



# Autonomous Soil Assessment System: A data-driven approach to planetary mobility hazard detection

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# Operations, Autonomy, Intelligence

Mission Control Space Services was established in 2015 with the goal of developing *software solutions to operate and automate space robotic assets* – both government and private. Combining expertise in space robotics, planetary science, machine learning and machine vision to create new value in downstream space exploration applications.

NASA-JPL



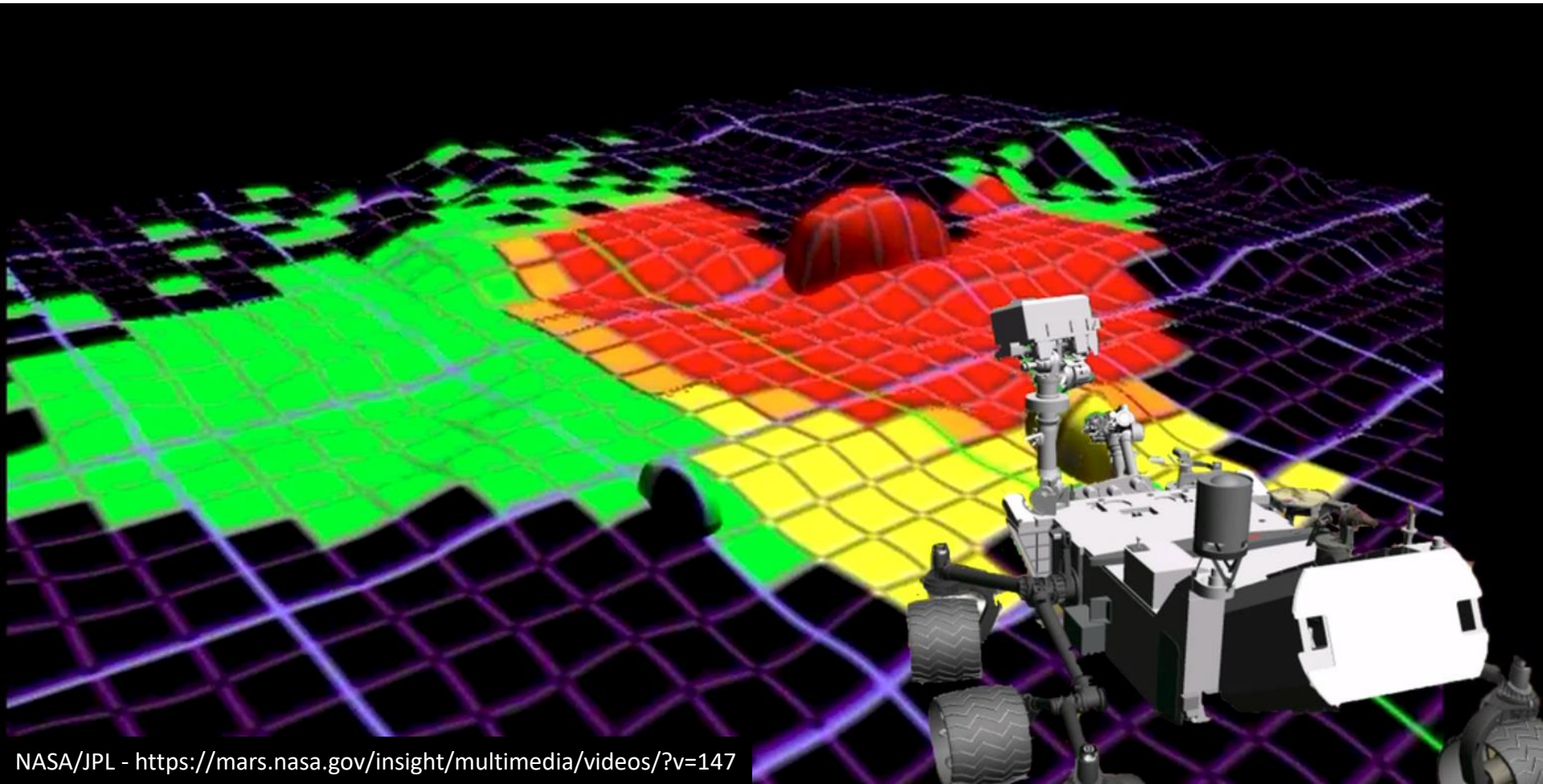
# Operations, Autonomy, Intelligence



- Lean start-up of **multidisciplinary** space professionals
- Strong heritage in **space flight** mission operations, **academic** research, **analogue** deployments and **rover technology development** for CSA
- **Staff of 12** plus external advisors
- Located on **Carleton University** campus with strong research ties to **aerospace engineering** department

