Aerosol observations using S-GLI sensor

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and CI team

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1. GCOM satellite series
   GCOM-C1 / SGLI
2. Aerosol retrieval for SGLI
   2ch polarization method
   by POLDER

   2ch polarization & 1ch total radiance method
   by POLDER + GOSAT / CAI
3. $PM_{2.5}$ retrieval
4. Summary

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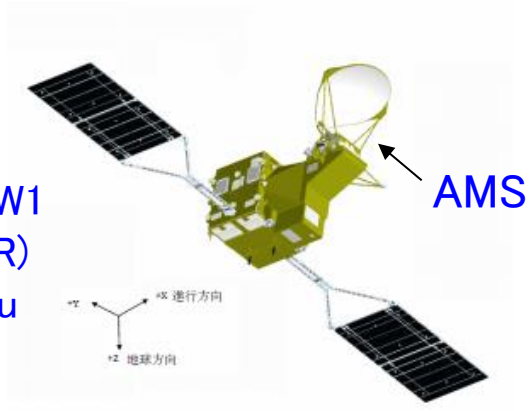
Global Change Observation Mission (GCOM)

2 satellite series for 5 years, total 13 years observation.

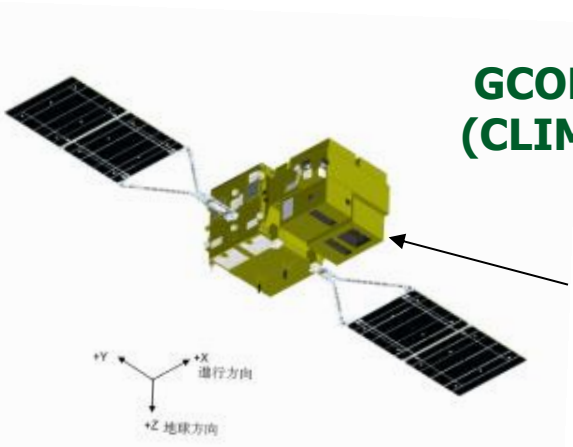
- ✓ **GCOM-W** AMSR2 (AMSR-E follow on microwave radiometer) for **WATER CYCLE** (Satellite name : 雫)
- ✓ **GCOM-C** SGLI (GLI follow on) for **RADIATION BUDGET** and **CARBON CYCLE**

GCOM-W1
(WATER)
Shizuku



Sensor	Advanced Microwave Radiometer 2 (AMSR2) Passive Microwave Observation Water vapor, soil moisture etc

GCOM-C1
(CLIMATE)

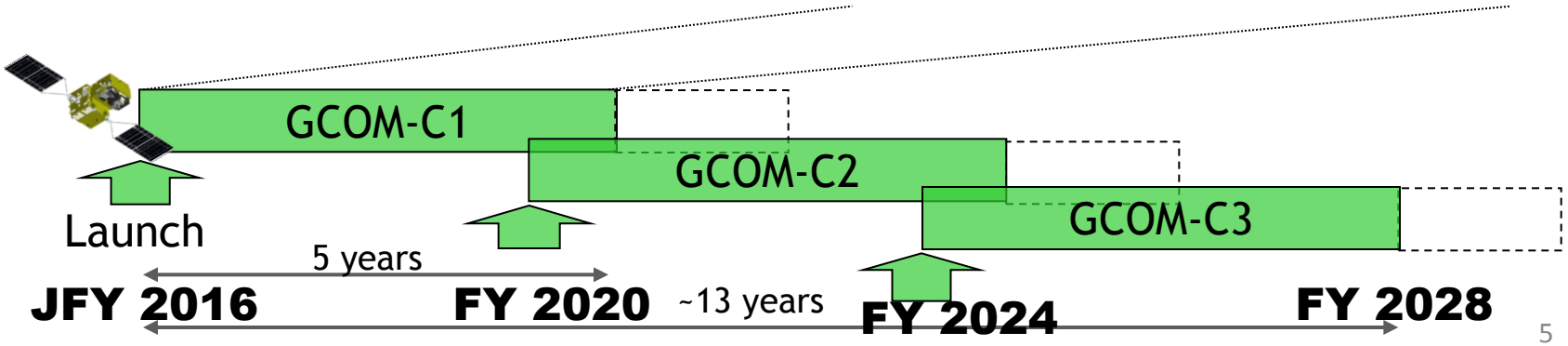


Sensor	Second Generation Global Imager (SGLI) Optical Observation 380nm – 12 micron Cloud, Aerosol, Vegetation, Chlorophyll etc

Courtesy of Dr. Tanaka (JAXA/EORC)

Impremention Plan : Milestone

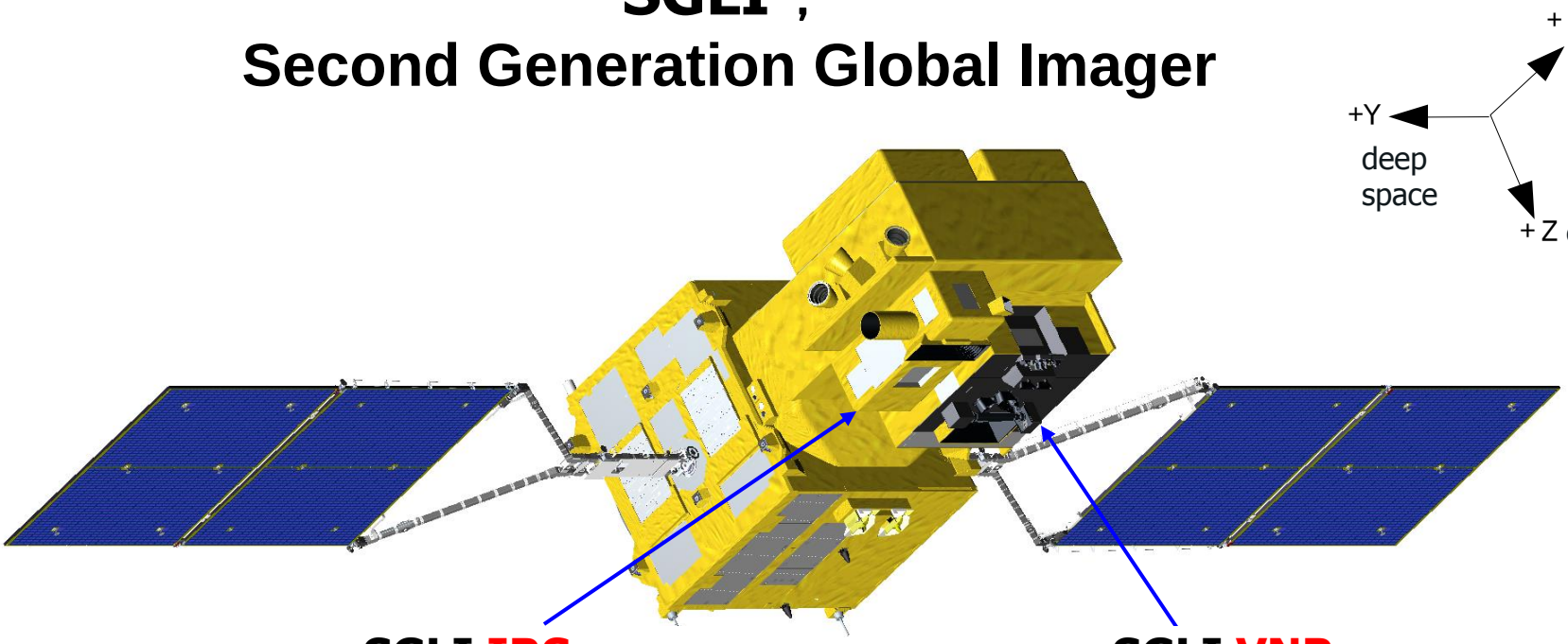
Japanese Fiscal Year Apr~	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Sensor development & calibration	1. Design and trial manufacturing		2. Sensor manufacturing & tests				3. Initial calibration	4. Operation phase				
	BBM		EM			PFM						C2 Launch
	Phase-A	Phase-B	Phase-C		Phase-D							
	Project start		System PDR		System CDR		GCOM-C1 launch			Data Release	Mission result evaluation	
Research Announcement	RA#1					RA#2			RA#3			
Product version ups & Software implementation					Selection	Ver.0	Ver.1	Ver.2	Ver.2.5	Ver.3 for C-1&2		
	Analysis using existing satellite data				Inplementation-1 Performance test	Imple. -2 Operation test	Intensive Cal/Val phase	Improvement with product version up		Implement for C2	Version-ups & improvement	
Algorithm development & improvement	1. Initial development		2.Performance development		3. Operational algorithm		4. Post-launch development and improvement phase					
	• Preparation study • Investigation of candidates		• Theoretical performance and applicability		• Selection & development of operational algorithm		• Product validation and improvement • Achievement of GCOM-C science targets • New algorithm and usage • Succession to the GCOM-C2					
	Development of algorithm performance and operational code											



Courtesy of Dr. Murakami (JAXA/EORC)

SGLI on GCOM-Climate #1 satellite

SGLI ;
Second Generation Global Imager

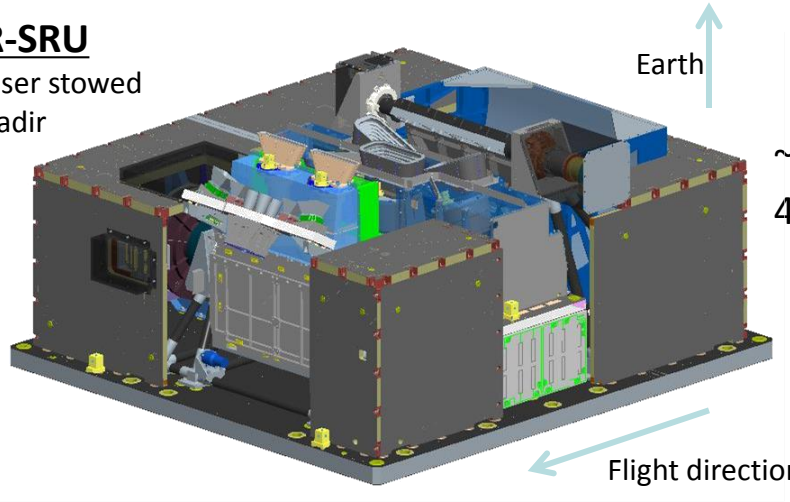


Mission Life	> 5 years
Solar Paddle	> 4000w（End of Life）
Mass	about 2,000kg

Courtesy of Dr. Tanaka (JAXA/EORC)

SGLI Visible and Near infrared radiometer (SGLI-VNR)

VNR-SRU
- Diffuser stowed
- PL Nadir

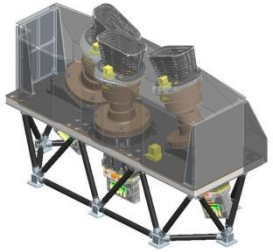


~290kg
400 W max

October 2011 Post Acoustics Alignment

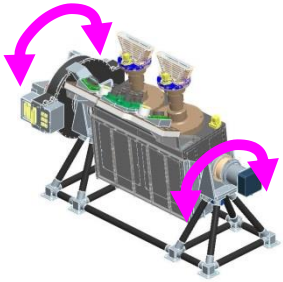
■ VNR non Polarized Obs. (NP)

- 3 telescopes with 24deg FOV realize the total 70 deg FOV Observation (1,150km)
- Wide wavelength range Observation from **380** to 869 nm.



■ VNR Polarized Obs. (PL)

- 2 telescopes with 55 deg FOV each for **674** and **869** nm Observation.
- **AT tilting** mechanism for **+ / - 45deg**
- 55 deg FOV with 45 deg tilting



674 & 869 nm telescopes

±45deg tilting

Courtesy of Dr. Tanaka (JAXA/EORC)

SGLI Required Performance

Multi-angle obs. for 674nm and 869nm

250m over the Land or coastal area, and 1km over offshore

GCOM-C SGLI characteristics	
Orbit	Sun-synchronous (descending local time: 10:30) Altitude 798km, Inclination 98.6deg
Mission Life	5 years (3 satellites; total 13 years)
Scan	Push-broom electric scan (VNR) Wisk-broom mechanical scan (IRS)
Scan width	1150km cross track (VNR: NP & PL) 1400km cross track (IRS: SWI & TIR)
Digitalization	12bit
Polarization	3 polarization angles for PL
Along track direction	Nadir for NP, SWI and TIR, +45 deg / -45 deg for PL
On-board calibration	VN: Solar diffuser, LED, Lunar cal maneuvers, and dark current by masked pixels and nighttime obs. SW: Solar diffuser, LED, Lamp, Lunar, and dark current by deep space window T: Black body and sensor back ground by deep space window

SGLI channels						
CH	λ	Δλ	L_{std}	L_{max}	SNR at Lstd	IFOV
	VN, P, SW: nm T: μm		VNR, SWI: W/m²/sr/μm T: Kelvin		VNR, SWI: SNR T: NEΔT	m
VN1	380	10	60	210	250	250
VN2	412	10	75	250	400	250
VN3	443	10	64	400	300	250
VN4	490	10	53	120	400	250
VN5	530	20	41	350	250	250
VN6	565	20	33	90	400	250
VN7	*673.5*	*20*	23	62	400	250
VN8			25	210	250	250
VN9	763	12	40	350	1200	250/1000
VN10	*868.5*	20	8	30	400	250
VN11			30	300	200	250
PL1	*673.5*	20	25	250	250	1000
PL2	*868.5*	20	30	300	250	1000
SW1	1050	20	57	248	500	1000
SW2	1380	20	8	103	150	1000
SW3	*1630*	200	3	50	57	250
SW4	2210	50	1.9	20	211	1000
TIR1	10.8	0.74	300	340	0.2	250/500
TIR2	12.0	0.74	300	340	0.2	250/500

19 channels

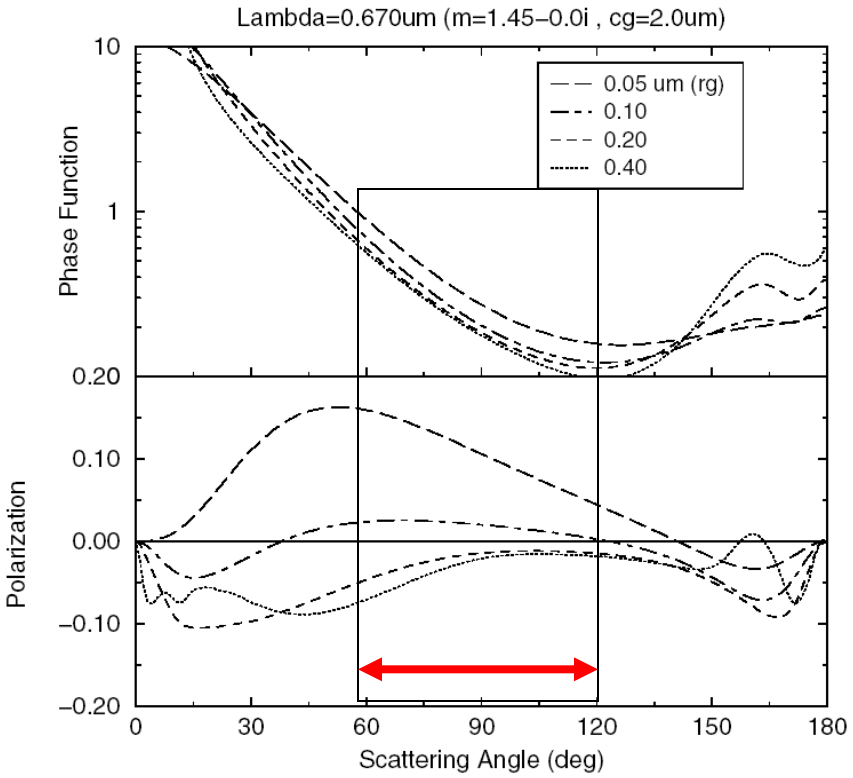
option

Courtesy of Dr. Tanaka (JAXA/EORC)

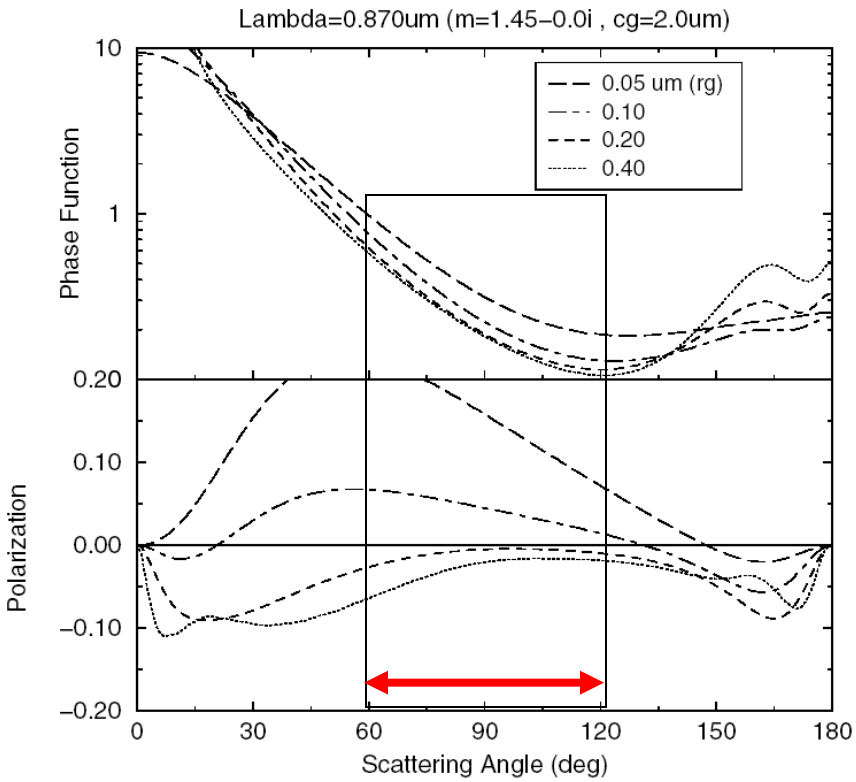
Polarized phase function : size information

(rg= 0.05, 0.1, 0.2, 0.4 μm, cg=2.0 μm fix)
m=1.45-0.0i fix

0.67 μm



0.87 μm



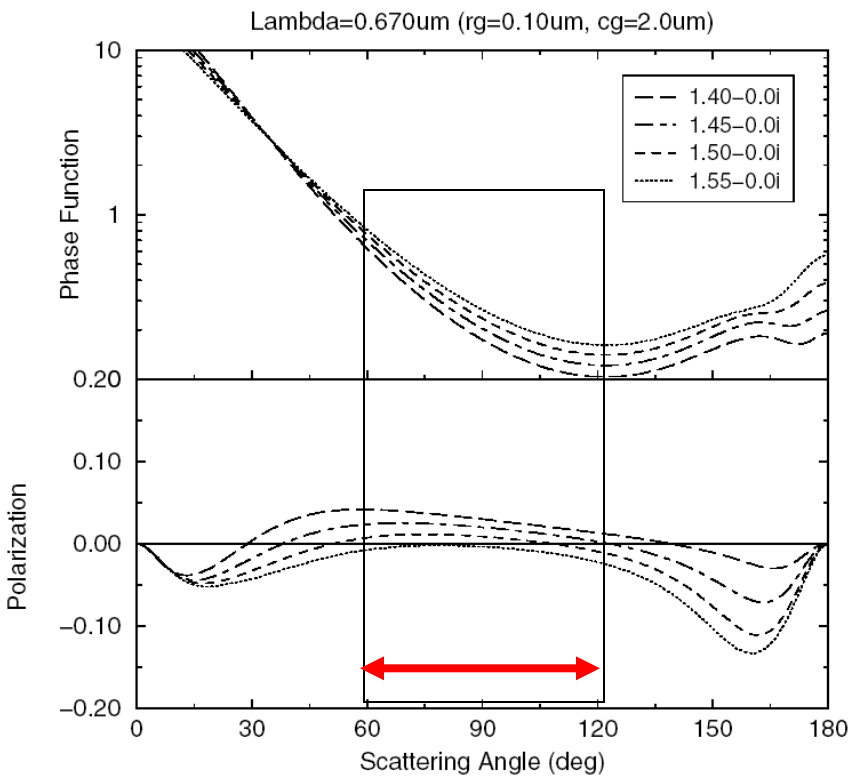
Middle scattering region

Polarized phase function : refractive index (real part)

