Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Lander Vision System

Workshop for Lunar Mapping for Precision Landing

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Jet Propulsion laboratory, California Institute of Technology

3/2/2021

Mars 2020 Terrain Relative Navigation

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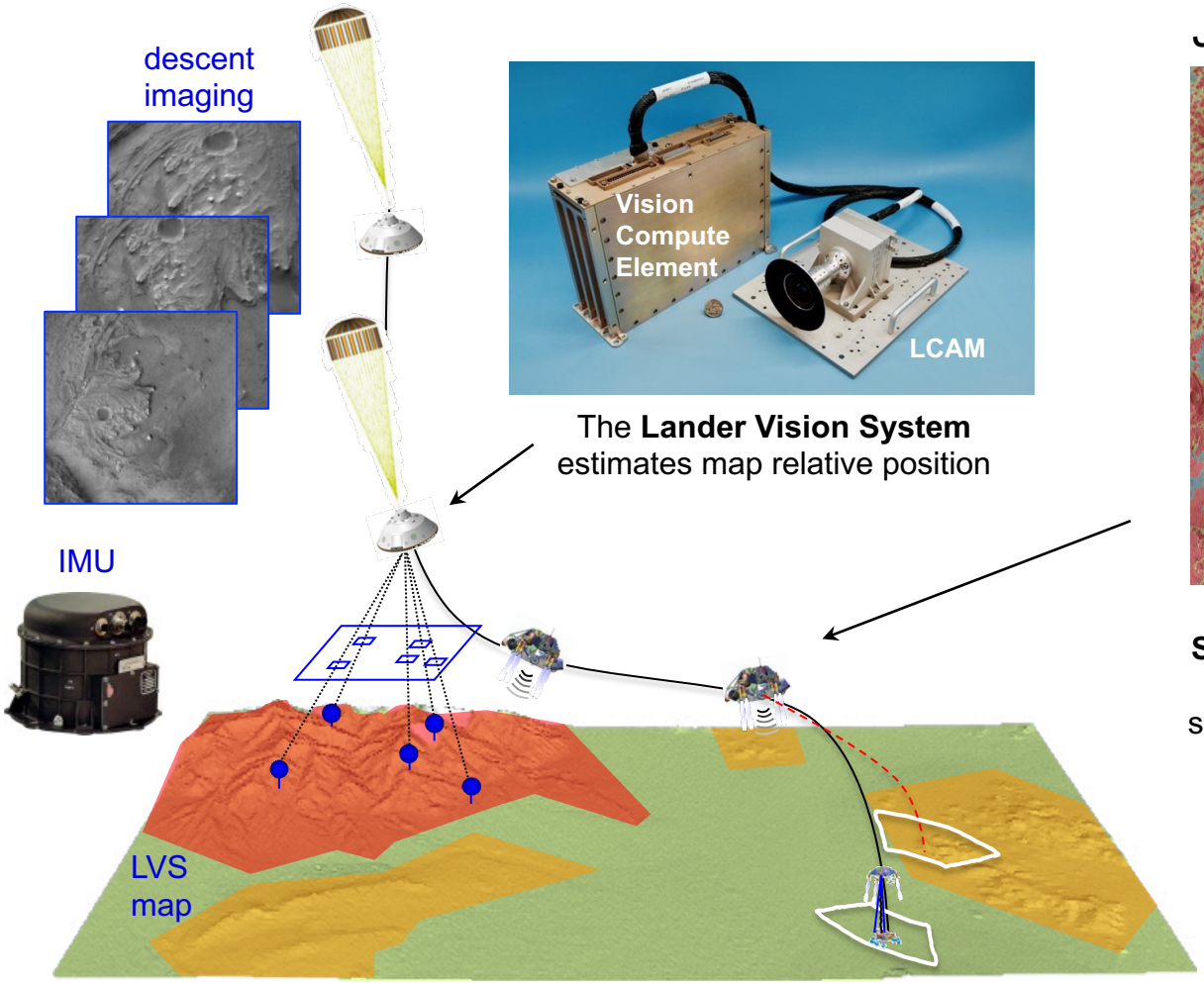
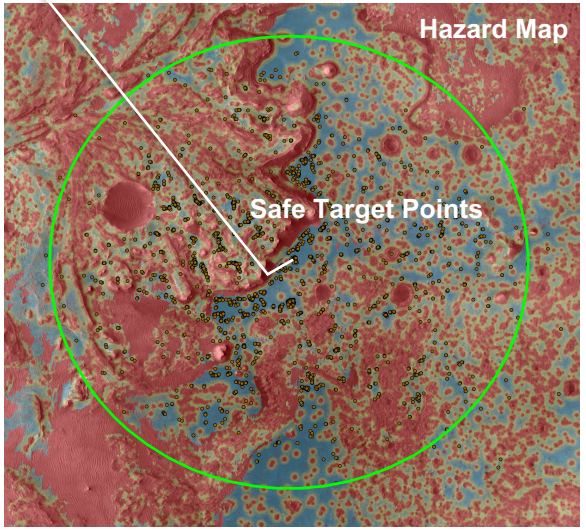


The **Lander Vision System** estimates map relative position

Jezero Crater Landing Site



Safe Target Selection picks a landing site that avoids hazards and existing MSL systems guide the vehicle to a safe landing

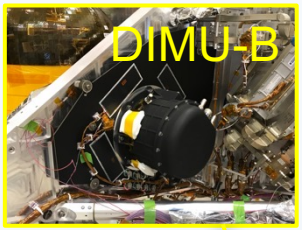
Simple TRN interface “does no harm” to MSL EDL

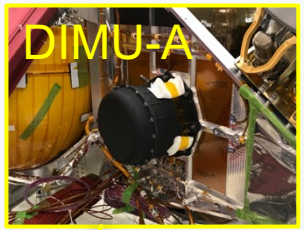
Can still land without TRN

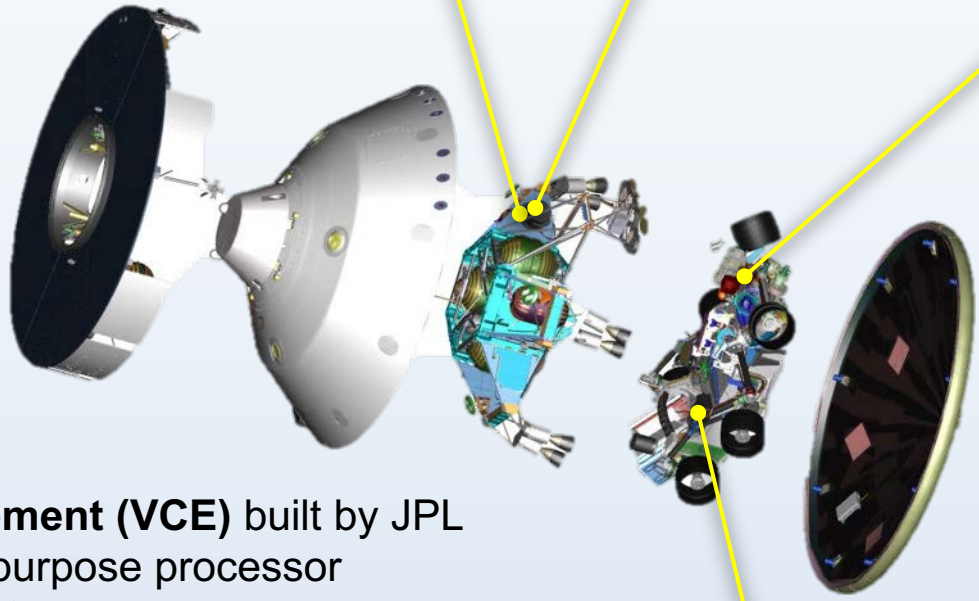
Launch: July 2020
EDL: February 18th, 2021

LVS Hardware operated nominally during EDL.

