Simultaneous retrieval of aerosol optical thickness and chlorophyll concentration from multi-wavelength measurement over East China Sea

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Abstract

A flexible inversion algorithm is proposed for simultaneously retrieving aerosol optical thickness (AOT) and surface chlorophyll *a* (Chl) concentration from multi-wavelength observation over the ocean. In this algorithm, forward radiation calculation is performed by an accurate coupled atmosphere–ocean model with a comprehensive bio-optical ocean module. Then, a full-physical nonlinear optimization approximation approach is used to retrieve AOT and Chl. For AOT retrieval, a global three-dimensional spectral radiation transport aerosol model (SPRINTARS) is used as the priori constraint to increase the retrieval accuracy of aerosol. To investigate the algorithm's availability, the retrieval experiment is conducted using simulated radiance data to demonstrate that the relative errors in simultaneously determining AOT and Chl are mostly controlled to within 10% using multi-wavelength and angle covering in and out of sunglint. Furthermore, the inversion results are assessed using the actual satellite observation data obtained from Cloud and Aerosol Imager (CAI)/Greenhouse gas Observation SATellite (GOSAT) and MODerate resolution Imaging Spectroradiometer (MODIS)/Aqua instruments through comparison to Aerosol Robotic Network (AERONET) aerosol and ocean color (OC) products over East China Sea. Both the retrieved AOT and Chl compare favorably to the reported AERONET values, particularly when using the CASE 2 ocean module in turbid water, even when the retrieval is performed in the presence of high aerosol loading and sun glint. Finally, the CAI and MODIS images are used to jointly retrieve the spatial distribution of AOT and Chl in comparison to the MODIS AOT and OC products.

Background

- Aerosols are considered to exert considerable effects on global and regional climate change. Besides, It is also important to retrieve the optical properties of aerosols to improve the remote sensing of ocean color.
- In the conventional ocean color remote sensing algorithms, the atmosphere and ocean systems are decoupled in two independent steps of atmospheric correction procedures to remove the influence of atmosphere and retrieval of the surface chlorophyll *a* (Chl) concentration
- Another method using the direct inversion algorithm, that is simultaneous retrieval of atmospheric and oceanic optical parameters, may be also a feasible way of complementing the prevailing schemes using the radiative transfer model to minimize the simulation output and measured reflectance

Research Objective

◆ To develop a comprehensive bio-optical ocean module and coupled into a radiative transfer model in the atmosphere-ocean system

◆ To develop a flexible inversion algorithm to simultaneously retrieve the atmospheric and oceanic optical parameters.

RT Model

- Radiative Transfer Scheme: Pstar3 (*Ota et al.*, 2010)

Accuracy Validation

Atmosphere

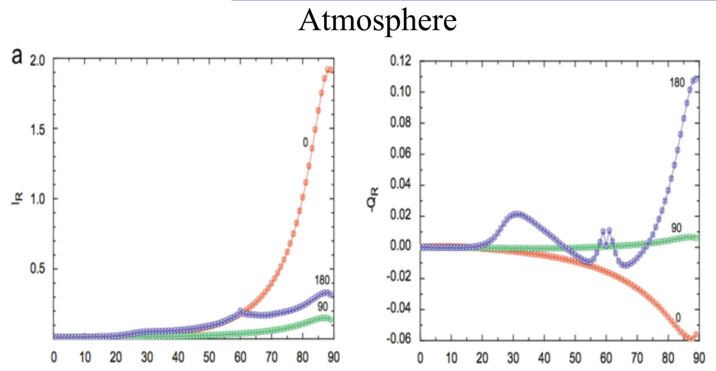

Figure 1 : The normalized Stokes vector elements for the aerosol scattering in the reflected light (line-SCIATRAN, circles-Pstar, crosses-MYSTIC) (Kokhanovsky et al., 2010)

Ocean

τ	$E_d (mw \cdot cm^{-2} \cdot \mu m^{-1})$	$E_{0u} (mw \cdot cm^{-2} \cdot \mu m^{-1})$	$I_u (mw \cdot cm^{-2} \cdot \mu m^{-1} \cdot sr^{-1})$
Pstar			
1	1.144E-1	3.533E-2	2.03E-3
5	4.379E-2	1.233E-2	7.51E-4
10	1.503E-2	3.709E-3	2.50E-4
Standard Values			
1	1.14±0.02E-1	3.55±0.08E-2	2.09±0.07E-3
5	4.33±0.04E-2	1.22±0.04E-2	7.63±0.28E-4
10	1.48±0.02E-2	3.65±0.08E-3	2.49±0.07E-4

