LADEE Lunar Dust Risk Mapping & Path Optimization

Problem Statement:

Lunar dust particles have shards unlike those on Earth, which makes traversal and exposure highly hazardous for rovers. Predicting the impact of these particles is critical for planning safe paths on the lunar surface.

Workflow Overview:

1. Data Preparation and Model Inputs

- Only calibrated and derived science products were used; housekeeping and diagnostic telemetry were excluded to avoid instrument-state bias.

- Original dataset was created with particle properties including mass, radius, and impact location.

- Additional datasets were generated:

  - Hourly Average & Standard Deviation per particle feature.

  - Sum of Kinetic Energy ($\frac{1}{2} mv^2$) per particle over an hour.

2. Particle Impact Modeling

- Big Particle Risk Model: Uses sum of mass × kinetic energy to quantify the effect of large dust particles over an hourly average.

- Terminator Effect Model: Calculates dust cloud impact at any lunar time and altitude using cleaned data.

- Both models are scaled 0–5 for risk scoring and added together to generate an overall risk assessment.

3. Simplified Sample-Based Model

- Input features for the predictive model:

  - Average particle size & standard deviation

  - Average particle velocity & standard deviation

  - Local lunar time & altitude

- This allows rapid risk estimation from a sample rather than the full dataset.

4. Simulation in PyBullet

- Simulates 100,000 particles falling on a terrain with optional micrometeoroid impacts nearby.

- Assumes constant particle density and normalized radius values.

- The simulation predicts total exposure and maps risk across a raster.

- Pathfinding is applied to determine the least-risk route for a rover using Dijkstra's algorithm.

5. Model Performance

Big Particle Risk Model

- Mean Absolute Error (MAE): 0.198

- R^2: 0.912

Terminator Effect Model

- Test MSE (0–5 scale): 0.015

- Test R^2 (0–5 scale): 0.857

Note: Velocity was excluded from the final model due to complexity and improved accuracy; only particle mass and number are used.

