Hyperspectral and Multispectral Atmospheric Correction Algorithms for Supporting the NASA PACE Mission

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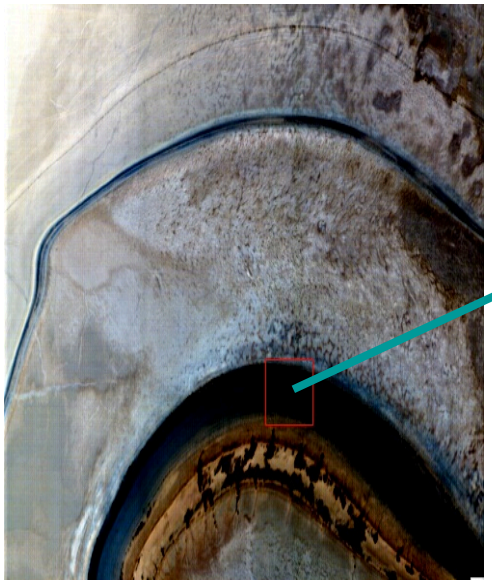
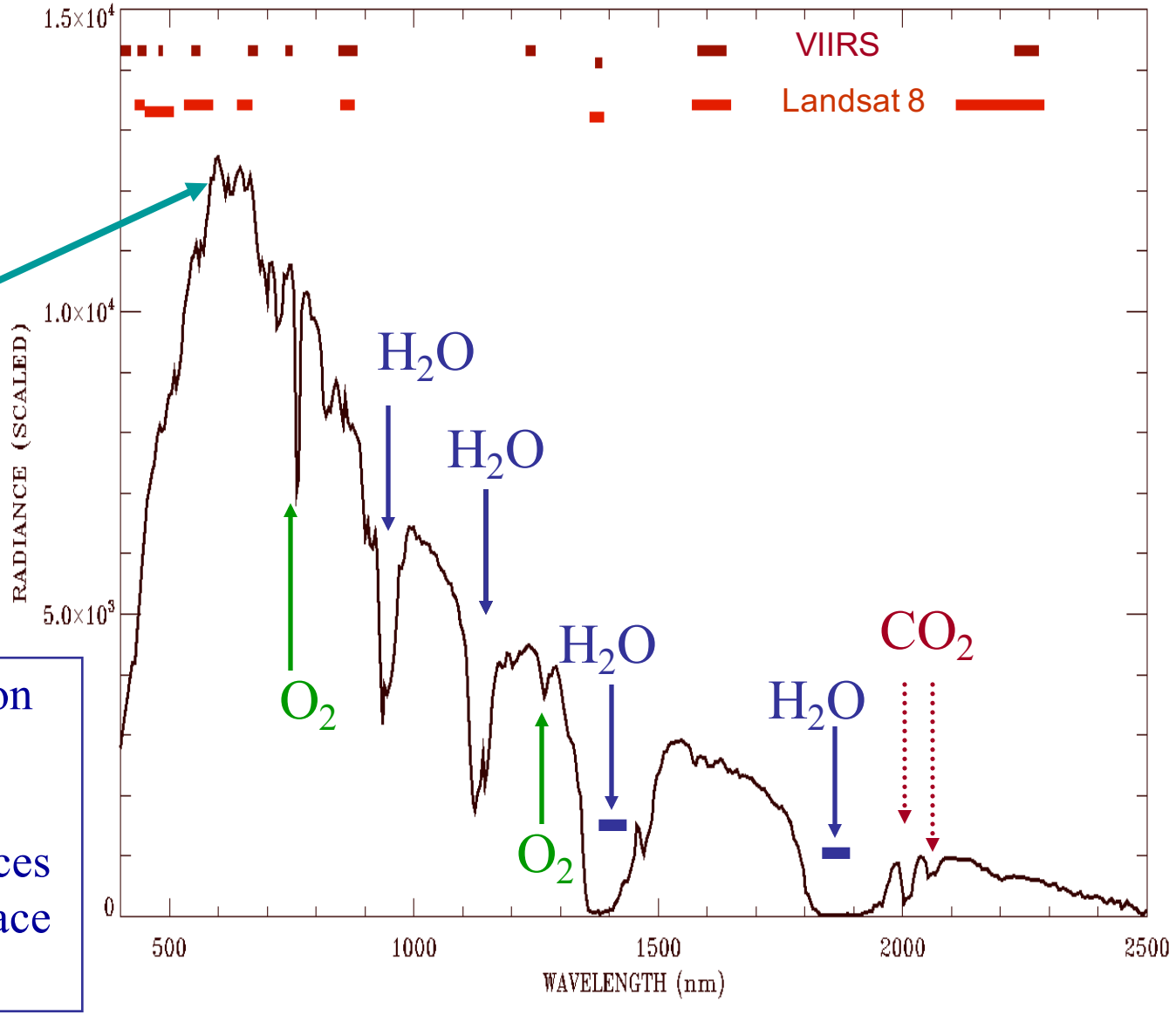
A Radiance Curve at 6 nm Spectral Resolution + VIIRS and Landsat8 Bands

A NIS Image + A Radiance Spectrum





Atmospheric absorption and scattering effects need to be removed from measured radiances in order to obtain surface spectral reflectances.

Selected Publications On Atmospheric Corrections and on the Analysis of AVIRIS, HICO, & MODIS Data

- **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. (Cited by **426** journal articles – till January 6, 2016).

- **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. (**195 citations**).

- **A Review Paper Published on a Special RSE Issue in Honor of Dr. Alex Goetz:**
  2009 – Atmospheric correction algorithms for hyperspectral remote sensing data of land and ocean, RSE, 113, S17–S24. (**143 citations**).

- **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. (**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. (**122**).

- **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 (9 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:

$$\pi L_{obs} / (\mu_0 E_0) = \pi L^*_0 / (\mu_0 E_0) + \pi L_g\, t'_u\, [t_d / (\mu_0 E_0\, t_d)] + \pi L_w\, t_u\, [t_d / (\mu_0 E_0\, t_d)] \quad (2)$$

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

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

$\rho^*_{atm} = \pi L^*_0 / (\mu_0 E_0)$, (4)

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

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

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

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

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

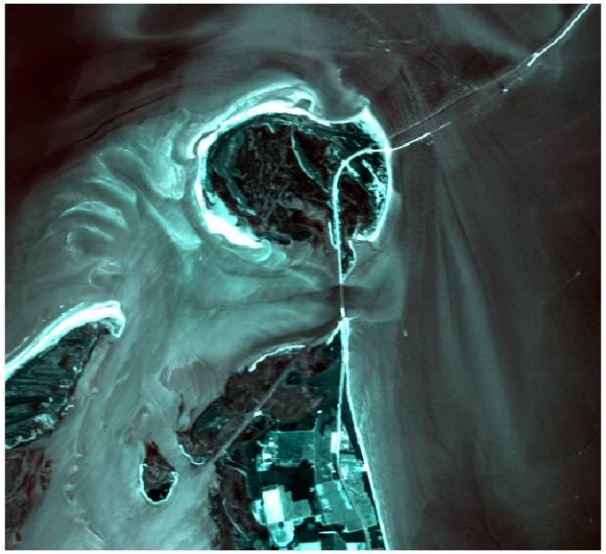
After consideration of gas absorption and multiple reflection between the atmosphere and surface, & denoting $\rho^*_{atm+glint} = \rho^*_{atm} + \rho_g\, t_d\, t_u$, we can get:

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

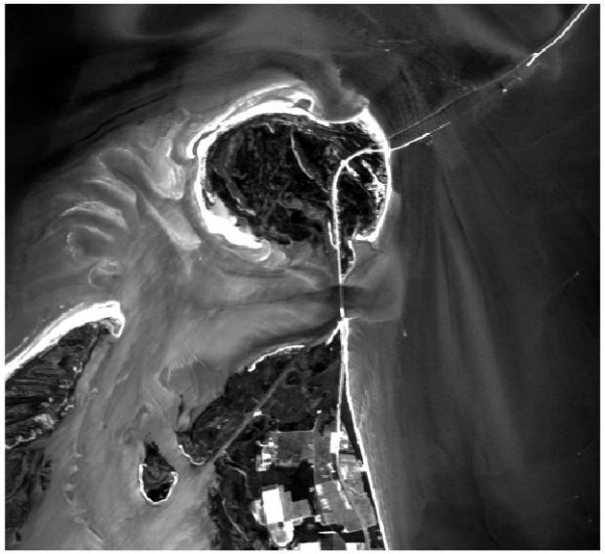
Gao, B.-C., M. J. Montes, Z. Ahmad, and C. O. Davis, Appl. Opt. 39, 887-896, February 2000

Coastal Waters Are Dark Above 0.86 Micron (AVIRIS Norfork Images)

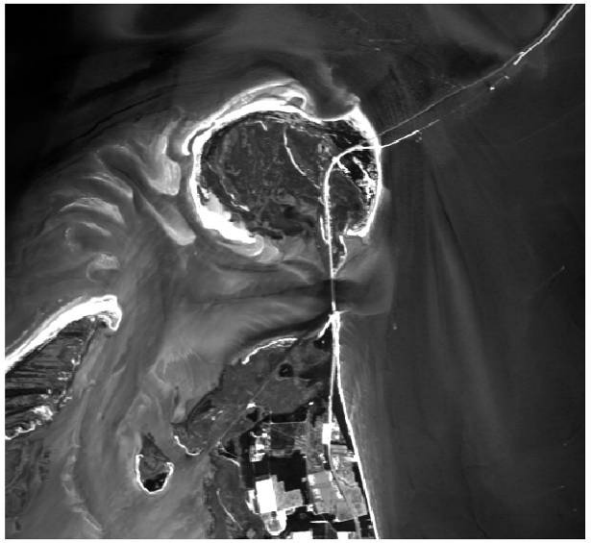
RGB (0.66, 0.55, 0.47 μm)