Table 1: Comparison of Pstar with standard values in the ocean body with a rough ocean surface

Bio-optical ocean module

✧New Sea water optical properties considering the influence of Temperature an Salinity
✧New Chlorophyll Inherent Optical Properties dataset
✧CASE 2 water including sediment and Color Dissolved Organic Matter (CDOM)

Components	Parameters	Formulation
Sea Water	Absorption	$a_w(T,S,\lambda)=a_w(T_0,S_0,\lambda)+(T-T_0)\psi_T(\lambda)+(S-S_0)\psi_S(\lambda)$
	Scattering	$b_w(T,S,\lambda)=\frac{8\pi}{3}\beta_w(90^\circ,T,S,\lambda)\frac{2+\delta_w}{1+\delta_w}$
	Phase function	$\beta_w(\psi,T,S,\lambda)=\beta_w(90^\circ,T,S,\lambda)(1+\frac{1-\sigma}{1+\sigma}\cos^2\psi)$
Chlorophyll	Absorption	$a_{ph}(\lambda)=A(\lambda)[Chl]^{1-B(\lambda)}$
	Scattering	$b_{ph}(\lambda)=0.347[Chl]^{0.766}[\lambda/660]^{v([Chl])}$
	Phase function	Fournier–Forland phase function
Sediment	Scattering	$b_{sed}(\lambda)=b_s(550)(\lambda/550)^{n_s}S$
	Phase function	Fournier–Forland phase function
CDOM	Absorption	$a_y(\lambda,[Chl])=a_y(\lambda_0,[Chl])\exp(-S(\lambda-\lambda_0))$

Optimization method

Method: MAP + LM method

- MAP (Maximum a posteriori) cost function:

$$J(x)=[\mathbf{y}-\mathbf{F}(\mathbf{x})]^T\mathbf{S}_\varepsilon^{-1}[\mathbf{y}-\mathbf{F}(\mathbf{x})]+[\mathbf{x}-\mathbf{x}_a]^T\mathbf{S}_a^{-1}[\mathbf{x}-\mathbf{x}_a]$$

- Newton iteration combined with Levenberg-Marquardt method

$$\mathbf{x}_{i+1}=\mathbf{x}_i+\left[\left(\mathbf{K}_i^T\mathbf{S}_\varepsilon^{-1}\mathbf{K}_i+(1+\lambda_i)\mathbf{S}_a^{-1}\right)\right]^{-1}\cdot\left[\mathbf{K}_i^T\mathbf{S}_\varepsilon^{-1}\left(\mathbf{y}-\mathbf{F}(\mathbf{x}_i)\right)-\mathbf{S}_a^{-1}\left(\mathbf{x}_i-\mathbf{x}_a\right)\right]$$

y: measurement vector (Radiance…); **F(x):** forward RT model
x: state vector (AOT, *Chl-a*…) ; $\mathbf{x_a}$: apriori state vector (AOT, *Chl-a*…)
$\mathbf{S}_a$: measurement error covariance matrix $\mathbf{S}_\varepsilon$: priori variance-covariance matrix

State vector (x)	Apriori value (x_a)
AOT_fine particle	SPRINTARS Model
AOT_seasalt	SPRINTARS Model
AOT_dust/yellow sand	SPRINTARS Model
Volume soot fraction in fine particle	0.1%
Wind speed	NCEP data
Chl-a	MODIS annual average value in 2009
Sediment (CASE II ocean)	1.0 (g/m^3)
CDOM (CASE II ocean)	0.1 (m^{-1})

