Optical Depth retrievals from and atmospheric correction of HRSC stereo images of Gusev crater: validation by comparing with Spirit’s ground truth

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1. Retrieval of atmospheric optical depths with the **stereo method** from HRSC stereo images

2. Atmospheric correction
   - Observations from orbit 24 (Jan 16 2004)
   - Comparison with Spirit’s ground truth
DLR’s HRSC Stereo Camera

Filters: 5 panchromatic and 4 color

- **Nadir**: 675 (+- 90) nm
- **Outer stereo (2)**: 675 (+- 90) nm
- Inner stereo (2): 675 (+- 90) nm
- Blue: 440 (+- 45) nm
- Green: 530 (+- 45) nm
- Red: 750 (+- 20) nm
- Near Infrared: 970 (+- 45) nm

Radiometric resolution: 8 bit
Active pixels per sensor: 5184
Operational lifetime: >4 years
Typical operations duration: 4-30 min
Stereo angles [degrees]: -18.9, -12.6, 0, +12.6, +18.9
Pixel on the ground: 12 x 12 m^2 at 300 km altitude
Swath width on the ground: 11.9 degrees or 62.2 km at 300 km
SNR: blue >40, rest >80, panchrom. >>100
Coverage first Martian year: 50% at 15m/pix panchromatic in nadir
Typical image: 62 x 330 km^2
Stereo method in theory (I)

- HRSC takes images in 3 or 5 angle stereo
- Contrast differences between the images tell about atmospheric optical depths

\[ I = B * e^{-\tau/\mu} + A \]

Usually contrast in \( A \) is small

\[ \text{contrast}(I) \approx e^{-\tau/\mu} \text{contrast}(B) \]

\( I \): observed image
\( B \): image of surface before atmospheric extinction
\( \mu \): cos of observation angle
\( A \): aerosol contribution
Stereo method in theory (II)

\[
\begin{align*}
\text{contrast}(I_1) & \approx e^{-\tau/\mu_1} \ast \text{contrast}(B_1) \\
\text{contrast}(I_2) & \approx e^{-\tau/\mu_2} \ast \text{contrast}(B_2)
\end{align*}
\]

If \(\text{contrast}(B_1) \approx \text{contrast}(B_2)\) then

\[
\tau \approx \frac{\mu_1 \mu_2}{\mu_1 - \mu_2} \ast \ln\left(\frac{\text{contrast}(I_1)}{\text{contrast}(I_2)}\right)
\]

Default nadir pointing: \[
\frac{\mu_1 \mu_2}{\mu_1 - \mu_2} \approx 17.6
\]

Factor is determined by 18.9° stereo angles

In these images HRSC is looking sideways by 14—32°

\(\Rightarrow\) here the factor varies between 12 and 14
Theory versus reality

Usually \( \text{contrast}(B1) \neq \text{contrast}(B2) \) since hills and holes, and especially shadows look different from different viewing angles. I.e., perspective has a big impact on errors

1) Measure contrasts from images in which perspective effects are as small as possible… ➔
   Fit images onto Digital Terrain Model ➔
   ortho-images

2) …in way that is not too sensitive on such perspective effects ➔
   Use difference between brightest and darkest pixels to quantify contrasts
Same as previous, but contrast is sharply enhanced

Apollinaris Patera

Cloudy Northern Plains

Dusty Northern Plains

Going North further: very flat at elevation $<-3$ km; $\tau >3$ everywhere

Dusty Northern Plains

PLEASE TAKE A LOOK AT OUR POSTER FOR OUR ANALYSES OF THESE REGIONS
Validate the stereo method with Spirit’s ground truth

Geometry of observations is quite favorable

- Very flat region
- Rich in contrast due to dark patches on crater floor
- Camera is looking sideways ➔ larger difference between optical paths of ‘nadir channel’ and stereo channels than with default nadir pointing
- Solar illumination almost perpendicular to the flight direction ➔ not much change in phase angles between the channels
Reduce spatial resolution to improve intensity resolution

- Original pixels --- roughly 20—40 meter/pixel
  - The stereo method does not need such high spatial resolution
  - On the other hand, only 30—40 intensity bins are used
  - Very crude intensity distribution, not good for stereo method
- We used pixels rebinned at 200 meter/pixel
  - These have less spatial, but better intensity resolution
In and around Gusev

- Gusev, stereo method: $0.91 \pm 0.04$
- Gusev, Spirit’s ‘ground truth’: $0.87—0.89$
- Very good result for the floor of Gusev crater

