Impact of the South-Atlantic Anomaly radiations on DORIS Ultra-Stable Oscillator: resulting effects on DORIS measurements and orbit determination for Sentinel-3A and Sentinel-6A

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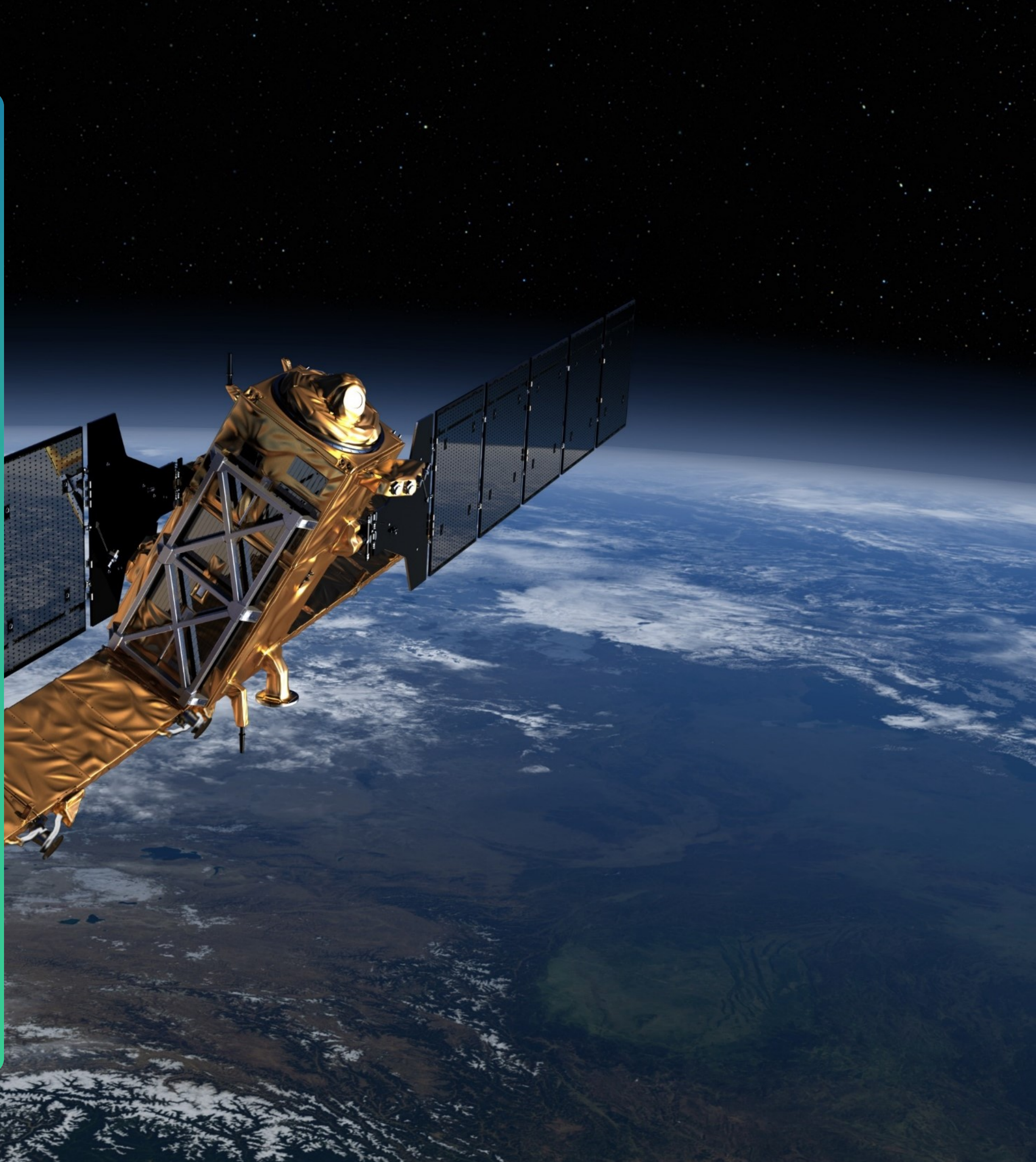


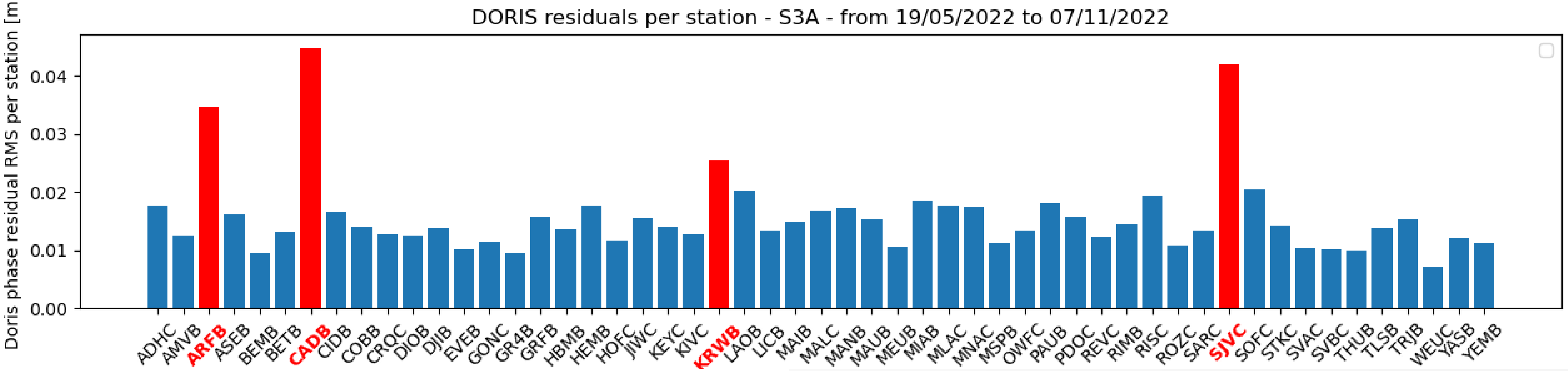
Introduction

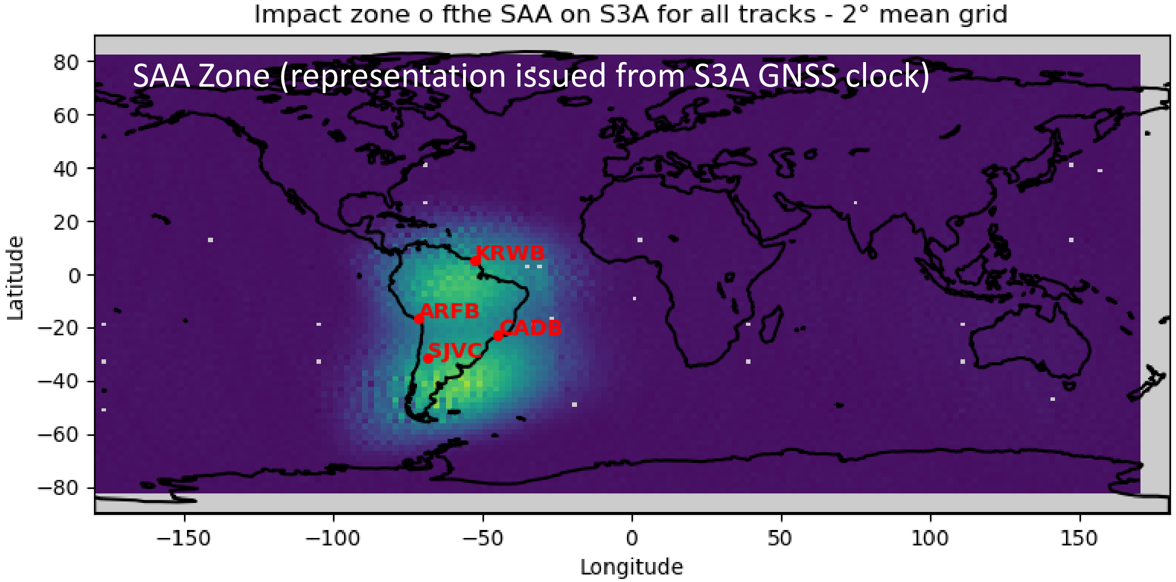
- All DORIS on-board operations are derived from a clock reference at 10Mhz set by an USO (Ultra Stable oscillator)
- USO behaviour may be affected by irradiation rates
- Modelled as a 3rd order polynomial through the DORIS processing

Problematic

This doesn't take into account the USO rapid variations

Introduction





Important radiations in the South Atlantic Anomaly (SAA)

↓

Poor DORIS RMS for the stations in the vicinity of the SAA

Introduction

How to mitigate this issue ?

- Model the response of the USO to SAA irradiation rates

  Lemoine, J. M., & Capdeville, H. (2006). A corrective model for Jason-1 DORIS Doppler data in relation to the South Atlantic Anomaly. Journal of Geodesy, 80, 507-523.

  Lemoine, J. M., & Biancale, R. (2004). A model of DORIS frequency correction for JASON in relation to the SAA. In 35th COSPAR Scientific Assembly (Vol. 35, p. 2898).

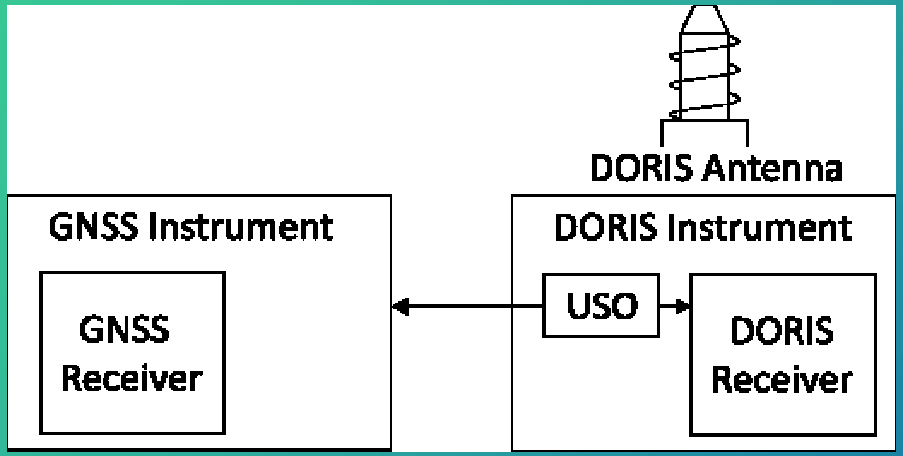
  Capdeville, H., Štěpánek, P., Hecker, L., & Lemoine, J. M. (2016). Update of the corrective model for Jason-1 DORIS data in relation to the South Atlantic Anomaly and a corrective model for SPOT-5. Advances in Space Research, 58(12), 2628-2650.

- Determine the USO behaviour from GNSS processing
  The “GNSS clock” will be used to describe the high frequency USO behaviour especially through the SAA

  Jalabert, E., & Mercier, F. (2018). Analysis of South Atlantic Anomaly perturbations on Sentinel-3A ultra stable oscillator. Impact on DORIS phase measurement and DORIS station positioning. *Advances in Space Research*, *62*(1), 174-190.

  Štěpánek, P., Duan, B., Filler, V., & Hugentobler, U. (2020). Inclusion of GPS clock estimates for satellites Sentinel-3A/3B in DORIS geodetic solutions. *Journal of Geodesy*, *94*(12), 116.

