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Analysis of Polarization Ratio of Greenland Ice Using L-Band ALOS PALSAR Data

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Abstract:

L band ALOS PALSAR radar sensors data are available for studying terrestrial surfaces. Polarization products like Linear Polarization Ratio (LPR) and Circular Polarization ratio (CPR) derived from Stokes Parameters utilizes the horizontally and vertically polarized received signals from the targets. LPR and CPR values for ice and water can be computed from the terrestrial surface covering ice deposits over Greenland and water bodies like fresh water lakes rivers, oceans etc. In the present study, LPR values are derived from Greenland ice sheets from L band datasets. LPR values of ice from different datasets of Greenland are observed to have similar LPR values irrespective of incidence angle.

Keywords **— Greenland, LPR, incidence angle, planets.**

I. INTRODUCTION

Vast stretch of ice capped, world's largest non-continental glacier Greenland is located between Arctic Ocean to its north and Atlantic Ocean to its south and Canada to its West [1]. It is geographically, located at 59° to 83°N latitude and 11° to 74°W longitude. The ice sheet coverage over Greenland is 1,755,637 km^2 (about 81%) out of the total area of Greenland which is 2,166,086 km^2. The total volume of ice mass is 2.6 x 10^6 km^3 [2]. Most of the landmass of Greenland is more than 1,500 m in height where Gunnbjorn Fjeld is the highest point at an elevation of 3,700 m. The central portion of Greenland is depressed forming a basin lying 300 m below mean sea level due to overlying weight of ice sheet. The coastal bedrock region is at higher elevation than central region. The flow of ice is from central portion towards coastal region [3]. Except for the outer areas, Greenland is covered by thick ice as shown in Fig. 1. The range of thickness of ice shown in Fig, 1 is from 10 m to 3205 m above bed rock and mean sea level. Being covered by thick ice deposits, it could be an experimental ground for ice related studies, which can be modeled for planetary surfaces like Moon, Mars etc. From the available topographic maps, ice thickness map and the observed results, it is also possible to predict the expected radar penetration for ice.

The Greenland ice sheet contains nearly 3 million cubic kilometers of glacial ice. If the ice melts, the sea level would rise by 7 meters across the globe [4]. Fig. 1(a) is the Greenland bedrock map above mean sea level (msl). Fig. 1(b) shows the thickness of Greenland ice above the bedrock and msl.

Information content in an image can be represented, mathematically in terms of four stokes parameters S_1, S_2, S_3 and S_4 [5, 6] and are defined as, $S_1 = |E_H|^2 + |E_V|^2$, $S_2 = |E_H|^2 - |E_V|^2$, $S_3 = 2\,Re\,\langle E_H E_V^* \rangle$ and $S_4 = -2Im\langle E_H\ E_V^* \rangle$. First stokes parameter represents, total power (or total intensity) of received, polarized, horizontal and vertical components of electromagnetic field (EM) and is the sum of horizontal and vertical components. Second stokes parameter is the difference between the two polarized components. Third stokes parameter is the cosine of the average phase between the two components and the fourth stokes parameter is sine of the average phase between the two components [7]. It can be represented in terms of co-polarized HH (horizontal transmit and

horizontal receive) and cross-polarized HV (horizontal transmit and vertical receive) bands of ALOS Advanced Land Observing Satellite) PALSAR (Phased Array type L-band Synthetic Aperture Radar), where Band1 is the horizontal portion of received EM field (i.e. HH), Band 2 is the vertical portion of received EM field (i.e. HV) and δ is the phase difference between HH and HV. This can be represented in terms of bands of microwave radar data as S1= Band1 + Band2, S2= Band + Band2, S3 = 2*Band1$^{1/2}$ * Band2$^{1/2}$* $\cos\delta$ and S4 = −2 * Band1$^{1/2}$ * Band2$^{1/2}$ * $sin\ \delta$ [6].

