Hyperspectral Atmospheric Correction

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BACKGROUND

The concept of imaging spectroscopy, or hyperspectral imaging, was originated from NASA JPL in the early 1980s (Goetz et al., Science, 1985), mainly for geological remote sensing.

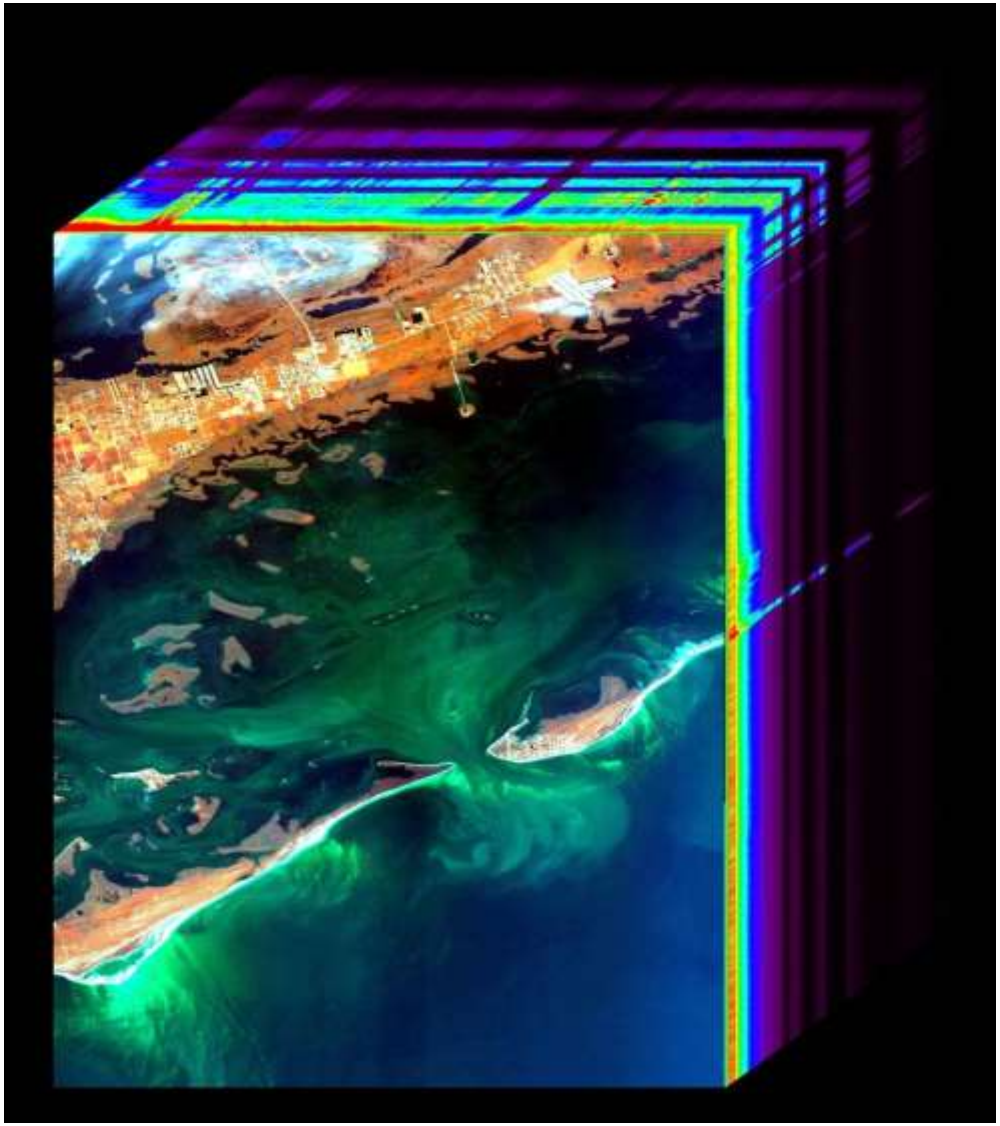
Over the past 30 years, imaging spectrometry has found important applications in remote sensing of land, ocean, and atmosphere.

At present, the Hyperion instrument on board the EO-1 Spacecraft is still functioning, but the signal to noise ratio of Hyperion data is low.

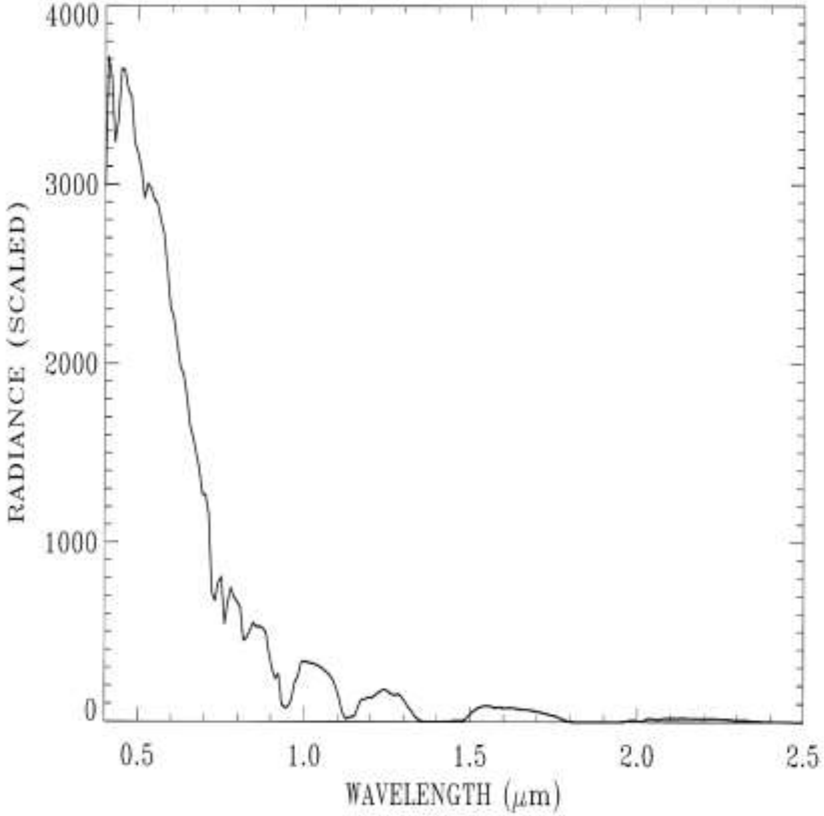
In the near future, the NASA PACE mission will carry a spaceborne hyperspectral ocean color imager (OCI), which will offer improved capability for remote sensing of case 2 waters.

Because the solar radiation on the sun-surface-sensor path is affected by absorption and scattering from atmospheric gases, aerosols, and clouds, the atmospheric effects need to be removed from measured data for improved remote sensing of ocean color and land surfaces.

