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Satellite remote sensing of aerosols – Past, present and future

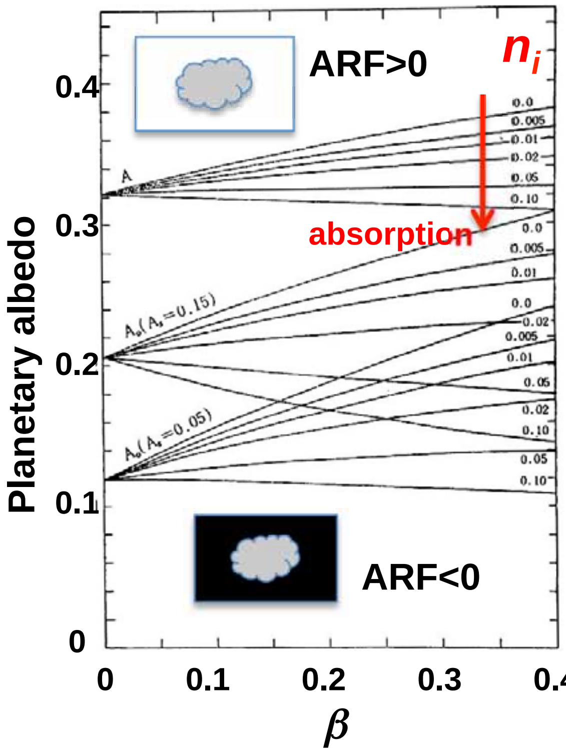
Terry Nakajima

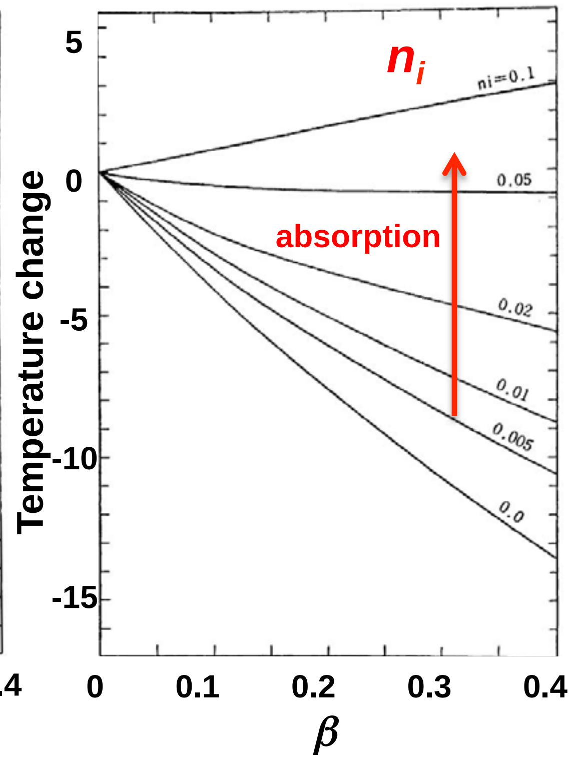
Atmosphere and Ocean Research Institute, University of Tokyo

teruyuki.nakajima@aori.u-tokyo.ac.jp

Aerosol impact on the earth's climate

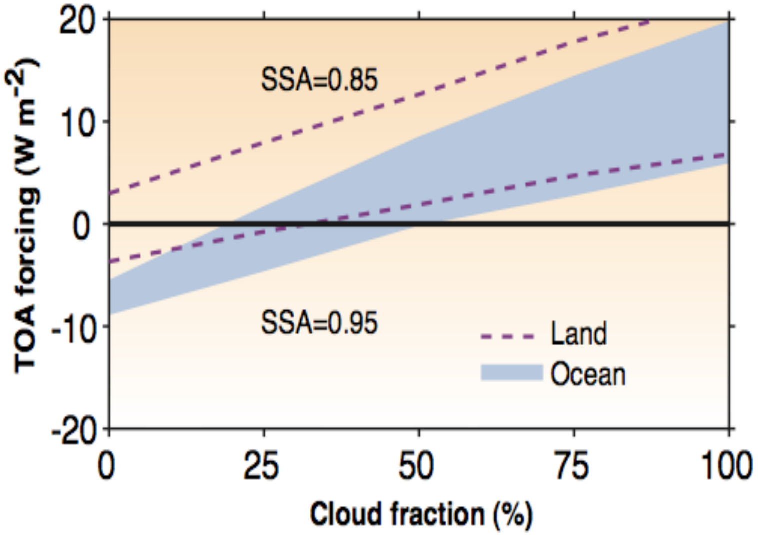
Yamamoto & Tanaka (JAS 72)





- ***Hansen et al. (JGR 97)***
  Global modeling result:
  ω_0 > 0.9: cooling
  ω_0 < 0.9: warming

- ***Ramanathan et al. (Science 01)***



Ångström's law

α : exponent

β : turbidity factor

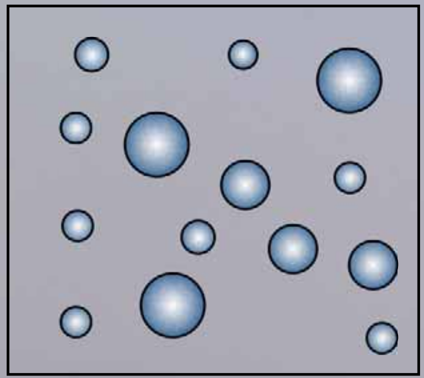
AOT

$$\tau_\lambda = \beta \lambda^{-\alpha}$$

***Yamamoto et al. (JMSJ 68)*: IGY data**

β=0.05-0.075 -> doubling

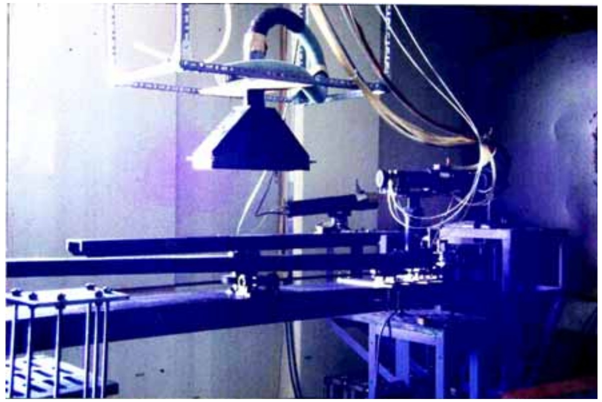
-> $-\Delta T_s$= 1.3-1.8C for n_i=0.01; 1.0-1.2 for n_i =0.02

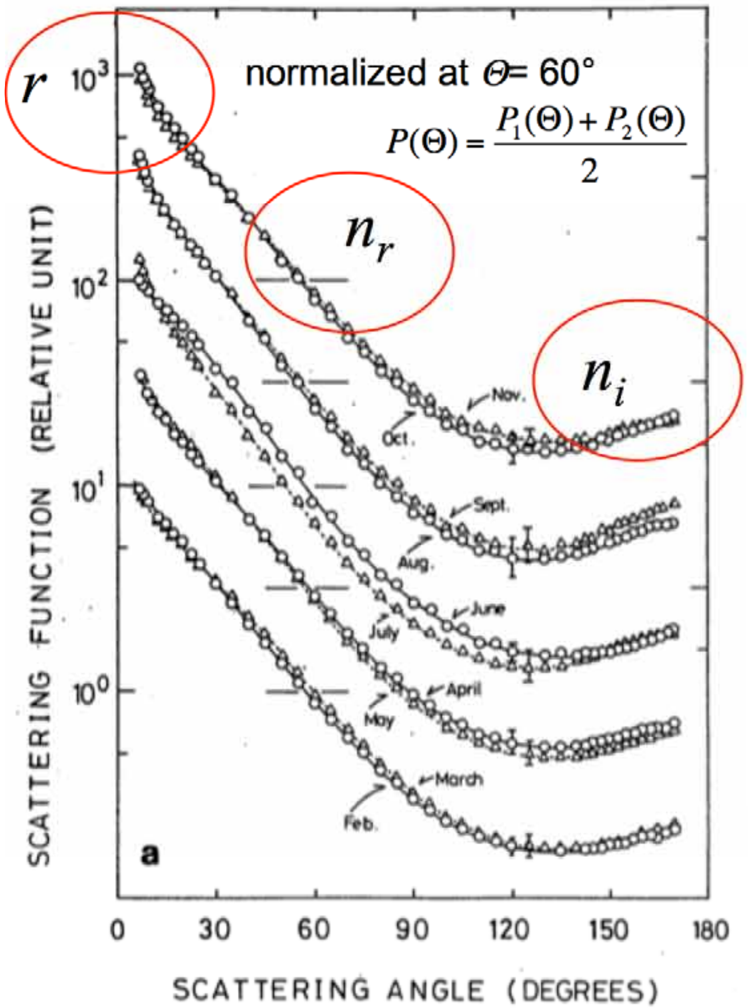


- **Emission sources?**
- **Gas to particle conversion?**
- **Particle size (*r*) ? Size distribution ? *n*(*r*)**
- **Shape?**
- **Mixing state (internal, external, heterogeneous...)?**
- **Stratification?**
- **Scattering cross section (C_s) ? , absorption cross section (C_a) ?**
- **Extinction cross section? ($C_e = C_s + C_a$)**
- **Optical thickness: AOT= $\Sigma\, C_e(z)\, \Delta z$?**
- **Single scattering albedo (SSA, ω)= Cs/Ce ?**
- **Wavelength dependence?**

