Synthetic Aperture Radar Data Quality Characterization and Calibration Analysis of EOS-04

S. Sri Sudha*, S. Jaya Bharathi, S. Hari Priya and B. Santhisree

National Remote Sensing Centre, Indian Space Research Organisation, Dept. of Space, Govt. of India
srisudha_s@nrsc.gov.in

Abstract

EOS4 satellite is launched on 14th Feb 2022 by PSLV C-52 in sun Synchronous polar Orbit of 529Km. This paper presents the data products quality evaluation of Earth Observation Satellite -04 in terms of Geometric and Radiometric aspects by using Data Quality Evaluation Software Modules. Geometric and Radiometric Quality Parameters were estimated periodically using Level-1 and Level-2 data products of Strip Map and ScanSAR Imaging modes. The parameters like Background to Peak Ratio (BPRatio), Integrated Side Lobe ratio (ISLR), Peak to Side Lobe ratio (PSLR), Radar Cross Section (RCS) of the Corner Reflector (CR) and geometric resolution are computed and validated against the specification periodically using Level-1 Single Look Complex data to validate the SAR- antenna performance. The parameters like sigma naught, speckle index, radiometric resolution, signal-to-noise ratio are computed over Amazon forest to monitor and validate the radiometric stability using Level-1 Single Look Complex products. For the estimation of Polarimetric Quality Parameters, the Level-1 Single Look Complex Datasets acquired over Cal-Val sites is used.

Keywords: EOS04, Calibration, StripMap, ScanSAR, geometric and radiometric parameters

1. INTRODUCTION

EOS04 /RISAT-1A is a C-Band SAR launched by ISRO on 14th Feb 2022 by PSLV C-52 in sun Synchronous polar Orbit of 529Km. It is a Radar Imaging Satellite designed to provide high quality images under all weather conditions for applications such as Agriculture, Forestry & Plantations, Soil Moisture & Hydrology and Flood mapping. EOS04 operates over 4 identified modes -Fine Resolution Stripmap (FRS-1/FRS-2), Medium Resolution ScanSAR MRS Mode-(6 beams /8 Beams), Coarser Resolution ScanSAR CRS Mode (12 beams), n-beam ScanSAR mode and High-Resolution Spot Mode. Data is acquired in various Transmit/Receive Polarization combinations as Single, Dual, Quad and Hybrid Circular Modes. Data processing is carried out to generate Level-1 -SLC and Ground Range, Level-2 - Geo-Referenced Map-Projected and Level-1C and Level-3A polarimetric products for dissemination to users.

In order to maintain, data interoperability and to substantiate time- series measurements, the Data Quality Parameters are evaluated on a continual basis and at regular time lined intervals. This paper presents the data products quality evaluation of Earth Observation Satellite -04 in terms of Geometric and Radiometric aspects by using Data Quality Evaluation Software Modules. Geometric and Radiometric Quality Parameters were estimated periodically using Level-1 and Level-2 data products of Strip Map and ScanSAR Imaging modes. For the estimation of Polarimetric Quality Parameters, the Level-1 Single Look Complex Datasets acquired over Cal-Val sites is used.

Geometric quality of Standard Geo reference products were assessed for relative location accuracy (with Carto Ortho reference image for FRS1/FRS2 modes, with LISS3/L8 reference for MRS/CRS modes), maximum error budget could be within 30m. Absolute Geometric accuracy (with CR deployment), Calibration parameters are analyzed time to time with various deployments of CRs at different Geographic locations for FRS1 and MRS modes. Systematic data collection for 3 cycles is assessed for mosaickability at different latitudes,

*Corresponding author: E-mail: srisudha_s @nrsc.gov.in

spatial consistency and radiometric response consistency for pseudo invariant targets. Sigma naught response is studied for various targets across different incidence angles and Gamma naught response on the Uniform target 'Amazon' for radiometric fidelity across the swath pixels. The Raw data analysis is more critical and important, the data being microwave, I and Q channel amplitude and phase imbalance is studied and established and continuing to monitor over many strips. The temperature at payload junctions is important to monitor based in which image quality varies. Designated junction temperatures are being monitored for every data collection against specific threshold. Internal calibration data is analysed for replica response consistency and noise data analyzed for the amplitudes across different Calibration passes as well as with the Lab data.
In the subsequent chapters details are provided for each quality parameter along with the quantifiable numbers.