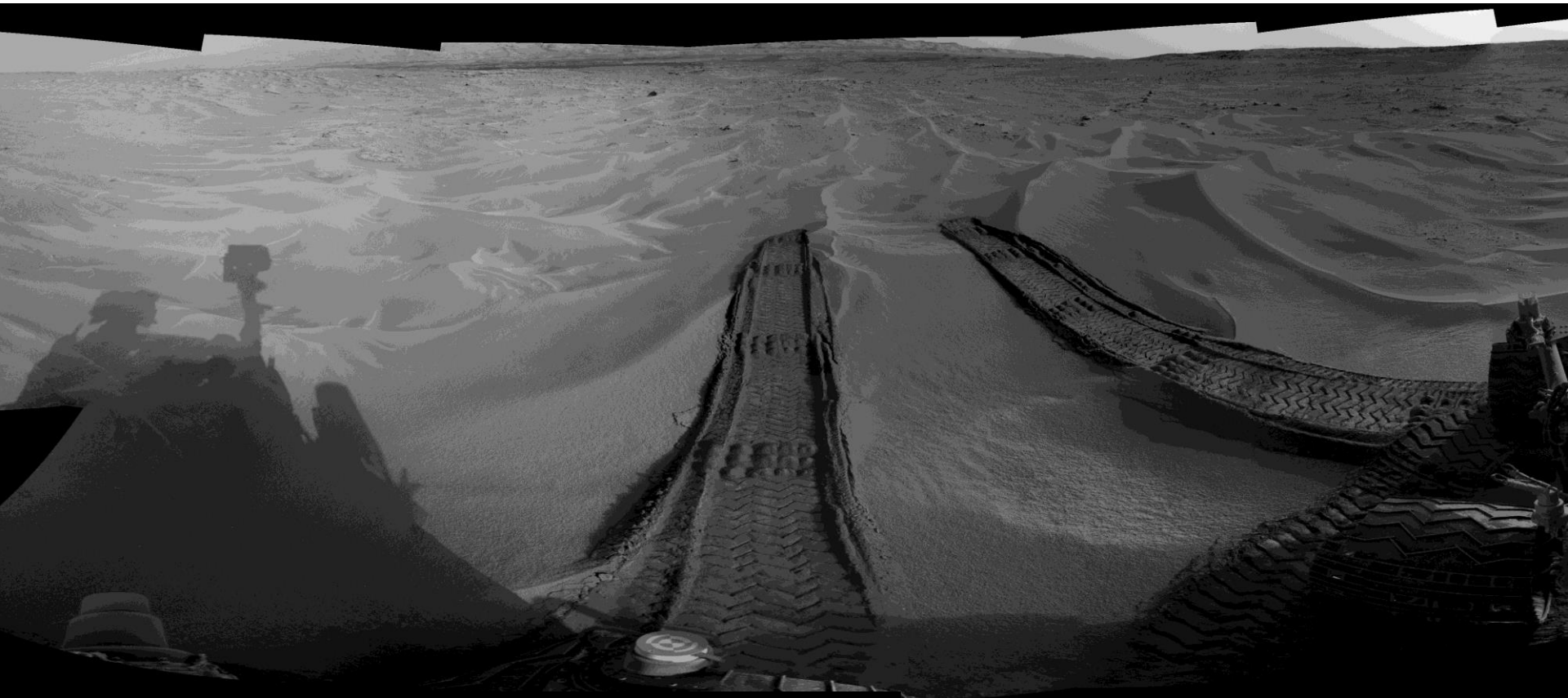
April 26, 2018

# Planetary Mobility Challenges



# Planetary Mobility Challenges

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# Autonomous Soil Assessment System

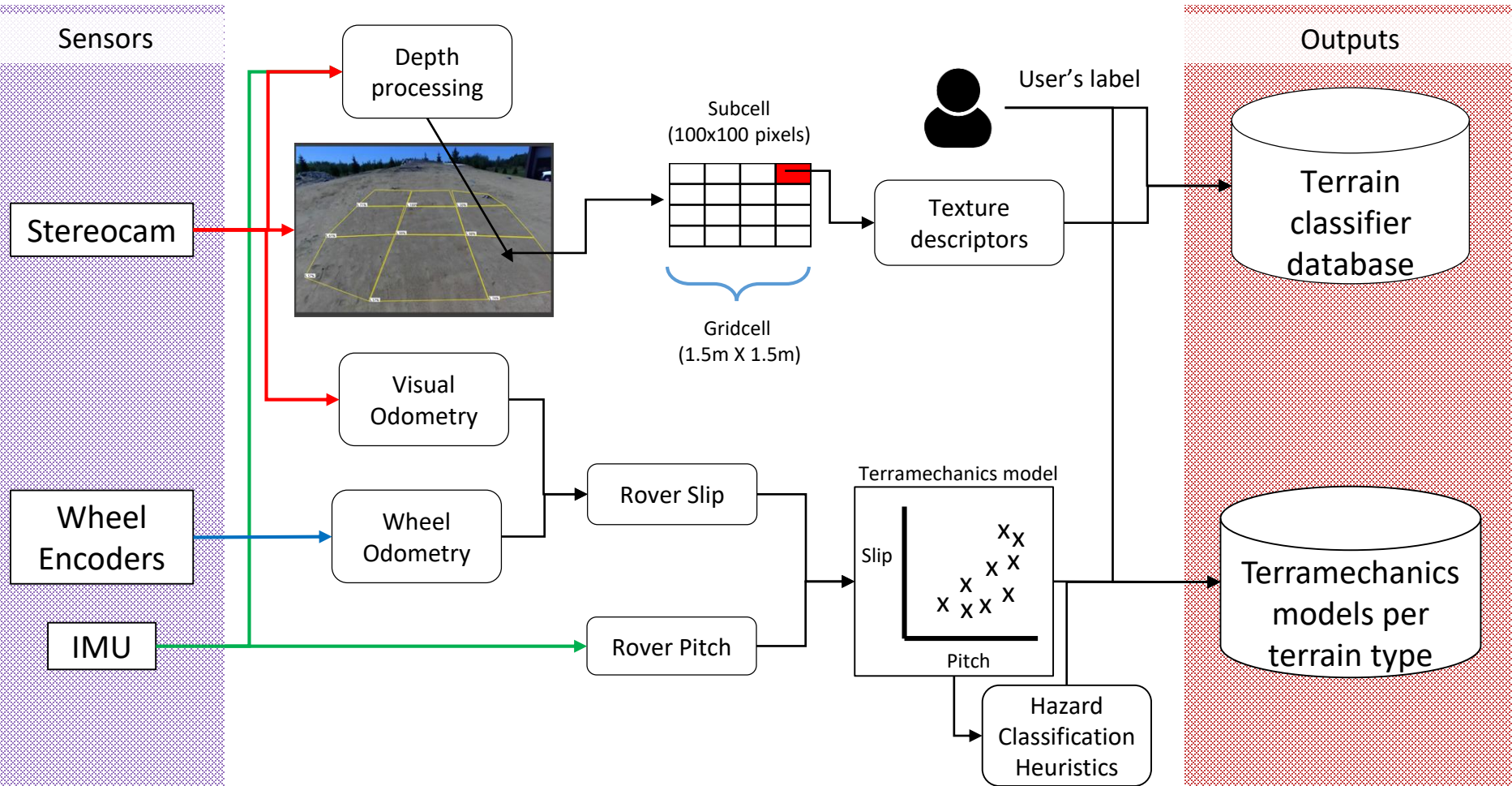
Detect Hazards  
[Non-Geometric]

