National Aeronautics and Space Administration

Mission Design for the Lunar Pallet Lander

Scott Craig/NASA Marshall Space Flight Center/EV42

Authors

- Scott Craig, Aerospace Engineer, Guidance Navigation and Mission Design Branch, NASA MSFC
- James Holt, Pathways Intern, Guidance Navigation and Mission Design Branch, NASA MSFC
- Juan Orphee, Aerospace Engineer, Guidance Navigation and Mission Design Branch, NASA MSFC
- Mike Hannan, Team Lead, Control Systems Branch, NASA MSFC

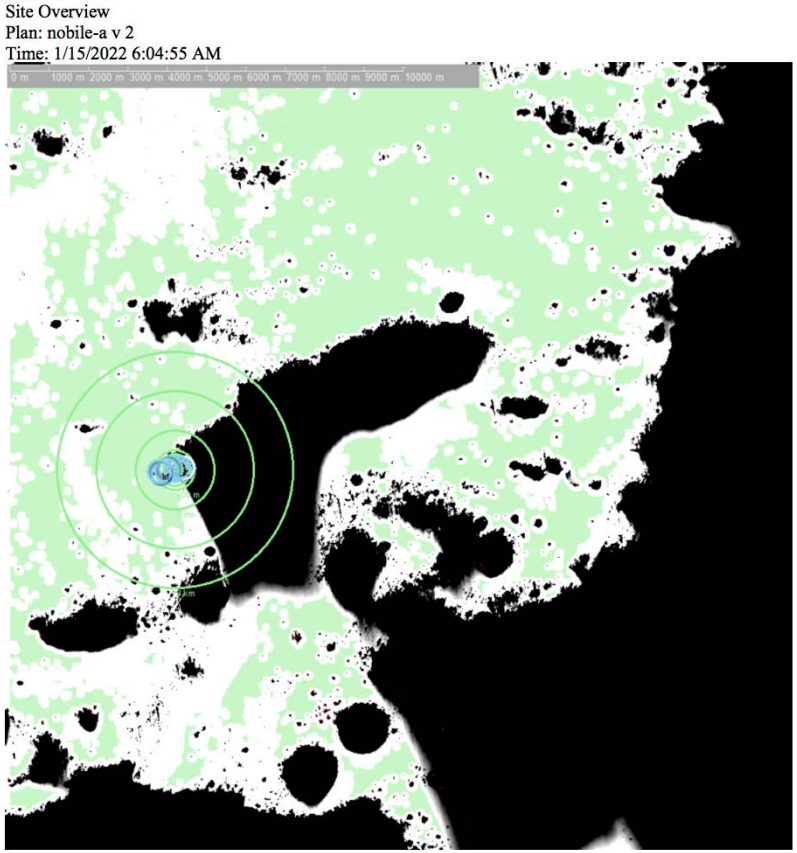
Introduction

- MSFC led program to develop a small lunar lander
- Targeting a 300 kg payload of either a rover or static science instruments
- Second main objective of showing precision autonomous landing capability on the Moon
- Covers work starting with the SLS variant and ending with the current configuration on an EELV

Specific Resource Prospector Landing Sites & Traverses

Courtesy of Ryan Vaughan, NASA ARC

Snapshot of a N. Nobile Candidate



- Within each candidate area RP has examined many specific candidate landing sites and traverses (example of a N. Nobile candidate landing site shown to left)
- Specific landing site coordinates for each site given below. NOTE: These are individual examples of any number possible landing sites and traverses in these areas
- Elevation is in meters, and landing time in UTC

Site	Lat	Lon	Elevation*	Landing Time
N. Shoemaker	-87.2407	59.1363	321.1781	1/18/2022 5:26:27 AM
N. Nobile	-85.0642	33.2857	5949.758	1/15/2022 2:50:58 PM
Hermite A	87.6105	-45.7969	-259.7765	9/18/2021 7:44:18 AM
Erlanger	86.7532	30.7537	-569.8153	9/25/2020 6:59:20 PM

*from reference lunar radius, reference lunar radius=1737.4 km

SLS GR&A

- SLS EM-2 trajectory flown in Copernicus v4.4 from LEO insertion through the end of mission
  - Ascent to LEO insertion modeled by calling a database of ascent trajectories flown in POST
  - Due East ascent - 28.5 degree parking orbit inclination.

SLS Variant of LPL

- Two Star 37 motor configuration
  - First motor performs LOI, lander performs the cleanup burn
  - Second motor performs the braking burn, lander again cleans up burn and performs final descent
  - Lander also performs the descent initiation and any correction maneuvers required
  - Hot and Cold SRM's flown at 40 and 90 degrees F
    - Trajectory optimized for a 70 degree SRM
    - Hot and Cold SRM's require additional impulse from the lander for cleanup
    - No knowledge of SRM temperature other than in this temperature range

- SLS/MPCV trajectory optimized first
  - Maximizes CPL mass
  - RP trajectory optimized off the initial SLS/MPCV trajectory

