High-Speed Atmospheric Correction Algorithms for Spectral Image Processing*

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* NASA SBIR Phase I, D. Mandl (NASA GSFC TPOC)
Topics

• SSI Overview
• VNIR-SWIR Atmospheric Correction
• Thermal IR Atmospheric Correction
• MODTRAN
• MCScene (3D Scene Simulation)
Spectral Sciences, Inc. Overview

• Incorporated: January, 1981
  – Near to Burlington Mall
• Annual Sales: $10M
• Full-Time Staff of 42
  – 33 Ph.D. and 2 M.S.
• Major Business Areas
  – Remote Sensing, Physics Modeling, Basic Research & Software Development
  – Field Experiment Planning and Data Analysis
  – Trace Gas/Industrial Sensor Development

We apply basic scientific research to challenging problems in the National Defense and Commercial sectors.
Atmospheric Correction Basics

Scattered Sunlight off Earth Surface

Observed Signal
Atmospheric Correction Algorithm
True Spectral Reflectance
FLAASH Overview

- Development
  - SSI lead with primary support from AFRL, additional support from NGA, NASA, SSI
  - ENVI commercial product with ITT-VIS
  - FLAASH-C developed for NGA parallel processing system

- Science/Features
  - MODTRAN radiative transfer; pixel-by-pixel water retrieval; scene visibility retrieval; adjacency effect and spectral smile compensation; spectral polishing; wavelength self-calibration

- Operating Modes
  - Interactive (IDL) or batch (FLAASH-C)
  - High-speed MODTRAN LUT option (ongoing development)

- Demonstrated Sensor Support
  - AISA-ES, ALI, ARTEMIS, ASAS, ASTER, AVHRR, AVIRIS, CASI, Compass, GeoEye-1, HYDICE, HyMap, Hyperion, IKONOS, Landsat, LASH, MaRS, MASTER, MODIS, MTI, Probe-1, QuickBird, RapidEye, SPOT, TRWIS, WorldView-2
FLAASH Science

RT Equation

\[ L^* = \frac{a \rho}{1 - \rho_e S} + \frac{b \rho_e}{1 - \rho_e S} + L_a^* \]

MODTRAN-derived

Adjacency Compensation

Validation with Ground Truth

Visibility Retrieval
FLAASH Comparison to “Truth”

FLAASH (black lines)    ASD Spectra (colored lines)

AVIRIS (NASA Stennis)
Current Phase I SBIR Program

• Problem
  – High duty cycle of upcoming missions (e.g., HyspIRI) requires high accuracy, fully automated, low latency, near real-time atmospheric correction (AC) processing
  – NASA’s current AC algorithms require upgrades in science and coding

• Solution
  – Transition NASA’s current and future AC processing to a fast version of the C++ language FLAASH-C code

• SBIR Program Objectives
  – Port FLAASH to the Elastic Cloud or IAAS
  – Develop a look-up table (LUT) for near-real-time FLAASH processing
  – Phase II: implement on prototype flight hardware

• Team: Spectral Sciences, Inc. (S. Adler-Golden) and Vightel Corp. (P. Cappelaere)
• **Ground-based system:**
  - Will support Hyperion, Landsat, ALI, MODIS, ASTER

• **On-board system:**
  - For direct broadcast of products from HyspIRI, LDCM in near real-time
FLAASH Speedup via Look-up Table (LUT)

- Large LUT replaces the custom MODTRAN calculations
  - Eliminates Fortran module and results in a ~2x Speed Up
  - FLAASH-C timing with LUT - ~ 10 sec for Hyperion data strip using a single 2.7 GHz micro-processor
- In feasibility demo in a 2000 NASA Ph 1 program
  - “Giant” LUTs (GLUTs) built for AVIRIS (20 km alt) and HYDICE (3 km alt) data
- SSI recently delivered FLAASH-C with the 20 km GLUT to Goddard for testing
  - Installing on Elastic Cloud system
- In Phase I new LUTs are being build for space applications
  - TOA (Top Of the Atmosphere) nadir and off-nadir
- Storage: original GLUT ~ 615 Mb; new LUT database will require compression — e.g., ~10x (slightly lossy) with SVD
Infrared Atmospheric Correction

Goal: Remove atmospheric effects and retrieve surface emissivity \( \varepsilon \) and temperature \( T_s \).
IR Atmospheric Correction Algorithms

• Underlying problem – more unknowns than knowns, thus one needs to introduce a physically meaningful constraint

• Spectral Smoothness (C. Borel): Vary atmosphere and $T_{\text{surf}}$ to retrieve spectrally smoothest emissivity $\varepsilon$
  – Limited to Hyperspectral data

• Minimum $T_{\text{surf}}$ Variance (SSI & NG): Vary atmosphere and $\varepsilon$ until narrowest distribution of $T_{\text{surf}}$ is obtained
  – Applicable to Hyper- and Multi-spectral data

• Minimum $T_{\text{surf}}$ Variance with Endmember Expansion (SSI & LM): Only need to correct endmembers
  – Very fast

• Fully automated ENVI/IDL prototypes for all three methods
MODTRAN5 Overview

• Overview
  – IR-Visible-UV Spectral and Channel Transmittances, Radiances, Fluxes, and … from 0.1, 1.0, 5.0 or 15.0 cm\(^{-1}\) Band Models
  – Stratified (1D) Molecular / Aerosol / Cloud Atmosphere
  – 2-Stream and DISORT Solar and Thermal Scattering
  – Spherical Refractive Geometry

• Applications
  – Sensor Design
  – Atmospheric Correction
  – Measurement Planning
  – Data Analysis
  – Scene Simulation
  – Algorithm Development
  – Local chemical plume

**PLUG IN for MODTRAN5.3**

• **PNNL Data Base**
Remote Sensing of Volcanic Plumes from Space

• The NASA Decadal Survey suggests that impending volcanic eruptions may be signaled by changes in gas emissions rates

• SO$_2$ column abundances >1g/m$^2$ (~350 ppm-m) have been derived from MODIS data

• MODTRAN local gas plume option provides a tool for modeling SO$_2$ contrast signatures
  – H$_2$O absorbance interferes with the stronger SO$_2$ absorption bands
Simulated SO$_2$ Release

- Long-wave sensitivity study using MLOS option
- Contrast includes thermal emission and a small thermal scatter component
- Near 4\(\mu\)m, scatter component is \(~\)an order of magnitude larger than the thermal
- Ignoring the scatter contrast would produce a large error
• 3D atmospheres with 3D clouds and cloud fields
• 3D surfaces with BRDF’s and object insertion
• 3D faceted object insertion
• MODTRAN optical properties, profiles, and spectroscopy
Simulation of Visibility

- **Davis CA scene**
  - Reflectance from HYMAP data
  - 121 spectral bands
  - 2.75 m GSD
- **Sensor altitude**
  - 50 km
  - nadir view
- **45 deg solar zenith angle**
- **Uniform atmosphere**
  - Mid-latitude summer
  - Rural aerosol
- **Reflectance outside of scene is assigned the in-band average**
CSSM*  
(Cloud Scene Simulation Model)

- Realistic high-resolution cloud features, defined by larger-scale weather conditions in 4D
- Relies on stochastic field generation techniques and convection physics
- 3D cloud voxels contain cloud properties which are used in MCScene
  - Water state
  - Water density
  - Precipitation density

Thank You

Any Questions?