2014.1.14-17 GCOM-C/SGLI PI mtg.

Aerosol remote sensing and assimilation process development

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EORC-support: S. Fukuda

Collaboration with M. Yoshida (RESTEC)

Objectives

- **Aerosol retrieval algorithms over ocean and land**
  - **Cloud shadow correction for 380nm (land)**
  - **2 channel method (ocean)**
  - **Kaufman & Modified Kaufman method (land)**
  - **Generalized method (multi-wavelength, angle, pixels over land and ocean)**

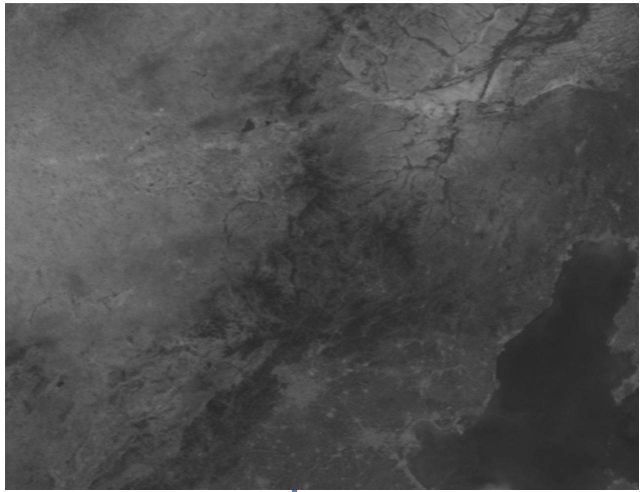
- **MIROC+SPRINTARS aerosol assimilation system for various data sets**

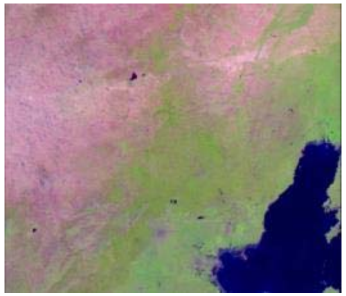
- **NICAM+SPRINTARS aerosol assimilation system development (Stretched and Diamond grids)**

Modified Kaufman's method for 380nm UV band

$Rmin$ (1) → Rayleigh correction → $A'(1) = A(1) + c \text{ AOT}(1)$

$Rmin$ (2)~
$A'(2) = A(2) + c \text{ AOT}(2)$





Aug 2009, China

$$A'(1) - aA'(2)$$
$$= A(1) - aA(2) + c[AOT(1) - aAOT(2)]$$
$$\approx cAOT(1)$$
$$\text{if } A(1) = aA(2) \text{ and AOT}(1) > \text{AOT}(2)$$

c from Radiative transfer model, and

$$a = -0.192309 \exp(-9.62693 \cdot NDVI) + 0.3$$

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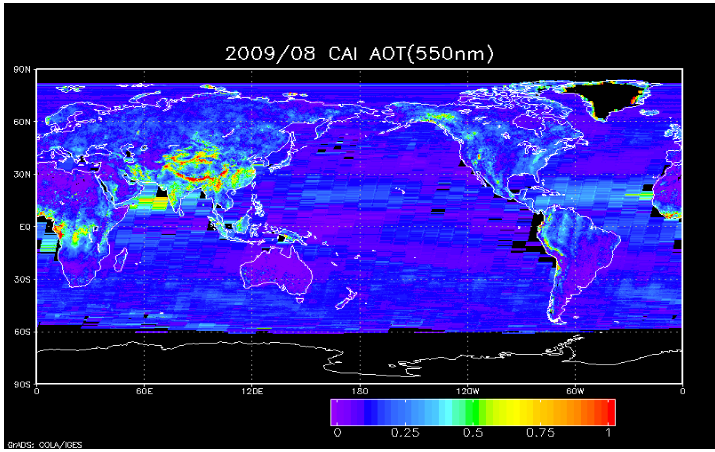
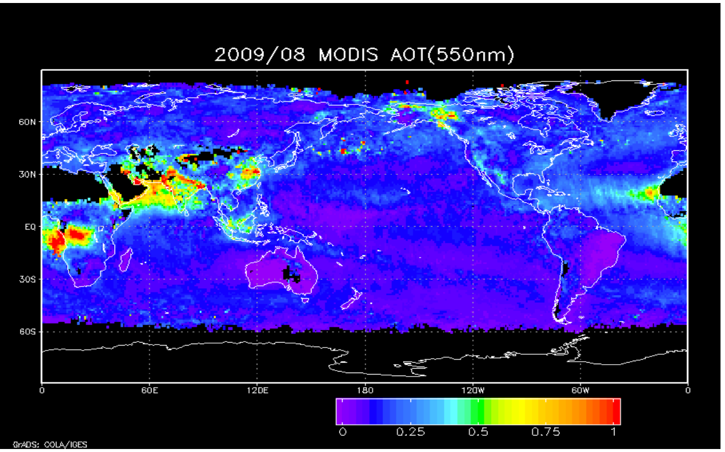
Retrieval of AOTs

S. Fukuda (PHD)

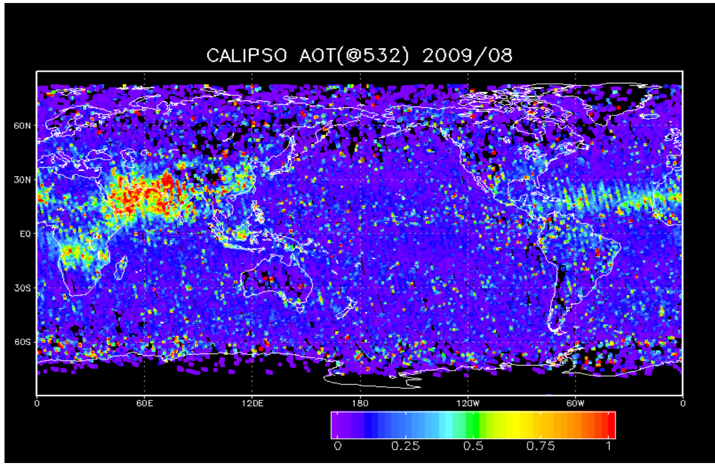
Ocean: Two channel method of Higurashi et al. (JC'00), 670nm, 870nm
Land: Kaufman & modified Kaufman methods (Kaufman et al., GRL'02; Fukuda, JGR'13) over dark target, 380nm, 670nm, 870nm, 1.6 μm, 2.2 μm



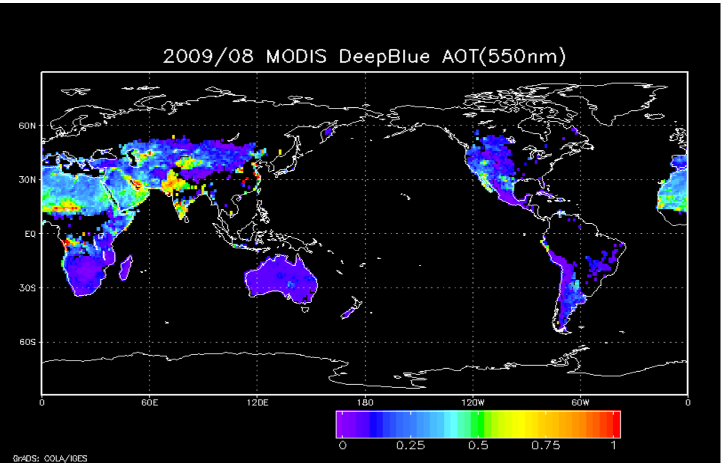
CAI (This algorithm)