- 500 km lunar parking orbit

- 10 km minimum perilune on descent orbit

- Point mass lunar model until descent with a 120 x 120 GRAIL gravity model

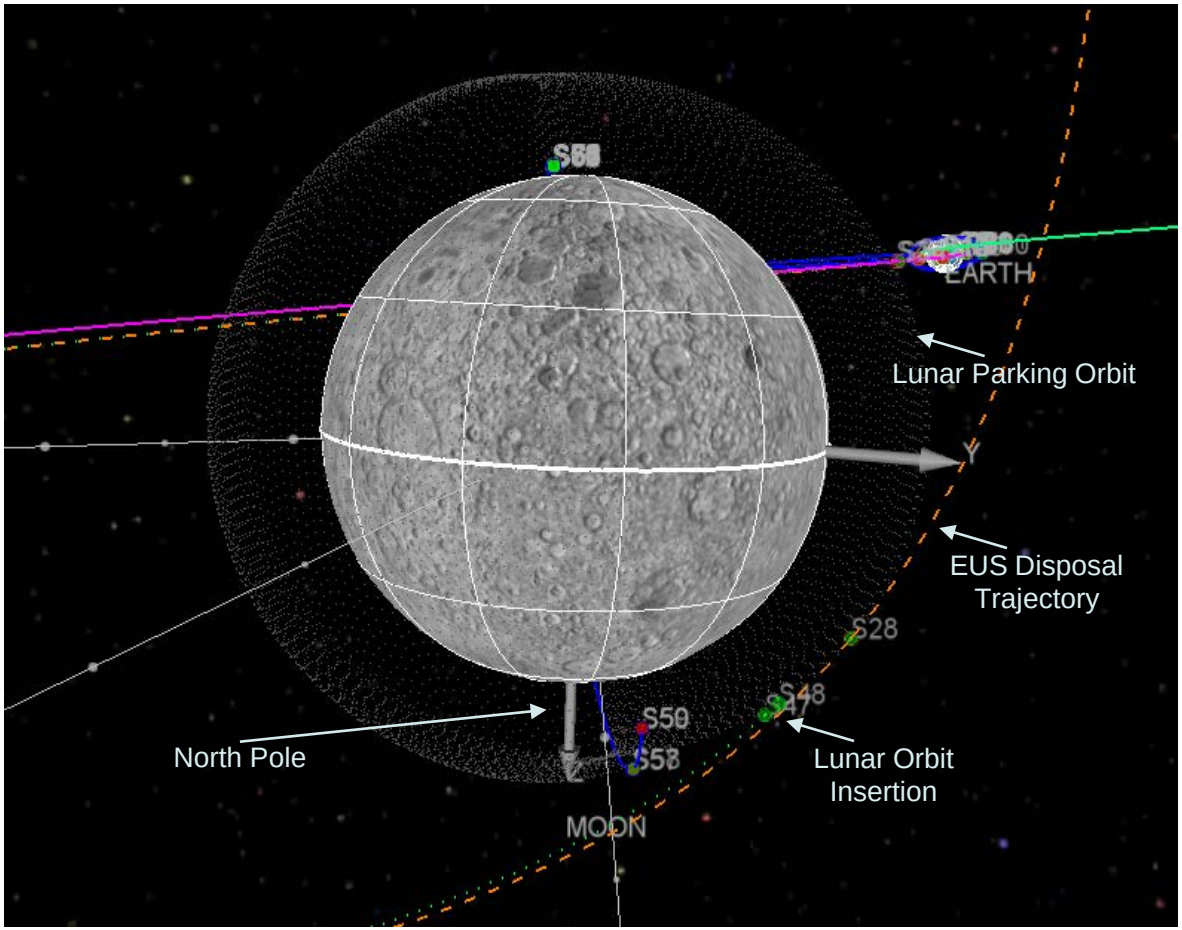
- Trajectory is backward propagated from the surface and connects with the SLS disposal trajectory.
  - N. Shoemaker landing site
    - Landing time corresponds well with launch time
    - More conservative delta-V wise than N. Nobile

- Single Launch Date Trajectory
- December 24, 2021
  - LOI insertion delta-V close to average on this launch date

LPL LOI

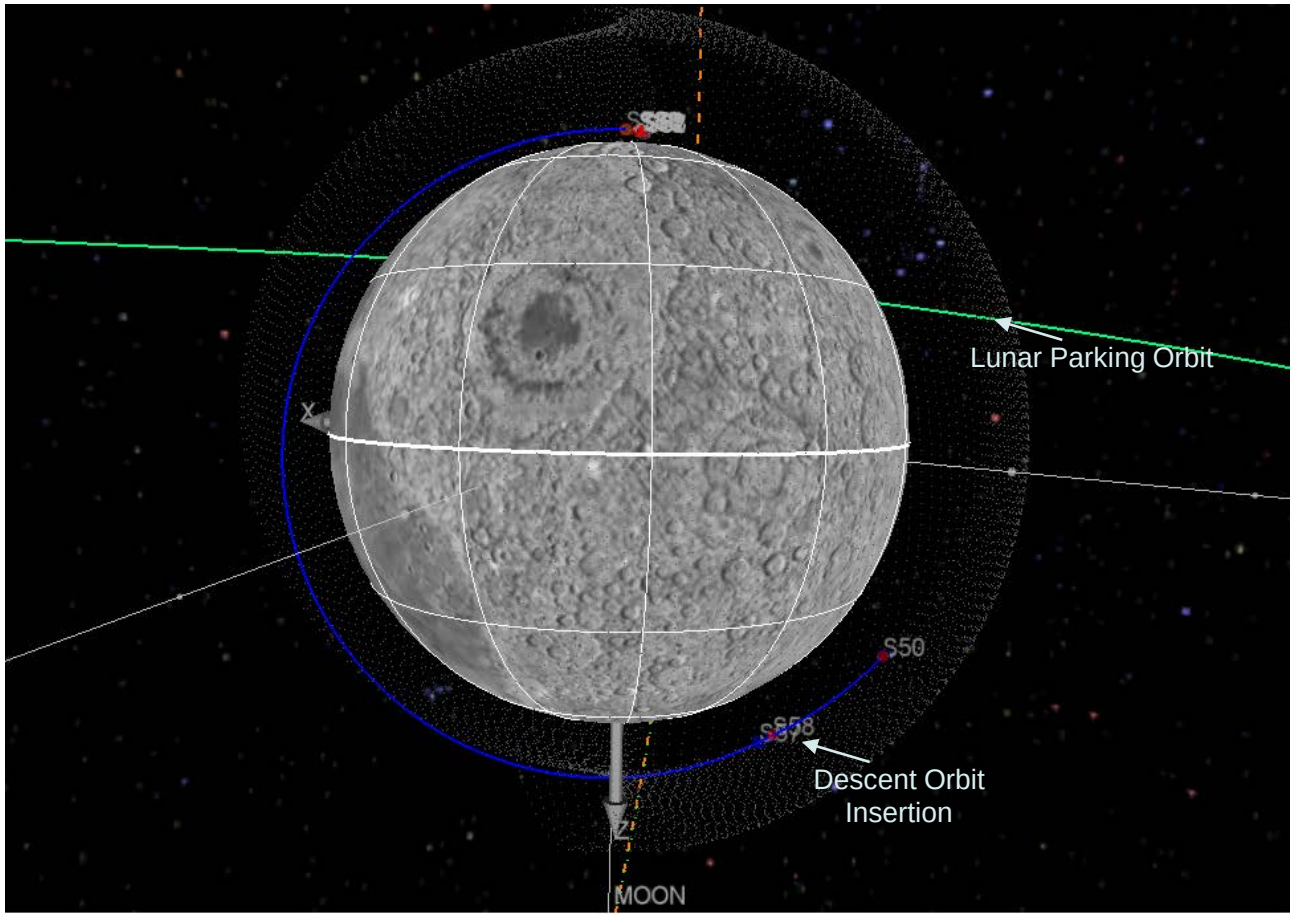
- North Pole pointing down, landing site at South Pole

