Planetary Surface Reconstruction with the NASA Ames Stereo Pipeline (ASP)

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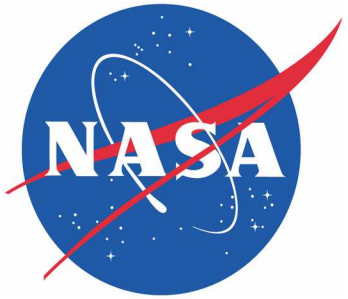
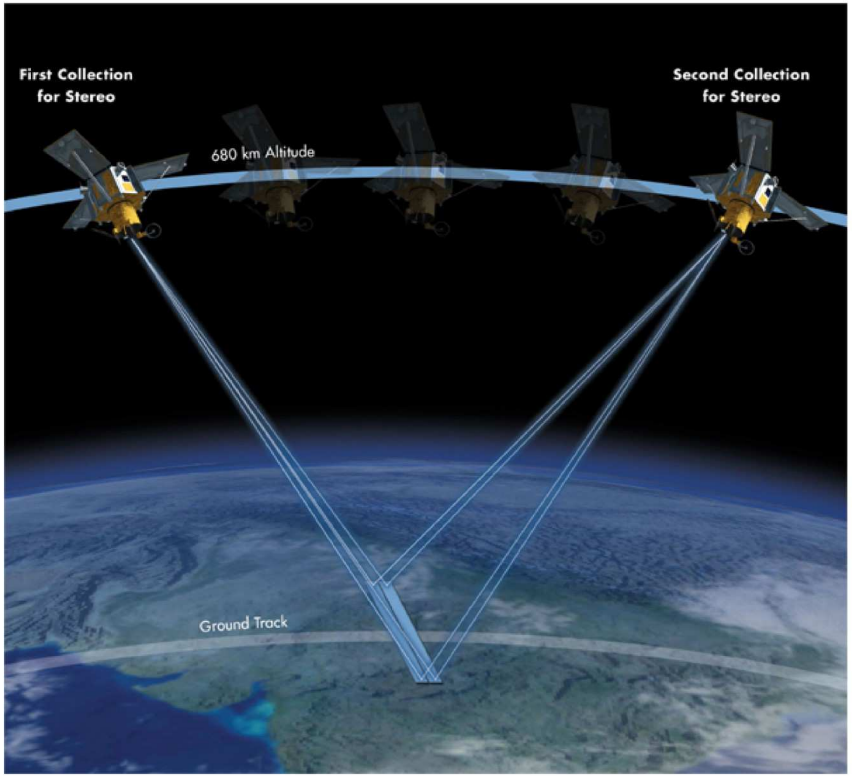


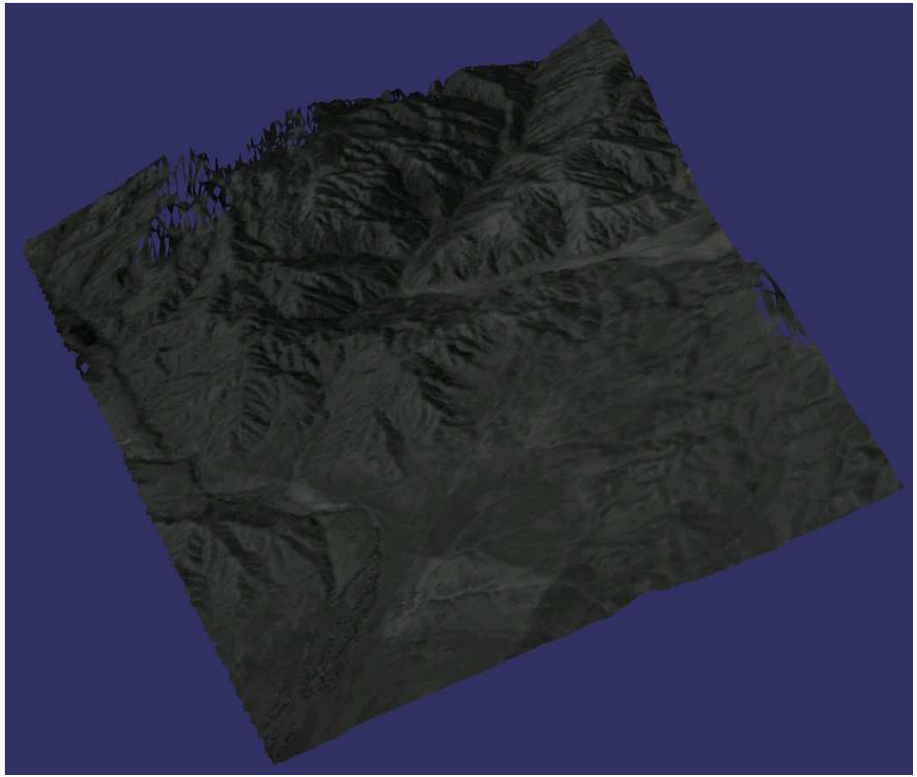
Who Are We?

- Research engineers from NASA Ames, in Mountain View, California
- Planetary scientists and computer vision enthusiasts

Ames Research Center

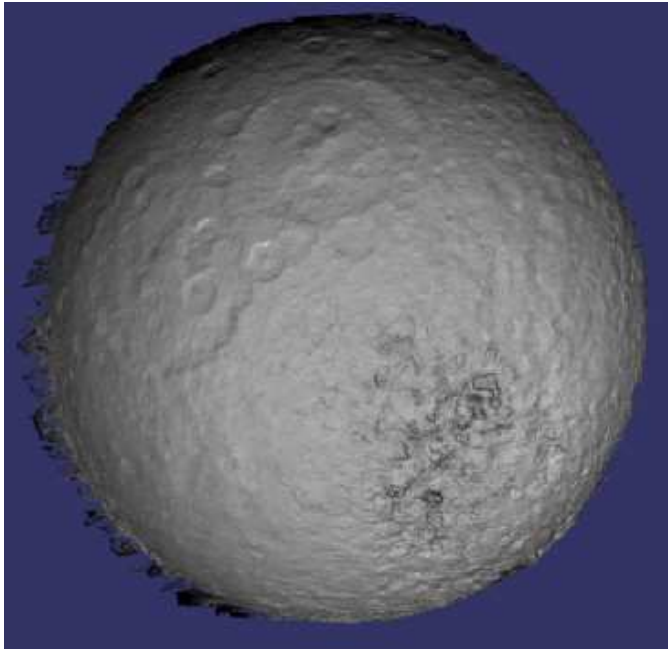
ASP Creates 3D Terrain from Stereo Images





ASP Background

- Originally developed to support planetary rovers and satellites but now evolved to handle terrestrial satellites and aerial cameras.
- Emphasizes parallel processing without manual intervention.

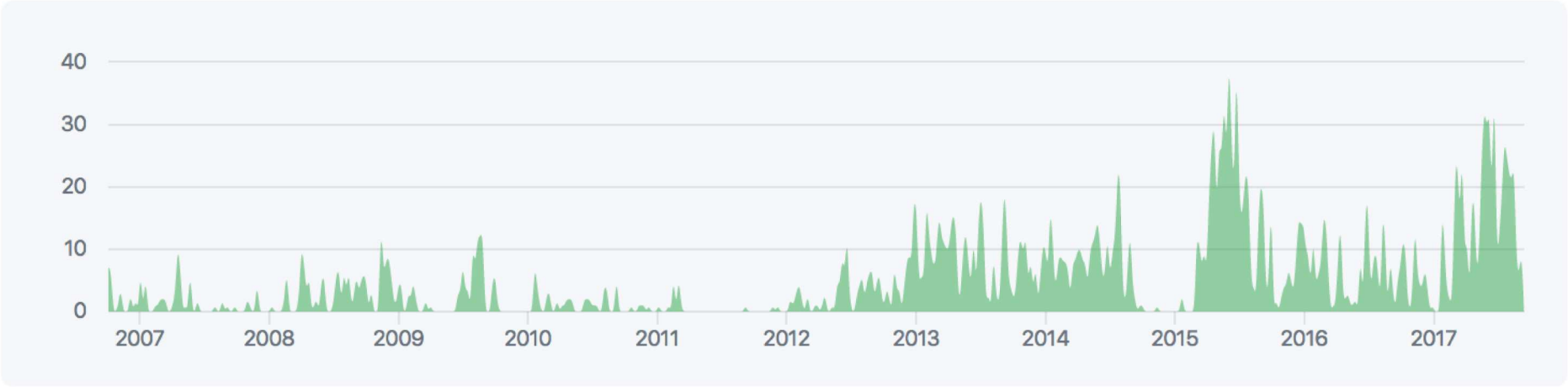


ASP has been developed for more than 10 years

Dec 3, 2006 – Nov 13, 2017

Contributions: **Commits**

Contributions to master, excluding merge commits



Incorporates the USGS Integrated Software for Imagers and Spectrometers

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WELCOME

This is the home page for ISIS, a digital image processing software package. The focus of the software is to manipulate imagery collected by current and past NASA and International planetary missions sent throughout our Solar System.

ANNOUNCEMENTS

Visit the ISIS Support Center for the latest news and announcements.

POPULAR DESTINATIONS

- ISIS 2 Home Page
- ISIS 3 Application Table of Contents

U.S. Department of the Interior | U.S. Geological Survey

How to Get It

- Ames Stereo Pipeline v2 is available as open-source software
  - Worldwide release (no country restrictions)
  - Can be freely reproduced and distributed, with or without modifications
- Apache 2 Licensed

- C++ code and executables for Linux and Mac are hosted on Github:

github.com/NeoGeographyToolkit/StereoPipeline

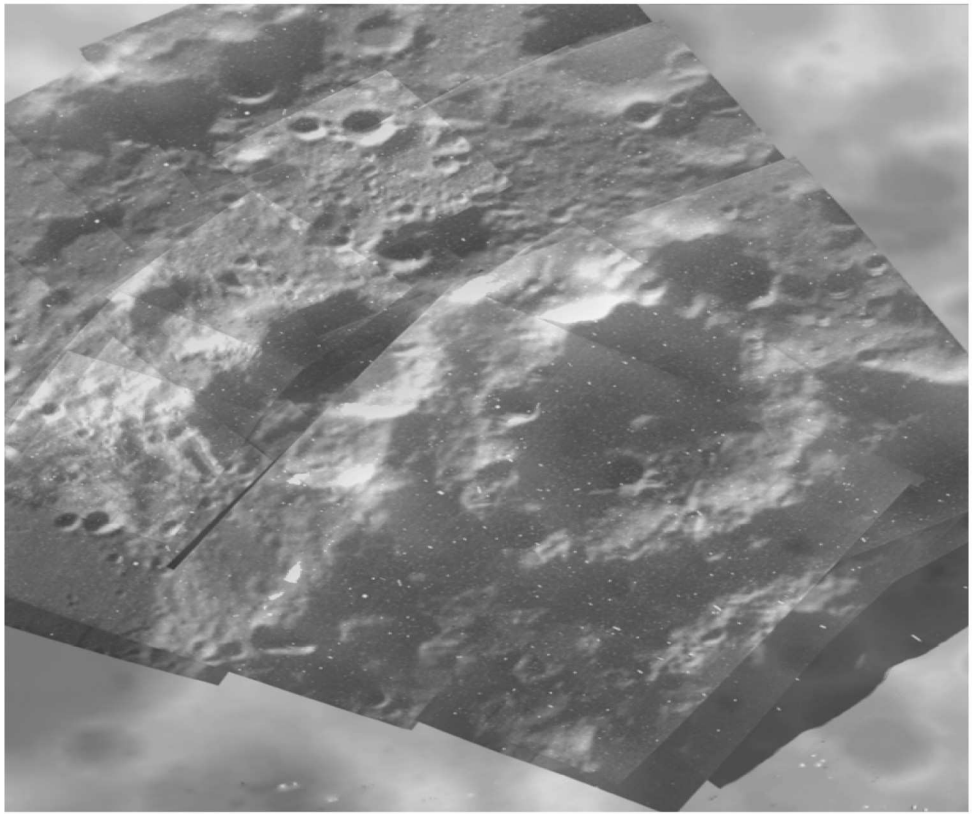
ASP Users and Uses

- Planetary researchers.
- Constructing maps of potential landing sites for NASA's Resource Prospector Mission (RPM).
- Generated 1001 LRO-NAC terrain models as a demonstration of automated processing abilities.
- Used with WorldView data to study glacial movement in Earth's polar regions[1].
- Processing declassified images from the U.S. KH-9 spy satellite program in order to evaluate ice cover changes since the 1970s.
- Currently processing 5 million Operation IceBridge aerial polar images.

