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Evaluation and quality monitoring of SCATSAT-1 scan mode data

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Abstract: Accurate wind products generation, depends on the accuracy of sigma-0 estimation from the scatterometer data. Similar to Oceansat-2 (OSCAT) scatterometer, SCATSAT-1 scatterometer works on dual pencil beam (inner beam HH and outer beam VV) approach at 13.5 GHz frequency by conically scanning the earth surface and collecting the backscatter. The scatterometer data is signal processed on-board and radiometrically corrected on ground. In contrast to OSCAT-2 scatterometer, SCATSAT-1 sensor is designed with advanced techniques for providing better sigma-0 (directory.eoportal.org). This work discusses the quality aspects of SCATSAT-1 data (scan mode). Level-1B scan mode is the basic data and it is very significant to evaluate and monitor the quality of this data as it forms the basic input to the Level-2A cell-grid sigma-0, which in turn results in the formation of wind product (Level-2B). The level-1B product carries information about the radiometry (sigma-0, Signal to Noise Ratio (SNR)), geometry (azimuth angle, incidence angle, geolocation), calibration constant and sigma-0 quality flag at both slice and footprint level. For evaluation of data quality these parameters are categorised into static and dynamic parameters based on the sensor scan mechanism and the wave target interaction. Doppler frequency, X-Factor, Range, incidence angle and azimuth angle are the static parameters which varies systematically over the orbit data and shows consistency and are well within the specification. The dynamic parameters like sigma-0, SNR and brightness temperature (BT) are observed for the scan mode data acquired for each orbit/revolution. For calibration/validation, sigma-0 and BT of well-known calibrated sites (viz. Amazon rain-forest, Antarctica) are monitored and results show that variation in Sigma-0 over the Amazon rainforest is less than 0.3 dB, as expected. The results from trend analysis ensures that parameters are behaving well within the specifications and assures stability and consistency of system parameters. The analysis suggests that the products from the SCATSAT-1 can be taken for climate studies.

Key words: Sigma-0, Brightness Temperature, Footprint, X-Factor, Fore, Aft

1. Introduction

SCATSAT-1 is a continuity mission to Oceansat-2 Scatterometer (OSCAT-2) in providing Ku Band data to global user community. SCATSAT-1 mission was launched in September 2016 by ISRO's PSLV-C35, the payload carries a dual pencil beam scatterometer in Ku (13.5 GHz) band to study the ocean wind vector and associated phenomena. It operates day and night and covers the entire globe in two days. Like its predecessor Oceansat-2 scatterometer, SCATSAT-1 mission is a global science mission and its data is used by international agencies such as National Aeronautical and Space Administration (NASA), National Ocean and Atmospheric Administration (NOAA), Royal Netherlands Meteorological Institute (KNMI), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) etc., (www.nesdis.noaa.gov/OPPA/indec-scatsat.php; OSI-SAF winds Team) to generate wind over the ocean and to forecast various phenomenon over the ocean such as storms, cyclones etc., which requires accurate sigma-0 data over the sea. For near real time monitoring and forecasting of weather phenomenon, it is required to analyse, assess and monitor the quality of the data at each level (Maneesha et al., 2011; Risien and Chelton, 2008).

The Data Quality Evaluation (DQE) system monitors the quality aspects at each level of data starting with the basic raw data to Level-2B global wind product in near real time. Further, if any anomaly or high deviation from the defined specifications is observed, DQE raises alerts to the concerned team for taking necessary actions. The key objective of DQE system is to ensure the dissemination of best quality of data to the end user.

The Level-1B data in SCATSAT-1 is acquired in every half orbit in contrast to its predecessor OSCAT-2, to improve the turn-around-time for data dissemination. In this paper, quality of Level-1B scan mode data is monitored using the in-house designed DQE software in an automatic manner. The results are interpreted based on the statistics from the slice and footprint data. Section 2 briefly defines the data sets used and the methodology to evaluate the data quality followed by results and analysis in section 3.

2. Data and methodology

The data used for this work is radiometrically corrected and geotagged Level-1B product at slice and footprint. The data is taken from operations generated through Data Product Generation System (DPGS) at National Remote Sensing Centre (NRSC) Hyderabad. The same data is shared at Meteorological and Oceanographic satellite data archival centre at Space Applications Centre Ahmedabad (www.mosdac.gov.in). It has both inner (HH) and outer (VV) beam data. The data of inner and outer beam has 281 and 282 footprints respectively.