Imaging Spectrometry Concept

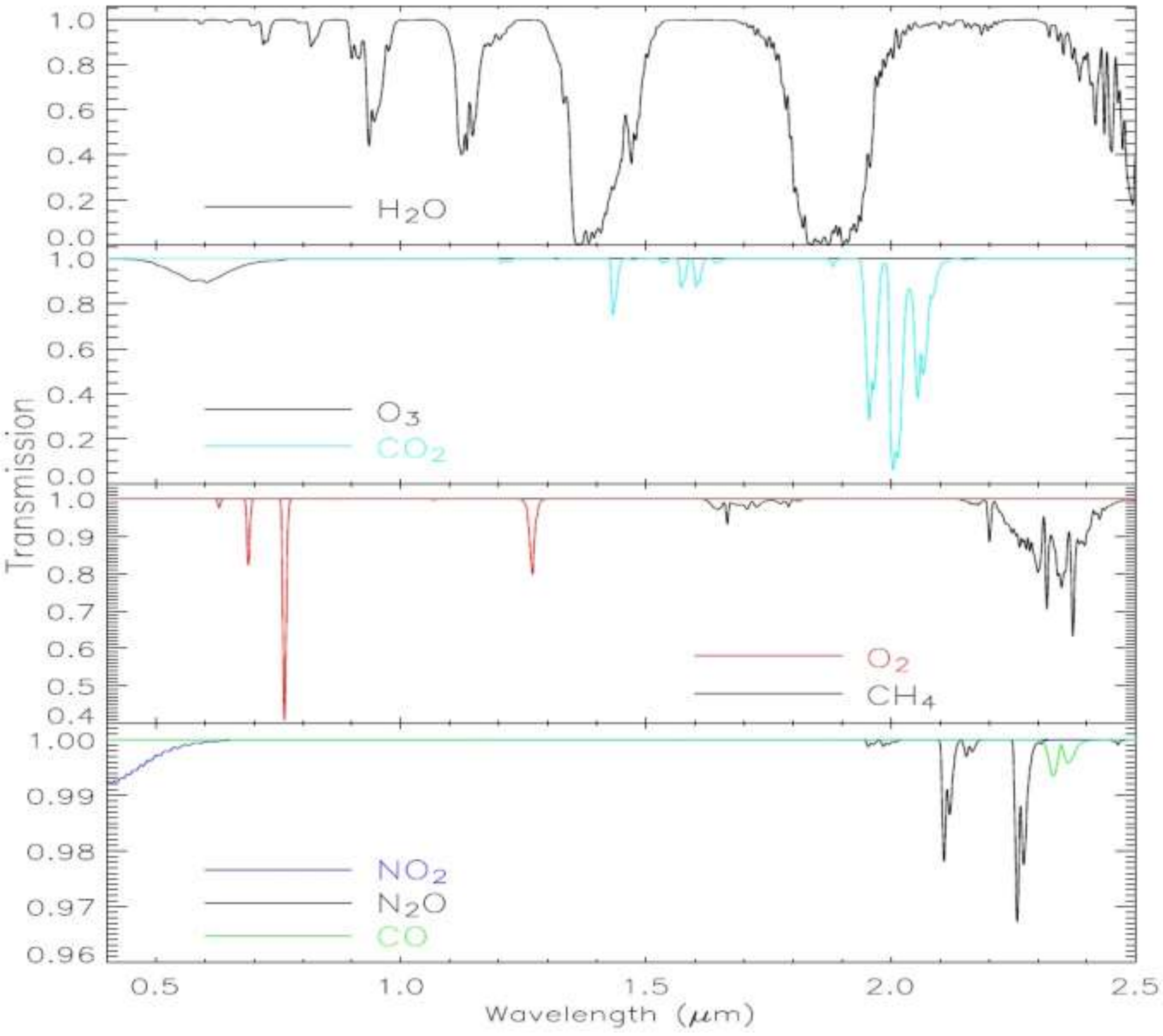


A Sample Spectrum



Radiances above 1 μm are very small over water surfaces. Atmospheric absorption and scattering effects need to beremoved in order to recover the water leaving reflectance spectra.

Atmospheric Gas Transmittances



The Present Status of Hyperspectral Atmospheric Correction Algorithms

- So far, there are very limited number of hyperspectral atmospheric correction algorithms available, including ATREM, FLAASH, ACORN, ATCOR, etc. A review on the subject was given by Gao et al. (RSE, 2009).

- Most of atmospheric correction algorithms developed till present are multi-spectral in nature. A summary on these algorithms has recently been given by R. Frouin et al. in the paper entitled “Bayesian methodology for inverting satellite ocean-color data”.

Traditional Gordon & Wang (1994) Formulation of

Satellite-Measured Reflectance (Radiance)

$$\rho_t(\lambda) = \underbrace{\rho_r(\lambda)}_{\text{Rayleigh}} + \underbrace{\rho_A(\lambda)}_{\text{Aerosols}} + \underbrace{\underbrace{t(\lambda)t_0(\lambda)}_{\text{Transmittance}}\underbrace{\left[\rho_w(\lambda)\right]_N}_{\text{Ocean}}}_{\text{Satellite-Measured Ocean Contribution}}$$

$$\rho(\lambda) = \pi L(\lambda)/\mu_0 F_0(\lambda)$$

$$\rho_{path}(\lambda) = \rho_r(\lambda) + \underbrace{\rho_A(\lambda)}_{\rho_a(\lambda)+\rho_{ra}(\lambda)}$$

Menghua Wang, IOCCG Lecture Series--Atmospheric Correction

This is not a physical quantity, and can be negative. When aerosol optical depths are large (> 0.4) or in the presence absorbing aerosols, atmospheric effects cannot be decomposed into Rayleigh, aerosol, and Rayleigh aerosol interaction terms.

Fraser’s Formulation and Definitions

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

$$L^*_{obs} = L^*_0 + L_g\, t'_u + L_w\, t_u, \qquad (1)$$

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:

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

$$+ \pi L_w\, t_u\, [t_d / (\mu_0\, E_0\, t_d\,)] \qquad (2)$$

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:

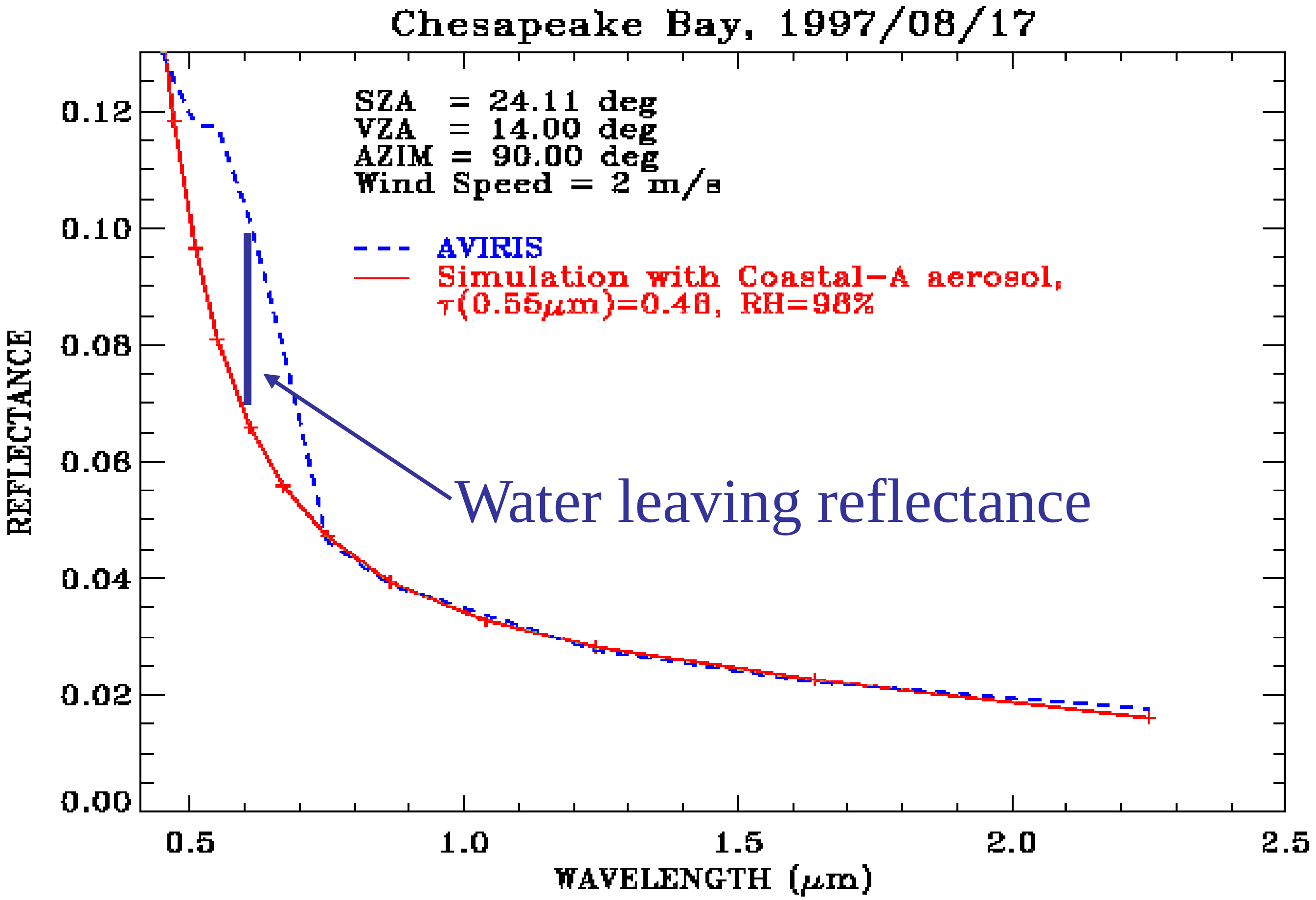
$$\rho^*_{obs} = \rho^*_{atm} + \rho_g\, t_d\, t_u + \rho_w\, t_d\, t_u \qquad (7)$$

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:

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

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

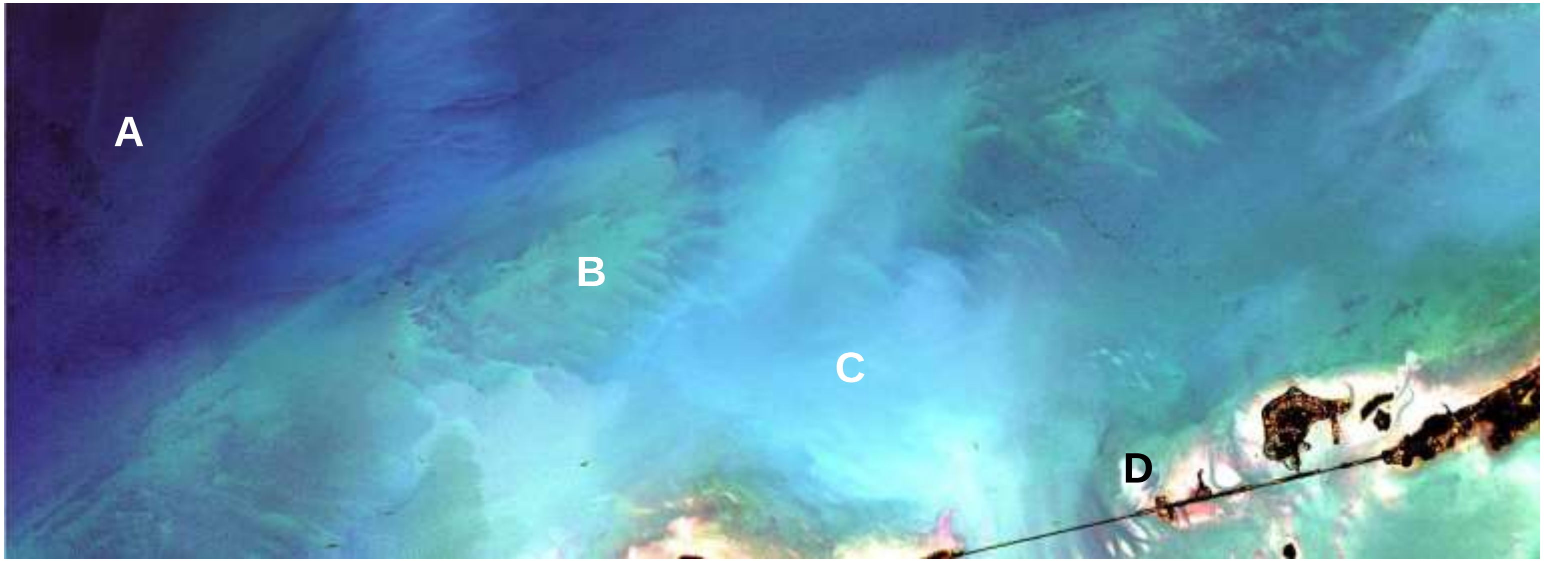
Atmospheric Correction for Water Surfaces

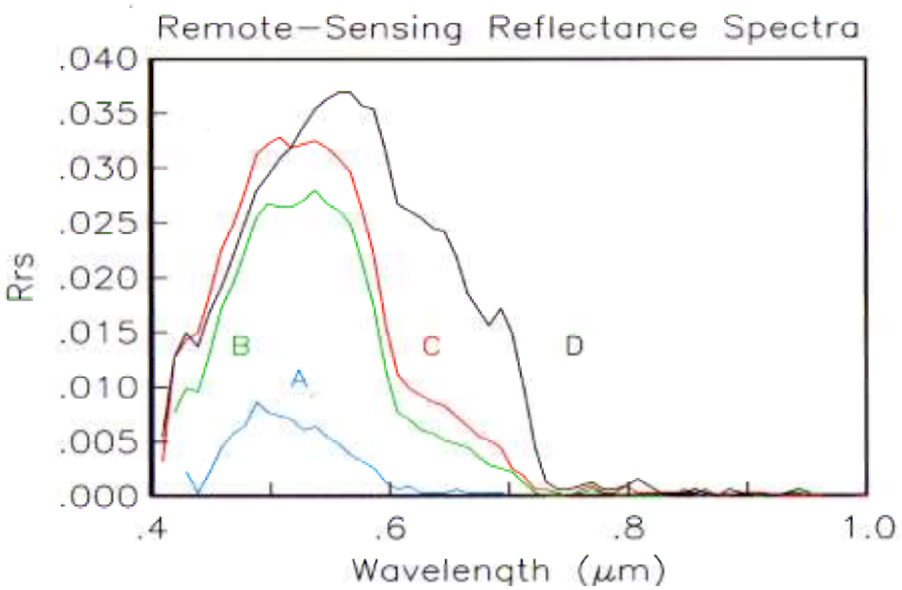


Water leaving reflectance

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.