Polarization products like Circular Polarization Ratio (CPR) derived from Same Sense Circular Polarization (SC) and Opposite Sense Circular polarization, Degree of Polarization (m) [7], Linear Polarization Ratio (LPR) etc. are calculated as SC = 0.5*$S1$ – 0.5*$S4$, OC= 0.5*$S1$ + 0.5*$S4$, $CPR = SC / OC$, $m = (S_2^{\ 2} + S_3^{\ 2} + S_4^{\ 2})^{1/2} / S_1$, $LPR = (S_1 + S_2) / (S_1 - S_2)$. CPR is extensively used for study of planetary ice [8]. To obtain the LPR value of Greenland ice LPR is found to be suitable.

II. STUDY AREA AND DATASETS

Eight L-band ALOS PALSAR datasets of distinct locations of Northern Greenland is acquired from Alaska Satellite Facility [9] to study the LPR ratio effects over ice sheets of Greenland and its possible application over planetary surfaces like Moon and Mars. The details of datasets are shown in Table 1. An area of more than 1000 m of ice thickness is chosen to study the effects of penetration capability of L-band SAR on ice landmass, the information of which is obtained from Fig. 1(a) and 1(b).

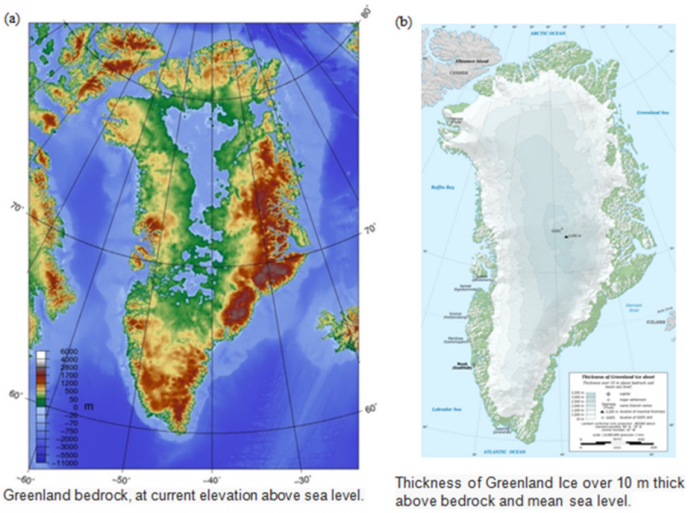

Fig. 1 Bedrock and thickness map of Greenland ice cover [10]

TABLE I
DETAILS OF DATASETS OF L- BAND ALOS PALSAR

Datasets	Date/Time	Latitude/ Longitude	Incidence angle (degree)
ALPSRP080221600	28/07/2007 00:31:36	79°23′ N, 50°55′ W	38.77
ALPSRP080221590	28/07/2007 00:31:28	78°55′ N, 50°11′ W	38.77
ALPSRP081971600	09/08/2007 00:27:17	79°22′ N, 50°06′ W	38.78
ALPSRP078761610	18/07/2007 00:18:53	79°49′ N, 48°57′ W	38.76
ALPSRP060381520	14/03/2007 00:13:26	74°59′ N, 47°48′ W	23.89
ALPSRP149061630	10/11/2008 22:47:44	79°45′ N, 39°20′ W	23.93
ALPSRP150961580	23/11/2008 23:23:46	77°40′ N, 41°22′ W	23.89
ALPSRP059501530	07/03/2007 23:26:21	75°27′ N, 36°52′ W	23.87

III. METHODOLOGY USED

The step by step methodology to study LPR values of L-band from thick ice cap in the northern portion of Greenland is shown in the flow chart of Fig. 2. Preliminary analysis of the images is done in ENVI software. Stokes Parameters are calculated from the bands. The L-band ALOS PALSAR images of the study locations are overlaid over Google Earth image of the same locations.

