EDAP+ TN on Quality Assessment of NovaSAR-1

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AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
0.1	18/07/2023	First draft of the document including results of L1 and L2 products assessment. For ESA and Airbus review.
1.0	09/01/2024	First issue of the TN addressing feedback from ESA and data provider
1.1	18/03/2024	Minor fixes implemented. First issue published on EDAP website.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The results of the independent assessment of NovaSAR-1 data quality can be found in the following sections of this report. The main outcomes of the assessment are summarised as follows:

- The documentation is well-detailed and mostly available on-line.
- The data acquired over Australia are easily accessible by the users through the CSIRO on-line datahub. For other data, users must refer to Airbus DS UK.
- The assessment of the Impulse Response Function (**IRF**) quality has shown that geometric resolution is in line with the products specification.
- The assessment of the geolocation accuracy has shown that the measured geolocation accuracy widely meets the mission requirement. On the other hand, a discrepancy in the geolocation accuracy between SLC and GRD levels can be observed, which can be explained with a not enough accurate ground to slant polynomial annotated in the metadata.
- The assessment of the rain forest products has underlined that the Elevation Antenna Pattern (**EAP**) is in general quite well-compensated and that the radiometric level is in general homogeneous among different acquisitions. Still, in ScanSAR Multi Look Detected (**SCD**) products, some beam-to-beam residual radiometric variations can be observed.
- The assessment of the residual scalloping profile does not reveal significant issues.
- The absolute radiometric calibration analysis performed on SLC and GRD products gives quite good results. On the other hand, results obtained for SCD products are not reliable due to the size of the CRs with respect to the SCD resolution.
- The sensitivity analysis results match the expectations, being the estimated NESZ level well below the worst-case reference level (reported in [RD-6]).
- For Analysis Ready Data (**ARD**), a selection of Airbus DS UK NovaSAR-1 products have been obtained for different scenarios: including variable terrain and ocean sites. The analysis included:
    - A visual validation that reviewed the provided products but showed there was uncertainty caused by the lack of provided documentation.
    - The ascertained geometric accuracy was not as high as determined for the L1 products, but within the specified target.
    - The products are not CEOS conformant and areas that would need to be addressed have been identified.

1.1 References

The following is a list of reference documents with a direct bearing on the content of this assessment. Where referenced in the text, these are identified as [RD-n], where 'n' is the number in the list below:

RD-1. Earth Observation Mission Quality Assessment Framework, EDAP.REP.001, v2.2, December 2022. Available at https://earth.esa.int/eogateway/documents/20142/37627/Mission-Quality-Assessment-Guidelines-v2.2.pdf/033c703e-02f8-d993-9859-560aeb61d2a0?t=1676561363850

RD-2. Earth Observation Mission Quality Assessment Framework - SAR Guidelines, EDAP.REP.060, v1.0, November 2021. Available at:

https://earth.esa.int/eogateway/documents/20142/37627/SAR+Mission+Quality+Assessment+Guidelines.pdf/a608bb6f-a3e1-0e7b-c652-2812049431cc

RD-3. EDAP+ TN on Methods and Reference Data for SAR Data Quality Assessments, EDAP+.REP.007, v1.0, March 2023. Available at: https://earth.esa.int/eogateway/documents/20142/37627/EDAP%2B.REP.007%20EDAP%2B%20TN%20for%20Methods%20and%20Reference%20Data%20for%20SAR%20Data%20Quality%20Assessments%20v11.pdf/9d8e8d28-025a-1e98-0342-7e644e8fe96a?version=1.0&t=1684419934084

RD-4. NovaSAR Level 1 Products, SSTL ref: 0342129, release number 003, June 2020. Available at https://research.csiro.au/cceo/wp-content/uploads/sites/252/2020/09/NovaSAR-1_Level-1_Products.pdf

RD-5. NovaSAR Imaging Modes, SSTL ref: 0320909, release number 008, July 2020. Not available on-line.

RD-6. NovaSAR Payload Calibration June 2022, SSTL ref: 0381787, release number 001, August 2022. Not available on-line.

RD-7. NovaSAR-1 National Facility Datahub Terms and Conditions. Available at https://research.csiro.au/cceo/novasar/novasar-introduction/governance/novasar-1-national-facility-datahub-terms-and-conditions/

RD-8. NovaSAR-1 Datahub User Guide. Available at https://research.csiro.au/cceo/novasar/novasar-introduction/data/datahub-user-guide/

RD-9. NovaSAR-1 User Guide. Available at https://research.csiro.au/cceo/novasar/novasar-introduction/novasar-1-user-guide/#overview

RD-10. NovaSAR Resources. Available at https://research.csiro.au/cceo/novasar/novasar-introduction/resources/

RD-11. NovaSAR L2 product description document [not supplied at the time of this issue]

RD-12. EDAP+ TN on Validation of Optical Image Matching Tools, EDAP+.REP.029, version 0.2, 15/06/2023

RD-13. CSIRO Geolocation Accuracy Assessment of NovaSAR-1 Analysis Ready Data Products, July 2023. Available at https://research.csiro.au/cceo/geolocation-accuracy-assessment-of-novasar-1-ard-products

RD-14. Product Family Specification v5.5, Normalised Radar Backscatter. Available at https://ceos.org/ard/files/PFS/NRB/v5.5/CARD4L-PFS_NRB_v5.5.pdf

1.2 Glossary

The following acronyms and abbreviations have been used in this Report.

Airbus DS	Airbus Defence and Space
ALE	Absolute Localisation Error

ARD	Analysis Ready Data
ATBD	Algorithm Theoretical Basis Document
CR	Corner Reflector
CW	Calm Water
DEM	Digital Elevation Model
EAP	Elevation Antenna Pattern
GRD	Ground Range Detected
IRF	Impulse Response Function
ISLR	Integrated to Side Lobe Ratio
L1	Level 1
L2	Level 2
LTAN	Local Time of the Ascending Node
NESZ	Noise Equivalent Sigma Nought
PSLR	Peak to Side Lobe Ratio
PT	Point Target
RCS	Radar Cross Section
RF	Rain Forest
RMSE	Root Mean Square Error
rRMSE	radial Root Mean Square Error
RTC	Response Terrain Corrected
SCD	ScanSAR Multi Look Detected
SLC	Stripmap Single Look Complex
SRD	Stripmap Multi Look Detected
SSTL	Surrey Satellite Technology Ltd
TC	Terrain Corrected
UKSA	UK Space Agency

1.3 Cal/Val Maturity Matrices

1.3.1 Summary Cal/Val Maturity Matrix

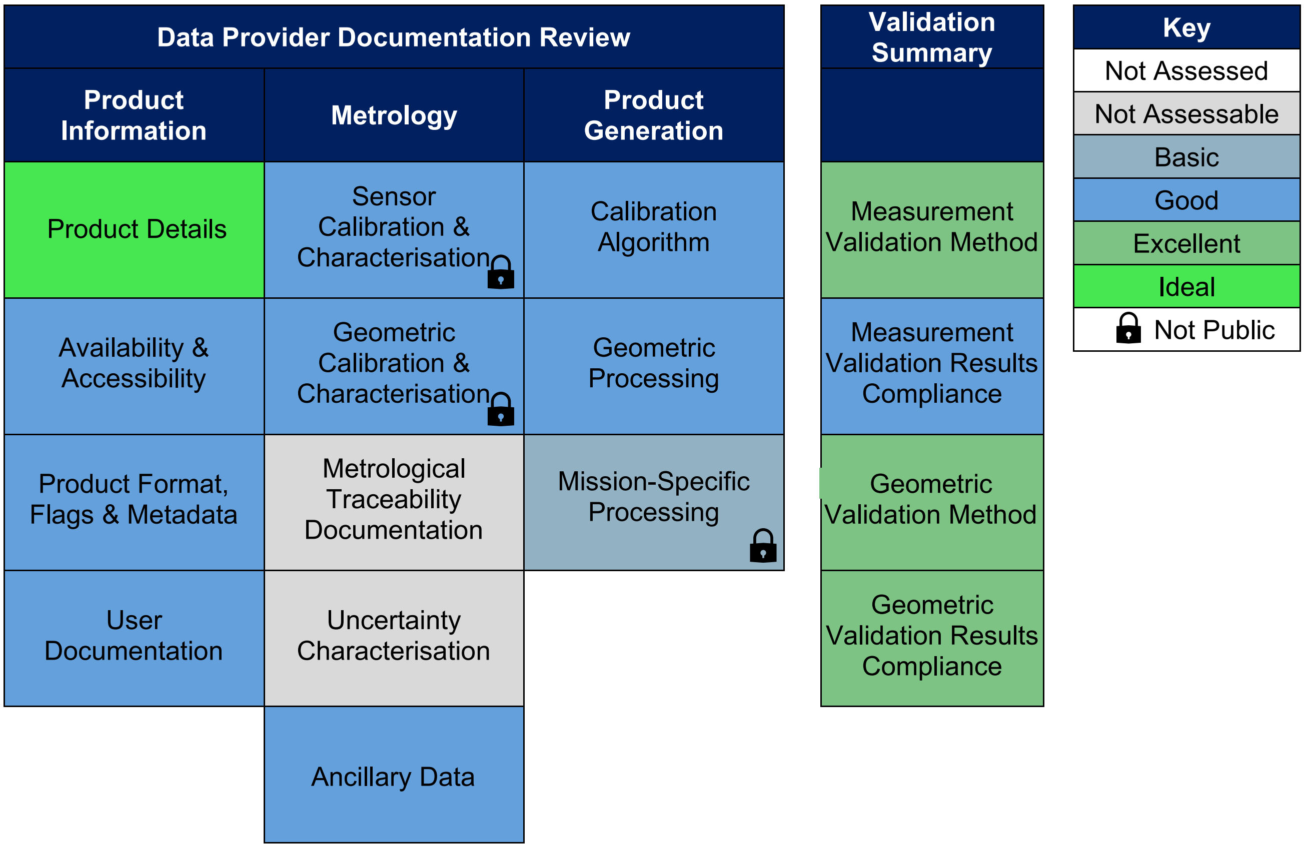


Figure 1-1: Summary Matrix Cal/Val Maturity Matrix

1.3.2 Validation Cal/Val Maturity Matrix

Aresys Detailed Validation			
Measurement		Geometric	
Radiometric stability: EAP compensation and Beam-to-beam calibration Method	Radiometric stability: EAP compensation and Beam-to-beam calibration Results Compliance	Spatial Resolution and IRF Analysis Method	Spatial Resolution and IRF Analysis Results Compliance
Radiometric stability: Residual Azimuth Scalloping Method	Radiometric stability: Residual Azimuth Scalloping Results Compliance	Geolocation Accuracy Method	Geolocation Accuracy Results Compliance
Absolute Radiometric Calibration Method	Absolute Radiometric Calibration Results Compliance		
Sensitivity Validation Method	Sensitivity Validation Results Compliance		

Key
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal
Not Public

Figure 1-2: Validation Cal/Val Maturity Matrix

2. DATA PROVIDER DOCUMENTATION REVIEW

2.1 Product Information

Product Details	
Grade: Ideal	
Justification	*All required information is available.*
Product Name	*NovaSAR_01 L1 SLC/GRD/SCD Product*
Sensor Name	*NovaSAR_01*
Sensor Type	*S-Band SAR*
Mission Type	*Single satellite*
Mission Orbit	*583km SSO 10:30am LTAN*
Product Version Number	*003 (according to [RD-4])*
Product ID	*NovaSAR_01_acqID_prodType_prodID_date_time_polList*
Processing level of product	*Four types of products, all Level 1, are available to the users:* • *Stripmap Single Look Complex (**SLC**) (slant range)* • *Stripmap Multi Look Detected (**SRD**) (slant range)* • *Stripmap Multi Look Detected (**GRD**) (ground range)* • *ScanSAR Multi Look Detected (**SCD**) (ground range)* *Among these, SLC, GRD and SCD products have been selected for the assessment.*
Measured Quantity Name	*The squared pixel is the radiometric scattering cross section (SLC: β^0, GRD/SCD: σ^0)*
Measured Quantity Units	m^2 or m^2/m^2 *(depending on SCL or GRD/SCD)*
Stated Measurement Quality	*Radiometric stability: standard deviation of 0.41 dB (according to [RD-9])* *Requirement for geolocation error: <50m (according to [RD-9])*
Spatial Resolution	*Among many product types, the selected ones for the assessment have the following resolution:* • *Stripmap (SLC, GRD): 6 x 6 m (ground range x azimuth)* • *ScanSAR (SCD): 20 x 20 m (ground range x azimuth)*
Spatial Coverage	*SLC, GRD: 13-20 km* *SCD: 50-100 km*
Temporal Resolution	*16 days*
Temporal Coverage	*2019 to now (launched: 2018, design life: 7 years)*
Point of Contact	*Robert.Fletcher@airbus.com*

Product locator (DOI/URL)	*Airbus DS UK - Robert.Fletcher@airbus.com CSIRO (Australia) - https://data.novasar.csiro.au/#/home*
Conditions for access and use	*Data have been provided directly by the data originator (Airbus DS UK). A portion of data, those acquired over Australia, can be downloaded by users from CSIRO online catalogue which provides free and open access to all (terms and conditions apply, see [RD-7])*
Limitations on public access	*CSIRO online catalogue: registration and acceptance of terms and conditions required, while no charge is applied for data access.*
Product Abstract	*SLC: stripmap, single look, complex, slant range. SRD: stripmap, multi-look, detected, slant range. GRD: stripmap, multi-look, detected, ground range (using ellipsoid). SCD: scanSAR, multi-look, detected, ground range (using ellipsoid). Calibration status specified in product metadata. No terrain correction applied.*

Availability & Accessibility	
Grade: Good	
Justification	*Data acquired by CSIRO, predominantly over Australia, are easily accessible by the user through the CSIRO on-line datahub (at https://data.novasar.csiro.au/#/home, user guide available on-line at [RD-8]). For data acquired over other regions, users must refer to Airbus DS UK.*
Compliant with FAIR principles	*No*
Data Management Plan	*From CSIRO datahub, data can be retrieved according to: • product directory name • geographical extents • sensing/ingestion time • product type • pass direction • antenna pointing • polarisation • operational mode*
Availability Status	*Data found on CSIRO datahub are ready for the download.*

Product Format
Grade: Good

Justification	*Data format is well-documented.* *Metadata are well-populated and well-documented apart from:* • *Zero-Doppler reference frame not well defined* • *Attitude angles order (expressed as Euler angles) not defined*
Product File Format	*Product is delivered in the form of a zip file including a metadata stylesheet xsl file and one or more (if the product is sliced for size reasons) product folders each one containing:* • *one metadata xml file* • *one image product GeoTIFF tif file per each polarization* • *one quick-look tif file per each polarization* *The product format is fully described in [RD-4] (document available online, see reference).*
Metadata Conventions	*xml*
Analysis Ready Data?	*Analysed in Section 6*

User Documentation		
Grade: Good		
Justification	*The online user guide ([RD-8]) is well-detailed while the Algorithm Theoretical Basis Document (**ATBD**) is not available.*	
Document	*Reference*	*QA4ECV Compliant*
Product User Guide	*A well-detailed product overview is available on-line at [RD-9] with further links at the resources page [RD-10].* *In addition, further documentation can be distributed, upon request, by Airbus DS/SSTL, providing there are no sanctions or end use/end user concerns, giving an extensive description of:* • *imaging modes [RD-5]* • *results from the calibration campaign led in June 2022 [RD-6]*	*No*
ATBD	*Not available*	*N/A*