MODIS Dark target



Calipso

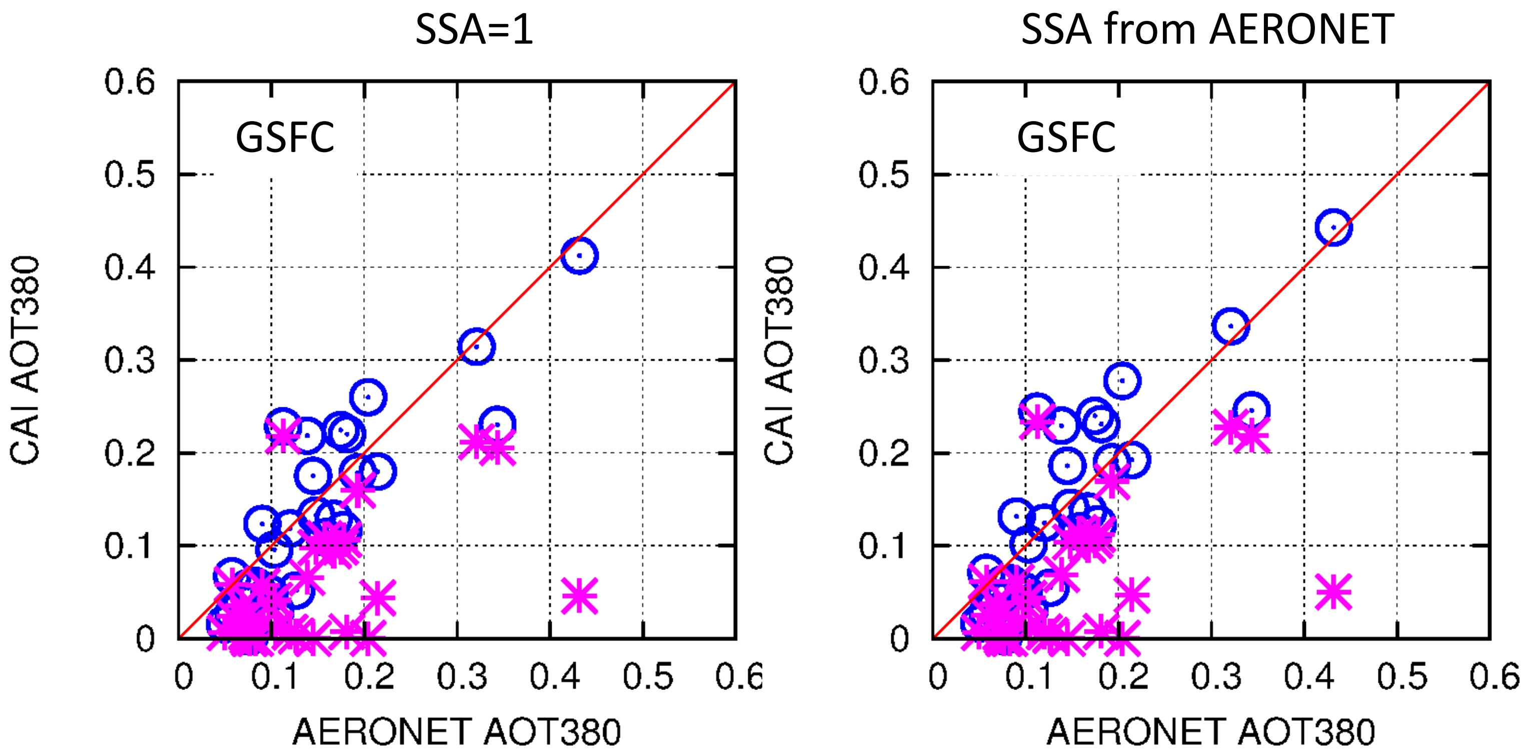


MODIS Deep Blue

Validation of AOT

- **FY2013: Tuning of SSA with AERONET; Fukuda et al. (JGR'13)**

○ **Modified Kaufman (This study)**
* **Minimum reflectance method: difficult to remove persistent aerosols with 3 day recurrence orbit of GOSAT**



Fukuda@JAXA

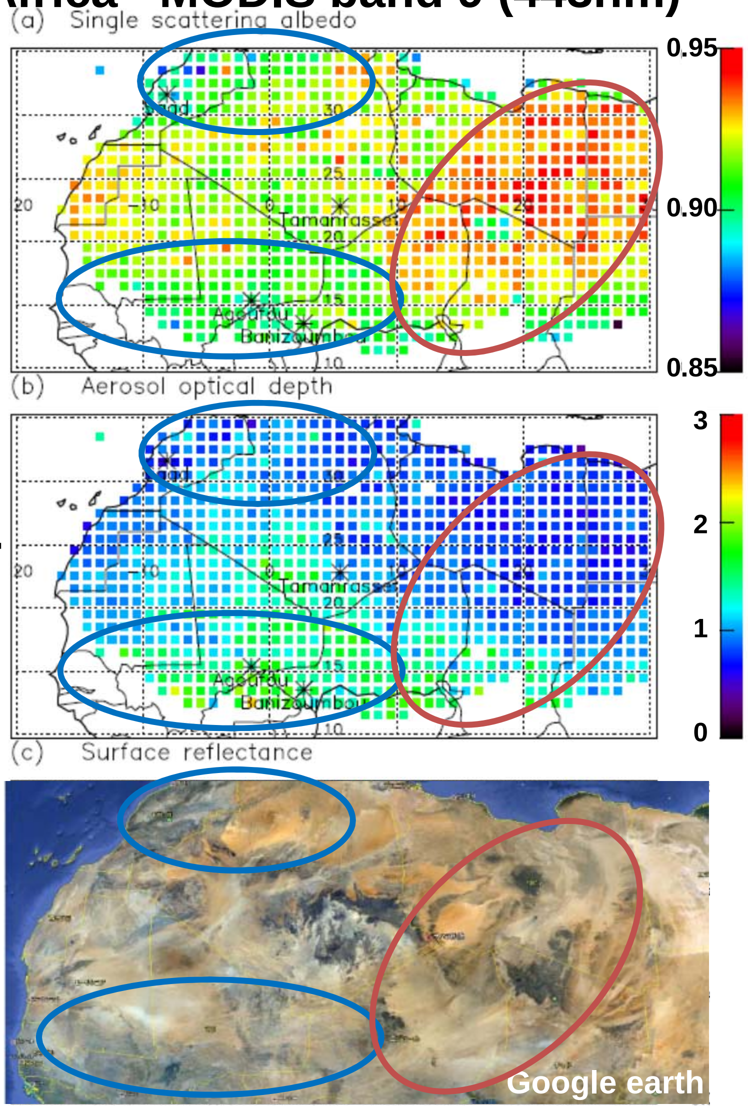
Algorithm of *Yoshida et al. (ACP'13) for* dust optical properties

- **Extension of Neutral reflectance method (Kaufman, JGR'87)**
- **9 year mean (2003-2011), OMI prescreen**
- **Lower SSA in Asia: Dust and soot mixed**
- **SSA related with land albedo**

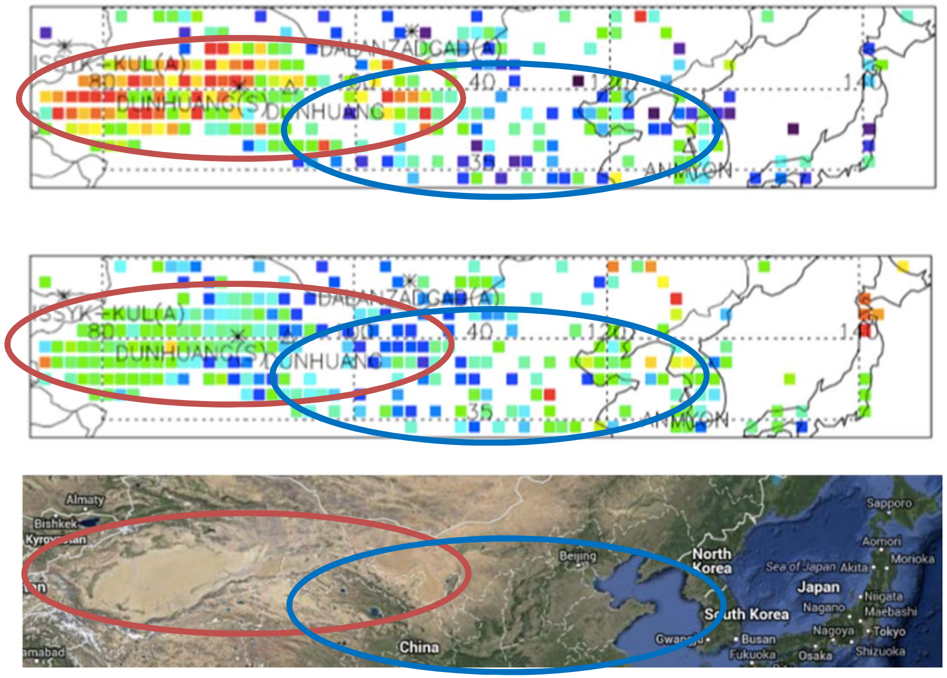
Africa MODIS band 9 (443nm)

