



**TFAWS**  
MSFC • 2026

## Meshed Lunar Terrain Thermal Model Building Short Course

**The LUMENATE Team:**

William Birmingham, NASA MSFC

Will Grier, NASA LaRC

Lisa Erickson, NASA JSC

Presented By

William Birmingham

Thermal & Fluids Analysis Workshop

TFAWS 2026

August 31 – September 4, 2026

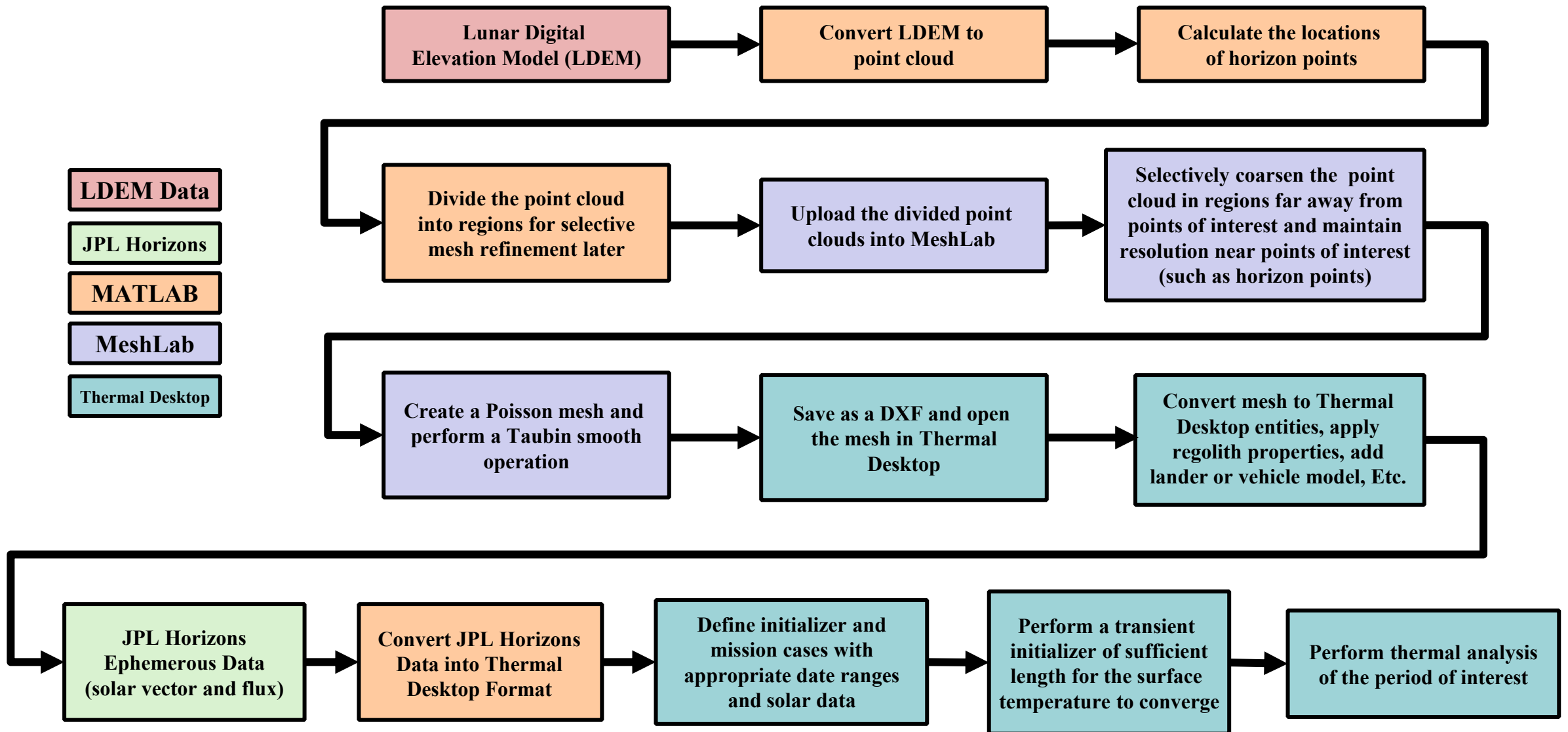
NASA Marshall Space Flight Center

Huntsville, AL

# Terrain Modeling Process Overview

- This procedure describes one method for using lunar digital elevation models (LDEMs) to build detailed meshed terrain models of the lunar south pole in Thermal Desktop.
- Data sources include:
  - LDEMs from the Lunar Orbiter Laser Altimeter (LOLA) instrument, packaged into rasterized polar stereographic projections
  - JPL Horizons provides ephemerous data, used to track the position of the sun as a function of time from the perspective of the lunar surface
- Software tools include:
  - MATLAB
  - MeshLab
  - Thermal Desktop
- The procedure and code used here are applicable only to south polar locations. If a method for building terrain thermal models closer to the equator is desired, the same general procedures apply. However, the ideal (less distorted) map projection for such locations is the cylindrical projection ([LOLA GDR Cylindrical projection information](#)), so the code must be modified to accommodate cylindrical LDEMs.

# Terrain Modeling Process Overview



# Lunar Data Processing in MATLAB

This section describes the process of converting Lunar Digital Elevation Maps (LDEM) into a format that can be read imported into MeshLab

# LDEM Download

- Go to:  
<https://pgda.gsfc.nasa.gov/products/90>
- Download the lunar digital elevation model titled:  
***LDEM\_60S\_60MPP\_ADJ.TIF***
- This is a 60 meter/pixel terrain elevation model of lunar surface south of the 60°S latitude line
- The map is a polar stereographic projection
- For more detail and context on these maps, see the following publication:

Barker et al., 2023 Planet. Sci. J., 4, 183. <https://doi.org/10.3847/PSJ/acf3e1>

LDEC\_80S\_20MPP\_ADJ.TIF - LOLA Digital Elevation Counts (LDEC, number of LOLA spots per pixel)  
LDEM\_80S\_20MPP\_ADJ.TIF - LOLA Digital Elevation Model (LDEM) giving surface height (in meters)  
LDEM\_80S\_20MPP\_ADJ\_EFFRES.TIF - LDEM effective resolution (in meters)  
LDEM\_80S\_20MPP\_ADJ\_ERR.TIF - LDEM surface height error (in meters)  
LDEM\_80S\_20MPP\_ADJ\_HILL.TIF - LDEM hillshade (45 deg altitude, 45 deg azimuth)  
LDSM\_80S\_20MPP\_ADJ.TIF - LOLA Digital Slope Map (LDSM, in degrees)  
LDSM\_80S\_20MPP\_ADJ\_ERR.TIF - LDSM slope error (in degrees)

LDEC\_60S\_240MPP\_ADJ.TIF - 131M  
LDEM\_60S\_240MPP\_ADJ.TIF - 210M  
LDEM\_60S\_240MPP\_ADJ\_EFFRES.TIF - 248M  
LDEM\_60S\_240MPP\_ADJ\_ERR.TIF - 255M  
LDEM\_60S\_240MPP\_ADJ\_HILL.TIF - 93M  
LDSM\_60S\_240MPP\_ADJ.TIF - 247M  
LDSM\_60S\_240MPP\_ADJ\_ERR.TIF - 248M  
LDEC\_60S\_120MPP\_ADJ.TIF - 463M  
LDEM\_60S\_120MPP\_ADJ.TIF - 785M  
LDEM\_60S\_120MPP\_ADJ\_EFFRES.TIF - 1000M  
LDEM\_60S\_120MPP\_ADJ\_ERR.TIF - 1016M  
LDEM\_60S\_120MPP\_ADJ\_HILL.TIF - 354M  
LDSM\_60S\_120MPP\_ADJ.TIF - 972M  
LDSM\_60S\_120MPP\_ADJ\_ERR.TIF - 1001M  
LDEC\_60S\_60MPP\_ADJ.TIF - 1.5G  
**LDEM\_60S\_60MPP\_ADJ.TIF - 2.9G**  
LDEM\_60S\_60MPP\_ADJ\_EFFRES.TIF - 3.9G  
LDEM\_60S\_60MPP\_ADJ\_ERR.TIF - 4.0G  
LDEM\_60S\_60MPP\_ADJ\_HILL.TIF - 1.4G  
LDSM\_60S\_60MPP\_ADJ.TIF - 3.8G  
LDSM\_60S\_60MPP\_ADJ\_ERR.TIF - 3.9G  
LDEC\_75S\_30MPP\_ADJ.TIF - 489M  
LDEM\_75S\_30MPP\_ADJ.TIF - 2.7G  
LDEM\_75S\_30MPP\_ADJ\_EFFRES.TIF - 3.8G  
LDEM\_75S\_30MPP\_ADJ\_ERR.TIF - 3.8G  
LDEM\_75S\_30MPP\_ADJ\_HILL.TIF - 1.3G  
LDSM\_75S\_30MPP\_ADJ.TIF - 3.6G  
LDSM\_75S\_30MPP\_ADJ\_ERR.TIF - 3.7G

# Convert the LDEM to a Point Cloud and Identify Horizon Point Clouds

- With the JP2 LDEM in the file path, enter a latitude [degrees], longitude [degrees], local elevation [meters], surface offset height [meters], and map crop radius [meters] for the center point of the area of interest....and then run the code:

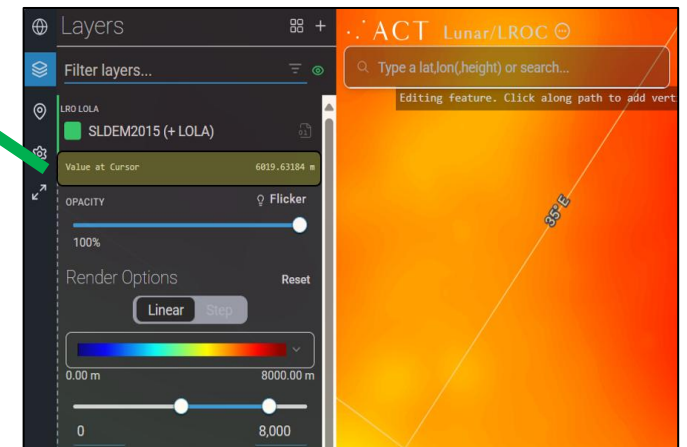
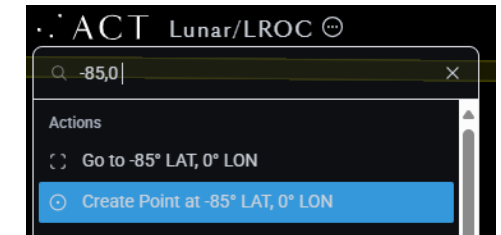
**MapProcessorSouthPole\_HorizonPoints\_V4.m**

- Note offset height is height at which the horizon points are calculated.** For best results, this should be set to the height of a critical component on the vehicle of interest (such as radiator height or the top of the vehicle)
- Note horizon points are the most distant points in the point cloud that are visible from a given location of interest.** Horizon points may be close or far away depending on observer location and local topography
- Multiple points of interest for horizon calculation can be provided if applicable. This is useful when capturing the terrain of a traverse or region of interest.
- Local elevation for each point of interest specified is required and can be obtained via LROC QuickMap (<https://quickmap.lroc.im-ldi.com/>)
- The code will output a point cloud of the location with the user defined radius and also the locations of horizon points

```
MapProcessorSouthPole_HorizonPoints_V6.m High_Res_Map
1 tic;
2 clearvars -except South_Pole_HeightMap
3 format long
4
5 % User-specified landing site center point and crop
6 LandingSite_LATITUDE = -85; % degrees
7 LandingSite_LONGITUDE = 35; % degrees
8 LandingSite_Elevation = 7000; % meters
9 LandingSite_OFFSETHEIGHT = 2; % meters
10 Cropped_Circle_Radius = 20000; % meters
11 quitcheck = 0;
12 edgemargin = 4; %degrees
13
14 % Additional reference points for horizon calculator
15 % longitude [degrees], Elevation [meters], Offset Height [meters]
16 refPoints_deg = [
17     -85,    36.9,    7000, 60;
18     -85.3,  36.8,    7050, 2;
19     -85.4,  36.9,    6900, 2;
20 ];
21
22 % Constants
23 Rmoon = 1737400; % Mean lunar radius in meters
24
25 % JP2 DEM obtained from: https://imbrum.mit.edu/BRO/
26 MapScaleFactor = 0.5; % Scaling factor for LDEM map,
27
```

## Obtain Site Elevation

<https://quickmap.lroc.im-ldi.com/>



# (Optional) Download High Resolution LDEM and Generate Point Cloud

- If higher resolution terrain data is desired in the immediate vicinity of the location of interest, this data can be incorporated in the final point cloud that is sent to MeshLab
- Download a 10m/pxl dataset from:  
<https://pgda.gsfc.nasa.gov/products/90>
- In the `High_Res_MapProcessorSouthPole_V4.m` code:
  - Enter the latitude and longitude previously specified for the larger point cloud, include a crop radius (defining the size of the zone where higher refinement data is desired)
  - Ensure the LDEM file name is correctly entered into the code
  - The output of this code is a LDEM that can now be included in the larger point cloud when combined in Mesh Lab.

LDEC\_80S\_20MPP\_ADJ.TIF - 1.3G  
LDEM\_80S\_20MPP\_ADJ.TIF - 2.6G  
LDEM\_80S\_20MPP\_ADJ\_EFFRES.TIF - 3.8G  
LDEM\_80S\_20MPP\_ADJ\_ERR.TIF - 3.7G  
LDEM\_80S\_20MPP\_ADJ\_HILL.TIF - 1.3G  
LDSM\_80S\_20MPP\_ADJ.TIF - 3.6G  
LDSM\_80S\_20MPP\_ADJ\_ERR.TIF - 3.7G  
LDEC\_83S\_10MPP\_ADJ.TIF - 415M  
**LDEM\_83S\_10MPP\_ADJ.TIF - 4.8G**  
LDEM\_83S\_10MPP\_ADJ\_EFFRES.TIF - 7.5G  
LDEM\_83S\_10MPP\_ADJ\_ERR.TIF - 7.5G  
LDEM\_83S\_10MPP\_ADJ\_HILL.TIF - 2.5G  
LDSM\_83S\_10MPP\_ADJ.TIF - 7.1G  
LDSM\_83S\_10MPP\_ADJ\_ERR.TIF - 7.0G

```
tic;
clearvars
format long

%NOTE: The high resolution data used in this code is only available south
%of the -83deg latitude line.

% User-specified landing site and crop radius
LandingSite_LATITUDE = -85; % degrees
LandingSite_LONGITUDE = 0; % degrees
LandingSite_Elevation = 0.00; % meters
Data_Resolution = 10; %meters per pixel
%Make sure all of the above match the data input in the Map Processor for
%the coarse data
High_Res_Crop_Radius = 100; %meters

% Constants
Rmoon = 1737400; % Mean lunar radius in meters
Map_Offset = 0; % meters

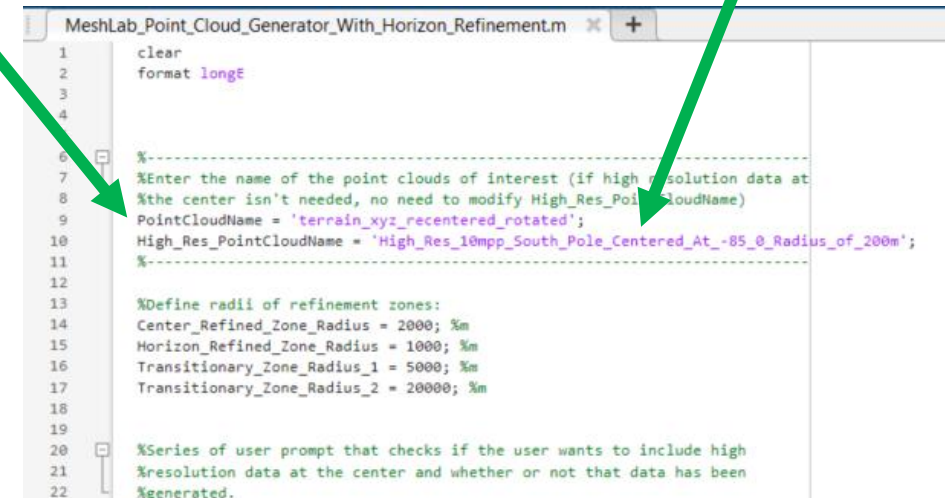
%Read the high resolution .tiff file, store the height map, x pixel numbers,
%and y pixel numbers.
t = Tiff('LDEM_83S_10MPP_ADJ.tiff','r');
A = read(t);
close(t);
A = single(A) + Rmoon;
```

# Use MATLAB to Divide the Point Cloud into Refinement Regions

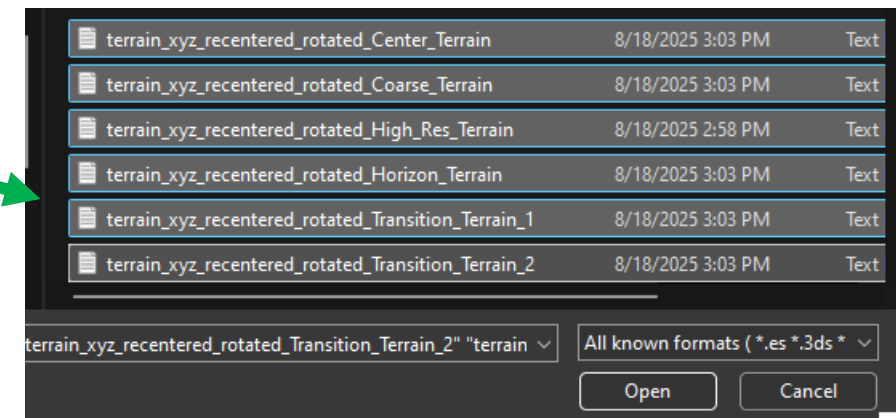
- To achieve higher mesh density near points of interest (horizon points and the center) and lower density far from points of interest, the point cloud must be selectively refined to reflect this. For this variable refinement to be reflected in the final mesh, the point cloud must also have variable refinement. To refine different parts of the point cloud differently, the point cloud must be divided into regions and saved to separate text files.
- The **MeshLab\_Point\_Cloud\_Generator\_With\_Horizon\_Refinement\_V4.m** code takes the point cloud previously generated, divides it into an optional highly refined zone, a central zone, a horizon zone, two successive transition zones, and a coarse far field zone.
- These six point clouds are saved as txt files that can be uploaded into MeshLab

MapProcessorSouthPole  
\_HorizonPoints\_V4.m

High\_Res\_MapProcessor  
SouthPole\_V4.m



```
1 clear
2 format longE
3
4
5
6 %-----
7 %Enter the name of the point clouds of interest (if high resolution data at
8 %the center isn't needed, no need to modify High_Res_PointCloudName)
9 PointCloudName = 'terrain_xyz_recentered_rotated';
10 High_Res_PointCloudName = 'High_Res_10mp_South_Pole_Centered_At_-85_0_Radius_of_200m';
11 %-----
12
13 %Define radii of refinement zones:
14 Center_Refined_Zone_Radius = 2000; %m
15 Horizon_Refined_Zone_Radius = 1000; %m
16 Transitional_Zone_Radius_1 = 5000; %m
17 Transitional_Zone_Radius_2 = 20000; %m
18
19
20 %Series of user prompt that checks if the user wants to include high
21 %resolution data at the center and whether or not that data has been
22 %generated.
```

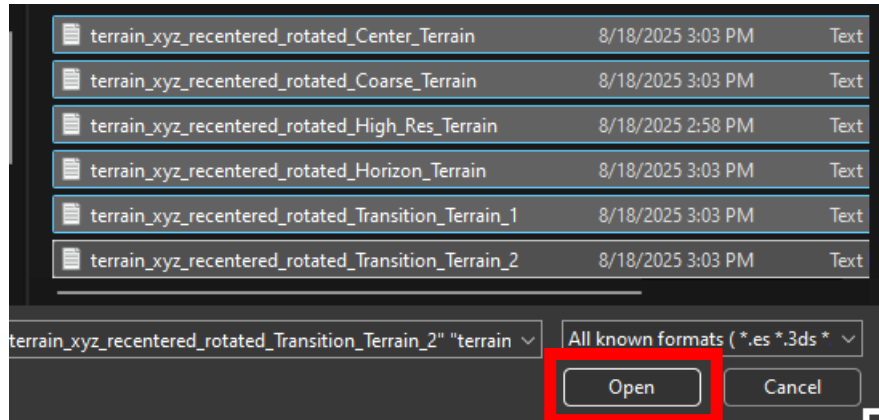
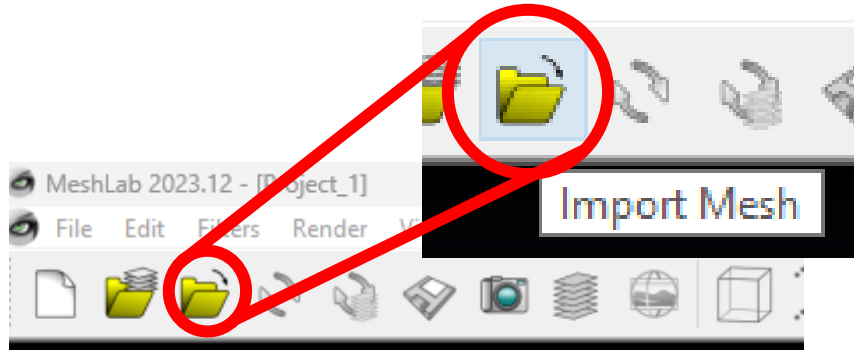


# Lunar Terrain Meshing in MeshLab

This section describes the process of converting the point clouds output by MATLAB into meshes that can be imported into Thermal Desktop