2. EOS04 Geometric Data Quality

In SAR imagery, geometric correction is a crucial step due to the very characteristic of the SAR imaging geometry. It depends upon local relief, imaging direction etc. Geometric quality evaluation was done on the Level-2 Enhanced Geo-referenced products generated in the Data Processsing chain. These products are primarily corrected for SAR imaging geometry like layover, foreshortening, range ambiguity, sensor viewing direction and imaging node. These products were acquired in different acquisition modes, incidence angles, different orbit and attitude source and different terrains. The parameters which are evaluated from geometric quality evaluation are location accuracy, scale and internal distortion.

Product Evaluation is carried out using Carto1- Ortho (2.5m) data and LISS3 data as reference which has spatial accuracy specification of 15m RMSE with 90% confidence.

2.1 *Location Accuracy*

This parameter is estimated by identifying dense well distributed points in target image (data product) and reference image (Carto1-2.5m Ortho) along the azimuth and range directions. Mean-Along, Mean-Across, RMSE Along and across, radial error, CE90 are derived from these points. It is computed by estimating mean differences between the coordinates of points obtained from reference image and points obtained from SAR image.

Fig 2.1.1 shows the location accuracy of FRS-1 mode data. From this figure it is observed that most of the samples taken are within 30m specification. Fig 2.1.2 shows the location accuracy of MRS mode data. From this figure it shows that 53% of the samples are within < 30m accuracy and 6% of the products are in 80-100m accuracy is with orbit source is SPS-PB. Fig 2.1.3 shows the location accuracy of CRS products and all products are within specification. Some samples are out of specification range which may be attributed to the preliminary orbit source.

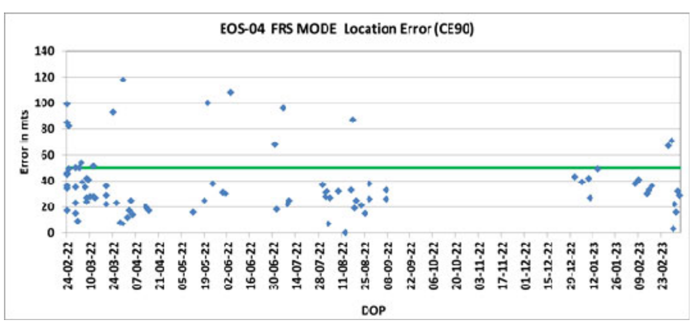


Figure 1: Location accuracy of FRS-1 mode data

ISBN - 978-93-95038-50-8

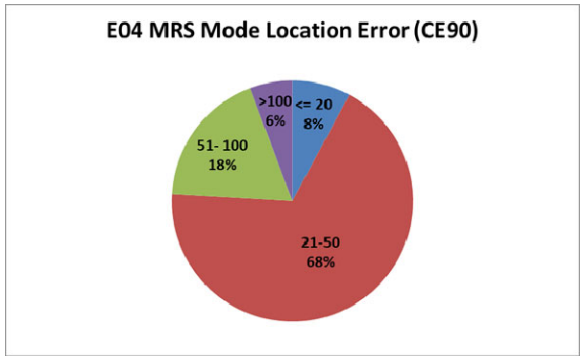


Figure 2: Location accuracy of MRS mode data

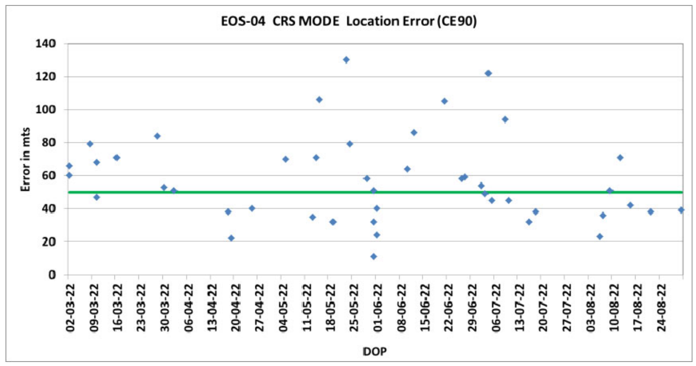


Figure 3: Location accuracy of CRS mode data

2.2 *SCALE*

Scale denotes the distance covered on ground corresponding to a pixel in the given image. It is calculated by taking mean of ratio of distance on reference image to target image for all identified control points on the product, all possible combinations of control-point pairs are considered for distance computation. This value of scale is compared with output resolution of the product and percentage variation is computed.

