Aerosol typing and space-borne lidars – potentials and limitations

Athena Augusta Floutsi, Holger Baars, Moritz Haarig, and Ulla Wandinger

01- Space-borne lidar missions, instruments and science
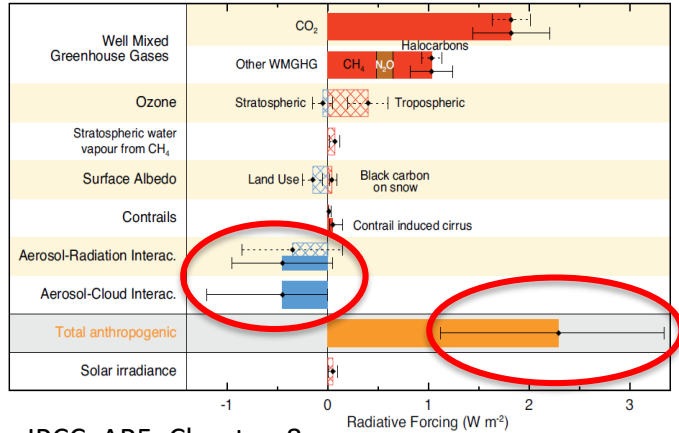
Thursday, 30 June 2022, 12:00

01_P04

Aerosol typing – why?

IPCC, AR5, Chapter 8

Still large uncertainties attributable to aerosol!

Different lidars require different typing schemes

- **Identification** of the main aerosol sources
- **Quantification** of the direct and indirect aerosol radiative effects & closure studies
- **Separation** between natural and anthropogenic radiative effect
- **Improvement** of measurement retrievals and modelling
- Satellite **validation** and **harmonisation** of datasets
- Data assimilation

	Ground-based	**CALIOP**	**ALADIN**	**ATLID**
Extinction	✓		✓	✓
Backscatter	✓ ✓	✓	✓ ✓	✓ ✓
Lidar ratio	✓		✓	✓
Depolarization ratio	✓	✓		✓
λ	355, 532, 1064 nm	532, 1064 nm	355 nm	355 nm

