

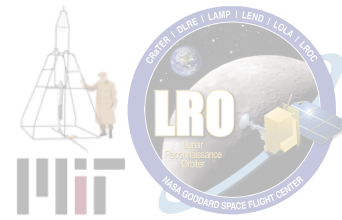
DIGITAL ELEVATION MODELS FROM LRO/LOLA

Mike Barker, Erwan Mazarico,
& the entire LOLA Science Team





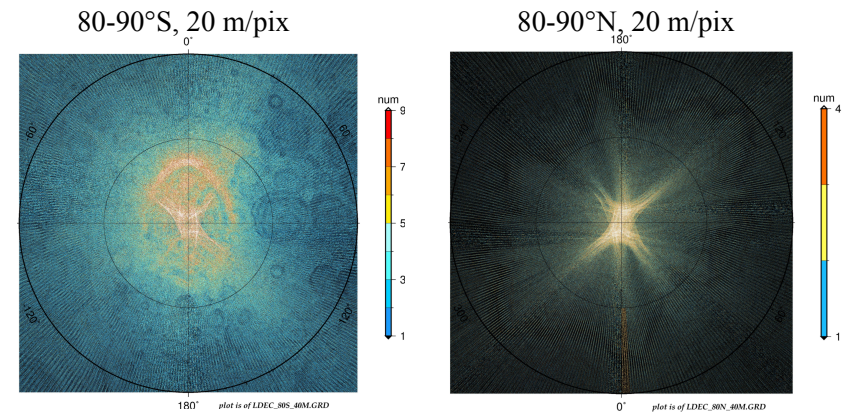
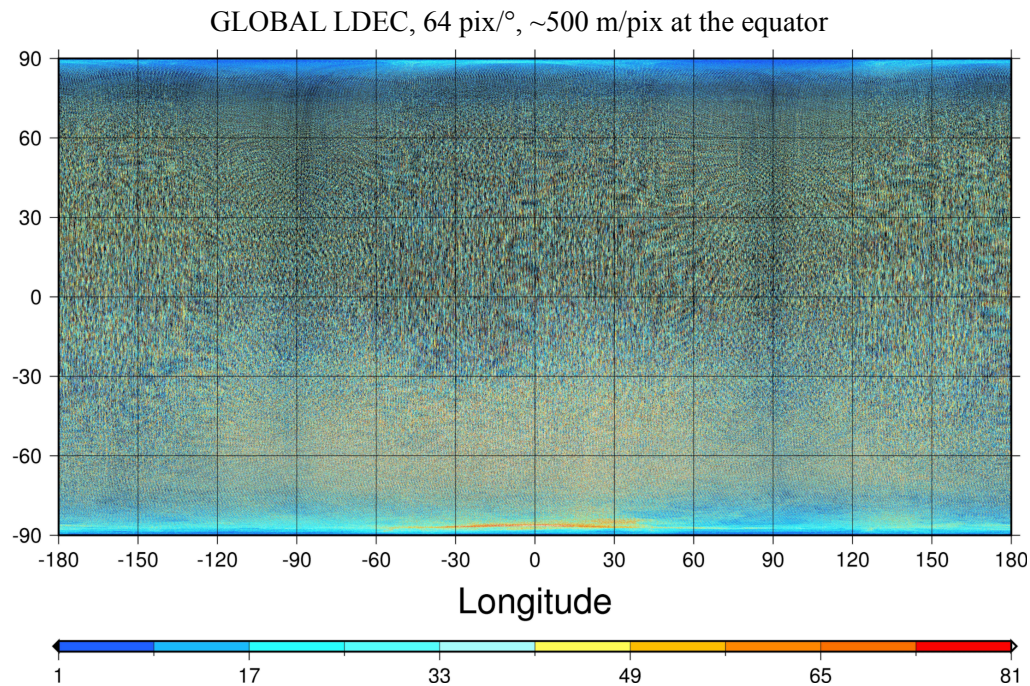
LOLA DEMs on PDS



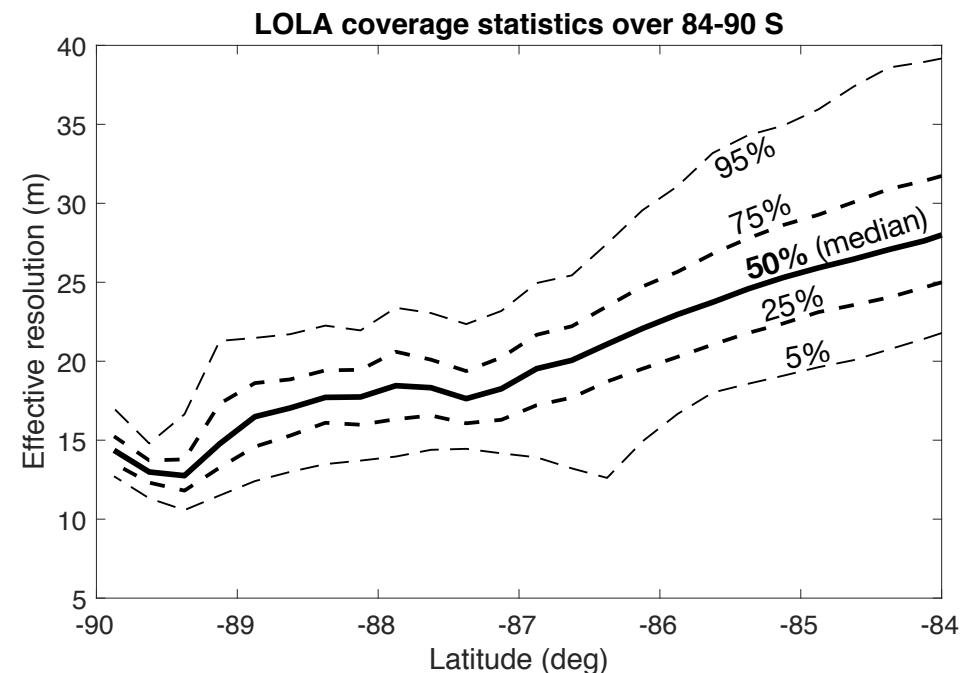
- As mentioned yesterday, all the LOLA data are on the NASA Planetary Data System (PDS; <http://imbrium.mit.edu>).
- The LOLA DEMs (Gridded Data Records, GDRs) are made in:
 - cylindrical projection
 - global, from 4ppd to 128ppd (~240, 480, 1900, 7500 m/pix)
 - global but tiled, from 256ppd to 512 ppd (60, 120 m/pix)
 - polar stereographic projection (both poles)
 - 45°-90° at 100/200/400 m/pix
 - 60°-90° at 120/240 m/pix
 - 75°-90° at 30/60/120/240 m/pix
 - 80°-90° at 20/40/80 m/pix
 - 85°-90° at 10/20/40 m/pix
 - 87.5°-90° at 5/10/20 m/pix

LOLA DEMs on PDS

- Data gaps in the DEMs are interpolated, but associated count maps (LDECs) can be used to mask the interpolated values.

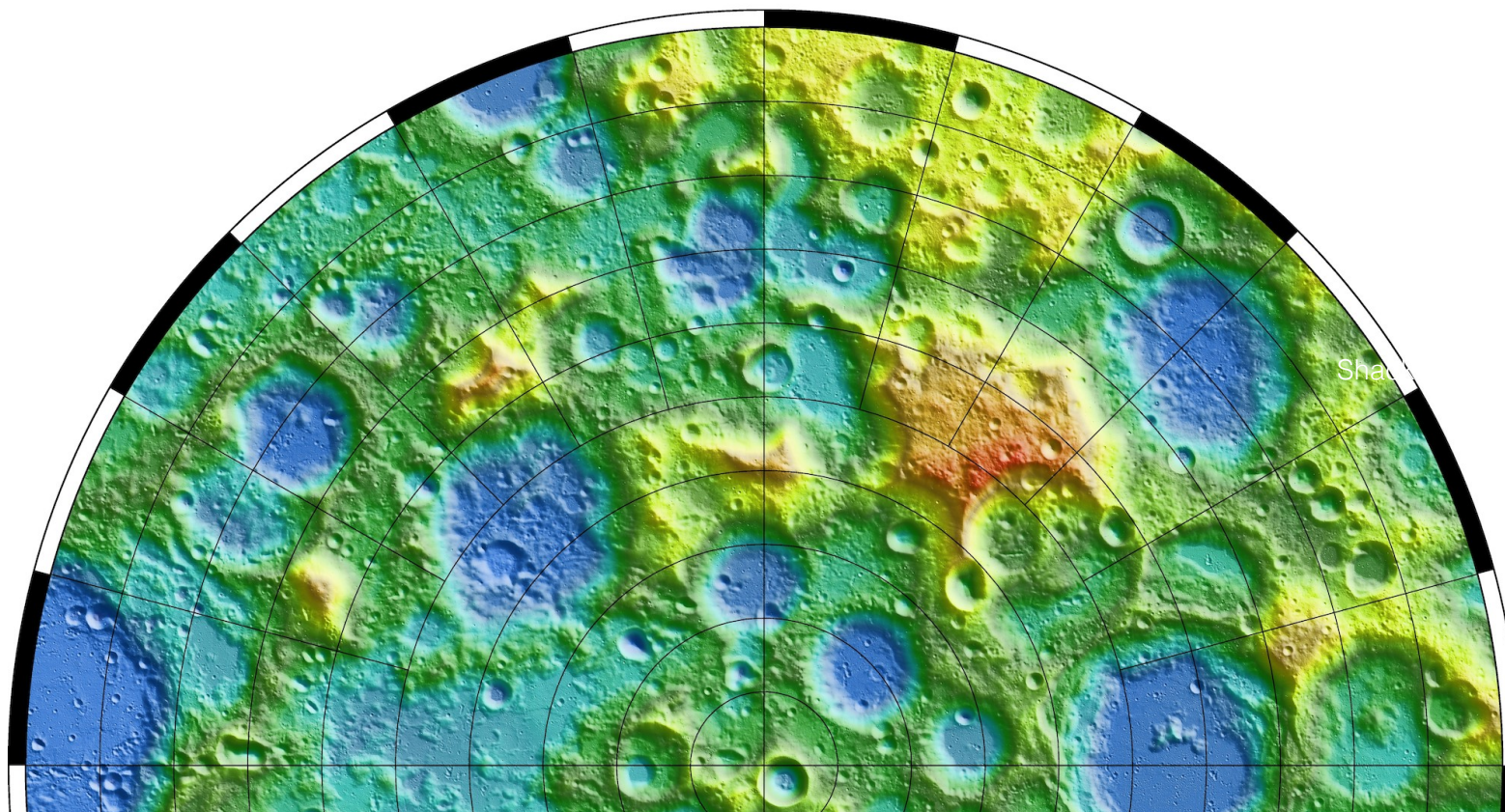


- The count maps can also be used to assess the effective resolution of LOLA locally.



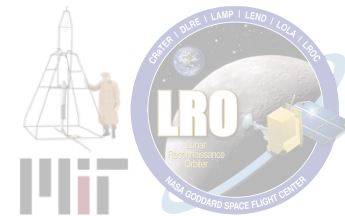
Regional DEMs

- Regional topographic maps of the entire polar regions support science analysis (e.g., illumination and thermal modeling, rectification) and exploration (e.g., approach path, communication).