For all modes like FRS, MRS&CRS products scale was computed for all the modes and is found to be as expected.

2.3 *INTERNAL DISTORTION*

Variation of location error within the scene is described as internal distortion. It is estimated by from the variation in relative between points within the processed image and the reference image. It states the stability of the satellite. It will be more if the disturbance of platform is high during imaging.

For EOS-4 products for all the modes with respect to terrain there is not much variations observed and found to be as expected.

3. RADIOMETRIC AND IMAGE DATA QUALITY

Overall interpretability of a SAR image is based on the image data quality. The radar measures the intensity of the reflected signal at each resolution cell in the image. The intensity depends on the transmitted power, antenna gain, distance between the scattered and the radar, and geometry, roughness, and material properties of the object being imaged.

ISBN - 978-93-95038-50-8

Radiometric data quality evaluation is done on. Sigma-naught, speckle index, radiometric solution and NESZ are the some of the metrics calculated on the Single Look Complex/Multi Look Ground data product generated using the data acquired EOS-04 satellite in various modes, beam and polarization to the quality of the radar image.
These values are provided to the mission and DP team for further analysis and fine tuning of some sensor parameters.

3.1 *SIGMA-NAUGHT*

Sigma-naught (σ°) is one of the important parameterswhich is estimated from the SAR image which gives the estimate of energy of the backscatter signal returned from the target area of interest. Table 1 shows the sigma0 values received over Amazon forest for FRS-1 and MRS mode data. Values are as expected for all polarizations over Amazon Forest.

Table 1 Sigma0 over Amazon Forest

Polarization	Sigma0 (dB)	
	FRS-1	MRS
HH	-7.08	-7.45
VV	-6.69	-8.50
HV	-14.13	-13.38
VH	-13.89	-13.78
RH	-8.71	-7.53
RV	-8.49	-7.36

3.2 *SPECKLE INDEX*

Speckle is caused by the reflection of the radar signal from multiple objects (scatterers) that are distributed within a resolution cell. The sum of the contribution from all the scatterers results in variation in the intensity of the measured signal in adjacent resolution cells. This variability in image intensity, called speckle, limits the radiometric resolution of a SAR sensor. Speckle index is computed as the normalized variance of the signal intensity in the image of a homogeneous target.Speckle index over low SNR region is 1 for others the values are in the range 0.5-0.8.

3.3 *RADIOMETRIC RESOLUTION*

Radiometric resolution is a metric that describes the ability of a sensor to discriminate between two objects that have similar radar cross sections (i.e., that are radiometrically similar). Radiometric resolution depends on the measured signal to noise ratio and the number of independent looks from which the pixel was formed. This parameter is evaluated on the uniform distributed target and is measured in dB.
Radiometric resolution of all modes (FRS-1, FRS-2, MRS and CRS) and all polarizations are observed to be 1.9dB.

3.4 *NOISE EQUIVALENT SIGMA ZERO*

he ability to make out objects against the inherent noise generated by the sensor, NESZ is a metric that informs about the system noise level in a SAR image. NESZ is usually provided as a log-scale quantity in dB, and more negative values indicate better image quality. For instance, calm lakes are highly reflective targets in the side-looking geometry and allow the characterization of the noise level of the sensor.

NE Sigma0 of

- MRS mode (in dB) : -20 (HH/VV) and -25 (HV/VH)
- CRS mode (in dB) : -25 (HH/VV) and -26 (HV/VH)
- FRS mode (in dB) : Less than the Specification

4. External Calibration and Data Quality

SAR Radiometric calibration is necessary to allow a valid conversion of the observed pixel intensity into a physical relevant unit, e.g., radar cross section (RCS). Therefore, the whole SAR system has to be calibrated and various geometric and radiometric corrections have to be applied. The internal calibration compensates gain and phase variations of the instrument which may occur due to different temperatures and ensures the specified radiometric stability of the instrument over time. The antenna pointing is important to apply proper antenna pattern correction during SAR data processing, which defines the relative radiometric accuracy within a SAR image. Absolute external radiometric calibration is done applied finally using ground truth measurements.