TROPOS

Aerosol typing – how?
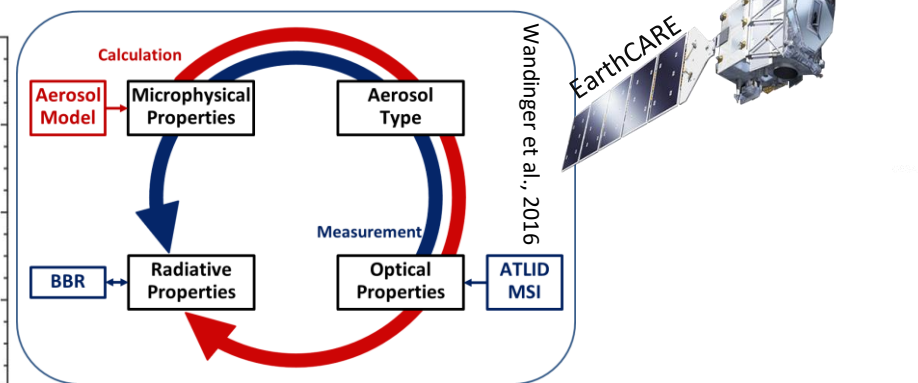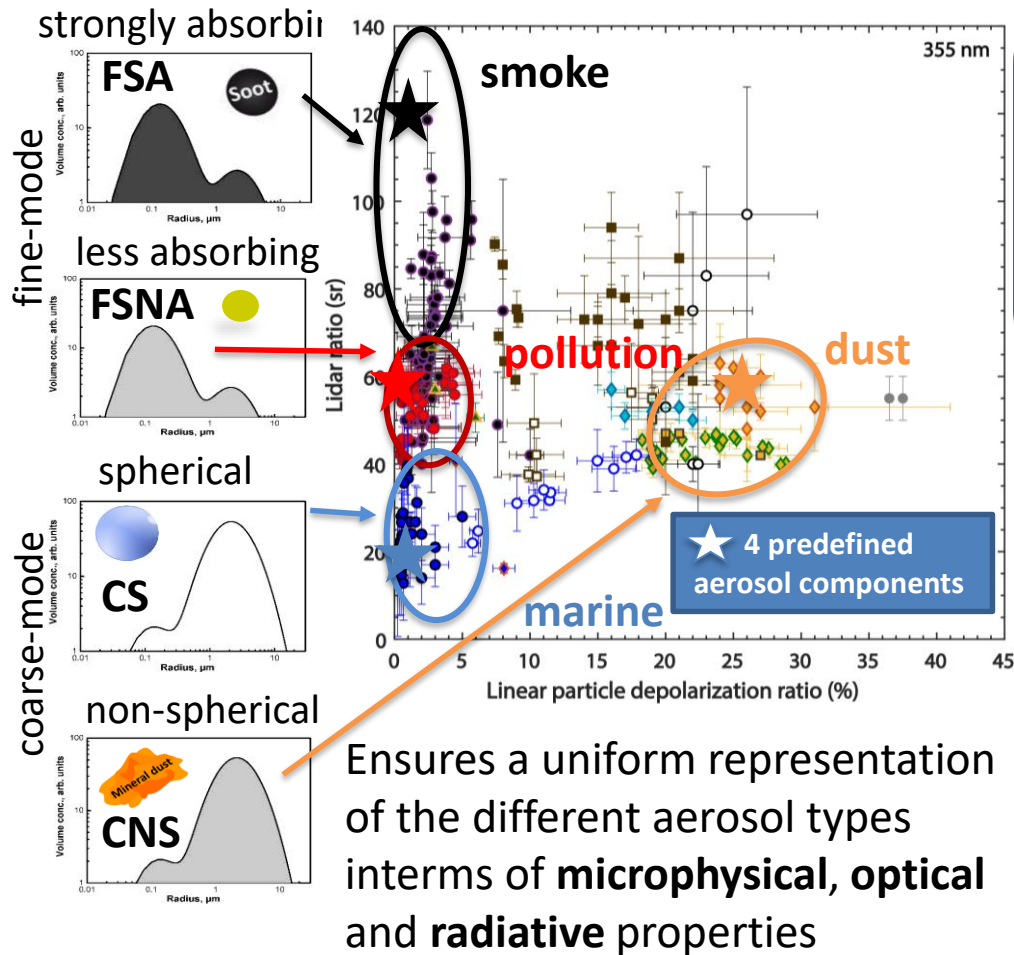
Intensive optical parameters

- Lidar ratio: S (355, 532 nm) (Ground-based + ALADIN + ATLID)
  size, shape, refractive index

- Depolarization ratio: δ (355, 532 nm) (GB + CALIOP+ATLID)
  shape, (size, refractive index)

- Ångström exponents (GB + CALIOP)
  backscatter-related: $\mathring{a}$(532/1064), $\mathring{a}$(355/532)
  extinction-related: $\mathring{a}$(355/532)
  size, (refractive index)
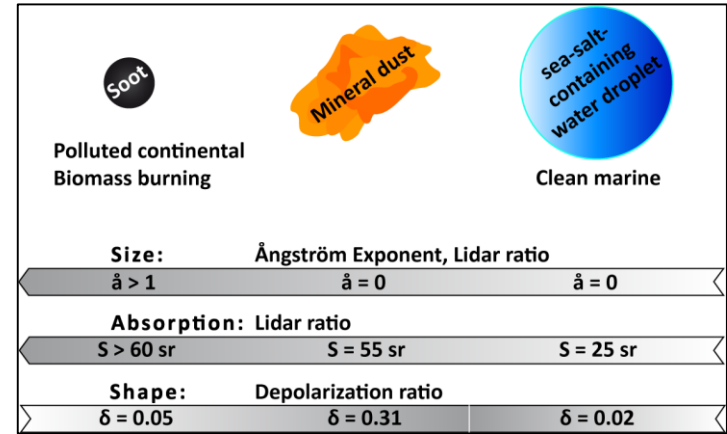
Tesche, PhD thesis, 2011

	Ground-based	**CALIOP**	**ALADIN**	**ATLID**
Methods	Threshold-based Cluster analysis Artificial Neural Networks	Decision tree	?	Hybrid-End-To-End Classification Model
	Sasano and Browell, 1989 …	Omar et al., 2009 Kim et al., 2018		Wandinger et al., 2016

