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Commercial Smallsat Data Acquisition Program: Airbus U.S. Synthetic Aperture Radar Quality Assessment Summary

Batuhan Osmanoglu and Minjeong Jo

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AMENDMENT RECORD SHEET

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

ISSUE	DATE	REASON
1.0	08/31/2023	First version

ACRONYMS

AEP	Antenna Elevation Pattern
CSDA	Commercial Smallsat Data Acquisition
COSAR	COmplex SAR (format)
CoSSC	Coregistered Single-look Slant-range Complex
EDAP	Earthnet Data Assessment Pilot
EEC	Enhanced Ellipsoid Corrected
ENL	Equivalent Number of Looks
ESA	European Space Agency
EULA	End User License Agreement
FAIR	Findable, Accessible, Interoperable, Reusable
GEC	Geocoded Ellipsoid Corrected
GeoTIFF	A format extension for storing georeference and geocoding information in a TIFF 6.0 compliant raster file
HR	High Resolution Spotlight
IRF	Impulse Response Function
ISCE	InSAR Scientific Computing Environment
ISLR	Integrated Side-Lobe Ratio
JPL	NASA's Jet Propulsion Laboratory
MGD	Multi-Look Ground-range Detected
N/A	Not Applicable / Not Available
NASA	National Aeronautics and Space Administration

NEBN	Noise Equivalent Beta Nought
NESZ	Noise Equivalent Sigma Zero
PSLR	Peak Side-Lobe Ratio
SC	ScanSAR
SL	Spotlight
SM	StripMap
SNAP	Sentinel Application Platform
SSC	Single-look Slant-range Complex
TSX	TerraSAR-X
TDX	TanDEM-X
USG	United States Government
XML	Extensible Markup Language

Contents

Executive Summary

Quality assessment of the Airbus X-band Synthetic Aperture Radar (SAR) satellite products was conducted by the Commercial Smallsat Data Acquisition (CSDA) program's radar subject matter experts, following the Joint NASA/ESA (European Space Agency) assessment draft guidelines. All three Airbus SAR spacecraft (TerraSAR-X, TanDEM-X, and PAZ) are based on the TerraSAR-X platform, and each have an active phased array antenna that is 4.8 x 0.7 m in the along-track and cross-track dimensions, respectively. TerraSAR-X and TanDEM-X are in a helical orbit, creating a bistatic imaging geometry, in addition to being capable of independent monostatic observations. The PAZ mission follows TerraSAR-X and TanDEM-X in the same 11-day orbit with a 5.5-day lag. TerraSAR-X and TanDEM-X are designed, developed, and operated through a Public-Private Partnership, while PAZ is a dual-use mission (civil and defense agencies), funded and owned by the Spanish Ministry of Defense and managed by Hisdesat (Hisdesat Servicios Estratégicos, S.A.), a Spanish private communications company.

The assessment presented in this document is divided into two main parts: documentation review and the assessment of test datasets. The documentation review in sections 2.1 through 2.4 includes the assessment of the Airbus documentation provided to the CSDA evaluation team. The grading of these documents is given in columns 1-4 of the maturity matrix shown in section 1.1. Section 2.5 summarizes the evaluation performed by NASA using the data purchased through the CSDA program. The grading for this is given in the last column of the maturity matrix. Section 3 provides more detailed explanations on the methods and the results of the data analysis performed by NASA.

Only the documents provided by Airbus for the evaluation were considered for the review. Additional documentation with more detailed description of the calibration and validation procedures may be available online but were not considered for this evaluation. The product information provided in the available documentation (RD-1, RD-2) and the product metadata together provided adequate information to work with the data. The product details in the metadata included the required information to work with the data in the common XML file format. Metrological traceability documentation was not provided to CSDA. All relevant characterization of the SAR system and data were provided, and the metadata include all relevant ancillary information. Documentation provided to CSDA included limited pre-flight and post-launch calibration information.

The quality assessment was performed on the Single-look Slant-range Complex (SSC) Level-1 products and the Multi-Look Ground-range Detected (MGD) Level-2 ScanSAR products. Additional Level-2 products were also used in science usability assessments by the evaluation team. Most of the uncertainty values relevant for SAR are provided in the product metadata (XML) files, such as the noise equivalent beta nought (NEBN) and geolocation accuracy. The integrated side lobe ratio (ISLR) and peak side lobe ratio (PSLR) were not provided in the documentation, but the alpha coefficient ($\alpha = 0.6$), which determines the width of the Hamming window, is expressed in the product specification document (RD-5). Theoretical PSLR and ISLR, which correspond to the alpha value, were used instead as a reference. Expected values for relevant metrics such as absolute radiometric accuracy, relative radiometric accuracy, noise equivalent sigma nought (NESZ), PSLR, and ISLR are discussed within the results compliance sections of this document. Pixel-wise uncertainty for several parameters (e.g., noise level) are provided in the product metadata. How the performance values are obtained are not documented. PAZ documentation (RD-2) also provides single performance values for relevant metrics but lacks a detailed description of the methods for assessing the radiometric accuracy and NESZ.

An independent quality assessment of the essential quality parameters of SAR, such as spatial resolution, PSLR, ISLR, equivalent number of looks (ENL), antenna elevation pattern (AEP), and NESZ was performed by the

CSDA team. Representative datasets collected by the Airbus SAR constellation from various test sites, including distributed targets and point targets were used. Data from the ScanSAR (SC), StripMap (SM), Spotlight (SL), and High-Resolution Spotlight (HS) acquisition modes were analyzed. The product type of the analyzed data was SSC for SM, SL, and HS imaging modes, and multi-look ground detected (MGD) for the SC imaging mode. The quality metrics derived from the Airbus data were compared with the corresponding values provided in the Airbus documentation and/or metadata. The validation by the CSDA program was mainly performed using software internally developed at NASA's Goddard Space Flight Center, but also leveraged NASA's Jet Propulsion Laboratory (JPL) InSAR Scientific Computing Environment (ISCE) software, GAMMA Remote Sensing, commercial software, and the Sentinel Application Platform (SNAP) toolbox distributed by ESA.

The quality analysis results were generally in agreement with the values provided by Airbus, such as the spatial resolution and geolocation accuracy. The measured PSLR values were generally close to the expected theoretical values. In general, PSLR values were at or slightly higher in the range direction and slightly higher in azimuth, even after considering the larger assessment uncertainties (Table 3.3). The data were successfully processed using ISCE, SNAP, and GAMMA SAR processing software. Based on the available Airbus documentation and our independent data analysis, we conclude that the Airbus SAR data are of good quality.