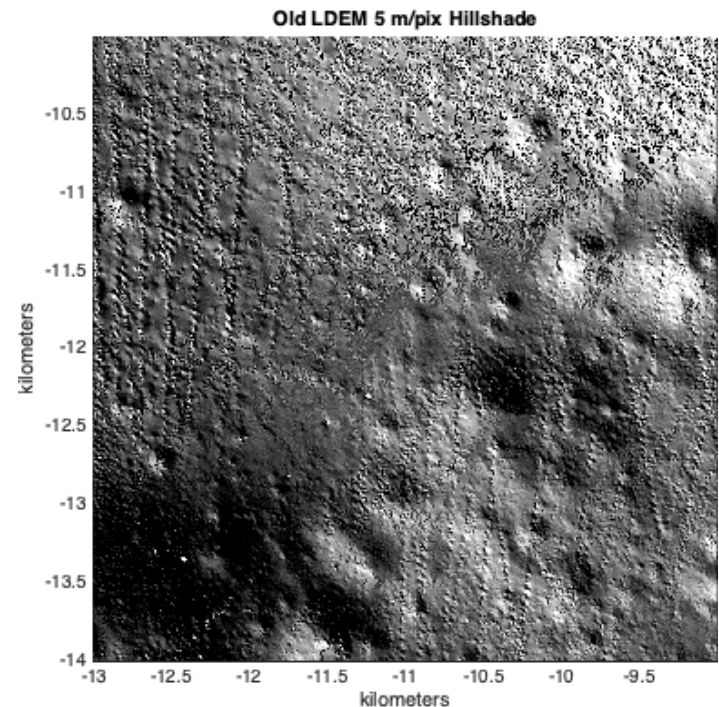
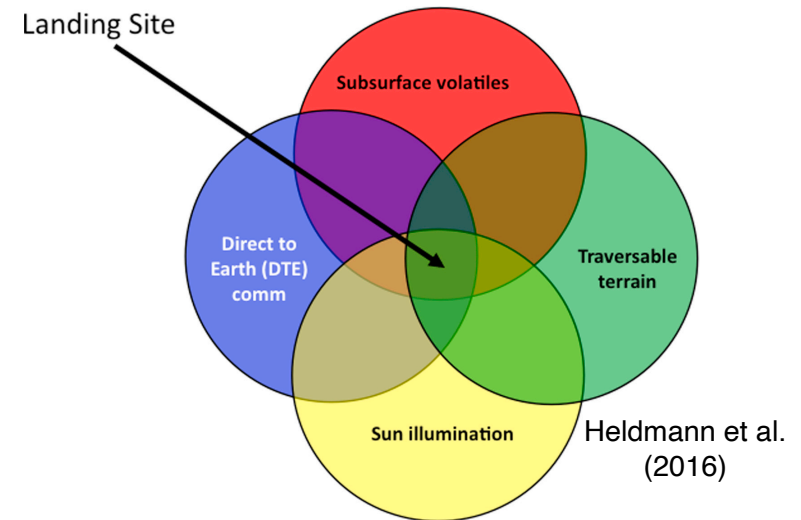
High-Resolution Polar DEMs



- To better support mission planning activities around Artemis, we worked to improve the accuracy of pure-LOLA DEMs near the south pole
- In particular, we focused on determining realistic error estimates of the elevation values
 - as a test case, we evaluated their impact on illumination conditions...

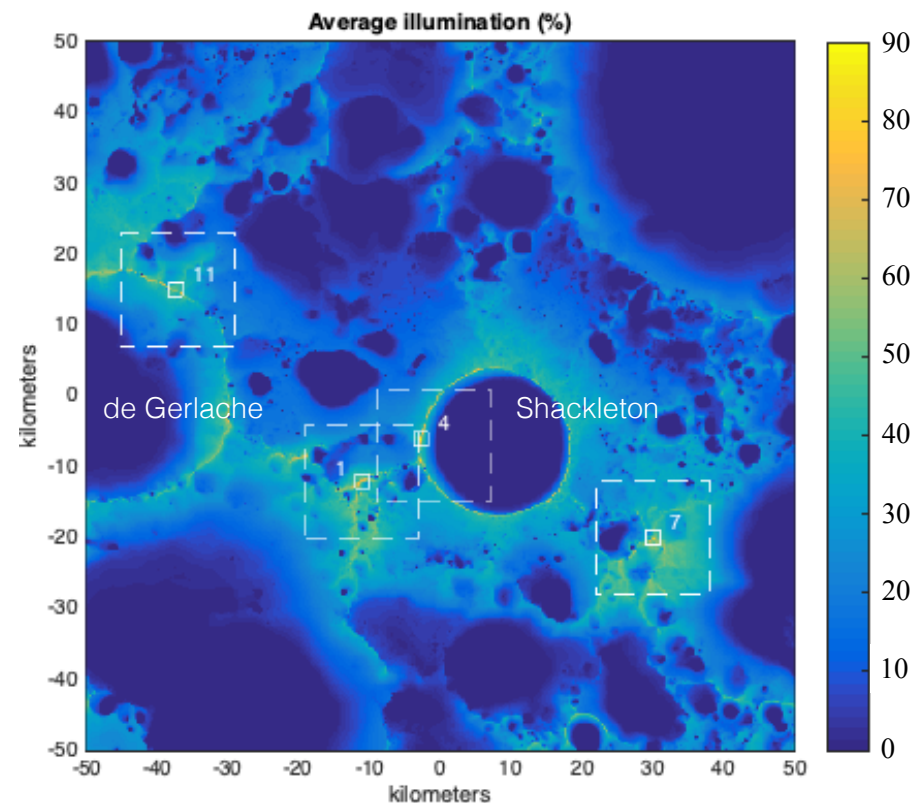
Detailed and accurate topographic maps are critical inputs to mission & site planning.

- Subsurface volatiles, traversable terrain, sun illumination, direct-to-Earth comm.
- Need to know the topography both *outside* and *within* permanently shadowed regions on lander-relevant scales (~1-5 m).
- Imaging-based techniques face challenges in polar regions due to the extreme shadowing.
- LOLA not hindered by shadows, but by gaps between tracks and laser spots which require interpolation to fill in.
- Small errors in the LRO orbit reconstruction (~ few meters horizontally & ~0.5 m vertically) can cause streaky artifacts in a LOLA digital elevation model (DEM) at ~5 m/pix.
- Estimating and mitigating these issues are two of the primary goals of this work.



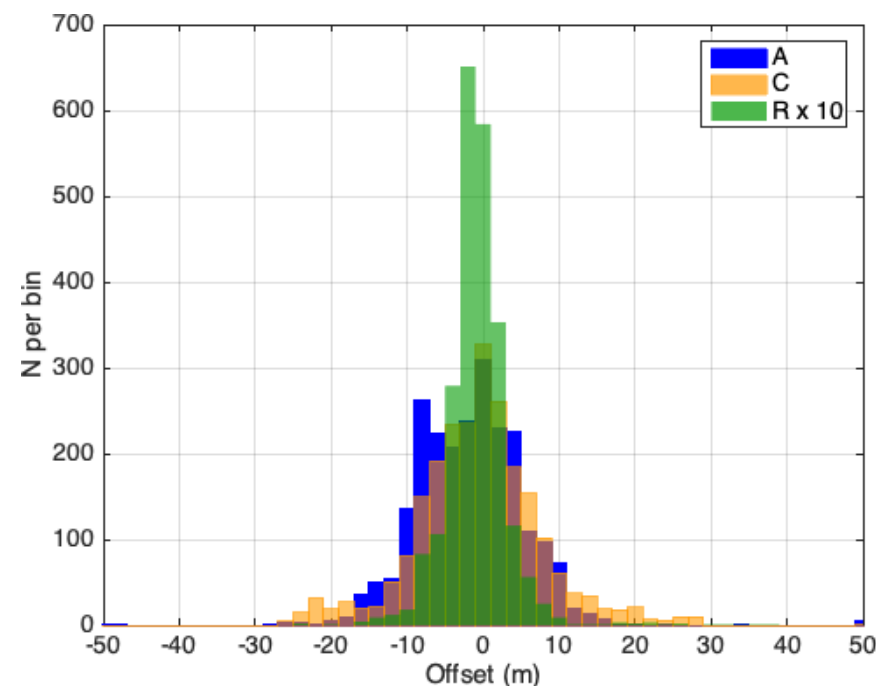
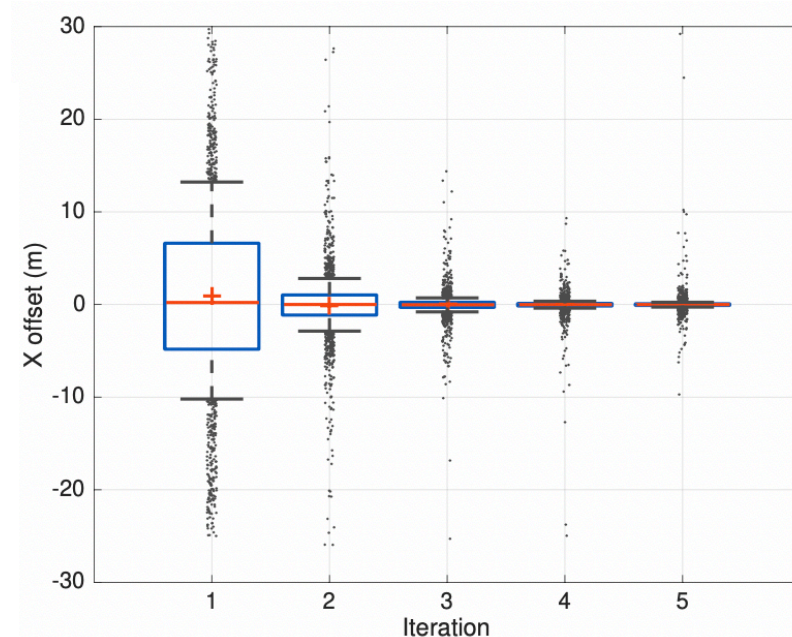
Introduction

- To support Artemis and CLPS, we worked to revise our LOLA-derived DEMs, quantify their uncertainties, and assess the impact on expected illumination conditions.
- An updated 5 m/pix LOLA DEM, with uncertainty estimates, will be more useful to landing site studies and as a constraint to higher-resolution models.
- The new methodology is applicable to both polar regions, but we first set on four South Pole high-priority sites:
 - sites 1, 4, 7, 11 [Mazarico et al., 2011]
 - 16x16 km areas, 5 m/pix
- Here we focus on the Site 1 data
 - ~2500 tracks (~1 million returns)
 - fill ratio ~10%



