Observation of air pollution aerosols and Asian dusts using the Asian Dust and aerosol lidar observation Network (AD-Net)

Nishizawa, T., N. Sugimoto, I. Matsui, A. Shimizu, A. Higurashi

NIES lidar group

Asian Dust and aerosol lidar observation Network (AD-Net)

Optical/microphysical properties of total aerosols and each aerosol component are essential to understand atmospheric environment and climate change.

Observation

Compact 2β (532, 1064nm) + 1δ (532nm) Mie lidar
with automatically measurement capability
20 sites ground based network observation in East Asia (2001~)
+ Ship-borne measurements (1999~, vessel "MIRAI" (JAMSTEC))

[Sugimoto et al., 2001; 2005]

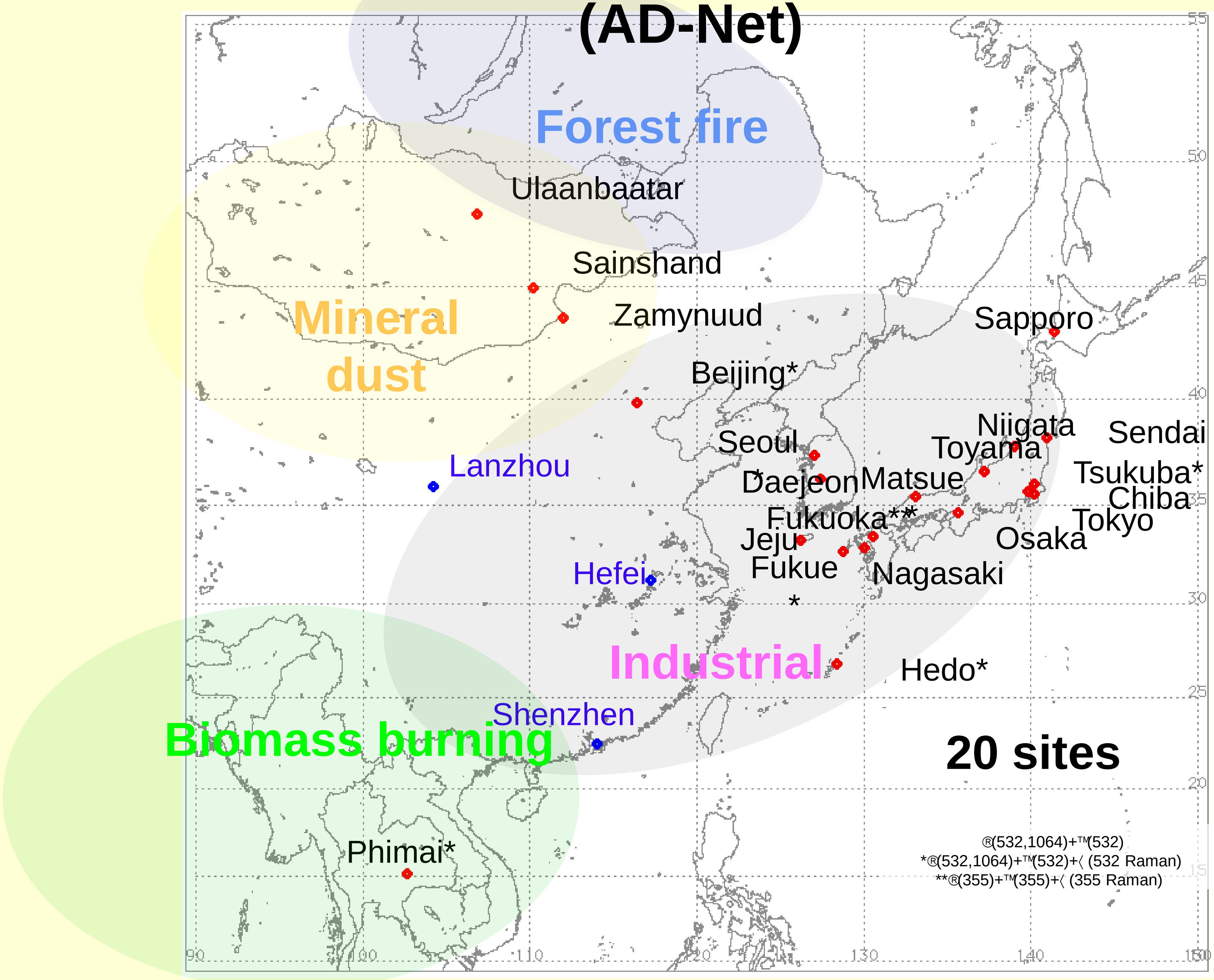
Data analysis

Classify aerosol components and Retrieve their extinctions at each layer
(assuming external mixture of several aerosol component)

- **1β(532)+1δ data→ (1β+1δ method)** Dust (nonSpherical) + Air-pollution (Spherical)
  [Sugimoto et al., 2003; Shimizu et al., 2004]
  ＝＞ Ground-based lidar data & Satellite-borne lidar (CALIOP)

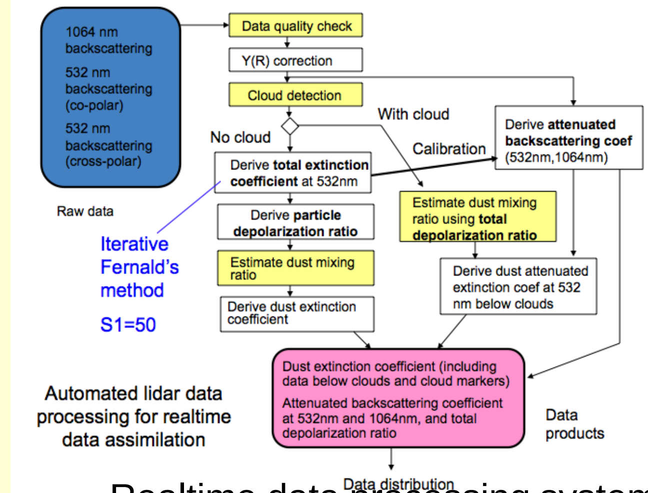
- **2β+1δ data→ (2β+1δ method)** Dust (nonSpherical) +
  Air-pollution (Spherical / Small) +
  Sea-salt (Spherical / Large) [Nishizawa et al., 2007,2008,2011]

Asian Dust and aerosol lidar observation Network (AD-Net)

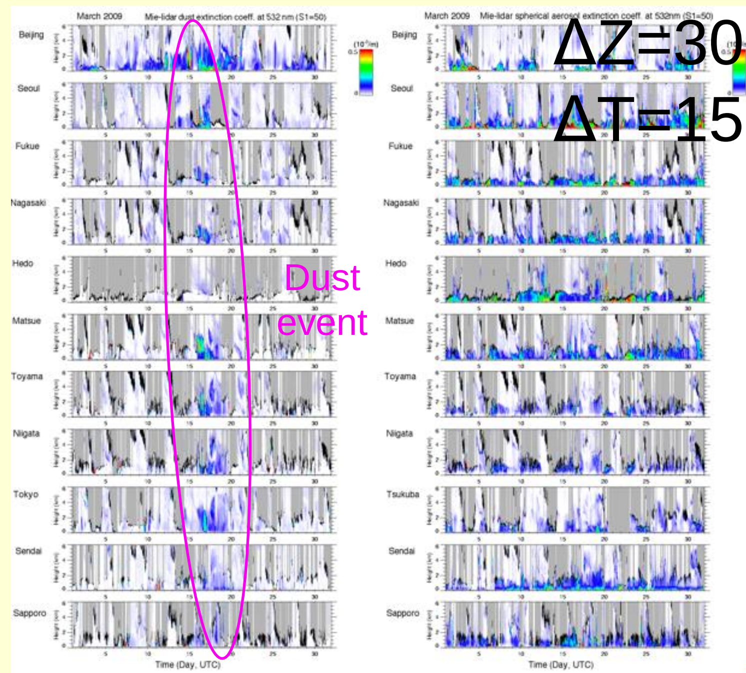


Lidar & Data analysis

Two-wavelength (1064nm, 532nm) Mie-scattering lidar with polarization channels at 532nm. (Raman receivers (607nm) are being added at several observation sites.)

