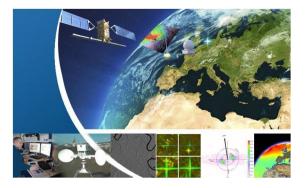


S-1 Annual Performance Report for 2022



Reference: SAR-MPC-588 Nomenclature: DI-MPC-APR Issue 1.1 – 13/03/2023







S-1 MPC

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1.0	31.01.2023	First version	SAR-MPC
1.1	06.03.2023	Second version Fix multiple typos, improve figure readability. Add section 5.8.3 on regular reporting of residual RFI	SAR-MPC
1.2	13.03.2023	Clean title of section 3.0.3 Correction of formatting for section 6.1.1 Update number for figures of section 6.2	

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1.Introduction

1.0 Purpose of this document

The purpose of this document is to provide the status on the S-1 constellation instruments and products performance during 2022.

1.1 Document organisation

The outline of this report is given below:

Chapter 1: This introduction

Chapter 2: Executive Summary

Chapter 3: Processing Updates

Chapter 4: Instrument Status

Chapter 5: Level 1 Product Status

Chapter 6: Level 2 Product Status

The following appendices are also provided:

Appendix A - S-1A & S-1B Technical Reports

Appendix B - S-1A Instrument Unavailability

Appendix C - S-1A & S-1B Quality Disclaimers

Appendix D - S-1A Orbit Cycles

Appendix E - S-1A Transmit Receive Module Failures

Appendix F - S-1A & S-1B Auxiliary Data Files

1.2 Applicable and Reference Documents

1.2.1 Applicable Documents

[AD-01]	Sentinel-1 Product Specific	ation. S1 RS-MDA-52-7441.	Issue 3/13, October 2022
[/ [0] 0]	Sentinet i roduce specific	acion, 51 no mor 52 7 111,	issue st is, occosel for

- [AD-02] Sentinel-1 Level 1 Detailed Algorithm Definition, SEN-TN-52-7445, Issue 2/5 November 2022
- [AD-03] Sentinel-1 IPF Auxiliary Product Specification, S1-RS-MDA-52-7443, Issue 3/10, November 2022
- [AD-04] Sentinel-1 Doppler and Ocean Radial Velocity (RVL) ATBD, ISSN 1890-5226, MPC-0534, Issue 01.6, October 2022
- [AD-05] Sentinel-1 Ocean Wind Fields (OWI) ATBD, MPC-0469 DI-MPC-IPF-OWI, Issue 02.2, October 2022
- [AD-06] Sentinel-1 Ocean Swell Wave Spectra (OSW) ATBD, S1-TN-NRT-52-7450, MPC-0469, DI-MPC-IPF-OSW, Issue 01.6, 12 October 2022
- [AD-07] Annual Performance Report 2021, DI-MPC-APR-0523, Issue 1.1, March 2022
- [AD-08] Sentinel-1 Level-2 Ocean Processor, Main ATBD, DI-MPC-LOP-MPC-0583, Issue 1.1, October 2022



1.2.2 Reference Documents

The following documents provide useful reference information associated with this document. These documents are to be used for information only. Changes to the date/revision number (if provided) do not make this document out of date.

- [S1-RD-01] Nuno Miranda, Peter Meadows, Riccardo Piantanida, Andrea Recchia, David Small, Adrian Schubert and Pauline Vincent, 'The Sentinel-1 Constellation Performance Status: 2019 Update', Proceedings of the CEOS SAR Workshop, November 18-22, 2019, ESA/ESRIN, Frascati, Italy.
- [S1-RD-02] Peter Meadows, David Small, Adrian Schubert and Nuno Miranda, 'Sentinel-1 Radiometric and Geometric Calibration', Proceedings of the CEOS SAR Workshop, November 18-22, 2019, ESA/ESRIN, Frascati, Italy.
- [S1-RD-03] Guillaume Hajduch, 'Mutual Interferences between C-Band SAR: Prediction of occurrences identification of sources', Proceedings of the CEOS SAR Workshop, November 18-22, 2019, ESA/ESRIN, Frascati, Italy
- [S1-RD-04] Medhavy Thankappan, Matthew Garthwaite, Christoph Gisinger, Adrian Schubert, Peter Meadows, Nuno Miranda, 'Improvements to the position coordinates for the Australian corner reflector array and new infrastructure to support SAR calibration and multitechnique validation at the Yarragadee fundamental geodetic station', Proceedings of the CEOS SAR Workshop, December 5-7, 2018, Buenos Aires, Argentina.
- [S1-RD-05] Schubert A., D. Small, N. Miranda, D. Geudtner, E. Meier. Sentinel-1A Product Geolocation Accuracy: Commissioning Phase Results. Remote Sens. 2015, 7, 9431-9449. doi: 10.3390/rs70709431.
- [S1-RD-06] Schubert A., D. Small, N. Miranda, D. Geudtner, E. Meier. Sentinel-1A Product Geolocation Accuracy: Beyond the Calibration Phase. Presented at CEOS SAR Calibration & Validation Workshop; Noordwijk, The Netherlands, 2015.
- [S1-RD-07] GMES Sentinel-1 Team. GMES Sentinel-1 System Requirements Document, Ref. S1-RS-ESA-SY-0001, Iss. 3, Rev. 3, 2010.
- [S1-RD-08] Rodriguez-Cassola M. et al., Doppler-related distortions in TOPS SAR images, IEEE Trans. Geosci. Remote Sens. 2015, 53, 25-35.
- [S1-RD-09] Piantanida R., A. Recchia, N. Franceschi., A. Valentino, N. Miranda, A. Schubert, D. Small, Accurate Geometric Calibration of Sentinel-1 Data, Proc. EUSAR 2018, 63-68.
- [S1-RD-10] Schubert A., N. Miranda, D. Geudtner, D. Small, Sentinel-1A/B Combined Product Geolocation Accuracy. Remote Sensing 2017, 9, 1-16. doi: 10.3390/rs9060607
- [S1-RD-11] Small, D., A. Schubert. Guide to Sentinel-1 Geocoding, UZH technical note for ESA-ESRIN, UZH-S1-GC-AD, Issue 1.10, 26.03.2019; University of Zurich: Zurich, Switzerland, 42p.
- [S1-RD-12] Niccolo Franceschi, 'Cross Sensor Calibration of Sentinel-1 Noise Level', Proceedings of the CEOS SAR Workshop, November 18-22, 2019, ESA/ESRIN, Frascati, Italy
- [S1-RD-13] Moiseev, A., Johnsen, H., Johannessen, J. A., Collard, F., & Guitton, G. (2020). On removal of sea state contribution to Sentinel-1 Doppler shift for retrieving Reliable Ocean surface current. Journal of Geophysical Research: Oceans, 125, e2020JC016288. https://doi.org/ 10.1029/2020JC016288
- [S1-RD-14] Schwerdt M., K. Schmidt, N. Tous Ramon, G. Castellanos Alfonzo, B. Döring, M. Zink, P. Prats. Independent Verification of the Sentinel-1A System Calibration. IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens. 2016, 9, 994-1007. doi:10.1109/JSTARS.2015.2449239.
- [S1-RD-15] Schwerdt M., K. Schmidt, N. Tous Ramon, N., P. Klenk, N. Yague-Martinez, P. Prats-Iraola, M. Zink, and D. Geudtner. Independent System Calibration of Sentinel-1B, Remote Sensing, 9(6), 511, doi:10.3390/rs9060511, 2017.



- [S1-RD-16] Reimann, J., M. Schwerdt, K. Schmidt, N. Ramon, B. Döring. The DLR Spaceborne SAR Calibration Center. Frequenz 71, 619-627. doi:10.1515/freq-2016-0274, 2017.
- [S1-RD-17] Schmidt, K., N. Tous Ramon, M. Schwerdt. Radiometric Accuracy and Stability of Sentinel-1A Determined using Point Targets. Int. J. Microw. Wirel. Technol. 10, 538-546. doi:10.1017/S1759078718000016, 2018.
- [S1-RD-18] Schmidt K, M. Schwerdt, N. Miranda N, J. Reimann. Radiometric Comparison within the Sentinel-1 SAR Constellation over a Wide Backscatter Range. Remote Sensing. 2020; 12(5):854
- [S1-RD-19] A. M. Guarnieri, C. Albinet, A. Cotrufo, N. Franceschi, M. Manzoni, N. Miranda, R. Piantanida, A. Recchia. Passive sensing by Sentinel-1 SAR: Methods and applications, Remote Sensing of Environment, Volume 270, 2022.
- [S1-RD-20] A. Recchia, D. Giudici, R. Piantanida, N. Franceschi, A. Monti-Guarnieri and N. Miranda, "On the Effective Usage of Sentinel-1 Noise Pulses for Denoising and RFI Identification," EUSAR 2018; 12th European Conference on Synthetic Aperture Radar, 2018
- [S1-RD-21] C.Gisinger, L. Libert, P. Marinkovic, L. Krieger L. Y. Larsen, A. Valentino A., H. Breit, U. Balss, S. Suchandt, T. Nagler, M. Eineder, N. Miranda, "The Extended Timing Annotation Dataset for Sentinel-1—Product Description and First Evaluation Results," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-22, 2022, doi: 10.1109/TGRS.2022.3194216.
- [S1-RD-22] T. Fuhrmann, J. Batchelor., T. McCall., M.C. Garthwaite. Positions and orientations for the Queensland corner reflector array, Australia: Report on geodetic surveys conducted in May and June 2018. RECORD 2020/034. Geoscience Australia, Canberra. doi 10.11636/Record.2020.034
- [S1-RD-23] B. Rommen, I. Barat, M. Chabot, C. Lambert and D. Williams, Joint Investigation on Radarsat-2 / Sentinel-1A Mutual RFI, Noordwijk, October 27 2015, <u>https://calvalportal.ceos.org/html/portal/sarc/documents/documents/05_CEOS_S1A_RS_AT2_final.pdf</u>
- [S1-RD-24] C. Gisinger, A. Schubert, H. Breit, M. Garthwaite, U; Balss, M. Willberg, D. Small. In-Depth Verification of Sentinel-1 and TerraSAR-X Geolocation Accuracy Using the Australian Corner Reflector Array," in IEEE TGRS, vol. 59, no. 2, pp. 1154-1181, Feb. 2021, doi: 10.1109/TGRS.2019.2961248
- [S1-RD-25] U. Balss, C. Gisinger, M. Eineder, H. Breit, A. Schubert, D. Small, Survey Protocol for Geometric SAR Sensor Analysis, April 28, 2018, <u>https://calvalportal.ceos.org/documents/10136/11045/FRM4SAR_TN200_Site_Survey_Protocol_Definition_V1_4.pdf</u>
- [S1-RD-26] H. Peter and M. Fernández, Sentinel-1 Full Mission Reprocessing 2021, GMV-CPOD-MEM-0052 v1.1, 2021, https://sentinel.esa.int/documents/247904/3455957/Sentinel-1-C-POD-Full-Mission-Reprocessing-2021-v1.1.pdf

A set of technical documents, issued by S-1 Mission Performance Centre or more generally relevant with respect to this report, given more information on the S-1A and S-1B products quality could also be cited as reference and is available on the <u>Sentinel Online Library</u>. The full list is provided on Appendix A -

1.3 Acronyms and Definition

AD	Applicable Document	
ADF	Auxiliary Data File	



ALE	Absolute Localisation Error	
AOCS	Attitude and Orbit Control Systems	
CFI	Customer Furnished Item	
СР	Commissioning Phase	
DC	Doppler Centroid	
EAP	Elevation antenna Pattern	
ECMWF	European Centre for Medium-Range Weather Forecasts	
EFE	Electronic Front End	
ENL	Equivalent Number of Look	
FDBAQ	Flexible Dynamic Block Adaptive Quantisation	
GMF	Geophysical Model Function	
IRF	Impulse Response Function	
IPF	Instrument Processing Facility	
MTF	Model Transfer Function	
NESZ	Noise Equivalent Sigma Zero	
OWI	Wind component of OCN products	
OSW	Swell component of OCN products	
OCN	Sentinel-1 Level 2 product	
PDGS	Payload Data Ground Segment	
PG	Power x Gain	
PSC	Permanent Scatterers Calibration	
QD	Quality Disclaimer	
QCSS	Quality Control SubSystem	
(N)RCS	(Normalised) Radar Cross Section	
Nv	Normalised Variance (of SAR image)	
RD	Reference Document	
RDB	Radar DataBase	
RFC	Radio Frequency Characterization mode	
RFI	Radio Frequency Interference	
RVL	Radial Velocity (component of OCN products)	
	Synthetic Aperture Radar	
SNR	Signal to Noise Ratio	
STT	STar Tracker	
ТВС	To be confirmed	
TBD	To be defined	
i		



2. Executive Summary

This report gives the status of the Sentinel-1 instruments and product performance during 2022. Unfortunately, S-1B instrument suffered of a severe anomaly last year resulting to a long-term instrument unavailability since the 23rd December 2021. The end of the S-1B mission was finally officially declared on the 3rd August 2022. No S-1B data are available for 2022. This report will then focus on the status for S-1A mission.

As will be seen in Chapter 3 (Processor Updates), Chapters 4 (Instrument Status), Chapters 5 (Level 1 Product Status) and Chapter 6 (Level 2 Product Status) many aspects of the Instrument Processing Facility (IPF), instrument and products are considered with the aim of ensuring users receive high quality products.

A summary of the report is provided below:

IPF and Auxiliary Files

- On 23rd March 2022, the IPF was updated to IPF v3.5.1, the most relevant changes are:
 - Level 1 content:

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- Correction of the misalignment between the elevation antenna pattern and the annotated thermal noise vector
- Reduction of the number of false positives in RFI time-domain detection
- Solving of inconsistency in the application of the results of the RFI pre-screening Level 2 content:
 - Implementation of a new algorithm for TotalHs computation
 - Review of the oswQualityFlag estimation (based on machine learning algorithm)
 - Rescalling of rvlNRCS
 - Wind inversion provided on the IceMask
- Relative to the IPF v3.5.1 usage, the functionality of RFI mitigation was activated for all TOPS mode products (L1 and L2), with the update of a set of AUX_PP1 on the same day (S1A_AUX_PP1 for all RDB 1 to 7 and S1B_AUX_PP1 for RDBs 1 and 2). The S-1A processing gains for EW/IW in HH polarisation were also updated at the same occasion only for OCN products, in order to align the wind performances between S1-A and S-1B.
- Relative to the IPF v3.5.1 usage, the AUX_PP2 was also updated to accommodate the change of format with the introduction of processing parameter velthresh and oswNoiseCorrection, currently velthresh parameters is set to previously existing default value and oswNoiseCorrection is set to False, meaning no activation of denoising.
- IPF 3.51 introduced a major regression on the mapping of auxiliary data for L2 OCN products higher to 60° latitude North and South; more details were provided in Quality disclaimer <u>QD-87</u>.
- Moreover, on 8^h April 2022, AUX_WND were changed to include hourly forecast instead of 3h forecast as previously available. With this change, the content of the ECMWF GRIB has evolved with unexpected additional variables (such as pressure), leading to a misinterpretation by the IPF of the a priori wind speed for the Swell module, impacting the OCN products (more details are provided in <u>QD-86</u>)
- On 12th May 2022, the IPF was upgraded to IPF v3.5.2, it only contains upgrades on the L2 part to correct the two above points.
- On 7th June 2022, a set of AUX_PP2 (relative to all RDB for S-1A and S-1B) was circulated, allowing the activation of oswTotalHs computation based on machine learning algorithms.

Instrument Status

- The analysis of RFC and Internal Calibration products shows that S-1A instrument is stable. No major instrument events have been recorded during 2022. No quality degradation associated to issues happened in previous years is observed in S-1 products.
- The analysis of Noise products shows that the instrument noise level is stable.



- S-1 interferometric performances in terms of interferometric baseline, burst synchronization and instrument pointing are within the mission requirements. During the month of September 2022 collision avoidance manoeuvres caused an increase in the interferometric baseline and burst synchronization error. The baseline remained below 10% of the critical value (5 km for the normal baseline), and the values of the burst synchronization error are within +/- 15 ms.
- S-1A DC is showing DC jumps up to 30 Hz when the STT configuration changes. The issue is continuously monitored and, in case the DC jumps get worse, could lead to the execution of a new STT alignment campaign during 2023.
- RFI mitigation was activated with IPF 3.5.1 on 23rd March 2022. However, some strong RFI contamination events have been observed during 2022. RFI contamination has no permanent effect on the instrument but reduces the quality of affected data takes introducing radiometric artefacts. For these strong events, the IPF mitigation strategy remains not effective.
- Sentinel-1B instrument is unavailable since the 23rd December 2021.

Level 1 Product Status

- The various image quality parameters such as spatial resolution, sidelobe parameters, equivalent number of looks and ambiguity ratios derived from distributed target or using DLR transponders & corner reflectors, and the Australian corner reflector array all give nominal results.
- The radiometric performance of S-1A has been monitored and the radiometric accuracy has been determined for IW mode DV polarization using point targets of the DLR calibration site. During 2022, the overall mean and standard deviation for the absolute calibration factor has been derived to be -0.08 dB ± 0.24 dB which includes the observation of both polarizations (VV and VH) and all three sub-swathes (IW1, IW2, and IW3). Including all error contributions, an absolute radiometric accuracy for the IW mode of 0.322 dB (1o) could be verified. Furthermore, the radiometric performance for IW mode HH polarization has been monitored using CRs over Australia. With respect to the expected RCS, a small bias of -0.23 dB has been found with a standard deviation of 0.20 dB.
- The channel imbalance in amplitude and phase has been derived from DLR transponder measurements. For both SAR instruments, the VV polarization channels show, in average, slightly higher values than VH polarization channels with remaining biases of 0.14 dB (refer to Figure 24). The phases are also well balanced with remaining biases below 2 degrees. The co-registration of the IRF peaks for both polarizations show deviations below 0.1 m in average. The cross-talk of S-1A derived from DLR corner reflector measurements are in average -42.6 dB which confirms the very good quality concerning the separation of the co-and cross polarization channels of both SAR instruments.
- Geolocation accuracy was assessed considering well-surveyed corner reflectors in Surat basin. Both out-of-the box (i.e., using the L1 SLCs as is without performing any post-processing correction) and best achievable accuracy (i.e., performing a set of corrections to remove instrument and geophysical biases and using the S-1 precise orbit products) have been tested The out-of-the box geolocation accuracy for S-1A measured during 2022 is:

-1A:	Range:	-3.462 ± 0.352 m	
	Azimuth:	+2.109 ± 0.833 m	

The best achievable geolocation accuracy for S-1A measured during 2022 is:

oS-1A:	Range:	+0.062 ± 0.056 m	
	Azimuth:	-0.112 ± 0.332 m	

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The ALE estimates for IW mode indicate a localisation performance well within the requirements. The ALE is within the specified 1σ of 3.33m, i.e. 10m at 3σ (section 5.5.2.2 of [S1-RD-07]).

• A few examples of radio frequency interference occurred during 2022 from (i) sources on the ground (ii) unknown source(s) causing long-duration interference, (iii) the Chinese GAOFEN 3 C-Band SAR satellite and the Canadian RCM Constellation C-Band SAR also causing long-duration interferences.



Level 2 Product Status

- Wind (OWI): no major changes occurred in 2022 on performance for OWI products on TOPS and SM modes. Since the 18th May 2022, the products are generated using ECMWF wind forecast with a time step of 1hour instead of 3hours and a grid spacing of 0.1 degrees instead of 0.125 degrees. This increase of spatial and temporal resolution was not aimed to change the statistical performances of the Wind (OWI) measurement but may improve the performances on some specific products.
- Swell (WV) measurements: The OSW product is produced from WV and SM modes. However, for SM the number of acquisitions is too small to perform any geophysical validation. The S-1 WV OSW wave spectra are systematically validated against global collocated WW3 spectra.

The OSW quality flag is used to assess the performance into five categories:" very good"," good"," medium", "low", and "poor". A new algorithmic method for estimating this indicator has been implemented and validated with IPF v3.5.1 in March 2022. This new approach is based on a machine learning model that exploits the estimated errors for the integer parameters of each partition to assess its quality. Considering all categories, the distribution of the different quality flag categories is almost homogeneous. That said, the data with "very good" and "good" category are now in massive quantities and their integrated parameters match well the wave parameters specifications.

On the 7th June 2022, the oswTotalHs variable started to be populated in L2 OCN products, based on Deep-Learning model approach [AD-06]. This variable is an "altimetric like" significant wave height.The Inputs of the model are SAR polar image cross spectrum (real and imaginary) plus high-level features: incidence angle, longitude, latitude, NRCS, Normalized variance... The performances are assessed with collocated data from altimeters, and show good agreement aligned with specification of RMSE<0.5 m and bias<0.1 m. However, a little overestimated bias (~5cm) could be observed on WV2 compared to altimeter while WV1 is underestimated (~10 cm). The accuracy and precision of oswTotalHs and its standard deviation could be improved by tuning other models, increasing the size of the training dataset (especially for acquisitions after the WV2 Antenna Elevation Pattern update) or adding extra information helping the model.

As for the wind sea Hs retrieval, the algorithm has undergone extensive quality control in order to qualify this feature.

A new exercise in reprocessing L2 products from the L2 products themselves was demonstrated to assess the ability to replay inversions only from L2 level products. This replay of inversions has been identified as an essential element in the development of the IPF insofar as it makes it possible to test new avenues for improvement and to have a rapid investigation of certain parameters:

- As for users, it is also a step forward that will allow them to play with the products to test their own approaches to estimating osw variables starting from L2 products.
- As for the IPF, this exercise allowed us to identify the lack of certain variables in the L2 products to have a correct replay of the swell inversion. This has been expanded and updated in the IPF and associated documentation.

An investigation of the SAR wave spectra has identified a defect in the spectral energy distribution as a function of azimuthal dimension. This behaviour is more pronounced for WV2 than WV1. The initial results show that improvements are required and optimizations of the current MTF to correct such defect.

Radial Velocity: The Sentinel-1 Level 2 Doppler centroid anomaly (DCA) and radial velocity (RVL) measurements are currently coloured by the AOCS derived Doppler frequency. The predicted Doppler centroid (DC) frequency computed from the downlinked quaternions does not reflect the actual DC frequency as measured by the SAR. This prevents the current version of the Level 2 processor to provide calibrated DCA and RVL estimates. However, promising results are achieved off-line using restituted attitude (RESATT) estimated from calibrated Gyro data (see



reference [S1-RD-13] for details). A post-processing approach has been implemented as part of the "Copernicus Sentinel-1 RVL Assessment" project. The results have been shown during 2022 Living Planet Symposium (talk entitled "Towards Calibrated Sentinel-1 OCN RVL Products"). For some IW and EW products, a sudden jump in DC (>10Hz) is still observed from one burst to another over all swaths. The investigations suggest that these jumps come from temperature compensation which subsequently alters the antenna characteristics. There is at present no means to predict when and where this occurs. A data driven approach is under consideration.

Another kind of jumps was observed for TOPS products, coming from the L0 to SL2 IPF processing whose modification is under consideration.



3. Processing Updates

The main improvements introduced in the Level-1 and Level-2 Processor and impacting data quality are described below, classified according to the release in which they have been included. The full details of IPF upgrades including date of usage and content description of the different IPF versions are available on https://sar-mpc.eu/ipf/

3.0 Processor

3.0.1 IPF 3.5.2 (from 12/05/2022)

• Level 1 content

No change compared to IPF 3.5.1

Level 2 content

Correction of regressions introduced by IPF 3.51

- issue on the projection of auxiliary data (Land / OSI SAF Ice / Ecmwf Wind / StokesDrift) for products above 60deg lattitude (North and South) [Quality Disclaimer-87]
- OWI processing failure for products crossing the Greenwich meridian.
- Issue on oswEcmfWindSpeed/oswEcmfWindDirection extracted from AUX_WND containing extra-variables [Quality Disclaimer-86]
- Content of L2S products:
 - population of L2 processing facility name/country/organisation in product manifest
 - xsd files in product support directory [Quality Disclaimer-81]

3.0.2 IPF 3.5.1 (from 23/03/2022 to 12/05/2022)

IPF 3.51 also includes the features from IPF3.50 (never deployed) whose description has been included below.