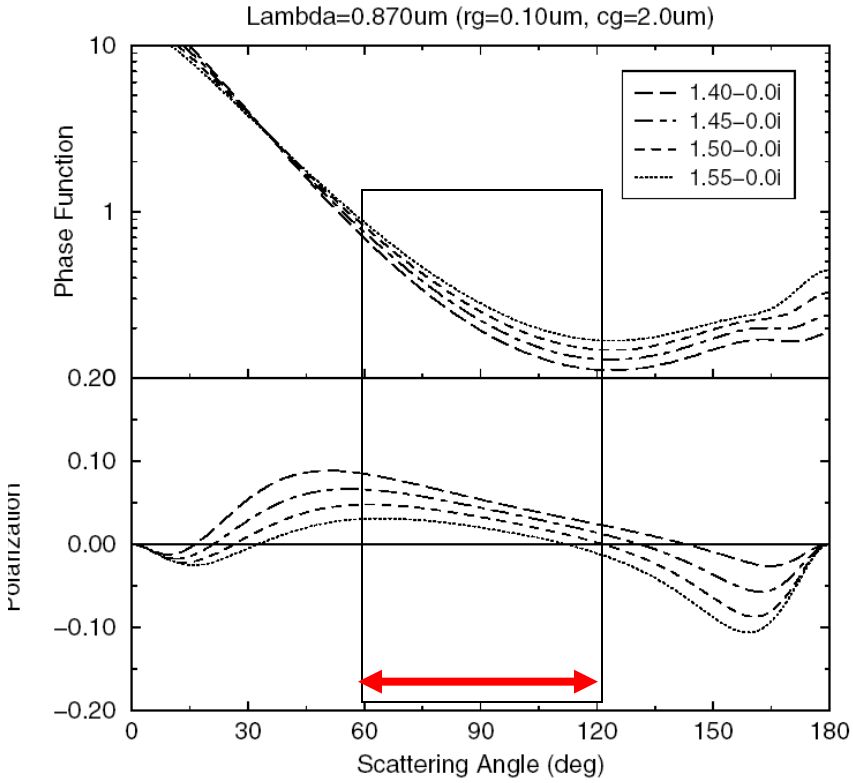
(rg= 0.1 μm, cg=2.0 μm fixed)

rfr=1.40, 1.45, 1.50, 1.55, rfi = 0.0 fixed

0.67 μm

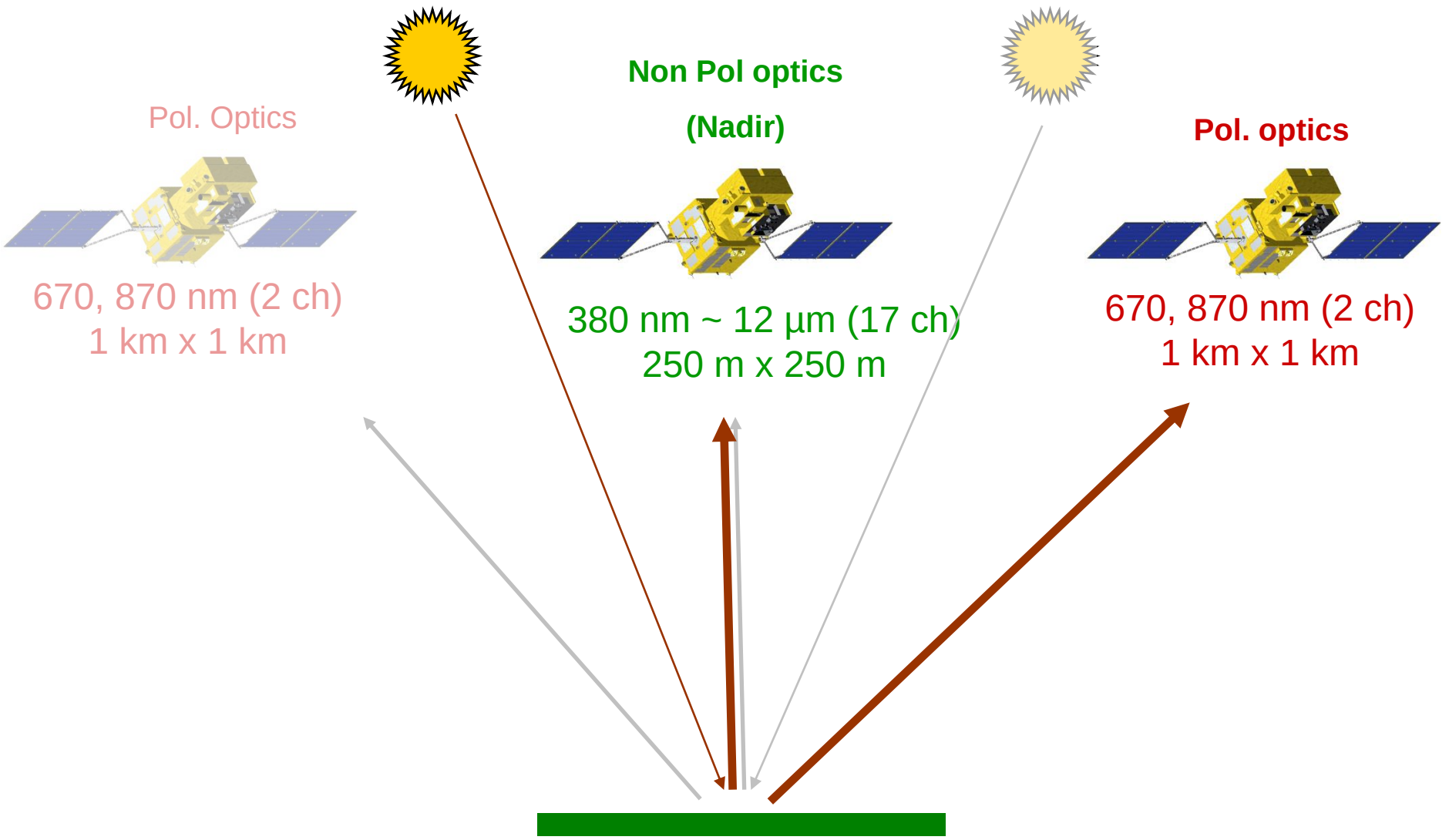


0.87 μm

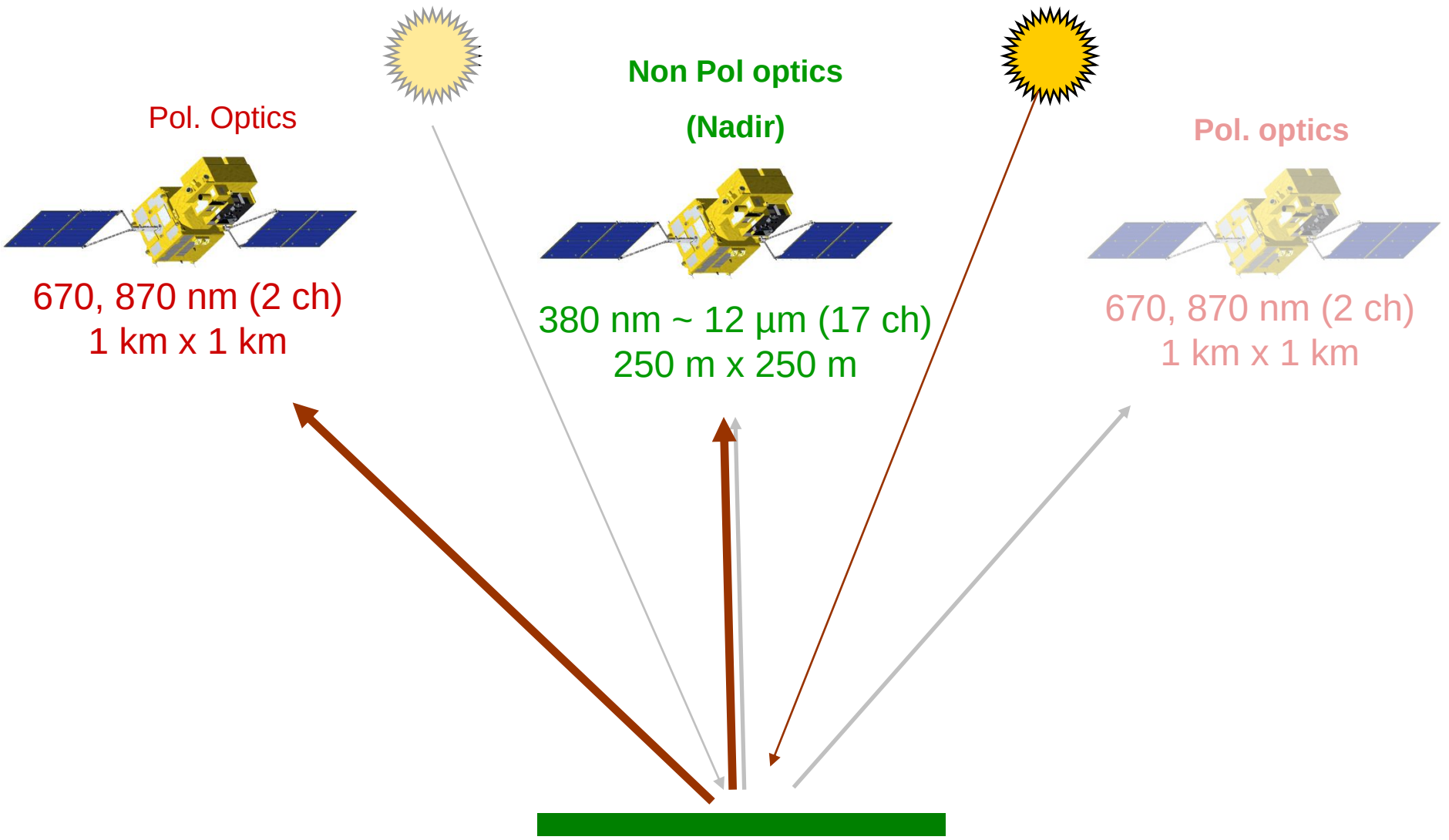


Middle scattering region

Two directional observations

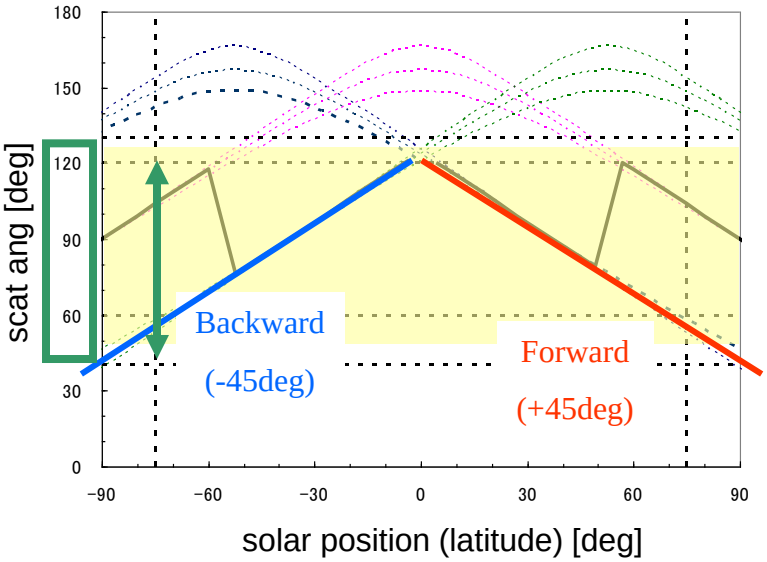


Two directional observations

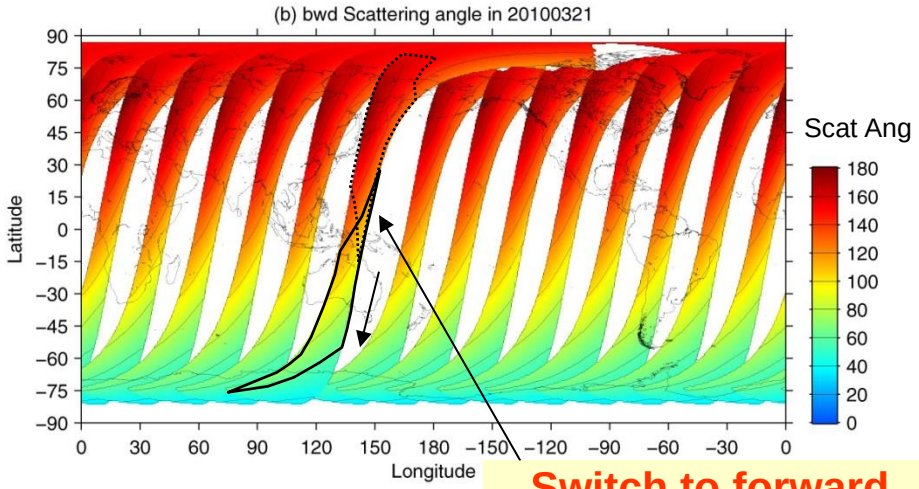


SGLI polarization measurements (tilting operation)

- SGLI measures the atmospheric light at the scattering angle from ~60 to ~120.

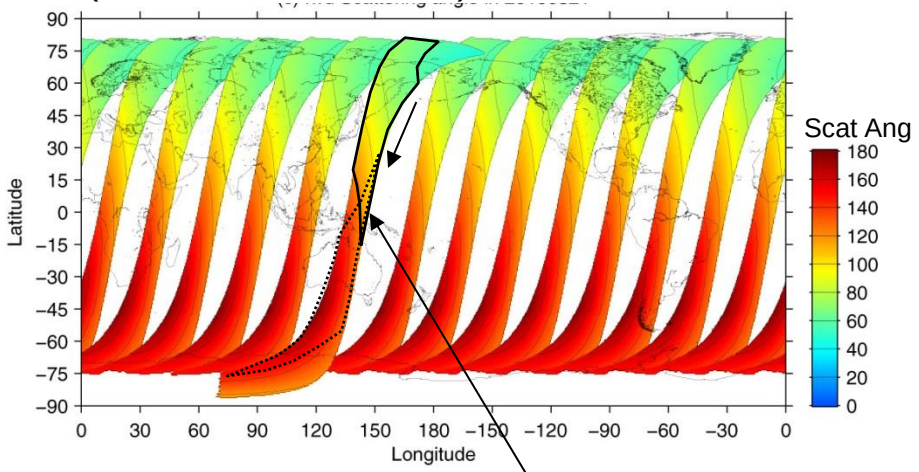


(-45 direction; backward)



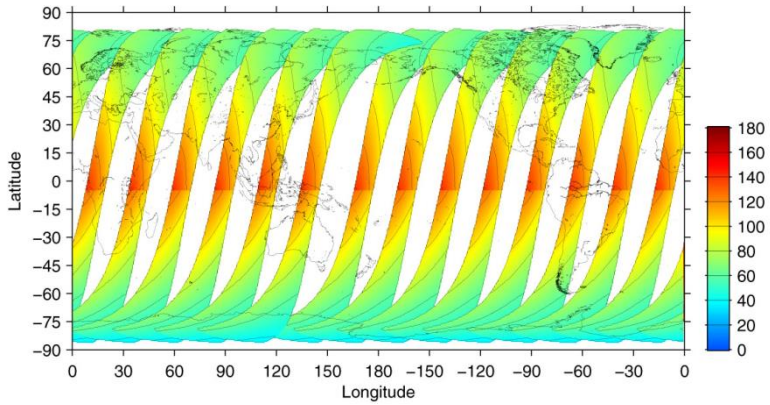
Switch to forward

(+45 direction; forward)

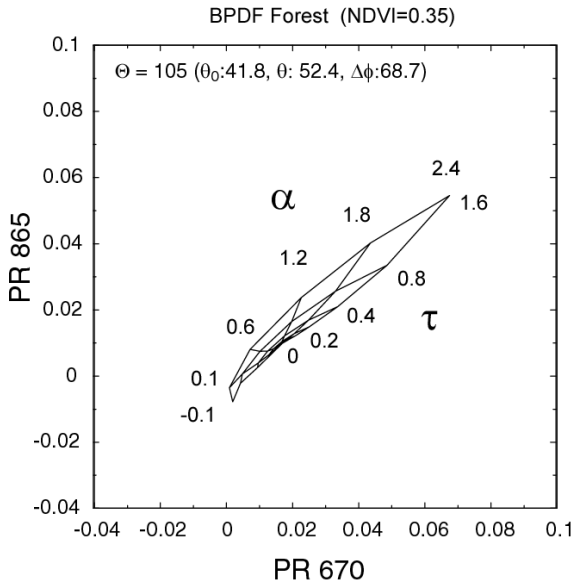


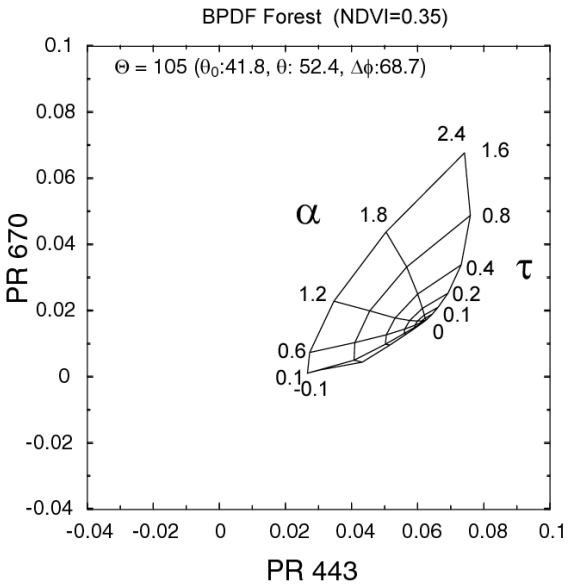
Switch to backward

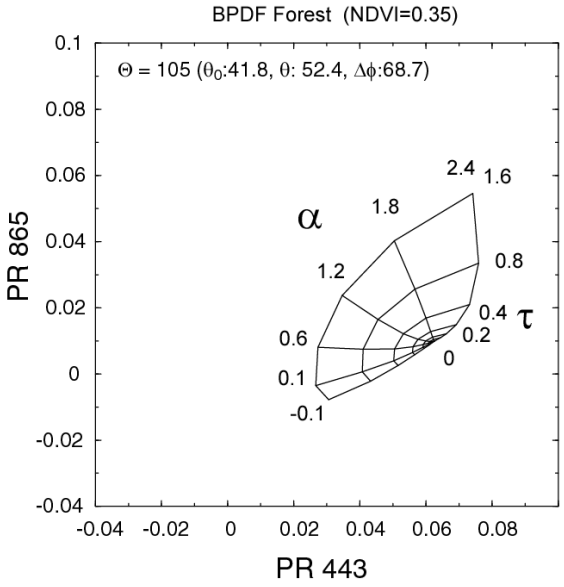
SGLI simulated scattering angle image



Selection of observational wavelengths







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SGLI aerosol products

ARV : Aerosol products over ocean derived from VNIR measurements
AOT, Ang. Exp., Aerosol classification

ARU : Aerosol products over land by Near UV measurements
AOT, Absorbing information

ARP : Aerosol products over land by Polarization measurements
AOT, and Ang. Exp.

