Jet Propulsion Laboratory
California Institute of Technology

Data-Driven Traversability Analysis for Mars 2020 Landing Site Selection

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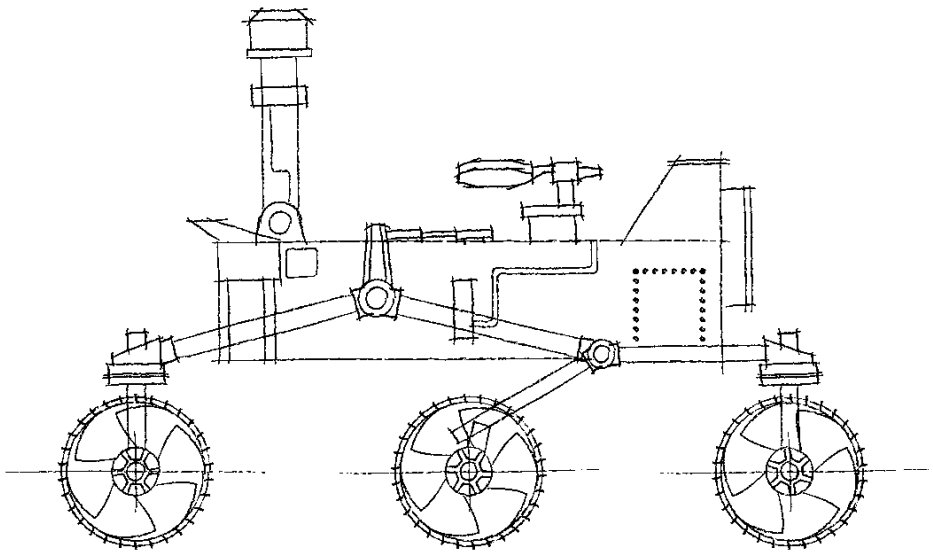
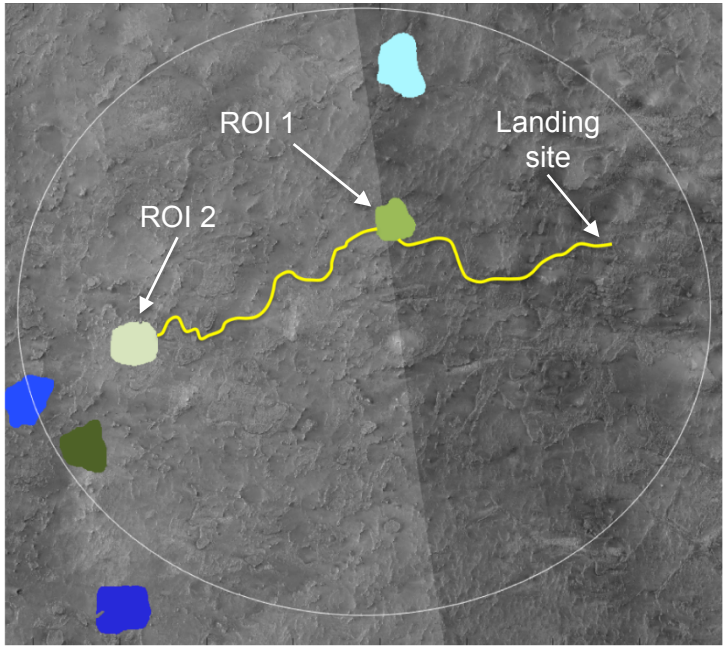


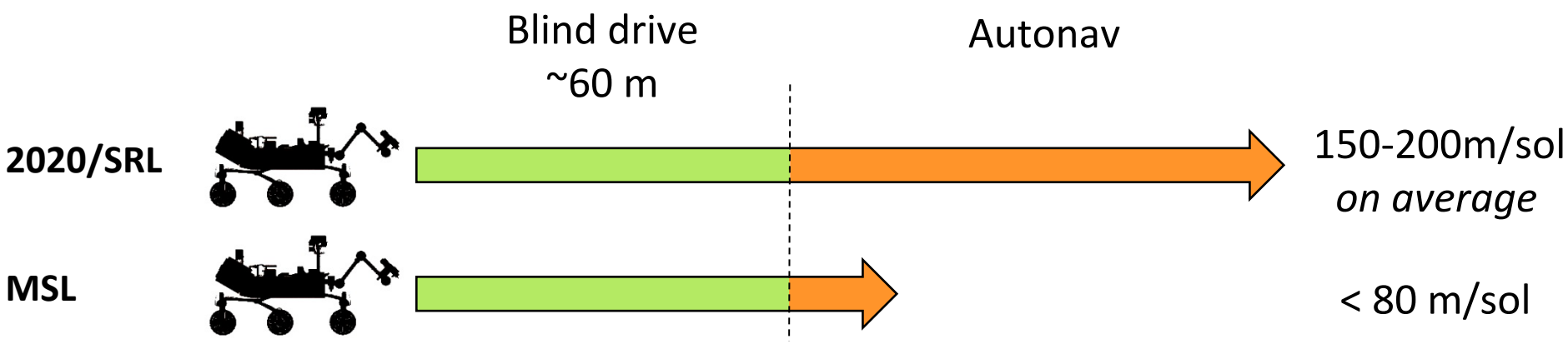
Mars 2020 Project

Pre-Decisional: For Planning and Discussion Purposes Only.

Mars 2020 Mission

- Collect rock and regolith samples that could be returned by future missions
- Required to visit prespecified regions of interest (ROIs)
- Baseline Reference Scenario:
  - Visit 2 ROIs in 1.25 Mars years
  - 12 km of traverse between ROIs
  - 85 Sols allocated for inter-ROI drives
  - Requires significantly faster rate than MSL
- **Mission success is more contingent on surface mobility than MSL**





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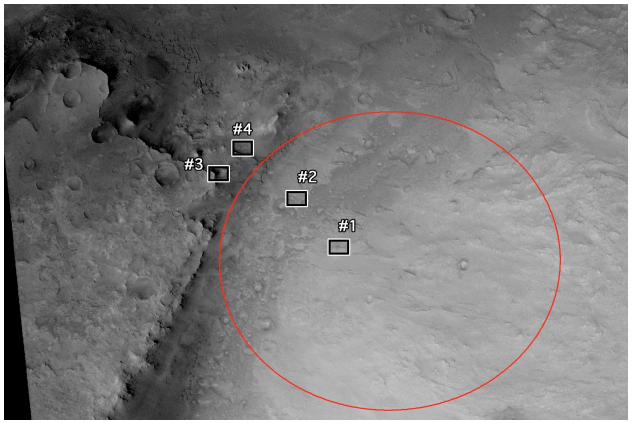
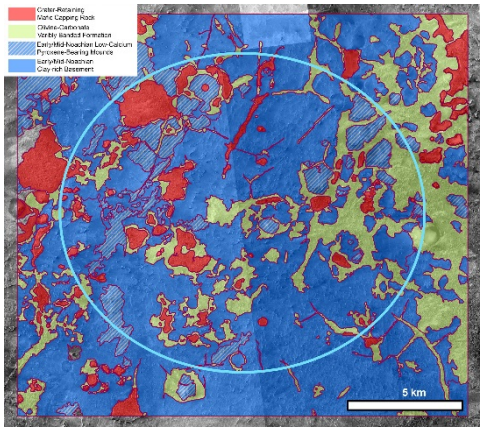
Regions Of Interest (ROIs)

- Site proposers submitted ROIs specific to the exploration of that site
- Site proposers defined what ROIs need to be visited for scientific success at the site
- ROI definition and “must visit” set have a big impact on traverse requirements at the site.
  - Project science team to work with site proposers after project PDR to refine ROIs and develop site specific mission scenarios
- Current evaluation is for visiting 2 ROIs per site



Nili Fossae Trough
Olivine rich deposit (ROI #3)
&
Either #1 or #2



North East Syrtis
Any Olivine-Carbonate formation (green)
&
Any of the Crater-Retaining Capping Mafic Rock (red)

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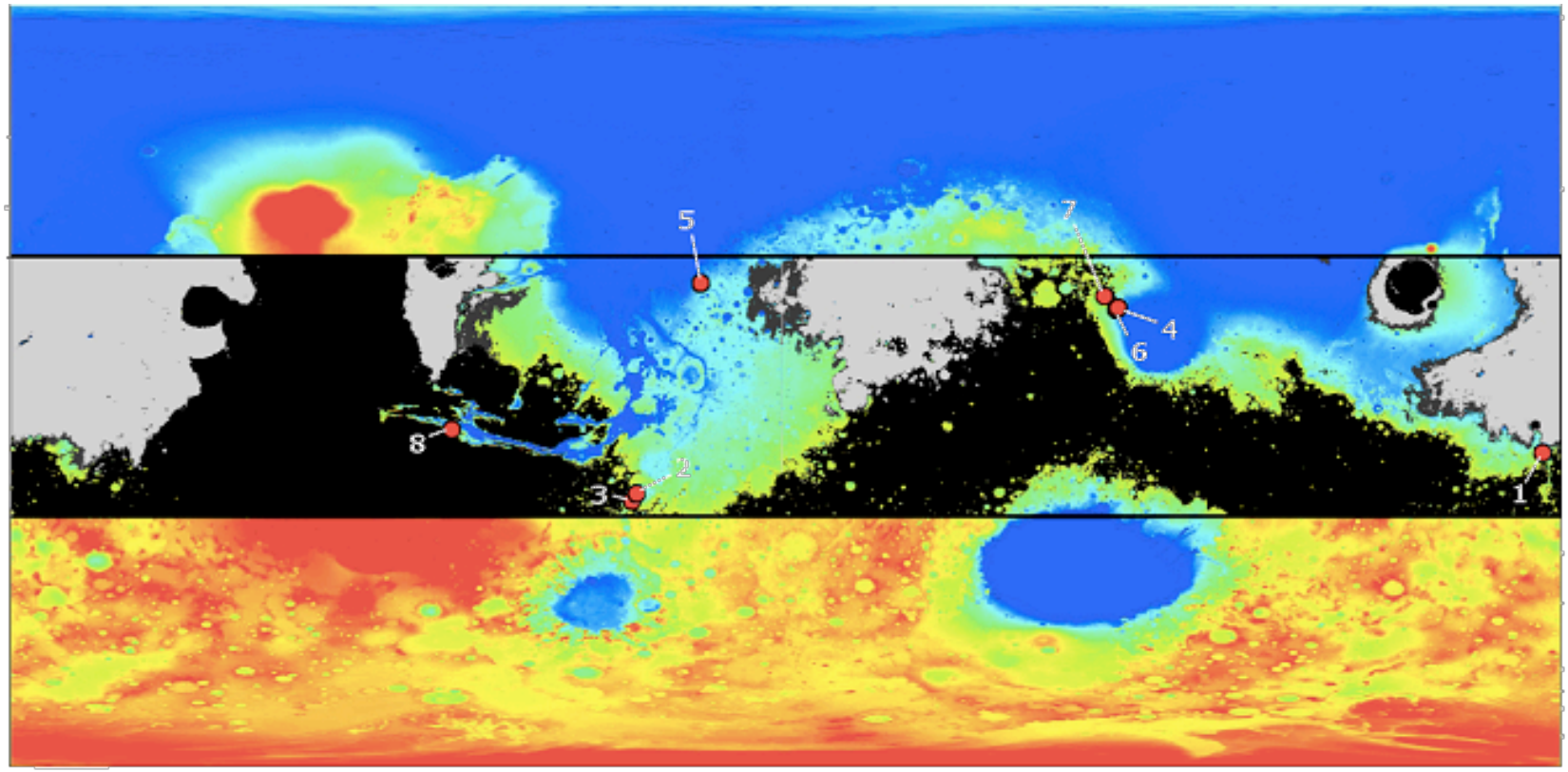
Landing Site Selection for M2020

8 Candidate sites considered for M2020



(alphabetical order)

1- Columbia Hills (Gusev)
2- Eberswalde
3- Holden
4- Jezero
5- Mawrth
6- NE Syrtis
7- Nili Fossae
8- SW Melas

Elevation above MOLA Geoid (m)

High: 4000 Low: -5000

Black elevation mask > 0.5 km

Thermal Inertia masks:

< 150 = Dark Gray

< 100 = Light Gray

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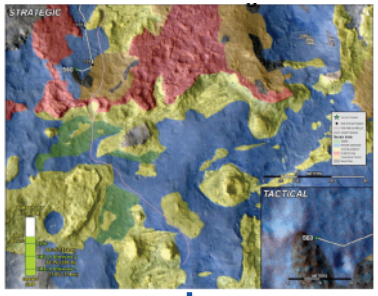
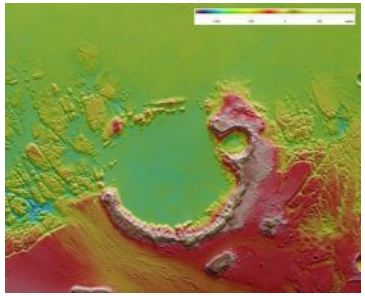
MTTTT Overview (Planned)

