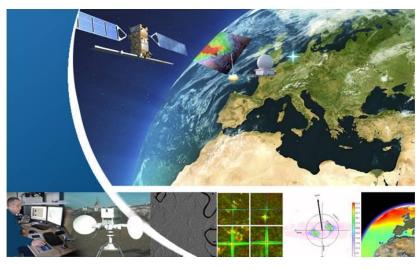




# S-1A & S-1B Annual Performance Report for 2020



Reference: MPC-0504 Nomenclature: DI-MPC-APR Issue 1.1 – 16/03/2021





Project funded under the European Union's Copernicus Program.

Copernicus, previously known as GMES (Global Monitoring for Environment and Security), is the European Programme for the establishment of a European capacity for Earth Observation.

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### CHRONOLOGY ISSUES/HISTORIQUE DES VERSIONS

Issue/ Version	Date	Object/Objet	Written Rédigé par	by/
1.0	08.feb.21	First Version	MPC	
1.1	16 Mar.21	<ul> <li>Executive Summary: <ul> <li>Add links to figure</li> <li>Add quantitative results of beamto-beam offset after EAP optimisation</li> </ul> </li> <li>Section 3: <ul> <li>Update the link to the QC Web Server due to migration of the server since first version of the document</li> <li>Section 5.1.7: <ul> <li>Figure links corrected</li> <li>Clarified that EAP and processing gain have been updated for S1B</li> <li>Typos corrected within the text for derived PT standard deviations</li> </ul> </li> <li>Section 5.1.8: <ul> <li>Simplify wording</li> </ul> </li> <li>Section 5.2: <ul> <li>Added clarification on antenna failure impact on results</li> <li>Range and azimuth ALE tables updated to include also swath-by-swath statistics</li> </ul> </li> <li>Appendix: <ul> <li>Update the link to the QC Web Server</li> </ul> </li> </ul></li></ul>	MPC	
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### DISTRIBUTION/LISTE DE DIFFUSION

Company/Organisme Means of distribution/ Format de diffusion		Names/Destinataires	
CLS	Notification	G. Hajduch	
ESA	Notification	N. Miranda	



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# 1.Introduction

### 1.1 Purpose of this document

The purpose of this document is to provide the status on the S-1A & S-1B instruments and products performance during 2020.

# 1.2 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 & S-1B Instrument Unavailability

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

Appendix D - S-1A & S-1B Orbit Cycles

Appendix E - S-1A & S-1B Transmit Receive Module Failures

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

# **1.3** Applicable and Reference Documents

### 1.3.1 Applicable Documents

- [AD-01] Sentinel-1 Product Specification, S1 RS-MDA-52-7441, Issue 3/7, February 2020
- [AD-02] Contract Change Notice N.2, Changes in ESRIN Contract No. 21722/08/I\_LG, June 21, 2010
- [AD-03] Sentinel-1 Level 1 Detailed Algorithm Definition, SEN-TN-52-7445, Issue 2/2, June 2019
- [AD-04] Sentinel-1 IPF Auxiliary Product Specification, S1-RS-MDA-52-7443, Issue 3/5, January 2020
- [AD-05] Sentinel-1 Doppler and Ocean Radial Velocity (RVL) ATBD, ISSN 1890-5226, Issue 01, 09 May 2011



- [AD-06] Sentinel-1 Ocean Wind Fields (OWI) ATBD, S1-TN-CLS-52-9049, Issue 02, 27 June 2019
- [AD-07] Sentinel-1 Ocean Swell Wave Spectra (OSW) ATBD, S1-TN-NRT-52-7450, Issue 01, 27 April 2011.
- [AD-08] Annual Performance Report 2019, DI-MPC-APR-0460, Issue 1.1, April 2020

### 1.3.2 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 multi-technique 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.

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 -

# 1.4 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	
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	
QCSS	Quality Control SubSystem	
(N)RCS	(Normalised) Radar Cross Section	
RD	Reference Document	
RDB	Radar DataBase	
RFC	Radio Frequency Characterization mode	
RFI	Radio Frequency Interference	
RVL	Radial Velocity (component of OCN products)	
SAR	Synthetic Aperture Radar	
STT	STar Tracker	
ТВС	To be confirmed	
TBD	To be defined	
TRM	Transmit Receive Module	



# 2. Executive Summary

This report gives the status of the S-1A & S-1B instruments and product performance during 2020.

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 29<sup>th</sup> January 2020: the IPF was update for v3.2.0. The most relevant changes in this version is the update of the geolocation grid information without any change on the image focusing and timing. This introduces varying altitude for each ground control point (GCP) and, for SLC product only, this corrects the lat/lon/height triplets for the GCP for consistency with the range/azimuth timing.
- On 12nd May 2020: The S-1A WV (VV) calibration has been updated to adapt to the new geophysical calibration methodology based on denoised NRCS compared to CMOD5n Geophysical Model Function. This modification applies for products acquired with all S-1A radar configurations (RDB#1 to RDB#7) and processed since then.
- On 12nd May 2020: The S-1B IW (VV/VH) calibration has been refined with the update of elevation antenna patterns estimated from the Rain Forest gamma profiles (circulation of S1B\_AUX\_CAL), jointly with a review of the processing gains (S1B\_AUX\_PP1). This modification applies for products acquired with the radar configuration RDB#1 and RDB#2 processed since then.
- On 23<sup>rd</sup> June 2020: the IPF was updated for v3.3.0. The most relevant changes in this version are related to the Level 2 OCN products:
  - the activation of the OWI and RVL processing modules enabling to populate gridded wind and radial velocity information in the WV OCN products. Jointly to this IPF deployment, new versions of S1A\_AUX\_PP2 were circulated to put in place the corresponding configuration.
  - The change of AUX\_SCS format and content performed to remove the several ad-hoc tunings applied to the initial Modulation Transfer Function (MTF) and to also propose a better compensation of the ocean wave spectral energy with respect to the ocean surface wind speed.
  - Introduction of an Doppler descalloping post-processing for TOPS.
  - The usage of the CMOD5n GMF in OSW processing.

The changes are applicable to all products acquired with all S-1A radar configuration (RDB#1 to RDB#7) and all S-1B radar configurations (RDB#1 to RBD#2) and processed since then.

- On 30rd June 2020: the IPF was updated for v3.3.1 to improve its robustness for specific production scenario (NRT Slicing Mode) without any change in the focusing algorithm and on the Level 2 processing.
- On 15<sup>th</sup> December 2020: The S-1A EW (HH/HV) calibration has been refined with the update of elevation antenna patterns estimated from the Rain Forest gamma profiles (circulation of S1A\_AUX\_CAL), jointly with a review of the processing gains (S1A\_AUX\_PP1). This modification applies for products acquired with the radar configuration RDB #6 and RDB #7 and processed since then.
- On 15<sup>th</sup> December 2020: The S-1B IW (VV/VH), EW (HH/HV) and EW (VV/VH) calibration has been refined with the update of elevation antenna patterns estimated from the Rain Forest gamma profiles (circulation of S1B\_AUX\_CAL), jointly with a review of the processing gains (S1B\_AUX\_PP1). This modification applies for products acquired with the radar configuration RDB #1 and RDB #2 and processed since then.



#### Instrument Status

- The analysis of RFC and Internal Calibration products shows that S-1A and S-1B instruments are stable. No major instrument events have been recorded during 2020.
- The analysis of Noise products shows that the instrument noise level is stable. The new TopSAR Noise products including rank echoes (introduced in 2018) are exploited to derive RFI contamination probability maps.
- S-1 interferometric performances in terms of interferometric baseline, burst synchronization and instrument pointing are better than the mission requirements.
- S-1A DC is showing increased jumps when the STT configuration changes. The issue will be monitored during 2021 and, if needed, a new STT alignment campaign will be performed.

#### Level 1 Product Status

- The various image quality parameters such as spatial resolution, sidelobe parameters, equivalent number of looks and ambiguity ratios derived using DLR transponders & corner reflectors and the Australian corner reflector array all give nominal results.
- The radiometric performance of S-1A and S-1B has been monitored and the radiometric accuracy has been determined for IW mode DV polarization using point targets of the DLR calibration site. During 2020, the overall mean and standard deviation for the absolute calibration factor has been derived to be -0.10 dB  $\pm$  0.21 dB for S-1A and -0.04 dB  $\pm$ 0.24 dB for S-1B which includes the observation of both polarizations (VV and VH) and all three sub-swathes (IW1, IW2, and IW3). The slightly higher variation of S-1B results is due to the EAP update in May 2020. Including all error contributions, an absolute radiometric accuracy for the IW mode of 0.302 dB (1 $\sigma$ ) for S-1A and 0.325 dB (1 $\sigma$ ) for S-1B could be verified which fulfills the requirement of 1 dB (3 $\sigma$ ) for both SAR instruments.
- 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 0.18 dB for S-1A and 0.20 dB for S-1B (refer to Figure 30). The phases are also well balanced with remaining biases below 2 degree for both SAR instruments. The co-registration of the IRF peaks for both polarizations show derivations below 0.1 m in average for both instruments. The derived cross-talk values from DLR corner reflector measurements are in average -44.4 dB for S-1A and -47.8 dB for S-1B which confirms the very good quality concerning the separation of the co-and cross polarization channels of both SAR instruments.
- Geolocation tests using well-surveyed corner reflectors indicated that given bias compensations, the absolute localisation accuracy was well within the original requirements. No further significant changes to the geolocation estimation methodology were made in 2020, though further automation was added to the geolocation processing and ALE estimation. S-1A and S-1B ALE scatterplots are shown separately here, to account for a relative azimuth bias introduced by the June 2016 S-1A antenna tile 11 loss.

The current best ALE estimates for S-1A/-B, using SLC products over the Australian *Surat Basin* calibration site, are specified in range and azimuth:

0	S-1A:	Range:	-0.120 ± 0.066 m
		Azimuth:	-0.240 ± 0.526 m
0	S-1B:	Range:	+0.013 ± 0.059 m
		Azimuth:	+0.190 ± 0.290 m

- The ALE estimates for IW mode indicate a localisation performance well within the requirements. The ALE is within the specified 1-sigma of 3.33m, i.e. 10m at 3 sigma (section 5.5.2.2 of [S1-RD-07].
- There were multiple updates to the S-1A and S-1B elevation antenna patterns (EAPs) during 2020. The S-1B EW DV EAP was updated on 12 May 2020. The S1B EW DV was updated on 15 December 2020 together with the EW DH EAP for both S-1A and S-1B. Those updates were aimed at reducing



sub-swath jumps and flattening the gamma profiles within each sub-swath. The maximal beam to beam offset is now below 0.1 dB for S1A EW VV/VH and S1B EW HH/HV, and below 0.2 dB for S1A EW HH and HV, An additional update of EAP for IW DH for both S-1A and S-1B was put in place on 4<sup>th</sup> January 2021 for the same reason.

• A few examples of interference occurred during 2020 from (i) sources on the ground (ii) an 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 measurements: Compared with the numerous changes operated in 2019, marginal improvements have been brought to the performances of OWI wind products. Mean biases with ECMWF forecast winds range between -0.04 and 0.11 m/s for S1A and -0.20 and -0.31 m/s for S1B (minus sign meaning underestimation of SAR compared to model), and RMSEs (Root Mean Square Errors) around 1.50 m/s with a 0.03 m/s deviation from subswath to subswath for both S1A and S1B. With IPF 3.30 this year, the main improvement is the activation of OWI processing on Wave Modes, which exhibit retrieval performances compliant with TOPS modes. Moreover, the wind measurement depends on the radiometric accuracy of the L1 product such that, EAP updates (S-1B IW VV in May 2020, and S-1B EW VV in December 2020) contribute to improve the wind retrieval quality within sub-swaths.
- Swell (WV) measurements: The OSW product is produced from WV and SM modes. However, for SM the number of acquisitions is too few to perform any geophysical validation. The S1 WV OSW wave spectra are systematically validated against global collocated WW3 spectra.

The main improvement of the OSW product from IP3.1.0 to IPF3.3.0 introduced in 2020, was an Update of OSW quality flag per wave spectra partition.

The OSW quality flag is used to assess the performance into five categories:" very good", "good", "medium", "low", and "poor". Considering all categories, the wavelength mean bias is within a range of 0m to 32m, the effective Hs mean bias is within a range of 0 cm to 48 cm, and the dominant wave direction mean bias is within a range of 7° to 26°.

The RMSE of the effective Hs is within the requirement (0.5m) for S-1A&B and WV1/WV2. Bias is outside the requirement (0.1m) for S-1A&B WV2. It is expected that with the new EAP for WV2 (to be uploaded in 2021), the performance of WV2 will improve.

• 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).

For some IW and EW products, sudden jumps in DC (<10Hz) from one burst to another that persist over all swaths are observed. The jumps are observed consistently in both Level 2 DC and raw data DC. Recent analysis allows correlating these jumps with the on-board temperature compensation scheme aligned with the imaging chops. However, there is so far no means to predict where and when these jumps occur. Investigations are undertaken to see whether a data driven method can be applied.

However, the IPF3.30, (installed in Ground Segment June 2020) provided some improvements of the TOPS RVL product: A de-scalloping of the IW and EW RVL product was introduced aiming at mitigating the azimuth scalloping (with burst period) observed in the Doppler. This reduced the scalloping in RVL variables from  $\pm$ 6Hz to below  $\pm$ 2 Hz.

For the WV RVL product a gridded product was introduced with IPF3.30, providing the RVL parameters on a grid of 13x13 pixels pr. Imagette. The mean DC acquired over land areas are for S1b wv1= 19.6Hz, S1b wv2 = 0.1Hz, S1a wv1 = 17.9Hz, S1a wv2 = 12.5 Hz. The differences in mean DC are mainly attributed to antenna electronics.



# **3.**Processing Updates

The main improvements introduced in the Level-1 and Level-2 Processor and impacting data quality are here below described, classified according to the release in which they have been included. The full description of IPF upgrade is available on the Release note for end users document link provided in Appendix A - . In addition, the description of the content of the different IPF versions are available on https://qc.sentinel1.copernicus.eu/

# 3.1 Processor

### IPF v3.3.1 (30/06/2020)

- The L1 changes were:
  - Fix failure in NRT Slicing mode on EW products when preamble and/or postamble are missing in LON products, then improving the robustness of the processor for production of NRT products for Copernicus Services.
- Level 2 content
  - No change compared to IPF 3.30

### IPF v3.3.0 (23/06/2020)

- The L1 changes were:
  - No change compared to IPF 3.20
- Level 2 content
  - RVL descalloping on TOPS modes
  - Cleaning of OSW processing removal of ad hoc tunning on swell retrieval. Review of RAR MTF.
  - Refinement of oswQualityFlag, coupled with the 2 new OSW variables relative to the spectrum variability (please ref to Product specification)
  - Activation of OWI on WV mode
  - $\circ \quad \text{Gridding of RVL on WV mode} \\$
  - Review of Cores allocation for WV processing
  - $\circ$   $\;$  Review of merger strategy for WV OCN NetCDF generation  $\;$
  - $\circ$  Change for Cmod5n in OSW
  - o Bug correction on Zhang Polarization Ratio implementation
  - Optimisation on OWI processing

### IPF v3.2.0 (29/01/2020)

- The L1 changes were:
  - Update of GeolocationGrid annotation without any change on image focusing and timing:
    - Introduce of varying altitude for each ground control point
    - For SLC products only: Correct lat/lon/hight triplets of the ground control points for consistency with slant-range/azimuth time
    - Handling of a new type of auxiliary orbit files:
      - AUX PREORB (predicted orbit having similar accuracy to the current RESORB)
- Level 2 content

0

No changes: strictly the same as previous IPF3.10



# 3.2 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 here below summarised:

### AUX\_INS

No update of AUX\_INS was required for S-1A and S-1B.

### AUX\_CAL

During 2020 the S-1A AUX\_CAL auxiliary files were updated once:

 15<sup>th</sup> December 2020 for Refinement of Elevation Antenna Patterns for EW DH for RDB#6 and RDB#7

During 2020 the S-1B AUX\_CAL auxiliary files were updated on two occasions:

- 12nd May 2020: Refinement of IW DV Elevation Antenna patterns for RDB#6 and RDB#7
- 15th December 2020: Refinement of EW DV and EW DH Elevation Antenna Patterns for RDB#1 and RDB#2

#### AUX\_PP1

During 2020 the S-1A AUX\_PP1 auxiliary files were updated on two occasions:

- 12nd May 2020: Review of the processing gains for WV: in order to adapt the new geophysical calibration methodology based on denoised NRCS vs Cmod5n for RDB#6 and RDB#7
- 15<sup>th</sup> December 2020: Refinement of S1A EW DH processing gains to accommodate refinement of Elevation Antenna patterns for RDB#6 and RDB#7

During 2020 the S-1B AUX\_PP1 auxiliary files were updated on two occasions:

- 12nd May 2020:
  - Review of the processing gains for WV: to adapt the new geophysical calibration methodology based on denoised NRCS vs Cmod5n for RDB#1 and RDB#2
  - Refinement of S1B IW DV processing gains to accommodate review of Elevation Antenna patterns for RDB#1 and RDB#2
- 15<sup>th</sup> December 2020: Refinement of S1B EW DV and DH processing gain to accommodate review of Elevation Antenna patterns.

### AUX\_PP2

During 2020 the S-1A AUX\_PP2 auxiliary files were updated once:

• 23<sup>rd</sup> June 2020: Update of AUX\_PP2 format supporting new parameters required by IPF 3.3.0 and enabling OWI (gridded wind) and RVL (gridded radial velocity) with the WV Level 2 products. This update applies to RDB#1 to RDB#7.

During 2020 the S-1B AUX\_PP2 auxiliary files were updated once:

• 23<sup>rd</sup> June 2020: Update of AUX\_PP2 format supporting new parameters required by IPF 3.3.0 and enabling OWI (gridded wind) and RVL (gridded radial velocity) with the WV Level 2 products. This update applies to RDB#1 to RDB#2.



### AUX\_SCS

During 2020 S-1A & S-1B AUX\_SCS auxiliary files were updated once:

• 23<sup>rd</sup> June 2020: update required by introduction of IPF 3.3.0 and aiming to place all the processing parameter within the AUX\_SCS file, and removing internal processing parameters.



# 4.Instrument Status

Hereafter, the status of the S-1A & S-1B instruments during 2020 is described:

# 4.1 RFC Monitoring

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

### 4.1.1 Antenna Status

Figure 1 shows the S-1A antenna Transmit/Receive Module (TRM) average status during November 2020. The images represent the gain (4 images on the left) and the phase (4 images on the right) deviation from the nominal antenna status (measured from the first in-orbit acquisitions on 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 whole 2020. Ten (10) failures 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 the antenna issue occurred on June 2016. On 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).

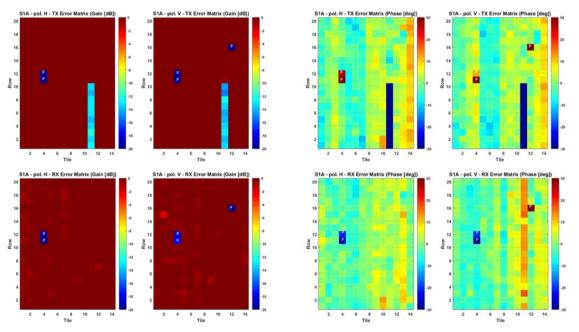


Figure 1: S-1A antenna status: gain (left) and phase (right) deviation of the TRMs from the nominal status. The white "F" marks the failed antenna elements.

Similarly, Figure 2 shows the S-1B antenna TRM average status during November 2020 (reference derived from the first in-orbit acquisitions on May 2016). No relevant changes in the S-1B antenna status occurred during the whole 2020. Seven (7) failures are counted in total among TX-RX and H-V. All the failed TRMs are connected to a single Electronic Front End (each EFE includes 8 TRMs).



