

A transponder calibration tool based on FFSAR: results for CryoSat from 10 years of operations

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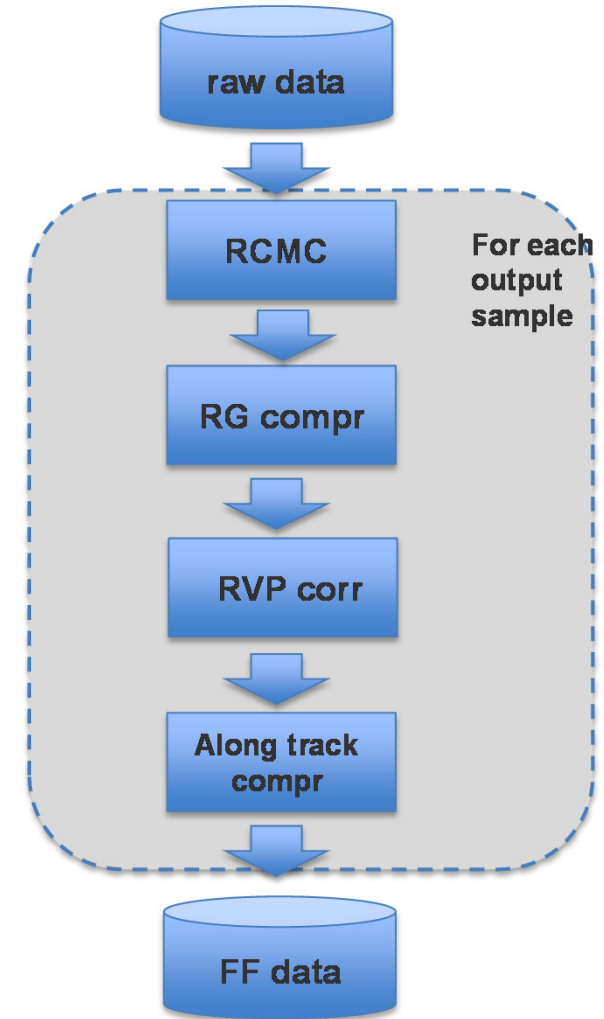
Outline

- Fully-Focused SAR Principle
- External calibration tool
 - Objectives
 - Interfaces
 - Algorithms
- Results from CryoSat
 - Dataset description
 - Long-term calibration parameters
- Conclusions

Fully Focused SAR principle

- The FFSAR has been proposed by Egido & Smith [1]
- FFSAR algorithm in time domain is based on Back Projection (BP): it aims basically at the progressive compensation of the different phase terms in the impulse response function.
- The echoes acquired from a target in all its visibility period are combined together to achieve the along-track resolution of about 0.5 m
- FFSAR was verified using CryoSat acquisitions over Svalbard Transponder as test case.

[1] A. Egido and W. H. F. Smith, "Fully Focused SAR Altimetry: Theory and Applications," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 1, pp. 392-406, Jan. 2017, doi: 10.1109/TGRS.2016.2607122.



FFSAR for external calibration

By applying FFSAR processing to acquisitions over transponder

- It is obtained a sharp point target response in correspondence of the external calibrator with along- and across-track resolution of about 0.5 m
- The along-track phase in correspondence of the external calibrator is expected to be flat (after range alignment and compensation of the different phase terms according to BackProjection principle)



The FFSAR was identified as an useful principle to define algorithms and to develop an external calibration tool to assess calibration bias and performance for an altimeter

FFSAR external calibration tool

An external calibration tool was developed in order to estimate for each acquisition over the external calibrator the following parameters

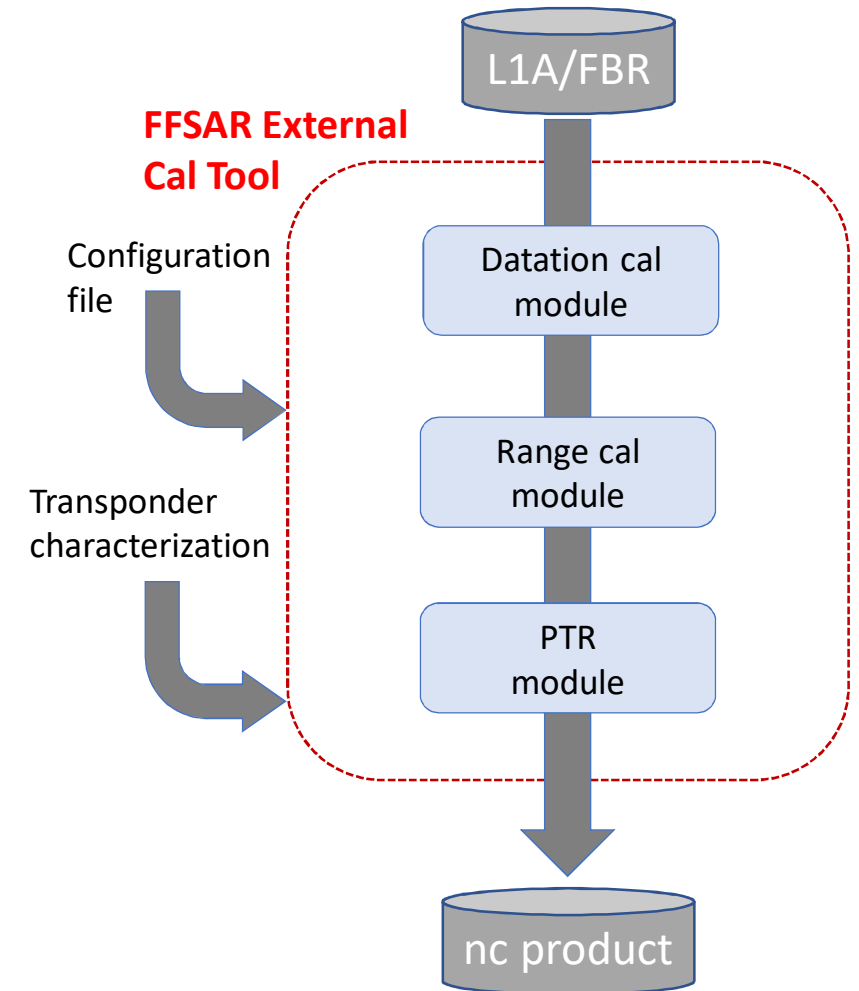
- Datation bias
- Range bias
- FFSAR Point Target Response (PTR) characterization (e.g. along- and across-track resolution, Peak-to-Side Lobe ratio, ecc.)

