Atmospheric Correction for Ocean Near-shore and Coastal Waters

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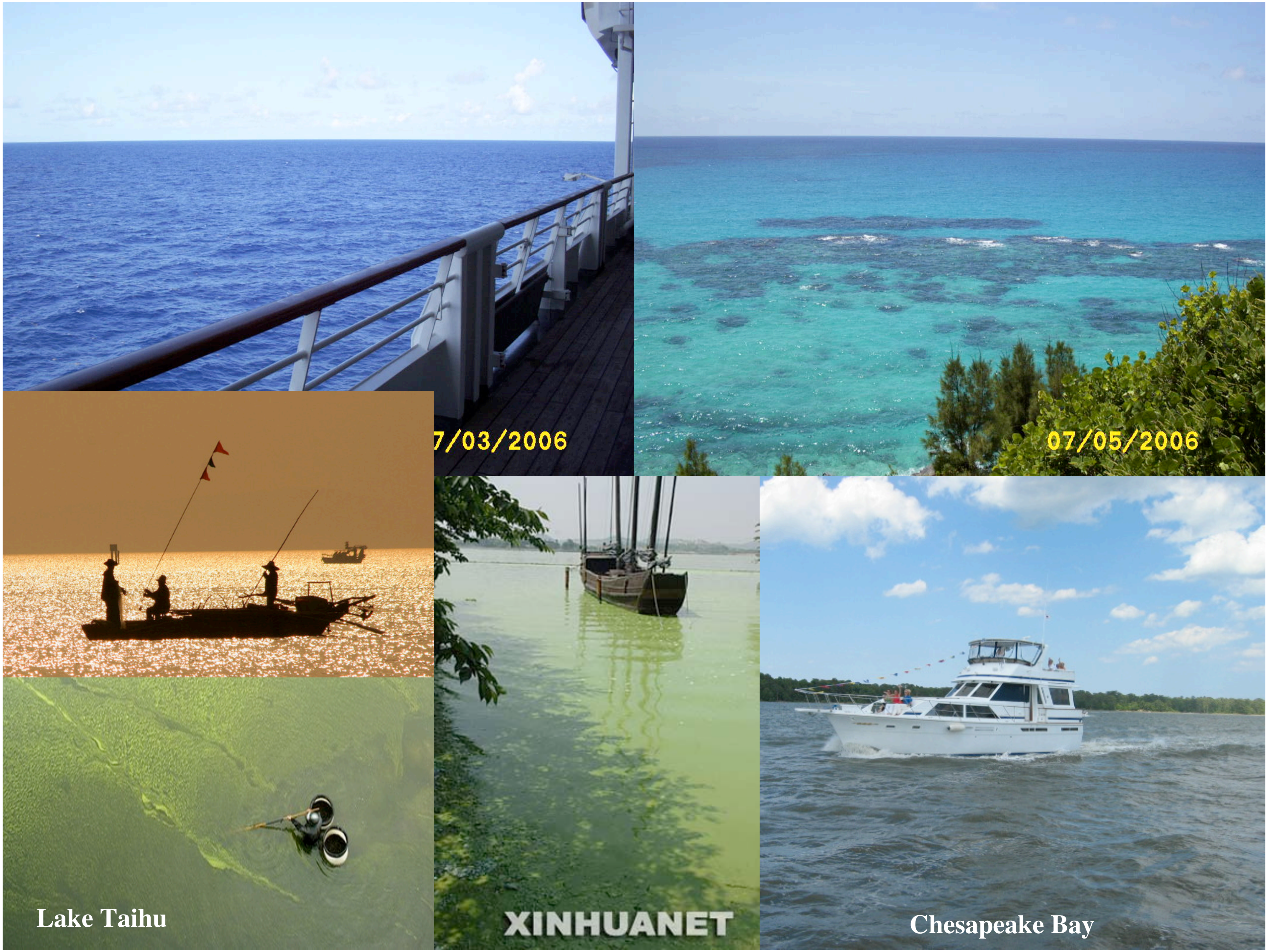
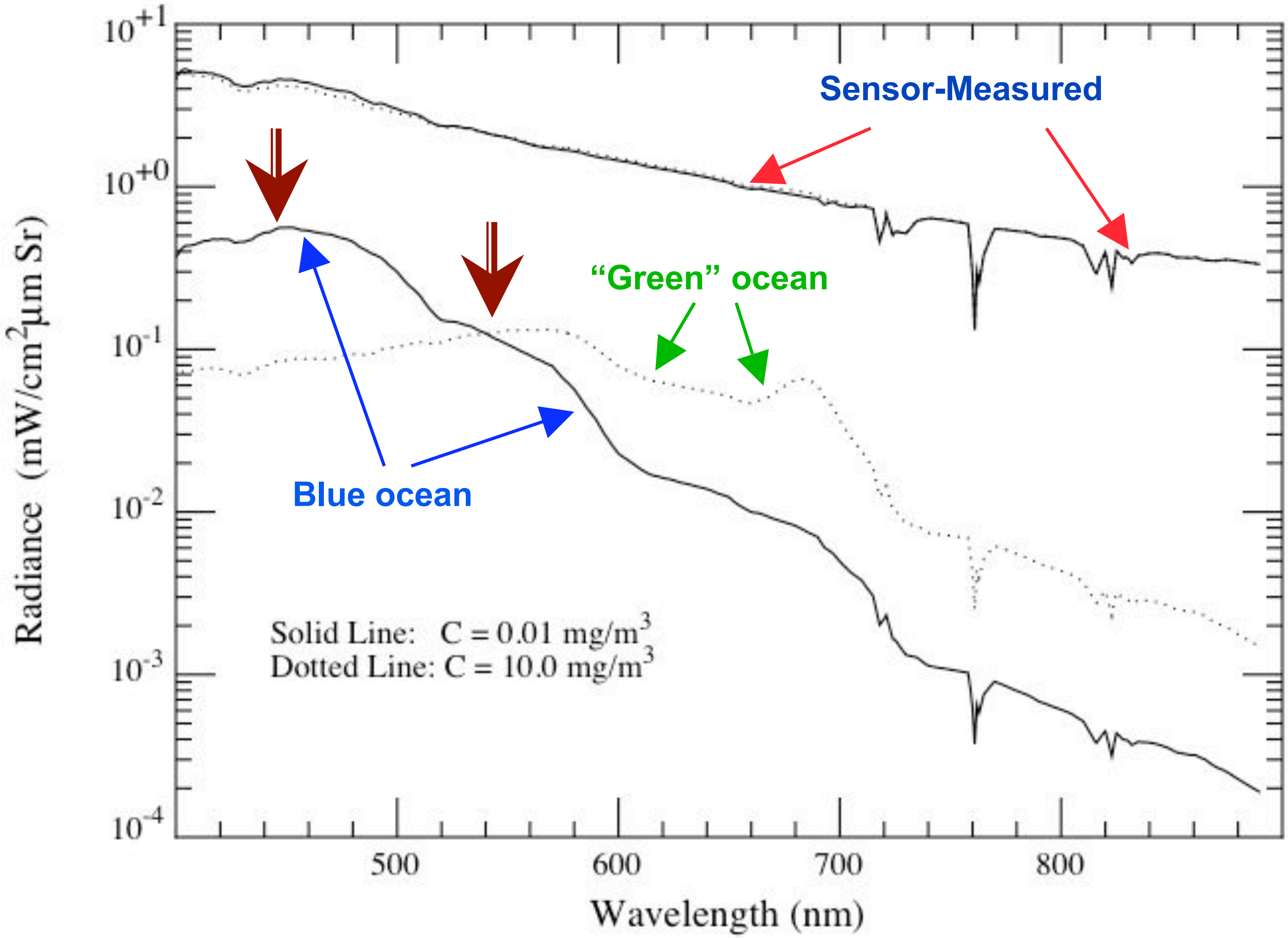

