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 :

ρ_p = Planetary reflectance

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

θ = Solar zenith angle

E_{sun} = Solar exoatmospheric irradiance

d = Sun-Earth distance

Atmospheric Correction Algorithm Implementations

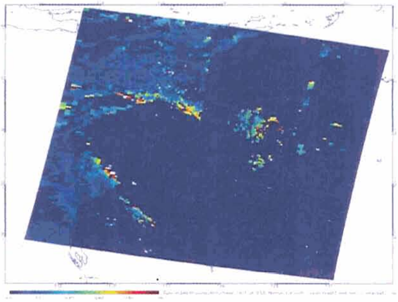
- Use knowledge of atmosphere to determine the constants necessary to convert satellite signals to scene reflectances
  - Ground-based reflectance measurements (direct method)
  - Pseudo-invariant targets
  - Ground-based atmosphere (aerosol) measurements
  - Scene-based aerosol estimates (based on dark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

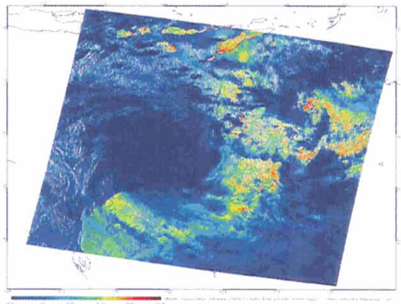
Atmospheric Correction Prototype Algorithm

- 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)

Optical Depth



Water Vapor, Near Infrared



Atmospheric Correction Approach

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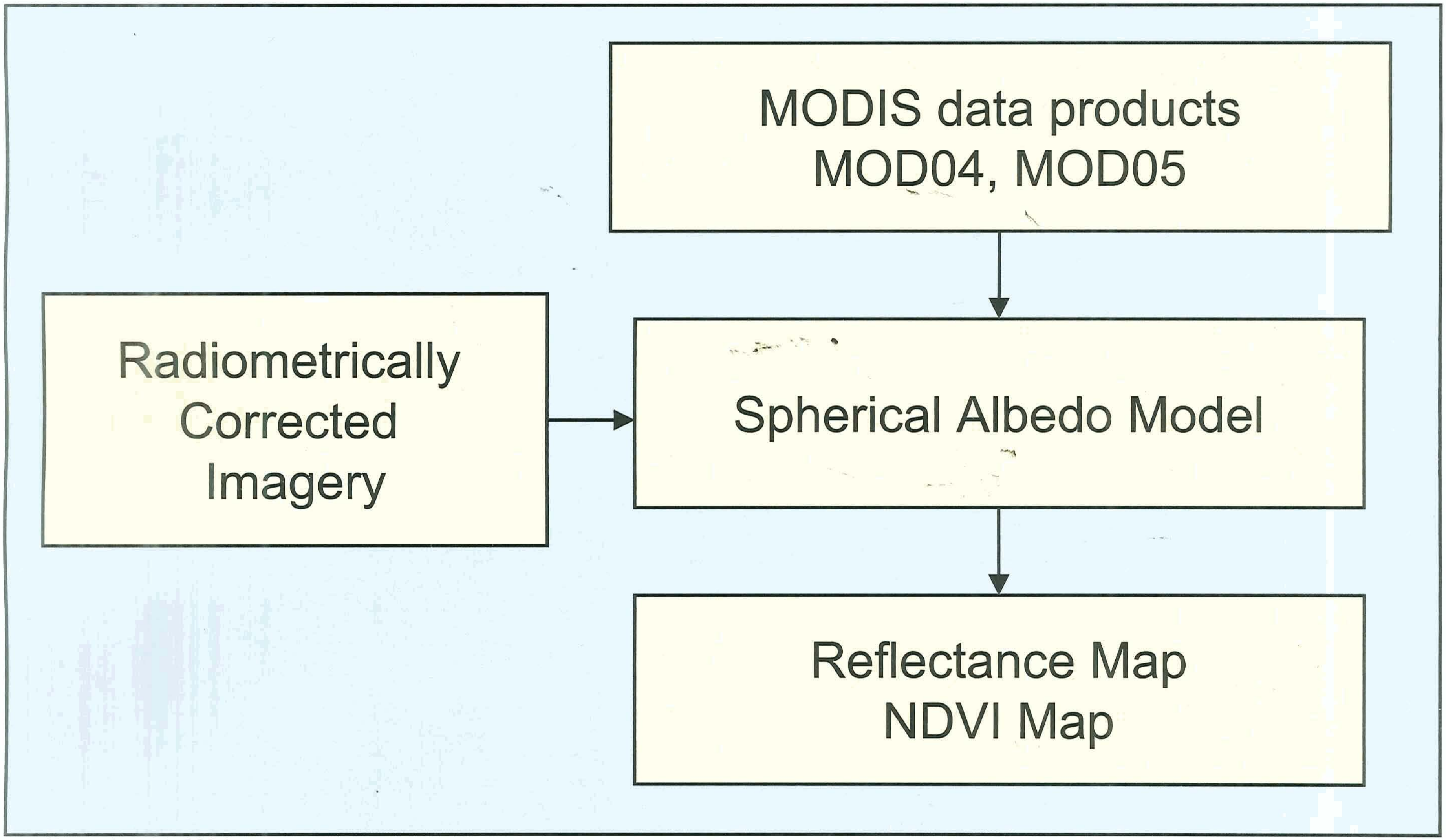