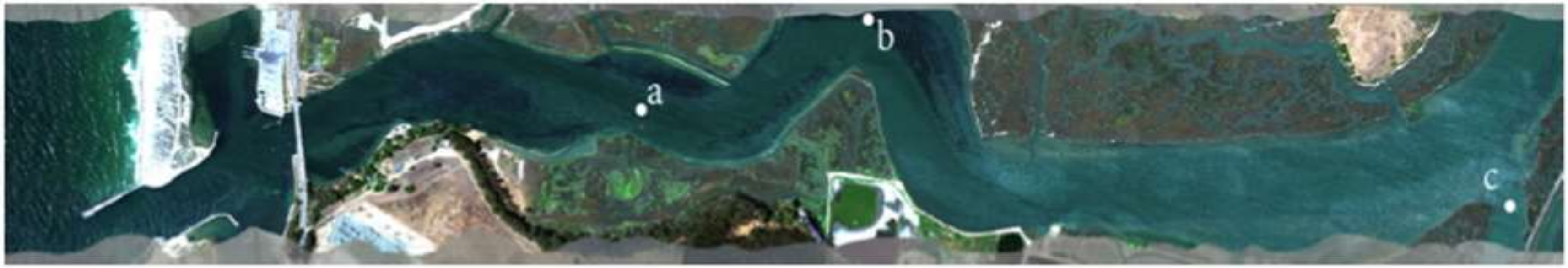
Atmospheric Corrections Using an Ocean Version Algorithm

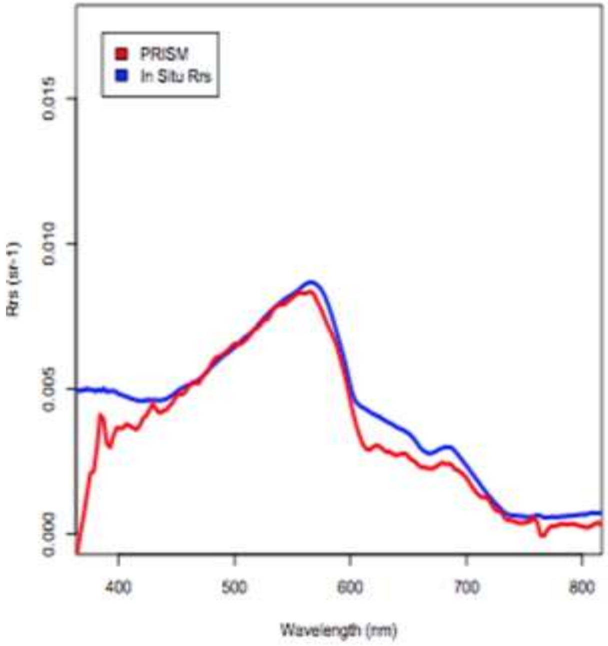




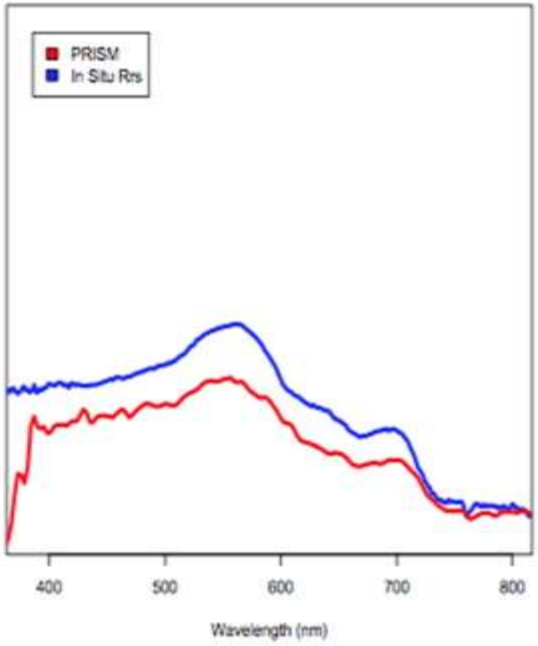
(B.-C. Gao, M. J. Montes, Z. Ahmad, and C. O. Davis, *Appl. Opt.* 39, 887-896, 2000.)

