EARLINET and CALIPSO

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Outline

- Motivation
- EARLINET activities during the CALIPSO mission
- Comparison of CALIPSO Level 1 data
- ESA-CALIPSO study (Level 2 data)
- Multiple-scattering effects
- Volcanic aerosol layers
- Conclusion and outlook

Motivation

EARLINET offers a unique opportunity for the validation and full exploitation of the CALIPSO mission.

- EARLINET provides long-term, quality-assured aerosol data.
- Because of its geographical distribution over Europe, EARLINET allows us to investigate a large variety of different aerosol situations with respect to layering, aerosol type, mixing state, and properties in the free troposphere and the local planetary boundary layer
  [e.g., Ansmann et al. 2003; Matthias et al., 2004; Mattis et al., 2004, 2009; Pappalardo et al., 2004a; Mona et al., 2006; Balis et al., 2003; Wandinger et al., 2004; Amiridis et al., 2005; De Tomasi et al., 2006, Papayannis et al., 2005, 2008, etc.].
- With a network on a continental scale it is also possible to study the representativeness of the limited number of satellite lidar cross sections along an orbit against long-term network observations.
- Direct validation of backscatter at 532 and 1064 nm, extinction at 532 nm and depolarization at 532 nm is possible from many EARLINET sites.

EARLINET – CALIPSO activities

- EARLINET started correlative measurements for CALIPSO on 14 June 2006, i.e. at the beginning of the CALIPSO operation.
- A strategy for correlative measurements has been defined on the base of the analysis of the ground-track data provided by NASA.
- While the majority of EARLINET stations contributed on a voluntary basis to this measurement program in the first two years of the mission, a dedicated ESA activity has supported correlative EARLINET-CALIPSO observations at 16 selected EARLINET stations for period of 18 months from May 2008 – October 2009.
- Data exploitation within this study (still ongoing) aims at a long-term aerosol and cloud data base providing type-dependent wavelength conversion factors as well as EARLINET-CALIPSO intercomparison data based on Level 2 profile and layer products.

EARLINET – CALIPSO publications

Pappalardo G., U. Wandinger, L. Mona, A. Hiebsch, I. Mattis, A. Amodeo, A. Ansmann, P. Seifert, H. Linné, A. Apituley, A. L. Arboledas, D. Balis, A. Chaikovsky, G. D' Amico, F. De Tomasi, V. Freudenthaler, E. Giannakaki, A. Giunta, I. Grigorov, M. Iarlori, F. Madonna, R-E. Mamouri, L. Nasti, A. Papayannis, A. Pietruczuk, M. Pujadas, V. Rizi, F. Rocadenbosch, F. Russo, F. Schnell, N. Spinelli, X. Wang and M. Wiegner, **EARLINET correlative measurements for CALIPSO: First intercomparison results** *J. Geophys. Res.,* 115, D00H19, doi:10.1029/2009JD012147, 2010

Mona L., G. Pappalardo, A. Amodeo, G. D'Amico, F. Madonna, A. Boselli, A. Giunta, F. Russo, V. Cuomo, **One year of CNR-IMAA multi-wavelength Raman lidar measurements in correspondence of CALIPSO overpass: Level 1 products comparison** *Atmospheric Chemistry and Physics,* 9, 7213-7228, 2009

Wandinger, U., M. Tesche, P. Seifert, A. Ansmann, D. Müller, D. Althausen, **Size matters: Influence of multiple scattering on CALIPSO light-extinction profiling in desert dust**, *Geophys. Res. Lett*., 37, L10801, doi:10.1029/2010GL042815, 2010

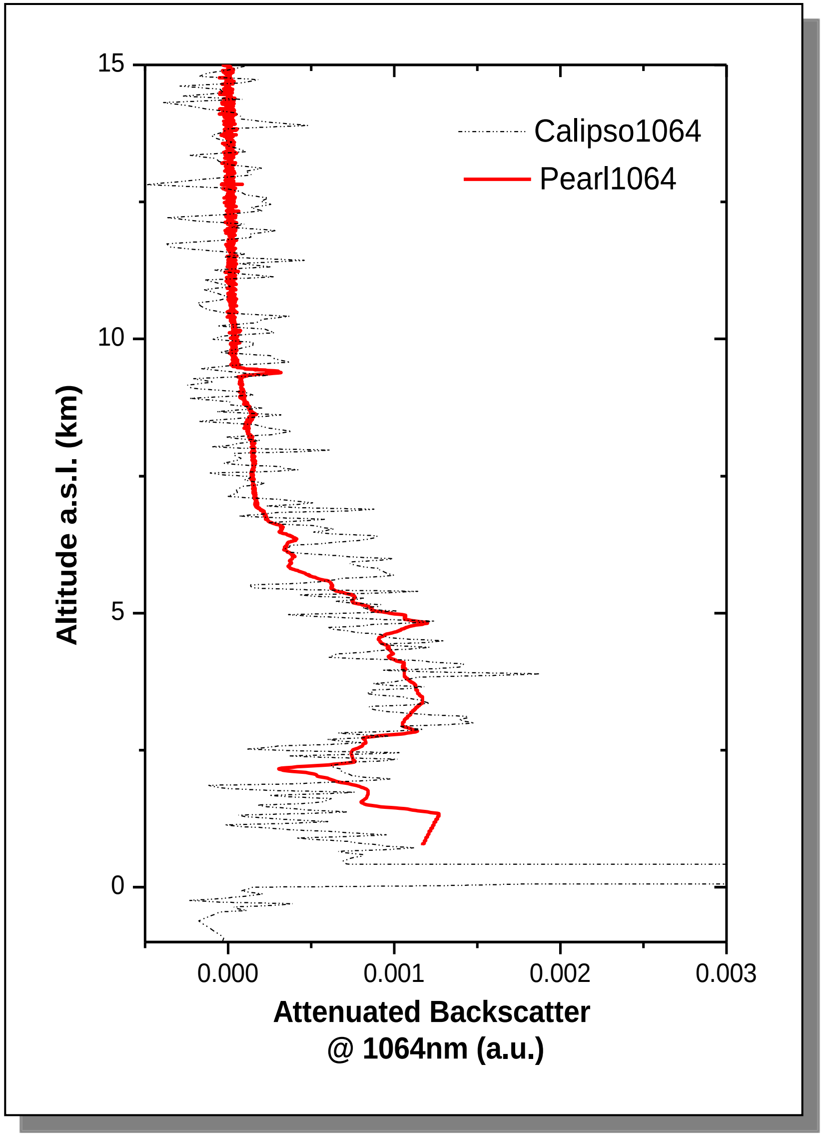
Mamouri R.E., V. Amiridis, A. Papayannis, E. Giannakaki, G. Tsaknakis, and D.S. Balis, **Validation of CALIPSO space-borne derived aerosol vertical structures using a ground-based lidar in Athens, Greece**, *Atmospheric Measurement Techniques*, 2, 513-522, 2009

Level 1 data comparison

- check unprocessed CALIPSO data (level 1 = attenuated backscatter) for biases

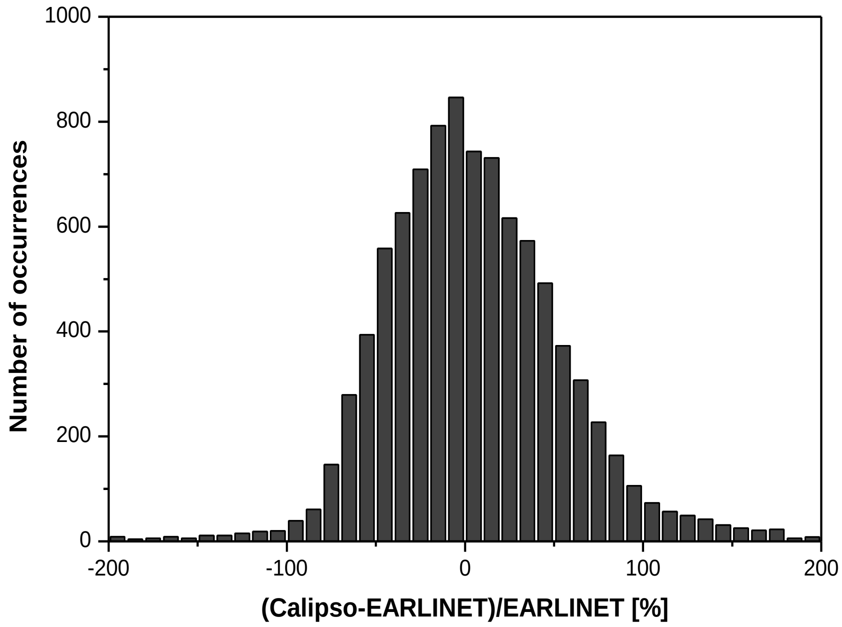
- comparison possible without assumptions, if independent extinction and backscatter profiles are available [Mona et al., ACP 2009]

- correlation in time and space has to be considered (e.g. shift temporal averaging period according to distance of overpass and horizontal wind speed)



Level 1 data comparison

(CALIPSO – EARLINET)/EARLINET (%) for 46 selected cloud-free cases
data from Napoli, Leipzig, Potenza, Madrid, and Barcelona
altitude range 1–10 km asl (within 100 km, nighttime only)



relative mean difference: 4.6%,
relative standard deviation: 50%

[Pappalardo et al., JGR 2010]

ESA–EARLINET activity

"Aerosols and Clouds: Long-term Database from Spaceborne Lidar Measurements"

Intensive observational period: Mayh 2008 – October 2010, 16 stations

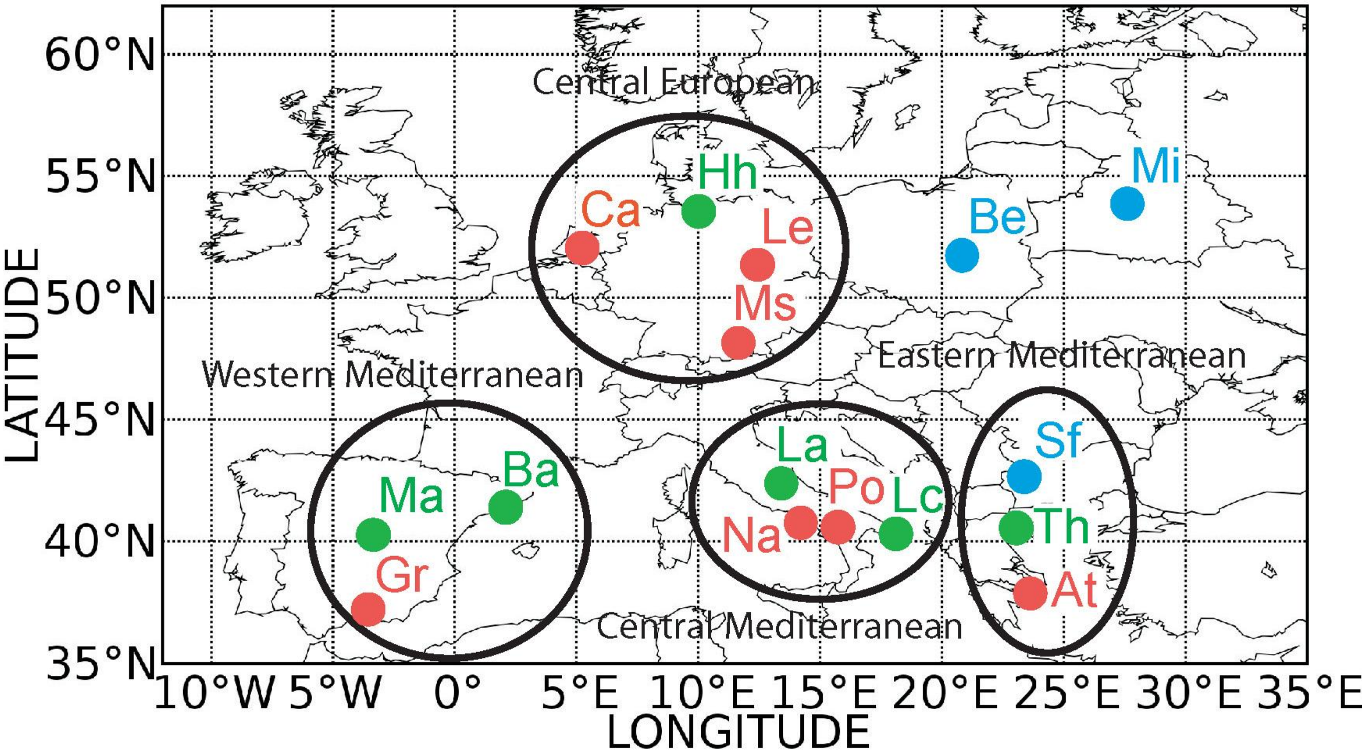
Objectives

- provide a tool for homogenizing long-term space-borne observations conducted with different lidar instruments, operating at different wavelengths, on various platforms
- study the representativeness of the limited number of satellite lidar cross sections along an orbit against long-term lidar network observations on a continental scale

