

Land and Ocean Versions of ATREM Codes for Processing Hyperspectral Imaging Data Sets

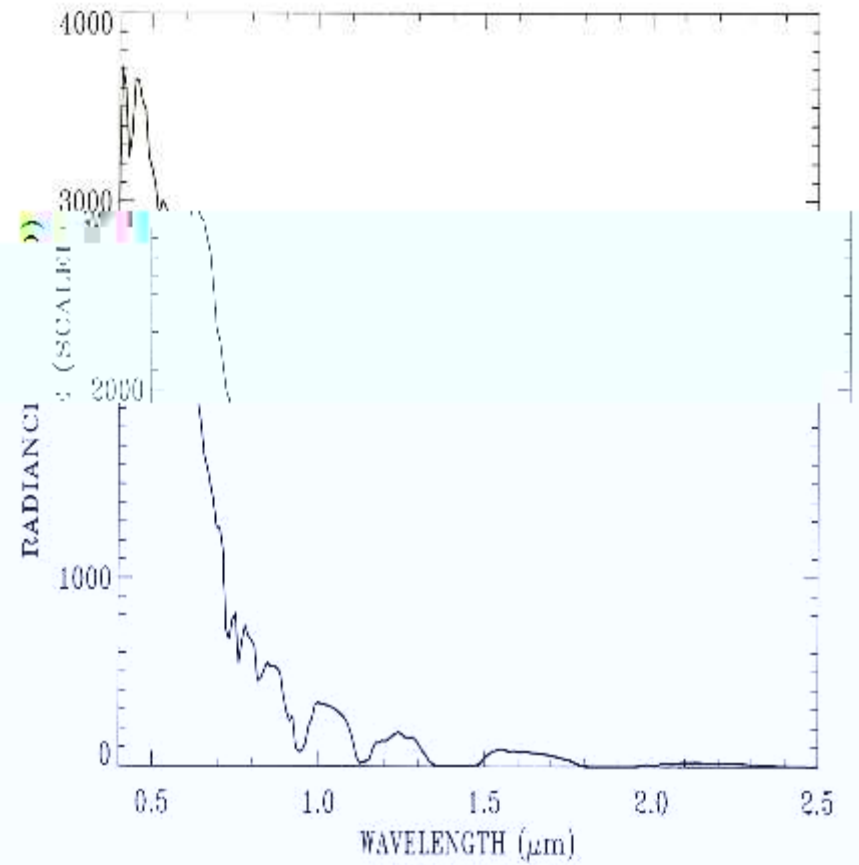
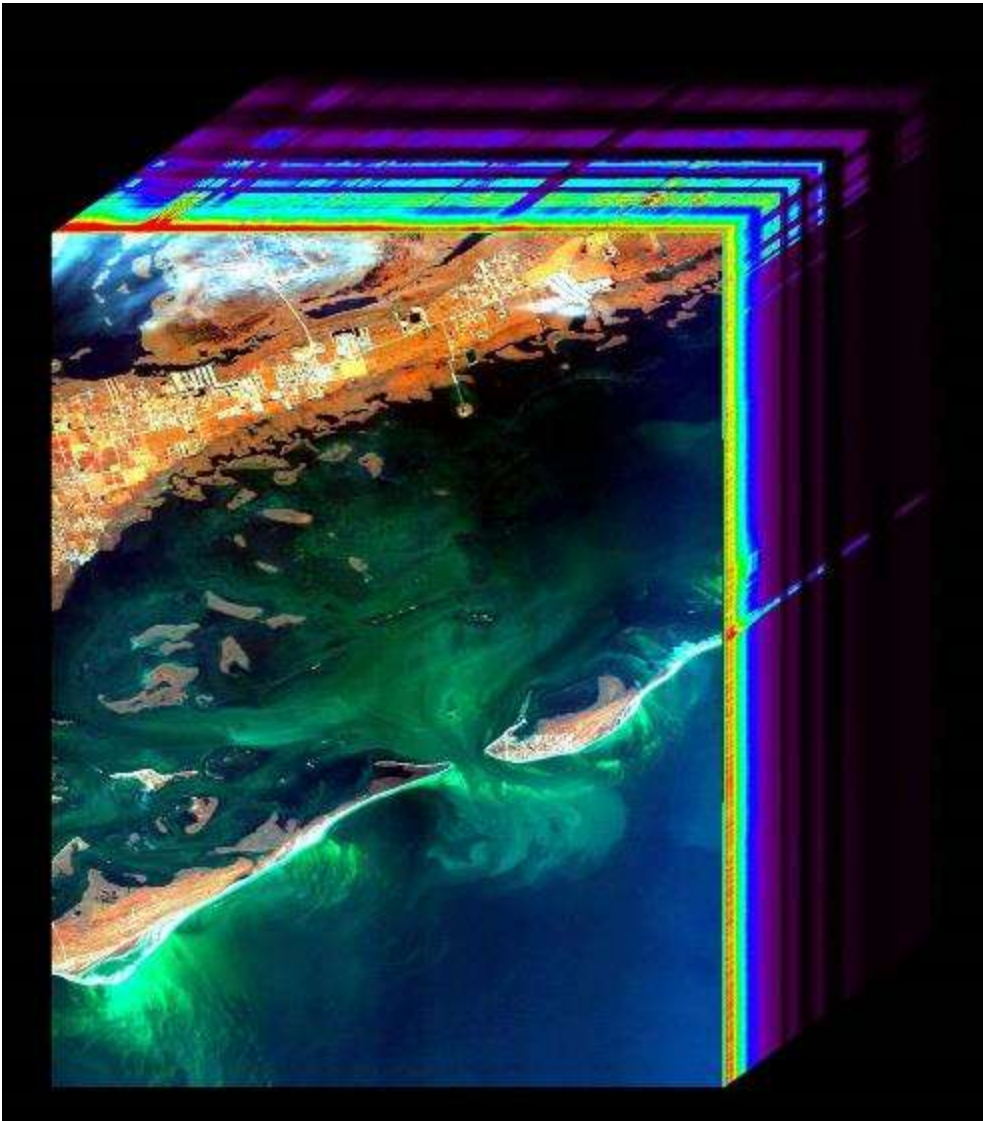
Bo-Cai Gao and Rong-Rong Li