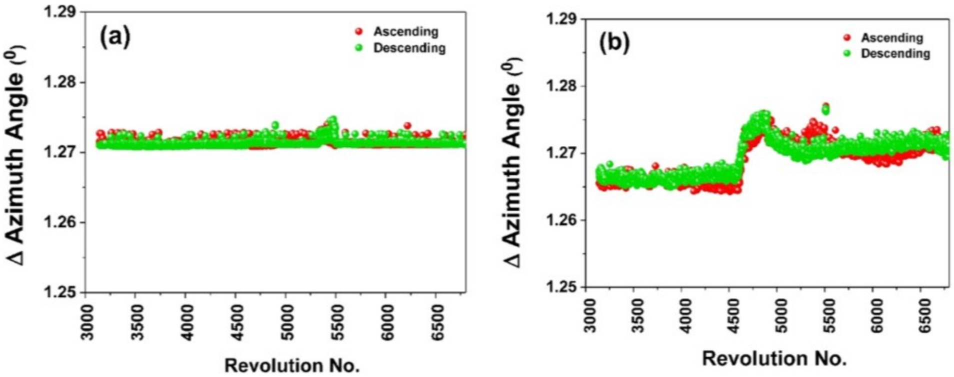

Figure 1: Footprint to footprint azimuth angle difference (a) HH and (b) VV beam

As scatterometer is an active sensor, the processing bandwidth of the signal processor and the 3dB power of the beam decides how many slices has to be taken to form the actual footprint on ground. Here, 9 inner slices and 14 outer slices are selected from the raw data to form the level-1B footprint along with appropriate weighting function. The basic data unit for Level-1B product is half orbit defined as north to south as descending and south to north as ascending (www.mosdac.gov.in/Scatsat-1-data-products). The data used in this work is generated from the SCATSAT-1 processing software version 1.1.2 from May 2017 to December 2017 and the analysis is based on each half orbit data, global cycle-wise data (two days) and long-term data.

The methodology used for evaluation and monitoring of quality metrics for SCATSAT-1 is based on identification and generation of quality metrics. The metric is categorized into static and dynamic parameters depending on the sensor scan mechanism and the wave target interaction (Maneesha et al., 2011). The static parameters are Doppler frequency, incidence angle, X-factor, azimuth angle, geolocation and kp whereas the dynamic parameters include SNR, sigma-0 (σ0) and Brightness Temperature (BT) explained elsewhere (Gupta et al., 2011). Behaviour of static parameters is monitored with respect to defined specifications (mentioned in Table 3.2) in half orbit revolution. The dynamic parameters are assessed in both half orbit and global one cycle data based on the sigma-naught quality flag which contains information of each slice/footprint in terms of location (land/sea), beam (inner/outer), node (ascending/descending), scan-direction (fore/aft), and sigma-0 quality (good/poor, valid/invalid). As scatterometer works for generating wind products which is governed by statistical averaging of Sigma-0. Thus to ensure the data quality and calibration aspects, the sigma-0 and BT are studied over the invariant sites and over land/sea using two days global cycle average.

3. Analysis, results & discussion

The analysis carried out on the parameters described in section 2 are discussed in this section. As per the quality metrics the results are shown in three categories namely (i) static parameter analysis (ii) dynamic parameter analysis (iii) invariant site monitoring.

3.1 Static parameters

In SCATSAT-1 there are certain parameters which are programmed for particular mode of operations and remains static within specifications. Range, X-factor, Incidence angle (inner and outer beam), Azimuth angle difference from footprint to footprint are the static parameters which varies within the defined specifications and depends on the geometry of the system. Figure 1 shows the azimuth angle difference for inner and outer beam footprints in ascending and descending passes. It varies within the defined limits ($1.27^0 \pm 0.01^0$) and is stable around 1.27^0 over the observed revolution data. In outer beam after revolution 4600 slight deviation of the order of 0.01^0 is observed which is highly stable as seen in figure1b, which might be the effect of orbit manoeuvring during the orbit-locking phase.

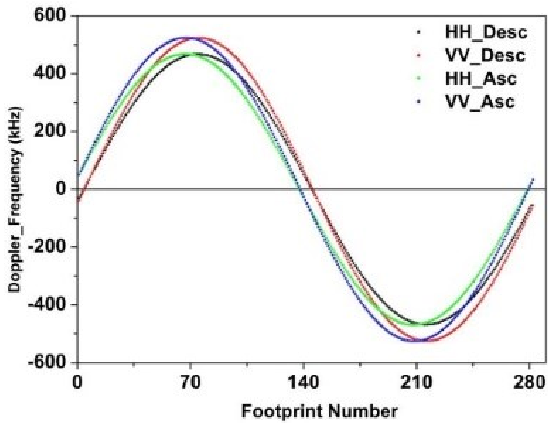

Figure 2: Doppler frequency (kHz) for half revolution data

Doppler frequency which is a function of scan forms a sinusoidal pattern for each scan and varies ±467 kHz for inner beam and ±523 kHz for outer beam. Figure 2 shows the typical plot of Doppler frequency shift over the footprints of a scan averaged over the half revolution data for revolution number 4773 (day-233). The expected sinusoidal pattern is observed for both inner (HH) and outer (VV) beam in every ascending and descending orbit. From the observed pattern (Figure 2), Doppler frequency at maxima is at footprint number 70 and 210, whereas the minima are at footprint number 1, 140 and 280 are analysed for multiple revolution data. Results are shown in figure 3(a) and 3(b) for inner and outer beam respectively.

