Making an Onboard Reference Map from MRO/CTX Imagery for Mars 2020 Lander Vision System

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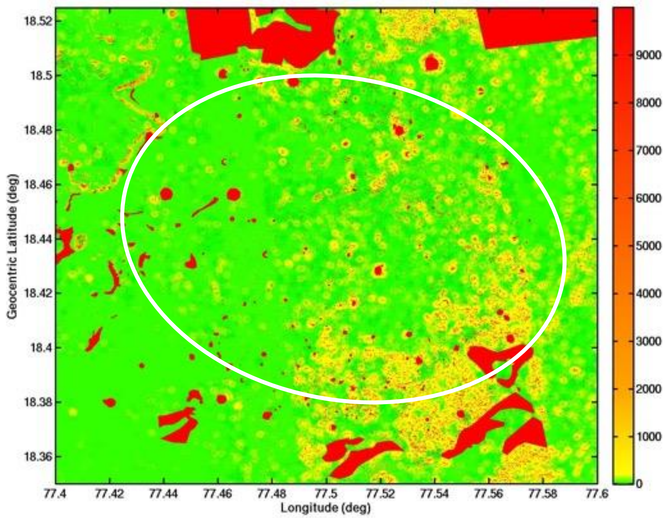
JPL

Mars 2020 Project

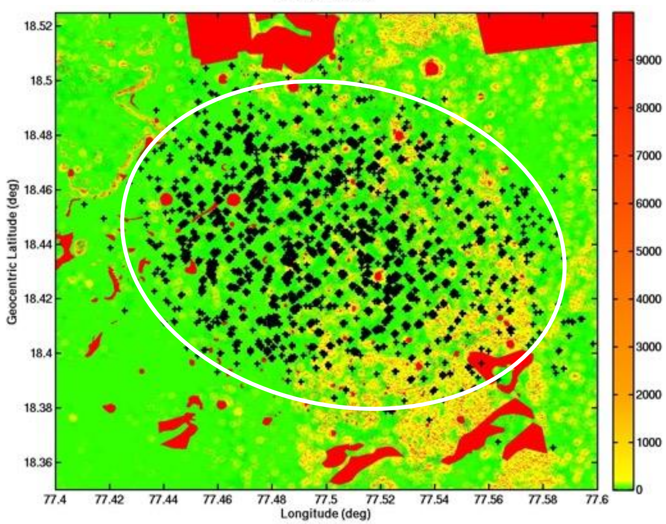
Terrain Relative Navigation

TRN enables access to hazardous landing sites



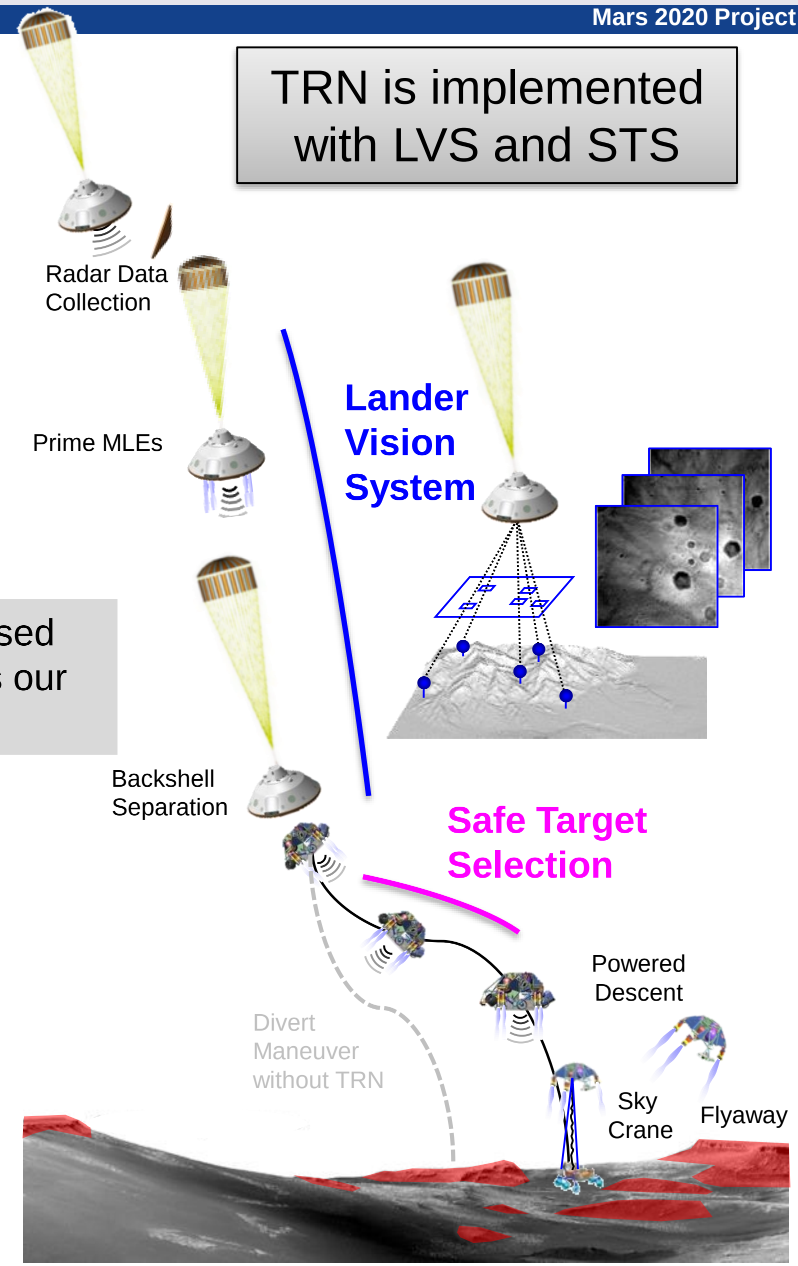
Mars 2020 landing ellipse can contain numerous hazards

