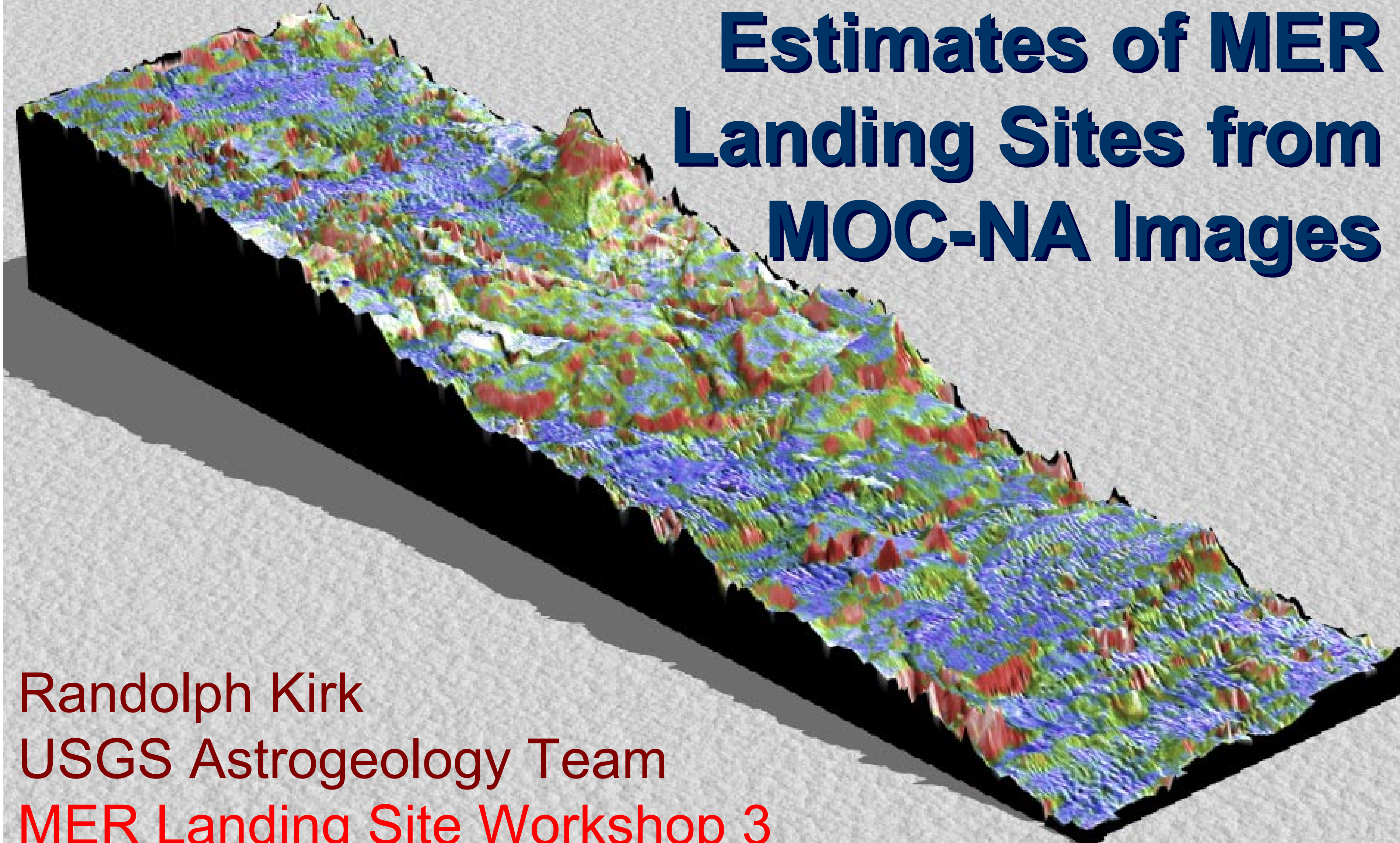
High-Resolution Slope Estimates of MER Landing Sites from MOC-NA Images



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USGS Astrogeology Team

MER Landing Site Workshop 3

28 March 2002

Introduction

Objective is to quantify slopes of MER sites at highest resolution (5 m baseline)

MER Safety criterion: P(slope≥15°) ≤ 1%

- Initial results reported at MER WS 2, 10/2001
  - 4 sites, 1 DEM each (Eos, Isidis, Gusev, Melas)
  - All were rougher than MER criterion
  - Fairly representative apart from Melas (only dunes sampled)
- Update for MER LS WS 3:
  - 12 datasets covering all 6 sites
  - Good consistency with previous results
  - Melas layers even *rougher* than dunes
  - Athabasca, Hematite smooth, meet criterion

Overview of Methodology

- Rely on MOC-NA images
  - 2x2 summation, ~3 m resolution (some 4x4, ~6 m)
- Stereoanalysis
  - Horizontal resolution ≥3 pixels (10 m)
  - Vertical precision ~2m w/high confidence
- 2D Photoclinometry (shape-from-shading)
  - Horizontal resolution ≥1 pixel
  - Model-dependent; calibrate amplitude to stereo to improve confidence
  - Subject to artifacts due to albedo variations
  - Samples smaller, usually slightly different areas
- Slope analysis based on DEMs produced

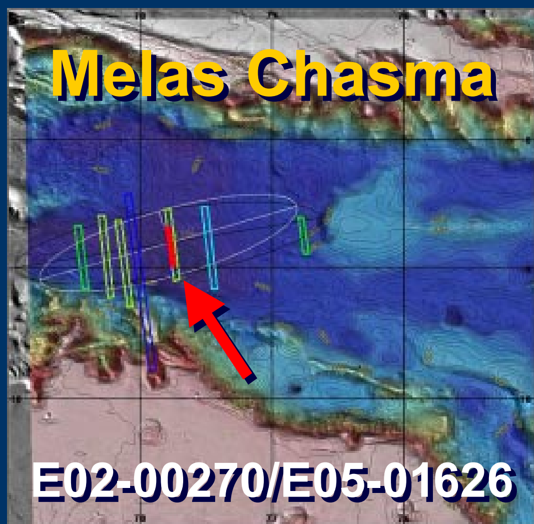
Software

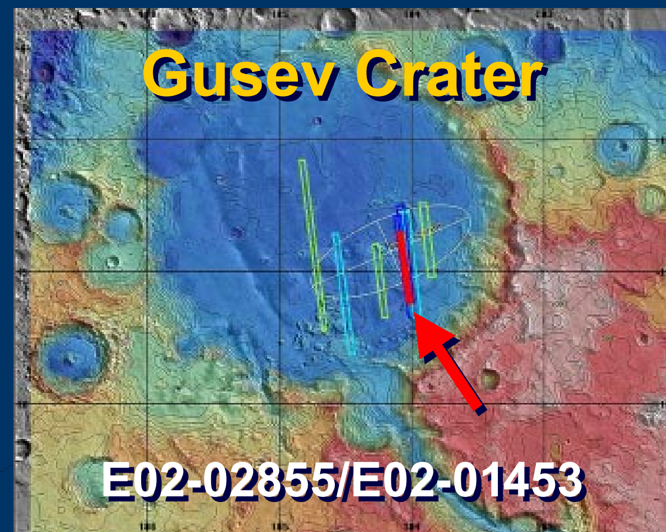
- We use commercial photogrammetric workstation (LH Systems SOCET SET) combined with ISIS
- Includes “generic pushbroom scanner” sensor model that can describe MOC
  - Adjustment capability limited
- Wrote software to ingest/setup images
- Also use Kirk’s 2D photoclinometry and slope analysis software

Identification of Images

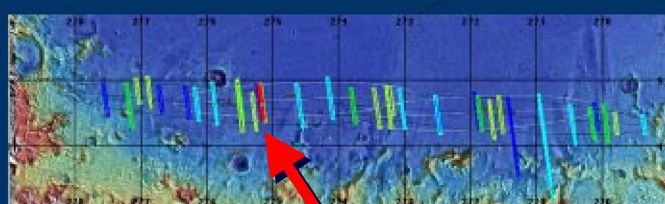
- Automated search of MOC cumindex
  - Searched releases through E12
  - Look for overlaps
  - Require compatible illumination
  - Validate image quality & overlap by inspection
  - Disappointing after our original search
- Manual search
  - Footprint maps on Marsoweb site
  - Compared E12, E13 image pages
  - We welcome suggestions from colleagues
- 23 candidate pairs/triplets found
  - 7 eliminated (hazy, poor o/l, surface changes,…)
  - 10 mapped
- Also used 2 images for photoclinometry only

Stereo Coverage—10/01

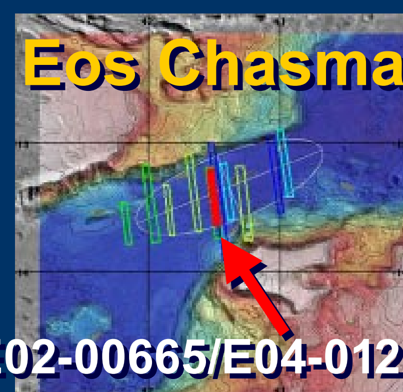




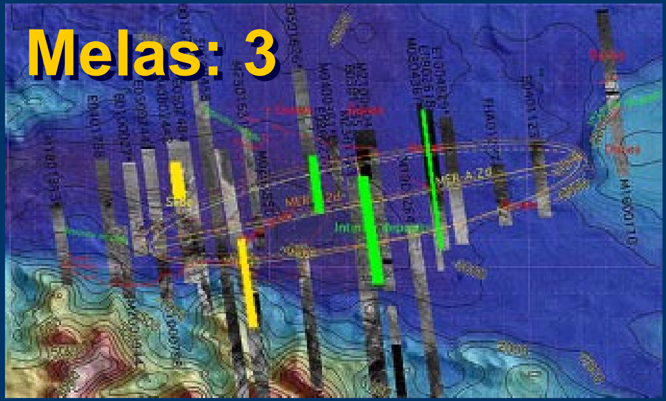
Isidis Planitia

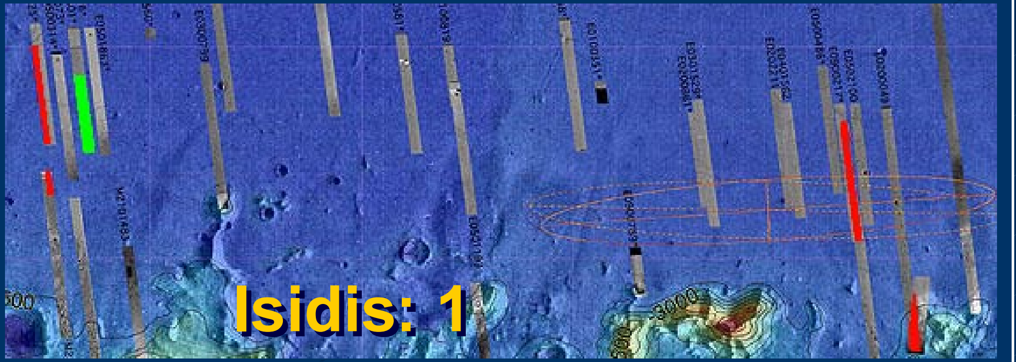


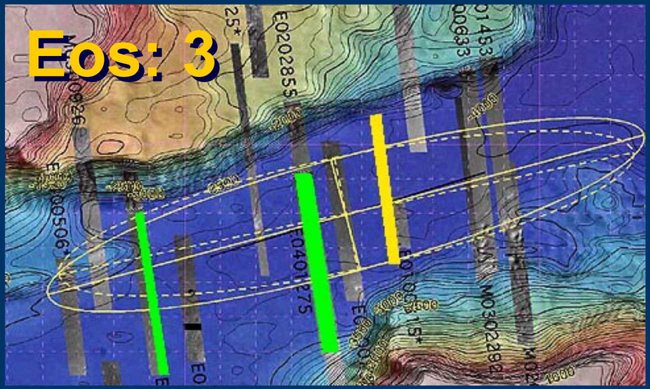
E02-01301/E02-02016

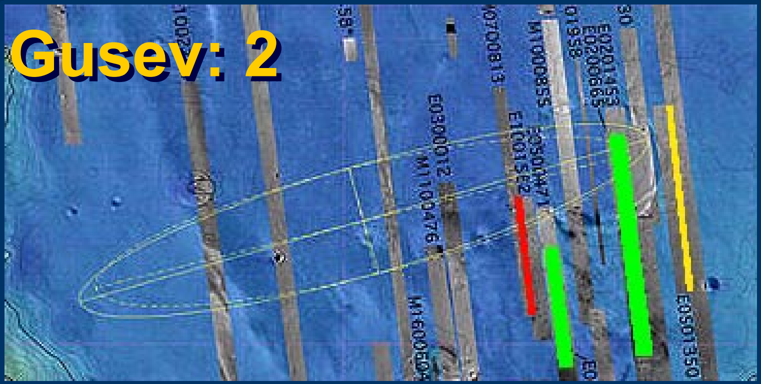


Stereo Coverage—Current





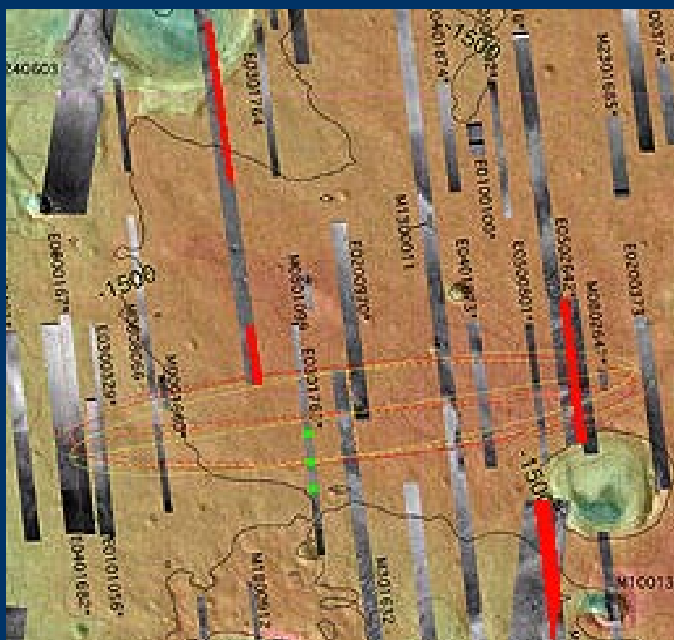




At least 1 more pair (not shown) found for Eos

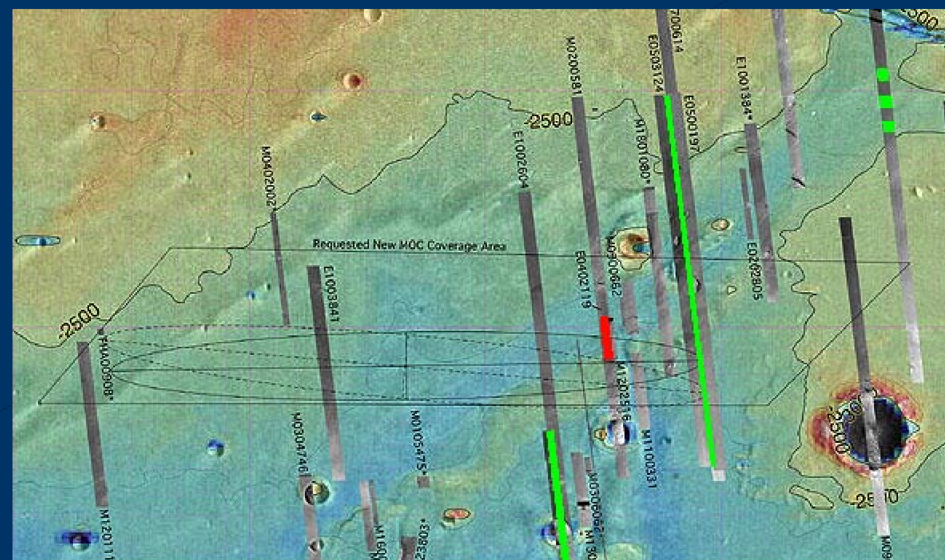
Stereo Coverage—Current

Hematite: PC only



Many more images with regions suitable for PC...