SSA

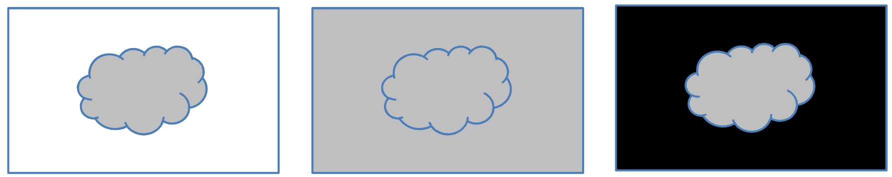
AOT



Asia



RE>0 **RE=0** **RE<0**



A generalized method for aerosols with a multi-wavelength, multi-angle imager and multi-pixel (Phase-II)

- **Past stduies: Lyapustin et al. (JC'04), Dubovik et al. (AMT'11), Yukio Yoshida et al. (ACP'13)**
- **Combined MAP algorithm and Twomey-Phillips algorithm (Rogers, 2000; Phillips, 1962; Twomey, 1963)**

Observation:

$$\zeta = f(u) + e, \quad u \in D(x, y, t, \lambda, r)$$

u: State vector of geophysical parameters
ζ: Observation vector for satellite radiances
(*x,y, t*): *space&time,* λ*: wavenegnth, r*: other parameters such as particle radius, angles etc

Cost function:

$$\phi = \left(\zeta - f\right)^{\mathrm{T}} S_{\mathrm{e}}^{-1}\left(\zeta - f\right) + \left(u - u_a\right)^{\mathrm{T}} S_a^{-1}\left(u - u_a\right) + \sum_k \gamma_k \left|A_k + D_k u\right|^2$$

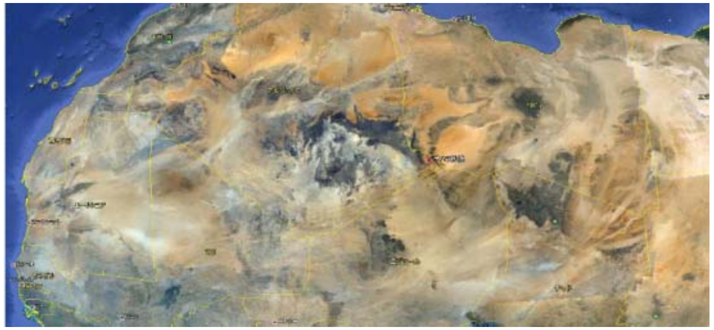
u_a: A priori knowledge of the state vector
Se & *Sa*: Error covariance matrices for observation and a priori knowledge
A, *D*: Smoothing constraint parameters for state vector

MAP solution:

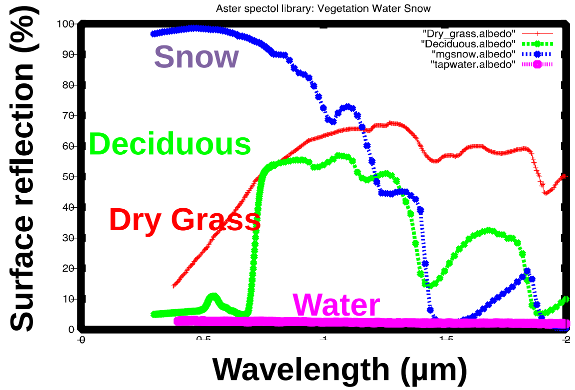
$$\delta u = \left[\left(U^{\mathrm{T}} S_e^{-1} U + S_a^{-1}\right) + \sum_k \gamma_k D_k^T D_k\right]^{-1} \cdot \left[U^T S_e^{-1}\left(\zeta - f\right) - S_a^{-1}\left(u - u_a\right) - \sum_k \gamma_k (D_k^T D_k u + D_k^{\mathrm{T}} A_k)\right]$$

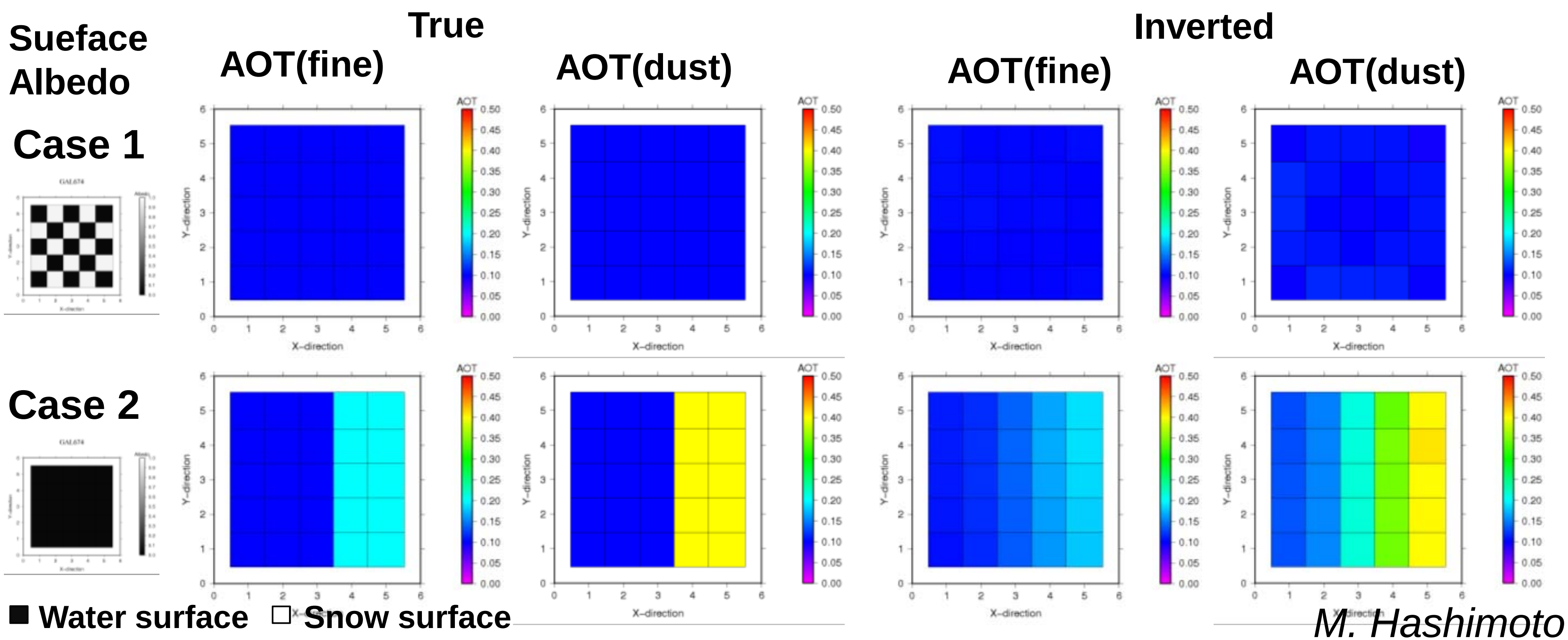
Multi-pixel multi-wavelength method

- **Fine mode with soot & coarse dust**
- **U= AOT(fine), AOT(coarse), Soot fraction, A_{g1}~A_{g4}**
- **GOSAT/CAI (380, 670, 870, 1600nm)**



