GNSS-Derived Clocks in DORIS: SAA Mitigation and Impact on Geodetic Parameters

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Using GNSS clocks estimates in DORIS Processing

- **Specific architecture of GNSS/DORIS receivers: the GNSS receiver clocks is driven by the DORIS USO.**
- **Only a polynomial clocksmodel can be estimated from DORIS observations.**
- **Epoch-wise clockscorrections can be estimated from GNSS observations.**
- **GNSS-derived clockscorrections enable the identification and correction of short-term USO instabilities that cannot be captured by the standard DORIS clocks model.**
- **The behavior of the DORIS USO can therefore be monitored using GNSS data.**
- **Applicable to Sentinel-3A/B, Sentinel-6A/B, and future satellites with the same receiver architecture.**
- **Particularly effective for detecting, characterizing, and mitigating the impact of the South Atlantic Anomaly (SAA) on USO stability.**

Clocks RINEX from GNSS processing

- **Software: Bernese 5.3 modified**
  - **Observations: S3-A/B: GPS only, S6-A: GPS + Galileo**
  - **GNSS products: CODE final GNSS satellite orbits, GNSS clocks (5 sec sampling), biases, and ERP parameters**
  - **Ambiguities: Fix to integer values**

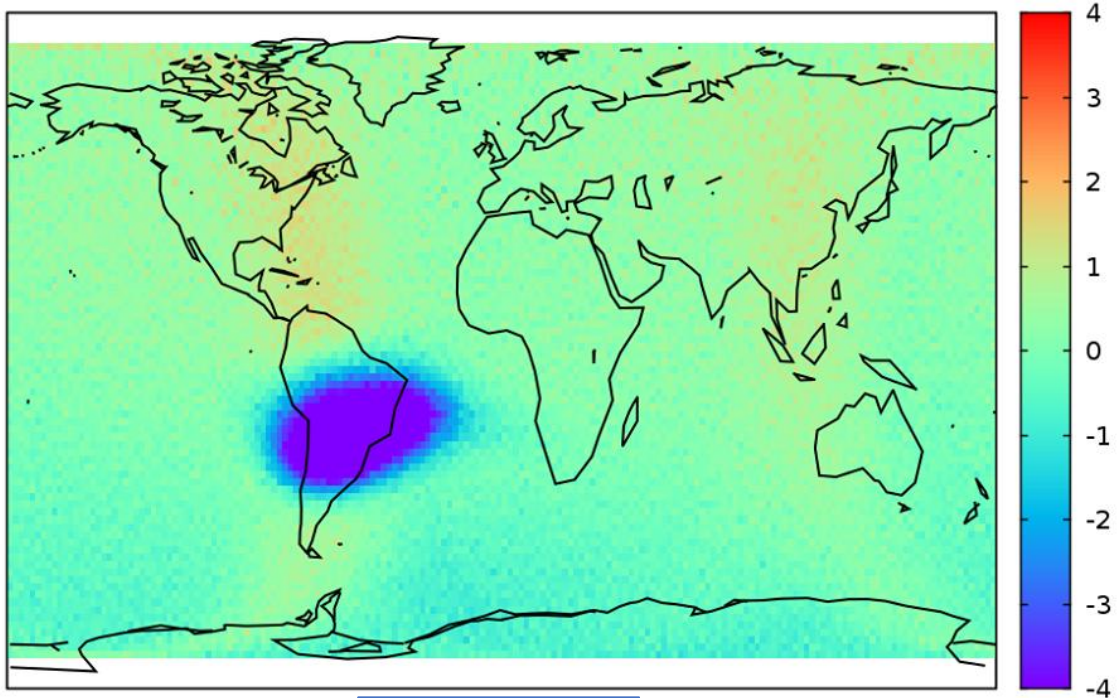
- **Model**
  - **IERS 2010 conventions**
  - **Origin: CoN**
  - **Ocean loading: CoN**
  - **Attitude: Quaterninions**
  - **Radiation pressure: Box-wing and 1-rev empiricals in along and cross-track directions**

- **Data span and sampling for Sentinel clocks**
  - **S3-A/B data from 2023 10 sec**
  - **S6-A data from 2023 30 sec**

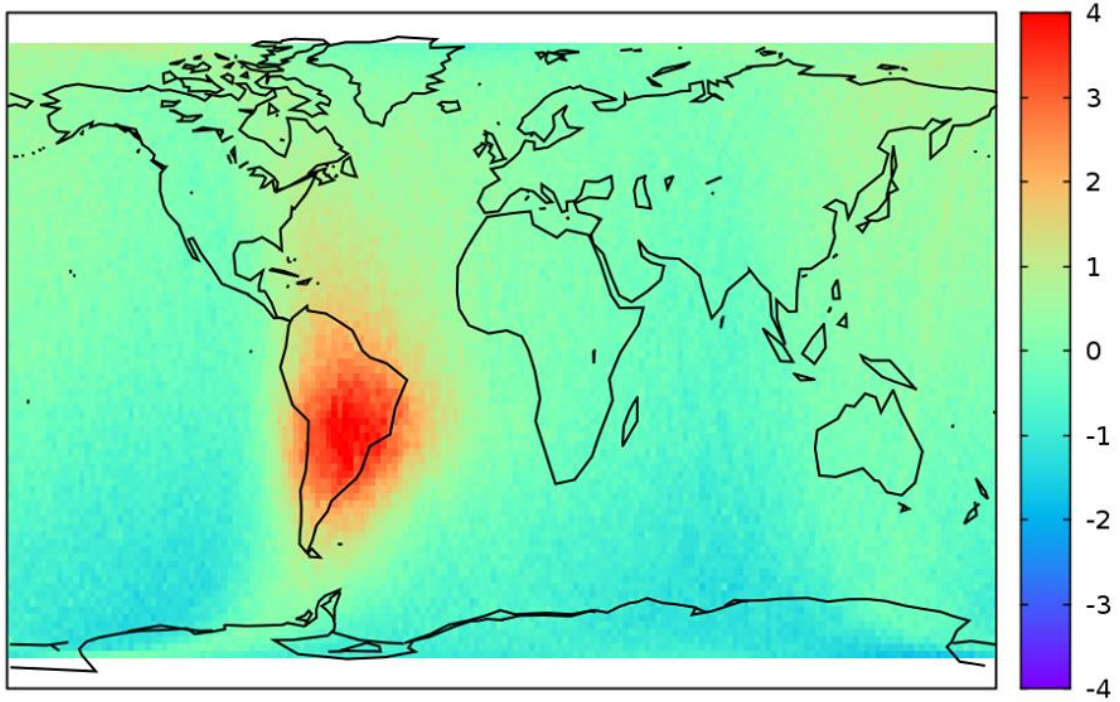
- **GNSS clocksRINEX (polynomial model + epochwise corrections data inconsistencies)**
  - **Missing intervals**
  - **Short data gaps (to be interpolated over)**
  - **Outliers**
  - **Jumps**

„Historical“ experiment on 2018.5-2019.5 data

- Štěpánek, P.; Bingbing, D.; Filler, V.; Hugentobler, U., 2020. Inclusion of GPS clocksestimates for satellites Sentinel-3A/3B in DORIS geodetic solutions, *JOURNAL OF GEODESY*, 94:116, DOI : 10.1007/s00190-020-01428-x
- USO frequency bias in ps/s
- Different sign of the effect for both Sentinels
- Differences in direct effect, recovery and memory effects