Raw HiRISE/CTX images

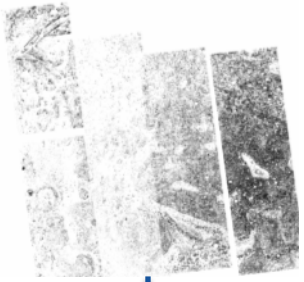
Terrain classes



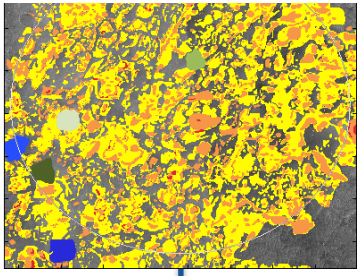
DEM/Slope



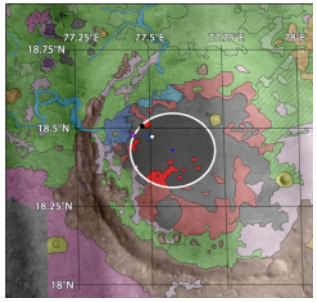
Rock abundance



Manual traverasability assessment

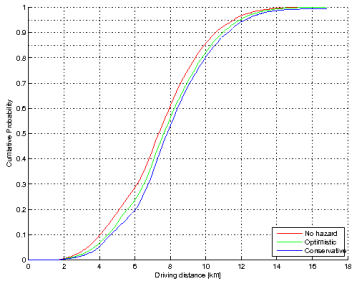


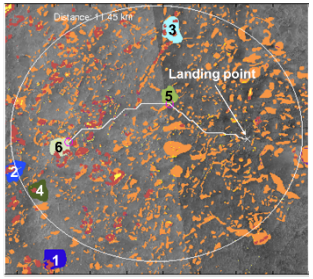
ROIs

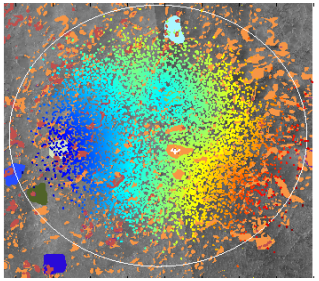


Mobility Model

Traversability Analysis







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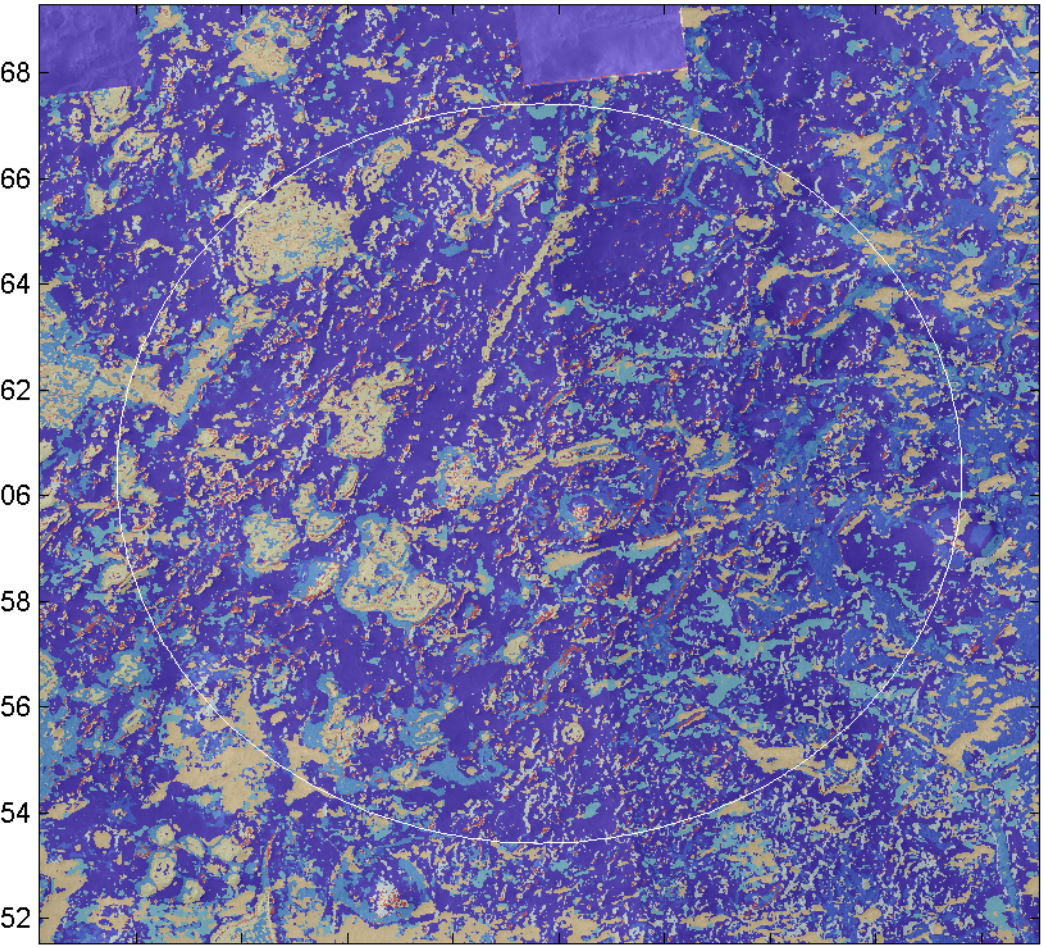
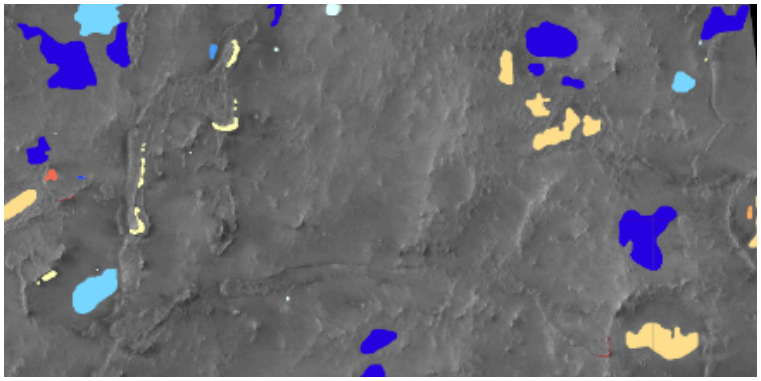
Automated Terrain Classification



Smooth regolith | Smooth outcrop | Fractured outcrop
Sparse linear ripples | Rough outcrop | Crater
Rock field | Dense linear ripples | Polygonal ripples
Deep sand | Scarps

- Visually identifies 11 terrain types over the entire site
- Uses machine learning: algorithm learns from examples provided by humans
- Currently used only for NES; will be deployed to all the sites by LSW3
- Learns from mistake: human's corrections improves algorithm
- Developed by B. Rothrock
- Issues: has difficulty in identifying rough outcrop; limited performance for sites other than NES



Human's example for training

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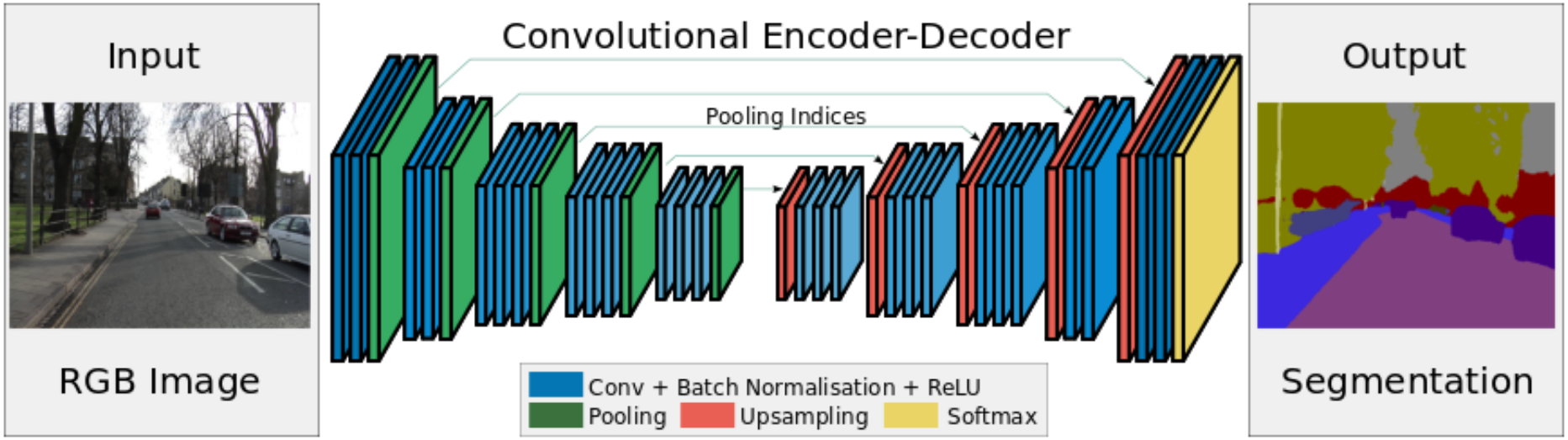
Fully-convolutional neural network

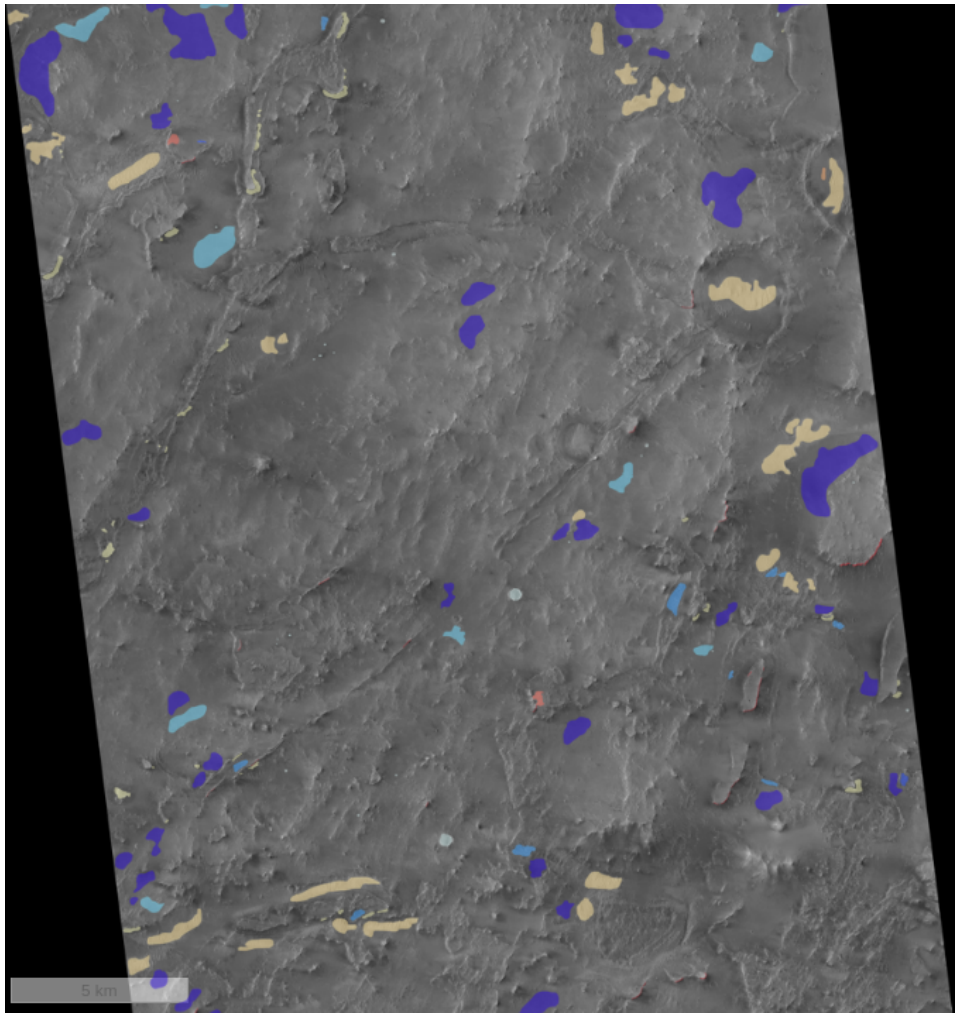
- Based on a “Deep Learning” method
- Uses convolutional neural network (CNN)

SegNet: encoder-decoder architecture with preservation of pooling indices
(Kendall et al., 2015)

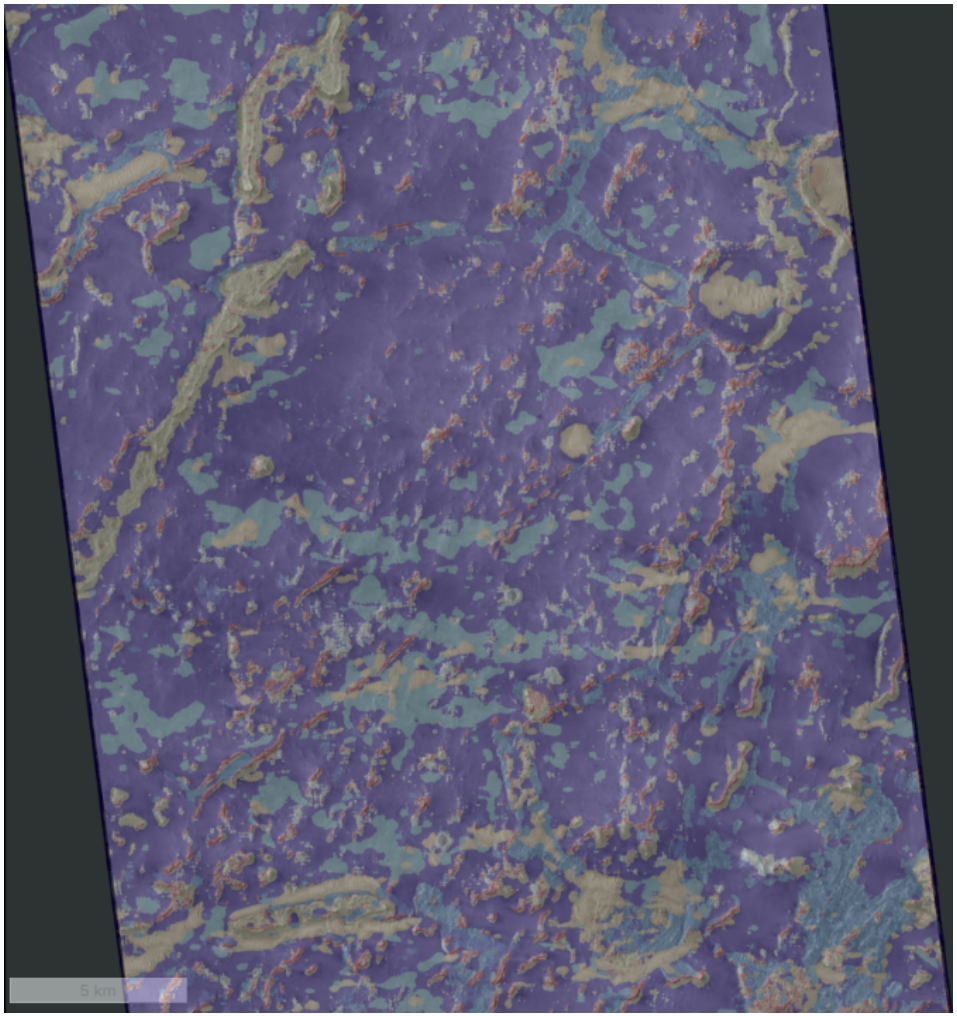


Terrain Classification (NE Syrtis)