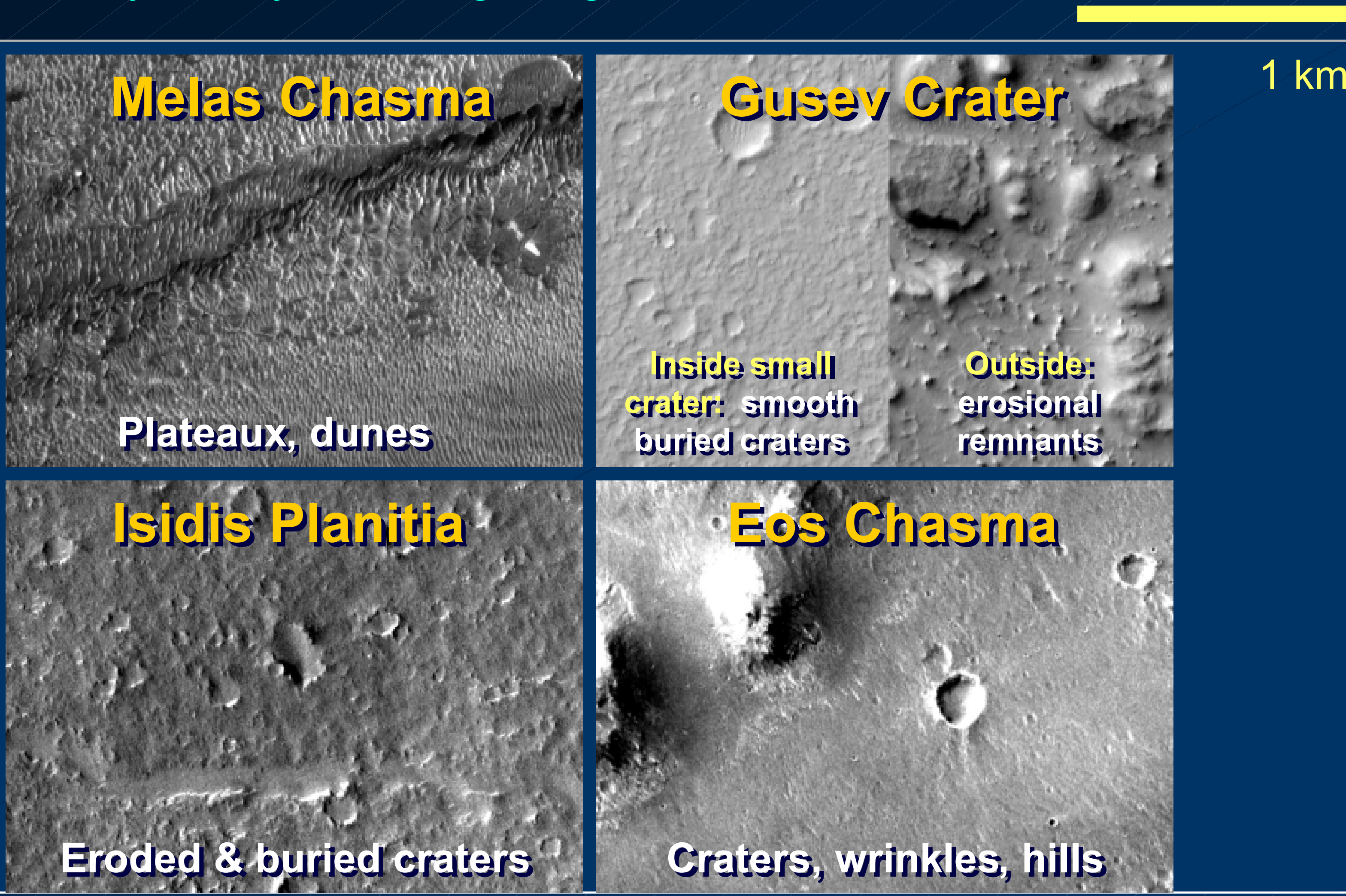
Athabasca: 3 + 1 PC only



At least 1 more pair (not shown) found for Athabasca

Characterization of the Sites

AKA “Why Randy is not a geologist…”



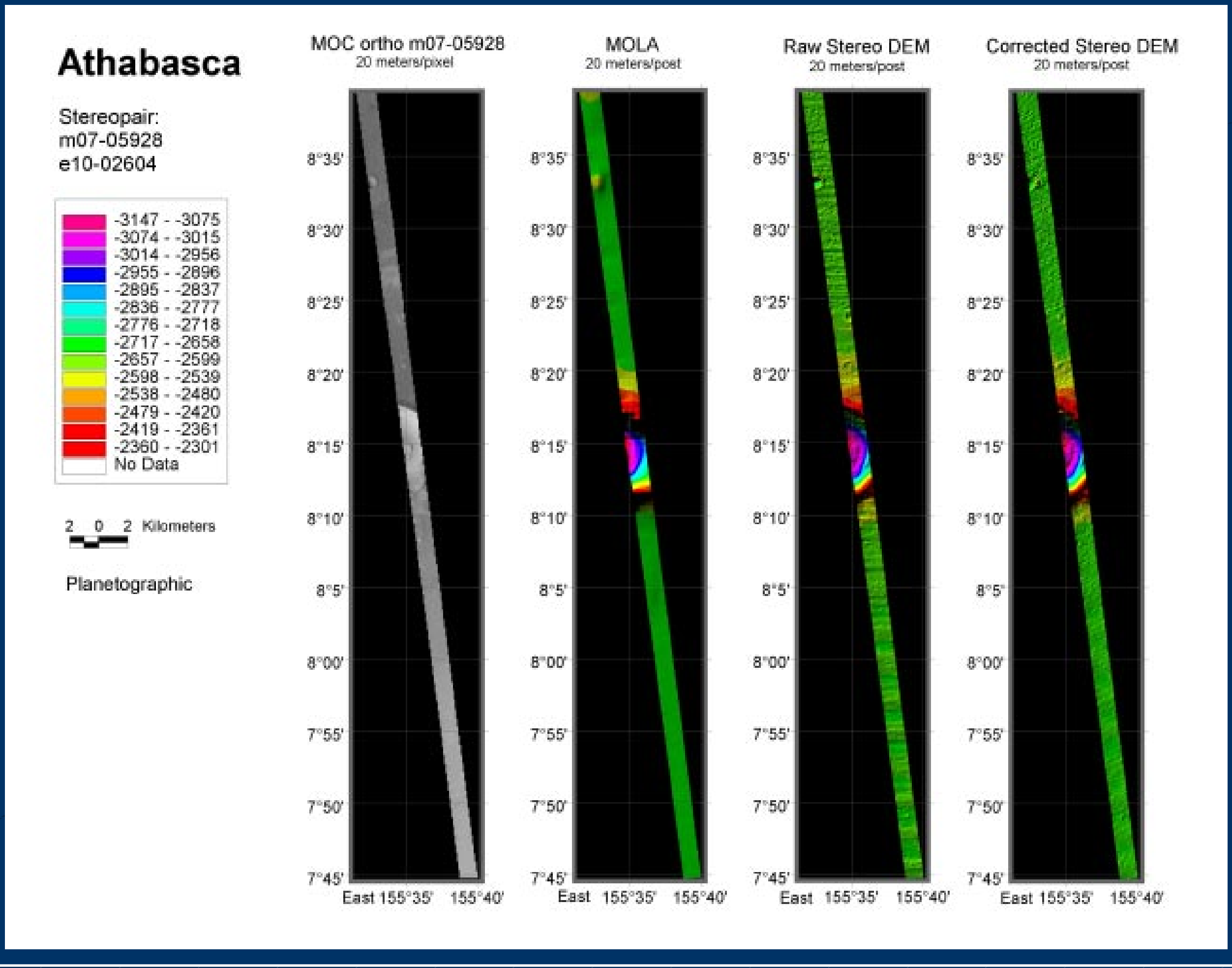
Stereo Image Control

- Do least-squares adjustment in SOCET
  - Position/velocity offsets in 3 axes
  - Rotation offset/vel/accn in 3 angles
  - Does NOT handle high-frequency “wiggles”
- Constrain tiepoints to elevations interpolated from MOLA (USGS 500m grid for each site)
- Did not attempt absolute horizontal control
  - Would require ties to MOLA via intermediate resolution images
  - Not necessary for roughnness analysis
  - Horizontal positions OK to few x 100 m

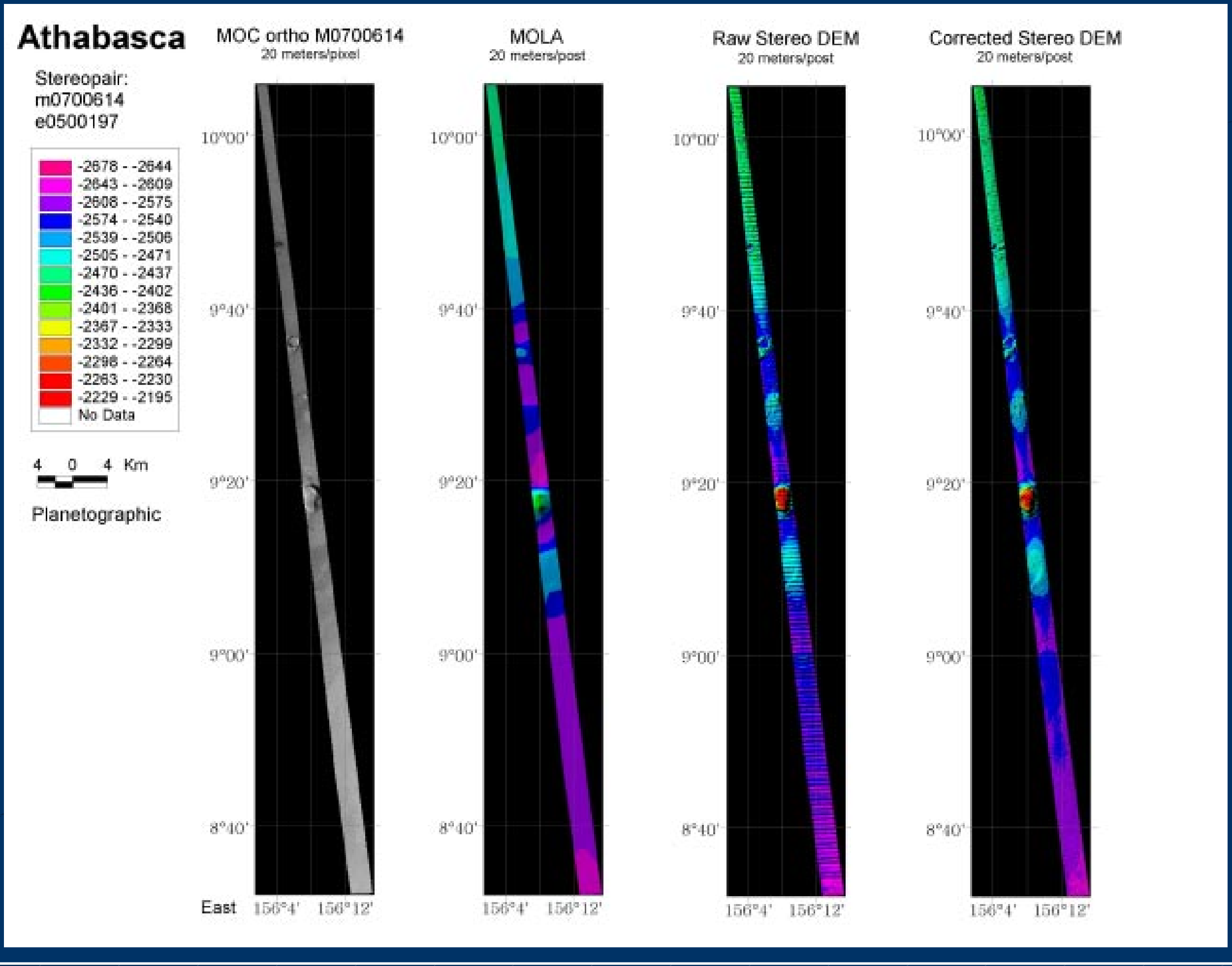
Stereo DEM Collection

- Collect by automatching,edit w/stereo display
- High-frequency s/c pointing oscillations cause *serious* problems for DEM collection & use
  - Periods 0.1–1 s, amplitudes ≤50 uRad
    - Also seen in SPICE CK but aliased to ≥4 s
  - Cross-track oscillations mimic stereo parallax, cause DEM to undulate (10s of m amplitude)
    - Digitally filter DEMs to suppress undulations
  - Along-track oscillations cause matching image lines to wander in and out of alignment.
    - Stereo matcher “loses lock” and fails
    - Collect in sections, adjusting for offset, then edit together
  - Workarounds more difficult in Relay-16 mode?

