# Atmospheric Correction Algorithms for Surface Reflectance Retrievals from VSWIR Measurements

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# INTRODUCTION

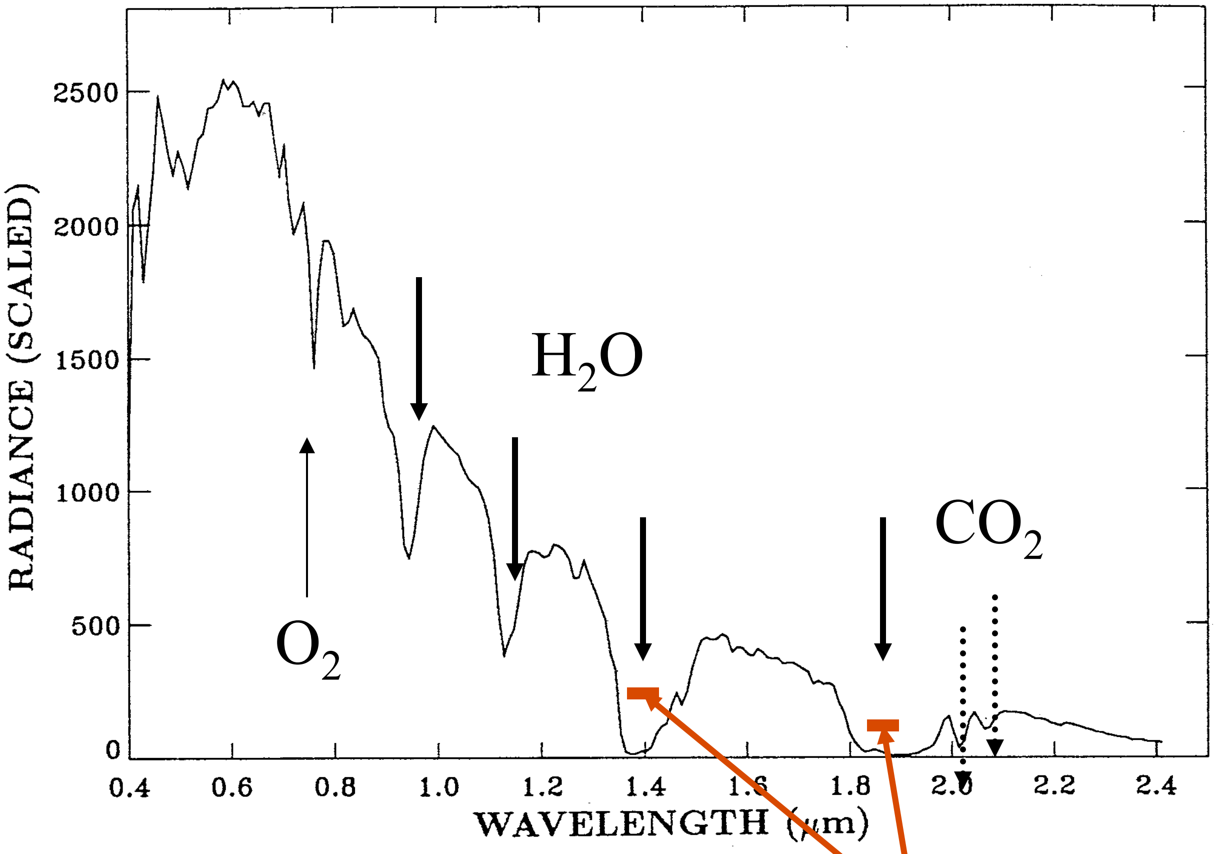
- Timeline of algorithm development:
  - ATREM – 1st land version (~1991, band model) to support the AVIRIS/HIRIS Project. A Paper was published in 1993 on RSE.
  - ATREM - upgraded land version (~1997, line-by-line model) to support the Navy COIS/NEMO Project. Reported in a 1997 SPIE extended abstract.
  - ATREM – 1st ocean version (~1999, line-by-line, spectrum matching using ***channels above 0.86 µm for Case 2 waters***, based on R. Fraser's formulation and multi-layer atmospheric model). A paper was published in 2000 on Applied Optics.
- Activities on prototyping the HyspIRI VSWIR Level 2 Algorithms
  Porting over a land version of algorithm to an AVIRIS computer, plus other functional versions of algorithms for hyperspectral data processing, including routines for refining wavelength calibrations, signal to noise ratio estimates, spectral convolution, and spectral smoothing.
- Sample results from AVIRIS and HICO data.
- Processing speed on an AVIRIS server computer.
- Summary

# Selected Publications from Analysis of AVIRIS Data

- **1993** - Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *RSE., 44*, 165-178. (Cited by **260**).
- **2000** - Gao, B.-C., et al., Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, Appl. Opt., 39, 887-896. (Cited by **103).**
- **2009** - Atmospheric correction algorithms for hyperspectral remote sensing data of land and ocean, RSE, 113, S17-S24. (Cited by 21).
- **1990** - Gao, B.-C., and A. F. H. Goetz, Column atmospheric water vapor and vegetation liquid water retrievals from airborne imaging spectrometer data, *JGR.*, *95*, 3549-3564. (Cited by **236**).
- **1993** - Gao, B.-C., A. F. H. Goetz, and W. J. Wiscombe, Cirrus cloud detection from airborne imaging spectrometer data using the 1.38 μm water vapor band, *GRL, 20*, 301-304. (Cited by **96**).
- **1996** - Gao, B.-C., NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space, *RSE, 58*, 257-266 (Cited by **555**).
- **2003** - Li, R.-R., Y. J. Kaufman, B.-C. Gao, and C. O. Davis, Remote sensing of suspended sediments and shallow coastal waters, TGRS, 41, 559-566, 2003. (Cited by 58).
- **2007** - Gao, B.-C., M. J. Montes, R.-R. Li, H. M. Dierssen, and C. O. Davis, An atmospheric correction algorithm for remote sensing of bright coastal waters using MODIS land and ocean channels in the solar spectral region, TGRS, 45, 1835-1843. (Cited by 10).

# Atmospheric Correction Over Land

An AVIRIS Spectrum




The AVIRIS spectrum is affected by atmospheric absorption and scattering effects. In order to obtain the surface reflectance spectrum, the atmospheric effects need to be removed.

