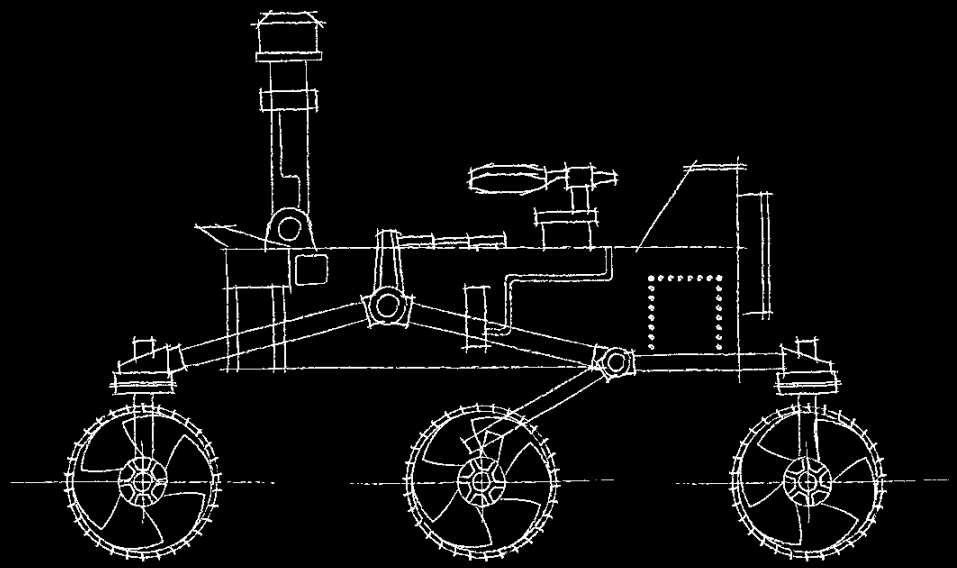
Jet Propulsion Laboratory
California Institute of Technology

ON-BOARD TERRAIN RELATIVE SAFE-TARGET SELECTION FOR THE MARS 2020 MISSION

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

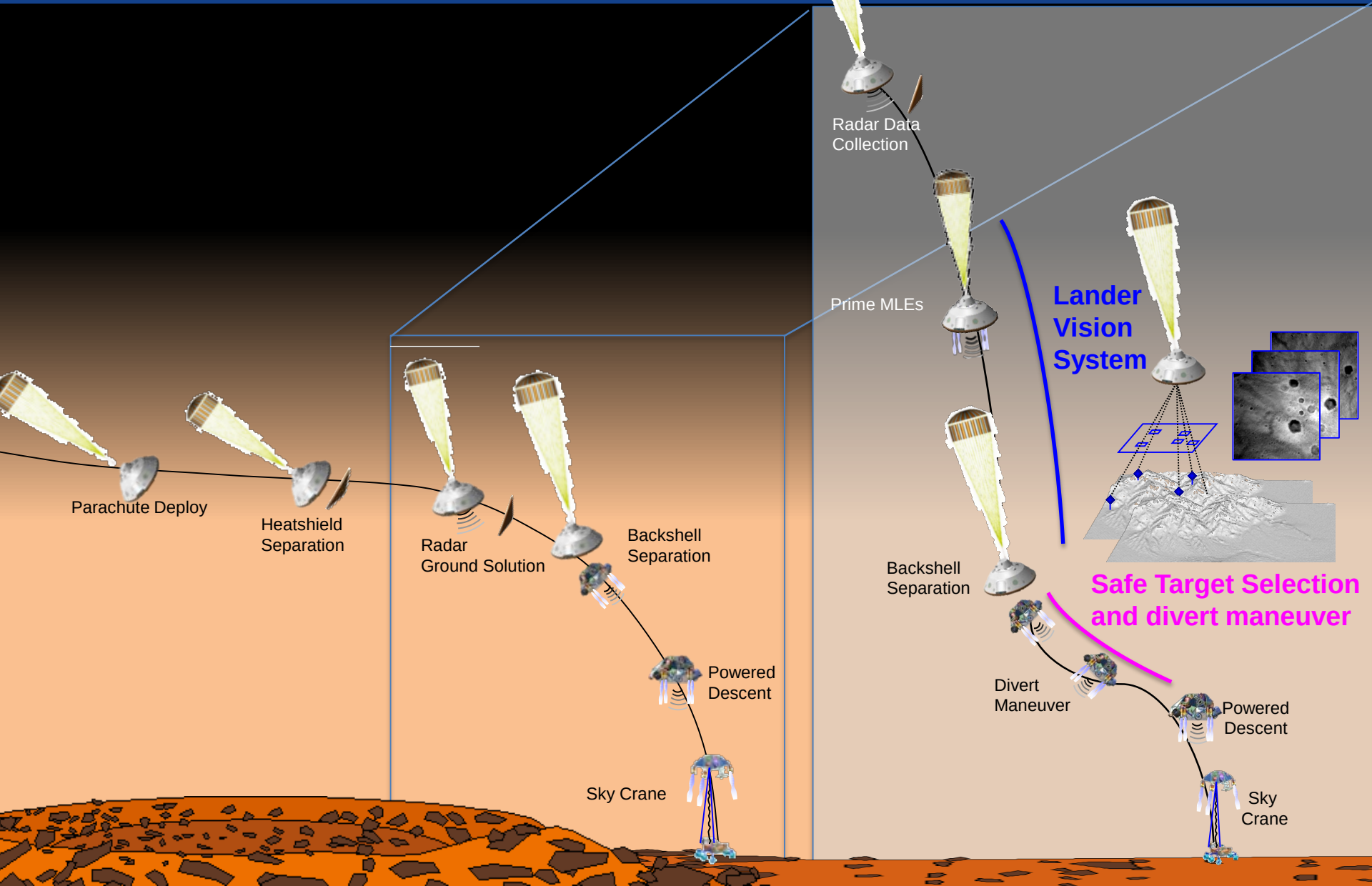
D. Way and S. Dutta
NASA Langley Research Center