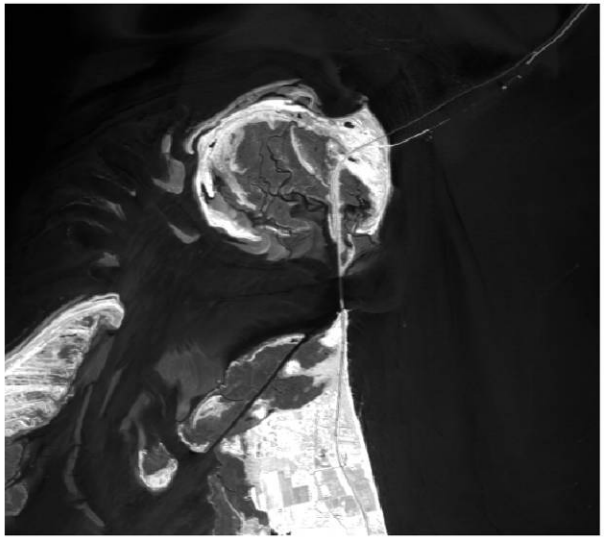
0.55-μm



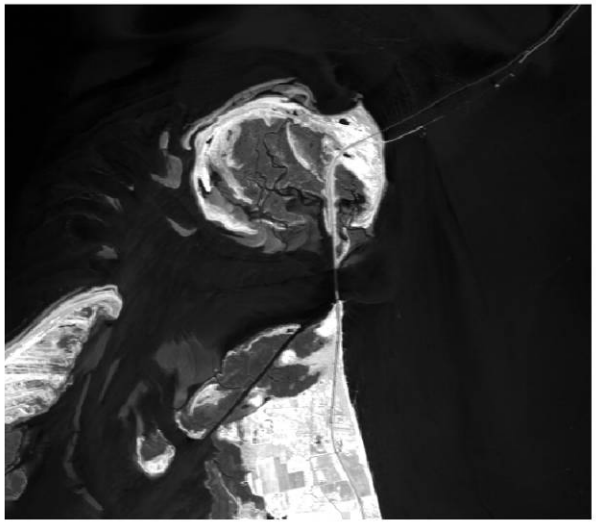
0.66-μm



0.75-μm

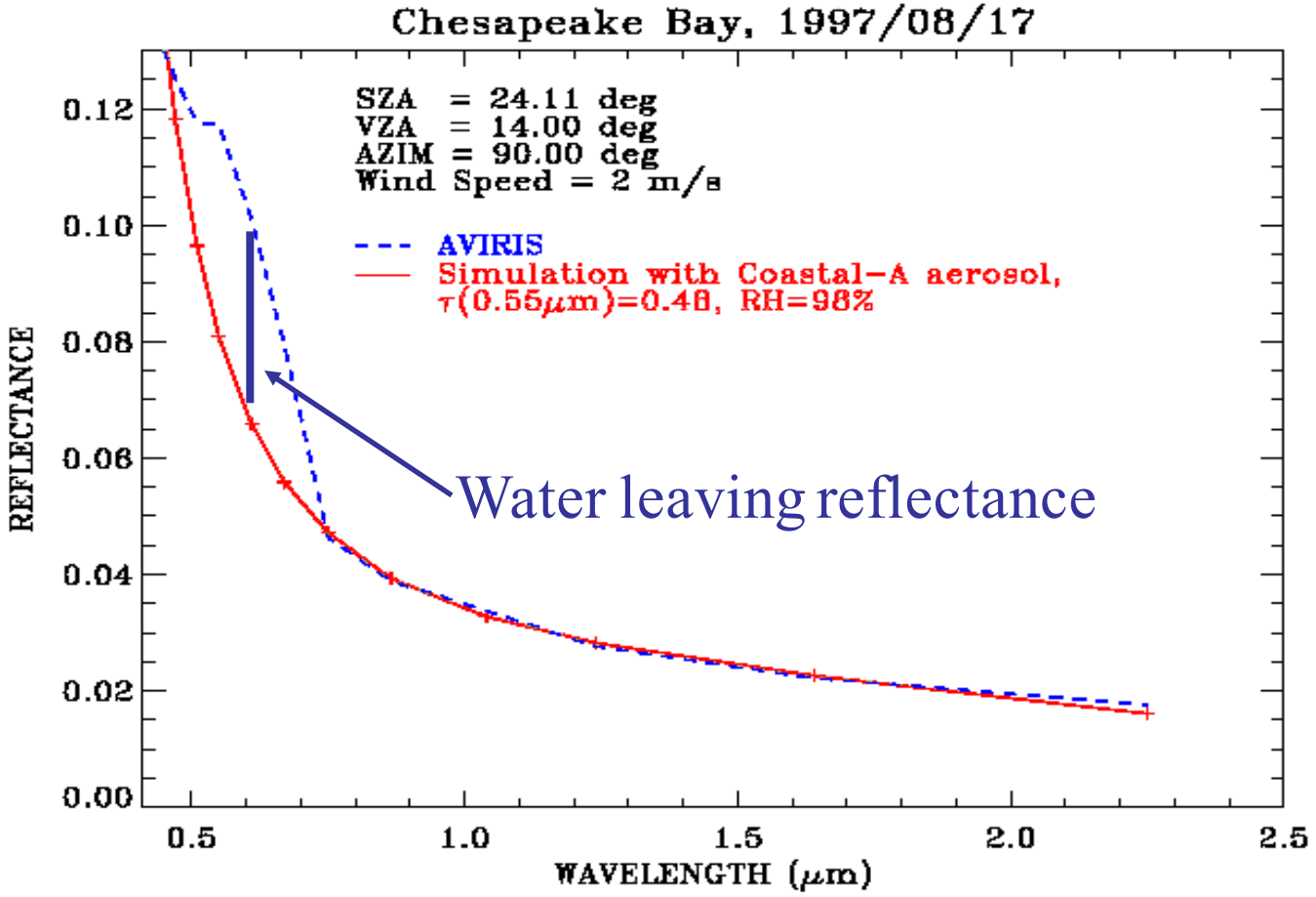


0.86-μm



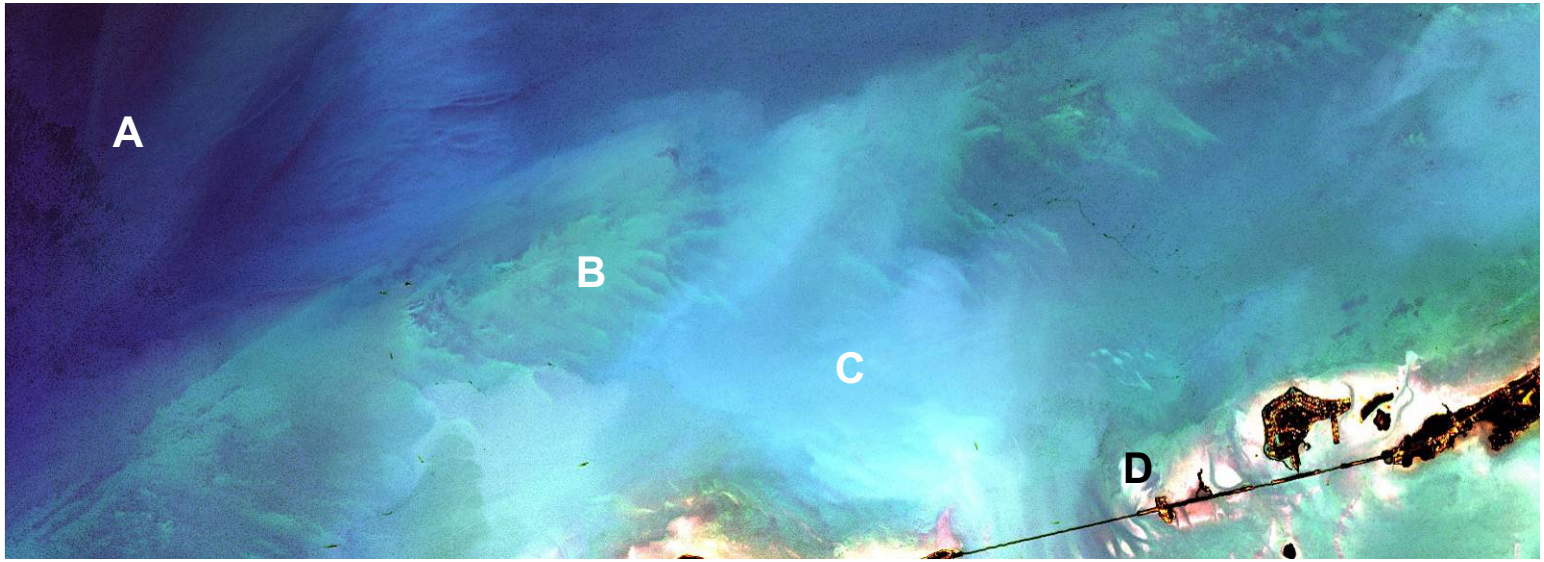
1.02-μm

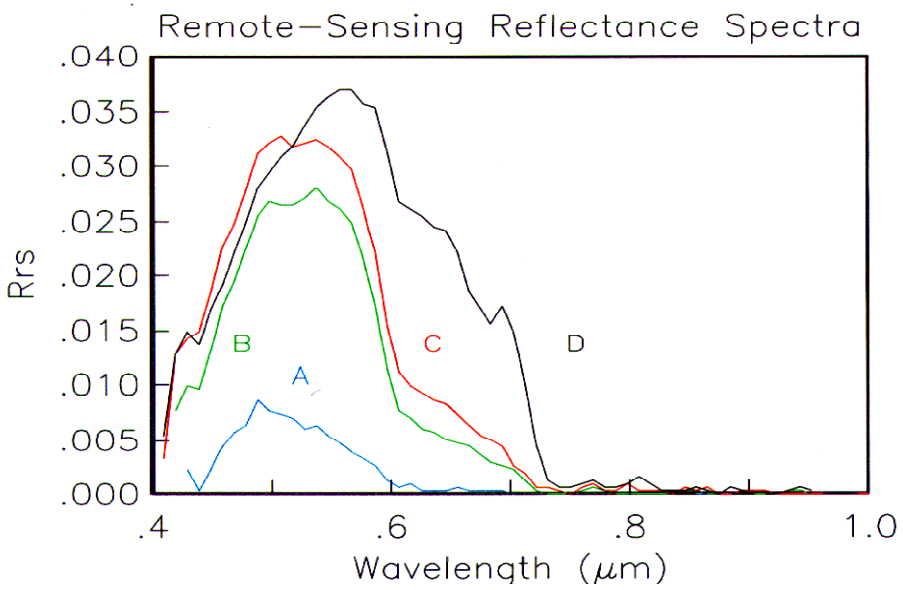
Atmospheric Correction for Water Surfaces