Real-Time,  
Data-Driven

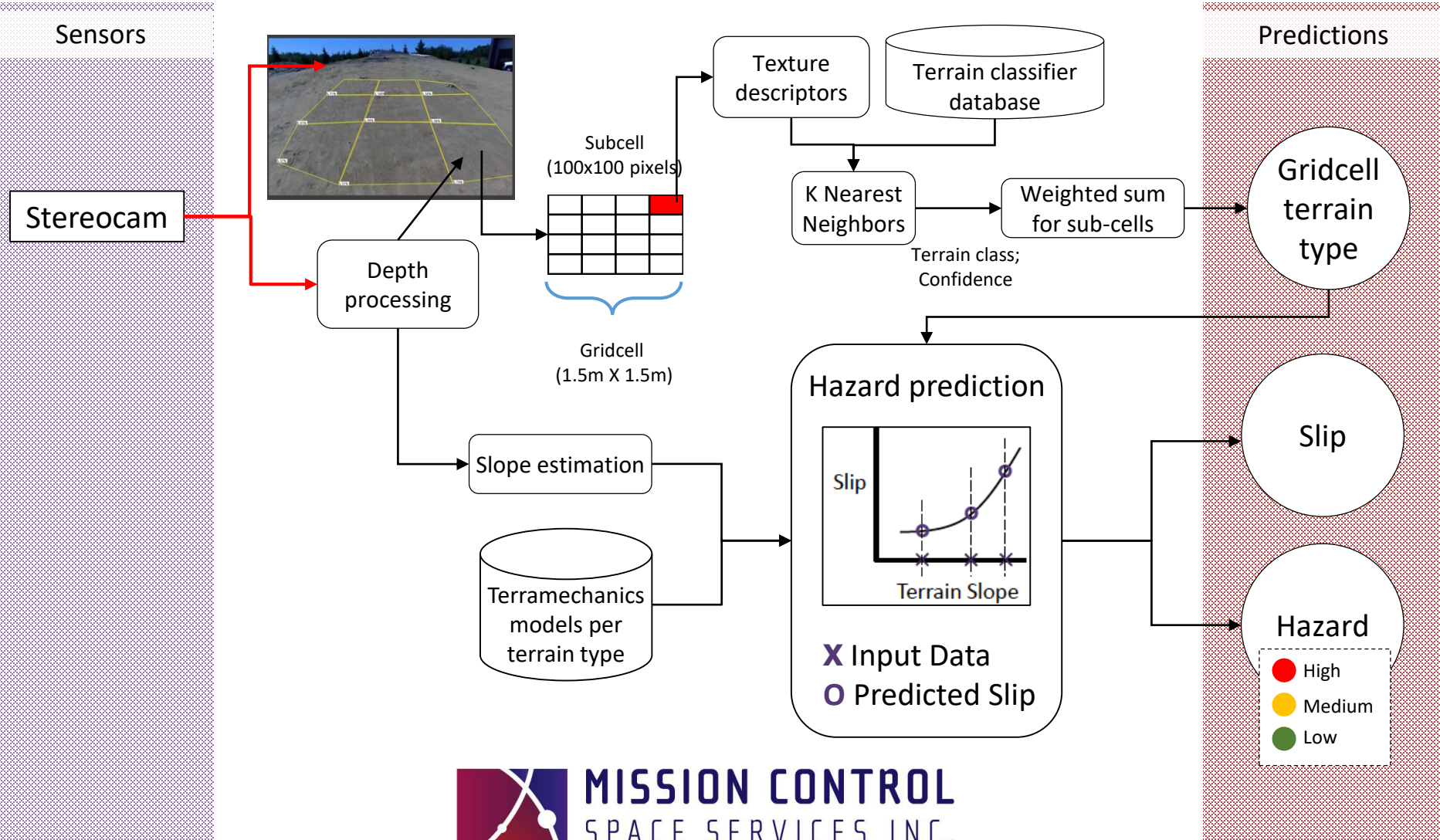
Software  
Payload

Rover  
Agnostic

# Training Phase



# Prediction Phase





# Demo at Canadian Space Agency



**Forward Camera**

**Cell Info**

Slope:	19°
Terrain Type:	Gravel
Confidence:	87%
Train	
Predicted Slip:	16%
Hazard Level:	0

**Rover Status**

Slip:	8.9%
Sinkage:	1.4 cm
Pitch:	14.4°
Motor Current - L:	1.6 A
Motor Current - R:	1.6 A
Distance from Origin:	18.5m
Reset Origin	