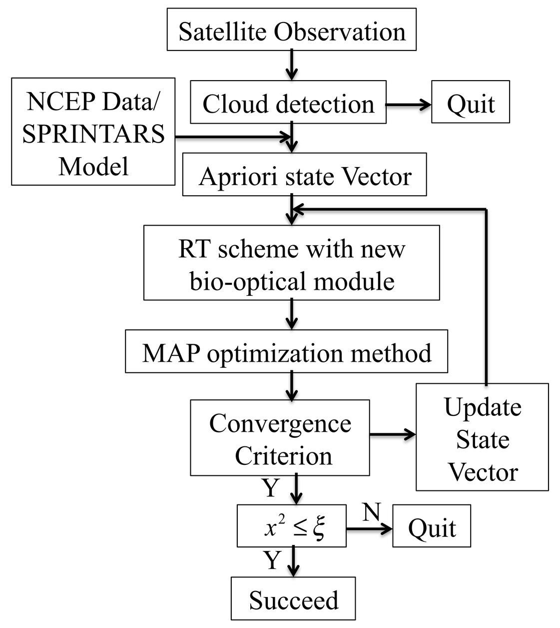

Figure 2: Flow chart of retrieval algorithm

Simulation results

Observations: Wavelengths: 380, 490, 550, 670, 765, 865 nm
Angles: Nadir, Sunglint, Backscattering

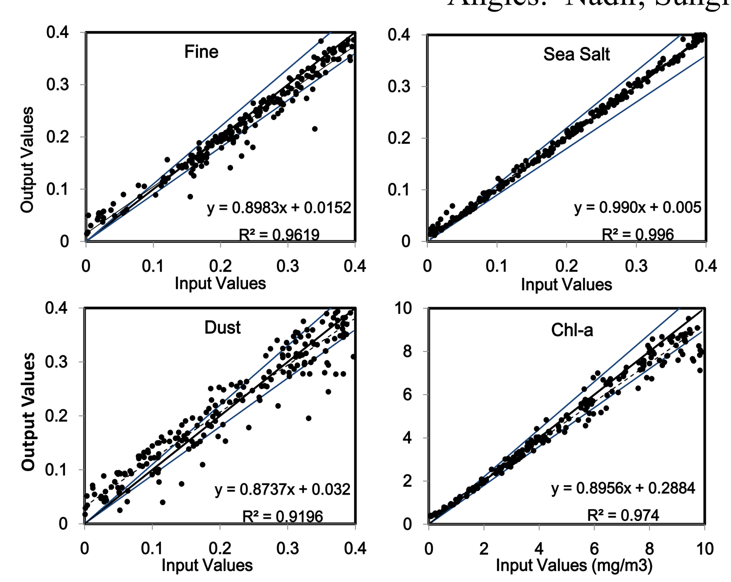

Figure 3. Simulation of simultaneous retrieval of AOTs for fine, sea salt, and dust particles at 550 nm, and chlorophyll *a* concentration with input values. The blue lines denote the values 10% smaller or larger than the input values.

Validation (GOSAT/CAI)