MODIS
(Moderate Resolution Imaging Spectroradiometer)

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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

LINKS:

- Sensor Site: http://modis.gsfc.nasa.gov/
- Data Sites:
  http://daac.gsfc.nasa.gov/ (ocean and atmospheric)
  http://edcdaac.usgs.gov/main.html (land)

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

Spherical Albedo Formulation

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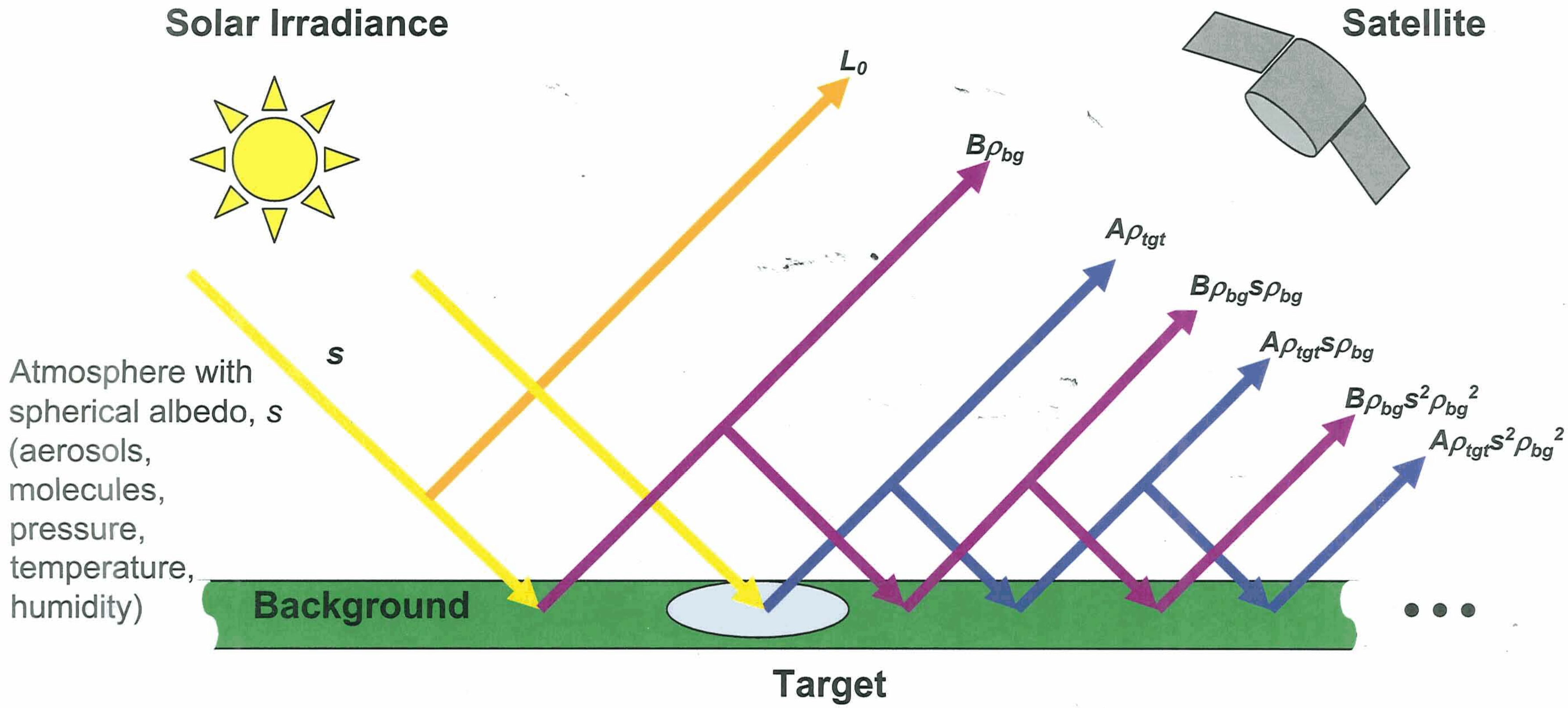
The spherical albedo approach approximates the signal observed by the satellite as the summation of the components illustrated below



$$L_{TOA} = L_o + A\rho_{tgt} + A\rho_{tgt}s\rho_{bg} + A\rho_{tgt}s^2\rho_{bg}^2 + \ldots + B\rho_{bg} + B\rho_{bg}s\rho_{bg} + B\rho_{bg}s^2\rho_{bg}^2 + \ldots$$