POLDER
2ch (red & NIR) polarization over land : AOT, and Ang. Exp.

Retrieval algorithms

POLDER

2ch (red & NIR) radiance over ocean : AOT, and frac. of bi-mode

2ch (red & NIR) polarization over land : AOT, and frac. of bi-mode

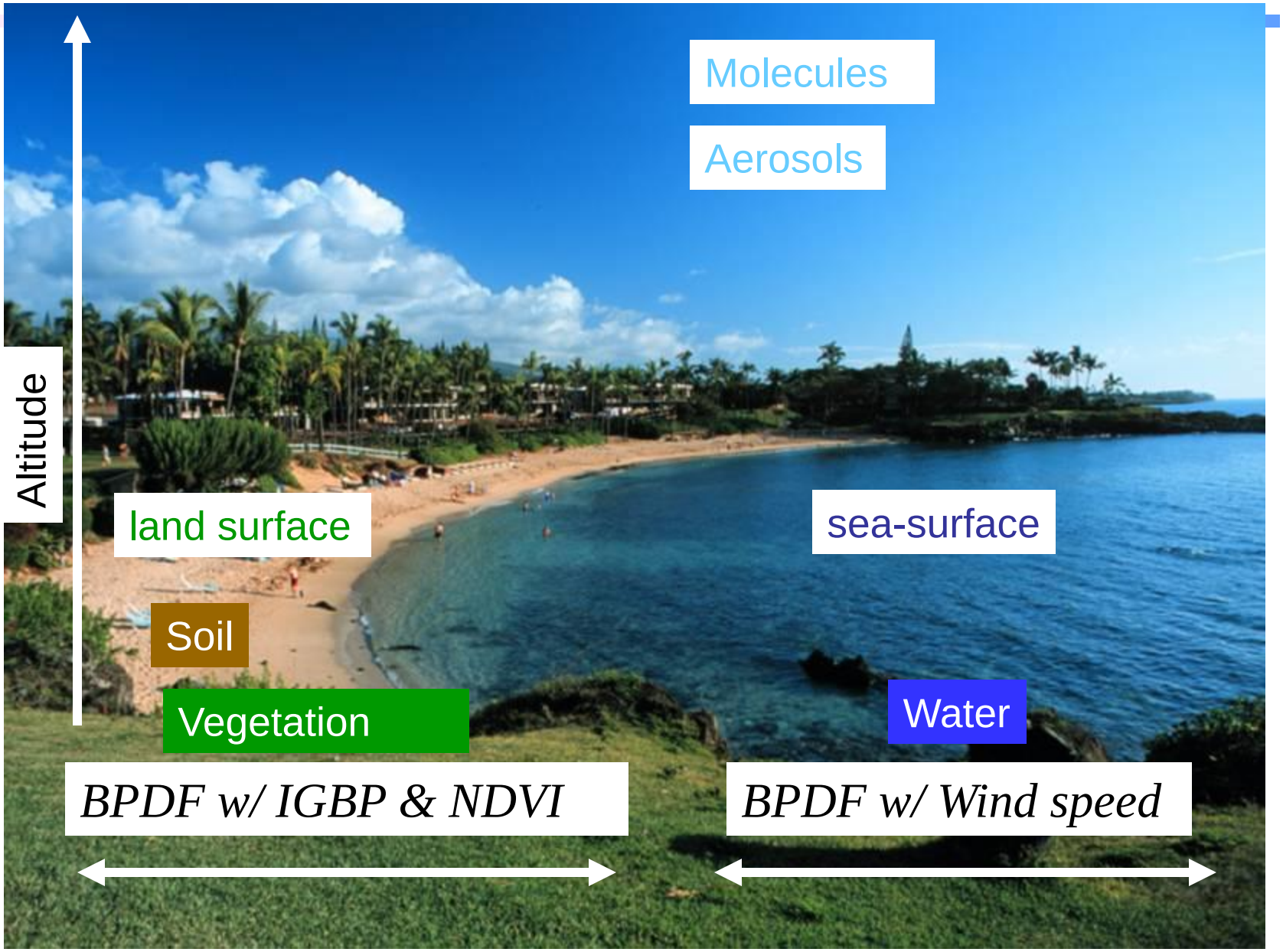
CAI + PARASOL

1ch (NUV) nadir radiance + 2ch (red & NIR) polarization over land : AOT, frac. of bi-mode, & SSA

SGLI (future algorithm)

multi-channels radiance + 2ch (red & NIR) polarization over land : AOT, fraction of bi-mode, & complex ref idx.

Land surface and Sea-surface model

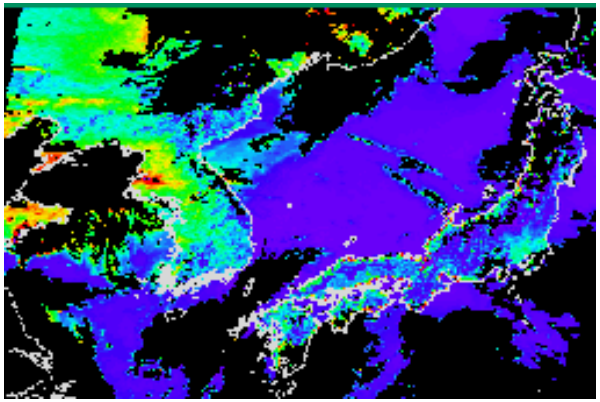
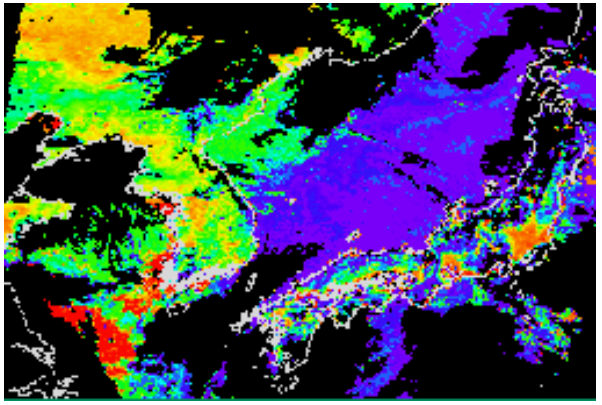
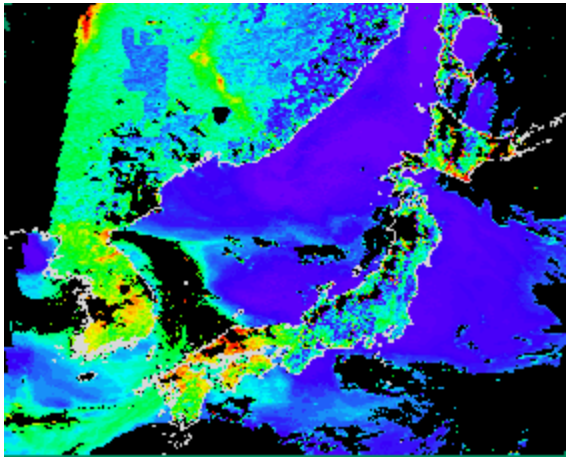
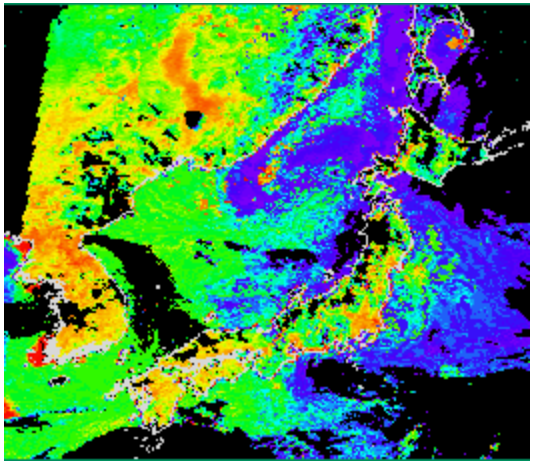


Atmosphere - ground/ocean surface model

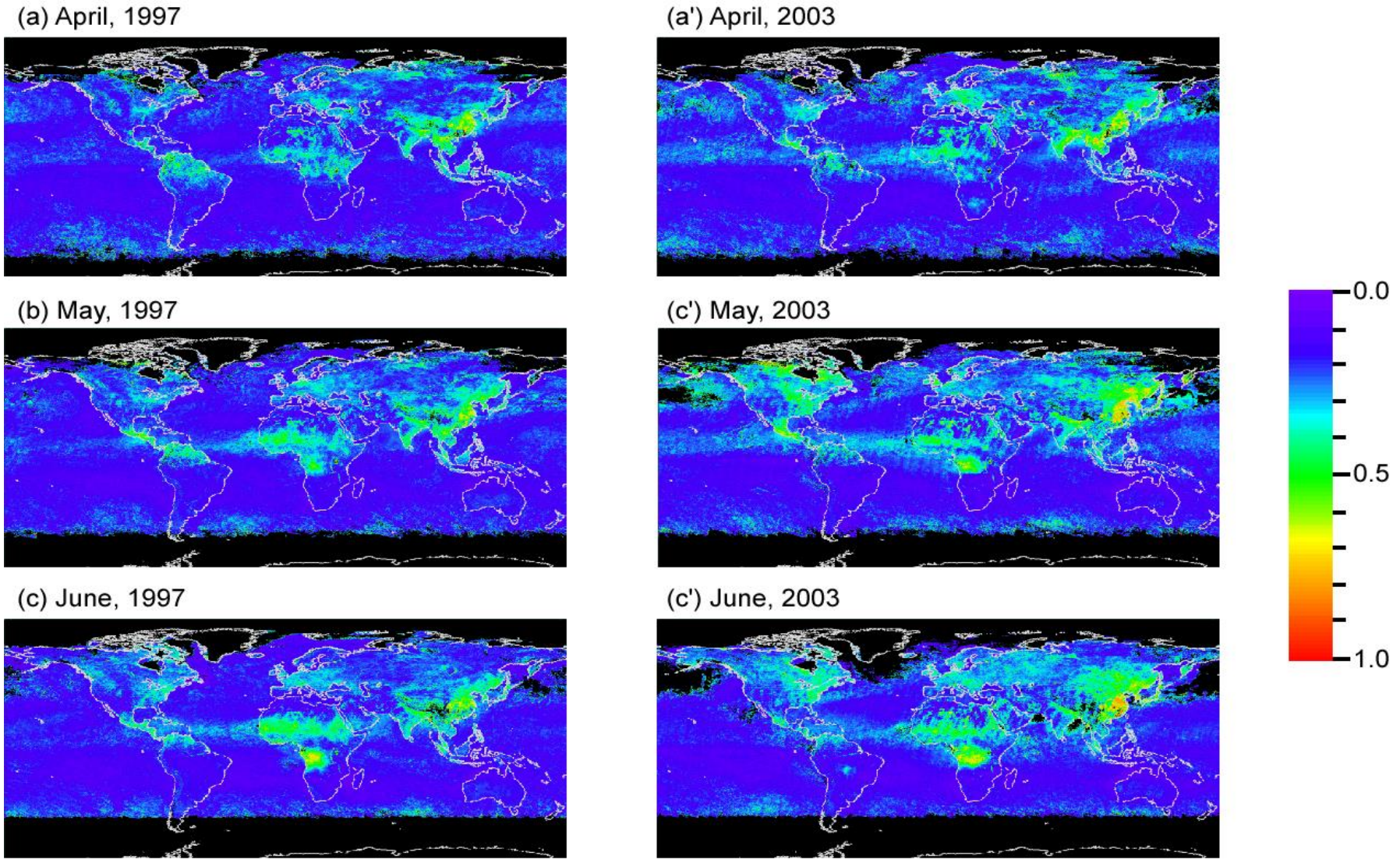
Table 1. Atmosphere-Earth surface system.

Models	Descriptions
Aerosol models	
1. concentration :	Optical thickness of aerosols (ta),
2. size :	Angstrom exponent (a), which is calculated from Mie-scattering theory assuming log- normal size distribution
3. chemical composition	Complex refractive index (m).
Molecular information	AFGL US standard by Kneizys et al. (1988)
Ocean surface model	Cox and Munk (1954) model with 5 m/s wind speed, for the clear day.
Ocean model	completely absorbent in the near infrared wavelength.
Land surface model	Bi-directional polarization distribution functions by Nadal and Breon (1999) is adopted for soil, vegetated, and mixed of both, which is selected by land surface condition at target area.
Land classification	IGBP land classification map (Loveland et al., 2000) and NDVI values from POLDER Vis.- NIR measurements.
Land altitude	5 cases; sea level, 1, 2, 3, 4 km height

Aerosols over Japan

	Aerosol optical thickness	Angstrom exponent
March 18, 1997		
April 25, 1997		

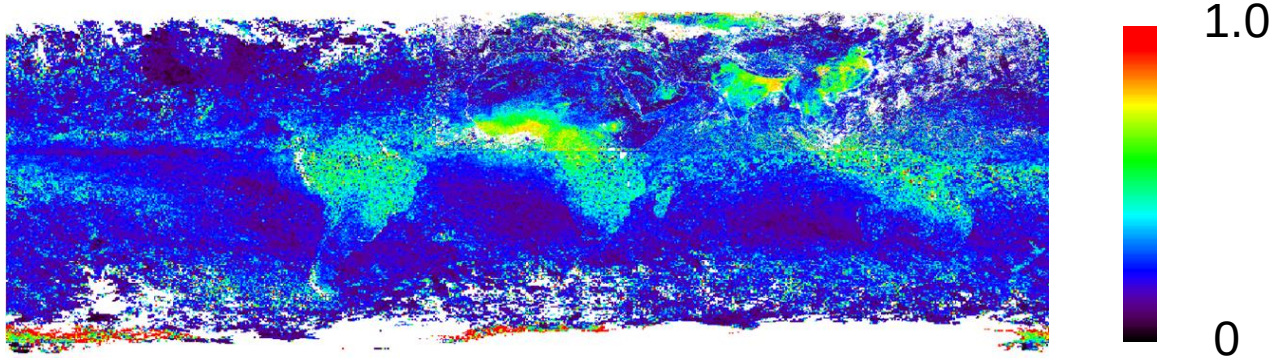
Monthly AOT (550 nm) distribution derived from ADEOS / POLDER and ADEOS-2 / POLDER-2



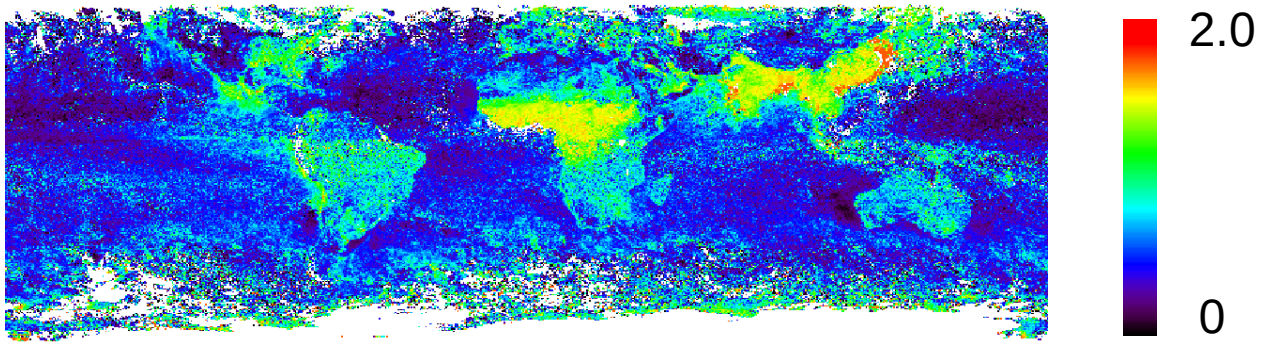
2ch polarization algorithm for SGLI

1 directional POLDER measurement
for SGLI simulation data

AOT @ 550 nm in Jan. 2009



Angstrom exponent in Jan. 2009



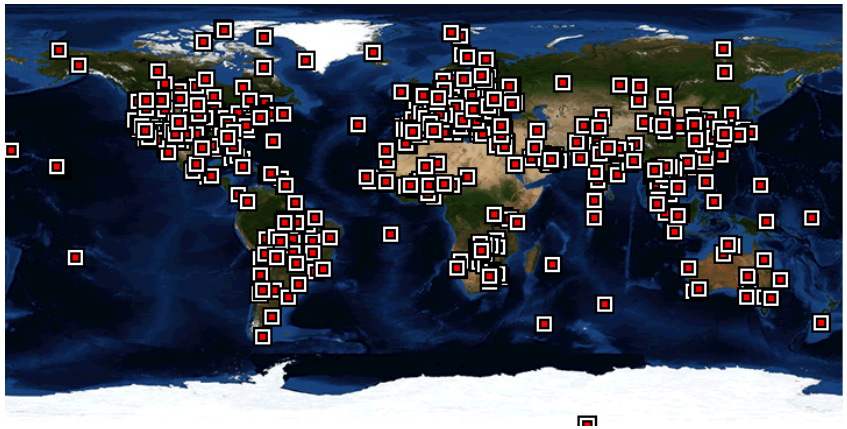
Courtesy of Dr. Hashiguchi (JAXA/EORC)

Validation Method

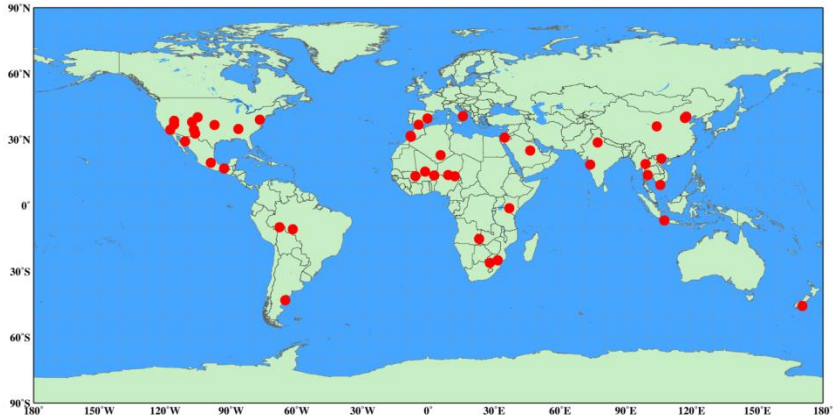
Validation data : AERONET level 2 (cloud-screened and quality-assured)

Validation are made according to the following rules

1. The measurements are selected within the ±30 min over satellite.
2. The AOT of 443 and 870 nm as ground based measurements are selected for calculating Angstrom Exponent.
3. The AOT of 550 nm is estimated based on the Angstrom Exponent and the measurement of 670 nm.