Angular coress section of aerosols

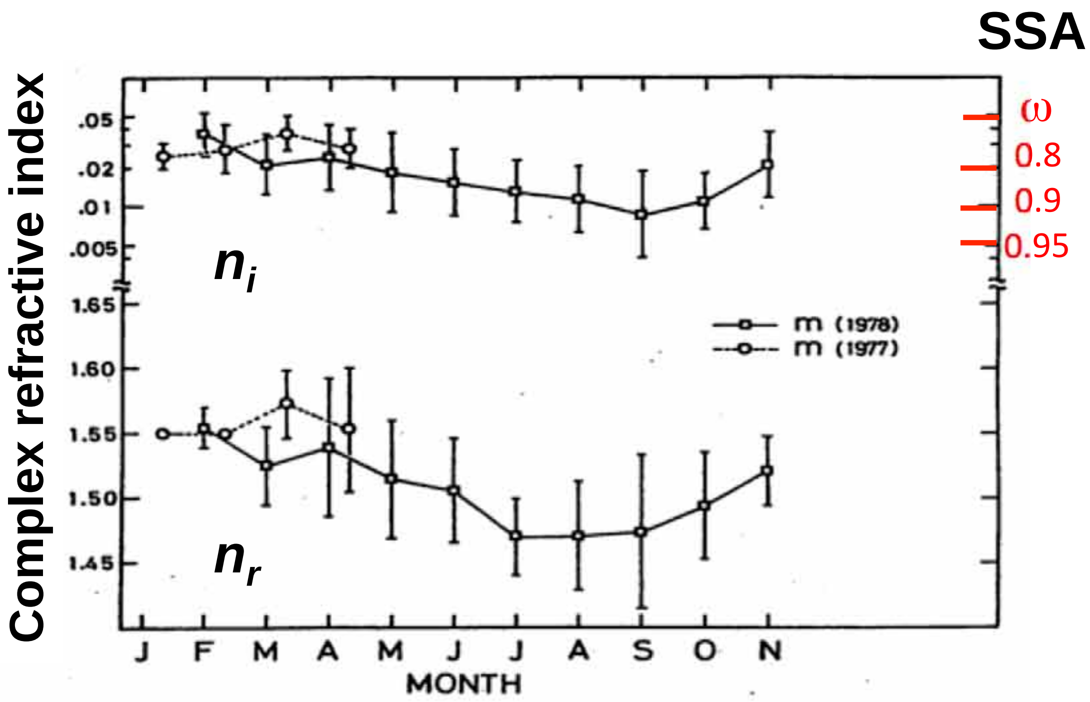
- *Grams et al. (JAM 74)*: Polar nephelometer
- *Tanaka, Takamura, Nakajima (JCAM 83)*
- Large absorption by aerosols
- Rejected by JAS





$$sP(\Theta)Ldx$$

Phase function

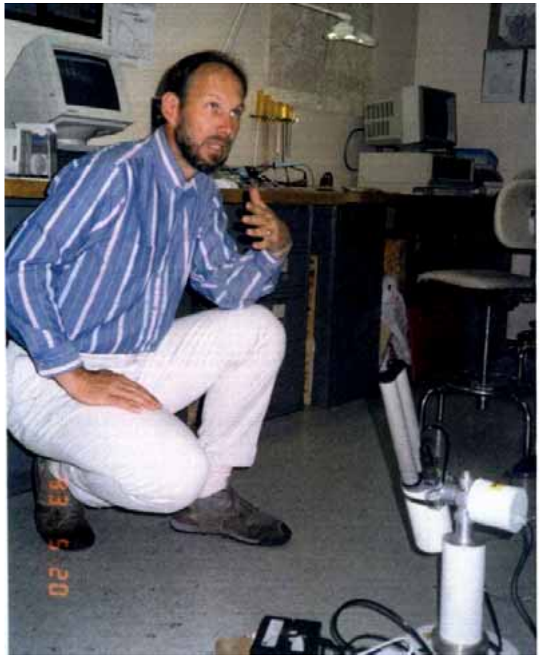


Data: 1978-78, Sendai, Japan

Sun and sky photometry

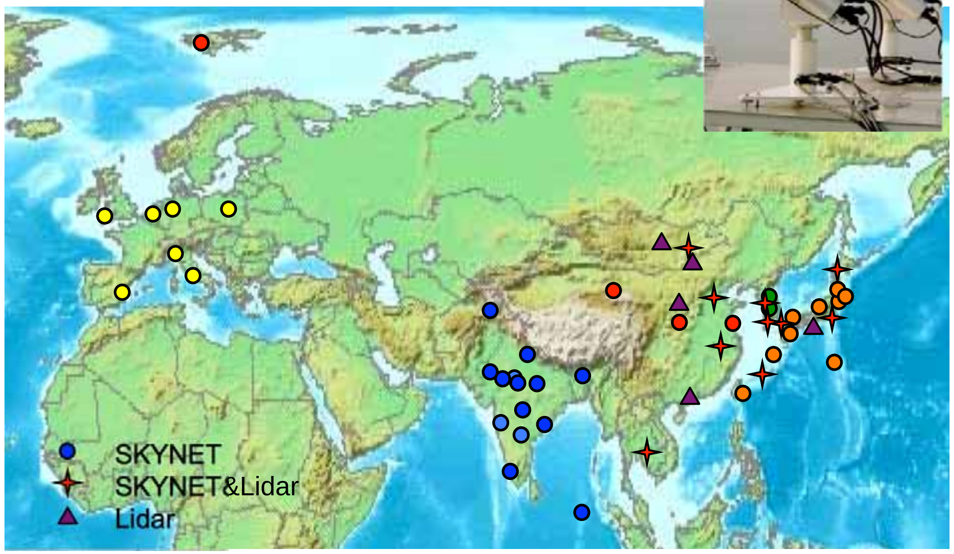
Aureole-meter in early 1980s

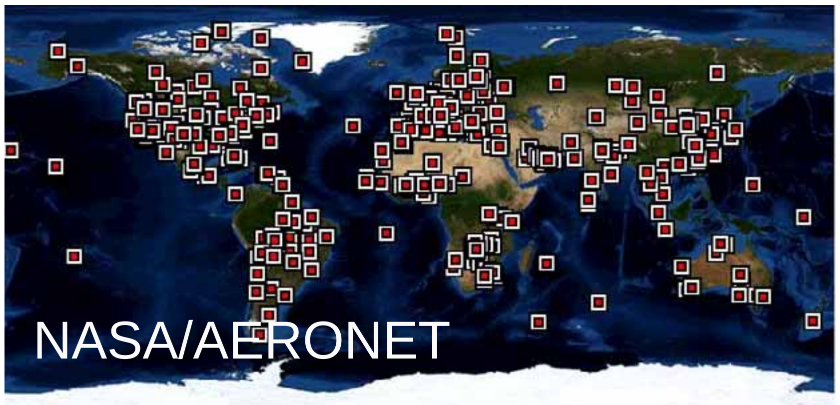
CiMel sun/sky photometer with Brent Holben in 1993



- **SW sun&sky photometry: Smithonian Institute ('23-'52)**
  (Roosen & Angione, BAMS'84)
- **Sunphotometer: *Ångström (Tellus'61)*, *Voltz (AO'74)***
- **Spectral sun&sky: *Nakajima et al. (AO'83)*, *Nakajima, Tonna, Rao, Kaufman, Holben (AO'96)***
- **Aeronet: *Holben et al. (Atmos. Envion 98)***
- ***Dubovik and King (JGR 00); Dubovik et al. (JAS 02)***
- ***Hashimoto, Nakajima and Dubovik (AMT'12)***