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Remote Sensing Division, Code 7230,
Naval Research Laboratory, Washington, DC USA

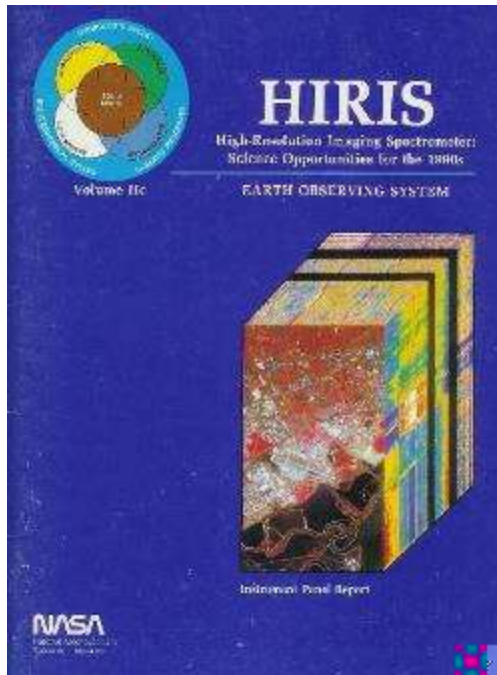
Imaging Spectrometry Concept

A Sample Spectrum



Radiances above one μm are very small.

Brief History on ATREM Algorithm Development



In the late 1980s, MODIS & HIRIS were envisioned to be parts of the massive NASA EOS Program. Dr. Alex. Goetz at University of Colorado in Boulder, Colorado was the NASA-selected HIRIS Team leader. He envisioned the need of a model-based atmospheric correction algorithm around 1987.

I worked with Dr. Goetz at U. of Colorado from 1988 to 1992 for the HIRIS Project to develop the 1st band-model-based hyperspectral atmospheric correction algorithm - ATREM. The ATREM source code was publicly released through U. of Colorado to more than 300 researchers worldwide in mid-1990s.

- 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.

Selected Publications Related to Atmospheric Corrections

- **Hyperspectral Land Version:**
1993 – Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *RSE.*, 44, 165–178. (current # of Citations = **483**; A year ago = 426).
- **Hyperspectral Ocean Version:**
2000 – Gao, B.-C., et al., Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, *Appl. Opt.*, 39, 887–896. (**240 citations**; 195).
- **A Review Paper on Hyperspectral Atmospheric Corrections:**
2009 – Atmospheric correction algorithms for hyperspectral remote sensing data of land and ocean, *RSE*, 113, S17–S24. (**225 citations**; 143).
- **Multi-Channel, MODIS, Ocean Version:**
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. (**43**; 40).
- **Remote Sensing of Coastal Waters:**
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. (**153**).
- **Wavelength Calibrations:**
2003 - Gao, B.-C., M. J. Montes, and C. O. Davis, Refinement of wavelength calibrations of hyperspectral imaging data using a spectrum-matching technique, *RSE*, 90, 424-433 (**87**).
- **HICO on International Space Station:**
2012 – Gao et al., Vicarious calibrations of HICO data acquired from the international space station, *Appl. Opt.*, 51, 2559 – 2567 (**16 citations**).

Fraser's Formulation and Definitions

In the absence of gas absorption, the radiance at the satellite level is:

$$L_{obs}^* = L_0^* + L_g t'_u + L_w t_u, \quad (1)$$

L_0^* : path radiance; L_w : water leaving radiance;

L_g : radiance reflected at water surface; t'_u & t_u : *upward transmittances*

Multiply Eq. (1) by π and divide by $(\mu_0 E_0)$, Eq. (1) becomes:

$$\begin{aligned} \pi L_{obs} / (\mu_0 E_0) &= \pi L_0^* / (\mu_0 E_0) + \pi L_g t'_u [t_d / (\mu_0 E_0 t_d)] \\ &+ \pi L_w t_u [t_d / (\mu_0 E_0 t_d)] \end{aligned} \quad (2)$$

where E_0 = solar irr., μ_0 = cosine of solar zenith angle. We define:

Satellite apparent reflectance: $\rho_{obs}^* = \pi L_{obs} / (\mu_0 E_0), \quad (3)$

$$\rho_{atm}^* = \pi L_0^* / (\mu_0 E_0), \quad (4)$$

Glint reflectance: $\rho_g = \pi L_g / (\mu_0 E_0 t_d) \quad (5)$

Water leaving reflectance: $\rho_w = \pi L_w / (\mu_0 E_0 t_d) = \pi L_w / E_d \quad (6)$

