International Cooperative for Aerosol Prediction (ICAP)
Nov. 5-8, 2013, Tsukuba

Development of EarthCARE ATLID data retrieval algorithm and validation plan using the ground-based lidar network

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Contents

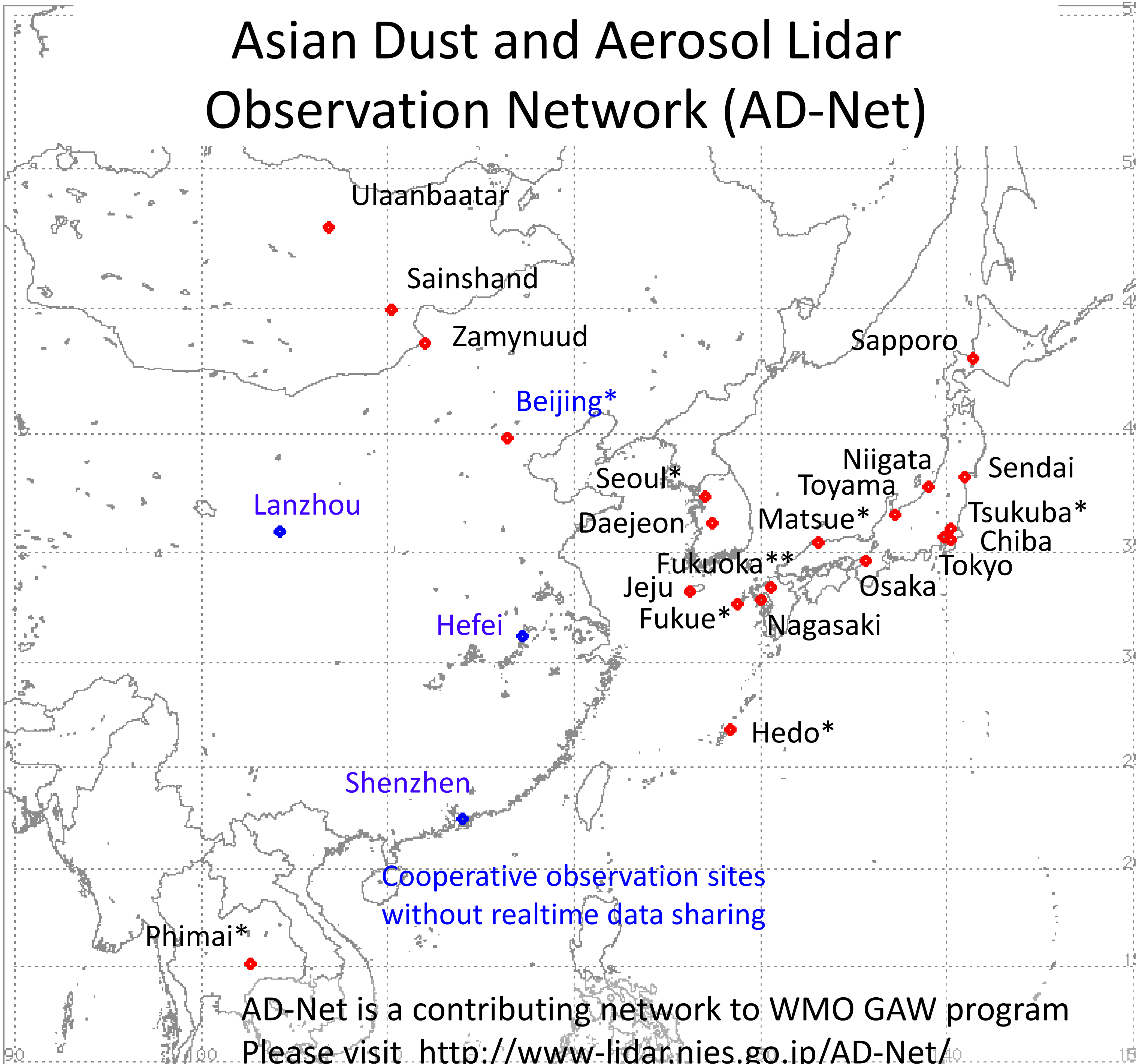
Introduction to AD-Net lidars and data analysis methods

EarthCARE ATLID data retrieval algorithm development in the Japanese Research Announcement studies

- Feature Mask, Target Mask (Aerosol Types), Aerosol Optical Parameters (Extinction, Backscatter, Depolarization)
- Aerosol Component Retrieval（Dust, Sea-salt, Water-soluble, Black carbon）

Validation plan using the ground-based lidar networks

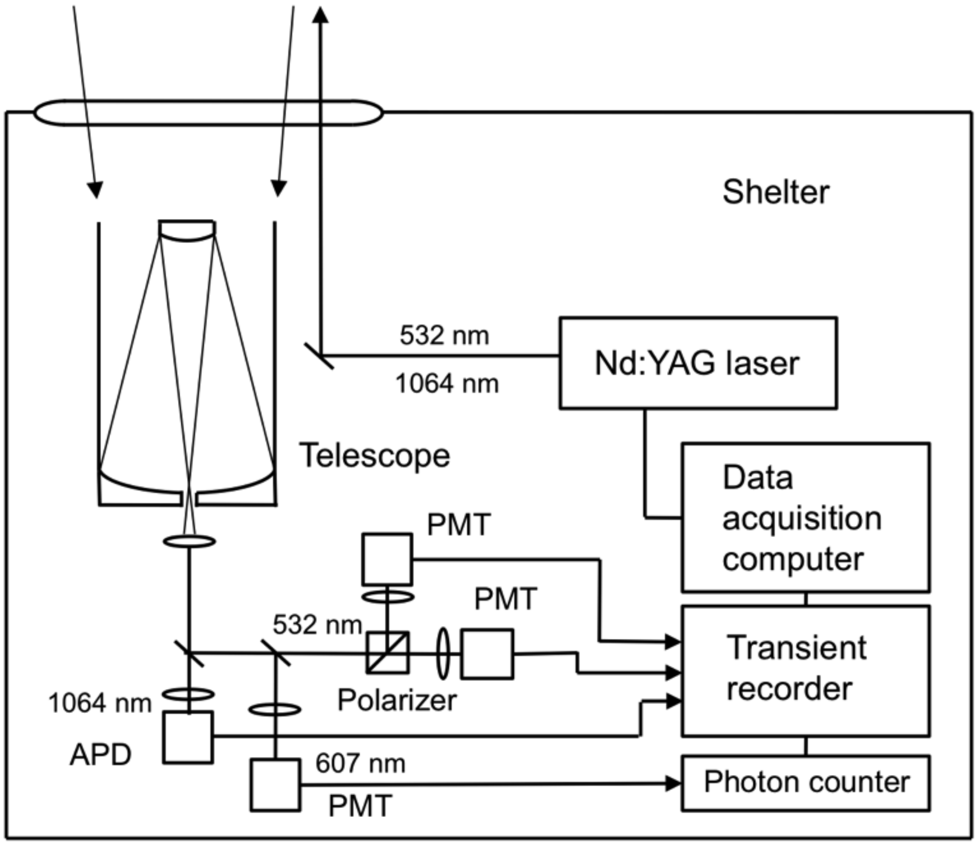
Asian Dust and Aerosol Lidar Observation Network (AD-Net)



AD-Net is a contributing network to WMO GAW program

Please visit http://www-lidar.nies.go.jp/AD-Net/

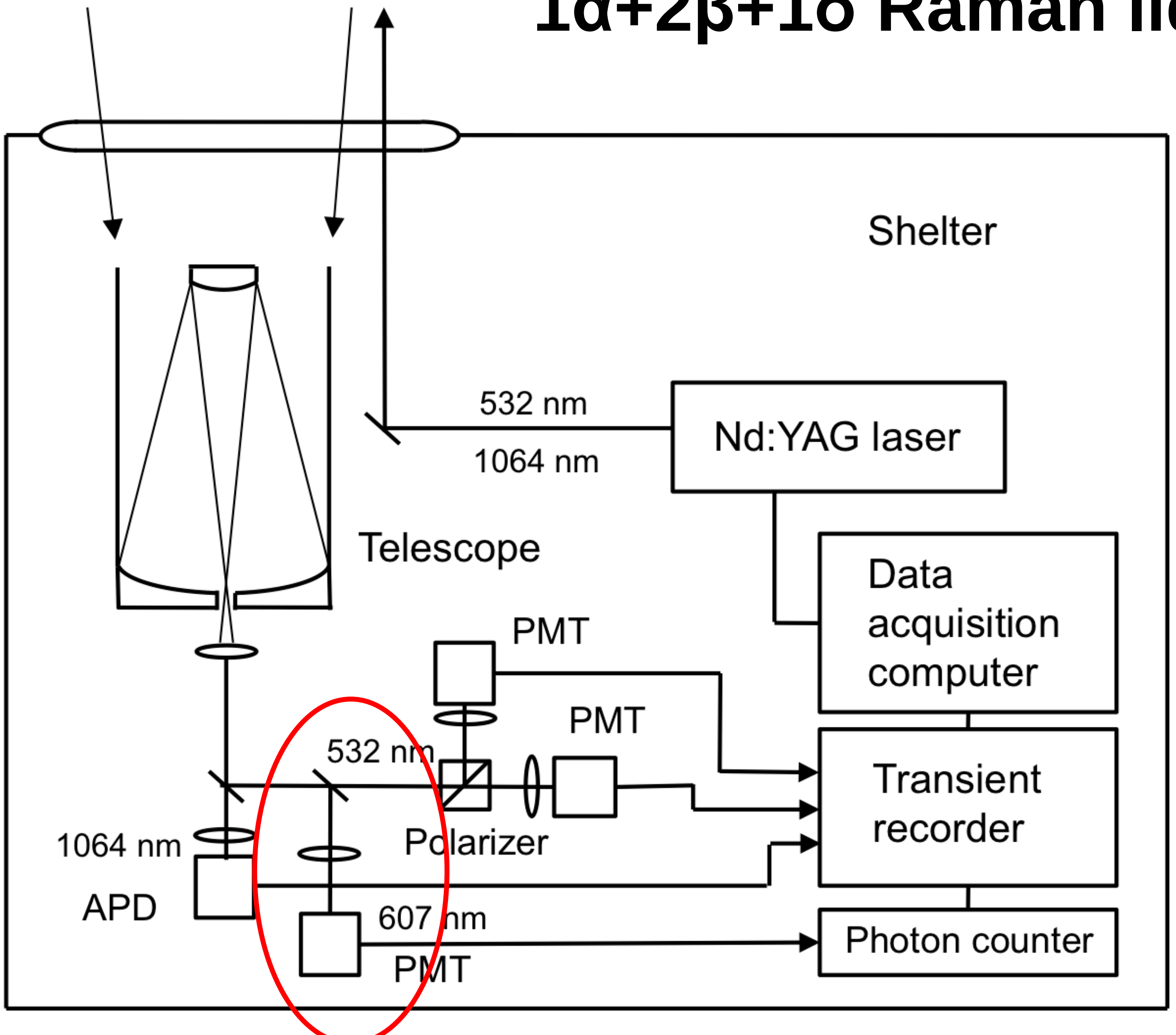
AD-Net Lidar



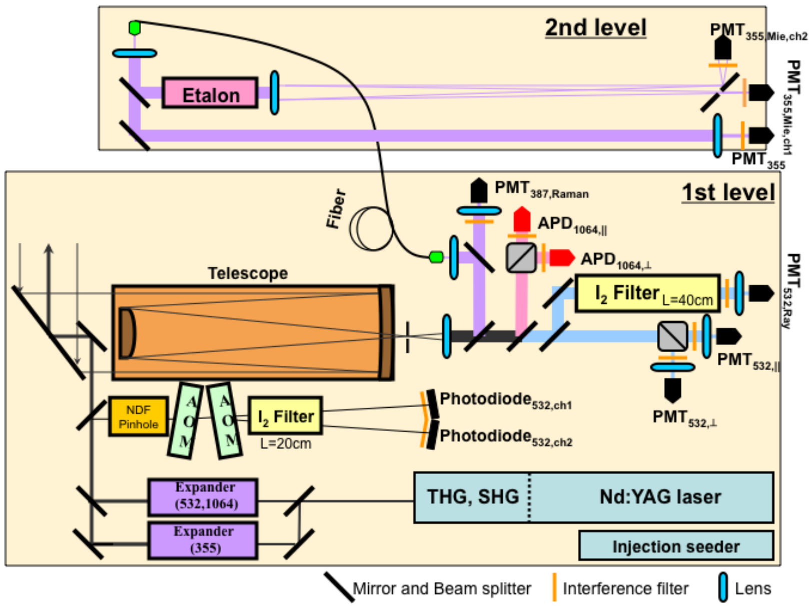
2β+1δ Mie-scattering lidar

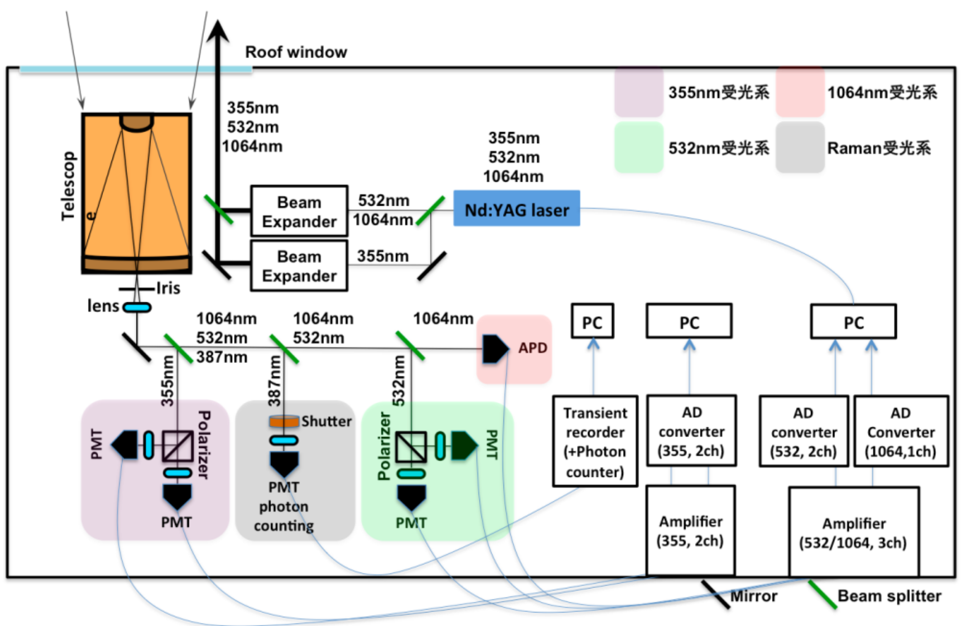
Addition of N_2 Raman receiver for independent extinction coefficient measurements

1α+2β+1δ Raman lidar



Development of lidars for the next generation AD-Net





We have developed a

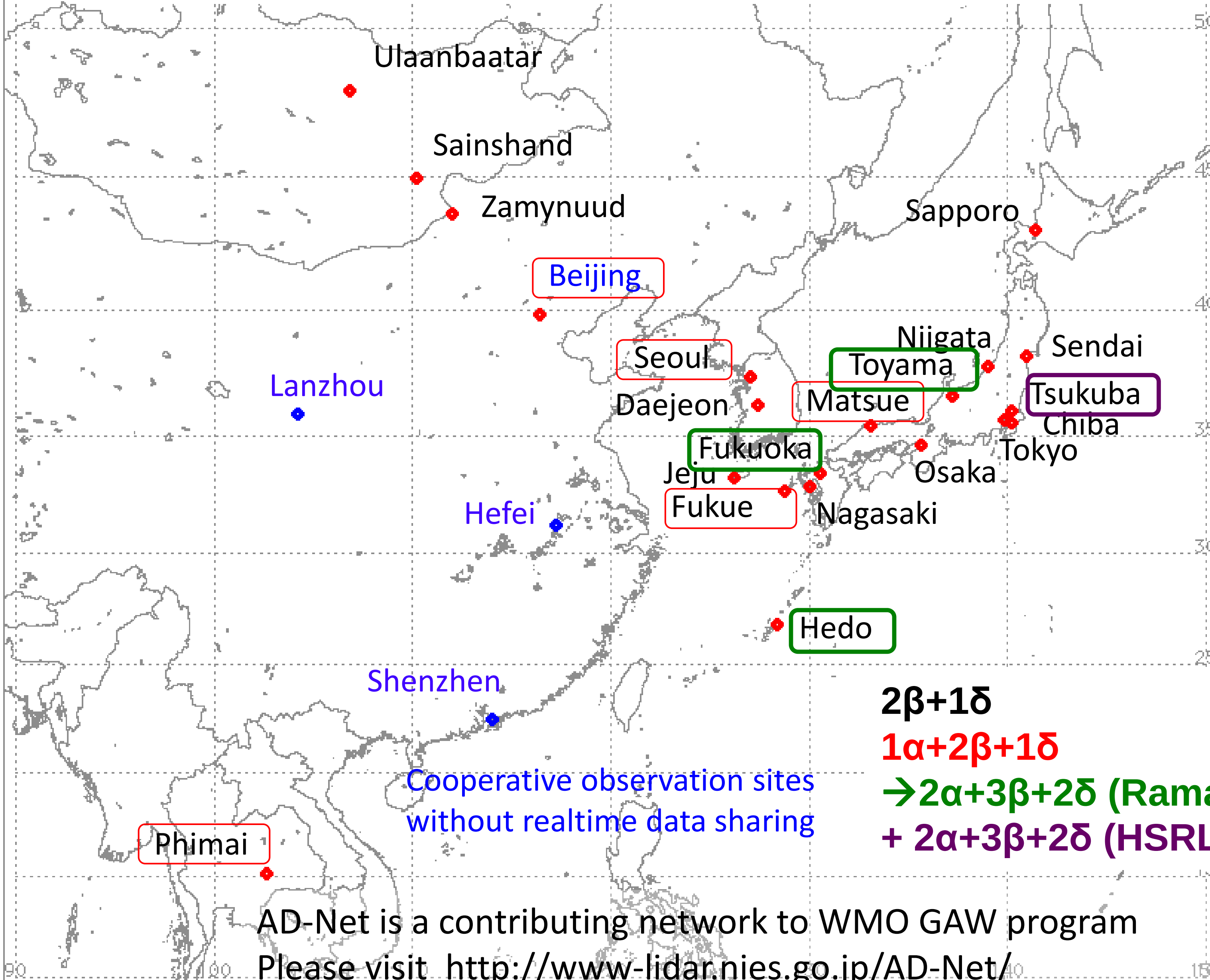
2α+3β+2δ HSRL

and

2α+3β+2δ Raman lidars

HSRL: High-Spectral Resolution Lidar

Asian Dust and Aerosol Lidar Observation Network (AD-Net)



2β+1δ

1α+2β+1δ

→2α+3β+2δ (Raman)*

+ 2α+3β+2δ (HSRL)

AD-Net is a contributing network to WMO GAW program

Please visit http://www-lidar.nies.go.jp/AD-Net/

Evolution of lidars and data analysis methods with AD-Net (Aerosol component analysis)

1β+1δ method to estimate dust and other spherical aerosols (Sugimoto et al., 2003; Shimizu et al., 2004)

2β+1δ method using spheroid dust model to estimate dust, sea salt and water soluble (Nishizawa et al., 2010)

