Atmospheric Correction Prototype Algorithm for High Spatial Resolution Multispectral Earth Observing Imaging Systems

Mary Pagnutti
Science Systems and Applications, Inc.
John C. Stennis Space Center, MS 39529
phone: 228-688-2135
e-mail: mary.pagnutti@ssc.nasa.gov

High Spatial Resolution Commercial Imagery Workshop
Reston, Virginia, USA
November 10, 2004
Contributors

NASA Applied Sciences Directorate, SSC
Tom Stanley            Vicki Zanoni

Science Systems and Applications, Inc.
Slawomir Blonski        Kara Holekamp
Kelly Knowlton          Don Prados
Jeff Russell            Robert Ryan

Lockheed Martin Space Operations
David Carver            Jerry Gasser
Randy Greer             Wes Tabor

This work was directed by the NASA Applied Sciences Directorate (formerly the Earth Science Applications Directorate) at the John C. Stennis Space Center, Mississippi. Participation in this work by Lockheed Martin Space Operations – Stennis Programs was supported under contract number NAS 13-650. Participation in this work by Computer Sciences Corporation and by Science Systems and Applications, Inc., was supported under NASA Task Order NNS04AB54T.

November 10, 2004
Overview

- **Objective**
  - Evaluate accuracy of a prototype algorithm that uses satellite-derived atmospheric products to generate scene reflectance maps for high spatial resolution (HSR) systems

- **Approach**
  - Implement algorithm in an end-to-end process
  - Compare algorithm generated scene reflectance maps with ground-truth data
  - Identify algorithm sensitivities
  - Provide recommendations

- **Constraints**
  - Ground truth available only in VNIR spectral range
Atmospheric Correction

- Atmospheric correction is the process of converting satellite signals (at-sensor radiance) to ground reflectances
  - Removes atmospheric and solar illumination effects
- Benefits
  - Improves change detection
  - Used with spectral library based classifiers
  - Simplifies satellite data intercomparisons
- Different levels of atmospheric correction yield different approximations of scene reflectance
  - Planetary reflectance – no knowledge of atmosphere
  - Ground reflectance using knowledge of atmosphere
  - Ground reflectance using knowledge of atmosphere and adjacency effects

November 10, 2004
Planetary Reflectance

First-order approximation – no knowledge of atmosphere

\[ L_{TOA} = \frac{\rho_p E_{sun} \cos \theta}{\pi d^2} \]

Where:
\( \rho_p \) = Planetary reflectance
\( L_{TOA} \) = Top of atmosphere (at-sensor) radiance
\( \theta \) = Solar zenith angle
\( E_{sun} \) = Solar exoatmospheric irradiance
\( d \) = Sun-Earth distance
Atmospheric Correction Algorithm Implementations

- Use knowledge of atmosphere to determine the constants necessary to convert satellite signals to scene reflectances
  - Ground-based reflectance measurements (direct method)
  - Pseudo-invariant targets
  - Ground-based atmosphere (aerosol) measurements
  - Scene-based aerosol estimates (based on dark pixels)
  - Climatological atmosphere
  - Satellite-based atmospheric measurements

This presentation will focus on preliminary results of only the satellite-based atmospheric correction algorithm. All algorithms will be evaluated in the coming year.

November 10, 2004
Atmospheric Correction Prototype Algorithm

- Leverage JACIE commercial imagery radiometric characterizations
  - IKONOS, QuickBird, OrbView-3 (future)
- Use daily coverage from MODIS to provide input data for atmospheric correction
  - MOD04 Aerosol Optical Thickness
  - MOD05 Total Precipitable Water (Water Vapor)
- Generate MODIS-like products
  - Surface Reflectance (MOD09)
  - Gridded Vegetation Indices – NDVI (MOD13)

November 10, 2004
Atmospheric Correction Approach

MODIS data products
MOD04, MOD05

Radiometrically Corrected Imagery

Spherical Albedo Model

Reflectance Map
NDVI Map

November 10, 2004
MODIS
(Moderate Resolution Imaging Spectroradiometer)

Stennis Space Center

MODIS provides long-term observations from which an enhanced knowledge of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere can be derived.