Training Data

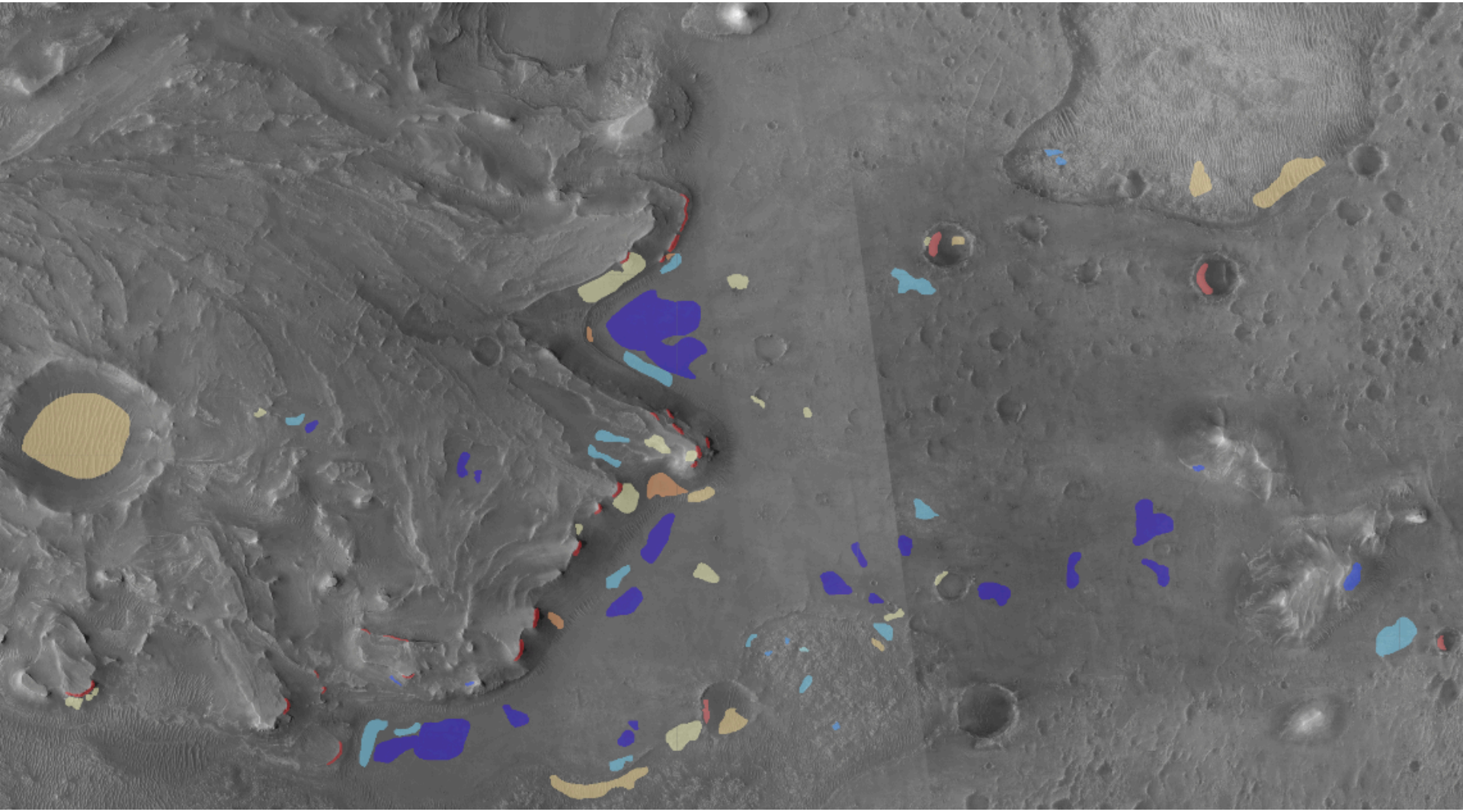


Output



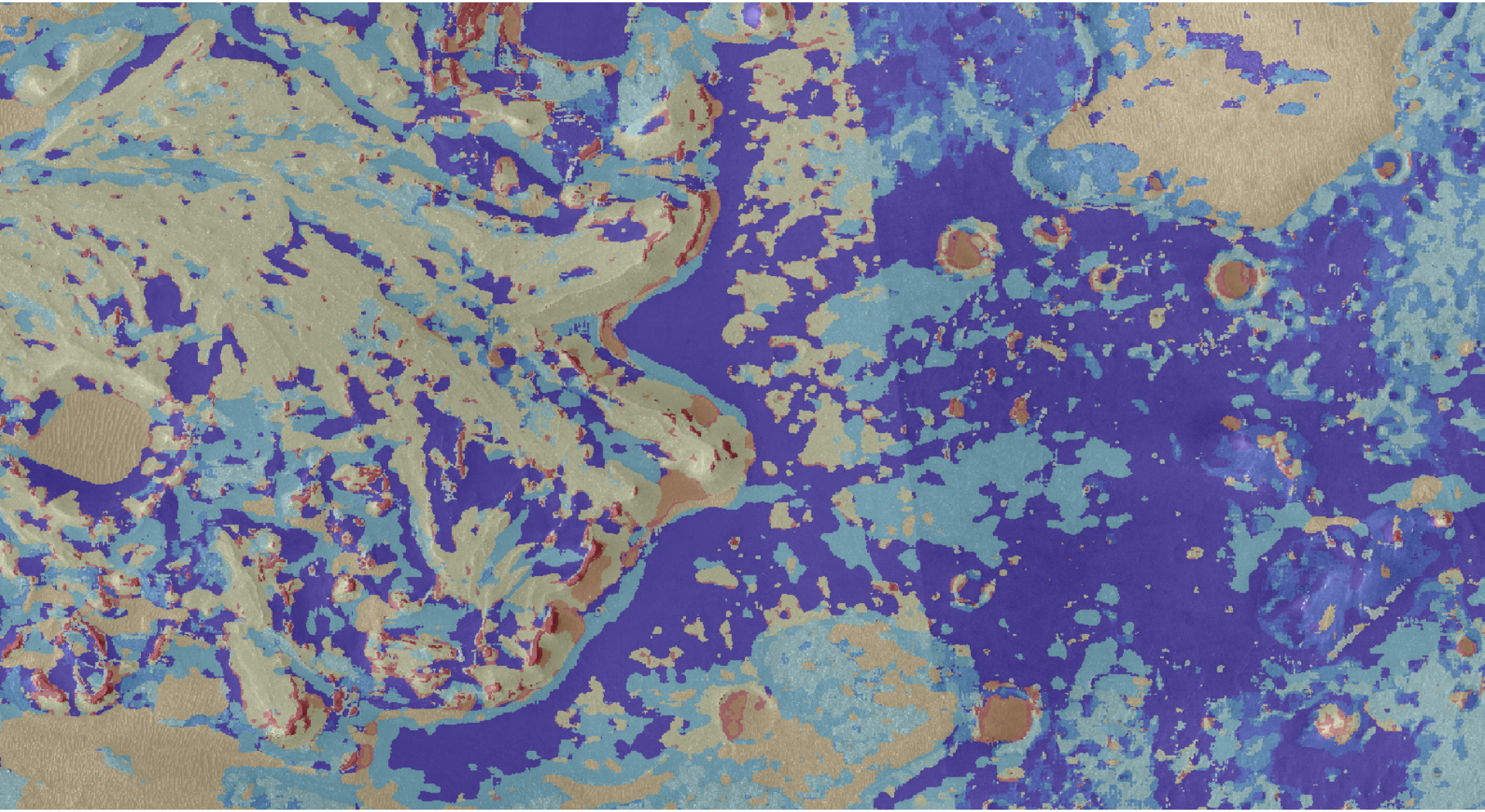
Terrain Classification (Jezero)

Training Data

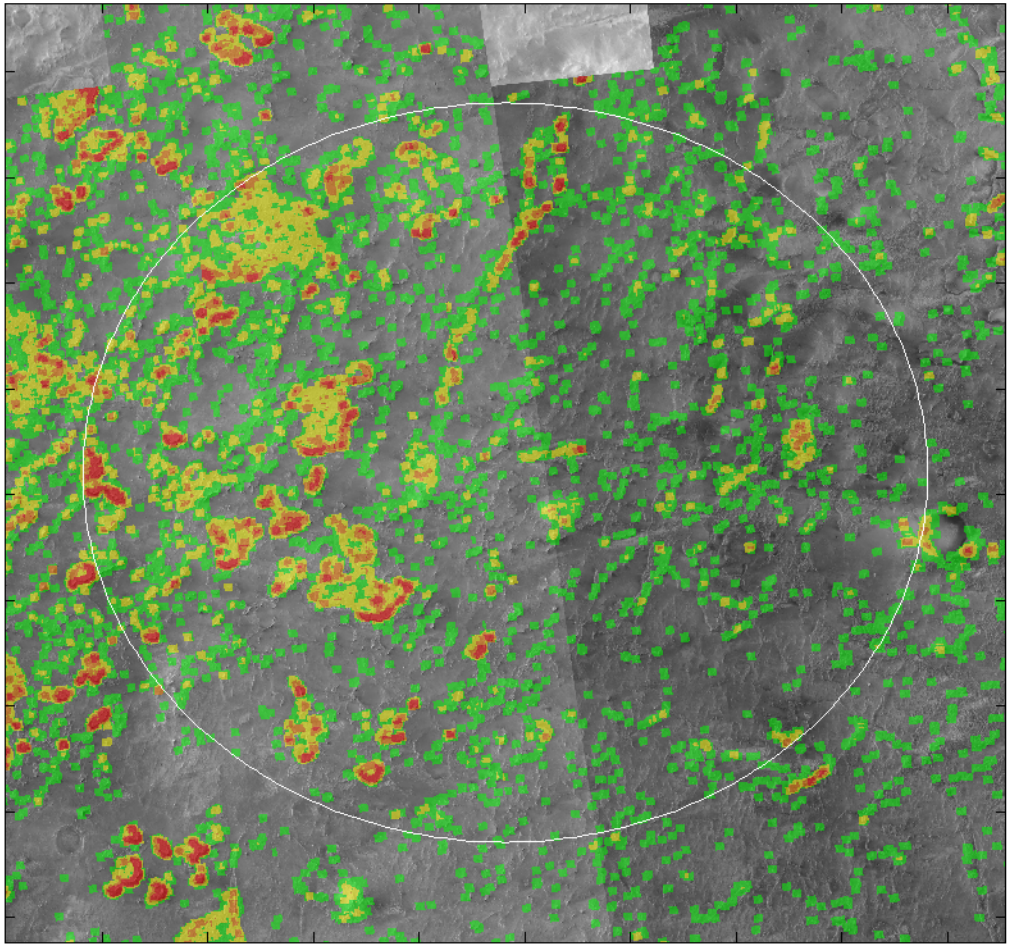


Terrain Classification (Jezero)

Output



Rock Abundance (CFA) Map



7%-10% 10%-15% 15%-20% >=20%

- CFA = **c**umulative **f**raction of **a**rea covered by rocks
- Based on rock counts on HiRISE images
- Automated rock detection algorithm by A. Huertas and E. Almeida
- Issue: the algorithm requires manual parameter tunings, resulting in uncertainty in the CFA value
- Current effort includes mitigation of uncertainty, evaluation of the “error bar,” and sensitivity analysis to distance/time

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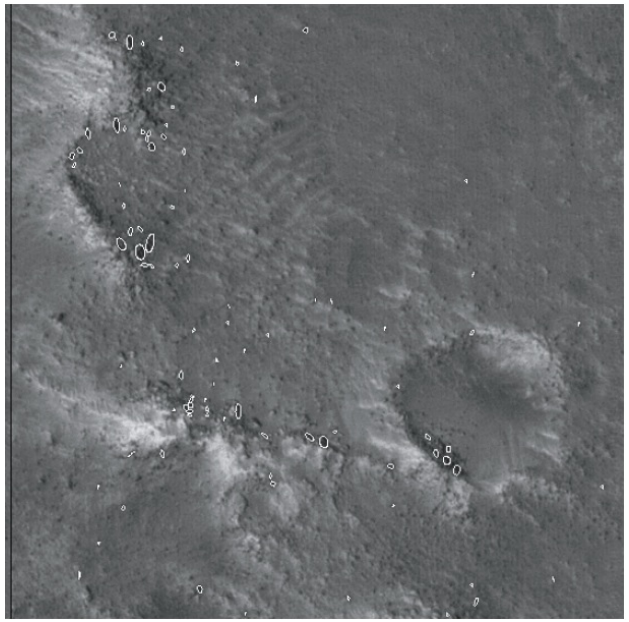
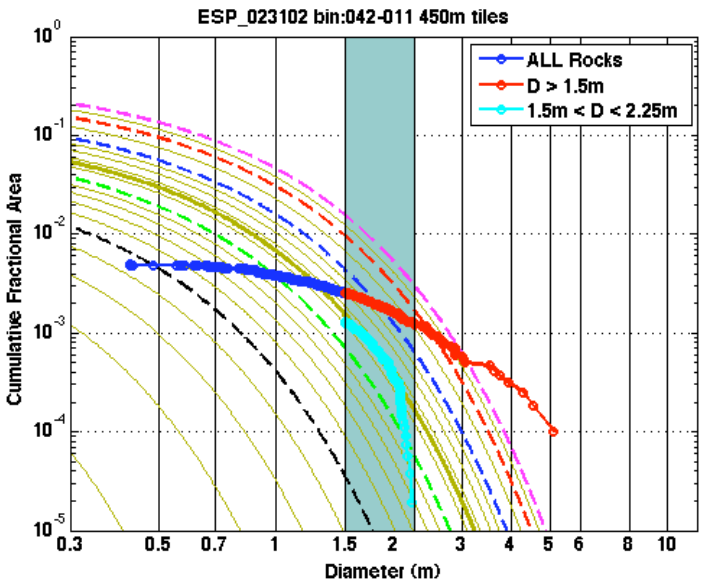
Automated Rock Detection





- Automatically detect the shadows of rocks on HiRISE images
- Also estimates the sizes
- Can reliably detect rocks that are >1.15 m in diameter
- Challenge: rocks <1.15 m affect rover traversability
- Solution: Estimate CFA of *all* sizes of rocks by fitting the observed size distribution to a theoretical size distribution