- Estimation of a frequency drift on DORIS residuals
  Current POE-G solution for every Jason and Sentinel-6A



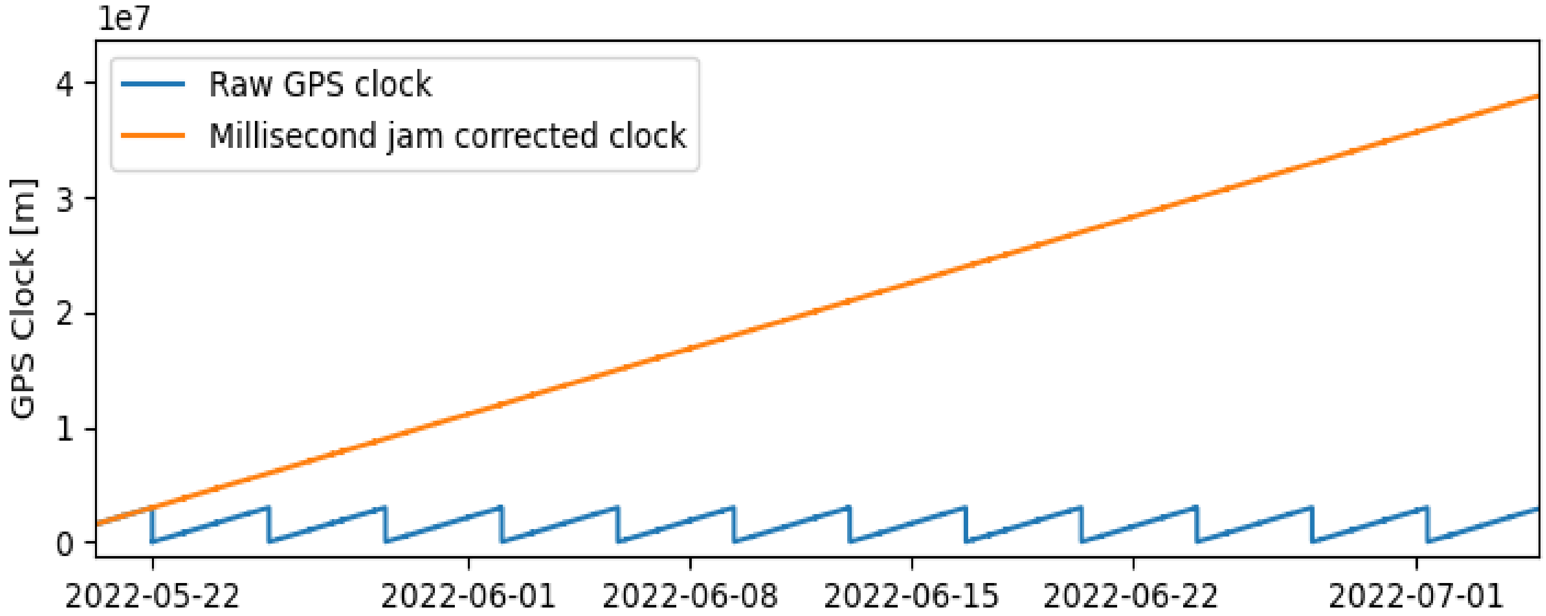
Sentinel Satellites on-board architecture

The USO drives both DORIS and GPS instrument frequency

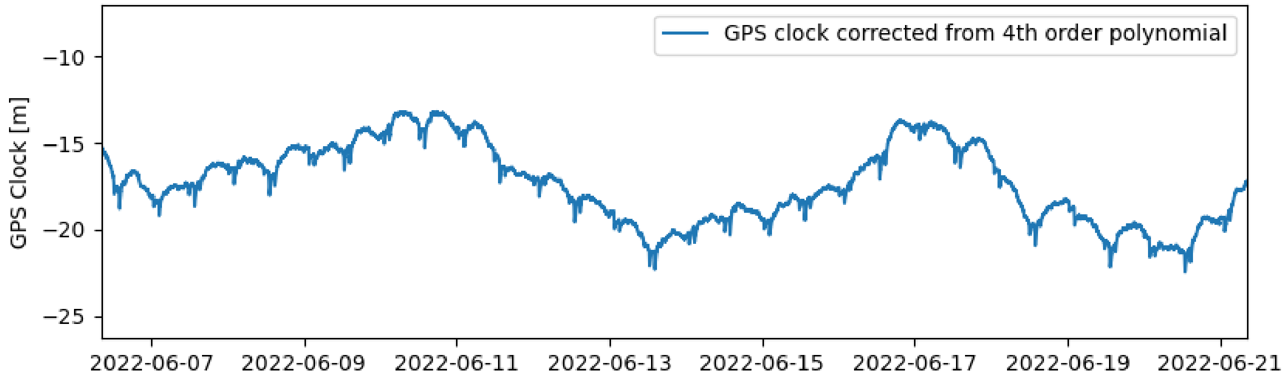
The GNSS Clock

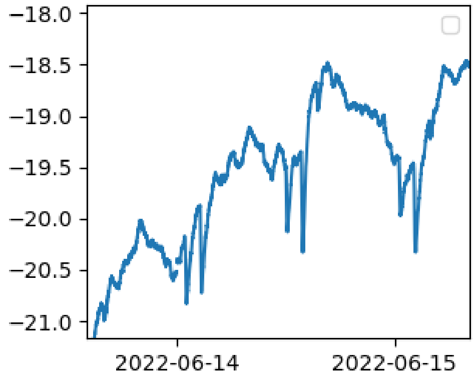
Sentinel-3A example

- Issued from CNES reduced dynamic orbit determination following POE-G standard (including receiver relativistic corrections)
- 30 seconds sampling in GPS time



Raw GPS clock are delivered in the context of the corresponding IDS WG

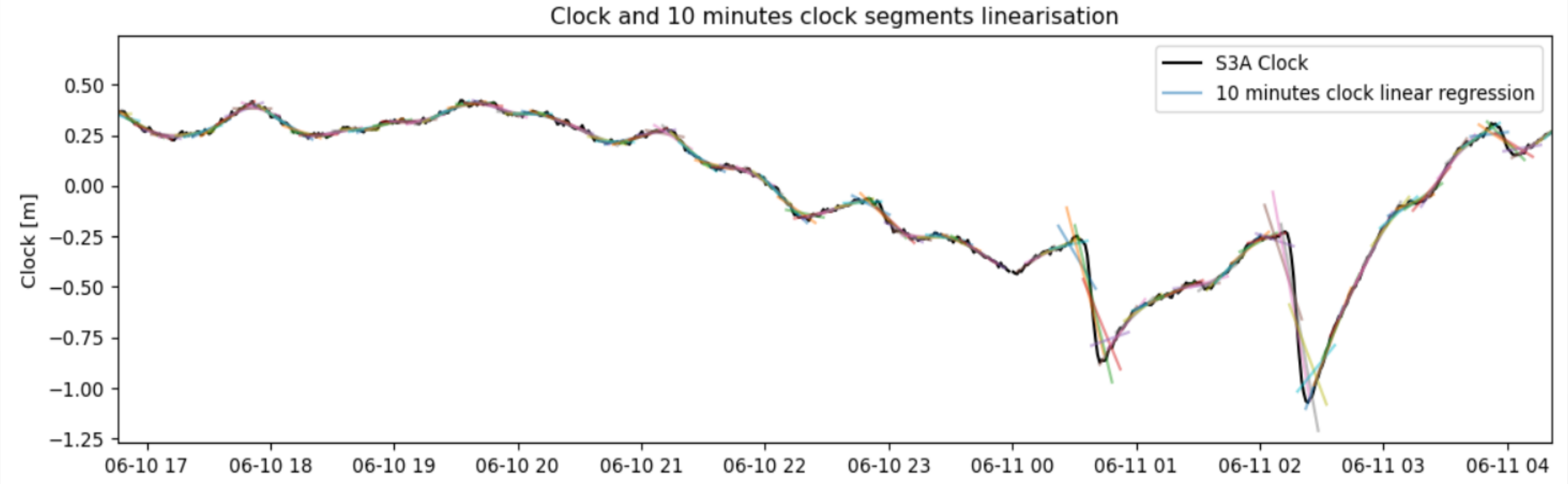




The GNSS Clock

Clock Analysis

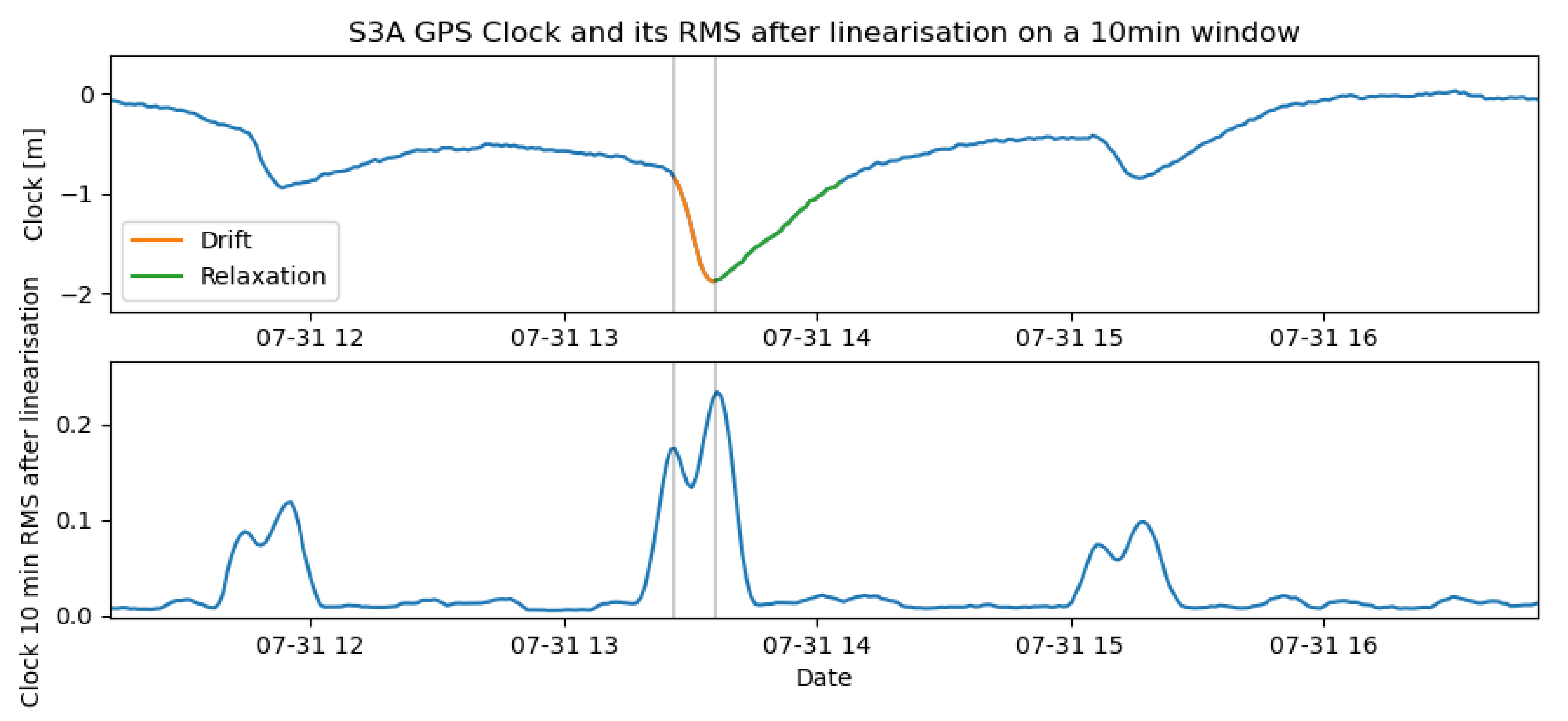
- DORIS pass length about 10 min
- 10 minutes linear regression ~ frequency bias estimation in DORIS processing