various land types

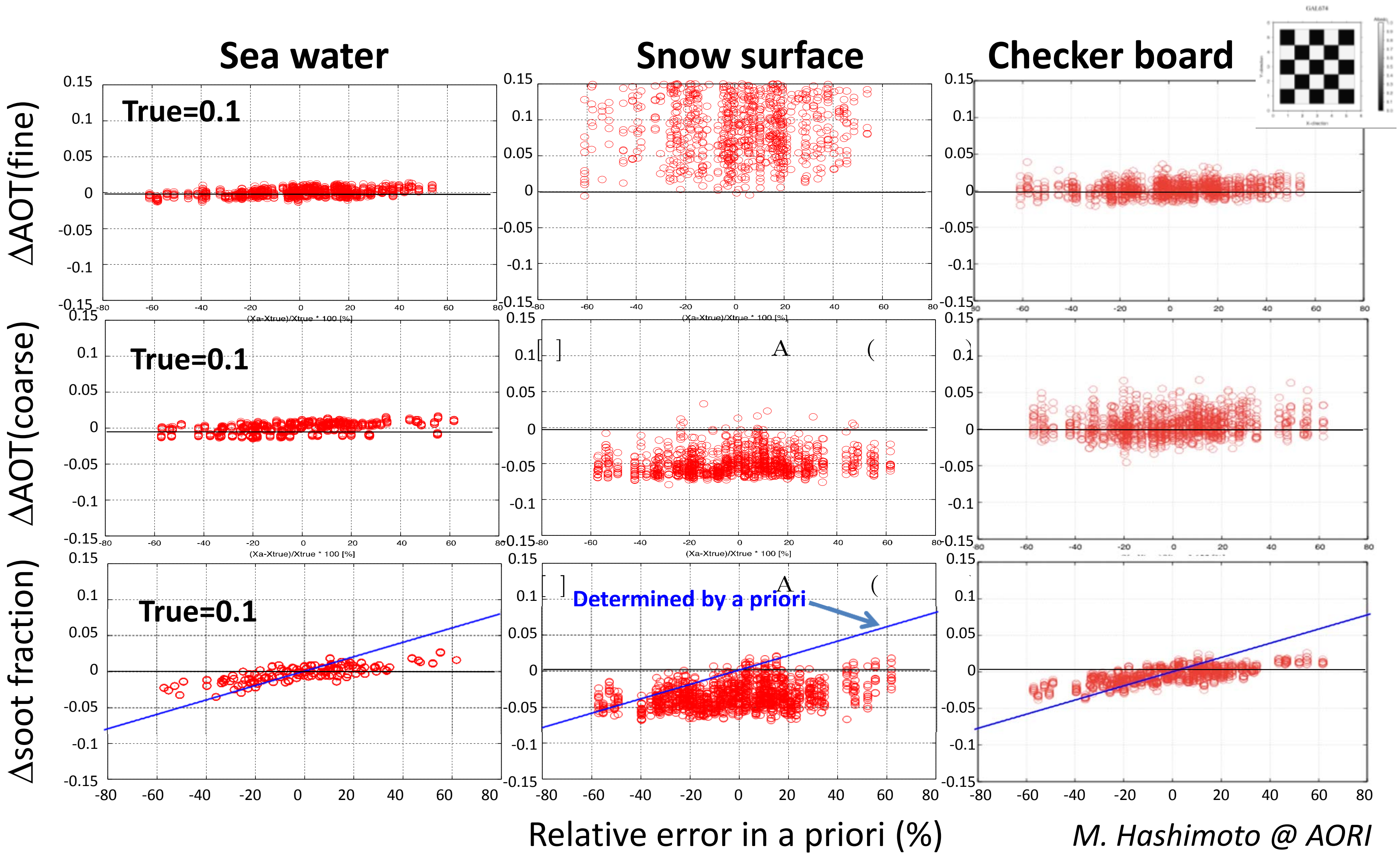




M. Hashimoto

An example of results from the new method

- Sea water: good AOTs and soot fraction retrievals
- Snow surface: AOT(coarse) error < 0.07; soot fraction retrieval possible but with bias
- Checker board: good AOTs and soot fraction retrievals



M. Hashimoto @ AORI

Screening and correction method for AOT and AE over ocean from an imager for assimilation

- **Corrections to the Collection 5 MODIS level 2 Aqua and Terra AOT and AE over ocean by comparison with coastal and island AERONET for years 2003–2009. Aqua: 2003–2009; Terra: 2003–2009**

MODIS AOT and AE selection and correction

A1 Data selection for MODIS AOT and AE

- Discard any MODIS pixel with the uncorrected $\tau_{550} > 3$;
- discard any MODIS pixel with cloud fraction > 0.8;
- discard any MODIS pixel that has no neighbours;
- discard any MODIS pixel whose standard error is larger than
  - Terra: $0.003 + 0.036\,\tau_{550} + 0.023\,\tau_{550}^2$;
  - Aqua: $0.002 + 0.040\,\tau_{550} + 0.021\,\tau_{550}^2$;
- discard any MODIS pixel with SZA $< 20°$;
- discard any MODIS pixel for which RH < 0.2 and $T < 260$ K.

Here τ_{550} is the MODIS AOT at 550 nm and SZA the solar zenith angle. RH is the relative humidity and T is the temperature, both at 2 m above surface (NCEP-DOE-II).

A2 Correction for MODIS AOT

The following equations should be processed sequentially, like FORTRAN computer code.

If Terra $\tau_{550} \le 0.049$ then

$$\tau_{550} = (1 + 0.181581 - 0.0168456\,w)\,\tau_{550} \quad \text{(A1)}$$
$$\tau_{550} = (\tau_{550} - 0.0287665)\,/0.243752 \quad \text{(A2)}$$
$$\tau_{550} = \tau_{550} + 0.0207946 - 0.000153499\,\Theta \quad \text{(A3)}$$
$$\tau_{550} = (1 - 0.364205 - 0.100776\,f_c)\,\tau_{550} \quad \text{(A4)}$$
$$\tau_{550} = (1.0 - 0.0822829 + 0.0781099\,\alpha)\,\tau_{550}. \quad \text{(A5)}$$

If Terra $\tau_{550} > 0.049$ then

$$\tau_{550} = \tau_{550} - 0.0122103 - 0.0358403\,f_c \quad \text{(A6)}$$
$$\tau_{550} = \tau_{550} + 0.0320079 - 0.000243895\,\Theta \quad \text{(A7)}$$
$$\tau_{550} = \tau_{550} - 0.0294600 + 0.0266009\,\alpha \quad \text{(A8)}$$
$$\tau_{550} = (\tau_{550} - 0.0142035)\,/0.898996 \quad \text{(A9)}$$
$$\tau_{550} = \tau_{550} + 0.00378178 - 0.000665484\,w. \quad \text{(A10)}$$

If Aqua $\tau_{550} \le 0.05$ then

$$\tau_{550} = (1 + 0.315863 - 0.0306199\,w)\,\tau_{550} \quad \text{(A11)}$$
$$\tau_{550} = (\tau_{550} - 0.0271628)\,/0.301162 \quad \text{(A12)}$$
$$\tau_{550} = \tau_{550} + 0.00514700 - 0.0274383\,f_c \quad \text{(A13)}$$
$$\tau_{550} = (1 - 0.350973 + 0.0378387\,\alpha)\,\tau_{550}. \quad \text{(A14)}$$

If Aqua $\tau_{550} > 0.05$ then

$$\tau_{550} = (1 - 0.258509 + 0.164087\,\alpha)\,\tau_{550} \quad \text{(A15)}$$
$$\tau_{550} = (\tau_{550} - 0.0328901)\,/0.760698 \quad \text{(A16)}$$
$$\tau_{550} = \tau_{550} + 0.00646153 - 0.0322341\,f_c \quad \text{(A17)}$$
$$\tau_{550} = \tau_{550} + 0.0106865 - 0.00186725\,w, \quad \text{(A18)}$$

where α is the uncorrected MODIS AE, Θ the scattering angle, w the NCEP-DOE-II 10 m wind speed and f_c the cloud fraction.

A3 Additional selection criterium for AE

For AE we use an additional selection criterium that optimizes the agreement between the original MODIS and AERONET AE

- Aqua: $\tau_{860} \ge 0.055$;
- Terra: $\tau_{860} \ge 0.057$

where τ_{860} is the (uncorrected) MODIS AOT at 860 nm.

A4 Correction for MODIS AE

The following equations should be processed sequentially, like FORTRAN computer code.