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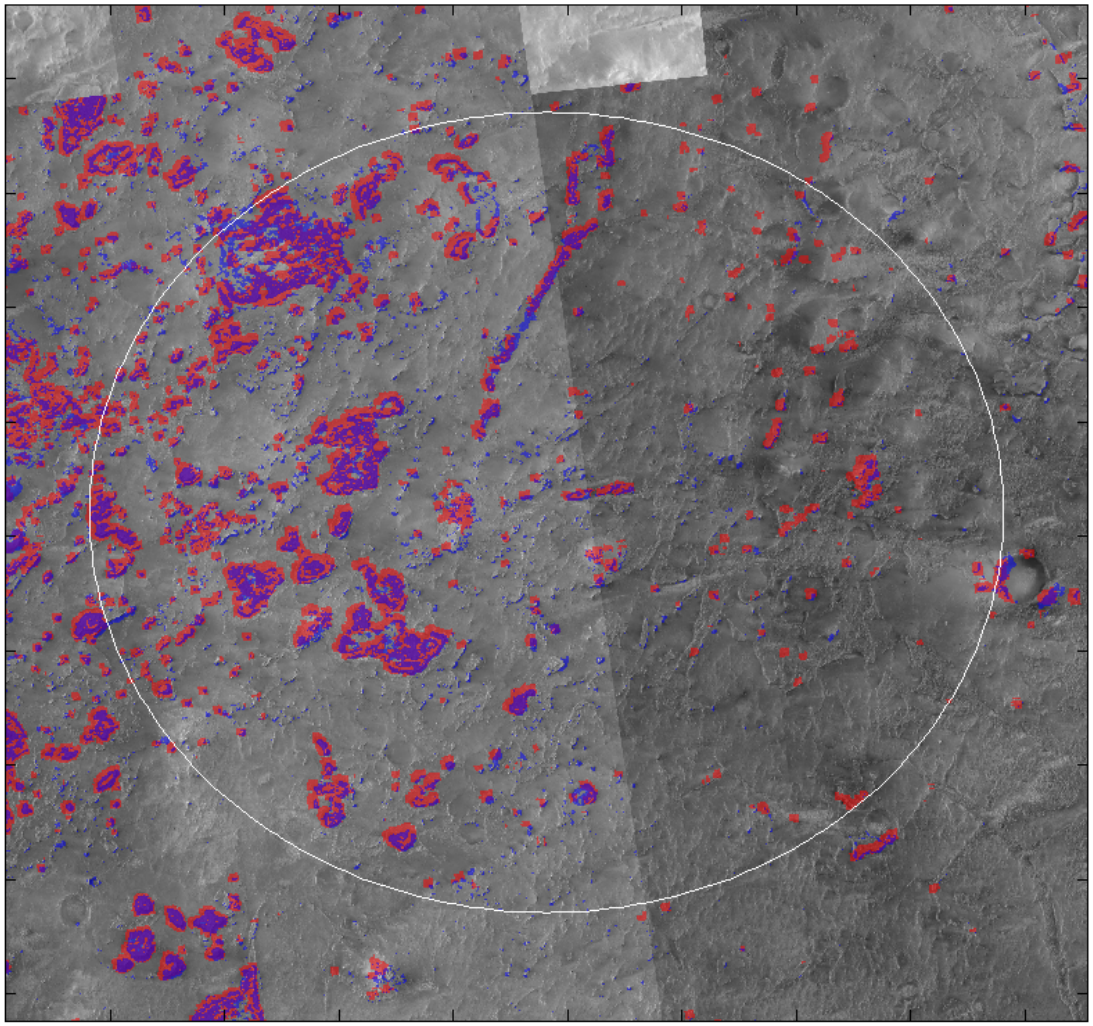
Cross validation of terrain classifier and automated rock detection



- : CFA>10% identified by the automated rock detection
- : rock field identified by terrain classifier
- Qualitatively both results have very good agreement
- TC picks up small rock fields (but not validated if they are correct)

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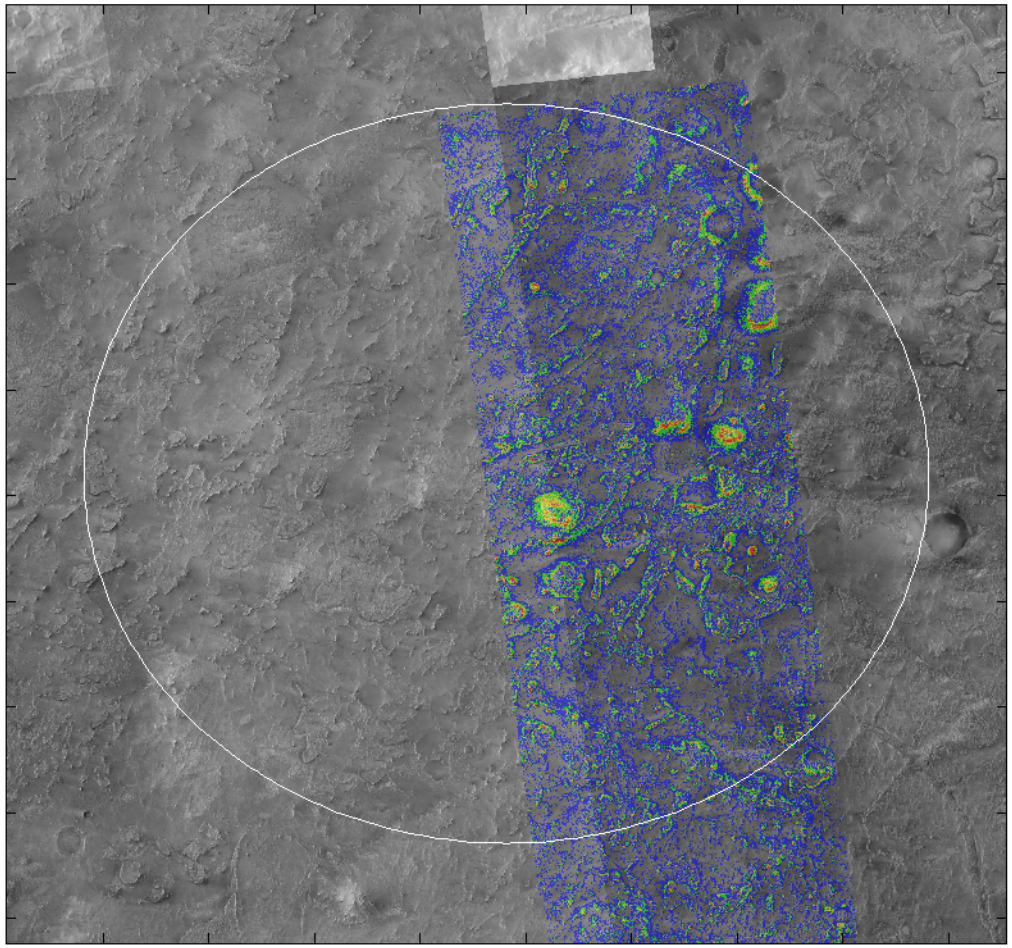
Slope Map



- Generated from HiRISE DEMs
- 1m resolution
- Typically does *not* cover the entire ellipse

5°- 10° | 10 °- 15 ° | 15 °- 20 ° | 20 °- 25 ° | >25°

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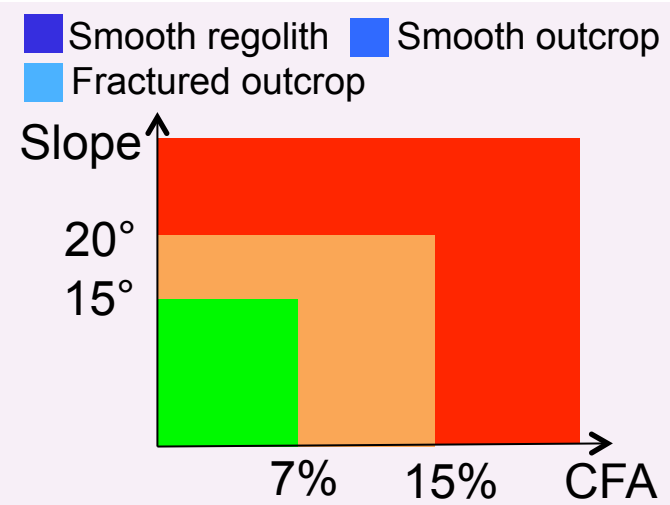
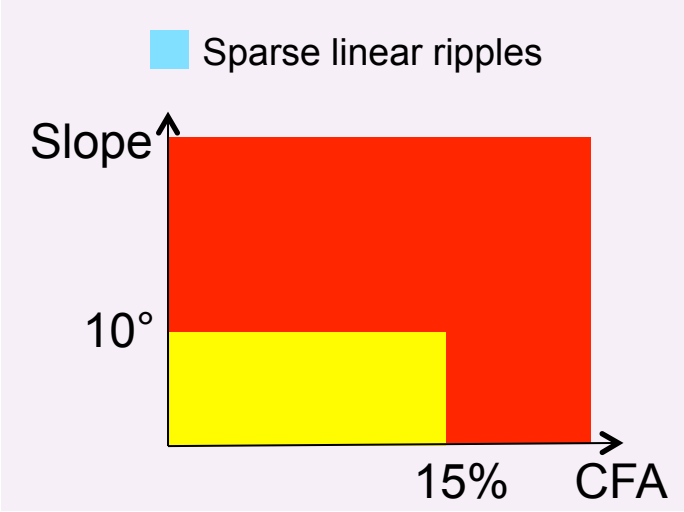
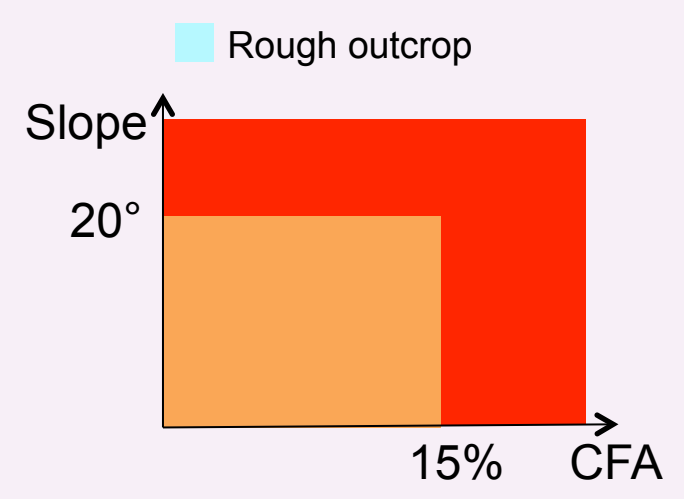
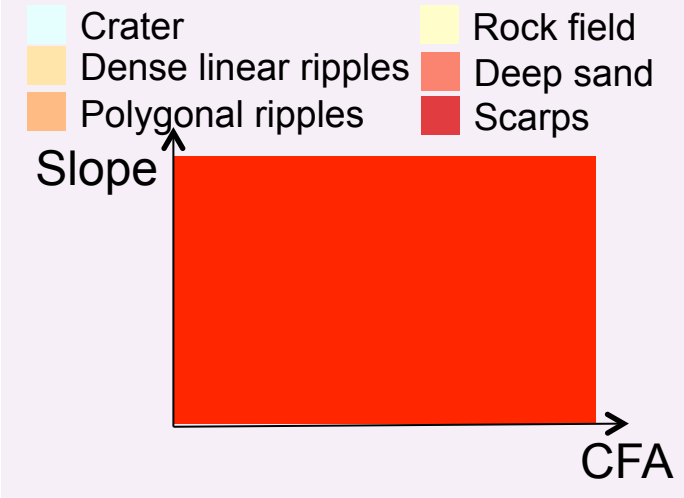
Mobility model (Baseline AutoNav)

- Maps terrain type, slope, and cfa to driving speed
- Used for the time-minimum route planning









Fast Autonav
80 m/hr

Slow Autonav
60 m/hr

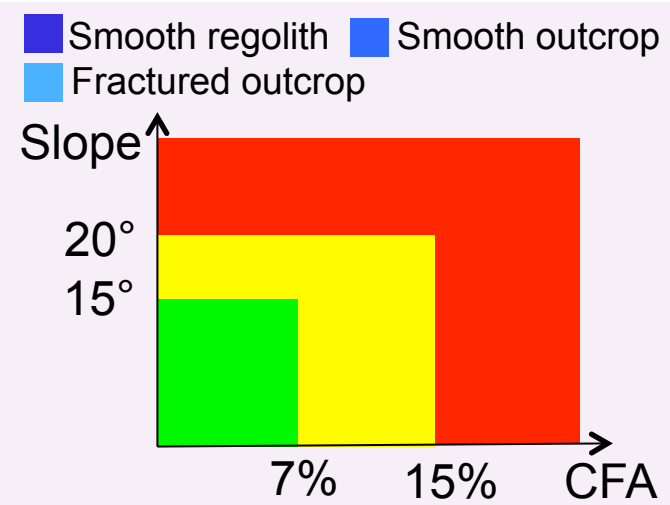
Blind drive only
50 m/sol

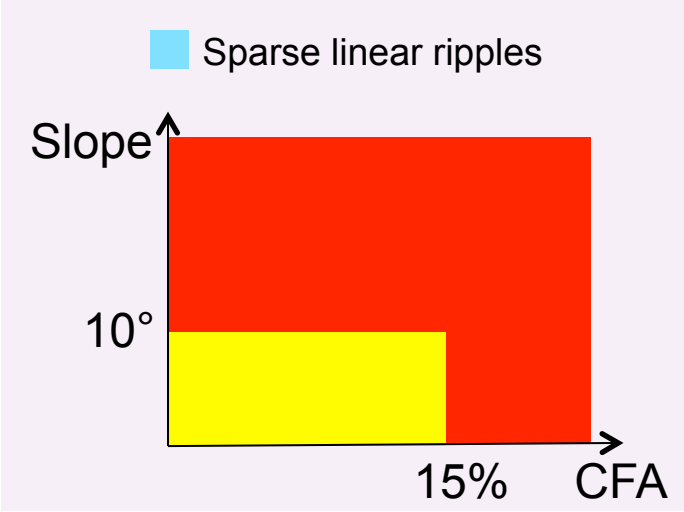
Untraversable

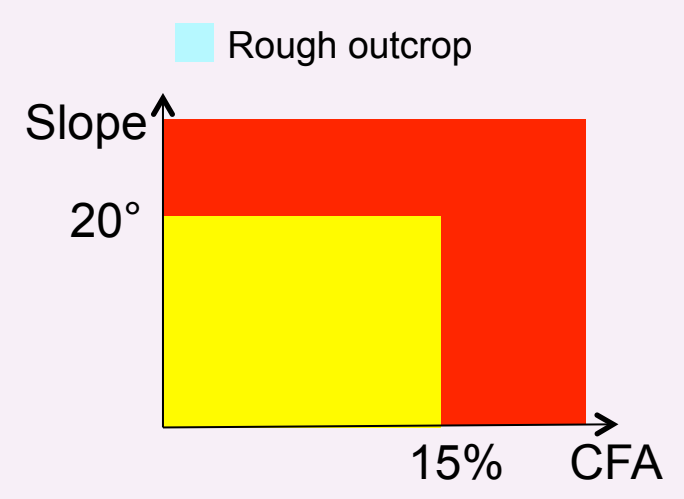
Pre-Decisional: For Planning and Discussion Purposes Only.

