Advances in Remote Sensing Data Processing Using the Modtran®5-Enhanced MODO and ATCOR Software

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Outline

1. Introduction
   - Using Modtran for Remote Sensing
   - Forward simulation and inversion problems

2. MODO and MODTRAN® 5
   - Using MODO in Imaging Spectroscopy
   - Recent enhancements
   - Open issues in forward simulation

3. ATCOR and MODTRAN® 5
   - Overview of the ATCOR code family
   - Aspects of atmospheric correction
   - Open issues in atmospheric correction

4. Conclusions and Outlook
Remote Sensing Related Use of Modtran®

- Atmospheric Gas Retrieval
- Aerosol Retrieval
- Atmospheric correction
- Sensor Design
- Sensitivity Analysis
- Energy Balance Models
- Scene Simulation

and many more…

… how to design add-ons to MODTRAN for Remote Sensing?

Forward Simulation?

Modtran built for forward simulation:

MODO being a helper to ease this part.
Inversion?

How to find the inputs from sensor radiance?

ATCOR being one of the solutions for that part...

MODO

‘Modtran Organizer’
MODO - Goals

GOAL:
Create a tool for scientists to ease the use of MODTRAN for remote sensing.

i.e.:
• Translate the original tape5’s,
• Create a bridge to remote sensing sensors,
• Support typical research tasks such as at-sensor radiance simulation and sensitivity analyses,
• Provide an open, programmable system.

MODO - Development

1994: Development started in 1994
1996: First version available
2000: New Foundation 2000 (for Modtran 3)
2004: Release of Version 3 for Modtran 4
License from AFRL for inclusion of Modtran 4
2010: Update to Version 4 for Modtran4 and in parallel Version 5 for Modtran5
soon: Release of the new versions including Modtran5

(Beta versions are available upon request, but without Modtran 5 components)
Dealing with Tape5’s

‘Scientific Approach’:

• Don’t hide the tape5’s given structure.
• Show as many options as possible
• Allow to use the original Modtran documentation manual efficiently
• Support import/export for batch processing
• Read/support all possible options (but not all are editable by GUI)
Sensor Simulation

Remote Sensing Specialists approach:
  - Hide unnecessary Modtran options
  - Use SI units common to remote sensing (i.e. W/(m² sr nm))
  - Include common sensor systems and characteristics
  - Extract the total radiance
  - Feed ground characteristics from external sources
  - Bridge to ENVI spectral libraries
Sensitivity Analyses

What for:
- Evaluate the discernability of spectral ground reflectance features after atmospheric ‘distortions’
- Show the range of impact of various atmospheric parameters
- Search for methods for atmospheric parameter retrieval
- Sensor design question (radiometric range and SNR requirements)
Sensitivity Analysis

Result
Introducing Modtran® 5 in MODO

- Extended internal data structure (naming consistent with Modtran manual)
- Added generic spectral shift analysis tool
- Support for new solar reference data options
- Added support for new Modtran atmospheric correction mode and added simple atmospheric correction tool (SACO)
- API for use of functionality from IDL applications

SACO – Simple Atmospheric Correction

Uses the *.acd output of Modtran® 5 directly for atmospheric correction.

Restrictions:
- No angular dependencies
- No terrain correction
- One set of parameters per spectral band

Advantages:
- Very fast processing.
- Baseline atmospheric correction for evaluation of atmospheric correction developments.
SACO Calculation

\[
\rho = \frac{\rho^*}{\tau_{\text{tot}, \text{dir}} + \tau_{\text{diff}} + \rho^* \cdot \tau_{\text{dir}, S}}
\]

Surface 'reflectance', directional (bottom of atmosphere reflectance)

\[
\rho^* = \frac{\left(\text{DN} \cdot c_i + c_o \right) - L_{\text{path}}}{E_o \cos \theta}
\]

Apparent at-sensor reflectance

\[
L_{\text{path}} = L_{\text{atm}, 0} + \frac{\tau_{\text{diff}} \cdot E_o \cos \theta \cdot \tau_{\text{dir}, S}}{\pi d^2 \left(1 - \rho^* \right)}
\]

Total path radiance
**SACO-Results of atmospheric correction**

- **HYSPEX Imaging**
- **Spectrometer Processing**
- **Black: ATCOR 4 Output**
- **Brown: SACO Output**
- (both unfiltered, single pixels)

**Open Items for MODO**

**Future enhancement options:**
- Scene simulation
- Sensor model inclusion
- Atmospheric profile editor
- BRDF visualisation and support
- LUT generation tools
ATCOR

Atmospheric Correction

Complete atmospheric and radiometric correction
ATCOR - Goals

To develop a complete and self-contained atmospheric correction software on the basis of MODTRAN for remote sensing systems in the VIS/NIR and IR.