2.2 Metrology

Sensor Calibration & Characterisation	
Grade: Good	
Justification	*Calibration campaigns are performed on annual basis by SSTL in which reference chirp, radiometric stability, radiometric correction across swath and sensitivity are assessed. Results are reported in dedicated documentation (not available on-line). Almost no details on the applied methods are reported. A summary of the results from the commissioning phase is available on-line.*
References	• *Results from the campaign led in June 2022 are reported in [RD-6] (which can be distributed by Airbus DS UK/SSTL, upon request, providing there are no sanctions or end use/end user concerns)* • *A summary of results from the commissioning phase calibration is available on-line at [RD-9]*

Geometric Calibration & Characterisation	
Grade: Good	
Justification	*Calibration campaigns are performed on annual basis by SSTL in which resolution, peak-to-side lobes parameters, and geolocation accuracy and stability are assessed. Results are reported in dedicated documentation (not available on-line). Almost no details on the applied methods are reported. A summary of the results from the commissioning phase is available on-line.*
References	• *Results from the campaign led in June 2022 are reported in [RD-6] (provided by Airbus DS UK upon request and not available on-line)* • *A summary of results from the commissioning phase calibration is available on-line at [RD-9]*

Metrological Traceability Documentation	
Grade: Not Assessable	
Justification	*No traceability documentation provided*
References	*Not available*

Uncertainty Characterisation	
Grade: Not Assessable	
Justification	*No pixel-level uncertainty characterization is reported in the product.*
References	*Not available*

Ancillary Data	
Grade: Good	
Justification	*Ancillary data are provided as xml file. The ancillary data are well-detailed and include information about acquisition, orbit, attitude and processing. Flags related to telemetry, radiometry, calibration are also provided. Information is missing on:* • *Zero-Doppler reference frame not well defined* • *Attitude angles order (expressed as Euler angles) not defined*
References	• *Ancillary data are well-detailed in [RD-4]*

2.3 Product Generation

Calibration Algorithm	
Grade: Good	
Justification	*Applied processing algorithm is specified in metadata (among Range Migration and Range Doppler – Interpolator/Fourier Shift/Chirp Scale). Calibration is sometimes performed according to what specified in metadata.* *Multilooking applied at GRD/SCD level.*
References	• *Specified in [RD-4]*

Geometric Processing	
Grade: Good	
Justification	*The SAR data in RADAR coordinates (SLC) are projected into geographical coordinates on WGS84 ellipsoid (GRD and SCD).*
References	• *Specified in [RD-4]*

Mission-Specific Processing	
Grade: Basic	
Additional Processing 1	
Justification	*The L2 ARD products have been analysed in Section 6, and they are showing promise in terms of being an easier-to-use product for the non-specialist. However, there are open questions that have been compounded by the details of the product processing not being available.*
Reference	• *NovaSAR-1 L2 product description document [RD-11] (not currently provided, as still been worked on by Airbus DS)*

3. MISSION OVERVIEW

NovaSAR-*1* is a joint technology demonstration initiative of Surrey Satellite Technology Ltd (**SSTL**), UK and Airbus Defence and Space (**Airbus DS**) (formerly EADS Astrium Ltd, Stevenage, UK), funded by the UK Government via the UK Space Agency (**UKSA**). NovaSAR-*1* is a relatively small satellite, with a mass of 450 kg. It was developed to be low-cost whilst still providing medium resolution data with wide coverage. This is achieved by:

- Reuse of SSTL heritage avionics (satellite platform) to reduce risk.
- Compatibility with existing SSTL satellite ground control segment.
- The payload back-end comes from the existing Airbus DS UK instrument architecture.
- Use of off-the-shelf component where suitable to reduce cost.

The satellite flies in a sun-synchronous orbit at 583 km altitude with a Local Time of the Ascending Node (**LTAN**) of 10:30. Each orbit shifts to the west by approximately 24.3° of longitude at the equator. There are 15 revolutions a day and the repetition cycle is 16 days.

The payload operates in the S-band microwave frequency (3.2 GHz), corresponding to a 9.4 cm wavelength. The sensor can operate both in right-looking or left-looking antenna pointing directions, from an ascending or descending orbit and in four operational modes:

- Stripmap
- ScanSAR
- ScanSAR Wide
- Maritime

with different resolution, coverage and polarization, as reported in Table 3-1 in which the most popular modes are described (for further modes and details please refer to [RD-9] and [RD-5].

Whilst Level-0 (raw SAR data) products are unavailable to the users, different Level-1 products are available to the users, represented in

Figure 3-1. It must be noted that for the purpose of this EDAP activity, whose objective is to address the most popular products, it was agreed to investigate the following modes/levels:

- SLC 6 m Stripmap (HH/VV)
- GRD 6 m Stripmap (HH/VV)
- SCD 20 m ScanSAR (HH/VV)

Table 3-1: Most popular NovaSAR-*1* modes

Mode type	Mode Name	Polarisation			Ground range resolution	Incidence angles (at 580km altitude)	No. of Swaths	Swath width (across track)	Worst Case Sensitivity (NESZ)	No. of looks
Maritime	Maritime	Single	Co	HH	6m range, 13.7m azimuth	34.5-57.3°	1	400 km	<-9.7dB	1 (1 range, 1 azimuth)
ScanSAR	20m_ScanSAR_HHHV	Dual	CoCross	HH & HV	20m	12.95-31.18°	8	25-27km	<-20 dB	3 (1 range, 3 azimuth)
	20m_ScanSAR_HHVV	Dual	Co	HH & VV	20m	13.98-30.6°	5	50-60 km	<-20.0 dB	3 (3 range, 1 azimuth)
	30m_ScanSAR_VVHHHV	Triple	CoCross	HH & VV & HV	30m	15.0-29.1°	3	50-56 km	<-27dB	2 (1 range, 2 azimuth)
	35m_ScanSAR_100km_VVHHHV	Triple	CoCross	HH & VV & HV	35m	14.39-29.08°	2	100 km	<-26 dB	1 (1 range, 1 azimuth)
ScanSAR Wide	33m_ScanSAR_195km_HH	Single	Co	HH	33m	11.82-30.26°	1	195 km	< -19.5 dB	3 (3 range, 1 azimuth)
	50m_ScanSAR_195km_HHHV	Dual	CoCross	HH & HV	50m	12.95-31.18°	1	195 km	<-19 dB (HH) <-22 dB (HV)	6 Co-pol (6 range, 1 Azimuth) 3 Cross-Pol (3 range, 1 azimuth)
Stripmap	6m_Stripmap_HH	Single	Co	HH	6m	16-25.38°	9	20 km	<-20 dB	3 (1 range, 3 azimuth)
						21.29-31.2°	11	13-20 km	<-19 dB	
	6m_Stripmap_VV	Single	Co	VV	6m	16-25.38°	9	20 km	<-20 dB	3 (1 range, 3 azimuth)
						21.29-31.2°	11	13-20 km	<-19 dB	

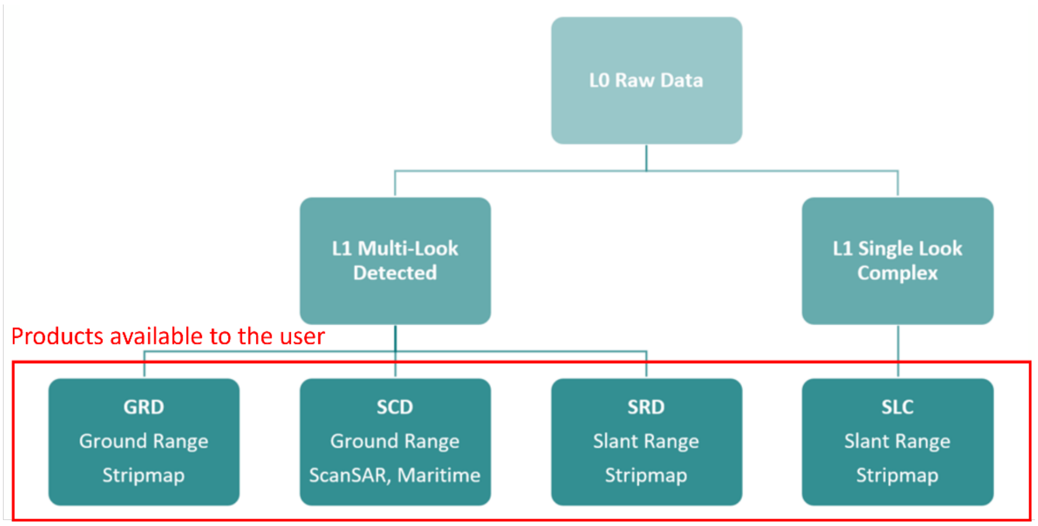


Figure 3-1: NovaSAR-1 product types

4. DETAILED VALIDATION – MEASUREMENT

4.1 Introduction

The measurement validation performed for NovaSAR-1 data includes the following topics:

- Radiometric Stability
- Absolute Radiometric Calibration
- Sensitivity Validation

For what concerns the Radiometric Stability, the following aspects were assessed:

- EAP compensation and (for ScanSAR products only) Beam-to-beam calibration
- Residual azimuth scalloping (for ScanSAR products only)

For this purpose, products acquired over Rain Forest (**RF**) distributed target calibration site (Cameroon area, see Figure 4-1) have been exploited, distributed as follows:

- 12 products, divided in slices (directly provided by Airbus DS UK)
  → 4 SLC + 4 GRD + 4 SCD

The Absolute Radiometric Calibration assessment was performed by analysing the measured Radar Cross Section (**RCS**) compared with the expected one, thus obtaining and evaluating the following metric:

- Residual Calibration Constant

Due to the unavailability of products acquired over transponders, which would be the best suited for this purpose, measurements obtained from Surat Basin calibration site Corner Reflectors (**CR**) have been considered (see Figure 4-2). The exploited products are distributed as follows:

- Valid measurements from 14 products acquired over Surat Basin
  → 6 SLC + 7 GRD + 1 SCD

For what concerns the Sensitivity Validation, the analysis was performed by comparing the expected sensitivity level (as reported in [RD-6]) with the Noise Equivalent Sigma Nought (**NESZ**) profiles as measured from the data.

For this purpose, the same products exploited for this analysis in RD-6 were provided by Airbus DS UK. Those products were acquired over Calm Water (**CW**) zones (see Figure 4-3) where the backscatter is low enough to measure the NESZ directly from the data. In particular the analysis covered:

→ 2 GRD products acquired over Maracaibo Lake
→ 2 GRD products acquired over Gulf of Panama

The full list of products acquired over Rain Forest, Surat Basin site and Calm Water areas is reported in tables in APPENDIX A.

Figure 4-1: Cameroon Rain Forest distributed target calibration site.

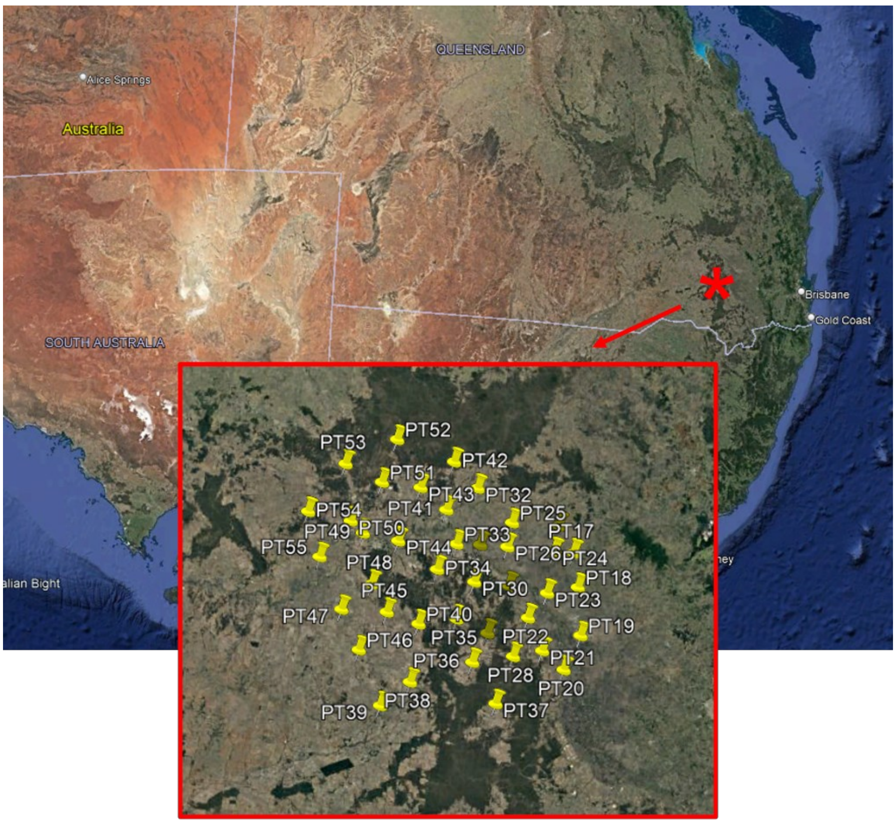


Figure 4-2: Surat Basin calibration site, Queensland, Australia. Corner reflectors size goes from 1.5 m to 2.5 m.

Figure 4-3: Calm Water areas: Gulf if Panama, Panama (left) and Maracaibo Lake, Venezuela (right).

4.2 Measurement Validation Activity #1 – Radiometric Stability: Elevation Antenna Pattern compensation and Beam-to-beam calibration

4.2.1 Method

By exploiting data acquired over RF, under the assumption that the γ^0 is independent from the incidence angle, it is possible to verify the agreement between the patterns exploited for data compensation and the actual patterns by assessing the flatness of the γ^0 profiles.

The RF acquisitions first undergo data masking, in order to discard non-homogenous areas, the geometric calibration is applied in order to convert β^0 or σ^0 values (depending on if the analysed product is SLC or GRD/SCD) into γ^0 and last, the obtained values are averaged in azimuth direction to get an elevation profile of the analysed product. It must be noted that the γ^0 profiles obtained according to the described processing refer to the corrections performed by the NovaSAR-1 processor: residual corrections, as the topography effects (the correction applied by the processor refers to the Ellipsoid), could be applied to the obtained profiles to compensate for effects not accounted by the processor. For further details on the method, please refer to [RD-3].

The obtained γ^0 elevation profiles are then exploited to assess EAP. Figure 4-4 shows a detail of a quick-look of a NovaSAR-1 SLC HH acquisition over Cameroon Rain Forest while Figure 4-5 shows the results of the γ^0 profiles estimation from the same product. The colour represents the number of points falling in a certain bin (off-boresight angle vs radiometric level) and the dashed black line is the estimated average γ^0 profile. In this example, the obtained profile is flat meaning that the EAP is correctly applied.

