RADIOMETRIC AND GEOMETRIC CALIBRATION OF MEDIUM RESOLUTION SAR OF RISAT-1

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ABSTRACT: To ensure the long term stability of the Synthetic Aperture Radar (SAR) system, periodic evaluation of radiometric and geometric performance of the Space-borne/Air borne microwave SAR sensors and its validation has become mandatory for accurate data products to the Remote Sensing user community. In 2012, ISRO launched first indigenously developed C-band SAR sensor, Radar Imaging Satellite (RISAT-1) with unique capabilities of imaging modes, polarizations, swaths and resolutions. India being a country of diversified natural resources, a suitable imaging mode with medium resolution of 25m having 25 days repetivity is planned to cater to dedicated civilian applications. During operational phase of RISAT-1, Medium Resolution ScanSAR (MRS) systematic coverage data was analysed regularly over designed corner reflector deployed in microwave Calibration-Validation Site at National Remote Sensing Centre, Hyderabad. Radiometric and geometric calibration analysis was performed on these systematic coverage data products for different imaging orbits. The experience gained in conducting external calibration exercise for RISAT-1 and its potential scope to extend for future ISRO's National and Internationally collaborated space borne and airborne EO SAR sensors (RISAT-1A, NISAR etc.,) are envisaged. The specifications of established Cal-Val site, details of data sets considered, deployment and orientation of corner reflectors, discussions on achieved radiometric and geometric calibration results are presented in this paper.

1. INTRODUCTION

In microwave remote sensing, recent advances have seen the development of Synthetic Aperture Radar (SAR) sensors. Because of their capability to obtain information independent of weather conditions and external illumination source made them potentially important, particularly in the tropics where persistent cloud cover limits the use of data from optical and near infrared satellite sensors. A SAR system provides high resolution images of radar backscatter of the earth surface. Many potential applications of space borne SAR systems including crop monitoring, forest monitoring, soil moisture measurement, sea ice classification etc., commands the system to be well calibrated particularly in terms of radiometry. In all these cases, the measured radar backscatter is uniquely related to the geophysical property of the targets. Any change in the geophysical property can therefore be determined by the measurement of its backscatter. Therefore characterization of SAR parameters is mandatory for providing good quality image products and to further their utilization

Radar Imaging Satellite (RISAT-1) is an active microwave remote sensing mission of ISRO carrying C- Band SAR antenna as the payload. RISAT-1 (Tapan Misra, 2013) was successfully launched on April 26, 2012 having the capability to image in Medium Resolution ScanSAR (MRS), Fine Resolution Strip map (FRS), Coarse Resolution ScanSAR (CRS) and High Resolution Spotlight (HRS) mode of acquisitions and its data is processed at different levels. RISAT-1 has the capability to cover the Indian Territory with temporal sampling of 25days with 25m resolution in dual polarization (HH+HV) acquired at 36^0 incidence angle in left look direction/descending node. In order to arrive at a good radiometric as well as a precise geometric calibration, it is vital to characterize and validate the SAR system by internal and external calibration procedures. As a part of this, external calibration exercises are carried out using corner reflectors deployed at NRSC calibration site during the operational phase of the satellite.

The objective of this paper is to describe the implemented methodology for evaluating RISAT-1 MRS data for point target and distributed target analysis to find out radiometric and geometric accuracies. The analysis of the results and the experiences gained are presented in the subsequent sections.

2. SIGNIFICANCE OF SAR CALIBRATION

There is a general need for accurate space borne SAR calibration in order to support applications oriented research programmers and to investigate the long term stability of the SAR instrument. SAR Calibration and Validation begins the stage on which the integrity of all data subsequently derived will be based. Without such calibration and validation, the data may be at best being qualitative. Both the elements of calibration and validation are required to have knowledge on whether the changes in the product are due to changes in the instrument or the environment. Validation involves significantly more than the original concept of ground truth or surface truth. It takes into account a broad range of variables not considered in the early developmental phases of satellite derived data and information. However, to fully exploit the available information contained in the SAR data, quantitative analysis of the target backscatter characteristics is required.