Cal/Val Maturity Matrices

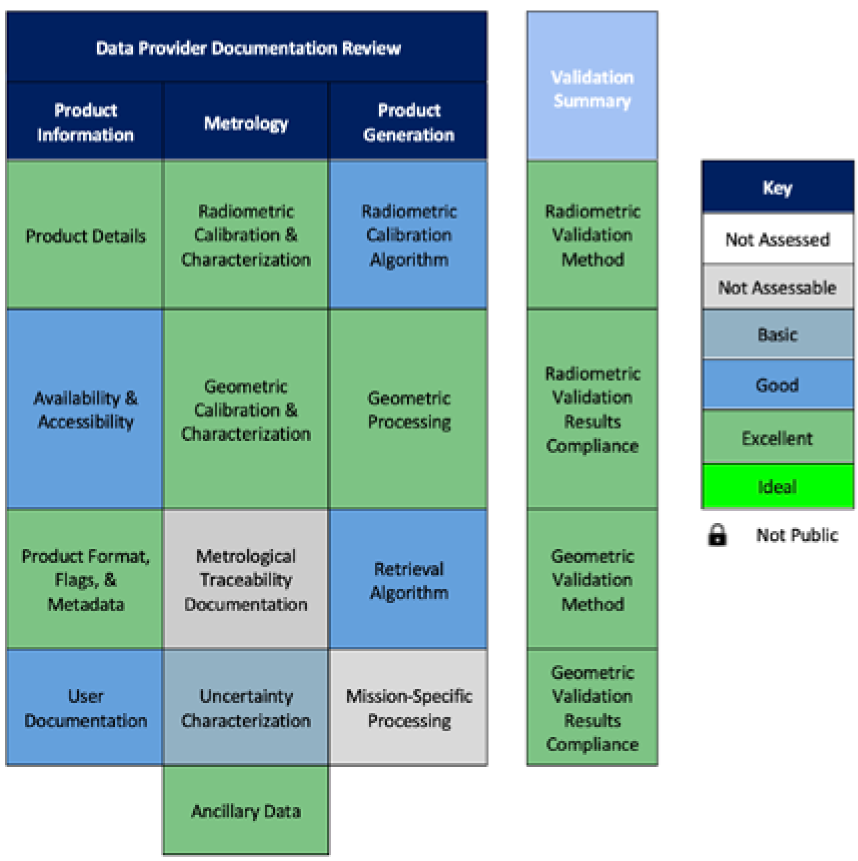

Figure 1.1. *Summary Matrix Cal/Val Maturity Matrix. Colors indicate assessment results shown on the key to the right. Details of validation can be found in Figure 1.2.*

Validation Cal/Val Maturity Matrix

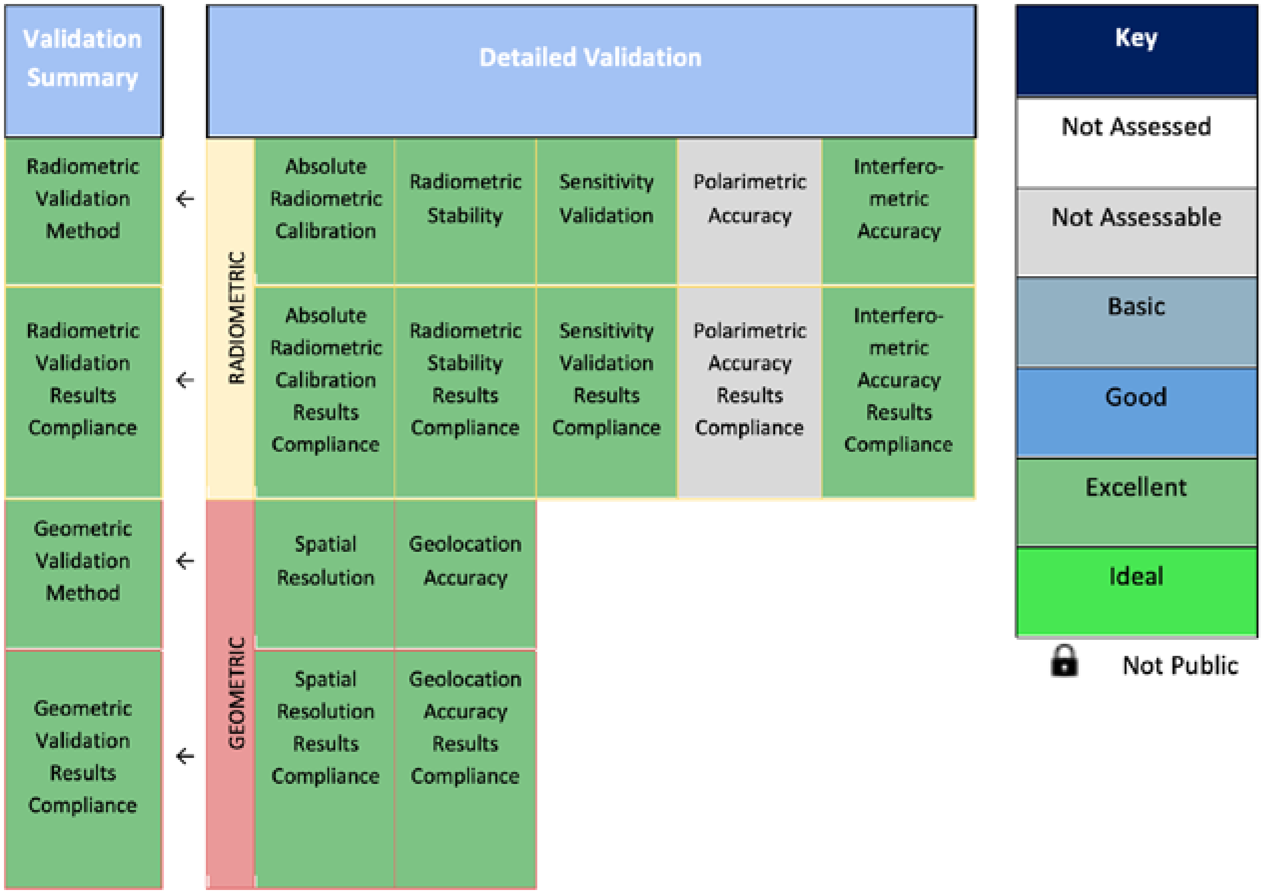

Figure 1.2. *Validation Cal/Val Maturity Matrix. The colors indicate assessment results based on the key to the right. All assessment categories had excellent scores.*

Data Provider Documentation Review

Product Information

Product Details	
Grade: Excellent	
Justification	Product details are well defined in the reference documents and metadata.
Product Name	Product file name contains information on the satellite (e.g., TSX), mode (e.g., SSC=Single look Slant range Complex), imaging mode (e.g., SM=Stripmap, ST=Spotlight), polarization (e.g., S=Single), and timing of acquisitions (start and stop times). Product identification scheme is detailed in section 3.7 of RD-5. e.g., TSX1_SAR__SSC______SM_S_SRA_20080223T015046_20080223T015054 TDX1_SAR__SSC______ST_S_SRA_20220407T164526_20220407T16452
Sensor Name	TSX / TDX / PAZ
Sensor Type	X-band SAR
Mission Type	Dual satellite bistatic constellation (TSX-TDX) / Monostatic SAR (PAZ)
Mission Orbit	Sun-Synchronous (98.X degrees)
Product Version Number	4.11
Product ID	e.g., C247_N167_A_SM_strip_013_R_2014-11-22T01:51:26.525000Z
Processing Level of Product	Level 1b (Reconstructed Data)
Measured Quantity Name	Radar backscatter and phase
Measured Quantity Units	dB
Stated Measurement Quality	0.6 dB absolute radiometric accuracy (0.3 dB relative)
Spatial Resolution (range X azimuth) [m]	ScanSAR: 1.7 x 18.5, 150 MHz bandwidth Stripmap single polarization: 1.2 x 3.3, 150 MHz bandwidth Spotlight single polarization: 1.48 x 1.7, Single Pol HR Spotlight single polarization: 0.74 x 1.1, Single Pol, 300 MHz bandwidth
Spatial Coverage (range X azimuth) [km]	ScanSAR: 100 x 150 Stripmap single polarization: 30 x 50 Spotlight single polarization: 10 x 10 HR Spotlight single polarization: 10 x 5