Figure 4-4: Detail of quick-look of a SLC acquisition slice over Cameroon Rain Forest NovaSAR_01_40080_slc_11_221210_092053_HH_1

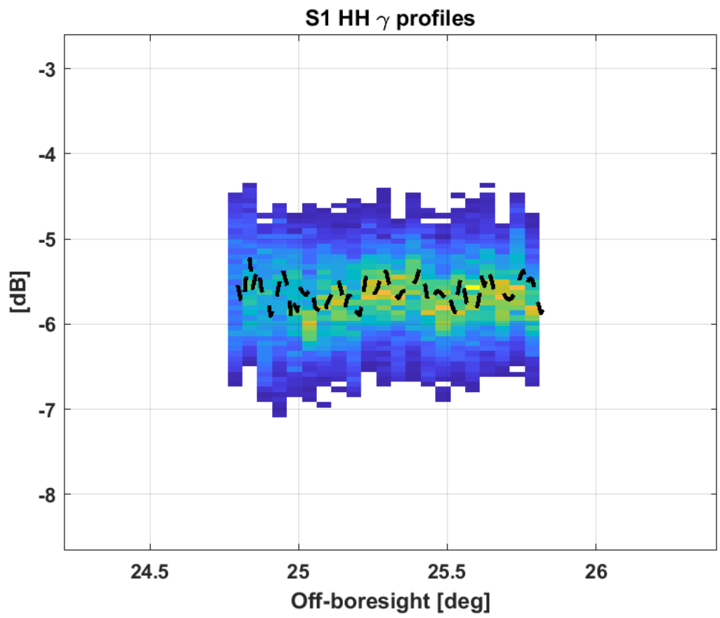


Figure 4-5: Results of γ^0 elevation profiles extraction from SLC acquisition over Cameroon Rain Forest NovaSAR_01_40080_slc_11_221210_092053_HH_1. The colour represents the number of points falling in a certain bin. The dashed black line is the estimated average γ^0 elevation profile.

4.2.2 Results Compliance

Figure 4-6 shows the γ^0 profiles estimated from all the analysed products. The profiles are plotted as a function of the off-boresight angle with regard to the antenna pointing. Top plots refer to HH products while bottom plots refer to VV products. Different colours correspond to different product types.

For what concerns the Stripmap acquisition (SLC and GRD products) very slight slope can be observed in some cases, which reveals that the EAP was not perfectly compensated. Moreover, ScanSAR SCD products, which includes different swath already merged, show more irregularity in the γ^0 profiles, which could be on the one hand due to EAP not correctly applied, on the other hand could reveal some beam-to-beam radiometric imbalance, which is actually confirmed by what is reported in RD-6 (1.4 dB radiometric variation across swath on average). Finally, it can be assessed that the overall radiometric level is quite homogeneous among the analysed set of products.

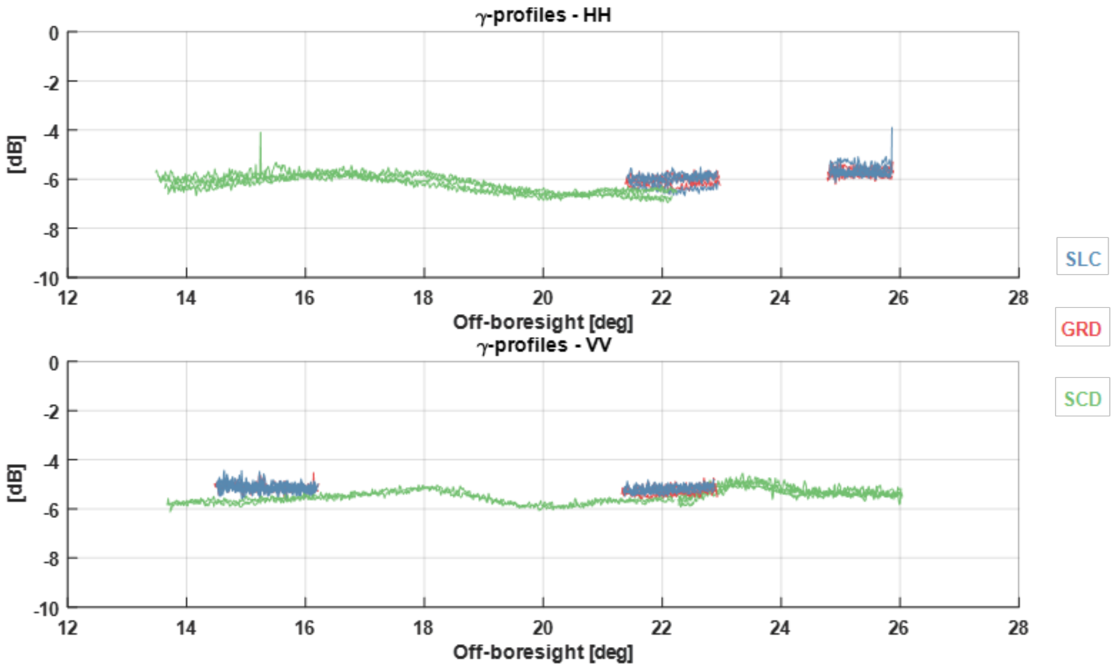


Figure 4-6: γ^0 elevation profiles measured from Cameroon Rain Forest acquisitions. Top plot refers to HH products while bottom plot refers to VV products. Different colours correspond to different product types.

4.3 Measurement Validation Activity #2 – Radiometric Stability: Residual Azimuth Scalloping

4.3.1 Method

A further analysis which can be performed on ScanSAR data acquired over Rain Forest is the derivation of the residual scalloping profile. Scalloping is a characteristic of ScanSAR images due to the azimuth elementary pattern of each TRM introducing an additional gain factor on the squinted beams. This gain is compensated during the processing exploiting a model of the azimuth elementary pattern. After scalloping compensation, each burst is expected to be flat in the azimuth direction.

The derivation of the residual scalloping profile is performed at the same time of the γ0 profile estimation and the processing is very similar, apart from the final summation which is performed along the range direction (instead of azimuth direction). For the residual scalloping profile estimation, the average data level is removed since the overall beam gain is already accounted for in the γ0 profile analysis. For further details on the method, please refer to [RD-3].

Figure 4-7 shows a detail of a quick-look of a NovaSAR-1 SCD HH acquisition over the Cameroon Rain Forest while Figure 4-8 shows the results of the residual scalloping profiles estimation from the same product. The colour is proportional to the points density considering that the whole acquisition has been analysed as a single burst. The dashed black line is the average residual scalloping profile. In this case it can be noticed that the profile is quite flat.

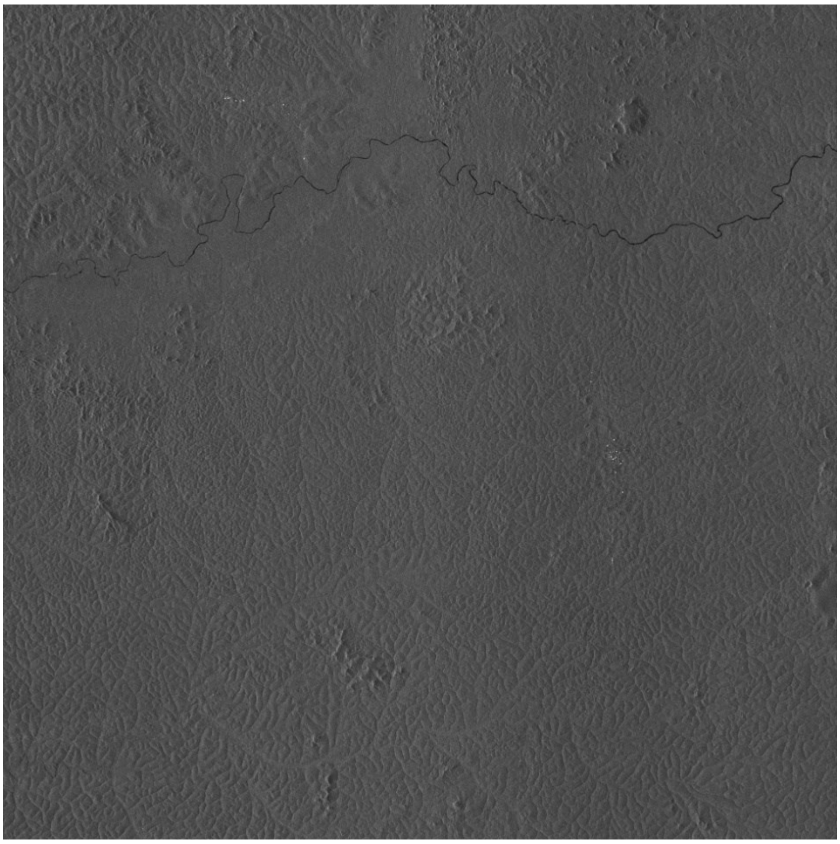


Figure 4-7: Quick-look of a SCD acquisition slice over Cameroon Rain Forest NovaSAR_01_40173_scd_20_221213_093803_VV_1

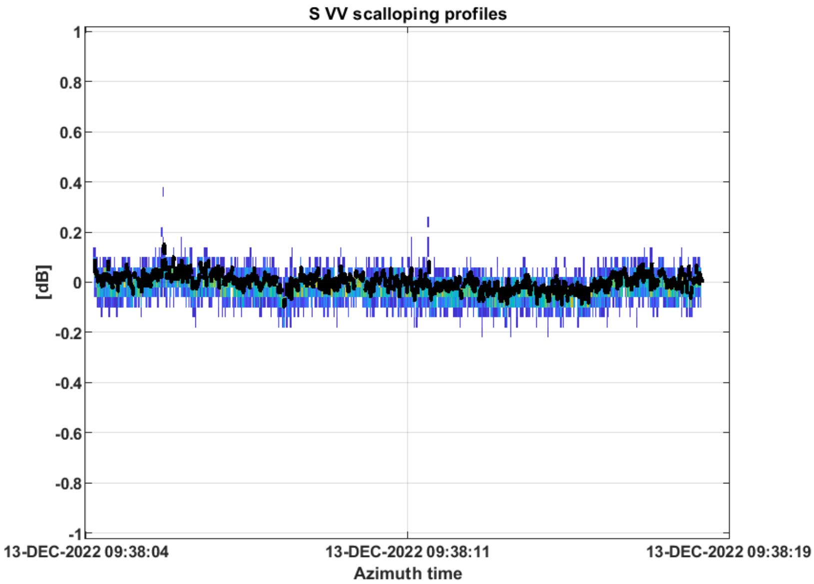


Figure 4-8: Results of residual scalloping profiles extraction from SCD acquisition over Cameroon Rain Forest NovaSAR_01_40173_scd_20_221213_093803_VV_1. The colour represents the number of points falling in a certain bin. The dashed black line is the estimated average residual scalloping profile.

4.3.2 Results Compliance

The results of the analysis for the residual scalloping profile assessment on the available SCD products acquired over the RF are reported in Figure 4-9. Profiles are plotted separately per acquisition while different slices of the same acquisition are plotted one next to the other.

From the results, descalloping is well applied and no clear artifacts can be observed apart from discontinuities due to the irregularity of the scene.

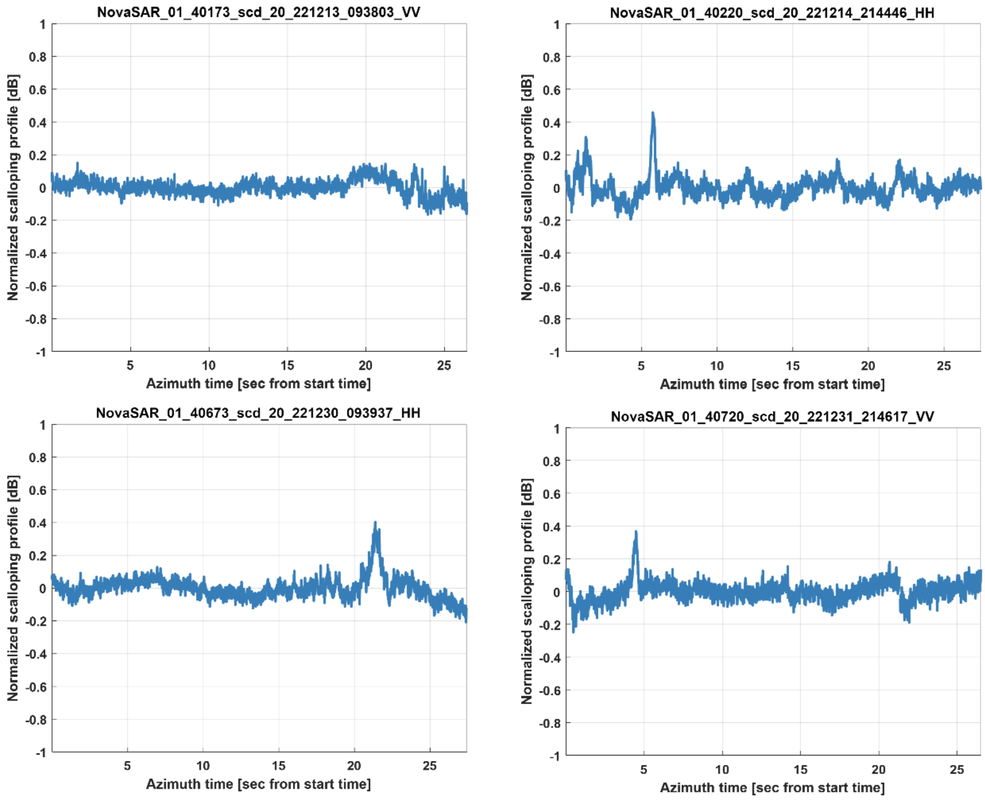


Figure 4-9: Residual scalloping profiles measured from Cameroon Rain Forest acquisitions. Profiles are plotted separately per acquisition.

4.4 Measurement Validation Activity #3 – Absolute Radiometric Calibration

4.4.1 Method

The absolute radiometric calibration of the NovaSAR-1 products is assessed by comparing the measured RCS against the theoretical one. In order to estimate the RCS of a point target in the image, it is necessary to first identify the IRF peak and then to remove the background backscattering contribution from the image under analysis before integrating the intensity over the IRF main lobe area. The obtained estimation is then compared with the theoretical RCS computed as a function of the target observation geometry in order to obtain the residual calibration constant. For further details on the method, please refer to [RD-3].

4.4.2 Results Compliance

The results of the absolute radiometric calibration assessment performed on data acquired over Surat Basin calibration site are reported in Figure 4-10 in terms of residual calibration constant. The plots report the results separately per product type as function of the incidence angle, the different colours represent CRs of different sizes, and different markers represent different polarizations. Results are also summarized in Table 4-1 where the mean and the standard deviation of the estimated residual calibration constant are reported.

The analysis performed by exploiting SLC and GRD products give good results, in fact just a slight residual of radiometric calibration can be observed. On the other hand the analysis on the SCD product results in higher residuals, but it must be noticed that those results are not really reliable due to the size of the CRs with respect to the resolution of SCD products..

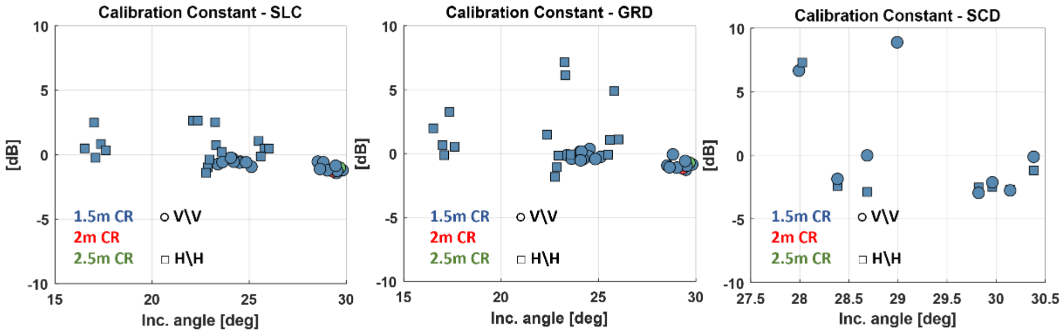


Figure 4-10: Residual calibration constant estimated from Surat Basin CRs and plotted as function of the incidence angle and separately for SLC, GRD and SCD products. Different colours represent CRs of different size. Different markers represent different polarizations.