- However, optical depth depends on altitude!
- Large variations in altitude within an analyzed area often prohibit proper retrieval
- Use so called ‘Normalized Cumulative Intensity Distributions’ (=NCID s) to judge the quality of the retrieval
- Best if curves for S1 and S2 are nearly identical

Shading: 500 m per step

In area 9: long strip with altitude differences $>2$ km gives $\tau < 0$
Atmospheric correction

• What is atmospheric correction? ➔
  – Make images that show Mars as it would look without its atmosphere

• Simplistic correction: multiply contrasts with $e^{\tau/\mu}$
  – Rather inaccurate, since the atmosphere can change the average brightness of the scene
Model I/F at the Top of Atmosphere with SHDOM

Surface: Lambert
Atmosphere: only dust
dust scattering properties: from IMP
Radiative transfer model: SHDOM

Geometry:
observation of Gusev

Atmospheric effect:
• Bright regions (albedo $\geq 0.22$) become darker
• Dark regions (albedo $\leq 0.22$) become brighter

\[ i = 25.34 \]
\[ e = 31.68 \]
\[ g = 51.96 \]
Example of Atmospheric Correction:
(Lambert approximation)

Gusev $\tau = 0.89$
Result, histogram

Corrected image:

- Dark surface has Albedo 0.2
- Bright surface has Albedo 0.3
- Good agreement with ground truth by Spirit
Corrected Color Image

Original RGB color

Corrected RGB color
What makes the atmospheric Correction difficult?

Not well known for Martian aerosols:

- Phase function
- Single scattering albedo
- The shape of dust particles, but we do know that they are not spherical
- The vertical distribution of aerosols

![Phase functions of various types of Aerosols](image)

reff = 1.6 mm Observation vs. Mie calculation of spherical particles
Summary

STEREO METHOD
• Careful consideration of topography is crucial
• For most flat regions the stereo method works,
  – If...there is enough contrast
• Check input carefully, use NCIDs to judge usability of regions

ATMOSPHERIC CORRECTION
• Atmospheric correction is performed with
  – Lambertian surface
  – Dust scattering properties from IMP data
• Martian atmosphere brightens or darkens the surface
• Improvements of atmospheric correction
  – Vertical distribution of aerosols
  – Scattering properties of non-sphere dust particles
  – More realistic surface reflectance model
Abstract:
A primary task for the Mars Express orbiter is to map Mars in high-resolution and in stereo with its High Resolution Stereo Camera (HRSC). The Martian atmosphere contains variable amounts of aerosols that scatter light and influence the images. For many applications, analysis of HRSC images requires atmospheric correction. Minimum required inputs for such a correction are the optical depth of the atmosphere and the single scattering properties of the aerosols.

Optical depths can be retrieved from stereo-images with the so-called 'stereo-method'. This method estimates optical depths by analyzing how contrasts differ between stereo images. Software for using the stereo-method has been developed at the Max-Planck-Institute for Solar System Studies (MPS) in Katlenburg-Lindau, Germany. The method uses map-projected ortho-stereo-images and complementary data on the imaging geometry from photogrammetric software developed at DLR. Once an optical depth is known, and a phase function is chosen, we can correct for atmospheric effects with other programs developed at MPS, such a MPAE_ATM_DUST.

For validation, we compared optical depths retrieved from HRSC stereo images of Gusev crater taken on January 16.04 with in-situ measurements by Spirit, the rover that landed in this crater. That day Spirit measured the local optical depth at 0.87-0.89 by looking up at the Sun. From HRSC images, we estimated 0.86 ± 0.08 for a small region around the landing site, and 0.91 ± 0.04 for the full crater. Both values are in good agreement with Spirit's ground truth. Spirit landed in a region that displays considerable contrast, which improves the accuracy of the retrieval considerably. In addition, very careful consideration of topography proves crucial since the retrieved optical depths, and especially their errors, depend very strongly on altitude variations within the analyzed field.

We calculated a corrected image of a region around the landing site, using an optical depth of 0.89 and an aerosol phase function as derived from Mars Pathfinder data. We find reasonably good agreement with local measurements from Spirit.
Aerosols, do they brighten or darken the view? (I)

Meridiani, 360° view. JPEG image is **not** calibrated.

Towards the Sun scene brightens with distance. Other directions little or no impact ➔ strong forward scattering.

How much? Educated guess: up-to 3--5%?
I’ll do this properly once I have calibrated images.

Horizon: 5—6 km?
τ↓≈0.7 ➔ 0 < τ→ < ~0.5