7/03/2006
07/05/2006
Lake Taihu
XINHUANET
Chesapeake Bay

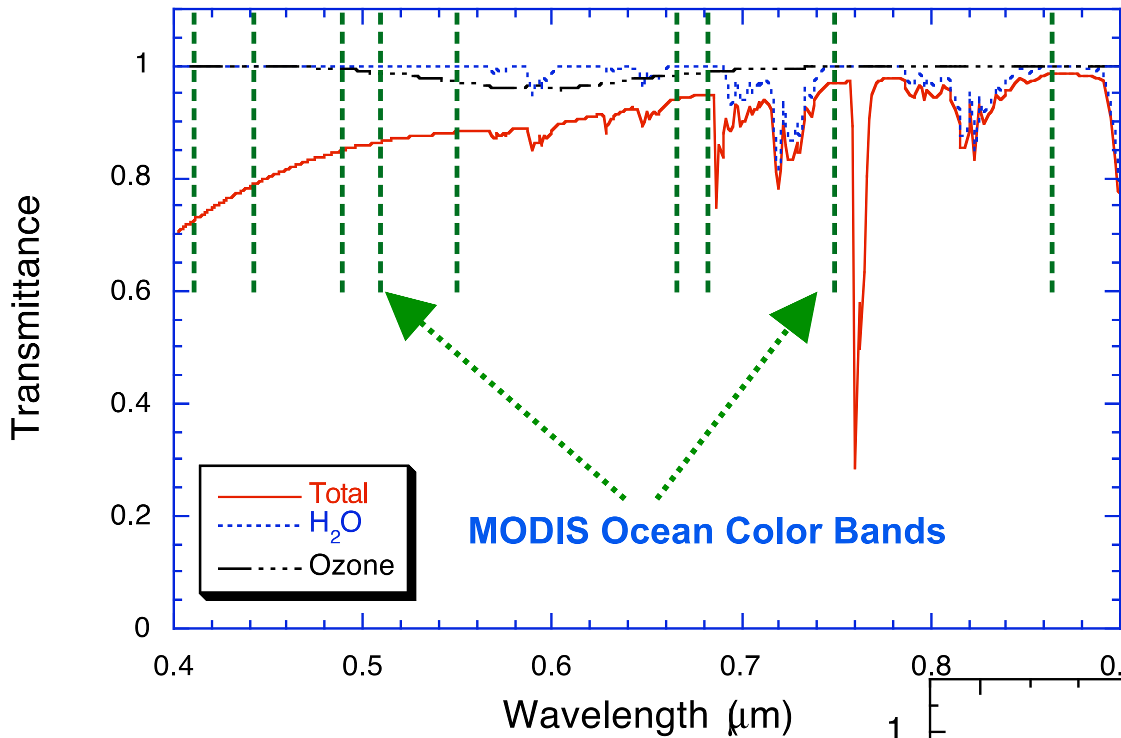
Ocean Color Remote Sensing

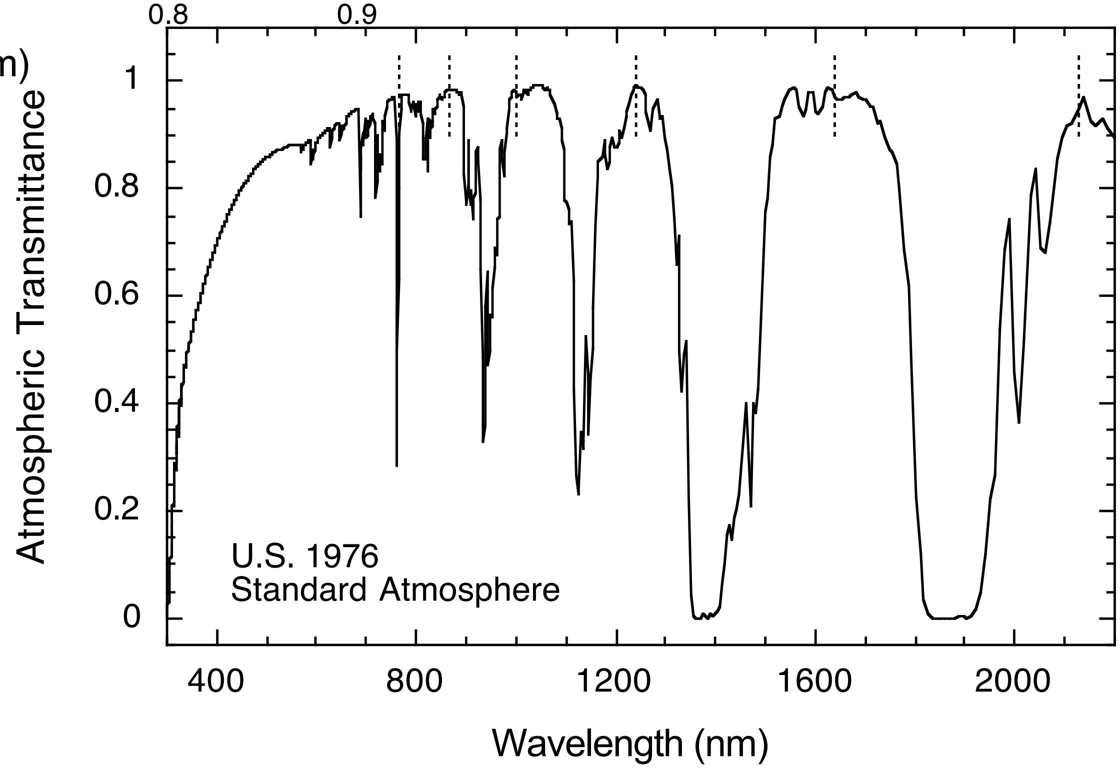


- Atmospheric Correction (removing >90% sensor-measured signals)
- Calibration (0.5% error in TOA >>>> 5% in surface)

From H. Gordon

Atmospheric Windows





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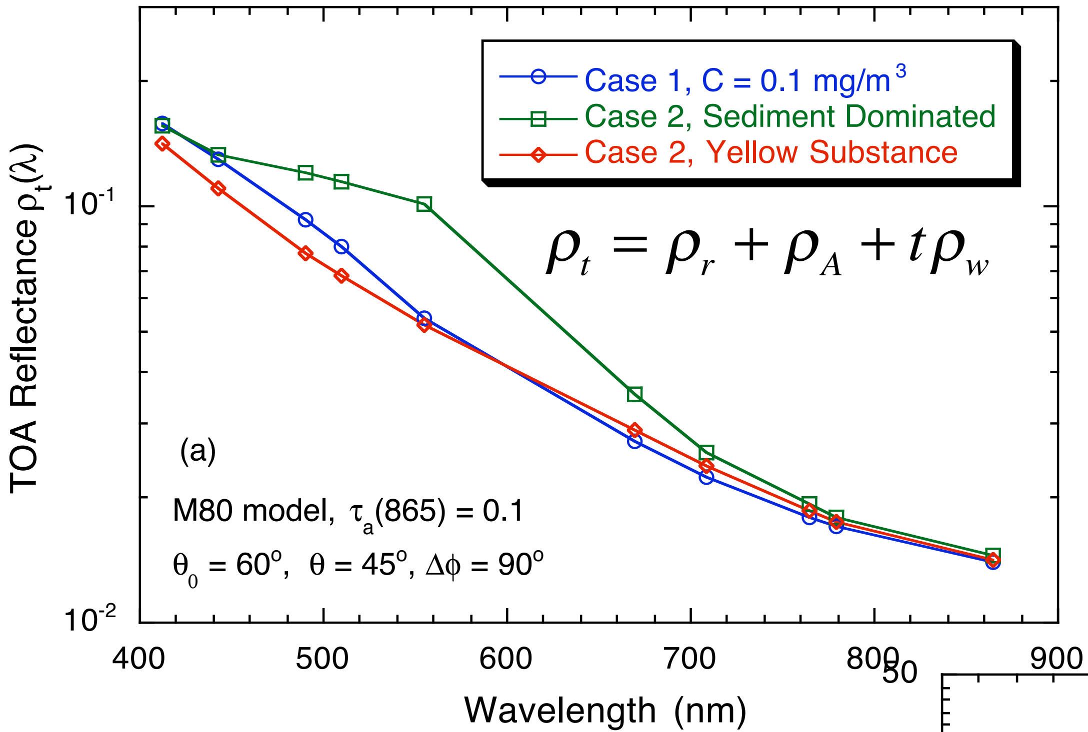
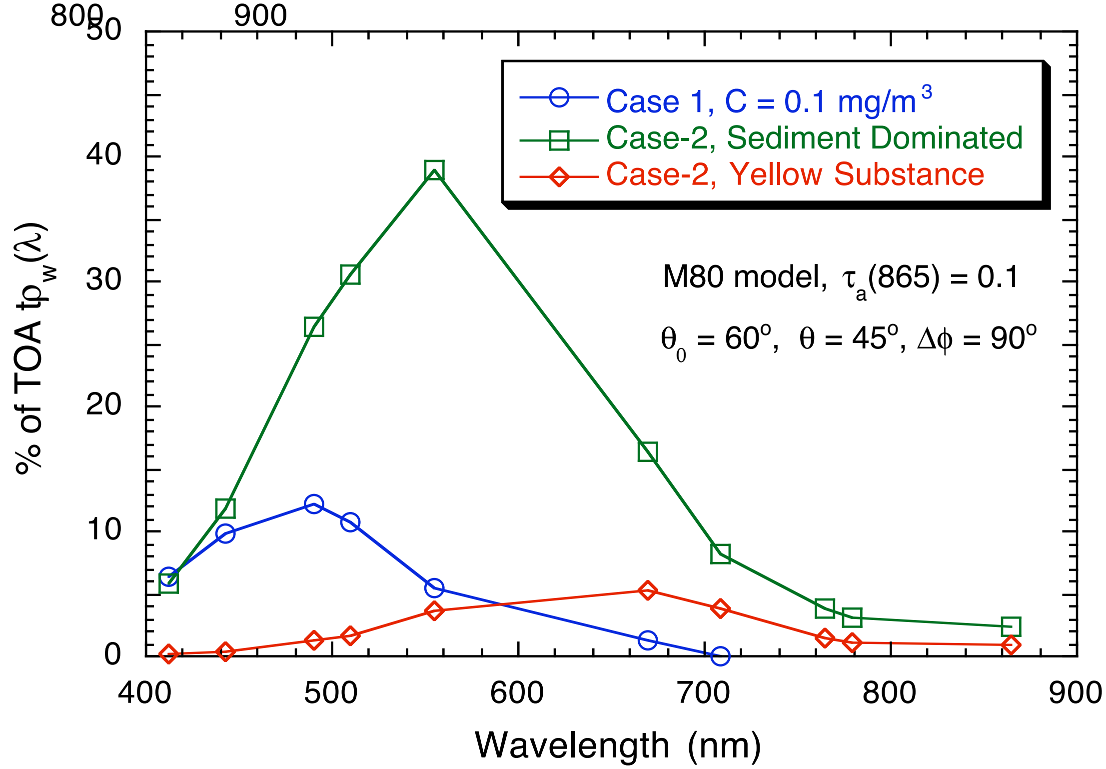
Satellite Sensor Measured TOA Reflectance Spectra

IOCCG Report-10



The TOA Ocean Contributions (%)



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At satellite altitude **~90%** of sensor-measured signal over ocean comes from the **atmosphere & surface**!

- It is crucial to have accurate **atmospheric correction** and **sensor calibrations**.
- **0.5%** error in <u>atmospheric correction</u> or <u>calibration</u> corresponds to possible of **~5%** error in the derived ocean water-leaving radiance.
- We need **~0.1%** sensor calibration accuracy.

Atmospheric Correction Algorithm

(Case-1 Waters)

MODIS and SeaWiFS algorithm (Gordon and Wang 1994)

$$\rho_t = \rho_r + \rho_A + t\rho_{wc} + T\rho_g + t\rho_w, \quad \rho = \pi L / \mu_0 F_0$$

- **ρ_w is the desired quantity in ocean color remote sensing.**
- $T\rho_g$ is the sun glint contribution—avoided/masked/corrected.
- $T\rho_{wc}$ is the whitecap reflectance—computed from wind speed.
- ρ_r is the scattering from molecules—computed using the Rayleigh lookup tables (vector RTE, wind speed, atmospheric pressure dependents).
- $\rho_A = \rho_a + \rho_{ra}$ is the aerosol and Rayleigh-aerosol contributions —estimated using **aerosol models**.
- For Case-1 waters at the open ocean, ρ_w is usually negligible at 750 & 865 nm. ρ_A can be estimated using these two NIR bands. Ocean is usually not black at NIR for the coastal regions.