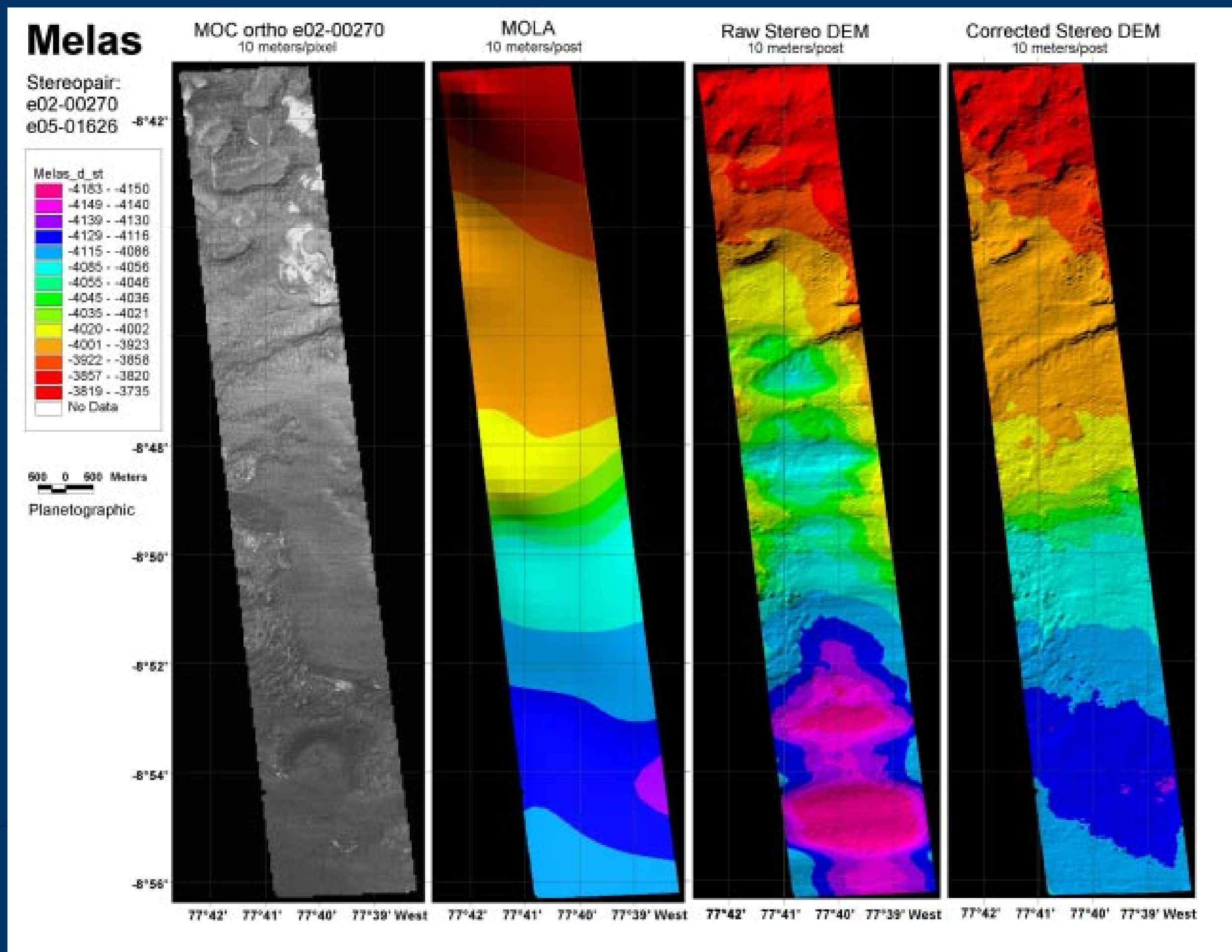
Atha 2: M07-05928/E10-02604



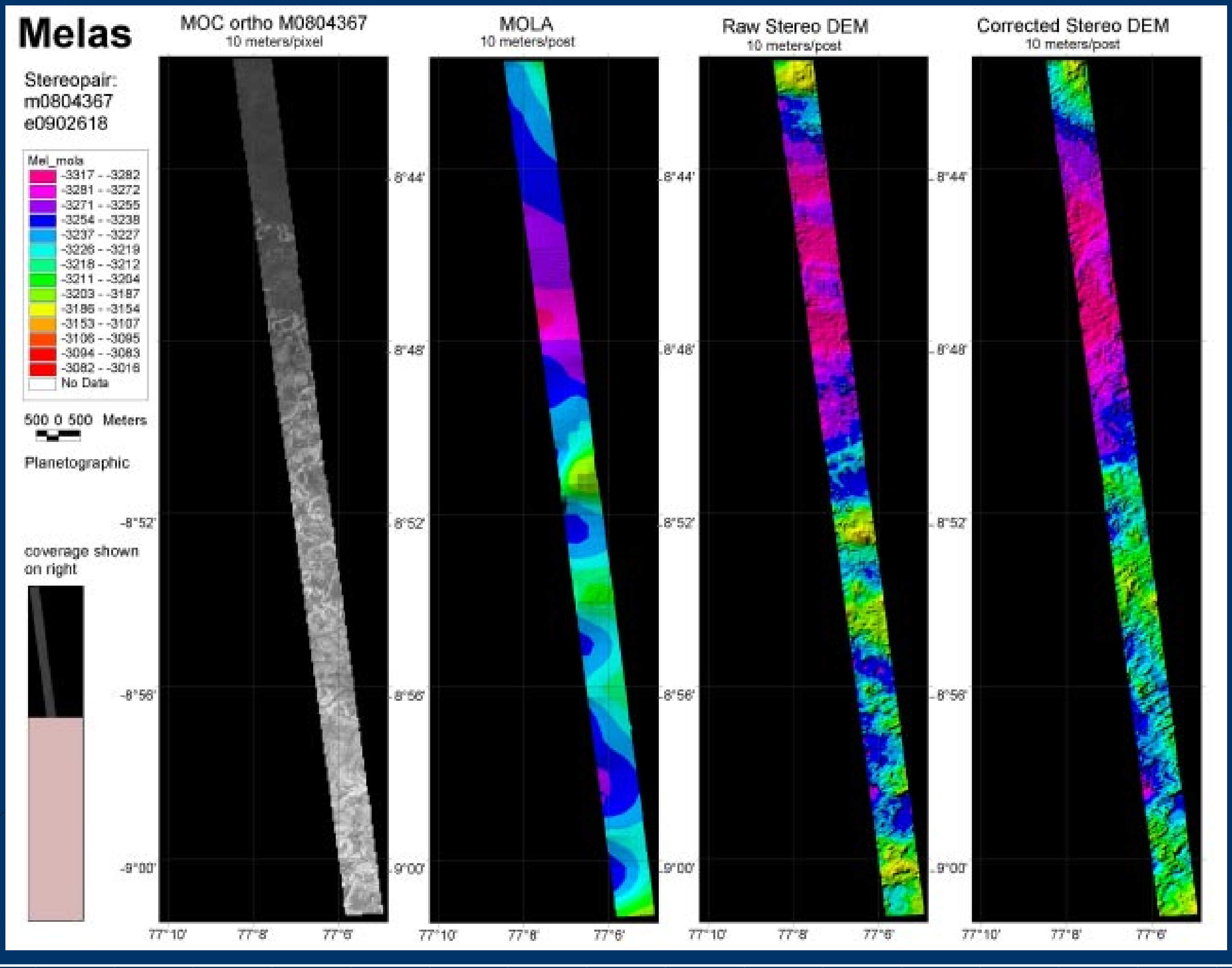
Atha 3: M07-00614/E05-00197



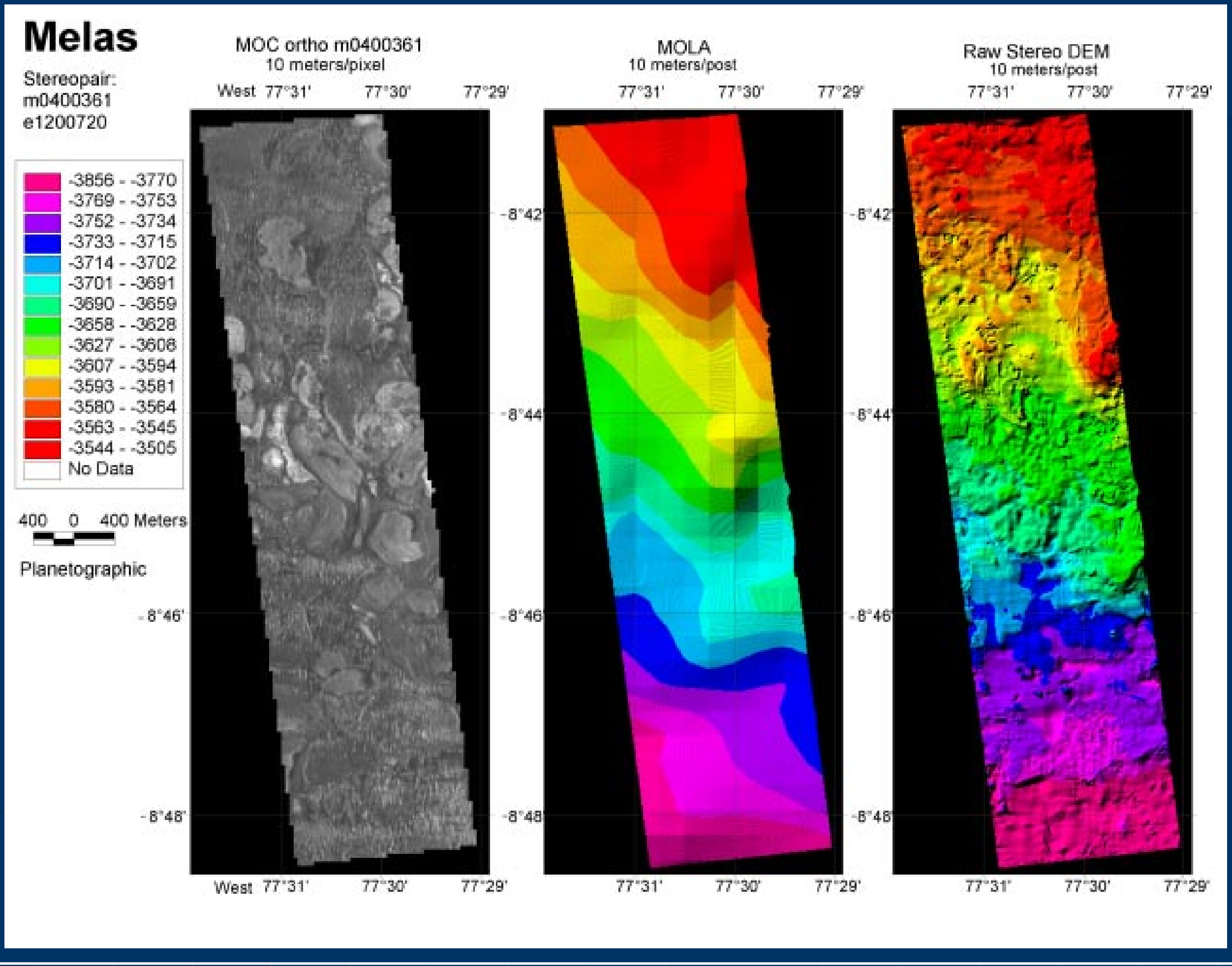
Melas 1: E02-00270/E05-01626



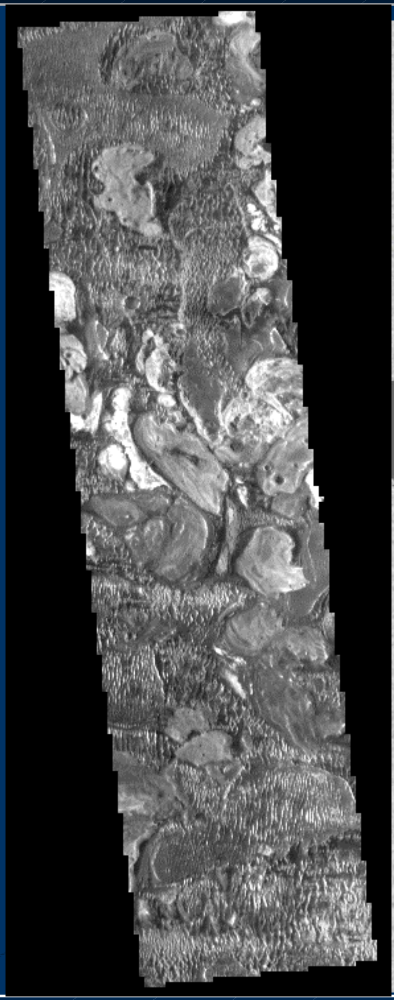
Melas 2: M08-04367/E09-02618

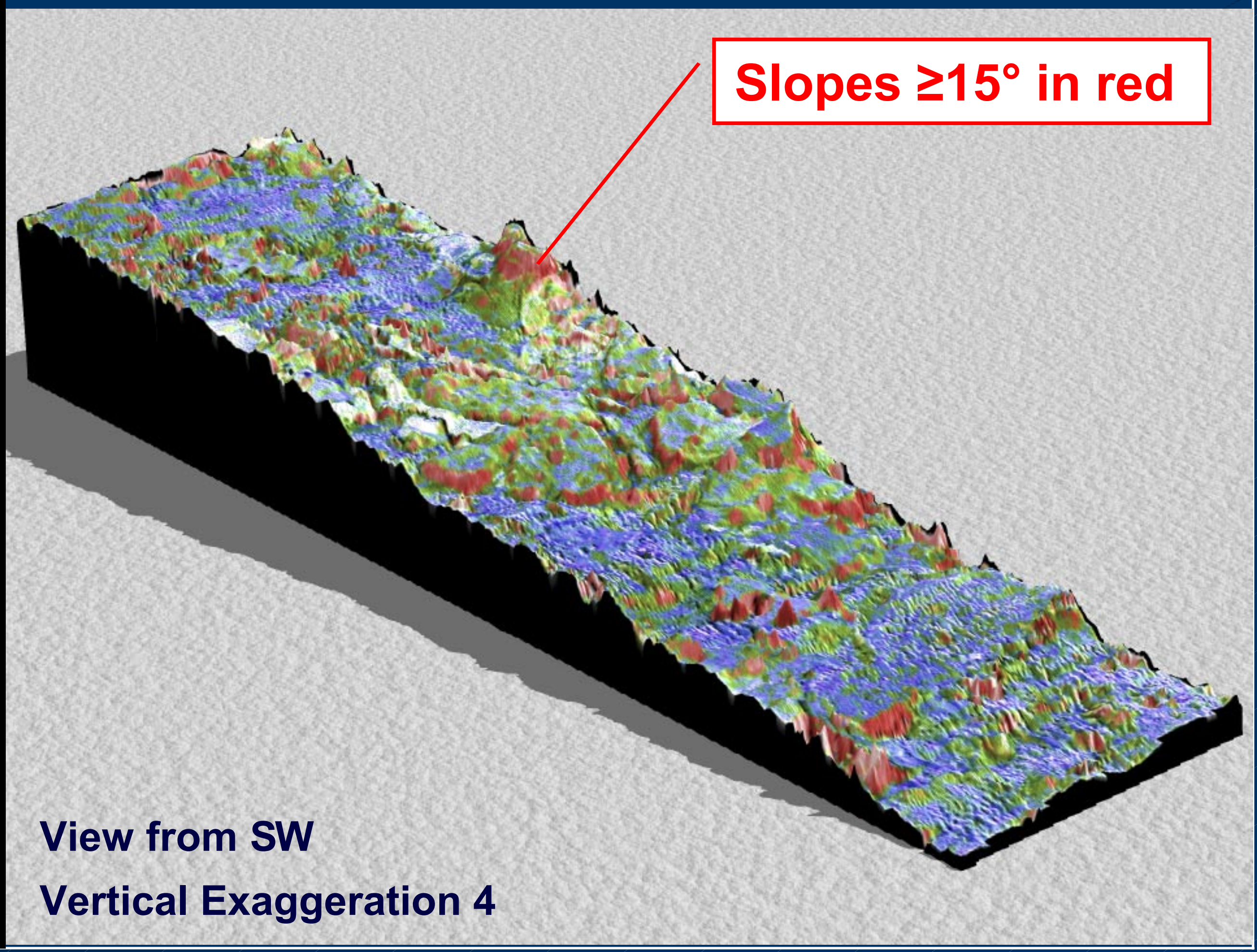


Melas 3: M04-00361/E12-00720

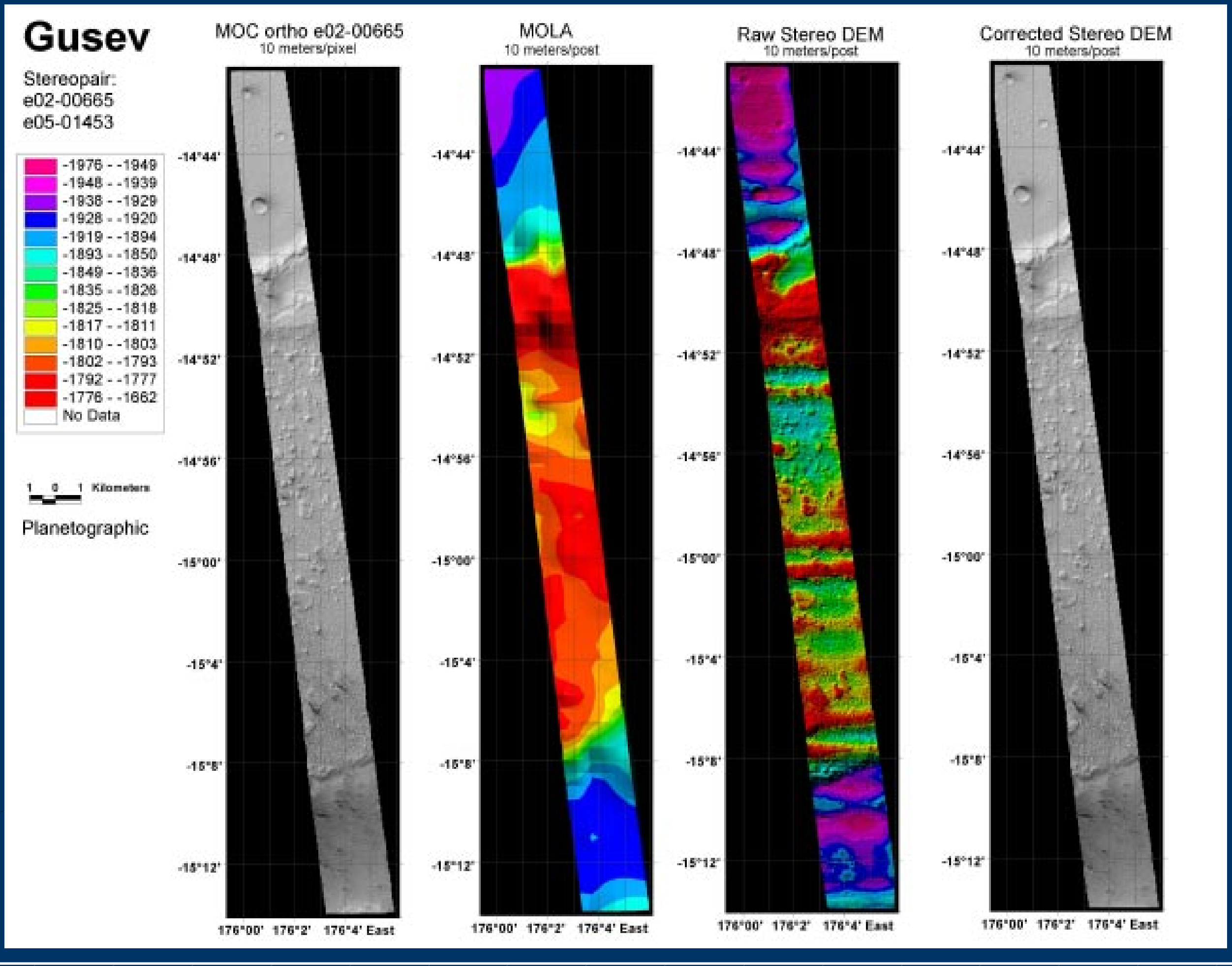


Melas 3 Visualized

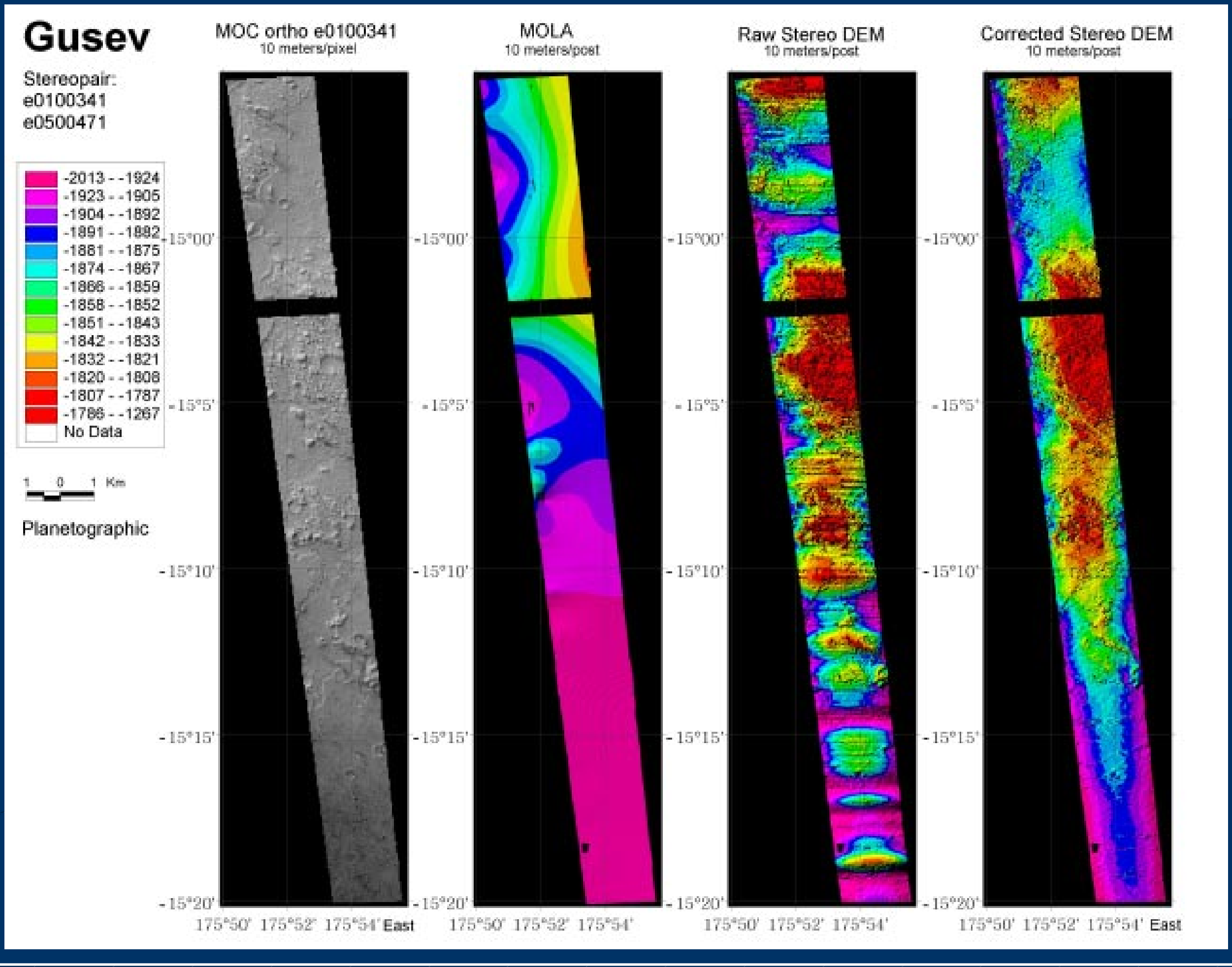




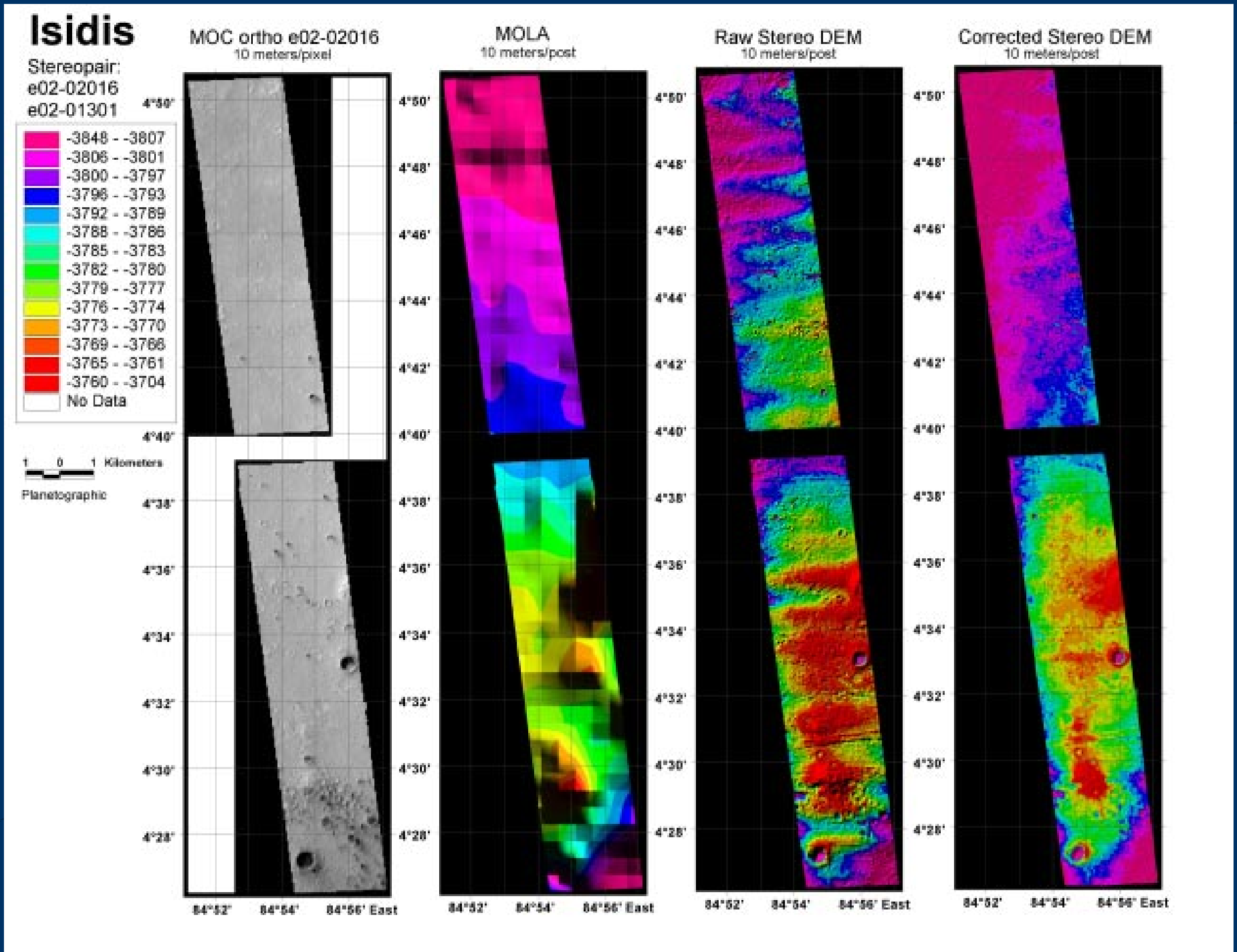