Iterative Adjustment Method

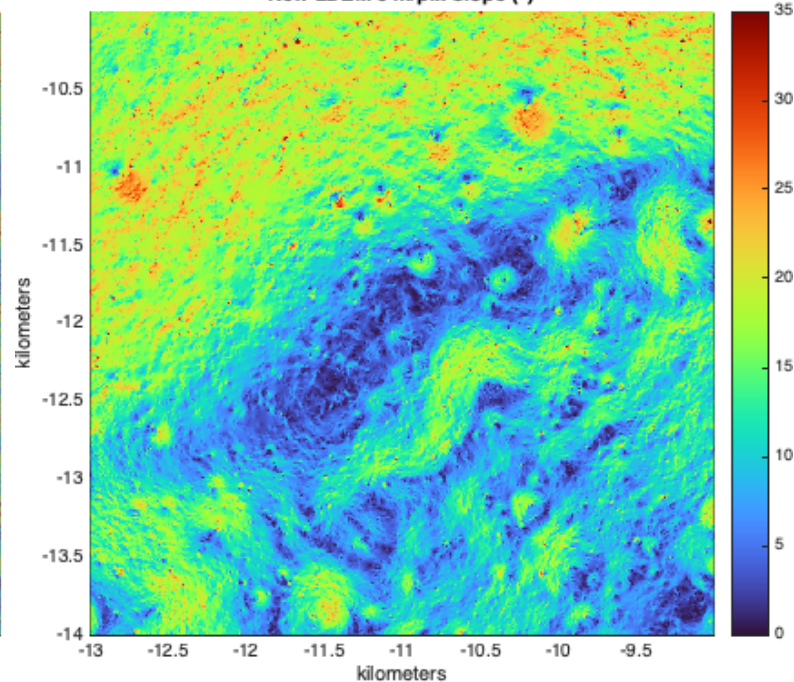
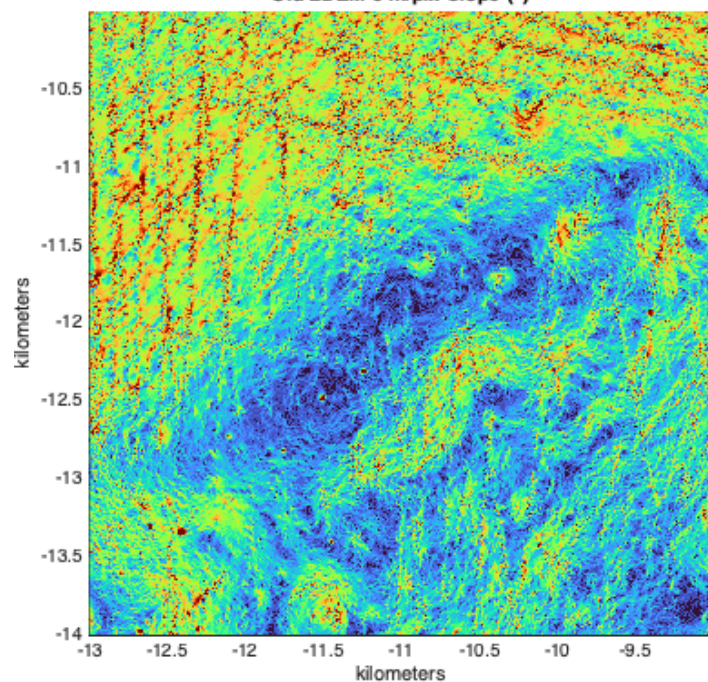
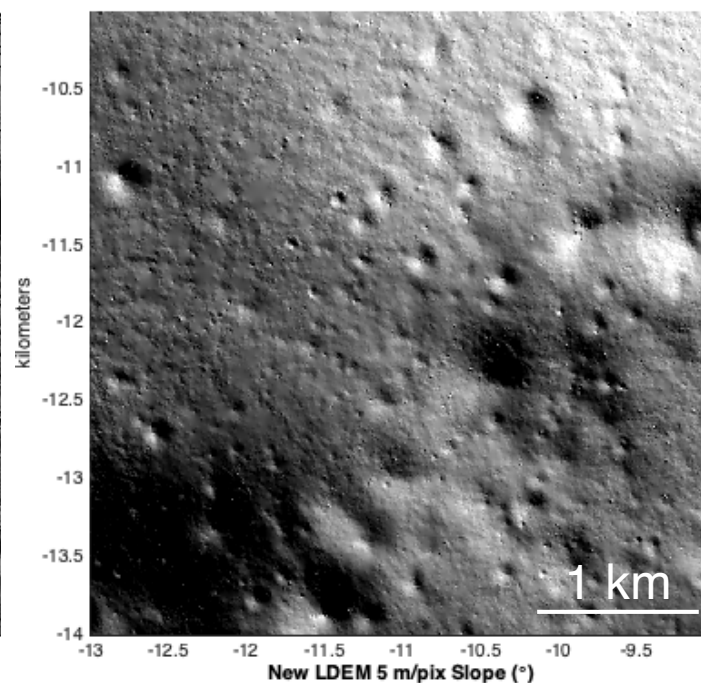
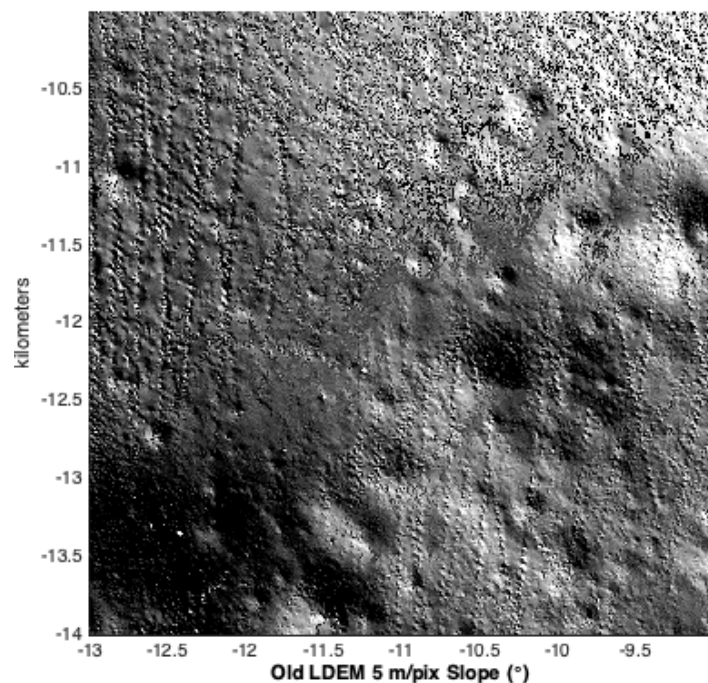
- 3-D offsets are estimated for each track against an independent basemap made of 98% of the tracks; so work in 50 batches
 - Track adjustments converge towards zero and their dispersion decreases with each iteration.
 - After 5 iterations, spread of offsets reduced by $>10\times$, to 0.14/0.12/0.02 m
 - Typical along-track/cross-track/radial (ACR) offsets 7.01/6.59/0.27 m, consistent with LRO orbit errors
- We also remove a small percentage ($\sim 0.1\%$) of outliers based on their abnormally high residuals and high slopes relative to local terrain.

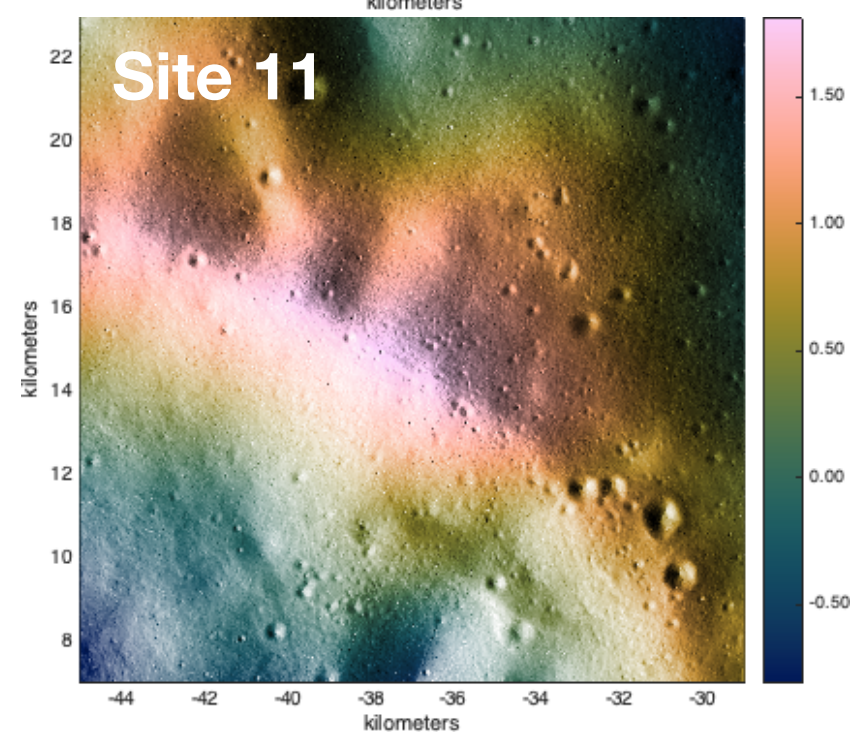
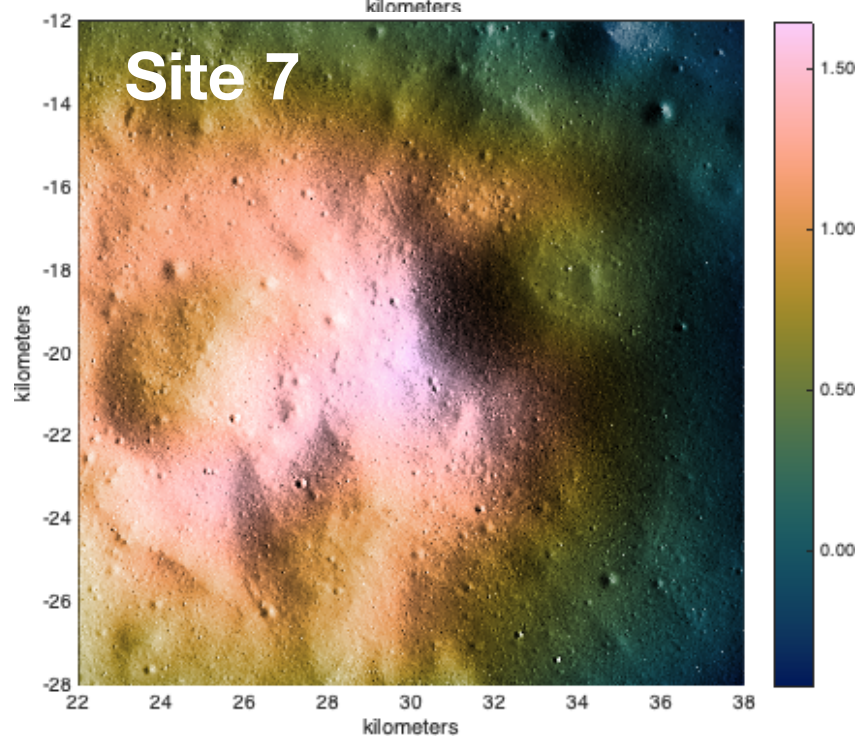
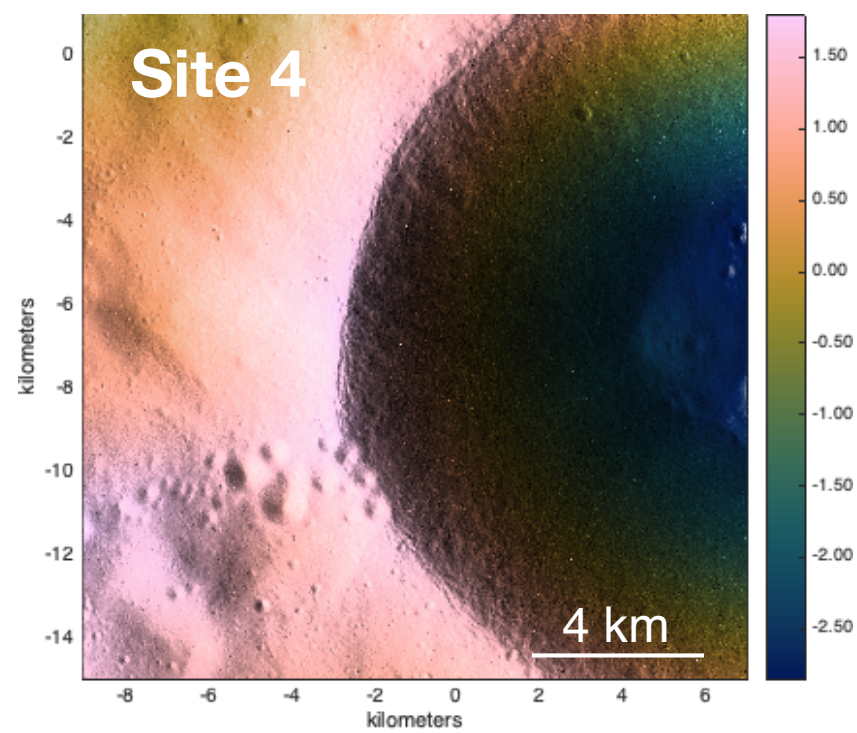
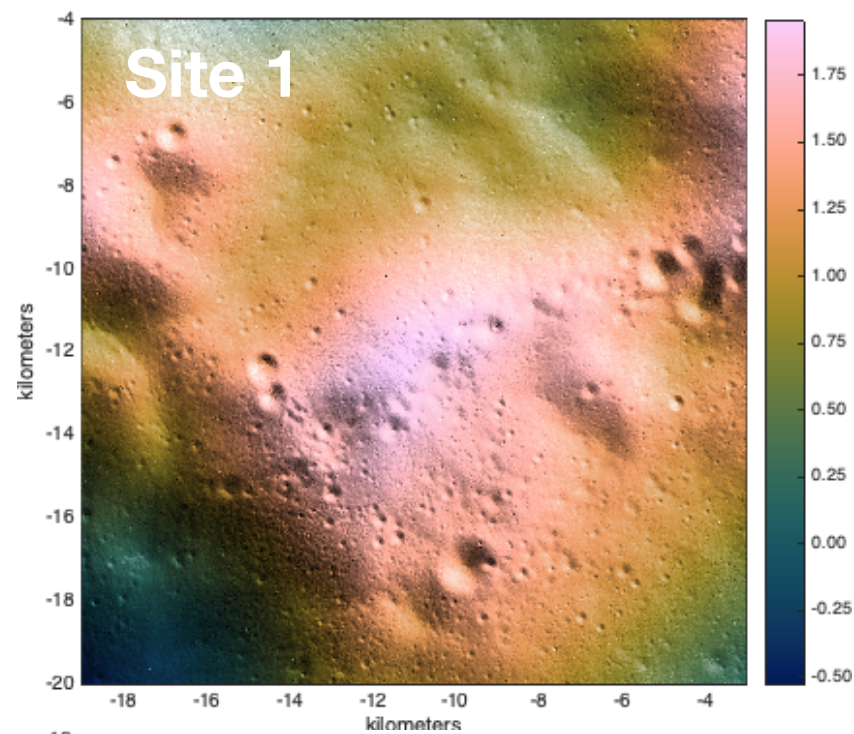