The external calibration tool was designed to be versatile in order to process data from

- Different external calibrators (e.g. Crete CDN1 or Svalbard transponder)
- Different instruments (i.e. deramp or matched filter in rx)
- Different missions (e.g. CryoSat, Sentinel-3, Sentinel-6)

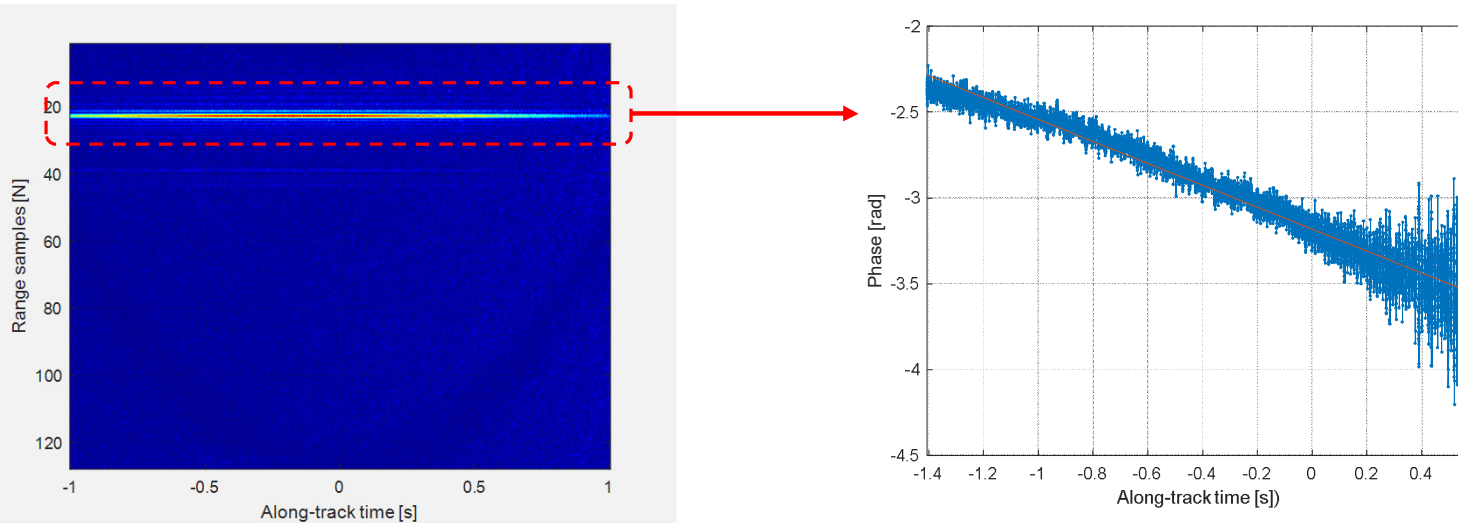
FFSAR external calibration tool: interfaces

- Input
 - L1A/FBR product
- Auxiliary
 - Configuration file, including all the parameters to tune the processing
 - Transponder characterization, including position, internal delay, colocated geophysical corrections
- Output
 - NetCDF product containing calibration parameters plus ancillary information
 - Graphical reports for FFSAR PTR

