Atmospheric Correction Enables Surface Characterization

Maple Leaf (True)

Apparent (Space)

Observed Spectrum
Atmospheric Correction
True Reflectance Spectrum
Objectives & Approach

• Use SSI’s FLAASH code to address the challenges of automated, high-speed, high-accuracy atmospheric correction in both on-board and ground processing systems

• Simplify data processing and distribution to NASA scientists

• Support NASA’s visible-through-shortwave-infrared (VSWIR) spectral imaging instruments, including:
  – Current EO-1 instruments Hyperion and ALI and operational Landsat satellites; Landsat Data Continuity Mission (LDCM)
  – HyspIRI and associated test missions;
  – AVIRIS, MODIS on Terra and Aqua

• Approach
  – Giant look-up tables (LUTs) of MODTRAN5 radiative transfer simulations enable near-real-time processing
  – Newly released C++ version of FLAASH for portability and speed, supports ground-based and onboard processing
Needs: Emergency Response

Mobile Bay Oil Spill Detection Using EO-1 Advance Land Imager Data

green = land
white = cloud & sand
black = cloud shadow
blue = clear water
grey = surface oil
• Example: Hyperion image of the 2011 New Mexico wildfires
• SWIR wavelengths diminish the effects of haze and smoke, highlight active hotspots and burn scars.
FLAASH Overview

• Codes
  – Originally developed by SSI with primary support from AFRL, additional support from NGA, NASA, SSI
  – ENVI commercial product developed from the original IDL code
  – FLAASH-C developed with DoD support; public release May 2011

• Science/Features
  – MODTRAN-5 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 lookup-table 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
Atmospheric Modeling
FLAASH Processing

- RT Equation

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

- Adjacency compensation reduces signature mixing

Retrieval vs. Ground Truth

MODTRAN-derived Water vapor map
Molecular absorption features are used to estimate wavelength calibration errors based on a Normalized Optical Depth Derivative (NODD) error metric. Smile-compensation factors are determined by analyzing the image in narrow, cross-track segments.
Ground-Leaving Radiance
2011 Los Alamos Fire

- Hyperion spectral radiance *before* and *after* atmospheric correction.
- *Thermal radiance* emitted by the ground, gases, and smoke in an active fire pixel (red) was estimated by simple background subtraction.
Phase I Program Accomplishments

• Giant LUT Development
  – Developed LUT for rural aerosol – ~1CPU-week of MODTRAN calculations
  – >100-fold compression with PCA (16 Gbytes → 100 Mbytes)

• FLAASH-C Development
  – Introduced support for compressed LUT format
  – Timing improved for MSI and HIS processing
  – New feature: atmospherically corrected radiance (blackbody emission in “hot” pixels for characterizing fires, volcanoes, etc.)

• Demonstrations: EO-1 Data (Hyperion, and ALI) - LUT and/or MODTRAN versions
  – On NASA Elastic Cloud automatically processing new scenes
  – As a WCPS algorithm re-processing archived scenes on-demand
  – Embedded on the Intelligent Payload Module (IPM), Telera
Speedup via Look-up Tables (LUTs)

- Large pre-calculated LUTs replace the custom MODTRAN simulations in the FLAASH atmospheric retrievals
  - Initial LUTs constructed for a rural aerosol model (5-300 km visibility)
  - ~146,000 MODTRAN calculations, 5 cm\(^{-1}\) resolution
  - Required ~1 week of serial runtime on a PC
  - Generated 800 GB of raw MODTRAN output (text)
  - Extracting the FLAASH LUT parameters reduced the data to 16 GB (binary)

PC Run Time (2.7 GHz)
**LUT Compression**

- Reduced the LUT data volume using a principal component analysis (PCA) transformation
  - Manageable size for onboard processing (100 – 200 MB)
  - Improve lookup and interpolation runtime performance by reducing file I/O

- PCA translates the LUT dimensions onto orthonormal basis vectors, ordered by variance:
  - Matrix diagonalization / inversion of high-dimensional data is challenging
  - Iterative methods are more efficient when a limited number of basis vectors are needed
  - Non-linear Iterative Partial Least Squares (NIPALS) algorithm

- Compressed each LUT component separately
  - Six 2.7 GB matrices, ~1 day to compute 64 eigenvectors
• Data compressed with 32 basis functions, 150x reduction
• Compressed data is roughly the size of a single Hyperion image
• Worst-case error localized around the 760 nm oxygen feature
LUT Evaluation

• RT parameters interpolated and extracted from the compressed LUTs
• Hyperion reflectance spectra compared against MODTRAN results
  – Retrieved Hyperspectral reflectance values agree to within +/- 0.01
  – Differences dominated by interpolation error, not compression
Future Plans

• **Code Development**
  – Expand LUTs to include more aerosols/dusts (rural, maritime, urban, desert), extend to lower altitudes for aircraft (e.g. EMAS)
  – Parallelize for multiprocessor systems (Tilera)
  – Include Thermal IR (TIR) atmospheric correction options
    • Fusion of VNIR/SWIR with TIR would benefit the AC process
  – Radiometric re-calibration, image de-striping

• **Code Integration**
  – Fully operational Sensor Web and IAAS data processing, distribution
  – Prototype demonstration for HyspIRI flight system using Space Cube and/or Maestro testbeds
  – Cloud data product generation and distribution
    • Water vapor mapping, cloud cover, vegetation analysis, coastal studies
End
Backup Slides
**Proposed System Concept**

- **Ground-based system:**
  - Cloud computing and distribution
  - Support Hyperion, Landsat, ALI, MODIS, ASTER

- **On-board system:**
  - For direct broadcast of products from HyspIRI, LDCM in near real-time
Automated FLAASH processing and distribution of archival data products via Elastic Cloud and Sensor Web

Web Coverage Processing Service (WCPS) integration grants control over the FLAASH correction process at the user’s request