Characteristics of the Aerosol Models

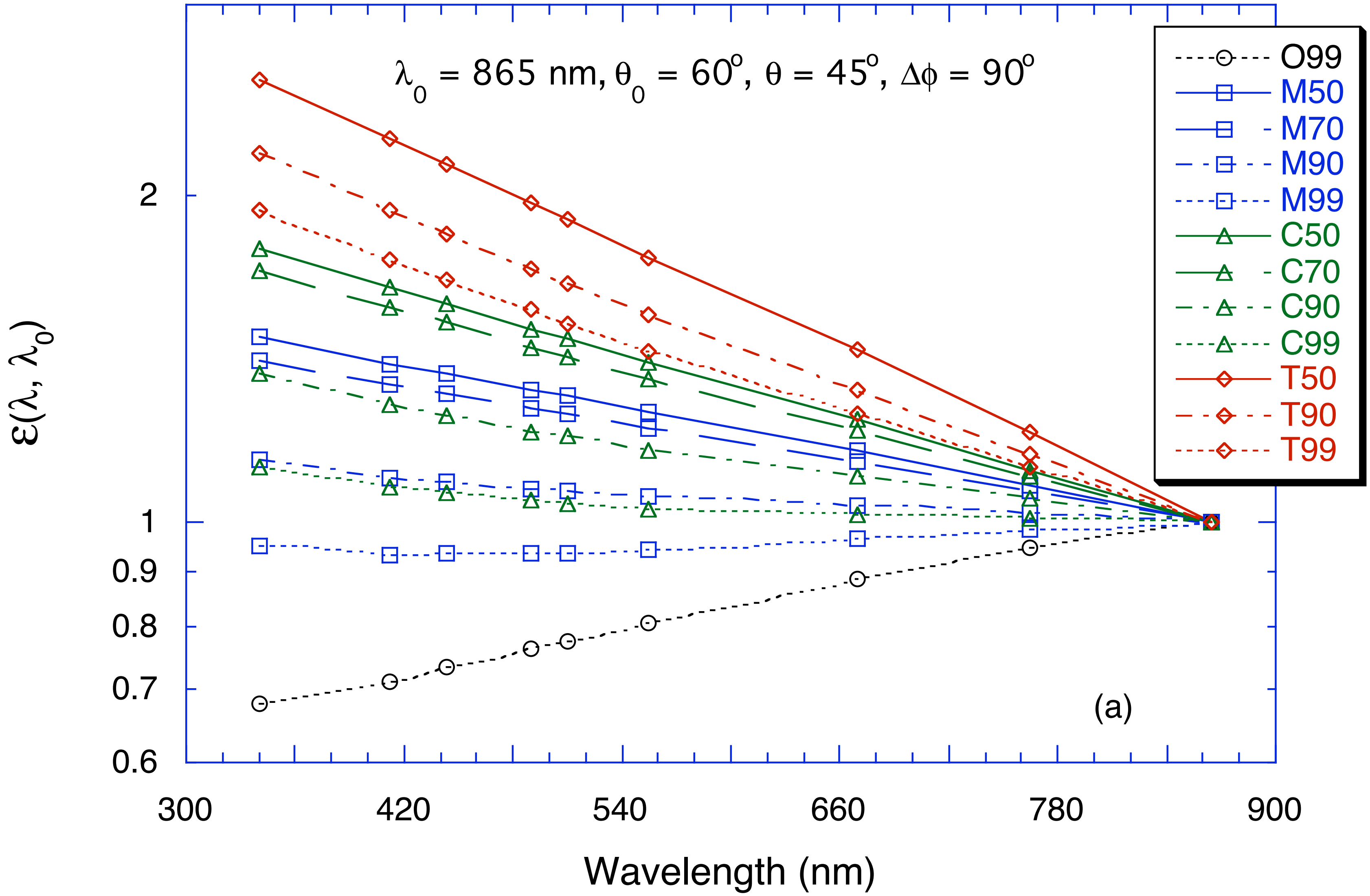
Aerosol Model	Single Scattering Albedo $\omega_a(865)$	Asymmetry Parameter g	Ångström Exponent $\alpha(510, 865)$
Oceanic†	1.0	0.724-0.840	-0.087~ -0.016
Maritime†	0.982-0.999	0.690-0.824	0.09-0.50
Coastal††	0.976-0.998	0.682-0.814	0.23-0.76
Tropospheric†	0.930-0.993	0.603-0.769	1.19-1.53
Urban†	0.603-0.942	0.634-0.778	0.85-1.14
Dust†††	0.836-0.994	0.662-0.763	0.29-0.36

† Shettle and Fenn (1979) aerosol models. ††Gordon and Wang (1994)

††† Shettle (1984) and Moulin et al. (2001).

A simple aerosol correction algorithm (Wang & Gordon, 1994)

Aerosol Single-Scattering Epsilon (λ_0 = 865 nm)



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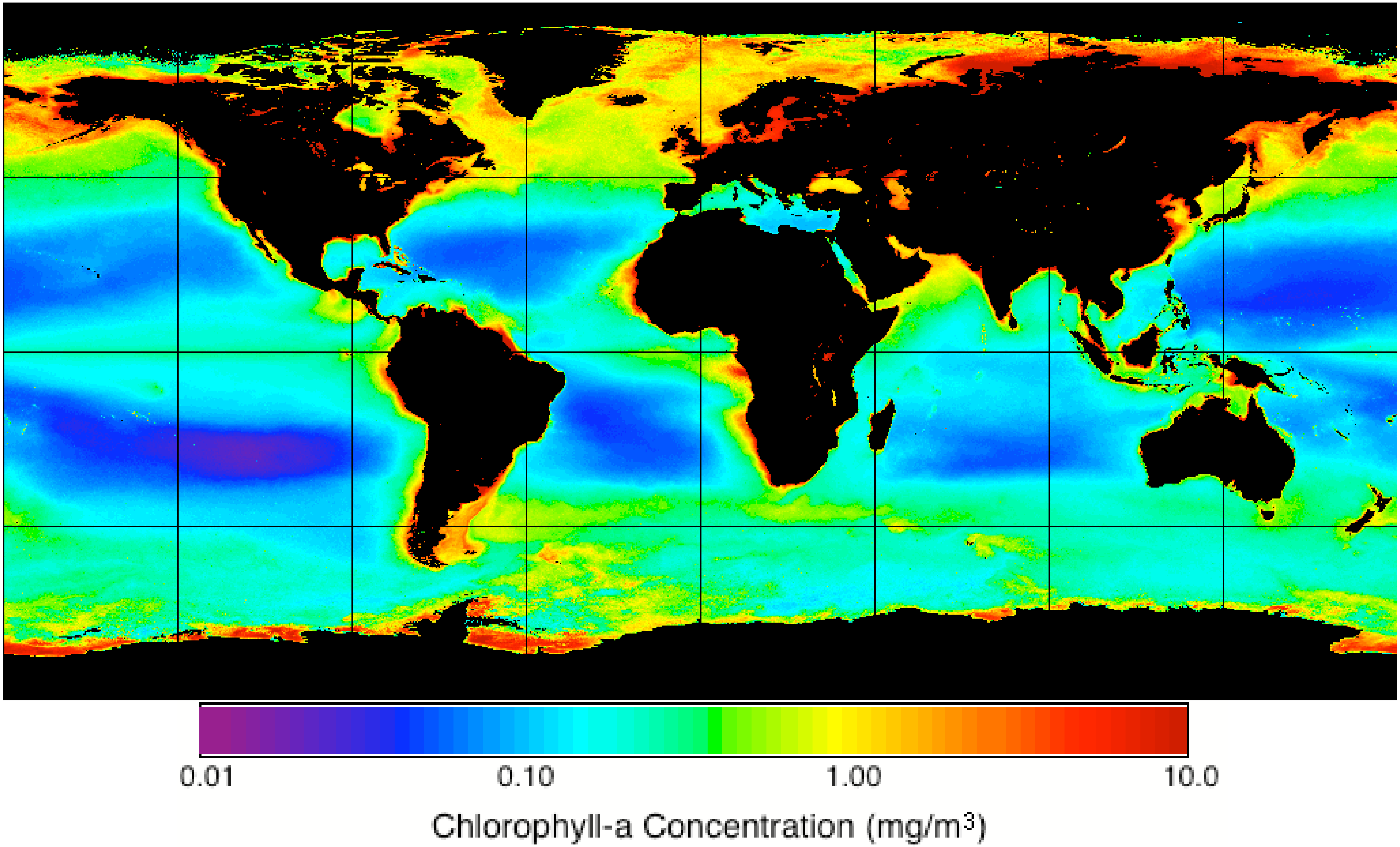
SeaWiFS Chlorophyll-a Concentration
(October 1997-December 2003)



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SeaWiFS and MODIS Experiences Show:

High quality ocean color products for the global open oceans (Case-1 waters).

Significant efforts are needed for improvements of water color products in the inland & coastal regions:

- **Turbid Waters**
  (violation of the NIR black ocean assumption)
- **Strongly-Absorbing Aerosols**
  (violation of non- or weakly absorbing aerosols)

Algorithm Developments for Productive Waters

- **Arnone** et al. (1998) and **Siegel** et al. (2000) to account for the NIR ocean contributions for SeaWiFS and MODIS NIR bands.
- **Hu** et al. (1999) proposed an *adjacent pixel method*.
- **Gordon** et al. (1997) and **Chomko** et al. (2003) *the spectral optimization algorithm*.
- **Ruddick** et al. (2000) for regional Case-2 algorithm using the *spatial homogeneity of the aerosol* in a given area.
- **Lavender** et al. (2004) regional bio-optical model (suspended sediments) for SeaWiFS application.
- **Wang** and **Shi** (2005) derived NIR ocean contributions using the MODIS shortwave IR (SWIR) bands.
- **Doerffer** et al. and others developed Artificial *Neural Network* for coastal Case-2 waters (implemented for MERIS data processing).
- **Wang** (2007) proposed atmospheric correction using the SWIR bands for the turbid coastal waters.

The NIR Ocean Contribution Modeling

Various investigators all sought to remove the NIR *nLw*(λ) contributions from the TOA NIR radiances, so that a "**black pixel**" could be provided to the *Gordon and Wang* (1994) type atmospheric correction:

- **Siegel** et al. (2000) used chlorophyll estimate to determine the NIR *nLw*(λ).
- **Lavender** et al. (2005) used a sediment estimate to determine the NIR *nLw*(λ).
- **Ruddick** et al. (2000) fixed the aerosol and backscatter type and then solved for both the NIR *nLw*(λ) and NIR aerosol reflectance simultaneously.
- **Stumpf** et al. (2003) used a bio-optical model for absorption coefficient at the red band and then used that with the red *nLw*(λ) to find the NIR *nLw*(λ).