AERONET sites in 2012

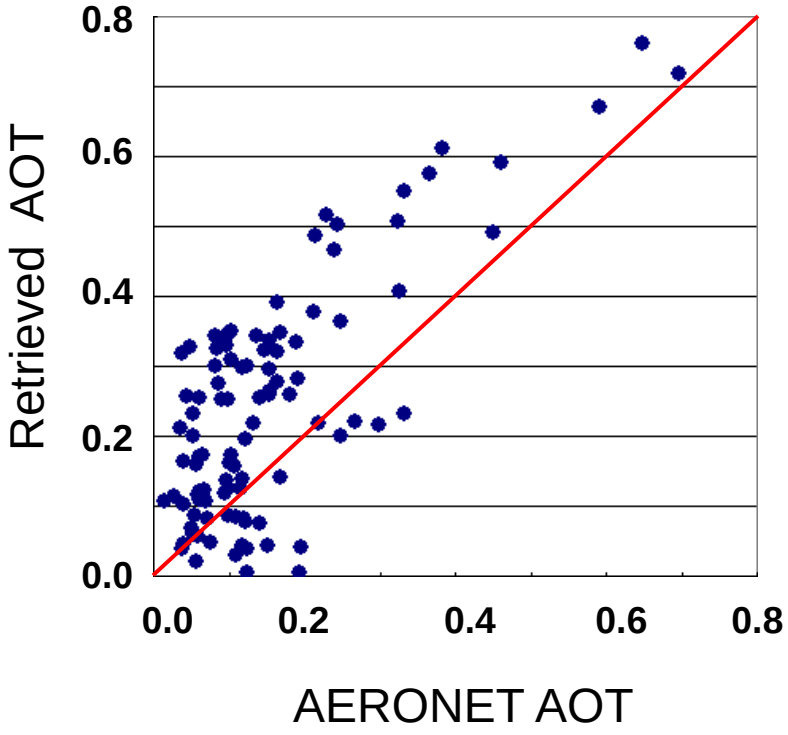


Selected AERONET sites

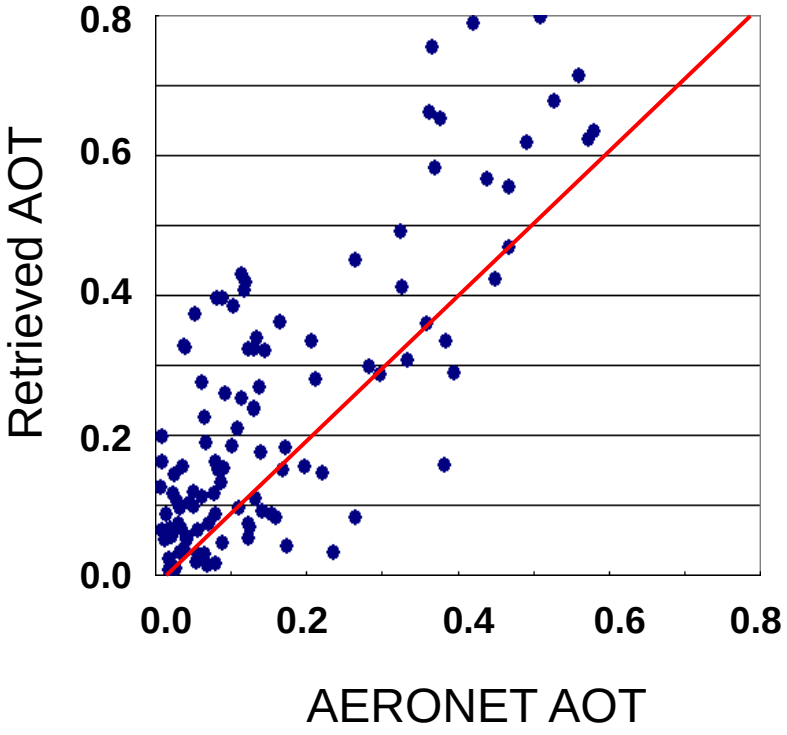
Courtesy of Dr. Hashiguchi (JAXA/EORC)

Validation of retrieved AOT (550 nm) with single mode size distribution

ADEOS-2 / POLDER-2
April and May in 2003
(RMSE=0.14, Corr. C=0.76)



PARASOL / POLDER
January and July in 2009
(RMSE=0.15, Corr. C=0.76)



Courtesy of Dr. Hashiguchi (JAXA/EORC)

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Retrieval algorithms

POLDER

2ch (red & NIR) radiance over ocean : AOT, and frac. of bi-mode

2ch (red & NIR) polarization over land : AOT, and frac. of bi-mode

CAI + PARASOL

1ch (NUV) nadir radiance + 2ch (red & NIR) polarization over land : AOT, frac. of bi-mode, & SSA

SGLI (future algorithm)

multi-channels radiance + 2ch (red & NIR) polarization over land : AOT, fraction of bi-mode, & complex ref idx.

TANSO - CAI on GOSAT

CAI – Cloud Aerosol Imager

a complimentary sensor for Fourier Transform Spectrometer (FTS) launched on 23rd January, 2009.

Four observing wavelengths : 380, 670, 870, 1600 nm.

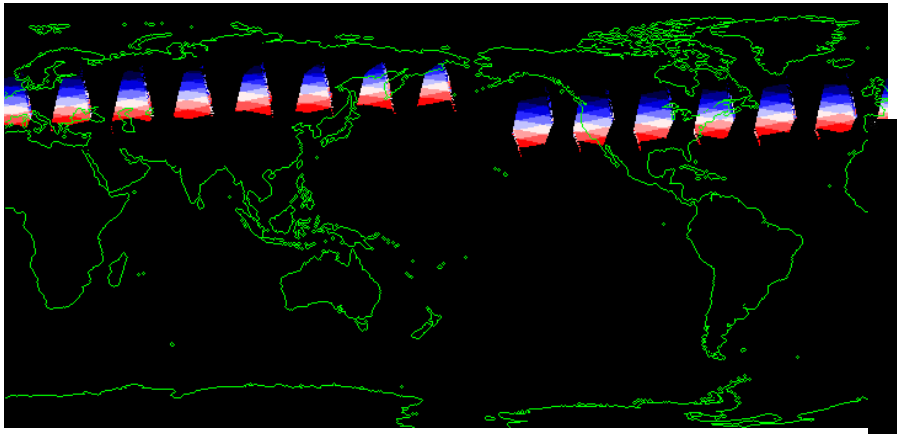
Level 1 data provide us with the TOA reflectance of the Earth.

	Band 1	Band 2	Band 3	Band 4
Spectral coverage (μm)	0.370-0.390 (0.380)	0.664-0.684 (0.674)	0.860-0.880 (0.870)	1.56-1.65 (1.60)
Targeted substances	Cloud and aerosol			
Swath (km)	1000	1000	1000	750
Spatial resolution at nadir (km)	0.5	0.5	0.5	1.5

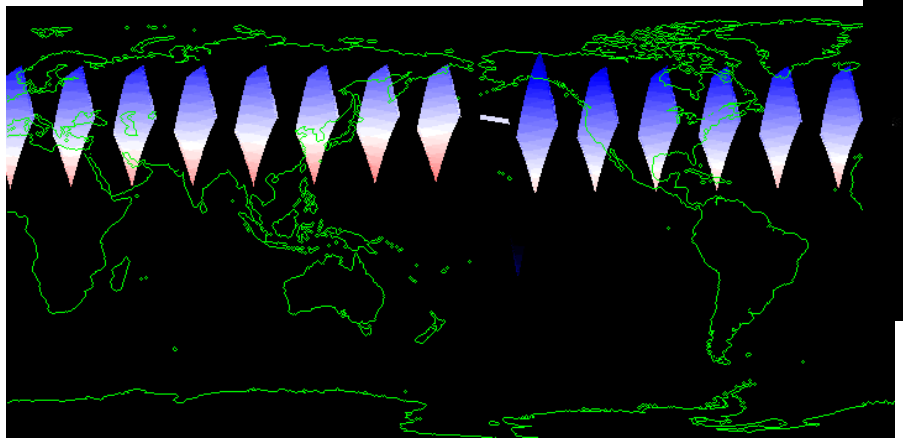
Dataset of A-Train's PARASOL and GOSAT : time difference

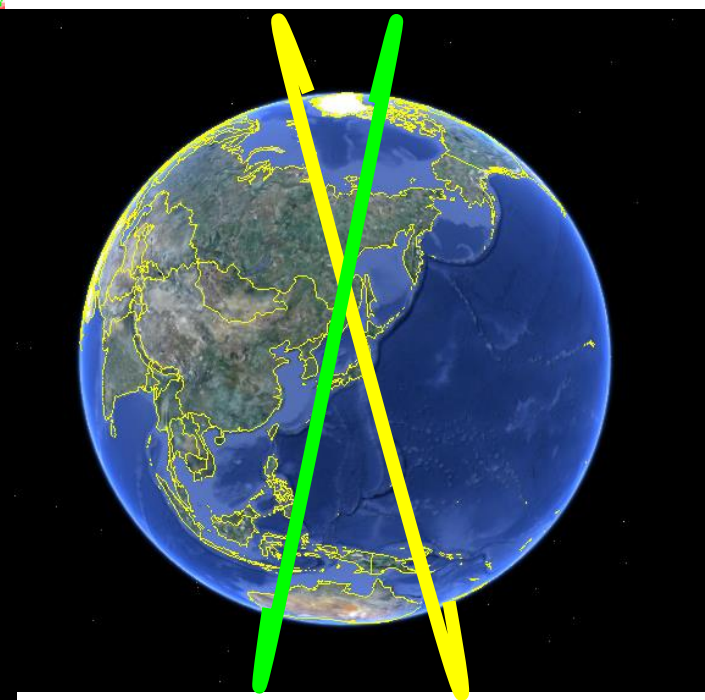
Apr. 25, 2009

± 5 min



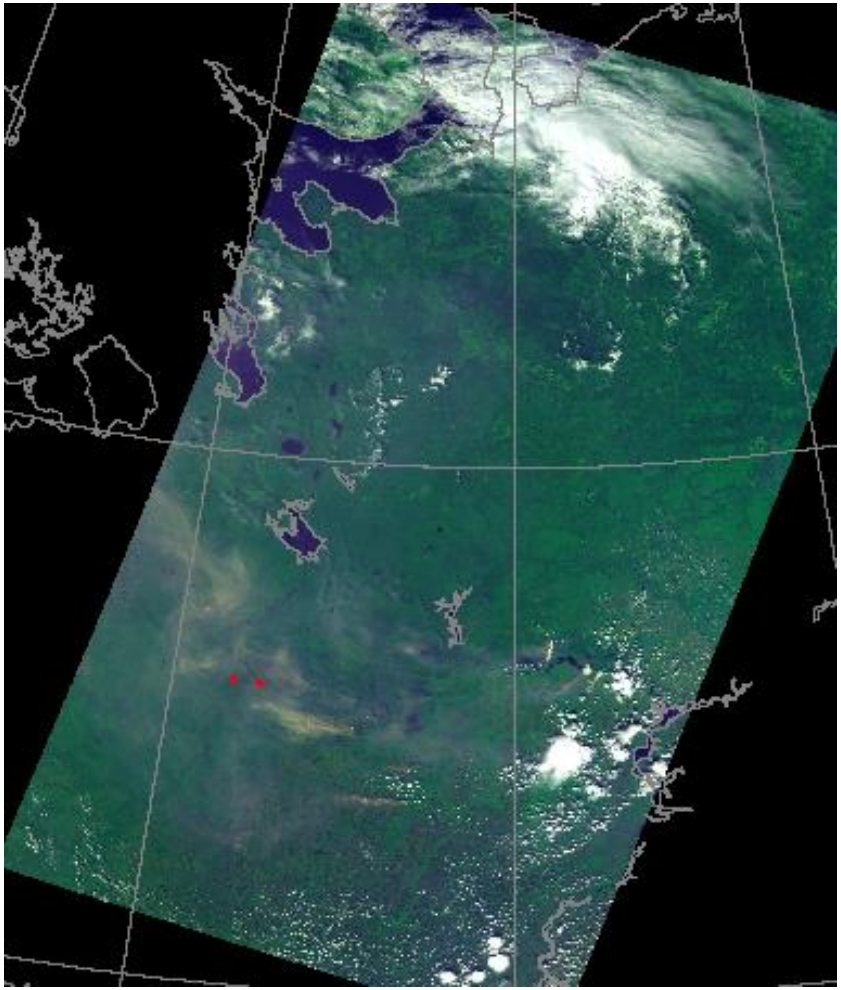
± 30 min



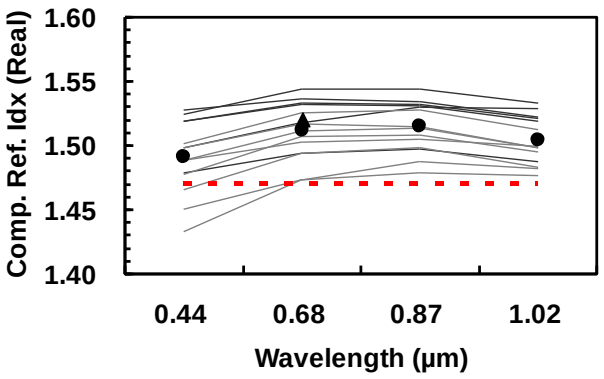


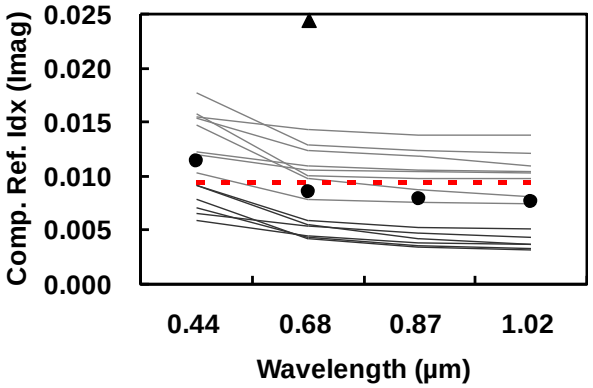
Forest fire event in Central Russia

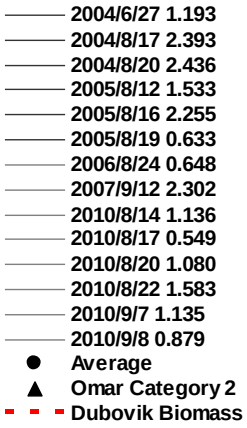
August 8 in 2010
Composite image by GOSAT / CAI



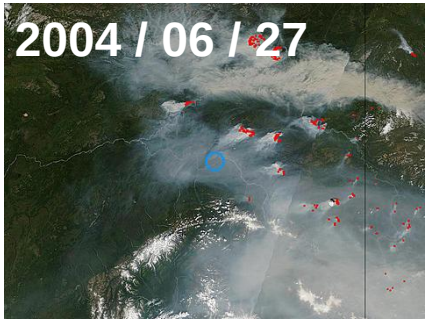
Biomass burning aerosols from AERONET
Alaska (Bonanza), Amazon (JI_Parana_SE)

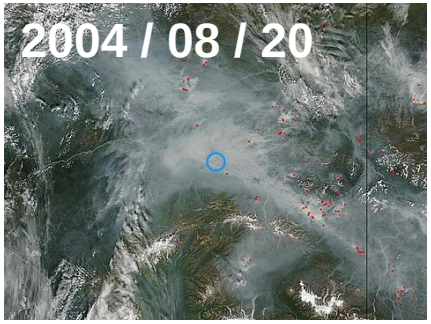


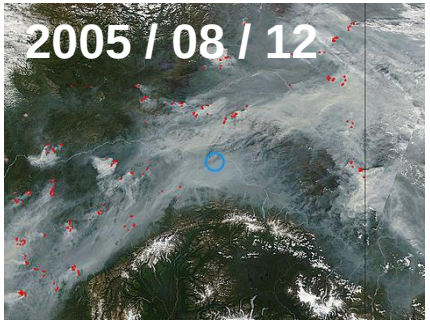




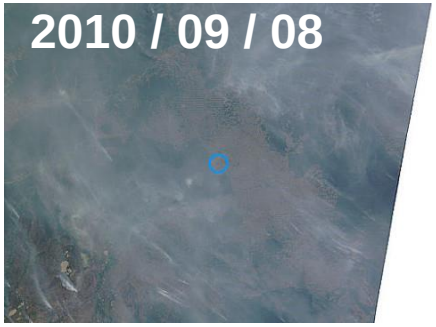
$\tau_{500} > 0.4$

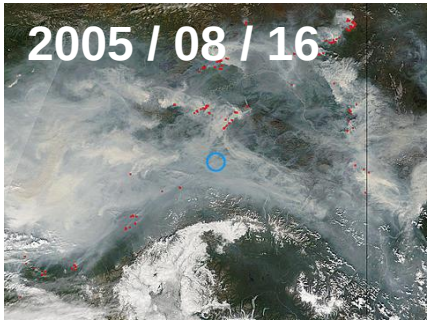






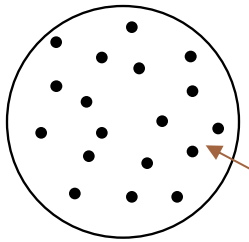
440 nm	1.491-0.0114i
670 nm	1.512-0.0085i
870 nm	1.515-0.0079i
1.02 um	1.505-0.0077i



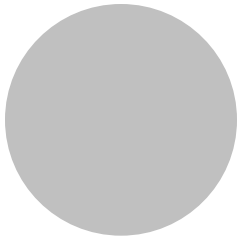


Composite property of particles:
internal mixing rule (biomass burning aerosols)

Maxwell-Garnett (MG) mixing rule : internal mixture of aerosols



f [%] : volume fraction of inclusions against matrix



ex) Matrix : m=1.46 - 0.0002i
Inclusions: m=1.61 - 0.022i

$$\varepsilon_{av} = \varepsilon_m \left[1 + \frac{3f(\varepsilon_{inc} - \varepsilon_m)(\varepsilon_{inc} + 2\varepsilon_m)^{-1}}{1 - f(\varepsilon_{inc} - \varepsilon_m)(\varepsilon_{inc} + 2\varepsilon_m)^{-1}} \right], \quad \mathrm{Re}\{\varepsilon_{av}\} = n^2 - k^2, \quad \mathrm{Im}\{\varepsilon_{av}\} = 2nk.$$

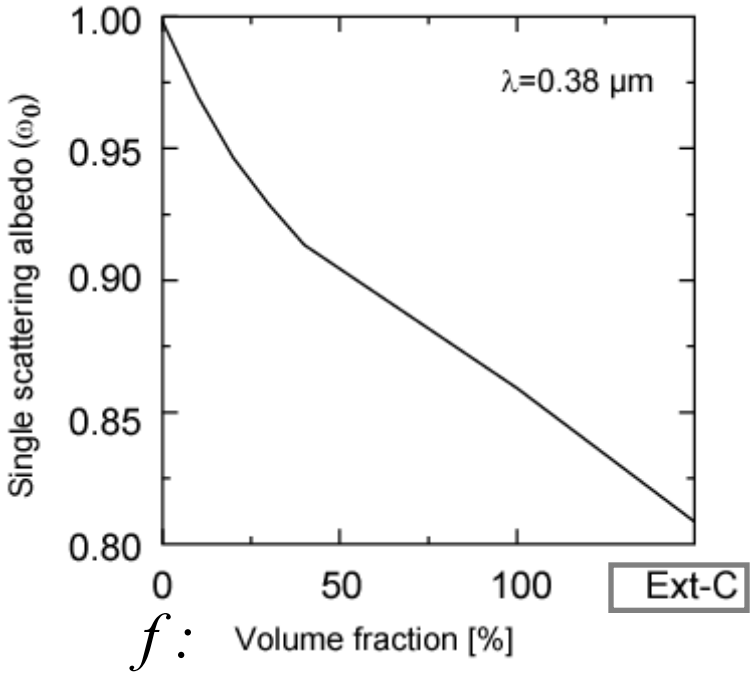
(Bohren and Wickramasinghe, Astrophys. Space Sci, 1977)

Composite property of particles:
internal mixing rule (biomass burning aerosols)

Refractive index (380 nm)
from Maxwell-Garnett

Volume fraction of inclusions [%]	Real part of refractive index	Imag part of refractive index
0	1.460	0.0002
10	1.475	0.0025
20	1.490	0.0050
30	1.505	0.0069
40	1.519	0.0089
100	1.610	0.022
Extreme case	1.710	0.042

Single scattering albedo (380 nm)



" SSA is decreasing according to the volume fraction of carbonaceous inclusions."