Feature matching based on LVS map gives us our initial location



TRN augments MSL EDL to avoid hazards and land safely

TRN is implemented with LVS and STS



Challenges and General Approach Strategy

- Challenges:
  - There is no reliable ground truth reference for Mars
  - All available orbital images are taken by push broom cameras, which introduce difficult-to-model artifacts
  - This is the first ever use of a reference map for real time EDL. No successful preceding example exists.
- Strategy:
  - Identify all possible error sources related to the final map product.
  - Choose the most reliable and suitable segment of data.
  - Refinement of input models and batch image motion refinement.
  - Validate the final map product by (1) comparing the LVS map with other maps from different platform such as HRSC, HiRISE and (2) Cross-validating independently generated maps.

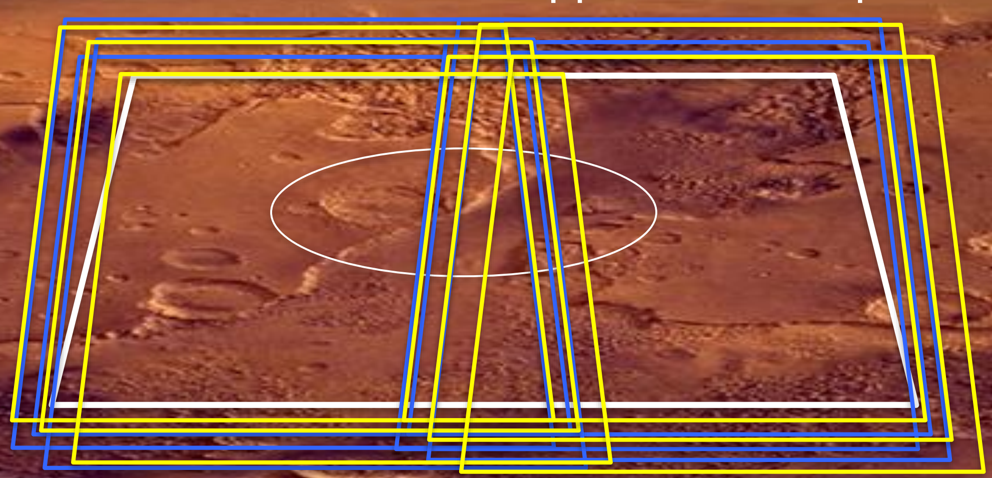
MRO CTX imaging is used to generate the LVS map

- CTX images are 6m/pixel and about 30km across
- MRO images the landing site around the time of landing (telecom constraint)
- stereo pairs are needed for elevation map generation while one of the stereo images is used for the appearance map

- 2 stereo pairs are needed to cover the map area
    - a third stereo pair is used to improve de-jittering (bundle adjustment)

