MULTIPLE SUN-ANGLE AIDED CRATER MORPHO-DYNAMICS AND VARIATION OF LOMMEL SEELIGER CORRECTED RADIANCE FACTOR WITH RESPECT TO PHASE ANGLES USING TERRAIN MAPPING CAMERA ONBOARD CHANDRAYAAN- 1 & 2. A.S. Arya[1*], Arup Roy Chowdhury[1], Amitabh[1], K. Suresh[1], Ajay Prashar[1], Ankush Kumar[1], Vishnu Patel[1], Rohit Nagori[1], Shubham Gupta[1], Sugali Sekhar Naik[1], S Gomathi[2], Vijaysree[2], [1]Space Applications Centre, Indian Space Research Organisation (ISRO), Ahmedabad-380015, India, [2]U. R. Rao Satellite Centre, ISRO, Bengaluru – 560017, India. (*arya_as@sac.isro.gov.in).

Introduction: Terrain Mapping Camera 1 and 2 (TMC 1 and 2) are panchromatic cameras with nearly identical specifications and have 5m spatial resolution with stereo imaging capability, i.e., images in three views of Fore, Nadir and Aft (+25°, 0°, -25°), and thus provides "multi-view angle" radiance measurements. TMC-2 acquired low sun elevation angles' images which when combined with TMC-1 data (high sun elevation angle) provided an opportunity to study Lunar surface at variety of phase angles for crater-ejecta characteristics [1] & photometric properties of the Lunar surface [2][3][4]. This study aims at understanding the effects of high & low sun elevation angles for mapping proximal & distal ejecta, its orientation and distribution pattern to understand impact dynamics as well as the variation in topographically corrected radiance factor (RADF) with respect to phase angles assuming the material to be similar in region.

Data: TMC-1 and TMC-2 images acquired on 5 January, 2009 and 15 October, 2019 respectively have been used in this study. Data set contains radiance/count images for all three views along with ortho-rectified Nadir image, Digital Elevation Model (DEM) image and files containing latitude-longitude and sun parameters information. Selective areas of interest from TMC-1 and TMC-2 images with varying sun elevation angle have been extracted. Figure 1 showing Region 1 (crater centered around of 53.52° E and 1.40° S) has been acquired by TMC-1 and TMC-2 at sun elevation angles of 70.46° and 15.03° respectively. Figure 2 showing Region 2 (crater centered around 53.69° E and 0.326° S) has been acquired by TMC-1 and TMC-2 at sun elevation angles of 70.79° and 15.13° respectively.

Methodology: TMC-1 and TMC-2 radiance images (Region 1) were seleno-referenced and co-registered with respect to TMC-2 ortho-rectified image. Topographically corrected incidence and viewing zenith and azimuth angles along with phase angles were generated on each pixel. Subsequently, RADF corrected using Lommel-Seeliger (LS) was computed and plotted against phase angles assuming material to have similar properties (Figure 2) in order to see the variations. As the study was carried out over a very small region providing an incomplete range of phase angles, fitting of photometric models was avoided. A marked difference is seen between the two images due to the differences in illumination setting over the area. TMC-1 image (Region 2) was used to map the crater ejecta (proximal and distal) and crater rim because of better contrast between ejecta materials and its surroundings. Similarly, boulders around the crater (Figure 3 & 4a) were mapped using their long shadows due to low sun elevation angles. A rose diagram for boulder distribution is plotted (Figure 4b).

Results and Discussion: The low sun elevation angle image (TMC-2) has long object-shadows thus aiding in additional feature identification in comparison to high sun elevation angles images with no object-shadows. The plot (Figure 2) between LS corrected RADF with respect to phase angles also shows a large surge in intensity at low phase angles (due to the opposition effects) thus increasing the dynamic range of count causing the high intensity value areas to appear extremely bright in contrast to its surrounding and as a result diminishing the distinguishability of other features (TMC-1 image). The crater's rim and other units are delineated from both the images (Figure 3) which is more or less circular in shape. The diameter of crater is 0.5 km and high reflectance of this small crater suggests a young age. Two types of crater's ejecta are delineated i.e., 1) Proximal ejecta (< 5 times of crater radius) surrounding the crater with very high reflectance and loose agglomeration and 2) Distal ejecta (> 5 times of the crater radius) (Figure 3 & 4a). It is observed that the proximal ejecta has a "forbidden zone" (minimal ejecta spread) towards west/south-west of the crater suggesting it to be the uprange direction & north/north east side as downrange. The skewness of ejecta distribution suggests that the crater is a result of an oblique impact. The distal ejecta is mostly distributed uniformly with a faint preference along the Northwest & South west of the crater. The low sun-angle in TMC-2 image formed longer shadows thus highlighting the boulders. Total 51 boulders are mapped shown by red boxes in Figure 3 & 4a. These boulders are not visible in TMC-1 image due to high sun-angle and virtually no shadows. The rose diagram (Figure 4b) shows the trend of boulders distribution around the crater. Although boulders are distributed all around the crater but most of them are oriented along NNE and SSE of the crater. The exact shape of boulders is not clearly discernible but some bigger boulders show sub-rounded to rounded shape. The biggest size of the boulder is 72 m and the smallest boulder is 35 m. Similarly, the area of biggest boulder is 302 m^2 and smallest boulder is 80 m^2 .