IPPW#13
June 17, 2016

Mars 2020 Project

EDL Timeline with TRN



Safe Target Selection

- Safe Target Selection (STS) is the function that selects a safe landing target to land on from an on-board Safe Target Map
- It uses the location knowledge (~40 m) provided by the Lander Vision System (LVS) Sensor
- It picks a target within reach of the powered flight divert capability (up to 650 m)

Safe Targets Map

- The Safe Targets Map is an onboard map that has
  - Range: 20x20km
  - Pixel size: 10x10 m
  - Safe Target pixel designation (2 bit)
    - Red
    - Orange
    - Yellow
    - Green
  - *Safe targets map sized to balance map coverage, resolution and precision within resources (memory use)*

Building the Safe Targets Map

- The Safe Targets Map needs to define safe targets based on:
  - the hazard level of the terrain
  - Terrain Relative Navigation errors [Ref Swati] (which require to buffer the areas around the hazards)
    - LVS localization error: ~40 m
    - Navigation error after localization: ~15 m
    - Control error: ~1 m

- Landing Site Hazard Maps are generated by the M2020 EDL Council of Terrains and include the following hazard levels:
    - 100% failure rates for high slopes (>35 deg), inescapable hazards, and large rocks (>1.5 m in diameter)
    - 15% failure rates for mid slopes (25-35 deg).
    - 0-20% failure rates for medium size rocks (0.5-1.5m), non observable from space, based on rock distribution models.

- Methodology to build Safe Targets Maps needs to be tunable
    - Different sites will have different distributions of hazard levels