- TANSO-CAI 4 bands (380, 674, 870, 1600nm)
- CASE 2 Module

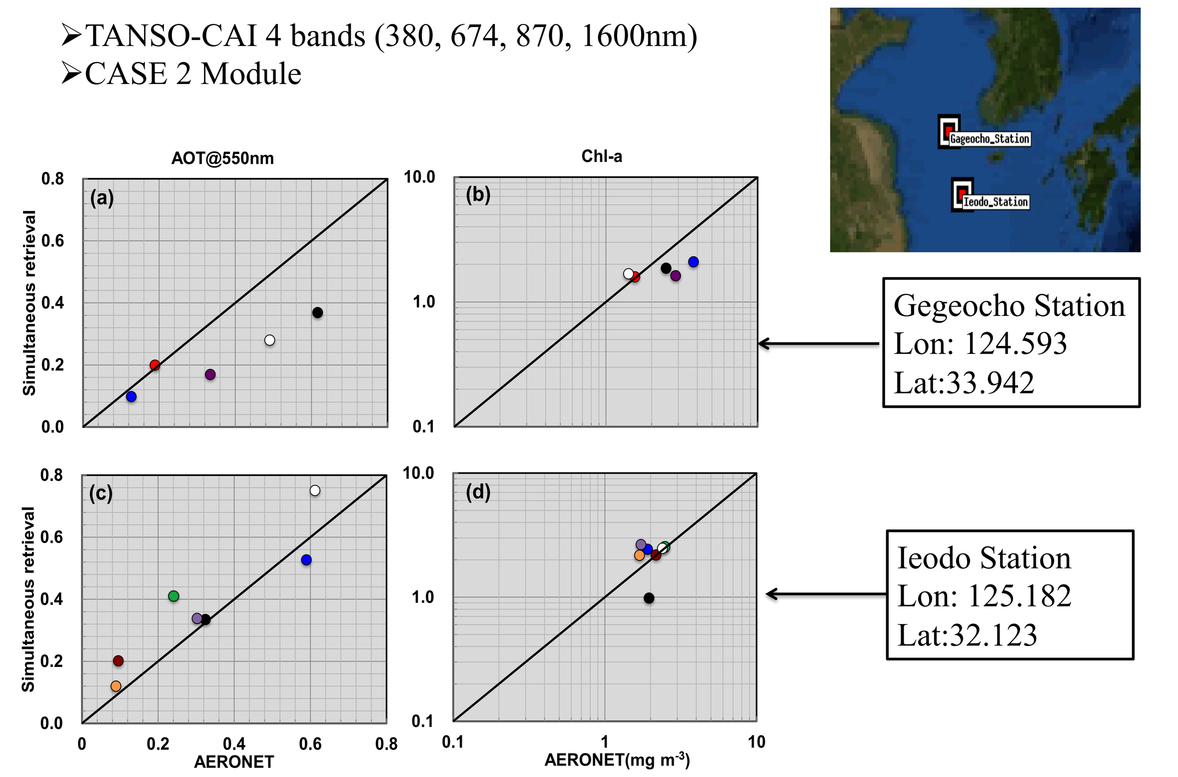

Figure 4. Comparison of satellite simultaneously retrieved AOT and Chl (mg m^{-3}) from CAI with AERONET observations at the Gageocho (a: 550 nm-AOT, b: Chl) and Ieodo (c: 550 nm-AOT, d: Chl) sites using CASE 2 water module. The simultaneous retrieved results of AOT and Chl are shown in same color.

CAI Image

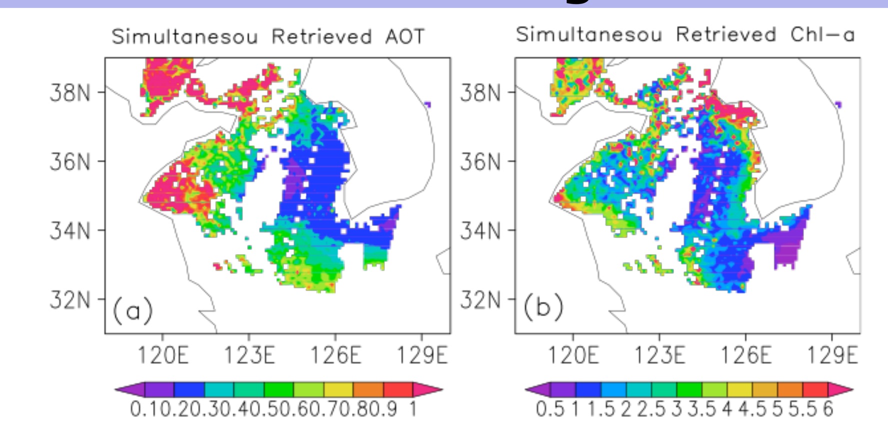

Figure 5. Spatial distribution of simultaneous retrieved total aerosol optical thickness (a) and chlorophyll concentration (b) using CAI imagery on 13 March 2012 over East China Sea

Validation (MODIS/Aqua)