- LOI performed by Star 37
  - 35 m/s bookkept for liquids to perform the solid dispersion cleanup and cover launch day variations
  - Different launch days require different LOI delta-V's due to geometry differences
  - 1 m/s bookkept for a separation burn



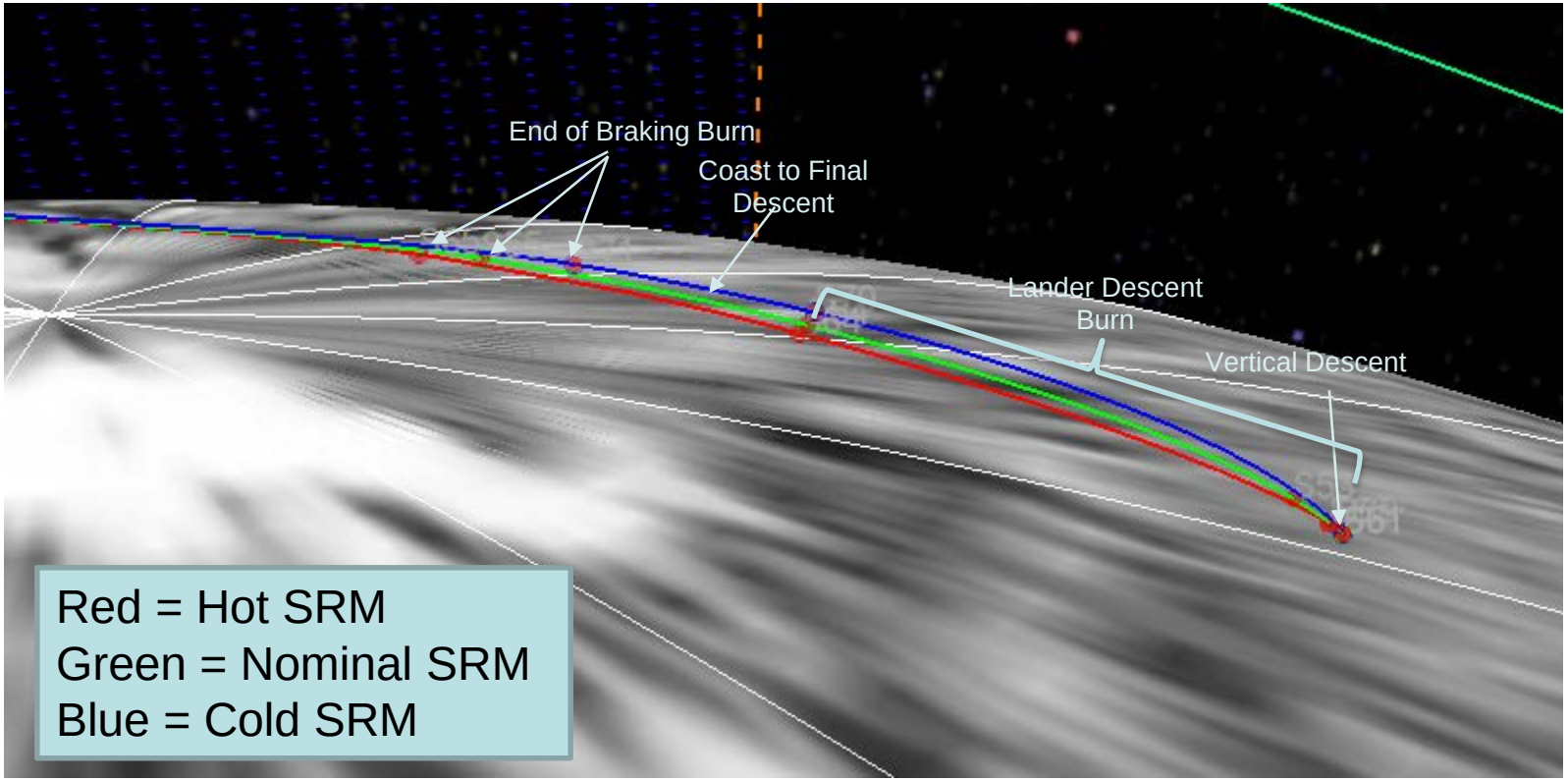
LPL DOI

- Image representative of actual trajectory
- Descent Orbit Insertion (DOI)
  - dV = 94.4 m/s