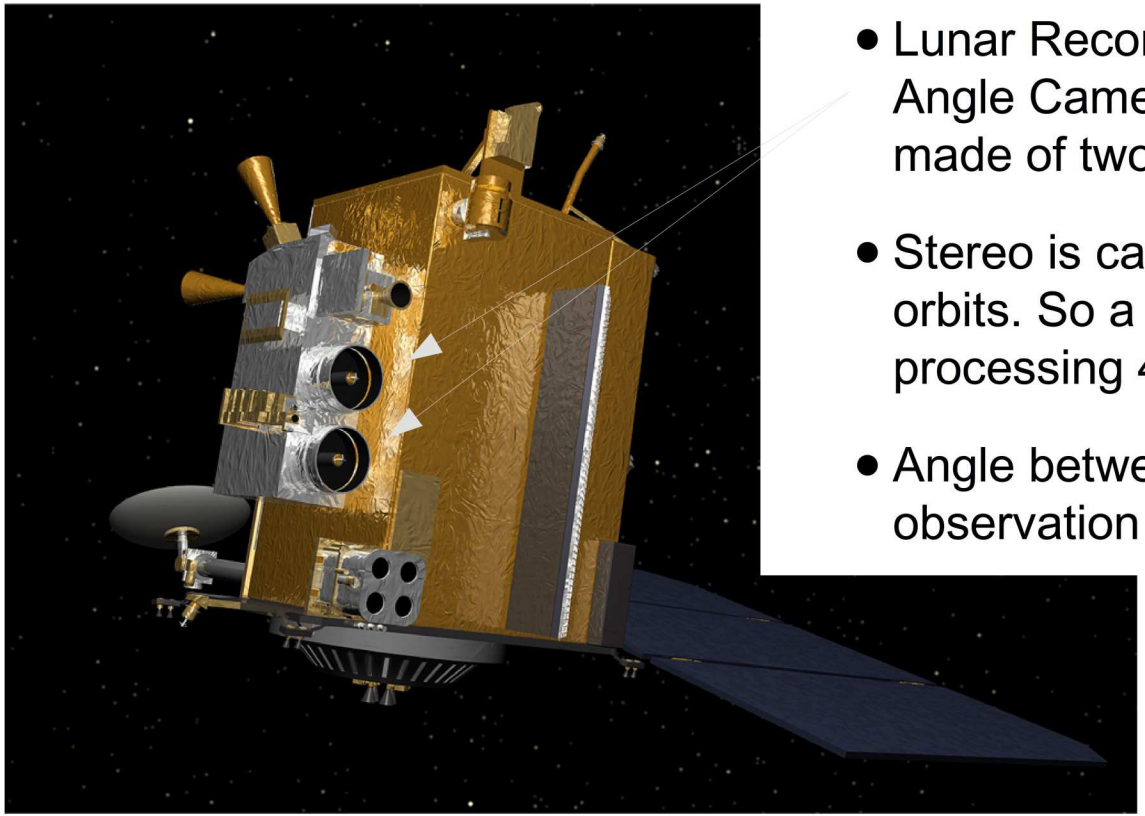
1. Shean, David E., et al. "An automated, open-source pipeline for mass production of digital elevation models (DEMs) from very-high-resolution commercial stereo satellite imagery." *ISPRS Journal of Photogrammetry and Remote Sensing* 116 (2016): 101-117.

Processing data with ASP

- Gather Images
- Image Correction
- Interest Point Gathering
- Bundle Adjustment
- Stereo
- Create terrain models (DEM)
- Align DEM
- Mosaicking
- Shape-from-Shading



Example Image Correction: LROC

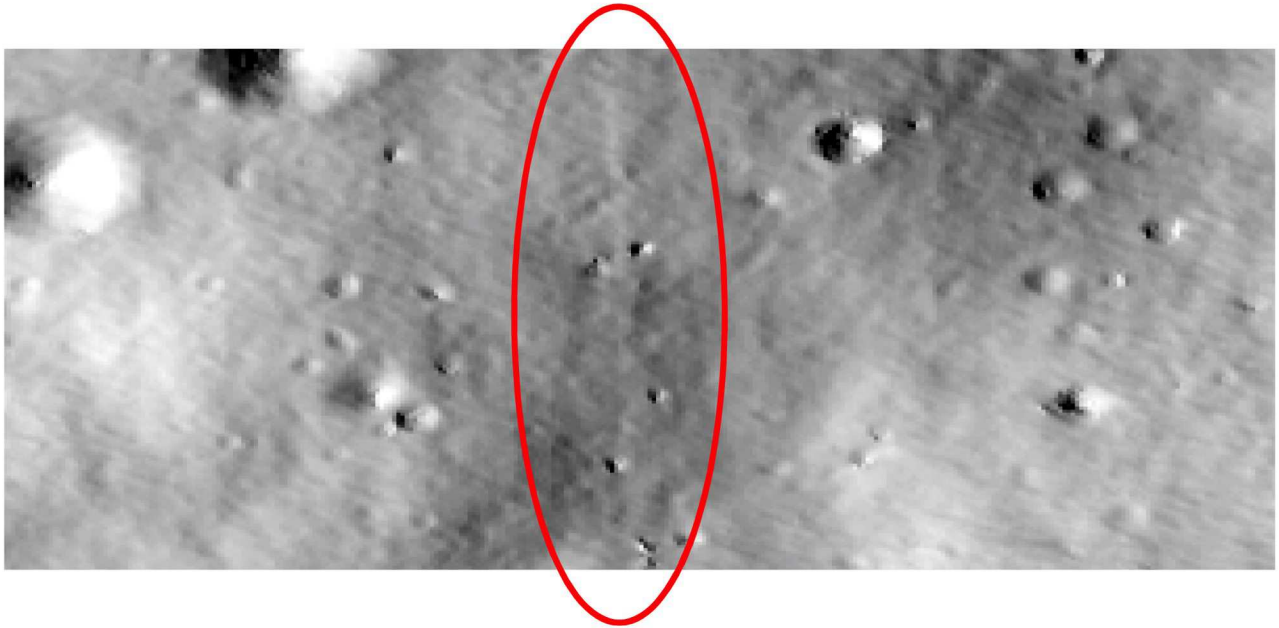


- Lunar Reconnaissance Orbiter Narrow Angle Camera (LRO-NAC) is actually made of two cameras.
- Stereo is captured through multiple orbits. So a stereo pair for LRO-NAC is processing 4 images.
- Angle between two sensors of a single observation changes with temperature.

LRO-NAC is made of two aligned telescopes. It is a linescan camera with 5064 px * 2 width.

LROC's Problem

- Temperature change causes misalignment of the two cameras
- Results in a "line" artifact in generated terrain



LROC's Solution

- For each observation, correlate overlap between left and right CCD.
- Solve for angle change between CCDs.
- Rewrite IK SPICE kernel per observation.

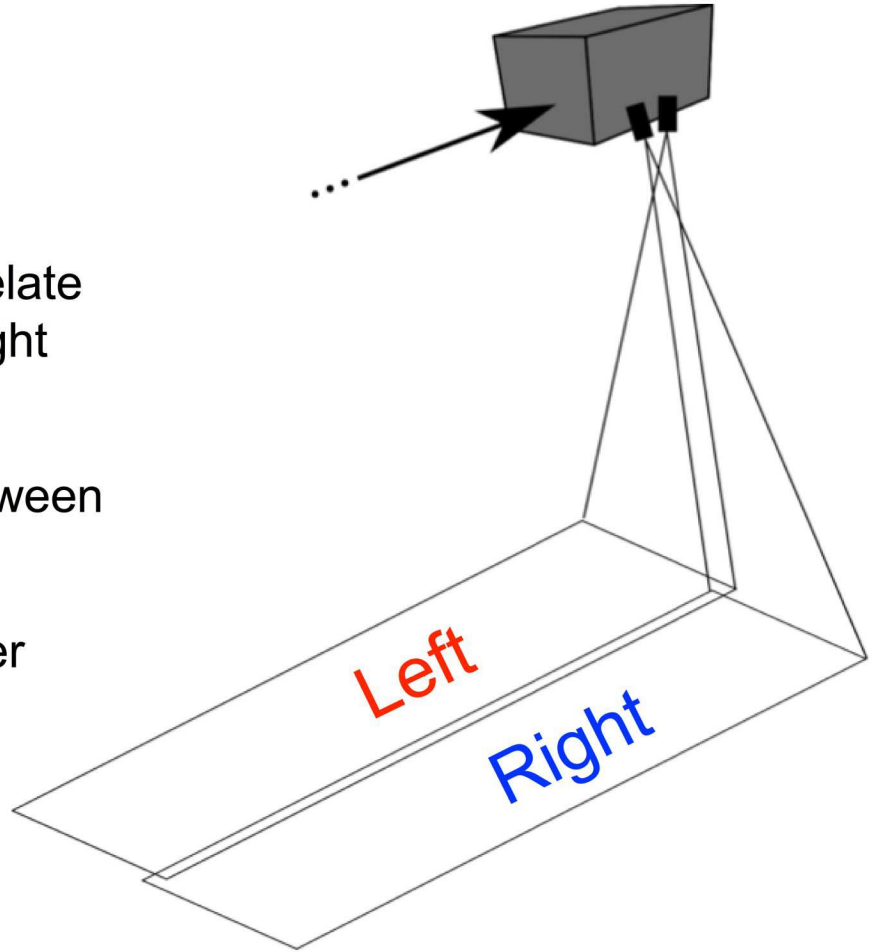
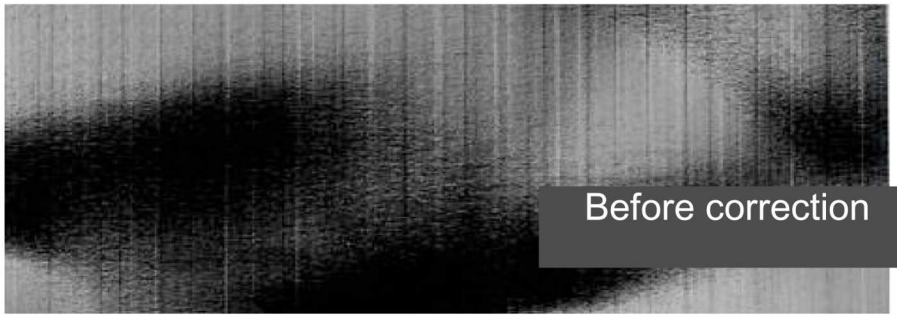


Image Correction: World View

- World View had a similar problem to LRO-NAC, but with more sensors at the focal plane.
- Results in DEM elevation noise of ~2 meters.

