Retrieving Water Leaving Radiances from MODIS Land and Ocean Color Channels

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BACKGROUND

- During previous MODIS meetings, I usually gave presentations on water vapor and cirrus clouds. I am the developer of the MODIS near-IR water vapor algorithm and the cirrus reflectance algorithm.

- Today, I will give a presentation on a different subject – remote sensing of ocean color using MODIS land and ocean channels.

INTRODUCTION

- Here I will briefly describe the MODIS land and ocean channels, saturation problems with the ocean channels, and limitations with the present MODIS operational water leaving radiance retrieving algorithm.

- I will describe the development of our hyperspectral and multi-spectral atmospheric correction algorithms, and present sample results.

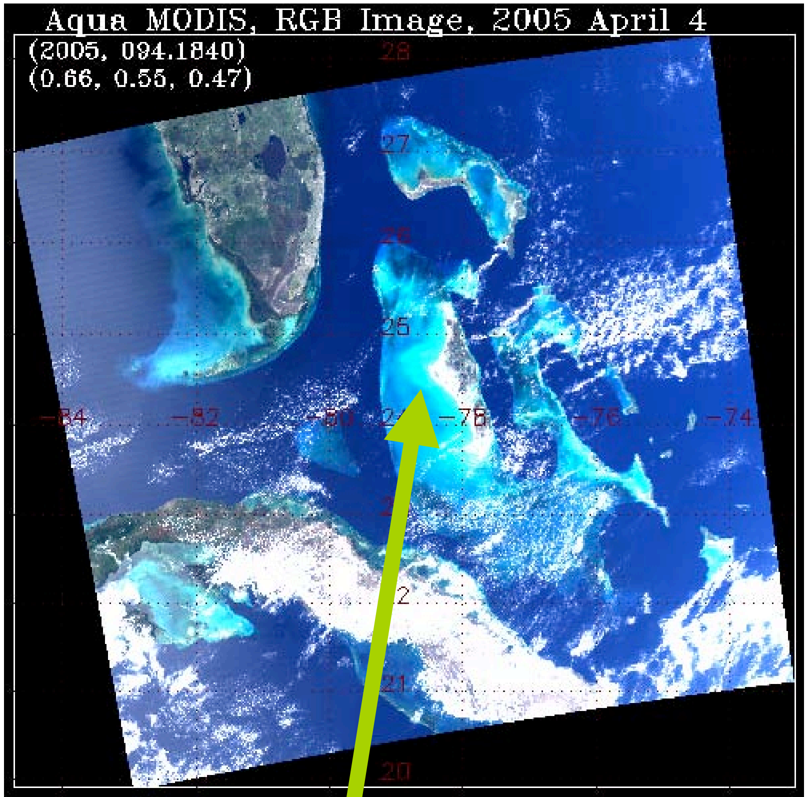
- I will also discuss possible future enhancements to our multi-channel algorithm for ocean color applications.

Two Sets of MODIS Channels For Remote Sensing of Land and Ocean

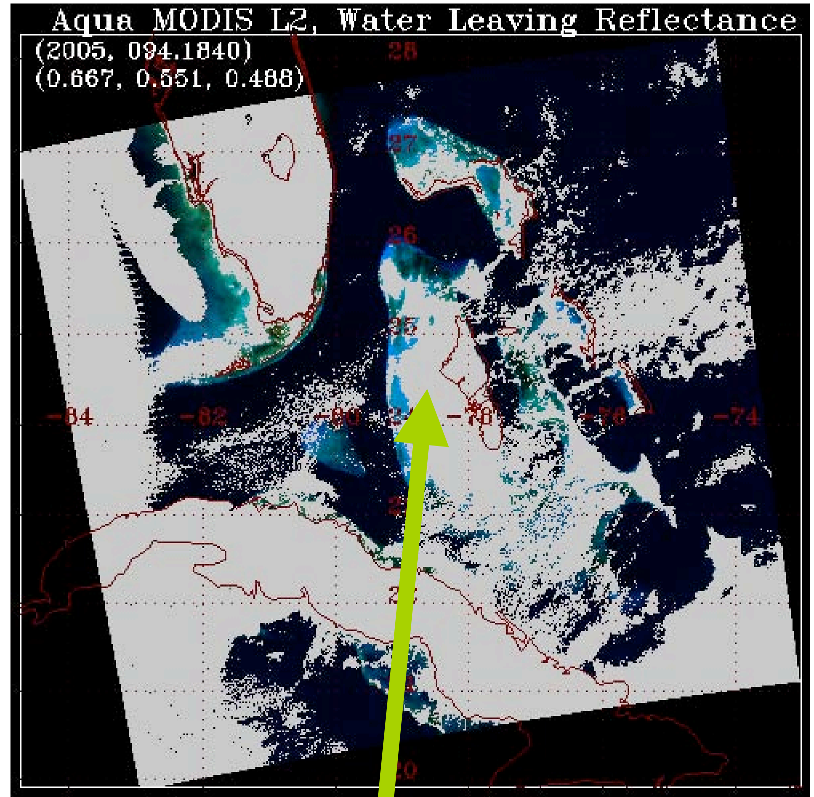
Primary Use	Channel	Bandwidth (nm)	Spectral Radiance	S/N Ratio
Land/Cloud	1	620 – 670	21.8	128
	2	**841 – 876**	**24.7**	**201**
	3	459 – 479	35.3	243
	4	545 – 565	29.0	228
	5	1230 – 1250	5.4	74
	6	1628 – 1652	7.3	275
	7	2105 – 2155	1.0	110
Ocean Color	8	405 – 420	44.9	880
	9	438 – 448	41.9	838
	10	483 – 493	32.1	802
	11	526 – 536	27.9	754
	12	546 – 556	21.0	750
	13	662 – 672	9.5	910
	14	673 – 683	8.7	1087
	15	743 – 753	10.2	586
	16	**862 – 877**	**6.2**	**516**

The ocean channels have higher S/N ratios but smaller spectral radiances. As a result, the ocean color channel can saturate over bright targets.

RGB Image from MODIS Land Channels



Water Leaving Reflectance Image Derived from Ocean Color Channels



The land channels can sense the bright and shallow water surfaces. Ocean color is not recovered over these surfaces from the MODIS ocean channels. Therefore, the land channels can be very useful for remote sensing of the brighter coastal waters.