Size distribution

Bi-modal log-normal volume distribution

$$\frac{dV}{d\ln r} = (1 - F_{coarse}) \exp\left[-\frac{(\ln r - \ln r_{fine})^2}{2\sigma_{fine}^2} \right] + F_{coarse} \exp\left[-\frac{(\ln r - \ln r_{coarse})^2}{2\sigma_{coarse}^2} \right],$$

Fine mode aerosols :

$r_{fine} = 0.135$ µm, $\sigma_{fine} = 0.43$ µm

Coarse mode

$r_{coarse} = 2.365$ µm, $\sigma_{coarse} = 0.63$ µm

(Dubovik et al., JAS, 2002)

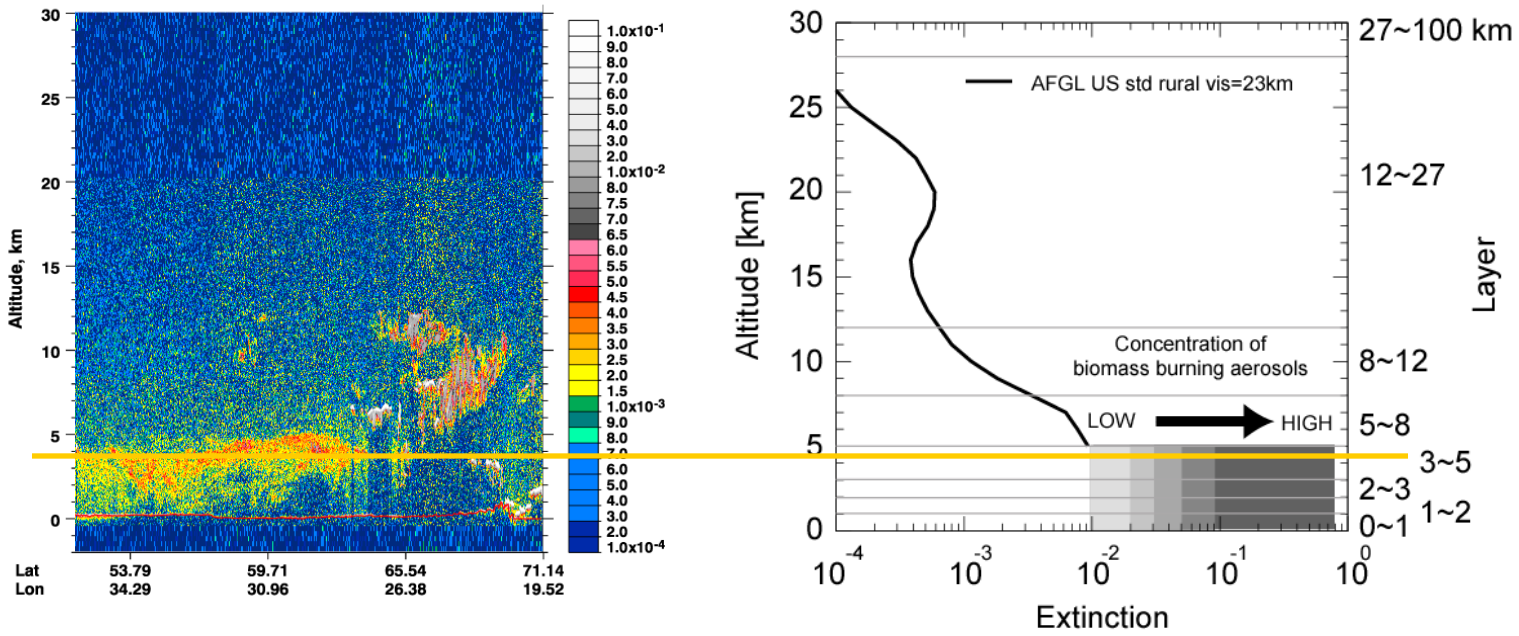
Adjustment parameter (F_{coarse})

Vertical profile of biomass burning plume

CALIPSO / CALIOP results show that the Biomass burning plume was concentrated under 3-5 km height.

Aerosol vertical structure is considered based on the US std profile with plume concentration under 5 km.

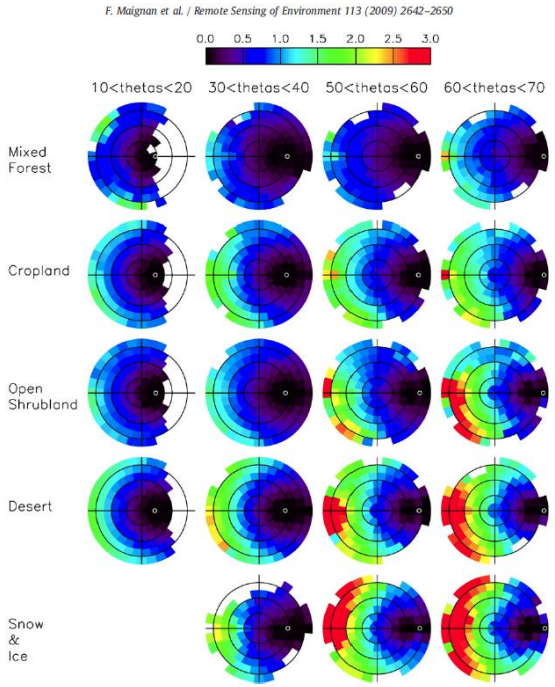
CALIOP 532nm Backscatter, on Aug. 8, 2010

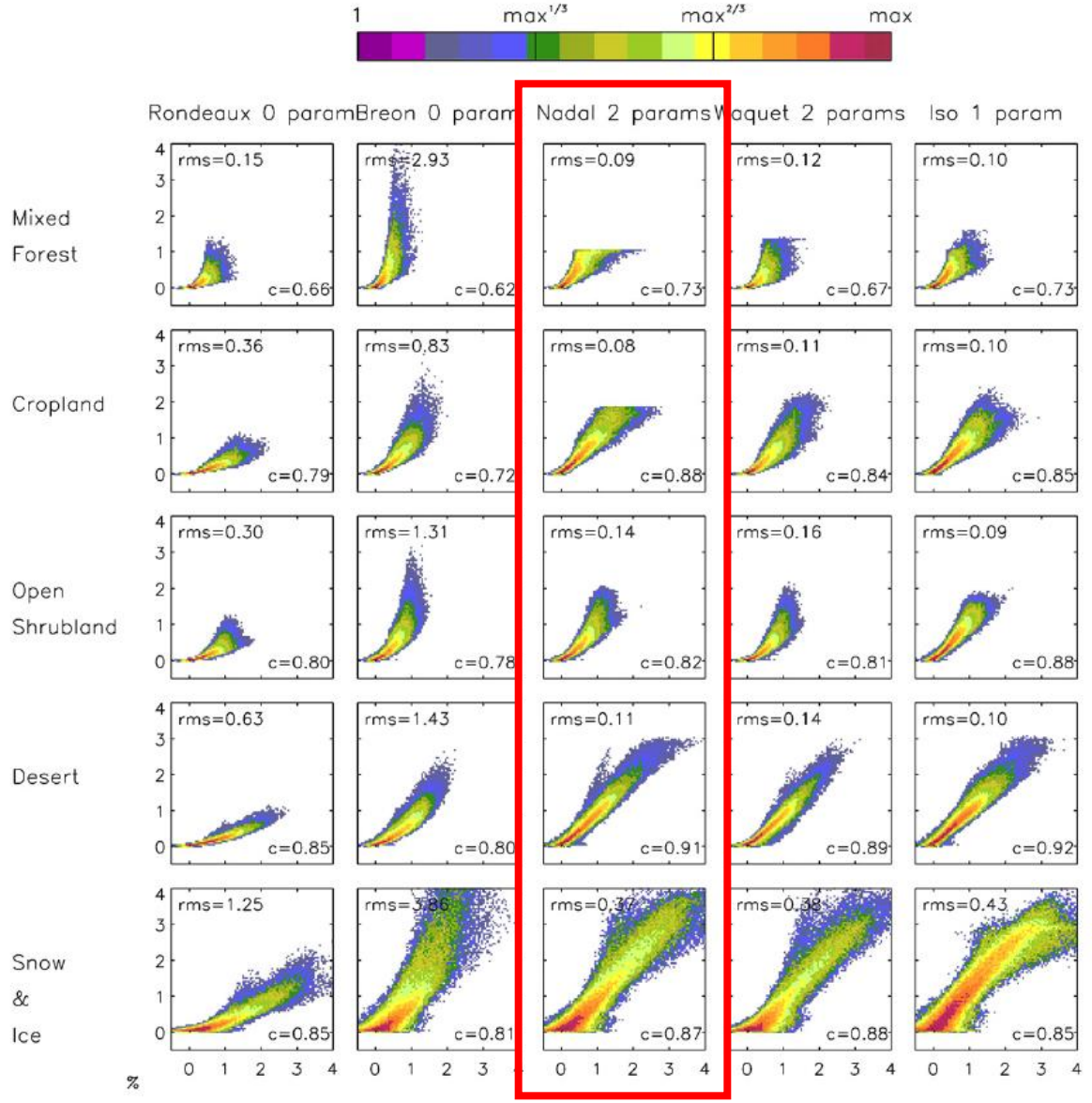


Surface polarization model ; BPDF

Nadal and Bréon, *1999*

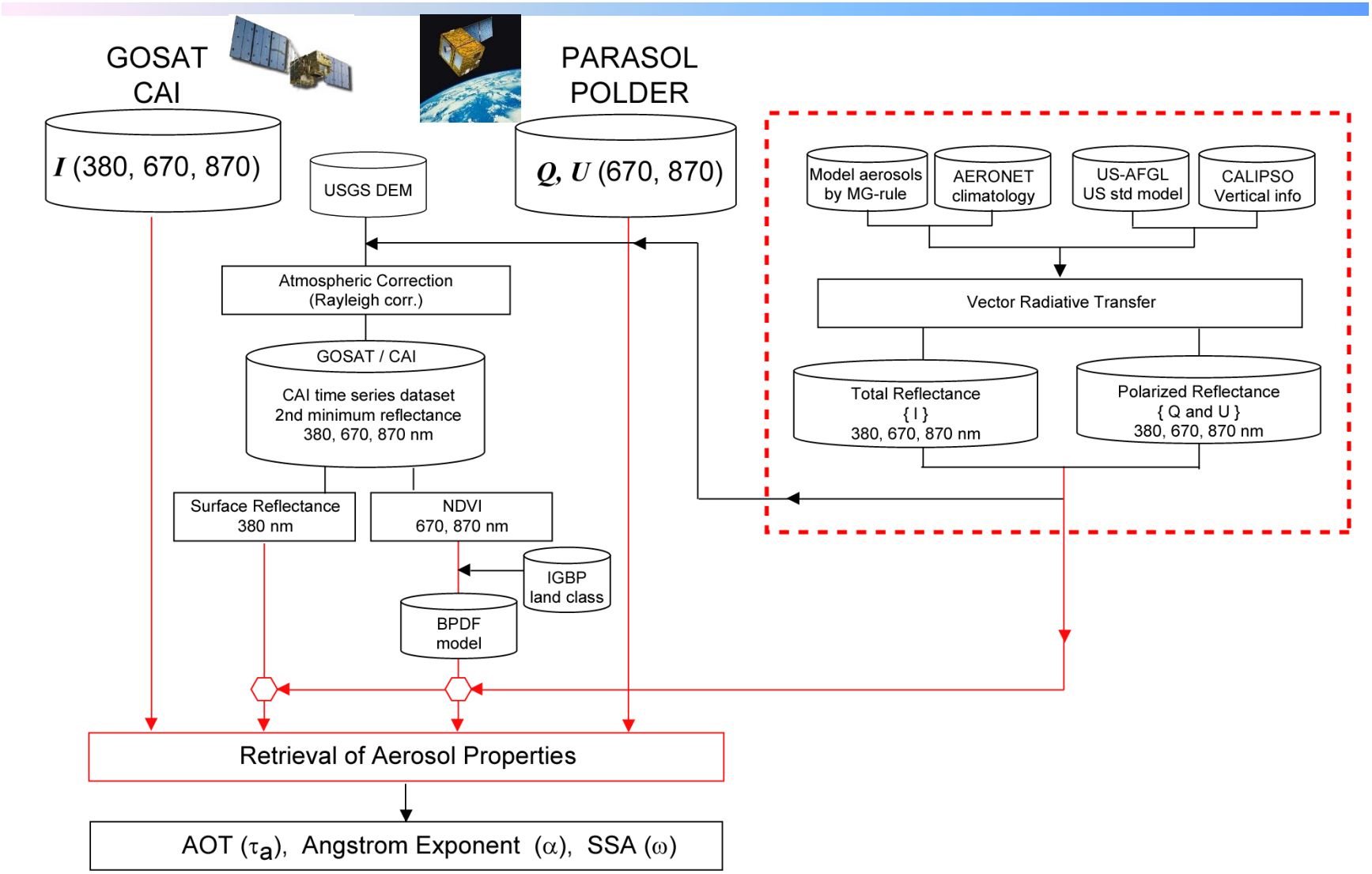
Maignan *et al. 2009*





F. Maignan et al. / Remote Sensing of Environment 113 (2009) 2642–2650

Retrieval flow (3ch)



Aerosol properties over Central Russia on August 8 in 2010

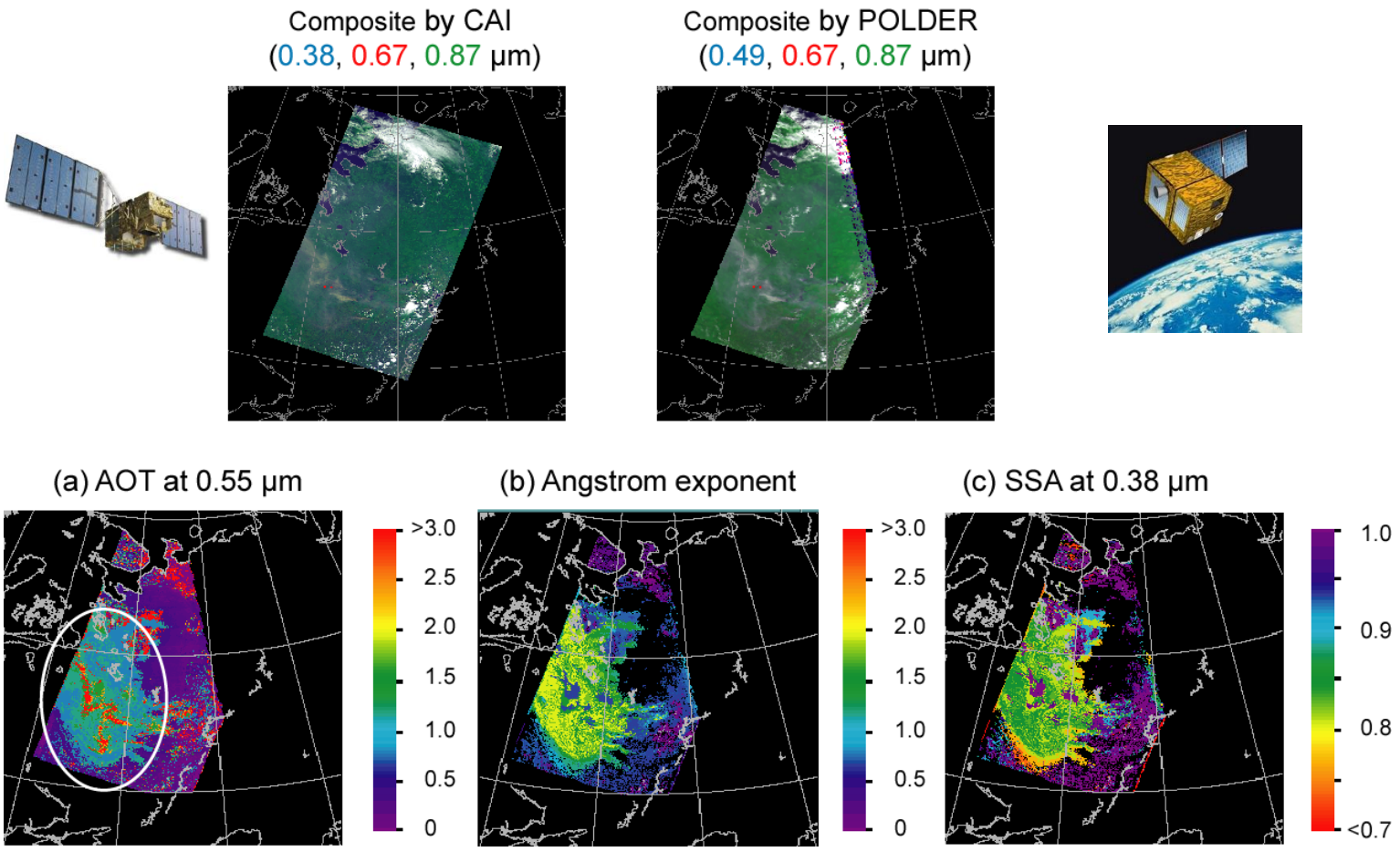
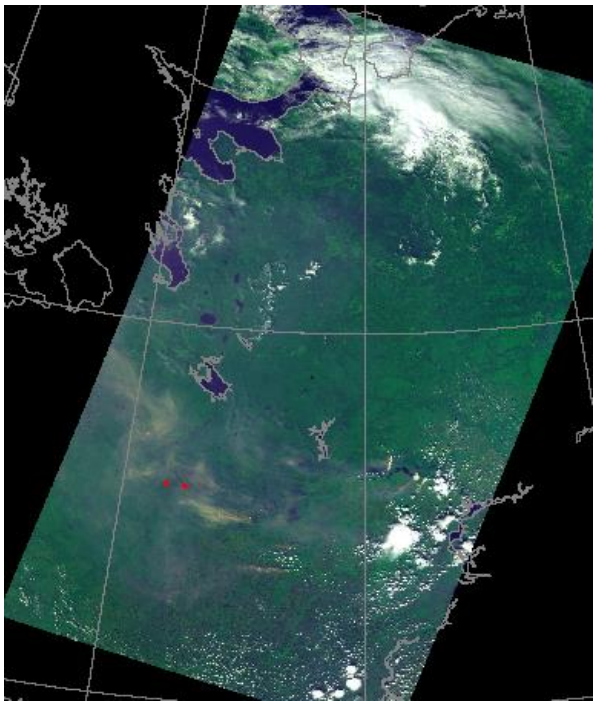
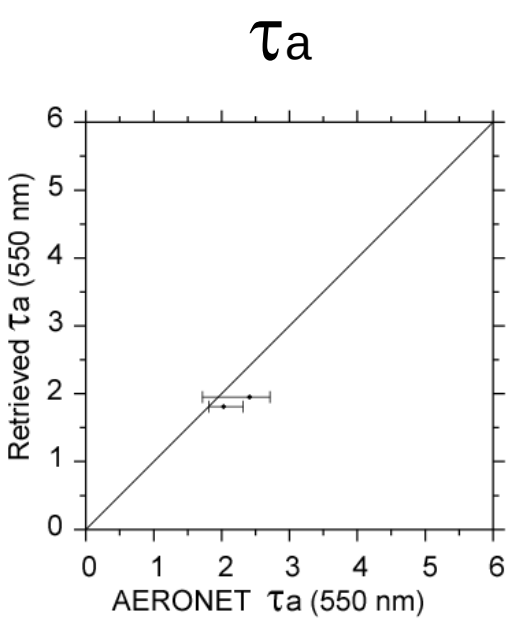


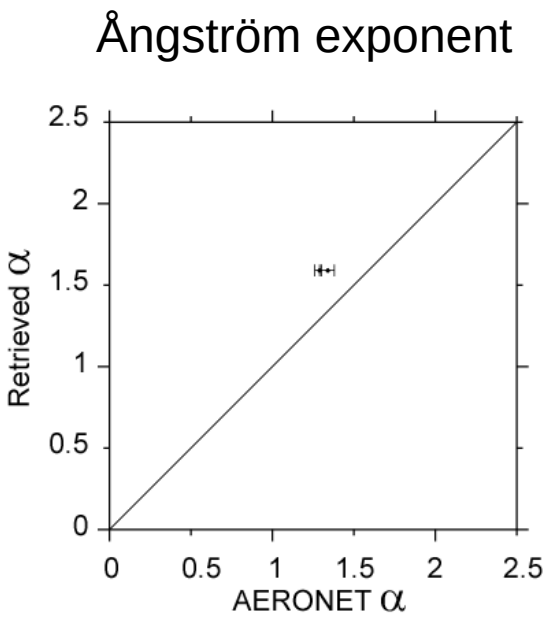
Figure Retrieved results of aerosol properties over Central Russia on August 8, 2010.
(a) AOT at 0.55 μm, (b) Angstrom exponent and (c) single scattering albedo at 0.38 μm.