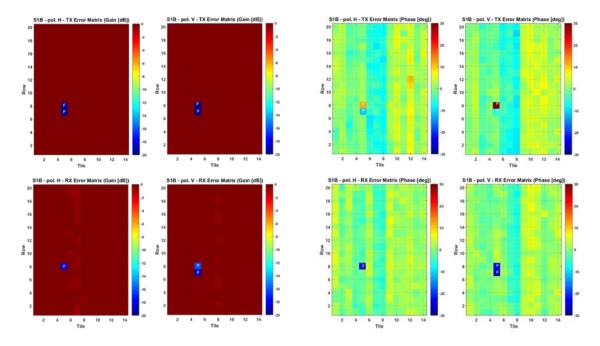


Figure 2: S-1B antenna status: gain (left) and phase (right) deviation of the TRMs from the nominal status. The white stars mark the failed antenna elements.

### 4.1.2 TRM Trends

The following plots show the TX and RX excitation coefficients (averaged per tile) obtained processing RFC products of 2020. The plots from Figure 3 to Figure 6 refer to S-1A whereas the plots from Figure 7 to Figure 10 refer to S-1B.

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 (see section 4.2) can be observed for the TX phase. 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 on June 2016.

S-1B tile 5 TX V gain shows small jumps which have been observed since the S-1B launch. The tile behaviour is continuously monitored but no issues on SAR performances have been observed so far.



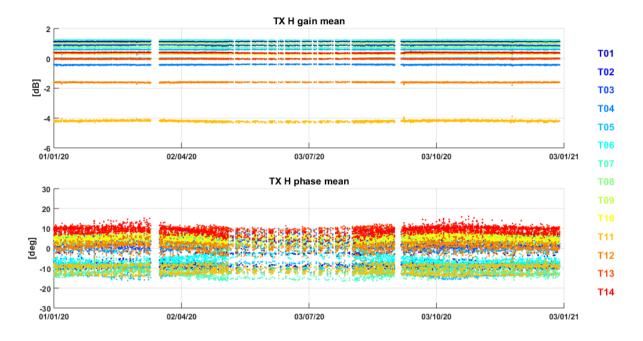


Figure 3: Gain (*top*) and phase (*bottom*) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in TX H over rows.

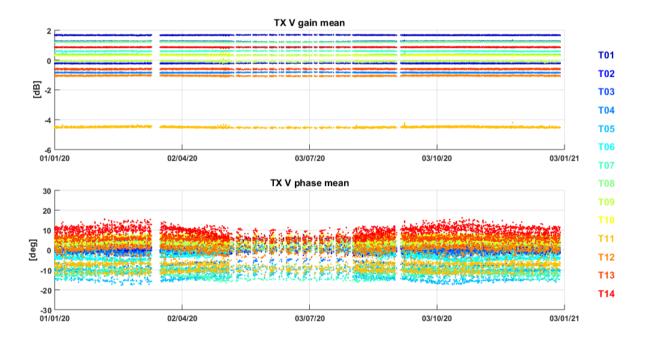


Figure 4: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in TX V over rows.



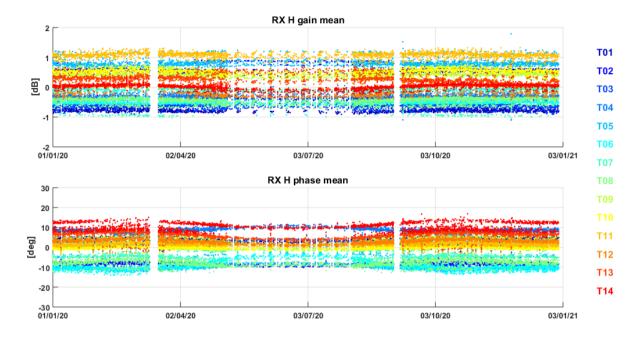


Figure 5: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in RX H over rows.

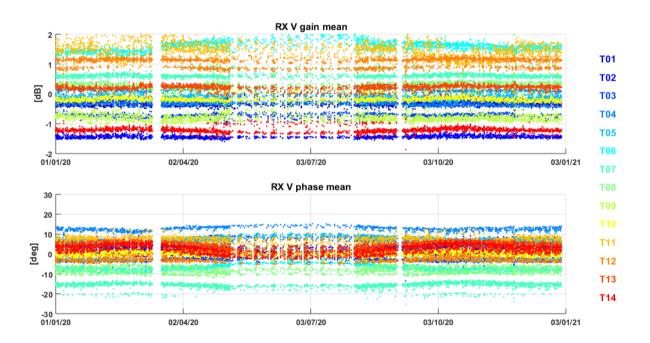


Figure 6: Gain (top) and phase (bottom) stability of the S-1A SAR antenna tiles: average of the RFC coefficients in RX V over rows.



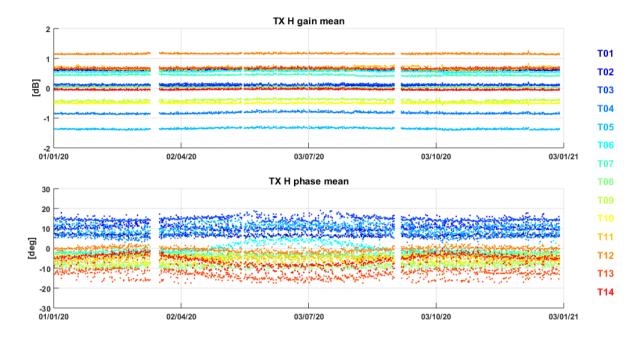


Figure 7: Gain (*top*) and phase (*bottom*) stability of the S-1B SAR antenna tiles: average of the RFC coefficients in TX H over rows.

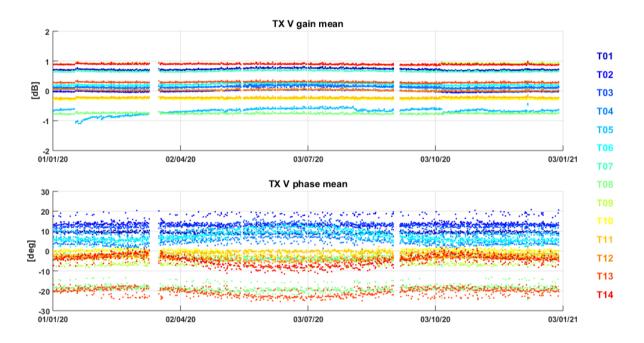


Figure 8: Gain (top) and phase (bottom) stability of the S-1B SAR antenna tiles: average of the RFC coefficients in TX V over rows.



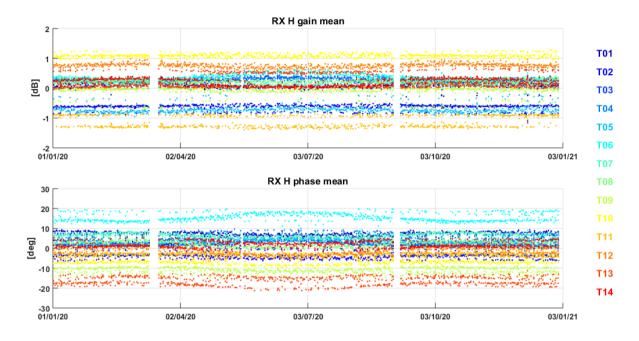


Figure 9: Gain (top) and phase (bottom) stability of the S-1B SAR antenna tiles: average of the RFC coefficients in RX H over rows.

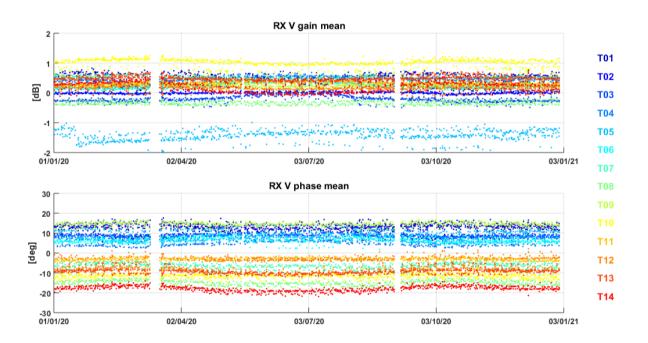


Figure 10: Gain (top) and phase (bottom) stability of the S-1B SAR antenna tiles: average of the RFC coefficients in RX V over rows.



### 4.2 Instrument temperature

The S-1 instrument temperature is monitored through the information annotated in the header of the SAR Space Packets. The following plots show the evolution of the temperature of the different antenna elements (Electronic Front End modules and Tile Amplifiers) during 2020 for S-1A (Figure 11) and for S-1B (Figure 12). The low temperature spikes observed in the plots correspond to the instruments switch-off. The yearly temperature trend is very similar for the two sensors as reported in Figure 13.

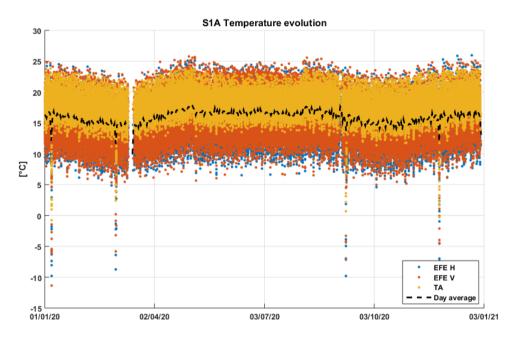


Figure 11: S-1A temperature evolution during 2020.

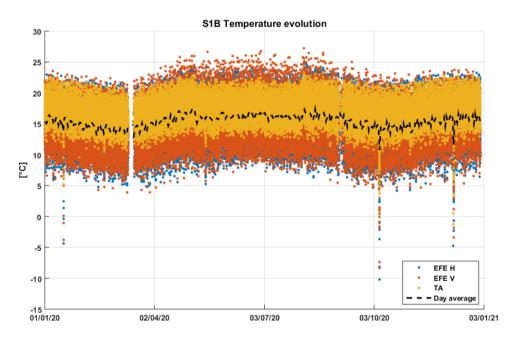


Figure 12: S-1B temperature evolution during 2020.



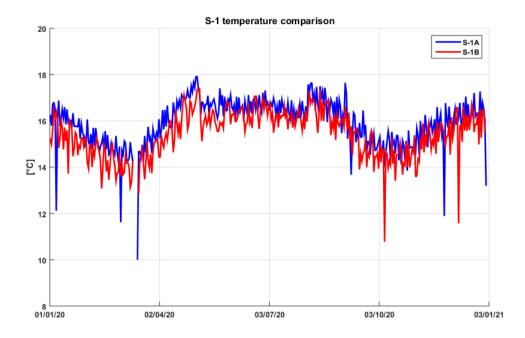


Figure 13: Comparison of S-1A vs S-1B temperature evolution during 2020.

Finally, Figure 14 shows the variation of the different antenna elements temperature as a function of the data takes duration for S-1A (left) and S-1B (right). 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.

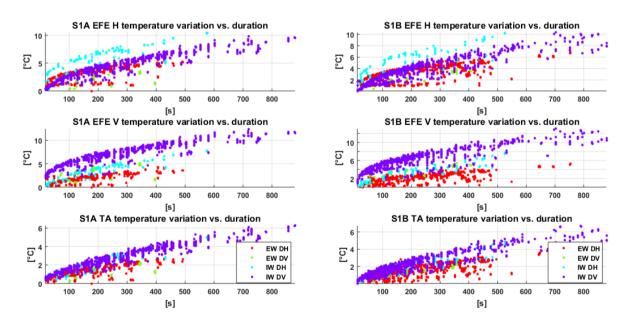


Figure 14: Variation of the antenna elements temperature as a function of the data take duration for S-1A (left) and S-1B (right). The colours represent the different acquisition modes and polarizations.



# 4.3 Internal Calibration

The S-1A & S-1B instrument stability over time is monitored through the internal calibration signals. The plots in Figure 15 (S-1A) and Figure 16 (S-1B) show the main parameters monitored:

- PG gain
- PG phase
- Internal delay
- Rx gain offset

All the parameters are stable in the reporting period. The PG phase and internal delay jumps observed are related to the instrument switch off resulting in a reset of the electronic status of the instrument Analog-to-Digital Converter.

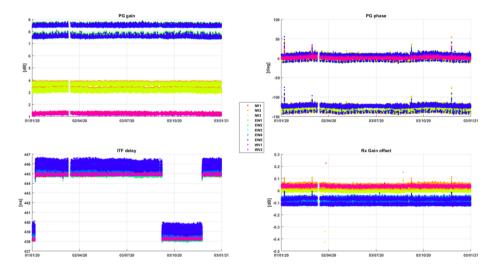


Figure 15: S-1A Internal Calibration parameters monitoring: (top, left) PG gain, (top, right) PG phase, (bottom, left) internal delay and (bottom, right) RX gain offset.

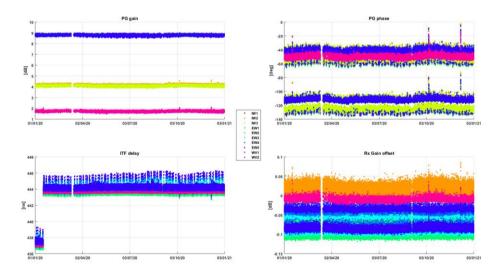


Figure 16: S-1B Internal Calibration parameters monitoring: (top, left) PG gain, (top, right) PG phase, (bottom, left) internal delay and (bottom, right) RX gain offset.



The most relevant Internal Calibration parameter is the gain of the PG product exploited to compensate for the instrument gain fluctuations to maintain the requested radiometric stability of the data. Figure 17 and Figure 18 show a more detailed picture of the S-1A PG gain evolution during the reporting period for IW and EW acquisitions. Figure 19 and Figure 20 show the same information for S-1B.

The PG trend (black dashed line in the plots) is quite stable in particular for S-1B as reported in Table 1, showing the measured yearly trends for the different acquisition modes and polarization. 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 0.1 dB and are more visible in receiving channel H for S-1A while can be observed on both channels for S-1B.

Mode	Polarization	S1A PG trend [dB/year]	S1B PG trend [dB/year]	
IW	VV	-0.04	-0.01	
	VH	-0.03	-0.01	
	HH	-0.02	0.00	
	HV	-0.02	0.00	
EW	VV	-0.04	-0.02	
	VH	-0.03	-0.02	
	HH	-0.03	-0.02	
	HV	-0.02	-0.01	

Table 1: PG yearly trends during 2020

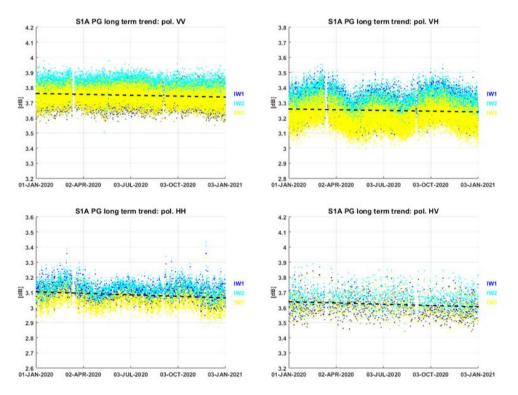


Figure 17: S-1A IW V/V (top, left), V/H (top, right), H/H (bottom, left), H/V (bottom, right) PG gain evolution during 2020.



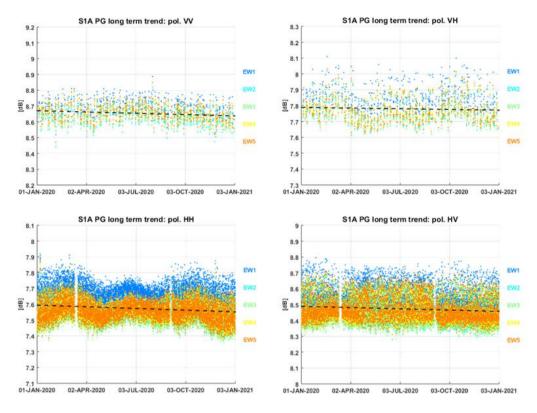


Figure 18: S-1A EW V/V (top, left), V/H (top, right), H/H (bottom, left), H/V (bottom, right) PG gain evolution during 2020.

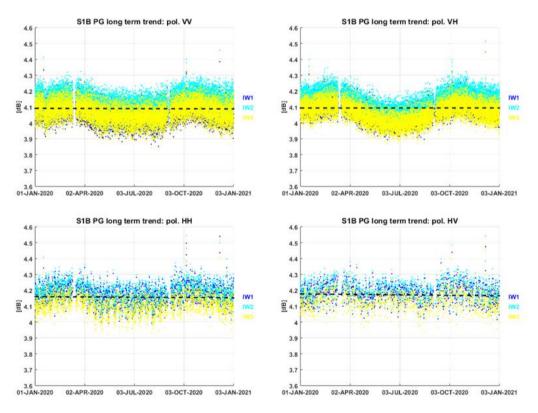


Figure 19: S-1B I W V/V (top, left), V/H (top, right), H/H (bottom, left), H/V (bottom, right) PG gain evolution during 2020.



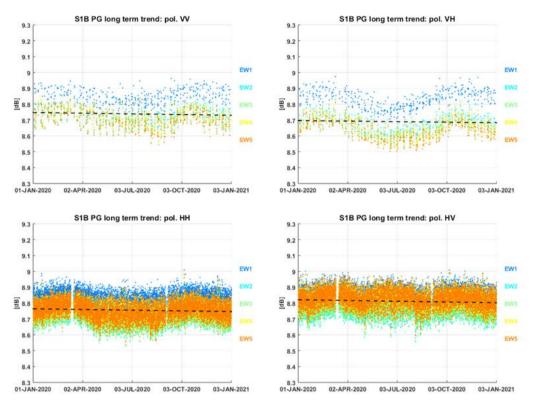


Figure 20: S-1B EW V/V (top, left), V/H (top, right), H/H (bottom, left), H/V (bottom, right) PG gain evolution during 2020.

### 4.4 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 26<sup>th</sup> 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", signal free echoes and hence can be considered as noise pulses.

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 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).

Table 2 provides the average noise power computed during December 2020 for sea and land echoes. Note that S-1B noise power is higher (offset depending on the mode) than S-1A but, thanks to the better status of the antenna, the S-1B Noise Equivalent Radar Cross-Section is lower (see Section 5.6 for more details). The values in parenthesis are the average noise power during December 2019 for comparison. The noise power is stable.

Figure 21 shows the noise power as a function of time in the period January-December 2020 for S-1A (top) and S-1B (bottom) WV products. The noise power is stable in the reporting period.



Acquisition mode	S-1A Noise power [dB]	S-1B Noise power [dB]	
IW1 V/V	Sea: 7.10 (7.12) Land: 7.86 (7.88)	Sea: 7.38 (7.41) Land: 8.15 (8.13)	
IW1 V/H	Sea: 6.44 (6.44) Land: 7.25 (7.26)	Sea: 7.31 (7.36) Land: 8.19 (8.19)	
EW1 H/H	Sea: 5.56 (5.59) Land: 6.30 (6.33)	Sea: 6.62 (6.62) Land: 7.42 (7.56)	
EW1 H/V	Sea: 6.64 (6.74) Land: 7.38 (7.43)	Sea: 6.66 (6.69) Land: 7.39 (7.42)	
WV1 V/V	Sea: 8.64 (8.63) Land: N/A	Sea: 9.44 (9.47) Land: N/A	

Table 2: Average noise power measured during December 2020. The value in parenthesis is theaverage noise power measured during December 2019.

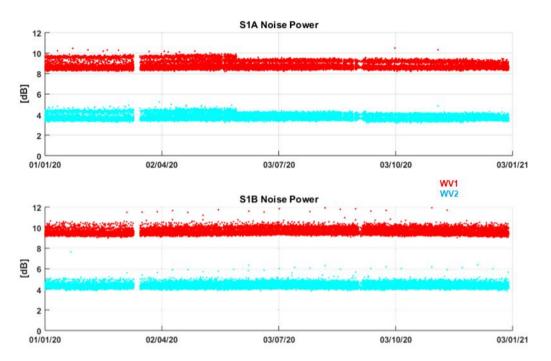


Figure 21: Noise power versus time from pre- and post-amble echoes of WV acquisitions for S-1A (top) and S-1B (bottom).