Honeywell MIMUs

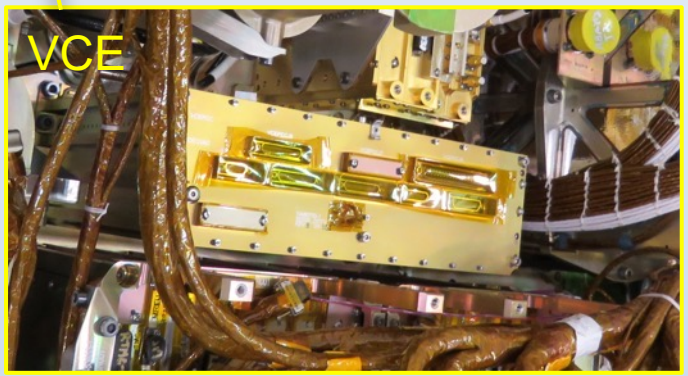






LVS Camera (LCAM)
- 1024x1024 pixels
- global shutter
- 90˚x90˚ FOV
- 100ms latency
- 200us exposure
- built by Malin Space Science Systems

Vision Compute Element (VCE) built by JPL
- RAD750 general purpose processor
  - VCE flight sofware
- Power conditioning card
- Computer Vision Accelerator Card (CVAC)
  - RTAX2000 housekeeping FPGA
  - reprogrammable Virtex5 FPGA
    - up to 7000 MIPS image processing
  - heat strap for thermal management
  - flash memory for maps and data products



Lander Vision System Processing

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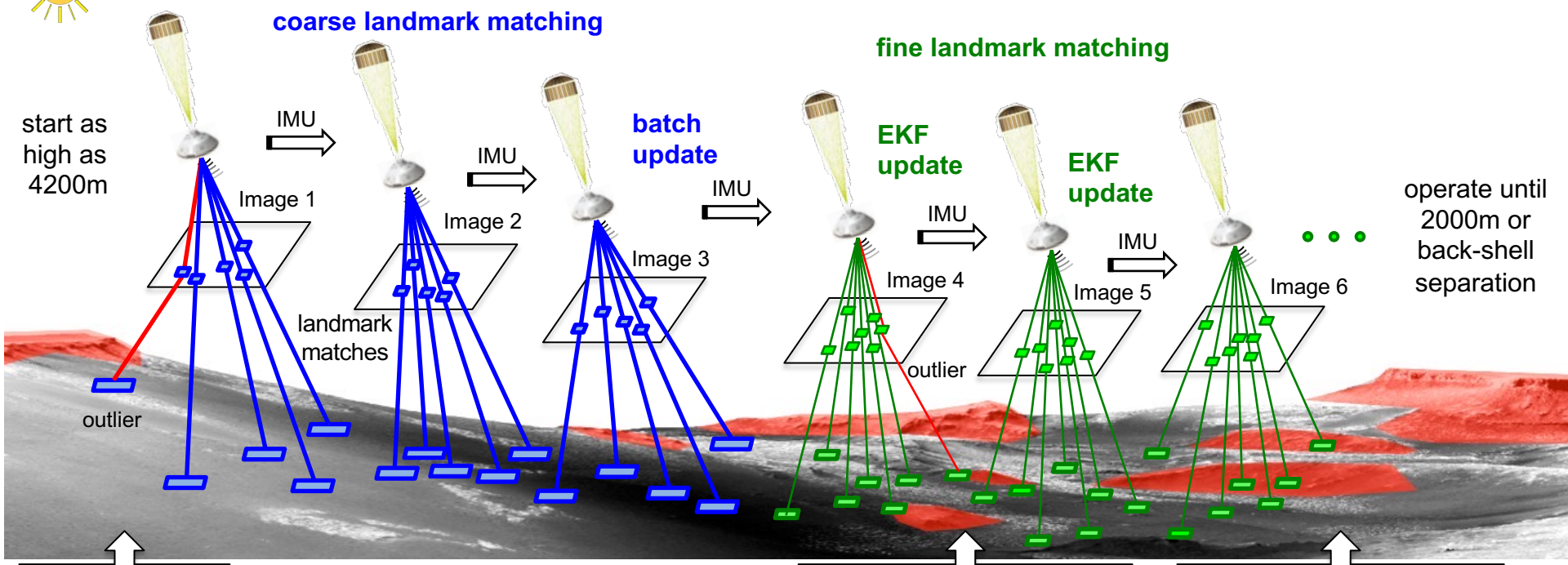
sun elevation between 25˚ & 55˚
sun azimuth between 240˚ & 310˚

off nadir angle < 45˚ & angular rates < 50˚/s
horizontal velocity < 70 m/s & vertical velocity between 60 and 115 m/s



Remove Initial Position Error of 3.2km

slope < 15˚
terrain relief < 150m
appearance entropy > 4

Reduced Position Error 40m 99%tile at 6 seconds (95% of time)

Nominal Position Error 40m 99%tile at 10 seconds (99% of time)

Coarse Landmark Matching

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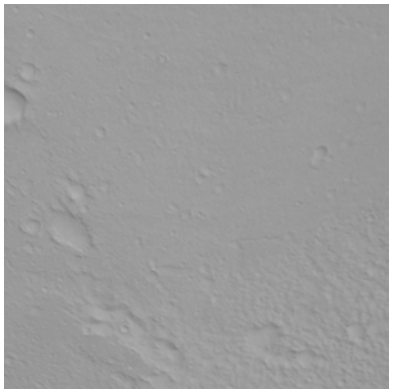
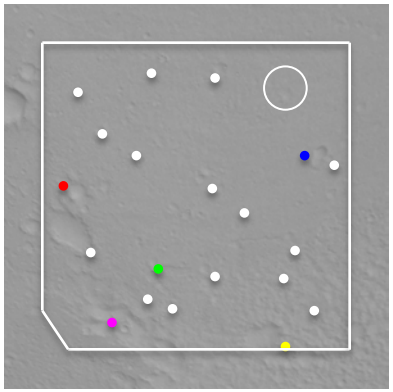
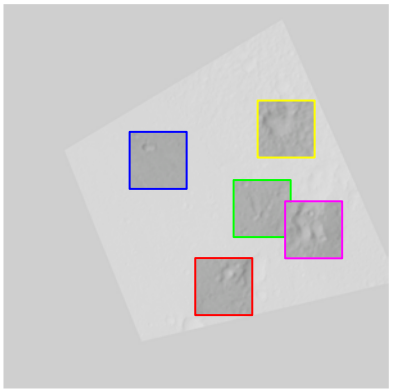
descent image