The Present SeaWiFS and MODIS Operational Atmospheric Correction Algorithm

- The algorithm was developed by Gordon and Wang (1994).
- In this algorithm, the apparent reflectance ρ^* is expressed as

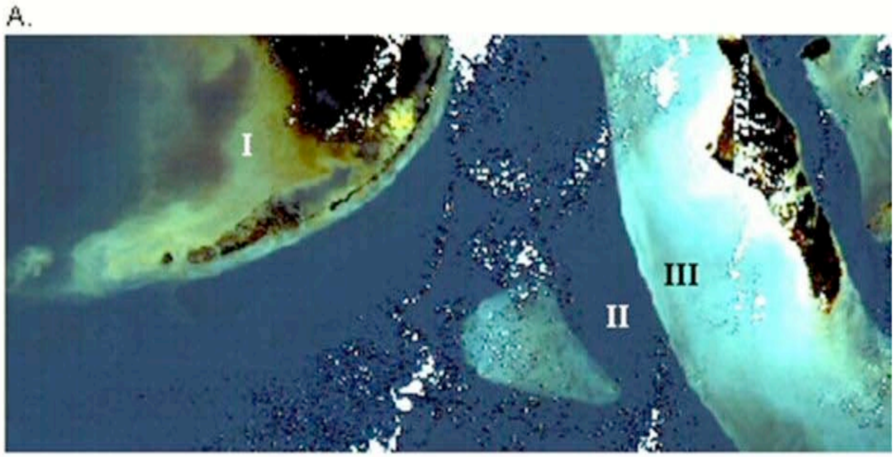
$$\rho^* = \rho_r + \rho_a + \rho_{ra} + t\,\rho_{wc} + T\,\rho_g + t\,\rho_w,$$

where $\rho^* = \pi L/(\mu_0 F_0)$,

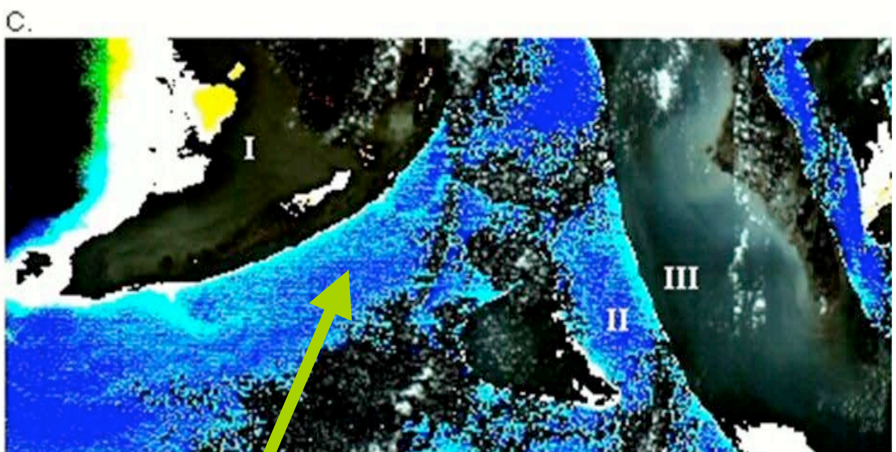
ρ_w is the desired water leaving reflectance

- The algorithm uses a two-layer model atmosphere – a Rayleigh atmosphere layer + an aerosol layer at the bottom, no mixing of atmospheric molecules and aerosols.
- The aerosol model and optical depths are basically derived from ratios of the two channels at 0.865 and 0.75 μm. The ratio technique adds together the noises from the two channels.
- Over the turbid coastal waters, the water leaving reflectances at 0.75 and 0.865 μm may not be close to zero. The two channels may not be useful for aerosol retrievals.

Noises in Water Leaving Reflectances Derived with Earlier Version of the SeaWiFS Algorithm



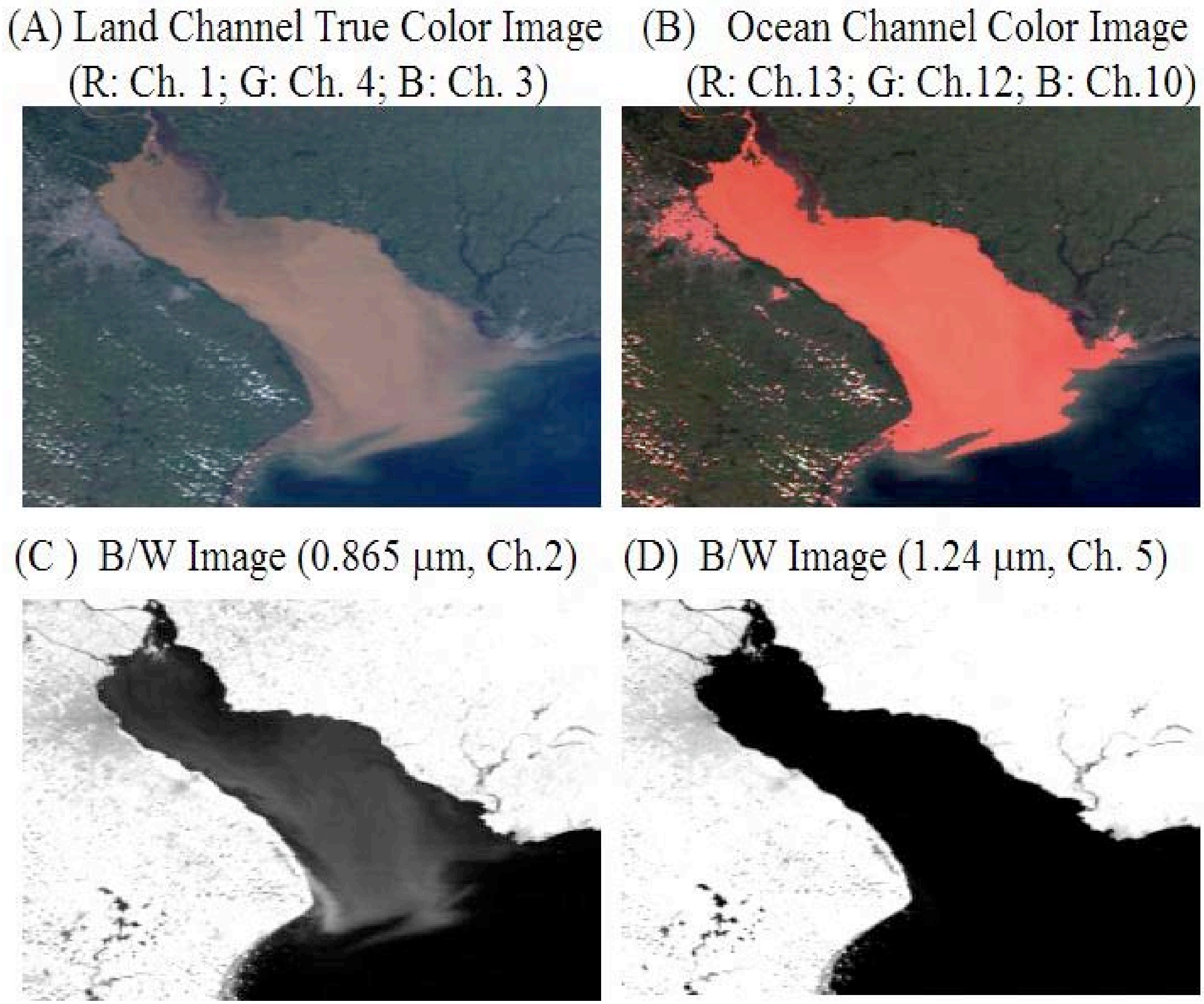
With our preliminary algorithm (1999 version)



With 1999 version of SeaWiFS algorithm. Improvements have been made later by doing a 5 x 5 box smoothing.