If Terra $\tau_{550} \le 0.083$ then

$$\alpha = \alpha + 0.239255 + 0.0181123\,w \quad \text{(A19)}$$
$$\alpha = (\alpha - 0.640555)/0.229146 \quad \text{(A20)}$$
$$\alpha = \alpha + 1.00041 - 0.00732544\,\Theta. \quad \text{(A21)}$$

If Terra $\tau_{550} > 0.083$ then

$$\alpha = \alpha + 0.423368 - 0.00279822\,\Theta \quad \text{(A22)}$$
$$\alpha = (\alpha - 0.334271)/0.667072 \quad \text{(A23)}$$
$$\alpha = \alpha - 0.128672 + 0.0246823\,w. \quad \text{(A24)}$$

If Aqua $\tau_{550} \le 0.087$ then

$$\alpha = (\alpha - 0.404072)/0.278597 \quad \text{(A25)}$$
$$\alpha = (1.0 + 0.200161 - 0.00561571\,\Theta)\,\alpha \quad \text{(A26)}$$
$$\alpha = \alpha + 0.155928 + 0.0268758\,w. \quad \text{(A27)}$$

If Aqua $\tau_{550} > 0.087$ then

$$\alpha = (\alpha - 0.429633)/0.586594 \quad \text{(A28)}$$
$$\alpha = \alpha - 0.166538 + 0.0317318\,w \quad \text{(A29)}$$
$$\alpha = \alpha + 0.101102 - 0.000775233\,\Theta \quad \text{(A30)}$$

where τ_{550} is the uncorrected MODIS AOT, Θ the scattering angle, w the NCEP-DOE-II 10 m wind speed and f_c the cloud fraction.

A5 Random error in MODIS AOT

For Terra, the random error in AOT at 550 nm can be modelled with

$$\epsilon = 0.045 - \tau_{550}\,e^{-\frac{\tau_{550}}{0.045}} + 0.24\left(\tau_{550}^2 - 0.045^2\right)\left(1 - e^{-\frac{\tau_{550}}{0.045}}\right) + 0.0125\,f_c + \begin{cases} 0 & \text{if } w \le 8\,\mathrm{m\,s^{-1}} \\ 0.003\,(w-8) & \text{if } w > 8\,\mathrm{m\,s^{-1}} \end{cases}. \quad \text{(A31)}$$

For Aqua, the random error in AOT at 550 nm can be modelled with

$$\epsilon = 0.0425 - 1.25\,\tau_{550}\,e^{-\frac{\tau_{550}}{0.0325}} + \left(0.25\left(\tau_{550}^2 - .0325^2\right)\right)\left(1 - e^{-\frac{\tau_{550}}{0.0325}}\right) + 0.0125\,f_c + \begin{cases} 0 & \text{if } w \le 8\,\mathrm{m\,s^{-1}} \\ 0.0035\,(w-8) & \text{if } w > 8\,\mathrm{m\,s^{-1}} \end{cases}, \quad \text{(A32)}$$

where τ_{550} is the *corrected* MODIS AOT (see Sect. 7), w the NCEP-DOE-II 10 m wind speed and f_c the cloud fraction.

A6 Random error in MODIS AE

For Terra, the random error in AE is reasonably well described by

$$\epsilon = 0.25 + 0.06\alpha + \exp\left(-3.75\sqrt{\tau_{550}}\right). \quad \text{(A33)}$$

For Aqua, the random error in AE is reasonably well described by

$$\epsilon = 0.25 + 0.08\alpha + \exp\left(-5\sqrt{\tau_{550}}\right), \quad \text{(A34)}$$

where τ_{550} is the *corrected* MODIS AOT and α the *corrected* MODIS AE (see Sect. 7).

N. Schutgens (AMT'13)

Corrections to MODIS AOT and AE

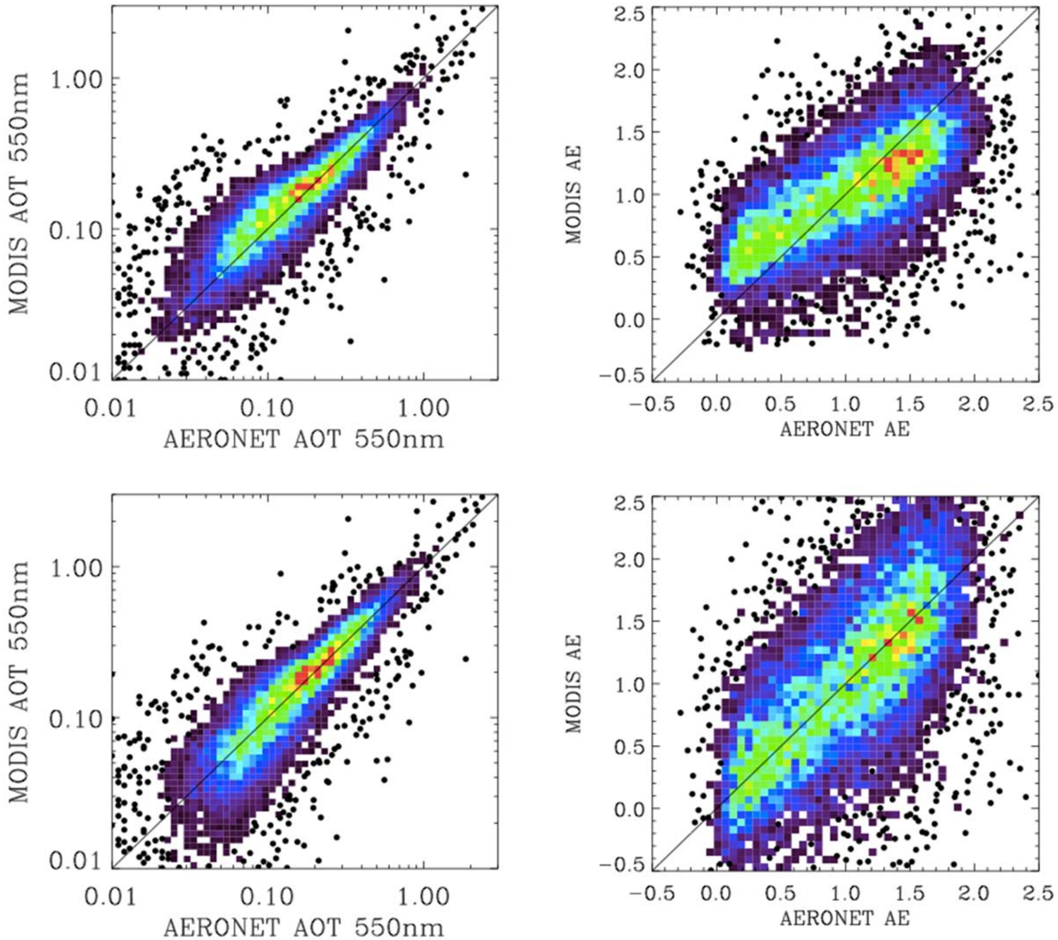
ΔAOT550~ 0.1 @ 0.2
ΔAE ~ 0.2 (σ~ 0.3) -> ΔAOT550 ~0.01