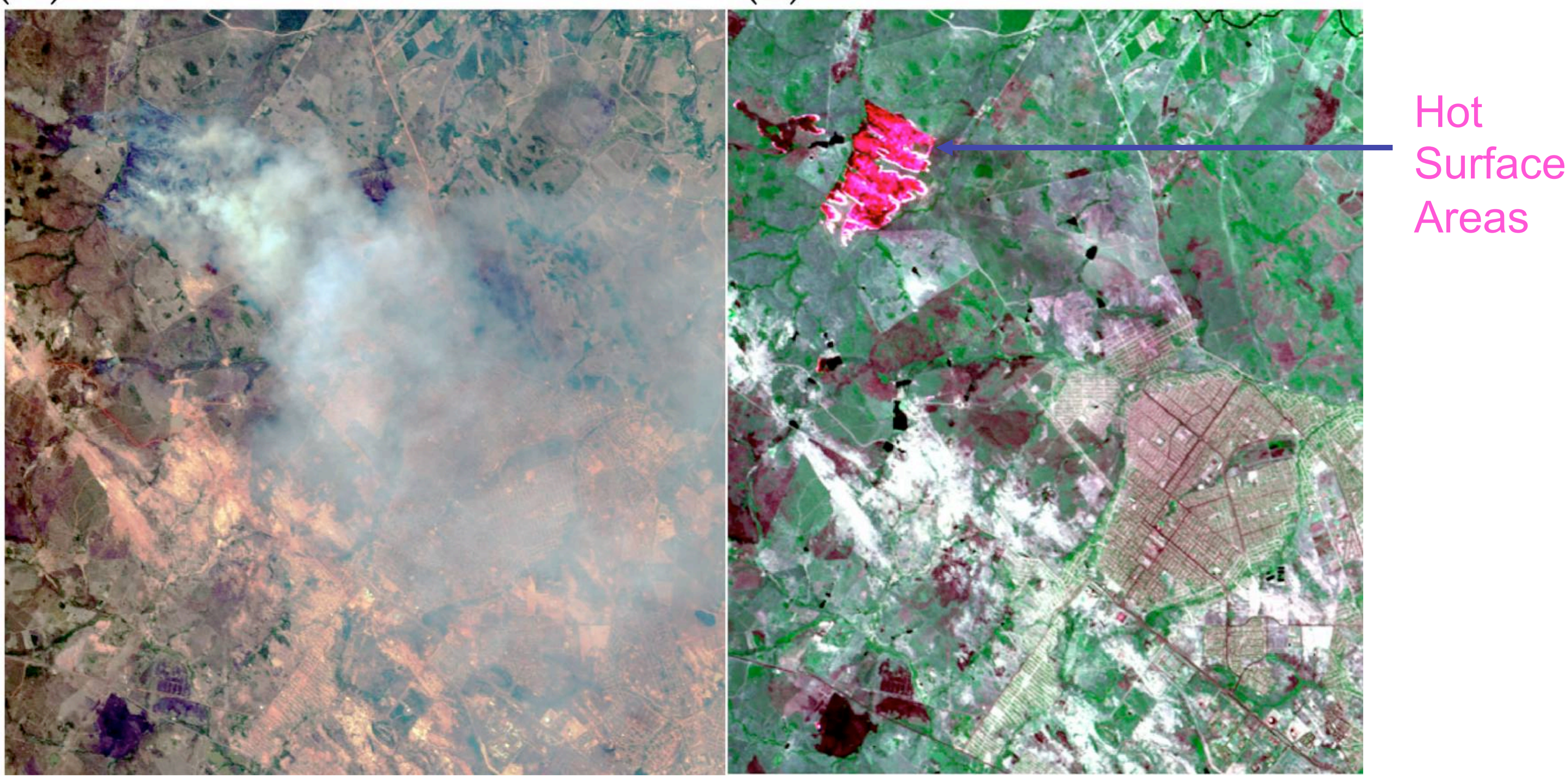
Strong water vapor bands are located near 1.38 and 1.88 micron. No signals are detected under clear sky conditions.

# Aerosol Scattering Effects

True Color Image
(R: 0.66, G: 0.55, B: 0.47 μm )

False Color Image
(R: 2.13, G: 1.24, B: 1.64 μm )

(A) (B)




Smoke is seen in visible channel images, but disappears in the near-IR channel images. Smoke particle size is ~0.1 – 0.2 μm.

# Equations For Atmospheric Correction Over Land

The measured radiance at the satellite level can be expressed as:

$$L_{obs} = L_a + L_{sun}\, t\, \rho \qquad (1)$$

$L_a$: path radiance;
$\rho$ : surface reflectance;
$L_{sun}$: solar radiance above the atmosphere;
t: *2-way transmittance for the Sun-surface-sensor path*

Define the satellite apparent reflectance as

$$\rho^*_{obs} = \pi L_{obs} / (\mu_0 E_0) \qquad (2)$$

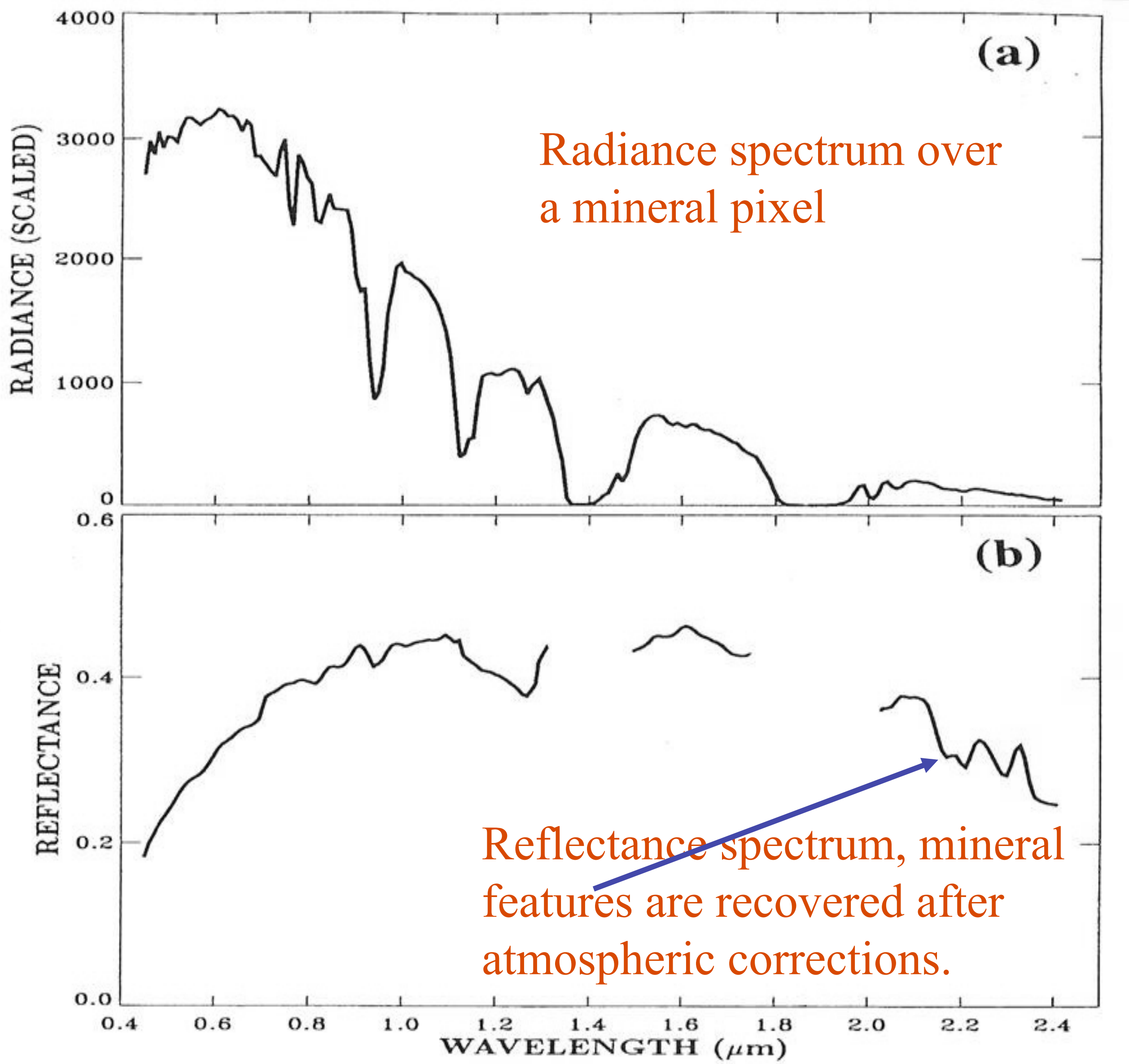
$$\rho^*_{obs} = T_g [\, \rho_a + t\, \rho / (1 - \rho\, s) \,] \qquad (3)$$

By inverting Eq. (3) for $\rho$, we get:

$$\rho = (\rho^*_{obs}/T_g - \rho^*_a) / [t + s\, (\rho^*_{obs}/T_g - \rho^*_a)\,] \qquad (4)$$

