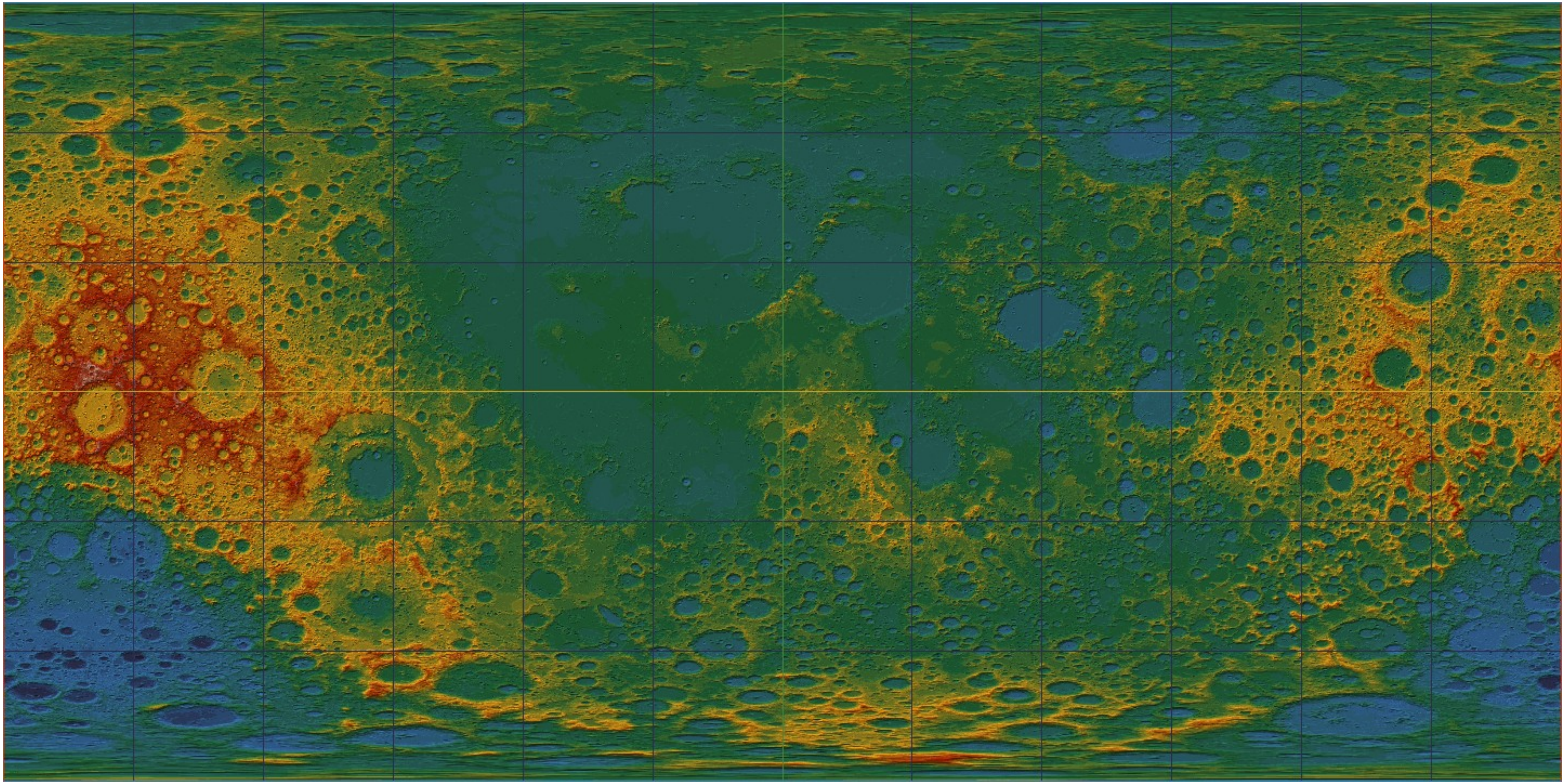
Accuracy Assessment of Ames Stereo Pipeline Derived DEMs Using a Weighted Spatial Dependence Model



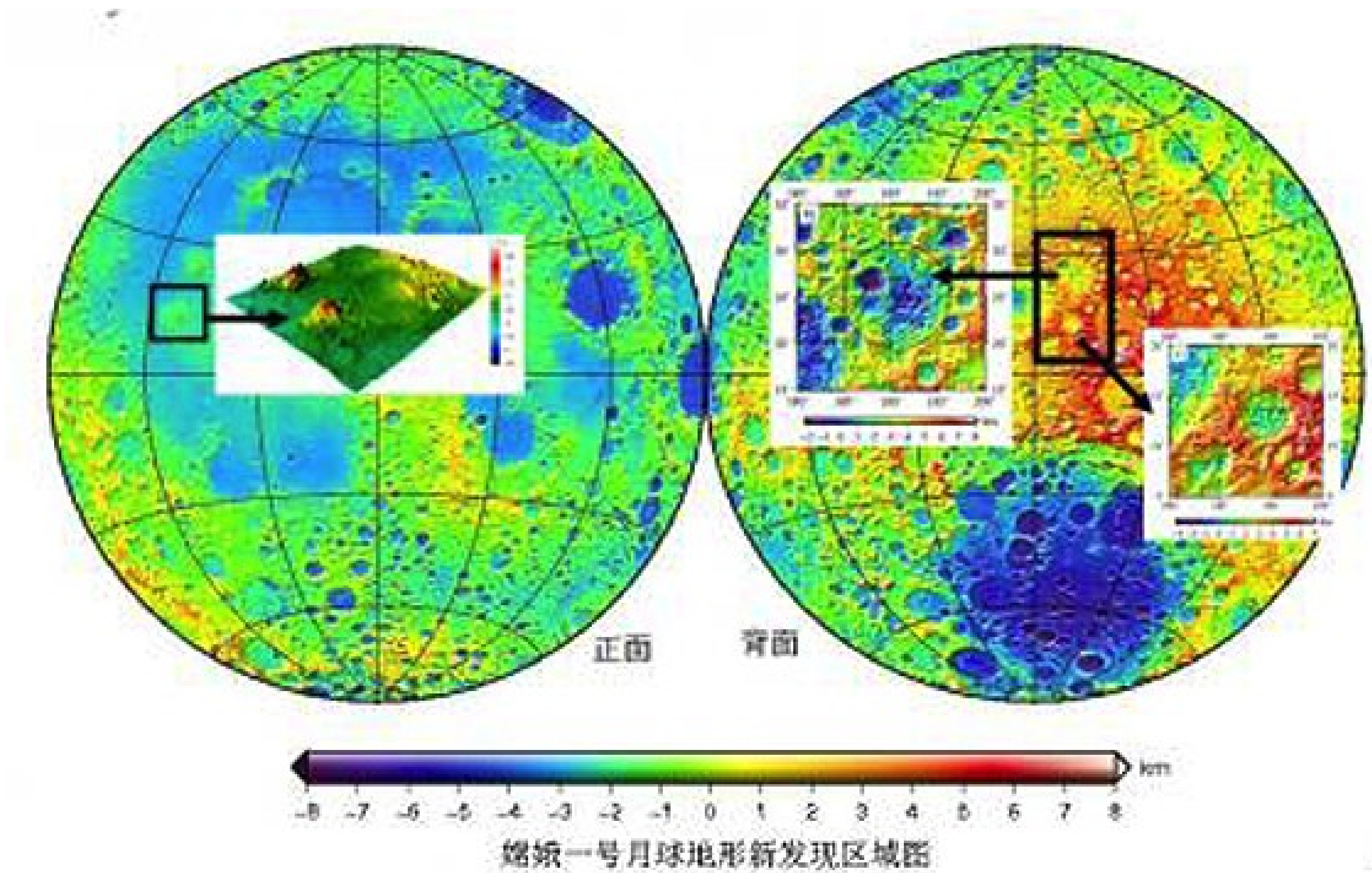
Problem Statement

- A successful lunar mission requires accurate, high resolution data products to facilitate site selection
  - Site selection for planetary missions broadly focuses on two problems:
    - Scientific merit (What good “stuff” is near by to investigate?)
    - Operational Safety (Are we going to break our lander on a big rock or crater?)
- Digital elevation models (DEMs) provide elevation data from which other data products are derived
- The ratio of high resolution images and derived DEMs is severely skewed. (We collect a ton more data than we can process.)
- As a member of The Penn State Lunar Lion team I am generating lunar DEMs to facilitate site selection.
- The accuracy of these DEMs is currently unknown.

Who is Lunar Lion?

What is a DEM?

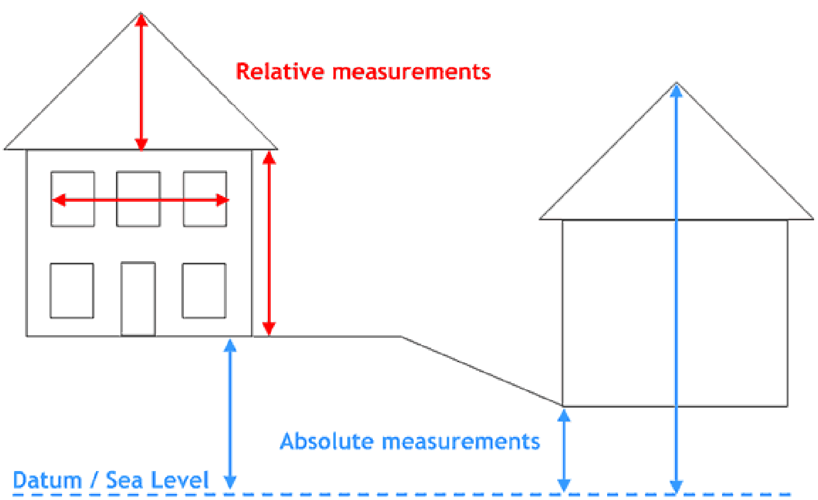
- A digital file
- Elevation data over a regular grid (raster)
- A single potential realization of the underlying surface.