Doppler frequency over the eight-month's data shows stable Doppler shift over the chosen footprints. At nadir, the Doppler for HH beam is less than VV beam by ~56 kHz.

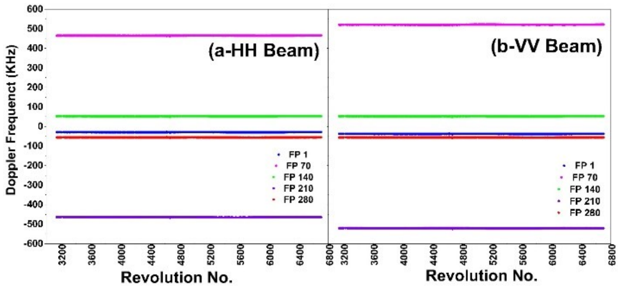

Figure 3: Doppler frequency (kHz) at different footprint locations over multiple revolutions data (FP –footprint)

Incidence angle is a static parameter for pencil beam scatterometer and form pattern with respect to ascending/descending pass and is a function of latitude due to spheroid shape of the earth. Figure 4 shows the incidence angle for both HH and VV beams is fixed at 49.06^0 and 57.96^0 respectively. It is observed to be stable in both ascending and descending node.

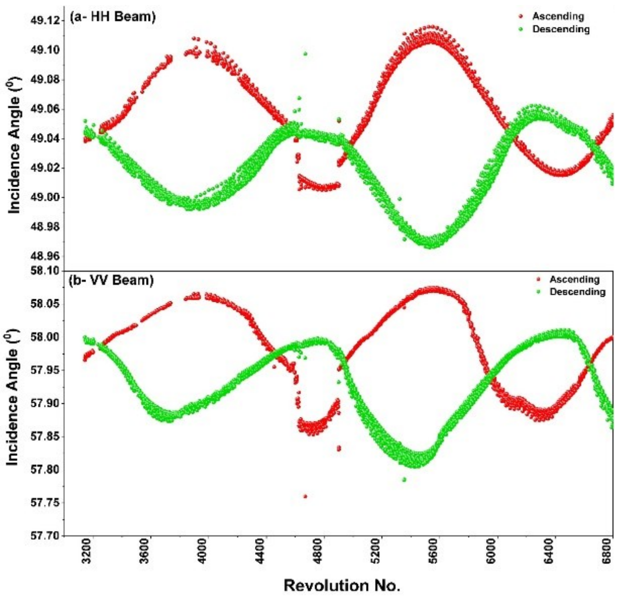

Figure 4: Incidence angle for inner and outer beam in both ascending and descending pass

Range and X-Factor from SCATSAT-1 is monitored for both HH and VV beam in ascending and descending revolutions are shown in figure 5 and figure 6 respectively. Similar patterns are observed for both beams in ascending and descending orbits. The range observed varies around 1241 km for outer and 1057 km for inner beam as expected. The variation in range is compensated in the calibration factor i.e. X-Factor and is shown in figure 6 (a & b). From the figure 5 a b there is a broadening in range seen and is compensated in cal factor (X factor). This broadening is due to orbit manoeuvring which took place during orbit 4600 and is confirmed from the satellite velocity and position (Figure 7).