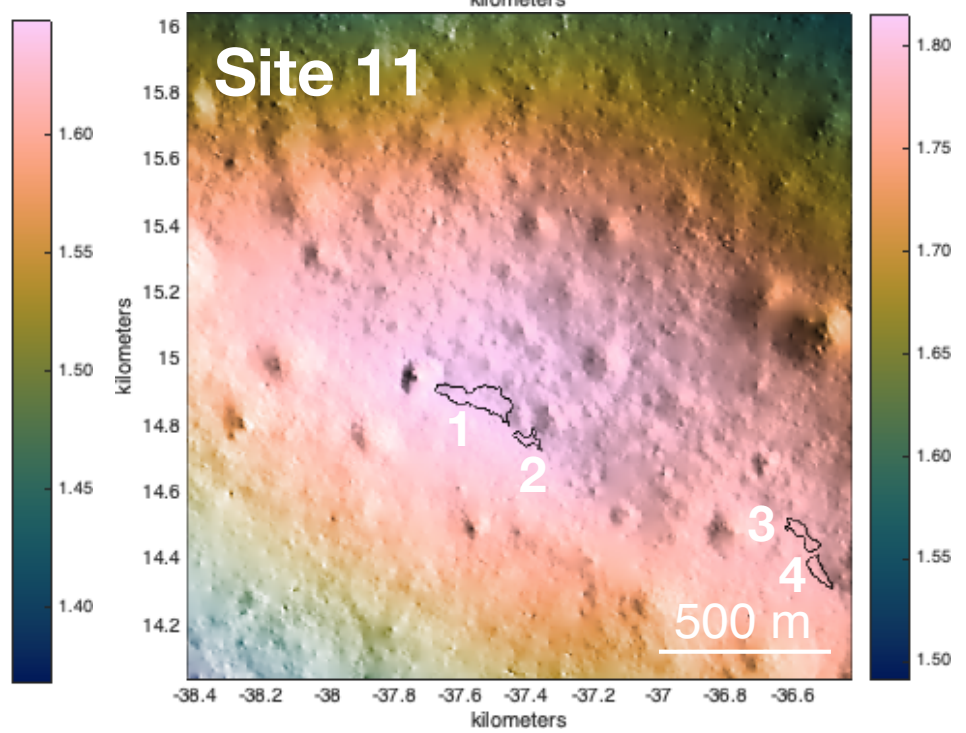
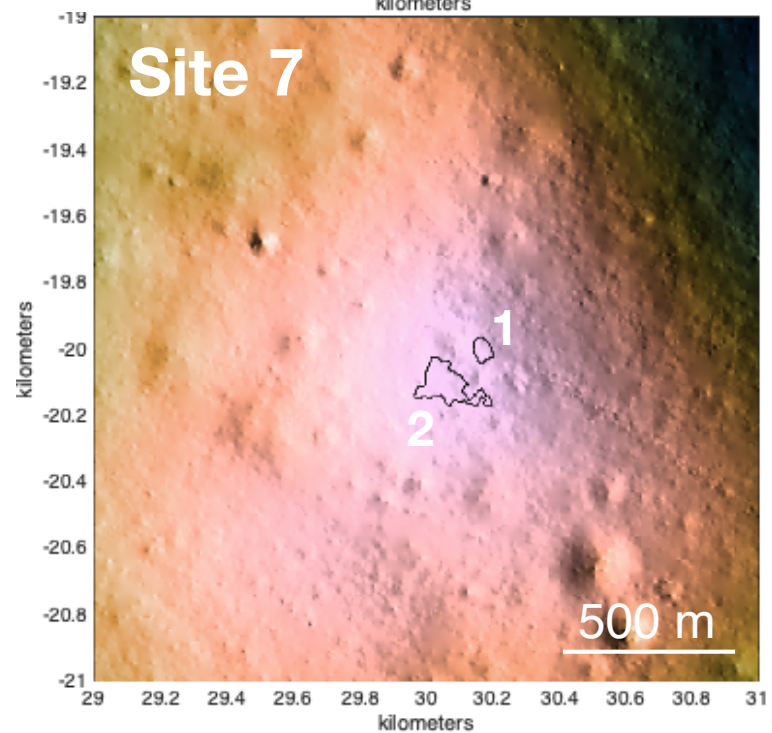
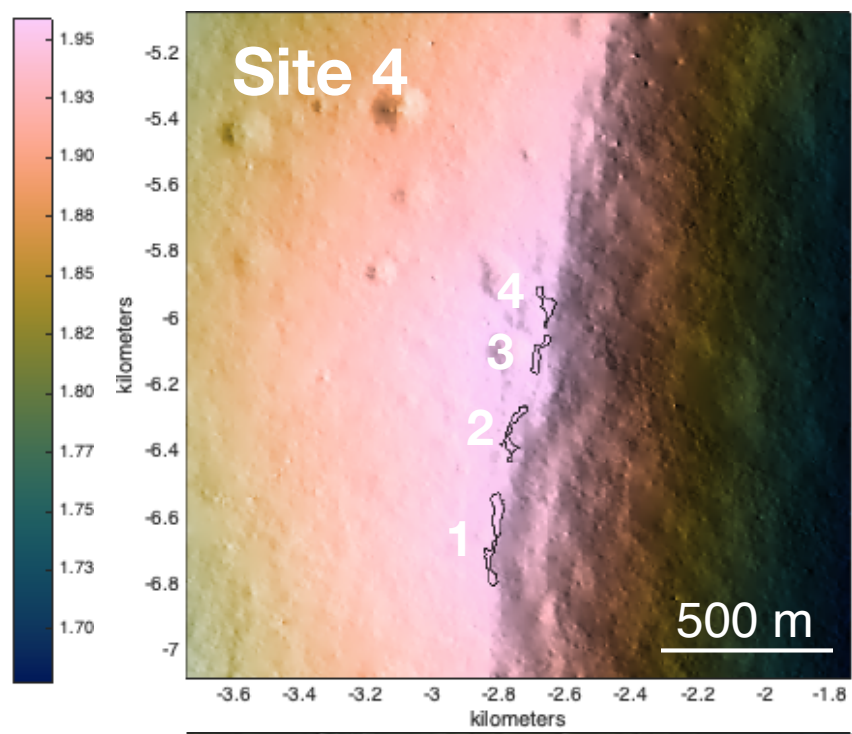
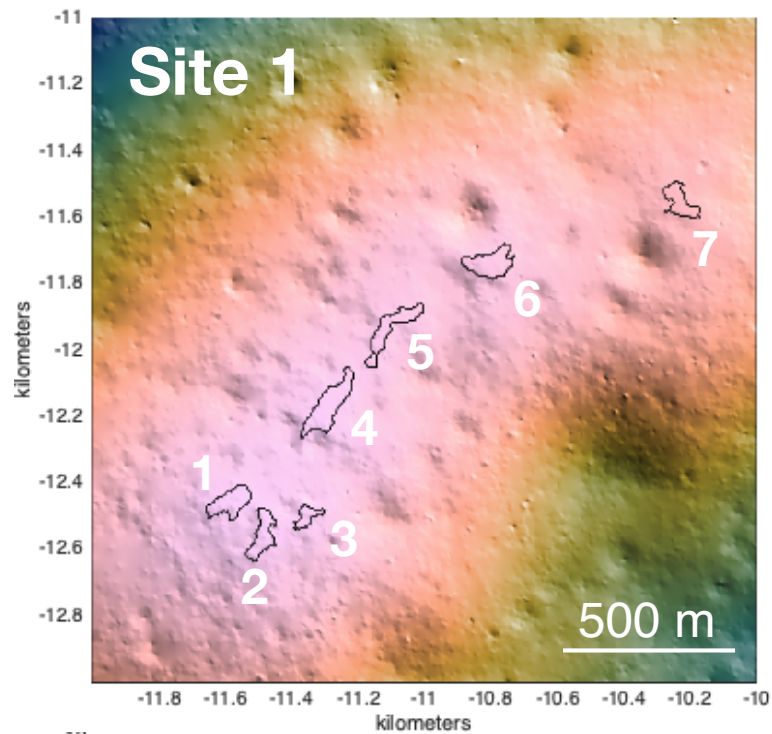
Improved DEM