Atmospheric Correction Using a Land Version Algorithm

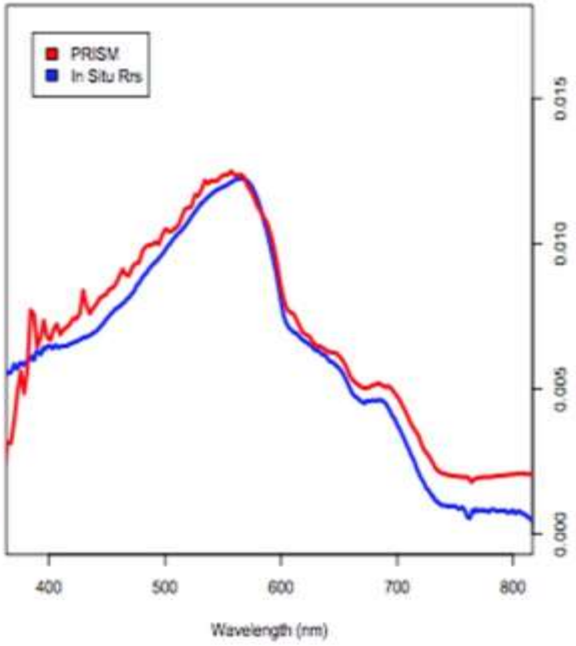




(a) West LOBO Buoy

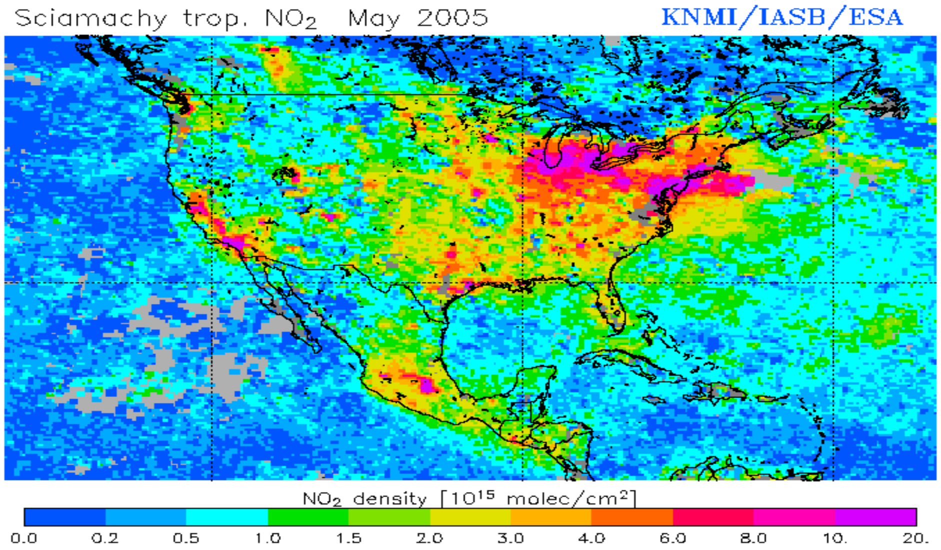


(b) Seal Bend Dense Eelgrass

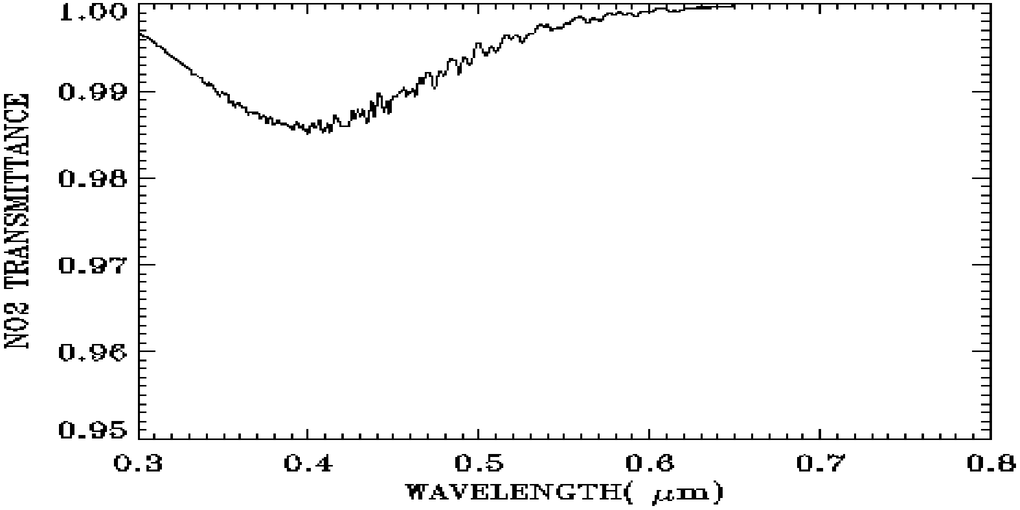


(c) East LOBO Buoy

Atmospheric Correction Challenges: NO_2 Absorption



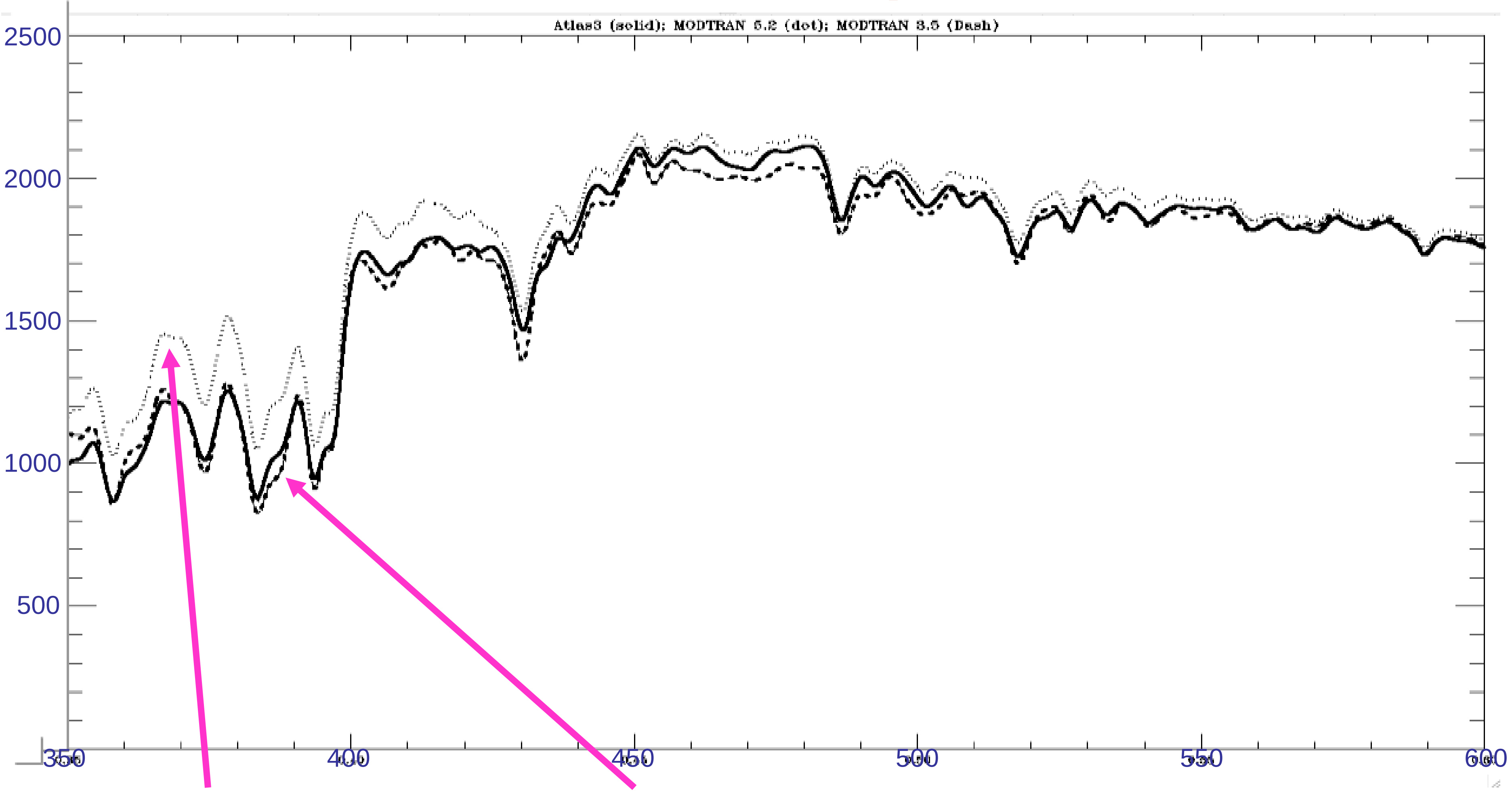
An NO_2 Transmittance Spectrum



- Spatial & temporal variations in atmospheric NO_2 column amounts.
- Enhanced NO_2 concentrations are observed in some geographical regions in certain months.
- NO_2 absorption needs to be properly modeled for improved remote sensing of ocean color in the UV & visible spectral regions.