AOT550 **AE**

MODIS-Aqua
Collection 5
2003-2009

Original

Corrected

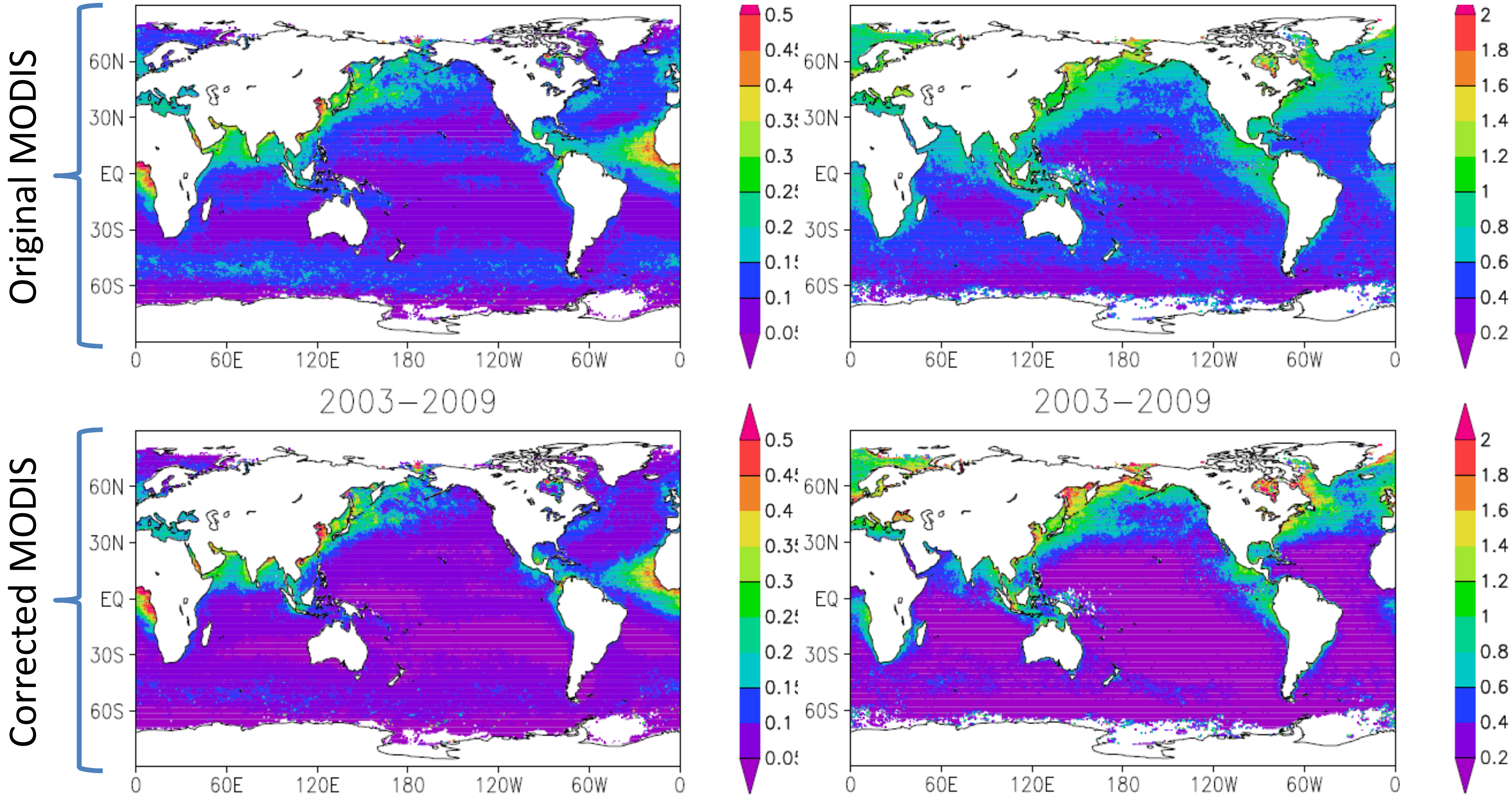


N. Schutgens (AMT'13)

Impact on MODIS climatology

There is a significant impact on MODIS climatology, with notable reductions of AOT and increased land-ocean contrast.

AOT 2003-2009 AE 2003-2009



N. Schutgens

MIRoC-SPRINTARS aerosol assimilation-Inversion system

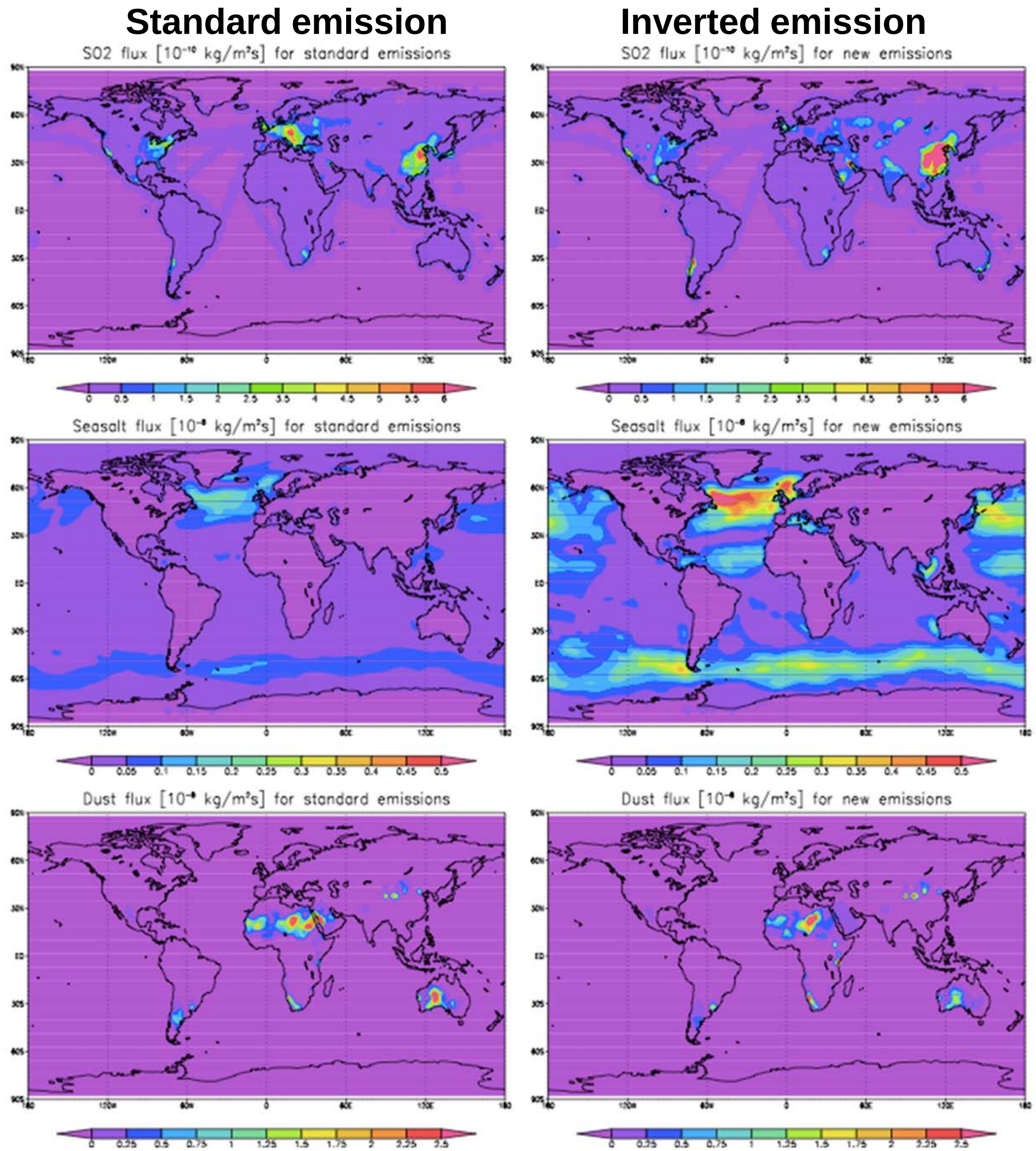
- Sulfate increased
- Sea salt increased
- dust reduced

by inversion

SO_2

Sea salt

Dust

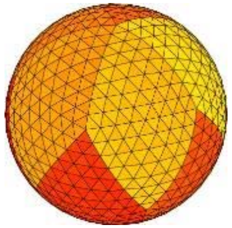


Mean, 9-30 Jan., 2009

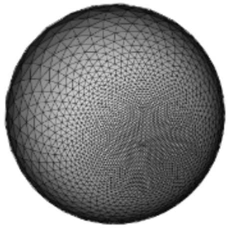
Schutgens et al., (Remote Sens. 2012)

