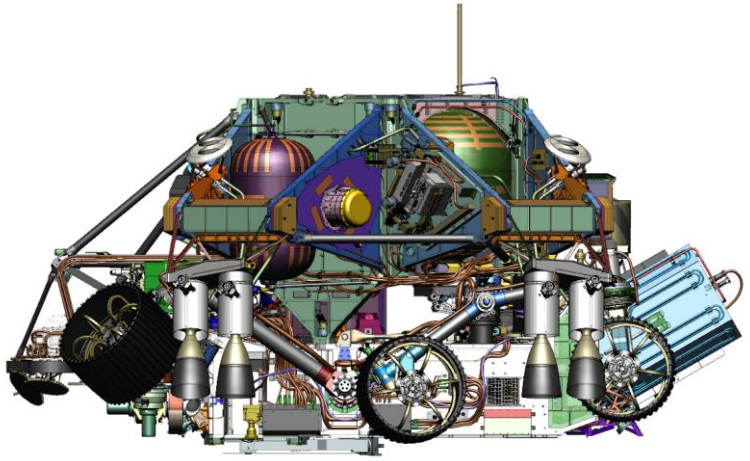
M2020 ON-BOARD TERRAIN RELATIVE NAVIGATION

P. B. Brugarolas, J. Casoliva, A. Chen,
A. Johnson, S. Mohan, A. Stehura
NASA Jet Propulsion Laboratory,
California Institute of Technology