Enable Terramechanics Model Training  Sinkage View

TM Training Rover Status

**Telemetry**

Data Selection: Terramechanics Model

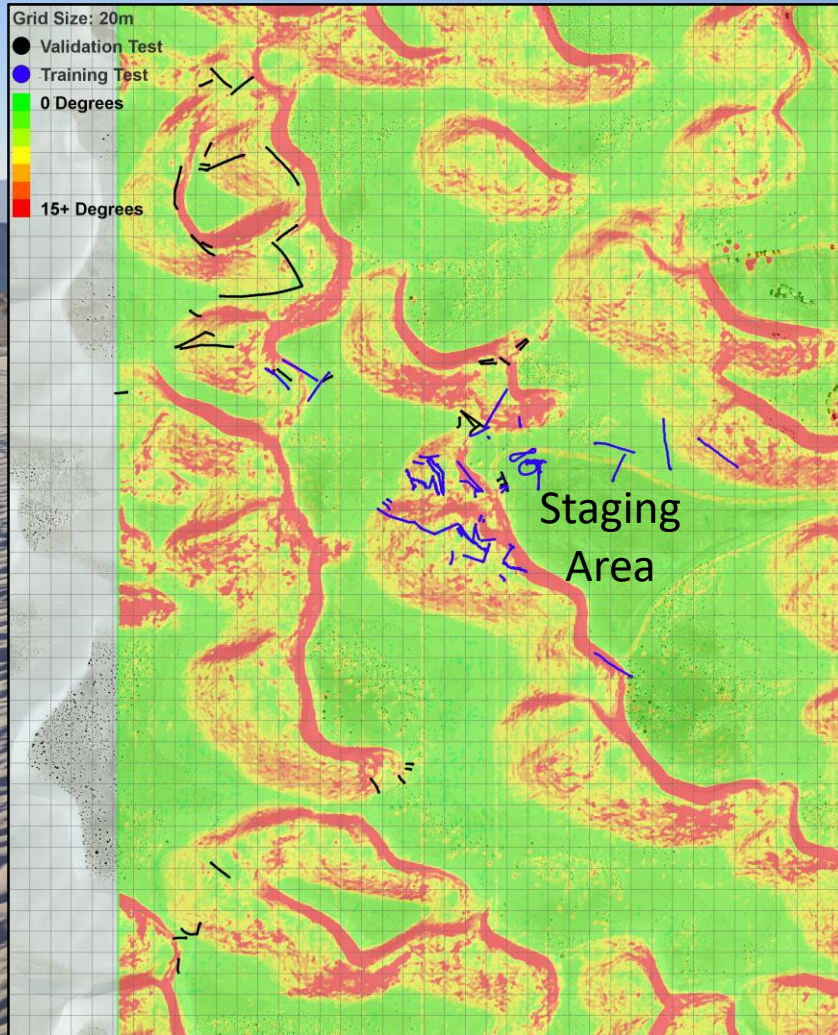
Terrain Type: Gravel

Highlight Training Data

Highlight Queue Data

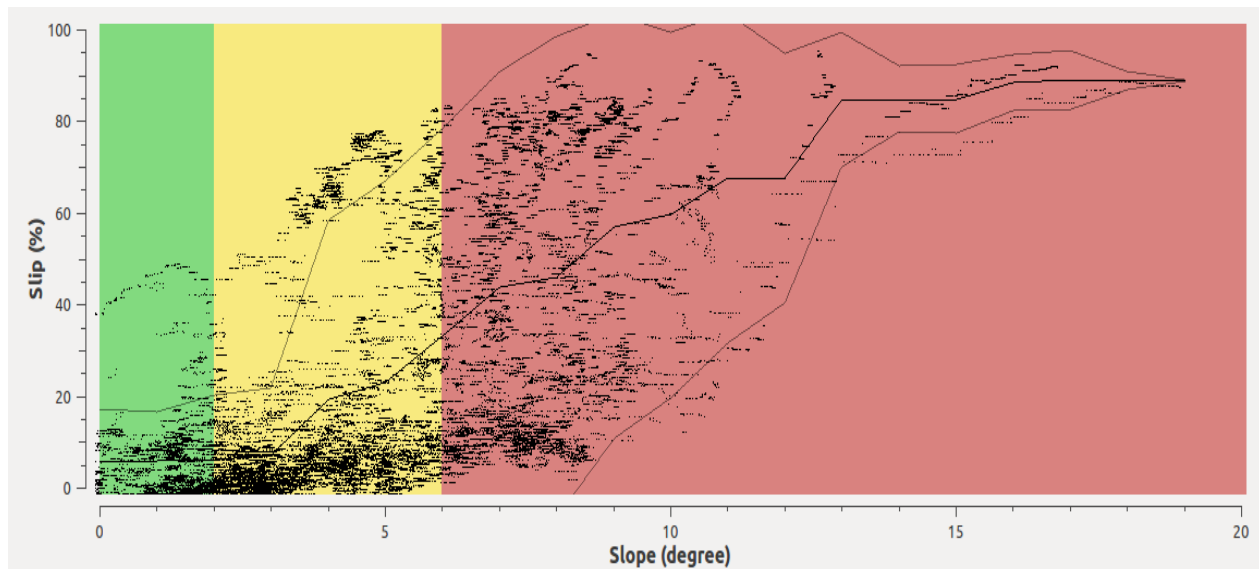
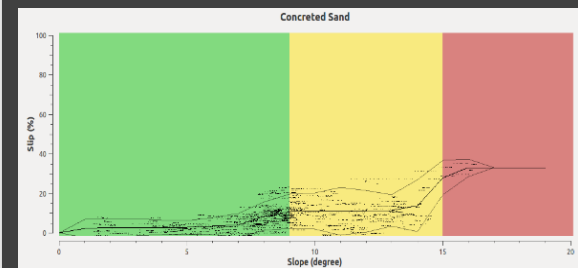
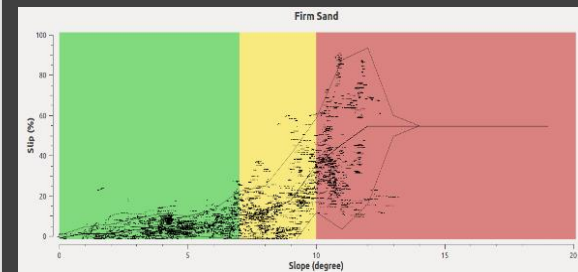
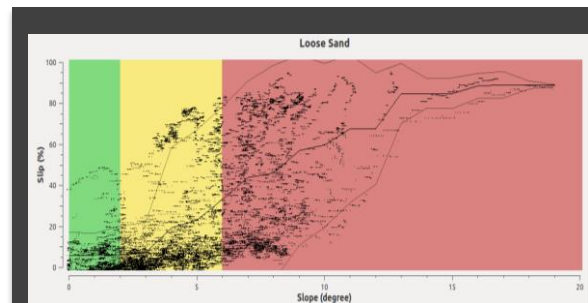
The telemetry graph plots Predicted Slip (%) on the y-axis (0 to 120) against Slope (degrees) on the x-axis (0 to 50). The graph is divided into three color-coded regions: green (0-20 degrees), yellow (20-25 degrees), and red (25-50 degrees). A line graph shows the predicted slip percentage, which remains low (around 10%) in the green and yellow regions and then rises sharply to approximately 100% in the red region. A scatter plot of data points follows the same trend.

