38 Indian Scientific Expedition to Antarctica

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8. Abstract	Space Applications Centre (SAC) is actively involved in the field of polar science studies and regularly participating in the Indian Scientific expedition to Antarctica (ISEA). ISEA is a part of SAC activity initiated under Meteorology and Oceanography Programme (MOP) and is organized by National Centre for Polar and Ocean Research (NCPOR), Goa. During the thirty-eighth Indian scientific expedition to Antarctica (38 ISEA), three scientists (Ms Shweta Sharma from EPSA and Shri Ananya Ray and Shri Nilesh Makwana from MRSA) were deputed to participate in 38th Indian Scientific Expedition to Antarctica. The main objective of the team was to establish Indian SAR calibration site at Maitri and Bharati research station for the across-swath data calibration of upcoming SAR sensor satellites like RISAT-1A and NISAR. The other objectives of the expedition were testing of the in-house developed Active Radar Calibrator (ARC) which will be used for polarimetric calibration, elevation mapping with the help of DGPS, densification of bamboo stakes for estimation of ice velocity and to conduct GNSS reflectometry experiment for land ice depth estimation. This report briefs out the studies carried out by SAC team at Indian research base stations Maitri and Bharati at Antarctica with respect to different objectives during the 38 ISEA (2018-2019).
10. Security classification	Unrestricted
11. Distribution statement	Unrestricted

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1.0 Introduction

Space Applications Centre (SAC) is actively involved in the field of polar science studies and regularly participating in the Indian Scientific expedition to Antarctica (ISEA). ISEA is a part of SAC activity initiated under Meteorology and Oceanography Programme (MOP). SAC has provided sea ice advisory to NCAOR, MoES for optimization of the voyage route during various expeditions. The in-house developed GPR (developed at MRSA/SAC) is being utilized to measure the sea ice and snow pack thickness for developing AltiKa based sea ice thickness retrieval technique. SAC team participated in the 38 ISEA with the major objectives of establishment of Indian SAR calibration site at Maitri and Bharati research station for the across-swath data calibration of upcoming SAR sensor satellites like RISAT-1 follow-on mission and NISAR. The other objectives of the expedition were testing of the in-house developed Active Radar Calibrator (ARC) for polarimetric calibration, elevation mapping with the help of Differential GPS, densification of bamboo stakes for estimation of ice velocity and to conduct GNSS reflectometry experiment for land ice depth estimation.

Upcoming Synthetic Aperture Radar (SAR) missions with larger swath like NISAR (~250 Km), requires large, flat and homogeneous low background site free from man-made structures for point targets deployment for calibration. Finding out such large, flat, homogeneous area, devoid of perceived sources of radar clutter is a challenging task. In this regard, Antarctica is a potential site for calibration as it fulfills many of the criteria required for the ideal calibration site. Hence, it is very much required to set up a network of corner reflector there for SAR calibration. At present only a few countries (US, Italy-France and Germany) have deployed CRs at different parts in Antarctica for various studies like mass-balance, InSAR and for localization accuracy related studies. As a part of this activity, in-house designed and developed CRs were installed near Indian research base stations Maitri and Bharati at Antarctica during the 38 Indian scientific Expedition to Antarctica (38 ISEA-2018-2019). The establishment of CR network at Antarctica will help in the calibration of present and future SAR sensors data (RISAT-1A and future SAR missions).

The GNSS-Reflectometry is a new way of Remote sensing using the abundantly available Global Navigation Satellite Systems (GNSS) L and S band CW signals in passive remote sensing of Earth from LEO platform or any ground based or Air borne platform which can

receive earth reflected GNSS signals. A specialized GNSS receiver was made in-house in SAC for establishing a proof of concept of GNSS-Reflectometry for cryosphere sensing. The receiver records the reflected data in raw digitized I-Q format from a down looking antenna along with direct reception of the same through another up-looking antenna.

2.0 Objectives

The objectives for 38th Antarctica expedition are as follows:

1. Establishment of Indian Cal-Val Network for SAR at Antarctica (for SAR calibration and InSAR studies)

   Work element at Antarctica: Confirmation/modification of pre-selected site positions, deployment of permanent corner reflector and identification of points for future point target deployment

   Work element at SAC: Response from reflector will be utilised to calibrate the SAR data products, displacement in position will be useful for ice velocity validation and to estimate changes in the surface elevation with time

2. GNSS Reflectometry for land ice depth estimation (in situ data collection and analysis) and validation of the results using GPR and snow fork.

3. Technique development and validation for estimation of ice velocity, sea ice thickness and surface elevation using altimeter data.

   Work element at Antarctica: DGPS measurements for ice velocity, elevation, GPR measurements over sea ice and land ice for snow & ice thickness

   Work element at SAC: Technique development & improvement, validation using in-situ data

3.0 Study Area

The surroundings of Indian research base Maitri and Bharti were selected as the study area. Figure 1 and Figure 2 show the locations of Maitri and Bharti respectively on Indian remote sensing satellite, Resourcesat-2 (Liss-4) False Color Composite (FCC) image.

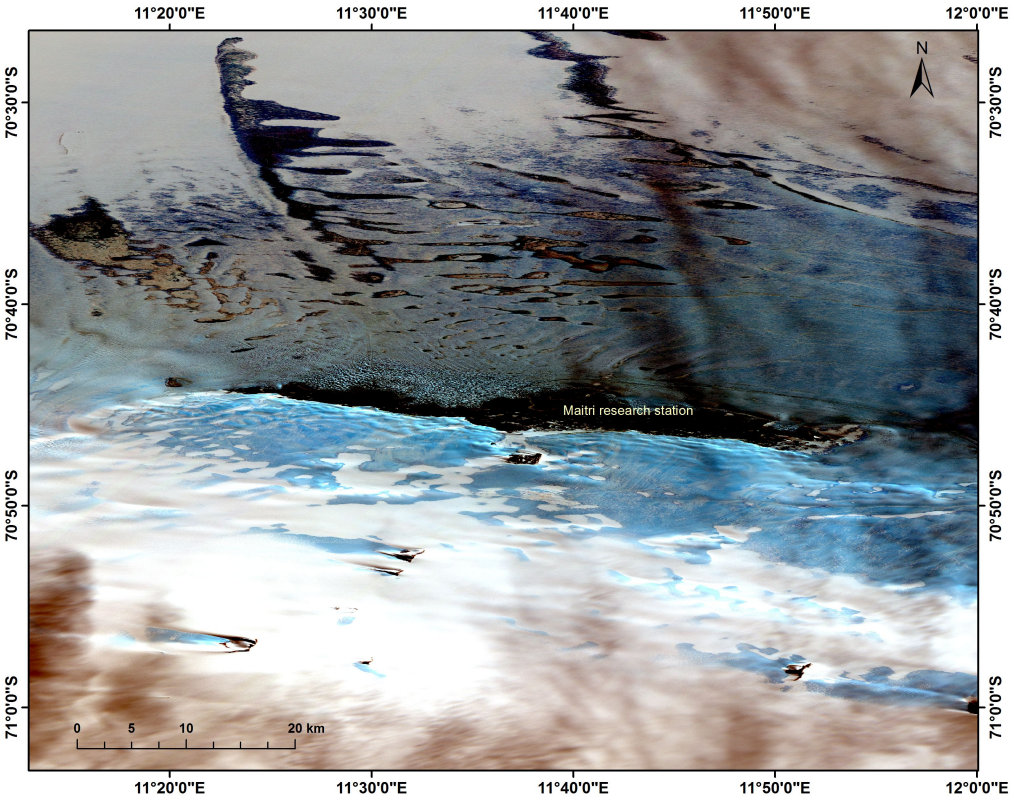


Figure 1: Location of Maitri Indian research base shown on Resouresat-2 Liss4 FCC image

