Detection of Vertical Aerosol Distribution with Active Remote Sensing

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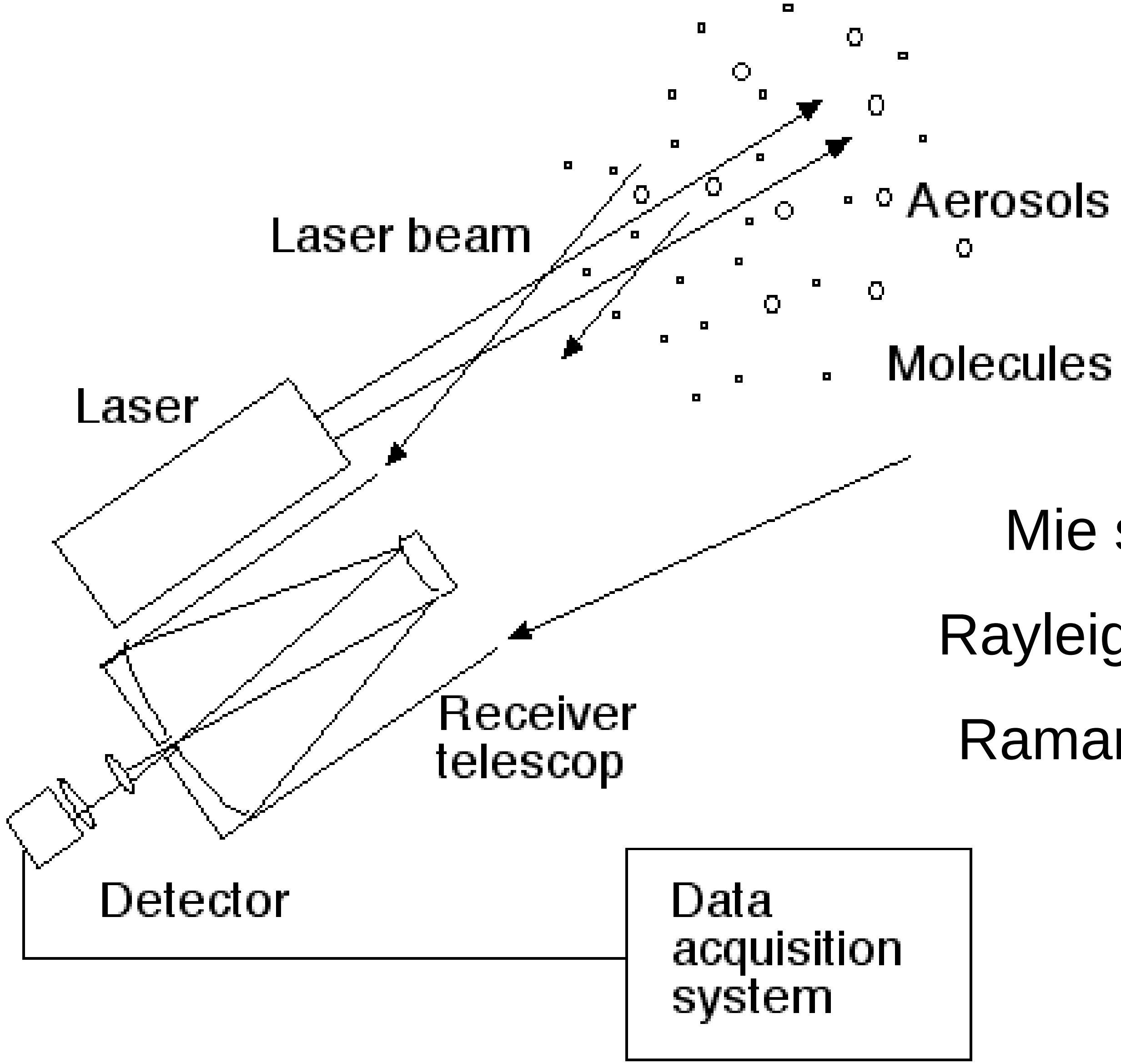


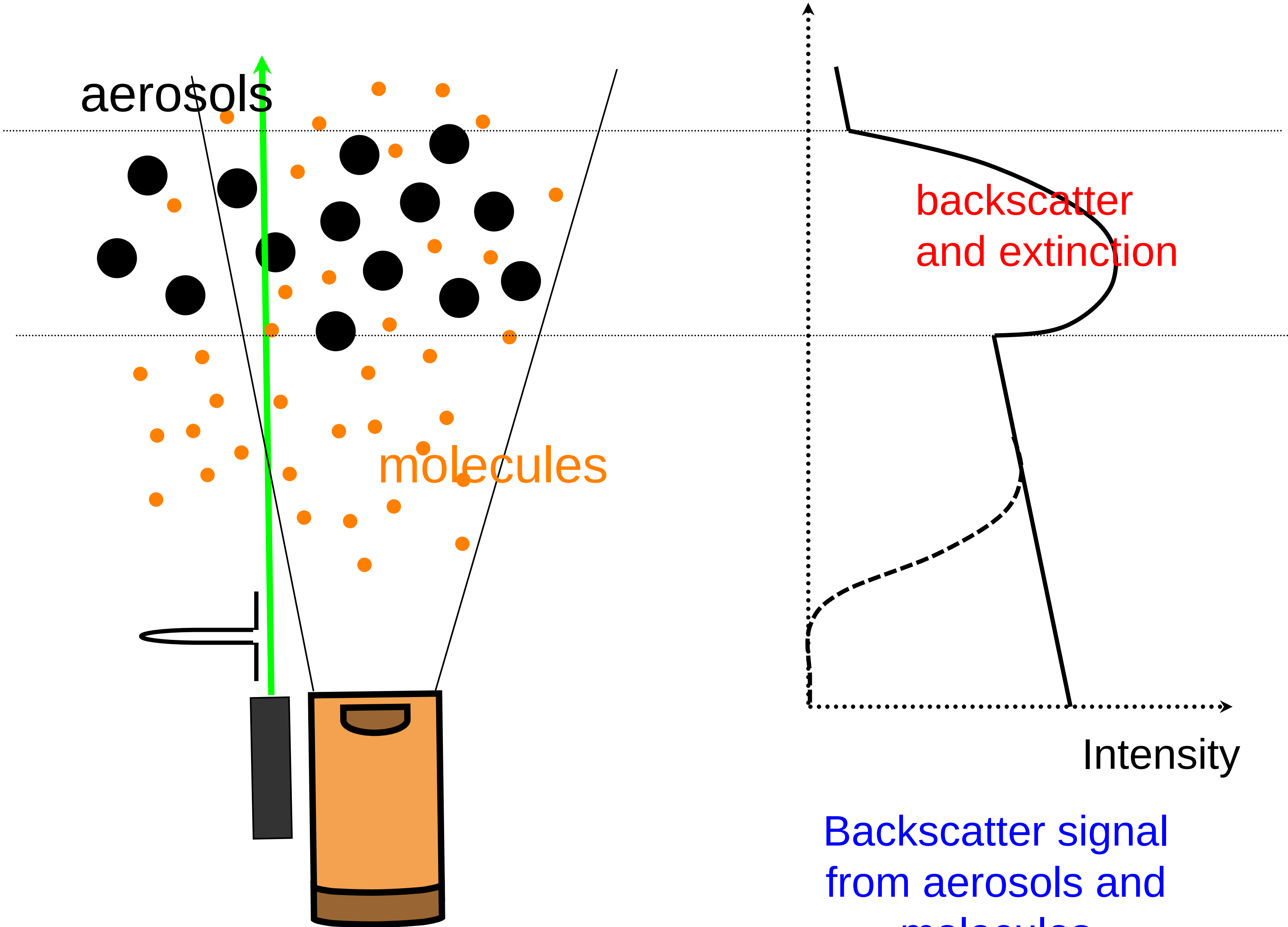
Mie scattering

Rayleigh scattering

Raman scattering

LIDAR: Light Detection and Ranging

Mie scattering lidar



Backscatter signal from aerosols and molecules

Lidar equation

$$P(r) = C\,Y(r)\,\frac{\beta(r)}{r^2}\exp(-2\tau)$$

$P(r)$: received power, r: range, C: system constant
$Y(r)$:geometrical form factor,
$\beta(r)$: backscattering coefficient $(\beta(r) = \beta_1(r) + \beta_2(r))$

1: aerosol 2: molecule

$$\tau = \int_0^r \alpha(r')dr'$$

$\alpha(r)$: extinction coefficient $(\alpha(r) = \alpha_1(r) + \alpha_2(r))$

β_2 and α_2 are known

β_1 and α_1 are the parameters to be derived

Lidar ratio (extinction-to-backscattering ratio)

$$S_1 = \alpha_1 / \beta_1$$

S_1 is dependent on aerosol type (refractive index, size distribution, and shape)