Validation of retrieved results

The AERONET AOT and Angstrom data are selected during the ± 30 min against the satellite overpass.
Error bars : Min and max values of the measurements.







Scattergram of retrieved values τa, α against AERONET data.

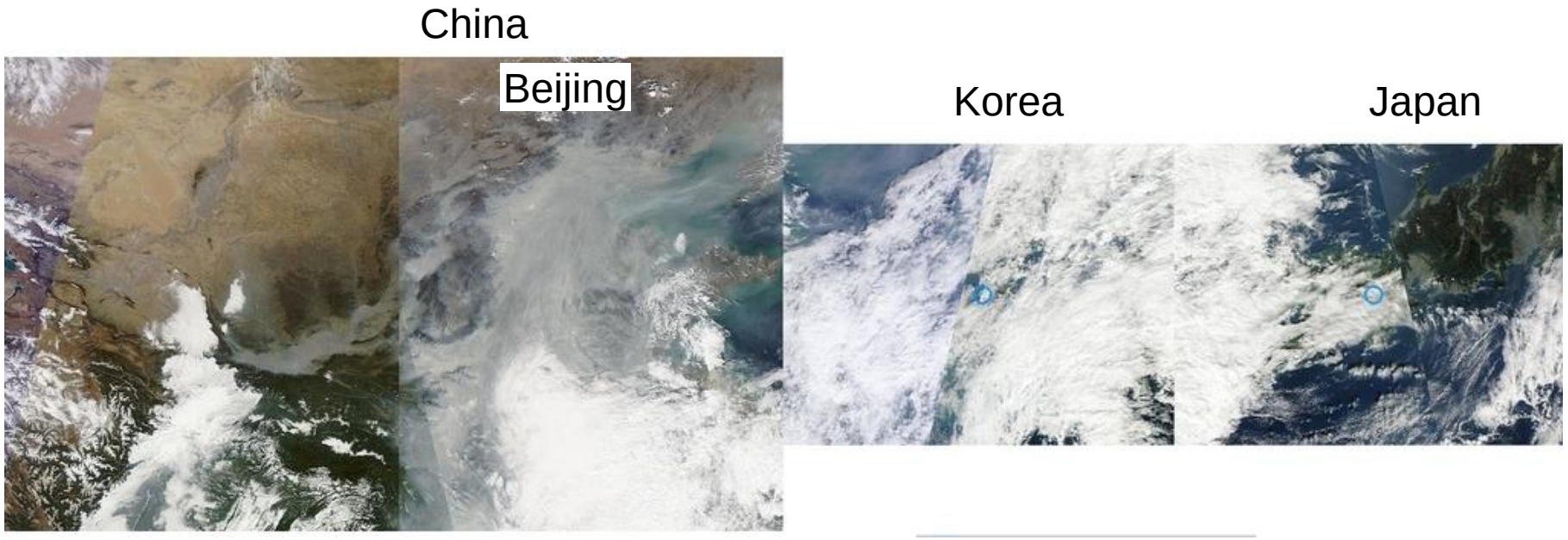
Contents

1. GCOM satellite series
   GCOM-C1 / SGLI
2. Aerosol retrieval for SGLI
   2ch polarization method
   by POLDER

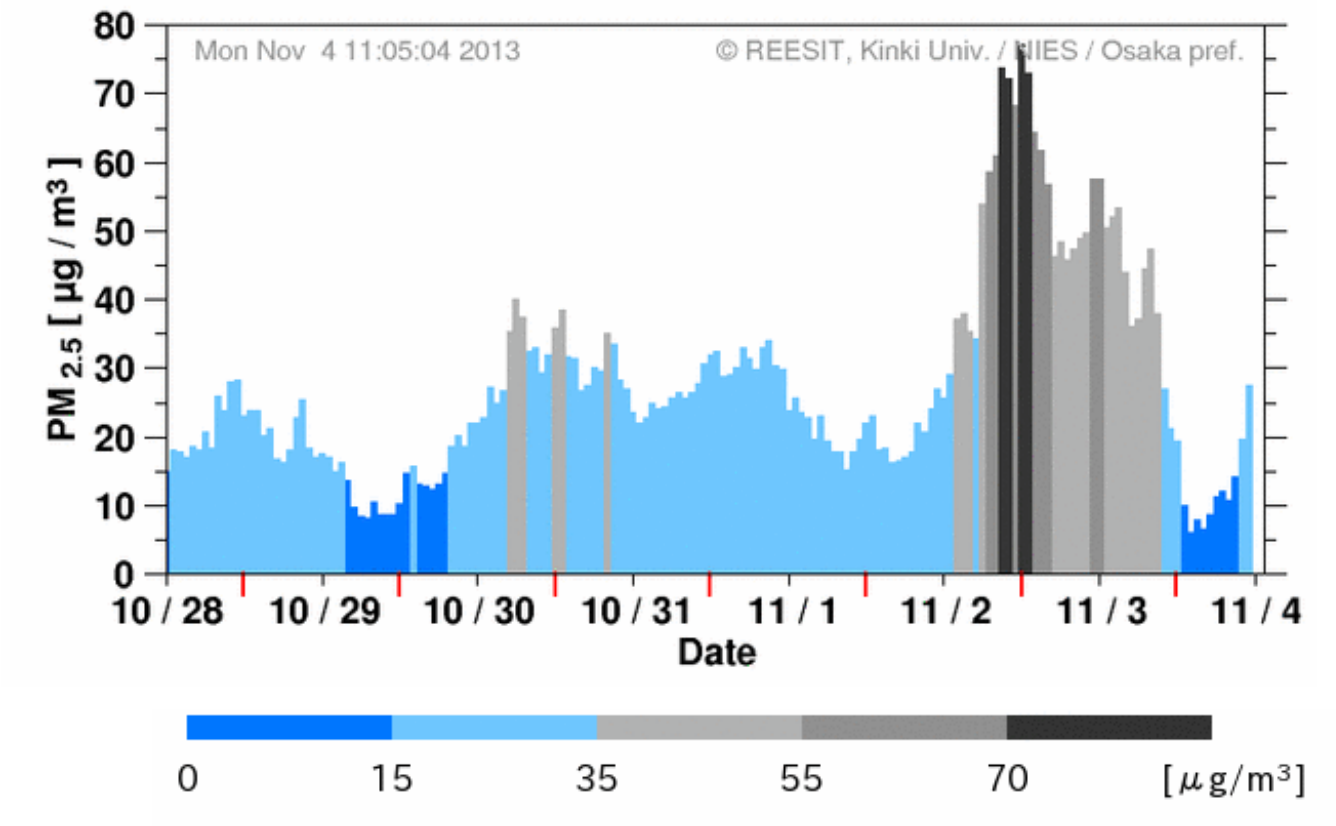
   2ch polarization & 1ch total radiance method
   by POLDER + GOSAT / CAI
3. $PM_{2.5}$ retrieval
4. Summary

Smog over China

MODIS rapid response image over East Asia
30th October 2011

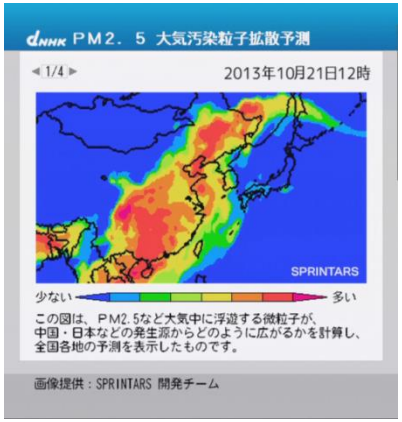


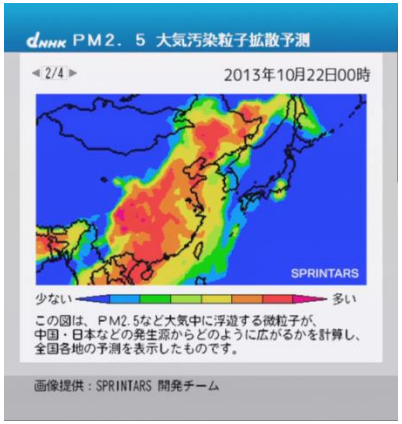
Recent $PM_{2.5}$ measurements at Osaka

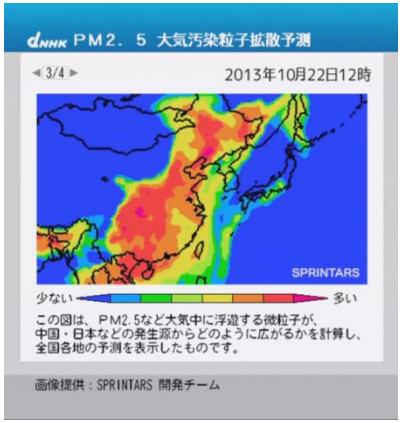


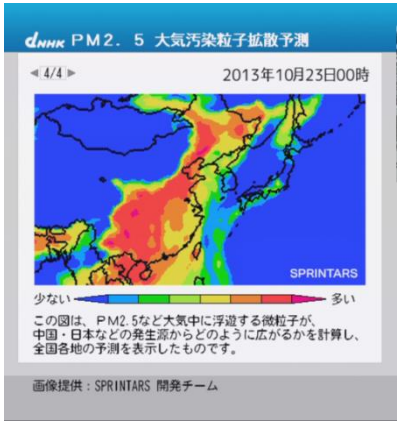
$PM_{2.5}$ forecast by SPRINTARS

NHK TV distributes PM2.5 information.







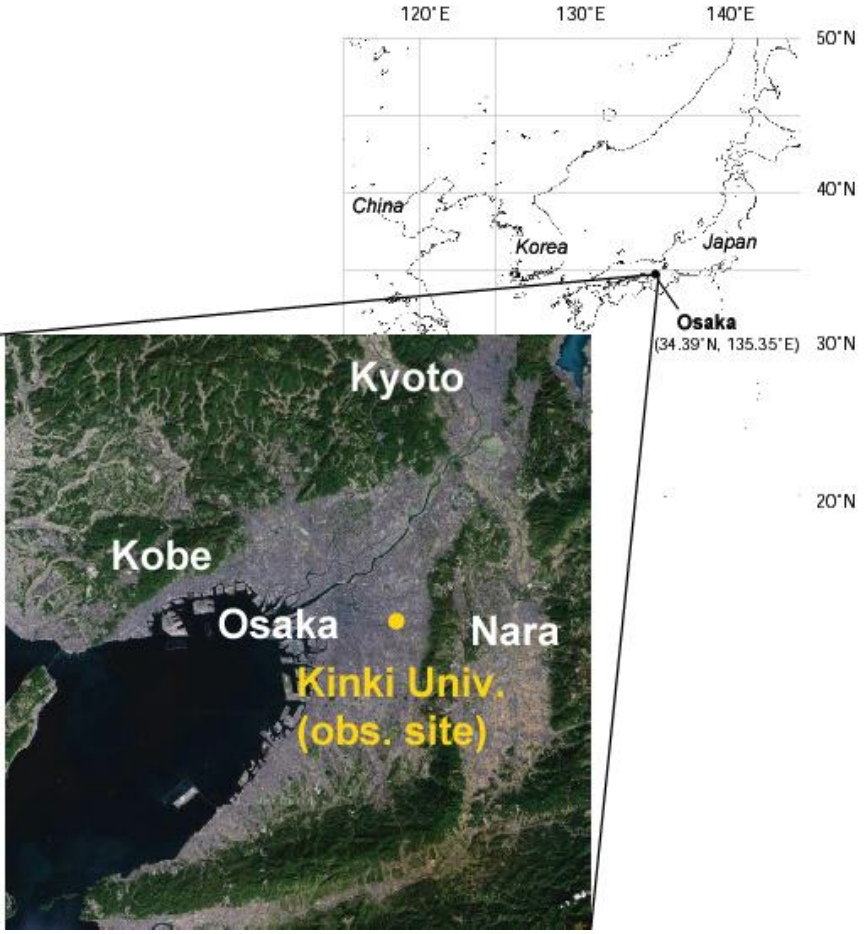


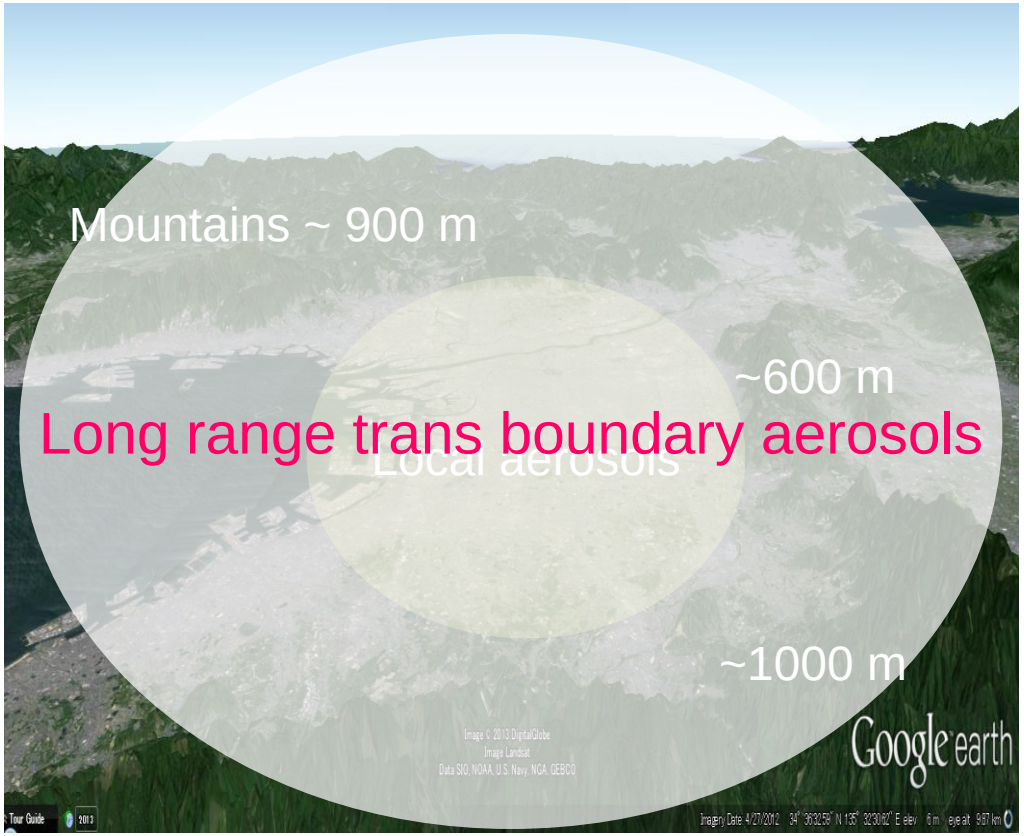
(PM2.5 images by Prof. T. Takemura)

Target megacity (Osaka, Japan)

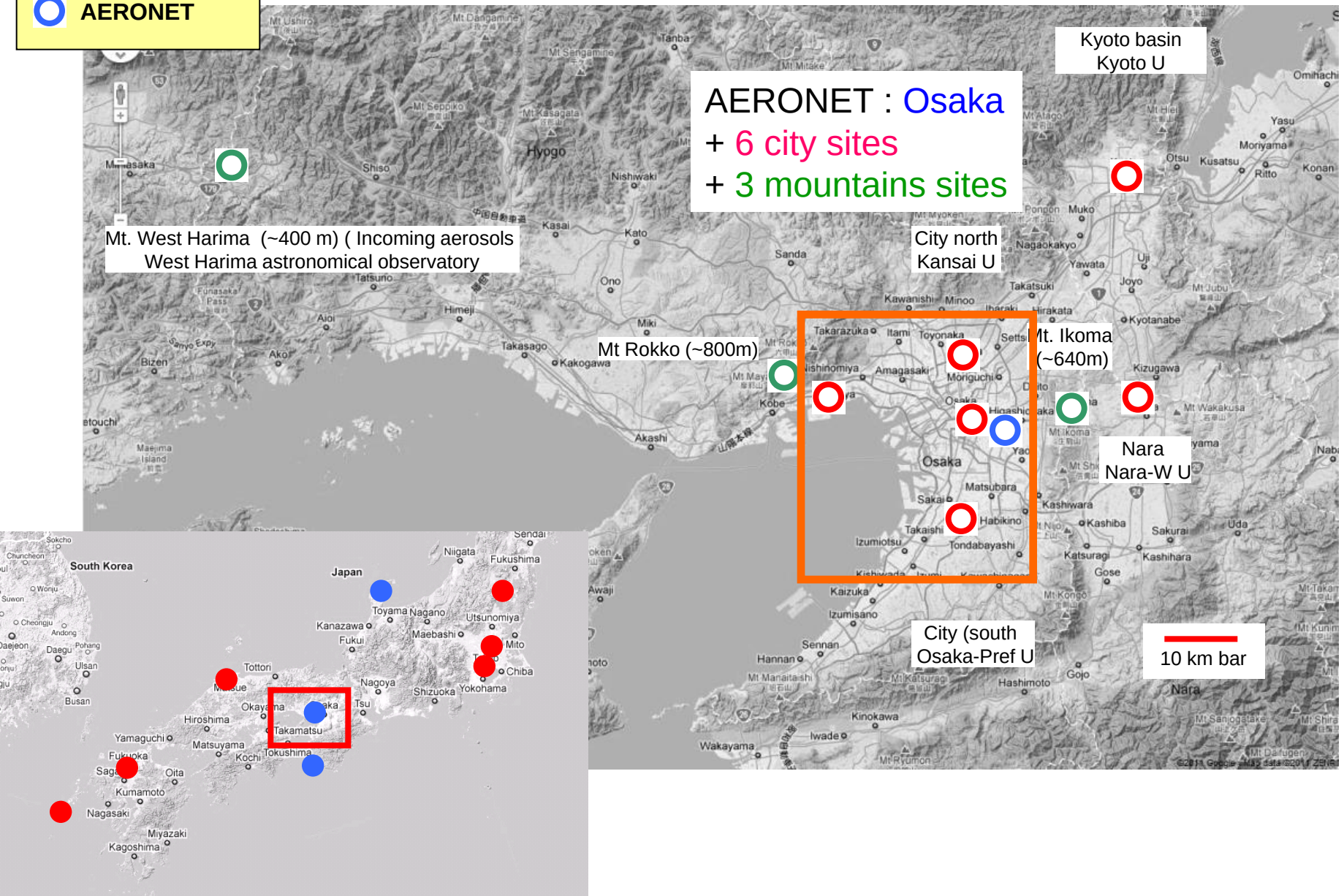
2nd large city in Japan

population : ~15 million





Sun photometer network in Spring of 2012 (DRAGON - Osaka, a part of DRAGON-Japan)



Aerosol retrieval procedure

1. Surface information

Assumption : Aerosol loading and types are constant in Osaka Plains,
(AERONET-Osaka measurement is a representative of aerosol information over the area).
Atmospheric correction with AERONET AOT(550 nm) and AE.