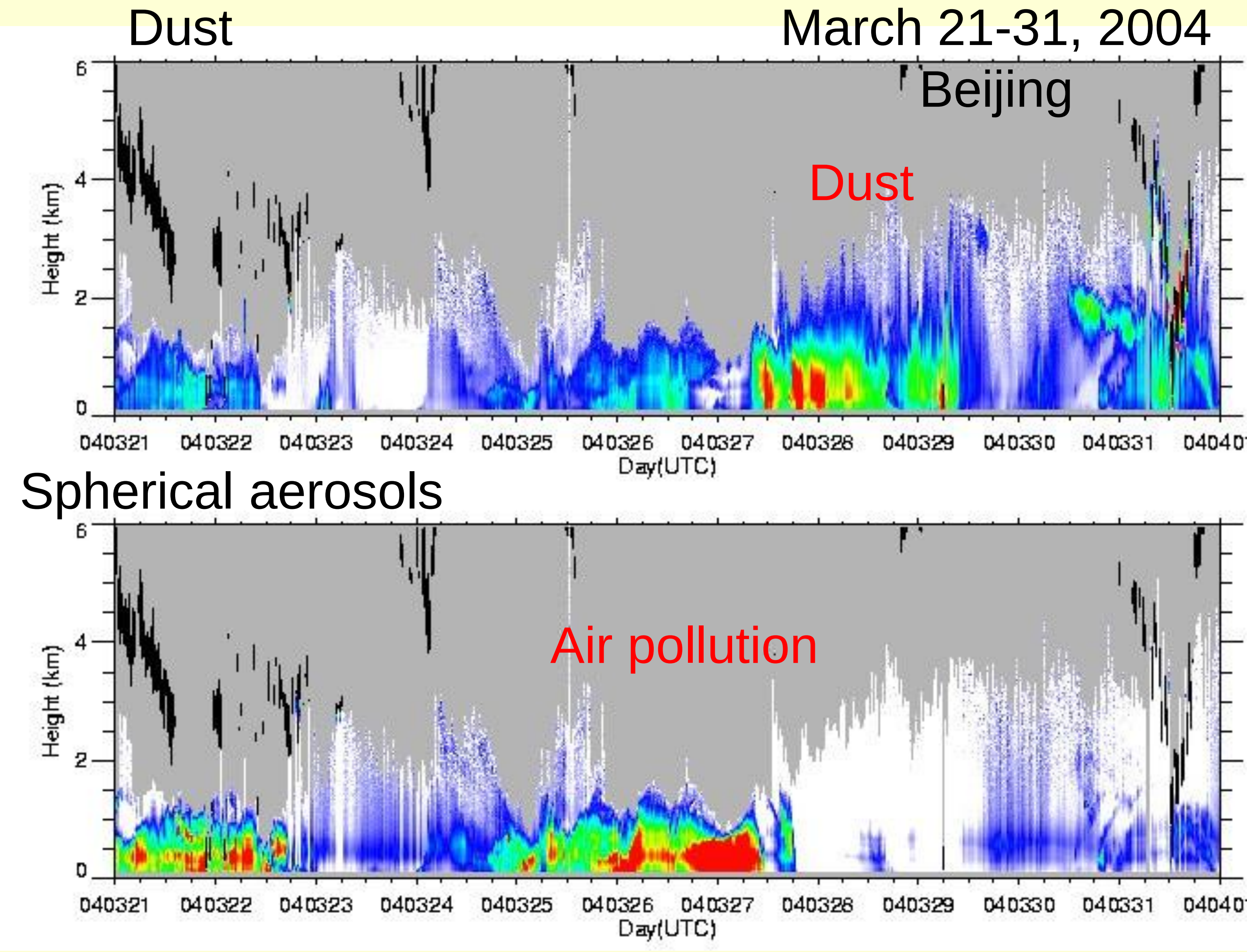


Realtime data processing system

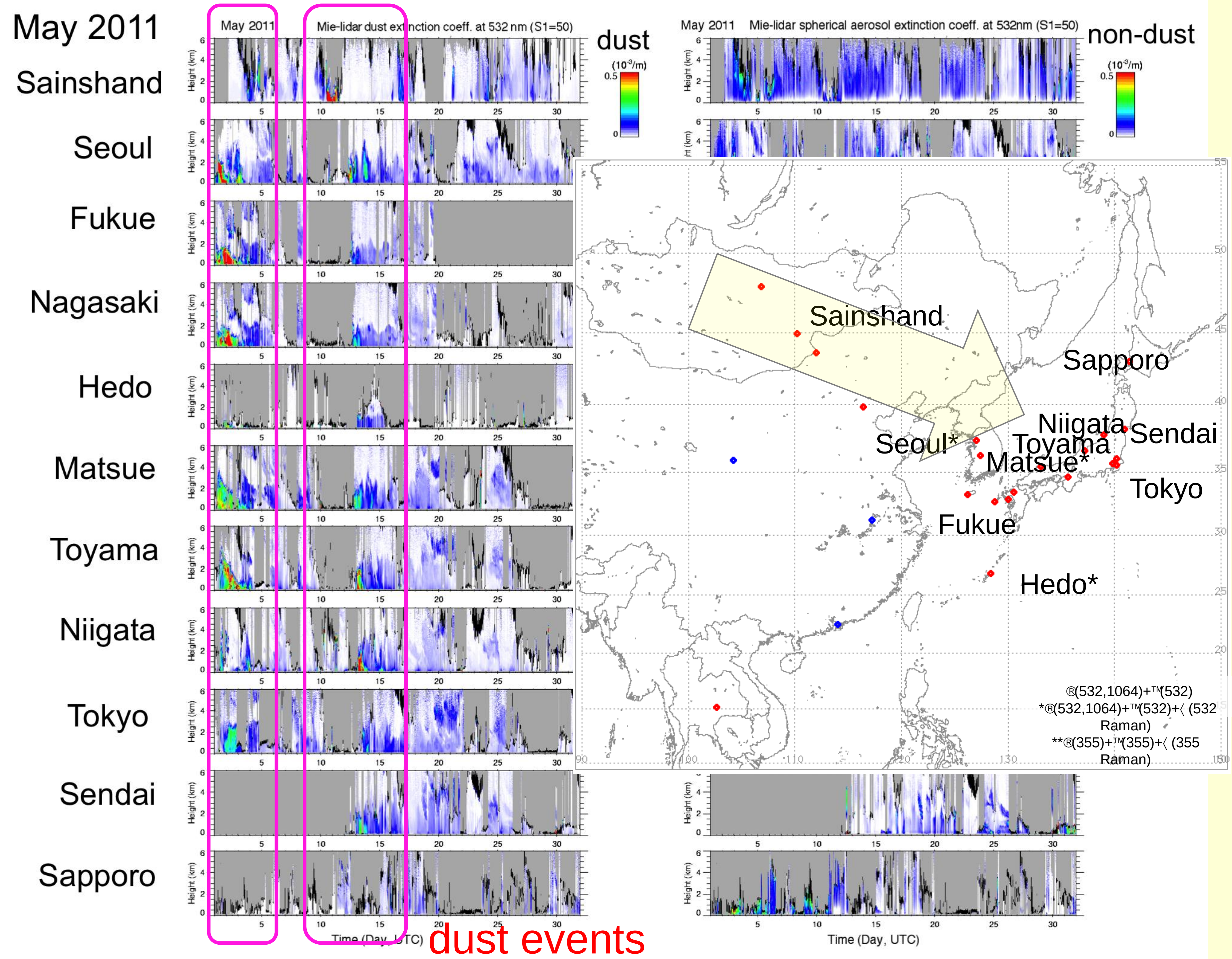


Extinction coefficient estimates of dust (left) and spherical aerosols (right) for primary locations (April 2009).

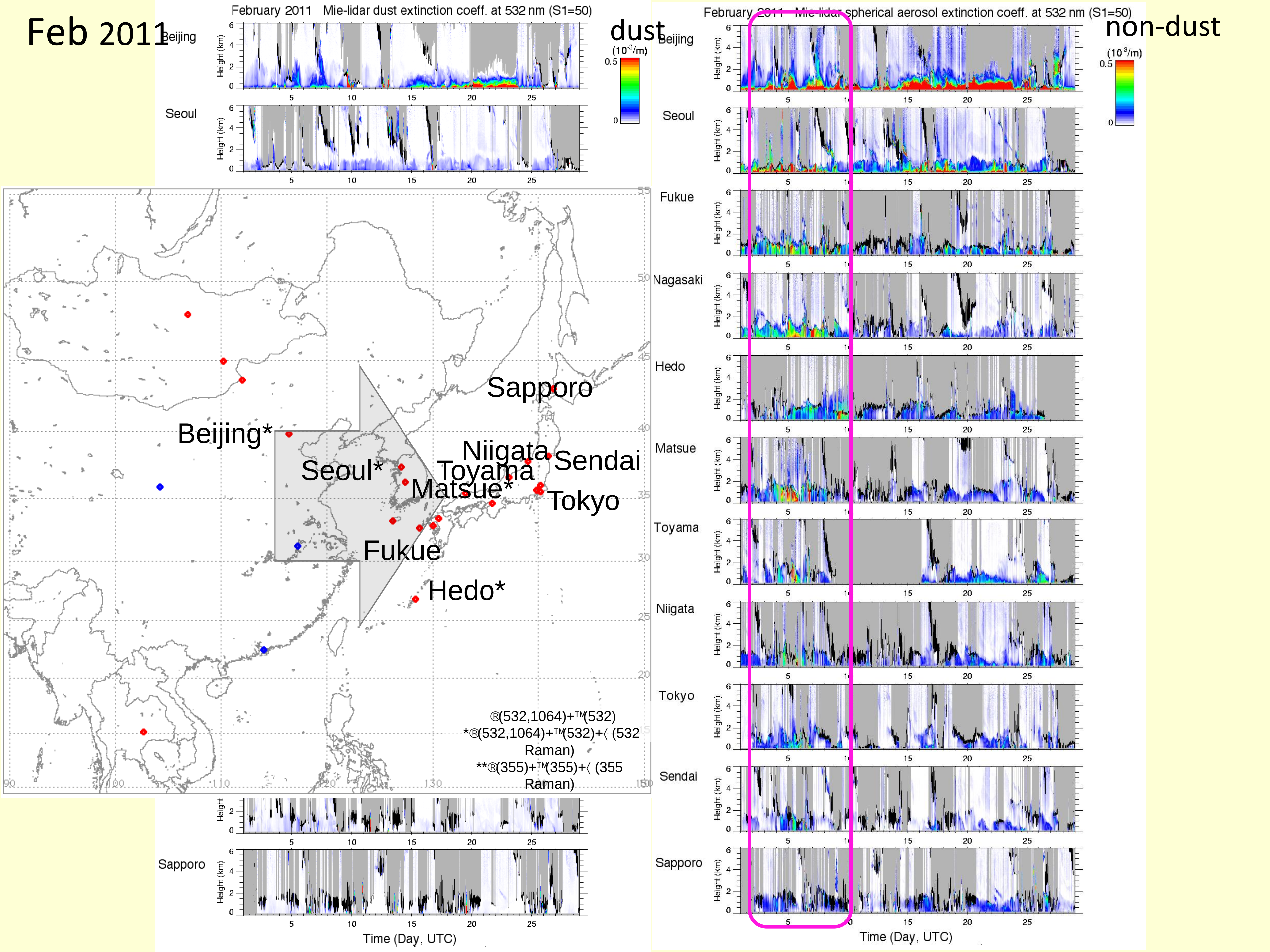
http://www-lidar.nies.go.jp/AD-Net/index.html



Method for estimating the extinction coefficients of dust and spherical aerosols using the depolarization ratio



May 2011
Sainshand
Seoul
Fukue
Nagasaki
Hedo
Matsue
Toyama
Niigata
Tokyo
Sendai
Sapporo
May 2011 Mie-lidar dust extinction coeff. at 532 nm (S1=50)
dust
(10⁻³/m)
May 2011 Mie-lidar spherical aerosol extinction coeff. at 532nm (S1=50)
non-dust
Height (km)
Time (Day, UTC)
dust events
Sainshand
Sapporo
Niigata
Sendai
Seoul*
Toyama
Matsue*
Tokyo
Fukue
Hedo*
®(532,1064)+™(532)
*®(532,1064)+™(532)+〈 (532 Raman)
**®(355)+™(355)+〈 (355 Raman)


Feb 2011
February 2011 Mie-lidar dust extinction coeff. at 532 nm (S1=50)
dust
(10⁻³/m)
0.5
0
Beijing
Seoul
Sapporo
Height (km)
Time (Day, UTC)
February 2011 Mie-lidar spherical aerosol extinction coeff. at 532 nm (S1=50)
non-dust
Beijing
Seoul
Fukue
Nagasaki
Hedo
Matsue
Toyama
Niigata
Tokyo
Sendai
Sapporo
Beijing*
Seoul*
Sapporo
Niigata
Sendai
Toyama
Matsue*
Tokyo
Fukue
Hedo*
®(532,1064)+™(532)
*®(532,1064)+™(532)+〈 (532 Raman)
**®(355)+™(355)+〈 (355 Raman)

Lidar dust extinction coefficient has high correlation with dust PM2.5

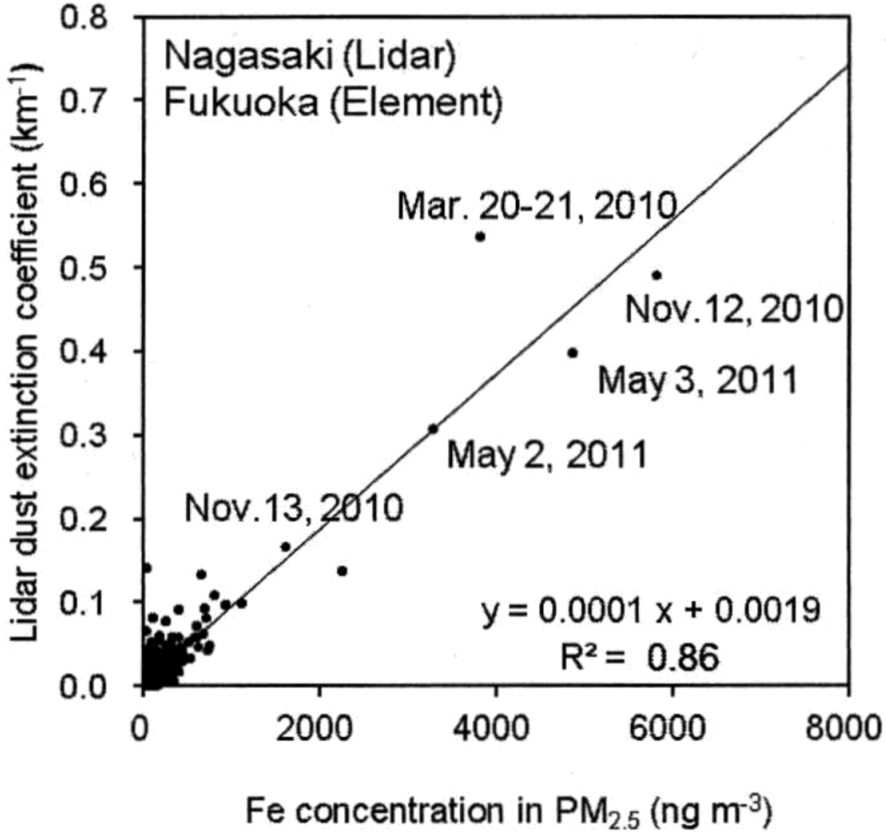
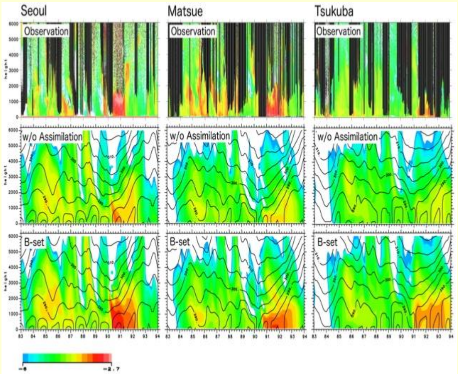
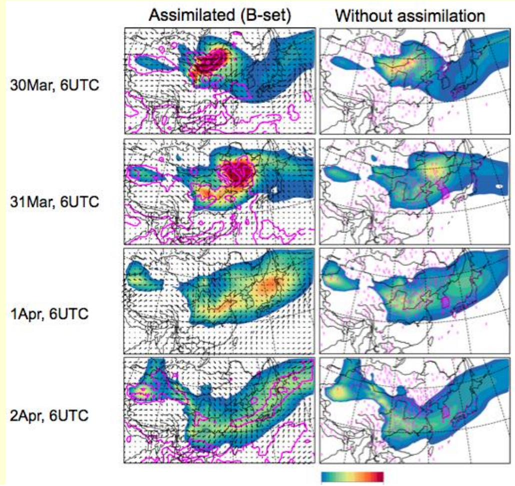


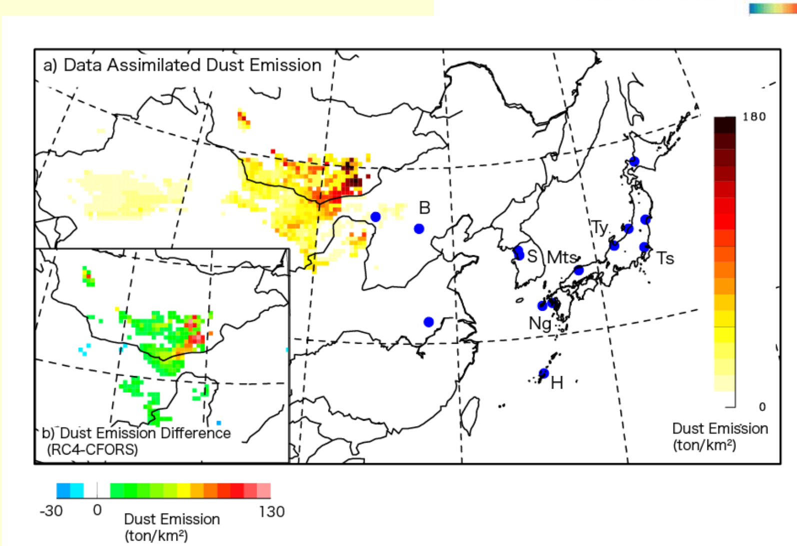
Fig.4 Comparison of daily averaged lidar dust extinction coefficients at Nagasaki and Fe concentration in $PM_{2.5}$ aerosol at Fukuoka (Dazaifu) from Oct., 2009 to May, 2011.