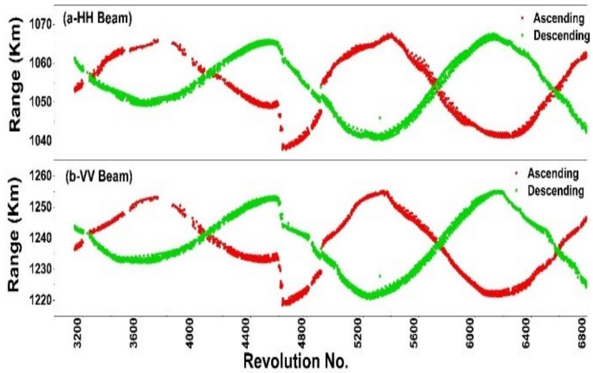

Figure 5: Range observed in SCATSAT-1

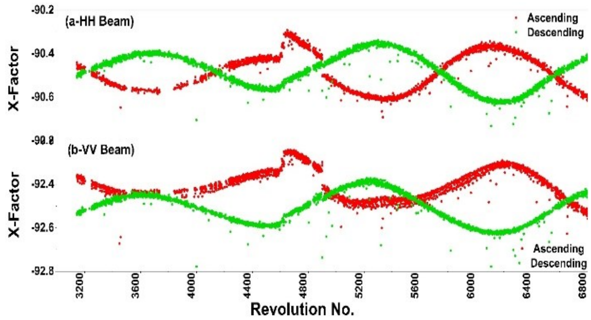

Figure 6: X-Factor from level-1b footprint data of SCATSAT-1

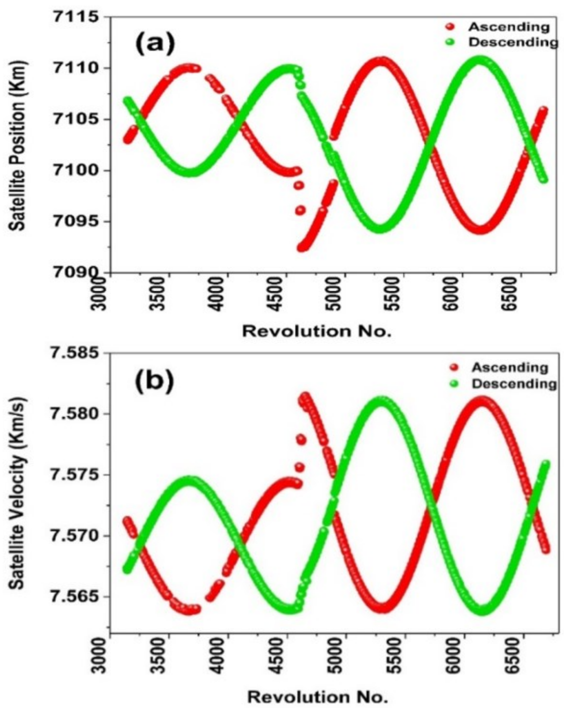

Figure 7: (a) Satellite position (b) Satellite velocity

The statistics from the long-term data (May- 2017 to December 2017) for static parameters is given in table 2. It is evident from the statistics that the behaviour of static parameters is stable with respect to time and is within the defined specifications mentioned in table 1.

Table 1: Specifications of static parameters

parameter	Range specifications (minimum and maximum)			
	Inner Beam (HH)		Outer Beam (VV)	
	Min	Max	Min	Max
Doppler Freq. (kHz.) sinusoidal pattern)	-467	467	-523	523
Incidence angle (deg)	48.95	49.15	57.8	58.1
Azimuth Angle (deg) (footprint to footprint variation)	1.25	1.29	1.25	1.29
X Factor(dBm)	-93	-88	-93	-90
Range(km)	1025	1095	1210	1260

Table 2: Statistics of static parameters

Parameter		Pass Node	HH beam Obs. value	VV beam Obs. value
Doppler Frequency (kHz)	*FP-1	D	-29.24	-37.84
		A	51.24	52.22
	FP-70	D	465.05	520.73
		A	466.94	523.57
	FP-140	D	52.32	52.25
		A	-26.89	-36.70
	FP-210	D	-464.07	-520.78
		A	-466.95	-523.05
	FP-280	D	-55.94	-56.16
		A	24.53	33.91
Incidence angle (degree)			49.05	57.96
Azimuth angle (variation footprint to footprint) (degree)			1.26	1.25
X Factor (dBm)		D	-90.49	-92.52
		A	-90.48	-92.40
Range (km)		D	1055.16	1239.74
		A	1055.15	1236.04

*FP is Footprint Number in a scan #D- Descending A-Ascending

3.2 Dynamic parameters

Level-1B Footprint data is made from slices i.e. 9 slices for inner beam and 14 slices of outer beam. The slices are a part of Level-1B data and are observed for each revolution data as these slices contribute in the collocation of footprint sigma-0 for both Level-1B scan mode footprints as well as Level-2A collocated footprints within the cell grid. Slices histograms are observed for sigma-0 at both sea and land for both beams. Peak of the histogram shows that there is less than 1dB variation among the slices for single orbit data. Results are shown in figure 8 for inner beam sea slices histogram (Figure 8 is histogram for inner beam slices (a) over sea; (b) is over land and (c) is histogram peak variation for land and sea).