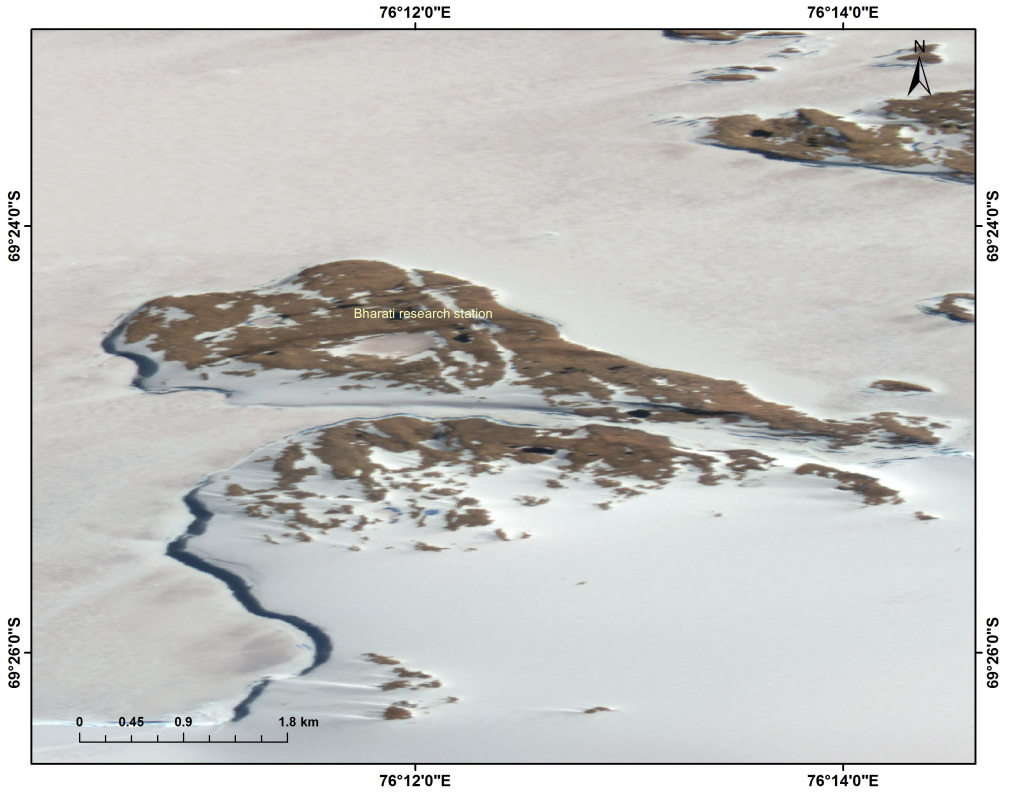


Figure 2: Location of Bharti Indian research base shown on Resouresat-2 Liss4 FCC image

4.0 Data Used

Due to the non-availability of the Indian imaging microwave data, freely available Sentinel-1 A and Sentinel-1B, Single Look Complex (SLC) data acquired over the study areas with different modes was used for analyzing the response of the Corner reflector for finalizing the site for permanent deployment. In order to monitor the performance of the 0.9 m CR, Integrated wide swath mode data of Sentinel-1 was needed regularly. Since only extended wide swath (EW mode) data coverage over Maitri was available, European Space Agency was requested to plan the regular acquisition of IW mode data in and around Maitri research base and ESA readily agreed to this request. Time series data of Sentinel-1 IW mode was analyzed and the results of the estimated data quality parameters are shown in the Results section.

5.0 Methodology and Studies carried out during 38ISEA

The details of the methodology and the work done with respect to each objective are as follows:

5.1 Establishment of CR Network

- **Work Done at Maitri**

Harsh environment of Antarctica demands the design of CRs to be robust and should be able to withstand high winds and low temperature. Corner reflectors were designed keeping in mind the harsh environment of Antarctica such as high katabatic winds, blizzards, snowfall and very low temperature. Super hydrophobic microwave transparent cover was designed and installed over it to protect snow accumulation. Hydrophobic radar absorbing materials were installed over central mount to decrease the background noise due to it. Various tests such as structural analysis of total CR system, thermal analysis of materials and RCS characterization of CR was done before sending it to Antarctica.

In order to find out the potential site for calibration target installation, temporal and seasonal analysis of radar backscatter data using available RISAT-1 and SENTINEL-1 SAR data covering Indian research bases and surroundings was carried out and few locations were identified. The 38 ISEA summer team from SAC, Ahmedabad surveyed the a-priori identified locations based on the factors such as site accessibility, relatively low wind and less snow accumulation area and background response of the site, few locations were selected

around Indian research base stations (Maitri and Bharti). In order to select the suitable site (among the sites identified) for permanent deployment, Corner reflector (CR) and active radar calibrator (ARC) synchronous to Sentinel-1A & 1B pass were deployed at different locations and for different modes (ascending, descending mode). The experiment was also done for by deploying point targets at near-, mid-and far range to study the response of the targets at different incidence angles. Based on the site survey, image analysis, response of CR in the image and other limitations, site near Maitri station was finalized and CR was deployed permanently corresponding to descending mode of Sentinel-1A. The details of the experiment are given in Table-1.

Table 1: Details of point target deployment experiment

S.No.	Date	Point Target Deployed	Location	Remarks
1	28-12-2018	CR & ARC both	Near Maitri sattion	40 m spatial resolution till 17th January 2019
2	29-12-2018	CR & ARC both	Near Maitri station	
3	02-01-2019	CR & ARC both	Icesheet	
4	08-01-2019	CR & ARC both	Icesheet	
5	09-01-2019	CR & ARC both	Icesheet	
6	14-01-2019	CR & ARC both	icesheet	
7	15-01-2019	CR & ARC both	icesheet	
8	16-01-2019	ARC	Point before shivling at ice sheet	Could not deploy CR due to snow drifting
9	17-01-2019	CR & ARC both	Icesheet	
10	18-01-2019	ARC	icesheet	10 m spatial resolution from 18th January onwards
11	21-01-2019	CR & ARC both	Icesheet	
12	22-01-2019	ARC	Near Maitri station	High wind conditions
13	24-01-2019	ARC	Near Maitri station	
14	25-01-2019	ARC	Near summer hut, Maitri	ARC testing near summer hut container using spectrum analyzer
15	29-01-2019	CR	Near Maitri station	
16	30-01-2019	CR	Near Maitri station	
17	24-02-2019	CR & ARC both	Near Maitri station	Ascending mode (2:34 am satellite pass time)
18	25-02-2009	CR & ARC both	Near Maitri station	Descending mode (19:51 hrs satellite pass time)
19	02-03-2019	CR & ARC both	Near Maitri station	
20	03-03-2019	CR & ARC both	Near Maitri station	
21	08-03-2019	CR & ARC both	Near Maitri station	
22	09-03-2019	CR & ARC both	Near Maitri station	
23	15-03-2019	CR & ARC both	Near Maitri station	**Permanent deployment of CR completed** Location: S70.767133 E11.722795