The noises here are due to instability in estimating aerosol models using the ratios of 0.865-μm / 0.75-μm channels. The ratios magnified noise effects.

Channels at wavelengths > 1 μm are dark over turbid waters and can be useful for atmospheric corrections



The Development of A Hyperspectral Atmospheric Correction Algorithm

- In 1997, we started the development of a hyperspectral atmospheric correction algorithm for retrieving water leaving reflectances over coastal regions to support various Navy research projects (i.e., COIS on NEMO) and later to support the NASA's EO-1 Hyperion Project.
- In this algorithm, we adopted the formulations of Fraser et al. (1997), and used their vector radiative transfer code to generate huge lookup tables.
- We also used channels at wavelengths of 0.86 μm or longer (because of darker surfaces) and a spectrum-matching technique to retrieve aerosol models and optical depths.

Fraser Algorithm

$$L_t = L_0(\lambda;\ \theta,\ \phi;\ \theta_0,\ \phi_0;\ z_{sen},\ z_{sfc}\ ;\ \tau_a) +$$
$$L_{\mathrm{sfc}}(\lambda;\ \theta,\ \phi;\ \theta_0,\ \phi_0;\ z_{sen},\ z_{sfc}\ ;\tau_a;\ W)\ t(\lambda;\ \theta;\ z_{sen},\ z_{sfc}\ ;\tau_a) +$$
$$L_{\mathrm{w}}(\lambda;\ \theta,\ \phi;\ \theta_0,\ \phi_0;\ W;\ C)\ t\_(\lambda;\ \theta;\ z_{sen},\ z_{sfc}\ ;\ \tau_a)$$

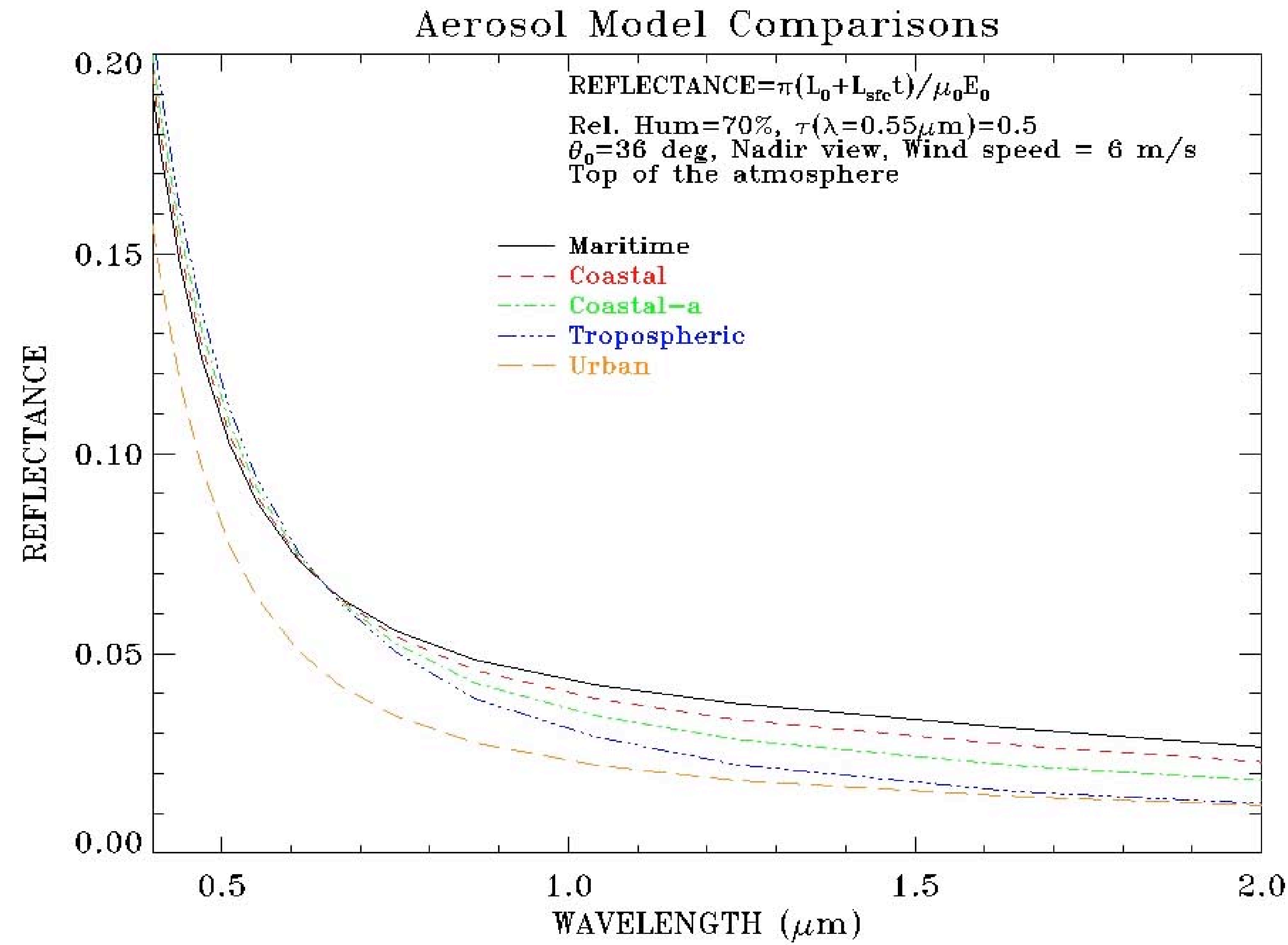
L_t	= measured radiance
L_0	= path radiance (i.e., atmospheric scattering)
L_{sfc}	= direct and diffuse radiance reflected off ocean surface
L_{w}	= water (or ground) leaving radiance
t	= diffuse + direct upward transmission
$t\_$	= diffuse upward transmission
τ_a	= aerosol optical properties
W	= wind speed
C	= water column and bottom constituents
$\theta,\ \phi$	= view zenith and azimuth angles
$\theta_0,\ \phi_0$	= solar zenith and azimuth angles
$z_{sen}\ ,\ z_{sfc}$	= sensor and surface altitudes