Steps to build Safe Targets Map

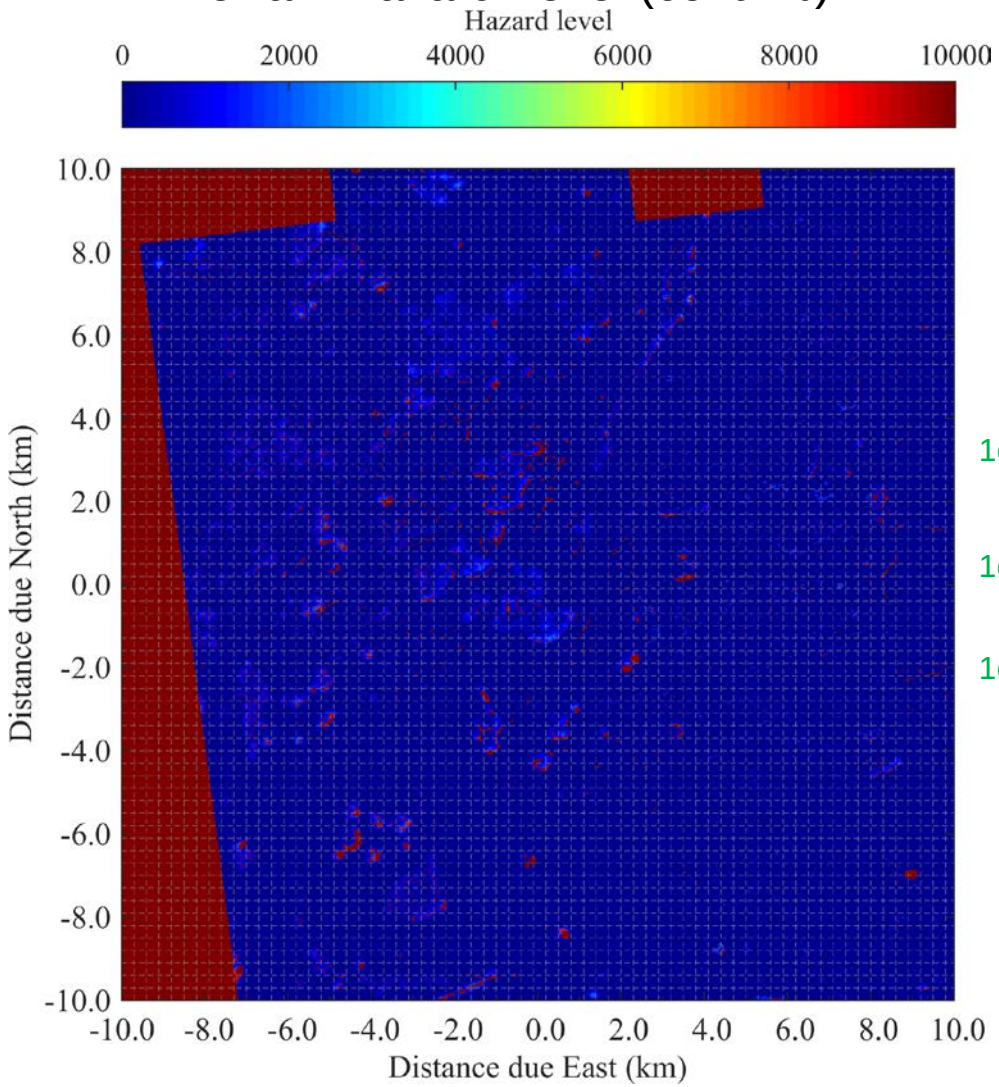
1. Analyze Hazard Map for a given landing site

2. Apply TRN padding kernel

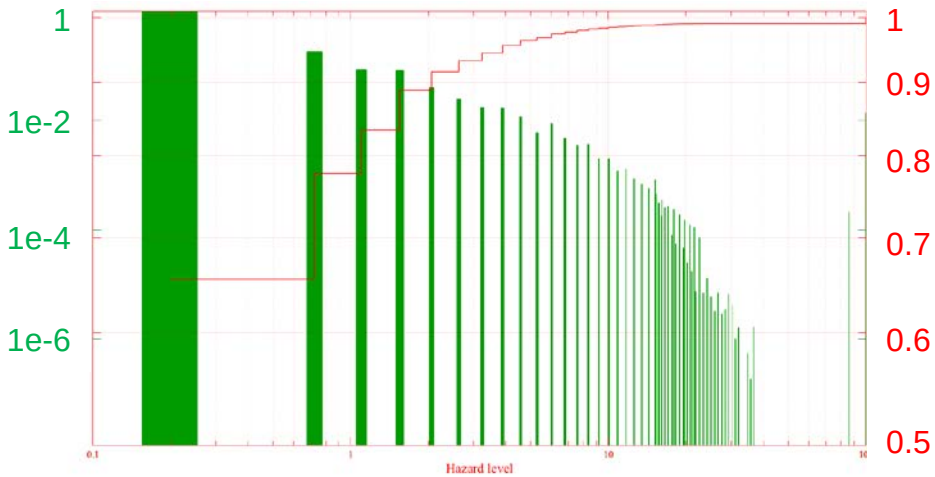
3. Generate safe target designations by thresholding at desired safety levels.