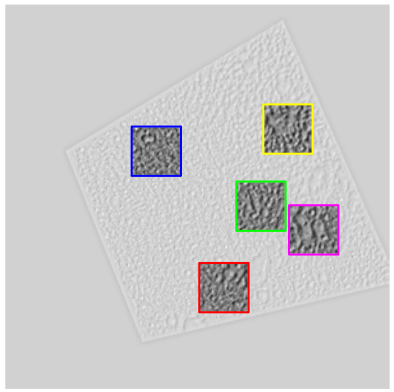
selected landmarks

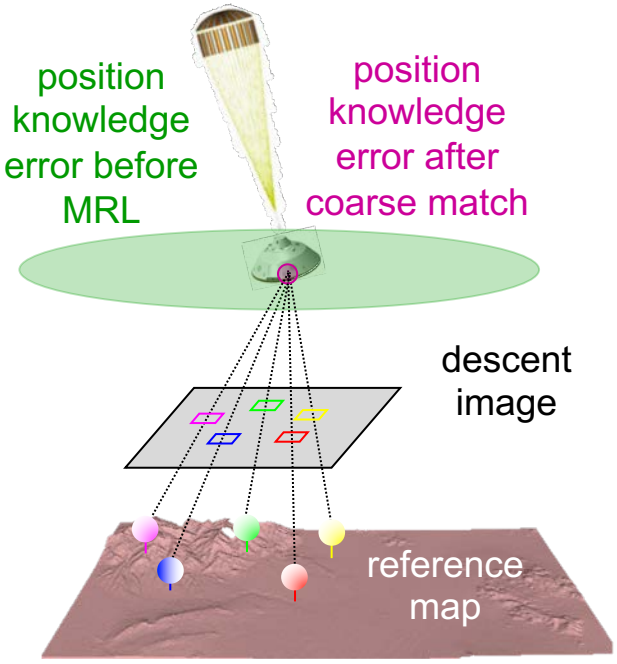


RDC/warped templates



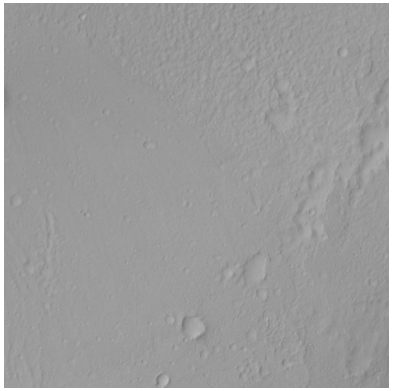
normalized templates



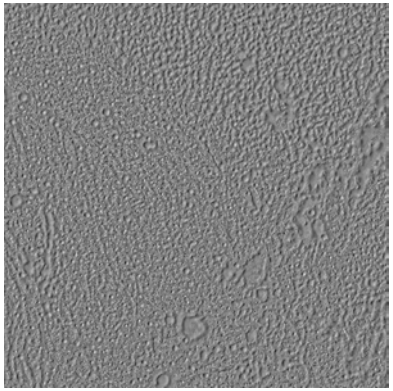


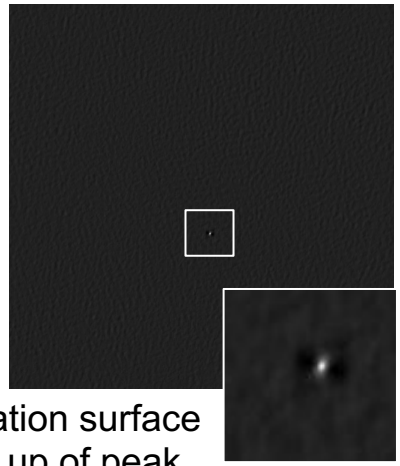
correlation template

coarse map image



normalized map





FFT correlation surface and close up of peak

LVS Flight Landmark Matches

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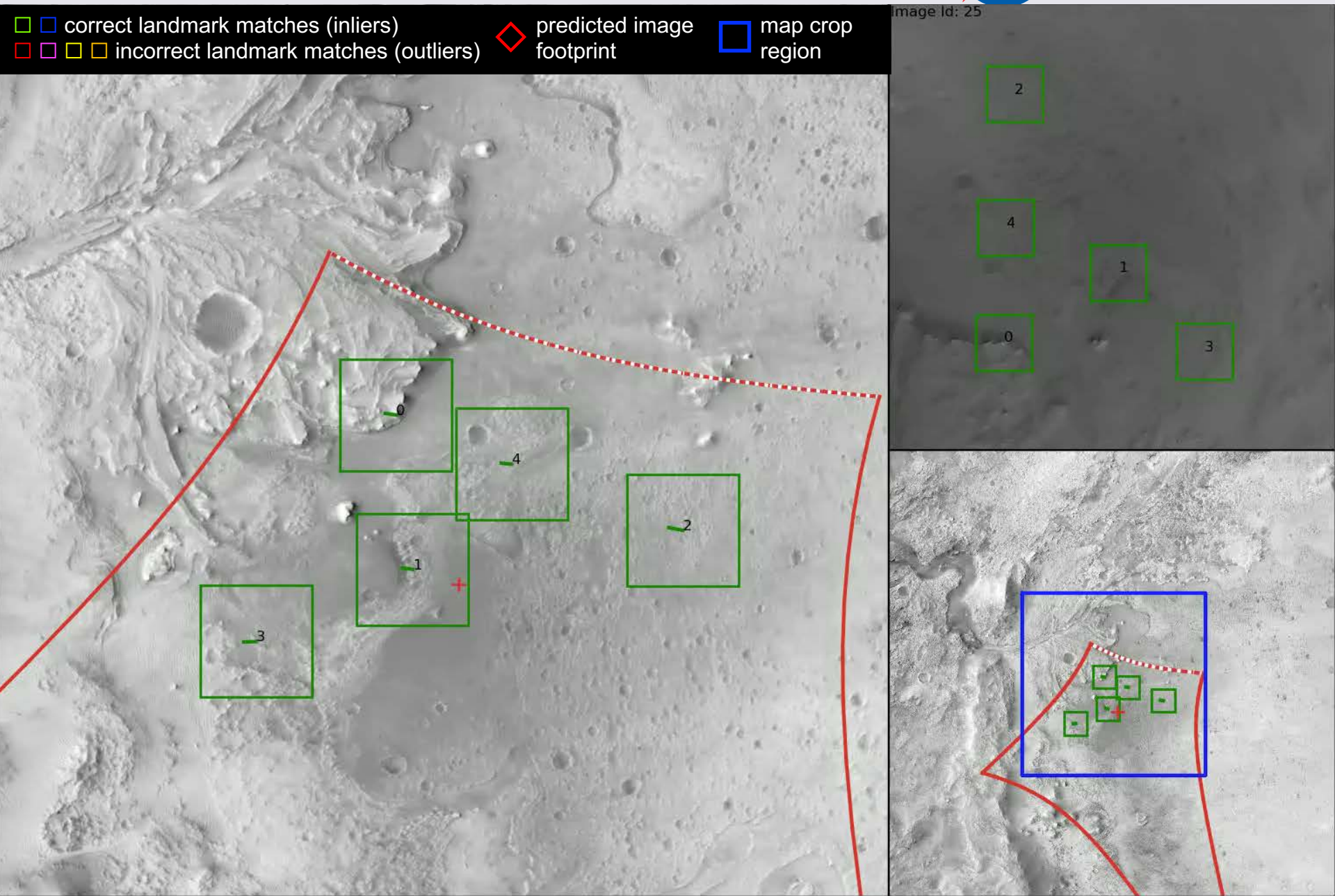

