A 1st Principles Approach for Absolute Radiometric Calibration Using Pseudo Invariant Calibration Sites

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First principles approach

Solar Model
MODTRAN’s NewKur solar model

Atmospheric Model
SDSU Atmospheric model was used for radiative transfer modeling

Sensor data

Validation

Surface Model
Surface spectra from Algodones Dunes

FROM JACIE 2014
Overview

• Overview
• SMACAA description and current status
• SMACAA validation
  – Dark sites
  – Bright sites
• A Surface BRDF Model for Algodones Dunes
• SMACAA application: A-PICS
• Conclusions

— Much of the work in this project was performed by students Sudeep Karanjit, Subash KC, Romain Richard

Acknowledgement:
This work was supported by the NASA Landsat Project Science Office and USGS EROS.
Atmospheric Model: Introducing SDSU Modtran

Atmospheric Correction Anytime Anywhere

• SMACAA was developed to do the following:
  • To atmospherically correct VIS/NIR/SWIR satellite images
    – No limits on collection time (back through 1972)
    – No acquisition location limits
    – No limits on the sensor being used
  • In particular: atmospherically correct all Landsat sensors
    – ETM, TM and MSS.
  • Consistent solution through time.
  • One size fits all solution to correct imagery requires a atmospheric radiative transfer model: Modtran
  • Allow for better cross calibration work for all platforms through time via the use of atmospherically compensated PICS
Inputs

• Three key inputs for doing the atmospheric compensation:
  – Aerosol
    • Affects Bands blue, green, and red with decreasing intensity
  – Water vapor
    • Affects Bands SWIR1, SWIR2, and NIR with decreasing intensity
  – Ozone
    • Affects Bands green and red with decreasing intensity

With these 3 atmospheric effects causing most of day to day variability and affecting all bands to some level they become the key components under investigation
Inputs - Ingest Status

Current Status:

- All NOAA NCEP data (water vapor key)
  - **OPERATIONAL**: Automatic processing and ingest

- All OMI / TOMS Ozone ingested
  - **OPERATIONAL**: Automatic processing and ingest

- All MISR/TOMS Aerosol data ingested
  - **OPERATIONAL**: Automatic processing and ingest

Input Storage and Status

- All Inputs placed in a MySQL database
- Currently the database is holding $46 \times 10^9$ (as of 2014) entries (~3.5TB) with regular automated weekly updates.
  - Data is automatically screened and cleaned with uncertainty for each value being determined and assigned.
  - Data exists in MySQL database for local and remote access, used to drive SMACAA and other lab research projects.
Inputs – Examples of Meteorological Data

- Top Left: Example of Aerosol* Loading profile for 40 years over Banizoumbou
- Top Right: Water vapor loading for Libya 4
- Bottom Left: Ozone* Over Brookings, SD

*Multi data source and sensors used to develop the entire history and to cover the entire globe
Automated Process - Flow Chart

- Local MYSQL Databases are actively being updated via external links – NASA & NOAA
- All data is automatically pulled via Matlab scripts from the database
- Images local to the SDSU Archive are ingested in bulk or individually, screened and processed.
- Finally all inputs are passed through Modtran, with the results being applied to the imagery.
SMACAA Validation - Dark Site
SMACAA versus LEDAPS versus ground truth @ SDSU Test Site

• Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS)—default atmospheric correction code for Landsat
• A comparison of SMACAA and LEDAPS to ground truth was performed using the SDSU Test site
  – Compare the capability to a “known” correction
  – Validate the atmospheric understanding for a known site.
• Ground truth comprised 63 field hyperspectral reflectance measurements covering the summer months for the years of 2004 – 2014, these include L5, L7 and L8 acquisitions.
  – L1T Images were collected for the 63 dates, and processed with SMACAA,
  – 41 LEDAPS reflectance images collected and ROIs extracted
    • Only 41 of the 63 scenes in LEDAPS acquired; unknown why the other 22 images and not available.
Small amount of under correction in the aerosol affected Blue Band; little scatter in the NIR/SWIR2 channels.
Hyperspectral Ground truth banded to L5/L7 RSRs, and plotted against LEDAPS-corrected satellite images.

Little less under correction for Band 1, but a bit more scatter over all and a “bias” in Band 5, along with a number of “missing” images.

Hyperspectral Ground truth banded to L5/L7 RSRs, and plotted against LEDAPS-corrected satellite images.
SMACAA Validation:
SMACAA versus LEDAPS versus ground truth @ SDSU Test Site

- SMACAA: On average, Band 1 is off by 0.014 units of reflectance and the rest are under 0.005 units.

