ALHAT

Assessing Safe Lunar Landing Site Statistics With Synthetic DEMs

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ALHAT Overview

- Autonomous Landing and Hazard Avoidance Technology (ALHAT)
- Develop and deliver a lunar GNC descent and landing subsystem and certify it to a TRL 6 through analysis and testing
  - Functional on robotic, cargo and human missions
  - Place a lander anywhere on the lunar surface under any lighting conditions within 10's of meters of certified landing sites
  - Detect surface hazards so the lander can re-designate to a hazard free landing area.
- Involves JSC, JPL, APL, Langley, Draper, SAIC, Fastmetrix, Jacobs, Utah State Univ, Univ of Texas

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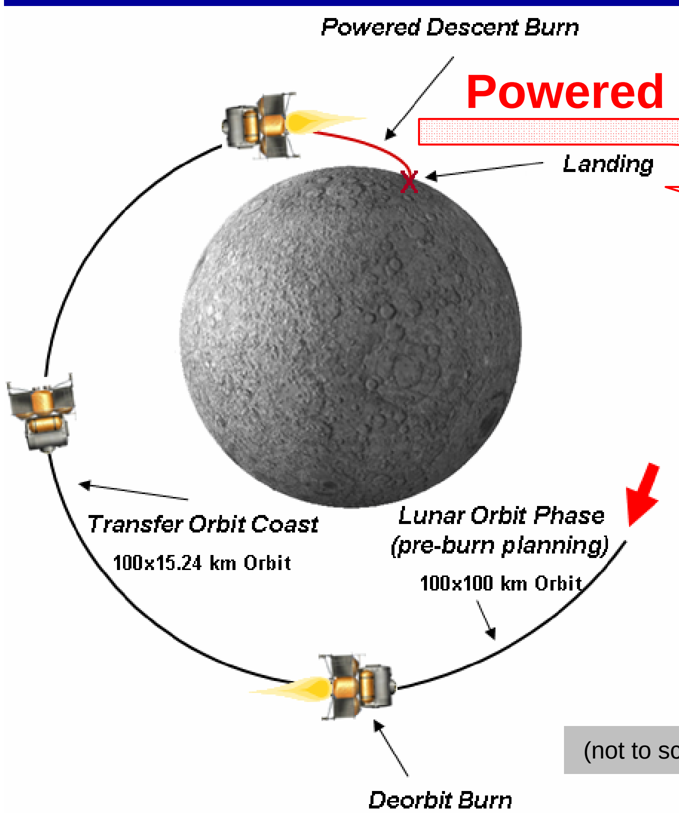
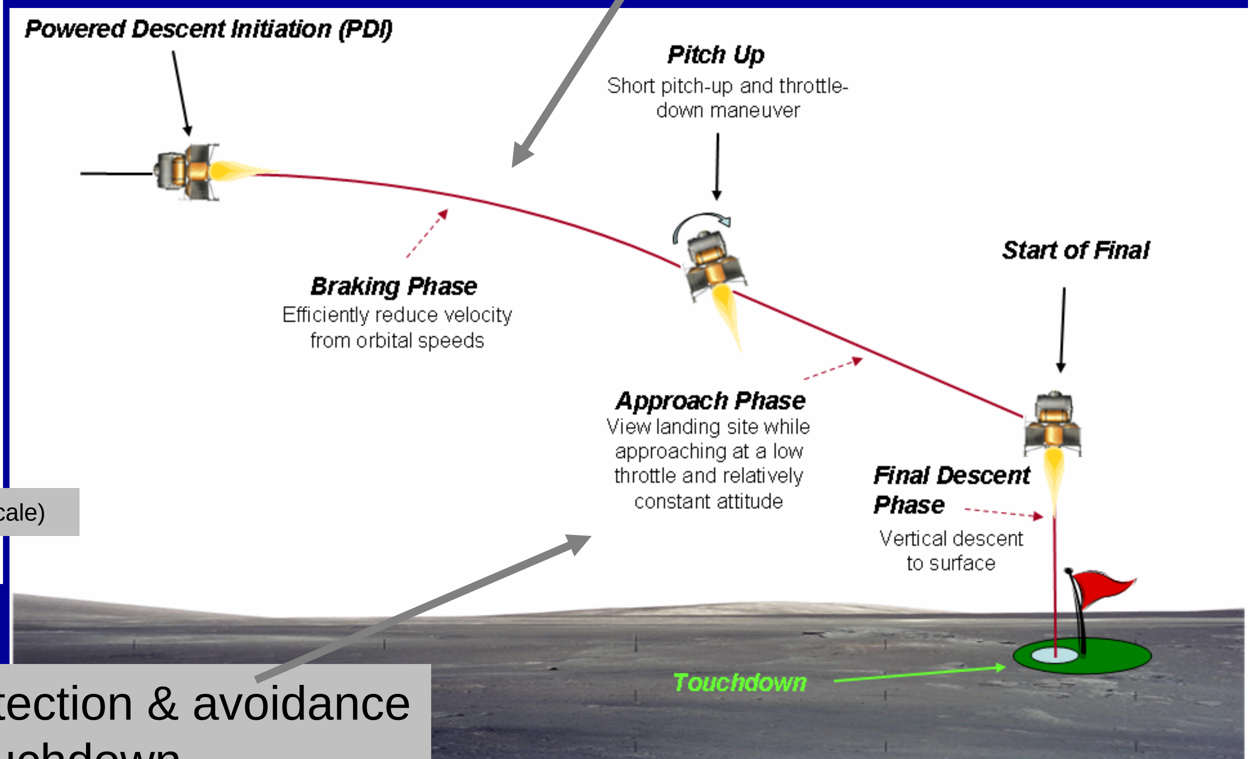
Landing Phases