Site 1 Before

Site 1 After

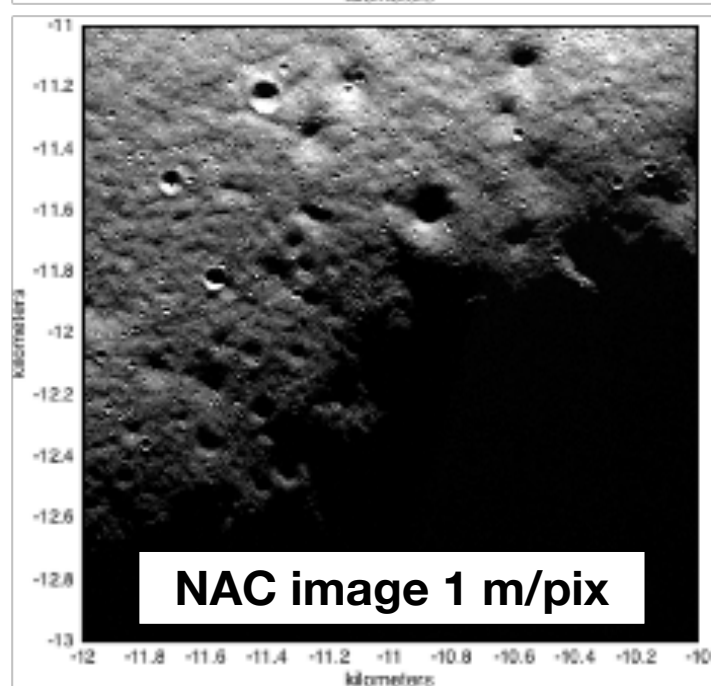
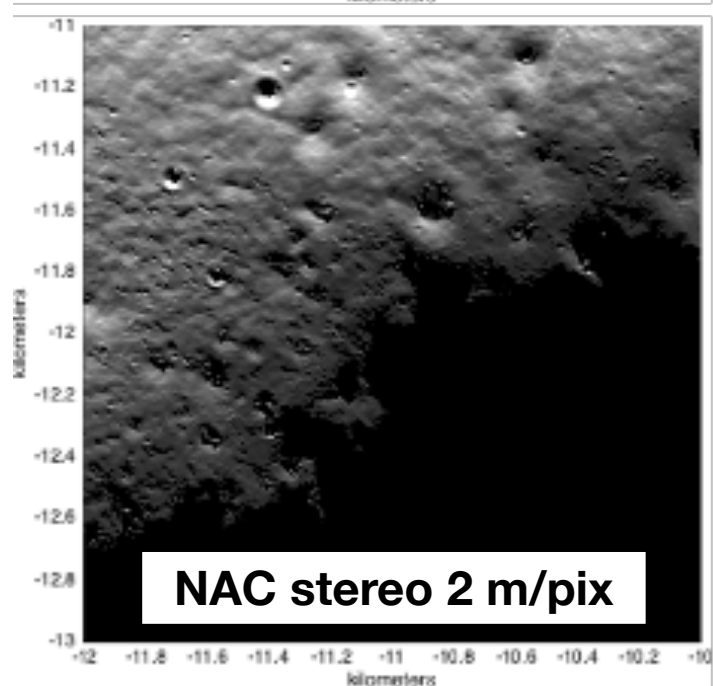
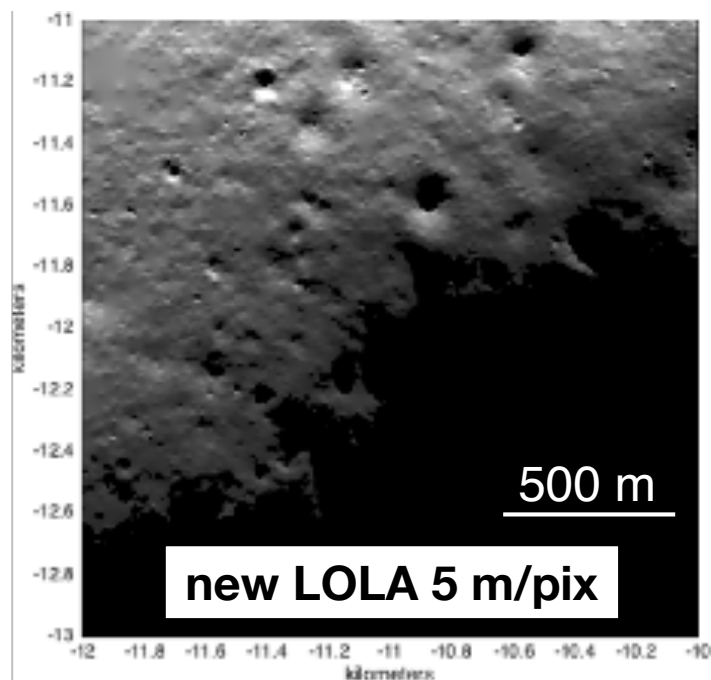
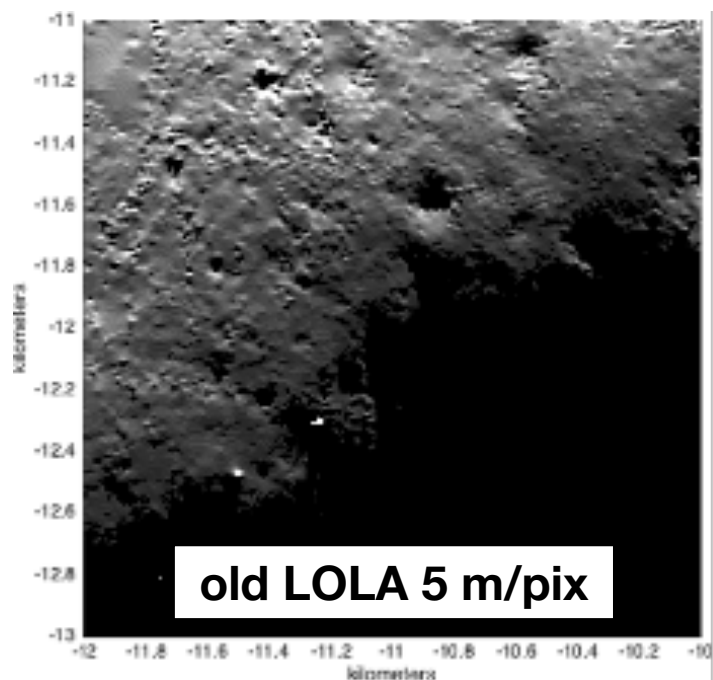






black contours show $>2500\text{m}^2$ regions with $> 70\%$ average illumination in 2024 - 2025