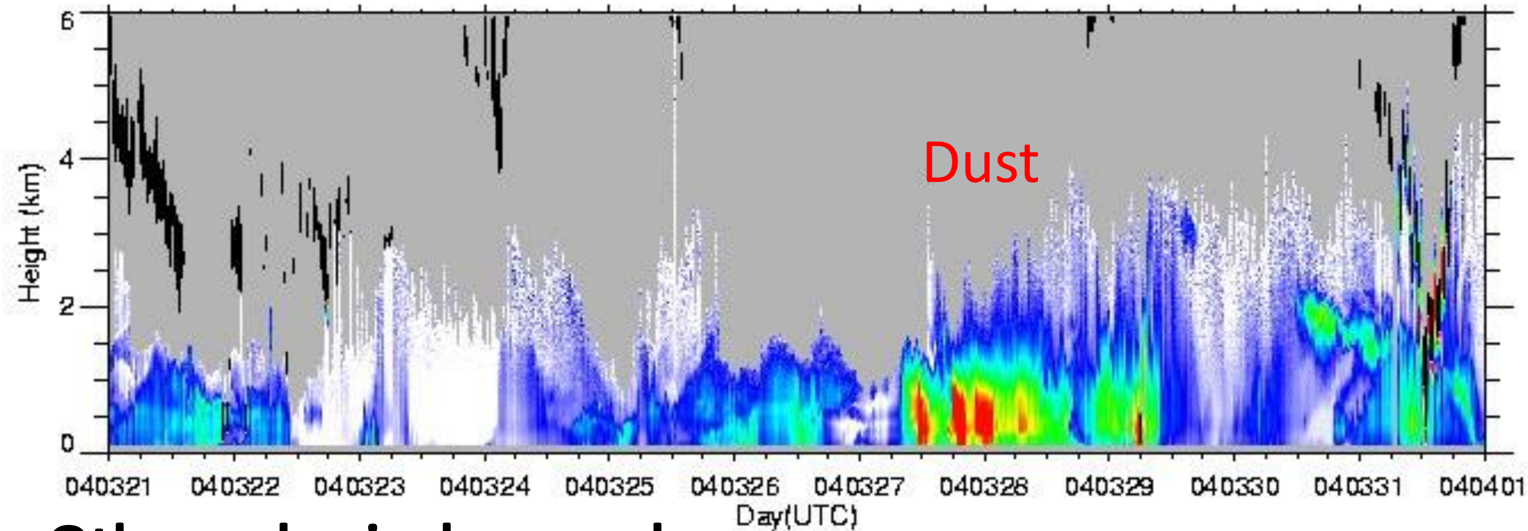
1α+2β+1δ method to estimate dust, sea salt, water soluble and black carbon (Nishizawa et al., 2008)

1α+1β+1δ method to estimate (dust or sea salt), water soluble and black carbon (Nishizawa et al., 2010) → EarthCARE

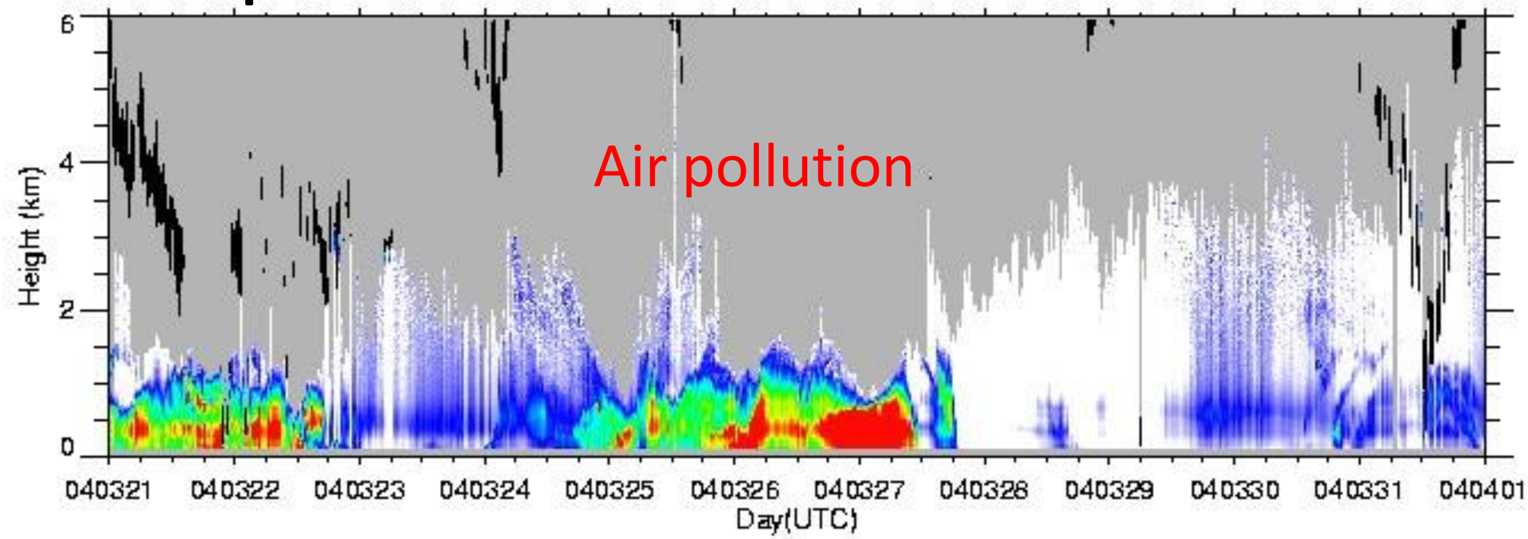
2α+3β+2δ method to estimate dust, sea salt, water soluble, black carbon and particle size of water soluble, dust, sea salt (being developed)

Dust

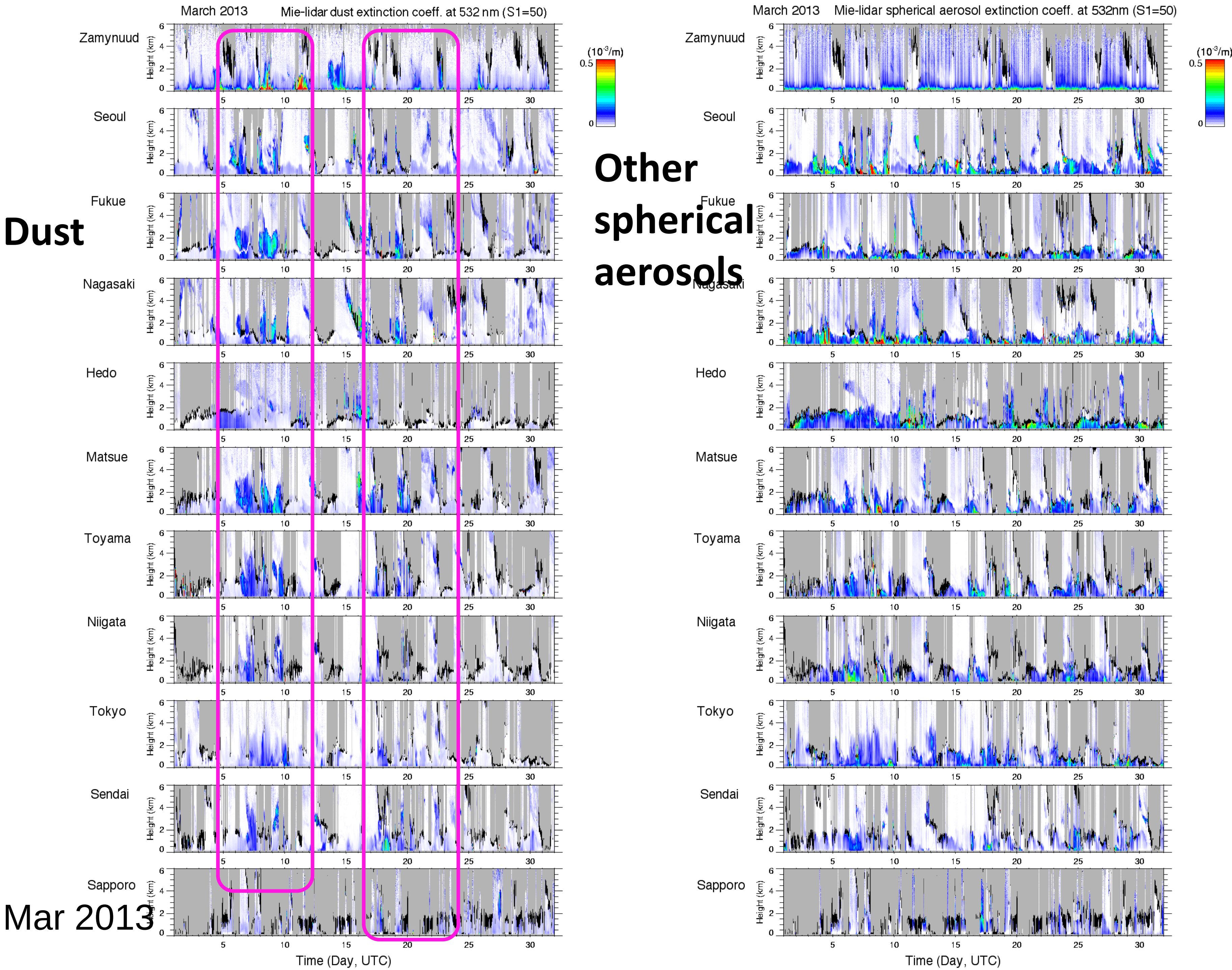
March 21-31, 2004 Beijing



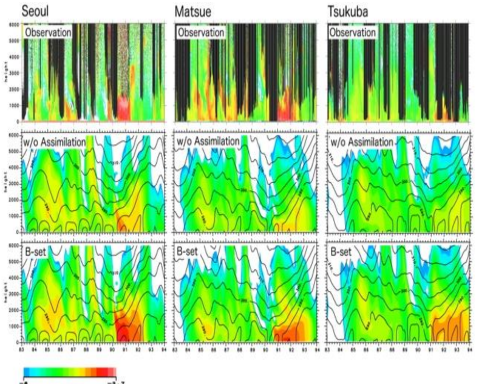
Other spherical aerosols

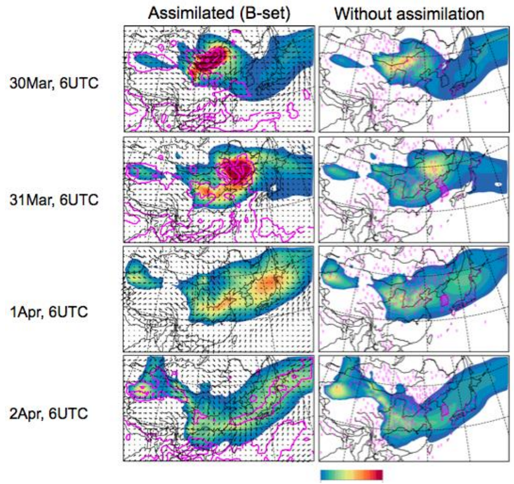


1β+1δ method for estimating the extinction coefficients of dust and spherical aerosols

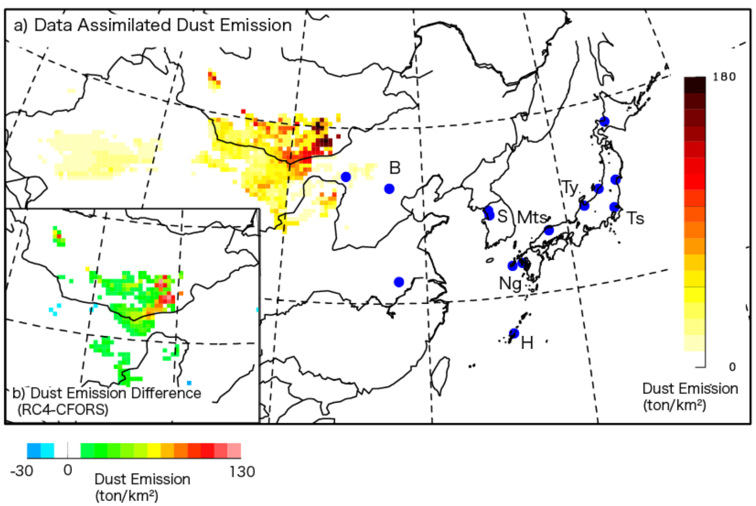

March 2013
Mie-lidar dust extinction coeff. at 532 nm (S1=50)
Mie-lidar spherical aerosol extinction coeff. at 532nm (S1=50)
Dust
Other spherical aerosols
Mar 2013
Zamynuud
Seoul
Fukue
Nagasaki
Hedo
Matsue
Toyama
Niigata
Tokyo
Sendai
Sapporo
Height (km)
Time (Day, UTC)
(10^-3/m)
0.5
0

Asian dust study using 4D-Var data assimilation

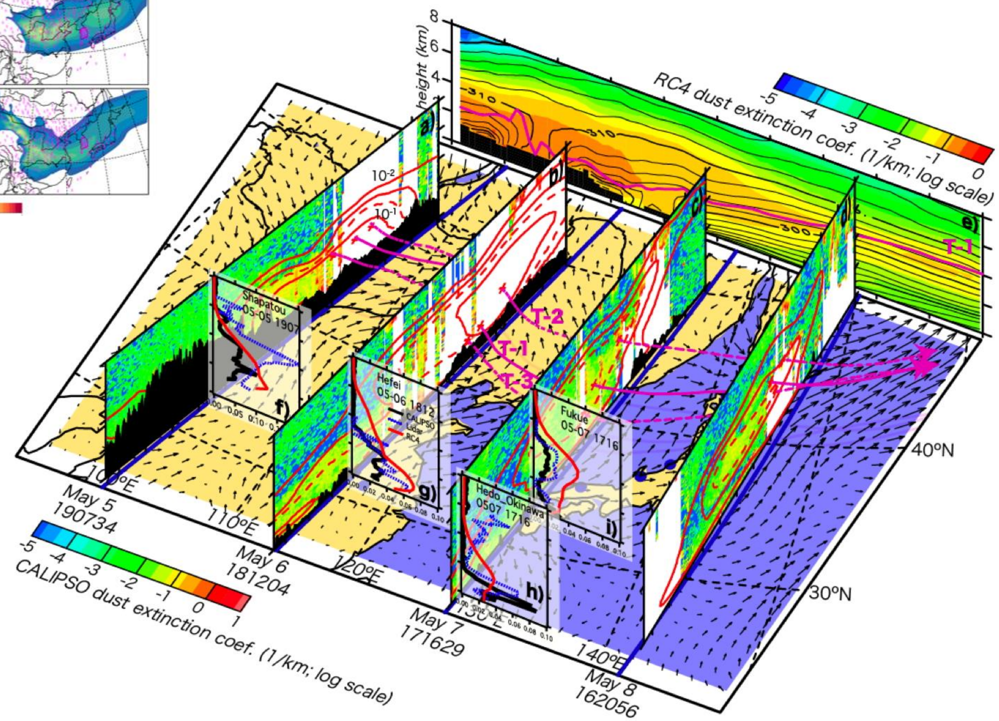




→ Keiya Yumimoto's presentation



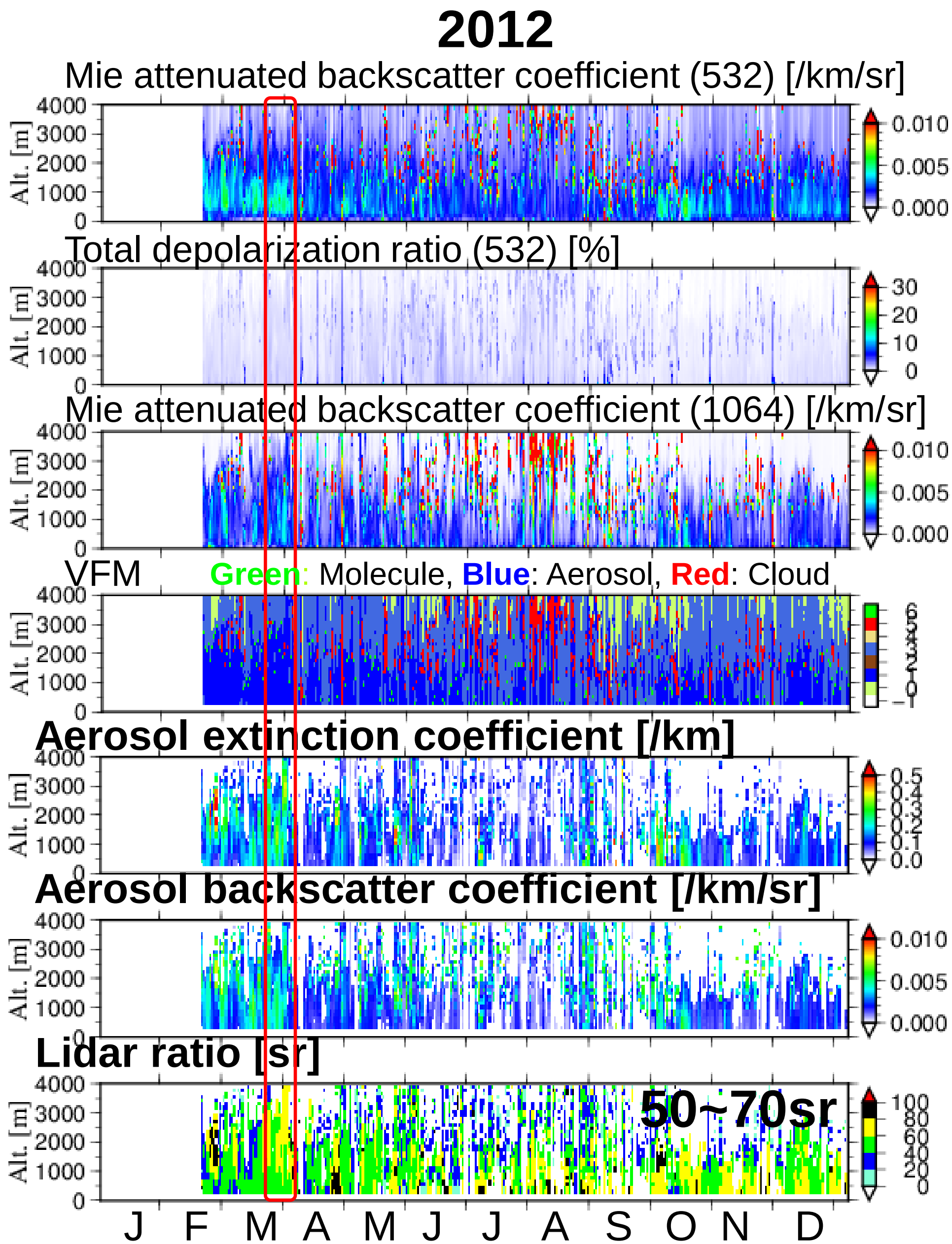
4DVAR data assimilation of Asian dust using the NIES lidar network data (Yumimoto et al. 2007, 2008)

