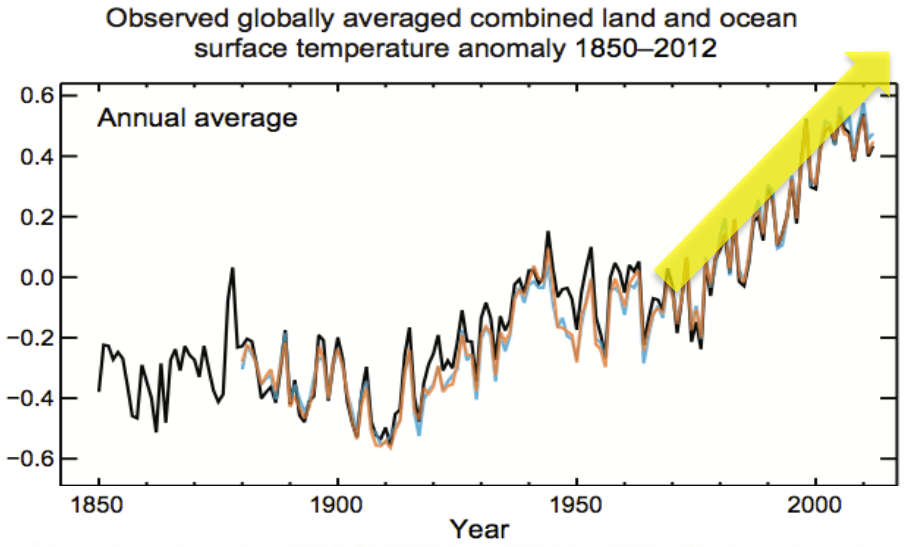
Development of approximation calculation of radiation flux and retrieval algorithm of particles in atmosphere-ocean system

Chong SHI(石崇)
Teruyuki Nakajima
Makiko Hashimoto
Hideaki Takenaka

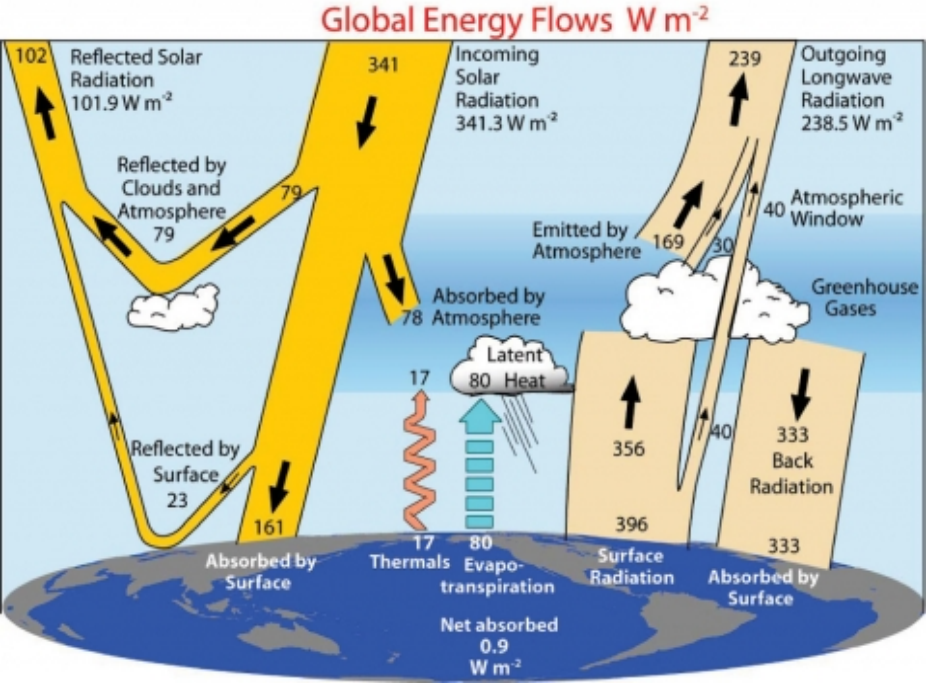
Topics

- The Eddington approximation calculation of radiation flux in atmosphere-ocean system
- Development of algorithm for simultaneous retrieval of aerosol optical thickness (AOT) and chlorophyll concentration (Chl-a) in atmosphere-ocean system