Step 1: Analyze Landing Site Hazard Map

North East Syrtis
Terrain Hazard Level (centi-%)



- Landing Site Hazard Map provided by M2020 Council of Terrains (R. Otero)
  - 20x20 km
  - 1x1 m pixel
  - Hazard level resolution: 0.01%
  - Hazard map co-registered to LVS map
- Histogram of hazard levels and its cumulative distribution in log/log scale

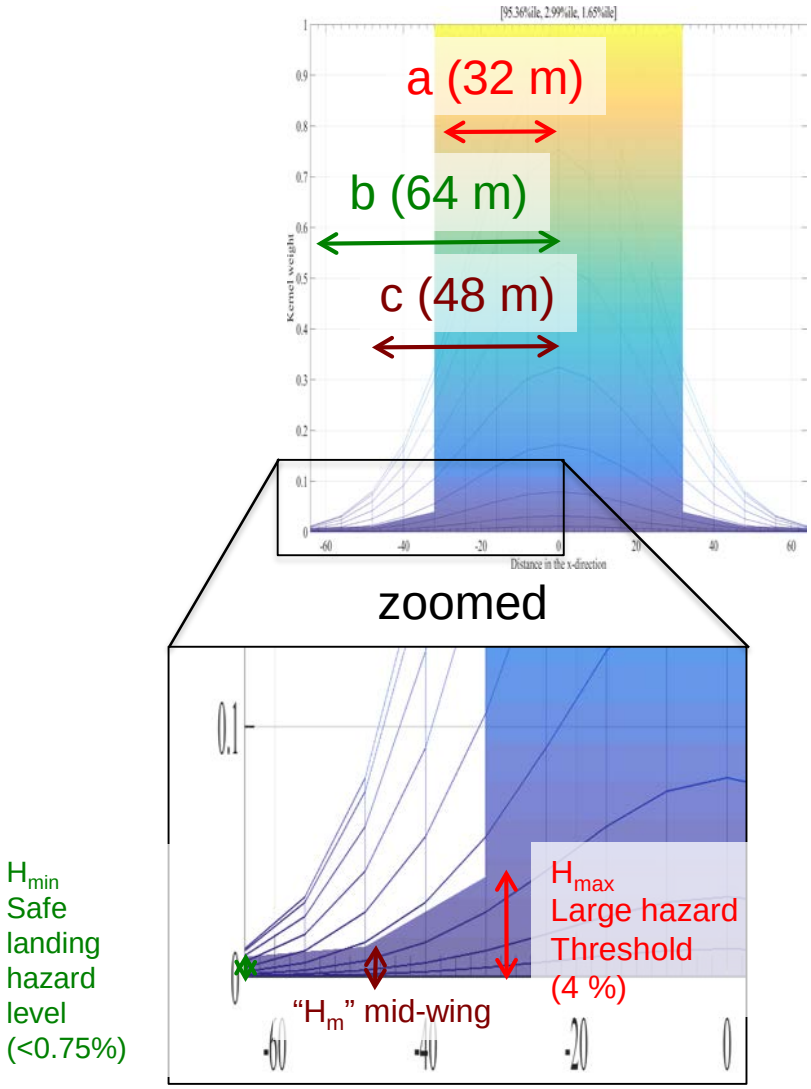


- Assess distribution and magnitude of hazards
  - Define "large hazards" => to be avoided
    - H_{max} (NES: >4%)
  - Define "safe landing level" => ok to land
    - H_{min} (NES: <0.75%)