Table Dimensions

- 14 wavelengths (λ = 0.39 to 2.25 μm)
- 4 lower boundaries: a rough ocean surface at 3 different wind speeds (2, 6, and 10 m/s) and a Lambertian with 0 reflectance.
- 10 aerosol optical depths at 0.55 μm (from τ = 0.0 to 2.0)
- 5 aerosol models at 5 relative humidities (RH=50, 70, 80, 90, 98%)

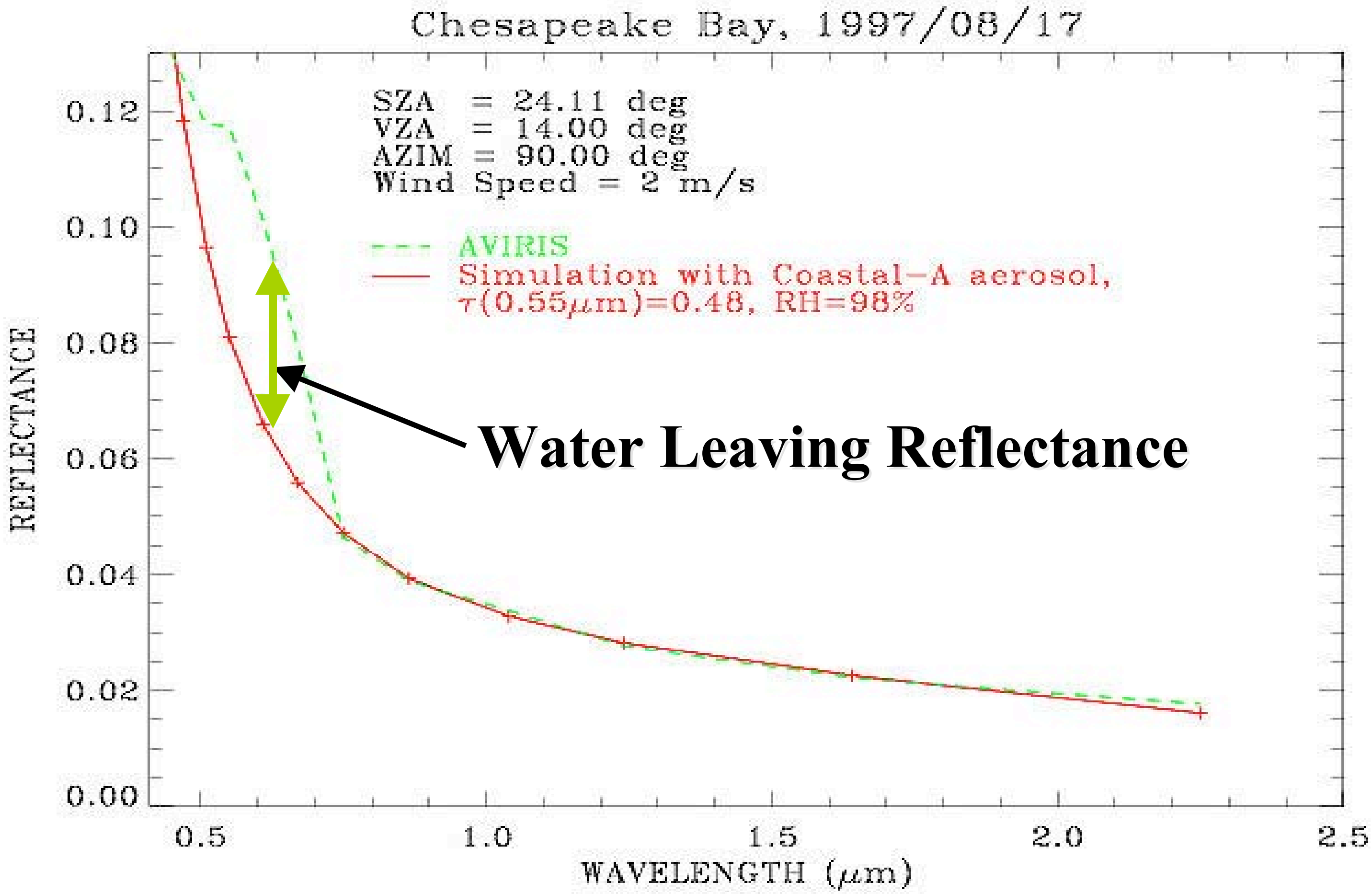
Urban	99.9875% small continental/ 0.0125% soot-like
Tropospheric	100% small continental/ 0% large oceanic
Coastal-a	99.8% / 0.2%
Coastal	99.5% / 0.5%
Maritime	99.0% / 1.0%

- 9 solar zenith angles (θ_0)
- 17 relative azimuth angles ($\phi - \phi_0$)
- 17 view zenith angles (θ)
- Calculated at the top of the atmosphere and at 9 sensor altitudes (z_{sen}) from 0.0 to 22.0 km
- There are ~ 330 million elements in the reflectance tables.
- Several much smaller tables are also calculated and used.



Aerosol Model Comparisons
REFLECTANCE=π(L0+Lsfc t)/μ0E0
Rel. Hum=70%, τ(λ=0.55μm)=0.5
θ0=36 deg, Nadir view, Wind speed = 6 m/s
Top of the atmosphere
Maritime
Coastal
Coastal-a
Tropospheric
Urban
0.20
0.15
0.10
0.05
0.00
REFLECTANCE
0.5
1.0
1.5
2.0
WAVELENGTH (μm)

Spectrum-Matching Technique for Water Leaving Reflectance Retrievals

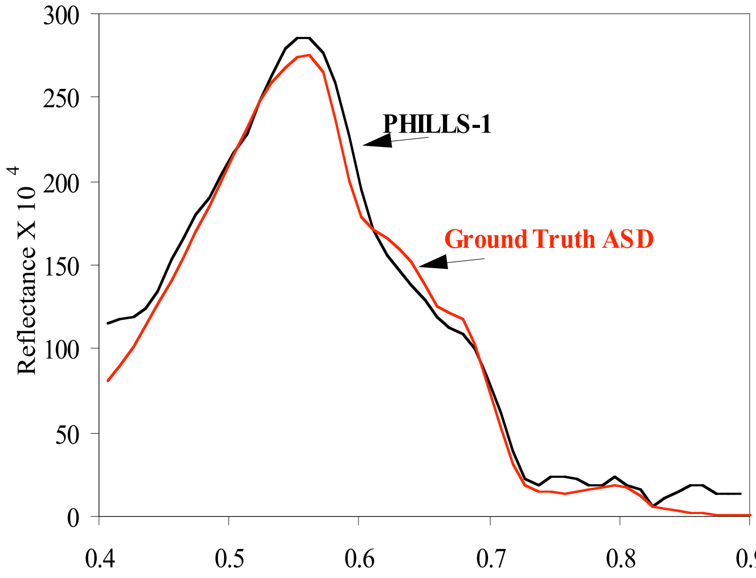


Because several channels at 0.86 mm or longer wavelengths are used simultaneously in the retrievals, the noise effects are decreased.