Radiometric and Geometric Calibration

The main purposes of calibration are twofold: (a) Conversion of the radar output units into predetermined reference units. (b) Measurement of dynamic system characteristics which fluctuate throughout the life of the system to enable correction of the final product for such features. In broad terms, calibration is a comparison between instrument's measuring accuracy and a known standard over the life of the instrument. Slight changes that may occur in either the calibration of a sensor or its validated product may generate erroneous data records unless the data are of very high quality. SAR calibration is generally divided into two categories: radiometric and geometric calibration. Radiometric calibration defines and corrects system-induced errors to provide a known relation between image pixel brightness values and the normalized backscatter coefficient, σ_0. Geometric calibration refers to the determination of various location errors within an image, or between multiple images. Both categories of calibration can be defined in absolute and relative terms.

3. DETAILS OF CALIBRATION SITE AND DATA SETS

To perform Geometric and Radiometric calibration of SAR, Corner reflectors provide one of the best solutions to use as standard point targets. To cater to the Microwave SAR system calibration, a microwave Cal-Val is established at NRSC, Shadnagar to deploy the corner reflectors as shown in Figure 1(Jayasri, 2012). Open areas with flat topographic surfaces having smooth surroundings with minimum background scattering contribution are preferred as deployment sites for corner reflectors. Based on SAR sensor specifications, square trihedral and dihedral Corner Reflectors (CR) of various sizes ranging from 40 to 125cm are designed and fabricated with strict fabrication tolerances. For each calibration exercise, the orientation angles are computed and then the corner reflectors are oriented for their azimuth and elevation angles with respect to bore sight of SAR antenna. Details of trihedral and dihedral CRs and relevant measurement devices are shown in figure 1.

In order to calibrate RISAT-1 SAR, external calibration methodology was implemented using standard Corner Reflectors. To analyze the long term stability, a dedicated square trihedral of 125cm is deployed to analyze regularly MRS systematic coverage data at CAL_VAL site, Shadnagar. With 25 days repetitvity, this data has been monitored for about one year to access the accuracy. The details of the MRS systematic coverage data sets are provided in Table 1 along with relevant imaging orbit numbers and data of pass.

Table 1: Details of Data sets

S. No	Imaging Orbit	Date of Pass
1	20450	12-1-2016
2	20827	6-2-2016
3	21204	2-3-2016
4	21581	27-3-2016
5	21958	21-4-2016
6	23089	05-7-2016
7	23466	30-6-2016
8	23843	24-8-2016
9	24220	18-9-2016
10	26844	11-3-2017

Figure 1. Corner Reflectors deployment in CAL-VAL site

4. RISAT-1 CALIBRATION AND VALIDATION – IMPLEMENTATION

The realization of RISAT-1 calibration is catered with the established calibration facility equipped with ground calibration hardware as well as software tools for evaluation. Measurements were made for MRS systematic coverage mode of 25m resolution in dual polarization (HH+HV). 125cm square trihedral corner reflector is identified for this calibration exercise as it provides best solution for medium resolution data. Point target and distributed target analysis is performed on ground range products provided in CEOS format.