### 4.5 Instrument Unavailability

A list of S-1A & S-1B instrument unavailabilities during 2020 is given in Appendix B -.



# 4.6 Radar Data Base Updates

During 2019, Radar Data Base #7 for S-1A and #2 for S-1B were circulated. The RDBs were updated to include the optimised excitation coefficients of the WV2 beam without any other change to instrument configuration.

The S-1A RDB #7 was used on board from 28<sup>th</sup> February to 12<sup>th</sup> March while S-1B RDB#2 was used from 14<sup>th</sup> May to 28<sup>th</sup> May.

Those new RDBs were not reactivated during 2020.



# 5.L1 Products Status

Hereafter, the status of the S-1A & S-1B products during 2020 is described below. A general summary of status of S-1A & S-1B Level 1 products was presented at several conferences and workshops during 2020 (see [S1-RD-01], [S1-RD-02], [S1-RD-03], [S1-RD-04] and [S1-RD-12]).

# 5.1 Level 1 Basic Image Quality Parameters

The DLR Transponders & 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 2020 and processed with the Sentinel-1 IPF v3.10, IPF v3.20, v3.30.

### 5.1.1 Spatial Resolution

The Figures and Tables below give the azimuth and range spatial resolutions derived from S-1A & S-1B IW SLC data (there were no measurements for SM and EW modes during 2020). The numbers in brackets indicate the number of measurements.

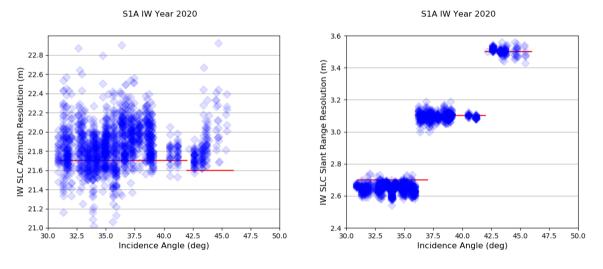


Figure 22: S-1A IW Azimuth and Slant Range Spatial Resolutions

Mode/Swath	Azimuth Spatial Resolution (m)	Slant Range Spatial Resolution (m)
IW1	21.80 ± 0.22 (972)	2.65±0.03 (972)
IW2	21.93 ± 0.20 (657)	3.09±0.02 (657)
IW3	21.86 ± 0.29 (168)	3.51±0.02 (168)

Table 3: S-1A IW Azimuth and Slant Range Spatial Resolutions



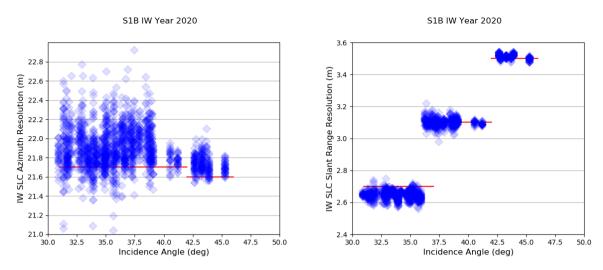


Figure 23: S-1B IW Azimuth and Slant Range Spatial Resolutions

Mode/Swath	Azimuth Spatial Resolution (m)	Slant Range Spatial Resolution (m)
IW1	21.88±0.22 (929)	2.65±0.03 (929)
IW2	21.94±0.20 (632)	3.10±0.02 (632)
IW3	21.73±0.09 (271)	3.51±0.01 (271)



The above results show nominal spatial resolutions with very similar results for S-1A and S-1B.

### 5.1.2 Sidelobe Ratios

Table 5 below gives the measured impulse response function sidelobe ratios derived from S-1A and S-1B IW SLC data - these indicate acceptable values and good comparison between the two satellites.

Satellite/Mode	Integrated Sidelobe Ratio (dB)	Range ISLR (dB)	Azimuth ISLR (dB)	Peak Sidelobe Ratio (dB)	Spurious Sidelobe Ratio (dB)
S-1A IW	-10.89±3.38	-15.60±1.29	-16.17±1.53	-19.58±1.13	-22.95±3.38
S-1B IW	-11.20±3.60	-15.63±1.24	-16.50±1.52	-19.93±1.22	-23.33±3.39

Table 5: S-1A & S-1B IW Sidelobe Ratios



### 5.1.3 ENL and Radiometric Resolution

Large uniform distributed targets are used to measure the equivalent number of looks (ENL) and radiometric resolution (RR) in imagery as given in Table 6 below for S-1A and S-1B. 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	3.84, 1.79	3.86, 1.79	4.01, 1.76
S-1B GRDH	3.13, 2.07	3.49, 1.88	3.41, 1.88

The above results are comparable with expected ENL and RR measurements for IW mode - as expected similar results are obtained for S-1A & B.

#### 5.1.4 Azimuth Ambiguities

Table 7 below gives mean azimuth ambiguity ratio for DLR transponder targets acquired in IW mode for S-1A and S-1B during 2020. The measurements indicate low ambiguity ratios for S-1A and S-1B.

Satellite/Mode	Early Azimuth Ambiguity Ratio (dB)	Late Azimuth Ambiguity Ratio (dB)
S-1A IW	-26.73±4.10	-29.05±3.71
S-1B IW	-29.95±2.69	-29.41±2.48

#### 5.1.5 Range Ambiguities

No S-1A or S-1B imagery suitable for range ambiguity measurements were identified during 2020.

#### 5.1.6 Radiometric Calibration

The DLR Transponders & Corner Reflectors, the BAE Corner Reflector and the Australian Corner Reflector array have been used to measure their radar cross-section as described below. The products analysed were acquired in 2020 and processed with the Sentinel-1 IPF v3.1.0, v3.2.0, IPF v3.3.0, IPFv3.3.1.

#### 5.1.7 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 2020 SAR acquisitions with IW mode and DV polarization (VV+VH) have been acquired regularly over the DLR calibration site located in Southern Germany for both SAR systems



(S-1A and S-1B). 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 24** for S-1A and **Figure 25Figure 26** for S-1B for the observation period in 2020. 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.

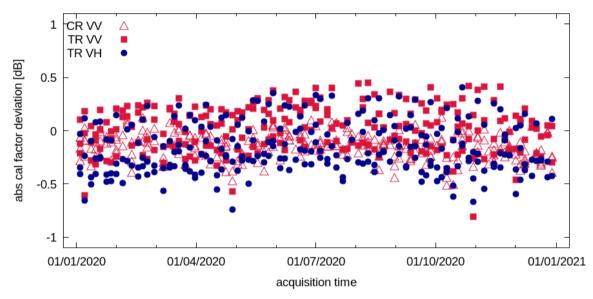


Figure 24: S-1A calibration factor for IW acquisitions in 2020 derived from DLR reference targets; the polarization is depicted by colour: VV in red, VH in blue.

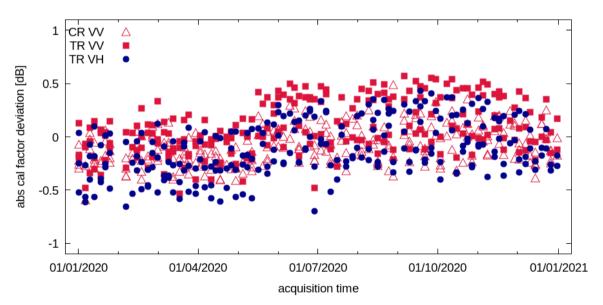


Figure 25: S-1B calibration factor for IW acquisitions in 2020 derived from DLR reference targets; the polarization is depicted by colour: VV in red, VH in blue.



The calibration factor deviations spread around 0 dB with a remaining bias of -0.10 dB for S-1A and -0.04 dB for S-1B (see Table 8) These low biases indicate that both SAR instruments are well balanced in terms of absolute radiometric calibration. A higher spread visible for certain acquisitions (in Figure 24 and Figure 25) Figure 26Figure 27may 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. Note, that the discontinuity (step) visible for S-1B in Figure 25 is due to an EAP and processing gain update (AUX\_CAL and AUX\_PP1) for the DV polarization of S1B's IW mode which is operational since mid of May 2020 (see section 3).

Furthermore, a standard deviation of the absolute calibration factor of 0.21 dB for S-1A and 0.24 dB for S-1B has been derived for the observation period in 2020 (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 0.302 dB for S-1A and 0.325 dB for S-1B (both  $1\sigma$ ) is derived. The slightly higher standard deviation derived for S-1B is due to the different auxiliary file versions used before and after the update in May 2020 within the related SAR data products.

	S-1A IW (VV and VH)	S-1B IW (VV and VH)
Mean value ± standard deviation	-0.10 dB ± 0.21 dB	-0.04 dB ±0.24 dB
Absolute radiometric accuracy (1o)	0.302 dB	0.325 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 2020 for S-1A and S-1B.

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 26 for S-1A and Figure 27 for S-1B. The mean values are marked by symbols, the standard deviations by error bars, VV polarization results are shown in red, VH polarization in blue. These plots show the elevation dependency of the calibration factor for the IW mode for all three sub-swathes.

For VV polarization the mean values vary over elevation angle between -0.21 dB and 0.25 dB for S-1A and between -0.24 dB and 0.30 dB for S-1B. These variations are slightly higher for VH polarization; for S-1A we found mean values between -0.42 dB and 0.19 dB, for S-1B between -0.41 dB and 0.14 dB.

The standard deviation found for each configuration is an indicator for the radiometric stability. These deviations are remarkable small and vary between 0.08 dB and 0.26 dB. On average they are slightly smaller for S-1A (with 0.12 dB) compared to S-1B (with 0.15 dB). The slightly higher standard deviations found for S-1B compared to S-1A certainly arise from the AUX files update for S-1B's IW mode in May 2020.



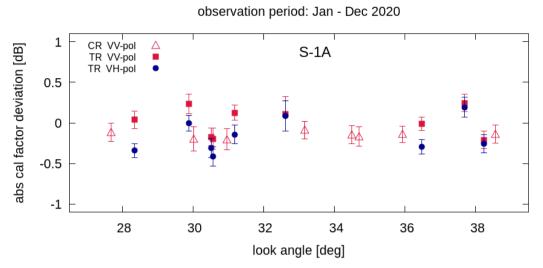


Figure 26: S-1A calibration factor derived from each DLR target under constant acquisition geometry (i.e. same elevation or look angle) acquired in 2020. The symbols depict the mean value, error bars the standard deviation; each target type can be identified by its symbol: corner reflectors as open triangles, transponders as filled squares or circles. The polarization is depicted by colour, VV in red, VH in blue.

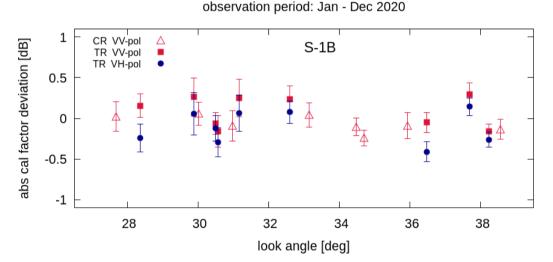


Figure 27: S-1B calibration factor derived from each DLR target under constant acquisition geometry (i.e. same elevation or look angle) acquired in 2020. The symbols depict the mean value, error bars the standard deviation; each target type can be identified by its symbol: corner reflectors as open triangles, 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 both satellites S-1A and S-1B for all acquisitions over DLR point targets in 2020. 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 both SAR instruments are well balanced indicated by low mean values (biases) found within each sub-swath for both S-1A and S-1B. In particular for VV polarization all biases are below



0.1 dB; for VH polarization slightly higher biases are found. However, the biases between S-1A and S-1B are very similar and do not exceed a difference of 0.15 dB.

Furthermore, the standard deviation is very similar for all sub-swathes and both satellites. In all cases (except of IW3, VH polarization) S-1A reaches a slightly lower standard deviation compared to S-1B for the observation period in 2020. As already mentioned, the slightly higher variation of S-1B results is due to the AUX files update in May 2020.

Sub-swath	polarization	S-1A	S-1B
		μ [dB] ± σ [dB]	μ[dB] ± σ[dB]
IW1	VV VH	-0.06 ± 0.20 -0.25 ± 0.18	0.05 ± 0.23 -0.11 ± 0.25
	VV and VH	-0.13 ± 0.21	-0.01 ± 0.25
IW2	VV VH	-0.09 ± 0.16 -0.10 ± 0.24	-0.07 ± 0.20 -0.18 ± 0.28
	VV and VH	-0.09 ± 0.18	-0.09 ± 0.22
IW3	VV VH	-0.04 ± 0.23 -0.04 ± 0.25	0.00 ± 0.24 -0.17 ± 0.23
	VV and VH	-0.04 ± 0.24	-0.03 ± 0.24

Table 9: Mean value and standard deviation of the absolute calibration factor for IW Mode derivedfrom acquisitions over the DLR calibration site in 2020.

An array of 40 corner reflectors has been deployed near Brisbane, Australia as a component of the Australian Geophysical Observing System (AGOS). 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 or S-1B. However, for IW acquisitions (relative orbit 111) the reduction in radar cross-section compared to the case of a perfect orientation is small at less than 0.05dB. Table 10 gives the radiometric accuracy and stability for all corner reflector measurements during 2020 together with results for IW1 and IW2 sub-swaths and for HH polarisation (no imagery was acquired in VV polarisation or the IW3 sub-swath). The numbers in brackets refer to the number of measurements. The results indicate an accuracy close to zero while the stability is less than 0.5dB but larger than the one derived from the DLR transponders.

Satellite	All	IW1 HH	IW2 HH
S-1A	0.17±0.44	0.16±0.41	0.17±0.47
	(1102)	(642)	(460)
S-1B	-0.01±0.44	0.02±0.43	-0.04±0.47
	(1056)	(629)	(427)

No EW, SM and WV acquisitions over Corner Reflectors were available on 2020 for absolute radiometric calibration.

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



### 5.1.8 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 28: assessment of the WV SLC calibration (denoised Sigma0) using geophysical approach i.e. comparison with Cmod-5n with ECMWF0.125° (3h).

In the past, for example in 2018 (last reporting period, see annual performance report of 2018 **[AD-07]**), the monitoring was done using not denoised NRCS compared to predicted values from the GMF Cmod-ifr2 (Quilfen, et al., 2002). However, it has been shown some deficiencies of this GMF, mainly a positive bias of about 0.6dB in average, compared to more recent GMFs derived from Cmod5n (Herbash, 2008). That is why, at the end of 2019, the geophysical methodology has been reviewed to set the comparison with Cmod5n. In addition, since the SAR backscatter from the sea surface is low, the relative impact of NESZ is not negligible mainly for high incidence angles. As a correct way to apply the geophysical calibration methodology, the "denoised" NRCS is now used to be compared with the reference, which was not the case until 2019.

In addition, the former calibration approach for WV mode products was biased by two cumulative effects:

- Firstly, the NRCS was compared to a positively biased GMF Cmod-ifr2. As a result, a positive bias has been artificially introduced in the SAR NRCS to align it with this GMF.
- Secondly, the SAR NRCS was not denoised, so NRCS was overestimated. And, this overestimation was balanced by the GMF choice (Cmod-ifr2). Then it has leaded to aligned overestimated SAR data with an overestimated reference.

For WV1, the non-removal of NESZ contribution has in average few impact because the NESZ is low (S-1A NESZ ~-27.8dB, S-1B NESZ ~ -29dB). In addition, at this range of incidence angle the average NRCS over sea surface is relatively high, being in average around -6dB (of course the values are individually strongly dependent of the wind conditions). However, for WV2, due to higher incidence angle, the sea surface backscattering has lower energy, in average -16dB. The impact of the NESZ is then significantly more important than for WV1, especially when considering S-1A RDB#6 and S-1B RDB#1 configurations which present quite high NESZ levels (respectively -22.2dB and -22.6dB), compared with the optimised WV2 configurations (NESZ ~ -27dB, S-1A RDB#7 and S-1B RDB#2). The not denoised SAR NRCS WV2 was higher than the predicted NRCS values given by Cmod-Ifr2 at this range of incidence angle (S-1B being less impacted by NESZ than S-1A, thanks to lower NESZ level). Thus, the previous method of geophysical calibration artificially introduced a negative bias on WV2 calibration from the beginning of the mission up to May 2020.

With the new calibration method, used since May 2020, using denoised NRCS and CMOD5n GMF the previous issues have gone and we have a properly calibrated WV SLC.



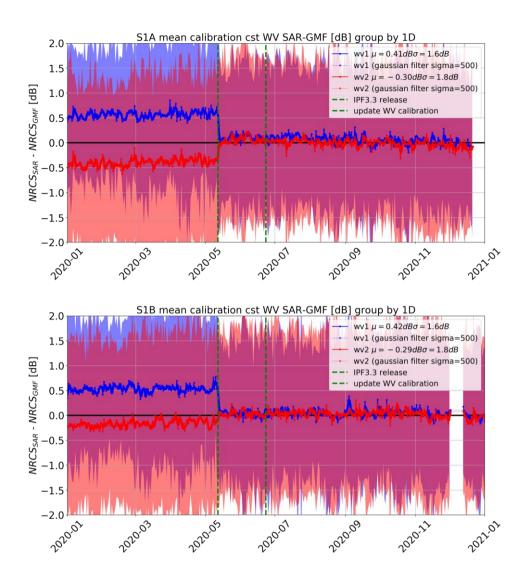


Figure 28: assessment of the WV SLC calibration (denoised Sigma0) using geophysical approach i.e. comparison with Cmod-5n with ECMWF0.125° (3h)

Time evolution: On the 12<sup>th</sup> May 2020, the processing gains have been updated for S-1A and S-1B (S1A\_AUX\_PP1\_V20190228T092500\_G20200512T125926.SAFE &

S1B\_AUX\_PP1\_V20190514T090000\_G20200512T124816.SAFE). This update allowed to reduce the positive bias 0.5dB of WV1 and reduce the negative 0.3dB of WV2. The SLC WV denoised NRCS can be considered as calibrated wrt CMOD5n(ECMWF).

This evolution can be seen on the Figure 28: assessment of the WV SLC calibration (denoised Sigma0) using geophysical approach i.e. comparison with Cmod-5n with ECMWF0.125° (3h), in green colour.

Two Quality Disclaimers were published with reference to the products generated before the 12 May 2020 (QD 66 and 67). The introduction of this radiometric improvement has temporary impact on the performance of the OSW/wind measurement (single value per WV imagette, refer to quality disclaimers 62 to 65) but no negative impact on the OWI/wind measurement (gridded wind value for each WV imagette).

Inter comparison: S-1A/S-1B present very close performances for both WV1 and WV2.



**Performances with respect to specifications:** The NRCS bias since the update of the processing gains in May 2020 is close to zero dB, the standard deviation of this NRCS bias 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 but it could be improved. Especially, the optimized WV#2 beam configuration (S-1A RDB#7 and S-1B RDB#2) will be activated in 2021 and it will improve the signal to noise ratio for WV2 and avoid the FDBAQ threshold effect in the compression of signal power values.

#### 5.1.9 Permanent Scatterer Calibration

No new permanent scatterer measurements were made during 2020.

#### 5.2 Geometric Validation

S-1 geolocation quality was monitored regularly throughout 2020 using SLC products from the IW mode. EW- and SM-mode acquisitions, while not acquired during 2020 over considered calibration sites, were obtained during the earlier S-1A and -B calibration and validation campaigns.

The monitoring was performed over *Surat Basin* (Australia) and *Rosamond* (USA) calibration sites, while *Torny-le-Grand* and *Dübendorf* (Swiss) ones, used as reference for the previous reporting periods, were decommissioned at the end of 2019.

The methodology underlying Sentinel-1 geolocation was published in a technical note [S1-RD-11], available now from ESA's Sentinel document library on the web.

The stability and reliability of the larger test site in Australia (*Surat* Basin) continued to gain in importance. The site includes 41 trihedral CRs covering an area of nearly 13000 km<sup>2</sup>, most of them with 1.5m side lengths. Their positions were confirmed by several research groups to be both accurate and stable enough for precise geolocation monitoring over long periods. 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.