Remote sensing reflectance: $R_{rs} = \rho_w / \pi = L_w / E_d \quad (6')$

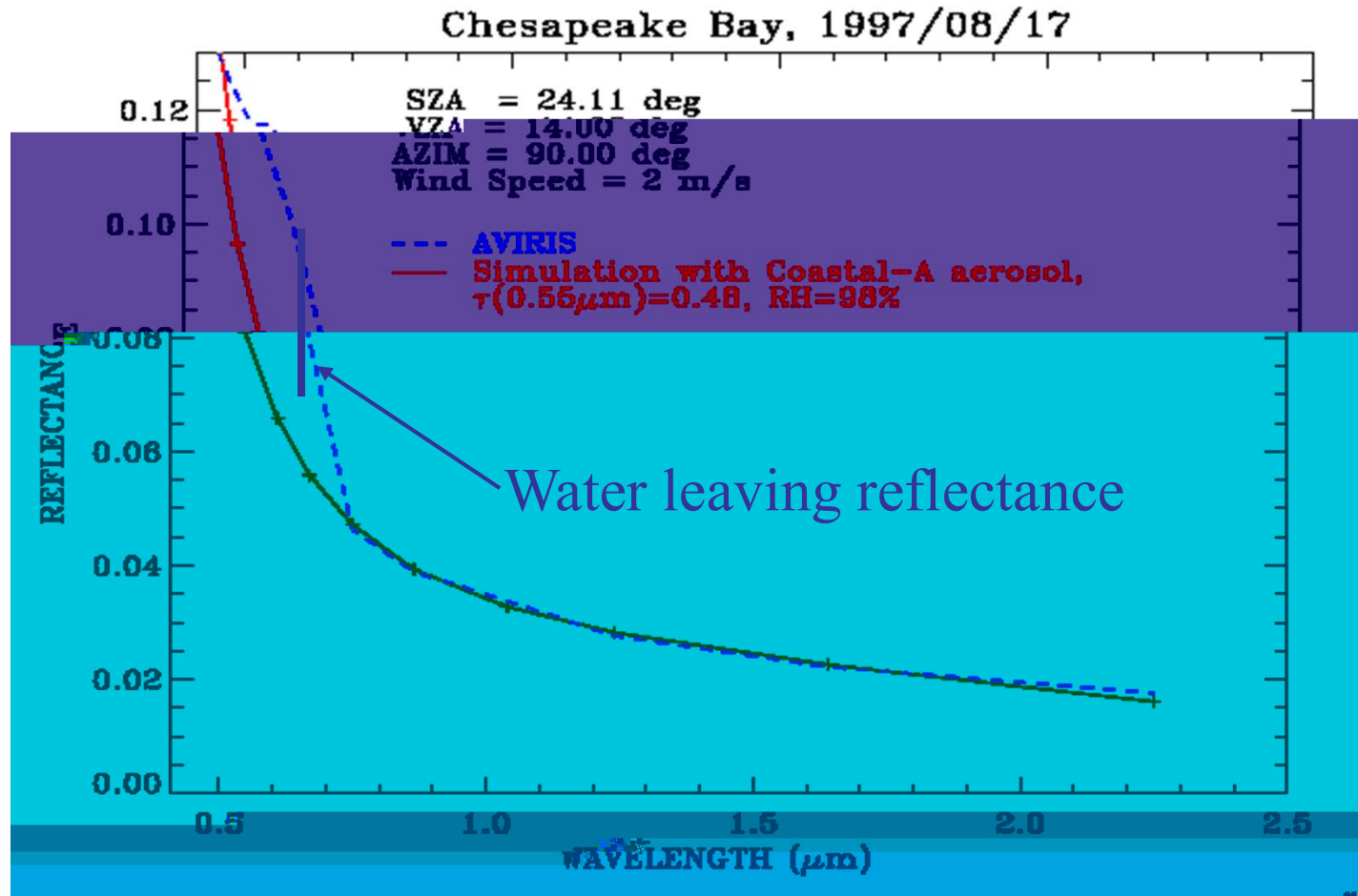
Substitute Eqs (3) – (6) into Eq. (2), we get:

$$\rho_{obs}^* = \rho_{atm}^* + \rho_g t_d t_u + \rho_w t_d t_u \quad (7)$$

After consideration of gas absorption and multiple reflection between the atmosphere and surface, & denoting $\rho_{atm+glint}^* = \rho_{atm}^* + \rho_g t_d t_u$, we can get:

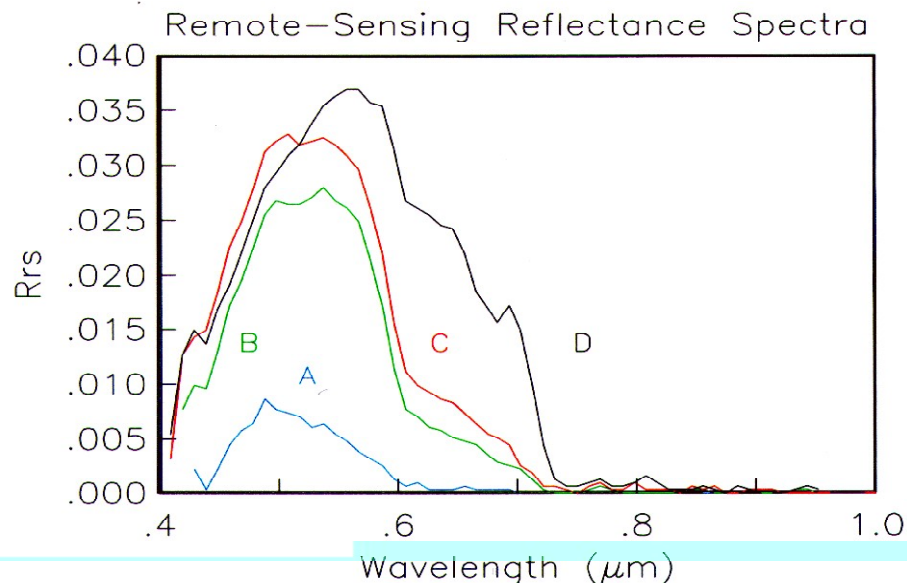
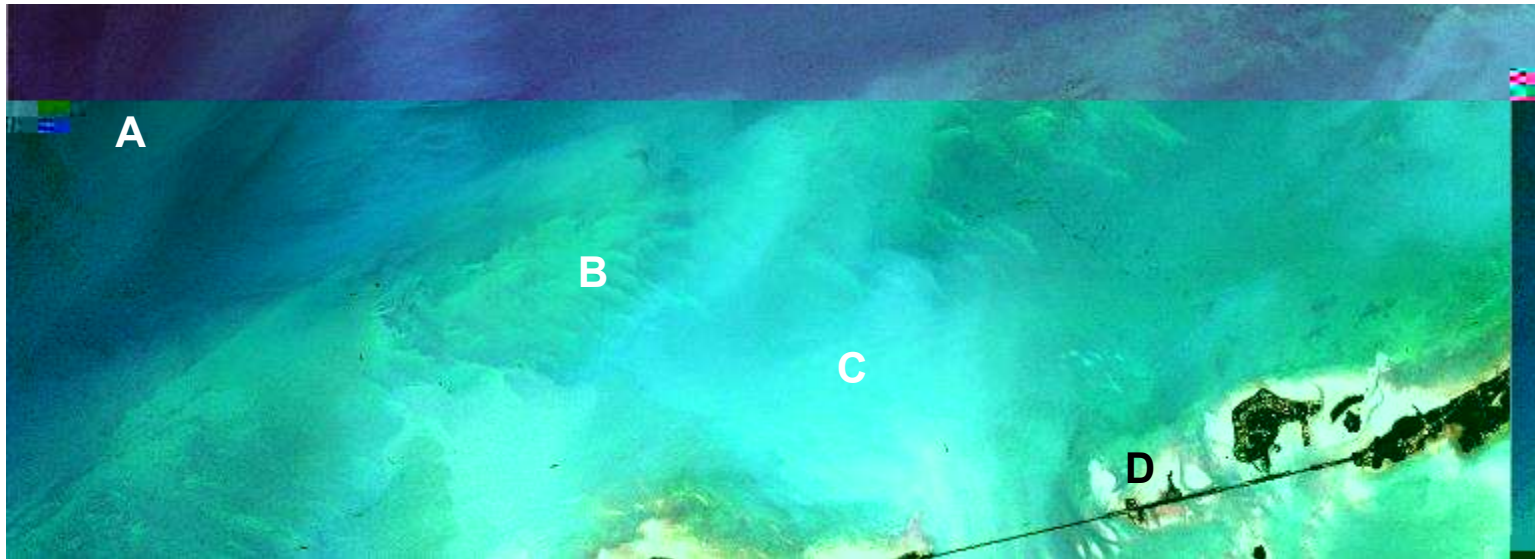
$$\rho_w = (\rho_{obs}^* / T_g - \rho_{atm+glint}^*) / [t_d t_u + s (\rho_{obs}^* / T_g - \rho_{atm+glint}^*)] \quad (8)$$

Atmospheric Correction for Water Surfaces



Channels at 0.86 and longer wavelengths are used to estimate atmospheric effects, and then extrapolate to the visible region. The differences between the two curves above are proportional to water leaving reflectances.

Atmospheric Corrections Using an Ocean Version Algorithm



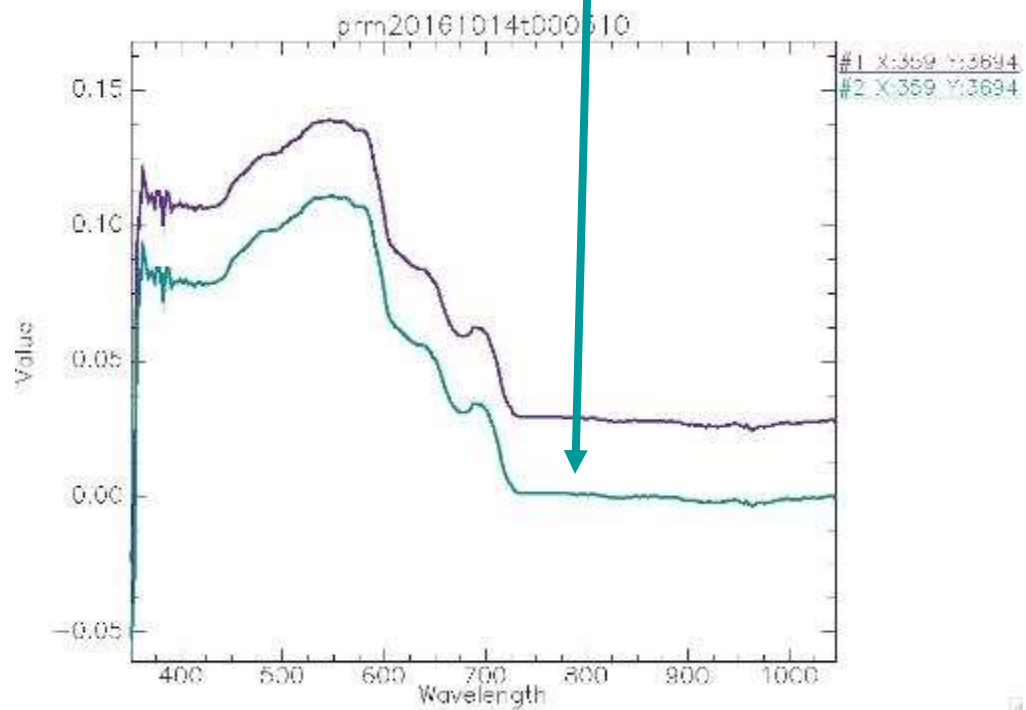
(B.-C. Gao, M. J. Montes, Z. Ahmad, and C. O. Davis, *Appl. Opt.* 39, 887-896, 2000.)