Point Target Analysis

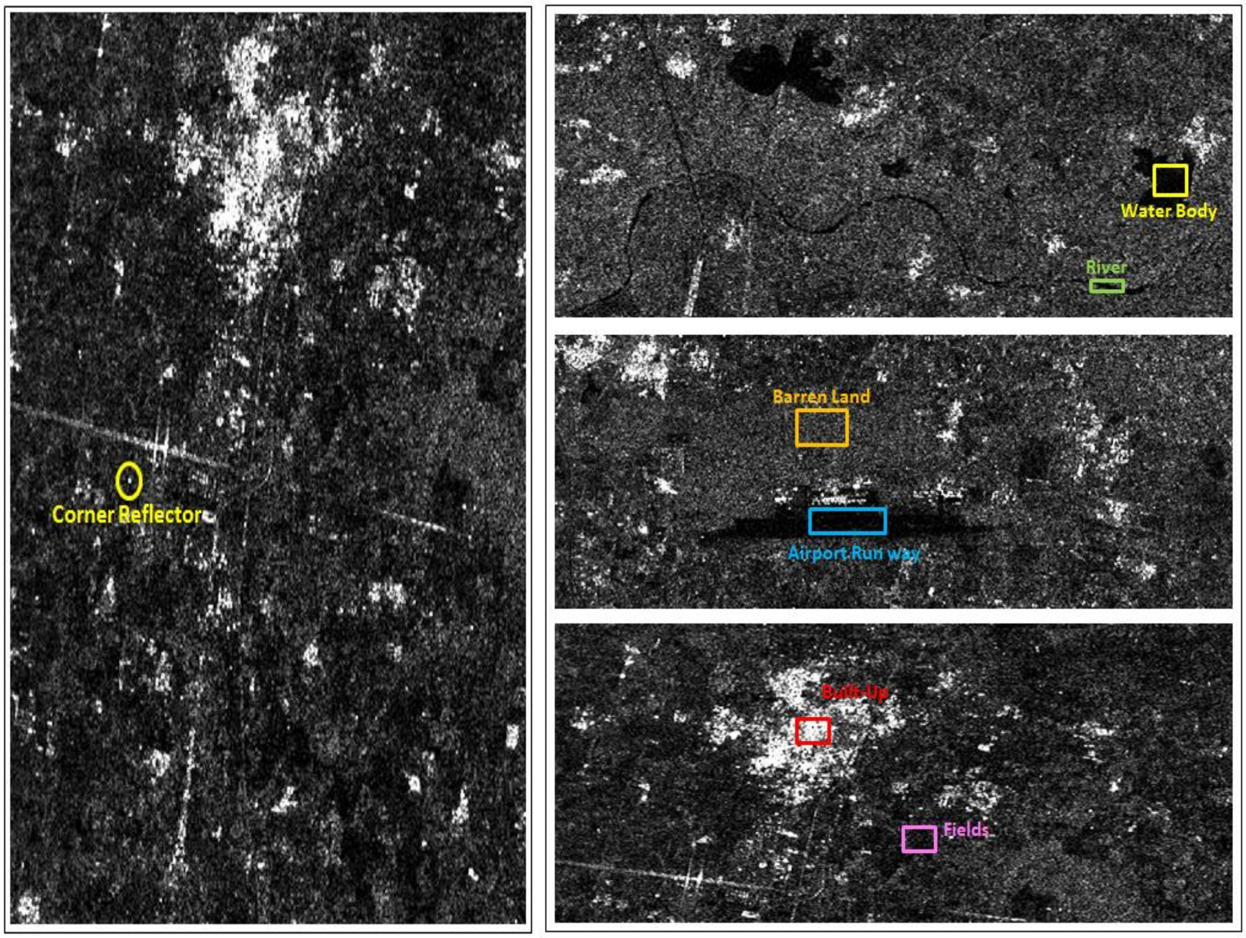
For point target analysis, MRS image with deployed corner reflector in calibration site is considered as shown in figure 2a. The point target response is derived by extracting a sub-image of 128 x 128 pixels centred on the point target where image coordinates and target peak position are estimated. This ensures that nearby bright points can be discarded so as to make accurate determination of the mean background from uniform areas located within the window.

