Sentinel-1 interferometric parameters monitoring by SAR-MPC and Burst IDs in TOPS products

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Introduction

- Doppler Centroid pointing
- Interferometric baseline
- Burst synchronization error
- Burst cycle IDs
- Burst ID maps

Acknowledgements

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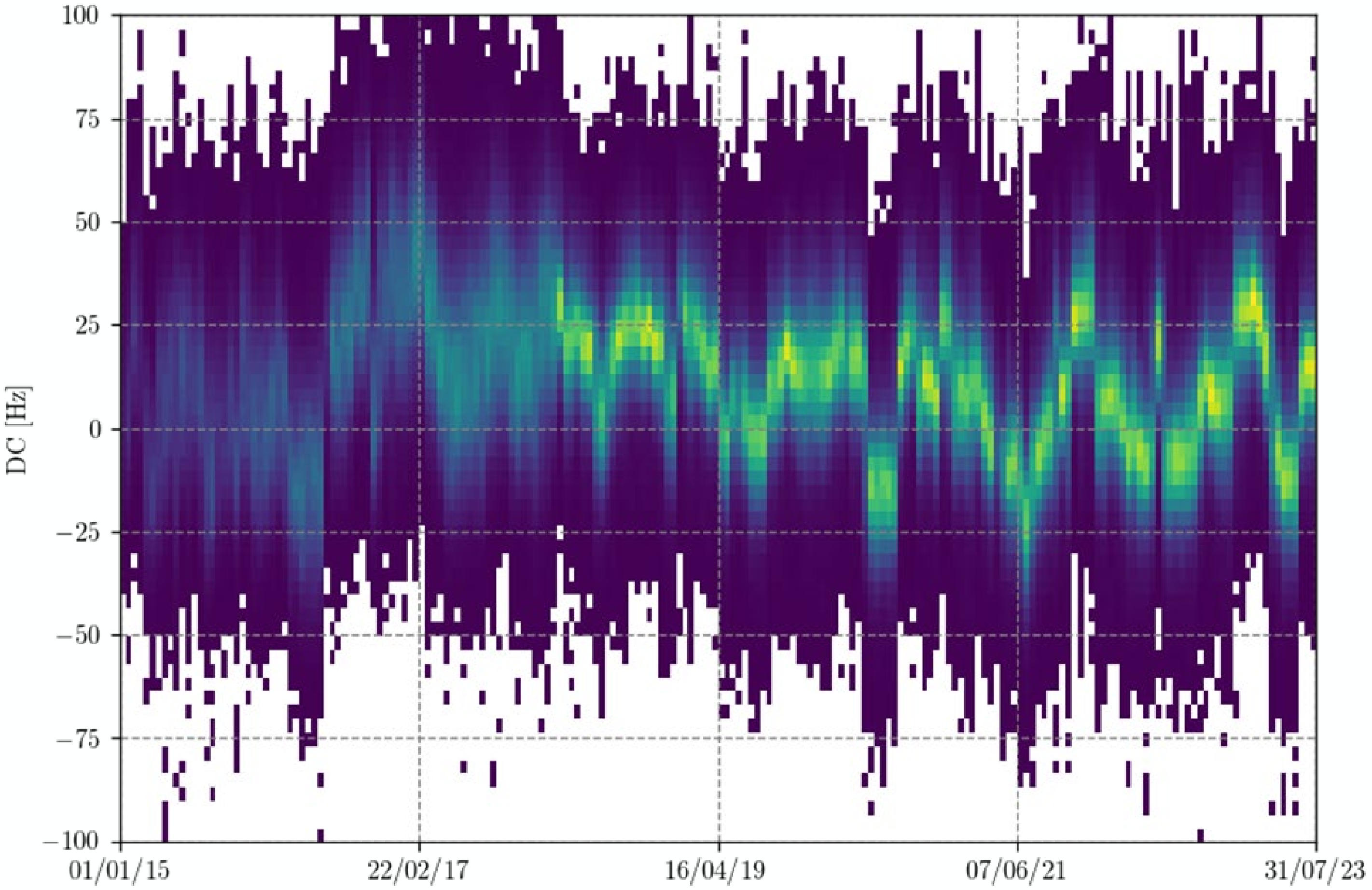
SAR-MPC

Doppler centroid

DC measurements since 2015

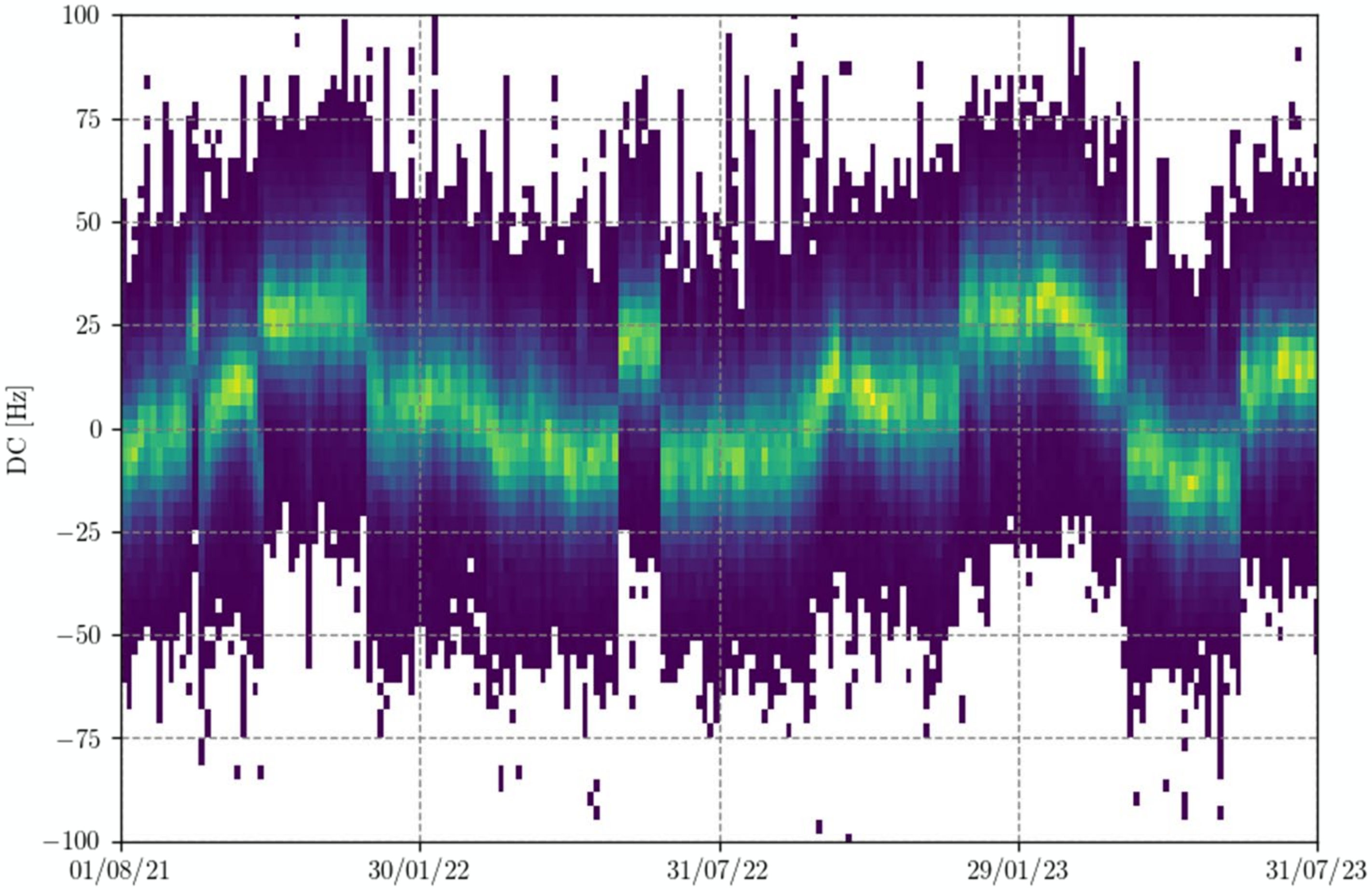


- When the on-board Star Trackers (STTs) configuration changes there can be DC jumps up to 30 Hz. This is a known problem due to the non-perfect alignment of the on board STTs.

- A pointing difference between the two acquisitions of an interferogram can cause a loss in interferometric coherence.