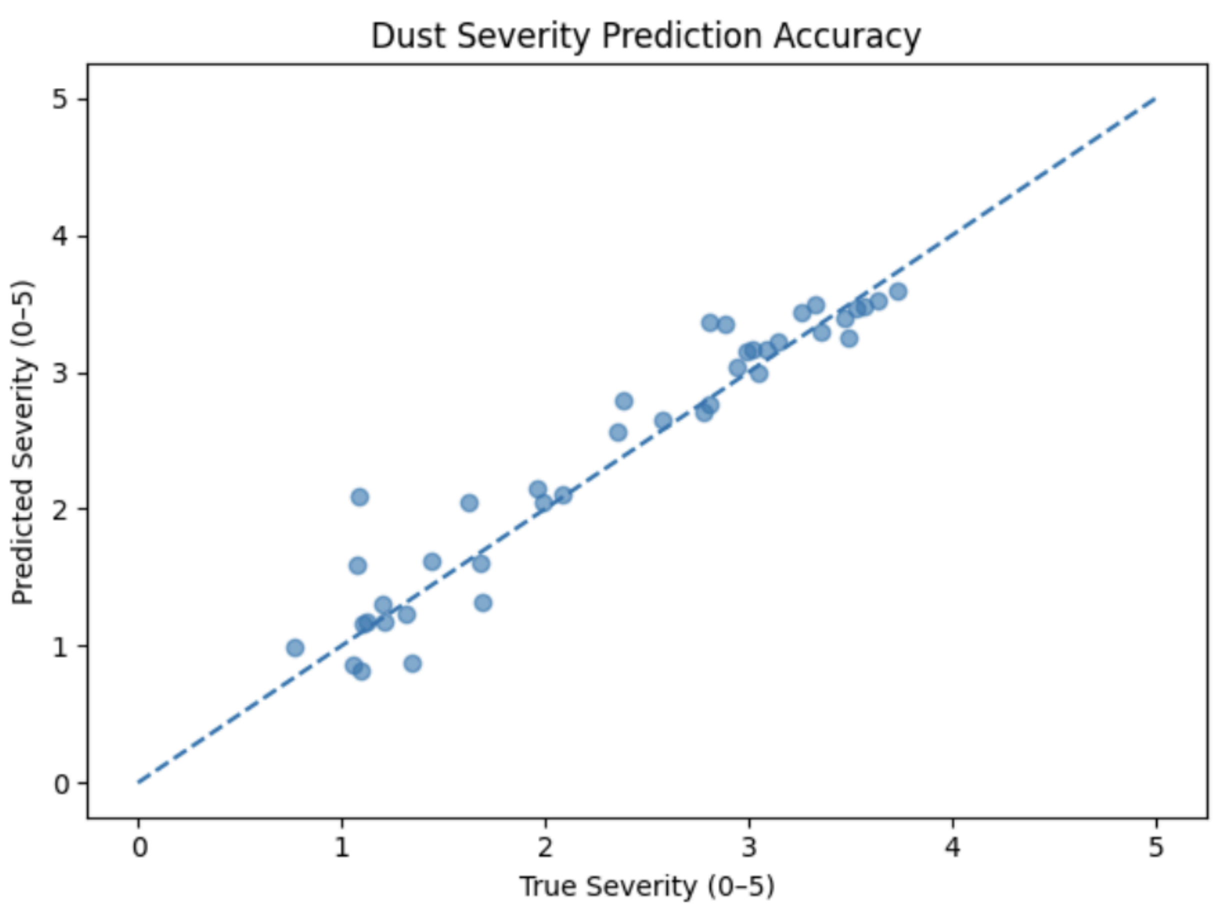
Code Modules

DustAssessmentTest.py	Train and combine the models for risk assessment
ExampleTerrainGenerator.py	Generate custom or numpy-based terrain for simulations
TerrainDustSettlementAnalysis.py	Simulate particle fall and generate raster of dust accumulation