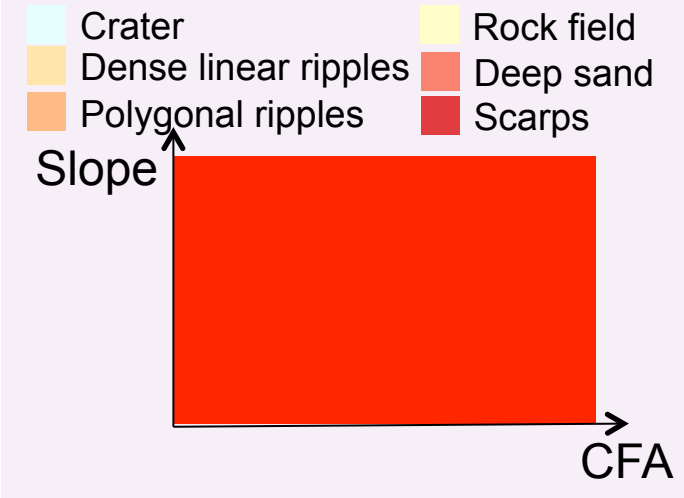
Mobility model (New AutoNav)

- Maps terrain type, slope, and cfa to driving speed
- Used for the time-minimum route planning









Fast Autonav 80 m/hr

Slow Autonav 60 m/hr

Untraversable

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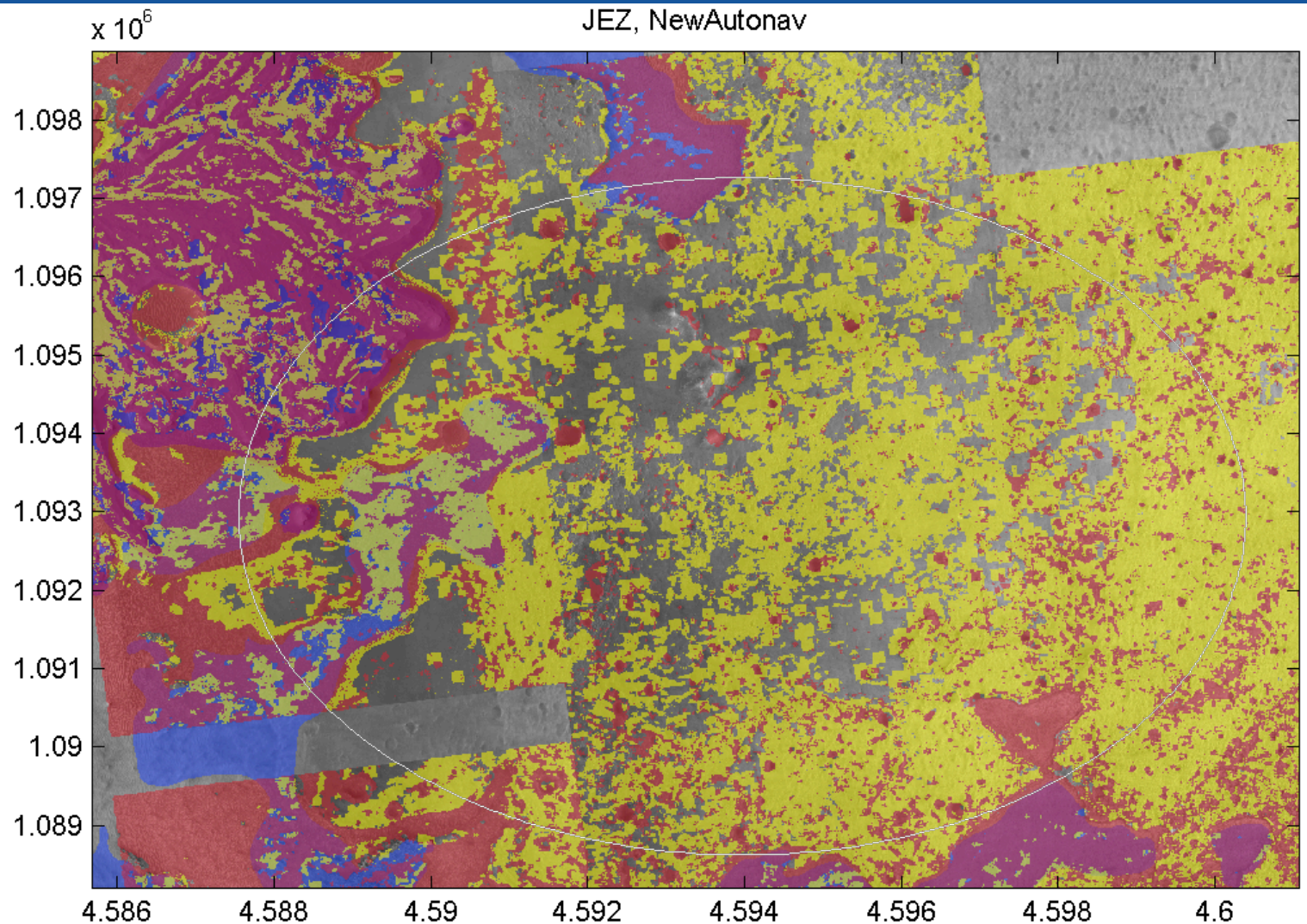
JEZ Traversability (New Autonav)



Fast Autonav (80 m/hr)
Slow Autonav (60 m/hr)
Blind drive only
Untraversable

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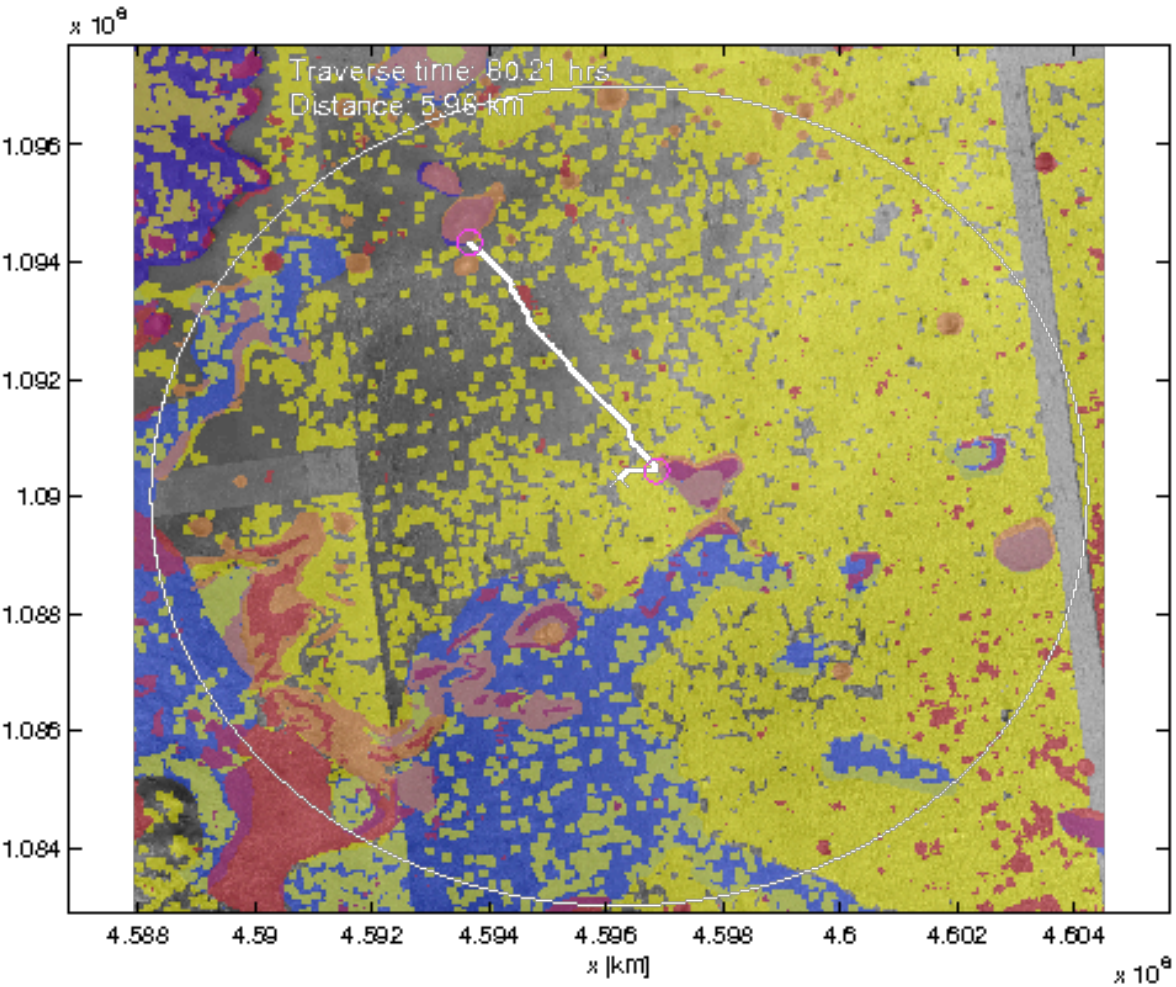
Optimal Route Planning

Example: Jezero



- Minimize time to achieve the minimum ROI requirement from a given landing point
- Driving speed estimated from local terrain type, rock abundance, and slope (details on later slides)
- Optimal route computed by the Sequential Dijkstra algorithm
- Online route planner at: http://lorentz.jpl.nasa.gov:5002/

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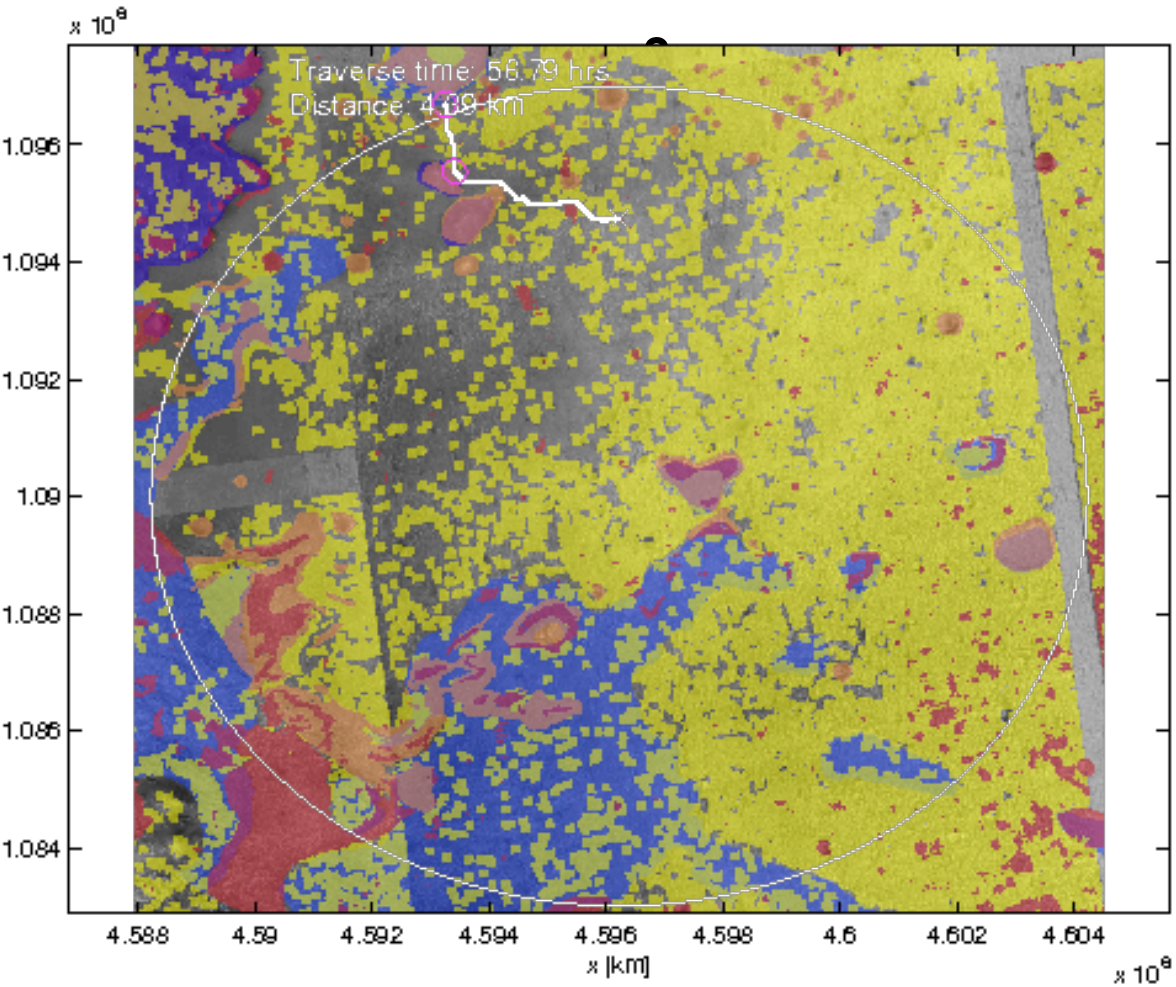
Optimal Route Planning