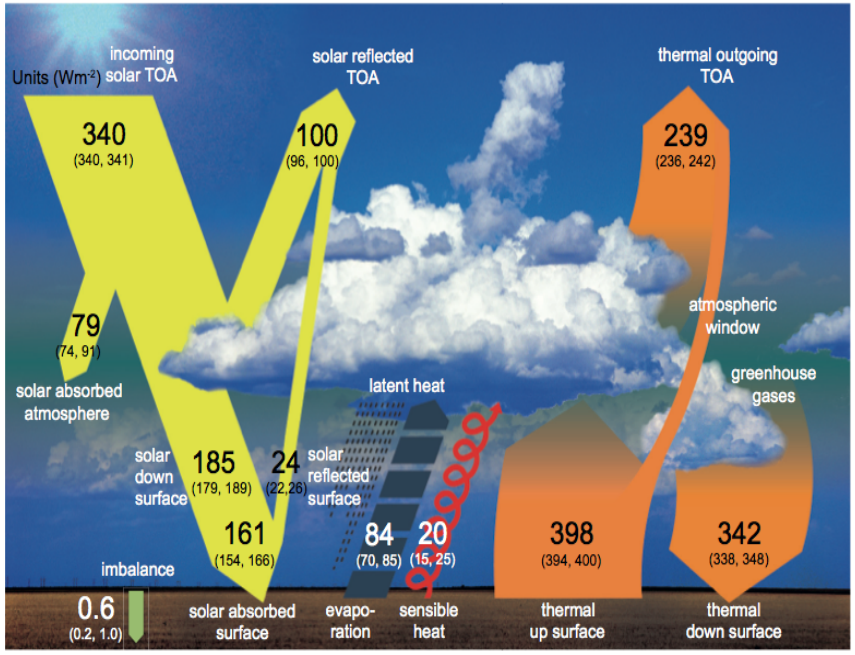
Background



Radiative transfer is one of the most significant processes in A-O system, it plays a critical role in the climate research and remote sensing



Trenberth, Fasullo, and Kiehl, BAMS, 2009



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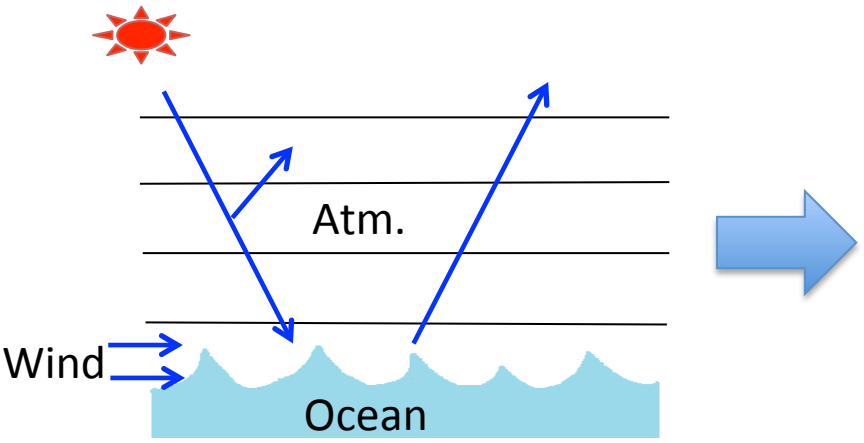
The Eddington approximation of radiation flux in A-O system



Diffused Flux: $F_d^{\uparrow\downarrow}(\tau) = \int_\Omega L(\tau;\theta,\phi)\cos\theta d\Omega$

Radiance Fourier expansion:

$$L(\tau;\mu,\phi) = \sum_{m=0}^{N} L^m(\tau;\mu)\cos m(\phi-\phi_0)$$

$$L^0(\tau;\mu) = \frac{1}{2\pi}\int_0^{2\pi} L(\tau;\mu,\phi)d\phi$$

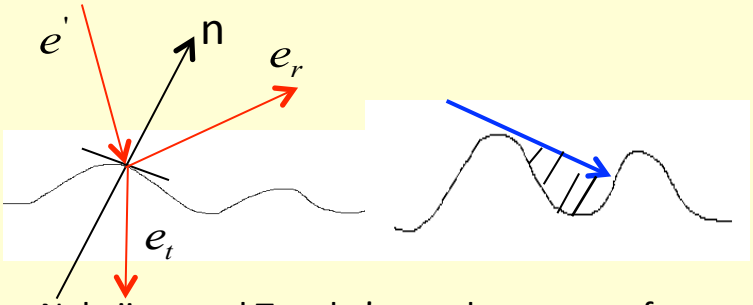
Eddington Approximation:

$$L^0(\tau;\mu) = \sum_{i=0}^{N} L_i(\tau)P_i(\mu) = L_0(\tau) + L_1(\tau)\mu \quad (N=1)$$

Diffuse RT equation

- TOA: no diffused radiance from outer space
- Just Above Ocean surface Energy Conservation

Boundary



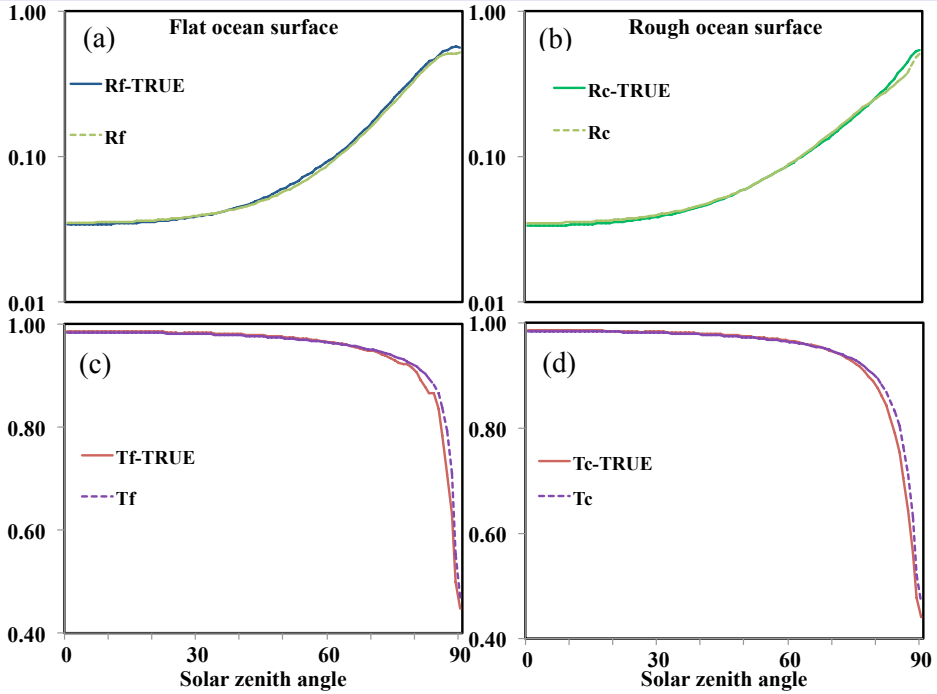
Nakajima and Tanaka's rough ocean surface model