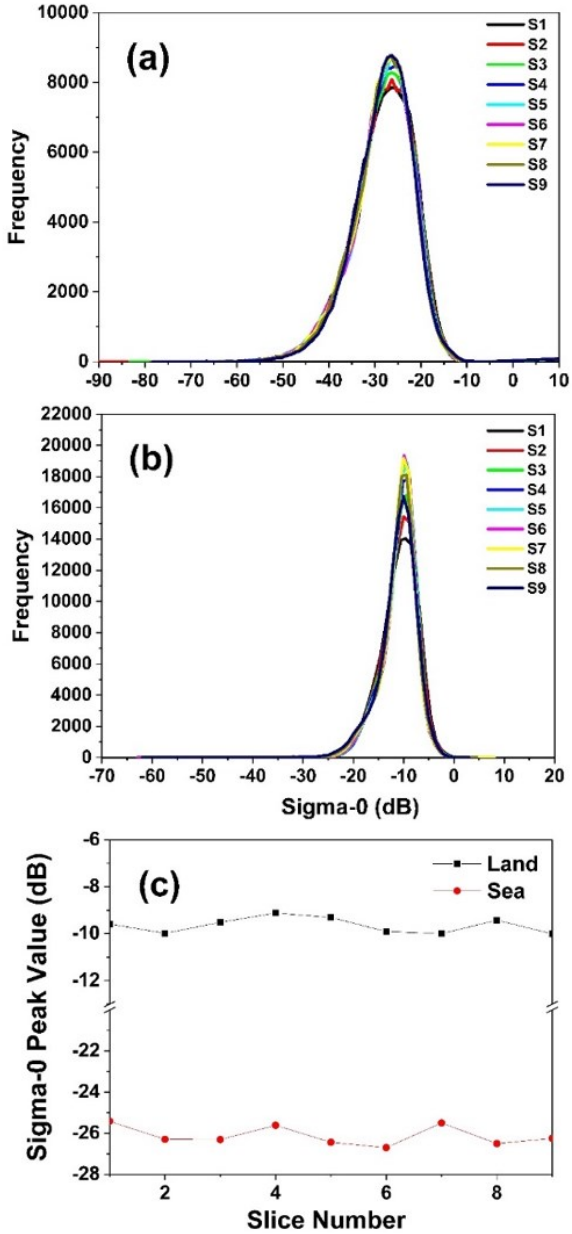

Figure 8: Sample snapshot of slices histogram of inner beam for revolution number 6339 in ascending pass (a) sea; (b) land and (c) histogram peak variation

Similar results are observed at land and sea for outer beam (figure not shown here). This analysis suggests that the SCATSAT-1 processor is picking slices (9 out of 40 in Inner and 14 out of 40 for outer) well within the specifications. As per specifications sigma-0 peak over land lies at -10.5±0.5dB (HH beam) and -11.5 ±0.5dB (VV beam) and for sea sigma-0 peak lies at -26±0.5dB (HH beam) and -23±0.5dB (VV beam).

