*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)**

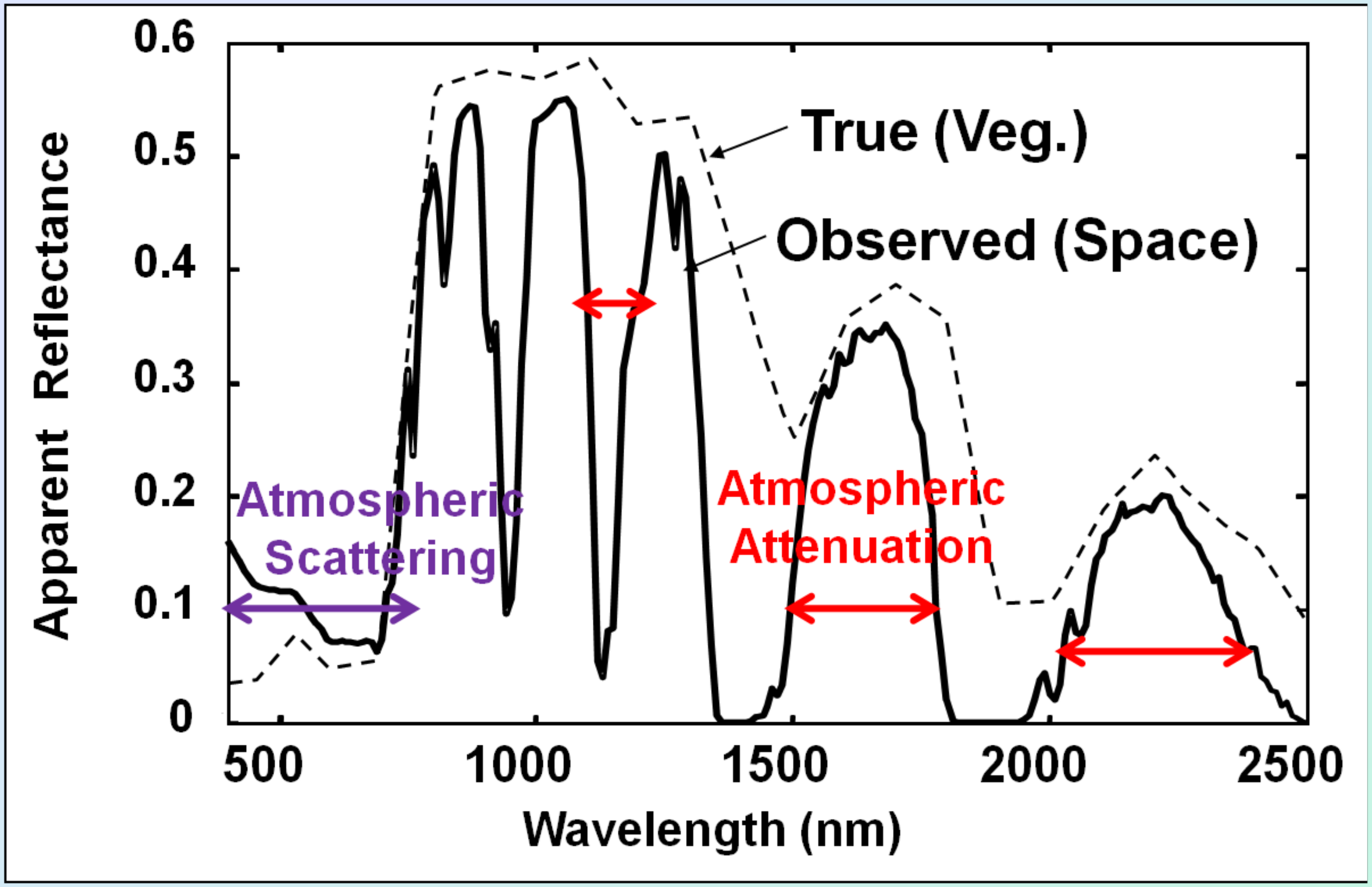
Spectral Sciences, Inc. Overview

- *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

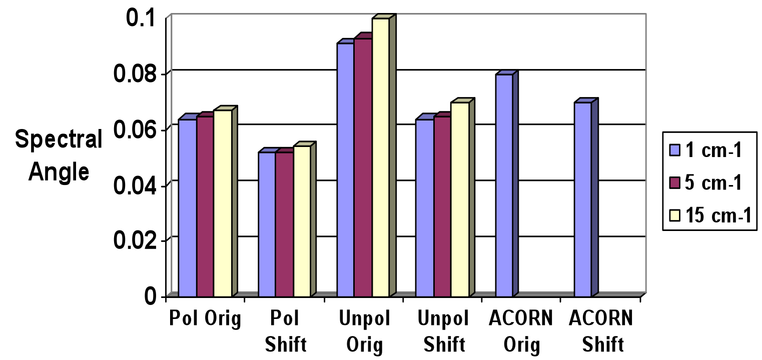
FLAASH Science

RT Equation

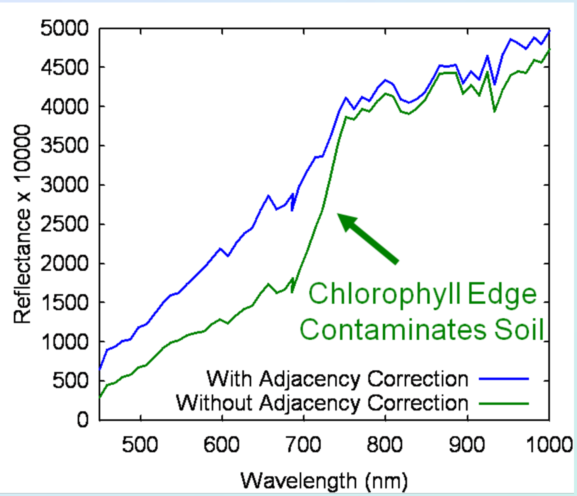
$$L^* = \frac{a\,\rho}{1-\rho_e S} + \frac{b\,\rho_e}{1-\rho_e S} + L_a^*$$