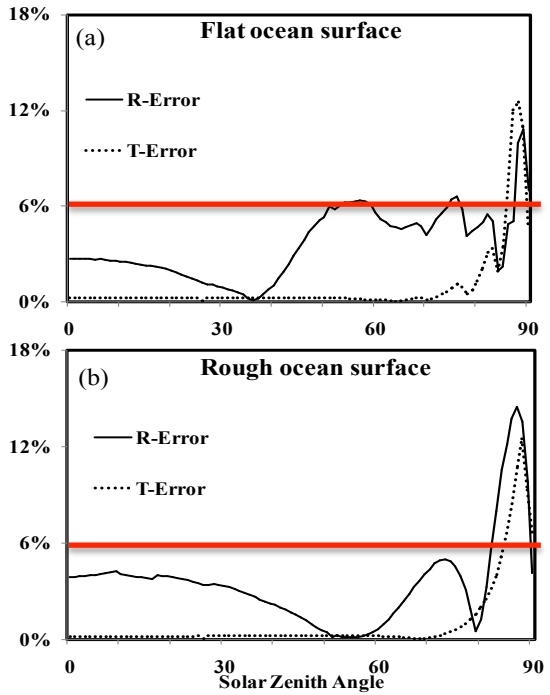
$$R^*(\mu,\mu',\phi-\phi') = \frac{1}{4\mu_n\mu}G(\nu,\nu')p(\mu_n)r(\cos\beta,m)$$

$$F_d^{\uparrow\downarrow}(\tau) = 2\pi\int_0^{\mp 1}[L_0(\tau)+\mu L_1(\tau)]\mu d\mu$$
$$= \pi[L_0(\tau) \mp \frac{2}{3}L_1(\tau)]$$

Shi and Nakajima, *JQSRT*, 2015

The Eddington approximation of radiation flux in A-O system

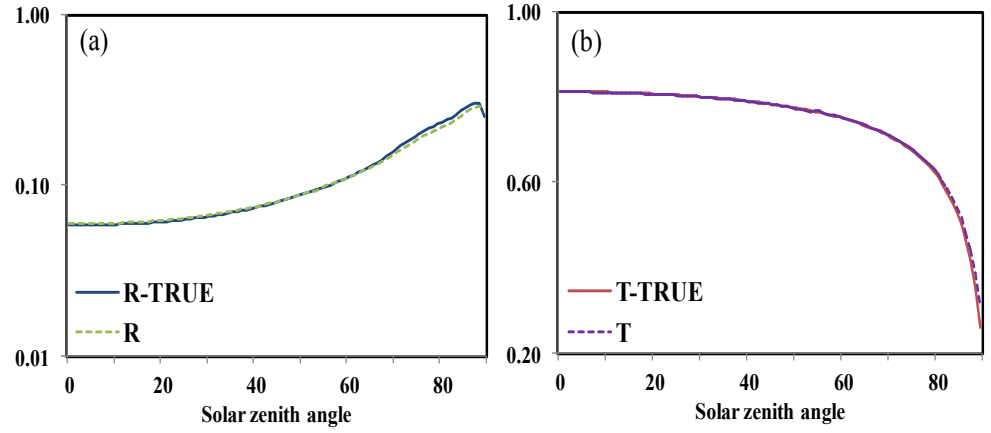




$\tau_a = 0.0763; \quad \omega = 0.978; \quad g = 0.541; \quad f = 0.438$

R: flux reflectivity at TOA in 0.87um T: flux transmissivity at ocean surface in 0.87um

Solid Line: Rstar6b Model result (20streams) Dashed Line: Eddington Approximation



$$F_d^{\uparrow\downarrow}(\tau) = \pi[L_0(\tau) \mp \frac{2}{3} L_1(\tau)]$$

Solid line: mstrn-X model result (0.185-4um)

Dashed line: Eddington approximation

Shi and Nakajima, *JQSRT*, 2015

Simultaneous retrieval of AOT and Chl-a in A-O system

Method: Maximum a posteriori (**MAP) +** Levenberg-Marquardt **(LM) method**

1: MAP (Rodger, 2000)

