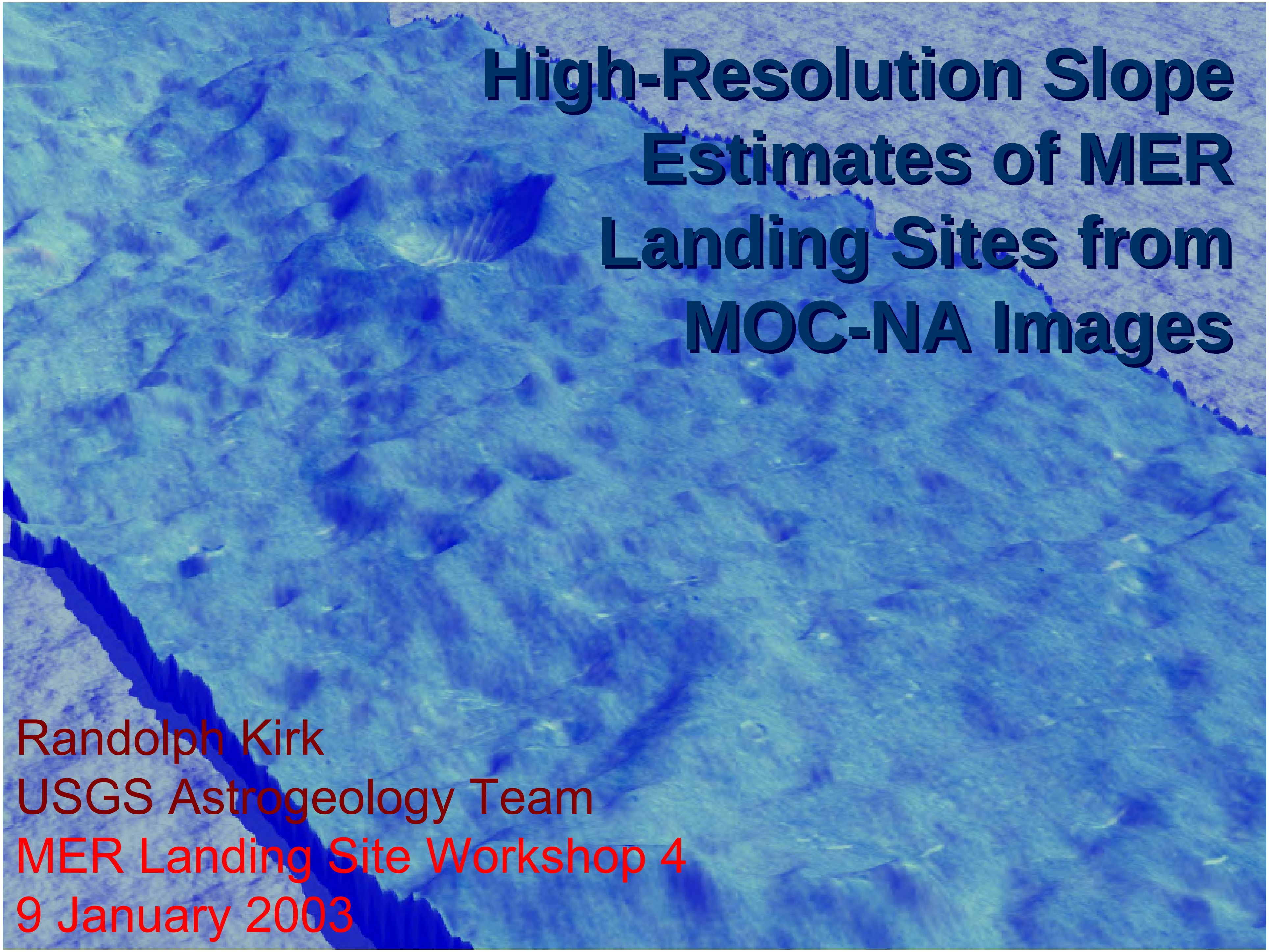


High-Resolution Slope Estimates of MER Landing Sites from MOC-NA Images

Randolph Kirk
USGS Astrogeology Team
MER Landing Site Workshop 4
9 January 2003

Outline

- Objectives
- DEM Count
- Methodology
- Error assessment
- New results
- Summary

Objectives

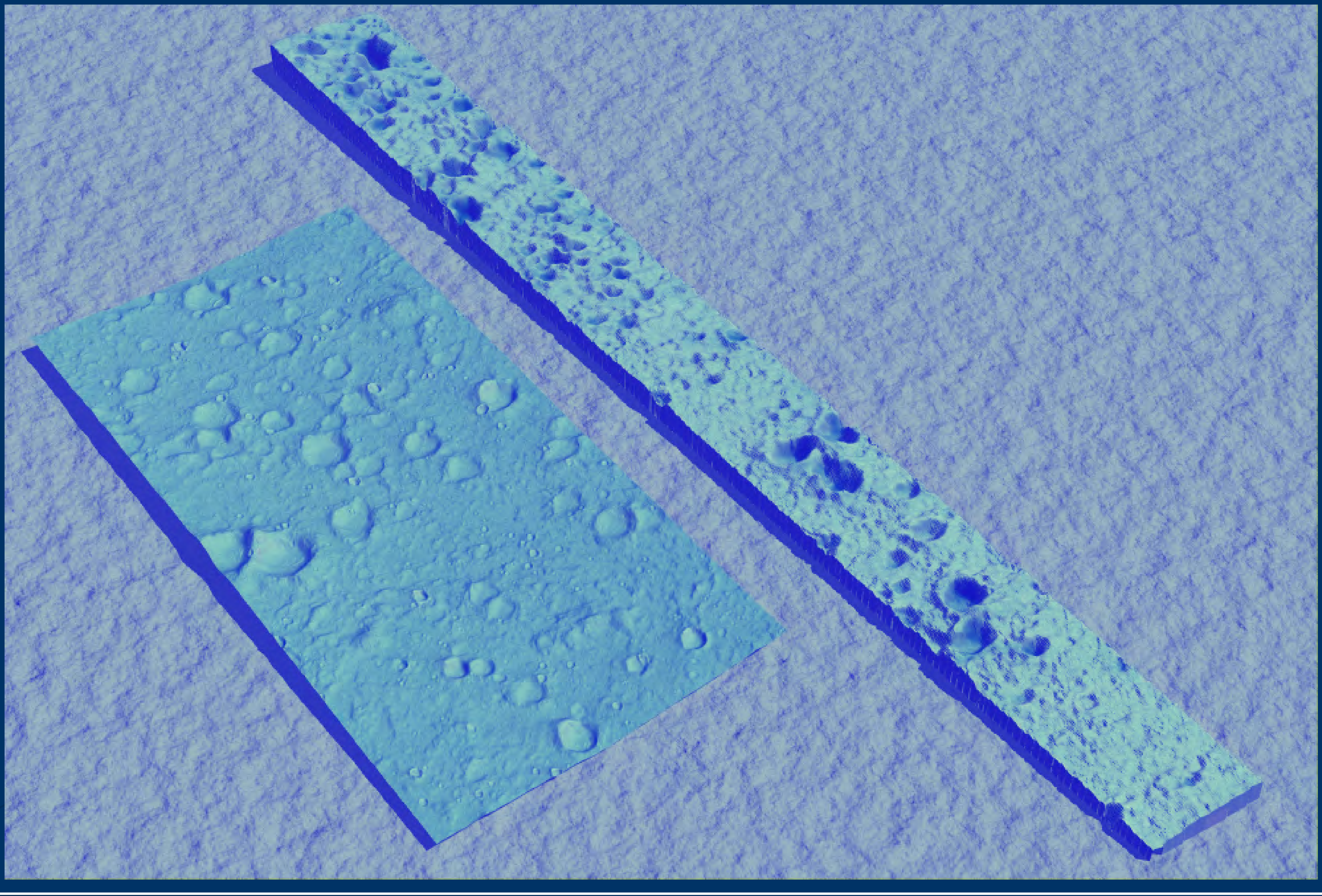
Objective is to assess safety of MER sites in terminal phase of landing with airbags

- Safety to be assessed by Monte Carlo simulation of bounce trajectory
  - Failure mode 1: bounce too vertically (crunch!)
  - Failure mode 2: bounce too horizontally (rip!)
  - Failure mode 3: bounce or drop off cliff (spoofing)
- USGS supplying DEMs of each site & morph-ologic unit; simulations weighted by unit area
- Summary statistics of slopes at 5-m baseline (airbag diameter) will be presented here
  - Useful for purposes of comparison
  - Not the official criterion

Topographic Model Count

Site	WS2	WS3	PR	WS4	Totals
MPF					2
Elysium					1
Gusev					6
Hematite					3
Isidis					2
Athabasca				3	
Eos					2
Melas					3
Totals	5	8	2	7	22

Photoclinometry & Stereo



Methodologies Compared

Photoclinometry

- Single image
- Horizontal res 1 pixel
- Measure, ∫ *slopes*
  - Neighbor hts to << 1 pix
  - Errors grow w/baseline
- Radiometric
  - Artifacts if albedo varies
  - Scale error if haze not calib. to stereo/MOLA
  - No absolute heights
- CPU & labor intensive

Stereo

- Two convergent images
- Horizontal res ≥3 pixels
- Vert res 0.2 pix / (b/h)
  - ~1 pix for MOC
  - Independent of baseline
- Geometric
  - Ignores albedo
  - Ignores atmosphere
  - Absolute heights require control (e.g. to MOLA)
- CPU & labor intensive

Which Results to Use?

Prefer stereo when

- Samples larger, more representative area
- PC is compromised by albedo variations

Prefer PC when

- Albedo variations not dominant
- Stereo fails to resolve relief elements
- Stereo matching/editing errors severe

Slope Analysis of DEMs

Direct calc of slopes

- Adirectional (gradient) or bidirectional (e.g. E-W)
- Gives shape of entire slope distribution
  - Distributions are long-tailed: extreme slopes are more common than RMS slope might suggest
- Limited to single horizontal baseline at a time

Fourier transform

- Limited to bidirectional slope
- Gives RMS slope only, not distribution
- Quickly gives variation with baseline
  - Are slope-producing features adequately resolved?
- Requires care in mirroring and (not) windowing data to avoid end effects

Error Assessment

Tests to quantify stereo,PC errors for

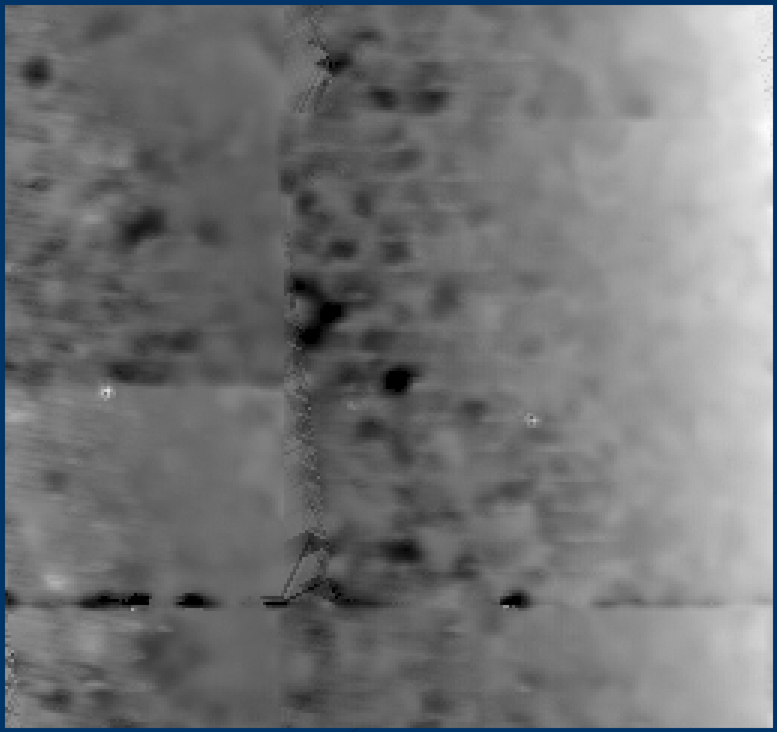
- MER LS Slopes Peer Review (9/02)
- JGR special issue

- Assess matcher errors w/ parallax-free image
- Compare USGS/MSSS/JPL stereo DEMs
- Compare overlapping stereopairs of MPF site with each other and other datasets
- Trough/ridge in stereo DEMs now understood
- Assess PC errors with synthetic images of fractal surfaces
- Compare 2D photoclinometry results (fractal and real) with point photoclinometry

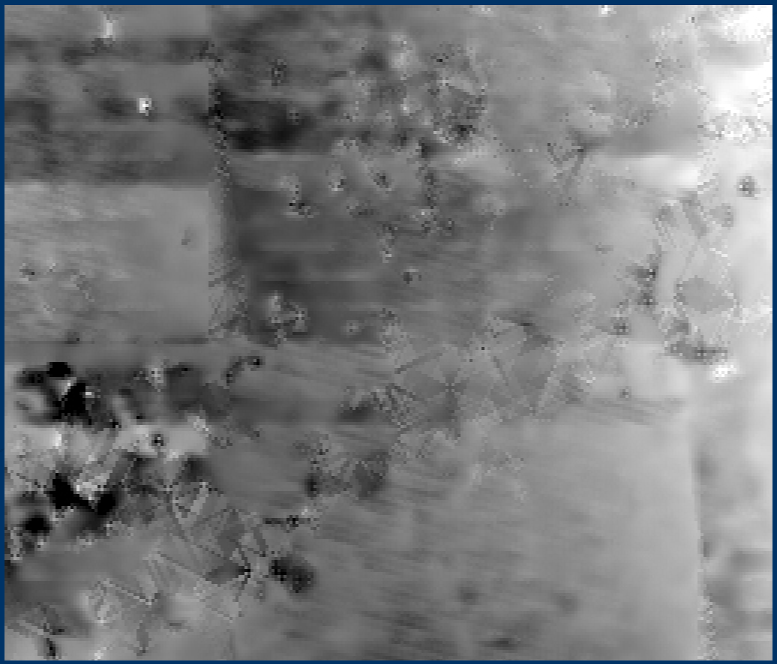
Test of Matching Errors

- Utilize “typical” MOC stereopair (Gusev)
- Resample nadir image to approximate size, skew, etc. of oblique image
- Collect DEM as if this were the oblique image (result should be flat, or at least planar)
- Remove residual tilt of DEM, examine “relief”, ascribable to matcher errors
- Amplitude of error 0.22 pixel (vs 0.2 pix ROT)
- Amplitude+correlations —> statistical model of “slopes” caused by matching errors
- Observed slopes exceed error slopes for all but the smoothest units