Skynet PREDE skyradiometer

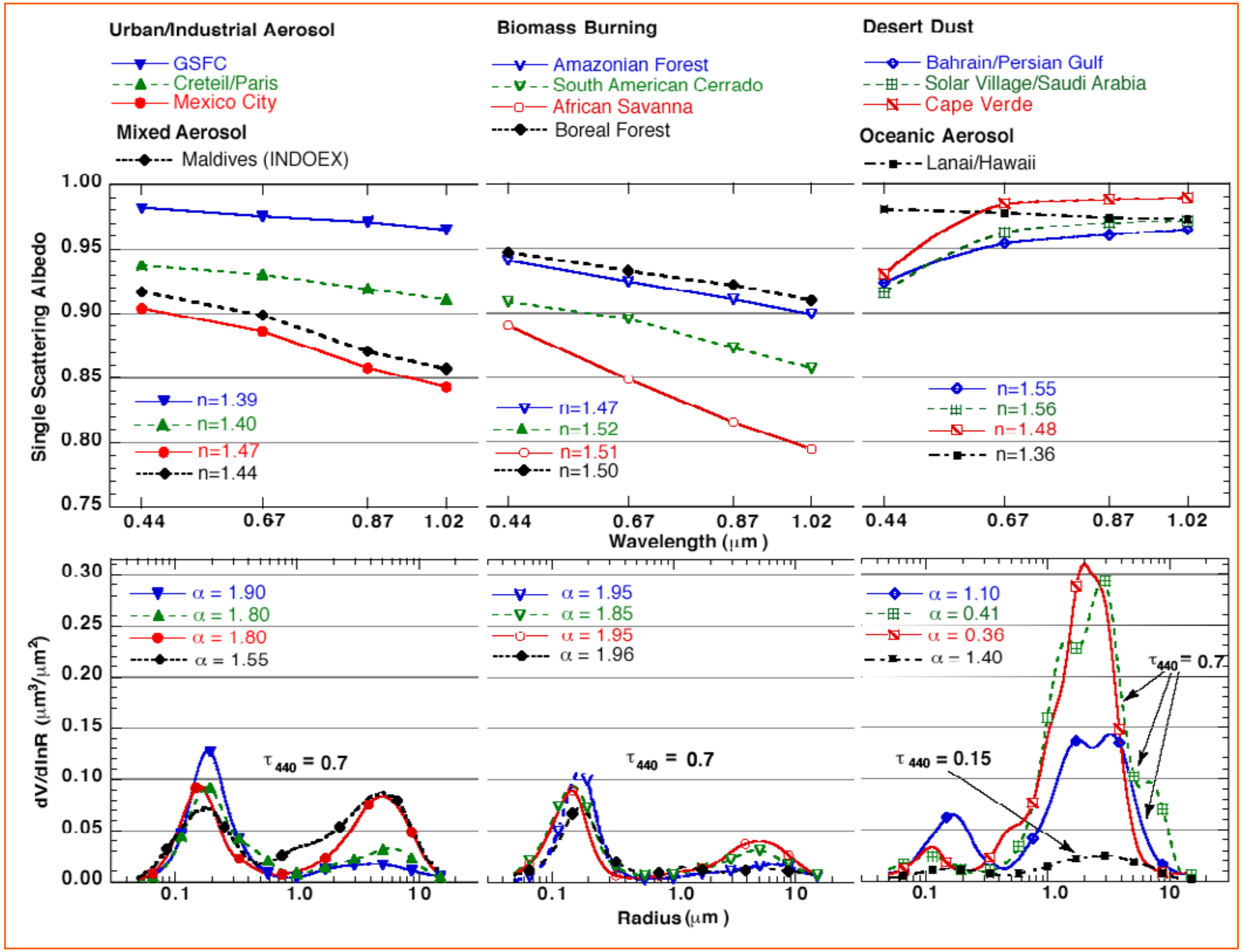




Sky-sunphotometry measurement: Optical properties of various aerosol types

- *Dubovik and King (JGR 00)*
- *Dubovik et al. (JAS 02)*

A man from Minsk
to NIES and GSFC
in IRS2000



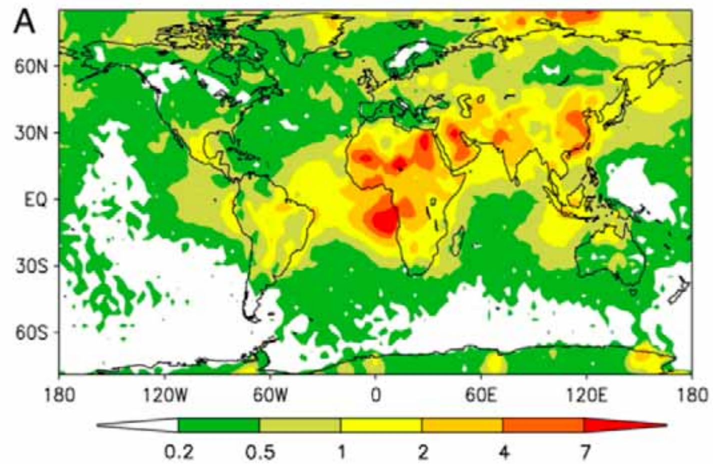
New BC and BrC DRF estimates

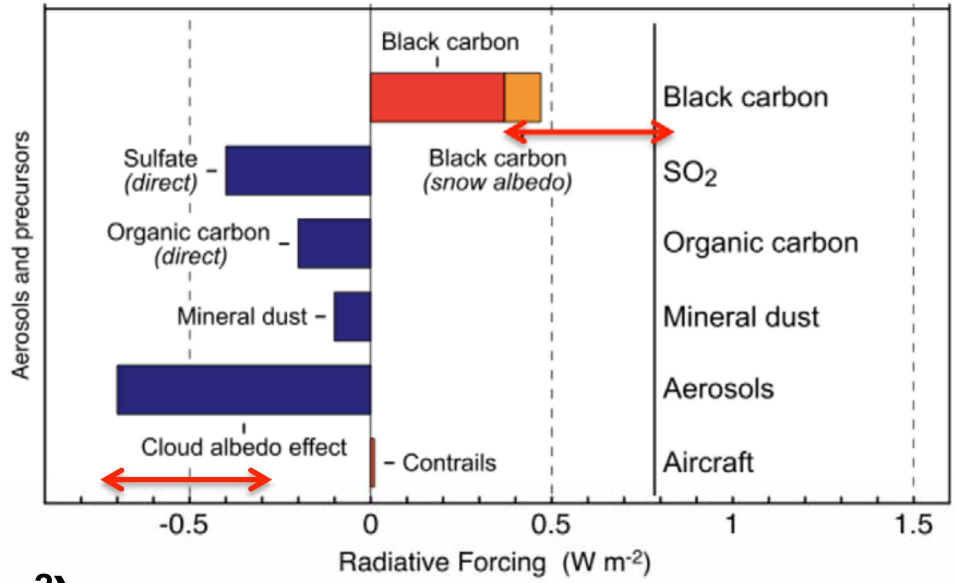
Chuan et al., PNAS 12)
Bond et al. (JGR 13)

Table 2. Empirical estimates of global average annual mean optical depths and DRE

	CA	BC	OM	BrC
Absorption optical depth (550 nm)	0.0095 (0.008 ~ 0.01)	0.0077 (0.006 ~ 0.009)	0.0018 (0.001 ~ 0.003)	0.0018 (0.001 ~ 0.003)
Optical depth (550 nm)	0.022 (0.015 ~ 0.03)	0.0095 (0.007 ~ 0.015)	0.012 (0.007 ~ 0.02)	
TOA DRE (Wm^{-2})	0.75 (0.5 ~ 1.0)	0.75 (0.6 ~ 0.9)	0.0 (−0.2 ~ +0.2)	
TOA clear-sky DRE	0.6 (0.4 ~ 0.8)	0.7 (0.6 ~ 0.8)	−0.1 (−0.3 ~ +0.1)	
Atmosphere DRE	3.8 (3.3 ~ 4.3)	2.75 (2.3 ~ 3.2)	1.1 (0.8 ~ 1.4)	
Surface DRE	−3.05 (−2.7 ~ −3.6)	−2.0 (−2.3 ~ −1.7)	−1.1 (−1.50 ~ −0.75)	

The baseline value (for optical depth) or central value (for forcing) is shown along with the range stemming from parameter uncertainties and observational errors (Tables S3 and S4 and *SI Text, Uncertainty of Our Global Estimates*). The global average AOD and AAOD are 0.153 and 0.0104, respectively. ***Chuan et al., PNAS'12)***



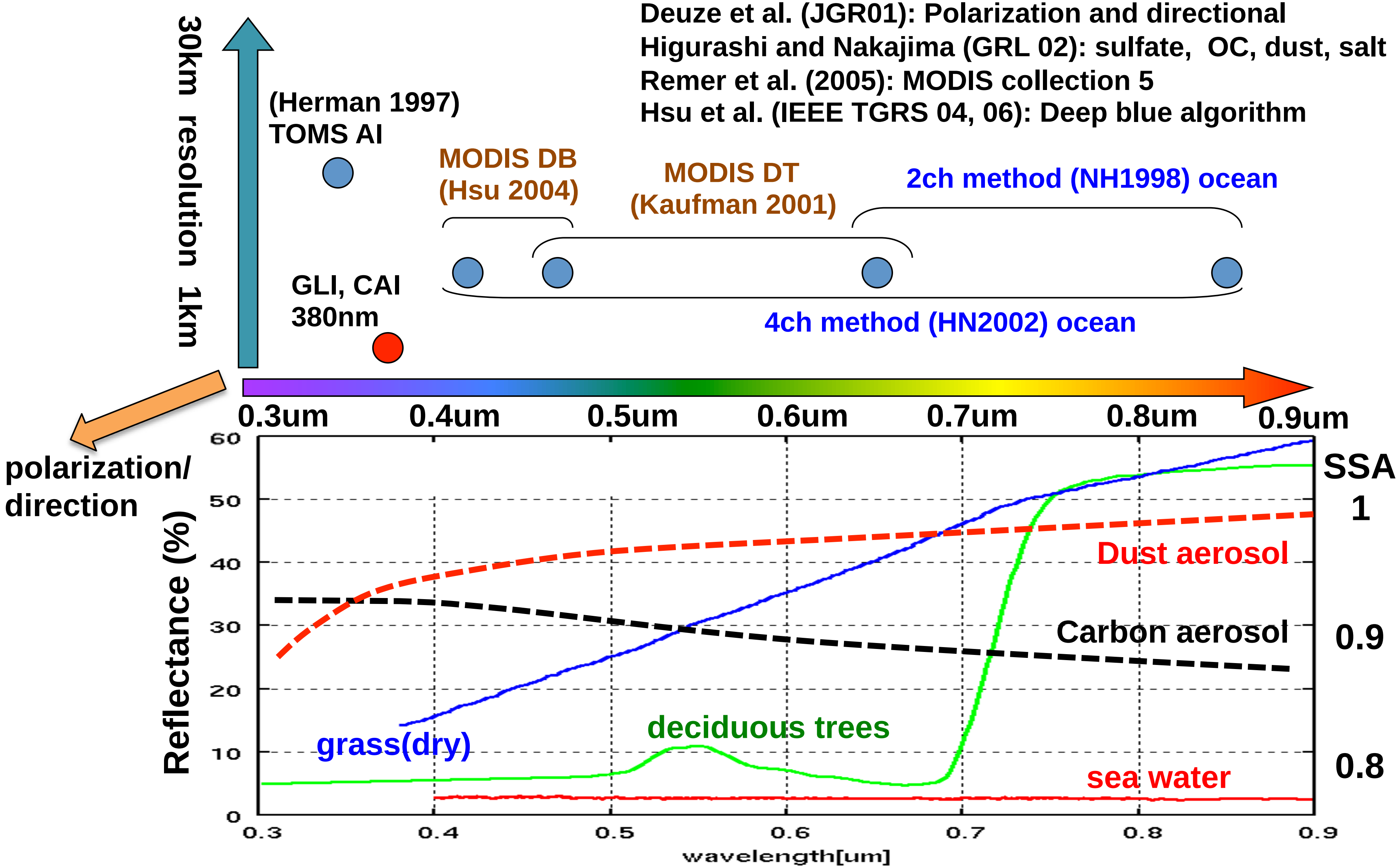


IPCC-AR4 (2007)

- **AERONET data used**
- **Large absorption (DRE~+0.7 Wm^{-2}) by BC and brown aerosols**
- ***AAOD= (1-SSA)*AOD***

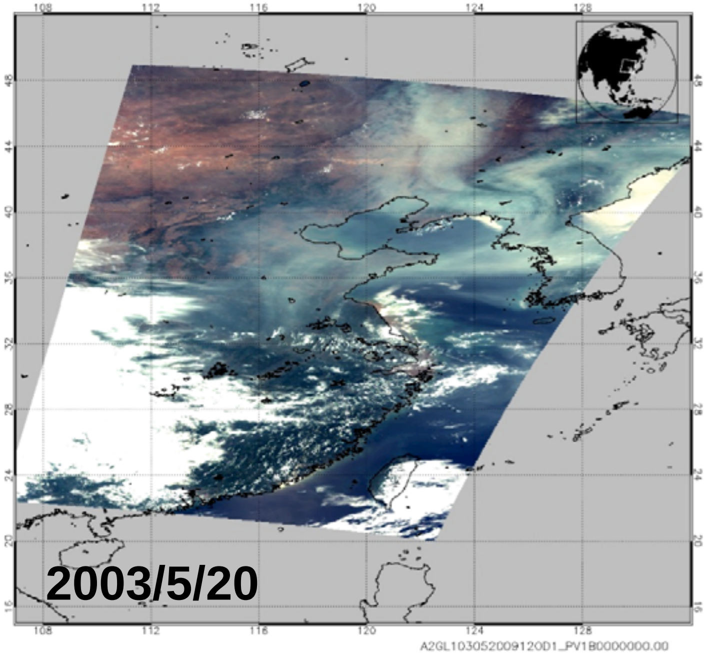
Passive aerosol remote sensing

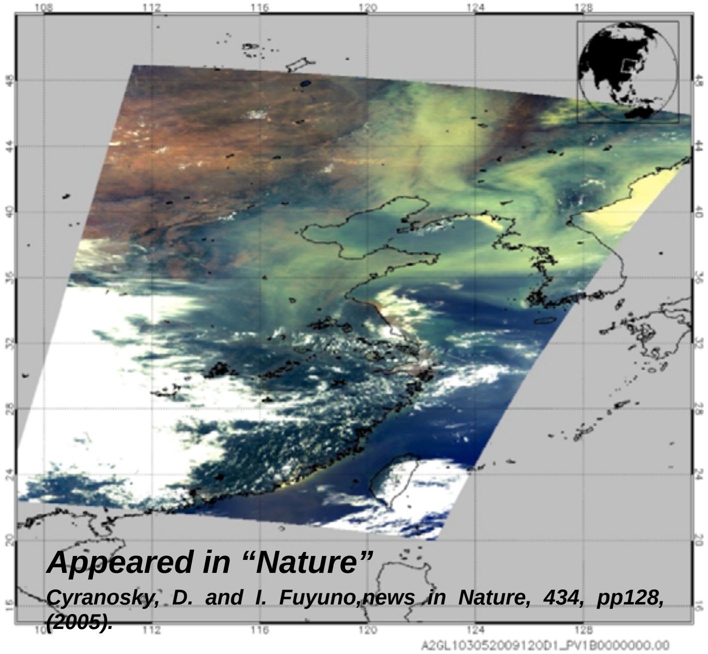
Herman et al. (JGR 97): TOMS AI
Nakajima and Higurashi (GRL 98): 2ch over ocean
Kaufman, Tanre, et al. (GRL01) Dust SSA
Deuze et al. (JGR01): Polarization and directional
Higurashi and Nakajima (GRL 02): sulfate, OC, dust, salt
Remer et al. (2005): MODIS collection 5
Hsu et al. (IEEE TGRS 04, 06): Deep blue algorithm