$S_1 \sim 20 - 100$ sr

Klett's Method (single-component backward solution, 1981)

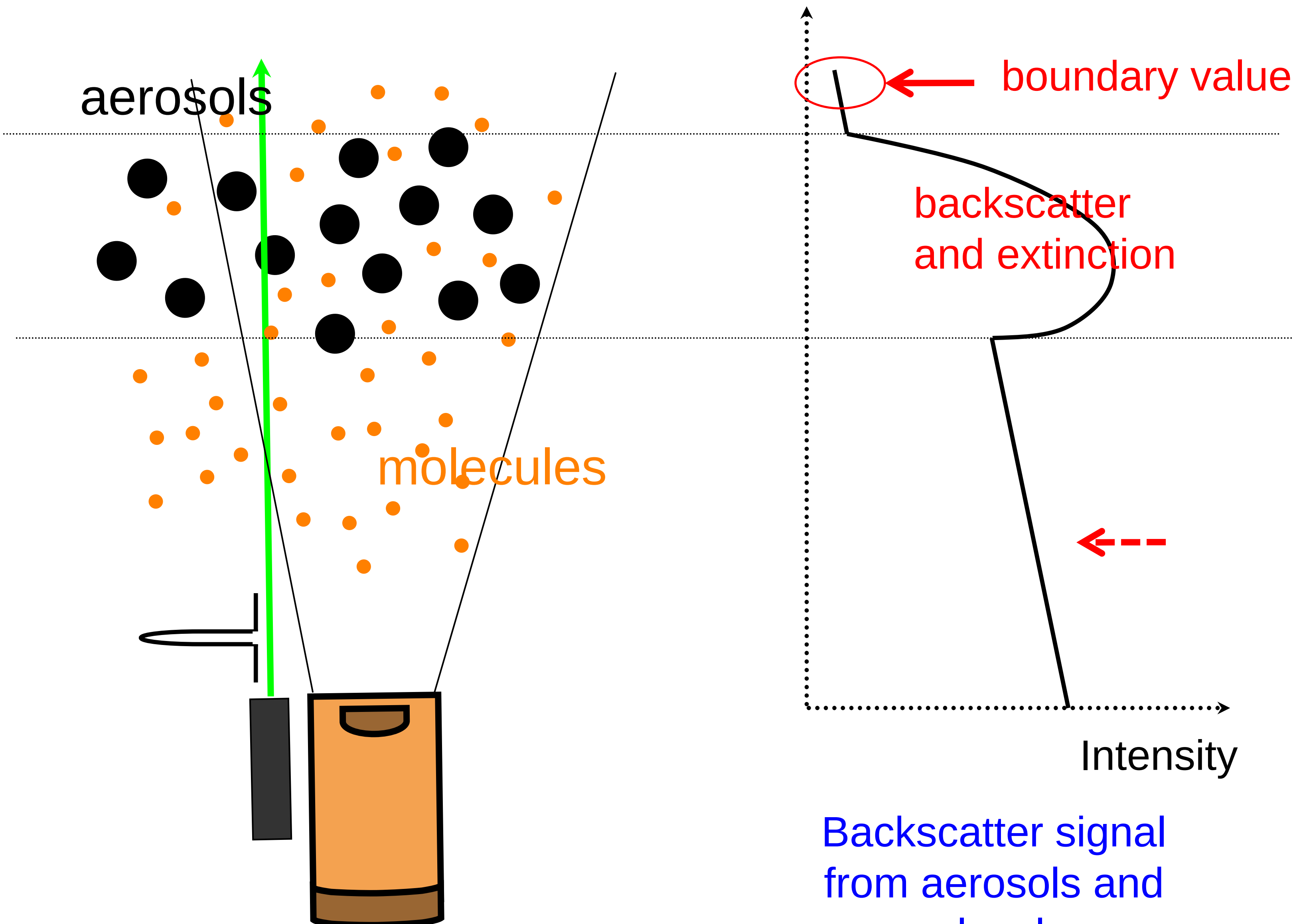
Fernald's method (two-component backward solution, 1984)

$$\beta(r) = -\beta_2(r) + \frac{X(r)\exp[2(\frac{S_1}{S_2}-1)\int_r^{r_m}\alpha_2(r')dr']}{\frac{X(r_m)}{\beta_1(r_m)+\beta_2(r_m)} + 2S_1\int_r^{r_m} X(r')\exp[2(\frac{S_1}{S_2}-1)\int_{r'}^{r_m}\alpha_2(r'')dr'']dr'}$$

$$\alpha_1(r) = -\frac{S_1}{S_2}\alpha_2(r) + \frac{X(r)\exp[2(\frac{S_1}{S_2}-1)\int_r^{r_m}\alpha_2(r')dr']}{\frac{X(r_m)}{\alpha_1(r_m)+\frac{S_1}{S_2}\alpha_2(r_m)} + 2\int_r^{r_m} X(r')\exp[2(\frac{S_1}{S_2}-1)\int_{r'}^{r_m}\alpha_2(r'')dr'']dr'}$$

