THE LRO PERSPECTIVE ON THE LATERAL AND DEPTH DISTRIBUTION OF WATER (ICE) AT THE LUNAR POLES. G. W. Patterson[1], N. Petro[2], J. Keller[2], K. E. Mandt[1], T. McClannahan[2], M. Siegler[3], K. Retherford[4], J.-P. Williams[5], D. Paige[5], B. Greenhagen[1], B. W. Denevi[1], E. Speyerer[6], E. Sefton Nash[7], and the LRO Science Team. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (Wes.Patterson@jhuapl.edu); [2]Goddard Space Flight Center, Greenbelt, MD, USA; [3]Planetary Science Institute, Dallas, TX, USA; [4]Southwest Research Institute, San Antonio, TX, USA; [5]University of California, Los Angeles, CA, USA; [6]Arizona State University, Tempe, AZ, USA; [7]European Space Research and Technology Centre, Noordwijk, Netherlands.

Introduction: The Planetary Science Decadal Survey, *Visions and Voyages* [1] sets characterization of the lunar volatile cycle as a top priority for lunar exploration, seeking to address questions dealing with the sources of volatiles, if and how they migrate across the surface, and what is their ultimate fate. The NASA Lunar Reconnaissance Orbiter (LRO) has been gathering data to address these questions for nearly 10 years and, in that time, has revolutionized our understanding of lunar volatiles [e.g., 1-16]. Despite these advances questions remain, including: how does hydration (OH, H_2O) vary on the surface of the cold polar craters (including PSRs); why do some polar crater PSRs provide no indication of volatiles; what are the thermophysical properties (thermal conductivity, infrared emissivity) of polar craters; are polar crater thermophysical properties variable at cm, m or km length scales; and what are the surface characteristics of the polar craters? As LRO concludes it third extended mission, and looks toward the possibility of its next one, two polar targets stand out for their potential to address these questions: Cabeus and Amundsen.

Background: A diverse set of LRO observations suggest that the Moon not only possesses extensive reservoirs of volatiles concentrated in the polar regions [2-5], but that the volatiles exhibit abundance variations in terms of latitude and time of day [6]. Diviner surface temperature diurnal and seasonal temperature measurements have constrained the thermal environment and provided context for other observations [7]. FUV reflectance observations from LRO LAMP, which probe the top few 100 nm, showed water frost on the surface of PSRs [8] and coincide with regions where Diviner finds the temperature to be low enough for water ice to be stable on the surface [2]. LOLA normal albedo observations similarly suggest surface frost which coincides with low temperature surfaces [9], but also that the spatial distribution of surface frost varies and that some PSRs appear to be free of surface frost. This LOLA heterogeneous distribution was confirmed with reflectance spectra measurements made with the Moon Mineralogical Mapper (M^3) on Chandrayaan-1 [10] (Fig. 1). LEND observations, which probe the upper m of the regolith, have shown that the spatial distribution of hydrogen-bearing volatiles is heterogeneous [5,11] (Fig. 1), and can vary within larger PSR's [4]. Mini-RF observations, which probe up to several meters beneath the surface, have found evidence of craters with potential water-ice signatures [12,13].

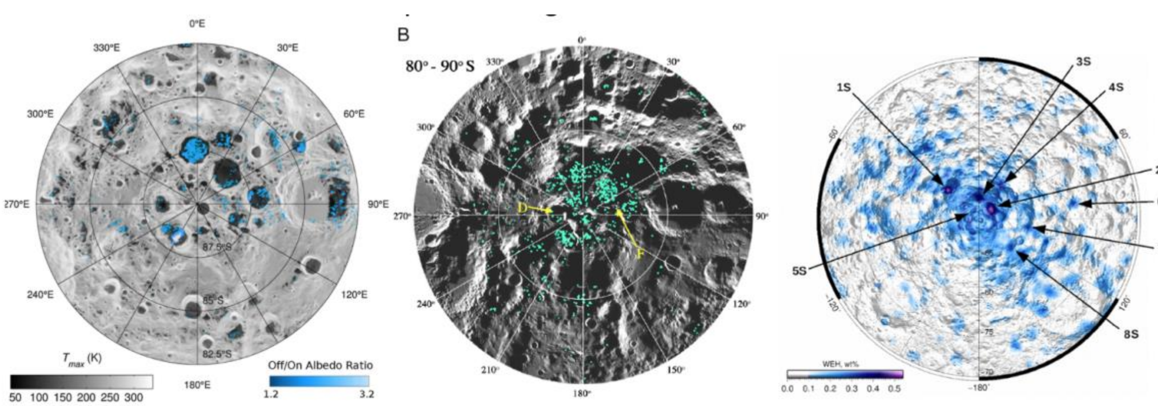

Fig. 1 Maps of the Lunar south pole show heterogeneous distributions of surface frost observed in PSR's from LAMP, M^3, and spatial distribution of water-equivalent-hydrogen (WEH) from LEND. Left: LAMP shows a heterogeneous mixture of surface frost [2]. Center: M^3 shows patchy surface ice [10]. Right: colored regions show that some WEH concentrations do not always coincide with PSRs (Fig. 2 from [11]). These combined datasets demonstrate that the distribution of water ice on the Moon laterally and with depth is complex and poorly understood.