Product Details	
Grade: Excellent	
Temporal Resolution	Repeat period of 11 days for a single satellite (TSX/TDX or PAZ). 5.5 days for combined constellation
Temporal Coverage	TSX was launched in June 2007 and TDX in June 2010. Both have performed beyond their 5.5-year design lifetime. PAZ was launched in 2018 with an expected design life of 7 years. The constellation observing plan is mainly tasking-based, except for CoSSC collections, which cover the entire globe in a systematic way.
Point of Contact	Jen Kennedy, John Collins Address: Airbus 2550 Wasser Terrace, Ste 9100 Herndon, VA 20171 Telephone: 571-422-2202, 703-624-9959 Email: kennedy@airbus-na.com, collins@airbus-na.com
Product locator (DOI/URL)	N/A
Conditions for access and use	All data used in this evaluation were purchased by CSDA under U.S. Government-wide license. License can be found at the CSDA website.
Limitations on public access	N/A
Product Abstract	N/A

Availability & Accessibility	
Grade: Good	
Justification	Meets most of the FAIR principles (Wilkinson 2016) except: A2. metadata are accessible, even when the data are no longer available I3.Metadata and data include qualified references to other (meta)data.
Compliant with FAIR principles	87%
Data Management Plan	Airbus radar portal is available for anyone to register and search the available imagery and a subset of their metadata. However, the CoSSC data are not available through the radar portal. Orbital baseline information is also not provided as part of the search tool, requiring users to download the complete dataset to identify image pairs that fit their use case.
Availability Status	The data are commercially available and can be accessed via the Airbus radar portal.

Product Format	
Grade: Excellent	
Justification	User orders are delivered in a zip file with a standard folder structure containing each image inside a parent folder. The parent folder contains subfolders with various metadata (doppler centroid, antenna pattern), quicklook imagery, and Google Earth KML files, binary image data, and metadata files in XML format. The SAR image data of the MGD products are embedded in a GeoTIFF raster file.
Product File Format	Binary COSAR / GeoTiff, XML
Metadata Conventions	1.0
Analysis Ready Data?	No

User Documentation		
Grade: Good		
Justification	The user documentation provided to CSDA evaluators and references therein provide a detailed resource about the products. However, the documents do not provide traceable quality information for the provided uncertainty values.	
Document	**Reference**	**QA4ECV Compliant**
TSX Product Guide v2.1	RD-1 (Provided to CSDA, also available online)	No
PAZ Image Product Guide v1.1	RD-2 (Provided to CSDA, also available online)	No
USG EULA	RD-3 (Available on the CSDA website)	No
TerraSAR-X L1B Product Format Specification v1.3	RD-4 (Referenced in RD-1, accessed online)	No
TerraSAR-X Basic Product Specification Document v1.9	RD-5 (Referenced in RD-1, accessed online)	No
SAR Level 1b Product Format Specification for PAZ SAR Processor v1.1	RD-6 (Referenced in RD-2, accessed online)	No

Metrology

Sensor Calibration & Characterization	
Grade: Excellent	
Justification	Data calibration procedures and remaining uncertainties are outlined in RD-5.
References	RD-5

Geometric Calibration & Characterization	
Grade: Excellent	
Justification	Pixel localization accuracy is stated to be intrinsically “sub-pixel.” Depending on the height errors used for geocoding and the incidence angle, a table is provided to describe resulting geocoding errors.
References	RD-5

Metrological Traceability Documentation	
Grade: Not Assessable	
Justification	The evaluation team did not have access to any metrological traceability documentation.
References	N/A

Uncertainty Characterization	
Grade: Basic	
Justification	While most of the relevant parameter values are provided in the metadata files and the documentation, the methods used to retrieve the estimates are not described.
References	RD-5

Product Generation

Geometric Processing	
Grade: Excellent	
Justification	The SAR systems are characterized in RD-5 and RD-6. Metadata includes all reasonable aspects. Basic Level-1b products include SSC, MGD, MGD with geocoded ellipsoid correction (GEC), and MGD with enhanced ellipsoid (with terrain) correction (EEC). The documentation explains the basic processing methods for these products. Higher level (DEM, GCP) products were not assessed.
References	RD-5 RD-6

Image Formation and Calibration Algorithm	
Grade: Good	
Justification	Image formation and radiometric corrections are outlined in RD-5 and RD-6. Airbus does not include pre- and post-calibration procedures in these documents. However, corrections are applied to the product and most relevant processing parameters are described in the metadata. Pre- and post-calibration procedures are not covered in these documents, but corrections are applied to the product. The focusing algorithm is not defined in the documentation and the chirp replicas are not provided in the Level-1 products. Basic Level-1b products include SSC, MGD, MGD with geocoded ellipsoid correction (GEC), and MGD with enhanced ellipsoid (with terrain) correction (EEC). The Airbus documentation explains the corrections applied to these products.
References	RD-5 RD-6

Mission-Specific Processing	
Grade: Not Assessable	
Justification	The assessment was limited to radar imagery and did not include mission specific products like digital elevation models.

Detailed Measurement Validation

This analysis includes data from TSX, TDX, and PAZ sensors from the Airbus SAR constellation as shown in Table 3.1.

Table 3.1

All Airbus Data Products Included in the Data Analysis and Evaluation

Test Area	Date	Sat.	Mode	Polarization	Beam	Product	Version
Rosamond	20080223	TSX	SM	S	strip_013	SSC	4.11
	20080407	TSX	SM	S	strip_013	SSC	4.11
	20080601	TSX	SM	S	strip_013	SSC	4.11
	20120910	TDX	SM	S	strip_013	SSC	4.11
	20130327	TDX	SM	S	strip_013	SSC	4.11
	20141122	TSX	SM	S	strip_013	SSC	4.11
Amazon	20080521	TSX	SM	S	strip_008	SSC	4.11
	20080806	TSX	SM	D	stripFar_007	SSC	4.11
	20090816	TSX	HS	D	spot_070	SSC	4.11
	20100719	TSX	SM	S	strip_013	SSC	4.11
	20140116	TDX	SM	S	strip_004	SSC	4.11
	20140127	TDX	SM	S	strip_005	SSC	4.11
	20140223	TDX	SM	S	strip_010	SSC	4.11
	20140721	TDX	SL	S	spot_098	SSC	4.11
	20140727	TDX	SM	D	stripFar_011	SSC	4.11
	20140730	TDX	HS	S	spot_077	SSC	4.11
	20140801	TDX	HS	S	spot_098	SSC	4.11
	20140804	TSX	SM	D	stripFar_007	SSC	4.11
	20140810	TSX	HS	S	spot_077	SSC	4.11
	20140812	TDX	HS	S	spot_098	SSC	4.11
	20140821	TDX	SL	S	spot_077	SSC	4.11
	20140923	TSX	HS	S	spot_077	SSC	4.11
	20140925	TSX	HS	S	spot_098	SSC	4.11
	20140925	TSX	HS	S	spot_095	SSC	4.11