Table 4-1: Resume of absolute radiometric calibration assessment

Type	Mode	# Prods	Cal. Constant H/H [dB]		Cal. Constant V/V [dB]	
			Mean	Std.	Mean	Std.
SLC	SM	6	0.69	1.24	-0.82	0.36
GRD	SM	7	1.56	2.56	-0.51	0.47
SCD	SS	1	-0.99	3.69	0.71	4.53

4.5 Measurement Validation Activity #4 – Sensitivity Validation

4.5.1 Method

The performed analysis, based on the NESZ level estimation from the SLC/GRD data is quite simple. The dataset is divided into blocks of 2000 azimuth lines to cope with the natural variability of the observed scene, then, a multi-looking operation is performed to enhance the radiometric resolution of the noise level estimation process. The second step is the statistical analysis of the filtered block of data to identify for each range line the most likely NESZ level. Lastly, a NESZ profile for each analysed data block is obtained. For further details on the method, please refer to [RD-3].

As an example, Figure 4-11 shows the detail in the quick look of an acquisition over the Maracaibo Lake area, in which it can be observed how the backscatter is particularly low in the region over the lake. In Figure 4-12 the NESZ profiles obtained from the analysis of the same acquisition are reported. The image represents the 2D distribution of the profiles.

Figure 4-11: Detail of quick-look of a GRD acquisition over Maracaibo Lake NovaSAR_01_29655_grd_13_211218_150627_HH.

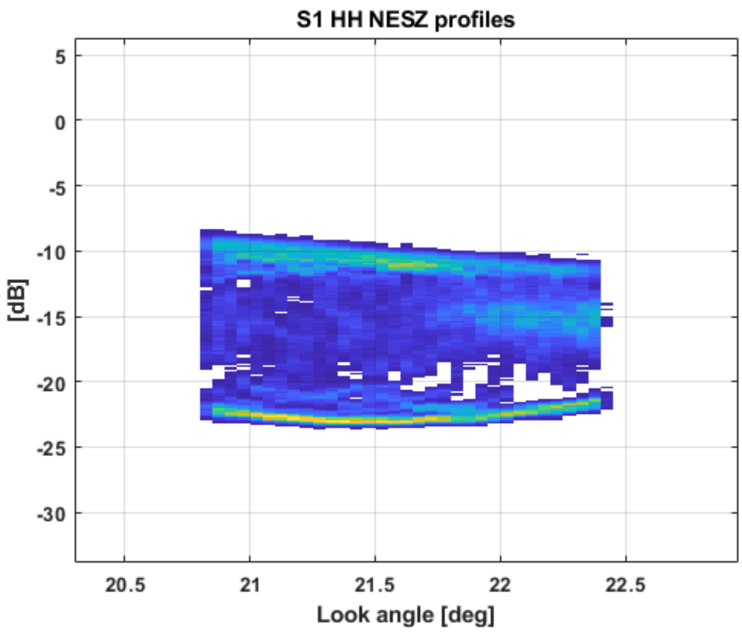


Figure 4-12: Results of σ^0 profiles extraction from GRD acquisition over Maracaibo Lake NovaSAR_01_29655_grd_13_211218_150627_HH.

4.5.2 Results Compliance

The resulting NESZ profiles as measured from the 4 analysed products are plotted in Figure 4-13, as a function of the look angle. The black lines are the NESZ levels as measured during the payload calibration performed in June 2022 (as reported in [RD-6]).

As can be observed from the plot, the estimated NESZ levels are well below the expected level. Being the expected level to be considered as a worst-case level, as confirmed by the data provider, the obtained results have a good match with the expectations.

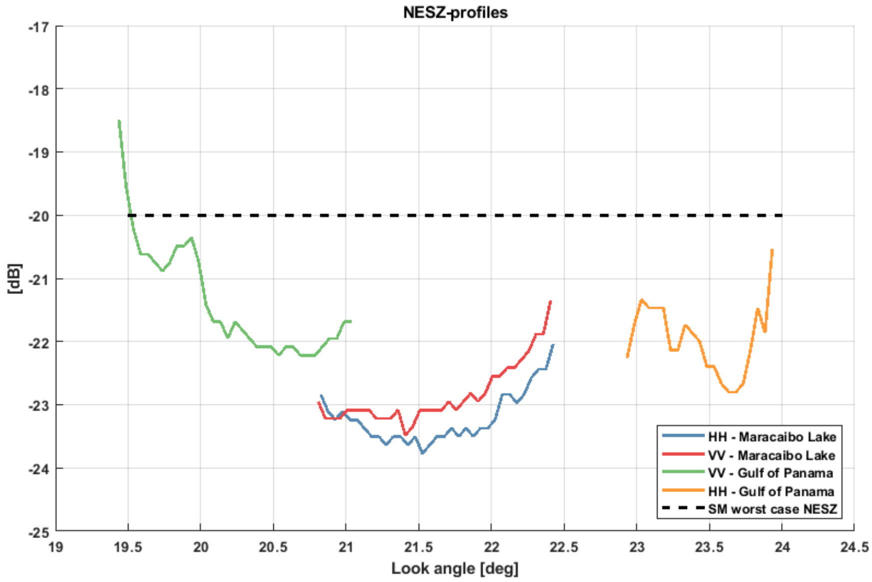


Figure 4-13: Results of sensitivity analysis: NESZ profiles measured from acquisitions over calm water areas compared to the NESZ level as measured during the payload calibration performed in June 2022 and reported in [RD-6].

5. DETAILED VALIDATION – GEOMETRIC

5.1 Introduction

The geometric validation performed for NovaSAR-1 data includes the following aspects:

- Impulse Response Analysis
- Geolocation accuracy

For this purpose, products acquired over Point Target (**PT**) calibration sites (Surat Basin and Rosamond, see Figure 4-2 and Figure 5-1, respectively) have been exploited, distributed as follows:

- 20 products acquired over Surat Basin (downloaded from CSIRO datahub, see [RD-8])
  → 9 SLC + 9 GRD + 2 SCD
- 7 products acquired over Rosamond (directly provided by Airbus DS UK)
  → 2 SLC + 2 GRD + 3 SCD

The full list of the analysed products is reported in tables in APPENDIX A.

Figure 5-1: Rosamond calibration site, California, US. Different sizes of corner reflectors are represented with different colours: 0.7 m (purple), 2.4 m (orange), 4.8 m (green).

5.2 Geometric Validation Activity #1 – Spatial Resolution and IRF Analysis

5.2.1 Method

The Impulse Response Function of NovaSAR-1 products has been validated by extracting the range and azimuth profiles from CRs in the calibration sites mentioned above. The IRF was characterized in terms of the following parameters:

- Range and Azimuth resolution
- Range and Azimuth Peak to Side Lobe Ratio (**PSLR**)
- Range and Azimuth Integrated to Side Lobe Ratio (**ISLR**)

Figure 5-2 provides an example of the IRF analysis performed over a Surat Basin corner reflector for a SLC HH acquisition. The point target response is first automatically detected within the data (the detection starting point is the expected target position according to the orbit information) and the 2D IRF is then oversampled to allow a better estimation of the IRF parameters. The parameters are estimated independently in the azimuth and range directions. For further details on the method, please refer to [RD-3].

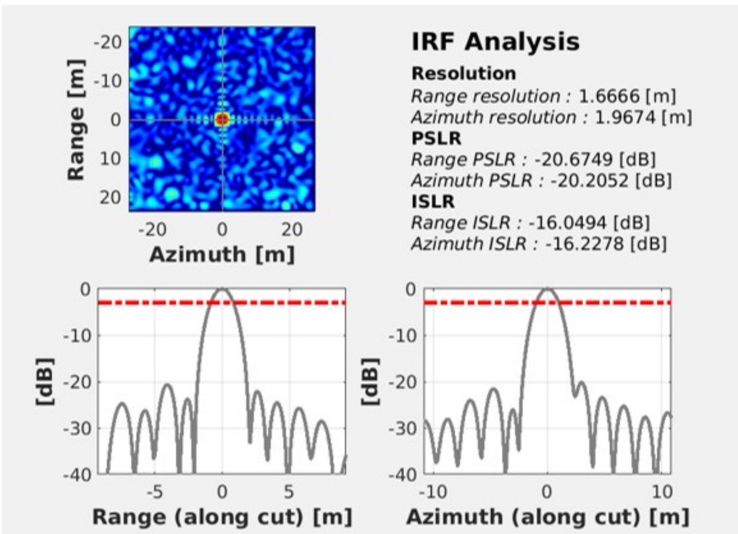


Figure 5-2: Example of IRF analysis performed over a Surat Basin corner reflector for acquisition NovaSAR_01_30262_slc_11_220108_005418_HH

5.2.2 Results Compliance

Figure 5-3 and Figure 5-4 show each, respectively for acquisitions over Surat Basin and Rosamond calibration sites, the measured resolution as functions of the incidence angle in the ground range direction (top line of plots) and in the azimuth direction (bottom line of plots). The measurements are plotted separately for SLC, GRD and SCD products and the different colours represent different polarizations. The black dashed lines represent the expected resolution values as specified in the products filename and extensively described in [RD-5]. Table 5-1: provides an overview of the resolution analysis showing the average and the standard deviation of the ground range and azimuth, separately per product type and calibration site.

In general, there is a very good agreement between the measured and the expected values, and in case of SCD products, the azimuth resolution is sometimes even better than the expectation. Furthermore, it must be noted that to ensure the expected azimuth resolution in GRD products, since a multilooking step is applied during the processing from SLC to GRD, a smaller azimuth resolution must be achieved by SLC products, as confirmed by the plotted results.

Also, the range and azimuth PSLR and ISLR have been estimated during the analysis, whose results are summarized in Table 5-2**.** Almost satisfactory results were given for SLC and GRD products, which on average approach the expected value for PSLR, which is, according to [RD-6], slightly below -22 dB in both directions. Please note that no results are provided for SCD products acquired over Surat Basin, due to the fact that not enough large CRs (compared to the SCD resolution) are present to be reliable for this kind of analysis. On the other hand, the analysis of the products acquired over Rosamond has been limited to the largest CRs (4.8 m) which in fact leads to more satisfactory results, as Table 5-2 reports.

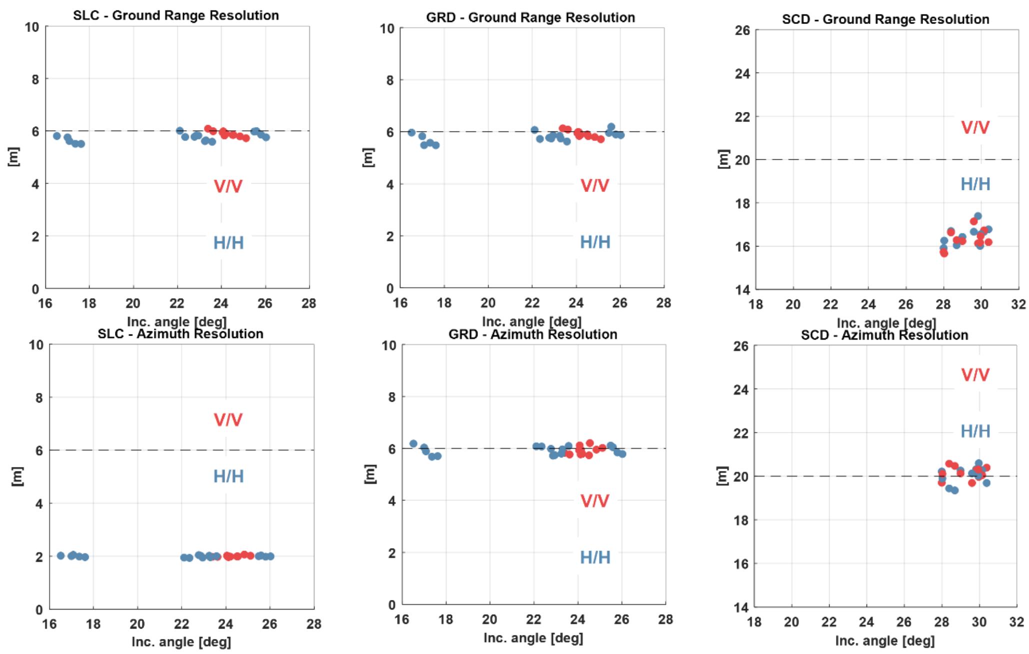


Figure 5-3: Ground range resolution (top) and azimuth resolution (bottom) measured from acquisitions over Surat Basin CRs as a function of the incidence angle, plotted separately for SLC, GRD and SCD products. Different colours represent different polarizations. Black dashed lines represent the expected resolution.

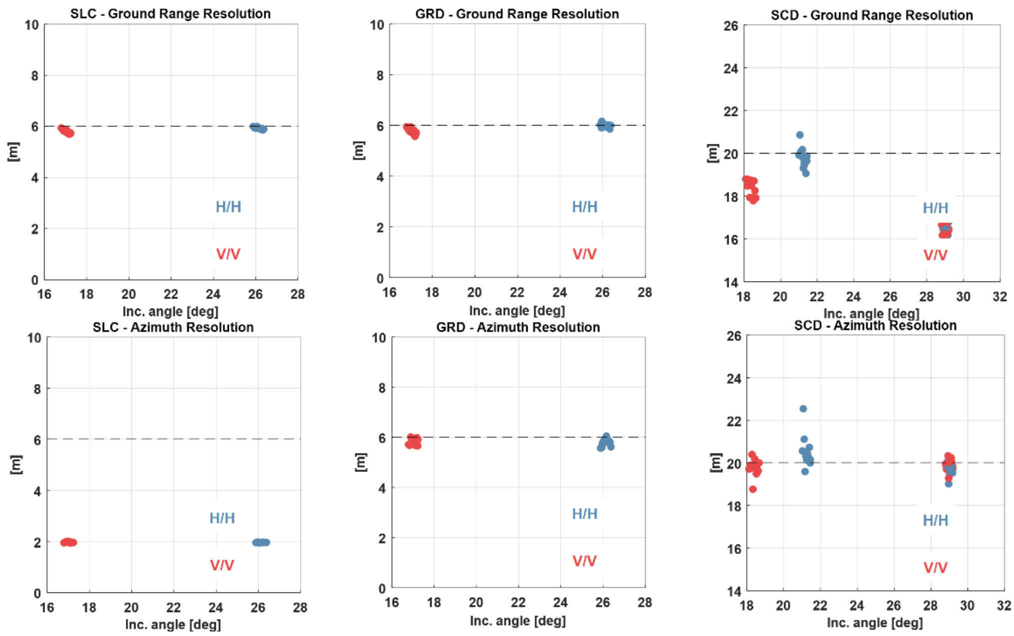


Figure 5-4: Ground range resolution (top) and azimuth resolution (bottom) measured from acquisitions over Rosamond CRs as a function of the incidence angle, plotted separately for SLC, GRD and SCD products. Different colours represent different polarizations. Black dashed lines represent the expected resolution.