Aerosol from high spatial resolution 1km in 380nm channel

Biomass burning in Asia captured by ADEOS2/GLI

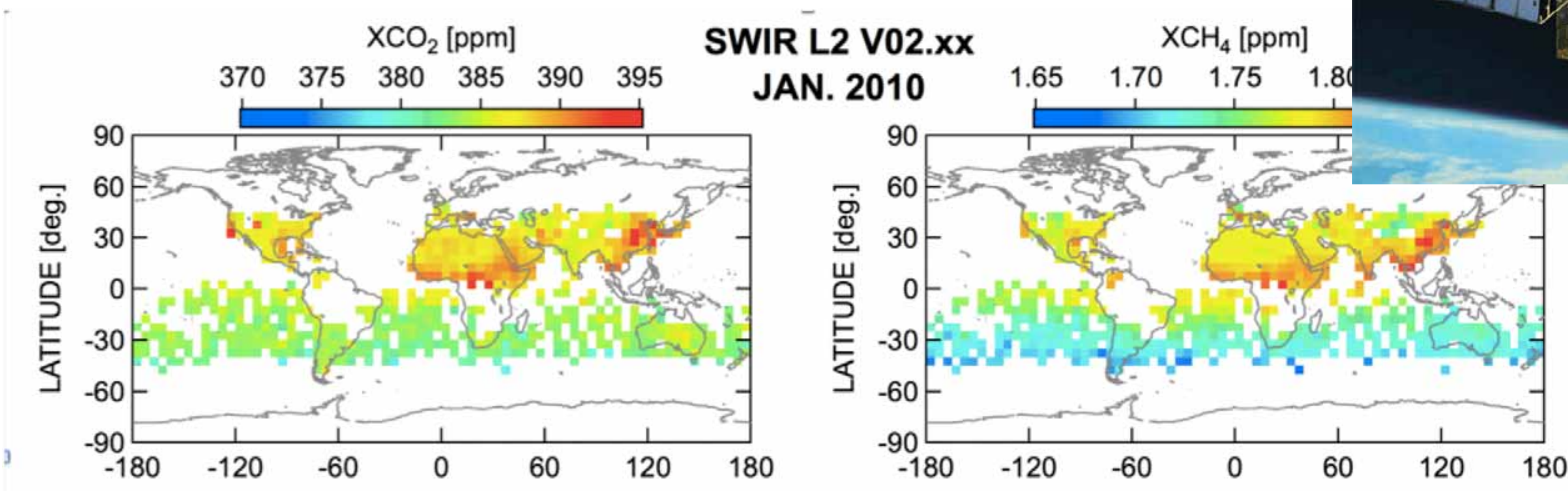


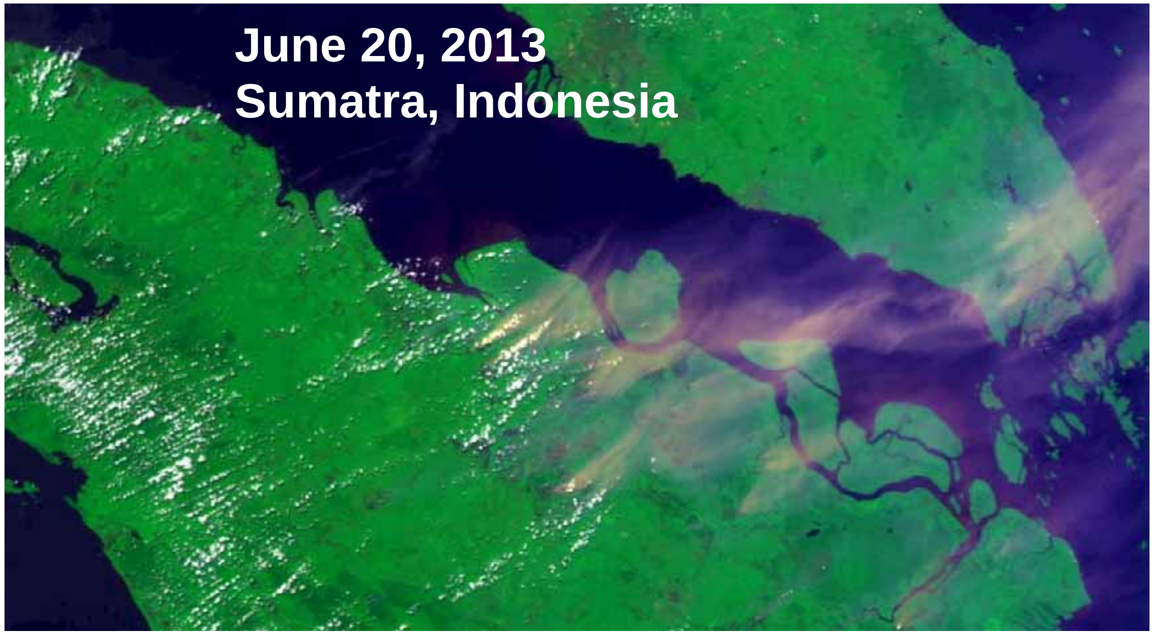


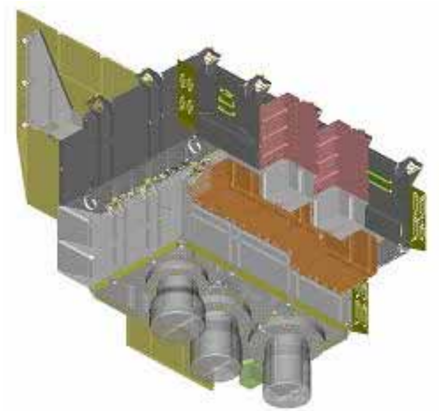
Red	13	0.678μm
Green	8	0.545μm
Blue	5	0.460μm

Red	13	0.678μm
Green	8	0.545μm
Blue	1	**0.380μm**

GOSAT XCO2, XCH4, aerosols



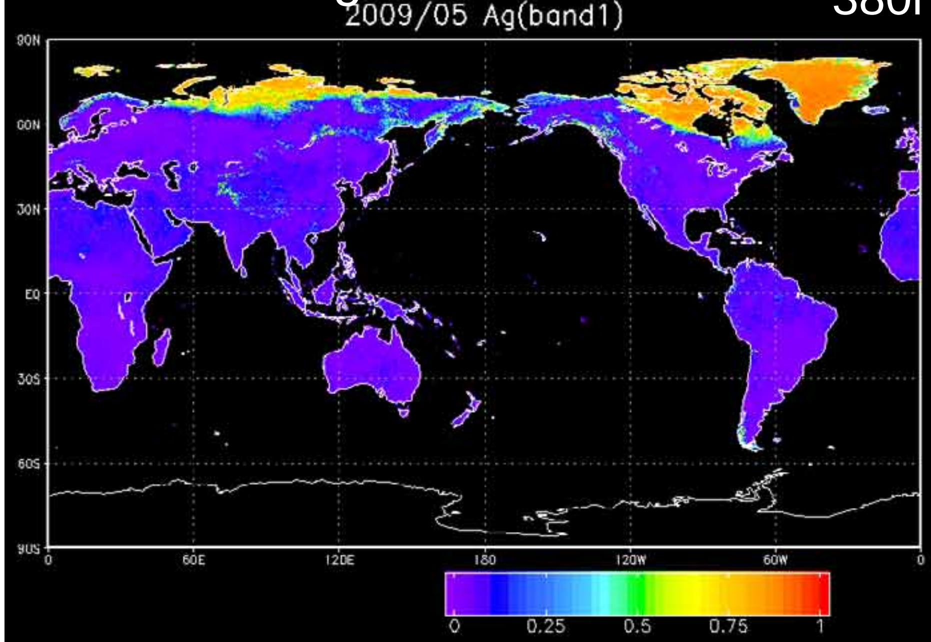




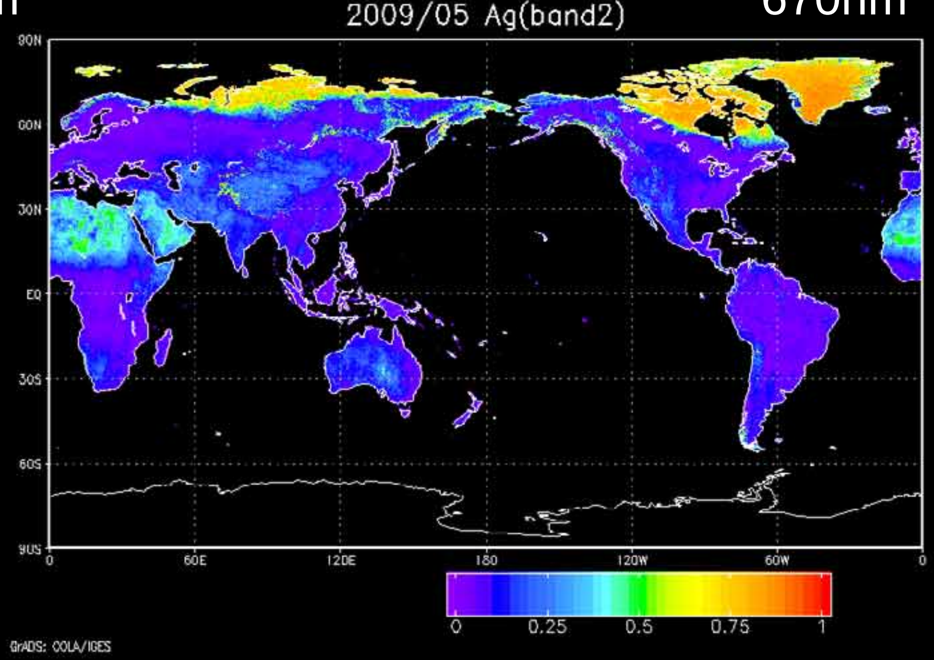
Cloud and Aerosol Imager (CAI)
380, 670, 860, 1600nm
FOV 500m 750m
Push-broom imager, Cheap!

