Quantitative Estimation of Land Surface Variables from EO-1 Data

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OUTLINE

♣ Introduction - historical development of inversion methods in quantitative remote sensing

♣ Brief summary of our EO1 project activities
  → Atmospheric correction methods (ALI & Hyperion)
  → Estimation of broadband albedos from ALI
  → Estimation of leaf area index (LAI) from ALI

♣ Data assimilation with crop growth models
The following background materials are largely from the book manuscript:


EO1 project is one of the major funding sources that enable me to complete this book.
Inversion methods in quantitative remote sensing

- **Statistical methods**
  - Vegetation indices
  - Image transformations

- **Physical methods**
  - Optimization algorithms
  - Look-up table algorithms

- **Hybrid algorithms**
Vegetation indices (VI) have been used to predict various land surface biophysical variables (y).
Multispectral VI

Liang, et al.

SR = \tan(\alpha)
NDVI = \tan(\alpha - 45^\circ)
TSAVI = \tan(\beta)
Hyperspectral VI

Liang, et al.
One example of the statistical model

Liang, et al.
Image Transformations

Liang, et al.

Table 8-3: Landsat-7 ETM+ Tasseled Cap transformation coefficients

<table>
<thead>
<tr>
<th>Feature</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ETM+1</td>
</tr>
<tr>
<td>Brightness</td>
<td>.3561</td>
</tr>
<tr>
<td>Greenness</td>
<td>-.3344</td>
</tr>
<tr>
<td>Wetness</td>
<td>.2626</td>
</tr>
<tr>
<td>Fourth</td>
<td>.0805</td>
</tr>
<tr>
<td>Fifth</td>
<td>-.7252</td>
</tr>
<tr>
<td>Sixth</td>
<td>.4000</td>
</tr>
</tbody>
</table>
Inversion methods in quantitative remote sensing

- **Statistical methods**
  - Vegetation indices
  - Image transformations

- **Physical methods**
  - Optimization algorithms
  - Look-up table algorithms

- **Hybrid algorithms**
Surface reflectance modeling

- Radiative transfer modeling
- Geometric optical modeling
- Monte Carlo ray-tracing modeling
- Radiosity simulation
Canopy radiative transfer

Liang, et al.

DART (Discrete Anisotropic Radiative Transfer)

1D

3D
Geometric-optical modeling

Liang, et al.

Sunlit crown, sunlit/shaded ground/crown, shaded ground/crown
Monte Carlo ray tracing

Simulated barley reflectance

Solar zenith angle = solar azimuth angle = 0°
Optimization methods

To minimize the following merit function by adjusting the parameter set

\[ f() \] is the predicted reflectance from canopy or coupled canopy/atmospheric radiative transfer models
MODIS look-up table methods for LAI/Fpar
Hybrid Inversion algorithms

Combination of physical simulations (reflectance modeling) and statistical analysis (nonparametric regression techniques)
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♣ Data assimilation with crop growth models
Calibrated TOA radiance

Atmospheric correction

Surface spectral reflectance

Inversion algorithms

Broadband albedos

LAI
Atmospheric correction


Are near-IR bands hazy or there shadows?

- **YES**
  - Histogram matching
  - Clustering analysis
  - Determining clear and hazy regions
  - Determining reflectance of clear regions
  - Mean reflectance matching of each cluster in both clear & hazy regions
  - Look-up tables searching for aerosol optical depth
  - Spatial smoothing of the estimated aerosol optical depth
  - Reflectance retrieval by considering adjacency effects

- **NO**
  - Clustering analysis
  - Determining clear and hazy regions
  - Determining reflectance of clear regions
  - Mean reflectance matching of each cluster in both clear & hazy regions
  - Look-up tables searching for aerosol optical depth
  - Spatial smoothing of the estimated aerosol optical depth
  - Reflectance retrieval by considering adjacency effects
ETM+ atmospheric correction

Liang, et al.
ETM+ atmospheric correction

Liang, et al.
MODIS imagery of Chinese northeastern coast, May 7, 2000

Liang, et al.
MODIS imagery of Chinese northeastern coast, May 7, 2000

Liang, et al.
Atmospheric correction of ALI imagery
Case 1: (Beijing, China, May 3, 2001)

Before | After
--- | ---

Before | After
--- | ---

Liang, et al.
Atmospheric correction of ALI imagery
Case 1: (Beijing, China, May 3, 2001)

Band 1 difference  Band 3 difference

Liang, et al.
Atmospheric correction of ALI imagery
Case 2: (Beijing, China, April 1, 2001)

Liang, et al.
Atmospheric correction of ALI imagery
Case 2: (Beijing, China, April 1, 2001)

Before (Band 1)  After (band 1)

Liang, et al.
Atmospheric correction of ALI imagery
Case 2: (Beijing, China, April 1, 2001)

Before (band 3)  After (band 3)
Atmospheric correction of ALI imagery
Case 2: (Beijing, China, April 1, 2001)

Before (band 5)                                      After (band 5)