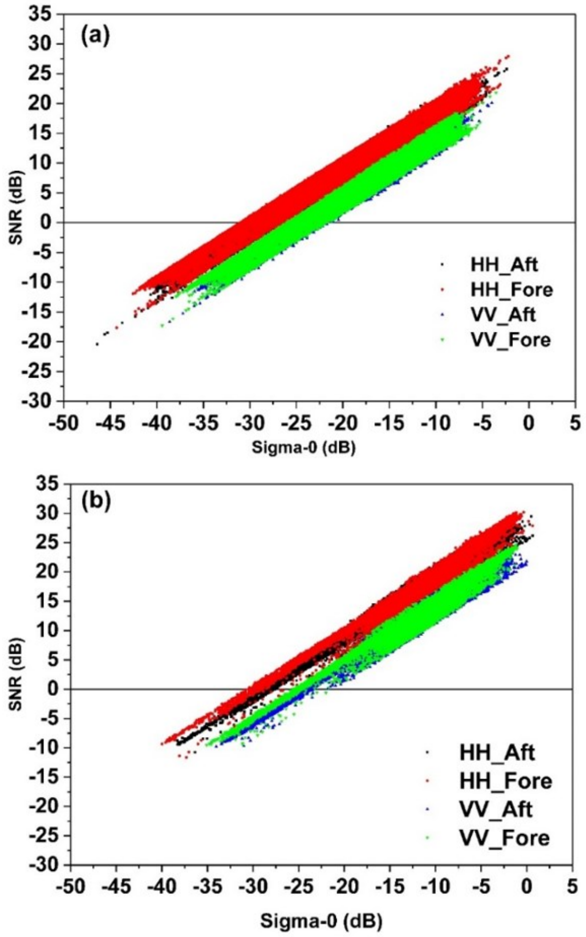

Figure 9: Sigma-0 vs SNR for inner and outer beam over (a) sea (b) land

Figure 9 shows the linearity between the Sigma-0 and SNR for the defined range for both the beams. Interpretation based on plots of figure 9(a) over the sea, suggests that for positive SNR of ~25dB(Inner) and ~20dB (outer), sigma-0 reaches to -5dB and on the other side at negative SNR of -10dB sigma-0 covers the range of -40dB for Inner beam and 35 dB for outer beam. Thus, the data under study covers the dynamic range well within the specified dynamic range (+10 to -96dB globally) of sigma-0. Similar behaviour is observed over the land (figure 9 b) with a difference of 5dB over the dynamic range. SNR is further observed as the mean value independently over multiple revolution data and is shown in figure 10a for land and figure 9b for sea. SNR on sea is less than on land (because of the return in Ku band for HH and VV beam from water surface is less than that from land) which is as expected. Over the land, SNR is 5 dB higher for HH w.r.t. VV (figure 10a) and forms pattern over the revolutions data whereas on sea (figure 10b) SNR from both beams (HH and VV) overlap with a difference of 3dB. Also, both plots of figure 10 suggest SNR is 2dB higher in fore look in comparison to aft look over the globe.

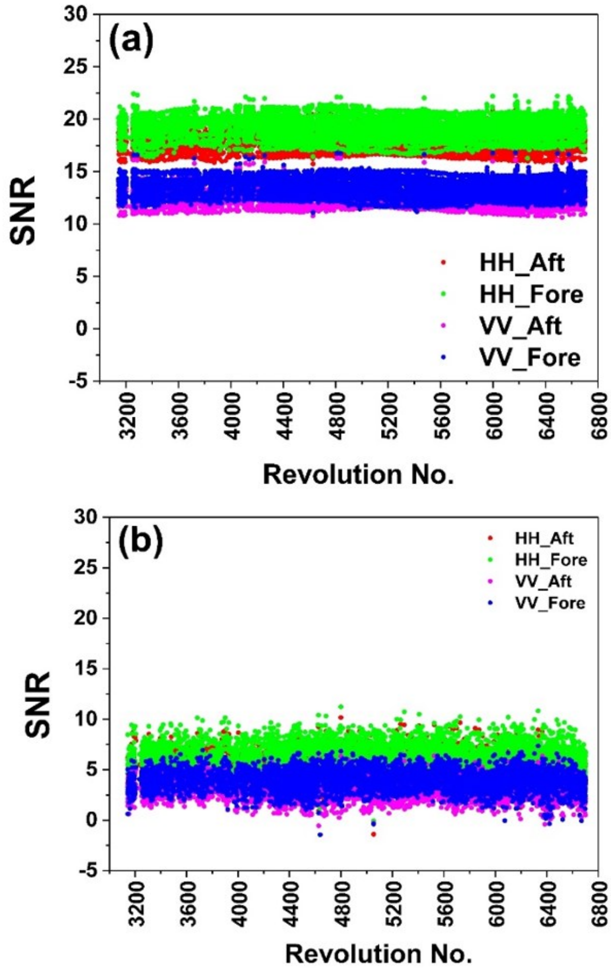

Figure 10: SNR behaviour for (a) land (b) sea

Kp is the normalized standard deviation in sigma-0 and tells the quality of data. The low value of kp indicates better sigma-0 value. Figure 11 shows the mean kp variation over multiple revolutions. From plots, kp is nearly 0.1 for land and on sea it varies from 0.1 to 0.5 which is well within the defined specifications (0 to 1) and confirms the high-quality product of SCATSAT-1.

Figure 12 is the typical colour coded sample snap shot of sigma-0 and brightness temperature respectively seen from the global coverage of two days (20st and 21st August 2017) inner beam data. The grid used is 50 km x 50 km for both sigma-0 and BT display. It also supports, that the radiometry acquired by the sensor in the scan mode data is of good quality and the brightness temperature observed over the land, sea, sea-ice matches well with the specifications (Raj Kumar et al., 2011)

The overall time series of sigma-0 and BT are shown in figures 13 and 14 respectively over the global land and sea average. The sigma-0 plot (figure 13a) shows a seasonal pattern in sigma-0 (-21 to -22 dB for VV beam and -24 to -26 dB for HH beam). In the mid of September, a systematic shift of 1 dB is observed which is constant thereafter might be due to greater noise as brightness temperature data (figure 14 a) also suggest that noise is large which is still not significant as per system specifications (as per the specification 10 K variation in BT is within acceptable limits). The figure 13b shows a constant behaviour of sigma-0 around -11.46 dB and -10.44 for land in HH and VV beam respectively which are well within specifications (discussed earlier). From figure 14(a, b) brightness temperature over the sea is stable and constant except getting down by 15 K in mid-September might be due to increase in noise for both HH and VV beams. Over the land an increase of Brightness temperature by 15K in VV beam is observed whereas in HH beam it is stable and within limits.