LPL Final Descent

Star 37 Temperature (deg F)	Descent dV required (m/s)
40	481.3
70	478.3
90	476.6

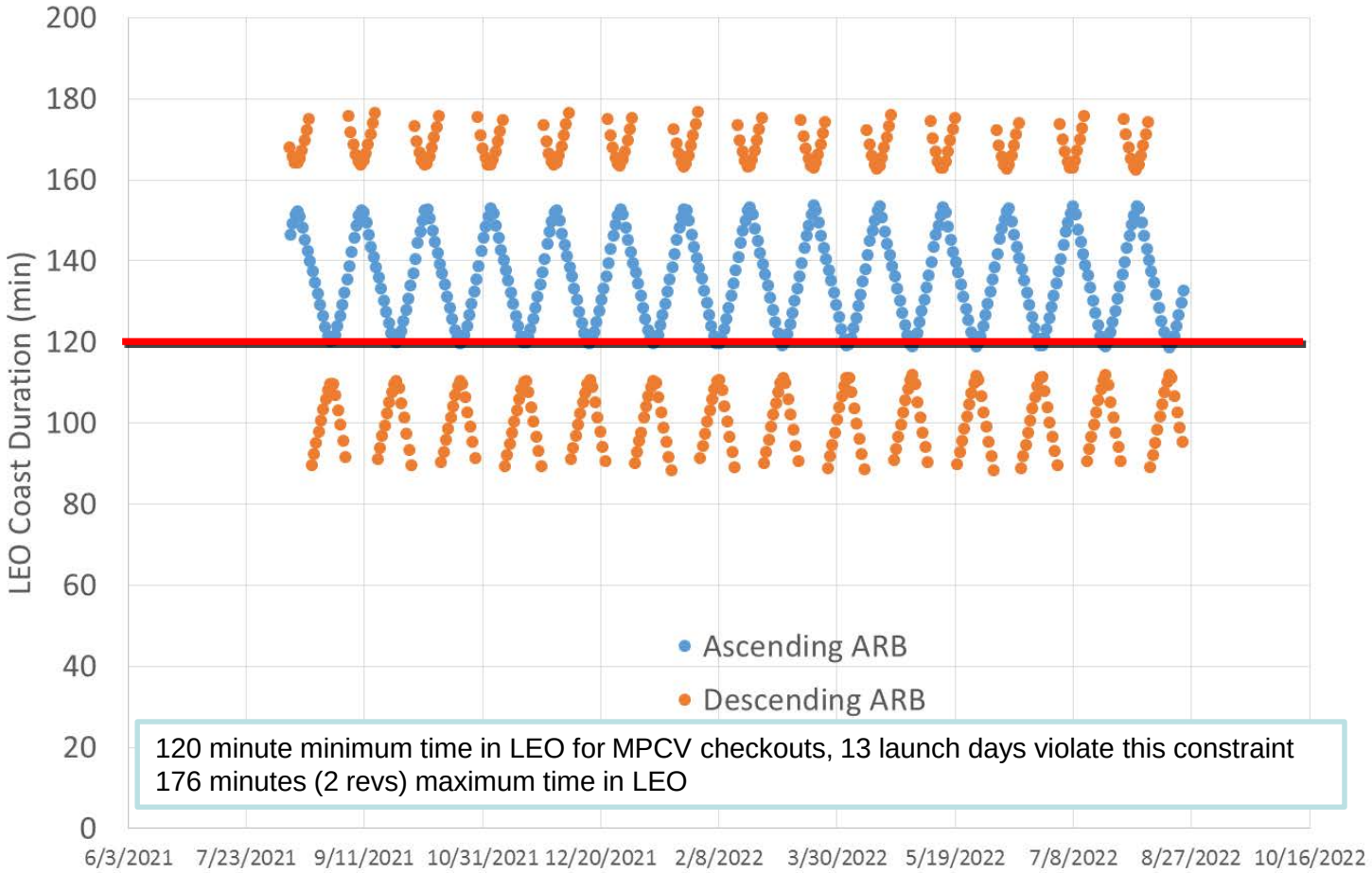


Performance Sweep

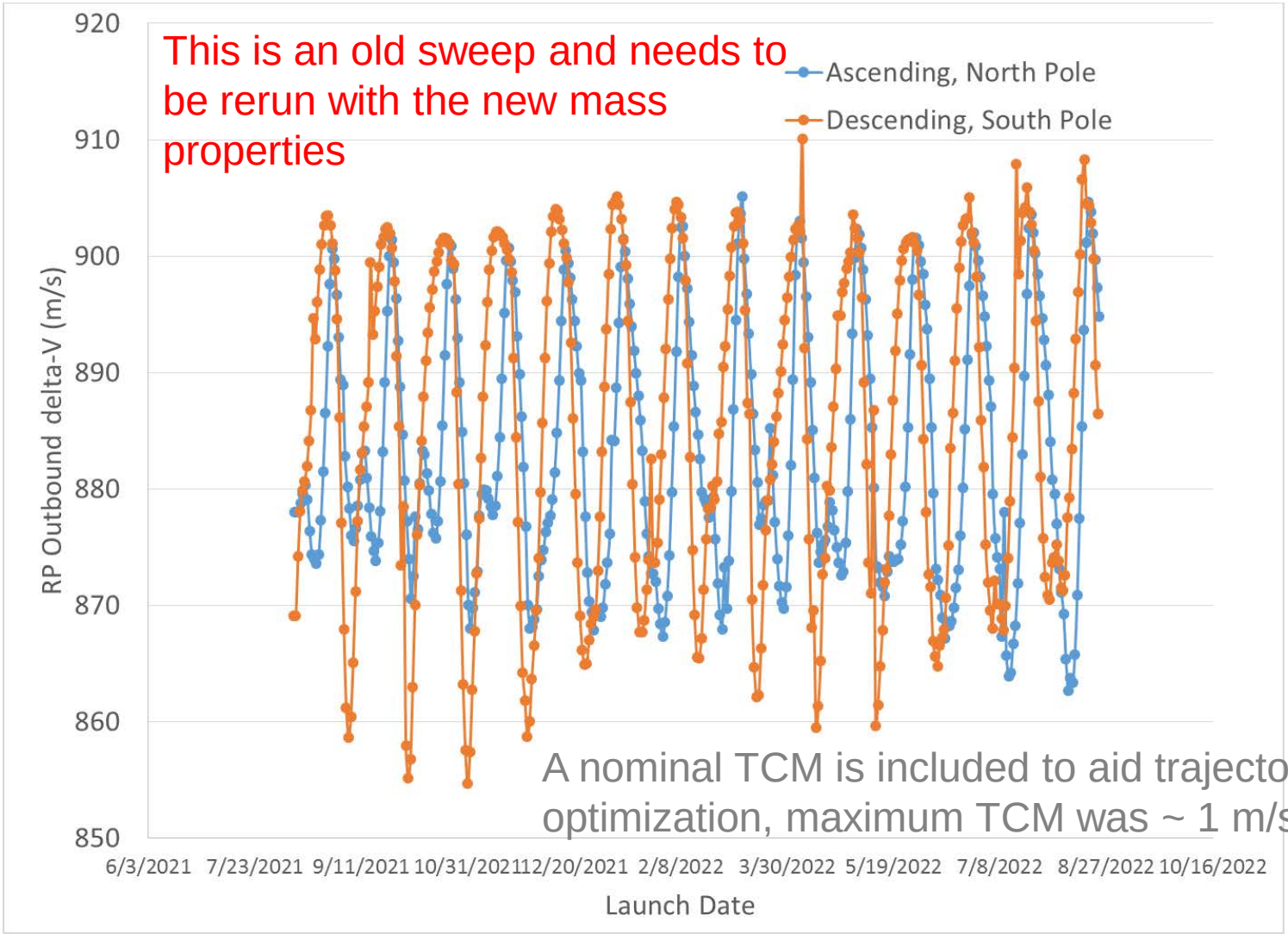
- Ascending ARB, North Pole lunar flyby
  - Starting August 10, 2021
  - Ending August 23, 2022
- Descending ARB, South Pole lunar flyby
  - Starting August 10, 2021
  - Ending August 23, 2022