D. Way and S. Dutta
NASA Langley Research Center



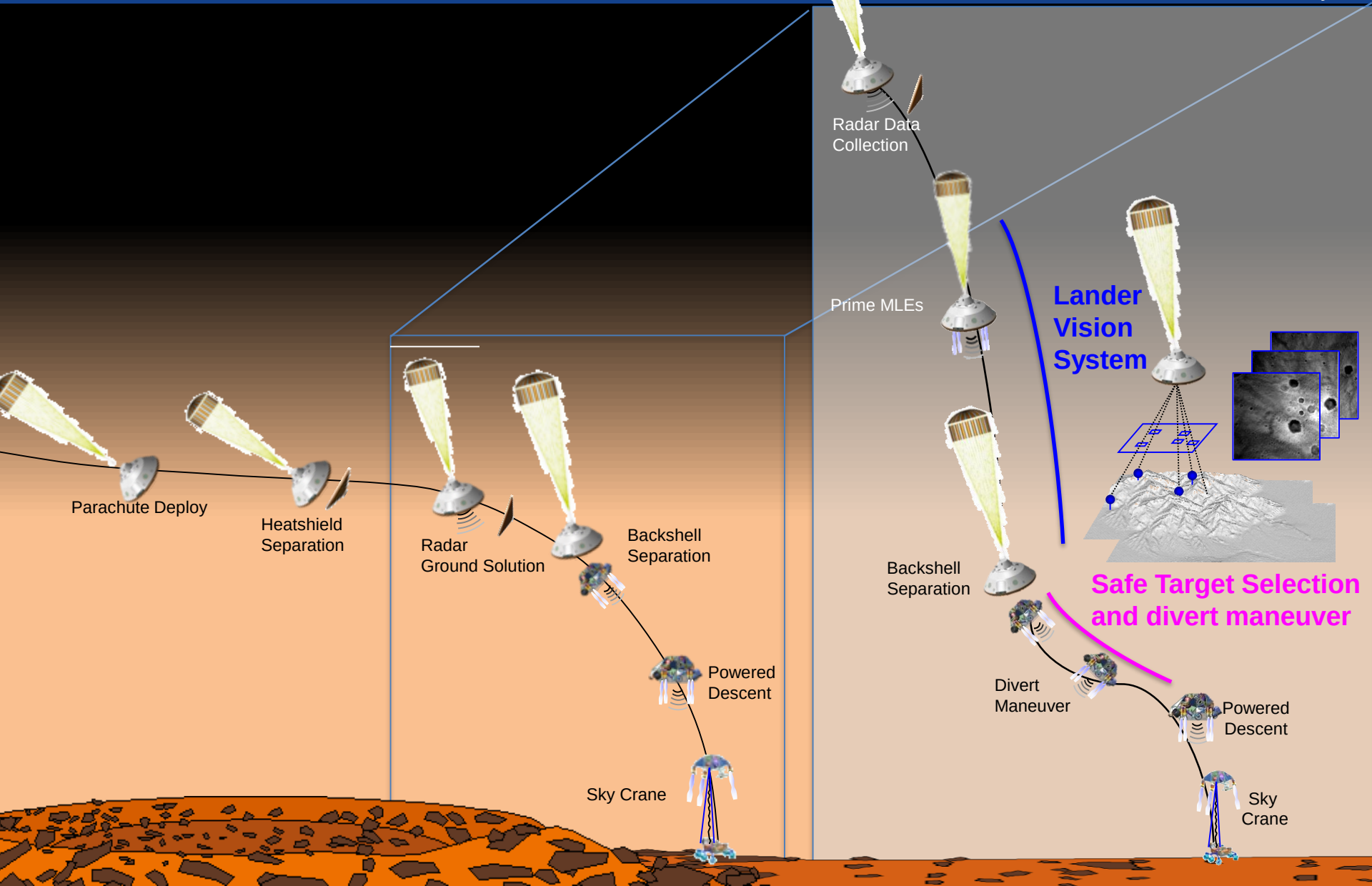
IPPW#14
June 12, 2017

Mars 2020 Project

EDL Timeline with TRN

Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Project



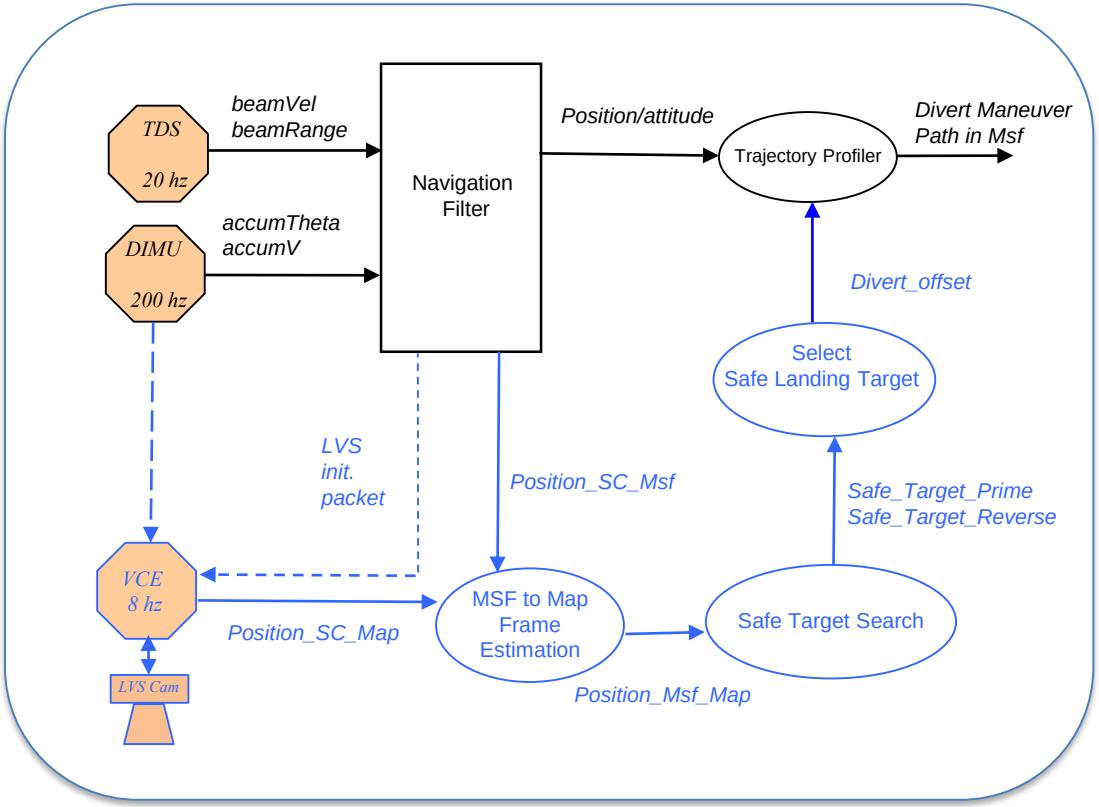
Terrain Relative Navigation

- Lander Vision System (LVS) is a sensor that provides map relative localization (~40 m)

