EXAMINING FROZEN WATER RESERVES IN MOON'S SOUTH POLAR CABEUS CRATER USING CHANDRAYAAN-2 DFSAR DATA.

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Introduction: The polar regions of the Moon, known for their cold traps or permanently shadowed regions (PSRs), have garnered significant interest due to their capacity to preserve volatiles over prolonged geological periods [1]. These PSRs, typically cooler than 120K, are primarily found near the lunar poles, a consequence of the Moon's minimal axial tilt of about 1.5° and the considerable topographical variations in these polar areas [1, 2]. Recognized as crucial sites for volatile storage, these areas have become focal points for detailed mapping and measurement in recent lunar exploration missions [3, 4]. Notably, missions such as the Lunar Reconnaissance Orbiter (LRO), equipped with the Miniature Radio Frequency (Mini-RF), Chandrayaan-1 featuring the Miniature Synthetic Aperture Radar (Mini-SAR), and Chandrayaan-2 carrying the Dual Frequency Synthetic Aperture Radar (DFSAR) have played a pivotal role in enhancing our understanding of the Moon's polar regions [4-6]. These instruments, each a sophisticated payload, have provided detailed microwave radar imagery, crucial for advancing the mapping and exploration of lunar polar landscapes, thereby offering valuable insights into the Moon's geology and potential resources. Results from the LRO Mini-RF and Chandrayaan-1 Mini-SAR have been crucial for mapping water-ice on the lunar poles, both on the surface and subsurface. However, their utility has been constrained by several factors, including lower resolution (75m for both Mini-RF and Mini-SAR), challenges in interpretation due to parallax error, complexities in deciphering scattering mechanisms, and the absence of corroborative ground truth data [7, 8]. These limitations have sparked ongoing discussions regarding the detection and measurement of lunar water-ice using SAR methodologies.

In this study, we focus on the identification of water-ice deposits in Cabeus crater region by analyzing Permanent Shadow Regions (PSRs) using Circular Polarization Ratio (CPR) and Degree of Polarization (DOP) at a spatial resolution of 11.47500 m × 19.986164 m (range × azimuth).

The identification of water-ice, was primarily limited to the high value of CPR (greater than 1). CPR, a key parameter used for radar based water ice detections, is calculated by comparing the same-sense (SC) polarization to the opposite-sense (OC) polarization. Though CPR serves as an important tool for assessing the presence of water-ice, its higher values are also found to be associated with surface roughness [4, 9-11]. Therefore, in this work, we use DFSAR data and derive CPR at and around Cabeus along with DOP parameters in order to examine water ice deposits. The DOP parameter provides additional constraints as explained by Raney et al., 2012 [12] and Verma et al., 2020 [13]. DOP is an indicator of the extent of polarization of the radar signal, which varies depending on the surface characteristics it reflects off. Water-ice, known to result in a lower DOP, signals volume scattering from icy particles [8, 13, 14]. This aspect of the DFSAR data is crucial in identifying and confirming the presence of water-ice on the Moon's surface.

Data Description and Method: The DFSAR operates at frequencies of 2.38 GHz in the S-band and 1.25 GHz in the L-band. It has a carrier frequency range of 75-2 MHz [4]. The acquisition duration for data is set at 2 minutes, covering a swath of 10 kilometers. The DFSAR system features four channels. In terms of polarization, the transmission is done using linear polarization, and the reception utilizes four polarizations, respectively, the power output for the system is 40 W in the S-band and 45 W in the L-band. The altitude of operation for DFSAR is around 100 kilometers. The resolution of the data captured by DFSAR varies from 2 to 75 meters per pixel [4].

The initial data stage, referred to as Level-1, consists of a Single Look Complex (SLC) image. downloaded from the ISRO Science Data Archive (https://pradan.issdc.gov.in/ch2/). The SLC data product is comprised of two distinct elements: the real and the imaginary parts. Subsequently, Level-1 A represents a multi-look image, while Level-1 B involves an image converted to ground range. At Level-2, the data advances to a ground range image that includes georeferenced details. Essential processing stages for this data involve techniques like multilooking, orthorectification, and radiometric calibration. After data corrections, CPR and DOP have generated using the mathematical formulation given in paper [4, 5].