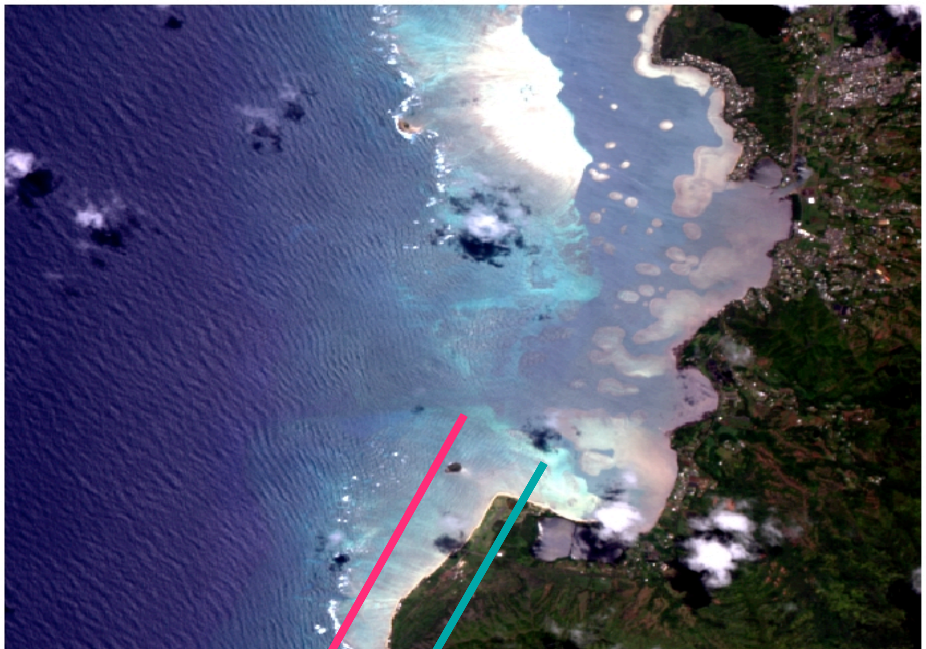
Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *Remote Sens. Env., 44*, 165-178, 1993.

# SAMPLE REFLECTANCE RETRIEVALS OVER MINERAL



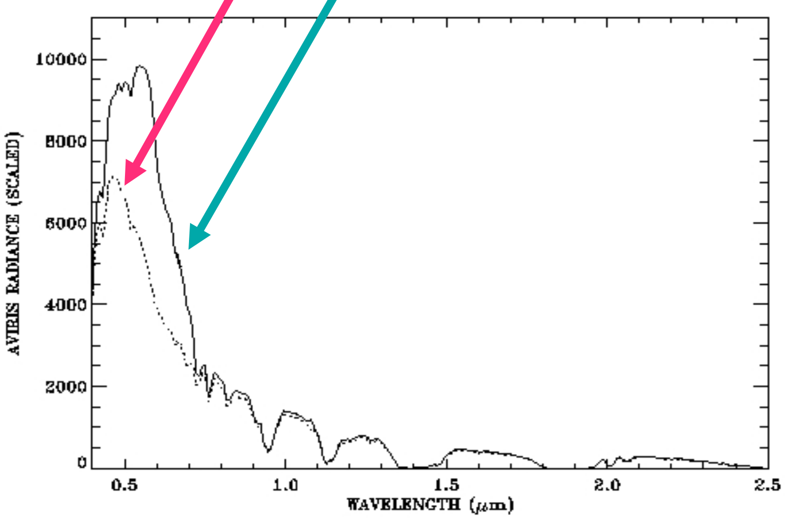
# A Case of Glint Removal Using AVIRIS Data Over Kaneohe Bay, HI