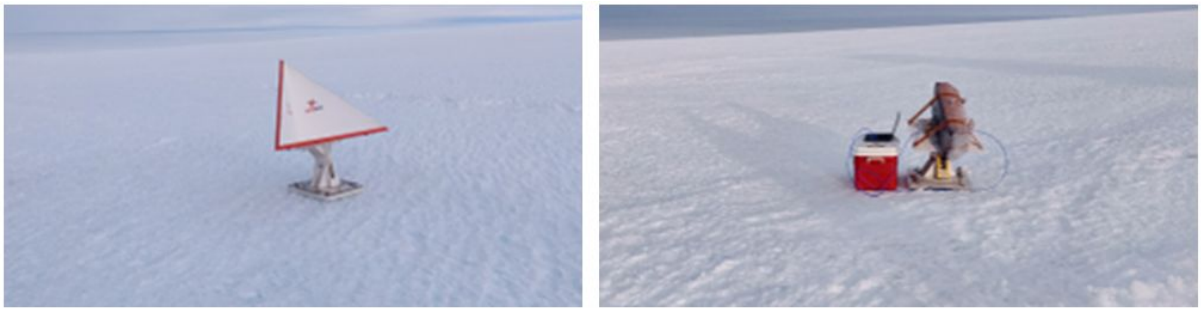


Figure 3: Deployed Corner Reflector and ARC at ice sheet on 8th Jan 2019

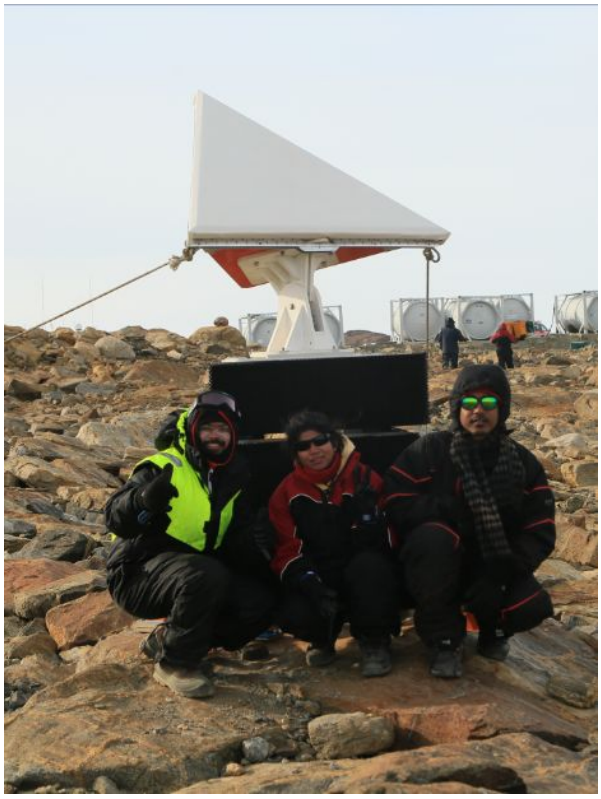


Figure 4: Permanently Deployed Corner Reflector set-up at Maitri and the SAC team

The ground snap of the deployed point targets (CR and ARC) at the icesheet and permanently deployed CR set-up are shown in Figure-3 and Figure-4 respectively. The ground snap of the installed wooden plank with ongoing DGPS measurements and the supporting team members are shown in Figure-5 and Figure-6 respectively.

Figure 5: Installed wooden plank with ongoing DGPS measurements at Maitri

Figure 6: Supporting logistics team members from NCPOR
(from left to right: Mr. Monu, Mr. Santosh and Mr. Kishan)

- **Work Done at Bharati and voyage**

Site survey was done on 9th & 15th February in the surroundings of Bharati station to select the suitable site for permanent deployment of Corner Reflector (CR). The base foundation was assembled (Radar absorbing material panels, base mount and CR) for permanent deployment. Deployed dihedral corner reflector (CR) made using two Aluminium sheets synchronous to Sentinel-1A pass on 17th February at the hilltop near Bharati station to study the response of the site. The experiment helped in analysing the background response in the

image. Based on the response in the image, site survey and other constraints like wind speed, snow accumulation, following location was selected for permanent deployment: Latitude: 69 24 17.2S, Longitude: 76 11 24.7E

Base foundation for CR was installed at the selected location on 20th February 2019 and final CR deployment was done on 22nd February as per the Sentinel-1B parameters. The image shows good response of CR. The estimated Radar Cross Section (RCS) for CR as estimated from 23rd February data was estimated to be 32.1 dB without Radom. On 24th February CR was covered with Radom.

The ground snap of the permanently deployed point target (CR) at Bharati and the supporting team members is shown in Figure-7.

Figure 7: Permanently Deployed Corner Reflector set-up at Bharati and the supporting team members

5.2 GNSS Reflectometry Experiment

- **Work Done at Maitri**

Field experiment details for this experiment are given in Table-2:

Table 2: GNSS experiment details

Date	Location	Details
27th Dec 2018	Dozzer Point	2 sets of GNSS-Relfectometry data has been recorded. GPR survey done on the field of view of the GNSS-R antenna.
3rd Jan 2019	Near Novo Station	2 sets of GNSS-Relfectometry data has been recorded. GPR survey done on the field of view of the GNSS-R antenna. Snow fork data also recorded
23rd Jan 2019	Veteheiya hills	One set of GNSS-R data followed by GPR survey on the snowy slopes under the cliff was taken.Snow fork data could not be taken here.
31st Jan 2019	Near the East end of Schrimature Oasis	GNSS-R data was taken from a cliff (height difference of 46 m) overlooking the Ice shelf. Here also, only GPR survey was done on the shelf lying in the field of view of the Antenna. Due to lack of snow, snow fork Experiment was not possible here.
3rd February 2019	7Km south-westward from Runway	GPR survey was done along with the snow fork experiment. A perfect site for GNSS-R marked for further surveys
14th Feb 2019	Beside Priyadarshini Lake	GNSS-R reading was taken from the Lake surface during High winds (up to 25 knots)
15th Feb 2019		Same thing was repeated during high winds of around 15-20 Knots
24th Feb 2019		Similar reading was taken during low winds of around 0-10 knots
25th Feb 2019		Similar reading was taken during 0-3knots wind speed
26th Feb 2019	7Km south-westward from Runway	A continuous reading of 2.5 hours of GNSS-R data was taken followed by GPR survey and Snow-fork experiment.

Figure 8: GNSS reflectometry set-up

(From left to right) Dozzer point; Near Novo; At Veteheiya hills, At the east end of Schirmacher oasis; At 7km South-West of runway,Beside Lake Priyadarshini; At 7km South-west of Runway with GNSS-R,GPR and Snow-fork; At Dozzer point with both the GPR

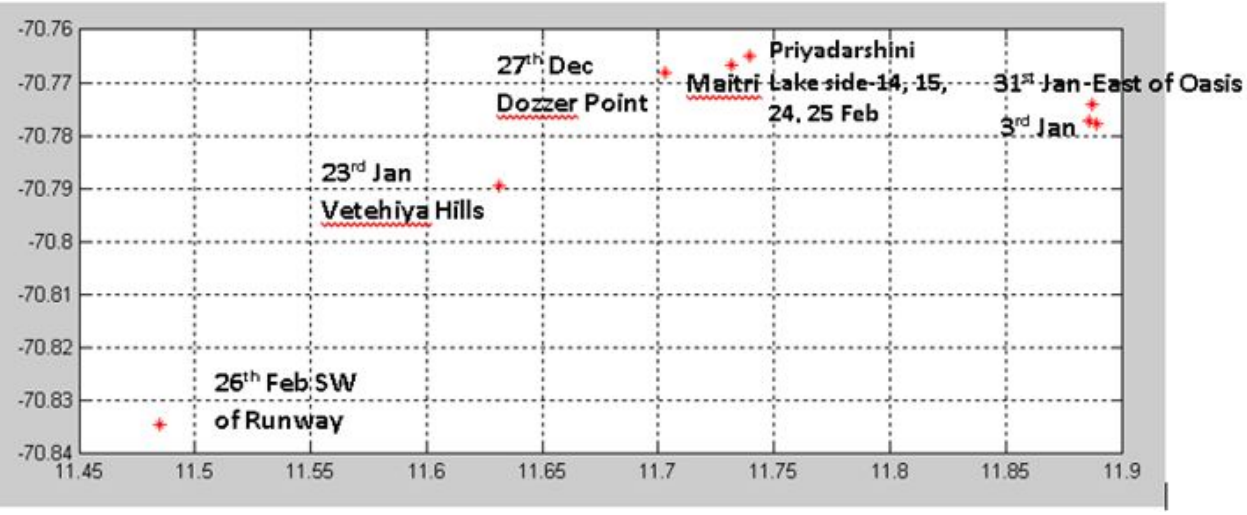


Figure 9: Latitude-Longitude of the GNSS field trips

5.3 Surface elevation and ice velocity measurements:

- **Work Done at Bharati and voyage**

For the estimation of ice velocity, Bamboo stakes installed at Polar Record Glacier and Dalk glacier, piston bully point and progress runway were surveyed. DGPS measurements of four stakes on 14th February 2019 were done. The stakes were found to be buried under snow at Polar Record Glacier. However, DGPS measurement for the elevation data was taken on of those point. DGPS measurements at Polar Record Glacier is shown in Figure-10.

Figure 10: DGPS measurement at Polar Record Glacier.