Image Quality Parameters: As the SAR system is linear, it is natural to characterize its performance through its impulse response function (IRF) by measuring the system response to a single, isolated scatterer on the ground, such as a corner reflector. As the SAR product is two-dimensional, some image quality parameters like a) spatial resolution (Impulse response width, IRW) b) Peak Side Lobe Ratio (PSLR) and c) Integrated Side Lobe Ratio (ISLR) that pertains to the image contrast/focusing are measured in both range and azimuth directions. Spatial resolution (Impulse Response Width) is derived from the width of the main lobe at a power level, 3 dB down the peak of the impulse response function in both azimuth and range directions. PSLR describes the power resolution between the main lobe and side lobe of IRF which is derived by estimating the ratio of the highest side lobe power to the peak power in the main lobe

$$PSLR = 20 * \log10 * (P_{sidelobe}/P_{mainlobe}). \quad [1]$$

ISLR describes the extent of energy spread around main lobe and is computed by taking the ratio of integrated energy of the side lobes to the integrated energy of the main lobe.

$$ISLR = 20 * \log10 * (\text{Side Lobe Energy}/ \text{Main Lobe Energy}). \quad [2]$$



(a) (b)

Figure 2a: MRS systematic coverage image with deployed corner reflector at microwave CAL_VAL site at NRSC.
2b: Various identified homogenous distributed targets to estimate radiometric calibration parameter

Estimation of Calibration Constant (K): Calibration constant is the prime parameter to generate sigma naught for the targets in the image. Estimation of calibration factor requires (a) details of Corner reflectors like type, shape, size. (b) CR location in processed SAR image (c) Product meta information of corresponding ground range product.Theoretical Radar Cross Section (RCS) is calculated as per operating frequency and dimensions of corner reflectors. This is used for final calculation of calibration constant (K) in dB. Derivation of K factor involves calculation of integrated power of point target from interpolated background corrected intensity image along with estimation of incidence angle at corner reflector location as shown in Figure 3a and 3b.

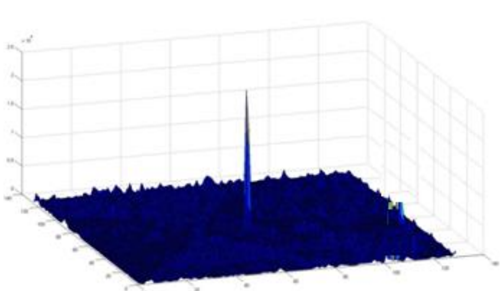


Figure 3a : IRF before background correction.

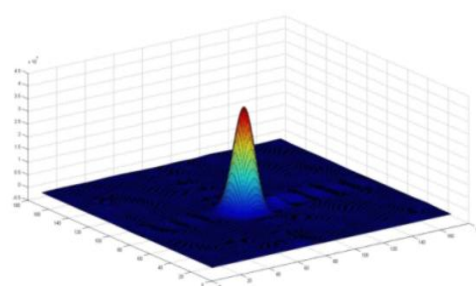


Figure 3b. IRF from interpolated background corrected intensity image

Distributed Target Analysis

Distributed target calibration refers to external calibration using natural targets of large areas with homogeneous backscattering properties. Knowledge of the scattering physics and SAR statistical properties are essential in accessing the behavior of SAR system to support various scientific and civilian applications. Therefore Radiometric parameters (P.J.Bird,1990) are estimated by selecting a window on a homogeneous area in the SAR image for both HH and HV polarizations. Radiometric resolution, Speckle Index, Signal to Noise Ratio (SNR), Equivalent Number of Looks (ENL) are derived by considering opportunistic homogenous distributed targets like river, Airport runway, water body, barren land, fields and built-up areas as shown in Figure 2b. Derivation of statistical parameters like mean, standard deviation and variance helps to estimate the above said radiometric parameters.