Example: Jezero



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Optimal Route Planning

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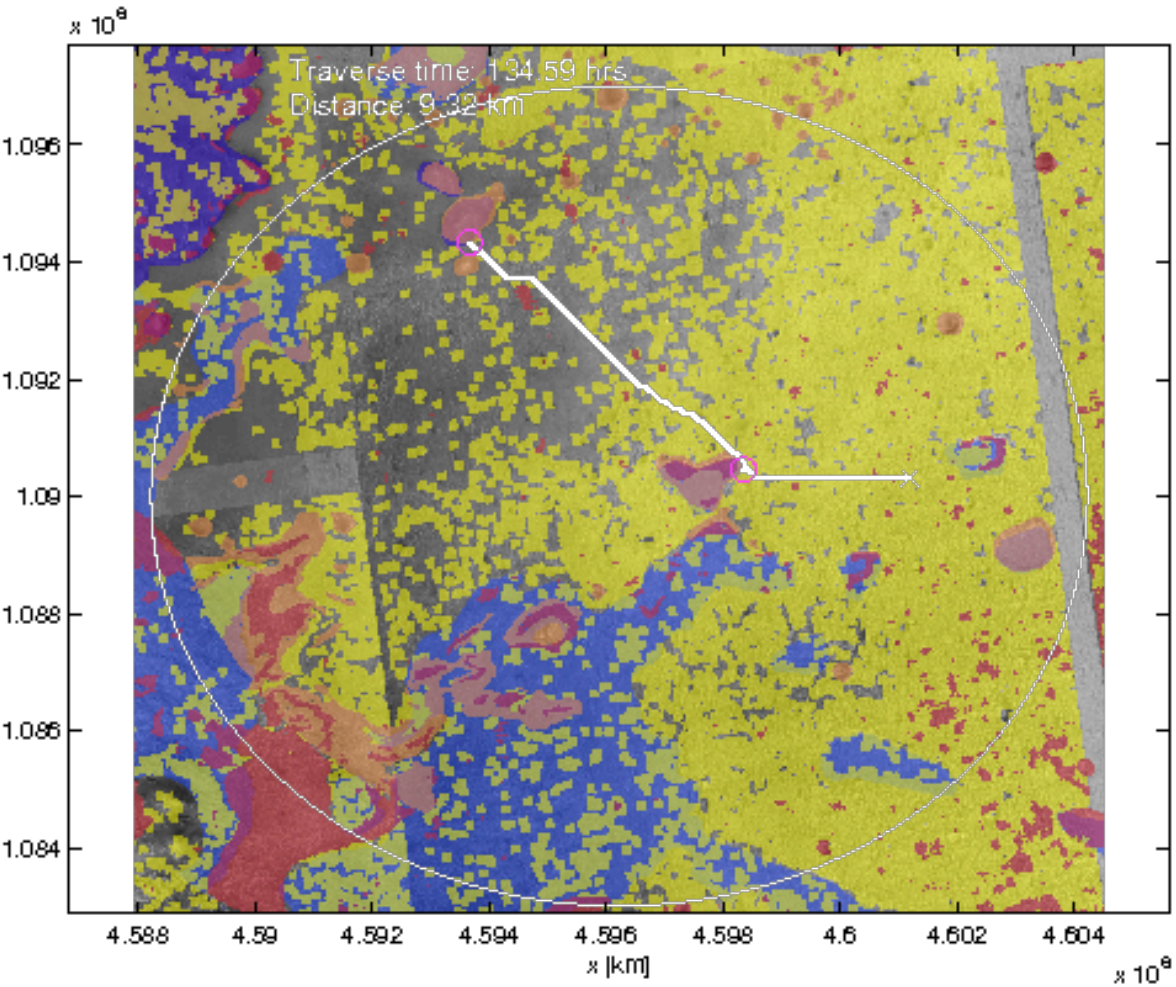

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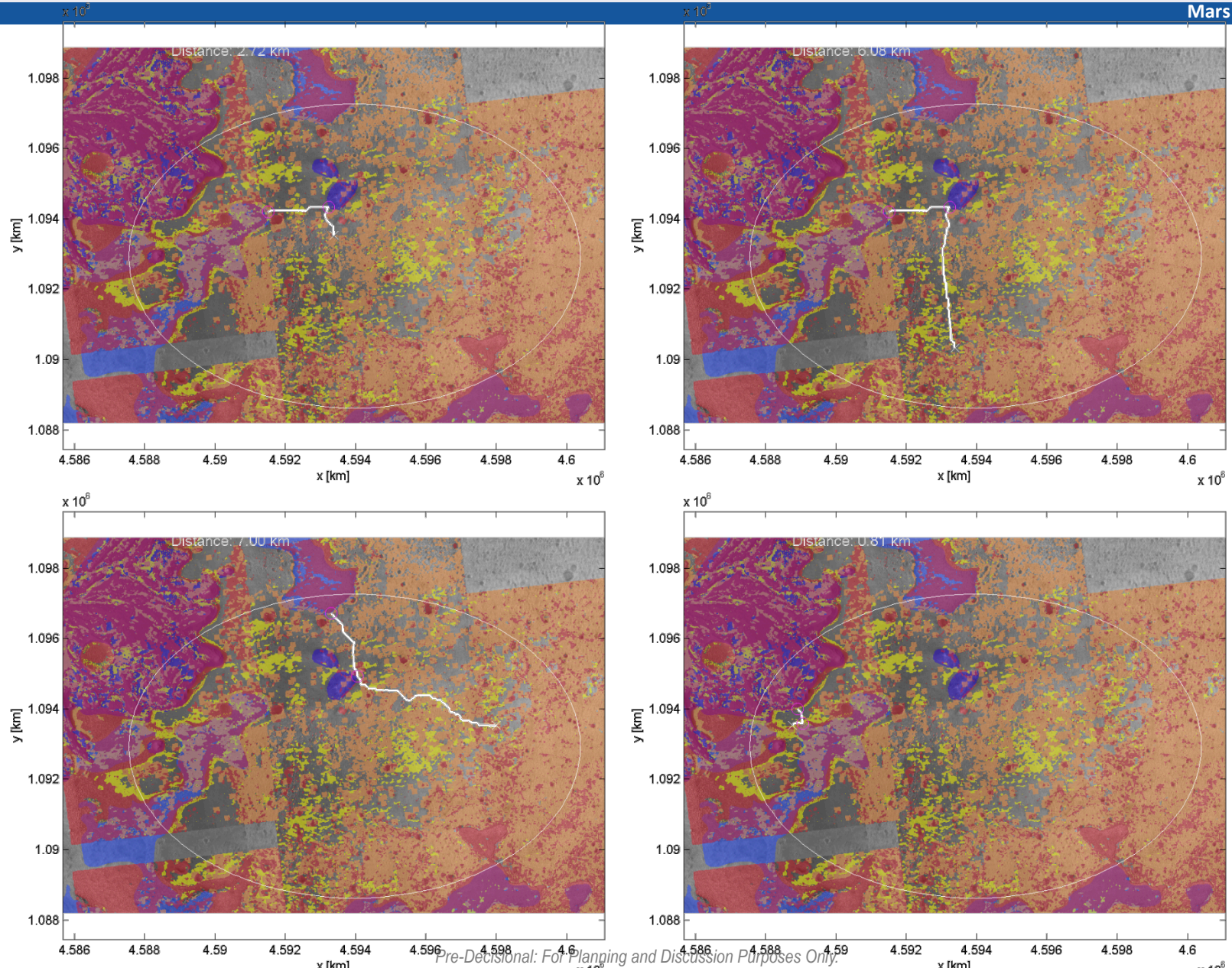
JEZ Sample Routes



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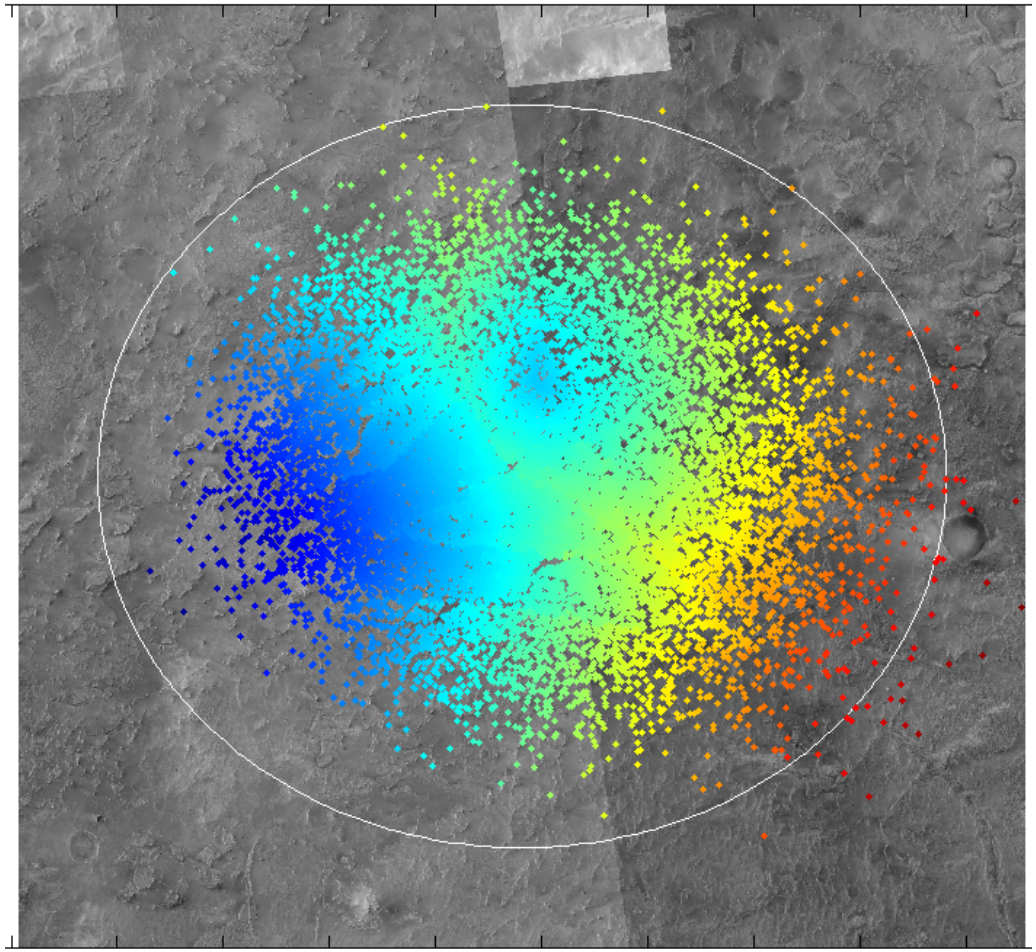
Monte-Carlo Simulation



Landing points provided by EDL team

16,000 samples are provided; downsampled to 2,000

Optimal route computed from *all* samples

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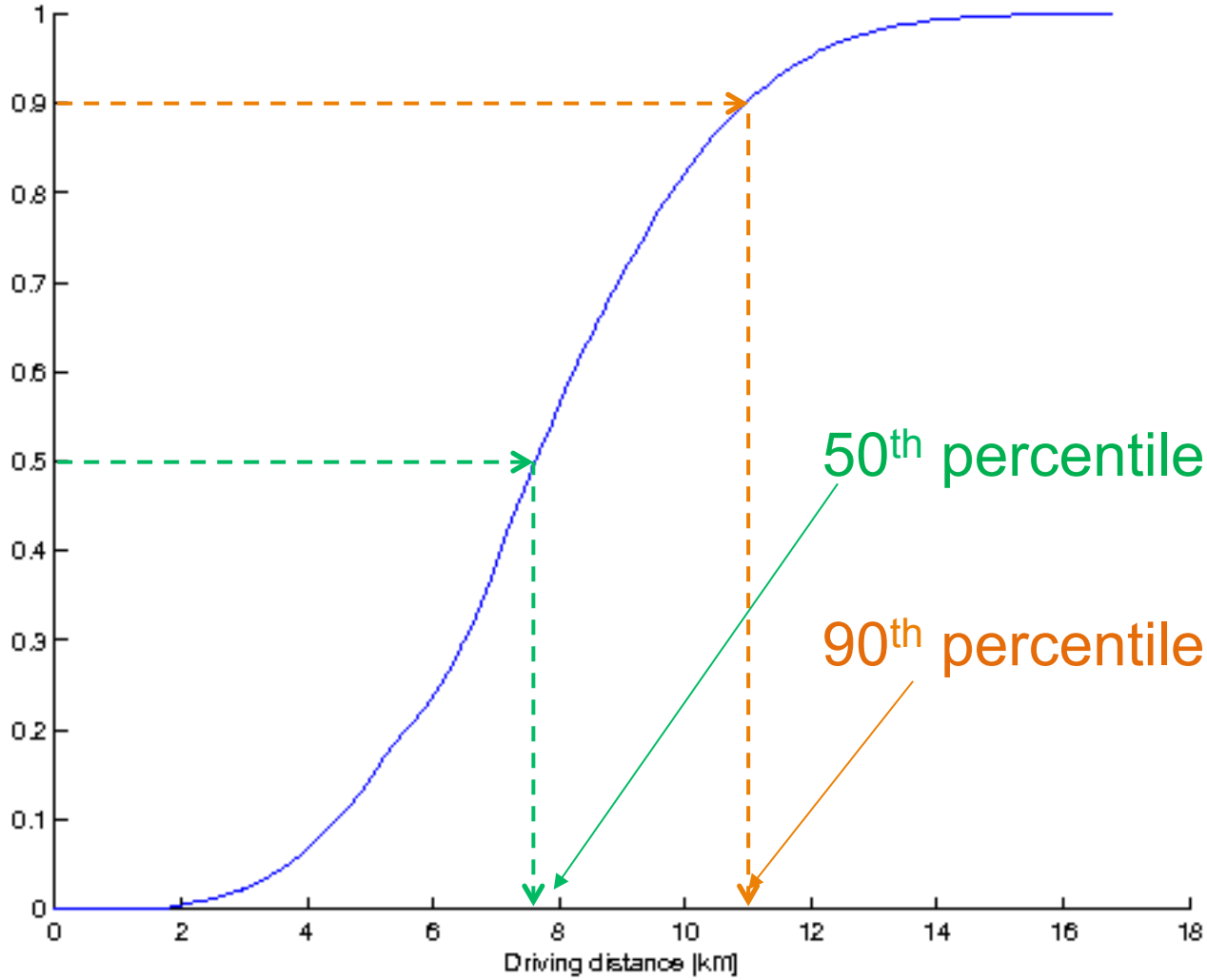
Cumulative Distribution of Distance