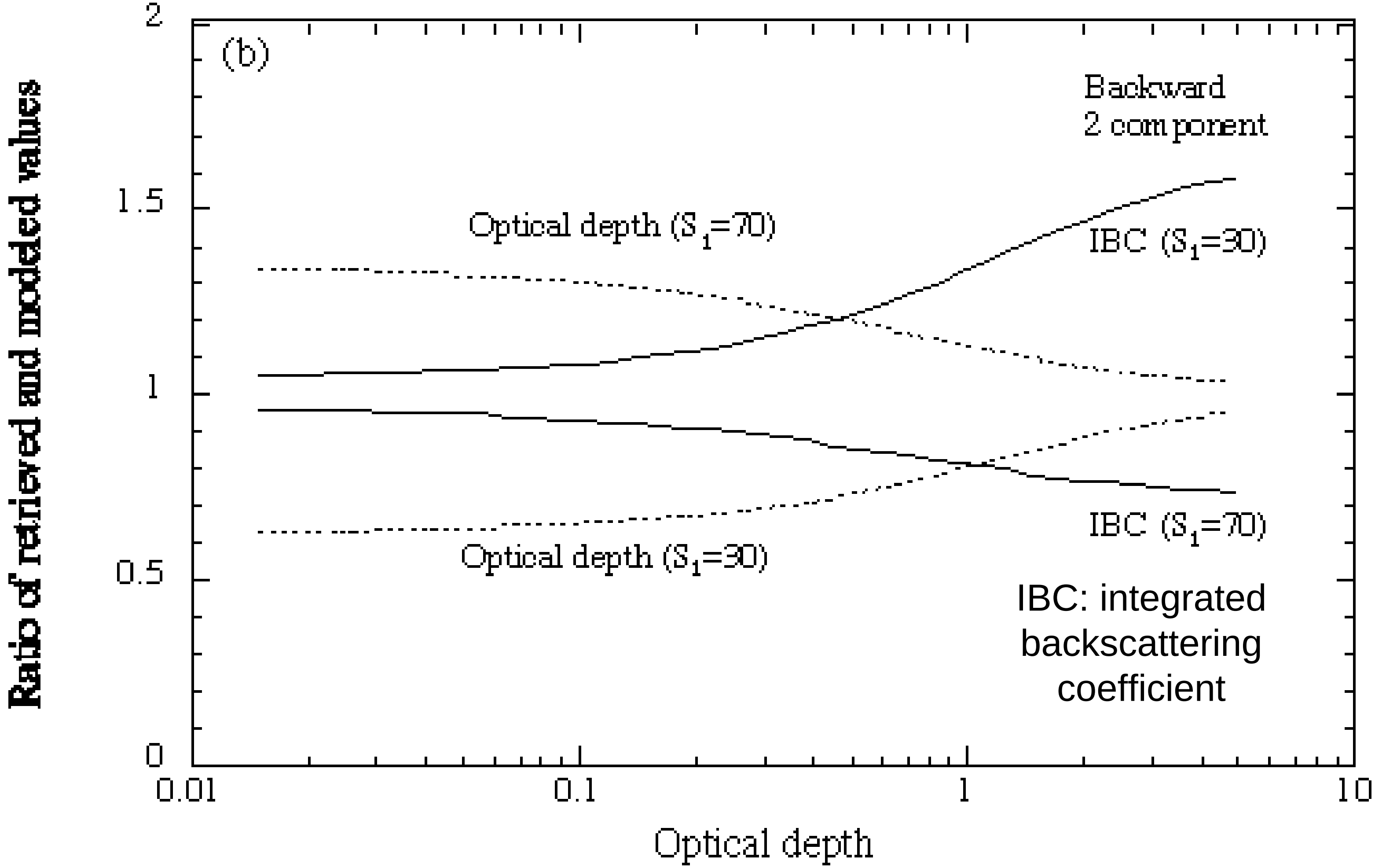
$X(r)=P(r)r^2$

Mie scattering lidar

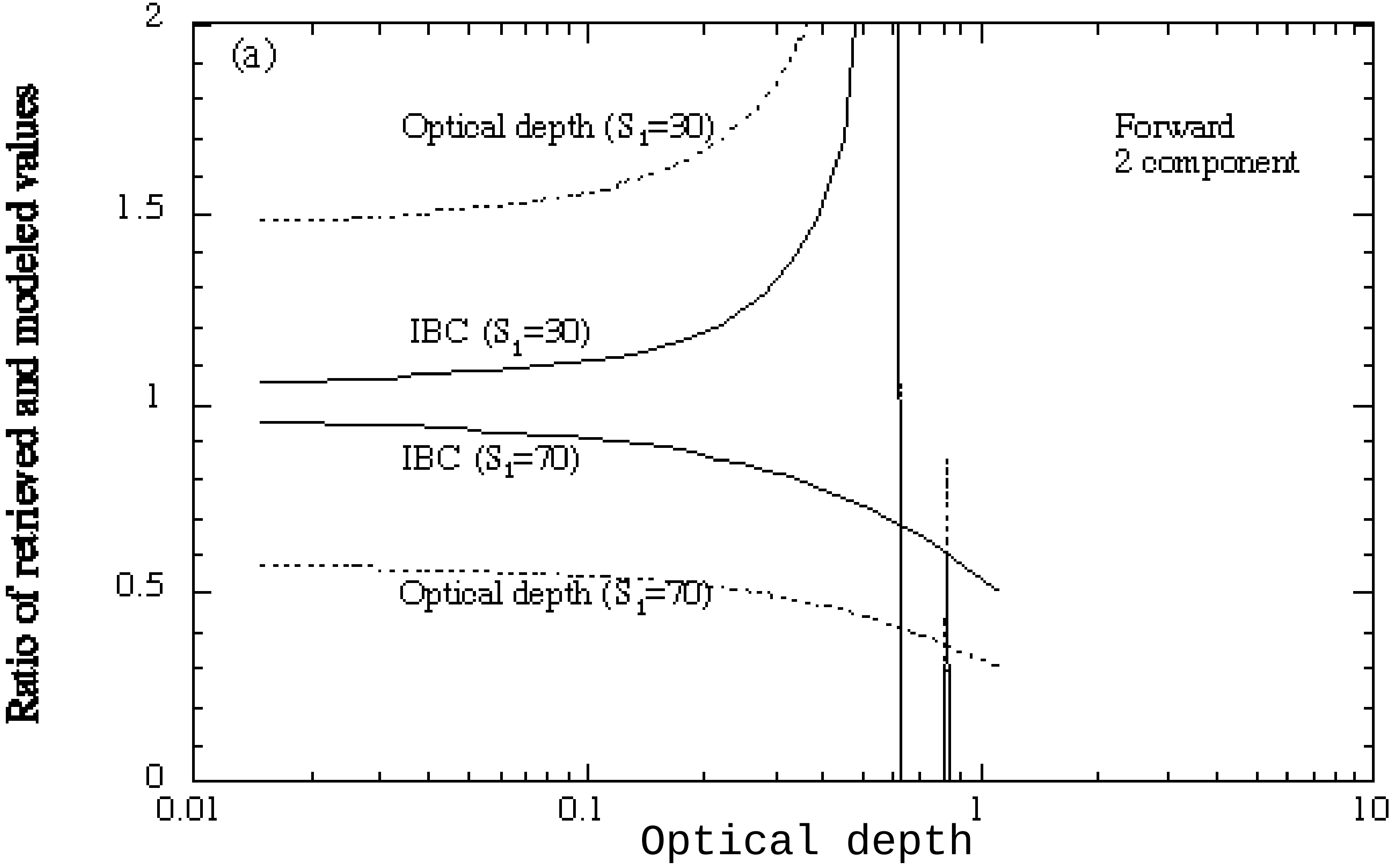


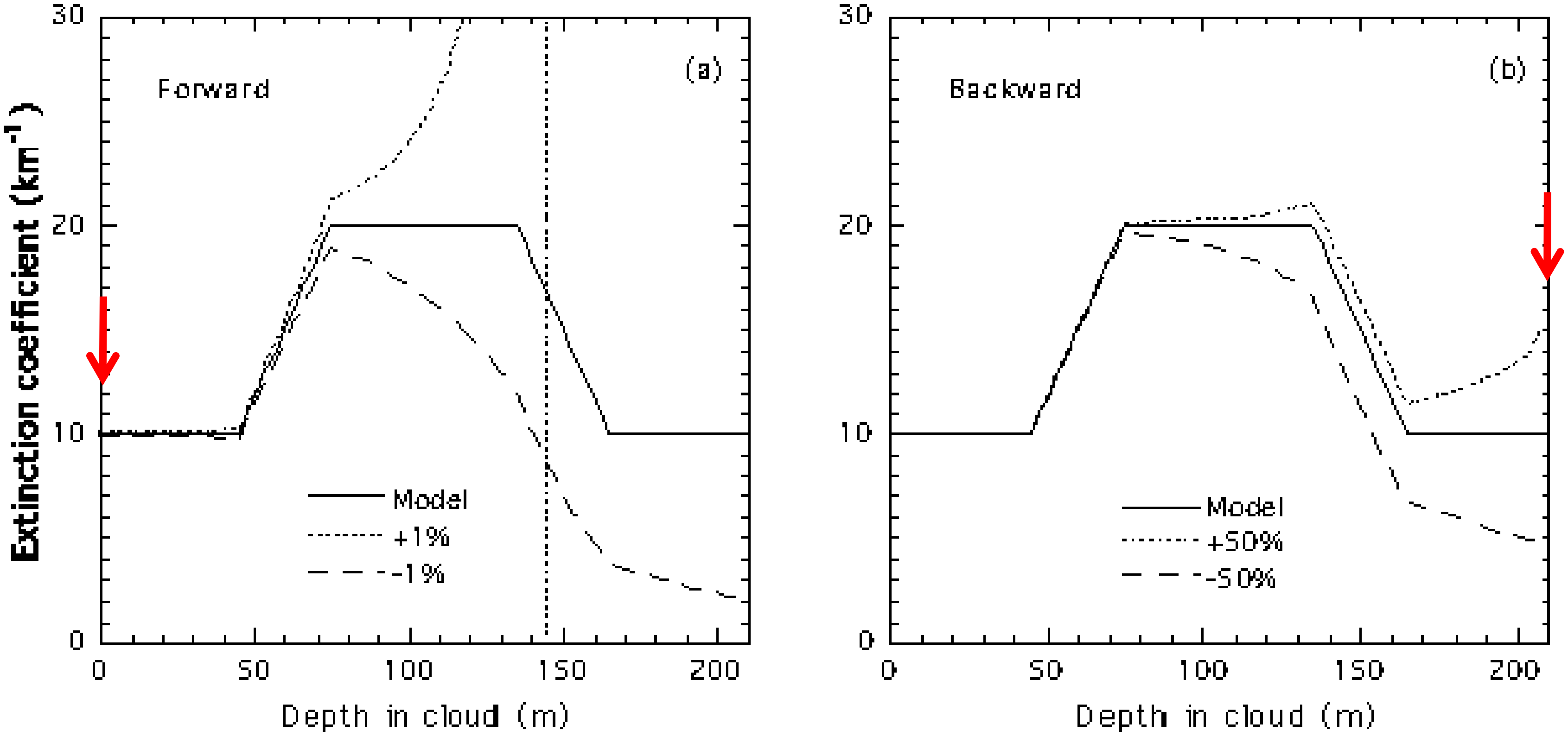
Backscatter signal from aerosols and molecules

True S_1 = 50 sr


(b)
Backward
2 component
Optical depth (S_1=70)
IBC (S_1=30)
IBC (S_1=70)
Optical depth (S_1=30)
IBC: integrated backscattering coefficient
Ratio of retrieved and modeled values
Optical depth
0
0.5
1
1.5
2
0.01
0.1
1
10