MISSIONS:
- Terra – Dec 1999
- Aqua – May 2002

HERITAGE:
- AVHRR
- High Resolution Infrared Radiation Sounder (HIRS)
- Landsat TM
- Coastal Zone Color Scanner

PRODUCT SUMMARY:
- Congruent observations of high-priority atmospheric, oceanic, and land-surface features

VITAL FACTS:
- Instrument: Whiskbroom imaging radiometer
- Bands: 36 from 0.4 and 14.5 μm
- Spatial Resolution: 250 m (2), 500 m (5), 1000 m (29)
- Swath: 2,300 km (±55°) from 705 km
- Repeat Time: Global coverage in 1 to 2 days
- Design Life: 6 years

OWNER:
- U.S., NASA

LINKS:
- Sensor Site: http://modis.gsfc.nasa.gov/
- Data Sites: http://daac.gsfc.nasa.gov/ (ocean and atmospheric)  

November 10, 2004
The spherical albedo approach approximates the signal observed by the satellite as the summation of the components illustrated below.

\[ L_{TOA} = L_o + A\rho_{tgt} + A\rho_{tgt}s\rho_{bg} + A\rho_{tgt}s^2\rho_{bg}^2 + \ldots + B\rho_{bg} + B\rho_{bg}s\rho_{bg} + B\rho_{bg}s^2\rho_{bg}^2 + \ldots \]
Atmospheric Correction Approximations

Spherical Albedo formulation simplifies to:

\[ L_{TOA} = L_0 + \frac{A \rho_{tgt}}{1 - s \rho_{bg}} + \frac{B \rho_{bg}}{1 - s \rho_{bg}} \]

Knowledge of atmosphere and adjacency

\[ L_{TOA} = L_0 + \frac{(A + B) \rho_{tgt}}{1 - s \rho_{tgt}} \]

Knowledge of atmosphere

Where:

\( \rho_{tgt} \) = Target reflectance

\( \rho_{bg} \) = Background reflectance

\( L_{TOA} \) = Top of atmosphere (at-sensor) radiance

A, B, s, and \( L_0 \) are constants that depend on atmospheric properties and geometry
Adjacency Effects

- Adjacency effects are caused by complicated multiple scattering in the atmosphere-land surface interactions
  - Dark pixels appear brighter and bright pixels appear darker
  - Significant in turbid atmospheres over highly heterogeneous landscapes

- Different methods have been employed for removing this effect
  - Atmospheric point spread function-PSF (Environmental Function)
  - Empirical formula
Spherical Albedo Benefits

- Commonly used and found throughout the literature
- Allows for analytical determination of target albedo/reflectance values
- Computationally efficient

November 10, 2004
Atmospherically Corrected Imagery

Stennis Space Center

January 15, 2002

includes material © Space Imaging, LLC

November 10, 2004
NDVI from IKONOS Imagery

Includes material © Space Imaging, LLC
NDVI Histogram Comparison

Tarp Site: Stennis Space Center
January 15, 2002
Atmospheric Correction Prototype Algorithm Verification
Scene Selection for Atmospheric Correction Algorithm Verification

- Criteria
  - Available ground-truth reflectance and atmospheric measurements
  - Available radiometric calibration coefficients
  - MODIS overpass close in time to IKONOS/QuickBird overpass
## Selected Scene Matrix