→ **Surface albedo**

2. Retrieval of aerosol properties

Pre-estimated surface albedo
Pre-defined aerosol model (RT -> look-up table)
Satellite data (CAI / GOSAT :380, 670, 870 nm)

↓

AOT, coarse mode fraction of bi-modal size dist, and SSA

Estimation of surface reflectance and aerosol retrieval

AERONET Climatology

US-AFGL US std model

Vector R.T. calc

AERONET Osaka site τ_a, α

USGS DEM

Look up table

GOSAT / CAI time series TOA reflectance data 380, 670, 870 nm

Ref idx is fixed to m = 1.45 - 0.0001 i

Atmospheric Correction

Time series surface reflectance

Min ref. for 3 weeks from no clouds scene

Surface reflectance 380, 670, 870 nm

surface reflectance (380, 670, 870 nm)

USGS DEM

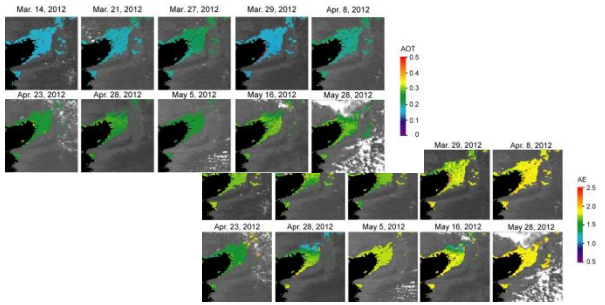
Look up table

GOSAT / CAI Level 1 (380, 670, 870 nm)

Aerosol Retrieval Col-AOT at 550, CMF, SSA

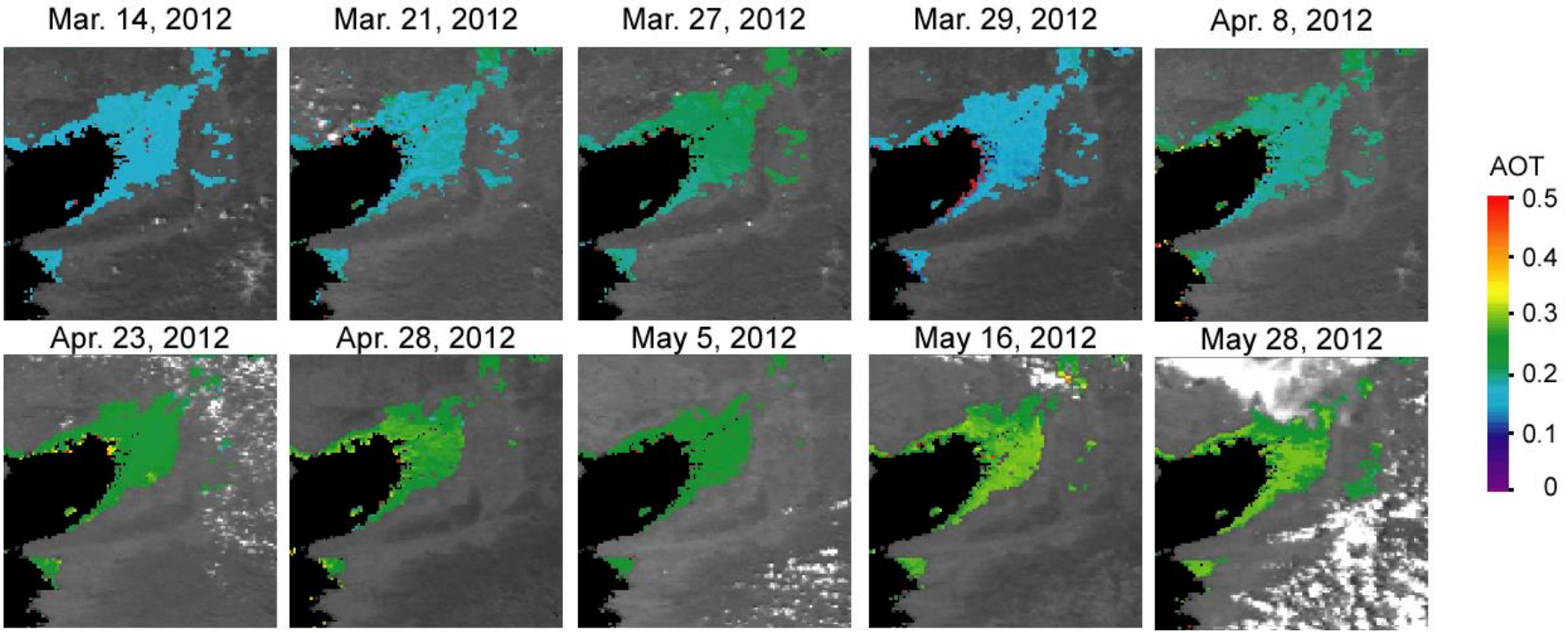
CMF : mixing ratio of coarse mode aerosol to fine and coarse mode

Col-AOT 380, 440, 670, 870 nm Ang. Exp, SSA



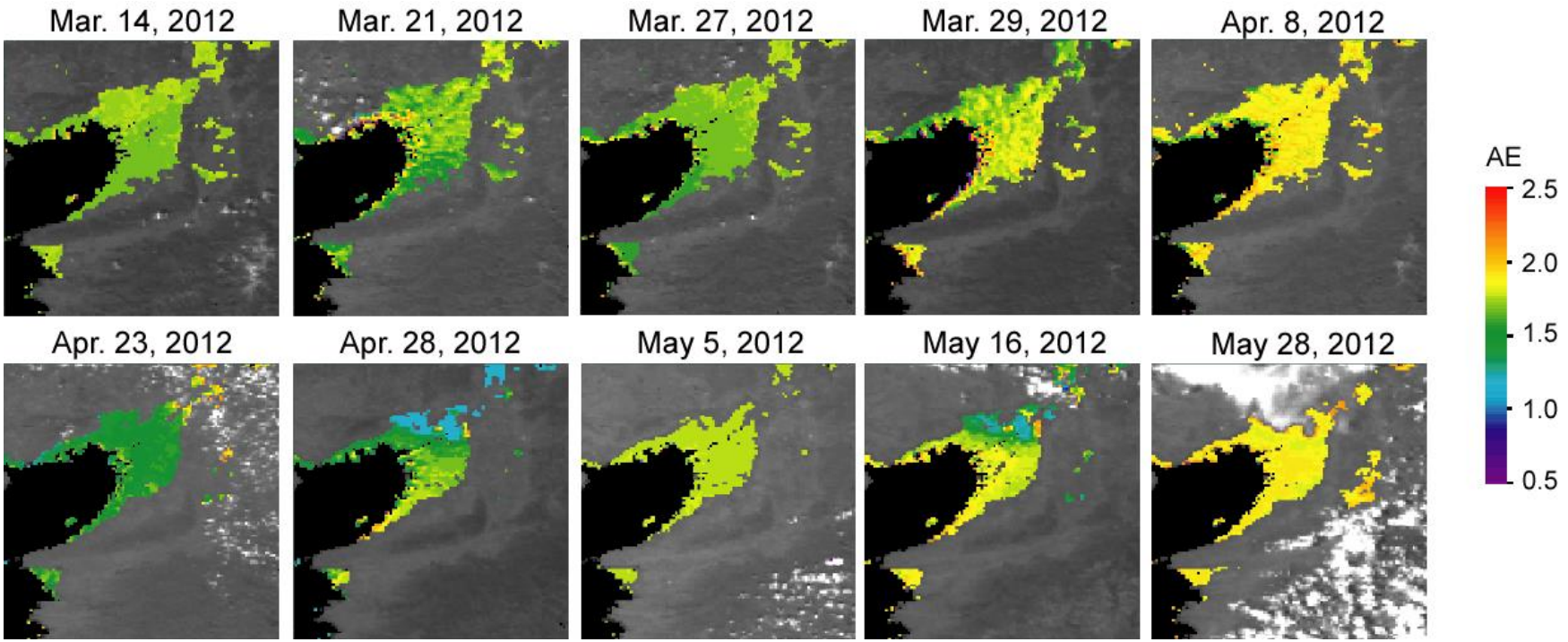
Aerosol properties over Osaka, Japan during DRAGON - Osaka

AOT (670 nm)



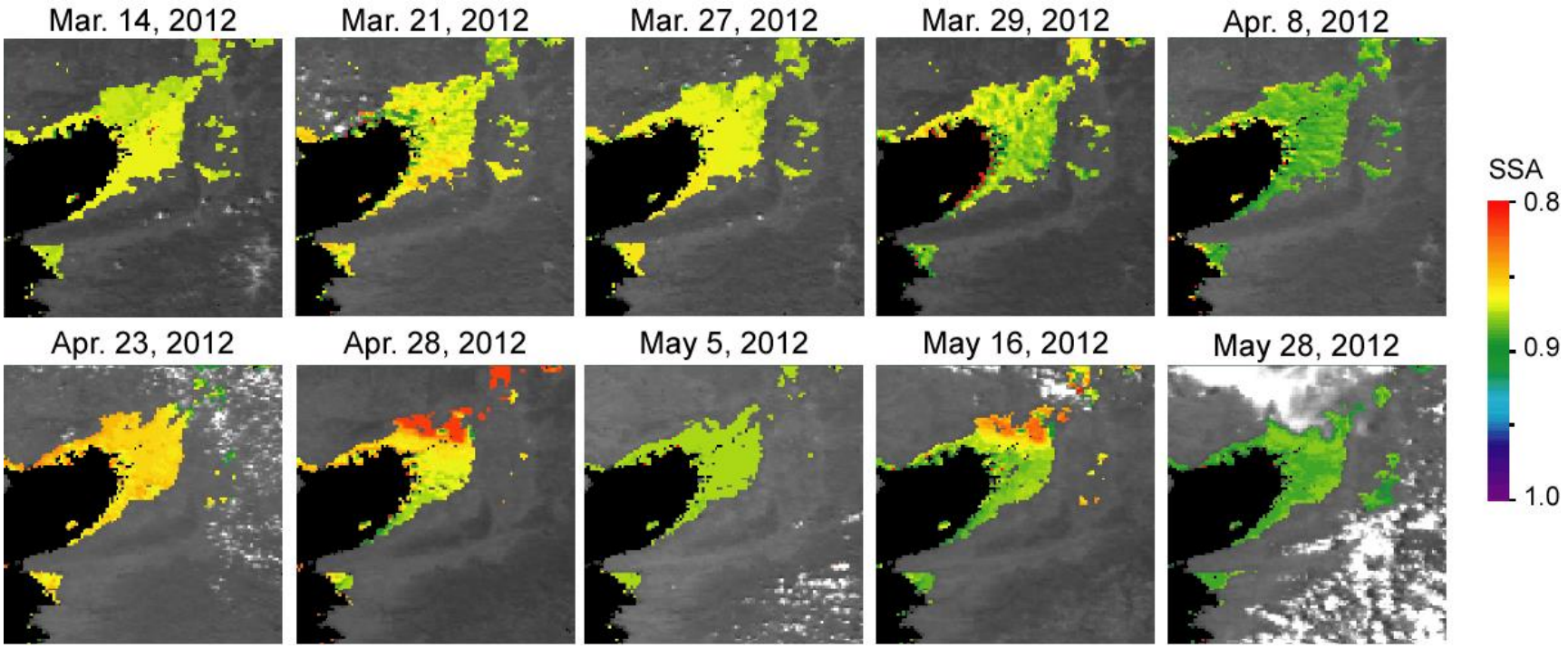
Aerosol properties over Osaka, Japan during DRAGON - Osaka

Angstrom exponent

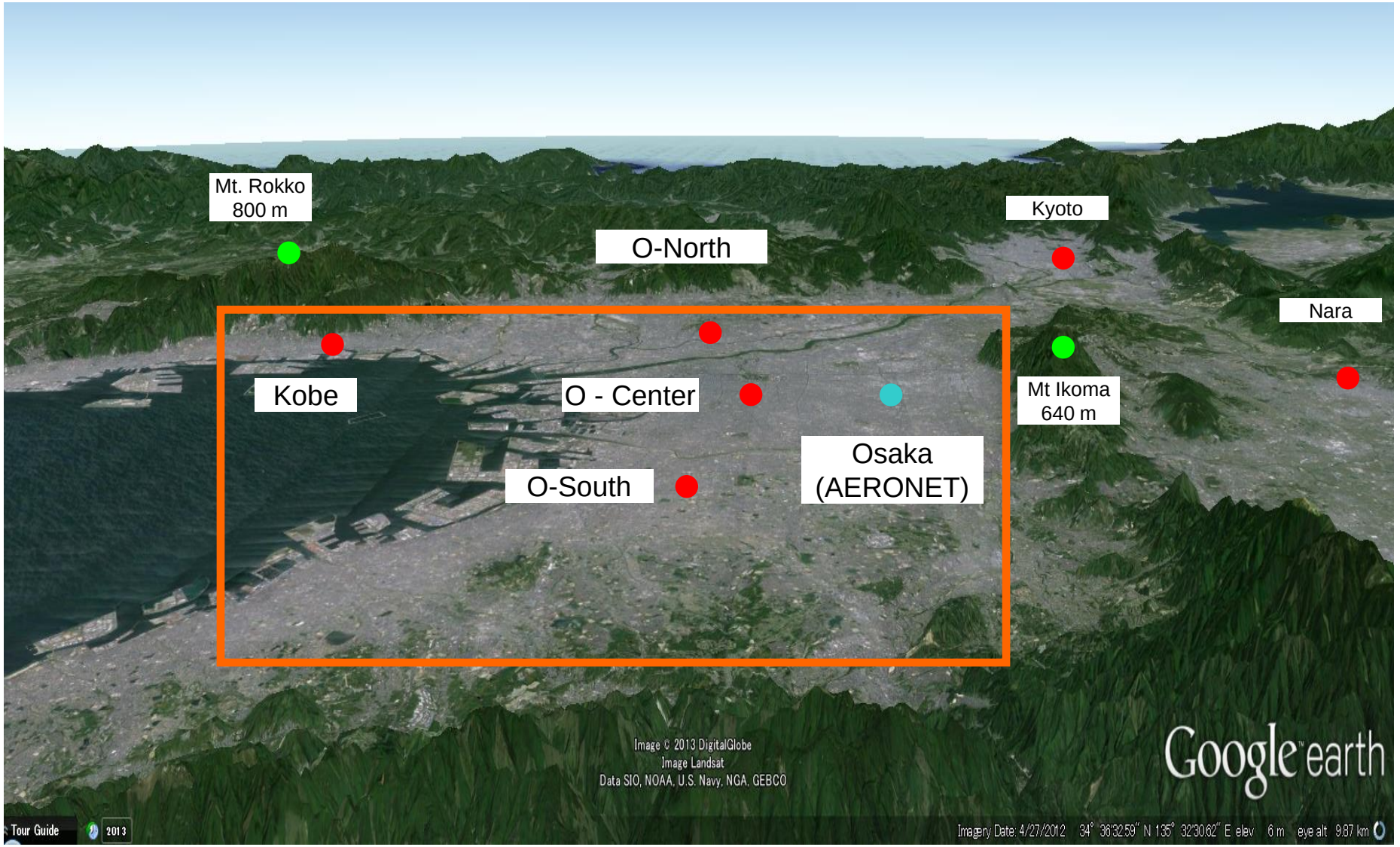


Aerosol properties over Osaka, Japan during DRAGON - Osaka

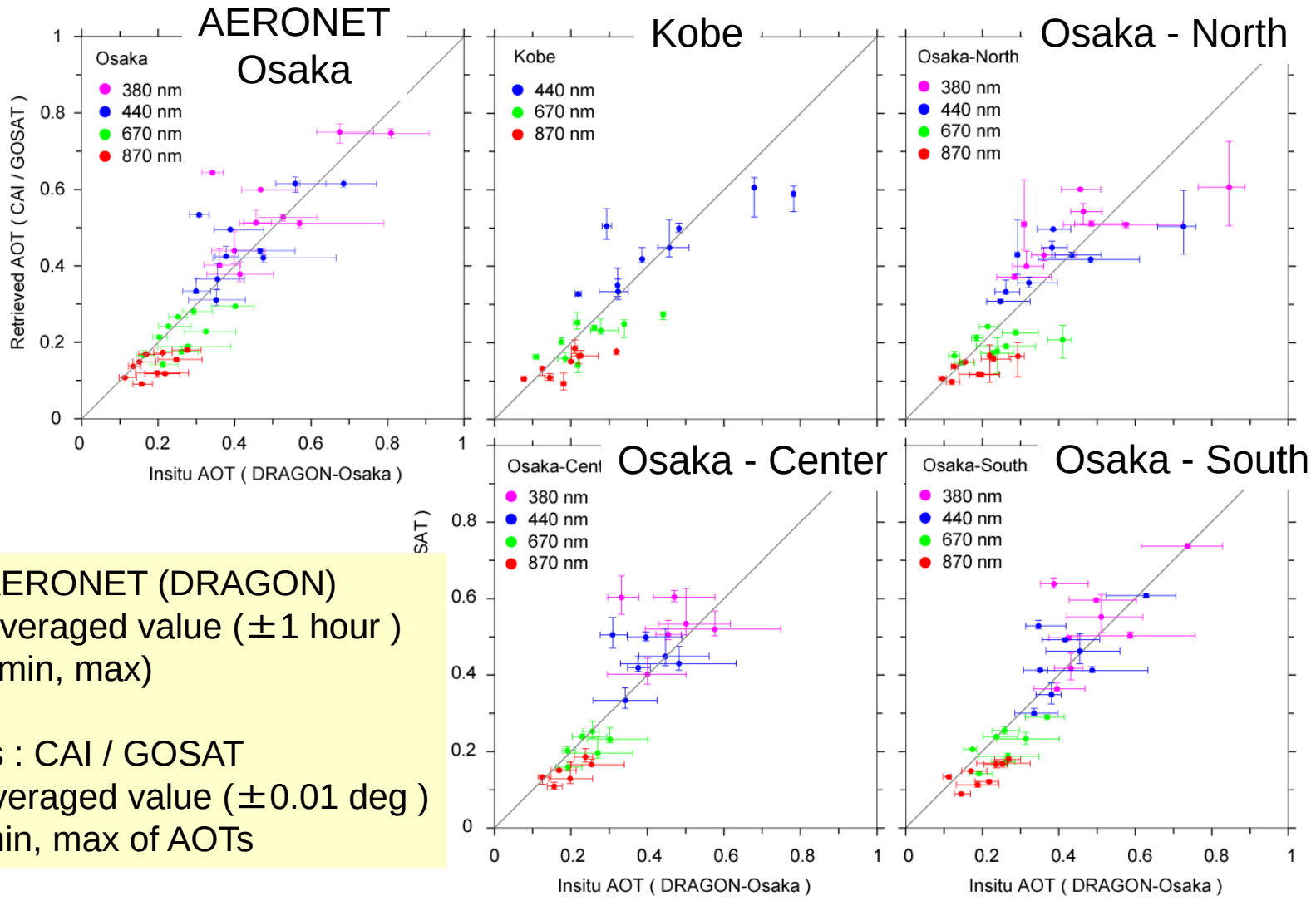
Single scattering albedo



Cimel deployment during DRAGON - Osaka (March - May in 2012)