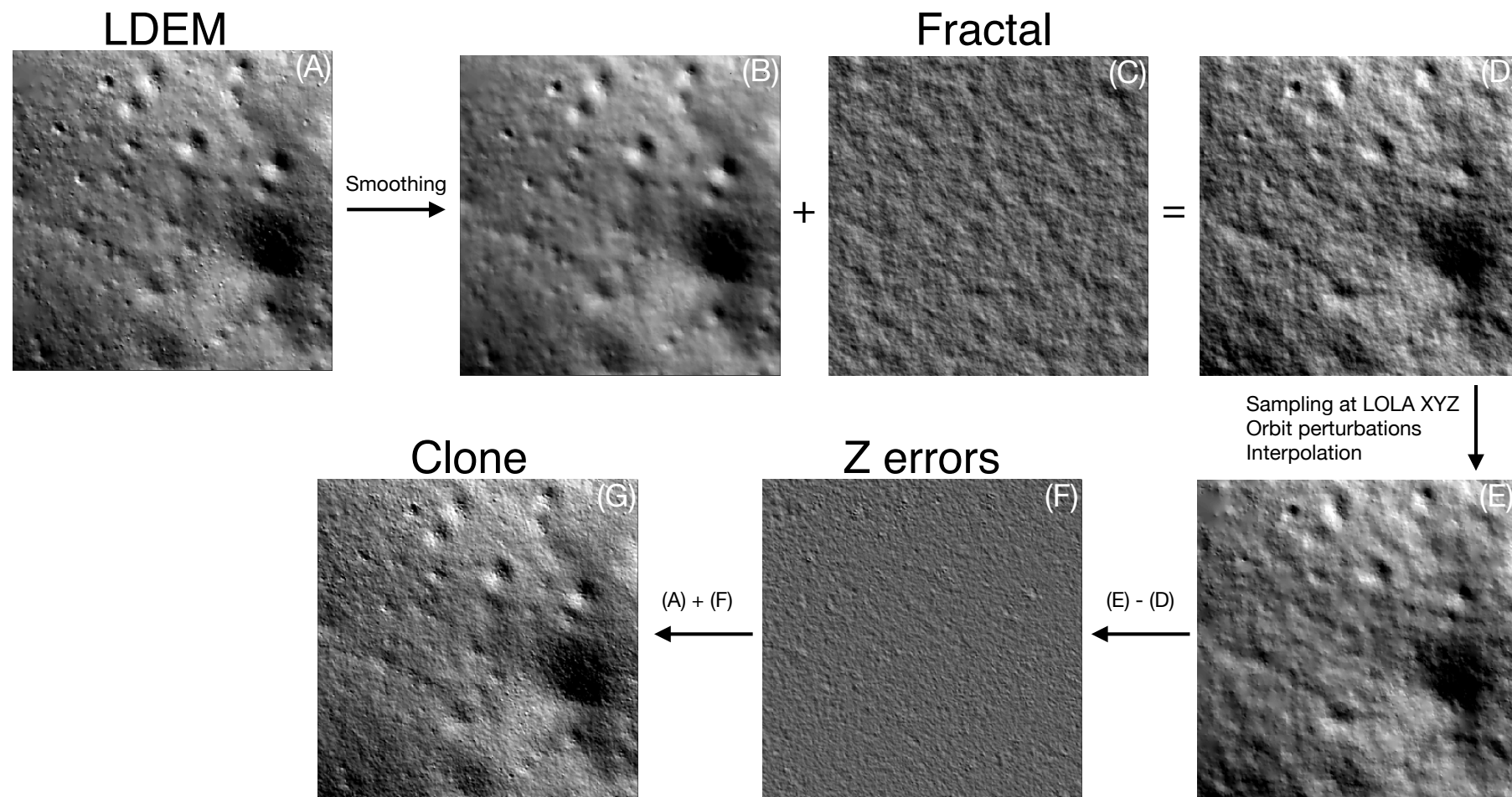
Image Simulation Comparison



**LROC Narrow
Angle Camera
(NAC) image
M139811097L/R**

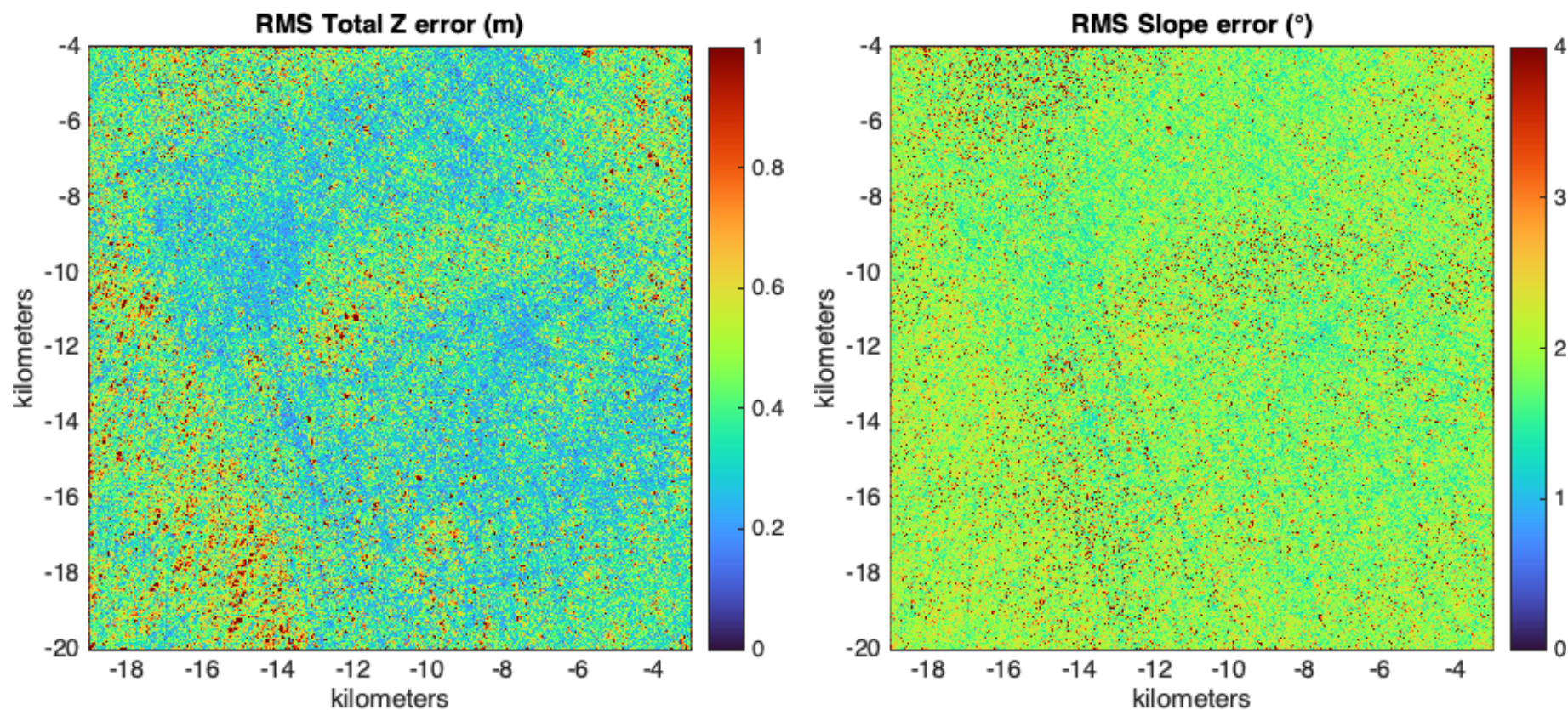
Assessing Uncertainty

- We circumvent the infeasible computation of the full error-covariance matrix of the DEM. Instead, we use the fractal nature of lunar topography to build a statistical ensemble
 - 100 “clones” with similar error properties as the data

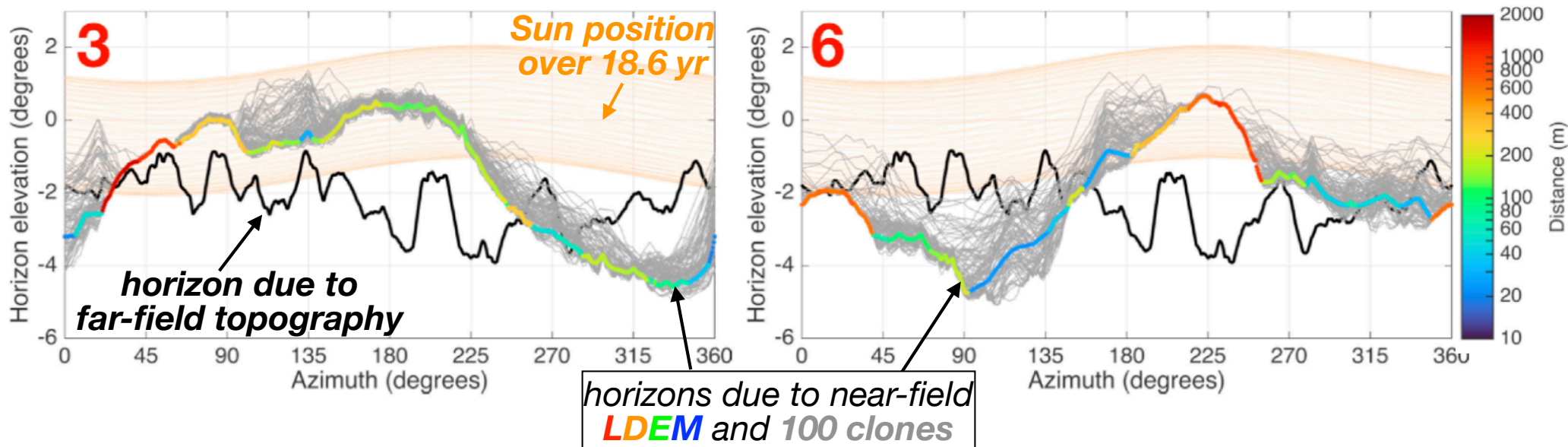


Assessing Uncertainty

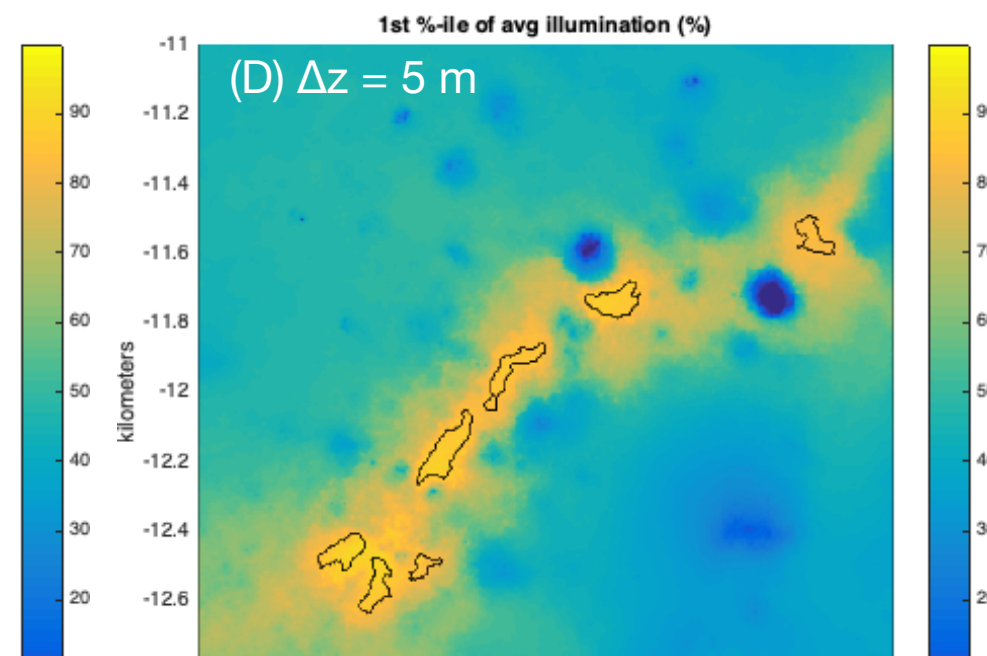
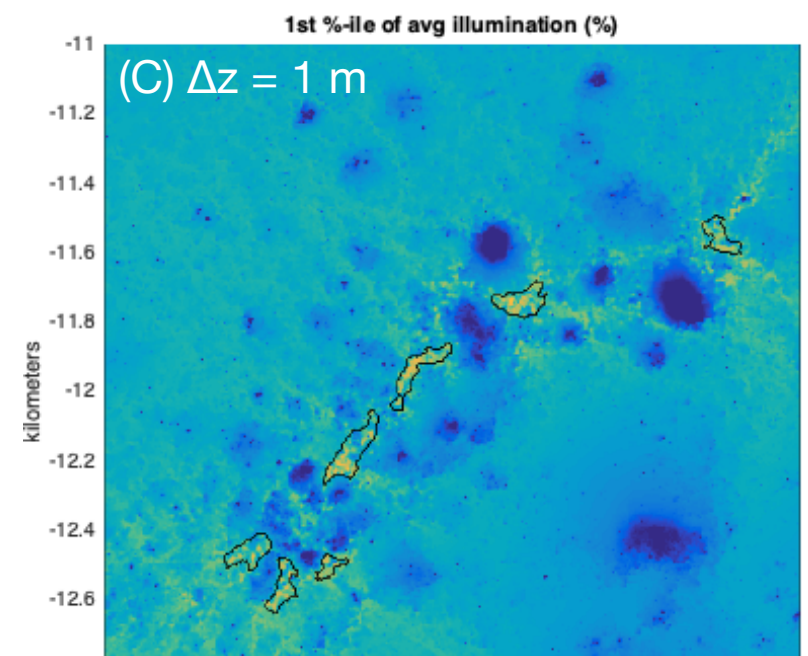
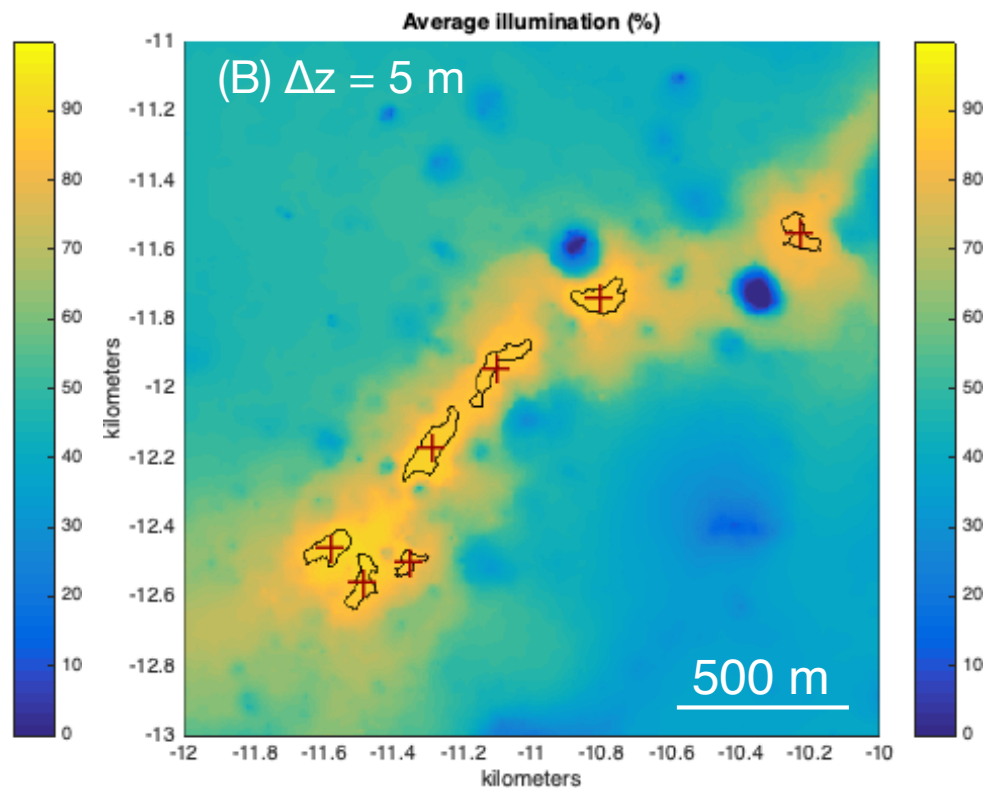
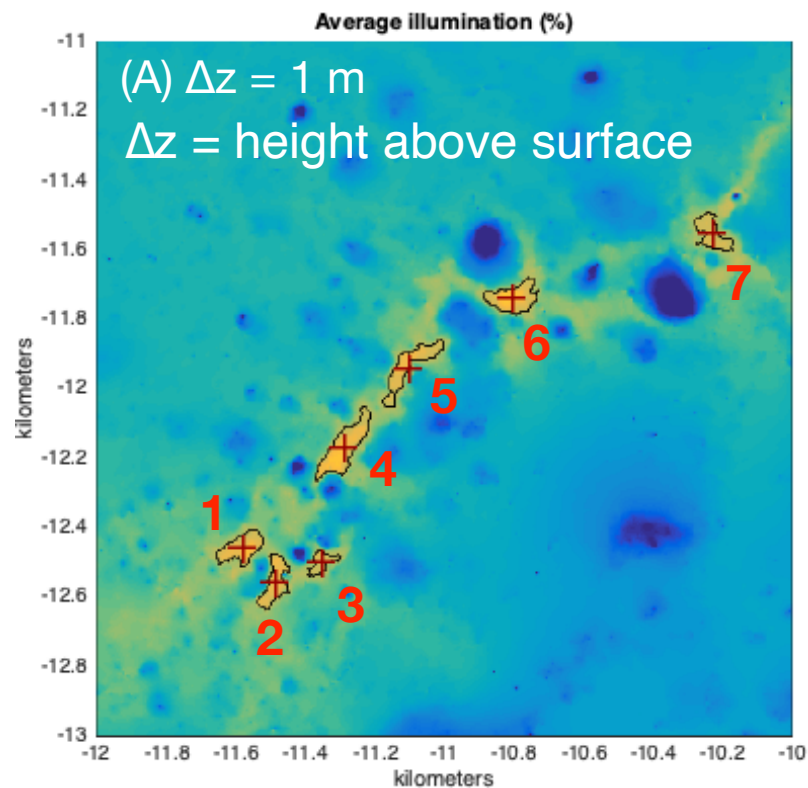
- Typical height / slope RMS uncertainties are 0.3-0.5 m / 1.5-2.5°
 - Interpolation and slope error are spatially correlated with gap size (inverse of LOLA point density) and with slope.
 - Can be used as weight maps when constraining higher-resolution models, solar array height, traverse planning, etc.