Specific tasks

⇨ develop common aerosol classification schemes
⇨ characterize the optical properties (lidar ratio, depolarization ratio, Ångström exponents) of major aerosol types
⇨ derive wavelength conversion schemes to harmonize space-borne observations
⇨ establish statistically significant datasets based on a correlative measurement strategy for verification/validation purposes and representativeness studies

ESA–EARLINET network measurements



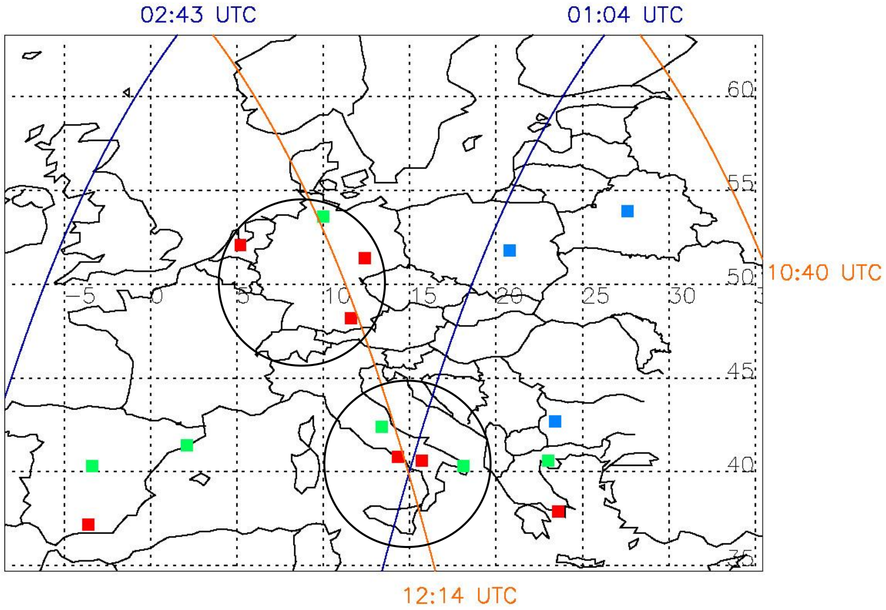
- high-performance stations = extinction and backscatter at 355 + 532 nm (+ backscatter at 1064 nm + depolarization)
- contributing stations = extinction and backscatter at one wavelength

Observational Strategy

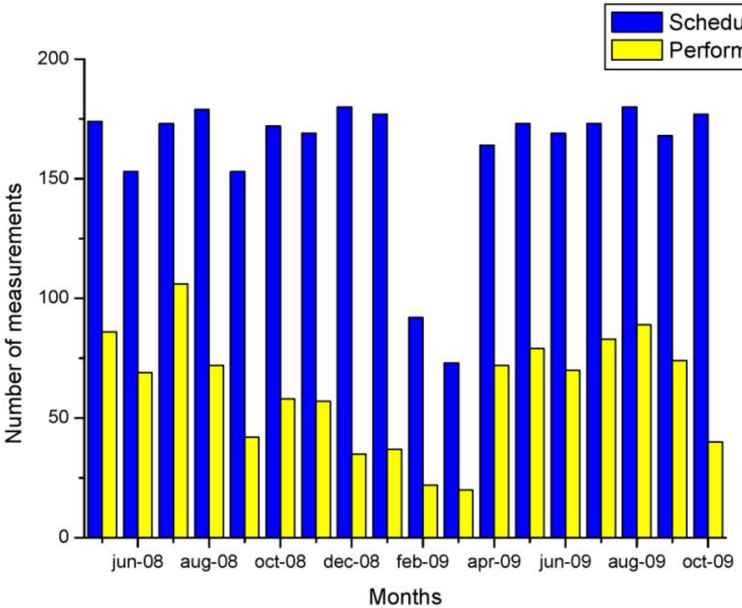
CASE A:
Measurements within 100 km of the overpass

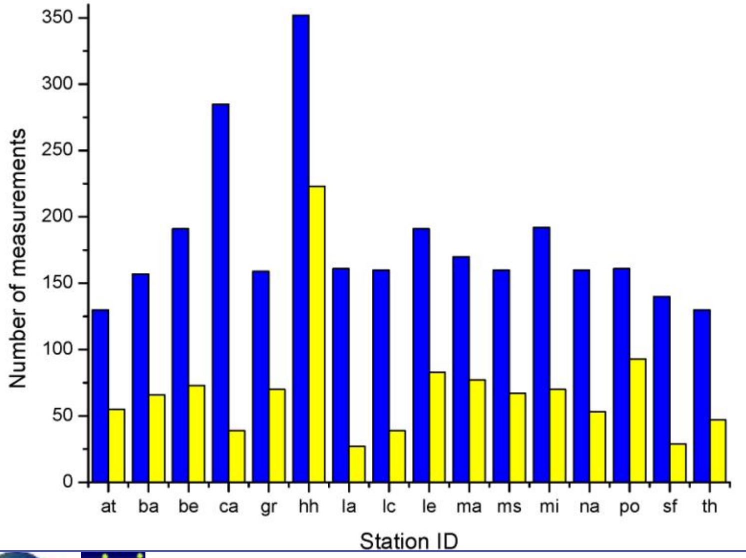
CASE B:
Simultaneous measurements of more than one station within the same cluster, when one station has a CASE A overpass

CASE C:
Measurements during special events (e.g., large Saharan dust intrusions, forest-fires smoke plumes, volcanic eruptions)



18-months measurement statistics

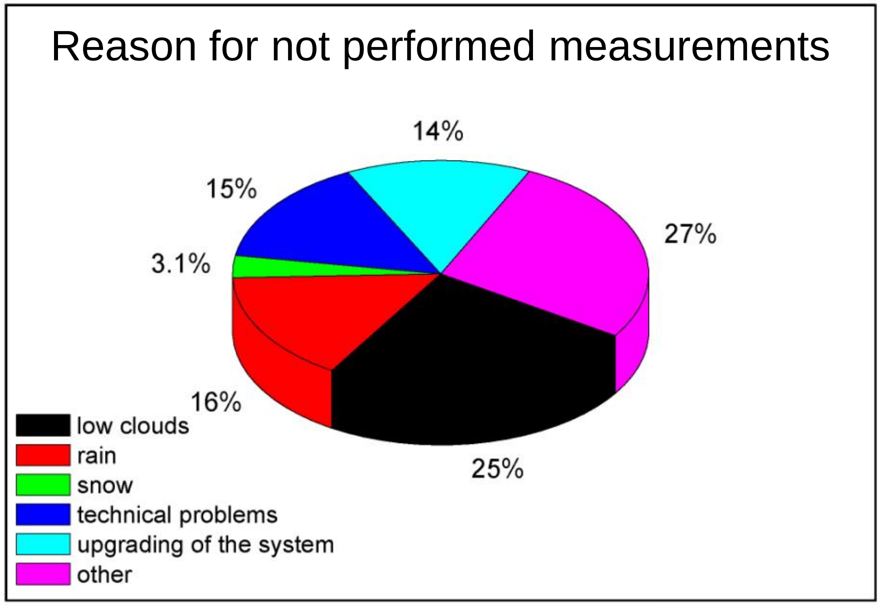




CASE A+B: 1111

CASE C: 276

TOTAL: 1367



ESA–EARLINET study approach

→ 18 months of correlative measurements of EARLINET and CALIPSO

→ evaluation of the geometrical and optical properties of aerosols and clouds

→ rely on CALIPSO aerosol and cloud classification schemes

- **Marine aerosol**
- **Mineral dust**
- **Polluted continental aerosol**
- **Clean continental aerosol**
- **Biomass-burning smoke**

+ dependence on source region
+ mixtures of different types
+ processing/aging during transport
+ humidity

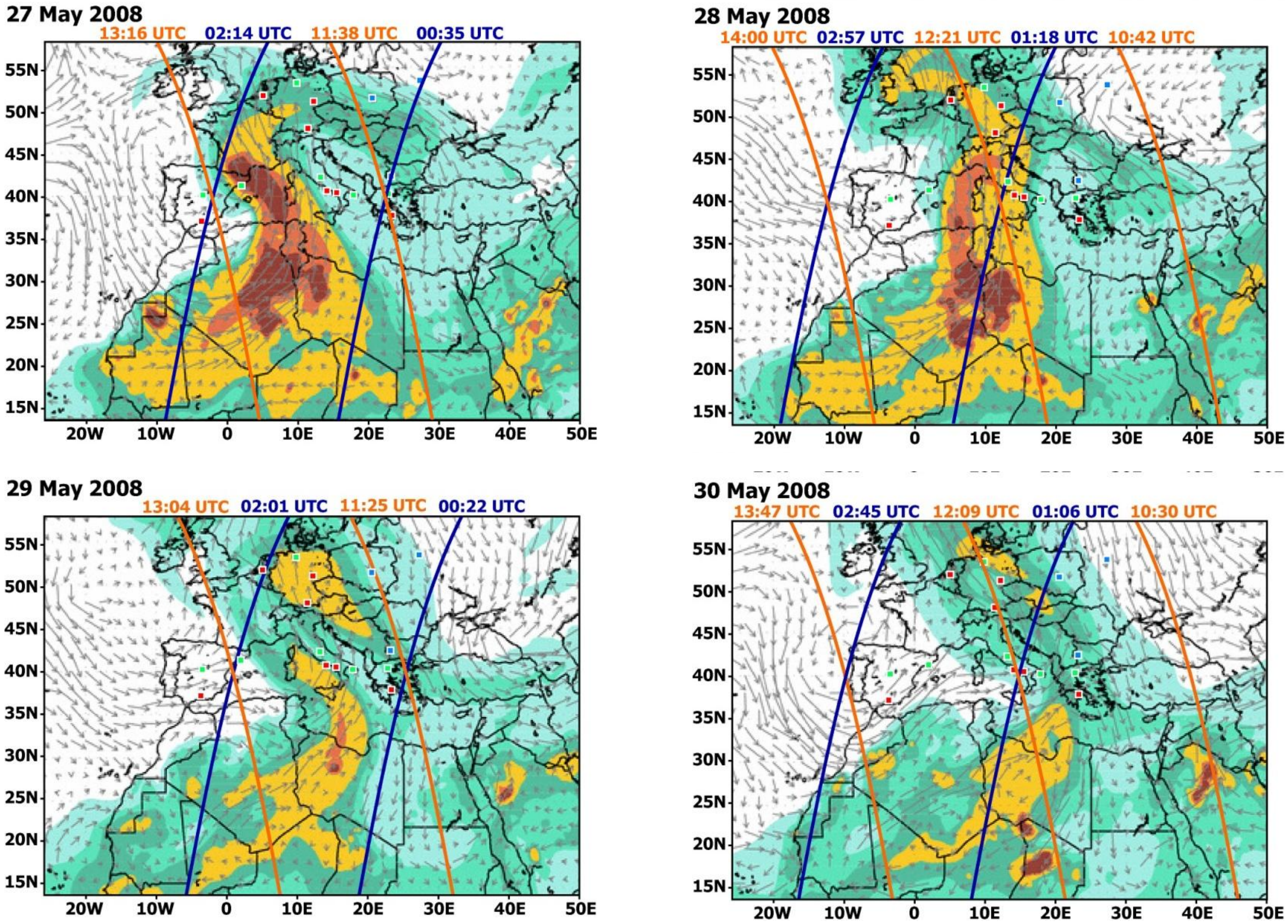
- **Ice clouds**
- **Water clouds**
- **Mixed-phase clouds**

