Commercial Satellite Data Acquisition Program

MDA RADARSAT-2 Synthetic Aperture Radar (SAR) Quality Assessment Report

Goddard Space Flight Center
Greenbelt, MD

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Preface

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Abstract

The evaluation summarized in this report was conducted by subject matter experts (SMEs) funded by NASA's Commercial Satellite Data Acquisition (CSDA) Program. The SMEs evaluated the findings of the scientific and academic community on the radiometric and geometric quality of RADARSAT-2 data. These results helped inform NASA on the potential use of RADARSAT-2 data for the NASA Earth science research and applications community. The results of this report help to inform NASA program management on the quality of the data for NASA science.

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Acronyms & Abbreviations

ATBD	Algorithm Theoretical Basis Document
CSA	Canadian Space Agency
CSDA	Commercial Satellite Data Acquisition
DEM	Digital Elevation Model
DOI	Digital Object Identifier
ESD	Earth Science Division
ESA	European Space Agency
FAIR	Findable, Accessible, Interoperable and Reusable
GCP	Ground Control Point
GPS	Global Positioning System
HH	Sensor polarization: Horizontal transmit, Horizontal receive
HV	Sensor polarization: Horizontal transmit, Vertical receive
ISA	Italian Space Agency
MDA GSI	MacDonald, Dettwiler & Associates Geospatial Services Inc
NESZ	Noise Equivalent Sigma Zero
QA	Quality Assessment
RCS	Radar Cross Section
RMS	Root Mean Square
SAR	Synthetic Aperture Radar
SGX	SAR Georeferenced Extra
SGF	SAR Georeferenced Fine
SLC	Single Look Complex
SME	Subject Matter Experts
URL	Universal Resource Locator
VH	Sensor Polarization: Vertical transmit, Horizontal receive
VV	Sensor Polarization: Vertical transmit, Vertical receive

Executive Summary

The Commercial Satellite Data Acquisition (CSDA) Program was established to identify, evaluate, and acquire data from commercial sources that support the National Aeronautics and Space Administration (NASA) Earth science research and application goals. NASA's Earth Science Division (ESD) recognizes the potential impact commercial satellite constellations may have in encouraging/enabling efficient approaches to advancing Earth System Science and applications development for societal benefit. Commercially acquired data may also provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. government agencies and those by international partners and agencies.

In this report, CSDA provides a summary of the quality of RADARSAT-2 Synthetic Aperture Radar (SAR) satellite data to support advancement of NASA's Earth system science research and applications. This summary of RADARSAT-2 data along with information about radiometric and geometric performance was developed by NASA subject matter experts (SMEs). RADARSAT-2 is owned and operated by MacDonald, Dettwiler & Associates (MDA) Geospatial Services Inc. (hereafter referred to as MDA GSI). The Canadian Space Agency helped fund the construction and launch of the satellite and works to recover this investment through a supply of RADARSAT-2 data to the Canadian government.

Findings in this report indicate that RADARSAT-2 continues to perform within the targeted errors in terms of radiometric calibration (less than1 dB) and geometric accuracy (< 10 – 20 m depending on beam mode). These findings by the scientific community were confirmed by NASA through collaborations with our partners at the European Space Agency (ESA). ESA shared their most recently completed evaluation of RADARSAT-2 data in the summer of 2023. ESA found that RADARSAT-2 continues operate well within of their targeted errors for both radiometric and geometric calibration and only on rare occasion does the instrument exceed them.

This report was primarily generated through an advanced literature search and review. The literature review was aided by the use of artificial intelligence tools that have been endorsed by NASA to increase productivity and efficiency, specifically Google Gemini. Gemini was used to aid in the search and identification of a number of scientific journal articles that have used RADARSAT-2 and to quickly summarize the major findings of those articles. All sources and findings that are included in this report were double checked by CSDA SMEs and personnel to ensure veracity.

1. RADARSAT-2 Background and Information

RADARSAT-2 is a C-band (5.6 cm) Synthetic Aperture Radar (SAR) satellite that is in Low Earth Orbit with an altitude of 798 km. RADARSAT-2 was launched in December 2007, declared operational in April 2008, and is in a sun-synchronous orbit at a 98.6° inclination. RADARSAT-2 operates at 6 AM/6 PM dawn-dusk descending/ascending nodes with a 24-day ground track revisit period. At equatorial latitudes, RADARSAT-2 revisit period is 2-3 days, and daily in polar regions.