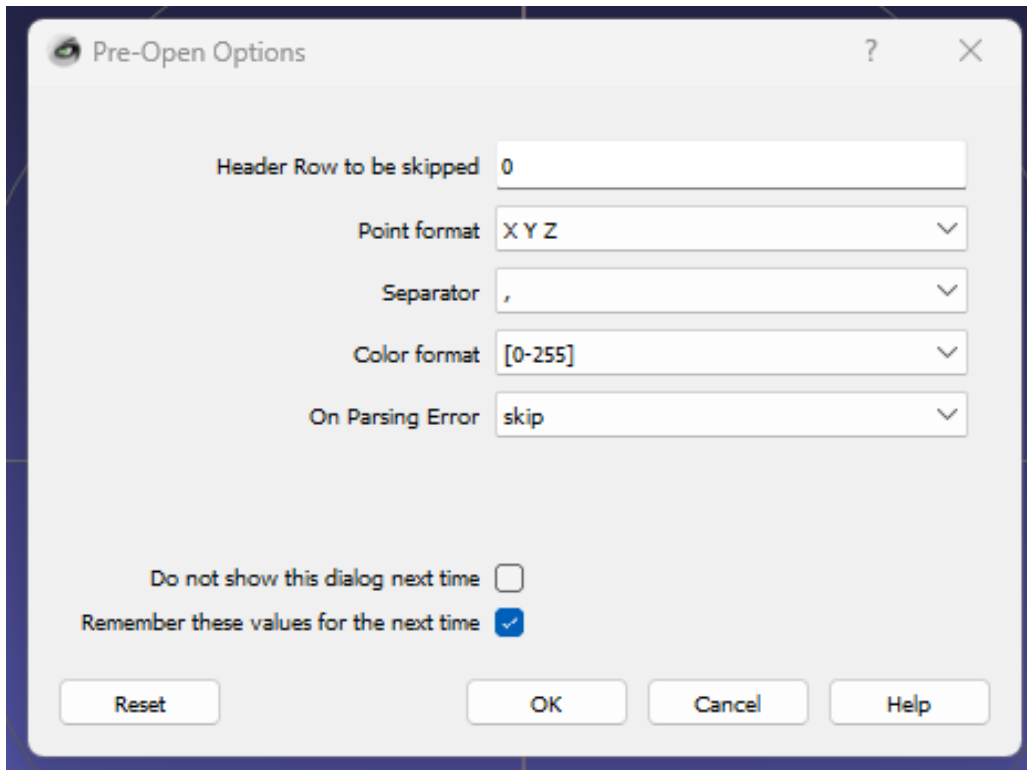
**WARNING: MeshLab has no “undo” capability**  
**Save often and be careful**

# Import Point Clouds



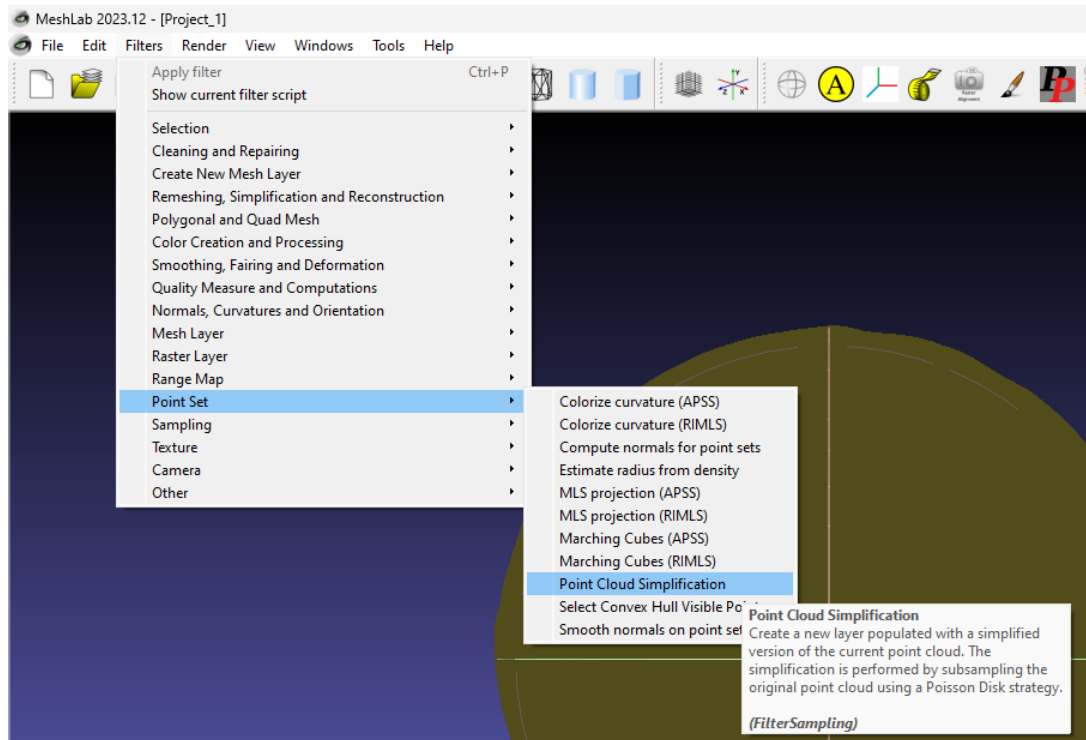
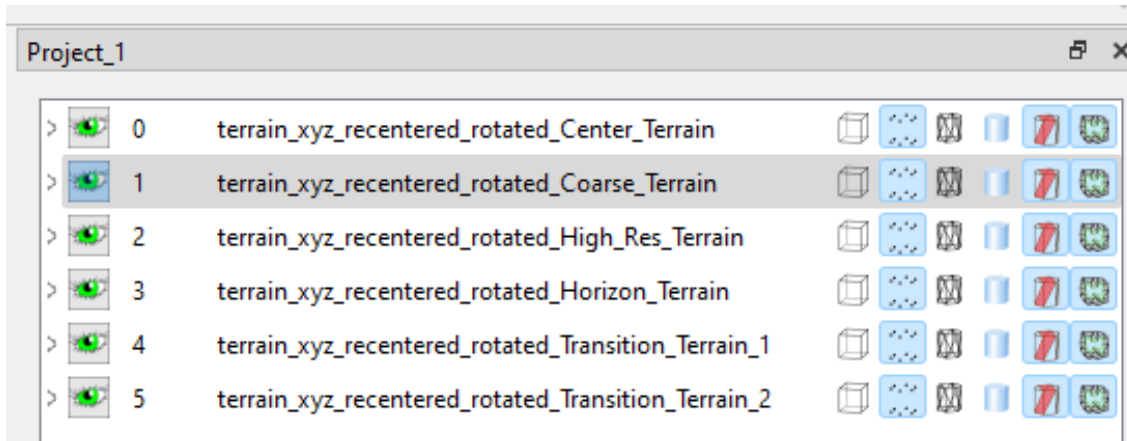
- After opening MeshLab (<https://www.meshlab.net/>) , select the Import Mesh icon
- Navigate to the point cloud txt files generated in the previous steps
- Select all the point clouds and open them

# Import Point Clouds



- Ensure the “Pre-Open Options” are as shown to the left, and select OK
- Note the separator should be set to “,”. The default separator may be set to “;”
- This window will appear for all point clouds you selected

# Point Cloud Simplification



- In this step, almost every point cloud is “simplified” (made more sparse)
- In the project window, select the point cloud you want to simplify
- Navigate to the following to use the “Point Cloud Simplification” function :

Filters->Point Set->Point Cloud Simplification

- The slide to follow will include a table of settings to use for each point cloud

# Point Cloud Simplification

Point Cloud Simplification

Create a new layer populated with a simplified version of the current point cloud. The simplification is performed by subsampling the original point cloud using a Poisson Disk strategy.

Number of samples

1000

Explicit Radius (abs and %)

world unit

perc on(0 .. 282977)

9000.0

4.241

Best Sample Heuristic

☒

Best Sample Pool Size

10

Precise sample number

☐

Precise sample number tolerance

0.005

PyMeshLab Filter

generate\_simplified\_point\_cloud

Copy PyMeshLab call to clipboard

Default

Help

Close

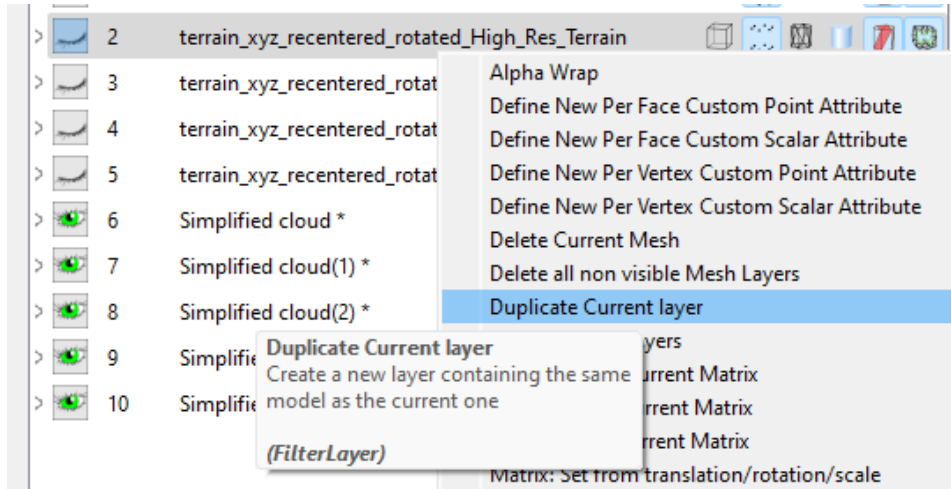
Apply

- The only parameter that needs to be edited for each point cloud simplification is the Explicit Radius (world unit)
- The table below summarizes good explicit radius settings to use for each. The world units are in meters
- Note these are just guidelines. **A larger explicit radius will result in a coarser mesh**, so if more or less mesh refinement is desired, these settings should be revisited
- Also note the ratios of explicit radii are ideal for preventing errors with meshing. **If a change is made to any one of these radii, the other radii should be changed to preserve the ratios used here**

| Point Cloud             | Explicit Radius (world unit) |
|-------------------------|------------------------------|
| Coarse Terrain          | 9000                         |
| Transition Terrain 2    | 3750                         |
| Transition Terrain 1    | 2250                         |
| Horizon Terrain         | 750                          |
| Center Terrain          | 150                          |
| High Resolution Terrain | N/A (Do not simplify)        |

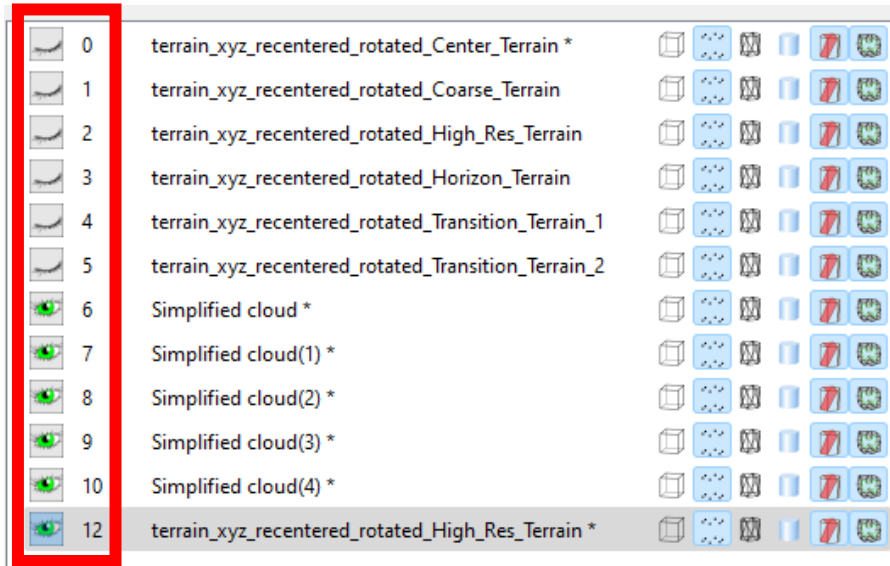
- Select Apply when finished
- Repeat until all point clouds are simplified according to the radius setting shown in the table

# Point Cloud Simplification

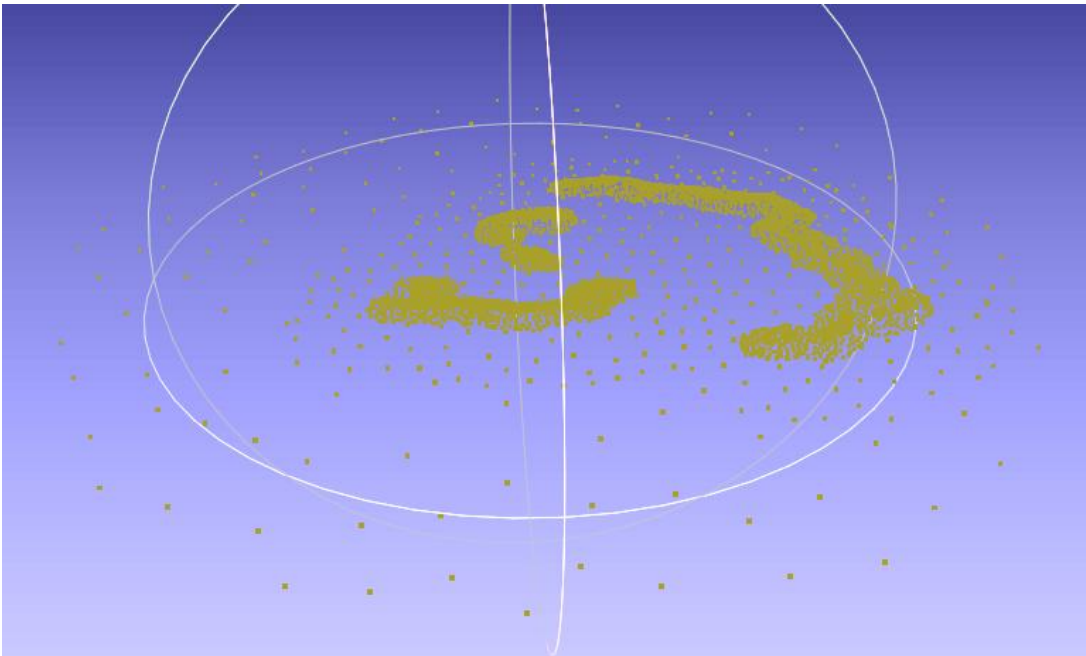


- For any point clouds that you don't simplify, it is recommended that you duplicate to avoid deleting this point cloud prematurely
- Right click the high-resolution terrain point cloud and select “Duplicate Current Layer”

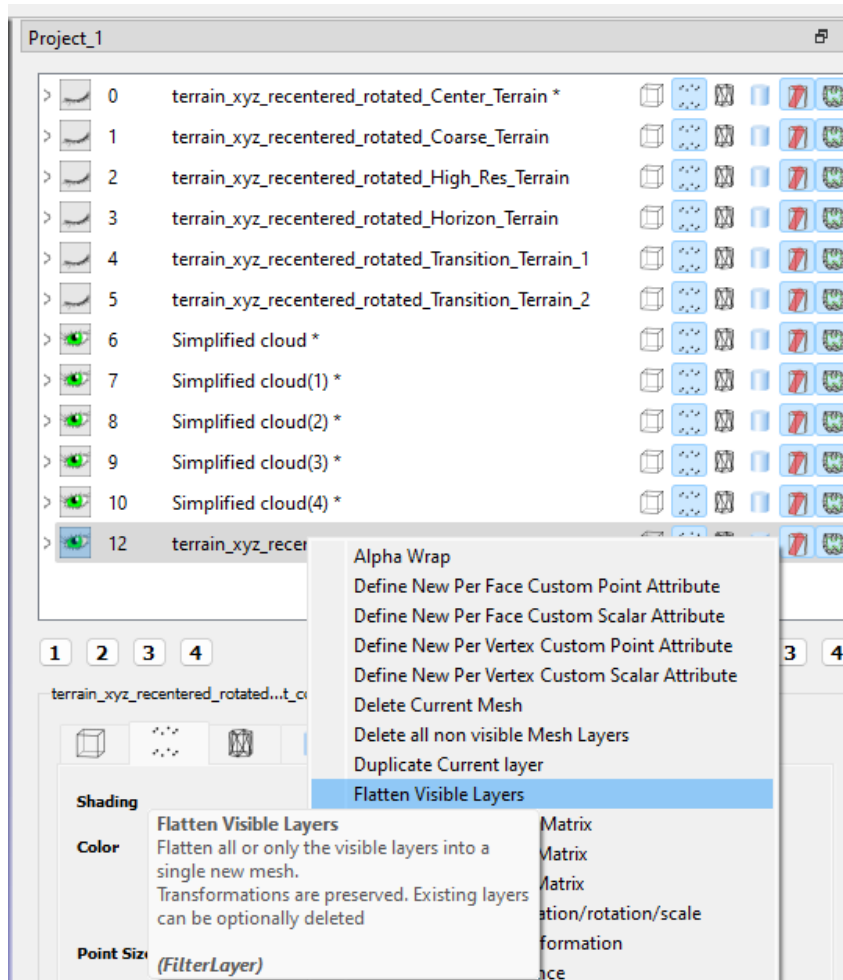
# Point Cloud Flattening



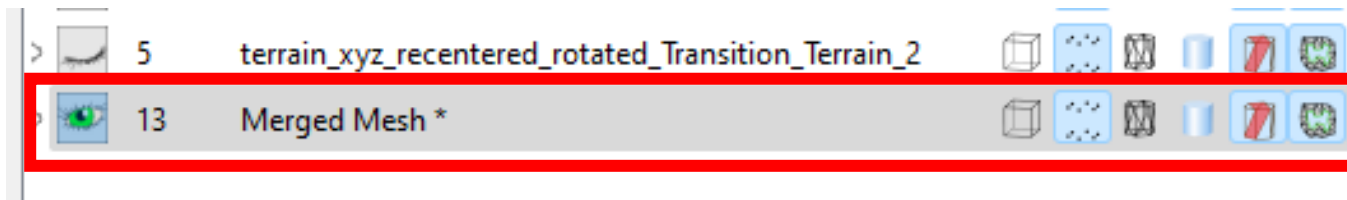
- In the Project window, turn off the visibility of all the original point clouds by selecting the green eye, and only leave the visibility of the new point clouds on
- Your visible point clouds should look something like the image to the bottom left (exact appearance will vary by location)



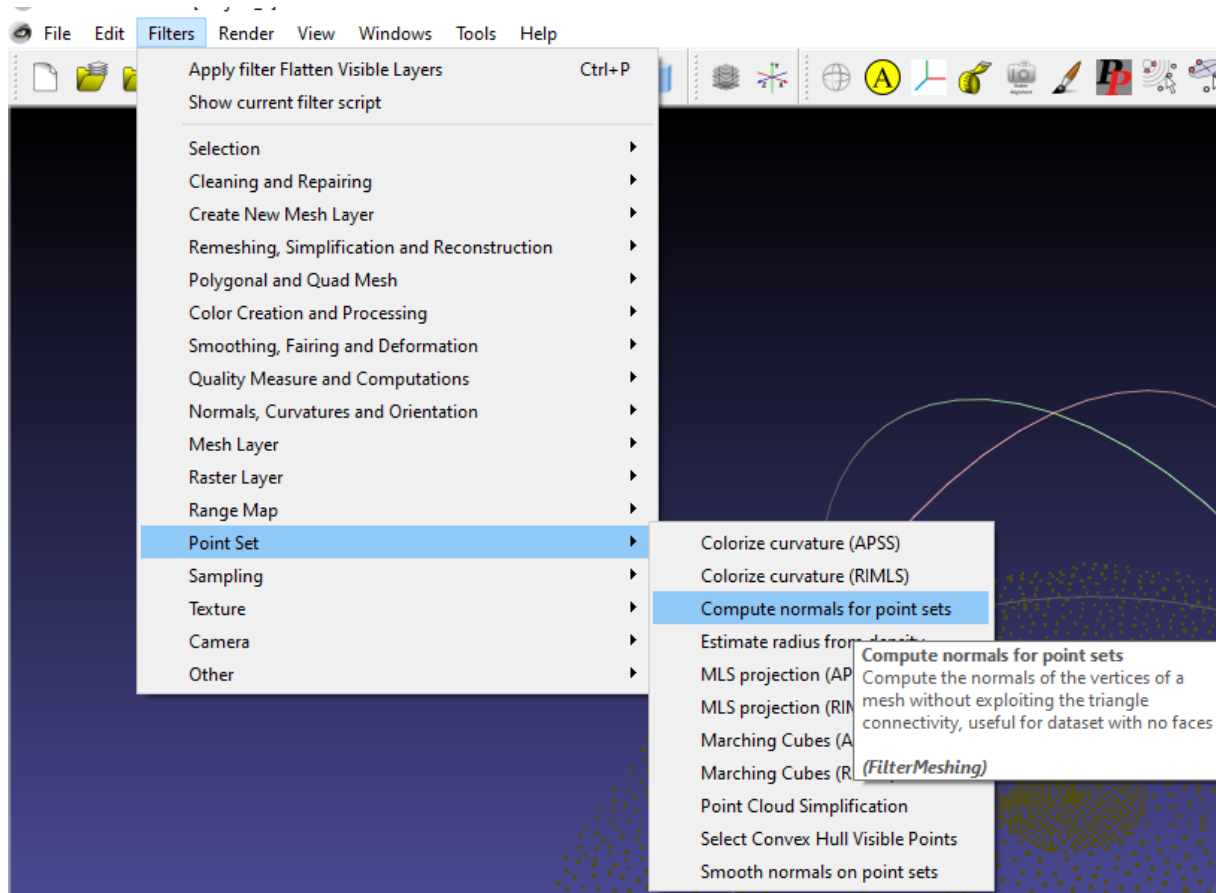
# Point Cloud Flattening



- Right click any one of the visible point clouds, and select “Flatten Visible Layers”
- A “Flatten Visible Layers” window will appear. Use the default settings, select Apply and Close
- All the simplified and duplicated point clouds that were left visible will merge into a single layer called “Merged Mesh \*”