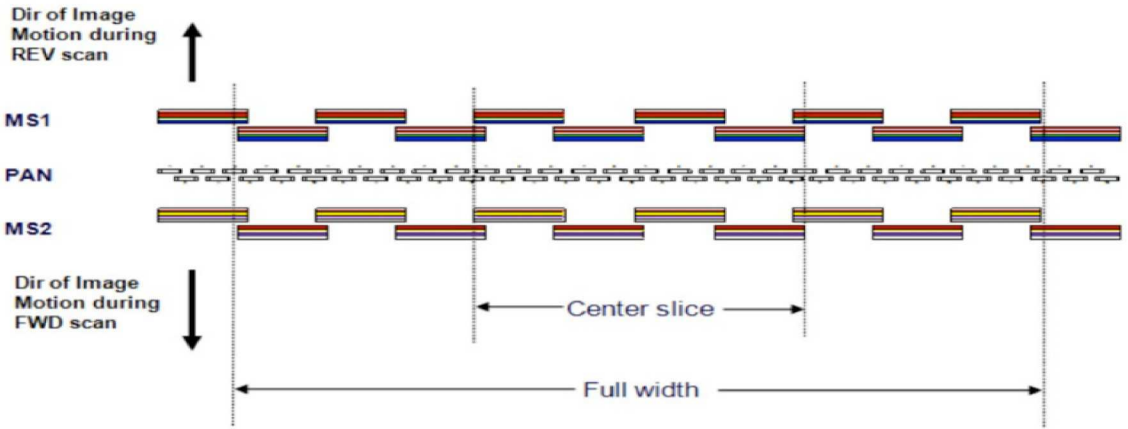
World View satellites are linescan cameras with 50 CCDs arranged side by side. Image size distributed to customers is ~1 Gpx.