Atmospheric Correction: SWIR Bands

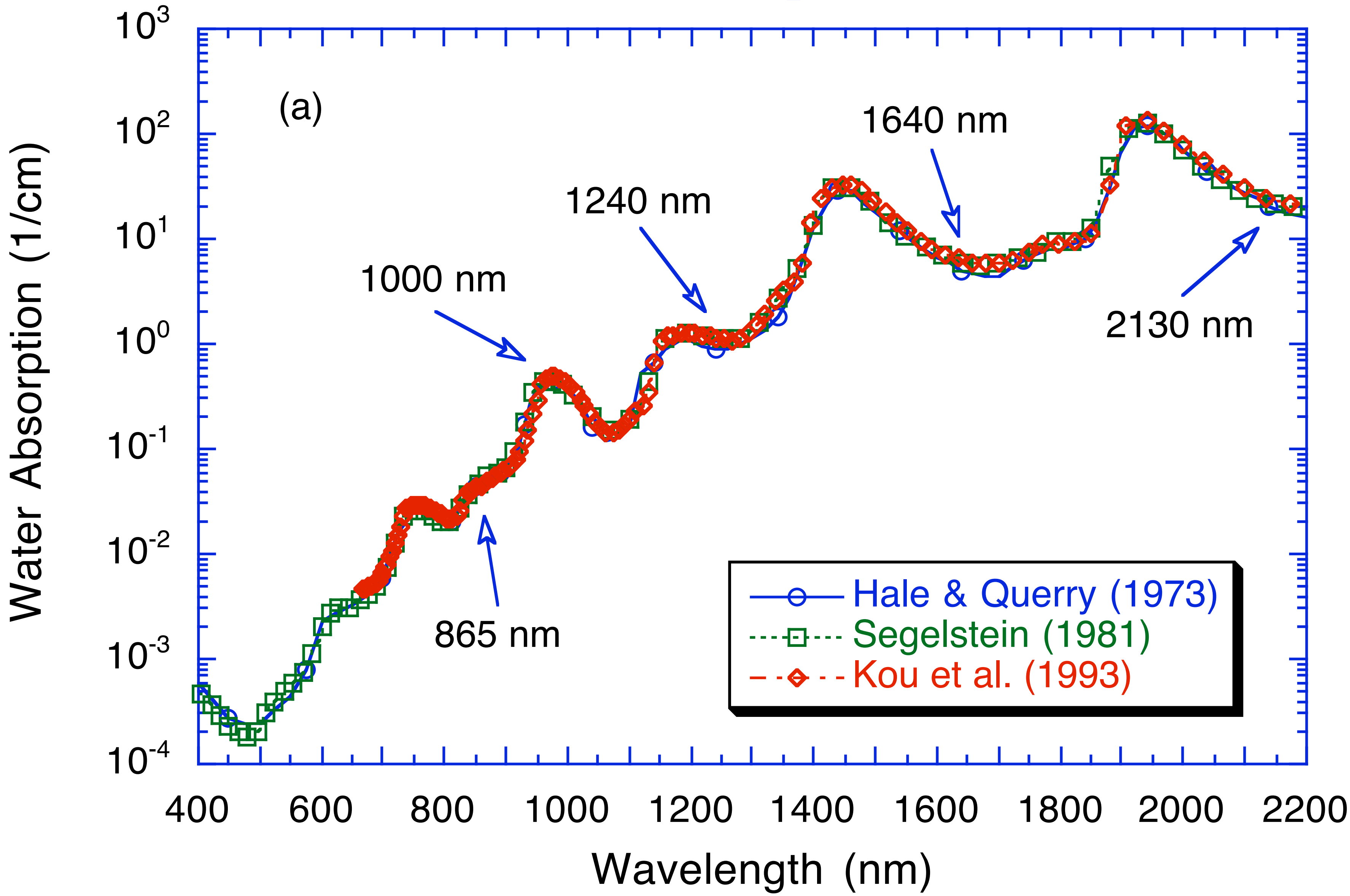
(Wang & Shi, 2005; Wang, 2007)

- At the shortwave IR (SWIR) wavelengths (>~1000 nm), ocean water has much strongly absorption and ocean contributions are significantly less. Thus, atmospheric correction can be carried out for coastal regions **without using the bio-optical model**.
- Water absorption for 869 nm, 1240 nm, 1640 nm, and 2130 nm are 5 m^{-1}, 88 m^{-1}, 498 m^{-1}, and 2200 m^{-1}, respectively.
- Examples using the MODIS Aqua **1240** and **2130 nm** data to derive the ocean color products are provided.

➢ We use the SWIR band (1240 nm) for the cloud masking. This is necessary for coastal region waters.

✓ Require sufficient **SNR** characteristics for the SWIR bands and the SWIR atmospheric correction has slight larger noises at the short visible bands (compared with those from the NIR algorithm).

Water Absorption



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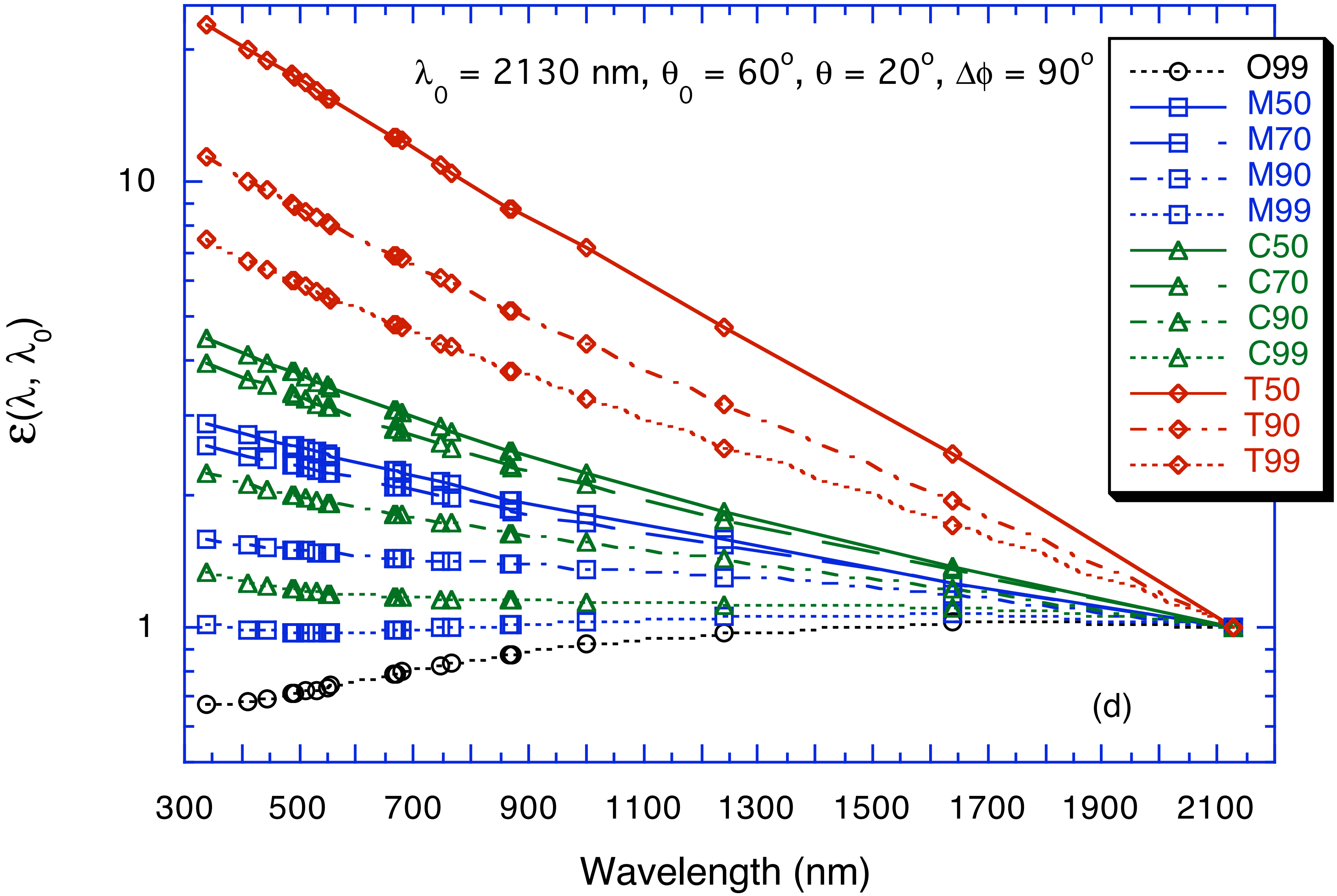
Aerosol Single-Scattering Epsilon (λ_0 = 2130 nm)



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Results from SWIR Atmospheric Correction for turbid ocean waters in US east coastal

