An Investigation of JCSDA-CRTM Capability for Water-Leaving Radiance Assimilation Development

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Outline

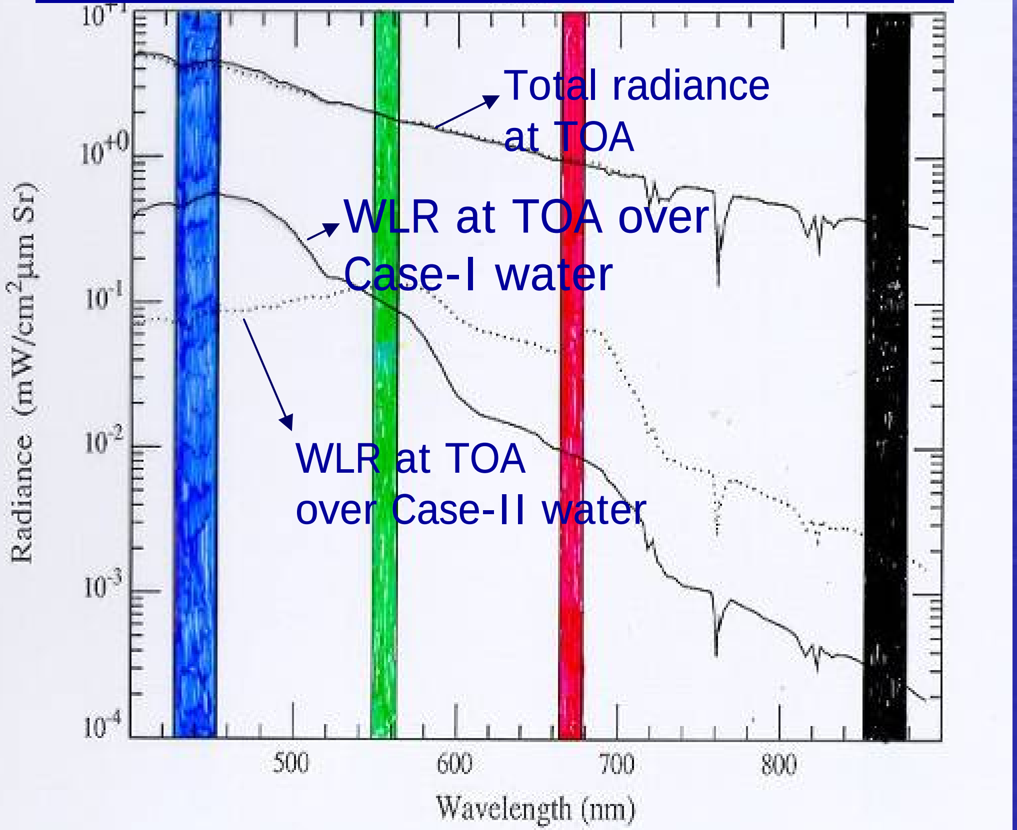
- Significance of Water-Leaving Radiance in Satellite Assimilation Development
- Current JCSDA-CRTM Capability for Ocean Surface Handling
- Considerations of Enhanced JCSDA-CRTM for Water-Leaving Radiance Assimilation
- Summary and Conclusions

Significance of Water-Leaving Radiance (WLR) Satellite Assimilation Development

- WLR is a key parameter for remote sensing algorithms of chlorophyll concentration which is responsible for ocean production
- WLR monitors ocean water quality (nutrition) from satellite observations

Characteristics of Water-Leaving Radiance

(Multiangle Imaging Spectro-Radiometer)



(http://www.physics.miami.edu/~chris/envr_optics.html)

- In the visible wavelength, at most 10% of the radiance measured by satellite sensor typically comes from ocean.
- Accurate atmospheric correction is an important prerequisite for reliable retrievals of water-leaving radiances.

SeaWiFS Operation Ocean Color Algorithm (Based upon A Decoupled RTM)

- Black Pixel Assumption (BPA) at NIR (water-leaving radiance=0) used is invalid for coastal regions.

- There remains a large uncertainty in doing accurate atmospheric correction of aerosol contribution unless BPA holds.

WLR at NIR and Its Effect on Atmospheric Correction of Ocean Color Imagery

TOA Radiance Deviation (%)