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

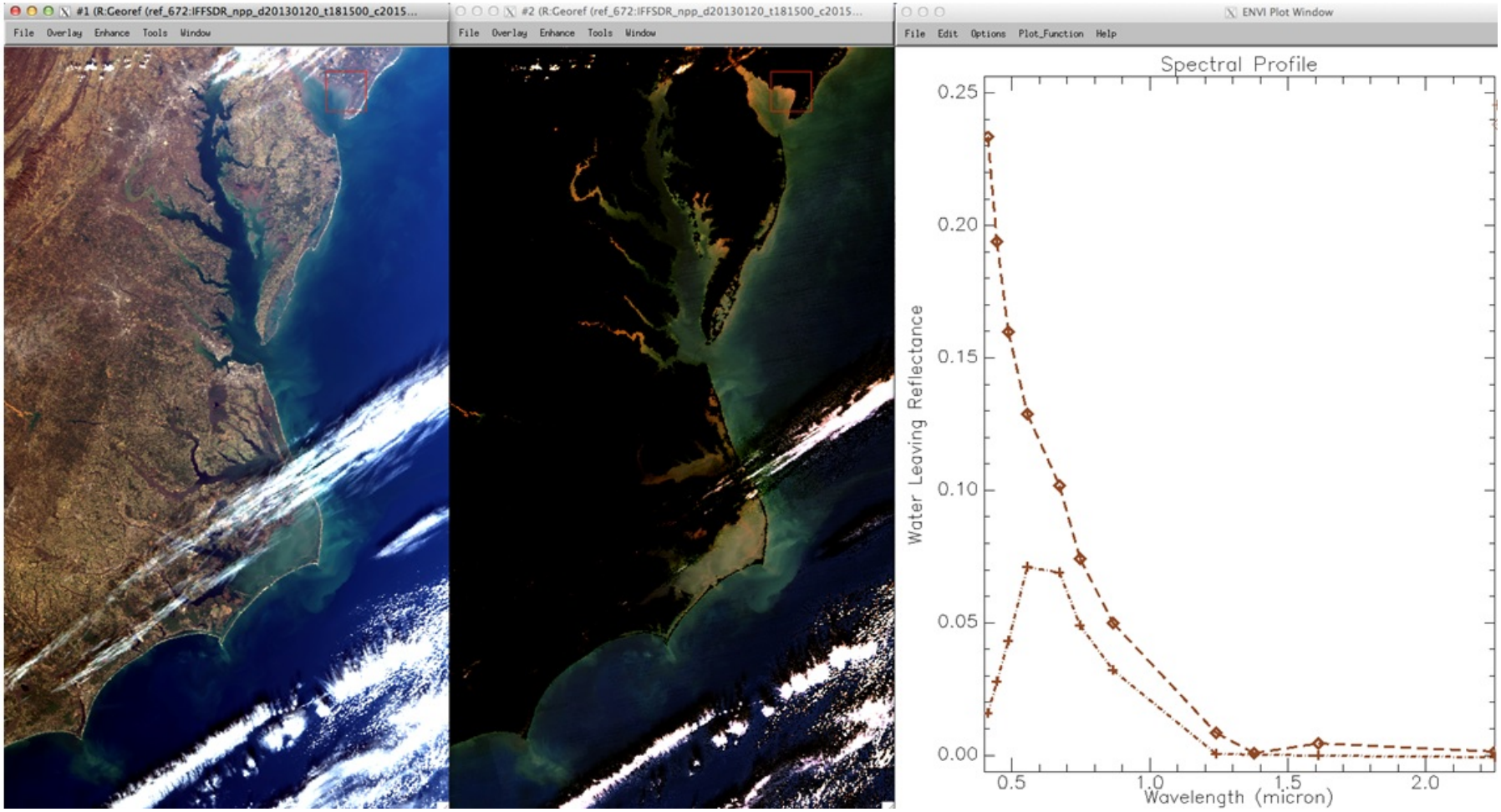




(B.-C. Gao, M. J. Montes, Z. Ahmad, and C. O. Davis, *Appl. Opt.* 39, 887-896, 2000.)

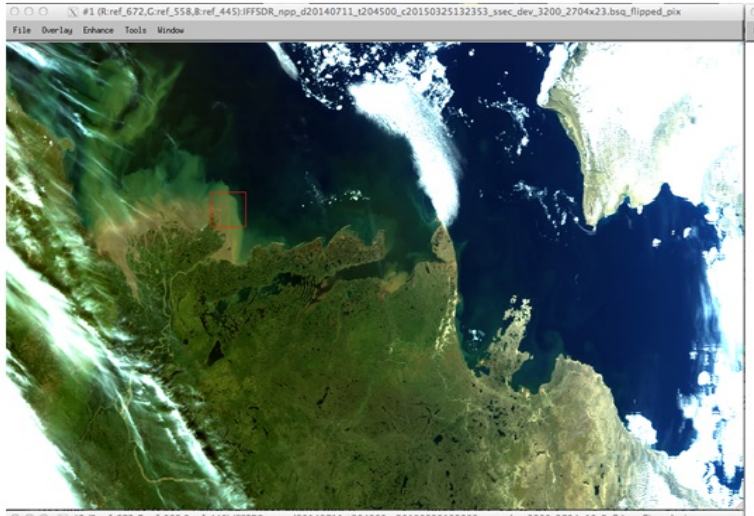
Sample VIIRS Water Leaving Reflectance Retrieval over Chesapeake Bay (Using Bands at 1.24, 1.61, and 2.25 μm for atmosphere correction)