Test Area	Date	Sat.	Mode	Polarization	Beam	Product	Version
Amazon	20140926	TDX	HS	S	spot_005	SSC	4.11
	20141004	TDX	HS	S	spot_077	SSC	4.11
	20141006	TSX	SM	D	stripFar_021	SSC	4.11
	20141007	TSX	SM	S	strip_002	SSC	4.11
	20141010	TSX	SM	D	stripFar_027	SSC	4.11
	20150224	TSX	SM	S	strip_014	SSC	4.11
	20150318	TDX	SM	S	strip_014	SSC	4.11
	20151214	TDX	SM	S	strip_017	SSC	4.11
	20180923	PAZ	SL	D	spot_021	SSC	1.6
	20181004	PAZ	SL	D	spot_021	SSC	1.6
	20210403	PAZ	SM	S	strip_004	SSC	1.6
	20210425	PAZ	SM	S	strip_004	SSC	1.6
	20210506	PAZ	SM	S	strip_004	SSC	1.6
	20210517	PAZ	SM	S	strip_004	SSC	1.6
	20210608	PAZ	SM	S	strip_004	SSC	1.6
	20210630	PAZ	SM	S	strip_004	SSC	1.6
Doldrums	20181015	PAZ	SM	D	stripNear_003	SSC	1.6
	20181014	PAZ	SM	D	stripNear_003	SSC	1.6
	20181001	PAZ	SM	D	stripNear_003	SSC	1.6
	20181007	PAZ	SM	D	stripFar_014	SSC	1.6
	20181022	PAZ	SL	D	spot_100	SSC	1.6
	20181014	PAZ	SL	D	spot_011	SSC	1.6
	20181015	PAZ	SL	D	spot_011	SSC	1.6
	20181020	PAZ	SL	D	spot_099	SSC	1.6
	20181021	PAZ	SL	D	spot_010	SSC	1.6
	20181023	PAZ	HS	D	spot_010	SSC	1.6
	20181025	PAZ	HS	D	spot_099	SSC	1.6
	20200304	PAZ	SM	S	strip_010	SSC	1.6
	20181020	PAZ	SL	D	spot_100	SSC	1.6
	20181017	PAZ	SL	D	spot_064	SSC	1.6
	20200716	TDX	SM	S	strip_013	SSC	4.11
	20200715	PAZ	SM	S	strip_009	SSC	1.6

Absolute Radiometric Accuracy Validation

Method

The absolute radiometric accuracy of the imagery was validated using point target analysis tools provided in the GAMMA software. The expected PSLR and ISLR values are not provided, but the Hamming window alpha coefficient (α) of 0.6 is defined in RD-5. The theoretical PSLR and ISLR values can therefore be calculated using the Hamming window (Table 3.2; Breit, et al., 2008). The resolutions obtained from point target analysis meet the Airbus specified values within the uncertainty of the analysis.

Table 3.2

Relationship between Hamming window alpha coefficient and theoretical impulse response function properties (Breit, et al., 2008)

α	PSLR (dB)	1-D ISLR (dB)
o.6	-31.6	-19.5

The point target response of the corner reflector (CR01) at the Rosamond, California, site is shown in Figure 3.1. In a well-focused image, a well-defined main lobe is formed that is clearly separated from the side lobes. PSLR can then be calculated by taking the ratio of the main lobe and the largest side lobe. Similarly, ISLR is calculated by taking the ratio of the total energy in the main lobe to the total energy in the side lobes.

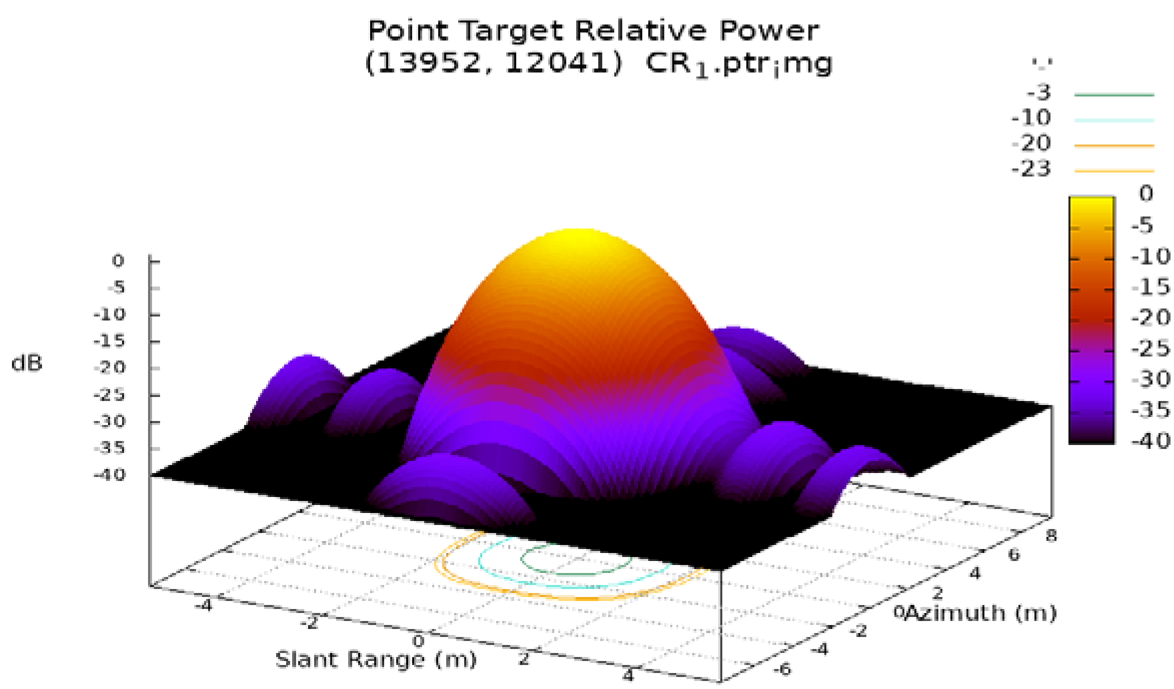

Figure 3.1. *Impulse response of corner reflector CR01 at Rosamond site observed by TSX on November 22, 2014. Observed sigma0 is within 0.07 dB of expected.*

Results Compliance

The absolute sigma0 accuracy over corner reflectors at Rosamond are around 1.8 dB for all corner reflectors, with some corner reflectors showing consistent bias in the range of ⍰3 db. The expected absolute root mean square accuracy is around 0.6 dB between the measured and the true radar cross section at different locations within one scene and also over time. The larger differences observed might be due to inaccuracies with the corner reflector orientation (Table 3.3) or system calibration. Following Breit, et al., 2008, Figure 3.2 displays the Fourier transform of a one-dimensional hamming window with alpha set to 0.6. The PSLR is measured as the difference between the peak of the main lobe and the highest side lobe as -31.6 dB. The ISLR is measured by summing up the power of the side lobes (i.e., area under the curve) and comparing that to the power in the main lobe, resulting in -19.5 dB expected value.