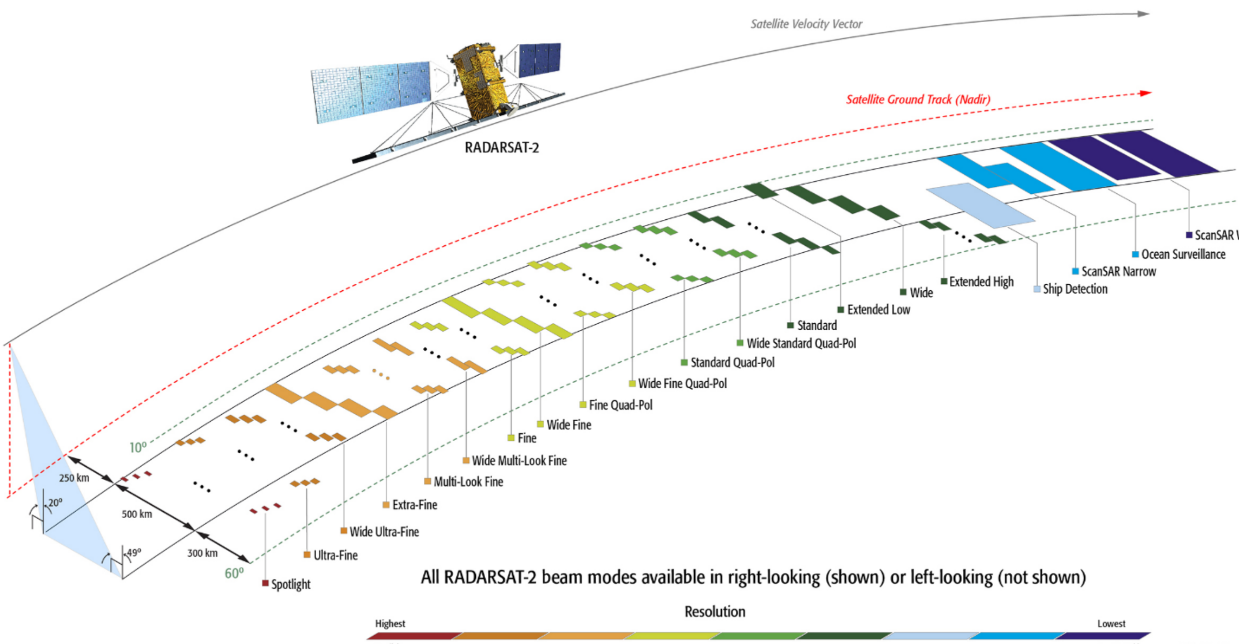

Figure 1. All RADARSAT-2 Imaging Modes visually represented along with swath area of each imaging mode.

RADARSAT-2 offers 20 different beam modes (1 Spotlight, 15 Stripmap, and 4 ScanSAR) that all have different corresponding polarization modes. RADARSAT-2 offers single polarization (HH, HV, VH, VV), dual polarization (HH+HV / VV+VH), and quad polarization (HH, HV, VH, VV) acquisitions (Figure 1, Table 1). Due to the high number of beam mode and polarizations available from RADARSAT-2, spatial resolution can range from as fine as 0.8 m in the Spotlight mode (single polarization) and as coarse as 163 m in the ScanSAR wide beam mode (single or dual polarization). Swath widths are also variable for RADARSAT-2 beam modes ranging from 18 km to 500 km. Figure 1 is visual representation of how the different beam modes, spatial resolutions and swath widths vary from this instrument.

RADARSAT-2 acquisitions are available in three different product types at different processing levels. The three different types of products are Slant Range, Ground Range, and Geocorrected. Slant Range products are oriented perpendicular to the track of the satellite path and are georeferenced using orbit information to calculate the latitude/ longitude for each pixel and are commonly referred to as Single Look Complex (SLC) products. Ground range products have range pixel spacing and range resolution that is measured along an assumed Earth surface that follows the shape of an ellipsoid at a local elevation height. Geocorrected products have the highest level of geometric correction for RADARSAT-2 products. Geocorrected products are projected on a standard map projection which effectively removes distortions caused by Earth's curvature and the sensor's viewing geometry.