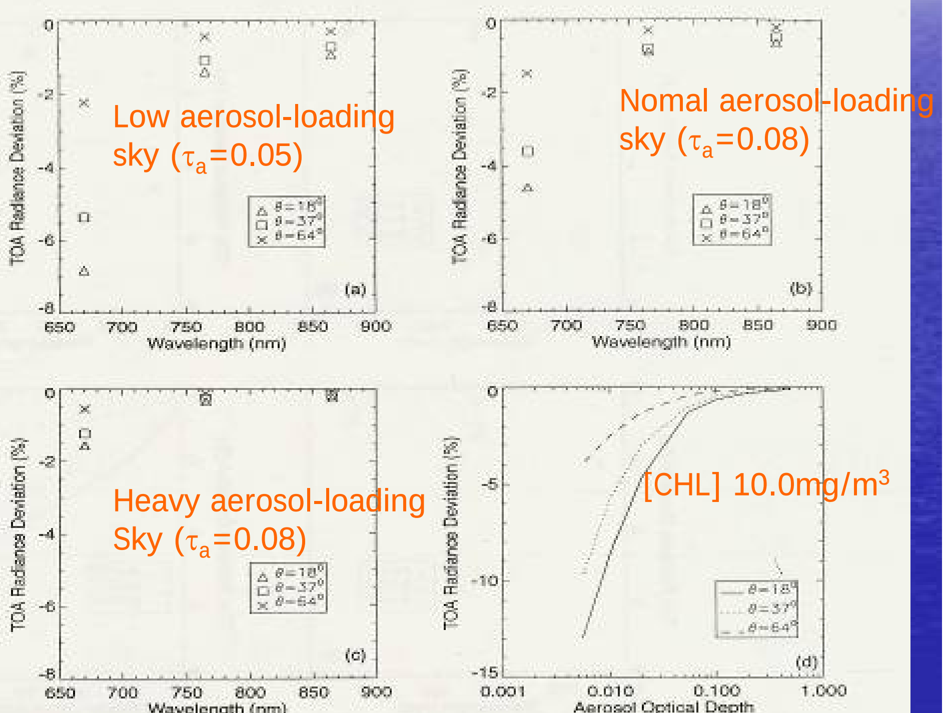
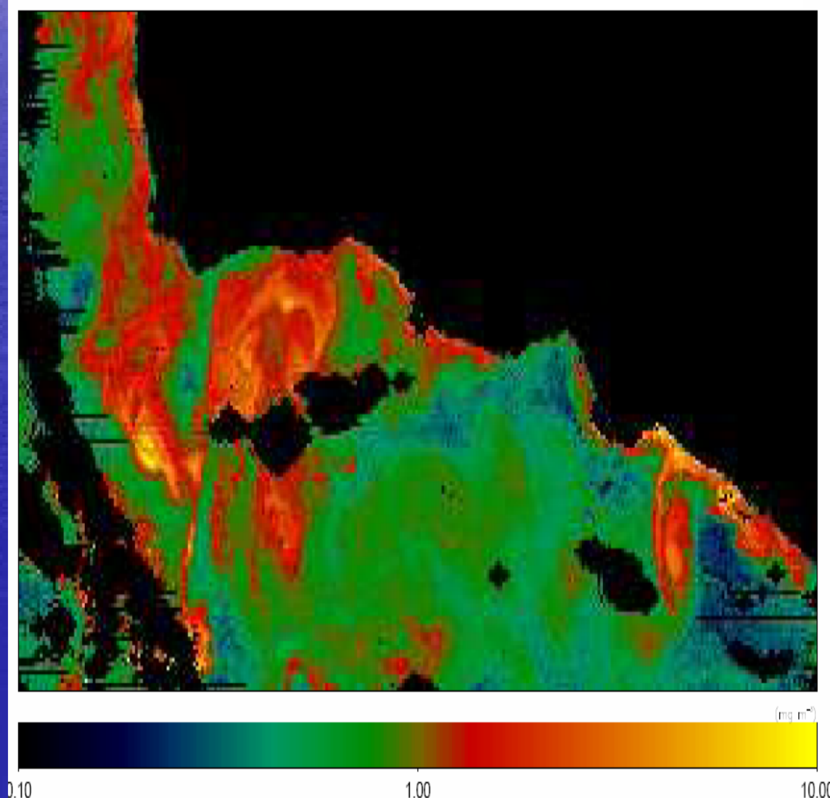


Fig. 3 Percentage deviation $100 \cdot (L_T' - L_T)/L_T$ between simulated TOA radiances obtained when ocean scattering at NIR wavelengths is ignored (L_T') or included (L_T). $\theta_0 = 35°$, $\phi = 60°$. The simulations in (a), (b), and (c) pertain to the phase function in Fig. 1b, a chlorophyll concentration of $C = 5\ mg/m^3$, and an aerosol optical depth of (a) $\tau_a = 0.05$; (b) $\tau_a = 0.08$; (c) $\tau_a = 0.2$. Panel (d) shows the percentage deviation as a function of aerosol optical depth at $\lambda = 865\ nm$ for the phase function shown in Fig. 1b, and for $C = 10\ mg/m^3$.

(Chen, Stamnes, Yan, 1998)

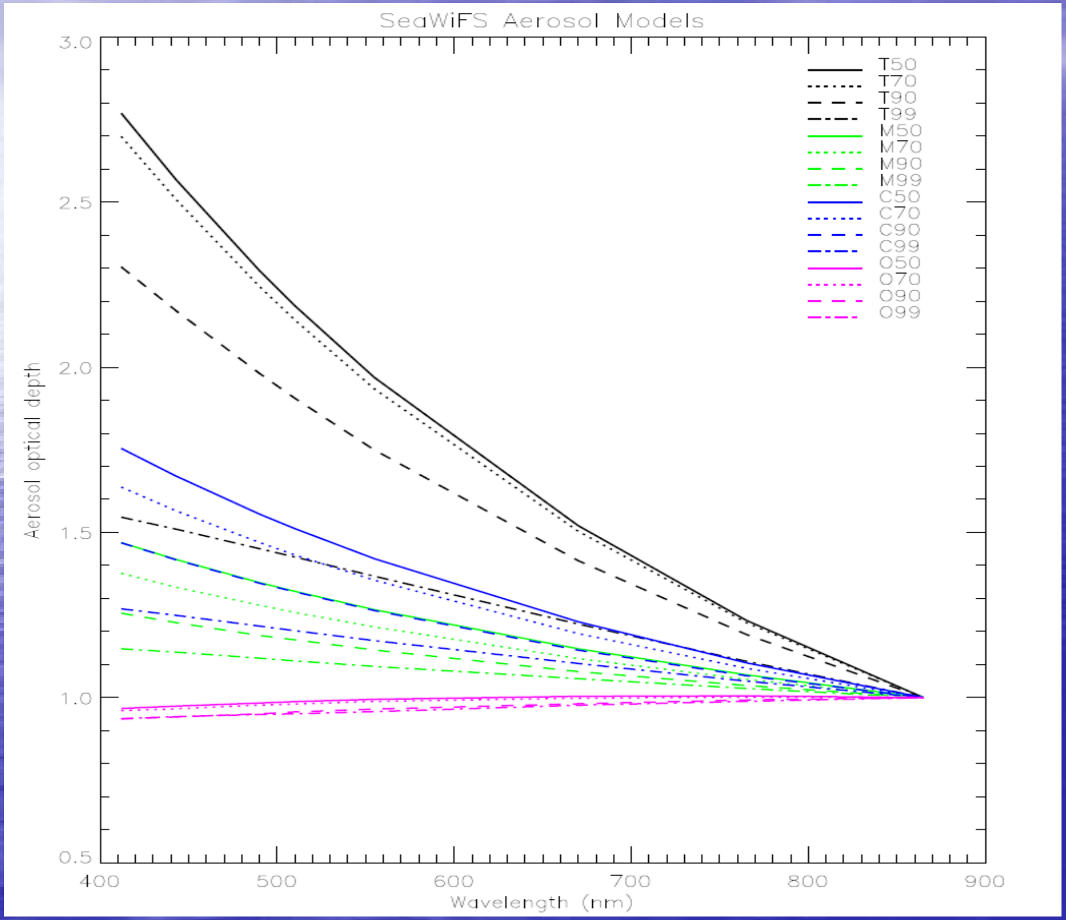
[CHL] (mg/m³) (Santa Barbara Channel)