- 732 total launch opportunities

SLS Launch Availability

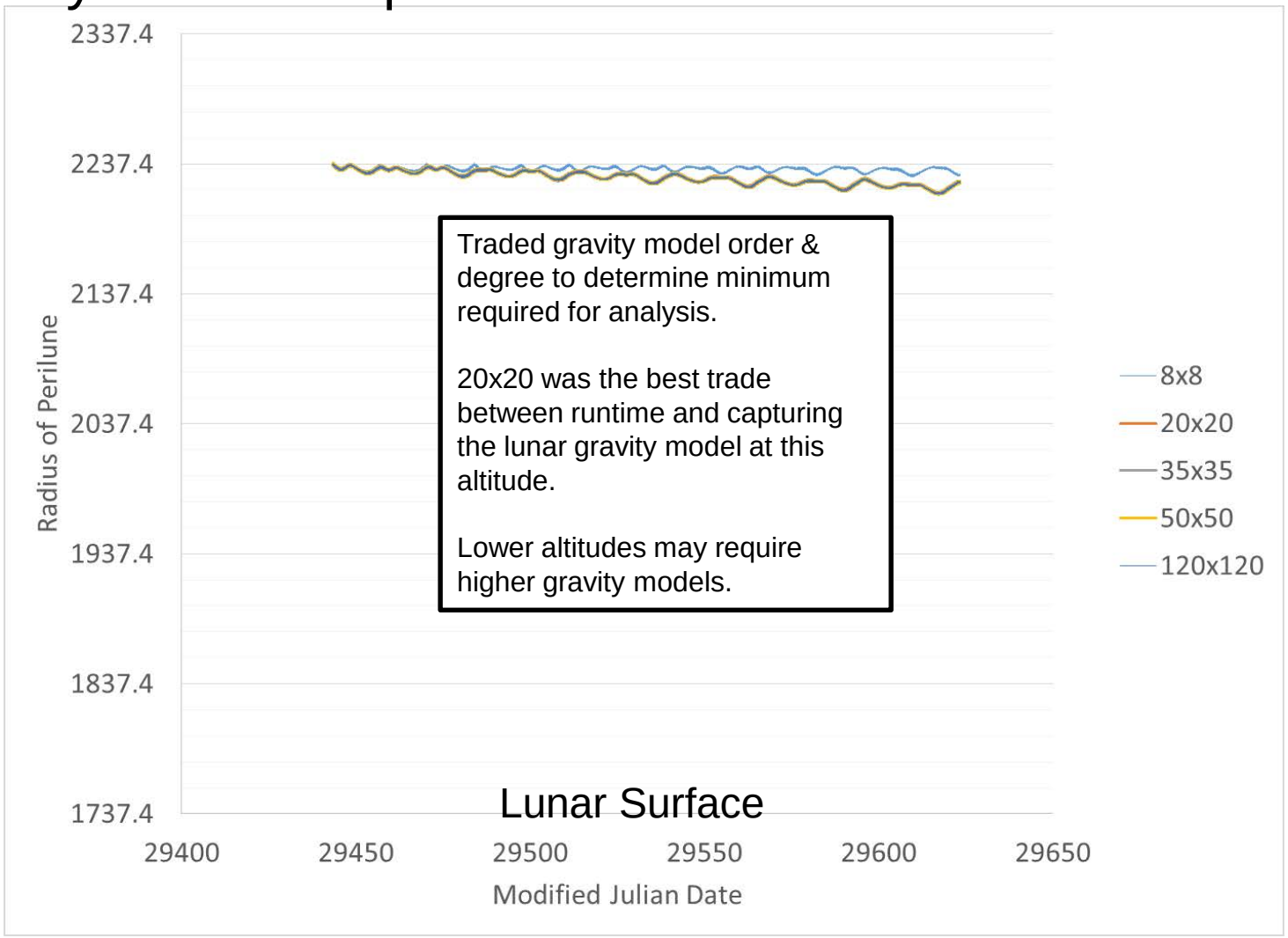


Resource Prospector delta-V through LOI



Station Keeping

- May not be required at the 500km orbit



EELV Variant of LPL

- Direct trajectory from a LEO parking orbit
  - 100 nmi circular, 28.5 degree inclination, RAAN consistent with an insertion from CCAFS
  - TLI burn modeled as an impulsive burn from this orbit
  - Launch vehicle data not available
- Reserve 25 m/s for Trajectory Correction Maneuvers (TCM) after separation
  - Venting excess TCM prop was required on the original Resource Prospector SLS trajectory
  - Need to verify it is still required for the direct trajectory
- Star 48AV motor used for braking burn
  - Zero offload assumed
- Solid motor burnout occurs at 9.6 km altitude (1747 km lunar radius)
  - Landing site at -510m altitude
- Point mass lunar gravity model until descent
  - Descent uses 120 x 120 GRAIL lunar gravity model
    - Probably overkill, but doesn't affect runtime or convergence significantly
  - Descent trajectory biased to protect for a 6km downrange and crossrange error after SRM drop off

LPL Landing Sites, courtesy of James Holt

Site	Latitude	Longitude	Altitude	Landing Time
A	85 deg	-108.64 deg	-510.34 m	2022 June 15 12:00 UTC
B	85 deg	-33.516 deg	-510.34 m*	2022 June 9 12:00 UTC

*Used the same altitude for both landing sites for this phase of analysis. The altitude is consistent with the performance driving Site A. Next phase will use landing site specific altitudes.

Lunar Pallet Lander Mission Timeline Overview

Launch Vehicle provided Trans-Lunar Injection

Trajectory Corrections, GNC Cal Maneuver Burns

Lunar Transit ~4 days

Powered Descent by Star 48BV Burnout altitude = 9.6 km

Separation initiates the power-up sequence

Coast ~ 0.5 minutes

SRM Lunar Impact TBD downrange

Descent Initiation by Lander

Descent ~ 3 minutes

6 km

Vertical Descent by Lander

Terrain Relative Navigation (no hazard avoidance)

1 km

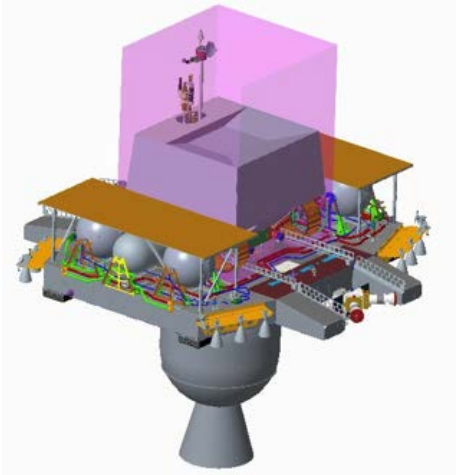
Powered Operation for the remaineder of the lunar day