- Basic formula: $\mathbf{y} = \mathbf{F}(\mathbf{x},\mathbf{b}) + \varepsilon$
- Bayes' theory: $P(\boldsymbol{x} \mid \boldsymbol{y}) = \dfrac{P(\boldsymbol{y} \mid \boldsymbol{x}) P(\boldsymbol{x})}{P(\boldsymbol{y})}$
- Maximum P(x|y) is defined by minizing Cost function

$$J_{MAP}(x) = [\mathbf{y} - \mathbf{F}(\mathbf{x})]^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x})] + [\mathbf{x} - \mathbf{x_a}]^T \mathbf{S_a}^{-1} [\mathbf{x} - \mathbf{x_a}]$$

y : measurement vector (Radiance ..)
x : state vector (AOT ..)
ε : error vector
F(x,b): Forward model
$P(\boldsymbol{x})$: a priori probability function
$P(\boldsymbol{x} \mid \boldsymbol{y})$: a posteriori probability function

2: Levenberg-Marquardt method (Levenberg, 1944, Marquardt, 1963, Press et al., 1995)

- Solution is achieved by newton iteration combined with simplified L-M method

$$\boldsymbol{x}_{i+1} = \boldsymbol{x}_i + \left[\left(\mathbf{K}_i^{\mathrm{T}} \mathbf{S}_e^{-1} \mathbf{K}_i + (1+\gamma) \mathbf{S}_a^{-1} \right) + \sum_k \gamma_k \mathbf{H}_k \right]^{-1} \cdot \left[\mathbf{K}_i^{\mathrm{T}} \mathbf{S}_e^{-1} \left(\boldsymbol{y} - \boldsymbol{f} \right) - \mathbf{S}_a^{-1} \left(\boldsymbol{x} - \boldsymbol{x}_a \right) - \sum_k \gamma_k \left(\mathbf{H}_k \boldsymbol{x} + \mathbf{D}_k^{\mathrm{T}} \boldsymbol{x}_{\mathrm{b}} \right) \right]$$

3: Parameters setting

- State Vector (X): (Retrieved parameters) — AOT of fine, sea salt and yellow sand, volume soot fraction in fine particle, wind speed, chlorophyll concentration (Sediment, CDOM)

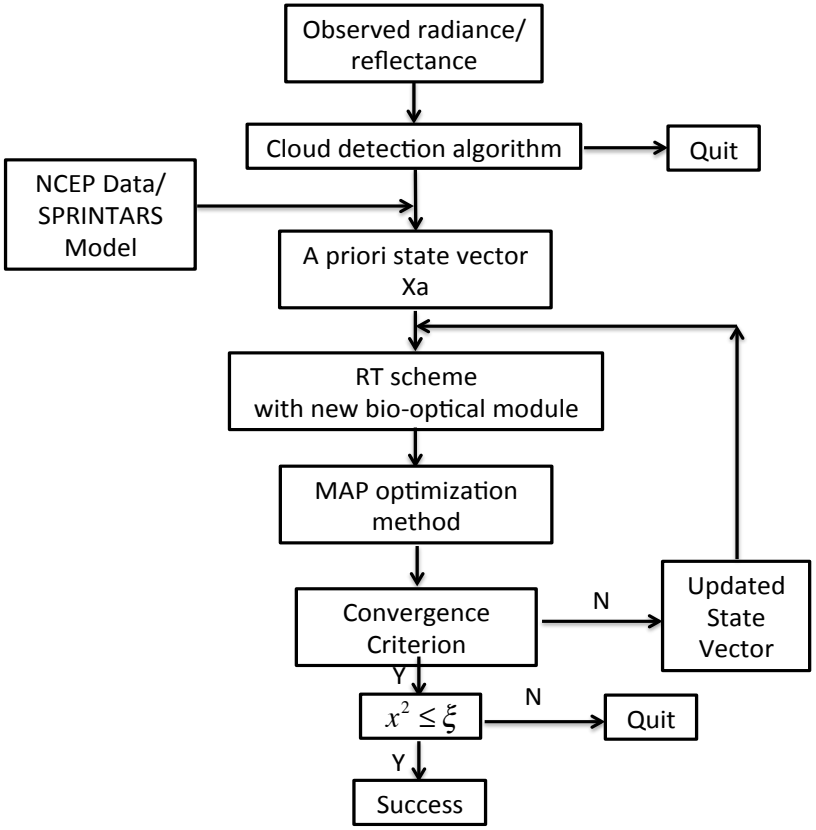
Pollution water

- Apriori values (Xa): SPRINTARS model, NCEP data
- Forward model F(x,b): Pstar3 RT model with a comprehensive bio-optical ocean module