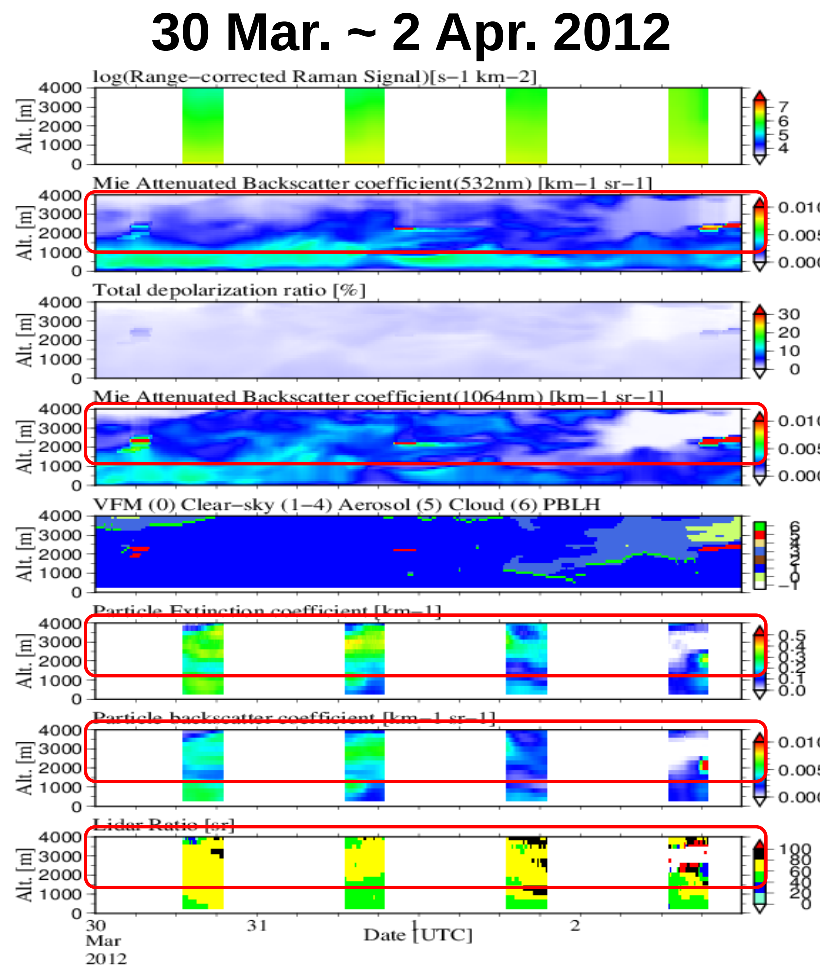


Comparison of the assimilated dust transport model with CALIPSO data (Hara et al. 2009)

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

1α+2β+1δ Raman lidar data (Phimai, Thailand)





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

AERONET :

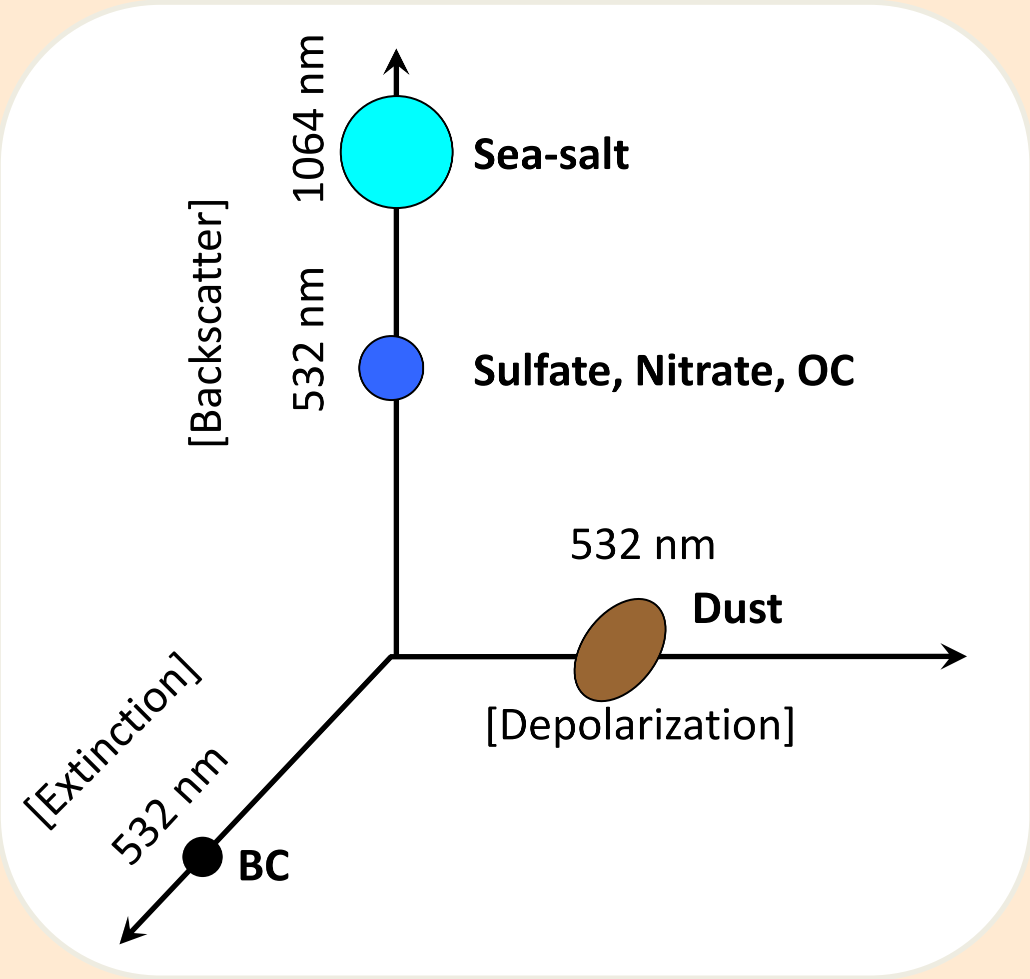
- Cattrall. 2005: 60±8 (Africa / S. America)
- Omar. 2009 : 70 (all AERONET data)

Lidar (EARLINET)

- Muller. 2007 : 53±11 (Siberia/Canada)

1α+2β+1δ algorithm

4 independent observation parameters → Retrieve extinction coefficient profiles of 4 aerosol components

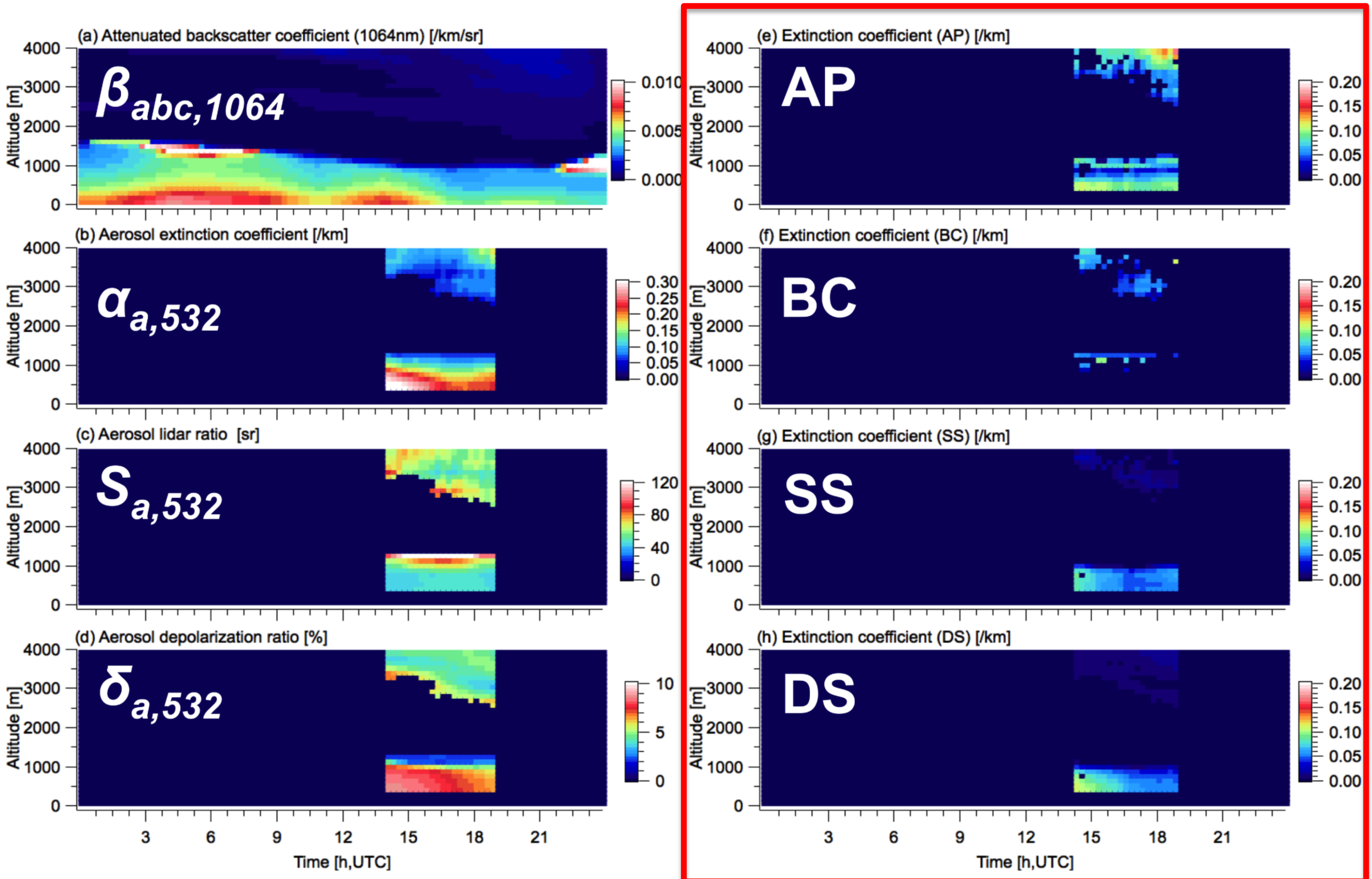


Assumption:

- External mixture of 4 components
- Lognormal size distribution
- Fix mode radii, refractive index
- Spheroid for dust

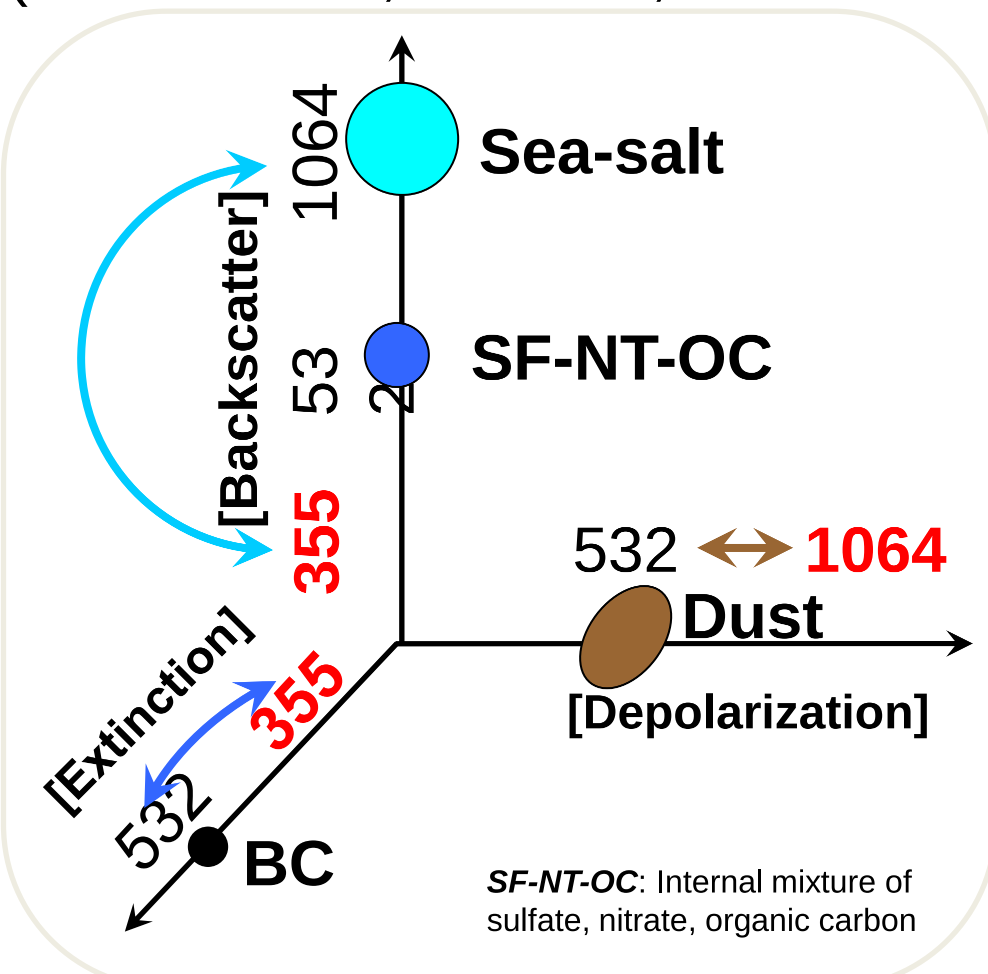
	SF-NT-OC	Dust	BC	Sea-salt
Mode radius [um] Standard dev.	0.13 1.6	2.0 2.2	0.05 2.0	3.0 2.1
Refractive index (532nm)	1.41 2×10^{-3}	1.51 3×10^{-3}	1.75 0.4	1.36 3×10^{-9}
Lidar ratio (532nm, sr)	55	48	101	20
Dep. (532nm)	0.02	0.30	0.02	0.02
Backscatter color ratio (1064/532)	0.34	0.98	0.23	0.67

Component analysis



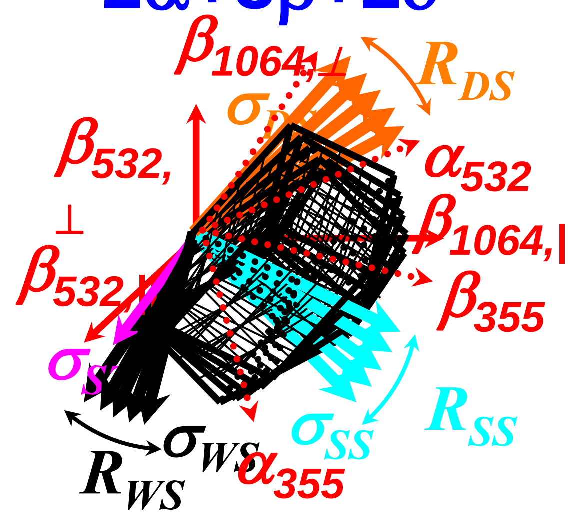
Algorithm for 2α+3β+2δ data

- **Extinction coefficients** for **4 aerosol components** at each layer (Mineral dust, Sea salt, Black carbon, Sulfate+Nitrate+OC)
- **Mode radii of 3 aerosol components** at each layer (Mineral-dust, Sea-salt, SF-NT-OC)



Assumption:
- External mixture of 4 components
- Lognormal size distribution
- Fix refractive index
- Spheroid for dust

2α+3β+2δ



Problems with aerosol component analysis

Are the **Definition of aerosol components and their optical models** reasonable?

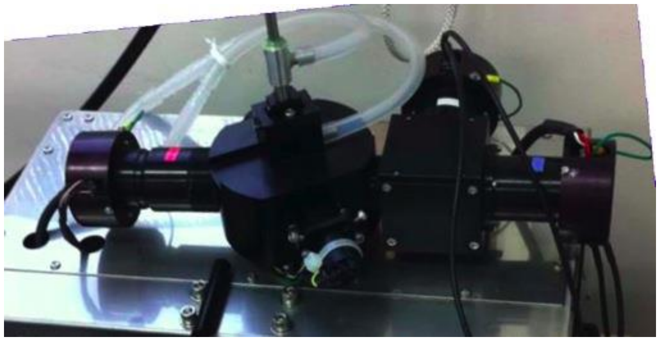
- Water soluble (Sulfate + Nitrate + OC): non-light-absorbing fine particles
- Mineral dust: non-spherical coarse aerosols
- Sea salt: optically non-light-absorbing coarse particles
- Black carbon: light-absorbing fine particles

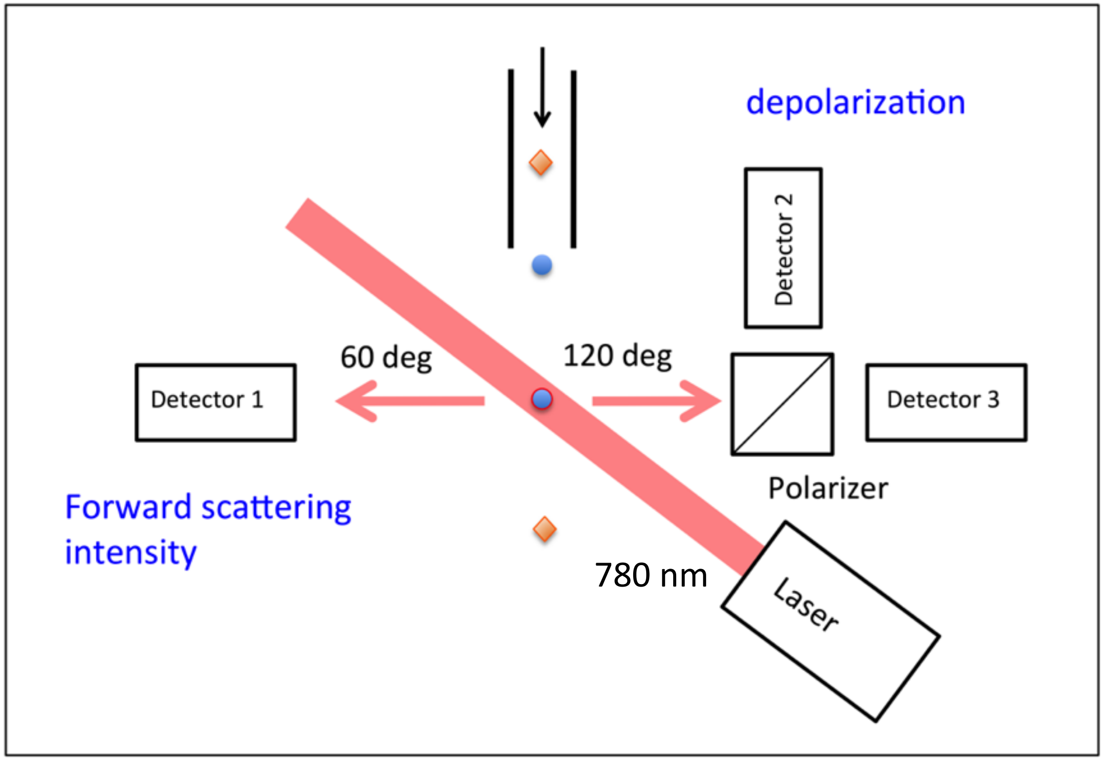
How **Internally mixed aerosols** are handled?
Are they optically detectable?

→ Polluted dust was observed with 2β+1δ lidars and identified with a Polarization Optical Particle Counter (POPC).