Powered Descent

(not to scale)

TRN: terrain relative navigation
- PDI to pitch-up



HDA: hazard detection & avoidance
- Pitch-up to touchdown

What is a Safe Landing Site?

Lander must either

- Do pinpoint landing at site known to be safe, or
- Assess local hazards and be capable of redirecting to a safe site

What is "safe" ?

- Free of steep slopes or boulders that could cause tipping or damage
- Often expressed as the maximum tilt that the lander can experience when it settles on the surface.

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Apollo LEM Tilts

Mission	Lander Tilt	Tilt Components
Apollo 11 Mare Tranq	4.5 °	4.5 ° roll
Apollo 12 Oc Proc	4 °	3 ° pitch up, 3.8 ° roll
Apollo 14 Fra Mauro	8 °	1 ° pitch down, 6.9 ° roll
Apollo 15 Palus Putred	11 °	6.9 ° pitch up, 8.6 ° roll
Apollo 16 Descartes	2.5 °	2.5 ° pitch up
Apollo 17 Taurus-Littrow	4-5 °	4-5 ° pitch up

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APL

Apollo 15

Landed on the inner rim of a small crater, "right where I wanted".

+Z and +Y footpads on a rise, –Z in shallow crater 5 to 6 m diameter; -Y footpad also in depression.

11 ° tilt.

Synthetic DEMs

The crater size-frequency distributions for surfaces of various ages have been measured.

We use APL's CraterGenerator & DEMmaker software to create Digitial Elevation Models (DEMs) for surfaces with a given crater distribution.

Craters are "dug" using the typical morphometry of craters in each size range (depth/diameter ratio, rim height, floor profile, etc.).

- Can use ULCN topography as the base, then superimpose smaller synthetic craters on the base

Rock distribution models, also based on observations, are currently being incorporated.

Therefore we can create a synthetic DEM for a surface of a specified age (e.g., Shackleton = 3.6 Ga, Spudis et al., 2008).

Spatial resolution can be finer than that of LRO data.

Synthetic DEMs, con't

By generating many DEMs with randomly placed craters, we can get an idea of the "average" surface that a lander would be expected to encounter.

Simple image processing can be used to determine a number of useful parameters related to the topography/safety of a particular site.