Gusev 1: E02-00665/E02-01453



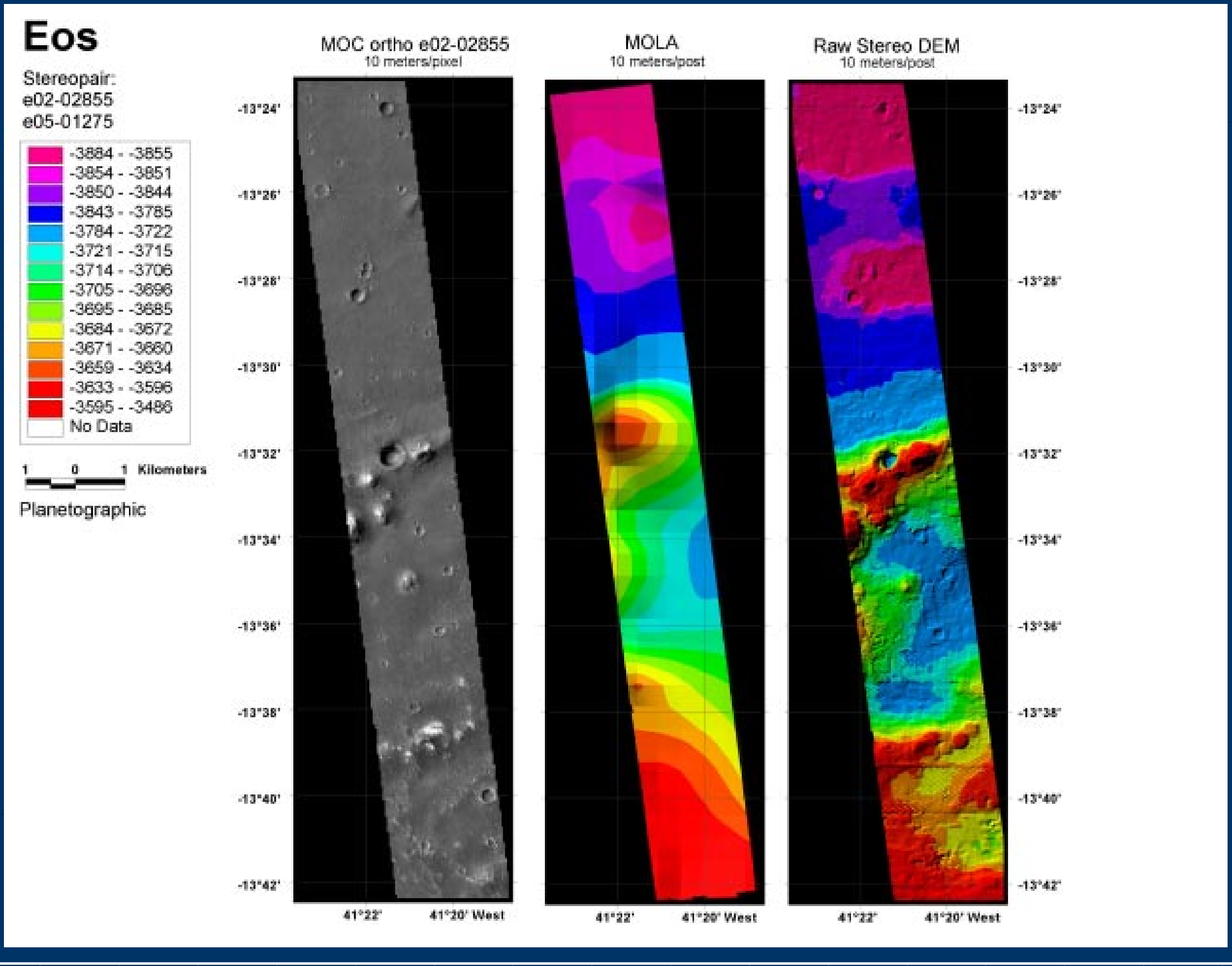
Gusev 2: E02-00341/E05-00471



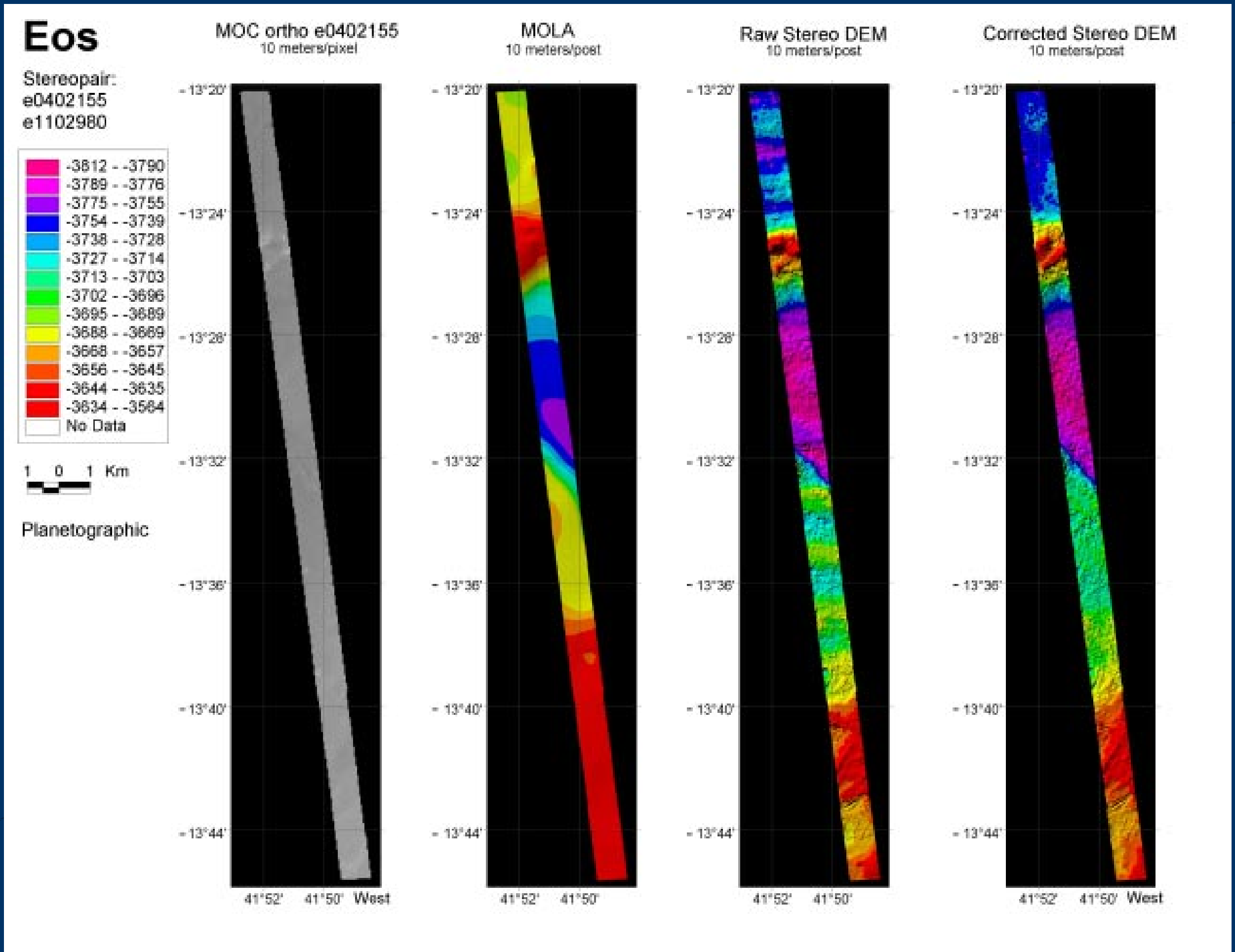
Isidis 1: E02-02016/E02-01301



Eos 1: E02-02855/E04-01275



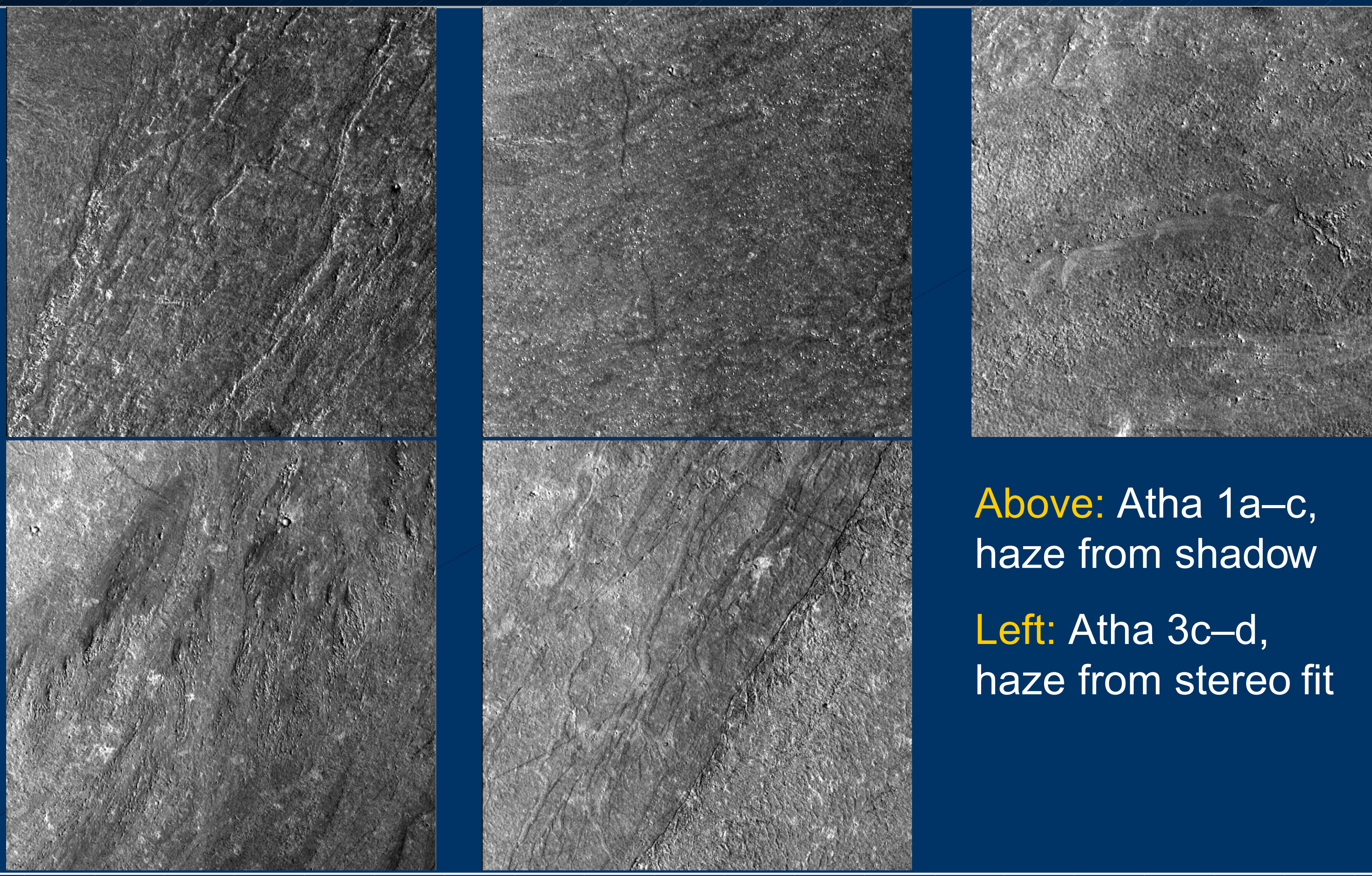
Eos 2: E04-02155/E11-02980



Photoclinometry “Control”

- Haze reduces contrast; must subtract correct haze to get correct DEM, slopes
- If possible use stereo DEM to get haze
  - Shade DEM with surface photom function
  - Regress image on shaded; intercept=haze
