Aerosol typing and microphysical properties from advanced lidar/radiometer observations

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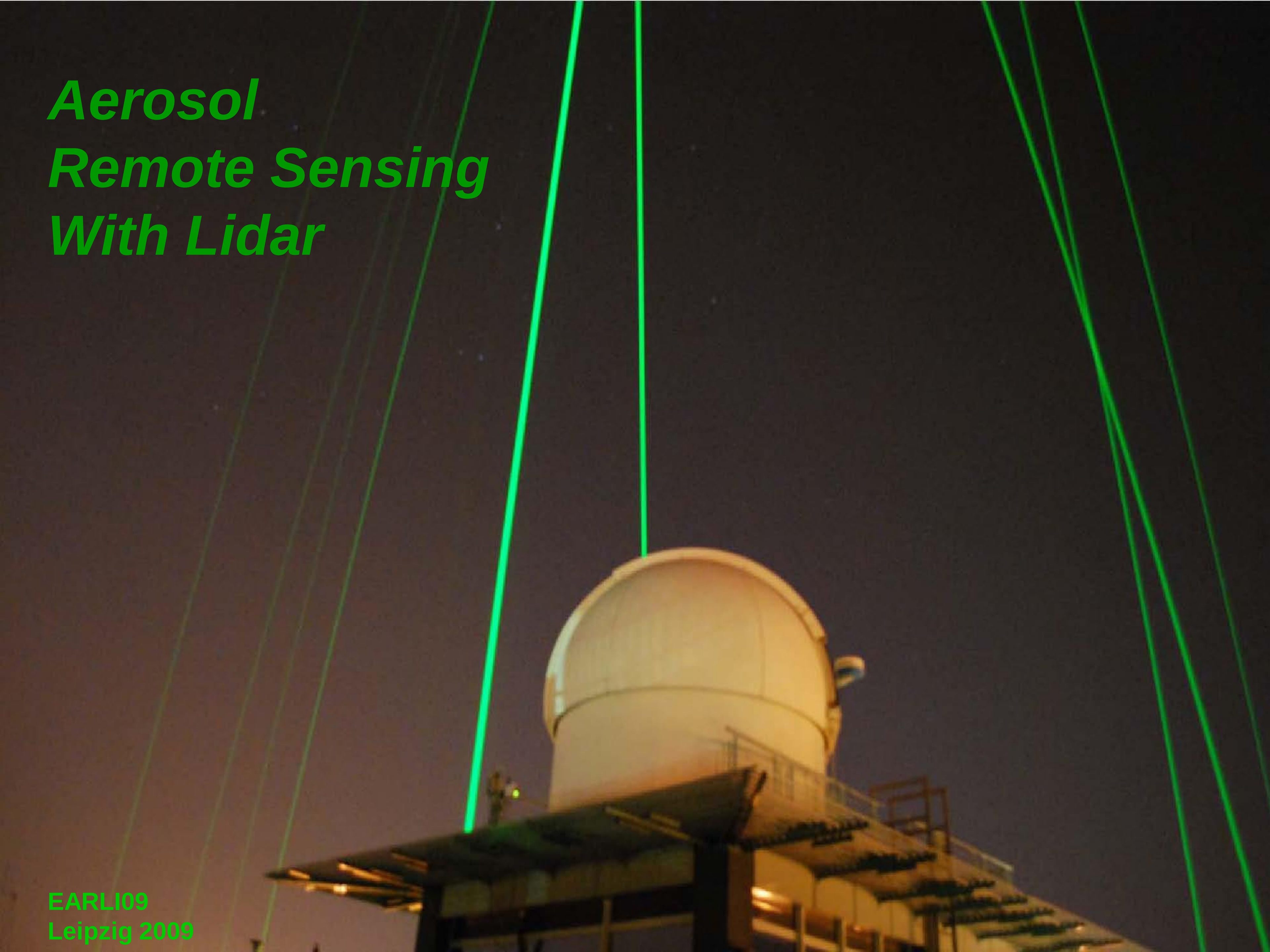
with many contributions from the
TROPOS Ground-Based Remote-Sensing Group
and the ACTRIS-EARLINET Consortium

Outline

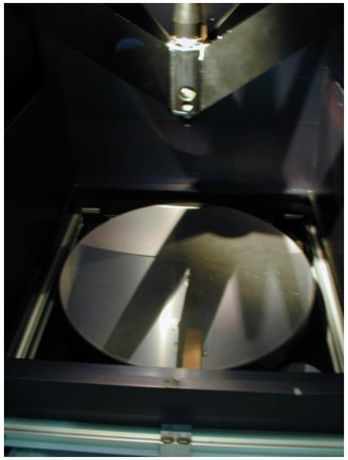
- Towards ACTRIS supersites
- Aerosol typing from lidar optical data
- Microphysical retrievals from combined lidar/sun photometer data

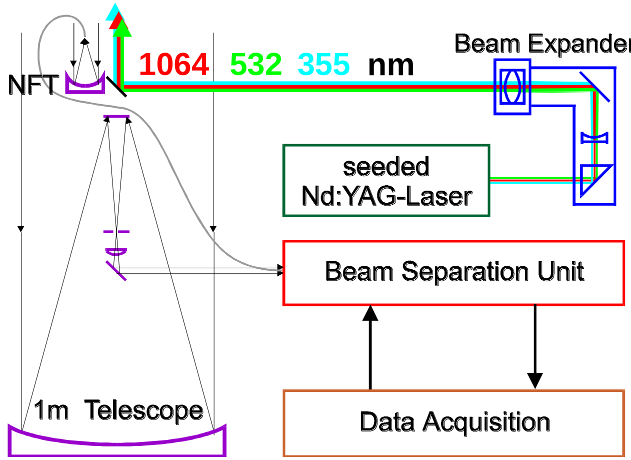
Aerosol Remote Sensing With Lidar

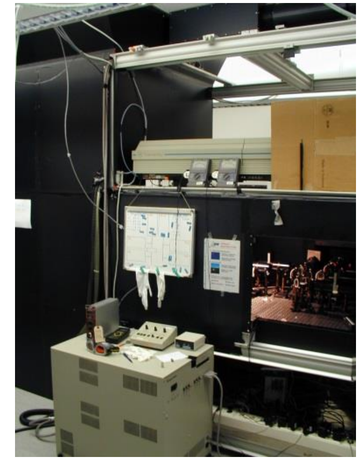


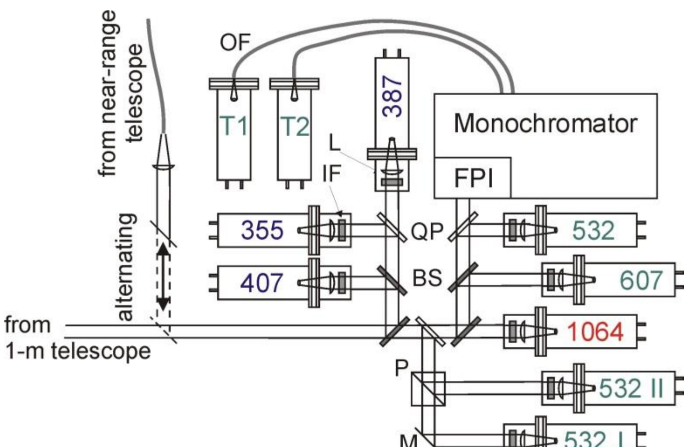
EARLI09
Leipzig 2009

EARLINET multiwavelength Raman Lidar









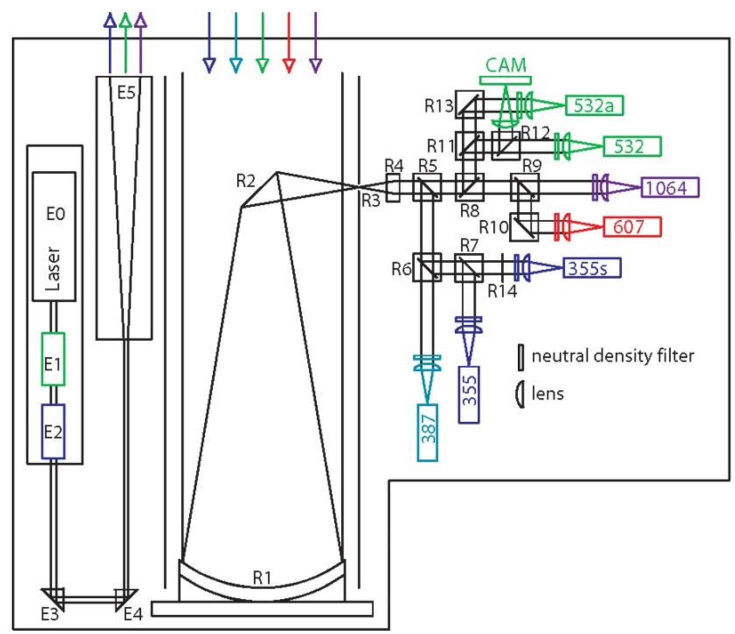
- particle backscatter coef. (355, 532, 1064 nm)
- particle extinction coef. (355, 532 nm)
- lidar ratio (355, 532 nm)
- Angström exponent (355/532 nm, height-res.)
- particle depolarization ratio (532 nm)
- water-vapor mixing ratio
- temperature

+ scattering model:

- particle mean size, volume concentration, refractive index (height-resolved)

Continuous observations – Raman Lidar Polly^{XT}

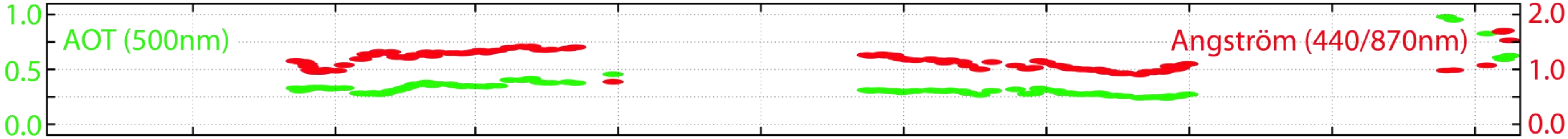
1: roof cover
2: sensors for outdoor temperature, air pressure, and rai
3: aircondition
4: uninterruptible power supply,
5: computer with data acquisition
6: laser power supply
7: laser head
8: beam expander
9: receiver telescope
10: receiver with seven channels