Down Range TBD km

Moon

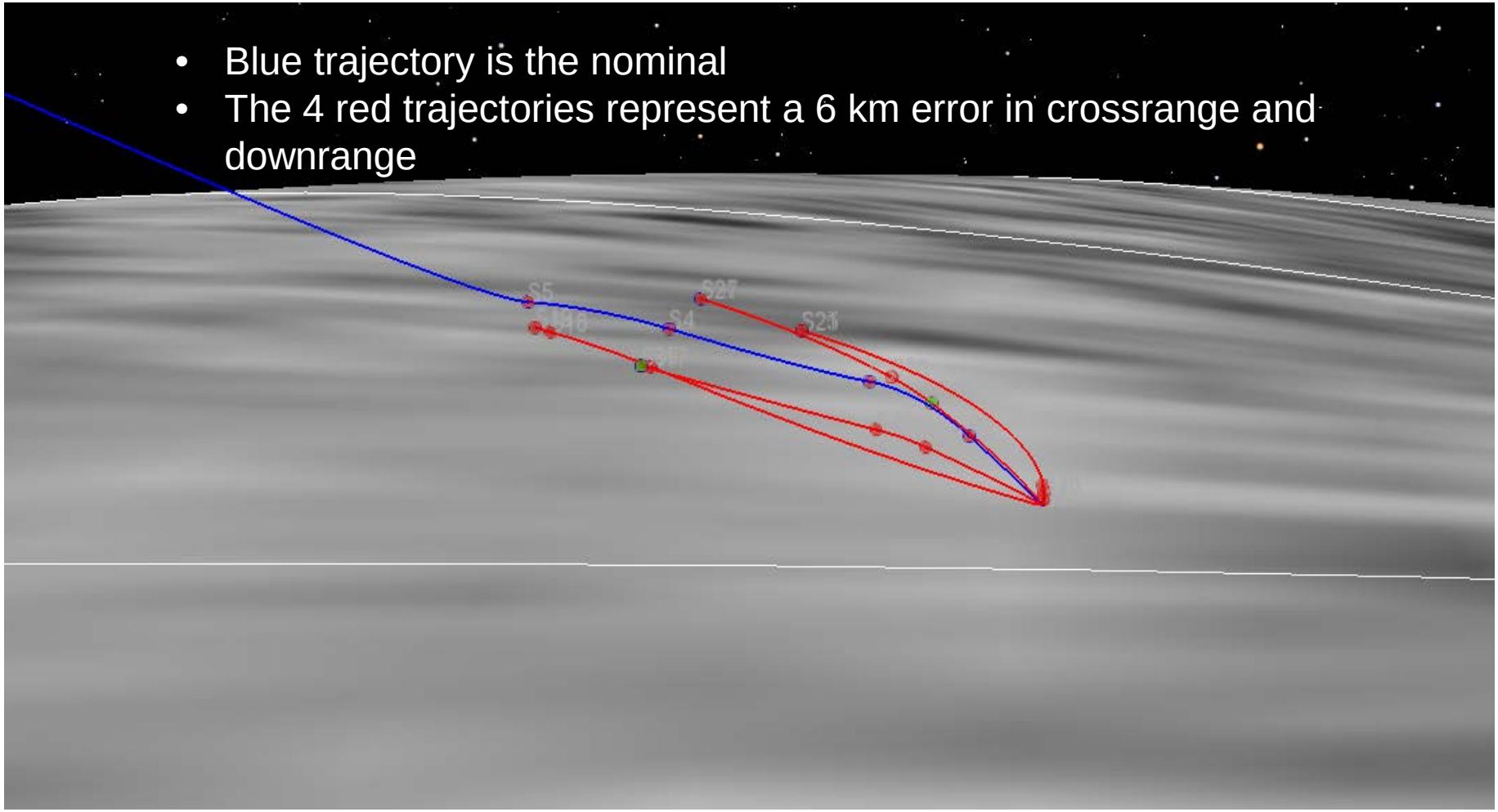
Site A: -85 N 108.64 W elevation -510m
Landing: 6/15/2022 12:00 (UTC)

Flight Phase	Delta-V (m/s)
After separation from ELV	
+440-N descent thruster	25
+22 N ACS thruster (10%)	2.5
SRM Operation	
+SRM operation	2390
+22-N ACS thruster (25% Duty)	0.24
Vertical Descent by Lander	
+440-N descent thruster	411
+22-N ACS thruster (10%)	41
+440-N descent thruster (redirect budget)	21

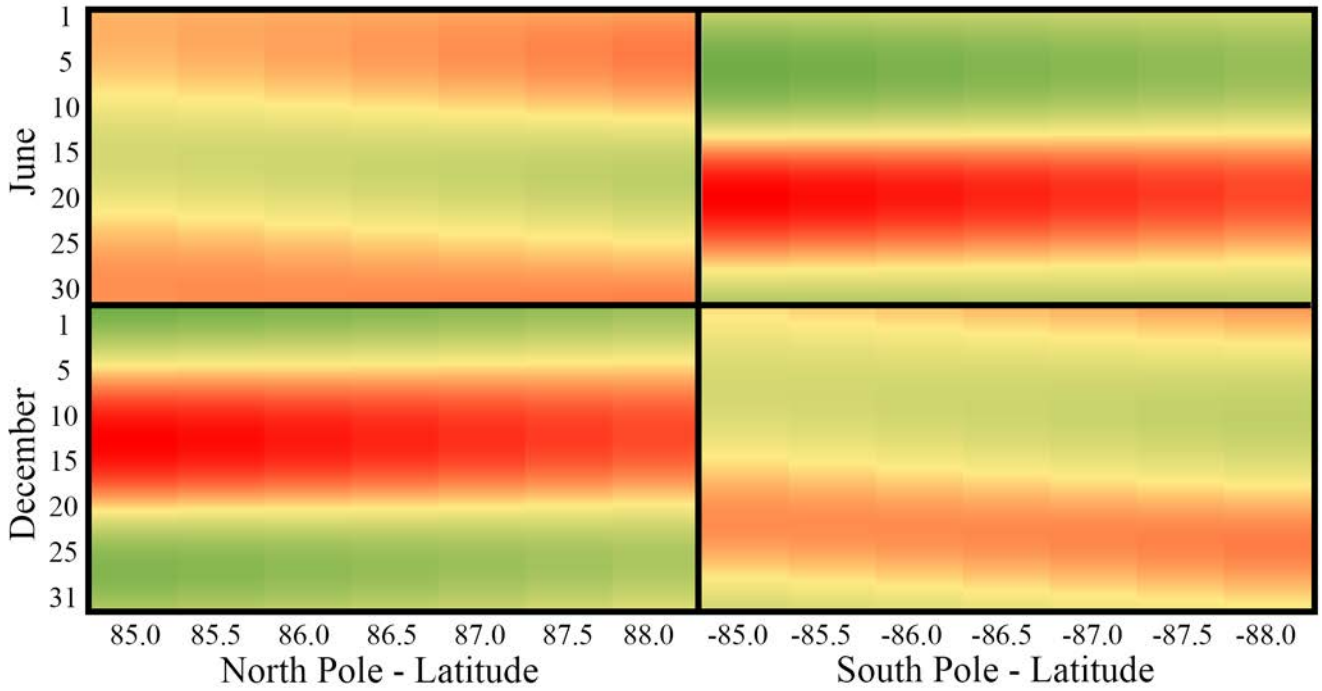


Lander Notes:
1. 37.6 kg Flight Performance Reserve of usable propellant load is added at the end
2. TVC assumed SRM
3. Altitudes above average lunar radius