- 8 bands (412, 442, 487, 554, 670, 746, 867, 1620nm)
- CASE1/2 module

CASE 1 module

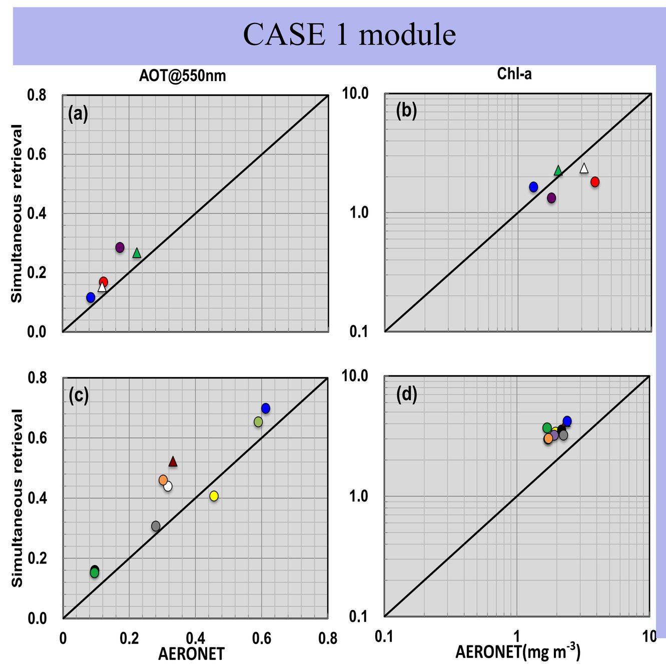

Figure 6. As in Fig. 4, but for retrieval using MODIS Aqua data and CASE 1 module. The triangle means the observation is covered in sunglint region.