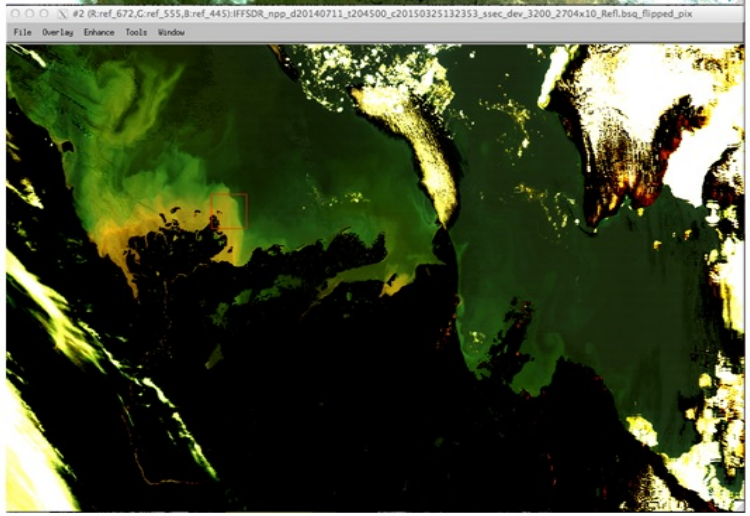
Chesapeake Bay

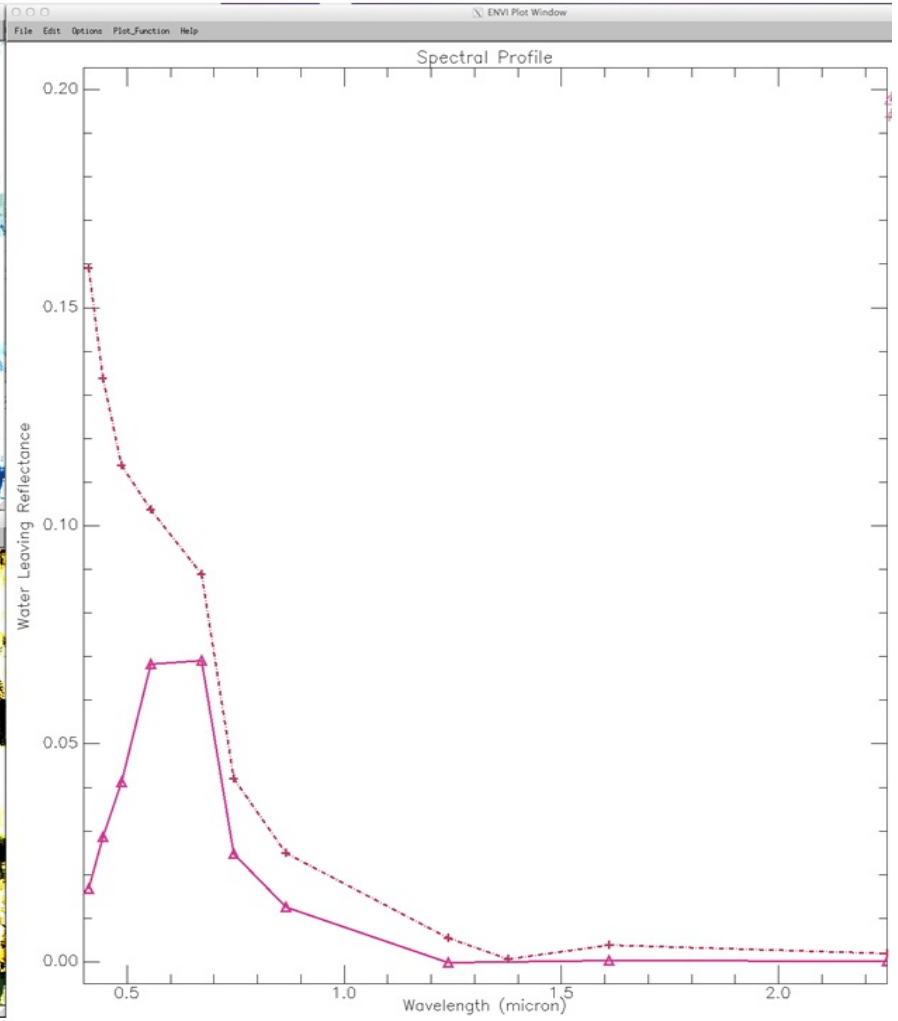


Sample VIIRS Water Leaving Reflectance Retrieval over High Latitude Region
(Using Bands at 1.24, 1.61, and 2.25 μm for atmosphere correction)

Beaufort Sea, North Western Canada

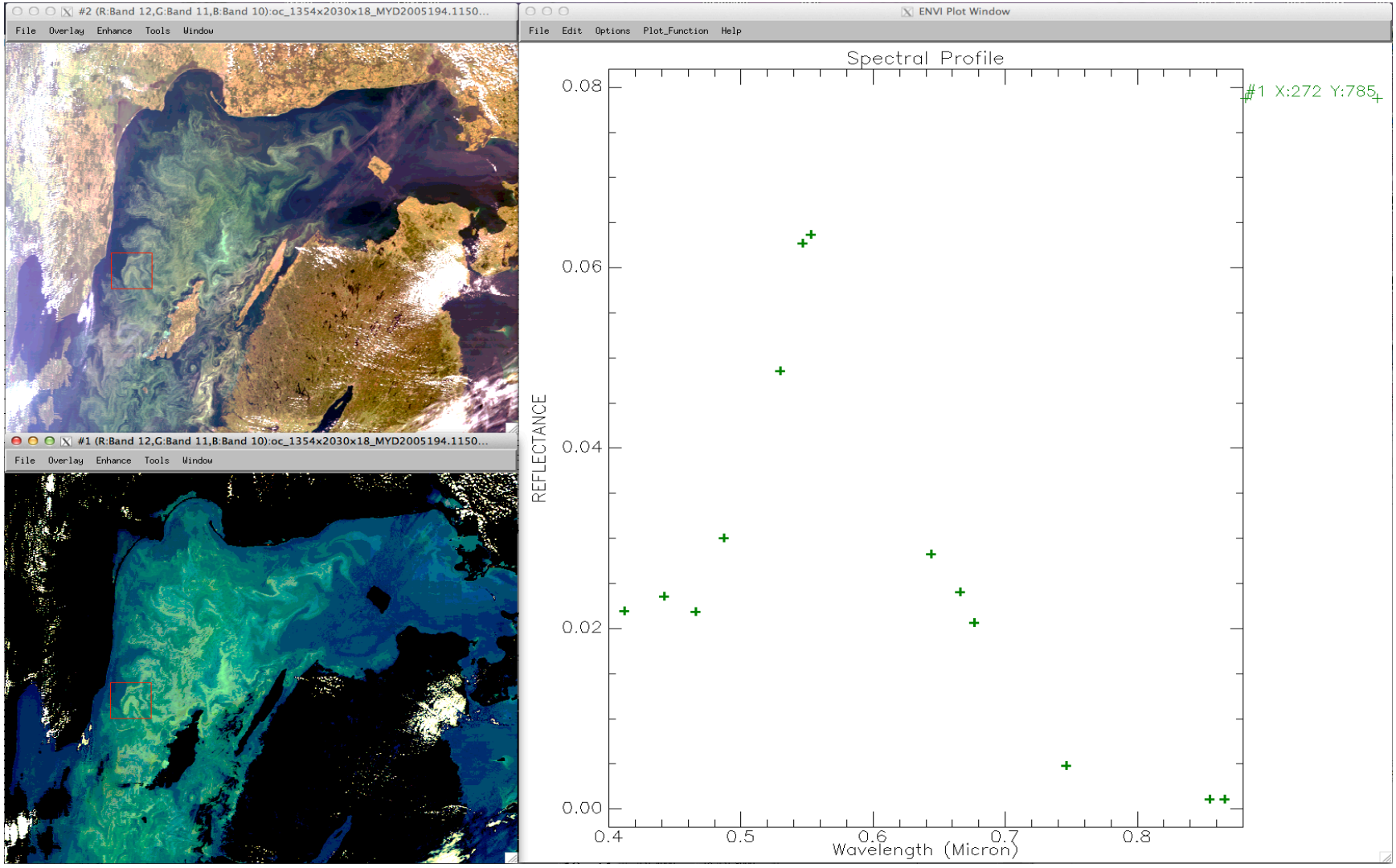






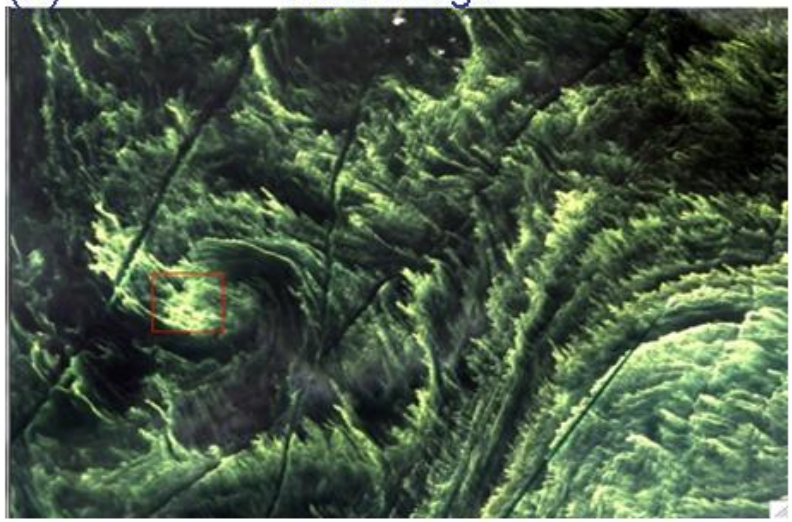
Sample MODIS Water Leaving Reflectance Retrieval over Baltic Sea

(Assuming AOD = 0.1 at 0.55 μm & R_{rs}(1.24 μm) = 0)