GOSAT/CAI ground reflectance

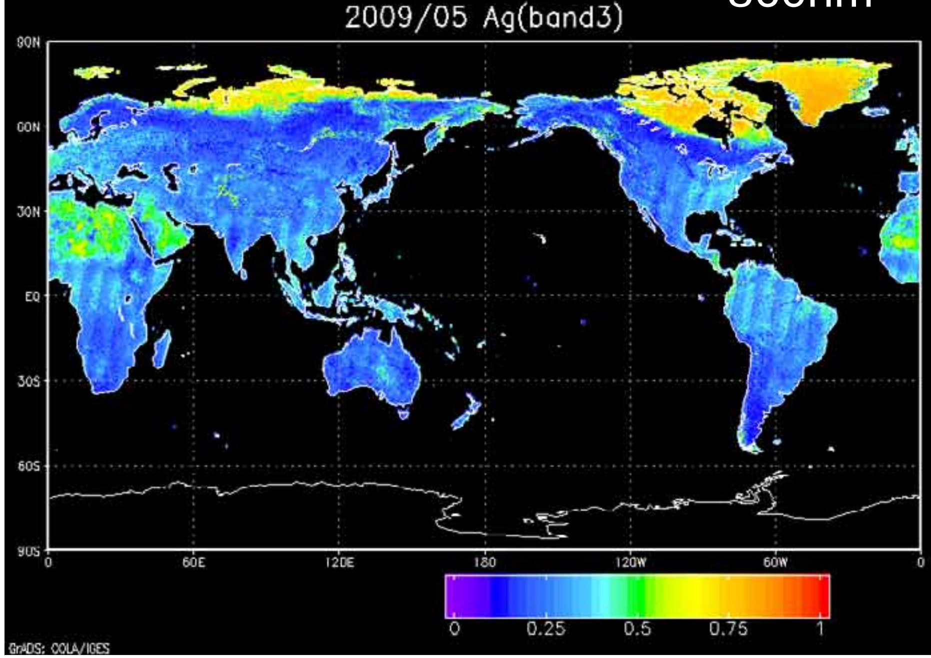
380nm



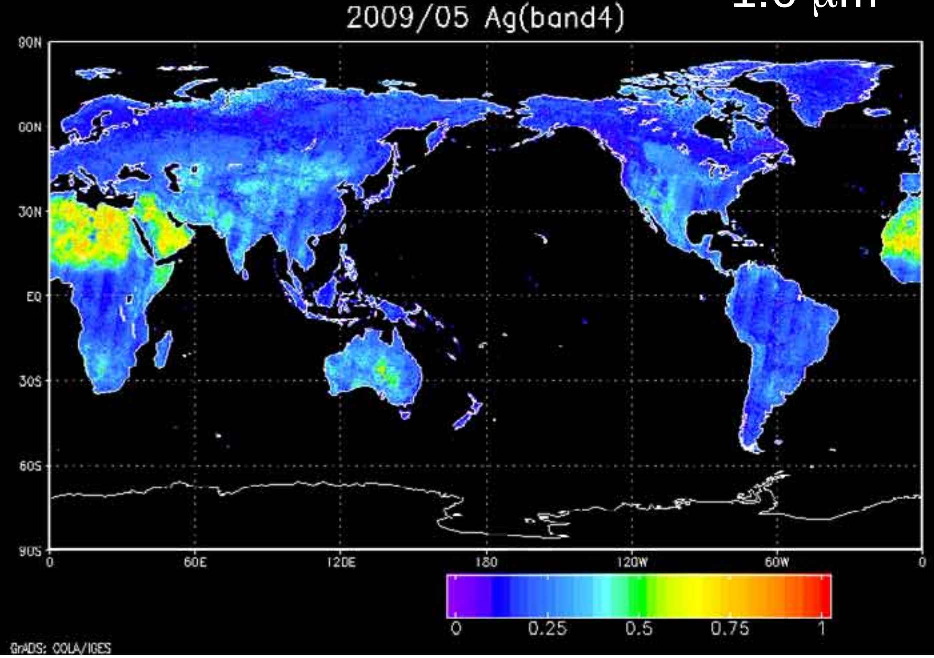
670nm



860nm



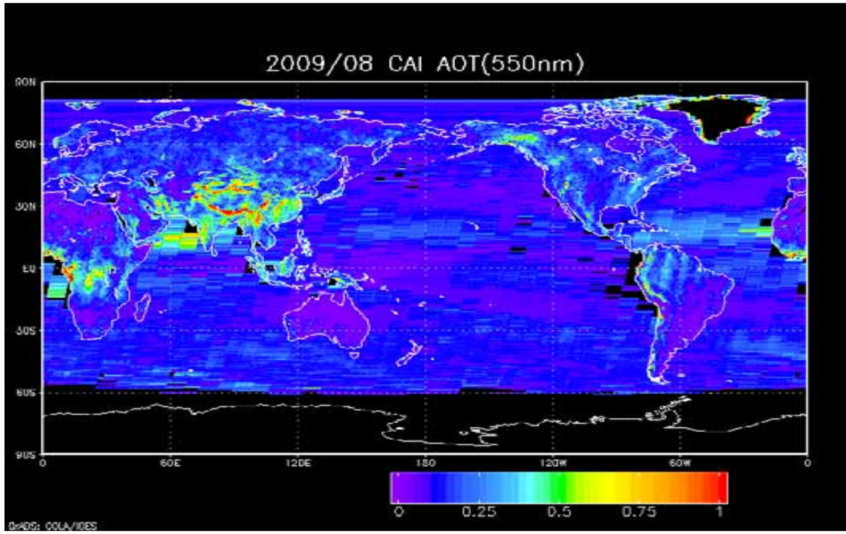
1.6 μm



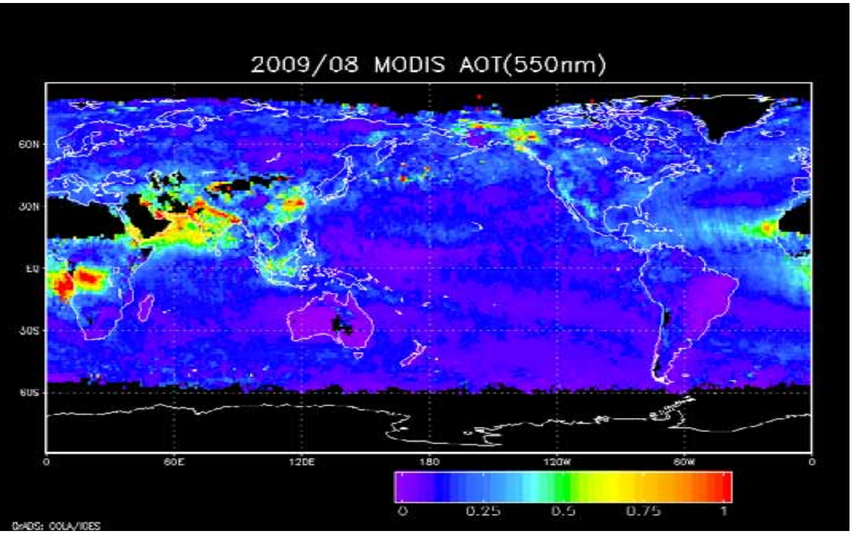
Various remote sensing methods for aerosols

Sept. 2009

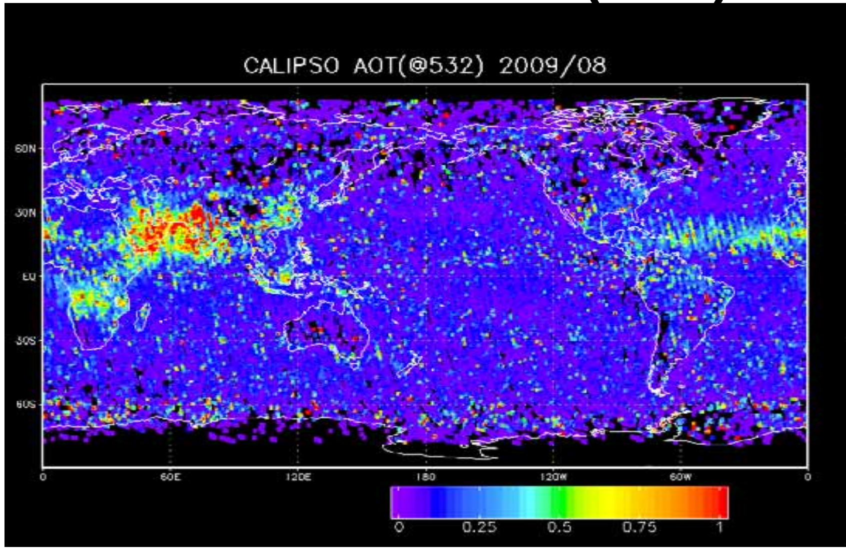
GOSAT/CAI (380nm, 1km)



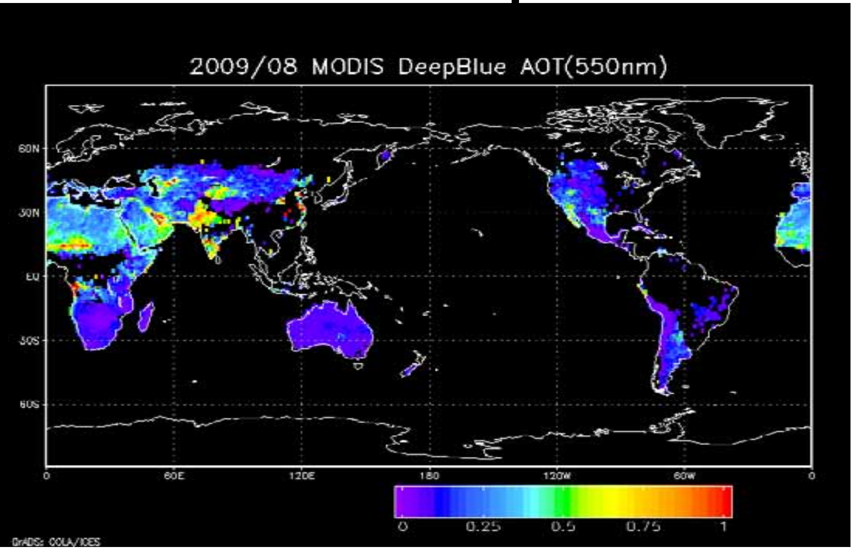
MODIS Dark Target



CALIPSO (lidar)