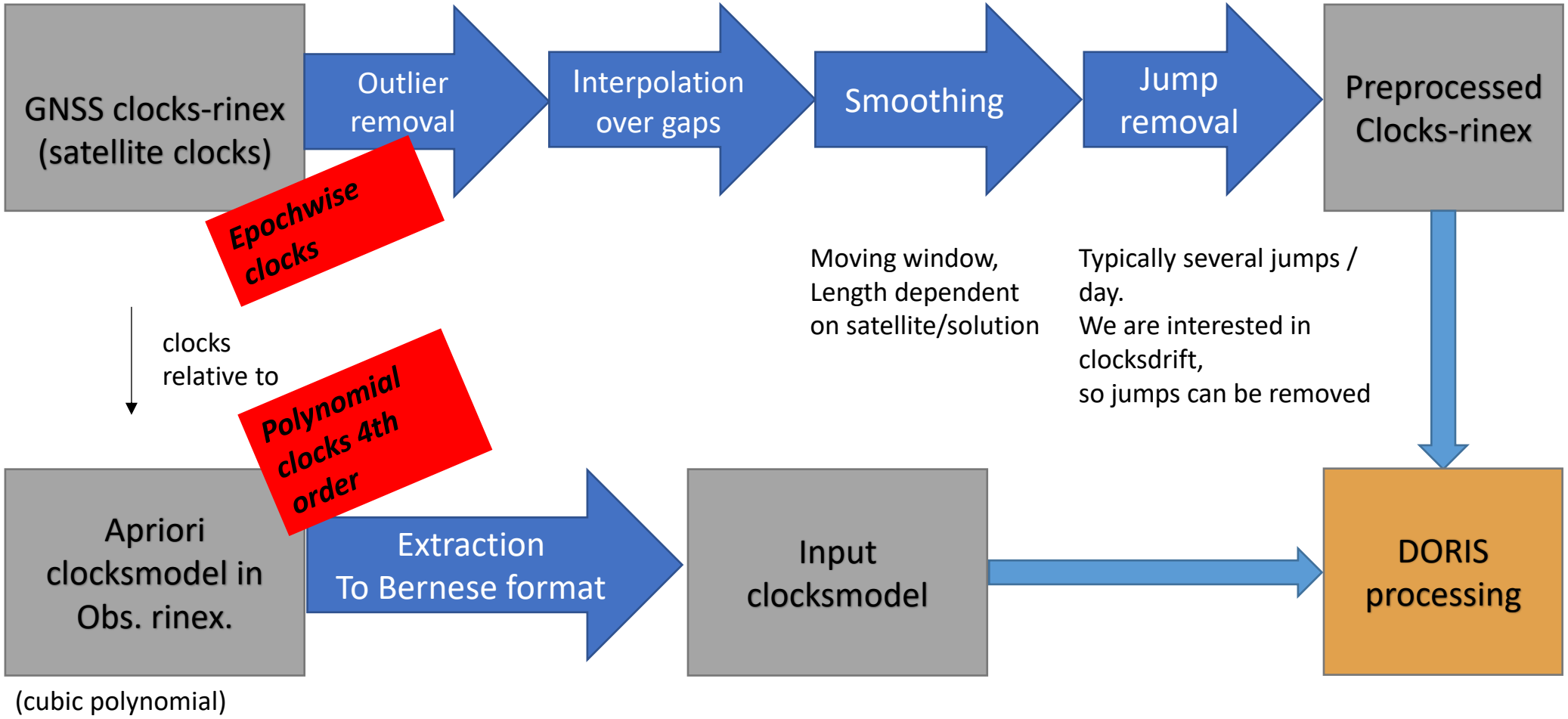


Sentinel-3A



Sentinel-3B

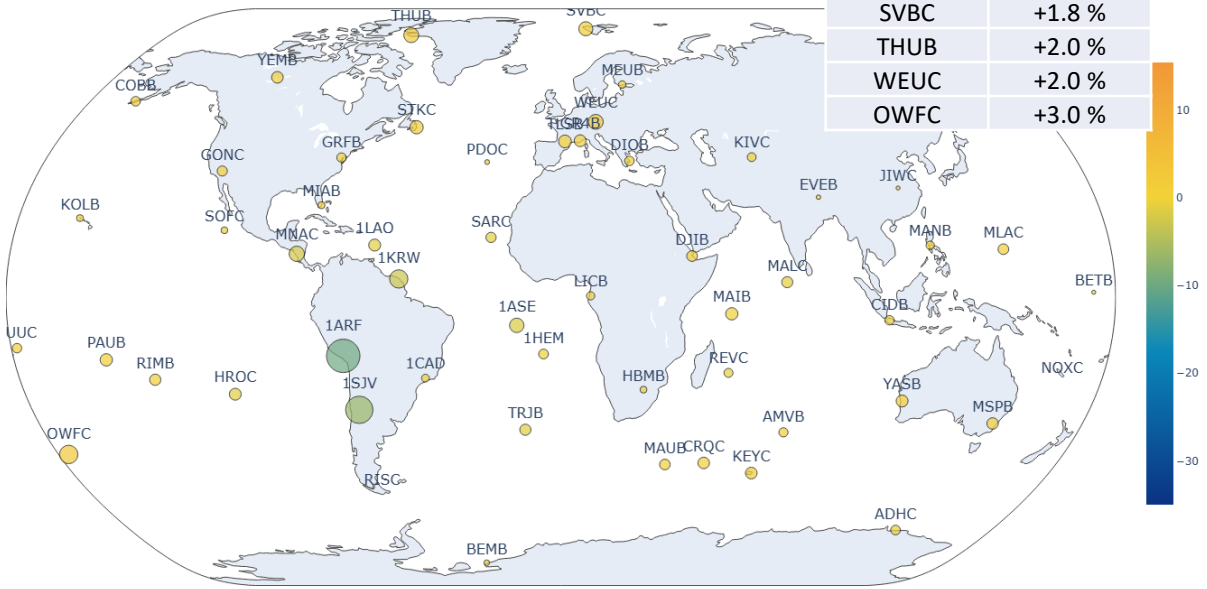
Clocks preprocessing chart



Residual RMS – change when using GNSS clocks (1)

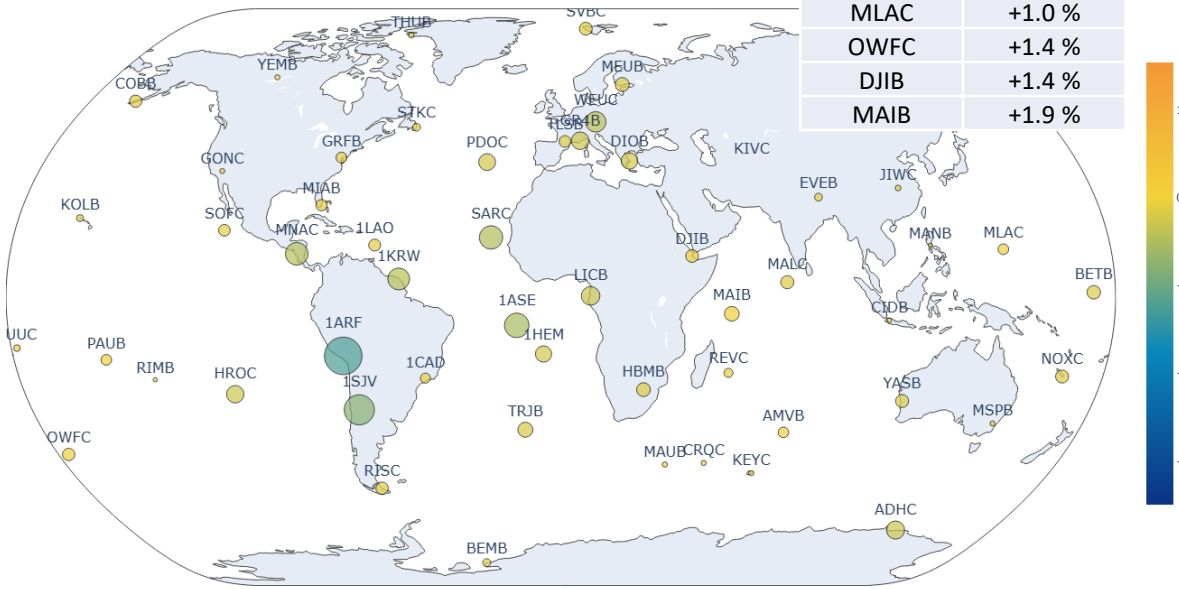
Sentinel-6A, smoothing level:9
Residual RMS change +0.1%
(whole network)

Site	RMS change
ARFB	-9.8 %
SJVC	-6.6 %
KRWB	-3.0 %
MNAC	-2.1 %
ASEB	-1.8 %
(…)	(…)
STKC	+1.6 %
SVBC	+1.8 %
THUB	+2.0 %
WEUC	+2.0 %
OWFC	+3.0 %



Sentinel-6A, smoothing level:3
Residual RMS change -1.6%
(whole network)