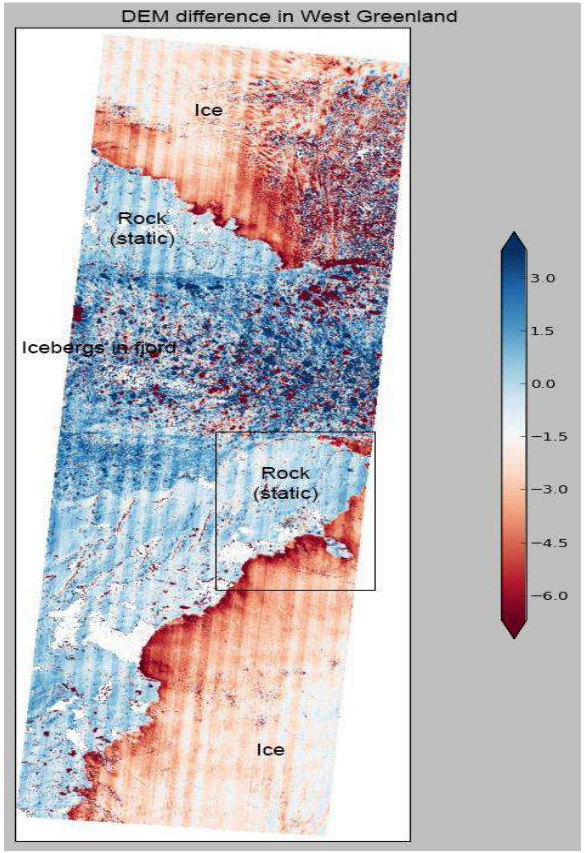


Before correction

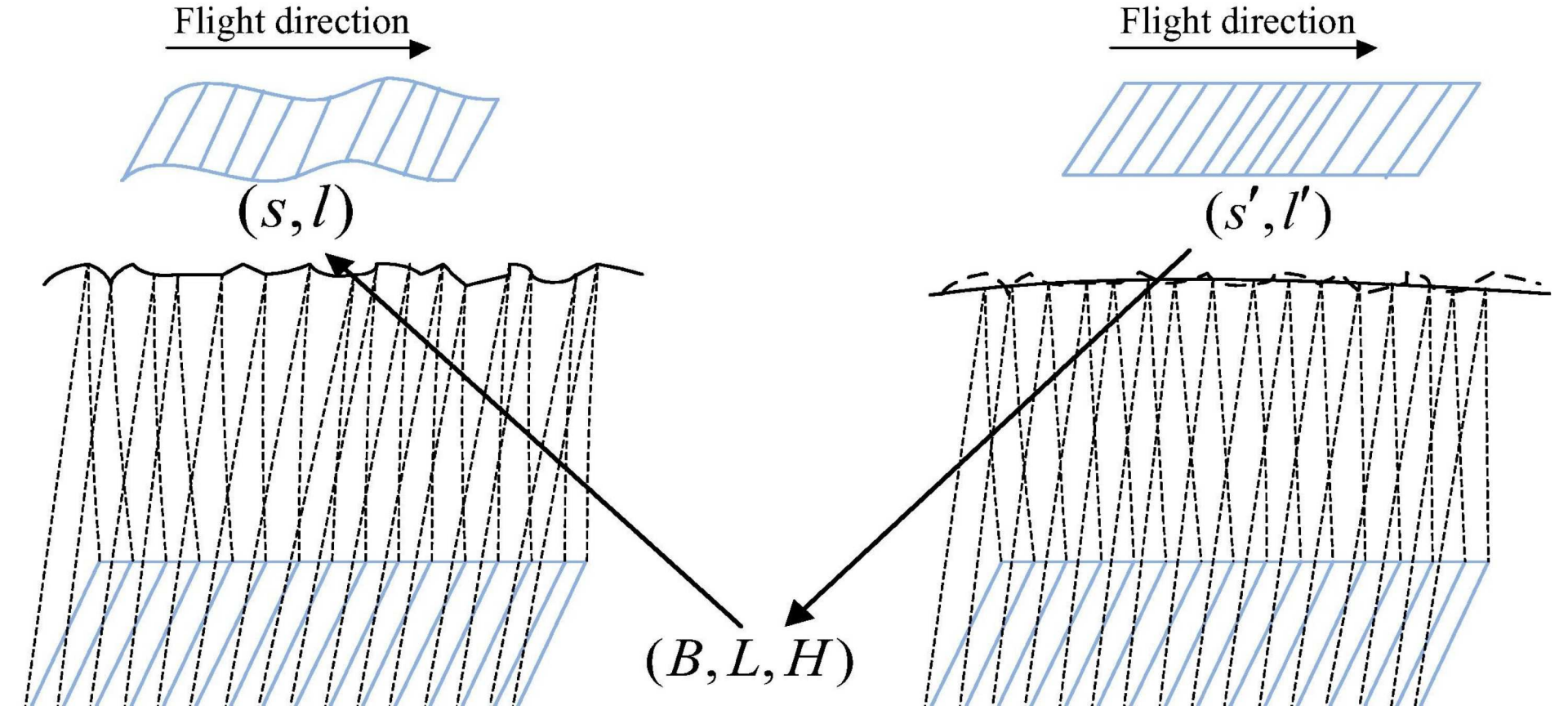
After correction

World View Sensor

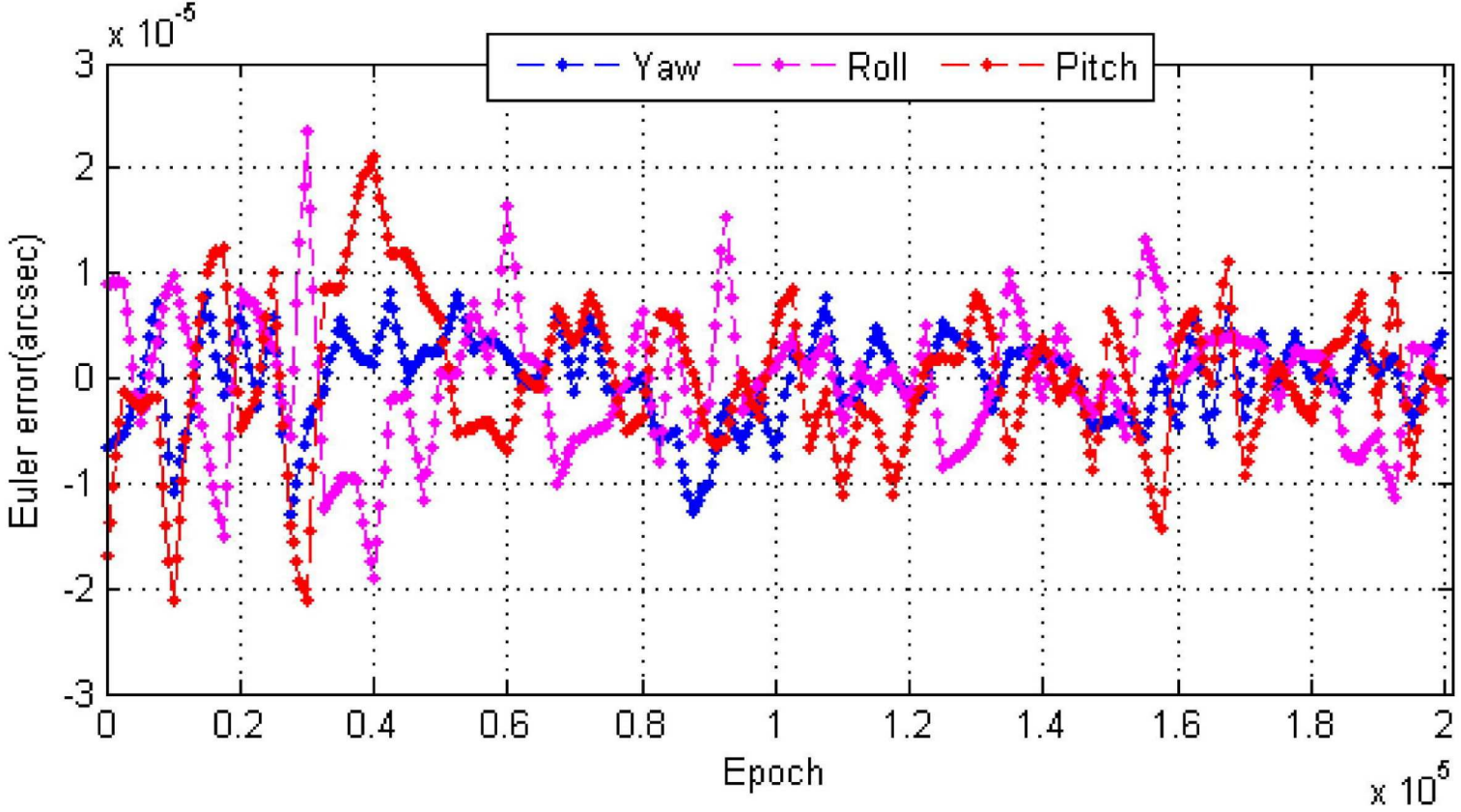




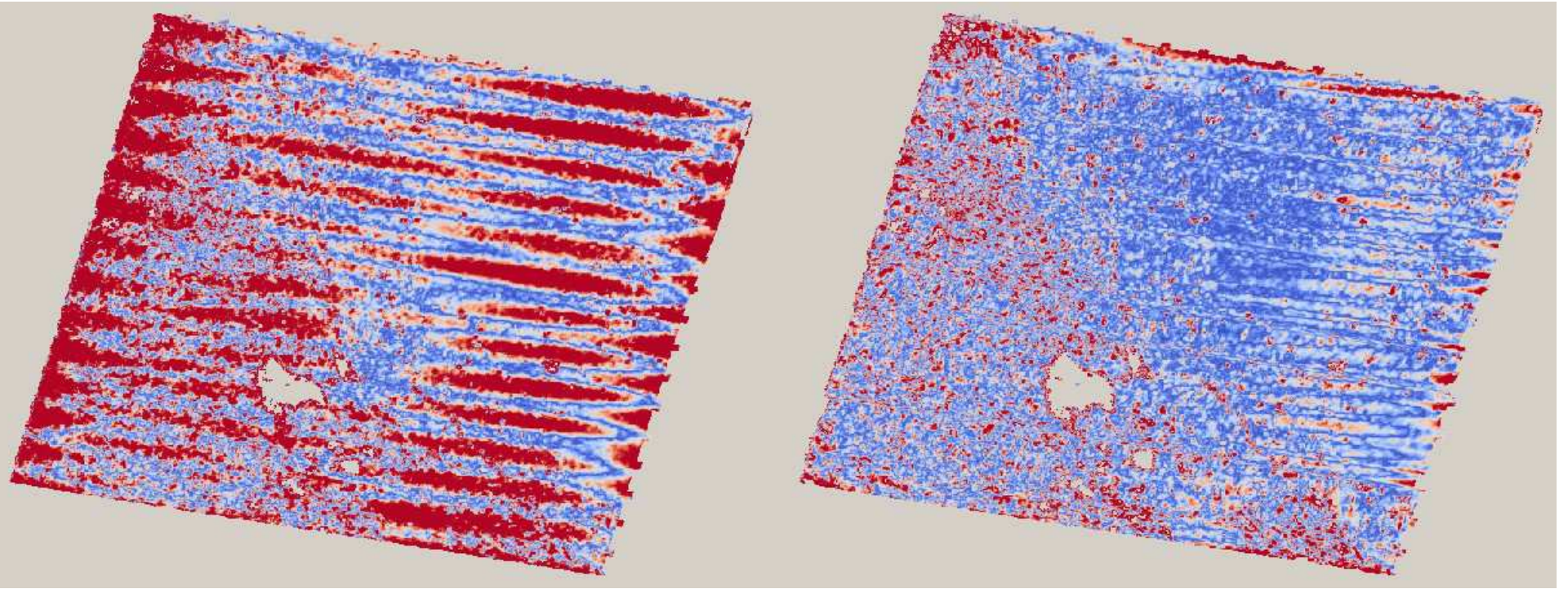
Spacecraft Jitter



Spacecraft Jitter

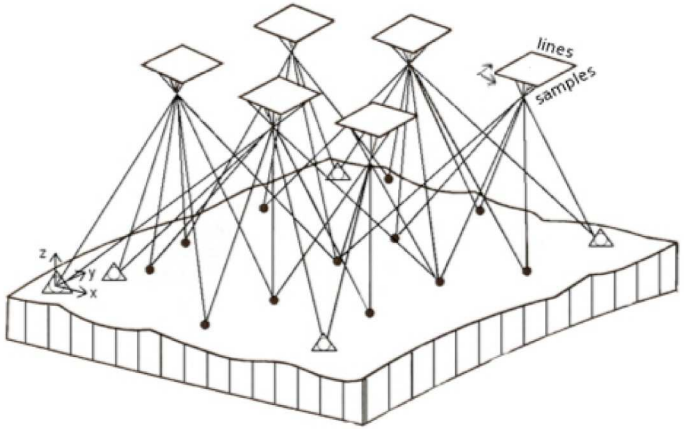


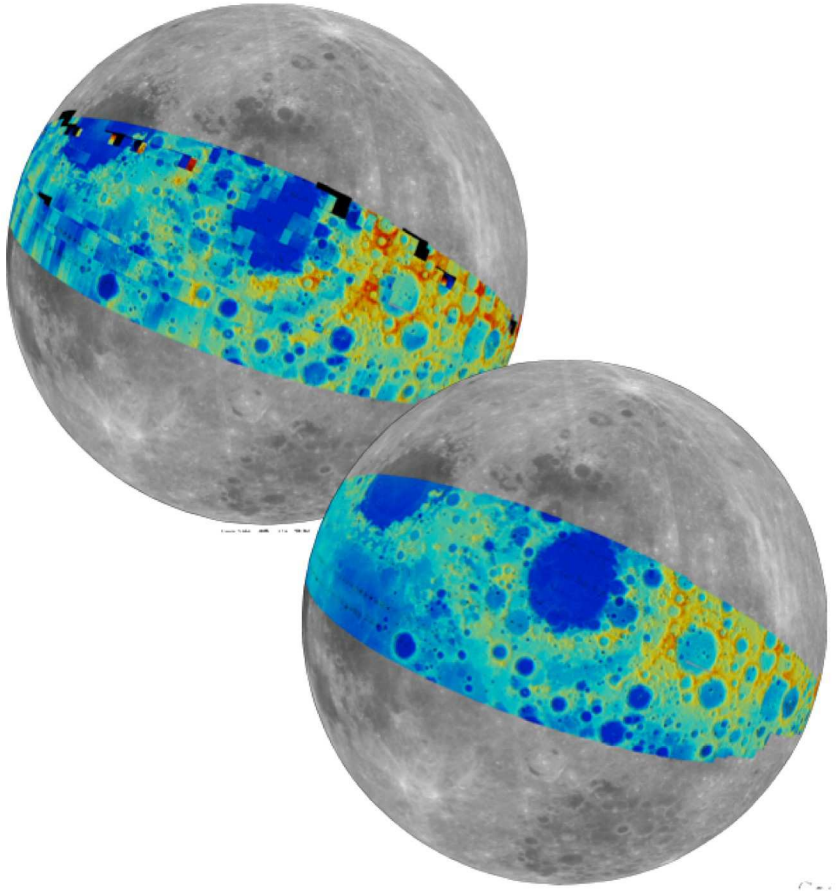
Jitter Correction for Digital Globe (Not Yet Mature)



Bundle Adjustment

By tracking all the feature correspondences between all images, solve for 3D location of points and their camera's location





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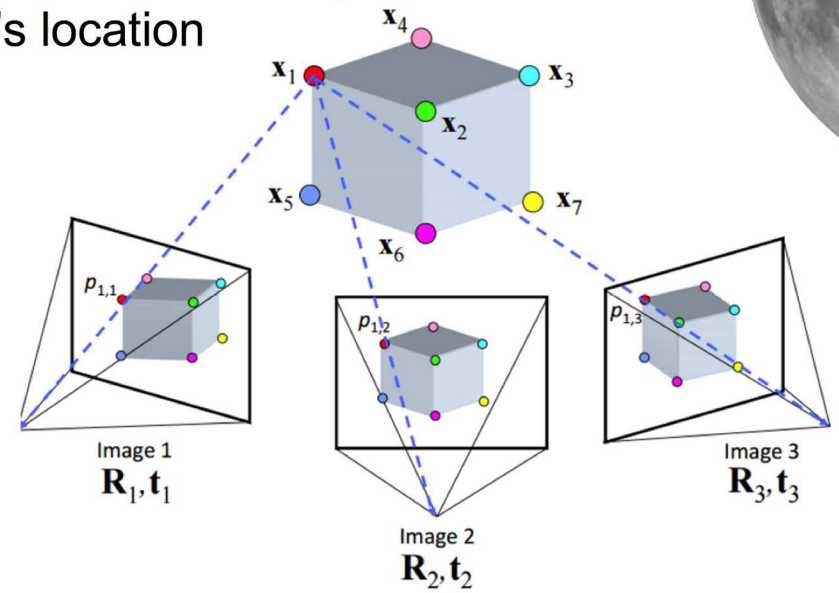
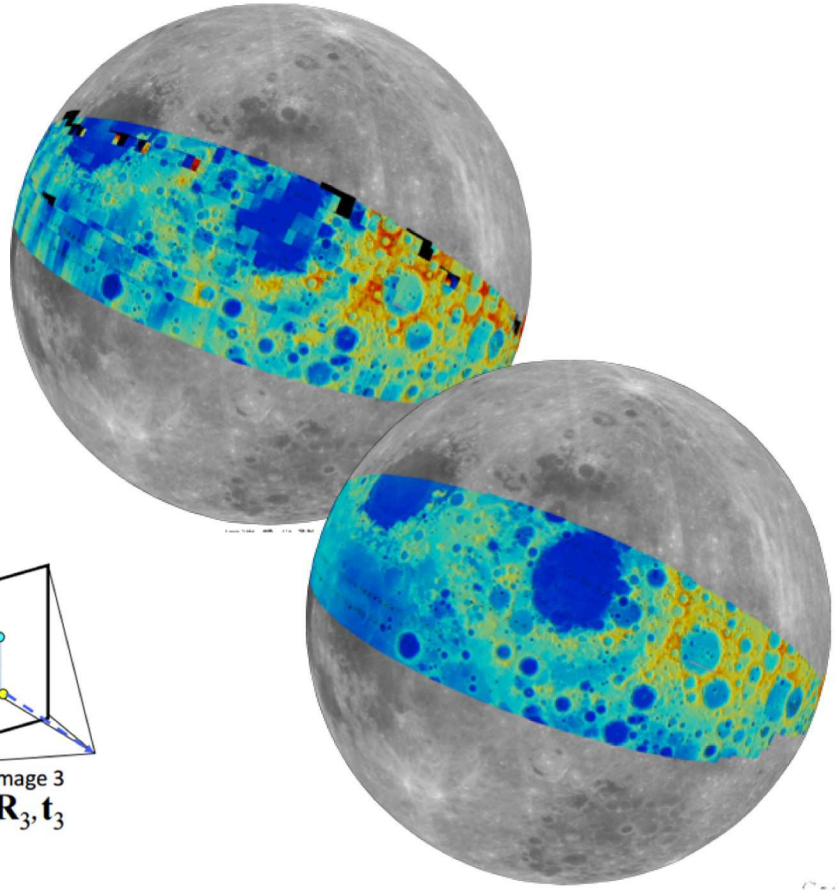
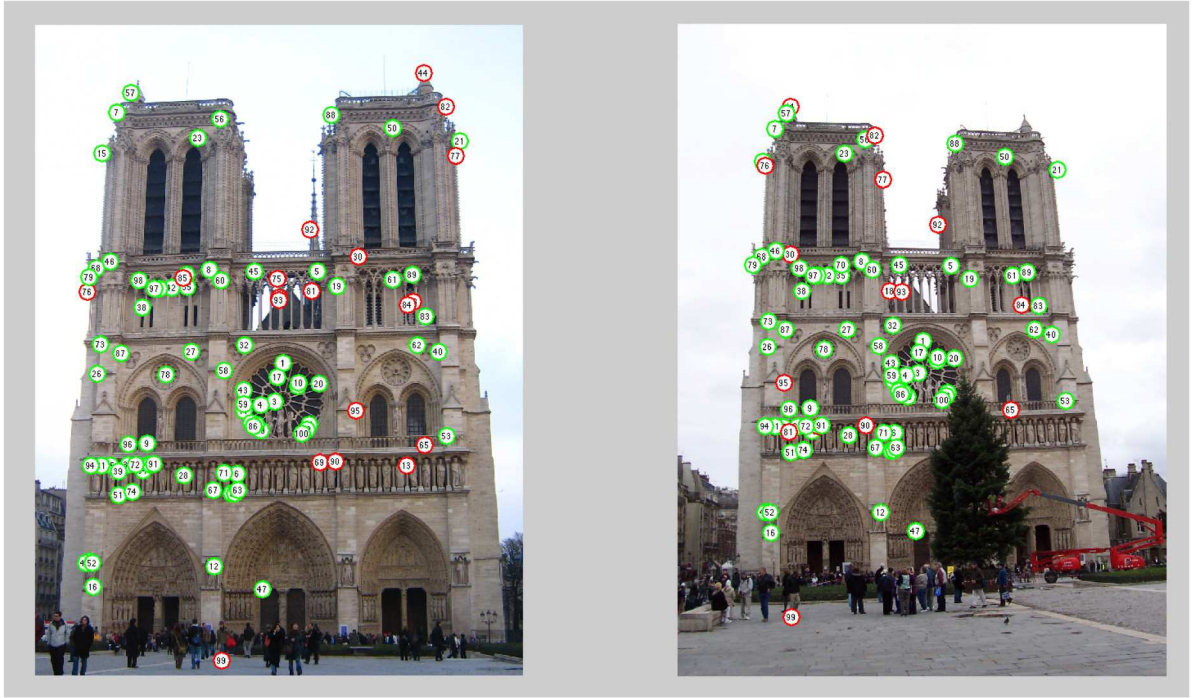