Table 5-1: Resume of IRF resolution analysis results

Calibration Site	Type	Mode	# Prods	Ground Range Resolution [m]		Azimuth Resolution [m]	
				Mean	Std.	Mean	Std.
Surat Basin	**SLC**	SM	6	5.865	0.17	1.995	0.03
	GRD	SM	7	5.910	0.20	5.911	0.16
	SCD	SS	1	16.397	0.43	20.084	0.34
Rosamond	**SLC**	SM	2	5.864	0.09	1.967	0.01
	GRD	SM	2	5.865	0.14	5.820	0.13
	SCD	SS	3	17.717	1.51	19.980	0.51

Table 5-2: Resume of IRF peak to side lobes analysis results

Calibration Site	Type	Mode	# Prods	Range PSLR [dB]		Azimuth PSLR [dB]		Range ISLR [dB]		Azimuth ISLR [dB]	
				Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Surat Basin	**SLC**	SM	6	-21.174	1.29	-20.485	2.01	-16.276	1.39	-16.312	1.36
	GRD	SM	7	-19.549	1.64	-20.439	1.31	-14.930	1.58	-15.552	1.40
	SCD	SS	1	-15.395	1.38	-16.076	1.65	-	-	-	-
Rosamond	**SLC**	SM	2	-21.473	0.65	-21.894	0.76	-17.494	0.71	-17.268	0.58
	GRD	SM	2	-19.959	1.33	-21.729	1.05	-16.455	1.16	-17.331	1.15
	SCD	SS	3	-18.309	1.92	-19.356	2.73	-12.777	2.83	-13.681	3.45

5.3 Geometric Validation Activity #2 – Geolocation Accuracy

5.3.1 Method

Figure 5-5 provides an example of the geolocation analysis performed over a Surat Basin CR for a SLC HH acquisition. The geolocation accuracy assessment is performed on products acquired over PT calibration sites by comparing the measured point target position against the expected one. The point target position in SAR coordinates is measured from the data by estimating the position of the maximum of the target IRF. The expected point target position in SAR coordinates is obtained performing an inverse geocoding over the sensor orbit annotated in the product, starting from the known target position in ECEF reference system. The Absolute Localisation Error (**ALE**) in azimuth and range direction is then computed as the difference between the measured and the expected position. No additional correction to compensate atmospheric propagation delay is applied. For further details on the method, please refer to [RD-3].

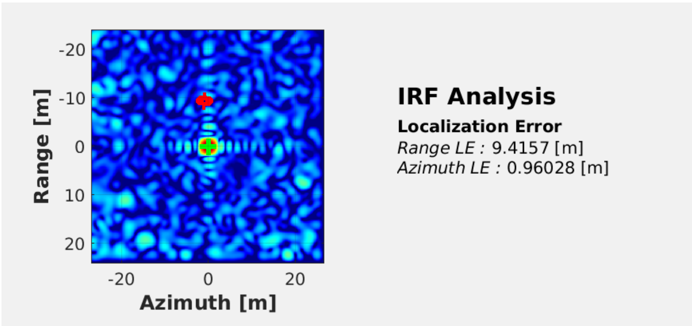


Figure 5-5: Example of geolocation analysis performed over a Surat Basin corner reflector for acquisition NovaSAR_01_30262_slc_11_220108_005418_HH

5.3.2 Results Compliance

The results of the geolocation accuracy assessment are reported in Figure 5-6 and Figure 5-7, for analysis performed on products acquired over Surat Basin and Rosamond calibration site, respectively. The measured geolocation errors have been plotted separately per product type and the colour of the triangles represents the polarization while their direction represents the orbit direction (ascending/descending). Results are also summarized in Table 5-3 where the mean and the standard deviation of the measured range and azimuth errors are reported.

In general, the obtained results are well above the requirement, which states that the geolocation error is expected to be lower than 50 m, according to [RD-9], even if it must be noticed that this is a quite relaxed requirement. It can also be observed that in Rosamond there is a clear clustering of the results: this is not due to polarization, as could be suggested by SLC and GRD plots, while it depends on the different products analysed (suggested by SCD plot and verified via detailed observation of the results).

On the other hand, the range error, which is not expected to change much from SLC to GRD, varies significatively, even if the data provider ensured that no correction is applied from SLC to GRD level that could affect the geolocation. Further investigation highlighted that this difference could be at least partially explained with a not enough accurate ground to slant polynomial annotated in the metadata. In fact, when the annotated polynomial does not reach the same order of the polynomial which is used during the processing, this leads to a discrepancy in the slant axis computed through the projection when compared to the original one from the SLC product, which in turns causes some degradation in the geolocation accuracy.

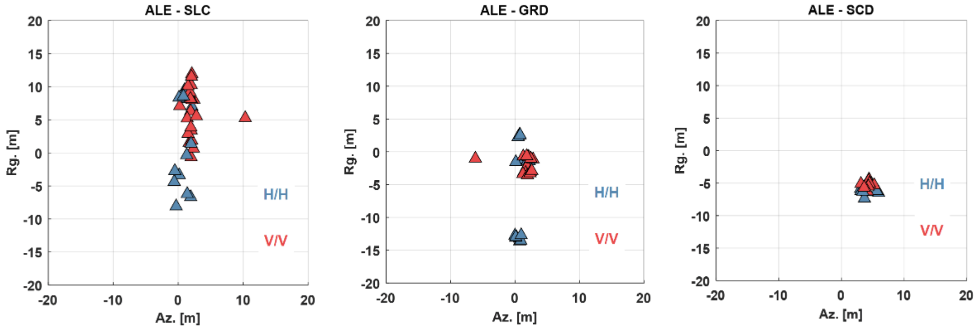


Figure 5-6: Absolute Localization Error measured from acquisitions over Surat Basin CRs, plotted separately for SLC, GRD and SCD products. The colours of the triangles represent different polarizations, and their direction represents the orbit direction.

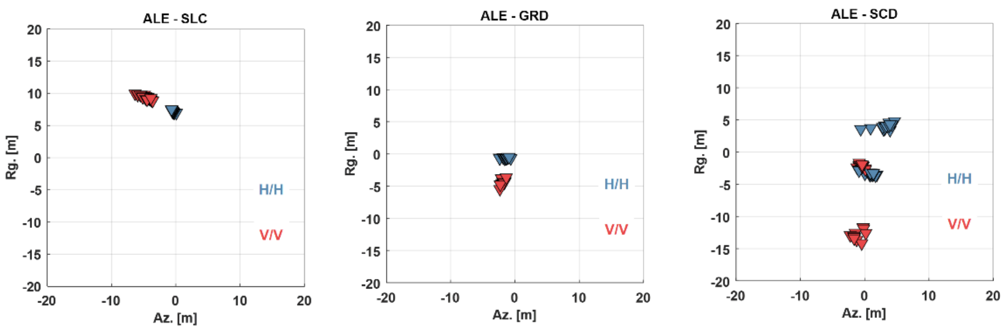


Figure 5-7: Absolute Localization Error measured from acquisitions over Rosamond CRs, plotted separately for SLC, GRD and SCD products. The colours of the triangles represent different polarizations, and their direction represents the orbit direction.

Table 5-3: Resume of geolocation accuracy results

Calibration Site	Type	Mode	# Prods	Range ALE [m]		Azimuth ALE [m]	
				Mean	Std.	Mean	Std.
Surat Basin	**SLC**	SM	6	4.555	5.58	1.359	0.84
	GRD	SM	7	-3.732	5.15	1.190	1.45
	SCD	SS	1	-5.682	0.70	4.349	0.86
Rosamond	**SLC**	SM	2	8.377	1.09	-3.255	2.16
	GRD	SM	2	-3.033	1.81	-1.716	0.39
	SCD	SS	3	-3.250	5.95	0.645	1.85

6. DETAILED VALIDATION – USABILITY (Level 2 ARD)

6.1 Introduction

Analysis has been based on the delivered Level 2 (**L2**) ARD products:

- Known site: La Crau (France) – to the East, Toulon delivered
- Variable Terrain: North Island (New Zealand) and near Palm Springs (USA)
- Ocean sites: Mauritius and Pitcairn Islands

6.2 Visual Validation Activity #2

6.2.1 Method

Each product in the dataset was opened inside QGIS and inspected visually for any obvious defects or interesting artefacts. Edge features (roads, rivers, etc.) were checked for alignment with an underlying geographical map (OpenStreetMap).

This first-look inspection used the 8-bit GeoTIFF images, which were scaled within QGIS using a 2-sigma stretch within QGIS.

6.2.2 Results Compliance

The overview of the products is shown in Figure 6-1.

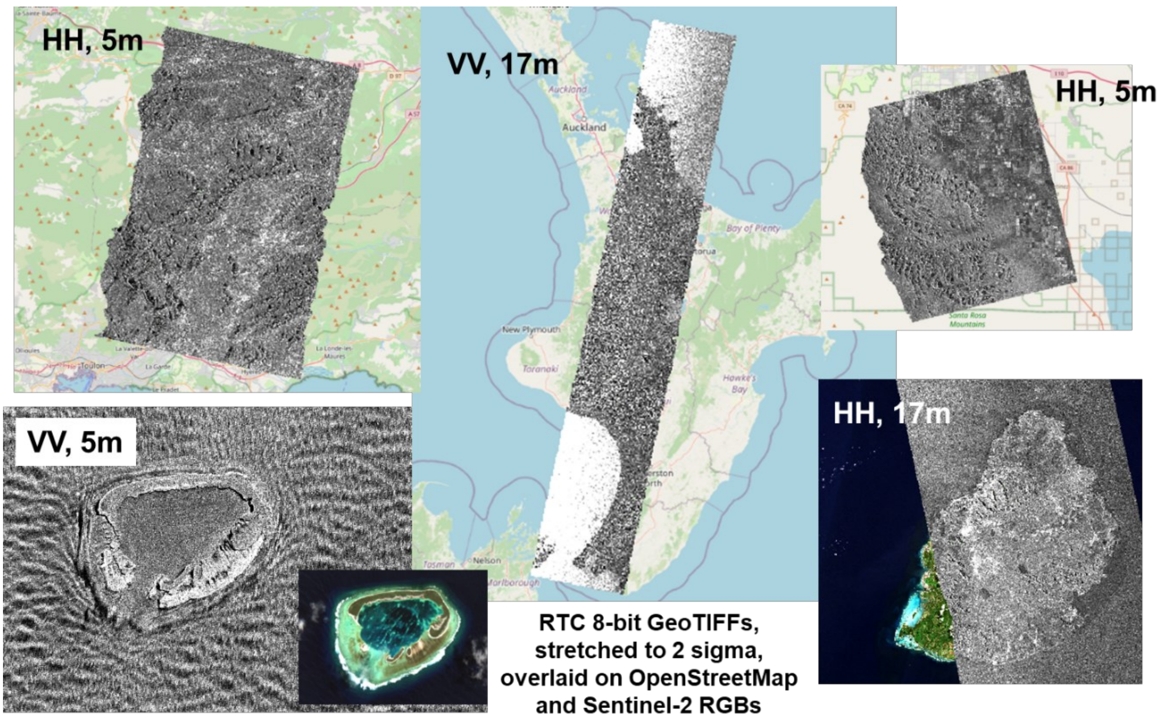


Figure 6-1: Delivered Level 2 ARD NovaSAR-1 products overlaid on OpenStreetMap or Sentinel-2 pseudo-true colour composites, with annotation to show the polarisation and spatial resolution.

The ARD products were generated from either the GRD or the SCD Level 1 (**L1**) products, according to whether they were acquired in Stripmap or ScanSAR mode. The L2 ARD data package includes (information provided in an email from Airbus DS UK and from analysis of the files):

- Normalised Radar Backscatter (Gamma-0) as Response Terrain Corrected (**RTC**) and Terrain Corrected (**TC**) products: UTM map projection 32-bit (float) and 8-bit GeoTIFFs – note the R in RTC is normally Radiometrically. It is unknown if the use of a different word (Response rather Radiometric for RTC) signifies that the processing differs from what would be expected.
- RTC Mask for layover and shadow

Currently, no L2-specific metadata or quicklook files exist. Metadata is delivered with the originating L1 products, which are also supplied within the L2 data package. Also, information about the map projection is provided via the file naming e.g.

`NovaSAR_17097_19112020_223239_HH_UTM_WGS84_RTC_swGamma.tif`

Figure 6-2 shows the TC, RTC and Mask files as both the full extent and a zoomed-in area to show further details for the Toulon Stripmap product at 6 m spatial resolution (once processed to L2, the Stripmap data was resampled to 5 m UTM pixels). When the RTC product is compared to the TC product, the impact of the terrain is lessened but still more evident than might be expected. Also, when zoomed-in, it can be seen that there is blurring in the TC product that becomes resolved when the full RTC correction is applied. The Mask product has zero values that are shown as transparent pixels, i.e., where the mask is being applied and for the pixels outside the valid data extent area. Airbus DS UK has delivered both the SLC and GRD L1 products, and the GRD L2 GeoTIFF metadata indicates the processing (data2geotiff v3.0) has been undertaken using the GAMMA software (www.gamma-rs.ch).

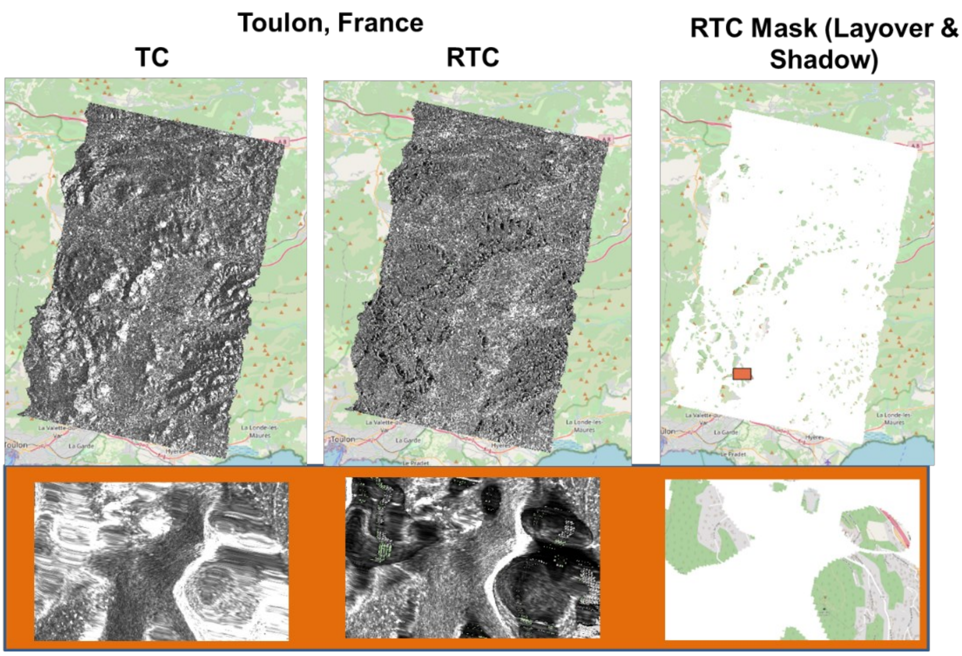


Figure 6-2: TC, RTC and Mask products for Toulon, including a zoomed-in area that is shown as an orange rectangle on the RTC mask.

