CHARACTERIZING LUNAR POLAR VOLATILES AT THE WORKING SCALE: GONG FROM EXPOLRATION GOALS TO MISSION REQUIREMENTS. A. Colaprete[1], R. C. Elphic[1], M. Shirley[1], [1]NASA Ames Research Center, Moffett Field, CA, anthony.colaprete-1@nasa.gov

Introduction: The economic evaluation of natural resources depends on the accuracy of resource distribution estimates. On Earth such estimates are necessary in making decisions about opening new mines or in planning future investment for operating mines or industrial deposits. A frequently discussed lunar resource is water ice, however, we are only at the first stages of understanding its potential as a resource. In particular, we currently do not have a sufficient understanding of the distribution of water or its form at the scales it would be extracted and processed, that is, the "working scale". Here the "working scale" is defined to be the scales at which sufficient material can be processed to meet some basic demand (for example, 100s of square meters), and the anticipated heterogeneity in the water distribution across those scales (scales <5 - 10s of meters). Several mission concepts have been developed to better understand lunar water, motivated by both scientific and exploration goals. This paper provides an analysis of the number and distribution of observations needed to provide the necessary next steps in lunar water ISRU. We use a combination of Monte Carlo studies and classic geostatistical approaches to go from the exploration goal of "understand the distribution of water" to quantification of specific mission sampling requirements.

The Need for Mobility and Subsurface Access: A number of existing data sets suggest that water ice is heterogeneous at scales down to meters. For example, to reconcile the LCROSS observed water concentrations of ~5% [1] with the observations of neutron counts the water would need to be either buried under a desiccated layer of regolith 20cm to 50cm deep and/or mixed laterally with an areal density of 20-40% [2]. These ranges of values for the lateral and vertical distributions are consistent with what one would expect due to the constant excavation/burial by impacts [3]. The dominant geological process affecting the top meter of regolith is small impact cratering. The distance between 10 m wide craters (~1 m deep) is ~50-150 m, consequently the top ~meter is likely to be patchy at scales of 10s-100s of meters. Individual static landers may provide a range of answers as to the total water content and distribution, leading to large uncertainties in the estimated resource reserves. A landed, mobile system is required to assess the water distribution across scales of 100s of meters with resolution of <10 meters. Additional modeling and geostatistical analysis is used to better quantify the scales needed to be measured and the minimum number of measurements required.

Geostatistics and Monte Carlo Modeling: The application of geostatistics in resource characterization dates back to the late 1970s and are useful for site assessment where data is collected spatially [4]. Typically a geostatistical study applies an iterative three-step approach involving:

1. Exploratory data analysis: summary statistics of the composite data (e.g., does the property exhibit a Gaussian distribution?)
2. Variogram modeling: investigate and quantify the spatial variability of the phenomenon being studied and reproduce the statistical properties of the variable depending on direction and distance
3. Making predictions (kriging estimation and/or simulations): use the variograms to create a prediction surface and then validate the model with cross-validation

These same techniques can be applied to lunar spatial data sets and / or model predictions to evaluate the

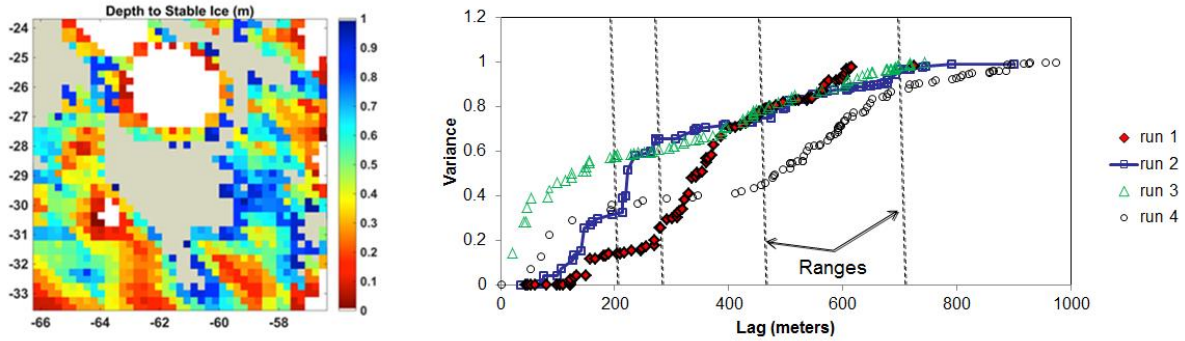

Figure 1 Map of the water ice stability depth (20 m pixel) (Left panel) and calculated variograms for four transects with the same origin but different directions (right panel)

