Improved Method for Estimating Lunar Volcanic Dome Volumes Using GIS Tools

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Introduction: Volume estimates of lunar volcanic domes usually approximate their topography with basic three dimensional shapes, such as paraboloids or cones, so that a simple volume equation can be used. For example, volume estimates of the Gruithuisen and Mairan domes calculated in 2003 [1] treated each dome as a simple paraboloid. More recent volume estimates [2] used a circular truncated cone approximation. However, more robust volume estimates and other dimensional measurements can be calculated using Digital Terrain Models (DTMs) and various Geographical Information System (GIS) tools. Here we discuss the tools and methods for determining volumes of volcanic constructs on the Moon using DTMs, common ArcGIS [3] tools, and the GeoEVE (Geologic Event Volume Estimator) tool [4]. We present the results from case studies of these tools with respect to putative lunar silicic volcanic constructs [5].

Methodology Overview: We use Lunar Reconnaissance Orbiter Camera (LROC) Wide and Narrow Angle Camera (WAC, NAC) imagery and their DTMs [6][7] with various GIS tools strung together using ArcGIS ModelBuilder and ArcPy scripting software to help improve defining and verifying the outlines of lunar volcanic domes and to measure their lengths, widths, heights, volumes and 3D surface areas. All GIS tools mentioned in this poster are ArcGIS built-in tools or custom tools/scripts, developed by the authors, for use with ArcMap 10.2.2 or later (the GeoEVE tool is available on request from the authors).

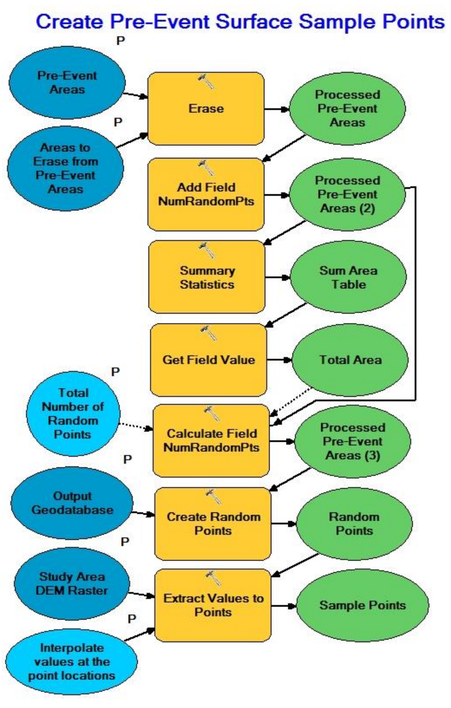
Case studies of lunar volcanic domes: Using the methods and tools described in this poster, we measured the dimensions and volume estimates of various lunar volcanic domes (Table 1), including:

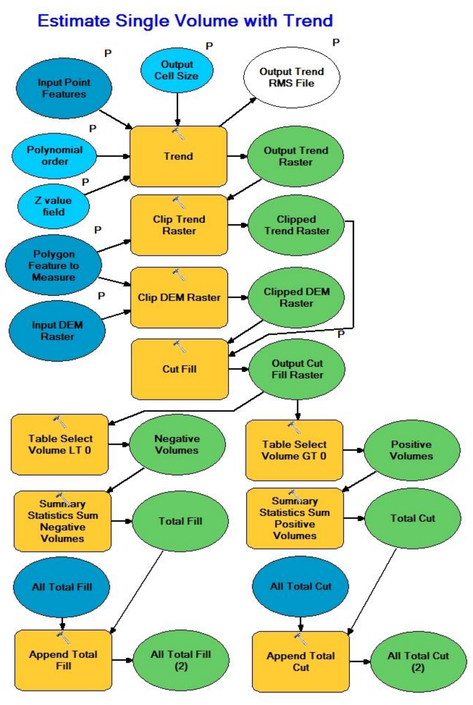
- Gruithuisen (Gh) Gamma, Delta and Northwest (NW)
- Mairan Northwest (M-NW)
- Compton-Belkovich (CB) volcanic complex's Beta
- Cauchy Omega (Ω), aka Donna
- Diana and Grace, south of Mons Esam
- Arago Alpha and Beta

For comparison, Table 1 lists in parentheses the dimensions and volume estimates for the Gruithuisen domes from [2], which also used WAC/NAC images and DTMs. The Gruithuisen domes' volume estimates in [1] were not used for comparison because their dimensions were derived from lower resolution Lunar Orbiter IV imagery and their paraboloid volume calculations used a dome's estimated maximum radial extent. Also, the Gh-Delta and Gh-NW domes' volume estimates in [1] were each partitioned into multiple dome components (e.g., lower and upper domes), making comparisons even less consistent. Volume estimates based on the paraboloid and truncated cone, using our dimension estimates, were also calculated and included in Table 1.