# Calculate Point Cloud Normal Unit Vectors

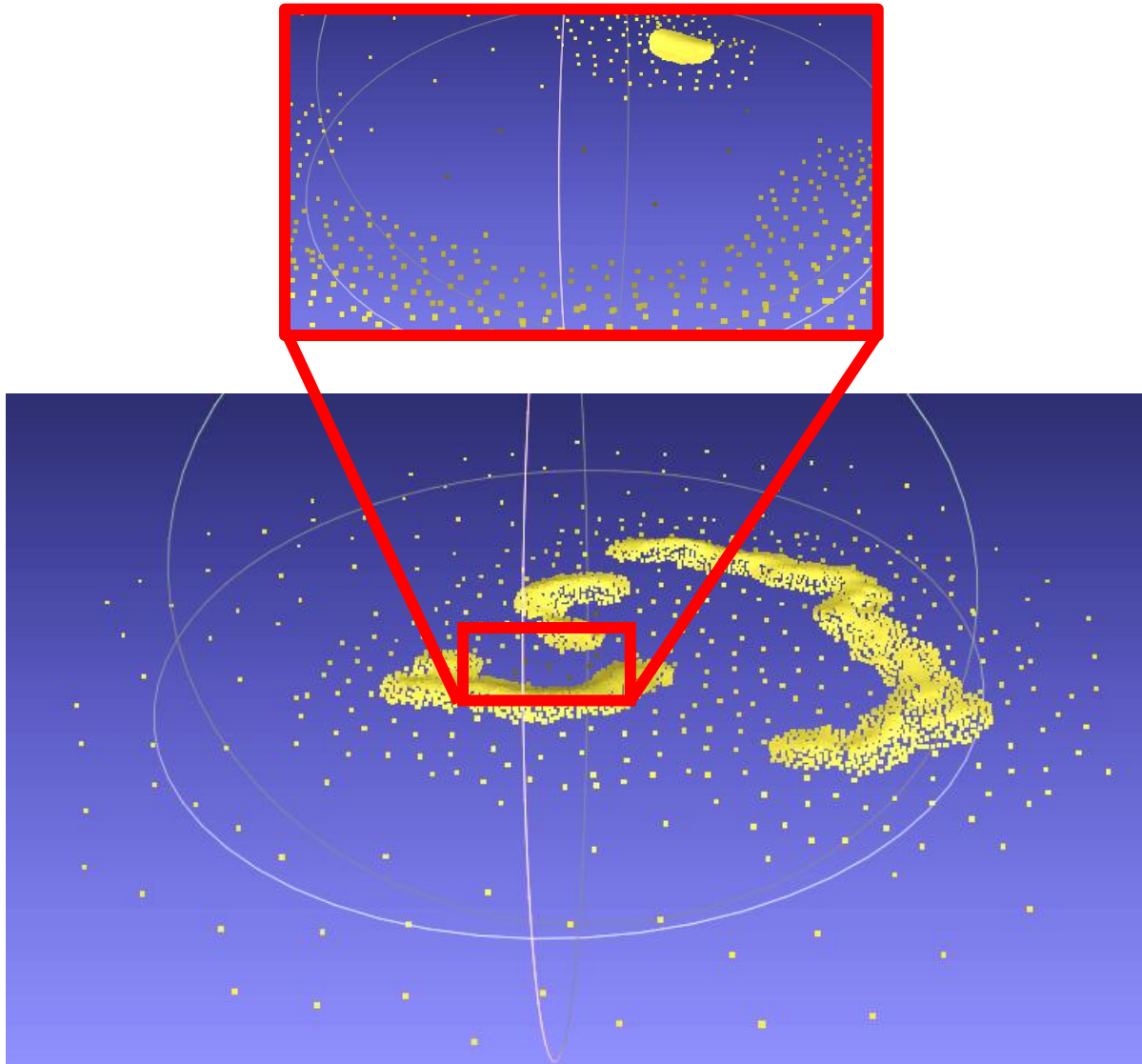


- In the project window, select the “Merged Mesh” point cloud
- Navigate to the following:

Filters->Point Set->Compute normal for point sets

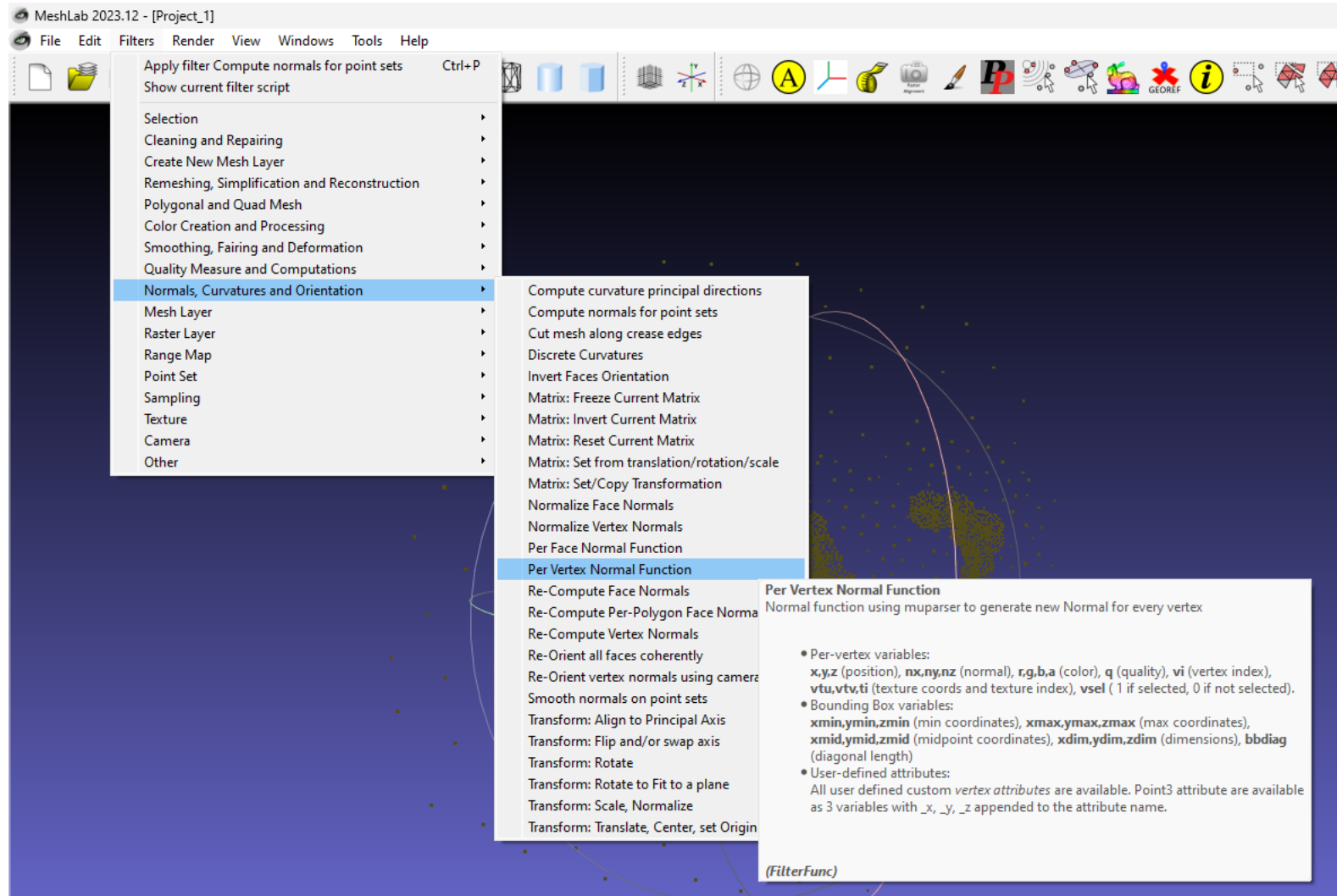
- A settings window will appear. Keep the default settings, select Apply, and then select Close

# Calculate Point Cloud Normal Unit Vectors



- Navigate around the point cloud. Note that the brightly colored side of the dots indicates the direction of the normal vector (a bright dot means you're looking at what MeshLab considers the "top" of the surface)
- Inevitably there will be dots with normals that are flipped in the wrong direction. Sometimes there are only a handful of problem nodes (as pictured here). Sometimes most or all of them are incorrect. Incorrect normal vector orientations will be dark when viewed from the top down
- These normal vectors must be selected and reversed (continued on the next slide)

# Calculate Point Cloud Normal Unit Vectors



Navigate to:

Filters->Normals, Curvatures, and Orientation->**Per Vertex Normal Function**

# Calculate Point Cloud Normal Unit Vectors

Per Vertex Normal Function

Normal function using muparser to generate new Normal for every vertex

- Per-vertex variables:  
**x,y,z** (position), **nx,ny,nz** (normal), **r,g,b,a** (color), **q** (quality), **vi** (vertex index), **vtu,vtv,ti** (texture coords and texture index), **vsel** ( 1 if selected, 0 if not selected).
- Bounding Box variables:  
**xmin,ymin,zmin** (min coordinates), **xmax,ymax,zmax** (max coordinates), **xmid,ymid,zmid** (midpoint coordinates), **xdim,ydim,zdim** (dimensions), **bbdiag** (diagonal length)
- User-defined attributes:  
All user defined custom vertex attributes are available. Point3 attribute are available as 3 variables with **\_x, \_y, \_z** appended to the attribute name.

func nx =

func ny =

func nz =

only on selection ☐

☐ Preview

**PyMeshLab Filter**  
compute\_normal\_by\_function\_per\_vertex

Default Help

Close Apply

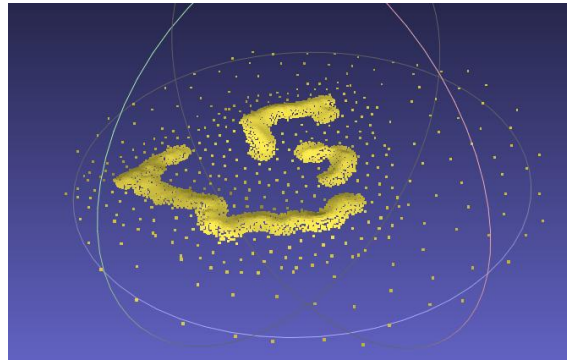
- In the Per Vertex Normal Function window, ensure there is NO check next to “only on selection” (as shown to the left)
- The following functions will automatically flip the normal vector if it is found to be facing the wrong way (toward the center of the moon):

func nx = **nx\*nz/abs(nz)**

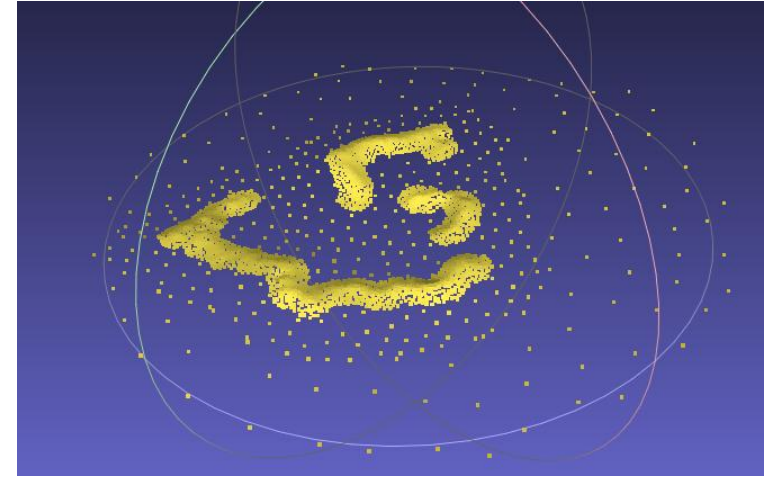
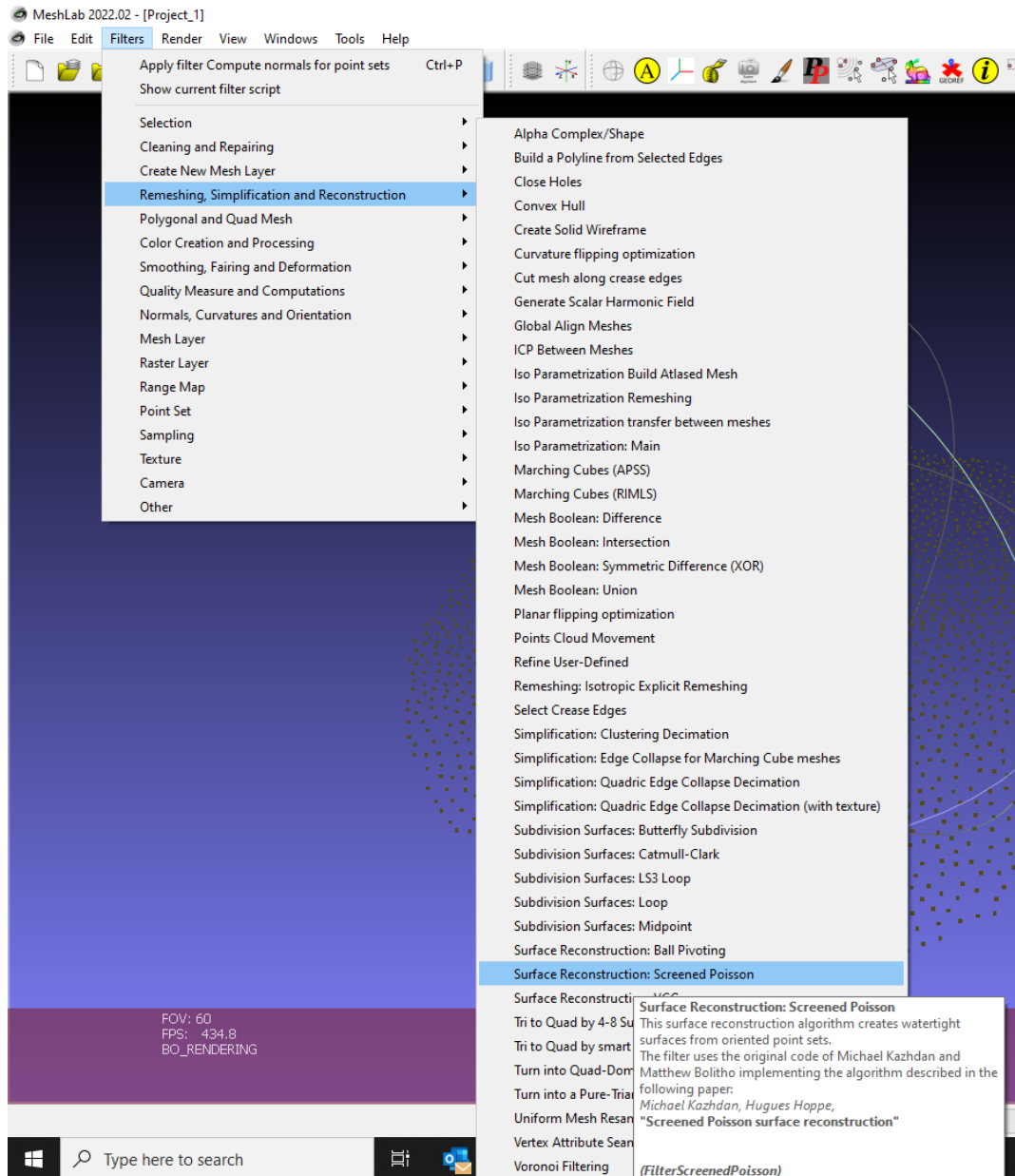
func ny = **ny\*nz/abs(nz)**

func nz = **nz\*nz/abs(nz)**

- Copy these functions into the respective text boxes as shown to the left
- Select Apply and inspect the point cloud. All the points should now appear bright yellow when viewed from the top and dark yellow when viewed from the bottom.



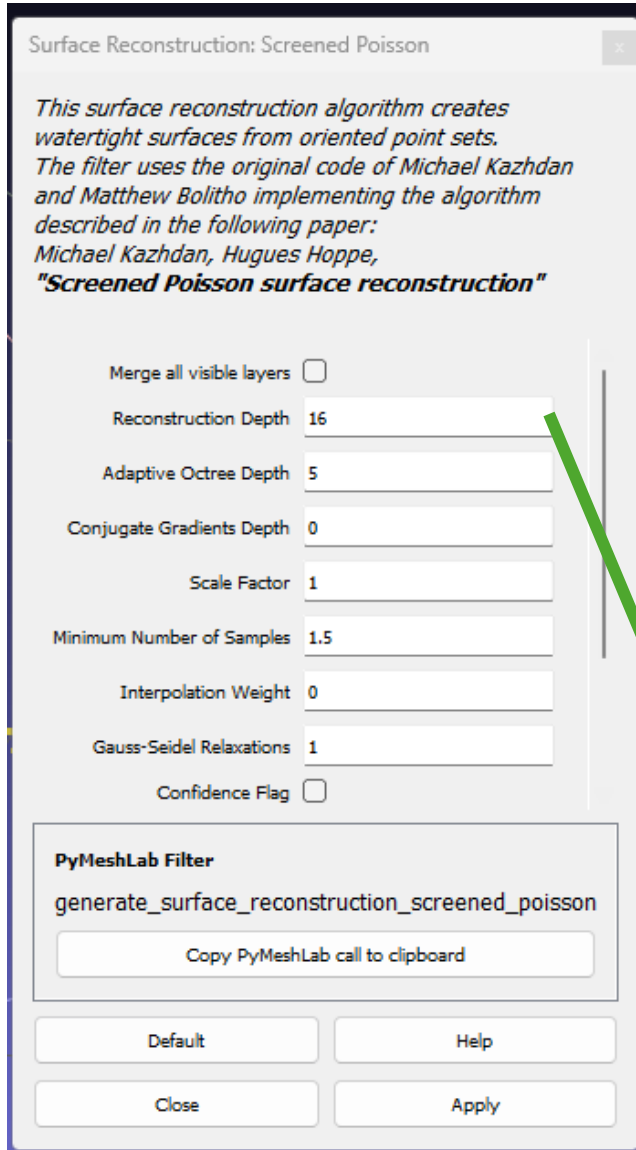
# Meshing



- Now that you have a merged point cloud with normal vectors facing the correct direction, the surface can be meshed
- With the “Merged Mesh” in the project window selected, navigate to the following:

Filters->Remeshing, Simplification, and  
Reconstruction->Surface Reconstruction:  
Screened Poisson

# Meshing



Surface Reconstruction: Screened Poisson

*This surface reconstruction algorithm creates watertight surfaces from oriented point sets. The filter uses the original code of Michael Kazhdan and Matthew Bolitho implementing the algorithm described in the following paper:  
Michael Kazhdan, Hugues Hoppe,  
"Screened Poisson surface reconstruction"*

Merge all visible layers ☐

Reconstruction Depth

Adaptive Octree Depth

Conjugate Gradients Depth

Scale Factor

Minimum Number of Samples

Interpolation Weight

Gauss-Seidel Relaxations

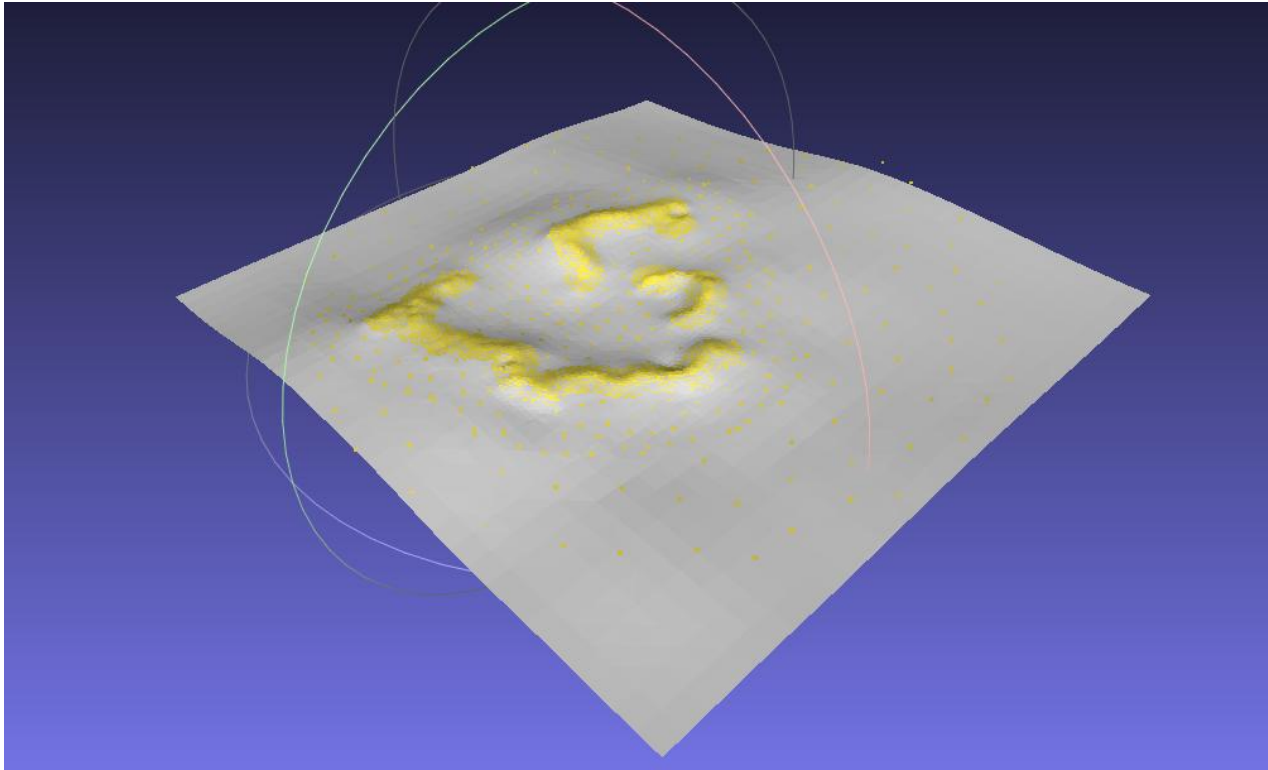
Confidence Flag ☐

**PyMeshLab Filter**  
generate\_surface\_reconstruction\_screened\_poisson

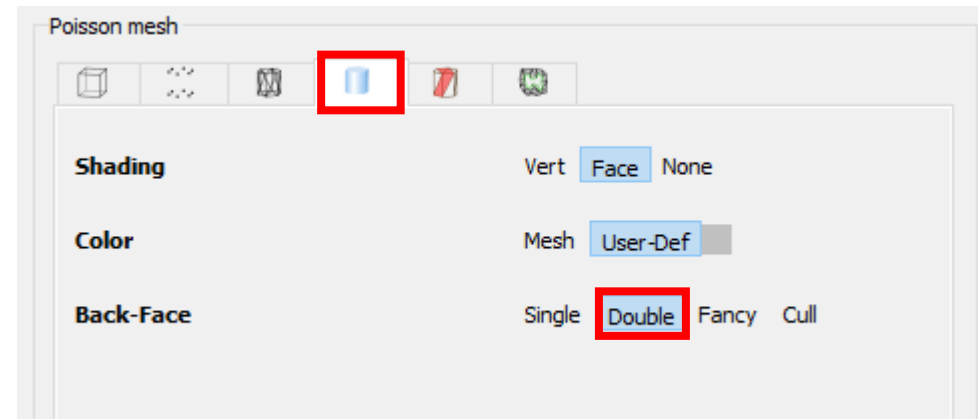
- In the “Surface Reconstruction: Screened Poisson” window, select the down arrow to view more advanced settings and enter the following :
  - Reconstruction Depth = 16 or 17 (17 is better but may take significantly longer)
  - Interpolation Weight = **0**
  - Scale Factor = 1
  - Gauss-Seidel Relaxations = 1
- Leave all other settings default
- Select Apply and once it is finished calculating, select Close