- Level 1 Content
 - Correction of the misalignment between the elevation antenna pattern and the annotated thermal noise vector
 - o Reduction the number of false positives in RFI time-domain detection
 - Solved inconsistency in the application of the results of the RFI pre-screening.
 - \circ Solved segmentation fault occurring on AlmaLinux8 VM

Level 2 Content

- RVL
 - Application of a rescaling of rvlNrcs
 - Refinement of orbit propagation, correction of geolocation issue on the RVL grid.
- OSW

- Addition of new variable oswNrcsNeszCorr and new global attribute oswNoiseCorrection
- Introduction of the option for OSW denoising and possibility to trigger its activation via the AUX_PP2



- Introduction of a new algorithm for TotalHs computation (activation of this feature is triggered by AUX_PP2)
- Review of the qualityFlag computation using learning model approach
- The processing parameter velthresh is now set on AUX_PP2
- OWI
 - Wind inversion is provided over sea ice. The ice OSISAF mask from AUX_ICE is still provided in the owiMask variable and can be used to mask the data¹.
 - Refinement of the interpolation of the Calibration and Noise LUT
- General
 - Preconditions on AUX usage:
 - AUX_WND becomes mandatory for WV_OCN
 - introduction of preconditions on AUX_ICE validity date
 - IdlVersion global attribute is no longer populated.
 - Capability to process S6 OCN

3.0.3 IPF 3.4.0 (from 04/11/2021 to 23/03/2022)

This is the version of the IPF operating at the beginning of the year 2022. The content was the following:

- Level 1 changes were:
 - Annotation of a burst cycle ID.
 - Introduction of RFI detection from noise measurements.
 - Introduction of possibility to perform RFI mitigation in time and frequency domains.
 - Discarded last EW rank echo from noise power estimation as it may be contaminated by nadir returns.
 - Fix failure in GRD creation caused by insufficient overlap between adjacent sub-swaths.
 - Added support to CentOS 7.
 - Added support to Intel Compiler v17.
- Level 2 changes were:
- RVL
 - Correction of artefacts at end/beginning of swath.
 - Correction of data in the overlap area between sub swath.
- OSW
 - Swell inversion on StripMap S-1 in HH.
- OWI:
 - Parallelised computation of OWI NRCS Cross Pol.
 - Clean OWI NRCS Cross Pol from Bright Targets.
 - OWI Wind direction set to fill_value for masked data.
 - OWI management of corrupted AUX_ICE.
 - Explicit processing error message in case of corrupted AUX_WIND.
 - Presence owiNoiseCorrection global attribute even when OWI process fails.
- General:

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• Migration to Python 3.



¹ Please note that at the time of the nominal processing workflow, the OSISAF mask (AUX_ICE) reflects the ice situation of the day before the product acquisition. Since ice mask may highly vary from a day to another, this mask may not be accurate as respect to the observed situation. To overcome this, it has been chosen to provide the wind inversion even on area which is a priori covered by sea ice, in order to let the possibility to the user of applying his own masking with a better accurate or using the one provided in the product with the OSISAF information provided at the moment of the processing.

• Correction on first/lastMeasurementTime in L2 NetCDF.

3.1 Auxiliary Data Files

In addition to the described L1 and L2 Processor upgrades, a summary of Auxiliary Data Files (ADFs) updates during the reporting period is provided, together with an explanation of the updates, in Appendix F -. The main ones are summarised below:

AUX_INS

No update of AUX_INS was performed during 2022.

AUX_CAL

No update of AUX_CAL was performed during 2022.

AUX_PP1

During 2022, the S-1A AUX_PP1 auxiliary files were updated once, coupled with IPF v3.5.1 deployment on the 23/03/2022 in order to:

1) allow the activation of RFI mitigation.

- flag rfiMitigationPerformed triggering the activation of RFI mitigation processing, is set to BasedOnNoiseMeas for all S1A TOPS products (IW/EW Level1 and Level2 products), so that the RFI mitigation is applied if RFI detection from noise measurements

- flag rfiMitigationDomain triggerring the method for RFI mitigation is set to TimeandFrequency

2) review the processing gains of SL2/GR2 EW/IW for HH channel, in order to align S-1A wind speed performance to S-1B for OCN products

During 2022, the S-1B AUX_PP1 auxiliary files were updated once coupled with IPF v3.5.1 deployment, on the 23/03/2022, in order to:

1) allow the activation of RFI mitigation.

- flag rfiMitigationPerformed triggering the activation of RFI mitigation processing, is set to BasedOnNoiseMeas for all S1A TOPS products (IW/EW Level1 and Level2 products), so that the RFI mitigation is applied if RFI detection from noise measurements

- flag rfiMitigationDomain triggerring the method for RFI mitigation is set to TimeandFrequency

AUX_PP2

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During 2022, there were two updates of S-1 AUX_PP2 auxiliary files (same content for S-1A and S-1B):

• On 23rd March 2022, linked to IPF 3.5.1: The AUX_PP2 format has evolved with the introduction of the following fields for OSW processing parameters:

 \cdot oswNoiseCorrection (set to False meaning that no denoising will be applied on OSW, at the moment)

- velthresh processing parameters is now set on the AUX_PP2 (values set is the same as the one internally set on previous IPF versions)

• On 7th June 2022 allowing the activation of TotalHs estimation (same content for S-1A and S-1B):

- Flag activateTotalHs triggering the activation of TotalHs estimation based on machine learning method is set to true for WV mode, for both sub swath WV1 and WV2. Consequently, oswTotalHs and oswTotalHsStdev will be populated for WV OCN products.

The change affects only WV mode.



AUX_SCS

No AUX-SCS update was performed in 2022.



4.Instrument Status

Hereafter, the status of the S-1A instruments during 2022 is described:

4.0 RFC Monitoring

The S-1A Antenna status is routinely monitored using the dedicated RFC calibration mode. The RFC products are processed to generate the Antenna Error Matrix, from which it is possible to retrieve the failure and drift of each TRM.

4.0.1 Antenna Status

Figure 1 shows the S-1A antenna Transmit/Receive Module (TRM) average status during December 2022. The images represent the deviations of the gain (4 images on the left) and the phase (4 images on the right) with respect to the nominal antenna status, measured from the first in-orbit acquisitions in April 2014. One image for each TX/RX and polarization combination is shown. No relevant changes in the S-1A antenna status occurred during the 2022. Ten (10) failures (happened before 2022) are counted in total among TX-RX and H-V corresponding to the antenna elements marked with a white "F" in the images. The figure also shows that half of tile 11 (TRMs from 1 to 10 in both polarizations) is transmitting with reduced power (about -13 dB) and with a phase offset (about -30 degrees) since an antenna issue occurred in June 2016. In October 2017 the tile 11 was electronically reconfigured to improve the status of the tile 11 TRMs still transmitting at full power (TRMs from 11 to 20 in both polarizations).

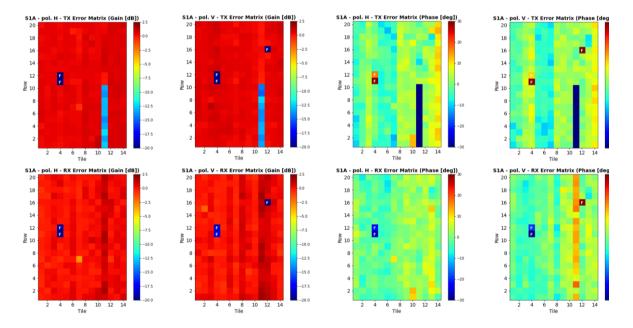


Figure 1: S-1A antenna status: gain (left) and phase (right) deviation of the TRMs from the nominal status. The white "F" marks the failed antenna elements.

The main recent S-1A antenna related event occurred on 04/01/21, when the TRM on tile 7 and row 7, both in TxH and RxH, suffered a small gain reduction and phase jump. The loss is about 1 dB in TX and 3 dB in Rx for H-pol channel. The TRM was then stable through 2022, as shown in Figure 2. The impact of this event on the overall data quality has been assessed and it is negligible.



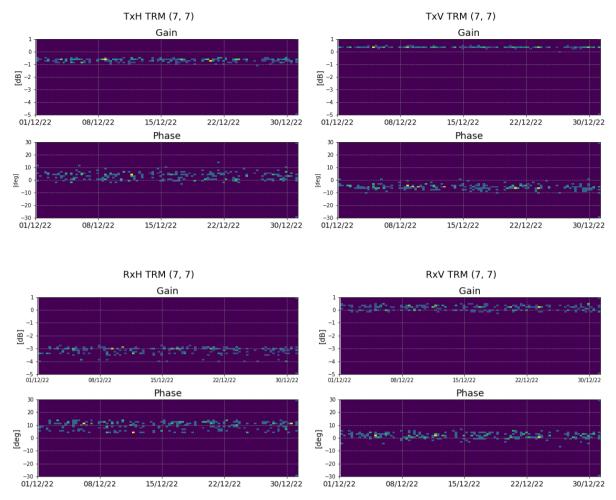


Figure 2: Gain and phase trend for the S-1A TRM (7, 7). Starting from 04/01/2021 it suffered a small gain reduction and phase jump for H polarization

4.0.2 TRM Trends

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The following plots (from Figure 3 to Figure 6) show the TX and RX excitation coefficients, averaged per tile, obtained processing the RFC products of 2022.

The overall TRMs behaviour is quite stable for both sensors. In particular, the TX gain is very stable while seasonal fluctuations related to the instrument temperature) can be observed for the TX phase (see section 4.1). The RX gain and phase coefficients appear noisier due to the thermal compensation performed on board, but their trend is stable for all the tiles.

S-1A tile 11 TX gain shows a reduced power (close to -4 dB) due to the antenna issue occurred in June 2016.



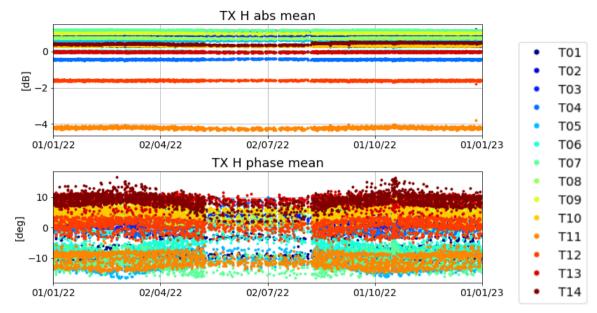


Figure 3: Gain (*top*) and phase (*bottom*) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in TX H over rows.

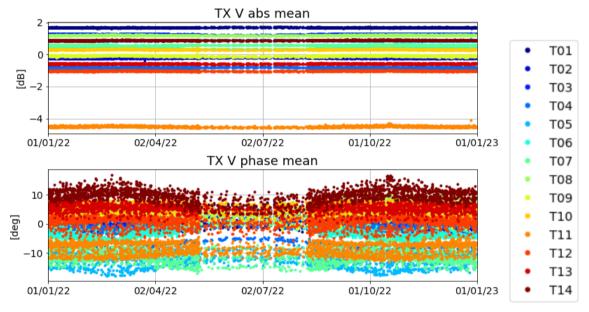


Figure 4: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in TX V over rows.

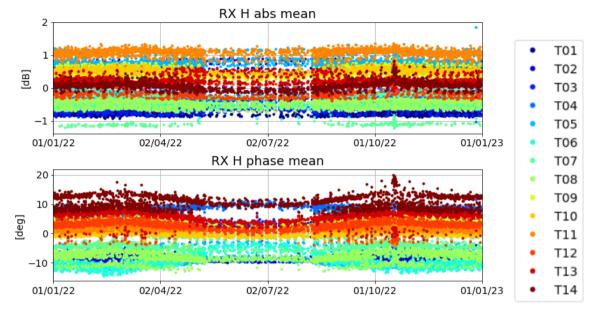


Figure 5: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in RX H over rows.

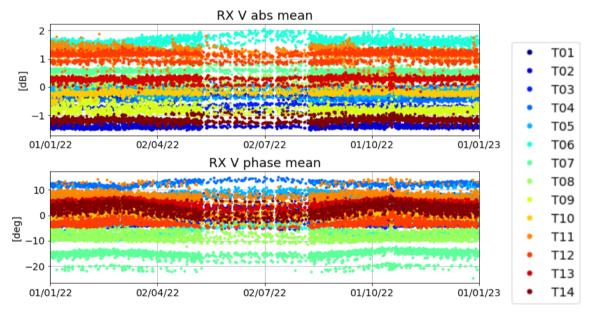


Figure 6: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in RX V over rows.

4.1 Instrument temperature

The S-1 instrument temperature is monitored through the information annotated in the header of the SAR Space Packets. Figure 7 shows the evolution of the temperature of the different antenna elements (Electronic Front End modules and Tile Amplifiers) during 2022 for S-1A. The low temperature spikes observed in the plots correspond to the instrument switch-off events or reduction of number of acquisitions at a given date.

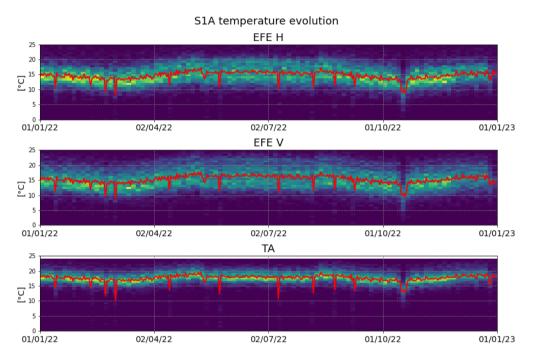


Figure 7: S-1A temperature evolution during 2022. The red solid lines show the daily averages.

Figure 8 shows the variation of the temperature of the different antenna elements as a function of the data takes duration for S-1A. The colours represent the different acquisition modes and polarizations. For long data takes (up to 15 minutes) the EFE temperature can increase up to 10 degrees and the TA temperature up to 6 degrees. This behaviour is expected, and the effects are compensated automatically on board.



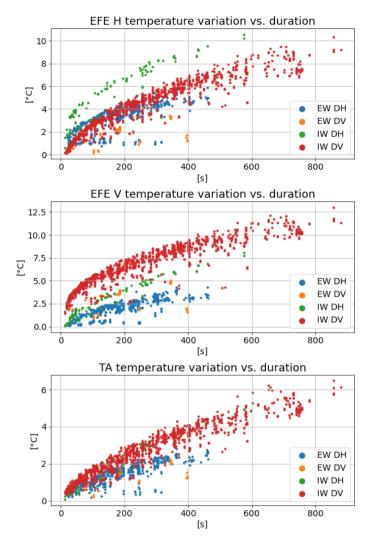


Figure 8: Variation of the antenna elements temperature as a function of the data take duration for S-1A. The colours represent the different acquisition modes and polarizations.

4.2 Internal Calibration

The S-1A instrument stability over time is monitored through the internal calibration signals.

The plots in Figure 9 show the PG gain and PG phase monitored during 2022. The different colours separate the different sub-swaths, and all the polarizations are plotted together. All the parameters are stable in the reporting period. The PG phase jumps observed are related to the instrument switch offs, in which case a reset of the electronic status of the instrument Analog-to-Digital Converter. Appendix B reports the dates of instrument unavailabilities, which eventually cause a reset of the ADC. For each of these events, a vertical dashed line is drawn in the figure. It can be observed that they are highly correlated with the PG phase jumps.



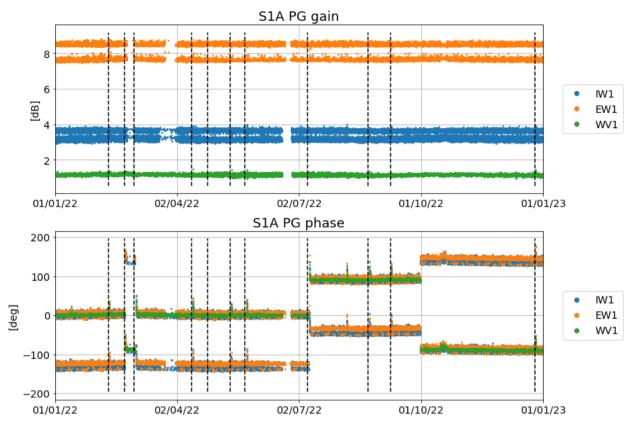


Figure 9: S-1A Internal Calibration parameters monitoring: PG gain (top) and PG phase (bottom). The vertical dashed lines mark events of instrument unavailabilities, which are correlated with the phase jumps.

The PG products are exploited to compensate for the instrument gain fluctuations to maintain the requested radiometric stability of the data. Figure 10 and Figure 11 show a more detailed picture of the S-1A PG gain evolution during the reporting period for IW and EW acquisitions.

The PG yearly linear trend for each mode and polarization is quite stable in the monitored period (red dashed line in the plots, the legend reports its angular coefficient). The yearly trend for the different modes and polarizations is better than -0.1 dB/year. Some slow fluctuations, correlated with the temperature variations reported in the previous section, can be observed. The fluctuations have a peak-to-peak variation of about 0.2 dB and are more visible in receiving channel H. Numerical values of the yearly trend computed separately per mode and polarization are reported in Table 1.

Table 2 reports the S-1A PG mean values of 2022 for each mode and polarization, compared with the Modeled PG products reported in the last S-1A AUX-INS file (S1A_AUX_INS_V20190228T092500_G20190227T100643.SAFE). The values are comparable, within a discrepancy of 0.1 dB.

Mode	Polarization	PG 2022 year trend
Widde	FUIdTIZation	[db/year]
	VV	-0.03
IW1	VH	0.00
1 1 1 1	HH	0.01
	HV	-0.02
	VV	-0.03
IW2	VH	0.01
IVVZ	HH	0.01
	HV	-0.02
	VV	-0.04
IW3	VH	0.00
100.2	HH	0.01
	HV	-0.02
	VV	-0.06
EW1	VH	-0.03
	HH	0.01
	HV	-0.02
	VV	-0.05
EW2	VH	-0.01
	HH	0.01
	HV	-0.02
	VV	-0.06
EW3	VH	-0.03
LWJ	HH	0.02
	HV	-0.01
	VV	-0.06
EW4	VH	-0.03
E 114	HH	0.02
	HV	-0.01
	VV	-0.06
EW5	VH	-0.02
EWJ	HH	0.02
	HV	-0.02

Table 1: PG yearly trends during 2022





	Dala tarta a	S-1A PG model	S-1A PG 2022	Delta
Mode	Polarization	[dB]	mean ± STD [dB]	[dB]
IW1	VV	3.70	3.67 ± 0.05	-0.03
	VH	3.27	3.23 ± 0.07	-0.04
	HH	3.09	3.07 ± 0.05	-0.02
	HV	3.55	3.56 ± 0.06	0.01
	VV	3.76	3.74 ± 0.05	-0.02
114/2	VH	3.28	3.25 ± 0.07	-0.03
IW2	HH	3.11	3.09 0.05	-0.02
	HV	3.61	3.61 ± 0.06	0
	VV	3.69	3.67 ± 0.05	-0.02
114/2	VH	3.20	3.16 ± 0.07	-0.04
IW3	HH	3.02	3.01 ± 0.05	-0.01
	HV	3.54	3.55 ± 0.06	0.01
	VV	8.70	8.63 ± 0.05	-0.07
EW1	VH	7.90	7.81 ± 0.08	-0.09
	HH	7.68	7.64 ± 0.06	-0.04
	HV	8.52	8.51 ± 0.07	-0.01
	VV	8.63	8.56 ± 0.05	-0.07
EW2	VH	7.81	7.72 ± 0.08	-0.09
E VV Z	HH	7.56	7.52 ± 0.06	-0.04
	HV	8.41	8.41 ± 0.07	0
	VV	8.63	8.57 ± 0.05	-0.06
E\\/2	VH	7.80	7.71 ± 0.08	-0.09
EW3	HH	7.55	7.51 ± 0.06	-0.04
	HV	8.40	8.41 ± 0.07	0.01
	VV	8.65	8.59 ± 0.05	-0.06
	VH	7.82	7.73 ± 0.08	-0.09
EW4	HH	7.57	7.53 ± 0.06	-0.04
	HV	8.43	8.43 ± 0.07	0
	VV	8.65	8.59 ± 0.05	-0.06
E\4/E	VH	7.82	7.72 ± 0.08	-0.1
EW5	HH	7.56	7.54 ± 0.06	-0.02
	HV	8.42	8.44 ± 0.07	0.02

Table 2: Comparison of PG model values and mean PG values registered during 2022, per mode and
polarization.

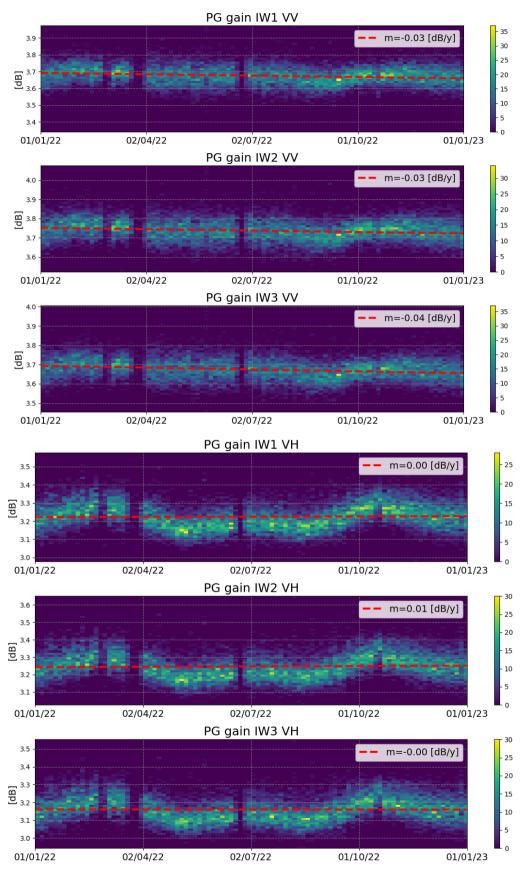
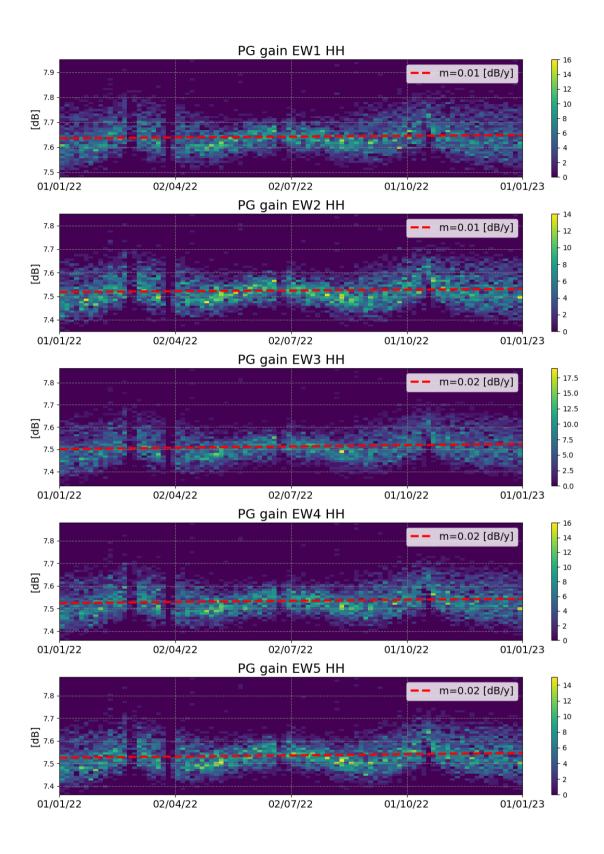


Figure 10: S-1A IW V/V and V/H, PG gain evolution during 2022.