Trajectory Dispersions after SRM burnout

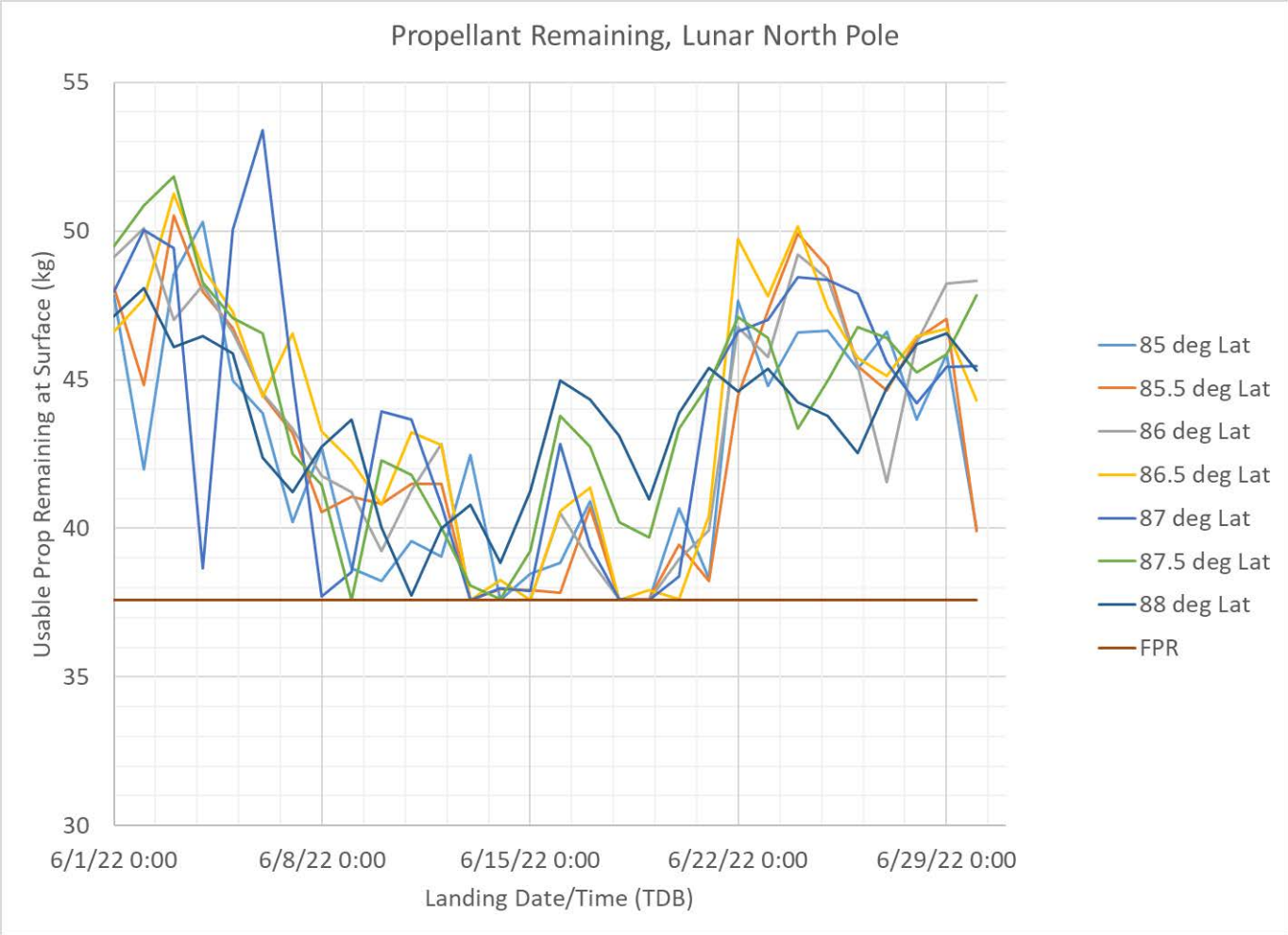


Landing Sites and Earth Line of Sight

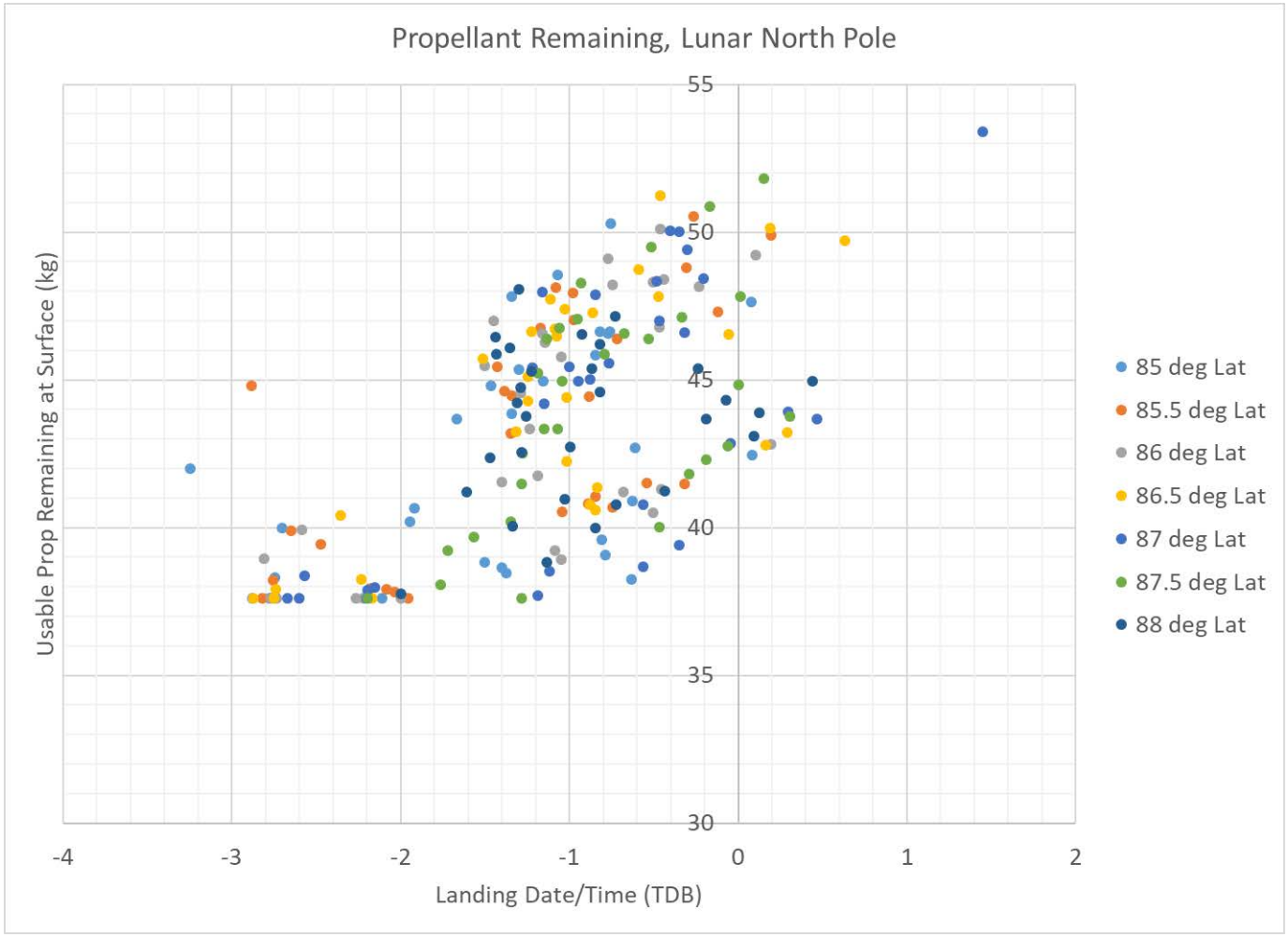


- Analysis based on a sphere, terrain data not included at this point
- Red indicates Earth angle is >90 degrees, line if sight is less likely