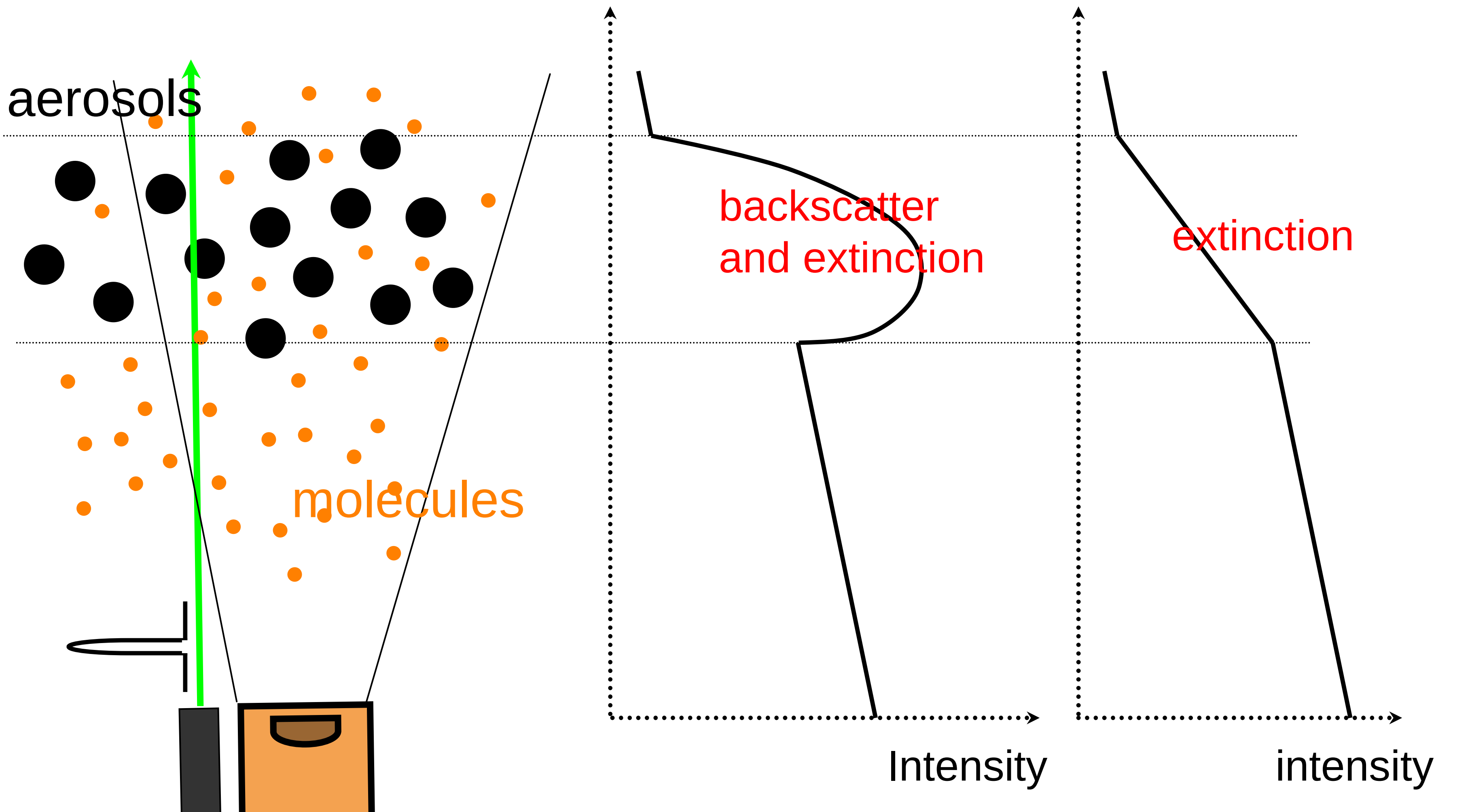
True S_1 = 50 sr


(a)
Optical depth (S1=30)
IBC (S1=30)
IBC (S1=70)
Optical depth (S1=70)
Forward
2 component
Ratio of retrieved and modeled values
0
0.5
1
1.5
2
0.01
0.1
1
10
Optical depth



Boundary error propagation in the forward and backward Klett's solutions for a modeled dense cloud.

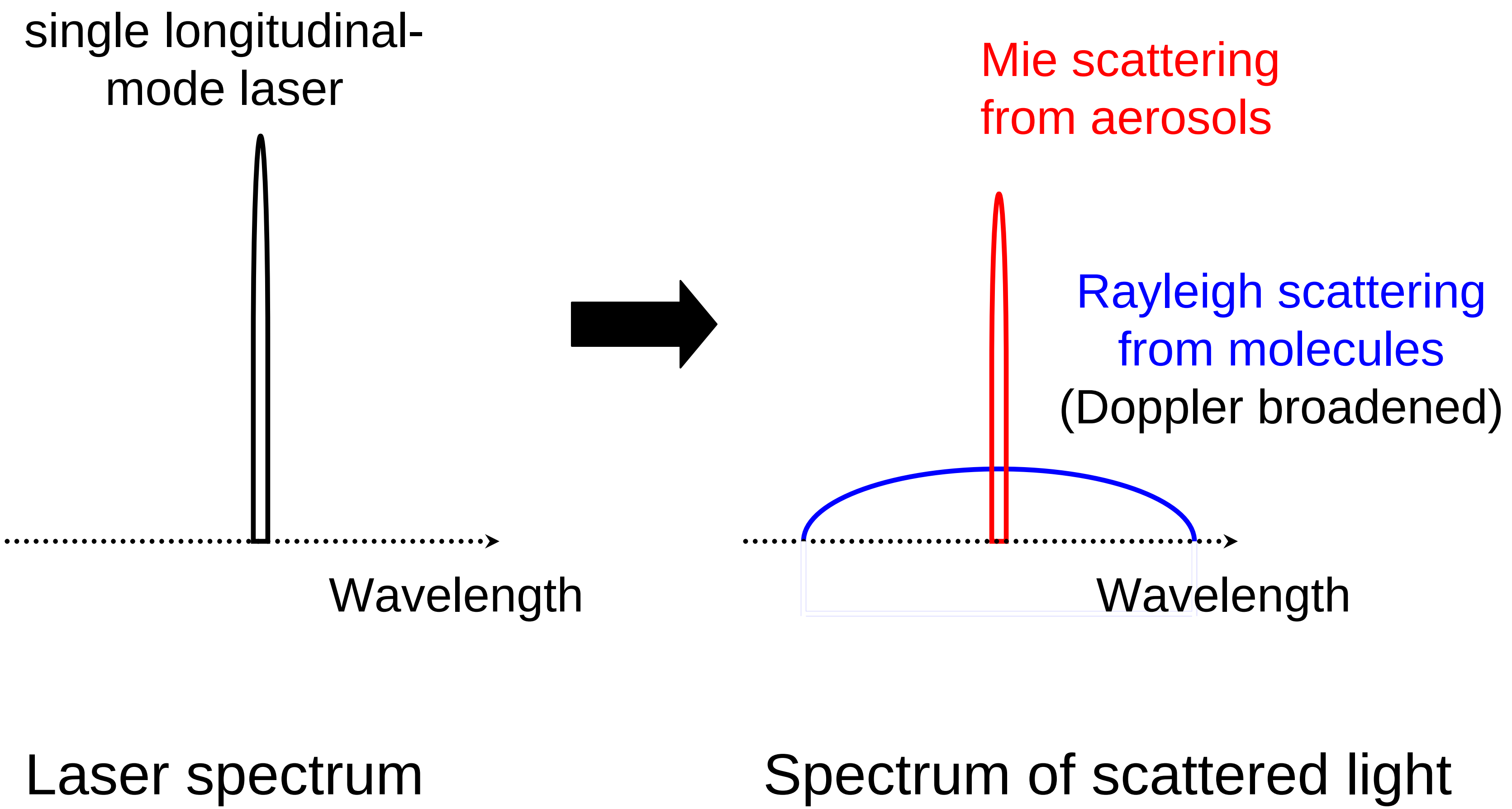
Concept of HSRL (or Raman lidar)



Backscatter signal from aerosols and molecules

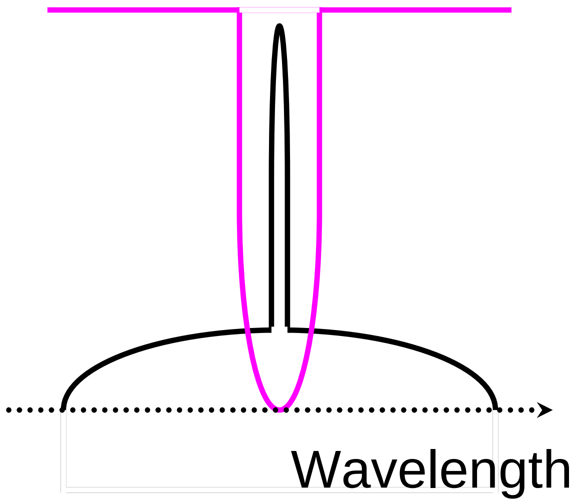
Rayleigh (or Raman) backscattering signal from molecules

HSRL method (1)