Data acquired from RADARSAT-2 are complementary to research and application areas in NASA's ESD. RADARSAT-2 data can be used to monitor surface dynamics, the cryosphere, ecosystems, ocean science, natural hazards, and disasters. The long time series of data currently in the RADARSAT-2 archive also provides a great opportunity to study both short- and long-term trends for multiple research and application areas.

2. Data Provider Documentation Review

2.1 Product Information

Product Details	
Product Name	RS2_OK153952_PK1408404_DK1372523_F21F_20231123_052042_HH_SGF • RS2 = RADARSAT-2 • OK153952 = Order Key • PK1408404 = Product Key • DK1372523 = Delivery Key • F21F = Beam Mode • YYYYMMDD = Acquisition Date (YYYYMMDD) • HHMMSS = Acquisition Time (UTC; HHMMSS) • HH = Polarization • SGF = Processing Level
Sensor Name	RADARSAT-2 C-Band Radar Satellite
Sensor Type	SAR
Mission Type	Single Platform SAR satellite
Mission Orbit	Sun Synchronous
Product Version Number	N/A
Product ID	PDS_10834210
Processing level of product	RADARSAT-2 offers up 9 different product types, many that correspond to the beam mode that was used for the acquisition. Single Look Complex (SLC) and SAR Georeferenced Extra/Fine (SGX/SGF) are the two most common processing levels.
Measured Quantity Name	Radar backscatter, Beta Nought (β_0) β0) product metadata
Measured Quantity Units	Radar backscatter (β_0) is a unitless quantity representing reflectivity per unit area.

Stated Measurement Quality	Unitless. Radar brightness and normalized radar cross sections are unitless quantities representing reflectivity per unit areas. RADARSAT-2 offers Sigma0, Beta0, and Gamma0 corrections.
Spatial Resolution	Spatial resolution ranges from 1 m to 100 m (Table 1).
Spatial Coverage	Global
Temporal Resolution	24-day ground track revisit
Temporal Coverage	December 2007 - present
Point of Contact	N/A
Conditions for access and use	All data and metadata for this this report were obtained from Sample data hosted by ESA (https://earth.esa.int/eogateway/ftp/missions/sample-data/third-party-missions/radarsat). Additional information for this report was generated through a thorough literature search and review.

Table 1. Nominal swath widths, maximal spatial resolutions and nominal incidence angles for RADARSAT-2.

Beam modes	Nominal swath width (km)	Maximal spatial resolution (m)	Nominal Incidence Angle Range (deg)
Selective Single or Dual Polarization Transmit H and/or V, receive H and/or V			
Fine	50	8	30 – 50
Wide Fine	150	8	20 – 45
Standard	100	25	20 – 52
Wide	150	25	20 – 45
ScanSAR Narrow	300	50	20 – 46
ScanSAR Wide	500	100	20 – 49
Ocean Surveillance	530	Variable	20 – 50
Polarimetric Transmit H and V on alternate pulses /Receive H and V on any pulse			
Fine Quad-Pol	25	12	18 – 49
Wide Fine Quad-Pol	50	12	18 – 42
Standard Quad-Pol	25	25	18 – 49
Wide Standard Quad-Pol	50	25	18 – 42
Single Polarization HH Transmit H, receive H			
Extended High	75	25	49 – 60
Extended Low	170	60	10 – 23
Selective Single Polarization Transmit H or V, receive H or V			
Spotlight	18	1	20 – 54
Ultra-Fine	20	3	20 – 54
Wide Ultra-Fine	50	3	29 – 50
Extra-Fine	125	5	22 – 49
Multi-Look Fine	50	8	30 – 50
Wide Multi-Look Fine	90	8	29 – 50
Ship Detection	450	Variable	35 – 56

3. Radiometric Calibration

RADARSAT-2 demonstrates high levels of radiometric and polarimetric accuracy which meet or exceed performance specifications. The radiometric error for the majority of RADARSAT-2 beam modes and product types is usually less than 1 dB. Certain RADARSAT-2 collection modes, such as the Wide Multi-Look Fine, Extra-Fine, Ship Detection and Ocean Surveillance can have radiometric errors under 1.5 dB. These estimates typically exclude errors from discrepancies between the base elevation, an estimated geodetic terrain height used for geometric and radiometric calculations, and true surface elevation, as well as potential effects of instrument noise (MDA 2018).