Doppler centroid

DC measurements in last two years



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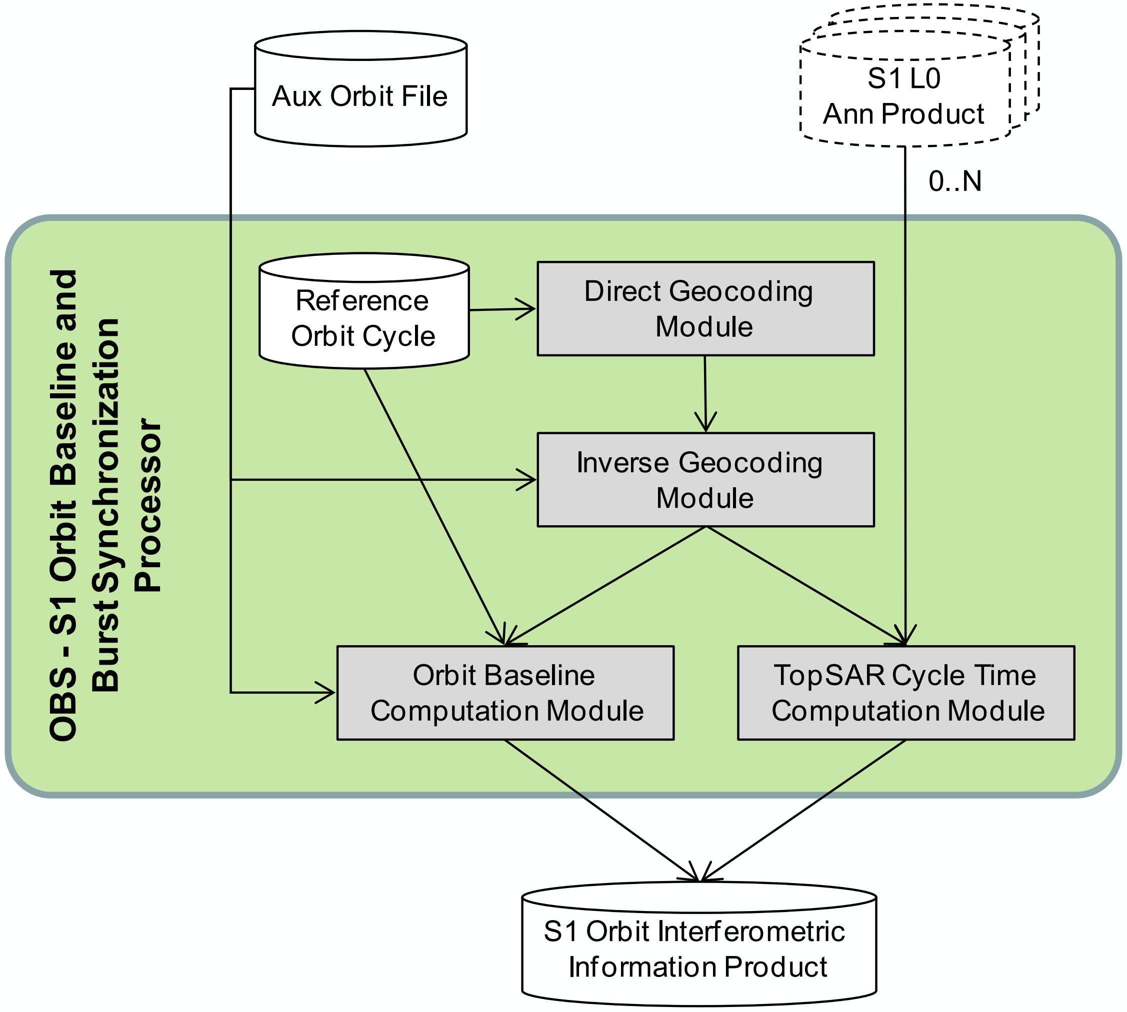
Monitoring of interferometric performances

- The quality of an interferogram depends, among others:
  - on the acquisition geometry, i.e., the interferometric baseline
  - for ScanSAR and TopSAR modes involving bursts, on the synchronization between bursts of different acquisitions
- The interferometric baseline and burst synchronization are estimated by first processing the S-1A orbit and L0 annotation products of an acquisition, creating an Orbit Baseline and Synchronization (OBS) product for each acquisition. Then two OBS products of two acquisitions are combined to estimate the quality of the corresponding interferogram



Baseline monitoring

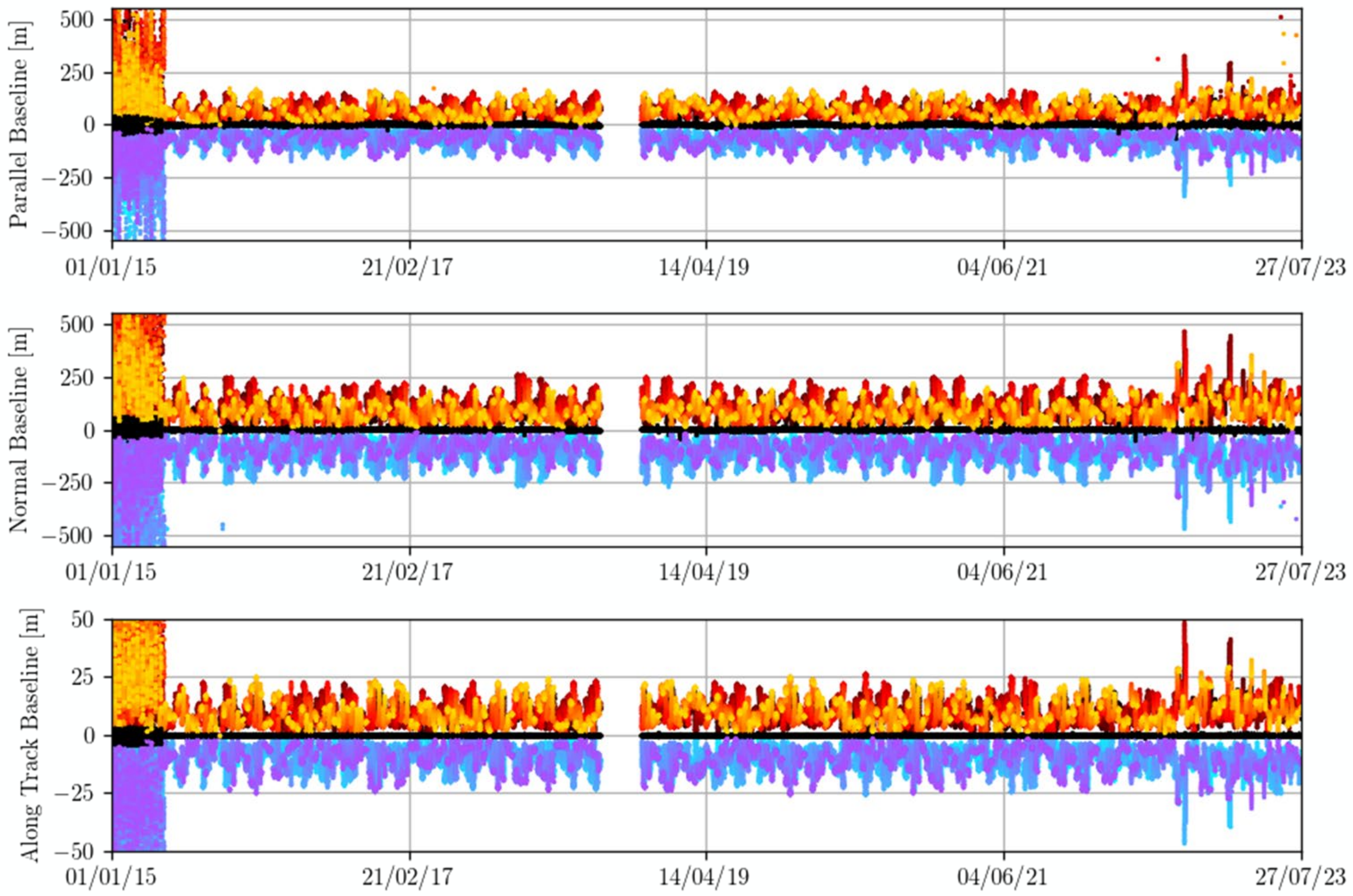
- For each acquisition, the OBS processor computes the interferometric baseline (in its three components) with respect to a reference orbit. Combining the OBS products of two acquisitions, the reciprocal baseline is retrieved
- Standard monitoring foresees the computation of the interferometric baseline of the current cycle with respect to a fixed reference cycle, namely cycle number 60 (from 30 September 2015 to 12 October 2015)
- A new monitoring has been implemented in which for each cycle the baseline is computed with respect to the previous cycle

Method	Pros	Cons
Reference Cycle	• Fixed term of comparison	• Seasonal trend • Values depend on the ref cycle and its properties
Previous Cycle	• Captures only current properties	• Secondary cycle always changes

Interferometric baseline, reference cycle

- The interferometric baseline is monitored with respect to a fixed reference cycle, namely cycle number 60 (from 30 September 2015 to 12 October 2015), projected in the parallel, normal, and along track components. The normal baseline (middle plot) is directly related to the quality of the interferogram between the two acquisitions.
- The normal baseline has reached at most values of 500 m in the last months, which is about 10% of the critical baseline for S-1A. Between 2016 and 2021, it always fell within 250 m.

Interferometric baseline components since 2015



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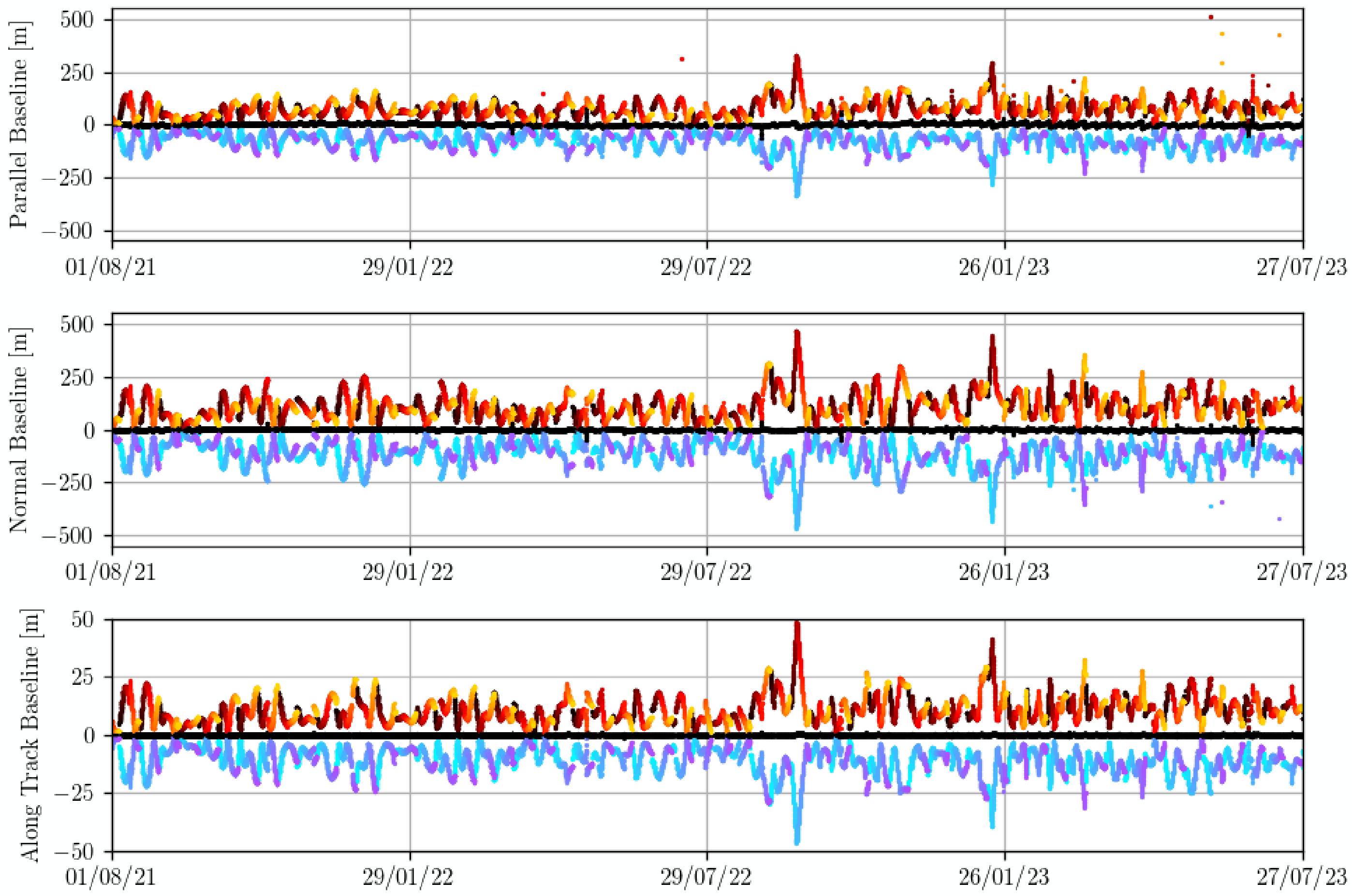
Interferometric baseline components in last two years



