High-Speed Atmospheric Correction for NASA Spectral Imaging Sensors

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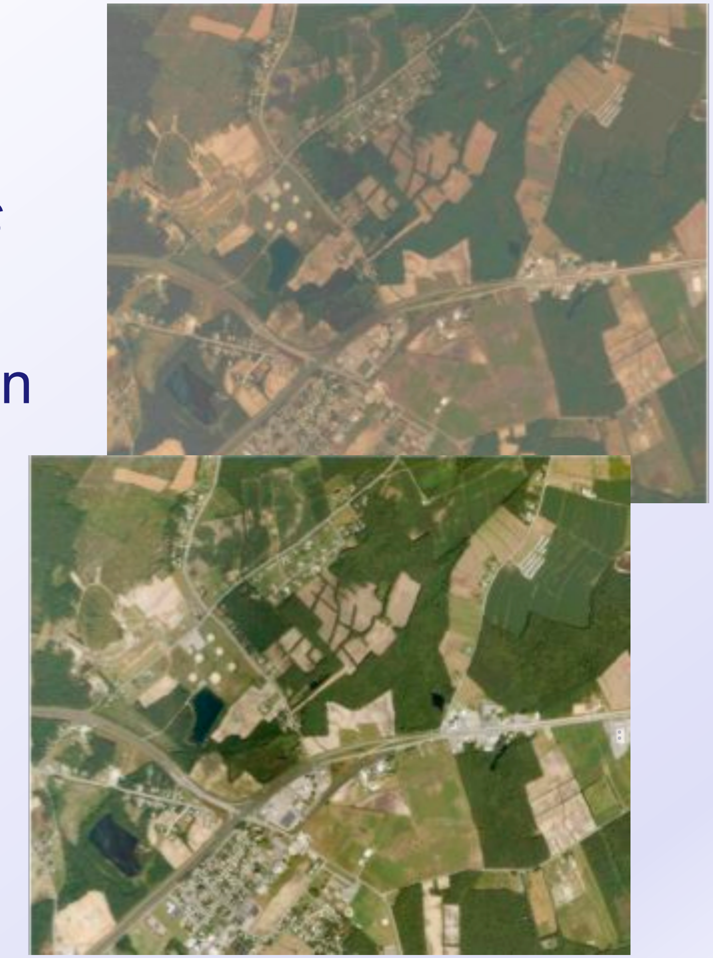
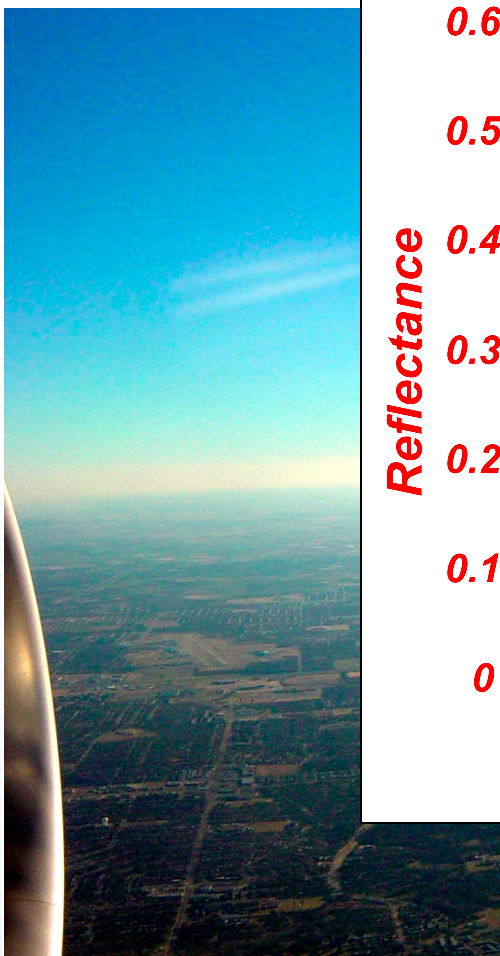
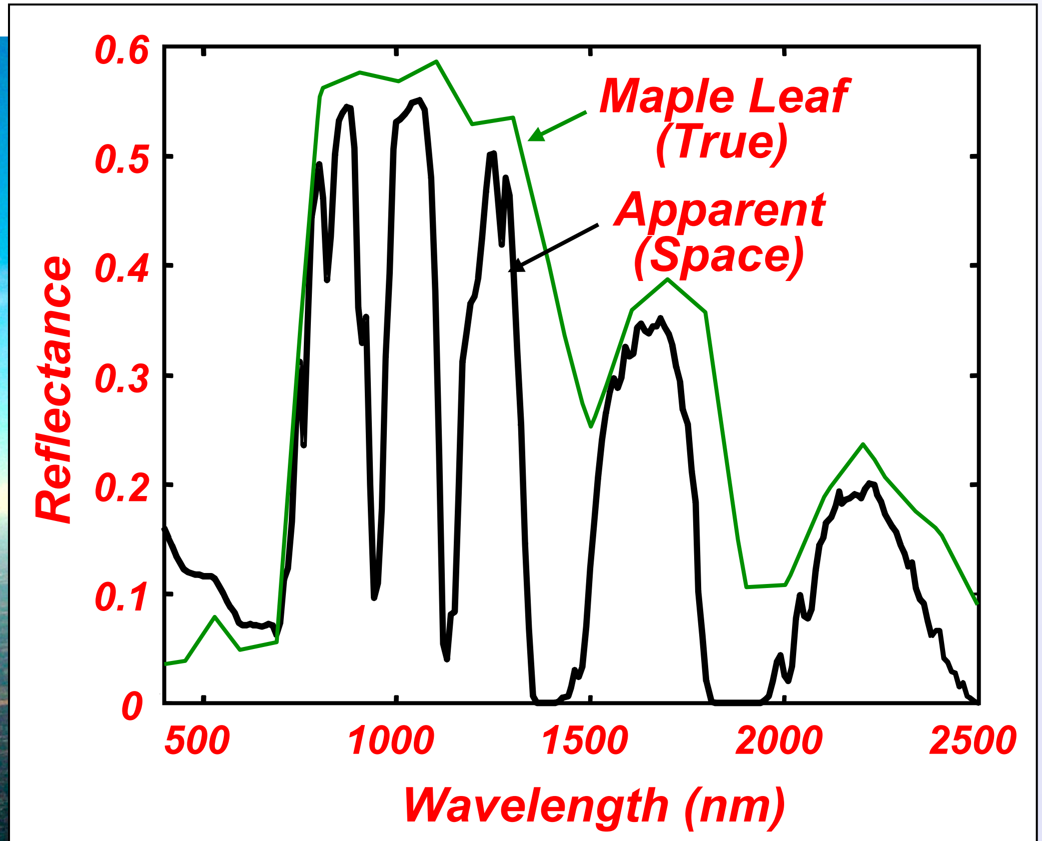