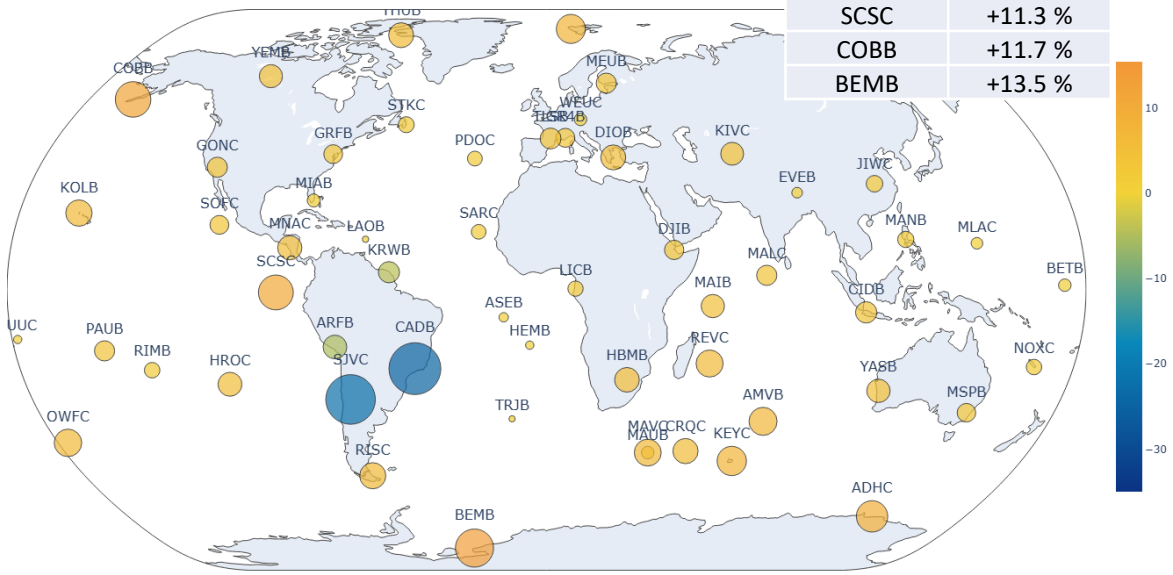
Site	RMS change
ARFB	-12.4 %
SJVC	-8.0 %
ASEB	-5.3 %
SARC	-4.8 %
MNAC	-4.6 %
(…)	(…)
PAUB	+1.0 %
MLAC	+1.0 %
OWFC	+1.4 %
DJIB	+1.4 %
MAIB	+1.9 %



Residual RMS – change when using GNSS clocks(2)

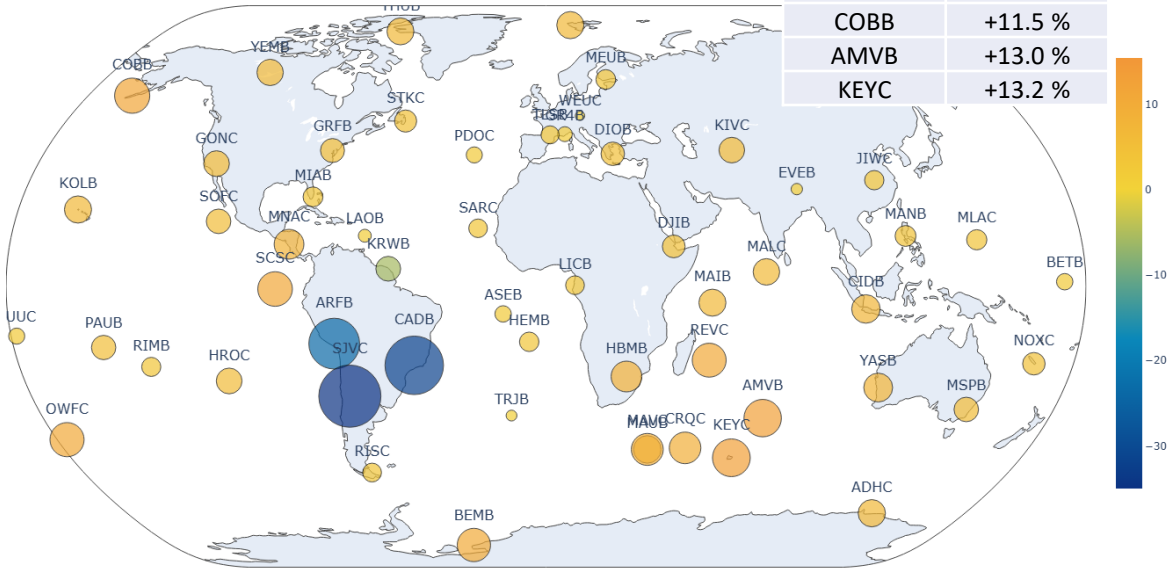
Sentinel-3A, smoothing level:21
Residual RMS change +3.0%
(whole network)

Site	RMS change
CADB	-25.0 %
SJVC	-22.9 %
ARFB	-5.2 %
KRWB	-4.2 %
TRJB	+0.4 %
(…)	(…)
KEYC	+8.0 %
ADHC	+9.2 %
SCSC	+11.3 %
COBB	+11.7 %
BEMB	+13.5 %



Sentinel-3A, smoothing level: 5
Residual RMS change +3.5%
(whole network)

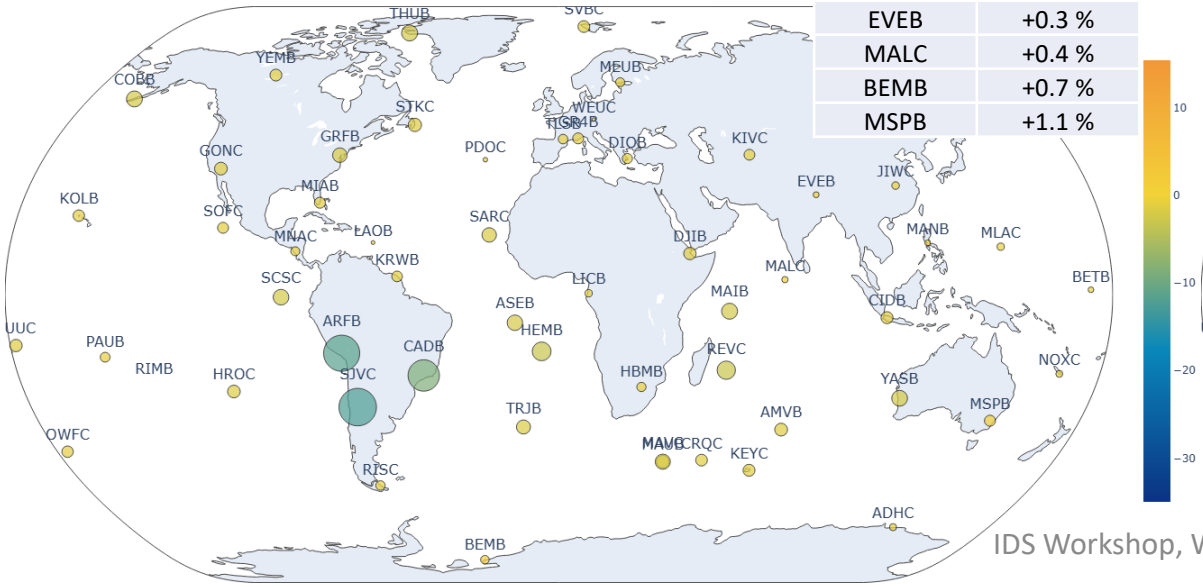
Site	RMS change
SJVC	-35.8 %
CADB	-31.8 %
ARFB	-23.9 %
KRWB	-5.7 %
WEUC	+0.8 %
(…)	(…)
OWFC	+10.8 %
SCSC	+11.1 %
COBB	+11.5 %
AMVB	+13.0 %
KEYC	+13.2 %



Residual RMS – change when using GNSS clocks(3)