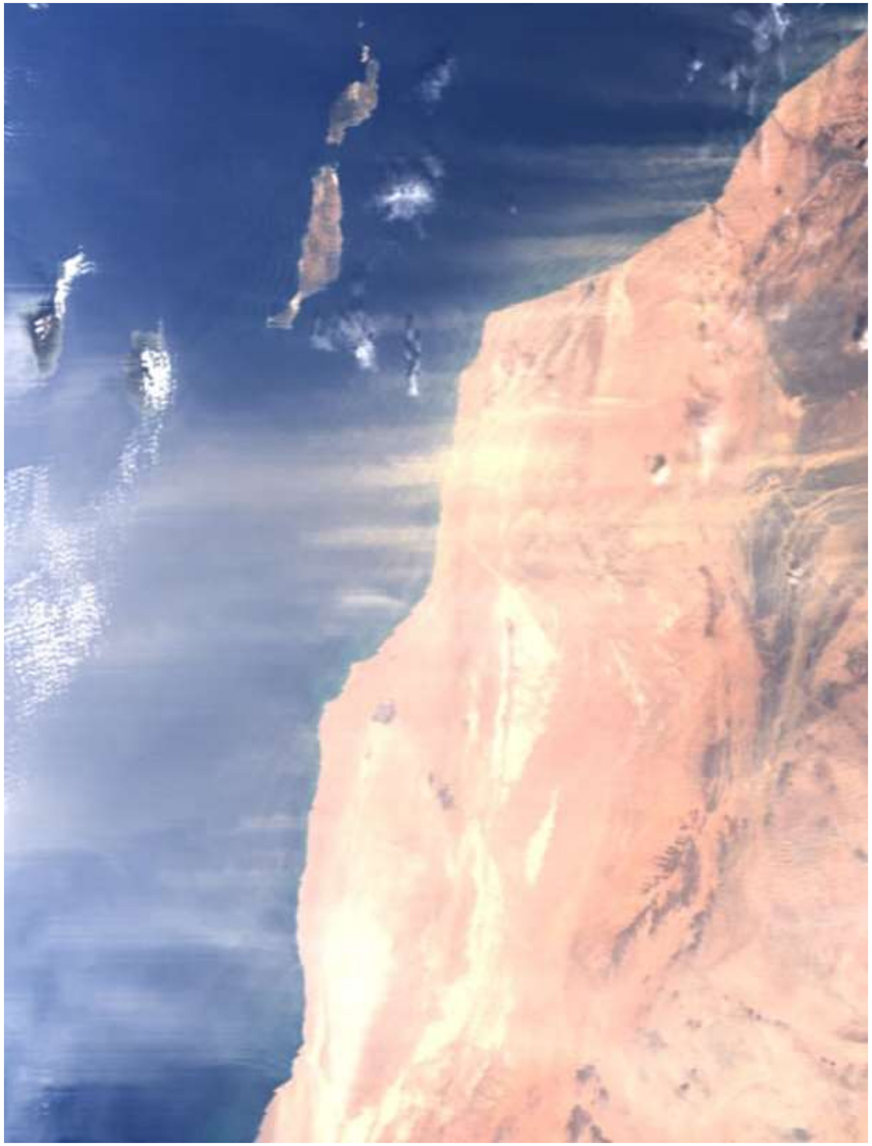
Atmospheric Correction Challenges: Solar Irradiance Curve

Comparisons of three solar irradiance curves: Atlas3, MODTRAN 5.2, & MODTRAN 3.5 (The data were smoothed to 3 nm spectral resolution)



The magnitudes and spectral shapes are very different for the 3 standard solar irradiance curves in the 350 – 600 nm wavelength range. An improved solar Irradiance curve is needed.

Atmospheric Correction Challenges: Absorbing Aerosols



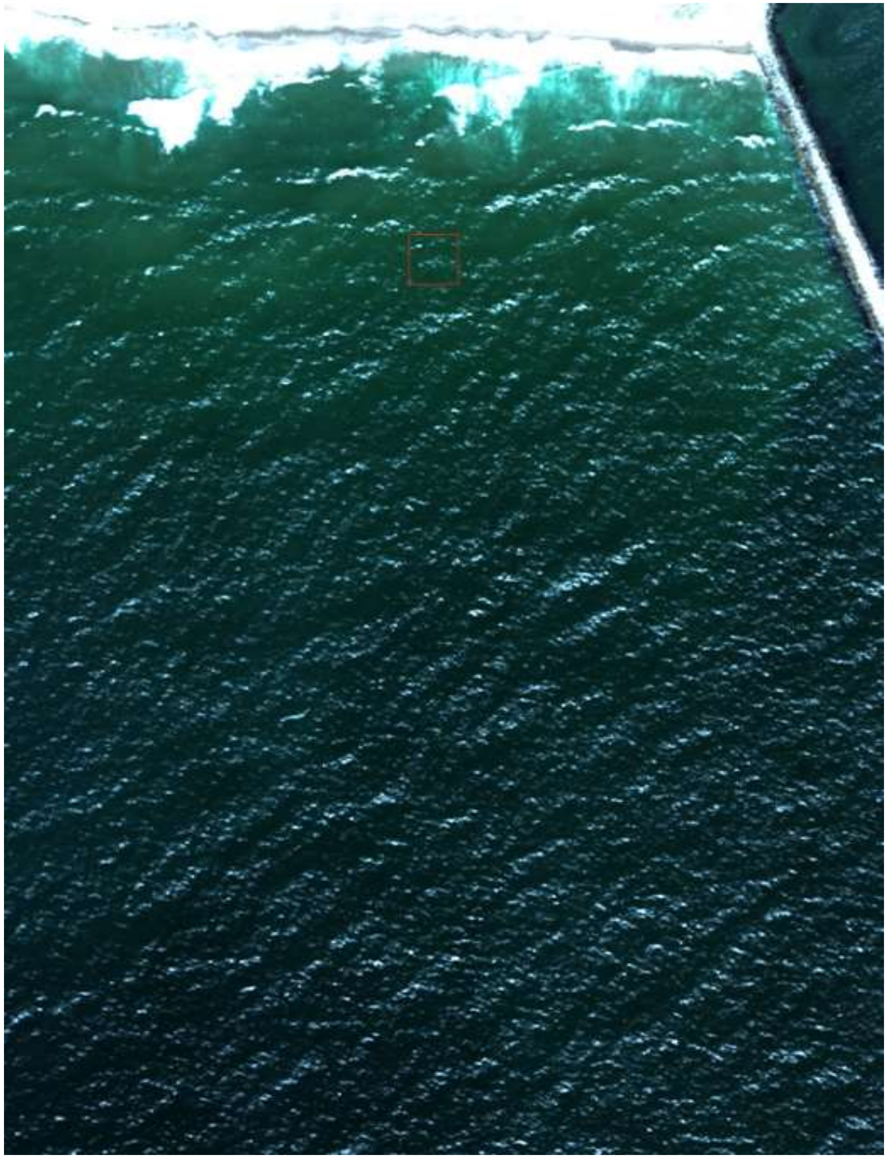
Dust

Smoke

Atmospheric Correction Challenges: Sun Glint

VIIRS data (750 m Spatial Resolution)