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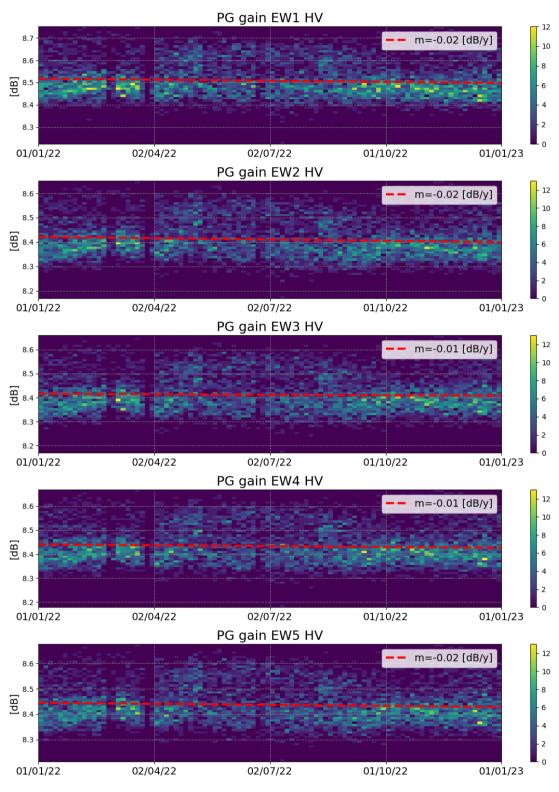


Figure 11: S-1A EW H/H and H/V PG gain evolution during 2022.



4.3 Noise Power

The noise power is monitored through the dedicated RX-only pulses embedded at the start/stop of each data-take. Furthermore, since the 26th June 2018 (deployment of IPF 2.9.1) the noise evolution in TopSAR data is also monitored exploiting the first echoes of each burst, the so-called "rank echoes", which are signal free echoes and hence can be considered as noise pulses [S1-RD-20].

The new noise tracking strategy was introduced to cope with the fact that the energy radiated from the Earth surface is recorded by the instrument, thus biasing the noise power measure. This results in an almost 1 dB offset between noise power measures over land (high noise power) and over sea (low noise power) [S1-RD-19].

Table 3 provides the average noise power computed during December 2022 for sea and land echoes. The values in parenthesis are the average noise powers during December 2021 for comparison. The noise power is stable since last year, with variations of at most 0.1 dB.

Figure 12 shows the distribution of noise power measurements as a function of time in 2022 for S-1A IW1, EW1, and WV1 products. The noise power is stable over the year.

Figure 13 shows the histograms of the noise measurements registered during December 2022, separated vertically by swath and horizontally by polarization. Separating by swath and polarization allows to clearly distinguish the distribution with two peaks, corresponding to noise measurements over sea and land.

Acquisition mode	S-1A Noise power [dB]	
IW1 V/V	Sea: 7.02 (7.05)	
	Land: 7.79 (7.75)	
IW1 V/H	Sea: 6.35 (6.34)	
	Land: 7.18 (7.16)	
EW1 H/H	Sea: 5.52 (5.42)	
	Land: 6.13 (6.08)	
EW1 H/V	Sea: 6.56 (6.15)	
	Land: 7.18 (7.25)	
WV1 V/V	Sea: 8.57 (8.59)	
	Land: N/A	

Table 3: Average noise power measured during December 2022. The value in parenthesis is the average noise power measured during December 2021.



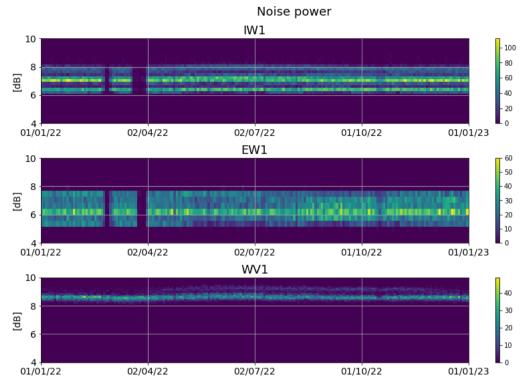


Figure 12: Noise power versus time for beams IW1 (top), EW1 (middle), and WV1 (bottom) of S-1A.

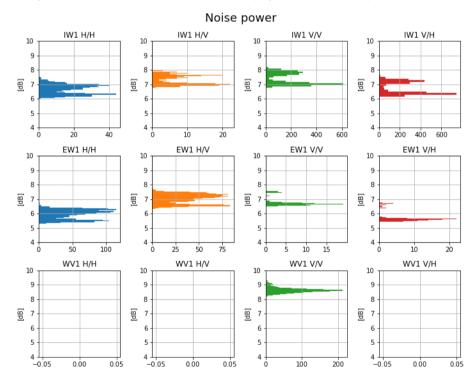


Figure 13: Histograms of noise measurements registered during December 2022, separated by swath (vertically) and by polarization (horizontally).



4.4 Instrument Unavailability

A list of S-1A instrument unavailabilities during 2022 is given in Appendix B -.

4.5 Radar Data Base Updates

There was no update of S-1A Radar Data Base in 2022.



5.L1 Products Status

Hereafter, the status of the S-1A products during 2022 is described. A general summary of status of S-1A & S-1B Level 1 products was presented at several conferences and workshops during 2022 (see [S1-RD-01], [S1-RD-02], [S1-RD-03], [S1-RD-04] and [S1-RD-12]).

5.0 Level 1 Basic Image Quality Parameters

The DLR transponders and corner reflectors and the Australian Corner Reflector array have been used to assess various impulse response function parameters as described below. The products analysed were acquired in 2022 and processed with the Sentinel-1 IPF v3.4.0, v3.5.1 and v3.5.2.

5.0.1 Spatial Resolution

Figure 14 and Table 4 below give the azimuth and range spatial resolutions derived from S-1A IW mode SLC data (there were no measurements for SM and EW modes during 2022). The numbers in brackets indicate the number of measurements.

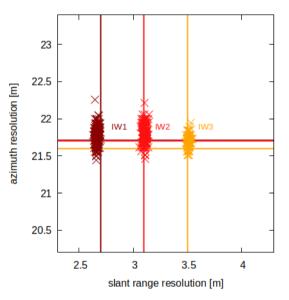


Figure 14: S-1A IW azimuth and slant-range spatial resolution (lines correspond to targeted performance from the product definition)

Mode/Swath	Azimuth Spatial Resolution (m)	Slant Range Spatial Resolution (m)
IW1	21.76 ± 0.11 (326)	2.67 ± 0.01 (326)
IW2	21.79 ± 0.11 (257)	3.10 ± 0.01 (257)
IW3	21.71 ± 0.08 (139)	3.51 ± 0.01 (139)

Table 4: Azimuth and slant-range spatial resolution for S-1A derived for IW mode

5.0.2 Sidelobe Ratios

Table 5 below gives the measured impulse response function sidelobe ratios derived from S-1A IW SLC data.

Satellite/Mode	Integrated Sidelobe Ratio (dB)	Range ISLR (dB)	Azimuth ISLR (dB)	Peak Sidelobe Ratio (dB)	Spurious Sidelobe Ratio (dB)
S-1A IW	-12.70±2.11	-15.75±0.87	-16.73±1.072	-20.22±0.8	-25.79±1.77

Table 5: S-1A IW Sidelobe Ratios

For point targets the derivation of the various Impulse Response Function (IRF) parameters is achieved by extracting a 128 by 128-pixel sub-image centred on the point target, deriving the mean background intensity, convert the sub-image to intensity and interpolate by a factor of 8, and subtract the mean background intensity from the interpolated image.

The integrated sidelobe ratio (ISLR) is computed as the ratio of the energy in the side lobes to the energy in the main lobe. The side lobe energy is estimated outside a rectangle 2x by 2y (red box) and within a rectangle of 20x and 20y (green box). The main lobe energy is estimated in 2x by 2y rectangle (red box).

The peak sidelobe ratio (PSLR) is the ratio of the intensity of the most intense sidelobe peak of the IRF to the peak intensity in the main lobe. The sidelobe peak is estimated outside a rectangle of 2x and 2y and within a rectangle of 10x by 10y (blue box). The main lobe peak is estimated in the rectangle 2x and 2y (red box).

The spurious sidelobe ratio (SSLR) is the ratio of the intensity of the most intense spurious sidelobe value of the IRF to the peak intensity in the main lobe. The spurious sidelobe value is estimated in the outside a rectangle of 10x and 10y (blue box) and within a rectangle of 20x by 20y (green box). The main lobe peak is estimated in the rectangle 2x and 2y (red box).

The various areas considered for the computation of IRF are described in following figure.

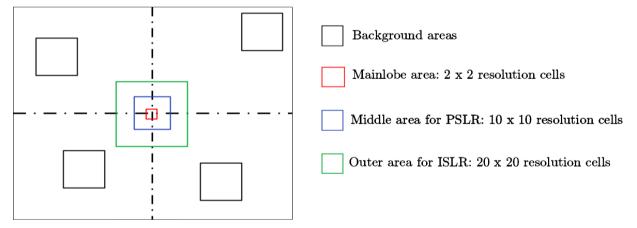


Figure 15: Definition of point target response area and background areas for IRF analysis and calibration



5.0.3 ENL and Radiometric Resolution

Large uniform distributed targets (mainly over ocean) are used to measure the equivalent number of looks (ENL) and radiometric resolution (RR) in the imagery. The results are given in Table 6 below. For each sub-swath and product type, the first number is the ENL while the second is the RR in dB.

Satellite/Product Type	IW1	IW2	IW3
S-1A GRDH	3.99, 1.76	4.01, 1.76	4.46, 1.70

The above results are comparable with expected ENL and RR measurements for IW mode.

5.0.4 Azimuth Ambiguities

Table 7 below gives mean azimuth ambiguity ratio for DLR transponder targets acquired in IW mode for S-1A during 2022. The measurements indicate low ambiguity ratios.

Satellite/Mode	Early Azimuth Ambiguity Ratio (dB)	Late Azimuth Ambiguity Ratio (dB)
S-1A IW	-27.87±2.38	-27.61±2.54

Table 7 : S-1A Azimuth Ambiguity Ratios

The early azimuth ambiguities refer to ambiguities from targets not yet in the main lobe of the antenna, while the late ambiguities refer to ambiguities from target that left the main lobe of the antenna.

In other words, the full patterns appear in the SAR images in increasing azimuth time: first the early azimuth ambiguities, then the main contribution from the object as observed in antenna main lobe and finally the late azimuth ambiguity.

5.0.5 Range Ambiguities

No S-1A imagery suitable for range ambiguity measurements were identified during 2022.

5.1 Radiometric Calibration

The DLR transponders and corner reflectors and the Australian Corner Reflector array have been used to measure their radar cross-section as described below. The products analysed were acquired in 2022 and processed with the Sentinel-1 IPF v3.4.0, IPF v3.5.1 and IPF v3.5.2.

5.1.1 Absolute Radiometric Calibration

The absolute radiometric calibration of each SAR instrument was initially performed during the respective commissioning phases in 2014 (S-1A) [S1-RD-14] and 2016 (S-1B) [S1-RD-15]. For this calibration purpose, reference targets like corner reflectors (CR) and transponders (TR) with well-known RCS were used. In particular, DLR's remote controlled transponders and remote-controlled corner reflectors with 2.8 m leg length [S1-RD-16] have been used operated continuously since the beginning of S-1A operation in 2014 [S1-RD-17], [S1-RD-18].



During the observation period in 2022 SAR acquisitions with IW mode and DV polarization (VV+VH) have been acquired regularly over the DLR calibration site located in Southern Germany for S-1A. Long-term monitoring of the radiometric performance has been systematically evaluated for this period.

In order to determine the radiometric accuracy, the absolute calibration factor derived from DLR's point targets has been analysed from the acquired datatakes by investigating each target's impulse response function and considering the nominal target RCS. The deviation of the absolute calibration factor as a function of time is depicted in Figure 16 for S-1A for the observation period in 2022. The trihedral corner reflectors produce impulse responses only for co-polarized products. Thus, results from the VV-polarization channel (red) appear more often compared to VH-polarization channel (blue) which represents the cross-polarization results derived from corresponding transponder measurements only.

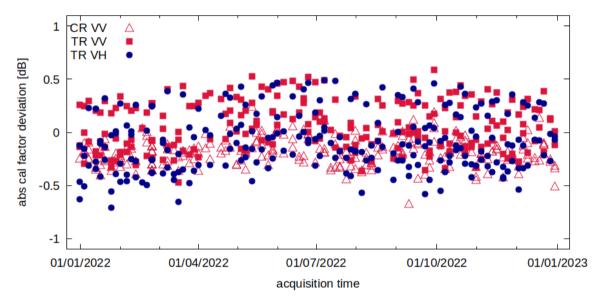


Figure 16: S-1A calibration factor for IW acquisitions in 2022 derived from DLR reference targets; the polarization is depicted by colour: VV in red, VH in blue.

The calibration factor deviations have a low remaining bias of -0.08 dB for S-1A (see Table 8). This indicates that the SAR instrument is well balanced in terms of absolute radiometric calibration. A higher spread visible for certain acquisitions (in Figure 16) may arise from rainy weather conditions during the respective measurement; small RCS drifts over time (up and down) may occur due to remaining SAR instrument drifts.

Furthermore, a standard deviation of the absolute calibration factor of 0.24 dB for S-1A has been derived for the observation period in 2022 (see Table 8) which includes the measurement of both polarizations (VV and VH) and all three sub-swathes (IW1, IW2, and IW3).

In order to derive the overall absolute radiometric accuracy of a spaceborne SAR system during the mission time, the following additional error contributions are further considered:

•	Long term stability of the instrument	0.05 dB (1σ)
•	Dynamic range error	0.067 dB (1σ)

• Reference target accuracy 0.20 dB (1σ)

Considering these error contributions an absolute radiometric accuracy of 0.322 dB for S-1A (1 σ) is derived.



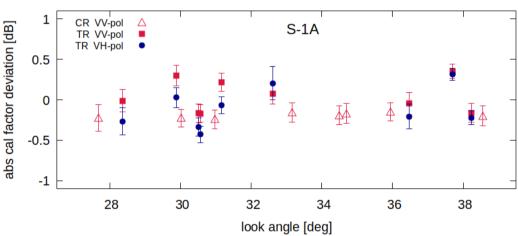
	S-1A IW (VV and VH)
Mean value ± standard deviation	-0.08 dB ± 0.24 dB
Absolute radiometric accuracy (1σ)	0.322 dB

Table 8 : Mean value, standard deviation and absolute radiometric accuracy derived from DLR targets (transponders and corner reflectors) for IW mode DV polarization (VV+VH) acquired over DLR's calibration site in 2022 for S-1A.

In order to focus on dependencies within the swath, statistics of the calibration factor for a given configuration (track, elevation angle, polarization) were derived. For a given track, each target has a specific geometric alignment w.r.t. the satellite, i.e., the target is "seen" by the SAR instrument under the same elevation or look angle. The mean values and standard deviations of the calibration factor are determined for each configuration with similar acquisition geometry and depicted in Figure 17 for S-1A. The mean values are marked by symbols, the standard deviations by error bars, VV polarization results are shown in red, VH polarization in blue. This plot shows the elevation dependency of the calibration factor for the IW mode for all three sub-swathes with no evident trend.

The mean values (symbols in Figure 17) show a low variation over elevation angle: between -0.24 dB and 0.35 dB for the VV polarization channel (red) and between -0.43 dB and 0.32 dB for the VH polarization channel (blue). The standard deviation found for each configuration is an indicator for the radiometric stability. These deviations (error bars in Figure 17) are remarkable small; the average value is 0.12 dB with variations between 0.08 dB (min) and 0.20 dB (max).

observation period: Jan - Dec 2022



look angle [deg] Figure 17: S-1A calibration factor derived from each DLR target under constant acquisition geometry (i.e. same elevation or look angle) acquired in 2022. The symbols depict the mean value, error bars the standard deviation; each target type can be identified by its symbol: corner reflectors as open triangles, transponders as filled squares or circles. The polarization is depicted

by colour, VV in red, VH in blue.

The absolute calibration factor is further analysed for each sub-swath (IW1, IW2, IW3) for all S-1A acquisitions over DLR point targets in 2022. The mean value and standard deviation are summarized for each sub-swath and also each polarization channel (VV and VH) in Table 9.



The table documents that the S-1A SAR instrument is well balanced indicated by low mean values (biases) found for each sub-swath. Furthermore, the standard deviation is very similar for all sub-swathes and both satellites. Slightly higher standard deviations are found for IW3 compared to IW1 and IW2.

Sub-swath	polarization	S-1A
		μ [dB] ± σ [dB]
IW1	VV VH	-0.07 ± 0.23 -0.21 ± 0.21
	VV and VH	-0.123 0.23
IW2	VV VH	-0.11 ± 0.15 -0.01 ± 0.27
	VV and VH	-0.09 ± 0.19
IW3	VV VH	0.01 ± 0.28 0.07 ± 0.28
	VV and VH	0.03 ± 0.28

Table 9 : Mean value and standard deviation of the absolute calibration factor for IW mode with V-polarization on transmit derived from acquisitions over the DLR calibration site in 2022.

An array of 40 corner reflectors has been deployed near Brisbane, Australia as a component of the Australian Geophysical Observing System (AGOS) (*Surat Basin* calibration site). The CRs are size 1.5m (34), 2.0m (3) and 2.5m (3) with fixed orientations. Given that these corner reflectors have a fixed elevation and azimuth orientation they will not be pointing directly at S-1A. For evaluating the radiometric accuracy and stability for HH polarization only large CRs (>= 2 m) have been selected for sufficient results. The six remaining CRs are all located in sub-swath IW2 only. The evaluated RCS deviation with mean value and standard deviation for each of the six CRs is depicted in Figure 18; Table 10 shows mean value and standard deviation summarizing all these measurements acquired in 2022. The numbers in brackets refer to the number of measurements. Variations and biases derived from this scenario (IW2 HH polarization over Surat Basin calibration site) are found to be comparable to the results derived from DLR targets (IW1-3; VV+VH) confirming the derived radiometric stability and accuracy of S-1A.



observation period: Jan - Dec 2022

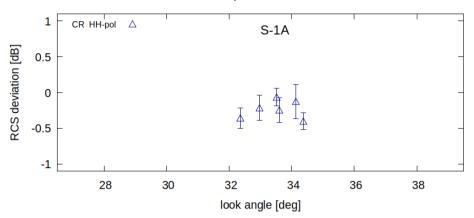


Figure 18: RCS deviation (measured - expected) for permanent installed six corner reflectors of the Australian observation area (*Surat Basin* calibration site) acquired in 2022 with S-1A for IW2 with HH polarization. The symbols depict the mean value, error bars the standard deviation.

Satellite	IW2 HH	
S-1A	-0.23 ± 0.20 (188)	

Table 10: Mean value and standard deviation for the Australian Corner Reflectors (dB)

No EW, SM and WV acquisitions over Corner Reflectors were available in 2022 for absolute radiometric calibration.

A specific method of geophysical calibration (see section below) is applied for WV SLC products.

5.1.2 Geophysical Calibration

Due to the absence of WV mode acquisitions over the DLR calibration site located in Germany, the WV mode calibration relies only on the geophysical calibration methodology. Geophysical calibration is performed comparing statistically the values of the SAR normalized radar cross section over oceans with a prediction given by a Geophysical Model Function (GMF) combined with Wind Model Information (ECMWF 0.125° 3h). The results are presented in Figure 19.

Since May 2020, the monitoring is performed using de-noised NRCS compared to Cmod5n GMF.



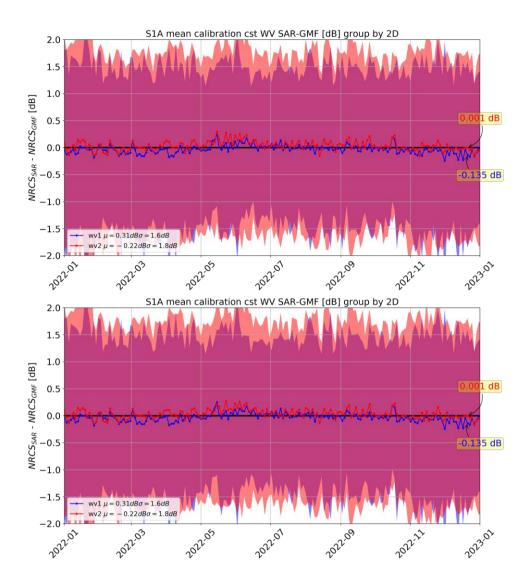


Figure 19: assessment of the WV SLC calibration (denoised Sigma0) using geophysical approach i.e. comparison with Cmod-5n with ECMWF0.125° (3h)

Time evolution: The WV SLC NRCS bias is stable in time on year 2022. There was no instrument nor processor evolution impacting the backscatter during the year.

Performances with respect to specifications: The NRCS bias since May 2020 is close to zero dB. The standard deviation of this NRCS bias is computed by double averaging of the sigma0, i.e., both at imagette level and at SAFE level. The computed standard deviation for 2022 is about 1.6dB for WV1 and 1.8dB for WV2.

Discussion about the performances: WV calibration is already in agreement with what most SAR applications required.

5.2 Geometric Validation

S-1 geolocation quality was monitored regularly throughout 2022 using SLC products from the IW mode. EW- and SM-mode acquisitions, while not acquired during 2022 over considered calibration sites, were obtained during the earlier S-1A and -B calibration and validation campaigns and are thus not considered for the report at hand.

The monitoring was performed over the *Surat Basin* (Australia) calibration site. The methodology underlying Sentinel-1 geolocation was published in a technical note [S1-RD-25], available now from ESA's Sentinel document library on the web.

The stability and reliability of the wide-area test site in Australia (*Surat* Basin) makes it ideal to perform geometric calibration and validation of SAR sensors. The site includes 40 trihedral CRs covering an area of nearly 13000 km², most of them with 1.5m side lengths and three targets with 2.0m and 2.5m side lengths, respectively. Their positions were confirmed by several research groups to be both accurate and stable enough for precise geolocation monitoring over long periods and were accurately re-surveyed in 2018 by its maintainer Geoscience Australia [S1-RD-22]. The site has only one significant disadvantage, i.e., all reflectors are oriented towards an *ascending* orbit, not allowing to easily detect azimuth timing errors via ascending/descending comparisons. For this reason (among others), observations from other sites remain important, especially as a cross-reference complementing larger, longer-term sites such as *Surat*. In this report, we show measurements from products acquired over the *Surat* site, established for many cycles as the reference site for the S-1A/B N-cyclic reports.

Overall, the post-processing corrections applied during geolocation estimation may be grouped into the broad categories: (1) geophysical effects, and (2) timing offsets due to inherent S-1 processor design.

For a given CR visible in an S-1 image product, its predicted azimuth and slant range image pixel position was calculated as follows:

• The surveyed CR position was adjusted for acquisition-time ("epoch") plate **tectonic drift** and **solid Earth tide** (SET), as described in [S1-RD-05].

• The relevant timing annotations were extracted from the product annotations; these included the azimuth zero-Doppler time stamps, the orbital state vectors, the near-range fast time, and the range and azimuth sample spacings. Please note that in case of post-processing corrections, the orbital state vectors are extracted from external orbit files (AUX_POEORB) provided at Copernicus Sentinels POD Data Hub (https://scihub.copernicus.eu/gnss) in order to ensure the maximum accuracy in the derived geolocation information.

• Range-Doppler geolocation was performed for the CR coordinate as described e.g., in [S1-RD-11], giving range and azimuth times as the output.

• The slant range prediction was corrected by adding the modelled **tropospheric and ionospheric path delays**, and the azimuth time was corrected by subtracting the **bistatic** residual. These effects and their associated corrections are described in detail in [S1-RD-09].

• For TOPS products (IW and EW), a **range shift caused by the Doppler shift dependent on the target azimuth position** within the TOPS burst was shown to be affecting the corresponding ALE estimates [S1-RD-24]. Correcting for these biases on a target-by-target basis resulted in a lower range ALE spread, and slightly shifted the mean bias.

• The beam-dependent azimuth biases previously observed in IW and EW analyses were shown to be caused by an error in the way the S-1 IPF was interpreting the azimuth timing annotations (during the so-called *bulk bistatic correction*). While this was mostly visible in TOPS-mode product analyses, the error was also shown to affect SM mode products [S1-RD-09].

• A subswath dependent error in the S-1 processor's interpretation of the line time tags was discovered and shown to be causing beam-dependent azimuth shifts corresponding to a given subswath's sampling window start time. The ensuing correction was called the *Instrument Timing Correction*. Correcting for this brought the ALE scatter from different IW sub/swaths closer together and moved them toward a zero mean [S1-RD-09].

