Seeing Through the Haze – removing effects of the atmosphere to improve geospatial data products

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Introduction

• For many geospatial applications, the reflectance property of materials on the ground is needed to produce data products

  • Material reflectance spectra are often characteristic and unique in one or more spectral regions.

  • The radiance signal observed at a sensor contains reflectance, modulated and offset by spectrally varying atmospheric contributions.

• Atmospheric effects vary spatially and temporally, distorting sensor data

• Atmospheric correction tackles these effects to retrieve material reflectance
What Atmospheric Effects?

- Transmission (gaseous absorption)
- Atmospheric scatter
  - Rayleigh – blue sky
  - Aerosols – haze, dust, pollution
- Adjacency – earth reflected scatter
- Clouds – shadows and reflected scatter
- Thermal emission and absorption (LWIR)
- Turbulence – not covered here
  - very high spatial resolution and long range
  - laser ranging and imaging

Radiance at sensor for two aerosol conditions
Sensor sees: $\rho \ast \text{direct solar} + \text{adjacent reflected} + \text{aerosol scatter} + \rho \ast \text{skyshine}$

**Goal** – surface reflectance, $\rho$
Sensor sees: adjacent reflected + aerosol scatter + $\rho \times$ skyshine

Vis/SWIR Sensor

adjacent reflected solar radiance

reflected skyshine

Goal – surface reflectance, $\rho$
Sensor sees: adjacent reflected + aerosol scatter + $\rho \times$ skyshine

Goal – surface reflectance, $\rho$
<table>
<thead>
<tr>
<th>Method</th>
<th>Software</th>
<th>Use When:</th>
<th>Limitations</th>
<th>Alternatives</th>
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<tbody>
<tr>
<td>Empirical</td>
<td>ELM</td>
<td>Well calibrated targets are available on the ground</td>
<td>Targets with known absolute spectral characteristics</td>
<td>Compare to previously corrected data</td>
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<tr>
<td>In-Scene</td>
<td>QUAC®*</td>
<td>Data calibration is questionable. Visible through SWIR, HSI/MSI/RGB</td>
<td>Works best with some variability in spectral data</td>
<td></td>
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<tr>
<td>Model Assisted</td>
<td>FLAASH®*</td>
<td>Most accurate correction is needed Visible through SWIR, HSI/MSI</td>
<td>Works best with well-calibrated data. Requires metadata.</td>
<td>ATCOR, ATREM, ACORN</td>
</tr>
<tr>
<td>Thermal HSI</td>
<td>FLAASH-IR</td>
<td>Long-Wave IR, retrieve reflectance and surface temperature</td>
<td>Works best with well calibrated data.</td>
<td>ISAC (limits on data and retrieval)</td>
</tr>
</tbody>
</table>

*Components of ENVI Atmospheric Correction Module*
Atmospheric Correction can Enhance Most Types of Spectral Imagery

- **Sensors**
  - Vis/SWIR solar HSI (200-300 bands)
  - Multispectral (RGB plus IR, 4-10 bands)
  - RGB
  - Thermal HSI

- **Platforms**
  - Satellite
  - Clouds below
    - Often seeking sub-pixel sized objects
  - Aircraft (typically 3000 to 20000 meters AGL)
    - Clouds above and below
  - Small UAVs (100-1000 meters AGL)
    - Clouds above
    - Very high spatial resolution
Correction for Non-Uniform Haze

QUAC offset parameter is derived from scene tiles
Correction for Cloud Shadow

- Shadows affect spectral radiance below and at boundaries.
- Partitioning of clear and shaded regions improves detection of materials in shaded regions.

**RIT Target Detection Self-Test Reflectance Scene**

**QUAC applied uniformly**

**QUAC partitioned**
Application to Change Detection

- Crop seasonal growth
- Comparison in different weather conditions benefits from atmosphere correction

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QUAC adjusts for illumination differences of clear vs. overcast sky.
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- Ground cover
  - strawberry leaf
  - soil

MicaSense RedEdge MSI from a UAV
Correction for Large Scale Mosaic Mapping

- Satellite Data (cloudless)
- Digital Elevation Map
- QUAC Atmospheric Correction
- Mosaic
- Color Match Algorithm
- Landsat Radiance Images
- Processed Scene
- ENVISymposium
Mosaic Map Result

- ~60 Landsat image mosaic
- 10º long x 10º latitude
- 1 arcsecond resolution
- No visible edges or color variation

Crops & Manmade Features

Natural Geologic Features

1080 km, 36,000 pixels
Application to Machine Learning

- Machine Learning can automate spectral classification, sub-pixel detection and change detection of geospatial data
- Larger training datasets will be needed to train against atmospheric variability
- Atmospheric correction to reflectance reduces dimensionality of training sets and test data

Value for Sensor Calibration

• Field calibration of instruments in flight
  • Temperature & humidity changes, and rough conditions can slightly alter instrument alignment

• ELM method works well if calibrated targets are available

• Vicarious calibration – using the materials you’ve got
  • Apply FLAASH correction using local weather conditions
  • Compare to previous atmospherically corrected data of same location (LANDSAT, Sentinel)

Planet Labs Dove images of San Francisco with overlapping coverage. At left, 11/7/2015; at right, 11/11/2015; the bottom images magnify an area near the airport.
A Long Wave Infrared Sensor (LWIR Sensor) sees the following:

\[ t \left( 1 - \rho \right) B(T) + t \rho \times \text{downwelling sky emission} + \text{upwelling sky emission} \]

Where:
- \( t \) is the atmospheric transmission,
- \( B(T) \) is the blackbody radiance at temperature \( T \),
- \( \rho \) is the surface emittance,
- \( B(T) \) is the blackbody radiance at temperature \( T \),

The goal is to have the surface emittance \( \rho \) equal to 1.

For different temperatures:
- \( T = 315K \)
- \( T = 298K \)

The chart shows Blackbody Radiance vs. wavelength (microns) for different temperatures.
Thermal HSI for Surface Material Classification

- FLAASH-IR corrected reflectance spectra compare favorably to mineral library
- Automated HSI classification using SMACC
- Mineral abundances compare favorably to independently obtained classification
- Applied to TEOLOPS, ITRES and SPECIM thermal HSI

Mineral Classification Map: Quartz, Alunite, Calcite

RGB false color SEBASS HSI: 9um, 10um, 11um
Summary

• Atmosphere effects result in increased data complexity that will likely increase computational load

• Atmospheric correction improves spectral data products by retrieving characteristic material properties
  • RGB to HSI
  • Vis/SWIR to Thermal IR

• Spatially and temporally variable effects like aerosols and shadows can benefit from advanced correction techniques

• Growing availability of continuous, daily, data collection could be used to enhanced correction opportunities and improve data analytics.
SSI’s Atmospheric Correction Team

• Dr. Larry Bernstein – Principal Developer of QUAC
• Dr. Steven Adler-Golden – Principal Developer of FLAASH and FLAASH-IR
• Dr. Lex Berk – Principal Developer of MODTRAN
• Mr. Timothy Perkins – Architecture and Programming of SSI ACC tools
• Dr Robert Sundberg – Atmospheric correction for world map mosaics

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