• 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 **atmospheric path delay**, and the azimuth time was corrected by subtracting the **bistatic** residual. These effects and their associated corrections are described in detail in [S1-RD-05].

• For TOPS products (IW and EW), a **range shift dependent on the target azimuth position** within the TOPS burst was shown to be affecting the corresponding ALE estimates [S1-RD-08]. 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 most 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.

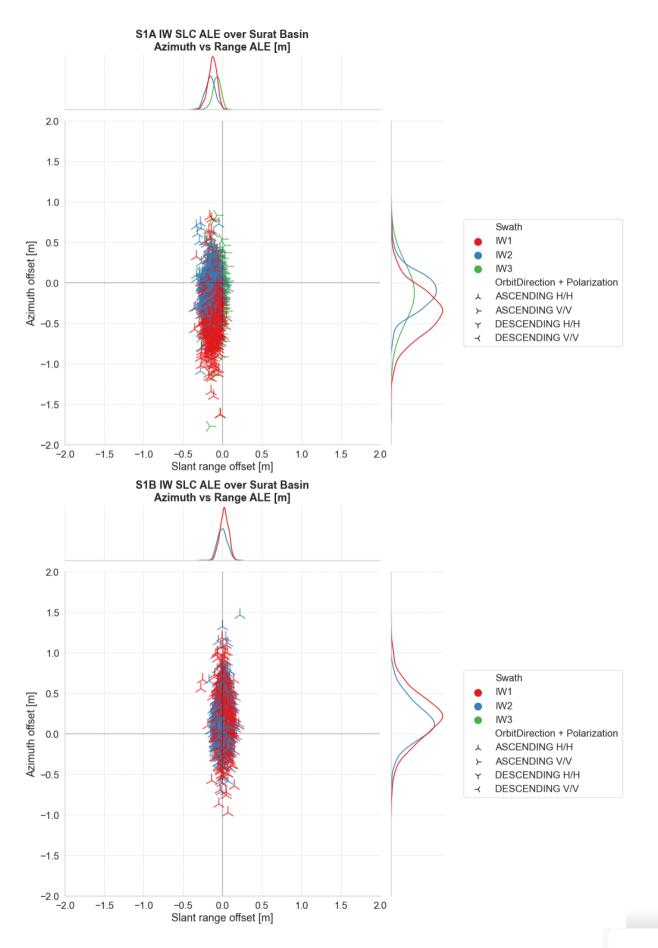
• Differences between the true height of a reference target and height approximations used by the S-1 processor were shown to be causing a **mismatch between the target azimuth FM rate** and the value annotated in each product. The effect was additionally dependent on the target azimuth position within 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.

The two effects mentioned above are described in more detail in [S1-RD-09].

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 and S-1B IW SLC ALE time series for products over the *Surat* site acquired in 2020 are shown in Figure 31. 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 and S-1B are shown separately in **Figure 29**. The overall statistics are also detailed on a swath basis in the tables below. As S-1A suffered the loss of tile #11 in June 2016, its azimuth bias subsequently shifted by ~40 cm in comparison with that of S-1B. Due to the same issue, also a swath dependency is clearly visible from separated azimuth ALE statistics. These differences notwithstanding, the ALE estimates indicate that given unit-specific bias compensations, the localisation performance was more than an order of magnitude better than the original requirement (specified as 10m at  $3\sigma$  according to sections 5.5.2.1 and 5.5.2.2 in [S1-RD-07]) for both units.







	Range ALE [m]	Azimuth ALE [m]
Sentinel-1A (206 products)	-0.120 +/- 0.066	-0.240 +/- 0.526
IW-1	-0.126 +/- 0.057	-0.357 +/- 0.308
IW-2	-0.152 +/- 0.065	-0.093 +/- 0.239
IW-3	-0.072 +/- 0.053	-0.221 +/- 0.897

	Range ALE [m]	Azimuth ALE [m]
Sentinel-1B (122 products)	0.013 +/- 0.059	0.190 +/- 0.290
IW-1	0.022 +/- 0.055	0.203 +/- 0.305
IW-2	0.002 +/- 0.061	0.172 +/- 0.268
IW-3	/	/

# Figure 29: IW SLC product ALE estimates for (a) S-1A and (b) S-1B for all 2020 acquisitions over the Australian *Surat Basin* calibration site.

## 5.3 Polarimetric Calibration

#### 5.3.1 Gain Imbalance

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.

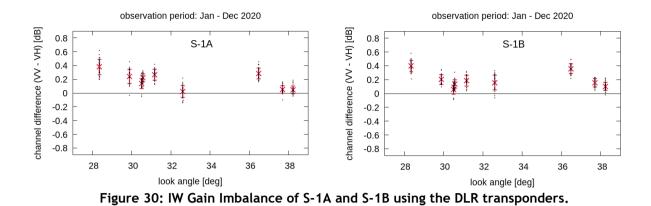
The gain imbalance is depicted in Figure 30 for the IW mode in DV polarization for S-1A (left) and S-1B (right) covering the observation period of 2020. The plot shows the mean values (red crosses) and standard deviations (red error bars) of the channel imbalance for each acquisition geometry, i.e. for measurements acquired with a certain elevation or look angle. For S-1A, a gain imbalance of 0.18 dB is determined on average with a standard deviation of 0.14 dB; the channel imbalance for S-1B is 0.20 dB on average with a standard deviation of 0.13 dB as listed in Table 11.

Within Figure 30 a slightly elevation dependency is seen with a bias up to 0.4 dB for near range acquisitions. Nevertheless, the difference between S-1A and S-1B is negligible low.

Satellite/Mode	Gain Imbalance (dB)
S-1A IW (VV/VH)	0.18 ± 0.14
S-1B IW (VV/VH)	0.20 ± 0.13

Table 11: Gain Imbalance using the DLR transponders.





#### 5.3.2 Phase Imbalance

The channel imbalance in phase is determined analogically 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 2020. 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 degree. Only small differences are seen between the results of S-1A and S-1B. The mean values and standard deviations are listed in Table 12.

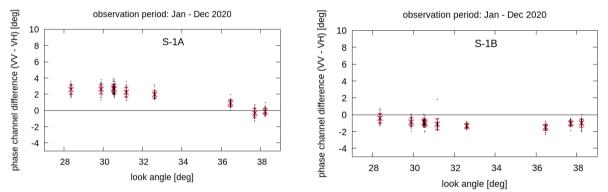


Figure 31: Phase Imbalance using the DLR transponders.

Satellite/Mode	Phase Difference [deg]
S-1A IW	1.70 ± 1.26
S-1B IW	-1.02 ± 0.53

Table 12: Phase Imbalance using the DLR transponders.



#### 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 13 below shows that the average measured polarimetric co-registration derived from SLC products acquired during 2020 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±0.08	0.07±0.33	213
S-1B IW	0.01±0.04	0.05±0.32	261

#### 5.3.4 Cross-talk

The trihedral corner reflectors of the DLR calibration site with a leg length of 2.8 m enable to derive the cross-talk of S-1A and S-1B since they provide an impulse response only for co-polarisation (HH or VV) with sufficient energy. The derived cross-talk of both SAR instruments are depicted in Figure 33 for the observation period in 2020. The mean cross-talk values with standard deviations for both instruments are listed in Table 14.

The derived cross-talk for both SAR instruments is very low and confirms the very good quality concerning the separation of the co-and cross polarization channels of both SAR instruments.

Satellite	Cross-talk [dB]	Number of Measurements
S-1A	-44.4 ± 4.8	259
S-1B	-47.8 ± 5.3	255

Table 14: Cross-talk Measurements

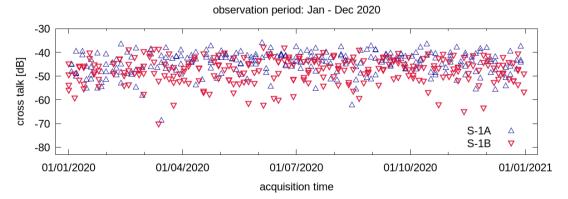


Figure 32: Cross-talk derived from DLR corner reflectors for S-1A (blue) and S-1B (red).



## 5.4 Elevation Antenna Patterns

During 2020 the Elevation Antenna Patterns (EAPs) were updated several times to improve the radiometric quality of the products, according to the  $\gamma$ -profiles measured over Rain Forest acquisitions. The aim was to remove sub-swath jumps and flatten gamma profiles within each sub-swath. The following updates were performed:

- S-1A EW HH/HV EAPs were updated with the AUX\_CAL file disseminated on the 15<sup>th</sup> December 2020. The difference between the new and previous EAPs is shown in Figure 33.
- S-1B IW VV/VH EAPs were updated with the AUX\_CAL file disseminated on the 12<sup>th</sup> May 2020. The difference between the new and previous EAPs is shown in Figure 34.
- S-1B EW HH/HV/VV/VH EAPs were updated with the AUX\_CAL file disseminated on the 15<sup>th</sup> December 2020. The difference between the new and previous EAPs is shown in Figure 35 for HH and HV beams and in Figure 36 for VV and VH beams.

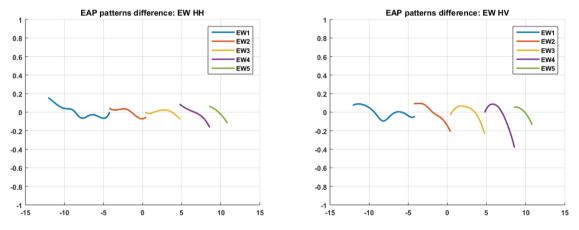


Figure 33: S-1A EW HH (left) and HV (right) Elevation Antenna Patterns difference following AUX-CAL update on 15<sup>th</sup> December 2020.

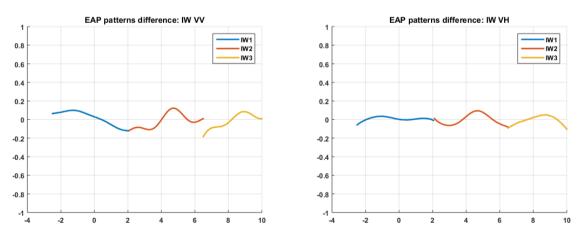


Figure 34: S-1B IW VV (left) and VH (right) Elevation Antenna Patterns difference following AUX-CAL update on 12<sup>th</sup> May 2020.



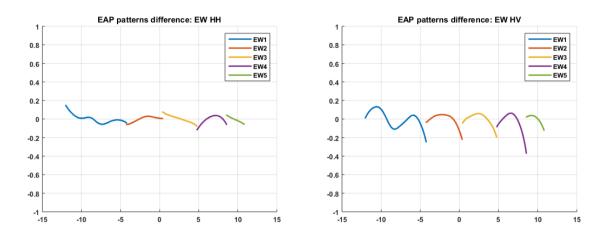


Figure 35: S-1B EW HH (left) and HV (right) Elevation Antenna Patterns difference following AUX-CAL update on 15<sup>th</sup> December 2020.

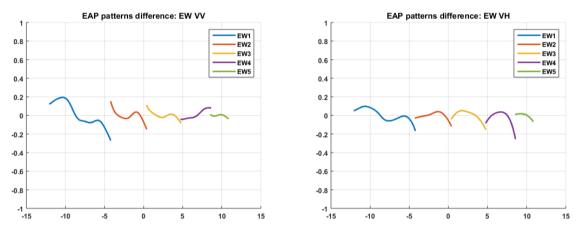
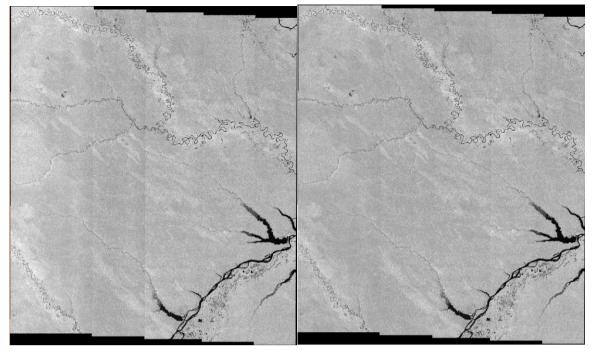


Figure 36: S-1B EW VV (left) and VH (right) Elevation Antenna Patterns difference following AUX-CAL update on 15<sup>th</sup> December 2020.

The following figures illustrate the flattening of gamma:

- On quicklooks of products acquired over rain forest and processed without the new configuration (left) and with new configuration (right).
- On transects of gamma for large number of products acquired over rain forest on selected tracks (track 32) and processed without the new configuration (top) and with the new configuration (bottom).





S1B\_EW\_GRDM\_1SDV\_20201110T223725\_20201110T223837\_024208\_02E057\_xxxx.SAFE Figure 37: Revised S1B EW Amazon Rainforest Gamma Profiles before & after EW DV EAP Update for VV (no denoising applied)



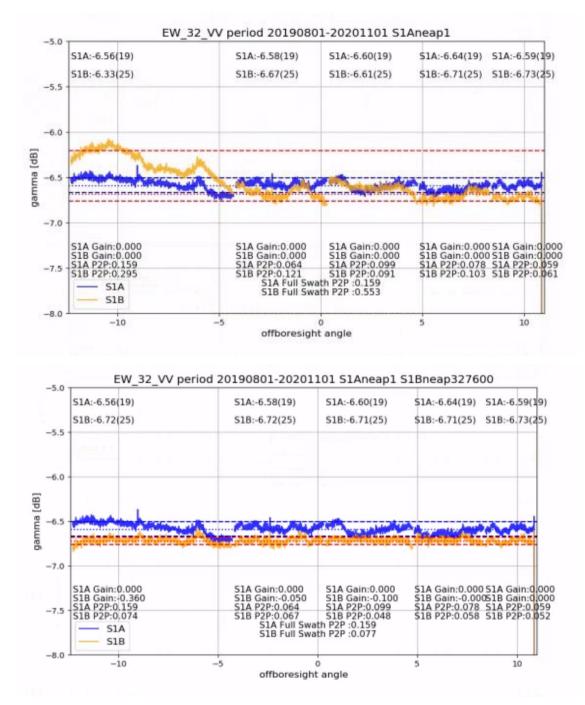
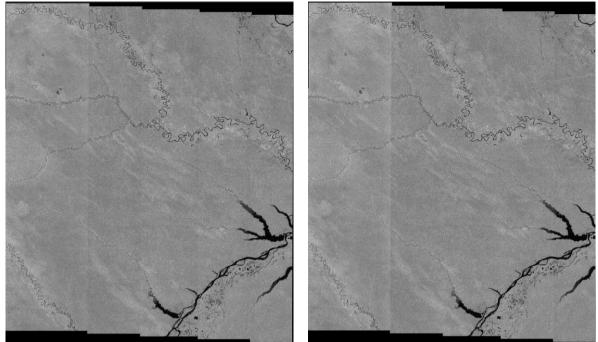


Figure 38: Revised S1B EW Amazon Rainforest Gamma Profiles before (top) & after(bottom) EW DV EAP Update (VV polarisation, S-1A unchanged)





S1B\_EW\_GRDM\_1SDV\_20201110T223725\_20201110T223837\_024208\_02E057\_xxxx.SAFE Figure 39: Revised S1B IW Amazon Rainforest Gamma Profiles before & after EW DV EAP Update for VH (no denoising applied)



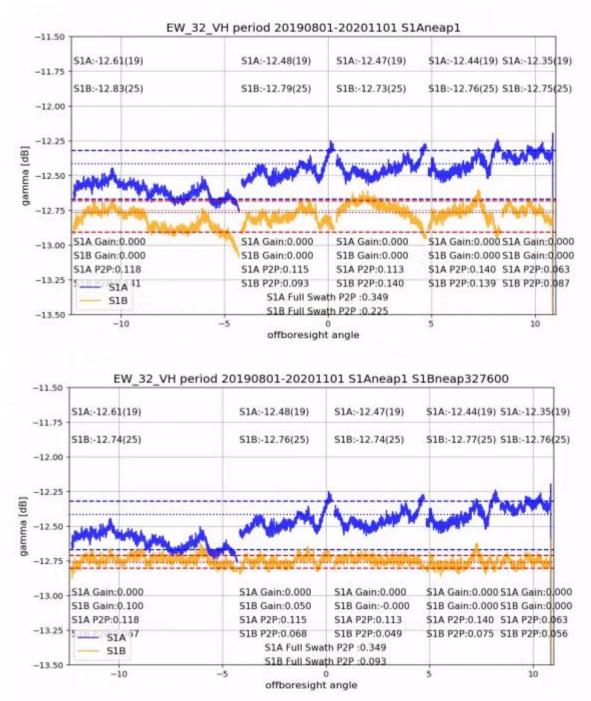
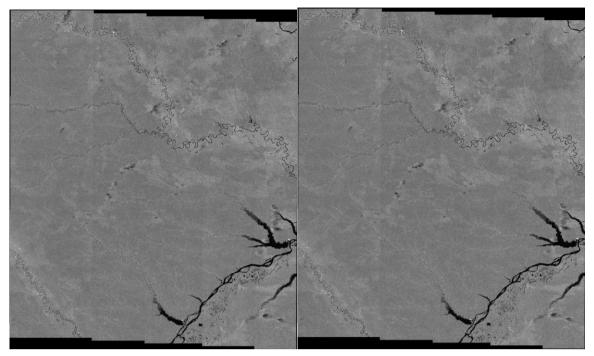
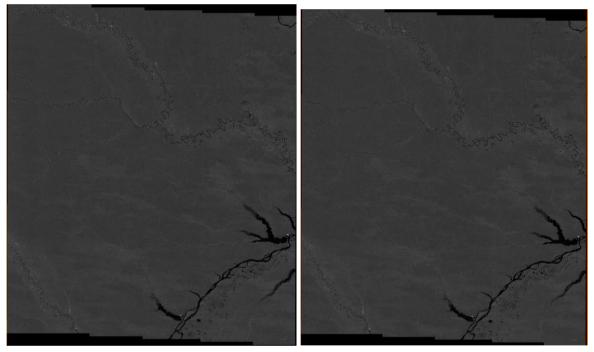


Figure 40: Revised S1B EW Amazon Rainforest Gamma Profiles before (top) & after(bottom) EW DV EAP Update (VH polarisation, S-1A unchanged)





S1A\_EW\_GRDM\_1SDH\_20201116T223807\_20201116T223919\_035279\_041EE0\_XXXX.SAF Figure 41: Revised S1A EW Amazon Rainforest Gamma Profiles before & after EW DH EAP Update for HH (no denoising applied)



S1B\_EW\_GRDM\_1SDH\_20201204T223724\_20201204T223837\_024558\_02EB6A\_XXX.SAFE Figure 42: RevisedS1B EW Amazon Rainforest Gamma Profiles before & after EW DH EAP Update for HH (no denoising applied)