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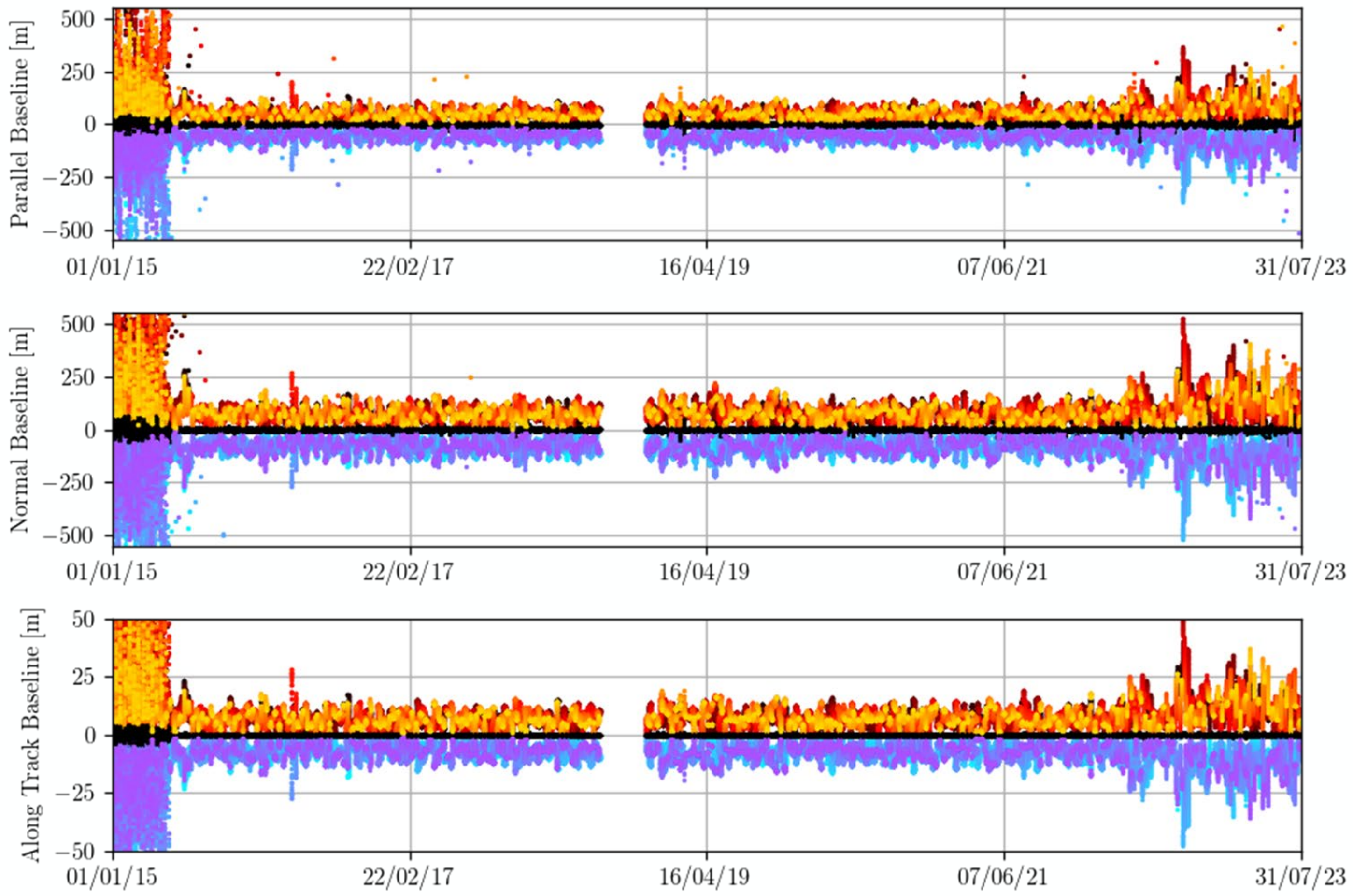

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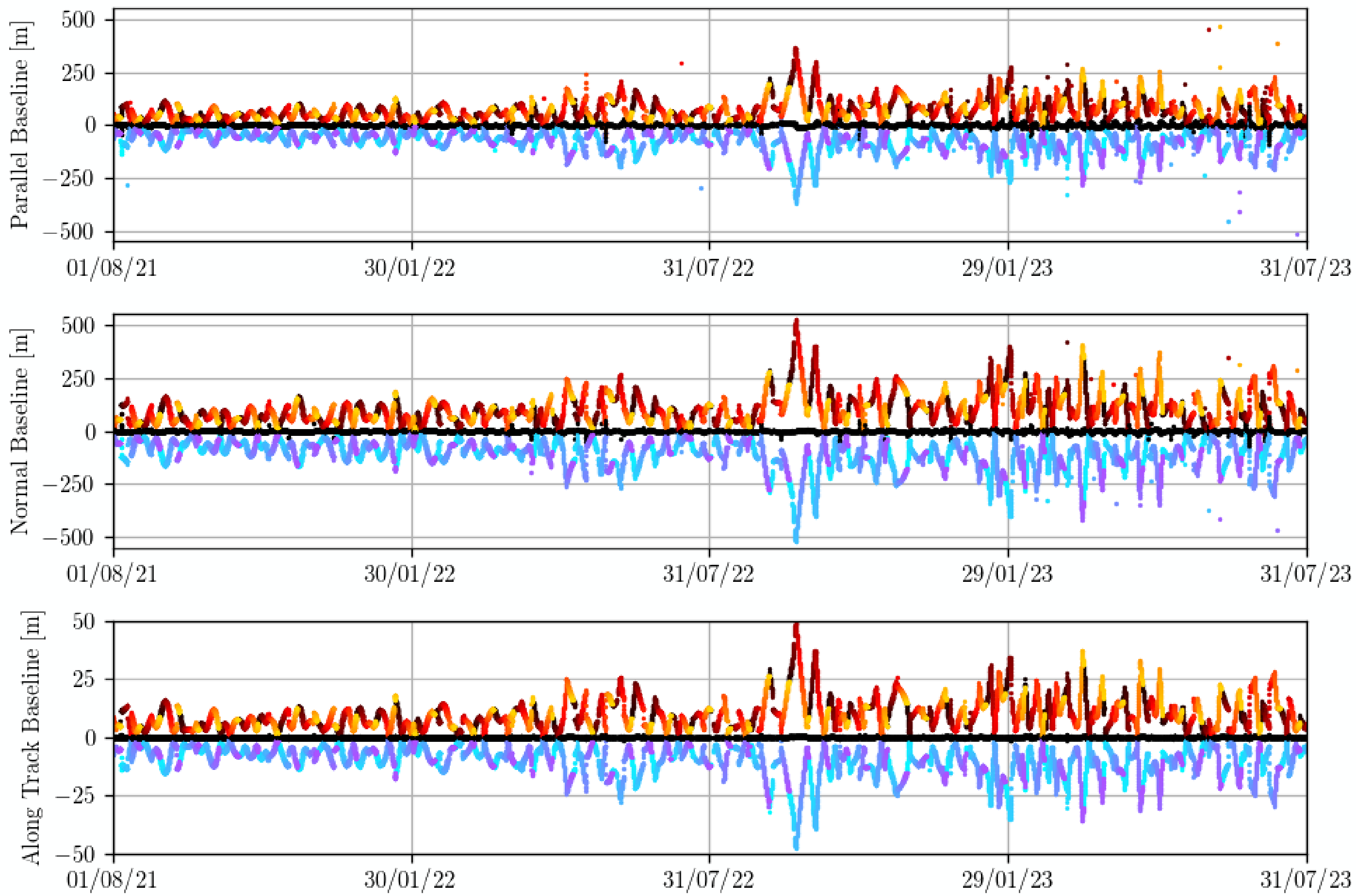

Burst synchronization

- For each acquisition, the OBS processor computes the time of acquisition for a fixed set of reference points that fall in the acquisition. First the reference points are determined via direct geocoding from a reference orbit to ground. Then the acquisition times are computed via inverse geocoding from ground to the actual orbit. The burst synchronization is eventually computed combining the OBS products of two acquisitions
- Standard monitoring foresees the computation of the burst synchronization of the current cycle with respect to a fixed reference cycle, namely cycle number 60 (from 30 September 2015 to 12 October 2015)
- A new monitoring has been implemented in which for each cycle the burst synchronization is computed with respect to the previous cycle