Both Internal and External calibration data need to be monitored periodically in order to ensure the quality of the calibrated products. Sensor performance is initially assessed the quality of the on-board calibration data and later evaluating the calibrated data product by analyzing reference targets on ground such as point targets like corner reflectors with well-known RCS and extended homogeneous site such as Amazon forest region.

For the external calibration of EOS-04 satellite, calibration site is established as a part at IMGEOS located at Shadnagar and SAC ground site Ahmedabad. This site consists of square trihedral/dihedral and triangular trihedral corner reflectors. Each target is aligned by schedule in the expected line-of-sight direction for a satellite overpass for both ascending and descending orbits. In order to estimate the absolute radiometric accuracy of a SAR system, the RCS values of reference targets are derived from SAR images and compared with the theoretical RCS of these targets. Impulse response is the most important factor, to characterize these components of SAR image quality. The key impulse response parameters in both range and azimuth are Impulse response width, height, phase for complex data and the properties of its side lobe. The RCS of a point target is estimated from SLC data for the Stripmap mode and Multi-look Ground Range product for the Scansar mode product of all EOS-04 by analyzing its impulse response function. If was found the difference between the theoretical RCS and estimated RCS is less than 1dB.

Peak Side Lobe Ratio -PSLR: It describes the power resolution between the main lobe and side lobe. If a SAR system has a poor PSLR, the side lobe of a strong target will be is classified as false targets. It is derived by estimating the ratio of the highest side lobe power to the peak power in the main lobe.

Integrated Side Lobe Ratio (ISLR) describes the extent to which energy is spread around the main lobe. If a SAR system has a poor ISLR, the response from a sufficiently strong target will submerge several weak targets and result in misclassification (loss of detection). ISLR is computed by the ratio of integrated energy of the side lobes to the integrated energy of the main lobe.

From Fig: 4.1.1 PSLR varies from -17dB to -23dB in range direction and -16dB to -22dB in azimuth direction for the corner reflectors deployed at Shadnagar and SAC ground, Ahmedabad. ISLR varies from -13dB to -18 dB in range and -12dB to -18dB in azimuth.

Fig: 4.1.2 shows an example of Corner reflector deployed at Shadnagar, SAC ground and Bopal Campus Ahmadabad.

Extended target analysis is carried out on the Amazon forest data. The expected gamma naught range from CEOS reference is -4dB to -7dB. The achieved sigma naught, gamma naught and beta naught values for FRS1 and MRS modes are in variation of a 2dB in HH, HV, VH and VV polarization and 4dB variation is observed in RH and RV polarization from near range to far range for FRS1 mode data. Variation is well within 2dB in Gamma0 for all polarization for MRS mode data.