• Differences between the true height of a reference target and height approximations used by the S-1 processor were shown to be causing a **mismatch between the target azimuth FM rate** and the value



annotated in each product [S1-RD-09]. The effect was additionally dependent on the target azimuth position within a burst (offset from the burst centre). Correction for this effect decreased the ALE standard deviation in azimuth. Because the effect is connected to the target burst position, the magnitude of the correction varies by site. It is generally a much smaller shift than the Instrument Timing Correction described above but in areas significant topographic variation it can amount to more than 1m [S1-RD-08].

• Empirically determined instrument range and azimuth timing calibration constants are applied to compensate for the overall systematic timing biases of the sensors. The numbers were derived from 3 years of S-1 IW data with the reference corner reflector at Metsähovi geodetic observatory, Finland, and amount to 0.1691m in range and 0.0875m in azimuth in case of S-1A [S1-RD-21].

Adding the above steps resulted in a range-azimuth *predicted* position for each target that could be compared to the position of the peak intensity in the image raster itself, i.e., the *measured* CR position. The differences between predicted and measured positions were then plotted. The S-1A SLC ALE time series for products over the *Surat* site acquired in 2022 is shown in Figure 20. Please refer to [S1-RD-05], [S1-RD-06] and [S1-RD-10] for details on the evolution of the standard IPF processing and the geolocation methodology.

The ALE measurements for S-1A are shown separately in Figure 20 (time series) and Figure 21. The overall statistics are also detailed on a swath basis in Table 11. As S-1A suffered the loss of tile #11 in June 2016, a swath dependency is clearly visible from separated azimuth ALE statistics. The observed range offset may be due to the re-processed precise orbit solution [S1-RD-21], which was not available at the time when determining the empirical instrument timing calibration, and unknown biases in the atmospheric path delay corrections. Further investigations and a possible update of the range and azimuth instrument timing calibration constants are planned for 2023.

In summary, the remaining differences for both units indicate a localisation performance for IW mode well within the mission's geometric requirements. The ALE is within the specified 1 σ of 3.33m, i.e. 10m at 3 σ (section 5.5.2.2 of [S1-RD-07])

For comparison, the same plots are generated considering the measured positions without postprocessing corrections (showing the "out of the box accuracy" of the measurements). These measures represent the geolocation accuracy of the S-1 products as delivered to the users, if no further correction is applied. Figure 22 (time series) and Figure 23 and show the ALE time series and the ALE measurements without post-processing corrections, respectively. The plots show that without corrections the overall bias and the spread are on the order of one or more meters for azimuth and range in both systems. With the corrections, the bias and spread are instead on the order of the decimetres or less. Nevertheless, these results confirm the consistent level 1 IW product generation throughout 2022 for the *Surat* test site and that the "out of the box accuracy" is within the 10m localization performance requirement.



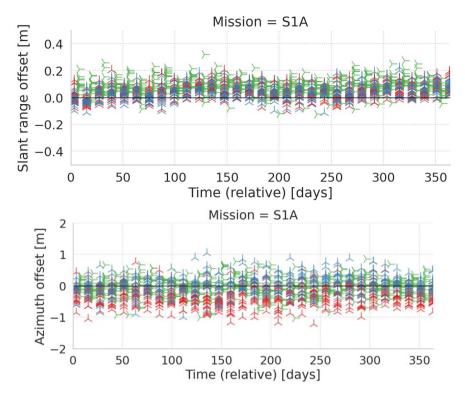


Figure 20: S-1A IW SLC ALE time series for products over the *Surat* site acquired in 2022, with post-processing corrections.

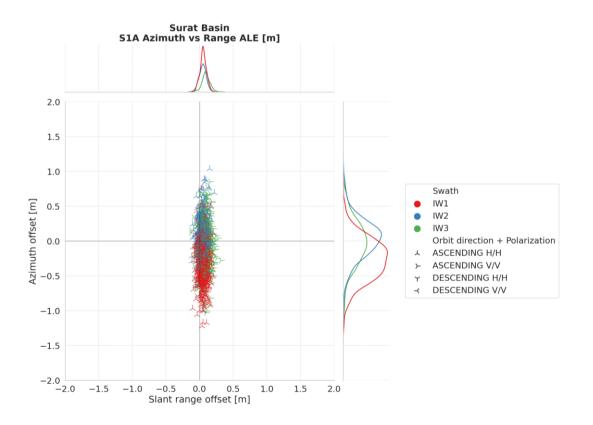


Figure 21: S-1A IW SLC ALE performance estimates for products over the *Surat* site acquired in 2022, with post-processing corrections.



	Range ALE [m]	Azimuth ALE [m]
Sentinel-1A (89 products)	0.062 ± 0.056	-0.112 ± 0.332
IW-1	0.054 ± 0.050	-0.266 ± 0.298
IW-2	0.048 ± 0.052	0.039 ± 0.288
IW-3	0.094 ± 0.062	-0.028 ± 0.325

 Table 11 : Summary of IW SLC product ALE estimates for S-1A for all 2022 acquisitions over the Australian Surat Basin calibration site with the post-processing corrections.

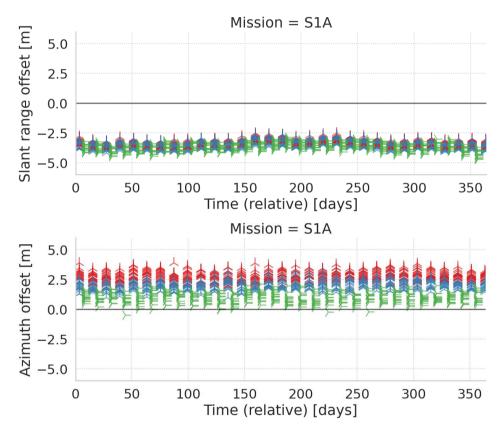


Figure 22: S-1A IW SLC ALE time series for products over the *Surat* site acquired in 2022, without post-processing corrections.

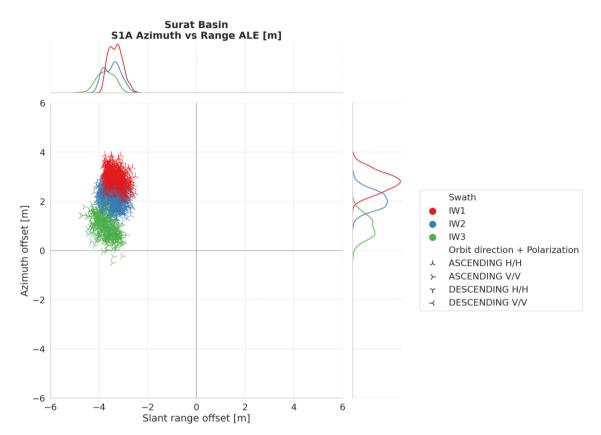


Figure 23: IW SLC product ALE estimates for S-1A for all 2022 acquisitions over the Australian Surat Basin calibration site without the post-processing corrections.

	Range ALE [m]	Azimuth ALE [m]
Sentinel-1A (89 products)	-3.462 ± 0.352	2.109 ± 0.833
IW-1	-3.322 ± 0.281	2.793 ± 0.399
IW-2	-3.460 ± 0.337	2.044 ± 0.371
IW-3	-3.723 ± 0.343	0.940 ± 0.433

Table 12: Summary of IW SLC product ALE estimates for S-1A for all 2022 acquisitions over the Australian Surat Basin calibration site without the post-processing corrections.

5.3 Polarimetric Calibration

5.3.1 Gain Imbalance

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The DLR transponders have also been used to derive the channel imbalance from the respective impulse responses. The gain imbalance is computed by the differences (in dB) between the calibration factor derived from the VV and the VH polarization images.

The gain imbalance is depicted in Figure 24 for the IW mode in DV polarization for S-1A covering the observation period 2022. The plot shows the mean values (red crosses) and standard deviations (red error bars) of the channel imbalance for each acquisition geometry, i.e., for measurements acquired with a



certain elevation or look angle. For S-1A, a gain imbalance of 0.14 dB is determined on average with a standard deviation of 0.17 dB as listed in Table 13.

Satellite/Mode	Gain Imbalance (dB)
S-1A IW (VV/VH)	0.14 ± 0.17

Table 13: Gain Imbalance using the DLR transponders.

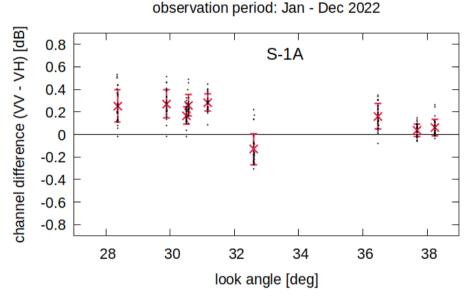


Figure 24: IW Gain Imbalance of S-1A using the DLR transponders.

5.3.2 Phase Imbalance

The channel imbalance in phase is determined similarly to the channel imbalance in amplitude as described in the previous section for the IW mode with DV polarizations acquired over the DLR transponders in 2022. The phase difference is computed by subtracting the VH polarization channel phase from the VV polarization channel phase. The remaining phase differences are very low and do not exceed 4 degrees. The mean values and standard deviations are listed in Table 14.



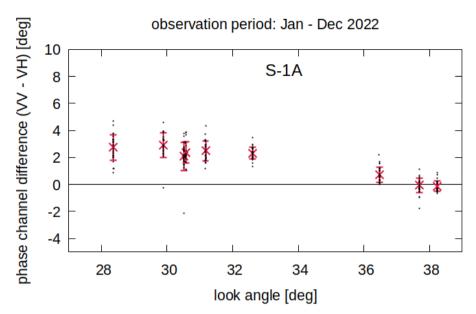


Figure 25: Phase Imbalance using the DLR transponders.

Satellite/Mode	Phase Difference [deg]
S-1A IW	1.66 ± 1.36



5.3.3 Coregistration

The DLR transponders provide an impulse response in both polarisations of dual polarisation imagery which enables coregistration to be performed between the two polarisation images. Table 15 below shows that the average measured polarimetric co-registration derived from SLC products acquired during 2022 is very small (the IRF peak position is measured to a 1/8 of a pixel).

Satellite/Mode	Range Co-registration Accuracy (m)	Azimuth Co- registration Accuracy (m)	Number of Measurements
S-1A IW	0.03±0.09	0.04±0.31	192

Table 15: Polarimetric Calibration	n Measurements
------------------------------------	----------------

5.3.4 Cross-talk

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The trihedral corner reflectors of the DLR calibration site with a leg length of 2.8 m enable to derive the cross-talk since they provide an impulse response only for co-polarisation (HH or VV) with sufficient energy. The derived cross-talk of S-1A is depicted in **Figure 26** for the observation period in 2022. The mean cross-talk values with standard deviations for both instruments are listed in Table 16.

The derived cross-talk is very low and confirms the very good quality concerning the separation of the co-and cross polarization channels of the S-1A SAR instrument.



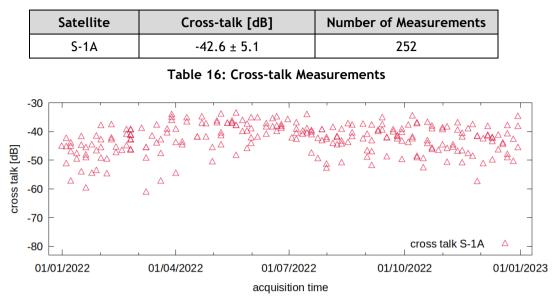


Figure 26: Cross-talk derived from DLR corner reflectors for S-1A.

5.4 Elevation Antenna Patterns

There was no update to the S-1A elevation antenna patterns during 2022.

5.5 Azimuth Antenna Patterns

There was no update to the S-1A azimuth antenna patterns during 2022.

5.6 Noise Equivalent Radar Cross-section

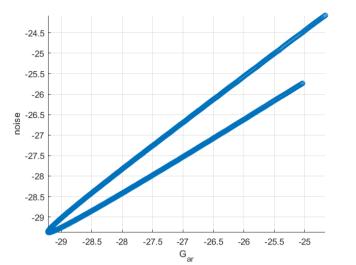
S-1 imagery with low ocean backscatter can be used to estimate the Noise Equivalent Radar Cross-Section (NESZ). The S-1 L1 Annotation file contains a sequence of noise vectors that users can employ to compute the NESZ content of the L1 image [AD-01].

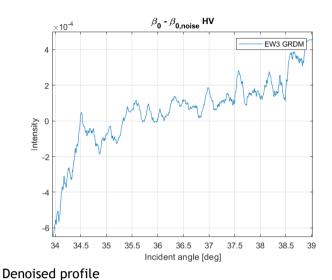
These annotated noise vectors presented a shift in range, further described in [QD-90] that was solved after the deployement of IPF v3.5.1 since 23rd March 2022.

To demonstrate the effectiveness of this correction, a product showing a particularly pronounced mismatch between noise vectors and EAP was selected: S1B_EW_RAW__0SDH_20200831T072002_20200831T072110_023164_02BFB9_77FD.

Figure 27 shows for IPF 3.4.0 the annotated noise vectors and the so-called range variant gain, i.e. the product of the EAP and range spreading loss. These quantities differ only by a scaling factor. It is evident that in IPF 3.4.0 noise vectors and range-variant gain is not aligned, while there is a good match in IPF 3.5.1. The resulting de-noised profile is also flatter.

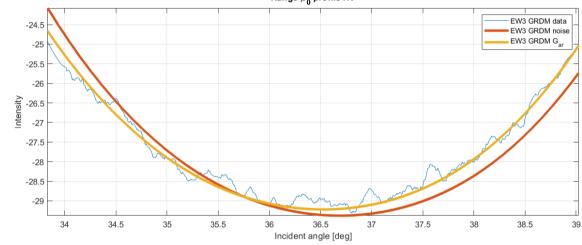






Noise vectors vs range-range variant gain

Range β_0 profile HV



IPF 3.4.0

Figure 27: S1B_EW_GRDM_1SDH_20200831T072006_20200831T072106_023164_02BFB9_C36E: Comparison between EAP and noise vector for 3.4.0

Additionally, for some specific acquisitions, the S-1 IPF contained a remaining software bug that resulted in the truncation of the annotated noise vectors. The following **Figure 28** shows the effects of this anomaly and its resolution in the future version of S-1 IPF v3.6.0, planned for beginning 2023.





Figure 28: Annotated denoising vectors compare to measured NESZ. Green: low-backscatter image profile Orange: annotated noise vector with IPF 3.5.2. Blue: annotated noise vector with IPF 3.6.0

5.7 Interferometric Performances

The interferometric performances, and in particular, the coherence level of an interferogram between two S-1 images, depend on several factors including:

- Stability of the imaged scene (temporal coherence)
- Thermal noise level of the considered acquisitions (see sections 4.3 and 5.6)
- Geometric decorrelation due to different acquisition geometry (orbit baseline)
- Volumetric decorrelation due to targets structure
- Synchronization of the acquisitions (for TOPSAR modes only)
- Stability of the sensor pointing to ensure Doppler spectrum overlap

The S-1A performances related to geometric decorrelation and synchronisation of the acquisitions are reported in the following sections.

5.7.1 S-1 Orbit Baseline

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Repeat pass interferometry requires that acquisitions at different times are performed with a similar orbit to ensure high coherence interferograms. The "distance" between the orbits of a pair of interferometric acquisition is called the interferometric baseline. The interferometric baseline is continuously monitored by the MPC, comparing S-1 State Vectors of current orbits (from AUX-RESORB files) with those of an arbitrary selected reference cycle in the past, namely the cycle number 60 (30 September - 12 October 2015) for S-1A.

Figure 29 shows the evolution during 2022 of the three interferometric baseline components (Parallel on top, Normal in the middle and Along-Track at the bottom). The hot colours are used for the maximum baseline value and the cold colours for the minimum baseline value measured for each orbit. The different colours represent the track number evolving for each cycle from 1 to 175.

The most critical baseline component for the interferometric coherence is the normal one, which shall be lower than a certain threshold named critical baseline (about 5 km for S-1 and depending on the considered swath). The measured normal baseline (mid plot) shows that normal baselines are below 10% of the critical one, i.e., the worst-case coherence loss due to the interferometric baseline is always well



below 10%. Please note that some outliers can be observed in the S-1A plot. They are regularly spaced in time, meaning that they come from the reference cycle rather than from the 2022 orbits. They are most likely related to orbit manoeuvres performed in 2015. This will be confirmed in next studies in order to remove the outliers.

Due to an issue in the generation of the OBS products within the PDGS, it was not possible to monitor the baseline through the whole 2022. This issue corresponds to the gap between end of April and July in the plots below. The issue is now fixed, and the burst synchronization monitoring is re-started. No degradation can be observed after the re-start of the monitoring.

During September 2022 large baselines (larger than before) were observed, caused by specific successive collision avoidance manoeuvres. The values are far below the critical baseline and are not considered as anomalies.

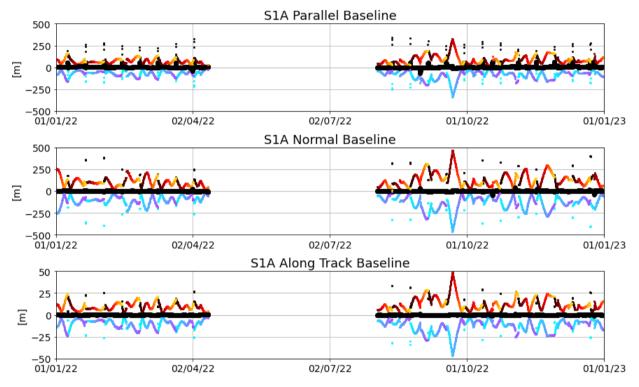


Figure 29: S-1A parallel (top), normal (mid) and along-track (bottom) interferometric baseline during 2022. Warm colours are used for the maximum value and cold colours for the minimum value of each orbit. The colours represent the track number.

5.7.2 S-1 Burst Synchronization

The burst synchronization between repeat pass interferometric acquisitions is relevant for the TOPSAR modes (IW and EW), to provide an indication of the quality of the interferometric phase that can be expected. The SAR acquisition start time is planned over a discrete set of points round orbit with precision down to milliseconds. The burst synchronization is systematically monitored by the MPC comparing the times of TopSAR acquisitions derived from current LOA products.

Figure 30 shows the burst synchronization error over time for EW (top plot) and IW (bottom plot) mode. In these figures, the colours represent the number of repeat pass acquisitions falling in a certain temporal and burst synchronization interval (light blue meaning few points and purple meaning many points).



The daily average synchronization is reported with a continuous black line. The average synchronization is good, with a small seasonal trend common to both sensors (less than 5 ms peak-to-peak), suggesting a common external origin due to some long-term orbit perturbation.

The black dashed lines represent the S-1 synchronization requirement (about ± 7 ms). This value is obtained by multiplying the timing requirement for single acquisitions (5 ms) by $\sqrt{2}$ since all the values in the image are obtained by combining the timing error of two independent acquisitions. The synchronization performance in terms of percentage of acquisitions within mission requirement is 96% for EW and 93% for IW.

A synchronization timing error between two bursts causes a mis-match in the Doppler bands under which targets are observed, which in turn causes a loss of coherence. It can be shown that the loss of coherence is approximately linearly proportional to the timing error, such that for S-1 an error of 5 ms, corresponding to a Doppler spectrum overlap reduction of about 10 Hz in the SLC products. This represents a coherence loss of about 3% for IW mode that has a processed bandwidth around 300 Hz. This estimate is obtained considering only the Doppler mis-match due to the burst de-synchronization; an additional error in pointing may either increase or decrease the Doppler error depending on the sign, thus increasing or decreasing the coherence loss. Due to an issue in the generation of the OBS products within the PDGS, it was not possible to monitor the burst synchronization through the whole 2022. This issue corresponds to the gap between end of April and July in the plots below. The issue is now fixed, and the burst synchronization monitoring is re-started. No degradation can be observed after the re-start of the monitoring. The burst synchronization of the performance in the period not covered by the monitoring, and the fact that no degradation of interferometric coherence was reported by the users during 2022 seems to confirm it.

During September 2022, a larger variation of the burst synchronization errors mean value was observed, caused by specific successive collision avoidance manoeuvres.



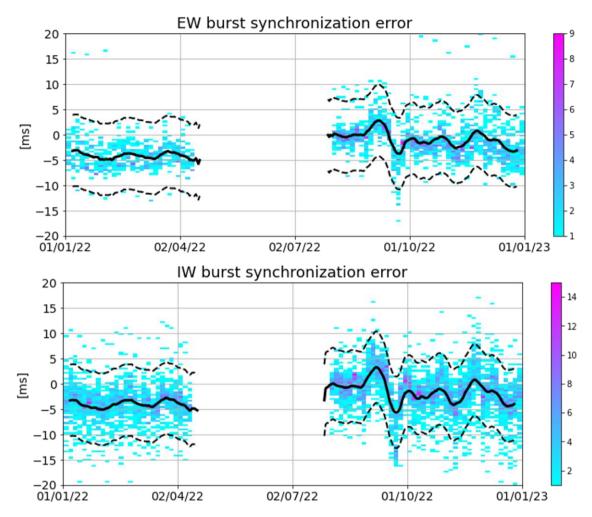


Figure 30: S-1A EW (top) and IW (bottom) burst synchronization during 2021. The colour represents the number of points (light blue few points, purple many points). The black line is the average synchronization per day and the dashed lines are the S-1 requirement limits.

5.7.3 Instrument Pointing

The instrument pointing is continuously monitored exploiting the DC estimates from the data annotated in the L1A products. Figure 31 shows the average Doppler Centroid evolution during 2022 on a slice basis (dots) and daily (red line). DC jumps up to 30 Hz when the on-board Star Trackers (STTs) configuration changes can be observed. This is a known issue due to the non-perfect alignment of the on board STTs. In case the jumps should worsen in the future, a new STT alignment campaign could be performed (as occurred in 2019).

The DC evolution is in line with the expected pointing performances (Total Zero Doppler steering).



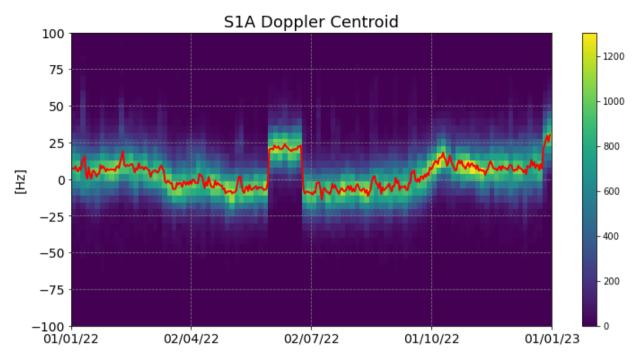


Figure 31: S-1A product (dots) and daily (red dashed line) average Doppler Centroid versus time.

5.8 Radio Frequency Interferences

5.8.1 RFI annotations and RFI mitigation

On the 4 of November 2021, a new version of the SAR processor (IPF v3.4.0) was introduced. From this version the processor can perform an RFI mitigation based on various processing strategy.

The behaviour of the S-1 IPF for what concerns the RFI mitigation is based on three main successive steps:

- 1- A pre-screening of RFI evidence in noise measurements from specific pulses in the acquisition timeline. This pre-screening is performed (or not) depending on the configuration of the processor and the availability of the required noise measurements.
- 2- A detection of RFI from the measurement data. This detection step is configurable and can either be not applied at all, or only applied when RFI evidence are provided by the pre-screening step, or systematically applied.
- 3- A mitigation of RFI applied on the measurement data depending on the results of the previous steps.

The processing configuration applied in 2022 is such that:

- For TOPS modes (EW and IW), the pre-screening of RFI is performed and the results of this processing step is provided in a specific annotation file that can be used to collect evidence of potential RFI impacting the acquired data. <u>Before the 23rd March 2022</u>, no RFI detection (from date) and no mitigation is performed. Since this date, the detection (from data) and mitigation <u>are performed</u>.
- For SM and WV modes, no pre-screening is performed as the noise pulses are not available all along the data acquisition. No RFI detection (from data) and mitigation is performed.



The change of processing baseline concerning the RFI mitigation was applied through an update of AUX_PP1 auxiliary product (see section 3.1 and refer to Appendix F -for the list of ADF changes).