Before

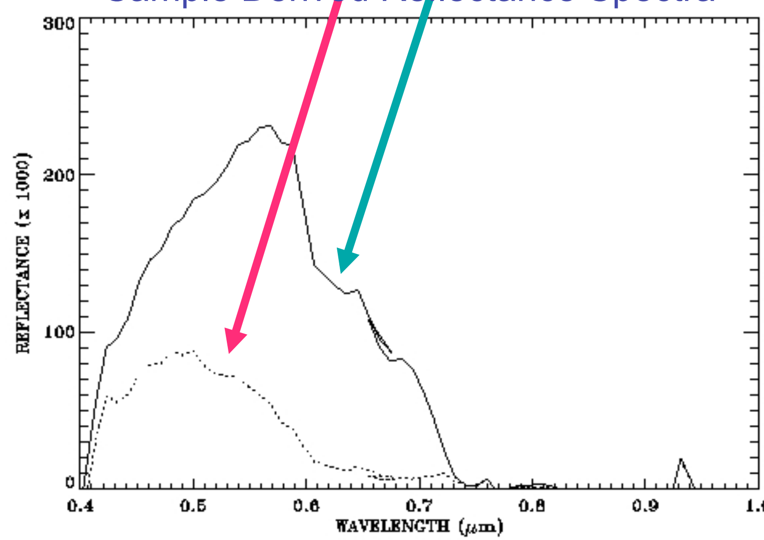


After

Sample Radiance Spectra

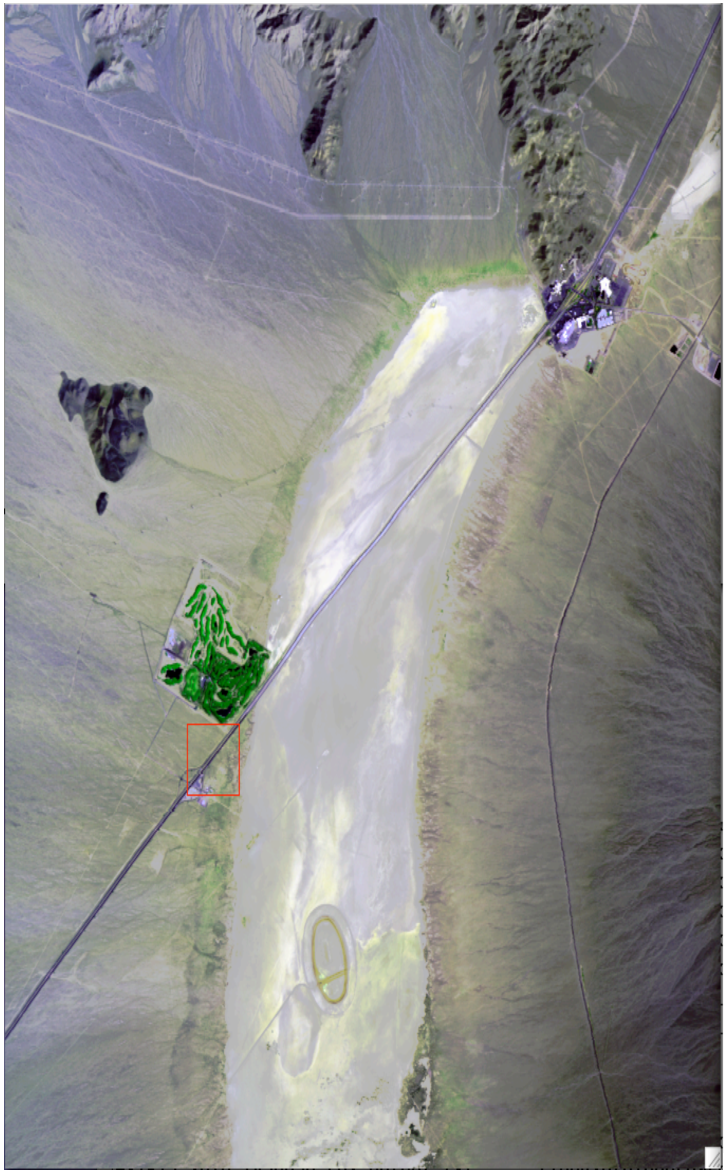



Sample Derived Reflectance Spectra

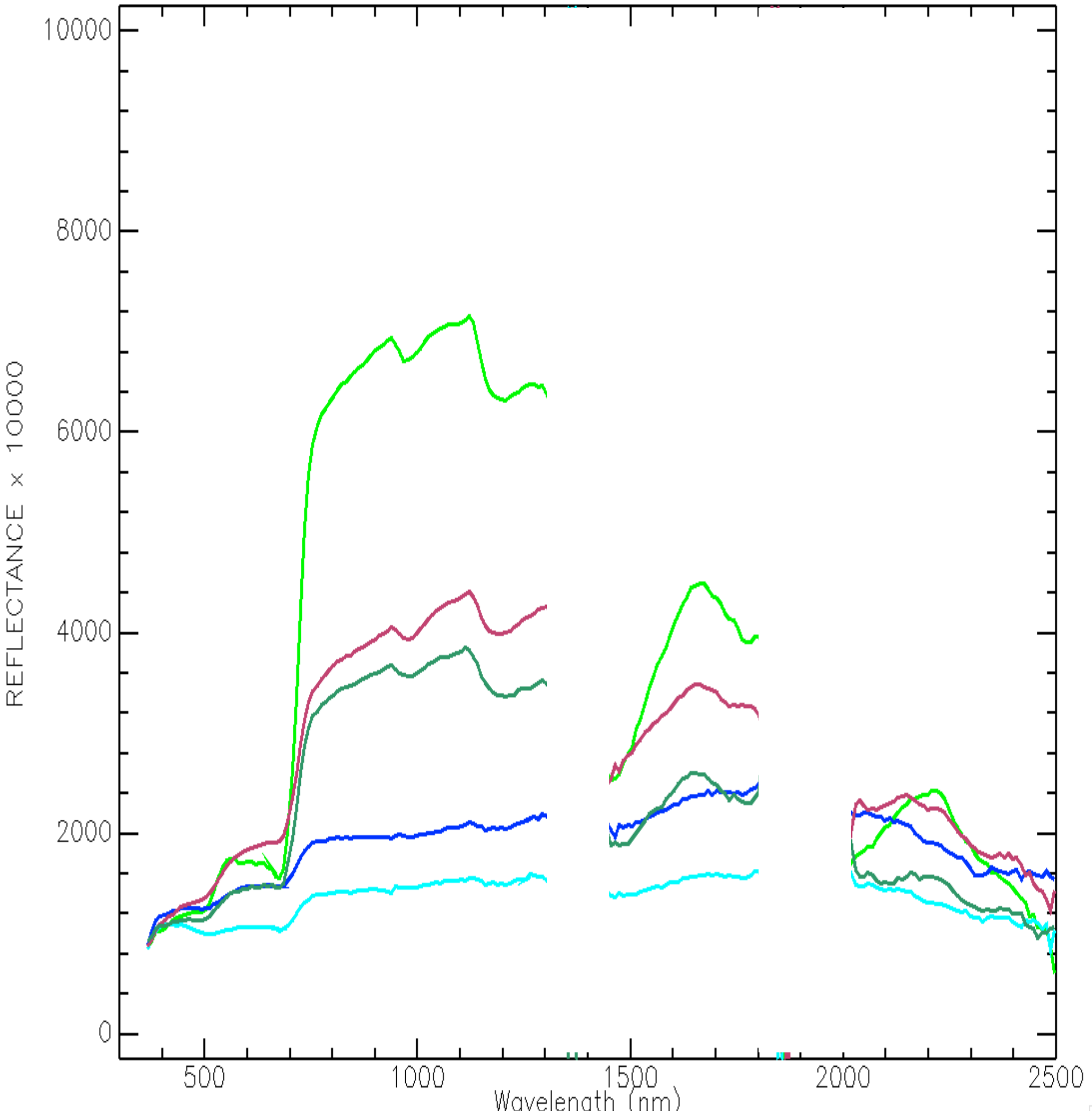


# AVIRIS Image & Spectra Over Ivanpah, California (April 26, 2010)

## AVIRIS Ivanpah Image



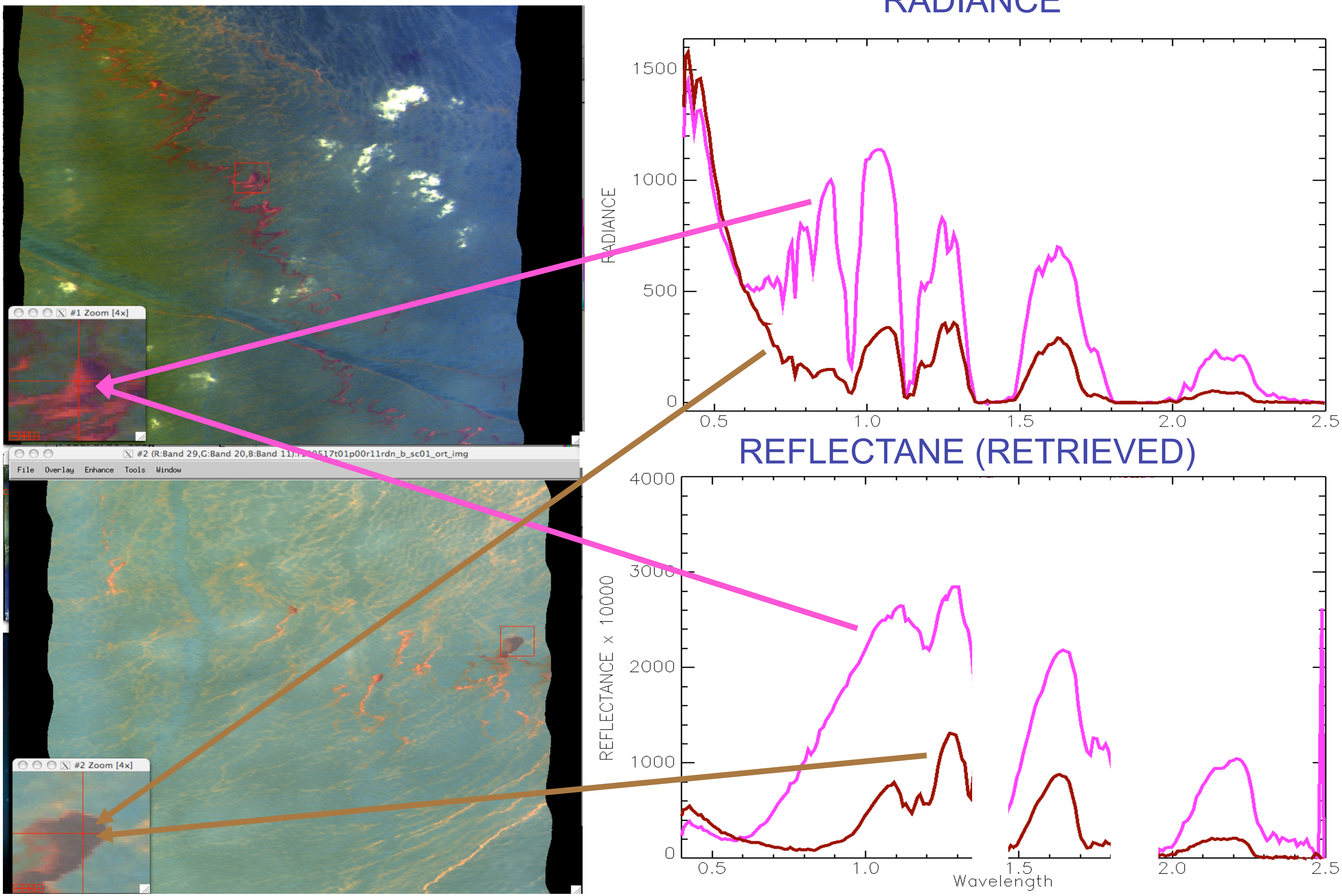
## Sample Retrieved Spectra



# AVIRIS Image & Spectra Over The Gulf of Mexico (Oil Spill, 5/17/2010)

## RGB IMAGES

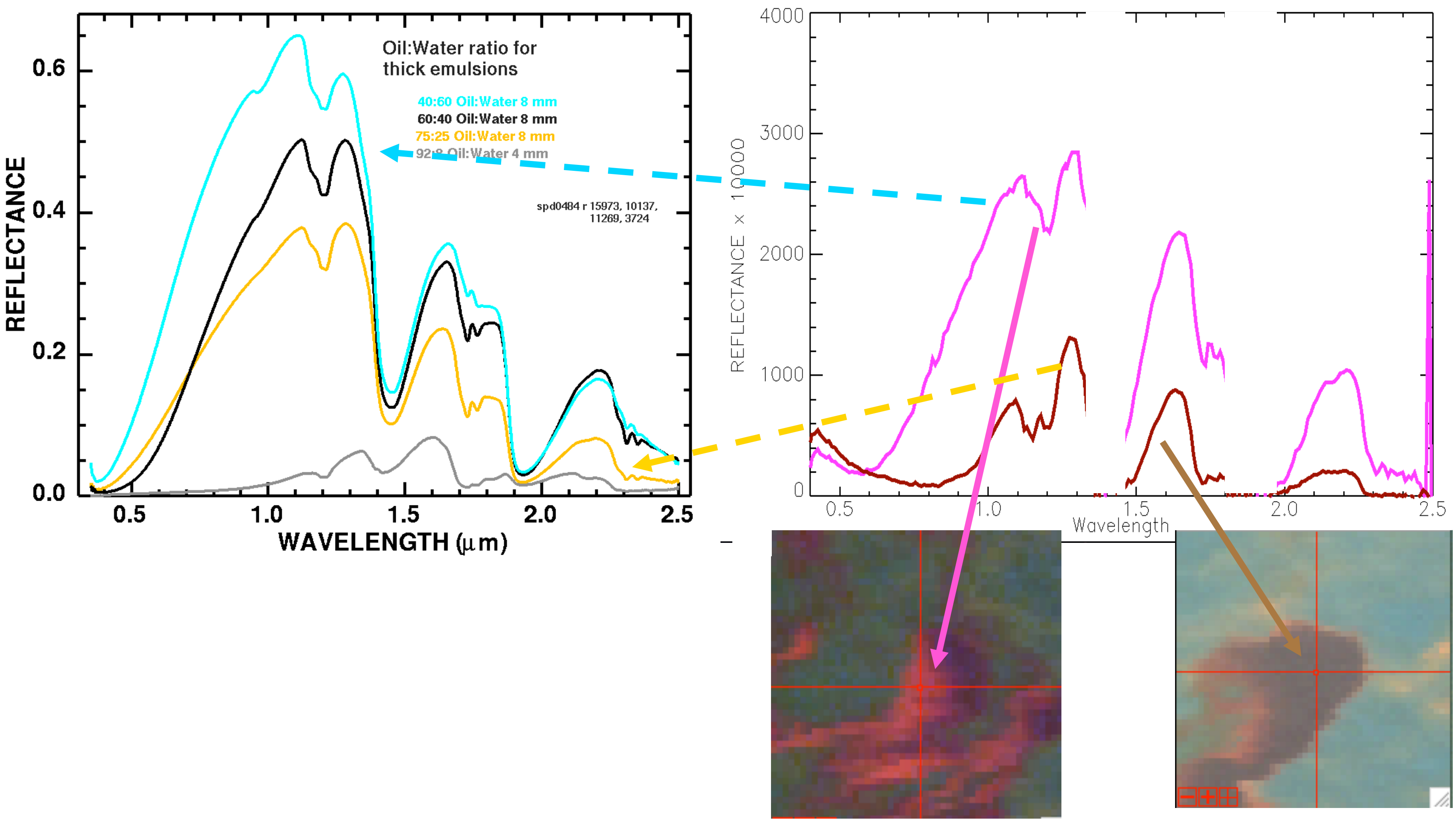
## RADIANCE



# SPECTRAL COMPARISONS

## Lab Reflectance Spectra of Optically Thick Oil Emulsion
(From R. Clark et al., USGS)

## Reflectance Spectra Derived From AVIRIS Data



# Earth Surface Images from HICO

Images are about 43 km wide and 190 km long

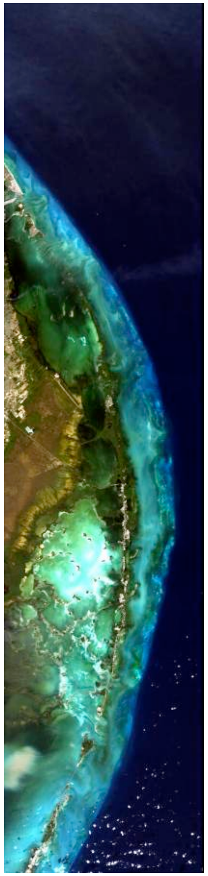
Orientations are given below