TROPOS

Hybrid End-To-End Aerosol Classification – HETEAC

strongly absorbing

FSA — Soot

fine-mode

less absorbing

FSNA

coarse-mode

spherical

CS

non-spherical

CNS — Mineral dust

smoke

pollution

dust

marine

355 nm

Lidar ratio (sr)

Linear particle depolarization ratio (%)

★ 4 predefined aerosol components

Ensures a uniform representation of the different aerosol types interms of **microphysical**, **optical** and **radiative** properties

Wandinger et al., 2016

EarthCARE

Calculation

Aerosol Model → Microphysical Properties → Aerosol Type

Measurement

BBR ← Radiative Properties ← Optical Properties ← ATLID MSI

New OEM-based typing scheme

Decision tree → First guess of state vector x_a

$\begin{bmatrix} x_{FSA} \\ x_{CS} \\ x_{FSNA} \\ x_{CNS} \end{bmatrix}$

Covariance matrix S_a

$\begin{bmatrix} \sigma^2_{FSA} & 0 & 0 & 0 \\ 0 & \sigma^2_{CS} & 0 & 0 \\ 0 & 0 & \sigma^2_{FSNA} & 0 \\ 0 & 0 & 0 & \sigma^2_{CNS} \end{bmatrix}$

Lidar measurements **y** Measurement errors S_ε

Optimal Estimation Method (OEM)

Forward model **F(x)** Jacobian **K**   Cost function J

Constraints on the relative volume contribution per aerosol component

A priori information $\alpha^*, \beta^*, \delta^*$

Retrieved optimal state vector $\hat{x}$ & Covariance matrix of the optimal state vector $\hat{S}$

Flexible + consistent with HETEAC

Cal/Val

Aeolus & aerosol typing

- ALADIN emits **circular-polarized** light but detects the **co-polar** component of the backscattered light only

- **Cross-polar** component missing

- **Transformation** of ground-based backscatter to Aeolus co-polar backscatter

Aeolus

Signal loss in case of polarizing particles!

$$\delta_{lin} = \frac{\beta_\perp}{\beta_\parallel}$$
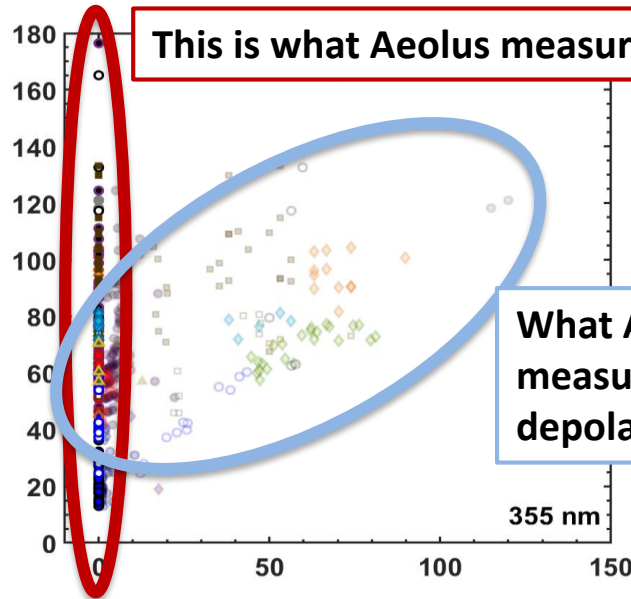
$$\delta_{circ} = \frac{2\delta_{lin}}{1-\delta_{lin}}$$