→ representativeness study

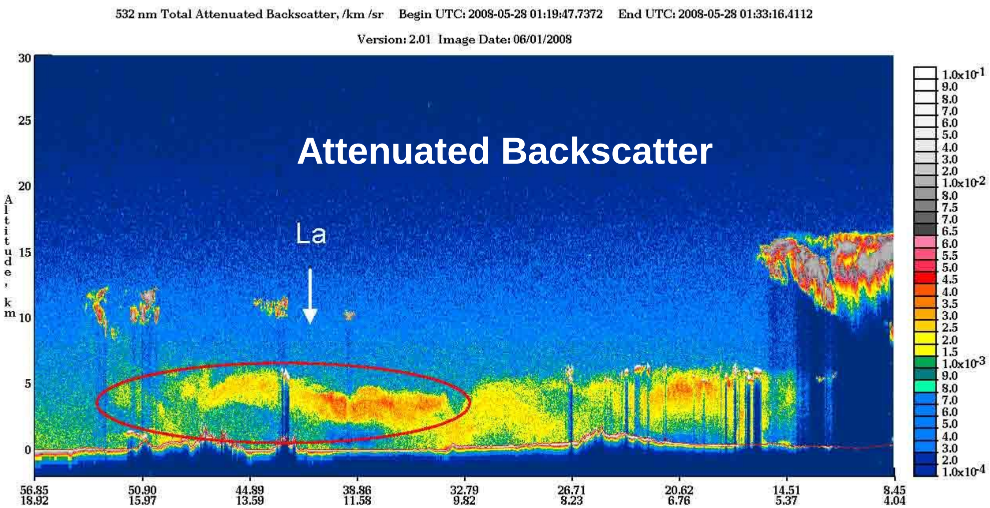
→ results stored in a long-term database for further use and extension during

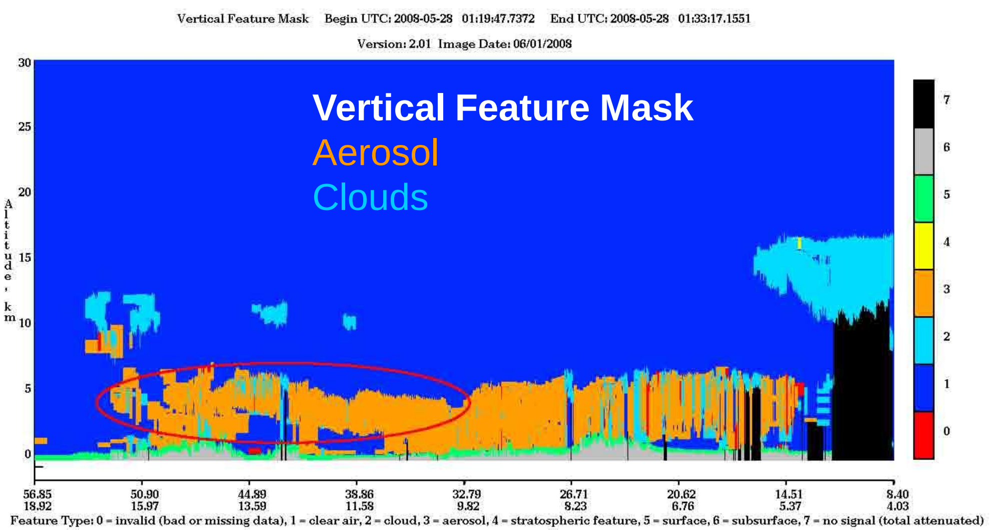
→ can be continued during future missions

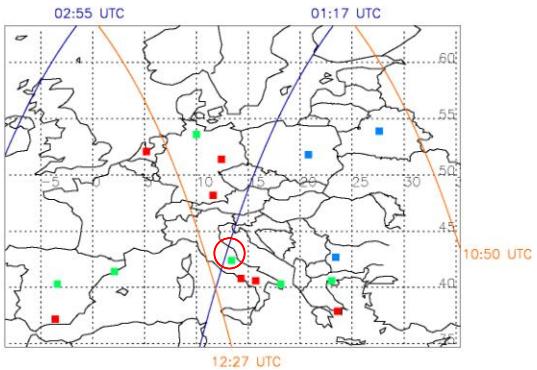
Case study: Saharan dust outbreak, 27-30 May 2009