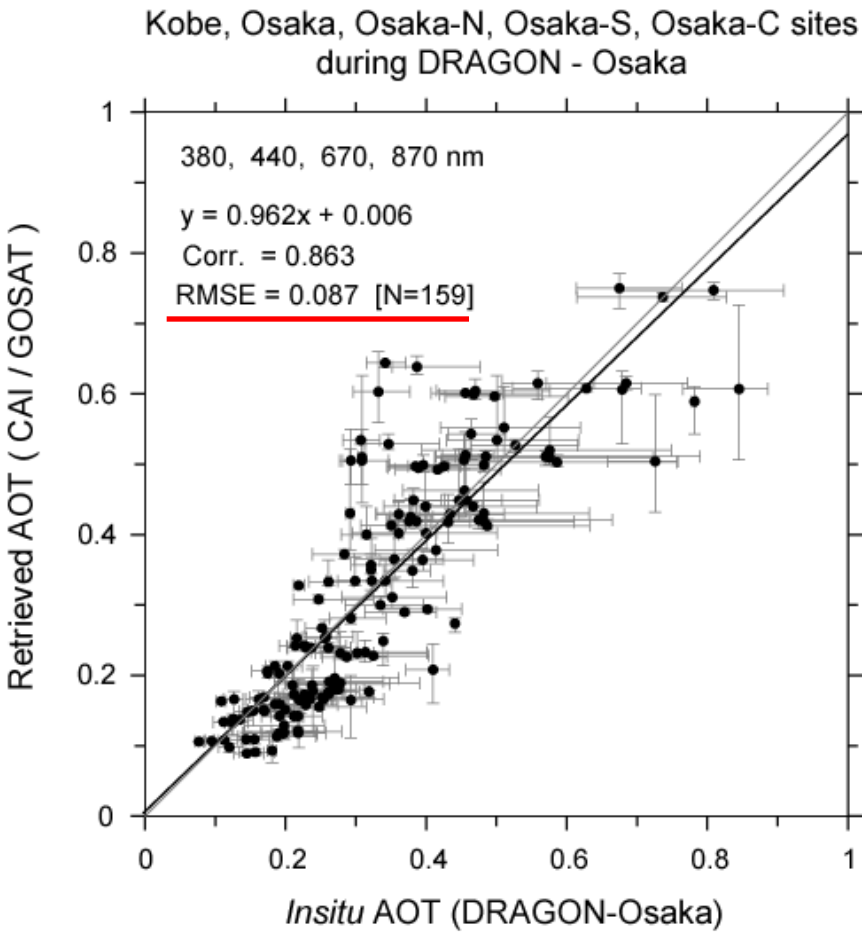
Validation of retrieved AOTs with DRAGON-Osaka

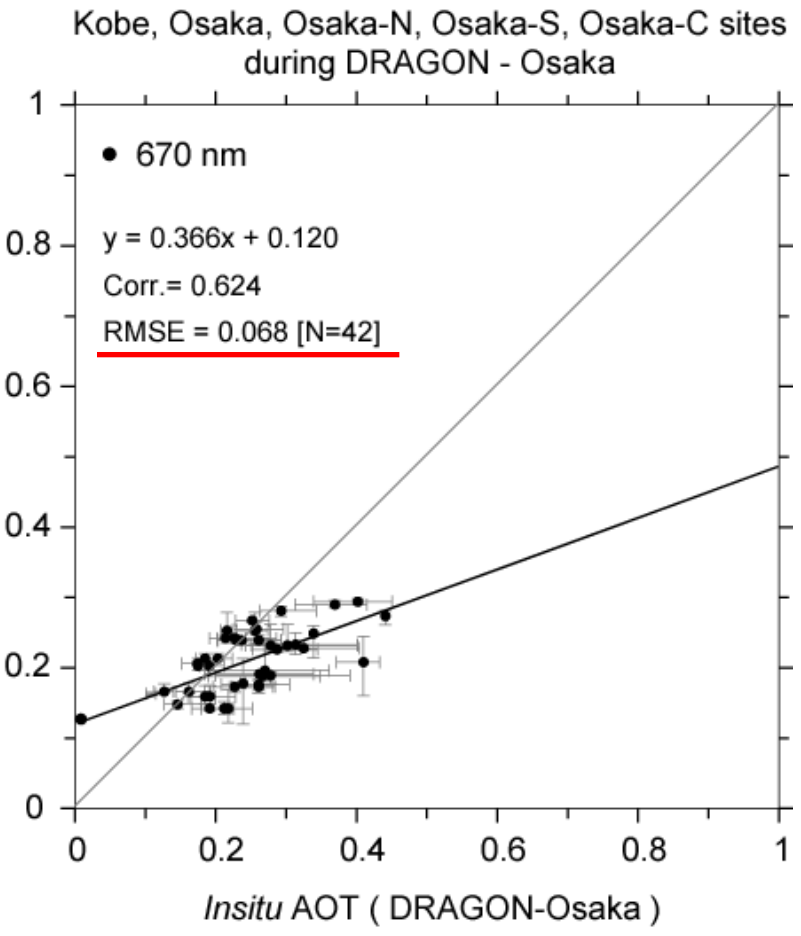


In situ AOTs : AERONET (DRAGON)
- Dots : averaged value (±1 hour)
- Error bars : (min, max)

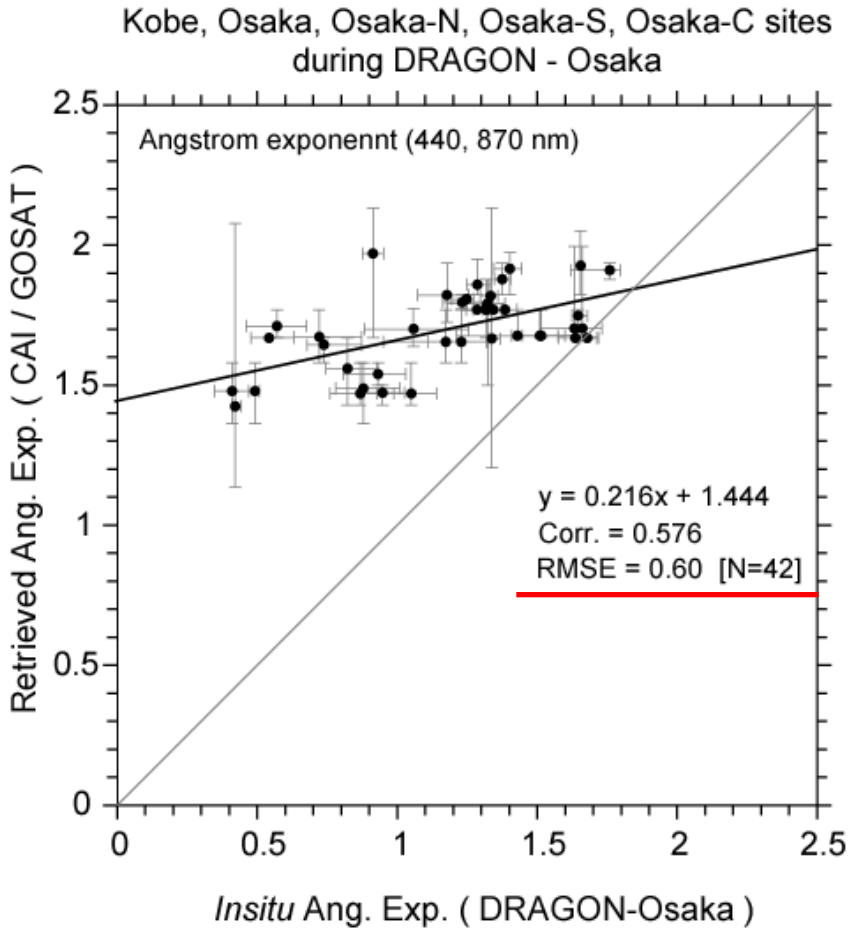
Retrieved AOTs : CAI / GOSAT
- Dots : averaged value (±0.01 deg)
- Error bars: min, max of AOTs

Validation of retrieved AOTs with DRAGON-Osaka





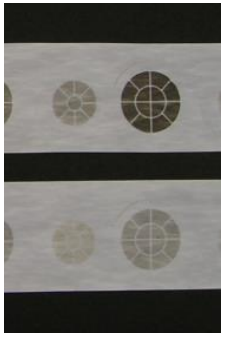
Validation of retrieved AE with DRAGON-Osaka



Ground based
columnar AOT, LIDAR and PM measurements

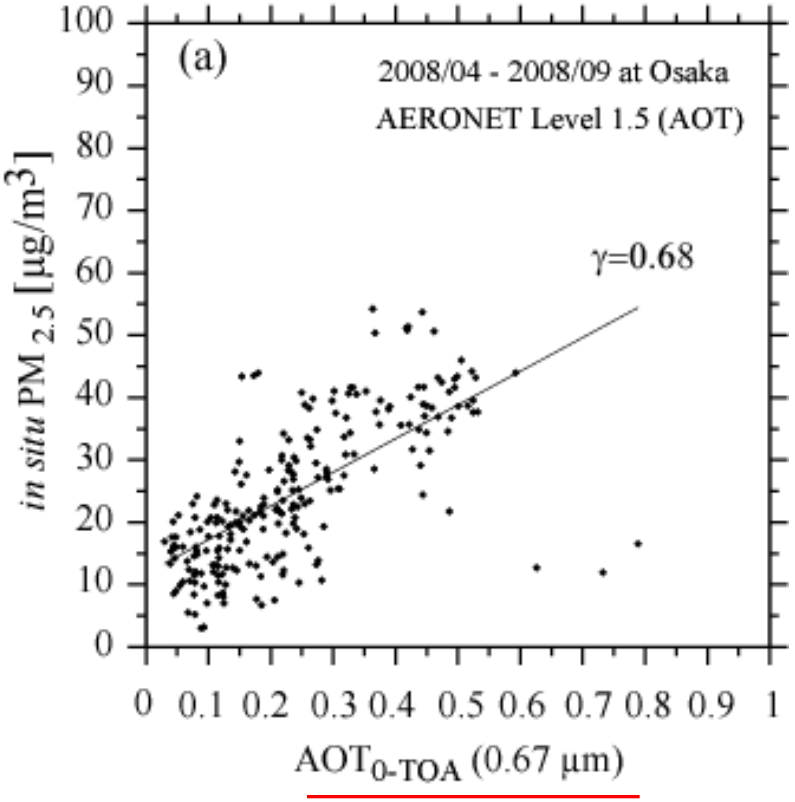
- Sun photometer and NIES 2ch Pol. LIDAR

- PM_1, $PM_{2.5}$ / PM_{10} / TSP sampling

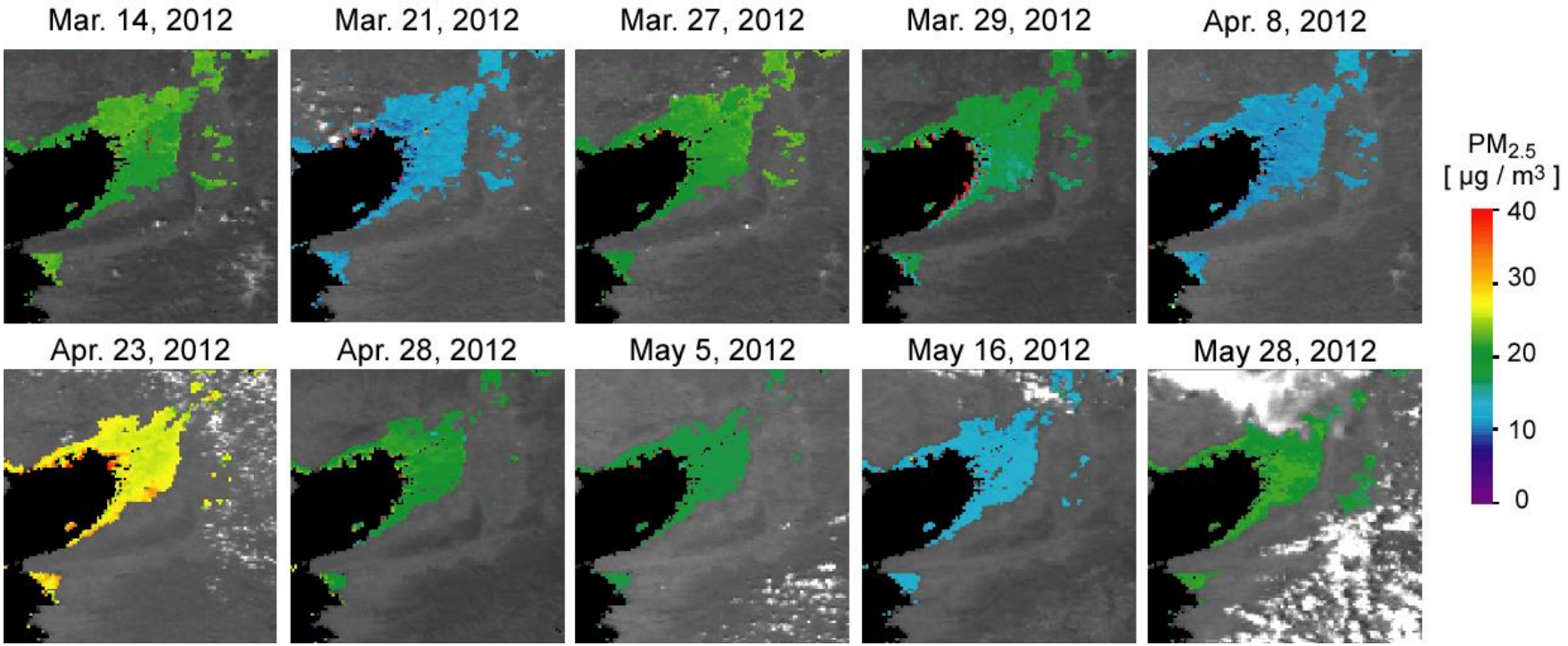


Relationship between $PM_{2.5}$ and columnar AOT (670 nm)

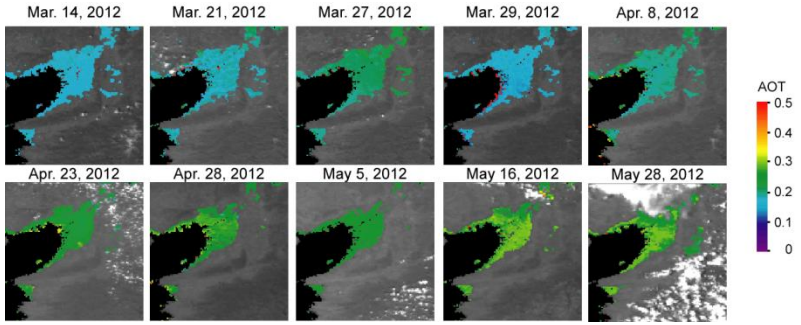
Columnar AOT



Satellite estimated $PM_{2.5}$ concentration during DRAGON - Osaka



AOT 670 nm



Validation with *in situ* $PM_{2.5}$ data

$PM_{2.5}$ Instrument

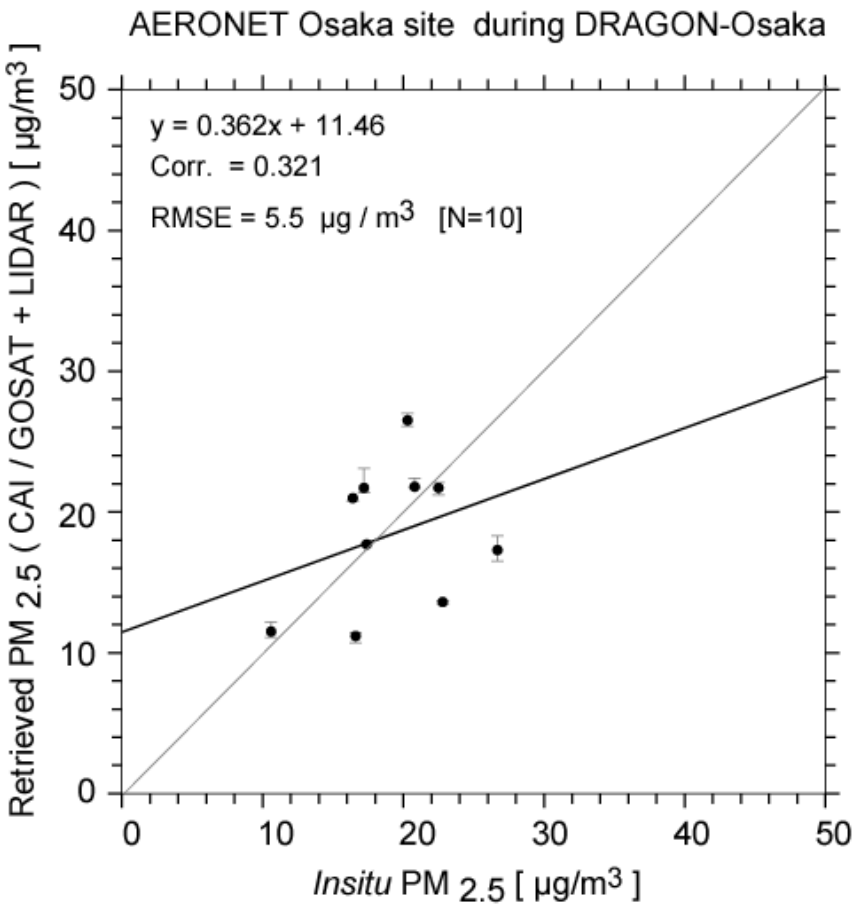
SPM-712 (Kimoto Elec. Co., Japan)

1 hour meas.

Beta ray gauge method

Teflon tape role

RH correction



Summary

Status of aerosol algorithm development has been reported from the viewpoint of polarization measurements.

The operational algorithms as POLDER two channel type method which give us with

aerosol optical thickness (550 nm) and Ångström exponent

will be implemented first.

Our algorithms will be modified to achieve more accurate and more aerosol parameters with CI's collaboration.

Acknowledgements

The authors thank to

CNES, Lille-U / PARASOL,

NIES / GOSAT, / LIDAR, and

NASA AERONET team

for operations of their instruments and data distributions.

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the GOSAT Project (NIES), and

the JSPS's Kakenhi - C (#25340019) fund.