MODIS-Aqua True Color Image

U.S. East Coastal

April 6, 2004

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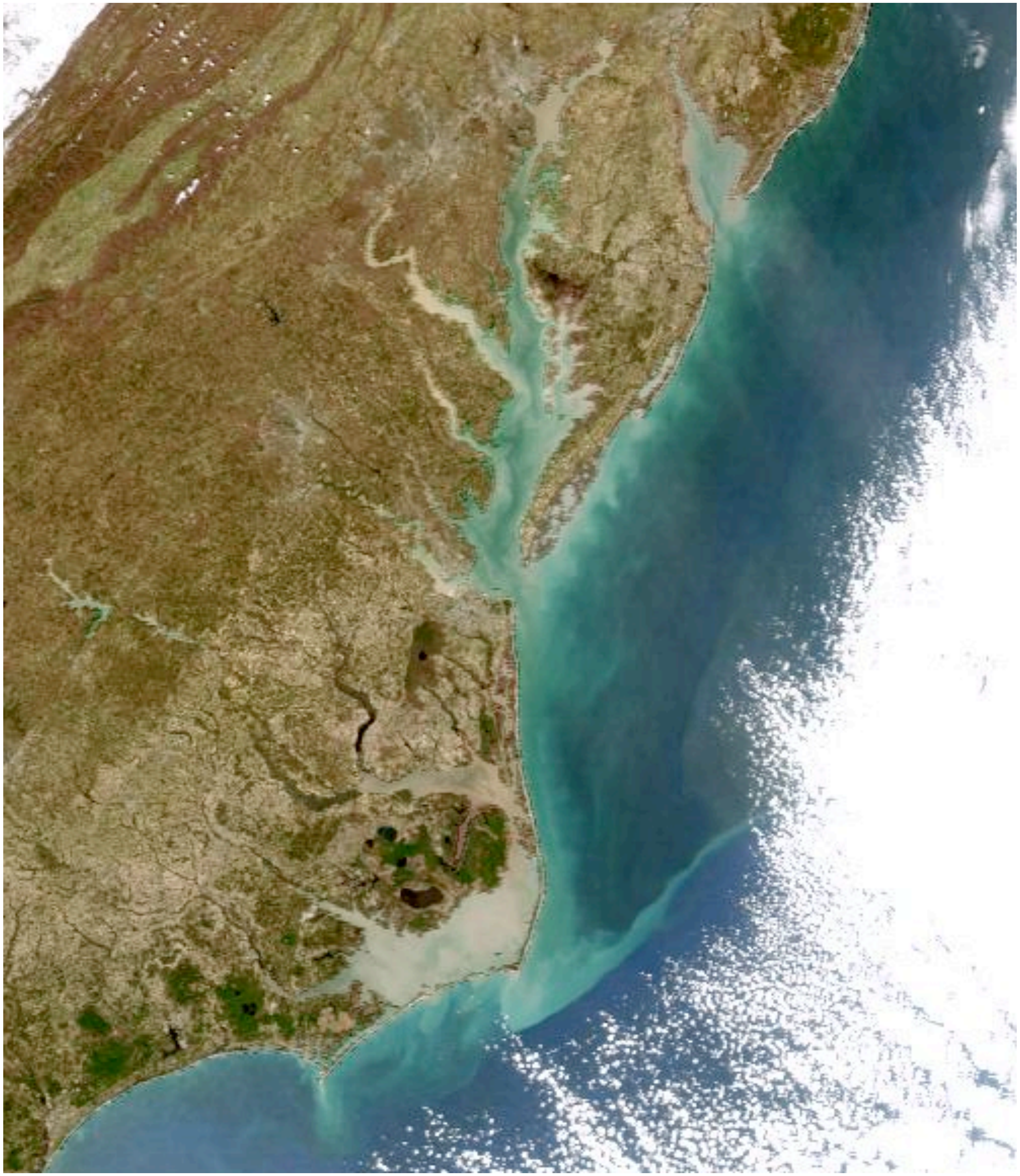
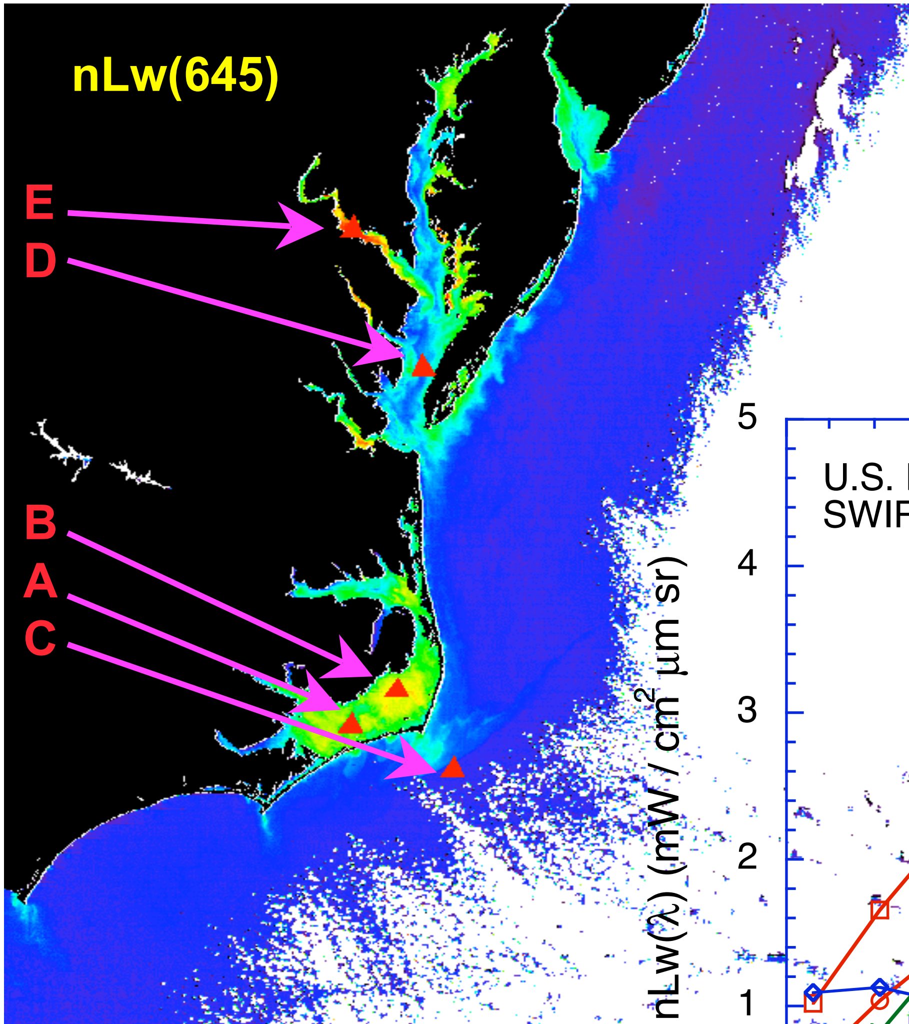
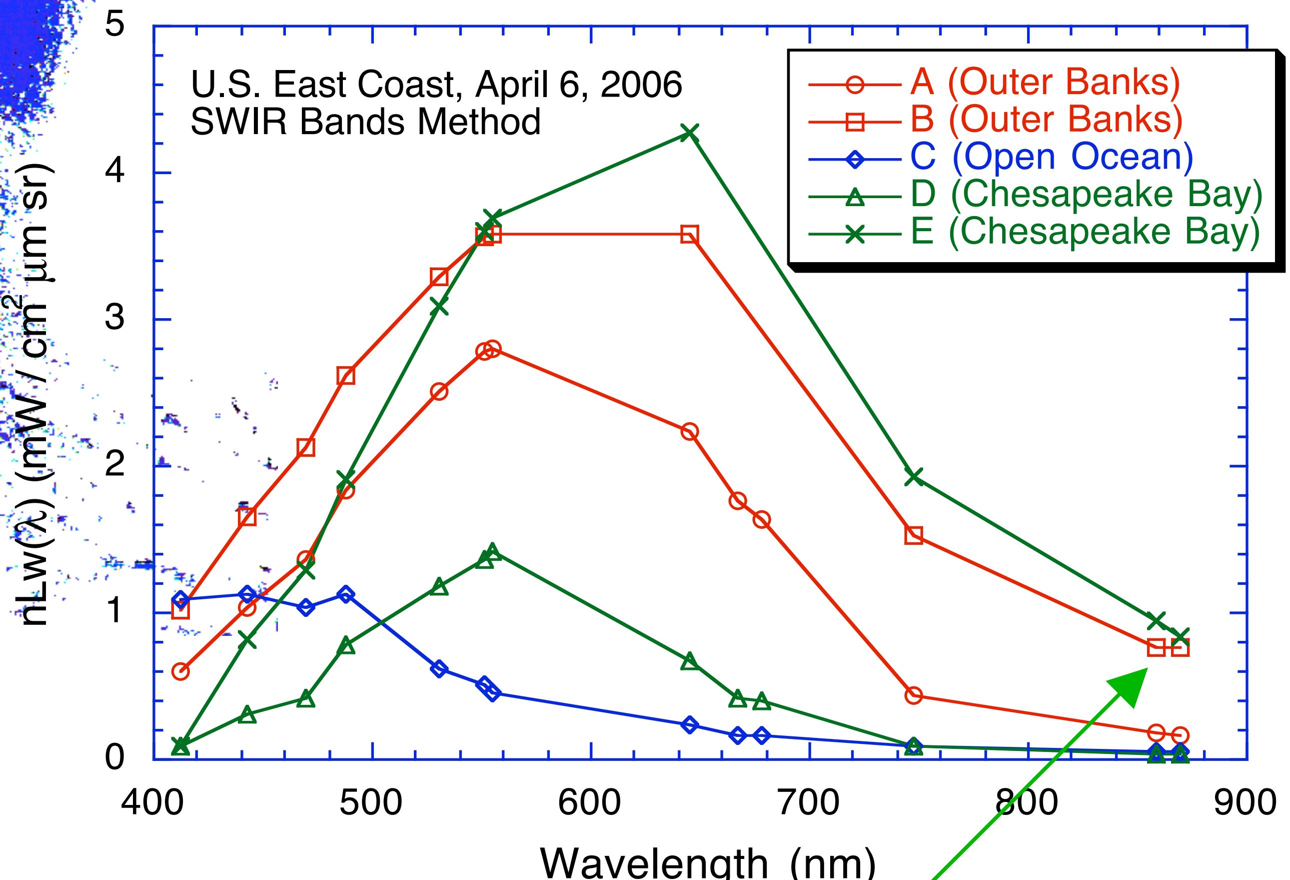