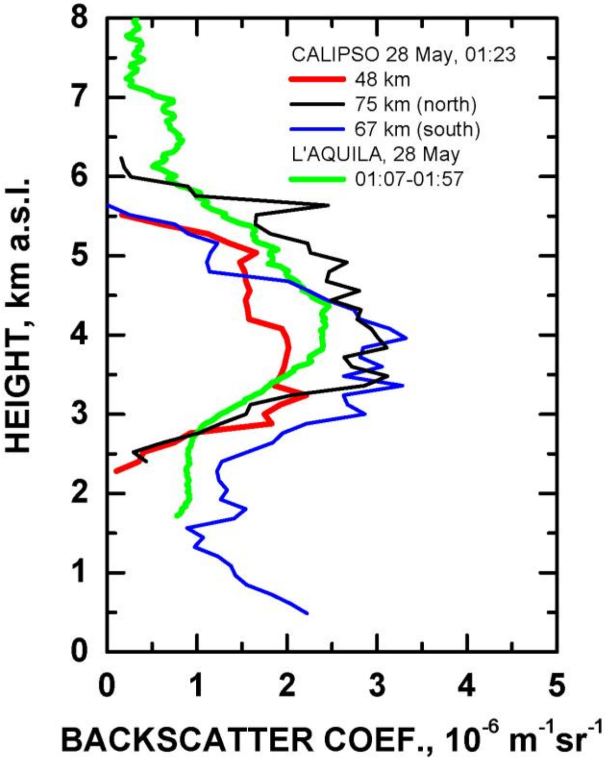


L2 product comparison: 28 May 2008, night

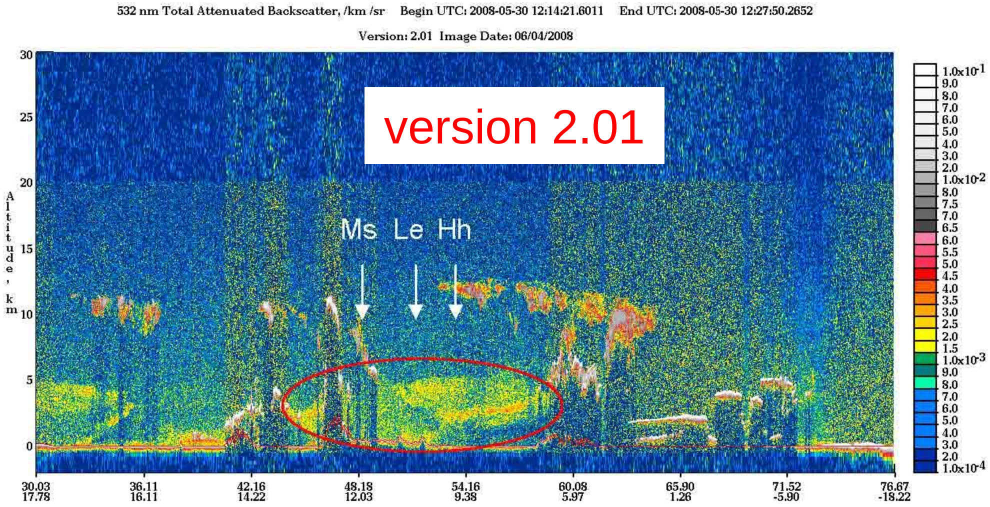


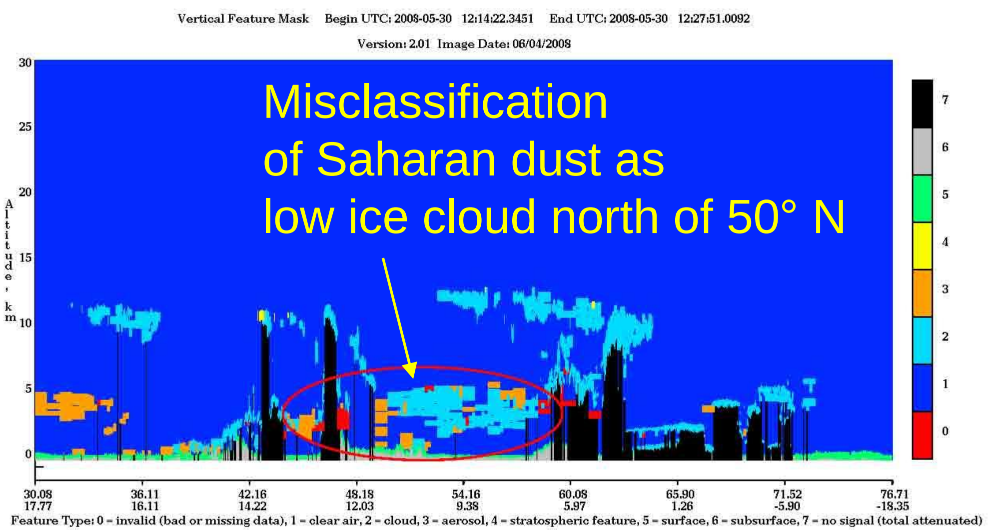


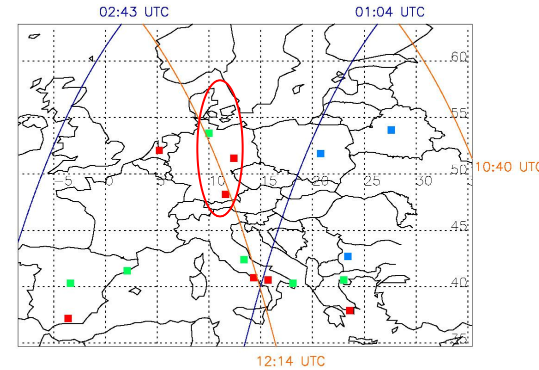


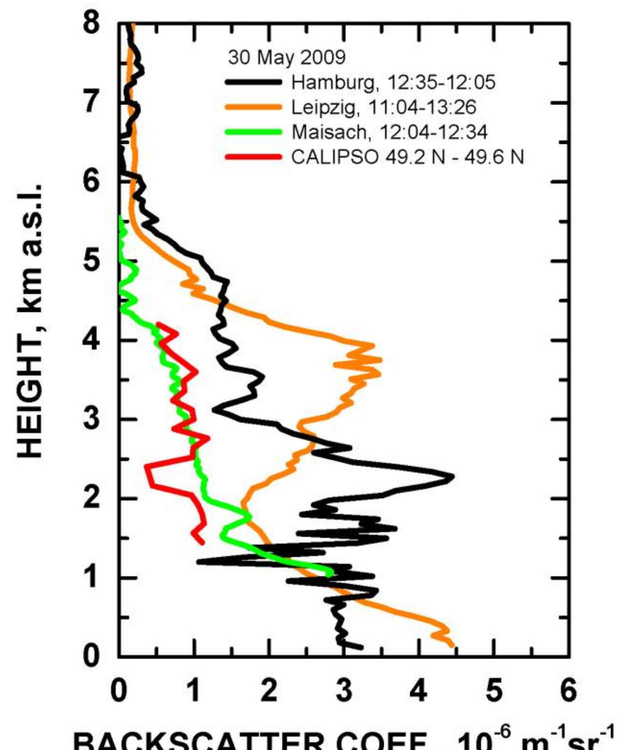


L2 product comparison: 30 May 2008, day

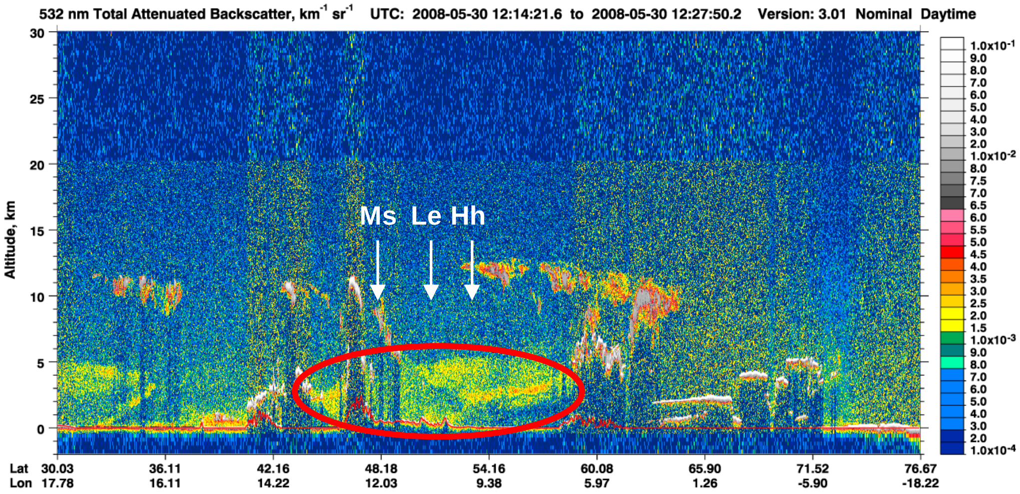


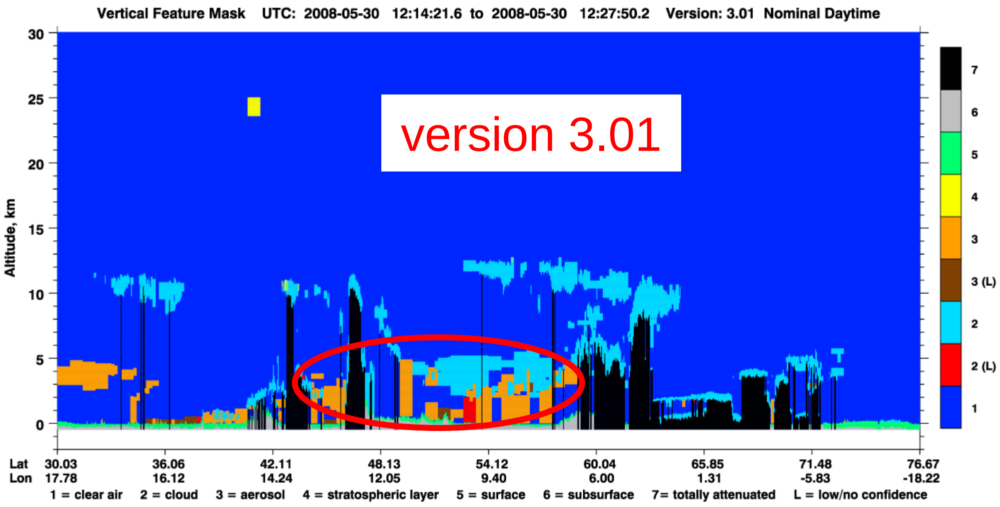


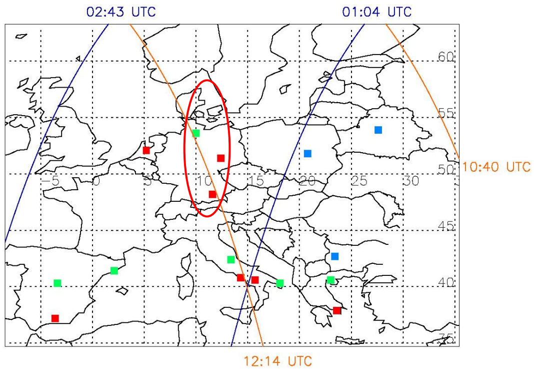


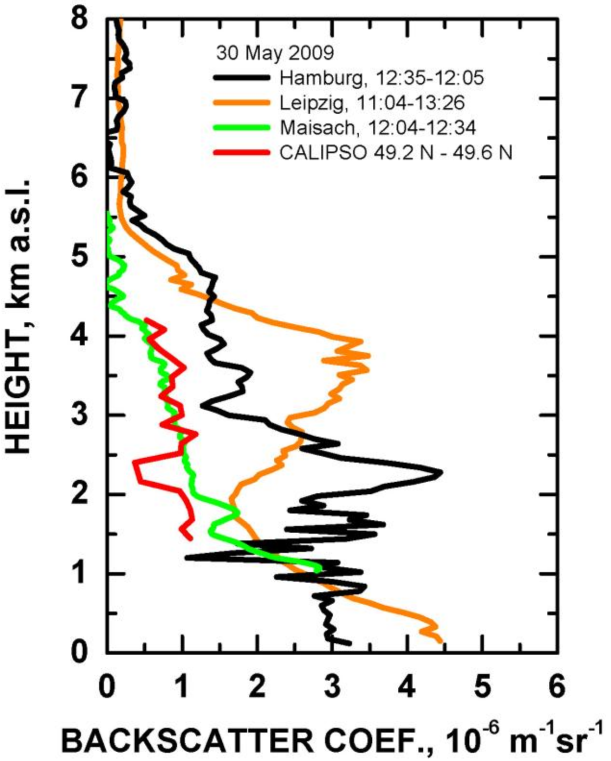


L2 product comparison: 30 May 2008, day

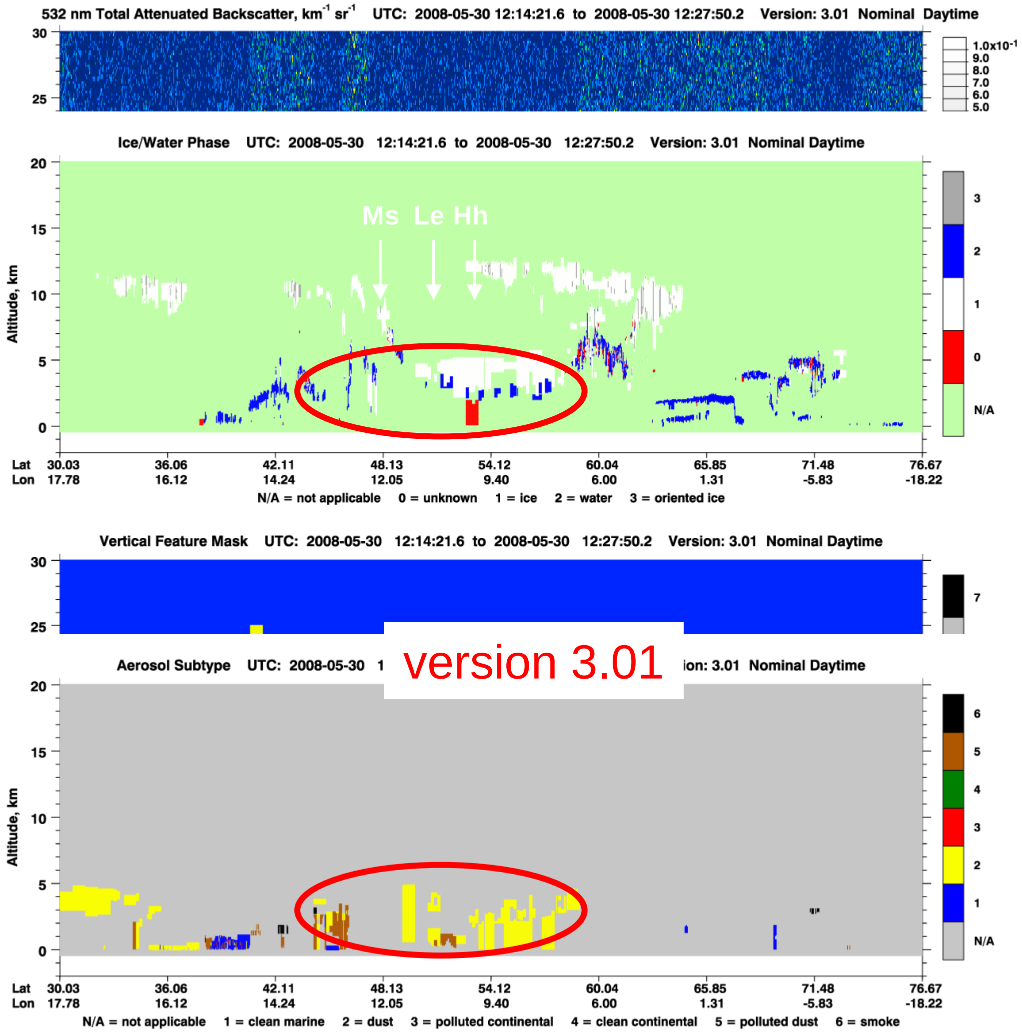


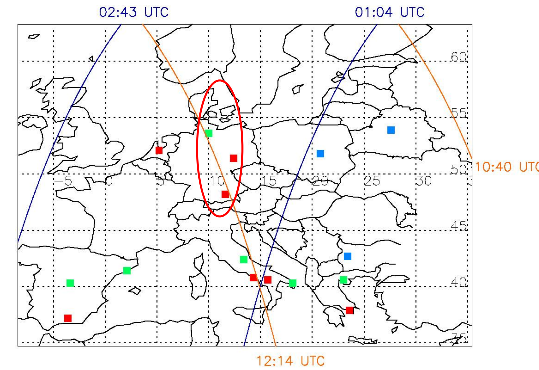


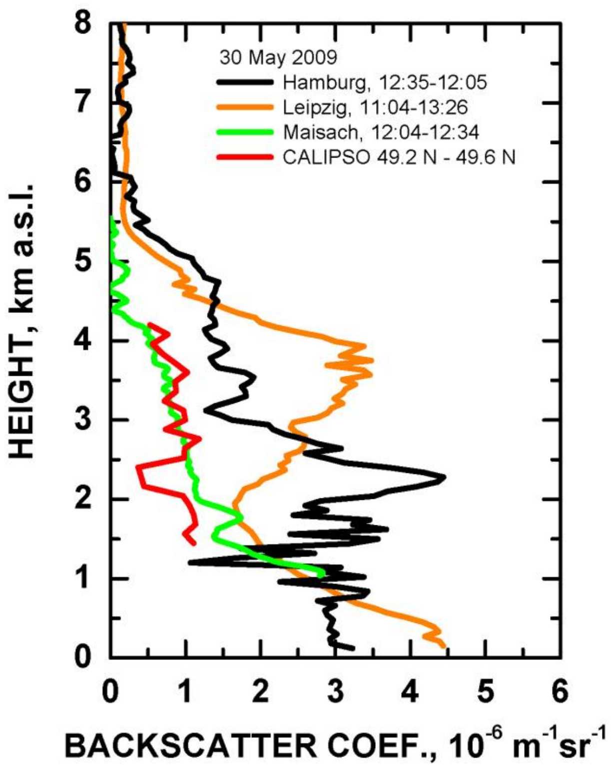




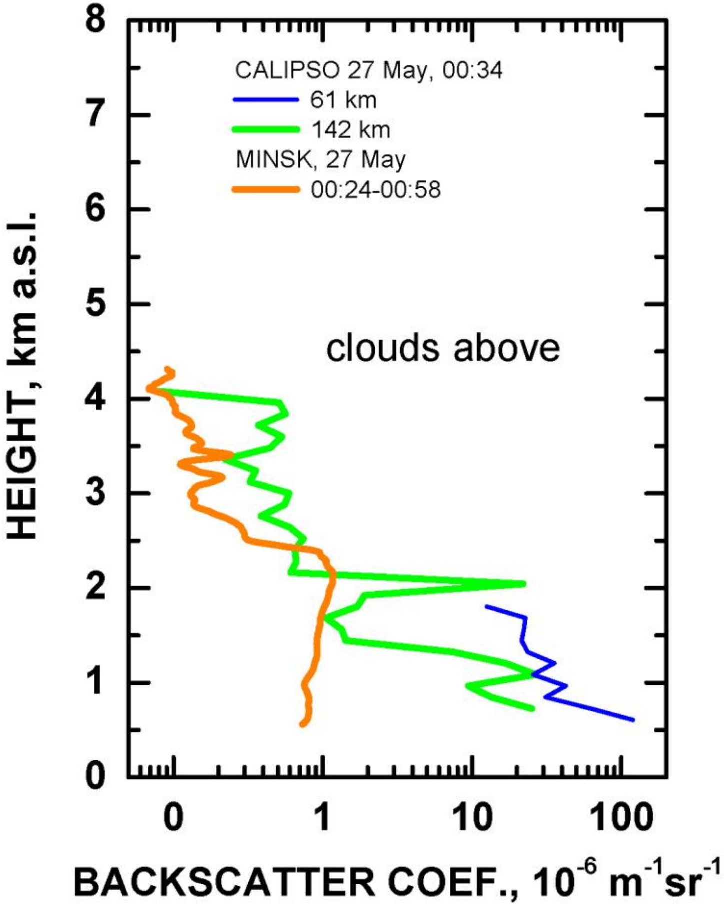
L2 product comparison: 30 May 2008, day

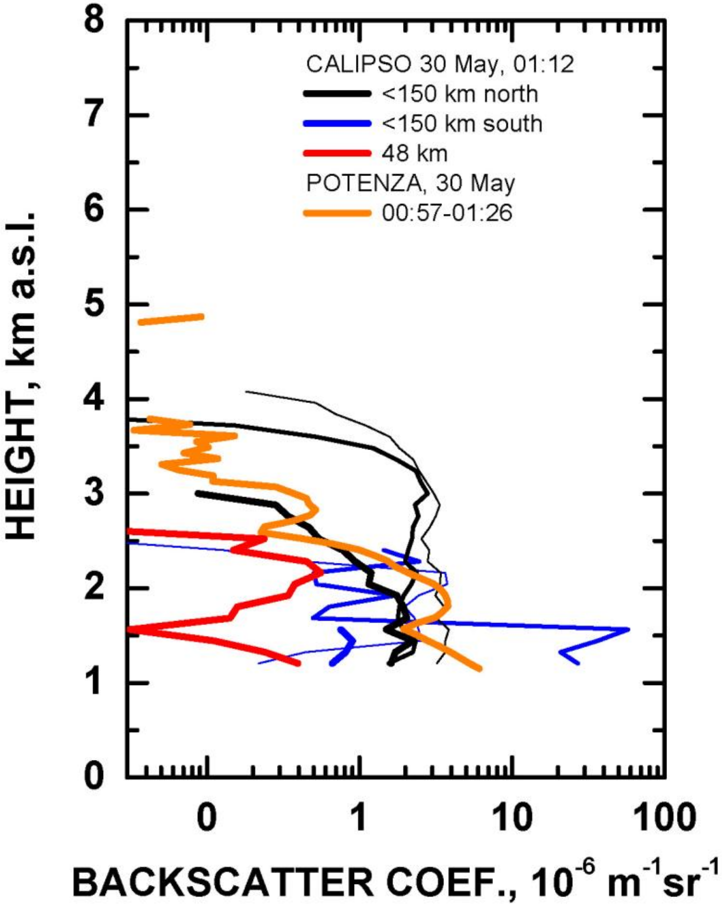






Observed problems





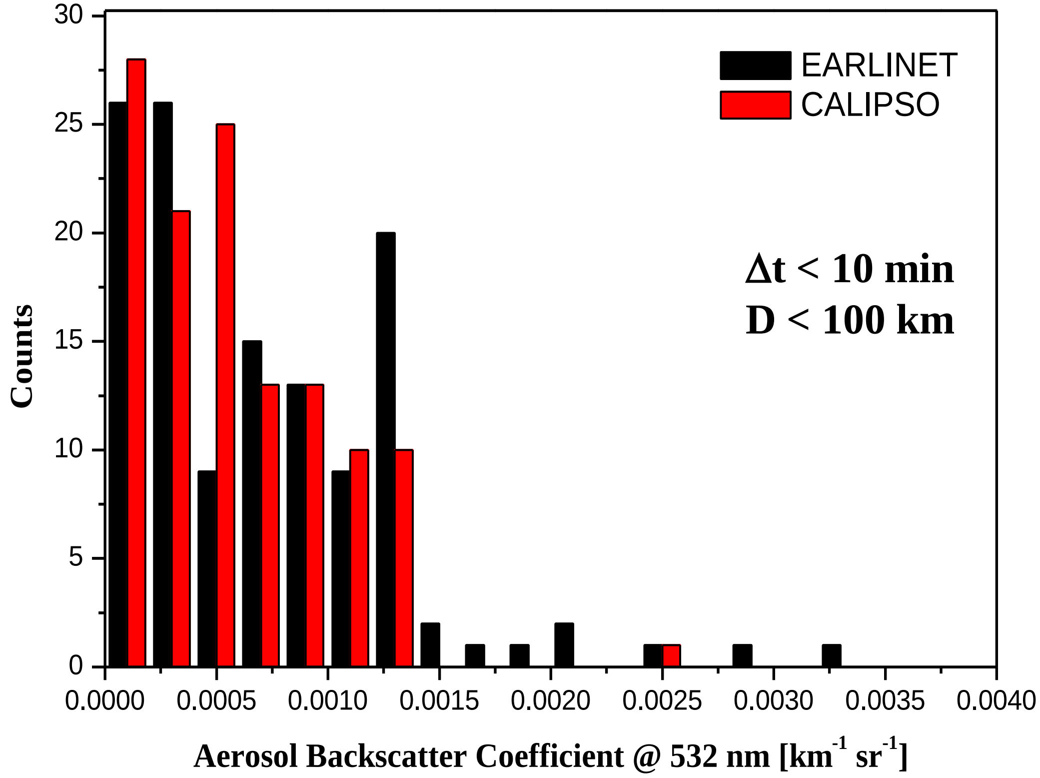
Multiple scattering influence???

Misclassification/cloud bias???

Klett retrieval failures???

Level 2 data comparison

Backscatter coefficient at 532 nm, count distribution
(Saharan dust event, 15 Case A, 7 Case B, 56 Case C measurements)

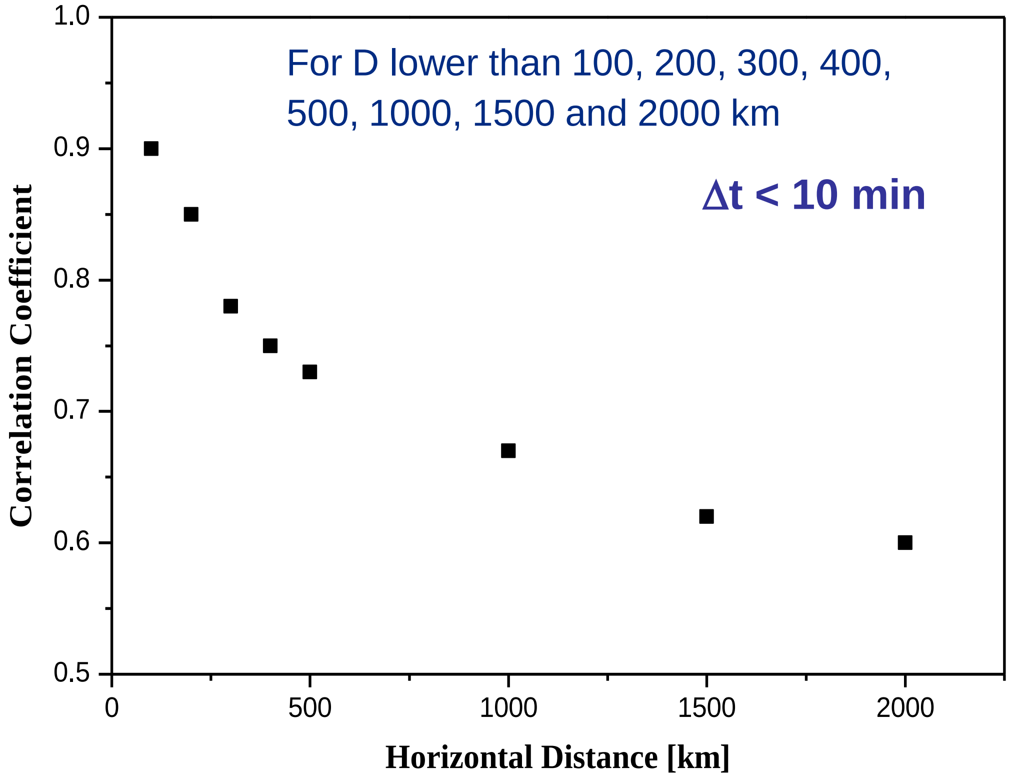


Mean Values
CALIPSO = 0.0040 km $^{-1}$ sr $^{-1}$