From these datasets, SAR backscattered coefficient (σ_0) (RISAT-1 data products format, NRSC web site) are generated by taking dual polarimetric images along with bi-linear interpolated incidence angle grid files.

$$\sigma_0(dB) = 20log_{10}(DN) - K_{cal(dB)} + 10log_{10}(\sin(i_p)/\sin(i_c)) \quad [3]$$

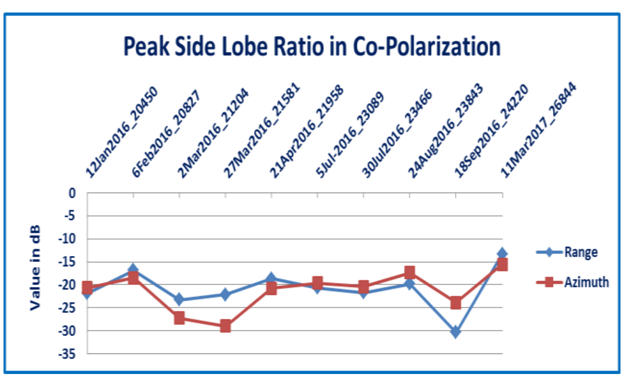
NES0 is the measure of radiometric capability of the SAR system. Lower values of worst case sigma naught imply better capability. This is calculated statistically by taking mean of the sigma0 values over the windows of homogenously very low backscatter areas in the image like calm waters for both HH and HV polarizations.

Geometric Calibration

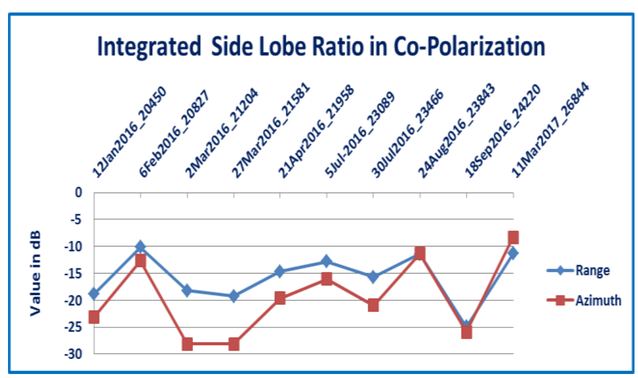
An accurate estimate of the target reflectivity requires precise knowledge of the relative geometry between the sensor and target. Geometric calibration refers to the determination of various location errors within an image, or between multiple images.This is done on passive corner reflectors with their geographical coordinates measured using Differential Global Position system (DGPS). Geolocation accuracy is estimated by considering location of corner reflector in a geo-referenced image against DGPS coordinates to arrive at latitudinal and longitudinal error margins.

5. RESULTS AND DISCUSSIONS

The long term stability of RISAT-1 medium resolution mode has been monitored and demonstrated by carrying out calibration exercises. Point target and distributed target analyzed is performed to completely calibrate and validate the data. Various SAR image quality parameters viz PSLR, ISLR and IRW, calibration constant are derived from the RISAT-1 calibration data products. Comprehensive analysis using in-house developed software has been done on the data acquired over microwave CAL site. The three image quality metrics e.g. spatial resolution, PSLR and ISLR in both azimuth and range direction are validated with the corner reflectors imaged in various orbits are shown in figures 4(a), (b), (c). It is observed that estimated spatial resolution in ground range image is as per the specification of MRS imaging mode. However, it is noticed to have increase in resolution for orbit acquired after RISAT-1 recovery in 2017. The values of PSLR in ground range are better than -17dB as expected. ISLR also followed the characteristics of a good point target response with specification better than –13 dB representing a typical one-dimensional ISLR. As cross polarization response for trihedral reflector is negligible, performing image quality analysis does not any significance.