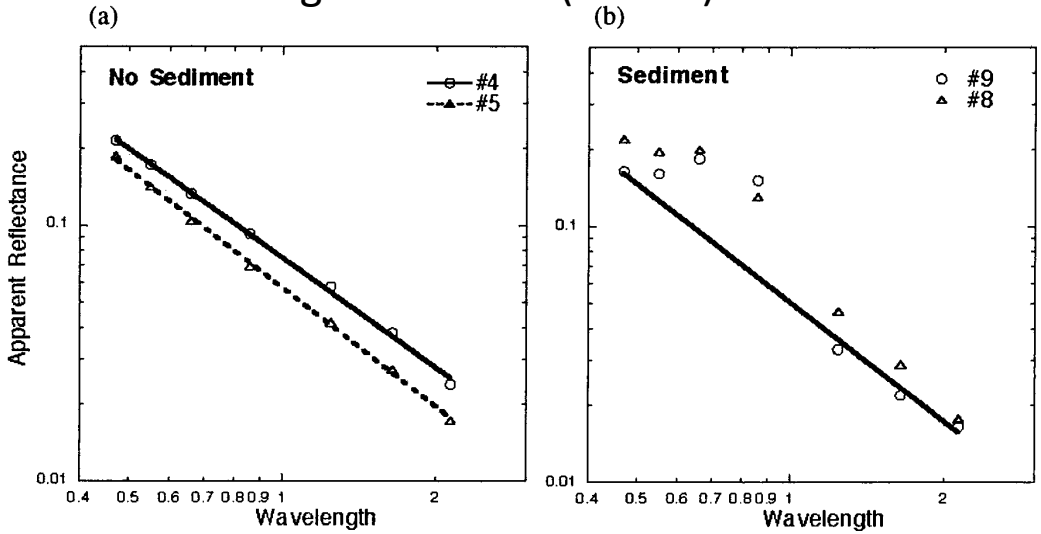
Simultaneous retrieval of AOT and Chl-a in A-O system

Comprehensive Bio-optical ocean module

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



Flow chart of retrieval algorithm



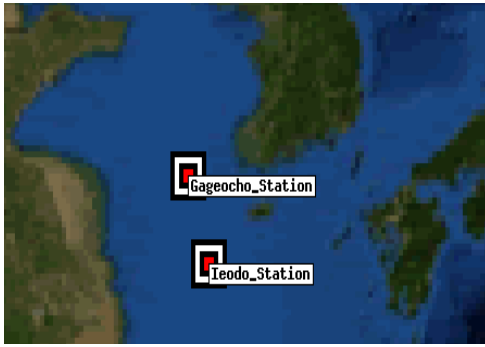
τ	F_d (w m^{-2} nm^{-1})		F_0u (w m^{-2} nm^{-1})		I_nadir (w m^{-2} nm^{-1} sr^{-1})	
	This Study	Standard	This Study	Standard	This Study	Standard
1	1.143E-1	1.14±0.02E-1	3.604E-2	3.55±0.08E-2	2.107E-3	2.09±0.07E-3
5	4.367E-2	4.33±0.04E-2	1.249E-2	1.22±0.04E-2	7.659E-4	7.63±0.28E-4
10	1.494E-2	1.48±0.02E-2	3.763E-3	3.65±0.08E-3	2.544E-4	2.49±0.07E-4