Figure 6-3 shows a comparison of the Float versions of the L2 product, TC and RTC. These float versions appear more along the lines of what might be expected, and so it appears the float to 8-bit conversion is exaggerating the data and should not be used for quantitative analysis. These flat files have the same Gamma GeoTIFF metadata, so the conversion to 8bit occurred before the GeoTIFF was generated. It is unknown which Digital Elevation

Model (**DEM**) has been used as the L2 product description document was not supplied at the time of this issue.

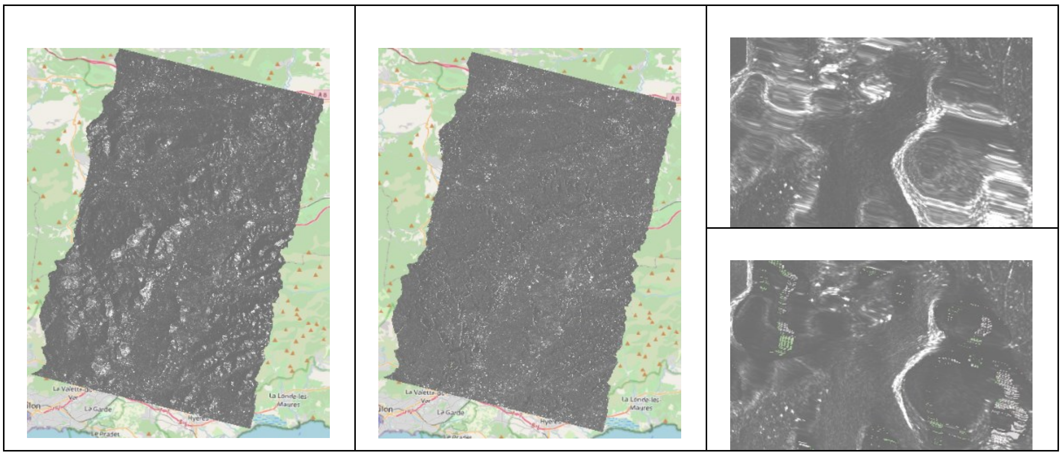


Figure 6-3: Comparison of the Float versions of the TC and RTC products (left and right) with the same zoomed-in area as shown in Figure 6-2 on the right as the top and bottom images.

Figure 6-4 shows a comparison of the L1 GRD product, as linear and dB versions, for the supplied L1 GRD file that has been reprojected to the same UTM projection (32 N) as the L2 products. It can be seen, that in comparison to Figure 6-3, the terrain-related artefacts have been reduced. The conversion to a non-linear scaling (dB) enhances the features, which may have been applied before the 8-bit files were generated.

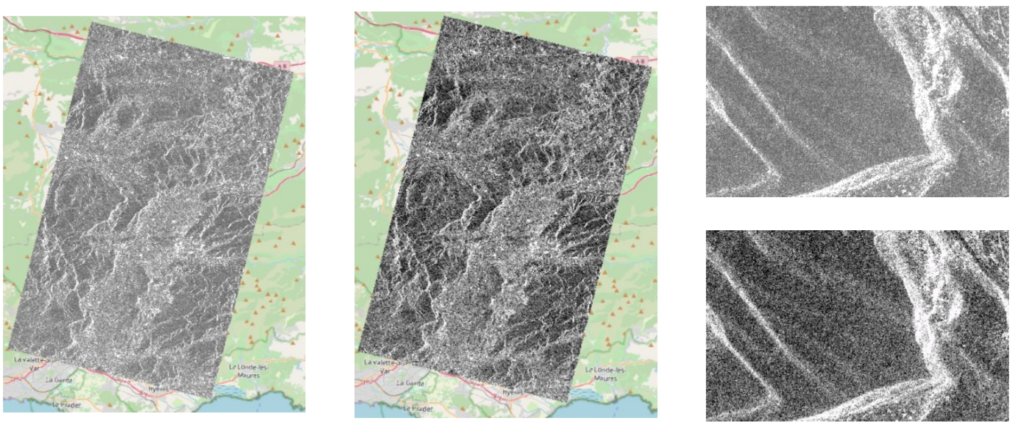


Figure 6-4: Comparison of the Level 1 GRD product as linear and dB versions (left and right) with the same zoomed-in area as shown in Figure 6-2 on the right as the top and bottom images.

6.3 Geometric Validation Activity #3

6.3.1 Method

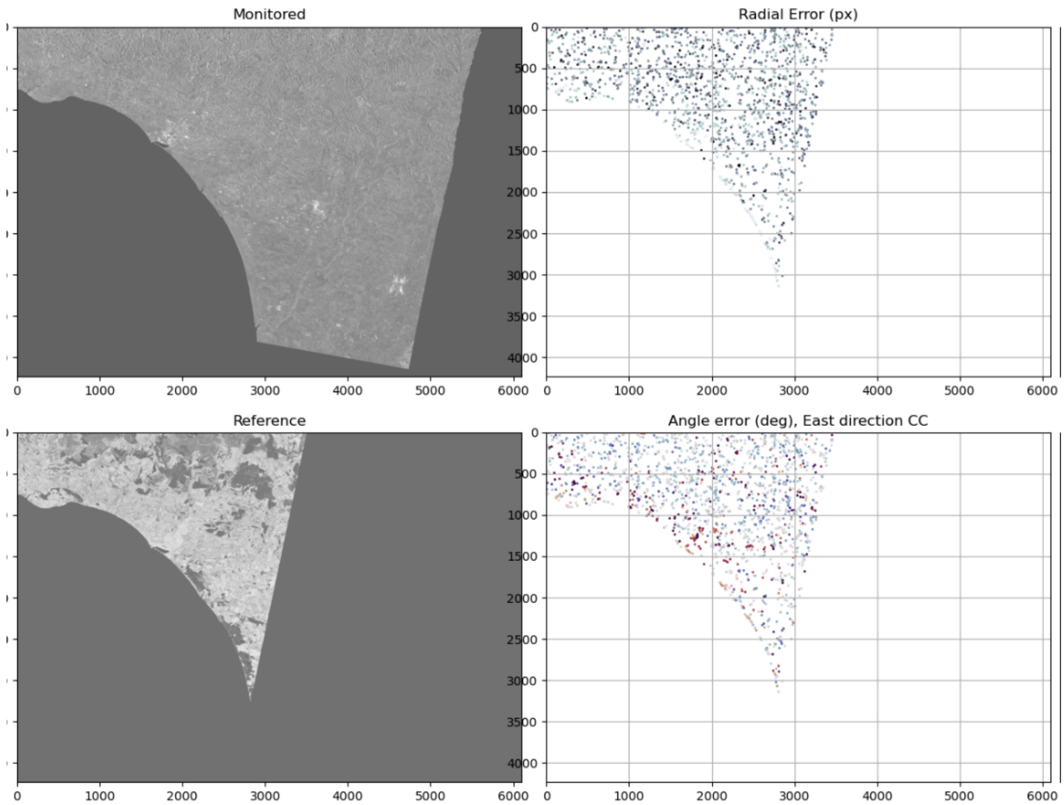
The KARIOS tool, developed by the EDAP+ Task 2 optical team (Telespazio France), has been used to assess the geometric accuracy of the ARD products. KARIOS performs feature-based image matching, based on the Kanade–Lucas–Tomasi Feature Tracker, associated with pre-processing techniques and outlier filtering, and including image matching and accuracy analysis modules [RD-12].

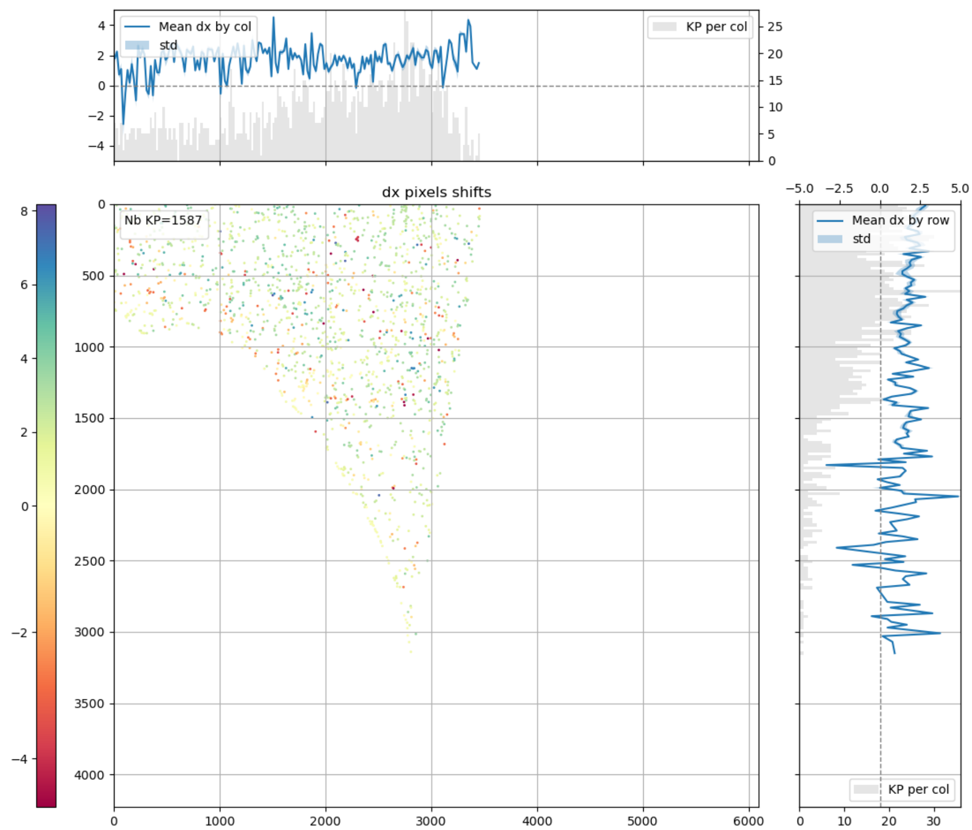
For KARIOS, reference imagery must be of a higher resolution than the product being assessed, so Sentinel-2 is only relevant for New Zealand and Mauritius. For the New Zealand comparison, the product is band 3 (560 nm) from a Sentinel-2 L2 product that has been orthorectified and is provided in the UTM zone 31 N projection with a spatial resolution of 10 m.

Therefore, for the Toulon assessment, a Worldview-1 panchromatic orthorectified product from 27 July 2020 has been used, which was already reprojected to UTM zone 32 N at 0.5 m pixel resolution that has a reported absolute geometric accuracy of 10.2 m CE90 (i.e., interpreted as at least 90% of horizontal errors and 90% of vertical errors being less than this specified Circular Error).

6.3.2 Results Compliance

For the New Zealand analysis, the Sentinel-2 product was reprojected to the UTM zone 32 N map projection using SNAP (version 9.0.0 with all updates applied as of 12 June 2023), then the water was masked. The pre-processing script was first run to extract matching subsets from both products (reference and comparison), and then the KARIOS tool was run to generate the outputs shown in Figure 6-5. For this comparison, 603 matching points were extracted between the two products and the Root Mean Square Error (**RMSE**) was calculated as 34.23 m in the Easting (dx) direction and 45.60 m in the Northing (dy) direction. The overall RMSE is 57.02 m, and the CE90 is 81.60 m with the dx/dy mean being –9.82/-28.14 m. There was no apparent trends in either the dx or dy direction when considering the rows and columns in the product, which can be seen if there are strong internal distortions. As this was a coastal product, we also tested the approach using the NovaSAR-1 scene that was further inland (NovaSAR_15751_06102020_103805_VV_UTM_WGS84_RTC_swGamma_8bit), and similar results were achieved: RMSE 9.38 m, CE90 17.20 m, dx/dy mean –2.60/-21.94 m.


Monitored
Radial Error (px)
Reference
Angle error (deg), East direction CC


Mean dx by col
std
KP per col
dx pixels shifts
Nb KP=1587
Mean dx by row
std
KP per col