- Safe Target Selection (STS) is the function that selects a safe landing target within reach of the powered flight divert capability (up to 650 m) from an on-board Safe Target Map (STM)
  - To do STS we need:
    - Safe Target Map (ground developed)
    - Mars Surface Frame (MSF), which is the onboard GNC reference frame, to Map Frame Estimation
    - Safe Target Map Search
    - Safe Target Selection

TRN GN&C Architecture

Addition of TRN (new in blue) to the heritage MSL EDL GN&C architecture (black)



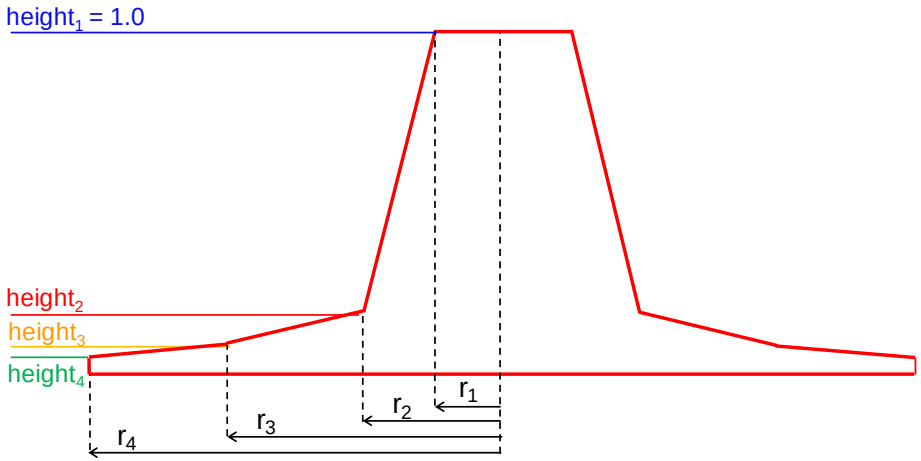
TDS: Terminal Descent Sensor (landing radar)
DIMU: Descent IMU
VCE: Vision Compute Element
LVS Cam: Lander Vision System Camera

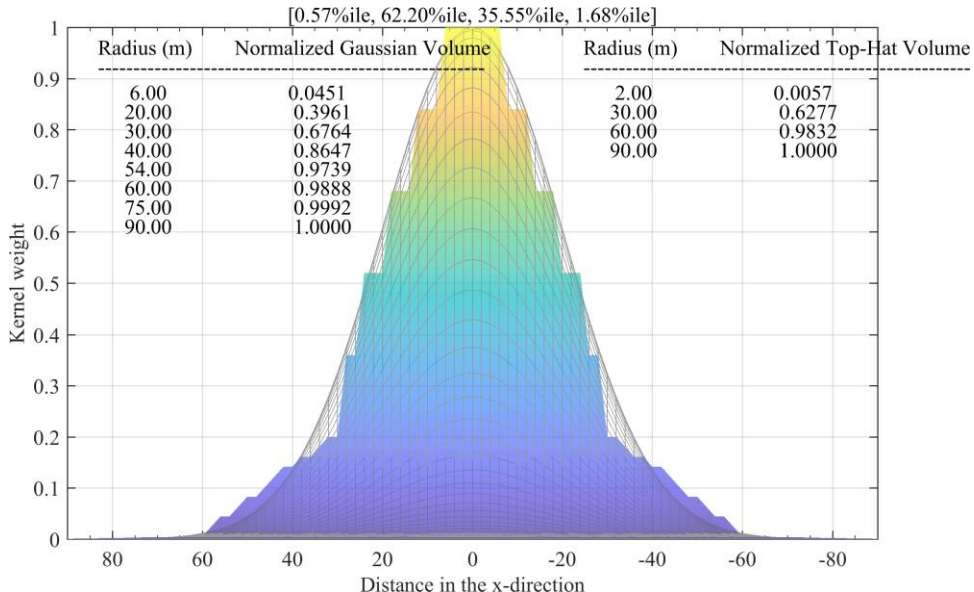
Safe Target Map

- EDL Landing Hazard Map captures landing risk due to terrain
  - 100% failure rates for high slopes (>35 deg), inescapable hazards, and large rocks (>1.5 m)
  - 15% failure rates for mid slopes (25-35 deg)
  - Typically <20% failure rates for medium size rocks (0.5-1.5m), non-observable from space, based on rock distribution models
- Safe Targets Map (STM) is a map of safe landing targets that pads the hazards to account for knowledge and control errors (30-90 m) based on the hazard level and identifies landing spots with benign slopes (<10 deg)