(Li, Stamnes, 2007)

- The Contribution of NIR WLR can be around 1% of the total TOA radiance as [CHL] = 5mg/m3, which may occur over coastal regions.

Aerosol Optical Depth Spectra for Sixteen Candidate Aerosol Models

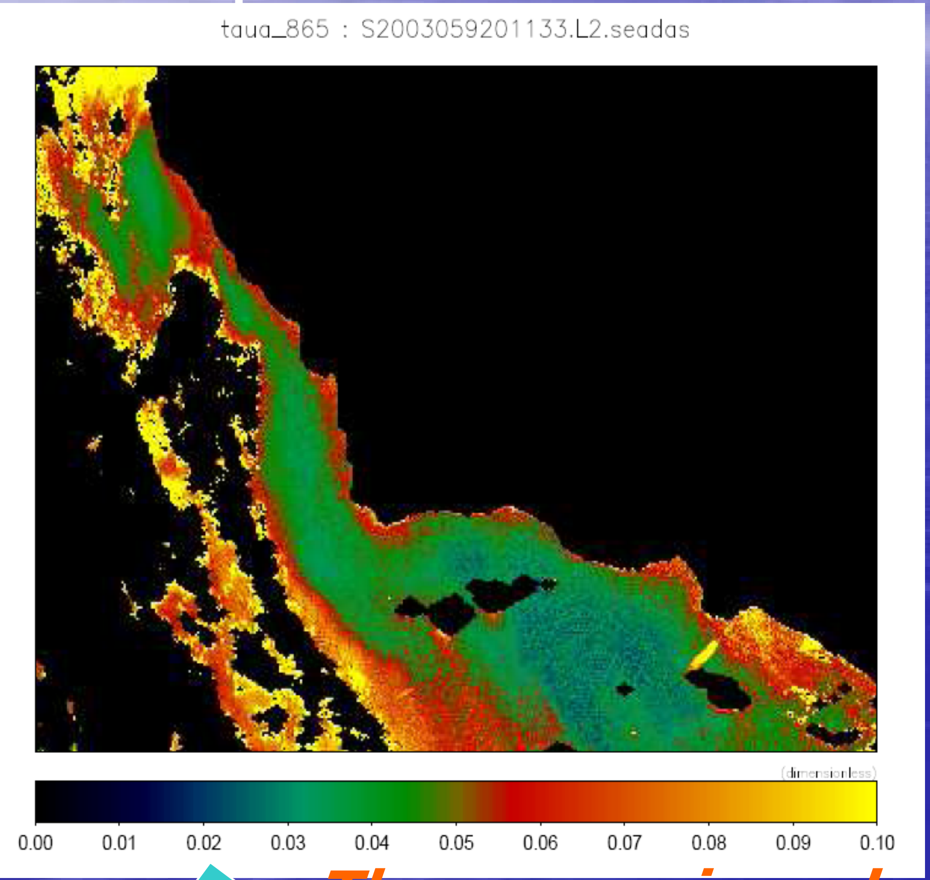


(Courtesy for Wei Li)

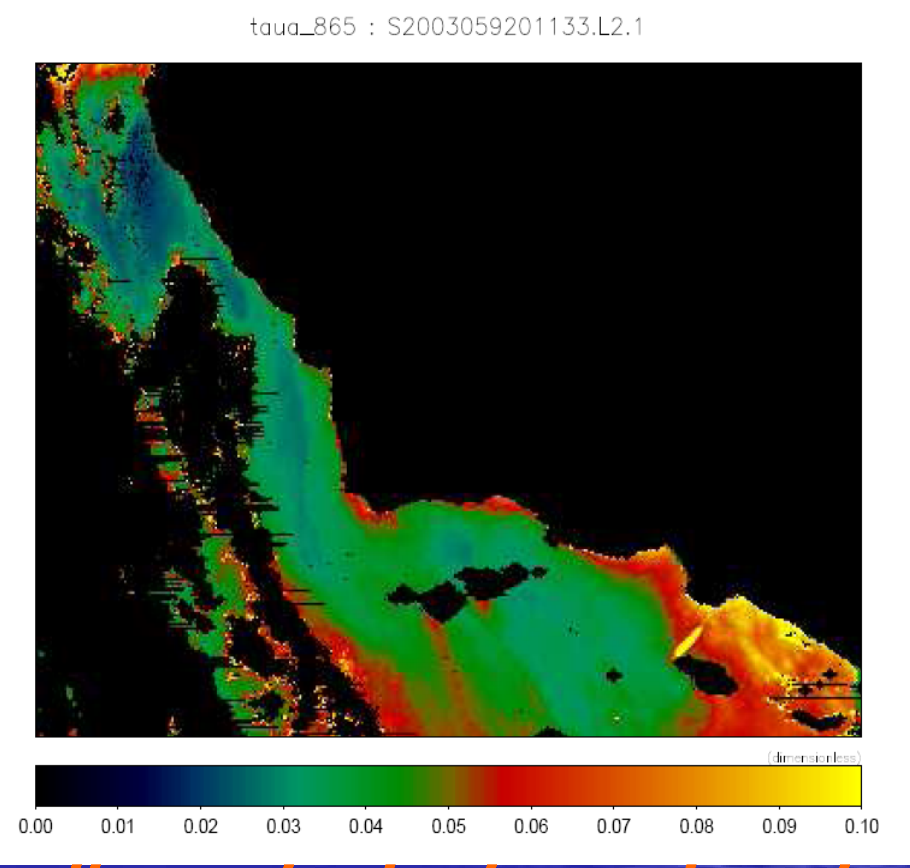
- A small uncertainty in retrieved aerosol properties in NIR results in a large uncertainty retrieved aerosol properties in visible region.
- A small uncertainty in the atmospheric correction may lead to a big error in the inferred chlorophyll concentration.

