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

Randolph Kirk
USGS Astrogeology Team
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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 & morphologic 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

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<th>WS3</th>
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Photoclinometry & Stereo
Methodologies Compared

**Photoclinometry**
- Single image
- Horizontal res 1 pixel
- Measure, \( \int \text{slopes} \)
  - 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 \( \geq 3\) 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 with ~0.2 matching errors
  - New data at landing point shows slope-baseline consistent with IMP results, etc.
USGS-MS$^3$ DEM Comparison

![Stereopair Image](image-url)
USGS-JPL DEM Comparison

Melas
USGS / JPL

Stereopair:
e02-00270
e05-01626

Color Legend
DTM
-413 - 4150
-4149 - 4140
-4139 - 4130
-4129 - 4116
-4115 - 4030
-4085 - 4056
-4055 - 4046
-4045 - 4036
-4035 - 4021
-4020 - 4002
-4001 - 3823
-3802 - 3758
-3887 - 3725
3819 - 3725

Planetographic

Color Legend Difference
-43 - 39
-36 - 32
-31 - 25
-24 - 18
-17 - 11
-10 - 4
-3 - 3
4 - 10
11 - 17
18 - 24
25 - 202
MPF 1: SP125603/SP123703
MPF 2: M1102414/E0402227
MPF 1-MPF 2 Comparison

**MPF1/MPF2 Comparison at Big Crater**

10 meters/pixel

**MPF1 Raw Stereo DEM**

**MPF1 - MPF2 Raw Stereo**

**MPF1 - MPF2 Corrected Stereo**

**MPF1 - MPF2 High Pass Filters**

**Planetographic**

Km

MPF1 Stereopair: sp123703/sp125603
MPF2 Stereopair: e0402227/m1102414
Comparison with Other Data

Mars Pathfinder Landing Site: RMS Slope vs. Baseline

- VO Stereo
- V/O Photoclinometry
- MOC Stereo—SW of Big Crater
- MOC Stereo—Landing Site
- IMP Stereo near field

RMS Bidirectional Slope (°)

Baseline (m)
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

Highpass
@ 16 pix

Lowpass
@ 16 pixels

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  RMS 2.14 (0.03) m  RMS 0.20 (0.04) m

exag 50  exag 50  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

Stereopair:
m0301042
e1701547

-2168 - 2132
-2131 - 2092
-2091 - 2052
-2051 - 2012
-2011 - 1987
-1986 - 1976
-1975 - 1964
-1963 - 1952
-1951 - 1940
-1939 - 1927
-1926 - 1912
-1911 - 1895
-1894 - 1875
-1874 - 1754

1 0 1 Km

Planetographic

MER LS Workshop 01/09/03  Kirk—MER LS Roughness from MOC
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 morphologic 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

Typical smooth plains

±15% ±50 m

±15% ±50 m
Hematite 4: E12-03255/E18-00595

[Image of a map showing different color-coded areas with a scale in kilometers and planetographic orientation]
Hematite 5:
E15-00023/E21-01653
Slope vs. Baseline at Hematite: Finally, an answer (It’s smooth!)

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

Consistent with previous PC slopes (uncontrolled) in areas without severe albedo variations.

Consistent with upper limit ~1° for failed stereo in area 3.
Isidis 2: E13-00965/E14-01522

Stereopair:
e1300965
e1401522

-3823 - 3817
-3816 - 3811
-3810 - 3804
-3803 - 3798
-3797 - 3791
-3790 - 3785
-3784 - 3778
-3777 - 3772
-3771 - 3766
-3765 - 3759
-3758 - 3753
-3752 - 3746
-3745 - 3740
-3739 - 3733

1 0 1 Km

Planetographic
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
Gusev 1: E02-00665/E02-01453
Gusev 2: E02-00341/E05-00471
Isidis 1: E02-02016/E02-01301
Athabasca 3: M07-00614/E05-00197
Slope vs. Baseline at Athabasca: Complicated

Stereo resolves main roughness elements

Photoclinometry confirms no unresolved 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
Slope vs. Baseline at Eos: Sampling effect on PC

Stereo resolves main roughness elements

Photoclinometry confirms no unresolved features

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

Stereo results preferred
Eos 2: E04-02155/E11-02980

MER LS Workshop 01/09/03
Kirk—MER LS Roughness from MOC
Melas 2: M08-04367/E09-02618
Melas 3: M04-00361/E12-00720

[Diagram showing topographical maps and color-coded elevation data for Melas 3 region]
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