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 :

ρ_{tgt} = Target reflectance

ρ_{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

Atmospherically Corrected Imagery

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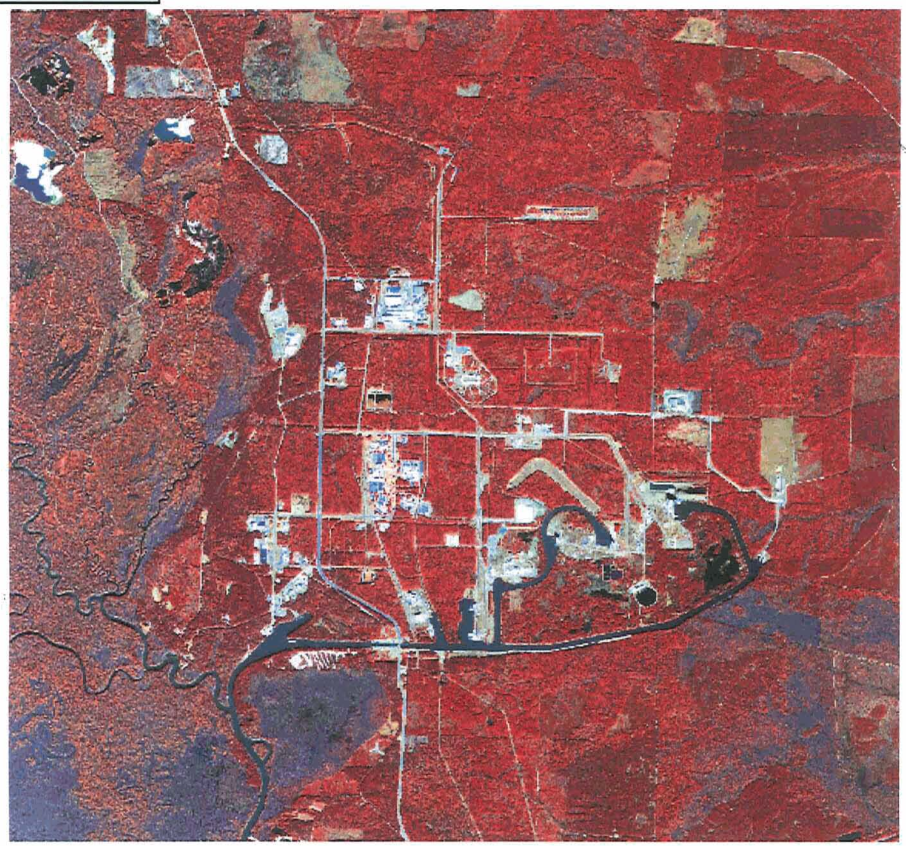

IKONOS CIR image
(rgb=431)

Atmospherically Corrected NDVI from IKONOS Imagery

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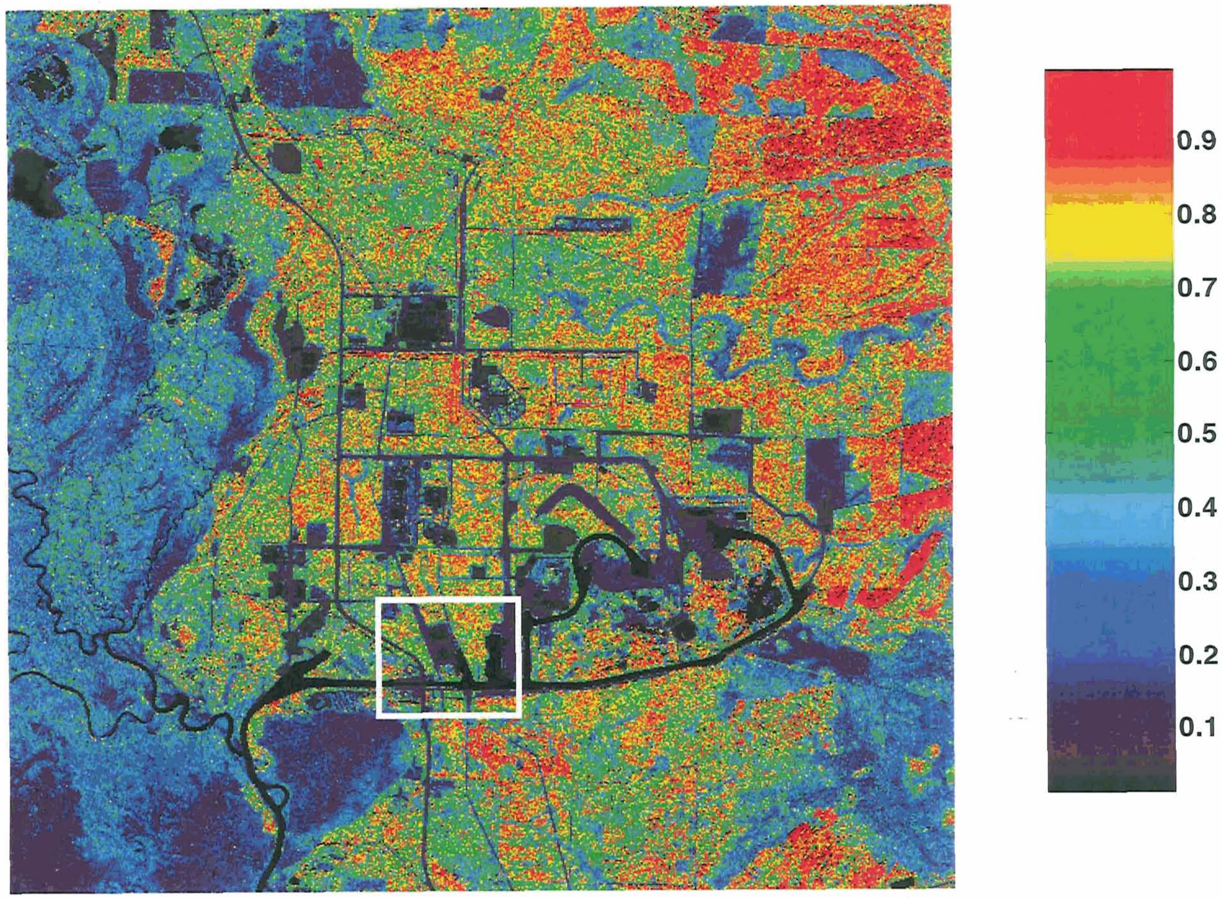