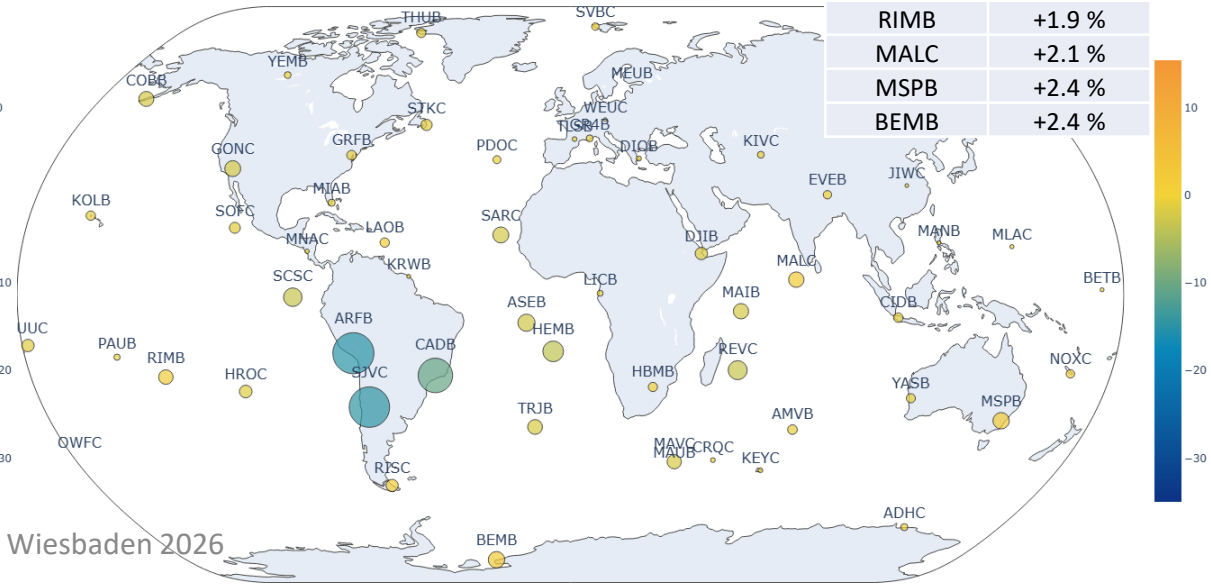
Sentinel-3B, smoothing level:9
Residual RMS change -1.6%
(whole network)

Site	RMS change
SJVC	-12.4 %
ARFB	-11.5 %
CADB	-8.7 %
HEMB	-3.1 %
REVC	-3.0 %
(...)	(...)
RIMB	+0.0 %
EVEB	+0.3 %
MALC	+0.4 %
BEMB	+0.7 %
MSPB	+1.1 %



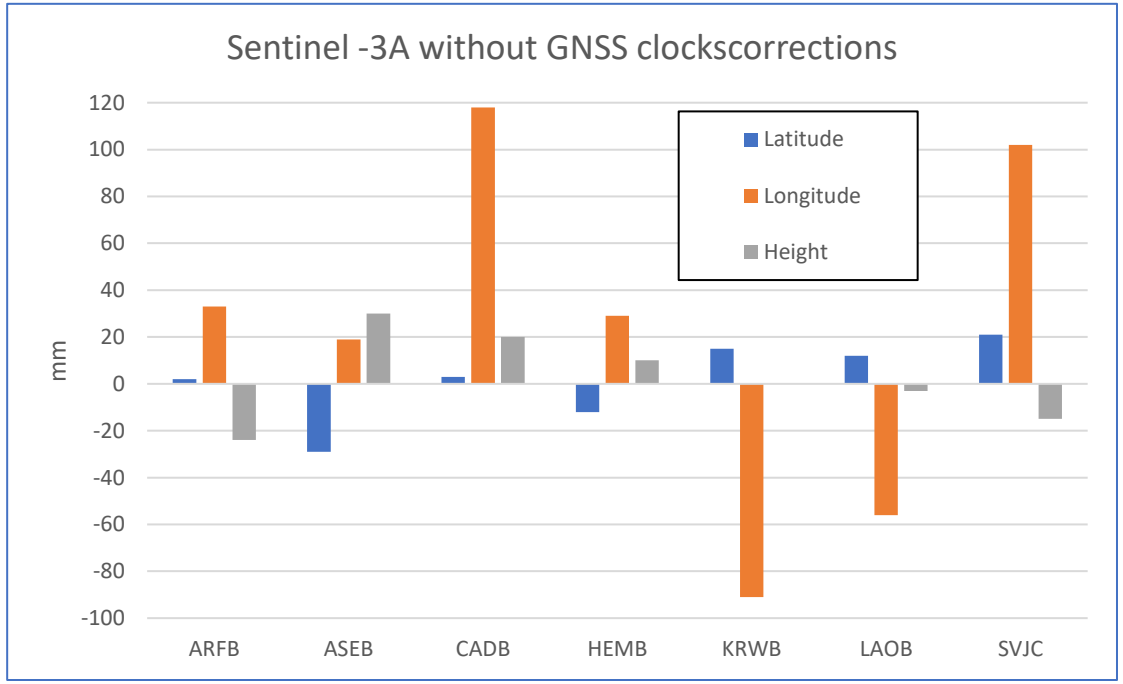
Sentinel-3B, smoothing level:3
Residual RMS change -1.0%
(whole network)

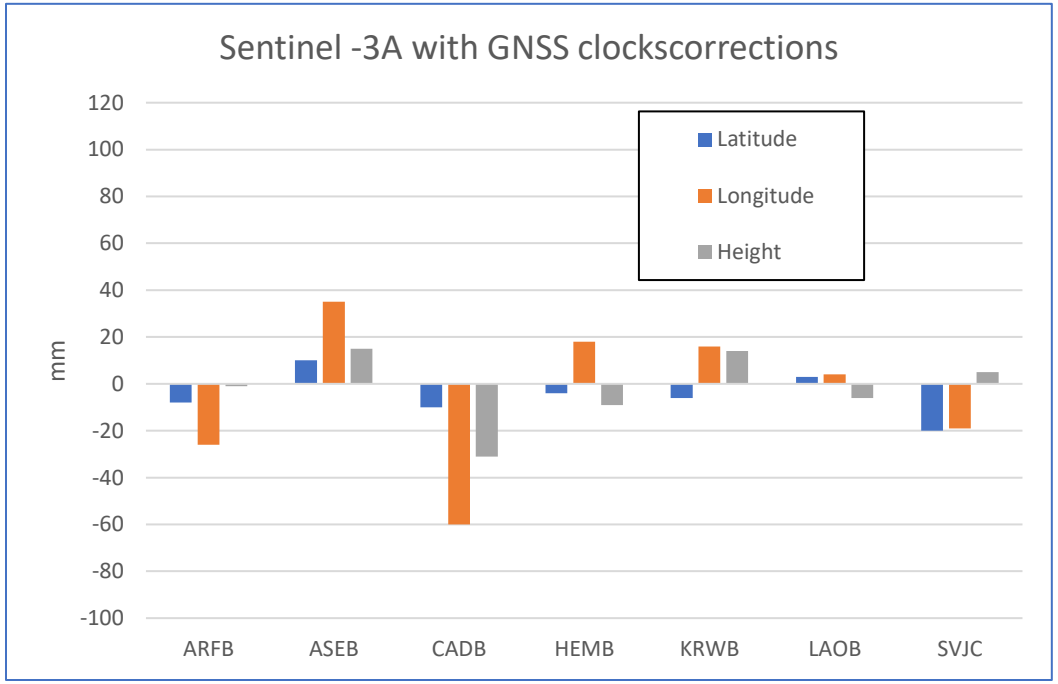
Site	RMS change
ARFB	-15.0 %
SJVC	-14.5 %
CADB	-10.5 %
HEMB	-3.8 %
REVC	-3.2 %
(...)	(...)
RISC	+1.3 %
RIMB	+1.9 %
MALC	+2.1 %
MSPB	+2.4 %
BEMB	+2.4 %