Cape Town, South Africa, Oct. 3, 2009. Orientation is from NW at top to SE at bottom.

Lower Chesapeake Bay, Oct. 7, 2009. Orientation is from NW at top to SE at bottom.

Coast of South China Sea, near Hong Kong, China, Oct. 2, 2009. Orientation is from SW at bottom to NE at top.

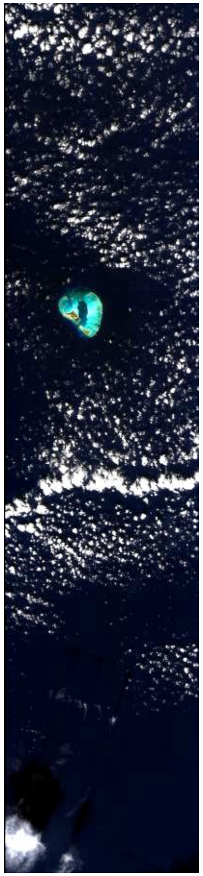
Part of the Grand Canyon, Sept. 27, 2009. The center of the image is at 35° 50' N, 111° 23' W and the orientation is from SW at bottom to NE at top.



Florida Keys, over Key Largo, Sept. 27, 2009. Orientation is from SW at bottom to NE at top.

Sahara Desert over Egypt, Sept. 27, 2009. Orientation is from SW at bottom to NE at top.

Taken over the Bahamas, Oct. 2, 2009. Orientation is from NW at top to SE at bottom.



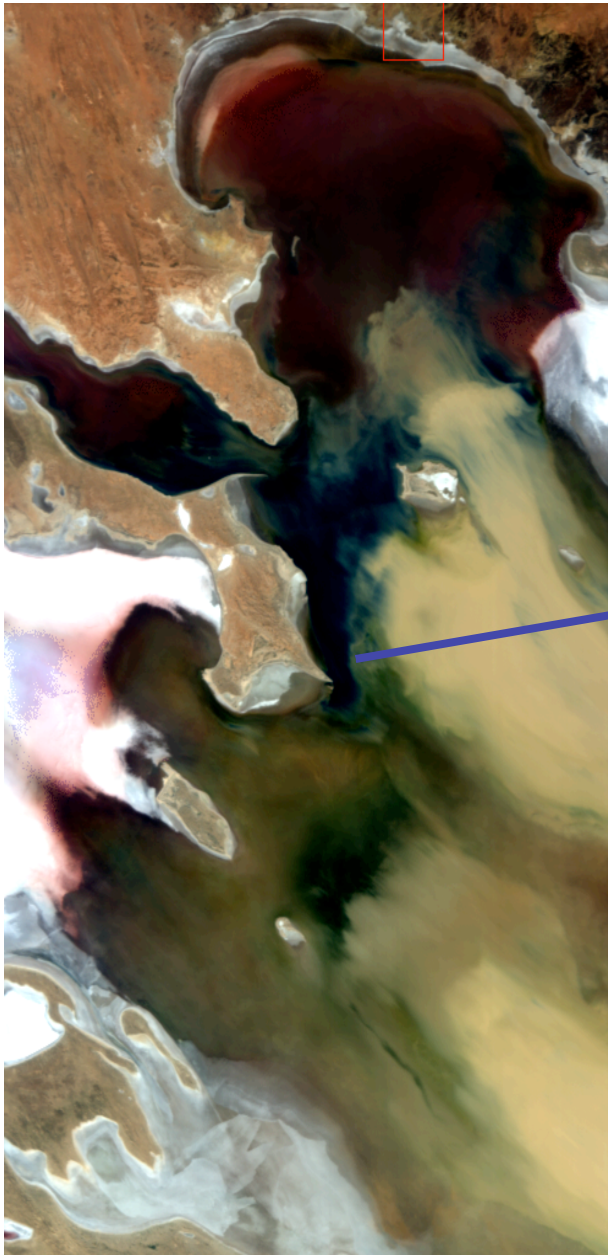
Gem of the Pacific. Midway Island, Sept. 27, 2009. Orientation is from NW at top to SE at bottom.