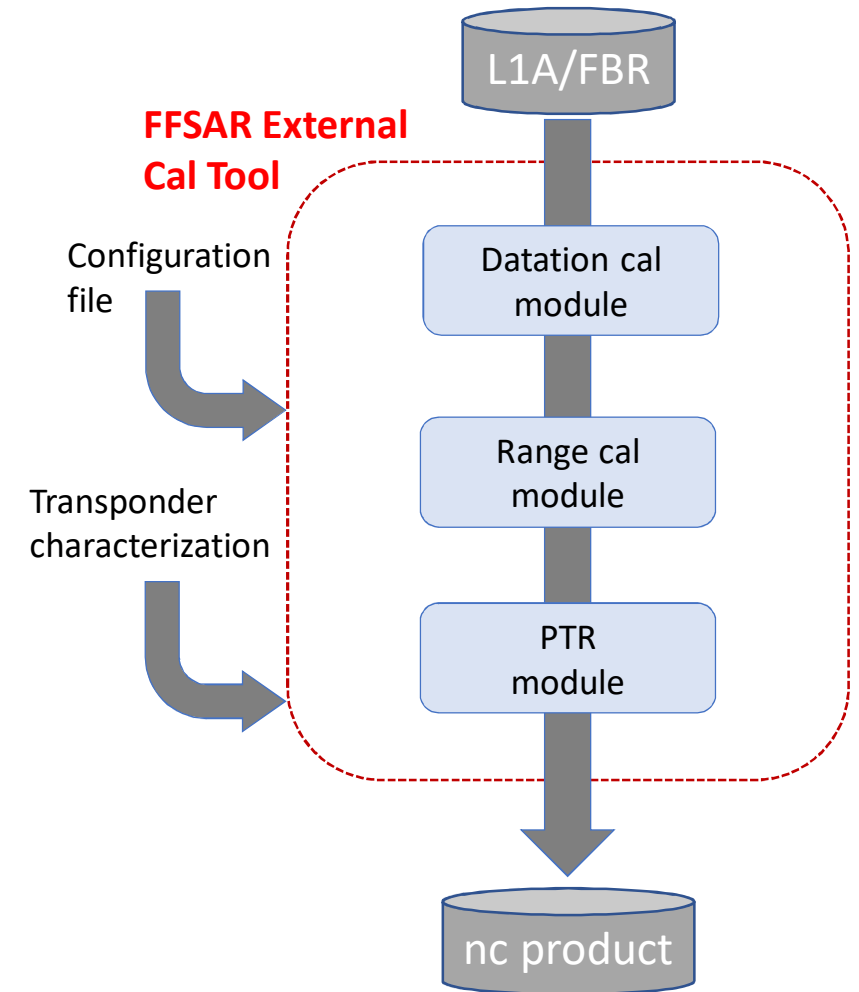


FFSAR external calibration tool: datation cal

According to the BackProjection principle, the along-track phase for a point target is expected to be flat in correspondence of the peaks of the range compressed echoes



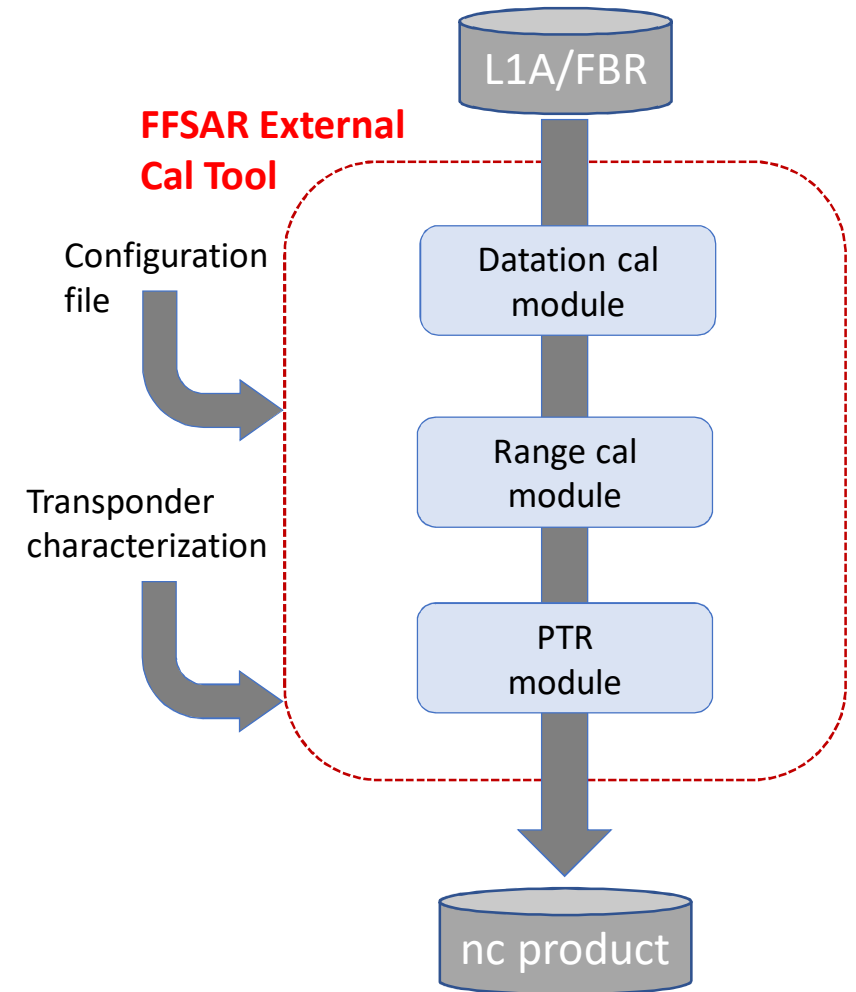
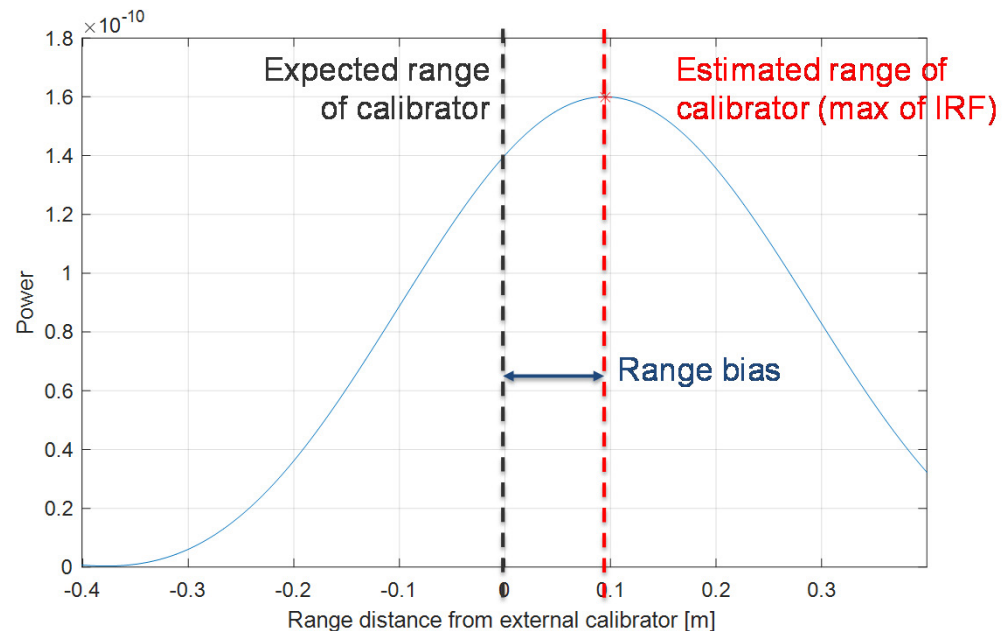
A slope in the along-track phase can be addressed to a datation bias, that can be estimated as the correction to datation to be applied in order to obtain a zero slope along-track phase [2]