Asian dust internally mixed with air-pollution aerosols

observed with a polarization optical particle counter
(in Seoul April 2013)

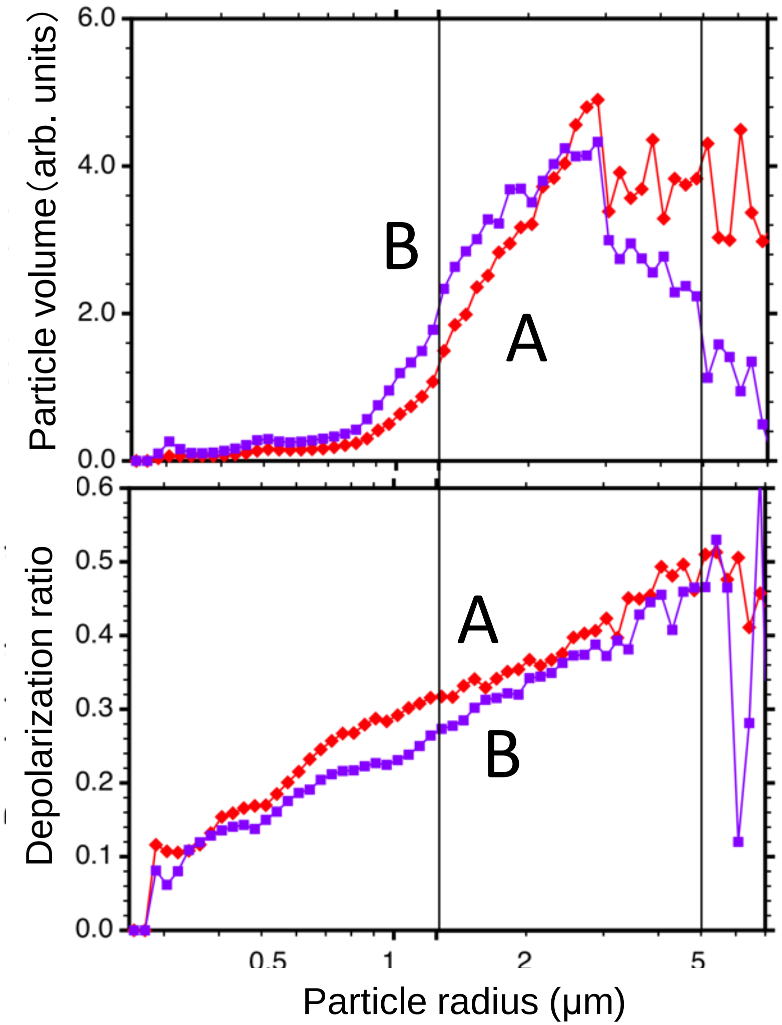




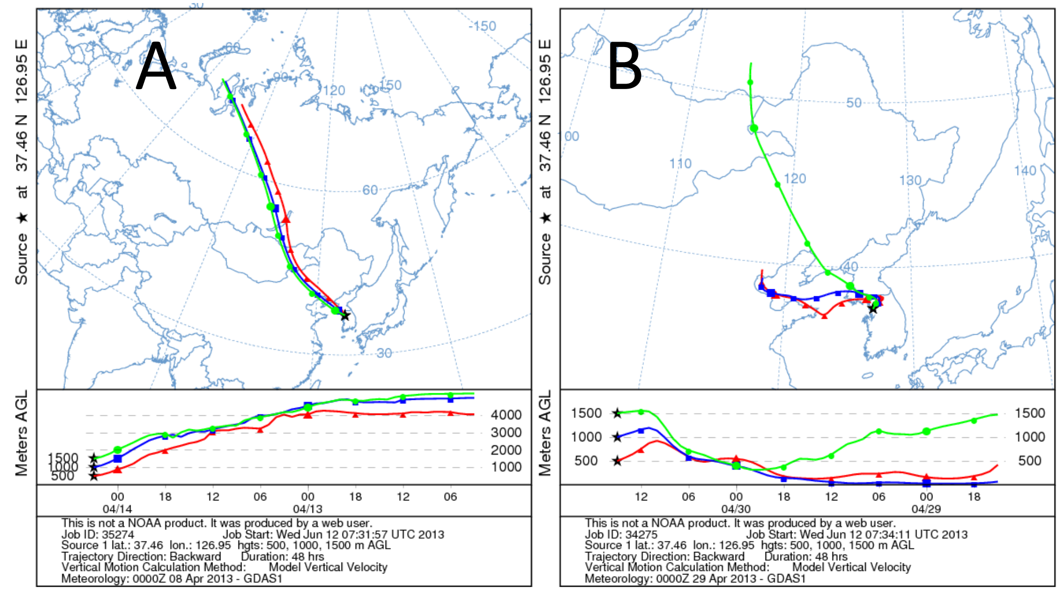
Forward scattering intensity and the backward depolarization ratio are measured simultaneously for every single particle.

Optical characteristics of pure and polluted Asian dust (Seoul, Apr. 2013)

Polarization OPC

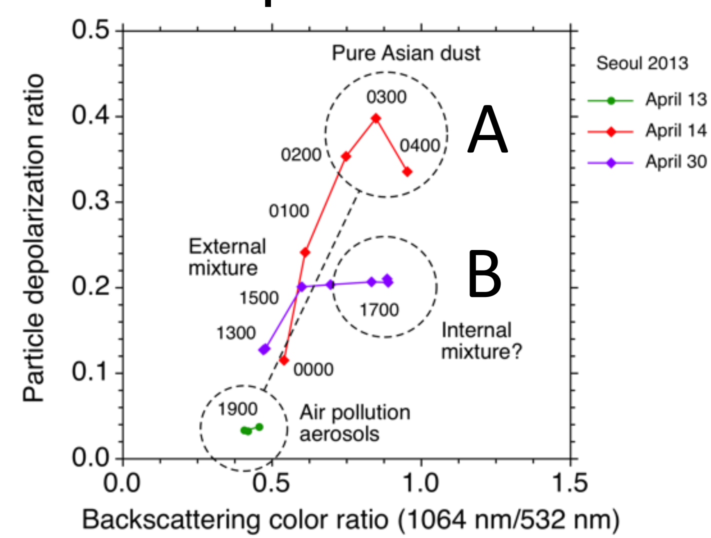


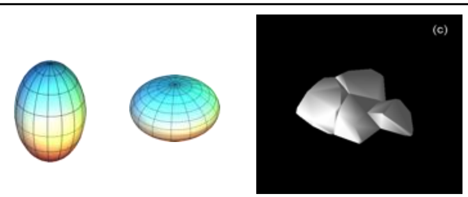
Back trajectory



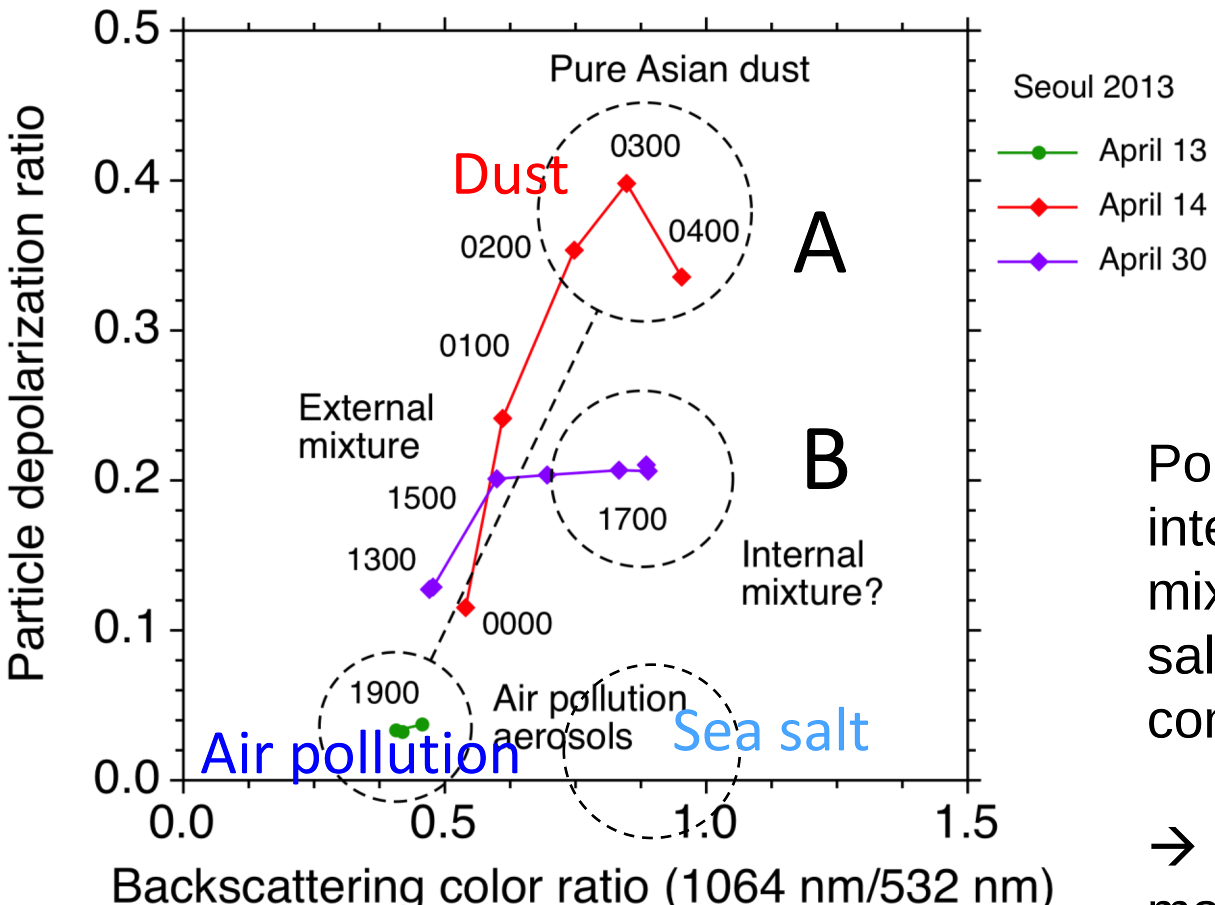
A: Relatively pure dust case (April 14, 2013, 0300 UTC; RH=22%)
B: Polluted dust case (April 30, 2013, 1500 UTC; RH=66%)

2β+1δ Lidar





Seeking optical models for pure and polluted dust



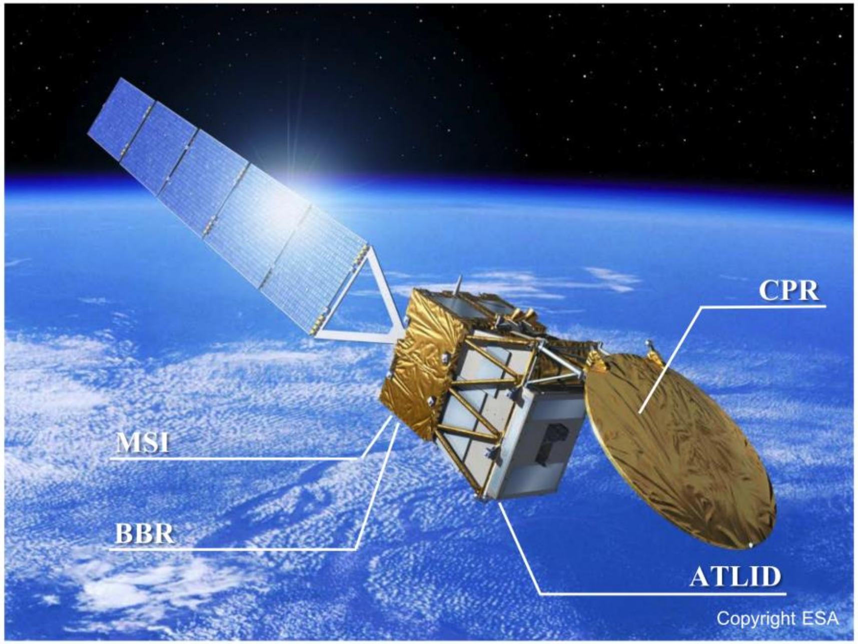
2β+1δ Lidar

Polluted dust is interpreted as external mixture of dust and sea salt in aerosol component analysis.

→ Data assimilation may solve the problem

EarthCARE Satellite

EarthCARE
Earth Cloud, Aerosol and Radiation Explorer
esa NICT JAXA



Institutions	European Space Agency (ESA) ／National Institute of Information and Communications Technology (NICT) ／ Japan Aerospace Exploration Agency (JAXA)
Launch	2015 using Soyuz or Zenit (by ESA)
Mission Duration	3-years
Mass	Approx. 2200kg
Orbit	Sun-synchronous sub-recurrent orbit Altitude: approx. 400km Mean Local Solar Time (Descending): 14:00
Repeat Cycle	25 days
Orbit Period	5552.7 seconds
Semi Major Axis	6771.28 km
Eccentricity	0.001283
Inclination	97.050°

EarthCARE

Earth Clouds, Aerosol and Radiation Explorer

ATLID: HSRL at 355 nm

Observation Instruments on EarthCARE

CPR	Cloud Profiling Radar	NICT JAXA
ATLID	Atmospheric Lidar	esa
MSI	Multi-Spectral Imager	esa
BBR	Broadband Radiometer	esa

Synergetic Observation by 4 sensors

ATLID L2A & ATLID+MSI L2B products

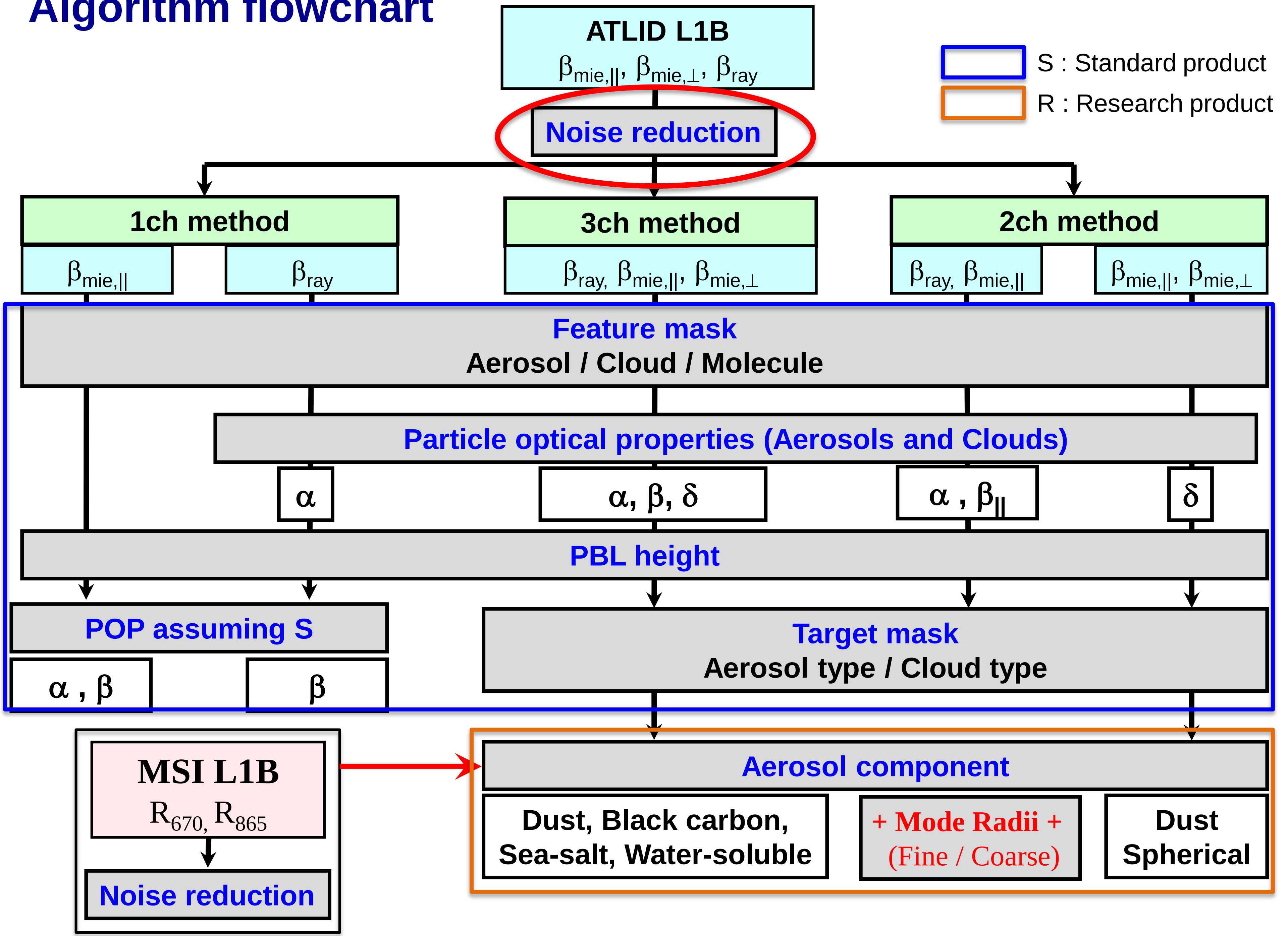
	Parameter	Used ATLID channel			Resolution (Note)
		1ch	2ch	3ch	
ATLID L2A (S)	**Feature mask** (Molecule/Aerosol/Cloud classification)	○	○	○	ΔZ=0.1km ΔH = 0.285km/1km/10km
	Target mask (Cloud type/Aerosol type classification)	×	○	○	ΔZ=0.1km ΔH = 1km/10km
	Aerosol optical property (**Extinction**, **Backscatter**, **Depolarization**, Lidar ratio)	△	△	○	ΔZ=0.1km ΔH = 1km/10km (1ch, 2ch: S1 assumption)
	Cloud optical property (Extinction, Backscatter, Depolarization, Lidar ratio)	△	△	○	ΔZ=0.1km ΔH = 1km/10km (1ch, 2ch: S1 ssumption)
	Planetary boundary layer height	○	○	○	ΔH = 1km/10km
ATLID L2A (R)	**Extinction of aerosol components** (Dust、Sea-salt、Water-soluble、Black carbon)	×	○	○	ΔZ=0.1km ΔH = 10km (2ch : Dust, Water-soluble)
ATLID-MSI L2B (R)	**Extinction of aerosol components**	×	○	○	ΔZ=0.1km ΔH = 10km
	Mode radii (Fine and Coarse)	×	○	○	ΔH = 10km (Constant in a column)

Validation: Comparison for various cases

✓Clean/Dirty ✓Land / Ocean, ✓ Industrial / rural

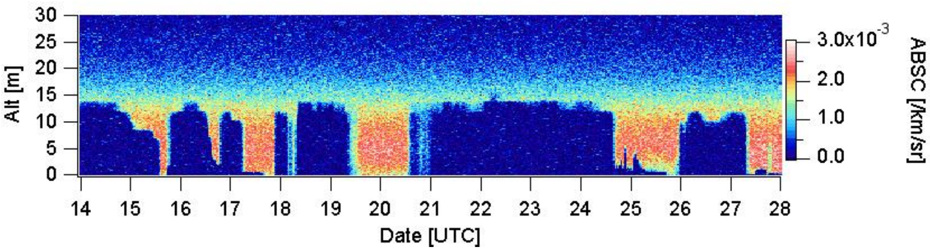
✓Asia / Europe / America … ✓ Dust / Biomass-burning / Pollution …

Algorithm flowchart

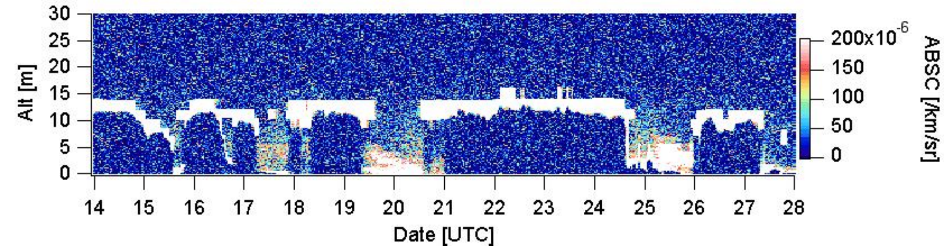


Noise reduction by Discrete Wavelet analysis

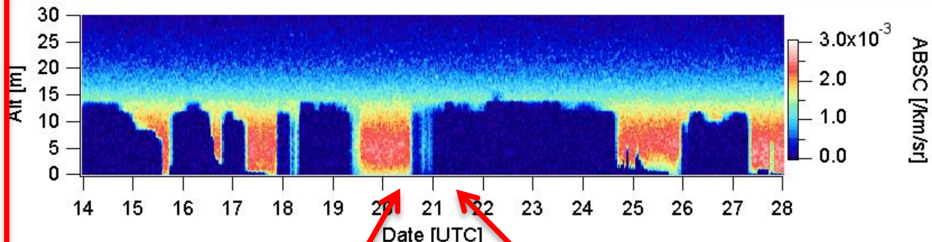
Rayleigh with random noises (SN~10)