Hazard Level	Hazard Type	Guaranteed Hazard Padding Distance [m]
(20%, 100%]	High slopes (>35 deg) Inescapable hazards	90
100%	Large rocks (>1.5 m)	70
(2%, 20%]	Mid slopes (25-35 deg) Medium size rocks (0.5-1.5 m)	[60, 90)
(0.02%, 2%]	Medium size rocks (0.5-1.5 m)	[45, 60)
(0.01%, 0.02%]	Medium size rocks (0.5-1.5 m)	[30, 45)

Top-Hat Padding Kernel

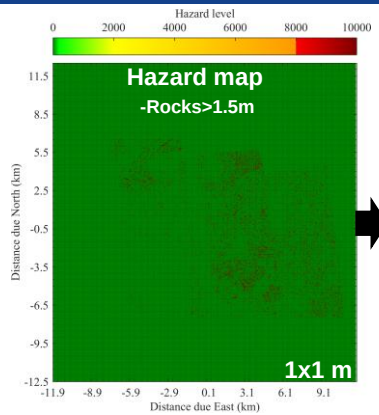




Safe Targets Map Generation

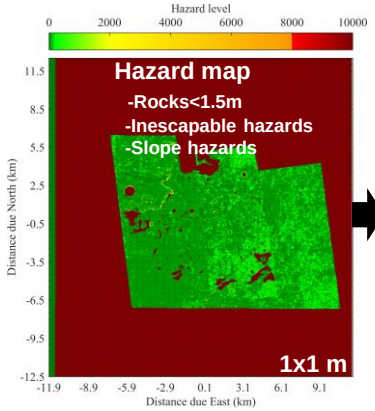
Jet Propulsion Laboratory
California Institute of Technology

INPUTS



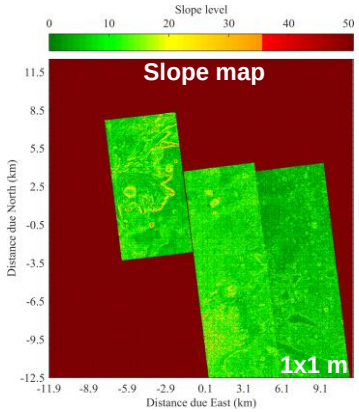
Apply Equirectangular projection to the STM orthographic projection transformation

Apply the TRN error padding kernels



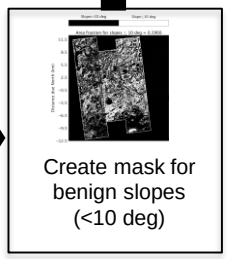
Apply Equirectangular projection to the STM orthographic projection transformation

Apply the TRN error padding kernels



Apply Equirectangular projection to the STM orthographic projection transformation

Apply the TRN error padding kernels



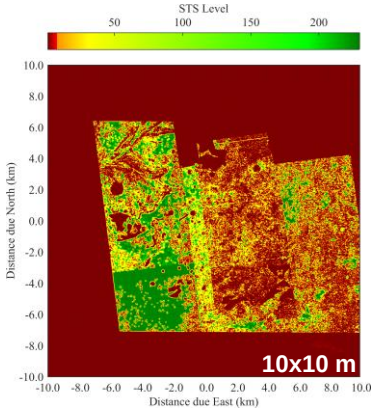
Create mask for benign slopes (<10 deg)

Assign Safe Target Level

0: No data
1: 100% risk and non benign slope
2: 100% risk and benign slope
3: 95% risk and non benign slope
4: 95% risk and benign slope
...
35: 15% risk and non benign slope
36: 15% risk and benign slope
37: 10% risk and non benign slope
38: 10% risk and benign slope
39: 9.9% risk and non benign slope
40: 9.9% risk and benign slope
...
235: 0.1% risk non benign slope
236: 0.1% risk and benign slope