The surveyed locations are as follows:

Latitude: 70 26 28.06754S, Longitude: 75 30 24.19683E;

Latitude: 70 25 33.23422S, Longitude: 75 34 34.80285E;

Latitude: 70 24 45.69081S, Longitude: 75 38 06.26128E;

Latitude: 70 18 40.78947S, Longitude: 75 40 07.66570E;

Five Bamboo stakes were installed at different locations at Polar Record Glacier in collaboration with NCPOR on 20th February, 2019 and it is shown in figure 11.

Figure 11: DGPS measurement of newly installed Bamboo Stack at Polar Record Glacier.

DGPS measurements of three bamboo stakes installed at Dalk glacier was completed on 22nd February, 2019 and shown in figure 12, along with their length which will be helpful to measure the ice velocity and mass balance studies. The surveyed locations are as follows:

1. ***Latitude: 69 26 09.0S, Longitude: 76 23 39.0E; Bamboo stakes length: 2m 9cm***
2. ***Latitude: 69 25 29.8S, Longitude: 76 26 21.9E; Bamboo stakes length: 3m***
3. ***Latitude: 69 25 15.3S, Longitude: 76 23 58.8E; Bamboo stakes length: 2m 70cm***

DGPS measurements of nine bamboo stakes installed at Dalk glacier were completed on 23rd February, 2019 and shown in figure 12, along with their length. The surveyed locations are as follows:

1. ***Latitude: 69 26 34.7S, Longitude: 76 21 34.4E; Bamboo stakes length: 71cm***
2. ***Latitude: 69 26 34.5S, Longitude: 76 21 32.4E; Bamboo stakes length: 50cm***
3. ***Latitude: 69 26 34.2S, Longitude: 76 21 30.3E; Bamboo stakes length: 62cm***
4. ***Latitude: 69 26 34.9S, Longitude: 76 21 29.63E; Bamboo stakes length: 63cm***
5. ***Latitude: 69 26 35.3S, Longitude: 76 21 31.4E; Bamboo stakes length: 70.2cm***
6. ***Latitude: 69 26 35.6S, Longitude: 76 21 33.6E; Bamboo stakes length: 59cm***
7. ***Latitude: 69 26 36.4S, Longitude: 76 21 32.9E; Bamboo stakes length: 78cm***
8. ***Latitude: 69 26 36.1S, Longitude: 76 21 30.7E; Bamboo stakes length: 90cm***
9. ***Latitude: 69 26 35.7S, Longitude: 76 21 28.5E; Bamboo stakes length: 58cm***

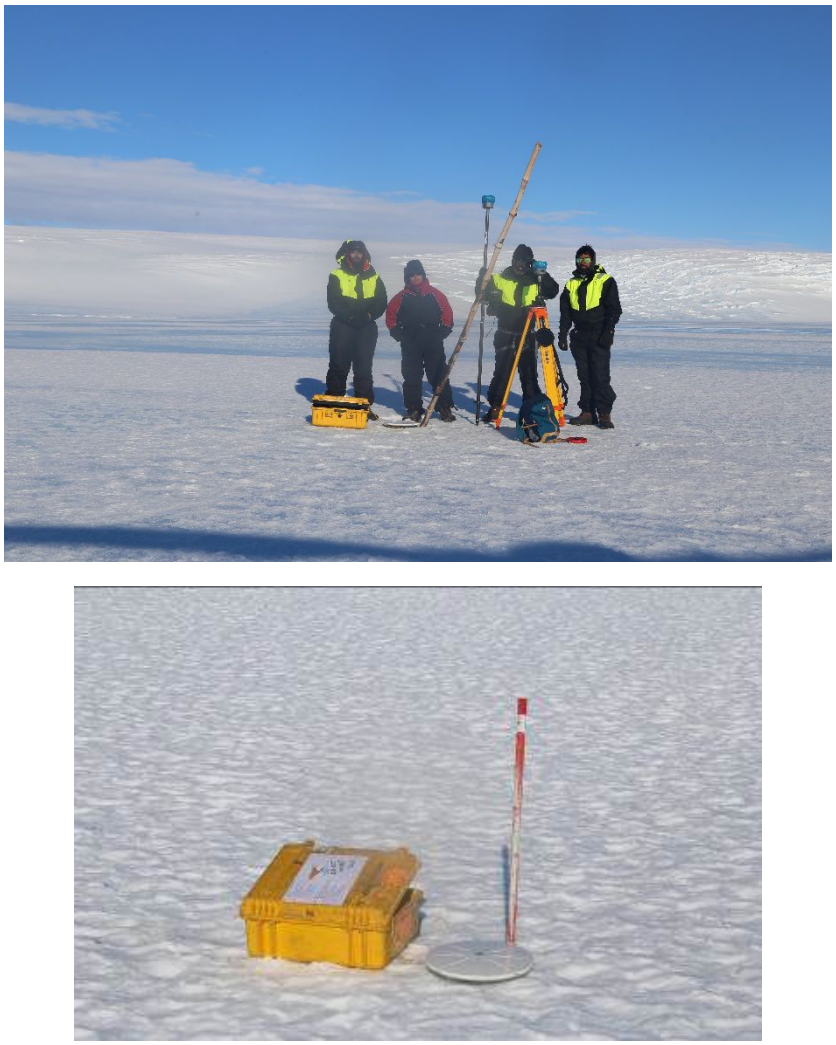


Figure 12: DGPS measurement of Bamboo Stack at Dalk Glacier

Grid wise elevation measurements were also completed at the above mentioned locations. DGPS measurements for elevation data at piston bully and near progress runway were completed on 13th February, 2019 and group photo of the same is shown in figure 13,. The surveyed locations are as follows:

Latitude: 69° 25' 12.8"S, Longitude: 76° 12' 54.4" E;

Latitude: 69° 26' 39.7"S, Longitude: 76° 16' 59.5"E;

Latitude: 69° 25' 12.8" S, Longitude: 76° 12' 54.5" E;

Latitude: 69° 26' 39.7" S, Longitude: 76° 17' 00.4"E;

Figure 13: DGPS measurement for Elevation data at Piston bully point and Near Progress runway, Bharati Station

- **Work Done at Maitri**

Seven points, five points at the icesheet and two points at the iceshelf were identified for the elevation data measurement. Out of seven points elevation data could be done only at the three points in the icesheet. Figure 14 shows photo taken on field during the DGPS measurement for Elevation data at one such point. Because of crevasses and other constraints other points could not be covered. Elevation data at three additional points (including one at the convoy route) was also taken. The location of the elevation data measurements points and details of the other experiments are given in Table-3 and Table-4 respectively.

Table 3: Location of elevation data measurement points

S.No.	Latitude (DD)	Longitude (DD)	Remarks
1	-70.68	11.77	
2	-70.7	11.51	
3	-70.92	12.16	Could not be completed due to crevasses
4	-70.98	12.25	
5	-70.97	12.51	Could not be completed due to crevasses
6	-71.03	12.34	
7	-71.08	12.33	Could not be completed due to bad weather
8	-71.12	11.60	
9	-71.25	11.20	
10	-70.88	12.01	
11	-70.7684 -70.7685 -70.7685 -70.7684	11.7038 11.7035 11.7031 11.7033	Elevation points at dozer point GPR survey
12	-70.764	11.741	7 elevation points taken around this location for contour map