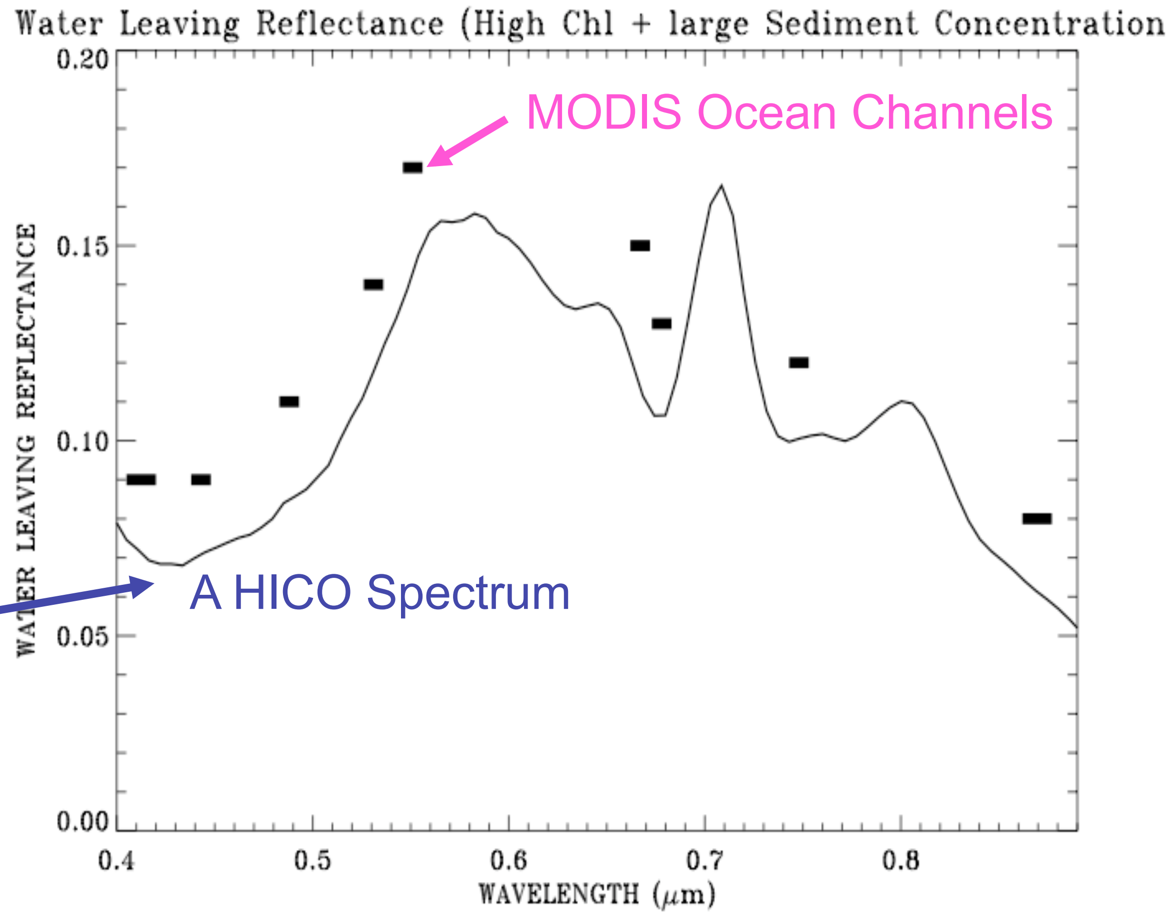

http://hico.coas.oregonstate.edu/

What is HICO?

The Hyperspectral Imager for the Coastal Ocean (HICO™) is an imaging spectrometer based on the PHILLS airborne imaging spectrometers. HICO is the first spaceborne imaging spectrometer designed to sample the coastal ocean. HICO will sample selected coastal regions at 90 m with full spectral coverage (380 to 960 nm sampled at 5.7 nm) and a very high signal-to-noise ratio to resolve the complexity of the coastal ocean. HICO is sponsored by the Office of Naval Research as an Innovative Naval Prototype (INP), and will demonstrate coastal products including water clarity, bottom types, bathymetry and on-shore vegetation maps. As an INP, HICO also demonstrates innovative ways to reduce the cost and schedule of this space mission by adapting proven PHILLS aircraft imager architecture and using Commercial Off-The-Shelf (COTS) components where possible.

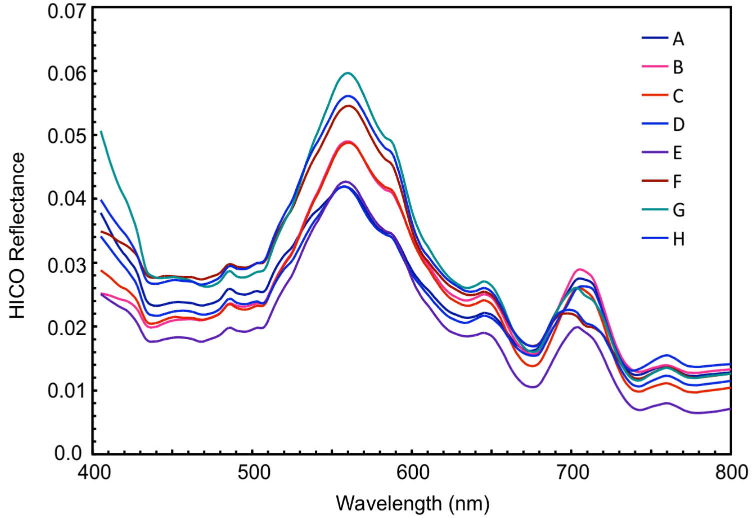
# Sample Water Leaving Reflectance Retrievals Over Lake Eyre, Australia