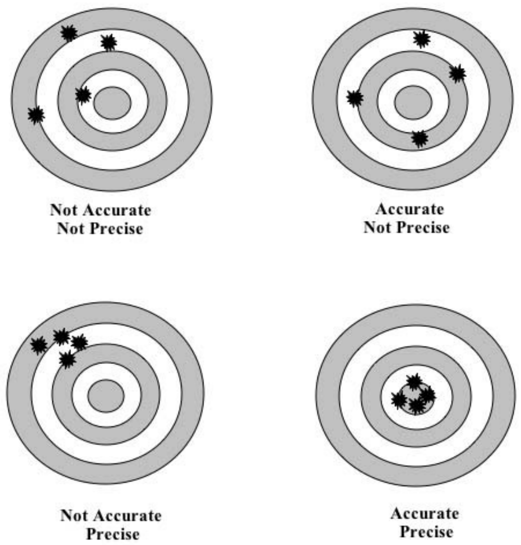


Accuracy
Relative vs. Absolute

- Absolute accuracy denotes error between "ground truth" and the mapping product
  - Is the elevation at point A on the map the same as point A on the body?

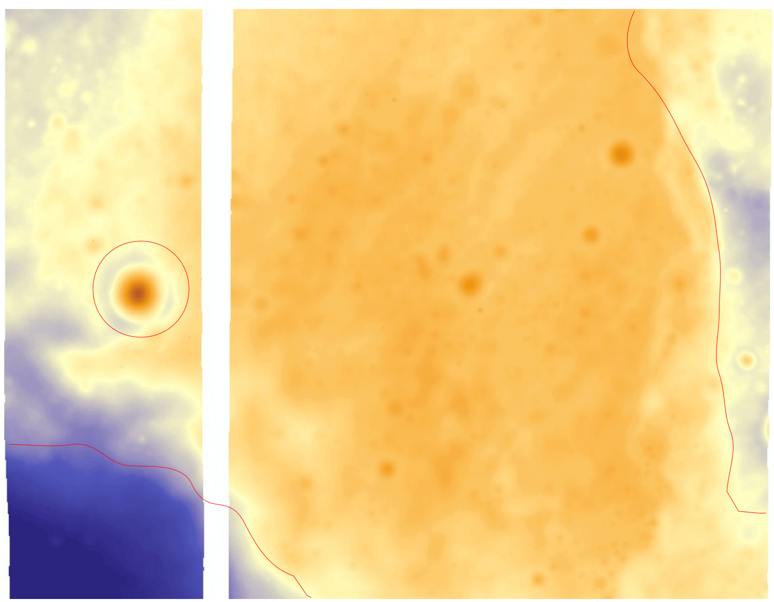
- Relative accuracy denotes internal error within a data product or across relative data products.
  - Relative to each other, what is the accuracy of elevations measured at points A & B?





Suitability
Coverage vs. Resolution

- High Resolution / High Accuracy (horizontal & vertical) datasets often exhibit low body coverage
- Lower resolution / accuracy data exhibits higher coverage

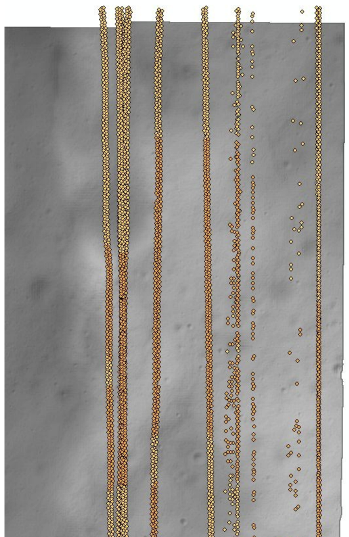


Stereopair Derived DEM

Map scale is identical!

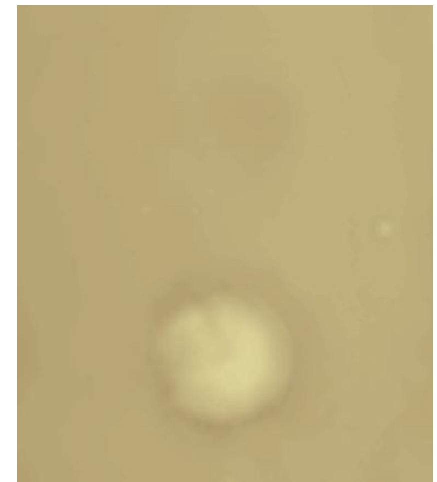
Laser Altimeter DEM

Where do Lunar DEMs come from?

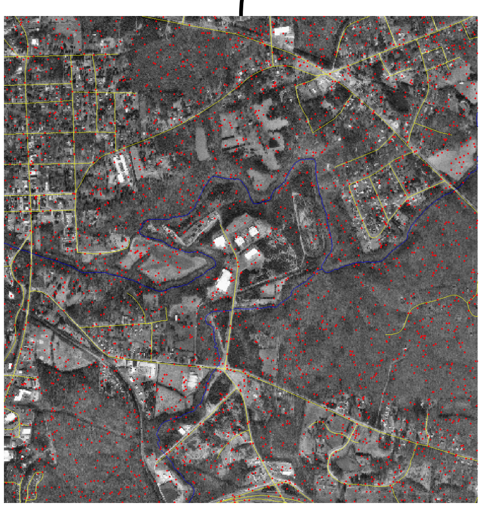


Lunar
Orbiter
Laser
Altimeter

<--Scale Differs-->

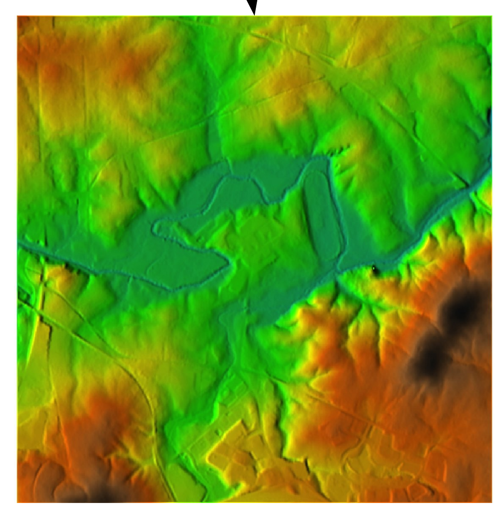


Interpolation / Extrapolation



Some Town USA

Imaged by Some Laser Altimeter



LOLA

Always read the metadata for relative and absolute accuracy assessments.

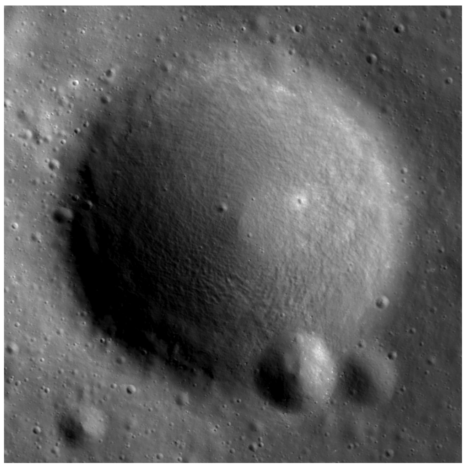
- Lunar Orbiter Laser Altimeter
  - Planetary coverage. Double, triple or higher coverage in some places – facilitates crossover analysis
  - Vertical Accuracy: 1-10m Absolute Accuracy / 1-5m Relative Accuracy
  - Horizontal accuracy: 10 – 300m Absolute Accuracy / 1-5m Relative Accuracy
    - Horizontal accuracy improves with crossover analysis and at poles.
  - Resolution: 240m / pixel (supplied) ; 120m / pixel (available)

Source: ftp://pdsimage2.wr.usgs.gov/pub/pigpen/moon/LROC/wac_mosaic_asu/LRO_WAC_Mosaic_Global_303ppd.html

Where do Lunar DEMs come from?

Lunar Reconnaissance Orbiter Stereopairs

Low Resolution: Wide Angle Camera (WAC) or High Resolution: Narrow Angle Camera (NAC)



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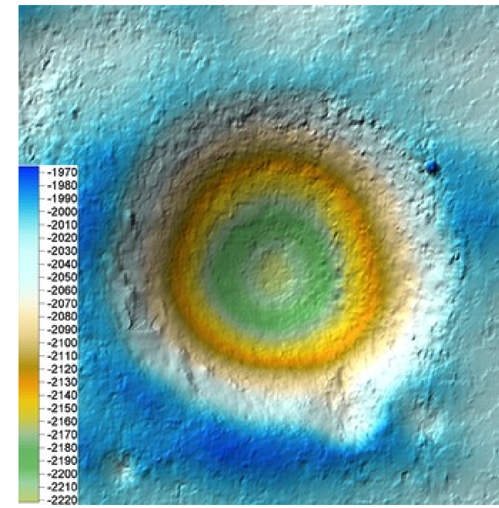
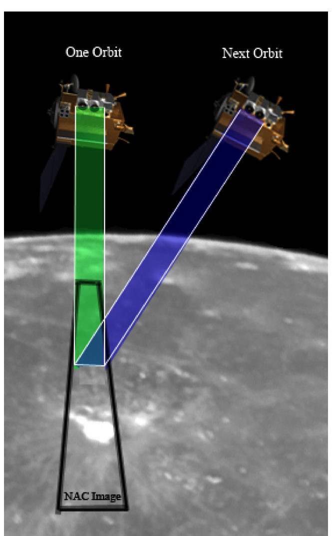
BAE SYSTEMS

SOCET SET®

=





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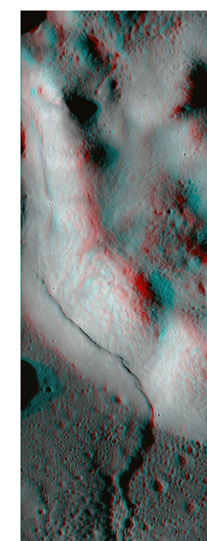
<u>Parallax</u> –
The effect by which the position of an object appears to differ when viewed from different positions.

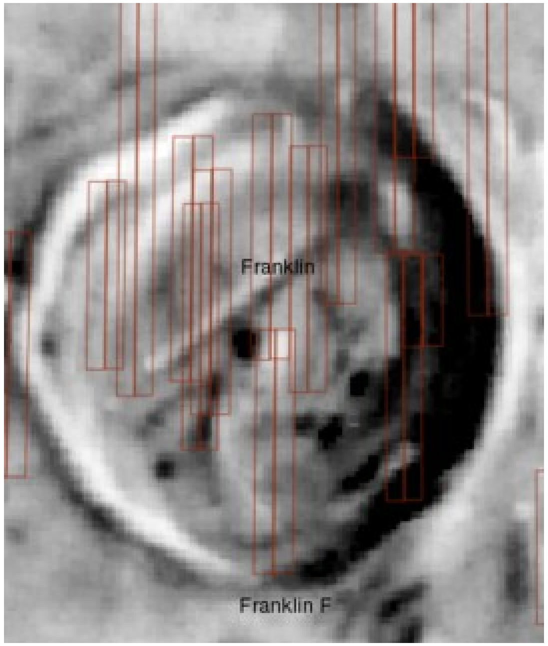
=



It is essential that images be both overlapping and captured from different angles!