# White Sands National Monument



# Terramechanics Models

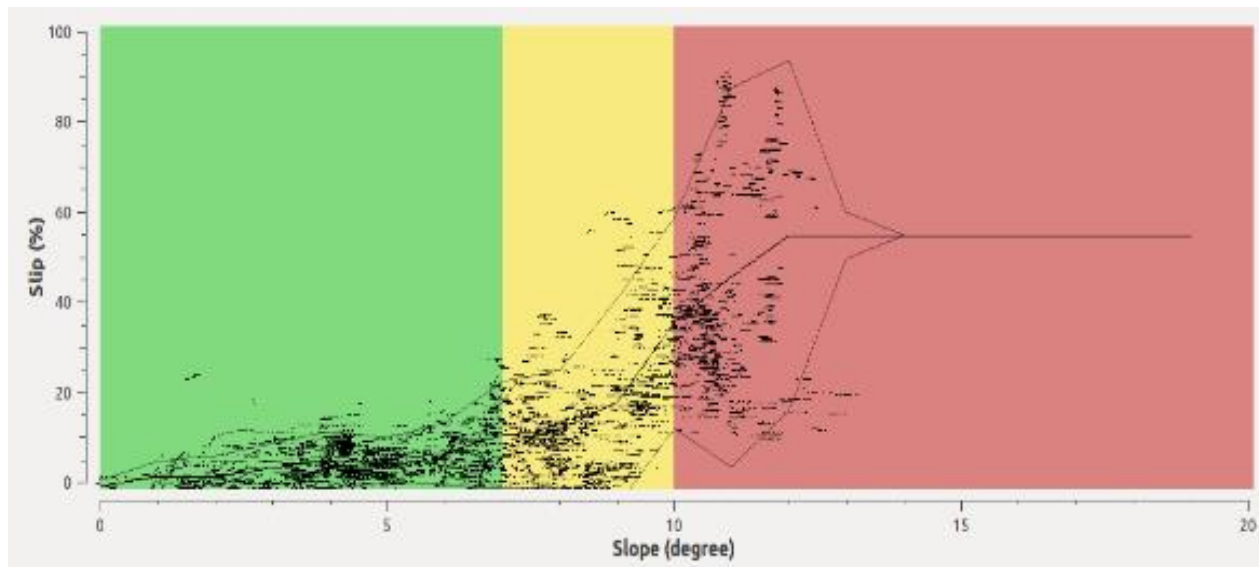
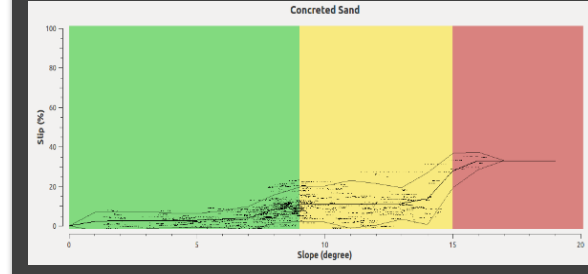
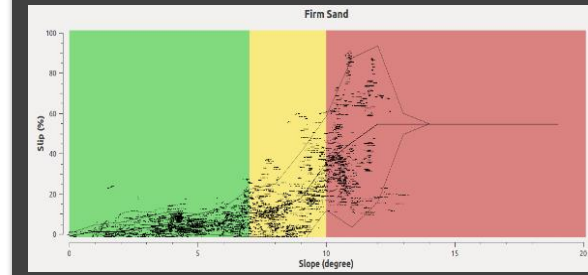
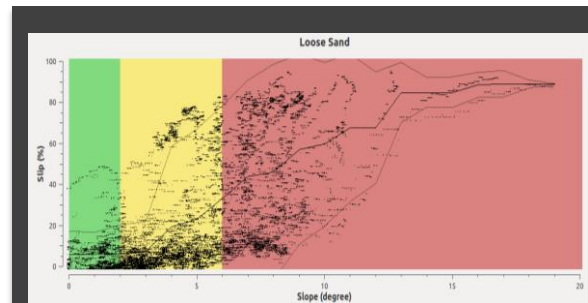
## Loose unconsolidated sand



Top: Loose unconsolidated sand  
Mid: Firm unconsolidated sand  
Bot: Cemented consolidated sand