Atmospheric Correction Enables Surface Characterization





Observed Spectrum

↓

Atmospheric Correction

↓

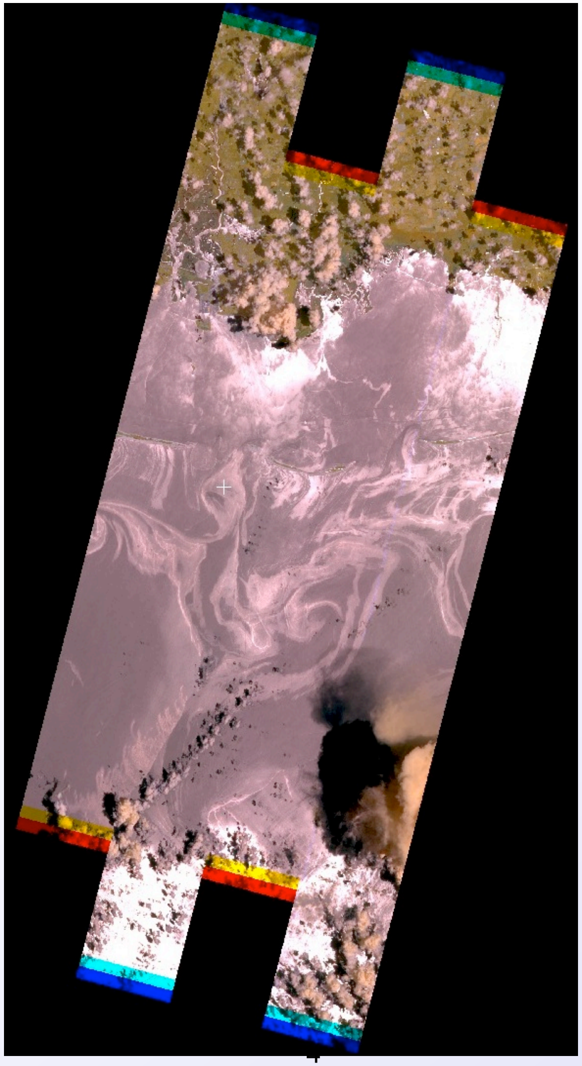
True Reflectance Spectrum

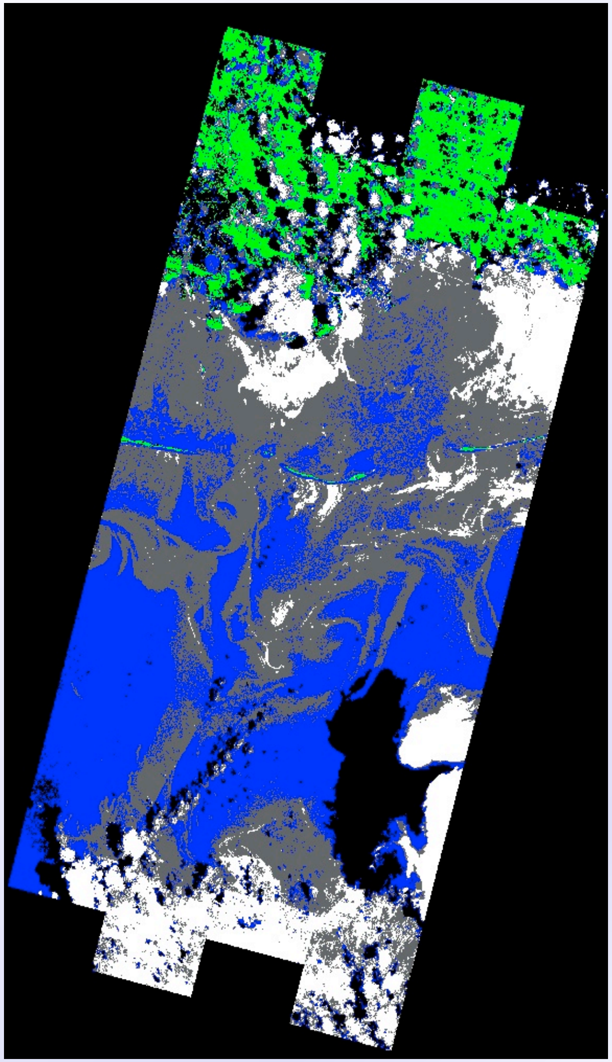
Objectives & Approach

- **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

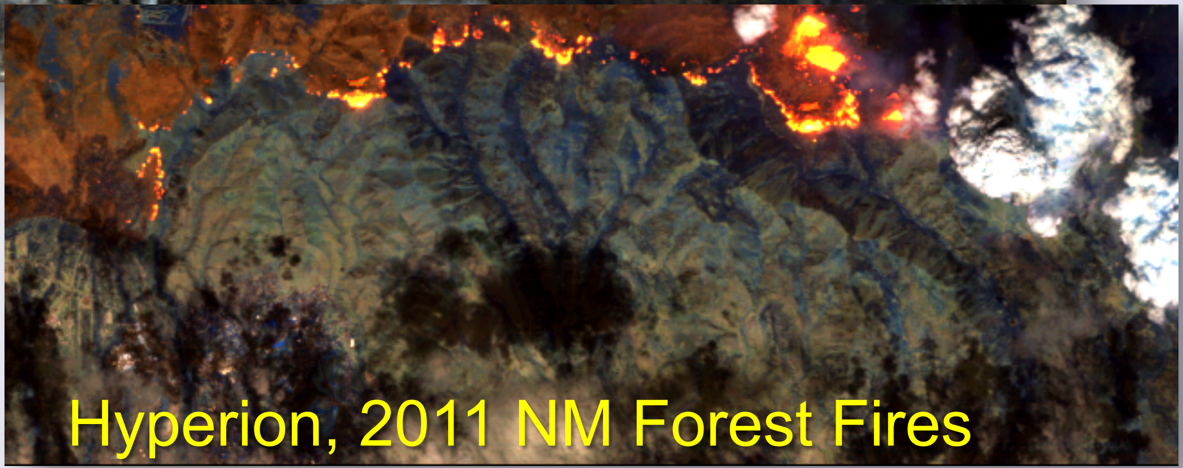
blue = clear water

grey = surface oil

NASA Archive Processing

- Example: Hyperion image of the 2011 New Mexico wildfires
- SWIR wavelengths diminish the effects of haze and smoke, highlight active hotspots and burn scars.