LRO NAC Stereopairs

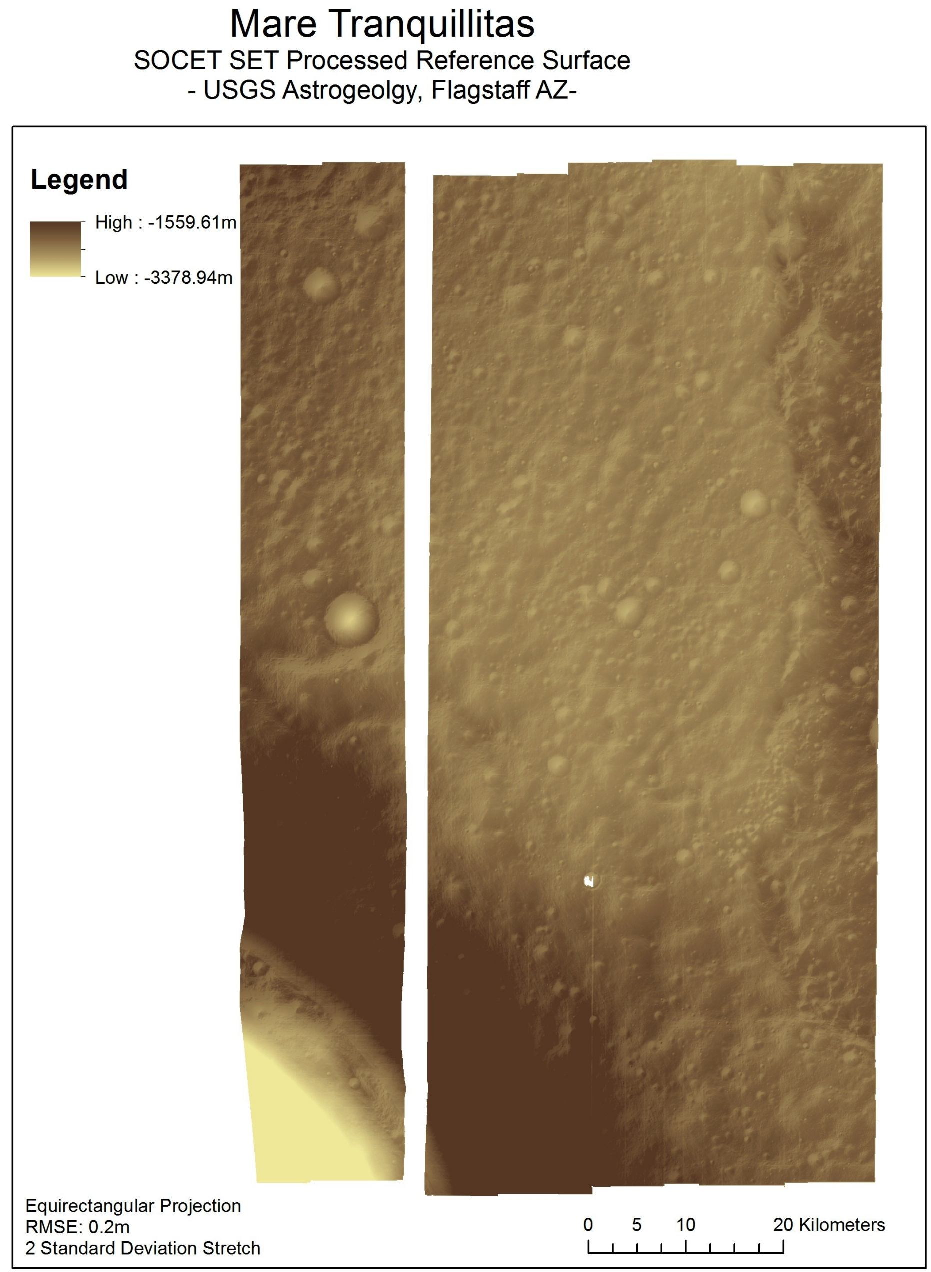
- Lunar Reconnaissance Orbiter Narrow Angle Camera (LRO NAC)
  - Low, but ever increasing
  - Coverage decreased because this method requires stereopairs within a limited parallax range
  - Resolution: 0.5m - 2m / pixel
  - Relative accuracy varies with convergence angle



Source: http://www.slideshare.net/sacani/generating-digital-terrain-models-using-lroc-nac-images

NAC DEM

- Limited Availability
- Purpose built by the data user (or a government contract.)
- Limited Body Coverage
- Anywhere from 1.5m to 0.5m per pixel!
- This is the highest resolution data available



Intro

Ames Stereo Pipeline (ASP)

“an automated suite of geodesy and stereogrammetry tools designed for processing planetary imagery...” (NASA Ames)

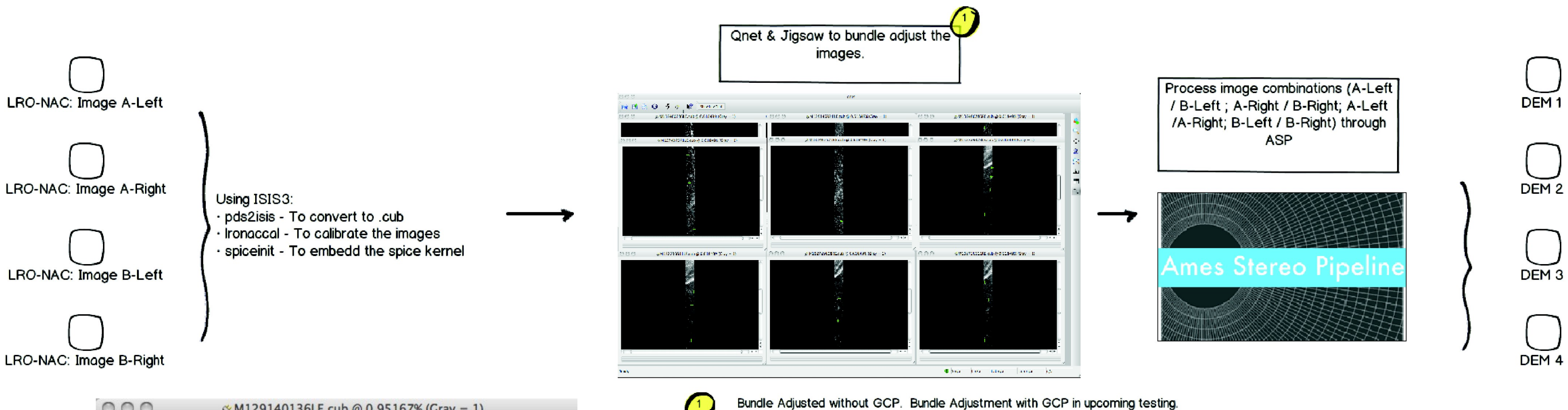
SOCET SET vs. ASP

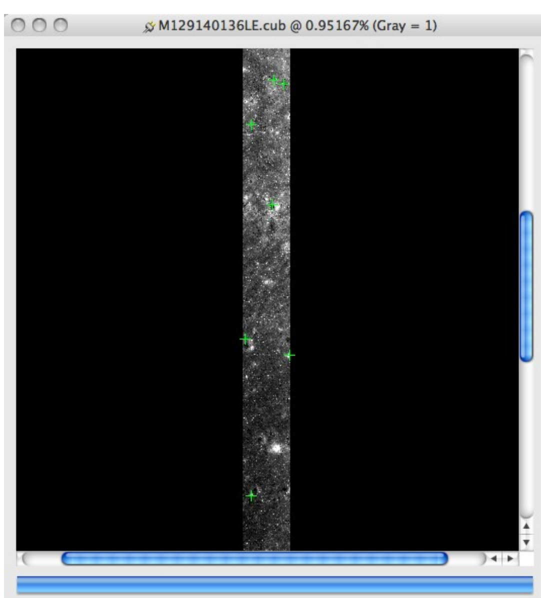
- ✗ Requires high human-computer time
- ✔ Allows for manual editing of problem areas
- ✗ Proprietary
- ✔ Can process multiple input images concurrently
- ✔ Produces a pixel suitability raster
- ✗ Requires a specific workstation setup

- ✔ Requires limited human-computer time
- ✗ Requires extensive computer wall time (quad-core can require anywhere from 4 days to 3 weeks)
- ✗ Does not allow for manual editing
- ✔ Open Source
- ✗ Can process only pairs of images
- ✗ Limited quality metrics generateds
- ✔ Runs natively on Linux and OSX. Can be run in a virtual machine on through windows.
- ✔ Prime candidate for use in the cloud

From overlapping images to DEMs – Data Prep

- A single NAC "image" consists of independent right and left camera
- Each stereopair is therefore 4 images
- Images are downloaded from PDS, the Planetary Data System
- ISIS3, the USGS planetary data processing suite is used to prepare the data





Why bundle adjust?

The bundle adjustment process "fixes" small errors in the camera angle. These small errors, if left in the process, result in large distortions. For example, at 50km, a 0.001 degree camera angle error results in a 0.9m ground error. (M. Rosiek, USGS via email).

From overlapping images to DEMs – ASP

- Correlation – Using a box filter, ASP attempts to correlate pixels in each image. This is optimized to estimate pixel location The map projection process assists in reducing the wall time required for this step.
- Refinement – Sub-pixel refinement occurs to improve upon correlation using a series of algorithms. All but the simplest are over my head!
- Triangulation – Generate a point cloud from the correlated pixels. This point cloud becomes our DEM!

But, what is ASP really doing?

In essence, ASP is doing what SOCET SET does, two images at a time. ASP outputs a point cloud which we process into a gridded (raster) DEM.

We control the process through a single configuration file, stereo.default.