MODTRAN-derived

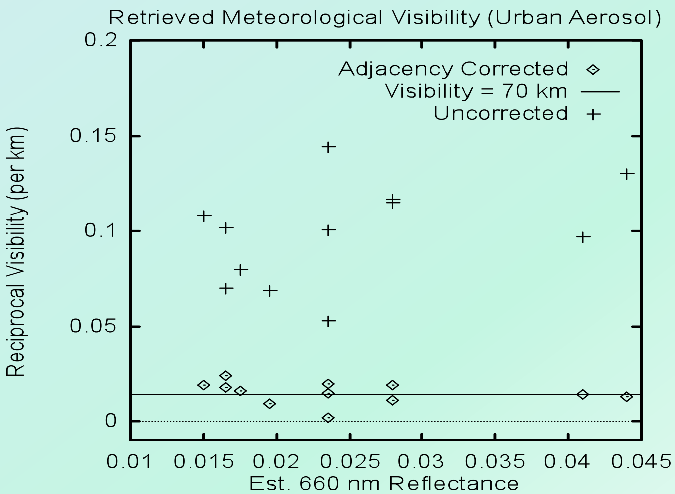
Validation with Ground Truth



Adjacency Compensation

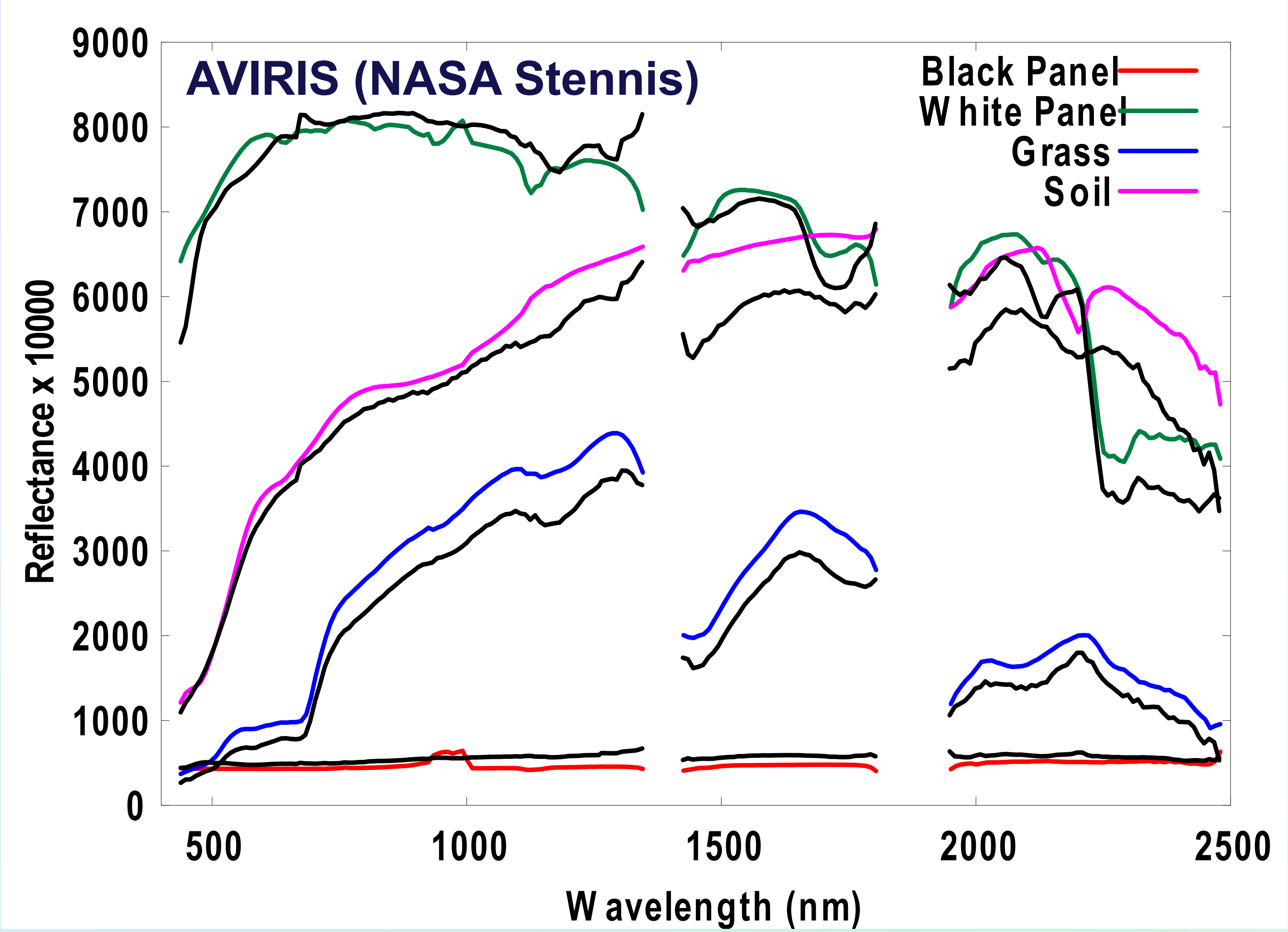


Visibility Retrieval



FLAASH Comparison to "Truth"