- an additional 3 stereo pairs will be used to build a separate map for V&V

LVS elevation and appearance map

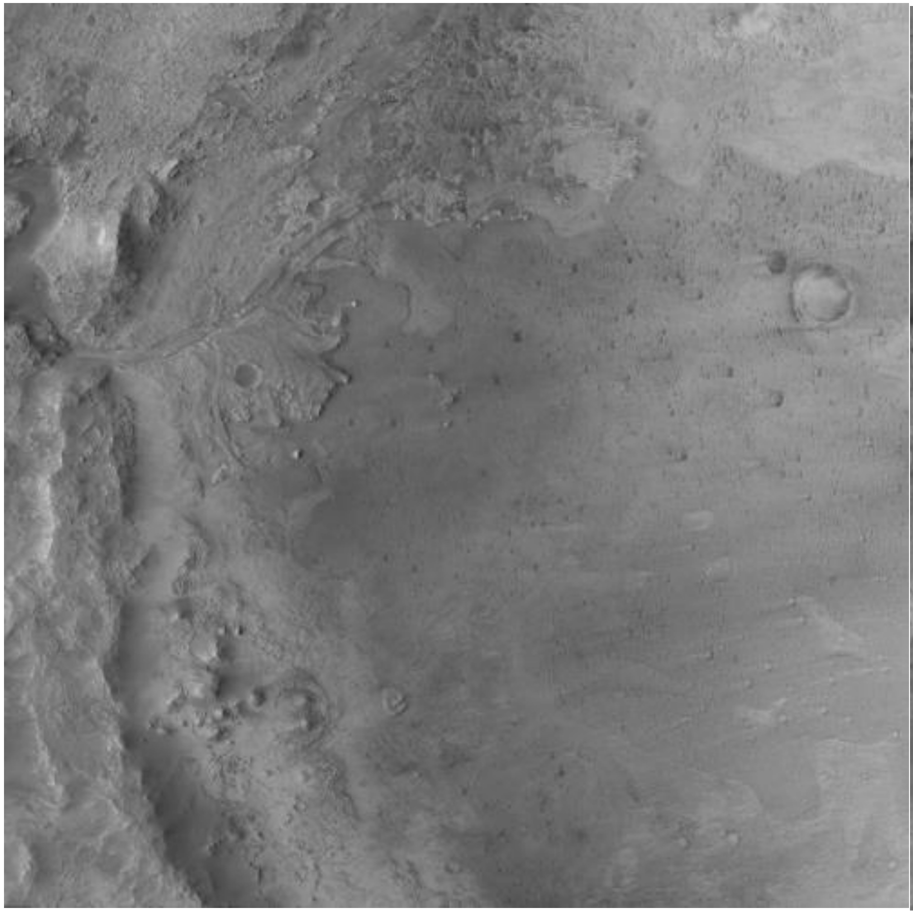


LVS Map Generation Improvements

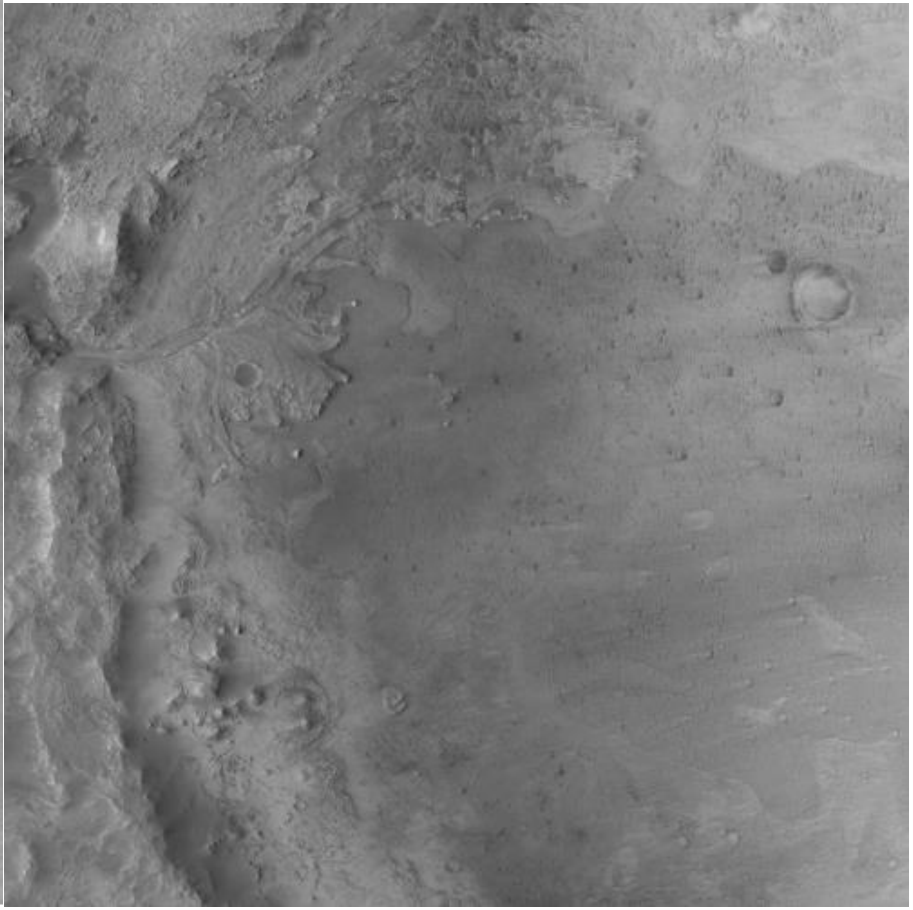
Action	Description	Result
CTX image and ancillary data selection	Used image, temporal, spatial, and weather information and associated ancillary data quality info to select the highest quality image set	Avoided poor quality (e.g. dusty) images and bad ancillary data (e.g. low quality orbit solution)
Camera model refinement	Errors were found in the available CTX camera models (Bell and Kirk). Refined the camera model using using HRSC/MSL MARDI and CTX images.	Reduced camera error from ~150 m to < 50 m and camera attitude error from 0.08˚ degree to <0.02˚
Time tag correction	The time tags of CTX images contain up to 30ms of error. Used stereo ray gap analysis to reduce this error.	Reduced map error from more than 100 m to less than 10 m
Bundle adjustment	MRO attitude file (CK kernel) does not capture MRO jitter (high frequency vibration) which can result DEM errors up to 10 m. Used multiple images to solve for the jitter and removed it from the attitude profile.	Reduced the map error to meters.

LVS Appearance Map

Jezero Mosaic A (30 by 30 km)



Jezero Mosaic B (30 by 30 km)



Compliance Approach

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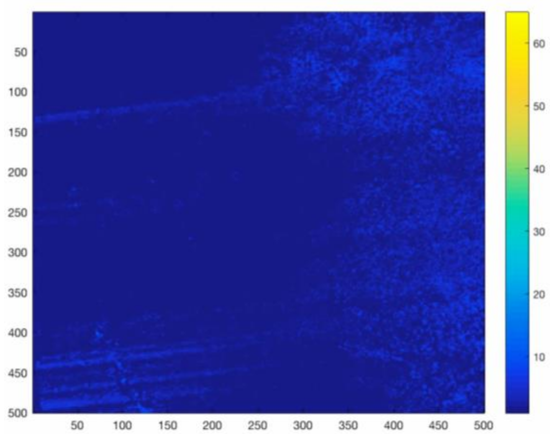
Map Distortion

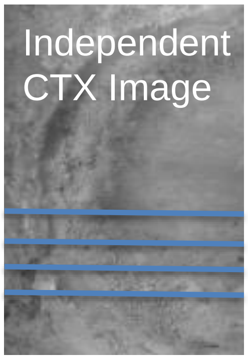
Compared LVS appearance map to HiRise: error < 3m

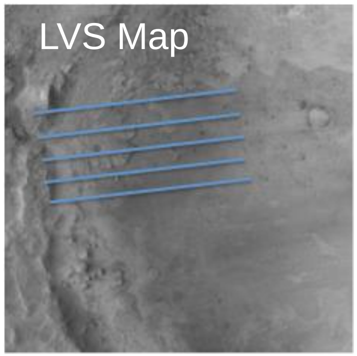
also compared LVS map to LVS map error < 3.5m