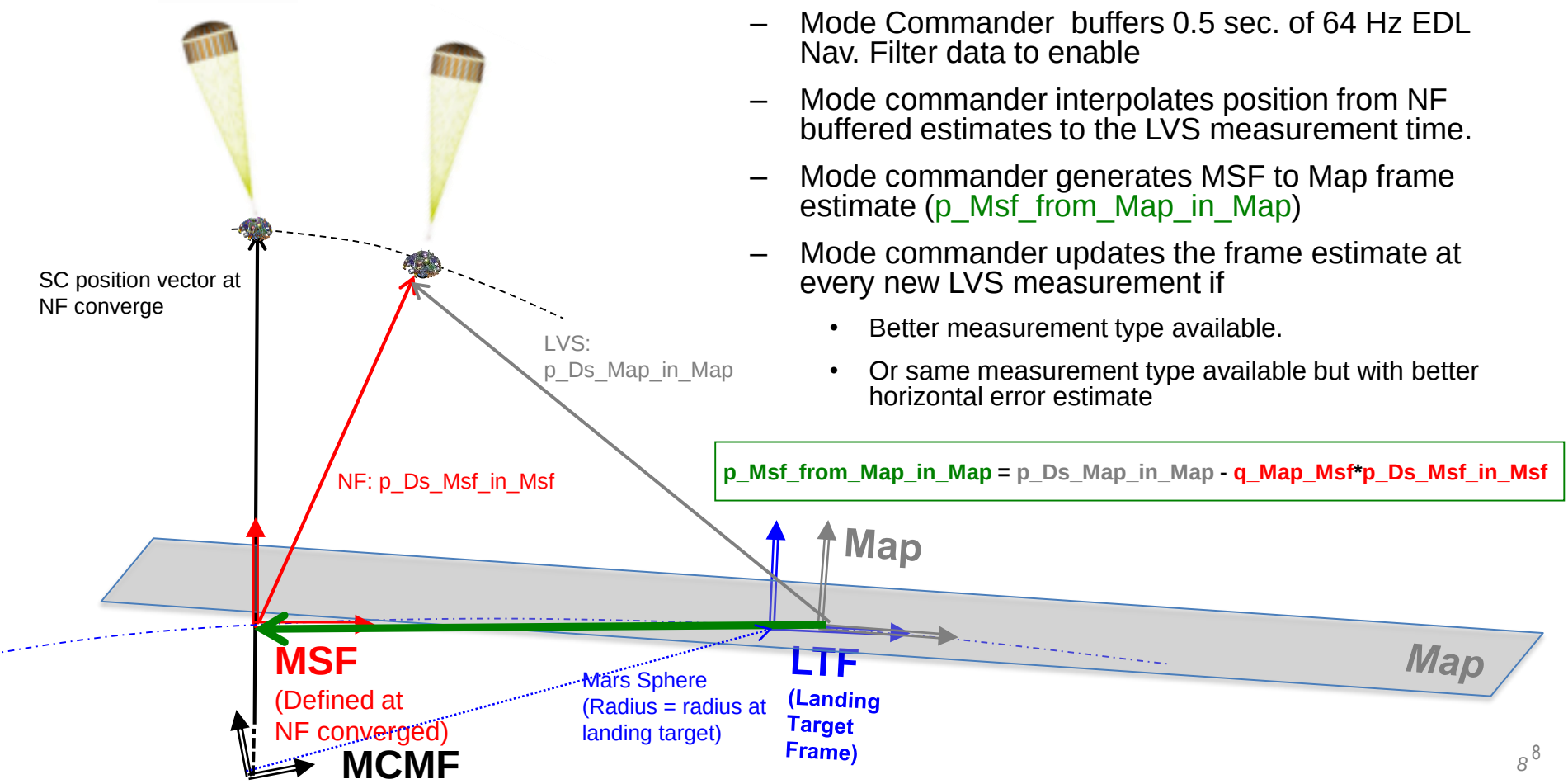
OUTPUT

Safe Targets Map (20x20 km, 10x10m/pxl, 0-255 levels)



MSF to Map frame estimation

- Estimate MSF frame origin with respect to the Map through time synchronization of the vehicle position in MSF (from Nav. Filter) and the vehicle position in the Map (from LVS)
  - LVS measurement data packets at 8 Hz (with < 0.5 s latency)
  - Mode Commander buffers 0.5 sec. of 64 Hz EDL Nav. Filter data to enable
  - Mode commander interpolates position from NF buffered estimates to the LVS measurement time.
  - Mode commander generates MSF to Map frame estimate (p_Msf_from_Map_in_Map)
  - Mode commander updates the frame estimate at every new LVS measurement if
    - Better measurement type available.
    - Or same measurement type available but with better horizontal error estimate