Matcher Test DEM Results



Typical image area



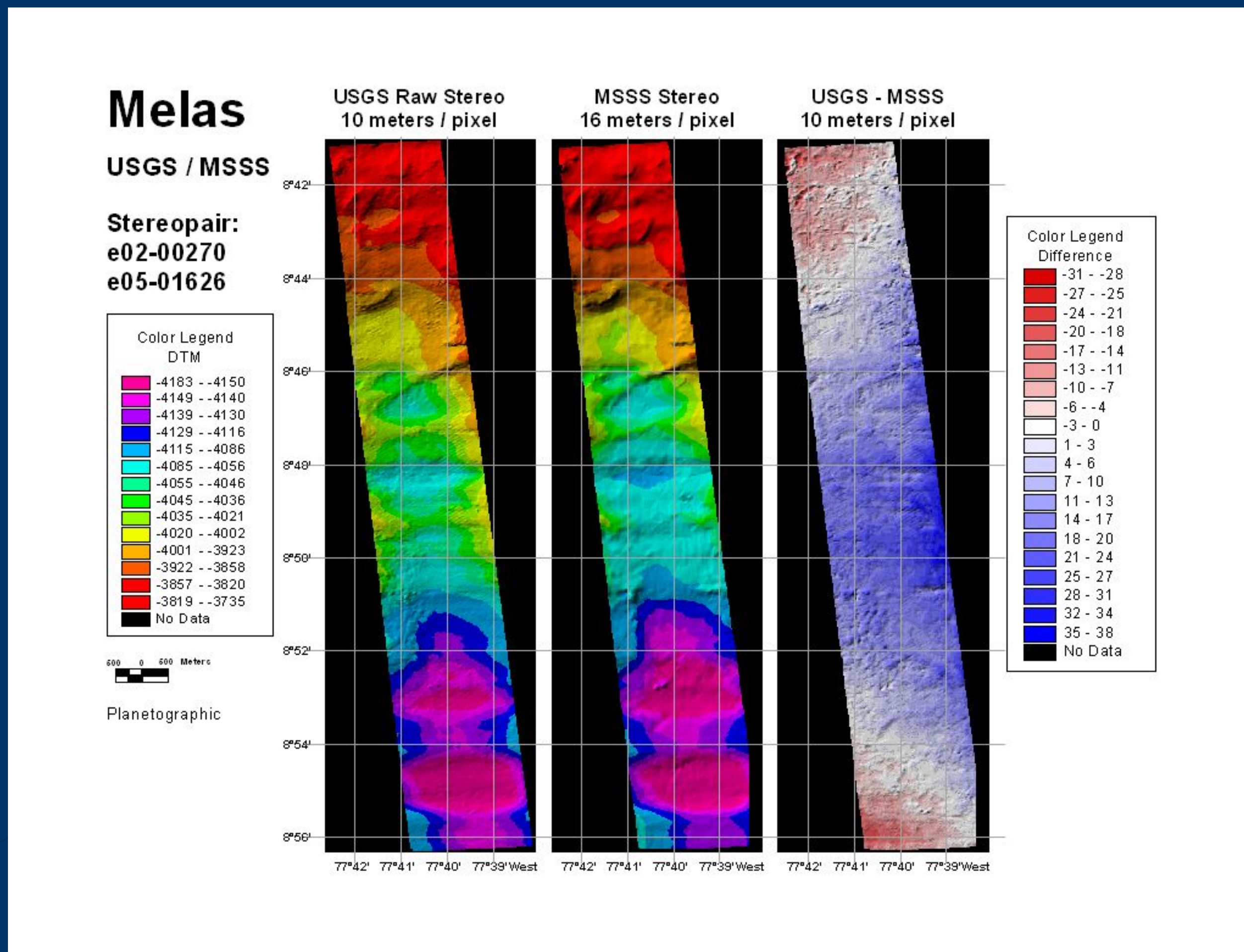
Bland image area

Stretch is ±7.5 m for both

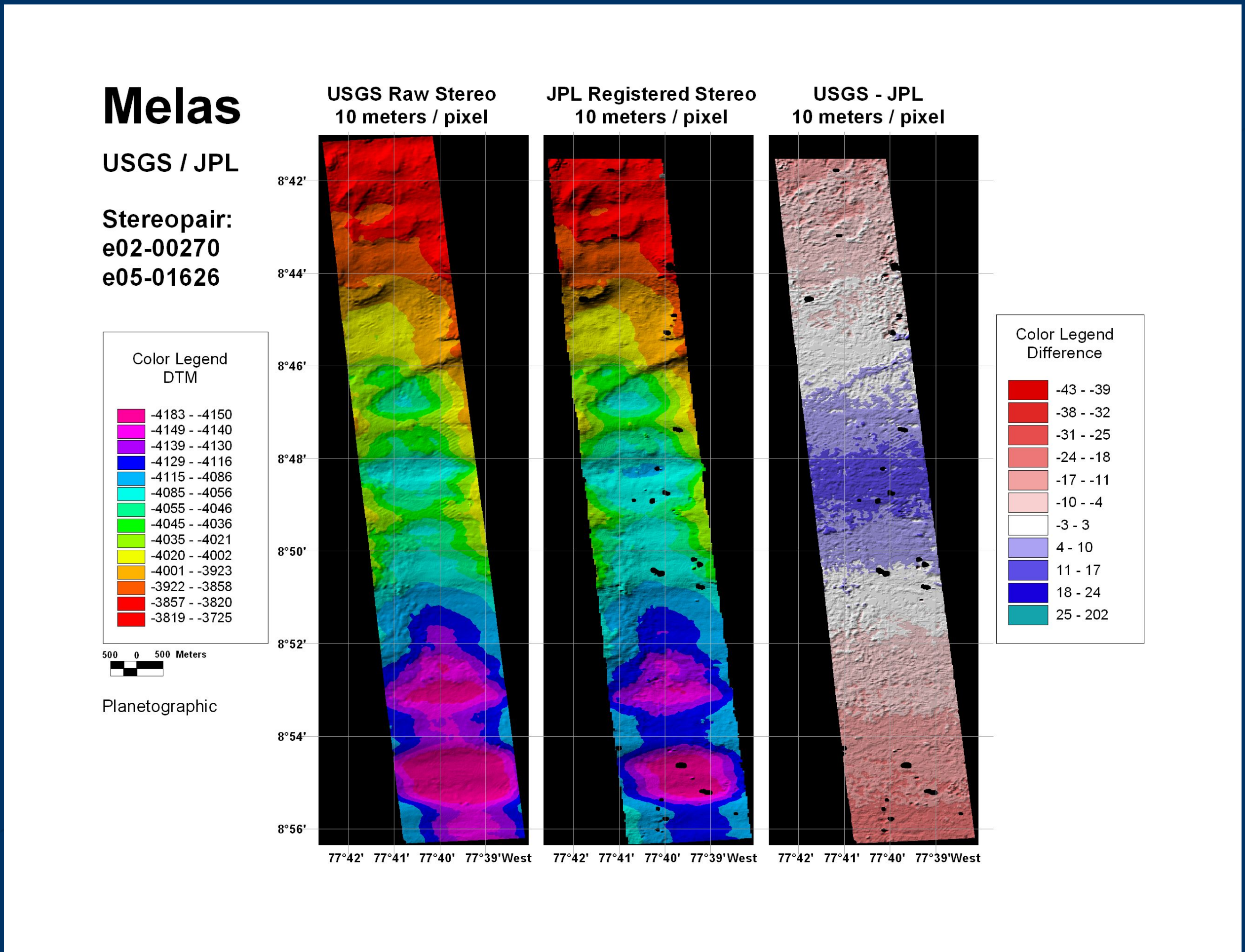
Comparison of Stereo DEMs

- Compare USGS/MSSS-Harris/JPL models of Melas Chasma pair
  - Must coregister to same sample spacing and coordinate system, remove tilt/arch
  - USGS-MSSS show random differences consistent with 0.22 pixel matching errors
  - USGS-JPL differences smaller; matcher behavior correlated?
- Compare new, old models of MPF site
  - Overlap consistent w/~0.2 matching errors
  - New data at landing point shows slope-baseline consistent with IMP results, etc.

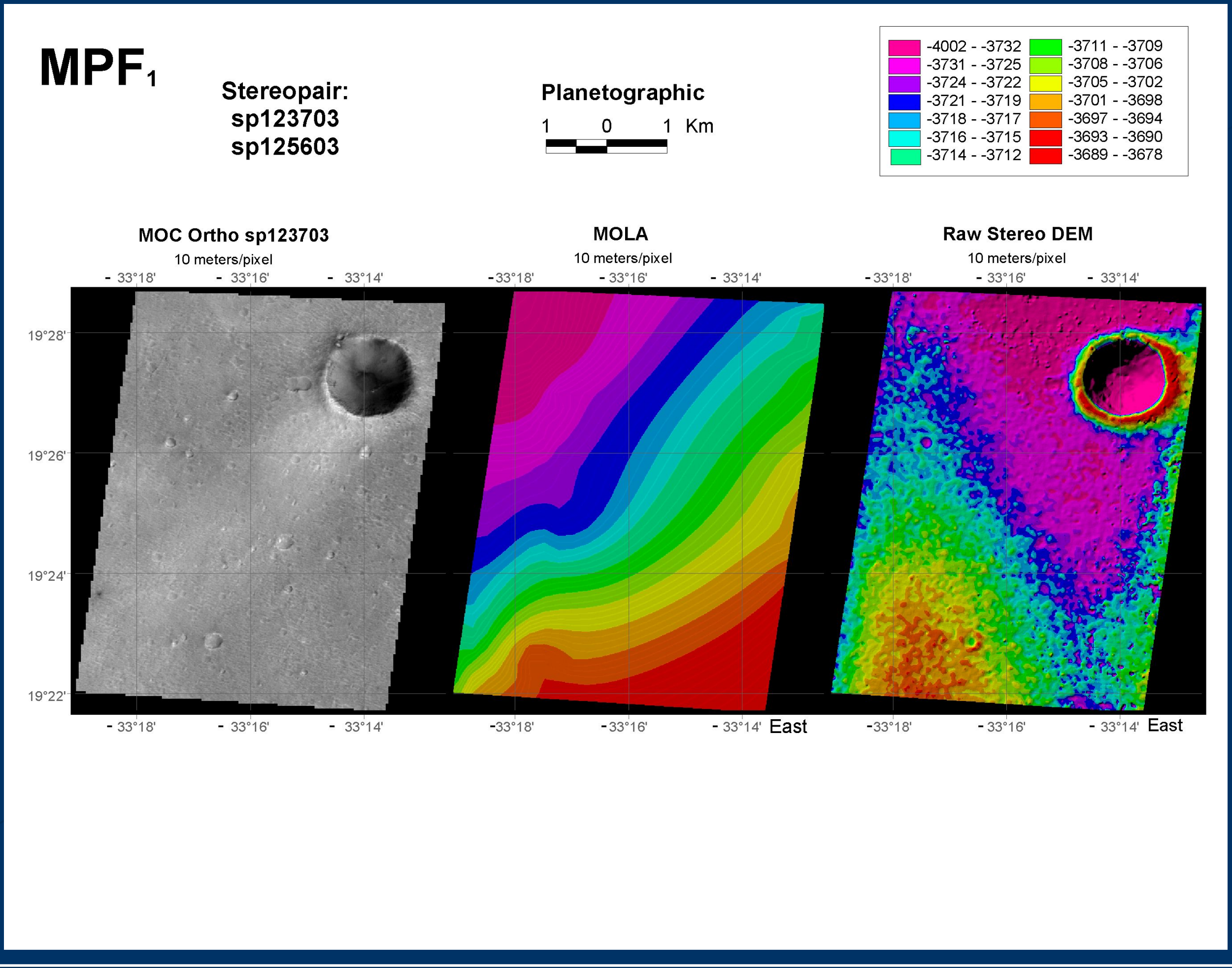
USGS-MS^3 DEM Comparison



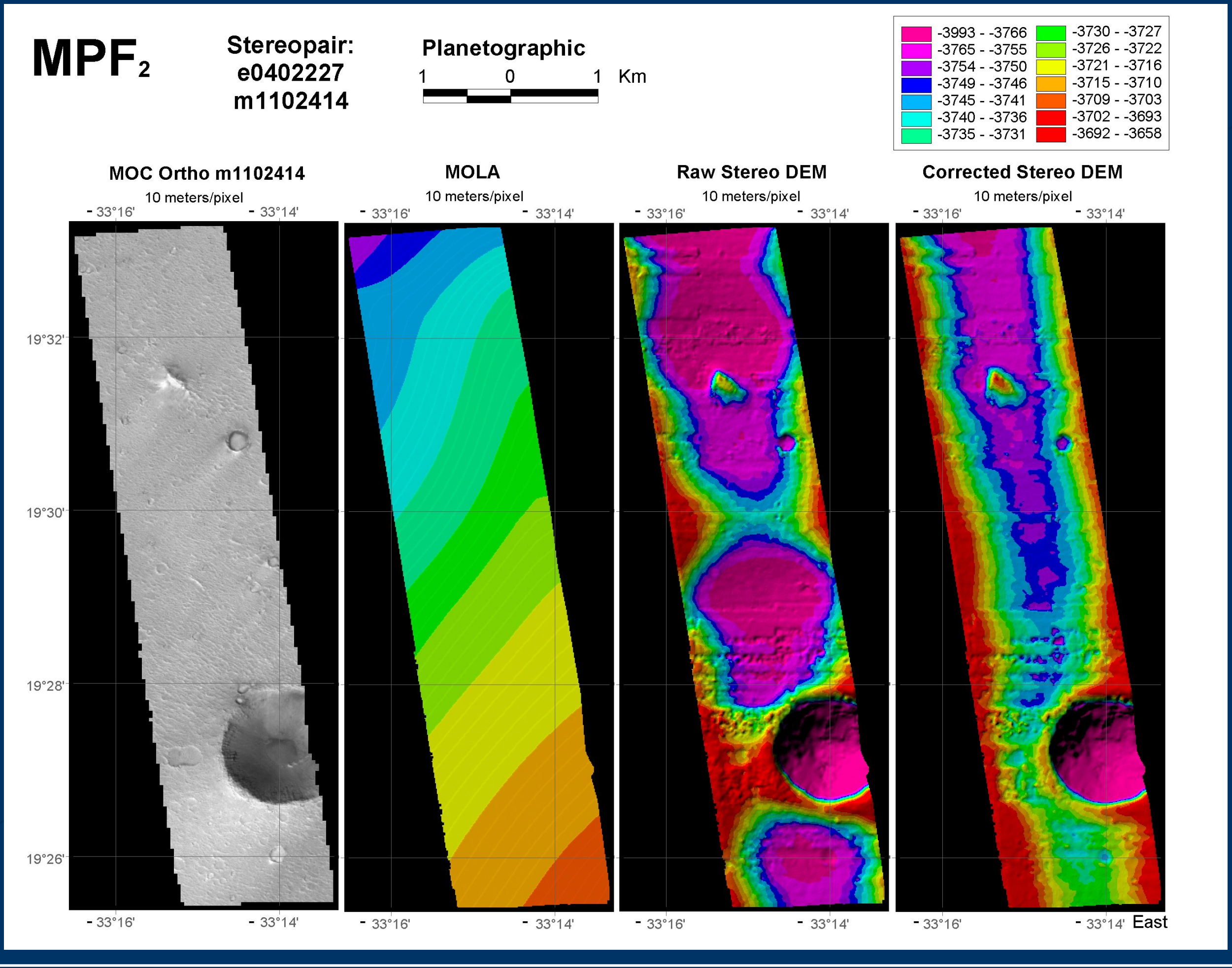
USGS-JPL DEM Comparison



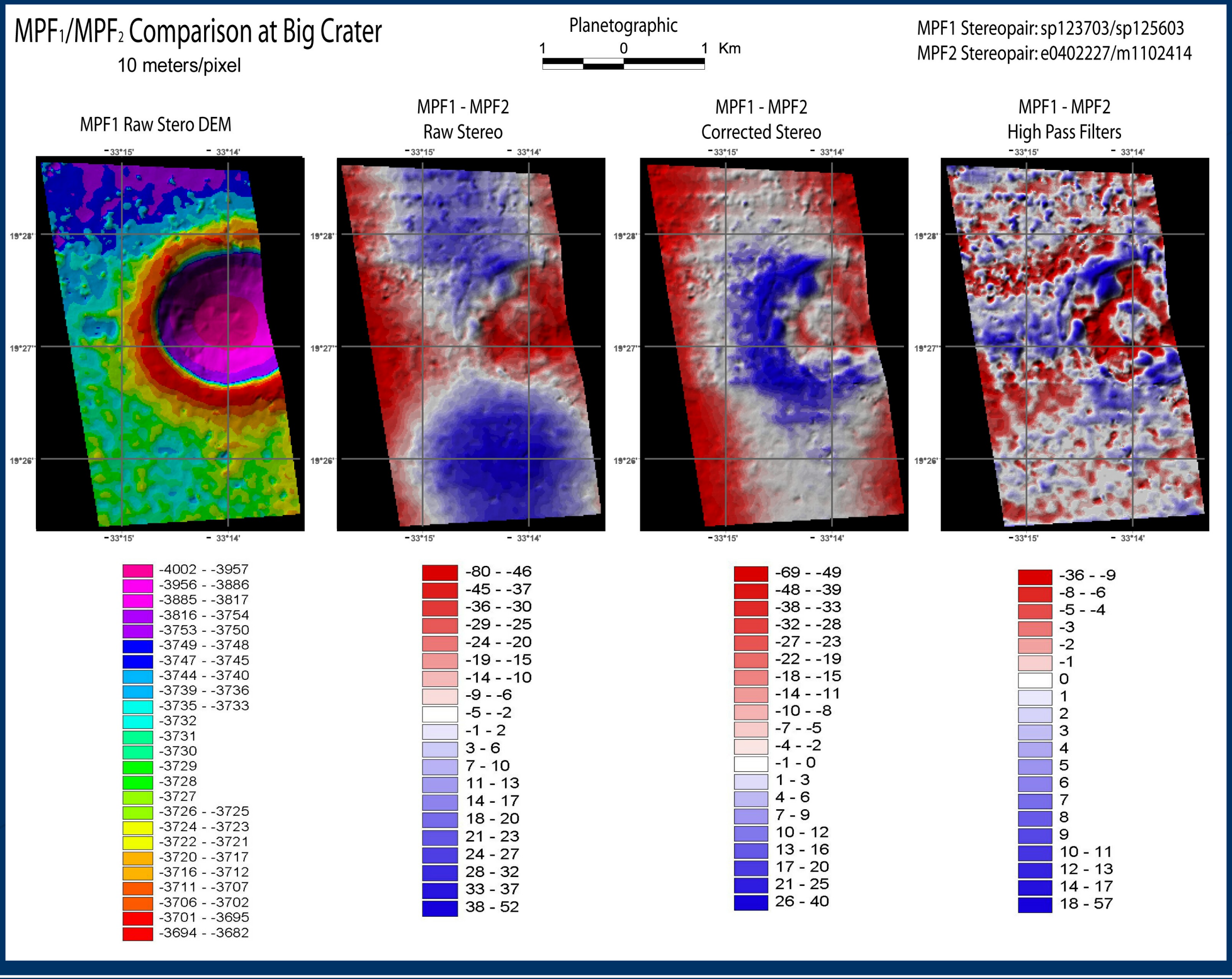
MPF 1: SP125603/SP123703



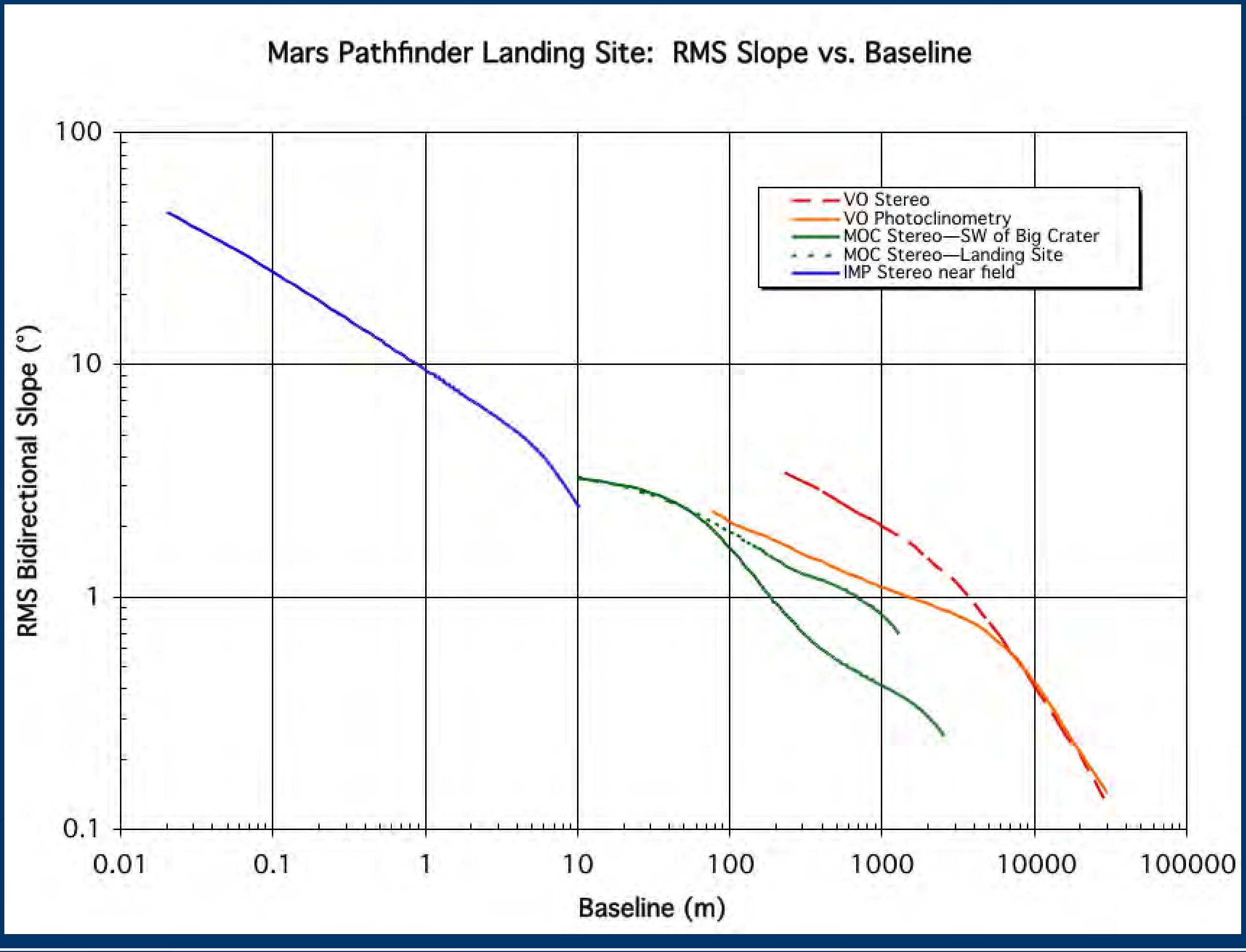
MPF 2: M1102414/E0402227



MPF 1-MPF 2 Comparison

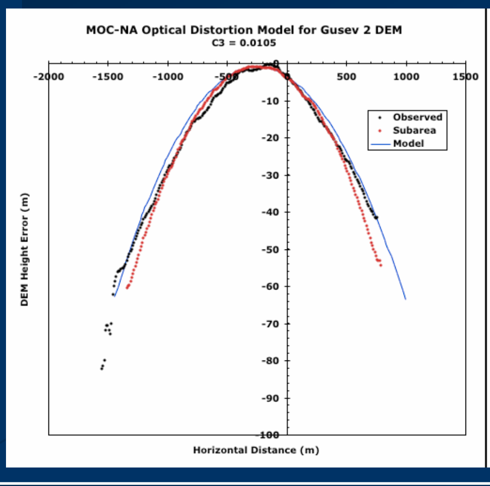


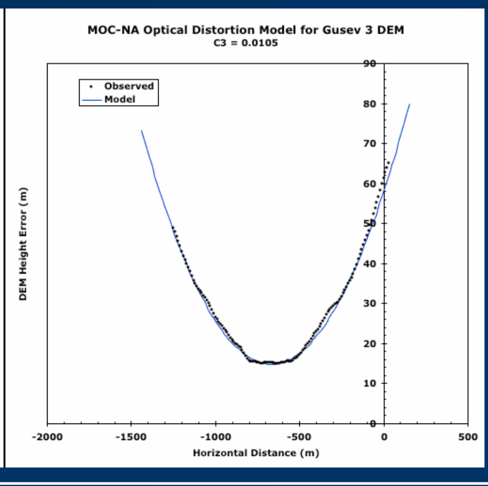
Comparison with Other Data

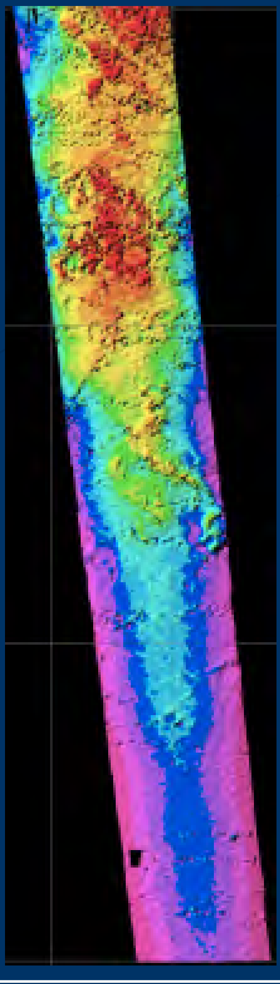


Trough/Ridge in Stereo DEMs

- Optical distortion (~1% pin-cushion) identified as cause
- Error proportional to
  - Amount of distortion
  - Inverse of (base/height)
  - Distance on ground between boresight tracks