# Terramechanics Models

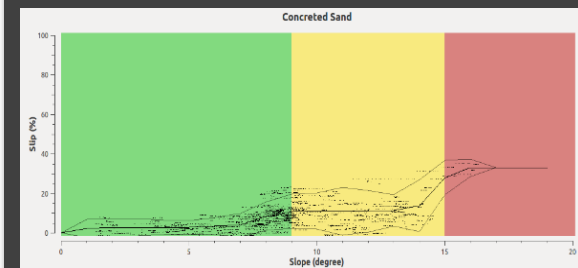
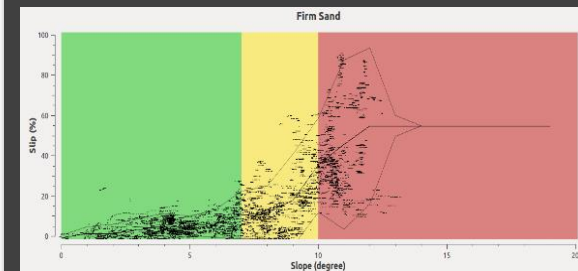
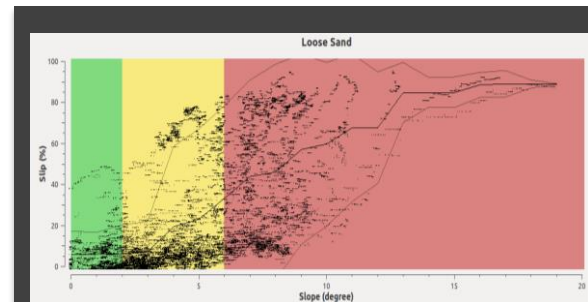
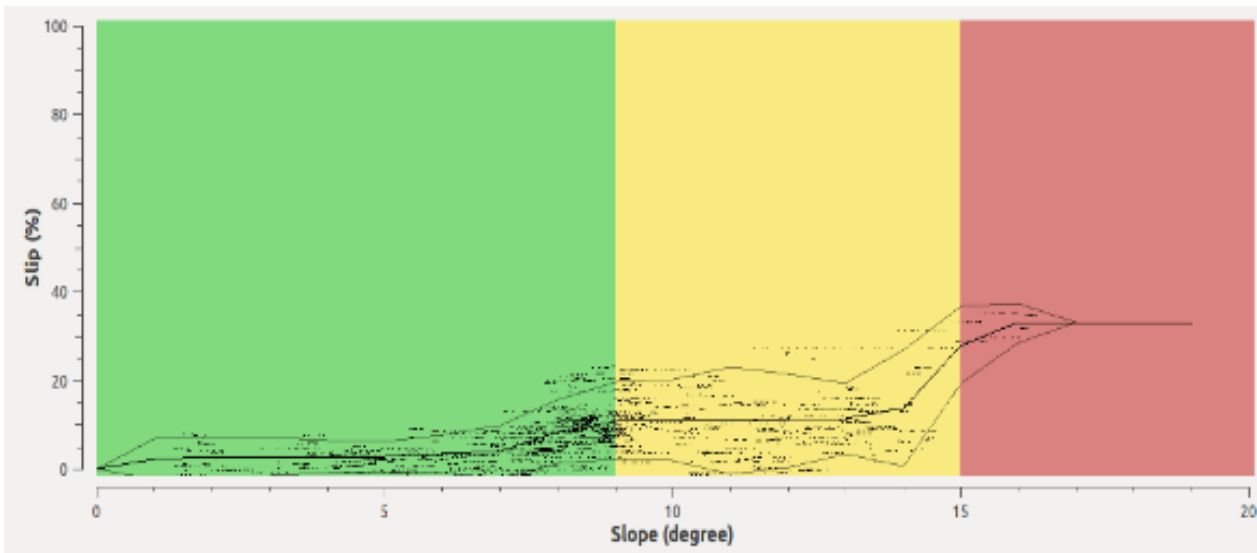
## Firm unconsolidated sand



Top: Loose unconsolidated sand  
Mid: Firm unconsolidated sand  
Bot: Cemented consolidated sand

# Terramechanics Models

## Cemented consolidated sand



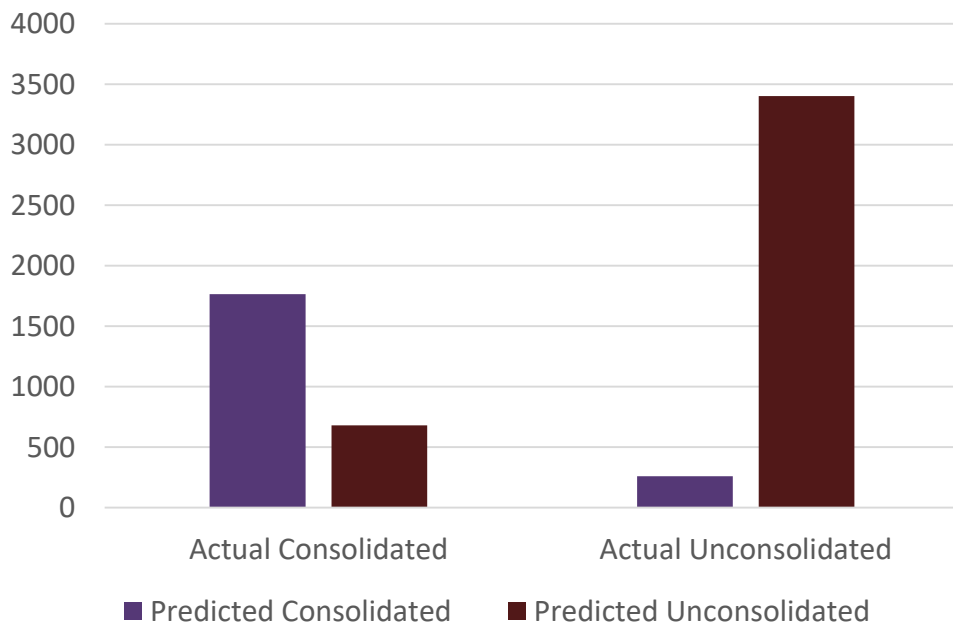
Top: Loose unconsolidated sand  
Mid: Firm unconsolidated sand  
Bot: Cemented consolidated sand

# Terrain Classifier Performance

- 2 Sand types considered
- Loose and firm unconsolidated sand were visually indistinguishable – even by humans!
- Gravel, rocky and sand also successful in past test campaigns at CSA mars yard

<b>Test Samples</b>	<b>6106</b>
<b>Accuracy</b>	<b>85%</b>
<b>Misclassification Rate</b>	<b>15%</b>
<b>Precision</b>	<b>83%</b>