Visible

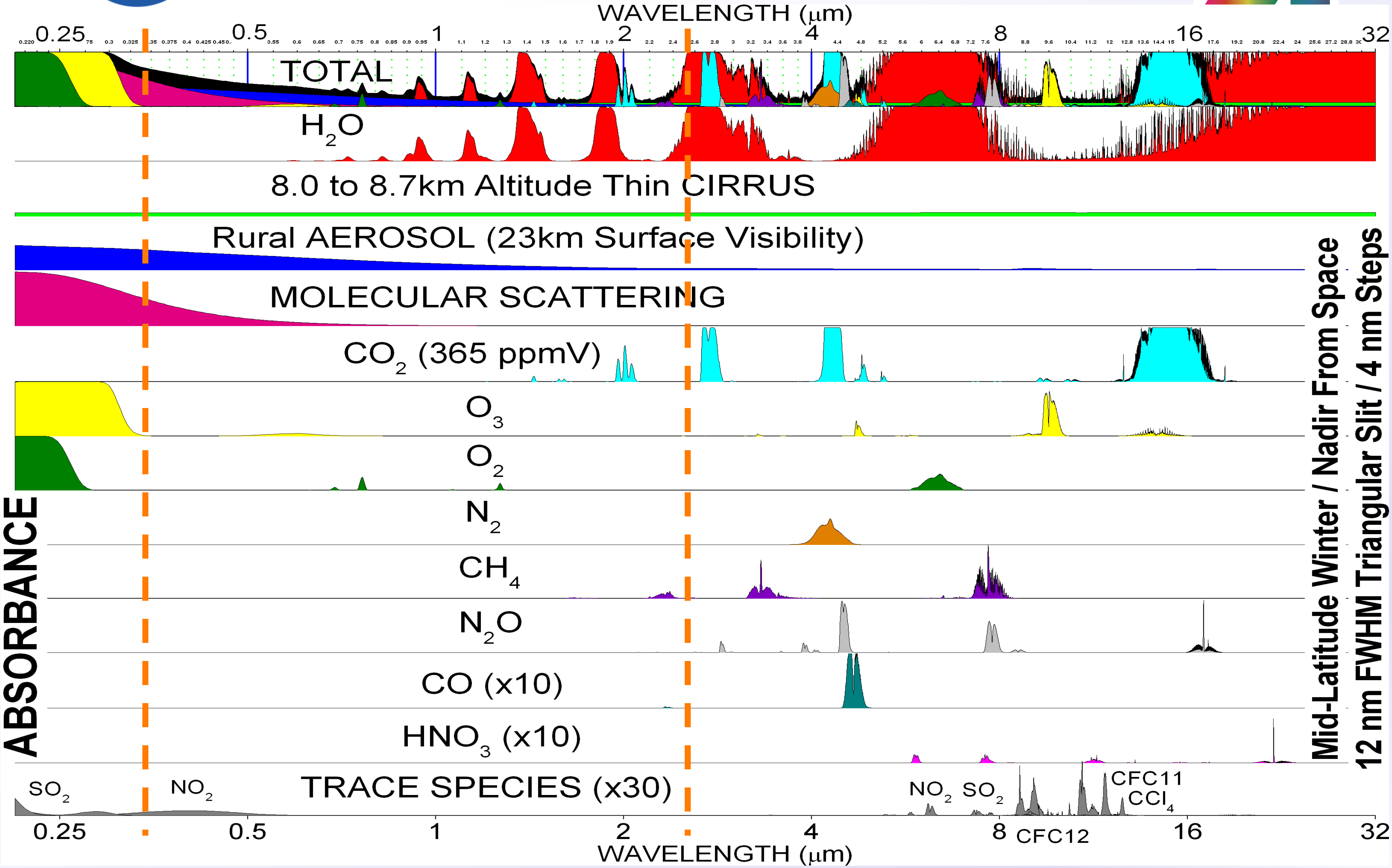


SWIR

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

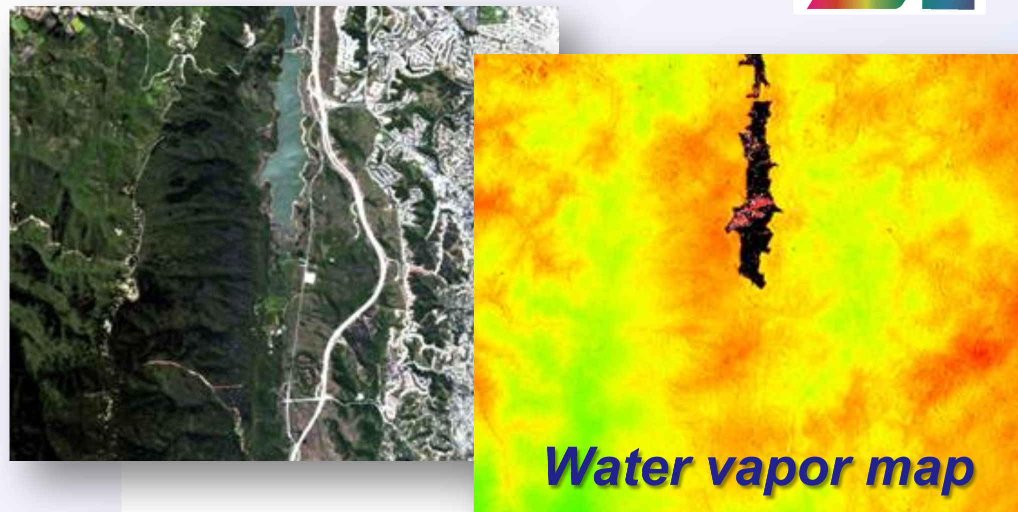


FLAASH Processing