EARLINET = 0.0008 km $^{-1}$ sr $^{-1}$

Median Values
CALIPSO = 0.0005 km $^{-1}$ sr $^{-1}$
EARLINET = 0.0006 km $^{-1}$ sr $^{-1}$

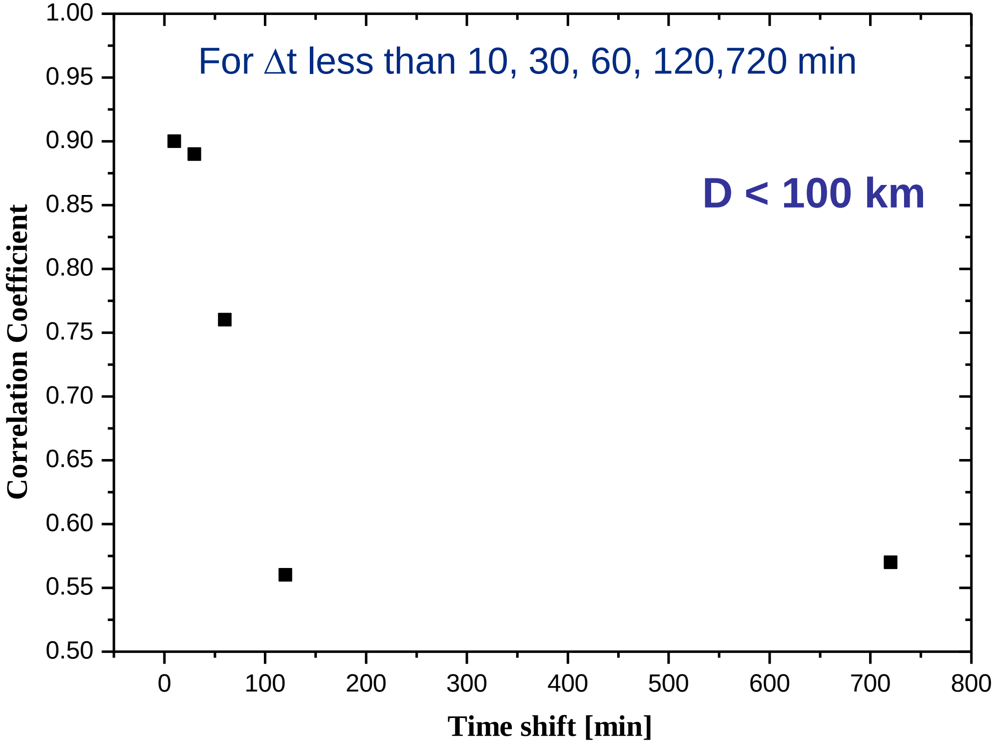
Correlation Coefficient = 0.9

Representativeness study



Comparisons within 10 minutes and different horizontal distances

Representativeness study



Comparisons within 100 km and temporal distances

Lidar ratios of Saharan dust at 532 nm

EARLINET, outbreak May 2008:	**56 ± 7 sr**
SAMUM-1 (Morocco):	**55 ± 7 sr**
SAMUM-2 (Cape Verde):	**54 ± 7 sr**
EARLINET, Leipzig long-term mean:	**59 ± 11 sr**

CALIPSO 40 sr

CALIPSO aerosol types and input lidar ratios

	532 nm	1064 nm
1 clean marine	20 sr	45 sr
2 dust	40 sr	~~30 sr~~ → 55 sr
3 polluted continental	70 sr	30 sr
4 clean continental	35 sr	30 sr
5 polluted dust	65 sr	30 sr
6 smoke	70 sr	40 sr

Based on Sun photometer observations and aerosol models
(size distribution and refractive index)

For dust a spheroid particle model is used to calculate scattering properties
(Mie scattering for the other types)

Omar, Ali H., and Coauthors, 2009: The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm. J. Atmos. Oceanic Technol., 26, 1994–2014.