STS Safe Target Search

- To mitigate computational loading the Safe Target Search has been spread over 2.6 seconds between EDLGNC modes “Wait for Backshell Separation” and “PD Detumble”

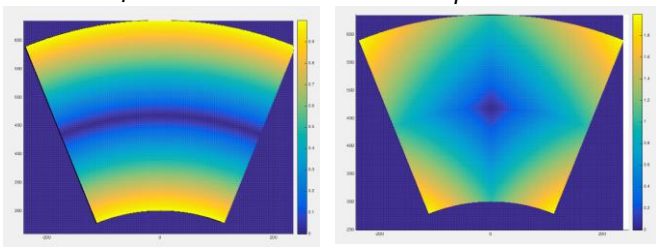
- The search approach is as follows:
  - STS computes a Zero Divert predict at “Wait for Backshell Separation”
  - STS generates the prime and reverse wedge regions for backshell avoidance
  - STS defines the STS map search area to cover the wedges
  - STS spreads the search over 2.6 seconds

- For each wedge the target selection algorithm will find the safest pixel.
  - If there are more than one safe pixel of the safest designation, it uses a cost function to select the best one

$$J = \frac{|r - r_{center}|}{r_{max} - r_{center}} + f_p \frac{|az - az_{center}|}{d_{az}}$$

f_p: penalty factor

f_p = 0 f_p = 1



  - Cost function is tunable and allows to trade fuel use and backshell recontact risk

STS Safe Target Decision

- Heritage MSL – backshell avoidance divert direction is used to define the “Prime” wedge. The other wedge is referred as the “Reverse” wedge.

- If `do_dual_wedge` parameter is enabled, it selects the best target in Prime or Reverse wedge based on the relative safety level.
  - A `delta_safety_level` parameter allows to trade landing risk with backshell recontact risk from selecting the reverse wedge

- Logic selects an ”MSL divert” if any of the following are true:

  a) `do_sts` parameter is set to disabled

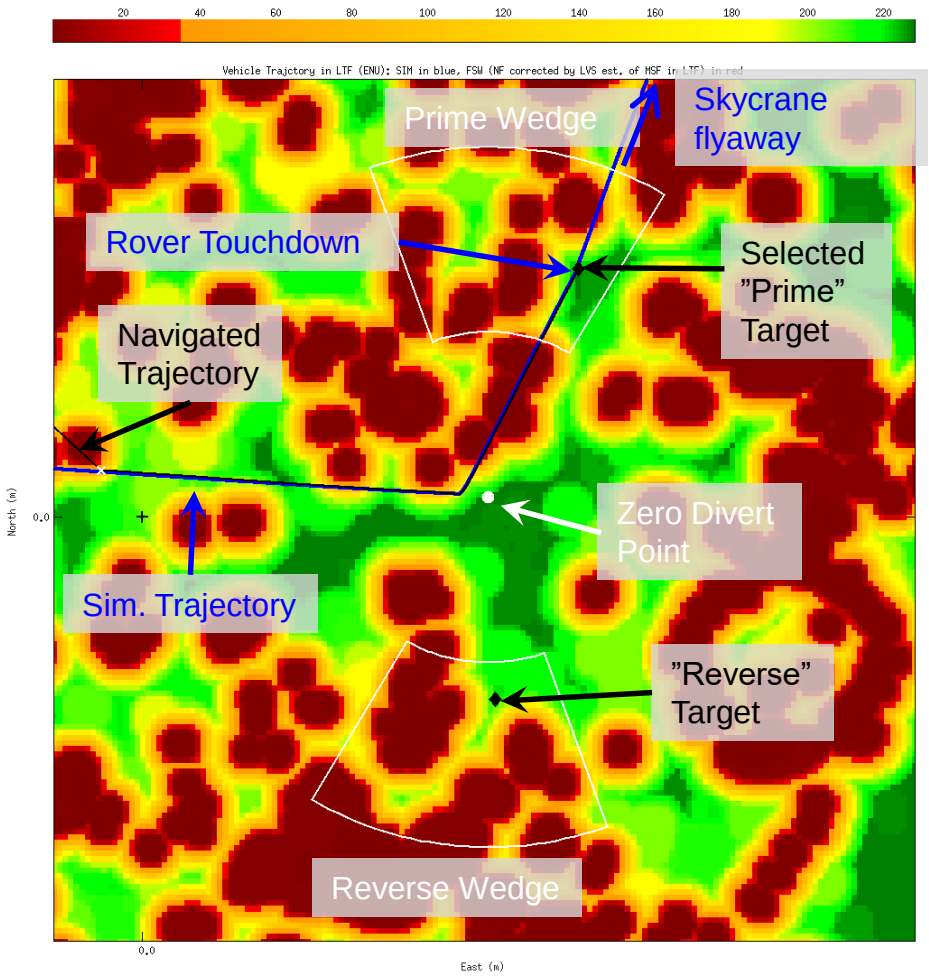
  b) LVS does not produce a valid measurement