CORAL: Lizard Island (O_44_2, prm20161024t000510)

RGB Image



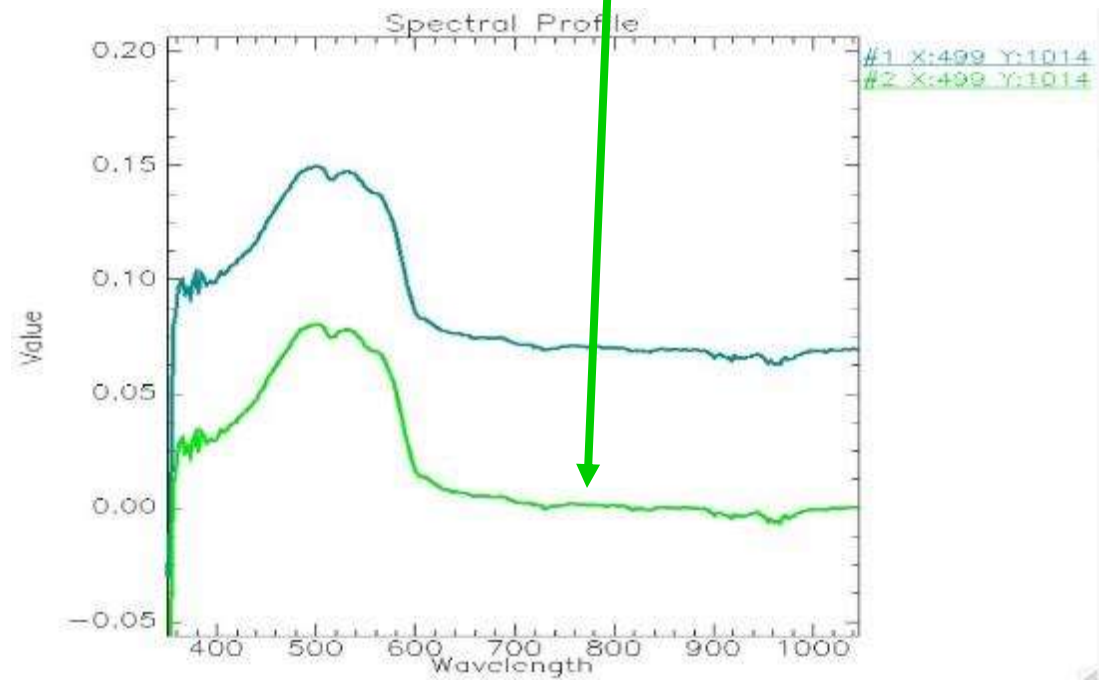
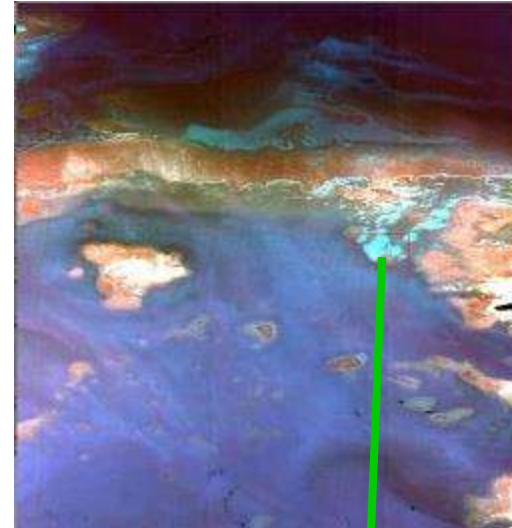
RGB + Glint Removal