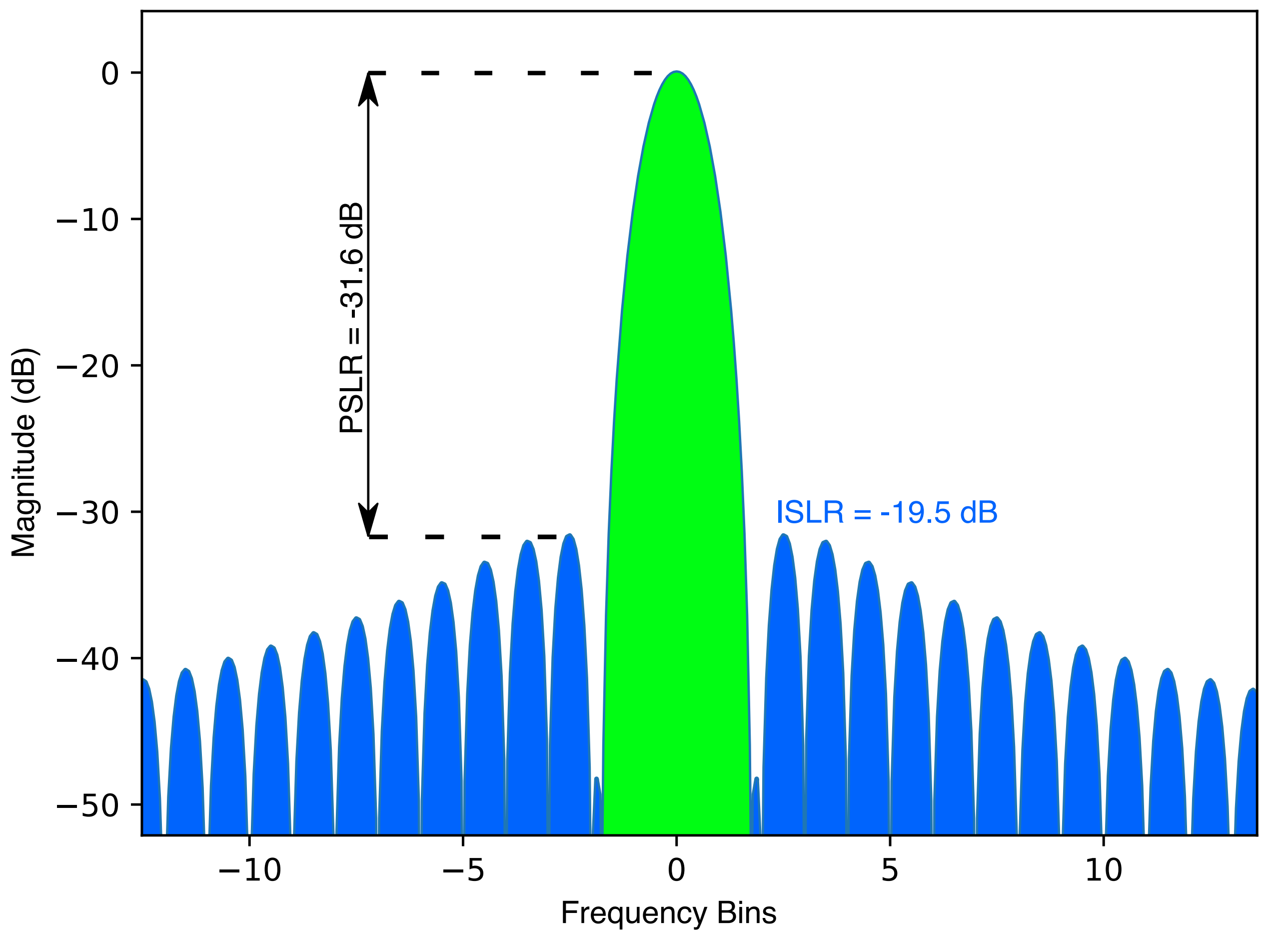

Figure 3.2. *Fourier transform of the hamming window with alpha set to 0.6. PSLR is measured peak to peak between the main lobe and the highest side lobe. The ISLR is the difference of energy stored in the main lobe (green) and side lobes (blue).*

The corner reflectors analyzed over the Rosamond corner reflector array were from TSX and TDX satellites over a 6-year period. The PSLR values for both range and azimuth directions were very close to the expected value considering the uncertainty values (Table 3.2). In this analysis, the mean and standard deviation of PSLR values were calculated based on the 13 corner reflectors used for the analysis (Table 3.4). It must be noted that the variation in azimuth dimension was observed to be higher than the variation in range for both the PSLR and ISLR values. The ISLR values were better than expected in both azimuth and range.

Table 3.3

Evaluation of Airbus SAR Data for Side Lobe Ratios in Impulse Response Function

SAR Acquisitions	Expected [dB]	Calculated [dB]			
	PSLR/ISLR	Range PSLR	Azimuth PSLR	Range ISLR	Azimuth ISLR
TSX1_SAR__SSC______SM_S_SRA_20080223T015046	-31.6 / -19.5	-29.41±1.69	-27.46±4.24	-26.58±1.51	-24.80±4.68
TSX1_SAR__SSC______SM_S_SRA_20080407T015048		-29.42±1.04	-22.66±4.53	-26.64±0.59	-21.31±4.52
TSX1_SAR__SSC______SM_S_SRA_20080601T015052		-29.57±1.18	-26.25±5.04	-26.62±0.98	-23.53±4.78
TDX1_SAR__SSC______SM_S_SRA_20120910T015115		-29.42±2.15	-27.95±3.53	-26.25±1.85	-25.53±3.67
TDX1_SAR__SSC______SM_S_SRA_20130327T015112		-29.17±2.27	-27.08±3.42	-26.06±1.98	-24.61±3.57
TSX1_SAR__SSC______SM_S_SRA_20141122T015125		-29.47±0.52	-30.37±0.51	-26.68±0.36	-27.56±0.45

Table 3.4

Corner Reflectors Used for the Analysis at the Rosamond Site

CR ID	Size (m)	Orientation (°)	Elevation (°)	Latitude (°)	Longitude (°)	Elevation (m)
CR00	2.4	172	11.24	34.796968	-118.0965259	660.90
CR01	2.4	170	8.39	34.7997624	-118.0870473	661.09
CR02	2.4	170	9.57	34.8052365	-118.0874563	660.89
CR03	2.4	174	8.78	34.8053416	-118.0819065	661.06
CR04	2.4	174	12.48	34.8054146	-118.0763749	661.14
CR05	2.4	173.17	9.09	34.8054929	-118.0708001	661.23
CR06	2.4	171.36	10.91	34.805584	-118.0652228	661.25
CR07	2.4	173.6	11.7	34.8056691	-118.0596638	661.31
CR08	2.4	172.83	9.84	34.8057512	-118.0540701	661.46
CR09	2.4	175.12	10.24	34.8058133	-118.0489123	661.45
CR10	2.4	174.2	8.11	34.8059246	-118.043364	661.52
CR11	2.4	171.5	8.36	34.8060234	-118.0376901	661.60
CR12	2.4	172.37	11.73	34.8060462	-118.0322784	661.91

Radiometric Stability Validation

Method

Assessment of radiometric stability is assessed through tracking of known target amplitudes over time (Schmidt, Ramon, and Schwerdt, 2018).