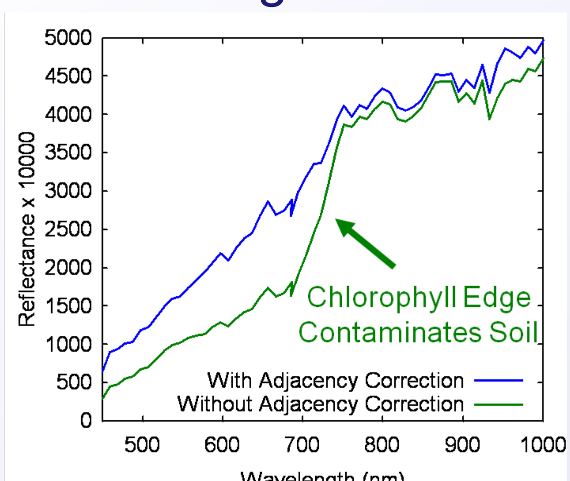
- RT Equation

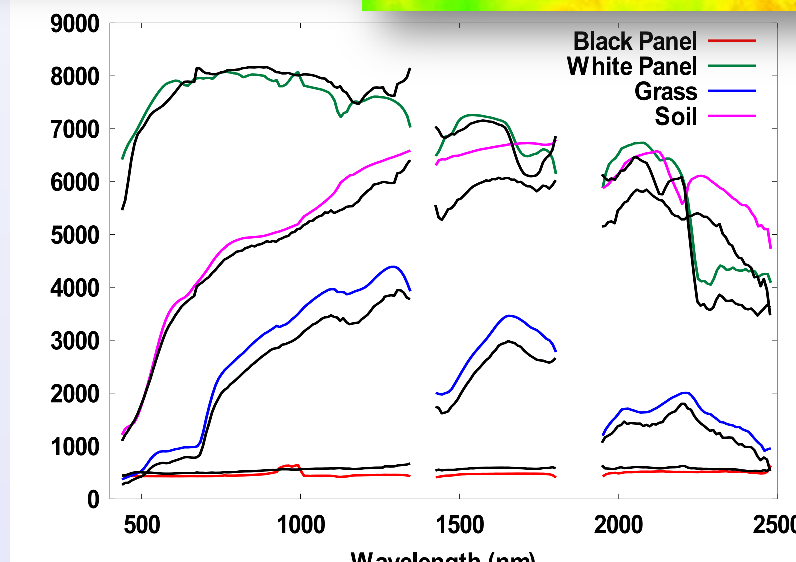
$$L^* = \frac{a\,\rho}{1-\rho_e S} + \frac{b\,\rho_e}{1-\rho_e S} + L_a^*$$