17 Should be  
standard for  
powerful  
workstations

# Mesh Inspection

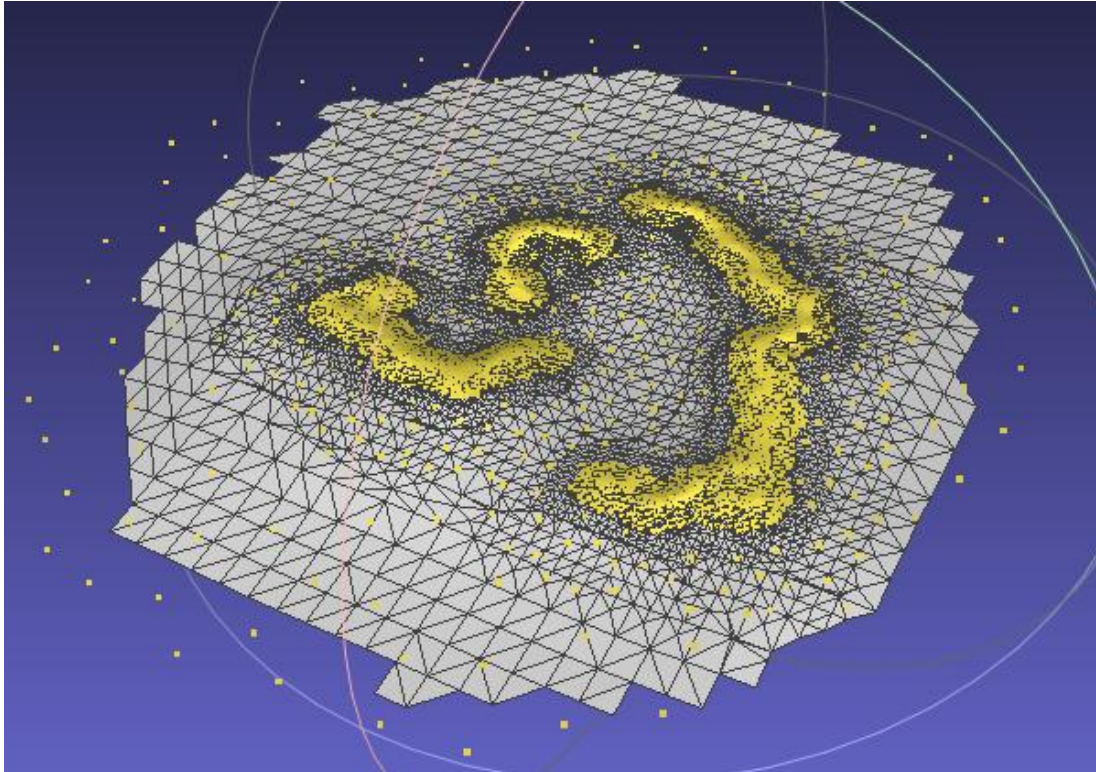


- With “Poisson mesh” selected in the project window, look below the project window to the view settings
- Navigate to surface settings as shown below, and select “Double” for Back-Face (This will allow you to see the mesh better)



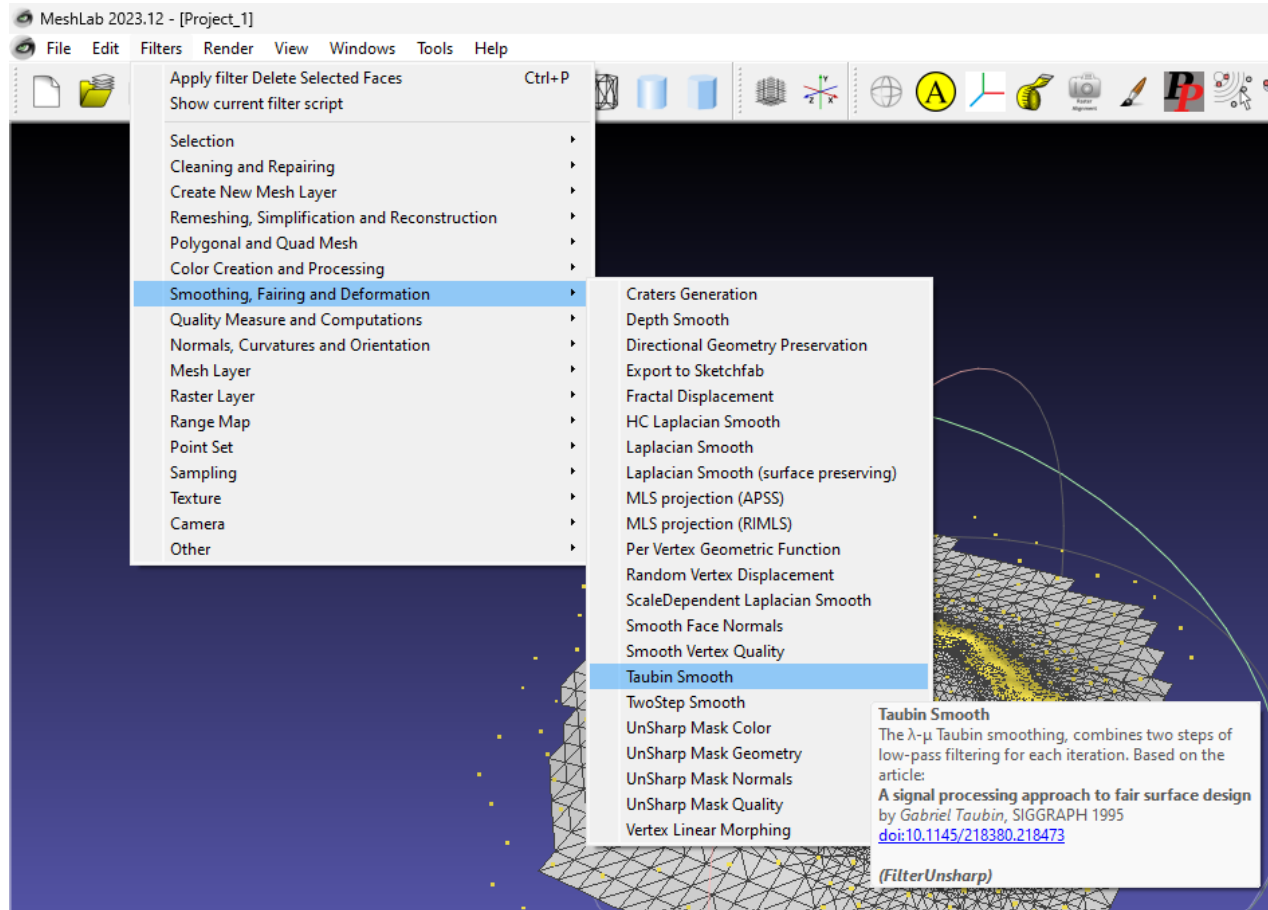
- Inspect the mesh for obvious abnormalities. The mesh should look similar to the mesh shown on the left

# Mesh Trimming



- In the top toolbar, first select **Wireframe** to better view mesh elements, and then select the **Select Faces in a rectangular region** tool to allow for selection of individual mesh elements
- Looking at the point cloud as a visual reference, carefully select and delete (hit the delete button on your keyboard) the erroneous corners of the mesh and any parts of the mesh that are not likely to influence the lunar surface asset in your thermal desktop model
- **Be careful not to delete too much. A mesh element may not be in the direct FOV of your lunar asset, but it may still have an indirect thermal influence over your vehicle (e.g. a hill that's not visible from the perspective of your lunar asset may be blocking the sun from warming a hill that *is* in your asset's FOV)**
- Depending on the mesh, you may be able to get away with deleting more or fewer mesh elements. The goal of deleting elements is to have a more efficient Thermal Desktop model that doesn't analyze unnecessary terrain
- An example of a trimmed mesh is shown to the left

# Mesh Refinement

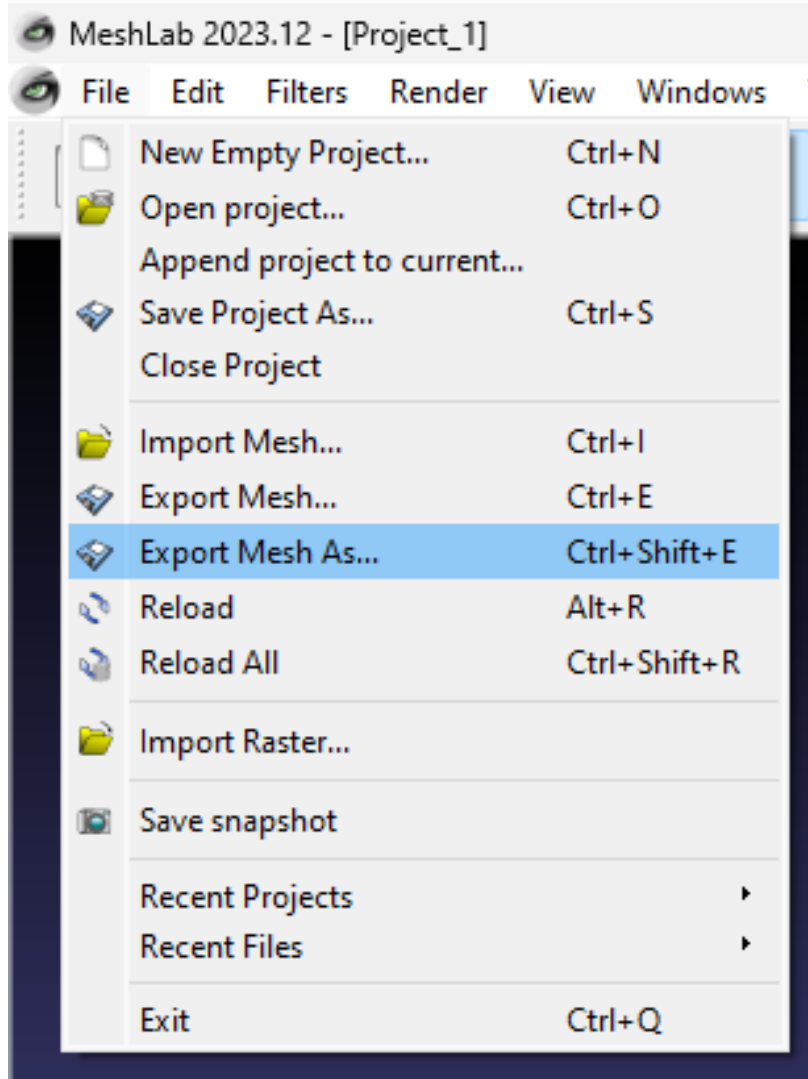


- With the Poisson Mesh selected in the Project window, navigate to the following:

Filters-> Smoothing, Fairing and Deformation-> **Taubin Smooth**

- A Taubin smooth will greatly improve the quality of mesh elements without sacrificing the accuracy of the surface
- A window will appear. Keep the default settings, select Apply, then Close

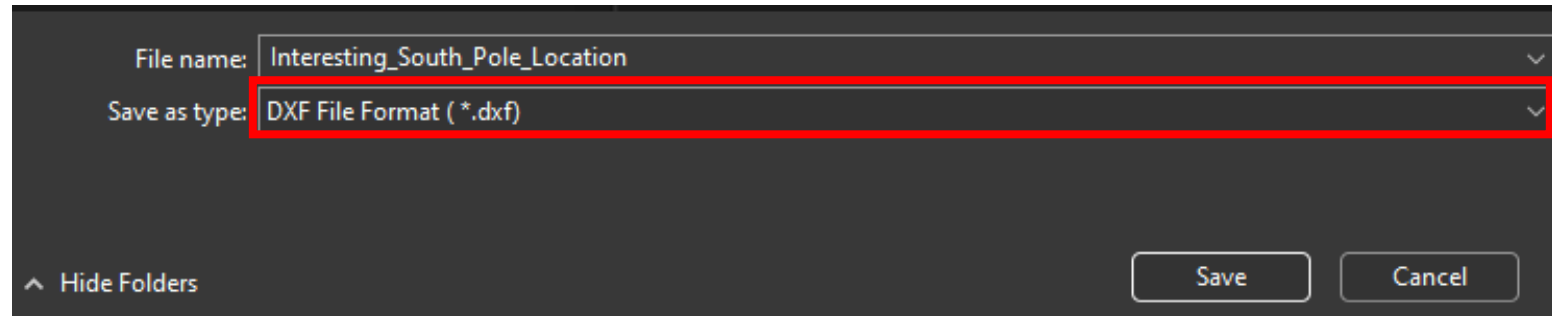
# Exporting the Mesh



- With the “Poisson mesh” selected in the project window, Navigate to the following:

File->Export Mesh As...

- In the Save window, enter a file name, and for “Save as type:” select DXF



- Keep the default settings in the “Choose Saving Options for:” window, and select OK
- You now have a terrain mesh that can be imported into AutoCAD/Thermal Desktop

*\*Note: Don't close MeshLab until you've inspected the mesh in AutoCAD. Sometimes it will unexpectedly save a corrupted version of the DXF, and the DXF may need to be saved again*

# JPL Horizons Data Processing

This section describes the process of gathering solar vector and flux data from JPL Horizons for the surface site of interest and converting it into a format useable by Thermal Desktop

# JPL Horizons Data Processing: Solar Vector

- Go to the JPL Horizons web interface found here:

<https://ssd.jpl.nasa.gov/horizons/app.html#/>

- For solar vector data, the Ephemeris Type to “Observer Table”**
- For Target Body, select “Edit” If the target body is set to something other than the sun
  - Select “Search for a specified body” in the drop-down menu
  - Type “Sun” into the search box, and hit “Search”
  - Sun should be automatically selected and return you to the main settings page

|   |                      |                   |
|---|----------------------|-------------------|
| 1 | Ephemeris Type       | Observer Table    |
| 2 | <a href="#">Edit</a> | Target Body: Mars |

## Specify the Target Body

Choose a method for specifying the target body:

Search for a specified body

### Lookup the Specified Body

Sun

Search

Search all available bodies (default)

To restrict your search to only small-bodies or only major-bodies, use the pulldown menu to the right of the

Show Examples

# JPL Horizons Data Processing: Solar Vector

- For Observer Location, select “Edit”
- Under “Choose a method:” select “Specify Coordinates” from the drop-down menu
- For Coordinate Body, select “Change” if it isn’t set to Moon already
  - Scroll all the way down to “Moon [Luna]” (it’s close to the bottom of the list) and hit “Select Indicated Body”
- Under Type of coordinates, select “Geodetic Coordinates” from the drop-down menu
- Enter the longitude and latitude of interest
  - South pole latitudes are negative
  - If you’re like me, you like to enter Latitude then Longitude – they are in reverse order here
- **Continued on the next slide....**

3 **Edit** Observer Location: **Geocentric** [code: 500]

Select Coordinate Body

[id: 801] Triton (NI)  
[id: 803] Naiad (NIII)  
[id: 804] Thalassa (NIV)  
[id: 805] Despina (NV)  
[id: 806] Galatea (NVI)  
[id: 807] Larissa (NVII)  
[id: 808] Proteus (NVIII)  
[id: 301] Moon [Luna]

Select Indicated Body

Coordinate Body: **Moon [Luna]** **change**

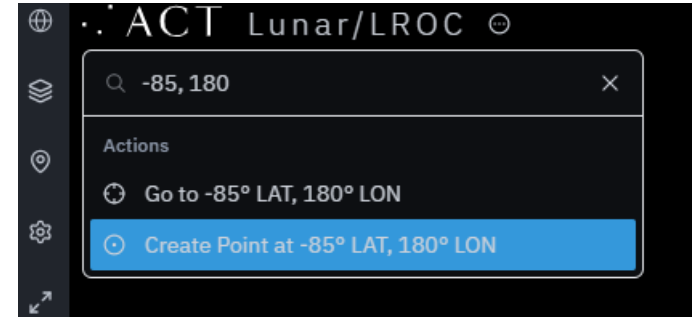
Type of coordinates: **Geodetic Coordinates** ▼

longitude: ? 180 (deg)

latitude: ? -85 (deg)

# JPL Horizons Data Processing: Solar Vector

- To find altitude, use LROC Quickmap. Go to the following link:
  - <https://quickmap.lroc.im-ldi.com>
- Enter the latitude and longitude into the search bar, separated by a comma, and select “Create Point”
- In the Object Inspector window on the right, navigate to the “Inspect” tab
- Copy the TerrainHeight, navigate back to JPL Horizons, and enter this into the “altitude”
- **Ensure the units are set to meters in JPL Horizons!**
- Select “Use Specified Coordinates”

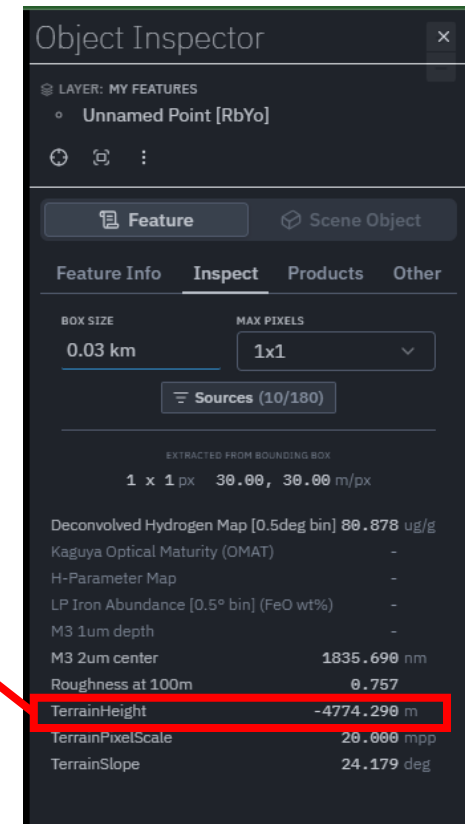


Type of coordinates: Geodetic Coordinates

longitude:  (deg)

latitude:  (deg)

altitude:  meters



# JPL Horizons Data Processing: Solar Vector

- For Time Specification, select “Edit”
- Enter a start and stop time that makes sense for your analysis:
  - The maximum transient initializer time span typically needed for subsurface temperatures to converge to a steady pattern is 20 years. However, for some sites and for some cases where perfect temperature stability is not needed, sometimes only 1 year of initializer data is acceptable.
  - The time span used for individual hot or cold cases varies significantly depending on the length of the phenomenon you are attempting to capture. The maximum is 28 days, but runs on the order of ~20 hours are more common.
- Set step size **units to hours** and enter an appropriate step size:
  - Multi-year transient initializer can typically be run with time steps on the order of 24 hours
  - Shorter single hot case or cold case runs can typically be run with 1-8 hour time steps depending on how long the case is and how many sharp transitions in solar access occur during the case.
- Select “Use Specified Time Span”

4 **Edit** Time Specification: Start=**2026-08-13** UT , Stop=**2026-09-12**, Step

## Time Specification

Choose a method for specifying output times:

Specify time span ▾

### Specify a Time Span

Start time: ? 2009-01-01

B.C. 9999-03-20 00

Stop time: ? 2029-12-31

A.D. 9999-12-31 12

Step size: ? 8

hours ▾

Optionally, select one of the presets below to set the time-span from

10 day

30 day

60 day

Use Specified Time Span

# JPL Horizons Data Processing: Solar Vector

- For Table Settings, select “Edit”
- Uncheck all boxes except “Apparent AZ & EL”
- Scroll down to “Additional Table Settings” and ensure “CSV format” is selected.
- Select “Use Specified Settings”
- In the main window, select “Generate Ephemeris”
- Select “Download Results” and save to a convenient location with a memorable file name

5 **Edit** Table Settings: *defaults*

|                                                                |                                                                   |                                                             |
|----------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------|
| 1. <input type="checkbox"/> Astrometric RA & DEC               | 17. <input type="checkbox"/> North Pole position angle & distance | 33. <input type="checkbox"/> Galactic longitude & latitude  |
| * 2. <input type="checkbox"/> Apparent RA & DEC                | 18. <input type="checkbox"/> Heliocentric ecliptic lon. & lat.    | 34. <input type="checkbox"/> Local apparent SOLAR time      |
| 3. <input type="checkbox"/> Rates; RA & DEC                    | 19. <input type="checkbox"/> Heliocentric range & range-rate      | 35. <input type="checkbox"/> Earth->obs. site light-time    |
| * 4. <input checked="" type="checkbox"/> Apparent AZ & EL      | 20. <input type="checkbox"/> Observer range & range-rate          | > 36. <input type="checkbox"/> RA & DEC uncertainty         |
| 5. <input type="checkbox"/> Rates; AZ & EL                     | 21. <input type="checkbox"/> One-way (down-leg) light-time        | > 37. <input type="checkbox"/> Plane-of-sky error ellipse   |
| 6. <input type="checkbox"/> Satellite X & Y, pos. angle        | 22. <input type="checkbox"/> Speed wrt Sun & observer             | > 38. <input type="checkbox"/> POS uncertainty (RSS)        |
| 7. <input type="checkbox"/> Local apparent sidereal time       | 23. <input type="checkbox"/> Sun-Observer-Target ELONG angle      | > 39. <input type="checkbox"/> Range & range-rate 3-sigmas  |
| 8. <input type="checkbox"/> Airmass & extinction               | 24. <input type="checkbox"/> Sun-Target-Observer ~PHASE angle     | > 40. <input type="checkbox"/> Doppler & delay 3-sigmas     |
| 9. <input type="checkbox"/> Visual mag. & Surface Bright       | 25. <input type="checkbox"/> Target-Observer-Moon angle/ Illum%   | 41. <input type="checkbox"/> True anomaly angle             |
| 10. <input type="checkbox"/> Illuminated fraction              | 26. <input type="checkbox"/> Observer-Primary-Target angle        | 42. <input type="checkbox"/> Local apparent hour angle      |
| 11. <input type="checkbox"/> Defect of illumination            | 27. <input type="checkbox"/> Sun-Target radial & -vel pos. angle  | 43. <input type="checkbox"/> PHASE angle & bisector         |
| 12. <input type="checkbox"/> Satellite angular separ/vis.      | 28. <input type="checkbox"/> Orbit plane angle                    | 44. <input type="checkbox"/> Apparent longitude Sun (L_s)   |
| 13. <input type="checkbox"/> Target angular diameter           | 29. <input type="checkbox"/> Constellation ID                     | * 45. <input type="checkbox"/> Inertial apparent RA & DEC   |
| 14. <input type="checkbox"/> Observer sub-lon & sub-lat        | 30. <input type="checkbox"/> Delta-T (TDB - UT)                   | 46. <input type="checkbox"/> Rate: Inertial RA & DEC        |
| 15. <input type="checkbox"/> Sun sub-longitude & sub-latitude  | * 31. <input type="checkbox"/> Observer ecliptic lon. & lat.      | 47. <input type="checkbox"/> Sky motion: rate & angles      |
| 16. <input type="checkbox"/> Sub-Sun position angle & distance | 32. <input type="checkbox"/> North pole RA & DEC                  | 48. <input type="checkbox"/> Lunar sky-brightness & sky SNR |

CSV format: ? ☒

Horizons Web Application

Save/Load Settings...

|   |                                                                                                                |
|---|----------------------------------------------------------------------------------------------------------------|
| 1 | Ephemeris Type: <input type="text" value="Observer Table"/>                                                    |
| 2 | <b>Edit</b> Target Body: <b>Sun [Sol]</b>                                                                      |
| 3 | <b>Edit</b> Observer Location: <b>180°E, -85°N, -4774.290 m @301 (Moon [Luna])</b>                             |
| 4 | <b>Edit</b> Time Specification: Start= <b>2009-01-01 UT</b> , Stop= <b>2029-12-31</b> , Step= <b>8</b> (hours) |
| 5 | <b>Edit</b> Table Settings: <i>custom</i>                                                                      |

After specifying settings above (items 1 to 5), generate an ephemeris by pressing the "Generate Ephemeris" button below

**Generate Ephemeris**

Ephemeris Results

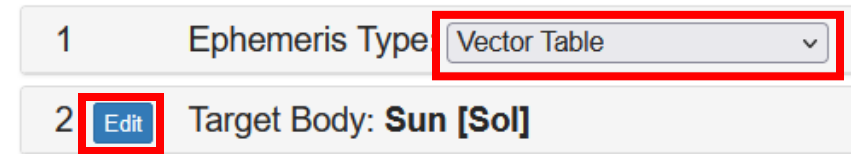
**Download Results** ?