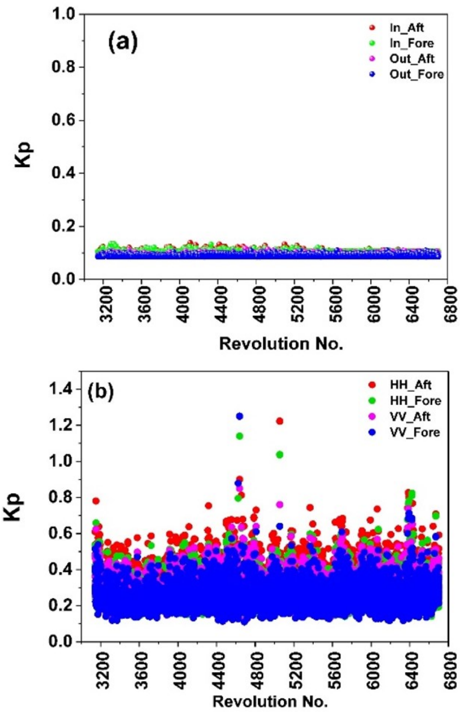

Figure 11: kp variation (a) land (b) sea (in-inner beam (HH), out-outer beam (VV), l-land, s-sea)

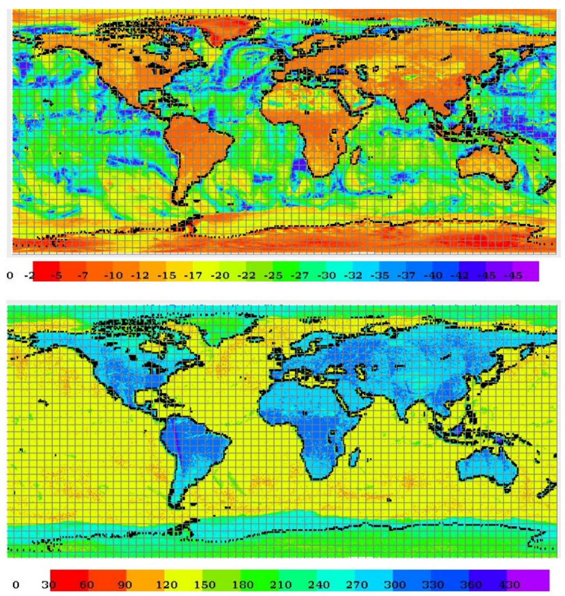

Figure 12: Cycle-wise global (top) sigma-0 and (bottom) brightness temperature (20-21st August 2017)

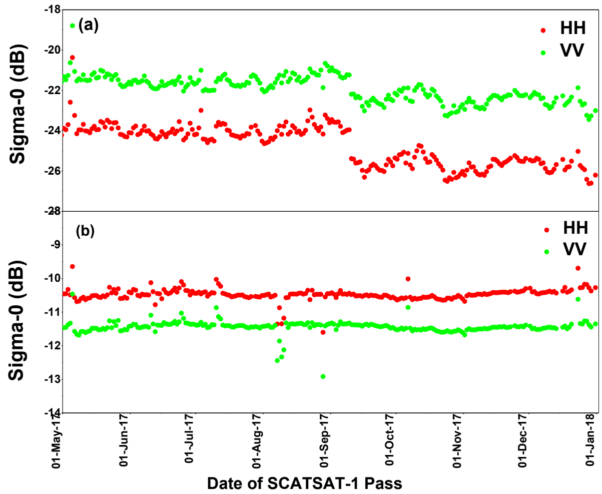

Figure 13: Time series of sigma-0 over (a) sea (b) land for both HHand VV beams

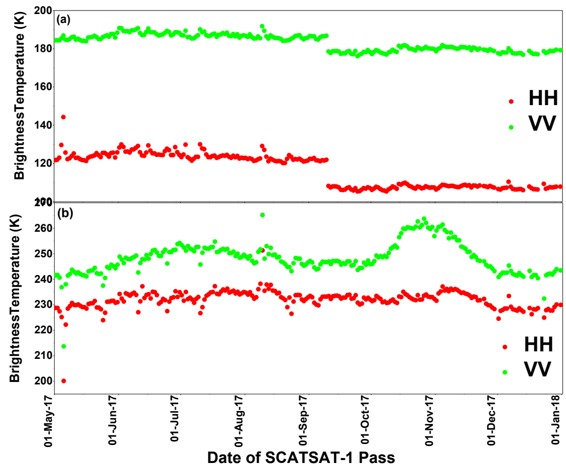

Figure 14: Time series of brightness temperature over (a) sea & (b) land for both HH and VV beams

3.3 Invariant site monitoring

For data calibration/validation, well-known calibrated sites (viz. Amazon rain-forest and Antarctica) are used for monitoring sigma-0 and brightness temperature (Raj Kumar et al., 2011). Figure 15a shows the sigma-0 Ascending pass and in fore/aft scan direction. Figure 15b shows the BT in ascending pass and in fore/aft scan direction over Amazon rain-forest for eight month's data. It is clear that BT is around 275 K over the Amazon rain-forest and is stable.