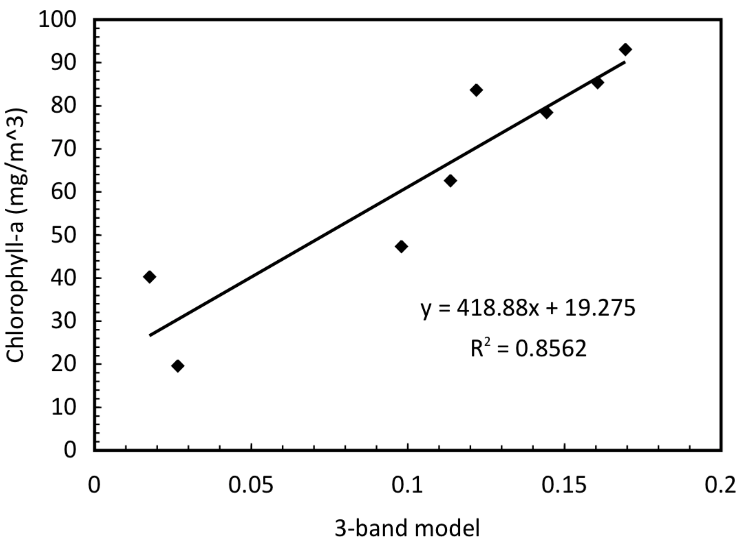


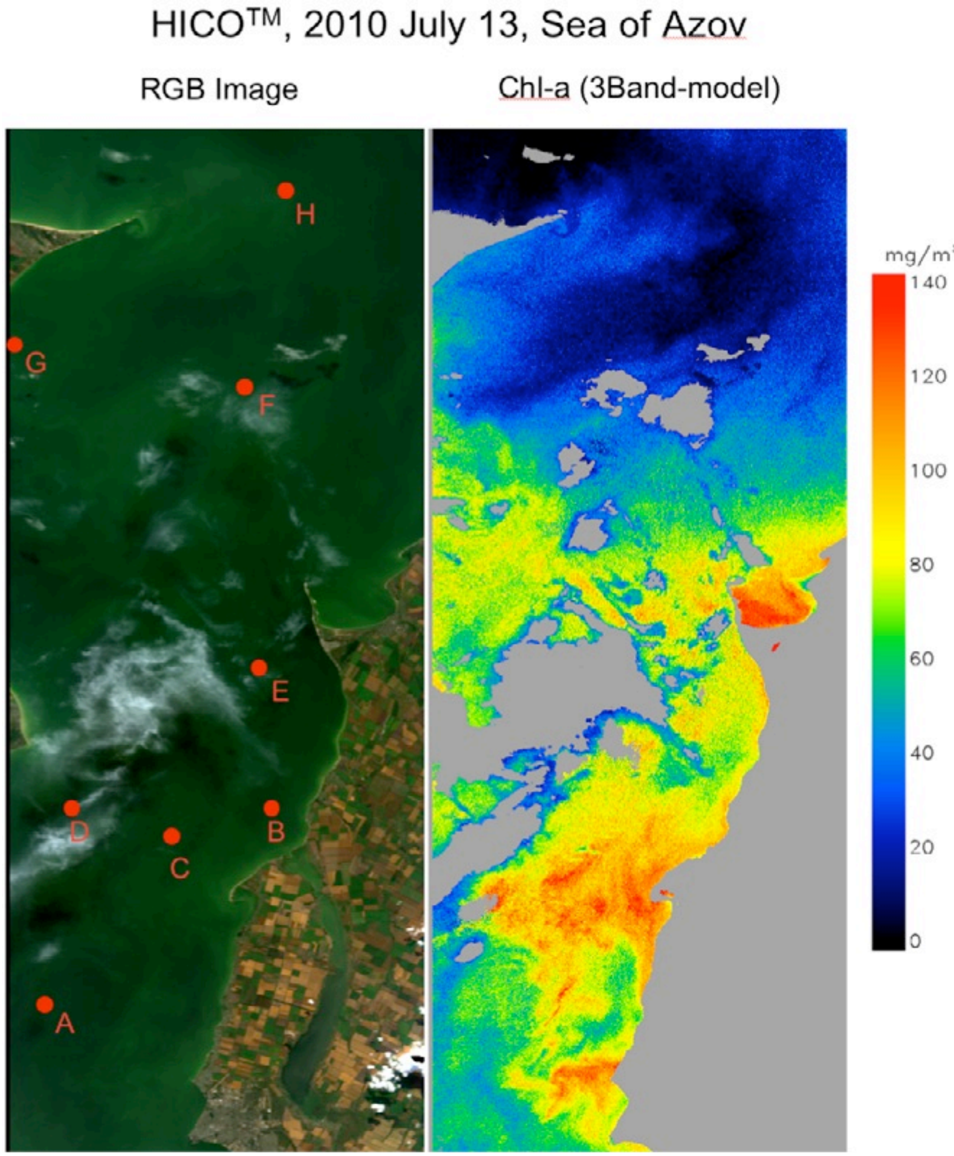



The discrete MODIS ocean channels missed several peaks in the HICO reflectance spectrum. Therefore, MODIS cannot fully characterize the shapes of the spectra acquired over the complex Case 2 waters.

# Estimation of Chlorophyll-a Concentration From HICO data Acquired over The Sea of Azov Using Narrow Channels within & Around the 700-nm Refl. Peak and the Method of Gitelson et al. (ERL, 2011, doi:10.1088/1748-9326/6/2/024023)

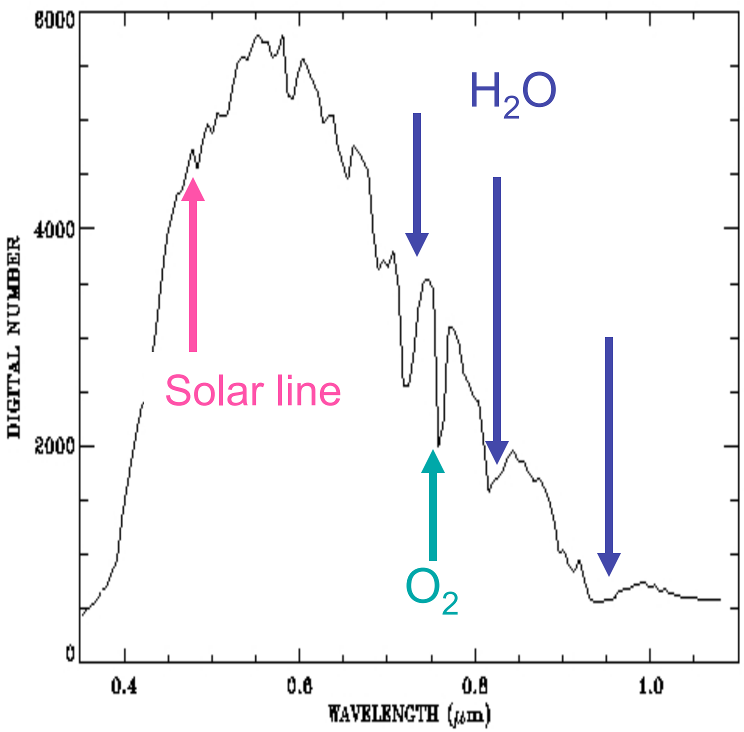


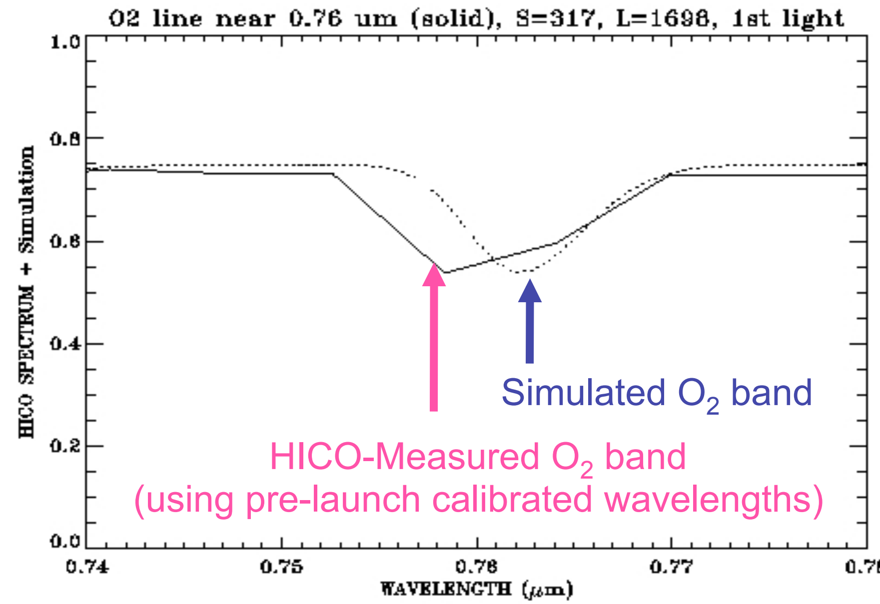



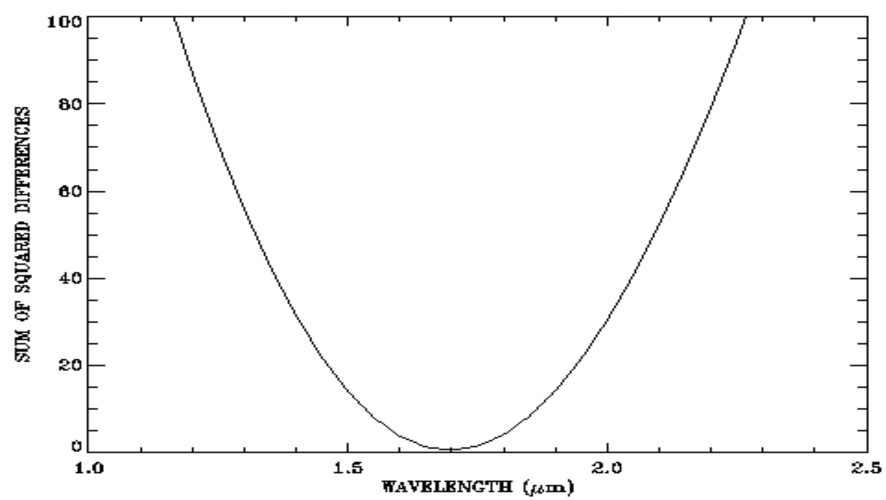
# Illustration of the Spectrum-Matching Technique (for HICO Post-Launch Wavelength Calibrations)