Fine Landmark Matching

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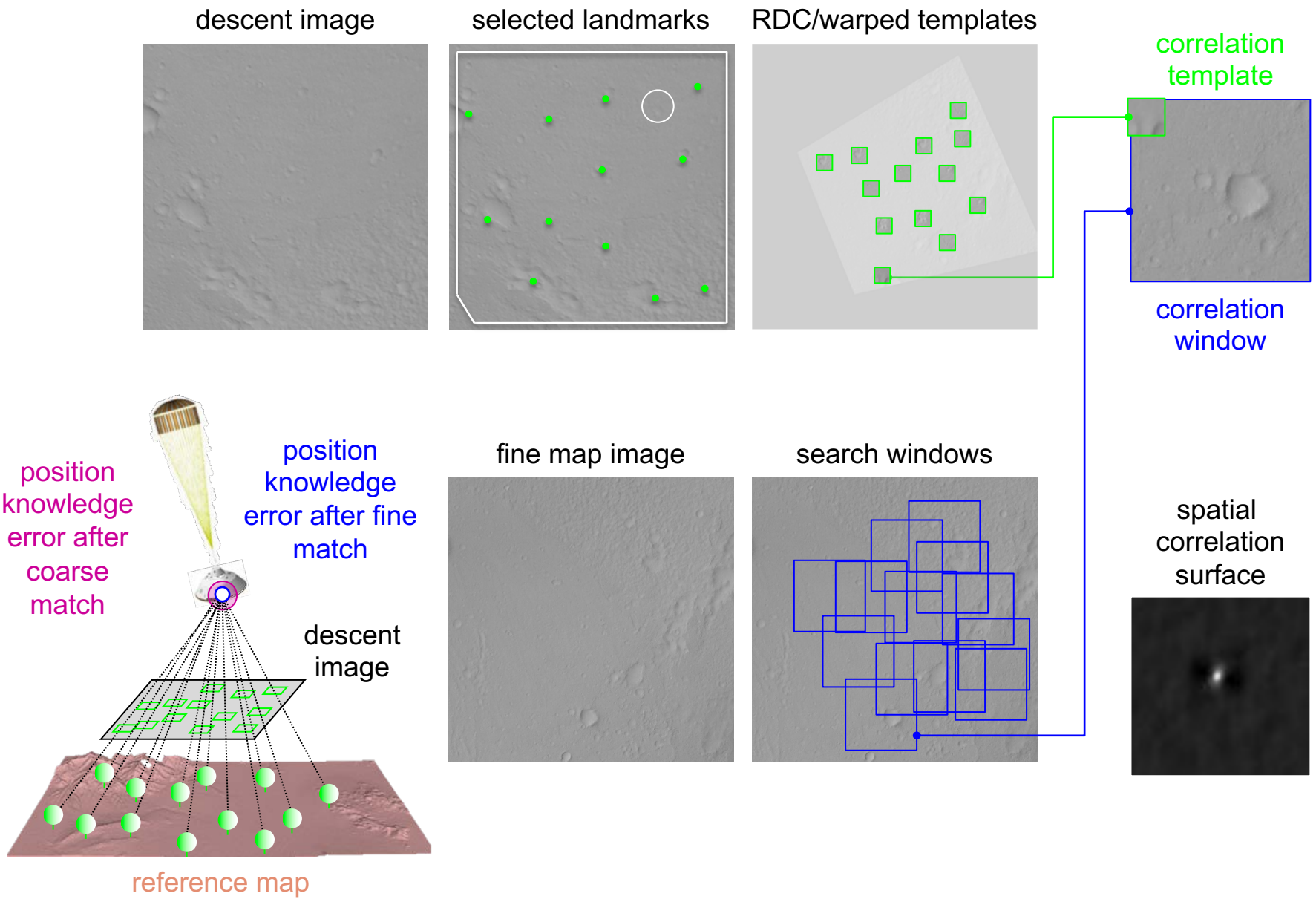