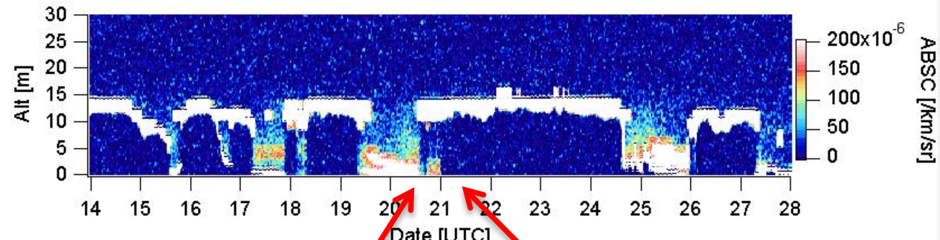


Mie copol with random noises (SN~10)



Apply wavelet analysis

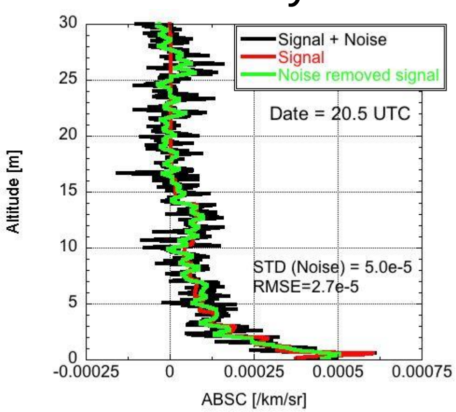




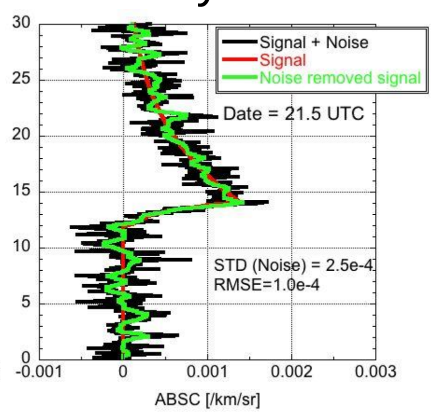
SN becomes twice (SN ~ 20)

SN becomes twice (SN ~ 20)

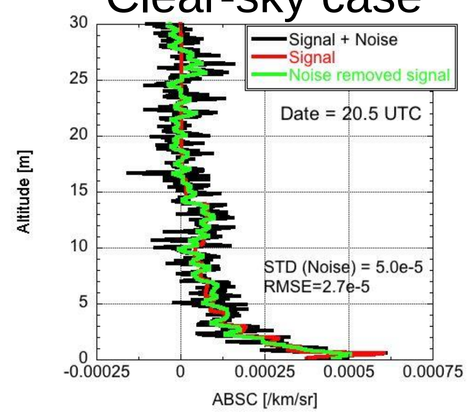
Clear-sky case



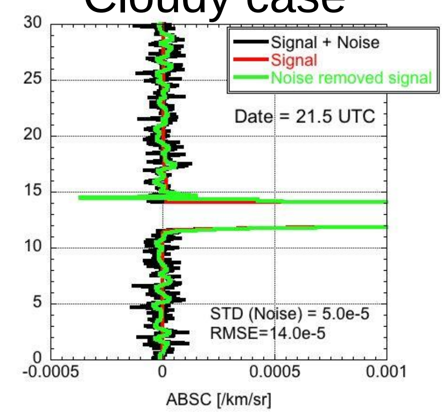
Cloudy case



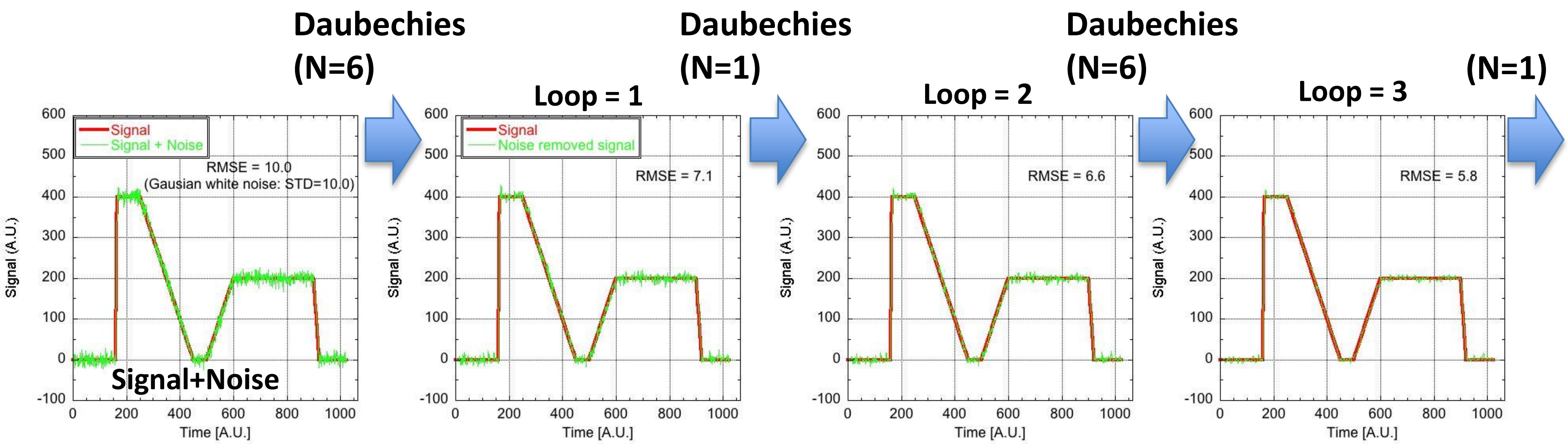
Clear-sky case

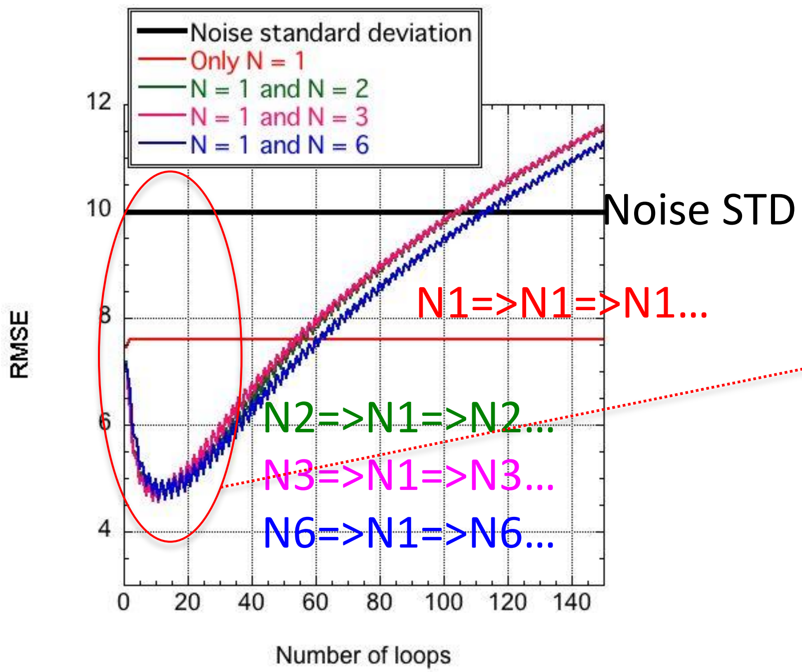


Cloudy case



Iterative computation



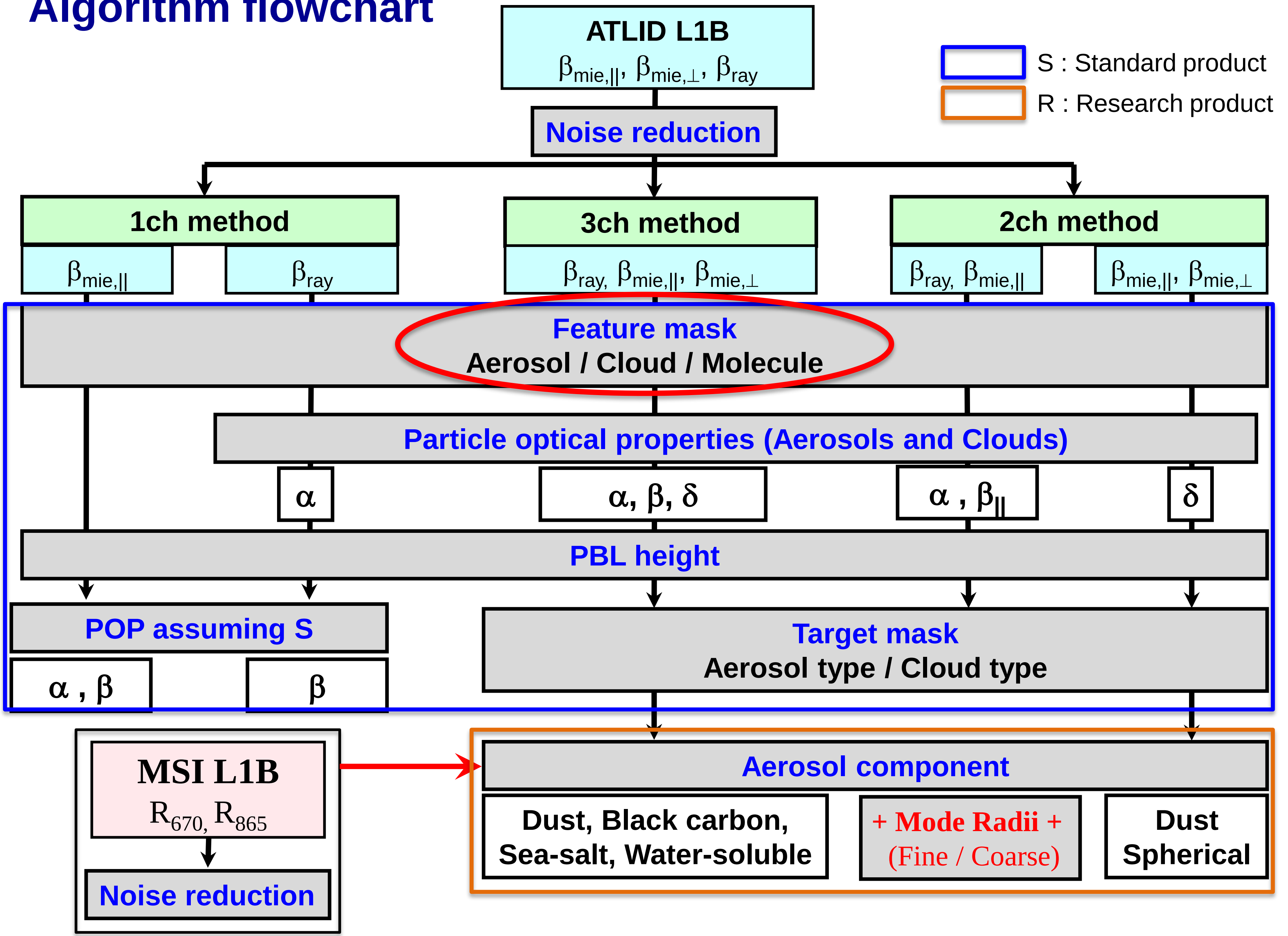


N6=>N1=>N6

Noises are reduced by 50%

(ΔNoise ~ −50%)

Algorithm flowchart



Vertical feature mask

Identify molecule-rich, aerosol-rich, or cloud-rich slab layer using the threshold method **[Vaughan et al 2009; Hagihara et al. 2009]**:

Molecule-rich: $P_{r,noise} > \mathbf{P_r}$

Aerosol-rich: $P_{r,cloud} + P_{r,noise} > \mathbf{P_r} > P_{r,noise}$

Cloud-rich: $\mathbf{P_r} > P_{r,cloud} + P_{r,noise}$

$P_{r,noise}$: Noise level, $P_{r,cloud}$:Threshold for cloud-rich slab layer

$\mathbf{P_r}$: Diagnostic parameter derived from ATLID L1b data

3ch method: $$P_r = \frac{\beta}{\beta_m} = \frac{\beta_{mie,\parallel} + \beta_{mie,\perp}}{\beta_{ray}}$$

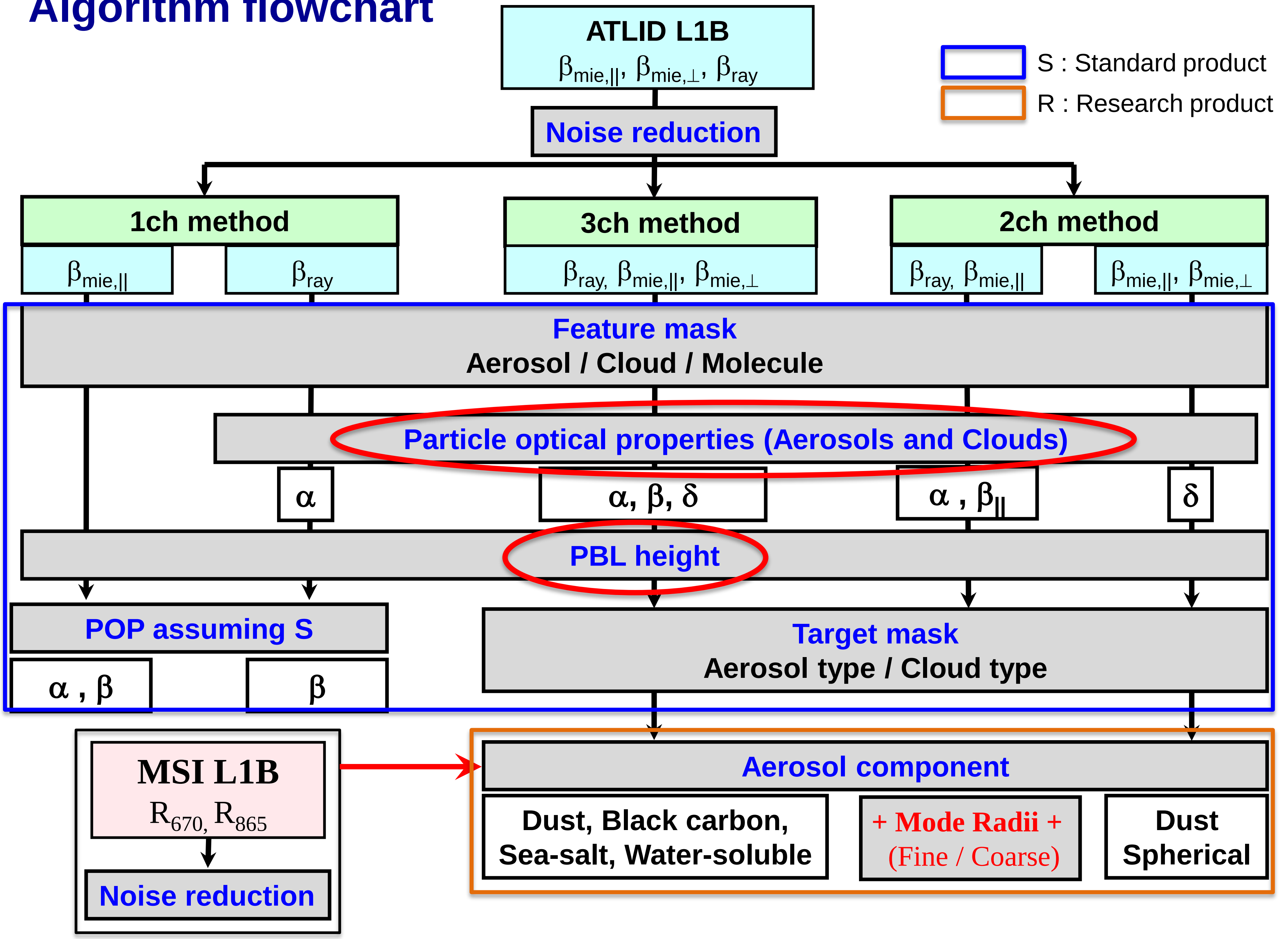
2ch method ($\beta_{mie,||}$, β_{ray}): $$P_r = \frac{\beta_\parallel}{\beta_m} = \frac{\beta_{mie,\parallel}}{\beta_{ray}}$$

2ch method ($\beta_{mie,||}$, $\beta_{mie,\perp}$): $$P_r = \beta(z)\exp\left\{-2\int_Z^{Z_{ATLID}} \alpha(z')dz'\right\} = \frac{\beta_{mie,\parallel} + \beta_{mie,\perp}}{\exp\left\{-2\int_Z^{Z_{ATLID}} (\alpha_m(z'))dz'\right\}}$$

1ch method ($\beta_{mie,||}$): $$P_r = \beta_\parallel(z)\exp\left\{-2\int_Z^{Z_{ATLID}} \alpha(z')dz'\right\} = \frac{\beta_{mie,\parallel}}{\exp\left\{-2\int_Z^{Z_{ATLID}} (\alpha_m(z'))dz'\right\}}$$

1ch method (β_{ray}): $$P_r = \alpha(z)$$

Algorithm flowchart



Equations for deriving α, β, and δ

Level 1

$$P_{Mie,co} = \beta_{Mie,co} \exp\left\{ -2 \int_{z}^{z_{ATLID}} (\sigma_{Mie} + \sigma_{Ray}) dz' \right\} \quad \text{[Mie co-pol]} \quad ①$$

$$P_{Mie,cr} = \beta_{Mie,cr} \exp\left\{ -2 \int_{z}^{z_{ATLID}} (\sigma_{Mie} + \sigma_{Ray}) dz' \right\} \quad \text{[Mie cr-pol]} \quad ②$$

$$P_{Ray,co} = \beta_{Ray,co} \exp\left\{ -2 \int_{z}^{z_{ATLID}} (\sigma_{Mie} + \sigma_{Ray}) dz' \right\} \quad \text{[Ray co-pol]} \quad ③$$

Level 2

$$\alpha = \sigma_{Mie} = \frac{\partial}{\partial z}\left(\frac{\ln P_{Ray,co}}{2} \right) - \sigma_{Ray} \qquad \leftarrow ③$$

$$\delta = \frac{\beta_{Mie,cr}}{\beta_{Mie,co}} = \frac{P_{Mie,cr}}{P_{Mie,co}} \qquad \leftarrow ①+②$$

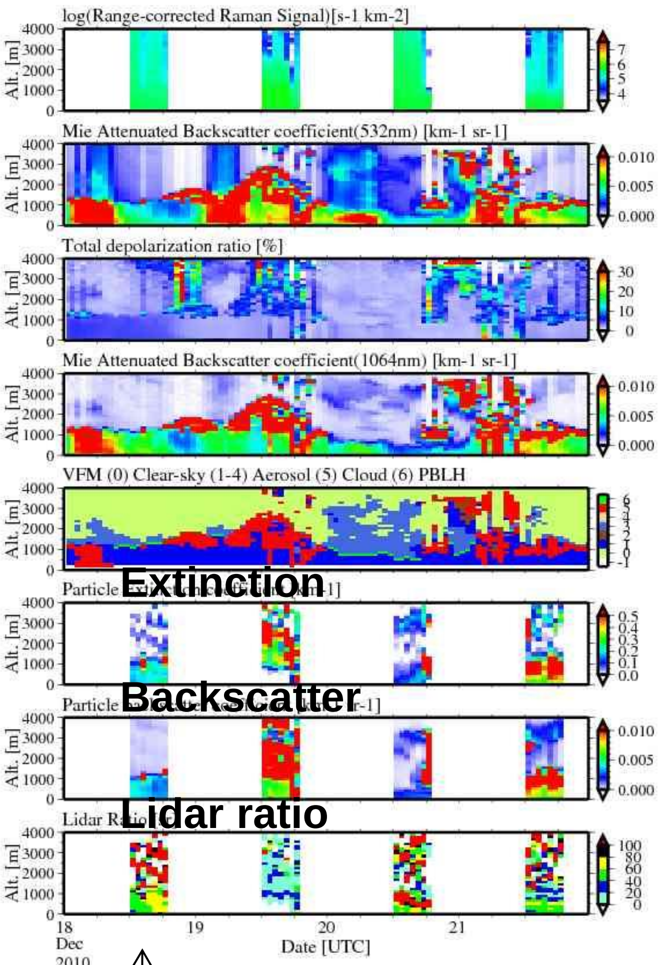
$$\beta = \beta_{Mie,co} + \beta_{Mie,cr} = (1+\delta)\beta_{Mie,co} = (1+\delta)\frac{P_{Mie,co}}{P_{Ray,co}} \beta_{Ray,co} \qquad \leftarrow ①+②+③$$

Testing particle extinction retrievals

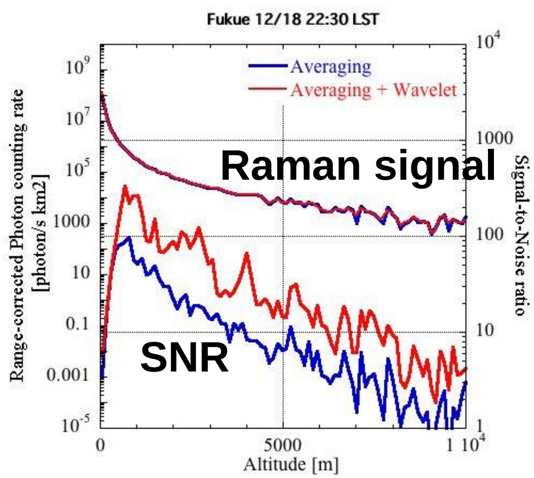
using AD-Net ground-based Raman lidar at 532nm

- ✓ Signal noise reduction
  Observed data（ΔZ=30m,Δt=15min)
  → Averaging（ΔZ=120m, Δt=1hour) ＋Wavelet analysis

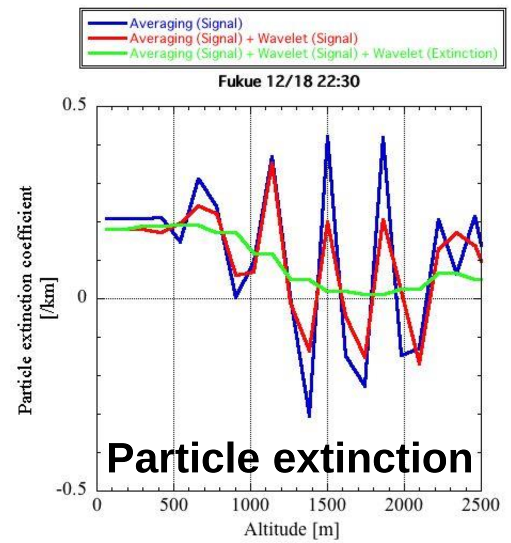
- ✓ Particle extinction is derived by direct method
- ✓ PBLH is retrieved by using vertical gradient of 1um backscatter data [Sugimoto et al. 2009].