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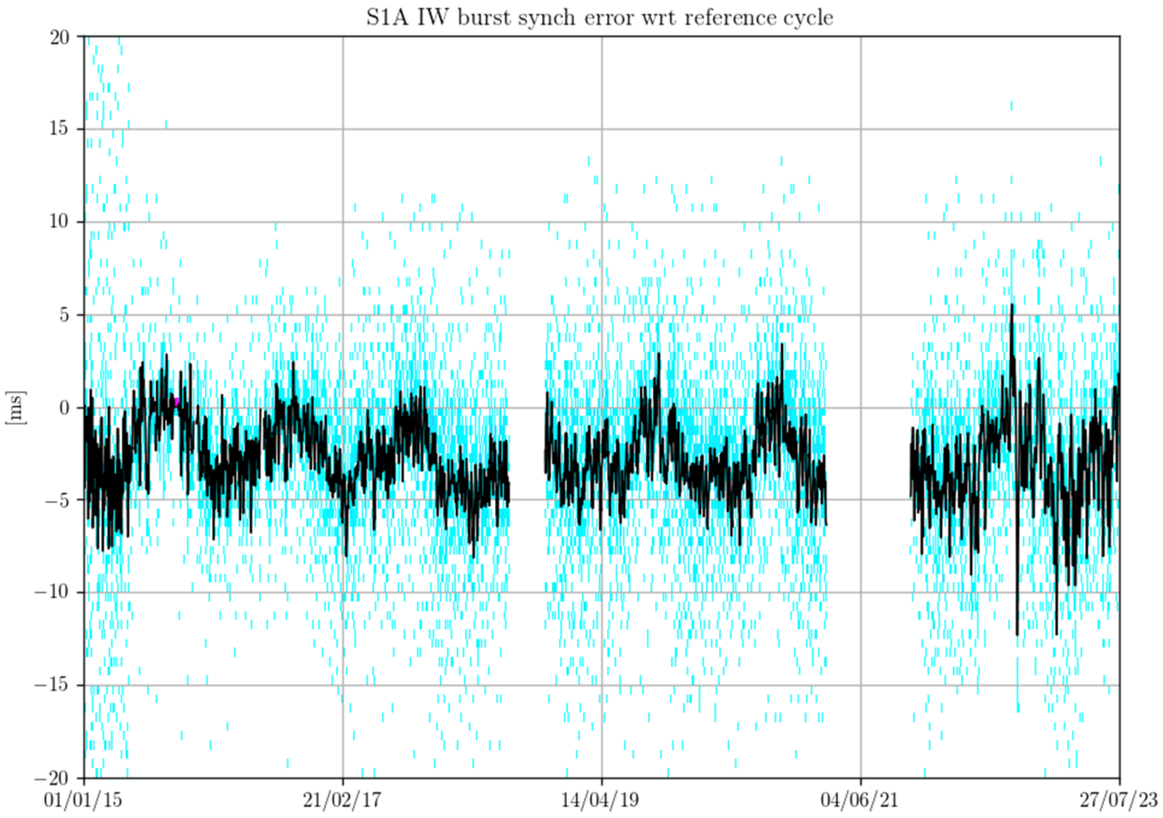
Burst synchronization, reference cycle

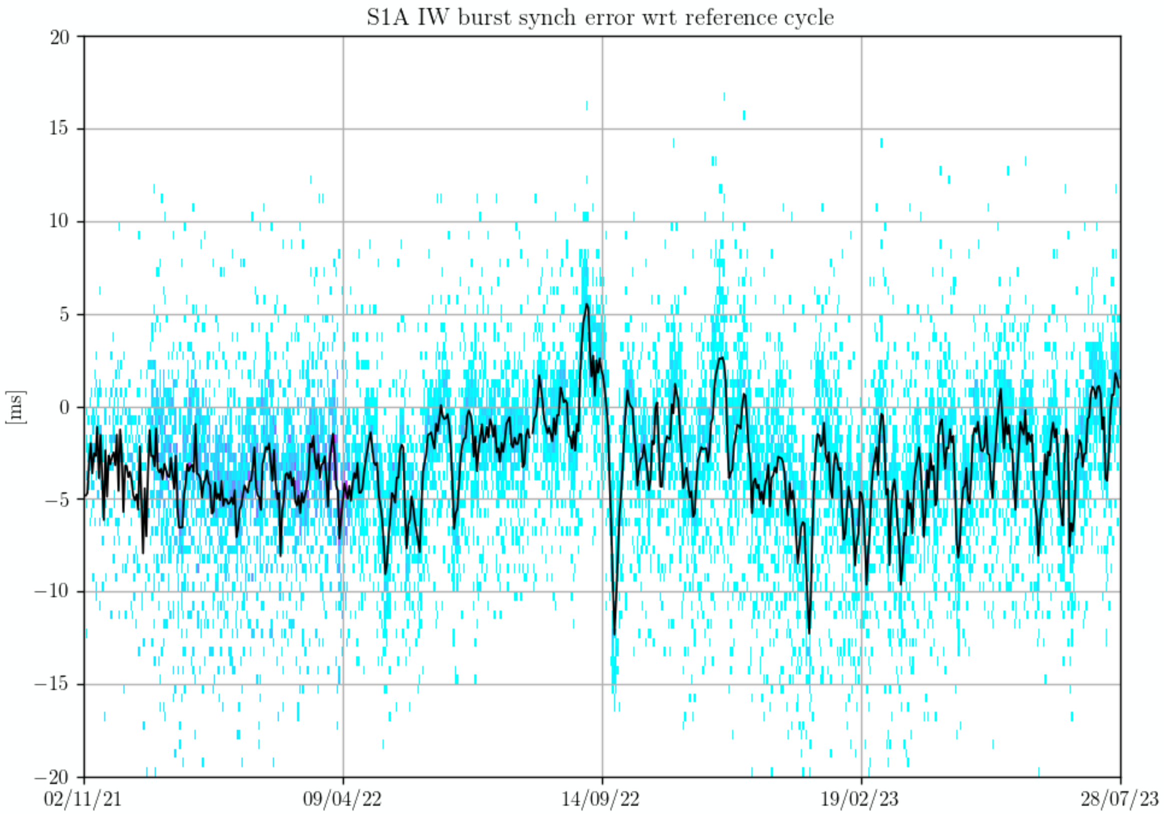
IW burst synch since 2015



- Standard monitoring evaluates burst synchronization in time with respect to a fixed reference cycle, namely cycle number 60 (from 30 September 2015 to 12 October 2015).
- This provides a fixed term of comparison for all acquisitions, but introduces a seasonal trend in the measurement. Hence, we focus on the daily average value (black line) and the dispersion with respect to it.
- N.B. the estimates of the interferometric baseline and burst synchronization depends not only on the instrument, but also on the orbit

Burst synchronization, reference cycle

IW burst synch in last two years



Compliance within average +/- 7 ms
IW: 93.7%, EW: 96.5%

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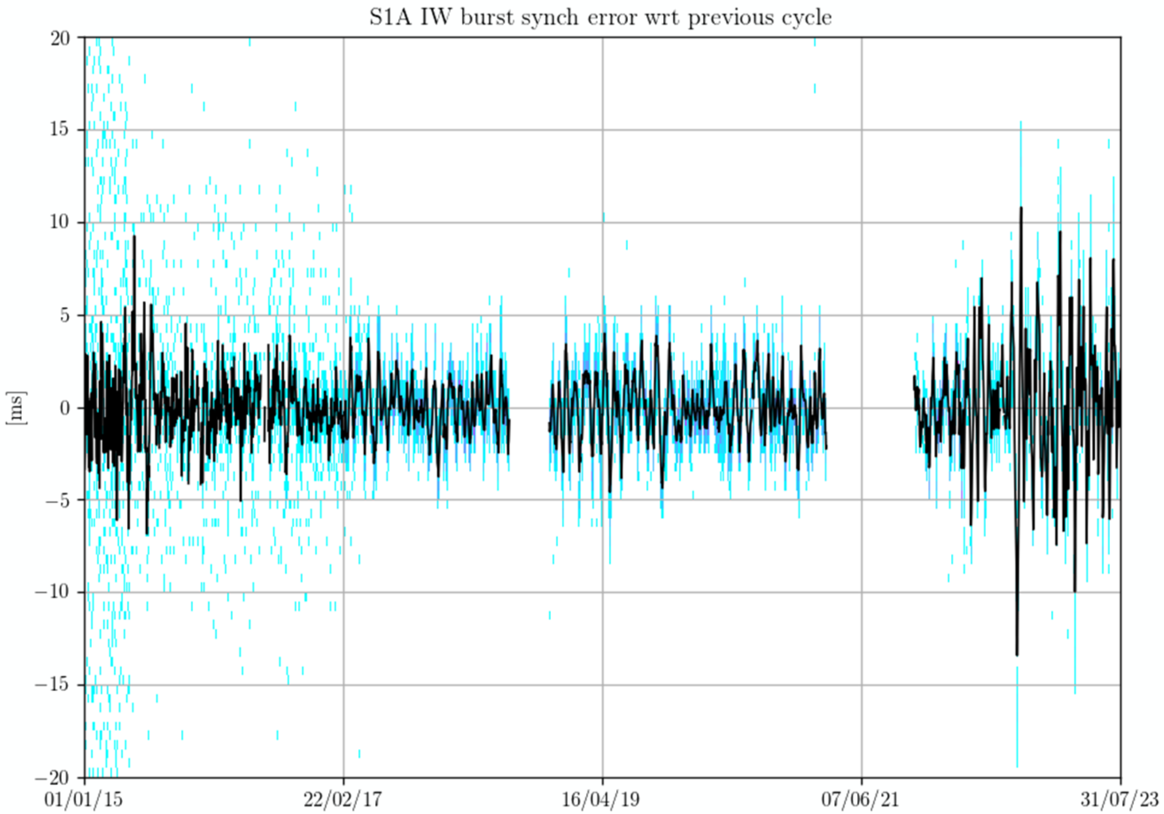

- A new monitoring of the burst synchronization has been implemented, in which each cycle is compared with its previous one.
- Results show an increase of the synchronization error since May 2022
- N.B. the estimates of the interferometric baseline and burst synchronization depends not only on the instrument, but also on the orbit