Florida Keys

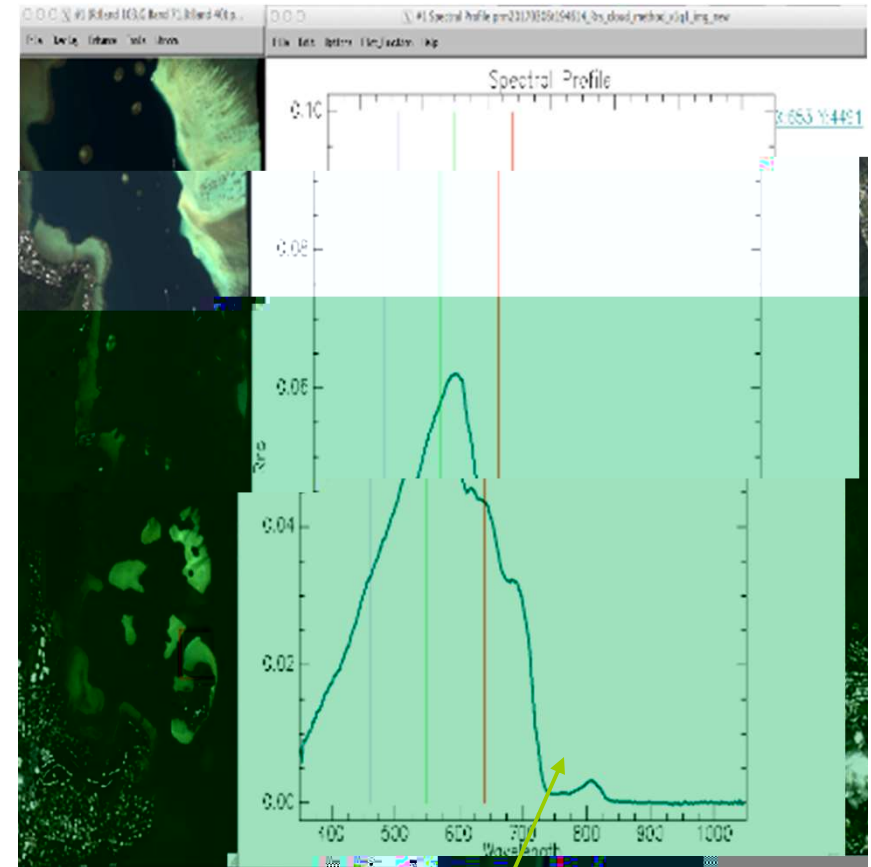
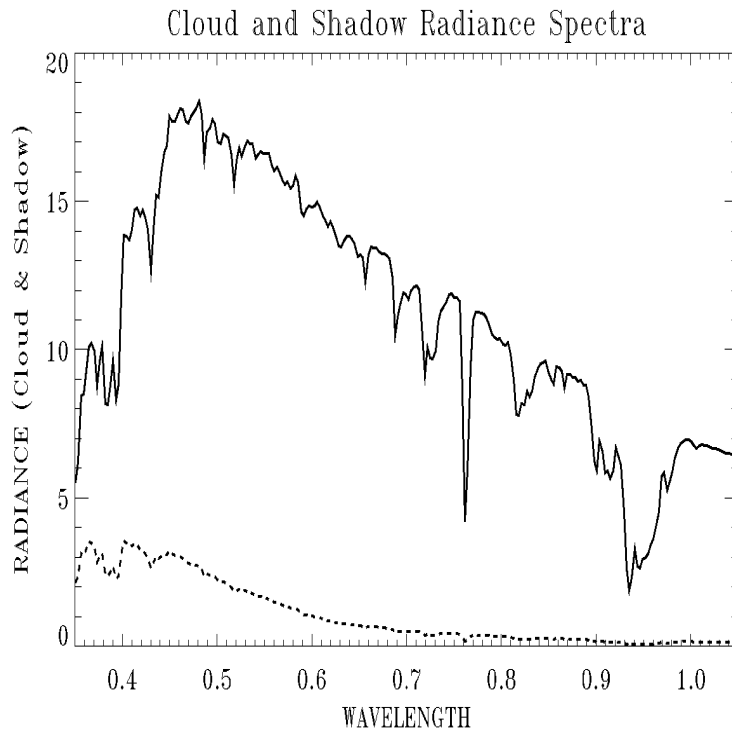
RGB Image

RGB + Glint Removal



An Empirical Cloud & Shadow Method for Water Leaving Reflectance Retrievals

$$R(\lambda) = R_{\text{cloud}}(0.86 \mu\text{m}) [L(\lambda) - L_{\text{shadow}}(\lambda)] / [L_{\text{cloud}}(\lambda) - L_{\text{shadow}}(\lambda)]$$