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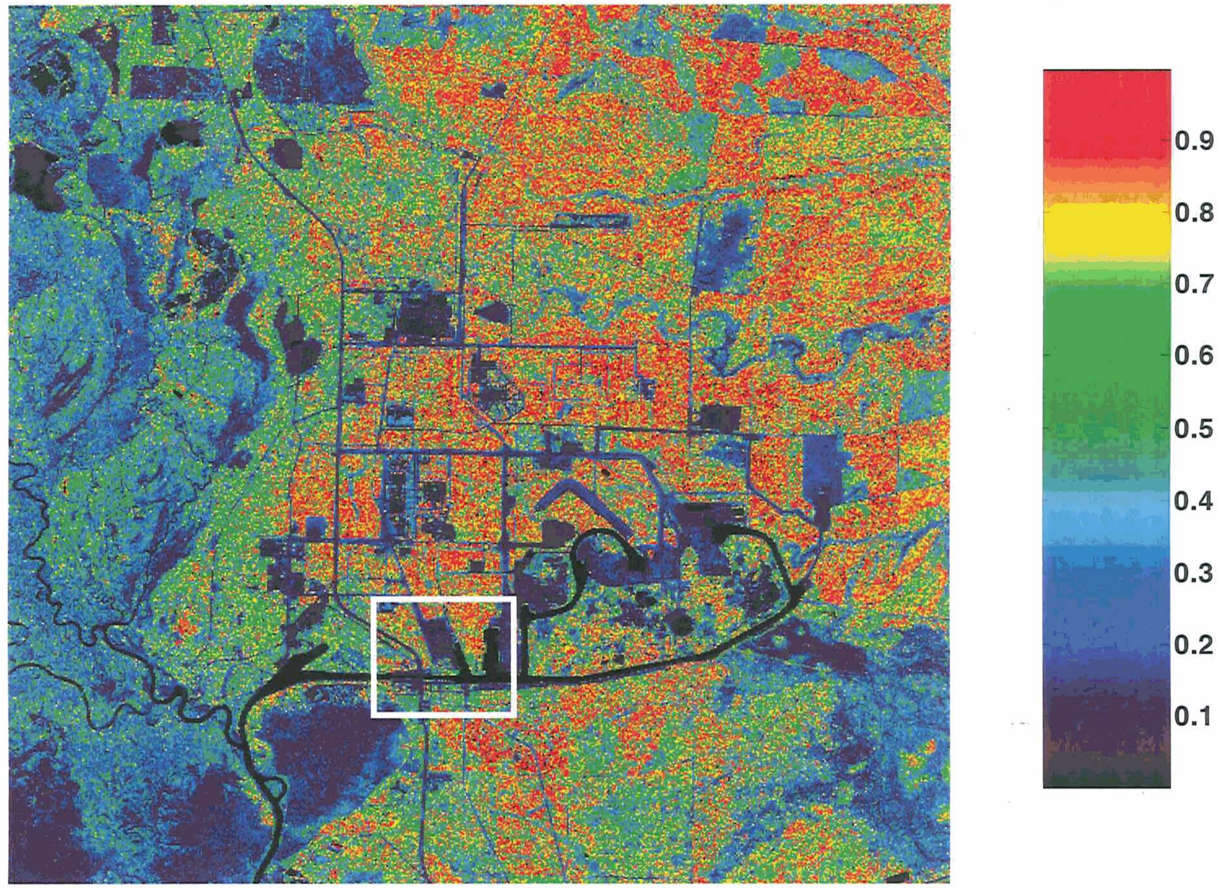
NDVI from IKONOS Imagery