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>HSR Sensor</th>
<th>Sensor Az/EI</th>
<th>Ground Truth</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC, MS</td>
<td>Jan. 15, 2002</td>
<td>IKONOS</td>
<td>113.0 / 77.2 deg</td>
<td>Targets = 3 tarps (3.5, 22, 52), grass, concrete ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, pressure, radiosonde, BRDF</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>IKONOS</td>
<td>100.7 / 81.9 deg</td>
<td>Targets = 3 tarps (3.5, 22, 52), grass, concrete ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, radiosonde, BRDF</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>QuickBird</td>
<td>10.5 / 67.3 deg</td>
<td>Targets = 3 tarps (3.5, 22, 52), grass, concrete ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, radiosonde, BRDF</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>July 20, 2002</td>
<td>QuickBird</td>
<td>349.8 / 64.1 deg</td>
<td>Targets = 2 tarps (3.5, 52), grass ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, radiosonde</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Sept. 7, 2002</td>
<td>QuickBird</td>
<td>191.0 / 74.9 deg</td>
<td>Targets = 2 tarps (3.5, 52), grass ASD FieldSpec FR Spectroradiometer, ASR/MFRSR</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Nov. 14, 2002</td>
<td>QuickBird</td>
<td>274.8 / 79.4 deg</td>
<td>Targets = 3 tarps (3.5, 22, 52), grass, concrete ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, pressure, radiosonde, BRDF</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Aug. 23, 2003</td>
<td>QuickBird</td>
<td>148.3 / 76.8 deg</td>
<td>Targets = grass ASD FieldSpec FR Spectroradiometer, ASR/MFRSR</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Oct. 21, 2003</td>
<td>QuickBird</td>
<td>279.5 / 81.3 deg</td>
<td>Targets = grass ASD FieldSpec FR Spectroradiometer, ASR/MFRSR</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Jan. 10, 2004</td>
<td>QuickBird</td>
<td>230.7 / 89.2 deg</td>
<td>Targets = 4 tarps (3.5, 22, 34, 52), grass, concrete ASD FieldSpec FR Spectroradiometer, ASR/MFRSR, pressure, radiosonde</td>
</tr>
</tbody>
</table>
## Satellite Overpass Times

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>HSR Sensor</th>
<th>HSR Satellite Overpass Time</th>
<th>MODIS Overpass Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC, MS</td>
<td>Jan. 15, 2002</td>
<td>IKONOS</td>
<td>16:44</td>
<td>17:10</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>IKONOS</td>
<td>16:47</td>
<td>16:14</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>QuickBird</td>
<td>16:45</td>
<td>16:14</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>July 20, 2002</td>
<td>QuickBird</td>
<td>17:26</td>
<td>17:42</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Sept. 7, 2002</td>
<td>QuickBird</td>
<td>17:22</td>
<td>16:47</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Nov. 14, 2002</td>
<td>QuickBird</td>
<td>16:44</td>
<td>16:25</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Aug. 23, 2003</td>
<td>QuickBird</td>
<td>17:07</td>
<td>16:57</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Oct. 21, 2003</td>
<td>QuickBird</td>
<td>17:11</td>
<td>18:17</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Jan. 10, 2004</td>
<td>QuickBird</td>
<td>16:30</td>
<td>17:27</td>
</tr>
</tbody>
</table>
Algorithm Validation using NASA/JACIE Generated Ground Truthing Datasets

- Laboratory Measurements
  - ASD FieldSpec FR Spectroradiometer calibrations
  - BRDF laboratory measurements

- Field Measurements
  - Radiometric calibration tarps, grass, and concrete targets
  - In-field calibrated sun photometers
  - In-field setup to check atmospheric model parameters
Calibration and Characterization of ASD FieldSpec Spectroradiometers

- NASA SSC maintains four ASD FieldSpec FR spectroradiometers
  - Laboratory transfer radiometers
  - Ground surface reflectance for V&V field collection activities
- Radiometric Calibration
  - NIST-calibrated integrating sphere serves as source with known spectral radiance
- Spectral Calibration
  - Laser and pen lamp illumination of integrating sphere
- Environmental Testing
  - Temperature stability tests performed in environmental chamber

November 10, 2004
Laboratory BRDF Measurements

Purpose
- Laboratory BRDF measurements are used to correct ground-based reflectance measurements for satellite viewing and for solar illumination geometry.