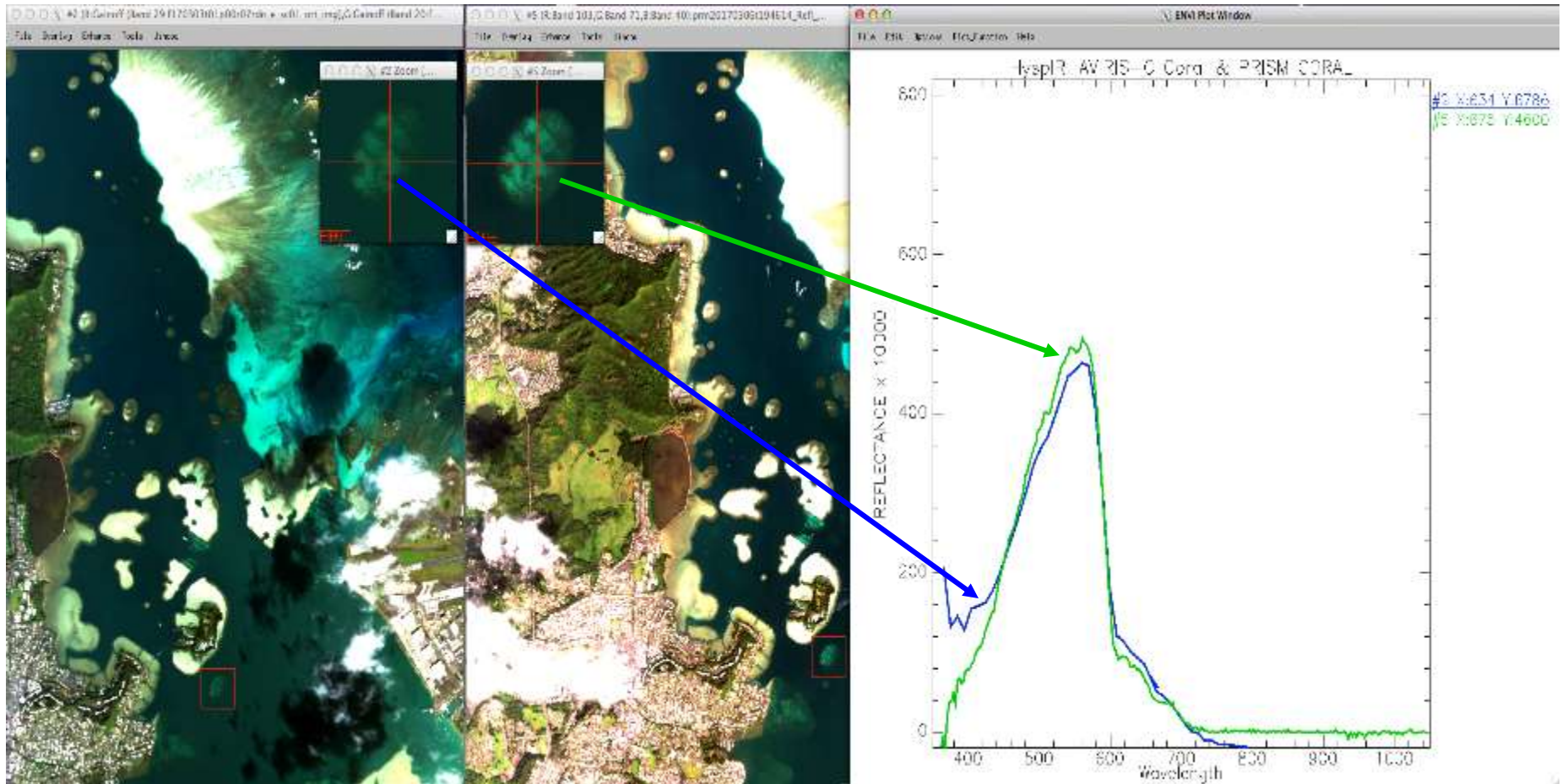
Cloud & Shadow
Empirical Method)

AVIRIS HypsIRI Coral & PRISM CORAL Comparison (Continued)

AVIRIS RGB

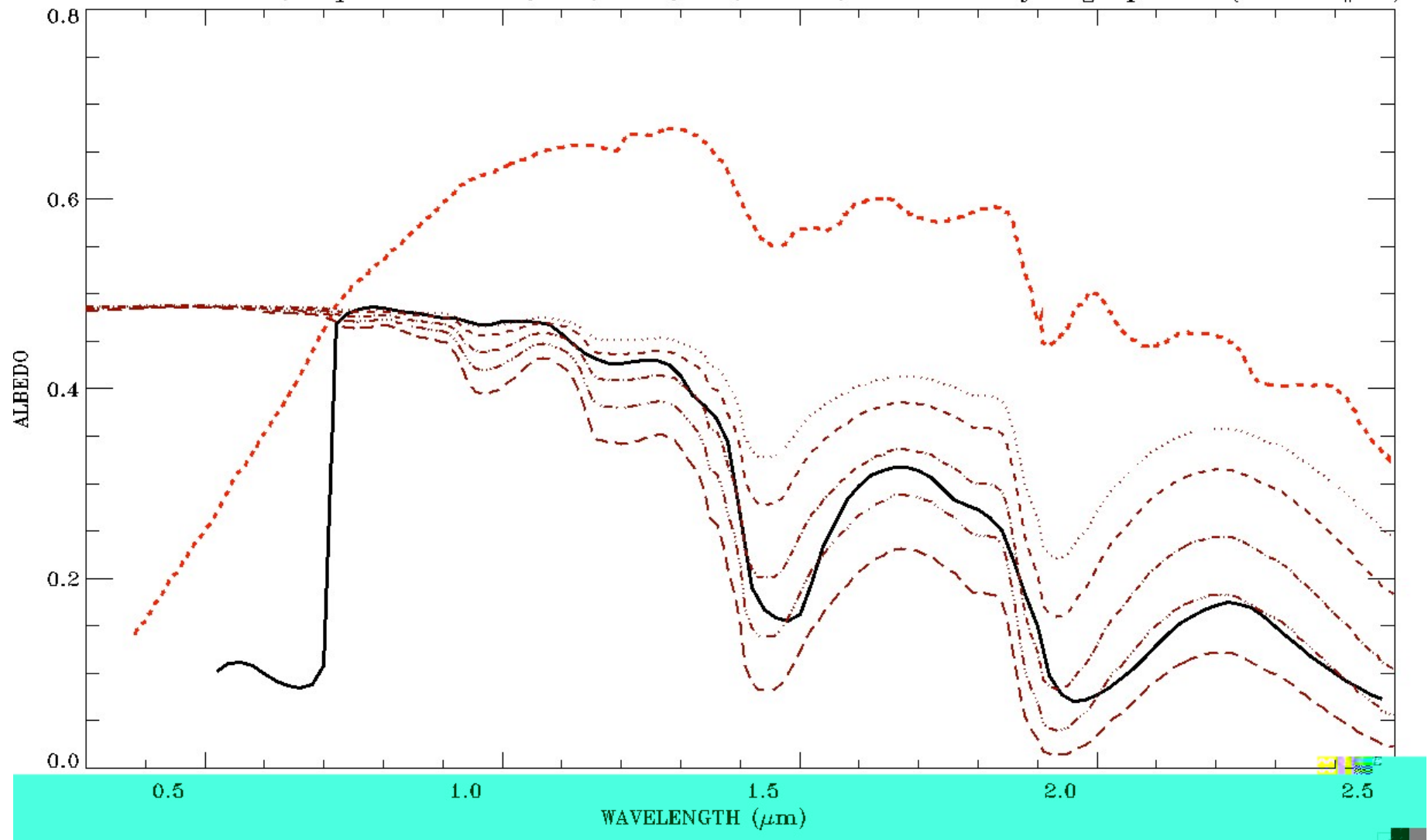
PRISM RGB

Reflectance Spectra
(Cloud & Shadow Method)