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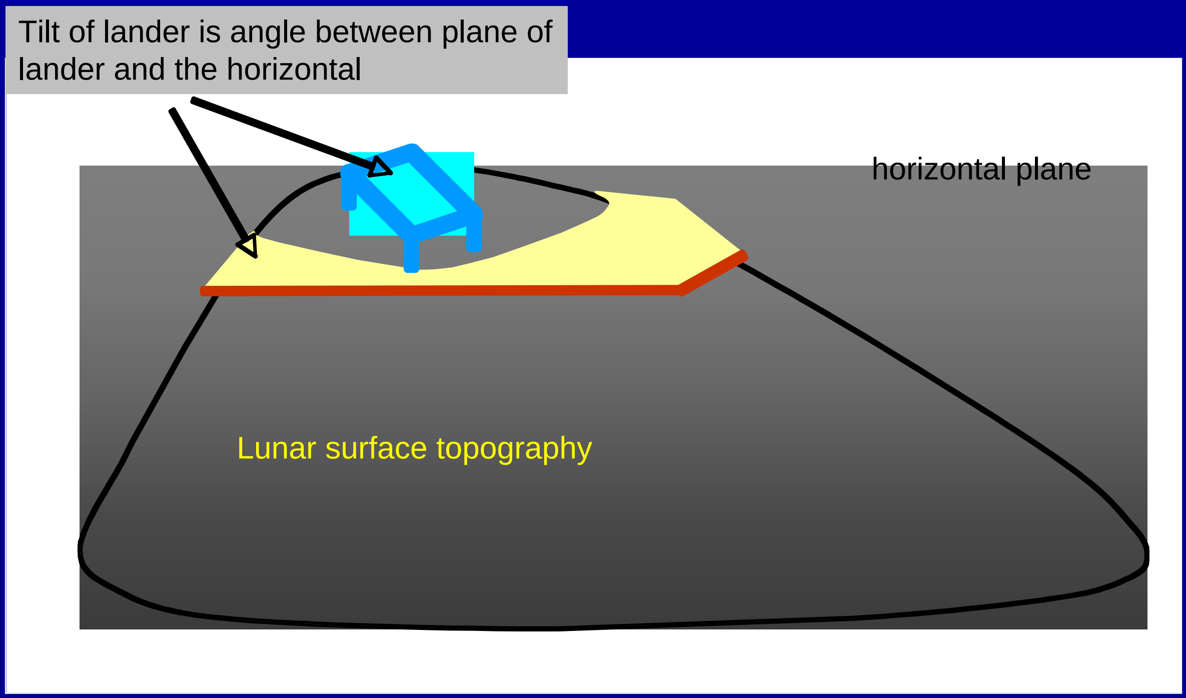
Assessing a Safe Landing Site

Assume a lander with legspan *d* (distance between the legs) (15 m)

Assume a footpad size (1 m)

Place the lander centered at every pixel in the DEM image. At each location, look at the elevations beneath the four footpads.

- Fit a plane to three of the points, compute worst-case tilt.



The resulting tilt image can be thresholded at any desired value, and the percentage of pixels below the threshold determined.

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Synthetic Shackleton DEM

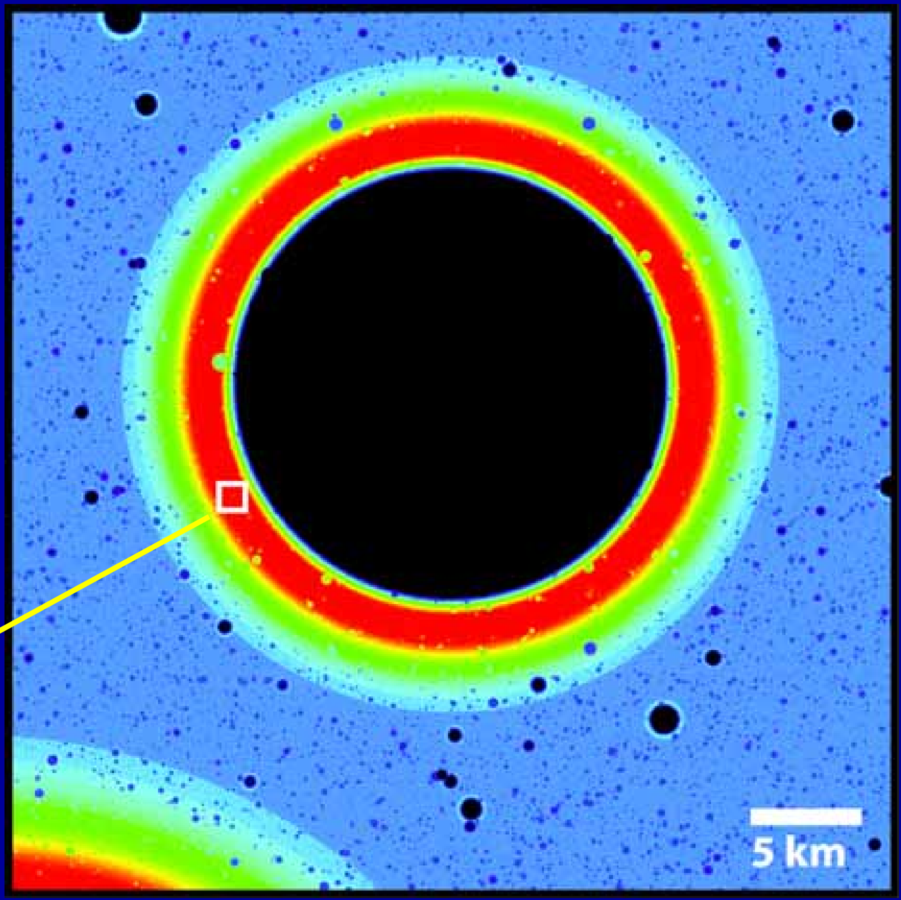
Created with CraterGenerator/ DEMmaker.