(a)



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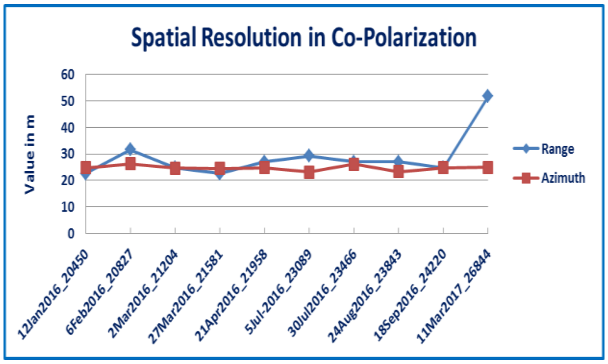

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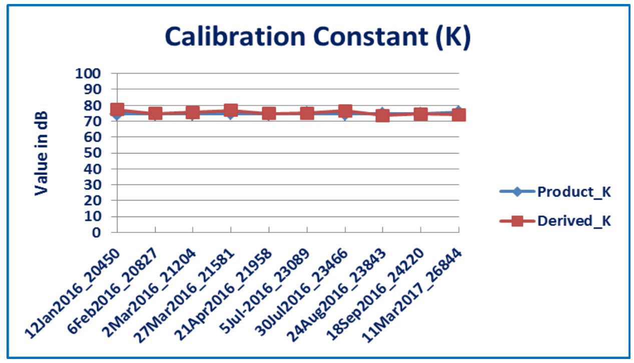


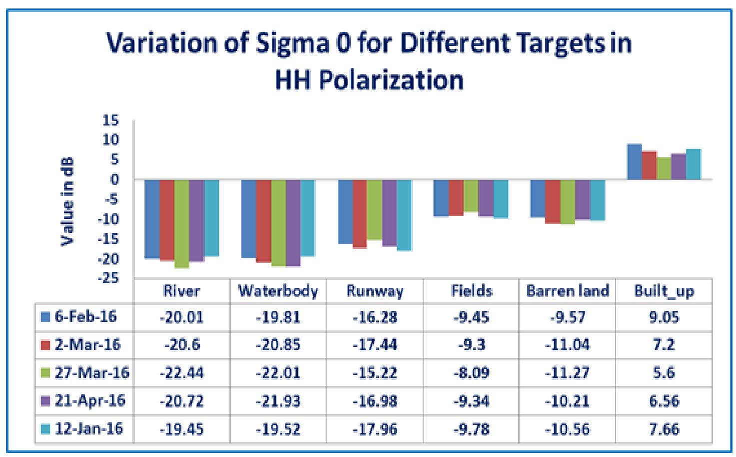
(d)

Figure 4: Plots (a),(b),(c) representing the trend analysis of PSLR, ISLR, Spatial resolution in Range and azimuth for HH polarisation and (d) Calibration constant (K)

The calibration constant for RISAT-1 SAR is estimated from the energy method using corner reflectors deployed at calibration site. Estimation of calibration constant and its validation is important before the data product is made available for applications. The average estimated K value for all these data sets has standard deviation of approximately ±2dB signifying the correctness of the implemented methodology. As shown in figure 4d, it is observed that the consistency in estimated calibration constant is on par with 'K' value provided in data product which was verified with Amazon rain forest (standard natural homogenous distributed target).

Table 2: Derived Radiometric Parameters on homogenous Distributed Targets

	Radiometric Resolution(dB)	Speckle Index	SNR	ENL
12-Jan-2016_20450				
River	2.34	0.62	1.34	1.81
Waterbody	1.97	0.76	1.32	1.75
Runway	2.34	0.72	1.4	1.95
Fields	2.43	0.75	1.34	1.79
Barren land	2.51	0.78	1.28	1.63
Built-up	3.56	1.27	0.79	0.62
6-Feb-2016_20827				
River	2.10	0.62	1.61	2.58
Waterbody	2.16	0.64	1.55	2.41
Runway	2.47	0.76	1.31	1.71
Fields	2.70	0.86	1.16	1.35
Barren land	2.58	0.81	1.24	1.53
Built-up	3.31	1.14	0.88	0.77
2-Mar-2016_21204				
River	2.58	0.81	1.24	1.53
Waterbody	2.22	0.67	1.50	2.25
Runway	2.08	0.62	1.62	2.64
Fields	2.42	0.75	1.34	1.79
Barren land	2.9	0.95	1.05	1.11
Built-up	2.98	0.98	1.02	1.03
27-Mar-2016_21581				
River	2.2	0.66	1.52	2.3
Waterbody	2.11	0.62	1.6	2.56
Runway	2.28	0.69	1.45	2.09
Fields	2.5	0.78	1.28	1.65
Barren land	2.69	0.86	1.17	1.36
Built-up	3.92	1.47	0.68	0.46
21-Apr-2016_21958				
River	2.22	0.67	1.5	2.24
Waterbody	2.50	0.78	1.29	1.66
Runway	2.29	0.69	1.44	2.08
Fields	2.45	0.76	1.32	1.74
Barren land	2.91	0.95	1.05	1.1
Built-up	3.54	1.26	0.79	0.63