Sentinel-3A positioning

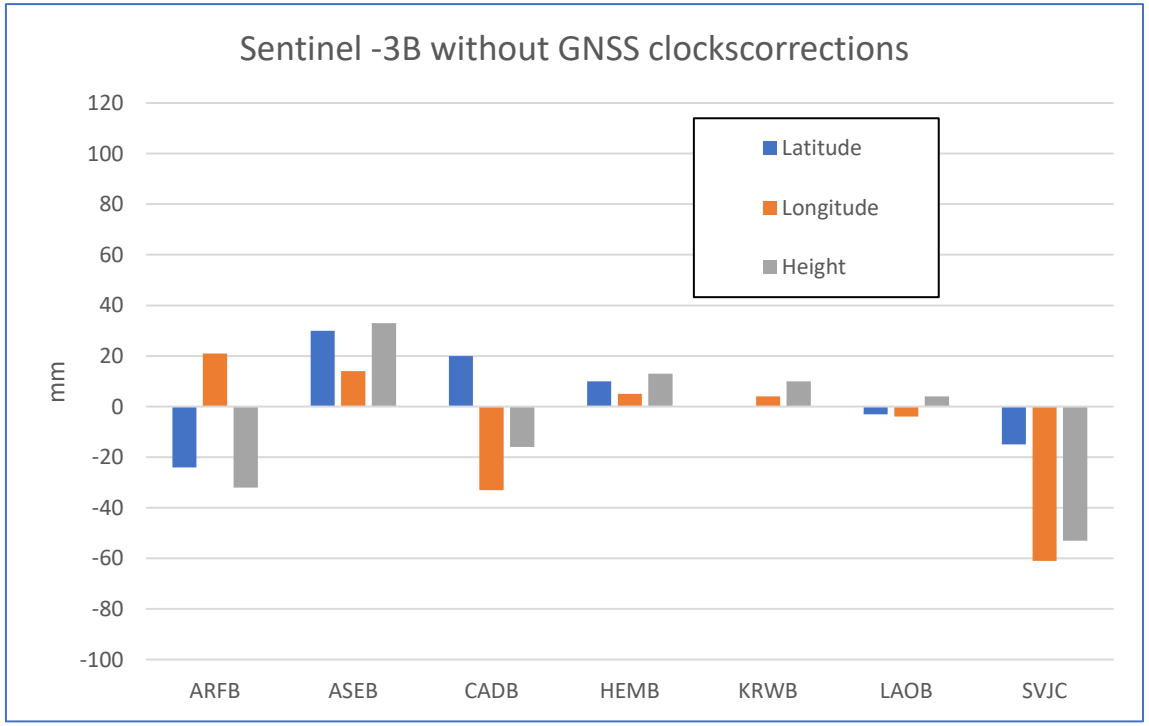
Single satellite solution
Differences vs DPOD 2025
Significant reduction for SAA stations when GNSS clocks applied

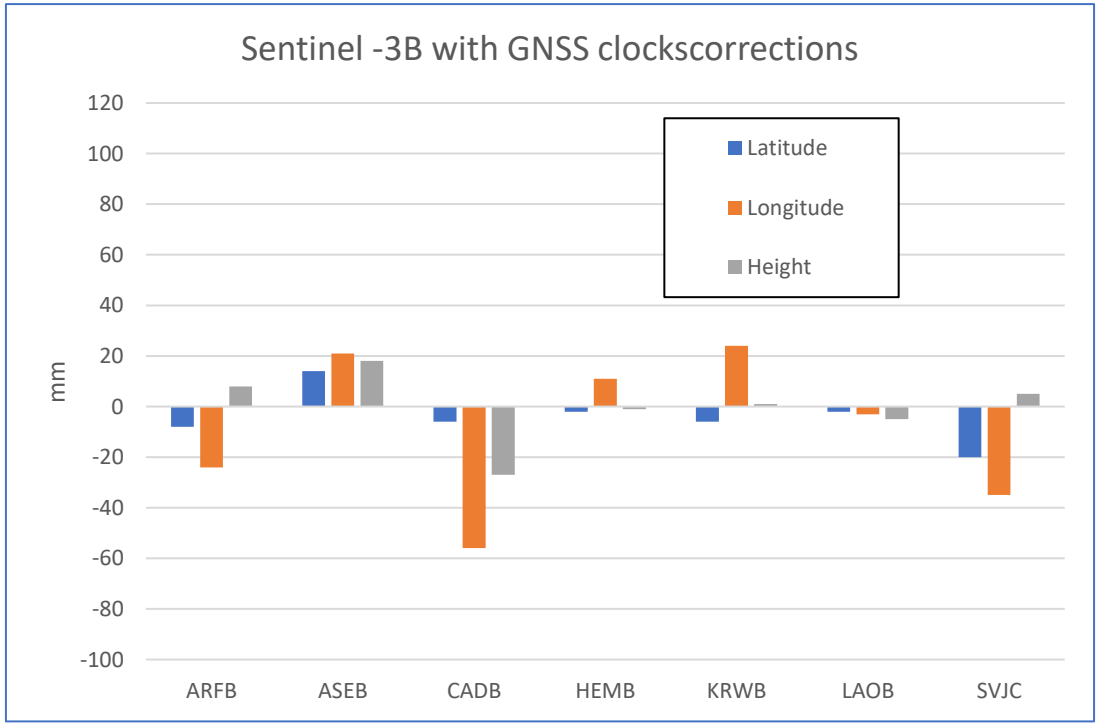




Sentinel-3B positioning

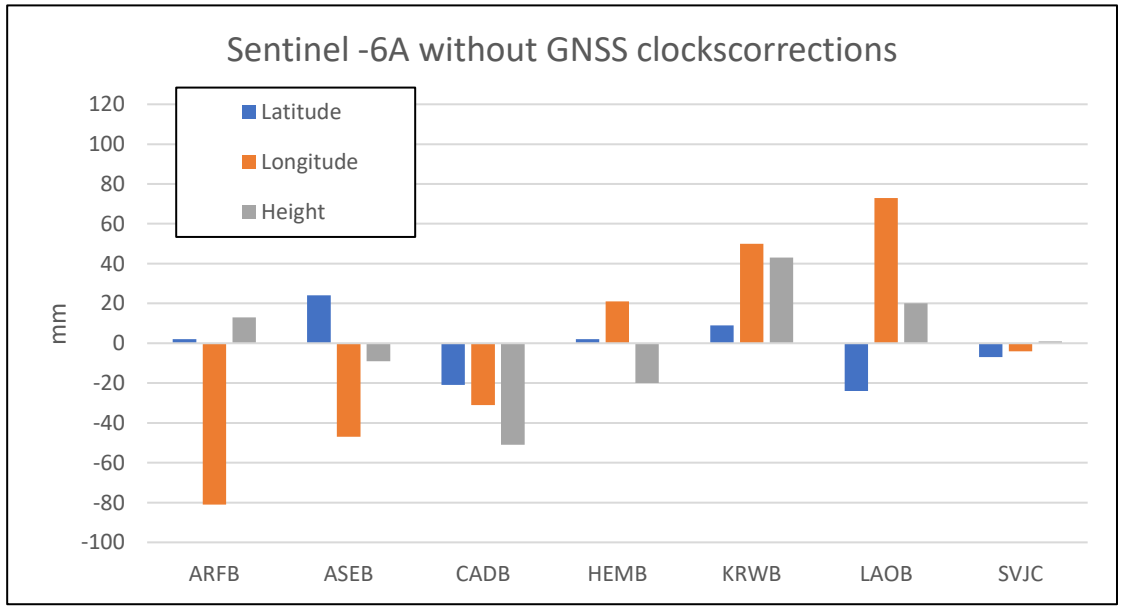
Single satellite solution
Differences vs DPOD 2025
Differences lower than for Sentinel-3A