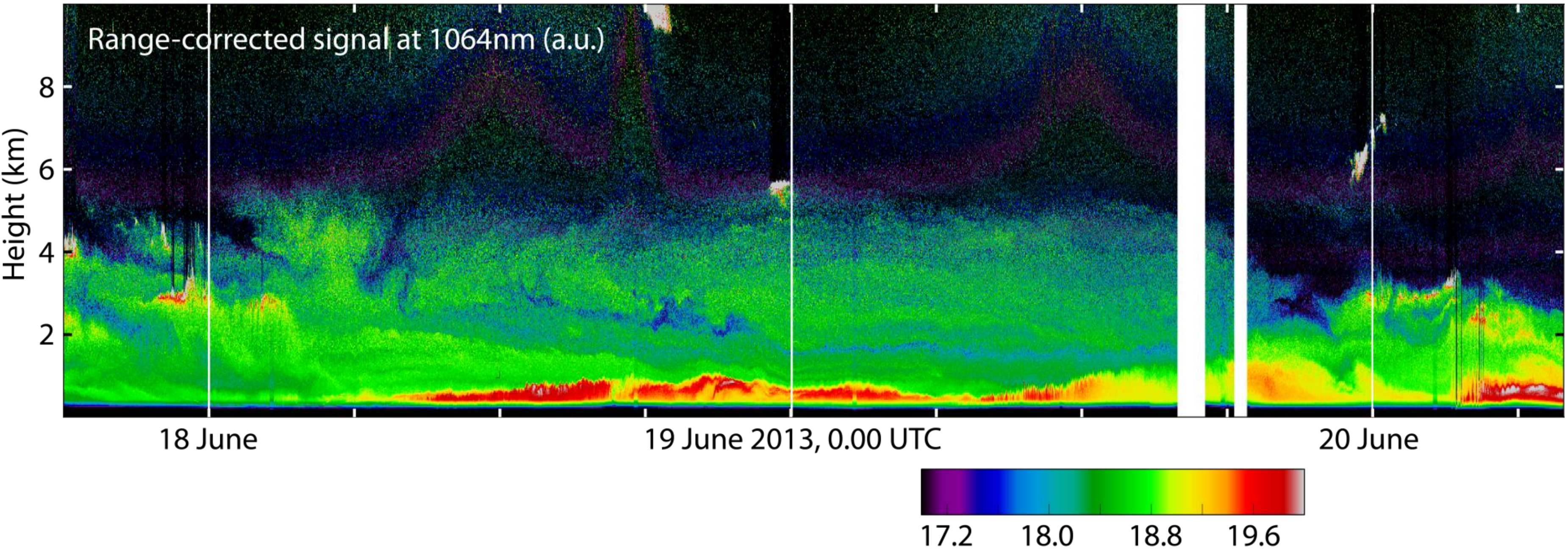
E0	laser
E1	second harmonic generation crystal
E2	third harmonic generation crystal
E3	quartz prism
E4	quartz prism
E5	beam expander
R1	primary mirror
R2	secondary mirror
R3	pinhole
R4	achromatic lens
R5	beamsplitter
R6	beamsplitter
R7	beamsplitter
R8	beamsplitter
R9	beamsplitter
R10	beamsplitter
R11	beamsplitter
R12	beamsplitter
R13	beamsplitter
R14	polarizer
CAM	camera

Continuous observations: AERONET and EARLINET

Sun photometer



Lidar



ACTRIS

Aerosol, Clouds and Trace gases Research Infrastructure Network

Ground-based remote sensing

EARLINET: ~27 aerosol lidar stations

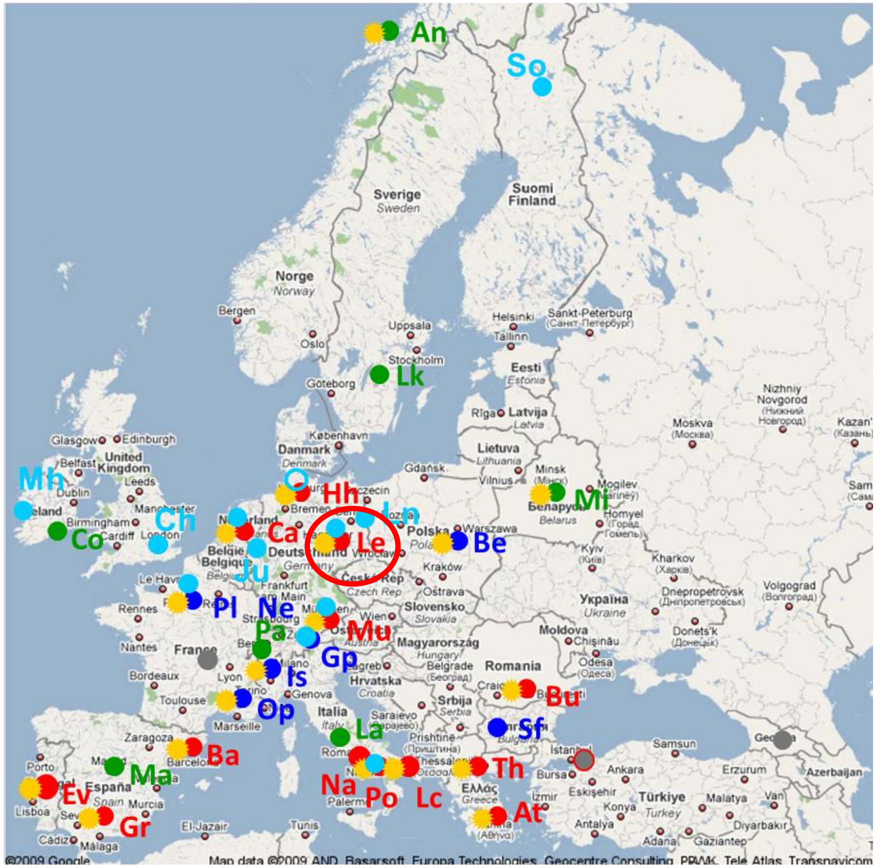
3+2 Raman lidars (aerosol typing, microphysics)

Raman lidars (extinction profiles)

backscatter lidars

CLOUDNET: ~10 cloud radar stations

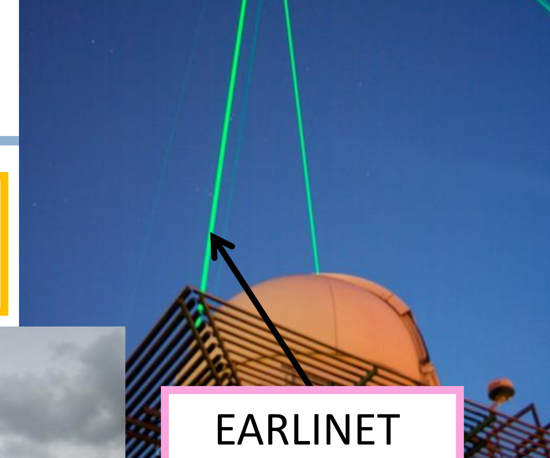
EARLINET- AERONET: ~17 stations and 3 calibration sites



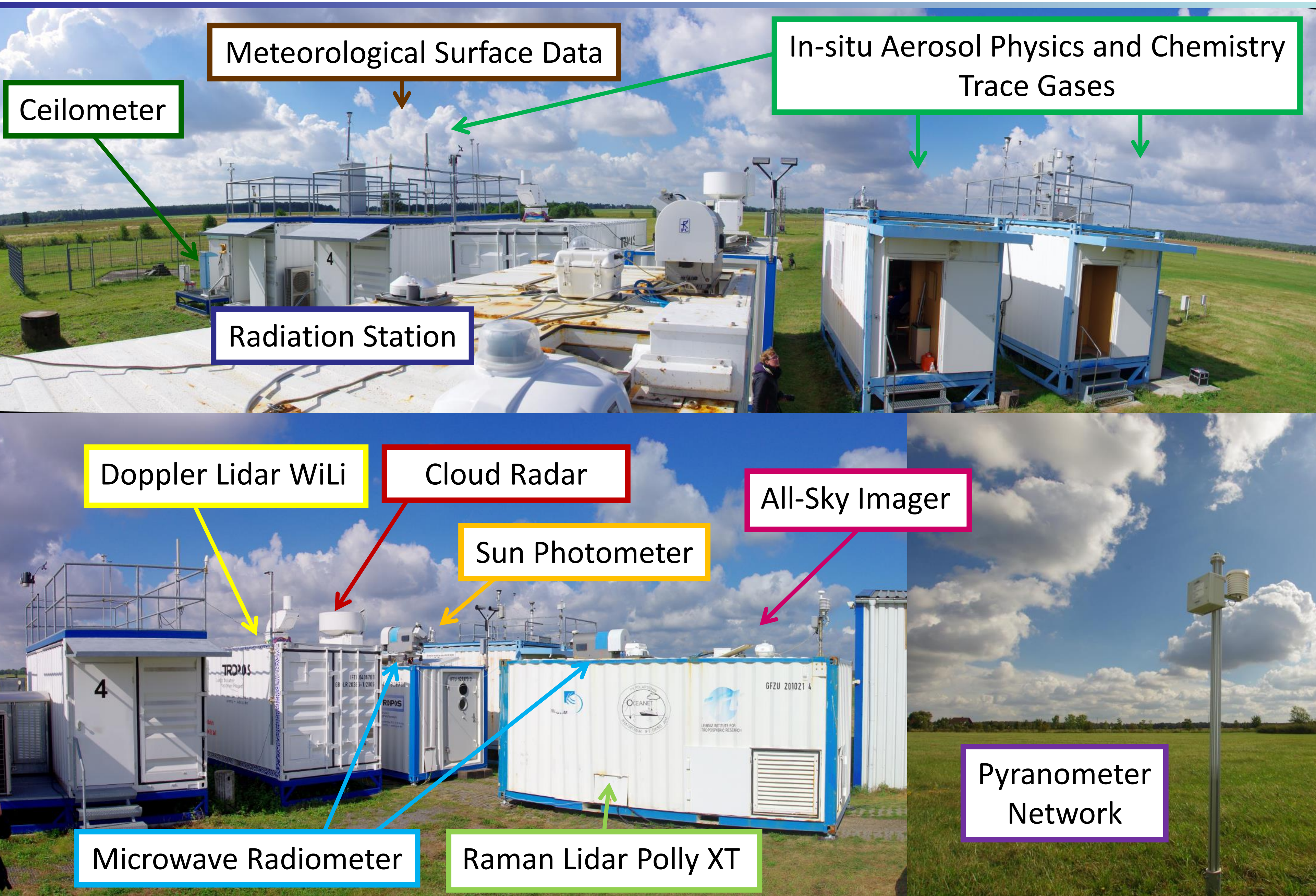
Ground-based in-situ observations

- about 30 ground-based stations for in-situ measurements of chemical, physical and optical properties of aerosols (former **EUSAAR**)
- about 20 ground-based stations for monitoring **short-lived trace gases**