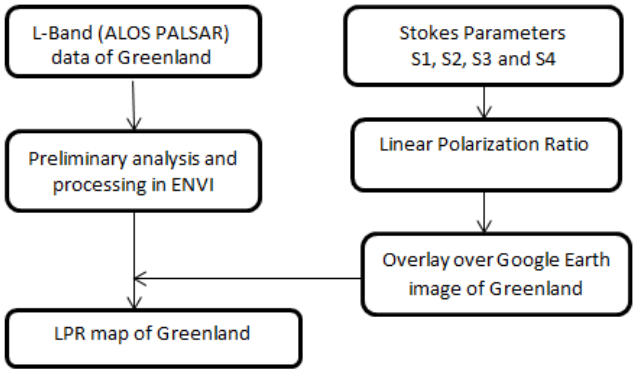

Fig. 2 Methodology to study LPR values of L-band for Greenland ice sheets

IV. RESULTS AND DISCUSSION

Eight different datasets from different locations of Northern Greenland are analyzed for polarization products like CPR, LPR derived from Stokes parameters are shown in Fig. 3 and Fig. 4. Fig. 3 is the co-polarized HH band of ALOS PALSAR, which is the horizontally received polarized EM signal. Derived products CPR and LPR, are applied to the original datasets where HH (horizontal transmit and horizontal receive) is band 1 and VH cross polarized (horizontal transmit and vertical receive) is band 2.

LPR values recorded from different locations of Greenland are observed to lie towards higher side and in many case these are above 4.5 values with mean value of LPR around 4.2. Some images show all the three representations of LPR values form lowest to higher values. This region could be one of the hot spot regions, having a subsurface volcano. These locations have lower LPR values. Since water is melted on both sides, a water storage reservoir is created below ice sheets.

A parameter linear polarization ratio of horizontal received power and vertically polarized signal is studied for the chosen samples. Sample 3 image is studied in details as it shows various criss-cross line, unexpected to be observed on the surface. Google map of Greenland of the same location, shows white colour. The difference of the same location as observed from Fig. 1 is approximately 1000 m. When the same location is observed in L-band SAR ALOS PALSAR data, the criss-cross lines are visible, showing the exposed bed rock and the potential of L-band signal to penetrate deep in to the thick ice deposits up to 1000 m.

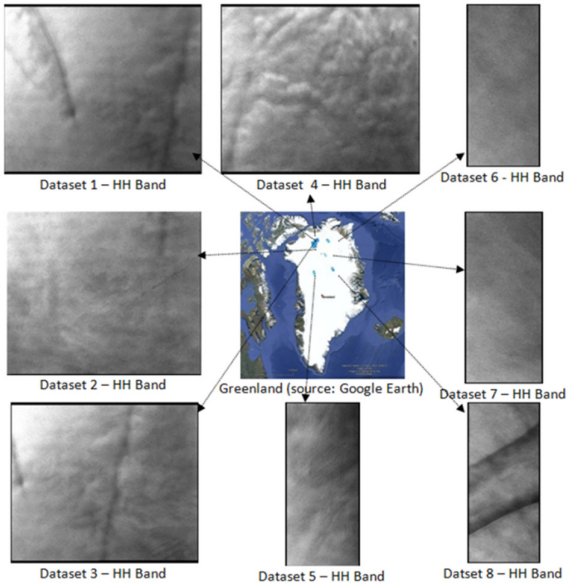

Fig. 3 Datasets (HH band) from 8 different locations over Greenland (Source: Google Earth, Alaska Satellite Facility)

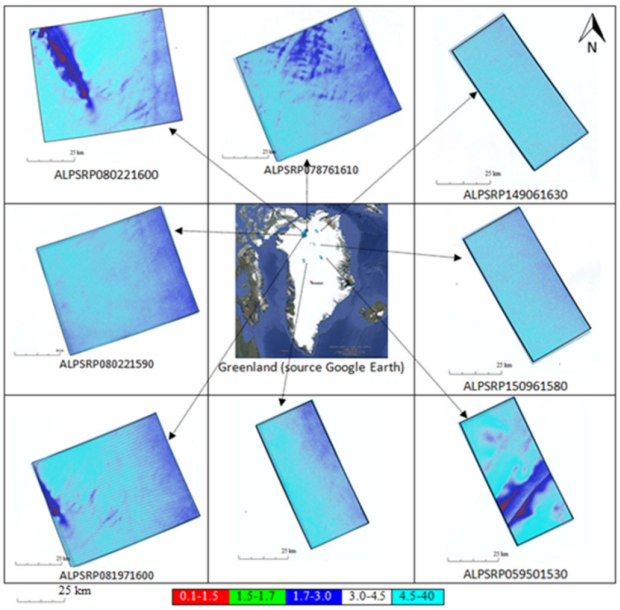

Fig. 4 Results from datasets from Greenland (datasets overlaid over Google Earth)

