Characterizing Lunar Polar Volatiles at the Working Scale: Going from Exploration Goals to Mission Requirements

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- To characterize an areas' water content for ISRU requires making spatially distributed point measurements
- Making the number of measurements required for accurate characterization can only be done with surface mobility that can span scales of 10s to 100s of meters

The Necessary Sampling to Characterize the Water Distribution

The mission must sufficiently characterize an area to evaluate the resource need or physical processes

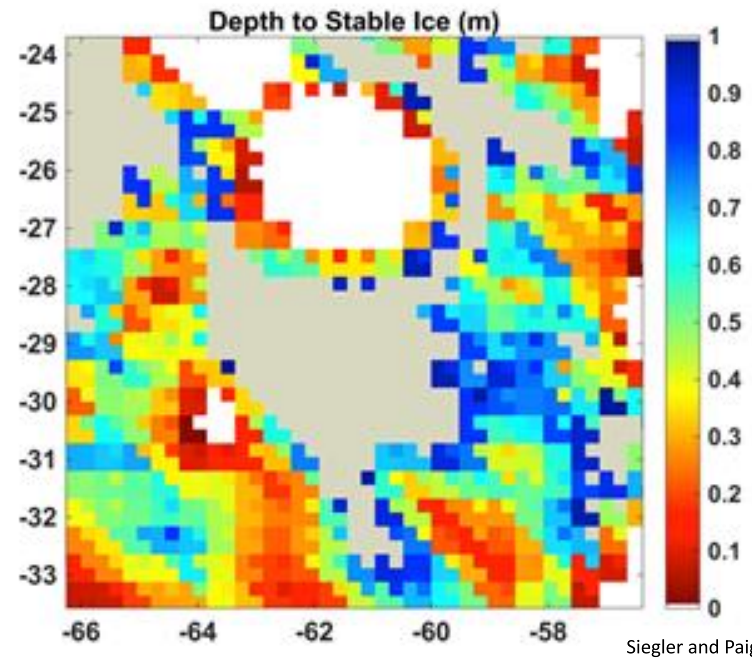
- Terrestrial mining companies have worked this problem for many years, developing "Mineral Models" for production evaluation
- Unfortunately the "Mineral Model" for lunar water is very uncertain, however many of the same techniques can be applied

A range of possible water distributions can be considered in order to determine sampling strategies and requirements

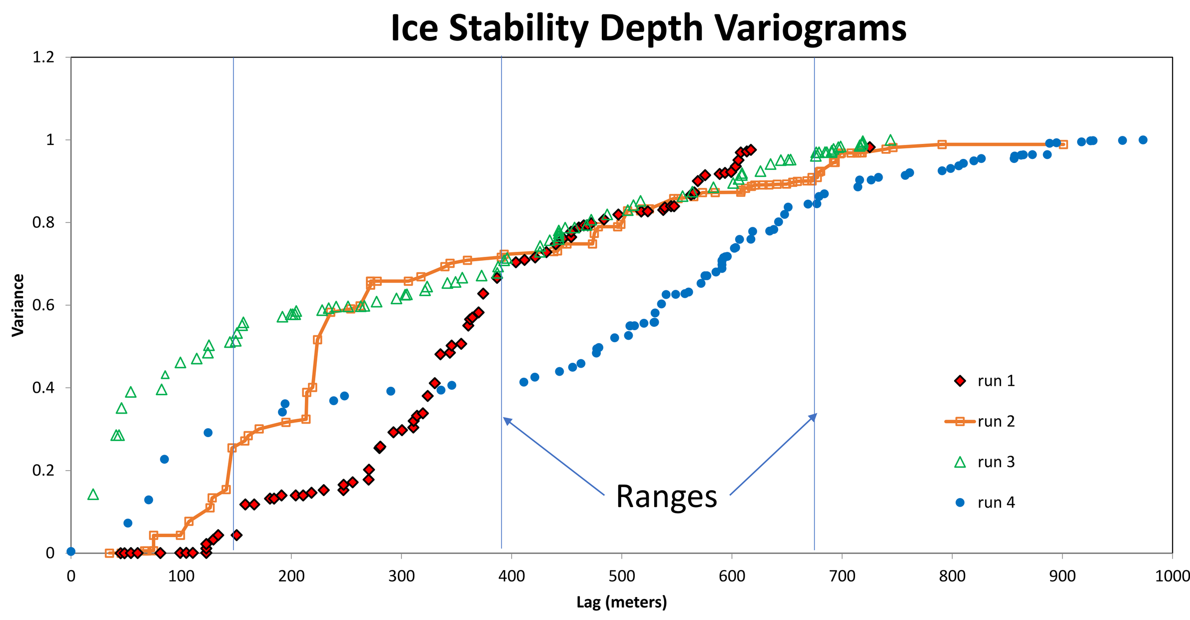
Existing data sets provide the spatial scales that measurements should cover

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

- This is essentially a measure of the spatial scales at which temperatures vary (and hence potentially water)
- Gives an estimate of the distances over which measurements are necessary
- The four "runs" represent different origins from which the lag (distance between points) was calculated
- Several "Ranges" are clear, indicating several physical scales, with the largest being **>600meters**
- Demonstrates that **sampling across scales from 10s to 100s of meters is required**



Siegler and Paige (2017)



How Much Sampling is Necessary to Characterize an Area?