Ocean Spectra from Visible to NIR for Various Ocean Waters





$\tau_a(869) \sim 0.3$

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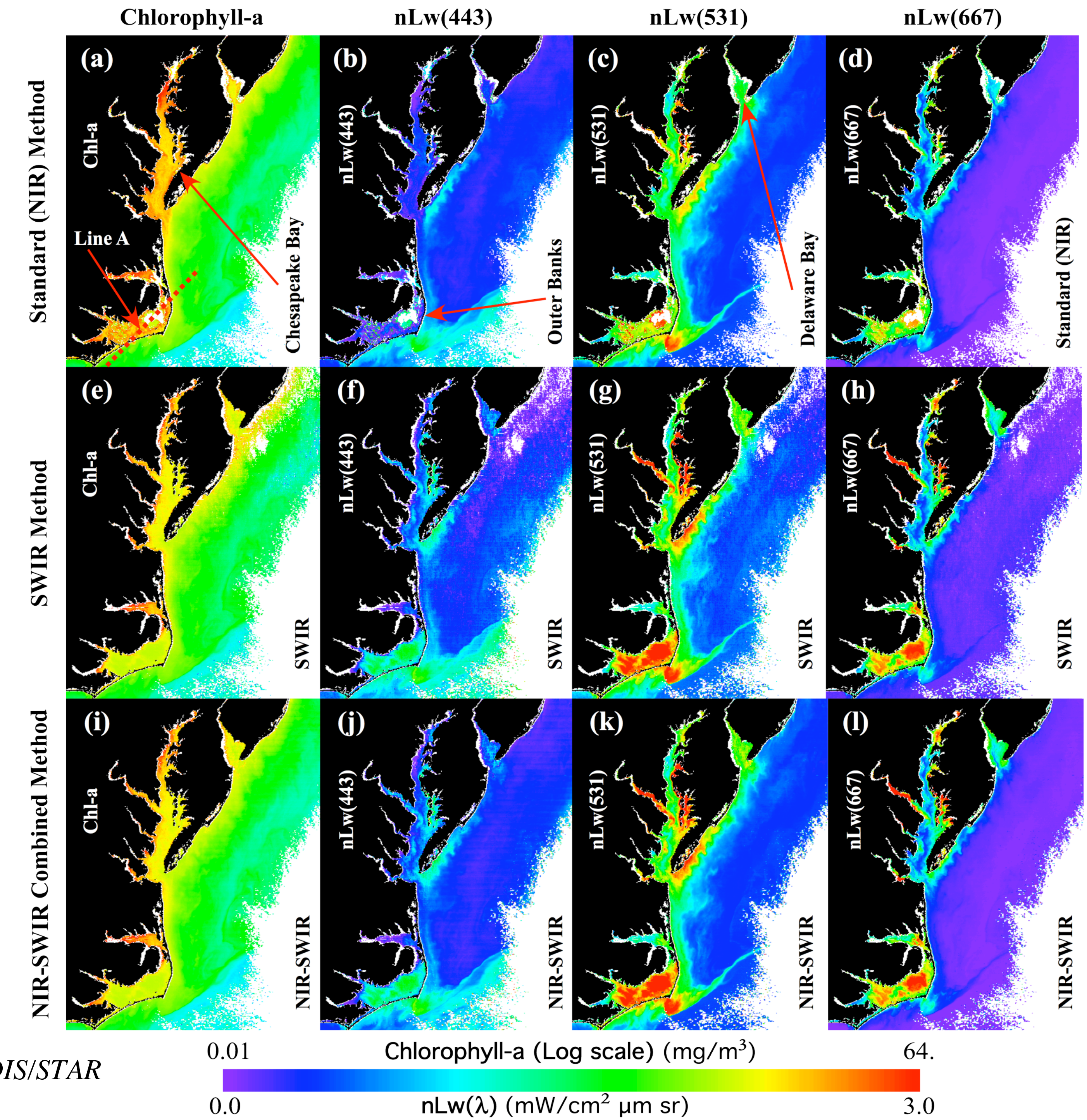
Comparisons of MODIS Ocean Color Products from NIR, SWIR, and NIR-SWIR Combined Methods

Example: U.S. East Coast

Wang, M. and W. Shi (2007), "The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing," *Optics Express*, **15**, 15722-15733.



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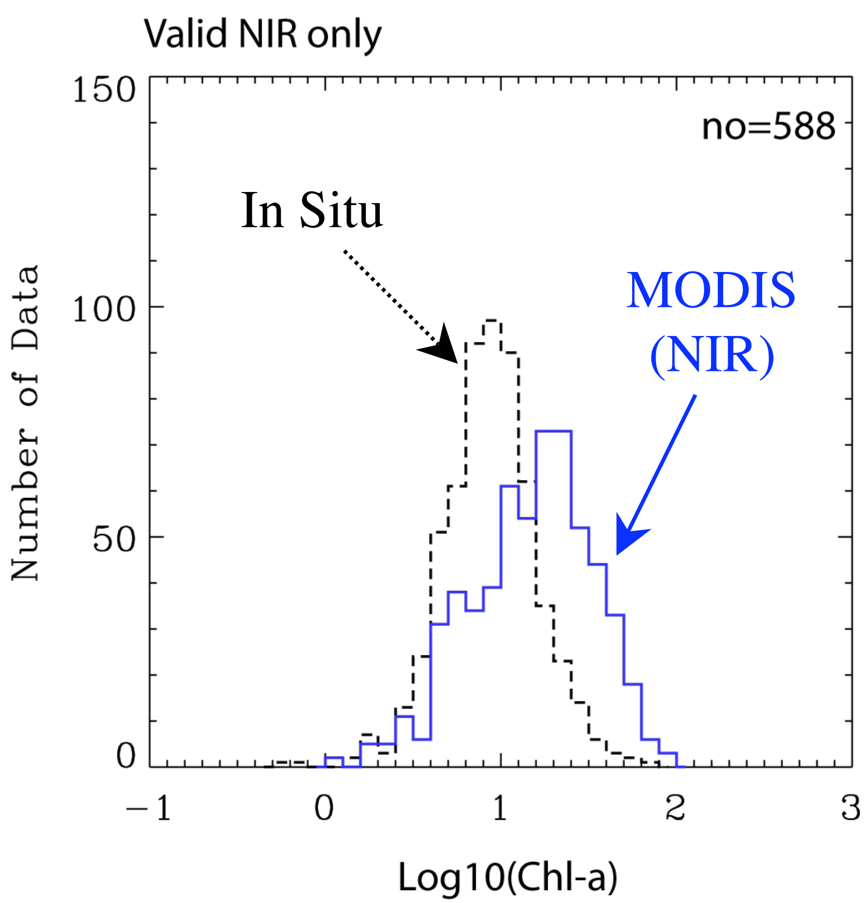
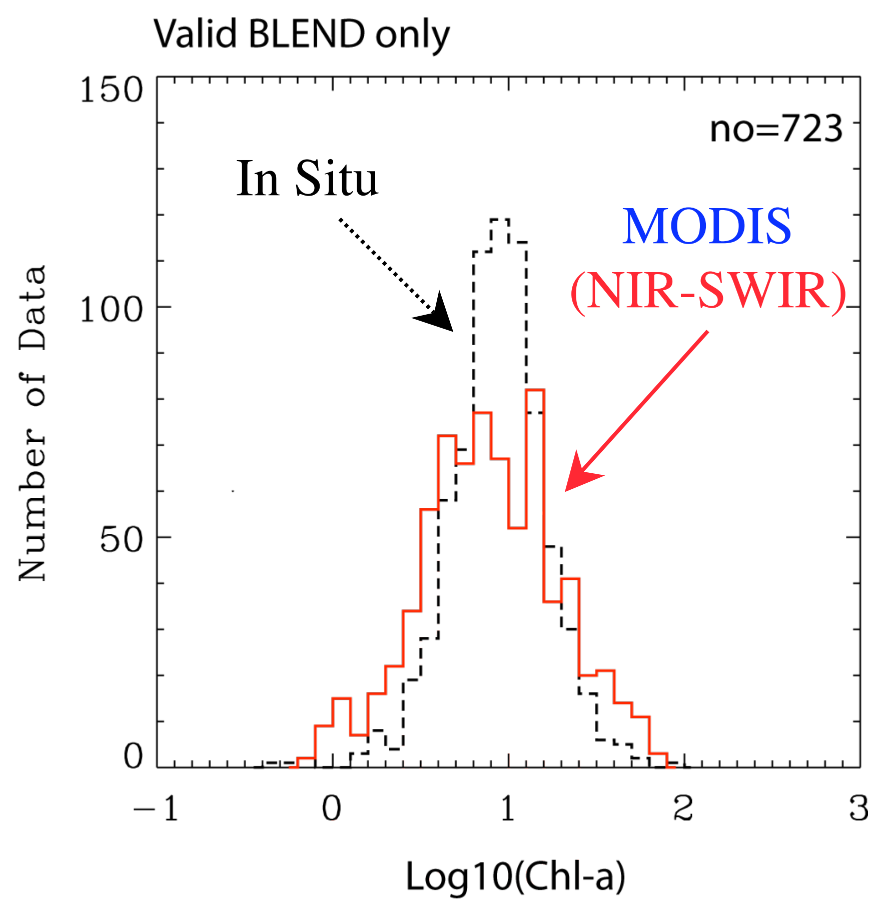
Chlorophyll-a Comparison Results in Chesapeake Bay

MODIS Matchup with CBnet Chl-a (< +/-3hrs)





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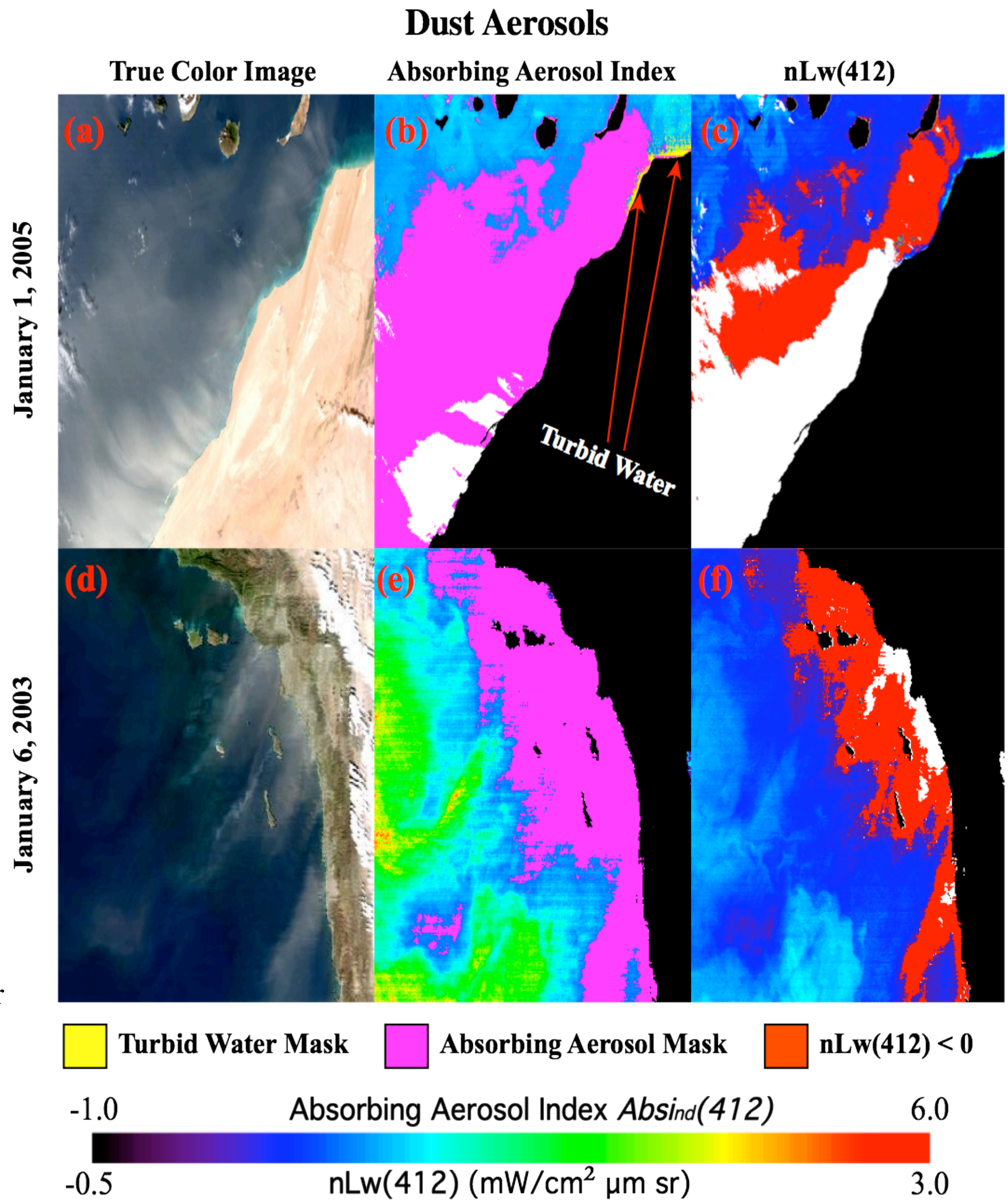
Issue of Absorbing Aerosols

For dust aerosols, the derived water-leaving radiances are biased low, *nLw*(412) often < 0.