ACTRIS @ TROPOS



ACTRIS supersite @ Melpitz

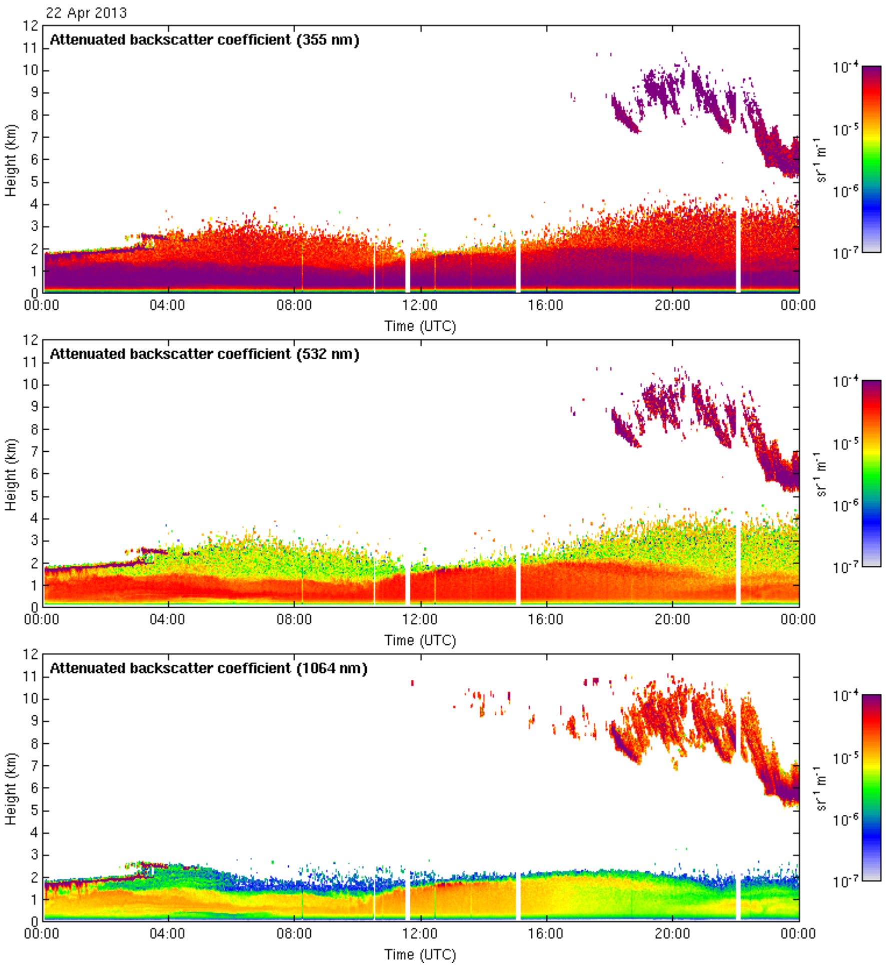


In-situ aerosol and cloud microphysics

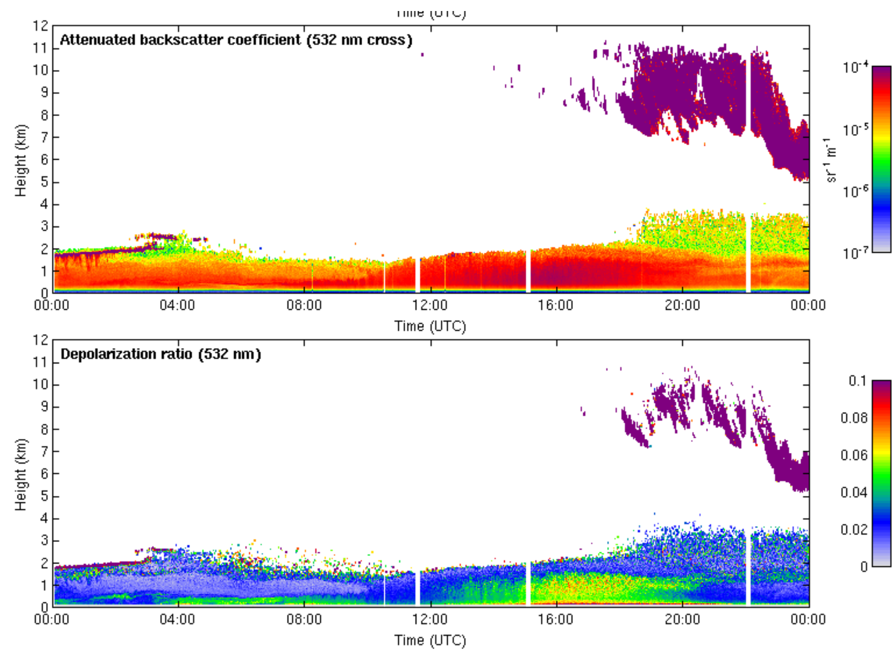
In-situ aerosol and cloud microphysics

CLOUDNET – EARLINET integration

Lidar 3λ

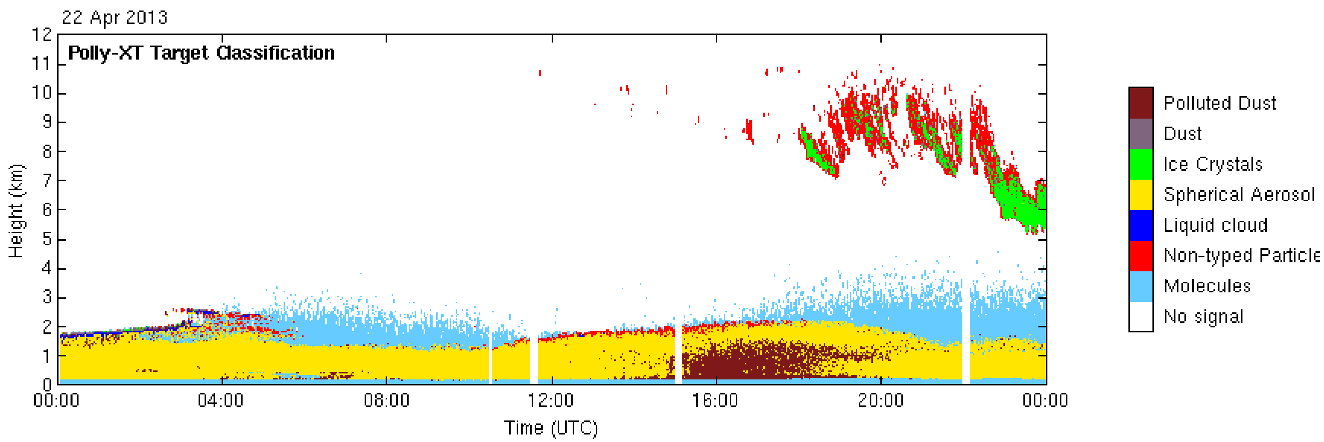


Lidar δ

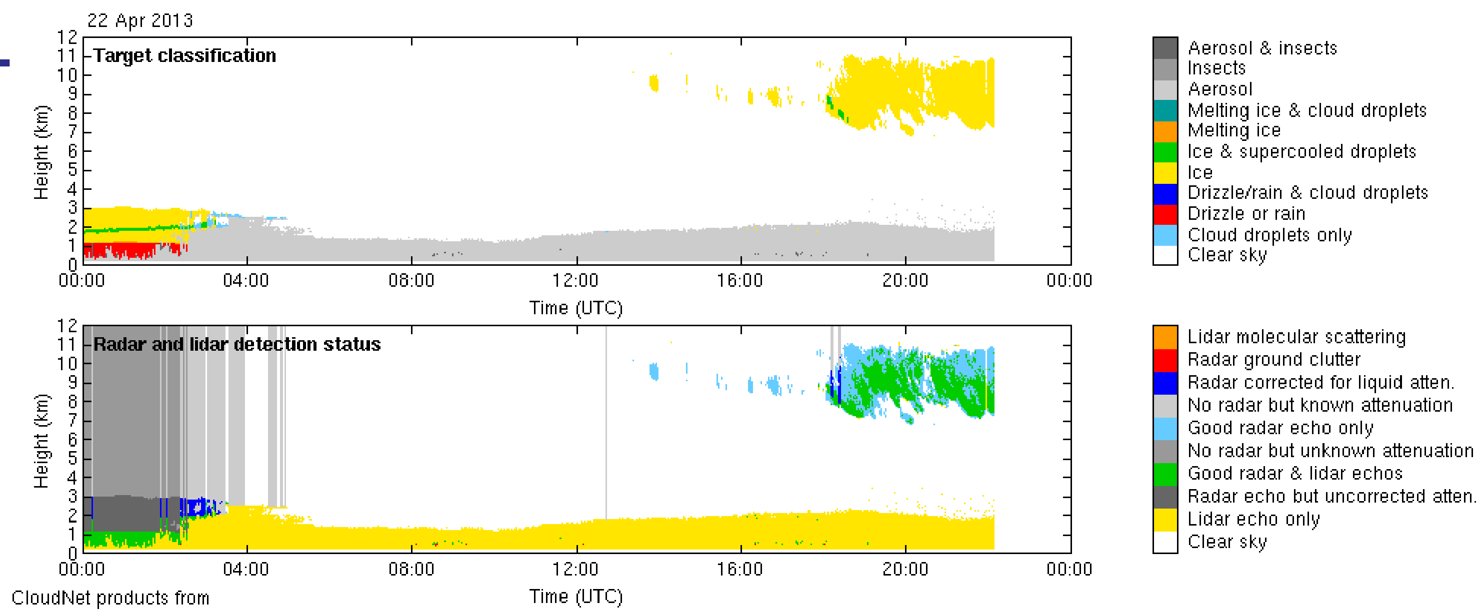


CLOUDNET – EARLINET integration

Lidar



CLOUDNET



Optical properties from lidar

Extensive optical parameters (concentration-dependent)