LROC has gathered a set of long exposure NAC observations of PSRs in polar regions that rely on scattered light from nearby illuminated crater rims or massifs to provide secondary illumination of PSRs. In contrast to the heterogeneities observed by other instruments, LROC has found no evidence for surface frost or ice, despite observing other fine details that include high-reflectance ejecta from small craters, boulder tracks, and landslides.

LRO's Next Extended Mission: Despite years of research, the Moon's Permanently Shaded Regions (PSRs) remain among the most important yet least understood lunar regions. Understanding the distribution of volatiles laterally and with depth requires a more detailed study of PSRs and their surrounding regions than has been conducted so far with LRO. In particular, focusing on targeted regions with intense coverage by multiple instruments will help to better understand not only how water ice is distributed laterally and with depth, but also what controls the distribution of water ice. One important area of focus will be to determine what role the material and thermophysical properties of the regolith in the PSRs, including thermal conductivity and infrared emissivity on the surface and at depth, play in volatile retention. Up to now the assumption has been that the regolith in the PSRs has similar properties to regolith in sunlit regions. Additionally, previous observations by LRO and M^3 have been insufficient to test for temporal variability of the lateral distribution of surface volatiles. A campaign targeting specific polar craters for intense coverage, in addition to intensified coverage of lower latitude regions, could provide enough data to evaluate differences over several months.

The Cabeus and Amundsen PSRs provide temperature conditions that allow water ice to be stable on the surface and water was detected in the plume produced during the LCROSS impact into Cabeus [14]. LAMP has detected surface frost in both craters [2] but M^3 only sees ice in Cabeus [10] (Fig. 1). Diviner, however, observes differential emissivity between nighttime observations of PSR and non-PSR regions within Amundsen which could be attributed to the presence of water frost [15]. Neutron maps show suppression of neutrons in the Cabeus region that is lacking in Amundsen [4]. Mini-RF bistatic observations of Cabeus crater suggest the presence of water ice [14] at S-band wavelengths (12.6 cm), but does not see a similar signature for Cabeus or Amundsen at X-band wavelengths (4.2 cm) [16]. These craters will receive increased coverage in the next potential LRO extended mission (Fig. 2), because of the current spacecraft orbital inclination, making them ideal targets for further investigation.

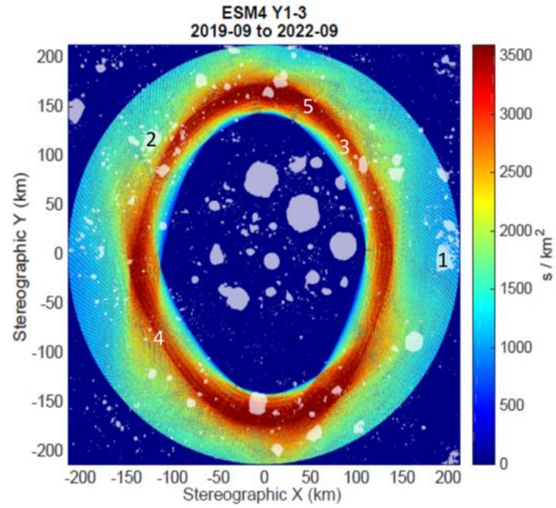

Figure 2: Map of the LRO coverage of the Lunar south pole during its next potential extended mission in seconds per square km. Red increased coverage of the surface afforded by the current LRO orbital inclination. The (1) Amundsen and (2) Cabeus PSRs will receive increasing coverage over time as the mission progresses.

Summary: As LRO concludes it third extended mission, and looks toward the possibility of its next one, the polar craters Cabeus and Amundsen stand out for their potential to address key lunar exploration questions prioritized in the Planetary Science Decadal Survey, *Visions and Voyages* [1]. The targeted observations outlined here will provide an important and new perspective on the distribution of volatiles in polar craters, as well as the role of regolith properties in controlling the distribution of volatiles.

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