Figure 14: DGPS measurement for Elevation data Near Maitri Station

***Table 4: Details* of all GNSS GPR, DGPS and snow fork experiment**

S.No.	Date	Experiment Done	Location	Remarks
1	22-12-2018	GPR Survey	At three different point Sankalp (3lines) Trijunction (2 lines) Point no. 9 towards novo station (2 lines at different parameters)	Snow fork experiment was also attempted but not much snow was available
2	24-12-2018	GPR Survey	Dozer point (2 lines)	
3	27-12-2018	GNSS experiment	Dozer point	
4	03-01-2019	GNSS, GPR	Near Novo station	
5	06-01-2019	Snow fork	Near Novo station	
6	23-01-2019	GNSS, GPR	Near Vattaiya point	
7	31-01-2019	GNSS, GPR	Near Novo station at ice shelf	
8	03-02-2019	GPR survey and Snow fork	GPR survey 13 kms and 7 kms west of Novo runway Snow fork experiment 7kms west of novo runway	
9	14-02-2019	GNSS	Priyadarshini lake	Data taken during 15-25Knots Wind speed
10	15-02-2019	GNSS	Priyadarshini lake	
11	24-02-2019	GNSS	Priyadarshini lake	Data taken during 0-10 Knots Wind speed
12	25-02-2019	GNSS	Priyadarshini lake	
13	26-02-2019	GNSS, GPR, Snow fork	7 kms west from Novo runway	
14	08-03-2019	GPR survey, DGPS	Dozer point 5 lines 1GHz and 500 MHz both	
15	12-03-2019	DGPS	Elevation measurement at 3 different points at icesheet and at CR location near MAitri station	
16	15-03-2019	DGPS	Location data at icesheet	Wooden plank was installed at icesheet for future CR deployment
17	16-03-2019	GPR survey	Icesheet 3 different locations South of Maitri 1GHz and 500 MHz both	
18	16-03-2019	DGPS	Elevation measurement at 3 different points at icesheet	
19	18-03-2019	DGPS	Contour profiling at GNSS-R point beside Priyadarshini Lake	
20	19-03-2019	DGPS		

6.0 Results and Discussions

6.1 Establishment of CR network for SAR calibration

The response of the deployed point targets was analysed and based on the image analysis suitable location for permanent set-up and future deployments were finalized. The response of CR in 21st January 2019 data can be seen in the figure-15. The point target response and impulse response function (IRF) in the range and azimuth directions are also shown below.

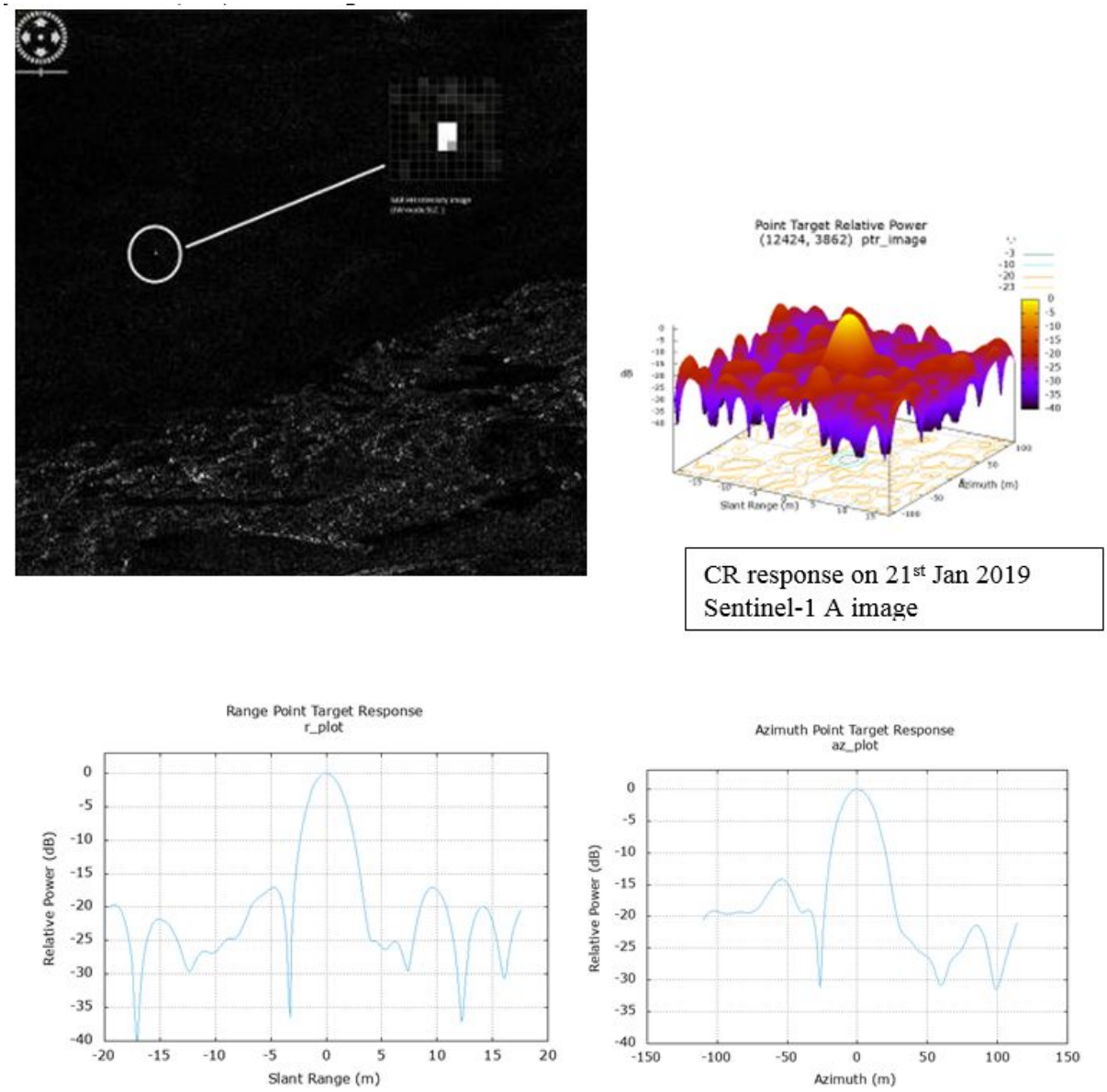


Figure 15: Response of Corner Reflector in the image and Impulse response function

CR response will be helpful in the calibration of the satellite data and Impulse Response Function (IRF) thus derived from CR response will be helpful in estimating the data quality of the SAR sensor. Spatial resolution of the SAR sensor is calculated from the 3-dB beam width of IRF in range and azimuth directions. The other parameters that are estimated from IRF is Peak-to-side lobe Ratio (PSLR), Integrated-side lobe-ratio (ISLR) in azimuth and range directions. The estimated Radar Cross Section (RCS) for CR deployed on 21st Jan 2019 data was estimated to be 31.97 dB. The difference between theoretical RCS and estimated RCS was found to be 2.46 dB.