Detailed statistics (Minimum, maximum, mean and Standard deviation) of sigma-0 are shown in table 3. It shows that sigma-0 accuracy over the Amazon rain-forest is less than 0.25dB which is as expected and accuracy of BT in all categories is less than 12K. Results from trend analysis ensures that parameters are behaving well within the specifications (varies wr.t sites typically within ±0.5dB variation in sigma-0 and ±10K variation in BT) and assures stability and consistency of the system and product quality parameters.

Table 3: Amazon Sigma-0 and BT statistics from May 2017 to December 2017 over Amazon Rainforest

Beam	Node	Scan Direction	Sigma-0 (dB)				Brightness Temperature (K)			
			Mean	Min	Max	Std dev	Mean	Min	Max	Std dev
Inner	#Asc	Aft	-8.38	-8.90	-7.50	0.23	261.2	237.8	279.8	8.6
		Fore	-8.03	-8.55	-7.37	0.24	259.1	240.9	274.9	7.9
	^Des	Aft	-7.99	-8.66	-7.22	0.22	262.9	214.8	278.6	9.2
		Fore	-8.08	-8.68	-7.57	0.18	263.1	240.3	278.9	8.9
Outer	Asc	Aft	-9.42	-10.08	-8.64	0.24	270.7	258.8	286.4	6.3
		Fore	-9.16	-10.01	-8.17	0.30	266.7	252.9	281.6	7.0
	Des	Aft	-9.17	-9.99	-8.16	0.27	278.8	253.7	321.5	12.0
		Fore	-9.32	-9.92	-8.57	0.22	273.6	246.1	304.7	9.8

*Asc= Ascending and ^Dsc=Descending

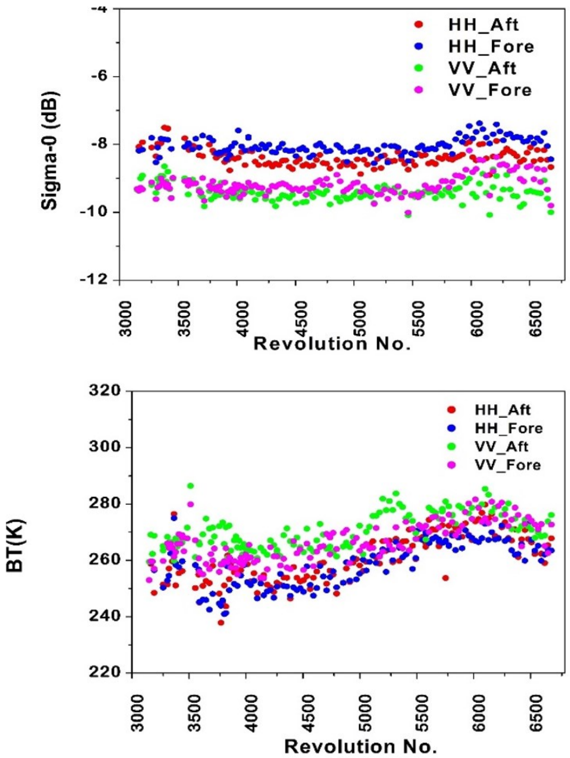

Figure 15: Temporal trend (a) sigma-0(dB) (b) BT for VV and HH beam in ascending pass

4. Conclusions

Data quality of SCATSAT-1 scatterometer scan mode data is discussed. Eight months of data is statistically analysed for monitoring the stability and accuracy of quality parameters. Results for the identified quality metrics show consistency in both fixed geometric parameters as well as dynamic radiometric parameters i.e. sigma-0, BT and SNR as per mission specifications. SNR, kp and sigma-0 are analysed for multiple revolutions data which shows as expected trends. The sigma-0 over the invariant sites is observed and found to be stable in defined range. Over Amazon rainforest, sigma-0 observation has an accuracy better than 0.24 dB in HH beam and 0.25 dB in VV beam. Also, Brightness temperature over the invariant sites is found to be stable with an accuracy better than 10 K suggesting that noise filter on board is stable. The analysis carried out in this paper will aid the end users in further analysis of the wind vector. The analysis clearly shows that SCATSAT-1 data is of very high quality and will be able to provide the climate quality products similar to QuikSCAT.

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