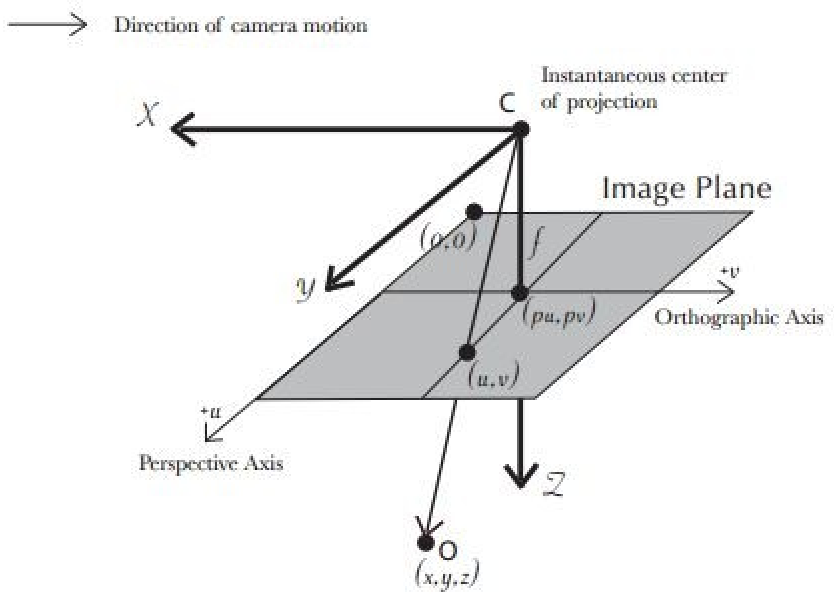
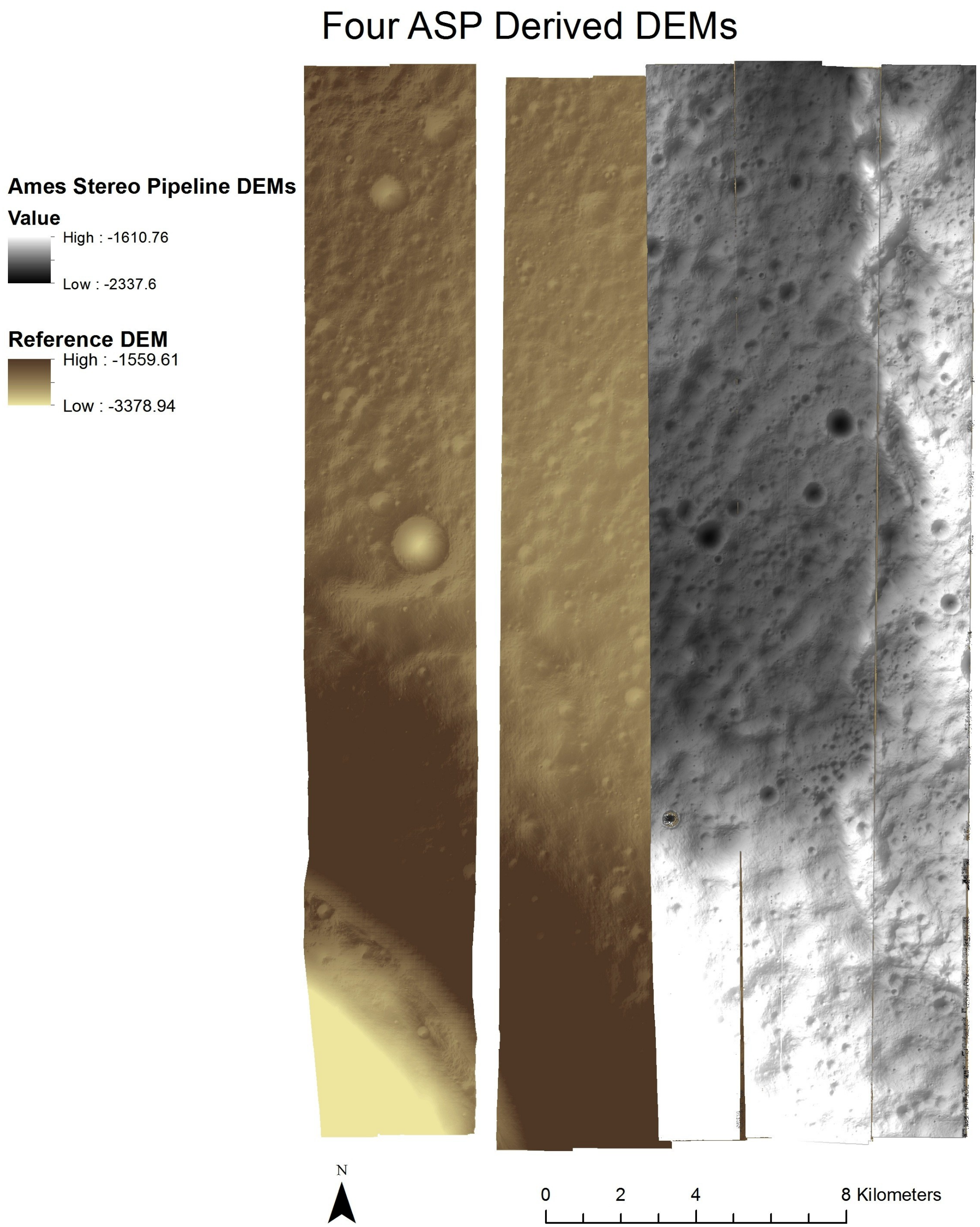


Image from ASP Manual

So we have a few DEMs to use for site selection.

- This will be derived into slope and roughness maps.
- Error in this DEM is exaggerated in derived datasets.
- Okay, we need to ask a few questions:
  - How much error is there?
  - Is it random or systematic?
  - Is it a product of image noise or shadow which impedes ASP?
- But, how do we assess DEM accuracy?

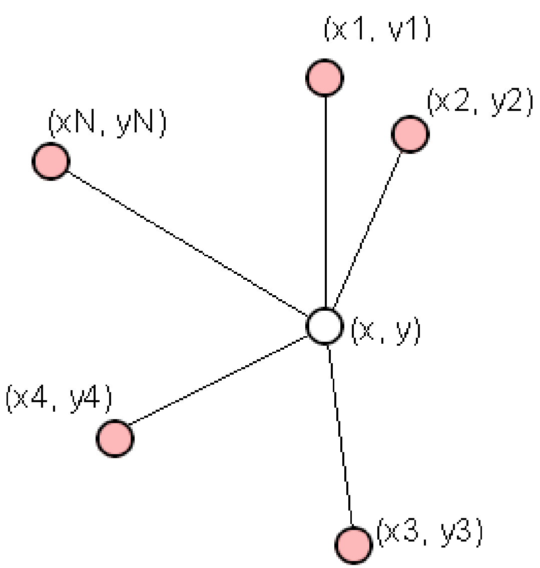


Assessing Terrestrial DEM Accuracy

- Calculation of the Root Mean Squared Error from control points.
  - Either from a higher resolution data set or in situ observation

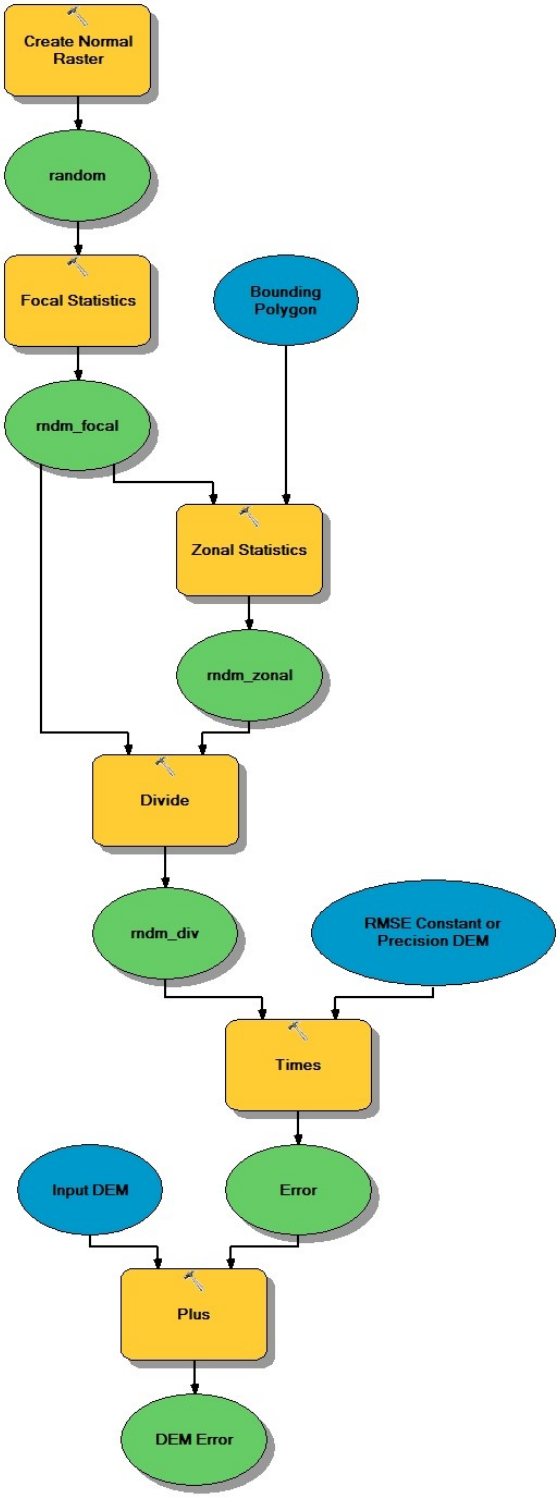
$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y - y_i)}{n}}$$

LOLA point data could be used, but a lot of the resulting surface is interpolated. We are interested in local phenomenon that could cause DEM error as well as overall RMSE.



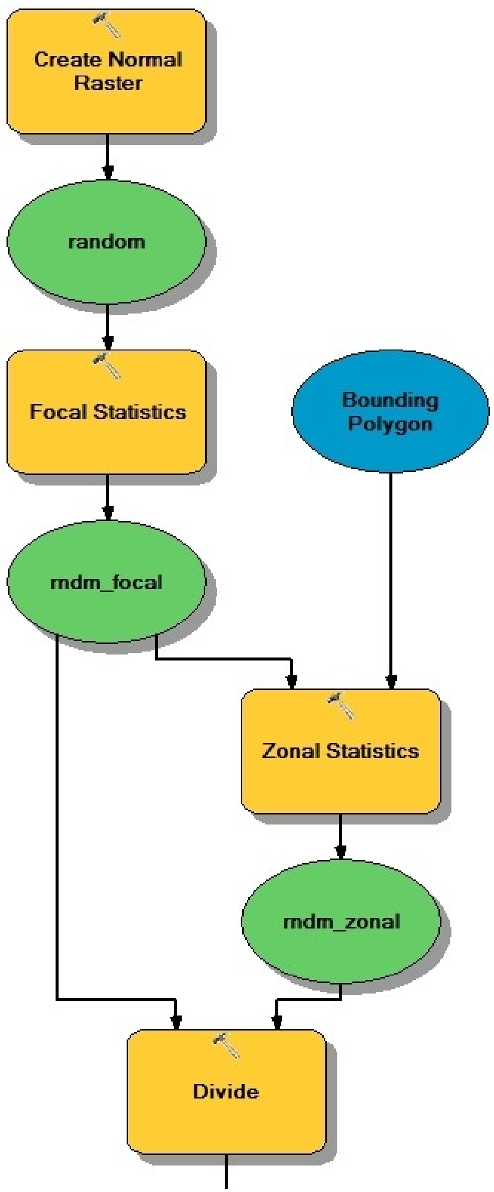
Okay, field trips are out and LOLA is not for us...