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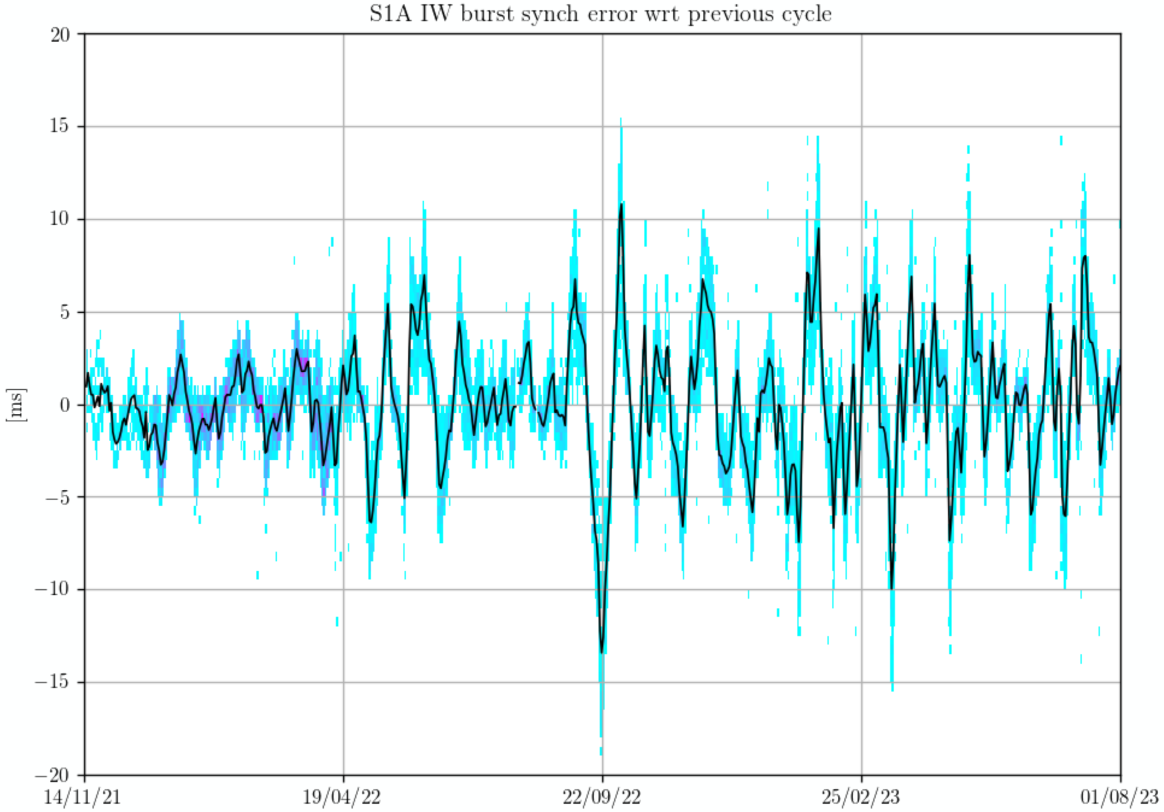

Compliance within average +/- 7 ms
IW: 99.8%, EW: 99.9%

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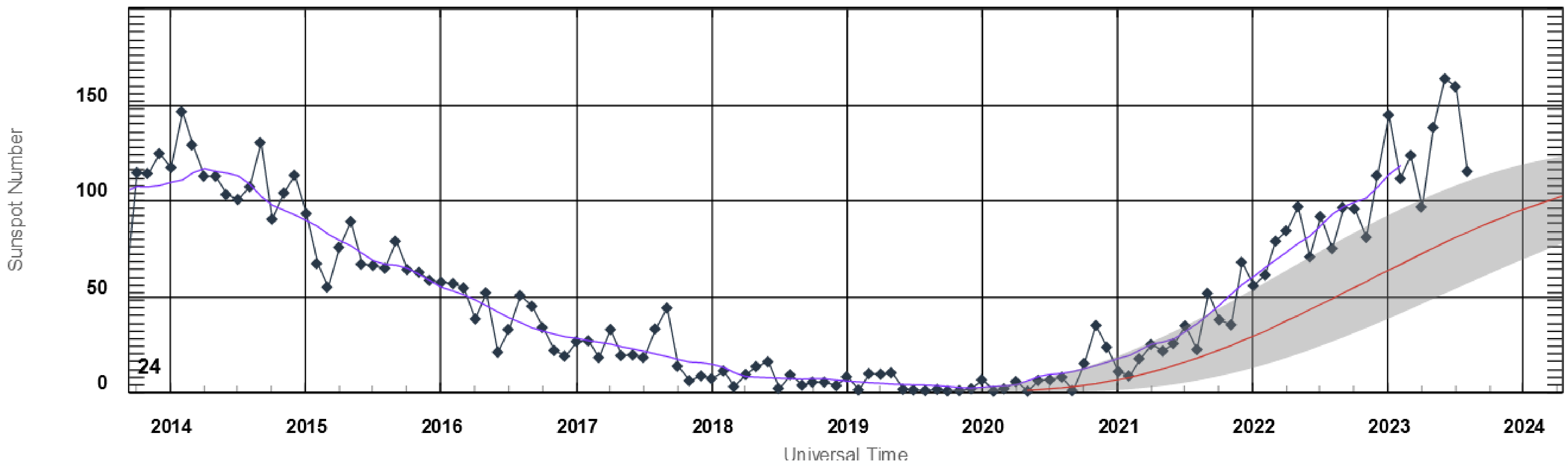
- Results show an increase of the synchronization error since May 2022
- N.B. the estimates of the interferometric baseline and burst synchronization depends not only on the instrument, but also on the orbit

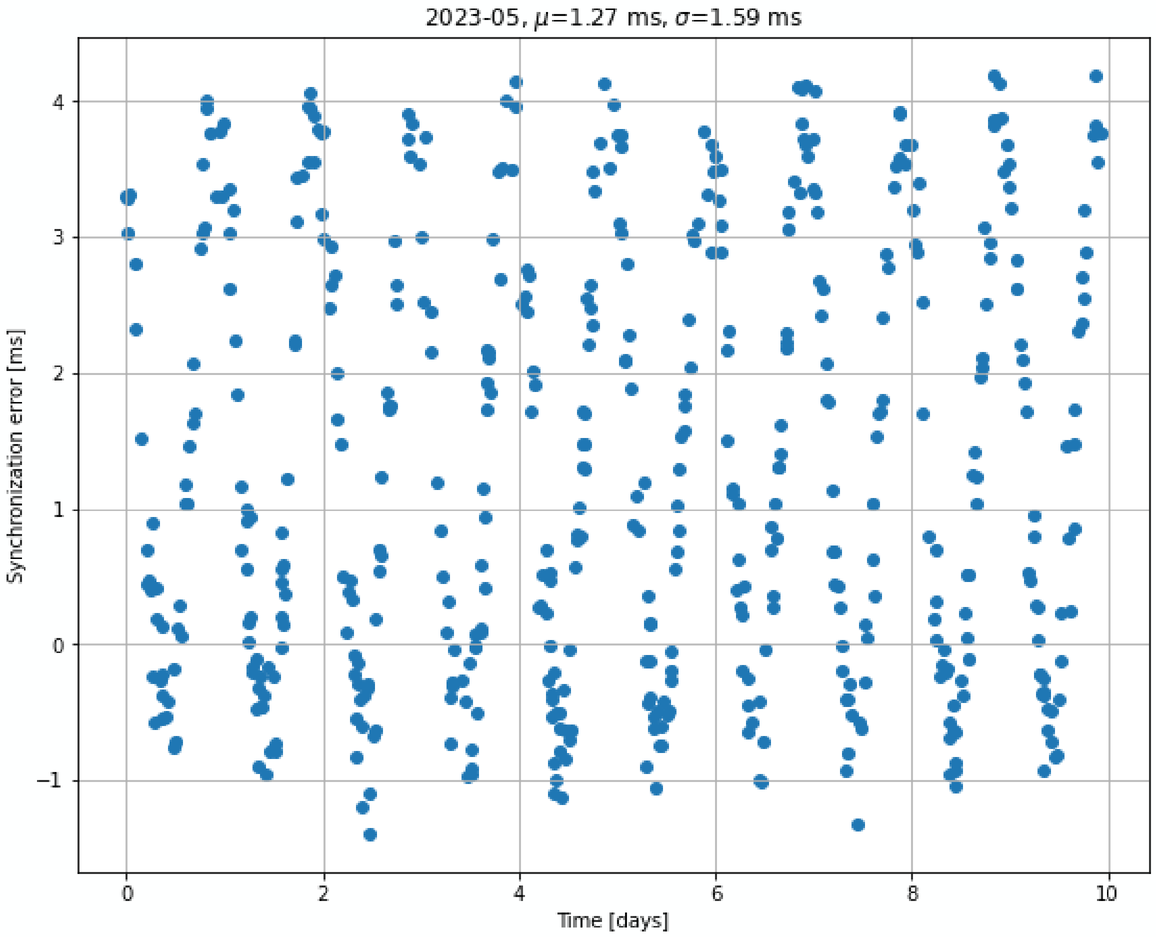
Correlation with solar activity

- Solar activity follows cycles of about 11 years. Current cycle began in 2019 and it is expected to continue until 2030. Observations of numbers of sunspots indicates a stronger cycle than expected.
- Significant increase in solar activity since 2022 has affected orbit control.