Map Orientation

Compared independent CTX image to LVS appearance map. error < 0.3mrad

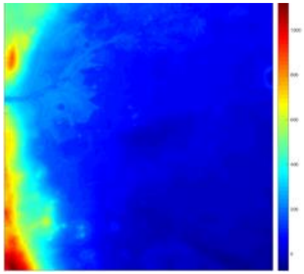


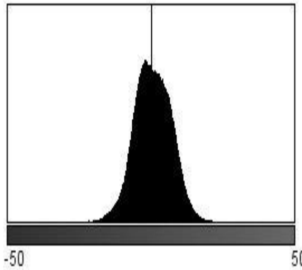


Elevation Map Noise

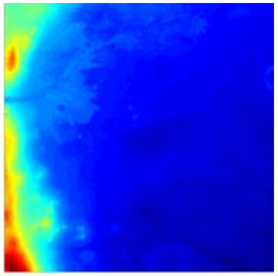
Compared 2 LVS elevation maps error < 15m (3 sigma)

Mosaic A





Mosaic B



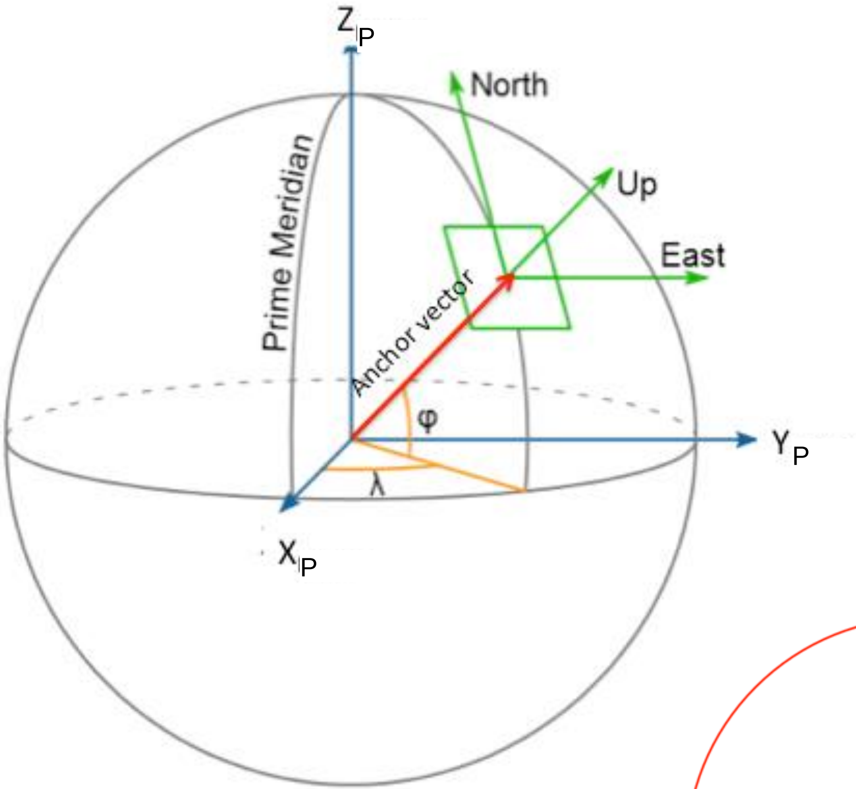
Co-registration Error

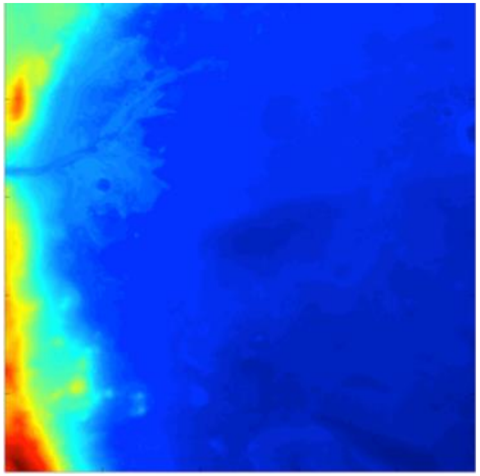
Summed stereo projection error (ray gaps) with mis-registration in overlap region between ortho-photos that make the appearance map error < 3m

