_TIME           2023 03 14 00 00   0.00000000000
 END_TIME             2023 03 20 00 00   0.00000000000
 EPOCH_INTERVAL       30
 COORD_SYSTEM         IGS20
 FRAME_TYPE           INE
 LIST_OF_REC_TYPES    ATT SP1 SP2
-FILE/DESCRIPTION
+SATELLITE/ID_AND_DESCRIPTION
 SWOT
-SATELLITE/ID_AND_DESCRIPTION
+EPHEMERIS/DATA
*ATT RECORDS: TRANSFORMATION FROM TERRESTRIAL FRAME COORDINATES (T) TO
*                              (0,B) = q.(0,T).trans(q)
*REC ID              N q0_scalar_ ___q1_x___ ___q2_y___ ___q3_z___
## 2023 03 14 00 00  0.000000000000   1
 ATT             SWOT 4  0.7454095 -0.2023413  0.6229767 -0.1237849
 SP1             SWOT 4  0.9659258 -0.2588190 -0.0000000  0.0000000
 SP2             SWOT 4  0.0000000  0.0000000  0.2588190  0.9659258
## 2023 03 14 00 00 30.000000000000   1
 ATT             SWOT 4  0.7547335 -0.2013071  0.6112403 -0.1274289
 SP1             SWOT 4  0.9659258 -0.2588190 -0.0000000  0.0000000
 SP2             SWOT 4  0.0000000  0.0000000  0.2588190  0.9659258
## 2023 03 14 00 01  0.000000000000   1
 ATT             SWOT 4  0.7638683 -0.2002416  0.5993701 -0.1310117
 SP1             SWOT 4  0.9659258 -0.2588190 -0.0000000  0.0000000
 SP2             SWOT 4  0.0000000  0.0000000  0.2588190  0.9659258
```

Attitude exchange using ORBEX

- Our processing software GINS **can read and generate ORBEX files** for all DORIS missions.
- **HY-2C & HY-2D** : we can produce ORBEX files to help implementing the nominal attitude law.
- **SWOT** : we developed a python script to convert the original attitude NetCDF file into ORBEX. If needed, we can share this tool.

Future work

- *Continue to analyze Origin and Scale factor from single satellite solutions*
- *We plan to continue the evaluation of GRG orbits:*
  - *by comparisons to internal orbits with GNSS*
  - *by comparison to external orbits*
  - *by Independent SLR RMS of fit*
  - *by Altimeter crossover Cycles*

- *Define a strategy to mitigate the impact of the solar activity*
- *Finalize the introduction of SWOT in our processing chain*
- *To mitigate SAA effect introduction of GPS epochwise estimated onboard clocks*
  - *Possible with at least Sentinel-3A, Sentinel-3B and Sentinel-6MF.*
- *Finalize the implementation of the second order ionospheric correction for DORIS measurement.*

Jalabert et al., 2018. Analysis of South Atlantic Anomaly perturbations on Sentinel-3A Ultra Stable Oscillator. Impact on DORIS phase measurement and DORIS station positioning, Adv. Space Res.
Štěpánek et al., U., 2020. Inclusion of GPS clock estimates for satellites Sentinel-3A/3B in DORIS geodetic solutions, J. Geod.