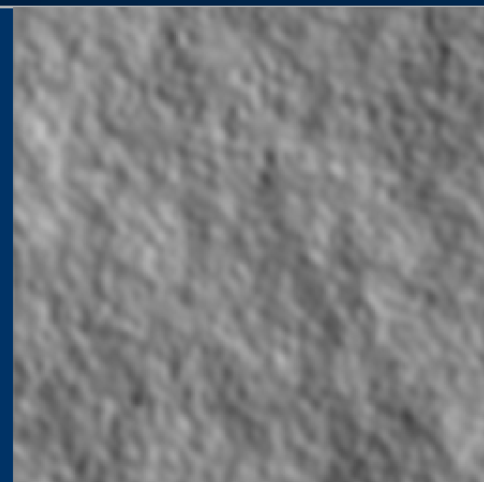






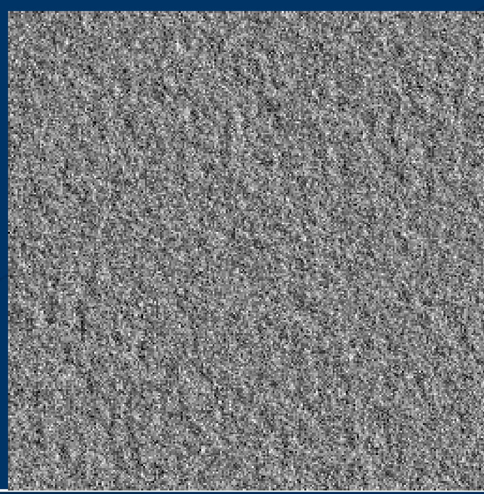
Simulated Images to Assess Photoclinometry Errors

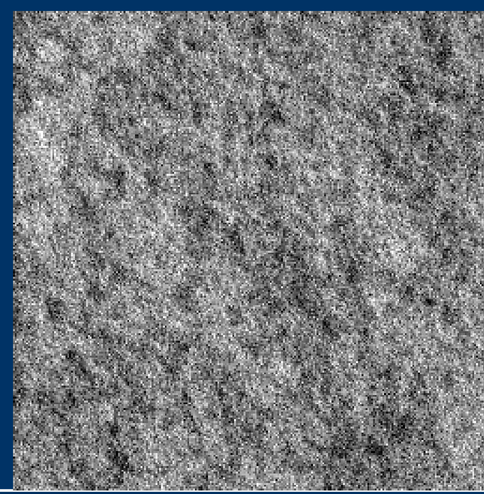
Fractal
H=0.8
1° slopes
i=45°
Sun ENE



Lowpass
@ 16 pixels

Highpass
@ 16 pix

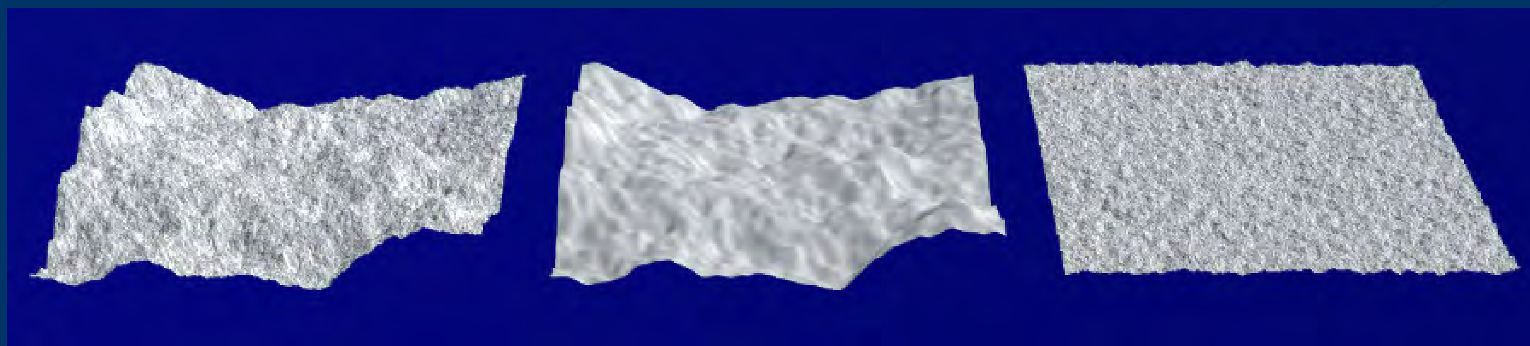




With 0.6%
albedo
variations

Example of Simulations

Fractal | Lowpass | Highpass



RMS 3.0m exag 50 | RMS 3.0m exag 50 | RMS 0.3 m exag 50

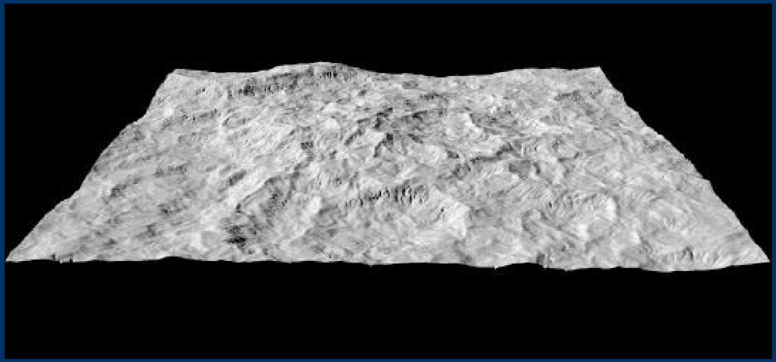
RMS 2.13 (0.20) m exag 50 | RMS 2.14 (0.03) m exag 50 | RMS 0.20 (0.04) m exag 500

Simulation Results

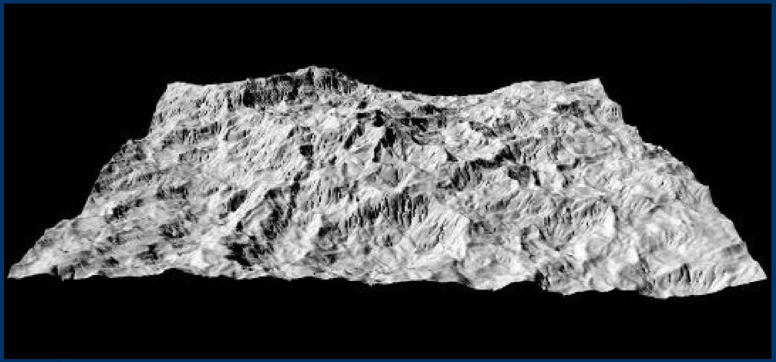
- Const albedo: 2D PC slopes accurate to ≤2%
- Varying albedo: stripe artifacts add to apparent slopes
  - Effect is *much* greater if slope baseline crosses stripe (sun) direction at an angle
  - Filtering DEM largely eliminates these errors
- Point PC and 2D PC results agree to <5% *when correctly interpreted & compared*
  - Point PC gives downsun slope across each pixel
  - 2D PC results usually quoted as slope between adjacent pixel centers, in sample direction
- Haze estimation may be the biggest error source in practice (10–20% ?)