Crater distribution for "average mare" surface.

Image is 40 × 40 km, polar projection centered on 90º S.

1 meter/pixel spatial resolution.

Take a small area from high point of rim, 1 × 1 km.



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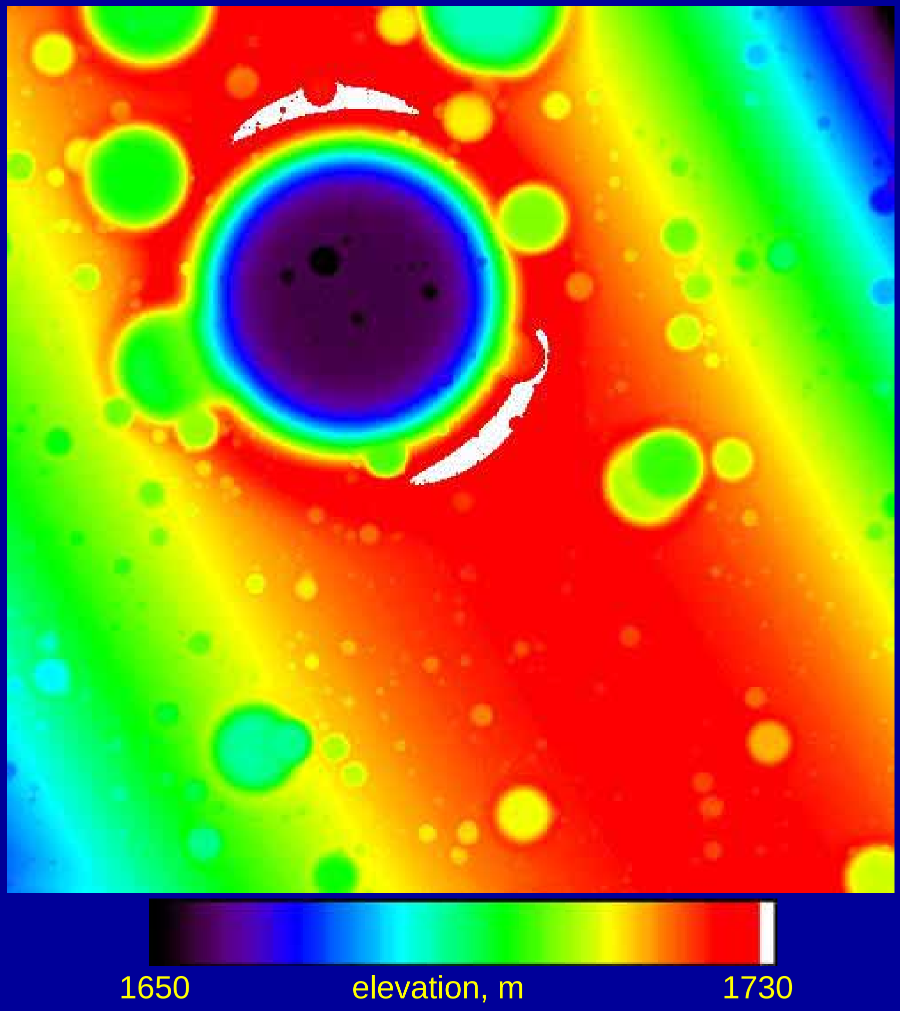
Synthetic Shackleton Rim DEM

Crater distribution for "average mare" surface.