- The DORIS residuals will rise when the linear regression does not fit the clock properly

The GNSS Clock: SAA response

Sentinel-3A



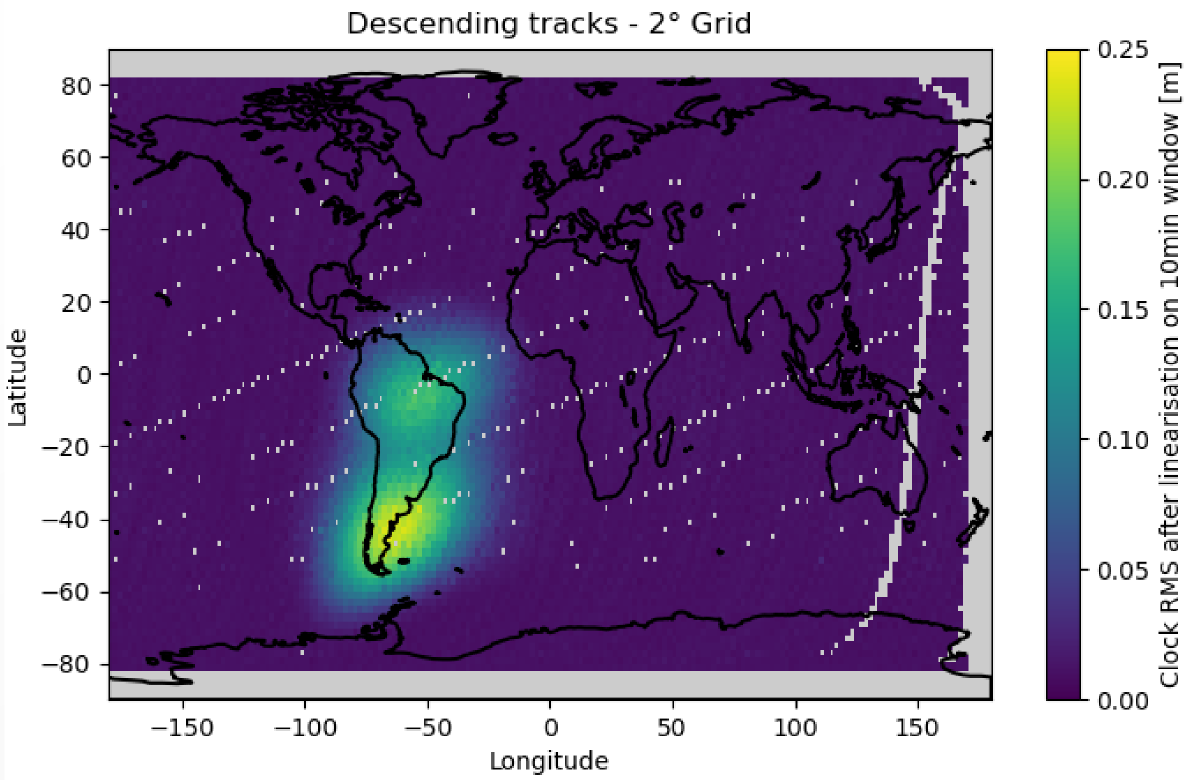
Clock rapid variations

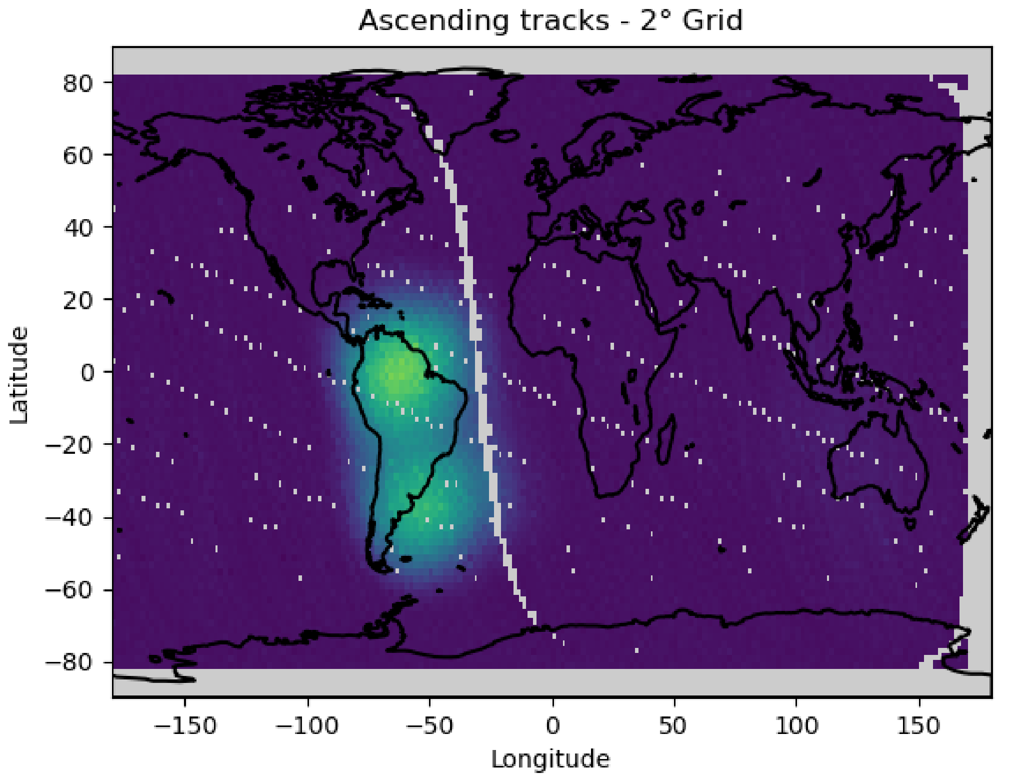
Non-linear behaviour

High impact on the DORIS processing residuals

The GNSS Clock: SAA response

Sentinel-3A clock RMS over 10 minutes after linearisation: **Maps**



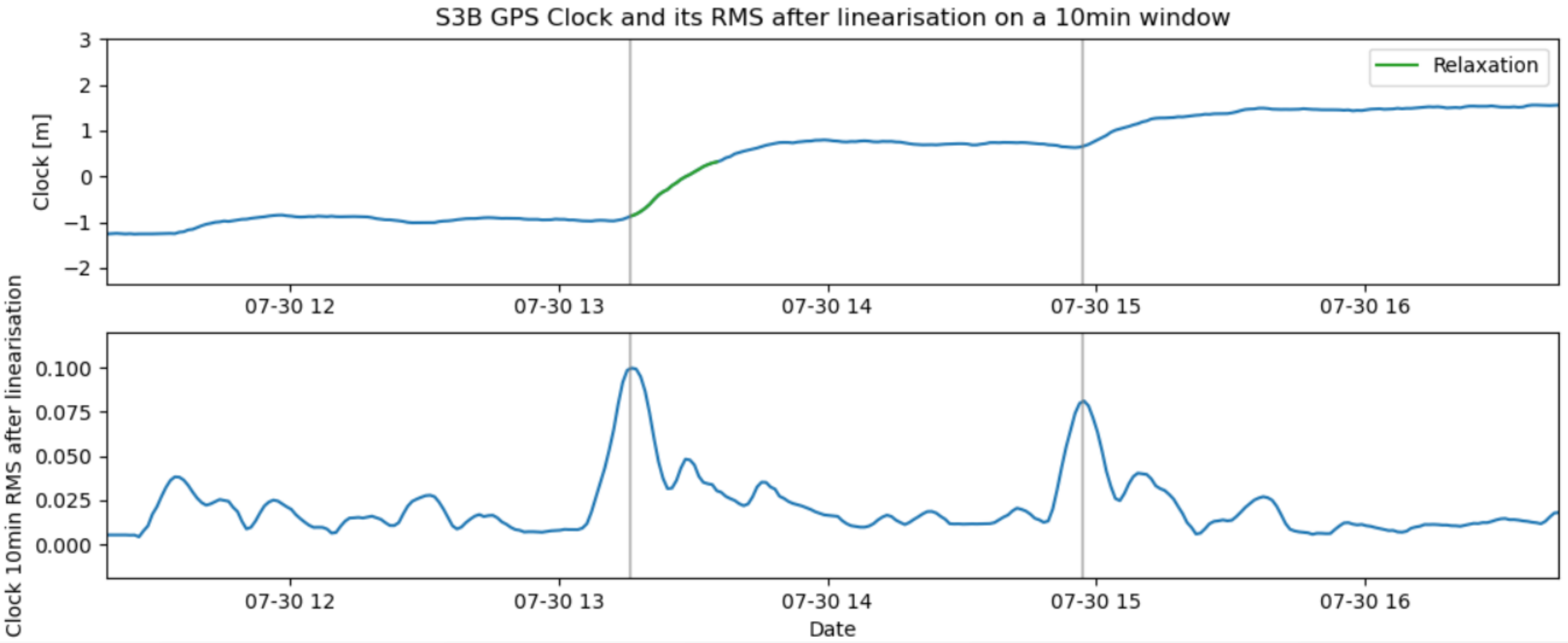


- The SAA signature is clearly visible for Sentinel-3A
- Different coverage for ascending/descending tracks