Effect of Haze and Albedo

Sun is from upper left in all examples

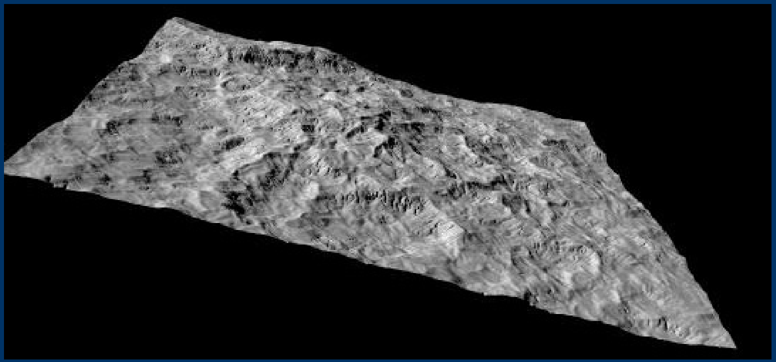


Correct Haze and Albedo



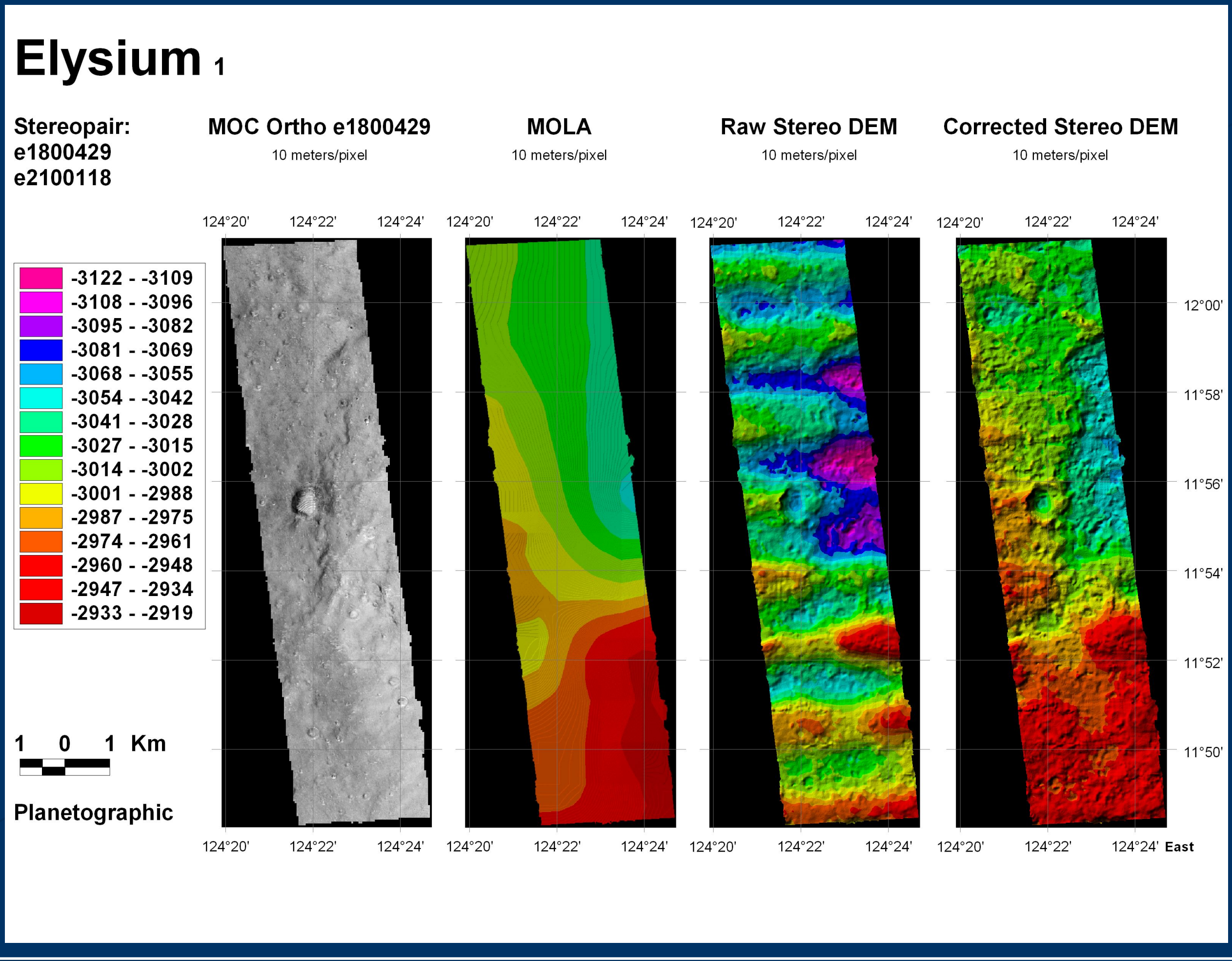
Too much Haze subtracted

Albedo underestimated

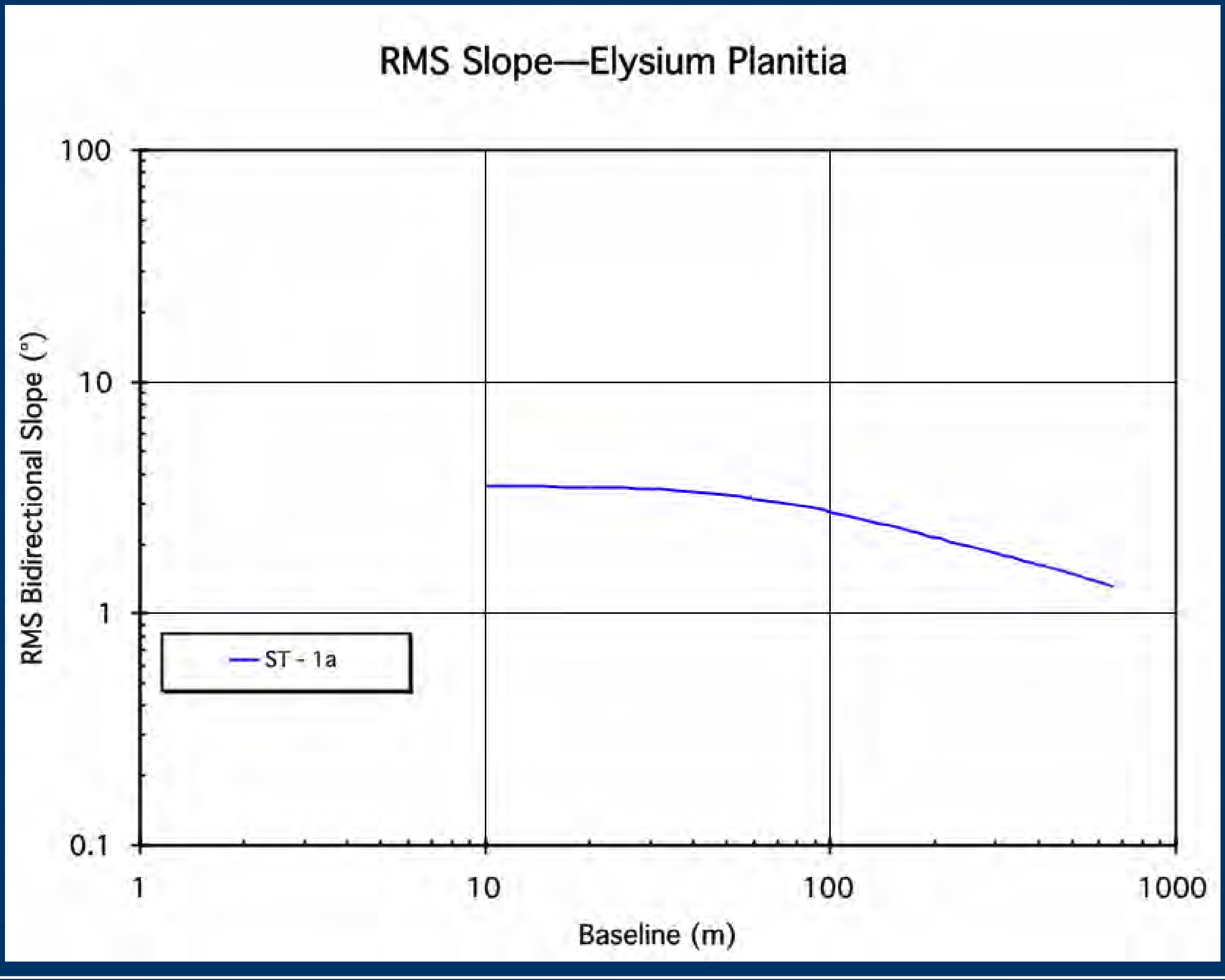


Albedo overestimated

Elysium 1: E18-00429/E21-00119

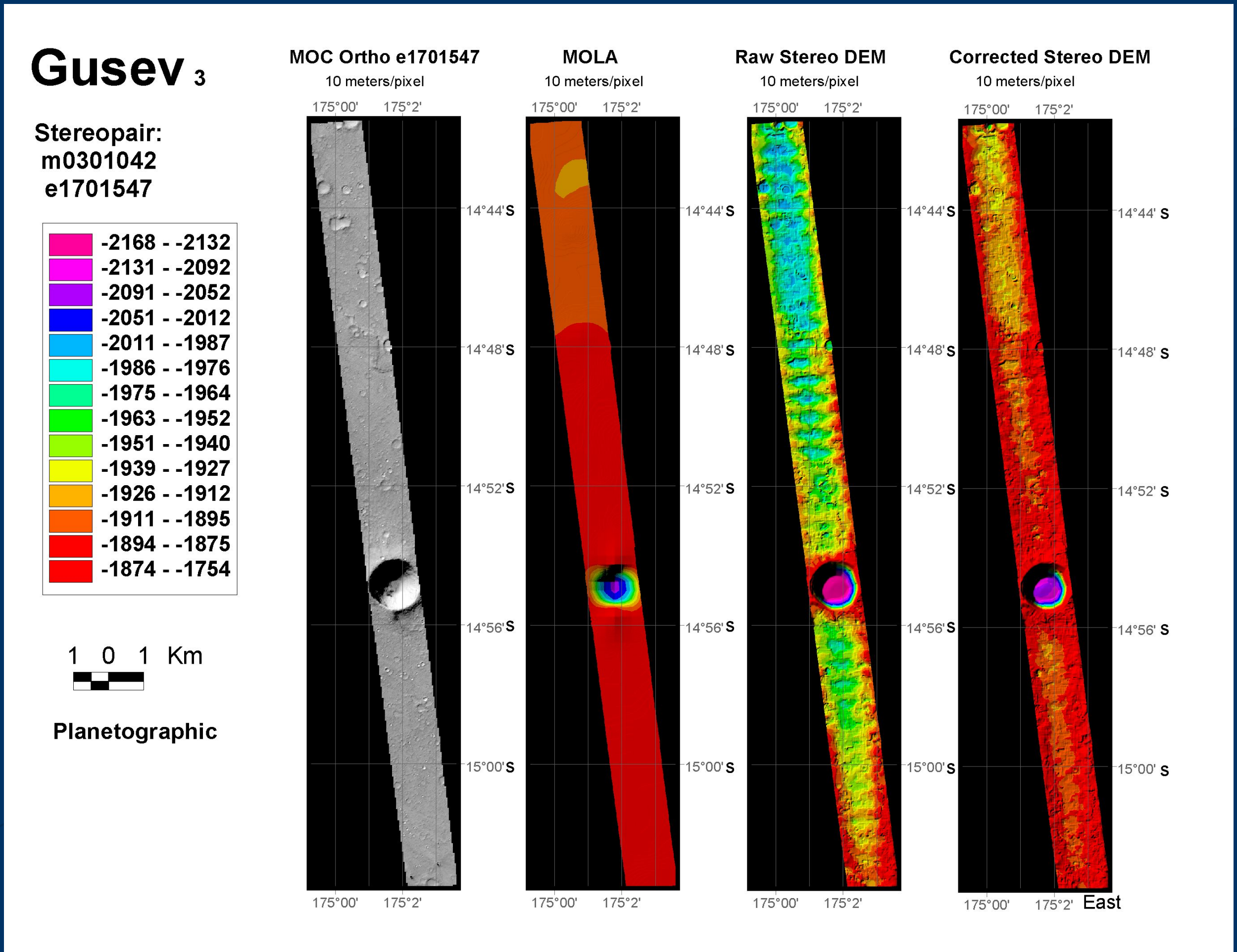


Slope vs. Baseline at Elysium: First stereo result; no PC

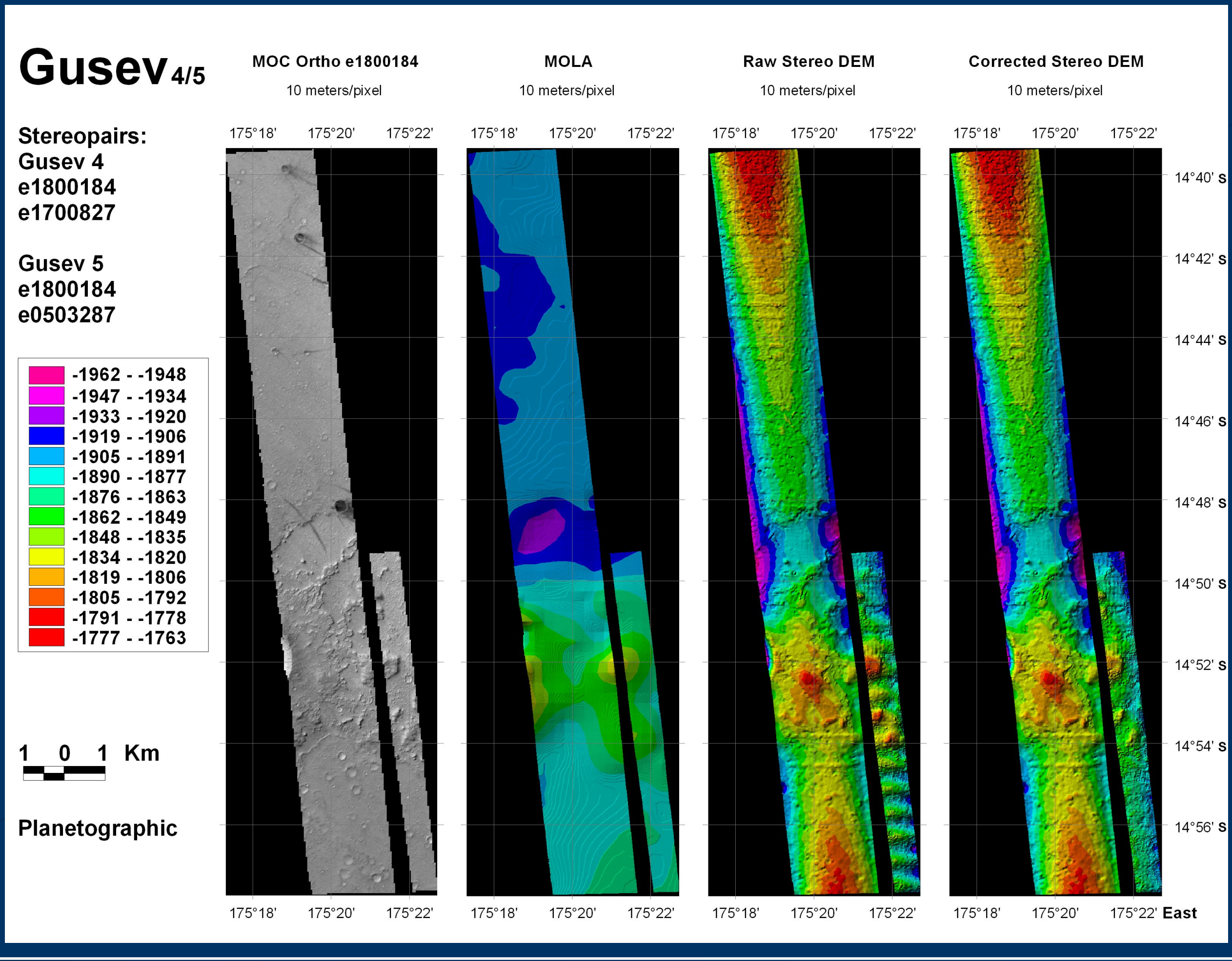


- One stereopair obtained and analyzed
- Stereo slopes intermediate: 3.5°
- Albedo appears to vary; consistent solution for haze not found so no PC slope results
- Does stereo resolve features?
- Is area representative of ellipse?

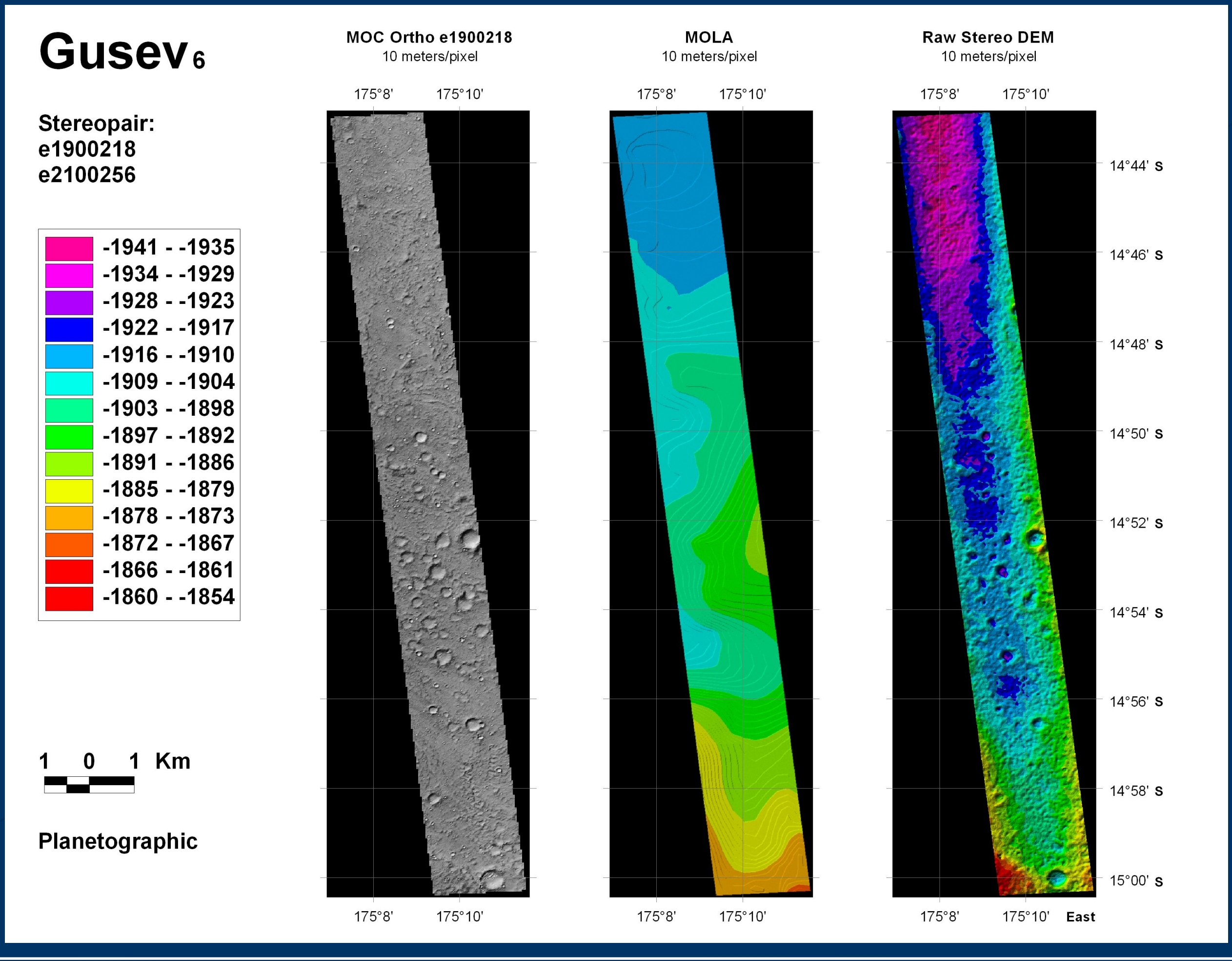
Gusev 3: M0-301042/E17-01547



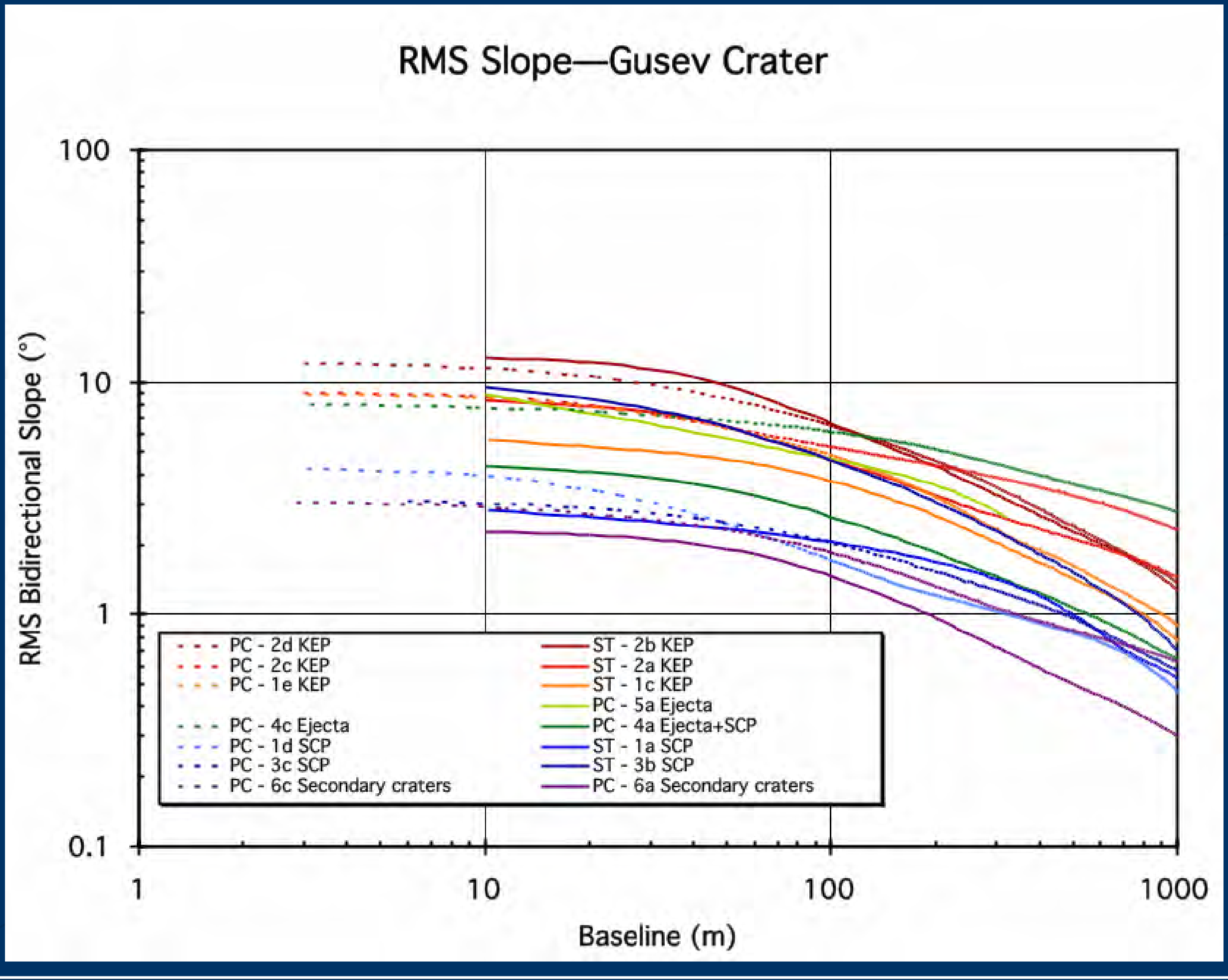
Gusev 4: E17-00827/E18-00184
Gusev 5: E05-03287/E18-00184



Gusev 6: E19-00218/E21-00256



Slope vs. Baseline at Gusev: Consistent data, geologic variety



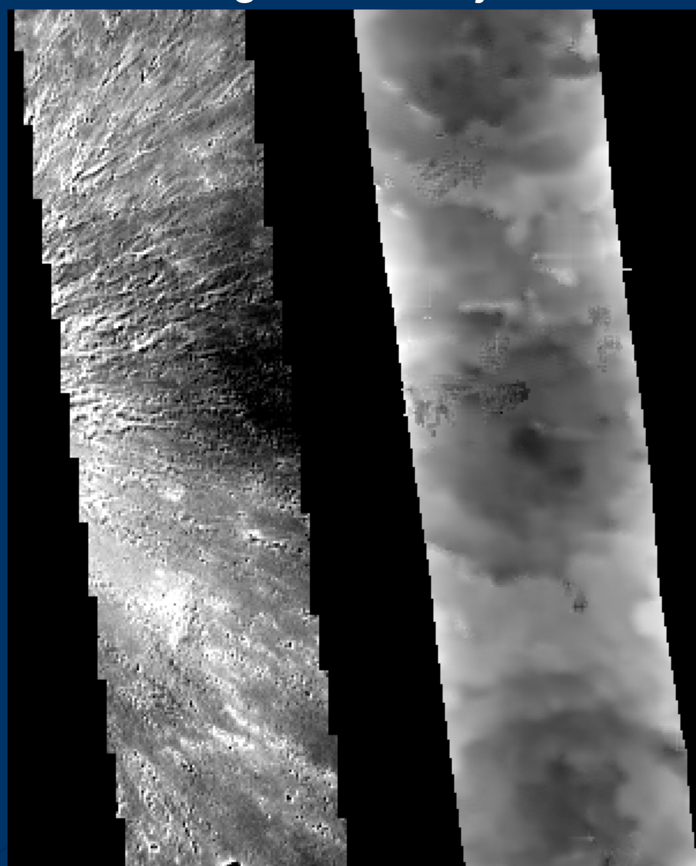
Stereo resolves main roughness elements but PC resolves them better, preferred

Many morpho-logic units with large range in roughness

Safety of site depends on area coverage as well as outcomes of simulations on individual units