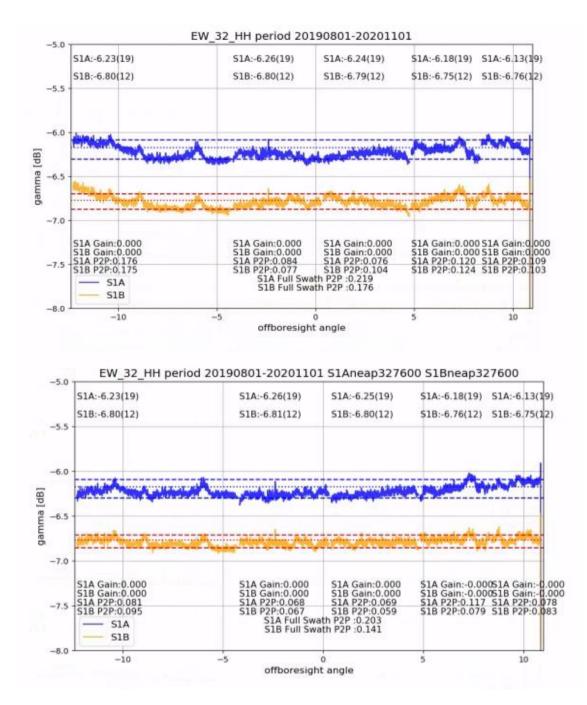
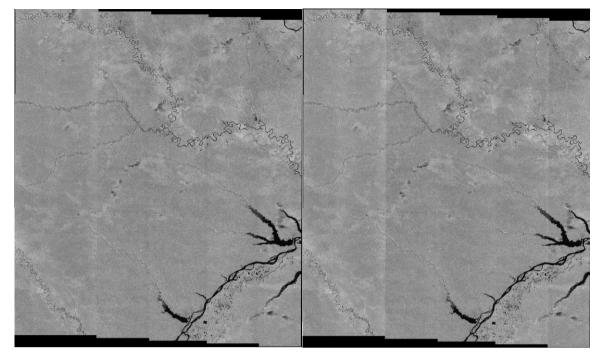
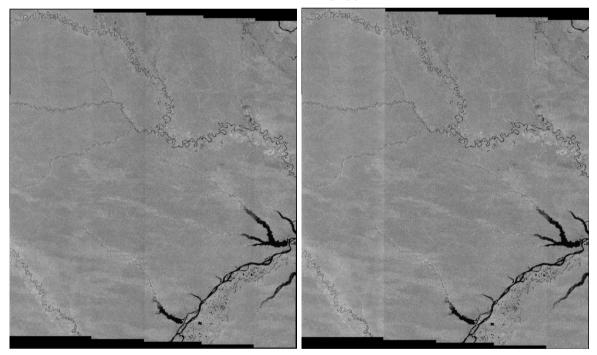


Figure 43: Revised S1A & B EW Amazon Rainforest Gamma Profiles before (top) & after(bottom) EW DH EAP Update (HH polarisation, both S-1A and S-1B updated)





S1A\_EW\_GRDM\_1SDH\_20201116T223807\_20201116T223919\_035279\_041EE0\_XXXX.SAF Figure 44: Revised S1A EW Amazon Rainforest Gamma Profiles before & after EW DH EAP Update for HV (no denoising applied)



S1B\_EW\_GRDM\_1SDH\_20201204T223724\_20201204T223837\_024558\_02EB6A\_XXX.SAFE Figure 45: RevisedS1B EW Amazon Rainforest Gamma Profiles before & after EW DH EAP Update for HV (no denoising applied)



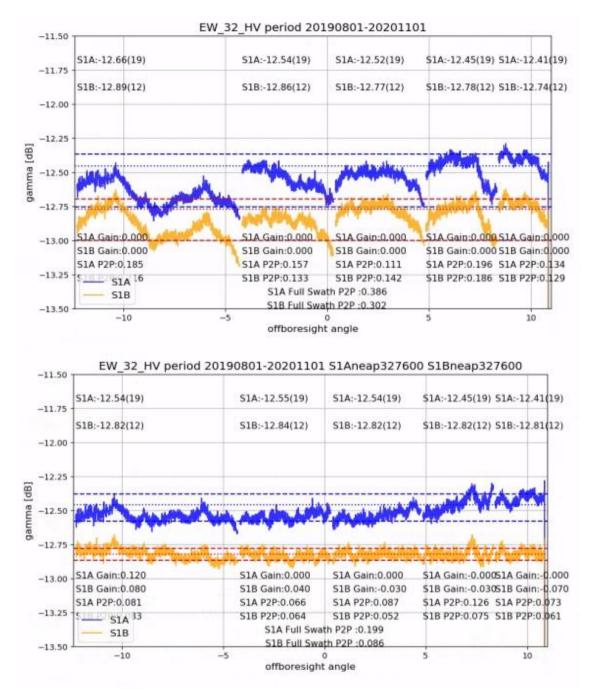


Figure 46: Revised S1A & B EW Amazon Rainforest Gamma Profiles before (top) & after(bottom) EW DH EAP Update (HV polarisation, both S-1A and S-1B updated)

#### 5.5 Azimuth Antenna Patterns

There were no updates to the S-1A or S-1B azimuth antenna patterns during 2020.

#### 5.6 Noise Equivalent Radar Cross-section

S-1A & S-1B imagery with low ocean backscatter can be used to estimate the Noise Equivalent Radar Cross-Section (NESZ). During 2019, NESZ measurements were made for WV mode primarily for deriving



new noise calibration factors that are used to calculate the noise vector annotation within S-1 WV products. For S-1A these related to RBD#6 and for RDB#7 (for acquisitions between 28th February and 11th March 2019 only) while for S-1B for RBD#1 and for RDB#2 (for acquisitions between 14th May and 28th May 2019 only).

The S-1A RDB#7 and S-1B RDB#2 configurations were used in 2019 for testing of improvements in the performance of WV2 including reduced NESZ. Those two new configurations were not activated in 2020 but may be activated in 2021.

One can refer to the Sentinel-1 Annual Performance Report of 2019 for illustration of the NESZ of WV for the current configurations (S1A RDB#6 and S1B RDB#1) and comparison to the one planned for future ones (S1A RDB#7 and S1B RDB#2).

#### 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 4.4 and 5.6)
- Volumetric decorrelation due to different acquisition geometry (orbit baseline)
- Synchronization of the acquisitions (for TOPSAR modes only)
- Stability of the sensor pointing to ensure Doppler spectrum overlap

The S-1A and S-1B performances related to the last three points are reported in the following sections.

#### 5.7.1 S-1 Orbit Baseline

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 interferometric baseline. The interferometric baseline is continuously monitored by the PDGS OBS tool, which compares each orbit with an arbitrary selected reference cycle:

- Cycle number 60 (30 September 12 October 2015) for S-1A
- Cycle number 39 (16 May 28 May 2017) for S-1B

Figure 47 (S-1A) and Figure 48 (S-1B) show the three interferometric baseline components (Parallel on top, Normal in the mid and Along-Track on the bottom) evolution during 2020. 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 the worst-case coherence loss due to the interferometric baseline is always well below 5%.

Finally, Figure 49 shows the cross-sensor interferometric baseline components, obtained comparing S-1B orbits with S-1A reference cycle. Again, the orbit control performance is very good and the loss of coherence due to the geometric baseline is negligible.



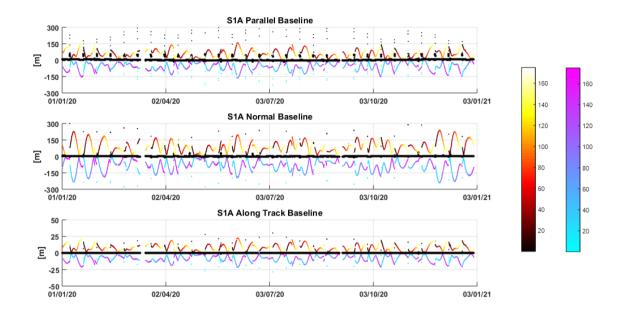


Figure 47: S-1A parallel (top), normal (mid) and along-track (bottom) interferometric baseline during 2020. Warm colours are used for the maximum value and cold colours for the minimum value of each orbit. The colours represent the track number.

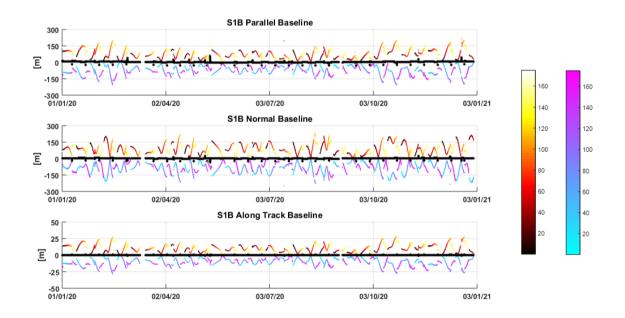


Figure 48: S-1B Parallel (top), normal (mid) and along-track (bottom) interferometric baseline during 2020. Warm colours are used for the maximum value and cold colours for the minimum value of each orbit. The colours represent the track number.



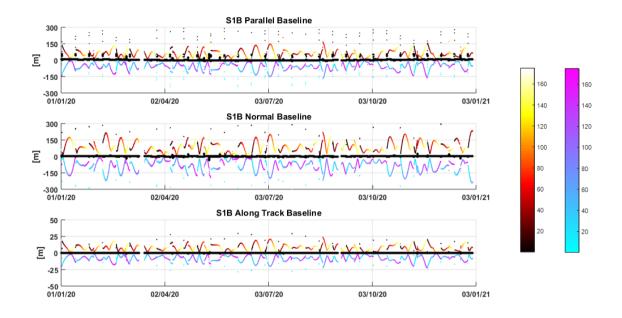


Figure 49: Cross-sensor S-1B vs S-1A parallel (top), normal (mid) and along-track (bottom) interferometric baseline during 2020. Warm colours are used for the maximum value and cold colours for the minimum value of each orbit. The colours represent the track number.

## 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 computed by the PDGS OBS processor.

Figure 50 (S-1A) and Figure 51(S-1B) show the burst synchronization error over time for EW (top plot) and IW (bottom plot) mode. The burst synchronization is evaluated w.r.t. the following reference cycles:

- Cycle number 60 (30 September 12 October 2015) for S-1A
- Cycle number 39 (16 May 28 May 2017) for S-1B

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. It can be noticed that the average synchronization is always very good with a small seasonal trend (less than 5 ms peak-to-peak) common to both sensors, suggesting a common external origin due to some long-term orbit perturbation.

The black dashed lines represent the S-1 synchronization requirement (about  $\pm 7$  ms). This value is obtained by multiplying the timing requirement for single acquisitions (5 ms) by  $\sqrt{2}$  due to the fact that 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 better than 93% for S-1A and better than 98% for S-1B. The better performance of S-1B is explained with the fact that the reference cycle for S-1B is more recent than for S-1A.

Figure 52 provides the same information for S-1B acquisitions compared against the S-1A reference cycle in order to evaluate the possibility to perform cross-sensor interferometry. The results in terms of trends and performance are quite similar to those obtained for S-1A and S-1B separately. The percentage of acquisitions better than the mission requirement is higher than 85% for EW and of 95% for IW.



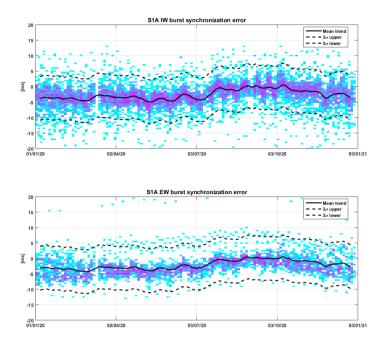


Figure 50: S-1A IW (top) and EW (bottom) burst synchronization during 2020. The colour represents the number of points (light blue few points, purple many points). The black line is the average synchronization per day and the dashed lines are the S-1 requirement limits.

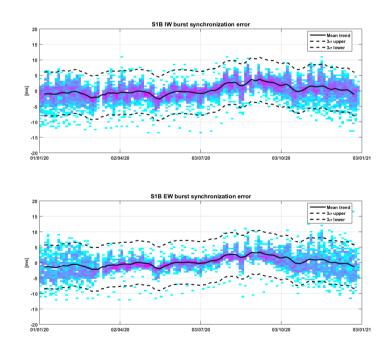


Figure 51: S-1B IW (top) and EW (bottom) burst synchronization during 2020. The colour represents the number of points (light blue few points, purple many points). The black line is the average synchronization per day and the dashed lines are the S-1 requirement limits.



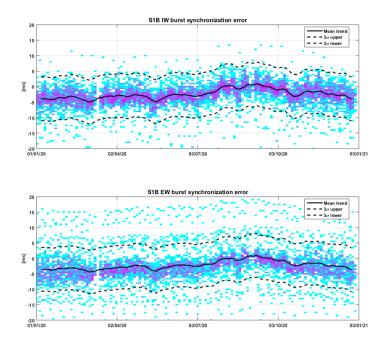


Figure 52: S-1B vs. S-1A IW (top) and EW (bottom) burst synchronization during 2020. The colour represents the number of points (light blue few points, purple many points). The black line is the average synchronization per day and the dashed lines are the S-1 requirement limits.

#### 5.7.3 Instrument Pointing

The instrument pointing is continuously monitored exploiting the DC estimates from the data annotated in the L1A products. Figure 53 (S-1A) and Figure 54 (S-1B) show the average Doppler Centroid evolution during 2020 on a slice basis (dots) and daily (black dashed line). The colours of the dots represent the Star Tracker configuration (STT) in operation during the acquisition. The information is retrieved from the S-1 telemetry since it is not reported n the L0 products. The nominal configuration foresees that two STTs are operated at the same time (STT 1+2, STT 1+3 or STT 2+3). For some periods a single STT is used. The none configuration represents the products for which no telemetry was available.

The DC evolution is in line with the expected pointing performances (Total Zero Doppler steering) for both sensors. The S-1B DC evolution is regular with a seasonal variation resulting in lower DC values during the eclipse season (from May to August). No DC jumps are observed when the STT configuration changes. When the sensor is operated with STT 2 only (light blue dots) DC values higher than the average range can be observed. The S-1A DC evolution shows jumps when the STT configuration changes as observed since the beginning of the mission. The S-1A STT alignment campaign performed in January 2019 only mitigated the issue. The DC jumps seem to be bigger (up to 30 Hz) since May 2020. In particular it seems that STT 1+2 configuration is always showing values higher than the other configurations. After STT alignment campaign, STT 1+2 configuration was aligned with STT 2+3 configuration while a bias of about 20 Hz can now be observed. It is worth to note that such DC jumps have a very limited impact on data quality. The monitoring of the issue will continue during 2021 and, if needed, could trigger a new STT alignment campaign.

Figure 55 provides a comparison between the daily DC average of S-1A (blue line) and S-1B (red line). The S-1B seasonal trend can also be observed for S-1A even if masked by the observed jumps. A good alignment between S-1A and S-1B DC can be observed in the period from May to July while S-1A STT configuration was STT 1+3.



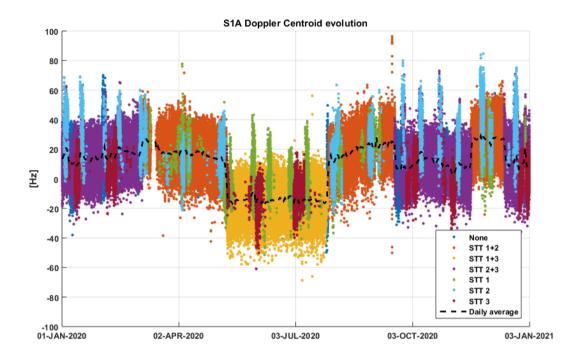


Figure 53: S-1A product (dots) and daily (black dashed line) average Doppler Centroid versus time. The colour of the dots represents the STT configuration in operation at the time of the acquisition.

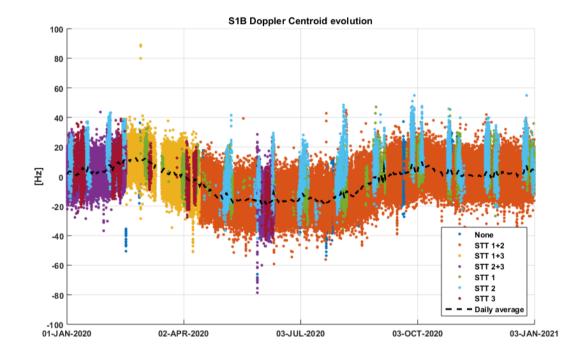


Figure 54: S-1B product (dots) and daily (black dashed line) average Doppler Centroid versus time. The colour of the dots represents the STT configuration in operation at the time of the acquisition.



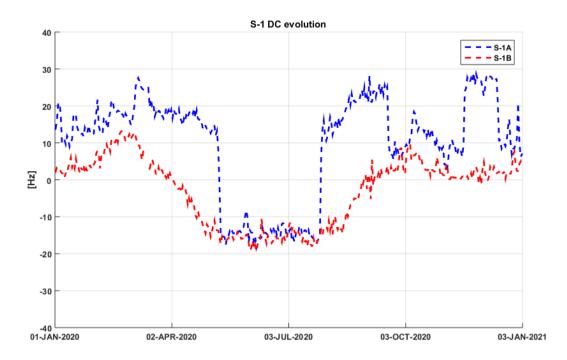
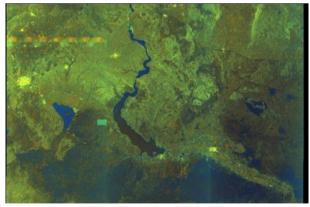


Figure 55: Comparison between S-1A (blue) and S-1B (red) Doppler Centroid daily average.

#### **Summary of Anomalies** 5.8

#### **Radio Frequency Interference** 5.8.1

A small percentage of S-1A & S-1B imagery is affected by the presence of Radio Frequency Interference from the ground. Two examples from 2020 are shown Figure 56. Usually, RFI only affects a few range lines of raw data.

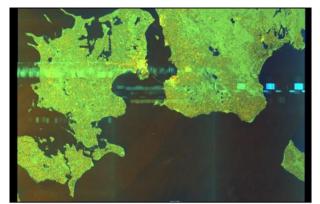


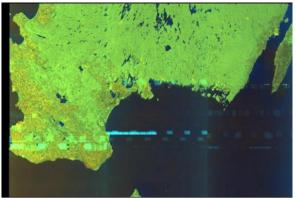
S1A\_IW\_GRDH\_1SDV\_20201228T152534\_20201228T S1A\_IW\_GRDH\_1SDV\_20201222T033533\_202012 152559\_035888\_0433F3\_07C2



22T033558\_035793\_043095\_396F







 S1A\_IW\_GRDH\_1SDV\_20201230T165310\_20201230T
 S1B\_IW\_GRDH\_1SDV\_20201231T164425\_202012

 165335\_035918\_0434F0\_BBFD
 31T164450\_024949\_02F81E\_DDB7

 Figure 56: Examples of Radio Frequency Interference during 2020

Since the introduction of TopSAR rank echoes in LON products in 2018, it is possible to exploit the extra available information to estimate the probability that a product over a certain area is affected by RFI contamination. The RFI contamination probability for a given location can be defined as the ratio between the number of products with detected RFIs and the number of total products (depending on the latitude of the location and on the acquisition plan).

RFI contamination probability maps are generated for each S-1 cycle and are available on line (<u>https://s1rfimap.aresys.it/</u>). Figure 57 and Figure 58 show an example of RFI probability map obtained from S-1A (cycle 218 from 08/12/2020 to 20/12/2020) and S-1B (cycle 148 from 14/12/2020 to 26/12/2020) data respectively. The threshold on RFI brightness temperature was set to 2500 K. RFI sources with lower temperatures have small impact on S-1 data. S-1 products acquired over Middle East and China have a higher probability to present RFI contamination.

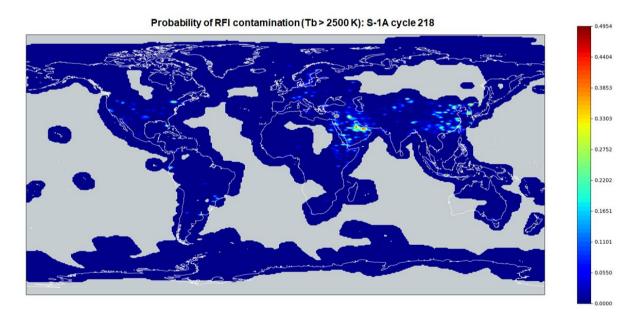


Figure 57: Map of RFI contamination probability for S-1A cycle 218 (from 8/12/2020 to 20/12/2020)



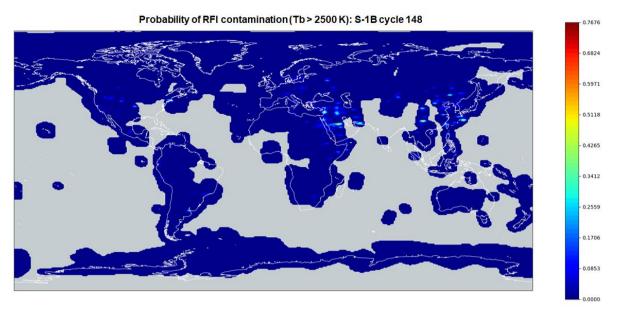


Figure 58: Map of RFI contamination probability for S-1B cycle 148 (from 14/12/2020 to 26/12/2020)

# 5.8.2 Long Duration Interference / interferences with other spacecrafts

#### Radarsat-2

Some potential mutual interference between Radarsat-2 and S-1A occurred during 2019 (none for S-1B). They can occur when the two spacecrafts are flying close on to the other and operating at the same time.