Standard Result : Proposed by Mobley et al., *AO*, 1993

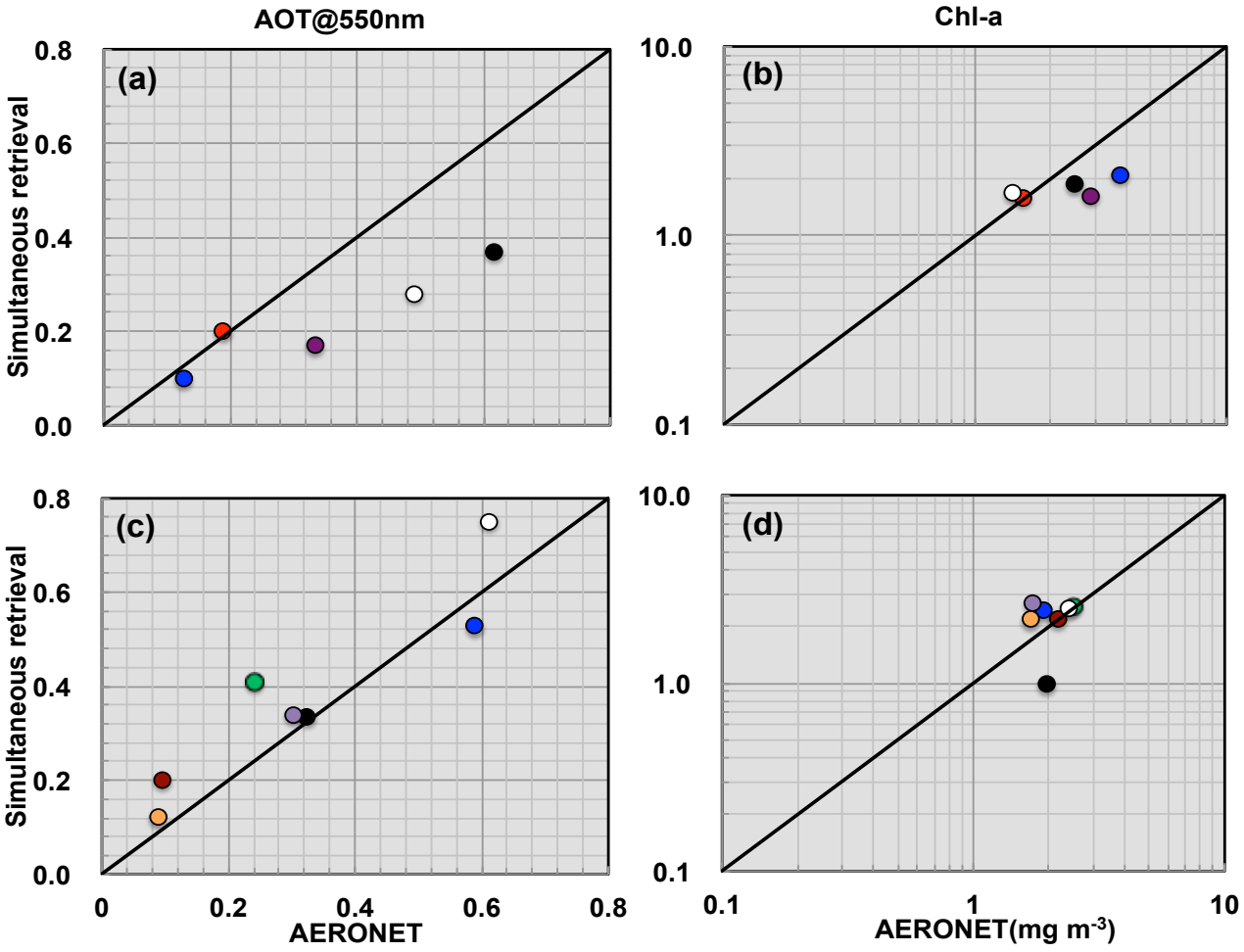
Shi et al., *AAS*, 2015

Simultaneous retrieval of AOT and Chl-a in A-O system

Using GOSAT/CAI data (380nm, 678nm, 870nm, 1620nm)



CASE 2 Ocean Module

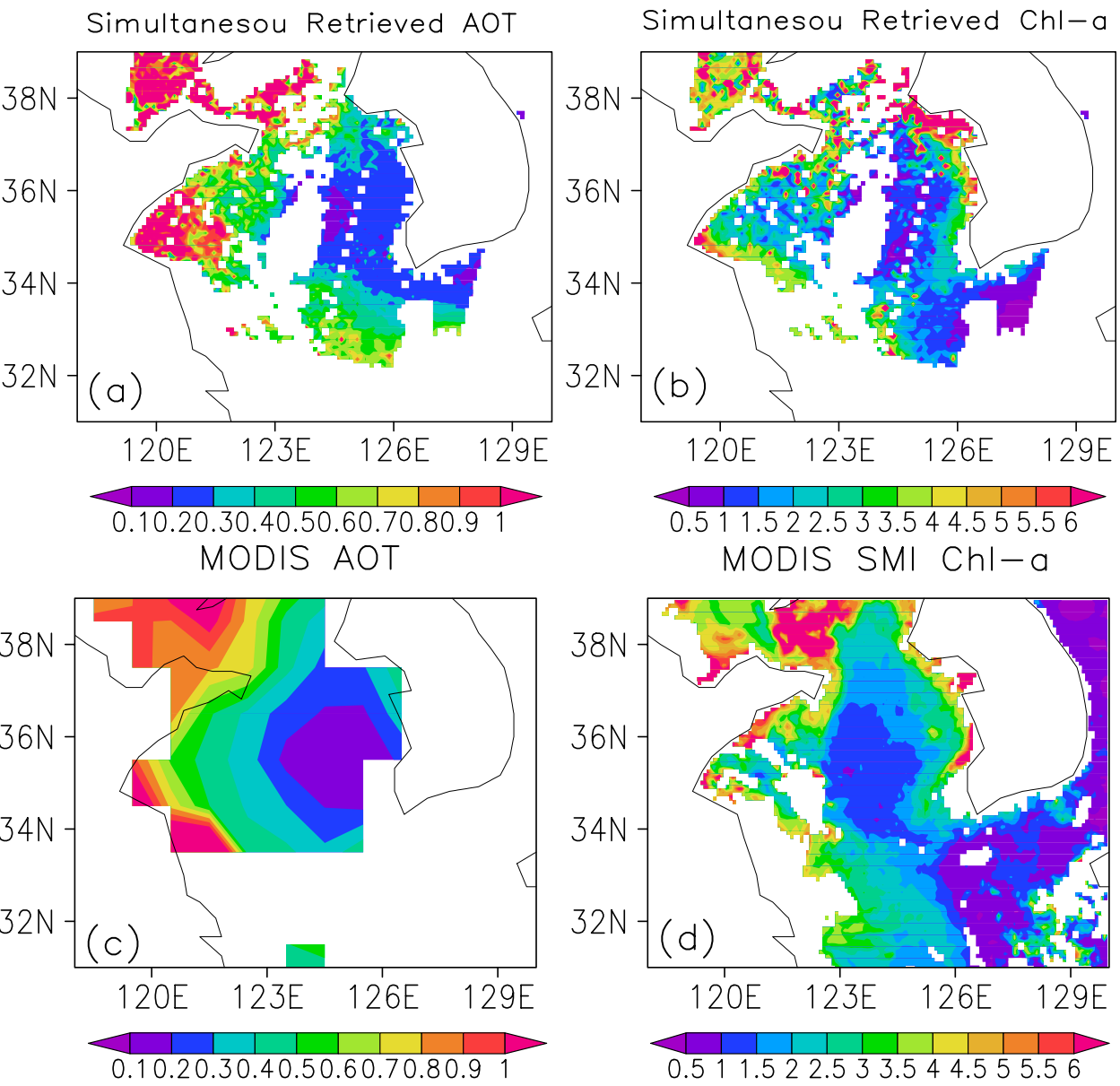


Gegeocho Station
Lon: 124.593E
Lat:33.942N

Ieodo Station
Lon: 125.182E
Lat:32.123N

Simultaneous retrieval of AOT and Chl-a in A-O system

DATA: CAI—20120313 (380nm, 678nm, 870nm,1620nm)