FLAASH (black lines)   ASD Spectra (colored lines)

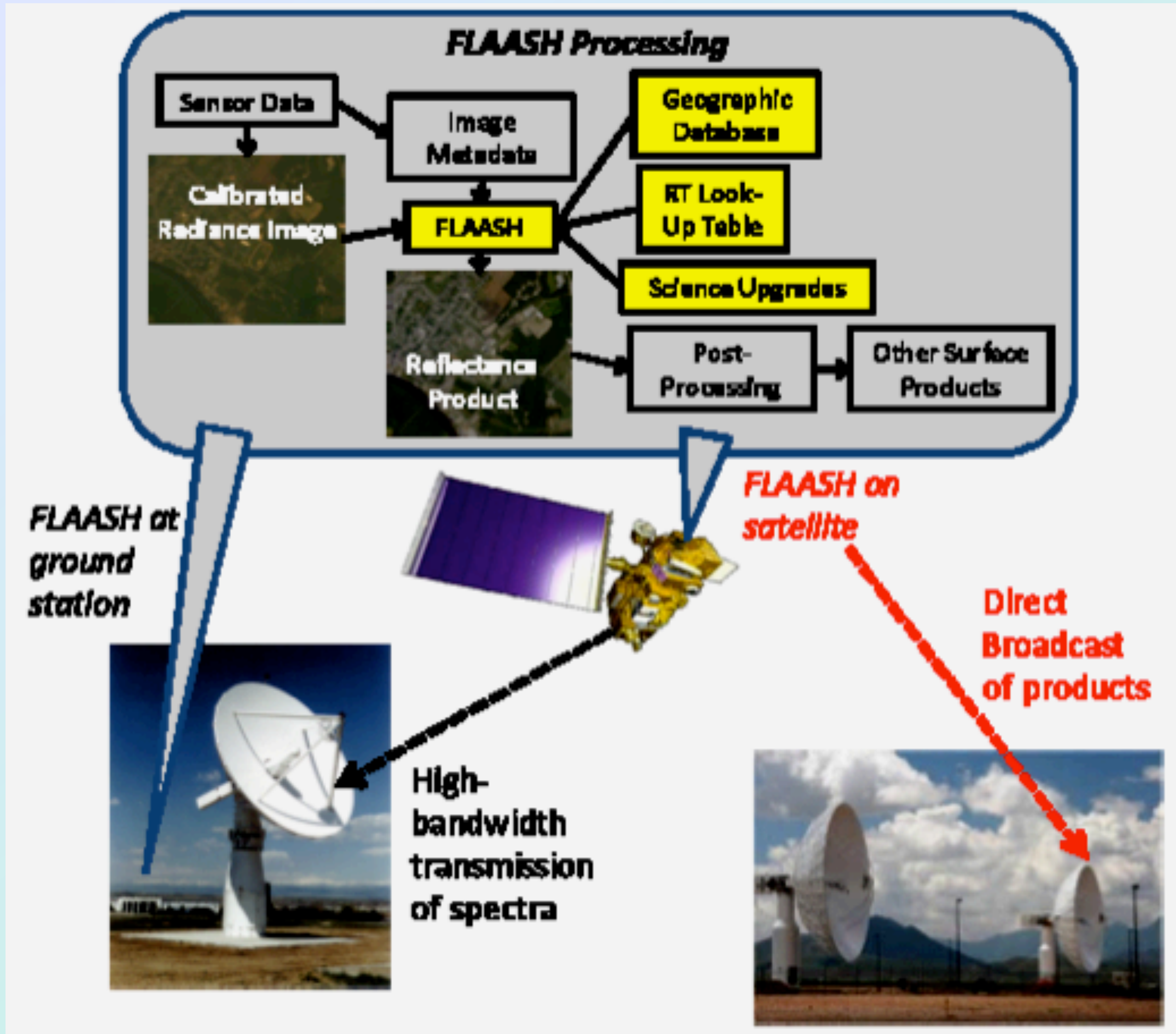


Current Phase I SBIR Program

- 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)