ATCOR-2: ‘two dimensional’, i.e. no terrain, multispectral

ATCOR-3: ‘three dimensional’, add terrain influences

ATCOR-4: ‘four dimensional’, add spectroscopy support and view angle dependencies for airborne data

ATCOR - Implementation

Uses a ‘universal’ spectral database (Look-Up-Table) at 0.4 nm resolution

New sensors are introduced by resampling the LUT.
Based on IDL technology for fast prototyping, continuously updated

History:
• Developed originally by Rudolf Richter, DLR:
• Development started in the late 80’s
• Patent held by German Aerospace Agency
• Sub-Licenses granted to ERDAS Imagine and Geomatica
• Original code co-developed and distributed by ReSe since 2002
## ATCOR - SACO

<table>
<thead>
<tr>
<th>ATCOR</th>
<th>SACO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image-derived inputs (aerosols/water vapor)</td>
<td>User-defined inputs</td>
</tr>
<tr>
<td>6-D Look-up Table</td>
<td>One parameter set per band</td>
</tr>
<tr>
<td>Terrain + viewing angle - aware</td>
<td>Nadir conditions only</td>
</tr>
<tr>
<td>30’ for 1600x3000x160 bands</td>
<td>15x faster</td>
</tr>
<tr>
<td>Processing chain component</td>
<td>Simple scientific test tool</td>
</tr>
<tr>
<td>Validated and broadly used</td>
<td>Non-validated</td>
</tr>
<tr>
<td>Side outputs (aerosol, water vapor, emissivity, temperature…)</td>
<td>No side outputs.</td>
</tr>
<tr>
<td>Haze, cirrus, shadow correction</td>
<td>No spatial variations in correction</td>
</tr>
</tbody>
</table>

### HYSPEX:
- VIS-NIR hyperspectral sensor,
- 3.6 nm resolution
- 160 bands
- 400-1000 nm
- 1600pix across track

Courtesy:
NEO, Norway
Hyspex Atmospheric Correction

Apparent reflectance (dashed) and corresponding surface reflectance (line) for dense vegetation (green) and bare soil (red); ATCOR-4 correction, no interpolation.

SACO Outputs On HYSPEX

32nd Trans. Meeting, Boston 2010, Page 15
Hyspex Overlap Comparison

HYSPEX reflectance spectra, overlap of two scenes

(all corrections done with ATCOR-4, small atm. features are interpolated, Spectra of 10x10 pixels samples)

HYMAP BRDF in Overlap

HYMAP data set
'Vordemwald' (Switzerland, 2004), mosaic after orthorectification
• 2400m above ground
• sun zenith: 38°
• 512 across track pixels
• Photogramm. DEM
• FOV: 61.4°

(data in courtesy of RSL, Zürich; PARGE orthorectification)
Spectra in Overlap - comparison

No-BRDF influence (Asphalt)

Strong BRDF effect (Soil)

HYMAP ATCOR-SACO

Vegetation

Bare Soil/River

Reflection [%]

Wavelength [nm]

Deviation [%]

Wavelength [nm]
Solved Problems in Atmospheric Correction

Relying on:

• Data calibration
• Accurate LUT generation or reference (MODTRAN…)

Implemented or used in ATCOR:

• Vicarious radiometric and spectral calibration
• Link of geometric and atmospheric correction
• Aerosol retrieval and haze correction
• Cloud- and cast shadow correction
• Correction of spectral smile
• Water vapor retrieval (over land)
• Topographic illumination correction
• Empirical illumination BRDF correction

Haze and Cirrus Correction
Cloud and Cast Shadow correction
Empirical BRDF Topographic Correction
Spectral Smile?

Across Track Pixel Number

Relative Smile [pixels]
Using Modtran 5 in ATCOR-4

- Completely updated atmospheric database at 0.4 nm internal spectral resolution (in order to support 2nm spectral resolution imaging spectrometers)
- Uses the Kurucz 2005 database as basis (Option to switch solar irradiance function)
- Using Correlated-K with DISORT for all calculations of database,
- Provided with universal 6.2GB database.

Differences: HYSPEX
Conclusions

Atmospheric and radiometric correction seems to be an ever evolving topic…

Recent advances have been made with respect to

- Coupling of geometric and atmospheric correction (i.e., raw-geometry based atmospheric processing)
- the correction of haze and cirrus,
- the incorporation of spectral smile,
- water vapor retrieval accuracy (including smile)
- automatic processing possibilities (e.g., aerosol type detection)
- spectral resolution
Outlook

Open Challenges
- Water vapor over water and dark objects
- Overcast sky (fully diffuse illumination) correction
- Aerosol size distribution and complete aerosol characterisation
- Inclusion of further gases based from imagery (oxygen, CH4)
- Coupling with water radiative transfer for limnology
- Cirrus correction
- Work on spectral polishing/pushbroom calibration residuals
and:
  - complete BRDF correction (‘BREFCOR’)

Model based BRDF correction (BREFCOR)

(see talk of T. Feingersh)
Model based BRDF correction (BREFCOR)

(see talk of T. Feingersh)

Thanks!

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