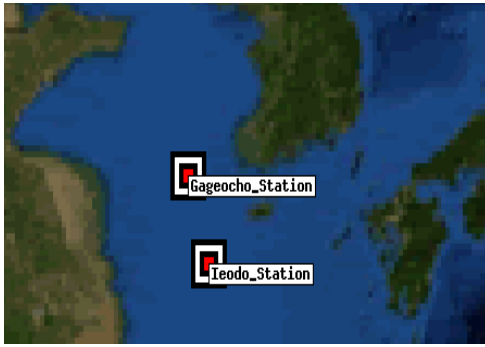


CAI

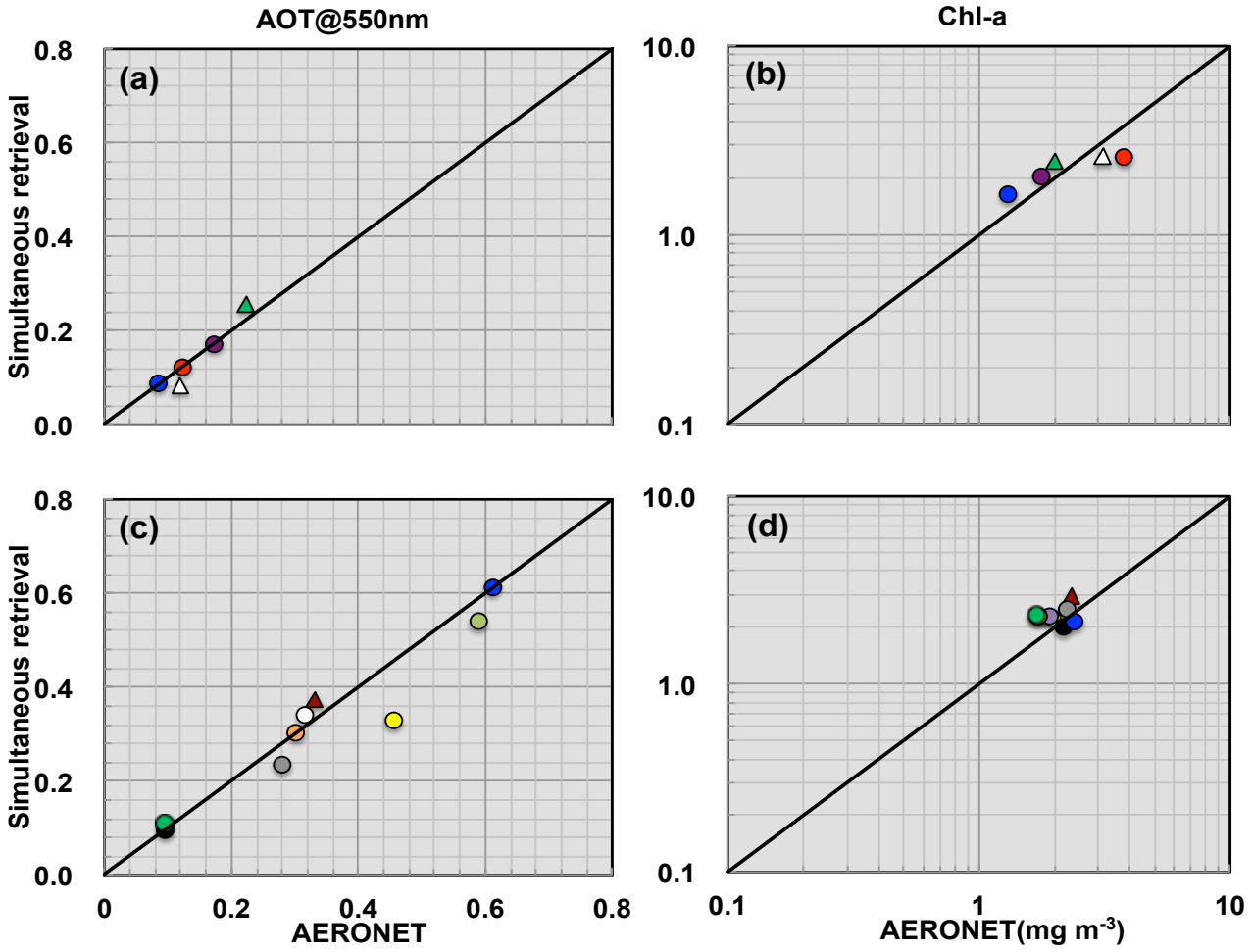
MODIS

Simultaneous retrieval of AOT and Chl-a in A-O system

Using MODIS/Aqua data
(412, 442, 487, 554, 670, 746, 867, 1620nm)