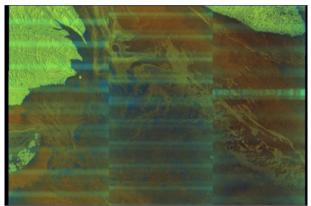
Orbit	Relative Orbit	Acquisition Date	Start Time (UT)	End Time (UT)	Approx. Latitude	Approx. Location	RS-2 operating mode
30942	70	24 <sup>th</sup> January 2020	11:43	11:45	38°N	China	U15W2
31342	120	20 <sup>th</sup> February 2020	22:02	22:05	45°N	Canada	SCWA

Table 15: Sentinel-1A and Radarsat-2 Mutual Interference Occurrences during 2020

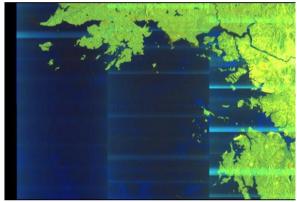


Orbit	Relative Orbit	Acquisition Date	Start Time (UT)	End Time (UT)	Approx. Latitude	Approx. Location	RS-2 operating mode
22083	7*	18 <sup>th</sup> June 2020	04:24	04:26	58°N	Estonia	U4W2, U8W2
22283	32*	1 <sup>st</sup> July 2020	21:35	21:36	52°N	East Russia	U12W2, XF0W2
22483	57*	15 <sup>th</sup> July 2020	14:45	14:46	51°N	Canada	DVWF
22983	32*	18 <sup>th</sup> August 2020	21:39	21:40	39°N	Korea	OSVN

Table 16: Sentinel-1B and Radarsat-2 Mutual Interference Occurrences during 2020



S1A\_IW\_GRDH\_1SDV\_20200220T220346\_20200220T S1B\_IW\_GRDH\_1SDV\_20200818T213956\_202008 220411\_031342\_039B5B\_7BE4 Figure 59: Examples of RFI with Radarsat-2 during 2020



18T214021\_022983\_02BA0C\_3674

#### Gaofen-3

The Chinese GAOFEN-3 (NORAD ID 41727) C-Band SAR satellite can interfere as well with Sentinel-1A and Sentinel-1B. Table 17 gives the orbital characteristics of S1 and GAOFEN 3. GAOFEN 3 is in a higher orbit than S1 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	

Table 17: Sentinel-1 and GAOFEN 3 Orbit Characteristics \*deduced values

Following figure shows example of such interference over Madagascar in 2019. No such long interference with GF-3 was observed in 2020.



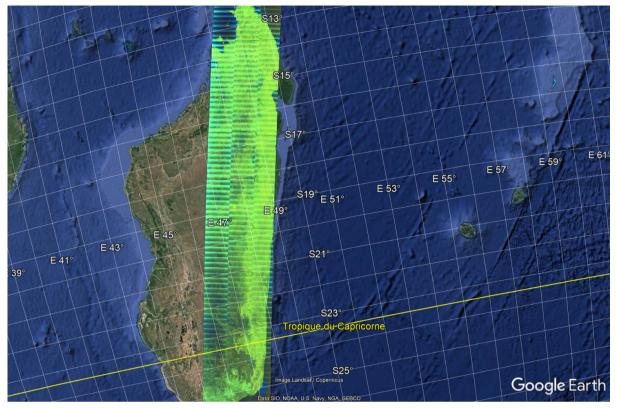


Figure 60: S-1A GAOFEN 3 Mutual Interference on 9 December 2019

#### <u>RCM</u>

The Radarsat Constellation Mission / RCM (NORAD ID 44322, 44323 and 44324) C-Band SAR satellites can interfere as well with Sentinel-1A and Sentinel-1B. Table 18 gives the orbital characteristics of S1 and RCM. RCM is in a lower orbit than S1 and in a dusk-dawn orbit. Figure 61 show such interference over Borneo.

The locations of potential S-1 RCM interference are geographically localised in some specific area over the globe and can be 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).

	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 18: Sentinel-1 and RCM 3 Orbit Characteristics



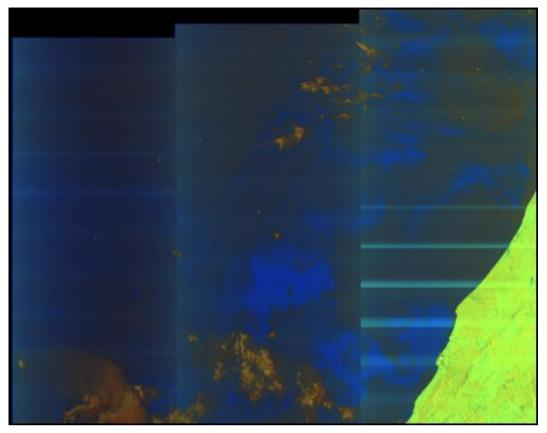


Figure 61: S-1A RCM Mutual Interference on 01 November 2019 (Borneo)

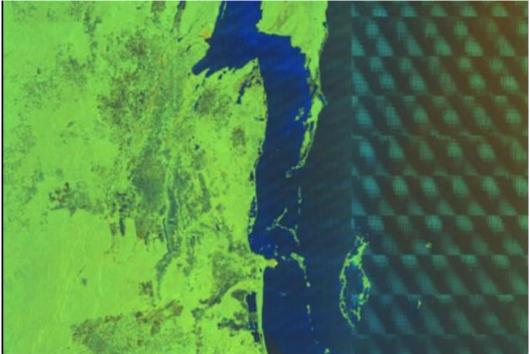
#### Unknown Source

Continuing on previous years, there was some further examples of long duration interference with an unknown satellite as given in Table 19 and shown in Figure 62.

Satellite	Orbit	Acquisition Date	Date Take	Start Time (UT)	End Time (UT)	Approx. Location
S-1A	34992	2020-10-28	0414E5	04.47	04.48	Hawai
S-1A	32225	2020-04-21	03BA40	11.14	11.47	Mexico

Table 19: Examples of Sentinel-1 and Unknown Satellite Mutual Interference Occurrences during2020





S1A\_IW\_GRDH\_1SDV\_20200421T114514\_20200421T114539\_032225\_03BA40\_2F5F Figure 62: S-1B Mutual Interference from 21 April 2020 (unknown source)

# 5.9 Quality Disclaimers

S-1A Quality disclaimers issued on L1 products during 2020 are given in Appendix C -.



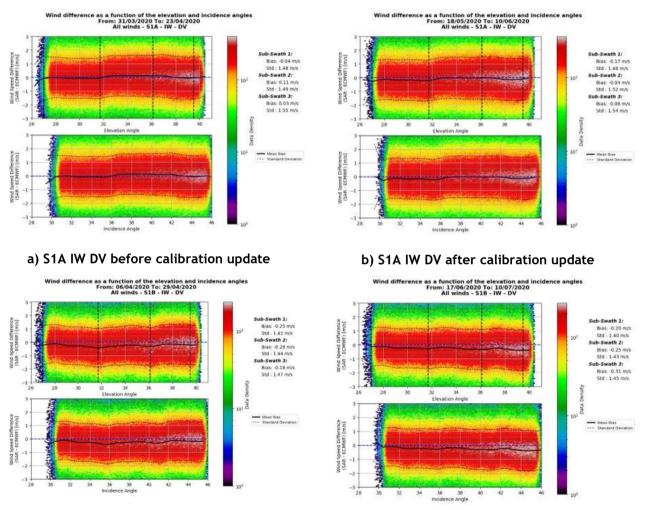
# 6.Level 2 Products

## 6.1 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, Ifremer has performed systematic collocations with such data (model: ECMWF (global), Arome, Arpege (European), hundreds of buoys, Metop scatterometers ASCAT- A/B, altimeters ex Cryosat, radiometer ex SMAP etc.) with core L2 OCN products.

## 6.1.1 Image Mode (IW-EW)

Few changes compared to previous year are to be declared in 2020. Among them, the calibration update of S1B IW DV (May 12 2020) can be noticed. On Figure 63 are represented the elevation (top) and incidence angle (bottom) distribution of the wind retrieval bias (SAR-ancillary) with respect to ECMWF model. While almost no change is perceptible on S1A, S1B elevation angle dependant bias (frames c and d) is diminished around the first subswath limit (32 degrees elevation angle). The impact of the calibration update on S1B EW DV and DH will be treated in 2021 annual report. Wave modes were also added to the OWI processing, and they are discussed in section 6.1.3.



c) S1B IW DV before calibration update

d) S1B IW DV after calibration update

Figure 63: Impact of S1B IW DV calibration update on S1A wind speed retrieval (control) and S1B.



Performances on the wind speed retrieval are similar to the ones observed in 2019. New diagnostics are now available on wind direction, which are presented on Figure 64 and Figure 65. Performances are in overall good agreement between SAR and ECMWF.

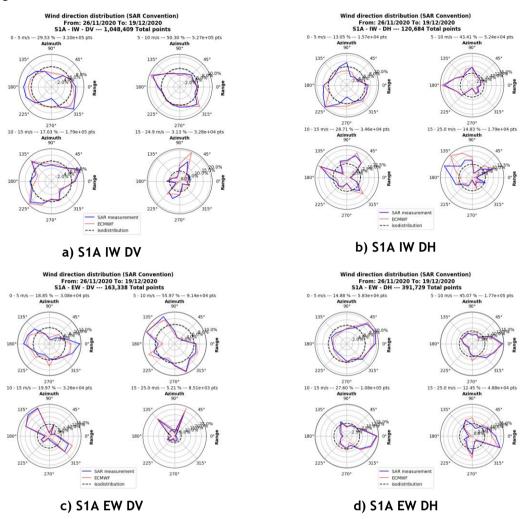


Figure 64: Ebuchi diagrams for S1A SAR retrieved and ECMWF wind directions detailed by wind speed domain in the sensor geometry between Nov. 26 2020 and Dec. 19 2020.



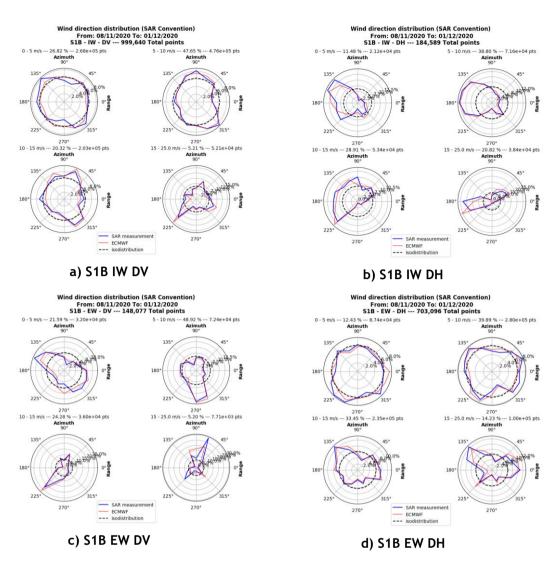


Figure 65: Ebuchi diagrams for S1B SAR retrieved and ECMWF wind directions detailed by wind speed domain in the sensor geometry between Nov. 8 2020 and Dec. 1 2020.



## 6.1.2 Wave Mode / OSW

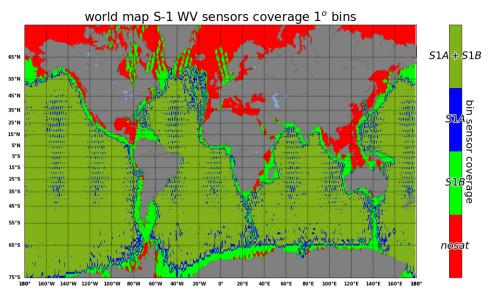


Figure 66: Coverage map of S-1 WV acquisition

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.

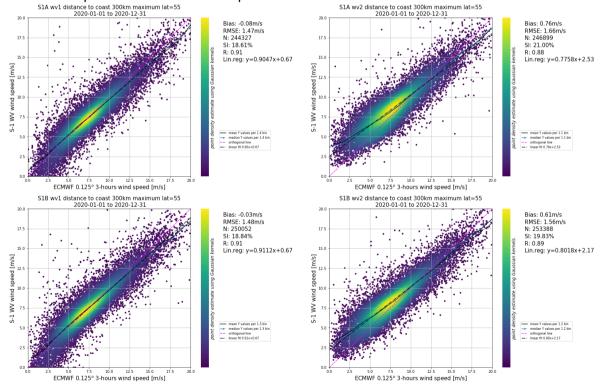


Figure 67: Scatter plot of oswWindSpeed as respect to ECMWF 0.125 (3h) Top left: S1A WV1, top right: S1A WV2, bottom left S1B WV1, bottom right S1B WV2.



Figure 68 are illustrating the difference between the wind speed annotated in S-1 Level-2 WV (osw component) products and associated colocations from ECMWF  $0.125^{\circ}$  3-hourly products with respect to time.

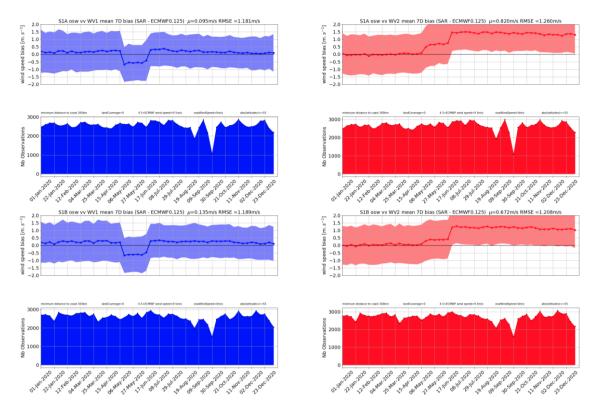


Figure 68: Difference in ocean surface wind speed between *oswWindspeed* S-1 WV OCN variable and ECMWF numerical model (0.125° spatial resolution grid and 3-hours for time resolution). Bold line is the daily mean of the individual measurement differences and the background colour is the daily standard deviation.

Time evolution: Two changes have to be reported in 2020 on osw WV wind speed.:

- The circulation of ADF AUX\_PP1 for update of calibration constant for WV1 and WV2 S1A/B: 12th May 2020. The usage of this new AUX\_PP1 in production at PDGS should have started at the date of IPF3.3 release, 40 days later. This is why we observe of first degradation of the wind speed performances in May and June.
- The second change observed in June (related to IPF 3.3 release) introduced at improvement for WV1 (performances at the level that we had at the beginning of 2020). But it degraded the WV2 wind speed performances because CMOD5n is supposed to work on denoised NRCS while NRCS in osw component is currently not denoised. The denoising of osw NRCS is foreseen/planned to align the NRCS values annotated within the 3 components owi, rvl and osw.

Inter comparison: Very similar results are obtained for S-1A/B and WV1/2.

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. The denoising of osw NRCS should greatly improve the WV2 wind speed performances.



## Wind Direction

The wind direction in WV OCN products is a copy the value given by the ECMWF numerical forecast available at the processing date. In the contrary to the image modes of Sentinel-1 (IW/EW/SM), there is no Bayesian inversion scheme to combine SAR and ECMWF information to get the wind direction. The validation in this section is basically a validation between the ECMWF forecast and ECMWF analysis.

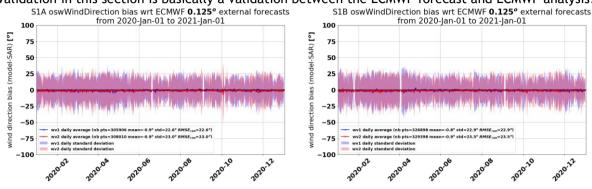


Figure 69: Difference of ocean surface wind direction between *oswWinddirection* S-1 WV OCN variable and ECMWF numerical model (0.125° spatial resolution grid and 3-hours for time resolution). Bold line is the daily mean of the individual measurement differences and the background colour is the daily standard deviation.

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

Inter comparison: Very similar results are obtained for S-1A/B and WV1/2.

Performances with respect to specifications: RMSE 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.



## 6.1.3 Wave Mode / OWI

Since IPF 3.30, the OWI processing has been activated on wave modes.

## Wind Speed

The performances of the wind speed retrieval for wave modes are presented on Figure Figure 70. Wave modes exhibit biases below -0.25 m/s with respect to ECMWF winds, which means that on average SAR underestimates the ECMWF wind speed. RMS errors are slightly larger for wave modes than for TOPS modes, between 1.68 and 1.77 m/s.

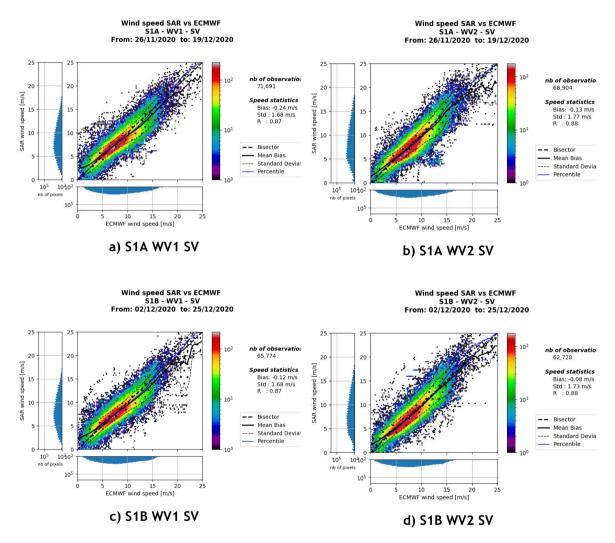


Figure 70: Scatter plots of SAR vs ECMWF wind speeds for Wave Modes in Dec. 2020, for both S1A and S1B.



## Wind Direction

As for TOPS modes, the performances of wind direction retrieval are diagnosed on Figure 71. Performances are compliant with TOPS modes.

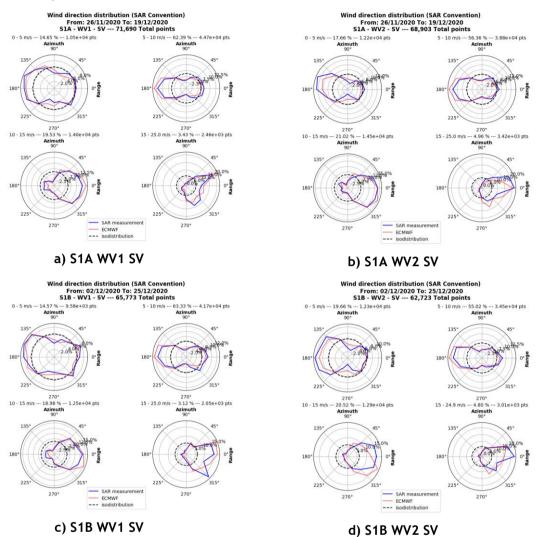


Figure 71: Ebuchi diagrams for S1A and S1B SAR retrieved and ECMWF wind directions detailed by wind speed domain in the sensor geometry in December 2020.