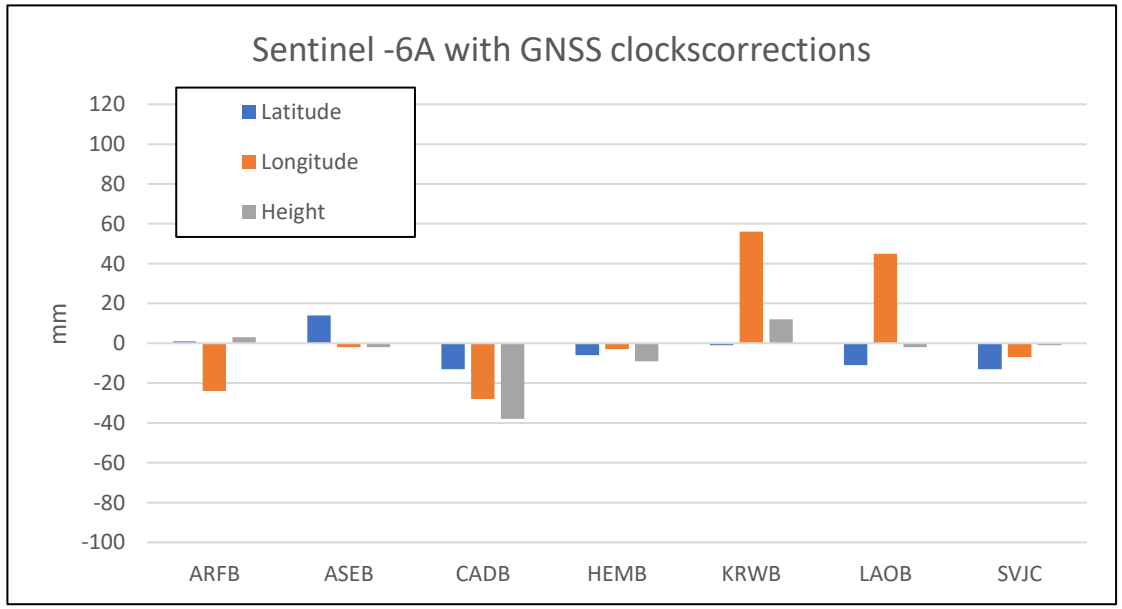




Sentinel-6A positioning

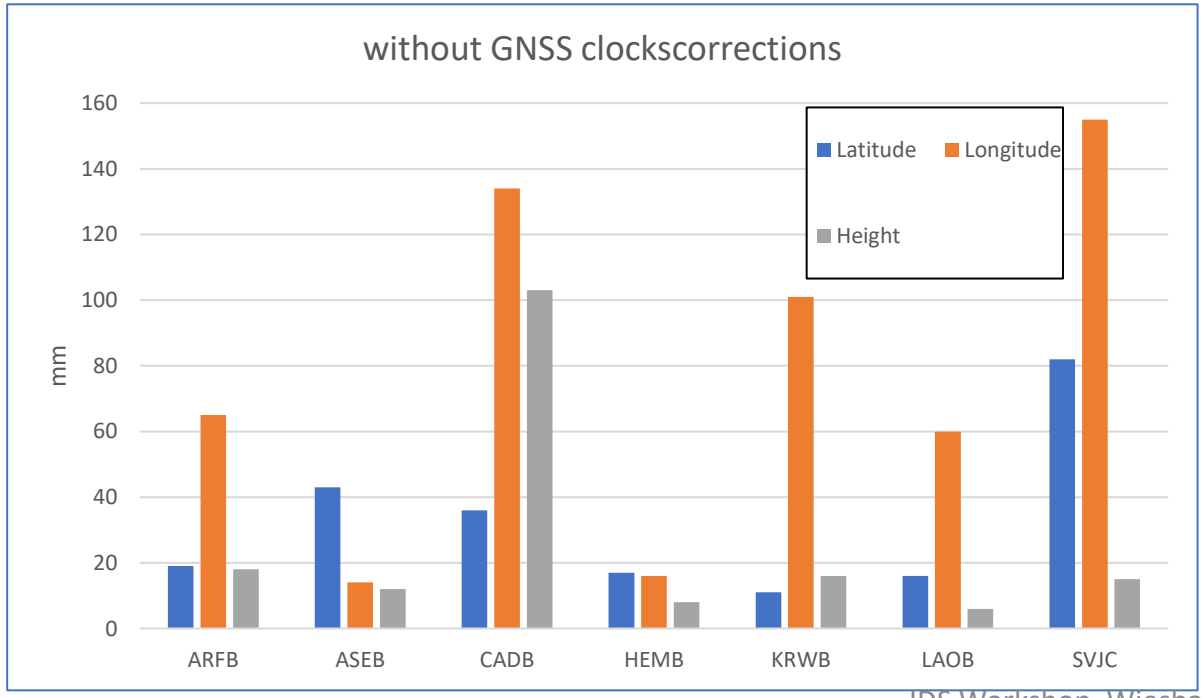
Single satellite solution
Differences vs DPOD 2025
Only 6 weeks
Significant reduction for SAA stations (except KRWB)

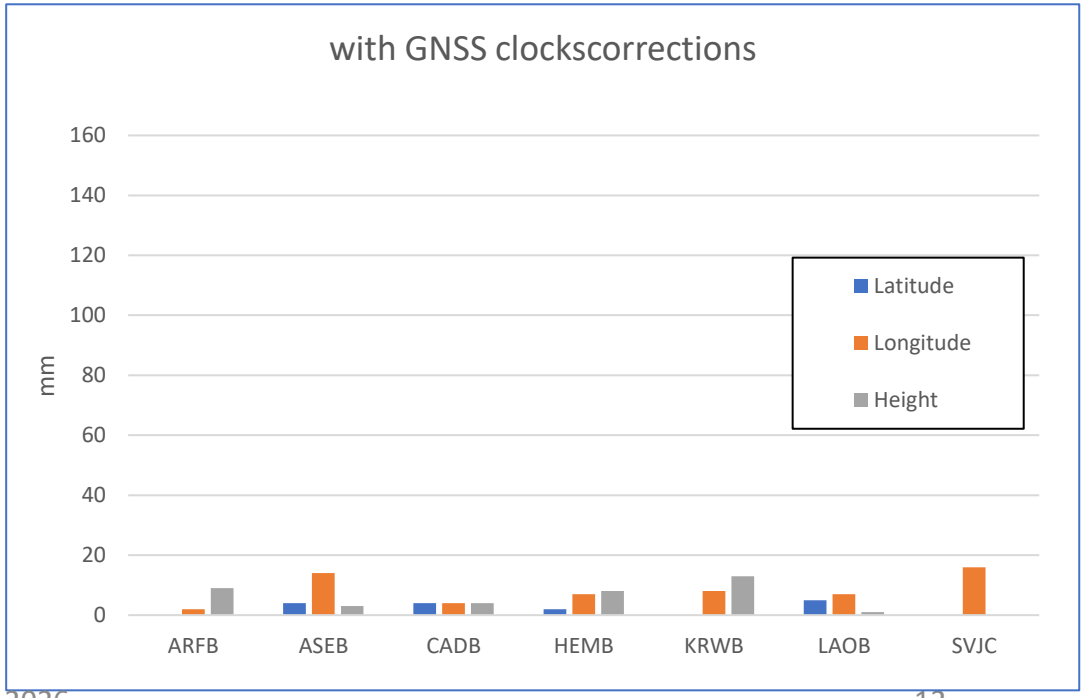




Differences between single satellite solutions

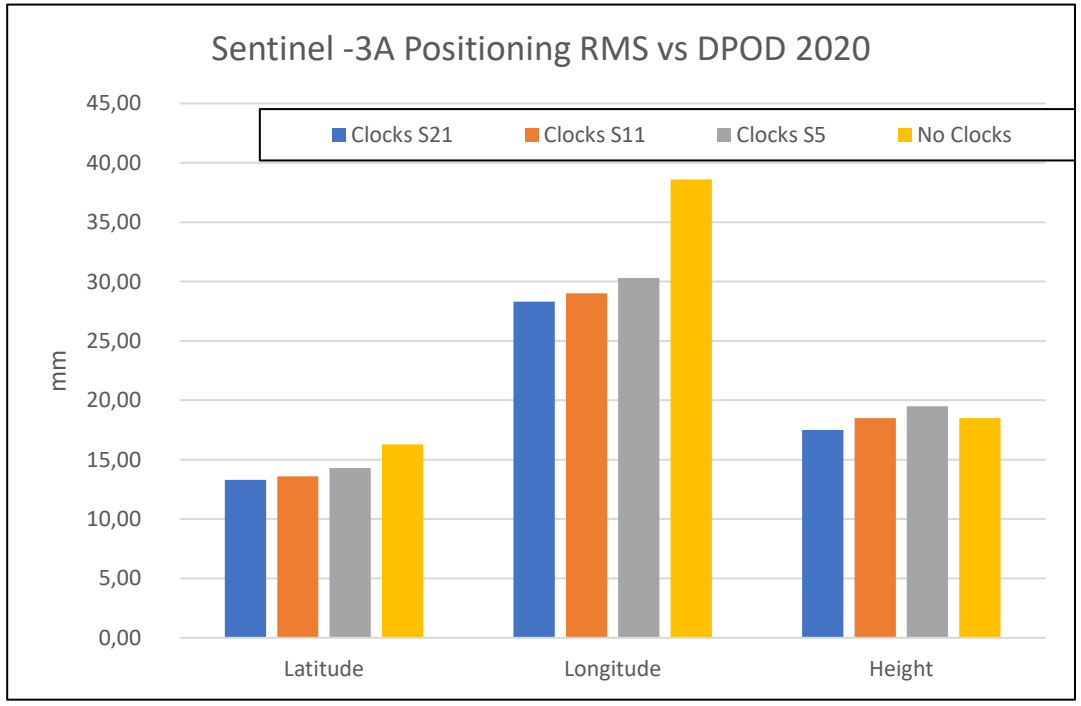
Station coordinates differences between single satellite solutions
Sentinel-3A vs Sentinel-3B
Very significant reduction for SAA stations when GNSS clocks applied