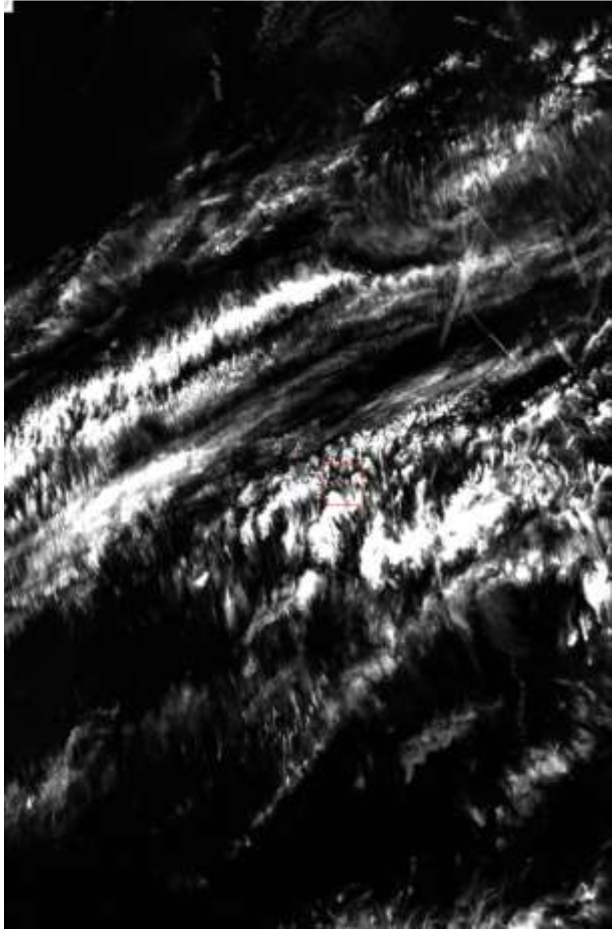
PRISM data (~1 m Spatial Resolution)