- LEDAPS: Less under correction for band 1, but a bit of over correction for band 5, too much “water” being removed?
With a dark comparison completed, a bright target was chosen. The only bright target we have “truth” for is Algodones Dunes (AD).

- Only have very limited (temporally) measurements of AD, but the assumption is it’s invariant.

Took all available AD images for ETM+ (348 Images) and OLI (45 Images)

Corrected them with SMACAA and compared to the ground truth.
The red circle around DOY 70 represents the ground truth.

As before a little under correction for shorter wavelengths

Yes there is a “smile” to the data – BRDF
SMACAA Validation - Bright Site
L5 TM SMACAA Reflectance for Algodones Dunes

- The red circle around DOY 70 represents the ground truth.
- Same over all shape, little more variation in longer wavelengths
SMACAA Validation - Bright Site
L8 SMACAA Reflectance for Algodones Dunes

- The red circle around DOY 70 represents the ground truth.
- Same over profile, with just a few more points.
A Surface Model for Algodones Dunes

Mahesh Shrestha

- Replicate field BRDF measurements of Algodones Dunes in our Optics Lab
- Develop a Bidirectional Reflectance model for Algodones Dunes
Algodones Dunes, California, March 2015

- U of A
  - Focus: Mobile BRDF / Hyperspectral measurements and Atmospheric modeling
  - Jeff Czapla-Myers
  - Nik Anderson

- SDSU
  - Focus: Mobile BRDF / Hyperspectral measurements and Atmospheric modeling
  - Dave Aaron
  - Larry Leigh
  - Dennis Helder
  - Morakot Kaewmanee

- Goddard
  - Focus: Large area, aerial mapping
  - Joel McCorkel
  - Kurt Thome
  - Bruce Cook
  - Brian Markham

- RIT
  - Focus: Hyperspectral fine angle BRDF measurements
  - Chip Bachmann

- U of Lethbridge
  - Focus: Hyperspectral fine angle BRDF measurements
  - Craig Coburn
What is a BRDF Model?

Bidirectional Reflectance Distribution Function (BRDF): BRDF describes the interaction of light with a given point on a surface by relating the incoming and the outgoing radiances at that point.

\[ r_{BRDF} = \frac{L(\theta_r, \phi_r)}{E(\theta_i, \phi_i)} [S_r^{-1}] \]

BRDF is given by the ratio of the radiance scattered into the direction described by the orientation angles \( \theta_r, \phi_r \) to the irradiance from the \( \theta_i, \phi_i \) direction.

Why BRDF Model is needed?
- Correction of view and illumination angle effects in image
- For atmospheric correction
- For deriving albedo

Figure: University of Massachusetts Boston
Polar Plot of Test Point 6A

<table>
<thead>
<tr>
<th>Time</th>
<th>Solar</th>
<th>Zenith</th>
<th>Azimuth</th>
<th>SN_Zenith</th>
<th>SN_PPP</th>
<th>SN_PP</th>
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<tbody>
<tr>
<td>16:29:29</td>
<td>59.14</td>
<td>116.74</td>
<td>4</td>
<td>1.86</td>
<td>3.56</td>
<td></td>
</tr>
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</table>
BRDF Of Sand: Algodones Dunes (6A Perpendicular to Principal Plane)

Date: March 12, 2015, Time: 16:29:29-16:32:47

$S_{\text{zenith}} = 59.14^\circ \quad S_{\text{Azimuth}} = 116.74^\circ \quad - \quad S_{\text{zenith}} = 58.51^\circ \quad S_{\text{Azimuth}} = 117.38^\circ$

- BRDF as measured by ASD banded to OLI RSRs for point 6A perpendicular to principle plane
- All bands have roughly the same angle dependences
Lab Set Up of 1A, 12 March 2015

During measurement:
V = 17 V and I = 6.11 A

Solar Zenith: 54.4°

Side View of Lab set up

Front View of Lab set up

50 degree
Comparison of Ground Measurement and Lab Measurement of Sand of Algodones Dunes for 6A Perpendicular to Principal Plane with view zenith 54.4°

Data from Lab are closely line up with the data from Algodones Dunes up to ± 20°

From ± 20° onwards the lab data is deviated from field data.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Time</th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-Mar-15</td>
<td>Start</td>
<td>9:30:00</td>
</tr>
<tr>
<td></td>
<td>End</td>
<td>9:39:00</td>
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Comparison Between data from Lab and Algodones Dunes

Best measurement we can simulate in Lab is test point 6A, where we can replicate field data in our lab within 7% except for NIR and SWIR1 band.