[2] M. Scagliola and P. Guccione, "Datation and Range Calibration of Radar Altimeter Exploiting Fully Focused SAR Processing," in *IEEE Geoscience and Remote Sensing Letters*, doi: 10.1109/LGRS.2020.2980635

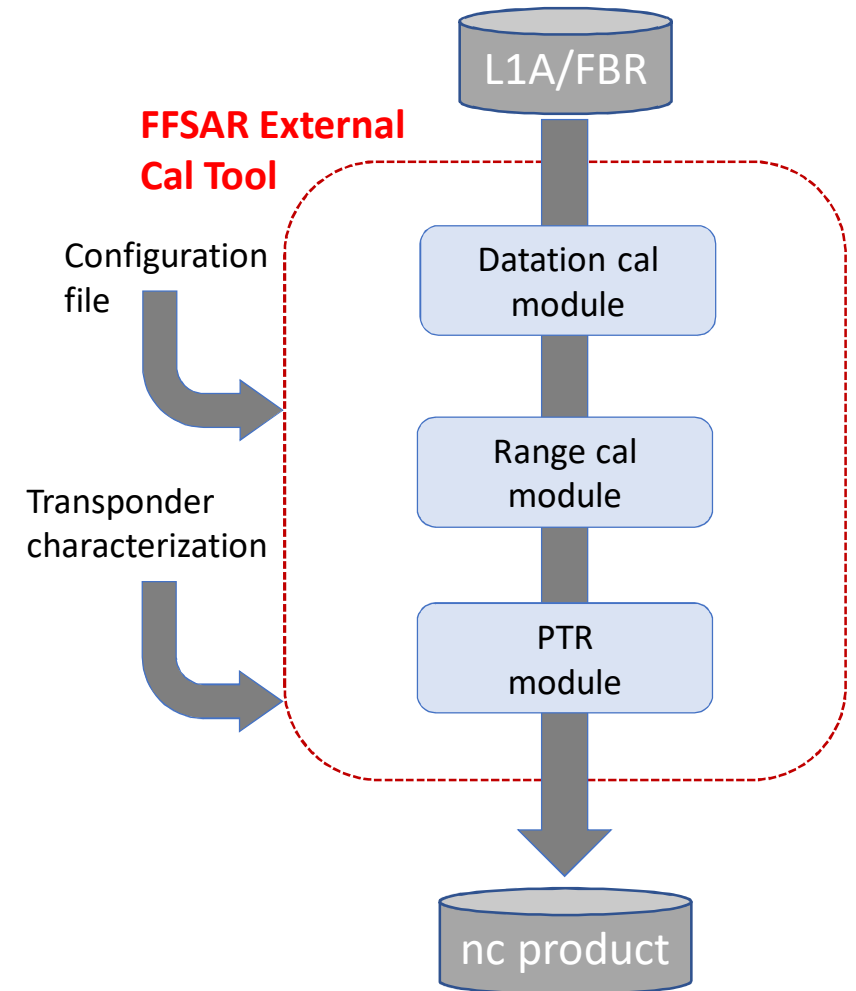
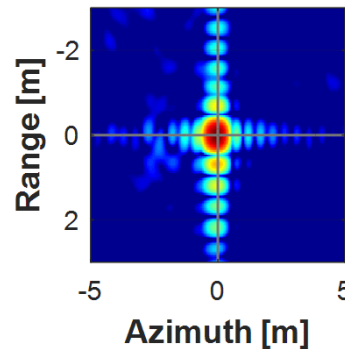
FFSAR external calibration tool: range cal

The range calibration is assessed by computing the power waveform by FFSAR processing in correspondence of the transponder and by comparison of the estimated range of calibrator (i.e. the peak of the waveform) and the expected range of calibrator from geometry and atmospheric delay



FFSAR external calibration tool: PTR

- The Surface Sample focusing point is placed in correspondence of the external calibrator position
- FFSAR Back-Projection is executed to obtain the PTR from acquisition over the external calibrator
- A reference PTR is computed using a theoretical model of the FFSAR processing
- The point target analysis tool is executed to assess the quality of the impulse response function