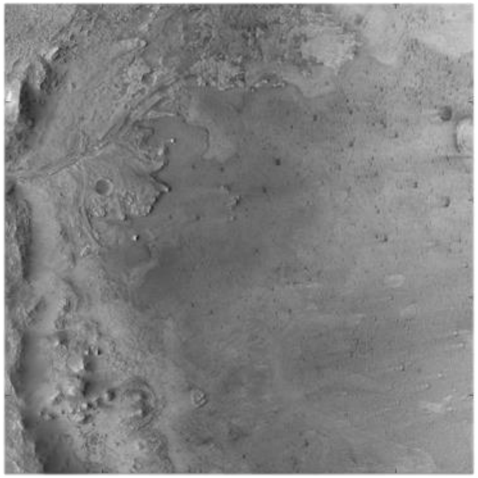
Conclusion

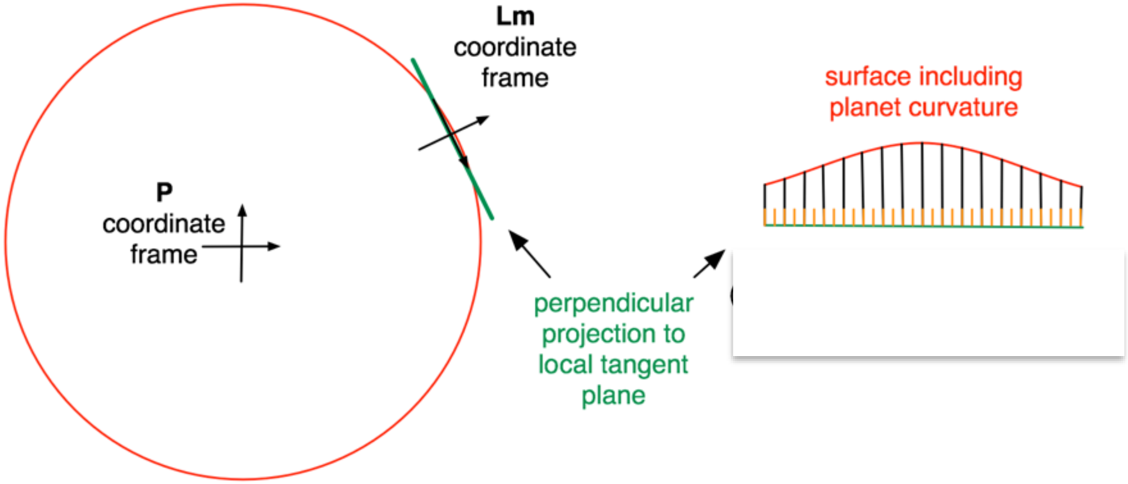
- In this paper we presented a new methodology for building the reference map from CTX imagery. Some error sources are identified and analyzed. Some of the errors, such as the time tag error and camera model error, have been addressed. For other errors, which are harder to remove, we have developed a procedure to reduce them as much as possible.
- Two independent LVS reference maps - Mosaic A & B - have been produced so far. We have validated both maps against each other and against other data such as HRSC and HiRISE maps. These maps have met and exceeded the mission requirements.

LVS Map Definition









Potential Error Sources

Error Name	Description	Magnitude	Source
MRO attitude error	There is up to 35 uRad uncertainty in the s/c quaternions relative to the Mars equator and IAU vector of date frame instance uploaded to the s/c	**35 uRAD**	**SPICE Team**
Attitude error between Mars and J2000	There is a few (<5) uRad variable error between the Mars equator and IAU vector of date frame instance uploaded to the s/c and the continuous implementation of this frame is SPICE	**<5 uRad**	**SPICE Team**
Mars orientation model	There is a ~10 uRad error in Mars rotation provided by IAU constants relative to higher fidelity Mars rotation model developed by JPL SSD group	**~10 uRAD**	**SPICE & SSD Teams**
MRO Trajectory error	MRO orbit solution can have up to 10s of meters error	**~10m**	**SSD team**
MRO CTX Time tag	MRO clock linear piecewise correlation function provided in SCLK kernel can have error of up to 20 *milliseconds*	**20 millseconds**	**SPICE Team**
MRO CTX camera model	MRO CTX camera model may have up to 10 pixels displacement error(LVS team);	**10 pixels**	**JPL/USGS Team**
Image Jitter	MRO CK does not capture high frequency jitter	**5 m**	**JPL team**

Careful CTX image data selection (Jezero) (93651)

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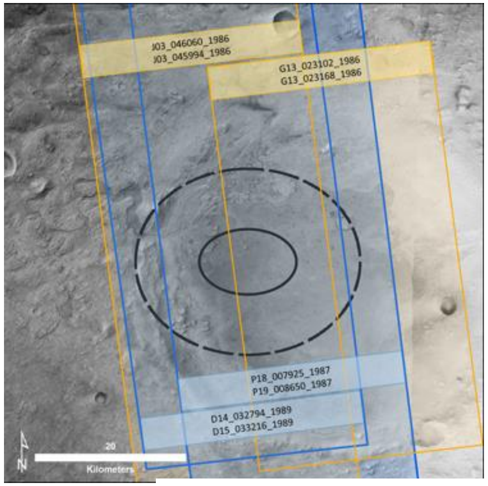


Requirement ID: 93651:The LVS appearance map shall be constructed from images with sun elevation angles in the Lm frame that are within +/-15˚ of the sun elevation angle at nominal landing time and are within +/-35˚of the nominal sun azimuth angle at landing time.

Jezero Landing Sun Illumination

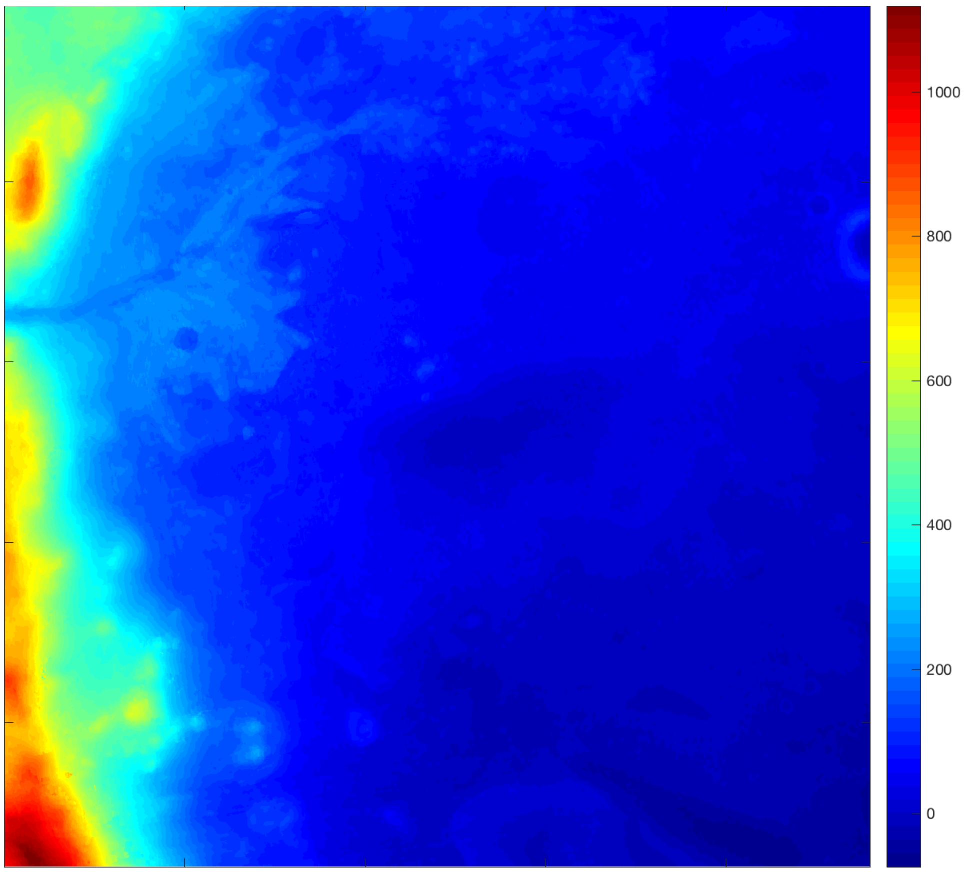
- elevation: 39.6º to 42.2º
- azimuth: 255.8º to 257.2º