- Highest impact on the clock at the beginning and ending of the drift

The GNSS Clock: SAA response

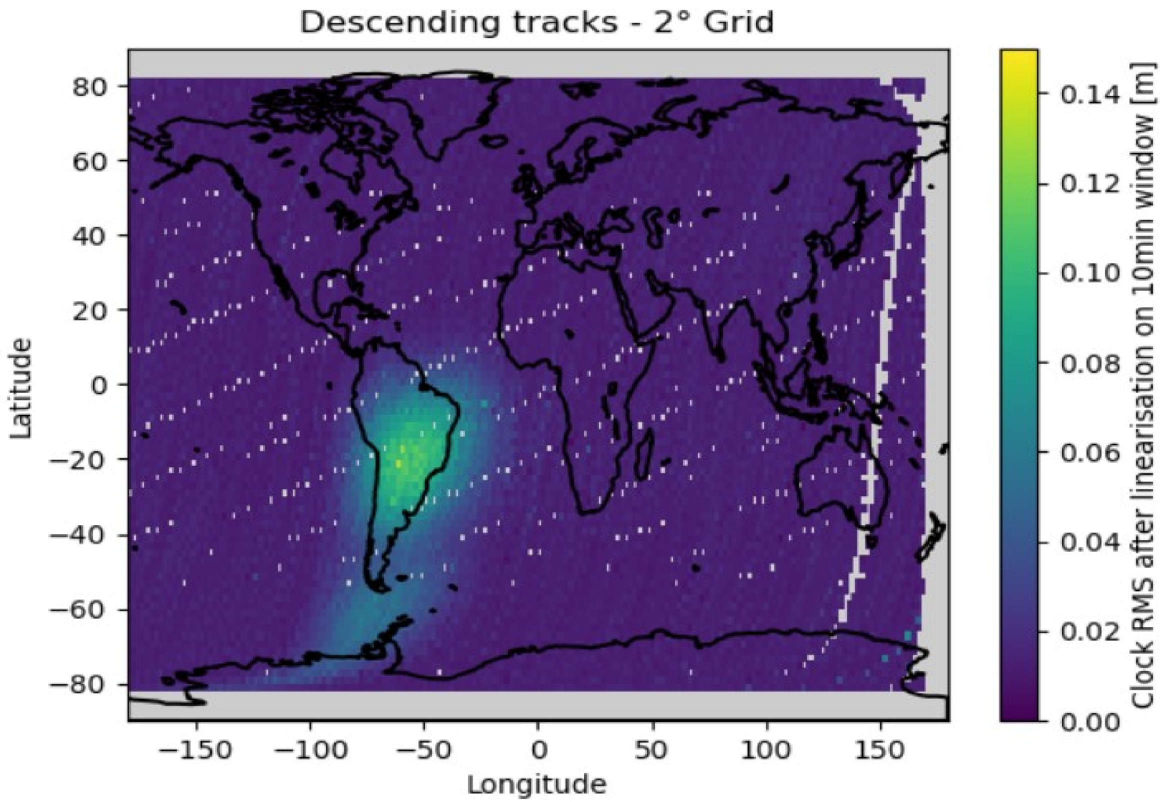
Sentinel-3B

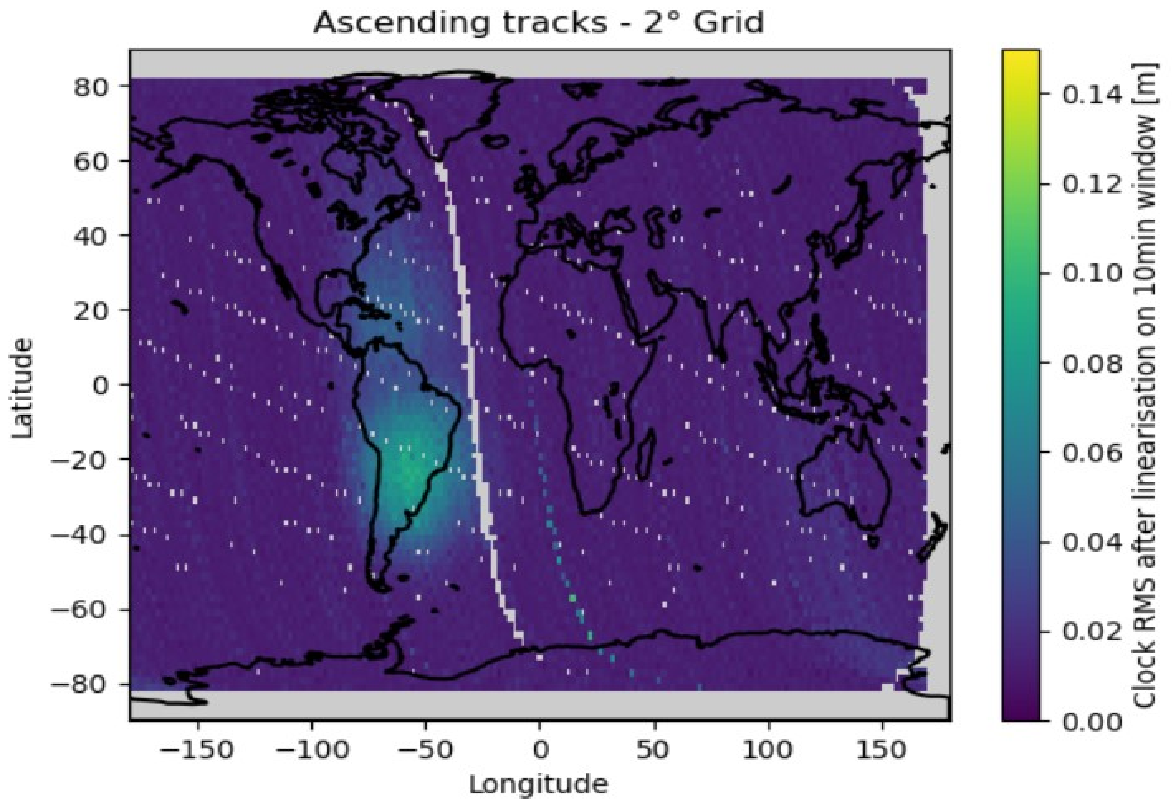


- Clear differences with S3A clock
- Almost no drift
- Lower RMS after linearisation : up to 20cm for S3A vs 10cm for S3B

The GNSS Clock: SAA response

Sentinel-3B clock RMS over 10 minutes after linearisation: **Maps**

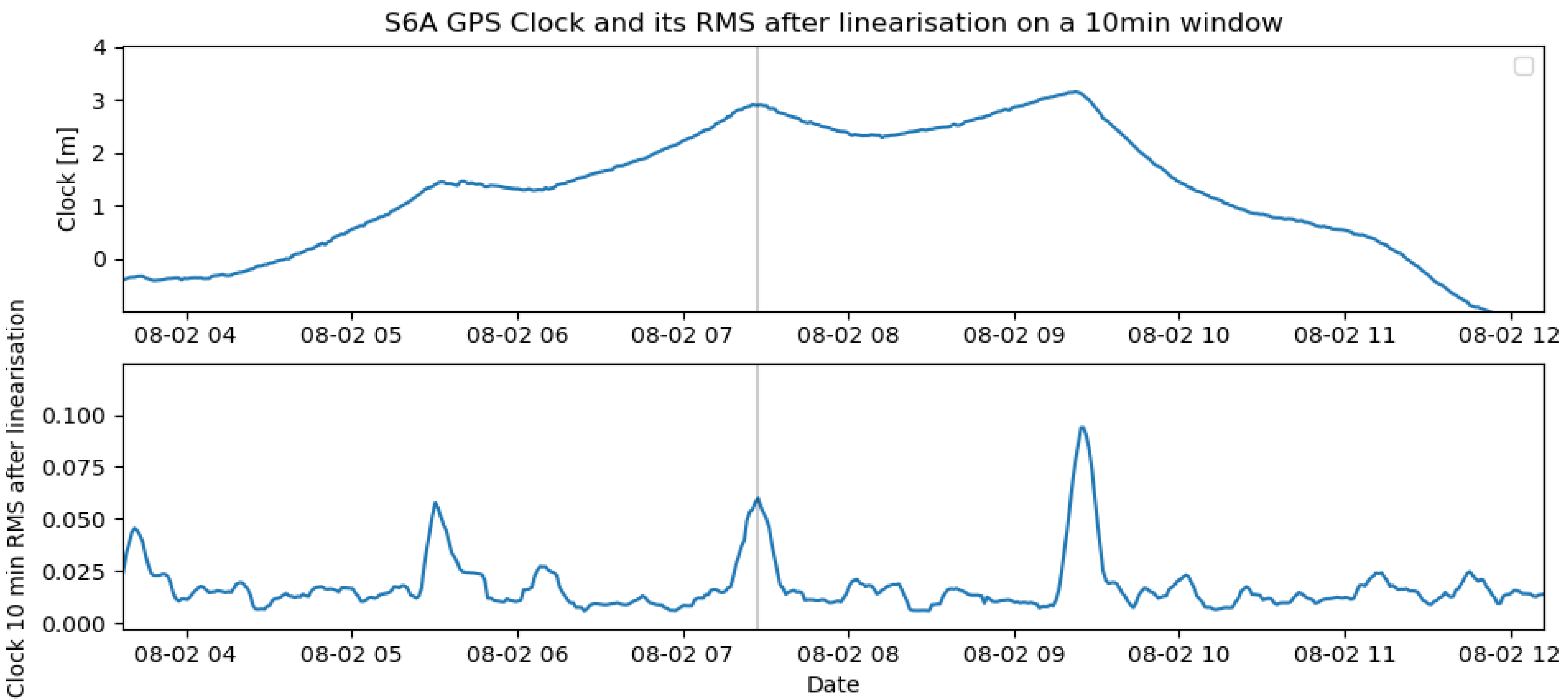




- Different spatial behaviour than for S3A (a smaller region is impacted)
- Smaller spatial differences between ascending and descending tracks

The GNSS Clock: SAA response

Sentinel-6A



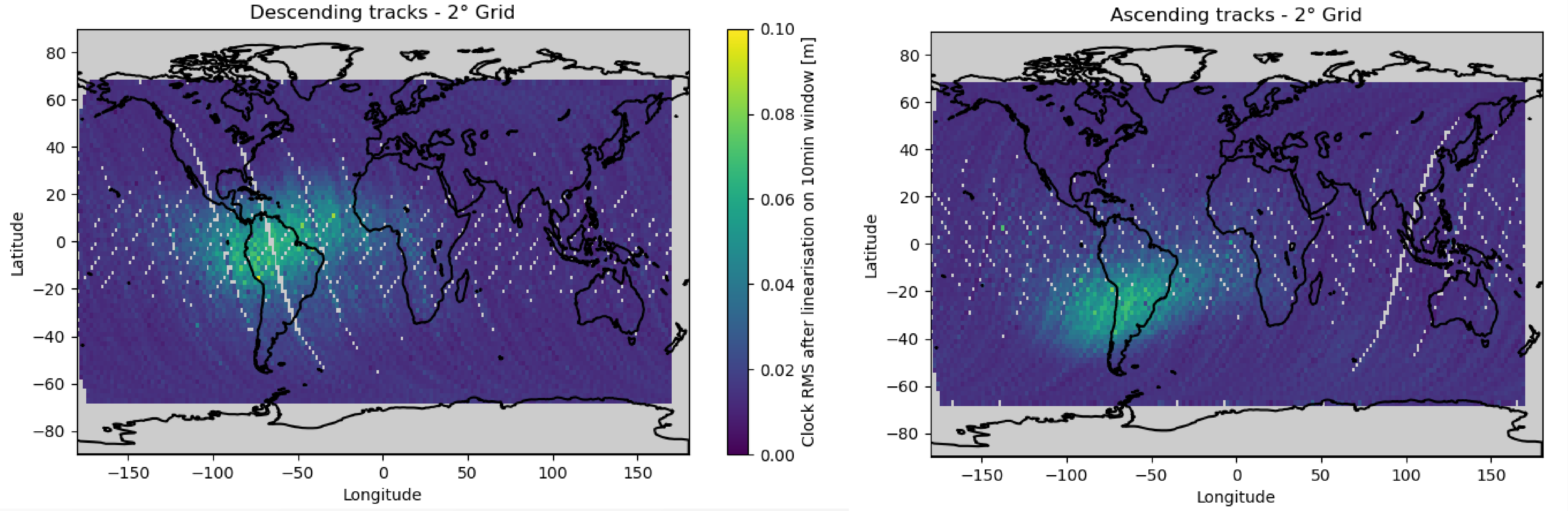
Signature of the SAA less visible than for S3A