Comparison of Retrieved τ_{865} from Decoupled/Coupled RTM

Decoupled RTM



Coupled RTM (Li and Stamnes, 2007



There remains a large discontinuity in retrieved atmospheric aerosol optical depth over some Regions, as a decoupled RTM is used.

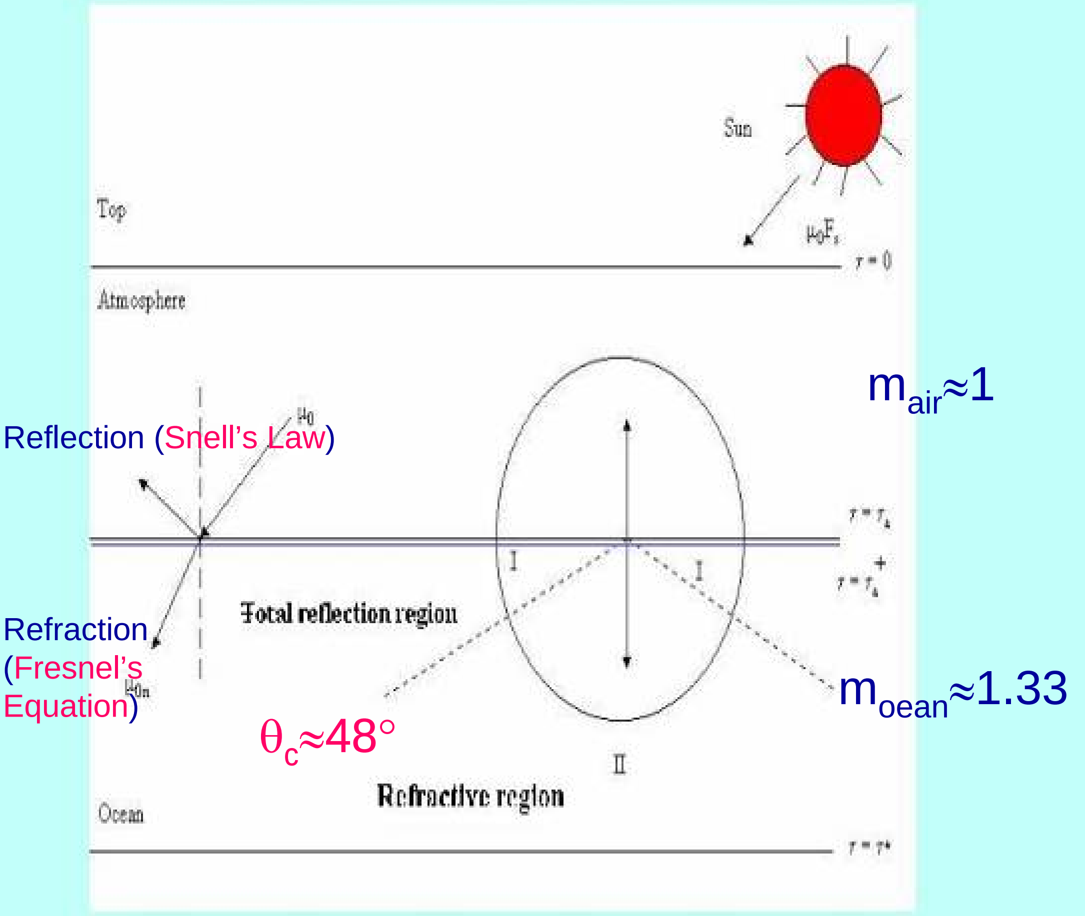
Therefore, retrievals of water-leaving radiances become a very challenging task over coastal regions, as the radiative transfer process is decoupled between atmosphere and ocean there.

How to solve this problem?

A radiative transfer modeling in the coupled atmosphere-ocean system is highly required

Radiative Transfer Methodology in Coupled Atmosphere-Ocean System

- Reflection and refraction occur in the interface between the atmosphere and ocean.
- Multi-scattering and absorption process of radiances are **coupled** in the atmosphere and ocean media



Current JCSDA-CRTM Methodology in Ocean Surface Handing

- Radiative transfer process between atmosphere and surface media is decoupled.