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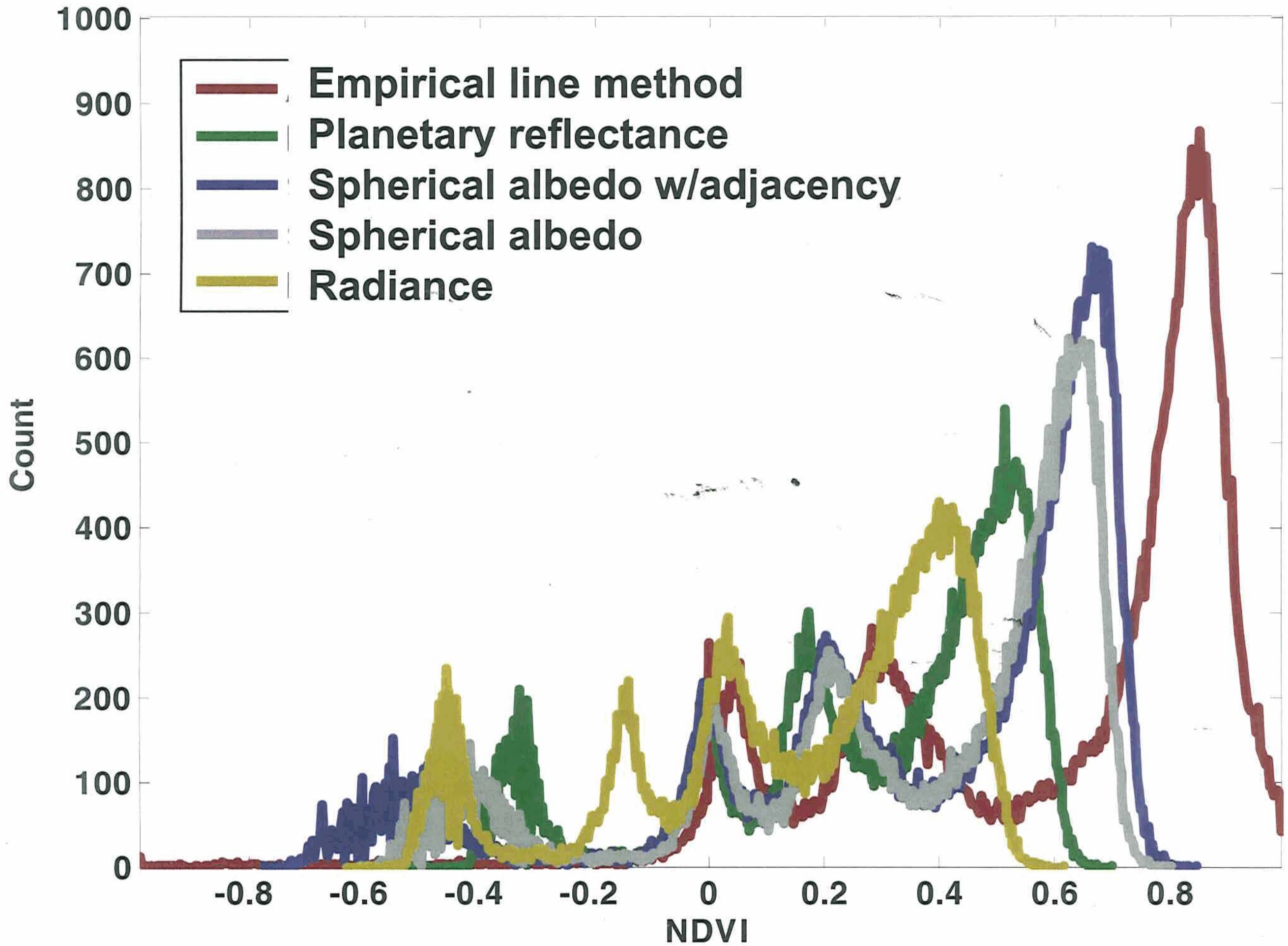
NDVI Histogram Comparison