(Kaneyasu et al., J. Jpn. Soc. Atmos. Environ. 2012)

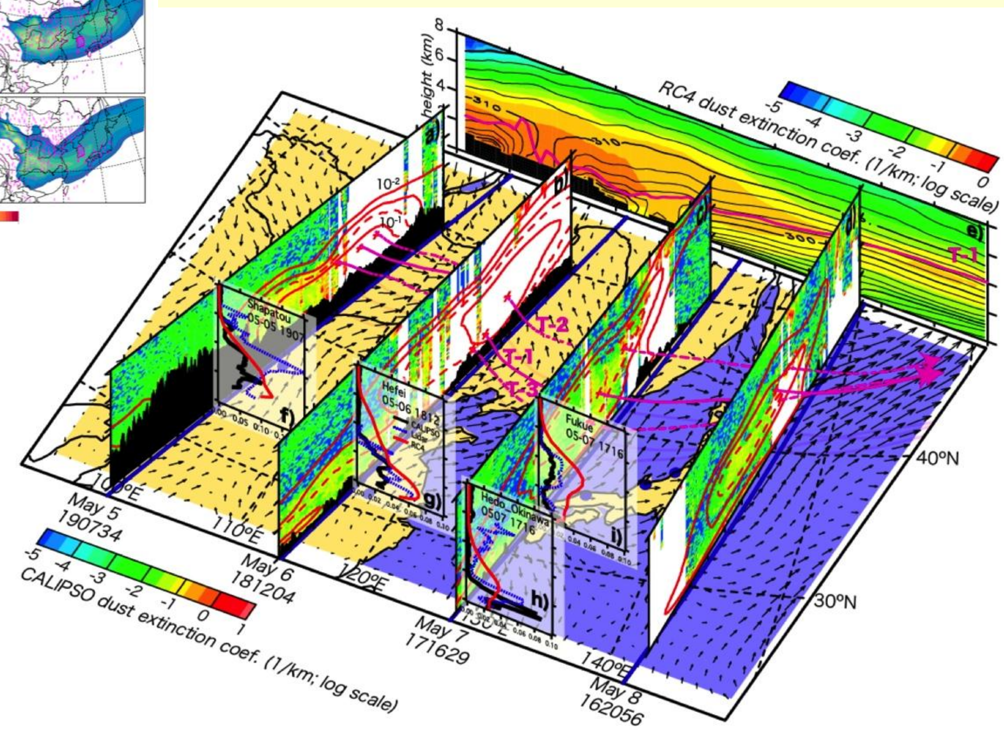
Asian dust study using 4D-Var data assimilation







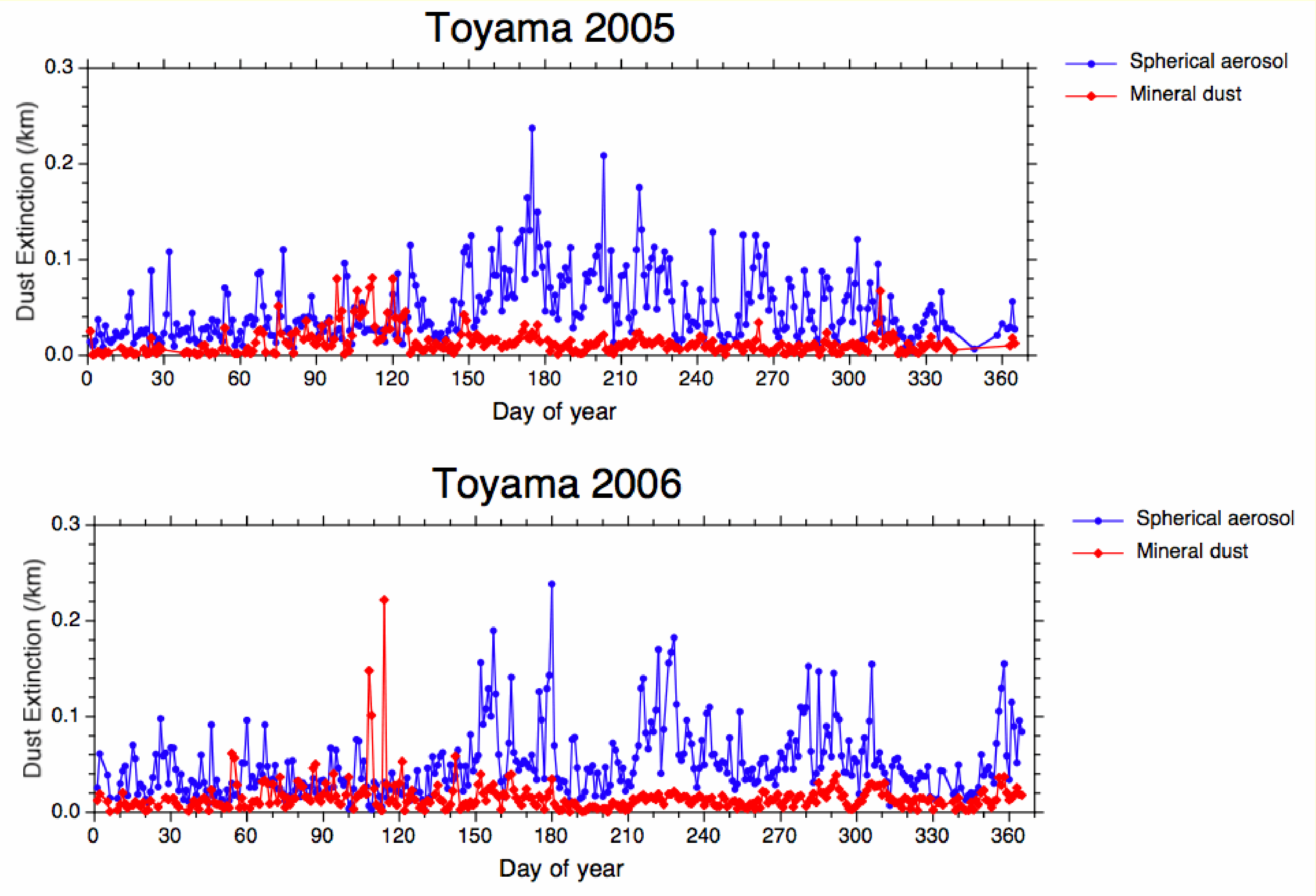
4DVAR data assimilation of Asian dust using the NIES lidar network data (Yumimoto et al. 2007, 2008)



Comparison of the assimilated dust transport model with CALIPSO data (Hara et al. 2009)

Please see the publication list at
http://www-lidar.nies.go.jp/~cml/English/PublicationsE.html

Application of the lidar data to epidemiological studies



Near-surface (120m-1km) dust and non-dust aerosol extinction coefficient used in the epidemiological study.

Publications on the epidemiological studies using the lidar data

-Kanatani, K. T., I. Ito, W. K. Al-Delaimy, Y. Adachi, W. C. Mathews, J. W. Ramsdell, and Toyama Asian Desert Dust and Asthma Study Team, 2010: **Desert-dust Exposure is Associated with Increased Risk of Asthma Hospitalization in Children**, Am. J. Respir. Crit. Care Med. 182(12) 1475-81, doi:10.1164/rccm.201002-0296OC.

-Onishi, K., Y. Kurosaki, S. Otani, A. Yoshida, N. Sugimoto, Y. Kurozawa, **Atmospheric transport route determines components of Asian dust and health effects in Japan**, Atmospheric Environment 49 (2012) 94-102, doi:10.1016/j.atmosenv.2011.12.018. (Subjective symptoms)

-Kashima, S., T. Yorifuji, T. Tsuda, A. Eboshida, **Asian dust and daily all-cause or cause-specific mortality in western Japan**, Occup Environ Med 2012;00:1–8. doi:10.1136/oemed-2012-100797.

-Ueda, K., A. Shimizu, H. Nitta, K. Inoue, **Long-range transported Asian Dust and emergency ambulance dispatches**, Inhal Toxicol. 2012 Oct;24(12):858-67. doi: 10.3109/08958378.2012.724729.

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[Sugimoto et al., 2001; 2005]

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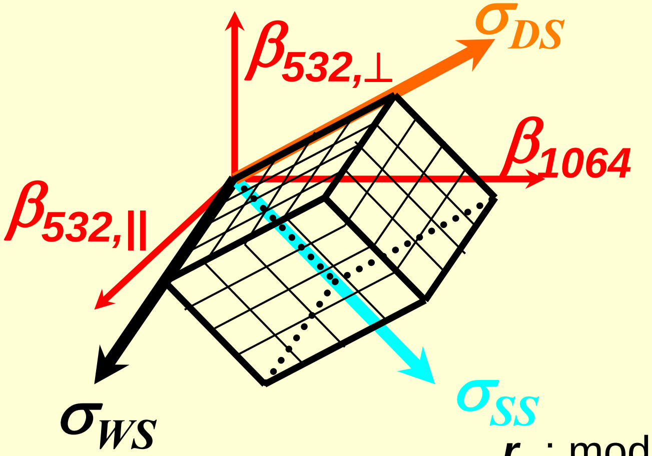
  (1β+1δ method) [Sugimoto et al., 2003; Shimizu et al., 2004]
  ＝＞ Ground-based lidar data

- **2β+1δ data→** Air-pollution (Spherical / Small) +
  (2β+1δ method) Sea-salt (Spherical / Large) +
  Dust (nonSpherical) [Nishizawa et al., 2007,2008,2011]
  => Ship-born lidar data & Satellite-borne lidar (CALIOP/NASA)

Aerosol component retrieval for Shipborn lidar & satelliteborn lidar (CALIOP/NASA)

[Nishizawa et al. 2011]

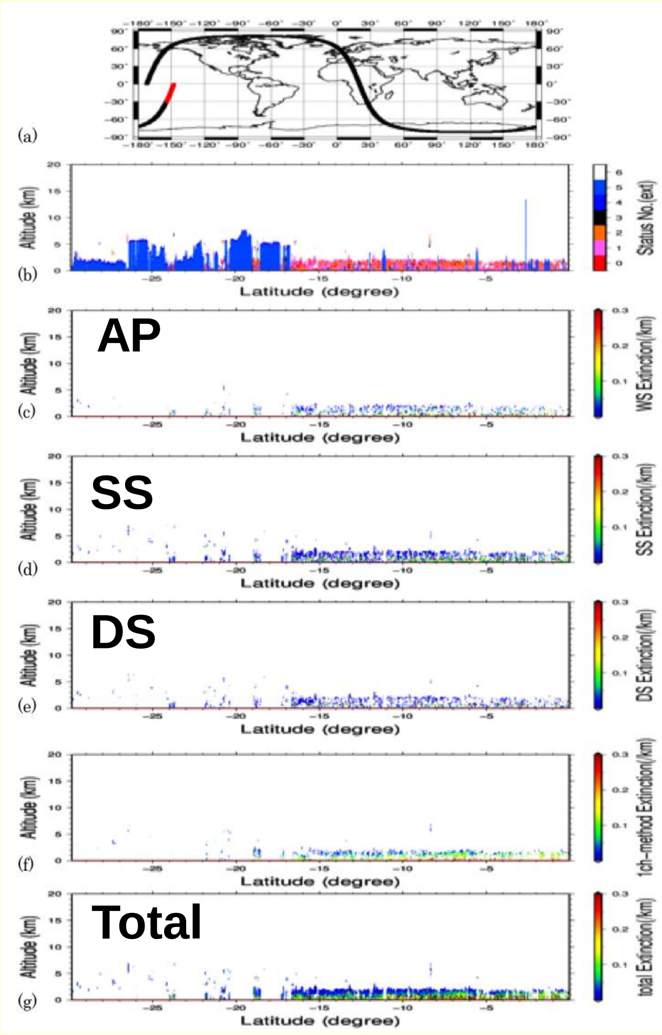


Optical model (RH=70%)

	AP	SS	DS
r_m	0.13	3.0	2.0
S	55	20	48
δ	0	0	0.3

r_m: mode radius, **S**: lidar ratio(532nm)
δ: depolarization ratio (532nm)

Pacific ocean, 8/2, 2006
Clean maritime environment
[Kurogi & Okamoto 2012]