PHILLS data processed with *Tafkaa* (HyCODE LEO-15 Experiment July 31, 2001)

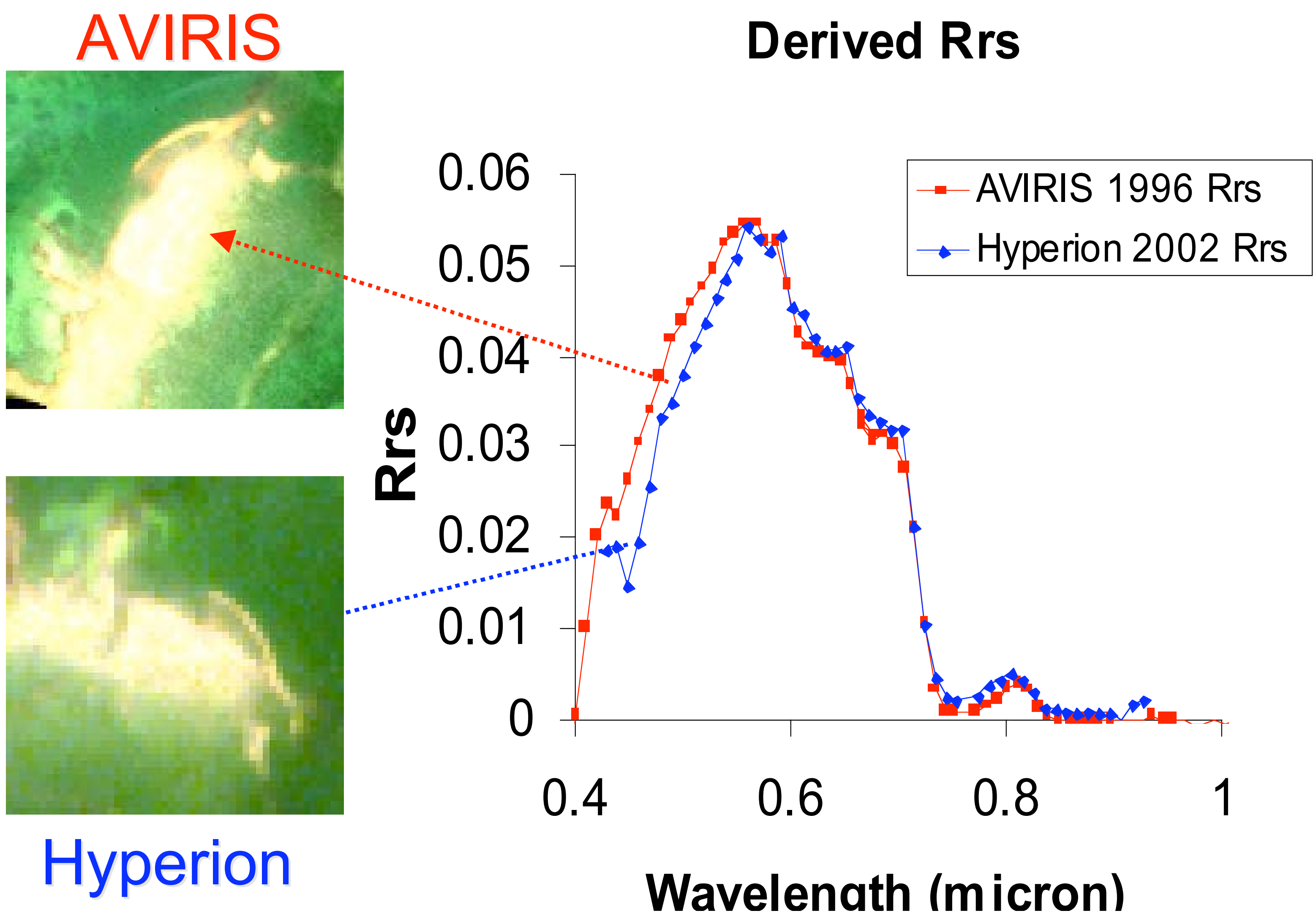
PHILLS image from the 2001 LEO-15 deployment (39 31 05 N and 74 20 47 W, 14:18 GMT, 31 July 2001.)

Courtesy W. Snyder (NRL)



Remote-sensing reflectance spectrum from the pixel indicated with an X in the image compared with a ground-truth measurement obtained with a hand-held radiometer

Shallow Sandy Areas



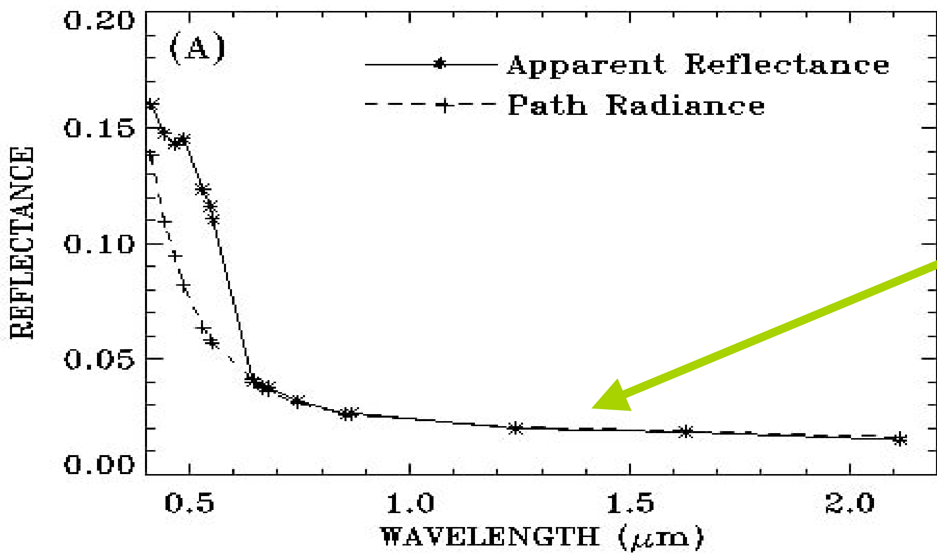
The Multi-Channel Atmospheric Correction Algorithm

- With previous funding from the NASA SIMBIOS Project, we modified our hyperspectral atmospheric correction algorithm for processing multi-channel imaging data.