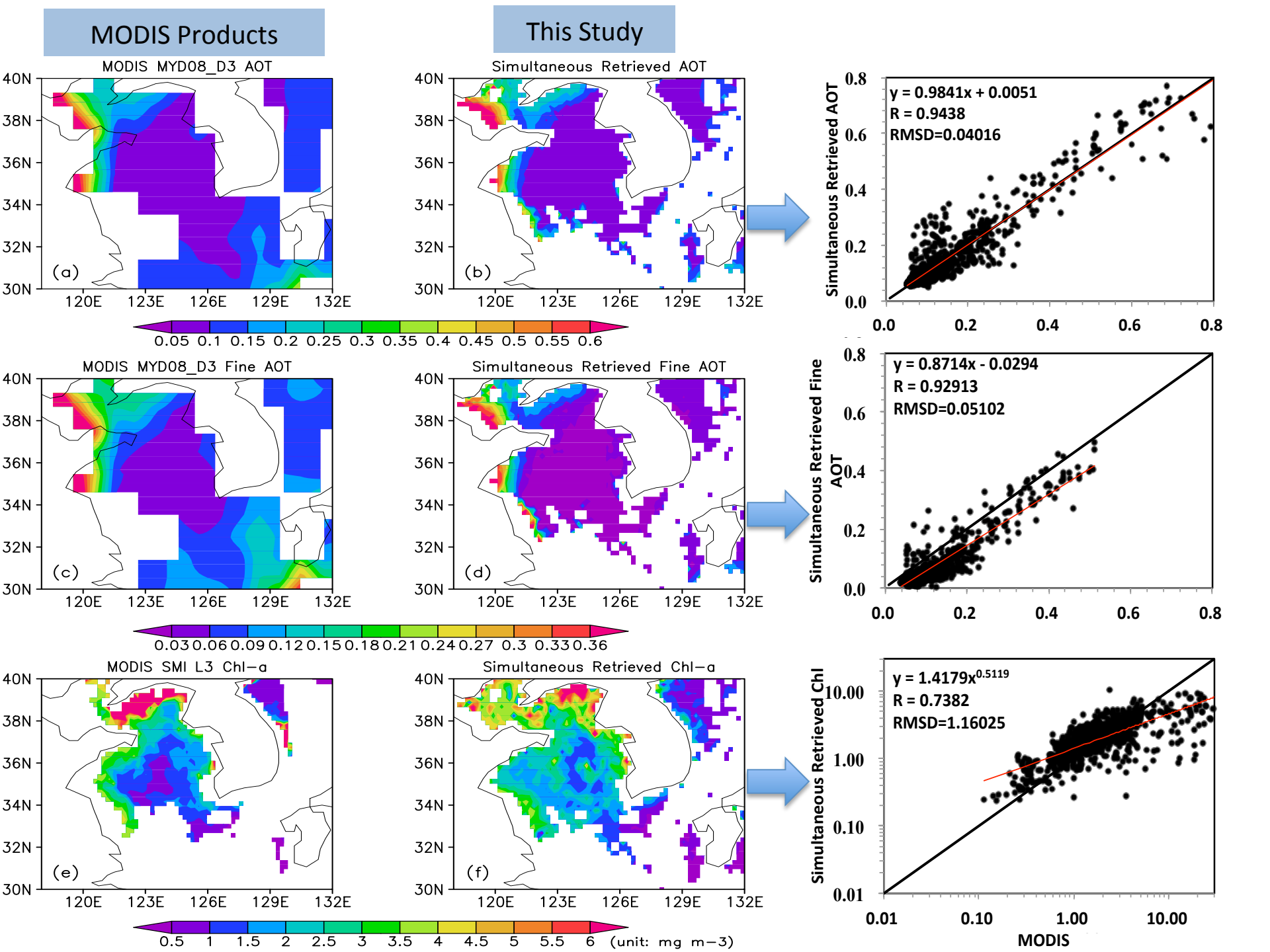
CASE 2 Ocean Module



Gageocho Station
Lon: 124.593E
Lat:33.942N

Triangle: observation is covered in sunglint region

Ieodo Station
Lon: 125.182E
Lat:32.123N


MODIS Products
This Study
MODIS MYD08_D3 AOT
Simultaneous Retrieved AOT
(a)
(b)
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6
y = 0.9841x + 0.0051
R = 0.9438
RMSD=0.04016
Simultaneous Retrieved AOT
MODIS MYD08_D3 Fine AOT
Simultaneous Retrieved Fine AOT
(c)
(d)
0.03 0.06 0.09 0.12 0.15 0.18 0.21 0.24 0.27 0.3 0.33 0.36
y = 0.8714x - 0.0294
R = 0.92913
RMSD=0.05102
Simultaneous Retrieved Fine AOT
MODIS SMI L3 Chl−a
Simultaneous Retrieved Chl−a
(e)
(f)
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 (unit: mg m−3)
y = 1.4179x^0.5119
R = 0.7382
RMSD=1.16025
Simultaneous Retrieved Chl
MODIS

Future work

- Application and improvement of the Eddington approximation in radiation flux estimation using satellite data
- Validation of retrieval algorithm using HIMAWARI-8 data
- Development of acceleration scheme for the retrieval algorithm