Results: The first three volume estimates listed in the bottom part of Table 1 use a flat, horizontal plane for the dome's base. Of these, given a roughly circular dome, the paraboloid seems to overestimate the volume and the truncated cone underestimates it. For a dome that is more rectangular (e.g., Gh-Delta, CB-Beta), its mean base radius misrepresents the dome's basic shape and causes these two 3D-shape volume equations to give high volume estimates. Also, for domes that have a volcanic vent or caldera (e.g., Cauchy Ω, Diana, Grace) or significant impact craters (e.g., Gh-Gamma), these two volume equations don't account for the missing volume. Since the Surface Volume and GeoEVE tools use DTMs that model a dome's actual surface, their volume estimates are closer to the true volume. Also, because the GeoEVE tool models a dome's base from the surrounding topography (see Figures below) using multiple Monte-Carlo-like runs, we suggest that its volume estimates are more robust.

ArcGIS ModelBuilder models of GeoEVE tool processing





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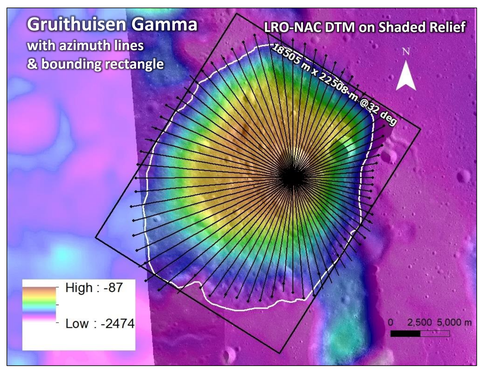
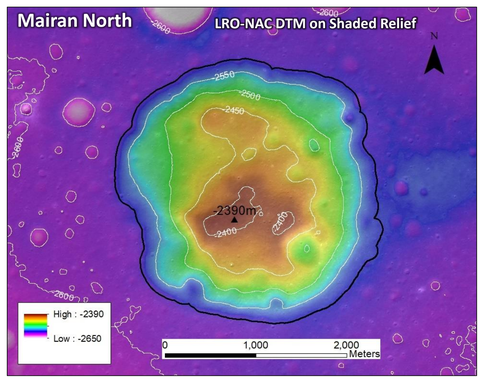
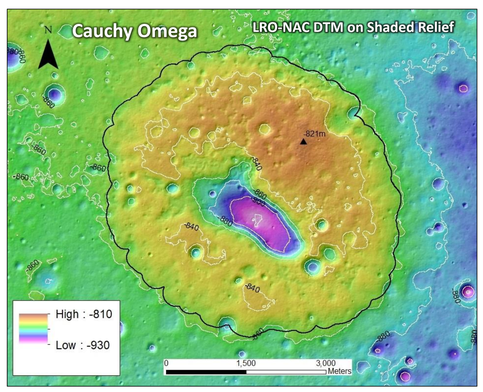
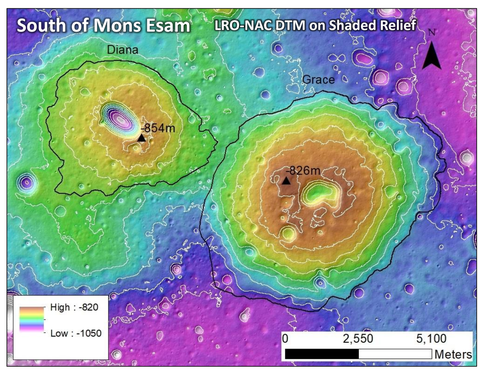








Methodology Steps

Create contour lines:

To find the approximate base height and outline of a volcanic dome, first contour lines were generated using LROC NAC/WAC DTM rasters [7] that covered the dome and surrounding area. Image and topography interpretation at the discretion of the geologist were also used.