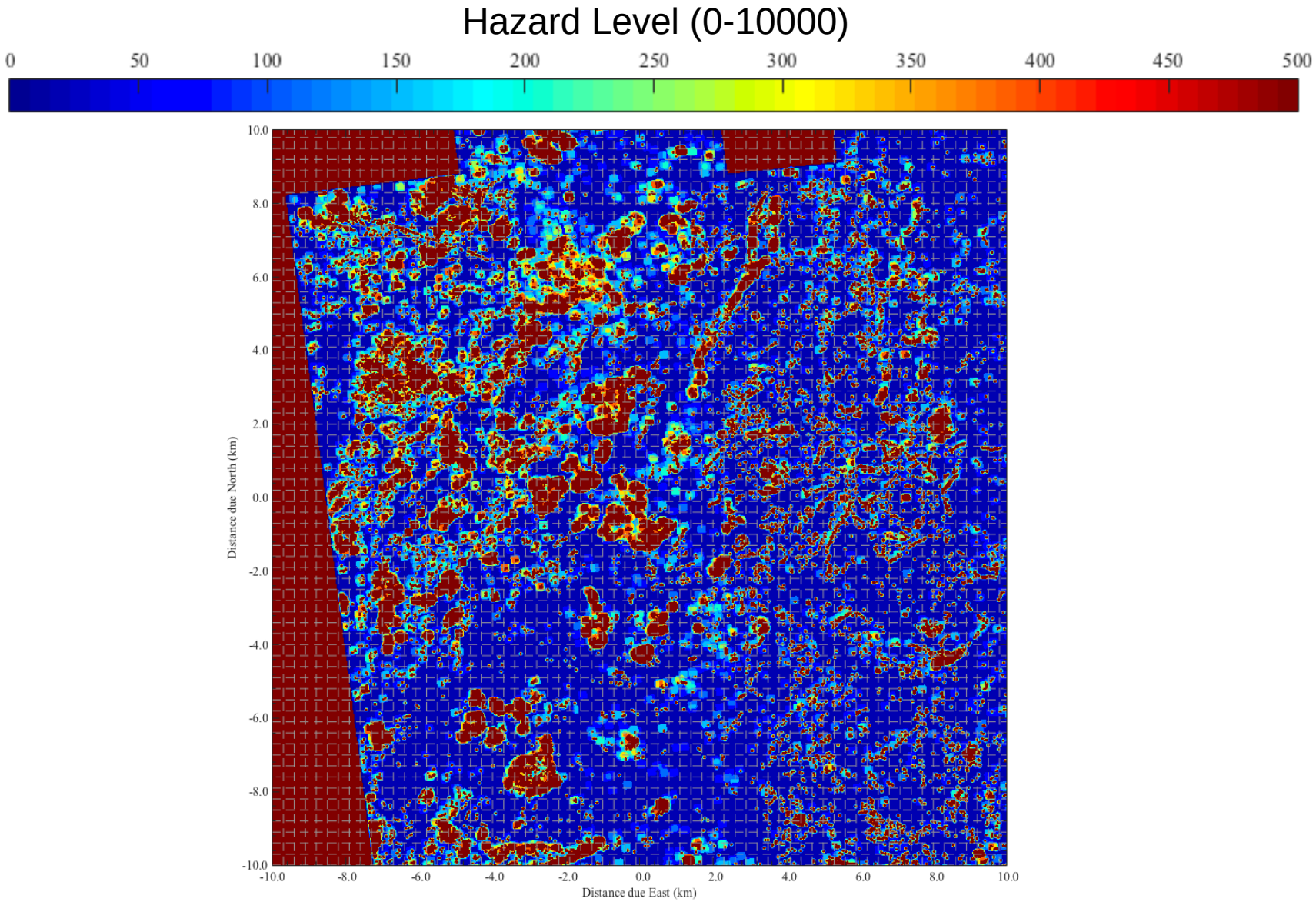
Step 2: Tune and apply TRN “top hat” padding kernel

- Objective of the “top hat” padding kernel is to provide a mechanism to make landing target pixel designations (Red, Orange, Yellow and Green) that can trade hazard level and TRN padding.