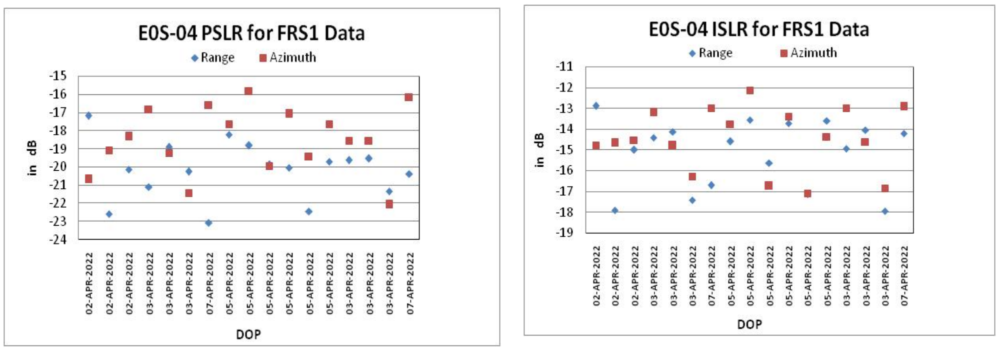


Figure 4: PSLR and ISLR of Corner reflector

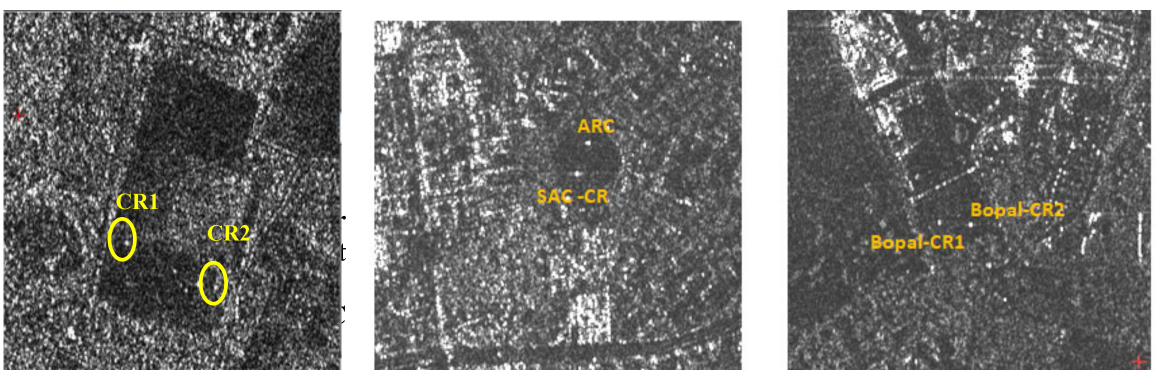
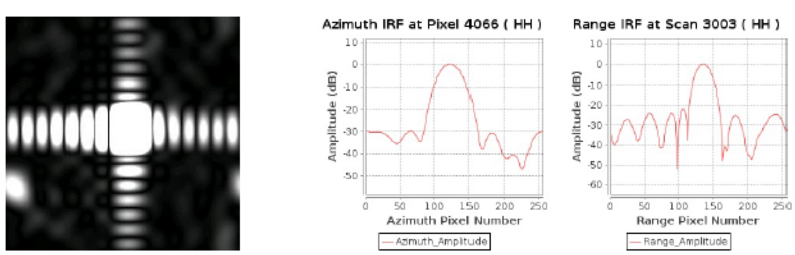


Figure 5: Impulse Response function of Corner reflectors at IMGEOS, SAC ground



5. Polarimetric Data Quality

A Polarimetric SAR system measures the scattering information of the surface of observation with microwaves emitted in Dual/Hybrid / Full Quad polarization architecture. The number of output data channels depends on the transmit /receive polarization configuration**.** The design of the radar results in single look complex (SLC) imagery structured in the range and azimuth directions.

Using in-house developed software, the Level-1 SLC data is ingested for generating the hybrid polarimetric parameters pertaining to the data quality. Key parameters like Relative Channel Phase, Degree of Polarization, Degree of Circular Polarization, Ellipticity are generated for the Calibration site over Ahmedabad, Gujarat.

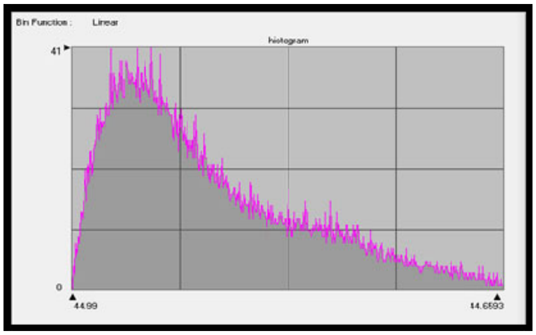
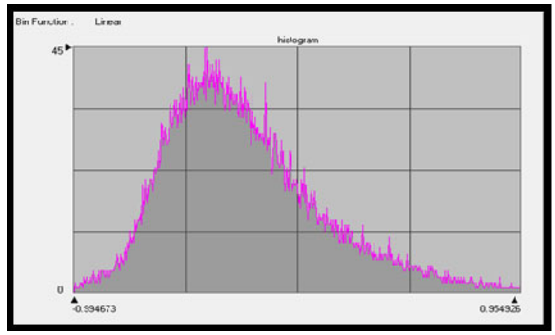
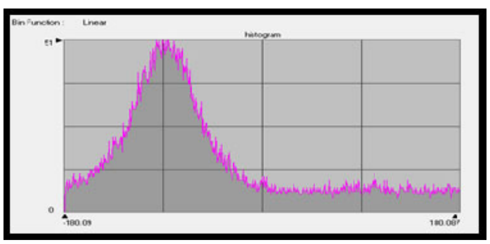