1 meter/pixel spatial resolution

Small area from high point of rim, 1 × 1 km



Shackleton_90S_0_1M_yoma_surfPR89S045P3L_subset_meters

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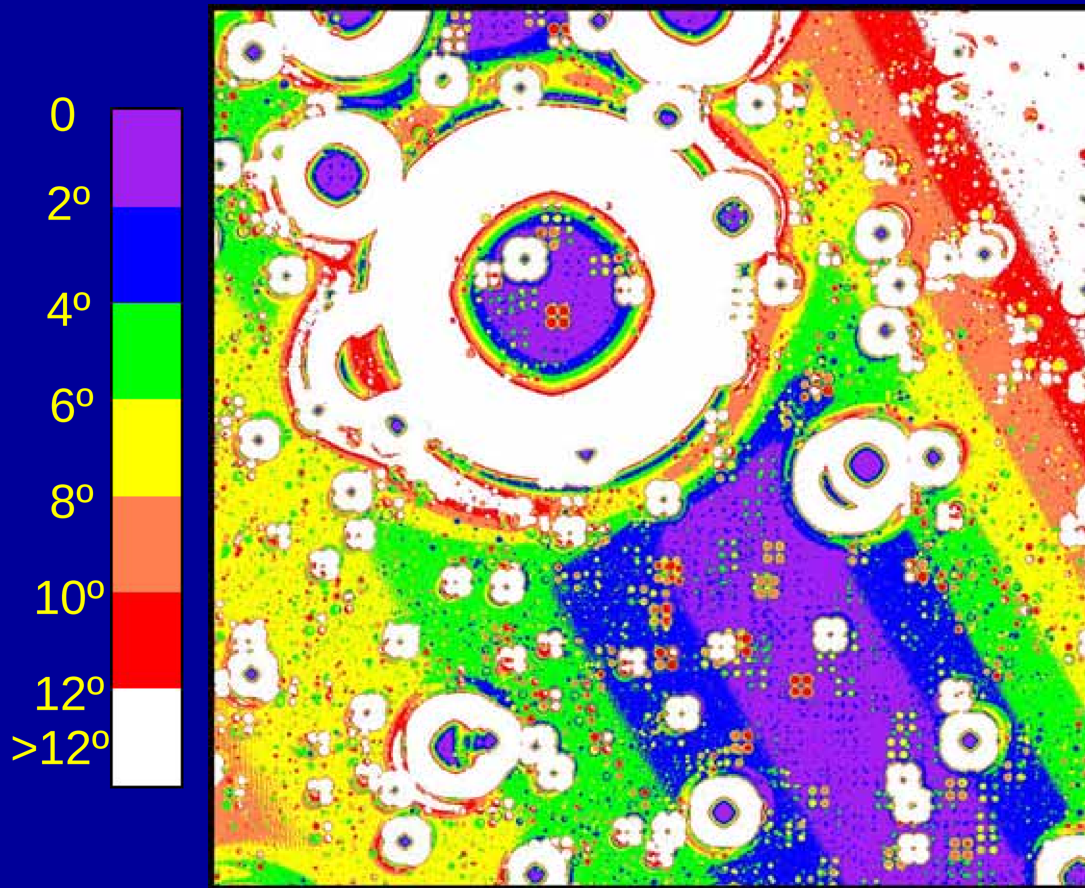
Synthetic Shackleton Rim: Tilt Map

Average mare crater distribution.

Proportion of area with tilt <5° is 25%.

Proportion of area with tilt <10° is 59%.



1 × 1 km area

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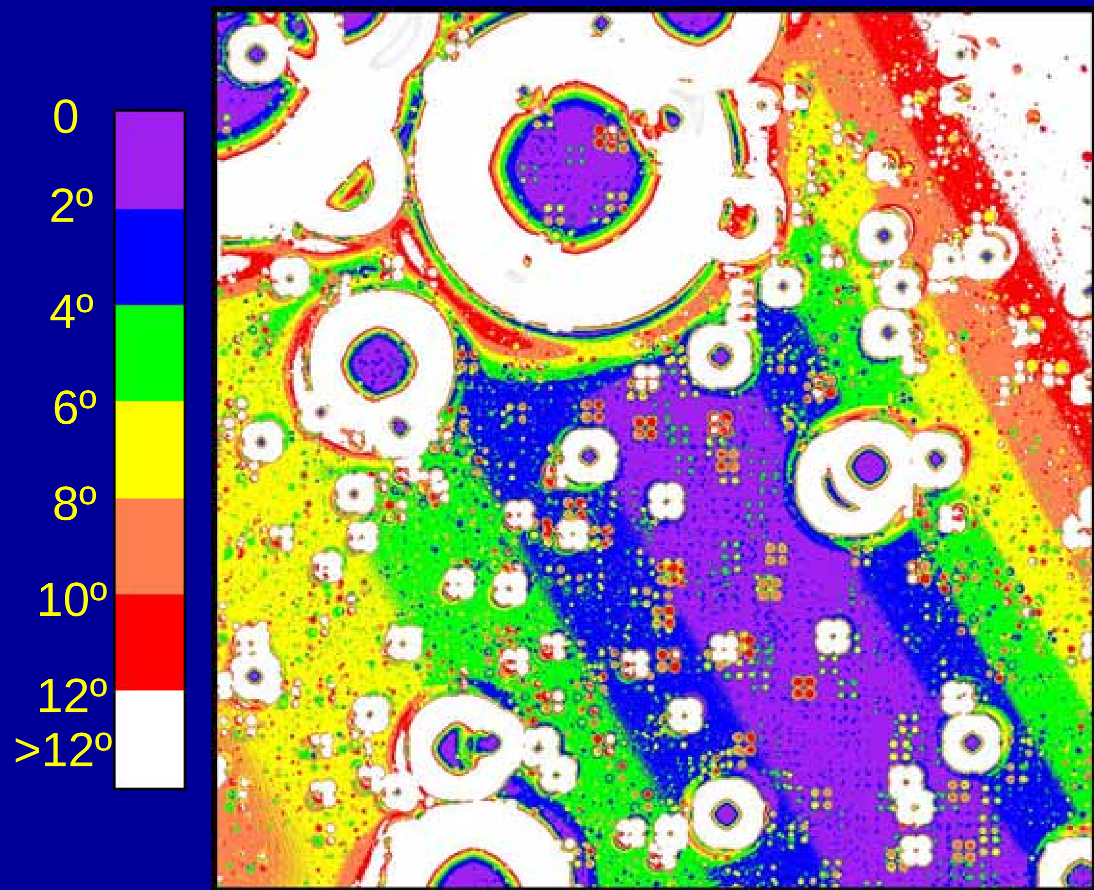
Synthetic Shackleton Rim: Tilt Map