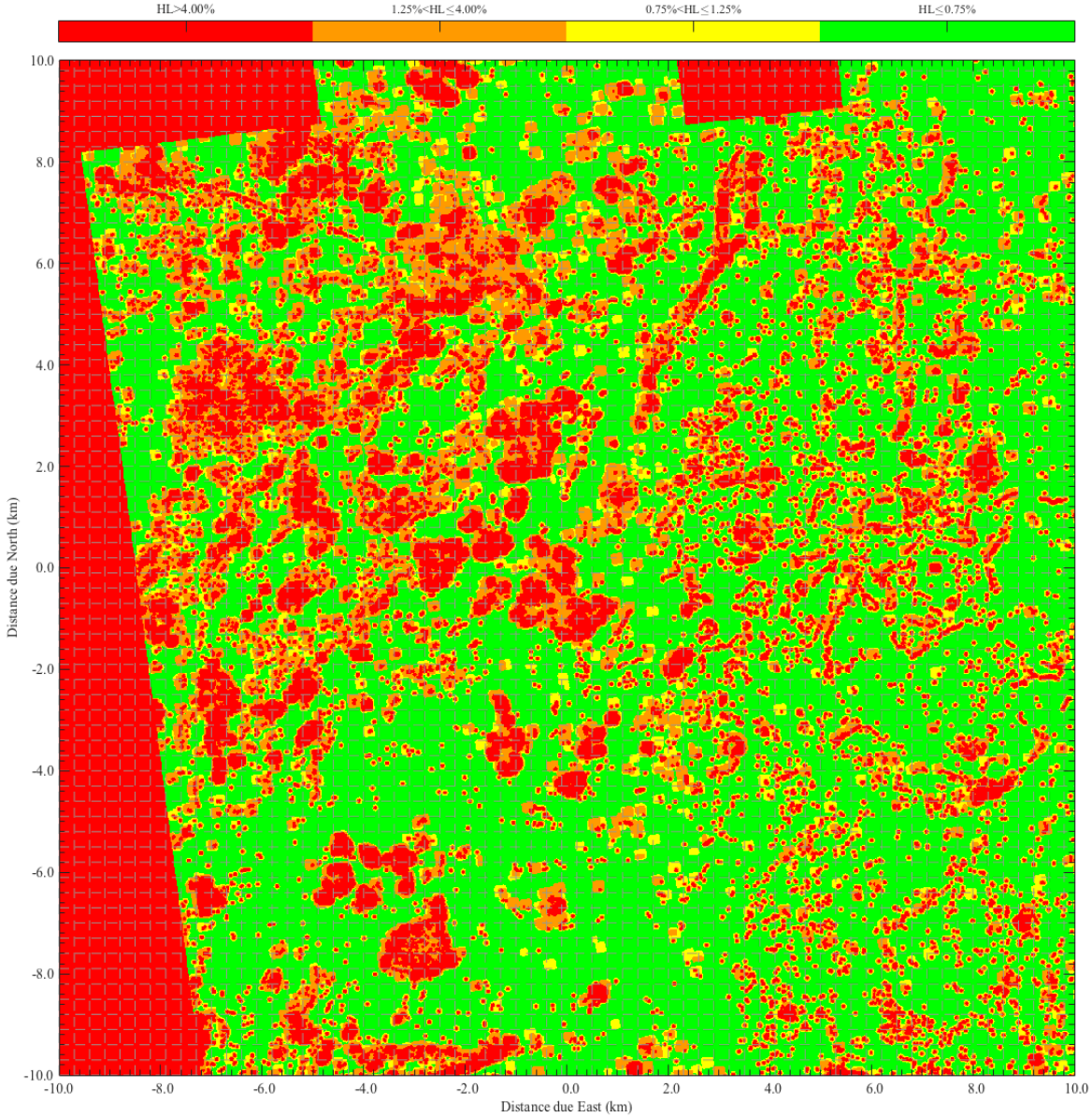
- “top hat” padding kernel features
  - (a) minimum padding for all hazards
  - (b and H_{min}) guarantee that Green designations around Red ($>H_{max}$) hazards will have maximum padding
  - (c and H_m) “top hat” mid-wing enable Yellow/Orange designations to trade mid-hazards and padding around Red hazards.



Step 2: “Top Hat” Padded Map



Step 3: STS Map



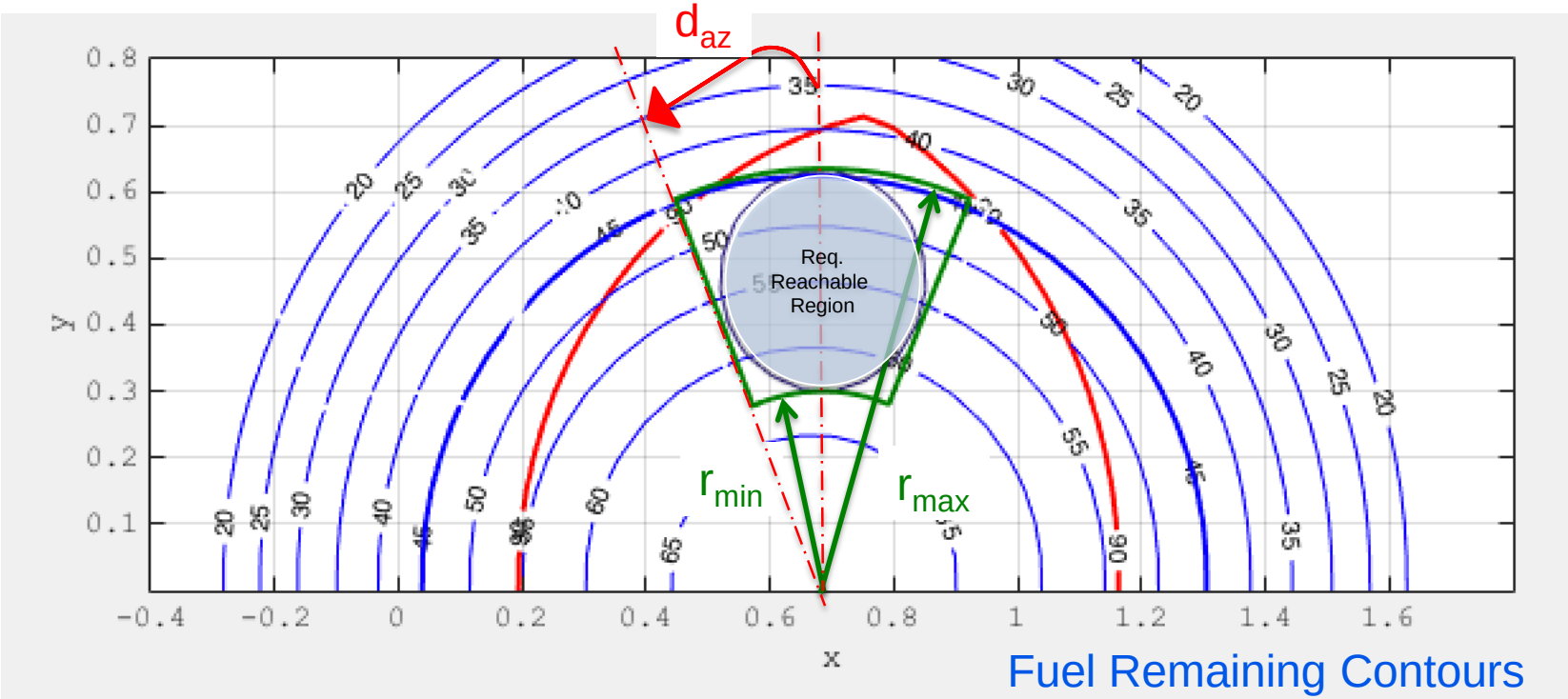
STS map generated by thresholding the padded map as follows:

- Red: Failure > 4%
- Orange: Failure 1.25-4 %
- Yellow: Failure 0.75-1.25%
- Green: Failure < 0.75 %

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}.



STS safe target decision

- Reverse wedge feature enables landing on the opposite wedge when there are extended hazards on the prime wedge.
  - This increases backshell recontact risk. However, MSL showed that the relative risk between the prime and secondary wedges was marginal (<0.5 %)
  - Feature enables to trade backshell recontact risk with landing hazard risk for areas with extended hazards.
  - Feature enabled by parameter.

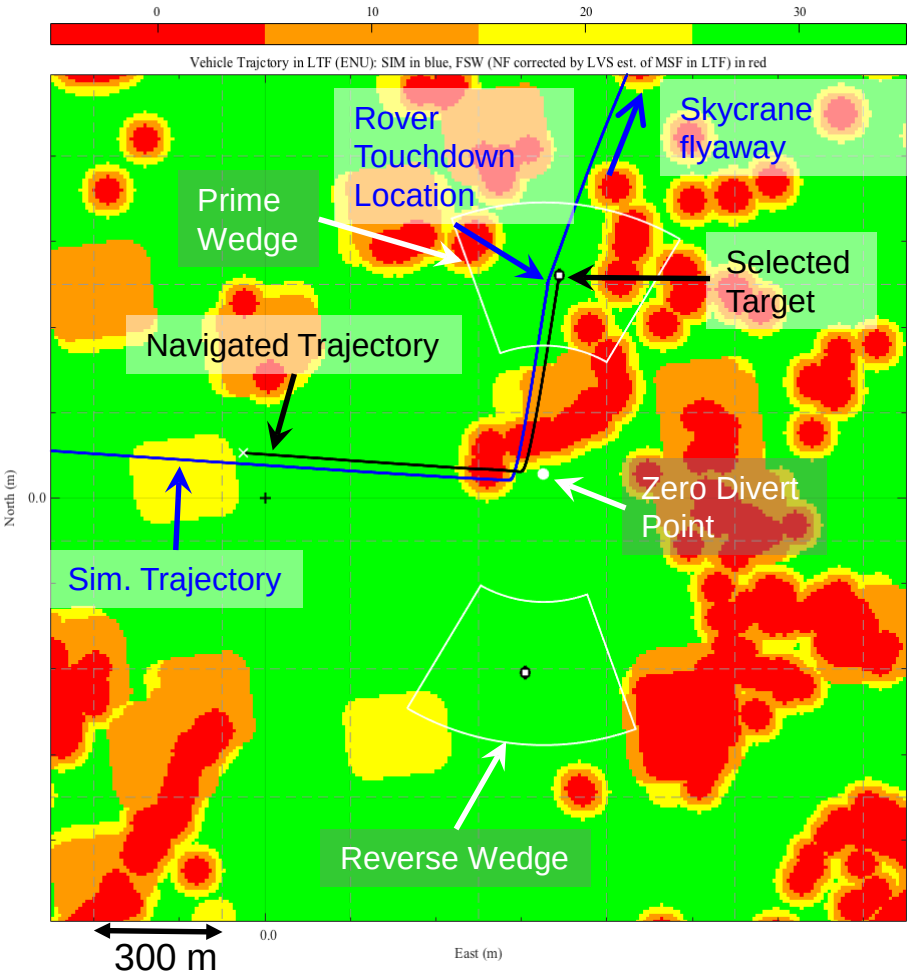
- Selection decision as indicated in the table