Processing Concept

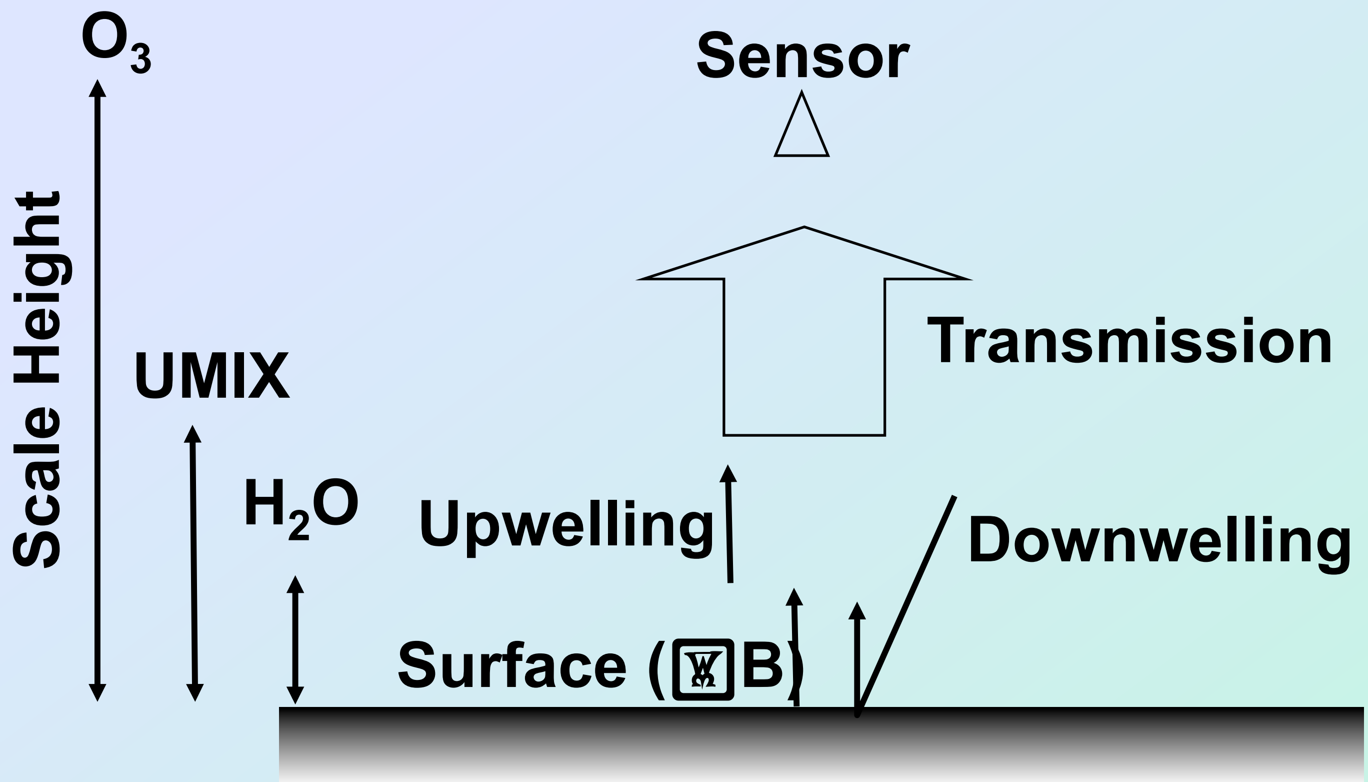
- ***Ground-based system:***
  - Will support Hyperion, Landsat, ALI, MODIS, ASTER
- ***On-board system:***
  - For direct broadcast of products from HyspIRI, LDCM in near real-time



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



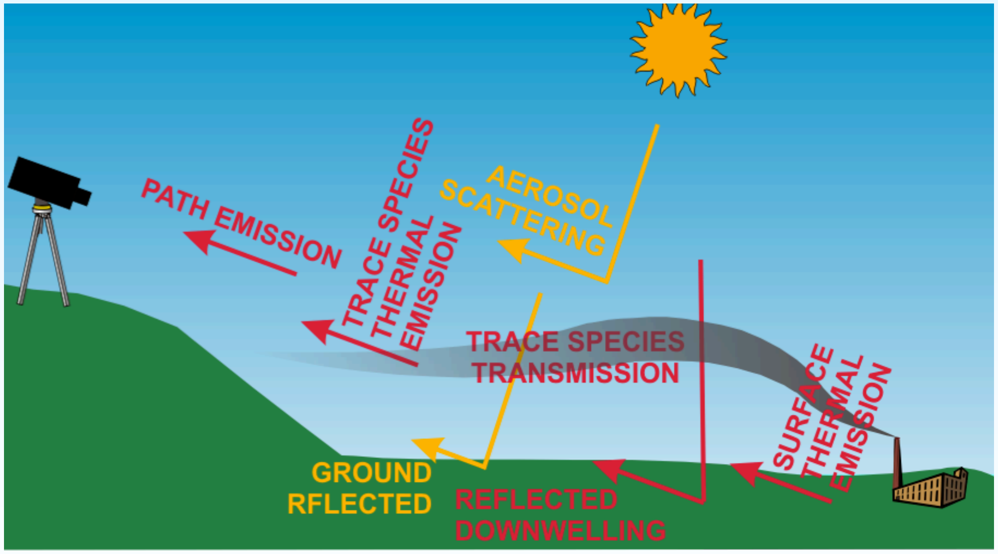
Goal: Remove atmospheric effects and retrieve surface emissivity ε and temperature T_s.