~ 5 cm RMS for S6A

~ 20 cm RMS for S3A

The GNSS Clock: SAA response

Sentinel-6A clock RMS over 10 minutes after linearisation: **Maps**

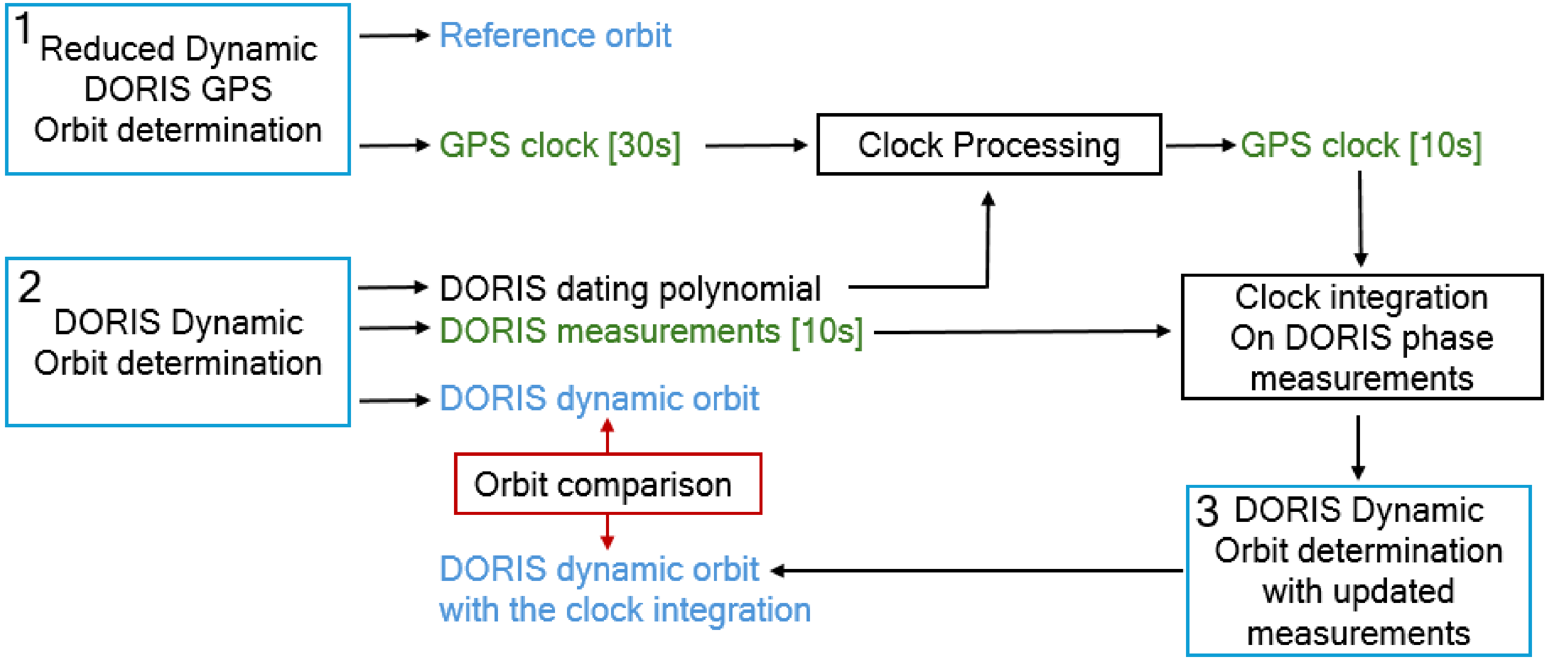


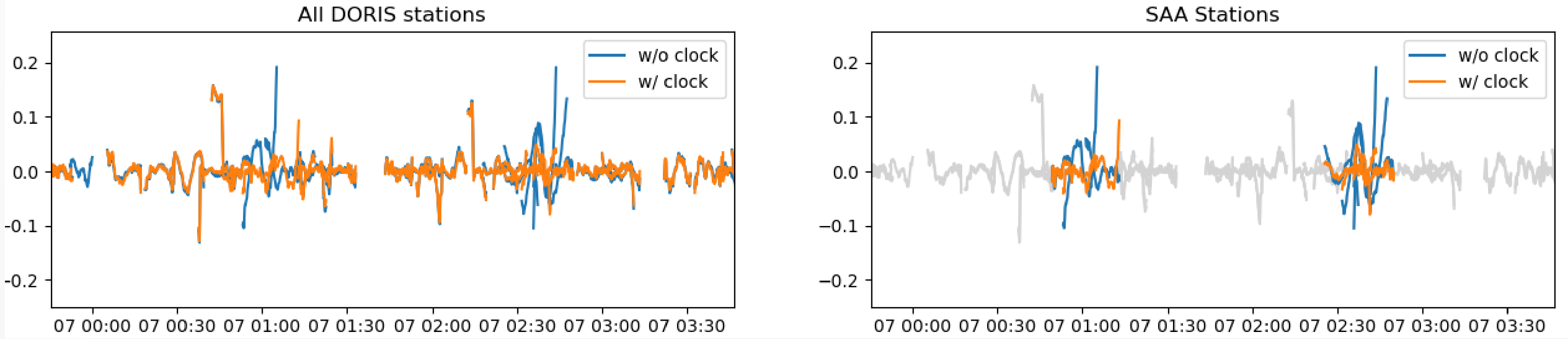
- Less visible than S3A
- Greater area of effect of the SAA (higher satellite)
- Different USO response

CLS

COLLECTE LOCALISATION SATELLITES

Integration of DORIS orbits

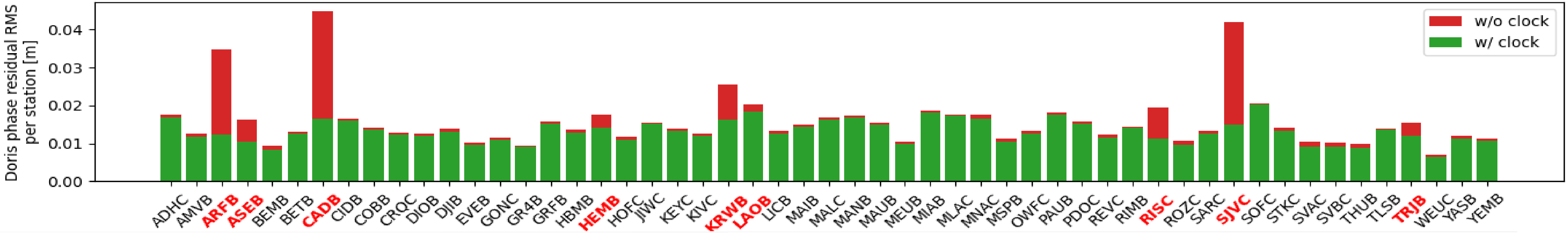




S3A DORIS dynamic orbit phase residuals before and after GPS clock integration – 07/08/22

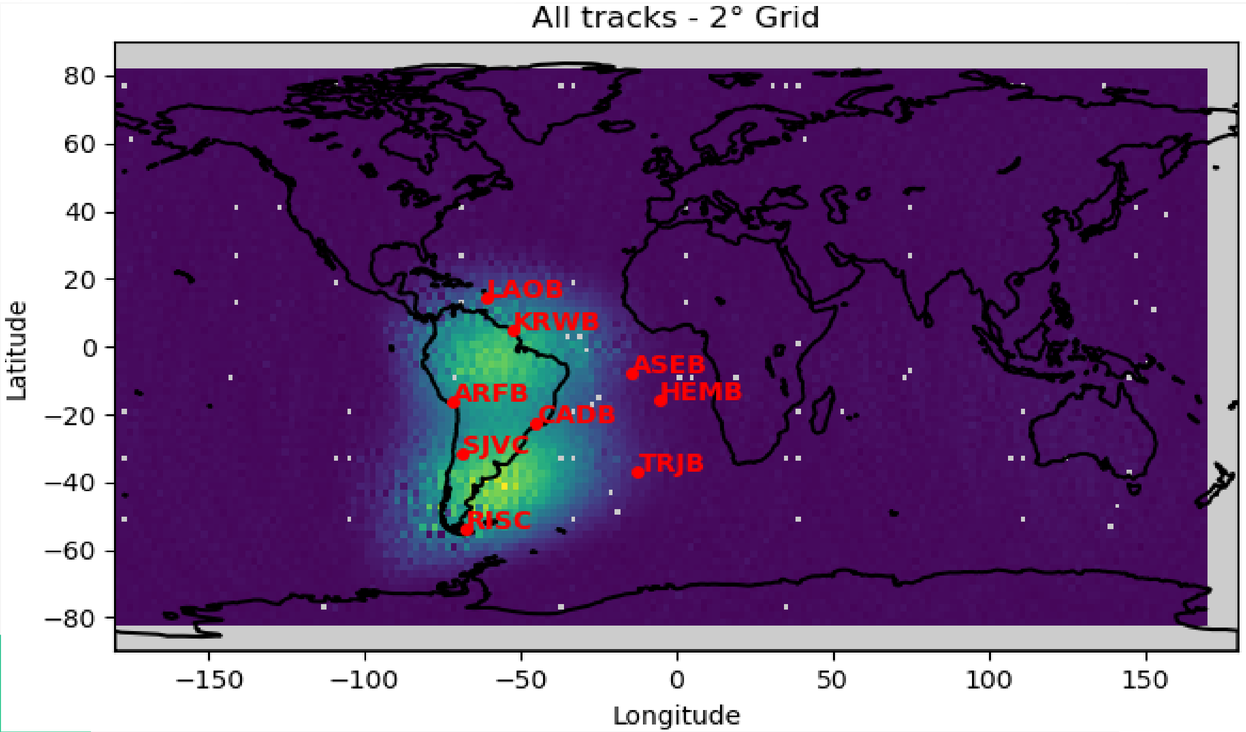
Integration of DORIS orbits: S3A

Sentinel-3A: Without any correction / With GPS clock integration - From 20/05/2022 to 07/11/2022 - 171 days



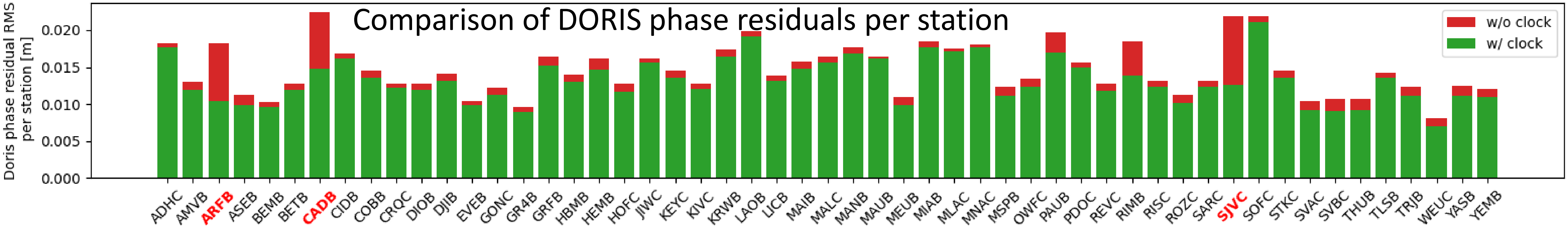
RMS of the DORIS dynamic orbits with a reference orbit (DORIS + GPS reduced dynamic)

[cm]	RMS Radial	RMS Normal	RMS Tang.
w/o clock	0.689	2.081	2.503
w/ clock	0.695	1.517	2.265