Backscatter coefficients: β (355, 532, *710*, 1064 nm)
Extinction coefficients: α (355, 532 nm)

Intensive optical parameters (type-dependent)

Lidar ratio: S (355, 532 nm)

size, shape, refractive index

$$S = \frac{\alpha}{\beta} = \frac{4\pi}{\omega_0 P_{11}(180°)}$$

Depolarization ratio: δ (355, **532**, *710*, 1064 nm)

shape, (size, refractive index)

$$\delta = \frac{\beta^{\perp}}{\beta^{\parallel}} = \frac{P_{11}(180°) - P_{22}(180°)}{P_{11}(180°) + P_{22}(180°)}$$

Ångström exponents
backscatter-related: å(532/1064), å(355/532)
extinction-related: å(355/532)

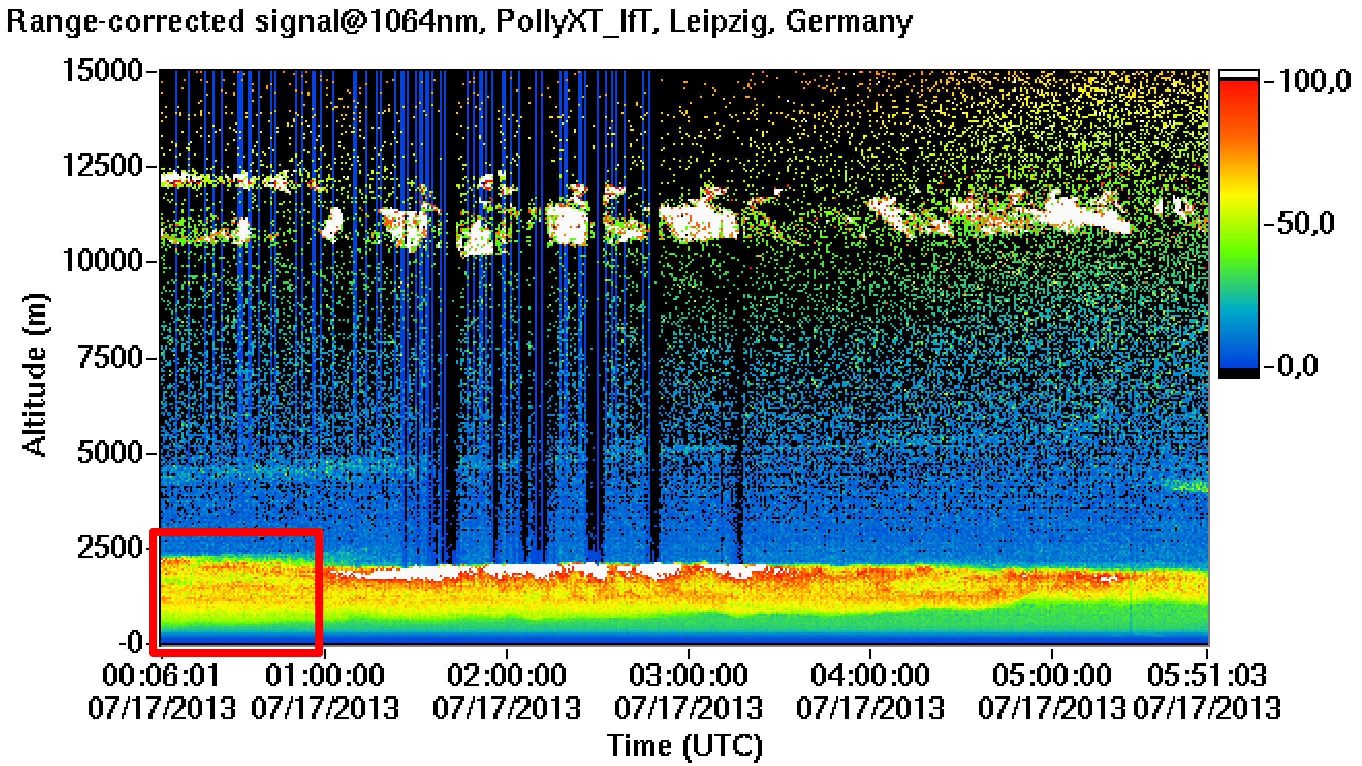
size, (refractive index)

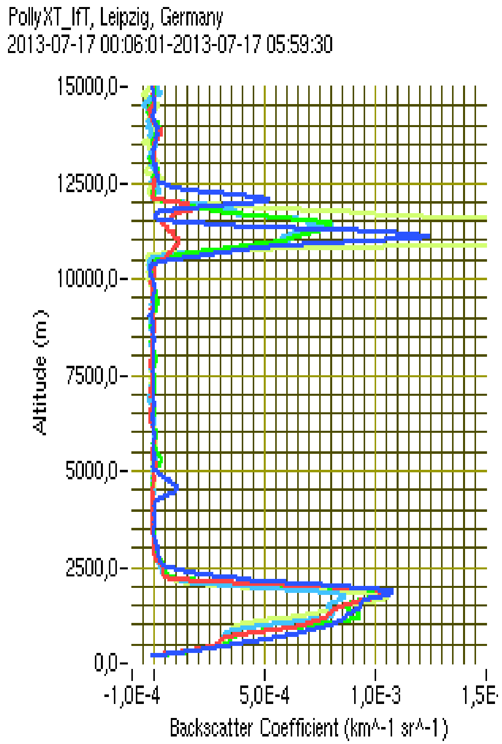
$$å_x = -\frac{\ln[x(\lambda_1)/x(\lambda_2)]}{\ln(\lambda_1/\lambda_2)}$$

Aerosol typing from optical parameters

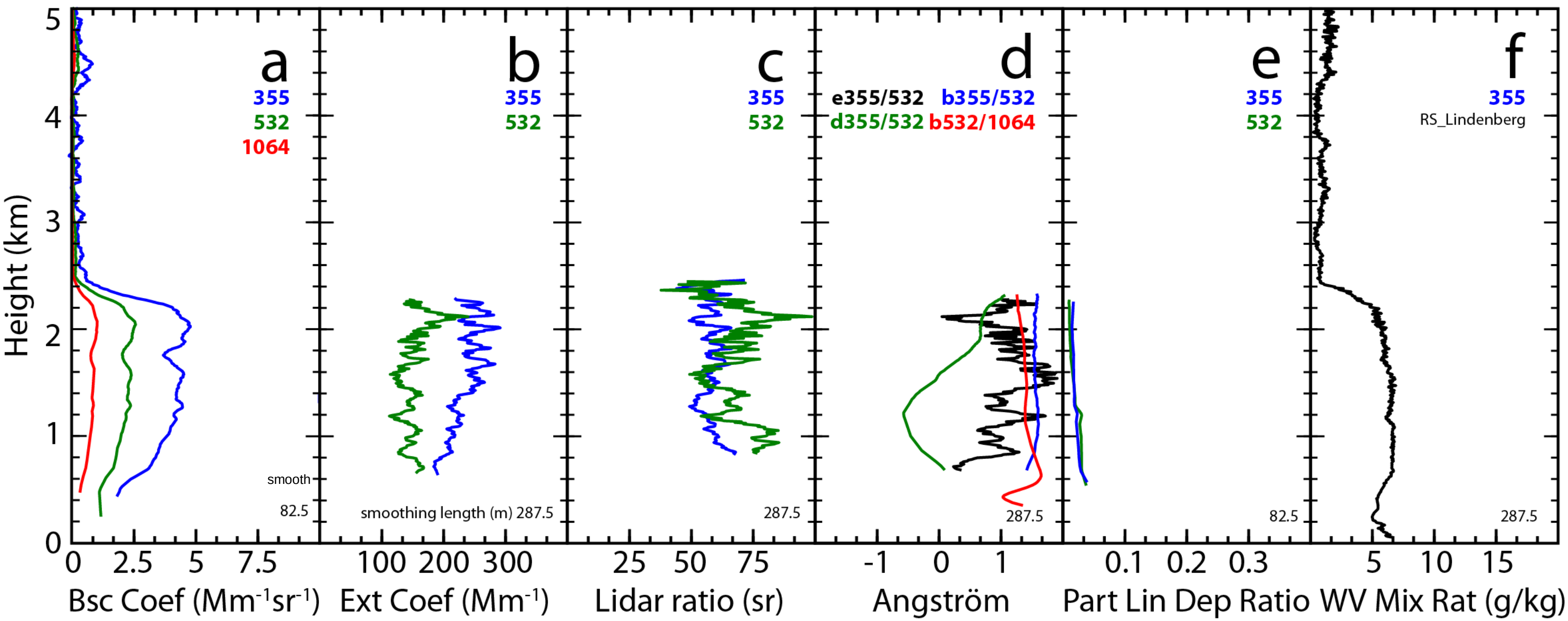
Polluted continental Biomass burning		Clean marine
Size: Ångström Exponent, Lidar ratio		
å > 1	å = 0	å = 0
Absorption: Lidar ratio		
S > 60 sr	S = 55 sr	S = 25 sr
Shape: Depolarization ratio		
δ = 0.05	δ = 0.31	δ = 0.02

