MINI-RF RADAR OBSERVATIONS OF POLAR CRATERS: ARE THEY ROUGH, SMOOTH, OR ICY?.

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Introduction: The possibility that water ice could be present in lunar polar craters has long been postulated [e.g., 1,2]. More recently, measurements from instruments on a number of spacecraft have all pointed to the presence of water at the lunar poles [e.g., 3-7]. The Lunar Crater Observation and Sensing Satellite (LCROSS) impact into a permanently shadowed portion of Cabeus crater (84.9°S, 35.5°W; 98 km dia.) has provided the most direct evidence for the presence of water in the form of ice [8]. Measurements of near-infrared absorption and ultraviolet emissions indicated that water ice and vapor were present in the resulting ejecta plume at between 3 and 10% by weight.

Water ice can exhibit a strong response at radar wavelengths in the form of a Coherent Backscatter Opposition Effect (CBOE) and the circular polarization ratio (CPR) of the returned data can be a useful indicator of such a response—i.e., measured CPRs for icy materials typically exceed unity [9]. This effect has been observed in radar data for the floors of polar craters on Mercury [9,10]. However, ground-based radar observations of the lunar south polar region did not observe this effect [11]. This result was supported by later Mini-RF and Mini-SAR (Chandrayaan-1) monostatic observations of Cabeus [12] but was contradicted by Mini-RF bistatic observations that showed a clear opposition response, at S-band (λ=12.6 cm) for Cabeus crater floor materials [13].

Mini-RF is currently operating as part of the Lunar Reconnaissance Orbiter (LRO) Cornerstone Extended Mission to address driving questions related to the form/abundance of water on the Moon and its vertical distribution. To support this effort, Mini-RF has collected X-band (λ=4.2 cm) bistatic observations of the south polar craters Cabeus and Amundsen (84.5°S, 82.8°E; 103 km dia.) and will be releasing monostatic controlled polar mosaics with resolutions of 30 m/pixel for the north and south poles that provide > 95% coverage poleward of 80° (Fig. 1). Here we use these data to address the question of whether radar observations of the lunar poles indicate they are rough, smooth, or icy?

Mini-RF Operations: Mini-RF is a hybrid-polarized, side-looking synthetic aperture radar (SAR) that was designed as a monostatic system – i.e., the antenna operated as a transmitter and receiver. In this operational mode, it transmitted a left-circular polarized signal and received orthogonal linear polarizations [14]. In December of 2010 the transmitter experienced a malfunction and ceased to operate, precluding further monostatic data collection. Prior to this malfunction, Mini-RF was able to collect S-band data that covered > 66% of the lunar surface and > 95% of the lunar poles. Controlled monostatic mosaics of these data for both poles have been produced by the USGS following the methodology outlined in [15]. These mosaics provide shadow-free access to polar crater floors at a resolution of 30 m/pixel (Fig 1.).

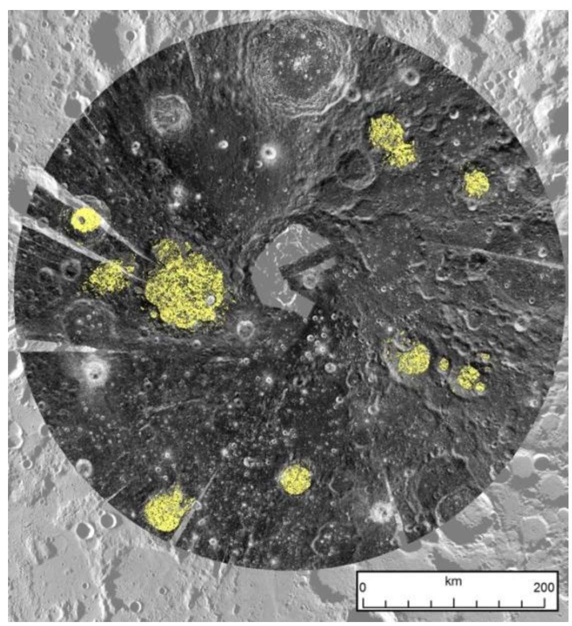

Fig. 1. Mini-RF controlled polar mosaic of the north polar regions (80°N to 90°N) overlain on WAC 100 m basemap. Yellow indicates crater floor areas analyzed in this study.