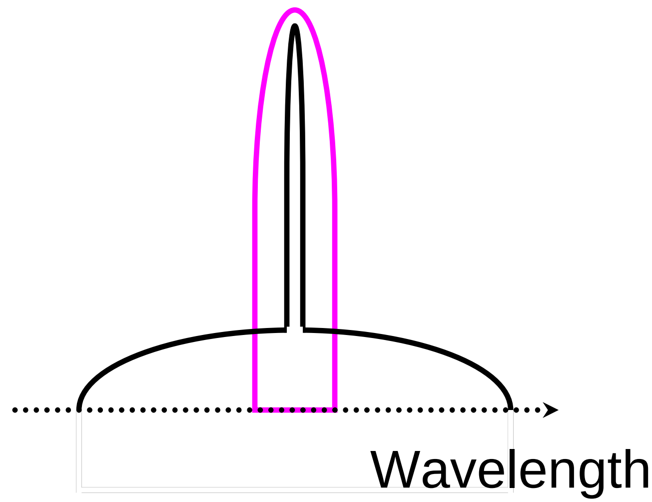


HSRL method (2)

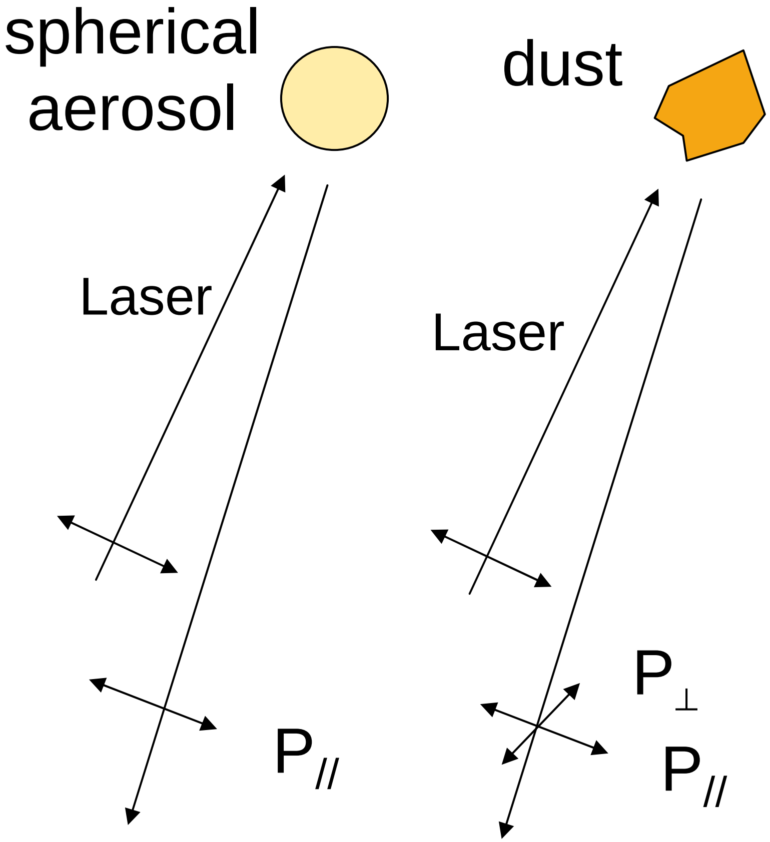
Molecular filter (Iodine)
(5 3 2 nm)

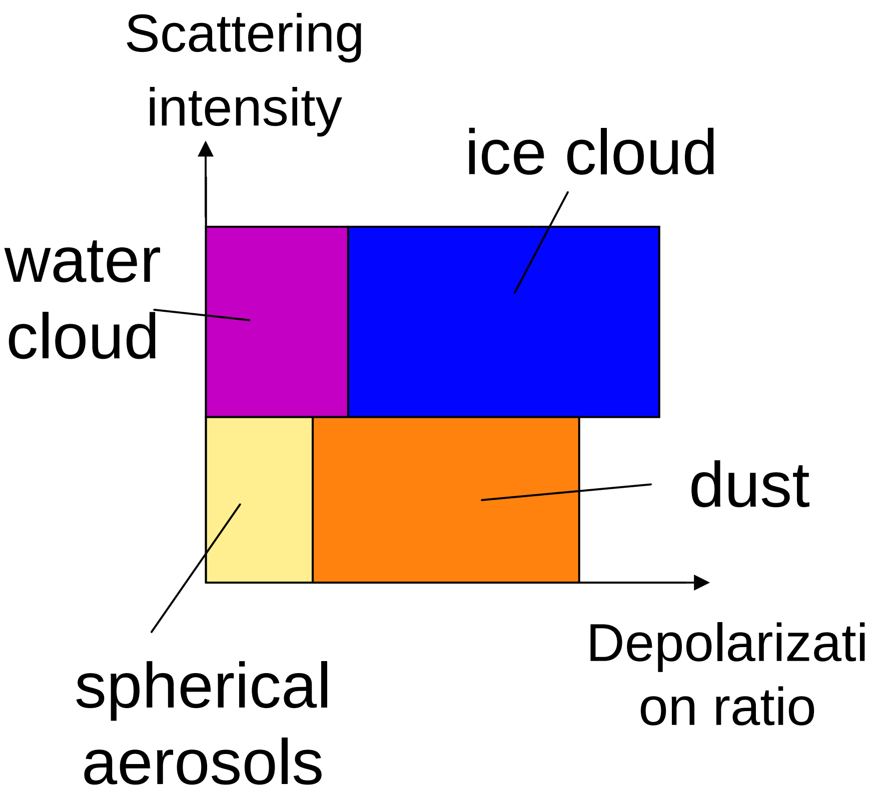


Fabry-Perot interferometer
(355nm)



Methods for separating Mie-scattering and Rayleigh-scattering signals





Volume depolarization ratio $\delta_{vol} = P_{\perp}/P_{//}$

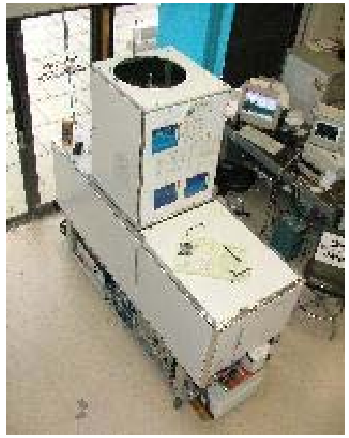
Depolarization ratio and target classification method

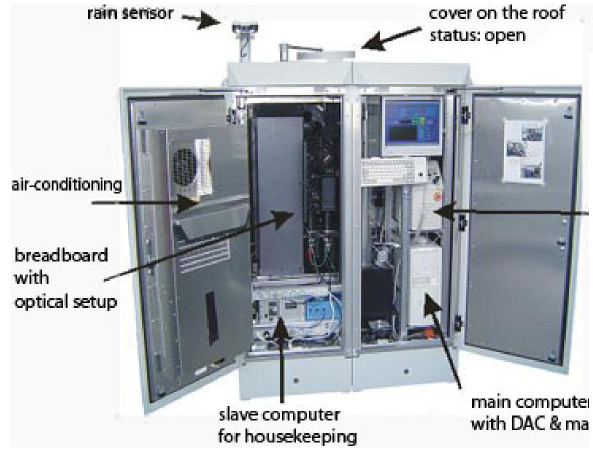
Particle depolarization ratio must be used in quantitative analysis.

Example of ground-based aerosol lidars

2α+3β+2δ

1α+1β+1δ





2α+3β

High-Spectral-Resolution lidar

Raman lidar

(1α+)2β+1δ

1β+1δ

1β

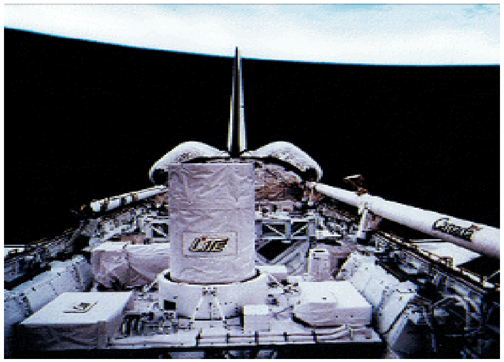
(Ceilometer)

Mie-scattering lidar

α :**extinction**
β :**backscatter**
δ :**depolarization**

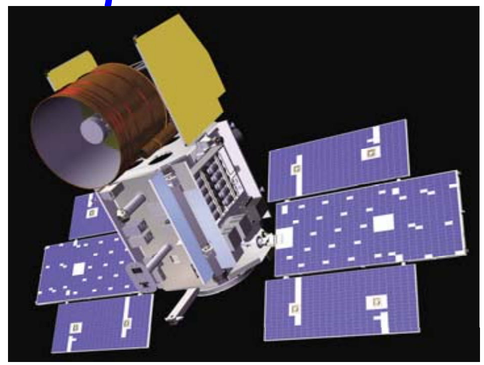
Space-borne lidars

3β Mie Lidar



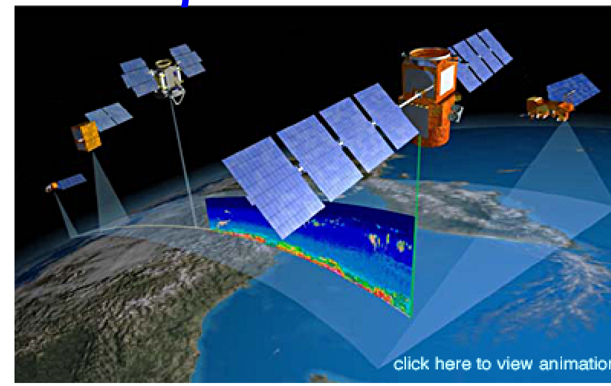
LITE/STS-64
(NASA,1994)

2β Mie Lidar



GLAS/ICESAT
(NASA, 2003-2009)

2β+1δ Mie Lidar



CALIOP/CALIPSO
(NASA, 2006--)

1α+1β HSRL

ALADIN/ADM-Aeolus
(ESA, 2013?)