	Role	Image name (Mosaic A)	sun ele.	delta ele	sun azi.	delta azi.
1	First pair	G13_023168_1986_XN_18N282W.cal.pgm	44.16	3.16	264.96	8.96
2	First Pair	G13_023102_1986_XN_18N282W.cal.pgm	44.49	3.49	264.49	8.49
3	Second Pair	F04_037396_1985_XN_18N282W.cal.pgm	34.7	-6.3	224.85	-31.15
4	Second Pair	F04_037330_2008_XN_20N282W.cal_sub.pgm	36.7	-4.3	222.85	-33.15
5	Support Pair	P18_007925_1987_XN_18N282W.cal.pgm	47.12	6.12	279.71	23.71
6	Support Pair	P19_008650_1987_XI_18N282W.cal.pgm	46.25	5.25	287.21	31.21

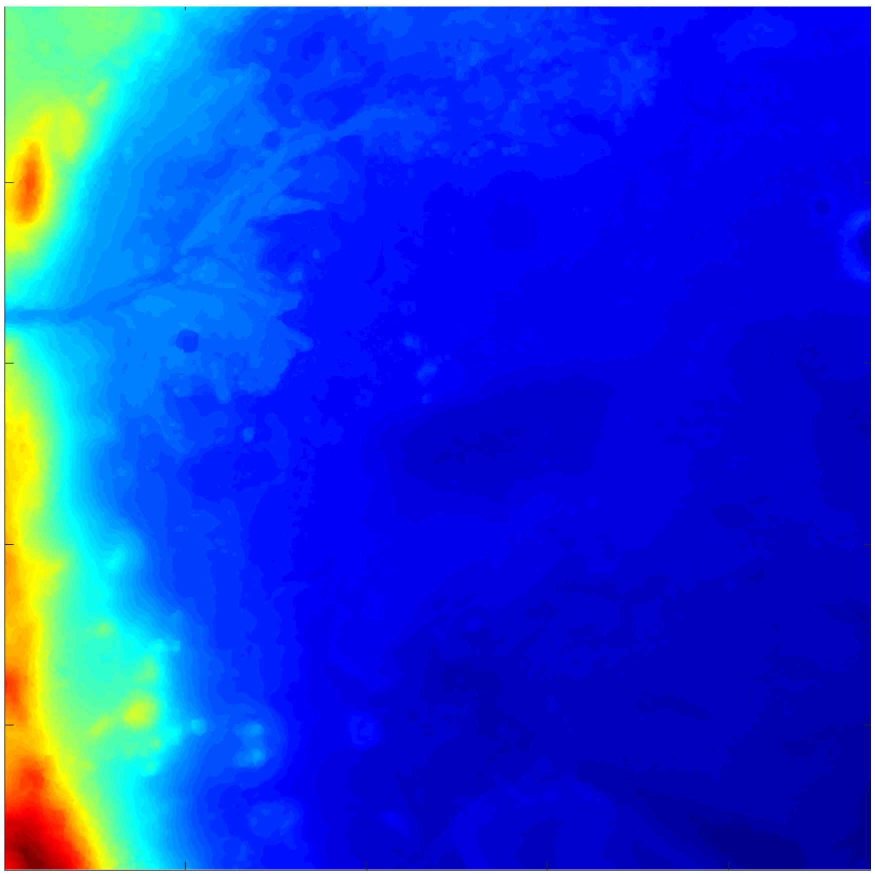
	Role	Image name (Mosaic B)				
1	First Pair	J03_046060_1986_XN_18N282W.cal.pgm	40.1	-0.9	240.3	-15.7
2	First Pair	J03_045994_1986_XN_18N282W.cal.pgm	42.4	1.4	237.6	-18.4
3	SecondPair	F05_037607_2008_XN_20N282W.cal_sub.pgm	32.7	-8.3	261.8	5.8
4	Second Pair	F05_037752_2008_XN_20N282W.cal_sub.pgm	32.4	-8.6	255.57	-0.43
5	Support Pair	D14_032794_1989_XN_18N282W.cal.pgm	51.9	10.9	241.3	-14.7
6	Support Pair	D15_033216_1989_XN_18N282W.cal.pgm	51.08	10.08	254.2	-1.8