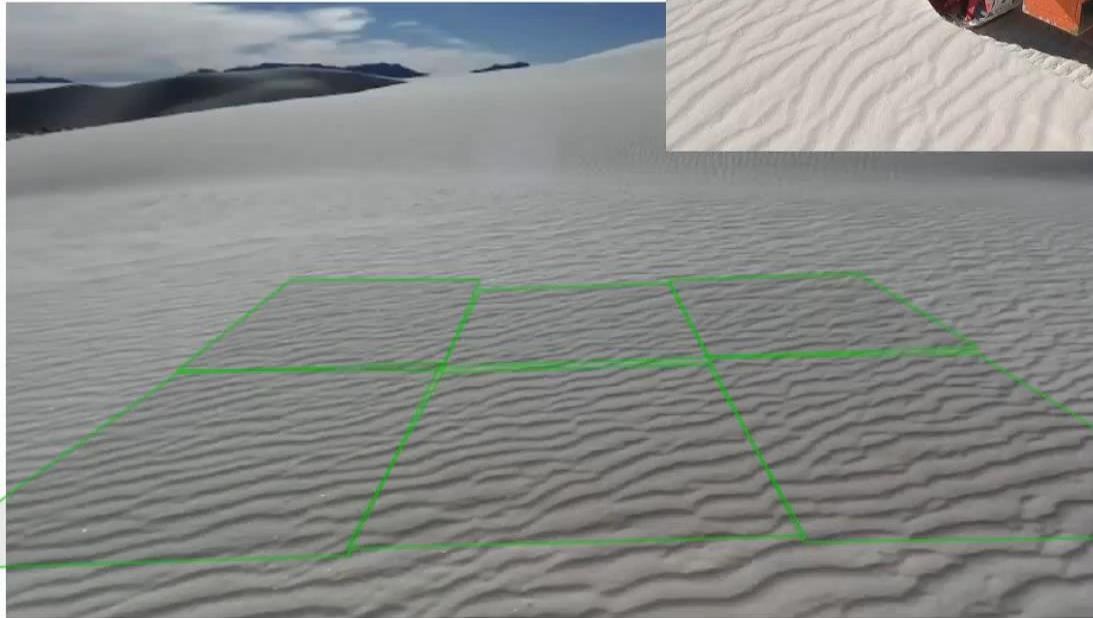
		Predicted	
	N = 6106	Consolidated	Unconsolidated
Actual	Consolidated	1764	680
	Unconsolidated	259	3403



# Slip and Hazard Prediction Performance



Stereocam View



### Cell Info

Cell Display



Slope: 0  
Terrain Type: Bedrock  
Predicted Slip: 0%  
Hazard Level: 0

### Rover Status

Slip: nan%  
Sinkage: 0.0 cm  
Pitch: 1.7°  
Motor L: 0.0A  
Motor R: 0.0A  
Distance: 326.3m

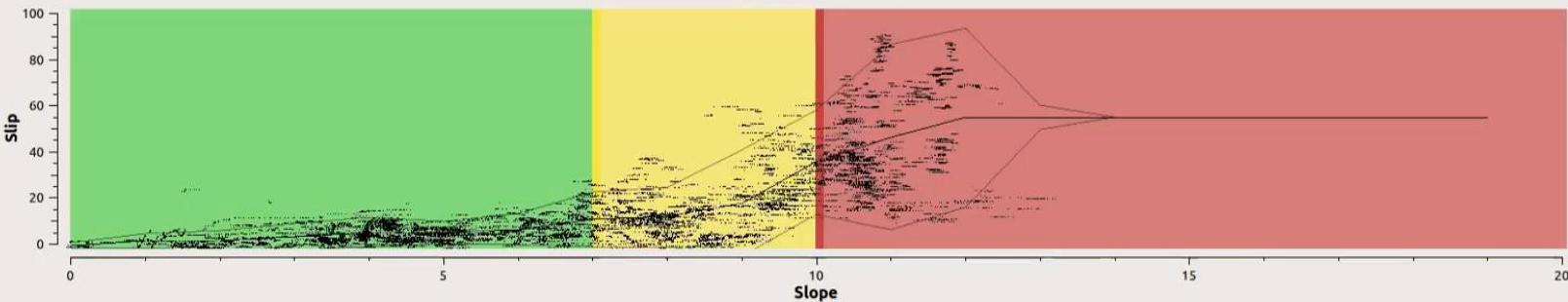


Sinkage View

TM Training Rover Status

### Telemetry

### Terramechanics



Data Selection: Terramechanics

Terrain Type: Sand

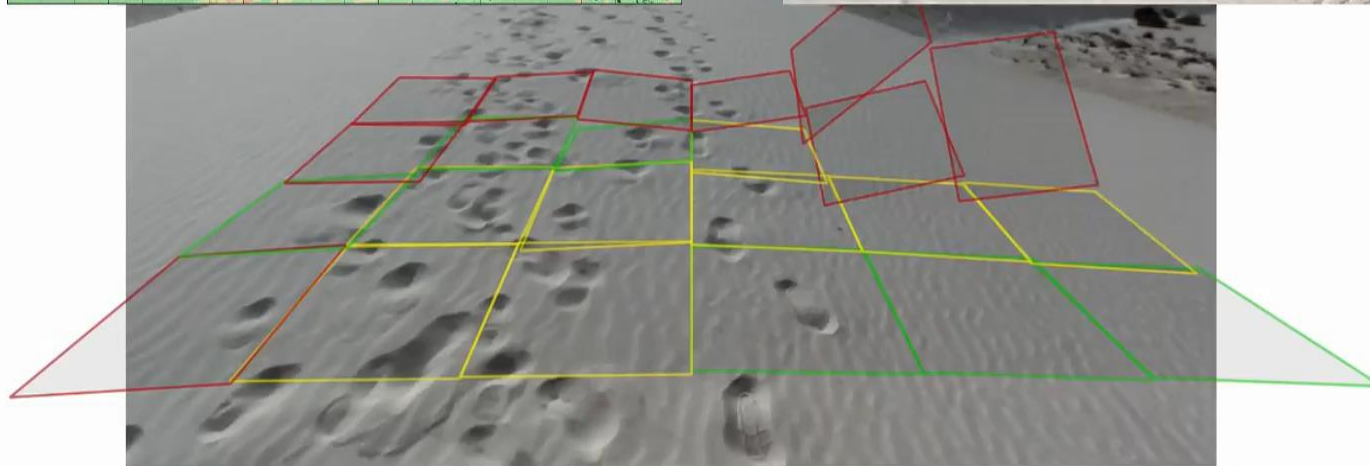
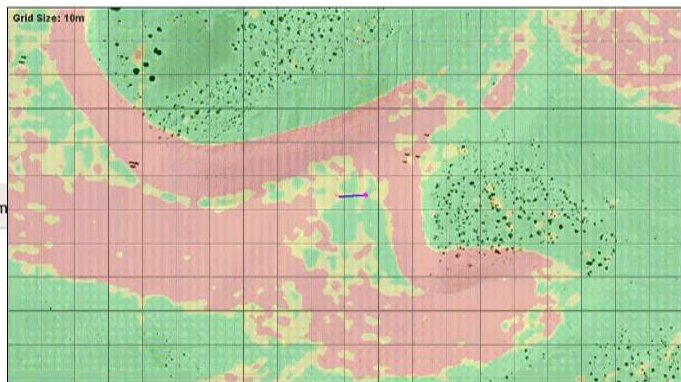
High Slip Bias Disabled