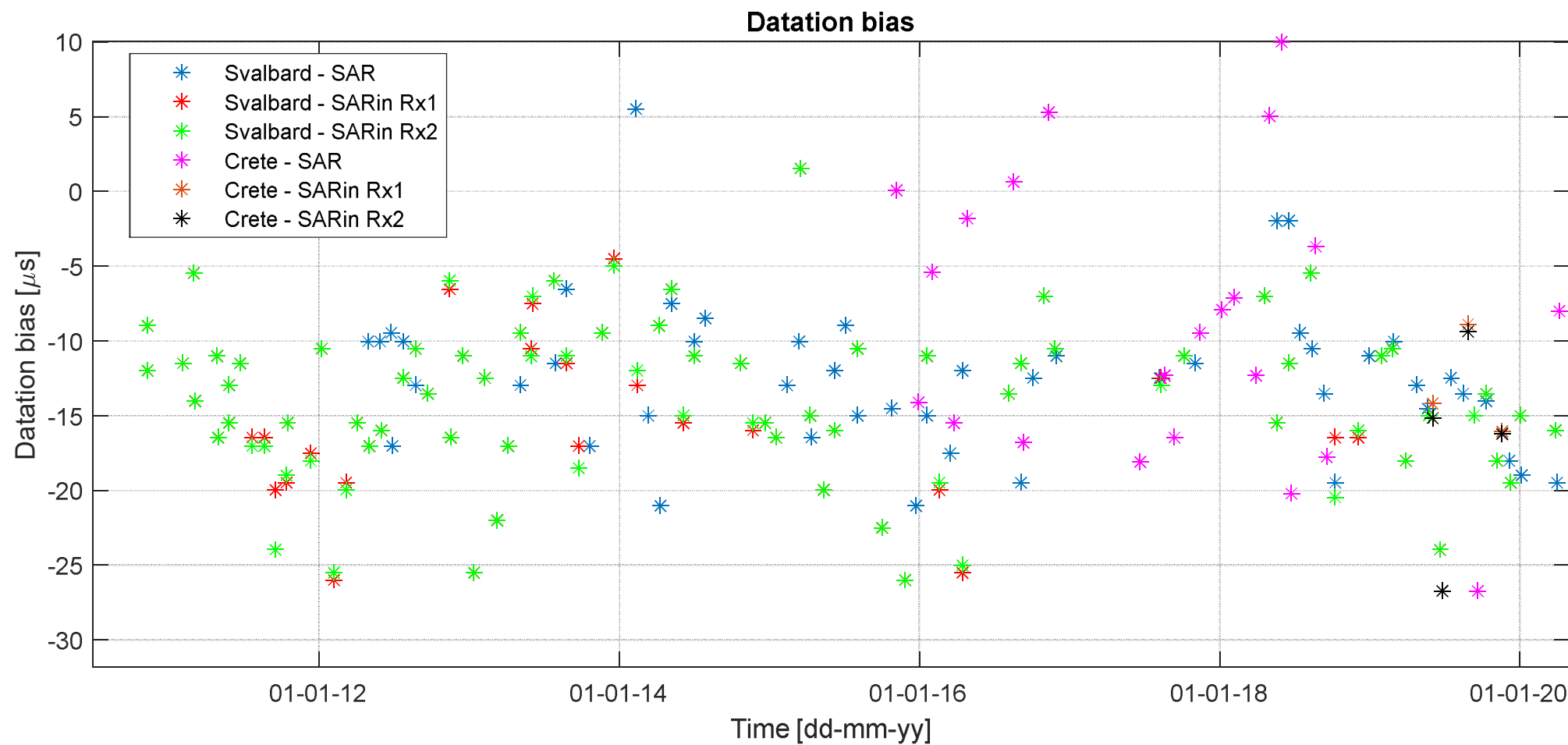
Dataset description

- The tool was exploited to process all the CryoSat acquisitions in SAR and SARin mode over the Svalbard and Crete CDN1 transponder starting from BaselineC FBR products

	Svalbard	Crete CDN1
SAR mode	49	27
SARin mode	85	4 (not included in performance results)

- The datation bias and the range bias are compared with the corresponding values from BaselineC data computed by the operational CryoSat IPF1 calibration tool, that is based on Delay/Doppler processing