Table 2 shows linear polarization ratio values of 3 sample locations from north eastern portion of Greenland. These values are very higher as compared to values obtained from drier locations like Sahara (Africa), Thar (Rajasthan, India), Barringer Crater of Arizona, Ramgarh crater of Rajasthan near Kota, Lonar crater of Maharashtra and fresh water lakes like Wular lake, Dal lake (Jammu and Kashmir), Mansarovar lake (Himalaya). All these locations give different values of LPR.

A sample size of 10,000 pixels is taken to consider the pure ice pixels. Fig. 3, shows the images with multiple pixels related to ice, water and some unexpected feature which lowers the LPR pixel values. Table 3 gives the LPR values of ice for four datasets. The mean LPR value obtained for pure ice pixels is 4.69 which is much higher as initially considered for ice.

TABLE III
MEAN LINEAR POLARIZATION RATIO (HH/HV)

Datasets	Mean Elevation (above msl)	Minimum LPR	Maximum LPR	Mean LPR	Std. Dev LPR
ALPSRP080221600	1980 m	0.32	36.84	4.03	1.44
ALPSRP080221590	2163 m	0.34	32.46	3.97	1.26
ALPSRP081971600	2036 m	0.36	34.59	4.16	1.39
ALPSRP078761610	1956 m	0.29	33.29	3.77	1.29
ALPSRP060381520	2644 m	0.42	29.75	4.28	1.30
ALPSRP149061630	2087 m	0.67	28.15	4.35	1.19
ALPSRP150961580	2497 m	0.52	31.92	4.13	1.16
ALPSRP059501530	2718 m	0.39	38.63	4.27	1.65
		Overall LPR Mean = 4.12			

TABLE IIIII
MEAN LPR VALUES FOR 10,000 PIXELS FOR FOUR DATASETS

Datasets	Mean Elevation (above msl)	Minimum LPR	Maximum LPR	Mean LPR	Std. Dev LPR
ALPSRP080221600	1980 m	1.30	14.43	4.62	1.31
ALPSRP080221590	2163 m	0.92	19.16	4.27	1.25
ALPSRP081971600	2036 m	1.28	17.24	5.11	1.48
ALPSRP078761610	1956 m	1.56	16.17	4.75	1.42
Overall Mean (datasets) = 4.69					

Fig. 5 shows the distribution curve for 10,000 pixels from four datasets, which is approximately similar for all the four datasets. In summer months, maximum temperature of Greenland rises to 10℃, which creates a layer of water over Greenland, the colour of which looks like blue sapphire (source: http://www.livescience.com/49519-greenland-new-subglacial-lakes-found.html), thereby increasing the dielectric constant of medium and reducing the penetration capability of L-band radar signal. LPR value obtained in such cases is lowered and is close to water as is shown in Fig. 4, however LPR values again rises in winter months. Ice also melts after intense summer rainfall where LPR value is lowered. Hence dry ice has higher values for LPR, but a melted ice will have lower LPR.

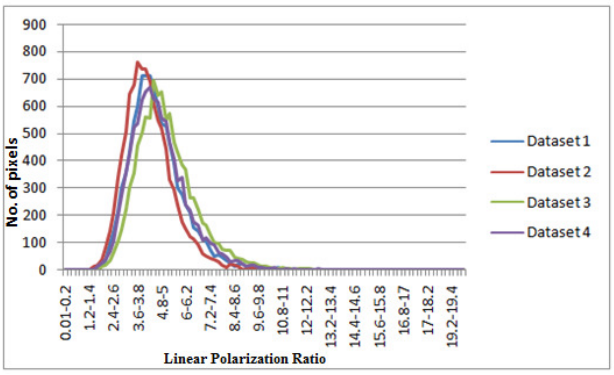

Fig. 5 Distribution curves for 10,000 pixels from four datasets

It is observed at some locations, where the LPR values are on the lower side, the water pixels covers larger area, indicating the potential existence of hot spots, which could be due to hot volcanoes or any hot geysers or geothermal springs.