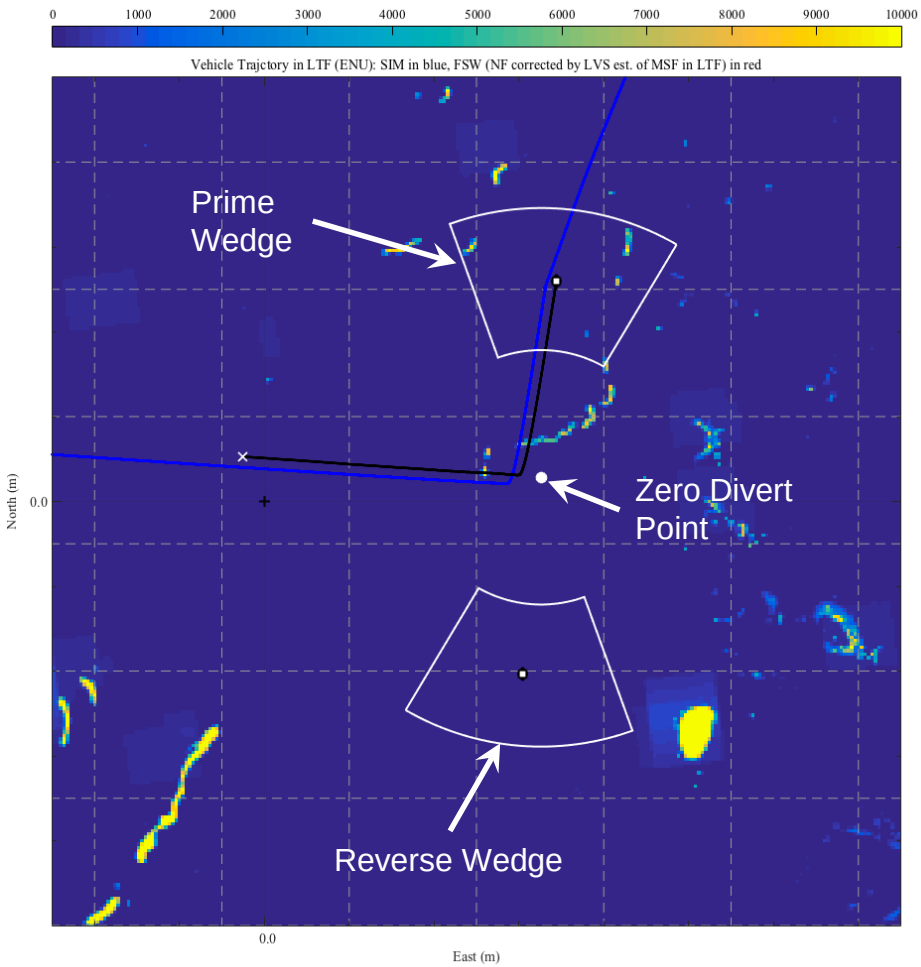
- Logic selects an ”MSL divert” if:
  a) do_sts parameter is set to disabled
  b) LVS does not produce a valid measurement
  c) A safe target (non Red) is not found

Prime Wedge	Reverse Wedge
G	G
G	Y
G	O
G	R
Y	G
Y	Y
Y	O
Y	R
O	G
O	Y
O	O
O	R
R	G
R	Y
R	O
R	R

Simulation Run

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





Conclusion

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

Thank you!

References

- A. Chen, “Mars 2020 Entry Descent and Landing Overview”, in IPPW#13, June 2016
- A. Stehura et al. “Mars 2020 Terrain Relative Navigation Accommodation” in IPPW#13. June 2016
- S. Mohan et al.” TRN Performance in Mars 2020” in IPPW#13. June 2016
- D. Way et al. “Mars 2020 Entry, Descent, and Landing System Performance with Terrain Relative Navigation” in IPPW#13. June 2016
- S. Dutta et al. “Mars 2020 Entry, Descent, and Landing Modeling and Performance” in IPPW#13. June 2016
- J. Montgomery et al. “The Mars 2020 Lander Vision System”
- R. Otero et al. “Mars 2020 Candidate Landing Site Case Study: Evolution of an Ellipse Placement” in IPPW#13. June 2016