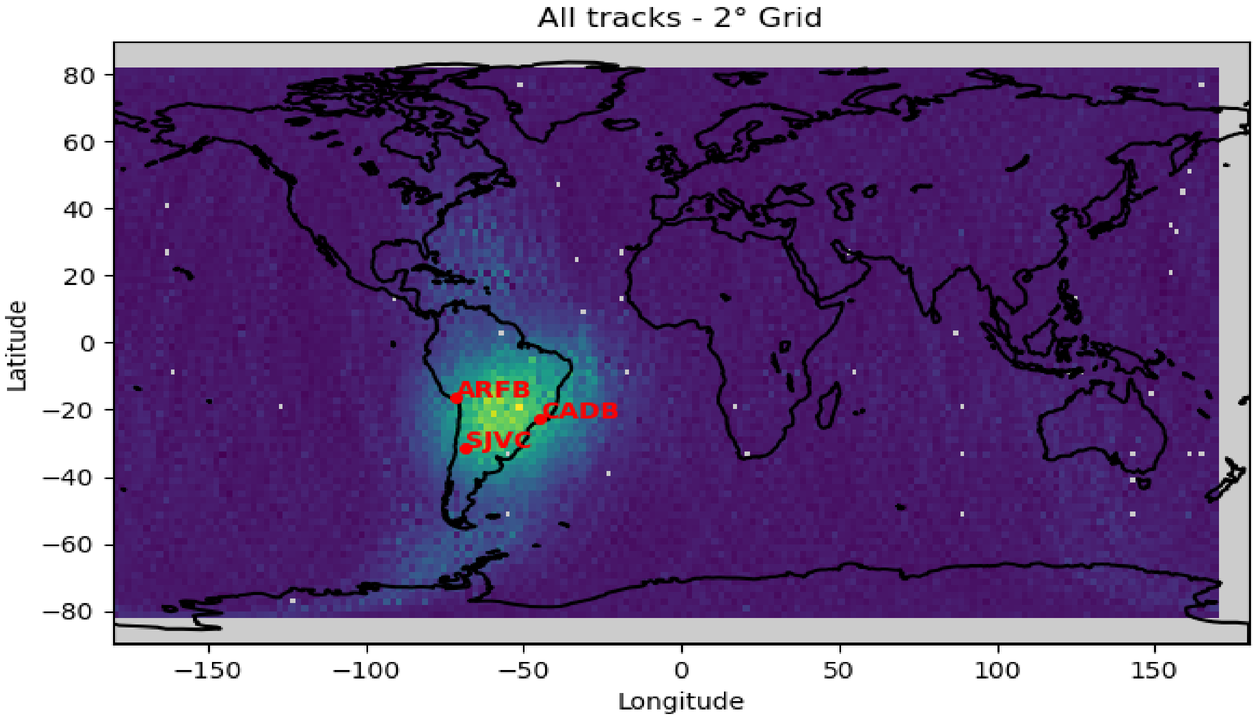
Integration of DORIS orbits: S3B

Sentinel-3B: Without any correction / With GPS clock integration - From 20/05/2022 to 16/11/2022 - 180 days



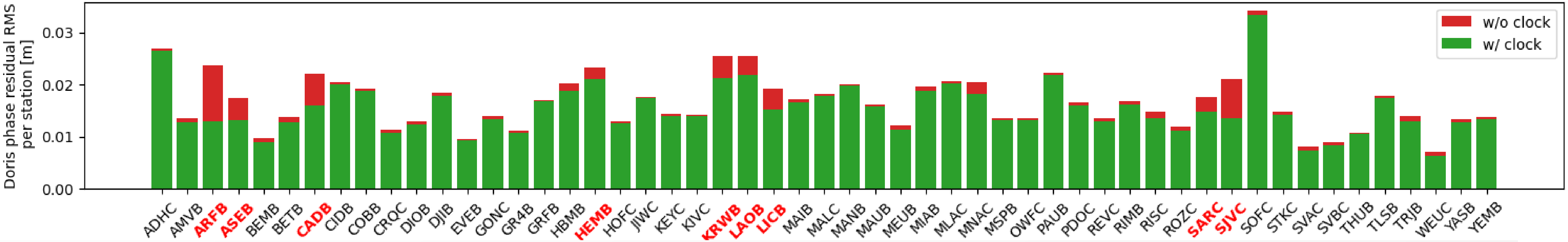
RMS of the DORIS dynamic orbits with a reference orbit (DORIS + GPS reduced dynamic)

[cm]	RMS Radial	RMS Normal	RMS Tang.
w/o clock	0.748	2.077	2.169
w/ clock	0.736	1.588	2.113



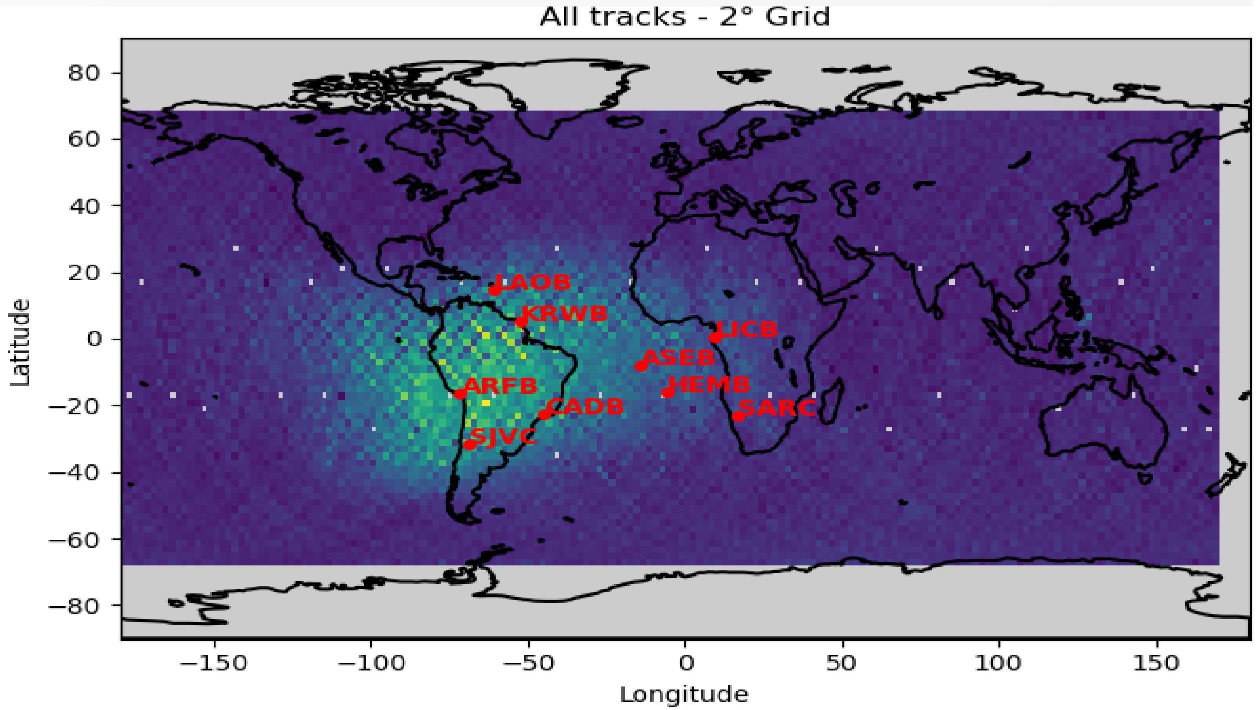
Integration of DORIS orbits: S6A

Sentinel-6A: Without any correction / With GPS clock integration - From 26/05/2022 to 02/11/2022 - 160 days



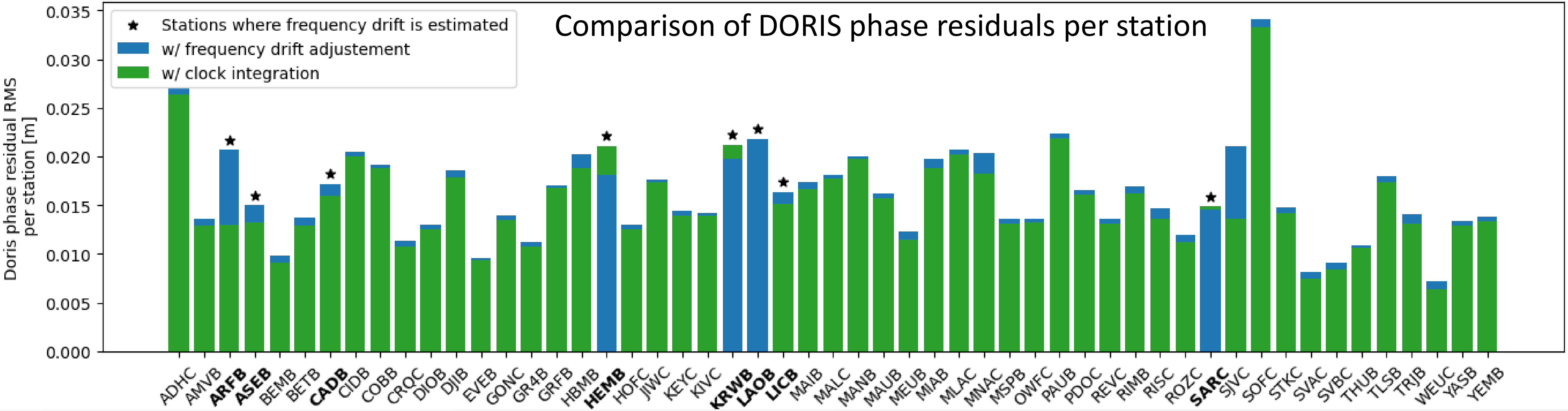
RMS of the DORIS dynamic orbits with a reference orbit (DORIS + GPS reduced dynamic)

[cm]	RMS Radial	RMS Normal	RMS Tang.
w/o clock	0.553	2.675	2.210
w/ clock	0.512	2.480	2.138



Integration of DORIS orbits: S6A

Sentinel-6A: With DORIS frequency drift estimation (current POE-F solution for S6A) / With GPS clock integration
From 26/05/2022 to 02/11/2022 - 160 days



RMS of the DORIS dynamic orbits with a reference orbit (DORIS + GPS reduced dynamic)

[cm]	RMS Radial	RMS Normal	RMS Tang.
w/ freq. drift	0.555	2.770	2.206
w/ clock	0.512	2.480	2.138

Conclusion

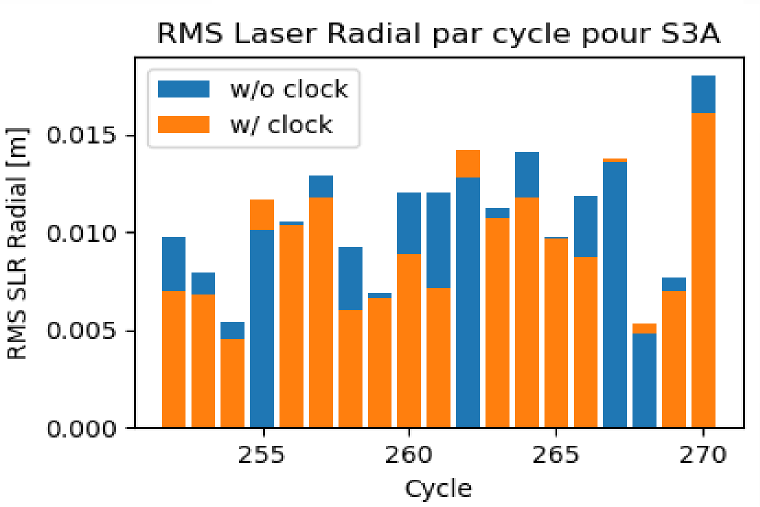
- The SAA effects on DORIS USO is satellite dependant (stronger for S3A than S3B and S6A) from oscillator observations