To deal with absorbing aerosols, we need to know aerosol vertical profile.



Shi, W. and M. Wang (2007), "Detection of turbid waters and absorbing aerosols for the MODIS ocean color data processing," *Remote Sens. Environ.*, **110**, 149-161.

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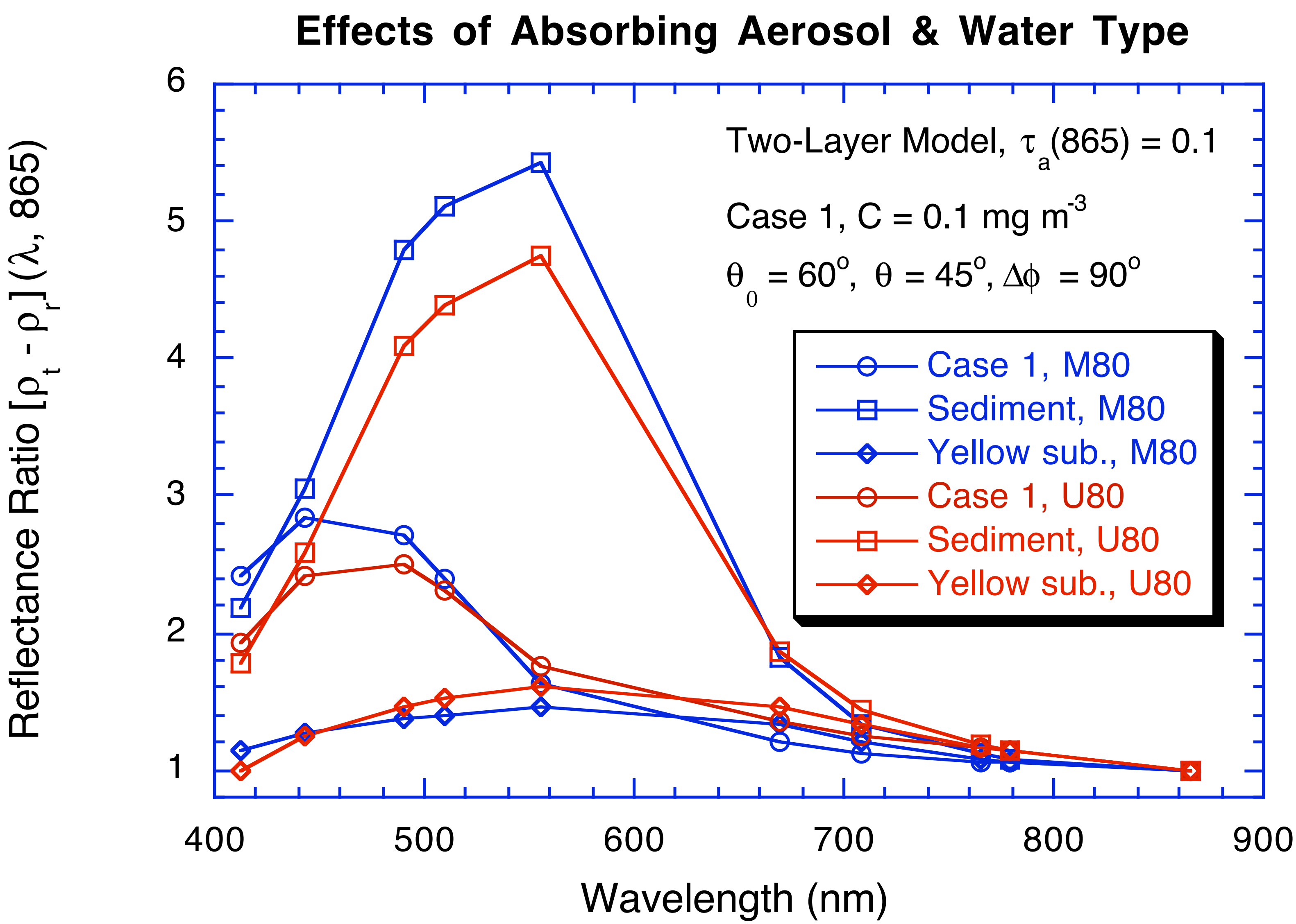

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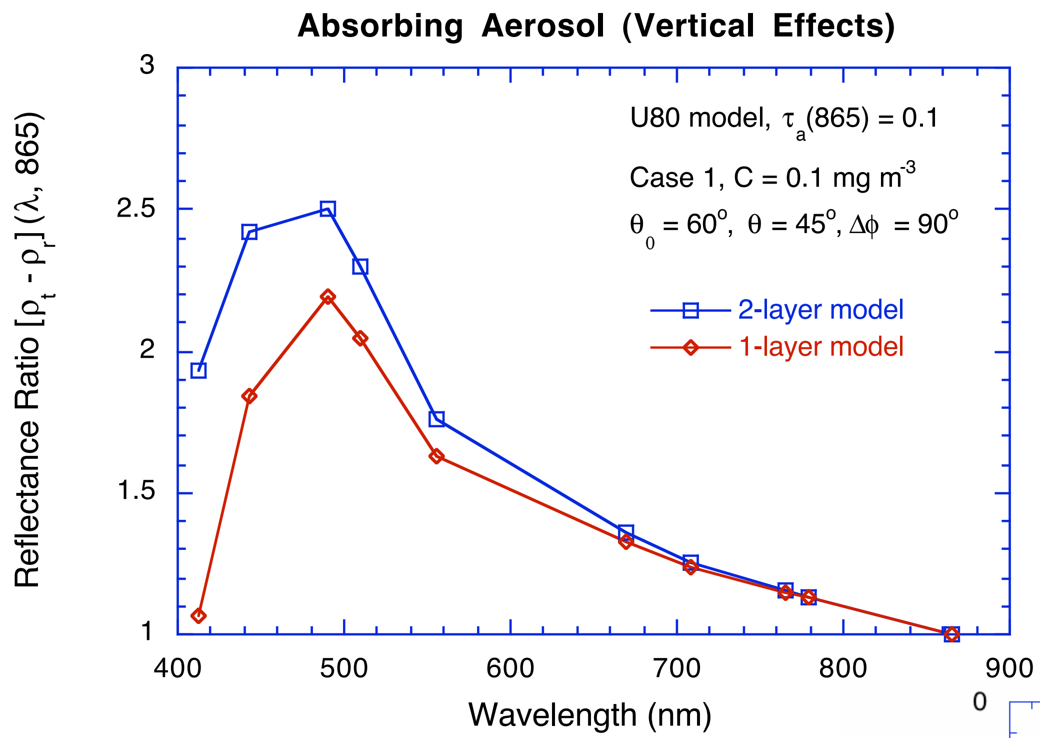
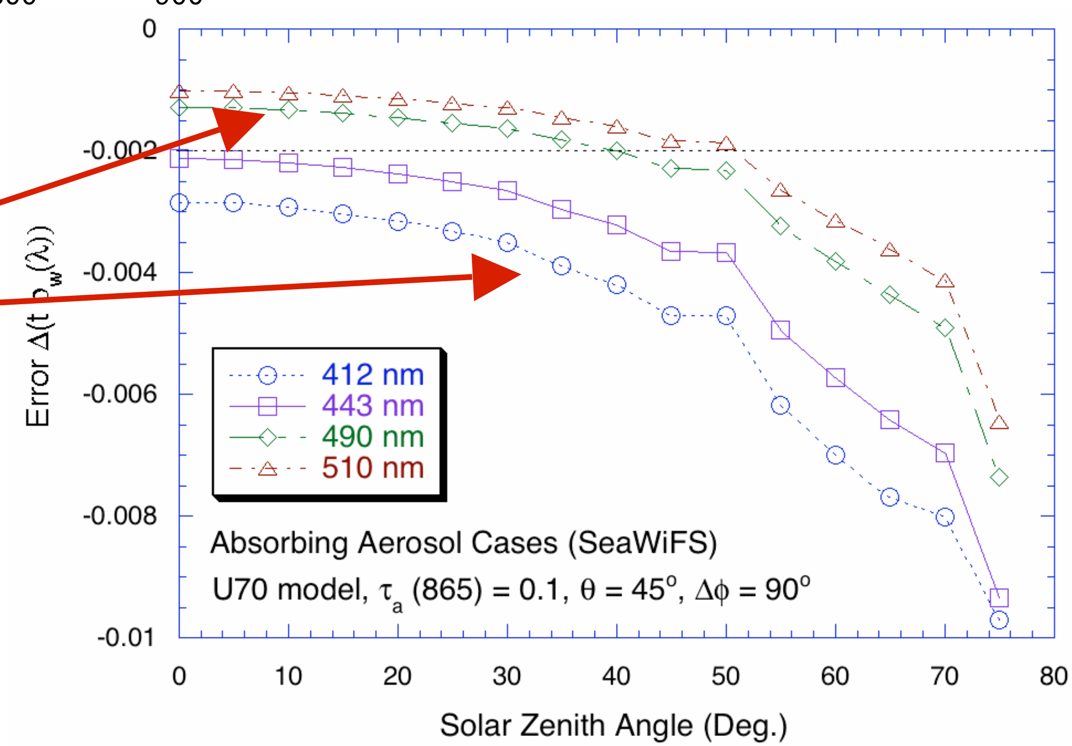