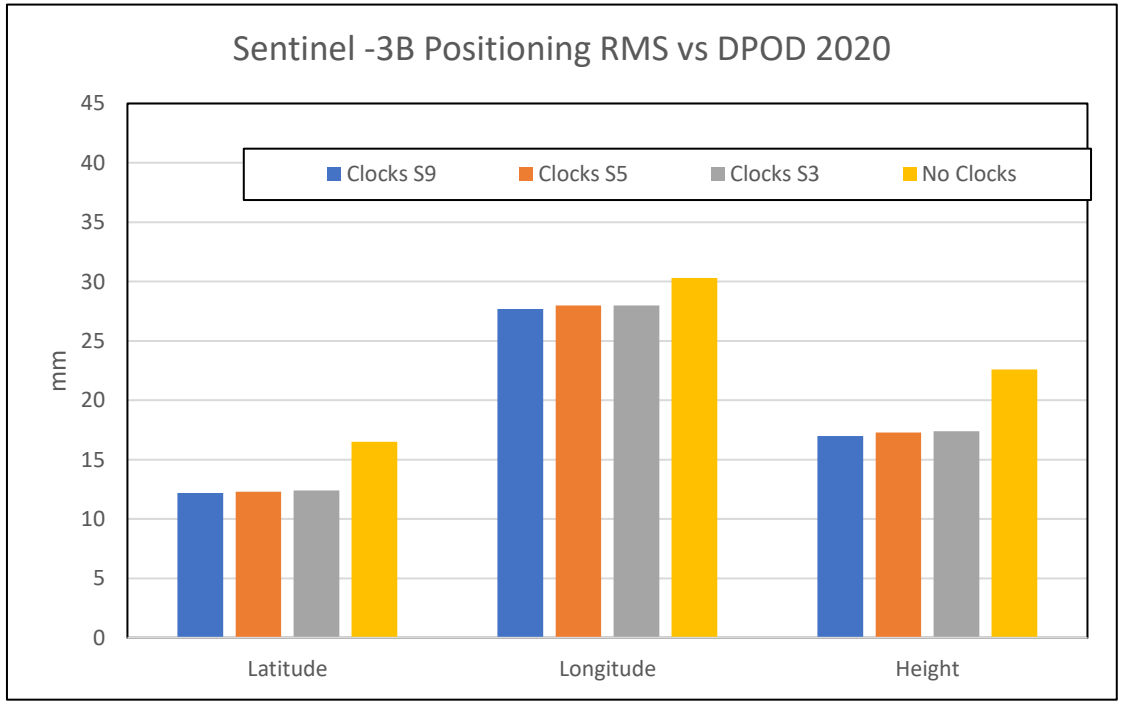




Positioning –whole network

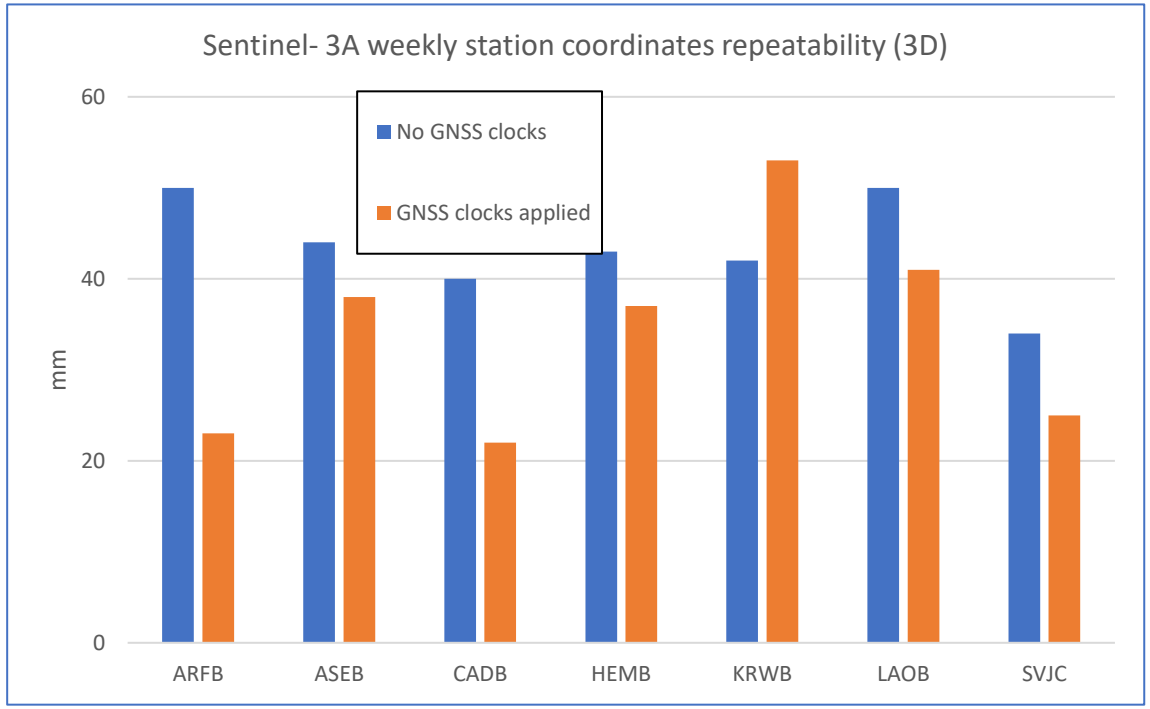
Sentinel-3A improvement for Latitude and Longitude
Sentinel-3A – higher level of smoothing – best performance
Sentinel-3B improvement for all components