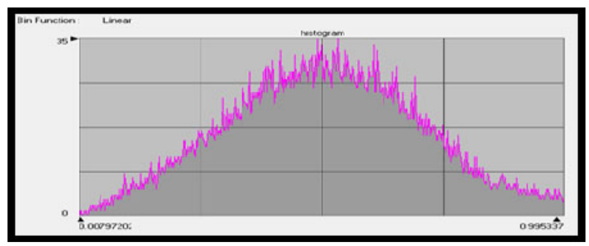
Figure 6: Ellipticity Parameter Plot



Degree of Circular Polarization (DoCP) Plot



The Relative Phase Plot (delta)



The Degree of Polarization (m factor)

The channel relative phase for hybrid polarimetric data is found to vary between -180 to +180. The Ellipticity factor is found to vary between +44.65 to -44.99 deg which is as per the nominal values.

The degree of polarization is found to vary typically in the range of 0.008 to +0.995. Nominal Range of values is 0 to 1 depending on the target polarimetric scattering. These parameters are crucial for polarimetric target decomposition and scattering mechanism analysis

6. Results and Discussions

The EOS04 Data Products are continually evaluated as per DQE norms and procedures and the following results are summarized as follows.

6.1 *Achieved Platform Stability*

- After ground processing achieved product accuracy better than 50m.
- As the designated Orbit source is SPS-RT, In case of SPS-PB, few cases lead to poor location error.
- Target accuracy: 2km (Azimuth Direction)

6.2 *ACHIEVED RADIOMETRIC STABILITY*

- FRS1/FRS2/MRS/CRS modes all polarisations data products are analysed.

- Near to Far range response difference is better than 1.5 dB (over Amazon)
- Absolute radiometric accuracy about 1dB.
- Scalloping issues in ScanSAR mode at low SNR regions.
- Sigma naught spurious values in Low SNR regions(crossing NE Sigma Naught with noise cal data corrections)

The achieved geometric,radiometric and polarimetric quality specifications of the various imaging modes is summarised in the following table:

Table 2: Data Quality Parameters

S.No	Quality Parameter	Imaging Mode			
		FRS-1	MRS	CRS	FRS-2
1	Spatial Accuracy (in m)	50	Better than 70	Better than 60	16
2	PSLR Range/Azimuth (in dB)	-20.1 / -18.4	-19.7 / -16.5	-	-
3	ISLR Range /Azimuth (in dB)	-15.1 / -14.5	-14.2 / -11.2	-	-
4	Radiometric Resolution (in dB)	1.9	1.9	1.9	2.2
5	Radiometric Accuracy (in dB)	1.23	0.68	-	-
6	Noise Equivalent Sigma Naught (in dB)	-19	-20	-25	-18
7.	Degree Of Pol(Hybrid Pol)	0 to 1	0 to 1	0.09 to 1	0 to 1
8.	Relative Phase (Hybrid Pol)	-180 to +180 deg	-	-	-

7. CONCLUSIONS

The EOS-04 data products at various imaging modes like FRS-1, MRS and CRS have been evaluated for the geometric, radiometric and polarimetric parameterization. The Geometric accuracy is found to be sustained for most of the cases. The radiometric quality parameters corresponding to distributed and standard point targets have been evaluated and found to be as per the data product specifications. As EOS-04 offers Full Polarimetric and Hybrid Polarimetric Data Products, the crucial polarimetric parameters are found to be in conformance for the Transmit Receive Channels.

ACKNOWLEDGEMENT

The Authors express their sincere thanks to Director, NRSC for guiding us with his technical expertise and encouragement. We express our deep gratitude to Deputy Director, DPA Mission and Project teams for the technical guidance in realizing data acquisition and processing. We also express our thanks to SAC DP and DQE teams for the incessant work in order to realize and maintain the data specifications.

REFERENCES

1. EOS-04 Data Format Specifications Document-Space Application Centre, ISRO
2. J. van Zyl, C. F. Burnette, H. A. Zebker, A. Freeman, and J. Holt, "Polcal user's manual," Jet Propulsion Laboratory, Tech. Rep., August 1992.
3. A. Freeman, Y. Shen, and C. Werner, "Polarimetric SAR calibration experiment using active radar calibrators," Geoscience and Remote Sensing, IEEE Transactions on, vol. 28, no. 2, pp. 224 –240, March 1990.
4. A. Freeman, "SAR calibration: an overview," Geoscience and Remote Sensing, IEEE Transactions on, vol. 30, no. 6, pp. 1107 –1121, November 1992.