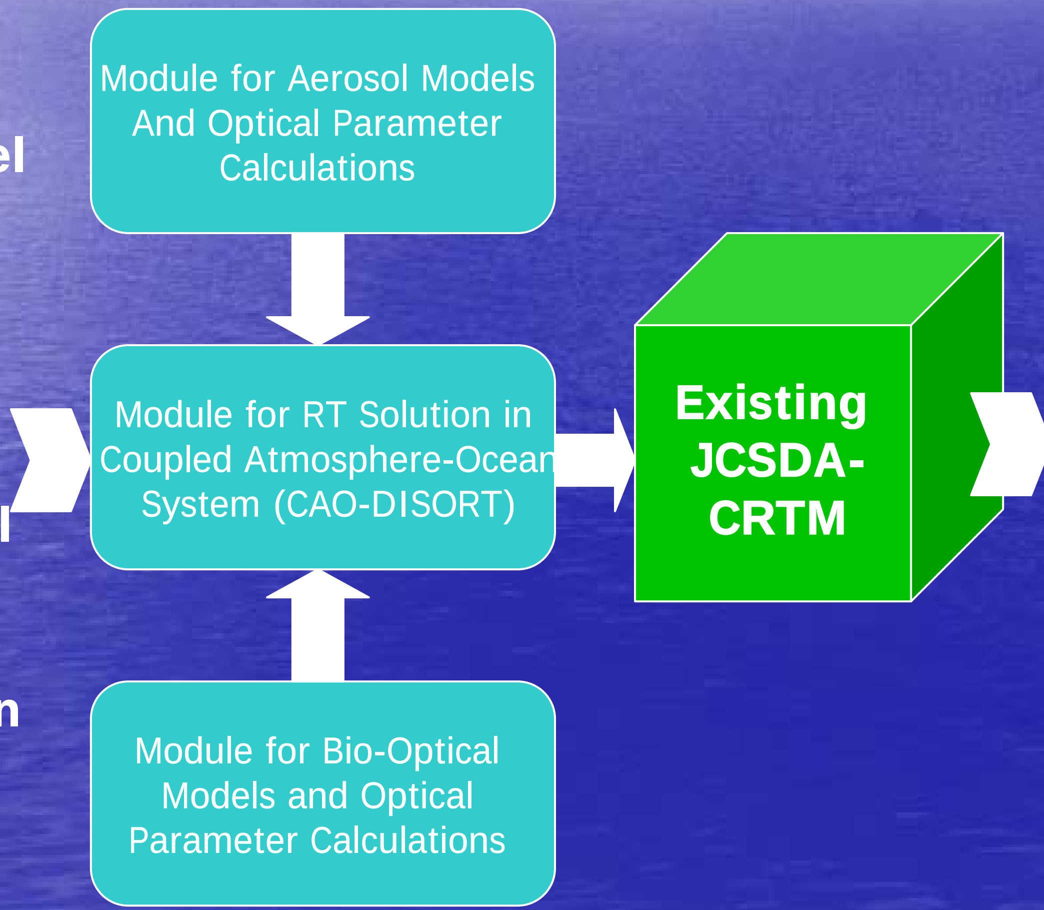
- Ocean surface is set to be a bottom boundary and its reflectance is calculated using MOREL bi-optical model for Case-I water (open ocean) (1988).

Therefore, we need to improve CRTM capability for water-leaving radiance satellite development.

Considerations for Enhanced JCSDA-CRTM for Water-Leaving Radiance Simulation

NEW INPUTS

- **Selection of aerosol model**
- **Selection of SC/MC approach**
- **Selection of ocean bio-optical model**
- **Oceanic particle and concentration (chlorophyll, sediment, CDM, air bubble…)**



NEW OUTPUTS

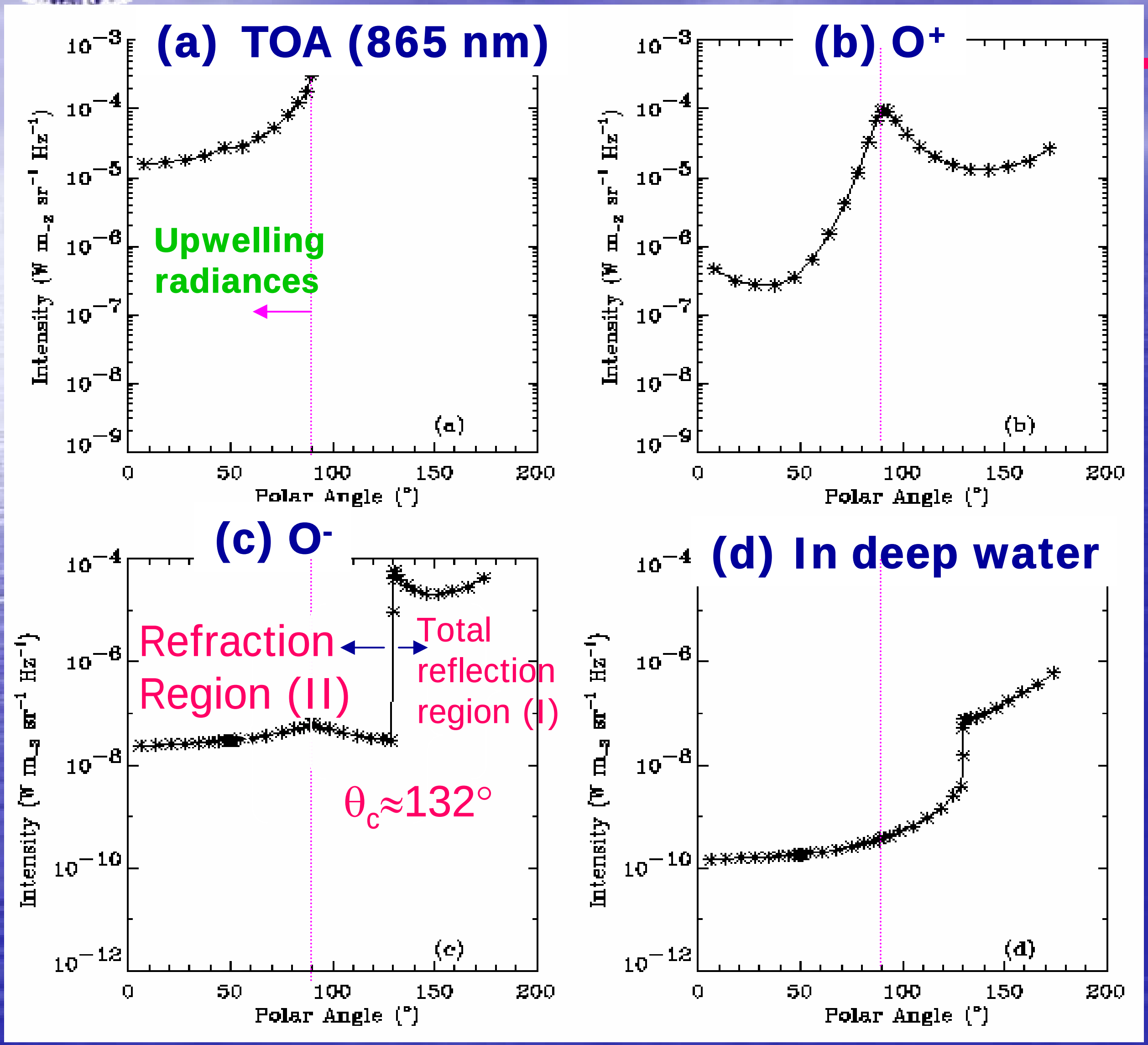
- Water-leaving radiance
- Optical parameters of oceanic particles such as chlorophyll
- Radiance distribution vs. polar angle under water, etc.