Source: http://cs.nyu.edu/~fergus/teaching/vision/11_12_multiview.pdf

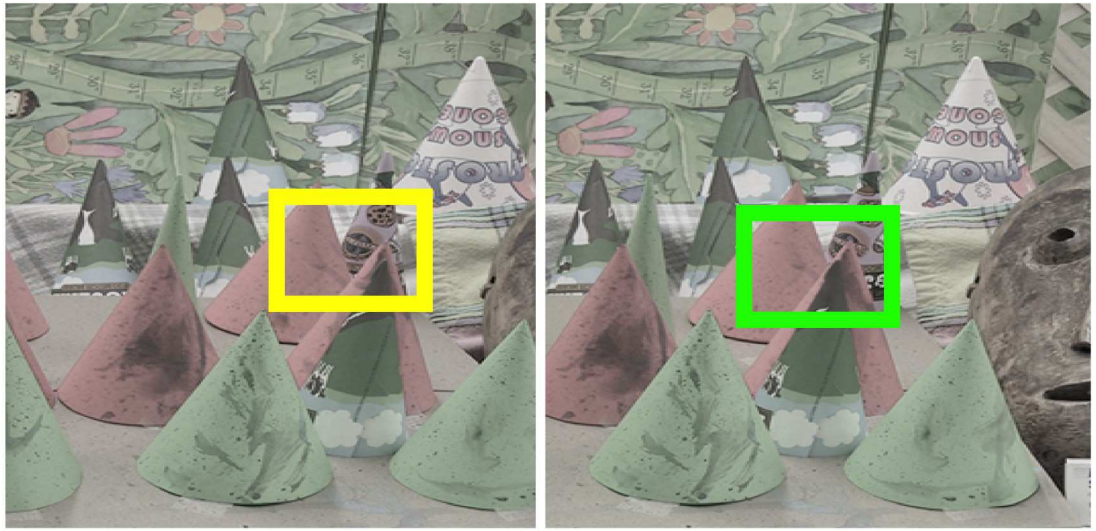
Interest Point Detection and Matching

- Used for image alignment, bundle adjustment, and search range estimation.
- ASP supports the ORB, SIFT, and OBALoG IP detection methods.



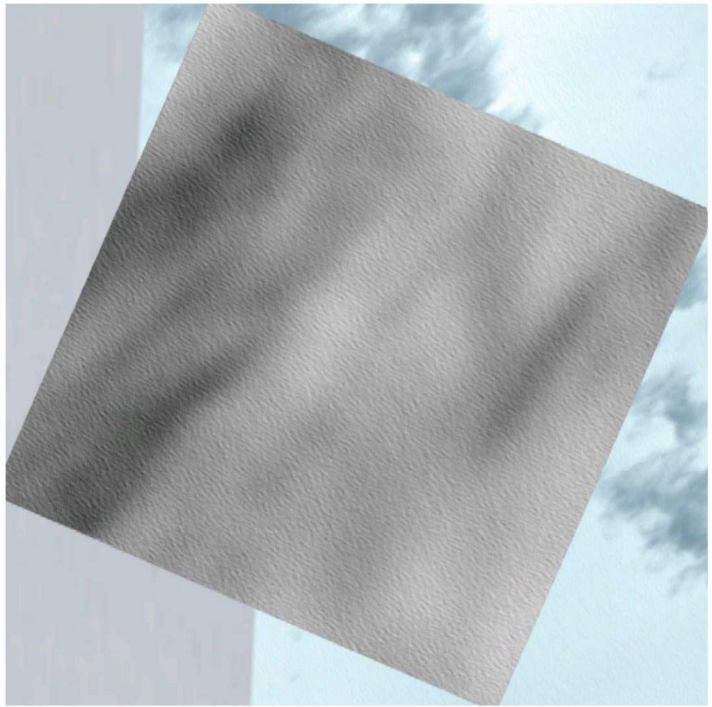
Stereo Generation

Given two images, solve for pixel-to-pixel correspondences for the whole image.



Stereo Limitations

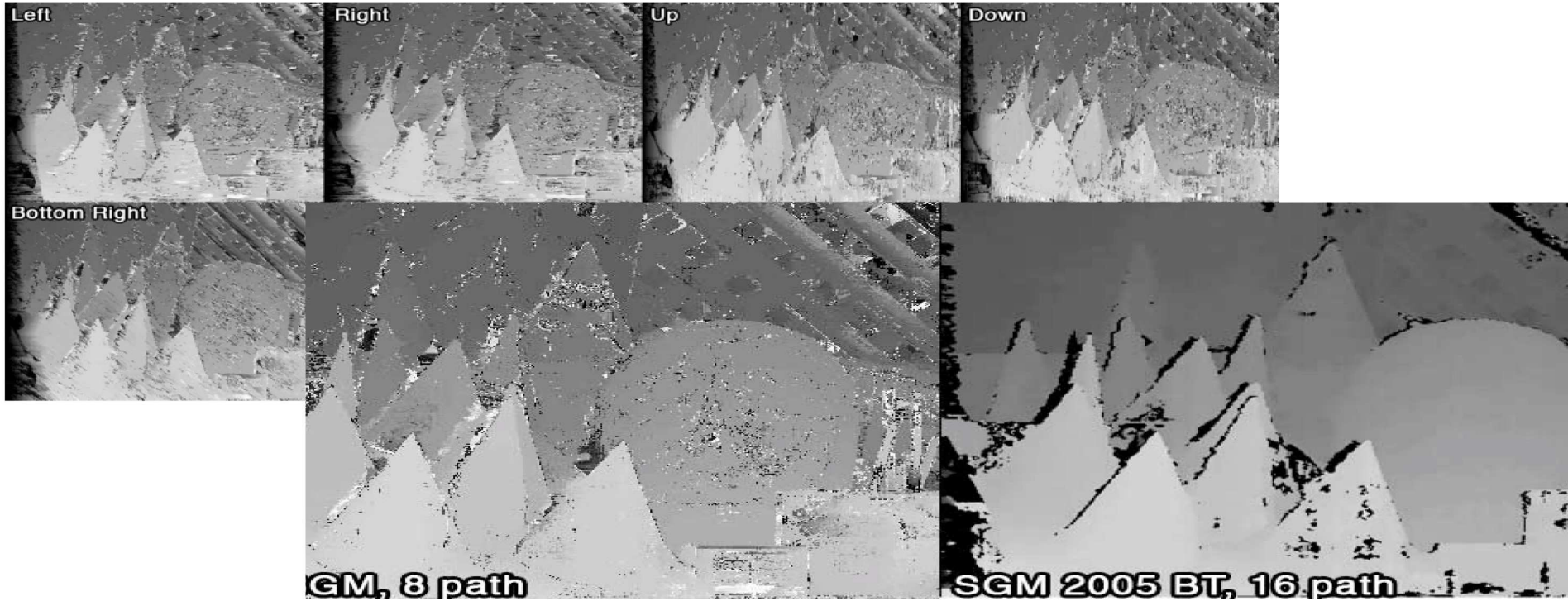
- Using a kernel bigger than one pixel will lose resolution.
- Clouds and water can confuse the pyramid correlator.
- Ice does not have texture at low resolution that can be correlated.



Popular Stereo Algorithms

Block Matching	Simple, fast, classic algorithm
Patch Match	Avoids the need for pyramid processing.
Semi-Global Matching	Optimizes disparity values along many lines.
Graph Cuts and Belief Propagation	Optimize Markov Random Field disparity model.
SETSM	Uses tightly integrated geometric model of terrain.

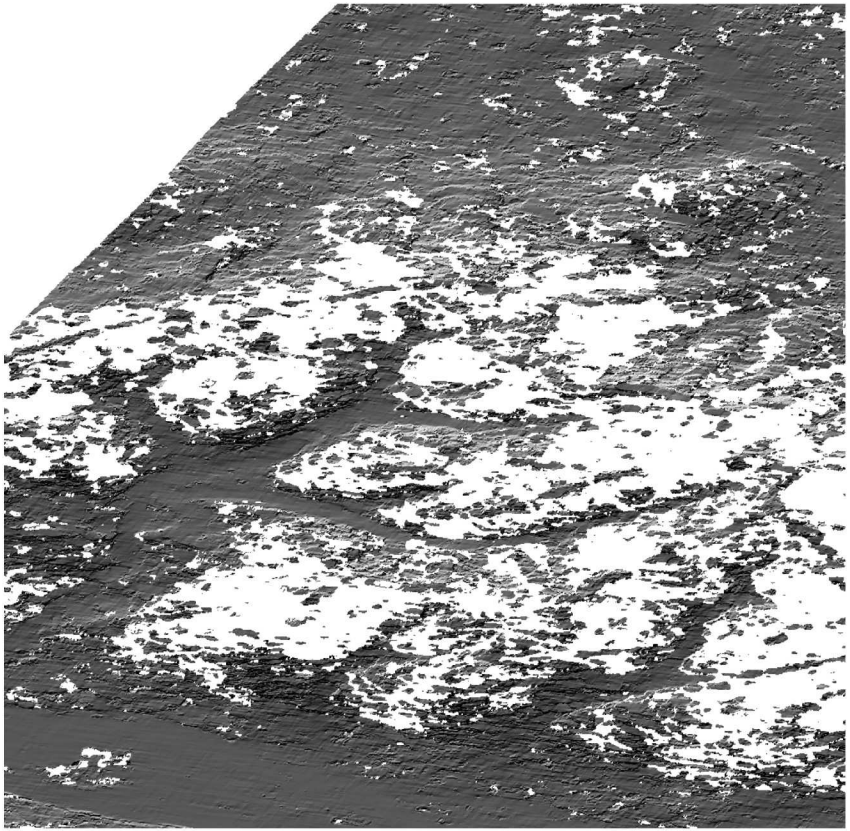
Semi Global Matching



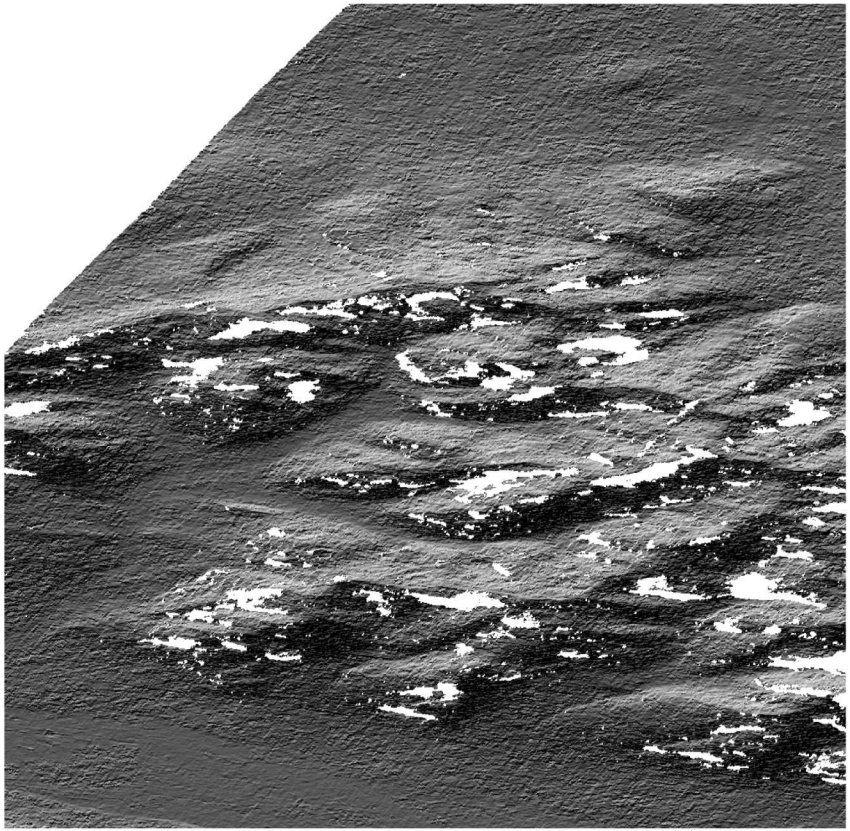
SGM / MGM results

- So far, these algorithms have produced much better results than our old block matching algorithm on terrestrial, arctic terrain images.
- Our block matching with iterative subpixel algorithm often works better on planetary images.
- Steep slopes are the regions that see the greatest benefit from switching to SGM.
- Our implementation can search over vertical disparities but the results are better when the input images are accurately aligned.
- Compared to SGM, MGM produces smoother and slightly more accurate images at the cost of increased run-time and memory usage.
- Both SGM and MGM suffer from a distinctive artifact pattern but this can be suppressed by incorporating more than two input images.