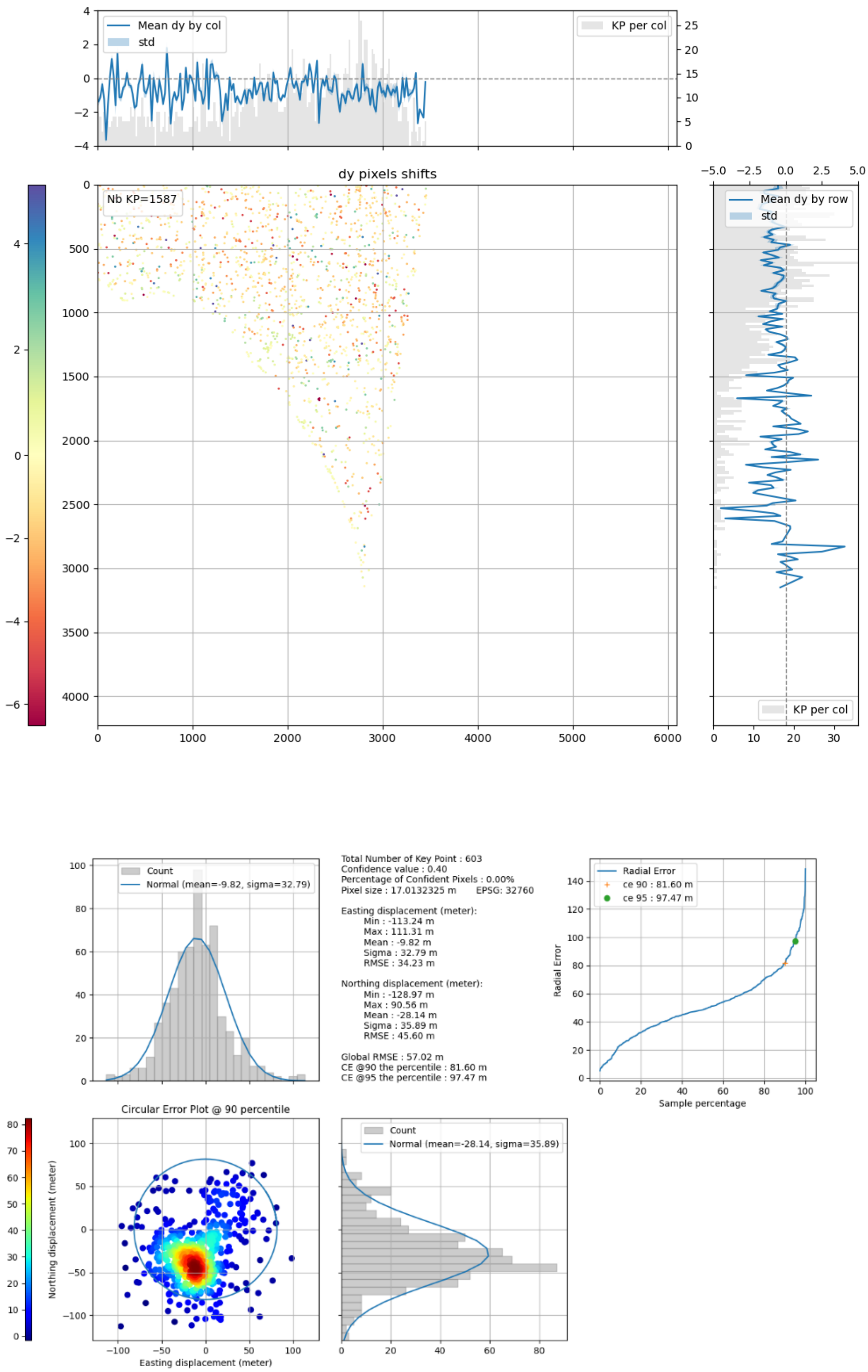
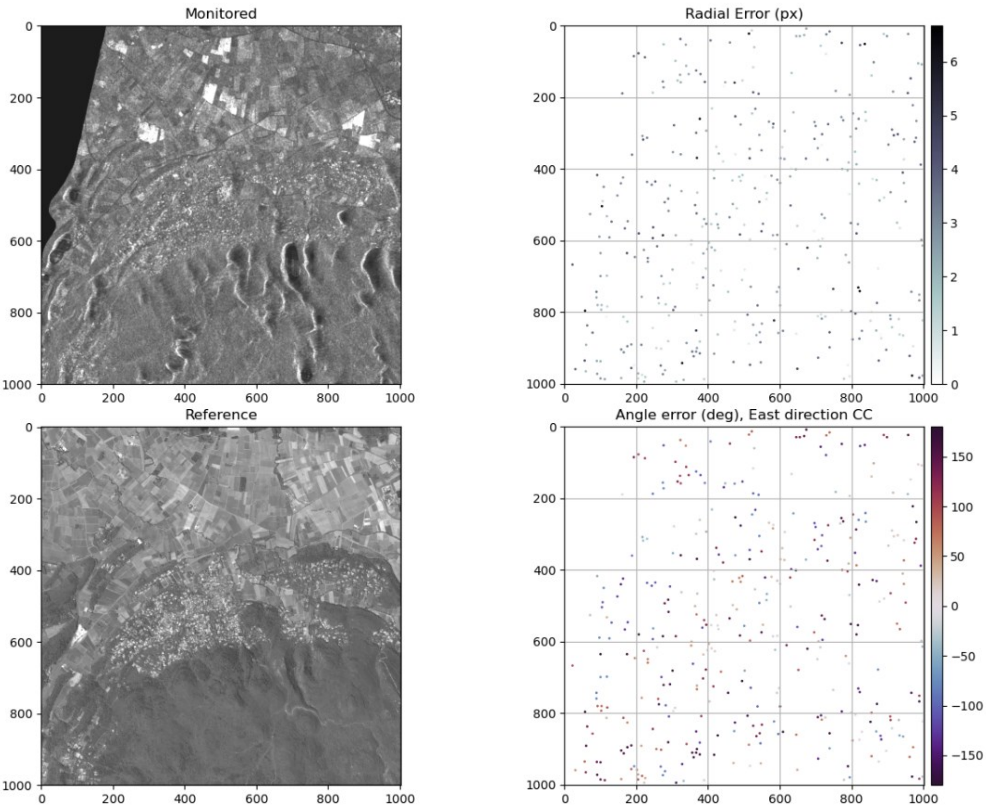
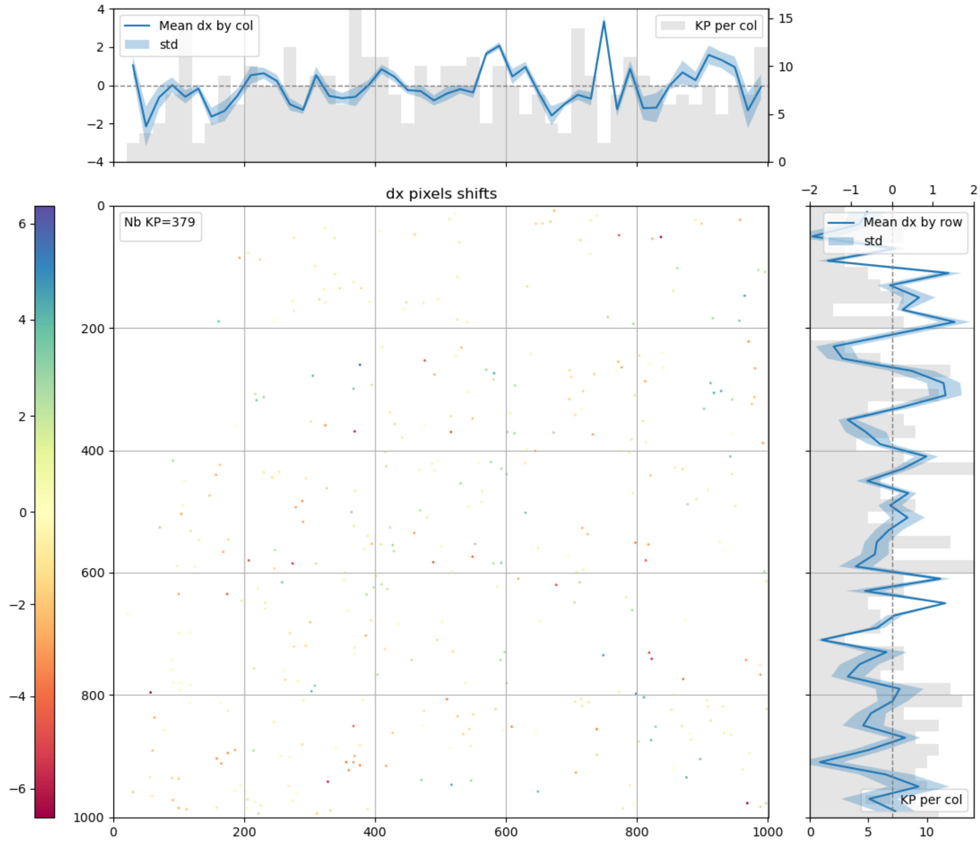
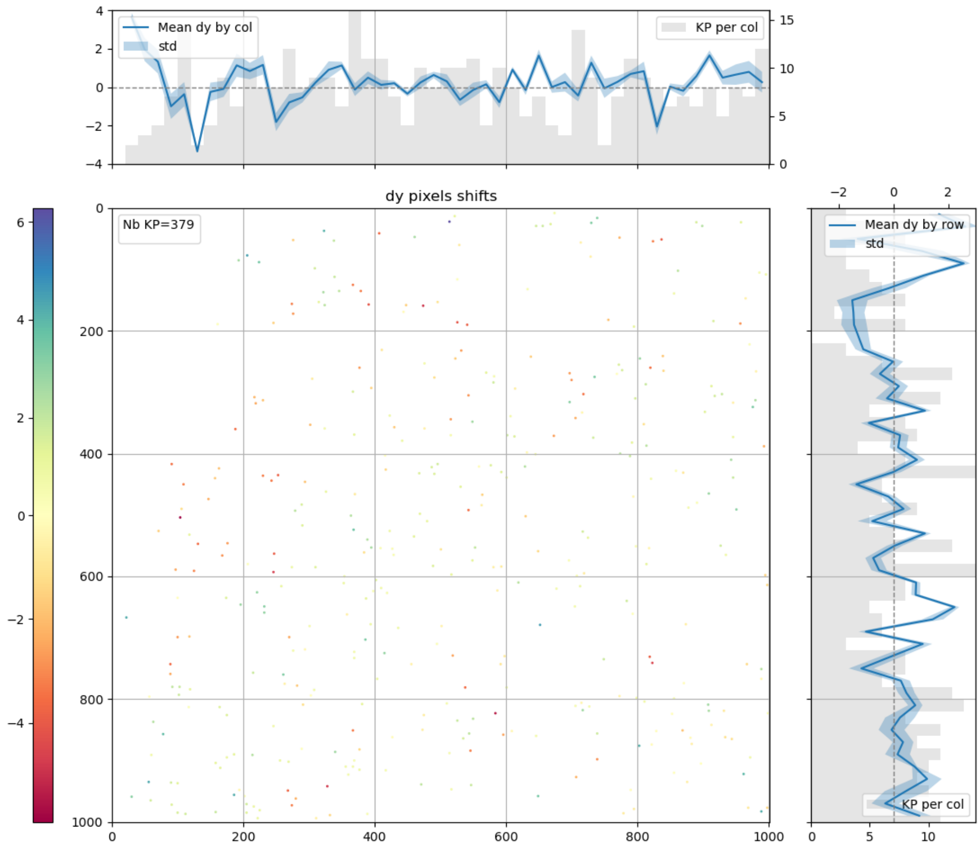


Figure 6-5: KARIOS results from comparison NovaSAR-1 (NovaSAR_15751_06102020_103819_VV_UTM_WGS84_RTC_swGamma_8bit) to Sentinel-2 (S2A_MSIL2A_20201015T222551_N0214_R029_T60GUA_20201016T001749) for a product acquired over New Zealand.

For Toulon, also, the pre-processing script was first run, then the KARIOS tool was used to generate the outputs shown in Figure 6-6. For this comparison, only a few matchup points have been achieved for the assessment (138), indicating difficulty matching the two data sources. The RMSE is calculated as 10.27 m in the Easting (dx) direction and 11.04 m in the Northing (dy) direction. The overall RMSE is 15.08 m, and the CE90 is 22.05 m. As with the New Zealand comparison, there is no apparent trend in either the dx or dy direction when considering the rows and columns in the product.




Mean dx by col
std
KP per col
dx pixels shifts
Nb KP=379
Mean dx by row
std
KP per col


Mean dy by col
std
KP per col
dy pixels shifts
Nb KP=379
Mean dy by row
std
KP per col

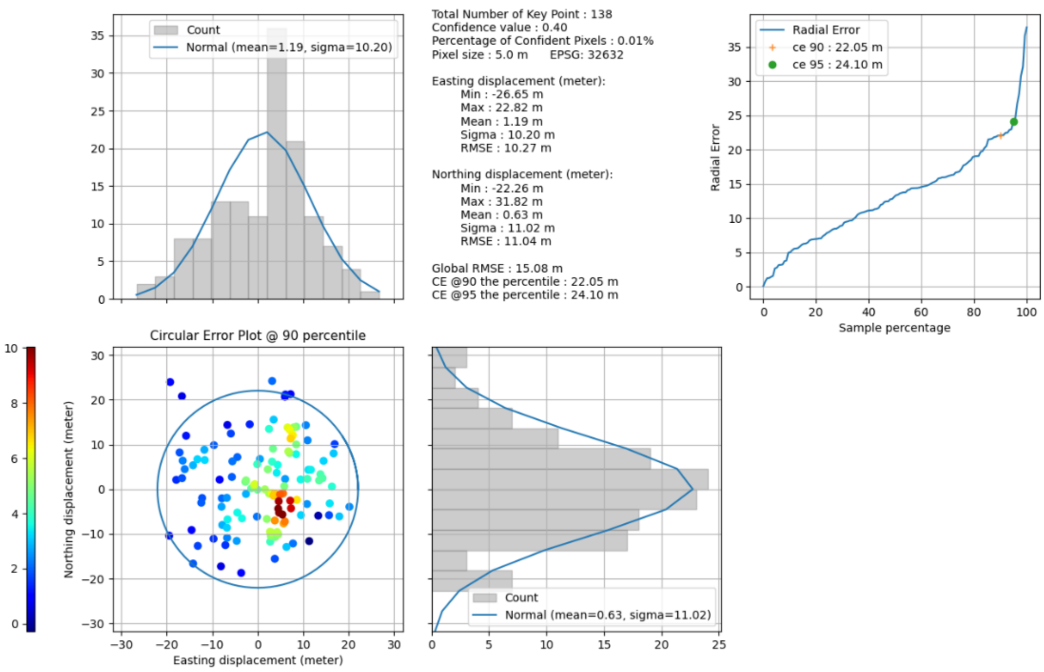


Figure 6-6: Results from comparison NovaSAR-1 (NovaSAR_17097_19112020_223239_HH_UTM_WGS84_RTC_swGamma_8bit) to Worldview-1 for a product acquired over Toulon (France). Worldview-1 (C) COPYRIGHT 2021 DigitalGlobe, Inc., Longmont CO USA 80503.

To test whether the number of matched points could be improved, filtering was applied to the NovaSAR-1 images using SNAP – a Lee 5x5 filter for speckle removal. However, the number of matched points reduced rather than increased, so the unfiltered results were kept.

In summary, these accuracy values can be compared to the L1 geometric accuracy reported in Section 5.3, which has been calculated as an Absolute Localization Error of less than 10 m (when all the values are considered), which is lower than the assessed geometric accuracy here. The CSIRO product overview states that geolocation error was expected to be lower than 50 m [RD-9] while an analysis of ARD products [RD-13] using the Surat Basin corner reflectors, calculated mean absolute geometric accuracies in the Latitude/Longitude directions of -4.976/ -1.048 m for Stripmap products. If we consider the RMSE dx and dy, then both L2 results are below this, while other statistics such as CE90 (more commonly used for optical imagery and intended to be conservative), have a higher value for the Sentinel-2 comparison.

To further investigate these results, after discussions with Airbus DS UK and CSIRO, ARD processed products over the corner reflector array in Surat Basin were supplied by CSIRO. From these, two GRD products were chosen that had a spatial resolution of 5 m and so the Sentinel-2 L2 data (Tile T56JKQ 31 October 2023) was resampled to 5 m, plus the ARD products needed to be reprojected (Sentinel-2 projection was chosen) as they didn't have a projection KARIOS could read stored in the GeoTIFF files. Running KARIOS for these scenes generated the following outputs:

- CEOS-ARD_NRB_v5.5_NovaSAR_01_31330_grd_13_220211_005855_VV_A_R – dx/dy Mean –1.23/-1.91 m, RMSE 9.38 m, CE90 17.20 m

- CEOS-ARD_NRB_v5.5_NovaSAR_01_38993_grd_13_221103_004941_HH_A_R – dx/dy Mean –2.63/-2.96 m, RMSE 10.25 m, CE90 17.60 m

These results are much closer to the accuracies obtained from the EDAP L1 geometric accuracy and CSIRO ARD product assessments, especially when the mean dx/dy values are considered but are greater than the NovaSAR-1 product's pixel size when the RMSE and CE90 statistics are considered. The approach used for KARIOS will have impacted the results as ideally a higher spatial resolution reference product should be used.

6.4 CEOS Conformance Assessment Activity #1

6.4.1 Method

This is a preliminary assessment of the Airbus DS UK delivered products against the CEOS Normalised Radar Backscatter Product Family Specification [RD-14]. The contents build on the analysis carried out in the previous two sections that included a visual analysis (Section 6.2) and geometric accuracy analysis (Section 6.3).

The CSIRO ARD products were not analysed and have since been formally assessed by CEOS as being complaint at the threshold specification level.

6.4.2 Results Compliance

In Table 6-1, the current products are compared against a selection of criteria applied as both the Threshold (Minimum) Requirements and Target (Desired) Requirements.