1α+1β+1δ HSRL

ATLID/EarthCARE
(JAXA/ESA, 2015)

α **:extinction**
β **:backscatter**
δ **:depolarization**

Parameters derived from lidar data

Mie-scattering lidar

-Attenuated backscattering coefficient, volume depolarization ratio

-Backscattering coefficient (extinction coefficient) with an assumption of S_1, particle depolarization ratio

-Boundary layer height, cloud base (top) height

-(Estimates of the extinction coefficients of non-spherical and spherical aerosols (a method used by NIES))

Raman lidar

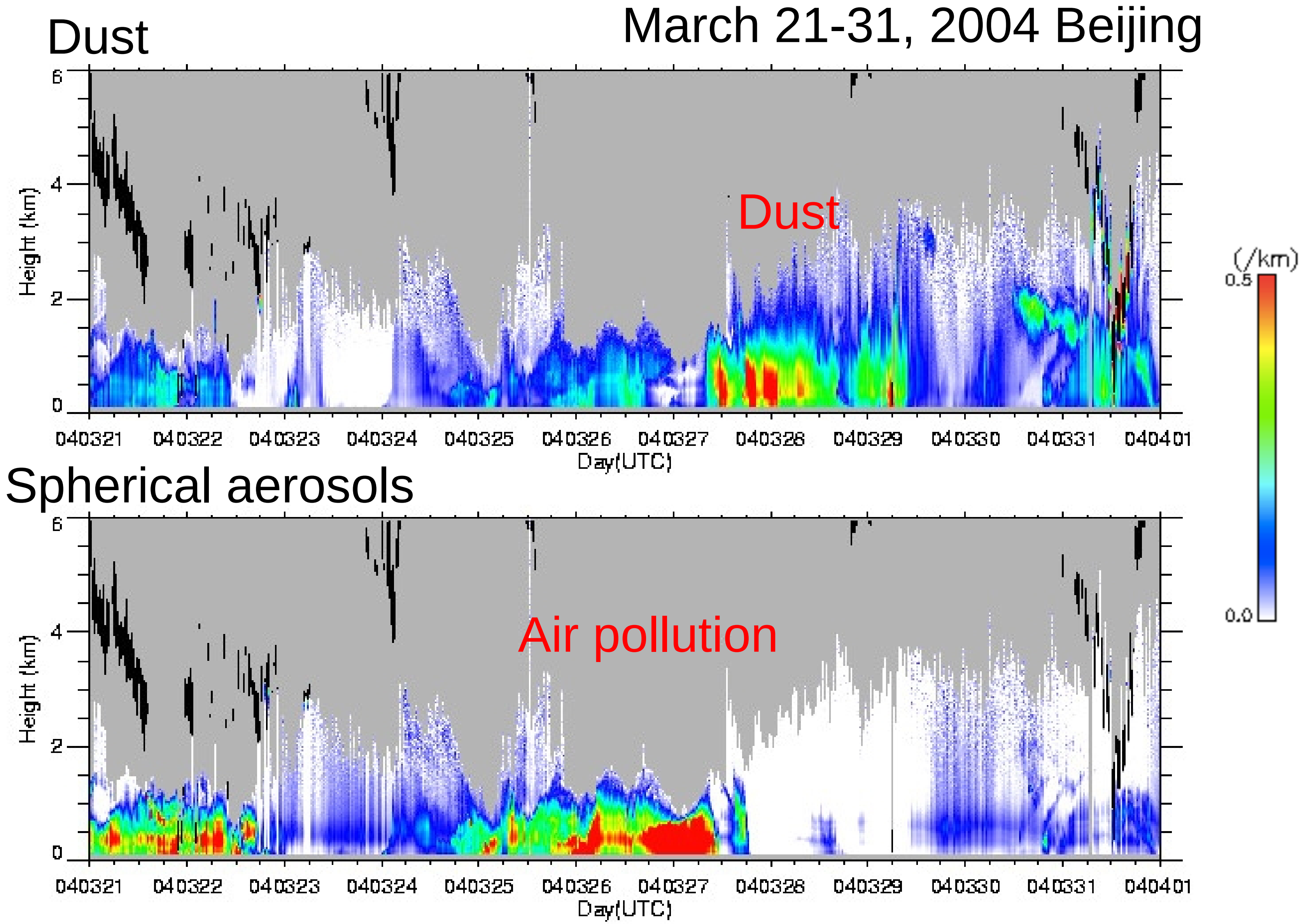
-Backscattering coefficient and extinction coefficient

-(2α+3β: Single scattering albedo and effective radius (Müller et al.)

-(Estimates of the extinction coefficients of aerosol components (dust, sulfate, BC, sea-salt,,) (a method used by NIES)