Request Raw Data

Deviation mult: 2.00

High Slip Bias: 0°

# High-Slip Bias Demo 1



### Cell Info

Cell Display

Slope: 9°  
Terrain Type: Sand  
Predicted Slip: 18%  
Hazard Level: 2

### Rover Status

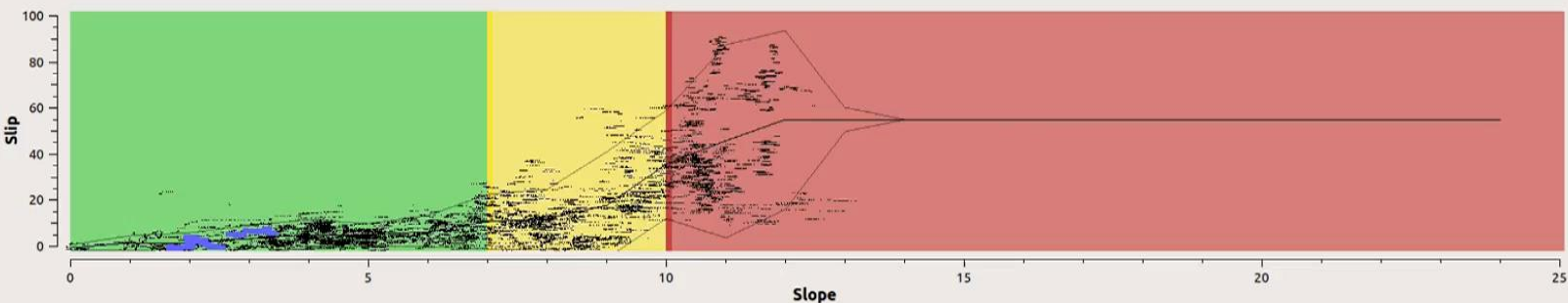
Slip	5.6%
Sinkage	0.0 cm
Pitch	3.4°
Motor L	0.8A
Motor R	0.8A
Distance	17.8m

Sinkage View

TM Training | Rover Status

## Telemetry

### Terramechanics



Data Selection: Terramechanics  
Terrain Type: Sand

**High Slip Bias Enabled**

Request Raw Data

Deviation mult: 2.00  
High Slip Bias: 0.0°



# High-Slip Bias Demo 2 [sled test]



Stereocam View



## Cell Info

Cell Display



Slope: 0  
Terrain Type: Bedrock  
Predicted Slip: 0%  
Hazard Level: 0

## Rover Status

Slip nan%  
Sinkage 0.0 cm  
Pitch 2.0°  
Motor L 0.0A  
Motor R 0.0A  
Distance 1.2m

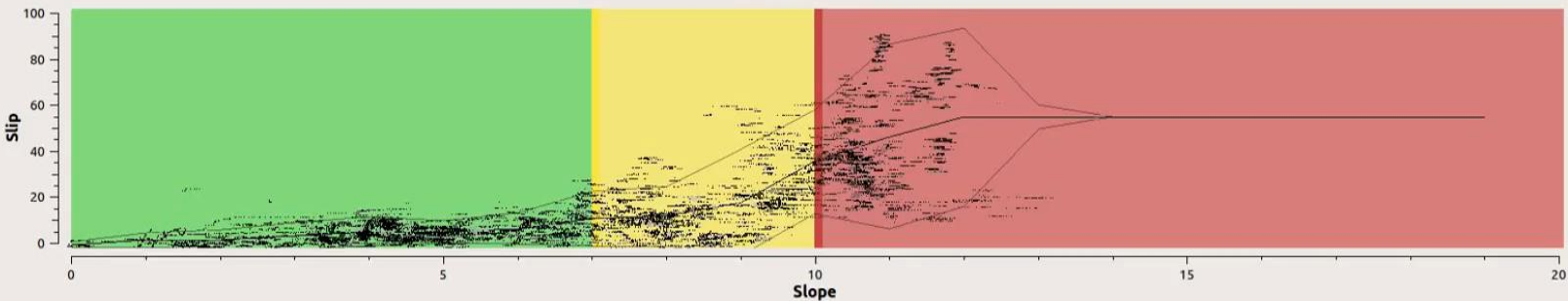


Sinkage View

TM Training Rover Status

## Telemetry

### Terramechanics



Data Selection Terramechanics

Terrain Type Sand

High Slip Bias Enabled

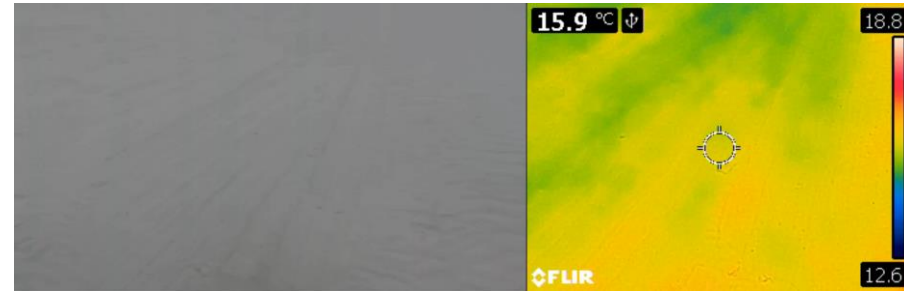
Request Raw Data

Deviation mult 2.00

High Slip Bias 0°

# Future Work

- Terrain classification
  - Thermal IR imagery
  - Deep learning (Convolutional Neural Networks)
- Terramechanics
  - Heterogeneous terrain
  - Wheel-scale prediction
  - Add more dimensionality
    - wheel sinkage from a wheel-facing hazcam





# Operations, Autonomy, Intelligence

How can we help YOU navigate the NewSpace landscape?

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