Blue : Only averaging, Red : Wavelet + Averaging
Green: Wavelet + Averaing + Wavelet (extinction)



SNR is improved by three times by wavelet analysis



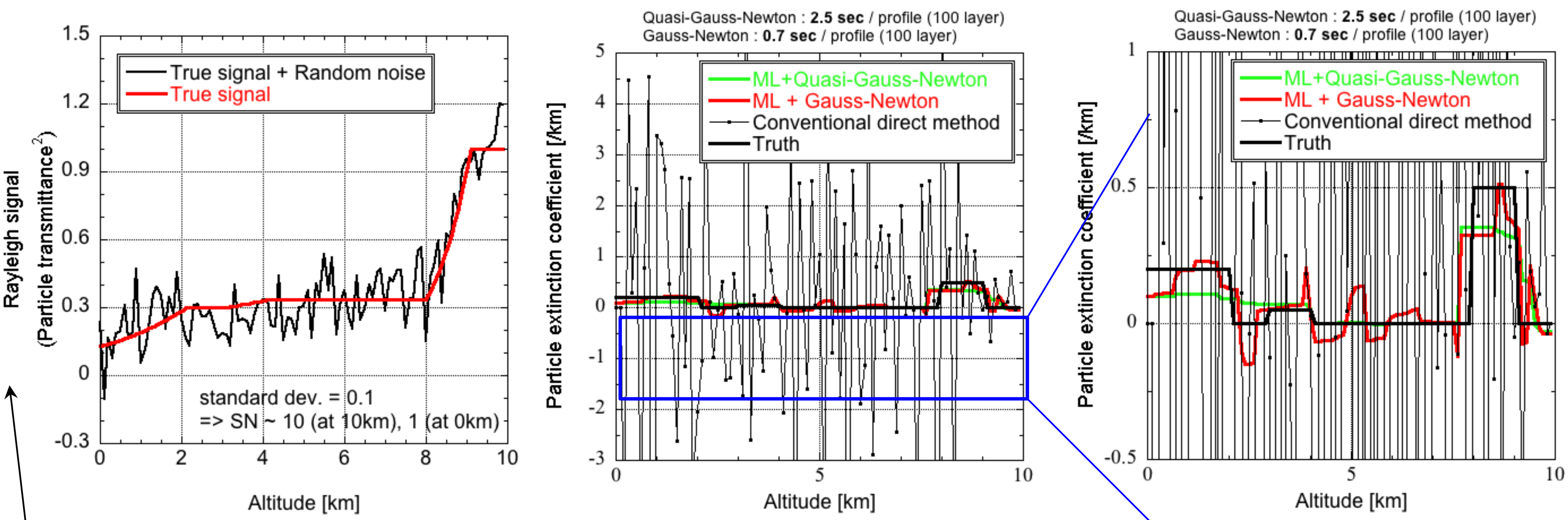
We improve estimation accuracy by applying wavelet to derived extinction.

↑

SNR is defined as SNR = Signal / Standard deviation (ΔZ=120m, Δt=1hour) × √N

Use of Inversion method to reduce noise

Maximum likelihood method (ML) + Gauss-Newton method



Rayleigh signal **Particle extinction** **Particle extinction**

$$T_p{}^2 = P_{Ray} / b_{mol} / T_{mol}{}^2$$

✓ Inversion method + Smoothing to more improve estimation accuracy

✓ Inversion method treating constraints (e.g., Penalty function method)

PBL height

[AD-Net Seoul, 12-15 May. 2010, Ground-based Mie-Raman lidar]

Raman signal (607nm)

Attenuated Backscatter (532nm)

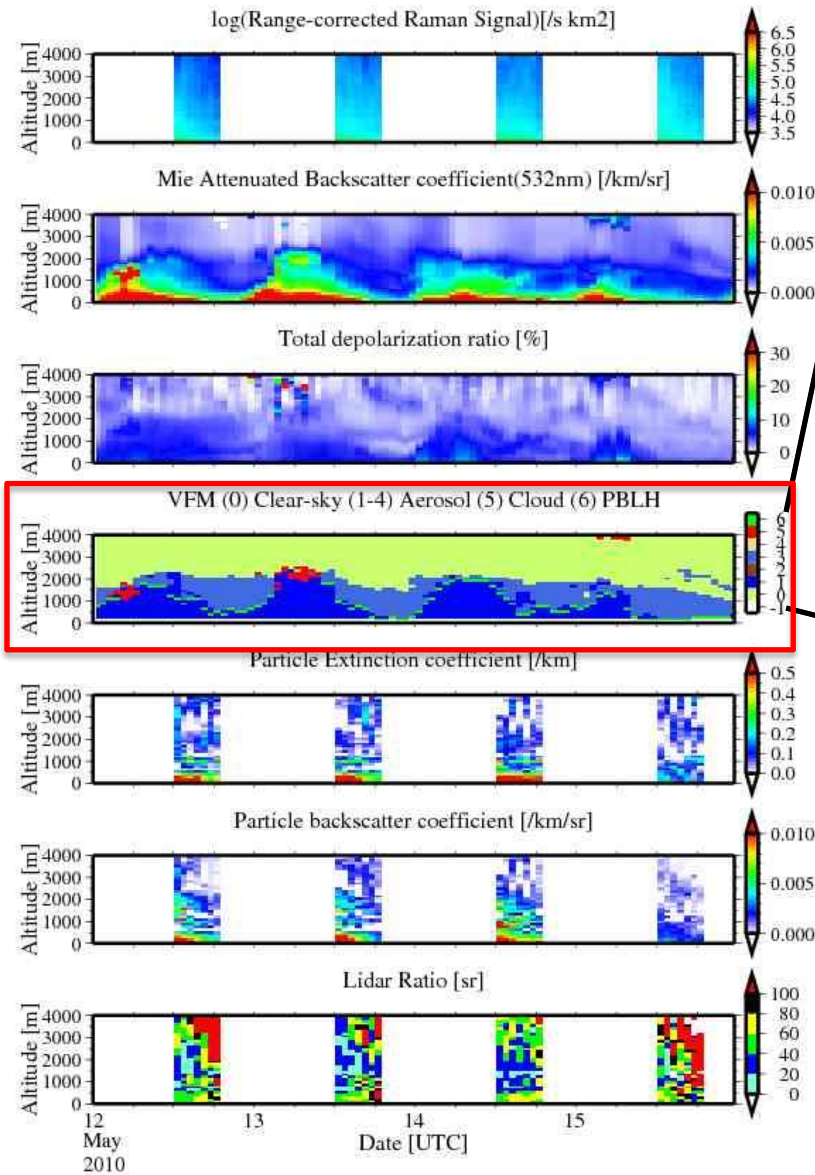
Total dep. (532nm)

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]

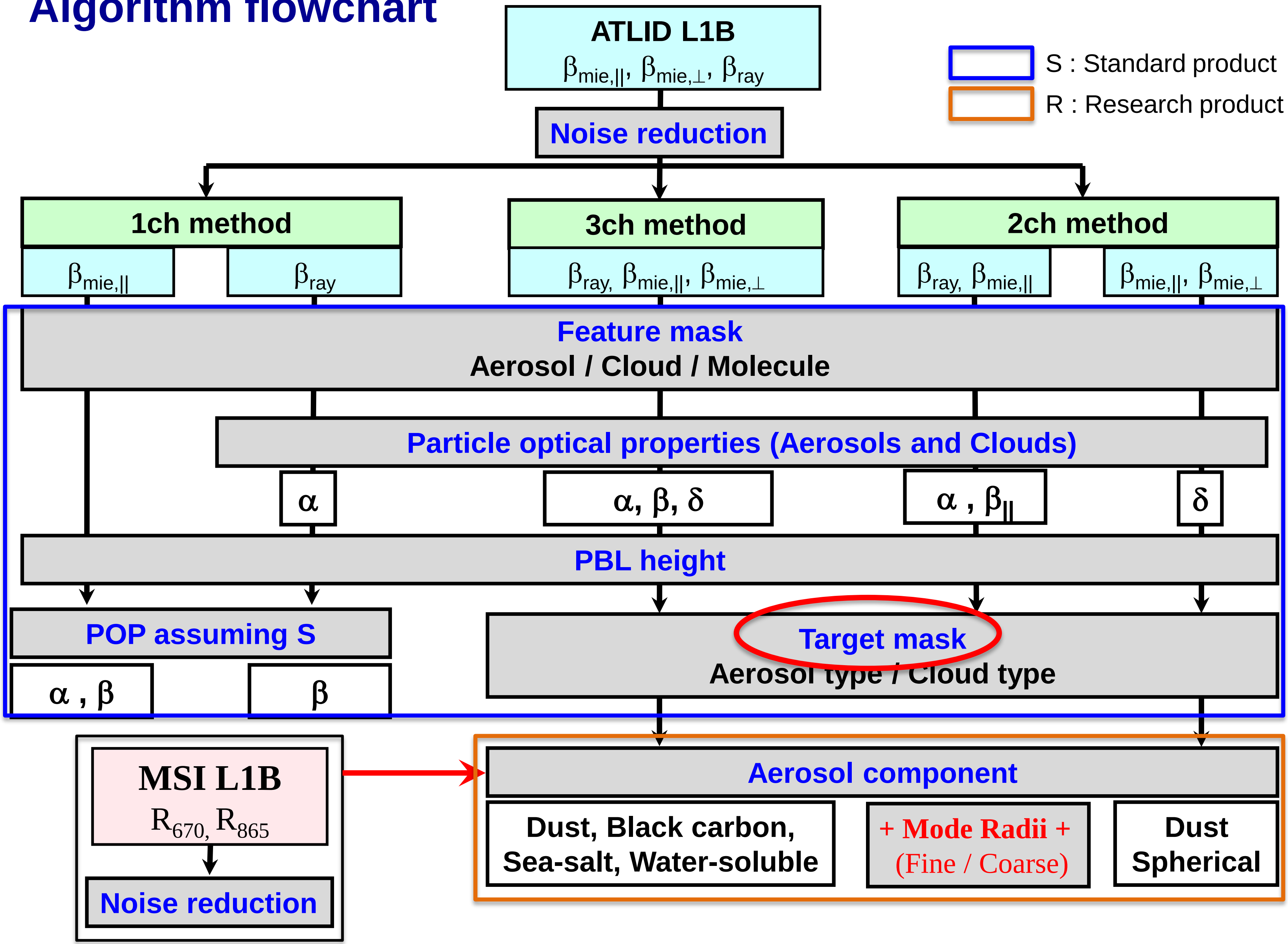
~0.3km^{-1}

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

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

40~80 sr

Algorithm flowchart



Aerosol Target Mask

Aerosol layer is classified into several types like CALIPSO aerosol types, **Clean-continental (CC)**, **Polluted continental (PC)**, **Polluted dust (PD)**, **Desert dust (DD)**, **Marine (MA)**, **Smoke (SM)**, and so on, using particle lidar ratio (S) and depolarization ratio (**δ**), and particle backscatter (β) with information on altitude, location, and surface type.

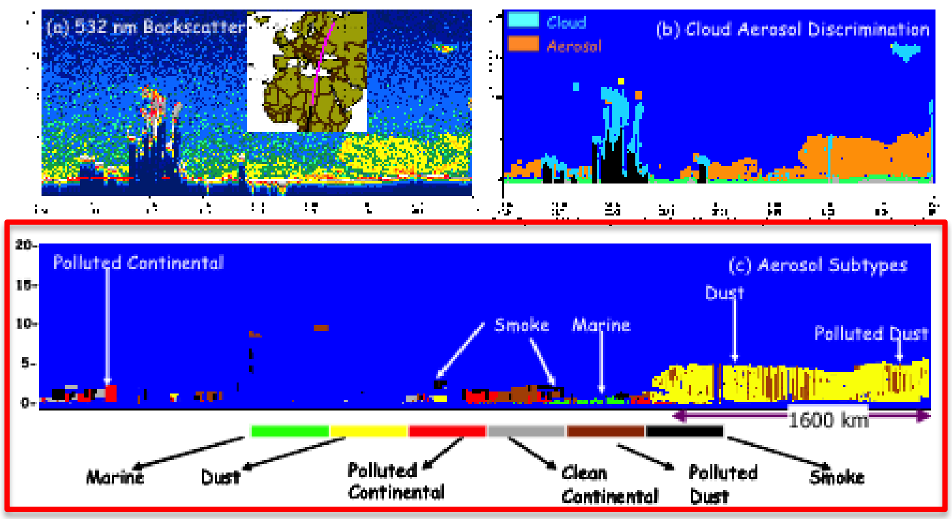
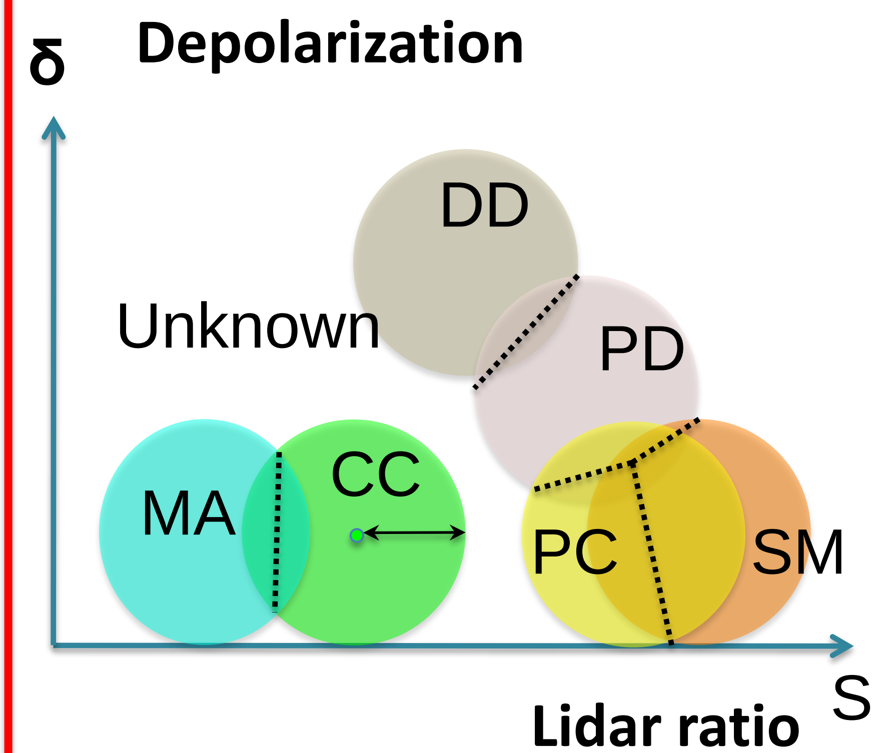


Figure 5 (a) 532-nm backscatter browse image, (b) cloud/aerosol feature mask, and (c) the aerosol subtyping plot of the same scene showing all the six aerosol types for this orbit section observed on Aug. 8, 2006. The relative scales of the three figures are as in Fig. 3

CALIOP aerosol target mask

[Omar et al. JTECH, 2009]