MODTRAN-derived



- Adjacency compensation reduces signature mixing

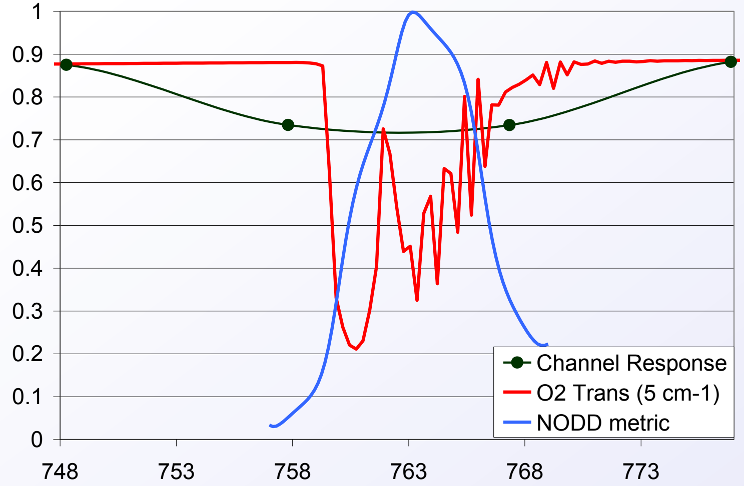




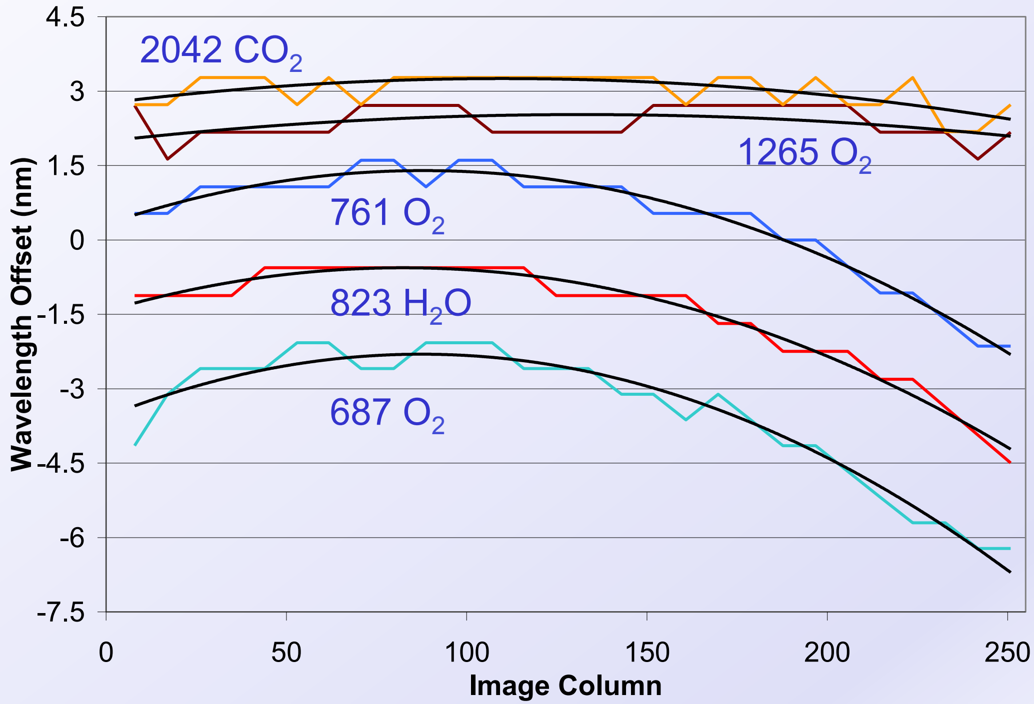
Retrieval vs. Ground Truth

Wavelength and Smile Calibration

- **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.**



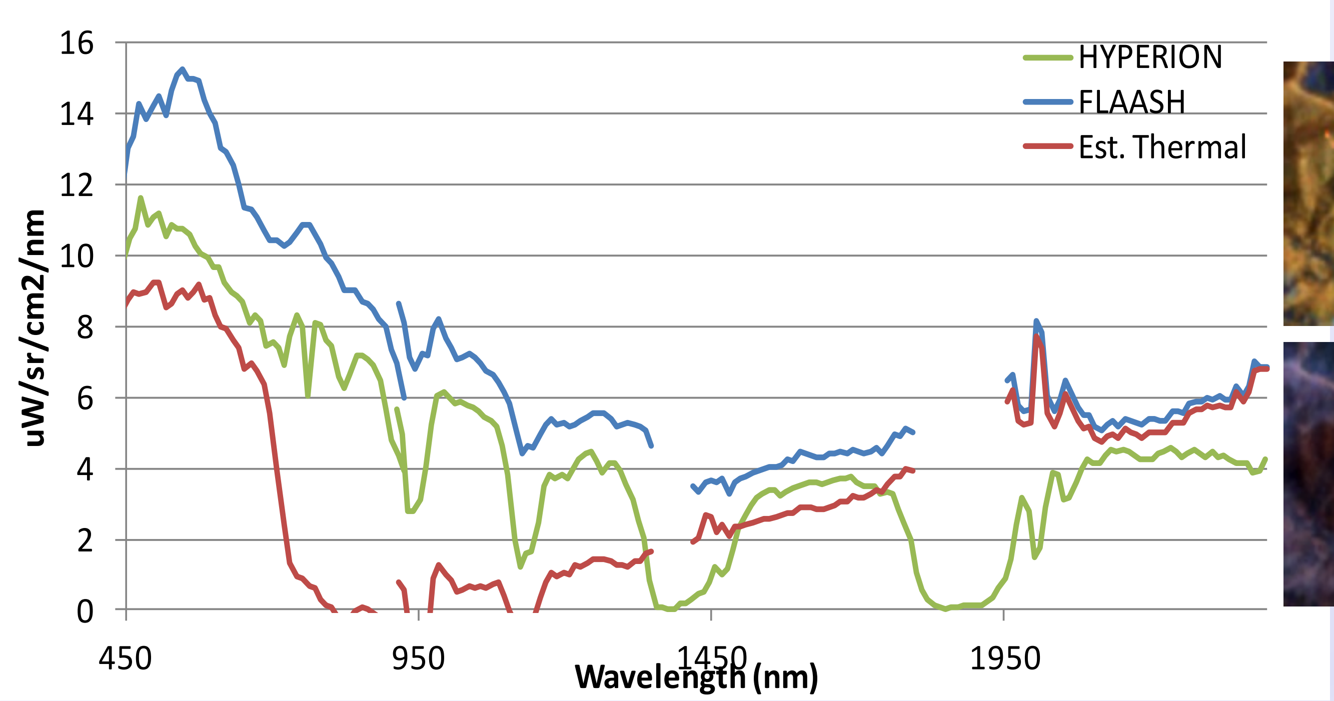
Shift (nm)