- Progress one: we have developed a relatively mature radiative transfer methodology in the coupled atmosphere-ocean system.

Existing Radiative Transfer Modeling in Coupled Atmosphere-Ocean System: CAO-DISORT

The Discrete-ordinate method was introduced by Chandrasekhar in 1940's	Concept
A methodology of Discrete-ORdinate Transfer (DISORT) in the atmosphere was developed By K. Stamnes, et. al. (1981)	at quadrature polar angles
DISORT in the atmosphere was upgraded to arbitrary polar angles using Iteration of Source-function By K. Stamnes, et. al. (1982)	at arbitrary polar angles
DISORT was extended to the coupled atmosphere-ocean system (CAO-DISORT) by Z. Jin and K. Stamnes (1994)	at quadrature polar angles
CAO-DISORT was upgraded to arbitrary polar angles by B. Yan and K. Stamnes (2003)	at arbitrary polar angles

Angle dependency of Radiances in Coupled Atmosphere-Ocean System



(B. Yan and K. Stamnes, 2003)

- Water-leaving radiance (Fig. b) is a small percentage of TOA radiance.
- Angle dependences of radiances at o$^+$ and o$^-$ are very different.

- Progress two: we have studied how to calculate optical parameters of a specific aerosol model containing multiple components.

Review of Aerosol Models Applicable for Ocean Color Field

Four Types of Aerosol Models (RURAL, URBAN, MARITIME, TROPOSPHERE)

With four different Relative Humidity (RH), e.g., RH = 50, 70, 90, 99%.

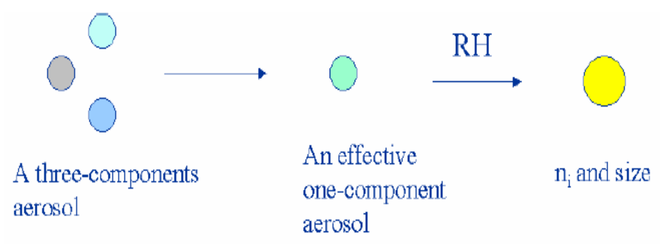
Aerosol Model	Size Distribution Parameters (RH = 70 ~ 80 %)			Type
	N_i	r_i	σ_i	
RURAL	0.999875	0.03	0.35	Mixture of water-soluble and dust-like aerosol
	0.000125	0.5	0.4	
URBAN	0.999875	0.03	0.4	Rural aerosol mixture with soot-like aerosols
	0.000125	0.5	0.4	
MARITIME Continental Origin	1.	0.03	0.35	Rural aerosol mixture
Oceanic Origin	1.	0.3	0.4	Sea salt solution in water
TROPOSPHERIC	1.	0.03	0.35	Rural aerosol mixture
Mode Size Distribution	$n(r) = \sum_{i=1}^{2} \left(\frac{N_i}{10(10) r_i \sigma_i \sqrt{2\pi}}\right) \exp\left[-\frac{(\log r - \log r_i)^2}{2\sigma_i^2}\right]$			

(Shettle and Fenn, 1979)

Calculations of Aerosol Optical Parameters: Two Approaches

SC approach (1979, Shettle and Fenn):

A multi-components of the aerosol model is combined into an effective, single-particle component (SC) with an average refractive index, and an average water activity.



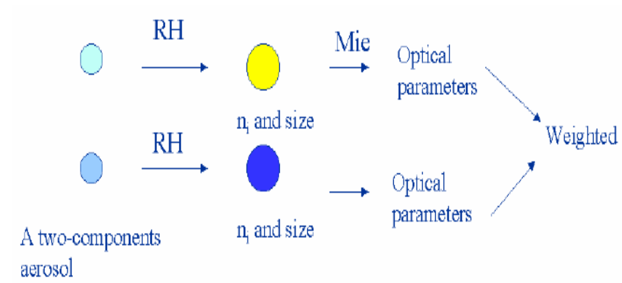
So,

in this approach, the evolution of the particle size and the refractive index with increasing humidity is computed for this effective particle.

MC approach (more realistic):

(Tsay and Stephens, 1990;Dalmeida, et.al., 1991)

Each type of particle is allowed to grow and change its refractive index independently with increased humidity.



The optical properties are computed separately for each component, and those of the mixture are obtained by proper averaging over the different components.