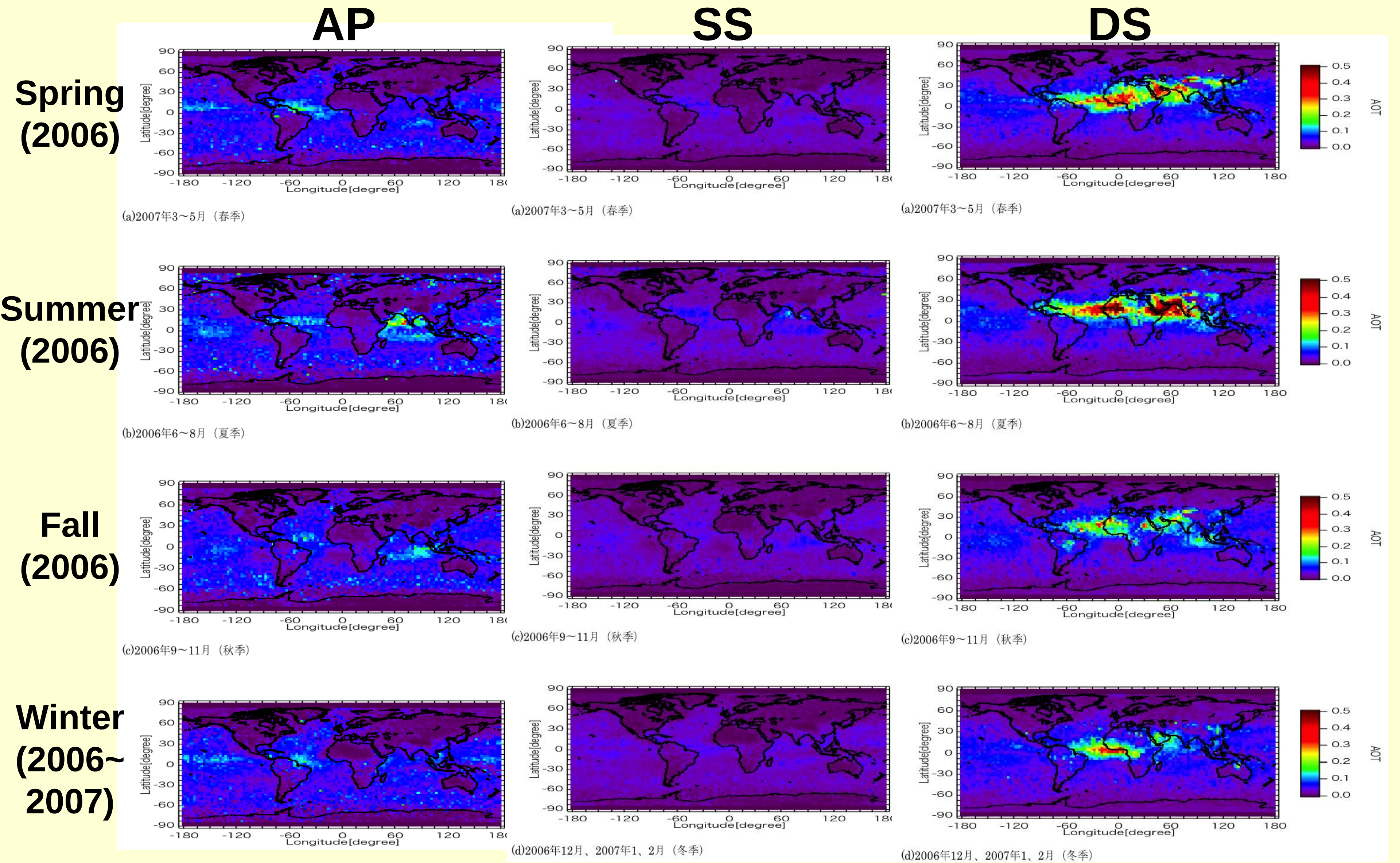
Air-pollution: small-size / spherical (moderate-absorption)
Dust : large-size / non-spherical (moderate absorption)
Sea-salt : large-size / spherical (weak-absorption)

<u>Assumption:</u>

- External mixture of 3 components at each layer
- Optical properties are prescribed
- DS (AP, SS): spheroid (spherical) <= Dubovik et al., [2006]
- WS, SS : hygroscopic growth
  => Change optical model depending on RH data (ECMWF)

Optical thickness for each component

[Kurogi & Okamoto 2012]

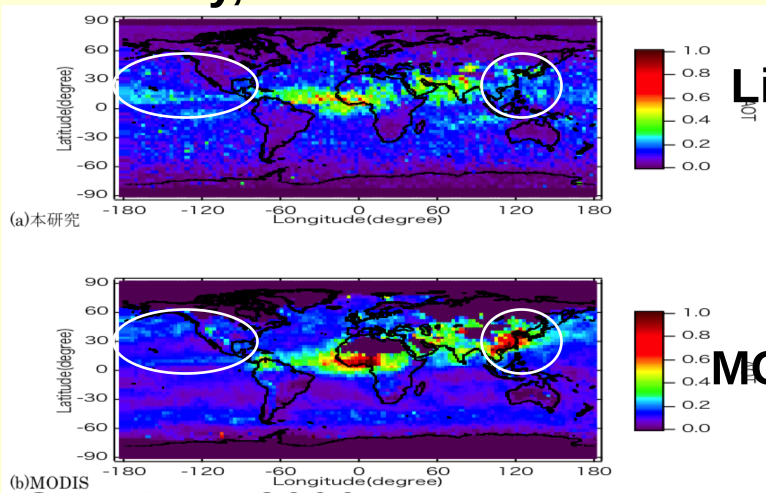


*Averaged every 3° ×3° grid for day and night

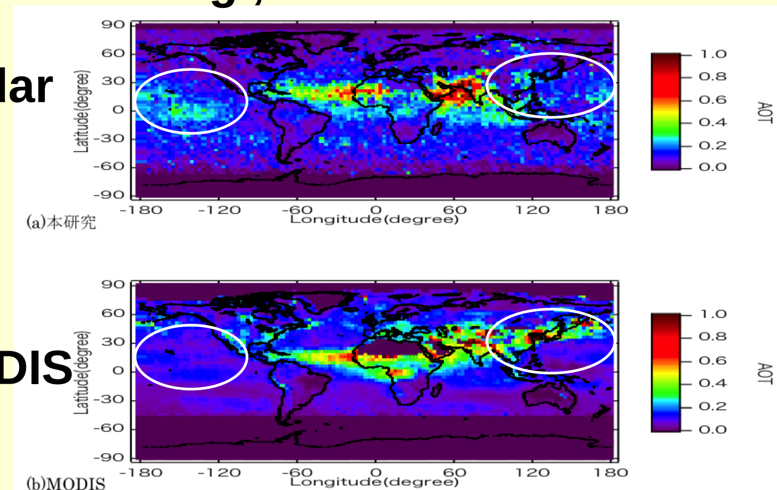
AOT comparison with MODIS

[Kurogi & Okamoto 2012]

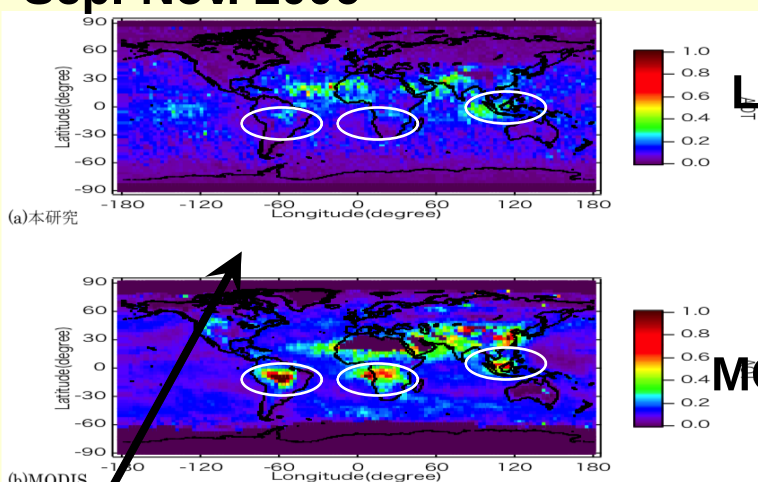
Mar.-May, 2006



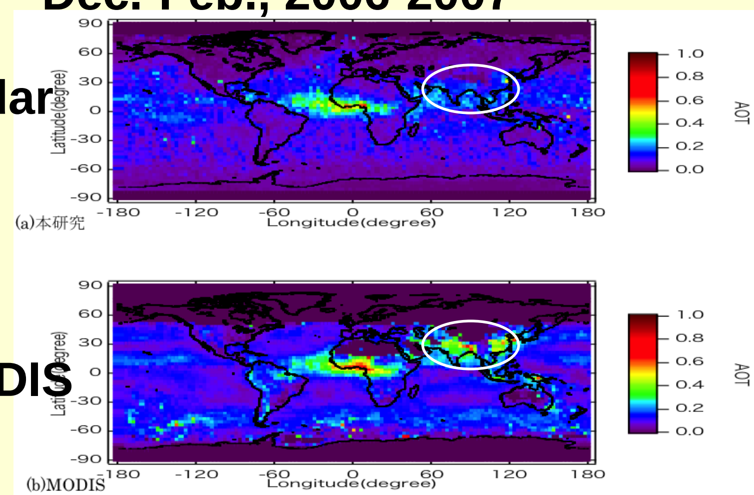
Jun-Aug., 2006



Sep.-Nov. 2006



Dec.-Feb., 2006-2007



Biomass-burning aerosols (BC, OC)

Ocean: AOT (MODIS) > AOT (Lidar)
Land: AOT (MODIS) < AOT (Lidar)

*Averaged every 3° ×3° grid for daytime

Introduction of more advanced lidar to AD-Net

Independent extinction (α) measurement is useful
to classify weak/strong light absorption particles [Nishizawa et al., 2008]
(Lidar ratio = extinction/backscatter: e.g., BC~100sr, Dust~50st, Sea-salt~20 at 532nm)

Data analysis

Combined use of HSRL(532) and 2β(532,1064) Mie lidar

- **1α+2β data→ (1α+2β method)** Sulfate-Nitrate-OC (Small / Weak absorption) + BC (Small / Strong absorption) + Dust (Large) [Nishizawa et al. 2008]

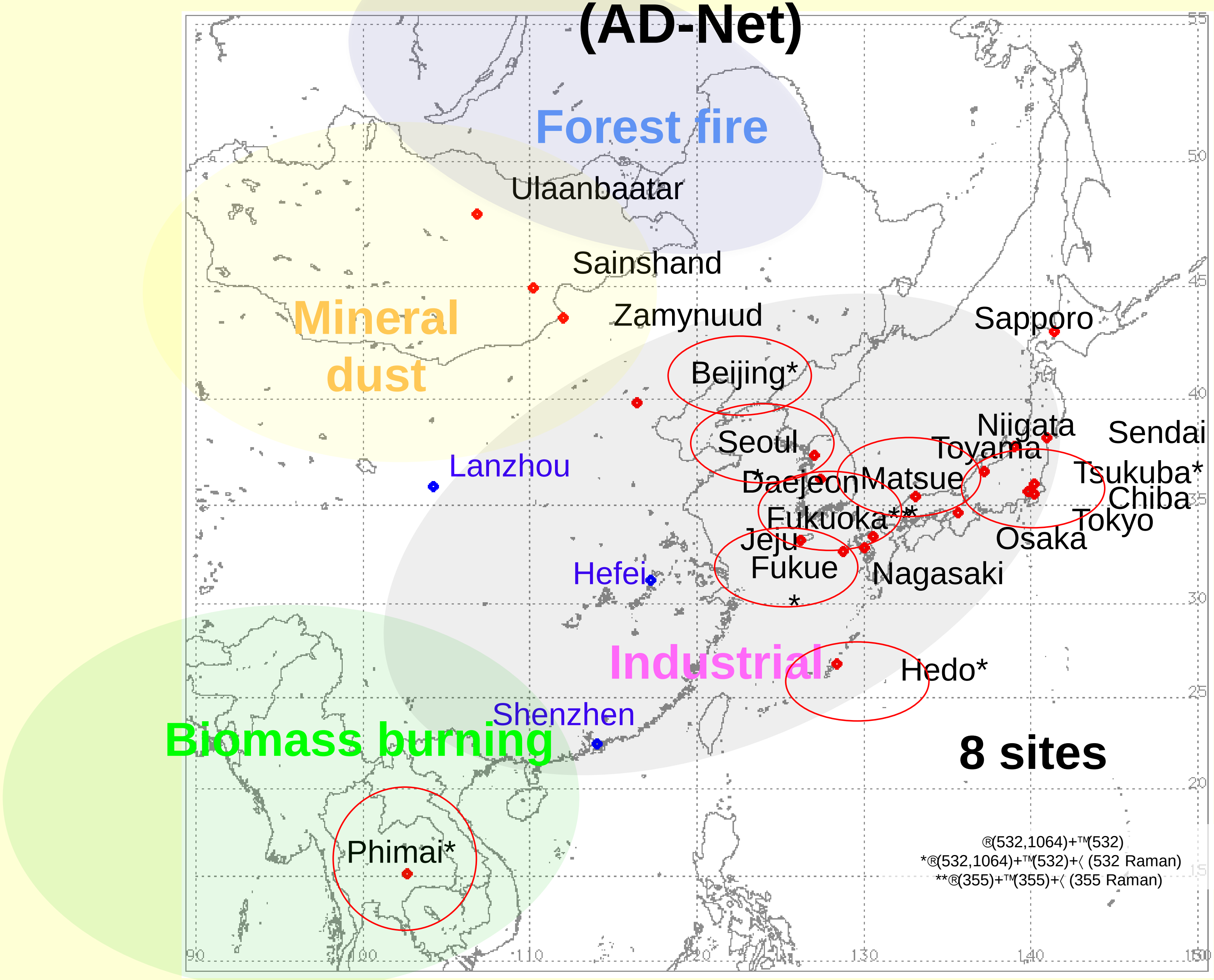
Ground-based network measurement

- 2β+1δ Mie lidar + 1α N_2 Raman (607) channel
  with automatically measurement capability [1α+2β+1δ lidar]
  (8 sites in the NIES Lidar Network) [Xie et al., 2008]
- Dual wavelength (355, 532nm) HSRL + 1β(1064)+2δ(1064,532) Mie lidar
  with automatically measurement capability [2α+3β+2δ lidar]
  [Nishizawa et al., 2008,2010]