RECCA/SALSA-NICAM+SPRINTARS+CHASER model

Quasi-homogeneous grid

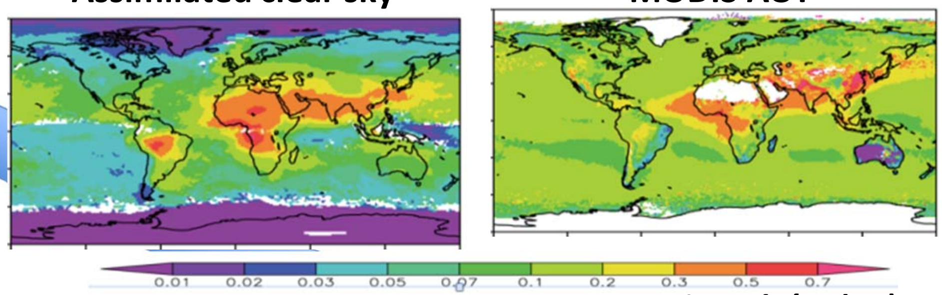


Stretched grid

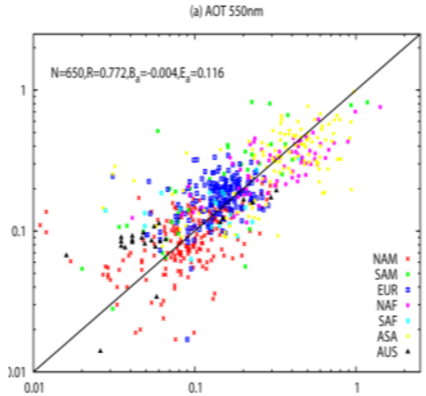


Period mean AOT550 (2006-2008)

Assimilated clear sky | MODIS AOT



Nakajima et al. (Simulation'13)

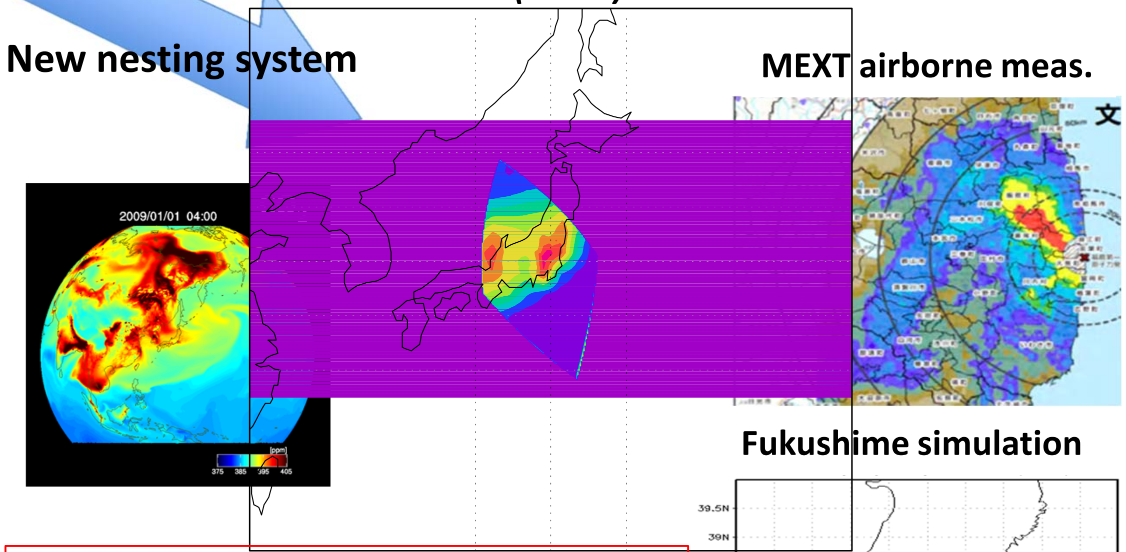


AERONET AOT550

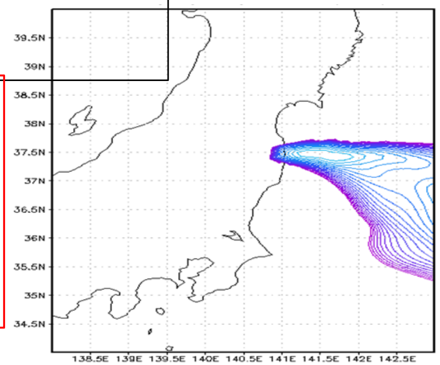
Dai et al. (AE'14)

New nesting system

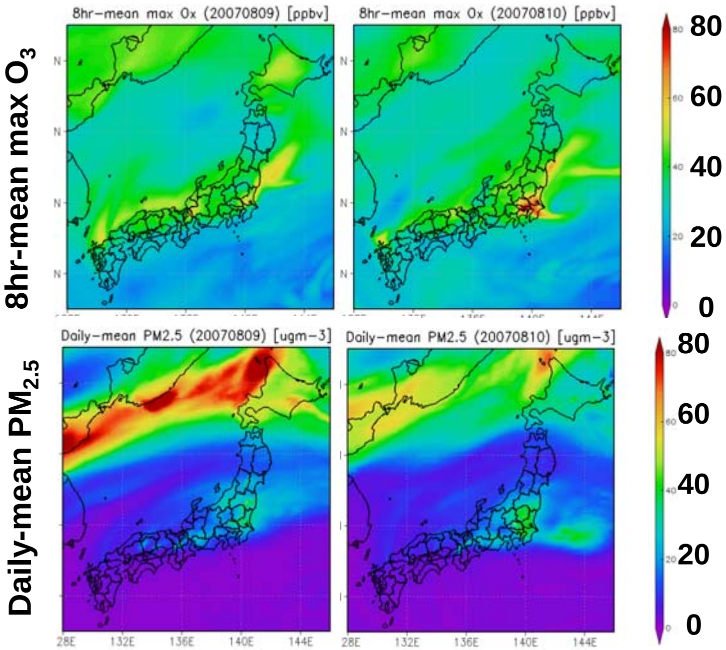
MEXT airborne meas.



Fukushime simulation



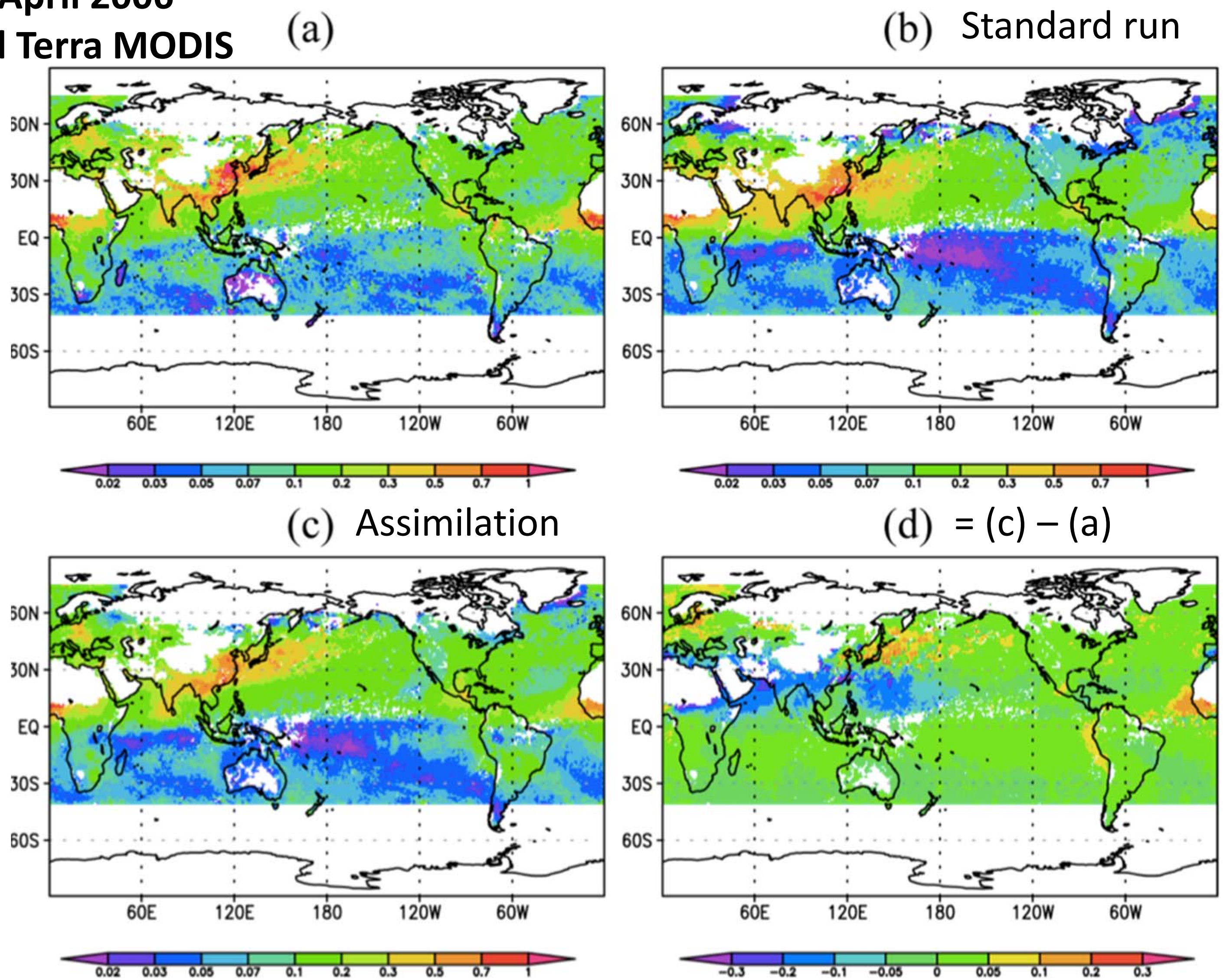
August 9, 2007 | August 10, 2007



- New nesting: global to region
- Aerosol (22 particle types); short-lived gases (54 species); CO2, DHO