Results Compliance

The corner reflector observations between 2008 and 2014 over the Rosamond, California, site do not indicate a discernible trend in the sigma0 observations (Figure 3.3). The spread among different corner reflectors might be due to inaccuracies in the corner reflector characterization provided in Table 3.4 or residuals in antenna pattern correction. The specified relative radiometric accuracy in RD-1 is 0.3 dB, which is observed at CR04.

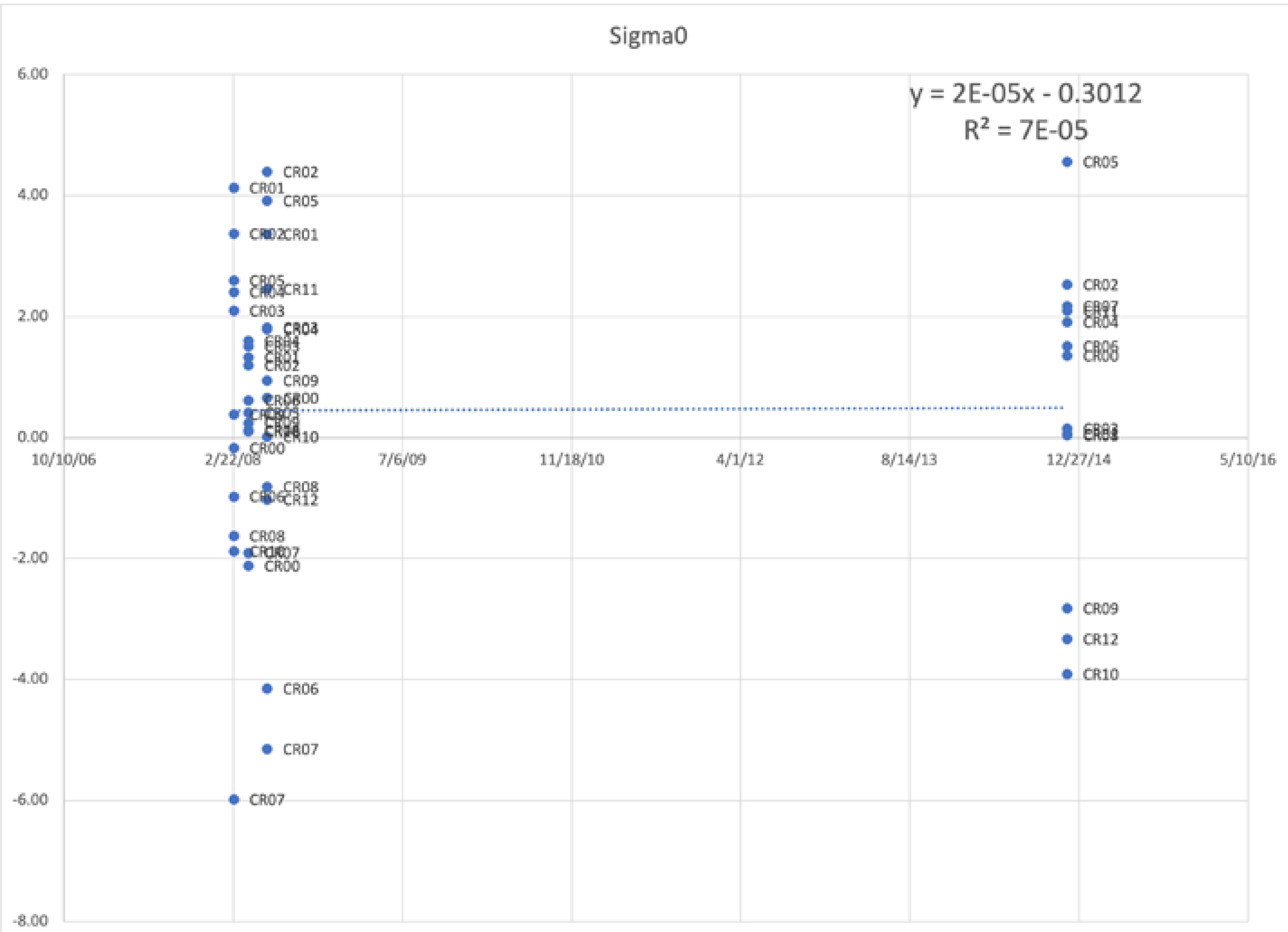

Figure 3.3. *Absolute calibration error estimates over Rosamond corner reflectors for TSX indicate very good temporal stability with a standard deviation of 2.4 dB over all available targets. CR04 returns have a standard deviation of 0.3 dB while CR07 has a standard deviation of 3.2 dB over the same period.*

Sensitivity Validation

Method

NESZ is estimated using signal-free regions (e.g., over very low or null backscatter targets, such as calm water or deserts) in the radar imagery.

Results Compliance

NESZ of a system can be estimated using data collected over radar quiet areas or areas with flat water surfaces, such as the ones found over the doldrums in the Atlantic and Pacific Ocean. Using imagery collected over such areas, Airbus SAR data NESZ over a range of imaging angles are estimated and shown in Figure 3.4. The observed NESZ values are at or below the expected values for the specific acquisition mode and beam. Acquisition 11 (PAZ_20200304) includes higher wind conditions and therefore appears as if it has a higher NESZ value. Acquisitions 4, 7, 10, and 12 perform better than the expected spotlight performance of -16 dB according to RD-5.