Although RADARSAT-2 has consistently demonstrated absolute radiometric accuracy better than 1 dB, some have reported accuracy closer to 0.3 dB (Luscombe 2009). The relative radiometric accuracy has been documented to be less than 0.5 dB (Zhou et al., 2013). The RADARSAT-2 Noise Equivalent Sigma Zero (NESZ) is approximately -30 dB, indicating a low noise floor and a high sensitivity to weak signals (Luscombe 2009).

Table 2. A comparison of critical radiometric calibration values of RADARSAT-2 and other global SAR missions.

Satellite Mission (Owner/ Operator)	Band	Absolute Radiometric Accuracy (dB)	Relative Radiometric Accuracy (dB)	NESZ (dB)	Channel Imbalance (dB/degrees)	Source
RADARSAT-2 (CSA/MDA GSI)	C-band	<1 (generally); ~0.3 reported	<0.5	~ -30	0.3	Luscombe 2009
Sentinel-1 (ESA)	C-band	1.0 (specified); 0.36-0.38 (achieved)	0.5 (specified); 0.25 (achieved)	-22 (specified)	N/A	Huang et al 2023.
TerraSAR-X (Airbus)	X-band	0.6 (Stripmap)	0.3 (Stripmap)	-22 to -19 (Stripmap)	N/A	DLR 2008
COSMO-SkyMed (ASI)	X-band	-1	-1	-22	N/A	ISA 2019
ALOS PALSAR (JAXA)	L-band	0.76 (corner reflector) 0.22 (Amazon)	N/A	<-23 to <-29	N/A	Shimada et al 2010.

A 2016 study found that RADARSAT-2 had demonstrated stable operations and performance without image degradation since its launch in December 2007 (Williams et al. 2016). Through its lifetime MDA Space has systematically tracked the stability of key RADARSAT-2 performance measures, including radiometric accuracy, geolocation accuracy, impulse response statistics, noise levels, polarimetric accuracy, and precise beam pointing. This includes ongoing SAR antenna diagnostic tests to monitor the health of the transmit/receive modules, ensuring component integrity and optimal performance (Williams et al., 2016).

Based on the comprehensive information derived from these post-launch monitoring activities, calibration adjustments are applied as necessary. These adjustments include minor refinements to phase balancing offsets, corrections to reduce residual radiometric oscillations, between antenna wings in dual-receive-aperture modes, specifically implemented for the continuous correction of seasonal variations (Williams et al. 2016). Simply calibrating at launch is insufficient for ensuring long-term data consistency. By continuously tracking performance metrics and applying targeted adjustments, MDA GSI mitigates the long-term degradation of radiometric quality, ensuring the reliability of RADARSAT-2 data for long-term environmental monitoring, time-series analysis, and change detection applications (Luscombe 2009).

In ESA's most recent analysis of RADARSAT-2's radiometric performance, their analysis found the Spotlight mode had a decrease of 0.3 dB, ScanSAR had a 0.4 dB decrease, and the Wide Ultra Fine and Extra Fine had no reported decrease (ESA 2023). RADARSAT-2's reported accuracy generally meets or exceeds the general SAR calibration requirements established by Freeman (1992), which stipulates an absolute calibration of ±1 dB, a long-term relative calibration of ±0.5 dB, and a short-term relative calibration better than 0.5 dB to satisfy most geophysical measurements. This adherence to established benchmarks underscores the mission's commitment to delivering high-quality, reliable SAR data.

4. Geometric Calibration and Geolocation

Initially, RADARSAT-2 achieved a geolocation accuracy of approximately 30 m during its commissioning phase (Jiang et al., 2023). Subsequent calibration and refinement processes led to a significant improvement in geolocation accuracy, reaching a level better than 10 m (Chenier et al., 2019, Jiang et al. 2023). Unlike its predecessor, RADARSAT-2 incorporates a yaw steering capability that simplifies image processing and enhances overall image quality, contributing to improved geometric fidelity for end-users (Eo Portal 2025). The spacecraft's orbit control system maintains ground track repeatability within at least ±5 km, with a goal of achieving ±1 km at any point in its orbit. The substantial enhancement in geolocation accuracy from the initial commissioning phase to its operational status underscores the critical role of in-orbit adjustments and calibration in optimizing the performance of SAR missions. The availability of both real-time and post-processed position data provides users with flexibility, allowing them to choose the appropriate level of accuracy based on the specific requirements of their applications.