## A Sample ISS HICO Spectrum



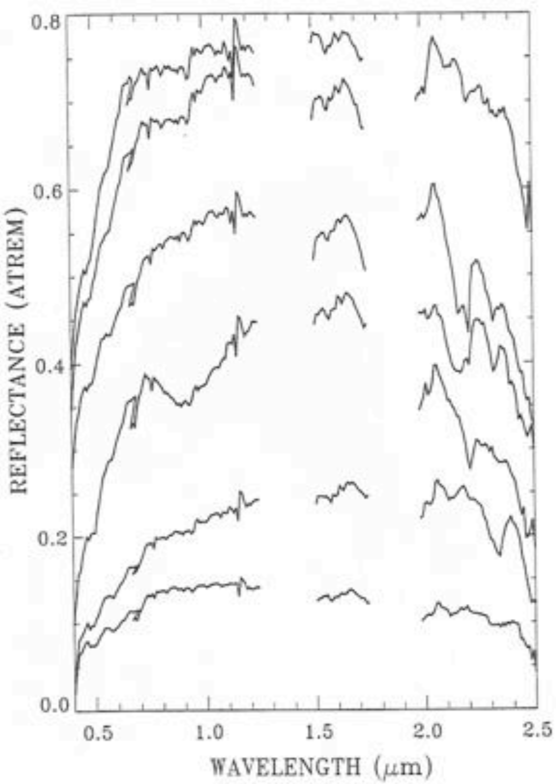

## HICO Post-Launch Wavelength Shift (~1.7 nm)



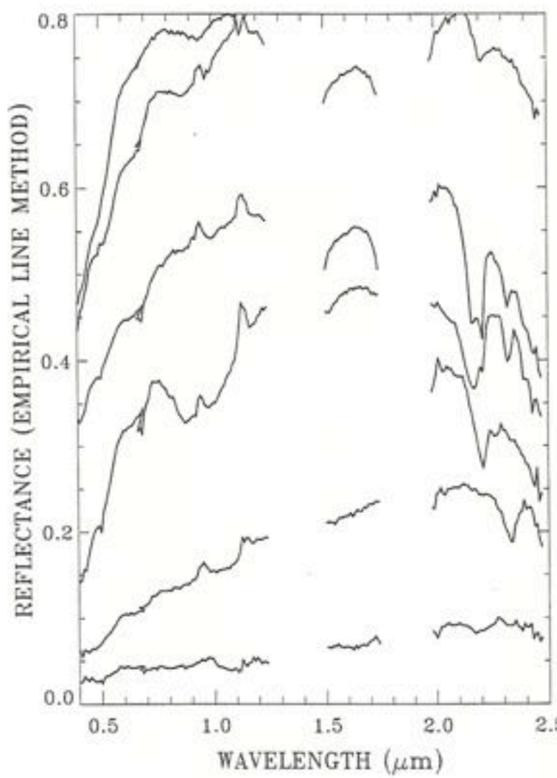

Post-launch FWHM remained the same

# Cubic Spline Smoothing – Post Processing

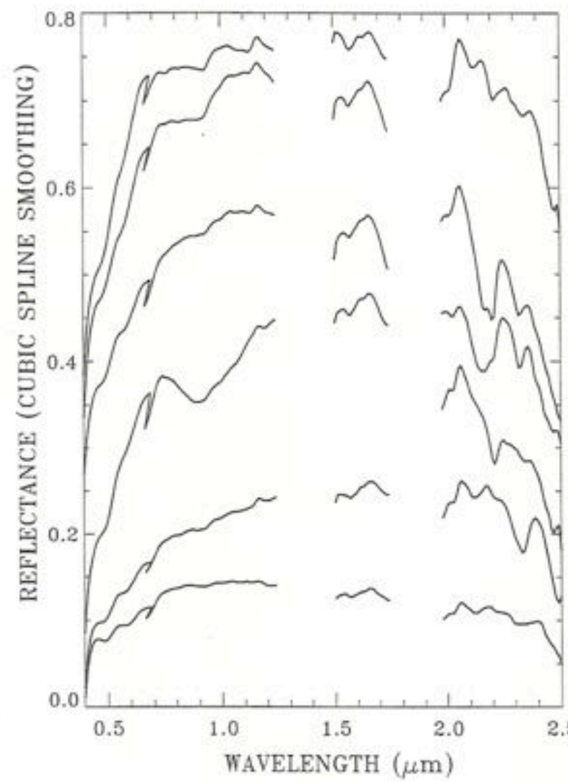
ATREM Refl Spectra




Spectra Derived with Empirical Line Method




ATREM Refl Spectra + Cubic Spline Smoothing



# Porting Over Algorithms to Mac and PC

- In order to support the processing of HICO data collected from the International Space Station, we ported over most algorithms from an old SGI workstation to a Mac in 2010.
- We have just finished porting over all the routines to an AVIRIS PC computer, and made it possible to do batch processing of large volumes of AVIRIS data. The tasks we conducted include:
  - Replacing old Fortran IV statements with F90 compatible statements in some of the routines
  - Developing a perl script to automate the process of generating input files for ATREM code (date, time, latitude, longitude, input and output file names, etc.)
  - Developing a new Fortran 90 I/O routine for ATREM to handle AVIRIS file names, which are often longer than 80 characters. The original I/O routine was written in mixed Fortran77 and C, and was unable to handle files with names longer than 80 characters.

# HyspIRI VSWIR Level 2 Algorithm Prototyping -
## ATREM Processing Speed

- **AVIRIS Server**
  OS: 64-bit Windows Server 2008
  Processor: Dual Intel Xeon X5560 2.80GHz Quad-Core Processors
  Installed memory (RAM): 24.0 GB ECC DDR3

- **Storage**
  4 RAID arrays populated with 24, 2TB 7200 RPM 64 MB Cache Enterprise Class SATA II HDD's
  4Gb Fibre Channel to SAS/SAS(SATA) Controller RAID unit
  Total of 156 TB usable storage

- After processing large batches of 2010 AVIRIS data through ATREM, the average processing speed is ~9 mb/s.

- In a rough estimate -

| | |
|---|---|
| ATREM 2011 daily rate: | 864 GB/day |
| HyspIRI VSWIR daily rate: | 1500 GB/day |

# SUMMARY

- We have Ported over a land version of ATREM algorithm to an AVIRIS computer, plus other functional versions of algorithms for hyperspectral data processing, such as routines for refining wavelength calibrations, signal to noise ratio estimates, spectral convolution, and spectral smoothing.

- We have developed a new Fortran 90 I/O routine for ATREM and a perl script for generating input files needed by ATREM. Batch processing of large volumes of AVIRIS data is now possible on an AVIRIS PC computer.

- Upgrades to ATREM code are still needed. For examples, adding absorbing aerosol models to ATREM and implementing new techniques for aerosol retrievals using UV channels (380 nm, 400 nm) are necessary.