LVS Flight Landmark Matches

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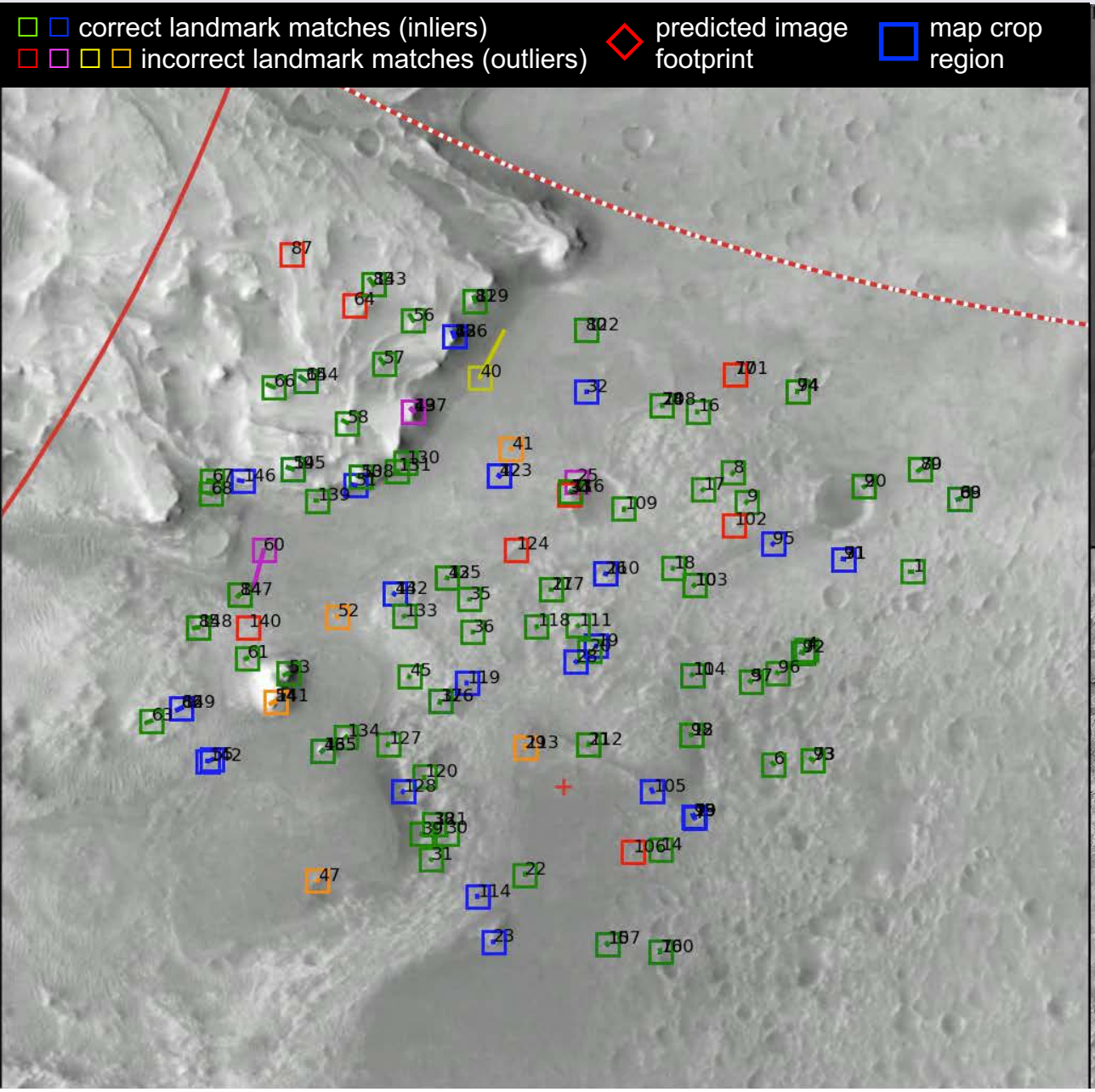
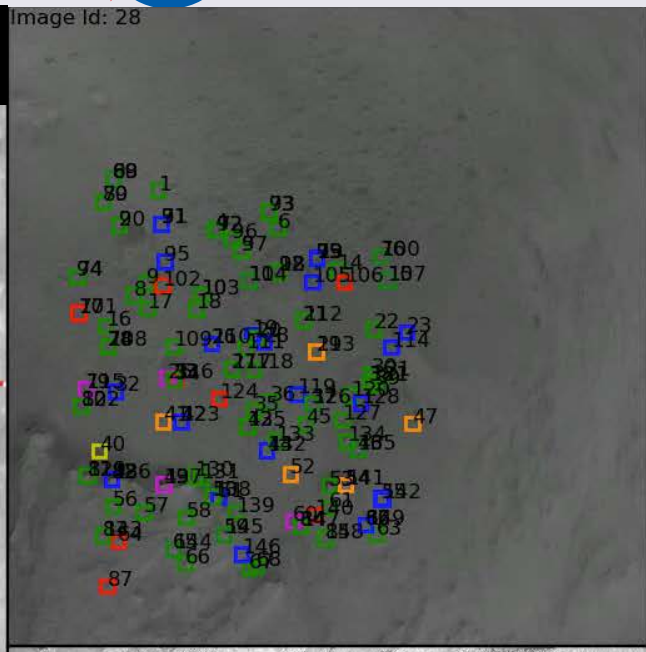
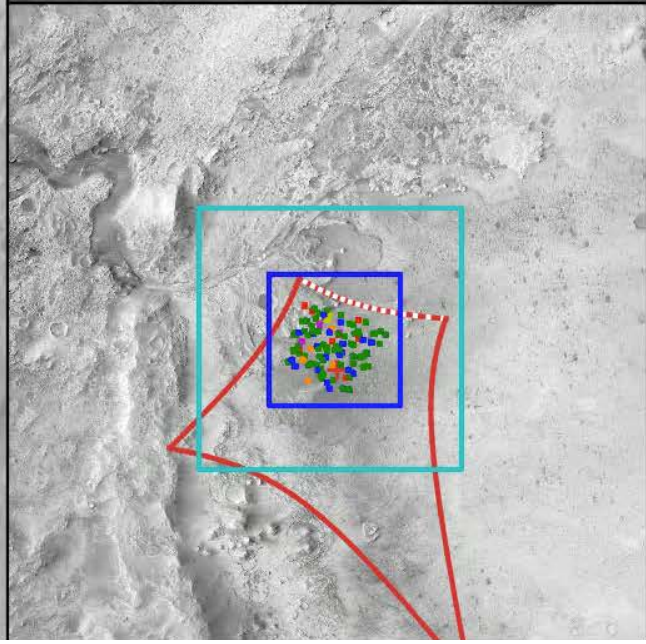
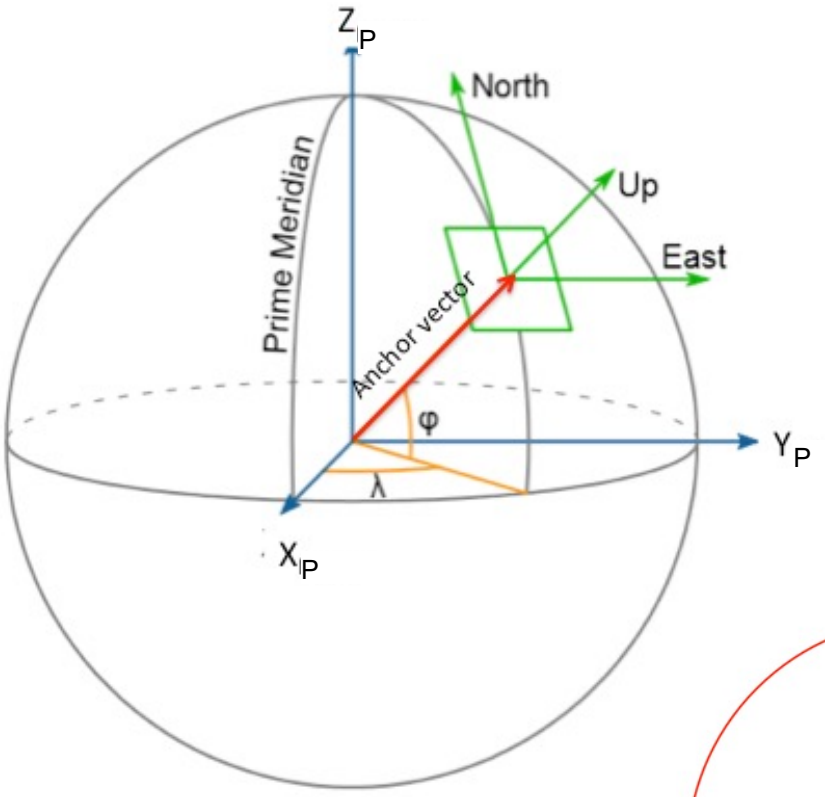