  - Similar aproach w/MOLA works at poles
- Determine haze from shadows (if any)
- Scale contrast of known slopes (dunes)
- Extrapolate atmospheric optical depth

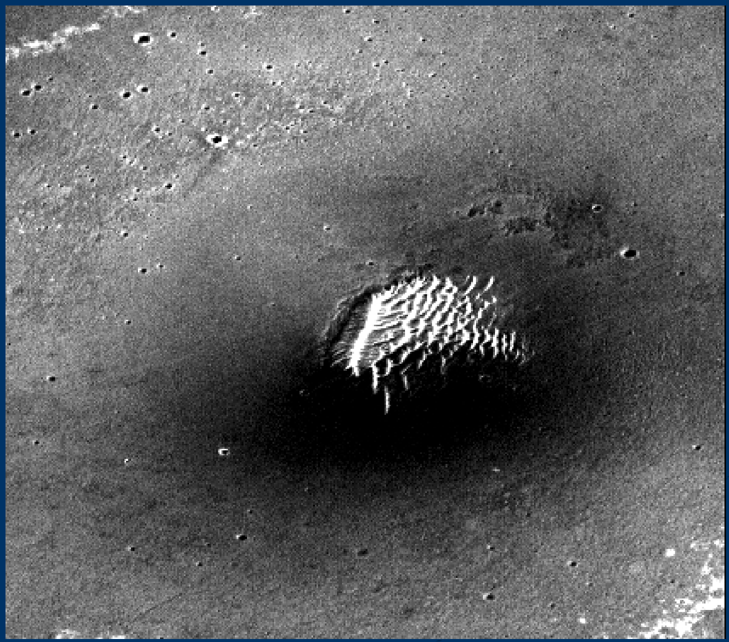
Athabasca PC Areas

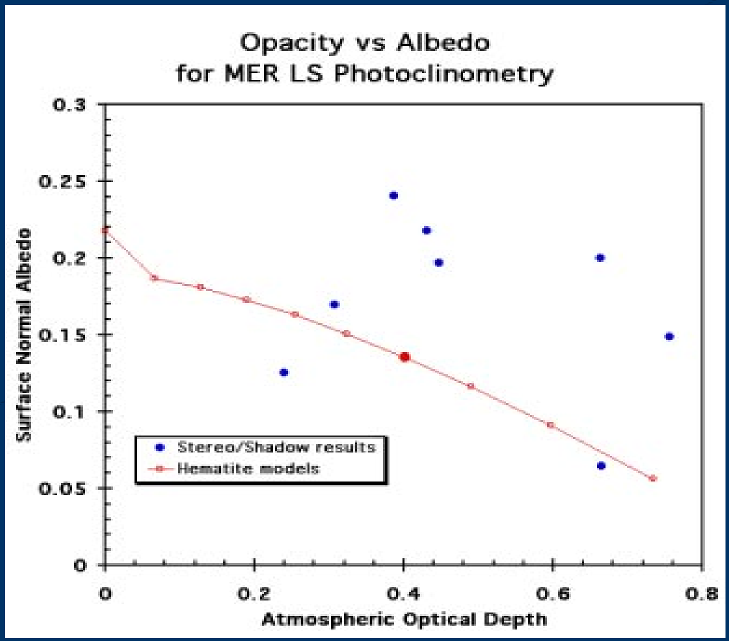


Above: Atha 1a–c, haze from shadow

Left: Atha 3c–d, haze from stereo fit

Haze Estimation for Hematite





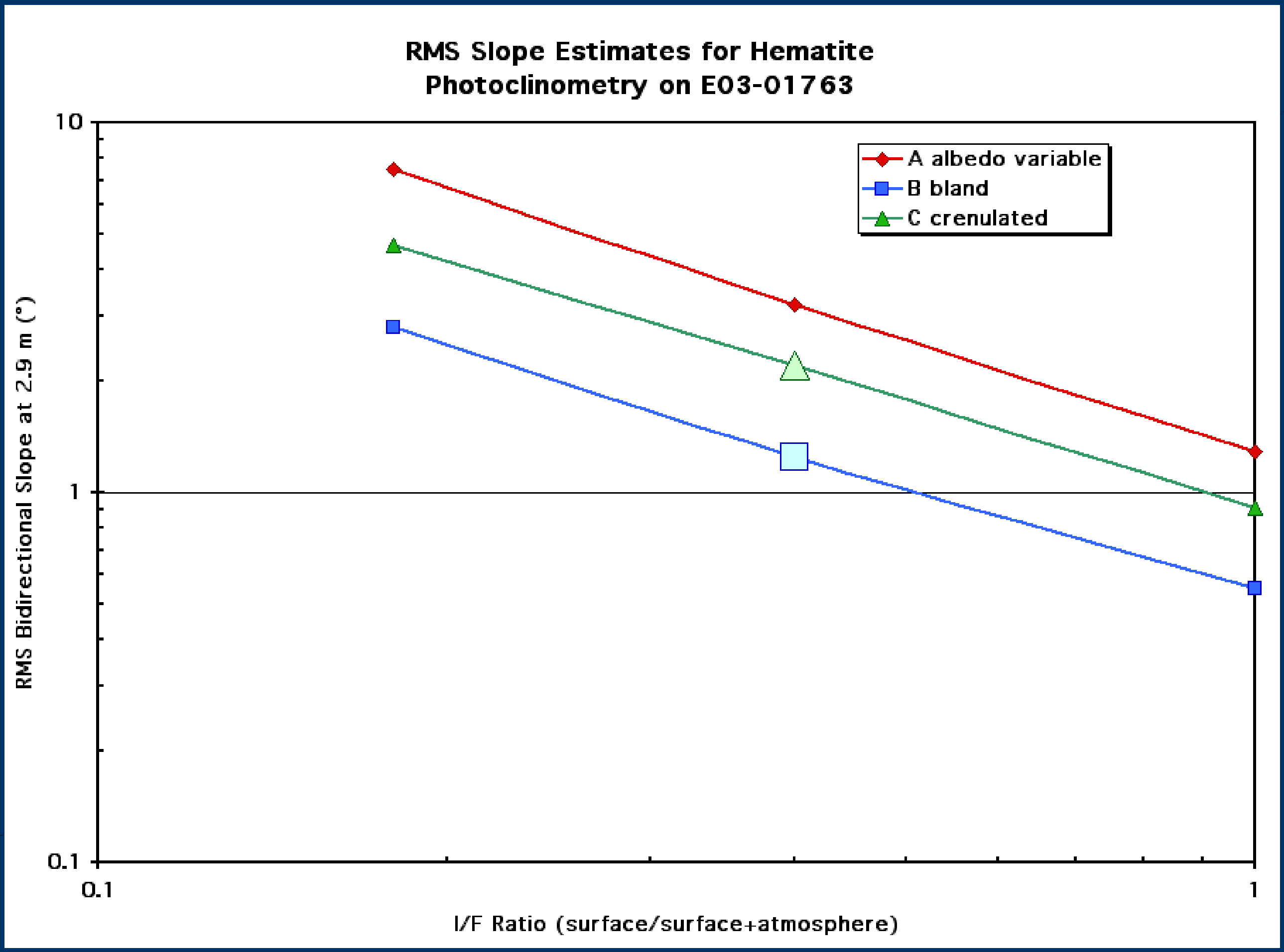
1) Give dunes in E04-01873 same haze-free contrast as Melas dunes