LVS DEM

Jezero A



Jezero B



Map Error Sources

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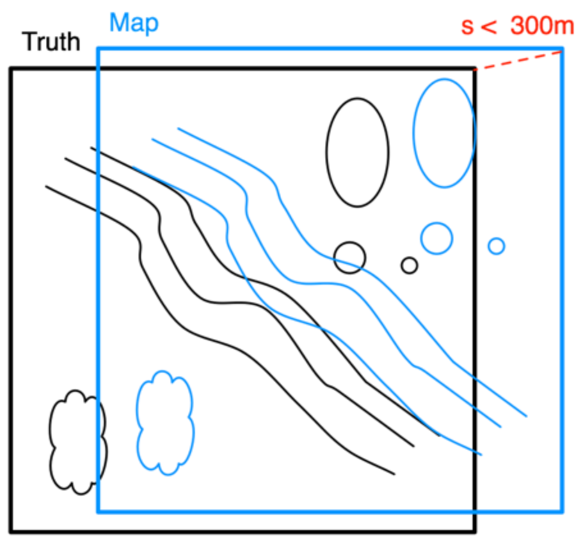
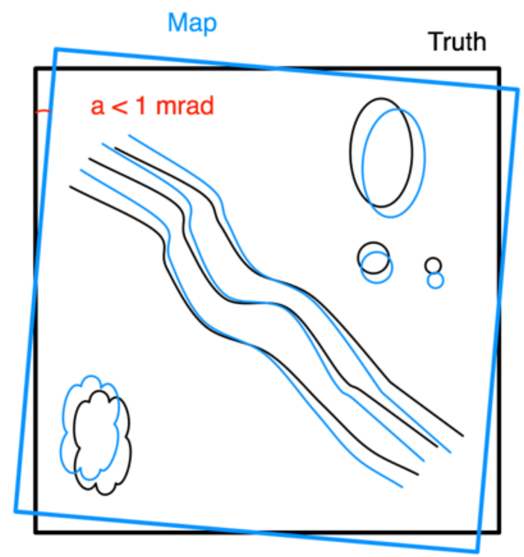
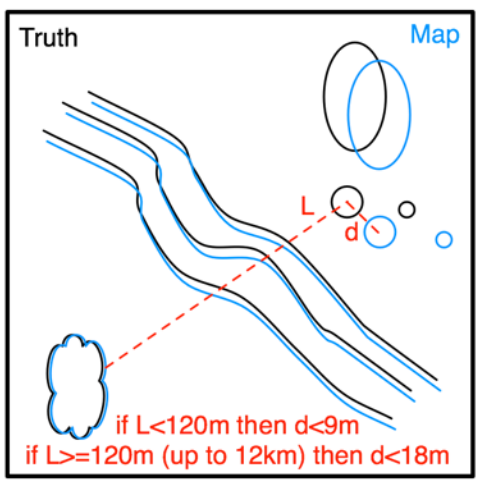
Map Absolute Position Error Requirement