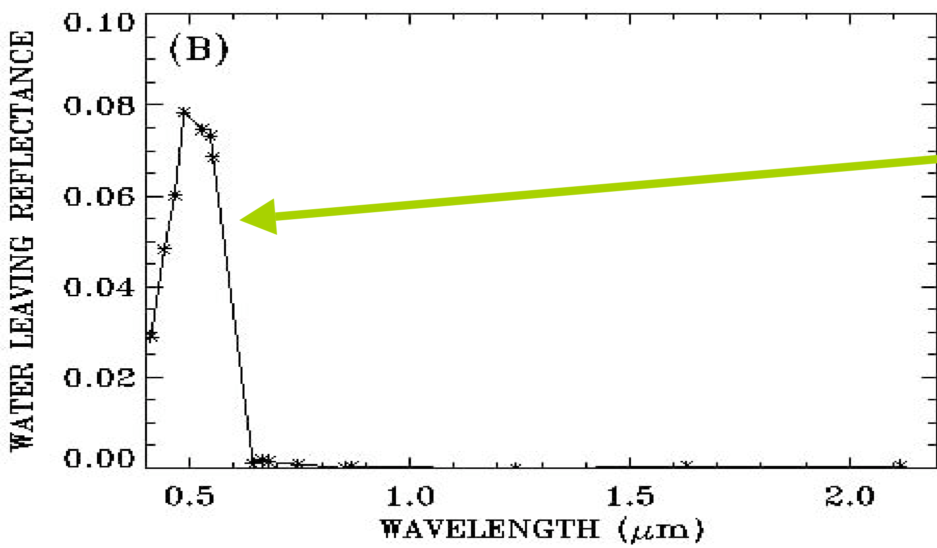
- The sizes of multi-spectral images are typically ~2000 km x 2000 km. The solar angles and viewing angles vary for each pixel in the scene. If we simply use the hyperspectral code to process one multi-spectral imaging data set, it would take more than 24 hours to do so.

- We explored numerous ways to speed up the retrievals. Now we have a multi-channel version code that can process one MODIS scene in about 10 minutes or less.

An Illustration of Water Leaving Reflectance Retrievals from MODIS Land and Ocean Channels



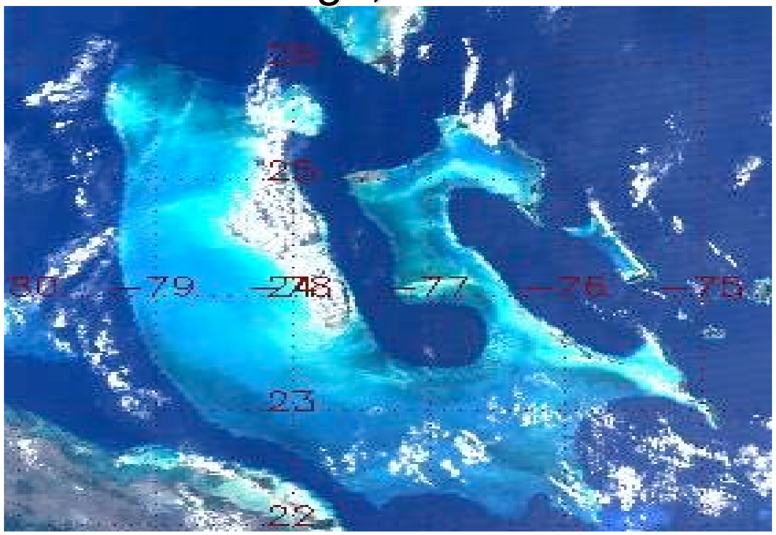
Matching with Channels at 0.86, 1.24, 1.64, and 2.13 μm



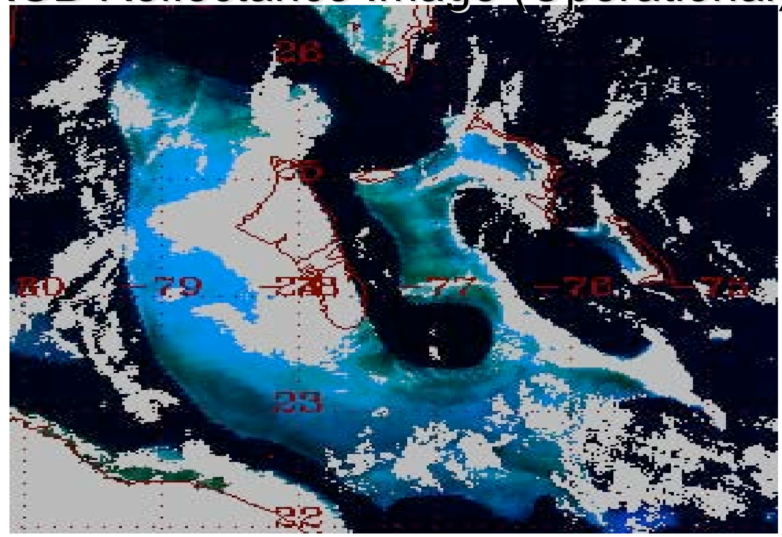
Water leaving reflectances of MODIS land & ocean channels in the visible spectral region