Method
- Collimated FEL lamp source
- NIST-calibrated Spectralon® panel serves as reference
- Goniometer-mounted sample controls illumination geometry
- Optronics OL750 hyperspectral instrument measures spectra

November 10, 2004
Algorithm Verification Case Matrix

• Three different atmospheric correction approximations
  – Case (1) Planetary reflectance
  – Case (2) Spherical albedo w/knowledge of atmosphere
  – Case (3) Spherical albedo w/knowledge of atmosphere & adjacency

• Three different sets of data used as input into approximation
  – Case (a) ground based-sun photometer (aerosol), TOMS (ozone), Radiosonde (water vapor)
  – Case (b) MOD04 (aerosol), TOMS (ozone), Radiosonde (water vapor)
  – Case (c) MOD04 (aerosol), MOD05 (water vapor), TOMS (ozone) Operational Case

• Nine different scenes
  9 cases (1) + 17 cases (2b/2c) + 20 cases (3a/3b/3c) = 46 cases

Planetary Spherical Albedo Spherical Albedo w/adjacency
MODIS/Sun Photometer Comparison

Total Optical Depth
Stennis Space Center
January 10, 2004

![Graph showing optical depth vs. wavelength with data points for different sources: ASR, MFRSR, MODIS, and Aeronet.](image-url)
Reflectance Map Over SSC Tarps

January 10, 2004 – Case 3c (Operational input of best approximation)
### Measured and Calculated Reflectance Values of 52% Tarp

Algorithm Approximation Effects

<table>
<thead>
<tr>
<th>CASE reflectance (Case reflectance – meas reflectance)</th>
<th>BLUE</th>
<th>GREEN</th>
<th>RED</th>
<th>NIR</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Reflectance (Truth)</td>
<td>0.52</td>
<td>0.52</td>
<td>0.53</td>
<td>0.53</td>
<td>--</td>
</tr>
<tr>
<td>Case 1 (Planetary reflectance)</td>
<td>0.46</td>
<td>0.46</td>
<td>0.48</td>
<td>0.50</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>(-0.06)</td>
<td>(-0.06)</td>
<td>(-0.05)</td>
<td>(-0.03)</td>
<td></td>
</tr>
<tr>
<td>Case 2c (Operational – no adjacency)</td>
<td>0.41</td>
<td>0.44</td>
<td>0.47</td>
<td>0.50</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>(-0.11)</td>
<td>(-0.08)</td>
<td>(-0.06)</td>
<td>(-0.03)</td>
<td></td>
</tr>
<tr>
<td>Case 3c (Operational – w/adjacency)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.51</td>
<td>0.52</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(-0.02)</td>
<td>(-0.02)</td>
<td>(-0.02)</td>
<td>(-0.01)</td>
<td></td>
</tr>
</tbody>
</table>

*Important to take into account the adjacency effect*

November 10, 2004
# Measured and Calculated Reflectance Values of Grass Target

<table>
<thead>
<tr>
<th>Algorithm Approximation Effects</th>
<th>Stennis Space Center January 10, 2004</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CASE reflectance (Case reflectance – meas reflectance)</th>
<th>BLUE</th>
<th>GREEN</th>
<th>RED</th>
<th>NIR</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Reflectance (Truth)</td>
<td>0.05</td>
<td>0.07</td>
<td>0.10</td>
<td>0.18</td>
<td>--</td>
</tr>
<tr>
<td>Case 1 (Planetary reflectance)</td>
<td>0.15 (0.10)</td>
<td>0.13 (0.06)</td>
<td>0.13 (0.03)</td>
<td>0.20 (0.02)</td>
<td>0.06</td>
</tr>
<tr>
<td>Case 2c (Operational – no adjacency)</td>
<td>0.06 (0.01)</td>
<td>0.08 (0.01)</td>
<td>0.11 (0.01)</td>
<td>0.20 (0.02)</td>
<td>0.01</td>
</tr>
<tr>
<td>Case 3c (Operational – w/adjacency)</td>
<td>0.06 (0.01)</td>
<td>0.08 (0.01)</td>
<td>0.11 (0.01)</td>
<td>0.20 (0.02)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*No adjacency effect*
## Measured and Calculated Reflectance Values of 52% Tarp