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_{surf} to retrieve spectrally smoothest emissivity ε
  - Limited to Hyperspectral data
- **Minimum T_{surf} Variance (SSI & NG):** Vary atmosphere and ε until narrowest distribution of T_{surf} is obtained
  - Applicable to Hyper- and Multi-spectral data
- **Minimum T_{surf} Variance with Endmember Expansion (SSI & LM):** Only need to correct endmembers
  - Very fast
- Fully automated ENVI/IDL prototypes for all three methods

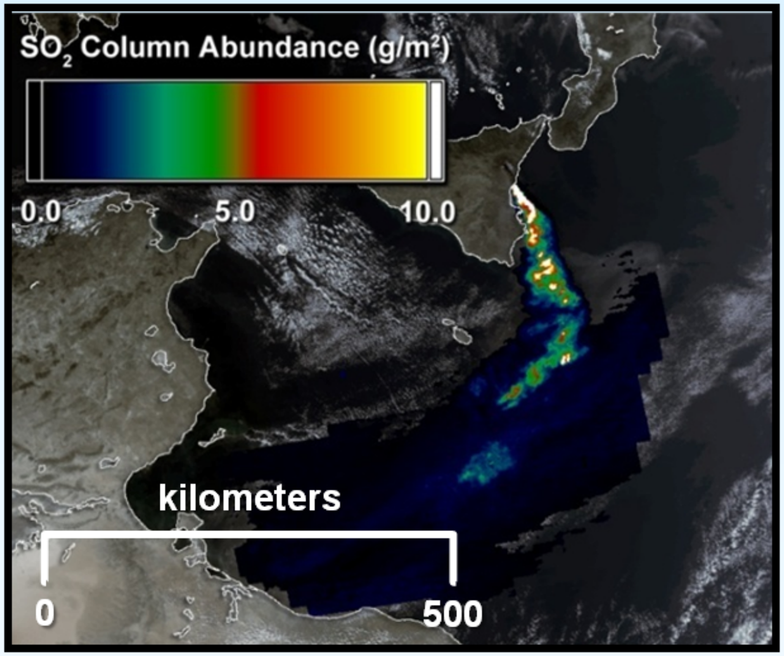
MODTRAN5 Overview

- 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***

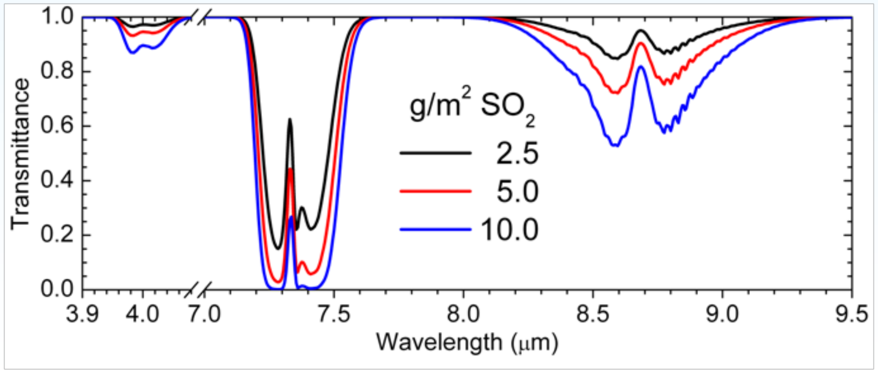


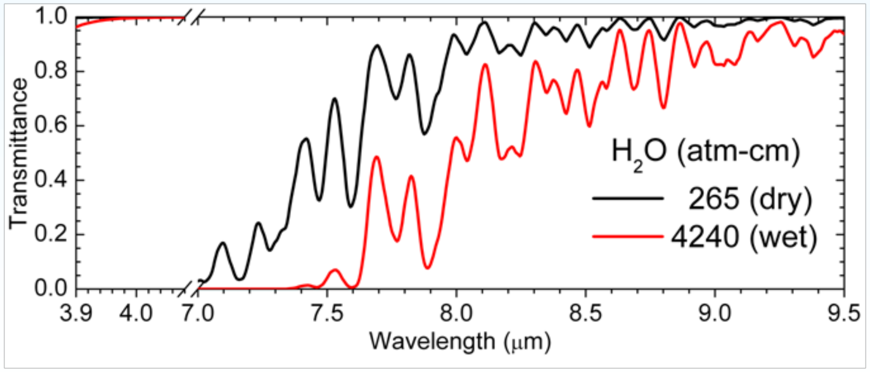
Remote Sensing of Volcanic Plumes from Space