A specific technical note explaining how the Sentinel-1 SAR processor annotates the RFI detection and performs the RFI mitigation (when activated) is available on Sentinel Online web site: Sentinel-1 Using the RFI annotations, Issue 1.0, published on 11 February 2022

5.8.2 Effectiveness of RFI mitigation

As expressed in previous section, the RFI mitigation in SAR processing is only applied since 23rd March 2022. However, the overall pre-screening and mitigation process does not guarantee that 100% of the RFI are filtered out. The process was designed to reduce the number of RFI impacting the product quality but avoiding over filtering. Multiple elements can explain the observation of residual RFI even with the pre-screening/mitigation:

- The mitigation is only applied after a pre-screening. The pre-screening may fail to detect evidence of RFI if the noise echoes are not impacted.
- The mitigation may fail to filter out the RFI impact. Typical failure cases are inter alia RFI from a SAR signal with characteristics too close to the one of Sentinel-1, or corruption of the entire spectrum.

Figure 32 presents the locations of residual RFI observed for the month of December 2022 through inspection of the quicklooks of the corresponding nominal production. The impacted products correspond to less than 1% of all products.



Figure 32: Residual RFI for S1A and the month of December 2022. The colour code corresponds to the result of the pre-screening from noise: either no detection from screening (red), detection from one of the two polarimetric channels (orange), or detection from both polarimetric channels (green)

The residual RFI from this map are spread all over the world on the area of actual image acquisitions. The products highlighted in this map are more frequently located in maritime and coastal areas. It may



be due to the type of interfering radar sources on these specific areas, or to the fact that they are easier to be spotted against the low background of sea clutter. The colour code of this map corresponds to the results of pre-detection from noise : no detection in red (66% of the residual), detection on one channel in orange (22%) and detection on two channels in green (12%). Most of the residual RFI are then due to misdetection at pre-screening level..

Figure 33 presents the approximate location of source of RFI from the reports of pre-screening from noise measurements for one cycle in December 2022. The locations of those sources are spread all over the world, and overrepresented on large populated areas. With this kind of analysis, we can report that around 22% of all products are associated with at least one pre-screening of RFI from the noise measurements.

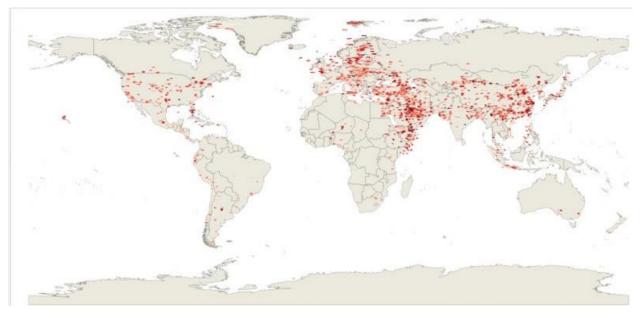


Figure 33: Approximate locations of RFI sources from noise measurements for the first part of December 2022



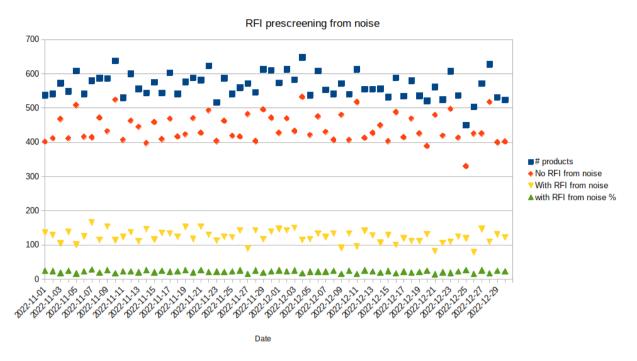


Figure 34: Statistics of RFI pre-screening from noise between November and December 2022

5.8.3 Regular reporting on RFI

Before the activation of the complete RFI mitigation process in the IPF (pre-screening, detection, and mitigation), the exhaustive list of impacted products was not reported.

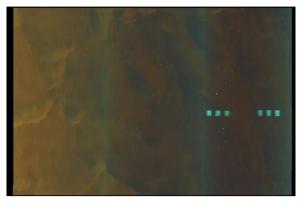
Starting with the activation of this RFI mitigation on 23 March 2023, a more systematic monitoring and reporting of residual RFI is in place through the publication of quality disclaimers (refer to Appendix C - for the list of quality disclaimers published during 2022):

- A set of two Quality Disclaimers (one for S1A and one for S1B) was published for the period between the start of each mission on the 23rd of March 2023, reminding that RFI can be observed on the products, but not providing a list of products.
- Monthly Quality Disclaimers are then published with the list of residual RFI as detected from systematic quicklook inspection.

5.8.4 Radio Frequency Interference from ground emitters

A small percentage of S-1A imagery is affected by the presence of Radio Frequency Interference (RFI) from the ground. Examples of classical RFI observed in 2022 are shown **Figure 35.** Usually, RFI only affects a few range lines of raw data.

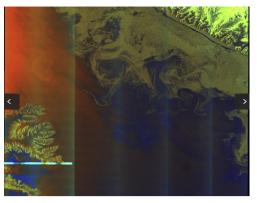
MPC-SAR



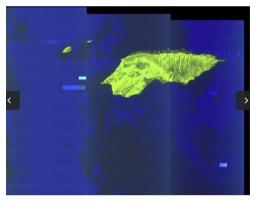
S1A_IW_GRDH_1SDV_20220101T221431



S1A_IW_GRDH_1SDV_202220220119T173440



S1A_EW_GRDM_1SDH_20220428T082214



S1A_IW_GRDH_1SDV_20220409T143758

Figure 35: Examples of usual Radio Frequency Interference during 2022

5.8.5 Mutual Interferences with Radarsat-2

Radarsat-2 is a Canadian satellite operating a SAR in C Band. Mutual Radio Frequency interference between Radarsat-2 and S-1A can occur when the two spacecrafts are flying close on to the other and operating at the same time.

Due to slight differences in orbital period and inclinations, the locations of potential interferences are evolving with time. The orbital period difference is 120.91 sec, i.e., each orbit Sentinel-1 moves 120.91 sec ahead of Radarsat-2. The two satellites approach each other every 3.5 days (50 orbits for Sentinel-1 & 49 orbits for Radarsat-2) [S1-RD-23]



	Sentinel-1	Radarsat-2
Orbit Type	Sun-Synchronous Sun-Synchronous	
Repeat Cycle (days)	12 24	
Repeat Cycle (orbits)	175 343	
Altitude	~693 km ~789 km	
Orbital Period	5924.57 s 6045.481*	
Orbital Inclination	98.18° 98.6°	
MLST	~18:00 hrs ~18:00 hrs	

Table 17: Sentinel-1 and Radarsat-2	2 Orbit characteristics.
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Location of potential RFI based on geometry

Figure 36 provides the potential location of IW images acquired during close fly-by of Sentinel-1A and Radarsat-2 during the year 2022. The colour code corresponds to different relative orbit numbers. The impacted relative orbit numbers are 20, 45, 70, 95, 120, 145 and 170. Those location are however only potential locations of RFI observations as Sentinel-1A is not acquiring constantly.

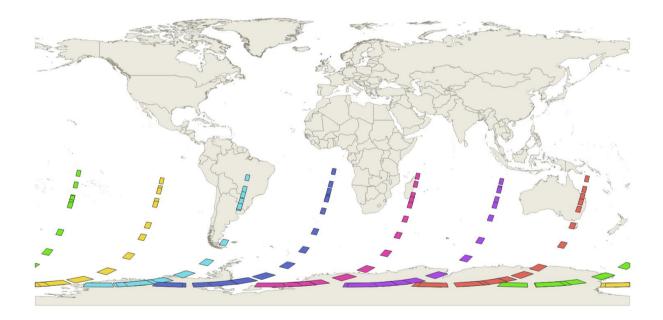


Figure 36: Potential location of S-1A IW images at the time of close S1A vs RS-2 fly by in 2022.

Observed residual RFI

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Among those orbits, there are only acquisitions in those areas over the relative orbits #20, 45, 70 and 170.



The following figure provides the location of residual RFI observed at the time of close fly by between Sentinel-1A and Radarsat-2. Only the relative orbits number 20 and 45 are impacted.

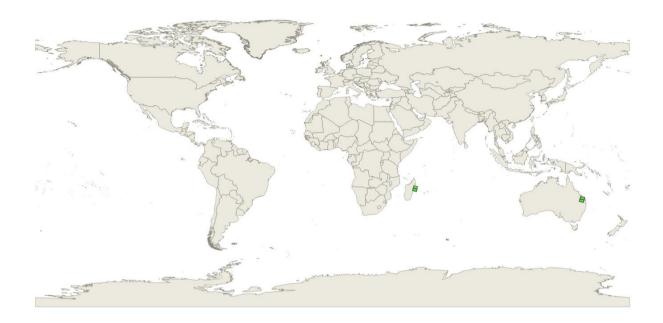
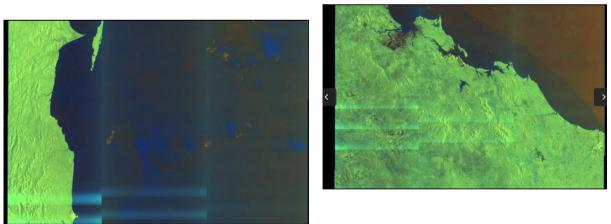


Figure 37: Location of residual RFI observed on S-1A images at the time of close S1A vs RS-2 fly by in 2022.



S1A_IW_GRDH_1SDV_20220110T021100_20221110T S1A_IW_GRDH_1SDV_20220312T192123_202203 021125

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12T192148

Figure 38: Examples of RFI with Radarsat-2 during 2022

The list of products impacted with residual RFI on S1A vs RS2 fly by is obtained via quick-look inspection and provided in the following table. All the residual RFI matching S1A vs RS-2 fly by are observed before the activation of the RFI mitigation in the S-1 IPF. This may be an indication of the effectiveness of the RFI mitigation. However, this may as well be due to the specific locations of the fly by in 2022 associated



to few acquisitions in this year for both S1 and RS2. As shown in Figure 36 the places of potential interferences are mostly located in open ocean / far off the coast were RS2 acquisition are less likely to occur and where S1 is mostly operated only in WV mode (then not with continuous acquisitions).

Products (without CRC)	orbit	Relative orbit
S1A_IW_GRDH_1SDV_20220110T021100_20220110T021125_041392_04EBE5	41392	20
S1A_IW_GRDH_1SDV_20220110T021125_20220110T021150_041392_04EBE5	41392	20
S1A_IW_GRDH_1SDV_20220216T192123_20220216T192148_041942_04FE9E	41942	45
S1A_IW_GRDH_1SDV_20220227T021124_20220227T021149_042092_0503C1	42092	20
S1A_IW_GRDH_1SDV_20220312T192123_20220312T192148_042292_050A8E	42292	45
S1A_IW_GRDH_1SDV_20220312T192123_20220312T192148_042292_050A8E	42292	45
S1A_IW_GRDH_1SDV_20220312T192148_20220312T192213_042292_050A8E	42292	45
S1A_IW_GRDH_1SDV_20220323T021124_20220323T021149_042442_050FA7	42442	20

 Table 18: List of S1A products with residual RFI on fly by with Radarsat-2 (identified by quick-look inspection)

5.8.6 Mutual Interferences with Gaofen-3 satellites

Gaofen-3 is a Chinese constellation of satellites operating a SAR in C Band. Three spacecrafts are currently operated (Gaofen 3, Gaofen 3 02 and Gaofen 3 03). Mutual Radio Frequency interference between Gaofen-3 and S-1A can occur when the two spacecrafts are flying close on to the other and operating at the same time.

Table 19 gives the orbital characteristics of S-1 and GAOFEN 3. GAOFEN 3 is in a higher orbit than S-1 and in a dusk-dawn orbit.

	Sentinel-1	GAOFEN 3
Orbit Type	Sun-Synchronous Sun-Synchronous	
Repeat Cycle (days)	12	29
Repeat Cycle (orbits)	175 419*	
Altitude	~693 km ~751 km	
Orbital Period	5924.57 s	5980 s*
Orbital Inclination	98.18° 98.42°	
MLST	~18:00 hrs ~18:00 hrs	
* Deduced values. Those values are computed considering mean altitude, and orbit inclination as we		

* Deduced values. Those values are computed considering mean altitude, and orbit inclination as we did not find authoritative information on orbital period and repeat cycle of the mission



Table 19: Sentinel-1 and GAOFEN 3 Orbit Characteristics.

Location of potential RFI based on geometry

The respective repeat cycles of the two spacecrafts in number of day is such that the close fly-by are spaced irregularly. The following figure presents to location of potential S1A acquisitions in IW mode that could be impacted by mutual RFI originating from Gaofen-3 due to their proximity at a given time. The colour code considered for this figure corresponds to relative orbit number (60 different relative orbit numbers)

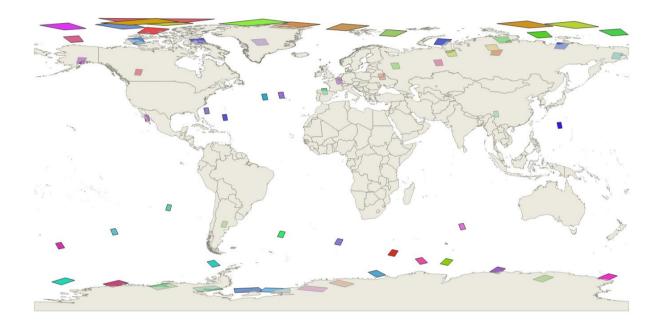


Figure 39: Location of S1A and Gaofen-3 fly by in 2022. The colour code corresponds to relative orbit number. Each polygon corresponds to a potential IW acquisition at a specific date

As for Goafen-3, there is no predefined regular pattern of location of potential RFI with Gaofen-3 02 and Gaofen 3 03. The maps of location of potential RFI with Gaofen-3 02 and Gaofen 3 03 are not provided in this report.

Observed residual RFI (Gaofen-3)

The inspection of the products acquired at those dates in 2022 does not allow to detect residual RFI originating from Gaofen-3.

Examples of S1A / GF3 mutual RFI were presented in the Annual Performance Report of previous years [AD-07].

Observed residual RFI (Gaofen-3 02)

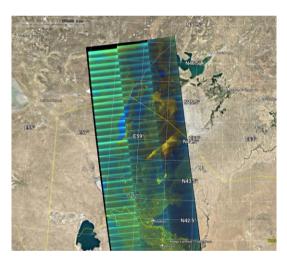
Table 20 provides the list of RFI originating from Gaofen-3 02 observed in 2022.

Date	Location	
2022-01-28 T 17:03	Libya	
2022-02-03 T 14:31	United Emirates (*)	
2022-02-09 T 12:05	Bangladesh	
2022-04-03 T 13:51	Ouzbekistan0	
2022-05-26 T 15:50	Finland	
2022-12-19 T 01:47	Afghanistan, Turkmenistan, Uzbekistan	
2022-12-24 T 23:18	China	
(*) This residual RFI is observed while both S1A and Gaofen-3 02 are close each other. It is likely that		

(*) This residual RFI is observed while both S1A and Gaofen-3 02 are close each other. It is likely that the interference is caused by a Gaofen-3 02 emission. However, the pattern of the RFI looks more like one of multiple ground emitters.

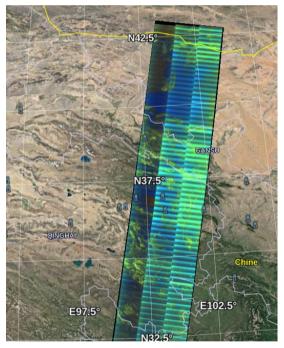
Table 20: Sentinel-1 and GAOFEN 3-02 residual RFI observed in 2022 (identified by quick-look inspection)

The following figure present some examples of RFI with Gaofen-3 02



03 April 2022

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24th December 2022 (datatake 0591AC)

Figure 40: RFI with Gaofen-3 02 observed on 24th December 2022 (datatake 0591AC)

Observed residual RFI (Gaofen-3 03)

The inspection of the products acquired at those dates in 2022 does not allow to detect residual RFI from Gaofen-3 03.



5.8.7 Mutual Interferences with the RCM constellation

The Radarsat Constellation Mission / RCM (NORAD ID 44322, 44323 and 44324) C-Band SAR satellites can interfere as well with Sentinel-1A. Table 21 gives the orbital characteristics of S-1 and RCM. RCM is in a lower orbit than S-1 and in a dusk-dawn orbit.

	Sentinel-1	RCM
Orbit Type	Sun-Synchronous Sun-Synchronous	
Repeat Cycle (days)	12 12	
Repeat Cycle (orbits)	175 179	
Altitude	~693 km ~592 km	
Orbital Period	5924.57 s 5784 s	
Orbital Inclination	98.18° 97.74°	
MLST	~18:00 hrs ~18:00 hrs	

Table 21: Sentinel-1 and RCM 1/2/3 Orbit Characteristics

Location of potential RFI based on geometry

The locations of potential S-1 RCM interference are geographically localised in some specific area over the globe. Those potential RFI and mostly mitigated through the acquisition plan of Sentinel-1 (no acquisitions of S-1 were planned in some of those areas even before the launch of the RCM Constellation). The impact now is considered small and no changes in the acquisition plan of neither S1 nor RCM is currently in place with the specific goal of mitigating cross-sensor RFI. The situation is contentiously monitored, and, if necessary, mitigation actions will be proposed and eventually coordinated with CSA.

Table 22 provides the list of area that can be potentially impacted by S1A vs RCM/1/2/3 mutual RFI. The figures below provide their geographic locations.

Spacecrafts	Orbit number	Pass	Location
S1A vs RCM-1	32	Descending	Antarctica around 22:12:50 UTC
	76	Descending	Indonesia / Malaysia around 22:15:34 UTC
	120	Ascending	Canada around 22:13:37 UTC
	163	Ascending	Amazon around 22:15:06 UTC
S1A vs RCM-2	18	Ascending	North Canada around 22:22:36 UTC
	61	Ascending	Amazon around 22:41:49 UTC
	105	Descending	Antarctica around 22:21:49 UTC
	149	Descending	Indonesia / Malaysia around 22:24:08 UTC
S1A vs RCM-3	3	Descending	Antarctica around 22:30:56 UTC
	47	Descending	Indonesia / Malaysia around 22:32:27 UTC
	91	Ascending	Amazon around 22:30:46 UTC
	134	Ascending	North Canada around 22:31:31 UTC



Table 22: Locations of potential S1A vs RCM 1/2/3 mutual RFI due based on geometry. The observation of RFI is not systematic (requiring that both spacecraft are operating at the same time and that the RFI mitigation in the processing is not sufficient).

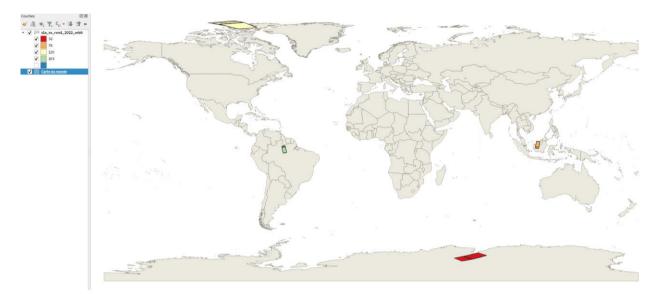


Figure 41: Locations of potential S1A vs RCM-1 RFI based on geometry (not associated to systematic observations)

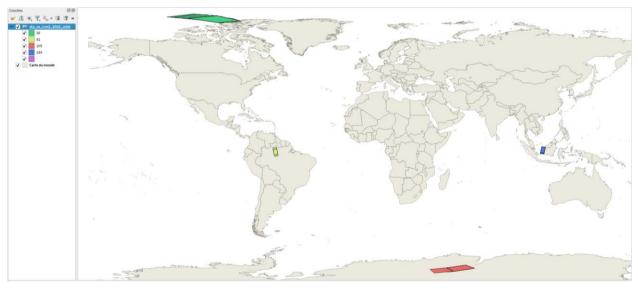


Figure 42: Locations of potential S1A vs RCM-2 RFI based on geometry (not associated to systematic observations)

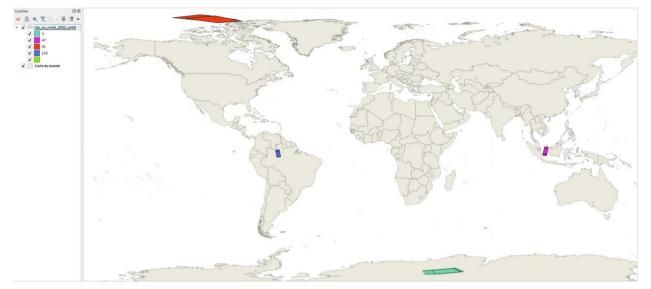
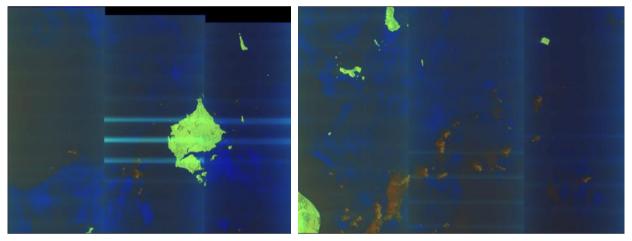


Figure 43: Locations of potential S1A vs RCM-3 RFI based on geometry (not associated to systematic observations)

Observed residual RFI



S1A_IW_GRDH_1SDV_20220405T223102

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S1A_IW_GRDH_1SDV_20220405T223131

Figure 44: Example of RFI between S1A vs RCM observed in 2022

Source / Orbit / Location	List of products (without CRC)
RCM1	S1A_IW_GRDH_1SDV_20220101T221431_20220101T221500_041273_04E7D1
relative orbit 76	S1A_IW_GRDH_1SDV_20220113T221431_20220113T221500_041448_04ED96
Indonesia / Malaysia	S1A_IW_GRDH_1SDV_20220125T221430_20220125T221459_041623_04F391
	S1A_IW_GRDH_1SDV_20220206T221429_20220206T221458_041798_04F994



	S1A_IW_GRDH_1SDV_20220302T221429_20220302T221458_042148_0505A9
	S1A_IW_GRDH_1SDV_20220314T221429_20220314T221458_042323_050B94
	S1A_IW_GRDH_1SDV_20220407T221430_20220407T221459_042673_05176E
	S1A_IW_GRDH_1SDV_20220525T221432_20220525T221501_043373_052DF5
	S1A_IW_GRDH_1SDV_20220922T221438_20220922T221507_045123_056478
	S1A_IW_GRDH_1SDV_20220922T221507_20220922T221532_045123_056478
RCM2	S1A_IW_GRDH_1SDV_20220130T222312_20220130T222341_041696_04F609
relative orbit 149	S1A_IW_GRDH_1SDV_20220130T222341_20220130T222406_041696_04F609
Indonesia / Malaysia	S1A_IW_GRDH_1SDV_20220130T222406_20220130T222431_041696_04F609
	S1A_IW_GRDH_1SDV_20220211T222431_20220211T222456_041871_04FC14
	S1A_IW_GRDH_1SDV_20220223T222311_20220223T222340_042046_050231
	S1A_IW_GRDH_1SDV_20220223T222340_20220223T222405_042046_050231
	S1A_IW_GRDH_1SDV_20220307T222340_20220307T222405_042221_050820
	S1A_IW_GRDH_1SDV_20220319T222340_20220319T222405_042396_050E0E
	\$1A_IW_GRDH_1\$DV_20220424T222342_20220424T222407_042921_051FAF
	S1A_IW_GRDH_1SDV_20220717T222347_20220717T222412_044146_0544F0
	S1A_IW_GRDH_1SDV_20221102T222350_20221102T222415_045721_0577D8
RCM3	S1A_IW_GRDH_1SDV_20220111T223103_20220111T223132_041419_04ECC9
relative orbit 47	S1A_IW_GRDH_1SDV_20220111T223132_20220111T223201_041419_04ECC9
Indonesia / Malaysia	S1A_IW_GRDH_1SDV_20220123T223103_20220123T223132_041594_04F28F
	S1A_IW_GRDH_1SDV_20220123T223132_20220123T223157_041594_04F28F
	\$1A_IW_GRDH_1\$DV_20220123T223157_20220123T223222_041594_04F28F
	\$1A_IW_GRDH_1\$DV_20220123T223222_20220123T223247_041594_04F28F
	S1A_IW_GRDH_1SDV_20220216T223102_20220216T223131_041944_04FEAE
	S1A_IW_GRDH_1SDV_20220216T223131_20220216T223156_041944_04FEAE
	S1A_IW_GRDH_1SDV_20220216T223156_20220216T223221_041944_04FEAE
	S1A_IW_GRDH_1SDV_20220228T223102_2022028T223131_042119_0504AB
	S1A_IW_GRDH_1SDV_20220228T223131_20220228T223156_042119_0504AB
	S1A_IW_GRDH_1SDV_20220228T223156_20220228T223221_042119_0504AB
	S1A_IW_GRDH_1SDV_20220324T223102_20220324T223131_042469_051092
	S1A_IW_GRDH_1SDV_20220324T223131_20220324T223156_042469_051092
	S1A_IW_GRDH_1SDV_20220324T223156_20220324T223221_042469_051092
	S1A_IW_GRDH_1SDV_20220405T223131_20220405T223156_042644_05167E
	S1A_IW_GRDH_1SDV_20220405T223156_20220405T223221_042644_05167E
	S1A_IW_GRDH_1SDV_20220417T223157_20220417T223222_042819_051C5F



S1A_IW_GRDH_1SDV_20220417T223222_20220417T223247_042819_051C5F
S1A_IW_GRDH_1SDV_20220429T223103_20220429T223132_042994_05221A
S1A_IW_GRDH_1SDV_20220429T223132_20220429T223157_042994_05221A
S1A_IW_GRDH_1SDV_20221026T223112_20221026T223141_045619_057468
S1A_IW_GRDH_1SDV_20221026T223141_20221026T223206_045619_057468
S1A_IW_GRDH_1SDV_20221026T223206_20221026T223231_045619_057468

Table 23: List of S1A products impacted by RCM residual RFI in 2022 (identified by quick-look inspection)

5.8.8 Mutual interferences with RISAT-1A (EOS4)

RISAT-1A (EOS4) is an Indian satellite operating a SAR in C Band. Mutual Radio Frequency interference between RISAT-1A and S-1A can occur when the two spacecrafts are flying close on to the other and operating at the same time.