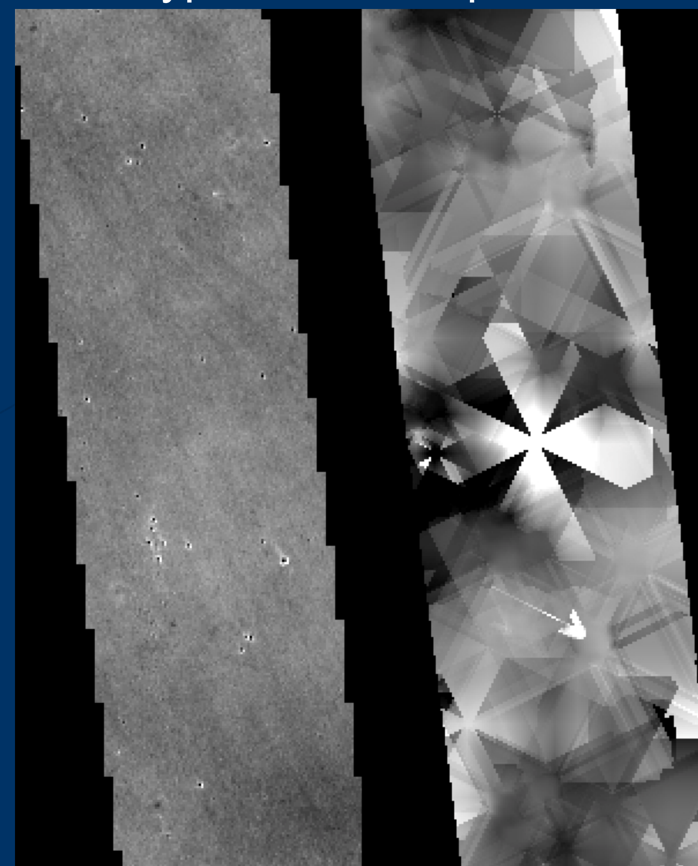
Hematite 3: E02-00970/E17-00918

"Rough" crater ejecta



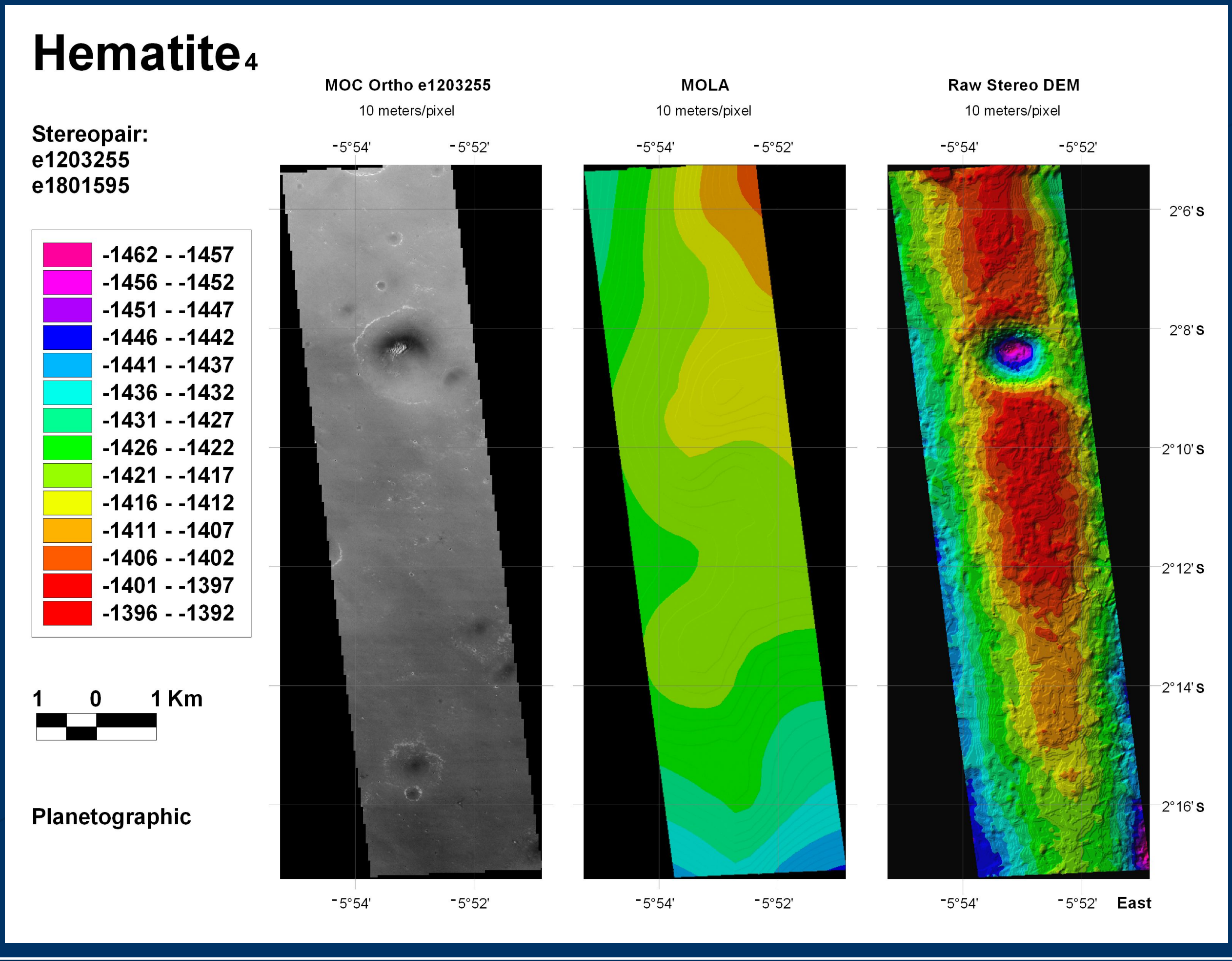
±15% ±50 m

Typical smooth plains

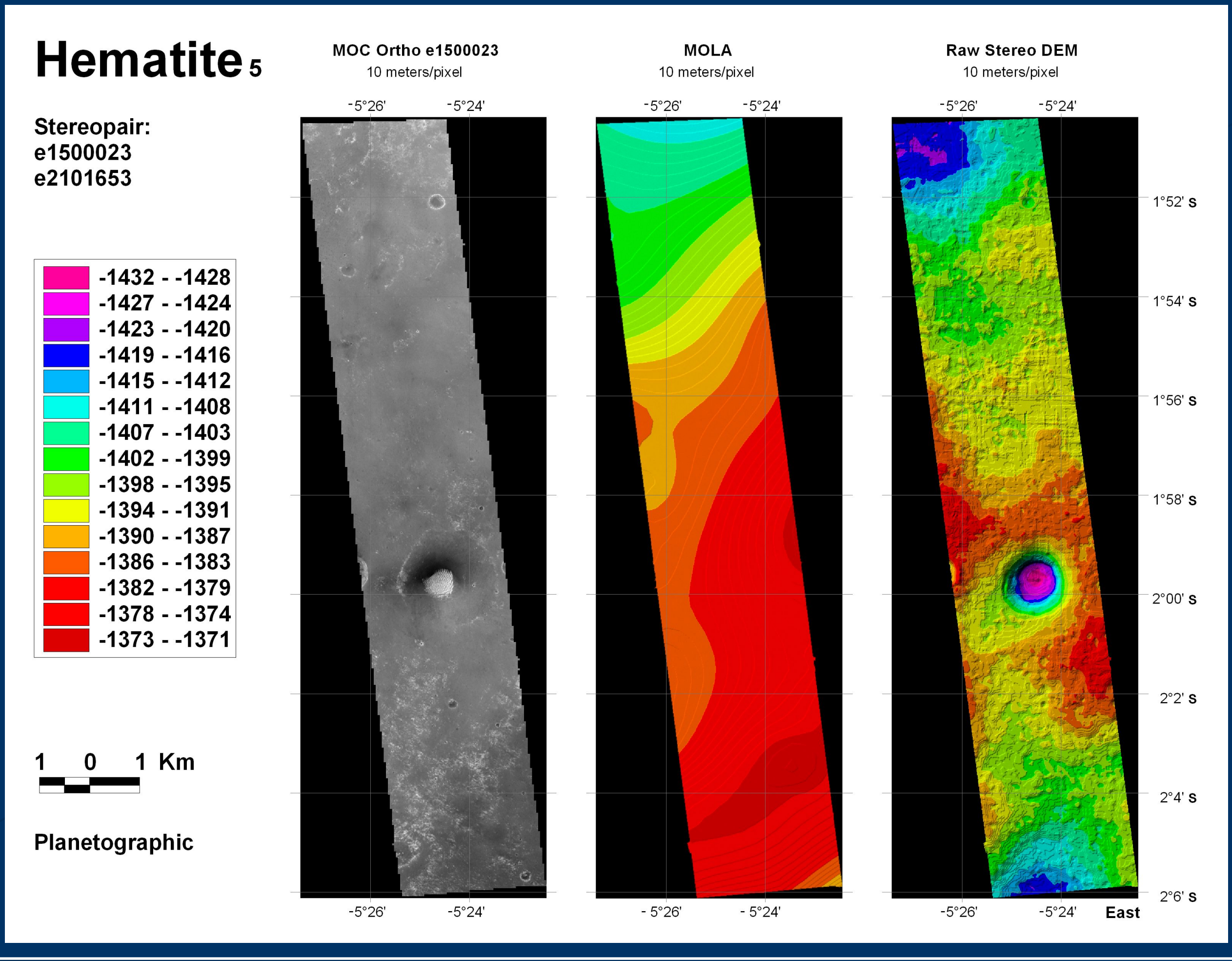


±15% ±50 m

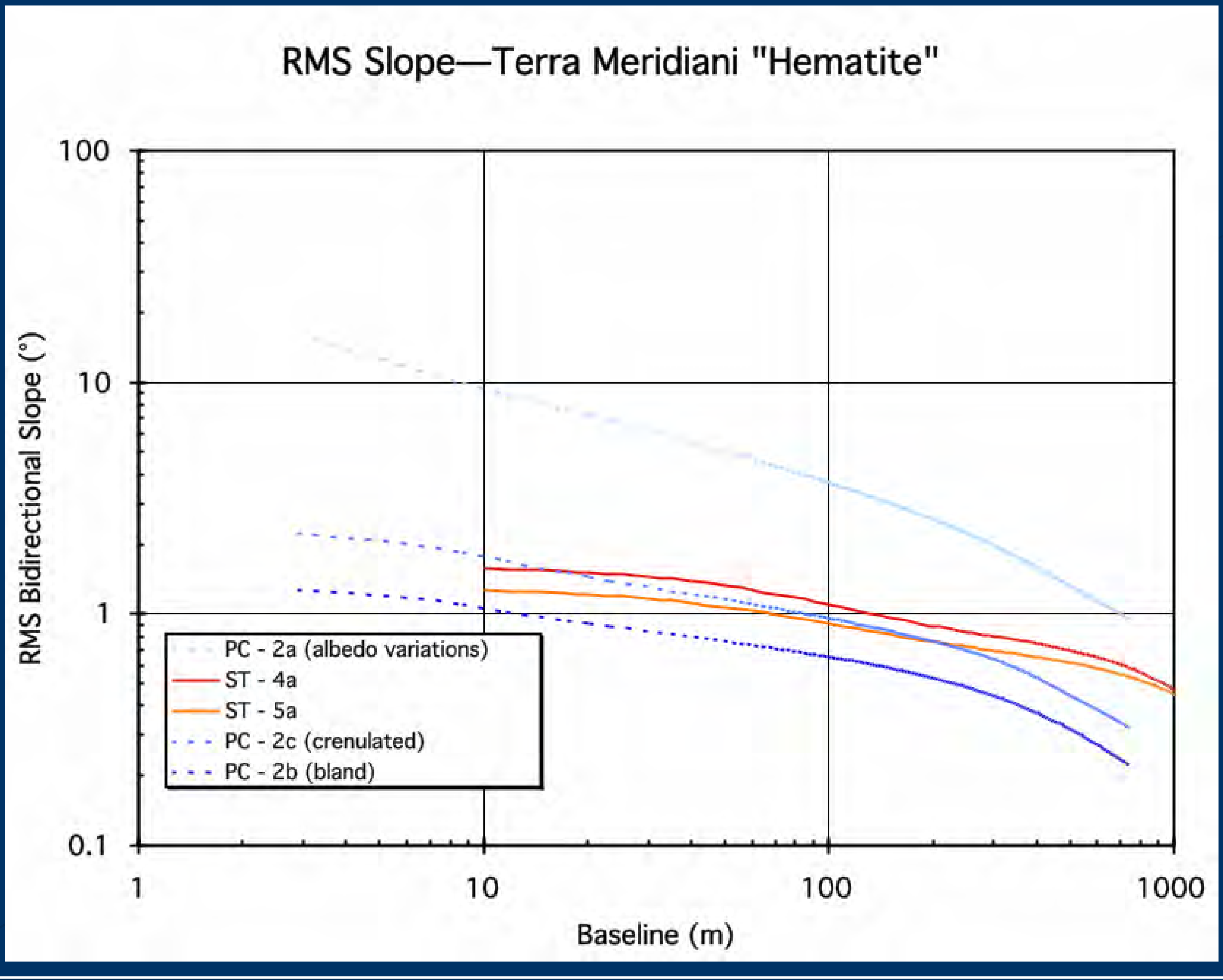
Hematite 4: E12-03255/E18-00595



Hematite 5: E15-00023/E21-01653



Slope vs. Baseline at Hematite: Finally, an answer (It's smoooth!)

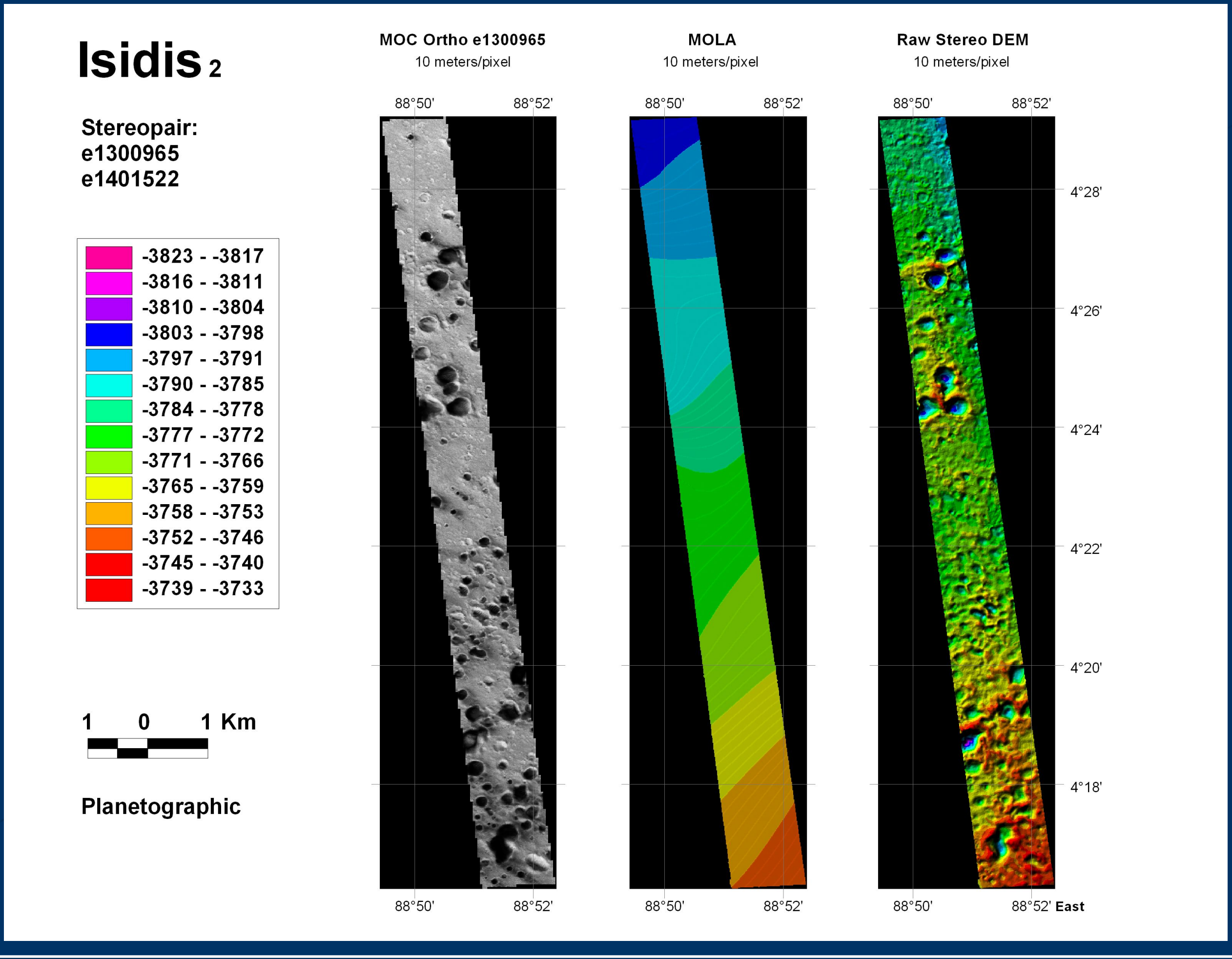


Stereo matching succeeded in areas 4, 5—RMS slopes 1.2°–1.5° despite crater in each area

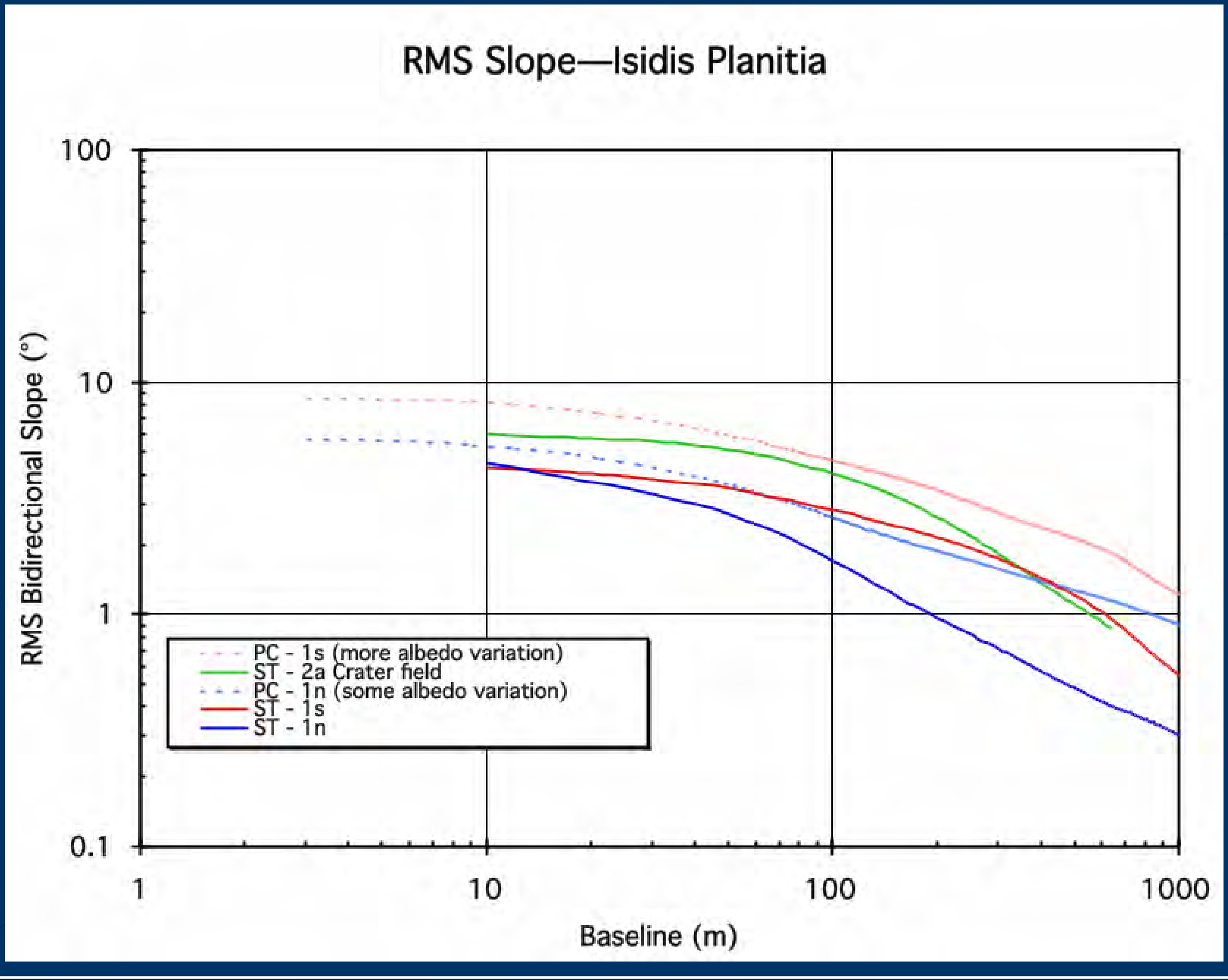
Consistent with previous PC slopes (uncon-trolled) in areas without severe albedo variations