The mission must characterize an area sufficiently to evaluate the resource need

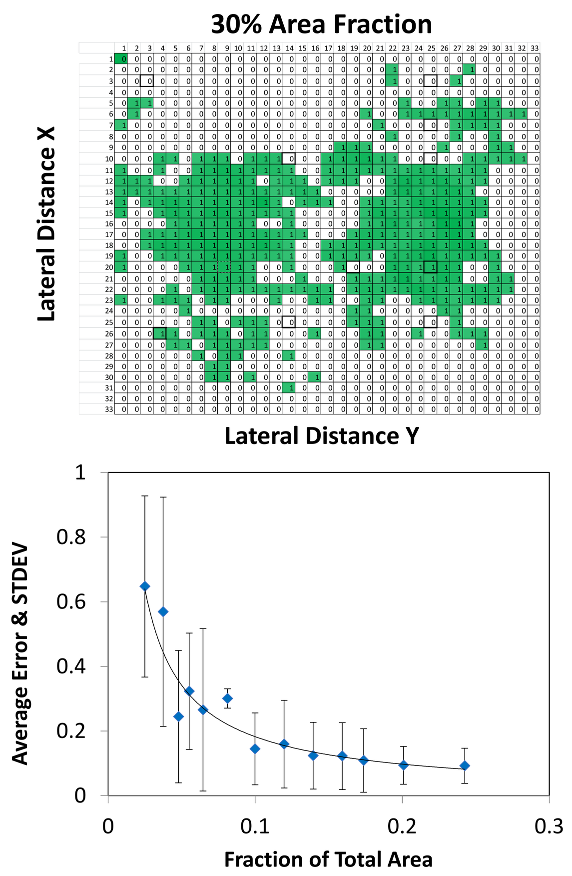
- Evaluated the required sampling using a series of Monte Carlo simulations with random distribution of water ice
- Sampled continuously along an arbitrary path, for example by a rover with a neutron spectrometer

Monte Carlo runs tested the uncertainty in sampling as a function of total distance or area coverage

- Sampled concentration was compared to "True concentration", calculated for each run, and the error in sampling calculated (Error = [True – Sampled]/True)
- Distribution of Errors provides likely (mean and median) uncertainty in a sampled

At a minimum need to traverse >180m with an area of 2500 m^2 to achieve a characterization uncertainty of <20%

Monte Carlo Results for Assumed 30% Area Density of Water
No Measurement error (binary Water or No-water "observation")



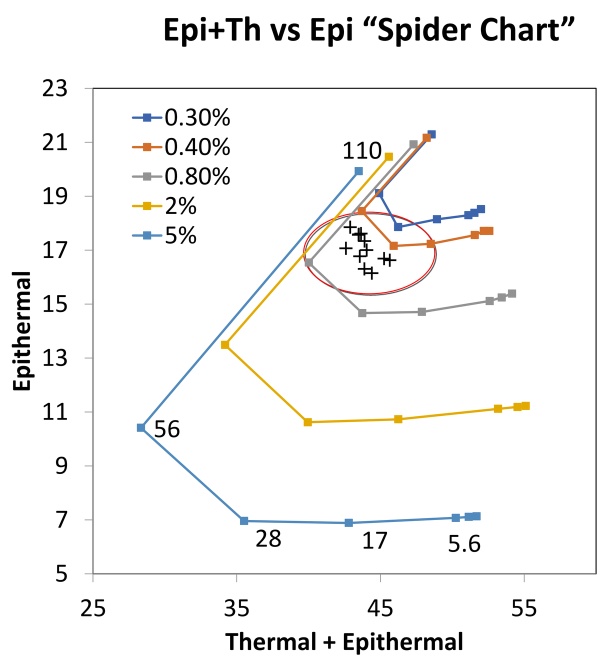
Modeling with Variable water Concentration and Burial Depth

Example of simulations with random mixes of water (not binary)