NICAM+SPRINTARS assimilation system

AOT550, April 2006
Aqua and Terra MODIS



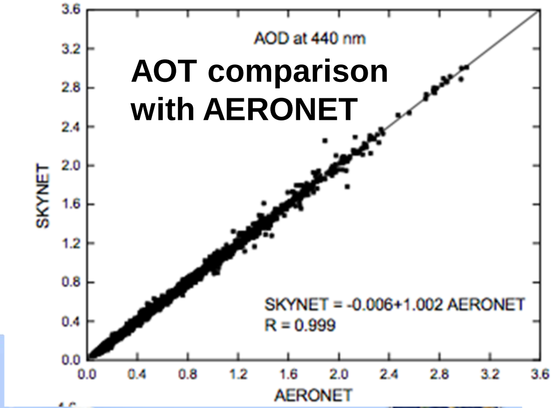
Dai et al. (Atmos. Environ'14)

Computation estimate

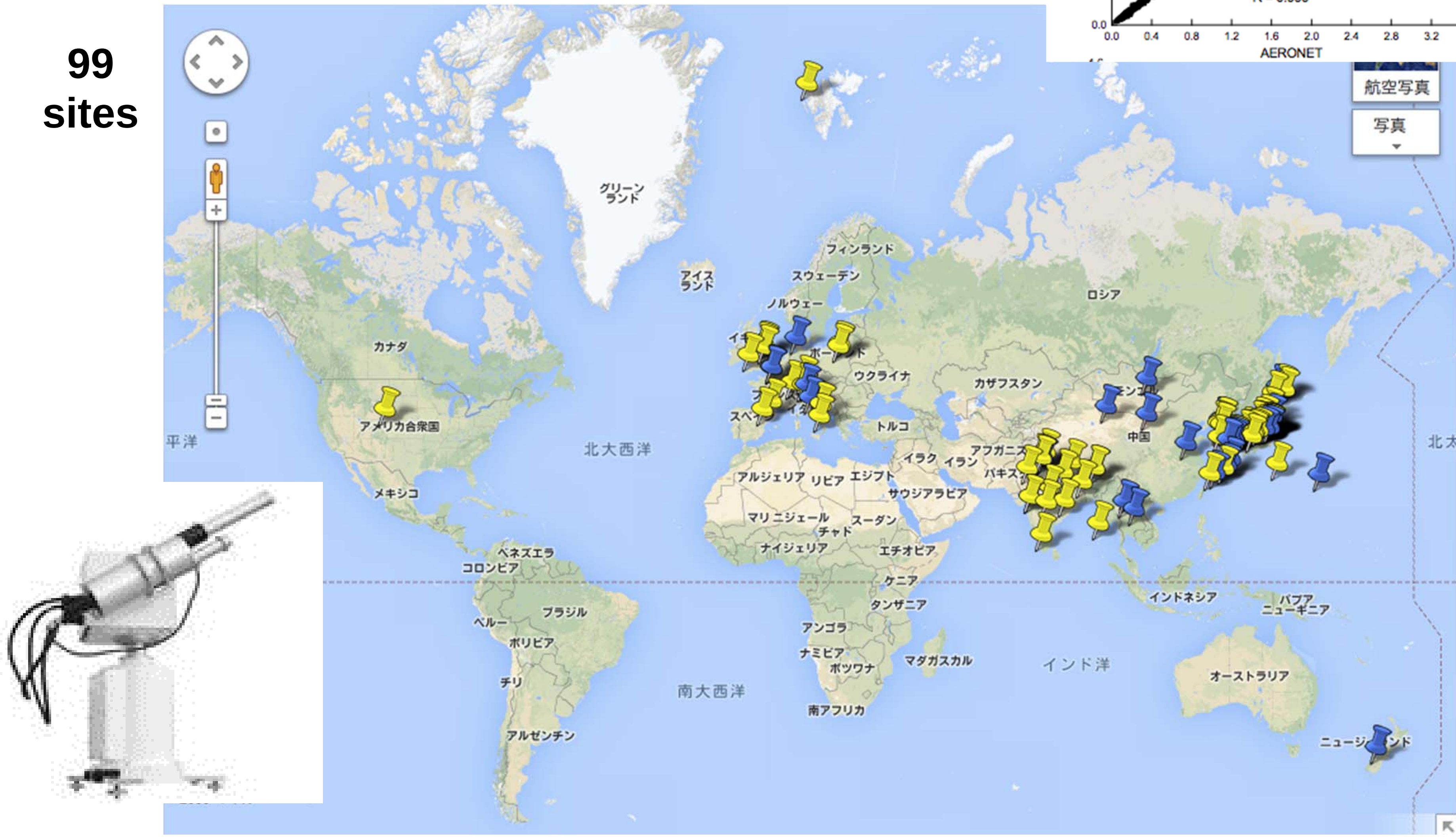
- Generalized aerosol algorithm
  - Performance of 4min for 4 wavelengths, 5x5 pixel case with 1 thread@ Xeon E5-2687W x2: 9000 pixels/day
  - 250m pixels to 1km by sampling or average
  - Pixel number (1km equivalent): 40k*1.5k*0.5day*0.3 clear sky*14 cycles= 126 M pixels/day (14000 threads)
  - Target resolution: 20x20 pixels (20kmx20km) analysis with 2 CPU (32 threads)
  - Neural network version will be developed in FY2014 for all pixel analysis
- MIROC+SPRINTARS assimilation system
  - NIES SX-8 super computer possible for real time
  - Being implemented to GOSAT operation system
  - JAXA/NAL super computer?

PREDE skyradiometer sites (SKYNET)

- Unique on-site calibration system
- AOT, SSA, SZF, COT, RE, O3, WV
- Approval process for GAW contributing network
- Co-location with ADNET lidar



99 sites



Research schedule

	FY2013	FY2014	FY2015
		▲ 1st program shipping	
● Cloud shadow			
● 2channel ocean	completed, revised		
● Modified Kaufman land	completed, revised	algorithm test, validation	
● Kaufman land	developing		
● Generalized method	developing	Neural network version	
● MIROC+SPRINTARS assimilation	completed	data set construction	
● NICAM+SPRINTARS assimilation	developing		

Summary

- **Phase-I (-FY2012)**
  - ✓ **Modified Kaufman method with 380nm, being used in GOSAT/CAI operation system**
  - ✓ **Cloud shadow screening method**
  - ✓ **Aerosol assimilation with MIROC-SPRINTARS, being introduced to GOSAT operation system**

- **Phase-II (FY 2013-)**
  - **Neutral reflectance method for dust aerosol retrievals: Yoshida et al. (ACP'13)**
  - **A new method with multi-wavelengths, -angles, and –pixels: Prototype developed**
  - **Aerosol assimilation with NICAM-SPRINTARS: Prototype developed**
  - **Skynet operation for aerosol validation: AERONET collaboration; Good agreement with AERONET AOT; SSA being improved**

back up slides

Multi-pixel multi-wavelength method

M. Hashimoto @ AORI