	Sentinel-1	RISAT-1A (EOS4)
Orbit Type	Sun-Synchronous	Sun-Synchronous
Repeat Cycle (days)	12	17
Repeat Cycle (orbits)	175	257
Altitude	~693 km	~525 km
Orbital Period	5924.57 s	5715,17 s
Orbital Inclination	98.18°	97.5°
MLST	~18:00 hrs	~18:00 hrs

Table 24 gives the orbital characteristics of S-1 and RISAT-1A.

Table 24: Sentinel-1 and RISAT-1A (EOS4) Orbit Characteristics

Observed residual RFI

Date	Location
2022-04-19 T 15:00	Iraq track 72
2022-04-24 T 15:08	lraq track 145
2022-05-06 T 15:08	lraq track 145
2022-05-25 T 15:00	Iraq track 72

Table 25: Sentinel-1 and RISAT-1A (EOS4) residual RFI observed in 2022 (identified by quick-look inspection)

5.8.9 Mutual Interferences with unknown sources

On previous years, RFI from unknown space sources were observed (refer to annual performance reports of previous years [AD-07])

No such occurrences were observed in 2022.



5.9 Quality Disclaimers

S-1A Quality disclaimers issued on L1 products during 2022 are given in Appendix C -.



6.Level 2 Products

6.0 Wind Measurement

As in past years, the accuracy of the wind retrieval is assessed by comparing it with auxiliary wind source used as reference. In this scope, ESL performed systematic collocations between such reference data and core L2 OCN products [AD-07]. The used reference data in the reporting period included:

- models: ECMWF (global), Arome, Arpege (European)
- hundreds of buoys
- Metop scatterometers ASCAT- A/B
- altimeters (ex Cryosat),
- radiometers (ex SMAP)

6.0.1 Image Mode (IW -EW)/ OWI

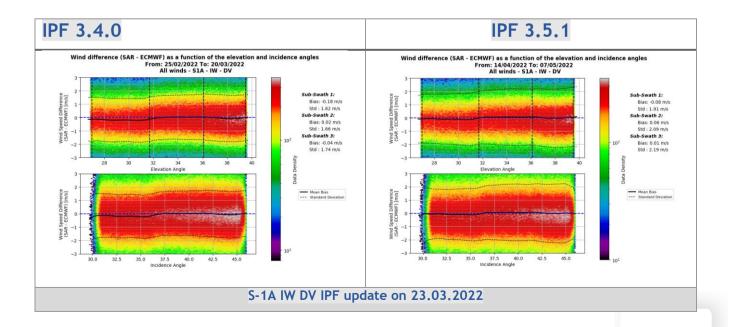
In 2022, the wind performance was mainly impacted by IPF and Auxiliary data updates (see section 3-Processing Updates)

Wind Speed

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IPF update impacting the wind performances

The first IPF change from version 3.4.0 to 3.5.1 occurred on March 23rd, 2022. The main changes were introduced in the section 3.0.2. This IPF change was not expected to change significantly the wind performances. Unfortunately, this update introduced a major regression with the projection of the auxiliary data (wind speed and direction from AUX_WND, land mask, sea ice *etc*) on the computed product grid. This behaviour impacted all products acquired for latitude higher that 60° (North or South), please refer to quality disclaimer [QD-87] for more details. It explains then the very poor performance wind speed retrieval of EW DH/SH (the main impacted mode due to the acquisition plan scenario), illustrated in Figure 45. A new IPF version (3.5.2) was released on May 12th, 2022 to correct this aspect. Please refer to Figure 46 for illustration of wind performance with the various IPF versions, where both the regression with IPF 3.5.1 and its correction with IPF 3.5.2 can be clearly observed.





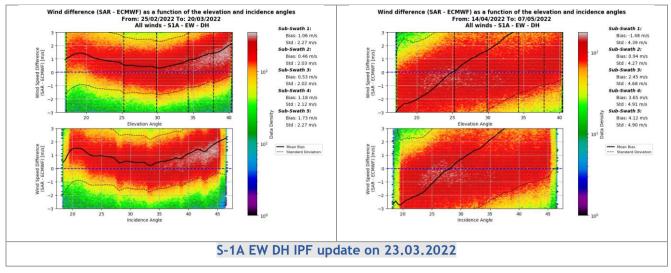


Figure 45: Effects of IPF update from 3.4.0 to 3.5.1 on the incidence and elevation angle dependent SAR wind speed bias with respect to ECMWF for the data sets concerned.

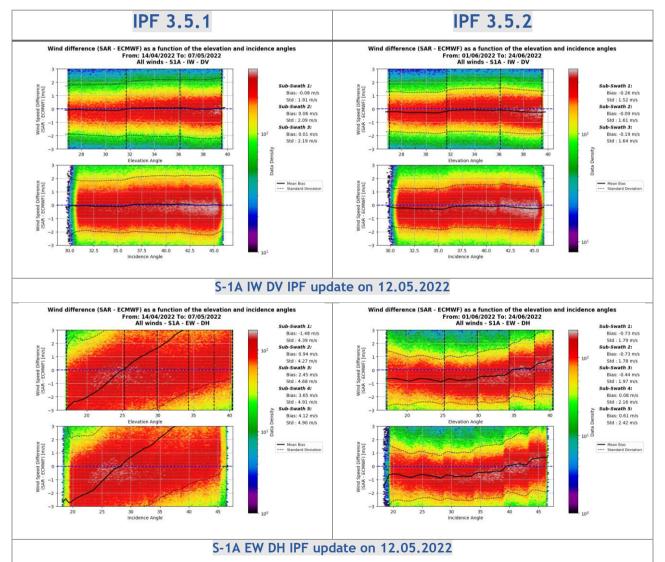


Figure 46: Effects of IPF update from 3.5.1 to 3.5.2 on SAR wind speed bias with respect to ECMWF as functions of the incidence and elevation angle.



Auxiliary data updates, impacting wind performances

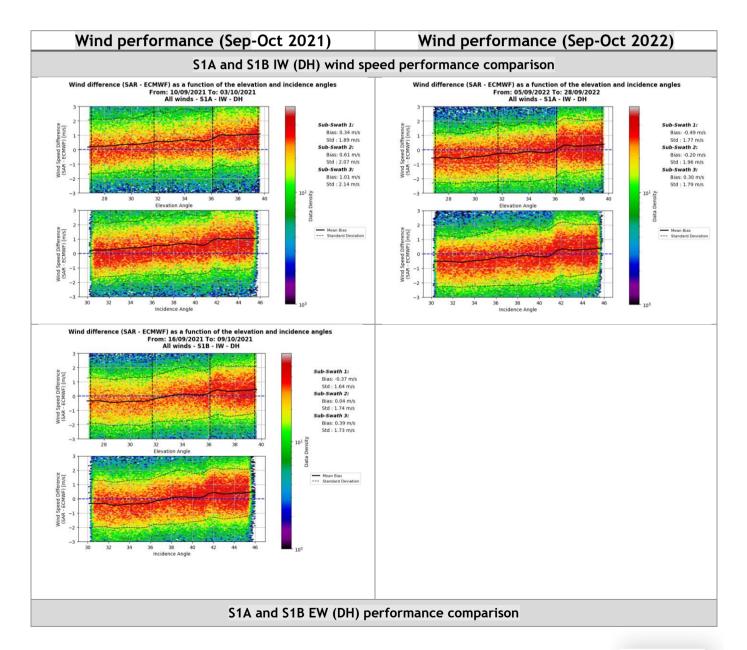
AUX WIND:

Since April 8th, 2022, the wind products are generated using ECMWF wind forecasts (AUX-WND) with a time resolution of 1 hour instead of 3 hours and a grid spacing of 0.1 degree instead of 0.125 degree. No improvement of wind retrieval performance in a statistical view is expected with this change. However, this spatial and temporal resolution improvement may enhance the performance for some specific scenes with higher wind variability.

AUX PP1:

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During 2022, the S-1A AUX_PP1 auxiliary files was updated once, in conjunction with the IPF v3.5.1 deployment on 23rd March 2022, to change the SL2/GR2 EW/IW processing gains for the HH channel with the aim to align S-1A wind speed performance with the S-1B performance. Figure 47 illustrates this update with comparing the performance of S-1A and S-1B for IW/EW DH on a same season period (1 year apart). It is clear in this figure that the performances of S1A become very close to those of S1B on the same seasonality.





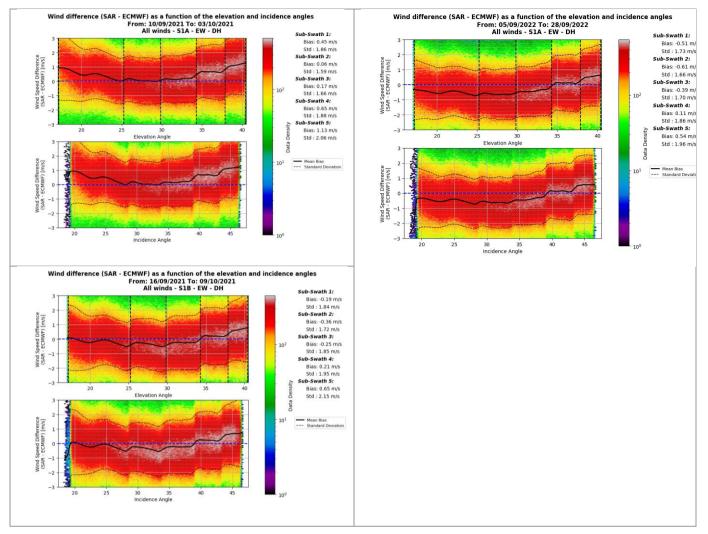


Figure 47: Effects of AUX_PP1 update (since 23rd March 2022) on SAR wind speed bias with respect to ECMWF as a function of the incidence and elevation angle: Left columns, to compare S1A and S1B performances (during the same period) before aux_pp1 updating, the right column S1A performance after updating.

Time series on the wind speed Performances

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Figure 48 and Figure 49 show the time series of S-1 Wind speed bias with respect to the ECMWF and NCEP model, respectively. Figure 50 and Figure 51 represent the same comparison but for the wind speed standard deviation. For the moment, only DV polarization acquisitions are presented (for EW and IW). The mean bias is computed by averaging the difference between SAR wind speed and reference model wind speed on a bi-cycle period (two consecutive cycles), sub-swath by sub-swath. The associated standard deviation is also referred as Root Mean Square Error (RMSE). The IPF updates are located in the upper part of all these plots. A significant RMSE increase is observed at the transition between IPF 3.4.0 and 3.5.1. This is related to the problem introduced in IPF v3.5.1 as discussed in the previous sections. Besides that, a seasonality similar to 2021 [AD-07] is observed.



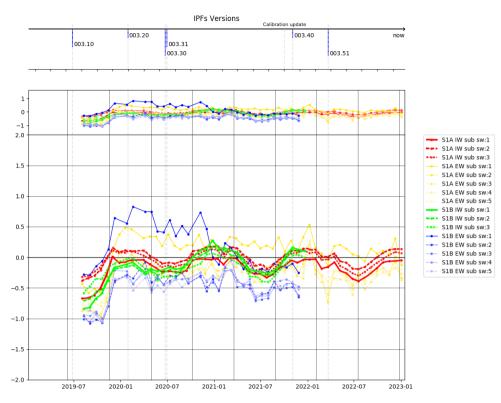
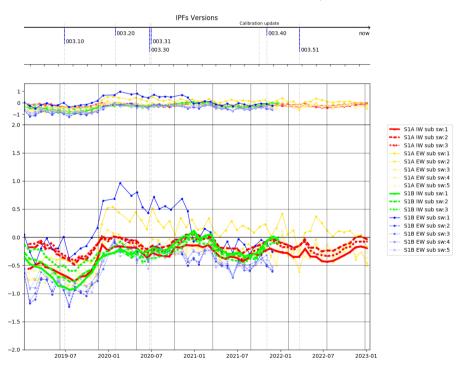


Figure 48: Mean SAR wind speed bias with respect to ECMWF model detailed by sub-swath along time for the DV polarization acquisitions. (Top: general trend, bottom: zoom on the trend curves)



Sub-swath bias statistic vs time for NCEP colocation and polarization DV.

Figure 49: Mean SAR wind speed bias with respect to NCEP model detailed by sub-swath along time for the DV polarization acquisitions. (top: general trend, bottom: zoom on the trend curves)



Sub-swath std statistic vs time for ECMWF colocation and polarization DV.

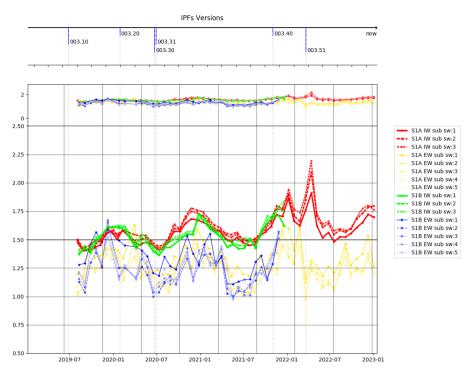
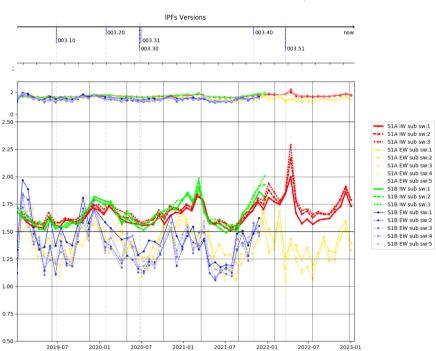


Figure 50: SAR wind speed standard deviation with respect to ECMWF model detailed by sub-swath along time for the DV polarization acquisitions. (Top: general trend, bottom: zoom on the trend curves)



Sub-swath std statistic vs time for NCEP colocation and polarization DV.

Figure 51: SAR wind speed standard deviation with respect to NCEP model detailed by sub-swath along time for the DV polarization acquisitions. (Top: general trend, bottom: zoom on the trend curves)



In conclusion, the analysis of this standard deviation and bias shows the presence of a peak just after the release of version 3.51 of the IPF, which had a poor data processing at high latitudes. Once the problem was corrected by version 3.5.2, the statistical indicators resumed their optimal evolution.

Wind direction

Ebuchi diagrams comparing between SAR and ECMWF wind direction are plotted in Figure 52. Both are in relatively good agreement.

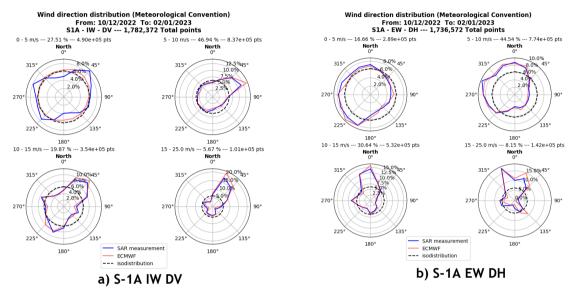


Figure 52: Ebuchi diagrams for S-1A SAR retrieved and ECMWF wind directions detailed by wind speed domain in December 2022.

6.0.2 Wave Mode / OWI

Since IPF 3.30, the OWI processing has been activated on Wave mode.

Wind Speed

The performances of the wind speed retrieval for wave modes are presented in Figure 53

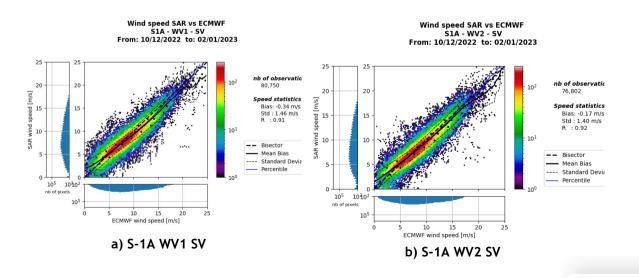




Figure 53: Scatter plots of SAR vs ECMWF wind speeds for Wave Modes in Dec. 2022, for S-1A.

Wind Direction

As for TOPS modes, the performances of wind direction retrieval are diagnosed on Figure 54. Performances are compliant with TOPS modes.

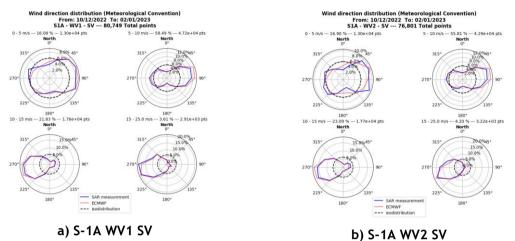


Figure 54: Ebuchi diagrams for S-1A SAR retrieved and ECMWF wind directions detailed by wind speed domain in December 2022.

6.0.3 Wave Mode / OSW

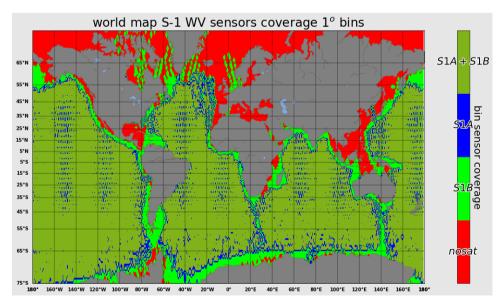
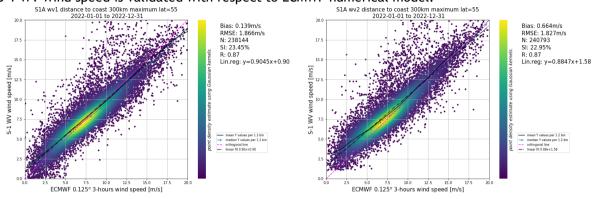


Figure 55: Coverage map of S-1 WV acquisition

Ocean surface wind speed and direction performances have been very stable during the past year, and they are within the specifications for both parameters.



Wind Speed



S-1 WV wind speed is validated with respect to ECMWF numerical model.

Figure 56: Scatter plot of oswWindSpeed as respect to ECMWF 0.125 (3h) left: S-1A WV1, right: S-1A WV2

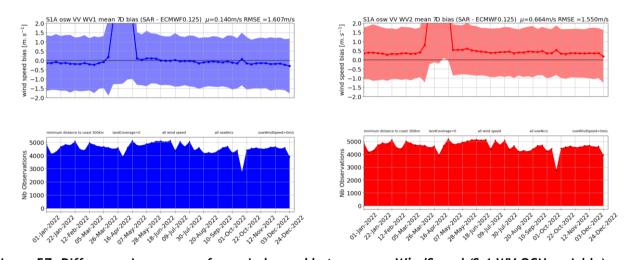


Figure 57: Difference in ocean surface wind speed between *oswWindSpeed* (S-1 WV OCN variable) and ECMWF numerical model (0.125° spatial resolution grid and 3-hours for time resolution). Bold line is the daily mean of the individual measurement differences and the background colour is the daily standard deviation.

Time evolution: Two changes have to be reported in 2022 on osw WV wind speed.:

- To be noticed, on 8th April 2022, a change in the AUX_WND, which since contains hourly ECMWF forecast. With this change, the content of the ECMWF GRIB has evolved with unexpected additional variables (such as pressure), leading to a misinterpretation by the IPF of the a priori wind speed for the Swell module (OSW) (more details are provided in <u>QD-86</u>). This issue has been solved with IPF v3.5.2 deployment on the 12th May 2022.
- With IPF v3.5.1, the *oswNrcsNeszCorr* variable is available (which is needed to do a direct GMF inversion with CMOD5n). But it is still *oswNrcs* (no noise correction) that is still used to estimate the *oswWindSpeed*.

Performances with respect to specifications: RMSE is within the 2m/s specifications.

Discussion about the performances: The wind speed performances are directly linked with the geophysical calibration and the use of the Geophysical Model Function. Once the direct wind inversion



will use denoised NRCS, it will improve the WV2 wind speed performances. This change is expected in 2023.

Wind Direction

The wind direction for *oswWindDirection* products is a copy of the value given by the ECMWF numerical forecast (data provided as AUX_WND input) available at the processing date. In the contrary to Sentinel-1 OWI wind inversion, there is no Bayesian inversion scheme for OSW module to combine SAR and ECMWF information to get the wind direction. The validation in this section comes basically equivalent to a validation between the ECMWF forecast (which is present in the products in oswWindDirection: SAR wind direction) and ECMWF analysis.

The same issue [QD-86] mentioned in Wind Speed section above, and reported in Quality Disclaimer 87 also impacted the wind direction of osw component. This issue induces the pic in the OSW wind direction distribution for the products at 180° and 270° in Figure 58), and a stronger RMSE when comparing oswWindDirection with ECMWF forecast for the time period from the 8th April to the 12th May 2022 (Figure 59).

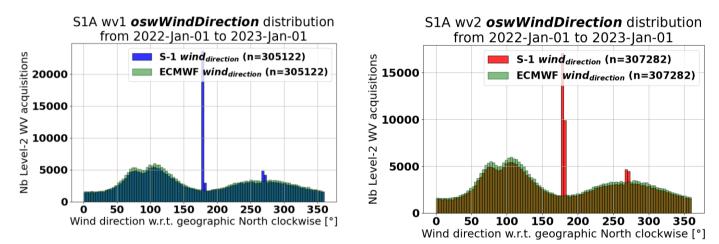


Figure 58: Distribution of the ocean surface wind direction, respectively oswWindDirection S-1 WV OCN variable and ECMWF numerical model (0.125° spatial resolution grid and 3-hours for time resolution).



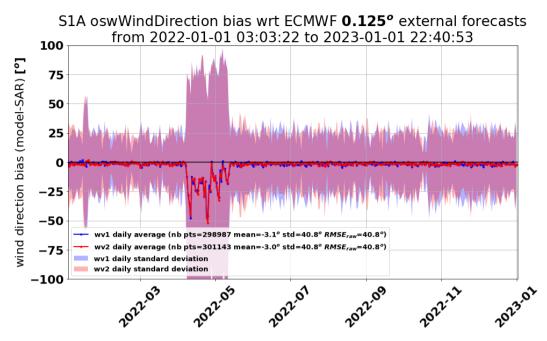


Figure 59 : ocean surface wind direction bias: oswWindDirection S-1 WV OCN variable compared to ECMWF numerical model (0.125° spatial resolution grid and 3-hours for time resolution) as function of Time.