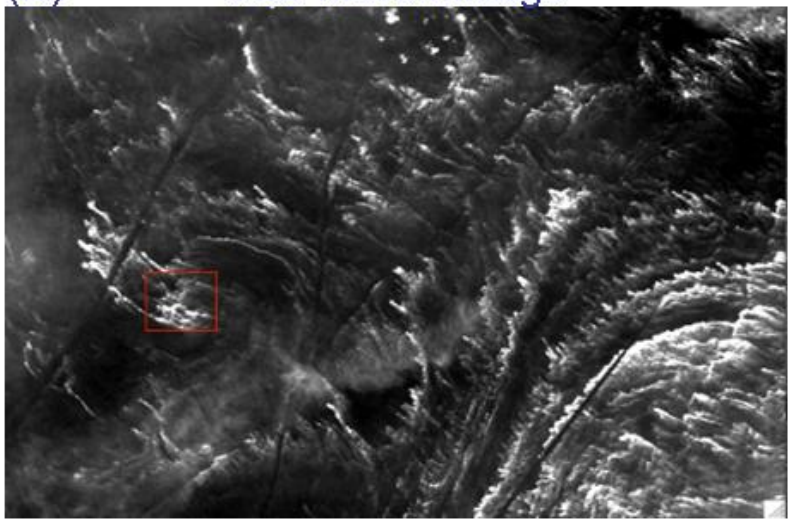


Water Leaving Reflectance Retrieval From L8 Data Acquired Over Baltic Sea

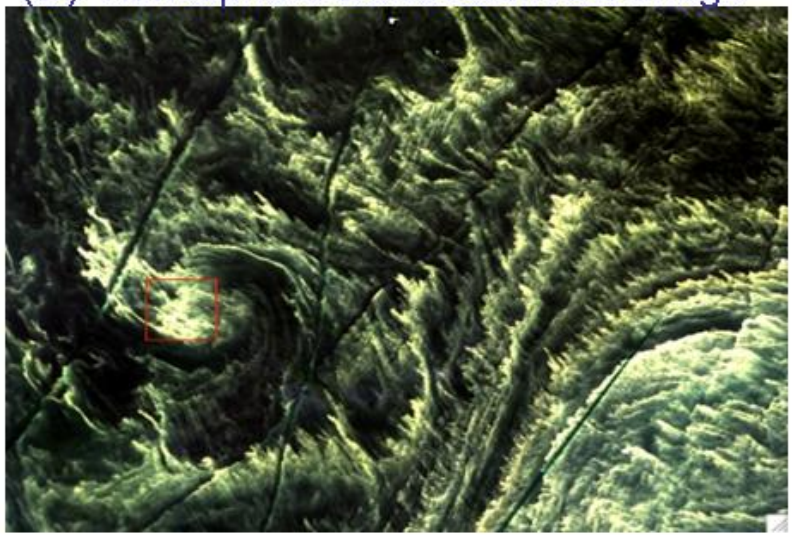
(A) RGB Image



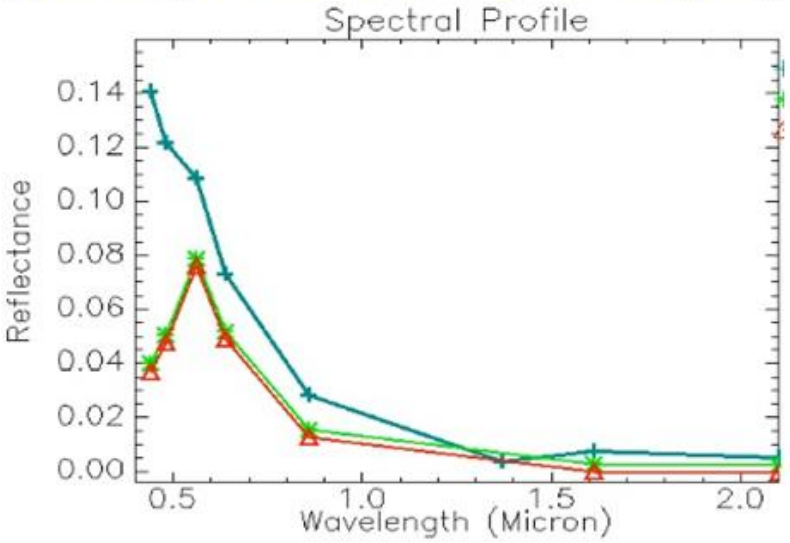
(B) 0.86-Micron Image



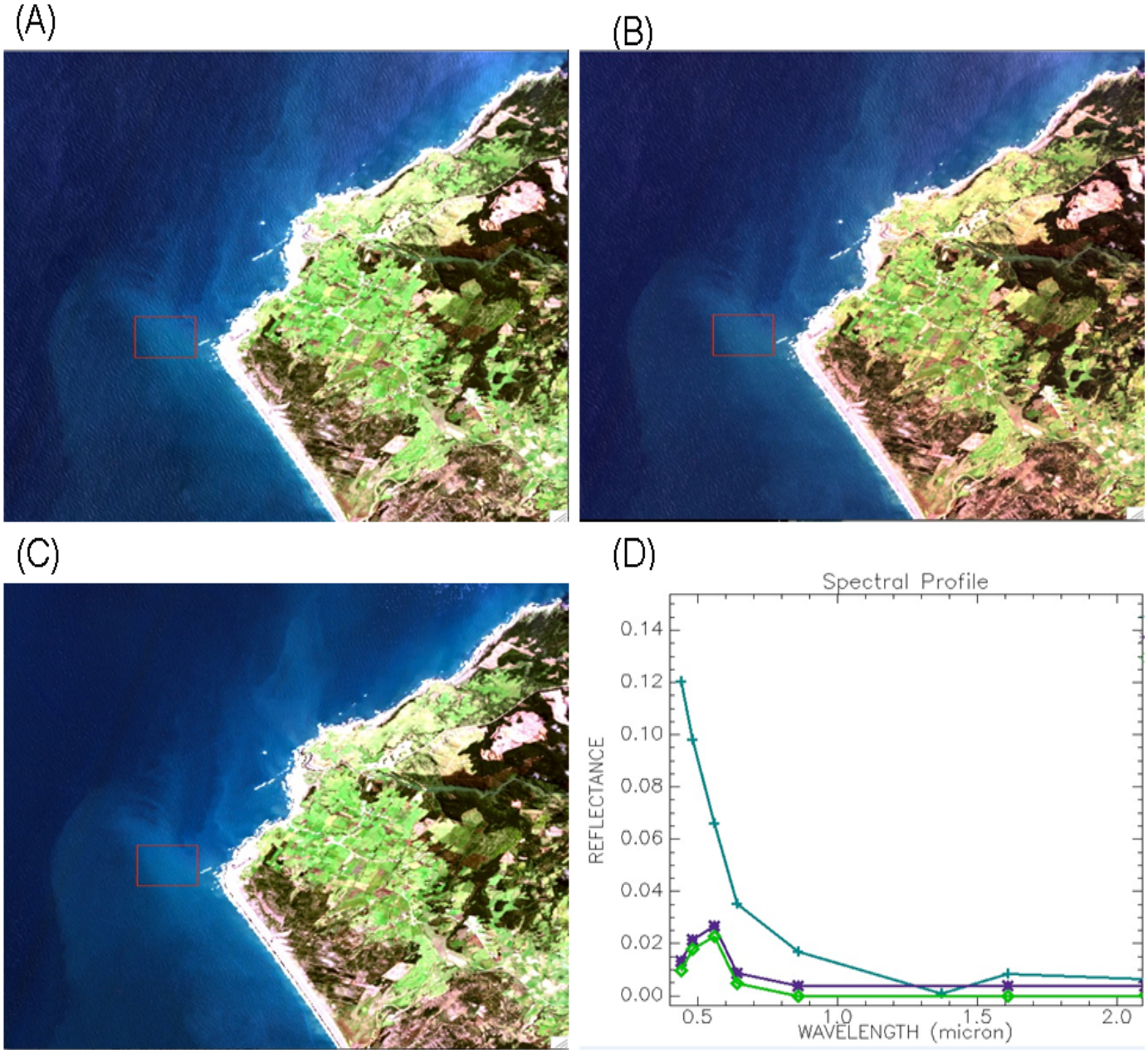
(C) Atmosphere-Corrected RGB Image