Example: PBL aerosol, LE, 17 July 2013





Example: PBL aerosol, LE, 17 July 2013



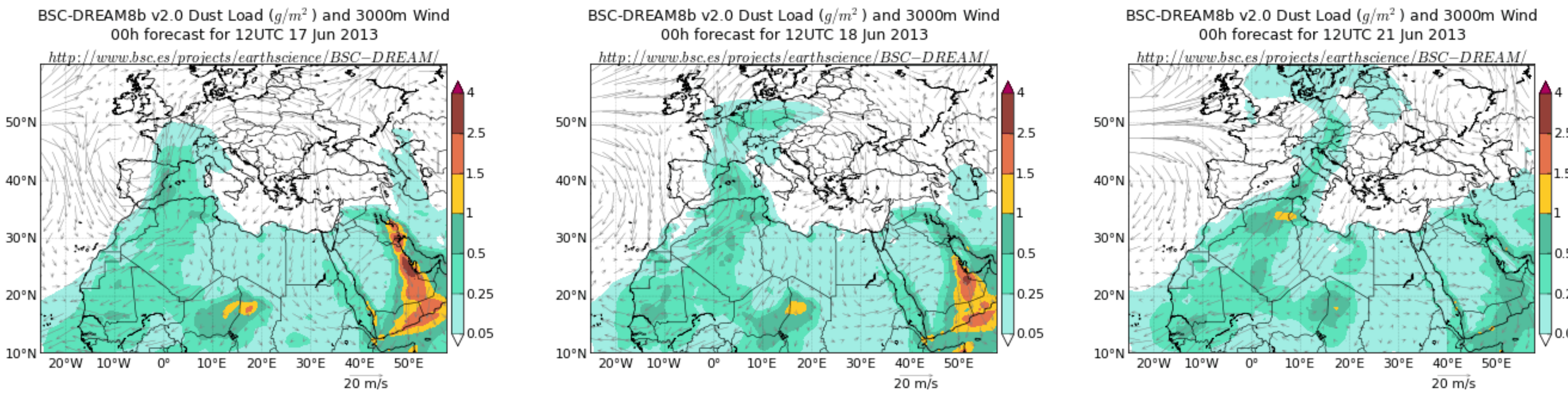
$LR_{355} = 51.1 \pm 5.4$ sr
$LR_{532} = 54.8 \pm 9.4$ sr

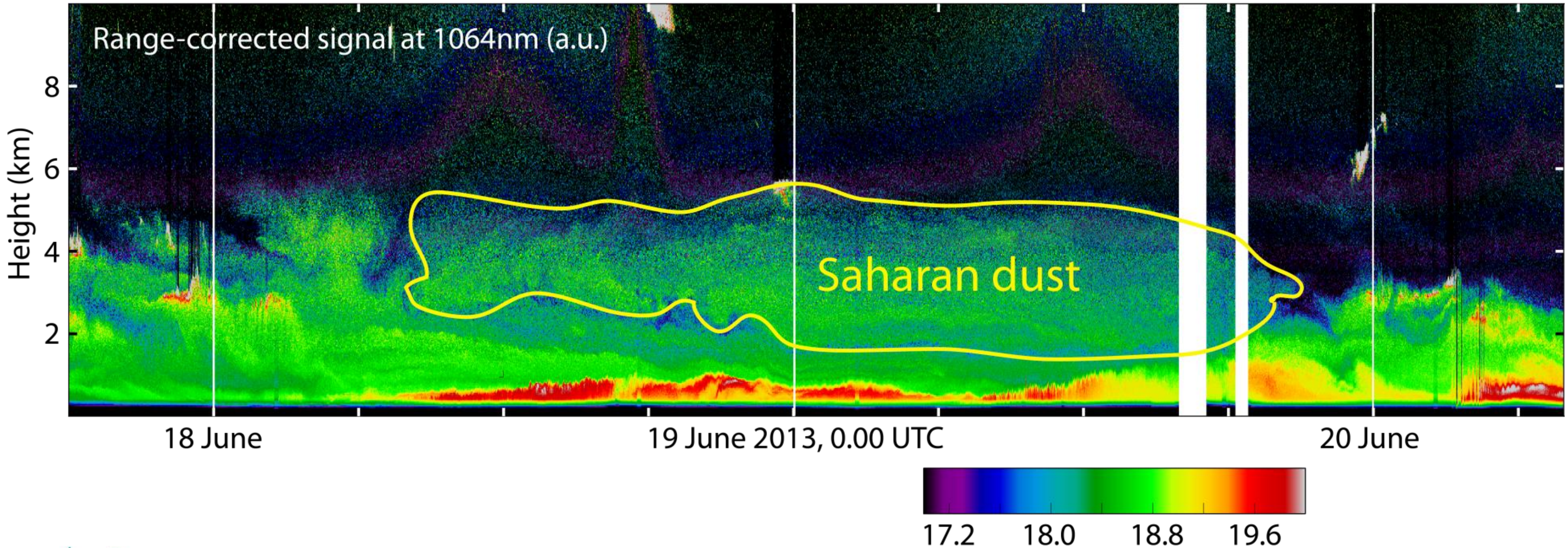
$Ang_{b355/532} = 1.5$
$Ang_{b532/1064} = 1.5$

$Ang_{e355/532} = 1.3$
$Ang_{d355/532} = 0.1$

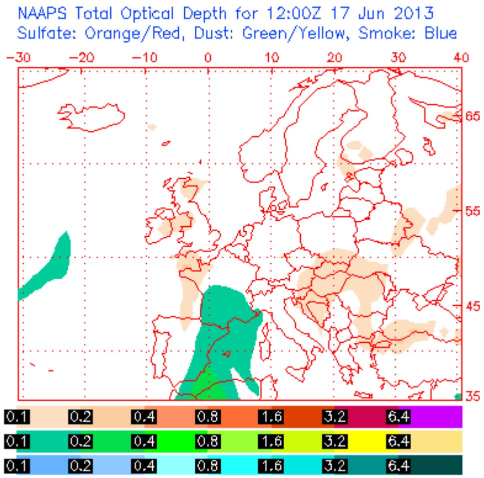
$\delta_{P355} = 2\%$
$\delta_{P532} = 2\%$