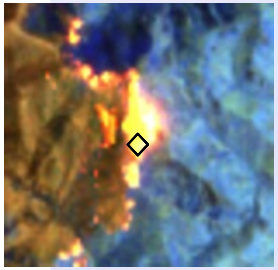


Hyperion Smile Adjustments

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



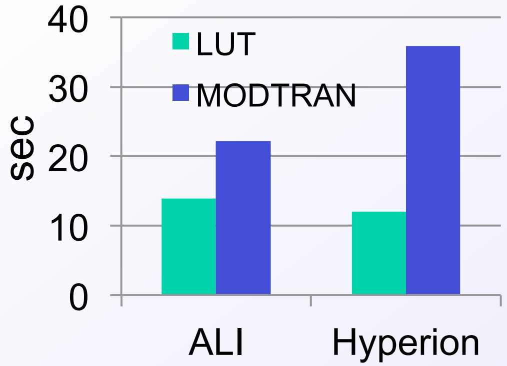


Phase I Program Accomplishments

- **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**



PC Run Time (2.7 GHz)

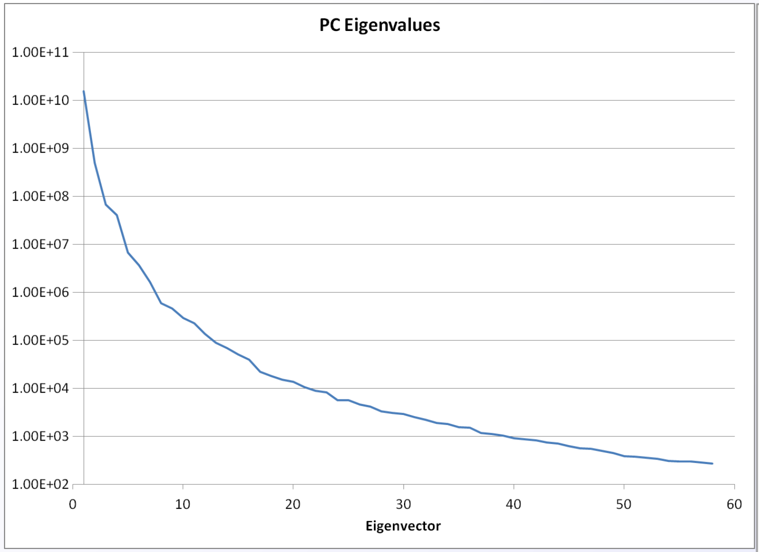
- **Space-based LUTs supporting nadir and off-nadir viewing**
  - *Initial LUTs constructed for a rural aerosol model (5-300 km visibility)*
  - *~146,000 MODTRAN calculations, 5 cm^{-1} resolution*
  - *Required ~1 week of serial runtime on a PC*
  - *Generated 800 GB of raw MODTRAN output (text)*
  - *Extracting the FLAASH LUT parameters reduced the data to 16 GB (binary)*