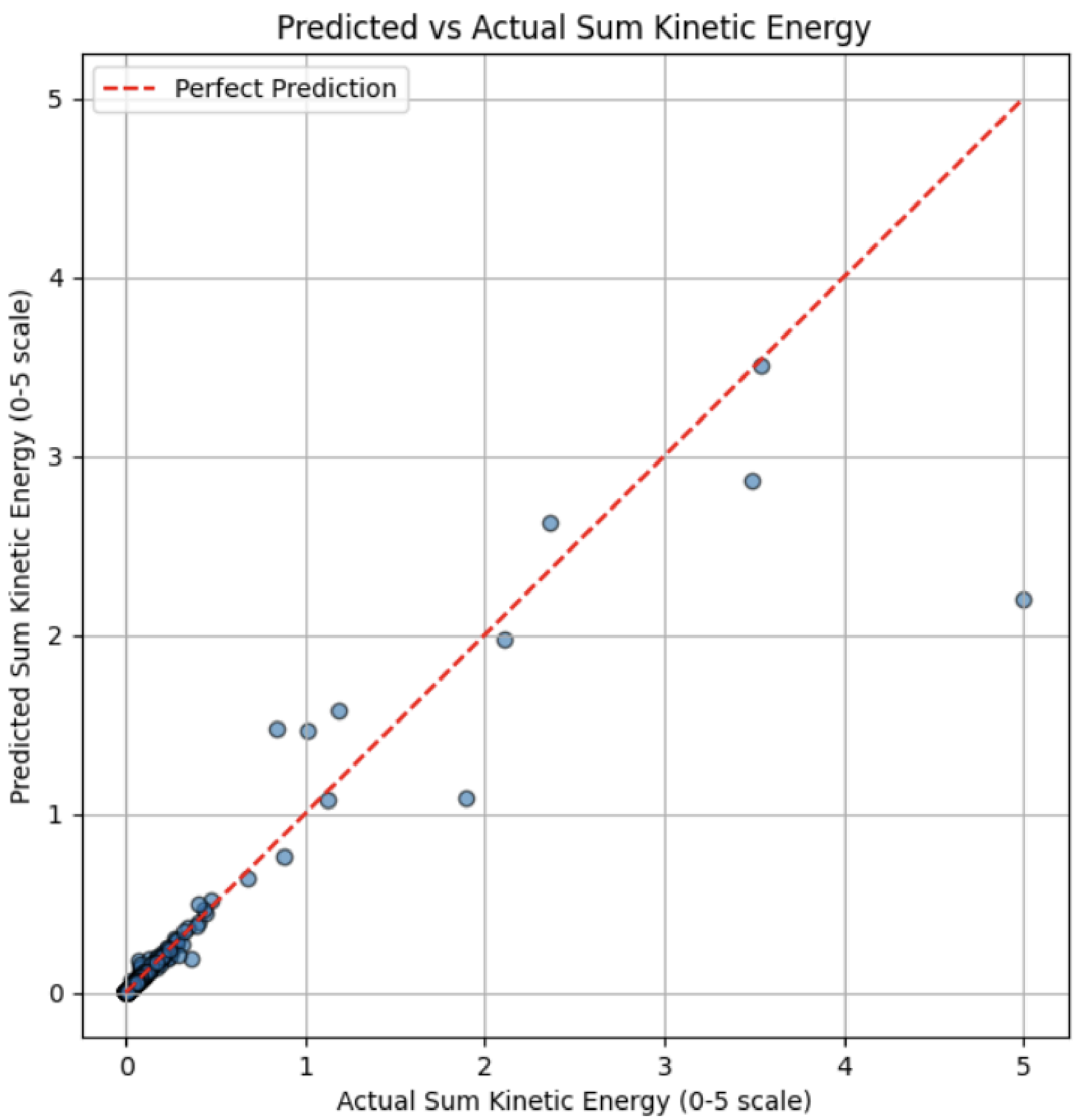
RasterRiskAssessment.py	Normalize raster into mass values and predict overall risk per cell
DijkstrasRoute.py	Compute the least-risk path (optional for visualization)
LeastRiskRouteSim.py	Visualize path in PyBullet; physics engine is for demo purposes only