# JPL Horizons Data Processing: Solar Flux

- Keep the existing instance of JPL Horizons open or go to the JPL Horizons web interface found here:

<https://ssd.jpl.nasa.gov/horizons/app.html#/>

- **For solar flux data, the Ephemeris Type to “Vector Table”**
- For Target Body, select “Edit” If the target body is set to something other than the sun
  - Select “Search for a specified body” in the drop-down menu
  - Type “Sun” into the search box, and hit “Search”
  - Sun should be automatically selected and return you to the main settings page



1 Ephemeris Type Vector Table

2 Edit Target Body: Sun [Sol]

## Specify the Target Body

Choose a method for specifying the target body:

Search for a specified body

### Lookup the Specified Body

Sun

Search

Search all available bodies (default)

To restrict your search to only small-bodies or only major-bodies, use the pulldown menu to the right of the

Show Examples

# JPL Horizons Data Processing: Solar Flux

- For Coordinate Center, select “Edit”
- Under “Choose a method:” select “Specify Coordinates” from the drop-down menu
- For Coordinate Body, select “Change” if it isn’t set to Moon already
  - Scroll all the way down to “Moon [Luna]” (it’s close to the bottom of the list) and hit “Select Indicated Body”
- Under Type of coordinates, select “Planetodetic Coordinates” from the drop-down menu
- **Enter the same lat, long, and altitude used to generate solar vector data (ensure units are set to meters for altitude)**

3 **Edit** Coordinate Center: **Solar System Barycenter (SSB)** [500@0]

Select Coordinate Body

|           |                    |
|-----------|--------------------|
| [id: 801] | Iriton (NI)        |
| [id: 803] | Naiad (NIII)       |
| [id: 804] | Thalassa (NIV)     |
| [id: 805] | Despina (NV)       |
| [id: 806] | Galatea (NVI)      |
| [id: 807] | Larissa (NVII)     |
| [id: 808] | Proteus (NVIII)    |
| [id: 301] | <b>Moon [Luna]</b> |
| [id: 403] | Phobos (MII)       |

Select Indicated Body

Coordinate Body: **Moon [Luna]** **change**

Type of coordinates: Planetodetic Coordinates ▾

|              |           |          |
|--------------|-----------|----------|
| longitude: ? | 180       | (deg)    |
| latitude: ?  | -85       | (deg)    |
| altitude: ?  | -4774.290 | meters ▾ |

# JPL Horizons Data Processing: Solar Flux

4 **Edit** Time Specification: Start=2026-08-13 UT , Stop=2026-09-12, Step

- For Time Specification, select “Edit”
- Set step size **units to hours** and enter the same start time, stop time, and step size used to calculate solar vector
- Select “Use Specified Time Span”

## Time Specification

Choose a method for specifying output times:

Specify time span ▾

### Specify a Time Span

Start time: ? 2009-01-01 B.C. 9999-03-20 00

Stop time: ? 2029-12-31 A.D. 9999-12-31 12

Step size: ? 8 hours ▾

Optionally, select one of the presets below to set the time-span from

10 day 30 day 60 day

Use Specified Time Span

# JPL Horizons Data Processing: Solar Flux

- For Table Settings, select “Edit”
- Under Select Output Quantities, select “Position components {x,y,z} only” from the drop-down menu
- Scroll down to “Additional Table Settings”
  - Switch units to “au and days”
  - Select all boxes
- Select “Use Specified Settings”
- In the main window, select “Generate Ephemeris”
- Select “Download Results” and save to a convenient location with a memorable file name

5 [Edit](#) Table Settings: *defaults*

Select Output Quantities

1. Position components {x,y,z} only

Statistical Uncertainties — comets and asteroids only

Select one or more of the following coordinate systems for output of uncertainty

☐ XYZ uncertainties (ICRF or FK4/B1950)  
☐ ACN uncertainties (along-track, cross-track, normal)  
☐ RTN uncertainties (radial, transverse, normal)  
☐ POS uncertainties (plane-of-sky; radial, RA, and DEC components)

Additional Table Settings

Reference frame: ? ICRF  
Reference plane: ? ecliptic x-y plane derived  
Vector correction: ? geometric states  
Calendar type: ? Mixed  
Output units: ? au and days

Vector labels: ? ☒  
Output TDB-UT: ? ☒  
CSV format: ? ☒  
Object summary: ? ☒

[Use Specified Settings](#) [Reset to Defaults](#)

1 Ephemeris Type: Vector Table  
2 [Edit](#) Target Body: Sun [Sol]  
3 [Edit](#) Coordinate Center: 180°E, -85°N, -4774.290 m @301 (Moon [Luna])  
4 [Edit](#) Time Specification: Start=2009-01-01 TDB, Stop=2029-12-31, Step=8 (hours)  
5 [Edit](#) Table Settings: custom

After specifying settings above (items 1 to 5), generate an ephemeris by pressing the “Generate Ephemeris” button below

[Generate Ephemeris](#)

Ephemeris Results

[Download Results](#) ?

# JPL Horizons Data Processing: MATLAB

- Open the Matlab code:  
JPLHorizons\_SolarVectorandSolarFlux\_TDFormat.m
- Enter the file names and paths to both the vector and flux files into the MATLAB code
- Run the code – this should output:
  - CSV **vector** file with data that can be directly copied into the “Vector Input” tab in Thermal Desktop’s **orbit editor**
  - CSV **flux** file that can be copied directly into **Solar flux vs Time Table** under the “Solar” tab in TD’s orbit editor

## Specify .txt location and Execute Matlab

```
JPLHorizons_SolarVectorandSolarFlux_TDFormat.m
1 clc; clear;
2
3 % Constants
4 SOLAR_CONSTANT = 1367; % W/m2
5
6 % File processing options
7 fprintf('1-Solar Vector Only, 2- Solar Flux Only, 3-Both: ');
8 choice = input('');
9
10 % File paths
11 vector_file = 'C:\Users\wgrier\Downloads\horizons_results_vector.txt';
12 flux_file = 'C:\Users\wgrier\Downloads\horizons_results_flux.txt';
13
14 if choice == 1 || choice == 3
15     process_vector_file(vector_file, 'sun_vectors.csv');
16 end
17 if choice == 2 || choice == 3
18     process_flux_file(flux_file, 'solar_flux.csv', SOLAR_CONSTANT);
19 end
20
21 %% Solar vector file processing
22 function process_vector_file(filename, output_file)
23     fprintf('Processing vector file...\n');
24     if ~exist(filename, 'file'), fprintf('Error: File not found\n'); return; end
25
26     data = []; date_strings = []; jd = []; data_section = false;
27     fid = fopen(filename, 'r');
28     if fid == -1, fprintf('Error: Cannot open file\n'); return; end
29
30     while ~feof(fid)
```

**Matlab File Name:**  
JPLHorizons\_SolarVectorand  
SolarFlux\_TDFormat.m

## Open Vector and Flux Files

|    | A                | B       | C        | D        | E        | F        | G        | H        | I     | J |
|----|------------------|---------|----------|----------|----------|----------|----------|----------|-------|---|
| 1  | Date             | Seconds | Sun_i    | Sun_j    | Sun_k    | Planet_l | Planet_j | Planet_k | Ratio |   |
| 2  | 10/23/2026 0:00  | 0       | -0.04156 | 0.993523 | 0.105757 | 0        | 0        | -1       | 1.001 |   |
| 3  | 10/23/2026 1:00  | 3600    | -0.05039 | 0.993117 | 0.105732 | 0        | 0        | -1       | 1.001 |   |
| 4  | 10/23/2026 2:00  | 7200    | -0.05921 | 0.992633 | 0.105701 | 0        | 0        | -1       | 1.001 |   |
| 5  | 10/23/2026 3:00  | 10800   | -0.06803 | 0.992072 | 0.105663 | 0        | 0        | -1       | 1.001 |   |
| 6  | 10/23/2026 4:00  | 14400   | -0.07685 | 0.991433 | 0.105619 | 0        | 0        | -1       | 1.001 |   |
| 7  | 10/23/2026 5:00  | 18000   | -0.08565 | 0.990716 | 0.105569 | 0        | 0        | -1       | 1.001 |   |
| 8  | 10/23/2026 6:00  | 21600   | -0.09445 | 0.989922 | 0.105512 | 0        | 0        | -1       | 1.001 |   |
| 9  | 10/23/2026 7:00  | 25200   | -0.10325 | 0.98905  | 0.105449 | 0        | 0        | -1       | 1.001 |   |
| 10 | 10/23/2026 8:00  | 28800   | -0.11203 | 0.988101 | 0.105379 | 0        | 0        | -1       | 1.001 |   |
| 11 | 10/23/2026 9:00  | 32400   | -0.12081 | 0.987075 | 0.105303 | 0        | 0        | -1       | 1.001 |   |
| 12 | 10/23/2026 10:00 | 36000   | -0.12958 | 0.985971 | 0.105221 | 0        | 0        | -1       | 1.001 |   |
| 13 | 10/23/2026 11:00 | 39600   | -0.13833 | 0.98479  | 0.105133 | 0        | 0        | -1       | 1.001 |   |
| 14 | 10/23/2026 12:00 | 43200   | -0.14708 | 0.983532 | 0.105038 | 0        | 0        | -1       | 1.001 |   |
| 15 | 10/23/2026 13:00 | 46800   | -0.15581 | 0.982197 | 0.104936 | 0        | 0        | -1       | 1.001 |   |
| 16 | 10/23/2026 14:00 | 50400   | -0.16453 | 0.980785 | 0.104828 | 0        | 0        | -1       | 1.001 |   |
| 17 | 10/23/2026 15:00 | 54000   | -0.17324 | 0.979297 | 0.104714 | 0        | 0        | -1       | 1.001 |   |
| 18 | 10/23/2026 16:00 | 57600   | -0.18194 | 0.977732 | 0.104594 | 0        | 0        | -1       | 1.001 |   |

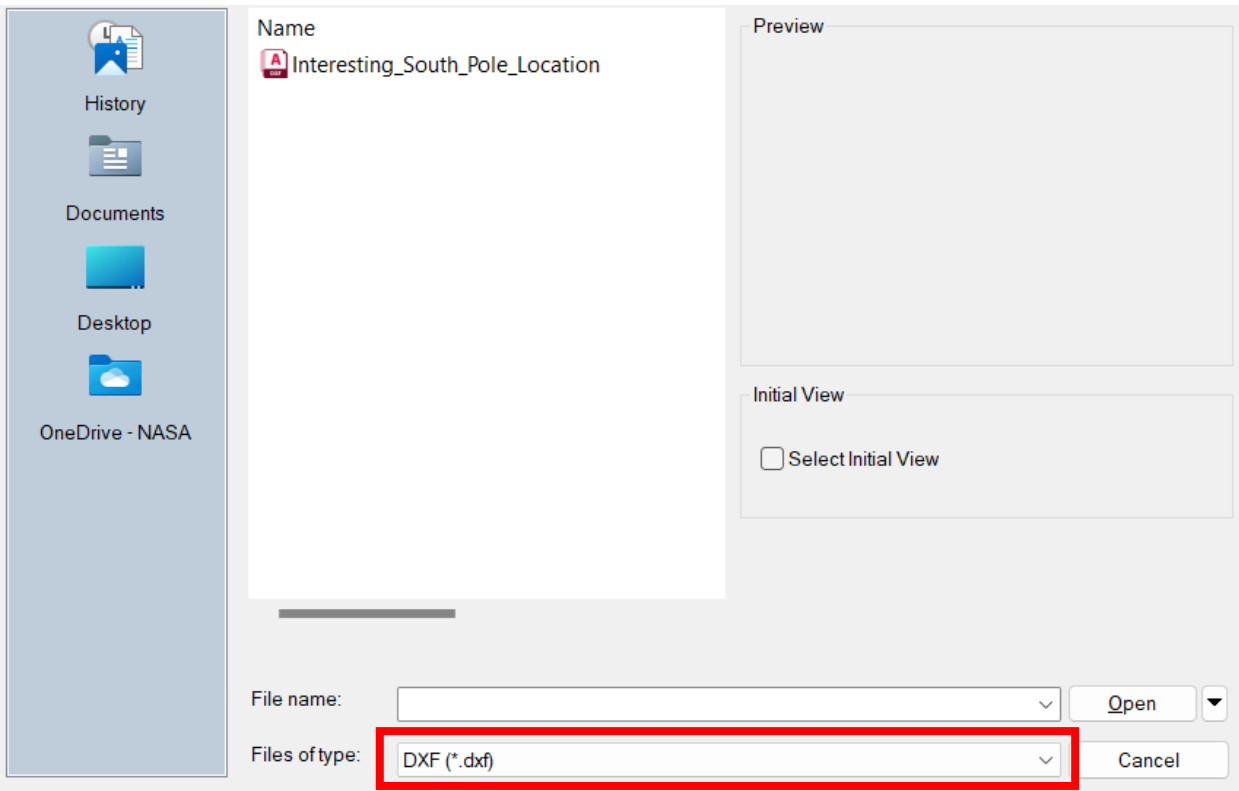
|    | A               | B       | C              | D | E |
|----|-----------------|---------|----------------|---|---|
| 1  | Date            | Seconds | SolarFlux_W_m2 |   |   |
| 2  | 10/24/2009 0:00 | 0       | 1384.328       |   |   |
| 3  | 10/25/2009 0:00 | 86400   | 1383.75        |   |   |
| 4  | 10/26/2009 0:00 | 172800  | 1383.114       |   |   |
| 5  | 10/27/2009 0:00 | 259200  | 1382.474       |   |   |
| 6  | 10/28/2009 0:00 | 345600  | 1381.88        |   |   |
| 7  | 10/29/2009 0:00 | 432000  | 1381.385       |   |   |
| 8  | 10/30/2009 0:00 | 518400  | 1381.039       |   |   |
| 9  | 10/31/2009 0:00 | 604800  | 1380.891       |   |   |
| 10 | 11/1/2009 0:00  | 691200  | 1380.985       |   |   |
| 11 | 11/2/2009 0:00  | 777600  | 1381.357       |   |   |
| 12 | 11/3/2009 0:00  | 864000  | 1382.037       |   |   |
| 13 | 11/4/2009 0:00  | 950400  | 1383.035       |   |   |

# Lunar Terrain Thermal Analysis in Thermal Desktop

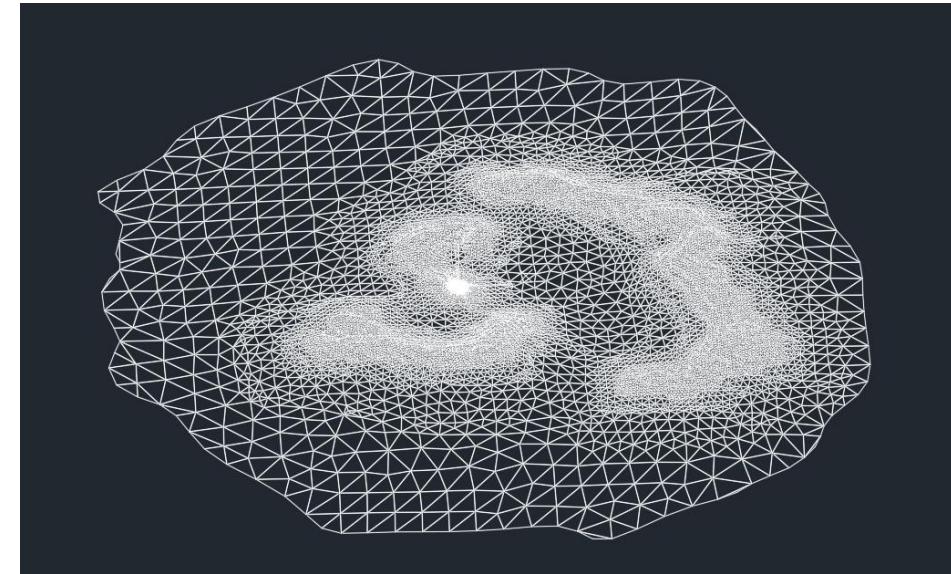
This section describes the process of building and running the final Thermal Desktop model.

Note these instructions were created using version 6.3 of Thermal Desktop

# Importing the Mesh

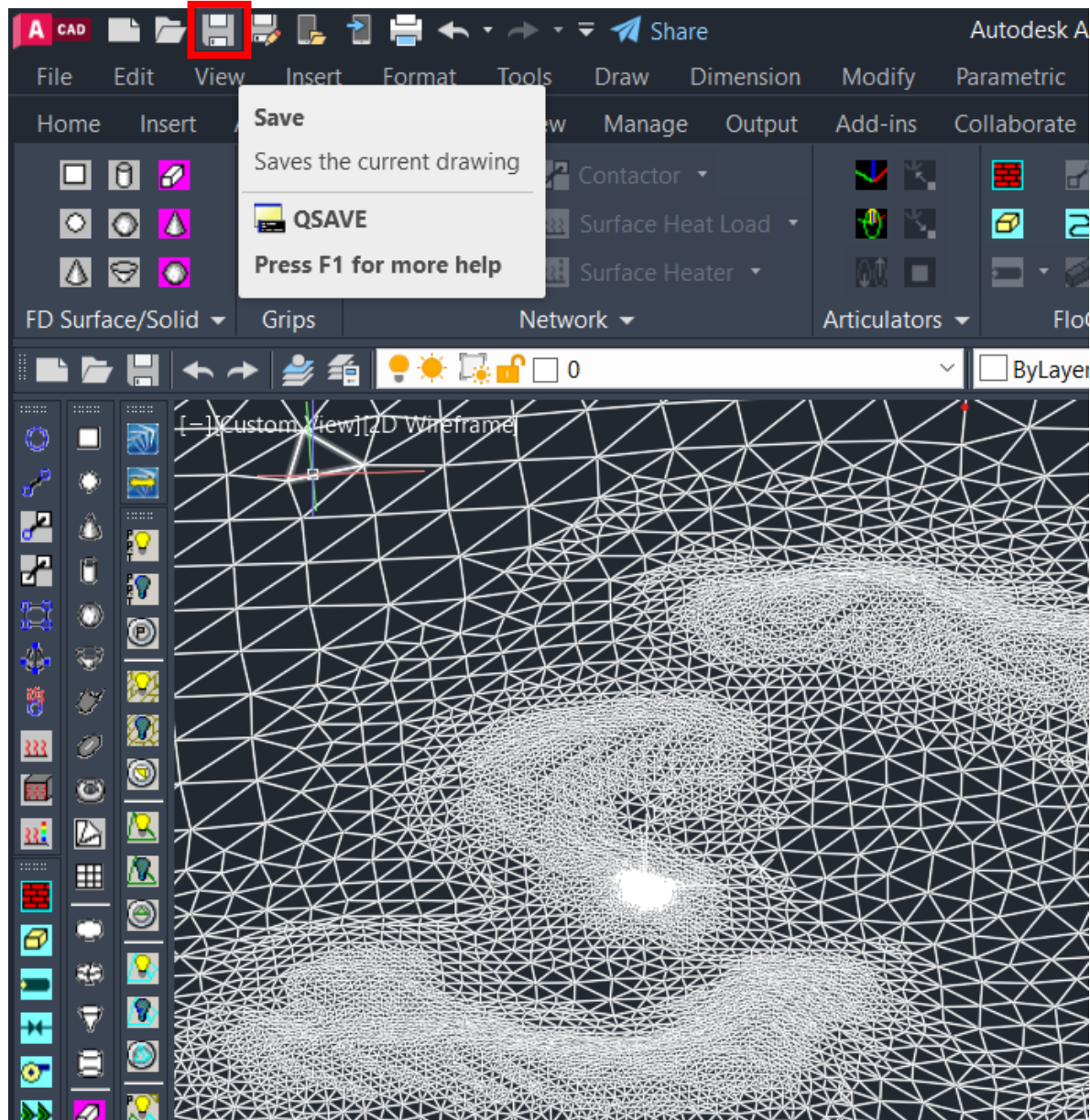


- **Open AutoCAD/Thermal Desktop\***
- Select the “Open” icon in the upper lefthand corner
- Navigate to the DXF file that was exported from MeshLab (ensuring the “File of type” is set to DXF) and Open
- Zoom out to view/Inspect the mesh.