Comparisons of Aerosol Optical Properties Using Two Approaches

Aerosol Optical Parameters | **TOA Reflectance Deviation (%)**

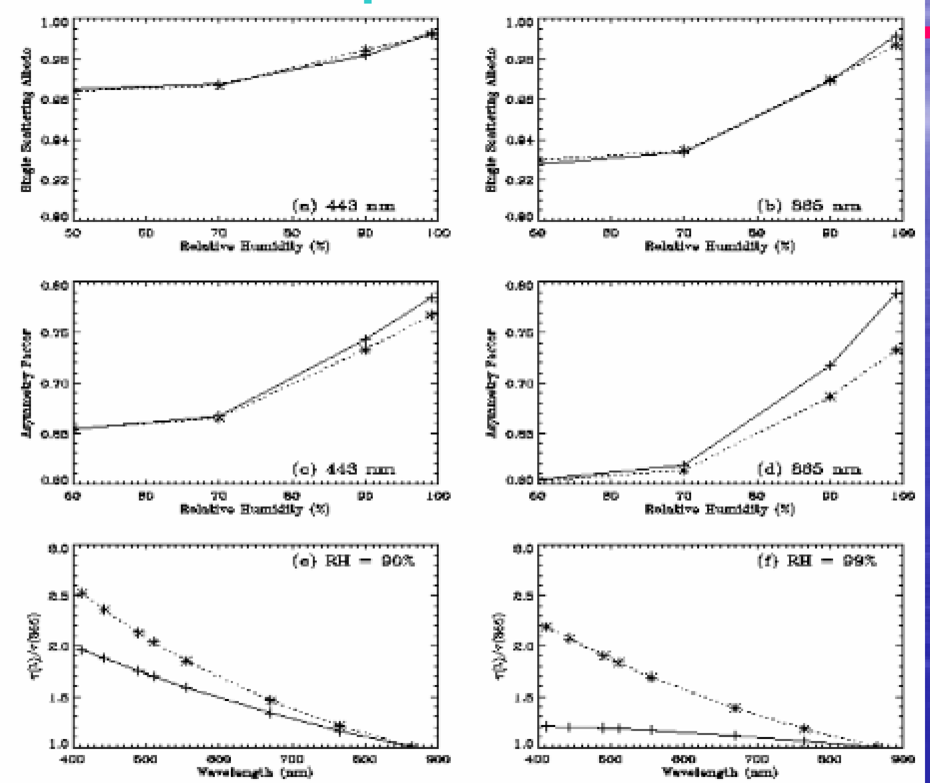


Figure 1: Comparison of SSALB, Asymmetry factor G, and optical depth τ(λ) for the Tropospheric aerosol mode computed using the MC approach (solid curves) and SC approach (dotted curves) at 443 and 865 nm.

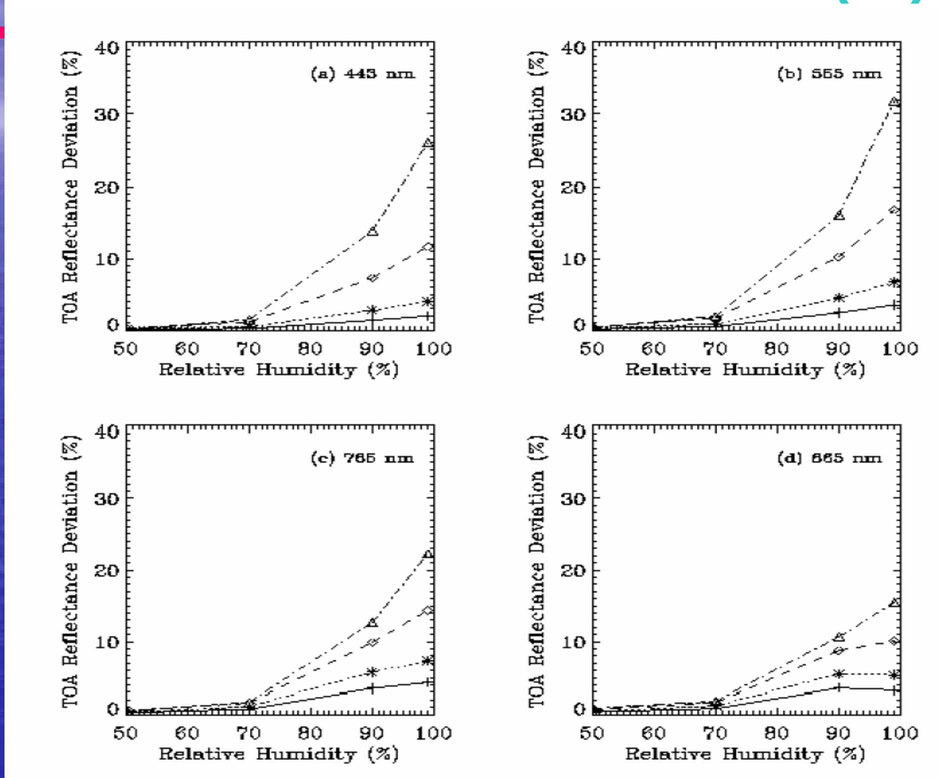


Fig.2 TOA reflectance deviation for Tropospheric aerosols

- It is important to how to treat the light scattering by aerosols containing multiple particle components (B. Yan and K. Stamnes, 2001)

- Progress three: some preliminary studies have been made in producing proper bio-optical models for coastal regions based upon the measurements of oceanic particle optical parameters.

A Three-Parameter Ocean Bio-Optical Model

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{cdm}(\lambda)$$

$$b(\lambda) = b_w(\lambda) + b_p(\lambda)$$

$$a_{ph}(\lambda) = \alpha_1(\lambda)[CHL]^{\alpha_2(\lambda)}$$

$$a_{cdm}(\lambda) = a_{cdm}(\lambda_0)e^{-S(\lambda-\lambda_0)}$$

$$b_{bp}(\lambda) = b_{bp}(\lambda_0)(\lambda / \lambda_0)^{-\eta}$$

where

λ : wavelength ($\lambda_0 = 443$ nm)

[CHL] : chlorophyll concentration

$a_{ph}(\lambda)$: phytoplankton absorption

$a_{cdm}(\lambda)$: combined absorption for Color Dissolved Organic Matter (CDOM) and detritus

$b_{bp}(\lambda)$: total particle backscattering

(W. Li and K. Stamnes, 2007)

However, more studies are needed to include ocean bio-optical models applicable various ocean regions.