CALIPSO aerosol models

Fixed size distribution
(fine + coarse mode)
Fixed refractive index

r_{eff} = 0.41 µm

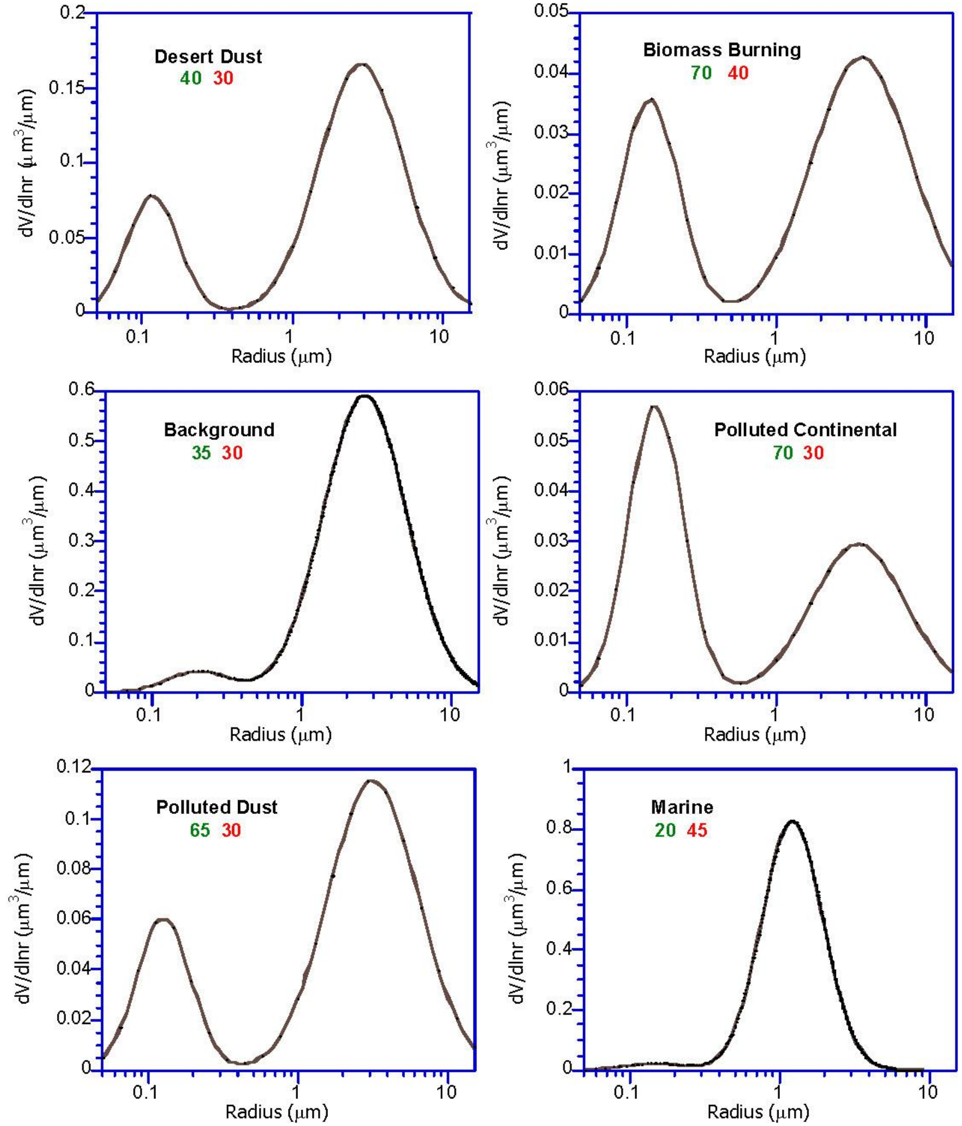
r_{eff} = 0.36 µm

r_{eff} = 1.4 µm

r_{eff} = 0.26 µm

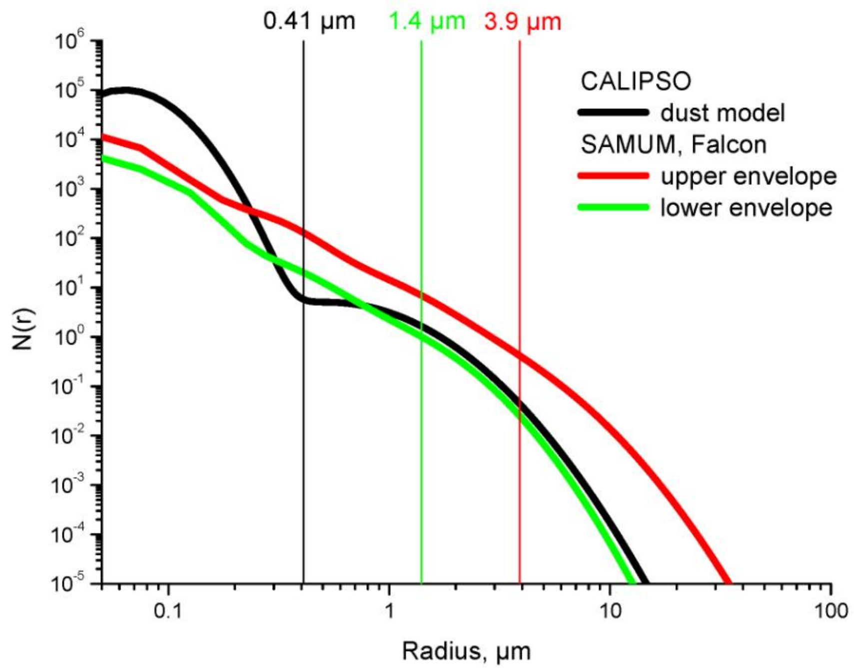
r_{eff} = 0.42 µm

r_{eff} = 0.92 µm

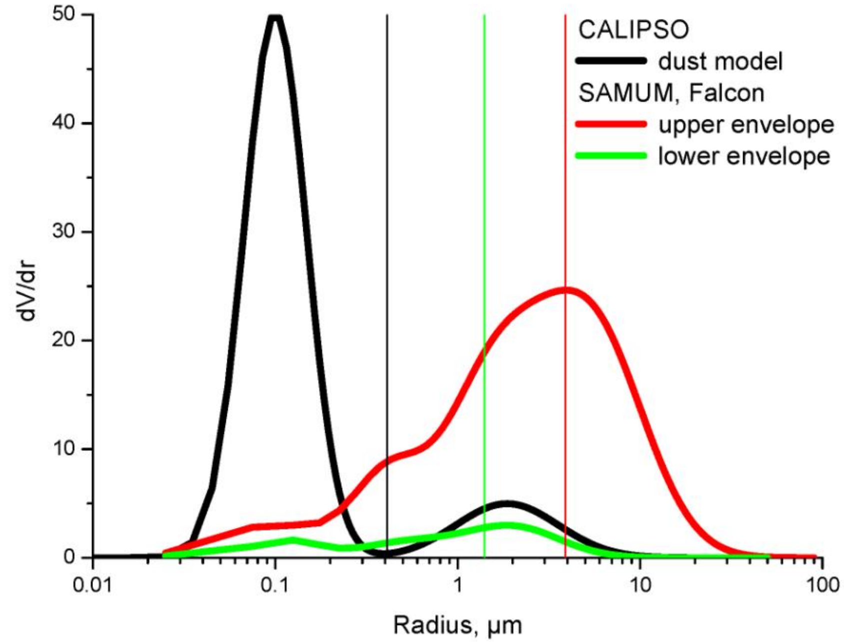


Dust size distribution CALIPSO model vs SAMUM in situ

Number concentration



Volume concentration



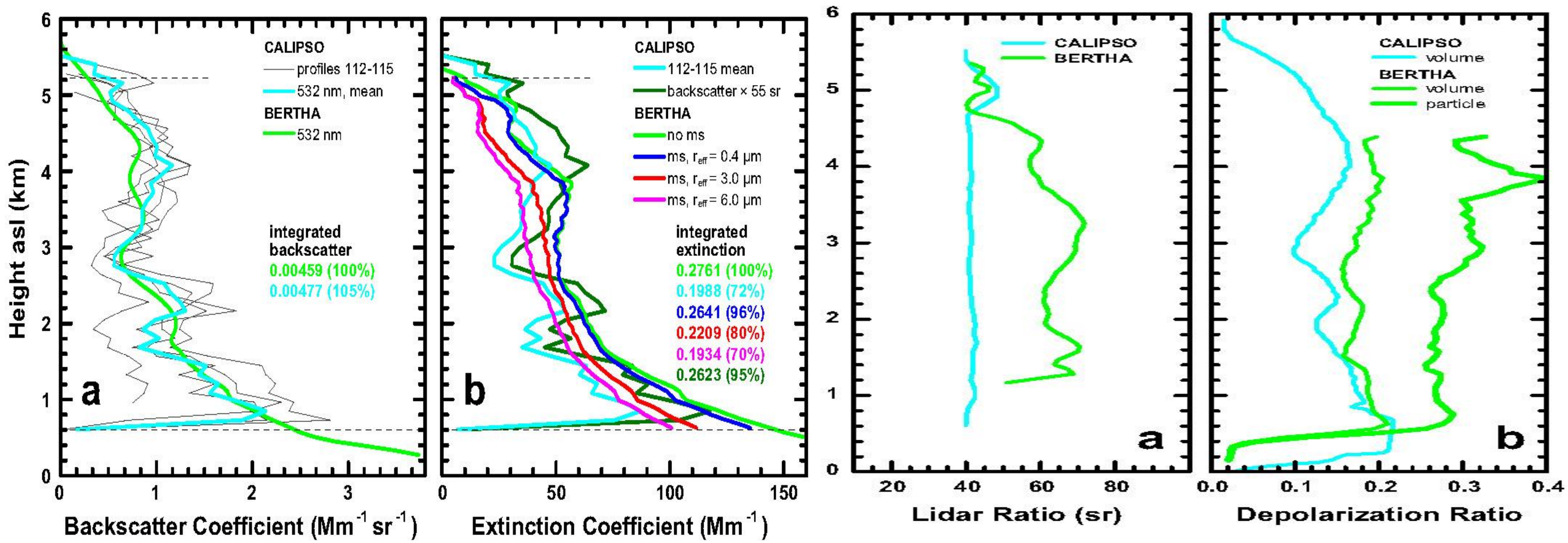
CALIPSO dust model underestimates effective size of dust particles

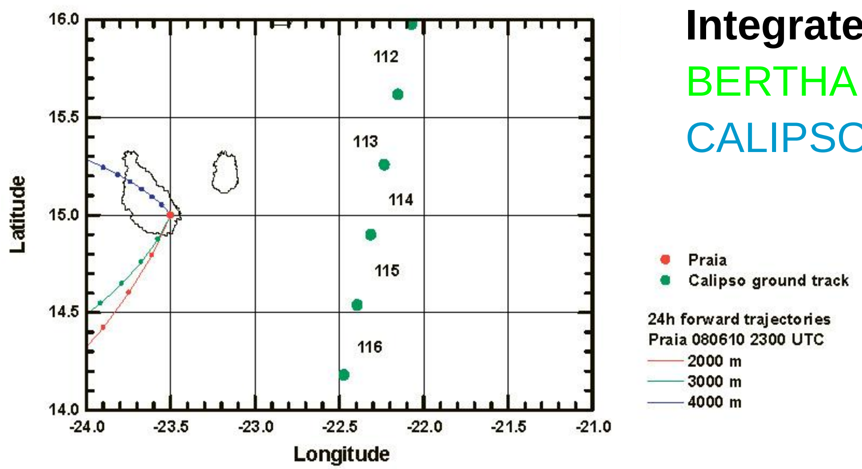
→ influence of multiple scattering on lidar ratio retrieval is underestimasted

→ influence of multiple scattering on optical depth calculation is underestimated

Measured range of r_{eff} during SAMUM: 1.2…6.8 µm

SAMUM case study: 11 June 2008





Integrated backscatter

BERTHA 4.59e-3 sr^{-1}

CALIPSO 4.77e-3 sr^{-1} (+5%)

Integrated extinction (OD)