Shortly after the transmitter failed, Mini-RF began operating in concert with the Arecibo Observatory (AO) in Puerto Rico and the Goldstone deep space communications complex 34 meter antenna DSS-13 to collect bistatic radar data of the Moon. In this architecture either AO (S-band) or DSS-13 (X-band) transmits a circularly-polarized signal to illuminate a portion of the lunar surface, and Mini-RF's receives the backscattered signal. This architecture allows for radar scattering properties of the lunar surface and subsurface to be measured over a range of bistatic angles (i.e., equivalent to phase angle for optical instruments), which was not possible in Mini-RF's original monostatic configuration (phase angle = 0º). In this bistatic configuration, 5 S-band observations of the floor of Cabeus crater and 3 X-band observations each of the floors of Cabeus and Amundsen craters have been acquired.

Analysis – Polar Mosaics: This analysis focused on comparing the radar response of permanently and non-permanently shadowed regions for the floors of craters polar craters with dia. > 15 km. The analysis regions were selected using LOLA-based shadow models and LOLA-based slope maps. Because sloped surfaces (such as crater walls or peaks) can result in spurious additions to the returned radar signal, we restricted our analysis to regions with slopes < 5°. These flat regions were then divided into permanently shadowed and non-permanently shadowed regions using the shadow model. Finally, we considered only craters where both the flat permanently and non-permanently shadowed regions were spatially expansive enough to be considered statistically significant (i.e., > 1 km^2 total).

Our final dataset included 10 north polar craters and 11 south polar craters (Fig. 1). Preliminary results indicate that the majority of the craters examined do not show an anomalous CPR signature indicative of the presence of water ice (for PSRs and non-PSRs within the craters). This is consistent with previous results from polar observations with bistatic angles < 0.5° [11, 12]. Three of the craters examined (Kocher, Wiechert E, and Wiechert J) have crater floor CPR values that are higher than surrounding terrain by a significant margin. Inspection of the floor morphology of those craters suggests that this signature is likely a result of surface roughness.

Analysis – Bistatic Observations: CPR measurements for the floor of Cabeus crater in S-band, as a function of bistatic angle, show a clear opposition surge; something not observed for the floors of nearby, similar-sized craters that were sampled during by Mini-RF bistatic observations (e.g., Casatus, Klaproth, Blancanus, and Newton A and G). Mini-RF X-band observations of the floor of Cabeus cover a smaller range of bistatic angles than were sampled at S-band. Based on the observations available, there is no indication of an opposition response. Data for the floor of Amundsen crater, on the other hand, do show an indication of an opposition response but it differs from what was observed for the floor of Cabeus at S-Band.

The Mini-RF bistatic data are currently being reprocessed with updated calibration parameters, adjustments to processing parameters that will reduce noise in the data, and the inclusion of low-resolution topography in the radar image formation process. These improvements to the data may impact the results of this analysis.

Conclusions: Preliminary analysis of the CPR of 18 polar craters in Mini-RF monostatic radar data suggest that a signature indicative of surficial/near-surface water ice is not present (i.e., at least not in quantities detectable at S-band wavelength). This is consistent with previous Mini-RF results from polar observations with bistatic angles < 0.5° [11, 12]. The CPR values of 3 other polar crater floors are elevated with respect to their surrounding but this signature is likely a result of surface roughness.

Mini-RF S-band bistatic observations, on the other hand, indicate that the floor of Cabeus crater is unique with respect to other materials observed on the Moon and has a CPR signature suggestive of water ice. That signature is not observed in shorter wavelength X-band bistatic observations of Cabeus and a different signature, indicative of surface roughness, is observed for the floor of Amundsen crater. Taken together, the bistatic observations could indicate that, if water ice is present in Cabeus crater floor materials, it is buried beneath ~0.5 m of drier regolith that does not include radar-detectible deposits of water ice.

Given some of the inherent ambiguities in interpreting radar data of silicate-ice mixtures, our continued objective is to integrate multiple wavelength observations over a range of bistatic angles (and concomitant penetration depths [16]) to help elucidate the structure of lunar polar regolith.

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