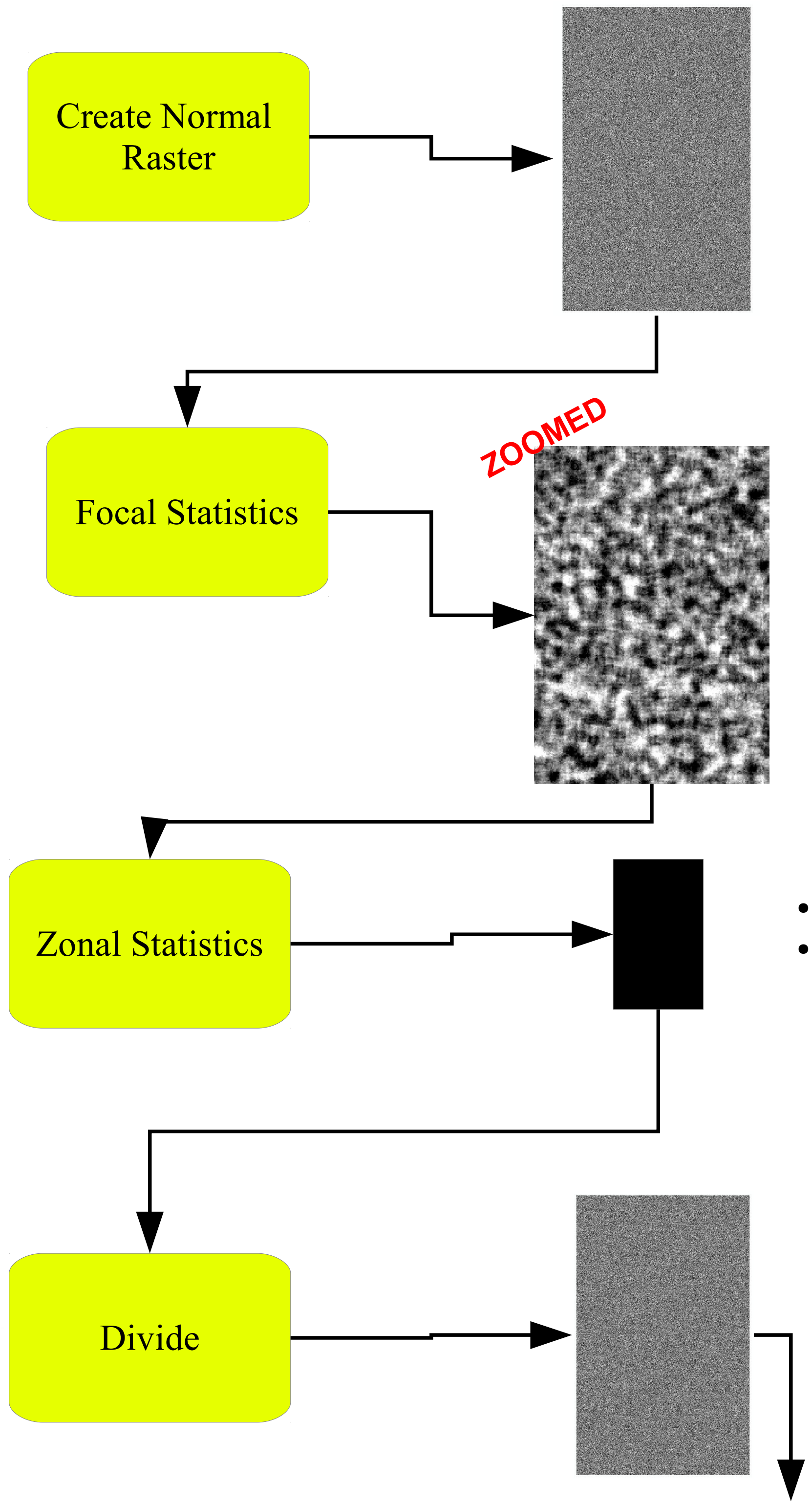
- To assess the affects of DEM error on derived topographic layers (slope, aspect, TPI/TRI) and hydrologic layers (flow), terrestrial methods have been developed to explore local DEM error where gridded, higher resolution data products are not available.
- Enter the Equipotential Surface
  - A realization of the underlying surface generated by randomly distributing error over the entire surface.



Creating an Equipotential Surface

- Requirements:
  - Repeatable & Automated
    - Monte Carlo Simulation Requires Multiple Iterations.
  - Allows for either a precision file or a constant for potential error
    - USGS DEMs may have a precision file derived from SOCET SET
    - RMSE provides a usable constant
  - Fast
    - < 20 Iterations is too few
    - 100 Iterations is great
    - 1,000 Iterations is ideal
  - Accessible
    - The process needs to be repeatable, transferable, and reusable by others
  - Tested
    - The technique should have been tested and peer reviewed.
    - The focus is not researching methods for surface creation.





- Normal Distribution
- Positive & Negative
- σ = 1

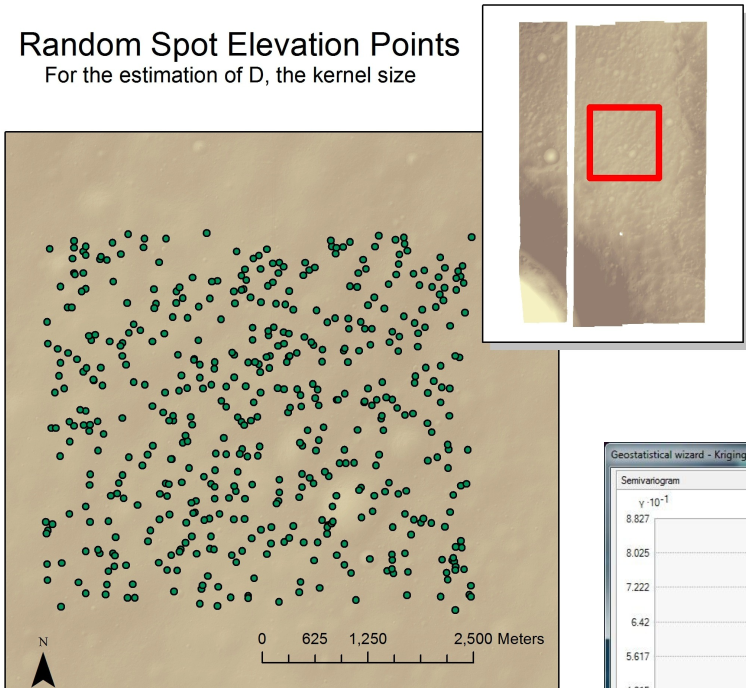
- Spatial Autocorrelation
- Weighted Box Filter
- Sill at 200m (~151 pixels)

- A Boring Looking Raster
- Calculates σ of focal raster

- Return Spatial Autocorrelated Raster to σ = 1
- “Structure” visible when zoomed