->Haze/Total = 0.6

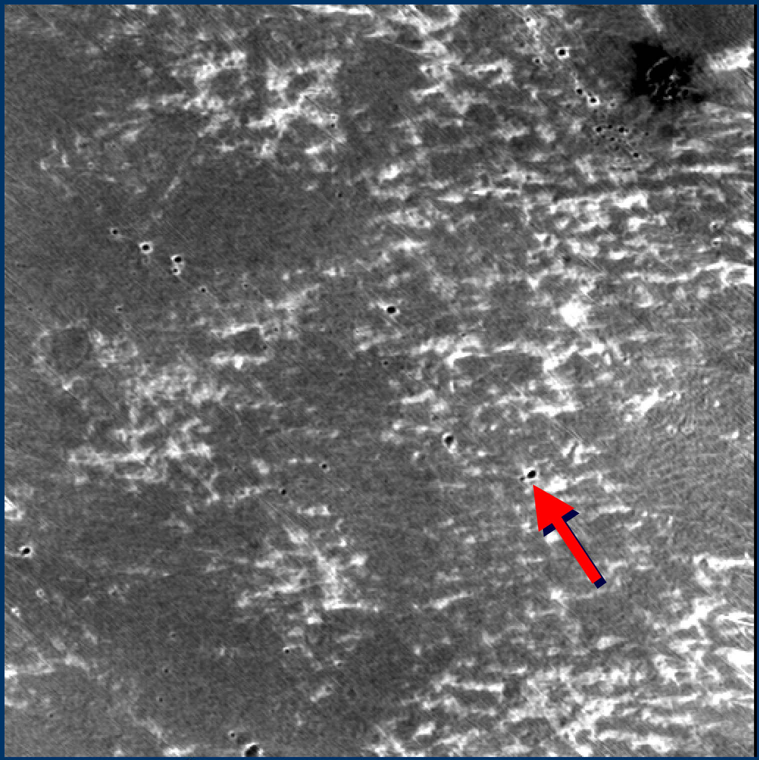
2) Compare site albedos & optical depths using radiative xfer model.

-> “reasonable” tau=0.4, A~0.14

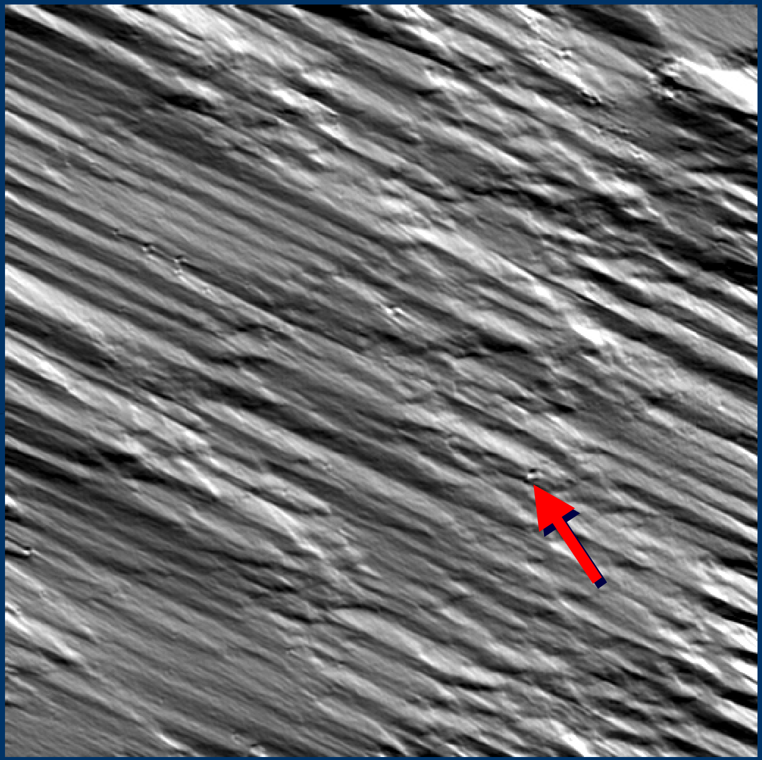
Effect of Haze Estimates on Hematite RMS Slopes



Hematite 2a "Slope"Maps: Effect of Albedo Variations

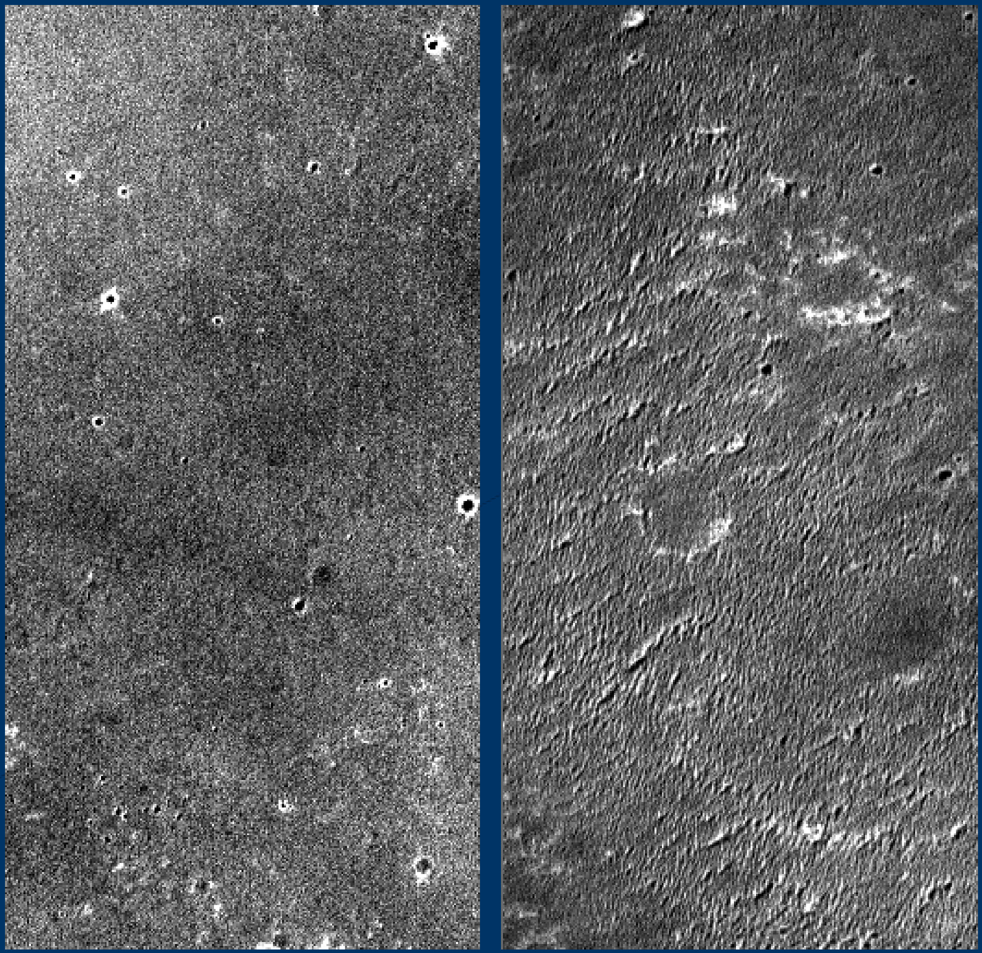


"Slope" in down-sun direction



"Slope" in cross-sun direction

Hematite: Areas 2b–c chosen for minimal albedo variation



Statistical Analysis

- Direct calculation of slopes
  - Adirectional (gradient) or bidirectional (e.g., E-W)
  - Gives shape of entire slope distribution
    - Distributions at all sites are similar and long-tailed: extreme slopes are more common than RMS suggests
  - Limited to single horizontal baseline at a time
- Fourier transform techniques
  - Limited to bidirectional slope
  - Gives RMS slope only, not distribution
  - Quickly gives variation with baseline
    - How do results compare w/other datasets?
    - Are slope-producing features adequately resolved?

Slope Map Example: Gusev 2a Stereo

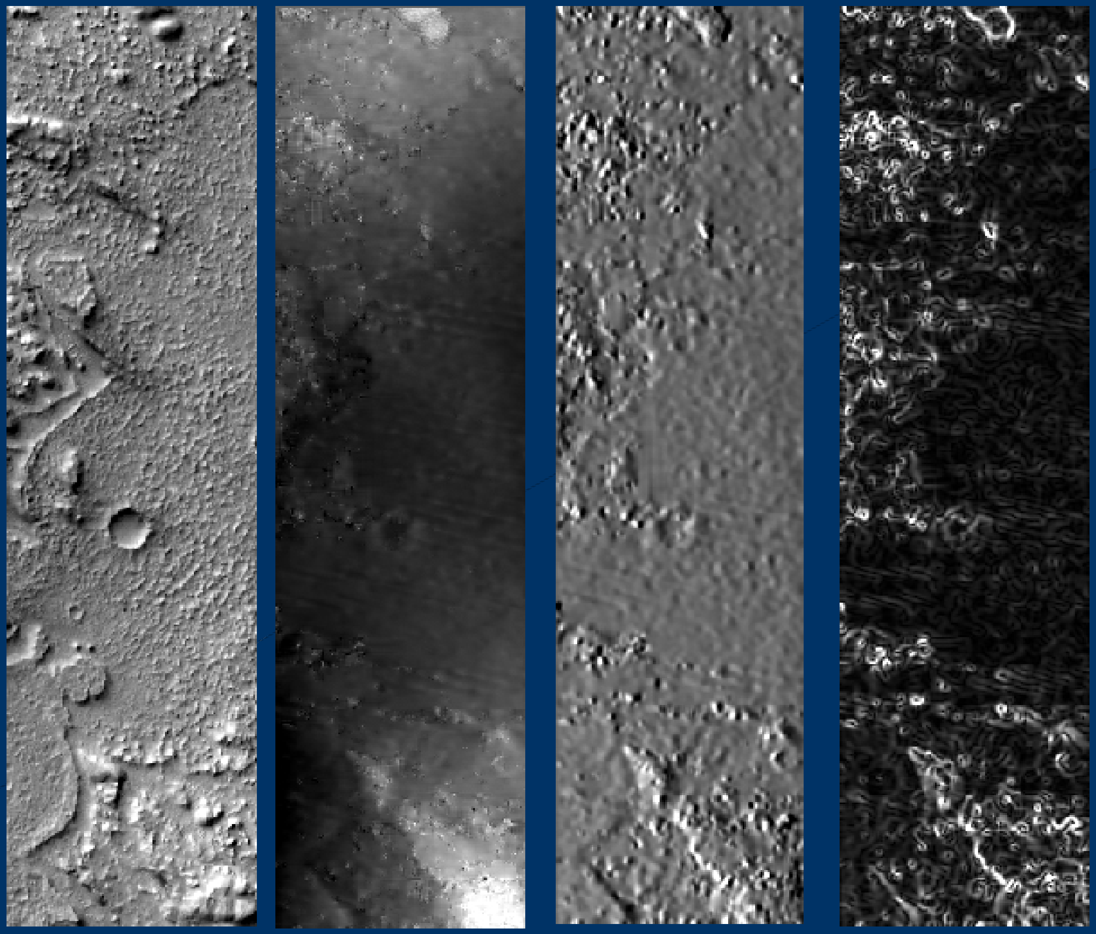
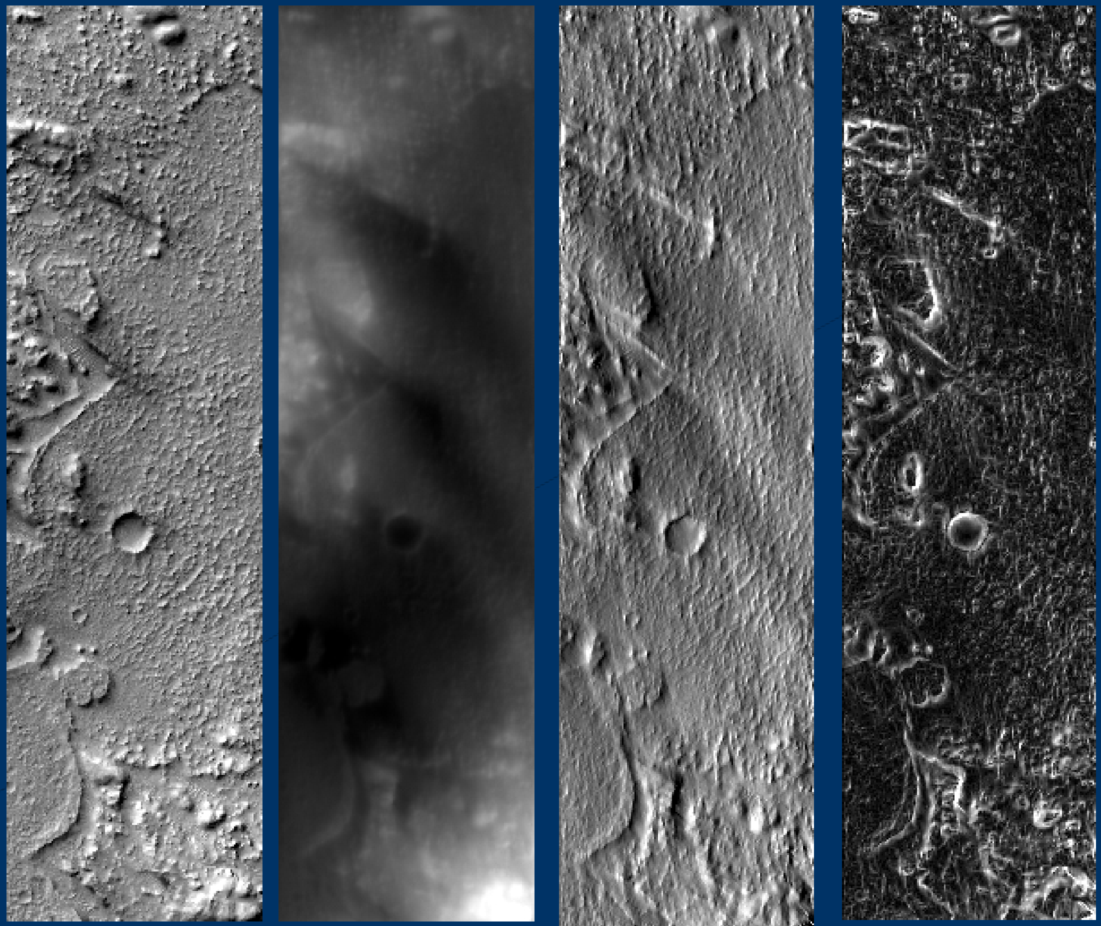