- The NASA Decadal Survey suggests that impending volcanic eruptions may be signaled by changes in gas emissions rates
- SO_2 column abundances $>1 g/m^2$ (~350 ppm-m) have been derived from MODIS data
- MODTRAN local gas plume option provides a tool for modeling SO_2 contrast signatures
  - H_2O absorbance interferes with the stronger SO_2 absorption bands

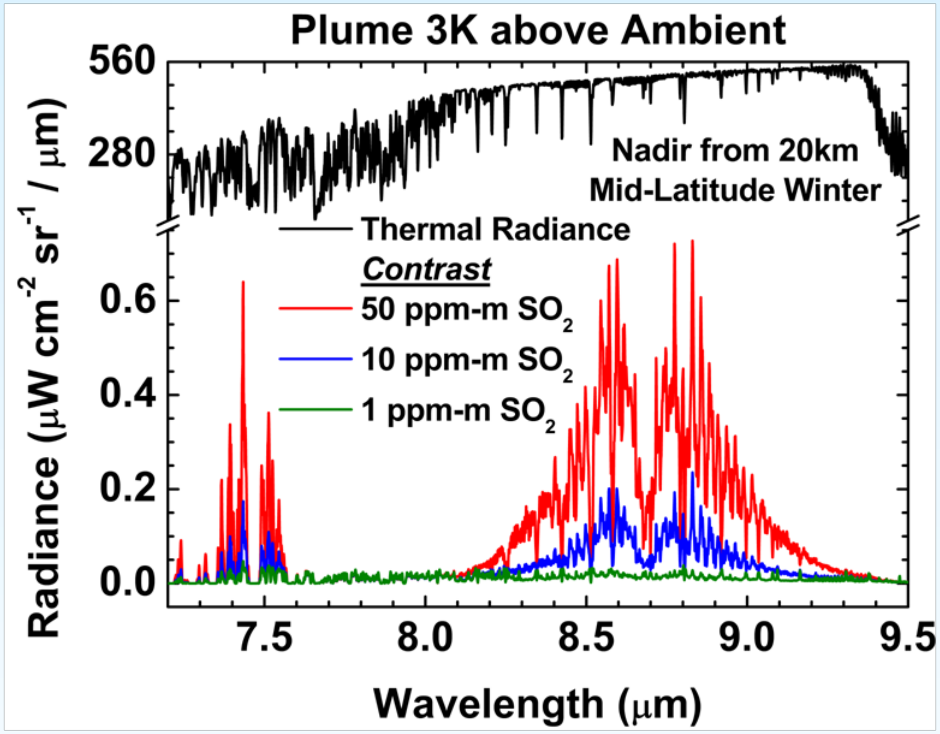


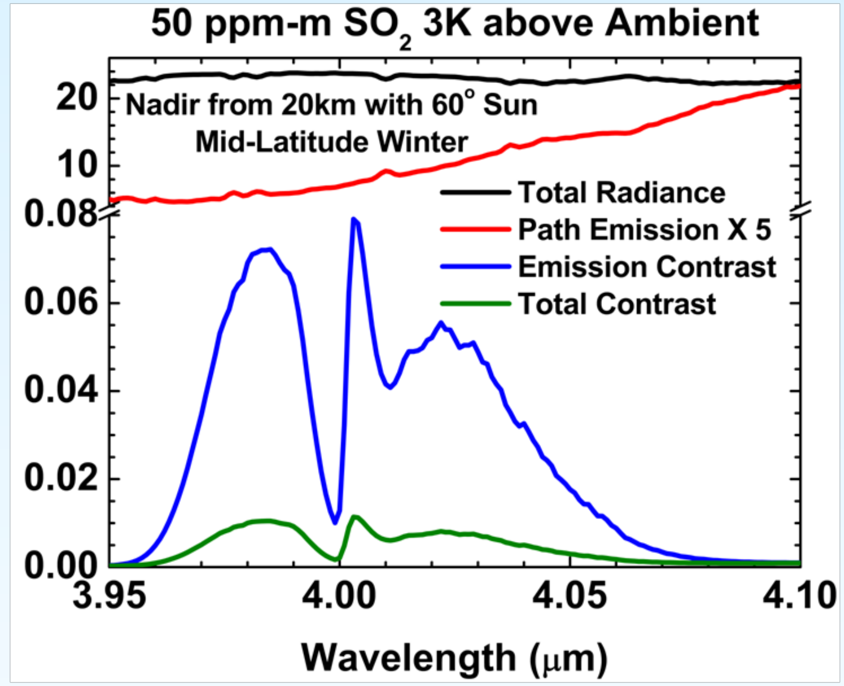
Klyuchevskoy Volcano
MODIS Retrievals of SO_2 column