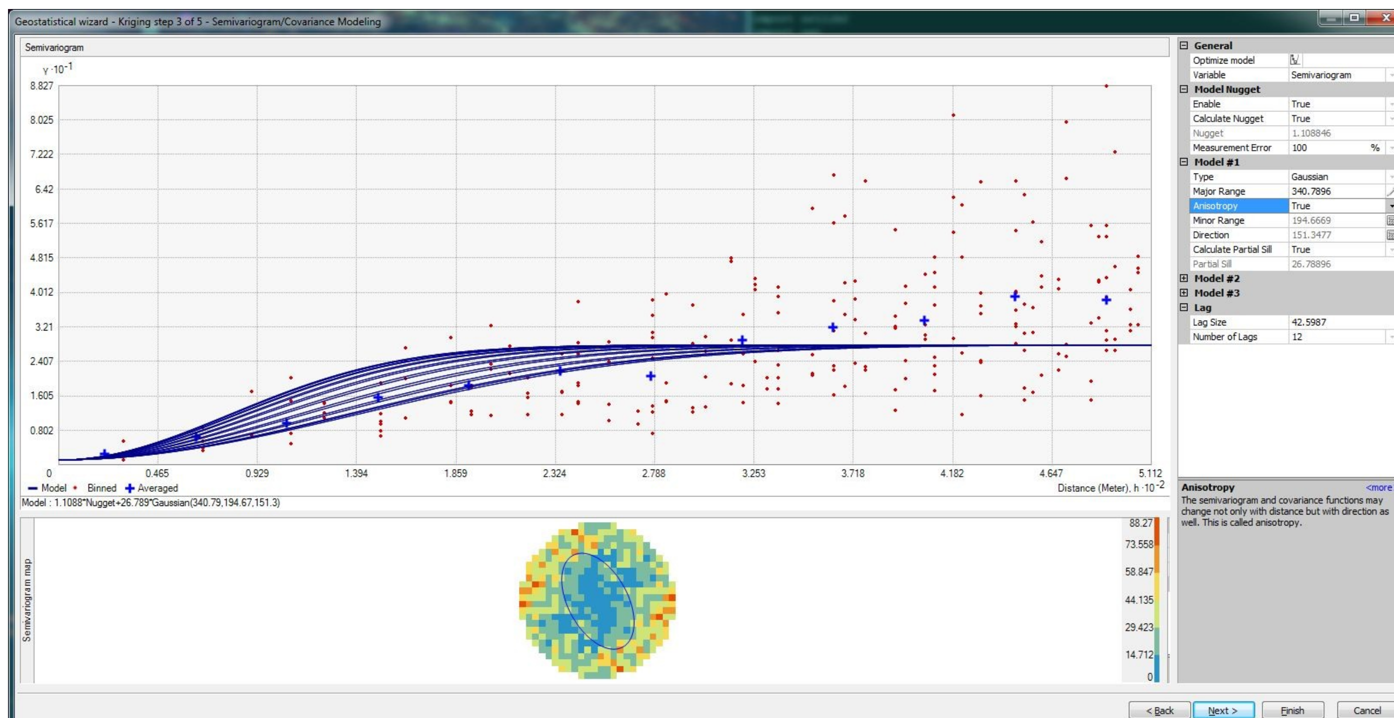
Calculating Our Kernel Size, *D*

Random Spot Elevation Points
For the estimation of D, the kernel size



USGS Processed DEM - Tranquillitas Mare

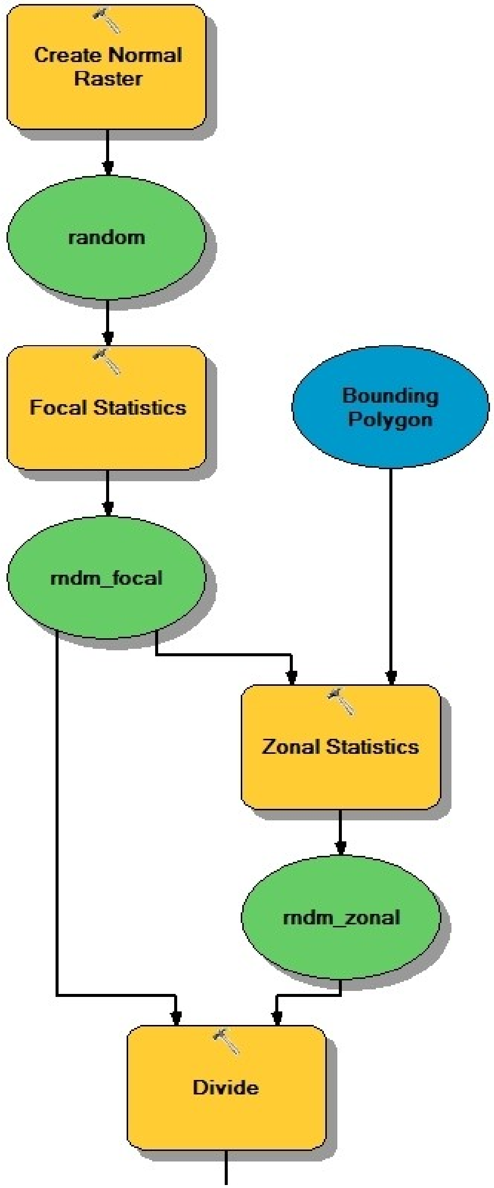
Sill at approximately 225m yielding a suggested kernel size of approximately 151 pixels.



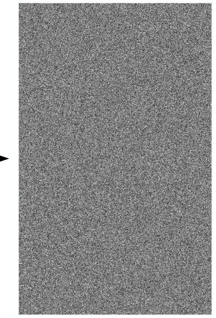
Semivariogram: *A continuous function which describes the estimated correlation between two points on a surface. It is an estimate, and may not accurately reflect correlation between two observed points.*

O'Sullivan & Unwin (2010). *Geographic Information Analysis, 2nd Edition*

Methodology

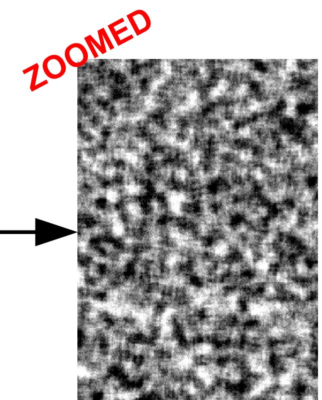


Create Normal Raster



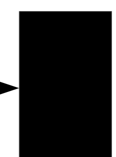
- Normal Distribution
- Positive & Negative
- σ = 1

Focal Statistics



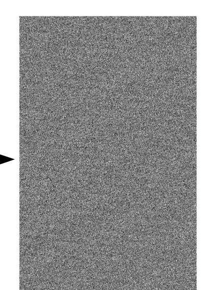
- Spatial Autocorrelation
- Weighted Box Filter
- Sill at 200m (~151 pixels)

Zonal Statistics

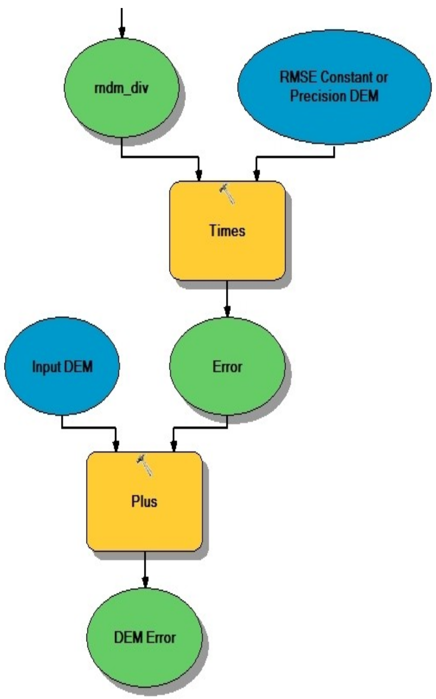


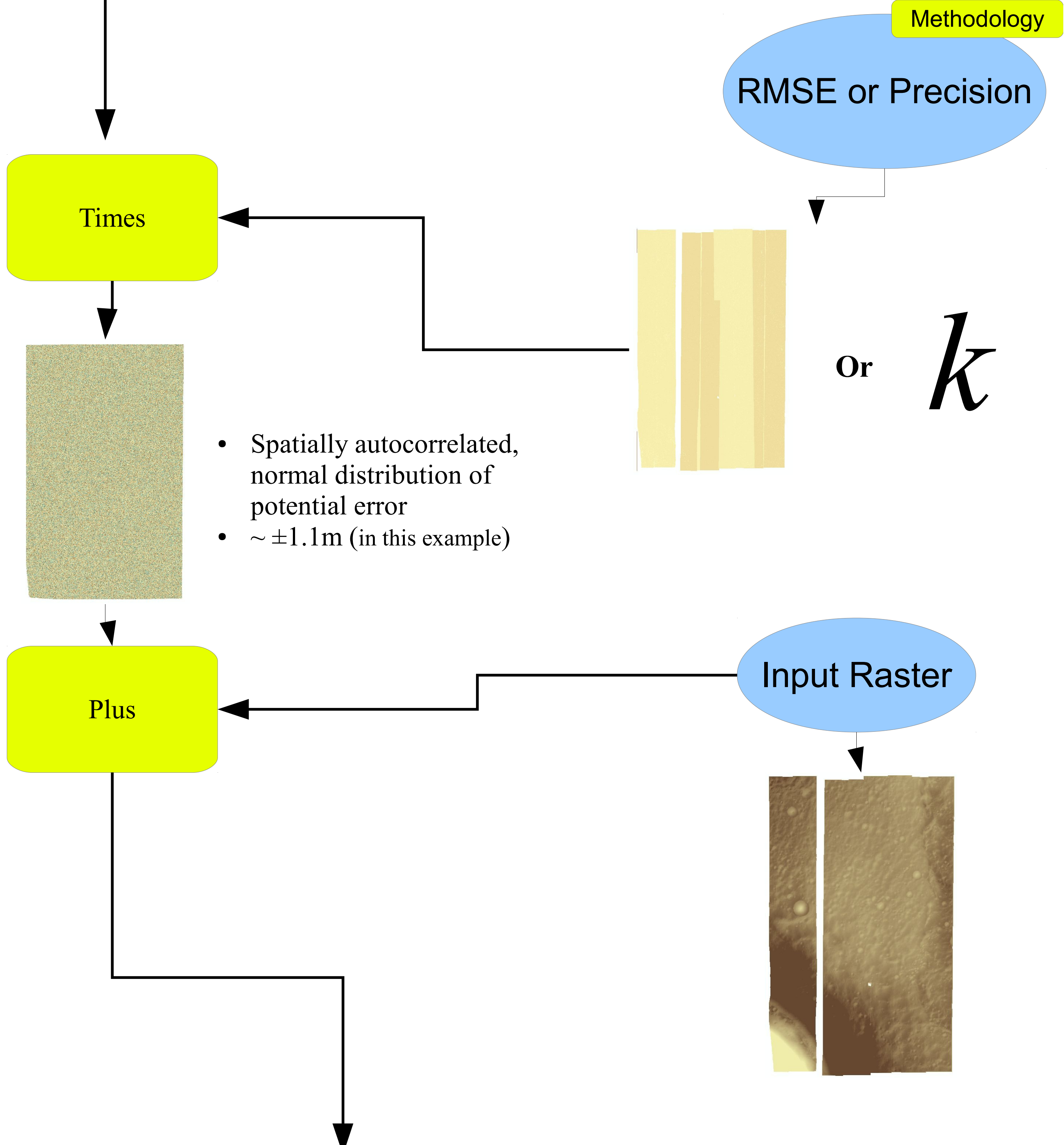
- A Boring Looking Raster
- Calculates σ of focal raster

Divide



- Return Spatial Autocorrelated Raster to σ = 1
- "Structure" visible when zoomed