Conclusion: The multi sun-elevation angles images have proved useful to understand the crater formation characteristics such as ejecta & boulder distribution, projectile direction, Crater's uprange and downrange directions and angle of impact. In this study, the crater's west /south west region is suggested as uprange direction & north / north east side as downrange. The projectile direction is suggested from the south west direction and angle of impact could be 45-60° [1]. The detail study of other geological characteristics like impact melt distribution and detail morphometric analysis of crater could be significant value addition in understanding crater /ejecta characteristics. The surge in intensity at low phase angles degrades the quality of image acquired at high sun elevation angles. In future, large area multiple images at various phase angles would be required to have a complete photometric models for understanding the Lunar photometric properties and create seamless mosaic of images . The present effort provides initial observations which will be further refined.

References: [1] Shoemaker, E.M. (1962) In: Kopal, Z. (Ed.), Physics and Astronomy of the Moon. Academic, New York, 283–359. [2] Besse S. et al. (2013) Icarus, 222, 229-242. [3] Hapke B. (1981) Journal of Geophys. Res., 86(B4), 3039-3054. [4] Hapke B. et al. (1993). Science, 260(5107), 509-511.

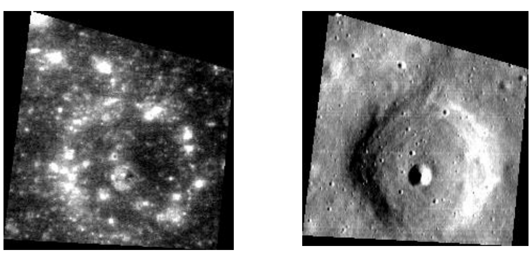

Figure 1: Region1, TMC-1(left) and TMC-2 (right).

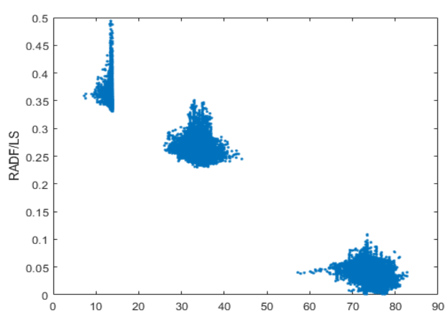

Figure 2: Figure showing the plot of Lommel-Seeliger corrected RADF with respect to Phase angles corresponding to region shown in Figure 1. A surge in intensity is seen at lower phase angles.

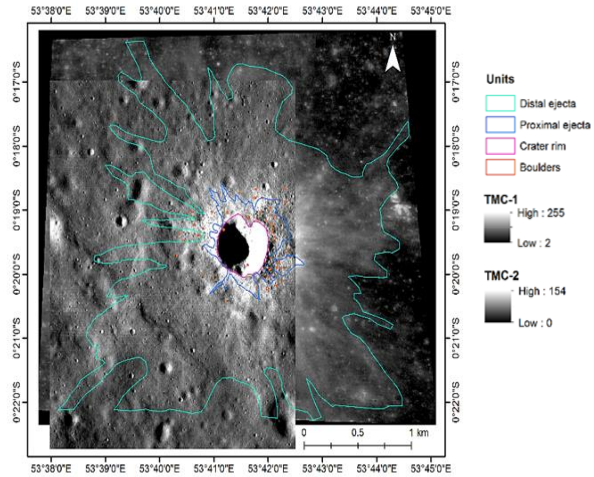

Figure. 3. Ejecta delineated from TMC-1 (right) & boulders/ejecta delineated from TMC-2 image (left).

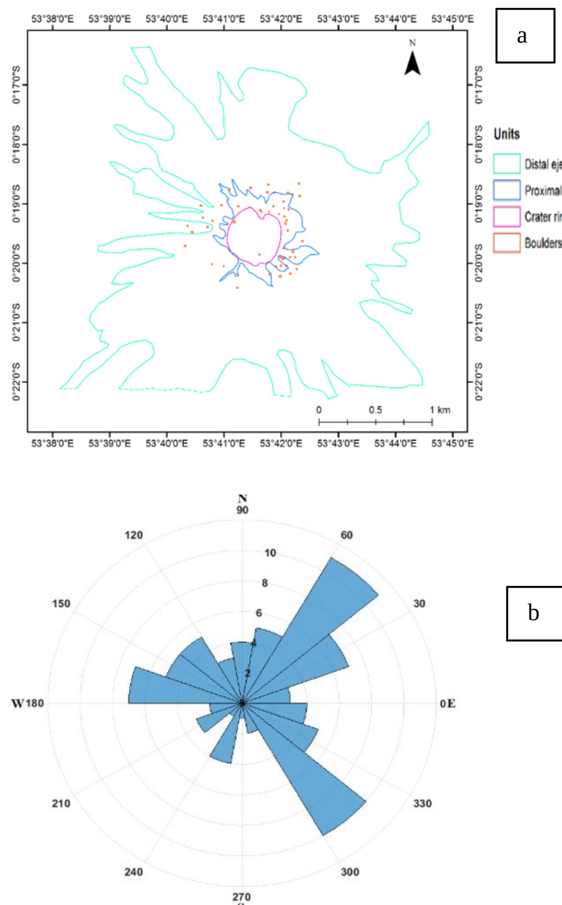

Figure 4. (a) Overlay of crater's units derived from TMC-1 and TMC-2 **(b)** Rose diagram showing boulder distribution trend.