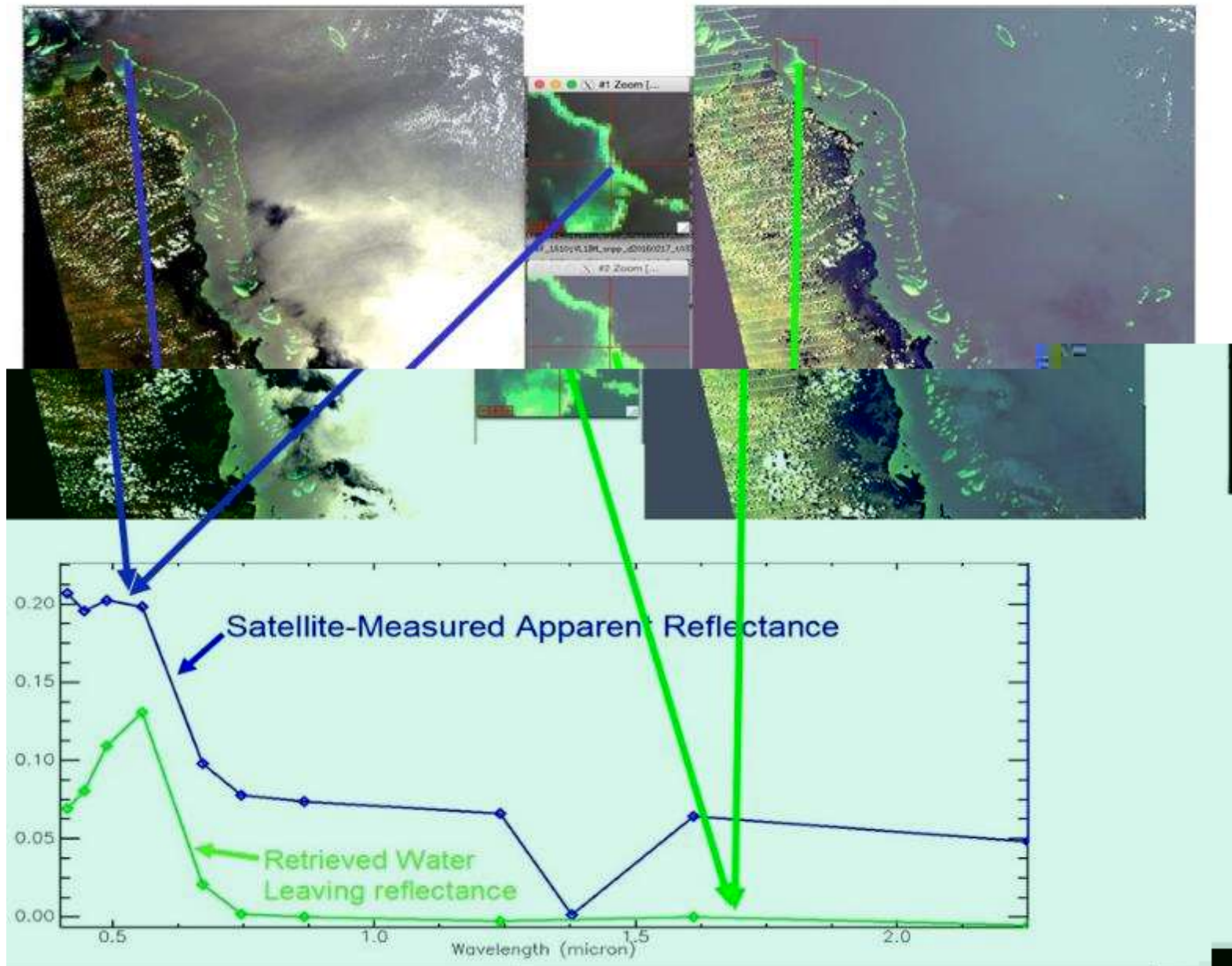


Modeling Green Vegetation Reflectance Spectra Above 0.8 micron Using A. Kokhanovsky's (2004) ART Liquid Water Spectral Reflectance Model & The Equivalent Water Thickness (EWT) Concept

ART Simu Refl, Liq Wat = 0.005, .01, .025, .05, .1 cm; Green & Dry Veg Spectra (Bowker#35)



VIIRS, Great Barrier Reef (with sunglint removal)



SUMMARY

- During the past PACE funding period, we developed or updated hyperspectral and multi-spectral atmospheric correction algorithms for remote sensing of case 2 waters. We tested the algorithms using AVIRIS, AVIRIS-NG, PRISM, MODIS, VIIRS, and Landsat 8 data.
- We also helped NASA GSFC & NASA JPL in developing hyperspectral data processing software packages.