rndm_div
RMSE Constant or Precision DEM
Times
Input DEM
Error
Plus
DEM Error

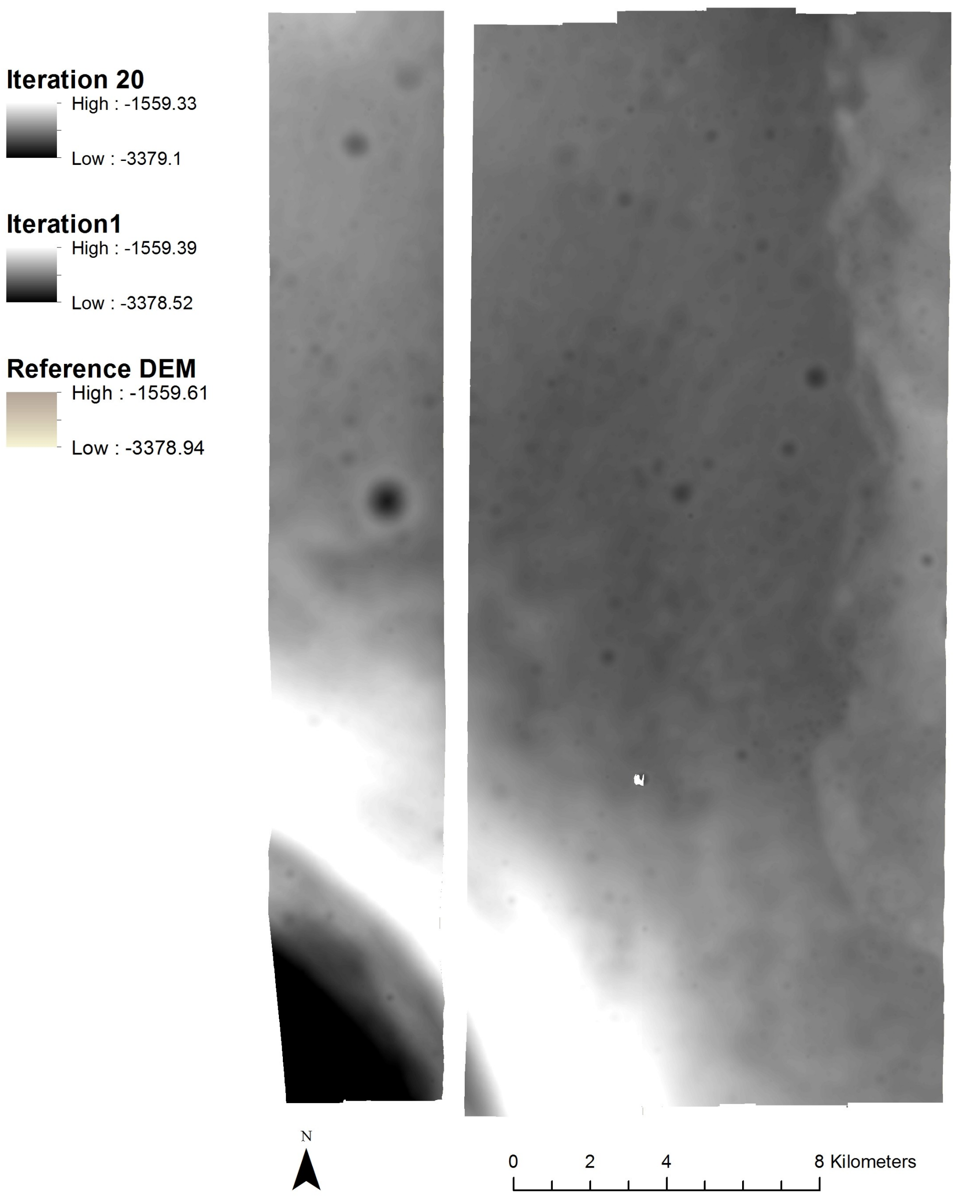

Methodology
RMSE or Precision
Times
Or
k
• Spatially autocorrelated, normal distribution of potential error
• ~ ±1.1m (in this example)
Plus
Input Raster

Sample Equipotential Surface

The model requires anywhere from a few minutes to 4+ hours to process.

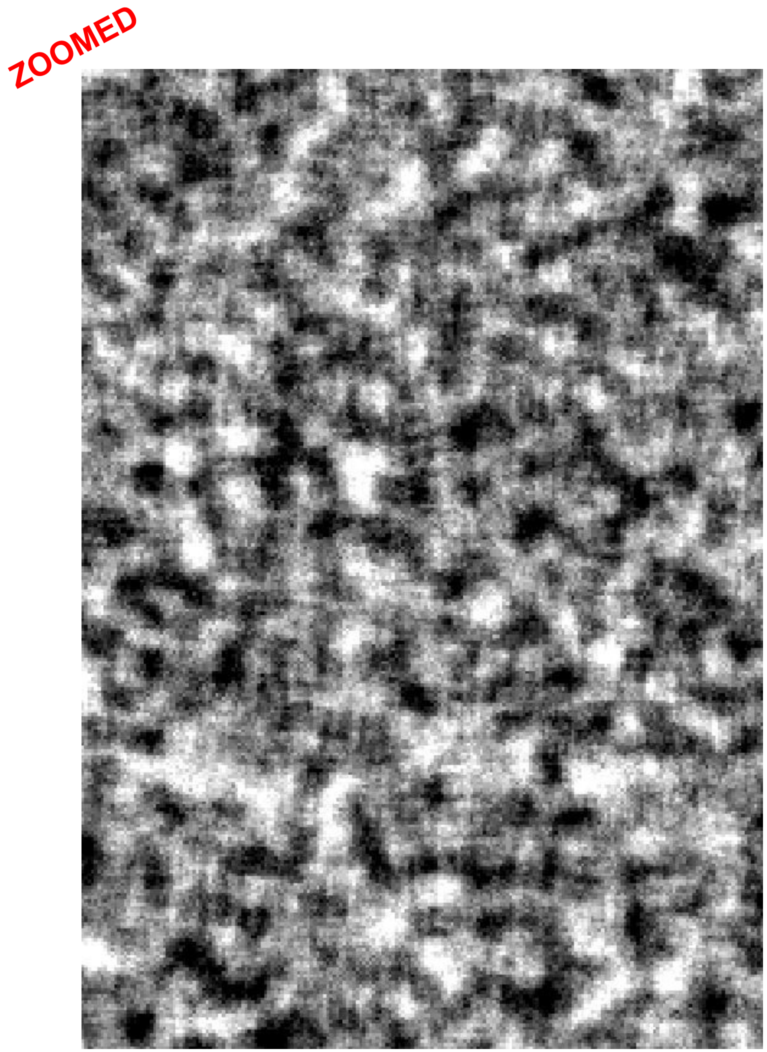
Time required is a function of kernel size...unfortunately.

Two Equipotential Surfaces



Edge Effects

- Is our kernel too large or are we having an issue with edge effects?