The rationale behind this analysis is the need to validate both SAR derived parameters but also auxiliary information ingested in the processor and annotated in Level-2 products.

Time evolution: There is no significant trend regarding the wind direction performances with respect to time.

Inter comparison: similar results are obtained for WV1 and WV2.

Performances with respect to specifications: except the issue related to <u>QD-86</u> in April/May, RMSE is within the 30° given by the specifications.

Discussion about the performances: The differences between the SAR wind direction (in fact forecast of ECMWF model) and ECMWF analysis are almost zero everywhere. The significant differences observed from time to time can be explained by specific meteorological situations such as low wind area of extreme events (cyclones) in which atmospheric front location in time and space show discrepancies between model forecast and analysis.



6.1 Swell Measurement

6.1.1 Wave Mode

Significant Wave Height without Partitioning

oswTotalHs performance

In June 2022, a variable *oswTotalHs* has been released in S-1 WV OCN products. This variable is an "altimetric like" significant wave height, using a Deep-Learning model result [AD-06]. The Inputs of the model are SAR polar image cross spectrum (real and imaginary) plus high-level features: incidence angle, longitude, latitude, NRCS, Nv time of day.

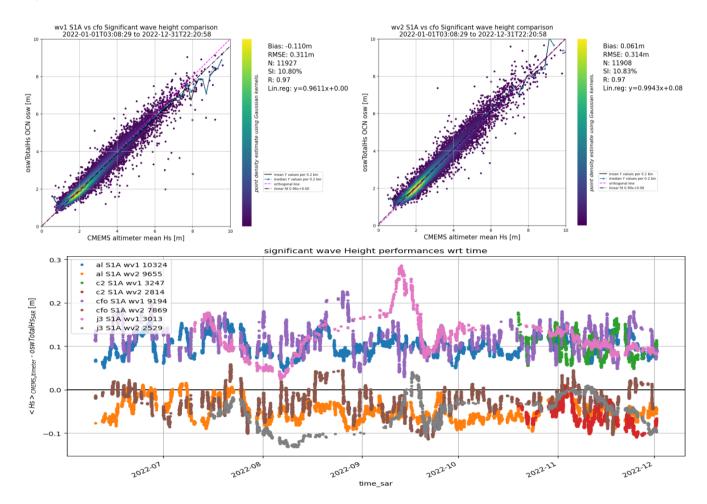


Figure 60 Top left: scatter plot of the *oswTotalHs* from L2 OCN WV1 products compared (and colocated) to CFOSAT nadir beam (product CMEMS WAV TAC L3). Top right: Same but with WV2. Bottom: SWH bias between S-1 WV1/2 versus different altimetric missions (j3: Jason-3, cfo: CFOSAT SWIM, al: SARAL-AltiKa, c2: Cryosat-2) from CMEMS WAV product.

Figure description: The methodology applied to produce the figures above is based on colocations SAR/Altimeters georeferenced in a 2° radius and ± 3 hours time window.

Time evolution: the bias evolution has different origins: the evolution of co-locations positions from cycle to cycle, the seasonal effect associated and the different sensor/calibration/inversion evolution of the currently flying satellites.



Inter comparison: WV2 SWH has a mean tendency to be overestimated compared to altimeter (e.g.: ~6 cm bias w.r.t. CFOSAT) while WV1 is underestimated (~11 cm bias w.r.t. CFOSAT). This is illustrated on the top left and top right graphs of Figure 60. The same tendency is as well observed while comparing vs other altimeters (Jason-3, SARAL-Altika, Cryosat-2) as illustrated in bottom graph of Figure 60.

Performances with respect to specifications: performances are aligned with specification of RMSE<0.5 m and bias<0.1 m

Discussion about the performances: Performances are described in papers cited in osw ATBD [AD-06], they reflect what was the best regression model at the time of publication, it is for sure possible to improve the accuracy and precision of SWH and its standard deviation by tuning other models, increasing the size of the training dataset (especially for acquisitions after the WV2 Antenna Elevation Pattern update) or adding extra information helping the model. The performances could be improved for the waves with Hs around 2 m but also for Hs > 10 m where the number of observations is low.

Significant wave height derived from elevation wave spectrum performance

The S-1 WV OCN product also allows to compute a significant wave height from the SAR ocean spectrum (*oswPolSpec*). To validate the energy of the WV ocean wave spectrum, the concept of effective significant wave height is used against WW3 wave spectra. It consists in computing the wave parameters from WW3 on the spectral domain where the inversion is considered valid (below the cut-off). On top of this mask applied on the spectral grid, a low frequency contamination mask is used to filter regions of the spectra SAR and also WW3. This contamination mask is provided in the WV OCN product since 26th June 2019 with IPF 3.1.0.

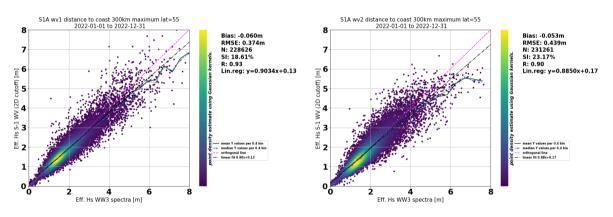


Figure 61: scatter plot of effective significant wave height computed on the whole spectra S-1 WV OCN and associated WW3 spectra. Top left: S-1A WV1, top right: S-1A WV2.

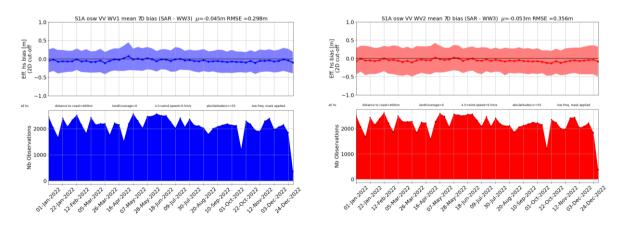


Figure 62: Daily difference of SAR effective azimuth + range 2D cut-off Hs and WW3 numerical model Hs (using same spectral cut-off domain). For each sensor, on the upper panel the bold line is



the daily mean of the individual measurement differences, and the background colour is the daily standard deviation. On the lower panel the colour indicates the number of available matchups between WV (20 km by 20 km) S-1 acquisitions and WW3 spectra computed at the nearest 0.5° resolution grid point.

Time evolution: There is no significant trend regarding the effective Hs bias performances with respect to time.

Inter comparison The performances of WV1 and WV2 are very similar using this concept of effective Hs against WW3.

Performances with respect to specifications: The RMSE and the bias are within the specifications (0.5 m resp. 0.1 m) for S-1A and WV1/WV2.

Discussion about the performances: MTF (Model Transfer Function) used to retrieve wave parameters is suffering of underestimation of the energy for strong Hs, plus an anisotropic bias that underestimates the Hs along the range axis. With this MTF the OSW spectra tends to show splitting over range axis for near range travelling waves at moderate to high winds (> 7ms/). We assume that this is attributed to non-linear effects in the RAR MTF, currently not properly accounted for. In addition, a residual signal in the phase plane is systematically observed and now understood² and a new inversion scheme is currently discussed to mitigate this anomaly that impacts the Hs performances and wave propagation ambiguity removal.

Wave Partitions

The L2 OSW component contains up to 5 different waves partitions corresponding to different waves systems.

The performance of each partition is assessed against WW3 numerical wave model with respect to the following three parameters: the significant wave height (oswHs), the wavelength (oswWl) and the wave direction (oswDirmet).

WW3 wave spectra are filtered according to the SAR cut-off wavelength and are partitioned to estimate wave system parameters. Finally, WW3 partitions are cross-assigned to SAR wave partitions to find the nearest in the spectral domain.

Performances per wave partition quality flag

Since the IPF v3.5.1, March 2022, the estimation of the performance of each partition is based on a machine learning algorithm to classify a partition quality as 'very good', 'good', 'medium', 'low' or 'poor', see osw ATBD [AD-06] for more details.

Improvement of quality flag before and after IPF 3.5.x (oswQualityFlag algorithm update)

In Figure 63 histograms and relative repartition of the partitions as respect to their quality flags before and after the improvement of quality flag labelling algorithm (IPF v 3.5.1) show the good balance of partitions between the different quality flag categories based on the new algorithm update while respecting the wave parameters specifications.

The partitions labelled as good and very good have the same occurrence as the other categories and cover larger wind range of values and wave parameters such as effective Hs, compared to previous algorithm. As example, the "very good" data are extended to Hs > 7 m whereas the domain was limited to 6 m by the old method. This behaviour is very well shown by the scatter plots in Figure 64.



² impact of local incidence angle which has been neglected for in the computation of the cross spectrum between one look and another.

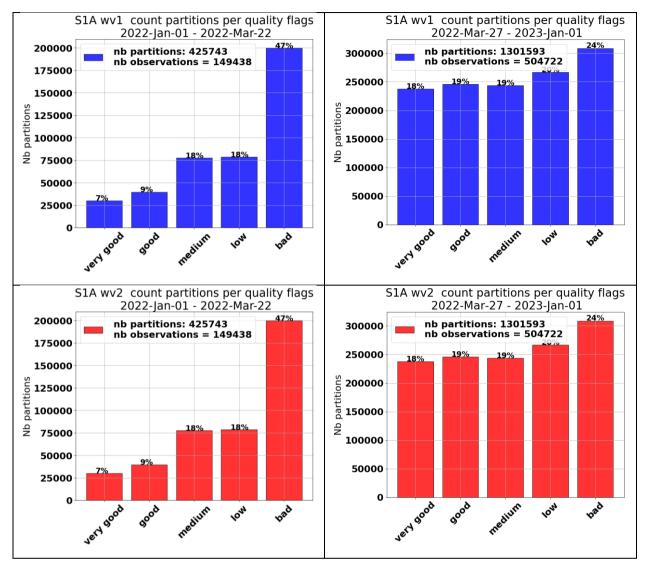


Figure 63: histograms and relative repartition of the partitions as respect to their quality flags before and after the improvement of quality flag labelling algorithm (IPF v 3.5.1)

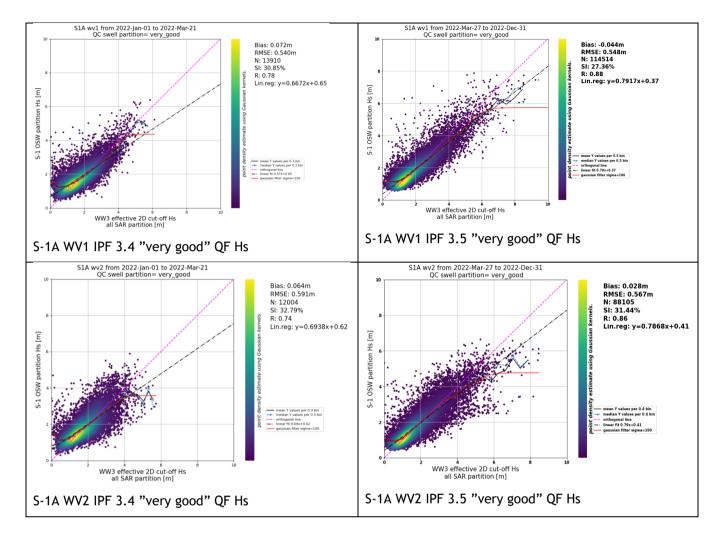


Figure 64: Swell parameters performance on partitions flagged with "very good" quality after IPF 3.5.1 (improvement of oswQualityFlag labelling computation based on machine learning)

Performances comparison per partition quality flag value

Considering all the partitions available for each SAR spectra (up to 5), this section illustrates the performances on significant wave height, wavelength and wave direction with respect to the peak parameter of the closest WW3 partition and separated by partition quality flag.



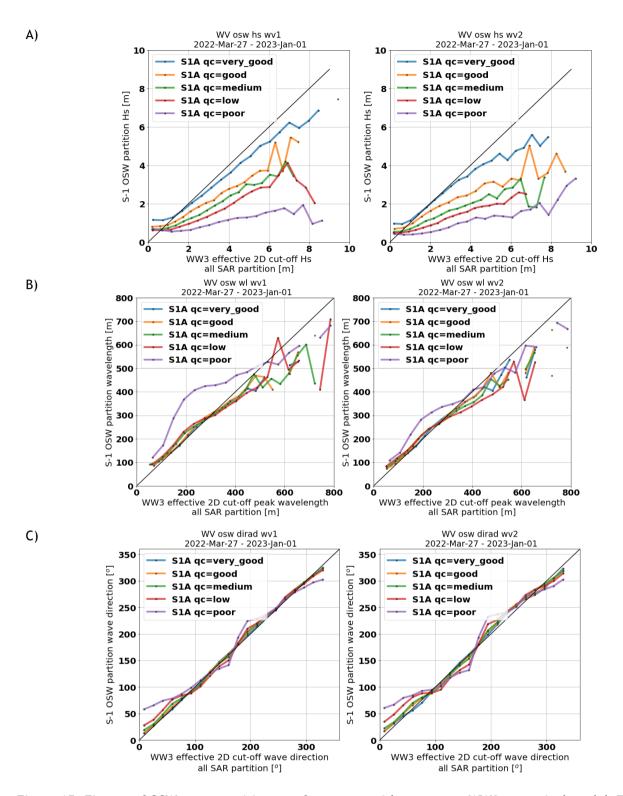


Figure 65: Figures of OSW wave partitions performances with respect to WW3 numerical model. The lines represent the mean bias for each wave partition quality flag. Minimum distance to coast is 100km. To avoid ice contamination: -55°<latitude<55°. Left column is WV1 (24° incidence angle), right is WV2 (37° incidence angle). A): Significant wave height B): Peak wavelength, C): Peak wave direction.

The figures above depict the performances for acquisition from IPF 3.5.1 (starting 26th March 2022) since a major change in the quality flag algorithm has been released at this date.

Time evolution: There is no significant trend regarding the performances of wave peak parameters bias with respect to time.

Inter comparison: Only S1A available.

Performances with respect to specifications: Only "very good" WV1 and "good" WV2 partitions are within Hs specifications (bias 0.1m RMSE 0.5m). For peak wavelength and peak direction, "very good" and "good" WV1 and WV2 are within the specs (bias 10 m RMSE 50 m resp. Bias 10° and RMSE 40°).

Discussion about the performances: The updated quality flag method is designed to make the "very good" and "good" partitions matching the wave parameters specifications. It is the case with the WV data acquired in 2022.

- The "very good" effective Hs for WV1 and WV2 is showing an overestimation at low Hs, this could be mitigated with a future ad hoc tuning of the MTF and the low frequency filter.
- Quality flag algorithm will be improved using larger training dataset. TThe peak wavelength is underestimated by Sentinel-1 WV above 400 m, the revision of low frequency filter and/or the future application of Koch filters on the roughness image prior to the wave inversion could help to improve the high wavelength retrieval.
- Effective Hs from low quality partitions is impacted by the fact that in some cases the ambiguity removal cannot be done (due to the lack of contrast in the imaginary cross spectra) and then a wrong propagation swell direction is attributed to the swell system which is mis-associated to a WW3 swell system. Future works on the wave inversion and especially direction ambiguity removal will improve performances on both wavelength and wave direction parameters.
- The 180° error on the wave direction is observed in some WV acquisitions. This issue is now understood. It comes from the local geometry change during the radar aperture, in particular local incidence angle can change the backscatter between the beginning and the end of the look/burst and thus the cross spectra computed between the 2 looks in absence of compensation of this effect will be interpreted as a change of phase.. A theoretical work to describe this effect is ongoing and a future strategy to mitigate the problem is under discussion.

The tables below are presenting the performances for effective significant wave height, peak wavelength and dominant wave direction, respectively Table 26, Table 27, Table 28. The tables are separated in 3 groups (mean bias, number of partitions, RMSE) of 2 columns (S-1A x WV1/WV2). The lines correspond to the value annotated in OCN osw WV products for the variable 'oswQualityFlagPartition'.

		bias		bias nb		rmse
id2	S1Awv1hs	S1Awv2hs	S1Awv1hs	S1Awv2hs	S1Awv1hs	S1Awv2hs
qcvals2						
0_very_good	-0.044138	0.028407	114514.0	88105.0	0.547923	0.567146
1_good	-0.027875	-0.118814	103172.0	106946.0	0.528386	0.607460
2_medium	-0.142943	-0.290329	81243.0	126548.0	0.623411	0.632739
3_low	-0.257423	-0.413612	72815.0	148838.0	0.795628	0.768375
4_poor	-0.376210	-0.727475	116631.0	129065.0	1.268193	1.173878

Table 26: Effective significant wave height performances (w.r.t.) WW3 model in meter for S-1 WVswell partitions depending on the swell partition quality flag

The effective Hs mean bias are within a range of 0 cm to 72 cm.

Number of partitions per level of quality flag is quite homogeneous. Hs Bias and RMSE are showing performances in agreement with the level of quality flag, i.e. smaller Hs bias and found for "very good" annotated partitions compare to "poor" annotated partitions. This last comment is true for both WV1 and WV2.



	bias nb		rmse			
id2	S1Awv1wl	S1Awv2wl	S1Awv1wl	S1Awv2wl	S1Awv1wl	S1Awv2wl
qcvals2						
0_very_good	-2.202378	-3.096606	114514.0	88104.0	34.404289	36.631081
1_good	3.126559	1.589831	103172.0	106946.0	41.224602	45.213287
2_medium	5.653741	1.868871	81243.0	126548.0	54.934223	54.225422
3_low	8.638009	0.972161	72815.0	148838.0	71.908035	70.723068
4_poor	105.417671	41.854733	116610.0	129045.0	159.810486	141.938339

Table 27: Peak wavelength performances (w.r.t.) WW3 model in meter for S-1 WV swell partitions depending on the swell partition quality flag

The wavelength mean bias are within a range of -3 m to 105 m. As expected, "good" swell partitions have better bias and RMSE than "poor" ones. Also, the mean bias and RMSE on wavelength are better for WV2 compared to WV1, except for "very good" partitions.

		bias		bias nb		rmse
id2	S1Awv1wdir	S1Awv2wdir	S1Awv1wdir	S1Awv2wdir	S1Awv1wdir	S1Awv2wdir
qcvals2						
0_very_good	7.831863	8.298994	114514.0	88105.0	7.425342	8.397818
1_good	10.628776	11.833857	103172.0	106946.0	11.231987	12.924582
2_medium	14.736667	15.442969	81243.0	126548.0	15.693406	15.460012
3_low	21.039999	23.275165	72815.0	148838.0	21.492902	21.621614
4_poor	38.665930	36.244622	116631.0	129065.0	33.193524	28.990964

Table 28: Dominant wave direction performances (w.r.t.) WW3 model in degree for S-1 WV swellpartitions depending on the swell partition quality flag

The dominant wave direction mean bias are within a range of 7° to 38°. As expected RMSE are higher for "poor" Quality Fag partitions compare to "good" partitions. RMSE for "very good" partitions is about 7° which is quite small knowing that the SAR imaging mechanism distorts energy distribution when cutoff effect is present. The fact that quality flag is cutoff dependent explain the high difference between "very good" and "poor" partitions performances on the wave direction retrieval.

6.1.2 Other modes

The wave inversion is currently also activated on Strip-Map (SM) acquisitions but the limited number of acquisitions and the coastal areas where they are acquired make the monitoring of performances on annual basis not relevant enough to be discussed in this report. Activation of wave inversion on Interferometric Wide Swath (IW) and Extra Wide Swath (EW) is an on-going topic of investigation for the Expert Support Laboratories of the Mission Performances Centre.

6.2 Radial Velocity Measurement

In this section, a status on the Level 2 OCN RVL products is provided for Wave mode and TOPS modes. The main events this year that impacted the RVL products are:



- the processing with and without the ERRMAT.: ERMATT is not used in production since the 06th April 2022. The use of ERRMAT shall only impact the rvldcMiss (Estimated Doppler Centroid from the antenna miss-pointing) variable of the OCN RVL product.
- rvlNRCS rescalling with IPF3.5.1, aiming to align this estimate with *owiNrcsNeszCorr* [AD-04AD-04]
- rvl Geolocation grid refinement with IPF 3.5.1: this change is a refinement of the orbit interpolator for RVL process, it is not expected to change significantly the RVL grid.

6.2.1 Wave Mode

The Sentinel-1 Level 2 Doppler centroid anomaly (DCA) and radial velocity (RVL) measurements are currently coloured by the Doppler frequency derived from AOCS. The attitude Doppler centroid (DC) frequency computed from the downlinked quaternions is around zero, and do not reflect the actual attitude DC frequency. This prevents the current version of the Level 2 processor to provide calibrated DCA and RVL estimates. The analysis of restituted attitude data and Gyro data shows DC variations of around 10Hz long the orbit. The use of these data sources is currently not part of the Level 2 processor. However, promising results are achieved off-line using the calibrated Gyro information provided by ESTEC [S1-RD-13], and a post-processing approach has been implemented and validated as part of the "Copernicus Sentinel-1 RVL Assessment" project.

The S-1A WV OCN RVL show nominal performance. The typical behaviour of the nominal daily mean WV OCN RVL Doppler (rvlDcObs) for one month is shown in the upper plot of Figure 66, here for November 2022. However, jumps (of around 20 Hz) in Doppler are sometimes observed, which can attributed to change in star-tracker configuration. This is shown in the lower plot of Figure 66, where we plot the mean S-1A WV OCN RVL Doppler (rvlDcObs) as function of day in month for December 2022. In the period when this happens the Doppler becomes noisier, which can be observed as a degradation of the correlation between Doppler and ECMWF range wind speed. This is shown by the difference between the scatterplots of Figure 67.

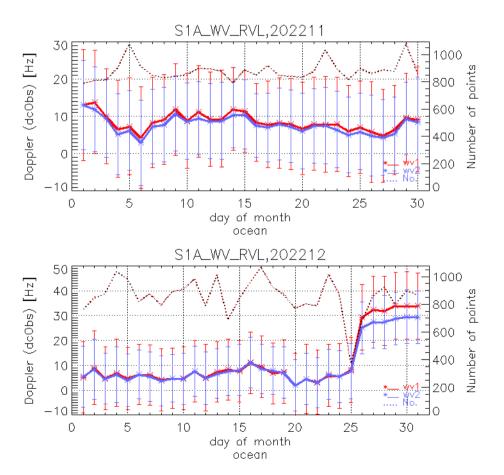


Figure 66: Daily mean S-1A WV OCN Doppler frequency (rvlDcObs) for November 2022 (upper) and December 2022 (lower). Note the jump in Doppler between 25 and 26 December.

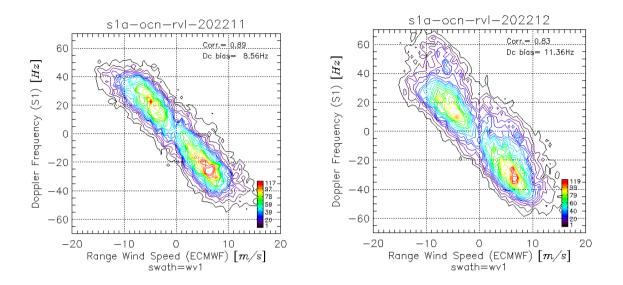


Figure 67: Scatterplot of of S-1A WV1 OCN RVL Doppler frequency (rvlDcObs) versus ECMWF range wind speed acquired over global ocean areas. Left: (November 2022), Right: (December 2022)

Time evolution: stable performance except for short periods related to change of star-tracker configuration.

Inter comparison: close performances between WV1 and WV2 Doppler.

Performances with respect to specifications: not applicable since absolute calibration of the DC is not feasible at present.

Discussion about the performances: the main problem is the fast attitude variations along orbit not predictable from the downlinked quaternions.

6.2.2 TOPS Mode

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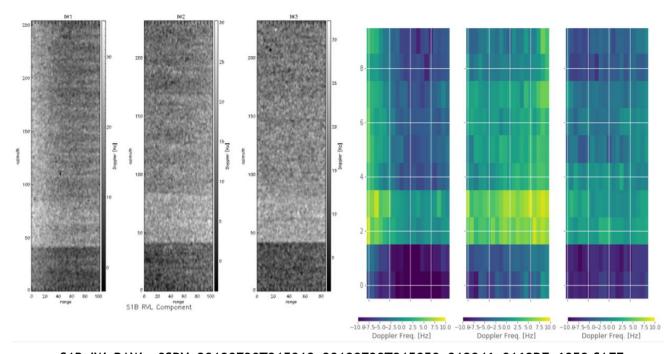
Time evolution: No specific degradation or improvements **Inter comparison:** Not applicable.