Results - KH9

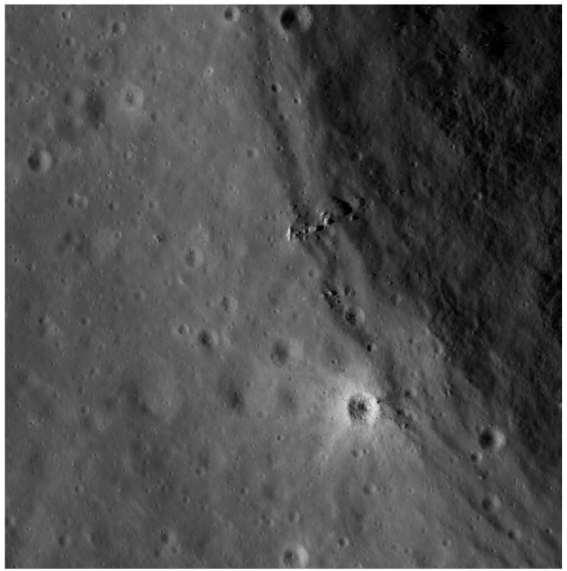


Block matching



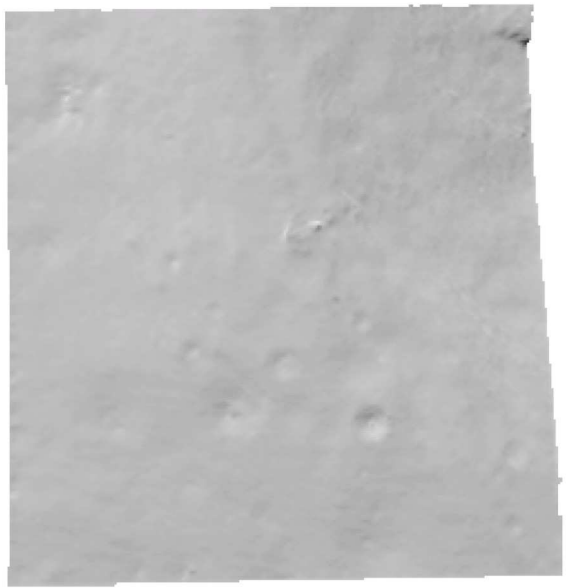
MGM

Results - LRO-NAC



Input image

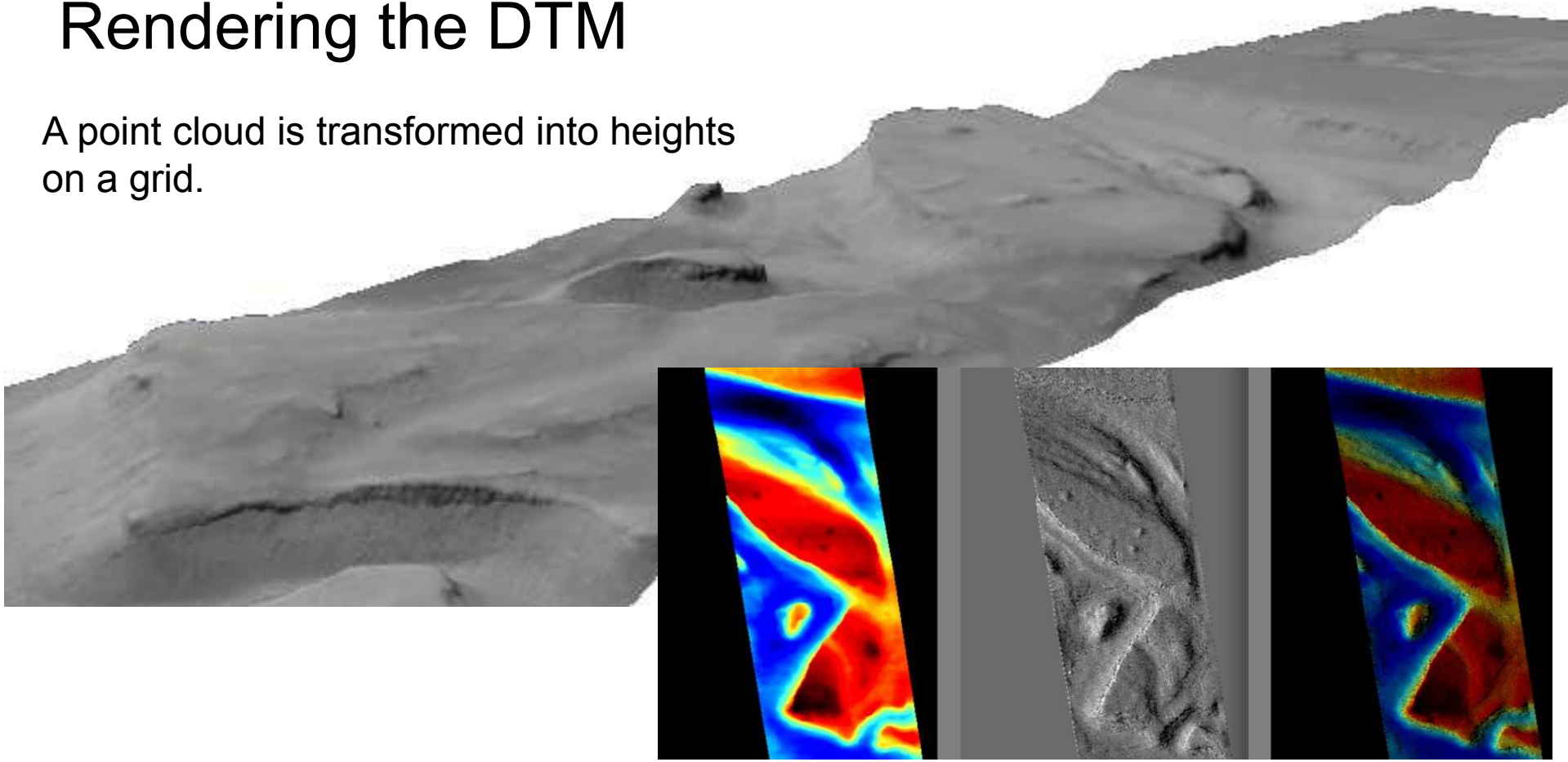
Block matching



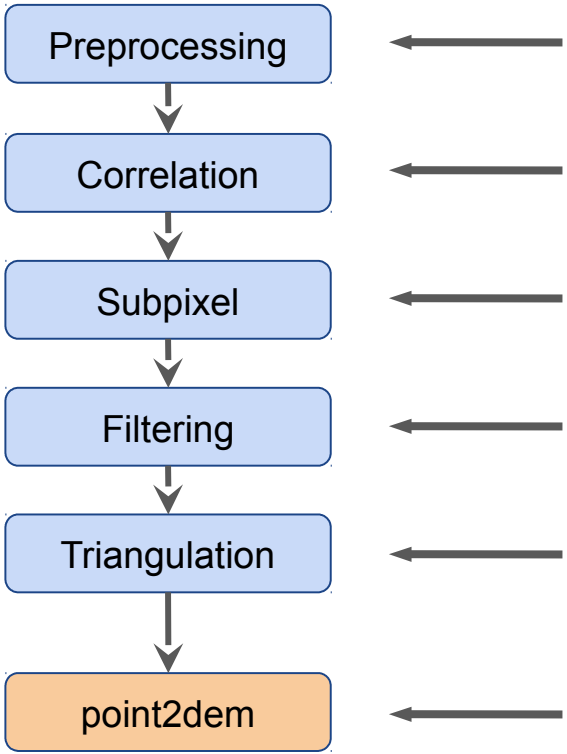
MGM

Rendering the DTM

A point cloud is transformed into heights on a grid.



Stereo Creation Steps



Format conversion, intensity normalization, and image alignment.

Integer stereo correlation using block matching.

Either a parabola method or an iterative affine fitting method.

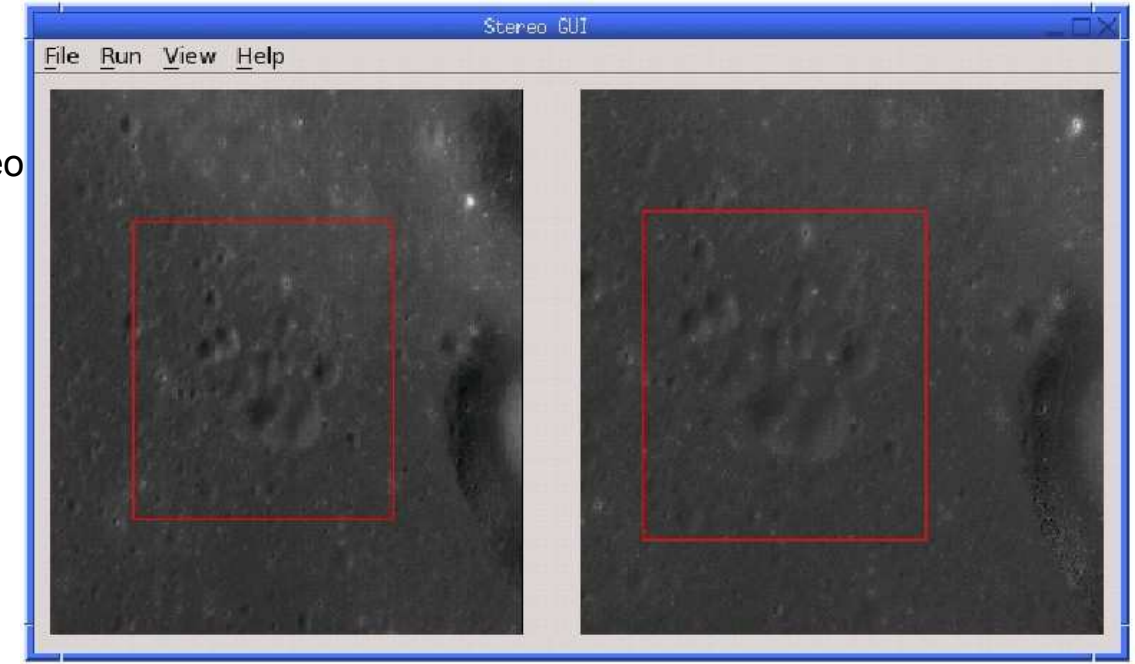
Options for statistical filtering, blob filtering, etc.

Produce point cloud from disparities.

Gridded terrain creation with options for filtering out points with high triangulation error and for hole filling.