Image DEM Bidir Slope Adir Slope

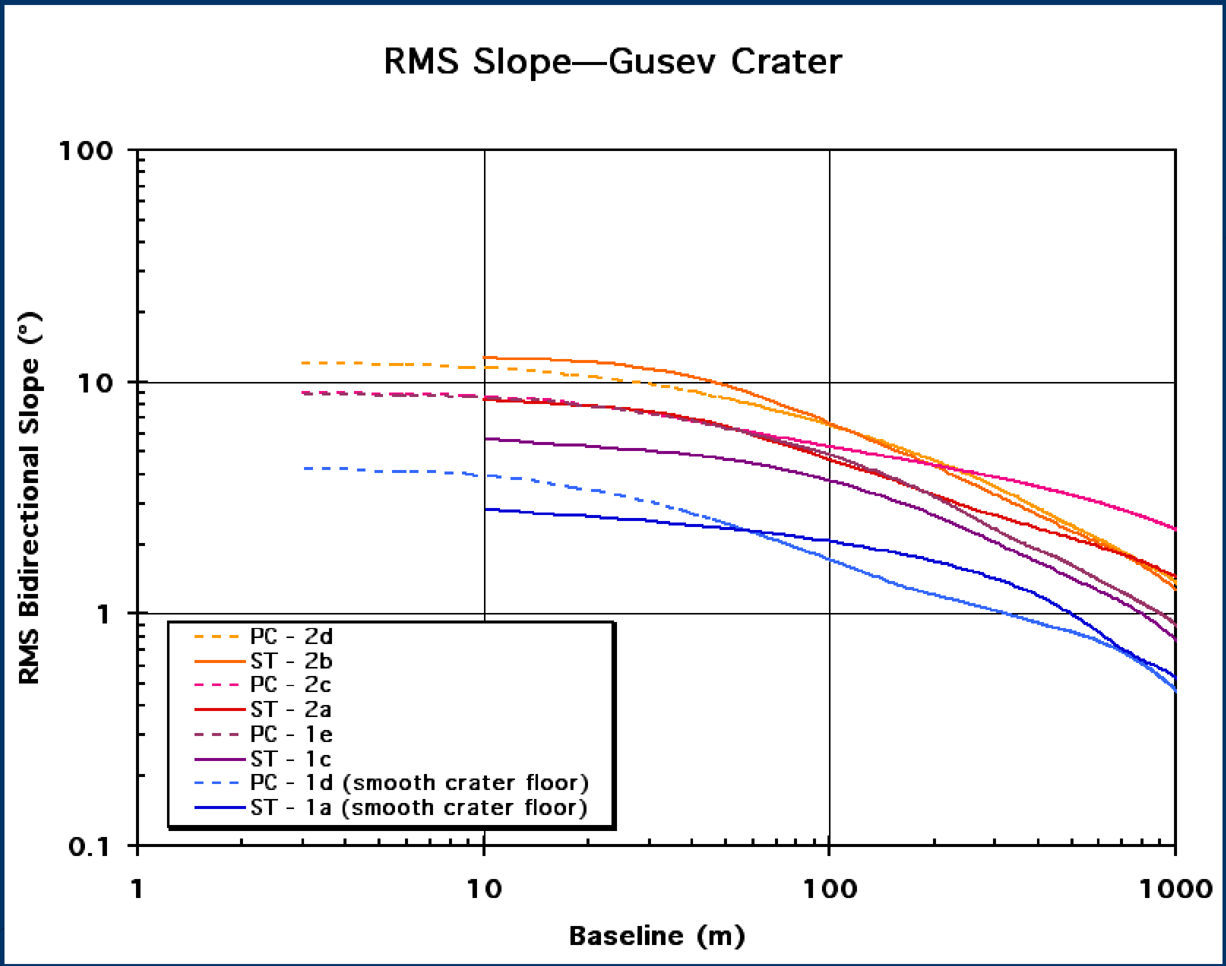
Slope Map Example: Gusev 2c Photoclinometry



Preferred Slope Estimates

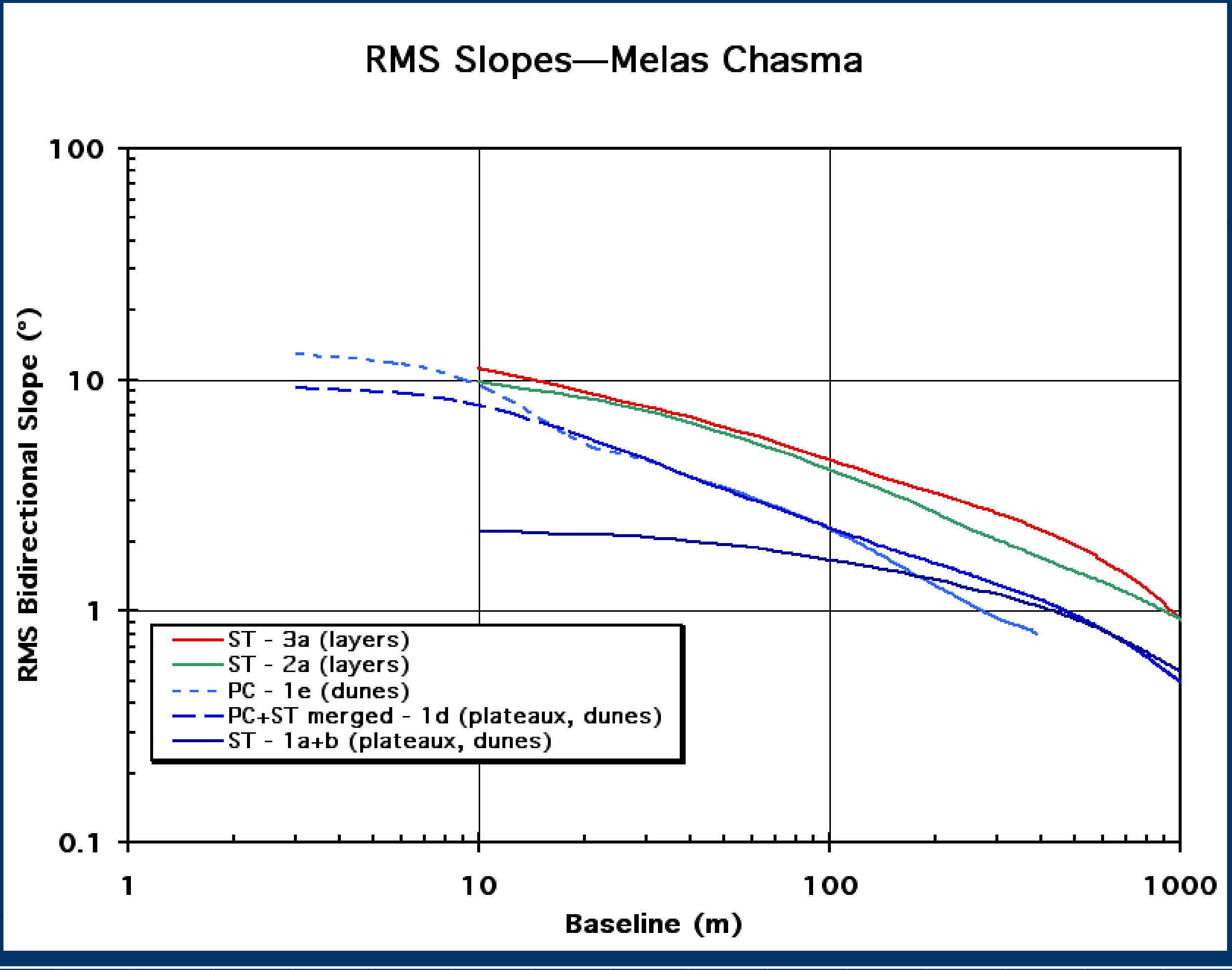
- Prefer stereo when
  - Samples larger, more represantative area
  - PC is compromised by albedo variations
- Prefer PC when
  - Albedo variations not dominant
  - Stereo fails to resolve relief elements
  - Stereo matching/editing errors severe

Slope vs. Baseline 1
Gusev: Highly consistent



- Stereo partly resolves main roughness elements
- Photoclinometry resolves these features better
- Long-base slope estimates are compatible, so photoclinometry results preferred
- Smooth crater floor is atypical, remainder are similar