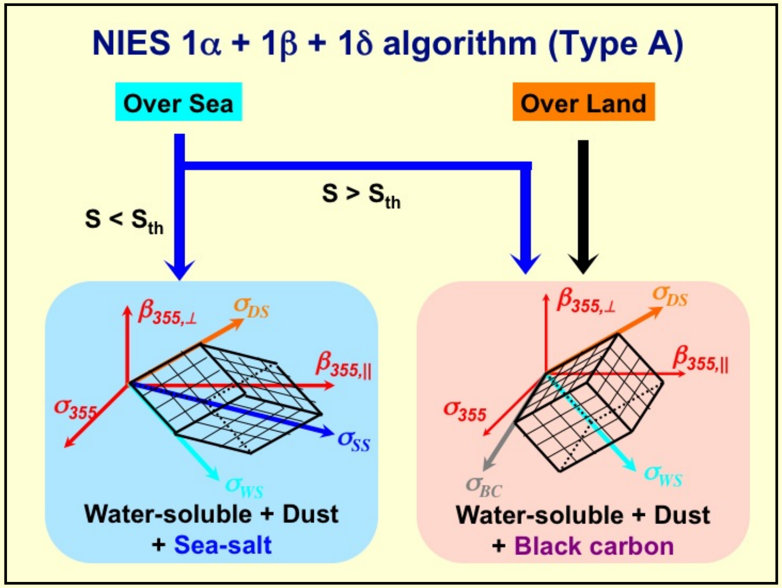
High-Spectral-Resolution lidar

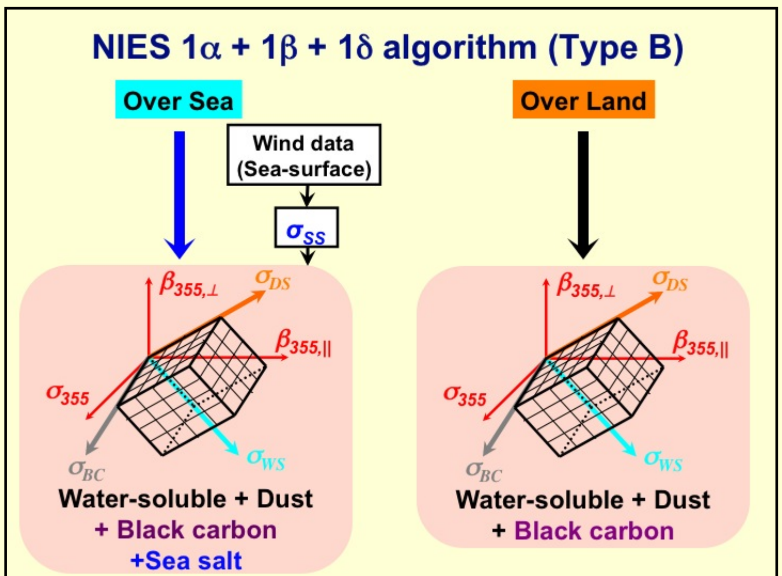
same as in Raman lidar with better SNR

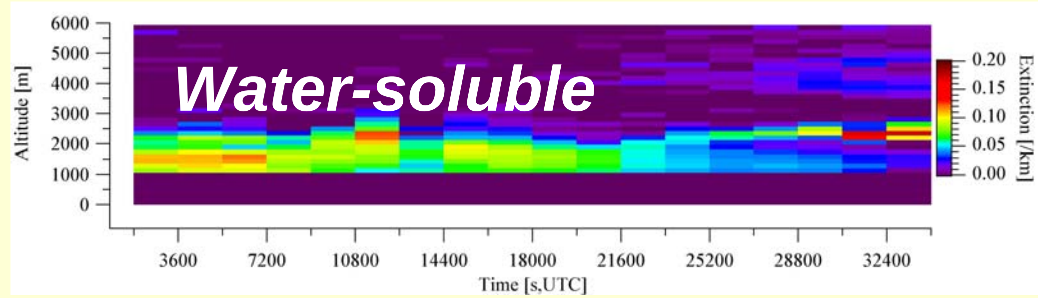


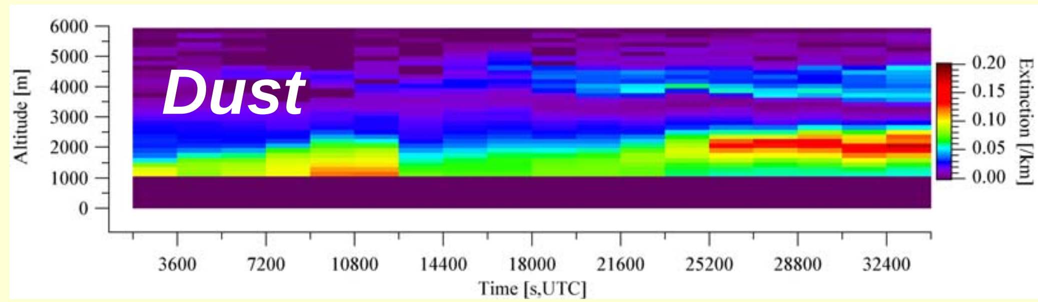
Method for estimating the extinction coefficients of dust and spherical aerosols using the depolarization ratio

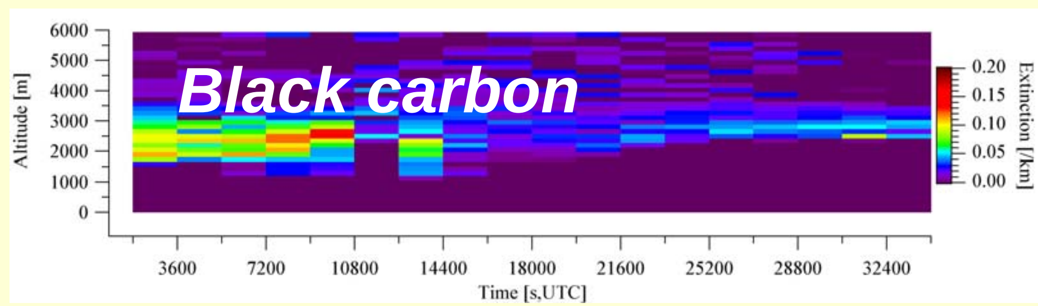
Demonstration of 1α + 1β + 1δ algorithm











- **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.

Problems in application to validation/assimilation of aerosol transport models

Mie-scattering lidar

-Attenuated backscattering coefficient (Good for space-borne lidar (e.g. Sekiyama et al.).) (The use of attenuated backscatter from ground-based lidar data is difficult because the model must reproduce the lower aerosols accurately.)

-Backscattering coefficient (extinction coefficient) with an assumption of S_1 (Reasonable. (Better with additional AOD data))

-Estimates of the extinction coefficients of non-spherical and spherical aerosols (a method used by NIES) (useful for analysis of aerosol events)

Raman lidar

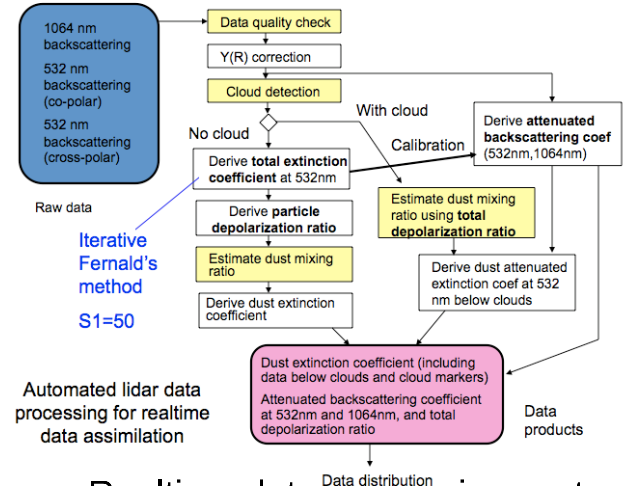
The signal-to-noise ratio (especially in the daytime) and the temporal resolution may not be sufficient.

High-Spectral-Resolution lidar

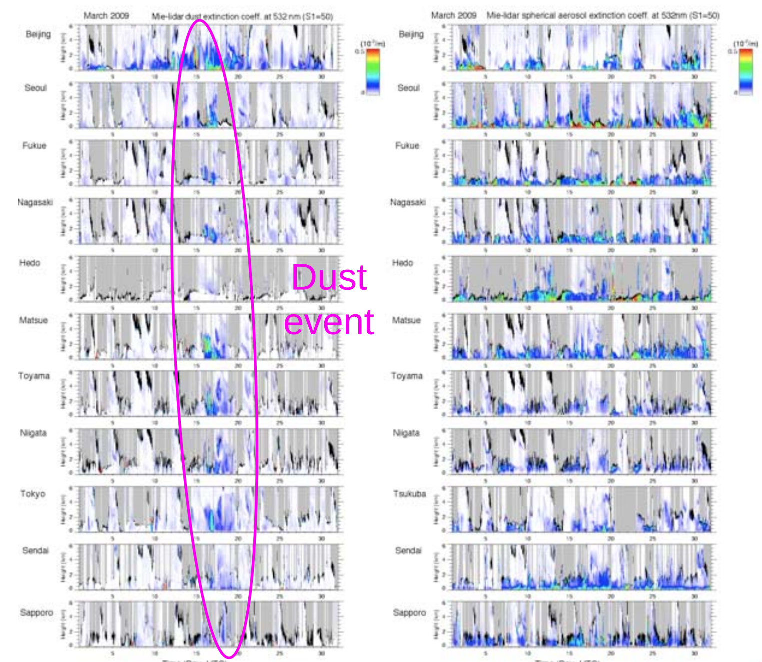
Ideal.

(NIES Lidar Network)

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

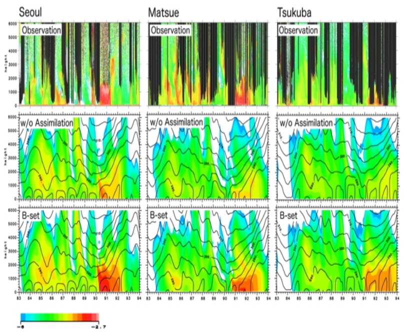


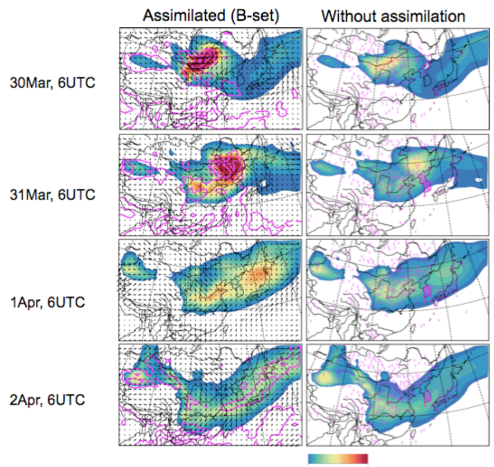
Realtime data processing system

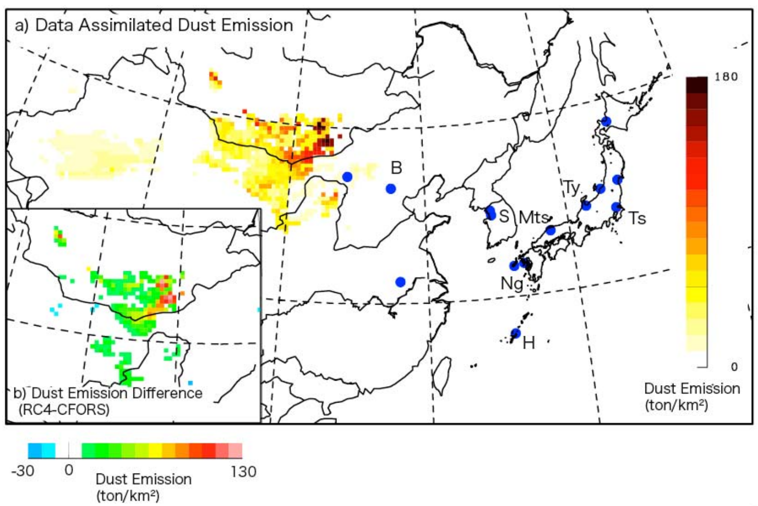


Extinction coefficient estimates of dust (left) and spherical aerosols (right) for primary locations (April 2009).