Datation bias

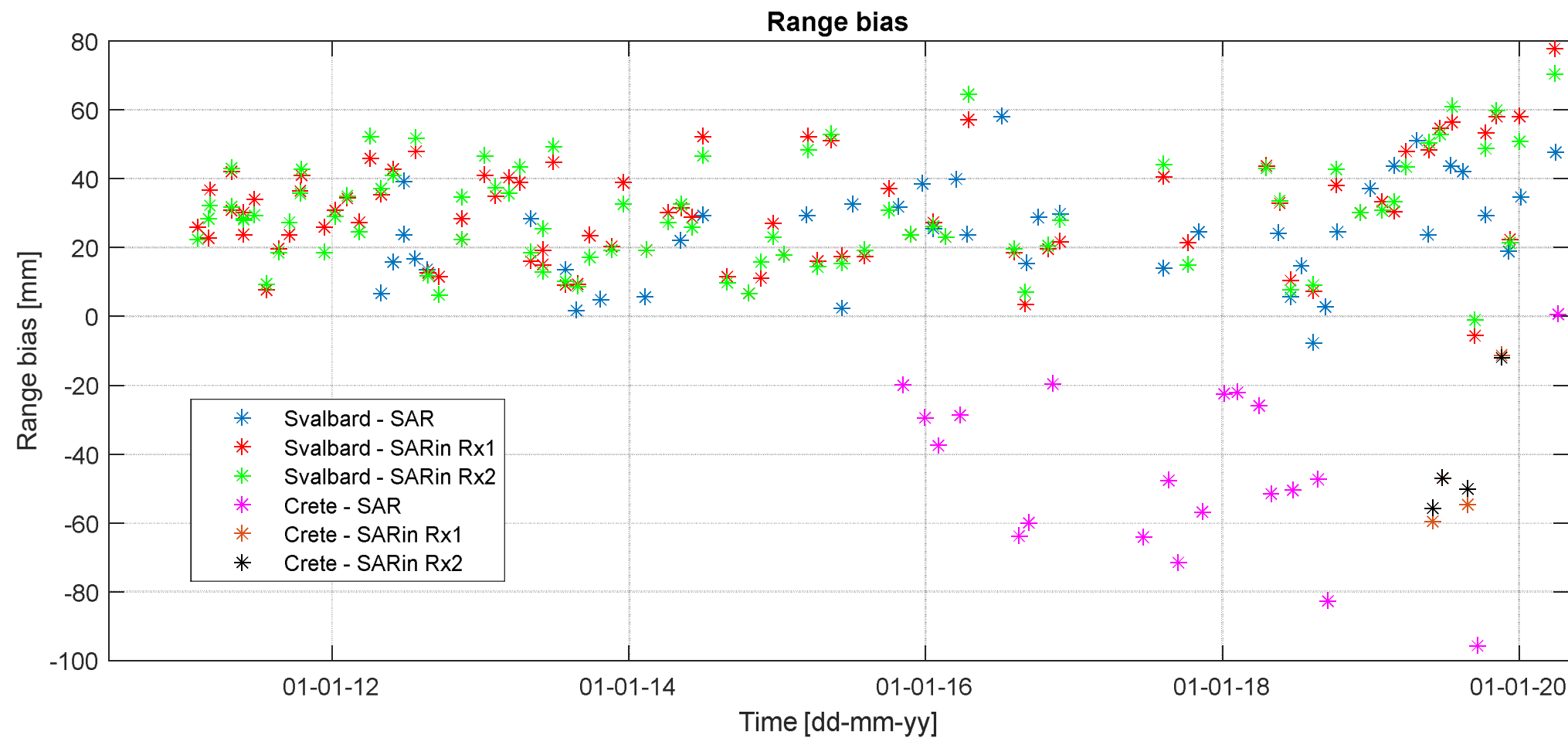


Datation bias: Performance comparison

- The FFSAR external calibration tool measures
 - a smaller datation bias than the CryoSat IPF1 tool
 - the standard deviation is reduced by a factor roughly equal to 4

		Svalbard			Crete
		SAR	SIN1	SIN2	SAR
CryoSat IPF1 calibration tool (last QWG)	Average datation bias [μ s]	-24.1	-28.0		-27.4
	STD of datation bias [μ s]	34.6	30.5		35.5
FFSAR BP calibration tool	Average datation bias [μ s]	-13.4	-14.4	-14.7	-8.8
	STD of datation bias [μ s]	8.4	7.8	7.6	9.3

Range bias



Range bias: Performance comparison

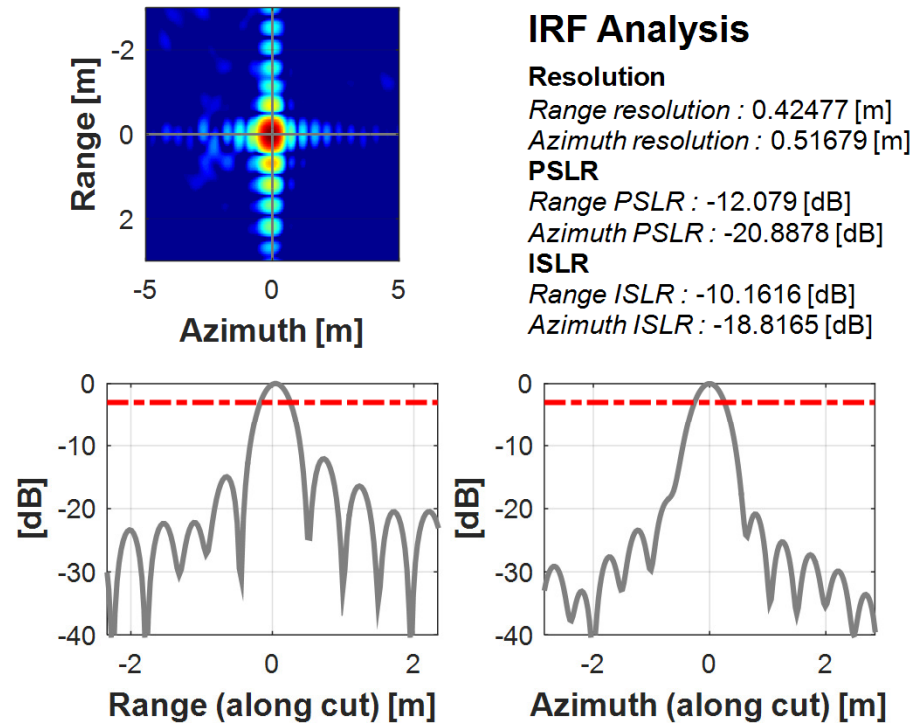
- The FFSAR external calibration tool measures
 - different range bias for Svalbard and Crete
 - Standard deviation of the range bias is comparable with CryoSat IPF1 tool

		Svalbard			Crete
		SAR	SIN1	SIN2	SAR
CryoSat IPF1 calibration tool (last QWG)	Average range bias [mm]	39.1	41.4		-91.1
	STD of range bias [mm]	11.7	12.8		57
FFSAR BP calibration tool	Average range bias [mm]	24.5	30.1	30.0	-44.9
	STD of range bias [mm]	14.8	15.4	15.4	24.2