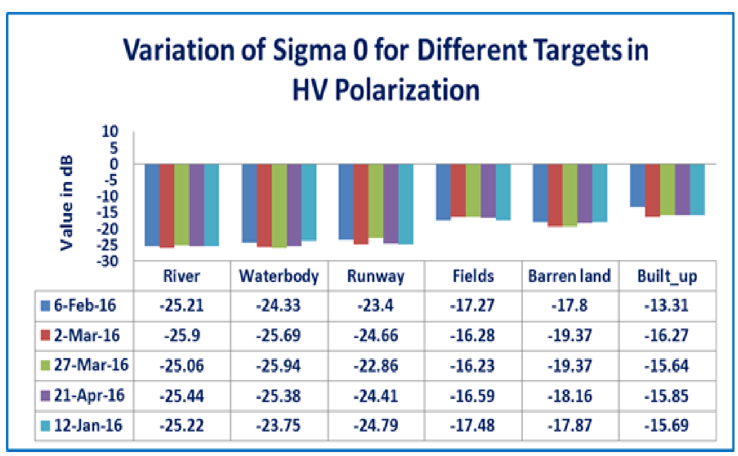


Figure 5: Derived Sigma 0 values on various distributed targets in HH and HV polarization

Distributed target analysis is performed on various opportunistic homogenous distributed targets as described in Table 2. To correctly analyze the radiometric performance of SAR system, the data acquired during winter and summer seasons are considered to avoid variation in backscatter charcteristics due to soil moisture in monsoon seasons. The selected homogenous regions covers the broad spectrum of generally available targets in remote sensing applications. It is observed that all the values like radiometric resolution, Speckle Index, SNR and ENL are quantified and following the trend as per standards of multilook processing. Radiometric resolution which measures the ability of the SAR system to discriminate differences in backscatter coefficients are well demonstrated in Table 2 where Built-up has more radiometric resolution and speckle Index compared to other homogenous features. This is because of the presence of linear and random structures along with corner reflector effect. Correspondingly, ENL was improved stating more than one statistically independent looks for ground detected images. These statistical parameters are calculated for both HH and HV polarizations in which the quantifying values are almost same.

Figure 5 represents the variation of back scatter coefficient for different homogenous distributed targets in HH and HV polarization. The sigma 0 values over waterbodies and runway have minimum backscatter demonstrating its nearness to the designed worst case sigma0 of RISAT-1 SAR sensor. Built-up showed high back scatter response in both polarizations due to corner reflector effect. Fields and barren lands had medium back scatter because of diffused scattering prevailing in heterogeneous targets. The consistency of NES0 against different AOIs in calm water for HH/HV is presented in Figure 6. The derived NES0 over calm water body having low backscatter coefficient is approximately -17dB which is as per RISAT-1 specifications. Slight variation in NES0 can be accounted for imperfect low backscatter region in calm river.