(D) Atmosphere-Corrected Spectrum (Red)



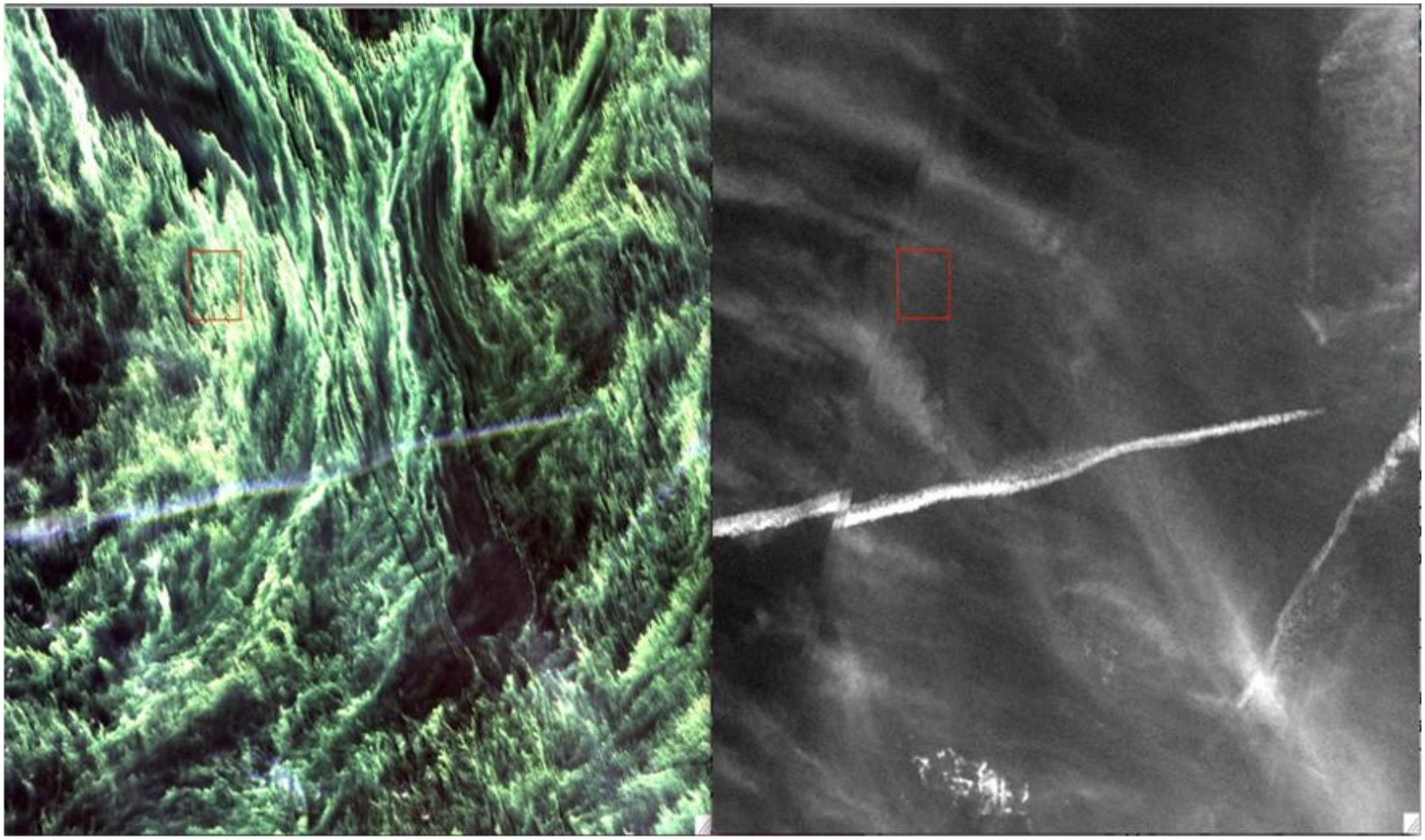
Second Example of Atmospheric Correction for Landsat 8 Data



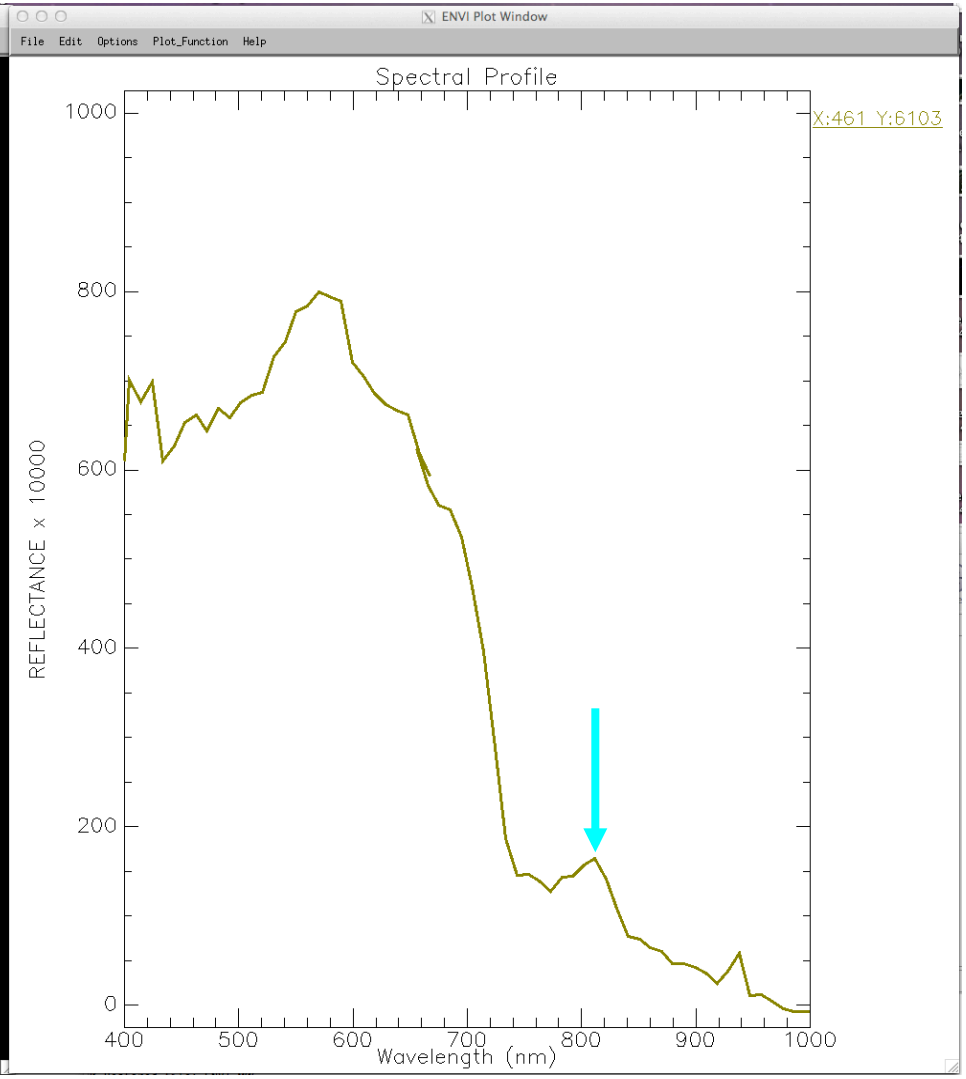
Spatial mis-registration of elevated cloud and aerosol features in different Landsat 8 band images (Parallax Effects)