Simulated SO_2 Release

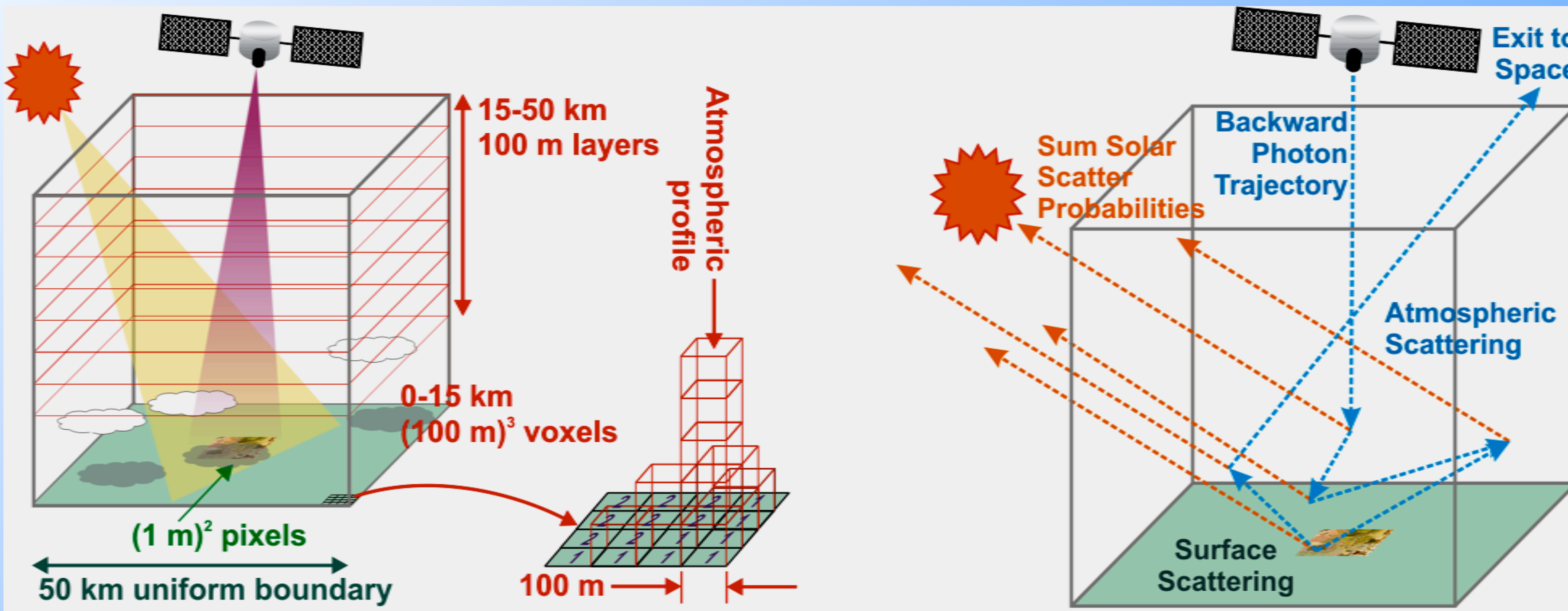




- Long-wave sensitivity study using MLOS option
- Contrast includes thermal emission and a small thermal scatter component

- Near 4μm, scatter component is ~an order of magnitude larger than the thermal
- Ignoring the scatter contrast would produce a large error