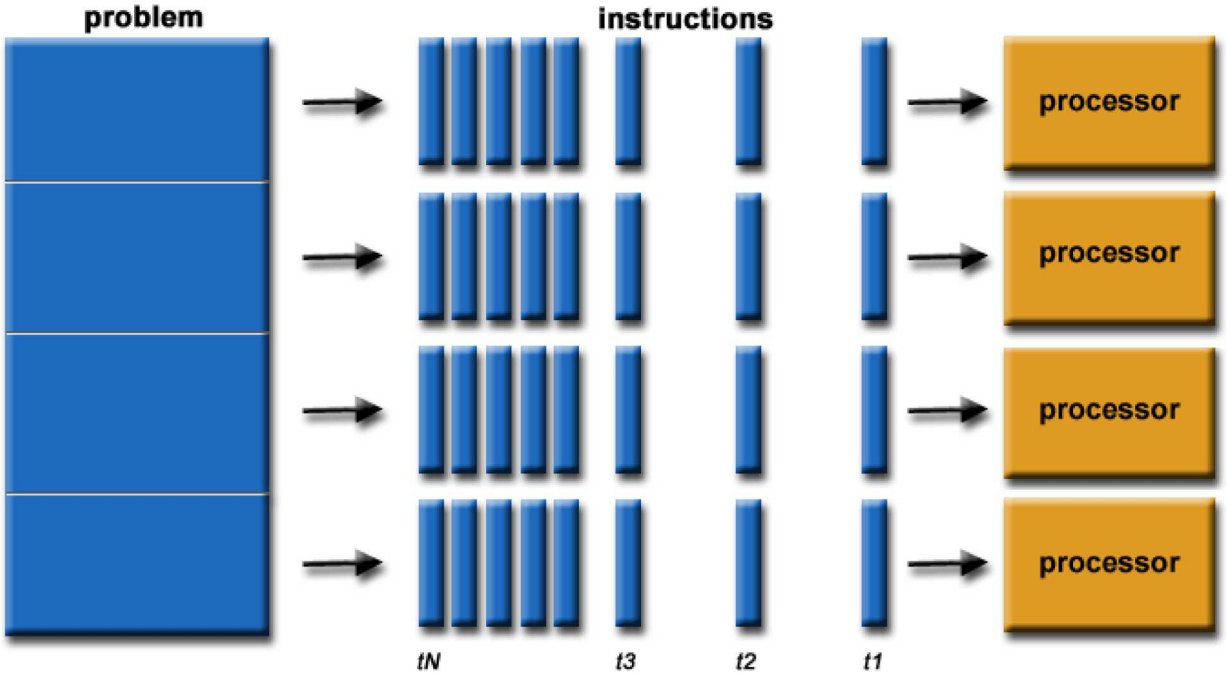
Graphical User Interface

- ASP has a basic optional GUI tool to assist with data processing and visualization.
- Displays supported input data.
- Displays detected interest points.
- Selects region of interest for stereo processing.
- Ground control point editor.
- Queries pixel values.
- Can launch stereo processing.
- View hill-shaded and georeferenced terrains.