Visualizations

Dust Severity Prediction Accuracy

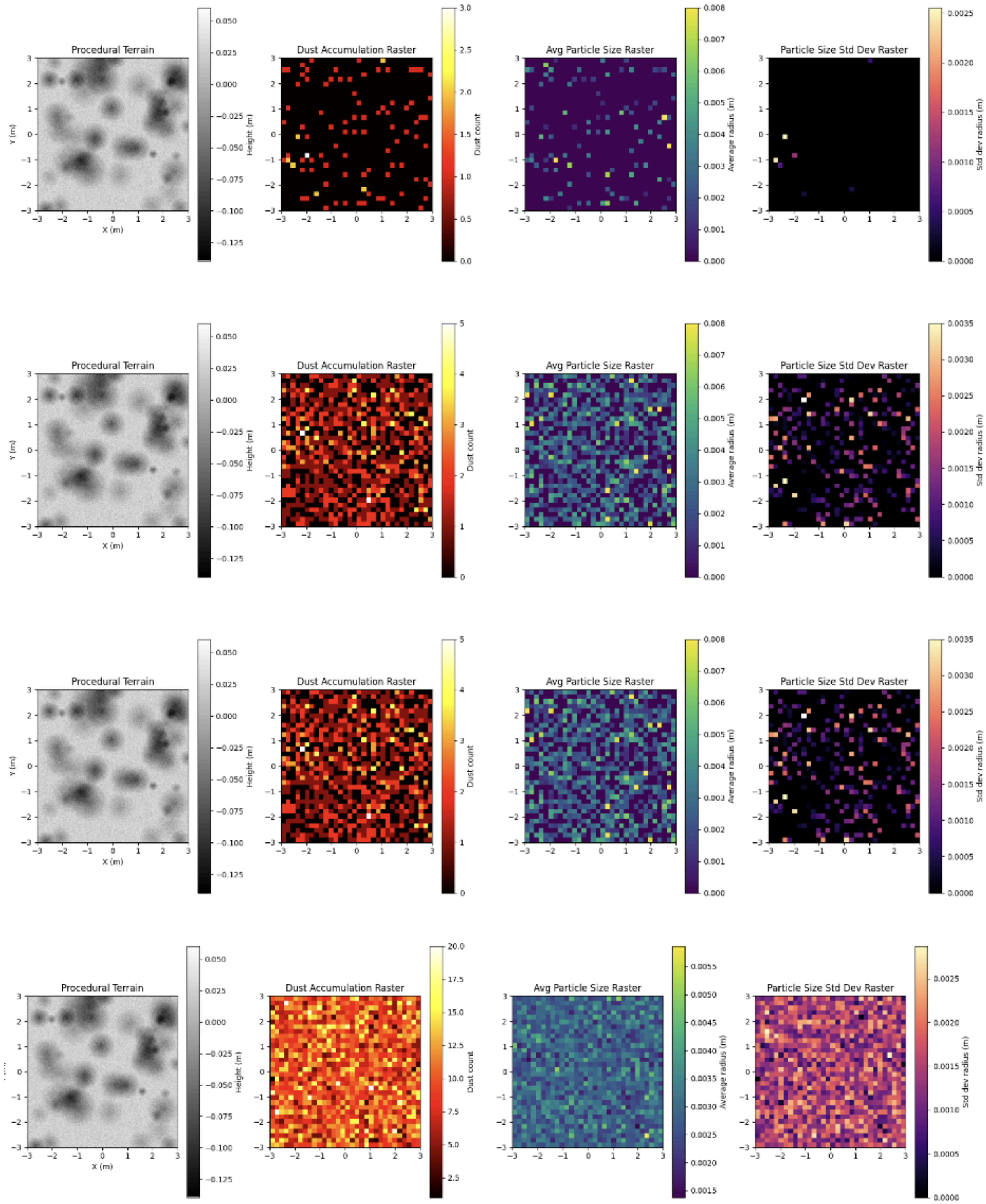


Predicted Kinetic Energy Impact Mode



Particle Simulations and Dust Accumulation

- Raster visualizations for 10, 100, 1,000, 10,000, and 100,000 particles:


Procedural Terrain
Dust Accumulation Raster
Avg Particle Size Raster
Particle Size Std Dev Raster
X (m)
Y (m)
Height (m)
Dust count
Average radius (m)
Std dev radius (m)
Procedural Terrain
Dust Accumulation Raster
Avg Particle Size Raster
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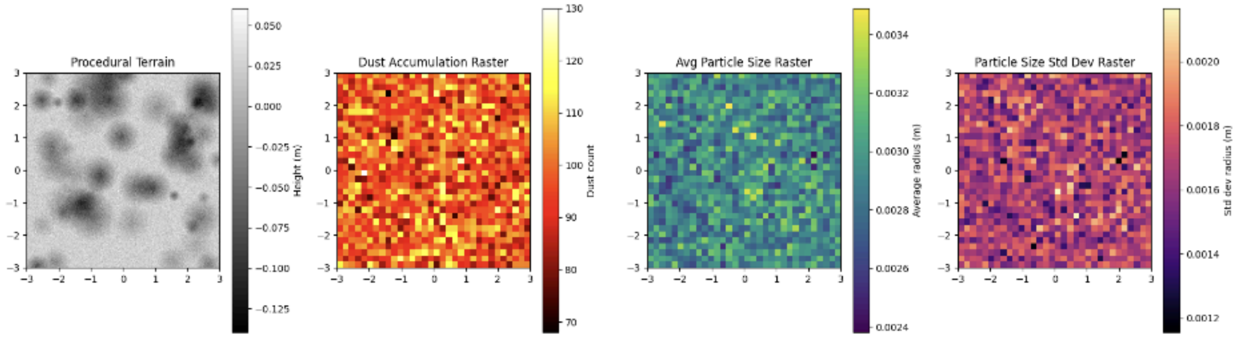
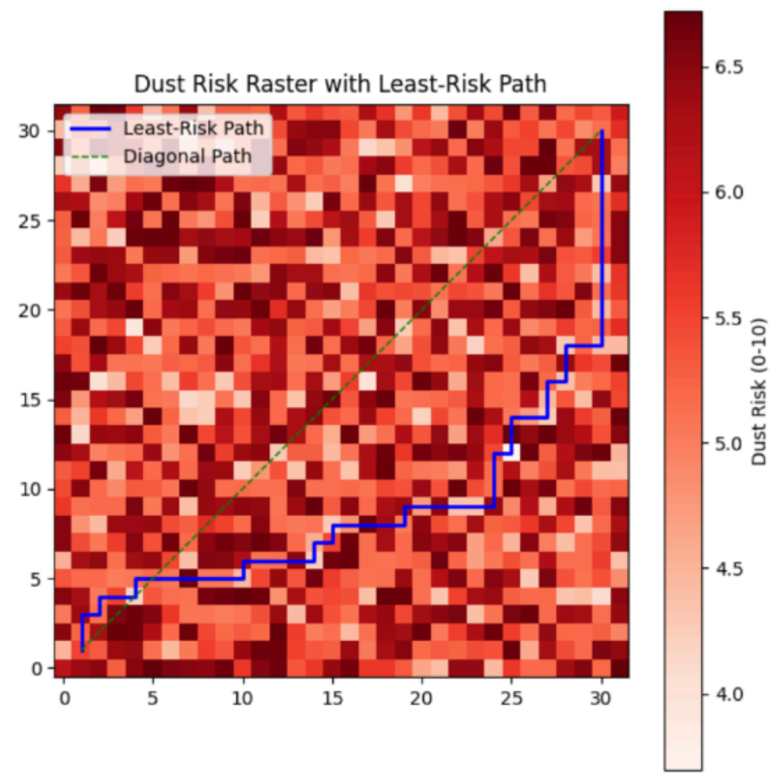
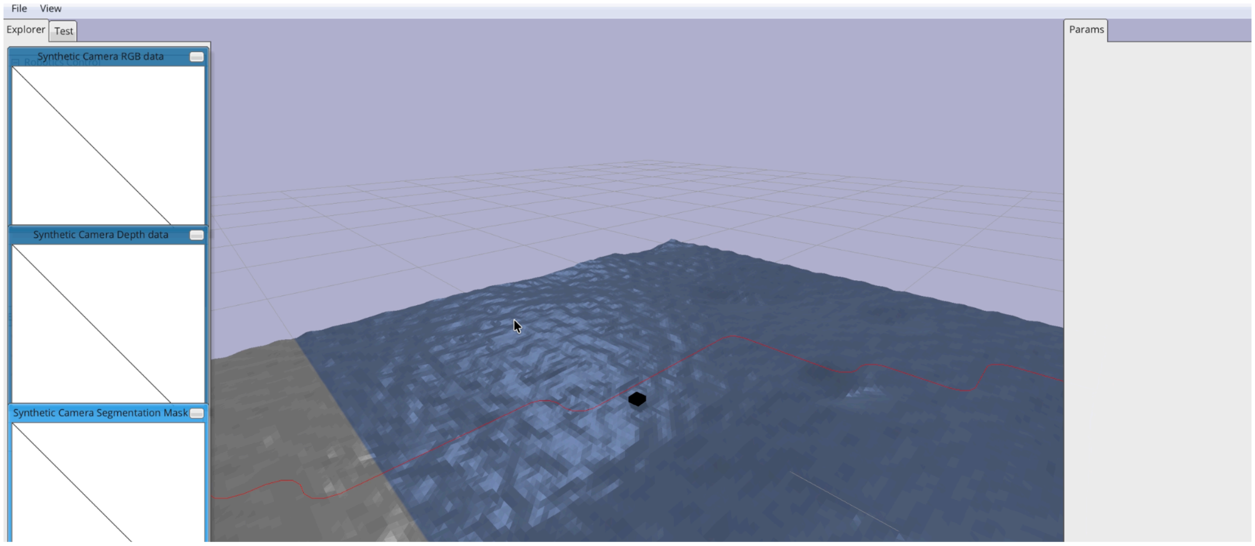


Least-Risk Path

- Static image of the computed path:



- Photo of rover following the path in PyBullet simulation:



Conclusion:

This workflow integrates data cleaning, predictive modeling, simulation, and pathfinding to assess lunar dust hazards efficiently. Validation shows that dust accumulates mostly in craters, as expected, and the model allows planning the safest possible rover routes.