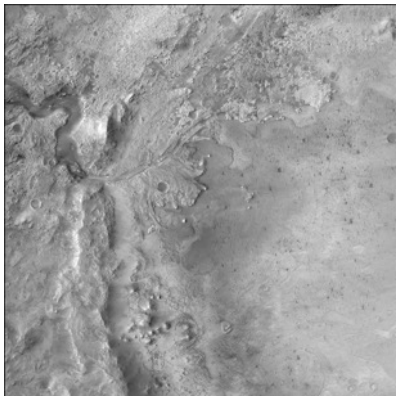




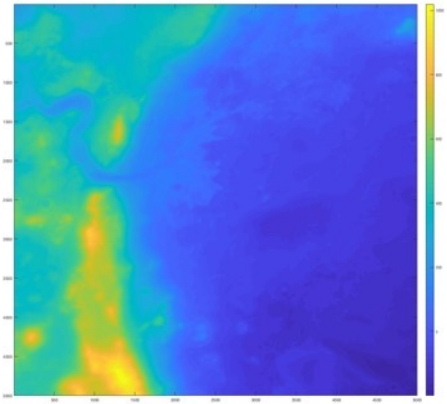
LVS Map Definition

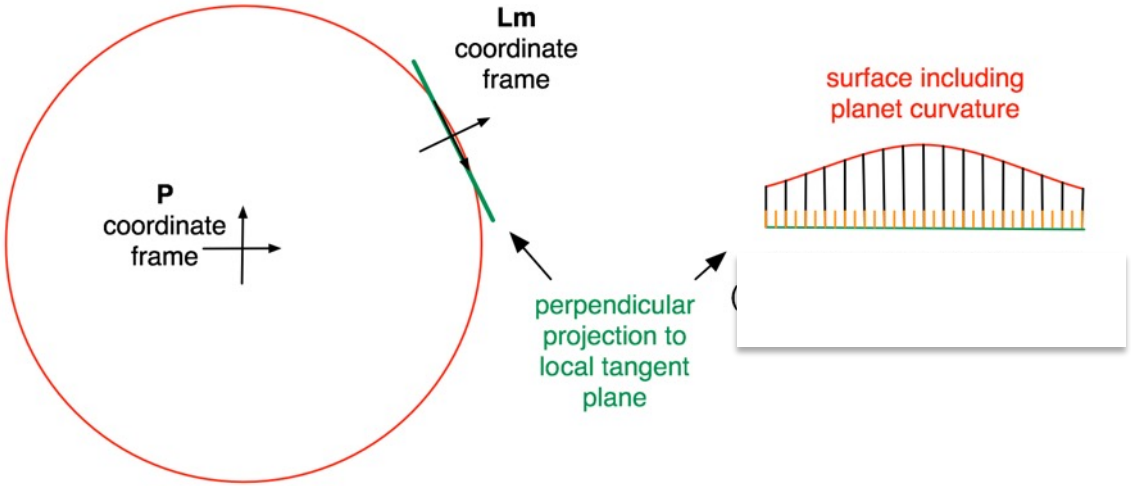


Appearance Map



Elevation Map





Mars 2020 Hazard Map

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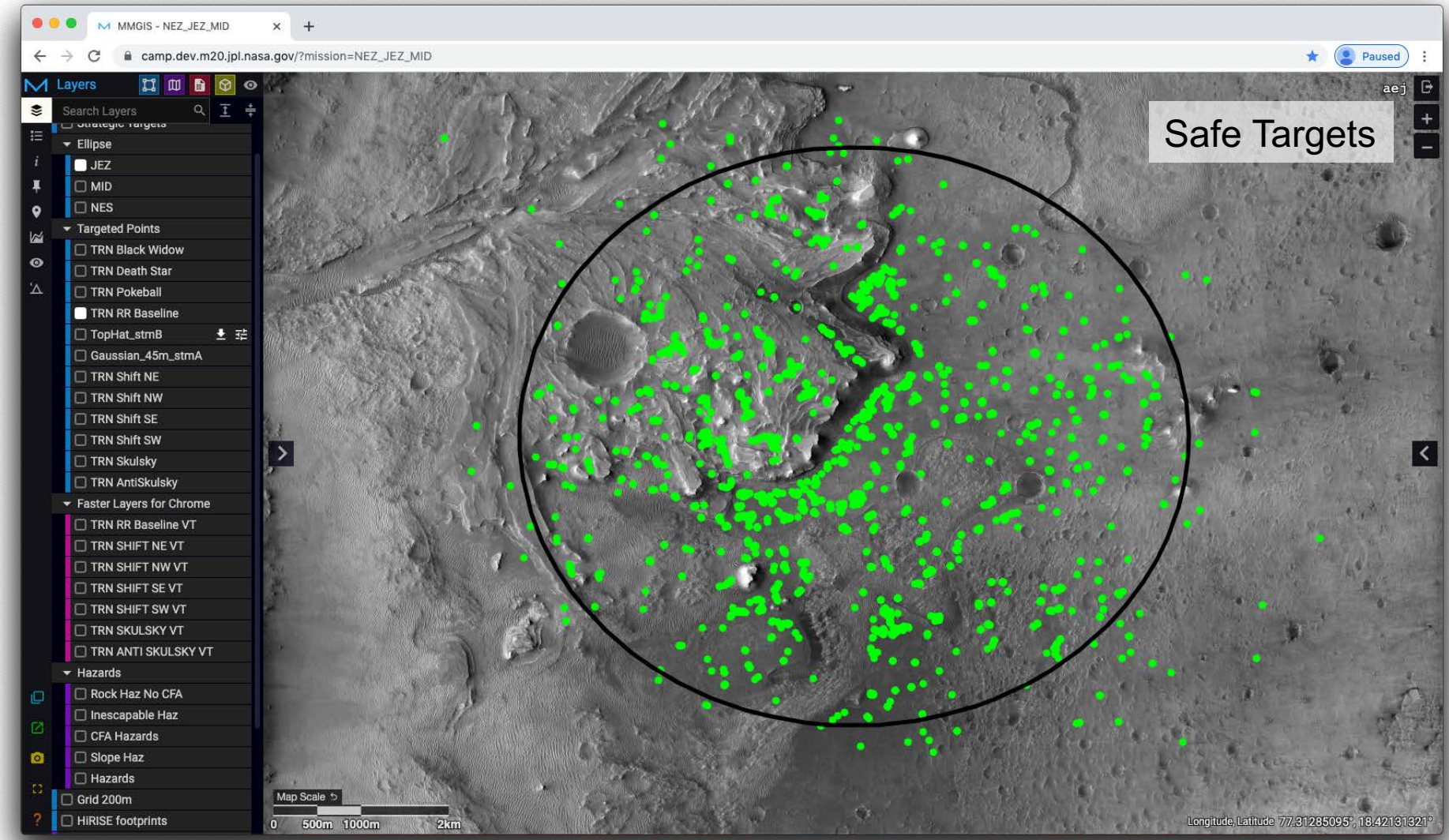

EDL V&V Trifecta

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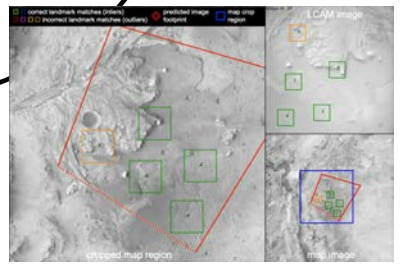
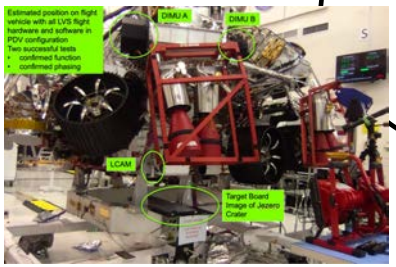
Simulations
- High fidelity models & FSW
- Cover operational envelope
- Sensitivity studies and stress testing
- Monte Carlo EDL system sim

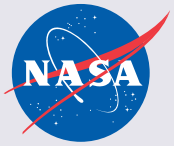


Field Test
- EM Hardware
- Real surface and Illumination
- Representative dynamics
- Used for model validation & retiring "worry beads"

HWIL Testbeds
- Flight and EM Hardware
- Low-level testing and debugging
- Complete EDL profiles
- Tests with M2020 avionics



Mars 2020 LVS Team



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GNC PDM/LVS Lead
Andrew Johnson

LVS SE
Jim Montgomery

VCE
Steve Schroeder - Lead
Chuck Bergh
Helene Bourdu
Jim Butler
Robert Donnelly
Allen Fong
Eddie Miller
Jimmy Roberts
Carson Umsted
Geoff Vaughan
Carlos Villalpando
Keyana Willcox
Jason Zheng

LCAM
Hugh Ansari - Lead
Mike Ravine (MSSS)
Jake Schaffner (MSSS)
Joe Shamah (MSSS)

VCEFSWE
Johnny Chang - Lead
Richard Cheng
Ken Clark
Kim Gostelow
Will Jay
Michael Jordan
Jack Morrison
Boris Shenker
George Sun

MRL
Nikolas Trawny - Lead
Seth Aaron
Dan Clouse

LVS Map
Yang Cheng
Robin Fergason (USGS)
Trent Hare (USGS)

LVS Field Test
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John Tamburro (Pursuit Aviation)
Doug Holgate (Pursuit Aviation)
Kyle Holgate (Pursuit Aviation)