- Green indicates Earth angle is <90 degrees, line of sight is possible

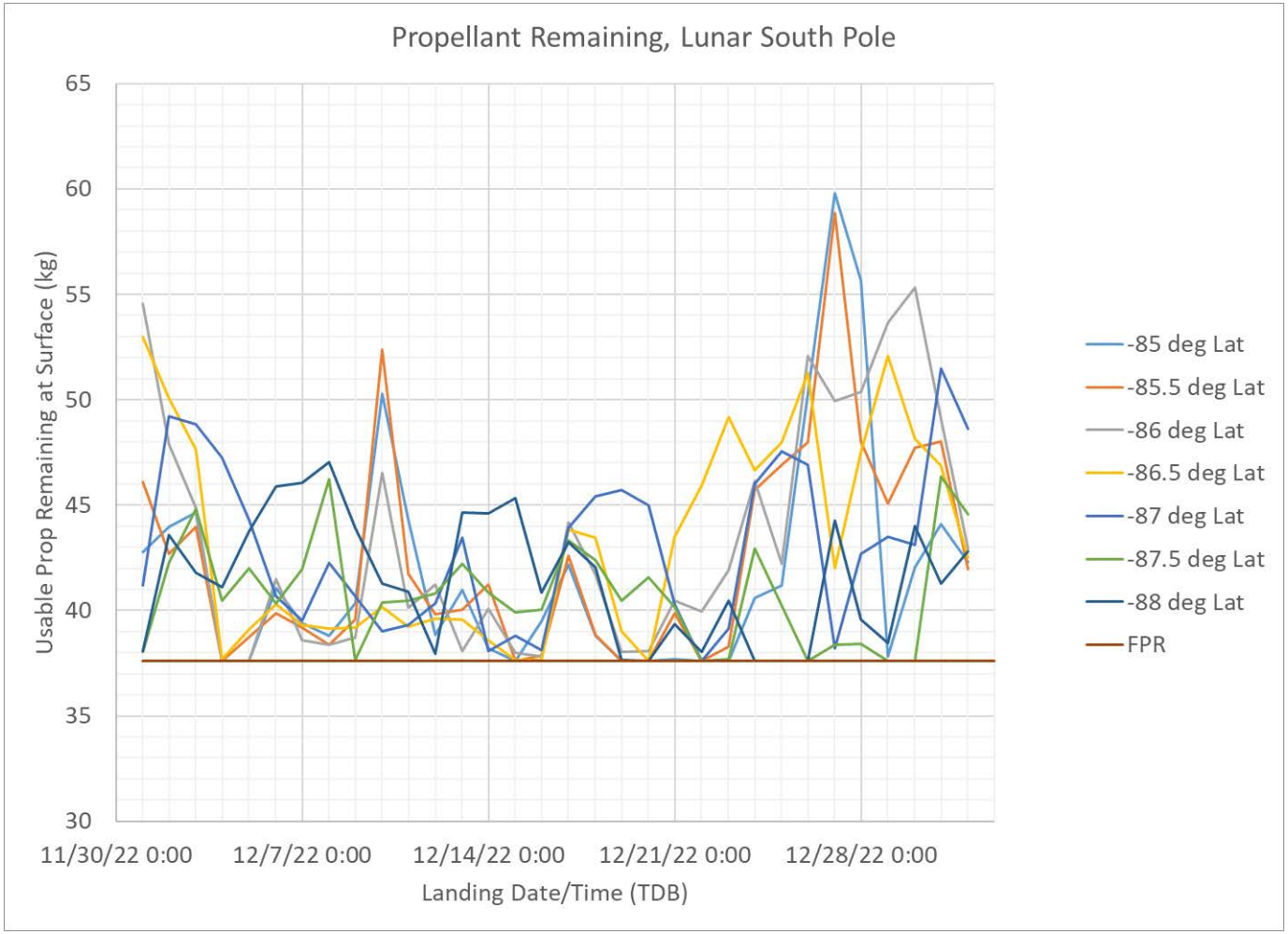
North Pole Landing Site Performance



North Pole Performance vs Landing Site Altitude



South Pole Landing Site Performance



South Pole Performance vs Landing Site Altitude