CASE 2 module

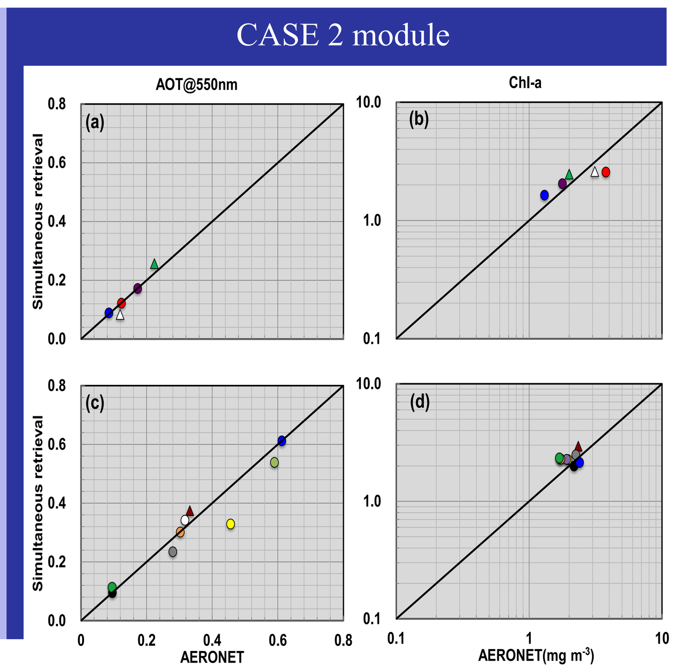

Figure 7. Similar to Fig. 6 but for retrieval using CASE 2 ocean module

More Results

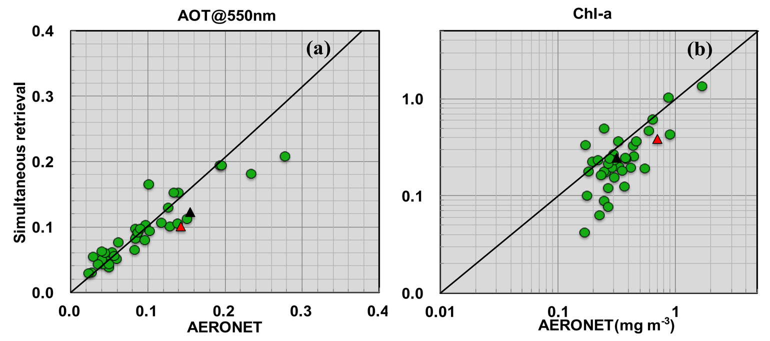

Figure 8. Similar to Fig. 7 but for the retrieval in USC_SEAPRISM site

MODIS Image

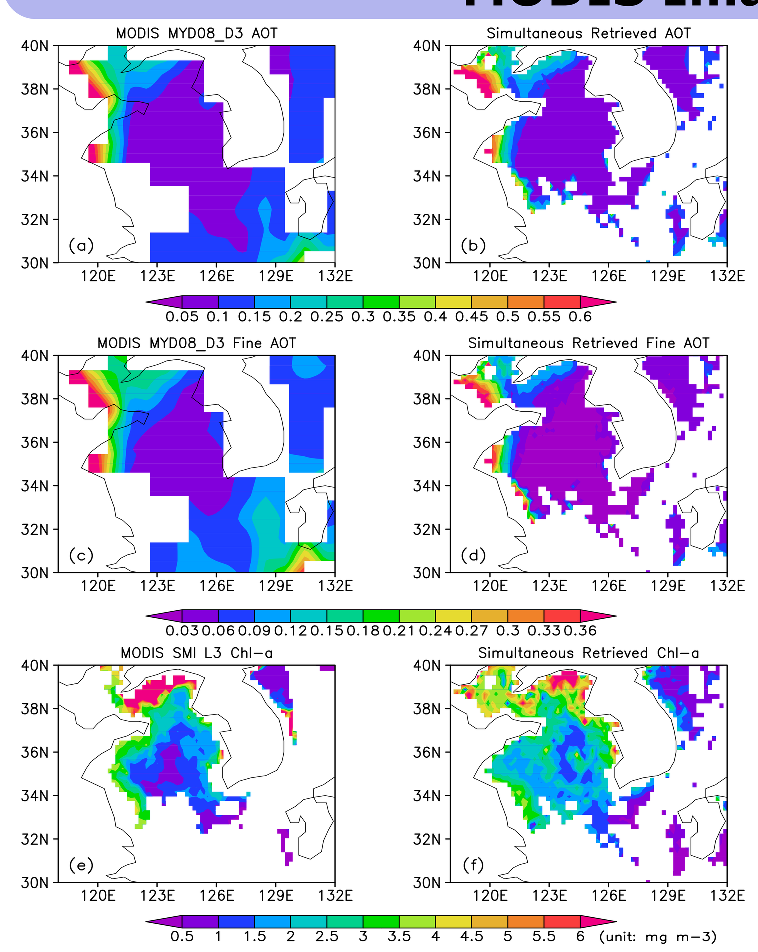

Figure 9. Comparison of MODIS products (a)Total AOT (c) Fine AOT (e) Chl with retrieved results using this alsorithm (b)Total AOT (d) Fine AOT (f) Chl

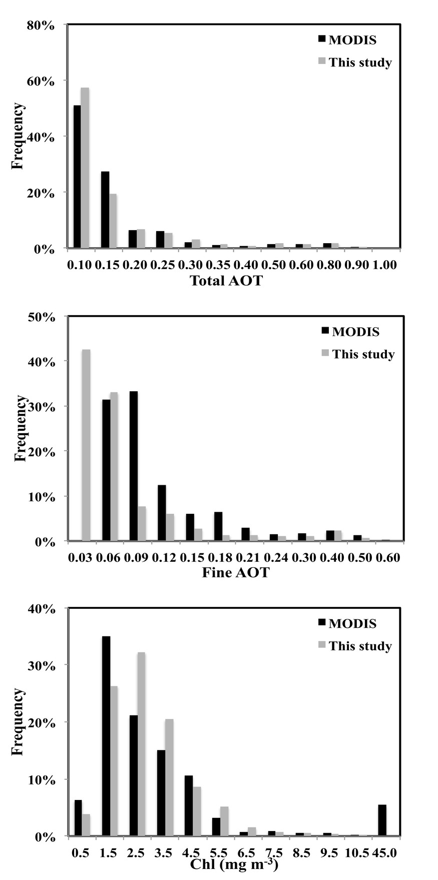

Figure 10. Statistic of histograms of the frequency values of total AOT (top), fine AOT (middle) and Chl (below)

Conclusions

- A flexible full-physical retrieval algorithm was developed to simultaneously determine AOT and Chl based on multi-wavelength measurements with one-step.
- The current algorithm uses an accurate radiative transfer model to simulate the forward radiation process in the atmosphere-ocean system based on an updated bio-optical module.
- The inversion results are assessed using CAI/GOSAT and MODIS instruments through comparison to AERONET aerosol and ocean color (OC) products. Both the retrieved results compare favorably to the reported AERONET values, particularly when using the CASE 2 ocean module in turbid water.
- Development of an acceleration algorithm using look-up-table or network method is also a part of our future work.

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Main References

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