GNC
Swati Mohan
Paul Brugarolas
Jordi Casoliva
Anup Katake

EDL
Aaron Stehura
Al Chen
Jenny Shatts

BACKUP

Coarse Match Mode Processing

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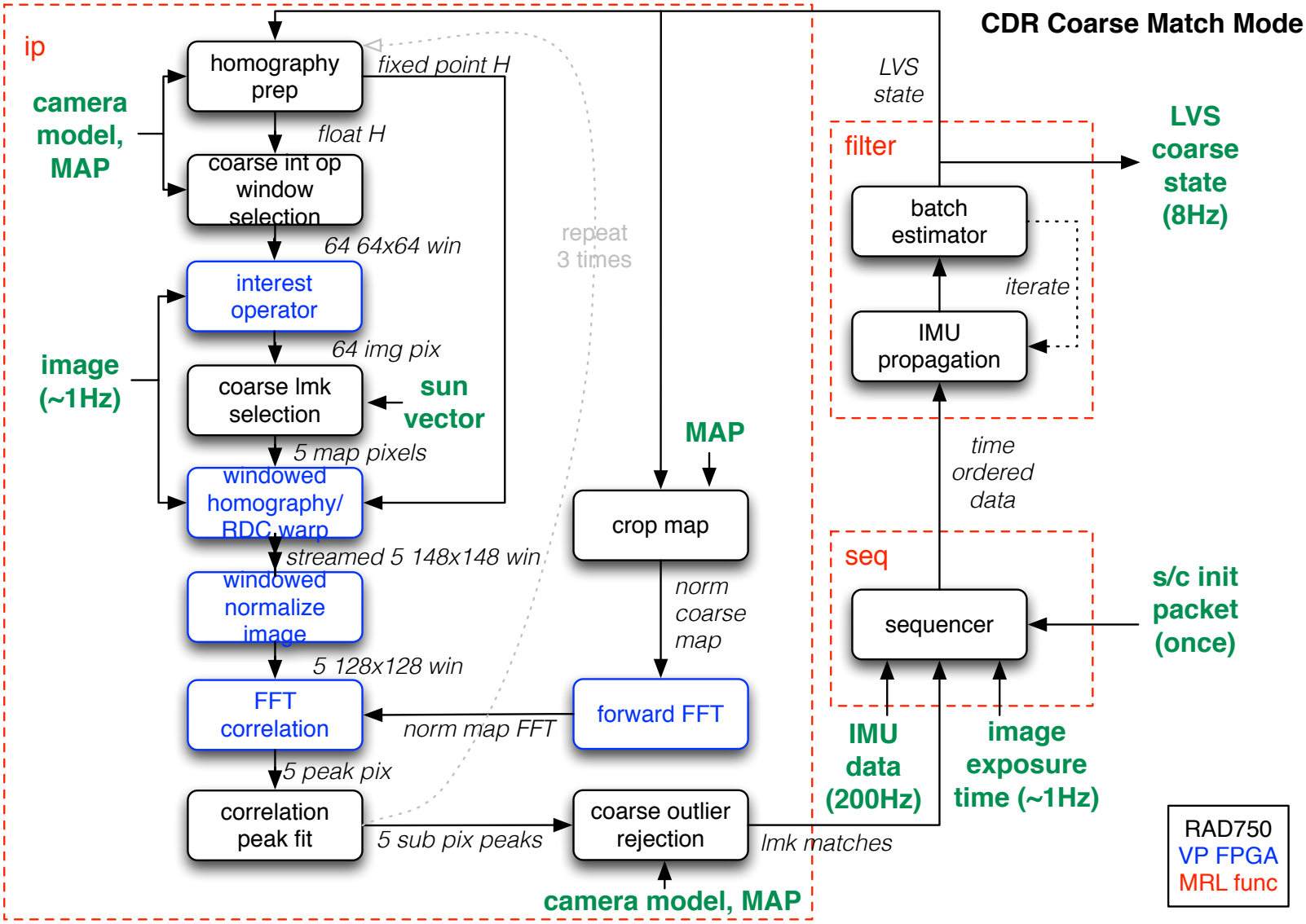

Fine Match Mode Processing

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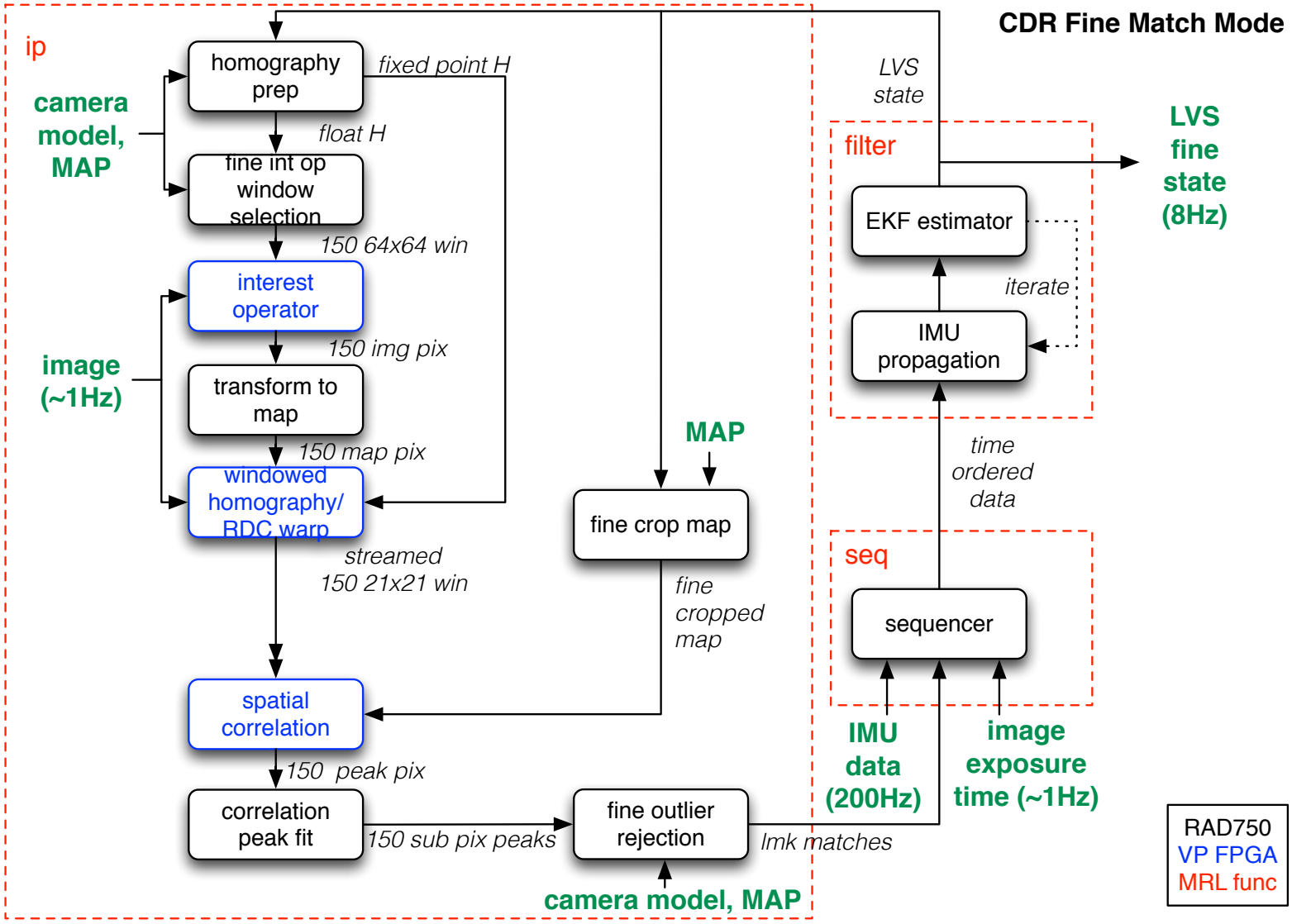