Atmospheric Correction Challenges: Cirrus Corrections

VIIRS RGB Image

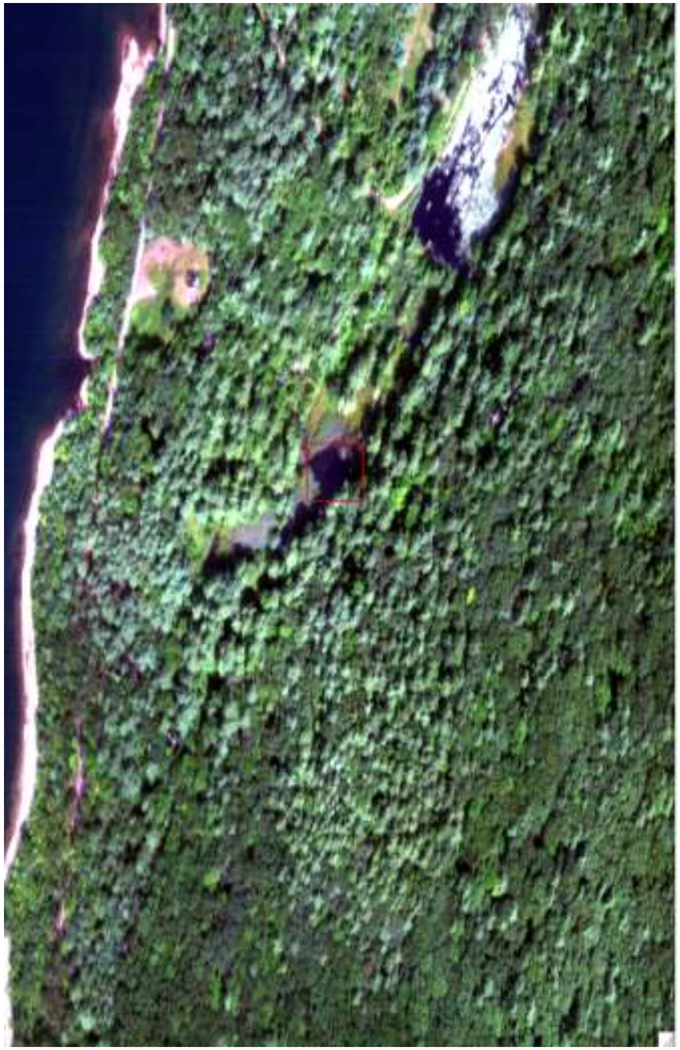
Cirrus Reflectance Image

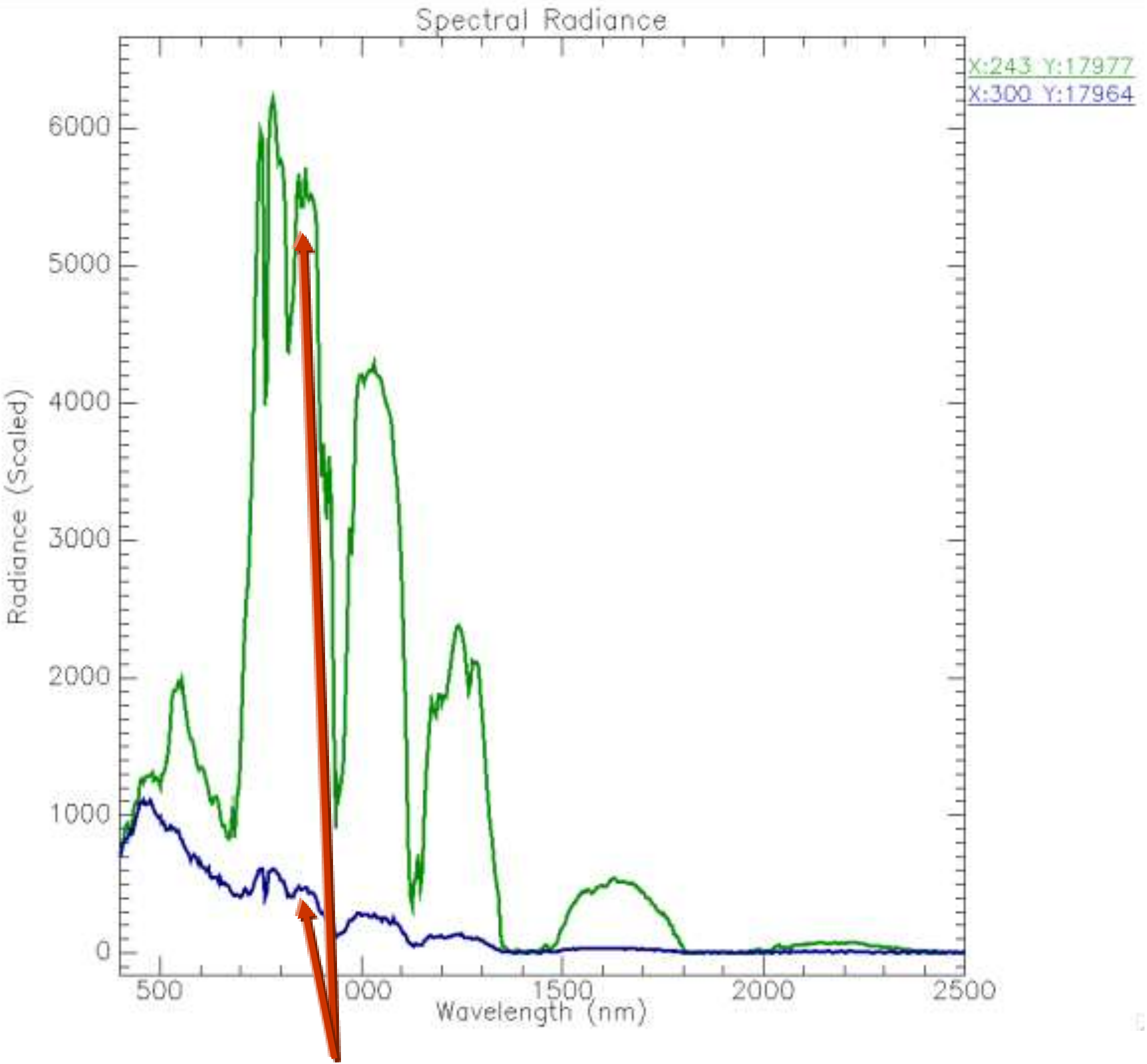


Cirrus-Removed RGB Image

Although the thin cirrus scattering effects can be removed, the downward path cirrus transmittances (e.g., cirrus shadows) and upward path cirrus transmittances are difficult to model because of 3-dimensional nature of cirrus clouds.

Atmospheric Correction Challenges: Adjacency Effects

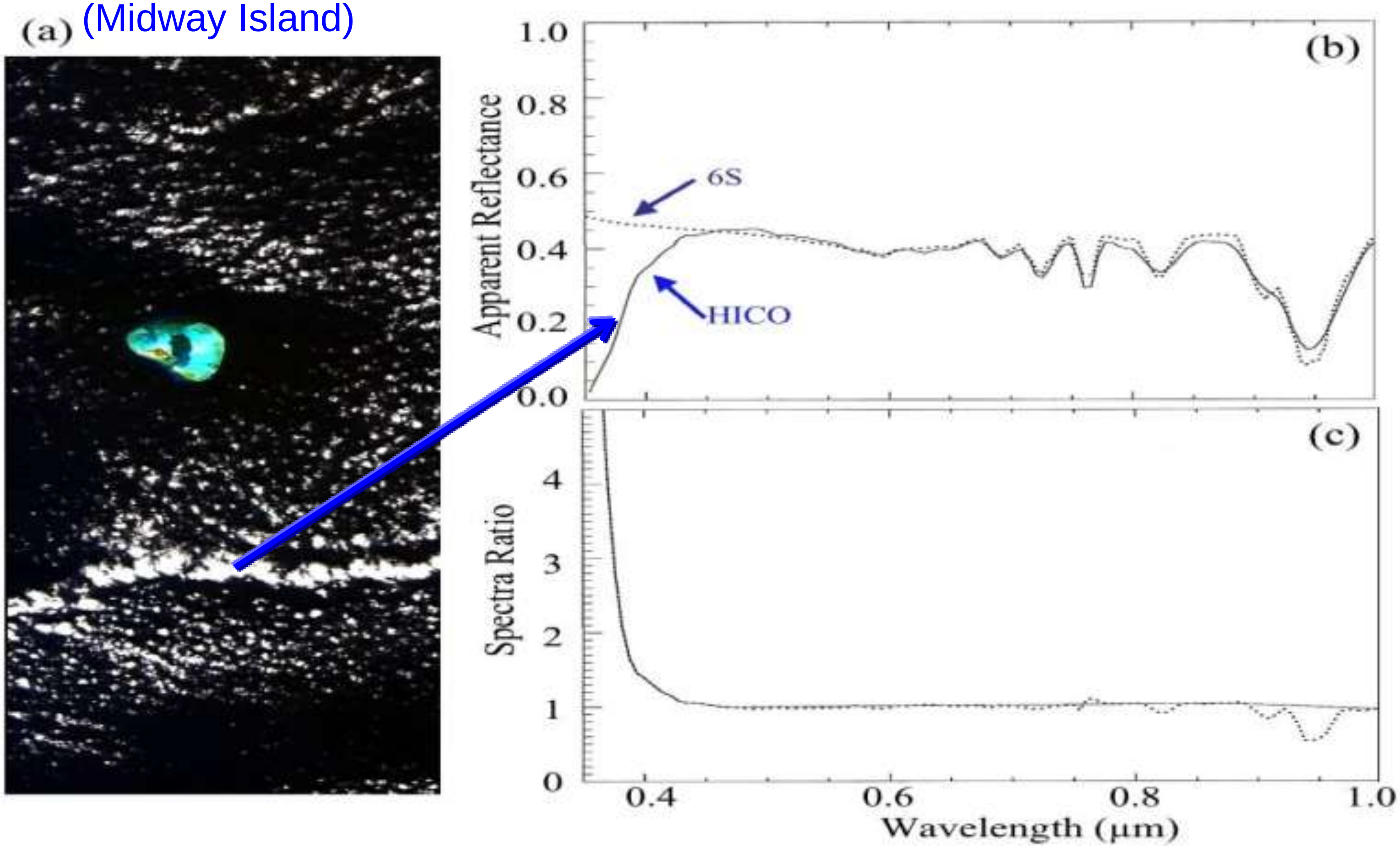




Vegetation signature is spilled over to nearby water pixels due to atmospheric and topographic adjacency effects.

Atmospheric Correction Challenges: UV Radiometric Calibrations

HICO RGB Image
(Midway Island)



For the white cloud spectrum, the calibrated HICO radiances in reflectance unit in the shorter wavelength region (350 - 450 nm) are too small. AVIRIS and other imaging spectrometers have the same UV calibration issue (little radiances emitted by the standard NIST light sources used in lab calibrations).

SUMMARY

- Most of atmospheric correction algorithms developed so far are multi-spectral in nature. Only a few model-based hyperspectral atmospheric correction algorithms have been developed till present.

- Major challenges in hyperspectral modeling include, but not limited to,
  - Atmospheric NO2 absorption effect
  - Accurate spectral solar irradiance curves
  - Absorbing aerosols, dusts
  - Sunglint effects (medium & high spatial resolution data)
  - Thin cirrus – scattered path radiance, downward and upward path cirrus transmittances.
  - Adjacency effects (atmospheric and topographic)
  - Absolute radiometric calibrations in 350 – 500 nm spectral range