Table 6-1: Comparison of Airbus DS UK NovaSAR-1 product to the Normalised Radar Backscatter specifications

Item	Threshold	Target	Current delivery
1.2 Metadata Machine Readability	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use	As threshold, but metadata is formatted in accordance with CARD4L NRB Metadata Specifications, v.5.5	Not currently provided in a suitable format, it should be easy to rectify to meet the Threshold criteria
2.2 Data Mask Image	Mask image indicating: - Valid data - Invalid data - No data	As threshold, including in addition e.g. - Layover (masked as invalid data in Threshold) - Radar shadow (masked as invalid data in Threshold) - Ocean water, etc.	The current Mask product includes aspects of the Target Requirements but must also include the Threshold requirements
2.4 Local Incident Angle Image	DEM-based Local Incident angle image is provided	As threshold	Not provided

Item	Threshold	Target	Current delivery
3.1 Backscatter Measurements	Terrain-flattened Gamma-Nought backscatter coefficient is provided for each polarization	As threshold	Provided, but needs to be appropriately documented in the metadata. It is not specified if the product is linear or the logarithmic decibel scale
3.3 Noise Removal	Flag if noise removal has been applied (Y/N). Metadata should include reference to algorithm as URL or DOI	As threshold	Not indicated
3.4 Radiometric Terrain Correction Algorithms	Metadata references: - a citable peer-reviewed algorithm - technical documentation regarding the implementation of that algorithm expressed as URLs or DOIs - the sources of ancillary data used to make corrections	Require resolution of DEM better than the output product resolution when applying terrain corrections	No details are currently provided
4.2 Digital Elevation Model	a) During ortho-rectification, the data provider shall use the same DEM that was used for the radiometric terrain flattening to ensure consistency of the data stack b) Provide reference to Digital Elevation Model used for Geometric Terrain Correction c) Provide reference to Earth Gravitational Model (EGM) used for Geometric Correction	a) A DEM with comparable or better resolution to the resolution of the output CARD4L product shall be used b) Resampling method used for preparation of the DEM c) Method used for resampling of EGM. d) As threshold	No details are currently provided

Item	Threshold	Target	Current delivery
4.3 Geometric Accuracy	An estimate of the absolute localisation error is provided as bias and standard deviation, provided in slant range/azimuth, or Northing/Easting	Output product sub-sample accuracy should be less than or equal to 0.1-pixel radial Root Mean Square Error (**rRMSE**) Provide documentation of estimate of absolute localisation error as DOI or URL	The Threshold requirement has been estimated by the EDAP+ team in this technical note using the L1 products In terms of the Target requirement, although rRMSE has not been estimated, the L2 statistics calculated indicate the products would currently be higher than this

6.5 Comparison To Other Missions Activity #4

6.5.1 Method

An ALOS PALSAR product has been downloaded from the Alaska Satellite Facility and is available as a L2 Radiometrically Terrain Corrected product at 10 m spatial resolution. This product's processing Level is recorded as 2.2 in the metadata, and it was generated using the AW3D30 DEM and EGM96 geoid model. The product is provided as GeoTIFFs at 12.5 m spatial resolution with metadata in a summary txt file, and the data shown is the HH polarisation.

A Sentinel-1 GRDH product has a Range Doppler Terrain Correction applied using SNAP using the Copernicus 30 m DEM, with the product shown being the VH polarisation Gamma0 product reprojected to UTM zone 40S.

6.5.2 Results Compliance

Figure 6-7 and Figure 6-8 show areas of Mauritius as seen by multiple Radar sensors alongside Sentinel-2. Figure 6-7 shows an overlapping comparison of a Sentinel-2 pseudo-true colour composite from 18 May 2023, NovaSAR-1 from 11 September 2022 and PALSAR from 13 August 2007. As it is not possible to see the same areas using Figure 6-7 because the products are overlaid on each other, Figure 6-8 shows a subsetted area for the same Sentinel-2 pseudo-true colour composite, NovaSAR-1 and PALSAR images alongside Sentinel-1. In the Sentinel-2 subset, areas of more recent forest felling can be seen as darker green. Similarly, for NovaSAR-1 and Sentinel-1, the same areas can be seen as darker areas. These areas are not visible in the PALSAR data as this was acquired at a much earlier point in time.

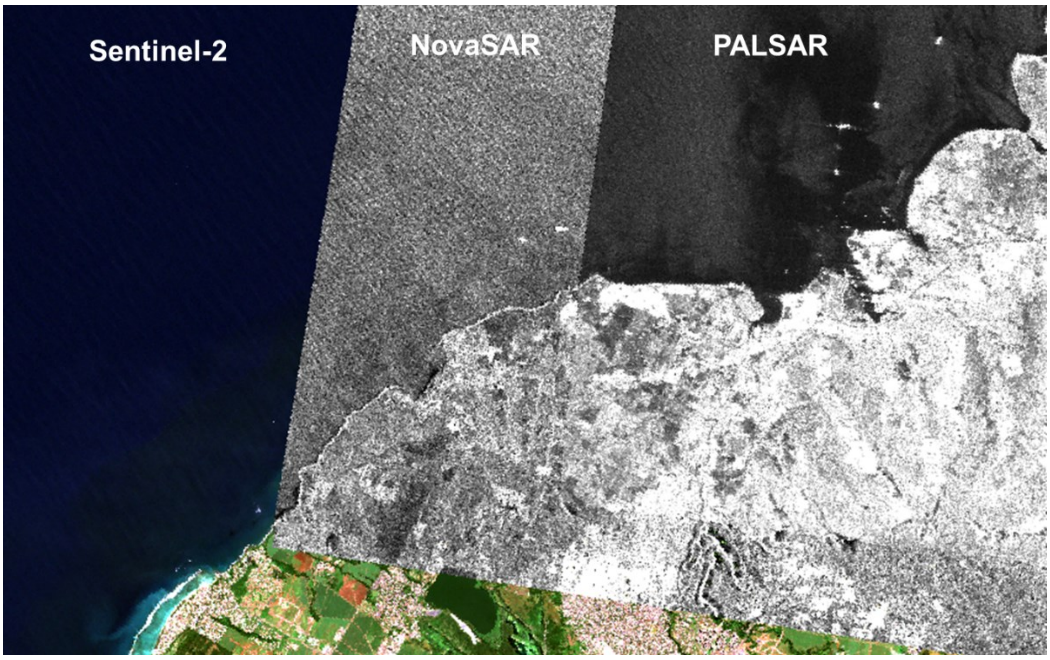


Figure 6-7: Overlapping products for Sentinel-2 (S2A_MSIL2A_20230518T062451_N0509_R091_T40KEC_20230518T083158), NovaSAR-1 (NovaSAR_37440_11092022_070040_HH_UTM_WGS84_RTC_swGamma_8bit) and PALSAR (HH-ALPSRP082666780-H2.2_UA) over Mauritius.

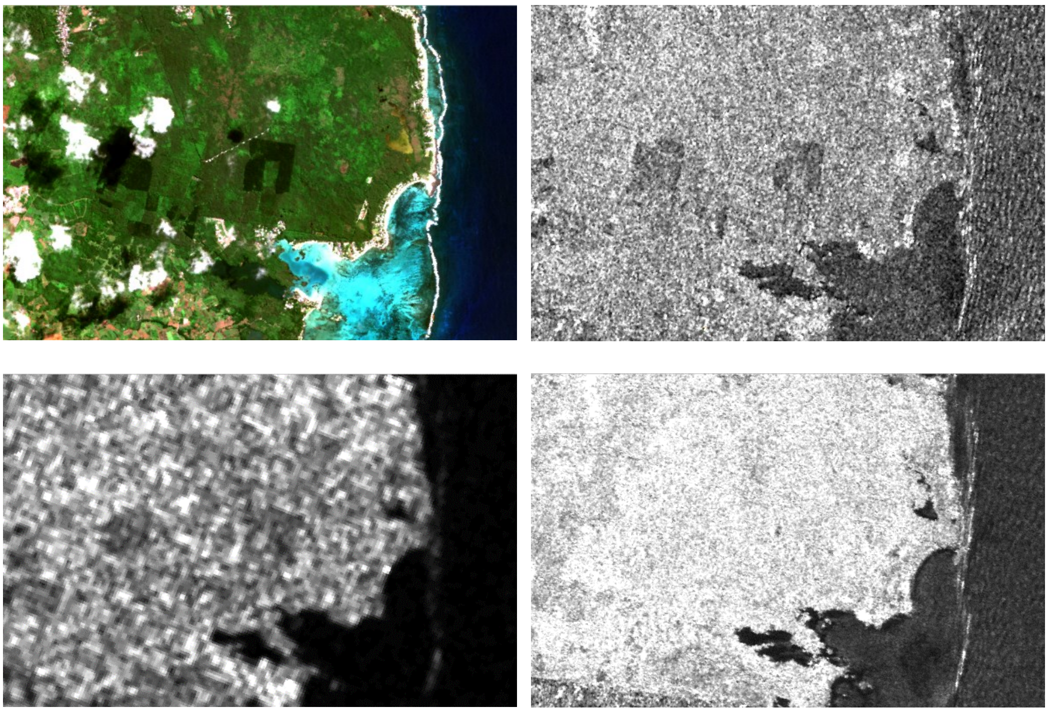


Figure 6-8: Zoomed-in identical area for the (top left) Sentinel-2 18 May 2023 pseudo-true color composite, (top right) NovaSAR-1 11 September 2022, (bottom left) 17 September 2022 Sentinel-1 and (bottom right) 13 August 2007 PALSAR products over Mauritius.

APPENDIX A Mission Test Dataset

Products downloaded from CSIRO datahub	
Site	**Product_Identifier**
Surat Basin (PT)	NovaSAR_01_28758_grd_13_211120_005853_HH
Surat Basin (PT)	NovaSAR_01_28758_slc_11_211120_005853_HH
Surat Basin (PT)	NovaSAR_01_29787_grd_13_211223_005731_VV
Surat Basin (PT)	NovaSAR_01_29787_slc_11_211223_005731_VV
Surat Basin (PT)	NovaSAR_01_30262_grd_13_220108_005418_HH
Surat Basin (PT)	NovaSAR_01_30262_slc_11_220108_005418_HH
Surat Basin (PT)	NovaSAR_01_30791_grd_13_220125_005640_VV
Surat Basin (PT)	NovaSAR_01_30791_slc_11_220125_005640_VV
Surat Basin (PT)	NovaSAR_01_31330_grd_13_220211_005855_VV
Surat Basin (PT)	NovaSAR_01_31330_slc_11_220211_005855_VV
Surat Basin (PT)	NovaSAR_01_38021_grd_13_221001_005216_HH
Surat Basin (PT)	NovaSAR_01_38021_slc_11_221001_005216_HH
Surat Basin (PT)	NovaSAR_01_38993_grd_13_221103_004941_HH
Surat Basin (PT)	NovaSAR_01_38993_slc_11_221103_004941_HH
Surat Basin (PT)	NovaSAR_01_39982_grd_13_221207_005313_VV
Surat Basin (PT)	NovaSAR_01_39982_slc_11_221207_005313_VV
Surat Basin (PT)	NovaSAR_01_41461_scd_23_230126_005204_VV_HH
Surat Basin (PT)	NovaSAR_01_43189_scd_23_230402_004724_VV_HH
Surat Basin (PT)	NovaSAR_01_8885_grd_13_191222_005359_VV
Surat Basin (PT)	NovaSAR_01_8885_slc_11_191222_005359_VV

Products provided by Airbus DS UK	
Site	**Product_Identifier**
Rosamond (PT)	NovaSAR_01_40108_grd_13_221211_065142_HH_2
Rosamond (PT)	NovaSAR_01_40108_slc_11_221211_065142_HH_2
Rosamond (PT)	NovaSAR_01_40494_scd_20_221224_063022_HH
Rosamond (PT)	NovaSAR_01_40580_scd_20_221227_064729_VV
Rosamond (PT)	NovaSAR_01_40960_scd_23_230109_062607_VV_HH_2
Rosamond (PT)	NovaSAR_01_40991_grd_13_230110_063147_VV_2
Rosamond (PT)	NovaSAR_01_40991_slc_11_230110_063148_VV_3

Products provided by Airbus DS UK	
Site	**Product_Identifier**
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092053_HH_1
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092057_HH_2
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092101_HH_3
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092106_HH_4
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092110_HH_5
Cameroon (RF)	NovaSAR_01_40080_grd_13_221210_092114_HH_6
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092053_HH_1
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092057_HH_2
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092101_HH_3
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092105_HH_4
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092109_HH_5
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092113_HH_6
Cameroon (RF)	NovaSAR_01_40080_slc_11_221210_092117_HH_7
Cameroon (RF)	NovaSAR_01_40112_grd_13_221211_092637_VV_1
Cameroon (RF)	NovaSAR_01_40112_grd_13_221211_092643_VV_2
Cameroon (RF)	NovaSAR_01_40112_grd_13_221211_092648_VV_3
Cameroon (RF)	NovaSAR_01_40112_grd_13_221211_092654_VV_4
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092637_VV_1
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092641_VV_2
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092644_VV_3
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092647_VV_4
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092650_VV_5
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092654_VV_6
Cameroon (RF)	NovaSAR_01_40112_slc_11_221211_092657_VV_7
Cameroon (RF)	NovaSAR_01_40173_scd_20_221213_093803_VV_1
Cameroon (RF)	NovaSAR_01_40173_scd_20_221213_093817_VV_2
Cameroon (RF)	NovaSAR_01_40204_grd_13_221214_094348_HH_1
Cameroon (RF)	NovaSAR_01_40204_grd_13_221214_094354_HH_2
Cameroon (RF)	NovaSAR_01_40204_grd_13_221214_094359_HH_3
Cameroon (RF)	NovaSAR_01_40204_grd_13_221214_094405_HH_4
Cameroon (RF)	NovaSAR_01_40204_slc_11_221214_094348_HH_1
Cameroon (RF)	NovaSAR_01_40204_slc_11_221214_094353_HH_2
Cameroon (RF)	NovaSAR_01_40204_slc_11_221214_094358_HH_3

Products provided by Airbus DS UK	
Site	**Product_Identifier**
Cameroon (RF)	NovaSAR_01_40204_slc_11_221214_094402_HH_4
Cameroon (RF)	NovaSAR_01_40204_slc_11_221214_094407_HH_5
Cameroon (RF)	NovaSAR_01_40220_scd_20_221214_214446_HH_1
Cameroon (RF)	NovaSAR_01_40220_scd_20_221214_214500_HH_2
Cameroon (RF)	NovaSAR_01_40673_scd_20_221230_093937_HH_1
Cameroon (RF)	NovaSAR_01_40673_scd_20_221230_093951_HH_2
Cameroon (RF)	NovaSAR_01_40720_scd_20_221231_214617_VV_1
Cameroon (RF)	NovaSAR_01_40720_scd_20_221231_214624_VV_2
Cameroon (RF)	NovaSAR_01_40720_scd_20_221231_214632_VV_3
Cameroon (RF)	NovaSAR_01_40720_scd_20_221231_214639_VV_4
Cameroon (RF)	NovaSAR_01_41082_grd_13_230113_092349_VV_1
Cameroon (RF)	NovaSAR_01_41082_grd_13_230113_092355_VV_2
Cameroon (RF)	NovaSAR_01_41082_grd_13_230113_092400_VV_3
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Cameroon (RF)	NovaSAR_01_41082_grd_13_230113_092412_VV_5
Cameroon (RF)	NovaSAR_01_41082_slc_11_230113_092349_VV_1
Cameroon (RF)	NovaSAR_01_41082_slc_11_230113_092354_VV_2
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Cameroon (RF)	NovaSAR_01_41082_slc_11_230113_092403_VV_4
Cameroon (RF)	NovaSAR_01_41082_slc_11_230113_092408_VV_5
Maracaibo Lake (CW)	NovaSAR_01_29655_grd_13_211218_150627_HH
Maracaibo Lake (CW)	NovaSAR_01_29740_grd_13_211221_152338_VV
Gulf of Panama (CW)	NovaSAR_01_42144_grd_13_230217_035208_VV
Gulf of Panama (CW)	NovaSAR_01_43324_grd_13_230408_035133_HH

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