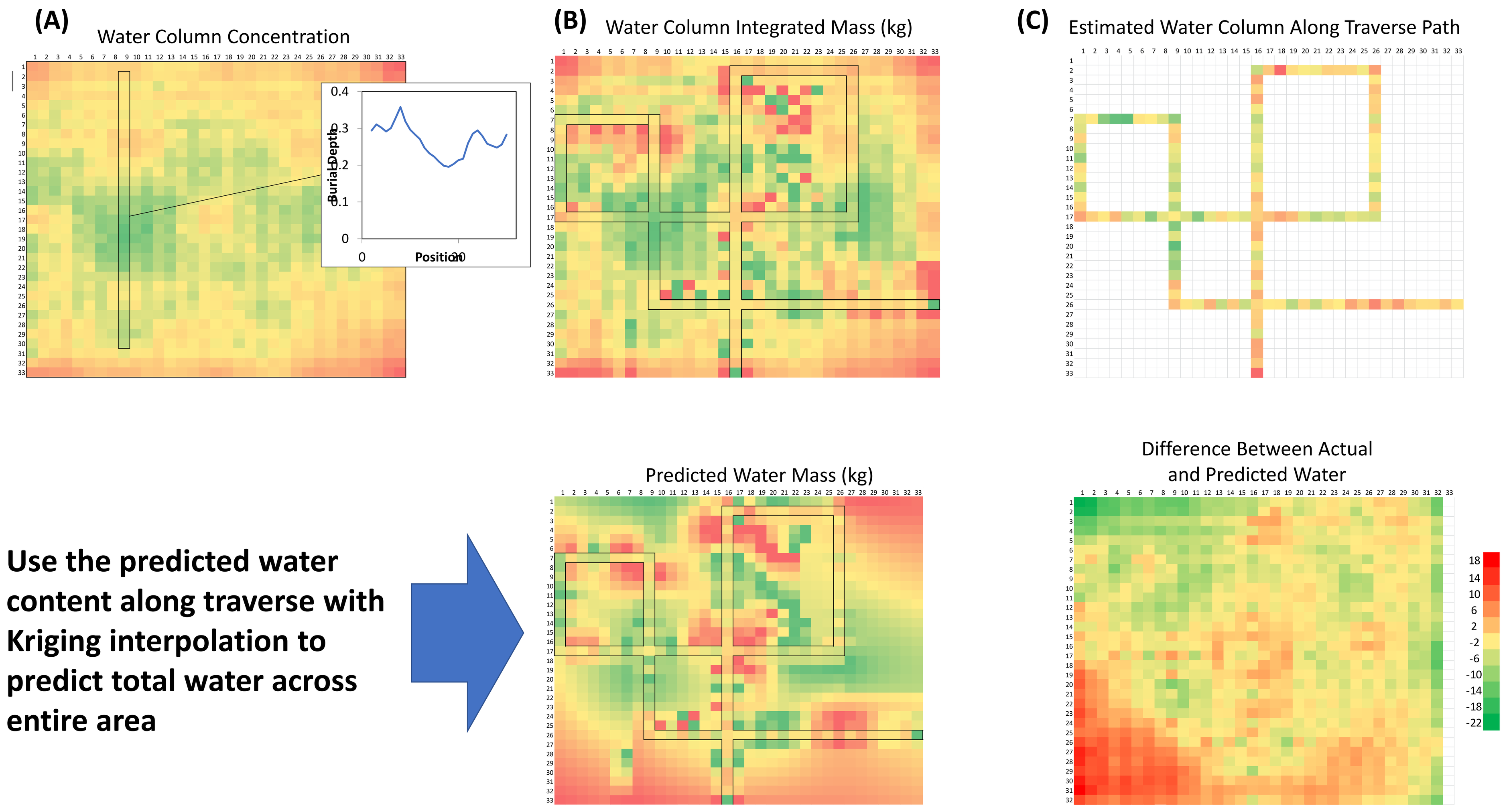
- Random concentrations and distributions (lateral and vertical) modeled and neutron observations modeled along arbitrary traverse (Fig. A and B, right panel)

For any point along the traverse the Epi-Thermal and Epi-Thermal + Thermal neutron counts are "observed"

- These observations include instrument error, but not position error
- The total water column along traverse is estimated from the Epi-Thermal and Thermal neutron count rates ("Spider Chart", right)



Example of Single Run with Variable Distribution and Burial



Use the predicted water content along traverse with Kriging interpolation to predict total water across entire area

Summary

- Have developed several models that can evaluate the necessary areal sampling to best characterize water distribution for ISRU
- Model includes measurement uncertainty (associated with a specific neutron spectrometer), random distributions of water and burial depth
- Areal sampling densities need to be >10-20% to reduce characterization uncertainty to <50%
  - Equivalent to ~100 static landers in a 75x75 m area