Liang, et al.
Validation of atmospheric correction

Liang, et al.
AVIRIS Imagery of Parana, Brazil acquired on August 23, 1995

Band 18 (549nm)  Band 26 (627nm)  Band 34 (673nm)
Atmospheric correction of AVIRIS Imagery

Composite imagery of Parana, Brazil, August 23, 1995
Bands 26 (627nm), 34(673nm) and 46 (788nm)
New module for Hyperion

1. Determining clear and hazy regions
2. Determining reflectance of clear regions
3. Predict reflectance of visible bands using near-IR & mid-IR reflectance
4. Look-up tables searching for aerosol optical depth
5. Spatial smoothing of the estimated aerosol optical depth
6. Reflectance retrieval
Hyperion imagery one
(Bucharest, Romania, May 18, 2001, Band 18)

Liang, et al.
Band 31

Liang, et al.
R31G23B14

Liang, et al.
Hyperion imagery two: Band 12

Liang, et al.
Band 14

Liang, et al.
Water vapor estimation

continuum interpolation band ratio (CIBR)
bands 79 and 80, and 86 (875.00 937.00 1003.37 nm)
Calibrated TOA radiance

Atmospheric correction

Surface spectral reflectance

Inversion algorithms

Broadband albedos

LAI
Broadband albedo estimation

Liang, et al.

Raw data → Atmospheric correction → BRDF modeling

Broadband albedos → Narrowband to broadband albedo conversion

Conventional

Alternative
Calibrated TOA radiance

Atmospheric correction

Surface spectral reflectance

BRDF angular modeling

Spectral albedo

Narrowband to broadband conversion

Broadband albedos

Liang, et al.
Conventional Method


An alternative solution

ALI narrowband to broadband albedo conversions

Liang, et al.

\[
\alpha_{\text{short}} = -0.0012 + 0.3466R_1 + 0.1435R_2 + 0.2278R_3 + 0.0985R_4 \\
+ 0.0574R_5 + 0.2159R_6 + 0.0385R_7 + 0.1139R_8 + 0.062R_9
\]

\[
\alpha_{\text{vis}} = 0.2812R_1 + 0.1248R_2 + 0.3592R_3 + 0.2353R_4
\]

\[
\alpha_{\text{nir}} = 0.2917R_5 + 0.2707R_6 - 0.0316R_7 + 0.2502R_8 + 0.2258R_9
\]
Albedo validation

Liang, et al.
Broadband albedos from ALI, Beijing, China (May 3, 2001)

Liang, et al.

Shortwave

Visible

Near-IR

UNIVERSITY OF MARYLAND
Three broadband albedos (Oct. 2, 2000)

Liang, et al.
ETM+/MODIS registration

Liang, et al.
Calibrated TOA radiance

Atmospheric correction

Surface spectral reflectance

Inversion algorithms

Broadband albedos

LAI
LAI Inversion algorithms


Hybrid inversion algorithm

Liang, et al.
Table 1: The best ALI band combinations for LAI retrieval. Spectral band are designated by band number; p represents panchromatic. Details can be found in Ungar et al., (this issue).