- Generate CDFs for distance AND time



50th percentile distance: 7.8 km

90th percentile distance: 11.2 km

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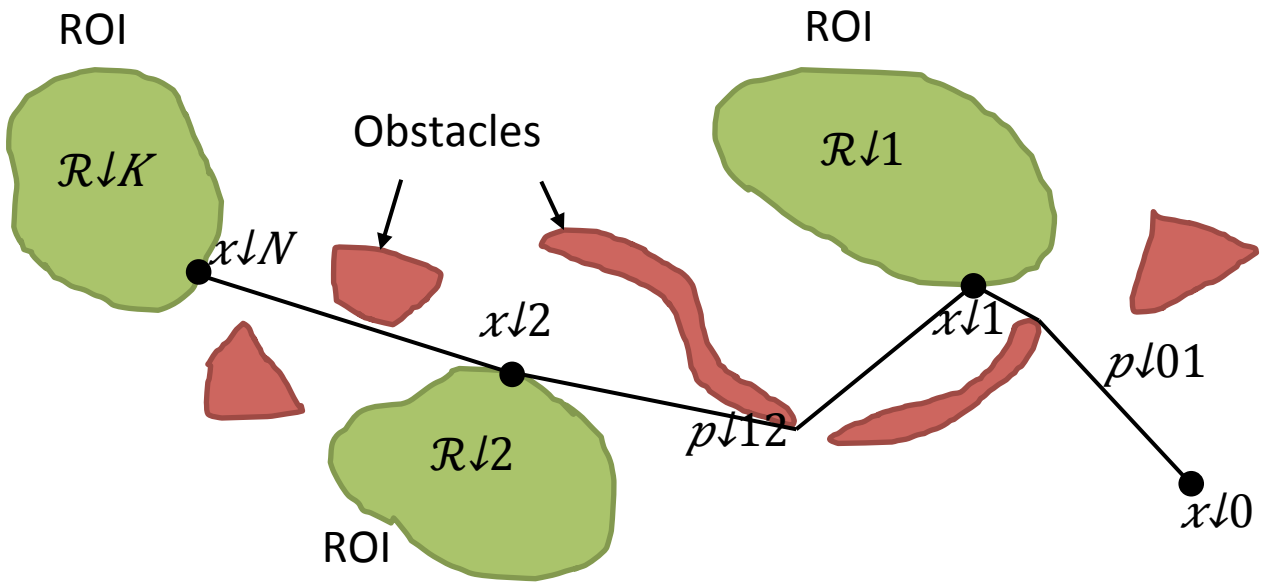
Generalized Traveling Salesman Problem



- Need to optimize:
  - The order to visit ROIs
  - Where in each ROIs to take samples
  - Routes between ROIs
- VERY difficult to solve; NP-hard

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Sequential Dijkstra Algorithm

- Efficiently co-optimizes routes *and* where to take samples for a *fixed* ROI order
- All the permutation of ROI order must be checked, but our problem typically have just 2 ROIs
- **The complexity of the proposed algorithm is exponential only in the # of ROIs**

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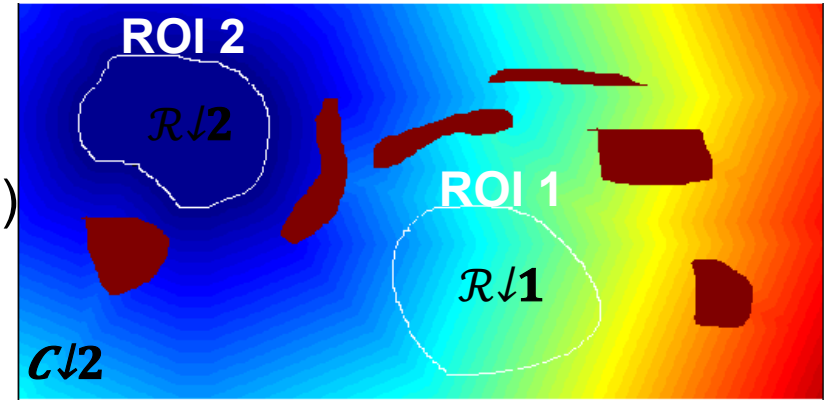
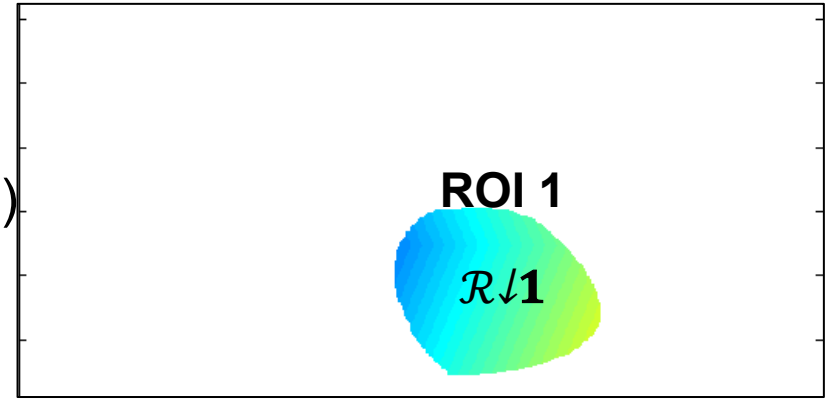
Sequential Dijkstra Algorithm

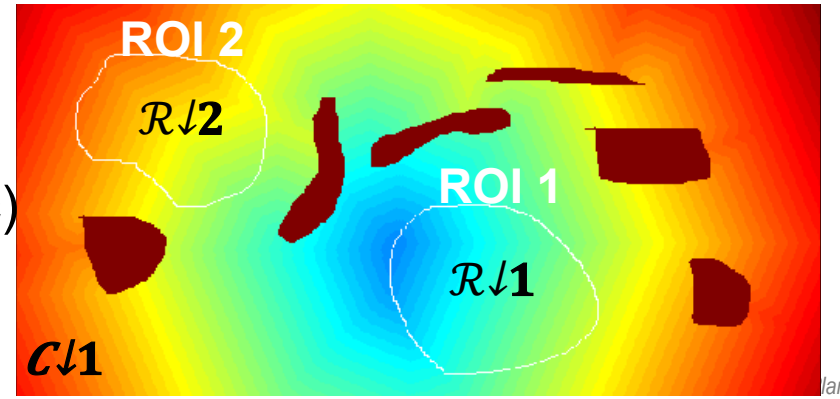
(a)



(b)



(c)



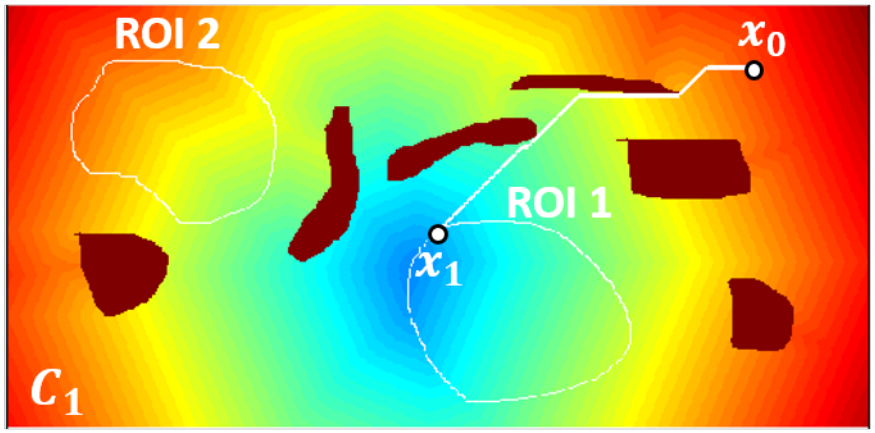
- Order: ROI1 -> ROI2
- The optimization process goes backward in time

- 1. Run Dijkstra Algorithm to obtain the shortest distances (cost) to get to **ROI2**
- 2. Leave the cost within ROI1 and wipe out the rest
- 3. Run Dijkstra Algorithm again with the initial cost in ROI1. The resulting cost is the distance to get **to ROI2 via ROI1**.

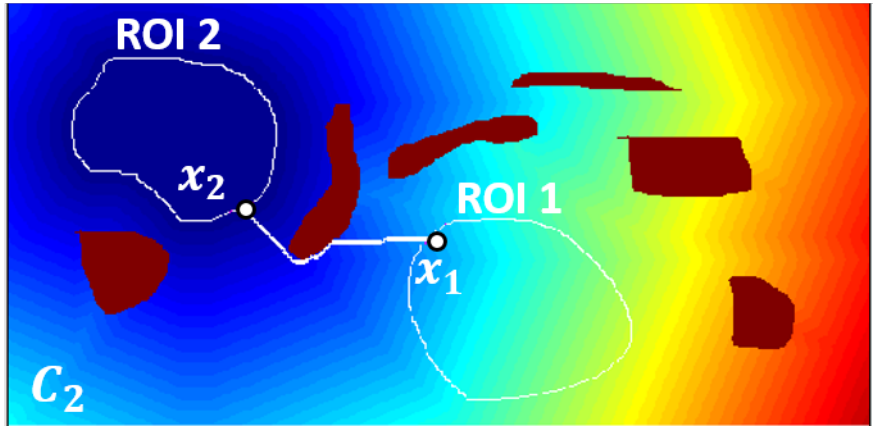
lanning and Discussion Purposes Only.

Route Reconstruction

(a)



(b)



- The saved cost maps are used to reconstruct the path
- Runs forward in time
- First, use the cost map to get to **ROI2 via ROI1**
- Starting from the landing point (x_0), a route is extended to the node that has the lowest cost among the neighbors until reaching ROI1
- Then use the cost map to get to ROI2
- Starting from ROI1's sampling point (x_1), extend the route in the same manner until hitting ROI2

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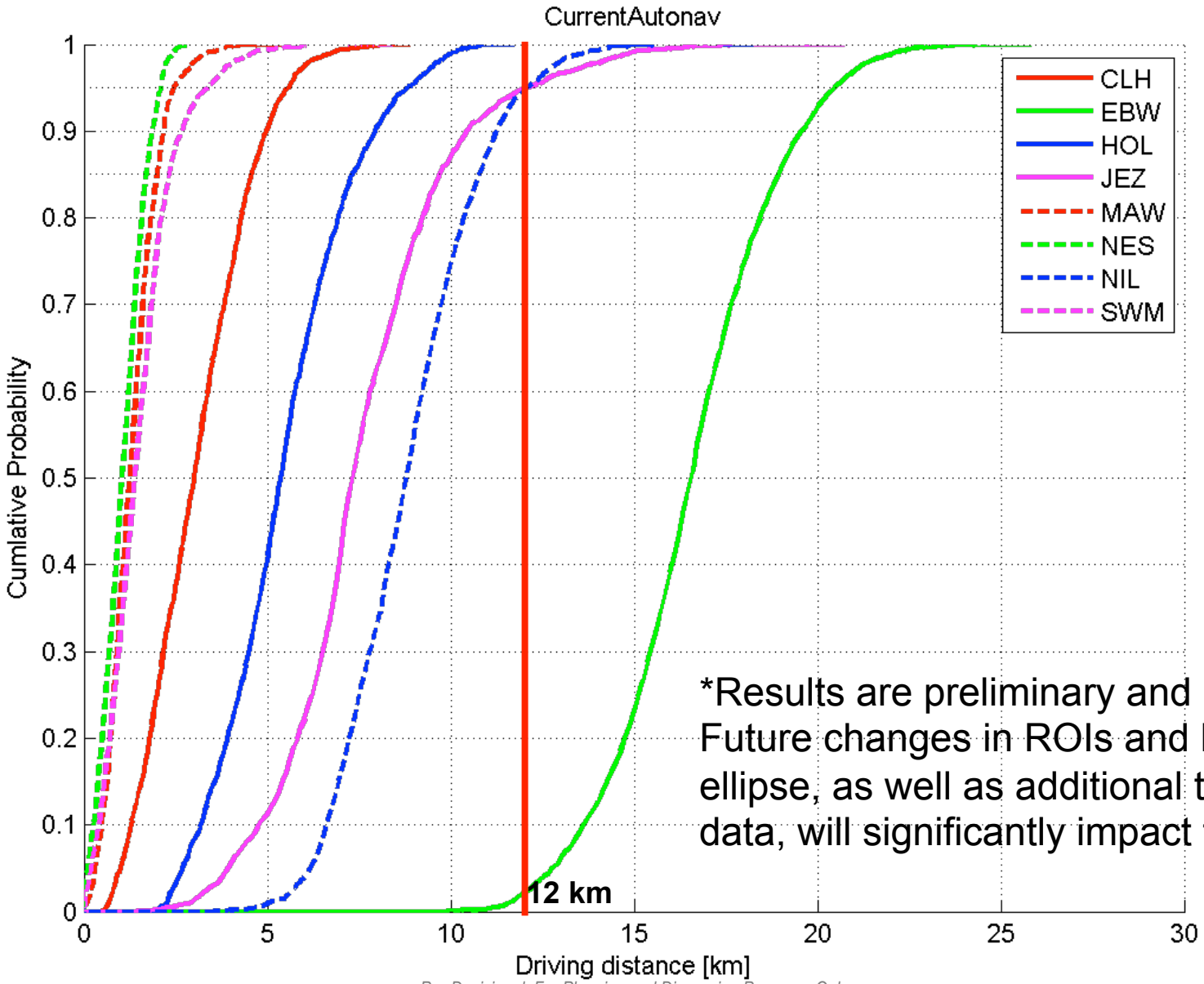
Results (Distance CDF)



*Results are preliminary and not final. Future changes in ROIs and landing ellipse, as well as additional traversability data, will significantly impact the results.