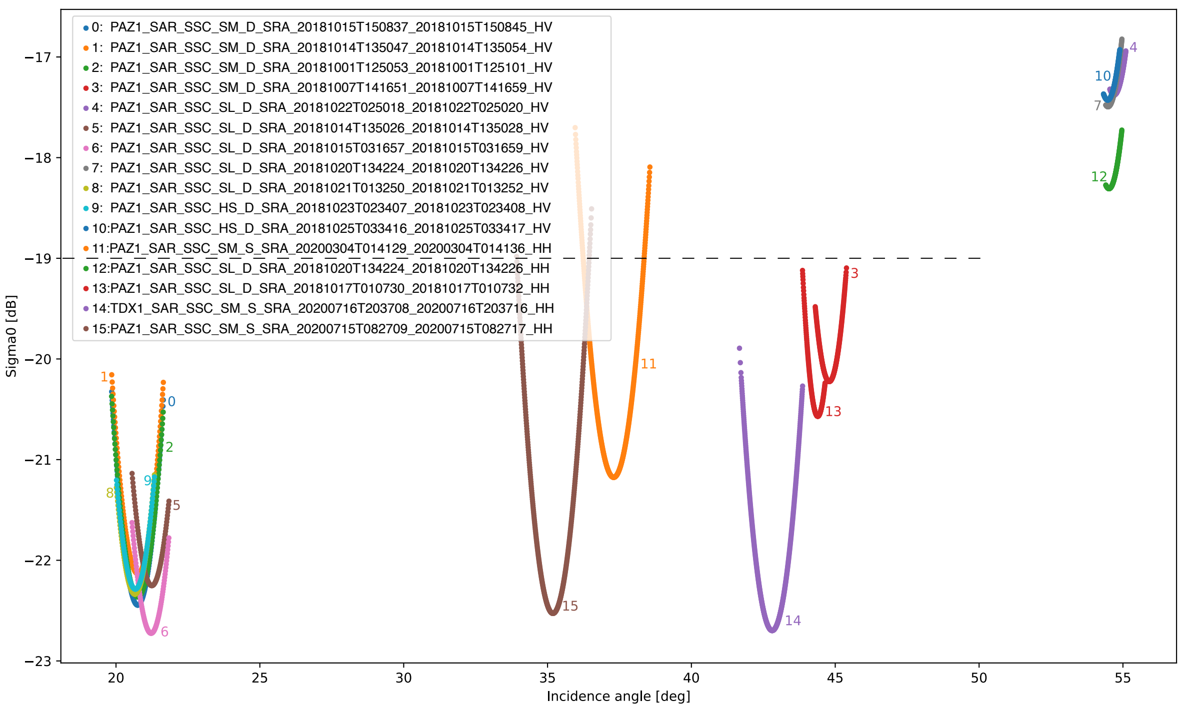

Figure 3.4: *NESZ estimated using data collections over wind-free acquisitions in the Atlantic and Pacific Ocean. The dashed line indicates the -19 dB expected performance level [RD-5].*

Polarimetric Accuracy Validation

Method

Polarization accuracy can be measured using corner reflectors if quad polarization imagery is available (van Zyl, 1990). The Airbus archive does not contain any quad polarization imagery. Therefore, polarimetric accuracy was not validated.

Despite the lack of quad polarization image availability in the archive, there are studies who used the experimental data collections (Bueso-Bello, et al., 2017).

Interferometric Accuracy Validation

Method

The interferometric quality is assessed through tracking of point target phase over time for various targets across the image swath (Marinkovic, Ketelaar, and van Leijen, 2007).

Results Compliance

For interferometric accuracy we collected two separate data stacks over the Rosamond, California, and Neustrelitz, Germany, corner reflectors. Unfortunately, the dataset over the Rosamond corner reflector array was not dense enough to conduct a time series analysis (Table 3.1). One of the acquired images over Rosamond had very limited overlapping area with the other images, which resulted in coregistration failure. Therefore, we were able to generate a single primary stack of four interferograms using the remaining five images. The Neustrelitz data stack has 35 images between 2009 and 2021, but only two corner reflectors seem to be stable over time. As a result, we were unable to use the time series methods to estimate phase noise.

The relationship between interferometric coherence, standard deviation of phase and signal to noise ratio (SNR) are well established (Just and Bamler, 1994). It is possible to calculate the expected coherence of a SAR instrument given its NESZ (Figure 3.4) and the expected return power through:

$$\gamma_{SNR} = \frac{1}{\sqrt{(1+N/S)}} \quad (1)$$

where γ is the coherence, *N* is the noise level, and *S* is the signal level in the image. In (2) the probability density function (pdf) of interferometric phase (φ) is obtained as a function of coherence, and a phase offset of (φ-φ_0; Just and Bamler, 1994).

$$pdf(\phi) = \frac{1-|\gamma|^2}{2\pi} \frac{1}{1-|\gamma|^2 cos^2(\phi-\phi_0)} \times \left(1 + \frac{|\gamma| cos(\phi-\phi_0) arccos(-|\gamma| cos(\phi-\phi_0))}{\sqrt{1-|\gamma|^2 cos^2(\phi-\phi_0)}}\right) \quad (2)$$

Expected returns for most surface types are defined in Ulaby et al. (2019). Figure 3.5 shows the range of observed signal levels (sigma0) for X-band between 20- and 55-degrees incidence angles within a 95% confidence interval.

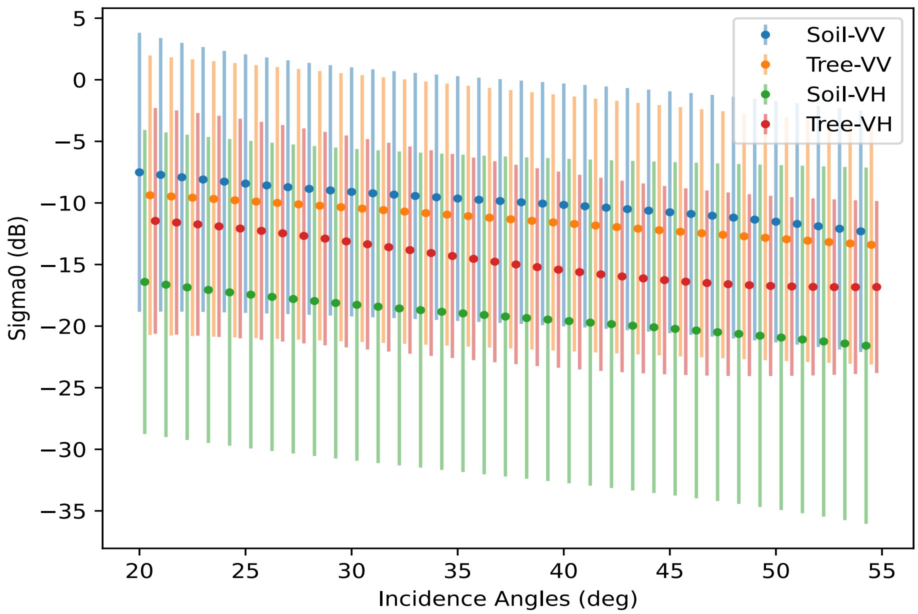

Figure 3.5. *Theoretical range of signal levels at VV and VH polarization in X-band (Ulaby et al, 2019)*

Human-created targets in urban areas and point scatterers can achieve a high SNR while the natural terrains tend to be lower, with the observed backscatter values reaching the NESZ over very smooth terrains and calm water. Figure 3.6 presents expected coherence and standard deviation of phase given an SNR.