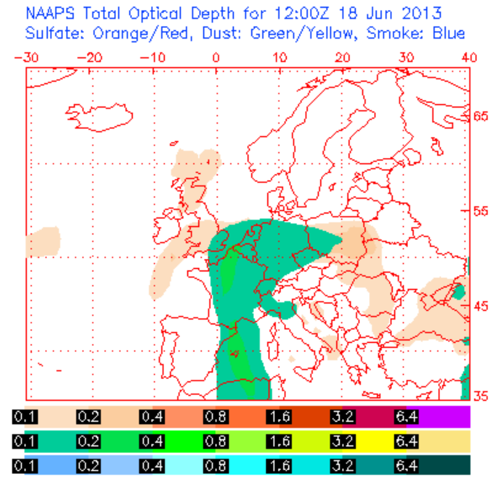
Example: Saharan dust, LE, 18 June 2013

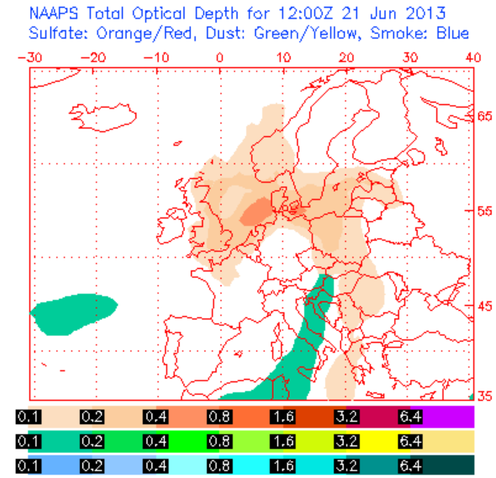


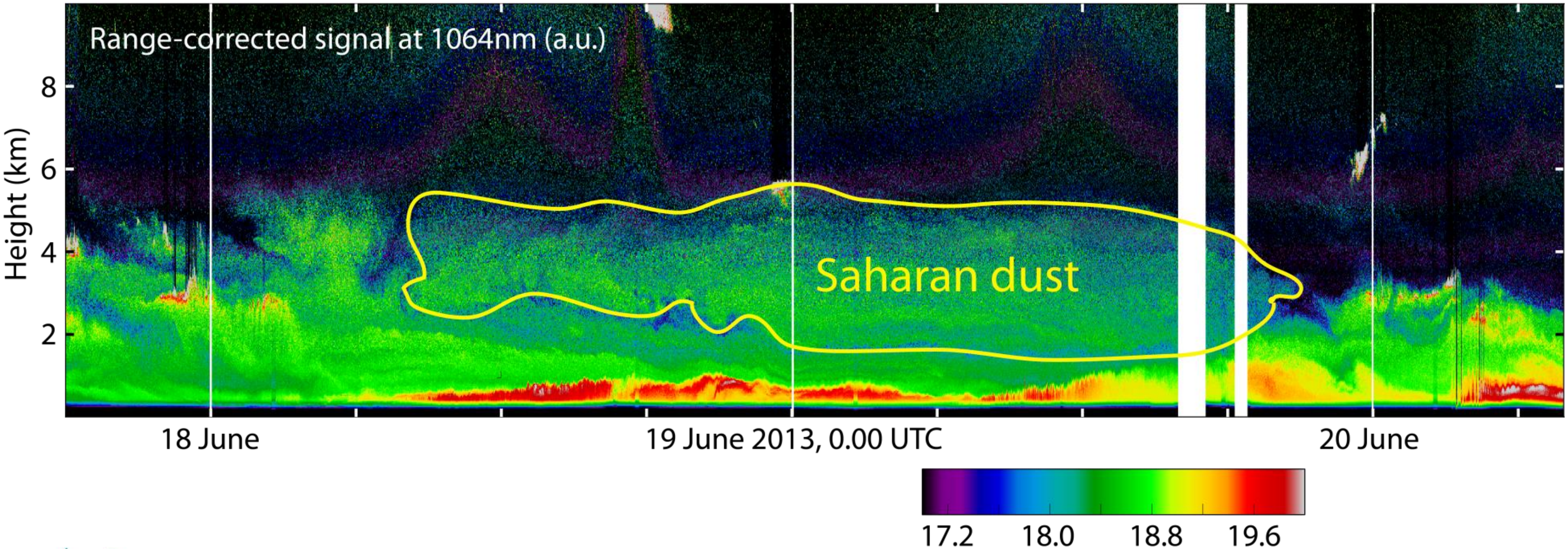


Example: Saharan dust, LE, 18 June 2013









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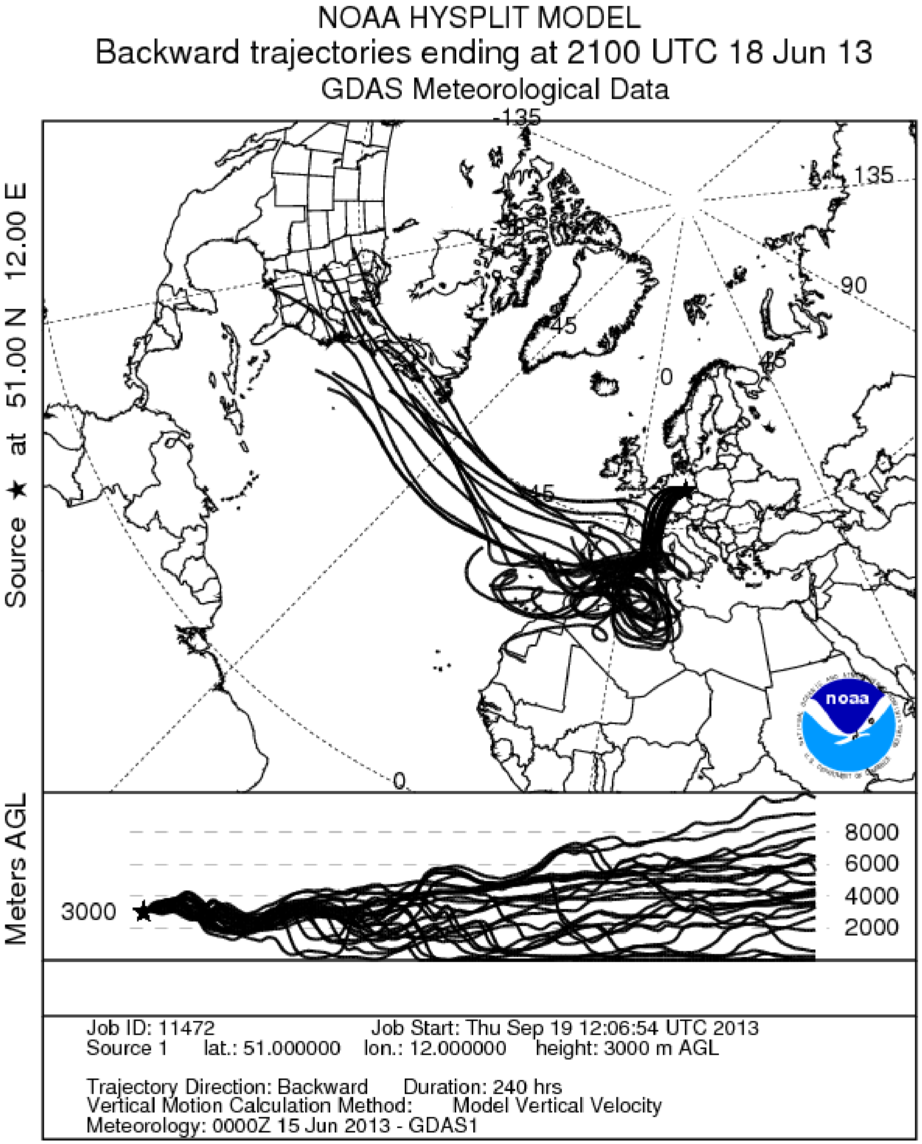
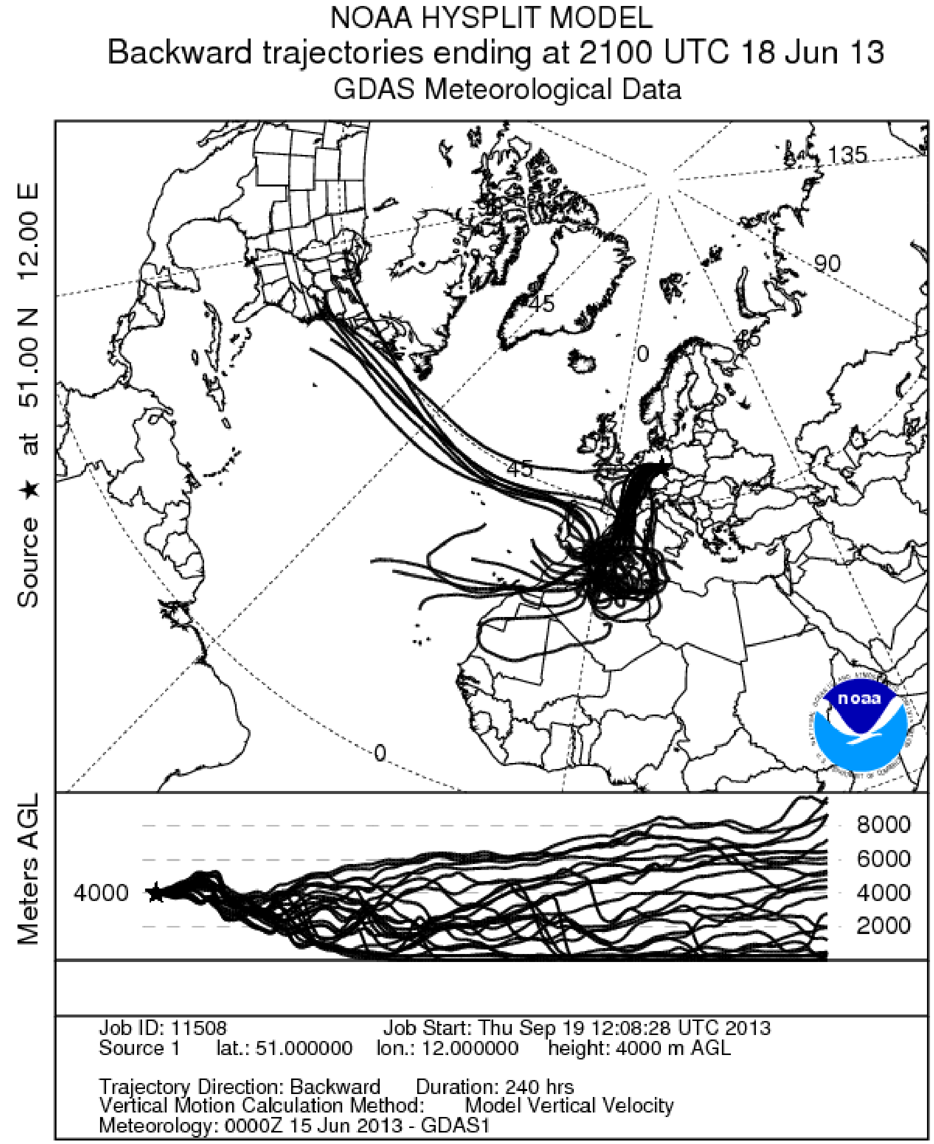
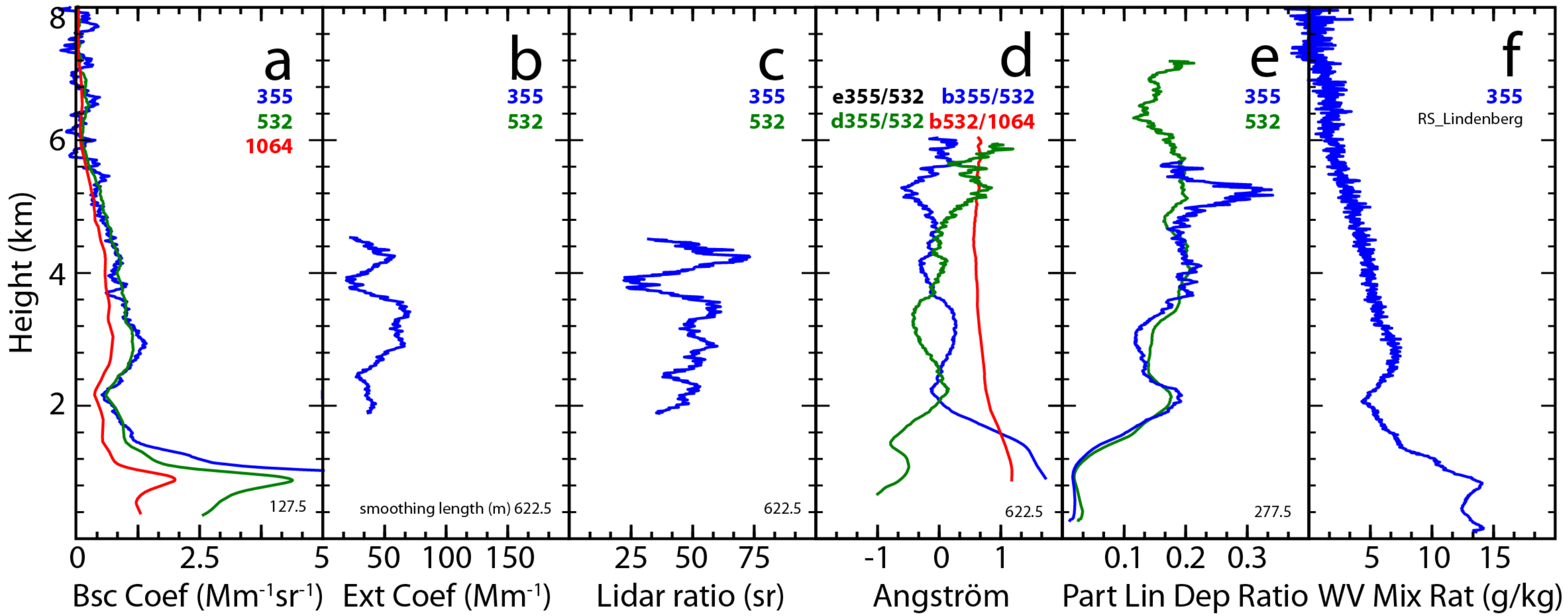
Example: Saharan dust, LE, 18 June 2013