Several scientific studies and technical reports have evaluated the geometric accuracy of RADARSAT-2 imagery. One study, utilizing corner reflectors, reported excellent geolocation accuracy, achieving less than 6 m RMS error in most Single-Beam (Ultra-Fine, Extra-Fine, etc.) and Spotlight modes, and less than 20 m RMS error in ScanSAR modes with downlinked orbit data. The RMS error dropped to less than 2 m in Single-Beam and Spotlight modes with definite orbit data, which is available 1-2 days after acquisition and is atmospherically corrected (Williams et al. 2016). Another evaluation of ultra-fine mode imagery using Toutin and Chenier (2009) 3-D radargrammetric model demonstrated high accuracy, with 2-D positioning achieving an accuracy of 2 m, and a 3-D accuracy of geometric and radiometric distortion reaching 1 m horizontal and 2 m vertical. Research has also indicated that RADARSAT-2 initially achieved a geolocation accuracy of around 30 m, which was subsequently improved to better than 10 m (Jiang et al 2023). However, some studies have found range geolocation accuracies on the order of ~2 m for Ultra-Fine products (Table 1), but with larger azimuth direction errors of approximately 10 m (Schubert et al 2012). An evaluation conducted using the Xianning, China validation field showed that RADARSAT-2 Ultra-Fine imagery could achieve sub-pixel positioning accuracy when four ground control points were used (Jiang et al. 2023). Small et al. (2011) evaluated the geolocation accuracy of the ScanSAR mode and found that there was good correspondence between multiple acquisitions. Toutin and Chenier (2009) achieved high vertical accuracy (1-2 m) which highlights the capability for precise 3D information extraction from RADARSAT-2 stereo imagery, a valuable application for topographic mapping and surface deformation and change, among others. Furthermore, the observed improvement in accuracy with the use of definitive orbit data reinforces the importance of leveraging the most accurate available auxiliary information to optimize geometric precision.

ESA performed a basic visual geolocation analysis on multiple scenes and determined the visual matching to be very good with a qualitatively estimate being one or few pixels (ESA 2023). This estimate would be in accordance with product specifications provided by RADARSAT-2.

Table 3. A comparison of geolocation accuracy without ground control points (GCPs) and highest spatial resolution of RADARSAT-2 and other global SAR missions.

Satellite	Frequency	Geolocation Accuracy	Highest Spatial Resolution	Reference
RADARSAT-2	C-band	< 10-20 m	1 m	MDA 2018
TerraSAR-X	X-band	< 1 m	0.25 m	Jiang et al. 2011
Sentinel-1	C-band	~ 20 m	5 m	Short and Fraser 2023
COSMO-SkyMed	X-band	> 1 m	< 1 m	Nitti et al. 2015

5. Summary

Numerous scientific studies have utilized the data acquired by RADARSAT-2 since its launch in 2007 and many of these studies have reported on the reliability and performance of the radiometric and geometric stability in the data that were acquired. A very small subset of the studies presented in this report show that the RADARSAT-2 data acquisitions have, and continue to, perform at or better than the level of accuracy that MDA GSI specified for this mission. In terms of radiometric calibration, RADARSAT-2 has performed at 1 dB or better accuracy. This level of performance sets the instrument on par with other global SAR missions such as Sentinel-1 or TerraSAR-X.

RADARSAT-2 also has consistently performed well in terms of geolocation accuracy. The various beam modes have all performed well within in their specified levels of accuracy, especially with the higher-level orbit processing.

The European Space Agency has been monitoring and reporting on RADARSAT-2 quality at regular intervals since 2015. In a report shared with NASA, ESA has determined that RADARSAT-2 continues to perform nominally in terms of radiometric and geometric performance (ESA 2023). This provides additional confirmation that RADARSAT-2 continues to perform well and within the levels of accuracy initially set forth for the mission.

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