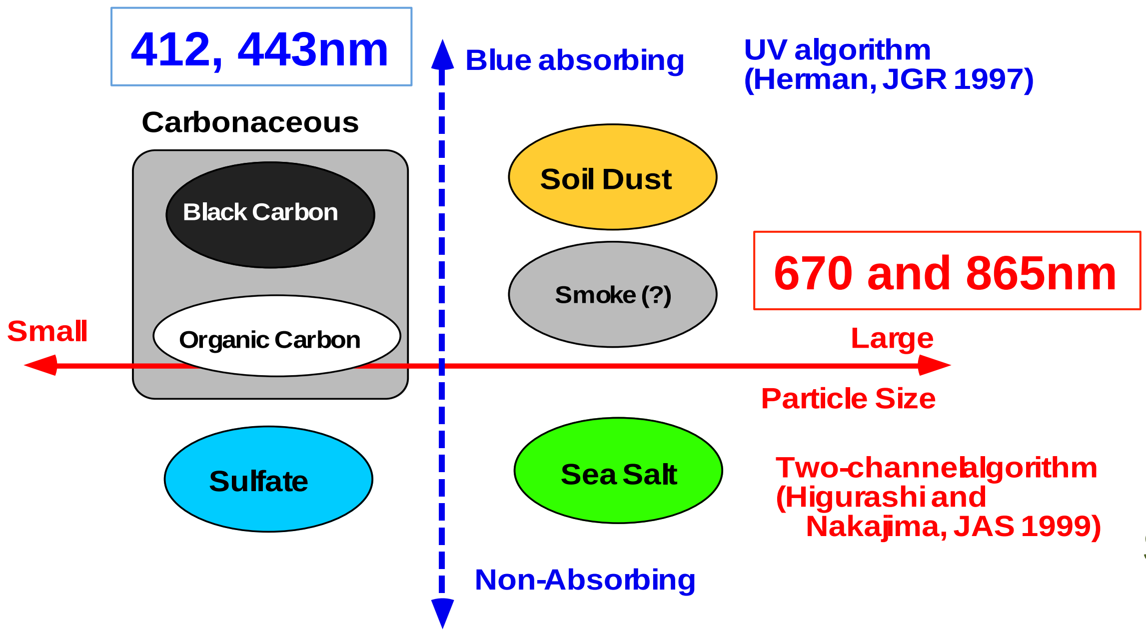


MODIS Deep Blue



S. Fukuda (PHD 2011)

Four channel method (ocean)



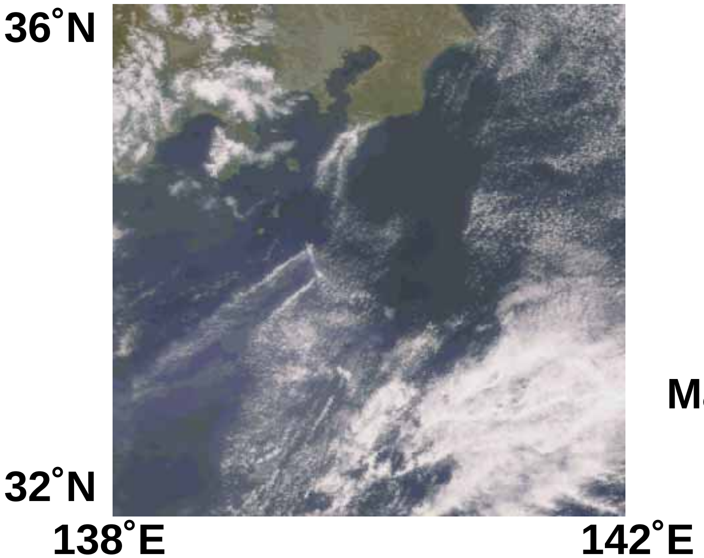
4,365 ton/day sulfate,
23% of SO2 gas

Volcanic Plume from Mt. Oyama, Miyakejima

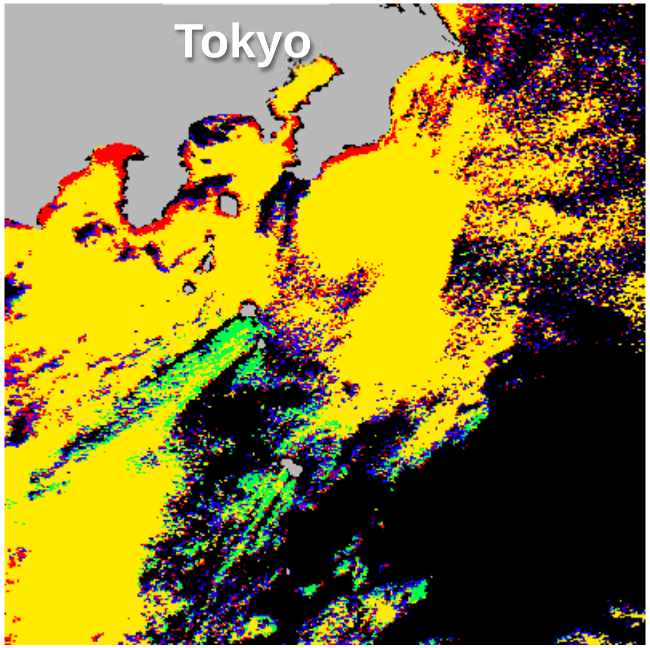
Aerosol Types

Sulfate, Carbon, Soil Dust, Salt

SeaWiFS Ture-color Image



May 5, 2001



Higurashi and Nakajima (GRL02)

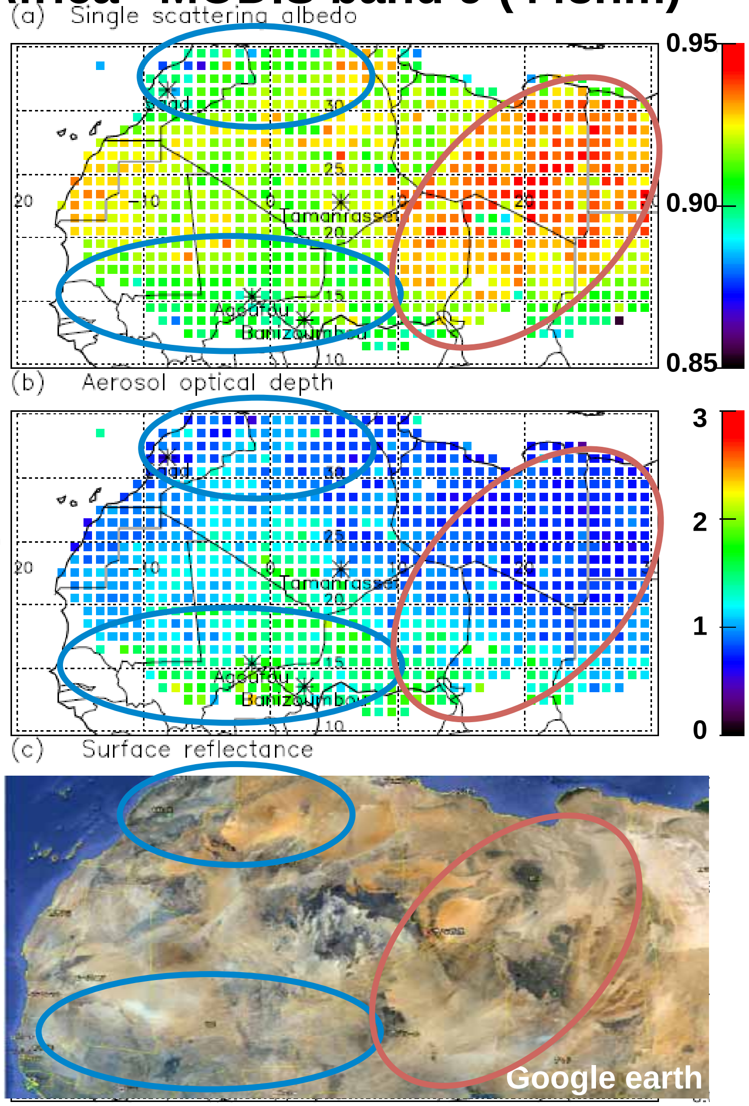
Dust optical properties
by Neutral (critical) reflectance method of Kaufman (JGR 87)
extended by *Yoshida et al. (ACPD 12)*

- 9 year mean (2003-2011), OMI prescreen
- Lower SSA in Asia: Dust and soot mixed
- SSA related with land albedo

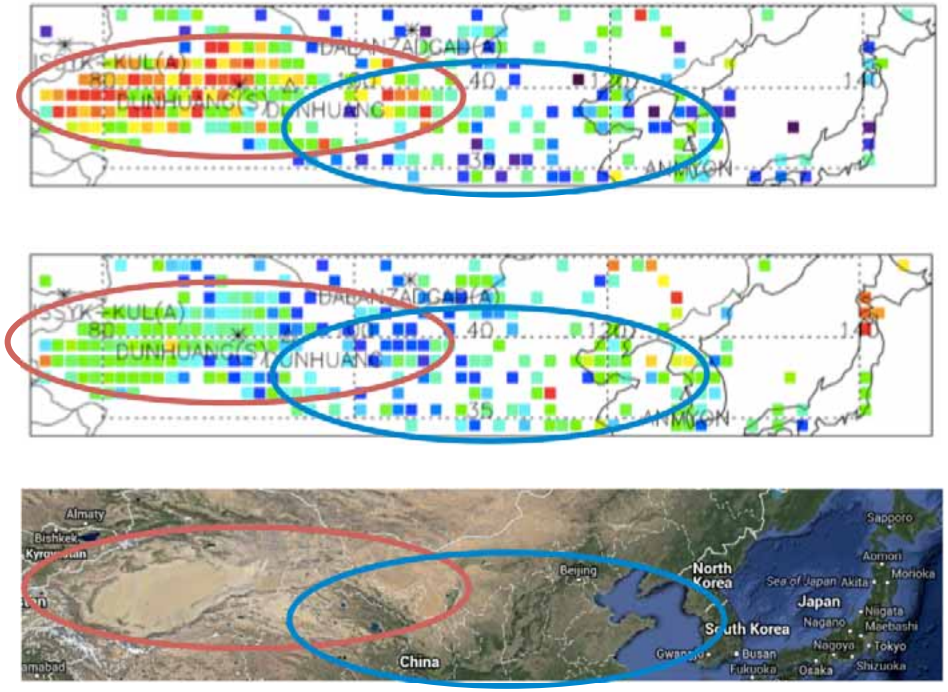
Africa MODIS band 9 (443nm)