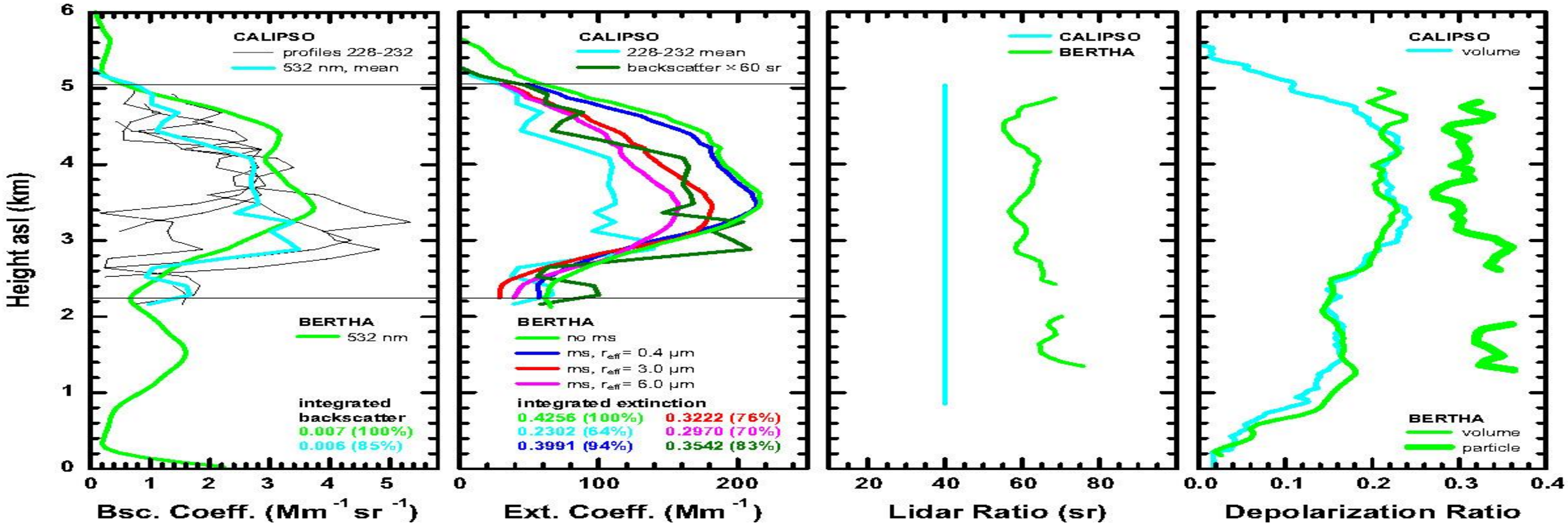
BERTHA 0.276

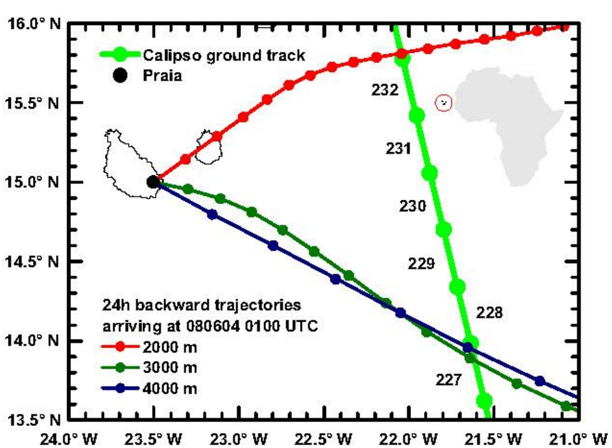
CALIPSO 0.199 (-28%)

4.77e-3 sr^{-1} × 55 sr = 0.262 (-5%)

Wandinger et al., GRL, 2010

SAMUM case study: 3 June 2008





Integrated backscatter		Integrated extinction (OD)	
BERTHA	6.95e-3 sr^{-1}	BERTHA	0.426
CALIPSO	5.90e-3 sr^{-1} (-15%)	CALIPSO	0.230 (-46%)

5.90e-3 sr^{-1} × 55 sr = 0.354 (-17%)

Summary of SAMUM case studies

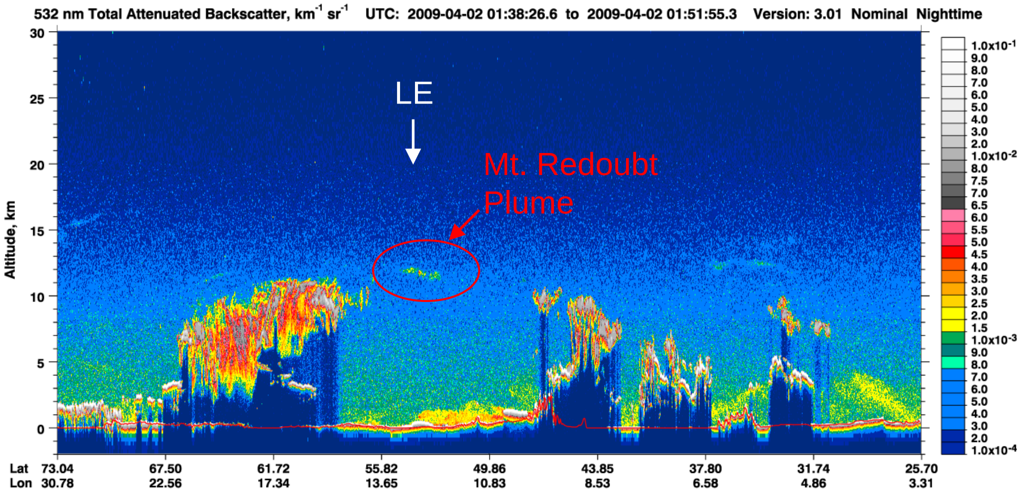
$$\Delta\tau = \left(1 - \frac{\tau_C}{\tau_B}\frac{\int \beta_B \mathrm{d}z}{\int \beta_C \mathrm{d}z}\right) 100\%$$

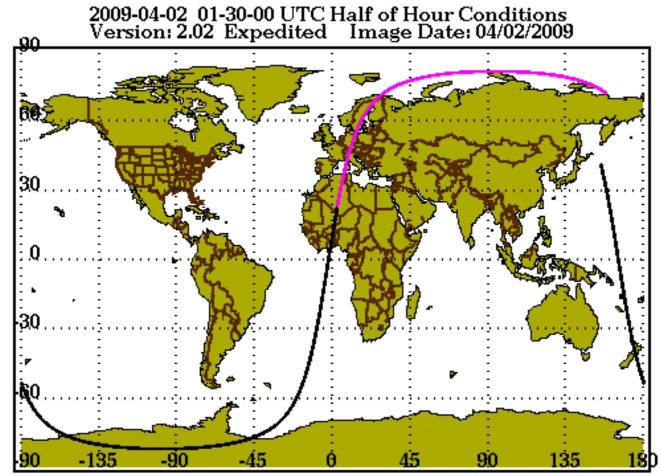
Date in 2008 Dust layer, km	3 June 2.25-5.05	11 June 0.63-5.23	15 June 2.00-5.05
BERTHA measured τ	0.426	0.276	0.318
CALIPSO observed $\Delta\tau$	36%	31%	26%
calculated $\Delta\tau$			
$r_{\mathrm{eff}} = 0.4\ \mu\mathrm{m}$	7%	4%	3%
$r_{\mathrm{eff}} = 3.0\ \mu\mathrm{m}$	27%	20%	19%
$r_{\mathrm{eff}} = 6.0\ \mu\mathrm{m}$	35%	30%	32%

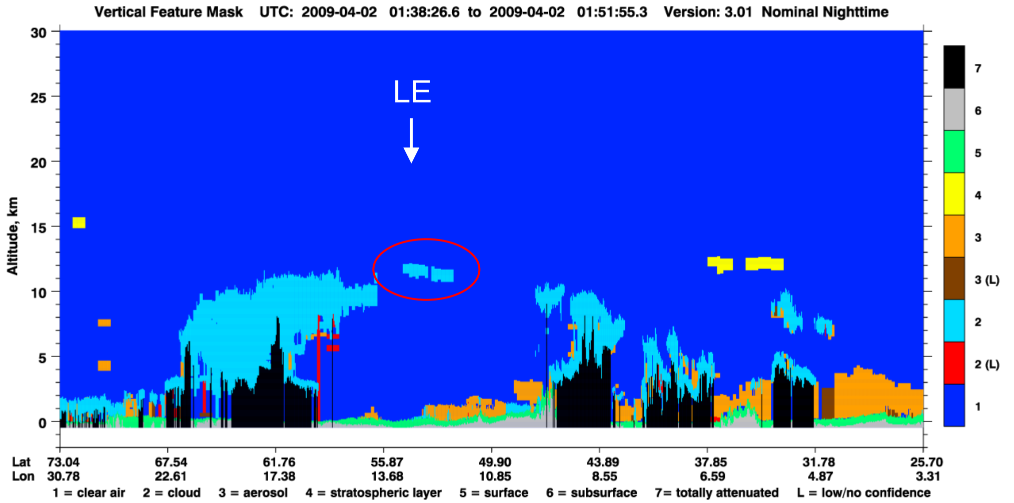
Identification of volcanic aerosol layers

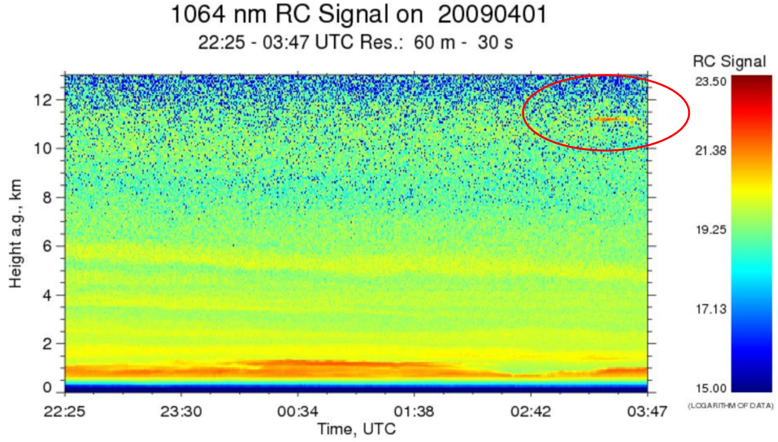
Mt. Redoubt plume (at tropopause)