$$> \delta_{lin}$$

$$\beta_{co} = \frac{\beta_{tot}}{(\delta_{circ}+1)}$$

underestimated

$$S_{co} = S(\delta_{circ}+1)$$

overestimated

This is what Aeolus measures

Aerosol typing difficult for Aeolus – additional information required

What Aeolus could have measured if it had depolarization capabilities

355 nm
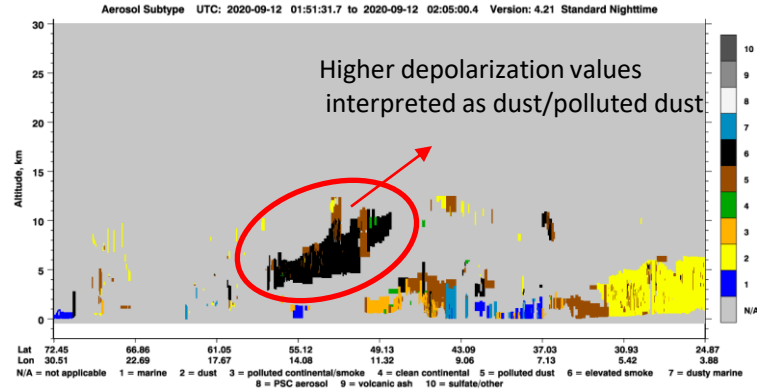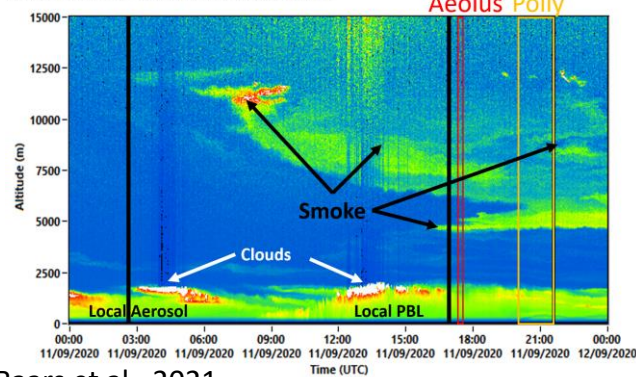
TROPOS

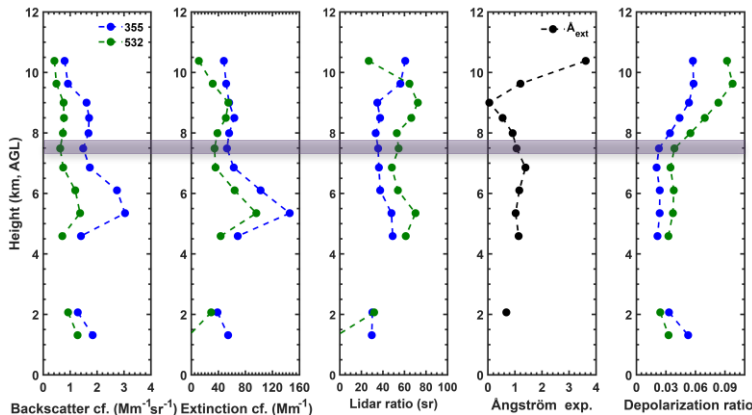# Californian Smoke Over Central Europe – 11/09/2020
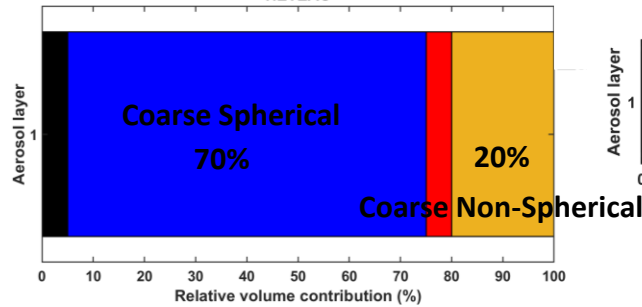
Ground-based

CALIPSO
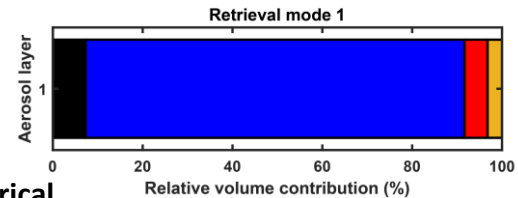
AEOLUS
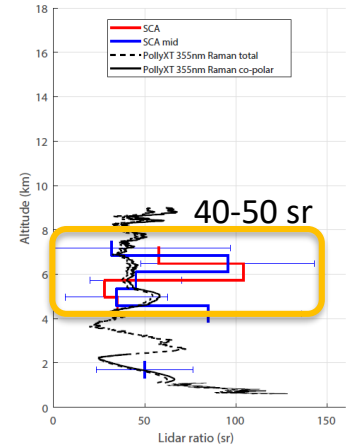
Baars et al., 2021

Wavelength dependency: footprint of aged smoke

EarthCARE - HETEAC

preliminary results

OEM typing scheme

Coarse, spherical aerosol component dominates in both typing schemes (HETEAC and OEM)