NIR reflectances are not enough to retrieve absorbing aerosol properties

Underestimation of water-leaving spectra significantly



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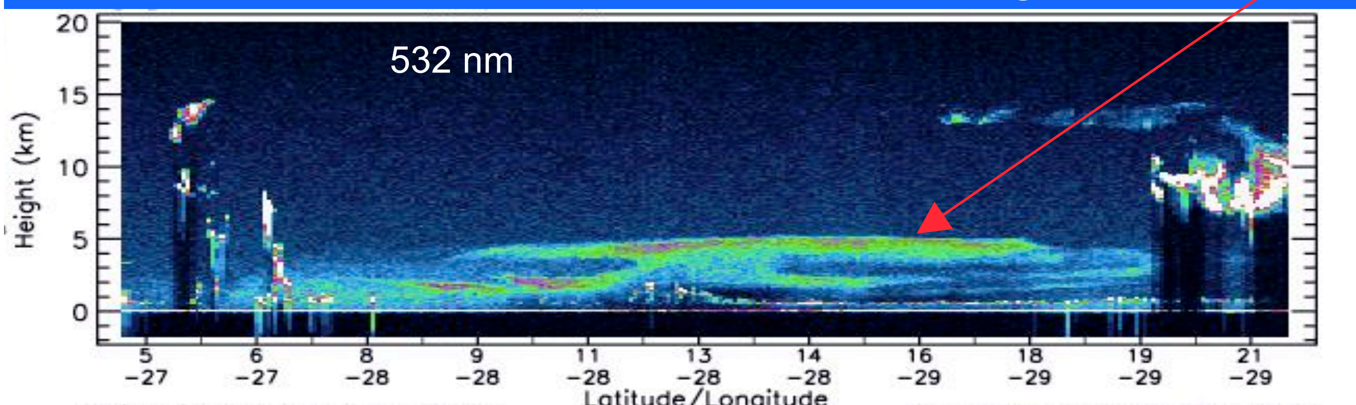
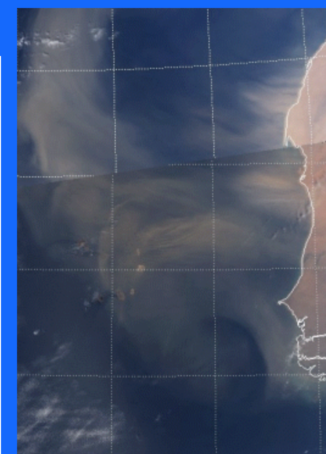
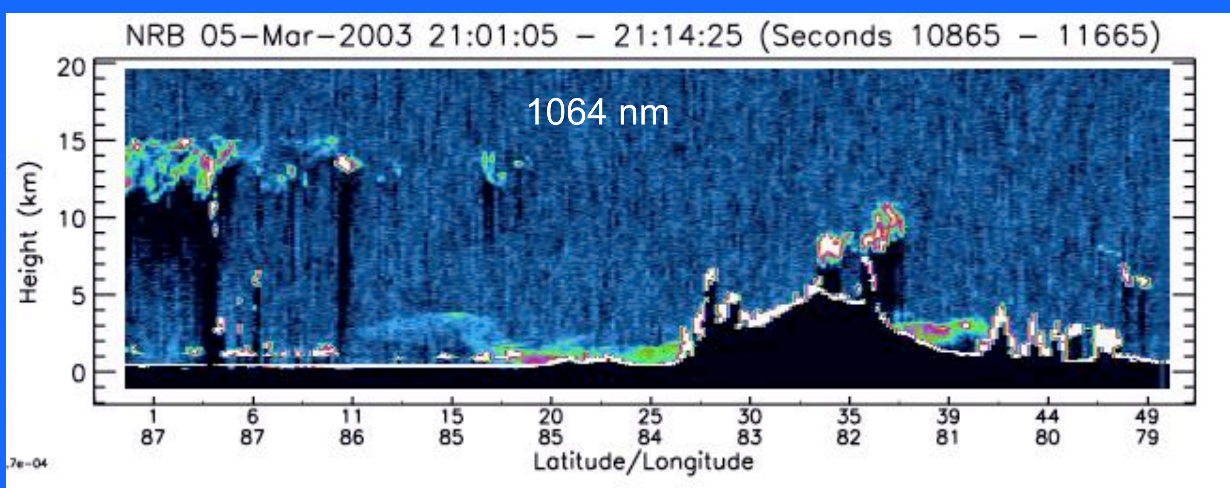
GLAS OBSERVATION OF THE DISTRIBUTION OF AEROSOL

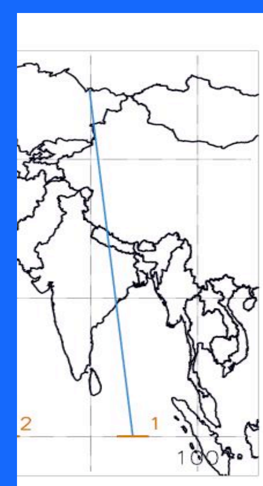
Multi-layer

GLAS View of Saharan Dust Layer









Asian Dust and Pollution

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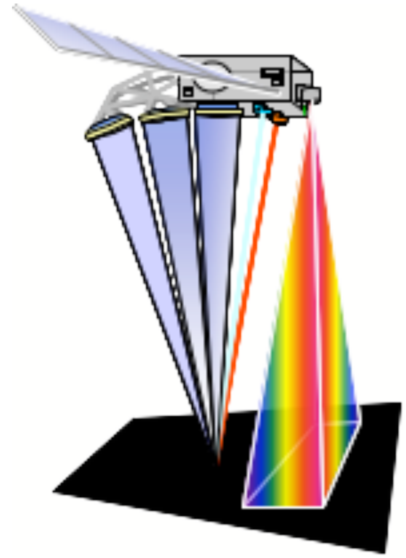
J. Spinhirne /GSFC January 2004

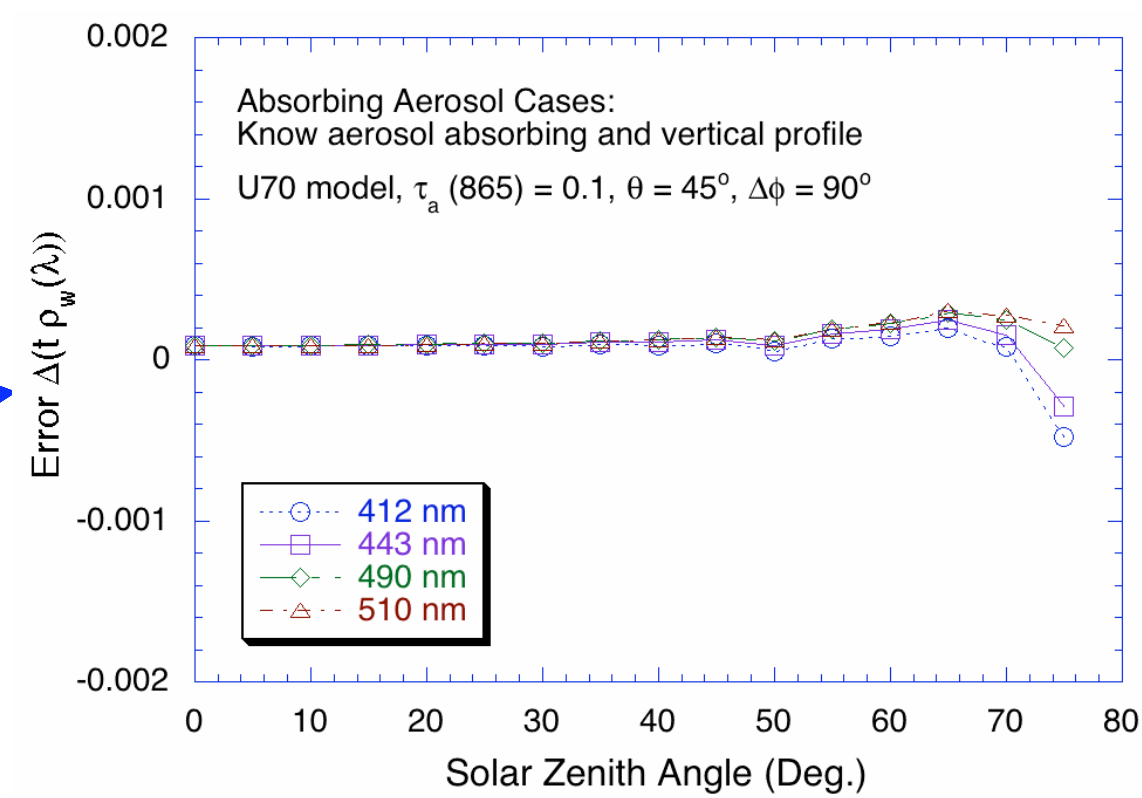
Absorbing Aerosols: Solutions



UV measurements identify the strongly absorbing aerosols + Lidar data provide the aerosol vertical profile

Then the proper aerosol lookup tables can be used for the atmospheric correction

Examples of atmospheric correction for the strongly absorbing aerosols with proper aerosol lookup tables



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Dealing with Strongly Absorbing Aerosols

For dealing with the strongly absorbing aerosols, it is necessary to first **detect the presence** of the strongly absorbing aerosols (e.g., using measurements in the **UV** bands where the TOA signal is sensitive to the aerosol absorption), and to derive the **aerosol vertical profile** (e.g., from Lidar measurements) with sufficient accuracy for atmospheric correction.

Conclusions

- Both SeaWiFS and MODIS have been providing high quality ocean color products in the global open oceans.
- At the coastal (or inland water) regions, however, not only the ocean is usually Case-2 waters, but also the aerosols are often absorbing.
- For the turbid waters in coastal regions, some regional algorithms and approaches in dealing with coastal complex ocean waters are useful (e.g., building regional reflectance relationship from in situ measurements).
- To deal with significant ocean contributions at the NIR bands in the turbid waters, shortwave infrared (SWIR) bands can be used for atmospheric correction because of significantly strong ocean absorption at the SWIR bands.
- For strongly absorbing aerosols, UV measurements (for detection of presence absorbing aerosols) and Lidar data (for aerosol vertical profile information) provide capability to solve the absorbing aerosol problems.
- Future ocean color sensor needs to include **UV** bands for a better detection of absorbing aerosols and requires **SWIR** bands with **the required sensor SNR** characteristics for dealing with the turbid waters in near-shore and coastal ocean regions.
- It is crucial we have on-orbit vicarious calibration.

Thank You!