<table>
<thead>
<tr>
<th>Bands</th>
<th>$R^2$</th>
<th>RMSE</th>
<th>Bands</th>
<th>$R^2$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 3</td>
<td>0.830</td>
<td>1.231</td>
<td>3 4 5p</td>
<td>0.785</td>
<td>1.678</td>
</tr>
<tr>
<td>2 4</td>
<td>0.783</td>
<td>1.786</td>
<td>3 4 5p</td>
<td>0.887</td>
<td>1.135</td>
</tr>
<tr>
<td>2 4p</td>
<td>0.817</td>
<td>1.535</td>
<td>3 4 5</td>
<td>0.735</td>
<td>2.087</td>
</tr>
<tr>
<td>2 5</td>
<td>0.720</td>
<td>2.202</td>
<td>3 4 5p</td>
<td>0.914</td>
<td>0.977</td>
</tr>
<tr>
<td>2 5p</td>
<td>0.679</td>
<td>2.215</td>
<td>3 4p 5</td>
<td>0.732</td>
<td>2.078</td>
</tr>
<tr>
<td>3 4</td>
<td>0.800</td>
<td>1.671</td>
<td>3 5p 5</td>
<td>0.721</td>
<td>2.133</td>
</tr>
<tr>
<td>3 4p</td>
<td>0.821</td>
<td>1.516</td>
<td>4 4p 5p</td>
<td>0.945</td>
<td>0.739</td>
</tr>
<tr>
<td>3 5p</td>
<td>0.762</td>
<td>1.900</td>
<td>4 4p 5</td>
<td>0.947</td>
<td>0.697</td>
</tr>
<tr>
<td>3 5</td>
<td>0.760</td>
<td>1.810</td>
<td>4 5p 5</td>
<td>0.947</td>
<td>0.705</td>
</tr>
<tr>
<td>4 4p</td>
<td>0.966</td>
<td>0.535</td>
<td>4p 5p 5</td>
<td>0.603</td>
<td>2.902</td>
</tr>
<tr>
<td>4 5p</td>
<td>0.878</td>
<td>1.197</td>
<td>2 3 4 4p</td>
<td>0.823</td>
<td>2.902</td>
</tr>
<tr>
<td>4 5</td>
<td>0.846</td>
<td>1.365</td>
<td>2 3 4 5p</td>
<td>0.887</td>
<td>1.141</td>
</tr>
<tr>
<td>4p 5p</td>
<td>0.951</td>
<td>0.682</td>
<td>2 3 4 5</td>
<td>0.714</td>
<td>2.263</td>
</tr>
<tr>
<td>4p 5</td>
<td>0.892</td>
<td>1.050</td>
<td>2 3 4p 5</td>
<td>0.916</td>
<td>0.941</td>
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<tr>
<td>5p 5</td>
<td>0.846</td>
<td>1.308</td>
<td>2 3 4p 5</td>
<td>0.729</td>
<td>2.102</td>
</tr>
<tr>
<td>2 3 4</td>
<td>0.780</td>
<td>1.794</td>
<td>2 3 5p 5</td>
<td>0.630</td>
<td>2.929</td>
</tr>
<tr>
<td>2 3 4p</td>
<td>0.807</td>
<td>1.614</td>
<td>2 4 5p 5</td>
<td>0.718</td>
<td>2.197</td>
</tr>
<tr>
<td>2 3 5p</td>
<td>0.737</td>
<td>2.078</td>
<td>2 4 5p 5</td>
<td>0.493</td>
<td>3.601</td>
</tr>
<tr>
<td>2 3 5</td>
<td>0.690</td>
<td>2.417</td>
<td>2 5p 5</td>
<td>0.793</td>
<td>1.783</td>
</tr>
<tr>
<td>2 4 4p</td>
<td>0.484</td>
<td>4.076</td>
<td>2 4p 5p 5</td>
<td>0.876</td>
<td>1.181</td>
</tr>
<tr>
<td>2 4 5p</td>
<td>0.873</td>
<td>1.240</td>
<td>3 4 5p 5</td>
<td>0.882</td>
<td>1.141</td>
</tr>
<tr>
<td>2 4 5</td>
<td>0.700</td>
<td>2.571</td>
<td>3 4 5p 5</td>
<td>0.873</td>
<td>1.182</td>
</tr>
<tr>
<td>2 4p 5p</td>
<td>0.933</td>
<td>0.826</td>
<td>3 4 5p 5</td>
<td>0.876</td>
<td>1.186</td>
</tr>
<tr>
<td>2 4p 5</td>
<td>0.738</td>
<td>2.207</td>
<td>3 4p 5p 5</td>
<td>0.947</td>
<td>0.704</td>
</tr>
<tr>
<td>2 5p 5</td>
<td>0.665</td>
<td>2.826</td>
<td>4 4p 5p 5</td>
<td>0.726</td>
<td>1.679</td>
</tr>
</tbody>
</table>
Figure 11: Comparisons of the retrieved LAI values with the measured LAI values over both BARC and CIAR.
ALI color composite imagery
(Colleambally, Australia, 2001)

Feb. 3, 2001

March 7, 2001

Liang, et al.
Figure 12: LAI maps over CIAR from three ALI images: January (A) February (B) and March (C), 2001.
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Data forcing methods

Remote Sensing and Ecological Process Models
Strategy 1 - Model input

- Non-RS Inputs, e.g., Interpolated Data/Models
- RS Inputs, e.g., Solar radiation
- Climate and Soils data
- RS - Classification, e.g., Land Cover
- RS - Variables, e.g., (LAI), f_c

Ecological Process Model

NPP, (LAI)
Data assimilation methods
On-going activities

- Crop yield estimation at the regional level – USDA
- Crop soil carbon sequestration – NASA
- Crop growth modeling for assimilation with remotely sensed data
The new algorithm works very well for ETM+, ALI and other sensors under the general atmospheric and surface conditions.

The additional blue band of ALI compared to ETM+ is very helpful to distinguish clear/hazy regions in our algorithm.

The revised version for aerosol correction also works very well for Hyperion.

Estimation of water vapor content from Hyperion using neural network is very promising but needs more testing and validation.
ALI narrowband reflectance can be effectively used for estimating broadband albedos that are essential to calculate surface shortwave radiation budget.

Narrowband to broadband conversion is a very important step and additional bands of ALI can provide more accurate conversion.
The **hybrid inversion algorithm** that combines canopy radiative transfer simulations with nonparametric regression techniques (e.g., neural network, projection-pursuit regression) is effective to retrieve LAI.

Additional bands of 4’ and 5’ of ALI are very useful to estimate LAI using this algorithm.
We have demonstrated that the additional three bands (1’, 4’ and 5’) of ALI compared to Landsat7 ETM+ are very important to estimate land surface variables quantitatively.
Acknowledgements

♣ EO1 Project leadership and supports (Ungar, …)
♣ Hongliang Fang, Chad Shuey, and Lynn Thorp at UMD
♣ Andy Russ, Wayne Dulaney and Monisha Kaul At USDA/BARC
♣ Drs. Tim McVicar & David Jupp & their groups, Australia
Thank you!