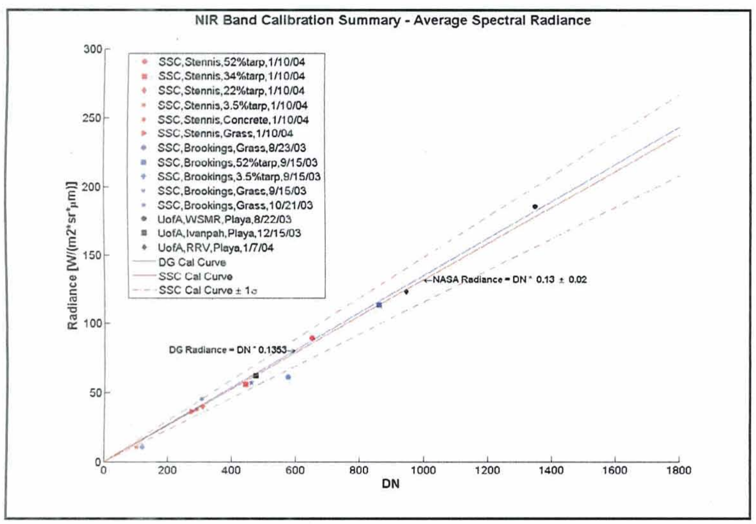


Tarp Site: Stennis Space Center
January 15, 2002

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

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

Satellite Overpass Times

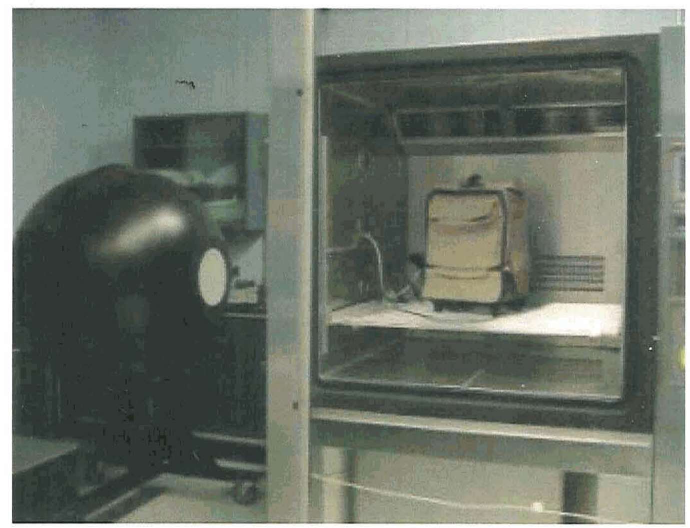
Location	Date	HSR Sensor	HSR Satellite Overpass Time	MODIS Overpass Time
SSC, MS	Jan. 15, 2002	IKONOS	16:44	17:10
SSC, MS	Feb. 17, 2002	IKONOS	16:47	16:14
SSC, MS	Feb. 17, 2002	QuickBird	16:45	16:14
Brookings, SD	July 20, 2002	QuickBird	17:26	17:42
Brookings, SD	Sept. 7, 2002	QuickBird	17:22	16:47
SSC, MS	Nov. 14, 2002	QuickBird	16:44	16:25
Brookings, SD	Aug. 23, 2003	QuickBird	17:07	16:57
Brookings, SD	Oct. 21, 2003	QuickBird	17:11	18:17
SSC, MS	Jan. 10, 2004	QuickBird	16:30	17:27

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

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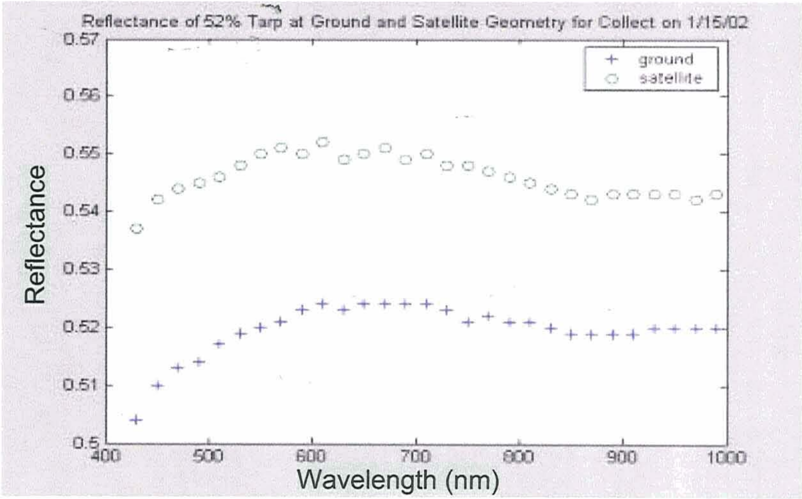
- Purpose
  - Laboratory BRDF measurements are used to correct ground-based reflectance measurements for satellite viewing and for solar illumination geometry