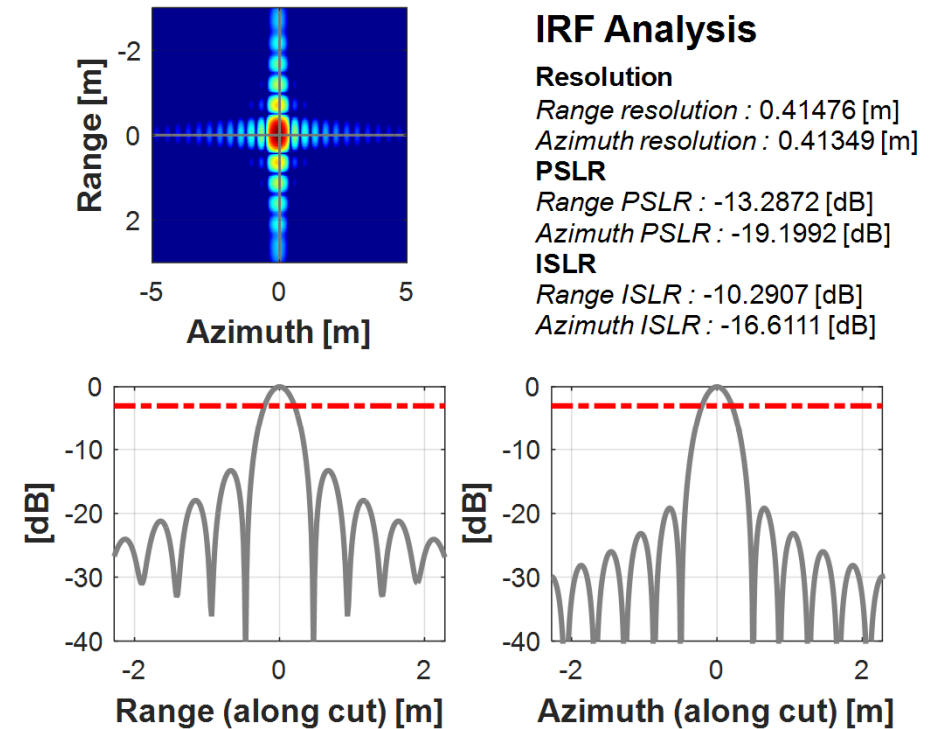
FFSAR Point Target Response

For each external calibrator acquisition the tool provides graphical reports to inspect the PTR parameters and to compare them with those expected from theoretical model of the FFSAR PTR