Ship-borne measurement (MIRAI)

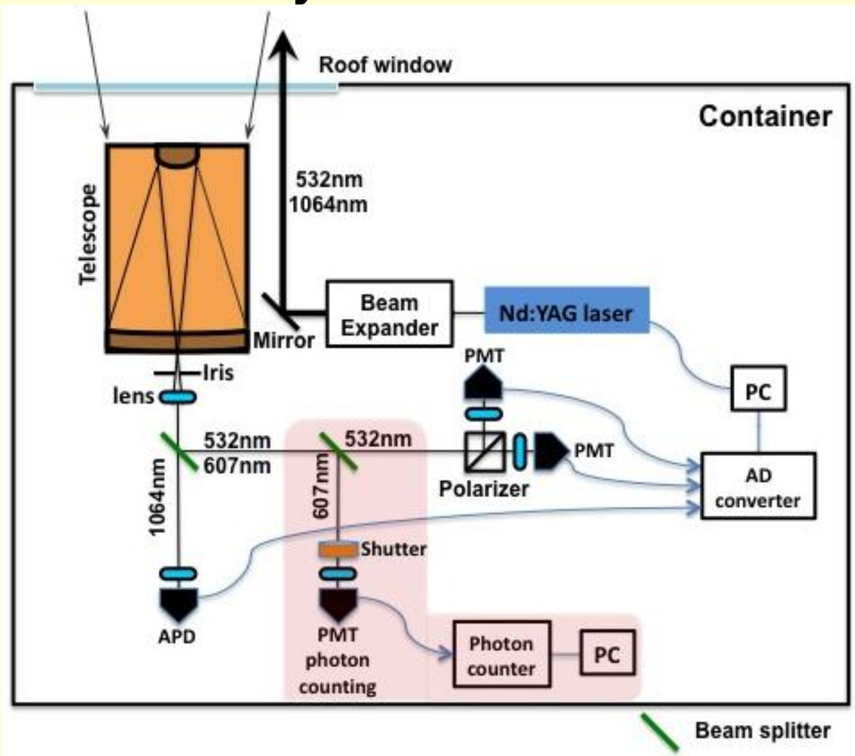
- One wavelength (532nm) HSRL + 1β(1064)+1δ(532) Mie lidar
  with automatically measurement capability [1α+2β+1δ lidar]

Asian Dust and aerosol lidar observation Network (AD-Net)

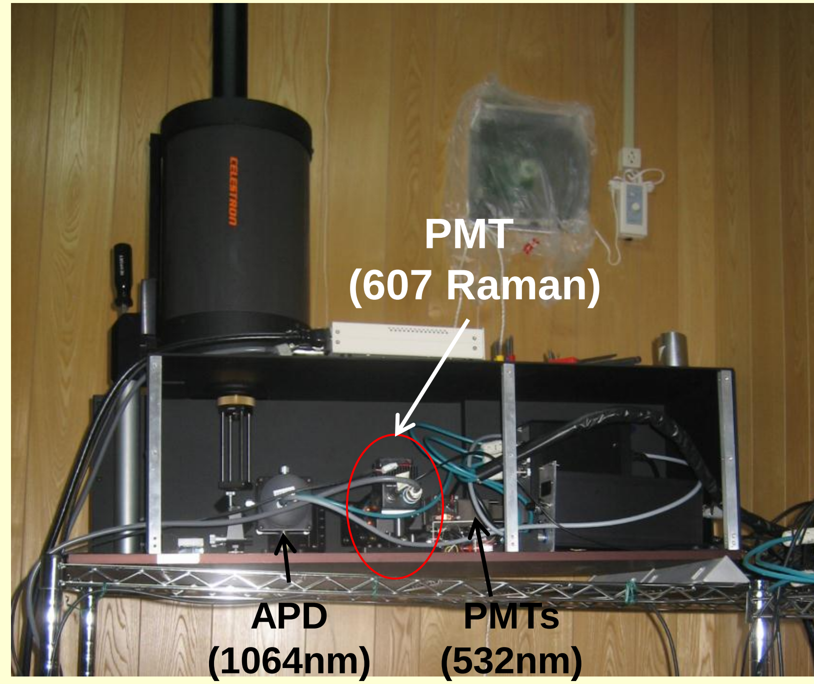


Mie-Raman lidar

System outline



System picture



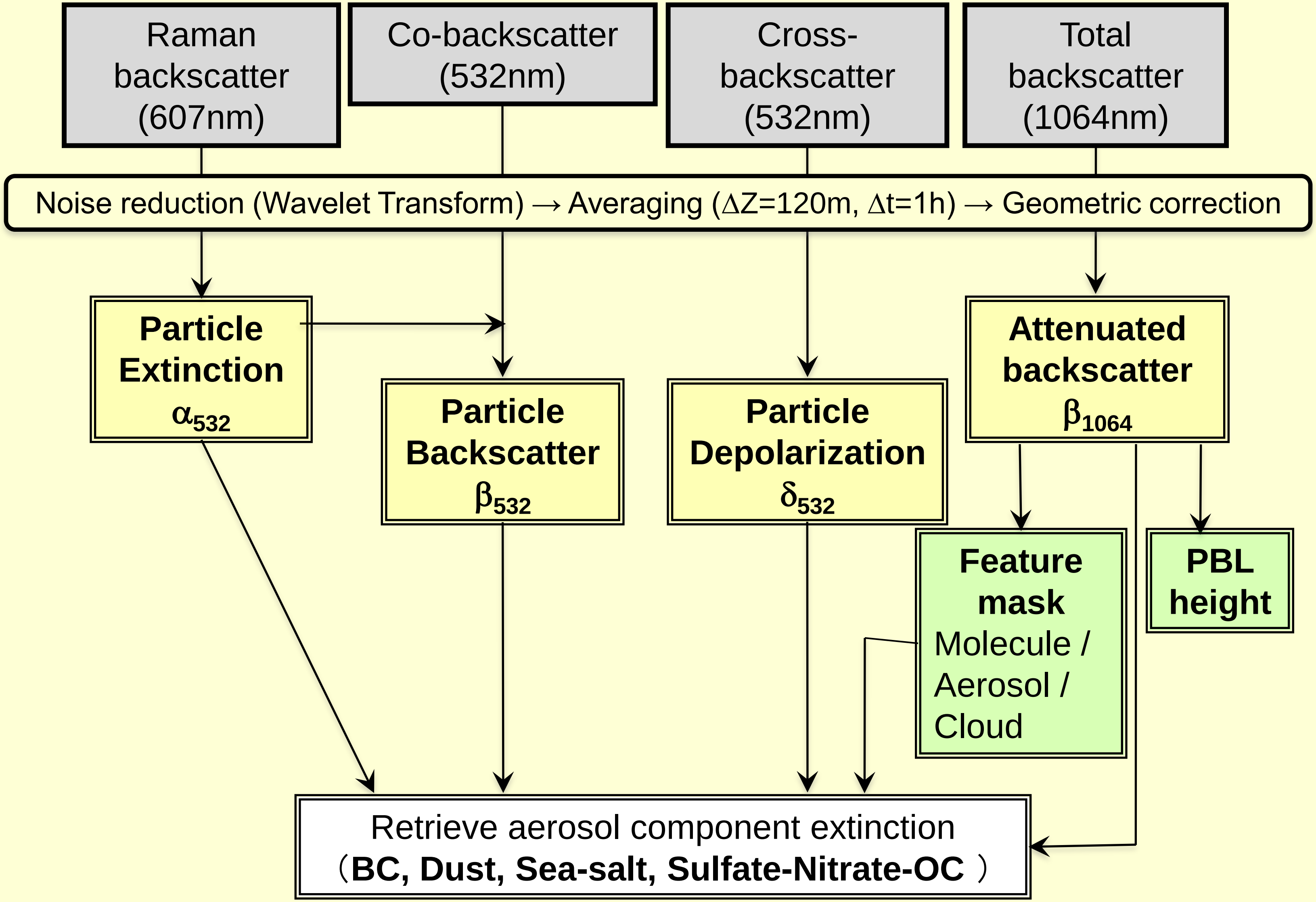
Measured parameters

- Copol backscatter (532nm)
- Crosspol backscatter (532nm)
- Total backscatter (1064nm)
- Raman backscatter (607nm)

Optical properties

- 532nm Particle Extinction (α_{532})
- 532nm Particle Backscatter (β_{532})
- 532nm Particle depolarization (δ_{532})
- 1064nm Attenuated backscatter (β_{1064})

Data analysis



Note: Daytime Raman channel data are not used due to contamination of sunlight.

Example of analysis [Seoul, 12-15 May 2010]

Raman signal (607nm)

Attenuated Backscatter (532nm)

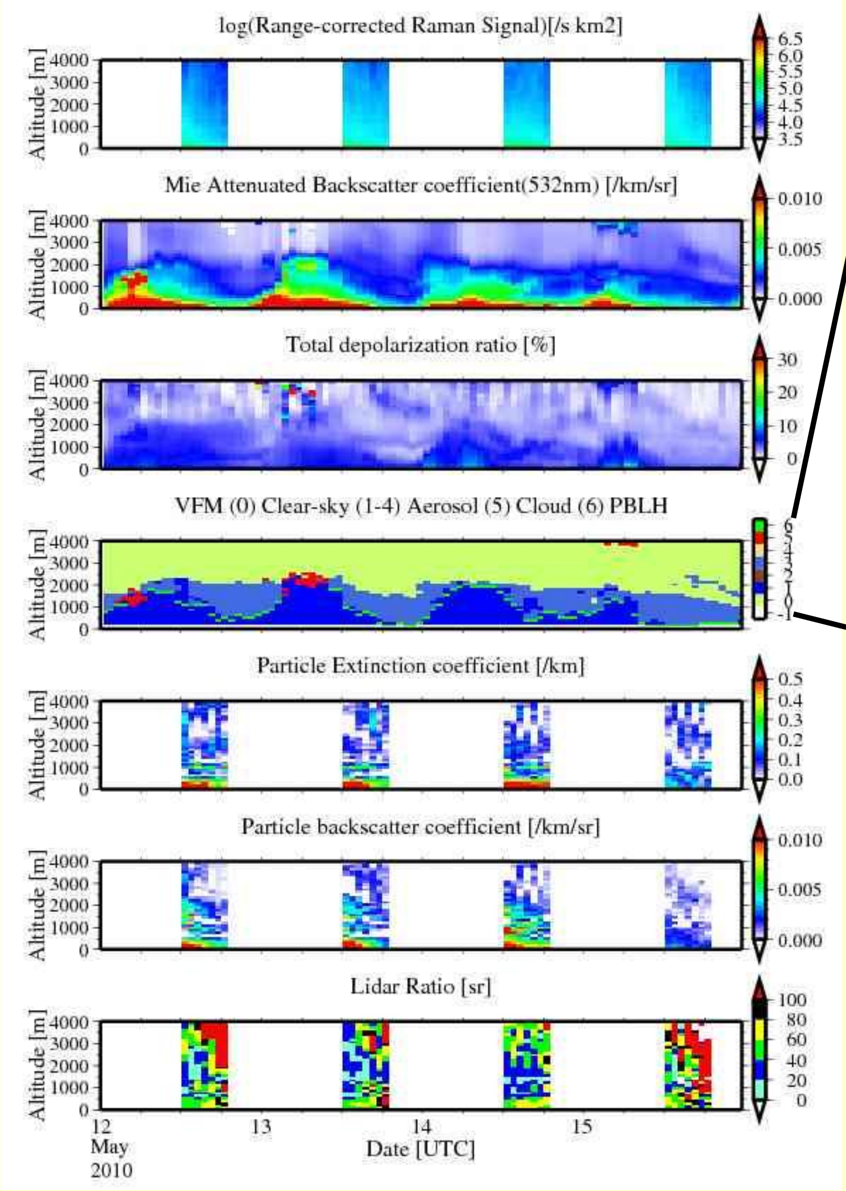
Total dep. (532nm)

Feature mask

Particle Extinction (532nm)

Particle Backscatter (532nm)

Lidar ratio (532nm)



Feature mask

- Blue : Spherical aerosols
- Brown: non-spherical aerosols
- Red : Clouds
- Yellowish green : Molecules
- Green : PBL height