Consistent with upper limit ~1° for failed stereo in area 3

Isidis 2: E13-00965/E14-01522



Slope vs. Baseline at Isidis: First result within ellipse is rough

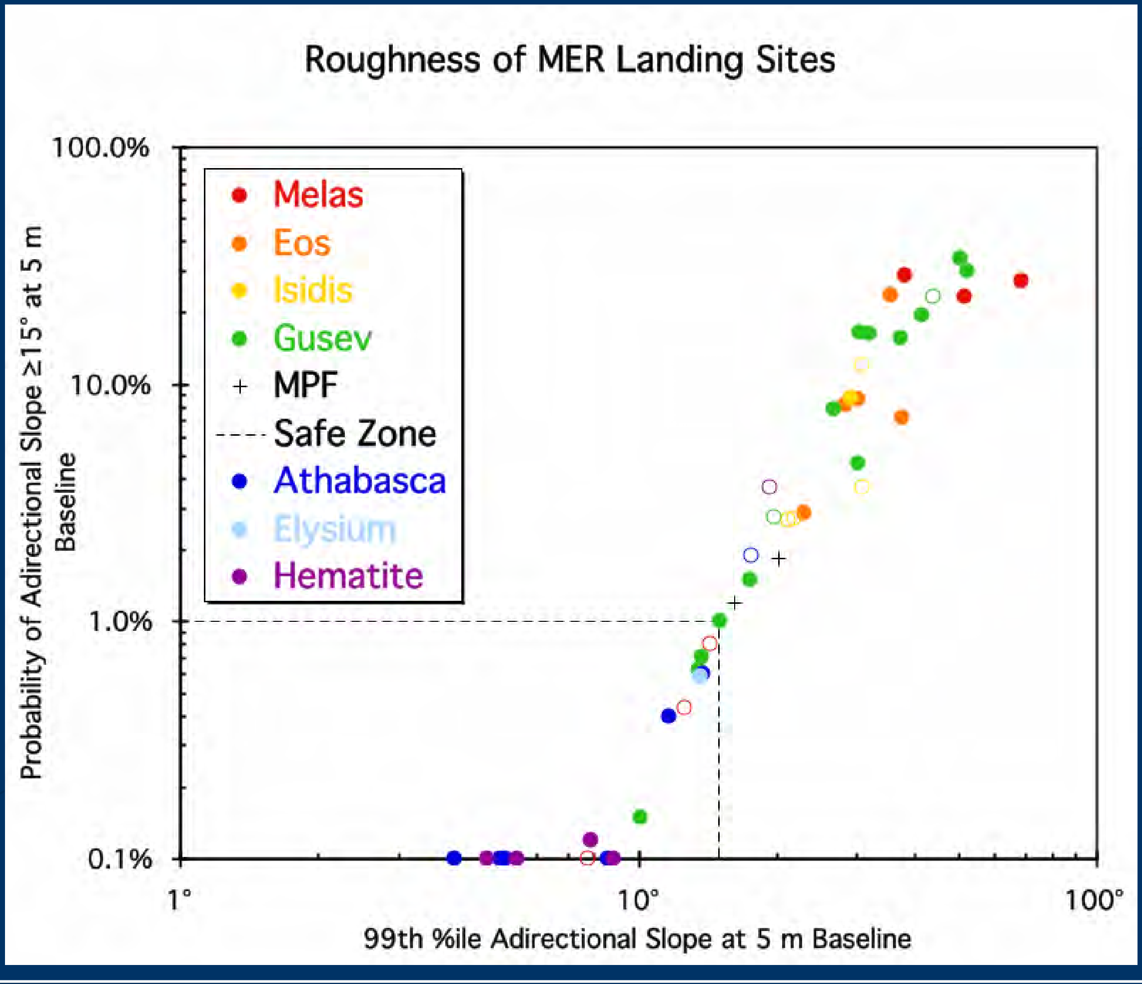


Now have stereo in ellipse; strong albedo variations prevent PC

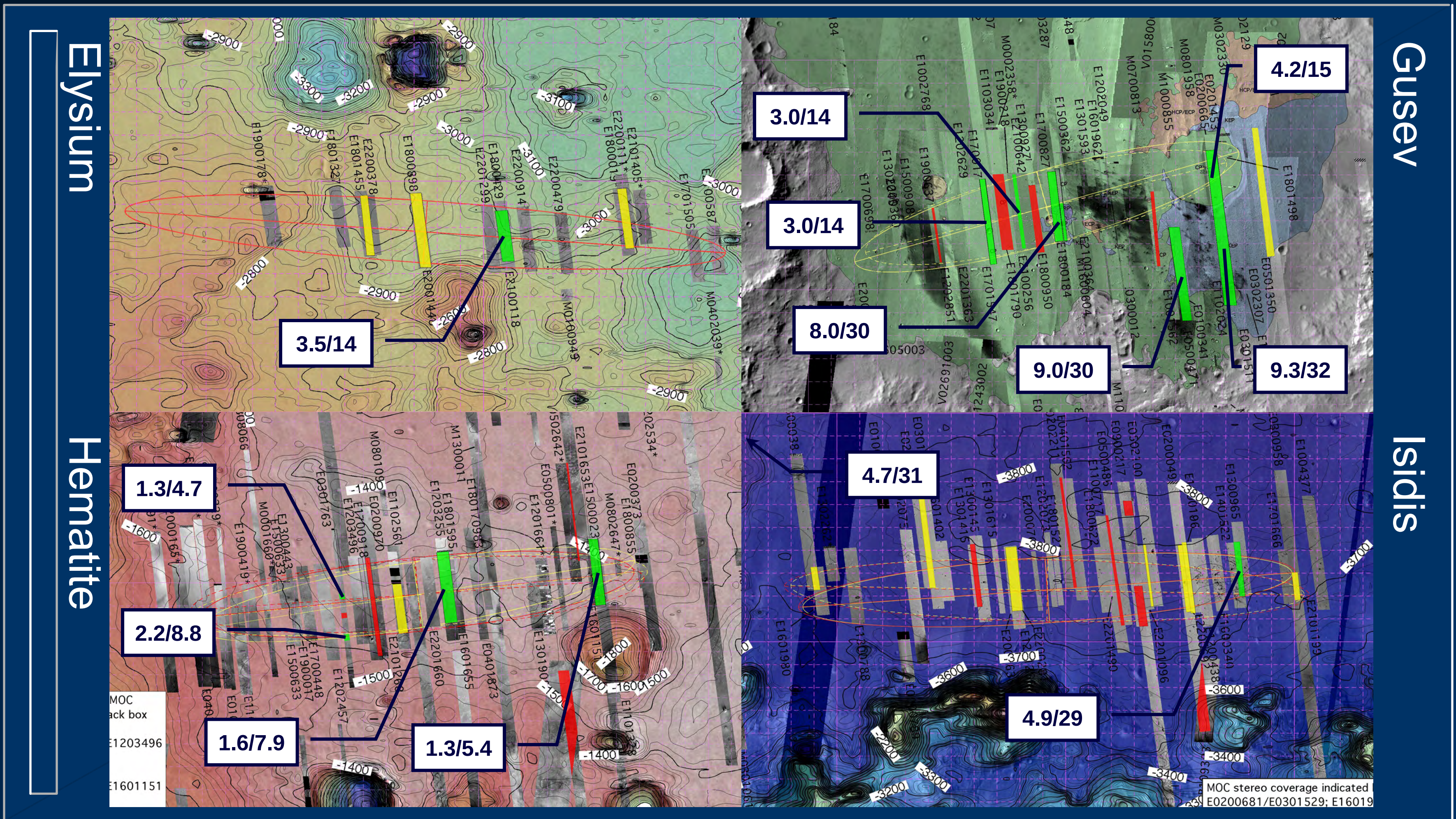
Stereo slopes similar to previous area ~150 km from ellipse, but rougher (6°)