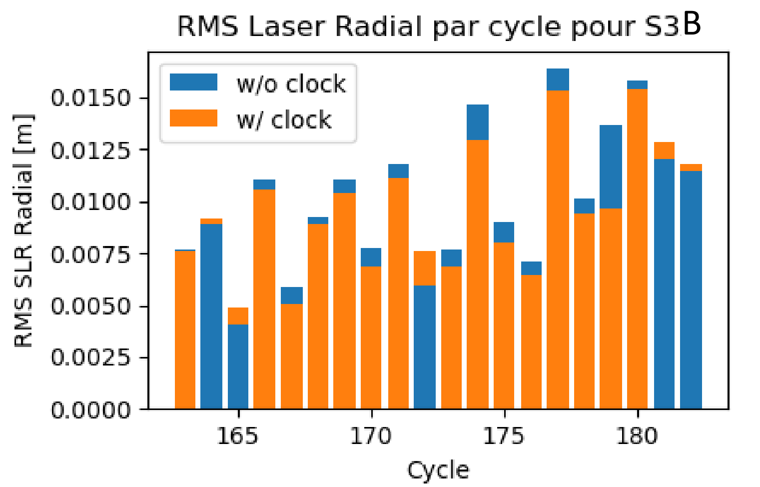
- The configuration of the Sentinel satellites (the USO driving both the GPS and DORIS instrument) can be used to determine USO high frequency variations

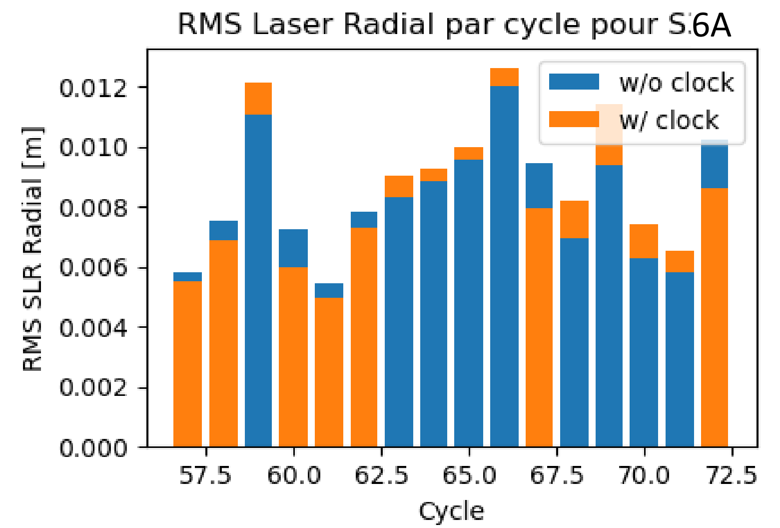
- The integration of the Sentinel GPS clocks allows to mitigate DORIS phase residuals for stations located in the SAA area (resulting SAA stations phase residuals are similar to non-SAA stations)

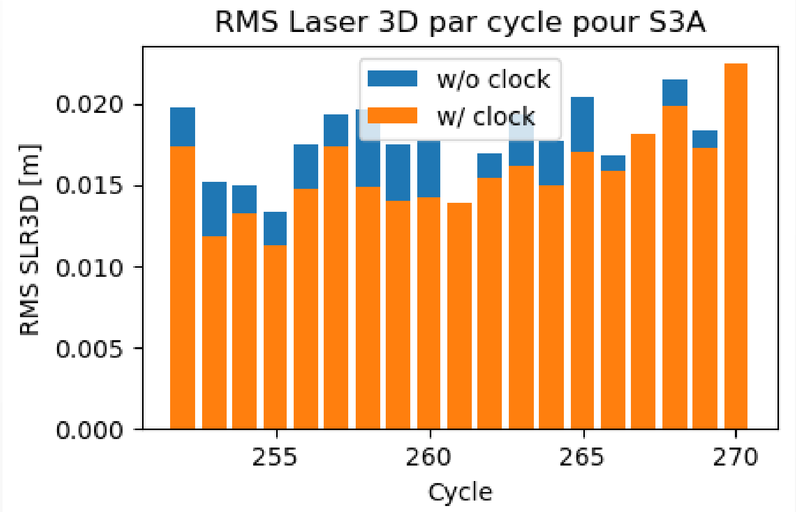
- Slightly better orbits with the clock integration even when comparing with orbits with DORIS frequency drifts corrections

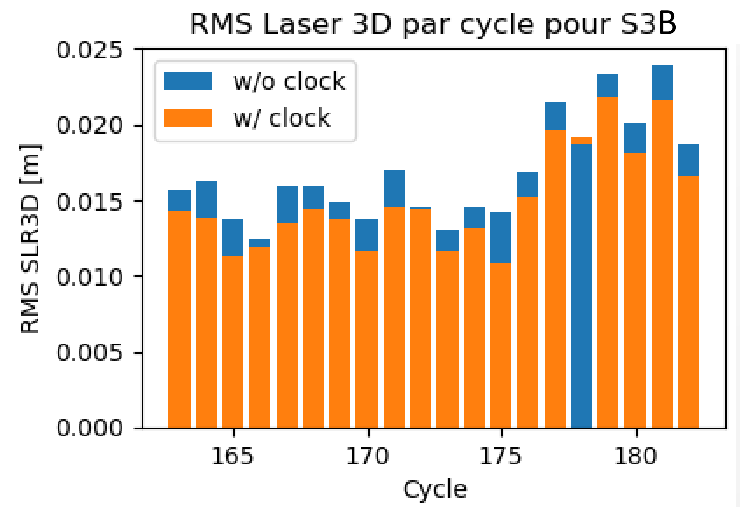
Integration of GNSS Clock : SLR validation

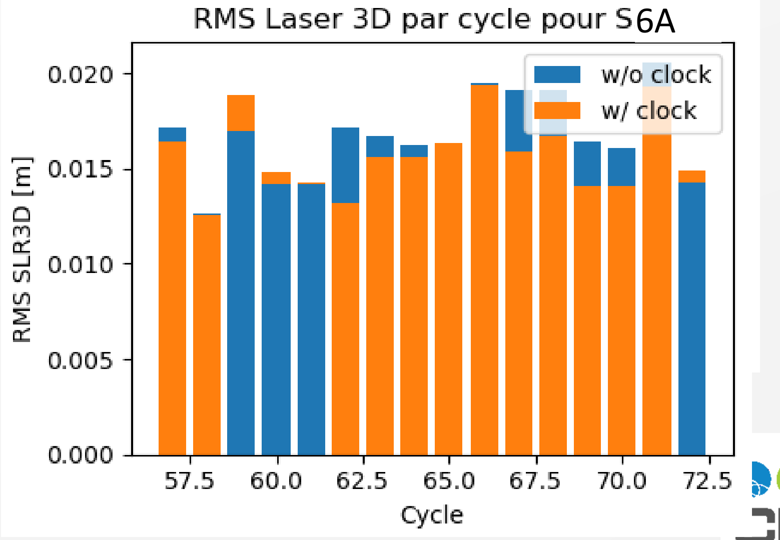




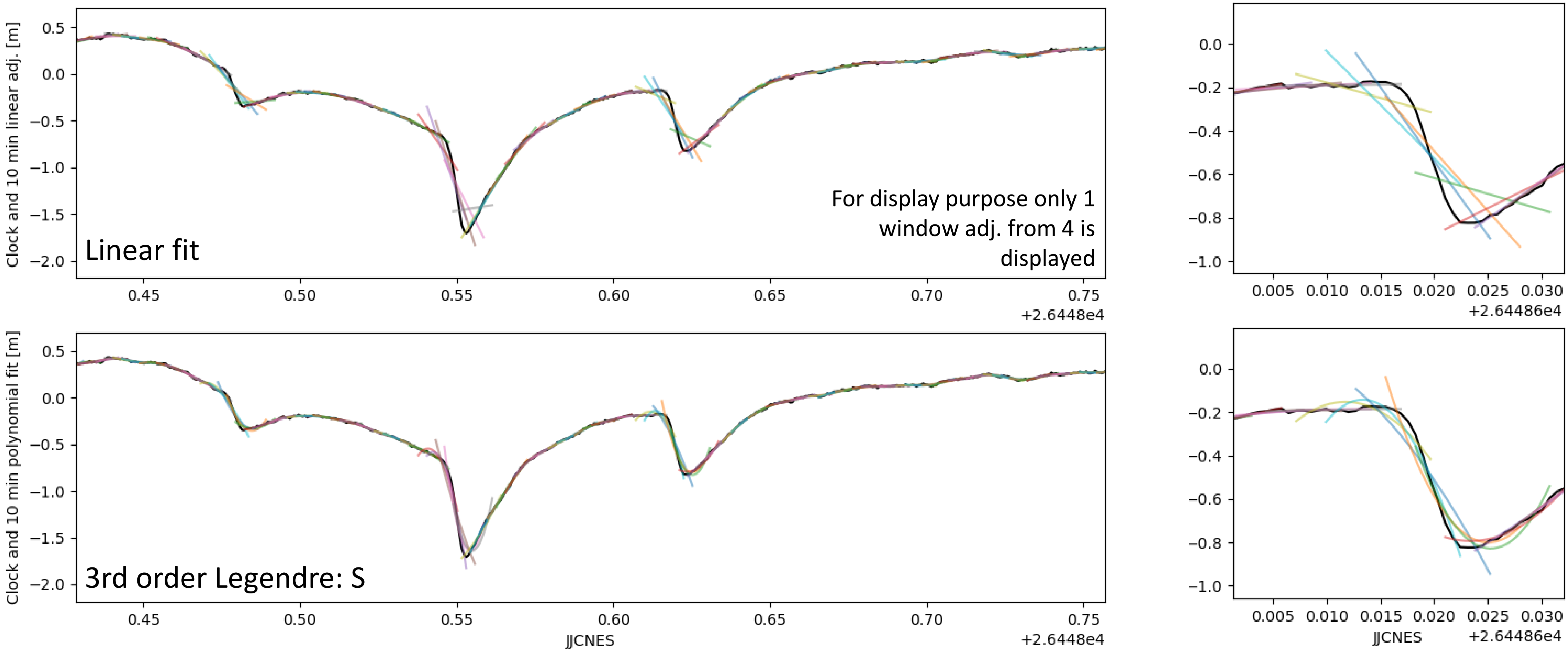








Decomposition of the clock signal: 10 minutes sliding windows (S3A example)