Example: Saharan dust, LE, 18 June 2013



LR_{355} = 48.3 ± 9.2 sr

$Ang_{b355/532}$ = 0.0

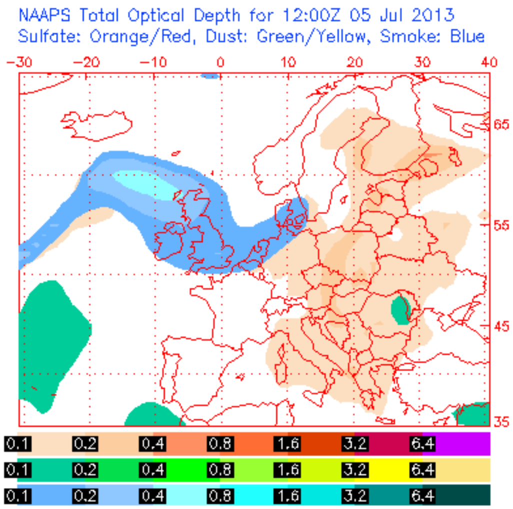
δ_{P355} = 19%

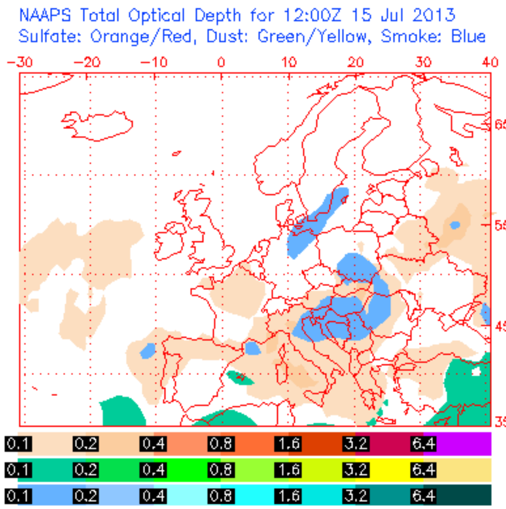
$Ang_{b532/1064}$ = 0.7

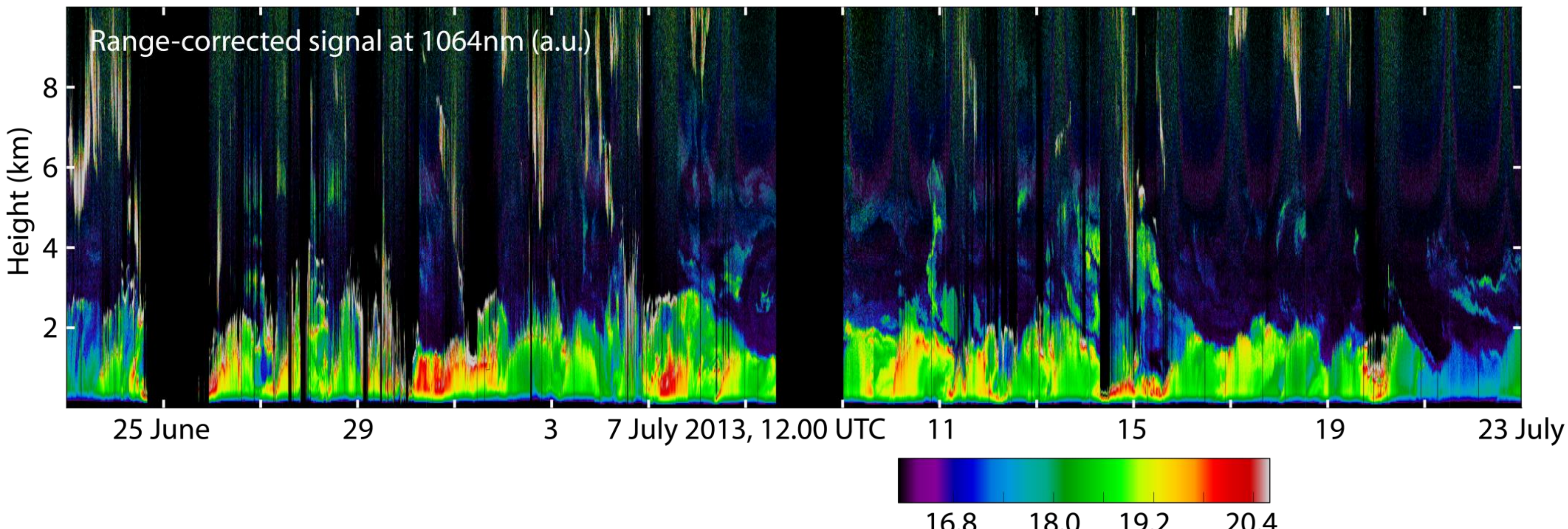
δ_{P532} = 19%

$Ang_{d355/532}$ = -0.1

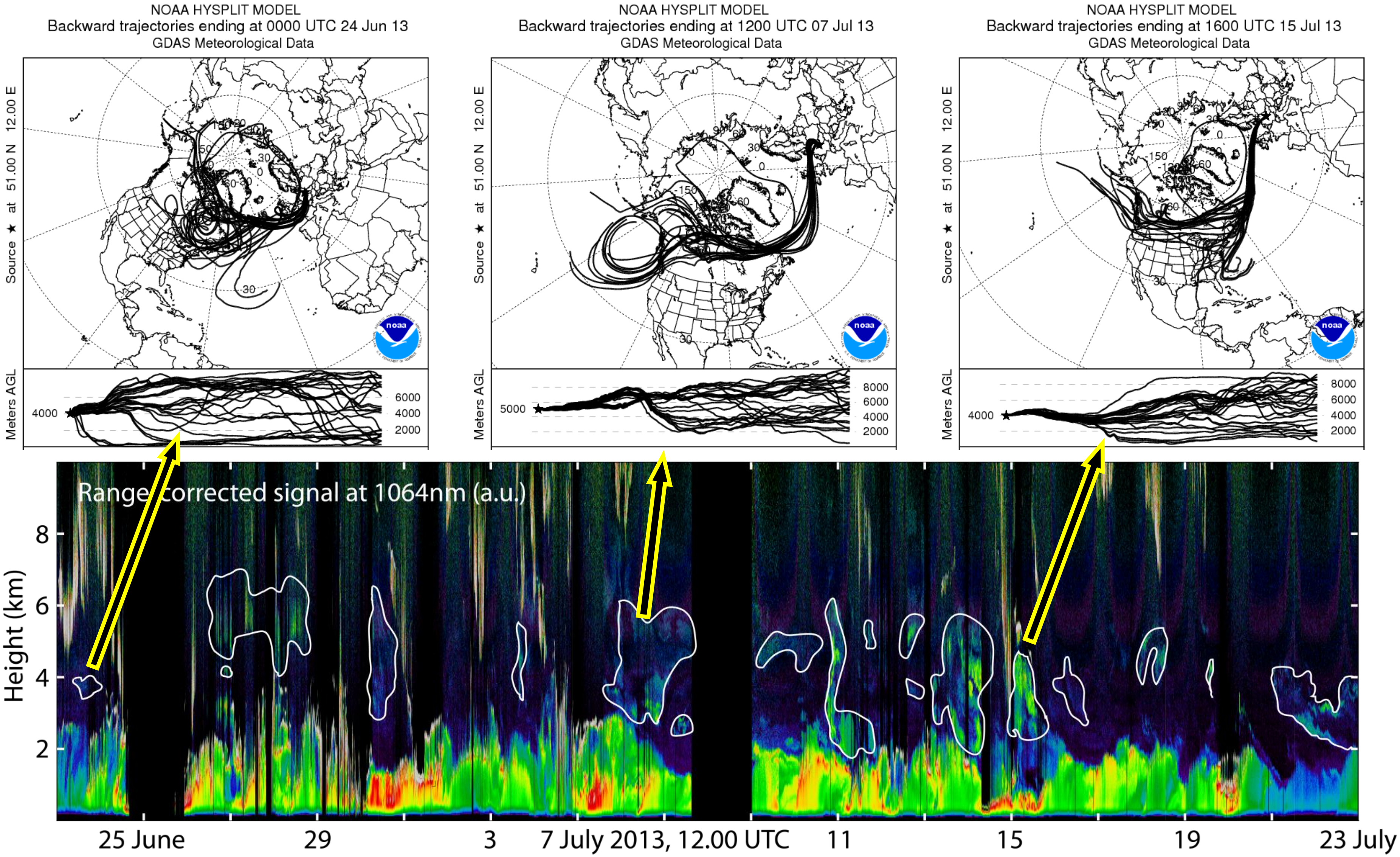
Example: Forest-fire smoke, LE, 18 June 2013