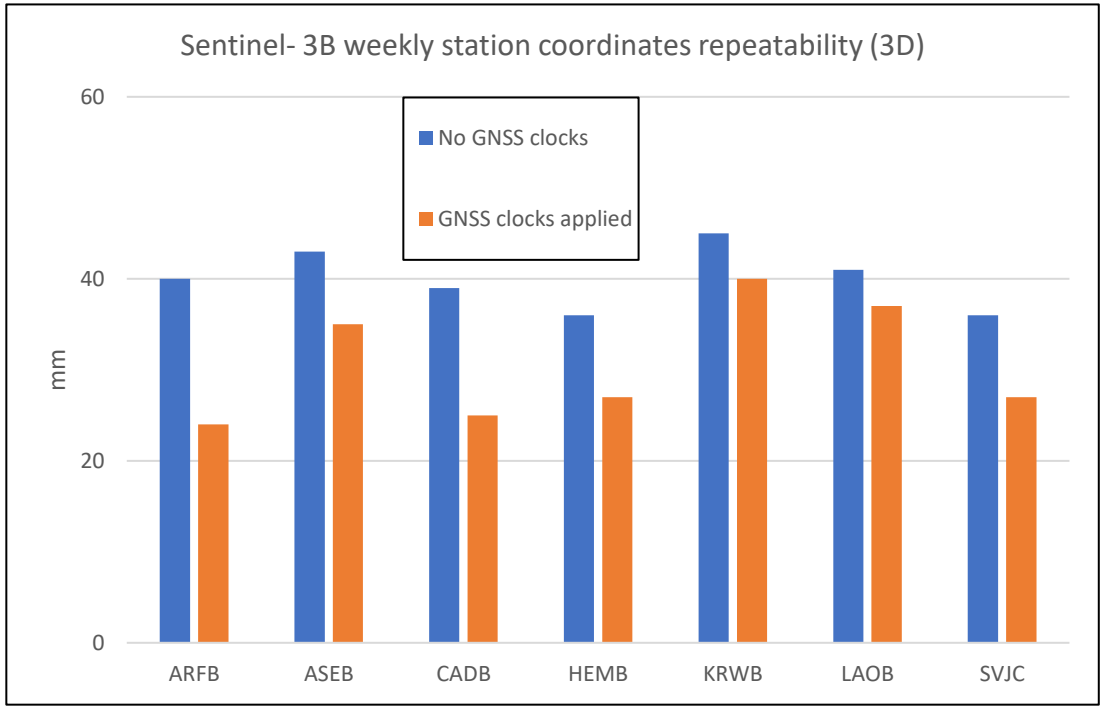




Weekly station coordinates repeatability 3D

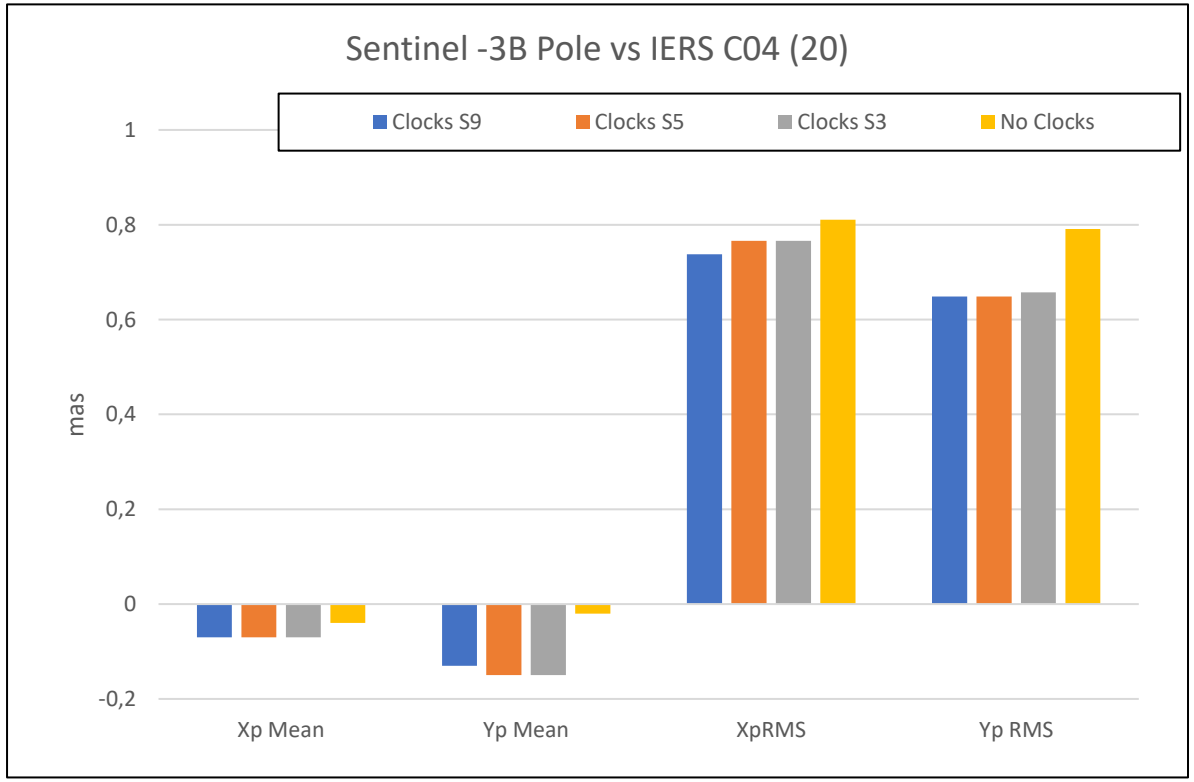
Sentinel-3A improvement for all the SAA stations except KRWB
Sentinel-3B improvement for all the SAA stations

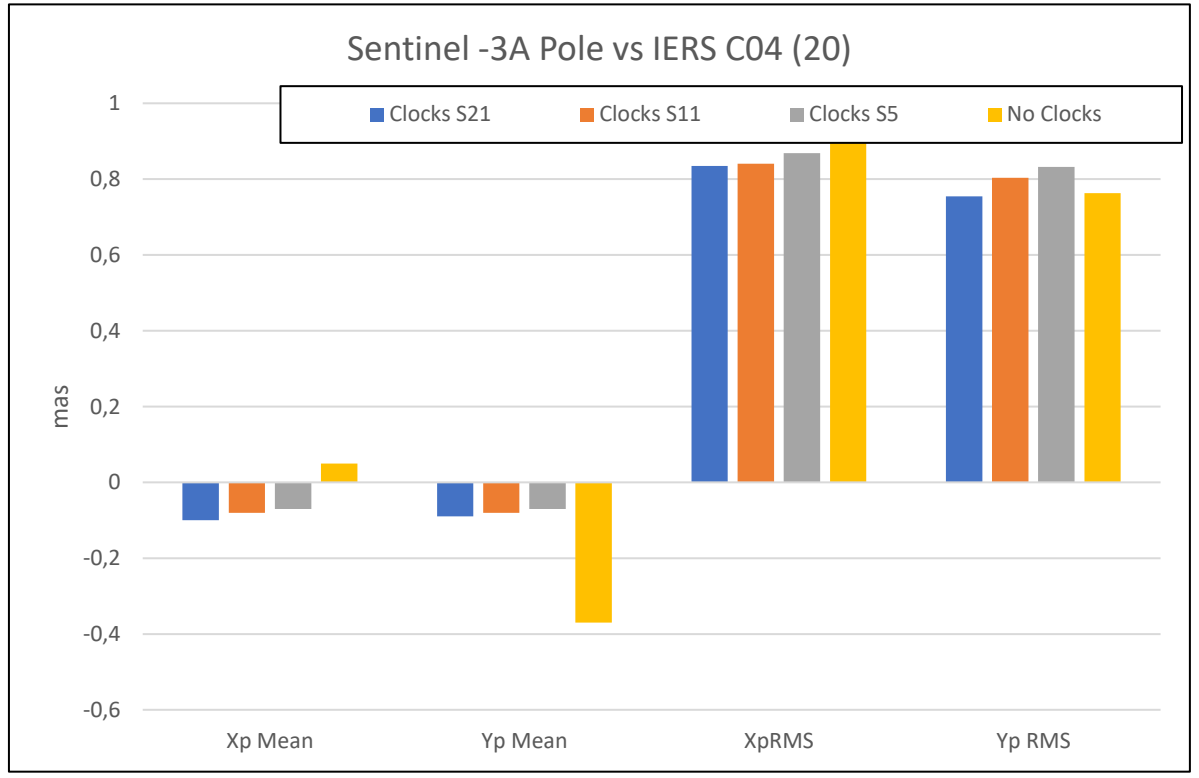




Pole coordinates estimation

Sentinel-3A – improvement in Yp Mean and Xp RMS
Sentinel-3A – higher level of smoothing – best performance
Sentinel-3B – improvement in Xp and Yp RMS





Conclusions

- **Determining the optimal smoothing level (higher for Sen-3A)**
- **Improving positioning characteristics for SAA**
- **Residual reduction for major SAA stations**
- **Sen-3A: Residual increase outside the SAA area when applying GNSS clocks**
- **Sen-6A results should be considered preliminary**
- **Excellent agreement in Sen-3A and Sen-3B positioning when GNSS clocks**

Outlook

- **Other GNSS clock solution, 5 sec sampling if available, less gaps if possible**
- **Noise in Sen-3A GNSS clocks series – can be reduced?**
- **GNSS clocks applied only in SAA area or for SAA stations?**
- **Correct Jason-3 observations profiting from the temporary tandem mode (Sentinel-6A and Jason-3)**