Slope vs. Baseline 2
Melas: Stereo lacks resolution

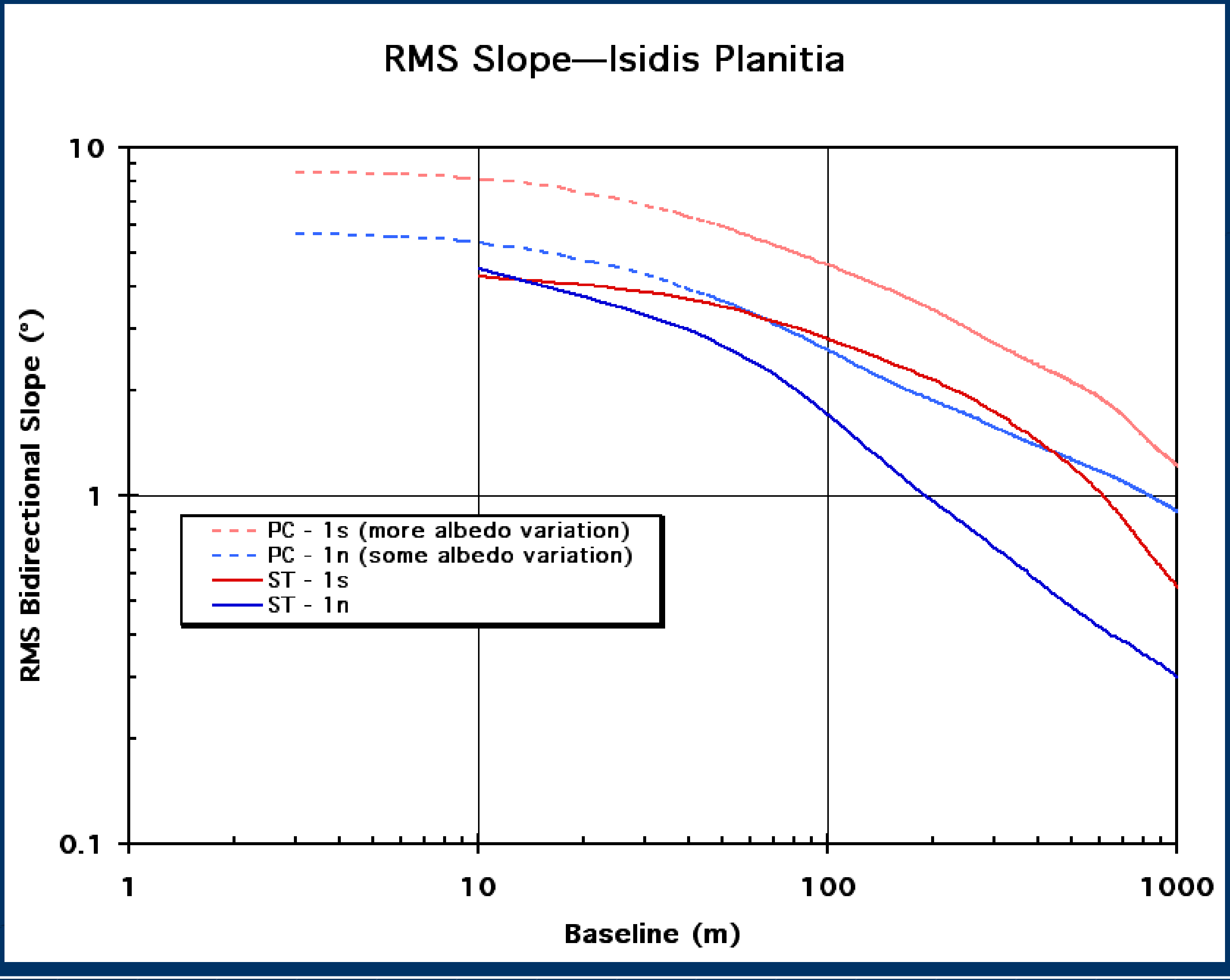


Stereo fails to resolve dunes

Photoclinometry resolves dunes, gives best slope estimates

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

Slope vs. Baseline 3
Isidis: PC affected by albedo

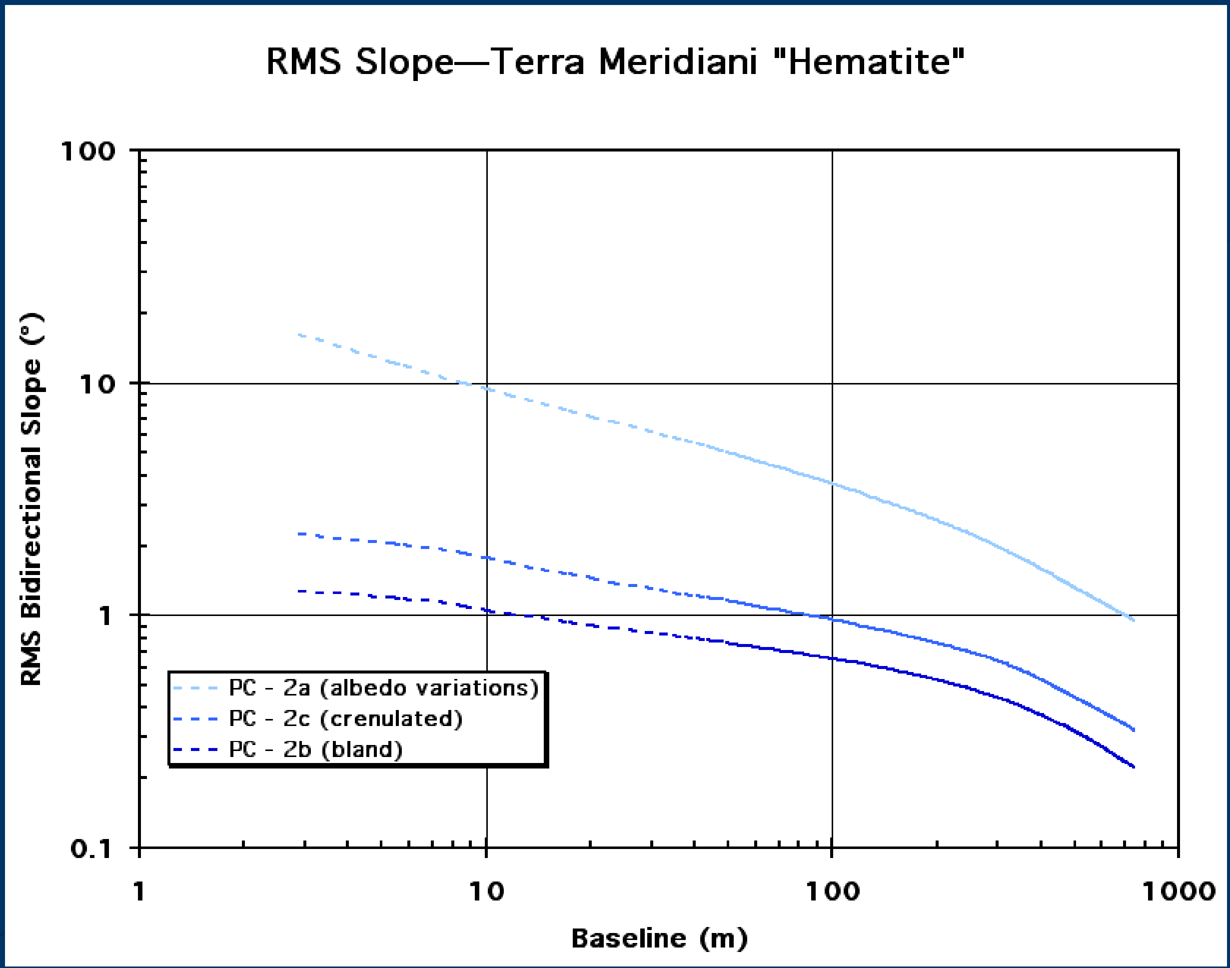


Stereo, photo-clinometry both resolve rough-ness elements

Photoclinometry slopes slightly higher (albedo-related artifacts, sampling effect)

Stereo results preferred

Slope vs. Baseline 4 Hematite: PC affected by albedo

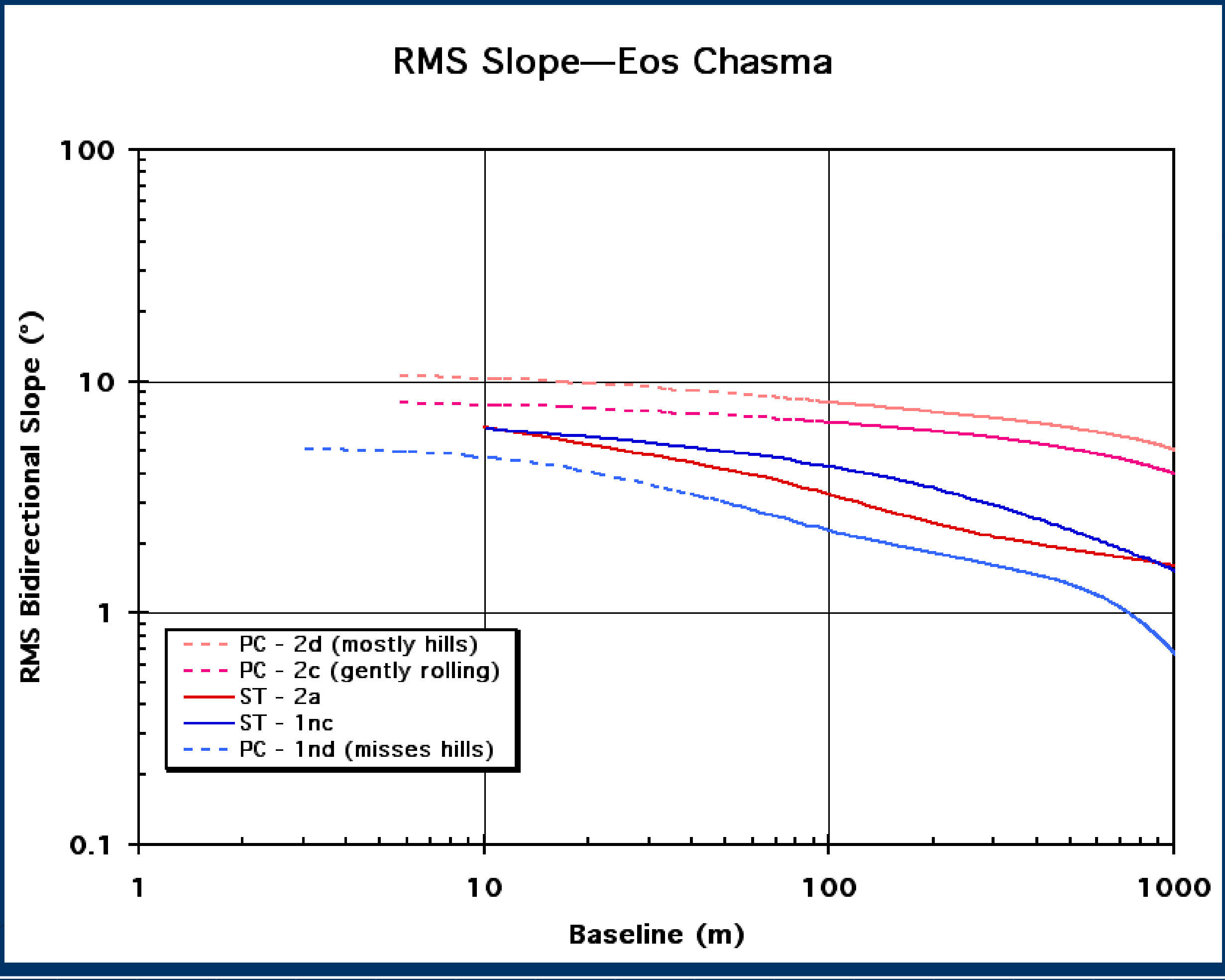


No stereo

Photoclinometry (areas b,c) resolves features

Albedo variations in area a are reflected in base-line dependence as well as apparent greater slopes

Slope vs. Baseline 5
Eos: Sampling effect on PC



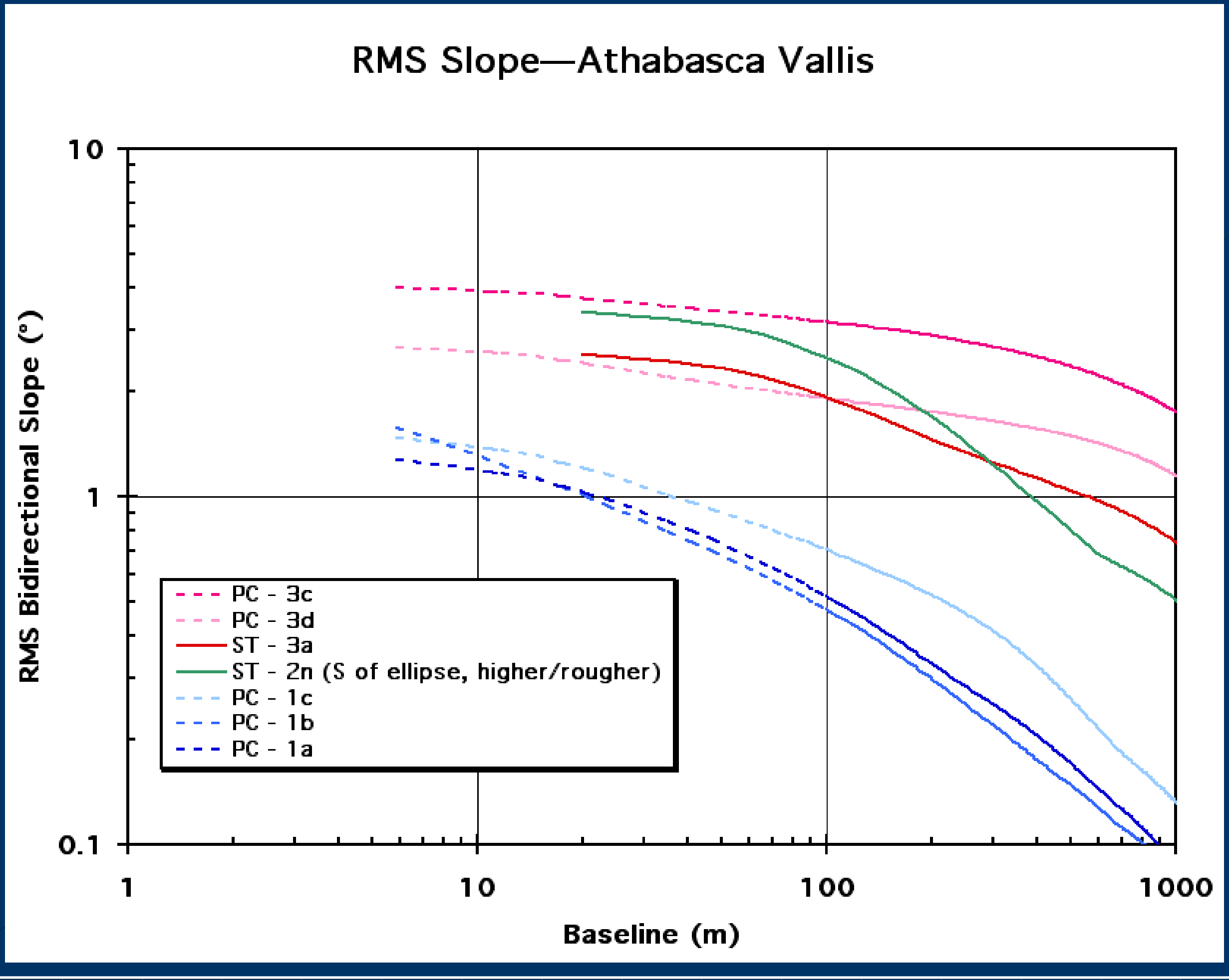
Stereo resolves main roughness elements

Photoclinometry confirms no un-resolved features

Photoclinometry slopes vary, depending on area sampled (amount of hills)

Stereo results preferred

Slope vs. Baseline 6
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

Results

Site	Set	Sub Area	DEM from	Baseline (m)	RMS Bidir Slope (°)	RMS Adir Slope (°)	99% Adir Slope (°)	Correction to 5 m Base	99% Adir Slope@ 5 m	P(Adir≥15°) @ 5 m (%)	Remarks
Athabasca	1	a	PC	5.87	1.26	1.72	5.02	1.020	5.12	0.001	NE of ellipse but similar
		b	PC	5.87	0.94	1.48	3.77	1.057	3.97	0.001	"
		c	PC	5.87	1.25	1.86	4.85	1.019	4.99	0.001	"
Athabasca	2	n	S1	10	3.39	4.72	15.67	1.125	17.64	0.019	S of ellipse, higher standing
Athabasca	3	a	S1	20	2.48	3.45	10.20	1.409	11.64	0.004	
		c	PC	5.87	3.99	5.35	13.79	[illegible]	13.88	0.008	
		[illegible]	[illegible]	5.87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Eos	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		nd	PC	3	5.82	7.07	23.50	0.927	22.95	0.029	PC area misses hills
Eos	2	a	S1	10	6.05	7.97	25.26	1.189	30.03	0.087	
		c	PC	2.87	8.10	9.61	28.20	[illegible]	28.33	[illegible]	
		d	[illegible]	[illegible]	[illegible]	13.82	[illegible]	[illegible]	[illegible]	[illegible]	PC [illegible] ted by hills
Gusev	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] of small crater
		c	S1	10	5.63	8.20	24.95	1.066	26.61	0.078	Knobby S of small crater
		d	PC	3	4.20	5.23	15.31	0.982	15.03	0.010	Smooth interior of small crater
		e	[illegible]	3	9.35	[illegible]	22.30	0.990	[illegible]	0.163	[illegible] small crater
Gusev	2	a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] to 1c/e
		b	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		c	PC	3	9.00	11.65	30.80	0.989	30.45	0.166	
		d	PC	3	12.23	15.92	42.99	0.985	52.36	0.299	
Hematite	2	a	PC	2.9	4.89	9.45	24.38	0.791	19.29	0.037	Albedo variations, not slopes
		b	PC	2.9	1.25	1.82	4.94	0.946	4.68	0.001	Bland area, typical
		c	PC	2.9	2.21	3.38	9.46	0.933	8.83	0.001	Exposed rougher area
Isidis	1	nb	S1	10	4.66	6.39	25.60	1.202	30.78	0.037	
		nc	PC	3	5.70	7.45	22.32	0.983	21.93	0.027	
		sa	S1	10	4.12	5.80	20.08	1.058	21.24	0.027	
		sb	PC	3	8.49	10.78	31.18	0.987	30.78	0.121	
Melas	1	a	S1	10	2.72	4.86	14.34	1.000	14.34	0.008	Does not resolve dunes
		b	S1	10	1.56	2.66	7.74	1.000	7.74	0.001	"
		c	S1	10	2.43	4.11	12.61	1.000	12.61	0.004	"
		e	PC	3	13.19	15.85	41.37	0.923	38.17	0.289	Dunes resolved!
Melas	2	a	S1	10	9.96	12.89	43.42	1.187	51.52	0.233	Layers
Melas	3	a	S1	10	11.37	14.37	53.80	1.273	68.49	0.274	"

See spreadsheet for readable version of this table, other tables, and a variety of plots

Digestible (?) Results