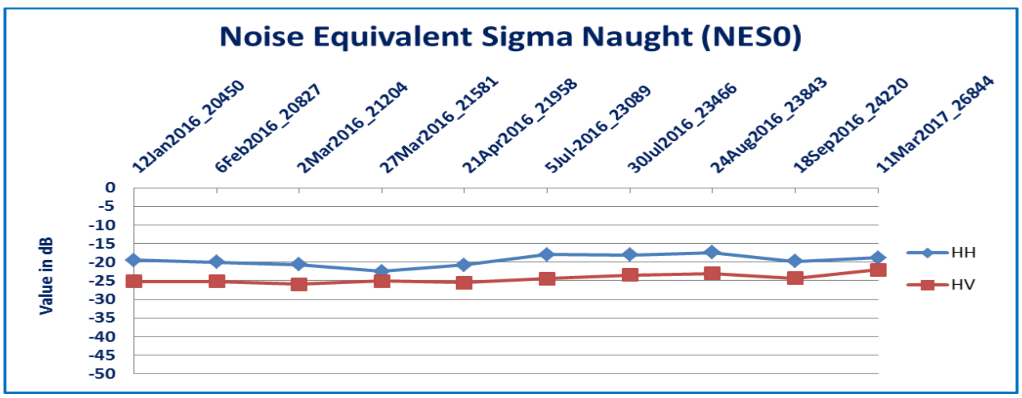


Figure 6: Plot depicting the consistency of NES0 for HH and HV Polarization

The geolocation accuracy for various MRS imaging orbits over deployed corner reflector is depicted in figure 7. It is observed that, location error at the reflectors position is more in longitude (across track or range direction) than in latitude (along track or azimuth direction).

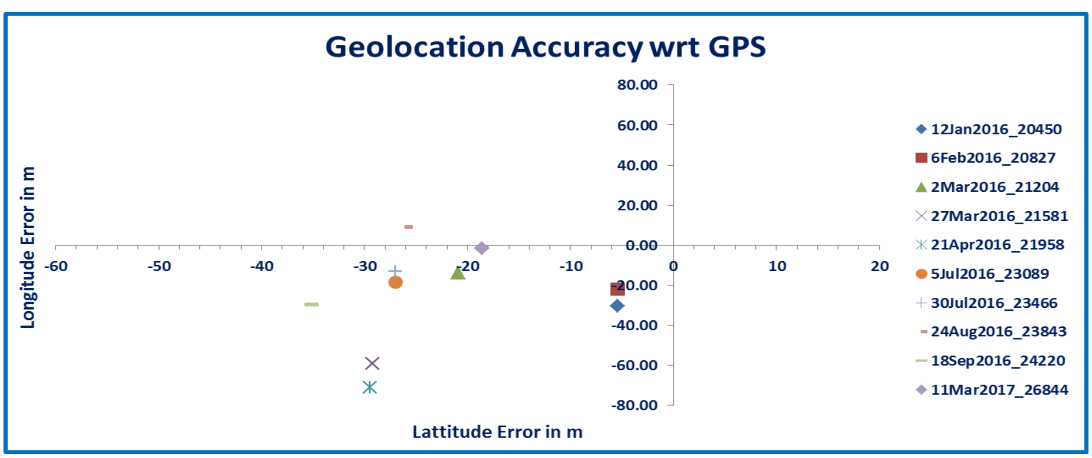


Figure 7: Spread of geo- location error is both latitude and longitude direction

However, the mean radial location error is varying with maximum extent up to 40m. But in case of data acquired on 21April 2016, more geo-location error is observed as orbit maneuver was planned in the same imaging orbit.

6. CONCLUSIONS

Radiometric and geometric calibration of RISAT-1 MRS systematic coverage data was performed on corner reflector deployed at microwave calibration site, NRSC. Point target and distributed target analysis was carried out to analyze the geometric and radiometric accuracies achieved w.r.t system specifications. The arrived results demonstrate the capability and performance stability of RISAT-1 to cater to civilian applications. The expertise gained during the calibration and validation of RISAT-1 system in campaign mode can be extended to the future SAR missions which are coming in line i.e., RISAT-1A (C band), NISAR (L and S band SAR) and X-band SAR missions.

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