Ancient highland crater distribution.

Proportion of area with tilt <5 ° is 29%.

Proportion of area with tilt <10 ° is 61%.



1×1 km area

Shackleton_90S_0_1M_anc_surfPR89S045P3L_subset_meters_tiltmap

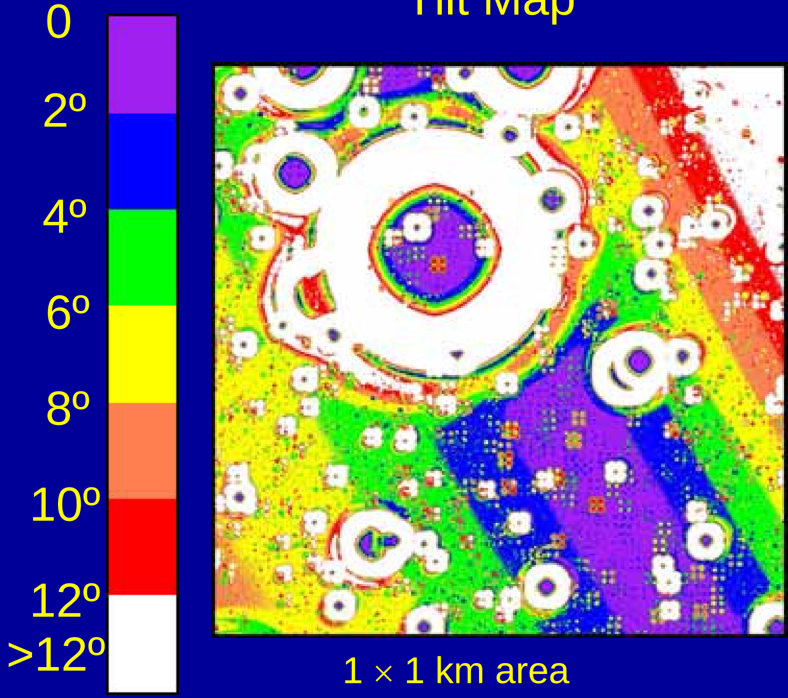
Safe Landing Zone Map

Process tilt image to produce additional parameters

Safe Landing Zone:
Choose a box size (e.g., 90 meters to represent landing ellipse).
Look at every 90-m box in the image.
What % of pixels have a tilt less than a threshold (e.g., 5º)?
If this % is greater than a threshold (e.g., 80%), declare the box "a safe zone".