∗ Use 1064 attenuated backscatter and 532nm total depolarization data [Shimizu et al., 2004; Hagihara et al., 2010]

~0.3km^{-1}

ΔZ = 120 m
ΔT = 60 min

~0.005sr^{-1}km^{-1}

40~80 sr

Example of analysis [Cape Hedo (Japan), 19-22 Mar. 2010]

Raman signal (607nm)

Attenuated Backscatter (532nm)

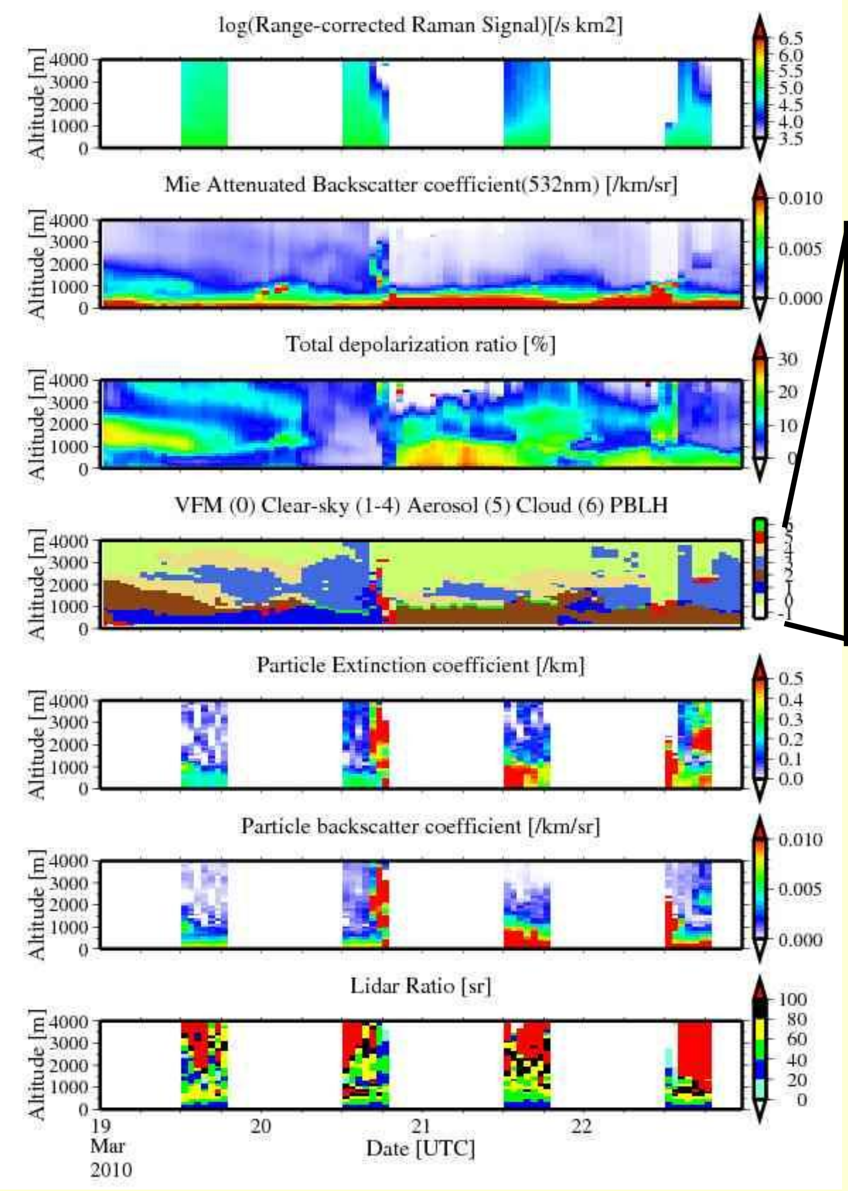
Total dep. (532nm)

Feature mask

Particle Extinction (532nm)

Particle Backscatter (532nm)

Lidar ratio (532nm)



Feature mask

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Yellowish green: Molecules

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* Use 1064 attenuated backscatter and 532nm total depolarization data [Shimizu et al., 2004; Hagihara et al., 2010]

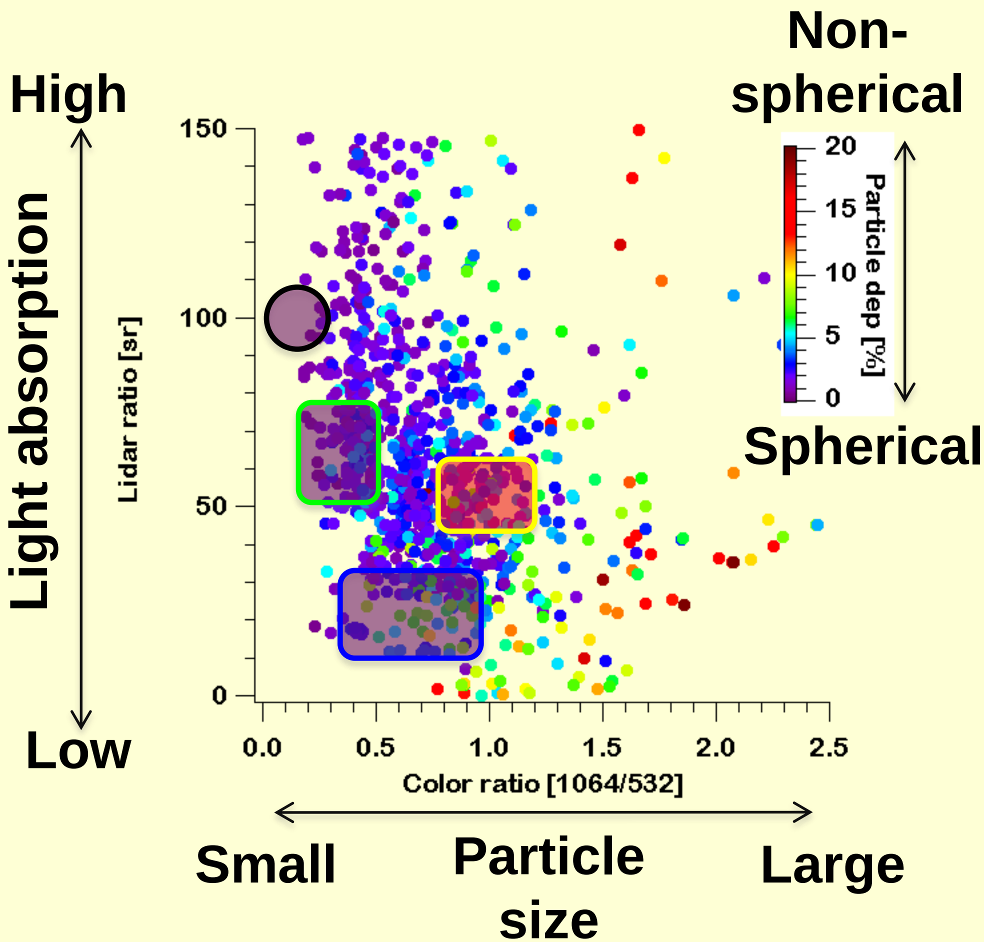
ΔZ = 120 m

ΔT = 60 min

20~80 sr

Scatter plot, Cape Hedo

- Aerosol optical properties averaged in PBL
- Plot data in autumn (Sep. ~ Nov.) in 2010 and 2011



OPAC model: BC SF-NT-OC Sea-salt

Spheroid dust model: Spheroid dust

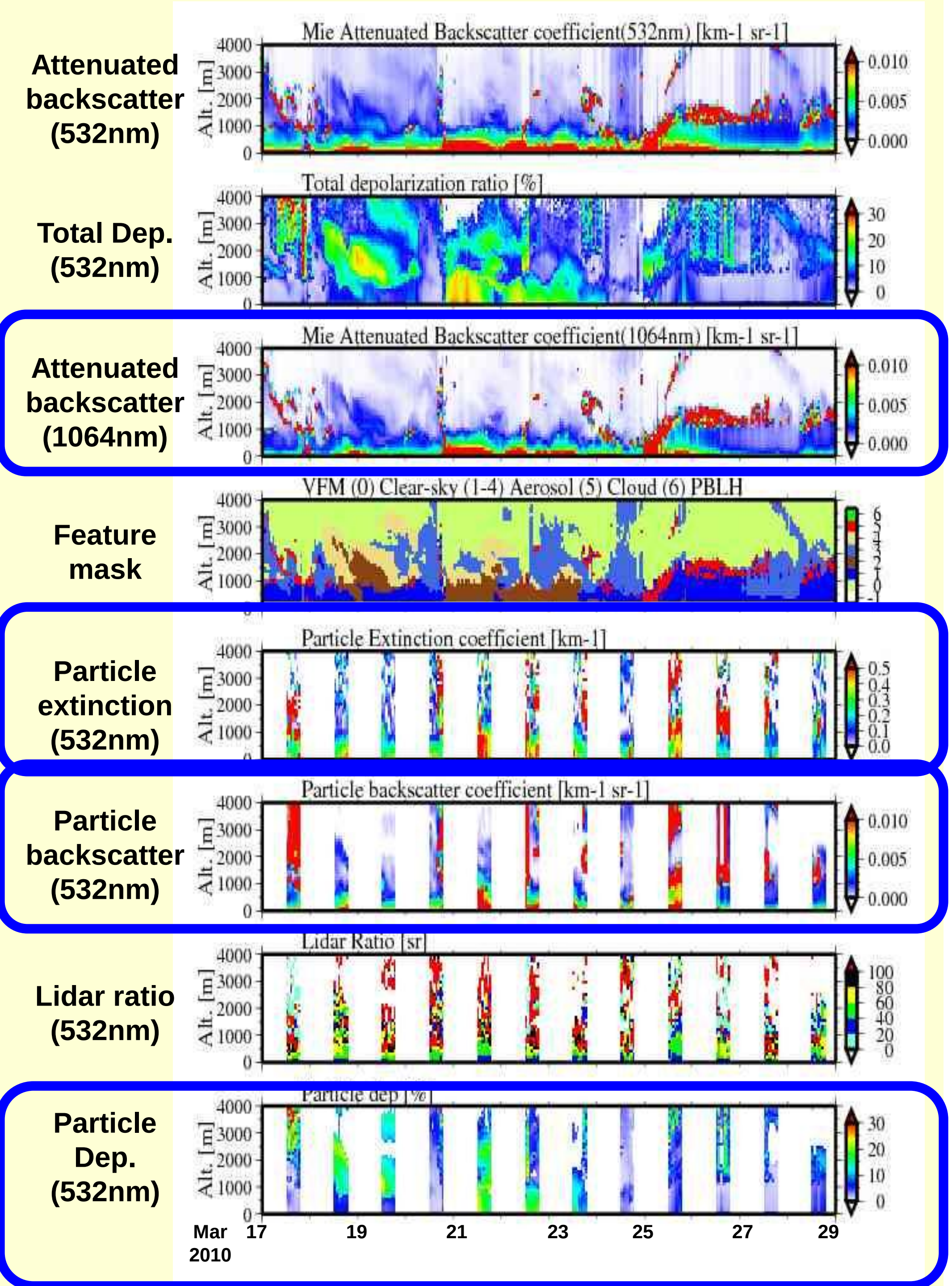
1α+2β+1δ algorithm

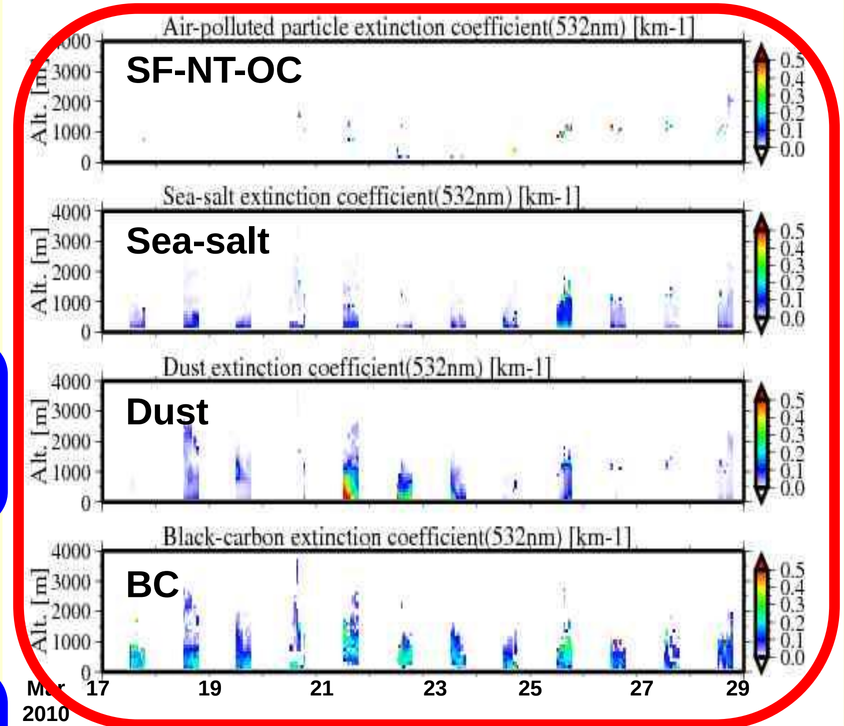
Retrieve extinction coefficients for 4 aerosol components