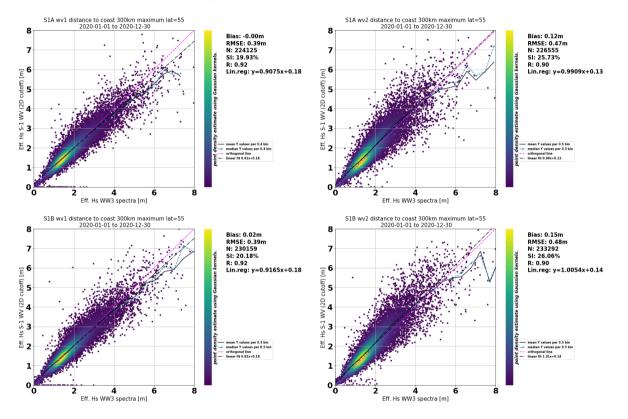


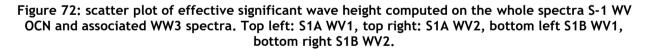
# 6.2 Swell Measurement

## 6.2.1 Wave Mode

## Significant Wave Height without Partitioning

In this section, the concept of effective significant wave height is used to validate S-1 wave algorithm 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 (provided in the WV OCN product since 26<sup>th</sup> June 2019 with IPF 3.1.0) is used to filter regions of the spectra SAR and also WW3.







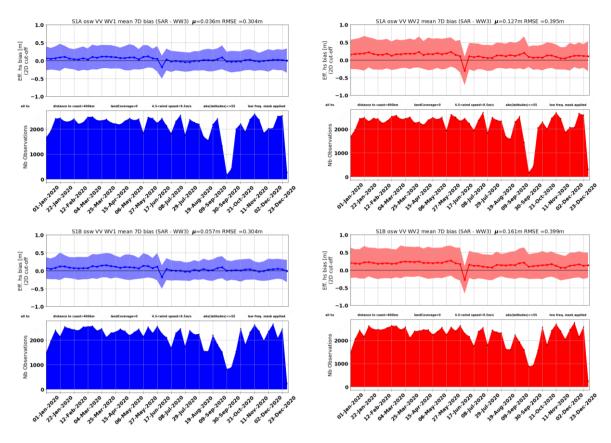


Figure 73: Daily difference of SAR effective azimuth + range 2D cut-off Hs and WW3 numerical model Hs (using same spectral cut-off domain). On the upper panel the bold line is the daily mean of the individual measurement differences and the background colour is the daily standard deviation. On the lower panel the colour indicates the number of available matchups between WV (20km by 20km) 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, except a very small degradation during 5 days after the IPF 3.3 release in June 2020 due to a mismatch between the code and the RDB (Appendix D QD 56 and QD 57).

**Inter comparison:** A very close performance between S-1A and S-1B is observed. For both sensors, WV2 systematically overestimate the effective Hs. This is not observed for WV1.

**Performances with respect to specifications**: The RMSE is within the specifications (0.5m) for S-1A&B and WV1/WV2. Bias is outside the specifications (0.1m) for S-1A&B WV2.

**Discussion about the performances:** MTF used to retrieve wave parameters is suffering of an overestimation of the energy for small Hs and an 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 in the phase plane is systematically observed 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 IPF 3.1.0 (June 2019), a quality flag is attributed to each wave partition delineated in the osw WV product **[AD-01] [AD-07]**. A partition can be considered as 'very good', 'good', 'medium', 'low' or 'poor' based on the following criteria: SnR, U10, Nv, partition contrast and intensity of the spectra normalized variance.

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.

#### Wave partitions with "good" or "very good" quality flag

In Figure 74 and Figure 75, we present the performances of the wave parameters for SAR WV swell partitions annotated as 'good' or 'very good'. Very close performances are observed for this subset of swell partitions from S-1A/B and WV1/2.



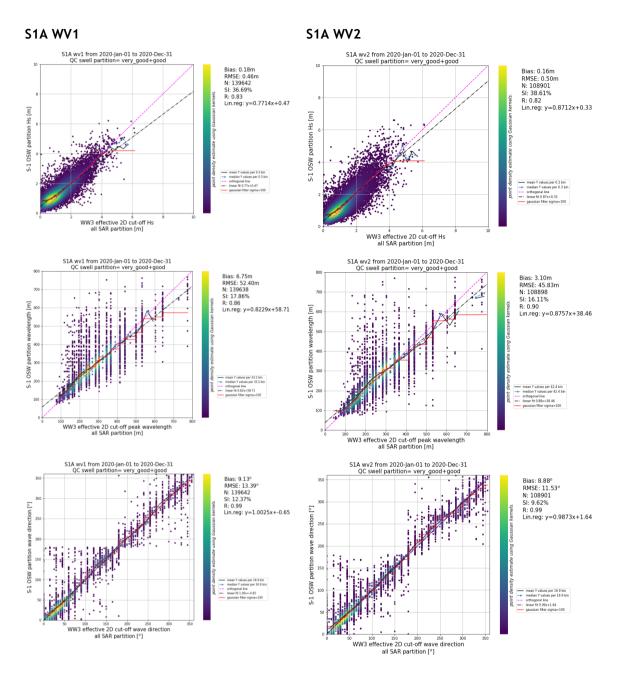


Figure 74: S1A Performances of the wave parameters (Hs, Wavelength, direction) for SAR WV swell partitions annotated as 'good' or 'very good' (right WV1, left WV2)



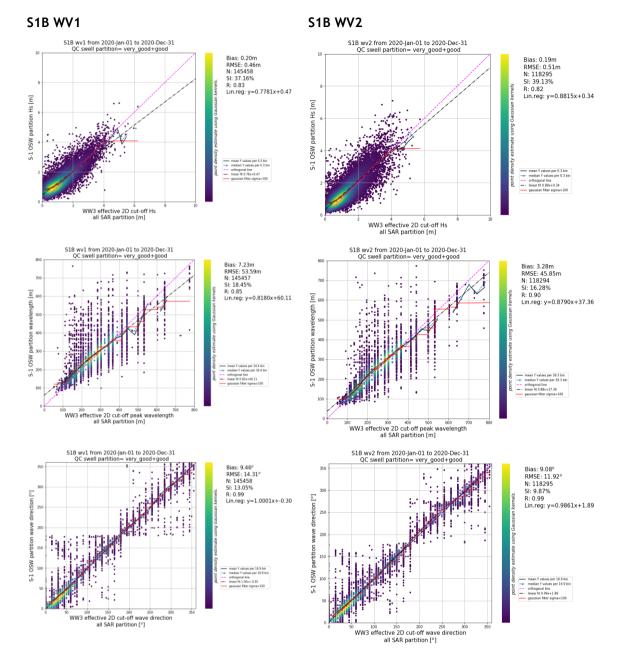
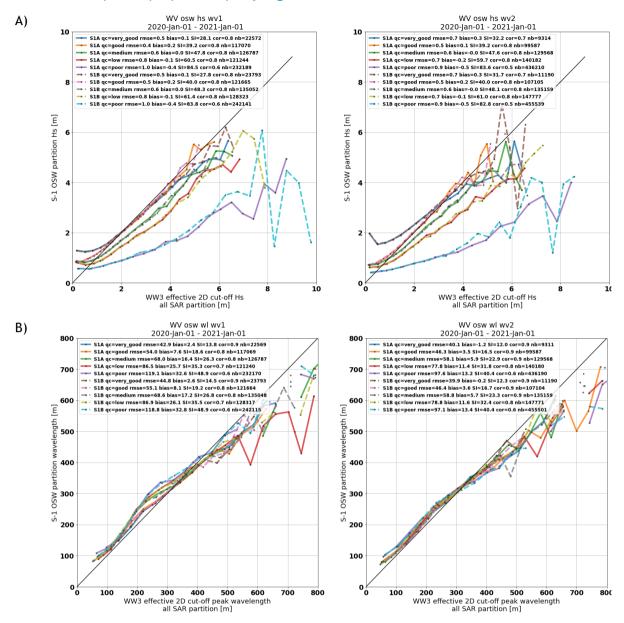


Figure 75: S1B Performances of the wave parameters (Hs, Wavelength, direction) for SAR WV swell partitions annotated as 'good' or 'very good' (right WV1, left WV2)



#### Performances comparison per partition quality flag value





S-1A & S-1B Annual Performance Report for 202086/108MPC-0504 - Issue 1.1 - 16/03/2021<br/>Internal/Interne © 2019 CLS. All rights reserved. Proprietary and Confidential.

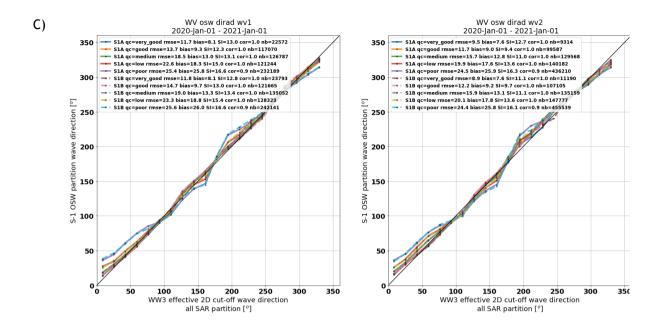


Figure 76: Figures of osw wave partitions performances with respect to WW3 numerical model. The lines represent the mean bias for each wave partition quality flag. Minimum distance to coast is 100km. To avoid ice contamination: -55°<latitude<55°. Left column is WV1 (24° incidence angle), right is WV2 (37° incidence angle). A): Significant wave height B): Peak wavelength, C): Peak wave direction.

**Time evolution:** There is no significant trend regarding the performances of wave peak parameters bias with respect to time, except a very small degradation during 5 days after the IPF 3.3 release in June 2020 due to a mismatch between the code and the RDB (<u>S1A quality disclaimer #56</u>, <u>S1B Quality</u> <u>Disclaimer #57</u>) IPF 3.3 release also introduced a modification in the quality flag associated to the partitions with the "very good" flag. It decreased the number of "good" partitions and the usage of 2 new parameters *HsNV* and *SNR* (on top of the previous ones: Nv, sigma0, wind speed, azimuth cut-off) to set the wave partition quality flag, increased the number of swell systems qualified as "low" and "poor" (not illustrated here).

Inter comparison: Very close performances between S-1A and S-1B are observed.

**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 10m RMSE 50m resp. Bias 10° and RMSE 40°).

**Discussion about the performances:** The current quality flag associated to swell partitions 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 2020. We can expect better performances for WV2 once the Antenna Pattern will be updated.

Some anomalies are visible in Figure 76-A):

- The "very good" effective Hs for 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.
- The WV1 peak wavelength is showing a 50m overestimation for the swells with wavelength between 250 m and 350 m.
- The 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 a lot on this issue.



The tables below are presenting the performances for effective significant wave height, peak wavelength and dominant wave direction. The tables are separated in 3 groups (mean bias, number of partitions, RMSE) of 4 columns (S-1A/S-1B WV1/WV2). The lines correspond to the value annotated in OCN osw WV products for the variable 'oswQualityFlagPartition'.

				bias				nb				rmse
id2	S1Awv1wl	S1Awv2wl	S1Bwv1wl	S1Bwv2wl	S1Awv1wl	S1Awv2wl	S1Bwv1wl	S1Bwv2wl	S1Awv1wl	S1Awv2wl	S1Bwv1wl	S1Bwv2wl
qcvals2												
0_very_good	2.400358	-1.209714	2.622328	-0.239386	22569.0	9311.0	23793.0	11190.0	42.945103	40.063690	44.786110	39.920918
1_good	7.584979	3.505068	8.134539	3.642200	117069.0	99587.0	121664.0	107104.0	53.993538	46.312069	55.099815	46.411404
2_medium	16.405264	5.916458	17.179323	5.728971	126787.0	129568.0	135048.0	135159.0	68.018539	58.111000	68.613342	58.843288
3_low	25.663185	11.369289	26.085669	11.601215	121240.0	140180.0	128317.0	147771.0	86.532906	77.778938	86.892525	78.848343
4_poor	32.643810	13.229018	32.782398	13.366368	232170.0	436190.0	242115.0	455501.0	119.092331	97.569054	118.765678	97.115463

# Table 20: Table for peak wavelength performances (w.r.t.) WW3 model for S-1 WV swell partitionsdepending on the swell partition quality flag

The wavelength mean bias are within a range of 0m to 32m. 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.

				bias				nb				rmse
id2	S1Awv1hs	S1Awv2hs	S1Bwv1hs	S1Bwv2hs	S1Awv1hs	S1Awv2hs	S1Bwv1hs	S1Bwv2hs	S1Awv1hs	S1Awv2hs	S1Bwv1hs	S1Bwv2hs
qcvals2												
0_very_good	0.121798	0.280452	0.137245	0.326357	22572.0	9314.0	23793.0	11190.0	0.520388	0.703913	0.506158	0.674025
1_good	0.193603	0.148709	0.208981	0.171803	117070.0	99587.0	121665.0	107105.0	0.447562	0.477530	0.451104	0.483716
2_medium	0.044394	-0.012185	0.048204	-0.002063	126787.0	129568.0	135052.0	135159.0	0.573978	0.610213	0.578064	0.614862
3_low	-0.103915	-0.161674	-0.094155	-0.147272	121244.0	140182.0	128323.0	147777.0	0.750691	0.733973	0.760870	0.743994
4_poor	-0.424351	-0.481693	-0.421045	-0.472021	232189.0	436210.0	242141.0	455539.0	0.982705	0.885525	0.985047	0.883482

# Table 21: Table for effective significant wave height performances (w.r.t.) WW3 model 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 48 cm. One can notice that the partitions classified as "medium" have slightly higher bias than "good" ones, it is explained by the fact that the Hs distribution is slightly modified between the two, with more Hs (over-estimated) at smaller Hs in the "good" distribution. Yet, the scatter index (normalized by Hs) confirms an improvement for "good" partitions (not shown in the table).

				bias				nb				rmse
id2	S1Awv1wdir	S1Awv2wdir	S1Bwv1wdir	S1Bwv2wdir	S1Awv1wdir	S1Awv2wdir	S1Bwv1wdir	S1Bwv2wdir	S1Awv1wdir	S1Awv2wdir	S1Bwv1wdir	S1Bwv2wdir
qcvals2												
0_very_good	8.109459	7.631575	8.143236	7.627920	22572.0	9314.0	23793.0	11190.0	11.715163	9.483532	11.761519	8.898821
1_good	9.320980	8.995803	9.722685	9.236827	117070.0	99587.0	121665.0	107105.0	13.677269	11.700340	14.745907	12.184468
2_medium	12.957766	12.789825	13.258000	13.107200	126787.0	129568.0	135052.0	135159.0	18.464297	15.668129	18.976352	15.915649
3_low	18.269807	17.564402	18.767792	17.787241	121244.0	140182.0	128323.0	147777.0	22.575816	19.866482	23.316847	20.059424
4_poor	25.791585	25.943962	26.025206	25.790769	232189.0	436210.0	242141.0	455539.0	25.356311	24.509537	25.550272	24.352788

# Table 22: Table for dominant wave direction performances (w.r.t.) WW3 model for S-1 WV swell partitions depending on the swell partition quality flag



The dominant wave direction mean bias are within a range of 7° to 26°. As expected RMSE are higher for "poor" Quality Fag partitions compare to "good" partitions. WV2 is slightly better than WV1 for most of the quality flag levels for both mean bias and RMSE.

#### **All SAR Partitions**

In the previous section, we show the results considering solely the first SAR partition, which is the one containing the most energetic value of the wave spectra. The performances of the 4 others depict lower performances compare to the first partition. Performances compare to WW3 are worst for significant wave height, wavelength and wave direction.

In Figure 77, we illustrate those lower performances not selecting any particular SAR partition. This means that each 5 wave systems delineated in the SAR wave spectra is cross assigned with the closest WW3 wave partition. And a single WW3 wave partition can be cross assigned with multiple SAR wave partitions.

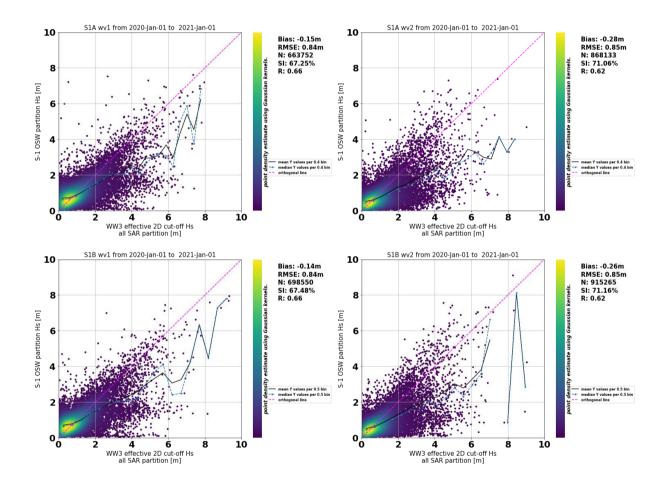


Figure 77: Scatter plots of effective Hs of all SAR partition (delineated within the 2D SAR cut-off domain) compare to effective Hs of the closest WW3 wave partition (on identical spectral domain).

Figure 77 is illustrating the fact that when we consider all the wave partitions independently of the quality flag associated and the rank (i.e., order in term of energy among the 5 partitions) the performances are much worst with RMSE about 85 cm, overestimation of energy for small sea state and underestimation for high sea state.



## 6.2.2 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 Center.

## 6.3 Radial Velocity Measurement

In this section, a status on the Level 2 OCN RVL products is provided for Wave mode and TOPS modes.

## 6.3.1 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. Analysis of restituted attitude data and Gyro data shows DC variations of around 10Hz long the orbit. 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 provided by ESTEC [S1-RD-13], and a post-processing approach is currently under implementation as part of the "Copernicus Sentinel-1 RVL Assessment" project.

Histograms of S1 WV OCN Doppler frequency is shown in Fig.75. The differences in mean Dc are mostly attributed to antenna electronics. The differences in shape of the histograms of S1a and S1b are mostly attributed to attitude variations. This can also be manifested in the scatterplot between Dc and ECMWF range wind speed as shown in Figure 76 for swath WV1 of S1a and S1b.

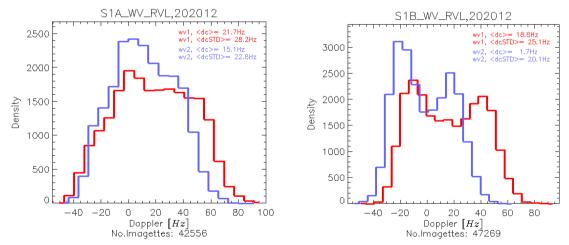


Figure 75: Histogram of one month (Dec. 2020) of S1 WV OCN Doppler frequency (rvldcObs) acquired over global ocean areas. Left: S1a, Right: S1b.



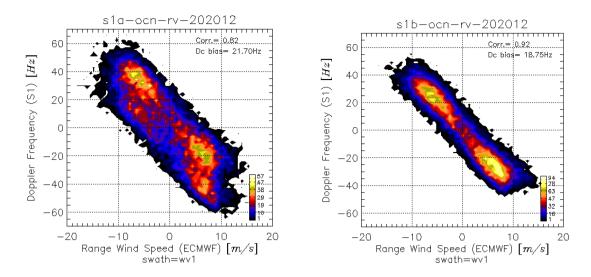
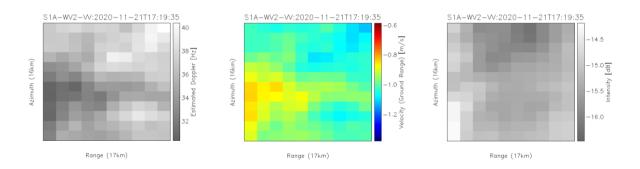


Figure 76: Scatterplot of one month (Dec. 2020) of S1 OCN Doppler frequency (rvldcObs) versus ECMWF range wind speed acquired over global ocean areas. Left: S1a WV1, Right: S1b WV1.

With the IPF3.30 a gridded RVL WV product was introduced. Instead of providing only one measurement pr. imagette, the upgrade provides an RVL product on a grid of typically 13x13 pixels pr. imagette. Example of gridded DC, RVL and NRCS from one imagette is shown in Figure 77.



#### Figure 77: Example of S1 WV OCN gridded product. Left: rvldcObs, Mid: rvlradvel, Rlght: rvlNRCS

**Time evolution**: stable performance even before and after the testing period of the optimised WV2 configuration.

**Inter comparison:** close performances between S-1A/S-1B and WV1/WV2, except for the DC bias which comes from the antenna electronics.