PTR from transponder acquisition

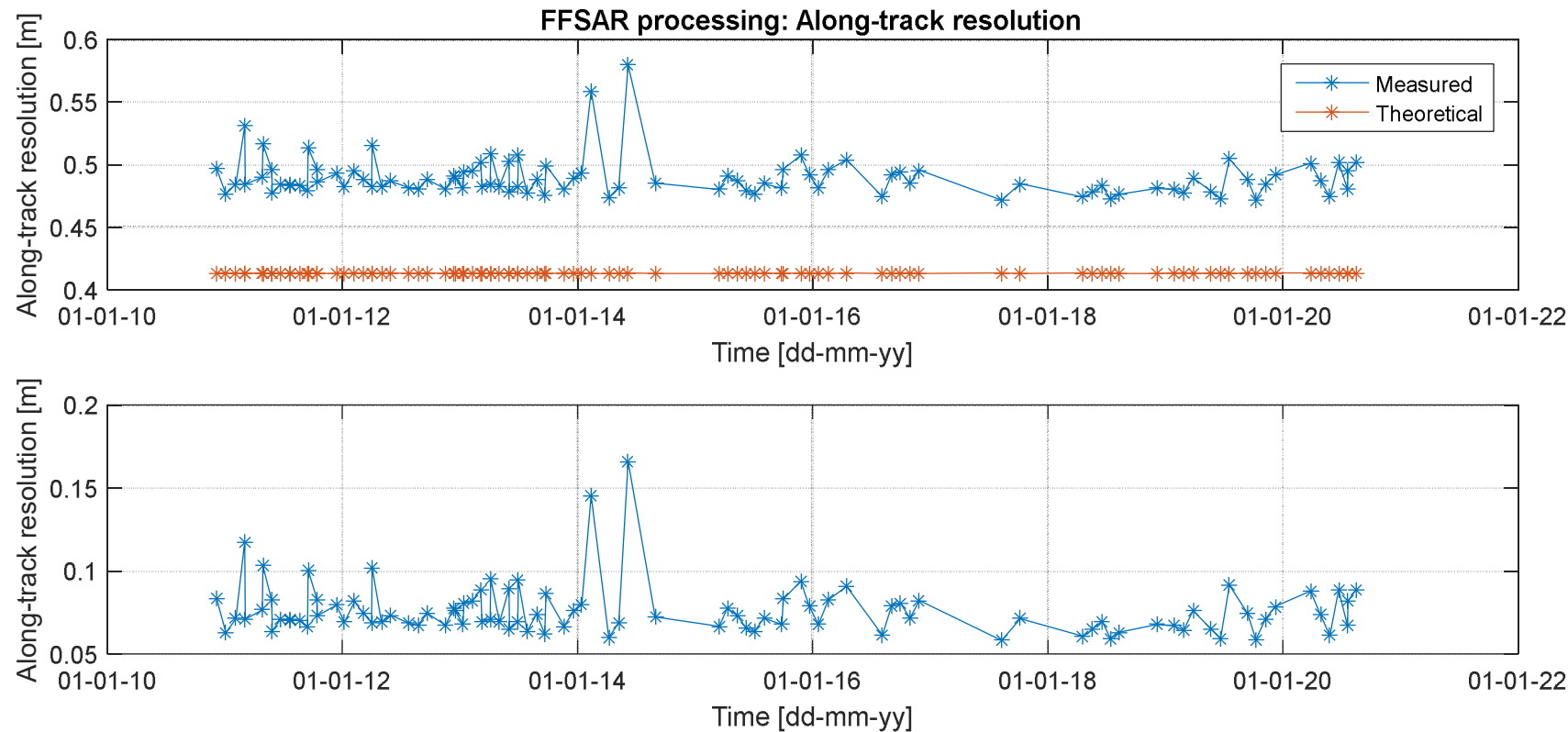


PTR from theoretical model



FFSAR Point Target Response: along-track

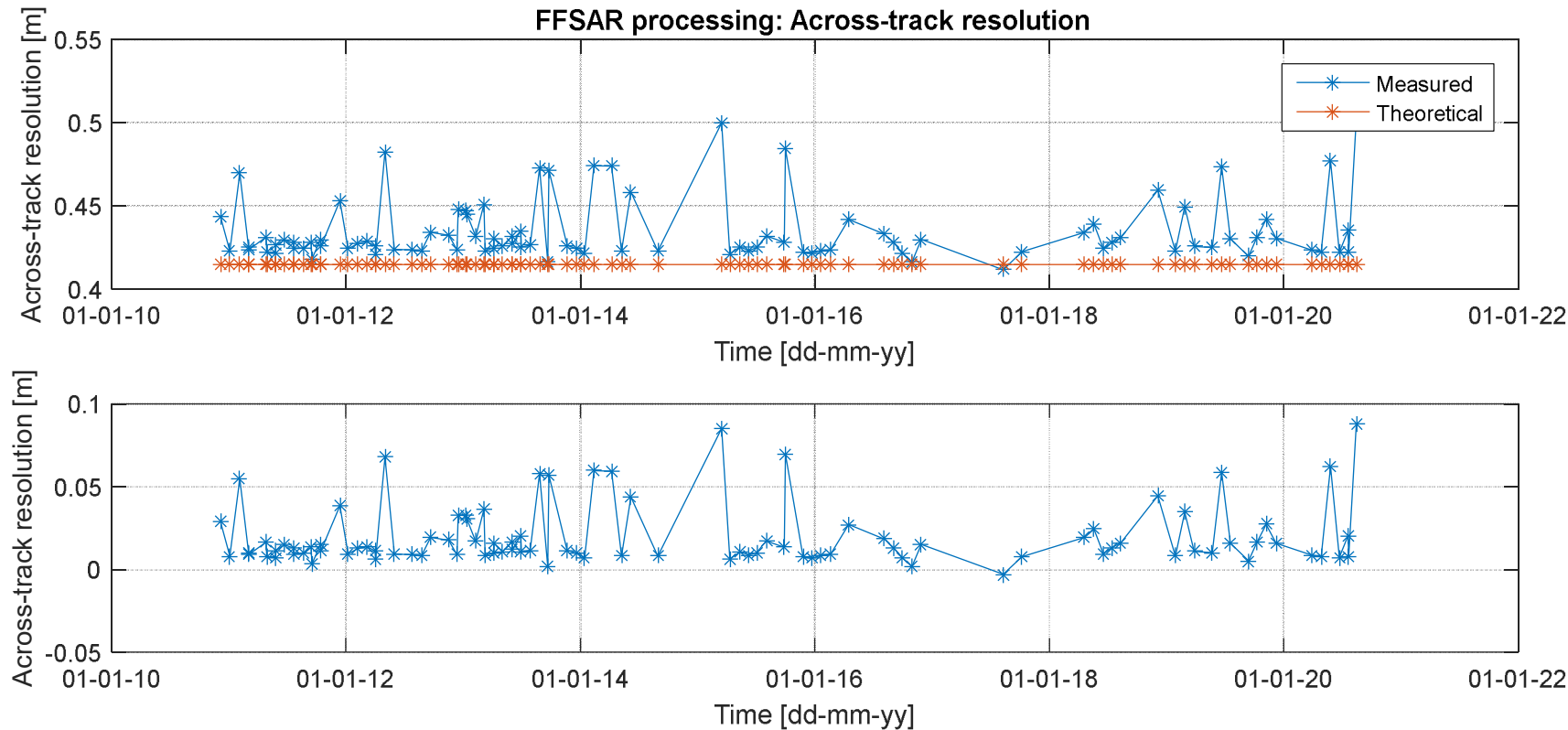
The along-track resolution at -3 dB of the FFSAR PTR for the SARin acquisitions over Svalbard transponder is shown here together with the error with respect to the theoretically expected one



- Average FF along-track resolution: 0.490 m
- STD FF along-track resolution: 0.016 m
- Average FF along-track resolution error: 0.076 m

FFSAR Point Target Response: across-track

The across-track resolution at -3 dB of the FFSAR PTR for the SARin acquisitions over Svalbard transponder is shown here together with the error with respect to the theoretically expected one



- Average FF across-track resolution: 0.435 m
- STD FF across-track resolution: 0.019 m
- Average FF across-track resolution error: 0.020 m

Conclusions

- A FFSAR external calibration tool was developed and tested with CryoSat transponder acquisitions
- The tool was verified to
 - estimate the datation bias with high precision
 - estimate range bias values comparable with those from the CryoSat IPF1 tool
 - estimate along- and across-track resolution values for the FFSAR PTR slightly higher than the theoretically expected ones
- Regarding CryoSat, the tool allows to verify
 - The stable performance of the SIRAL instrument
 - The good quality of the FBR products