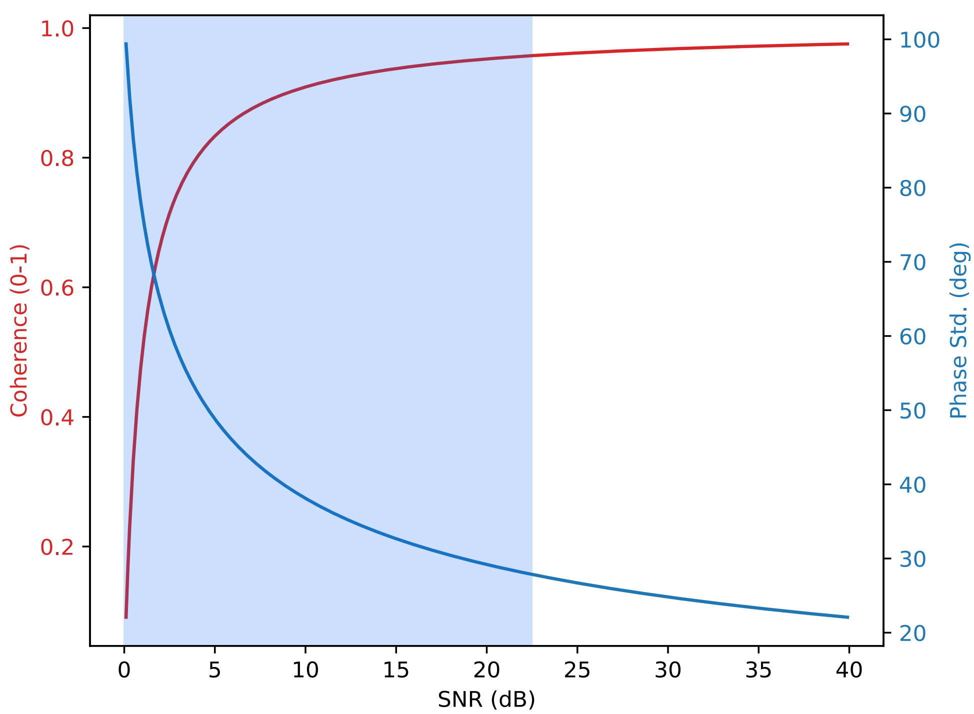

Figure 3.6. *Relationship between interferometric coherence and standard deviation of phase based on SNR. Blue shaded area denotes expected performance range for VV polarized soil with a -19 dB NESZ.*

Detailed Validation—Geometric

Spatial Resolution Validation

Method

The spatial resolution of the imagery was validated using point target analysis tools provided in GAMMA software, such as the SLC version of the point target analysis command, ptarg_SLC, which provides measured point target response for a given corner reflector. The expected slant range resolutions are provided in the product metadata XML files. The obtained resolutions from point target analysis meet the expected values within the uncertainty of the analysis.

Results Compliance

Table 4.1

Evaluation of Airbus SAR Data for Spatial Resolution Performance

SAR Acquisitions	Expected Resolution [m, metadata]	Calculated Resolution [m]	
	Slant Range /Azimuth	3 dB Range Res.	3 dB Azimuth Res.
TSX1_SAR__SSC______SM_S_SRA_20080223T015046	1.76 / 3.30	1.78±0.06	2.96±0.09
TSX1_SAR__SSC______SM_S_SRA_20080407T015048		1.77±0.05	2.97±0.14
TSX1_SAR__SSC______SM_S_SRA_20080601T015052		1.80±0.05	2.96±0.12
TDX1_SAR__SSC______SM_S_SRA_20120910T015115		1.77±0.04	2.99±0.10
TDX1_SAR__SSC______SM_S_SRA_20130327T015112		1.79±0.03	3.01±0.06
TSX1_SAR__SSC______SM_S_SRA_20141122T015125		1.76±0.05	2.95±0.06

Geolocation Accuracy Validation

Method

The geolocation accuracy was calculated based on the corner reflectors at the Rosamond, California, dry lake bed site maintained by NASA's JPL. The geolocation accuracy of the Airbus products has been assessed using the GAMMA Remote Sensing software and its SLC point target analysis tool (ptarg_SLC). Coordinates of the corner reflectors in the Rosamond corner reflector array (Table 3.4) are used to estimate the geolocation accuracy of the data.

Results Compliance

The results obtained using 12 corner reflectors (C00-C11) in the Rosamond corner reflector array indicate that the geolocation accuracy of the Airbus SAR data is within the specified range of 2 m, given the reported uncertainty values in Table 4.2. It must be noted that the uncertainty values are about 1 m in range direction, while the mean range location errors are about 2 m. In the flight (azimuth) direction, the estimated error is usually less than 0.2 m with an uncertainty of about 0.4 m. The overall localization uncertainty of all the reported values in Table 4.2 is 2.2 ±1.0 m.

Table 4.2

Evaluation of Airbus SAR Data for Geolocation Accuracy Performance

SAR Acquisitions	Expected Localization Error [m, RD-5]	Range Location Err. [m]	Azimuth Location Err. [m]
TSX1_SAR__SSC______SM_S_SRA_20080223T015046	2	2.16±1.06	0.08±0.14
TSX1_SAR__SSC______SM_S_SRA_20080407T015048		2.21±1.09	0.08±0.10
TSX1_SAR__SSC______SM_S_SRA_20080601T015052		2.26±1.01	0.23±0.46
TDX1_SAR__SSC______SM_S_SRA_20120910T015115		2.34±1.07	0.21±0.41
TDX1_SAR__SSC______SM_S_SRA_20130327T015112		2.18±1.02	0.08±0.12
TSX1_SAR__SSC______SM_S_SRA_20141122T015125		2.04±0.60	0.19±0.42

Reference

RD-1 TerraSAR-X Image Product Guide (https://www.intelligence-airbusds.com/files/pmedia/public/r459_9_20171004_tsxx-airbusds-ma-0009_tsx-productguide_i2.01.pdf)

RD-2 PAZ Image Product Guide v1.1 (https://www.hisdesat.es/wp-content/uploads/2019/10/PAZ-HDS-GUI-001-PAZ-Image-Product-Guide-issue-1.1-.pdf)

RD-3 CSDA Program USG EULA (https://www.earthdata.nasa.gov/s3fs-public/2022-05/CSDA_Program_USG_EULA-11-09-20_Rev3.pdf)

RD-4 TerraSAR-X Ground Segment - Level 1b Product Format Specification (https://www.intelligence-airbusds.com/files/pmedia/public/r460_9_030201_level-1b-product-format-specification_1.3.pdf)

RD-5 TerraSAR-X Ground Segment - Basic Product Specification Document (https://sss.terrasar-x.dlr.de/docs/TX-GS-DD-3302.pdf)

RD-6 SAR Level 1b Product Format Specification for PAZ SAR Processor (https://www.inta.es/export/sites/default/.galleries/Paz-Ciencia-Descarga/PAZ_Level_1b_Product_Format_Specification_v1.1.pdf)

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van Zyl, J.J. (1990). Calibration of polarimetric radar images using only image parameters and trihedral corner reflector responses. IEEE Transactions on Geoscience and Remote Sensing, 28(3): 337-348. doi:10.1109/36.54360