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

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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
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.

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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)

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Atmospheric Correction Approach

MODIS data products MOD04, MOD05

Radiometrically Corrected Imagery

Spherical Albedo Model

Reflectance Map NDVI Map
MODIS
(Moderate Resolution Imaging Spectroradiometer)

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)

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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

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Atmospherically Corrected Imagery

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IKONOS CIR image (rgb=431)

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Atmospherically Corrected NDVI from IKONOS Imagery

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NDVI from IKONOS Imagery

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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, ASWMFRSR, 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, ASWMFRSR, 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, ASWMFRSR, 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, ASWMFRSR, 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, ASWMFRSR</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, ASWMFRSR, pressure, radiosonde, BRDF</td>
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<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, ASWMFRSR</td>
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<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, ASWMFRSR</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, ASWMFRSR, pressure, radiosonde</td>
</tr>
<tr>
<td>Location</td>
<td>Date</td>
<td>HSR Sensor</td>
<td>HSR Satellite Overpass Time</td>
<td>MODIS Overpass Time</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td>------------</td>
<td>----------------------------</td>
<td>---------------------</td>
</tr>
<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
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

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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
Total Optical Depth
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Wavelength (um)

Optical Depth

ASR
MFRSR
MODIS
Aeronet

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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>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>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>
</tbody>
</table>

Important to take into account the adjacency effect

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# Measured and Calculated Reflectance Values of Grass Target

<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</td>
<td>0.13</td>
<td>0.13</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>(Operational – no adjacency)</td>
<td>(0.10)</td>
<td>(0.06)</td>
<td>(0.03)</td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td>Case 2c (Operational – w/adjacency)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.11</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td>Case 3c (Operational – w/adjacency)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.11</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.02)</td>
<td></td>
</tr>
</tbody>
</table>

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

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## MODIS Input Parameter 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 3a (Meas. aerosol and water)</td>
<td>0.52</td>
<td>0.52</td>
<td>0.53</td>
<td>0.53</td>
<td>0.00</td>
</tr>
<tr>
<td>(MOD04 &amp; meas. water)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td></td>
</tr>
<tr>
<td>Case 3b (MOD04 &amp; MOD05)</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>
<tr>
<td>Case 3c (MOD04 &amp; MOD05)</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>

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### Measured and Calculated Reflectance Values using Operational Inputs

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**CASE 3c**

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

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## 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 …)