SAMPLE MODIS RESULTS

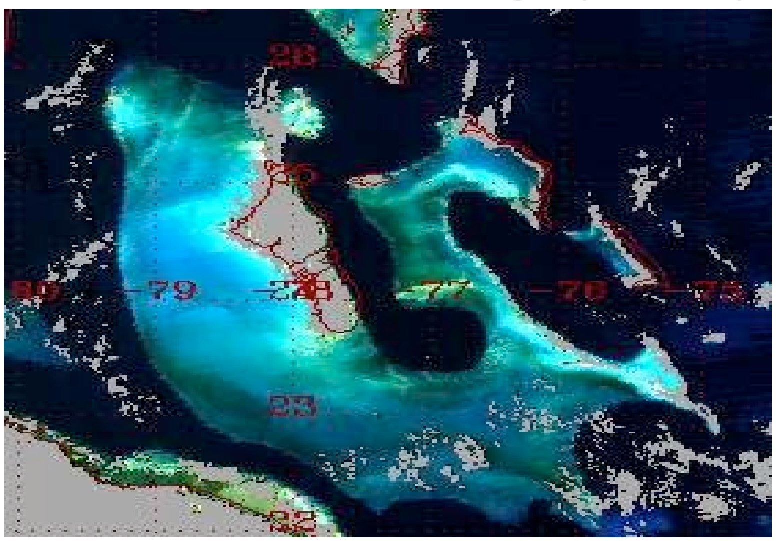
RGB Image, Land Channels



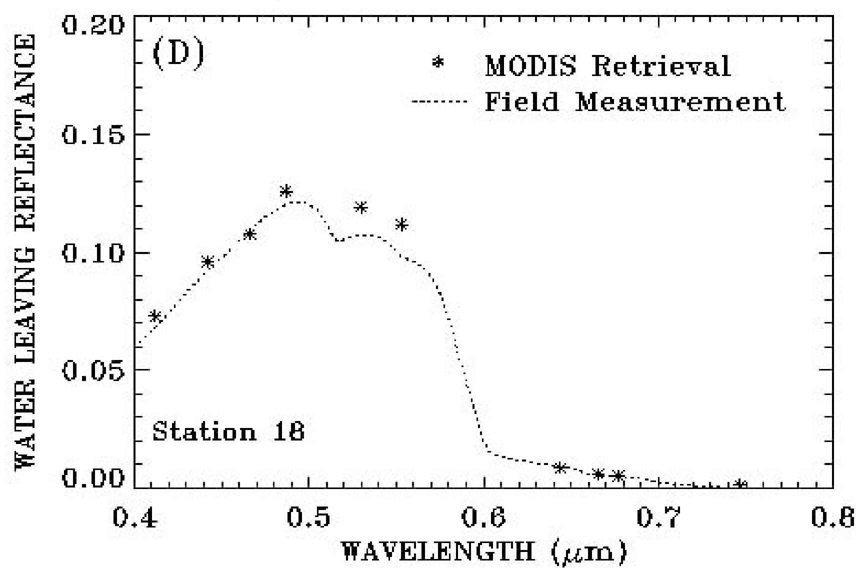
RGB Reflectance Image (Operational)



RGB Reflectance Image (Tafkaa)



Comparison with Field Data

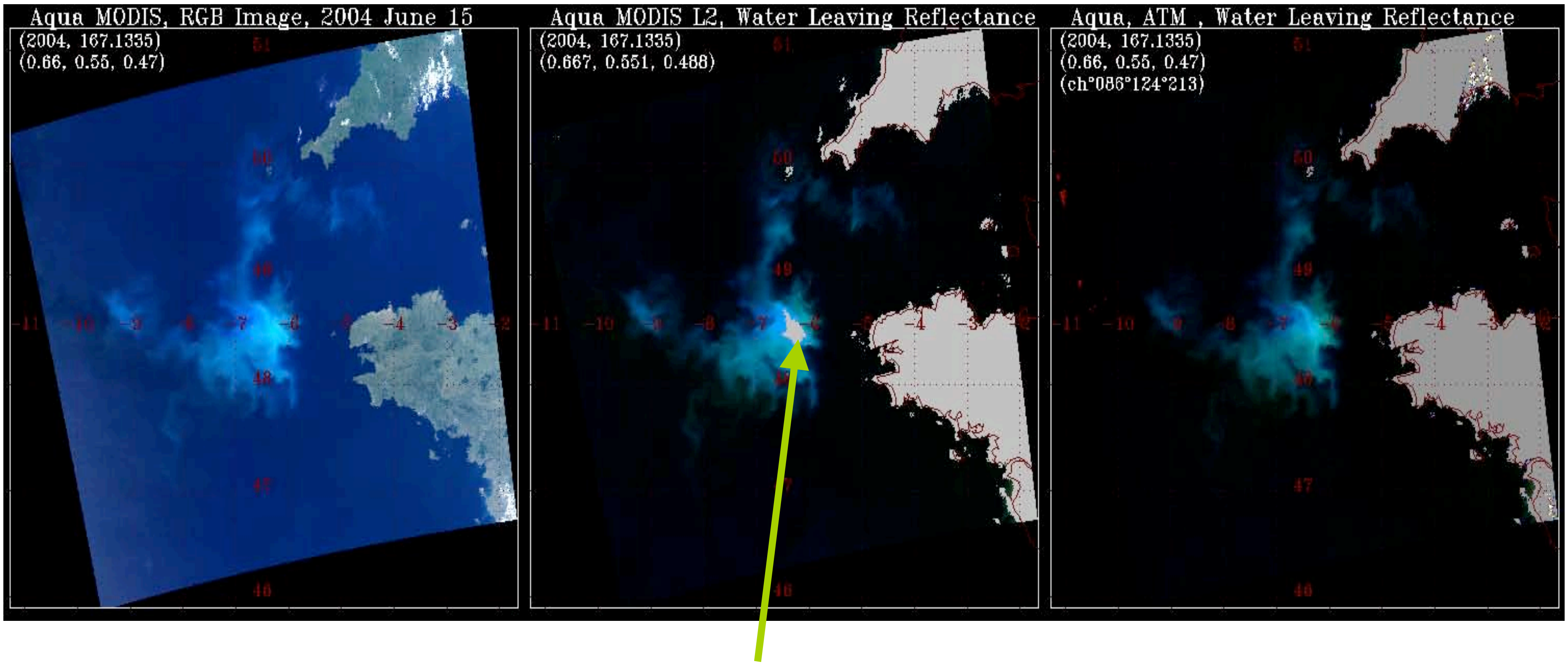


SAMPLE MODIS RESULTS

RGB Image
(Land Channels)

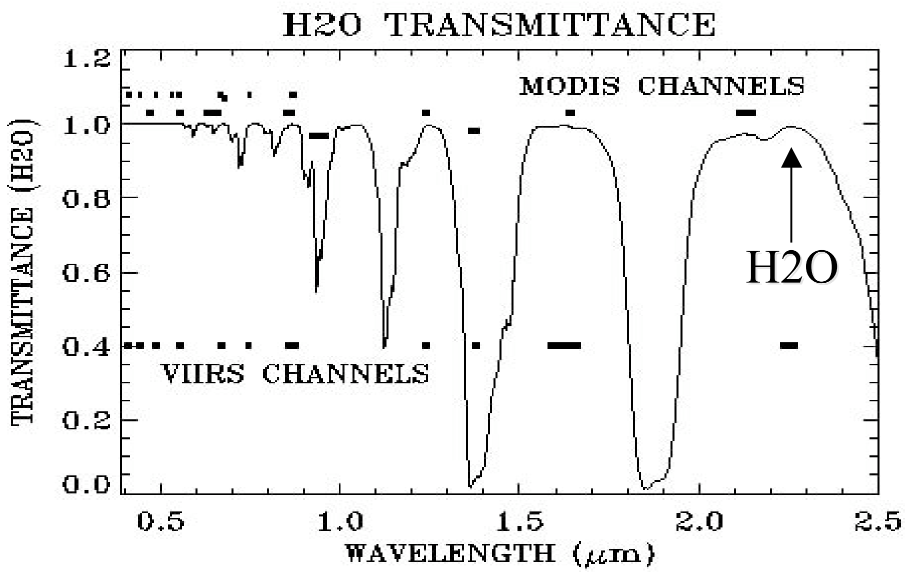
RGB Reflectance Image
(Operational Retrieval,
Ocean Channels)