Summary and Conclusions

- JCSDA-CRTM capability needs to be enhanced for water-leaving radiance calculation in coupled atmosphere-ocean system (CAO-CRTM).
- A basic structure of JCSDA-CRTM in coupled atmosphere-ocean system has been proposed.
- More investigations are needed on various bio-optical models applicable for global ocean areas.
- More investigations are needed of ocean roughness effect on CAO-CRTM.

RECOMMENDATION

Enhancement of JCSDA-CRTM capability in ocean surface handing (i.e., a CAO-CRTM) should be a new priority in our JCSDA near future plans.

Water-Leaving Radiance Satellite Assimilation Development Flow

Bio-optical Models

JCSDA-CRT Modeling Enhancement in CAO System for Ocean Surface Handling

Ocean Roughness Modeling

Aerosol Models

Coupling RT process at interface

New Algorithm for L_W and [CHL]

Retrievals of water-leaving radiance and chlorophyll concentration

OC-SMART
Algorithm for L_W and [CHL]
(W.Li and K. Stamnes, 2007)

Applications: water quality, Coral reef quality, calibration of satellites, etc

Acknowledge

Thanks go to Dr. Knut Stamnes and Ms. Wei Li for their providing latest references and results to support our investigations.

- Backup

Water-Leaving Radiance Related to Ocean Bio-Optical Model

Three-parameter bio-optical model

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{cdm}(\lambda)$$
$$b(\lambda) = b_w(\lambda) + a_{ph}(\lambda)$$
$$a_{ph}(\lambda) = \alpha_1(\lambda)[CHL]^{\alpha_2(\lambda)}$$
$$a_{cdm}(\lambda) = a_{cdm}(\lambda_0)e^{-S(\lambda-\lambda_0)}$$
$$b_{bp}(\lambda) = b_{bp}(\lambda_0)(\lambda/\lambda_0)^{-\eta}$$

where

λ : wavelength ($\lambda_0 = 443$ nm)

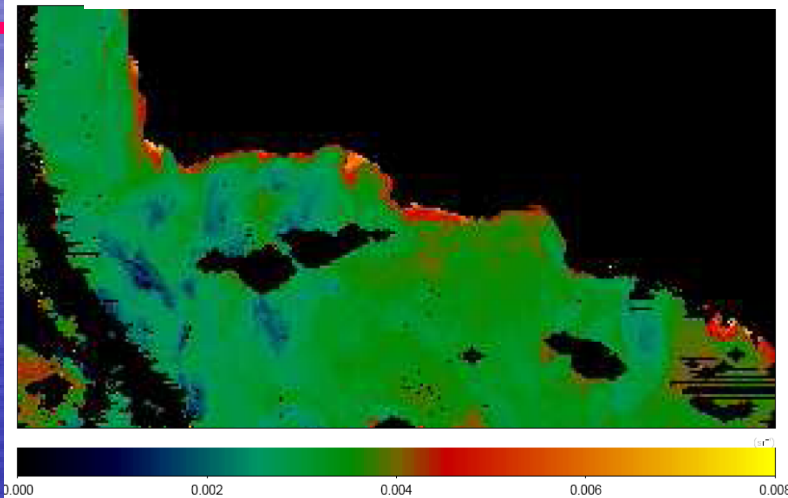
[CHL] : chlorophyll concentration

$a_{ph}(\lambda)$: phytoplankton absorption

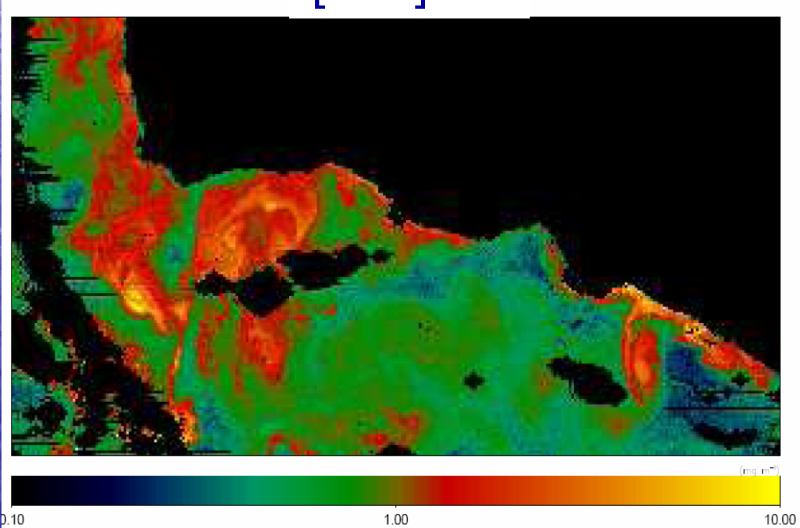
$a_{cdm}(\lambda)$: combined absorption for Color Dissolved Organic Matter (CDOM) and detritus

$b_{ph}(\lambda)$: total particle backscattering

Water-leaving radiance (490 nm)



[CHL]



TOA radiance (490 nm)

(W. Li and K. Stamnes, 2007)

Satellites Related to L_W Measurements

- Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (8 channels from 0.412 to 0.875 μm)
- MODIS (channels 8-16: 0.412 ~ 0.87 μm)
- Advanced Baseline Imager (ABI) (channels 1-3: 0.47 ~ 0.875 μm)
- Visible Imaging System (VIS)
- Spinning Enhanced Visible and InfraRed Imager (SEVIRI) (12 channels from 0.6 to 13.4 μm)