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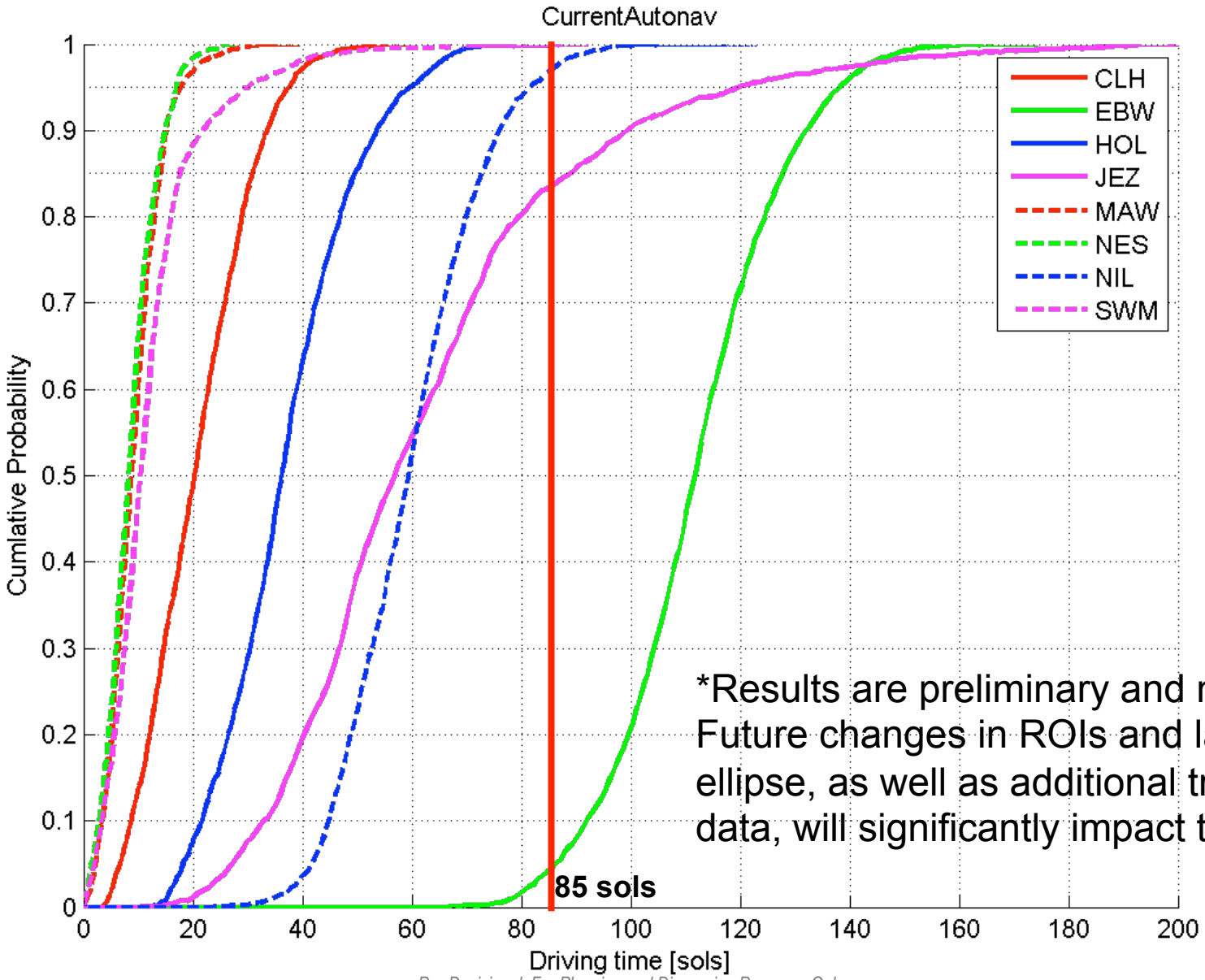
CDF (Time)



*Results are preliminary and not final. Future changes in ROIs and landing ellipse, as well as additional traversability data, will significantly impact the results.

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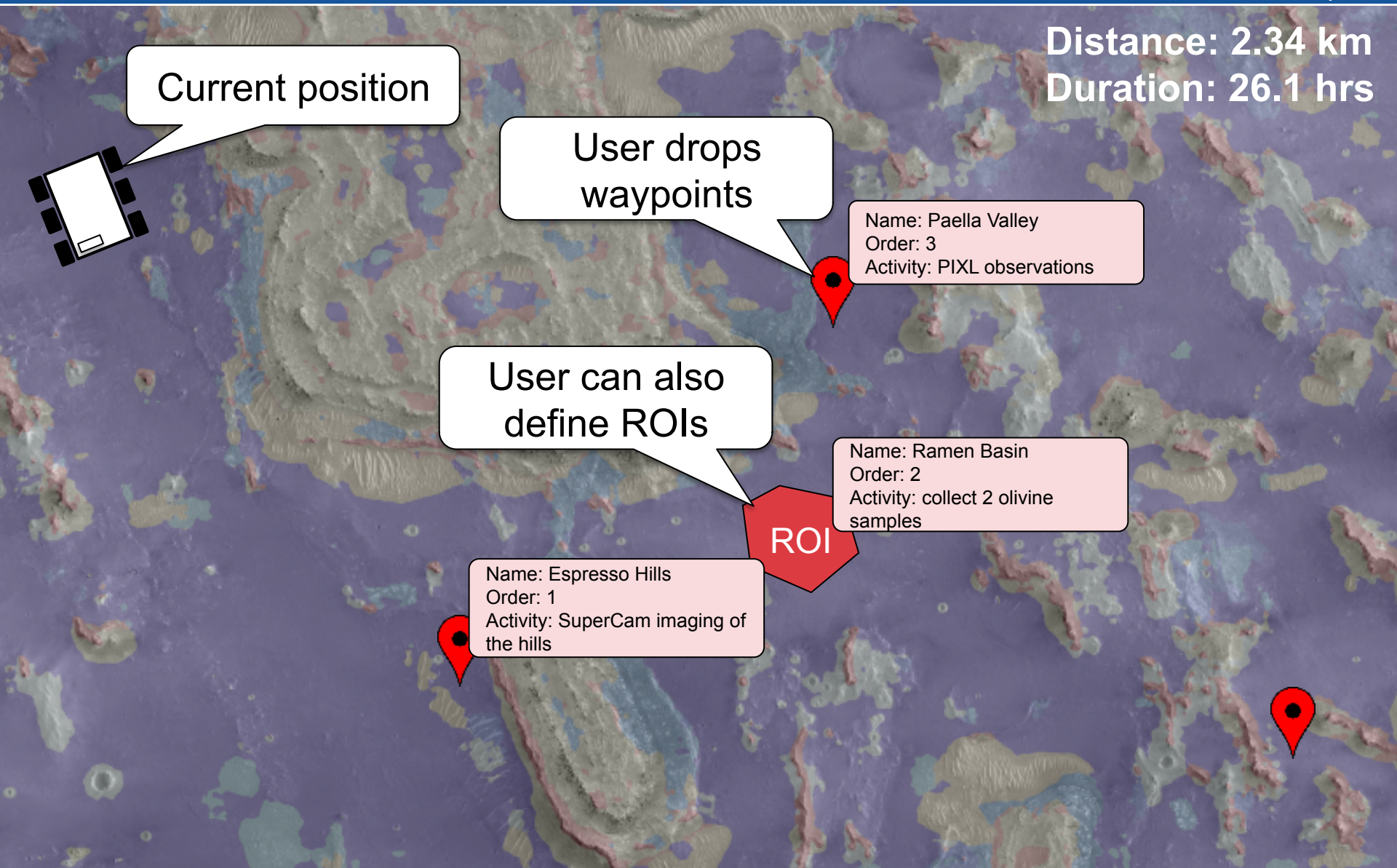
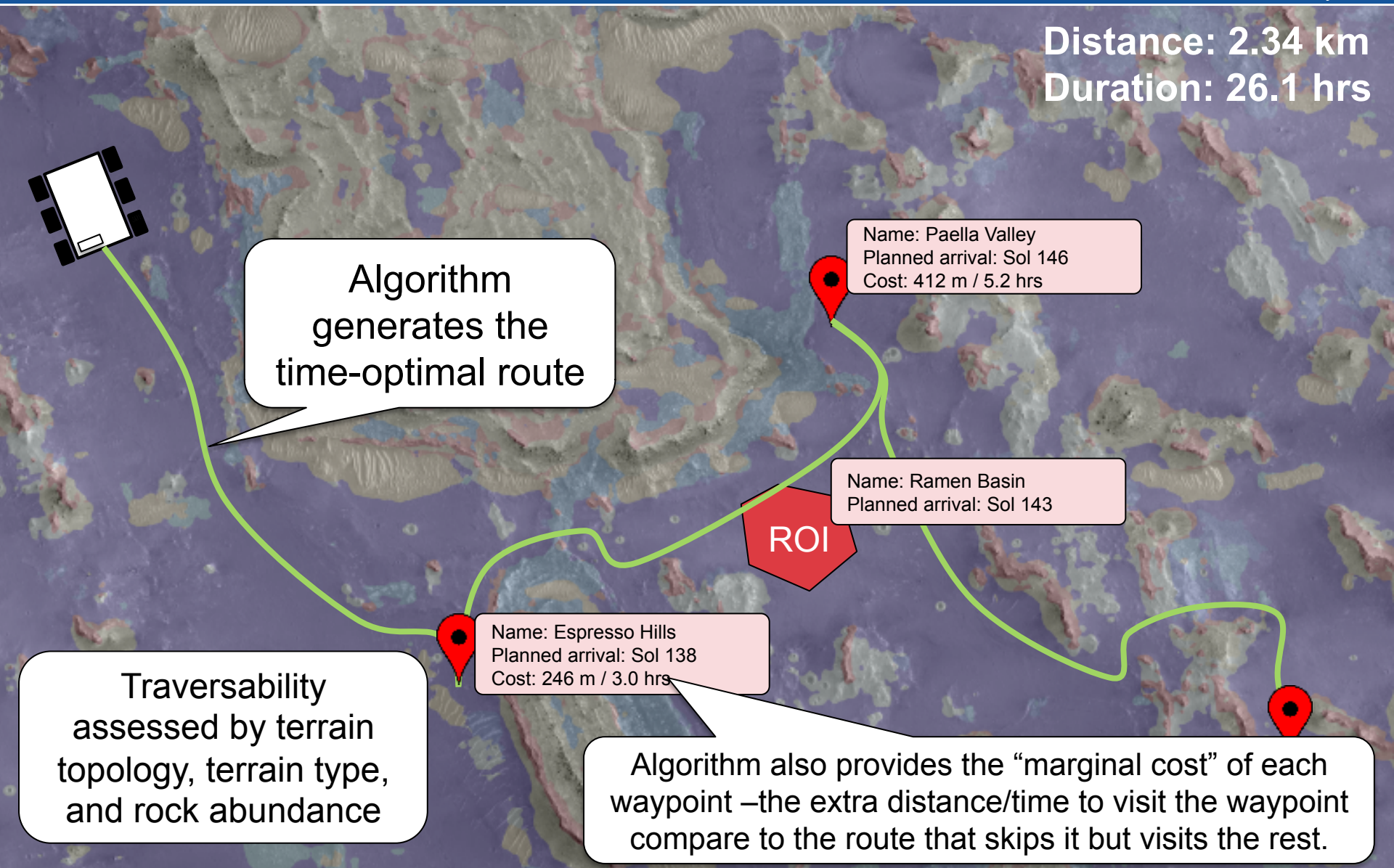
Extension for Strategic Planning



Example on NE Syrtis. Colors represent terrain types identified by the automated terrain classifier.

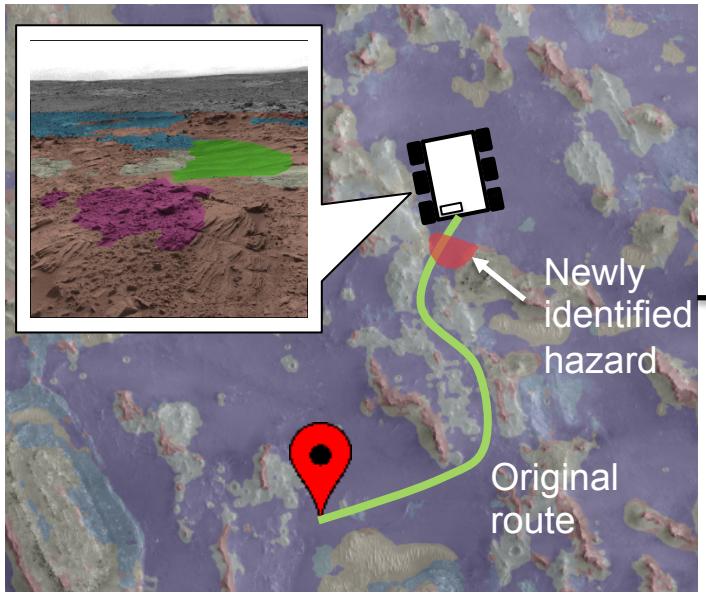
Extension for Strategic Planning



Example on NE Syrtis. Colors represent terrain types identified by the automated terrain classifier.

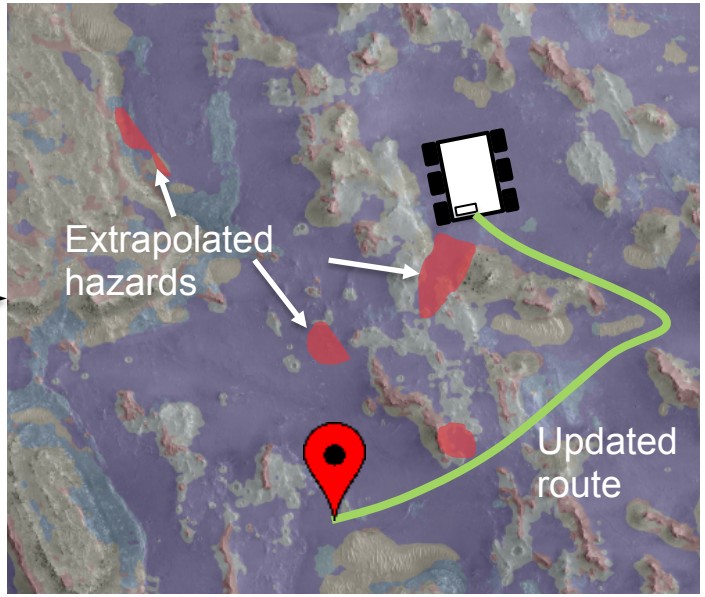
Constant Update of Traversability Assessment

- Adapts to new observations and updates traversability assessment throughout the surface operation
- Learn from local observation and apply the updated knowledge globally
  - E.g., If a new hazardous terrain type is observed from rover imageries, identify the regions that have similar terrain features on HiRISE and update the traversability assessment of the regions



Unexpected terrain observed by rover

- Re-train classifier
- Update traversability assessment
- Update route



Updated strategic route

Conclusions

- The mission success of M2020 is more contingent on surface mobility than MSL
- Developed MTTT (Mars Twenty Twenty Traversatility) tools that takes HiRISE images as inputs, and evaluates the CDF of driving time/distance to visit ROIs
- MTTT consists of
  - Automated terrain classification
  - Automated rock detection and CFA estimatin
  - DEM & slope map generation
  - Multi-ROI route planning w/ generalized TSP
- Performed preliminary analysis on the eight candidate landing sites for M2020
- Discussed future extension to strategic route planning

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