Example Landmark Matches from Field Test

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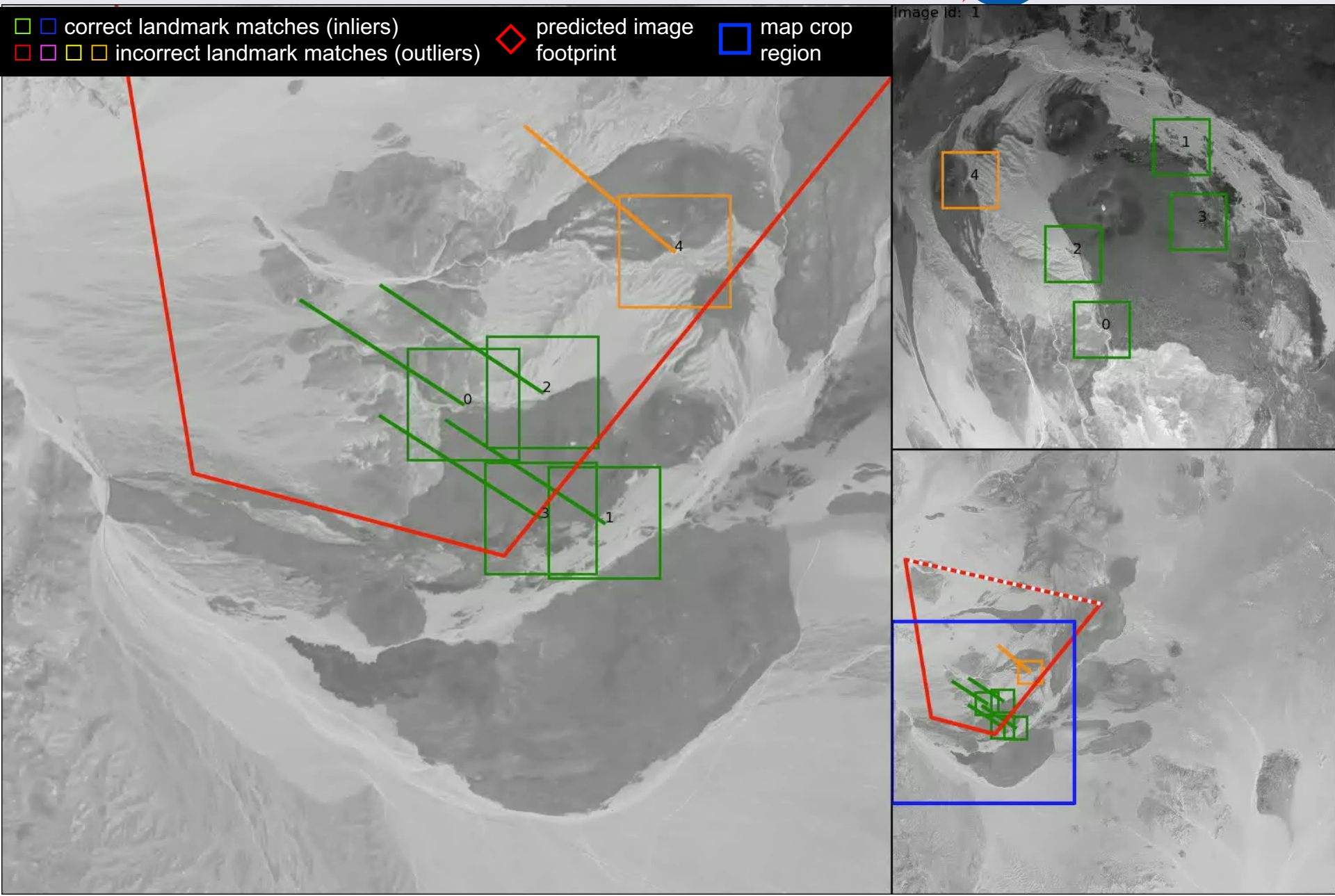

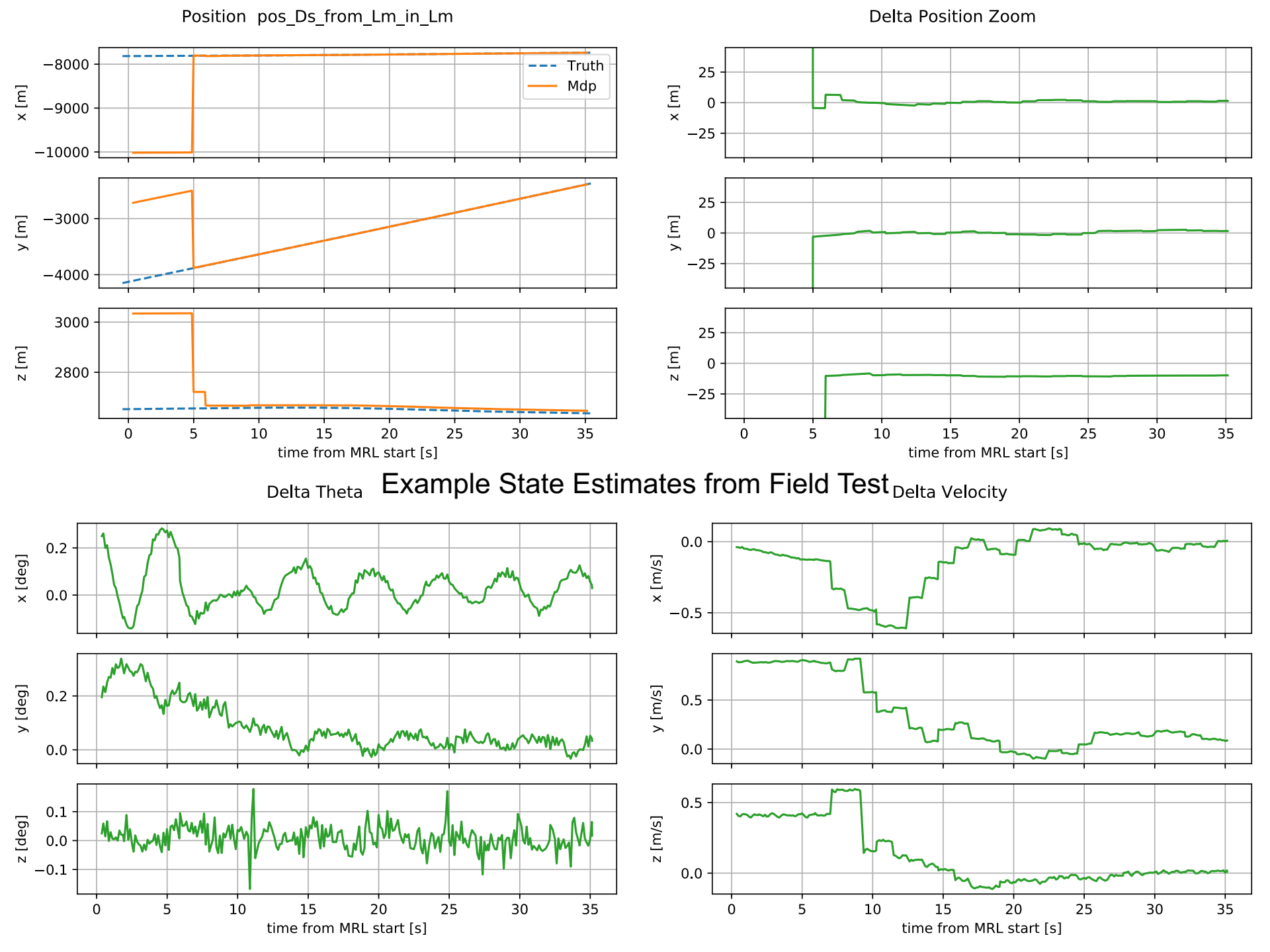
Position pos_Ds_from_Lm_in_Lm
Delta Position Zoom
Example State Estimates from Field Test
Delta Theta
Delta Velocity
Truth
Mdp
x [m]
y [m]
z [m]
x [deg]
y [deg]
z [deg]
x [m/s]
y [m/s]
z [m/s]
time from MRL start [s]