SSA

AOT



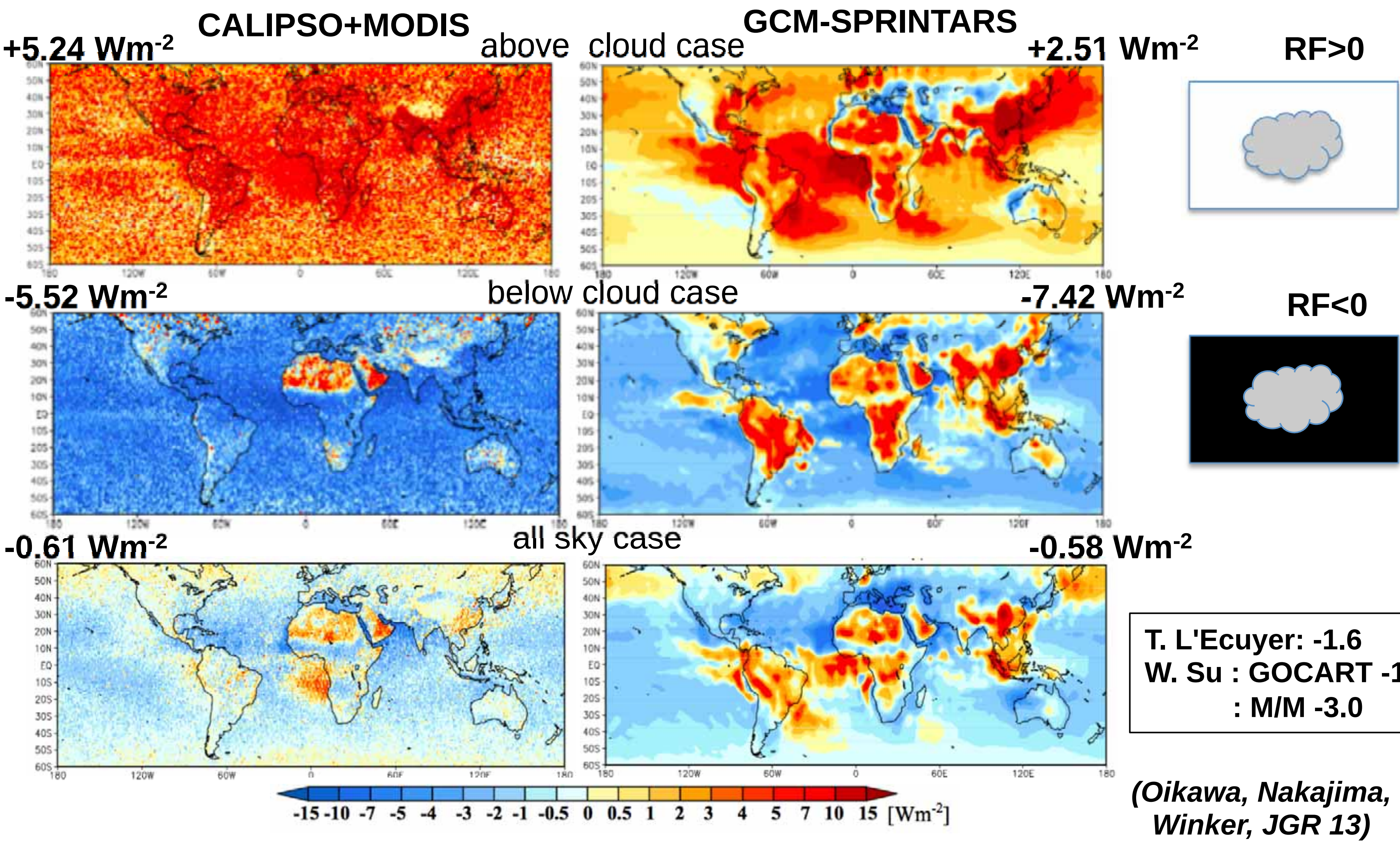
Asia



RE>0 RE=0 RE<0

TOA SW DRF for total aerosol from CALIOP

- **COT from MODIS; aerosol and cloud layering from CALIPSO**
- **Good agreement between satellite and mode; but large uncertainty in layer classifications**
- **Large uncertainty in model values**



T. L'Ecuyer: -1.6
W. Su : GOCART -1.9
: M/M -3.0

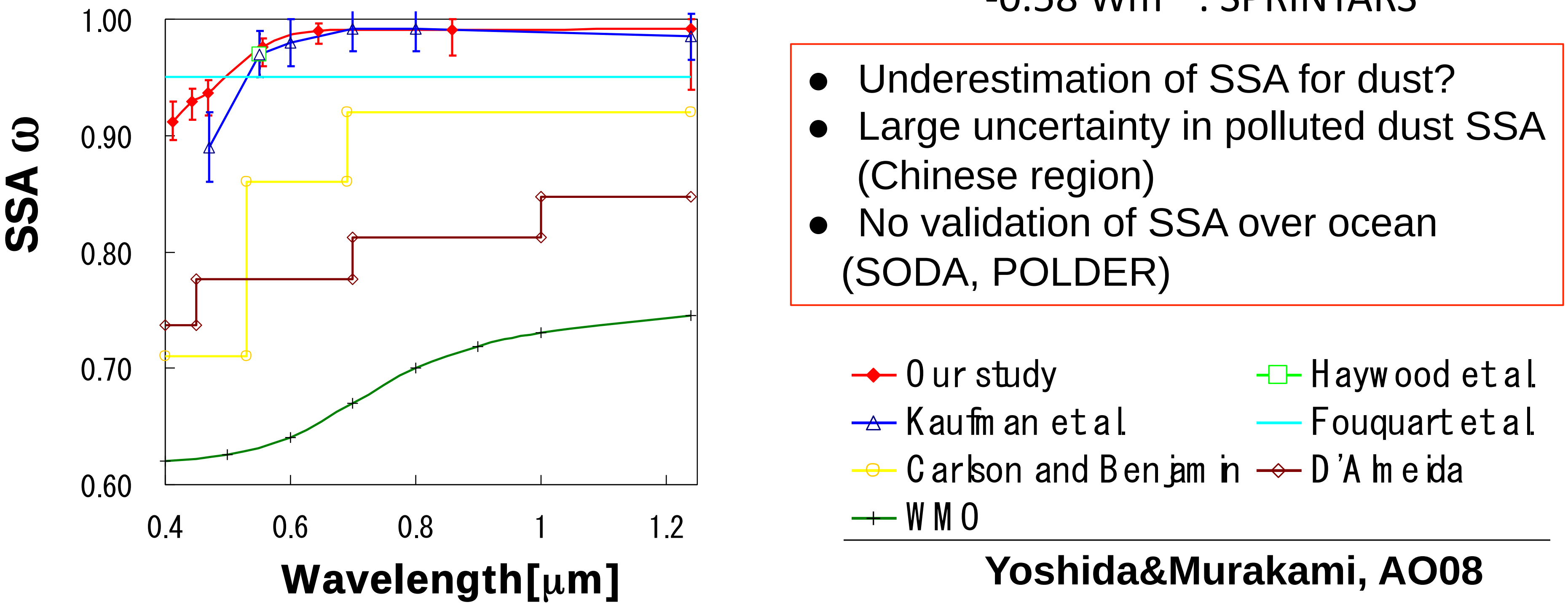
(Oikawa, Nakajima, Winker, JGR 13)

CALIOP aerosol optical models (Omar et al., JAS 09)

parameters @532nm	Desert dust	Smoke	Background	Polluted continental	Marine	Polluted dust
alfa	0.940	1.408	0.276	1.604	-0.137	1.154
ssa	0.919	0.833	0.904	0.935	0.986	0.851
sratio	42.3	74.9	38.2	69.2	23.6	62.0

$ARF_{anth\ direct}$= -0.2 : SPRINTARS

$ARF_{total,\ direct}$= -0.61 Wm^{-2} : CALIPSO
-0.58 Wm^{-2} : SPRINTARS



- Underestimation of SSA for dust?
- Large uncertainty in polluted dust SSA (Chinese region)
- No validation of SSA over ocean (SODA, POLDER)

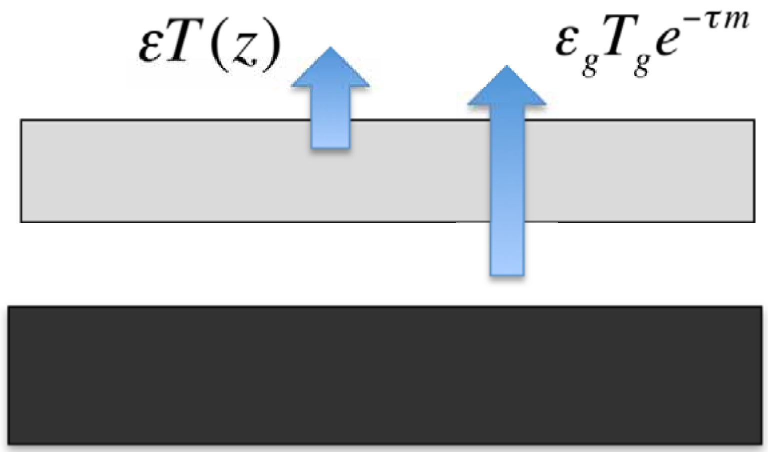
Yoshida&Murakami, AO08

For separation of coarse and fine particles

- **Use of TIR spectral region for coarse particle detection**

not available

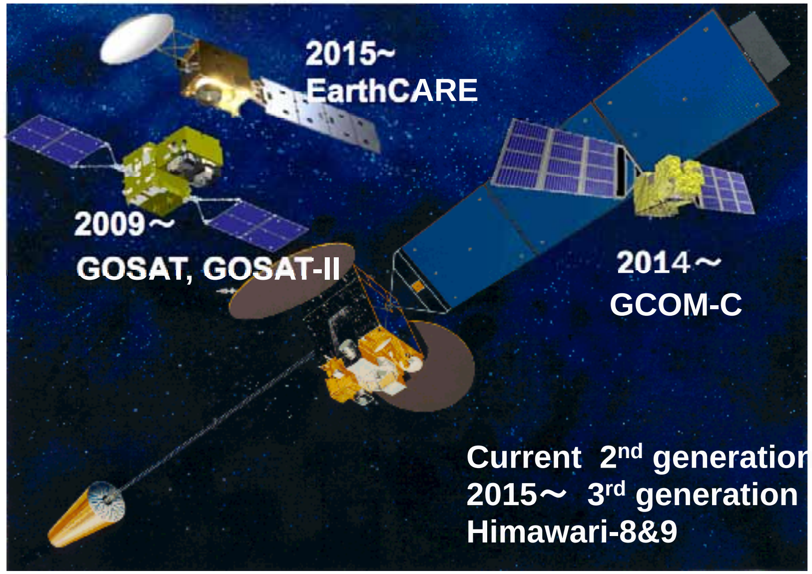
Courtesy: Hyojin Han & B.J. Sohn (2013)