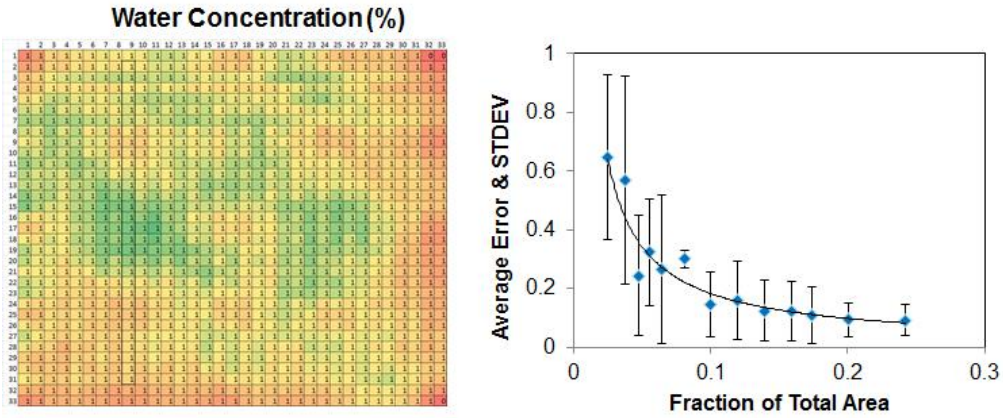

Figure 2 Simulated water distribution for Monte Carol simulations (left panel) and error in the estimated mean water concentration as function of rover traverse density across the model domain.

geospatial distribution of key physical parameters, including surface and subsurface temperatures, surface composition (e.g., from reflectance observations) or bulk subsurface composition (e.g., from neutron or radar measurements) or discrete subsurface observations (e.g., drill sampling). Comparing variogram analysis of observations to modeled data sets can identify critical spatial length scales and validate model results and physics. Furthermore models of the variograms can be used to develop kriging estimates of the observed parameter distribution.

Variograms: Cryogenic subsurface temperatures appear to be a necessary requirement, but not the only determinant of volatile presence, thus it represents one parameter that would govern the distribution of water. One way to look at the lengths scales associated with the distribution of water is to generate variograms of the subsurface water ice stability depth. The subsurface water ice stability depth is the depth at which subsurface temperatures are cold enough to retain water ice for extended periods (>1Gy). Figure 1 shows several variograms (each with the same origin but differing directions) calculated for an ice stability map near the north pole crater Hermite-A. The points at which the curves flatten represents a loss in autocorrelation between the parameter and distance (or lag), and are indicative of critical physical scales.

Monte Carlo Modeling: In addition to geostatistical analysis, Monte Carlo modeling of rover traverses has been carried out. These simulation aim to understand how much total distance and measurement density is required to achieve a specific uncertainty level in the overall characterization of an area/volume of regolith. The model generates maps of randomized water distributions with variable burial depth and concentration. A "Diamond Square" algorithm is used to create a randomized distribution, with parameters set to control the overall aerial density and uniformity. Examples of a distribution is shown in Figure 2. For each model run "samples" are taken along a prescribed traverse path. These samples are used to estimate the overall average water concentration and variability and compared to the actual average concentration and variability calculated for each run. The difference between the estimates from just the samples and the actual values represents the error in the traverse sampling. Multiple runs for a range of traverse distances and areal densities allows us to estimate the overall error in our estimate of the mean water concentration as a function of traverse distance and areal coverage. These estimates can be used to derive mission requirements for the necessary rover traverse distances. These estimates were made for a binary water presence (either the water was sensed or it was not). The next set of calculations applies instrument models for how they would actually sense the water (or hydrogen) along the traverse. For example, the Neutron Spectrometer System (NSS), an instrument that measures both thermal and epithermal neutrons while traversing, has been modeled, including its sensitivity (required counts per second) and noise characteristics. Again we can generate random distribution of water and along the prescribed traverse model the signal coming from the synthetic NSS instrument, and these "data", along with a model for neutron flux as function of burial depth and concentration, used to derive the average water concentration, burial depth and variability. Finally, simulated subsurface sampling can be added to better understand how the number of subsurface "tie-points" reduce the overall uncertainty in the estimates.

References: [1] Colaprete et al., (2010), Science, pp. 463. [2] Elphic, R. C. et al. (2012) *LPS XLII Abstract# 2751* [3] Yunsel, T. Y., (2012), The Journal of The Southern African Institute of Mining and Metallurgy, 112, pp. 239.