Concepts of ATLID aerosol target mask

Cluster Analysis Using AERONET Data

Method : Fuzzy c means

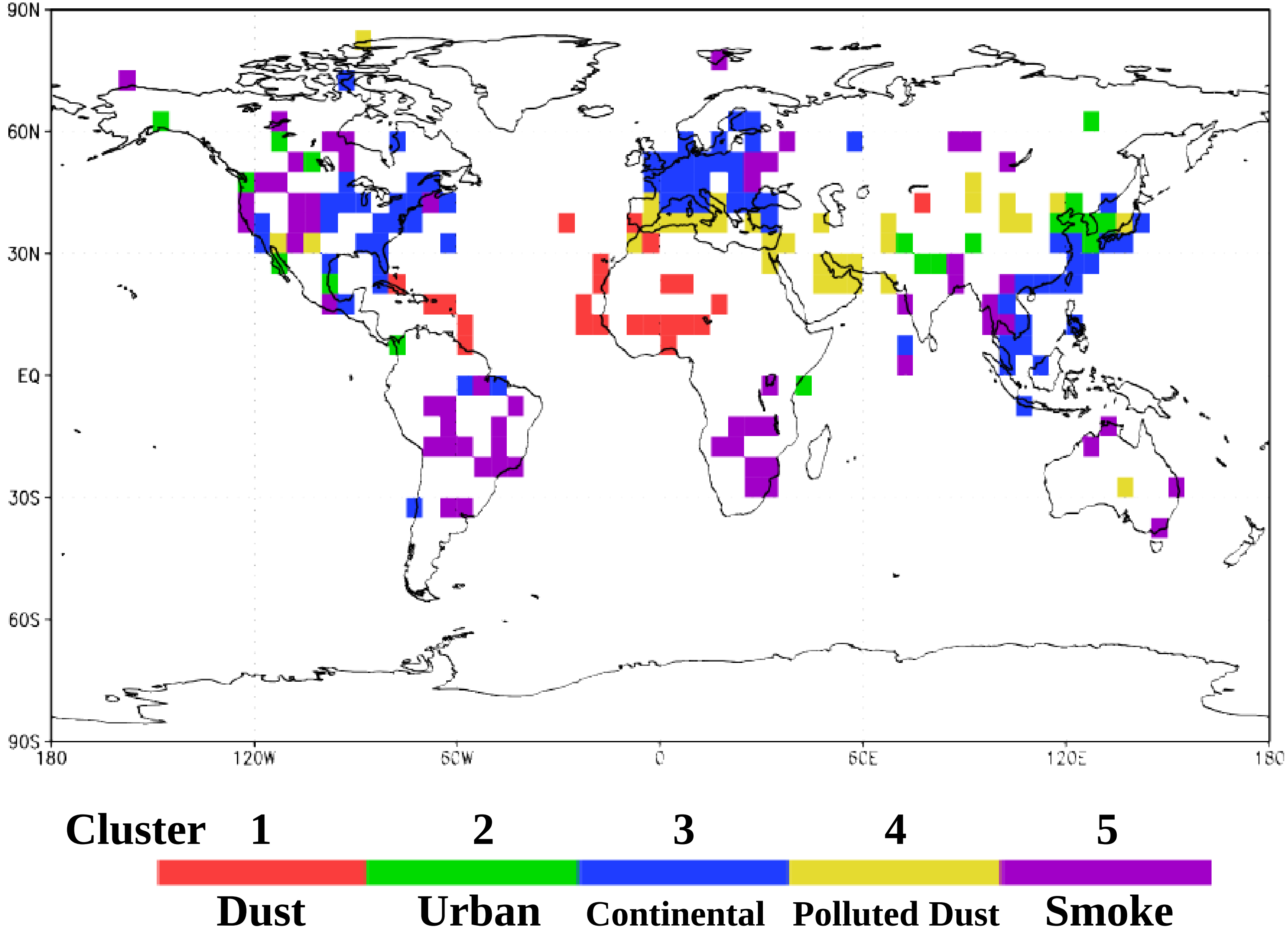
Data : AERONET Level 2 (1992 ~ 2012)

Input Parameters: 31 Parameters

AE (440-675/440-869/440-1020), AAE(440-675/440-869/440-1020), SSA(440/675/869/1020), ASYM(total) (440/675/869/1020), ASYM(fine) (440/675/869/1020), ASYM(coarse) (440/675/869/1020), mr (440/675/869/1020), Eff. Rad (total), Eff. Rad. (fine), Eff. Rad (coarse), Fine Mode Fraction, sphericity

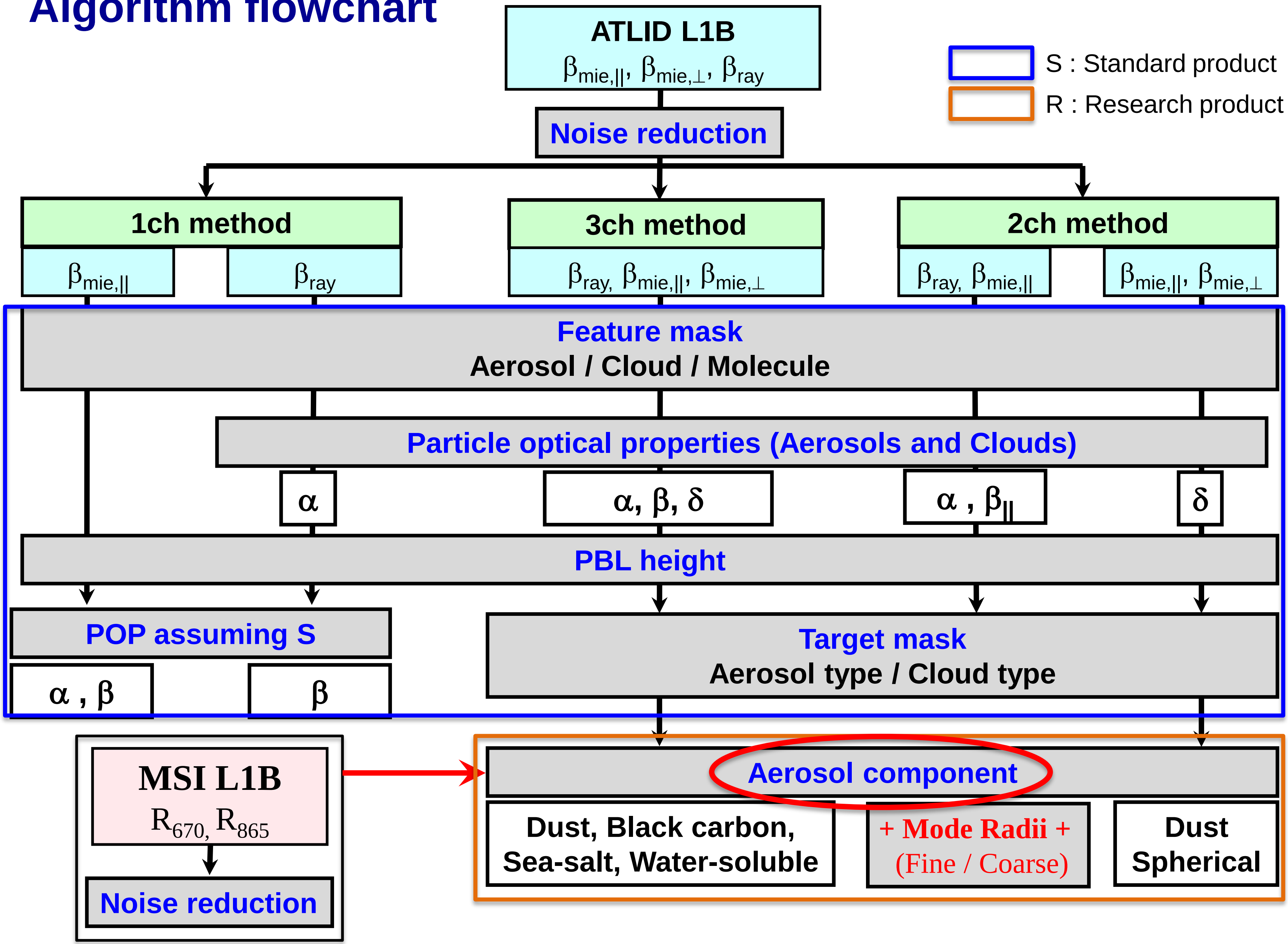
E. Oikawa, T. Nishizawa

Locations of the 5 clusters

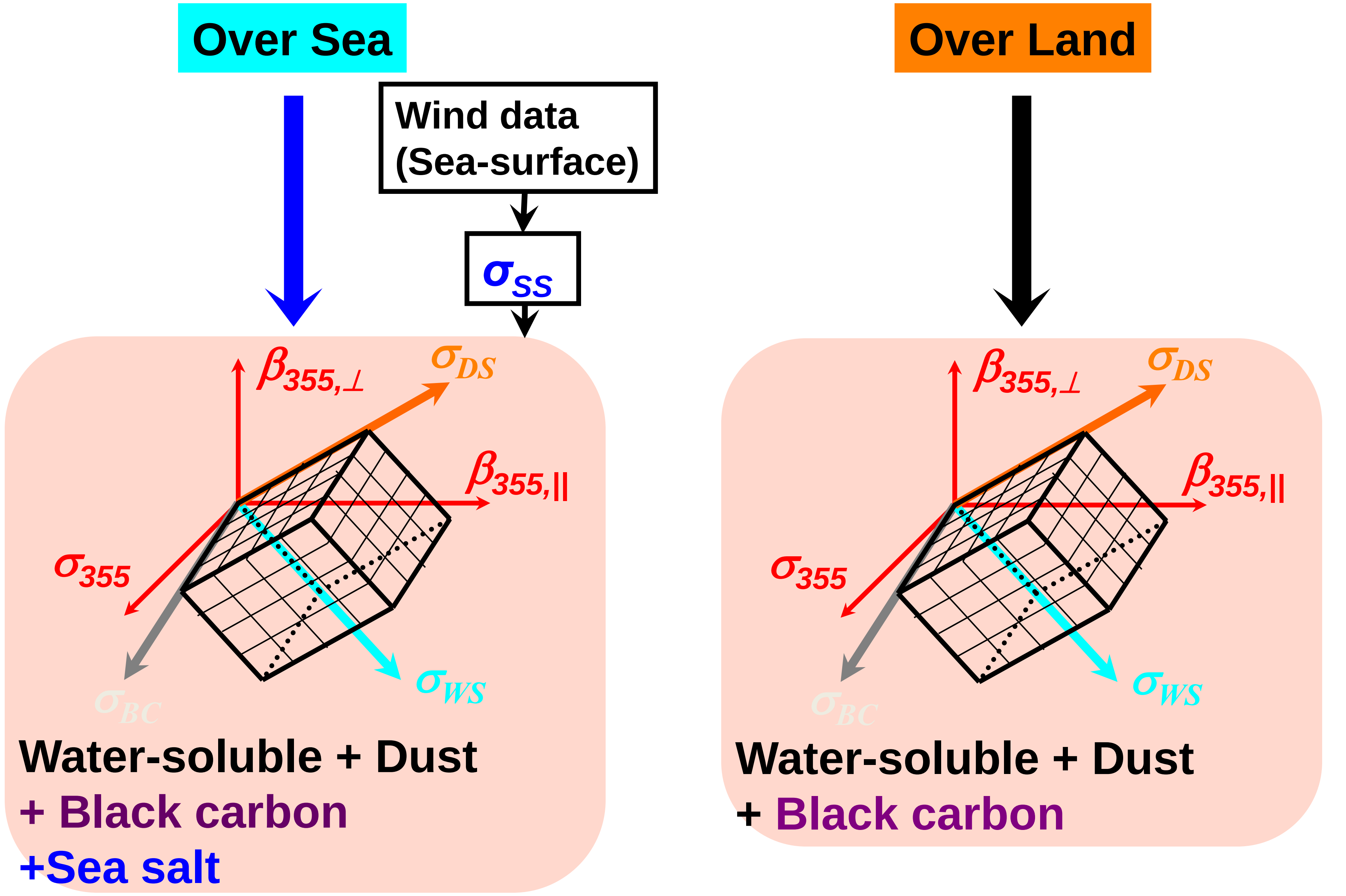


E. Oikawa, T. Nishizawa

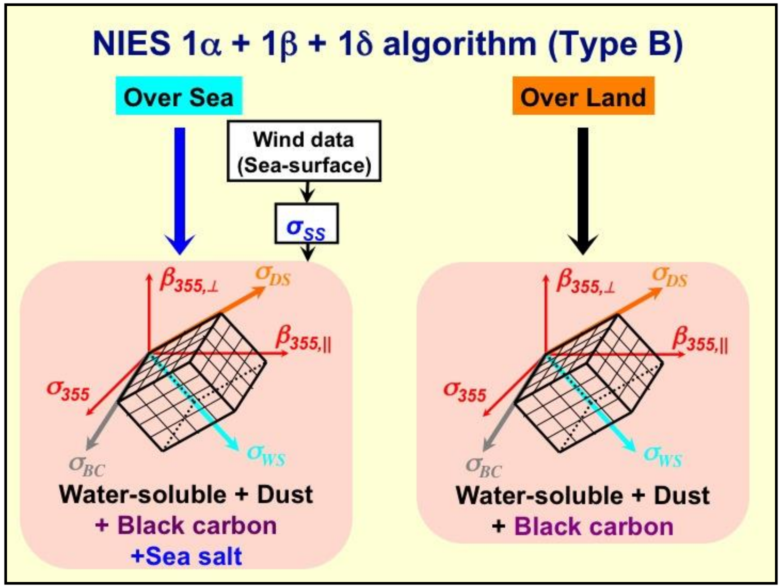
Algorithm flowchart

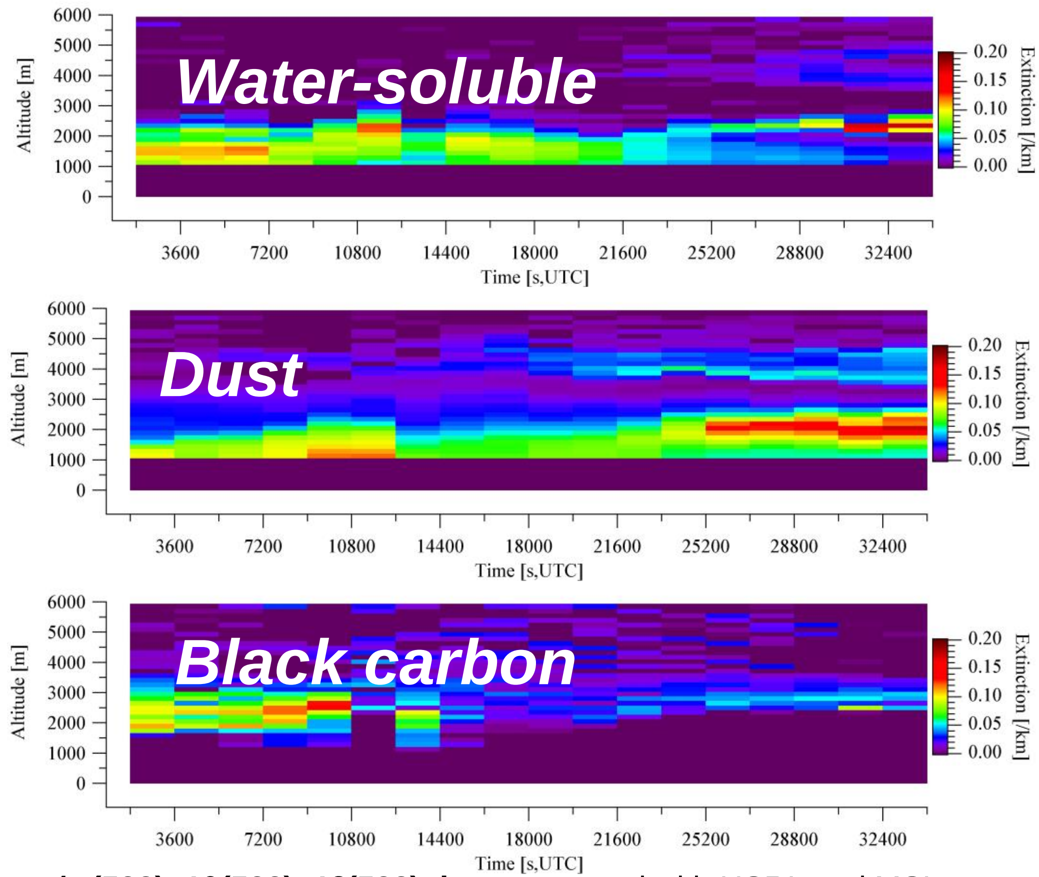


NIES 1α + 1β + 1δ algorithm (Type B)



Aerosol component retrieval





Assumption:

✓ External mixture of 4 components at each layer

✓ Optical properties for each aerosol component are prescribed (e.g., size dist., lidar ratio etc…)

- **1α(532)+1β(532)+1δ(532) data** measured with HSRL and MSL on Apr. 8 2005 were used in the analysis.
- **The aerosol properties at 532 nm** used in 2β+1δ algorithm were used.

Water-soluble: moderate-absorption / spherical (small-size)

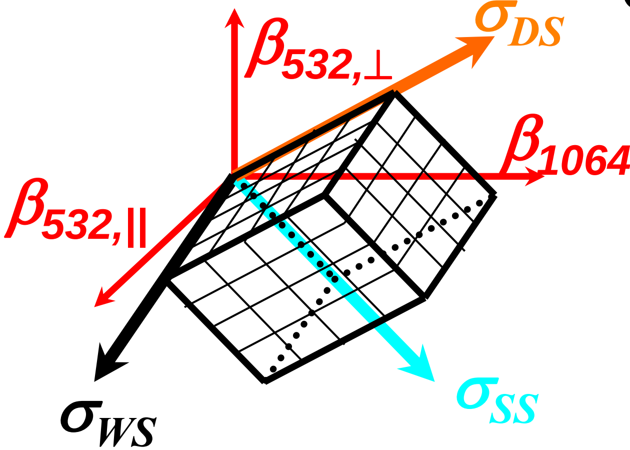
Dust : moderate absorption / non-spherical (large-size)

Sea-salt : weak-absorption / spherical (large-size)

Black carbon : strong-absorption / spherical (small-size)

2β + 1δ aerosol component retrieval for CALIOP

[Nishizawa et al. 2011]

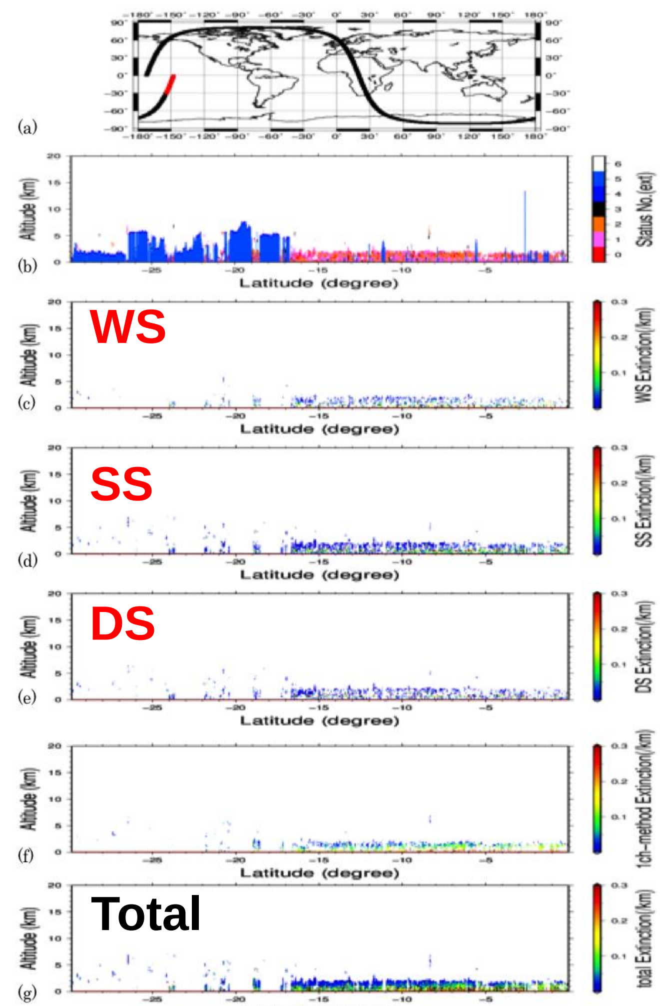


Optical model (RH=70%)

	WS	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]



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

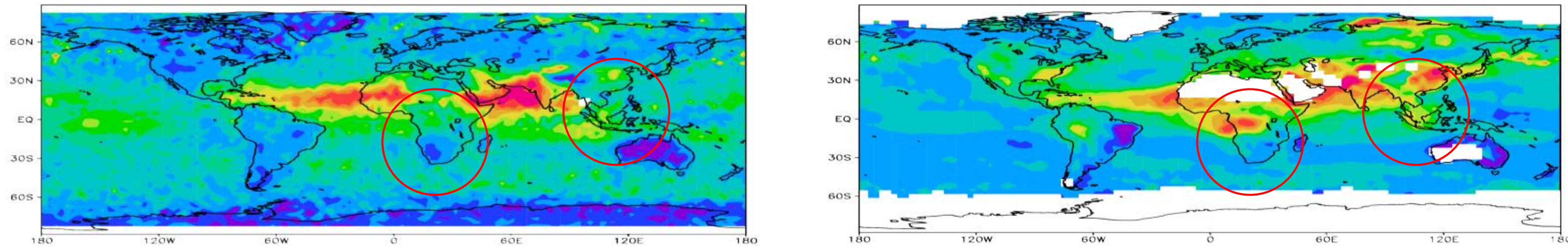
Assumption:

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

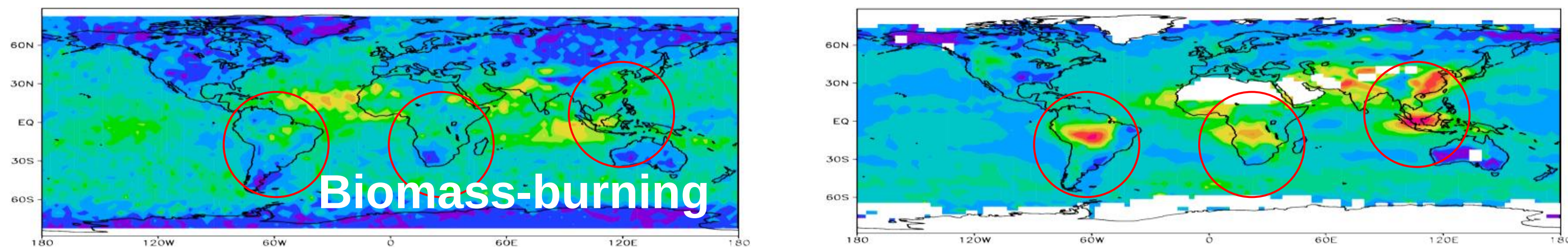
AOT comparison with MODIS (2006-2007)

CALIPSO (532nm) | **MODIS AOT(550nm)**

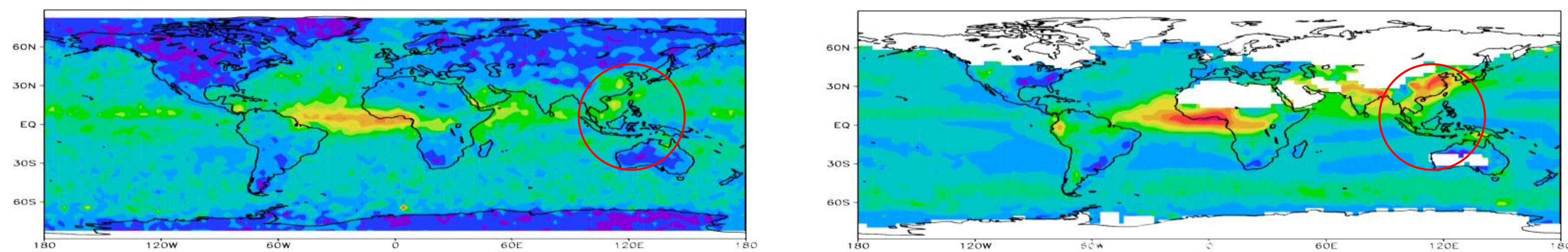
Summer (JJA)



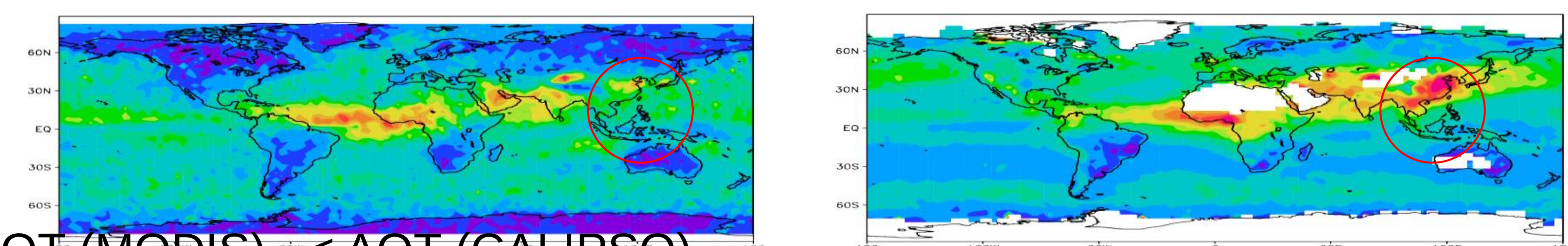
Autumn (SON)

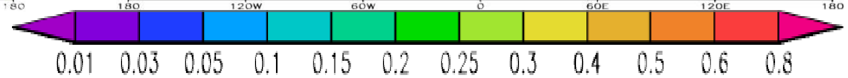


Winter (DJF)



Spring (MAM)





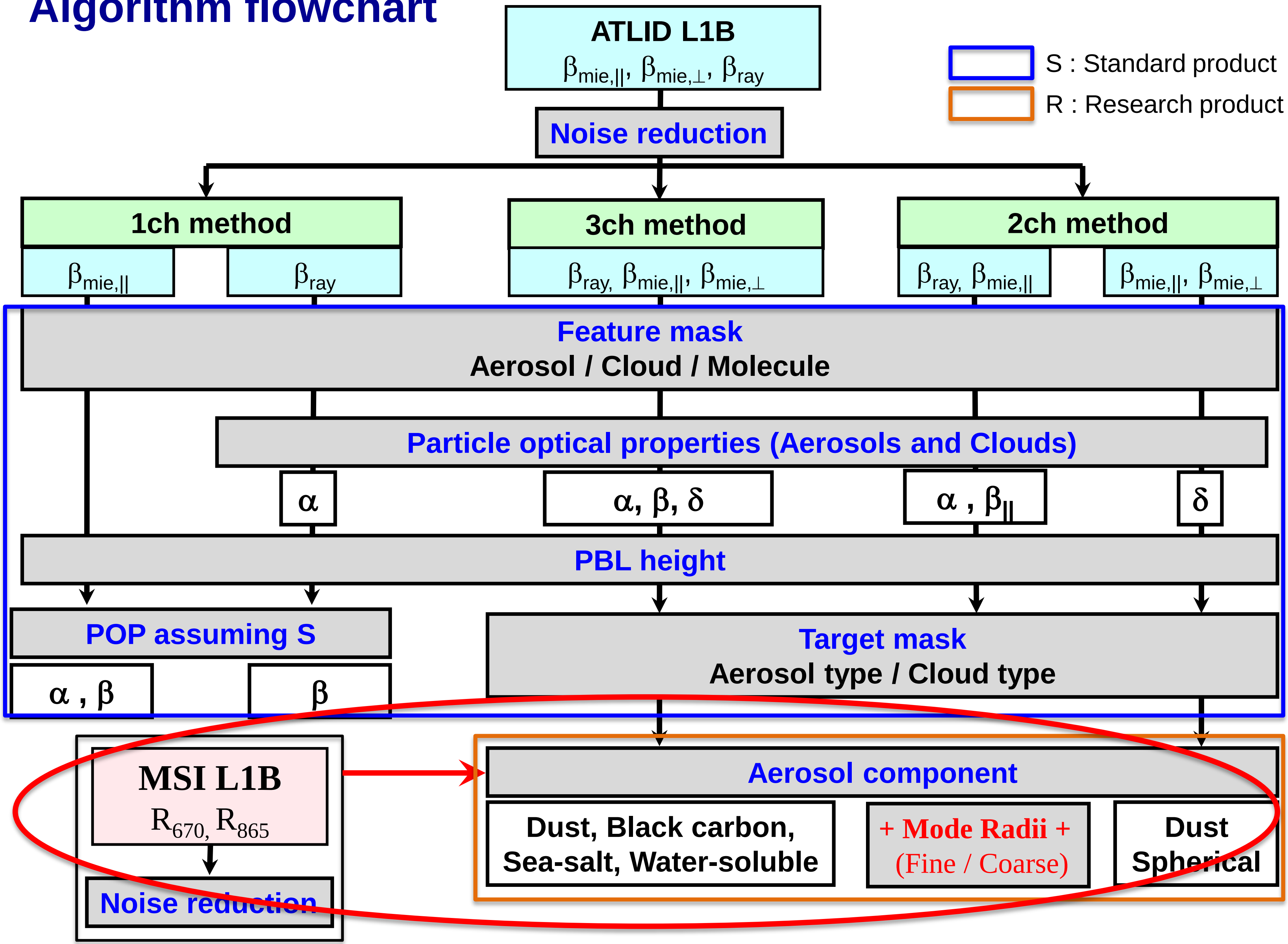
Ocean: AOT (MODIS) ~< AOT (CALIPSO)

Land: AOT (MODIS) > AOT (CALIPSO)

- ✓ **Biomass-burning aerosols** (BC, OC)
- ✓ **East Asia**

*Averaged every 3°×3° grid for daytime

Algorithm flowchart



Concepts

ATLID L2A aerosol component retrieval (ER)

✓ α, β, δ at 355nm => σ for WS, DS, BC

✓ Wind speed => σ for SS (over ocean)

External mixture of the 4 aerosol components

Assuming mode-radius, refractive index, shape

+MSI L1b : Radiances at 675 and 865nm (Over ocean)

✓ α, β, δ at 355nm => σ for WS, DS, BC

✓ Wind speed => σ for SS (over ocean)

✓ Column-mean mode-radii for WS & Dust

(Note: Mode radii of BC is prescribed)

WS (Water-soluble) : small-size / weak-absorption / spherical
DS (Dust) : large-size / moderate absorption / non-spherical
BC (Black carbon) : small-size / strong absorption / spherical
SS (Sea-salt) : large-size / weak-absorption / spherical

Validation plan using the ground-based lidar networks

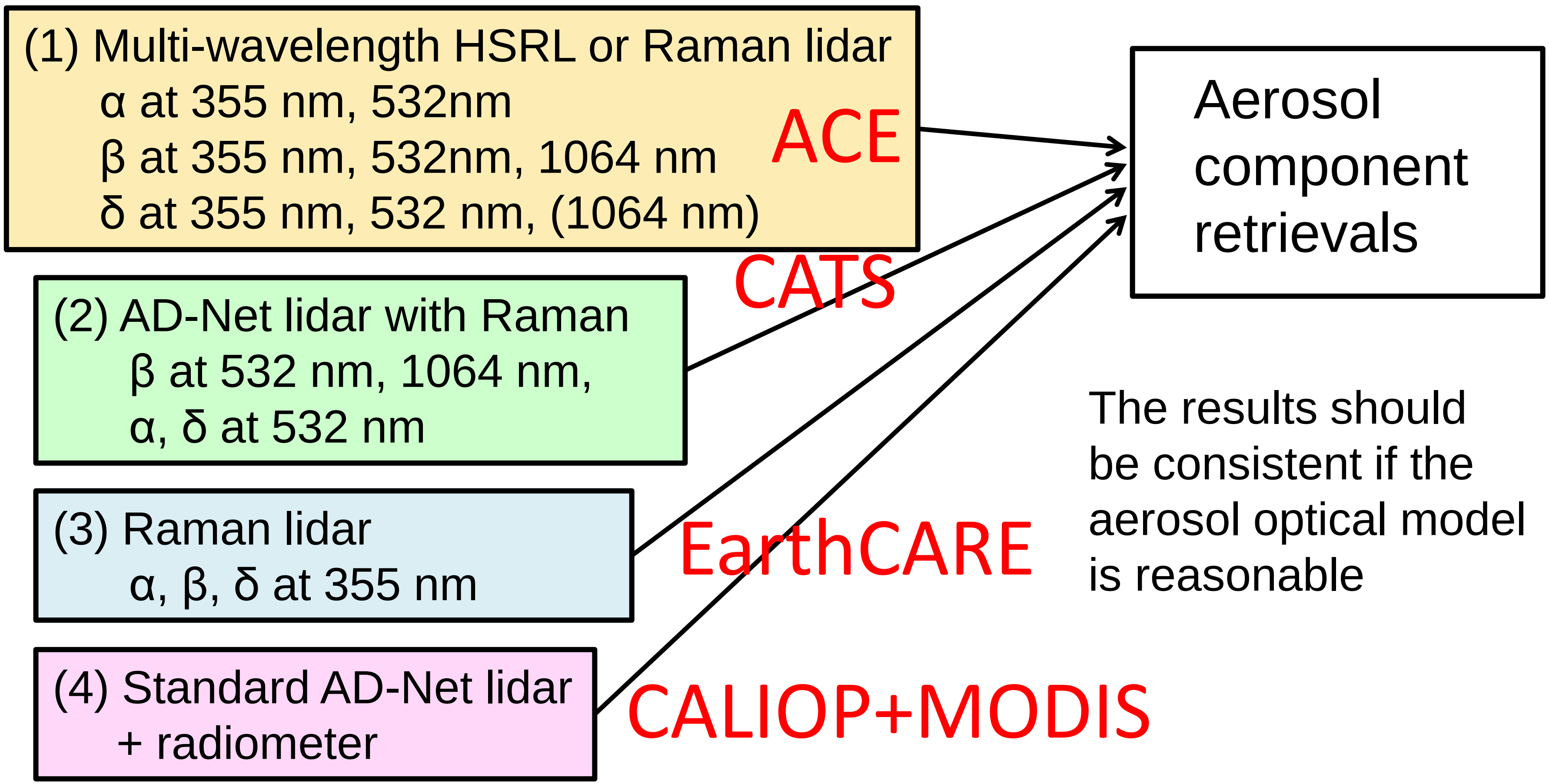
- Direct comparison of ATLID α, β, δ with ground-based Raman lidars and HSRLs

- Validation of the ATLID aerosol component product with ground-based multi-wavelength Raman lidar, HSRL, AD-Net+SKYNET

Validation of the ATLID aerosol component product

ATLID (α, β, δ at 355 nm) + supplementary data → Concentrations of 4 aerosol components (Mineral dust, Sea salt, Black carbon, Sulfate+Nitrate+OC)

Ground-based multi-wavelength HSRL and Raman lidars will be used for validating consistency of aerosol component analysis.



The results should be consistent if the aerosol optical model is reasonable

New project on data assimilation of multi-wavelength Raman (or HSR) lidars!

【Grant-in-Aid for Scientific Research(S)】

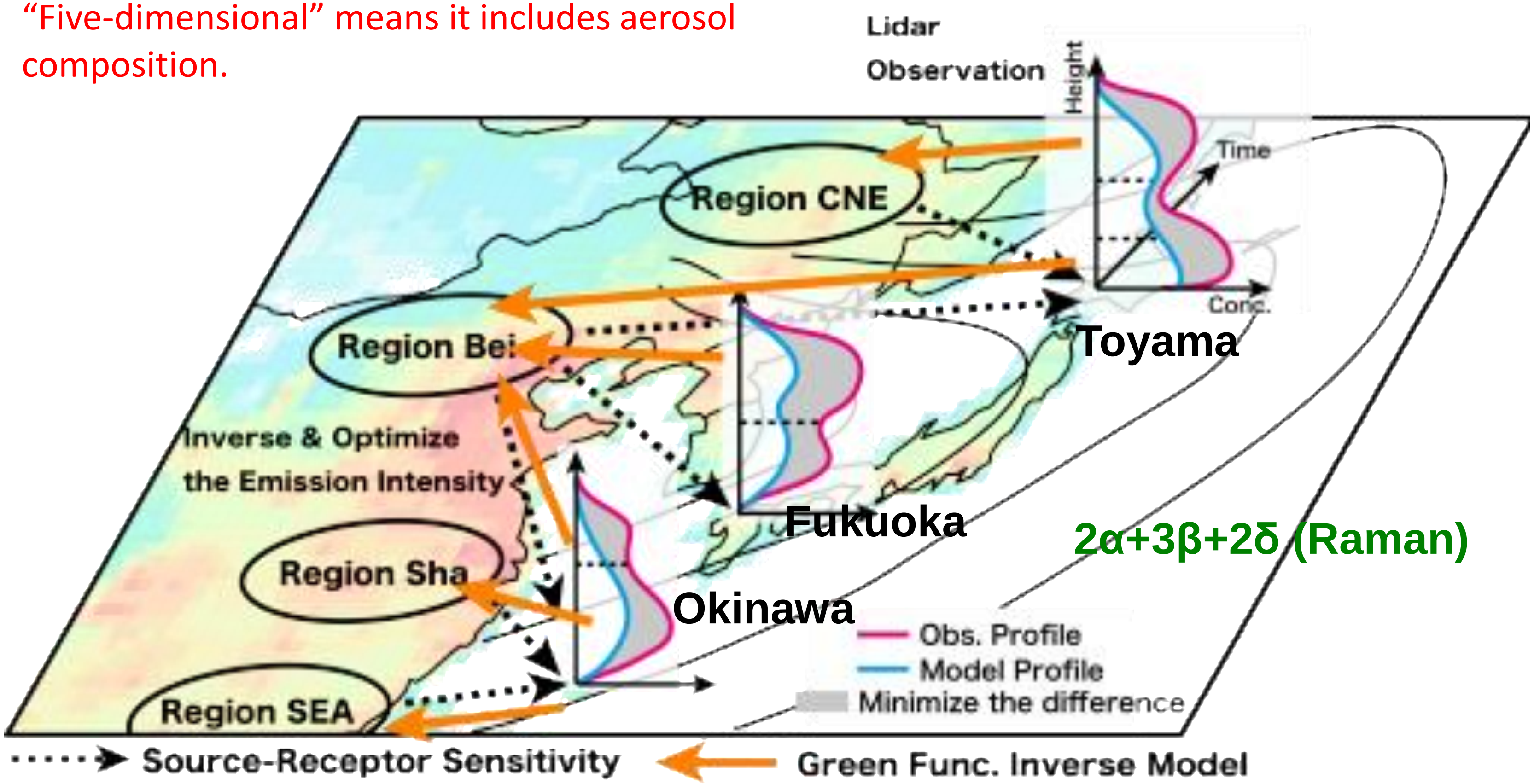
Integrated Disciplines (Environmental science)

Five-dimensional data assimilation of aerosol based on integrated analysis of multi-wavelength lidar and chemical transport model

PI: **Itsushi Uno**

(Kyushu University, Research Institute for Applied Mechanics)

"Five-dimensional" means it includes aerosol composition.



SATREPS Lidar Network in South America

2α+3β+2δ (Raman)

- CEILAP
- Bariloche
- C.Rivadavia
- Neuquén
- R.Gallegos
- Ezeiza

2α+3β+2δ (HSRL, Raman)

- Punta Arenas
- Córdoba
- Tucumán

ATLID L2A & ATLID+MSI L2B products

	Parameter	Used ATLID channel			Resolution (Note)
		1ch	2ch	3ch	
ATLID L2A（S）	**Feature mask**（Molecule/Aerosol/Cloud classification）	○	○	○	ΔZ=0.1km ΔH = 0.285km/1km/10km
	Target mask（Cloud type/Aerosol type classification）	×	○	○	ΔZ=0.1km ΔH = 1km/10km
	Aerosol optical property（Extinction, Backscatter, Depolarization, Lidar ratio）	△	△	○	ΔZ=0.1km ΔH = 1km/10km (1ch, 2ch: S1 assumption)
	Cloud optical property（Extinction, Backscatter, Depolarization, Lidar ratio）	△	△	○	ΔZ=0.1km ΔH = 1km/10km (1ch, 2ch: S1 ssumption）
	Planetary boundary layer height	○	○	○	ΔH = 1km/10km
ATLID L2A（R）	**Extinction of aerosol components**（Dust、Sea-salt、Water-soluble、Black carbon）	×	○	○	ΔZ=0.1km ΔH = 10km (2ch：Dust, Water-soluble)
ATLID-MSI L2B（R）	**Extinction of aerosol components**	×	○	○	ΔZ=0.1km ΔH = 10km
	Mode radii（Fine and Coarse)	×	○	○	ΔH = 10km (Constant in a column)

Validation: Comparison for various cases

✓Clean/Dirty ✓Land / Ocean, ✓ Industrial / rural

✓Asia / Europe / America … ✓ Dust / Biomass-burning / Pollution …

Thank you