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



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

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Total Optical Depth
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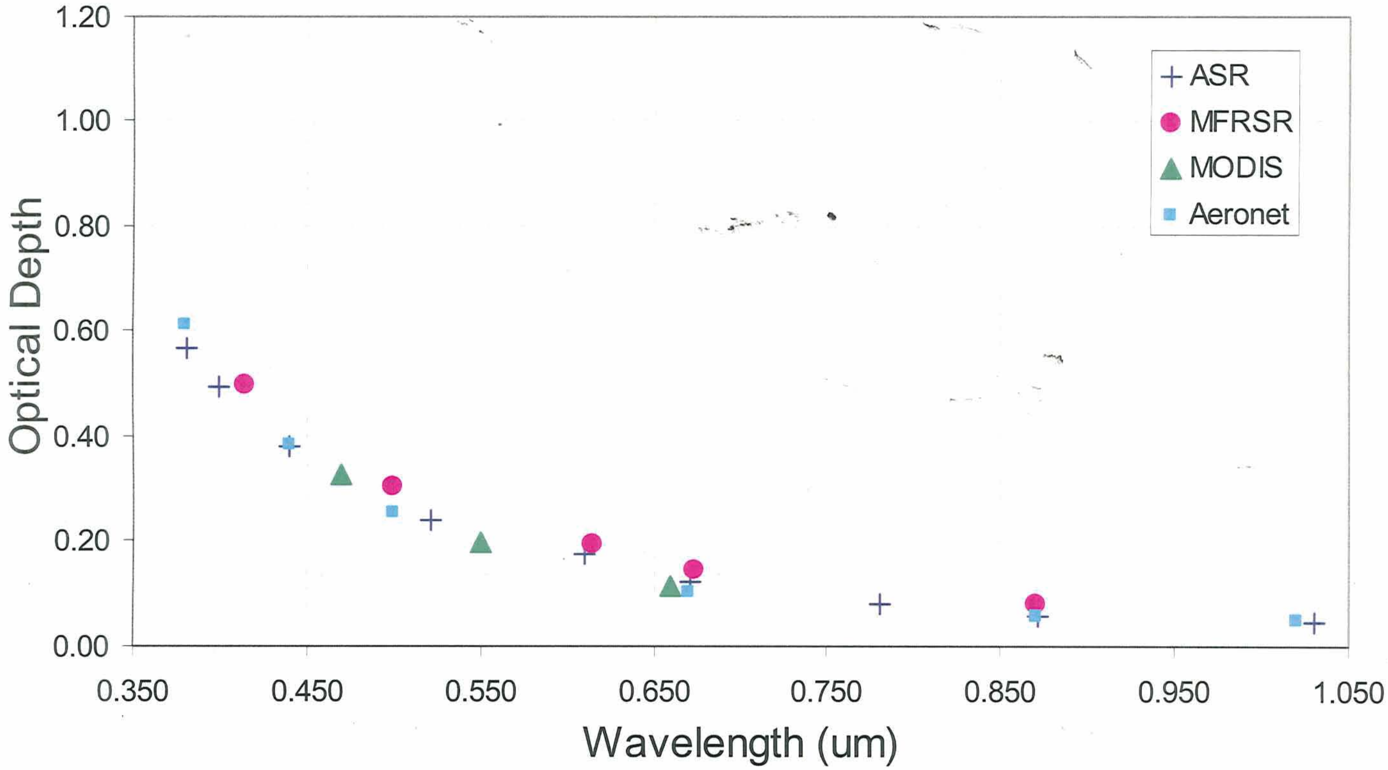
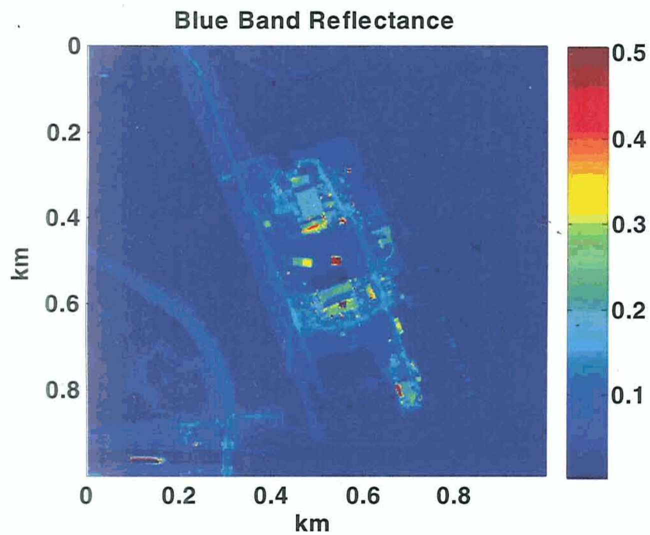
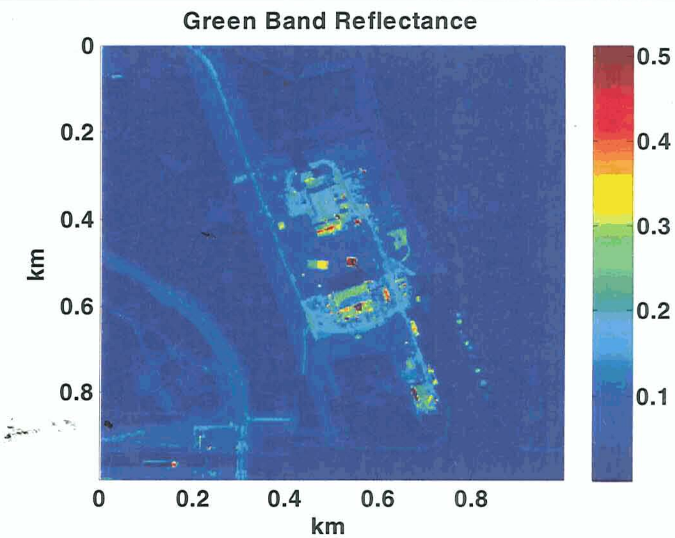
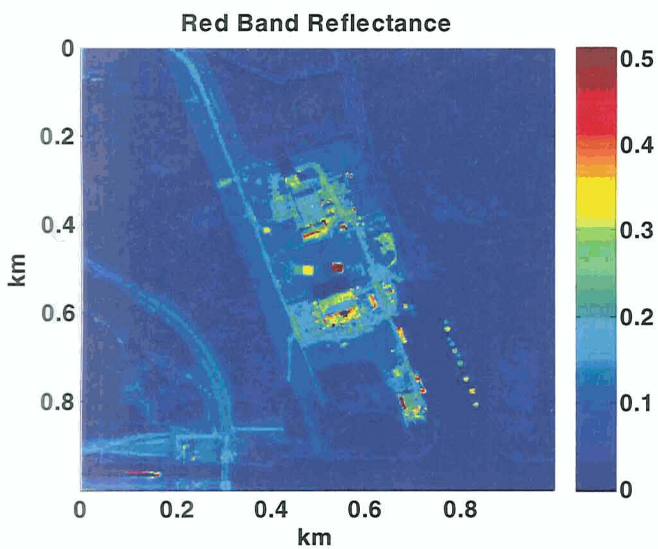