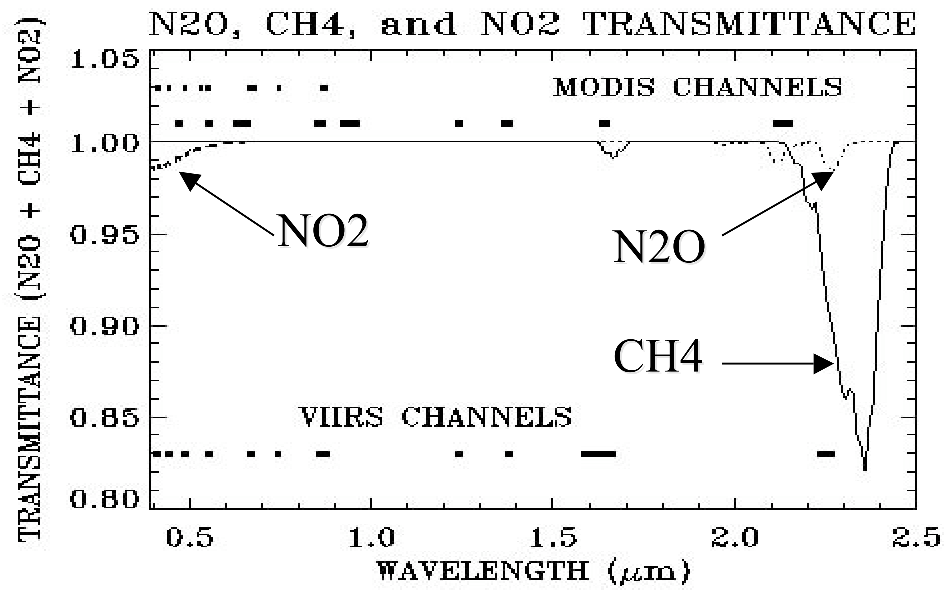
RGB Reflectance Image
(Tafkaa Retrieval,
Land Channels)

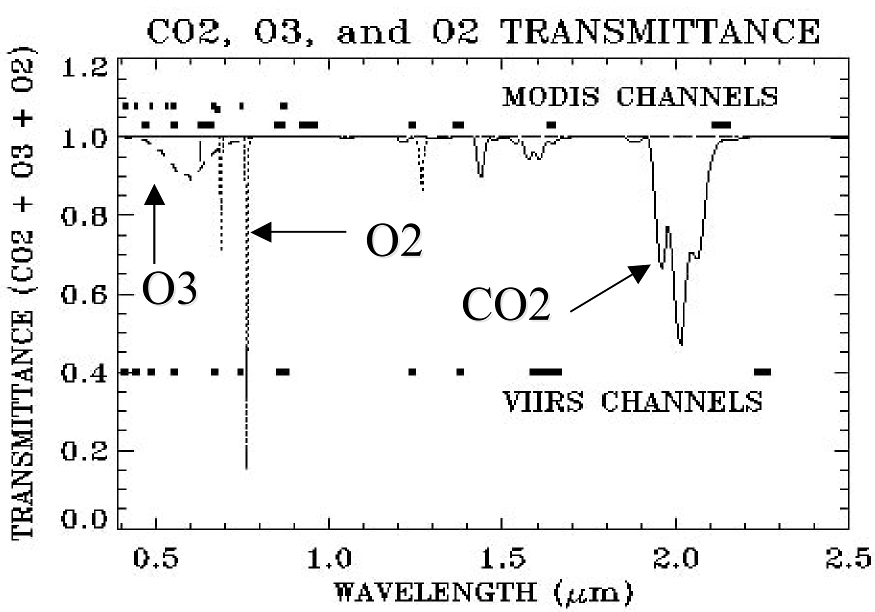


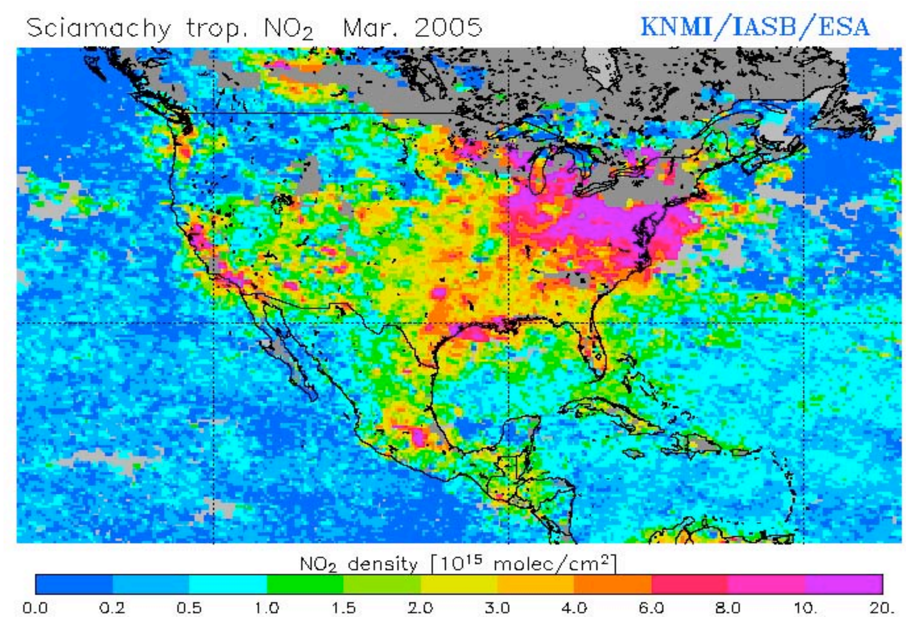
MODIS Ocean Channels Saturated

Future Enhancement – Proper Modeling of Gas Absorption, Including NO_2









SUMMARY

- Previously, we developed a hyperspectral atmospheric correction algorithm for remote sensing of coastal waters to support various Navy research projects and the NASA EO-1 Hyperion project.

- We have adapted the algorithm for retrieving water leaving reflectances from MODIS land and ocean color channels. The algorithm uses channels located at wavelengths longer than 0.8 μm and a spectrum-matching technique for the estimates of aerosol models and optical depths.

- Our algorithm can complement the operational MODIS atmospheric correction algorithm over brighter coastal waters, where the MODIS ocean channels are saturated, or the standard algorithm does not produce reasonable water leaving reflectances.