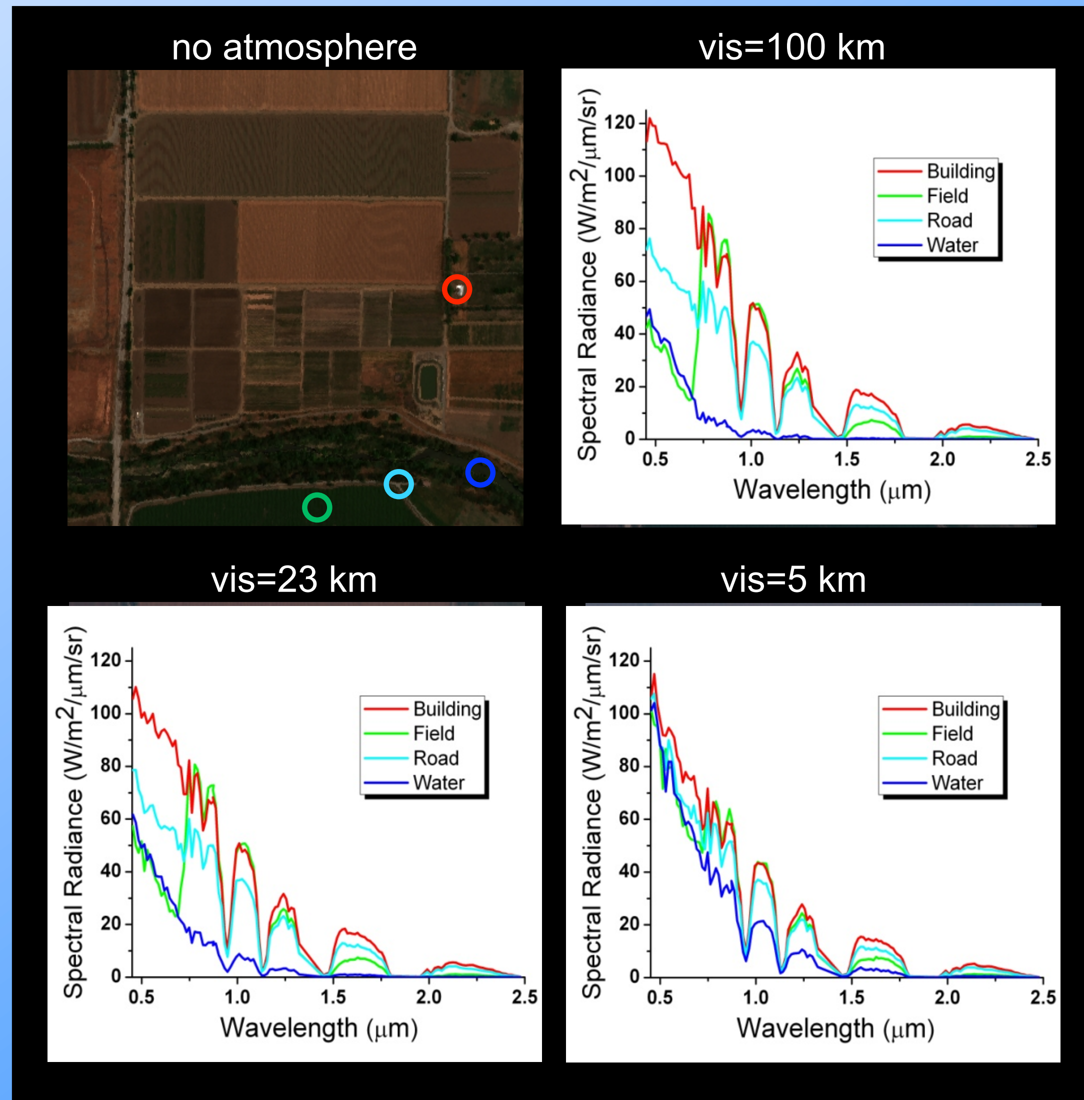
MCScene Reflective Domain Approach



- *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*

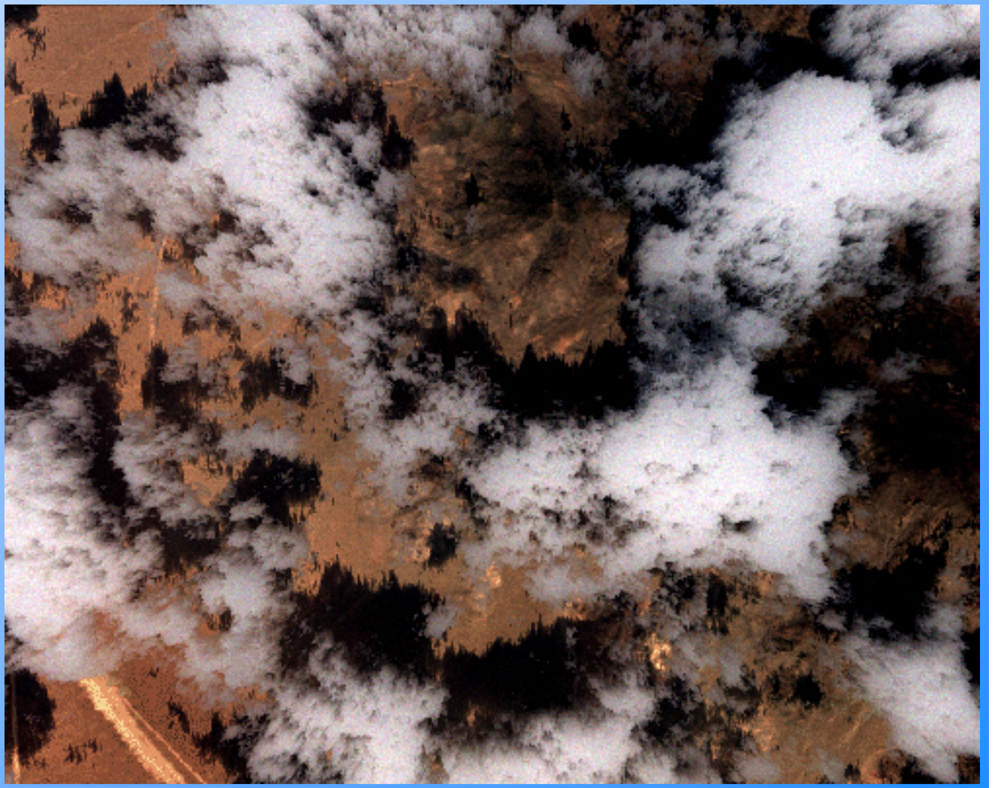
Simulation of Visibility

- *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



*Cianciolo and Raffensberger, "Atmospheric Scene Simulation Modeling and Visualization (AMV): Cloud Scene Simulation Model User's Guide," TASC Report TIM-07169-2,(1996).

Thank You

Any Questions?