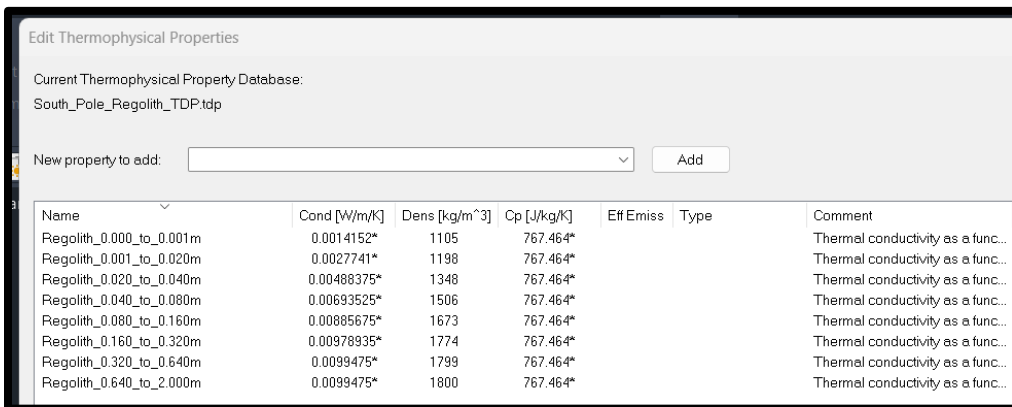
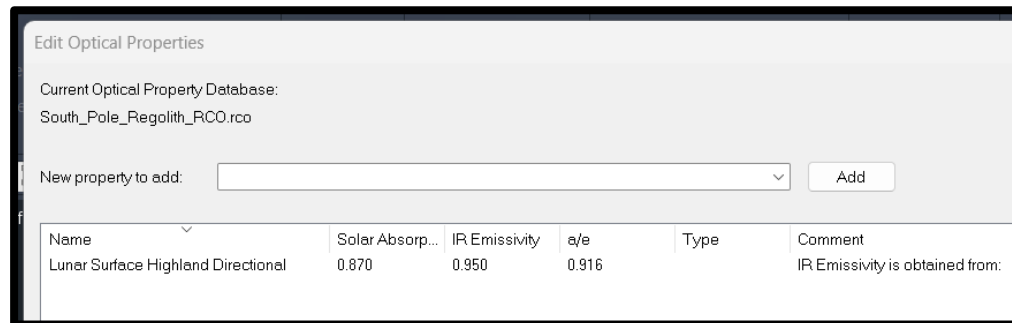
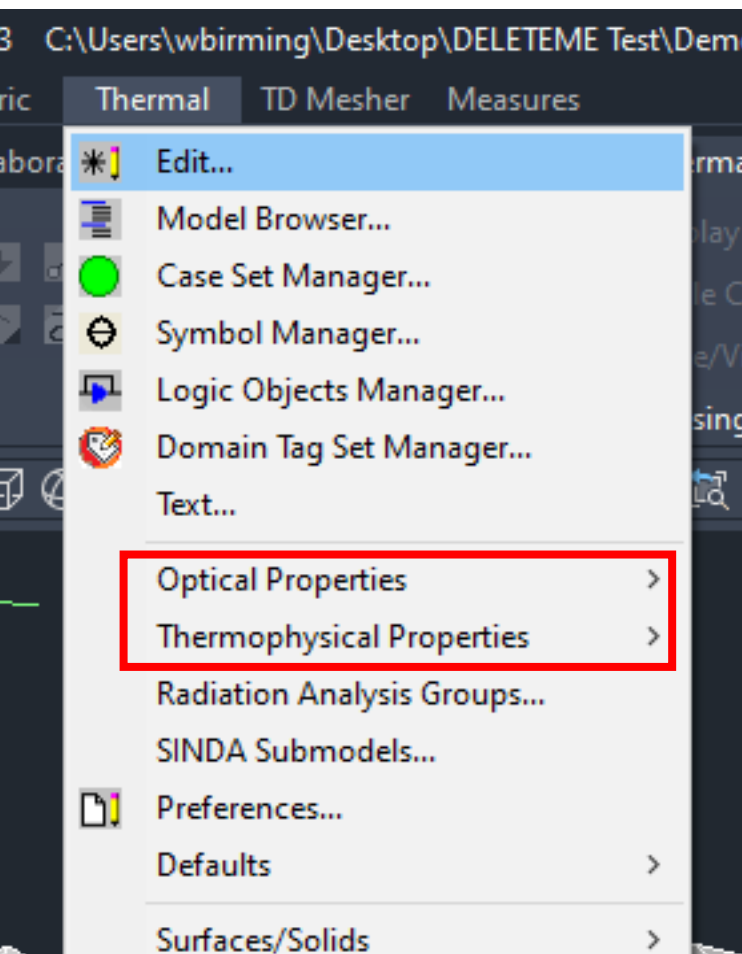
\*Note: Don't close MeshLab until you've inspected the mesh in AutoCAD. Sometimes it will unexpectedly save a corrupted version of the DXF, and the DXF may need to be saved again

# DWG Conversion



- Go ahead and select the Save Icon to save As a .dwg file. (Among other things, this step makes your TD model recoverable in the event of a crash)

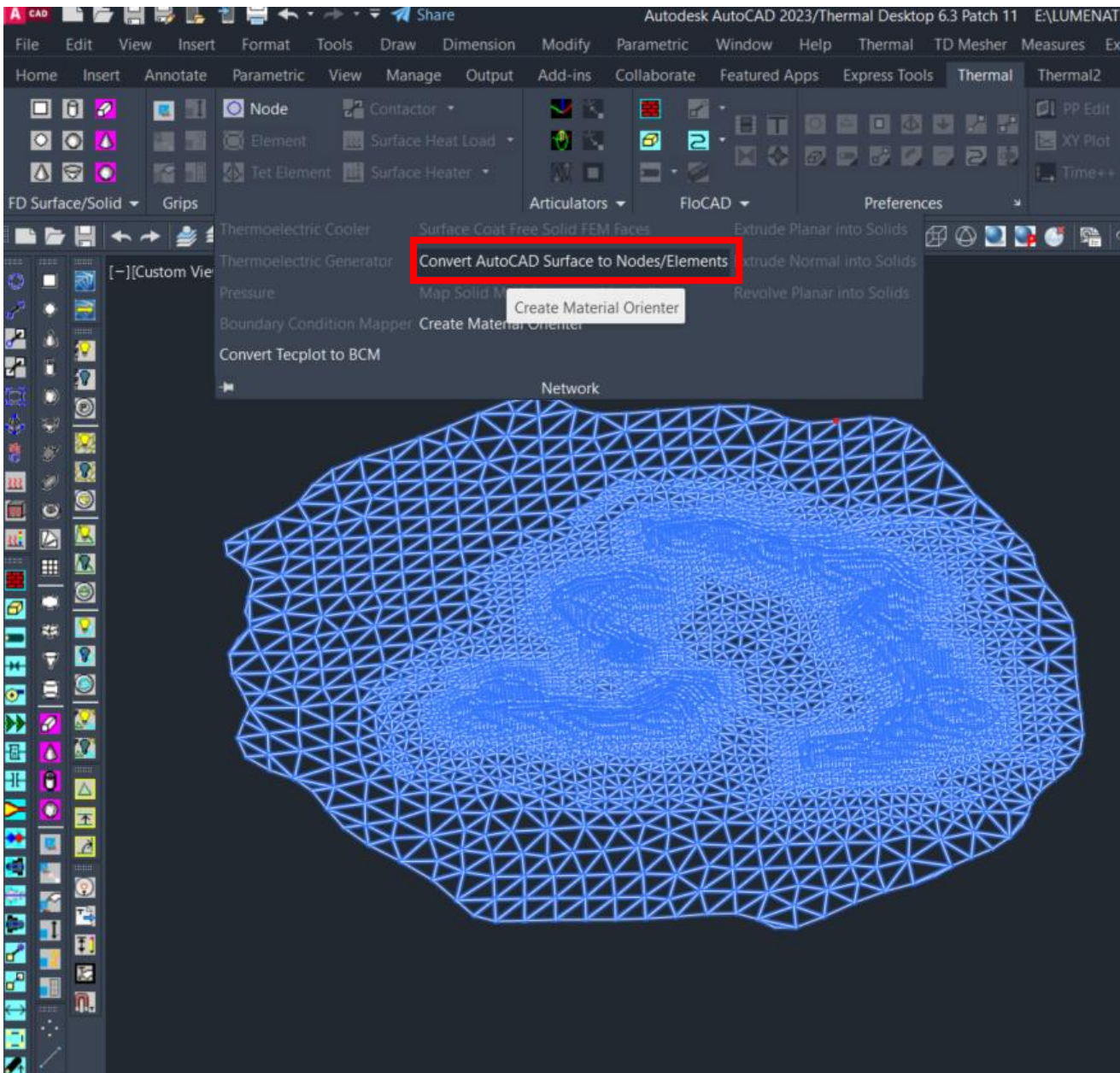
# Property Files



- Open TDP and RCO Files containing all the properties needed for the lunar terrain analysis (future steps will be much easier if this is done now)

- The basic properties used for this analysis are shown to the left (note lander-specific properties can be added later if desired)

# Conversion to Thermal Desktop



- Select the entire mesh
- Under “Network” select “Convert AutoCAD Surface to Nodes/Elements”

# Notes on Regolith Properties

- **Thermal conductivity as a function of temperature and density is obtained from:**

Martinez, A., & Siegler, M. A. (2021). A Global Thermal Conductivity Model for Lunar Regolith at Low Temperatures. *Journal of Geophysical Research: Planets*, 126, e2021JE006829. <https://doi.org/10.1029/2021JE006829>

- **Density as a function of depth is obtained from:**

Vasavada, A. R., Bandfield, J. L., Greenhagen, B. T., Hayne, P. O., Siegler, M. A., Williams, J., & Paige, D. A. (2012). Lunar equatorial surface temperatures and regolith properties from the Diviner Lunar Radiometer Experiment. *Journal of Geophysical Research: Planets*, E12. <https://doi.org/10.1029/2011je003987>

& Hayne, P. O., Bandfield, J. L., Siegler, M. A., Vasavada, A. R., Ghent, R. R., Williams, J.-P., ... Paige, D. A. (2017). Global Regolith Thermophysical Properties of the Moon from the Diviner Lunar Radiometer Experiment. *Journal of Geophysical Research: Planets*, 122, 2371–2400. <https://doi.org/10.1002/2017JE005387>

- **Specific heat as a function of temperature is obtained from:**

Woods-Robinson, R., Siegler, M. A., & Paige, D. A. (2019). A Model for The Thermophysical Properties of Lunar Regolith at Low Temperatures. *Journal of Geophysical Research: Planets*, 124, 1989–2011. <https://doi.org/10.1029/2019JE005955>

- **IR Emissivity is obtained from:**

Hayne, P. O., Bandfield, J. L., Siegler, M. A., Vasavada, A. R., Ghent, R. R., Williams, J.-P., ... Paige, D. A. (2017). Global Regolith Thermophysical Properties of the Moon from the Diviner Lunar Radiometer Experiment. *Journal of Geophysical Research: Planets*, 122, 2371–2400. <https://doi.org/10.1002/2017JE005387>

- **Directional Solar Absorptivity is obtained from:**

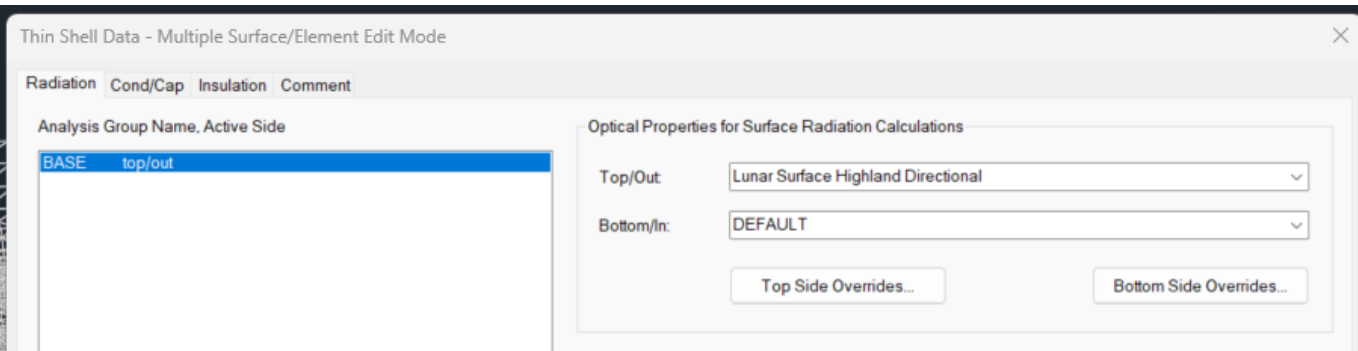
Feng, J., Siegler, M. A., & Hayne, P. O. (2020). New Constraints on Thermal and Dielectric Properties of Lunar Regolith from LRO Diviner and CE-2 Microwave Radiometer. *Journal of Geophysical Research: Planets*, 125, e2019JE006130. <https://doi.org/10.1029/2019JE006130>

The regolith properties used in this example were obtained from the sources listed to the left

For help applying these sources to your analysis (or selecting better sources for your specific situation), consult one of the following:

- The Cross-Program Design Specification for Natural Environments (DSNE) or SLS-SPEC-159
- The Lunar Thermal Analysis Guidebook (LTAG) or HLS-UG-001
- Contact the LUMENATE team:
  - Lisa Erickson ([lisa.erickson@nasa.gov](mailto:lisa.erickson@nasa.gov))  
NASA / JSC / EC611
  - Will Grier ([will.j.grier@nasa.gov](mailto:will.j.grier@nasa.gov))  
NASA / LaRC / D206
  - Will Birmingham ([william.j.birmingham@nasa.gov](mailto:william.j.birmingham@nasa.gov))  
NASA / MSFC / EV34

# Regolith Properties



Thin Shell Data - Multiple Surface/Element Edit Mode

Radiation Cond/Cap Insulation Comment

Analysis Group Name, Active Side

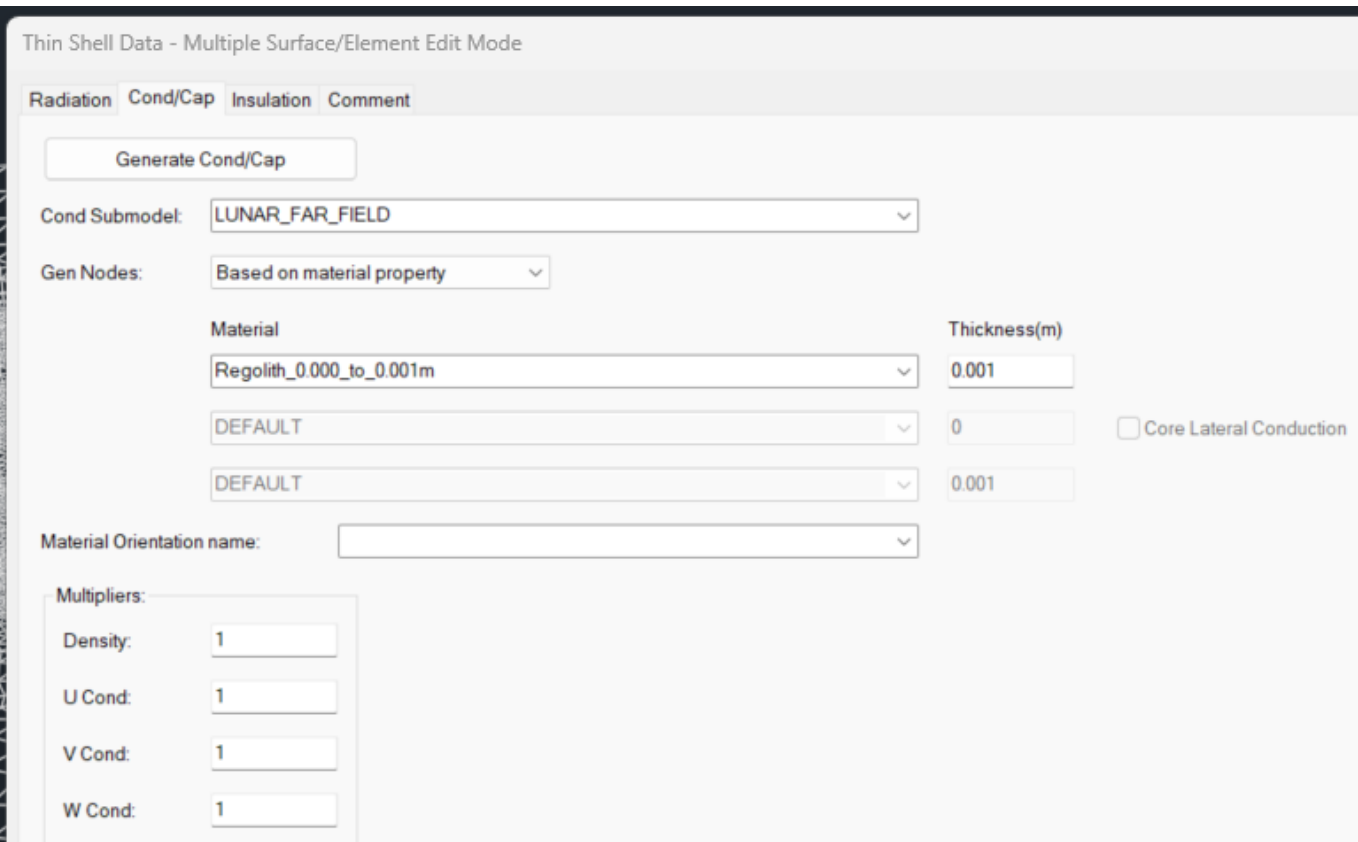
|      |         |
|------|---------|
| BASE | top/out |
|------|---------|

Optical Properties for Surface Radiation Calculations

Top/Out: Lunar Surface Highland Directional

Bottom/In: DEFAULT

Top Side Overrides... Bottom Side Overrides...



Thin Shell Data - Multiple Surface/Element Edit Mode

Radiation Cond/Cap Insulation Comment

Generate Cond/Cap

Cond Submodel: LUNAR\_FAR\_FIELD

Gen Nodes: Based on material property

Material Thickness(m)

|                          |       |
|--------------------------|-------|
| Regolith_0.000_to_0.001m | 0.001 |
| DEFAULT                  | 0     |
| DEFAULT                  | 0.001 |

☐ Core Lateral Conduction

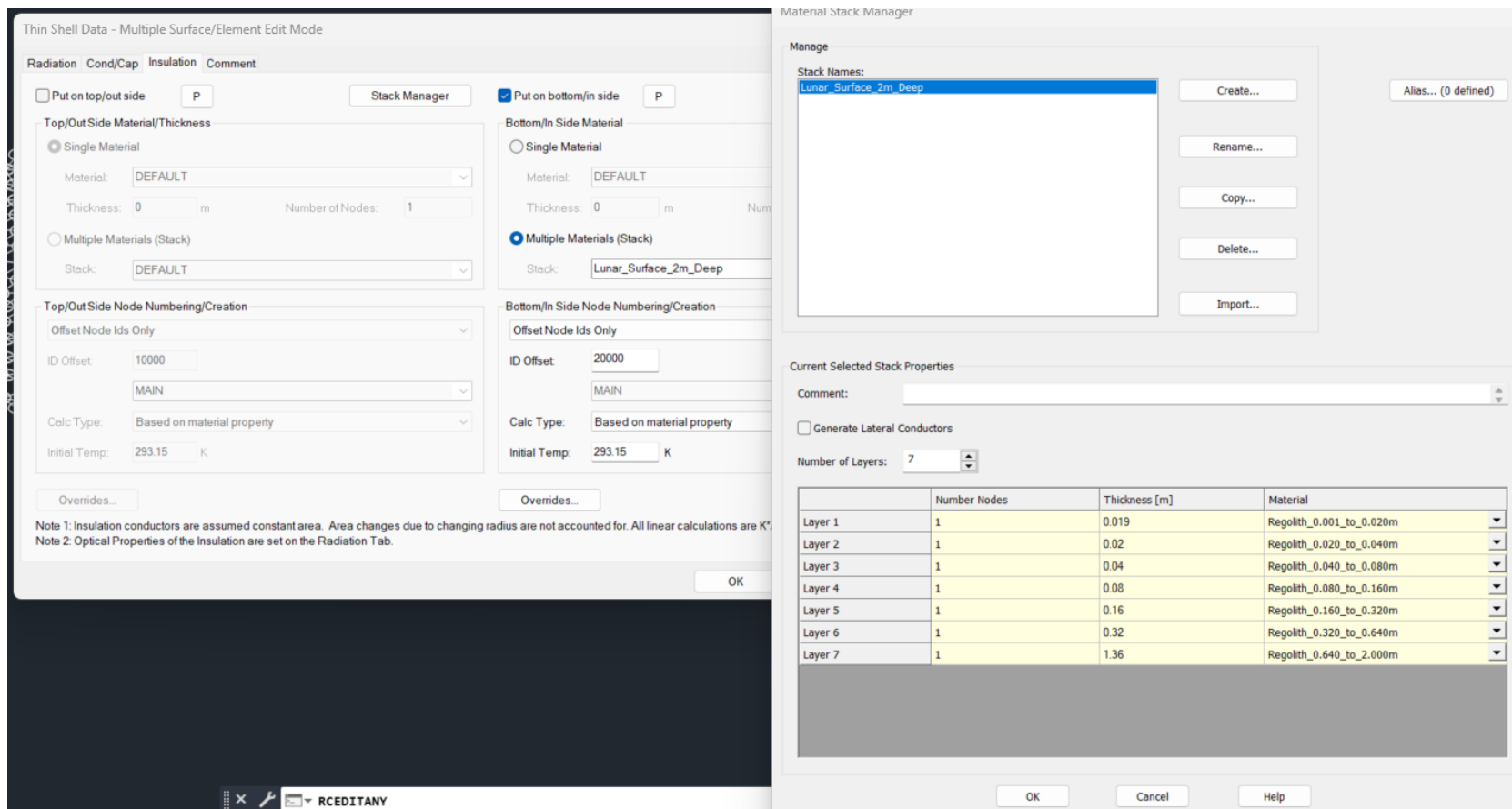
Material Orientation name: DEFAULT

Multipliers:

|          |   |
|----------|---|
| Density: | 1 |
| U Cond:  | 1 |
| V Cond:  | 1 |
| W Cond:  | 1 |

- If care was taken in MeshLab to ensure normal vectors pointed up, the Top/Out will be the active side to which optical properties should be applied (as shown to the left). **However, be sure to double-check this**
- Define optical and thermophysical properties as shown
- For Cond Submodel, Define a new submodel such as: LUNAR\_FAR\_FIELD