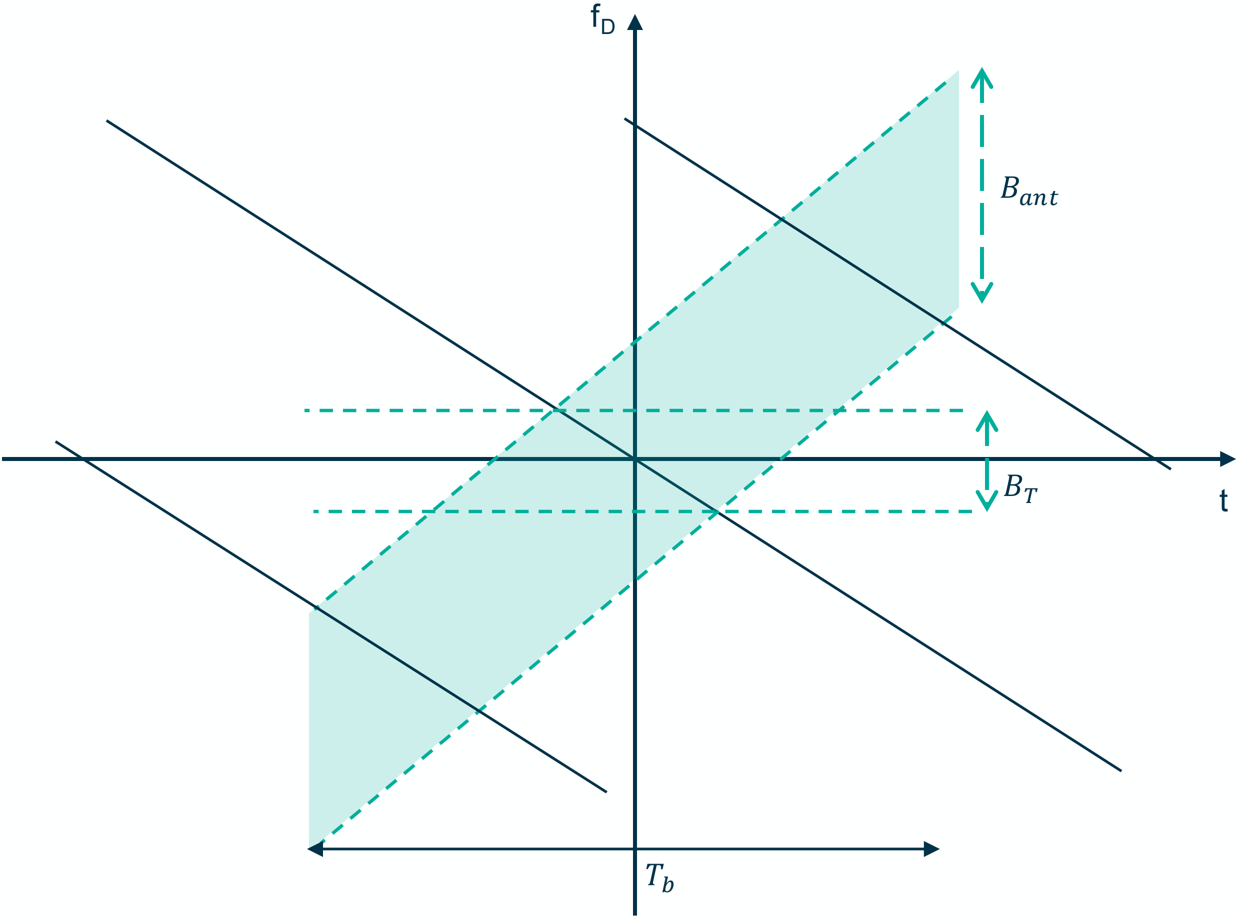


Comparison with Mission Plan

- To separate the instrument synchronization from other contributions, a study from the commissioning phase was replicated (see "Sentinel-1 SAR Interferometry Performance Verification", by Dirk Geutner et al.)
- The analysis evaluated the difference between the angles recorded in the mission plan with the angles computed from OBS and AUX_POEORB products, using the EOCFI library.
- Analysis from commissioning phase showed a mean time difference of 1.32 ms with a stdev. of 1.28 ms
- We replicated the same analysis for about ten days in Feb 2021 and in May 2023, No significant statistical difference was found.



Time Frequency Diagram of TopSAR acquisition



- Differences in pointing and burst synch cause loss of interferometric coherence
- Slope of the target history in the time frequency plane is the FM rate:

$$K_r = -\frac{2v^2}{\lambda R}$$

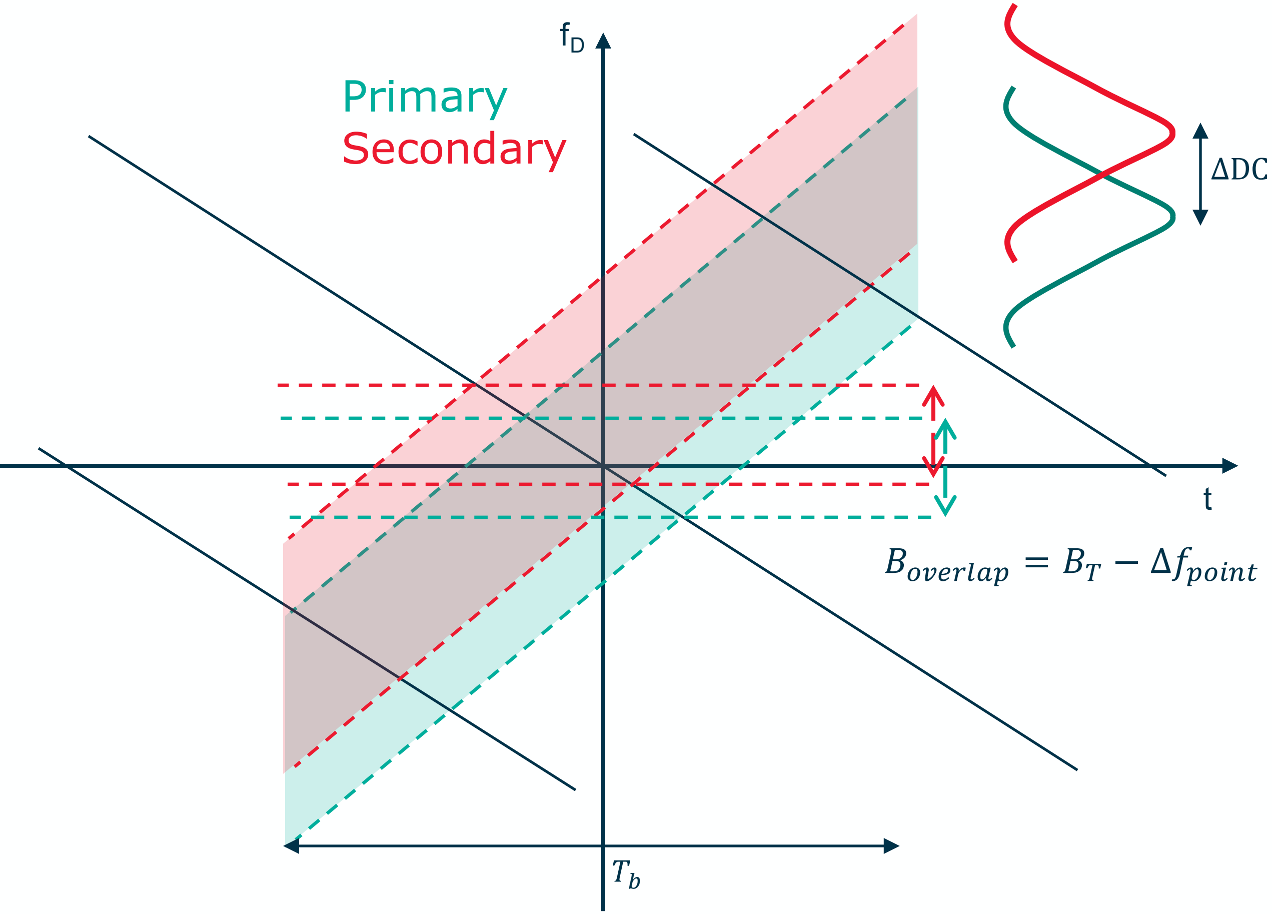
- Slope of the antenna pattern depends on the electronic steering rate ψ_{ant} :

$$K_{ant} = -\frac{2v}{\lambda}\psi_{ant}$$

- The relationship between target bandwidth (i.e., processed bandwidth) and antenna bandwidth is:

$$B_T = \frac{K_r}{K_r - K_{ant}} B_{ant}$$

Pointing Error Effect on Spectral Overlap



- In case of a pointing difference between two images (vertical shift), the Doppler error Δf_{DC} is measured on the raw data.

- The resulting Doppler mis-match to be considered for interferometric applications is:

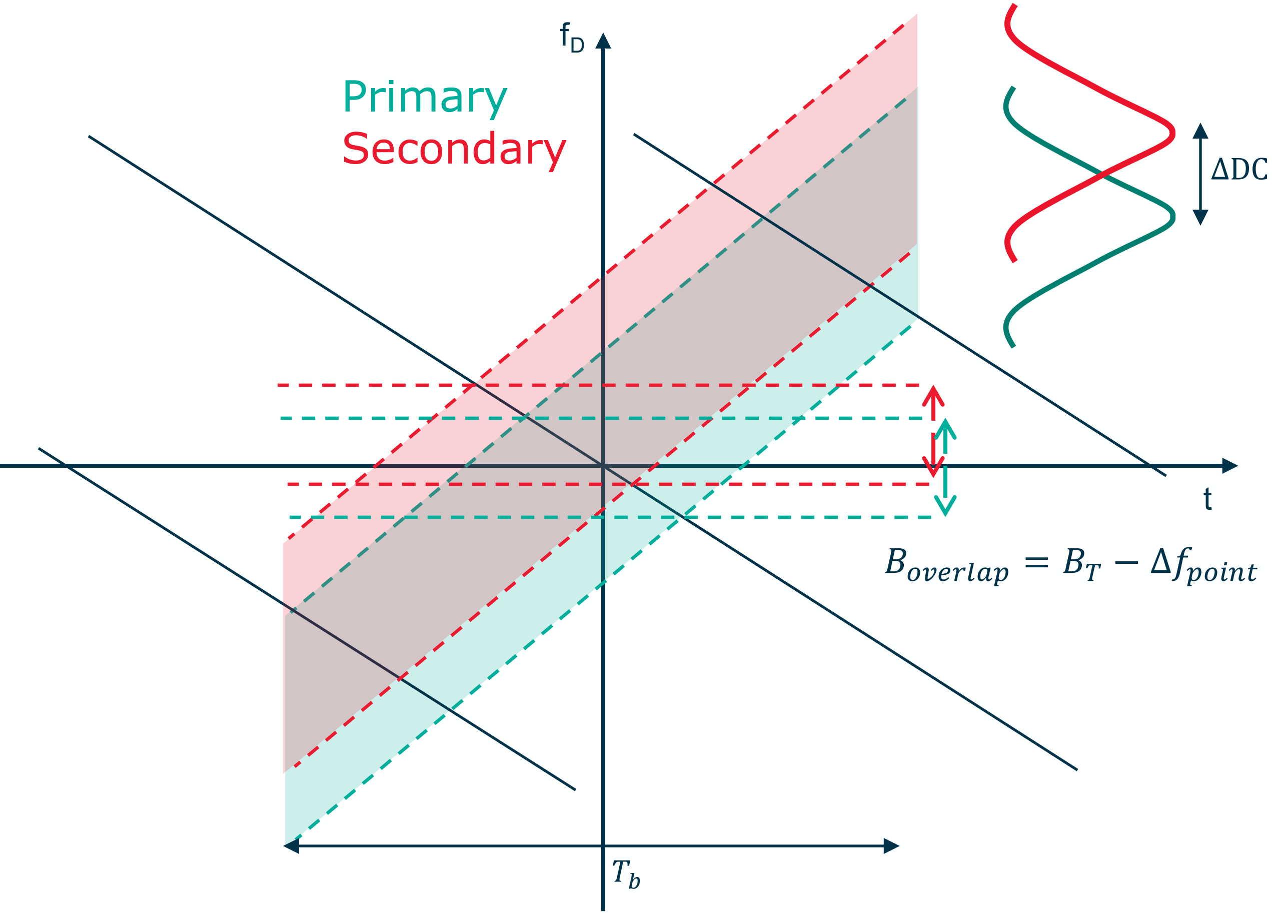
$$\Delta f_{point} = \frac{K_r}{K_r - K_{ant}} \Delta f_{DC}$$