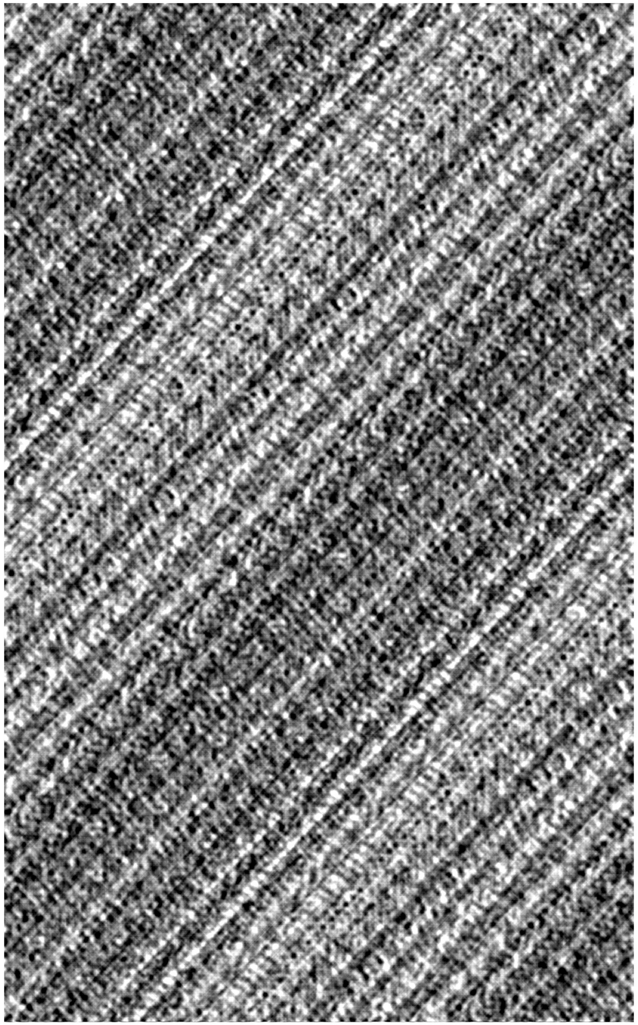


Unweighted box filter vs inverse distance weighted box filter

<--- D = 5

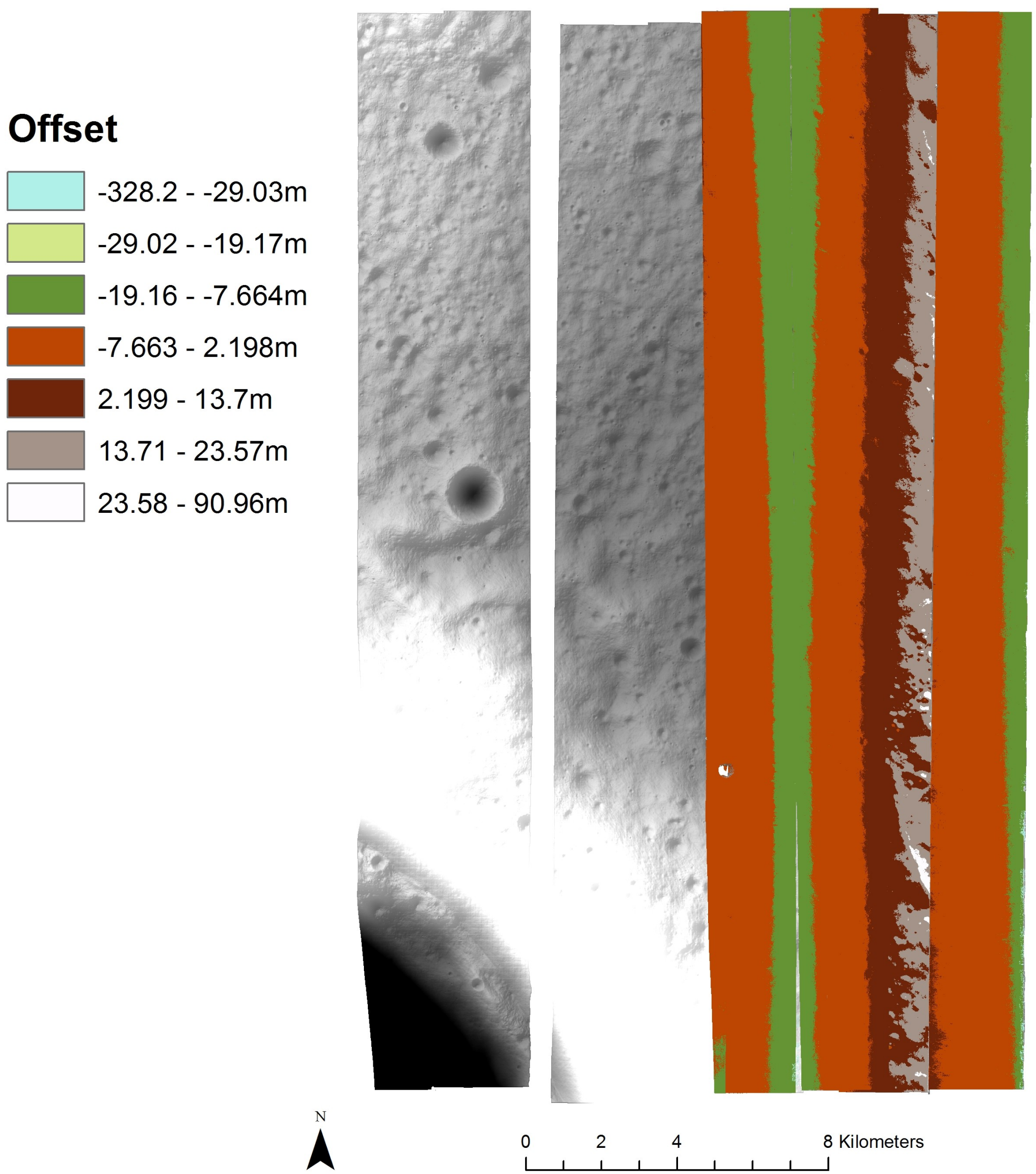
Vs

D = 151 --->



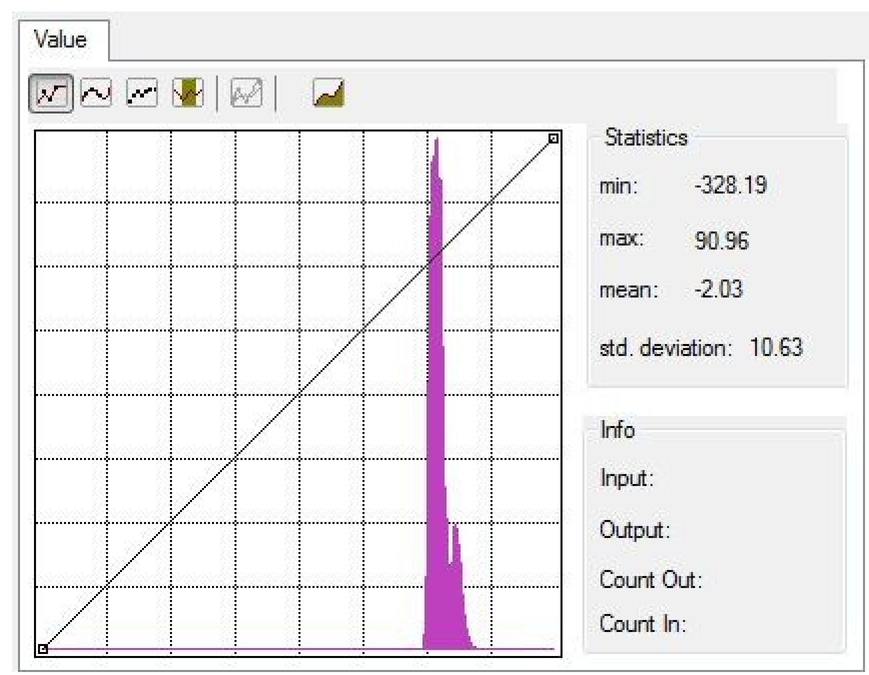
Initial Results

Offset between Equipotential Surface and ASP DEMs



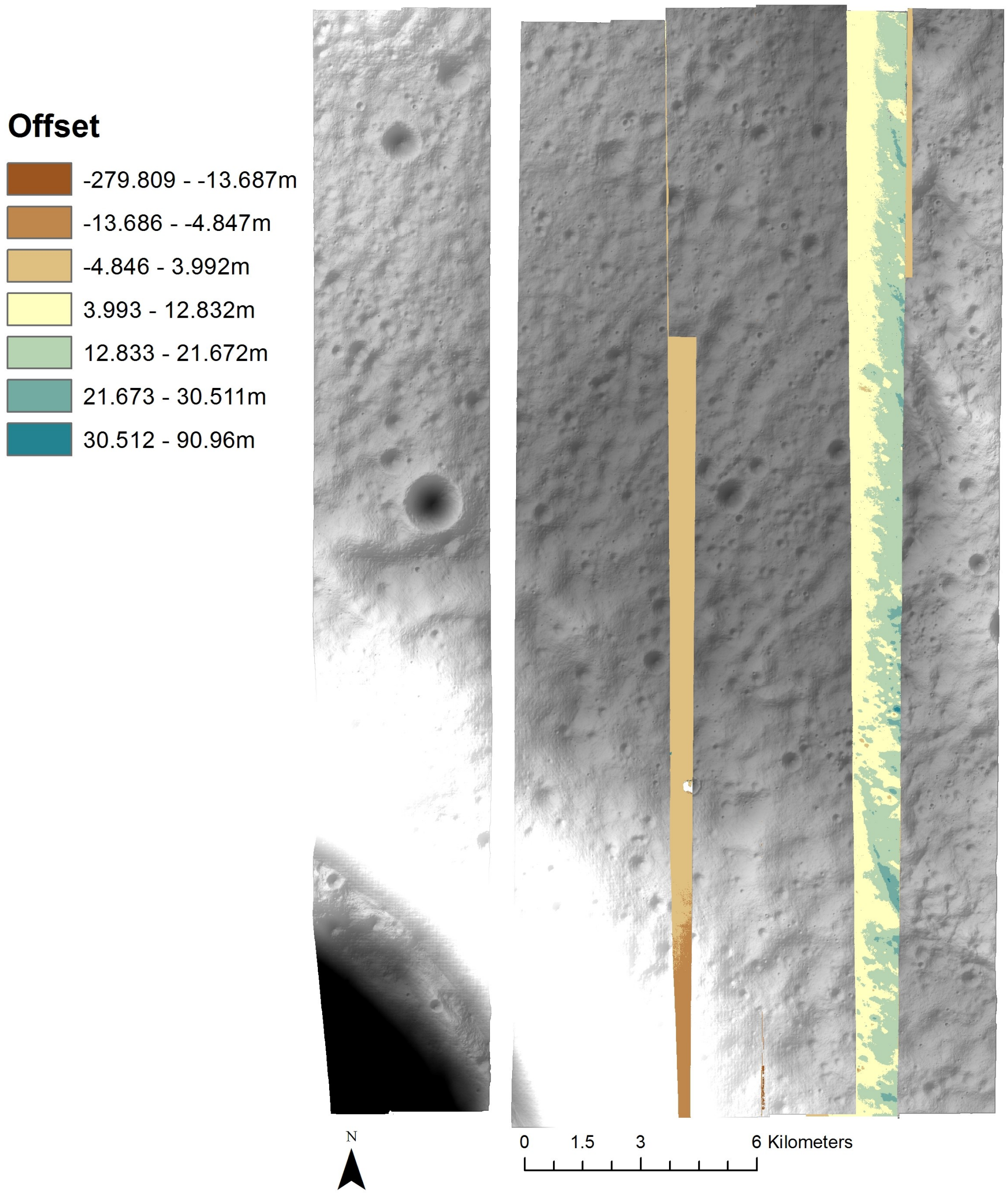
To calculate error:

1. Generate and mosaic four DEMs (ISIS3 / ASP)
2. Generate 20 spatially autocorrelated equipotential DEMs (Model Above)
3. Calculate the mean of the equipotential surfaces (Raster Calculator)
4. Subtract the reference surface from mean of the equipotential surfaces (Raster Calculator)

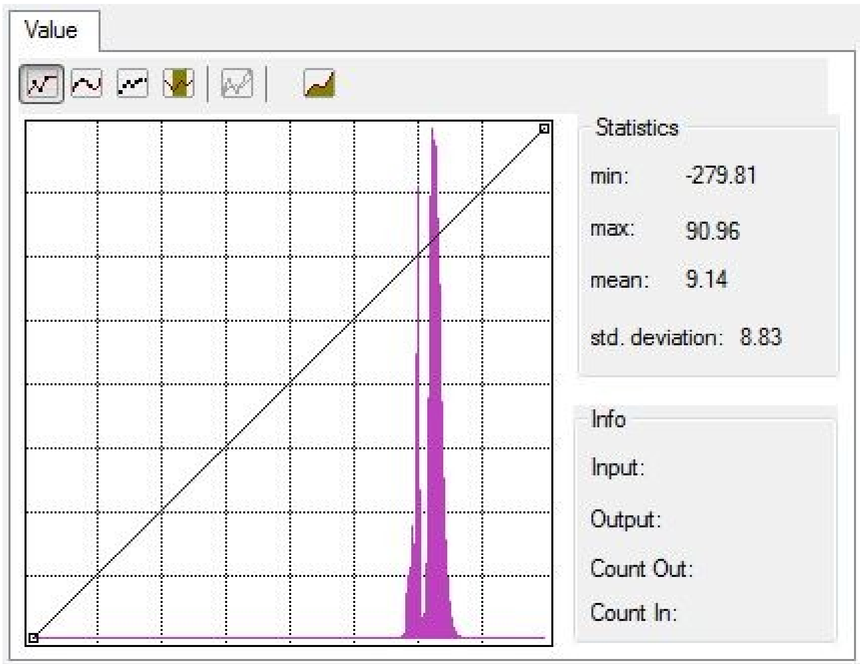


Initial Results – Clipped

Offset Between Equipotential Surface and Clipped ASP DEMs



Since we are using a SOCET SET DEM as a reference, we also get a confidence map. Here, all interpolated, extrapolated, and suspicious pixels have been removed. The ability to confidently assess accuracy on a pixel by pixel basis is the reason we went through the trouble of making so many surfaces.



Wait...what about site selection?

- Error in a DEM is exaggerated in derived products just like satellite angle errors are amplified in the creation of a DEM.
- Initial results show accurate internal results (across DEMs)
  - This means that we can be confident that other DEMs with similar qualities (lighting / noise), generated by the same means, will be consistent.
  - We can confidently use mosaiced DEMs to derive relative elevation, as well as slope and roughness
- Results are 'close' to the absolute LOLA reported elevation which allows us to generate DEMs in areas where LOLA is the only data set to test accuracy with.

Now What?

Where do we go from here?

- Most importantly – we can confidently move forward with methods for statistically analyzing and modeling the density and distribution of 'lander-killer' hazards.
- The preliminary results also generate more specific questions concerning the accuracy assessment:
  - Will accuracy improve by automating the bundle adjustment process in ISIS3?
  - Will accuracy improve by including ground control points?
  - How much influence are edge effects causing? Should an exclusion zone be used?
  - What is the spatial distribution of error within the ASP DEMs?
    - Are these caused by input images (lighting / noise), preprocessing (calibration / bundle adjustment), or ASP (refinement kernel size / LOLA correlation)?