AOT_{coarse}
$Height_{coarse}$

AOT_{fine} <<1 **in TIR**

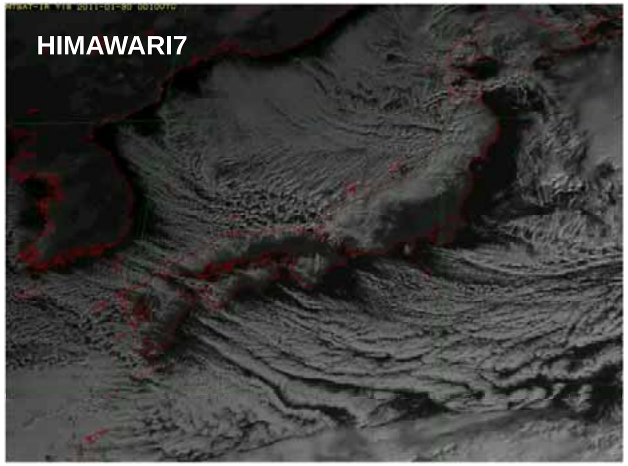
Next generation satellites



AHI specs, JMA/ HIMAWARI-8/9

16 bands (1km, 2km)
Full disk scan every 10min
Rapid scan every 2.5 min

Aerosol and cloud monitoring

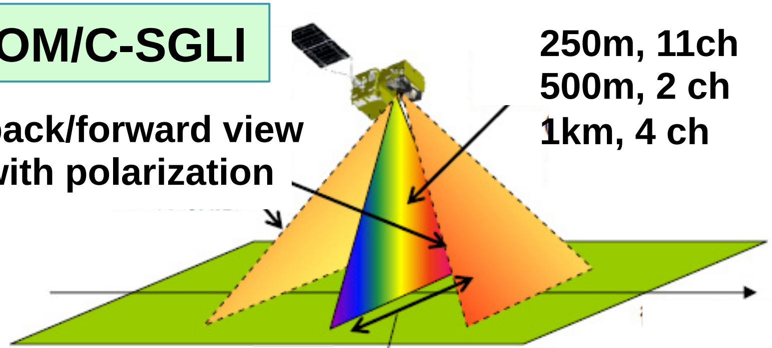


CGOM/C-SGLI

imager

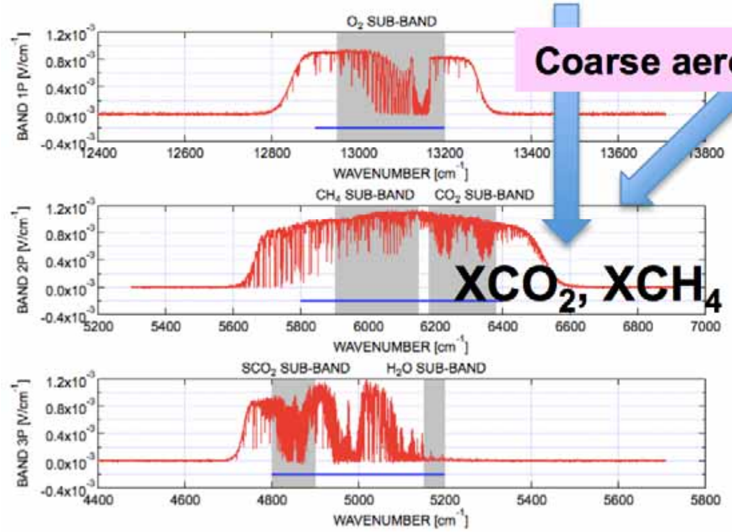
back/forward view with polarization

250m, 11ch
500m, 2 ch
1km, 4 ch



GOSAT2/FTS-SWIR **FTS-TIR** **CAI2**

Coarse aerosol correction

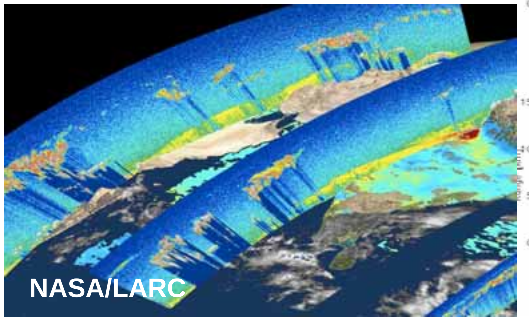


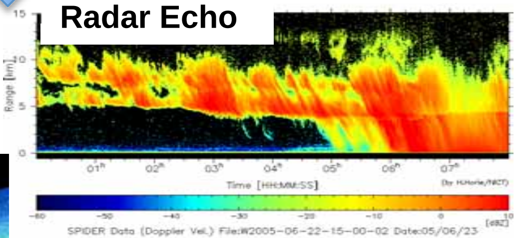
Imaging

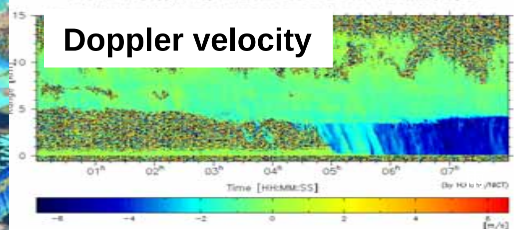
Dynamics with aerosol

ESA-JAXA/EarthCARE

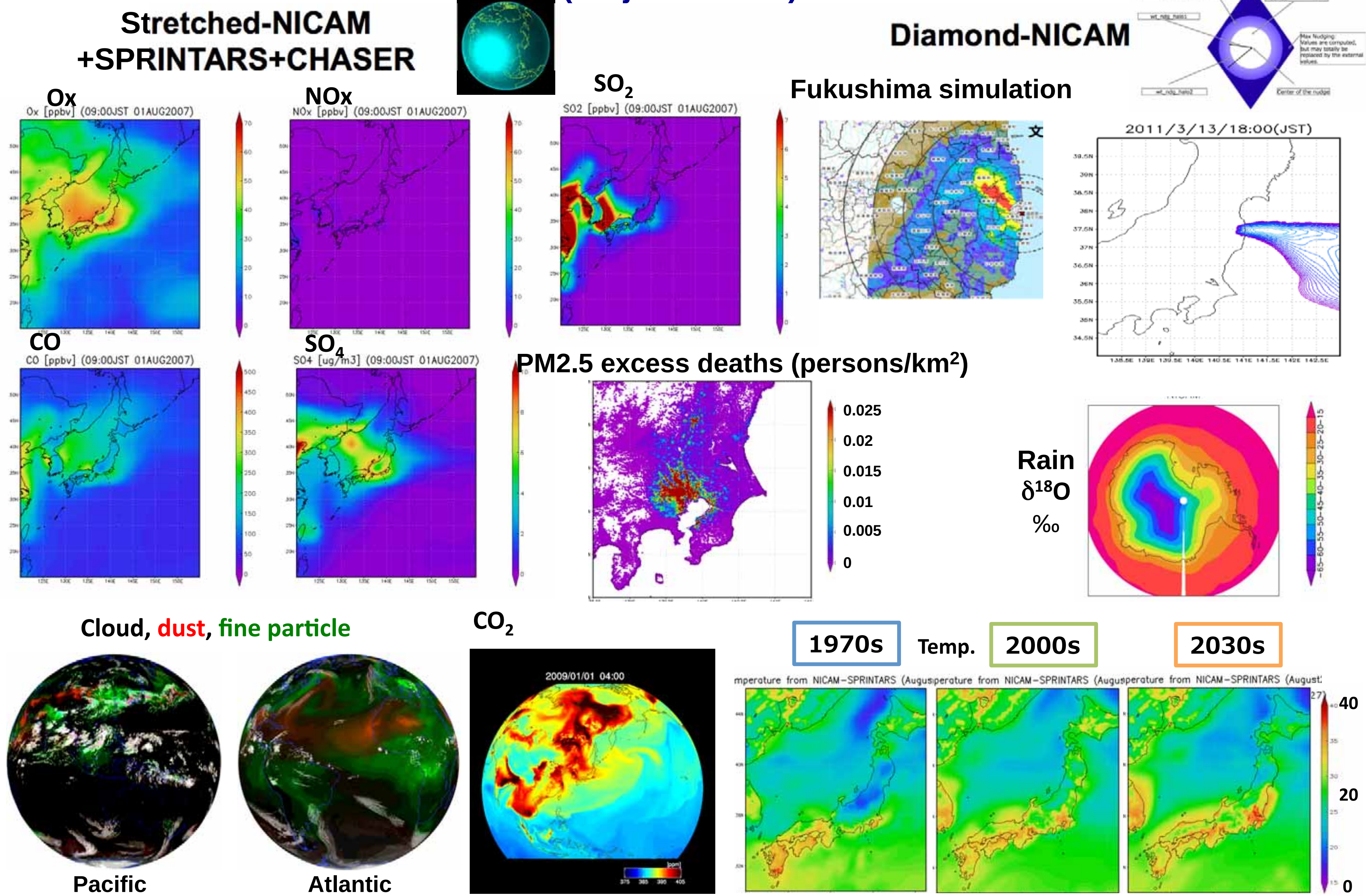
Aerosol forcing







MEXT/RECCA Programme
AssimiLation System and its Application for Atmospheric Environmental Materials (Project SALSA)



Conclusions

- **Awareness of absorbing aerosols for environmental and climate issues**
- **Man-made and dust aerosol mixture**
- **Information from NUV to TIR wavelength / multi-view and polarization useful**
- **Combined active/passive remote sensing for aerosol and cloud interaction**
- **Observation and modeling synergy in progress**