# Regolith Properties

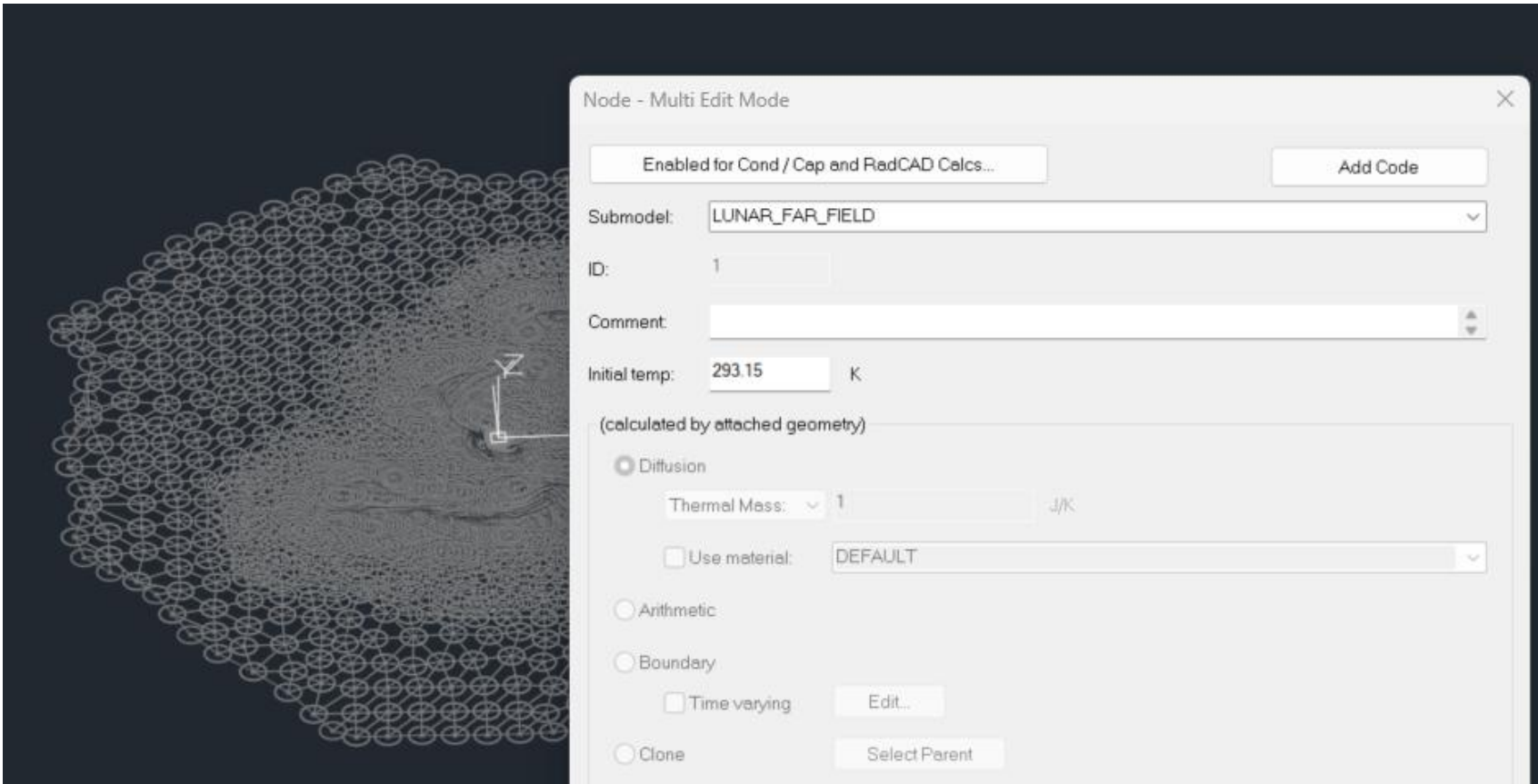


- Navigate to the Insulation Tab
- The methodology here presented, uses insulation layers to model subsurface regolith. Seven layers are used here as shown to the left.
- (Note this window is accessed by selecting the Stack Manager button under the Insulation Tab)
- Apply the insulation stack to the down-facing side
- Set up the insulation stack as shown to the left

**A version of the layer specifications that can be copied and pasted directly into the Material Stack Manager:**

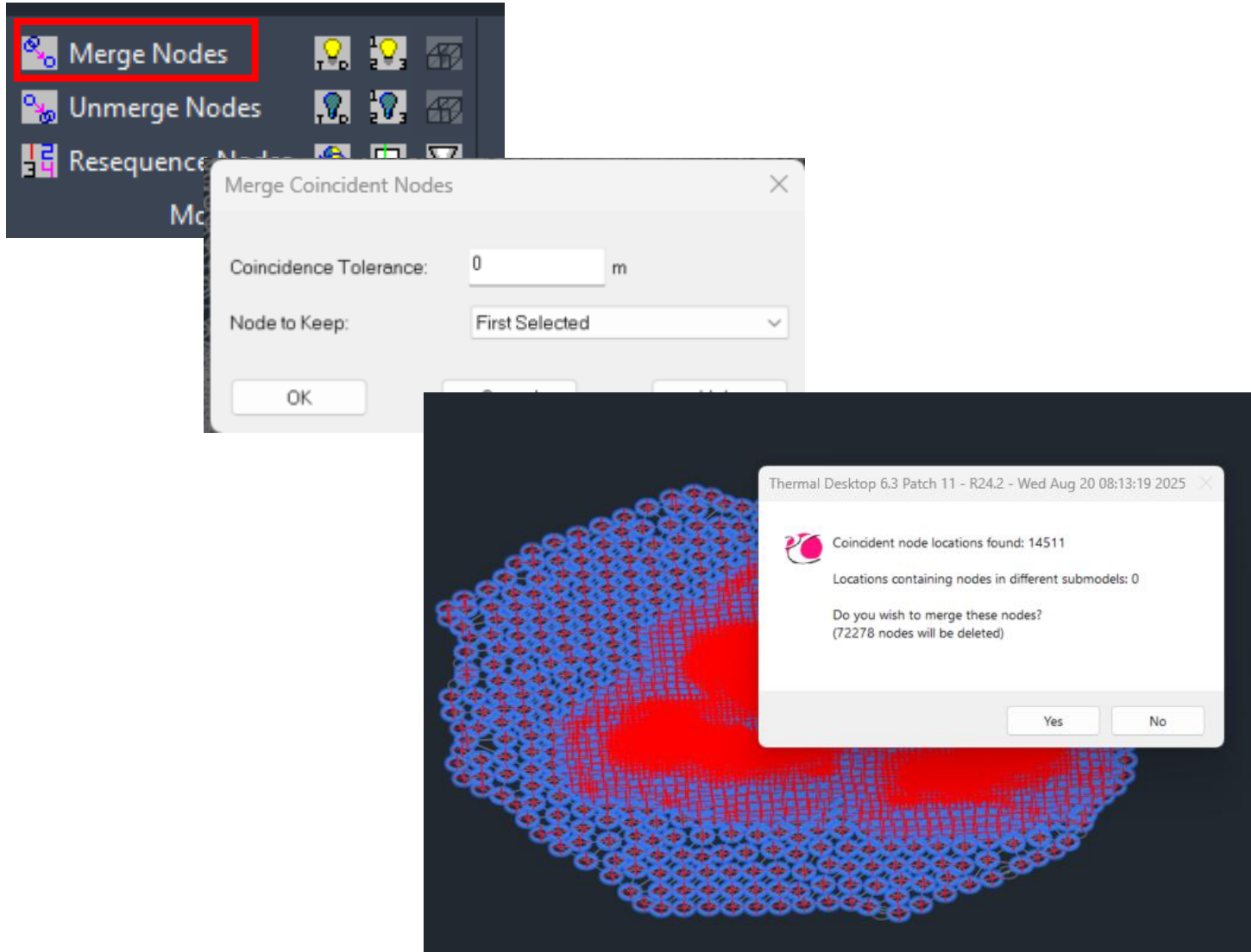
|   |       |                          |
|---|-------|--------------------------|
| 1 | 0.019 | Regolith_0.001_to_0.020m |
| 1 | 0.02  | Regolith_0.020_to_0.040m |
| 1 | 0.04  | Regolith_0.040_to_0.080m |
| 1 | 0.08  | Regolith_0.080_to_0.160m |
| 1 | 0.16  | Regolith_0.160_to_0.320m |
| 1 | 0.32  | Regolith_0.320_to_0.640m |
| 1 | 1.36  | Regolith_0.640_to_2.000m |

# Submodel Assignment



- Select all nodes and edit
- Change the submodel to something recognizable such as “LUNAR\_FAR\_FIELD”
- Select OK

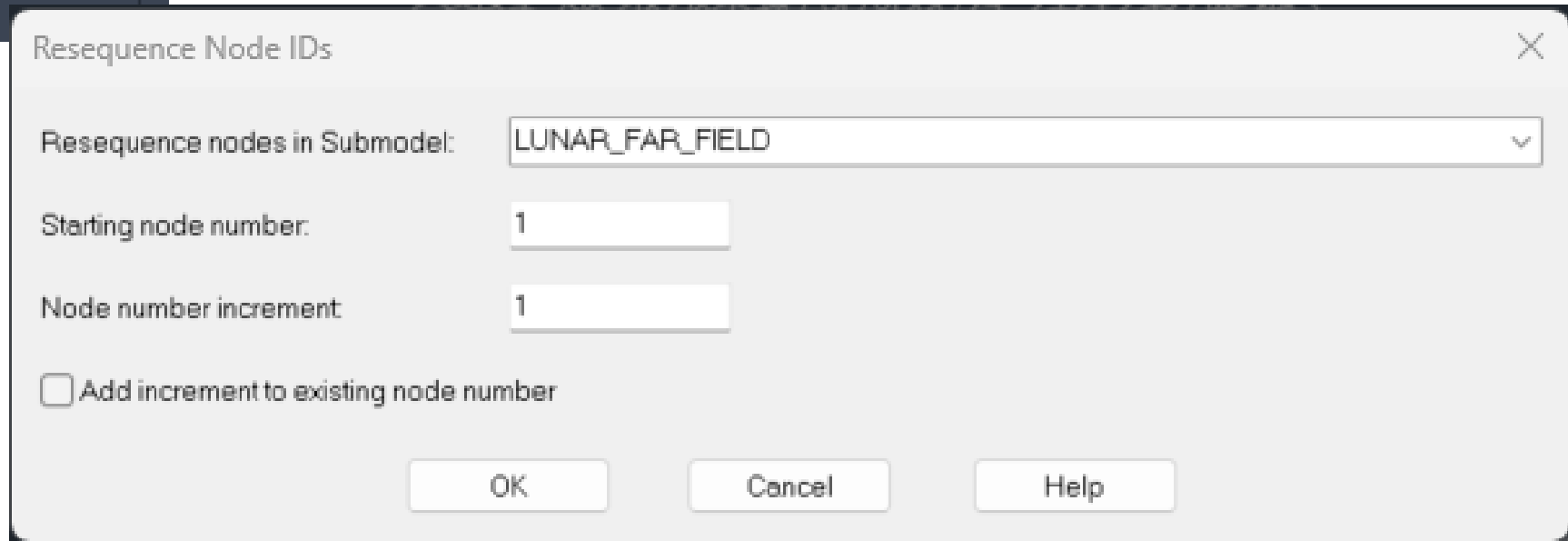
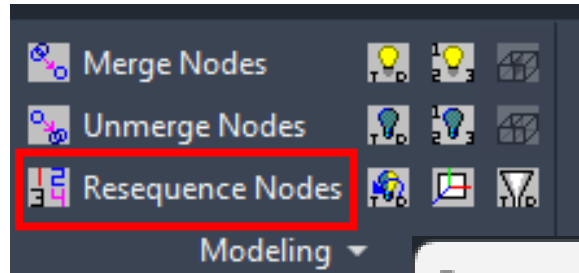
# Merge Nodes



- Select all nodes
  - Select Merge Nodes
  - Select OK then Yes
- 
- **NOTE: The number of nodes after merging should be less than 10,000. If it's significantly more than 10k, you will likely have to revisit the "Point Cloud Simplification" step in the MeshLab tutorial.**
  - **This example shows a mesh with too many nodes! It was not made using the recommendations in the table, and the mesh had to be remade.**

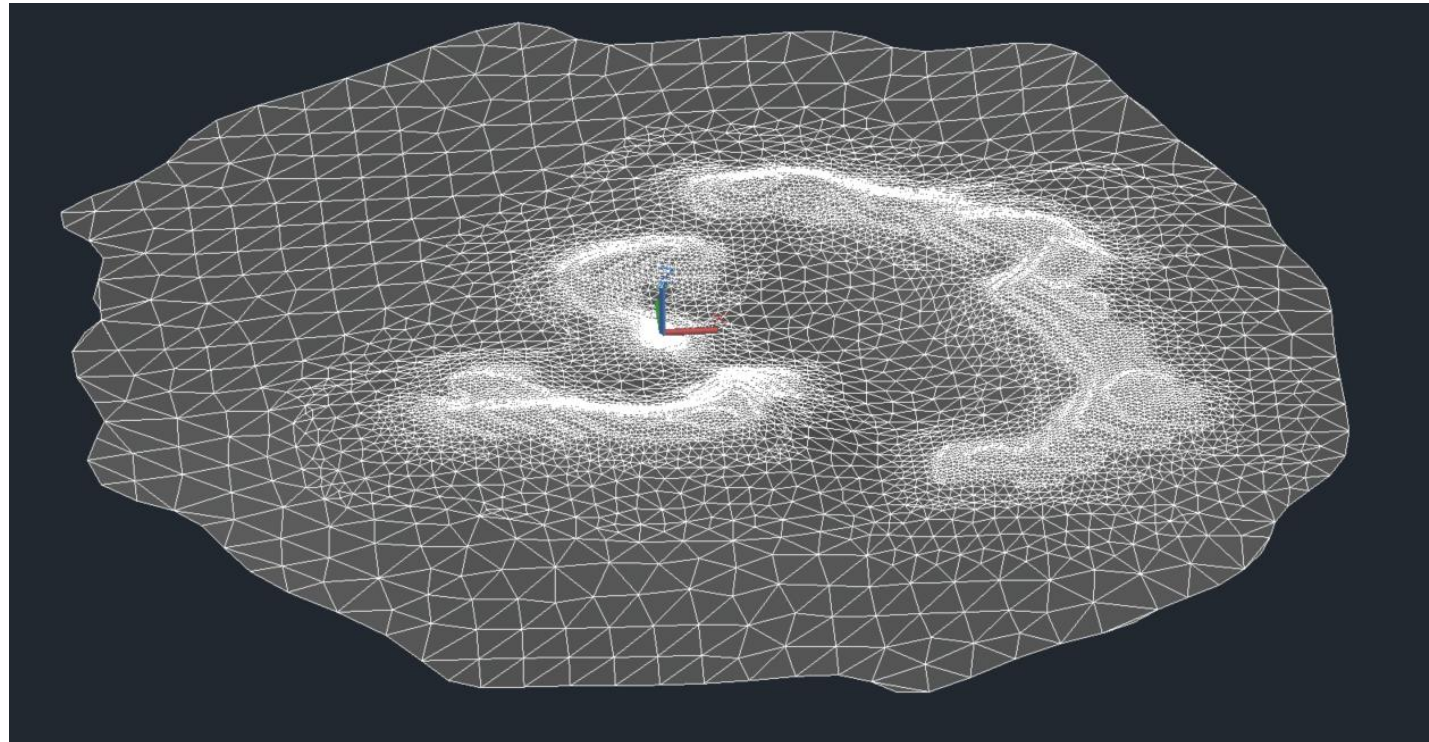
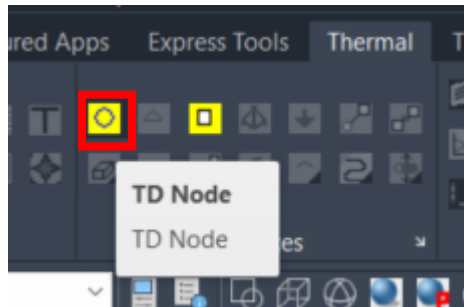
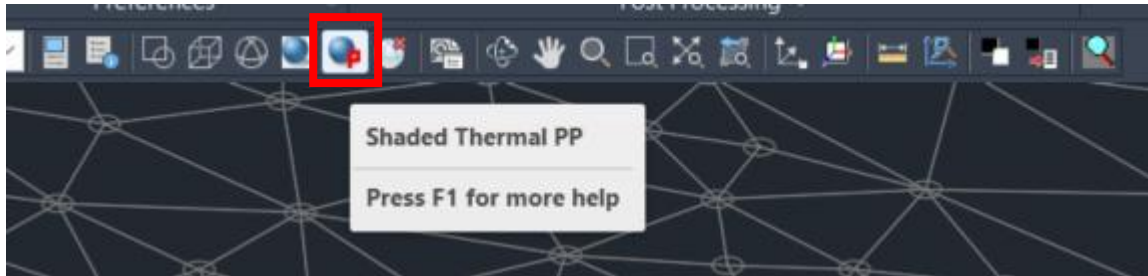
# Resequencing Nodes

- Select all nodes
- Select Resequencing Nodes
- Set the Starting node number to 1 and select OK



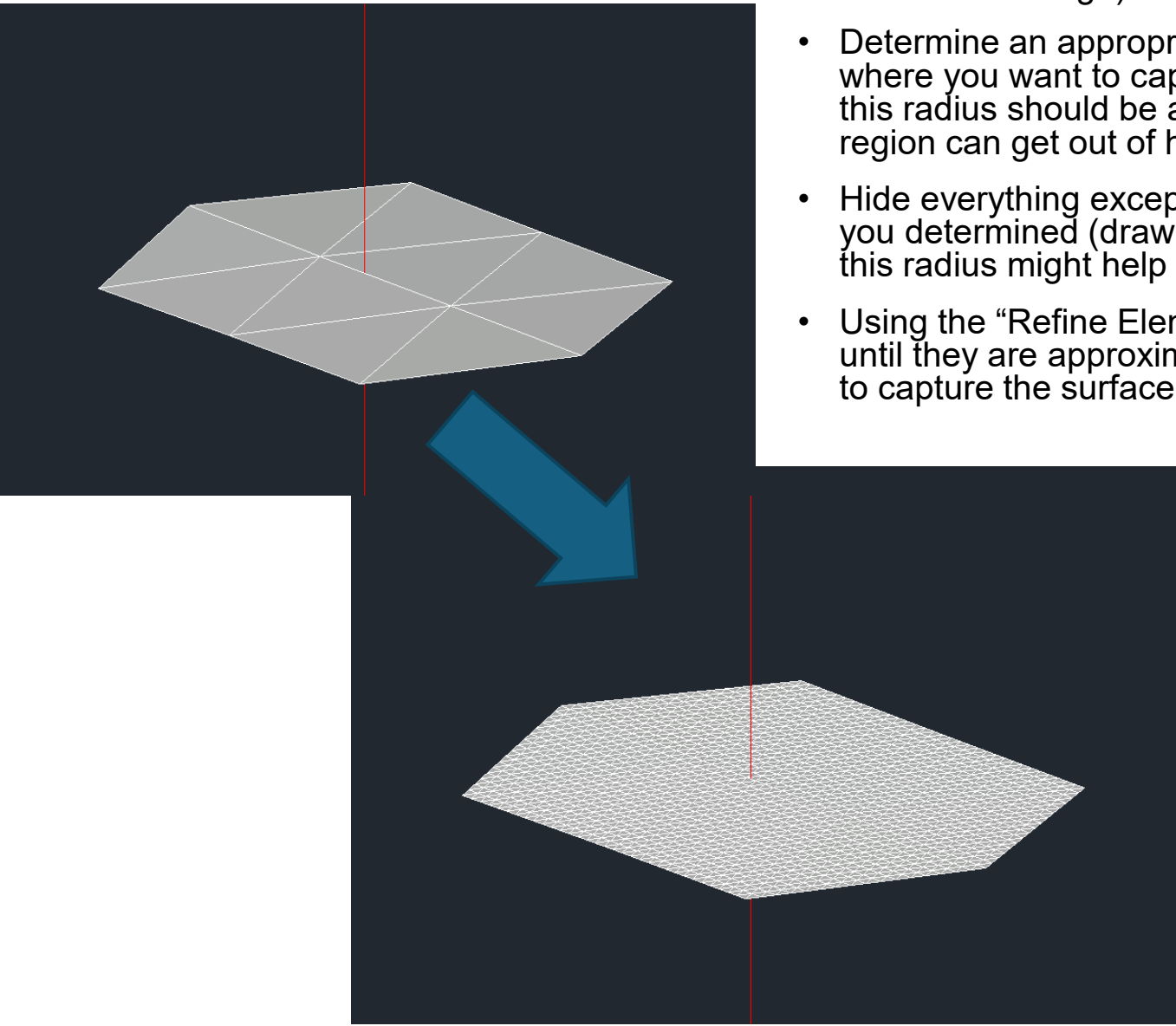
# View Settings

- Select the “Shaded Thermal PP” option from the upper toolbar to better view and select the mesh
- Select TD Node to turn off node visibility (the nodes slow down viewing significantly)
- Your model should look similar to the model shown below



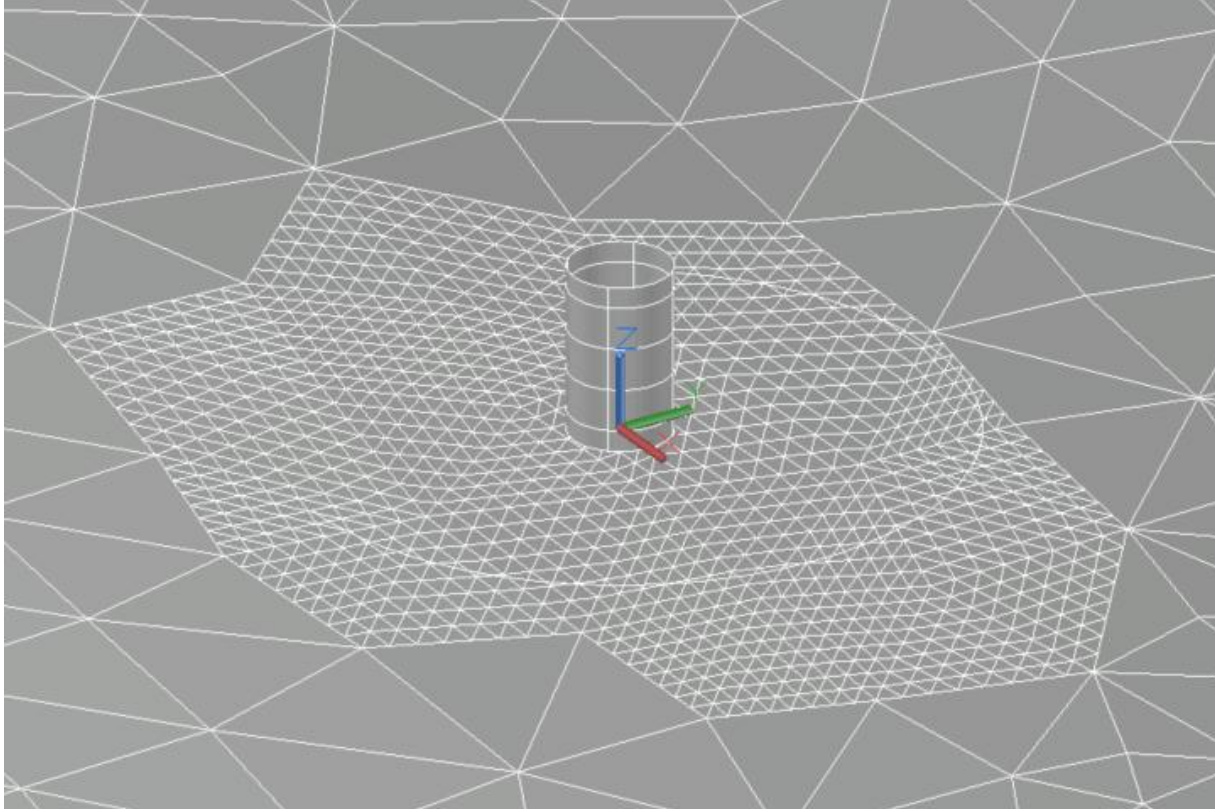
# Center Mesh Refinement

- Zoom into the origin of the world coordinate system (this is where your lunar asset will go)
- Determine an appropriate “refinement radius” around your vehicle where you want to capture shadows and heat reflections better (NOTE: this radius should be as small as possible! The number of nodes in this region can get out of hand quickly)
- Hide everything except the mesh elements that are within the radius you determined (drawing an **AutoCAD** circle centered at the origin with this radius might help with this process)
- Using the “Refine Elements” tool, continue to divide these elements until they are approximately 1m on the sides (this is normally sufficient to capture the surface interactions of a small to mid-sized)



- **Once refinement is complete:**
  - Edit the surfaces to have a new conduction submodel such as “LUNAR\_NEAR\_FIELD”
  - Using the Model Browser, select List By-> Surfaces/Solids, select Lunar\_Near\_Field, select “Display Only”
  - Select all the nodes, and edit the nodes to have a new submodel such as “LUNAR\_NEAR\_FIELD”
  - Merge the new nodes
  - Resequence the new nodes

# Lunar Asset Model



- Now a model of the lander can be copied into the model
- A simple cylinder is used for this example
- (Note: ensure that the **AutoCAD** units are the same between the two models before attempting to copy elements from one model to another)

# Orbit Definition

The image shows two overlapping dialog boxes from the Thermal Desktop software. The top dialog, titled 'Create New External Heating Environment', has a text field for 'New Heating Case Name:' containing 'Transient\_Initializer'. Below this is a 'Type' section with several radio button options: 'Basic Orbit', 'Keplerian Orbit', 'Planetary Latitude/Longitude/Altitude List', 'Orbital Sun/Planet/Radius Vector List' (which is selected), 'Free Molecular Heating Velocity Vector List', 'Free Molecular Heating with Reference O...', and 'Celestial Coordinate System Location/Ori...'. At the bottom are 'OK' and 'Cancel' buttons. The bottom dialog, titled 'Heating Rate Case: Transient\_Initializer', has a tabbed interface with 'Vector Input' selected. It contains several input fields: 'Radius of Planet:' (1738.2 km), 'Gravitational Mass (GM):' (4902.79 km^3/s^2), 'Inclination of Equator:' (1.54 Degrees), 'Sidereal Period:' (2.36058e+06 s), and 'Mean Solar Day:' (2.55144e+06 s). There is also a 'Color...' button. At the bottom, a 'Reset to:' dropdown menu is highlighted with a green box and contains the text 'Earth's Moon'.