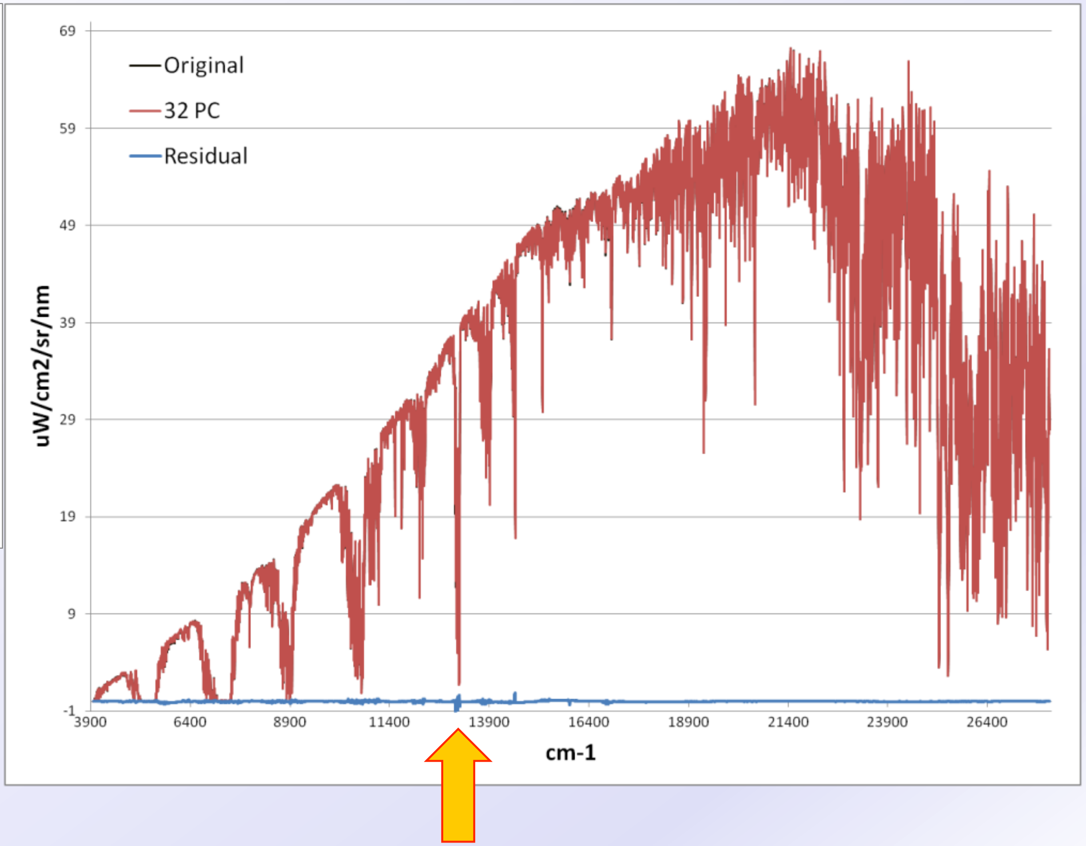
LUT Compression

- 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
  - **N**on-linear **I**terative **PA**rtial **L**east **S**quares (NIPALS) algorithm
- Compressed each LUT component separately
  - Six 2.7 GB matrices, ~1 day to compute 64 eigenvectors

LUT Compression Analysis

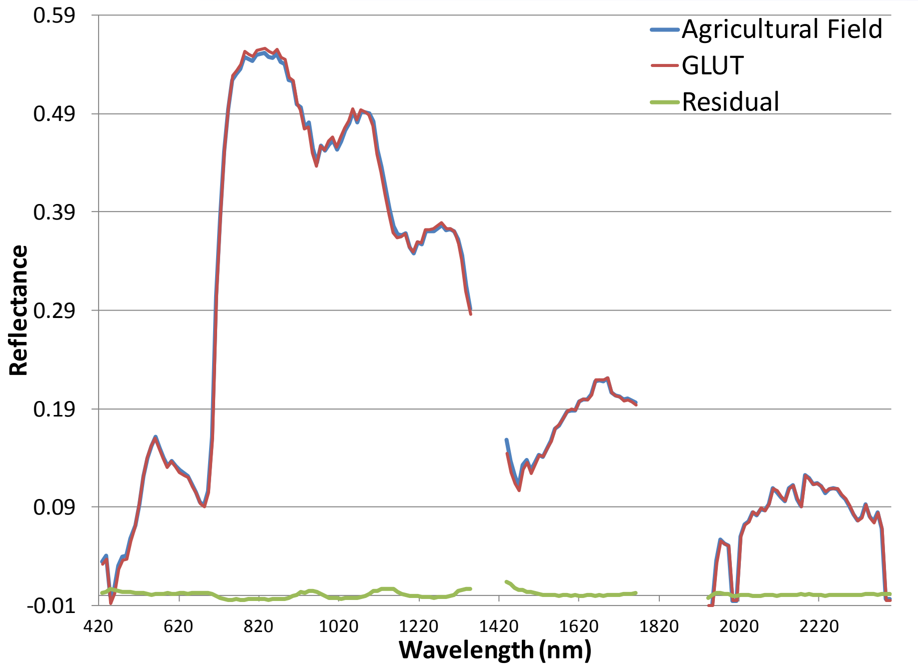
- Data compressed with 32 basis functions, 150x reduction
- Compressed data is roughly the size of a single Hyperion image
- Worst-case error localized around the 760 nm oxygen feature