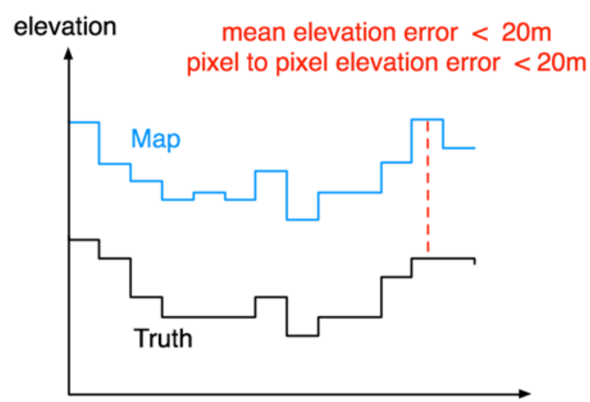




Map Absolute Attitude Error Requirement

Map Distortion Requirement

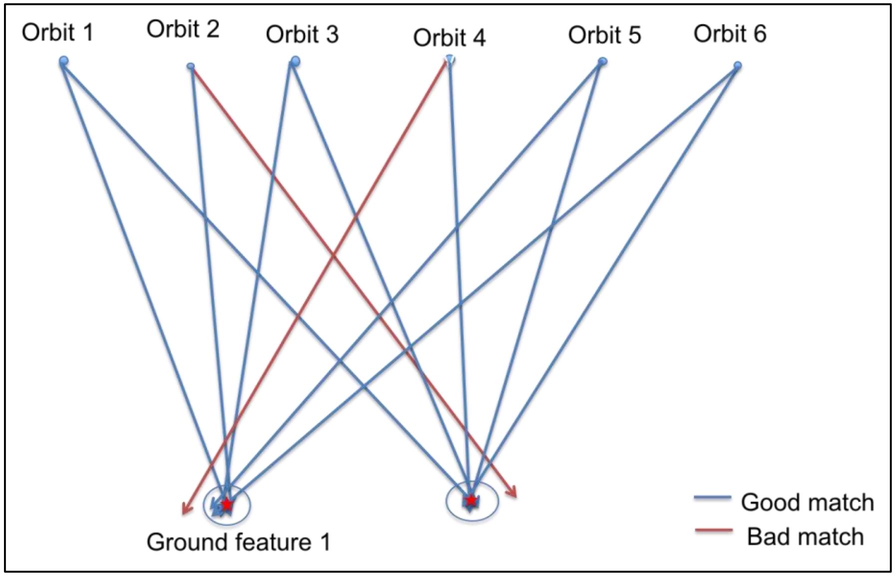




Map Elevation Error Requirements

Batch Image Bundle Adjustment

1. Image triangulation and outlier rejection



2. Attitude adjustment

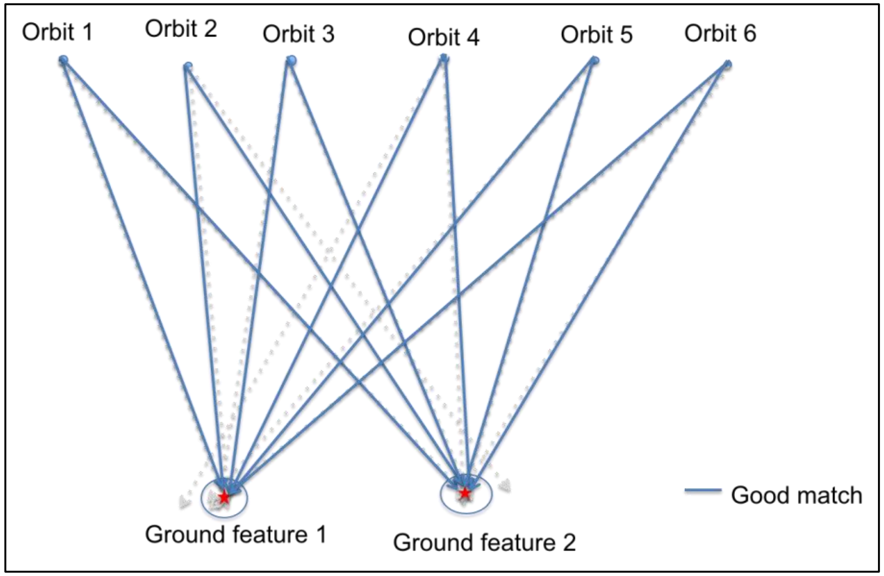
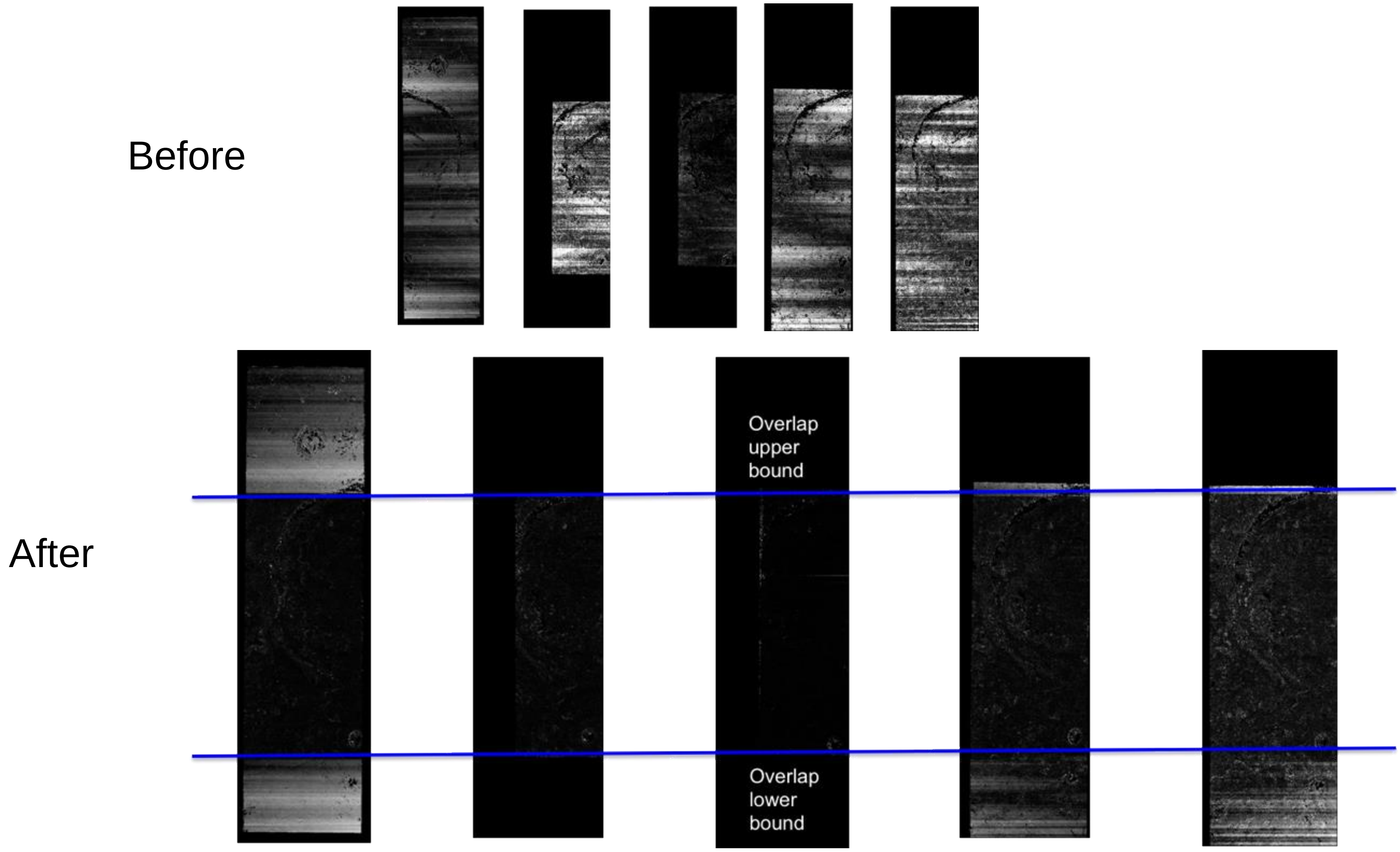


Image Dejittering (ray gaps (m))



Ray gap is reduced from 5 m to <1 m