SF-NT-OC:
small-size / spherical / moderate-absorption
Dust :
large-size / non-spherical / moderate absorption
Sea-salt :
large-size / spherical / weak-absorption
Black carbon:
small-size / spherical / strong-absorption

	SF-NT-OC	Dust	BC	Sea-salt
Mode radius [um] Standard dev.	0.13 1.6	2.0 2.2	0.05 2.0	3.0 2.1
Refractive index (532nm)	1.41 2×10^{-3}	1.51 3×10^{-3}	1.75 0.4	1.36 3×10^{-9}
Lidar ratio (532nm, sr)	55	48	101	20
Dep. (532nm)	0.02	0.30	0.02	0.02
Backscatter color ratio (1064/532)	0.34	0.98	0.23	0.67

Assumption:
- External mixture of 4 components at each layer
- Optical properties are prescribed
- DS (AP, SS, BC): spheroid (spherical)
  <= Dubovik et al., [2006]





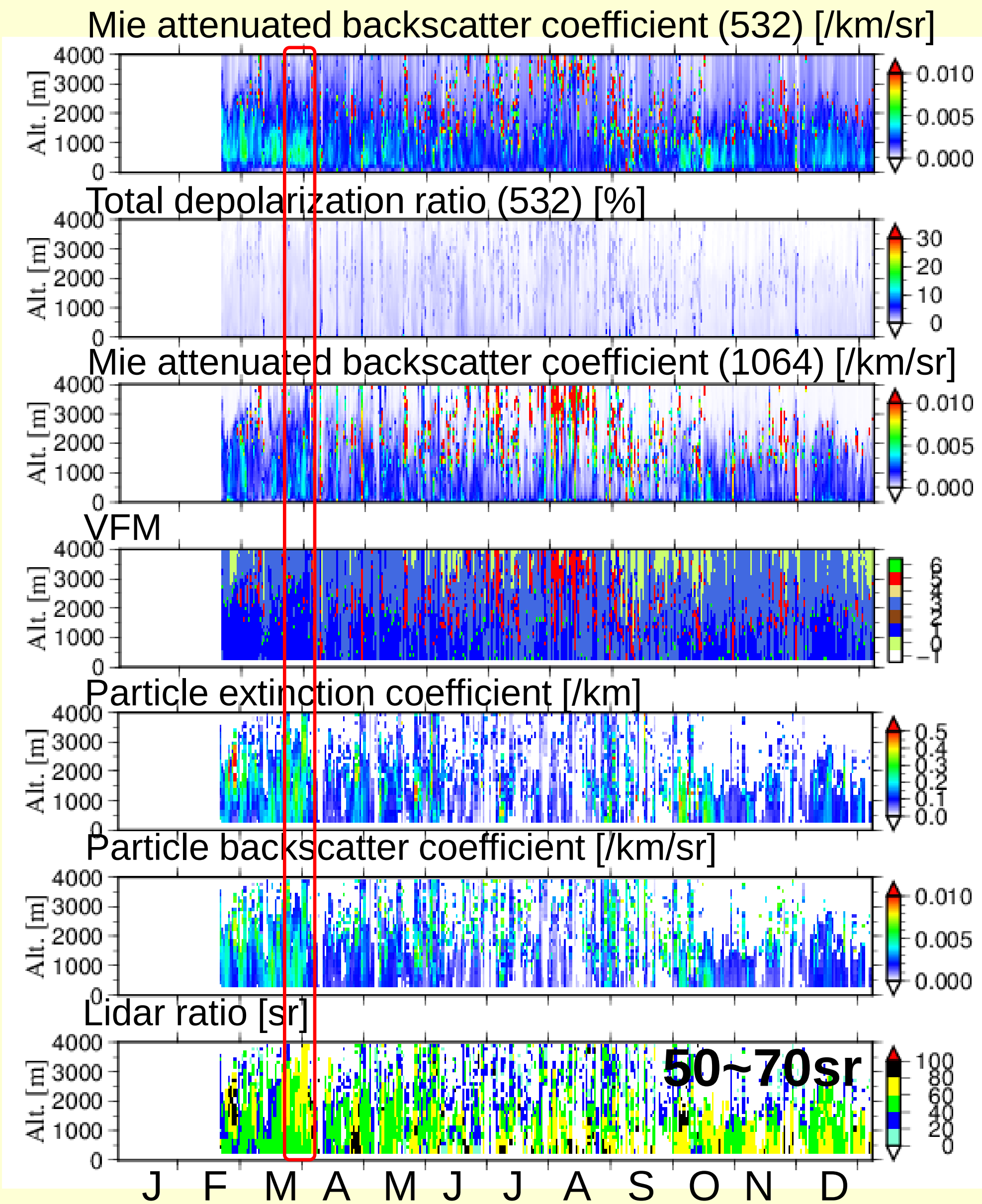
$\Delta Z = 120$ m
$\Delta T = 60$ min

BC extinction is too high ?
SF-NT-OC is too low ?
=> Validation is needed.
=> Aerosol optical models
should be improved

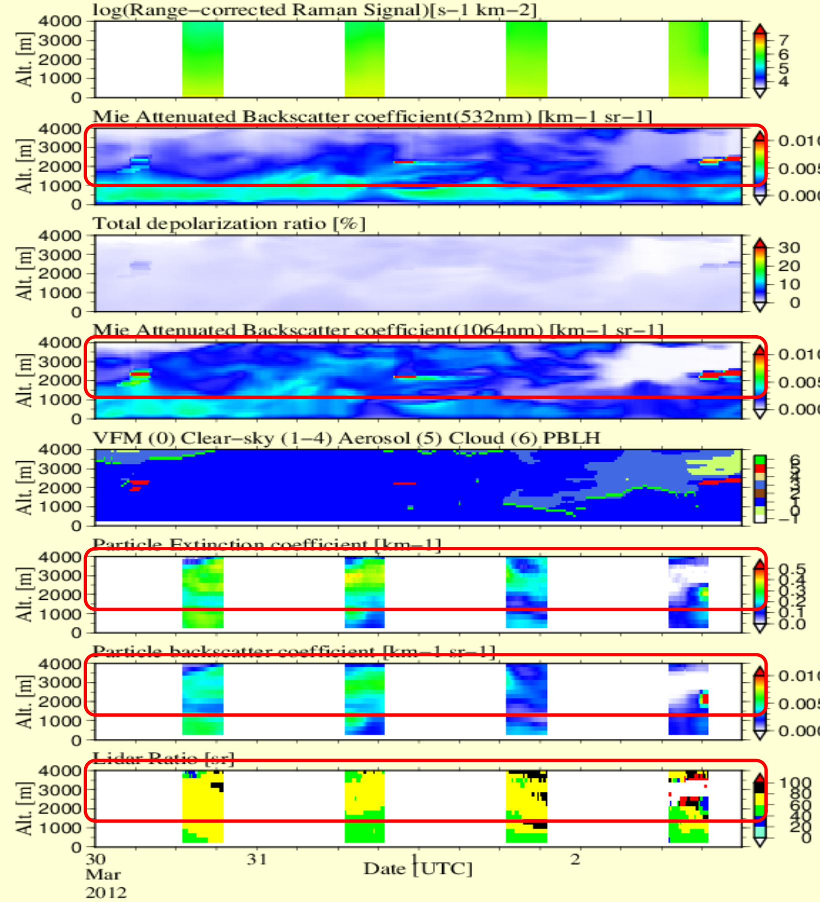
Cape Hedo, Okinawa, Japan
(3/17-28,2010)

Mie-Raman lidar observation at Phimai, Thailand (2012 ~)

2012



30 Mar. ~ 2 Apr. 2012



<u>Lidar ratio for biomass burning aerosols</u>

AERONET :

Cattrall. 2005: 60±8 (Africa / S. America)

Omar. 2009 : 70 (all AERONET data)

Lidar (EARLINET)

Muller. 2007 : 53±11 (Siberia/Canada)

Summary

 We have conducted ground-based lidar network observation and continue it. The provided data are useful for studying Asian dust and air pollution aerosols.

 We improved the NIES ground-based network lidars by adding a N_2 Raman scatter measurement channel (607nm). This system **provides 1α(532)+2β(532,1064)+1δ(532) data at nighttime.**

 We developed an algorithm to estimate **vertical profiles of 532nm extinction coefficients of black carbon**, **dust**, **sea-salt**, and **SF-NT-OC** aerosols using the 1α+2β+1δ data.

 The particle optical properties, PBL height, and scene classification identifiers are automatically estimated from the lidar data and their **quick-looks and archives are provided on the website** (http://www-lidar.nies.go.jp/shingakujutsu/Raman/).

✔ Error analysis and validation of the developed aerosol classification algorithm are needed in the future.

✔ Derived particle optical properties such as lidar ratio are useful for characterizing aerosol types such as biomass burning.

✓Application of the developed aerosol component classification algorithms to **EarthCARE** lidar "ATLID". EarthCARE is a joint Japanese (JAXA)-European (ESA) satellite observation mission for understanding the interaction between clouds, radiative and aerosol processes in the earth climate. ATLID is a HSRL providing 1α+1β+1δ at 355nm.

✓For more advanced aerosol component classification and aerosol typing,

•Observation by **multi-wavelength Raman lidar and HSRL** with more channels
=> Lidar development

•Simultaneous measurements by active sensor (lidar) and passive sensor (e.g., Skyradiometer) and their combined analysis.
=> Continue and develop the cooperative observation
between **SKYNET** and **AD-Net**

NIES lidar Network Data

* Only night time

Lidar	Data	Site	Status
Ground-based measurements			
Mie lidar	2β(532,1064) + 1δ(532)	14 sites in East Asia	2001~
Mie-Raman lidar	1α(532)*+2β(532,1064) +1δ(532)	7 sites (Japan, China, Korea, Thai)	2008~
Mie-Raman lidar	1α(355)*+1β(355) +1δ(355)	1 site (Fukuoka)	2012~
Two-wavelength HSRL	2α(532,355) 3β(1064,532,355) 2δ(1064,532)	1 site (Tsukuba)	Under development
Shipborne measurements			
Mie lidar	2β(532,1064) + 1δ(532)	R/V Mirai	1999~
One-wavelength HSRL	1α(532)+2β(532,1064) +1δ(532)	R/V Mirai	2011