RGB Image

Cirrus Image (1.375-μm Band)



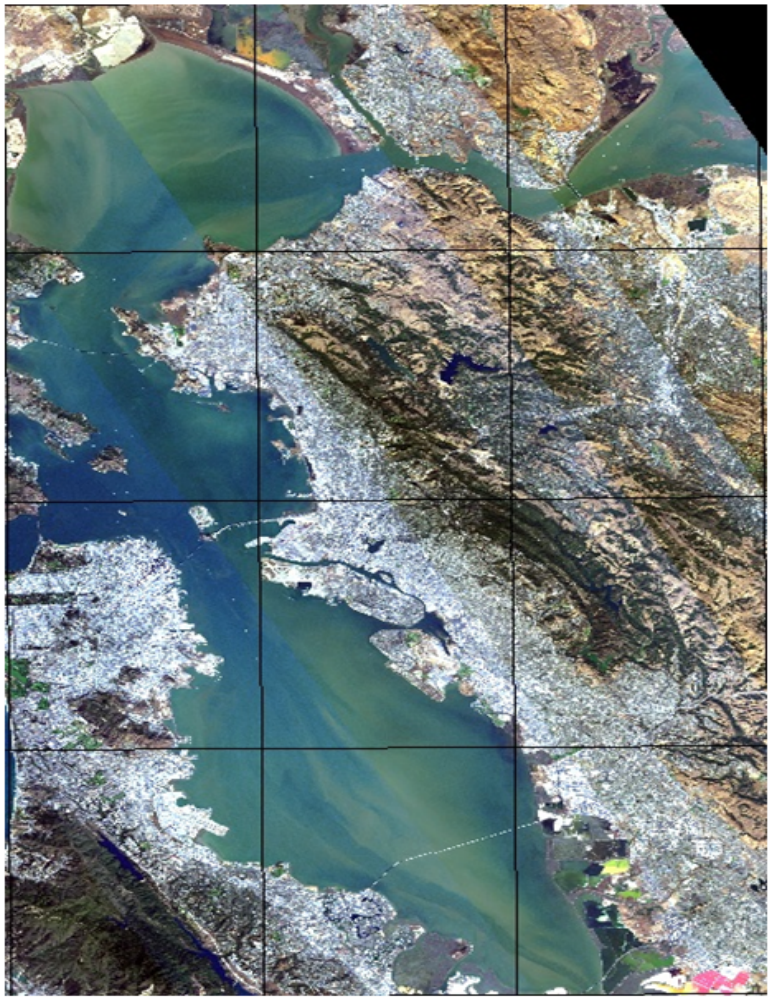
A Sample Water Leaving Reflectance Retrieval From AVIRIS data



Kd(490) Image Derived From AVIRIS Data

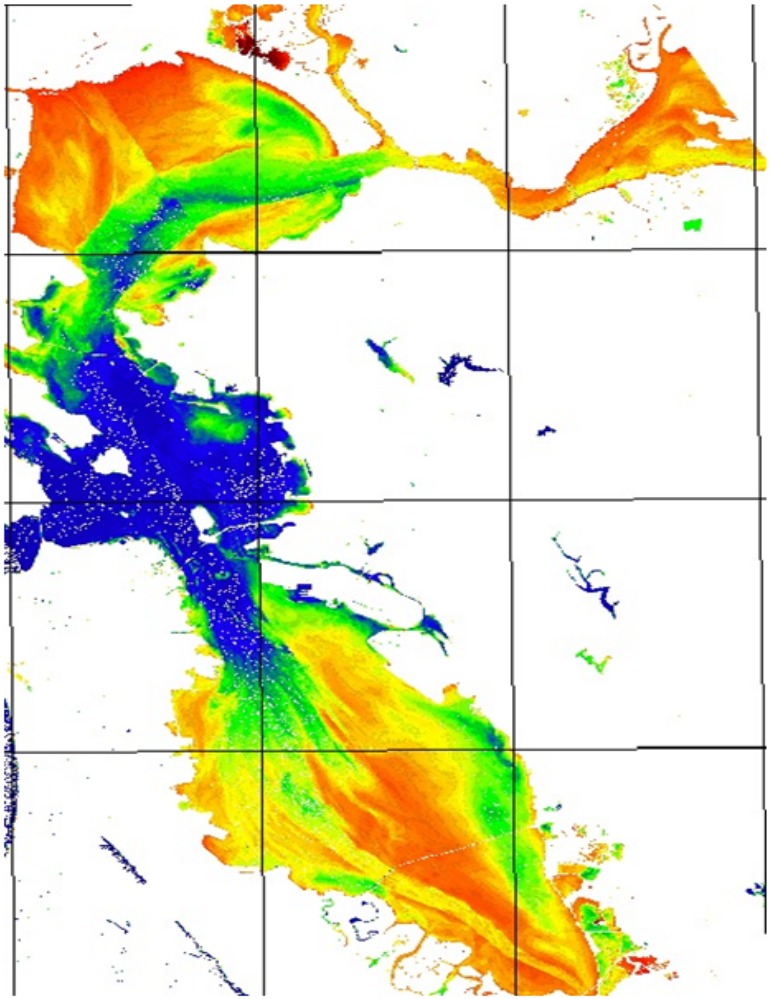
RGB Image
(Composited from several Flight Lines)

(A)



Kd_490 Image

(B)



HICO RGB Image Over Florida Keys

SUMMARY

- During the 1st year of PACE funding, we developed or updated hyperspectral and multi-spectral atmospheric correction algorithms for remote sensing of case 2 waters. We tested the algorithms using AVIRIS, MODIS, VIIRS, and Landsat 8 data.

- We also helped NASA GSFC in developing hyperspectral data processing capability for implementing into the "l2gen" software package.

- In the upcoming year, we plan to develop functional version of hyperspectral and multi-spectral atmospheric correction algorithms using a combination of UV, NIR, and SWIR channels. Lookup tables generated by Dr. Pengwang Zhai at the Physics Department of UMBC covering the 0.35 - 2.5 micron spectral range with a total of 50 aerosol models will be used in the new algorithms.