- The loss of coherence depends on the processed bandwidth:

$$\gamma = \frac{B_T - \Delta f_{point}}{B_T}$$

- The loss of coherence for S-1A IW is about 3% for 30 Hz of DC difference

Pointing Error Effect on Spectral Overlap



- For S1-A IW-1, assuming a pointing error of 30 Hz, we have

$$K_{ant} = -\frac{2v}{\lambda}\psi_{ant} = 7552\ Hz/s$$

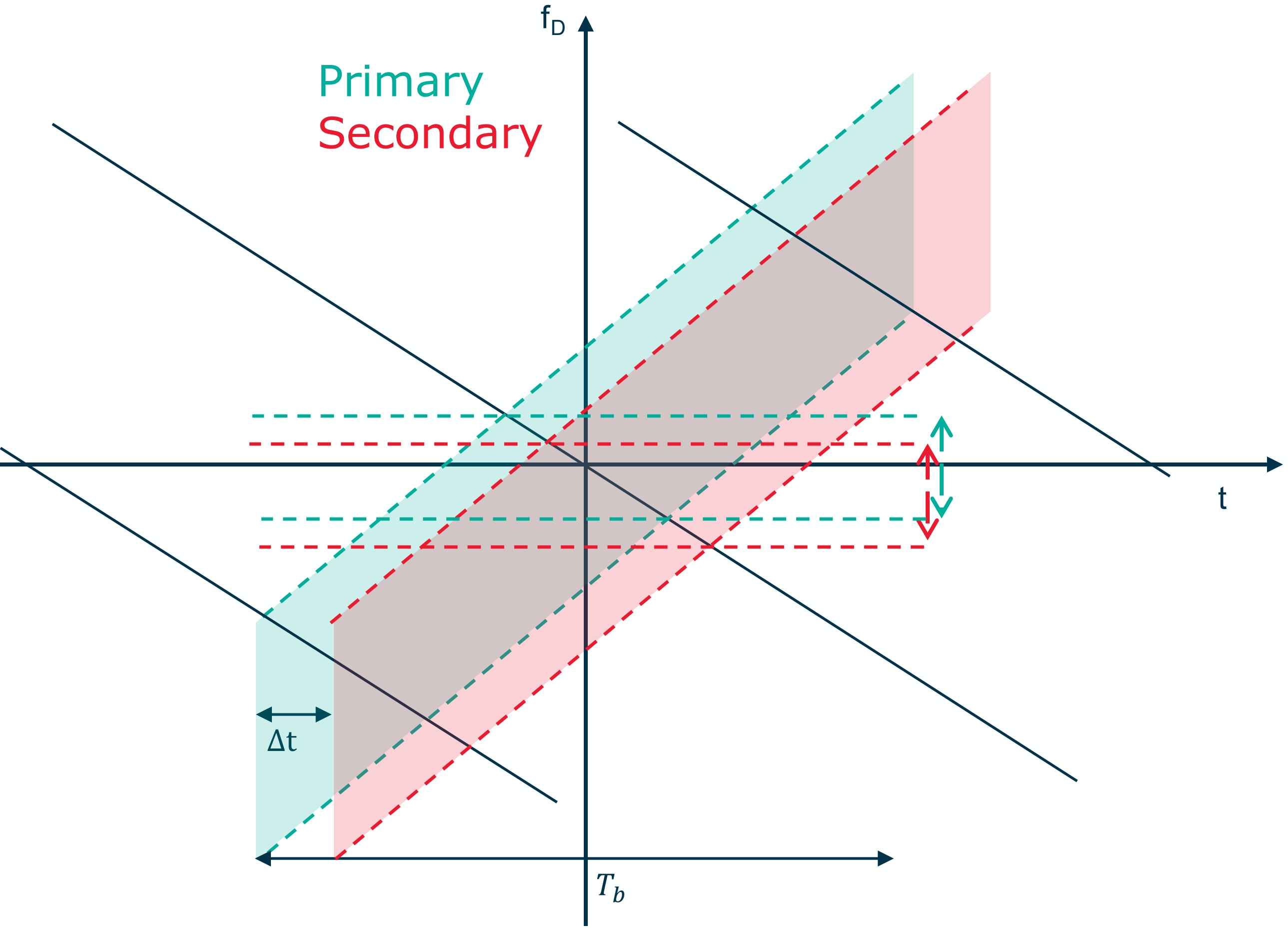
$$K_r = -\frac{2v^2}{\lambda R} = -2569\ Hz/s$$

$$\Delta f_{point} = \frac{K_r}{K_r - K_{ant}}\Delta f_{DC} = 7{,}62\ Hz$$

$$\gamma = \frac{B_T - \Delta f_{point}}{B_T} = 0{,}977$$

- Similarly for IW-2 and IW-3, we have a loss of about 3% of coherence per 30 Hz of pointing error

Synchronization Error Effect on Spectral Overlap



- A burst synch error (horizontal shift) can be translated into an equivalent pointing error:

$$\Delta f_{equi} = -\frac{2v}{\lambda}\psi_{\text{ant}}\,\Delta t_{\text{synch}} = K_{ant}\,\Delta t_{\text{synch}}$$

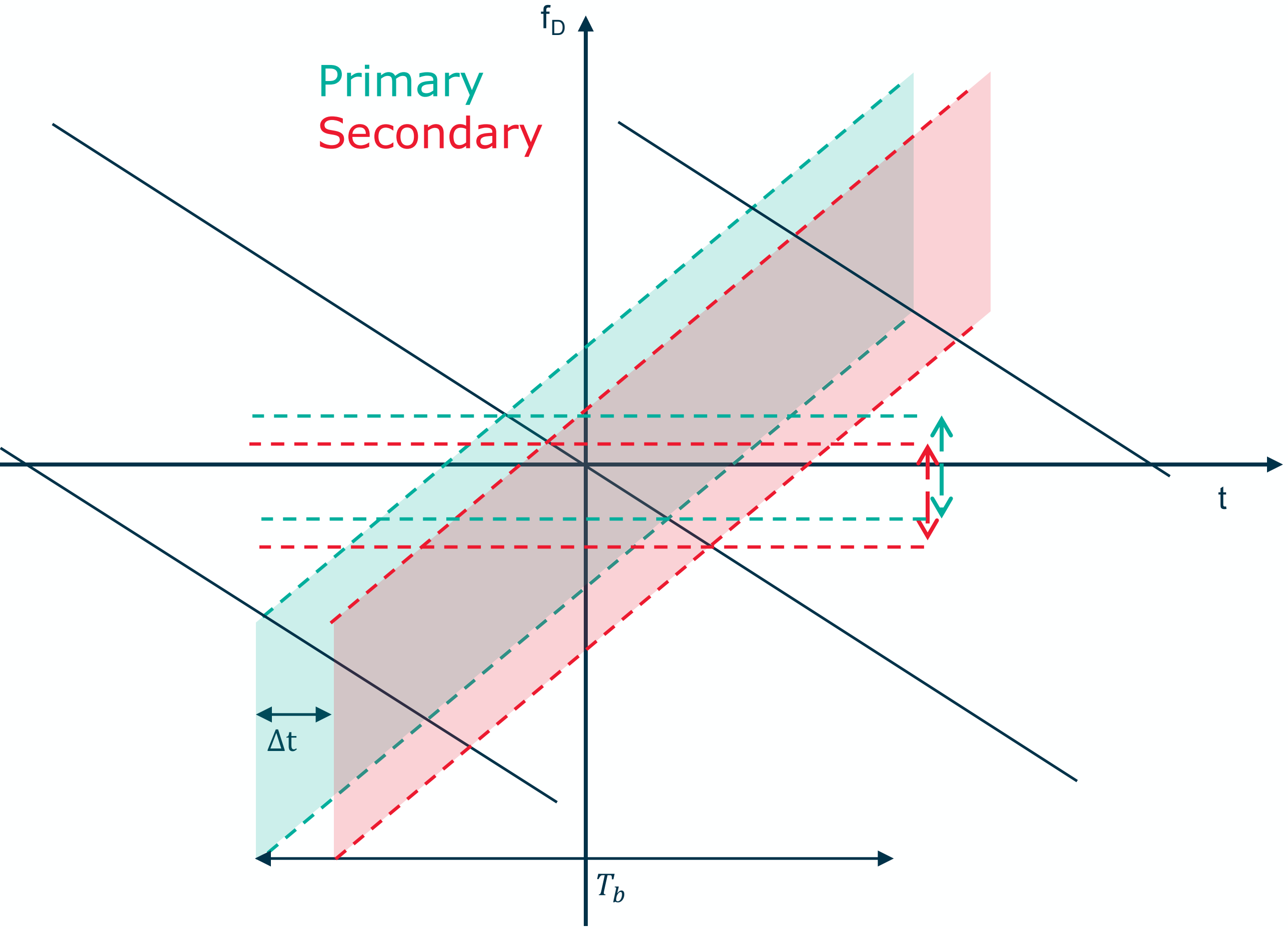
- The resulting Doppler mis-match to be considered for interferometric application is again:

$$\Delta f_{synch} = \frac{K_r}{K_r - K_{ant}}\Delta f_{equi}$$

- The loss of coherence depends on the processed bandwidth:

$$\gamma = \frac{B_T - \Delta f_{synch}}{B_T}$$

Synchronization Error Effect on Spectral Overlap



- For IW-1, assuming $\Delta t = 5\ ms$, we have

$$K_{ant} = -\frac{2v}{\lambda}\psi_{ant} = 7552\ Hz/s$$

$$K_r = -\frac{2v^2}{\lambda R} = -2569\ Hz/s$$

$$\Delta f_{equi} = K_{ant}\ \Delta t_{synch} = 37{,}76\ Hz$$

$$\Delta f_{synch} = \frac{K_r}{K_r - K_{ant}}\Delta f_{equi} = 9{,}58\ Hz$$

$$\gamma = \frac{B_T - \Delta f_{synch}}{B_T} = 0{,}971$$

- Similarly for IW-2 and IW-3, we have a loss of about 3% of coherence per 5 ms of mis-synchronization