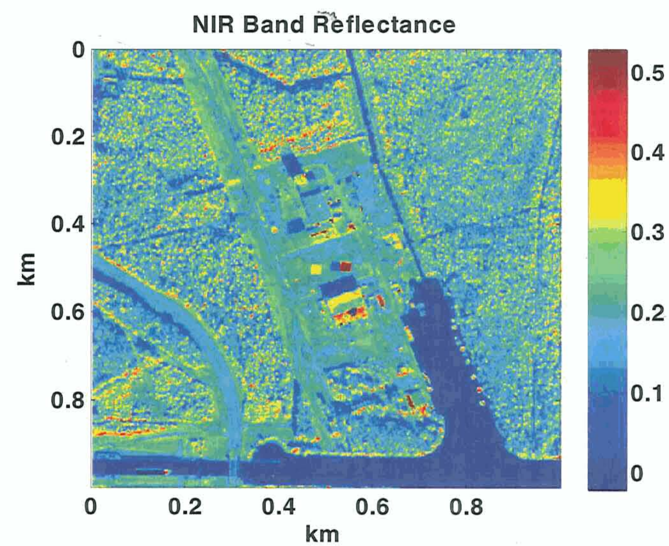
Reflectance Map Over SSC Tarps

January 10, 2004 – Case 3c (Operational input of *best* approximation)









Measured and Calculated Reflectance Values of 52% Tarp

Algorithm Approximation Effects

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

Important to take into account the adjacency effect

Measured and Calculated Reflectance Values of Grass Target

Algorithm Approximation Effects

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

No adjacency effect

Measured and Calculated Reflectance Values of 52% Tarp

MODIS Input Parameter Effects

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CASE *reflectance* *(Case reflectance – meas reflectance)*	BLUE	GREEN	RED	NIR	RMS
Measured Reflectance (Truth)	0.52	0.52	0.53	0.53	--
Case 3a (Meas. aerosol and water)	0.52 (0.00)	0.52 (0.00)	0.53 (0.00)	0.53 (0.00)	0.00
Case 3b (MOD04 & meas. water)	0.50 (-0.02)	0.50 (-0.02)	0.51 (-0.02)	0.52 (-0.01)	0.02
Case 3c (MOD04 & MOD05)	0.50 (-0.02)	0.50 (-0.02)	0.51 (-0.02)	0.52 (-0.01)	0.02

Measured and Calculated Reflectance Values using Operational Inputs

MOD04 – aerosol
MOD05 – water vapor

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

Operational Algorithm Verification Summary (Case 3c)

Location	Date	Sensor	Average RMS for all targets
SSC, MS	Jan. 15, 2002	IKONOS	0.02
SSC, MS	Feb. 17, 2002	IKONOS	0.04
SSC, MS	Feb. 17, 2002	QuickBird	0.01
Brookings, SD	July 20, 2002	QuickBird	0.01
Brookings, SD	Sept. 7, 2002	QuickBird	0.02
Brookings, SD	Aug. 23, 2003	QuickBird	0.00
Brookings, SD	Oct. 21, 2003	QuickBird	0.02
SSC, MS	Jan. 10, 2004	QuickBird	0.02

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 ...)