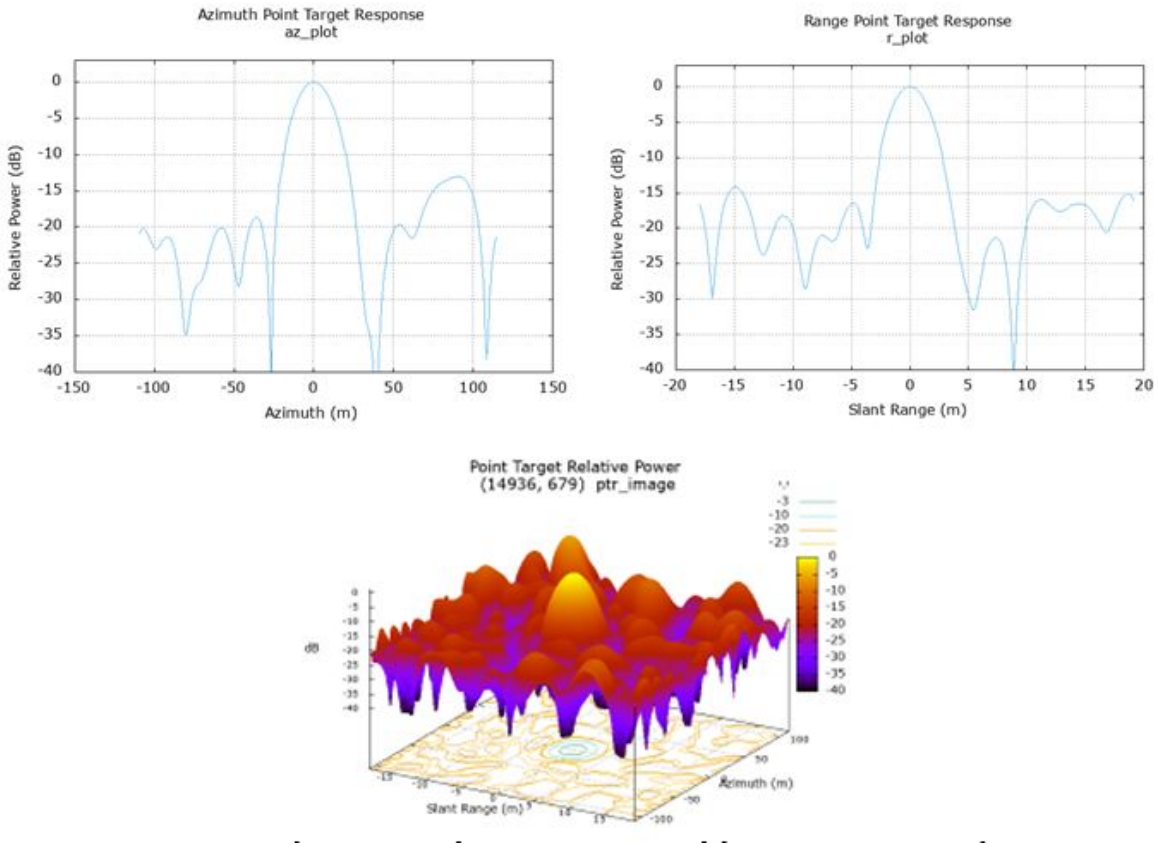


Figure 16: Impulse response function as computed from CR response in the image

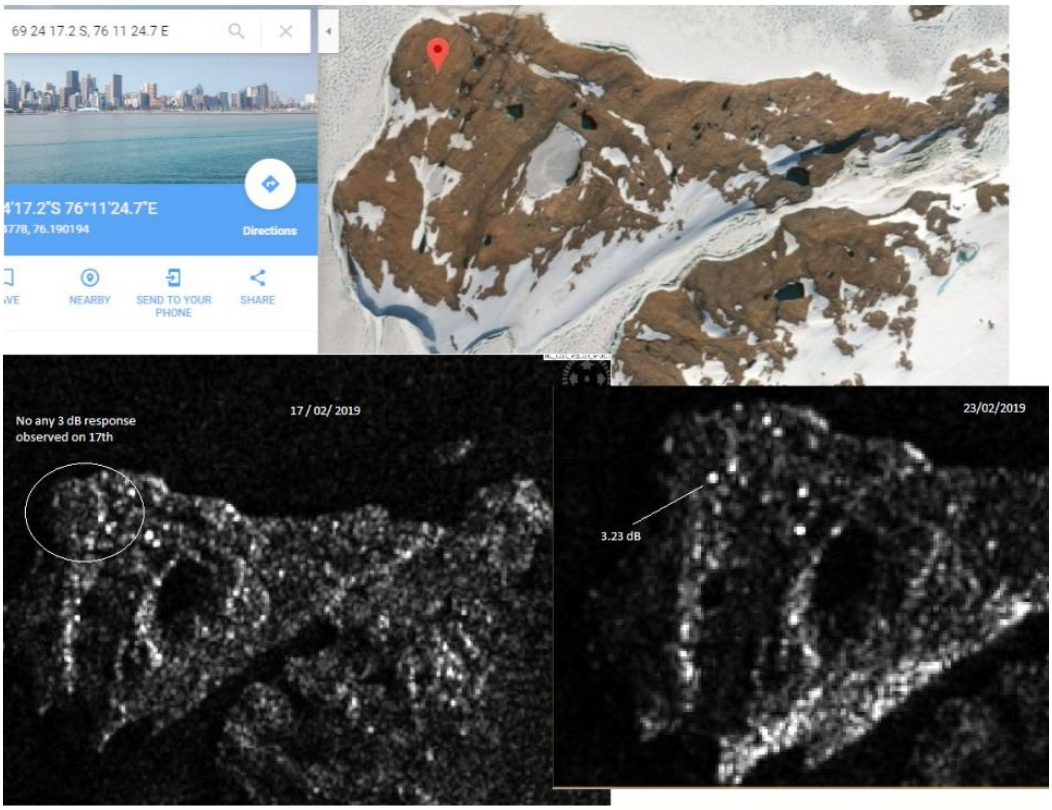


Figure 17: CR response deployed at Bharati in the image

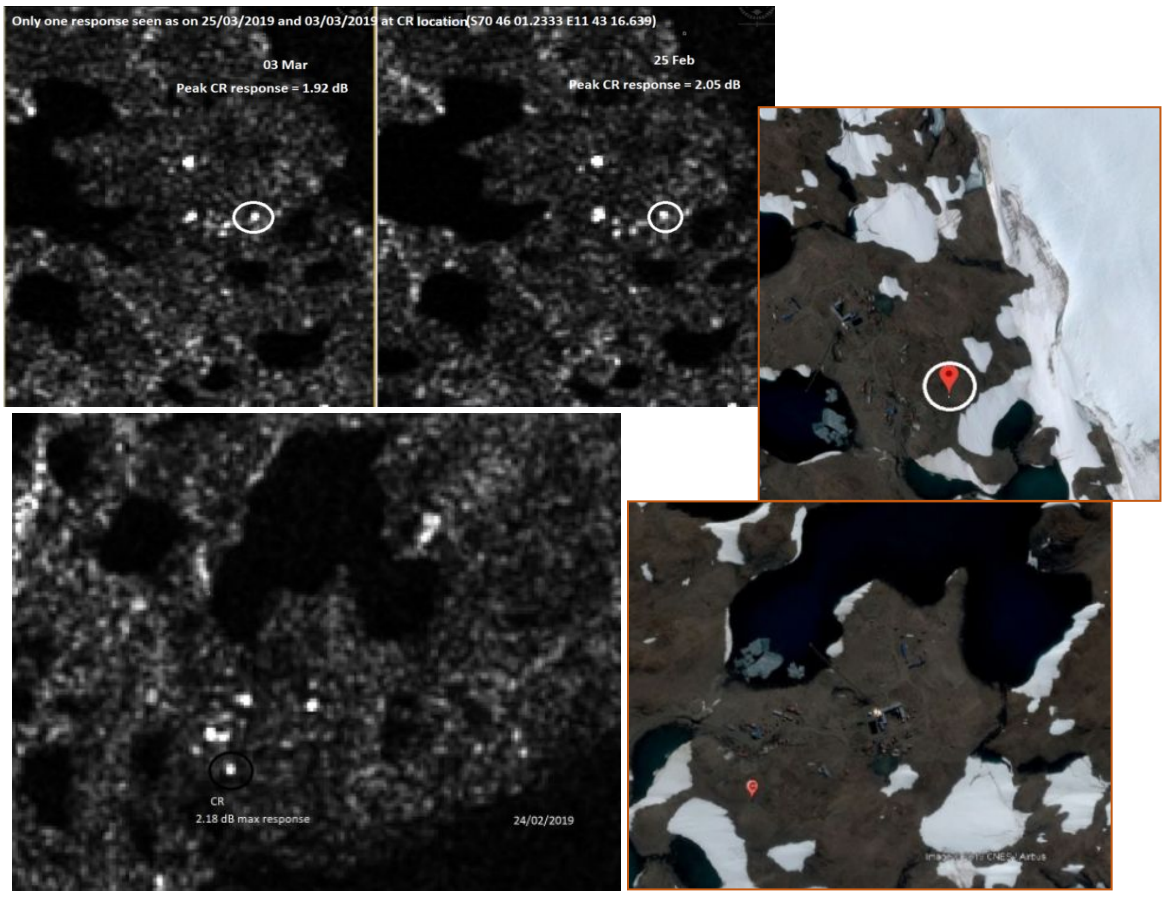


Figure 18: Response of Corner Reflector in the image on 24th Feb, 25th Feb and 3rd March at Maitri

The monitoring of CR response at Maitri and Bharti shows good results. At Maitri the CR response could be seen on the exact location of the CR deployments on 24, 25th Feb (2.05 dB), 2nd March (2.23 dB), 3rd March (1.92 dB) and 15th March (1.99 dB) (ref. Fig 7 & 8). But this time also no response observed at ARC location.