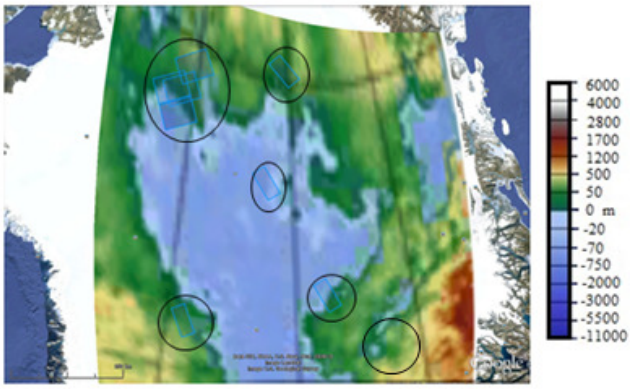

Fig. 6 Topography map of Greenland overlaid over Google Earth

Topography map of Greenland (source: https://en.wikipedia.org/wiki/Greenland) is overlaid over Google Earth image (Google Earth) to observe the topography of the selected images over bedrock.

TABLE IVV
OBSERVABLE PENETRATION DEPTH OF FOUR DATASETS (SOURCE: GOOGLE EARTH)

Datasets	Maximum elevation (msl)	Maximum observable depth	Depth of signal penetration (approx.)
ALPSRP080221600	1980 m	50-250 m	1730- 1930 m
ALPSRP081971600	2036 m	50-250 m	1730- 1930 m
ALPSRP078761610	1956 m	250- 1200 m	756-1730 m
ALPSRP059501530	2718 m	250	2468 m

The maximum elevation values are obtained from Google Earth and the observable depths are observed values from topographical map of Figure 6 from the locations of datasets. Fig. 6 shows that L-band signal can penetrate more than 1000 m in ice unless obstructed by a layer of water body.

As volcanoes would be on peaks hidden under thick deposits of ice sheets, the observable depth of the datasets is tabulated in Table 4. Hence from the elevation information of the datasets and maximum observable depth, based on the visibility of features, the maximum depth of penetration of L-band signal can be observed to upto 2500 m. Hence, L-band and possibly the higher P band are capable to map the topography below the thick deposits of ice of Greenland and Antarctica.

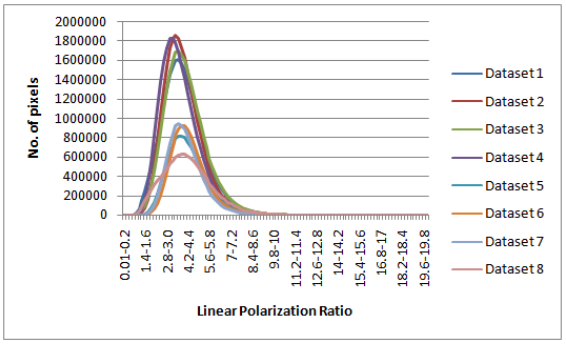

Fig. 7 Linear Polarization ratio for all the 8 datasets

Datasets 1 to 4 have more number of pixels than datasets 5 to 8, but they have approximately similar mean LPR value. The incidence angle of datasets 1 to 4 and 5 to 8 is approximately 38° and 23° respectively. Hence change in incidence angle does not have any effect on LPR value of ice. Fig.7 shows the distribution curves for all the eight datasets, with overall mean value of 4.12.

V. CONCLUSIONS

From above observation, it is clear that the elevation values of ice sheets vary from the 111 m to 1385 m, clearly showing undulations over the ice capped Greenland. From the comparison of three key maps viz. bedrock map of Fig. 1, ice thickness map of Greenland in Fig. 1 and the analysis of L-band Images suggests the possibility of penetration of L-band signal more than 1000 m in ice. As the values of polarization ratio is extremely higher in Greenland , this analysis is useful to discriminate water, ice and drier region on planetary surface like Moon, Mars, Saturn and other planets and their satellites. L-band penetrates into ice and dry surface at a considerable depth. The observed value of LPR for pure ice is obtained as 4.69. The LPR value in conjunction with LPR value of water and fresh craters can be extended to study planetary surface.

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