CALIPSO overpass Leipzig, 02 April 2009, 1.30 UTC



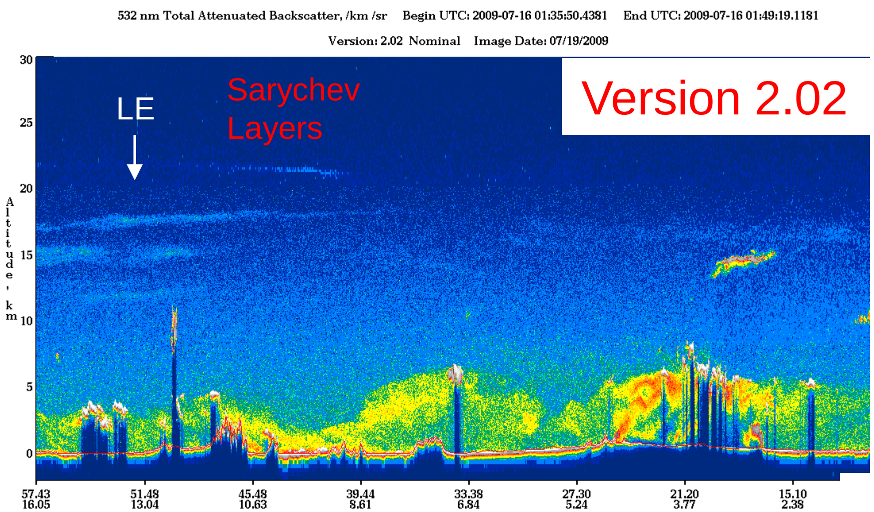


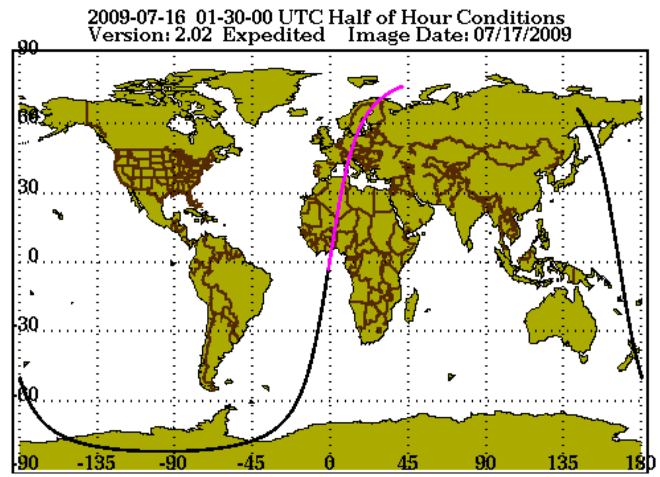


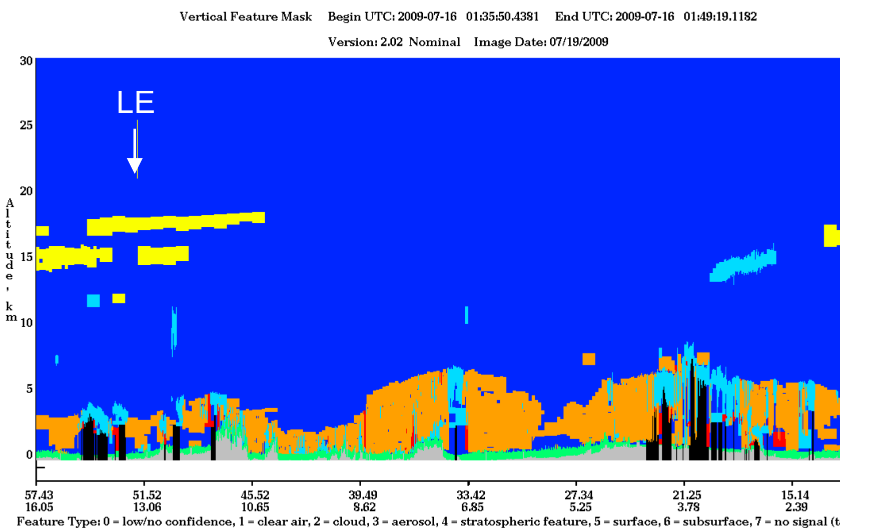


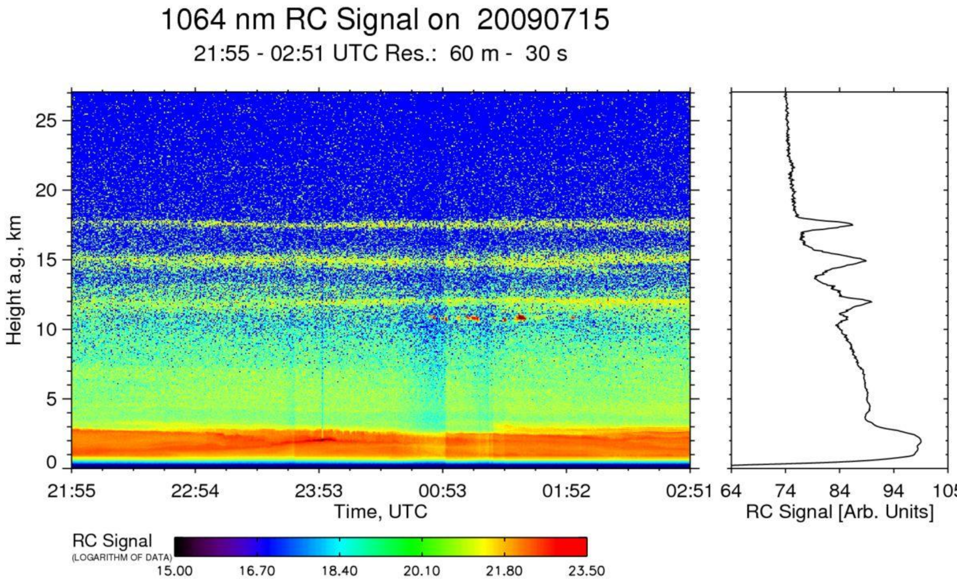
Sarychev layers (at tropopause and in the stratosphere)

CALIPSO overpass Leipzig, 16 July 2009, 1.50 UTC









Sarychev layers (at tropopause and in the stratosphere)

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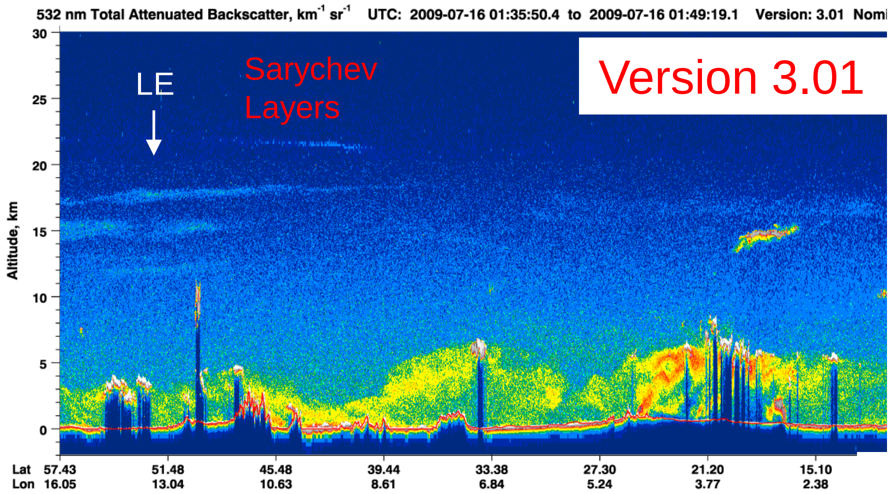
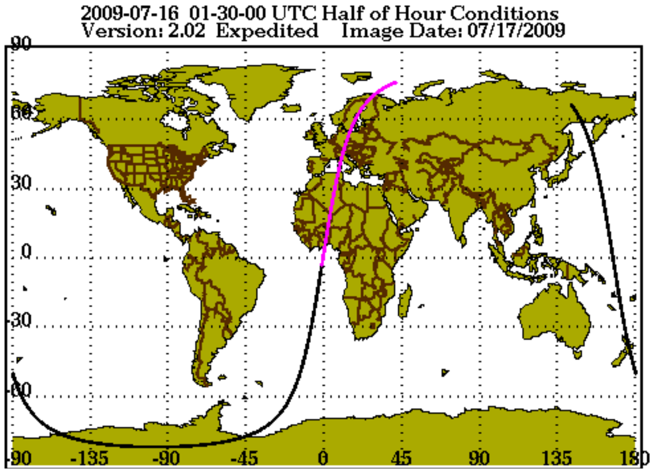
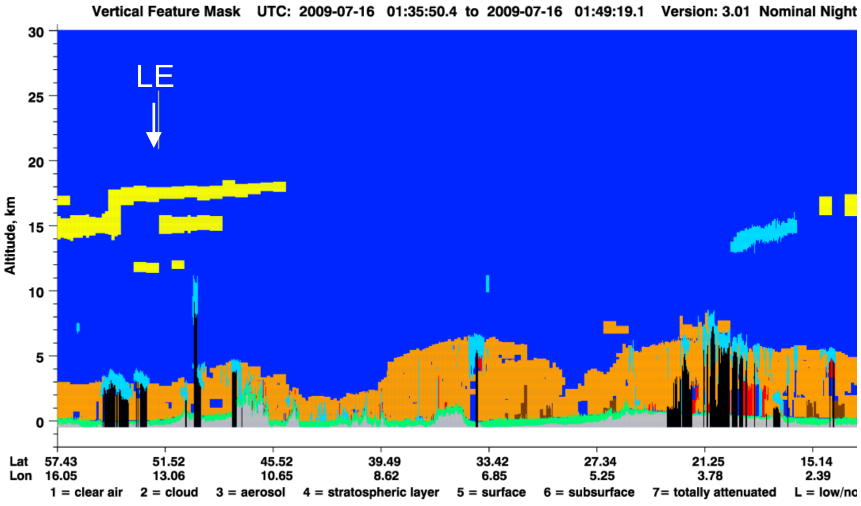
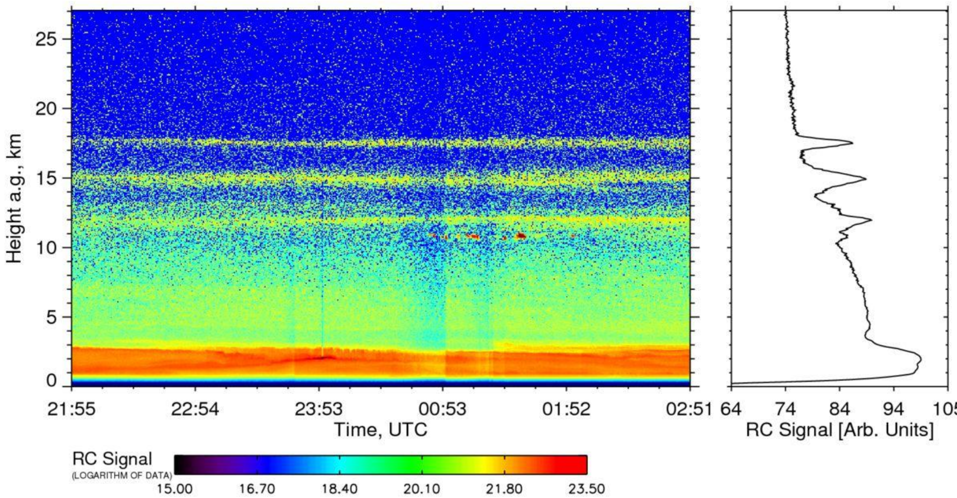
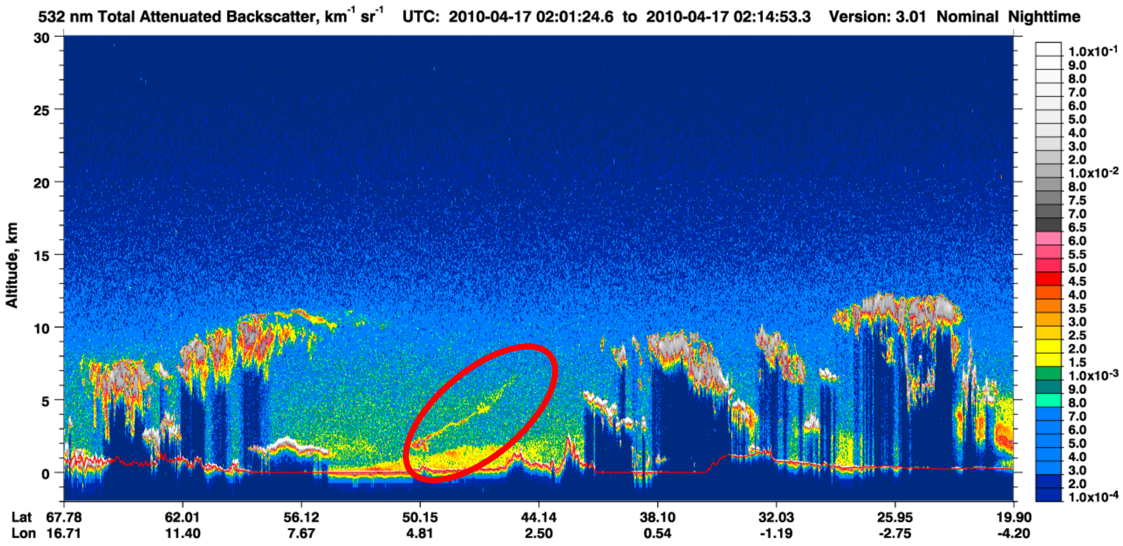


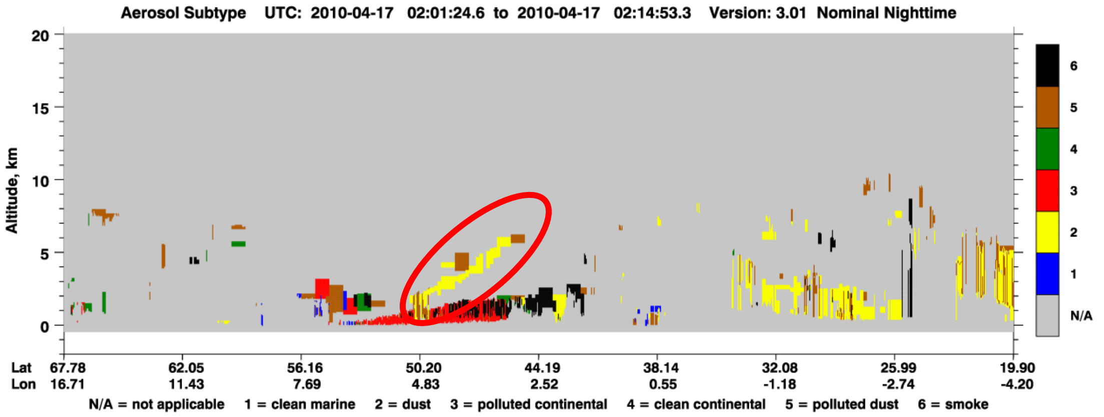






CALIPSO observation of the Eyjafjallajökull plume





Conclusions (1/2)

EARLINET-CALIPSO long-term correlative data set used for

- validation purposes
- identification of critical assumptions, needs for improvements
- representativeness studies
- long-term support for data harmonization purposes

Findings:

→ no obvious biases in CALIPSO Level 1 data

but we have to keep in mind:

→ cloud-aerosol discrimination is a critical issue, especially for dust/ash/volcanic aerosol vs ice clouds

→ uncertainties and underestimation of aerosol load result from the CALIPSO layer approach (aerosol layers which are seen in L1 data do not appear in L2 products)

Conclusions (2/2)

→ Multiple scattering is important!

Aerosol data below cirrus clouds seem to be corrupt

Large dust particles cause multiple scattering as well
→ extinction and optical depth might be underestimated
(aerosol typing is important!)

→ Conversion factors and common aerosol typing schemes are needed for harmonization with upcoming missions (CALIPSO → EarthCARE)

→ More information/better definition of mixed aerosols is required

→ Particle depolarization ratio is an essential parameter to allow the determination of the dust content (in mixed aerosols)

Up to now only a minor part of the dataset has been investigated!