Adjust dome outline:

For some dome outlines, a buffer was created from its base contour to uniformly extend the dome's outline. Dome outlines were also modified manually to account for geologic features (e.g., impact craters).

Verify base outline with topographic profiles:

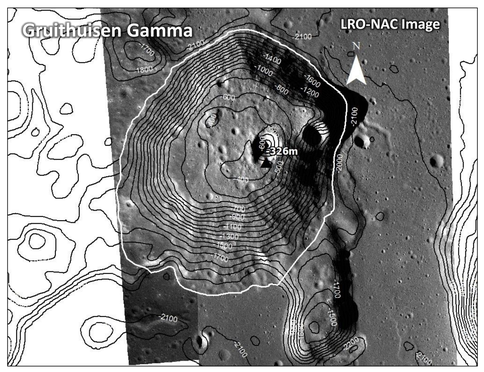
To help verify and refine each dome's outline, an ArcPy script was written that executed the following steps:

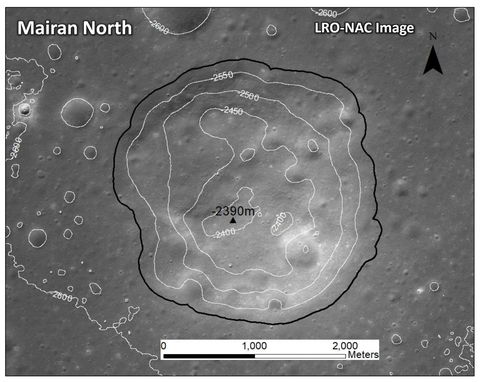
- Located the highest elevation DTM pixel within a dome's outline and created a point there.
- Created azimuth cross-section lines radiating from this summit point out to the edge of a buffer surrounding the dome's outline.
- Generated topographic profile tables and graphs, using the Stack Profile tool [8], along each azimuth cross-section line.
- Determined the horizontal distance from the summit to each topographic profile's minimum elevation.
- Created feature points, in the NAC DTM's coordinate system, at these horizontal distances by using ArcGIS' Linear Referencing [9] capability.

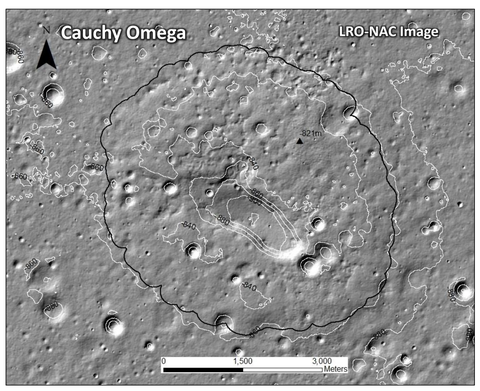
To help verify and manually adjust each dome's outline, 72 azimuth cross-section lines were used, spaced 5 degrees apart.

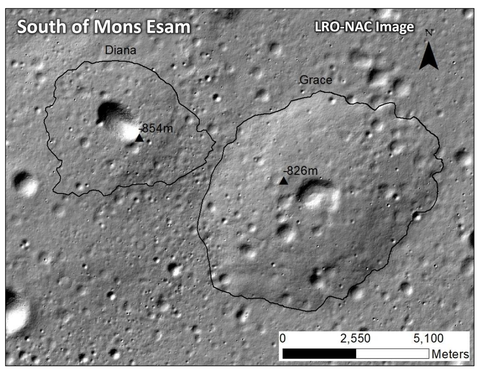
Measure dome's horizontal dimensions:

To measure the length, width, and orientation (i.e., azimuth of the longer side) of a dome's outline, the Minimum Bounding Geometry (MBG) tool [10] was used to create a rectangle of the smallest width enclosing the input feature. The MBG tool was also used to create a circle to measure a dome's mean base radius.









Estimate dome's 3D surface area and volume using a flat, horizontal reference plane as its base:

These two dome measurements were calculated using the Surface Volume (SV) tool [11] with NAC/WAC DTMs clipped to the dome's outline and a base height value derived from the contour line that most closely followed the dome's outline.