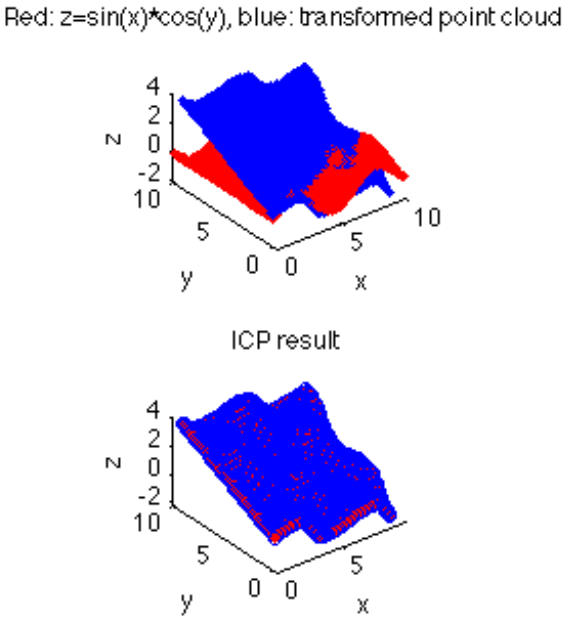


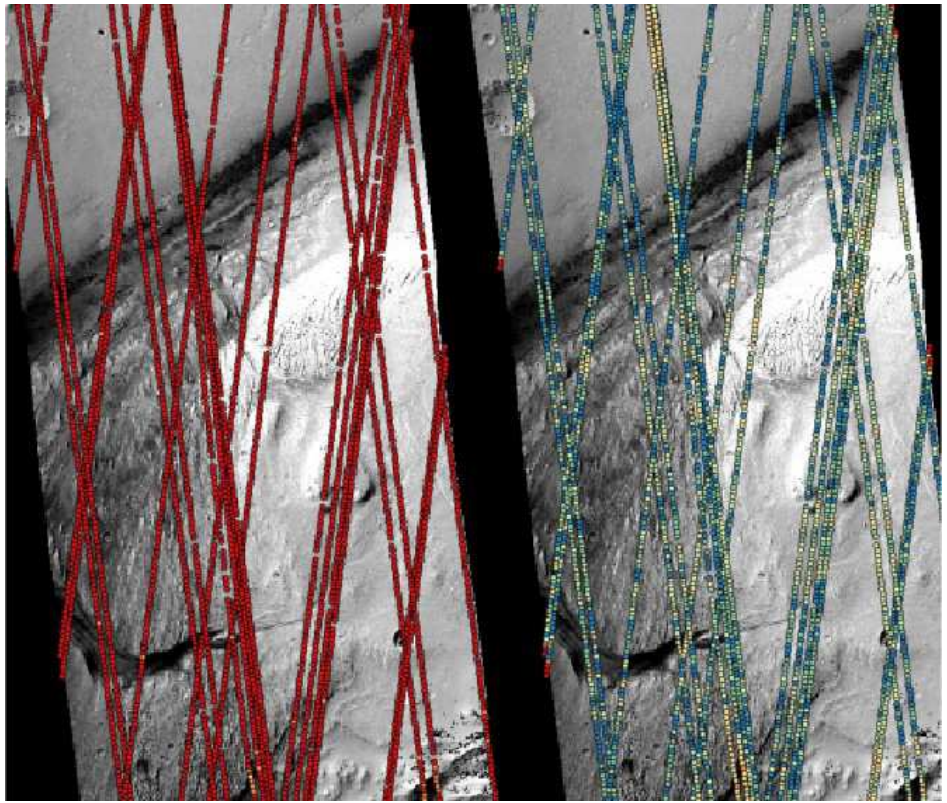
ASP is Parallelizable

It can run on multiple machines, using multiple processes and threads



Lidar-to-DEM alignment example

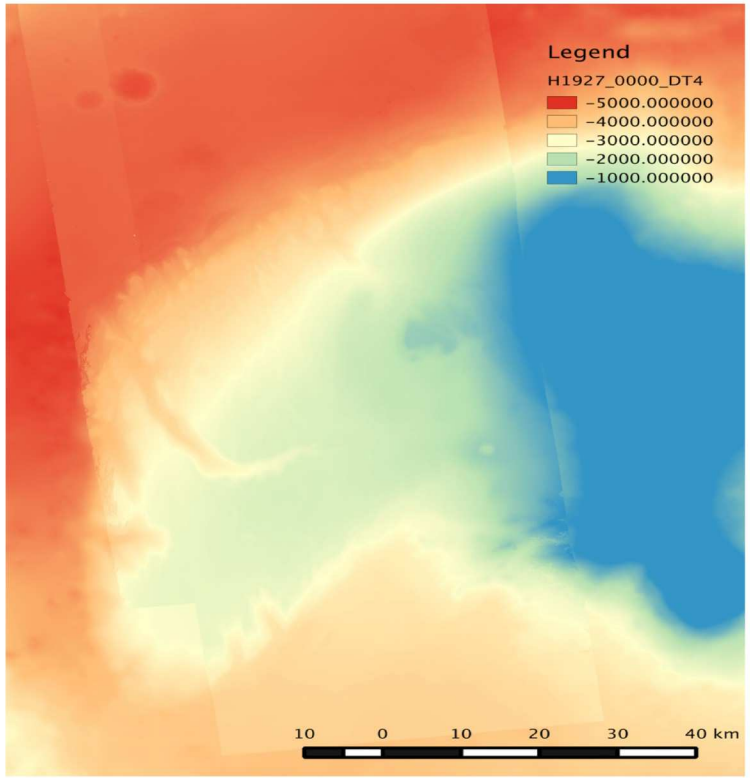


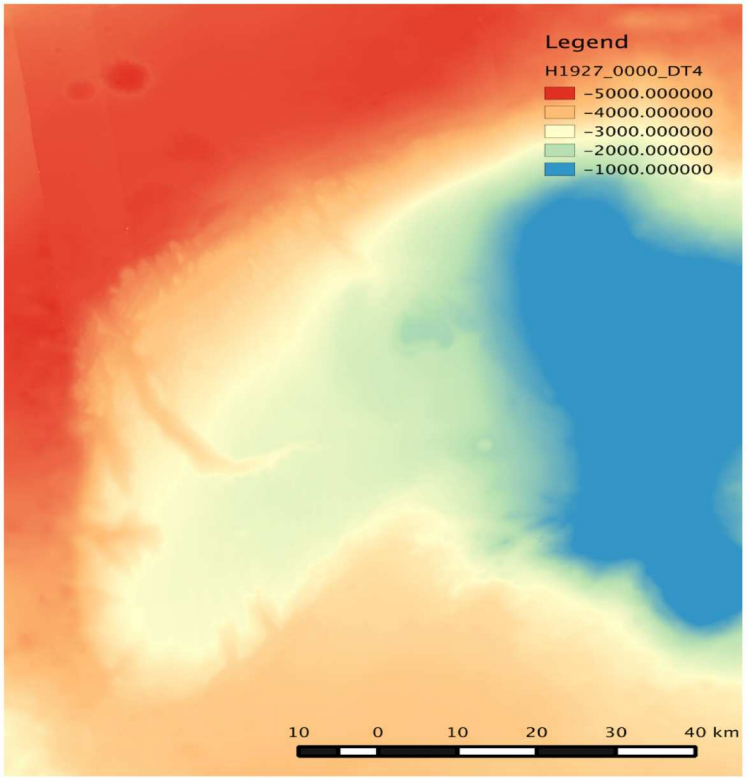


Red dots:
>100 m error

Blue dots <
5 m of error

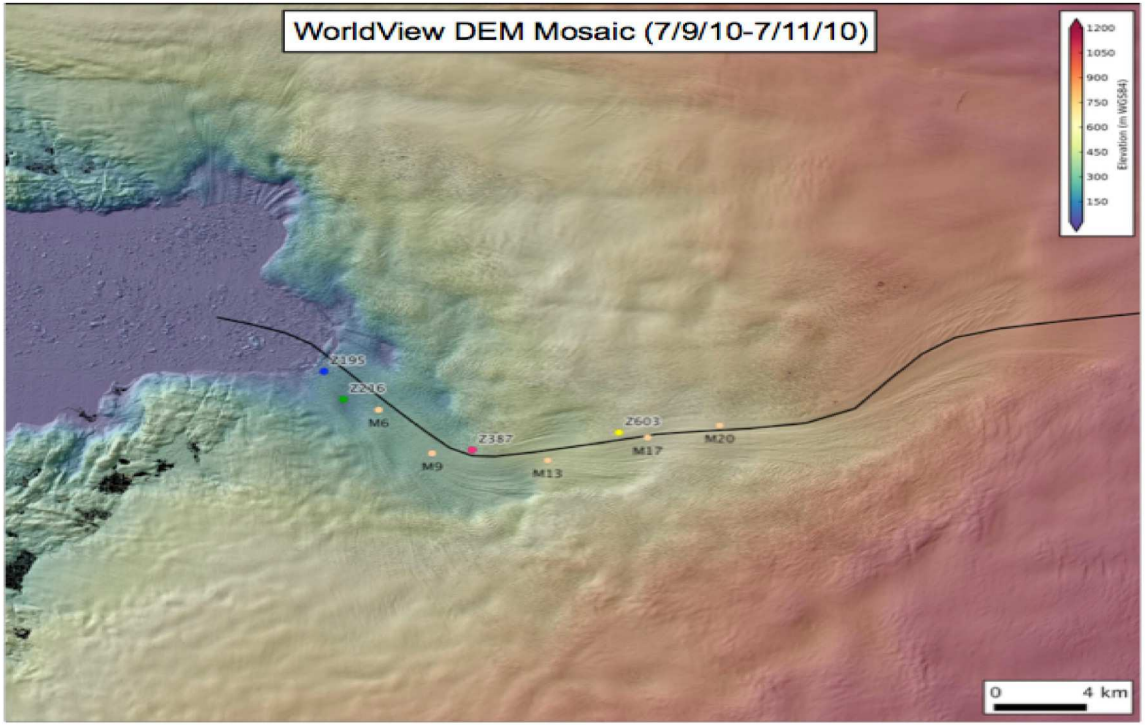
DEM Alignment Using ICP





Mosaicking

dem_mosaic is a large-scale mosaicking tool

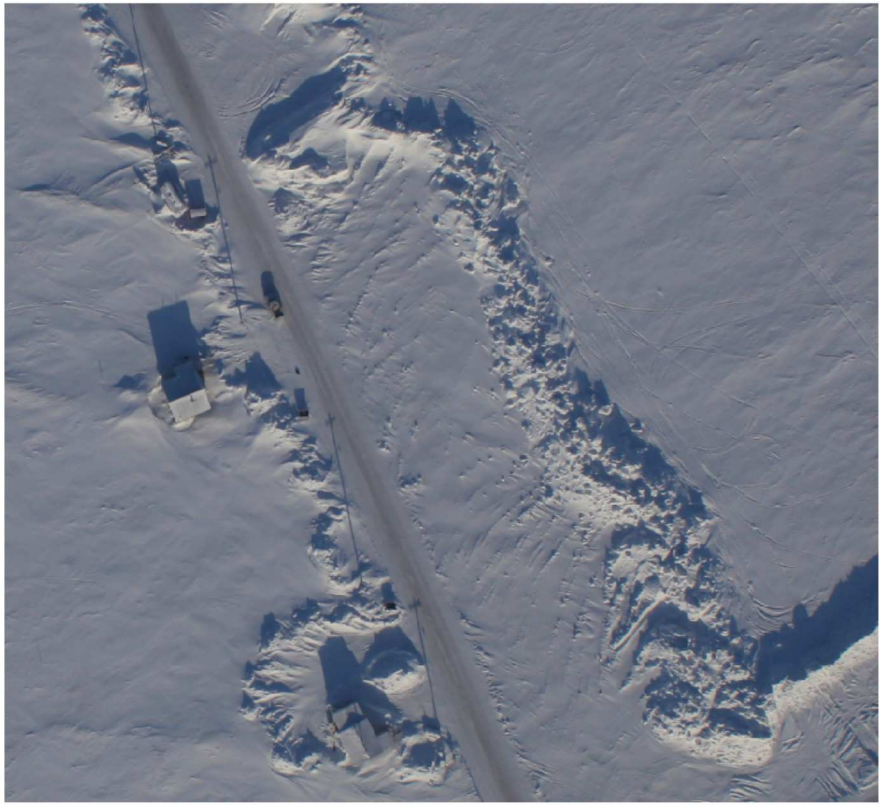


NASA IceBridge

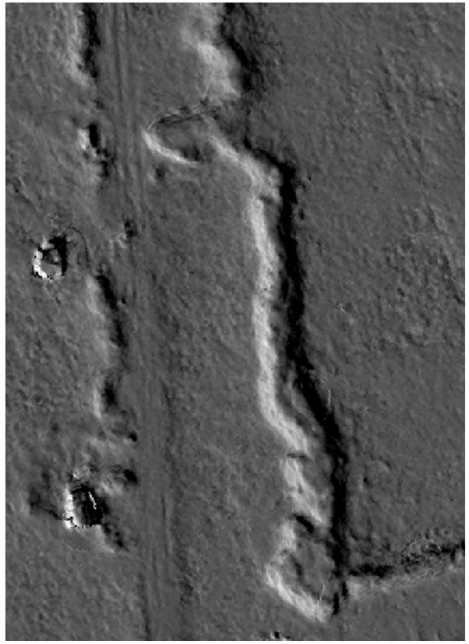
- Our major effort this year is to process a large backlog of frame camera images captured during NASA's IceBridge program flights.
- There are five million images which will be processed on the NASA Pleiades supercomputer.

- In addition to trying to obtain the best possible stereo results with no human intervention, another challenge is to accurately align the stereo DEMs with the narrow strip LIDAR data.
- Our results are comparable to DEMs produced with the Agisoft Photoscan software several years ago but we are much more robust to difficult circumstances.

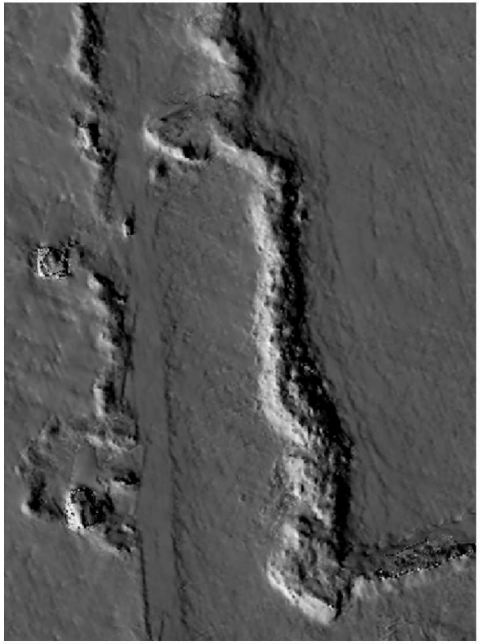
IceBridge Results



Input image



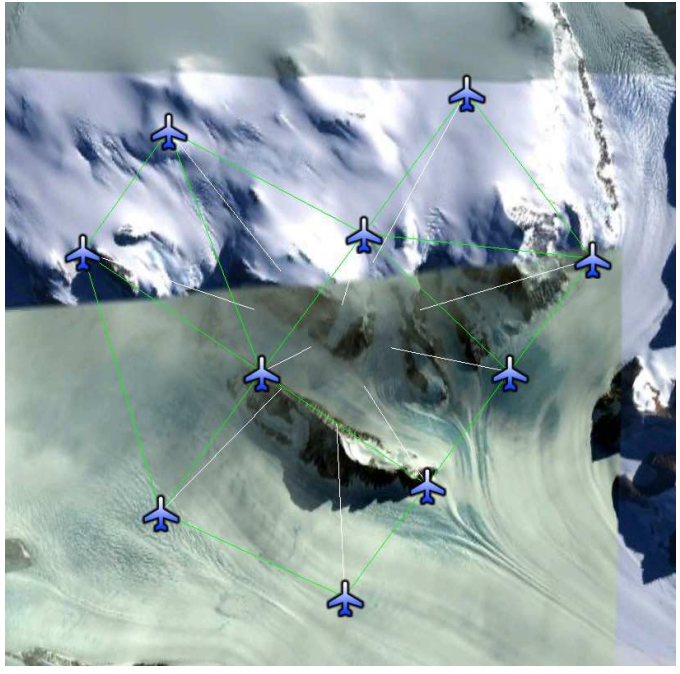
Fireball
(Agisoft Photoscan)



ASP MGM

Structure from Motion

- ASP has tools to solve for the position and orientation of frame cameras with incomplete metadata.
- ASP uses the Theia SfM software package to solve for relative camera positions[1].
- ASP's bundle adjustment tool uses Ground Control Points (GCPs) to refine the cameras and transform them to global coordinates.
- ASP's point cloud alignment tool can be used for final alignment (including scale) if the GCPs are not sufficiently accurate.

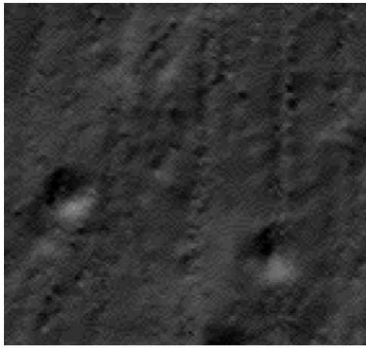


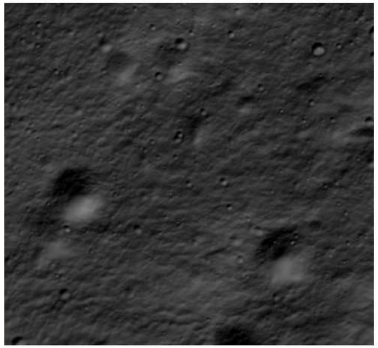
1) http://www.theia-sfm.org/

Shape from Shading

- By starting with the observation that the shading in an image is influenced by angle-dependent reflection, ASP is able to use multiple images taken with different lighting conditions to produce very accurate terrain models.
- ASP models reflectance, albedo, camera exposures, camera positions/orientations, and shadows.
- The surface starts with an initial guess from stereo or LIDAR and iterates until a solution is reached.
- This process can achieve a level of detail comparable to the input images.
- Though powerful, this method requires more input imagery, more computation time, and a good understanding of the material properties of the ground. Used with non-Earth imagery.

LOLA gridded DEM





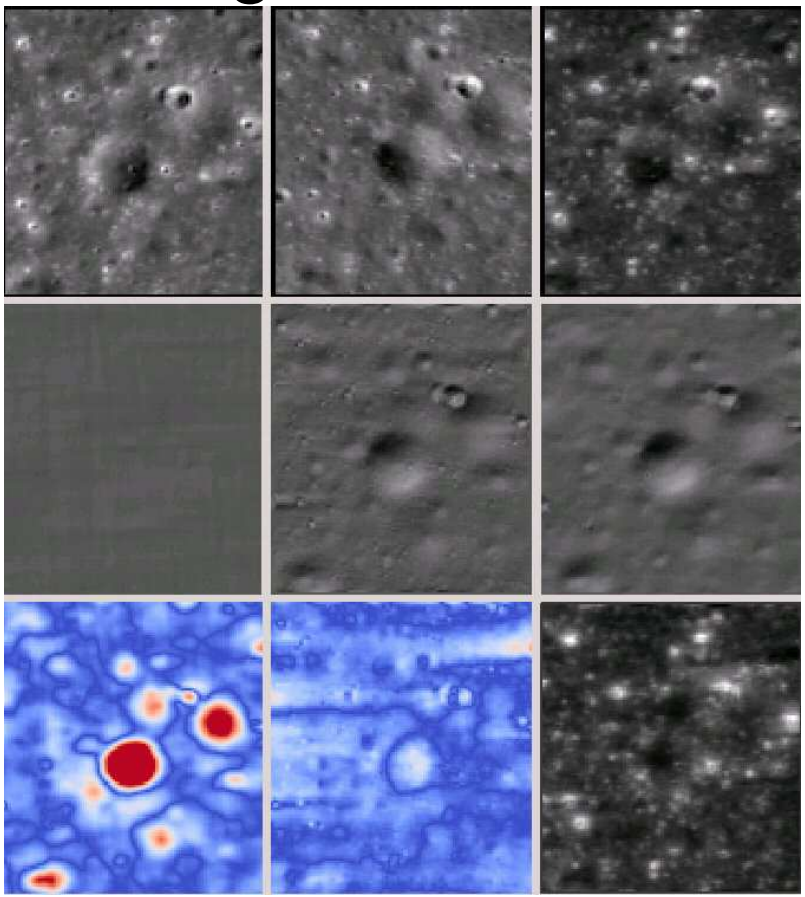
Shape from Shading DEM

Shape from Shading

LRO-NAC 10x. →

Stereo DEM from 10x,
SfS DEM from 10x,
Stereo DEM from 1x →

Error between SfS and 10x stereo,
error between SfS and 1x stereo,
and solved albedo. →



Future Development

- Add piecewise epipolar image alignment for pushbroom sensors
- Improve SGM/MGM results on extraterrestrial data
- Incorporate geometric filtering in correlation step
- Add new stereo algorithms
- Improve modeling of distortion
- Add more preprocessing options

Contact

Google group:
https://groups.google.com/forum/#!forum/ames-stereo-pipeline-support

Mailing list:
stereo-pipeline@lists.nasa.gov

Email the developers directly:
stereo-pipeline-owner@nasa.gov

Questions?