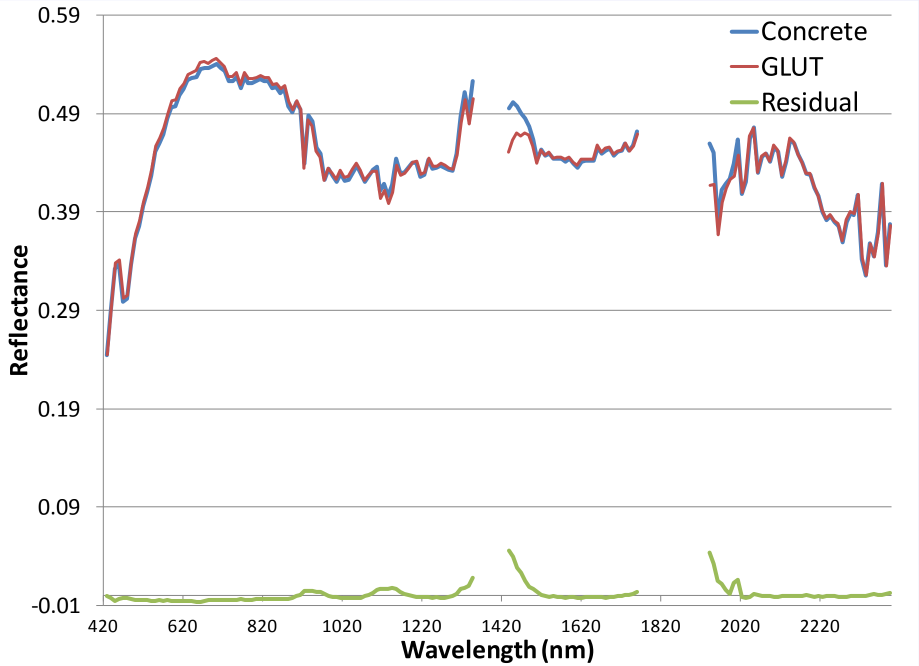




LUT Evaluation

- 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

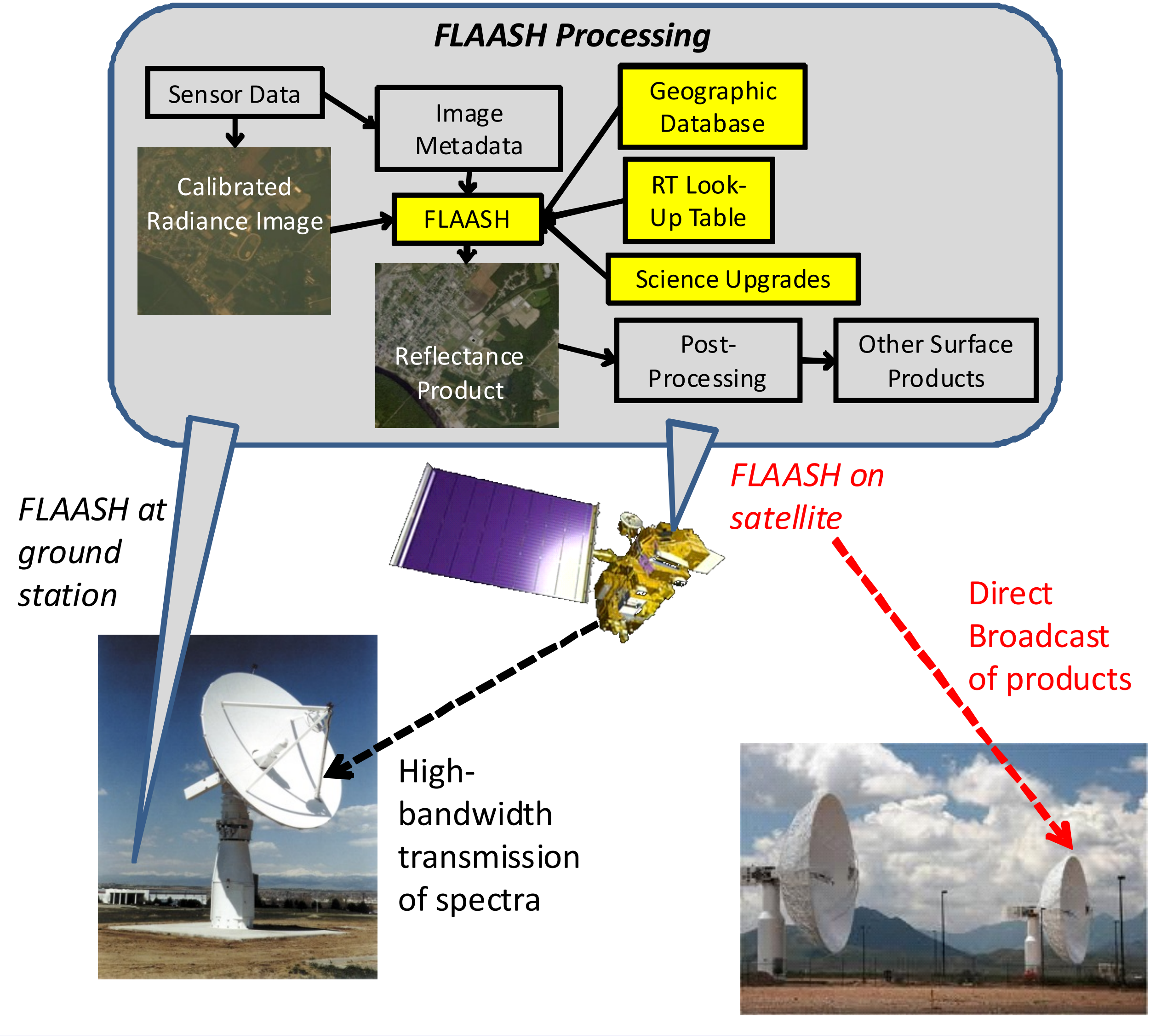
- **Code Development**
  - *Expand LUTs to include more aerosols/dusts (rural, maritime, urban, desert), extend to lower altitudes for aircraft (e.g. EMAS)*
  - *Parallelize for multiprocessor systems (Tilera)*
  - *Include Thermal IR (TIR) atmospheric correction options*
    - *Fusion of VNIR/SWIR with 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



FLAASH Deployment at NASA

- 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