Interferometric coherence

- Both the pointing error and the synchronization error can affect the spectral overlap between the two acquisitions
- The two effects can either have the same sign, causing a larger loss in interferometric coherence, or opposite signs, compensating each other

Burst cycle ID

- The Instrument Processing Facility (IPF) has introduced since version 3.4 the annotation of burst cycle ID numbers for the TOPS modes.
- Each burst in a sub-swath is labelled by an **absolute burst ID** (unique since the beginning of the mission) and a **relative burst ID** (unique since the beginning of current 12-day cycle). The bursts which belong to the same burst cycle (3 bursts for IW, 5 bursts for EW) share the same burst ID.

$$\Delta t_b = t_b - t_{ANX} + (r-1)\, T_{orb} \qquad \Delta t_{b,abs} = t_b - t_{ANX} + (a-1)\, T_{orb}$$

$$rel\ burst\ id = 1 + floor\left(\frac{\Delta t_b - T_{pre}}{T_{beam}}\right) \qquad abs\ burst\ id = 1 + floor\left(\frac{\Delta t_{b,abs} - T_{pre}}{T_{beam}}\right)$$

- Given that S-1 bursts are synchronized from one pass to the other, there is a univocal correspondence between the relative burst cycle ID (for a certain sub swath) and a region on Earth's surface.

Quality Disclaimers

- For some products, the burst ID annotation is invalid: the value of the burst ID (absolute and relative) is shifted by 1 compared to the expected value. About 1-2% of the SLC products acquired during the period are impacted.
- The issue is caused by the SAR processor computing the burst ID using the ANX time annotated in the meta data of the L0 products. This value is by design derived from predicted orbit information, which may not have a sufficient accuracy.
- To solve the issue, the ANX time will be recomputed a posteriori by the processor. This will be implemented in IPF 3.7, soon to be delivered.
- The list of impacted products is reported in quality disclaimers on https://sar-mpc.eu/disclaimer/

Burst ID maps

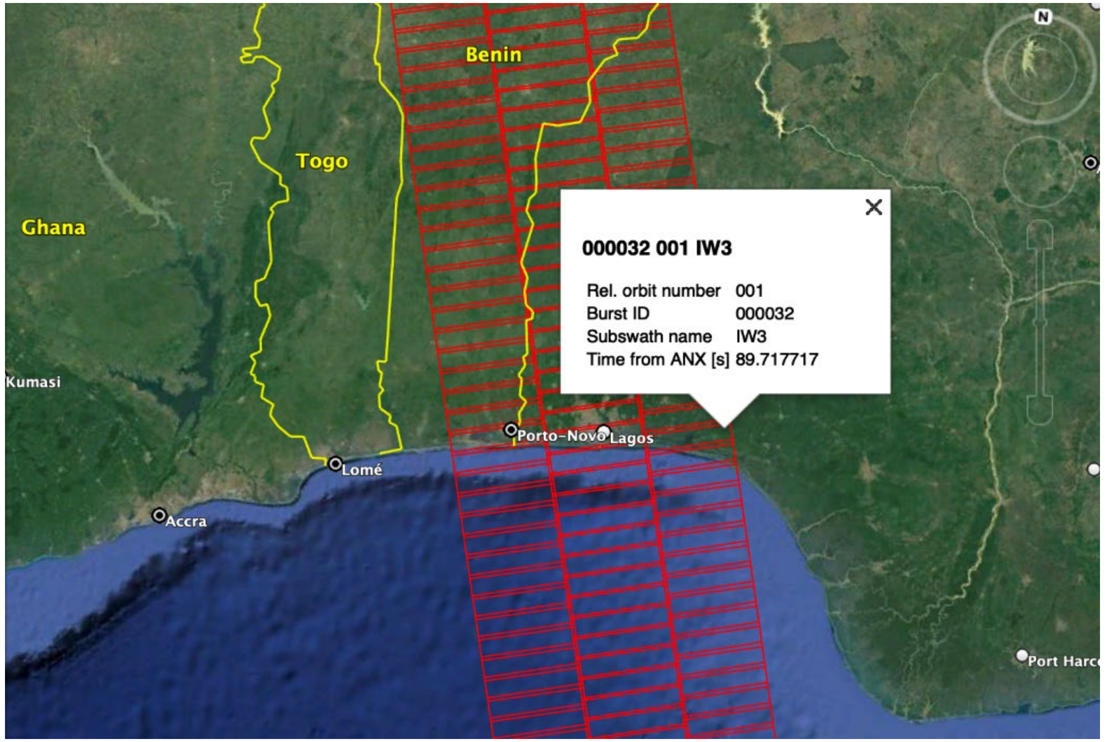
- A Burst ID map associates in a full 12-day cycle each relative burst ID with a geolocated polygon that delimitates the burst footprint.
- For each burst id and sub-swath, the map provides information on its relative orbit number within the 12-day cycle (ranging from 1 to 175), the orbit direction (ascending or descending), and the nominal time at which the burst starts. The maps are global, i.e., they provide information also where no SAR data is acquired.

https://sar-mpc.eu/test-data-sets/

Field	Type
Relative Burst Id	INT
Subswath	STRING
Relative orbit number	INT
Orbit pass	STRING
Time from ANX in seconds	DOUBLE
Footprint polygon	MULTIPOLYGONZ

Burst ID maps

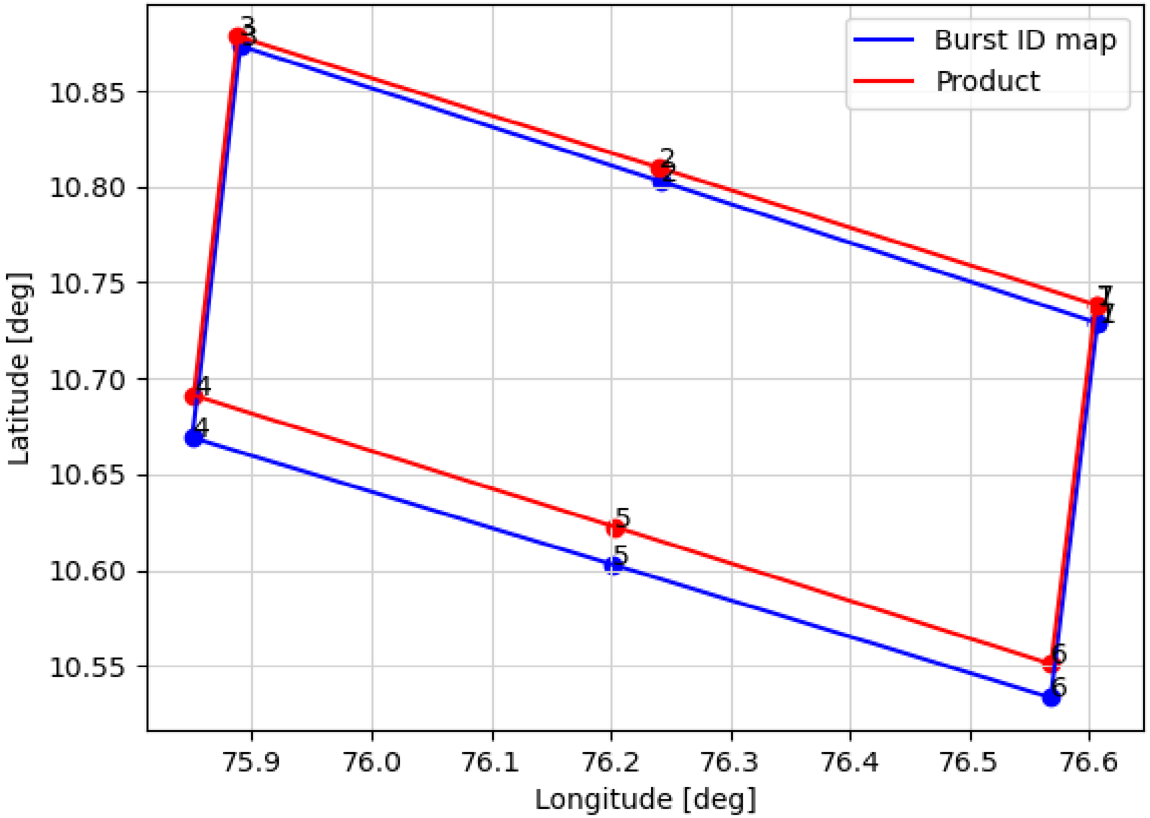
- Distinct maps have been created for the IW and EW TOPSAR acquisition modes
- The Burst ID maps are provided both as **sqlite3** databases (one per mode) and as **KMZ** files (one for each mode and relative orbit number).



Example of a Burst ID map for one orbit of IW, in KMZ format opened in Google Earth

Burst ID map validation

- The maps were generated by means of geocoding along the orbits of cycle number 213 (starting on 9th of October 2020), in the EPSG:4326 Coordinate Reference System (CRS) using the **WGS84** ellipsoid as horizontal datum and assuming zero height for each point. The maps have been validated with respect to cycle 240 (starting on 25th of February 2022), evaluating the distances between the corners of the same burst footprints in the two cycles. The analysis showed an average absolute discrepancy of 960 ± 553 m for IW mode and 996 ± 465 m for EW mode.



Conclusions

- S-1A instrument and interferometric performances (pointing, baseline, synchronization) are continuosly monitored in time.
- Monitoring during last year showed a deterioration in the synchronization since 2022. It does not seem to be related to the instrument itself. It may cause a loss in coherence.
- TOPSAR products now contain relative and absolute Burst ID annotations.
- Burst ID maps have been published in sqlite and kmz format