**MODIS Input Parameter Effects**

<table>
<thead>
<tr>
<th>CASE</th>
<th>BLUE</th>
<th>GREEN</th>
<th>RED</th>
<th>NIR</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measured Reflectance (Truth)</strong></td>
<td>0.52</td>
<td>0.52</td>
<td>0.53</td>
<td>0.53</td>
<td>--</td>
</tr>
<tr>
<td><strong>Case 3a (Meas. aerosol and water)</strong></td>
<td>0.52 (0.00)</td>
<td>0.52 (0.00)</td>
<td>0.53 (0.00)</td>
<td>0.53 (0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Case 3b (MOD04 &amp; meas. water)</strong></td>
<td>0.50 (-0.02)</td>
<td>0.50 (-0.02)</td>
<td>0.51 (-0.02)</td>
<td>0.52 (-0.01)</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Case 3c (MOD04 &amp; MOD05)</strong></td>
<td>0.50 (-0.02)</td>
<td>0.50 (-0.02)</td>
<td>0.51 (-0.02)</td>
<td>0.52 (-0.01)</td>
<td>0.02</td>
</tr>
</tbody>
</table>
# Measured and Calculated Reflectance Values using Operational Inputs

**NASA**

**Stennis Space Center**

**November 10, 2004**

<table>
<thead>
<tr>
<th>CASE 3c reflectance (Case reflectance - meas reflectance)</th>
<th>BLUE</th>
<th>GREEN</th>
<th>RED</th>
<th>NIR</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5% Tarp (0.04, 0.04, 0.03, 0.03)</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>22% Tarp (0.22, 0.22, 0.21, 0.20)</td>
<td>0.24</td>
<td>0.24</td>
<td>0.23</td>
<td>0.23</td>
<td>0.02</td>
</tr>
<tr>
<td>34% Tarp (0.31, 0.31, 0.31, 0.30)</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
<td>0.03</td>
</tr>
<tr>
<td>52% Tarp (0.52, 0.52, 0.53, 0.53)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.51</td>
<td>0.52</td>
<td>0.02</td>
</tr>
<tr>
<td>Grass (0.05, 0.07, 0.10, 0.18)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.11</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td>Concrete (0.11, 0.13, 0.16, 0.19)</td>
<td>0.12</td>
<td>0.15</td>
<td>0.17</td>
<td>0.21</td>
<td>0.01</td>
</tr>
</tbody>
</table>

MOD04 – aerosol
MOD05 – water vapor

| Stennis Space Center January 10, 2004 |
## Operational Algorithm Verification Summary (Case 3c)

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Sensor</th>
<th>Average RMS for all targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC, MS</td>
<td>Jan. 15, 2002</td>
<td>IKONOS</td>
<td>0.02</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>IKONOS</td>
<td>0.04</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Feb. 17, 2002</td>
<td>QuickBird</td>
<td>0.01</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>July 20, 2002</td>
<td>QuickBird</td>
<td>0.01</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Sept. 7, 2002</td>
<td>QuickBird</td>
<td>0.02</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Aug. 23, 2003</td>
<td>QuickBird</td>
<td>0.00</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Oct. 21, 2003</td>
<td>QuickBird</td>
<td>0.02</td>
</tr>
<tr>
<td>SSC, MS</td>
<td>Jan. 10, 2004</td>
<td>QuickBird</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Summary/Future Direction

- MODIS products (MOD04, MOD05) provide the necessary inputs to generate high-spatial-resolution reflectance products under many conditions
  - Average RMS differences range between 0.00–0.04 for the eight datasets evaluated (Case 3c-Operational input to best approximation)

- Adjacency can be an important component that needs to be accounted for to minimize errors

- Future Activities/Recommendations
  - Evaluate alternate algorithms
  - Compare algorithm results to MODIS products (MOD09, MOD13)
  - Compare algorithm results to commercial atmospheric correction algorithm results (FLAASH, ACORN, ATCOR ….)