At Bharti the peak response of the installed CR was found to be 3.23 dB. It was found to be decreased by around 5 dB in 01 March S1A pass data at same location compared to 23rd Feb data. The reason is the old radome which was installed on 01 March.

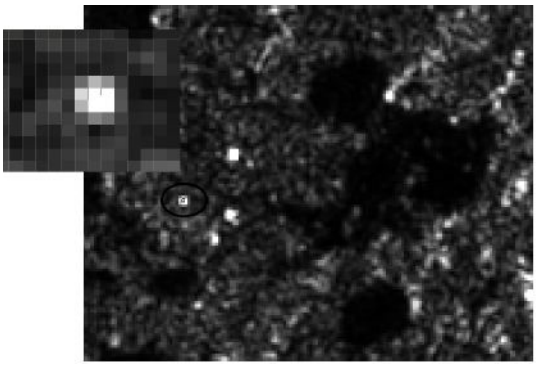
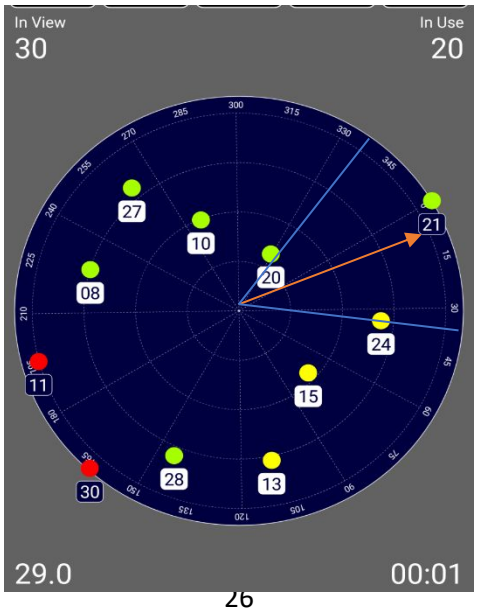


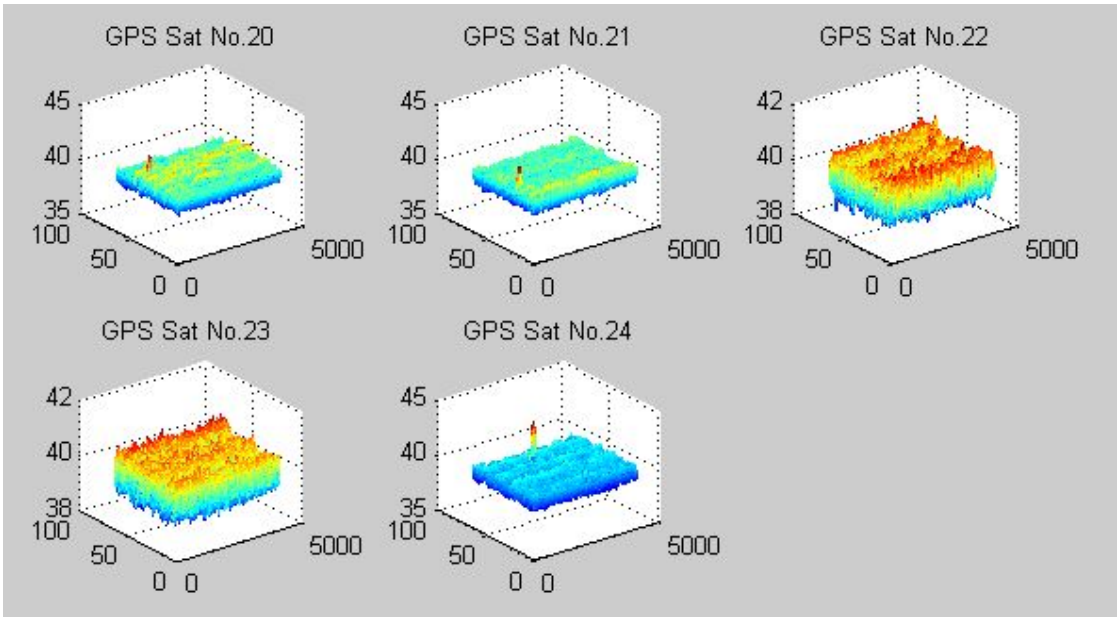
Figure 19: Response of Corner Reflector in the image on 15th March at Maitri

6.2 GNSS Reflectometry Results

The major results of the experiment are shown below:

a. The preliminary result of GNSS-Reflectometry shows most of the data are in good conditions and reflected satellites signals are locked properly.





The Sky plot shows the Azimuth of reflectometry antenna and the expected reflections of satellites of PRN no 21,20 and 24 , which is actually captured in the data, while PRN no 23 and 22 are not captured as expected. This is a sample data.

b. The input noise levels are showing a downtrend with time duration of observation in both the H and V channels, which is still a matter to be investigated.

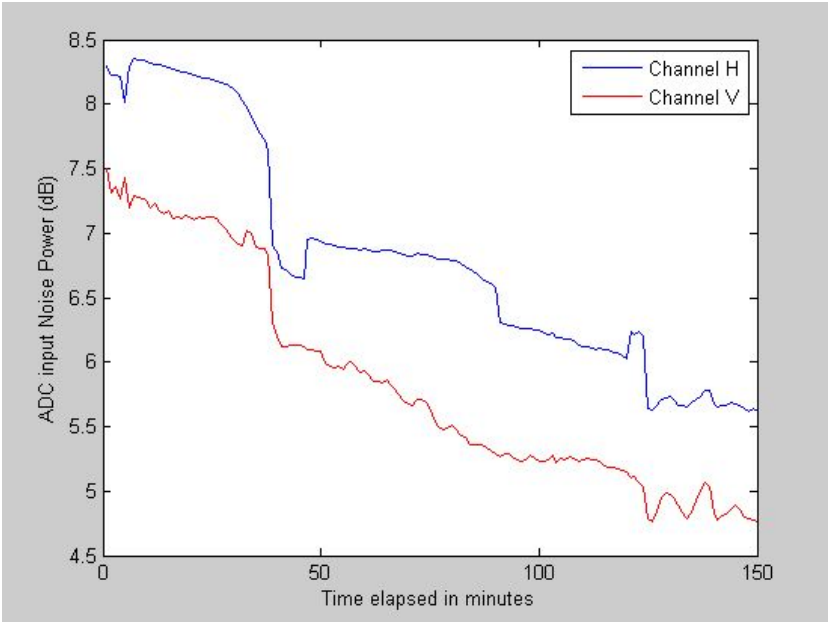


Figure 20: Output noise power of GNSS-R receivers' ADCs

c. The reflections from Snow surfaces captured by the direct looking RHCP antenna also shows clear indication of interference of direct signals and reflected signals. This is helpful for measuring snow properties with GNSS-R signals. More analysis is pending.

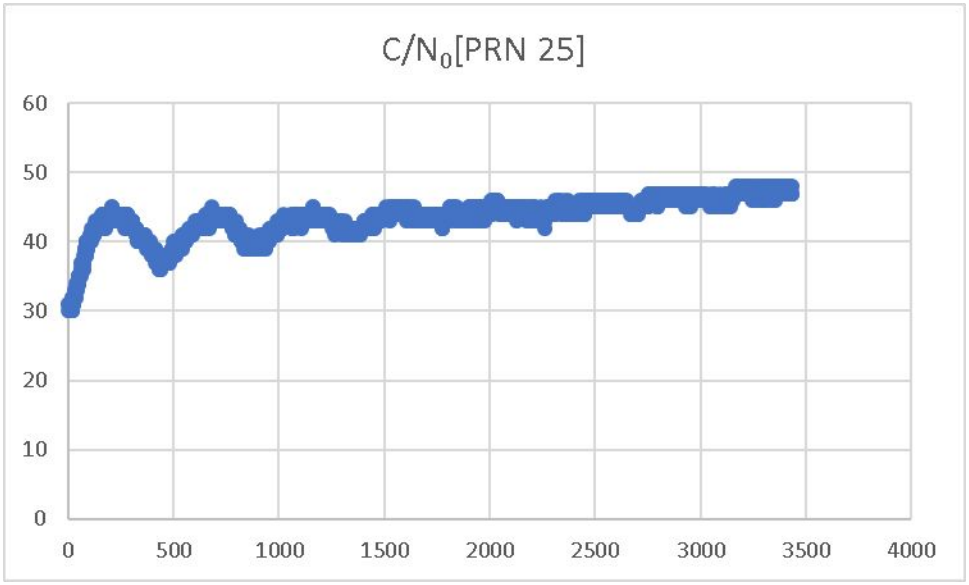


Figure 21: Interference pattern in C/N0 (SNR/BW) for satellite of PRN No 25

d. The GPR data of 500 MHz GPR is still to be processed. The following image is showing the data from The 3rd Feb GPR survey at the S-W of Novo Runway.