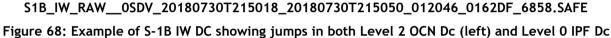
Performances with respect to specifications: not applicable since absolute calibration of the DC is not feasible at present.

Discussion about the performances: the relative DC bias due to electronic miss pointing, and the fast attitude variations along orbit are not predictable from the antenna model and downlinked quaternions, respectively.

The DC jumps (>10Hz) observed previously in the Sentinel-1 DC measurement are still present. These sudden jumps in DC (>10Hz) from one burst to another persist over all swaths Figure 68. These jumps are observed consistently in both Level 2 DC and raw data DC. Investigations show that the jumps come from temperature compensation which subsequently alters the antenna characteristics. There is at present no means to predict when and where this occurs. A data driven approach is under consideration.







. (right).

Another kind of DC jump was observed from one burst to another. These jumps come from the L0 to SL2 IPF processing which may alter the Doppler spectrum of SL2 products depending on L0 DC estimates. The SL2 products are then used as input for the L2 Doppler estimation. The modification of L0 to SL2 processing is under consideration. Unlike temperature compensation jumps, these jumps do not necessarily occur over all swaths as shown by Figure 69.

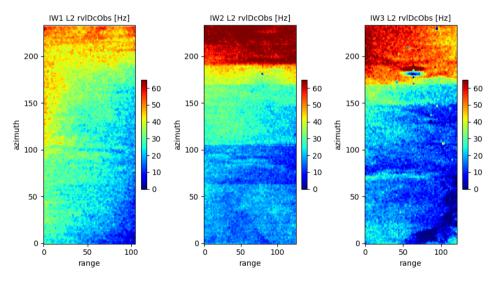


Figure 69: Another example of IW DC jumps (S1A_IW_OCN__2SDV_20191023T171202_20191023T171227_029589_035E66_FF1F.SAFE)



6.3 Quality Disclaimers

S-1A Quality disclaimers issued on L2 products during 2022 are given in Appendix C -.



Appendix A - S-1A & S-1B Technical Reports

Beyond this report, the following S-1A & S-1B Technical Reports can be of interest for the Sentinel-1 product users. Otherwise explicitly stated, this documentation is available on:

Sentinel Online Library

https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar/document-library

Sentinel-1 Level 0 Product Format Specification

This document, starting from SAFE documentation aims to provide the Level 0 format specifications for Sentinel-1 mission.

Sentinel-1 Level 0 Data Decoding Package

The purpose of this note is to gather in one place all the documentation necessary to decode Sentinel-1 Level-0 products. In addition to the documentation, it provides a sample of Level-0 product with the associated RAW decoded data in order to support the users.

Sentinel-1 Product Specification

This document provides the format specification of Sentinel-1 Level 1 and Level 2 products.

The format specification can change from one version of the SAR processor to another. In that case, the production specification is made available in advance to the end -users.

Sentinel-1 IPF Auxiliary Product Specification

This document describes the auxiliary data required by the Sentinel-1 Instrument Processing Facility (IPF) to perform L1 and L2 processing. It defines the content and format of auxiliary data files and provides references for the governing documentation. The corresponding parameters corresponds inter alia to the parameters considered by the SAR processor. As a complement, the full set of IPF ADF (for AUX_INS, AUX_CAL, AUX_PP1, AUX_PP2, AUX_SCS) is available here: <u>https://sar-mpc.eu/</u>

Sentinel-1 Level 1 Detailed Algorithm Definition

This document describes the processing algorithms employed by the Sentinel-1 Image Processing Facility (IPF) for the generation of Sentinel-1 Level 1 products. The algorithms apply to the processing of Sentinel-1 acquisition modes: Stripmap, Interferometric Wide-swath, Extra-wide-swath and Wave.

Sentinel-1 Burst ID Map

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Sentinel-1 performs systematic acquisition of bursts in both IW and EW modes. The bursts overlap almost perfectly between different passes and are always located at the same place. With the deployment of the SAR processor S1-IPF 3.4, a new element has been added to the products annotations: the Burst ID, which should help the end user to identify a burst area of interest and facilitate searches. Now, we publish complementary auxiliary products, the Burst ID maps allowing to index the bursts. The burst ID Map is available here: https://sar-mpc.eu/test-data-sets/

Sentinel-1 Level 2 Ocean Processor Main Algorithm Definition



The Level 2 Ocean Processor (OCN) is in charge to generate the Level 2 products constituted of three components related to Ocean Wind Field (OWI), Ocean Swell (OSW), and Ocean Radial Velocity (RVL). Each of those three components have a dedicated ATBD document (see below). However, they share few algorithms that are described in this Main ATBD.

Sentinel-1 Ocean Wind Fields (OWI) Algorithm Definition

The objective of this document is to define and describe the algorithm implemented in the S-1 L2 IPF and the processing steps for the generation of the Ocean Wind Field (OWI) component of the Sentinel-1 Level 2 Ocean (OCN) product.

Sentinel-1 Ocean Swell Wave Spectra (OSW) Algorithm Definition

This document describes and defines the prototype software for the generation of the Sentinel-1 Ocean Swell Spectra (OSW) component of the OCN product. The main objective of the document is to provide a clear definition and description of the algorithm and processing system that are consistent with the S-1 L2 processor.

Guide to Sentinel-1 Geocoding

This document describes methodologies to geocode S-1 images that present themselves in a single 2-D raster radar geometry (slant or ground range). It has been written for ESA to provide a reference for users wishing to know the details of Range-Doppler geocoding, and potentially also developers working on software to geocode S-1 SAR products.

Sentinel-1 long duration mutual interference

This technical note describes the long duration mutual interference that has occurred between Sentinel-1 and the Canadian RADARSAT-2 satellite, the Chinese Gaofen 3 satellite and an unknown satellite which operate at the same frequency as Sentinel-1. The mutual interferences are observed on specific locations and times of the orbits and only when both instruments are transmitting simultaneously.

Masking "No-value" pixels on GRD products generated by the Sentinel-1 ESA IPF

This technical note describes an approach for masking the "no-pixel" values for GRD products generated by the Sentinel-1 ESA IPF.

Release Note of S-1 IPF for End Users of Sentinel-1 products

This document was initially published on Sentinel online but was unpublished as deprecated. It initially contained the list of main changes of processing baseline (version of processor and auxiliary configuration). The same information can now be found on the Sentinel-1 QC Web Server here: https://sar-mpc.eu/ipf/

Thermal denoising of products generated by the Sentinel-1 IPF

This technical note describes the approach for removing the thermal noise contribution (aka product denoising step).

Sentinel-1 RadarSat-2 mutual interference

This technical note describes the mutual interference that can occur between Sentinel-1 and the Canadian Radarsat-2 satellite which operates at the same frequency as Sentinel-1. The mutual



interferences are observed on specific locations and times of the orbits and only when both instruments are transmitting simultaneously.

This document provides description of (1) the respective orbits of Sentinel-1 and Radardat-2 is described in Section 2, and (2) examples of the mutual interference given in Section 3. A list of mutual interferences found at the Mission Performance Centre (MPC) Coordination Centre are given in Appendices of the document.

Definition of the TOPS SLC deramping function for products generated by the Sentinel-1 IPF

This document defines the procedure for performing the deramping of Sentinel-1 TOPS IWS and EWS of Level-1 SLC products generated by the Sentinel-1 IPF.

Report on the debris impact on S-1A solar panel on 23rd August 2016

The present technical note discusses the debris collision that occurred on 23rd August 2016 whereby the Sentinel1-A solar panel was struck by a small mm sized particle. The implications for products are given in the report.

Sentinel-1A Antenna Failure - Anomaly Characterization Report

This technical note discusses the impact of the Sentinel-1A tile 11 issue that occurred during June 2016.

Sentinel-1 IPF: Impact of the Elevation Antenna Pattern Phase Compensation on the Interferometric Phase Preservation

The Elevation Antenna Patterns (EAPs) used by the S-1 Instrument Processing Facility (IPF) are derived from the S-1 Antenna Model (AM) which is able to predict with great accuracy the gain and phase patterns.

The EAP correction by the S-1 IPF was at launch only considering the gain, similarly to what was done for ASAR. As an outcome of the S-1A Commissioning Phase, it has been decided to upgrade the S-1 IPF to also compensate for the EAP phase, in order to correct for the induced phase difference between the polarimetric channels.

This correction was introduced in March 2015 with the IPF V243. Performing interferograms between products generated with the IPFV243 and the former version V236 leads to interferometric phase variation in range.

This technical note explains the nature of the phase offset and provides recommendation towards its correction.

Sentinel-1 Radiometric Calibration of Products

This document defines the procedure to radiometrically calibrate Sentinel-1 Level 1 products generated by the Sentinel-1 IPF.

Sentinel-1: Using the RFI annotations

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The purpose of this document is to guide the Sentinel-1 product users on how to use the Radio Frequency Annotations (RFI) introduced by the IPF (SAR processor) v3.4.0.

The document explains the different set of annotations that may be available depending on the processor versions and their actual configuration.

It complements the Sentinel-1 product specification (describing the product format) and the Sentinel-1 Detailed algorithm definition (describing the RFI mitigation process).



S-1A & S-1B Annual Performance Reports

Those documents provide information on the S-1 L1 and L2 product performance on a yearly period. These reports replace the N-Cyclic Reports covering the same period.

S-1A N-Cyclic Reports

Those documents provide information on the S-1 L1 performance on a 4-cycle period of time, for the current year. These reports are replaced by the Annual performance report covering the same period at the end of the year.



Appendix B - S-1A Instrument Unavailability

Start Date/Time	End Date/Time	MPC Reference	Summary
10/02/22 11:25	10/02/22 14:38	SOB-3691	Sentinel-1A Unavailability on 10/02/2022
22/02/22 04:54	22/02/22 14:37	SOB-3726	Sentinel-1A Unavailability on 22/02/2022
01/03/22 19:07	02/03/22 12:01	SOB-3727	Sentinel-1A Unavailability on 01/03/20022 and 02/03/2022
13/04/22 20:52	14/04/22 08:34	SOB-3809	Sentinel-1A Unavailability on 13/04/2022 and 14/04/2022
25/04/22 06:17	25/04/22 09:35	SOB-3810	Sentinel-1A Unavailability on 25/04/2022
12/05/22 14:26	12/05/22 21:12	SOB-3950	Sentinel-1A Unavailability on 12/05/2022
23/05/22 16:21	24/05/22 08:02	SOB-3951	Sentinel-1A Unavailability on 23/05/2022 and 24/05/2022
09/07/22 18:26	10/07/22 12:15	SOB-3952	Sentinel-1A Unavailability on 09/07/2022 and 10/07/2022
23/08/22 23:20	24/08/22 08:33	SOB-4005	Sentinel-1A Unavailability on 23/08/2022 and 24/08/2022
08/09/22 23:01	09/09/22 08:02	SOB-4015	Sentinel-1A Unavailability on 08/09/2022 and 09/09/2022
26/12/22 11:24	26/12/22 14:31	SOB-3183	Sentinel-1A Unavailability on 26/12/2022

The S-1A instrument was unavailable during 2022:



Appendix C - S-1A & S-1B Quality Disclaimers

The following S-1A & S-1B quality disclaimers were issued during 2022 and/or refer to products acquired/generated in 2022:

Num	Sensor	Description	Start Validity Date	End Validity Date	lssue Status
<u>#70</u>	S1A	S-1A products generated with inconsistent processing configuration following the IPF3.40 deployment	2021-11-03 03:43:32	2021-11-03 10:33:59	
<u>#71</u>	S1B	S-1B products generated with inconsistent processing configuration following the IPF3.40 deployment	2021-11-03 04:32:08	2021-11-03 07:12:35	
<u>#72</u>	S1A	For some IW products, a far range part of IW3 sub swath is missing	2014-10-14 09:10:48	2015-06-26 07:54:00	
<u>#73</u>	S1A	S-1A Products processed without using orbit file	2021-03-25 00:00:00	2021-12-14 03:51:31	
<u>#74</u>	S1B	S-1B Products processed without using orbit file	2021-03-25 00:00:00	2021-12-14 01:00:25	
# <u>75</u>	S1A	S-1A Level 2 OCN products not containing the OWI (gridded wind field) and OSW (Swell) information	2021-12-12 23:57:58	2021-12-14 11:12:43	
<u>#76</u>	S1B	S-1B Level 2 OCN products not containing the OWI (gridded wind field) and OSW (Swell) information	2021-12-12 23:15:29	2021-12-14 11:57:20	
<u>#77</u>	S1A	Invalid Burst ID for some S-1A products	2021-11-02 23:07:50	2030-01-01 00:00:00	
<u>#78</u>	S1B	Invalid Burst ID for some S-1B products	2021-11-02 23:42:03	2030-01-01 00:00:00	
<u>#79</u>	S1A	Invalid annotation of acquisition anxTime for some S1-A RAW products	2014-09-30 15:17:26	2030-01-01 00:00:00	
<u>#80</u>	S1B	Invalid annotation of acquisition anxTime for some S1-B RAW products	2016-10-13 15:36:00	2030-01-01 00:00:00	
<u>#81</u>	S1A	S-1A OCN products with invalid xsd files	2022-03-23 07:50:46	2030-01-01 00:00:00	



<u>#82</u>	S1A	S-1A Products generated without POD orbit file	2022-02-22 14:47:17	2022-02-25 13:16:37
<u>#83</u>	S1A	S-1A Products generated without POD orbit file	2022-03-02 12:11:35	2022-03-06 23:57:54
<u>#84</u>	S1A	S-1A products processed without using POD orbit file	2021-07-29 23:11:10	2021-08-08 17:03:56
<u>#85</u>	S1B	S-1B products processed without using POD orbit file	2021-07-30 00:11:39	2021-08-11 22:48:55
<u>#86</u>	S1A	Sentinel-1A swell inversion (OCN/OSW processing) performed using invalid a priori wind speed and direction	2022-04-08 00:00:00	2030-01-01 00:00:00
<u>#87</u>	S1A	Auxiliary product information not properly projected on the SAR image	2022-03-23 07:50:46	2030-01-01 00:00:00
<u>#88</u>	S1A	The Sentinel-1A StripMap OCN products are not operationally qualified	2014-10-04 02:43:30	2030-01-01 00:00:00
<u>#89</u>	S1B	The Sentinel-1B StripMap OCN products are not operationally qualified	2016-09-29 22:26:06	2030-01-01 00:00:00
<u>#90</u>	S1A	S-1A Range shifts of denoising vectors for GRDM, GRDH and OCN products	2014-09-30 15:17:26	2022-03-23 10:25:10
<u>#91</u>	S1B	S-1B Range shifts of denoising vectors for GRDM, GRDH and OCN products	2016-09-26 00:02:34	2021-12-23 06:53:12
<u>#92</u>	S1A	S-1A: Invalid POD orbit files used during the processing	2022-05-11 21:46:04	2022-05-12 13:15:58
<u>#93</u>	S1A	S-1A: Invalid POD orbit files used during the processing	2022-05-16 14:18:30	2022-05-17 06:40:32
<u>#94</u>	S1A	Sentinel-1A OCN products crossing Greenwich meridian with no OWI information and issue on rvlNrcs	2022-04-08 04:56:57	2022-05-12 08:25:01
<u>#95</u>	S1A	S-1A products with invalid data due to downlink issue through EDRS-C	2022-01-19 21:59:30	2022-02-18 18:08:52
<u>#96</u>	S1A	Degraded geolocation accuracy due to degraded AUX_PREORB	2022-10-12 10:56:30	2022-10-16 07:10:09



<u>#97</u>	S1A	Degraded geolocation accuracy due to degraded AUX_RESORB	2022-10-09 19:40:25	2022-10-15 22:05:46
<u>#98</u>	S1A	Product degradations due to acquisition during Orbit Control on 2022-10-18	2022-10-18 10:53:03	2022-10-18 20:54:23
<u>#99</u>	S1A	S-1A Products with RFI degradation acquired between 2014-09-15 and 2022-03-31	2014-09-15 00:00:00	2022-04-01 00:00:00
<u>#100</u>	S1B	S-1B Products with RFI degradation acquired between 2016-09-26 and 2021-12-23	2016-09-26 00:00:00	2021-12-23 06:53:58
<u>#101</u>	S1A	Products with residual RFI degradation acquired in April 2022	2022-04-01 00:00:00	2022-05-01 00:00:00
<u>#102</u>	S1A	Products with residual RFI degradation acquired in May 2022	2022-05-01 00:00:00	2022-06-01 00:00:00
<u>#103</u>	S1A	Products with residual RFI degradation acquired in June 2022	2022-06-01 00:00:00	2022-07-01 00:00:00
<u>#104</u>	S1A	Products with residual RFI degradation acquired in July 2022	2022-07-01 00:00:00	2022-08-01 00:00:00
<u>#105</u>	S1A	Products with residual RFI degradation acquired in August 2022	2022-08-01 00:00:00	2022-09-01 00:00:00
<u>#106</u>	S1A	Products with residual RFI degradation acquired in September 2022	2022-09-01 00:00:00	2022-10-01 00:00:00
<u>#107</u>	S1A	Products with residual RFI degradation acquired in October 2022	2022-10-01 00:00:00	2022-11-01 00:00:00
<u>#108</u>	S1A	Products with residual RFI degradation acquired in November 2022	2022-11-01 00:00:00	2022-12-01 00:00:00
<u>#109</u>	S1A	Products with residual RFI degradation acquired in December 2022	2022-12-01 00:00:00	2023-01-01 00:00:00

Appendix D - S-1A Orbit Cycles

The table below gives the S-1A cycle number with start and stop acquisition dates during 2021. The start of a cycle is at approximately 18:00 UT on the dates below.

Cycle	Start Date	End Date
250	27/12/2021	08/01/2022
251	08/01/2022	20/01/2022
252	20/01/2022	01/02/2022
253	01/02/2022	13/02/2022
254	13/02/2022	25/02/2022
255	25/02/2022	09/03/2022
256	09/03/2022	21/03/2022
257	21/03/2022	02/04/2022
258	02/04/2022	14/04/2022
259	14/04/2022	26/04/2022
260	26/04/2022	08/05/2022
261	08/05/2022	20/05/2022
262	20/05/2022	01/06/2022
263	01/06/2022	13/06/2022
264	13/06/2022	25/06/2022
265	25/06/2022	07/07/2022
266	07/07/2022	19/07/2022
267	19/07/2022	31/07/2022
268	31/07/2022	12/08/2022
269	12/08/2022	24/08/2022
270	24/08/2022	05/09/2022
271	05/09/2022	17/09/2022
272	17/09/2022	29/09/2022
273	29/09/2022	11/10/2022
274	11/10/2022	23/10/2022
275	23/10/2022	04/11/2022
276	04/11/2022	16/11/2022
277	16/11/2022	28/11/2022
278	28/11/2022	10/12/2022
279	10/12/2022	22/12/2022
280	22/12/2022	03/01/2023

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Appendix E - S-1A Transmit Receive Module Failures

There were no S-1A antenna Transmit/Receive Modules (TRMs) failures during 2022.

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Appendix F - S-1A & S-1B Auxiliary Data Files

The following S-1A Auxiliary Data Files (ADFs) were updated during 2022:

S-1A Instrument ADF (AUX_INS)

ADF	Update Reason

S-1A Calibration ADF (AUX_CAL)

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ADF	Update Reason

S-1A L1 Processor Parameters ADF (AUX_PP1)

ADF	Update Reason
<u>S1A_AUX_PP1_V20190228T092500_G20220323T153041.SAFE</u>	Circulation of S1A_AUX_PP1: 1)allowing the activation of RFI mitigation. - flag rfiMitigationPerformed triggering the activation of RFI mitigation processing, is set to BasedOnNoiseMeas for all S1A TOPS products (IW/EW Level1
	 and Level2 products), so that the RFI mitigation is applied if RFI detection from noise measurements flag rfiMitigationDomain triggerring the method for RFI mitigation is set to TimeandFrequency 2) reviewing the processing gains of SL2/GR2 EW/IW for HH channel, in order to aligned S-1A wind speed performance to S-1B for OCN products
	Relative to RDB#7
S1A_AUX_PP1_V20171017T080000_G20220323T144732.SAFE	As above but related to RDB#6.
<u>S1A_AUX_PP1_V20150722T120000_G20220323T144038.SAFE</u>	As above but related to RDB#5.



S1A_AUX_PP1_V20150519T120000_G20220323T143127.SAFE	As above but related to RDB#4.
<u>S1A_AUX_PP1_V20140908T000000_G20220323T142628.SAFE</u>	As above but related to RDB#3.
<u>S1A_AUX_PP1_V20140616T133500_G20220323T142238.SAFE</u>	As above but Related to RDB#2.
S1A_AUX_PP1_V20140406T133000_G20220323T141316.SAFE	As above but Related to RDB#1.

S-1A L2 Processor Parameters ADF (AUX_PP2)

ADF	Update Reason	
S1A_AUX_PP2_V20190228T092500_G20220607T093912.SAFE	Circulation of S1A_AUX_PP2 allowing the activation of TotalHs estimate	ion
	- Flag activateTotalHs triggering the activation of TotalHs estimation b machine learning method is set to true for WV mode, for both subswat WV2. Consequently, oswTotalHs and oswTotalHsStdev will be populate products.	h WV1 and
	The change affects only WV mode.	
	Relative to	RDB#7
<u>S1A_AUX_PP2_V20171017T080000_G20220607T093818.SAFE</u>	As above and compliant with RDB#6	
S1A_AUX_PP2_V20150722T120000_G20220607T093737.SAFE	As above and compliant with RDB#5	
<u>S1A_AUX_PP2_V20150519T120000_G20220607T093644.SAFE</u>	As above and compliant with RDB#4	
<u>S1A_AUX_PP2_V20140908T000000_G20220607T093557.SAFE</u>	As above and compliant with RDB#3	
S1A_AUX_PP2_V20140616T133500_G20220607T093510.SAFE	As above and compliant with RDB#2	
<u>S1A_AUX_PP2_V20140406T133000_G20220607T093358.SAFE</u>	As above and compliant with RDB#1	

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S-1A Simulated Cross Spectra ADF (AUX_SCS)

ADF	Update Reason

The following S-1B Auxiliary Data Files (ADFs) were updated during 2022:

S-1B Instrument ADF (AUX_INS)

ADF	Update Reason

S-1B Calibration ADF (AUX_CAL)

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ADF	Update Reason

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S-1B L1 Processor Parameters ADF (AUX_PP1)

ADF	Update Reason
<u>S1B_AUX_PP1_V20190514T090000_G20220323T152934</u> .SAFE	Circulation of S1B_AUX_PP1: allowing the activation of RFI mitigation. - flag rfiMitigationPerformed triggering the activation of RFI mitigation processing, is set to BasedOnNoiseMeas for all S1A TOPS products (IW/EW Level1 and Level2 products), so that the RFI mitigation is applied if RFI detection from noise measurements - flag rfiMitigationDomain triggerring the method for RFI mitigation is set to TimeandFrequency
<u>S1B_AUX_PP1_V20160422T000000_G20220323T140710</u> .SAFE	Same reason as above and compliant to RDB#1

S-1B L2 Processor Parameters ADF (AUX_PP2)

ADF	Update Reason
S1B AUX PP2 V20190514T090000 G20220607T093222.SAFE	Circulation of S1B_AUX_PP2 allowing the activation of TotalHs estimation
	- Flag activateTotalHs triggering the activation of TotalHs estimation based on machine learning method is set to true for WV mode, for both subswath WV1 and WV2. Consequently, oswTotalHs and oswTotalHsStdev will be populated for WV OCN products.

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	The change affects only WV mode.
S1B AUX PP2 V20160422T000000 G20220607T093106.SAFE	As above and compliant with RDB#1

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S-1B Simulated Cross Spectra ADF (AUX_SCS)

ADF	Update Reason	

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