Our study involved a thorough analysis of two lunar craters (Covering the Cabeus crater location) as shown in Figure 1, named as R1 (center latitude: -83.90°, center longitude: -21.93°) and nearby crater R2 (center latitude: -87.58°, center longitude: -47.41°), distributed over south pole. These craters have been the subject of previous research using Mini-SAR, Mini-RFand DFSAR data sets [3, 7, 15]. The intent behind selecting these craters is to corroborate our findings with those previously reported. In our analysis, we marked the interior and exterior areas of these craters in yellow and red, respectively, to delineate regions for deriving DFSAR-based parameters like CPR and DOP.

Results: To explore a possible link between CPR and DOP, we conducted a statistical examination. We extracted values of both CPR and DOP from within and around the craters at R1 and R2 locations, as illustrated in Figure 1. Our analysis, depicted in Figure 1, indicates that the average CPR (Figure 1(a)) values inside and outside the craters generally remain under one, with outliers comprising less than 2% of the data. Simultaneously, the average DOP (Figure 1(b)) values for these craters stand above 0.35. Further scrutiny of the outliers revealed a tendency for high CPR values to occur on the steep inner slopes of the craters. Based on these observations, our study suggests that the heightened CPRs in polar anomalous craters are more likely influenced by factors such as surface roughness, rather than being exclusively indicative of water-ice presence. This conclusion aligns with the findings of Eke et al., 2014 [16] and Fa and Eke, 2018 2018 [7], who also reported similar observations in polar anomalous craters using Mini-SAR and Mini-RF SAR data, respectively.

Conclusion: The study yielded several significant insights. Firstly, the CPR values, barring anomalies, consistently fell below 1, implying a lack of substantial increase in similar sense polarization. This finding suggests the absence of evident pure water-ice deposits in the craters. Moreover, the average DOP values, being above 0.5, pointed towards the lack of volume scattering in these areas. Additionally, our analysis uncovered a negative correlation between CPR and DOP, a pattern typically not associated with the presence of water-ice. This study holds significant implications for future lunar missions. It enhances the understanding of the lunar surface's scattering properties, which is crucial for improving the precision and interpretation of radar measurements. Looking ahead, we intend to integrate data from the Chandrayaan-2's Imaging IR Spectrometer (IIRS) to bolster our capability in identifying potential water-ice deposits.

Acknowledgments: The authors extend their heartfelt gratitude to the Physical Research Laboratory in Ahmedabad for the essential data analysis resources they provided. We are thankful to the Indian Space Research Organization (ISRO) data archival center and the NASA Planetary Data System (PDS) for their generous provision of DFSAR data, along with LOLA DEM and LRO WAC data, available freely to the public.

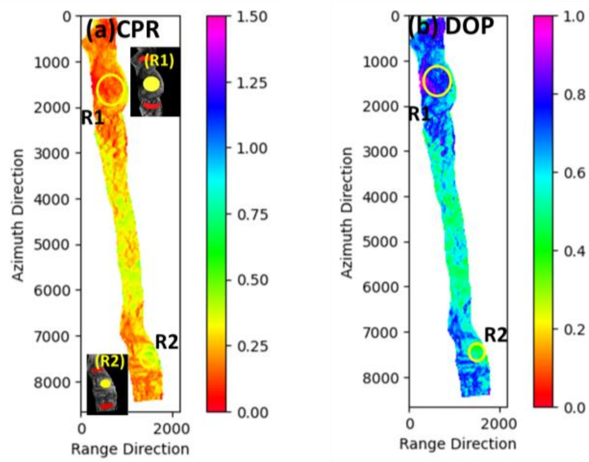

Figure 1 Maps derived using DFSAR strip id ch2_sar_ncxl_20191019t215745372_d_sli_xx_fp_xx_d18 that covers Cabeus crater; (a) CPR; (b) DOP

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