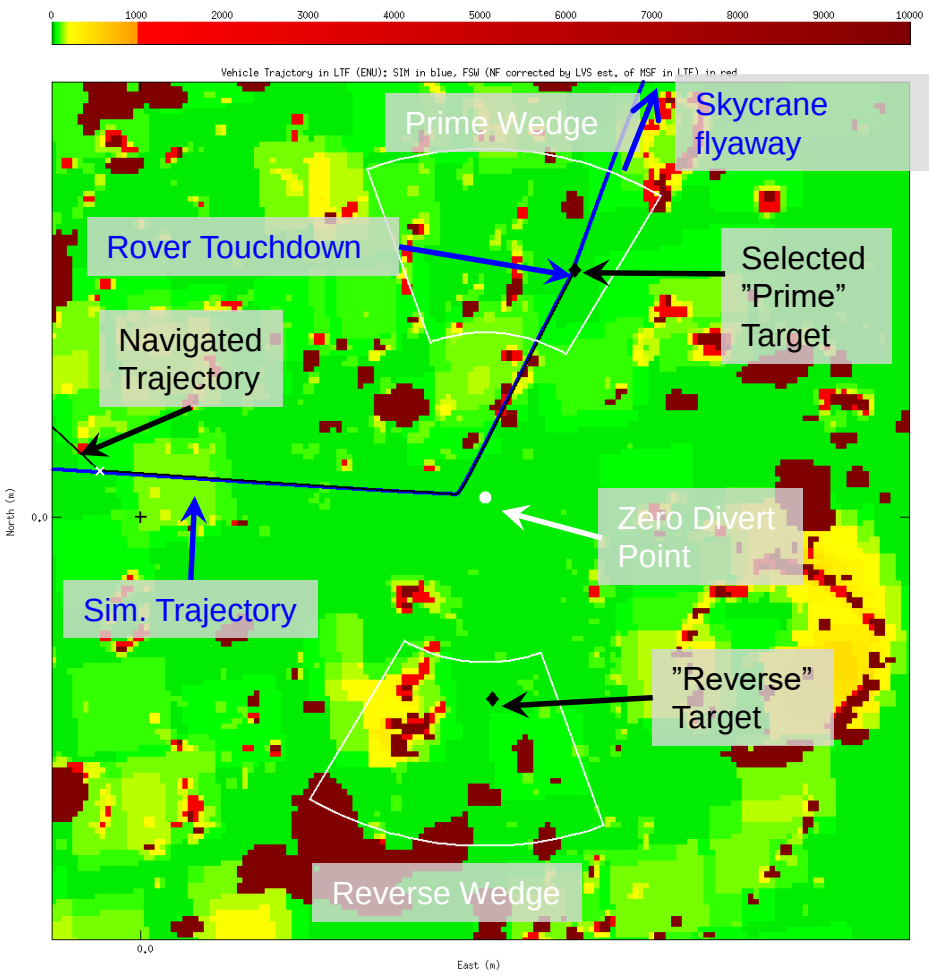
  c) A safe target (0 safety level) is not found

10

Simulation Run

Bird eye view of vehicle trajectory over STS Map and over Hazard Map





Conclusion

- *Developed a safe target selection approach for Mars 2020.*
  - *Proposed a methodology to generate the on-board safe targets map based on landing hazard maps and TRN capability*
  - *Developed algorithms for the onboard safe target selection*

Thank you!

BACKUP

Safe Target Search Region

Safe Targets Search Region ('the wedge')

- Spans 335 m diameter reachable region beyond the 300m MSL divert.
- Sized to minimize backshell recontact by limiting the wedge azimuth
- Within Powered Descent 90% throttle constraint.
- Parameterized by r_{min}, r_{max} and d_{az}.