Heavy dust case

Light dust case

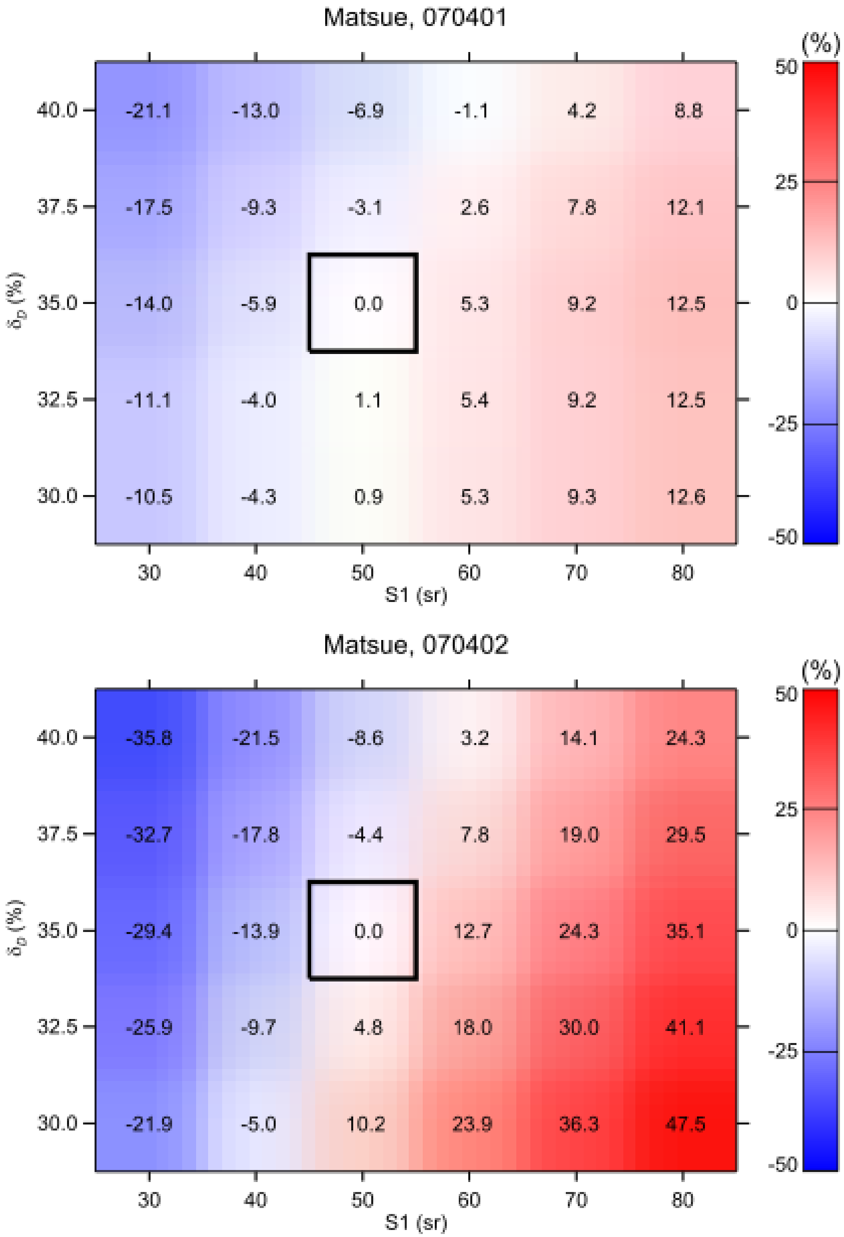
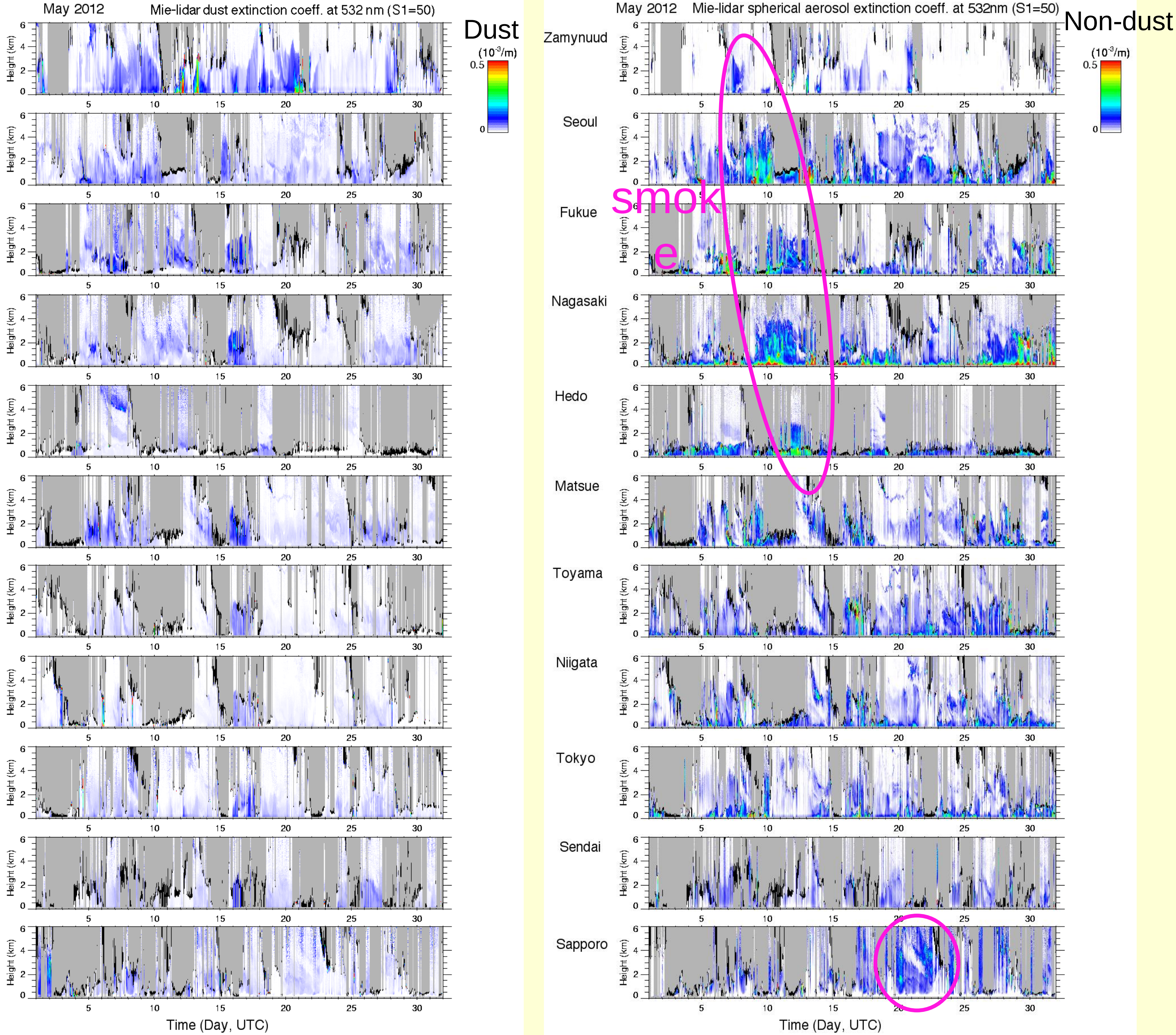


Fig. 2. Difference of dust extinction coefficient derived with S1 = 50 sr/δ_D = 35% (indicated by black box) and that derived with various pairs of S1/δ_D. (Top) Result in the case in Matsue on 1 April 2007 and (bottom) that in Matsue on 2 April 2007.

Error in the extinction coefficient caused by incorrect S_1 and δ_D

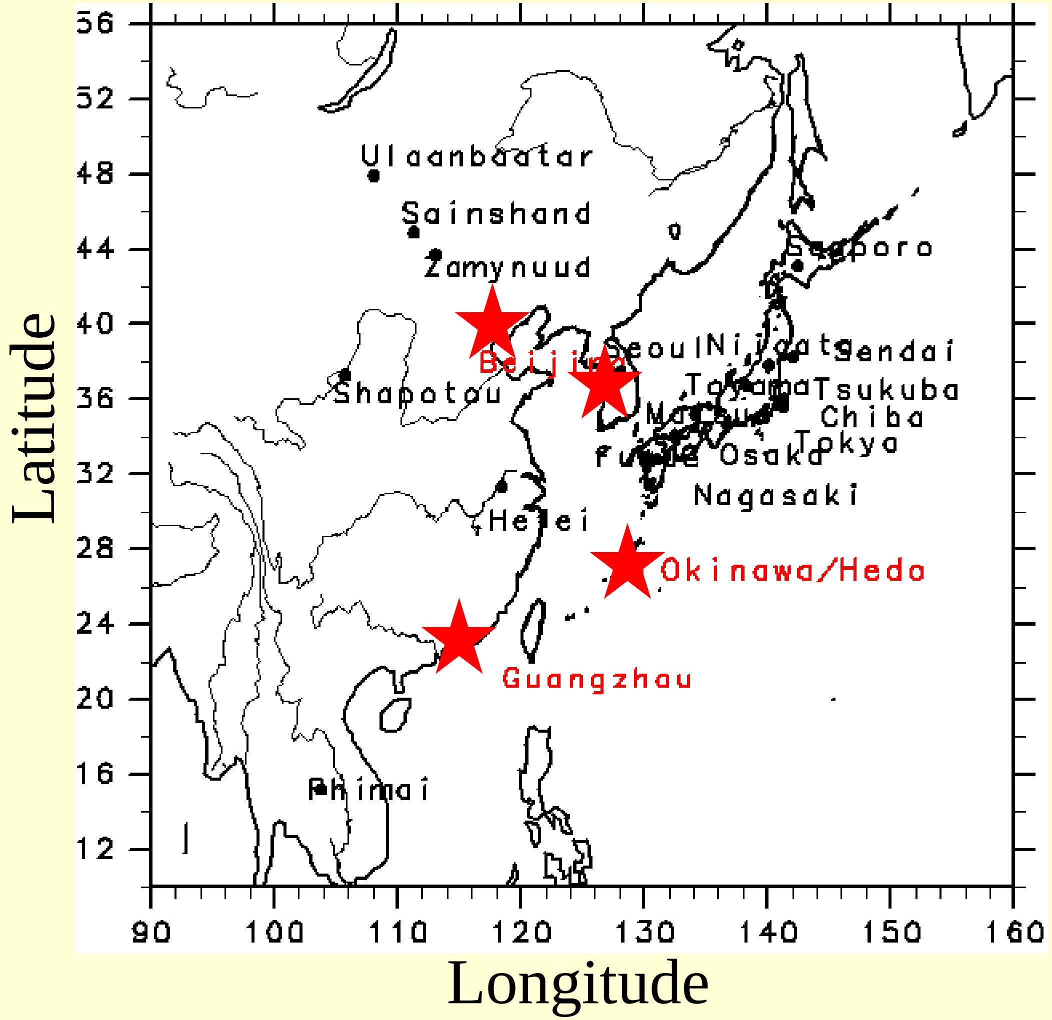
(Shimizu et al. SOLA 7A, 1-4, 2011.)

May 2012

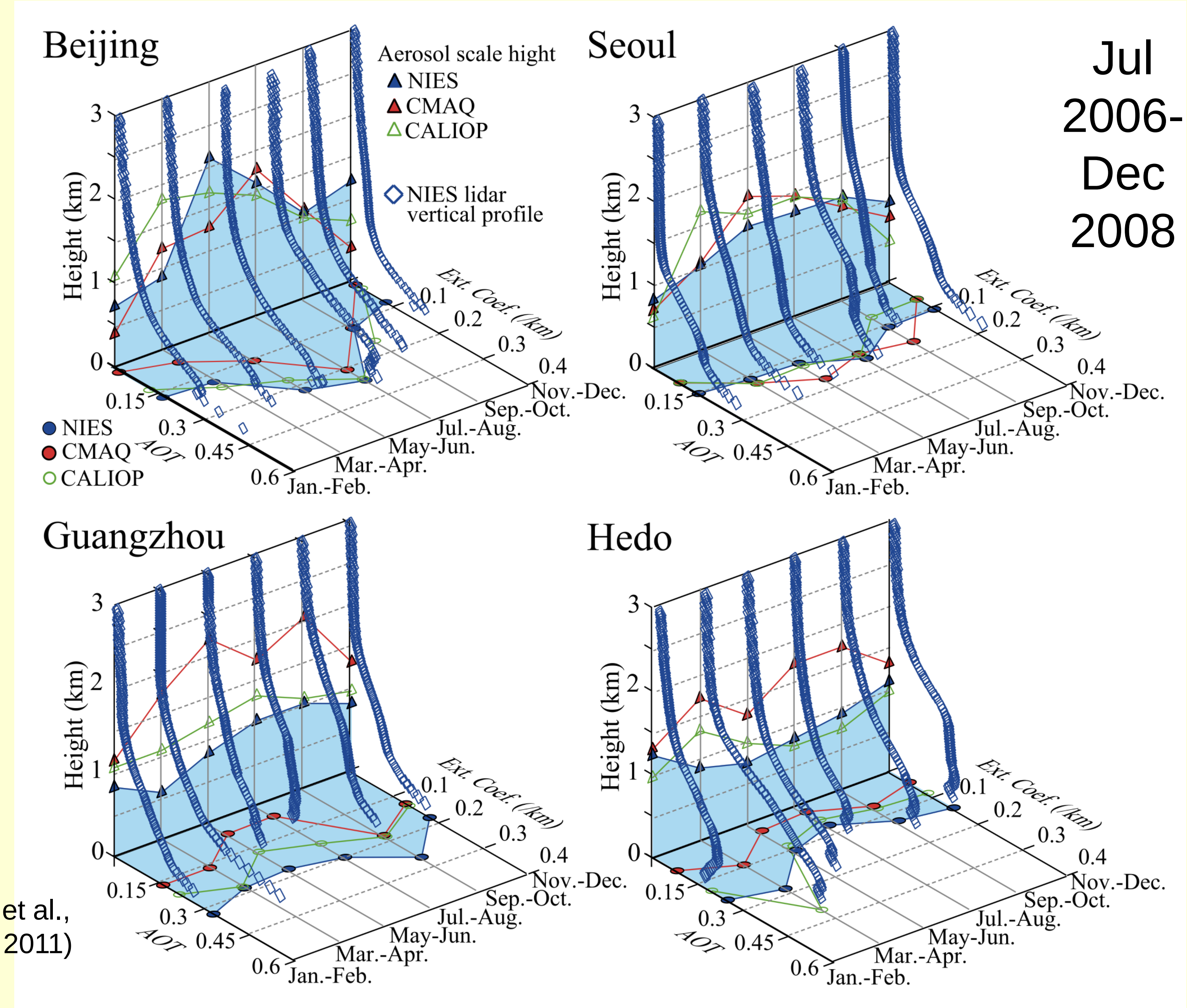


May 2012
Mie-lidar dust extinction coeff. at 532 nm (S1=50)
Dust
(10-3/m)
0.5
0
Zamynuud
Seoul
Fukue
Nagasaki
Hedo
Matsue
Toyama
Niigata
Tokyo
Sendai
Sapporo
Height (km)
Time (Day, UTC)
May 2012
Mie-lidar spherical aerosol extinction coeff. at 532nm (S1=50)
Non-dust
smoke

Study of regional air pollution
(Climatology of non-dust aerosols)



Seasonal variation of vertical profiles of non-dust aerosol



Jul 2006-Dec 2008

(Hara et al., SOLA 2011)

Matsue, Japan, 2010

BC extinction is too high ?
SF-NT-OC is too low ?
=> Validation is needed.
=>Aerosol optical models should be improved