<table>
<thead>
<tr>
<th>Band</th>
<th>Field</th>
<th>Lab</th>
<th>Diff</th>
<th>Diff_percent(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal</td>
<td>0.158</td>
<td>0.150</td>
<td>0.009</td>
<td>5.502</td>
</tr>
<tr>
<td>Blue</td>
<td>0.190</td>
<td>0.179</td>
<td>0.011</td>
<td>6.023</td>
</tr>
<tr>
<td>Green</td>
<td>0.292</td>
<td>0.277</td>
<td>0.015</td>
<td>4.972</td>
</tr>
<tr>
<td>Red</td>
<td>0.381</td>
<td>0.360</td>
<td>0.021</td>
<td>5.599</td>
</tr>
<tr>
<td>NIR</td>
<td>0.442</td>
<td>0.410</td>
<td>0.032</td>
<td>7.282</td>
</tr>
<tr>
<td>SWIR1</td>
<td>0.540</td>
<td>0.502</td>
<td>0.038</td>
<td>7.009</td>
</tr>
<tr>
<td>SWIR2</td>
<td>0.513</td>
<td>0.486</td>
<td>0.027</td>
<td>5.262</td>
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</tbody>
</table>

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<th>Lab</th>
<th>Diff</th>
<th>Diff_percent(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal</td>
<td>0.136</td>
<td>0.138</td>
<td>0.008</td>
<td>6.049</td>
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<tr>
<td>Blue</td>
<td>0.162</td>
<td>0.166</td>
<td>0.011</td>
<td>7.032</td>
</tr>
<tr>
<td>Green</td>
<td>0.246</td>
<td>0.267</td>
<td>0.026</td>
<td>10.398</td>
</tr>
<tr>
<td>Red</td>
<td>0.318</td>
<td>0.349</td>
<td>0.033</td>
<td>10.504</td>
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<tr>
<td>NIR</td>
<td>0.367</td>
<td>0.402</td>
<td>0.035</td>
<td>9.574</td>
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<tr>
<td>SWIR1</td>
<td>0.444</td>
<td>0.490</td>
<td>0.046</td>
<td>10.289</td>
</tr>
<tr>
<td>SWIR2</td>
<td>0.423</td>
<td>0.462</td>
<td>0.039</td>
<td>9.249</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Field</th>
<th>Lab</th>
<th>Diff</th>
<th>Diff_percent(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal</td>
<td>0.168</td>
<td>0.150</td>
<td>0.018</td>
<td>10.522</td>
</tr>
<tr>
<td>Blue</td>
<td>0.201</td>
<td>0.183</td>
<td>0.018</td>
<td>9.074</td>
</tr>
<tr>
<td>Green</td>
<td>0.305</td>
<td>0.281</td>
<td>0.024</td>
<td>7.971</td>
</tr>
<tr>
<td>Red</td>
<td>0.398</td>
<td>0.364</td>
<td>0.035</td>
<td>8.786</td>
</tr>
<tr>
<td>NIR</td>
<td>0.461</td>
<td>0.406</td>
<td>0.055</td>
<td>11.909</td>
</tr>
<tr>
<td>SWIR1</td>
<td>0.539</td>
<td>0.499</td>
<td>0.044</td>
<td>8.102</td>
</tr>
<tr>
<td>SWIR2</td>
<td>0.534</td>
<td>0.482</td>
<td>0.052</td>
<td>9.811</td>
</tr>
</tbody>
</table>
Combining Solar, Surface, and SMACAA models

→ A-PICS*

*Absolute Pseudo Invariant Calibration Sites
Comparison of Ground Measurement and Lab Measurement of Sand of Algodones Dunes with output of SMACAA for Site 1A Perpendicular to Principal Plane with illumination zenith 45°

- Green data represents banded BRDF of the ground measurement of Algodones Dunes
- Blue data represents banded BRDF of the lab measurement of Algodones Dunes
- Red data is Landsat 8 images (~50 images over 2 years) corrected for atmosphere (plotted versus sun angles)

This data is not “apples to apples” the Blue and Green data represent the same “area” of the dunes, while the red data is from an adjacent site, that did appear to be “different”. Work in progress to put everything to a “apples to apples” comparison.
Conclusions

• SMACAA database and processing system are complete from a prototype and in-house use perspective
  – Global Coverage
  – Temporal coverage to 1972 (for Landsat MSS)
  – Sensor independent
  – Consistent with other atmospheric correction systems (LEDAPS)

• SMACAA provides the atmospheric component to complete the A-PICS model.

• Currently finishing initial test case of processing all archived CONUS MSS data to surface reflectance (~1.5M runs!)

• Algodones Dunes Surface Model: Field data to understand surface BRDF behavior is captured; lab measurements agreeing with field data.

• Started applying some of the methodology to Libya 4.
Thank you!