Synthetic Shackleton: Safe Landing Zone Map

Tilt Map



1 × 1 km area

90 meter box

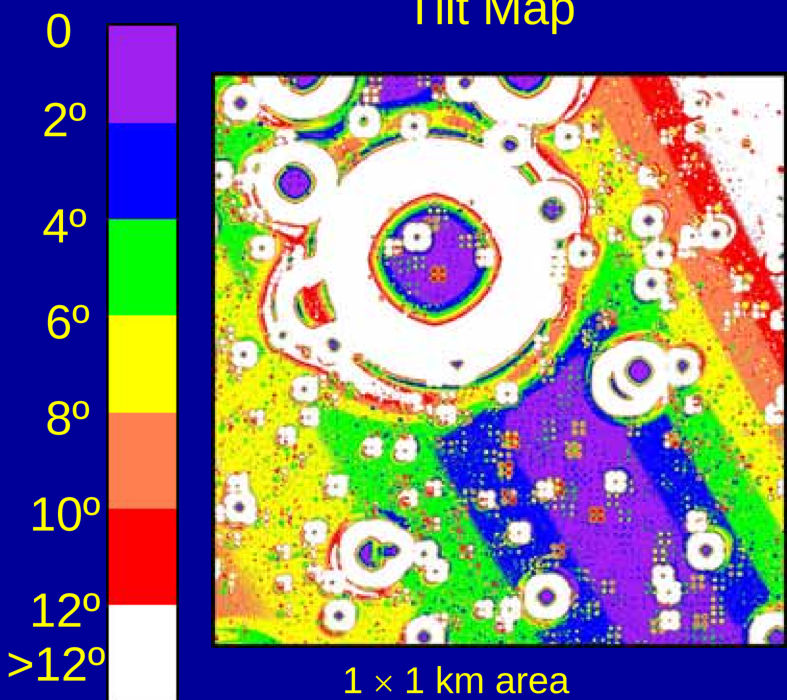
average mare crater distribution

Safe Landing Zone Map

Each white pixel is at the center of a 90 × 90 m box that has a tilt of <5º over more than 80% of the area.
9.7% of the pixels in the image meet this criterion.

Synthetic Shackleton: Safe Landing Zone Map

Tilt Map

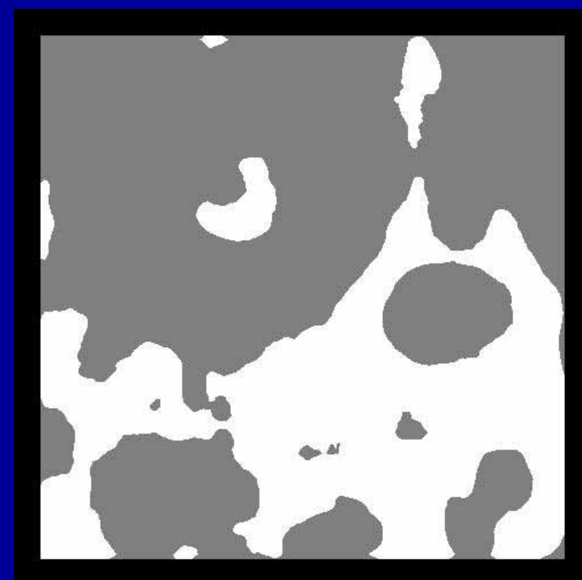


1 × 1 km area

90 meter box

average mare crater distribution

Safe Landing Zone Map

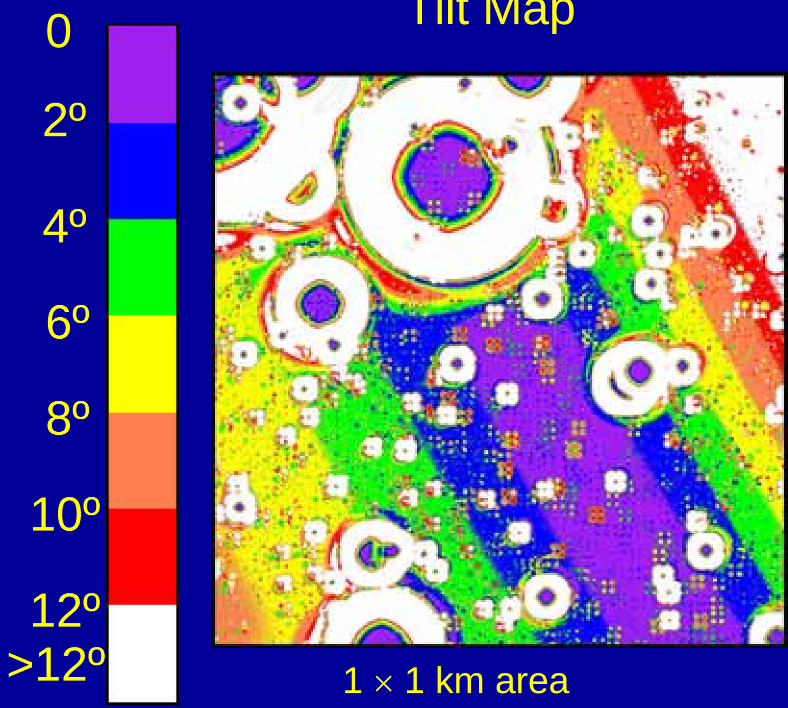


Each white pixel is at the center of a 90 × 90 m box that has a tilt of <10º over more than 80% of the area.
36% of the pixels in the image meet this criterion.