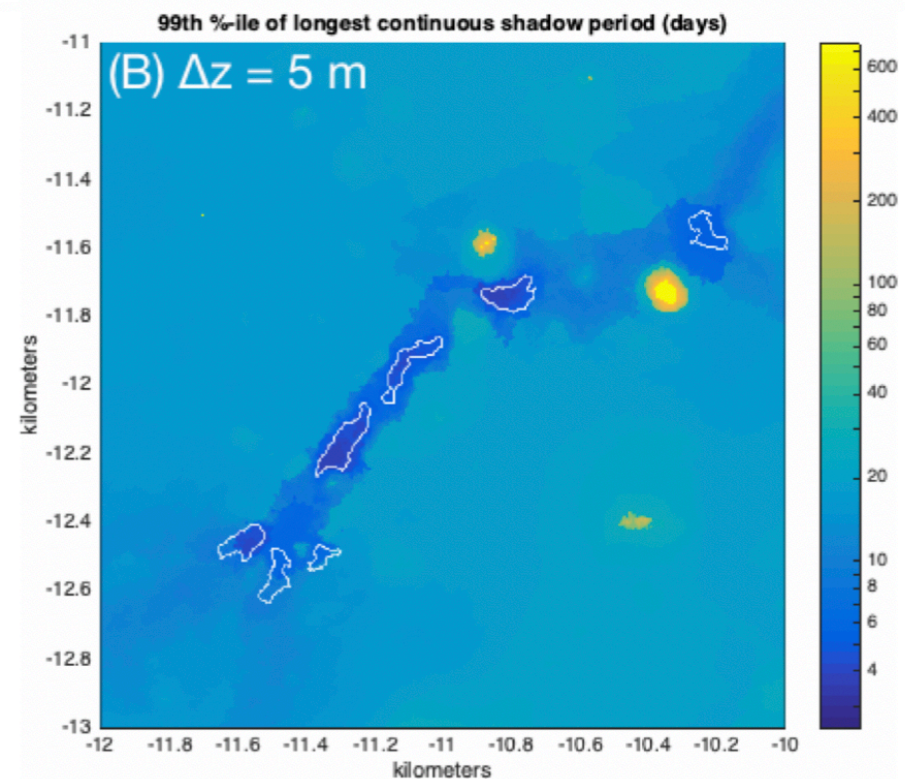
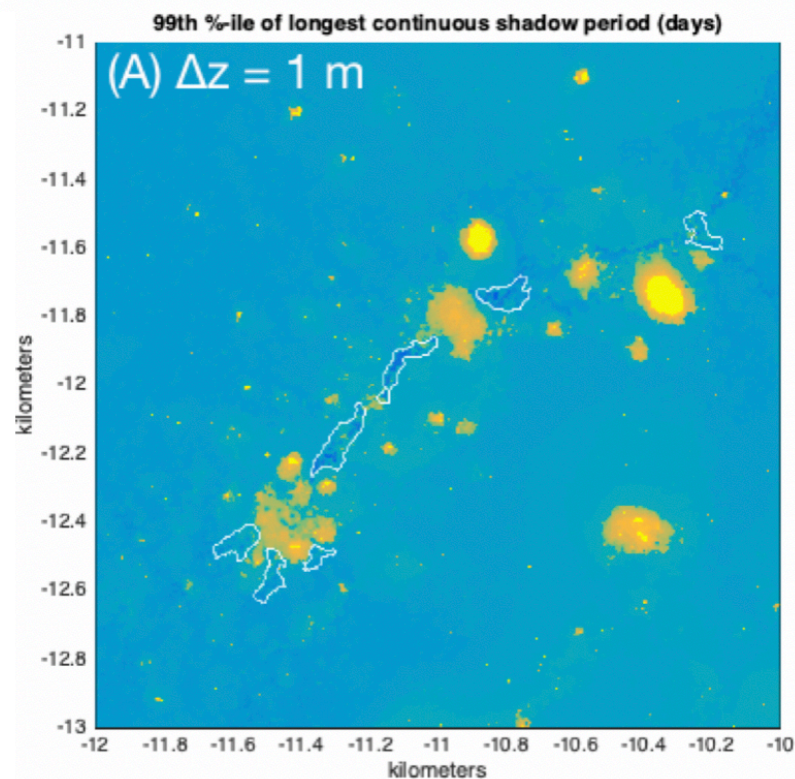
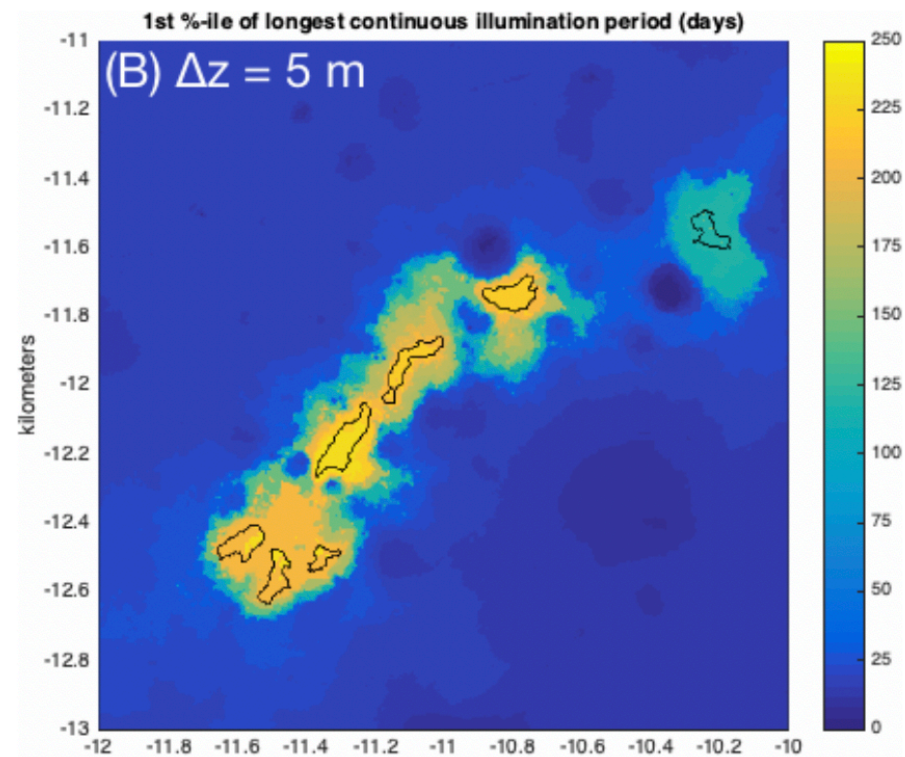
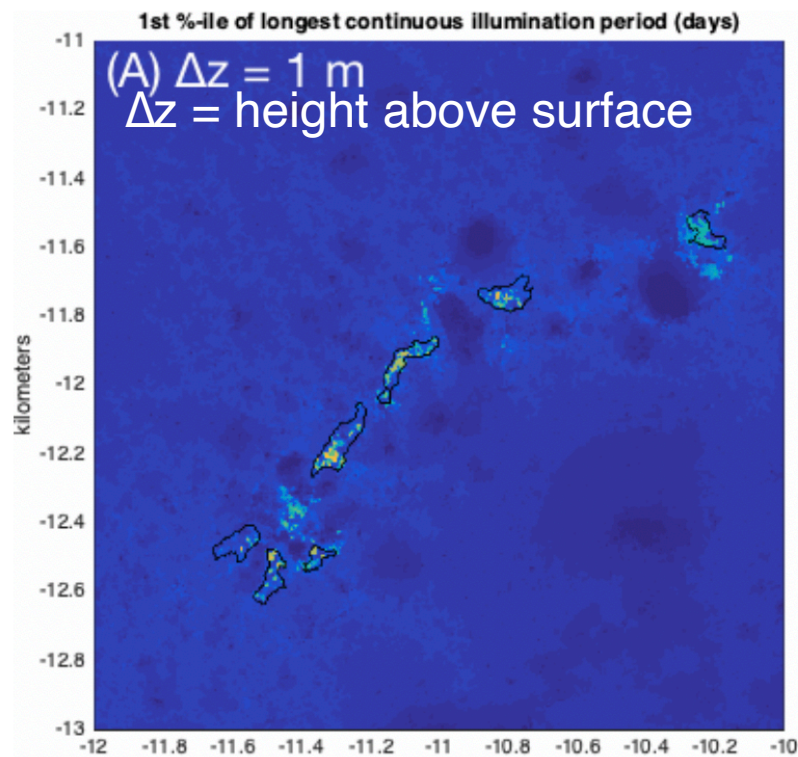
- We use the nominal DEM and its 100 clones to evaluate statistical spread of illumination condition properties
 - surface height errors translate to near-field horizon elevation errors and variations in illumination conditions.