Model pre-event surface and estimate dome's volume using the GeoEVE tool:

To calculate more robust volume estimates of each dome, our custom-built GeoEVE tool [4] was used to (a) model the dome's base (i.e., pre-event surface) as a flat, sloped plane interpolated from the surrounding topography and then (b) calculate a volume estimate of the clipped DTM located above this plane.

Table 1: Summary of dimension and volume estimates

Dome		Gruithuisen Gamma ([2])	Gruithuisen Delta ([2])	Gruithuisen Northwest ([2])	Mairan Northwest	CompBelk Beta	Cauchy Ω (Donna)	MonsEsam Diana	MonsEsam Grace	Arago Alpha	Arago Beta
Latitude (°) / Longitude (°)		36.56 / -40.72	36.07 / -39.59	37.1 / -41.1	43.7/-49.9	61.8/99.6	7.2 / 38.3	14.3 / 35.7	14.2 / 35.9	7.6 / 21.6	6.1 / 20.0
Length/m		22508 (~24500)	31646 (~35000)	8475 (~8000)	2962	4334	6085	5960	9338	19627	15226
Width/m		18505 (~19000)	20971 (~18000)	7941 (~6400)	2854	2216	5163	4702	7023	17379	12963
Orientation/deg		32	172	91	169	176	118	88	51	129	73
Mean base radius (R_b)/m		11562	16361	4627	1552	1579	3054	3293	4690	11308	7999
Mean summit radius (R_s)/m		6802	4335	~0 (N/A)	~0 (N/A)	184	~0 (N/A)	796	725	~0 (N/A)	~0 (N/A)
Base Elevation (E_b)/m		-1900	-1900 (~-2000)	-1750 (~-1600)	-2582	-2210	-860	-920	-980	-1875	-1200
Summit Elevation (E_s)/m		-326	-87 (~300)	-532 (~-600)	-2390	-1984	-821	-854	-826	-1564	-998
Dome Height ($H=E_s-E_b$)/m		1574 (~1400)	1813 (~1700)	1218 (~1000)	192	226	39	66	154	311	202
SV tool's 3D Surface Area (A_{sv})/km^2		316.31	488.41	51.73	6.84	7.84	21.07	19.17	44.33	240.65	140.51
DTM Raster Cell Size S /m		2 x 2	2 x 2	93 x 93	5 x 5	1.5 x 1.5	5 x 5	5 x 5	5 x 5	100 x 100	100 x 100
Pixel Count of dome feature (N)		80798765	110544817	5948	269318	3504726	939435	811388	1862009	27240	14346
Volume Estimates /km^3	paraboloid (V_p) [a]	330.51	762.32	40.96	0.73	0.89	0.57	1.12	5.32	62.47	20.30
	truncated cone (V_{tc}) [b]	426.23 (~290)	678.55 (~470)	27.31 (~20)	0.48	0.67	0.38	0.75	3.55	41.64	13.53
	Surface Volume tool (V_{sv})	229.96	322.30	20.72	0.58	0.64	0.35	0.52	3.56	23.71	13.08
	GeoEVE Tool Mean (V_g) (# runs)	265.67 (10)	399.64 (10)	25.53 (20)	0.61 (100)	0.43 (90)	0.52 (30)	1.44 (30)	3.70 (30)	38.51 (100)	22.56 (100)

[a] paraboloid volume Vp = [(π/2)Rb2H]; [b] truncated cone volume Vtc = [(πH/3)(Rb2+ RbRs+ Rs2)]

References: [1] Wilson, L. and Head, J. W. (2003) JGR, 108(E2), 5012, 6-1-6-7 [2] Ivanov, M. A., et. al. (2016) Icarus 273, 262-283 [3] **ArcGIS® 10.x software by Esri, (**http://esri.com**)** [4] Baum, F. and Zanetti, M. (2017) LPSC XLVIII, 2779 [5] Glotch, et. al. (2010) Science, 329(5998), 1510-1513 [6] Scholten, F., et. al. (2012) JGR 117, E00H17 [7] Henriksen, M. R., et. al., (2017) Icarus 283, 122-137 [8-11] ArcGIS Help: [8] Stack Profile [9] What is linear referencing? [10] Minimum Bounding Geometry [11] Surface Volume