**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.



## 6.3.2 TOPS Mode

In the previous versions of the IPF, the OCN RVL IW and EW products were coloured by a scalloping of the DC in azimuth with burst period. The amplitude of the scalloping of the DC was around  $\pm$ 5Hz. The OCN RVL products of IW and EW modes between January and June 2020 are affected by this. A new version (IPF3.30) was installed in June 2020.

With the IPF3.30 a post-processing step was introduced in order to mitigate the scalloping observed in the RVL IW and EW products. An example of improvements is shown in Fig.77.

Examples of de-scalloped RVL images from IW and EW modes are shown in Figure 78. A significant improvement is observed. The visible trends over the swaths are caused antenna electronic DC bias. This will be compensated for as part of the Gyro based calibration of the OCN RVL product, currently under implementation. The Gyro calibration will also remove most of the fast DC variations (not easily visible in a single image) caused by attitude/orbit oscillations.

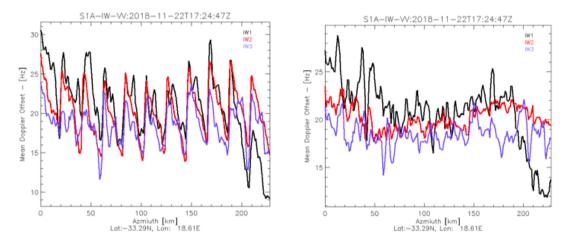


Figure 78 Example of S1A IW OCN RVL azimuth DC profiles before (left) and after (right) mitigation of the scalloping.

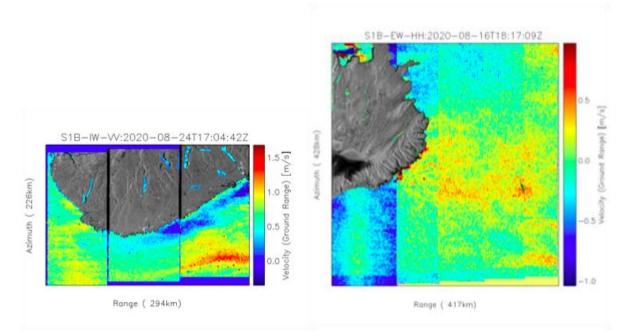


Figure 79 Example of S-1B IW (left) and EW (right) OCN RVL products (rvldcObs) processed with IPF3.30.



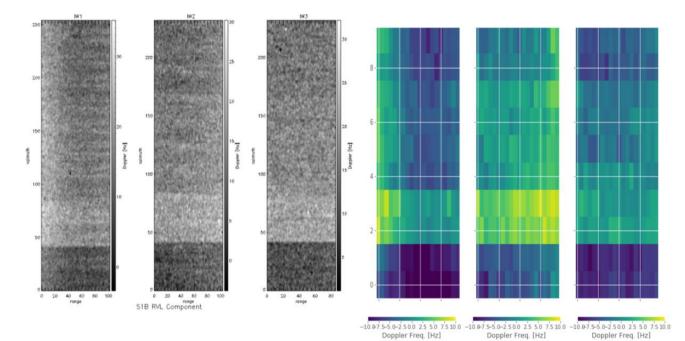
**Time evolution**: no trend in performance observed.

**Inter comparison:** very close performances between S-1A/S-1B, except for the DC bias which comes from the antenna electronics.

**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 not predictable from the downlinked quaternions.

Another artefact observed in the Sentinel-1 DC measurement is a sudden jump in DC (>10Hz) from one burst to another that persist over all swaths. These jumps are observed consistently in both Level 2 DC and raw data DC (as illustrated on the figure below). 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.



S1B\_IW\_RAW\_\_0SDV\_20180730T215018\_20180730T215050\_012046\_0162DF\_6858.SAFE Figure 80 Example of S1B IW DC showing jumps in both Level 2 OCN Dc (left) and Level 0 IPF Dc (right).

## 6.4 Quality Disclaimers

S-1A Quality disclaimers issued on L2 products during 2020 are given in Appendix C -.



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

The following S-1A & S-1B Technical Reports are available on <u>Sentinel Online Library</u> and of interest for Sentinel-1 product users

#### Sentinel-1 Level -0 Product Format Specification, issue 01, 20 December 2012

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, issue 1, 20 December 2012

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, issue 2.0, 27 June 2019

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

#### Sentinel-1 IPF Auxiliary Product Specification, issue 3.5, 07 January 2020

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 of the auxiliary data files that are beyond the scope of this document and covered by other documents.

#### Sentinel-1 Level 1 Detailed Algorithm Definition, issue 2.2, 07 June 2019

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 Ocean Wind Fields (OWI) Algorithm Definition, issue 2.0, 27 June 2019

The objective of this document is to define and describe the algorithm implemented in the S1 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, issue 1.3, 11 February 2020

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 S1 L2 processor.

#### Guide to Sentinel-1 Geocoding, issue 1.1, 27 March 2019

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, issue 1.0, 04th December 2018

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, issue 2.1, 29<sup>th</sup> January 2018

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://qc.sentinel1.copernicus.eu/

Thermal denoising of products generated by the Sentinel-1 IPF, MPC-0392, Issue 1.1, November 2017

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

#### Sentinel-1 RadarSat-2 mutual interference, MPC-0353, Issue 1.0, 28 November 2017

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.



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#### 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.

#### S-1A & S-1B N-Cyclic Reports

Those documents provide information on the S-1 quality on a four-cycle period. These reports aimed to be replaced by the annual performance report of their covering period, when the latter is available.

#### 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.



# Appendix B - S-1A & S-1B Instrument Unavailability

The S-1A instrument was unavailable during 2020 (a full list since launch can be found in Appendix C of any S-1A or S-1B N-Cyclic Performance Report):

Start Date/Time	End Date/Time	MPC Reference	Summary
06/01/2020 15:17	06/01/2020 15:42	SOB-1305	Sentinel-1A Unavailability on 06/01/2020
29/02/2020 14:43	29/02/2020 17:45	SOB-1396	Sentinel-1A Unavailability on 29/02/2020
09/09/2020 08:50	09/09/2020 11:05	SOB-1688	Sentinel-1A Unavailability on 09/09/2020
26/11/2020 10:06	26/11/2020 13:32	SOB-1839	Sentinel-1A Unavailability on 26/11/2020
26/11/2020 10:06	26/11/2020 13:32	SOB-1839	Sentinel-1A Unavailability on 26/11/2020

The S-1B instrument was unavailable during 2020 (a full list since launch can be found in Appendix C of any S-1B N-Cyclic Performance Report):

Start Date/Time	End Date/Time	MPC	Summary
		Reference	
16/01/2020 15:06	16/01/2020 18:47	SOB-1311	Sentinel-1B Unavailability on 16/01/2020
09/09/2020 08:50	09/09/2020 11:05	SOB-1746	Sentinel-1B Unavailability on 09/09/2020
07/10/2020 04:47	07/10/2020 07:59	SOB-1747	Sentinel-1B Unavailability on 07/10/2020
08/12/2020 01:56	08/12/2020 09:19	SOB-1867	Sentinel-1B Unavailability on 08/12/2020



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

The following S-1A & S-1B quality disclaimers were issued during 2020 and/or refer to products acquired/generated in 2020:

Num	Sensor	Description	Start Validity Date	End Validity Date	Issue Status
52	S-1A	S-1A Products generated without AUX_RESORB on 06 January 2020	2020-01-06 12:29:32	2020-01-06 13:33:35	Issued
53	S-1A	S-1A OCN Products generated with missing wind information (OWI) content on 11th March 2020	2020-03-10 18:41:02	2020-03-11 23:49:57	Issued
54	S-1B	S-1B OCN Products generated with missing wind information (OWI) content on 11th March 2020	2020-03-11 01:29:03	2020-03-12 01:46:50	Issued
55	S-1A	S-1A radiometric jumps on S1A IW products on 08/03/2020	2020-03-08 17:35:11	2020-03-08 17:36:01	Issued
56	S-1A	S-1A issue on the WV OCN: anomaly on swell spectrum energy with IPF 3.3x	2020-06-22 20:17:50	2020-07-02 02:00:46	Issued
57	S-1B	S-1B issue on the WV OCN: anomaly on swell spectrum energy with IPF 3.3x	2020-06-22 19:27:28	2020-07-01 21:17:10	Issued
58	S-1A	S-1A Phase artefacts for inSAR pairs acquired over geographic regions with strong variations of terrain height in range direction	2015-11-13 23:40:21	2016-04-13 10:04:58	Issued
59	S-1A	S-1A products on a same datatake processed with different processing configuration.	2015-03-23 17:14:52	2019-06-18 17:14:49	Issued
62	S-1A	Bias in OSW Wind Speed measurement for S-1A WV1 between 12th May 2020 and 23rd June 2020	2020-05-12 10:18:41	2020-06-23 01:38:51	Issued
63	S-1B	Bias in OSW Wind Speed measurement for S-1B WV1 between 12th May 2020 and 23rd June 2020	2020-05-12 11:07:24	2020-06-23 01:38:51	Issued
64	S-1A	Bias in OSW Wind Speed measurement for S-1A WV2 starting from 12th May 2020 2020	2020-05-12 10:18:41		Issued
65	S-1B	Bias in OSW Wind Speed measurement for S-1B WV2 starting from 12th May 2020	2020-05-12 11:07:24		Issued
66	S-1A	Bias in radiometric calibration of S1- A WV products acquired before 12th May 2020	2014-09-30 15:17:26	2020-05-12 10:18:41	Issued
67	S-1B	Bias in radiometric calibration of S1- B WV products acquired before 12th May 2020	2016-09-26 00:12:13	2020-05-12 11:07:24	Issued



# Appendix D - S-1A & S-1B Orbit Cycles

The table below gives the S-1A cycle number with start and stop acquisition dates during 2020. The start of a cycle is at approximately 18:00 UT on the dates below.

Cycle	Start Date	End Date
189	26/12/2019	07/01/2020
190	07/01/2020	19/01/2020
191	19/01/2020	31/01/2020
192	31/01/2020	12/02/2020
193	12/02/2020	24/02/2020
194	24/02/2020	07/03/2020
195	07/03/2020	19/03/2020
196	19/03/2020	31/03/2020
197	31/03/2020	12/04/2020
198	12/04/2020	24/04/2020
199	24/04/2020	06/05/2020
200	06/05/2020	18/05/2020
201	18/05/2020	30/05/2020
202	30/05/2020	11/06/2020
203	11/06/2020	23/06/2020
204	23/06/2020	05/07/2020
205	05/07/2020	17/07/2020
206	17/07/2020	29/07/2020
207	29/07/2020	10/08/2020
208	10/08/2020	22/08/2020
209	22/08/2020	03/09/2020
210	03/09/2020	15/09/2020
211	15/09/2020	27/09/2020
212	27/09/2020	09/10/2020
213	09/10/2020	21/10/2020
214	21/10/2020	02/11/2020
215	02/11/2020	14/11/2020
216	14/11/2020	26/11/2020



217	26/11/2020	08/12/2020
218	08/12/2020	20/12/2020
219	20/12/2020	01/01/2021
220	01/01/2021	13/01/2021

The table below gives the S-1B cycle number with start and stop acquisition dates during 2020. The start of a cycle is at approximately 18:00 UT on the dates below.

Cycle	Start Date	End Date
119	01/01/2020	13/01/2020
120	13/01/2020	25/01/2020
121	25/01/2020	06/02/2020
122	06/02/2020	18/02/2020
123	18/02/2020	01/03/2020
124	01/03/2020	13/03/2020
125	13/03/2020	25/03/2020
126	25/03/2020	06/04/2020
127	06/04/2020	18/04/2020
128	18/04/2020	30/04/2020
129	30/04/2020	12/05/2020
130	12/05/2020	24/05/2020
131	24/05/2020	05/06/2020
132	05/06/2020	17/06/2020
133	17/06/2020	29/06/2020
134	29/06/2020	11/07/2020
135	11/07/2020	23/07/2020
136	23/07/2020	04/08/2020
137	04/08/2020	16/08/2020
138	16/08/2020	28/08/2020
139	28/08/2020	09/09/2020
140	09/09/2020	21/09/2020
141	21/09/2020	03/10/2020
142	03/10/2020	15/10/2020
143	15/10/2020	27/10/2020



144	27/10/2020	08/11/2020
145	08/11/2020	20/11/2020
146	20/11/2020	02/12/2020
147	02/12/2020	14/12/2020
148	14/12/2020	26/12/2020
149	26/12/2020	07/01/2021



S-1A & S-1B Annual Performance Report for 2020101/108MPC-0504 - Issue 1.1 - 16/03/2021Internal/Internal (Internal Confidential)

# Appendix E - S-1A & S-1B Transmit Receive Module Failures

There were no S-1A or S-1B antenna Transmit/Receive Modules (TRMs) failures during 2020 (a full list since launch can be found in Appendix B of any S-1A or S-1B N-Cyclic Performance Report).



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

The following S-1A Auxiliary Data Files (ADFs) were updated during 2020:

### S-1A Instrument ADF (AUX\_INS)

ADF	Update Reason

### S-1A Calibration ADF (AUX\_CAL)

ADF	Update Reason
S1A_AUX_CAL_V20190228T092500_G20201215T124819.SAFE	Refinement of S1A EW DH Elevation Antenna patterns. Related to RDB#7
S1A_AUX_CAL_V20171017T080000_G20201215T124601.SAFE	Refinement of S1A EW DH Elevation Antenna patterns. Related to RDB#6

### S-1A L1 Processor Parameters ADF (AUX\_PP1)

ADF	Update Reason
S1A_AUX_PP1_V20140406T133000_G20200512T125143.SAFE	Review of the processing gains for WV : in order to adapt the new geophysical calibration methodology based on denoised NRCS vs Cmod5n.
	Related to RDB#1
S1A_AUX_PP1_V20140616T133500_G20200512T125349.SAFE	As above but related to RDB#2.
S1A_AUX_PP1_V20140908T000000_G20200512T125439.SAFE S1A_AUX_PP1_V20150519T120000_G20200512T125523.SAFE	As above but related to RDB#3.
S1A_AUX_PP1_V20150519T120000_G20200512T125523.SAFE	As above but related to RDB#4.
S1A_AUX_PP1_V20171017T080000_G20200512T125711.SAFE	As above but related to RDB#5.
S1A_AUX_PP1_V20190228T092500_G20200512T125926.SAFE	As above but with WV2 processing gain specific to RDB#7





	RDB#7 only affects WV2 mode (no impact on SM/IW/EW modes). Related to RDB#7.
S1A_AUX_PP1_V20171017T080000_G20201215T124539.SAFE	Refinement of S1A EW DH processing gain to accommodate refinement of Elevation Antenna patterns. Related to RDB#6
S1A_AUX_PP1_V20190228T092500_G20201215T124759.SAFE	Refinement of S1A EW DH processing gain to accommodate refinement of Elevation Antenna patterns. Related to RDB#7

## S-1A L2 Processor Parameters ADF (AUX\_PP2)

ADF	Update Reason
S1A_AUX_PP2_V20190228T092500_G20200623T082643.SAFE	S1A-AUX-PP2 compliant with IPF 3.30 and RDB#7.
	This version of the IPF activates the module OWI (surface wind measurement) on WV modes. The processing parameters have been adapted to provide OWI output variables on 1km2 grid (same parameters as for TOP and SM modes). In addition, with this version of IPF, the RVL variables on WV will be gridded (rvlAzSize and rvlRgSize approximatively 10x10, grid 2km2), the RVL parameter rangeBlockSize has also been updated.
S1A_AUX_PP2_V20171017T080000_G20200623T082615.SAFE	Compliant with RDB#6, with same content
S1A_AUX_PP2_V20150722T120000_G20200623T082546.SAFE	Compliant with RDB#5, with same content
S1A_AUX_PP2_V20150519T120000_G20200623T082512.SAFE	Compliant with RDB#4, with same content
S1A_AUX_PP2_V20140908T000000_G20200623T082447.SAFE	Compliant with RDB#3, with same content
S1A_AUX_PP2_V20140616T133500_G20200623T082421.SAFE	Compliant with RDB#2, with same content
S1A_AUX_PP2_V20140406T133000_G20200623T082350.SAFE	Compliant with RDB#1, with same content



### S-1A Simulated Cross Spectra ADF (AUX\_SCS)

ADF	Update Reason
S1AUX_SCS_V20140406T133000_G20200623T142050.SAFE	This new AUX_SCS files was specifically developed to accompany a modification of the MTF (Modulation Transfer Function) estimated in the Level-2 Ocean Processor (LOP) in the ocean swell processing on IPF 3.30. This modification was performed to remove the several ad-hoc tunings applied to the initial MTF and to also propose a better compensation of the ocean wave spectral energy with respect to the ocean surface wind speed. Note: this is a common configuration for both S1A and S1B

### The following S-1B Auxiliary Data Files (ADFs) were updated during 2020:

### S-1B Instrument ADF (AUX\_INS)

ADF	Update Reason

### S-1B Calibration ADF (AUX\_CAL)

ADF	Update Reason
S1B_AUX_CAL_V20160422T000000_G20200512T124236.SAFE	Revised S1B IW DV (VV/VH) Elevation Antenna Patterns for ICID#1. Related to RDB#1.
S1B_AUX_CAL_V20190514T090000_G20200512T124403.SAFE	As above but related to RDB#2.
S1B_AUX_CAL_V20160422T000000_G20201215T123756.SAFE	Refinement of S1B EW DV and DH Elevation Antenna patterns. Related to RDB#1
S1B_AUX_CAL_V20190514T090000_G20201215T124222.SAFE	Refinement of S1B EW DV and DH Elevation Antenna patterns. Related to RDB $\#2$



### S-1B L1 Processor Parameters ADF (AUX\_PP1)

ADF	Update Reason
S1B_AUX_PP1_V20160422T000000_G20200512T124627.SAFE	Refinement of S1B IW DV processing gains relative to the review of Elevation Antenna patterns.
	Review of the processing gains for WV: in order to adapt the new geophysical calibration methodology based on denoised NRCS vs Cmod5n.
	Related to RDB#1
S1B_AUX_PP1_V20190514T090000_G20200512T124816.SAFE	As above but with WV2 processing gain specific to RDB#2
	RDB#2 only affects WV2 mode (no impact on SM/IW/EW modes). Related to RDB#2.
S1B_AUX_PP1_V20160422T000000_G20201215T123723.SAFE	Refinement of S1B EW DV and DH processing gain to accommodate review of Elevation Antenna patterns. Related to RDB #1
S1B_AUX_PP1_V20190514T090000_G20201215T124143.SAFE	Refinement of S1B EW DV and DH processing gain to accommodate review of Elevation Antenna patterns. Related to RDB #2

### S-1B L2 Processor Parameters ADF (AUX\_PP2)

ADF	Update Reason
S1B_AUX_PP2_V20190514T090000_G20200623T082237.SAFE	S1A-AUX-PP2 compliant with IPF 3.30 and RDB#2.
	This version of the IPF activates the module OWI (surface wind measurement) on WV modes. The processing parameters have been adapted to provide OWI output variables on 1km2 grid (same parameters as for TOP and SM modes). In addition, with this version of IPF, the RVL variables on WV will be gridded (rvlAzSize and rvlRgSize approximatively 10x10, grid 2km2), the RVL parameter rangeBlockSize has also been updated.
S1B_AUX_PP2_V20160422T000000_G20200623T082204.SAFE	As above and compliant with RDB#1

### S-1B Simulated Cross Spectra ADF (AUX\_SCS)

ADF	Update Reason
S1AUX_SCS_V20140406T133000_G20200623T142050.SAFE	This new AUX_SCS files was specifically developed to accompany a modification of the MTF (Modulation Transfer Function) estimated in the Level-2 Ocean Processor (LOP) in the ocean swell processing on IPF 3.30. This modification was performed to remove the several ad-hoc tunings applied to the initial MTF and to also propose a better compensation of the ocean wave spectral energy with respect to the ocean surface wind speed. Note: this is a common configuration for both S1A and S1B



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