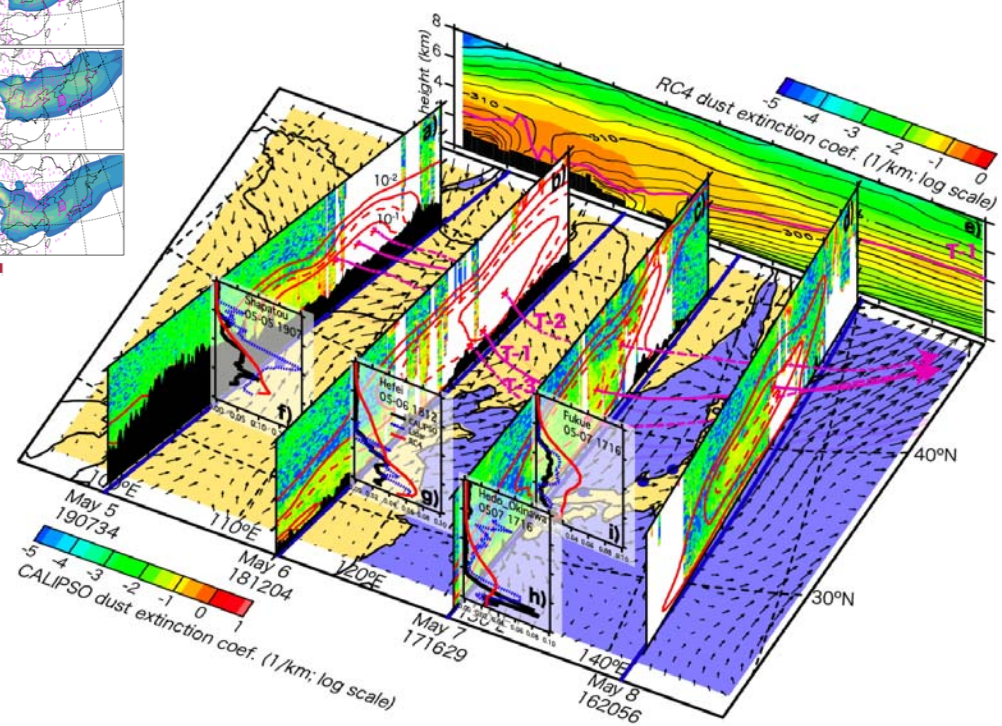
4D-Var data assimilation system for Asian dust







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 (Uno et al. 2008, Hara et al. 2009)

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

Conclusion

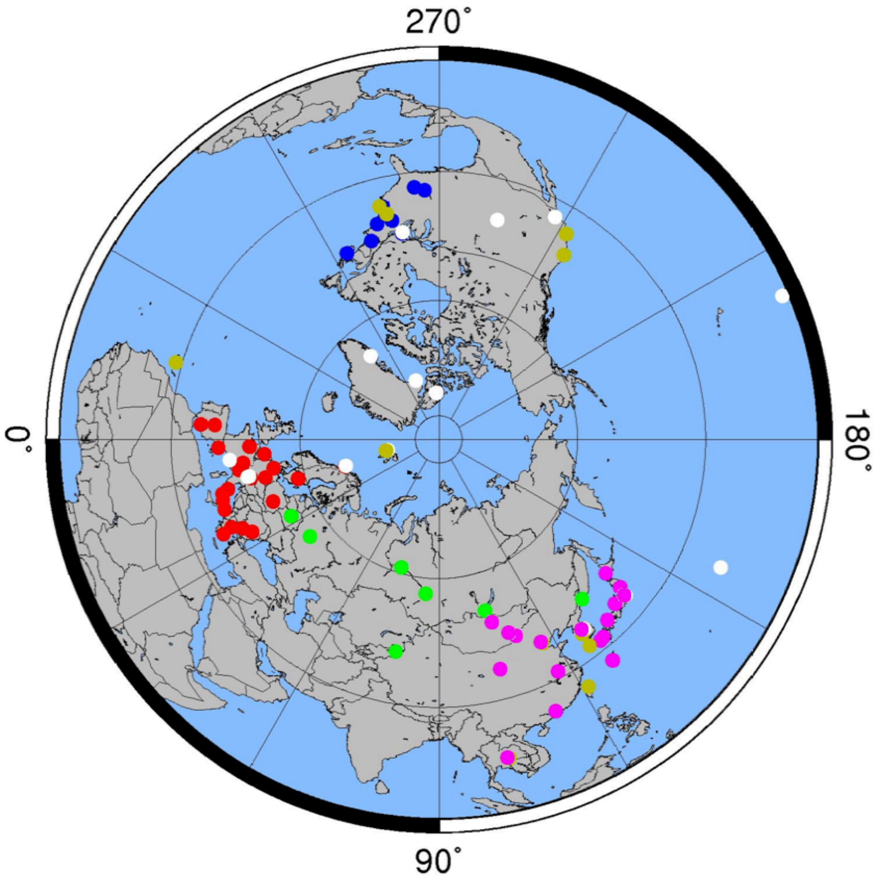
-For ground-based Mie-scattering lidars, it is reasonable to use the backscatter coefficient (or extinction coefficient) retrieval (with constant S_1 assumption). It is better to use additional AOD data.

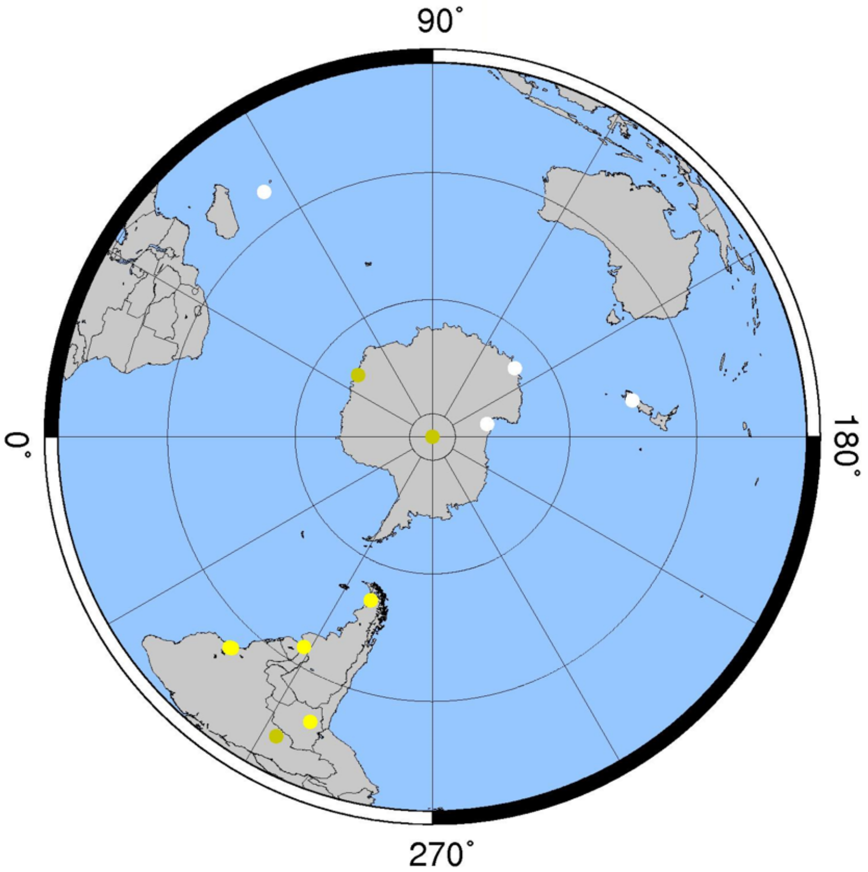
-It is not easy to use the attenuated backscattering coefficient for ground-based lidar, because it is difficult to reproduce aerosols in lower altitudes with models.

-High temporal resolution extinction and backscattering coefficient data will be available from HSRLs.

-Extinction coefficient estimates for aerosol components (dust, sea salt, sulfate, BC) would be useful for event analysis.

GAW Aerosol Lidar Observation Network (GALION)





Thank you