Shackleton_90S_0_1M_yoma_surfPR89S045P3L_subset_safebox2

Synthetic Shackleton: Safe Landing Zone Map

Tilt Map



1 × 1 km area

90 meter box

ancient highland crater distribution

Safe Landing Zone Map

Each white pixel is at the center of a 90 × 90 m box that has a tilt of <5º over more 80% of the area.
11% of the pixels in the image meet this criterion.

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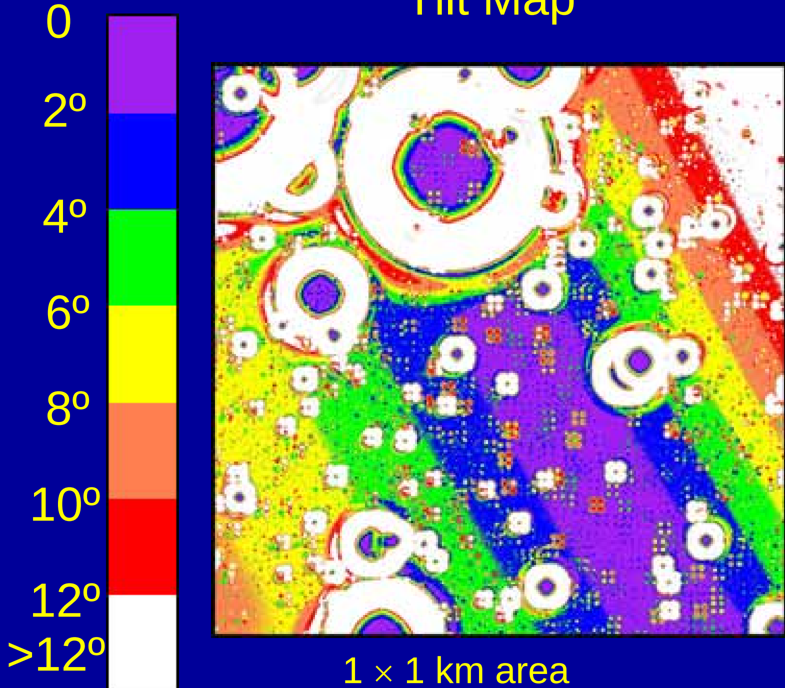
Synthetic Shackleton: Safe Landing Zone Map

Tilt Map

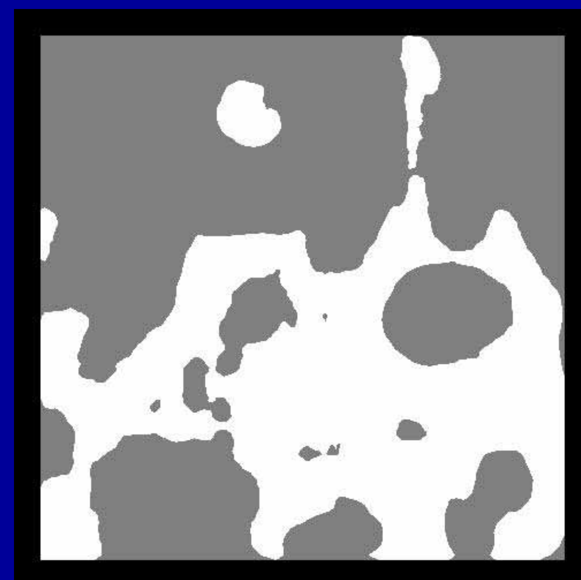


1 × 1 km area

90 meter box

ancient highland crater distribution

Safe Landing Zone Map



Each white pixel is at the center of a 90 × 90 m box that has a tilt of <10º over more than 80% of the area.

40% of the pixels in the image meet this criterion.

Shackleton_90S_0_1M_anc_surfPR89S045P3L_subset_safebox2

Conclusions

Synthetic DEMs provide a means to explore the topography of the lunar surface in a statistical sense.

DEMs can be created with realistic crater distributions for surfaces of a particular age.

Boulder/cobble distributions will be available soon.

Interesting landing site parameters can be computed using the DEMs:

- Lander tilt
- Safe landing zones
- Divert distance from any point to a safe zone, etc.

These parameters may be determined from LRO or other DEMs when available.

We plan to work with ALHAT engineers to develop parameters that would be most useful to them.

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Assessing a Safe Landing Site

Tilt of lander is angle between plane of lander and the horizontal