Area is heavily cratered, may be rougher than average ellipse

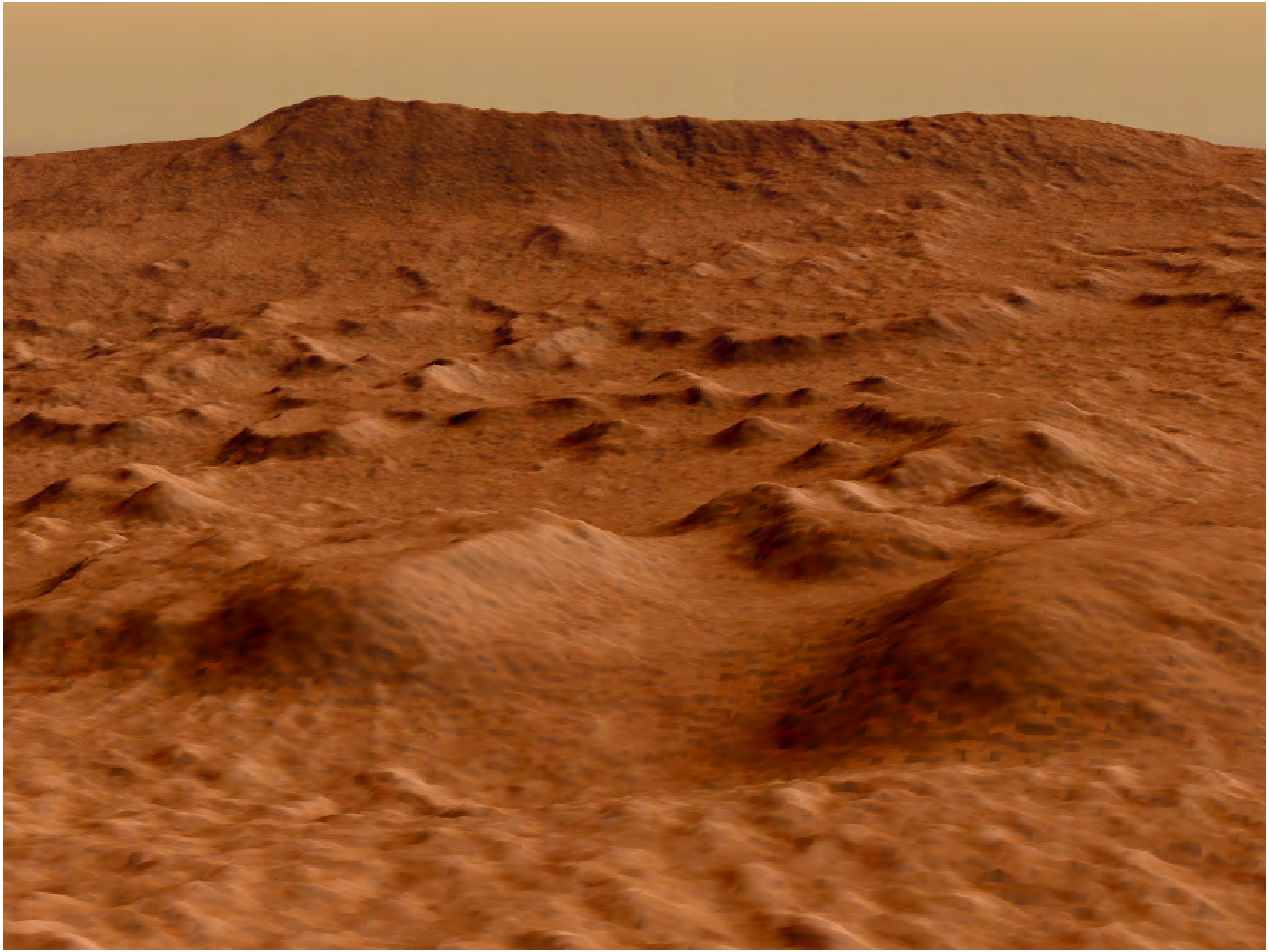
Summary of Slope Results



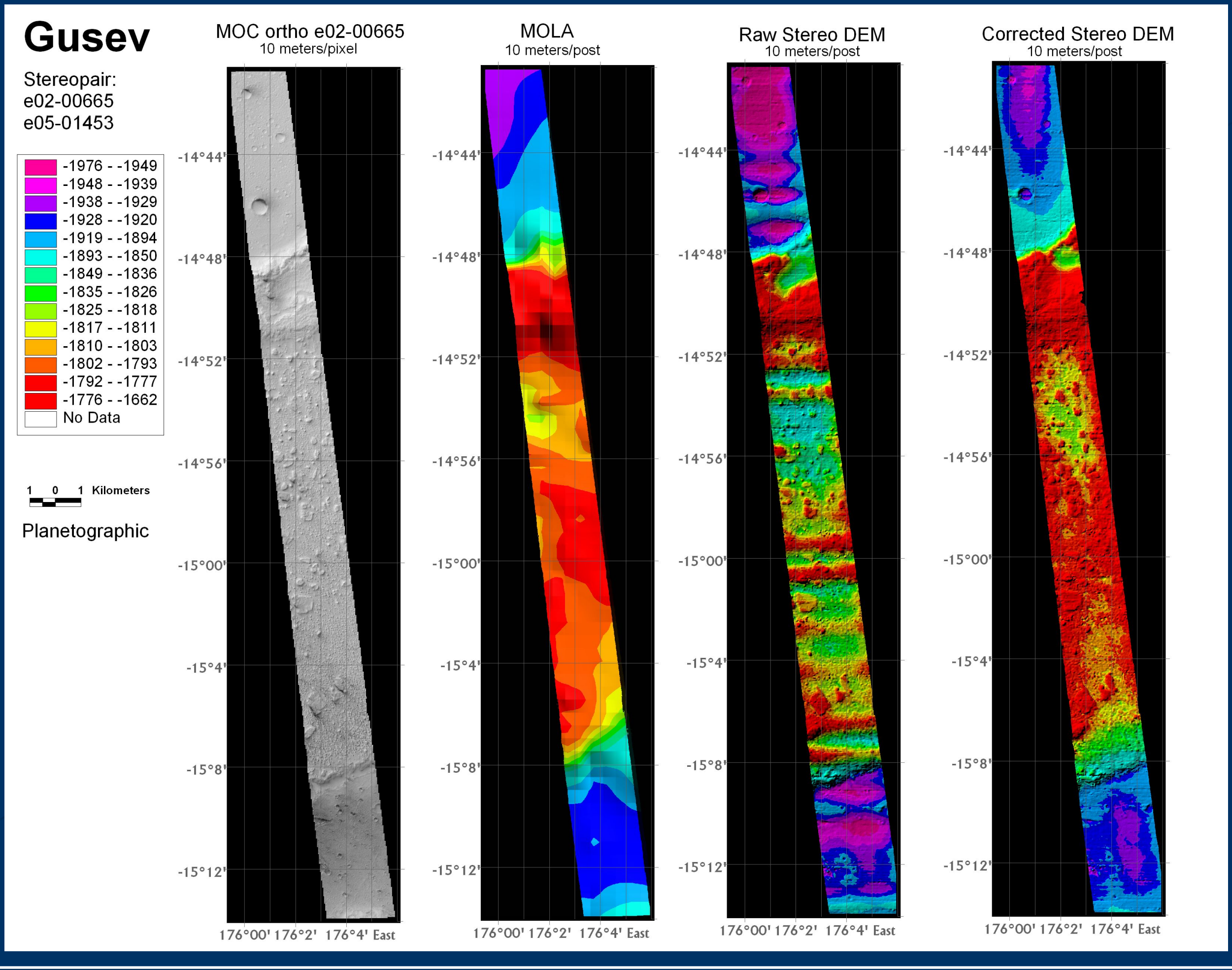
Slope Statistics & Locations



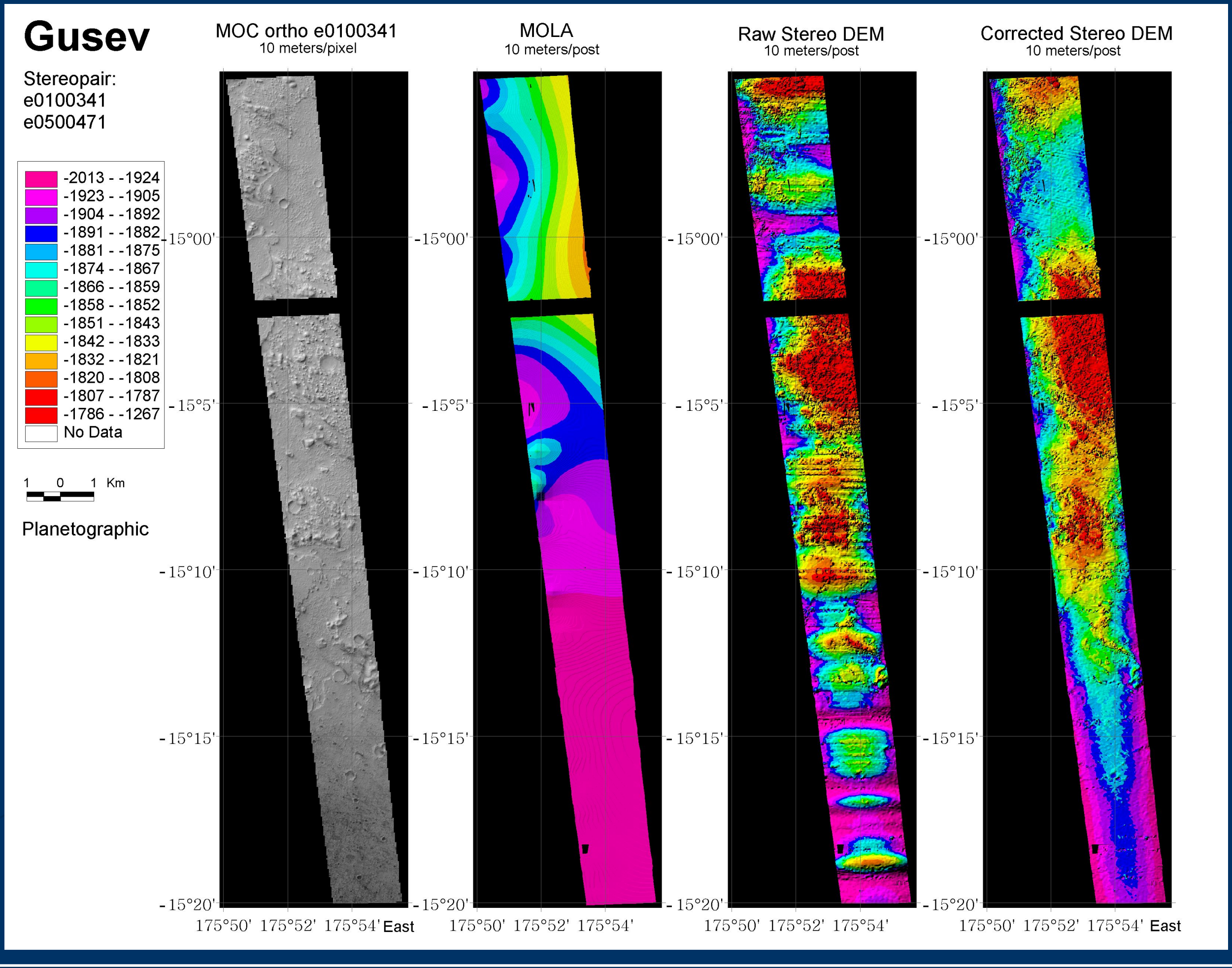
RMS Bidir / 99% Adir



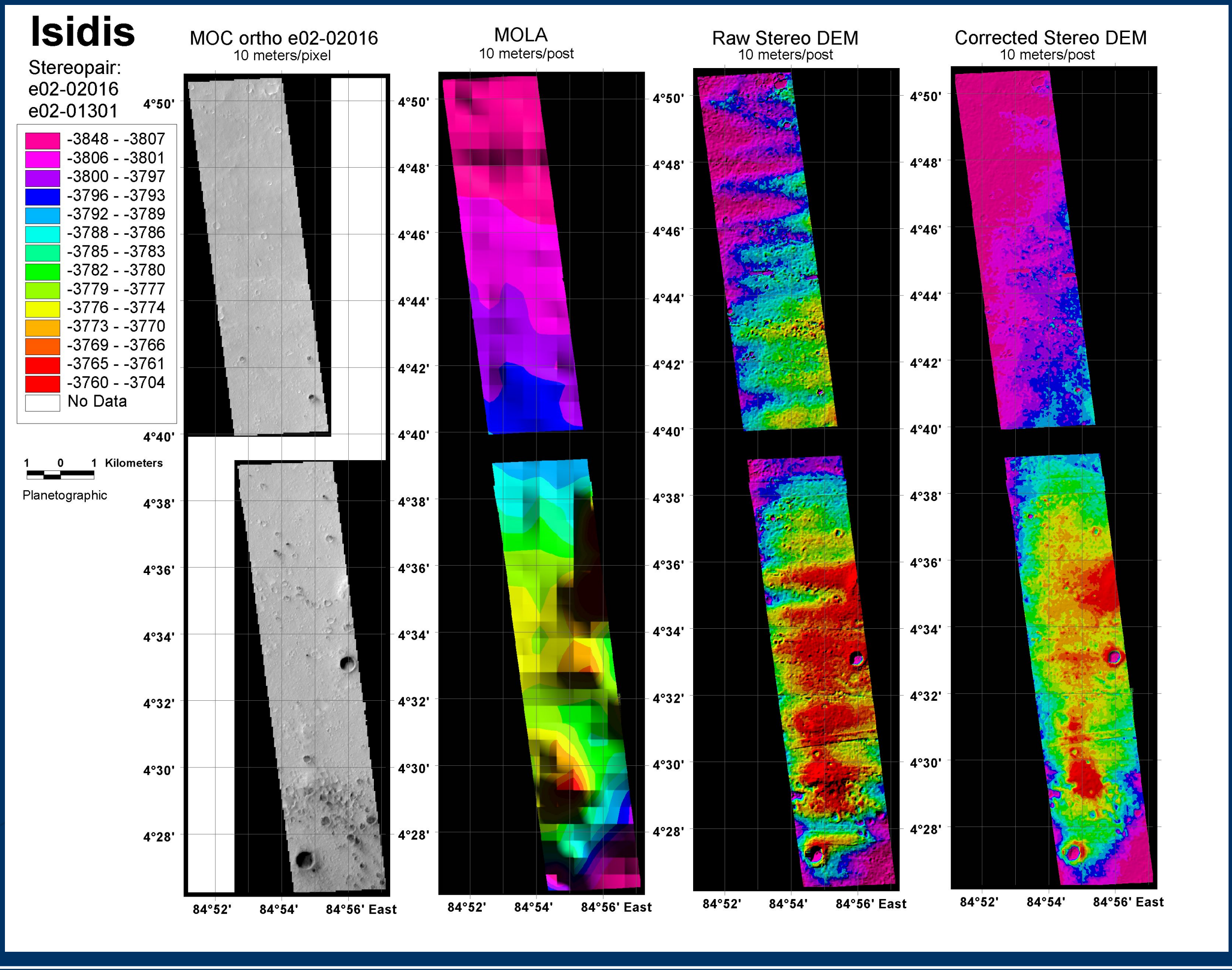
Gusev 1: E02-00665/E02-01453



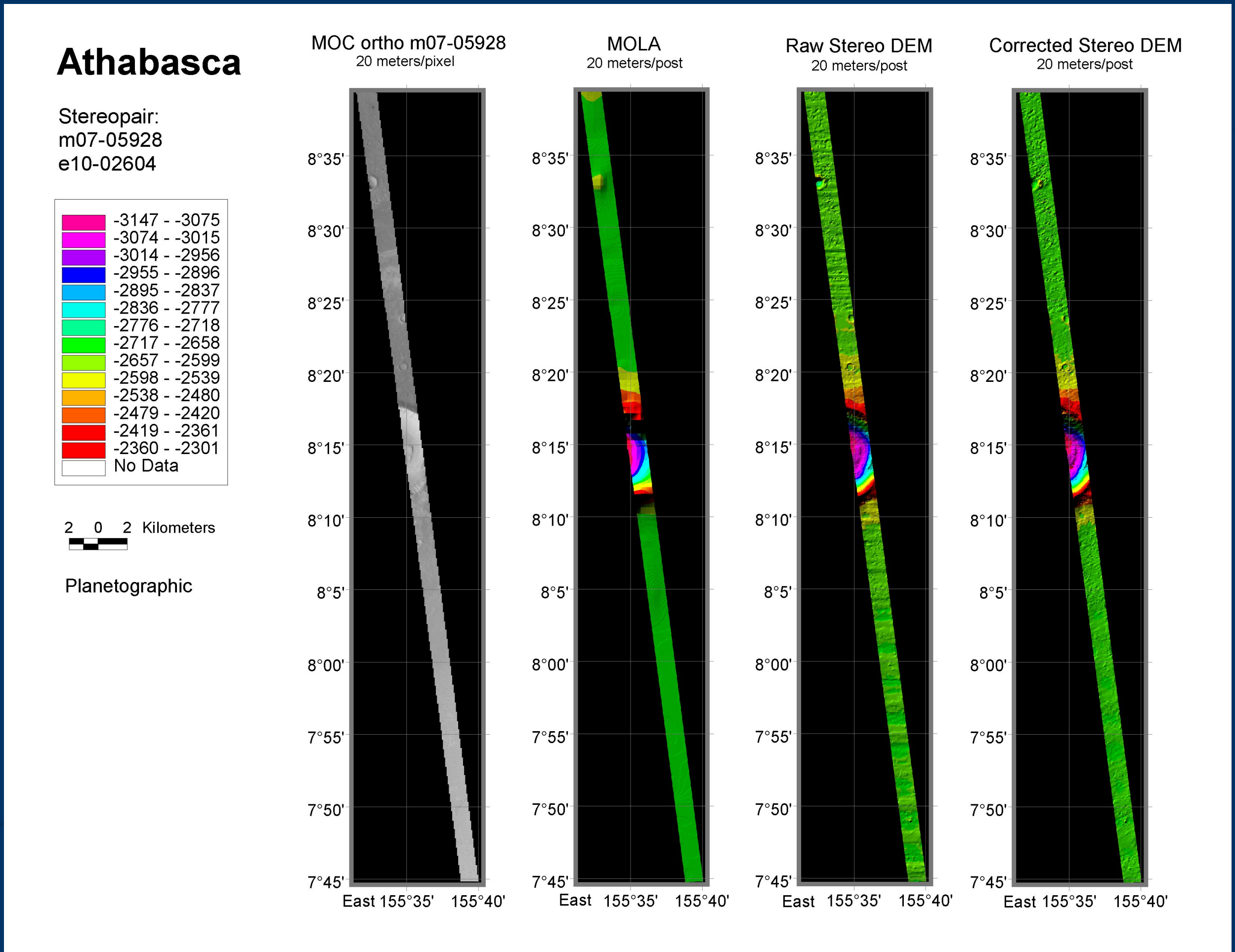
Gusev 2: E02-00341/E05-00471



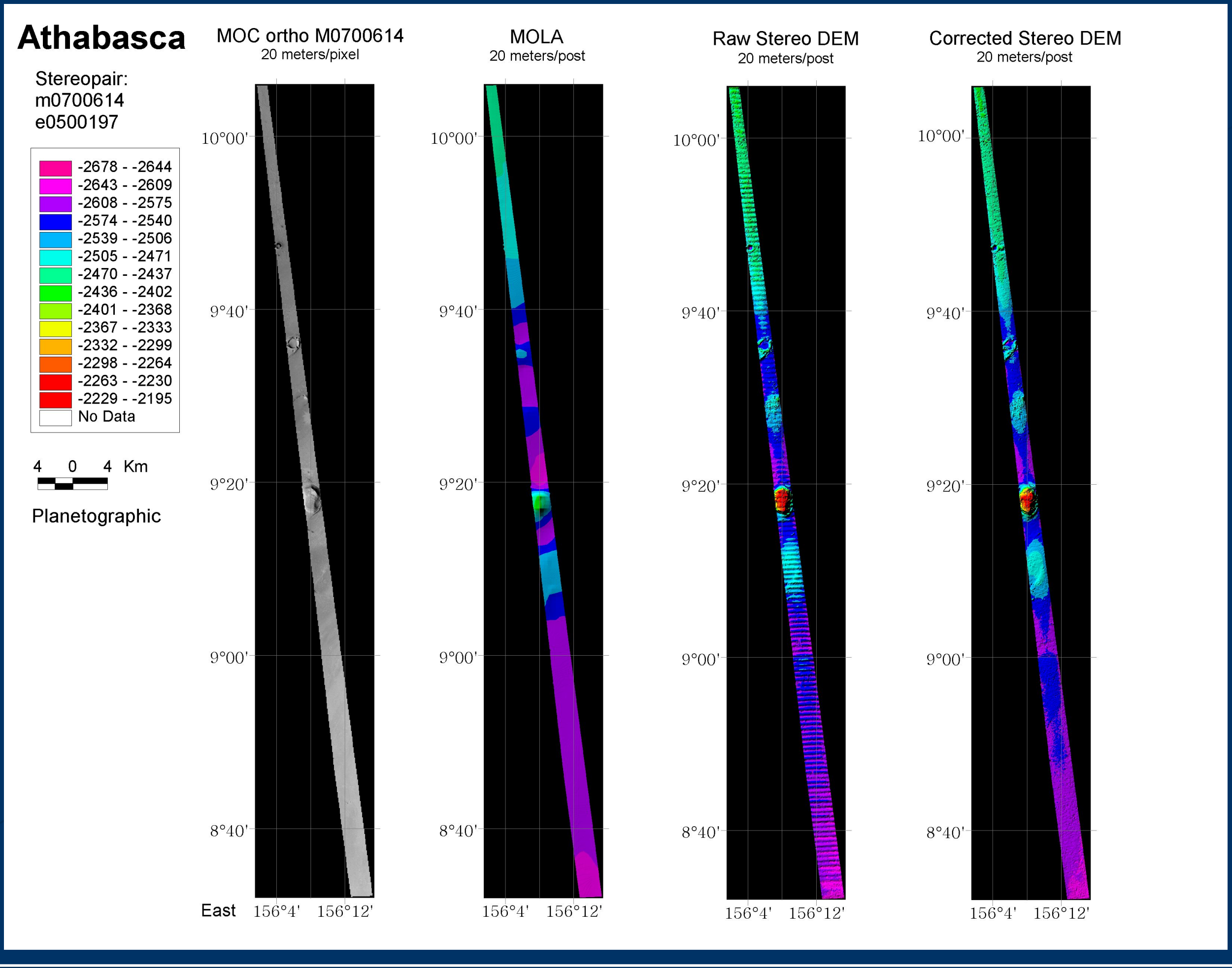
Isidis 1: E02-02016/E02-01301



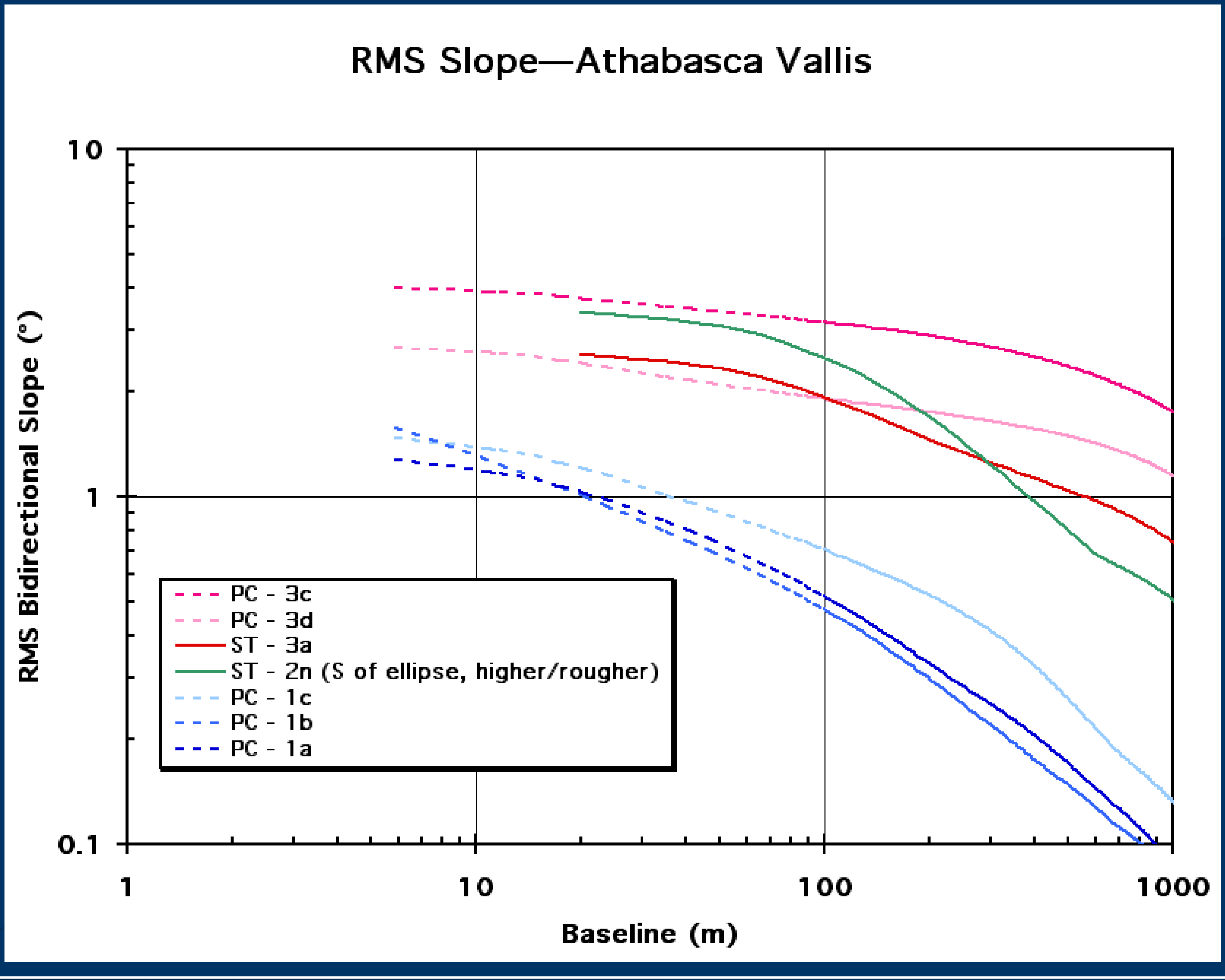
Athabasca 2: M07-05928/E10-02604



Athabasca 3: M07-00614/E05-00197

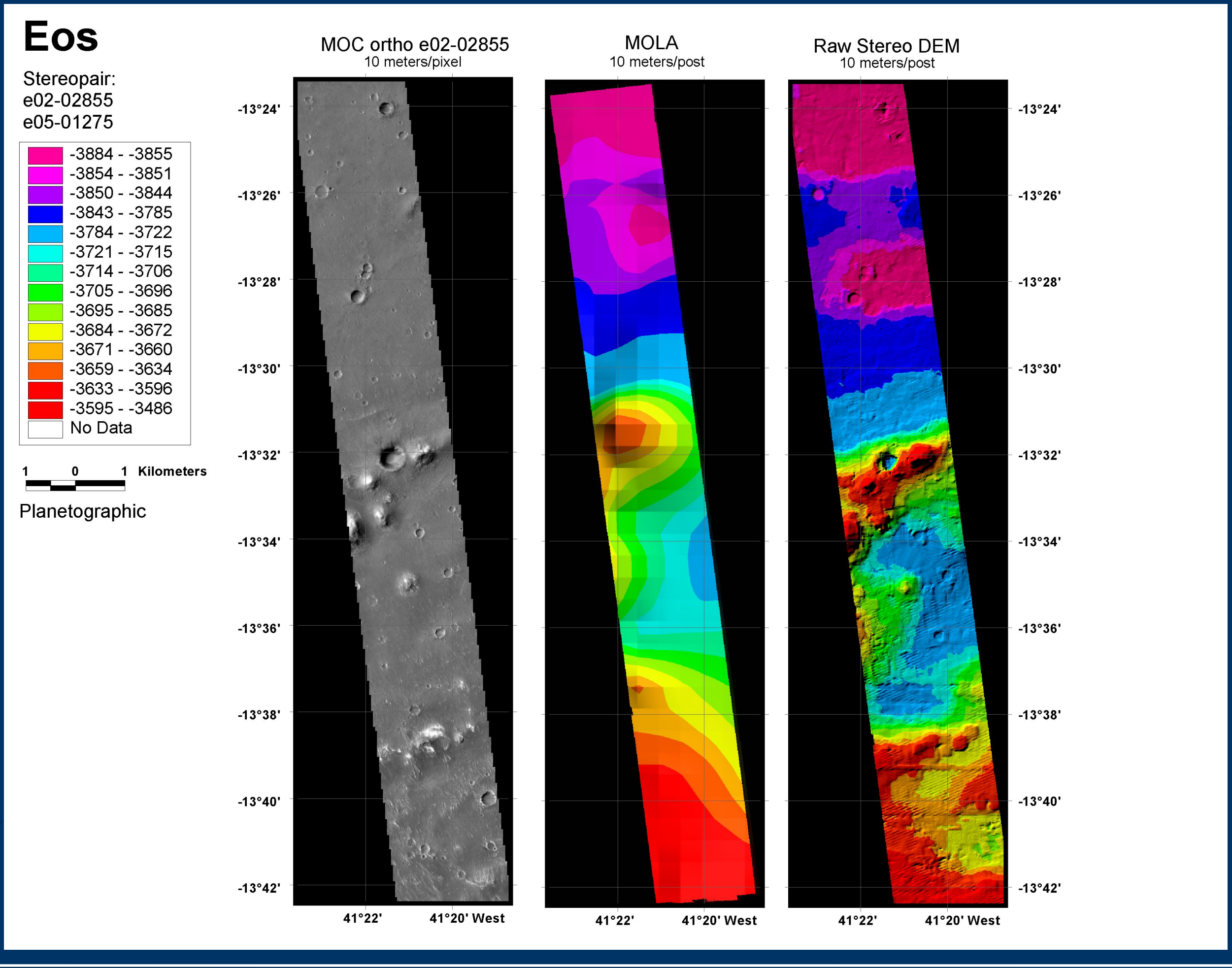


Slope vs. Baseline at Athabasca: Complicated

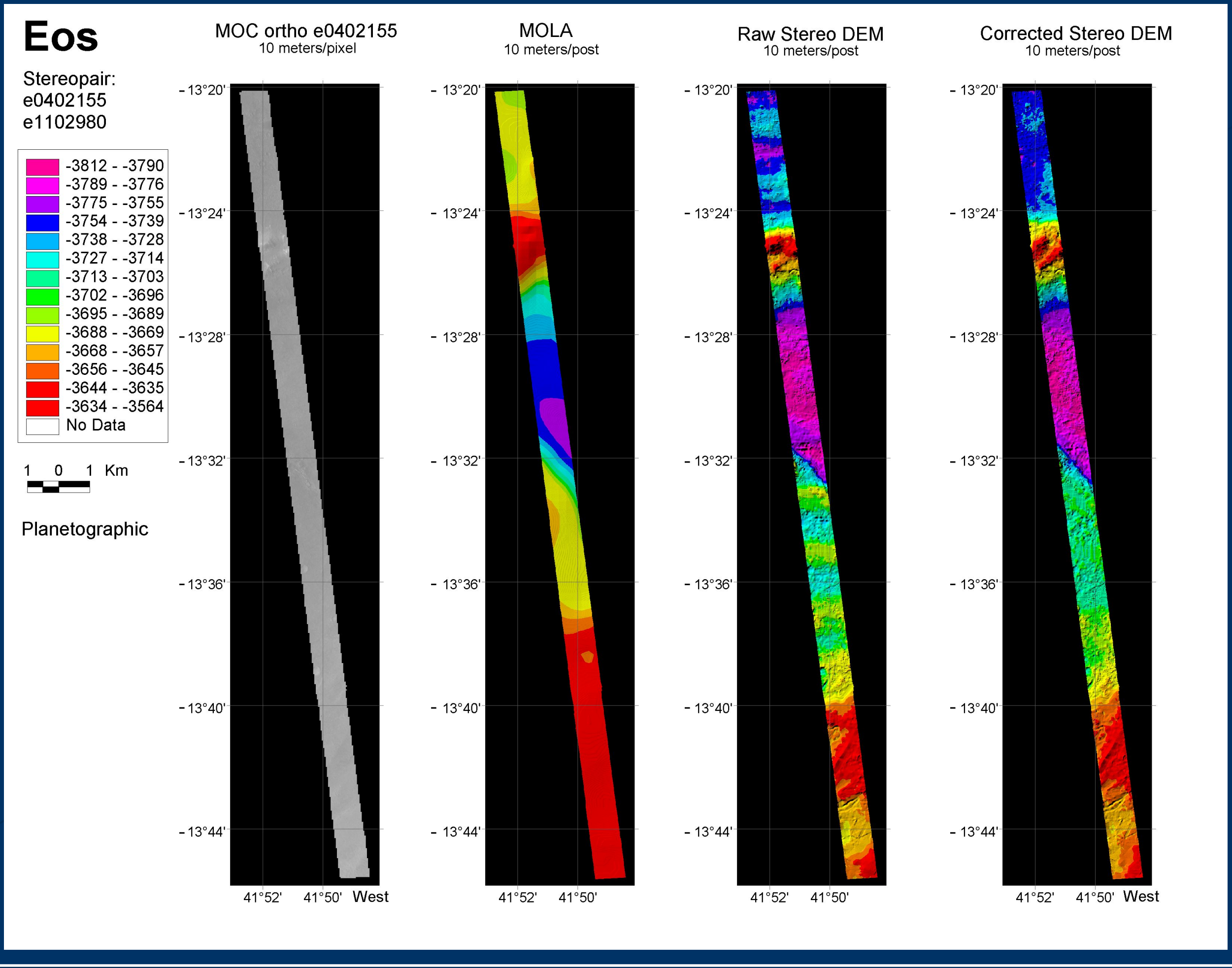


- Stereo resolves main roughness elements
- Photoclinometry confirms no un-resolved features
- Slopes vary with location
- Note high PC slopes at long baselines (rolling topography or albedo varying?)
- Stereo results preferred