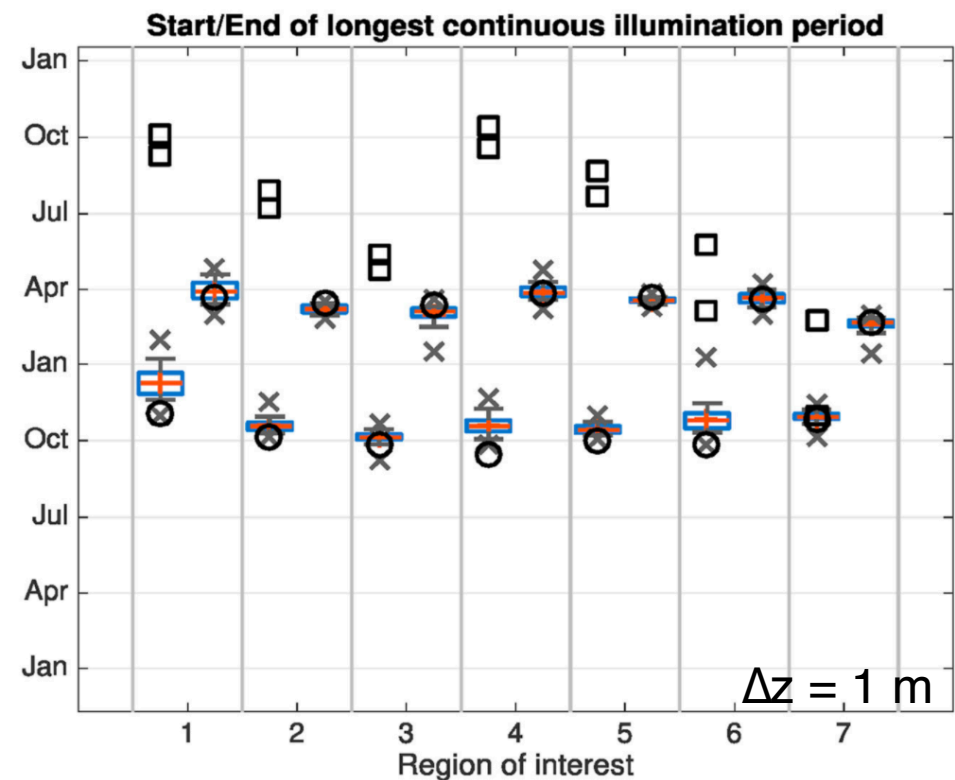
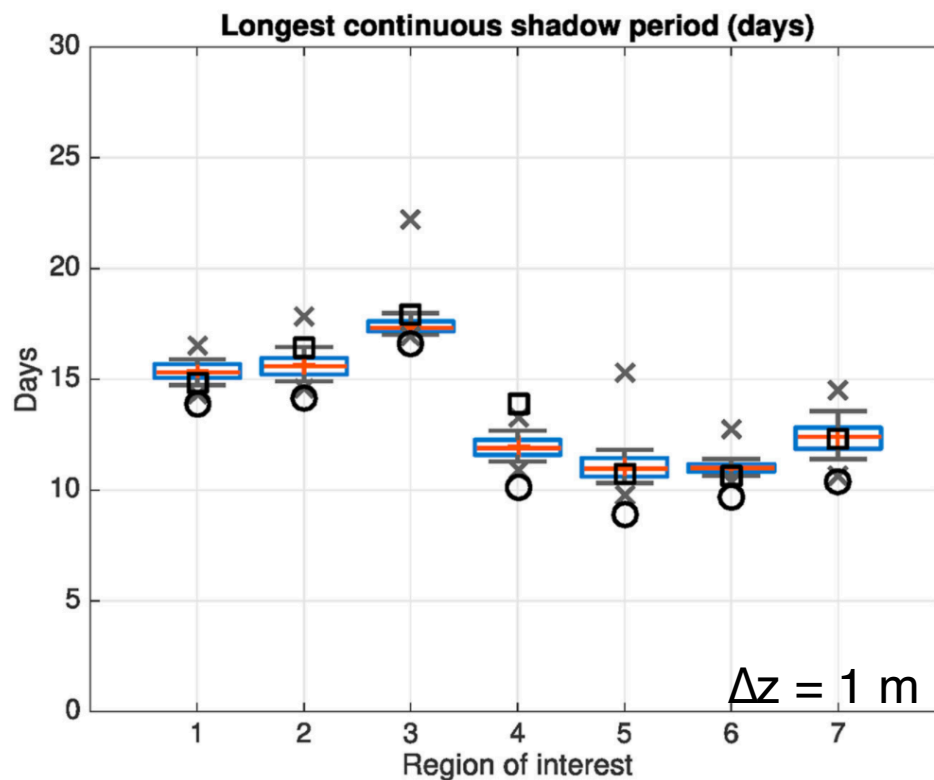
- We do that for the whole map at 2 heights above the surface
- Figures of Merit: Average illumination, Longest day, Longest night



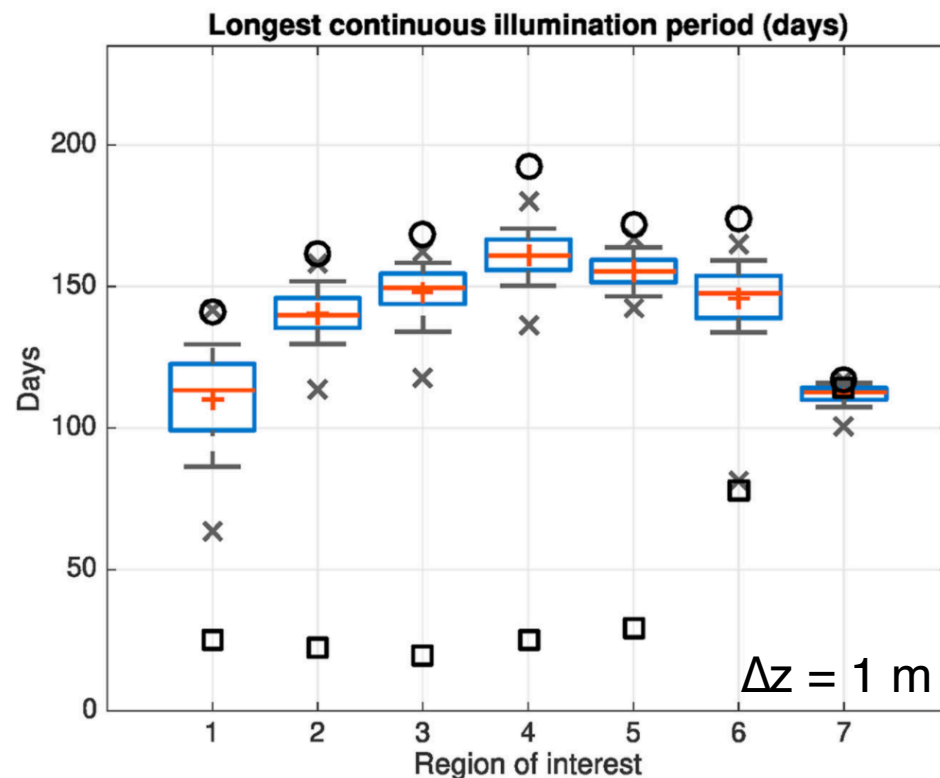
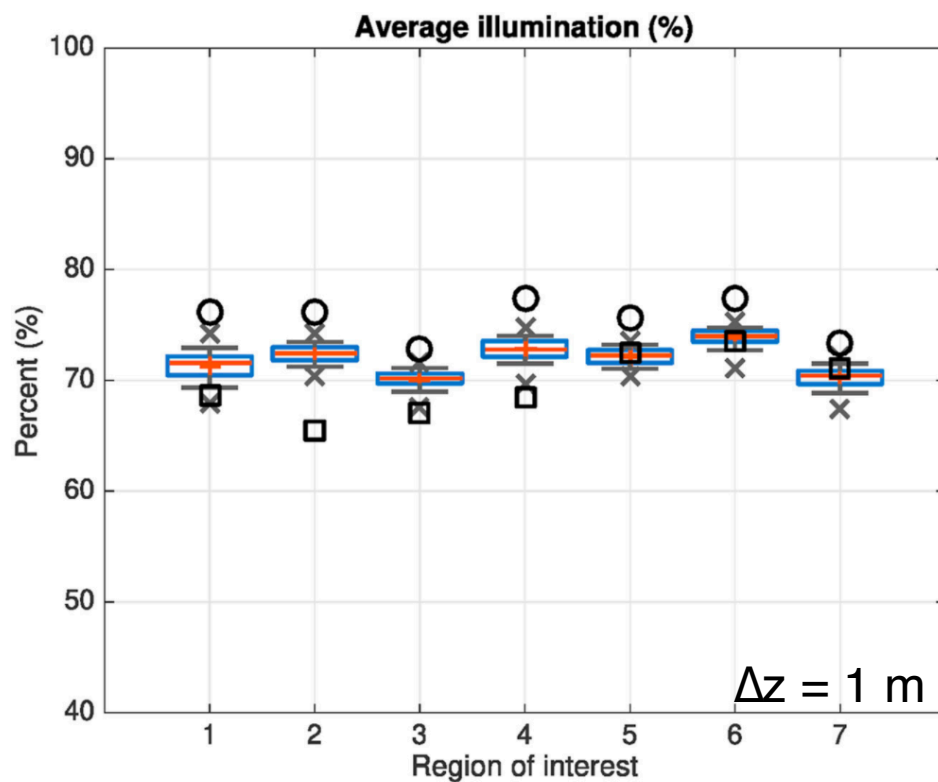
black contours: regions with $> 70\%$ average illumination in 2024 - 2025 at $\Delta z = 1$ m and area > 2500 m²



- Including the impact of DEM height errors can better bound the minimum and maximum values of key properties: average illumination, longest day, longest night, etc.
- RoI performance can vary in one metric vs. another

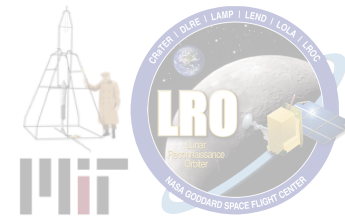


- Including the impact of DEM height errors can better bound the minimum and maximum values of key properties: average illumination, longest day, longest night, etc.
- RoI performance can vary in one metric vs. another





Summary



- New high-resolution topographic maps of 4 high-priority lunar south pole landing sites based exclusively on LOLA data.
- Most of the 5-m pixels are interpolated due to LOLA's cross-track and inter-spot spacing, but the interpolation errors are quantifiable and manageable.
- These DEMs have accurate geodetic control and are unaffected by shadows.
- Height uncertainties propagate to variations in horizon elevation and thus the predicted illumination conditions.
- Error characterization can inform landing site studies and figures of merit.
- For small-scale detailed site studies, recommend using all available datasets together (LOLA, images, image-based DEMs)

Paper: <https://doi.org/10.1016/j.pss.2020.105119>

Data: <https://pgda.gsfc.nasa.gov/products/78>