- Create a new orbit in Thermal Desktop using the “Orbital Sun/Planet/Radius Vector List” orbit type
- **Refer to the “Solar Vector” and “Solar Flux and Subtended Angle” Sections in this manual for instructions on how to use JPL Horizons and MATLAB code to build vector list orbits in Thermal Desktop. The solar flux data is used to make the solar flux a function of time.**
- You will be creating two orbits:
  1. Transient Initializer: A long multi-year transient case, the end of which will be used as the initial condition for the main case. This can use a very coarse time step (1 – 2 days is generally an acceptable range)
  2. Main Case: the single lunar day or surface stay that you’re interested in. This should use a much finer time step (1-6 hours is generally acceptable). Generally the more dynamic the shadow environment is expected to be, the finer the time step should be.
- Refer to the LTAG (section 9.2.4) to better understand how long to run the transient initializer. Anywhere from 1 to 20 years can a good amount of time to ensure the top layer of the regolith is converging to a consistent temperature.
- Select “Earth’s Moon” under planetary data

# Case Set Details

## Calculations

Calculations Radiation Tasks Output SINDA Dynamic Initialize Advanced Props Symbols Comments

**Processes**

- ☒ Calculate Radiation
- ☒ Generate Cond/Cap File:  
Main\_Case.cc
- ☒ Build SINDA Input File:  
Main\_Case.inp
- ☒ Run SINDA Model  
Plot...
- ☒ Post Process SINDA Results  
Current Time
- ☒ Execute Mapping To Stress  
Output File Options: None
- ☐ Execute Write Results Data to Text for this Save File
- ☒ Generate Log File  
Main\_Case.log

**Solution Type**

- ☐ Steady State Before Transient (if selected)
  - ☐ Hold Tanks constant during Steady State
  - ☐ Hold Diffusion nodes constant during Steady State
- ☒ Transient
  - Start Time: 0 s
  - End Time: 2.592e+06 s
- ☐ Cyclic Edit...
- ☐ Parametric Edit...
- ☐ Kicker Edit...

**Convergence Criteria**

|                                         |       |
|-----------------------------------------|-------|
| Max Steady State Iterations (NLOOPS):   | 1000  |
| Max Transient Iterations (NLOPT):       | 100   |
| Max Temperature Change (DRLXCA/ARLXCA): | 0.001 |
| System Level Energy Balance: (EBALSA)   | 0.01  |
| Nodal Level Energy Balance: (EBALNA)    | 0     |

OK Cancel Help

- For the transient initializer, consider turning on Steady State before Transient to likely reduce the number of years required for surface convergence
- For the main case, ensure this is off as this case should be initialized to the final time step of the transient initializer

- For both the transient initializer and the main case, ensure the start and stop times match the inputs of the vector list orbit

# Case Set Details

The RADK calculation for both Case Sets are setup as shown below:

## Radiation Tasks: Radks

The image displays three overlapping screenshots of the 'Radiation Analysis Data' dialog box, showing different tabs: 'Default', 'Oct Cells', and 'Radk Output'.

**Default Tab:**

- Calculation Type: ☒ Radks
- Analysis Group: BASE
- Orbit: Main\_Case
- Calculation Method: ☒ Monte Carlo
- Apply Reciprocity To View Factors: ☒
- Add to Database Name: None
- Delete Database After Output Is Generated: ☐

**Oct Cells Tab:**

- Use Oct-tree to accelerate calculations: ☒
- Subdivision Criteria:
  - Max oct-tree subdivisions: 15
  - Target max surfaces per cell: 10
- Random Number Seed Control:
  - ☒ Use unique random number seed at start of calculations
  - ☐ Use same random number seed sequence at start of calculations
  - ☐ Use same random number seed sequence at start of every node
- Nodalization Schemes:
  - ☒ General
  - ☐ Specific
  - ☐ Top/Bottom Surface
- Radk Calculation Spectrum - Used for Modeling Lamps:
  - ☒ Infrared
  - ☐ Solar
- Wavelength Dependent Properties - RADKS Only:
  - ☒ Enable Wavelength Dependent Calcs

**Radk Output Tab:**

- Generate SINDA/FLUENT input after calculations: ☒
- Load binary file (.k\_in) for fastest SINDA preprocessor execution: ☒
- Radk Output Filename: Main\_Case.k
- Form Factor Output Filename: Main\_Case.dat
- Output Submodel: Main\_Case
- Initial Conductor ID: 1
- Space Node Submodel ID: SPACE.1
- Space Node Temperature: 2.73 K
- List summary if % kept is off by more than: 10 %
- Which Radks Output To SINDA:
  - Bij/Fij Cutoff Factor: 2e-05
  - Output Bij's Until BijSum >= 0.9: ☐
  - Output 1-BijSum to ERN Node: BIJSUM.1: ☐
  - Consider ALL Radks for Output: ☒
  - Output as Heating Rates: ☐ Edit...

**Annotations:**

- A green box highlights the 'Rays Per Node' field (50000) in the 'Default' tab with the text: "100000 rays is better if this does not slow the radiation calculations too much".
- A green box highlights the 'Bij Cutoff Factor' field (2e-05) in the 'Radk Output' tab with the text: "Bij Cutoff should be less than: 1/(10\*number of nodes)".

# Case Set Details

The Heat Rate calculation for both Case Sets are setup as shown below:

## Radiation Tasks: Heat Rates

The image displays three overlapping screenshots of the 'Radiation Analysis Data' dialog box, illustrating the configuration for Heat Rate calculations.

**Left Screenshot (Calculation Type Tab):**

- Calculation Type:** Heating Rates (selected), Radks, Articulating Radks, Free Molecular Conduction, Articulating Free Molecular Conduction, View Factors, Articulating View Factors.
- Analysis Group:** BASE
- Orbit:** Main\_Case
- Calculation Method:** Monte Carlo (selected), Progressive Radiosity.
- Apply Reciprocity To View Factors:** (checked)
- Add to Database Name:** None
- Delete Database After Output Is Generated:** (unchecked)

**Middle Screenshot (Default Tab):**

- Rays Per Node:** 50000
- Total Absorbed Error:** 5 %
- Rays Before Initial Error Check:** 500
- Energy Cutoff Fraction:** 0.1
- Sources:** Solar (checked), Planetshine, Albedo, Diffuse Sky Solar, Diffuse Sky IR, Diffuse Sky Albedo.
- Nodes:** All (selected), List.
- Positions:** All (selected), List.

**Right Screenshot (Heatrate Output Tab):**

- Generate SINDA/FLUINT input after calculations:** (checked)
- Output Filename:** Main\_Case.hr
- Output Submodel:** Main\_Case
- S/F Starting Array ID:** 1
- Output Format:** LOADQ
- LOADQ Binary File for faster SINDA:** (checked)
- Combine SAP arrays into a single array:** (checked)
- Output as fluxes:** (unchecked)
- Sources:** Solar (checked), Planetshine, Albedo, Diffuse Sky Solar (checked), Diffuse Sky IR (checked), Diffuse Sky Albedo (checked).
- Output tracker data to file:** Main\_Case.dat
- Output HR Symbols to SINDA:** (unchecked)
- Advanced Logic...** (button)
- Multiple files will be produced:** "A" will be appended for ARRAY DATA, "L" will be appended for VARIABLES 0 Logic.

**Callout Box:**

100000 rays is better if this does not slow the radiation calculations too much

# Case Set Details

## Output

Editing 1 Case Set - Main\_Case

Calculations Radiation Tasks **Output** SINDA Dynamic Initialize Advanced Props Symbols Comments

Output Submodel: (AUTO)

Global Control

Thermal Output Increment: 3600 s

Fluid Output Increment: 0 s

Text Output

Output Filename: Main\_Case.out

☒ Temperatures

☒ Node Summary

☒ Incident Heat

☒ Capacitance

☒ Register S

☒ Heat Map

☒ Conductor

☒ Lump (TL

☒ Path Data

☒ Tie (UA, QDOT)

Text Output Control...

Output for Color Postprocessing and XY Plots

Save File: Main\_Case.sav

☒ All for Steady State/End of Transient

☒ All

☒ Temperatures

☐ Incident Heat

☐ Capacitance

☐ Conductors

☒ Register

☒ Lump Info

☒ Flowrates

☒ Tie Info

Save Output Control...

Recovery File

☐ Generate recovery file

Filename: Main\_Case.recovery

NOTE: For high performance machines, writing the .out file can slow SINDA run speeds significantly

Data must be saved at all time points in order to be XY Plotted. Registers need to be at all time points as well.

OK Cancel Help

- For both the transient initializer and the main case, ensure the output increment matches the time step used for the vector list orbit (or is at least larger than the vector list time step)

# Case Set Details (OPTIONAL)

Sinda: Control-> Thermal

Editing 1 Case Set ~ Main\_Case

Calculations Radiation Tasks Output SINDA Dynamic Initialize Advanced Props Symbols Comments

Global S/F Inputs:

Build Submodels

OPTIONS\*  
CONTROL\*  
REGISTER  
OPERATIONS  
SUBROUTINE  
OTHER

Set INSERT Directories

Insert Filenames:  
(One Per Line)  
Drag And Drop Enabled

For heatrates, radks  
INSERT Directories button on this page.

Sinda Control Information

Global Thermal Fluid Recession / Accretion

Steady State and Transient Parameters

A/DRLXCA 0.001 Temp convergence criteria

Solution Type: Auto Determine based on #nodes

EXTLIM 0.5 Maximum extrapolation of temps

ITERXT 3 # of iterations between extrap/  
Under relaxation criteria(<1.)

SPARSEG 0.01 Sparsification cut-off factor

Steady State Parameters

EBALSA 0.01 System energy balance criteria

EBALNA 0 Nodal energy balance criteria

ITEROT 0 Output every input iterations

ITHOLD 0 Hold converged submodels

Transient Parameters

OUTPUT 3600 Output Interval

ATMPCA 1e+30 Max Arithmetic temp change

DTMPCA 150 Max Diffusion temp change

FBEBALA 0.1 Transient energy error factor

DTIMEI -1 Timestep

DTIMEL 0 Minimum Time Step

DTIMEH 1e+30 Maximum Time Step

OPEITR 0 Output Each Time Step

CSGFAC 1e-05 Time step factor for FORWRD

NVARB1 ☐ Call Variables 1 each iteration

Time inputs units are: s

Reset To Defaults

OK Cancel Help

- Optionally, the SINDA thermal control parameters can be changed to improve speed.
- **These high-speed parameters should ONLY be used if the thermal model does not contain ANY heaters or logic objects**
- The red boxes to the left highlight the parameters that are changed from default settings to achieve higher speeds.

Credit to the Shawn Breeding MSFC, EV71 for recommending these settings and greatly improving terrain model speed

# Case Set Details

## Initialize

Editing 1 Case Set - Main\_Case

Calculations Radiation Tasks Output SINDA Dynamic Initialize Advanced Props Symbols Comments

Set Initial Temperatures and Register Values

☒ Read From Results:

Transient\_Initializer

Time: Set Time and Nodes...

Set the LOADT file name based on the SAVE file name

Set Initial Lump States

☐ Read From Results:

Set Time and Lumps...

Time:

Restart

☐ Restart Edit...

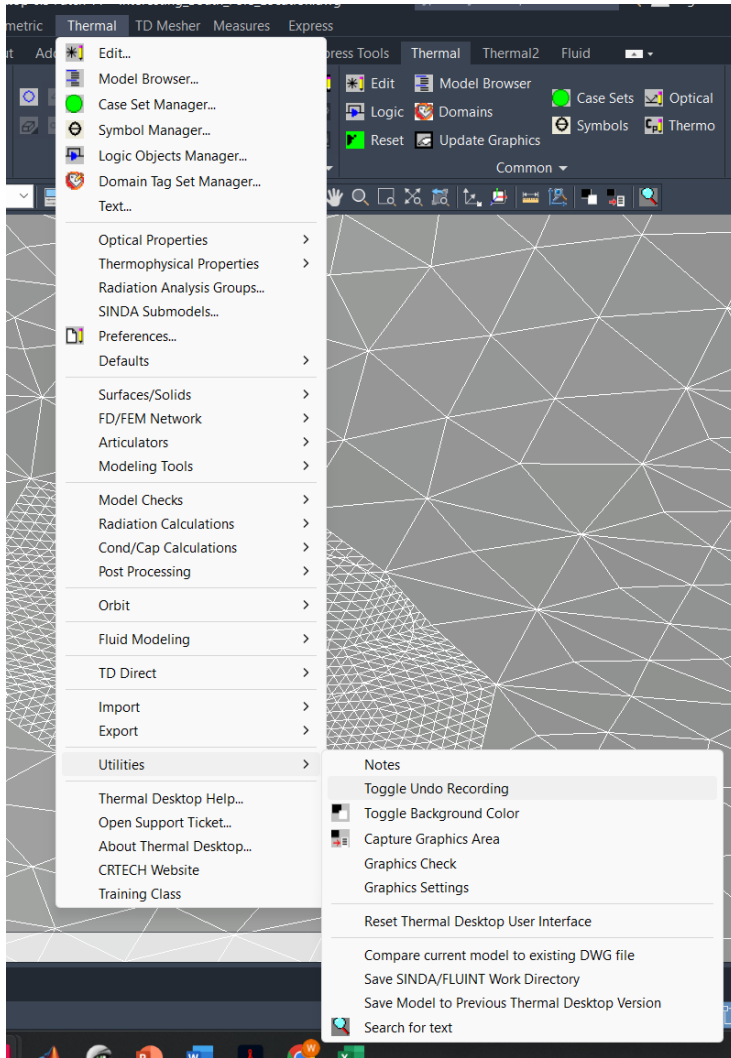
For continuing a previous run or recovering from a computer restart or crash.  
Requires both models to be identical in nodes, conductors, lumps, paths, etc...

☐ Disable loading and displaying actual time on this page

OK Cancel Help

- The transient initializer should be run first and not be initialized to another save file
- The main case should be initialized to the final time step of the transient initializer

# Memory

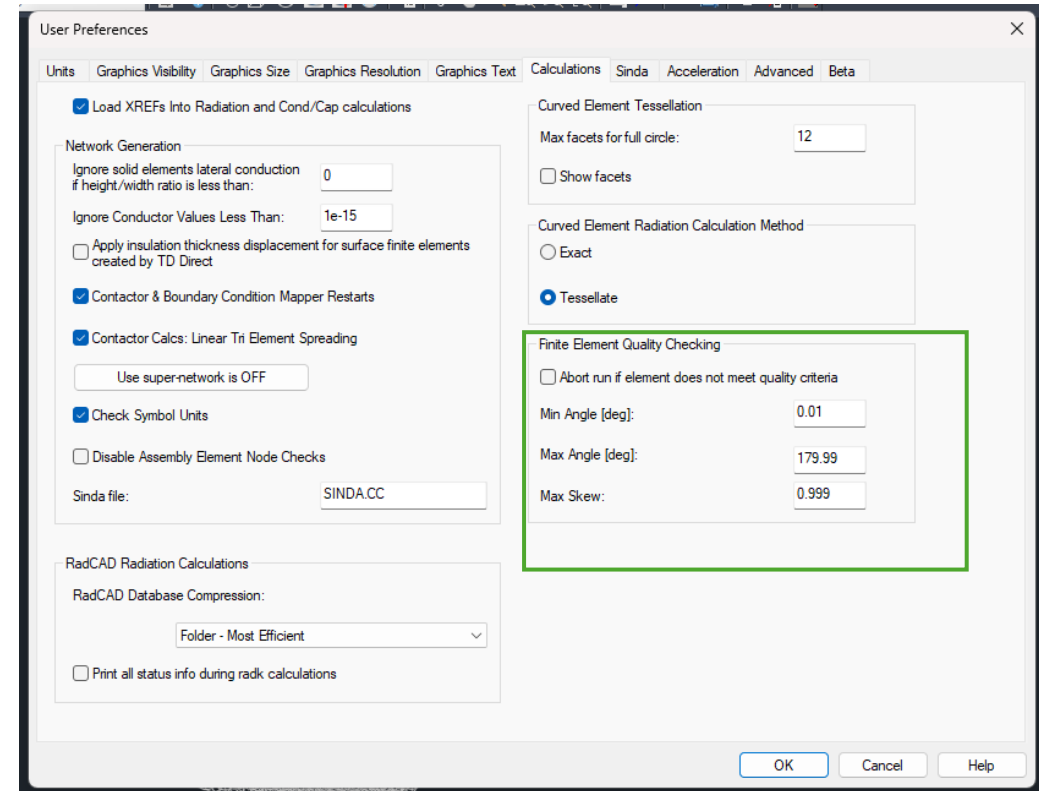


- A transient thermal model of this size run over so many time steps will take up a significant amount of memory. Ensure this model is run in a drive with 10's of Gb prior to starting
- To help reduce the quantity of unneeded temporary data stored, navigate to:

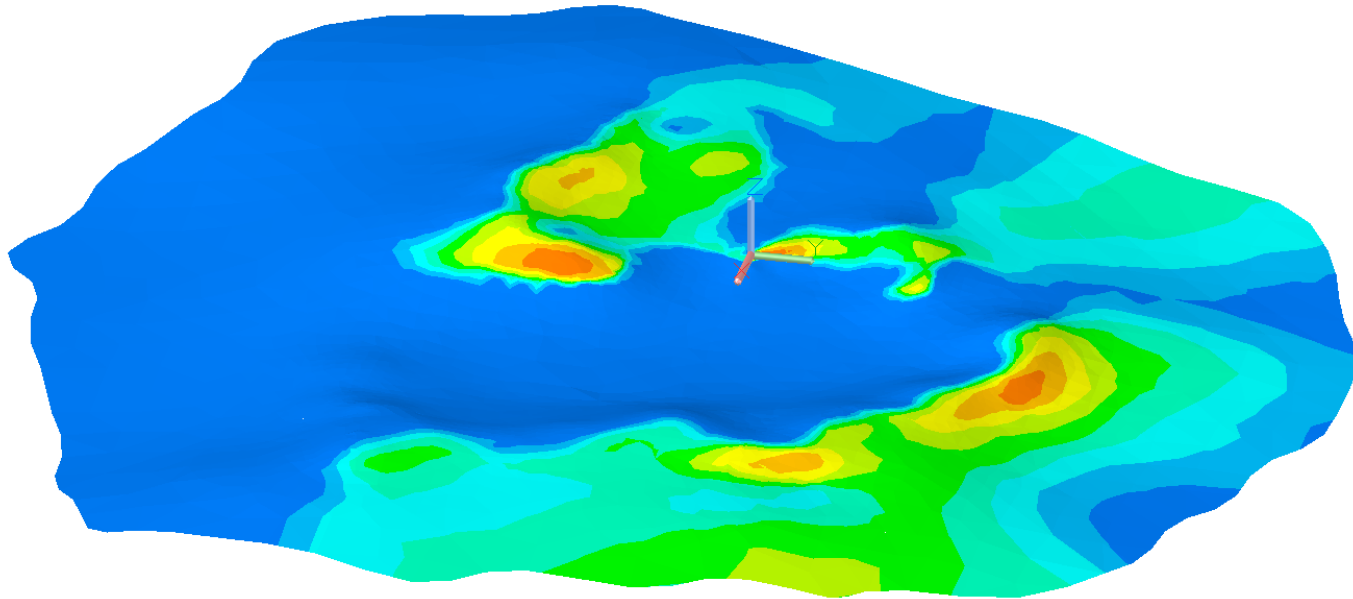
Thermal-> Utilities-> Toggle Undo Recording

# Mesh Quality Check

- Sometimes, the mesh created by this process can result in elements that fail quality checks
- It is recommended that the model be run with default quality check settings
- However, if Thermal Desktop terminates a run due to elements that fail quality checks, you can investigate the mesh elements that failed the check. If these elements are far from and/or do not have a direct line of site to the central location, it is generally acceptable to ignore this problem and uncheck the “Abort run if element does not meet quality criteria” box under User Preferences -> Calculations



# Run



- Run the transient initializer followed by the main case
- Inspect the final contour plots and post-process results