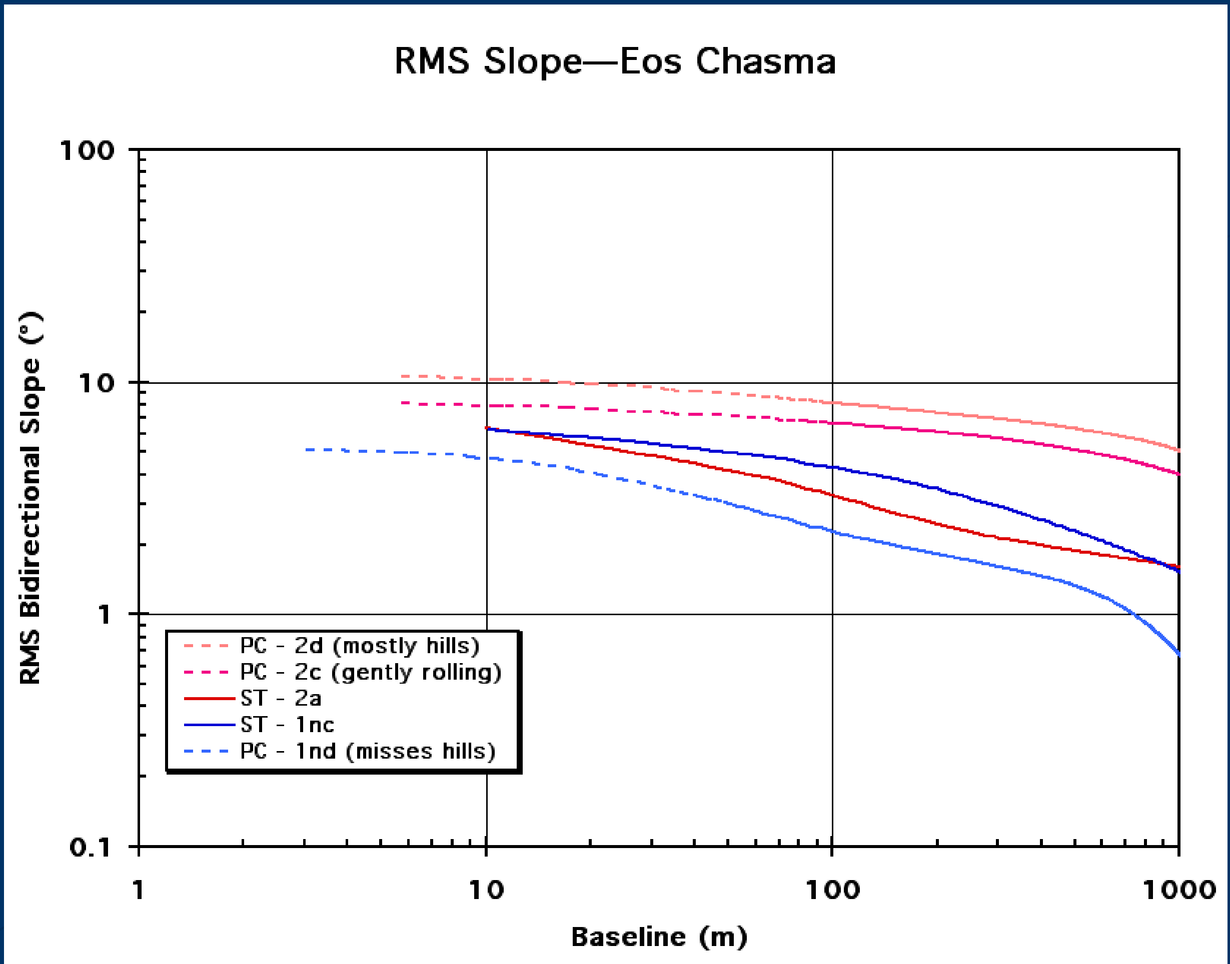
Eos 1: E02-02855/E04-01275



Eos 2: E04-02155/E11-02980

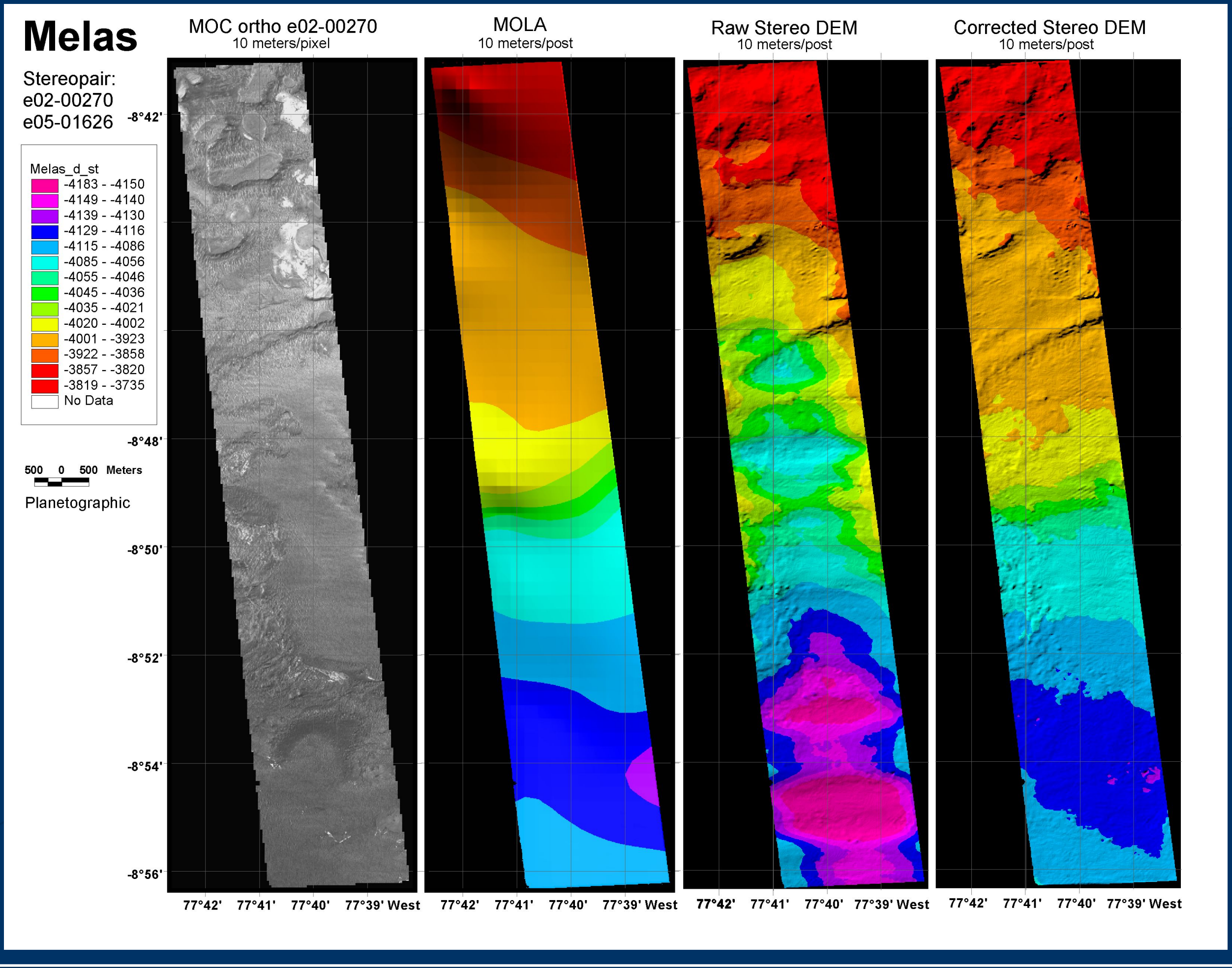


Slope vs. Baseline at Eos: Sampling effect on PC

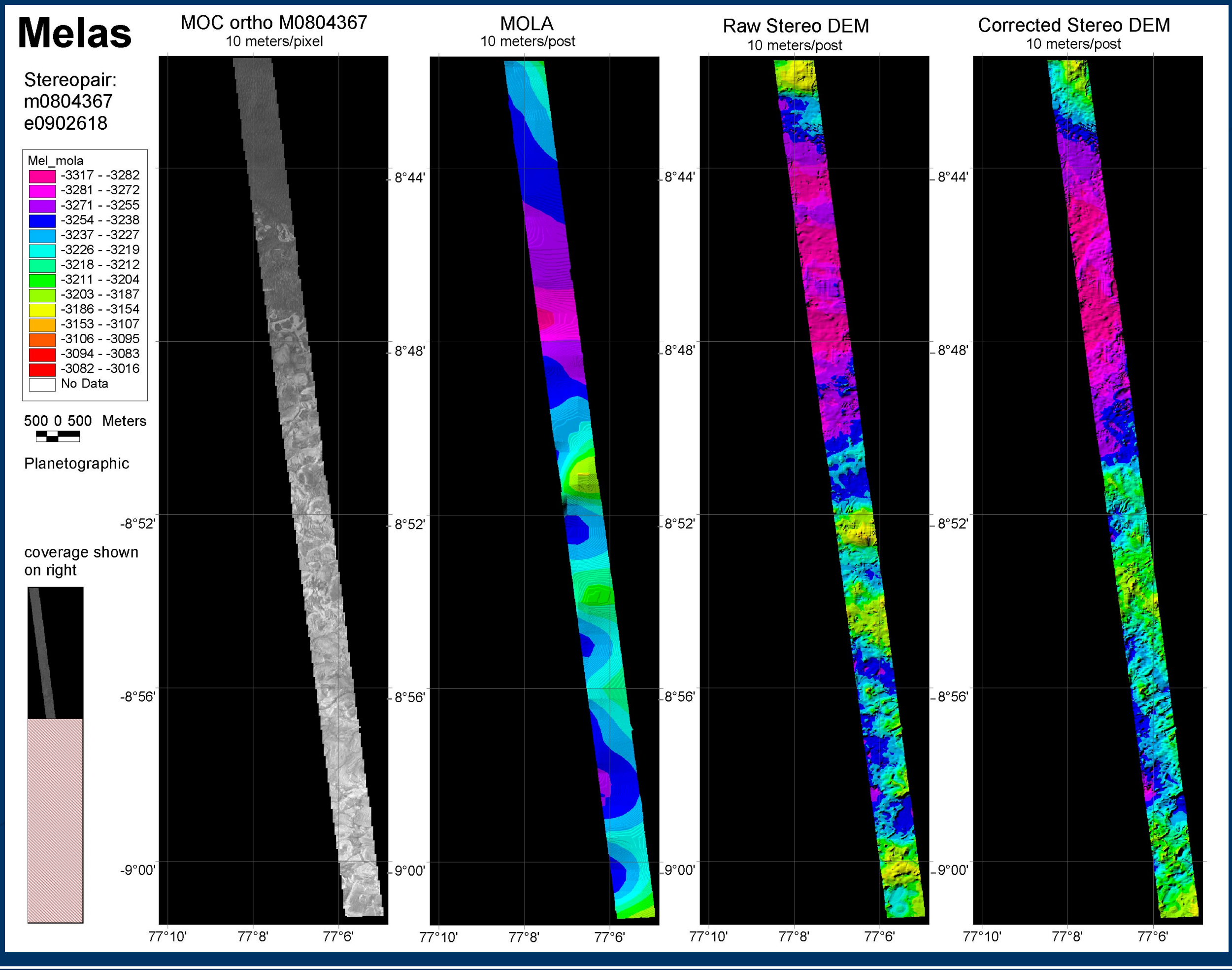


- Stereo resolves main roughness elements
- Photoclinometry confirms no un-resolved features
- Photoclinometry slopes vary, depending on area sampled (amount of hills)
- Stereo results preferred

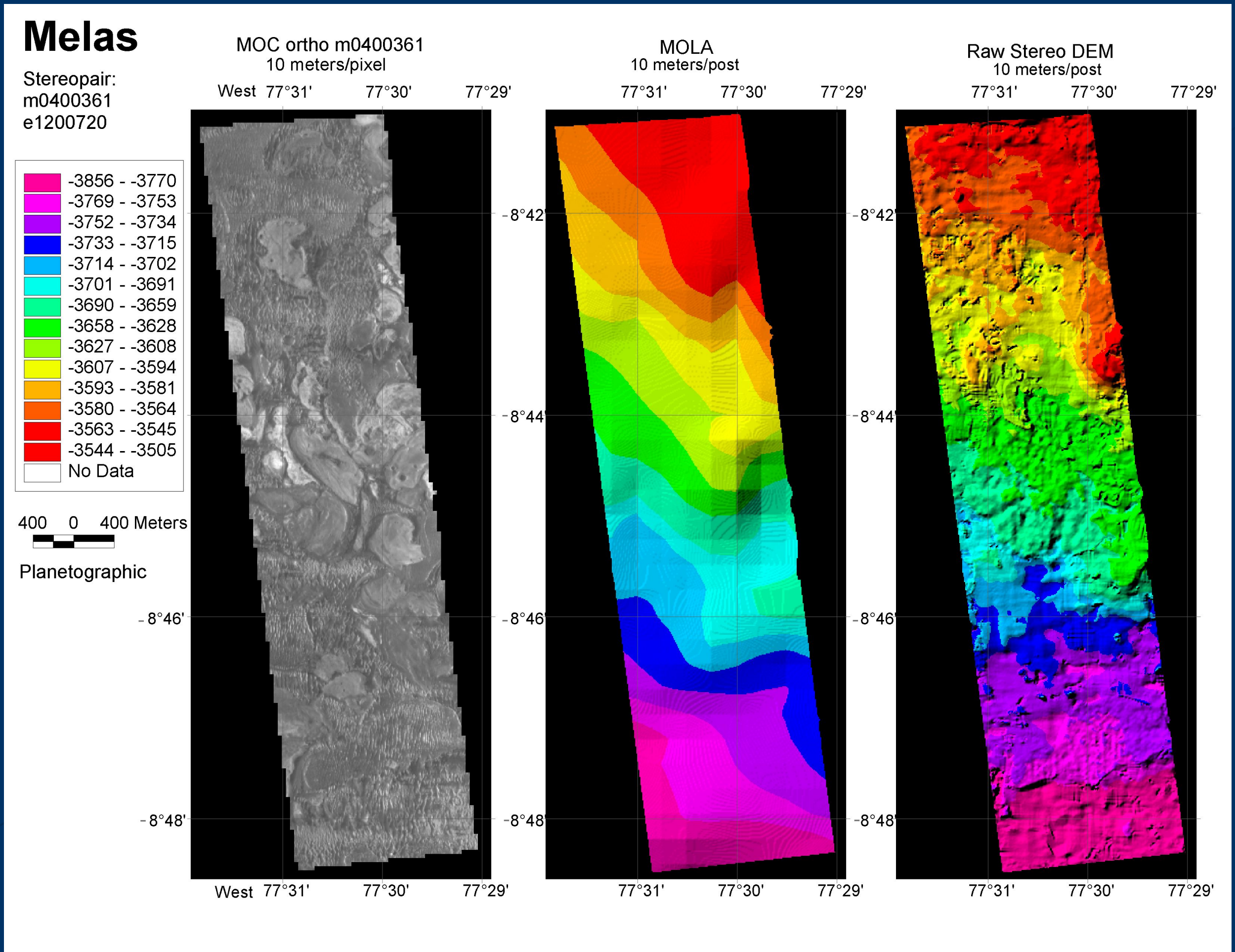
Melas 1: E02-00270/E05-01626



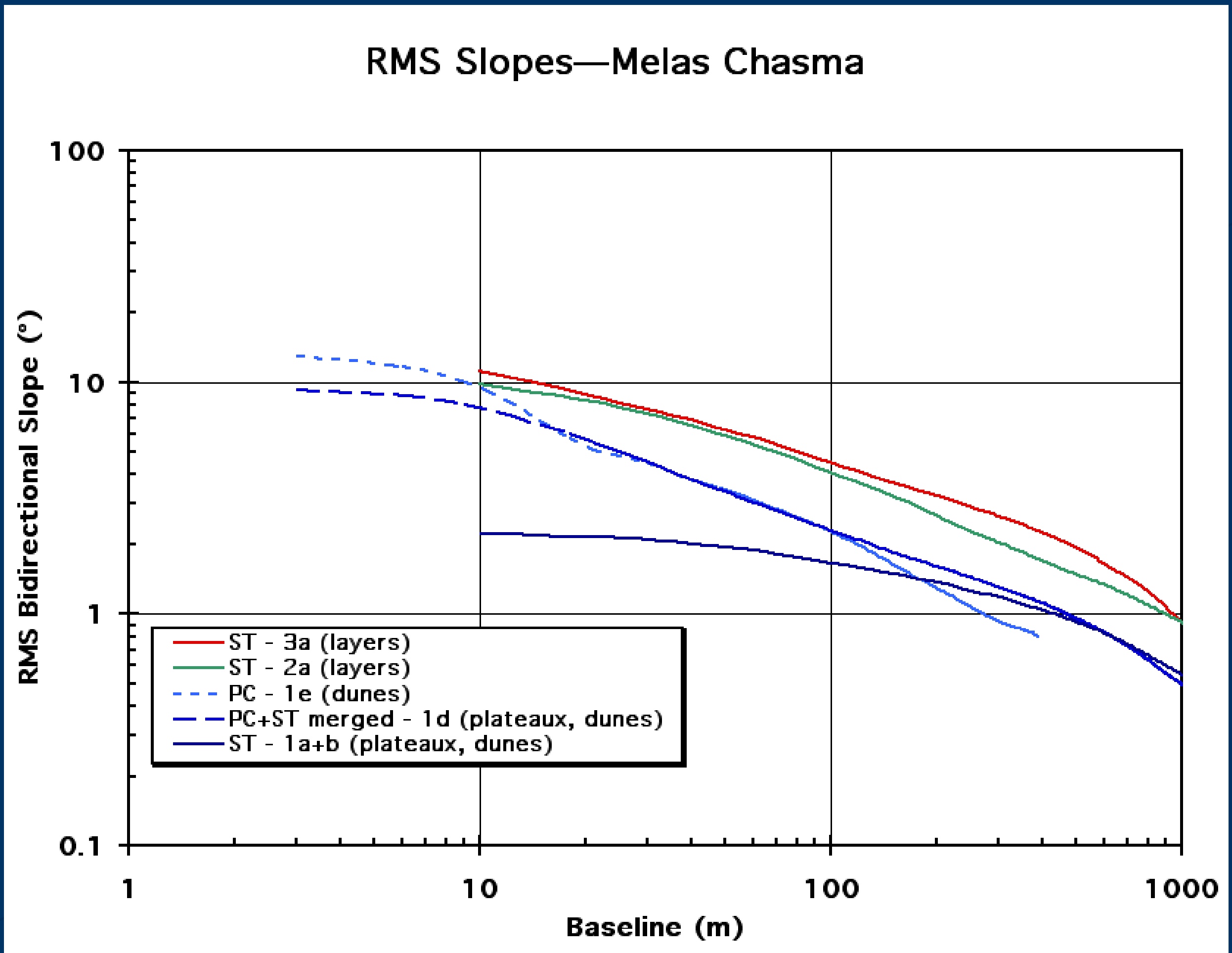
Melas 2: M08-04367/E09-02618



Melas 3: M04-00361/E12-00720



Slope vs. Baseline at Melas: Stereo lacks resolution



Stereo fails to resolve dunes

Photoclinometry resolves dunes, gives best slope estimates

Stereo appears to resolve layer topography—fortunate, since PC is impossible because of albedo