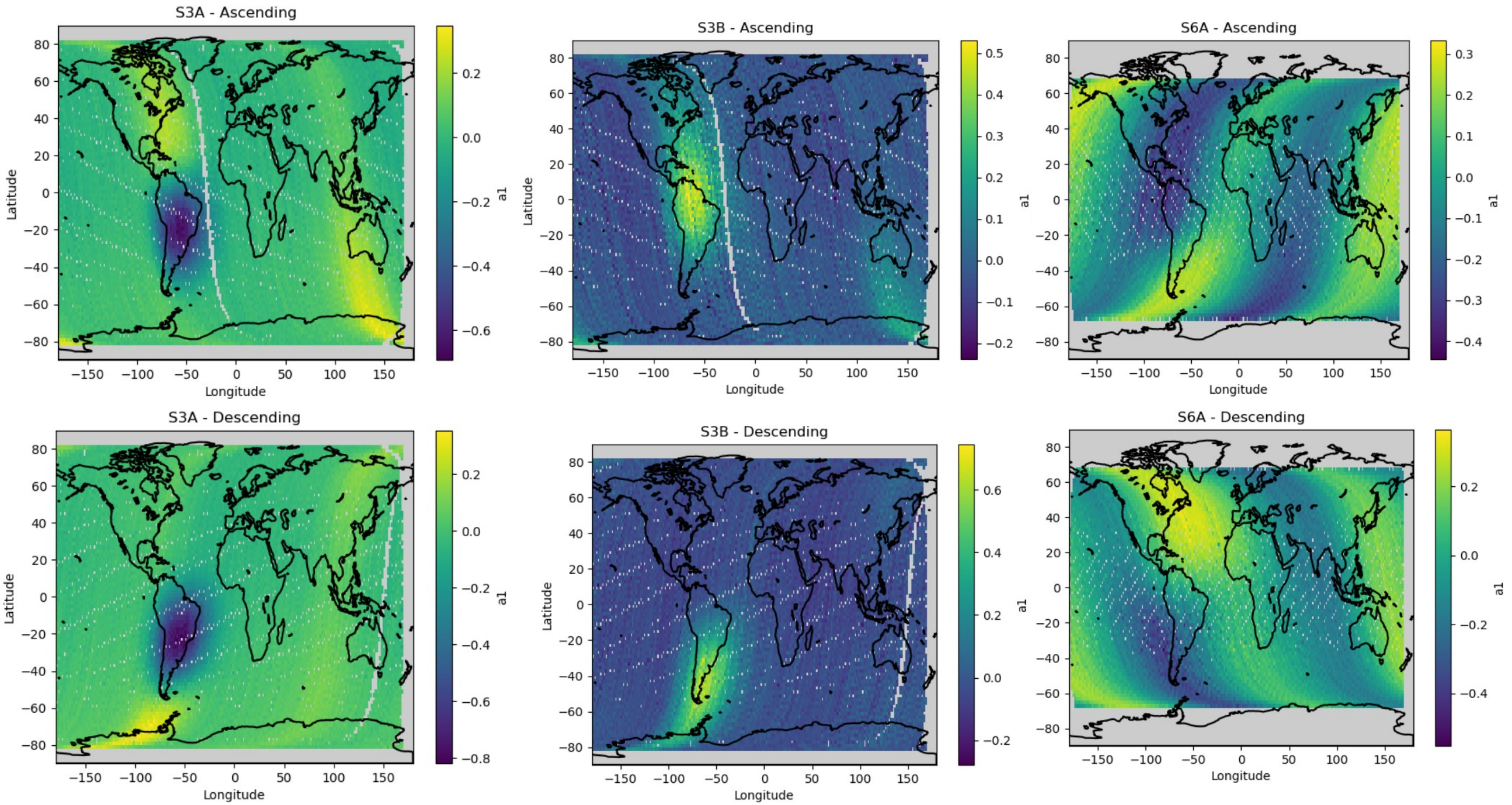


$$S = a_0 \cdot L_0 + a_1 \cdot L_1 + a_2 \cdot L_2 + a_3 \cdot L_3$$

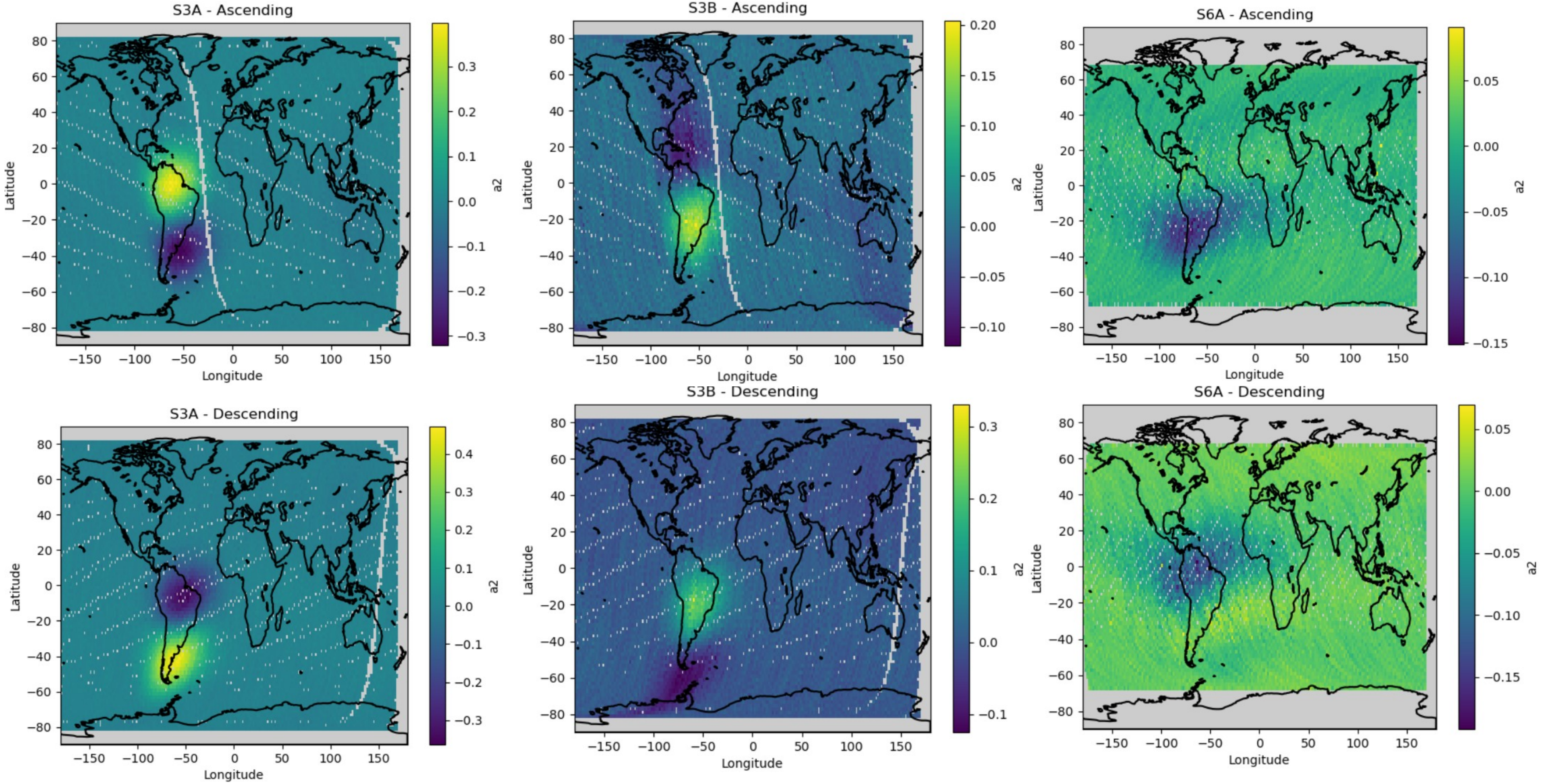
L_n: Legendre degree n

a_0: phase bias
a_1: frequency bias
a_2: frequency drift
a_3: frequency 2[nd] order

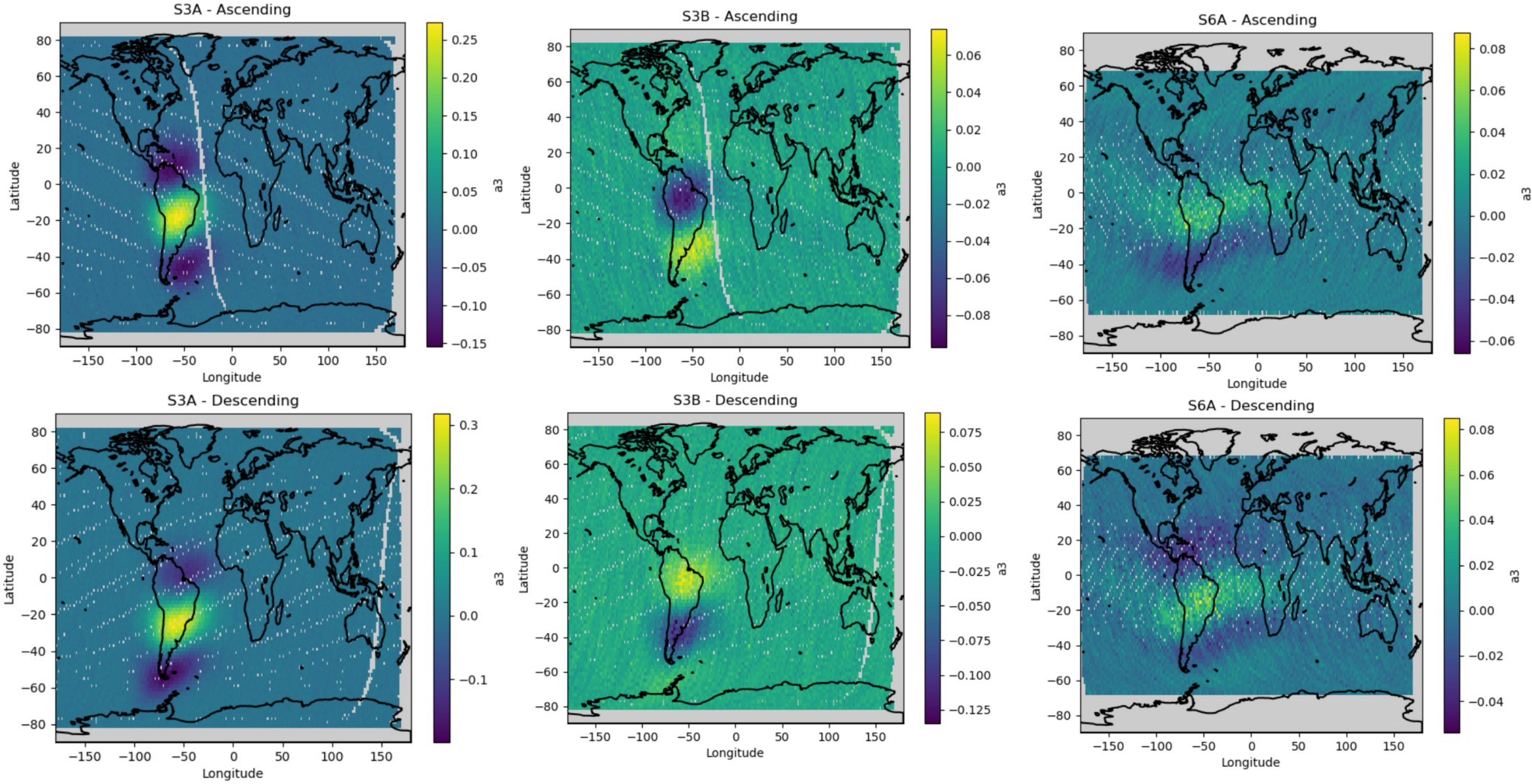
Frequency bias / a1



Frequency drift / a2



Degree 2/ a3


S3A - Ascending
S3B - Ascending
S6A - Ascending
S3A - Descending
S3B - Descending
S6A - Descending
Latitude
Longitude
a3