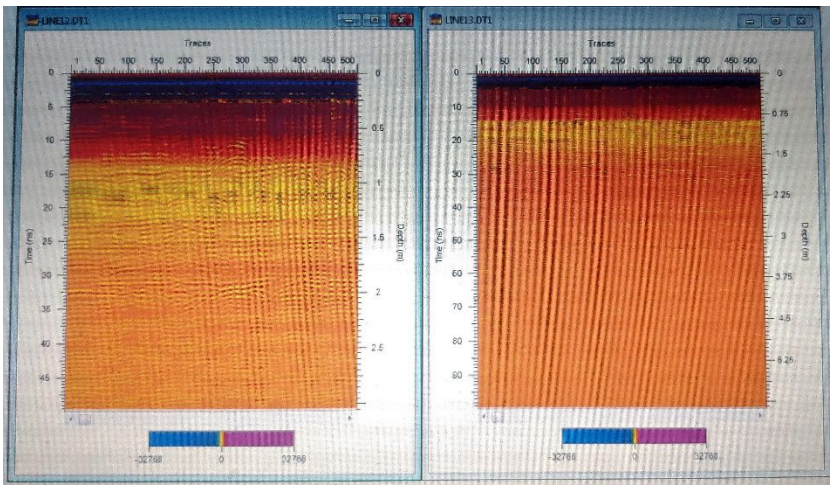


Figure 22: 1GHZ GPR data of 100ns (left) and 50 ns(right) time window for the same line

e. Up to 4 NavIC satellites were locked successfully at Maitri. Though due to low signal power the available software could not lock the position. NMEA Data has been recorded for post processing.

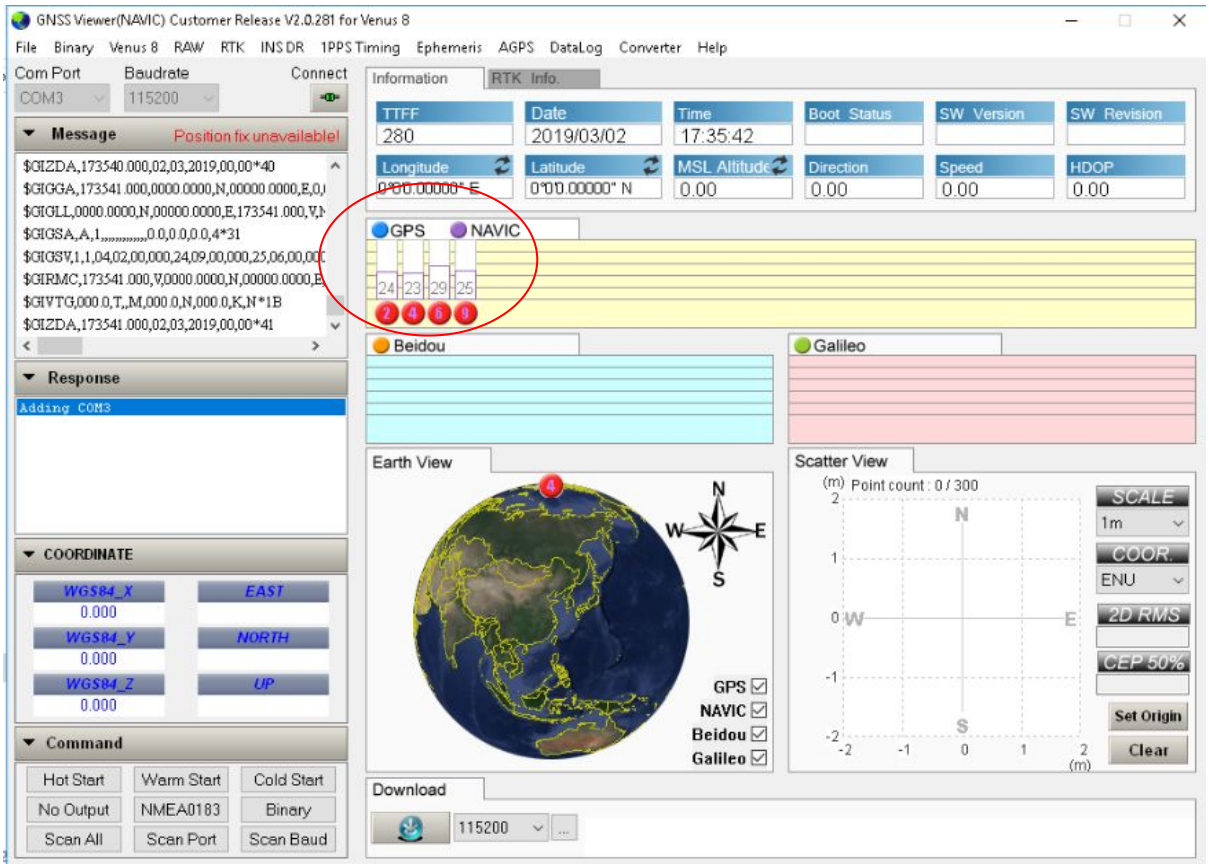


Figure 23: Detection of NavIC Signals at Maitri Antarctica

7.0 Summary and Conclusions

This report presents the stufies carried out during the thirty-eighth Indian scientific expedition to Antarctica. For the first time in the Indian history, Corner reflector (i.e. CR) was deployed in Antarctica and permanent SAR calibration site was established. The site near Maitri and Bharati stations were chosen for the permanent set-up. For the future deployment of CRs for across-swath absolute calibration, site survey was carried out in the surroundings of Maitri and four points were selected. Reflector was deployed at the icesheet towards East of Maitri and after analysing its response and background power, one point was finalized and a wooden plank was installed at that site. Differential Global Positioning System (DGPS) data was also recorded at that point for getting the accurate location. Permanent deployment of the CR at the selected sites is planned in the next expedition. Survey and testing of more sites by deploying point targets for the establishment of point target network for SAR calibration and ice velocity estimation will also be taken in 39th ISEA. GNSS reflectometry experiment was carried out at six different locations with different settings for ice sensing with synchronous

GPR and snow fork experiment. For wind sensing, the set up was installed near Priyadarshini lake in high and low wind conditions. As all the data are yet to be analysed to details, the proof of concept of Ice sensing through reflected GNSS signals is still pending. Once the science is proved or optimistic results are found out, more refinements can be done in order to achieve better sensitivity with GNSS-R instrument and find more data points with Snow top of more than 500m Ice surface. Ground Penetration Radar survey was also carried out at different locations with 1 GHz and 500MHz frequency set up. Elevation data at six different points at the icesheet was also taken to validate the technique developed at SAC to derive surface elevation product using space-borne altimeter. Almost all the objectives corresponding to the 38 ISEA have been met. Only elevation data at two points could not be taken due to bad weather. Establishment of permanent SAR calibration site at Antarctica can be considered the major achievement of this expedition as with this, India joined the league of few countries that have permanent CR set up in Antarctica. Once operational, this CR network will be useful for Synthetic Aperture Radar (SAR) calibration and ice movement study using advanced Differential Interferometric SAR (DInSAR) technique.

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We express our heartfelt gratitude to the concerned persons in European Space Agency for agreeing to our special request for arranging the regular satellite pass of Sentinel-1 A and 1B at 10 m resolution over Maitri and surroundings for calibration work.

This list will be incomplete without mentioning all the logistics and scientific team members of 37 & 38 ISEA along with the voyage team for their constant support throughout the duration of work.

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