Example: Forest-fire smoke, LE, 18 June 2013



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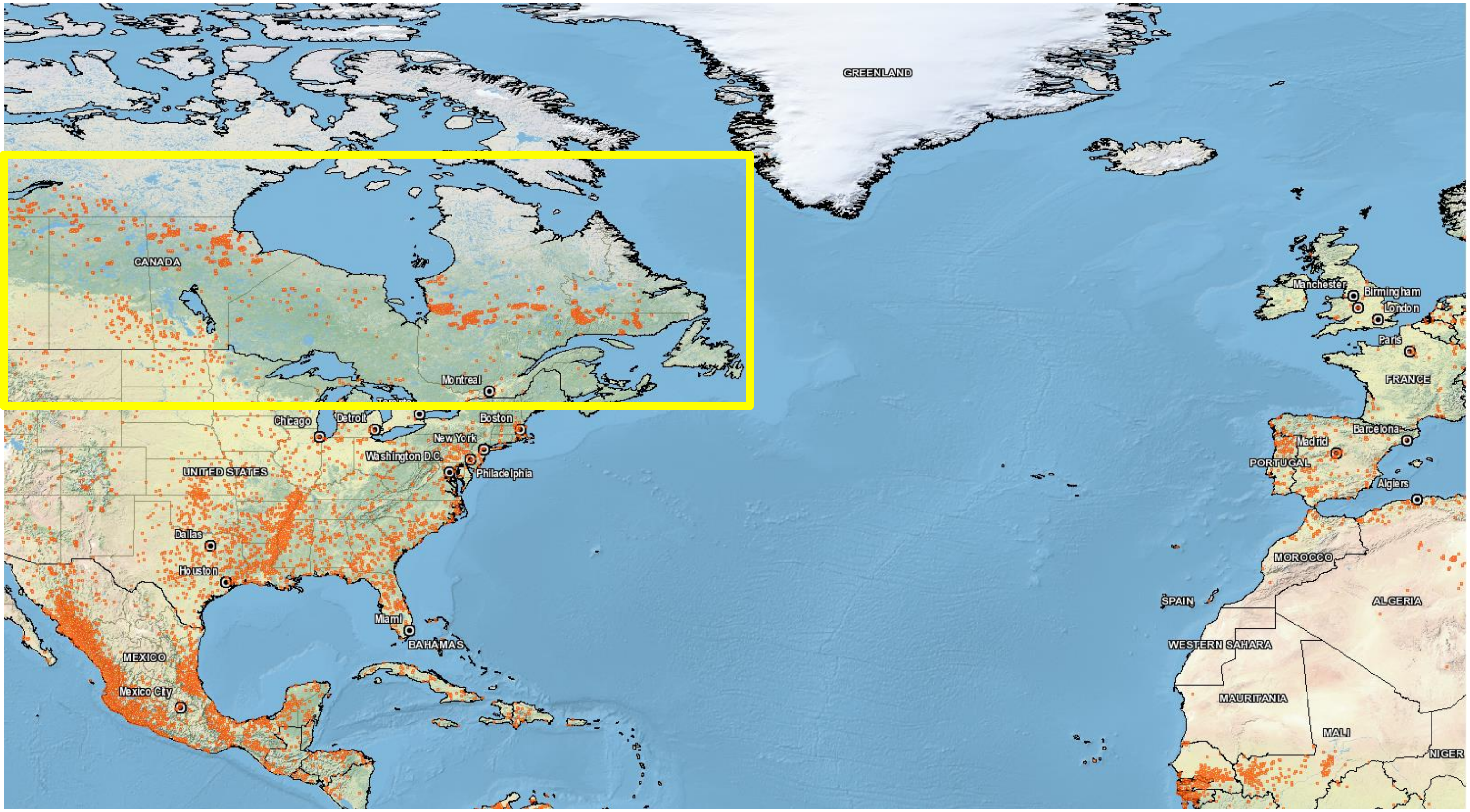
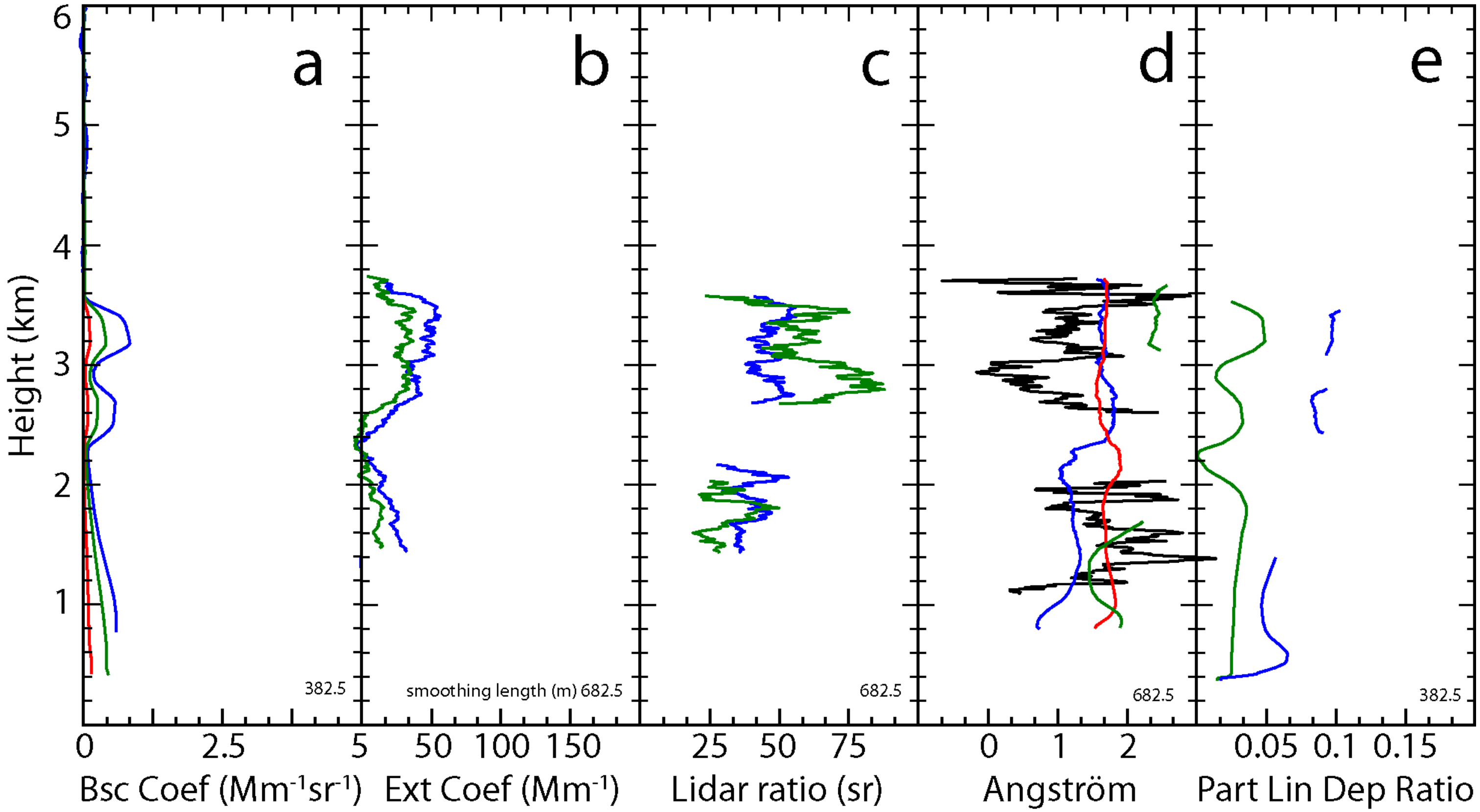
Example: Forest-fire smoke, LE, 18 June 2013

MODIS firemaps, 1 June to 25 July 2013



Example: Forest-fire smoke, LE, 18 June 2013



LR_{355} = 47 ± 5 sr
LR_{532} = 61 ± 1 sr

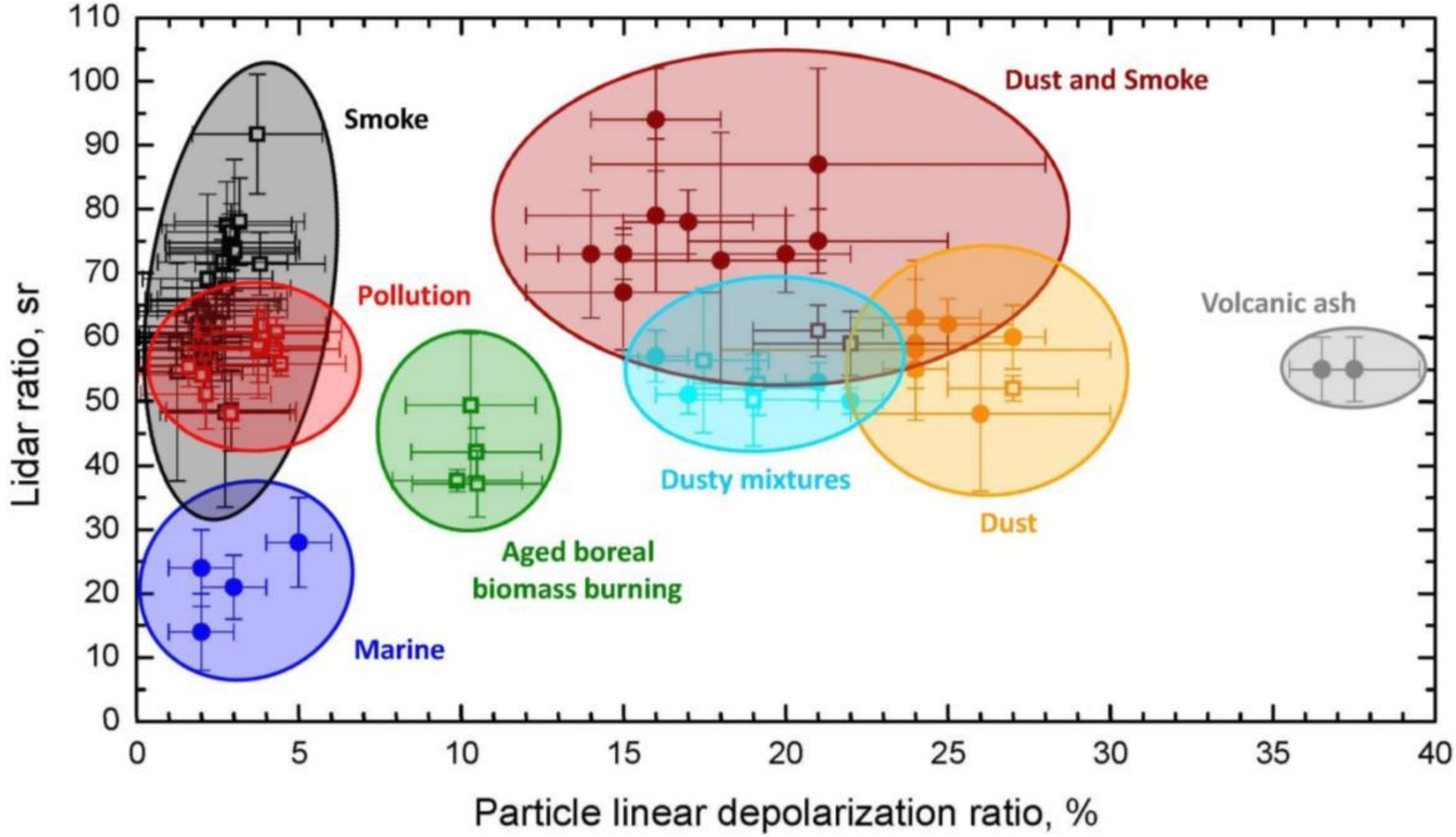
$Ang_{b355/532}$ = 1.7
$Ang_{b532/1064}$ = 1.7

$Ang_{e355/532}$ = 1.1
$Ang_{d355/532}$ = 2.1

δ_{P355} = 9%
δ_{P532} = 4%

Aerosol typing – EarthCARE observables

Aerosol classification from measurements of lidar ratio and particle linear depolarization ratio at **355 nm**



Measurements from EARLINET, SAMUM-1/2, Polarstern, Amazonia; TROPOS and MIM

Multiwavelength Raman polarization lidar (EARLINET)

Identification and location of aerosols (4-dimensional)

Characterization/typing of aerosols

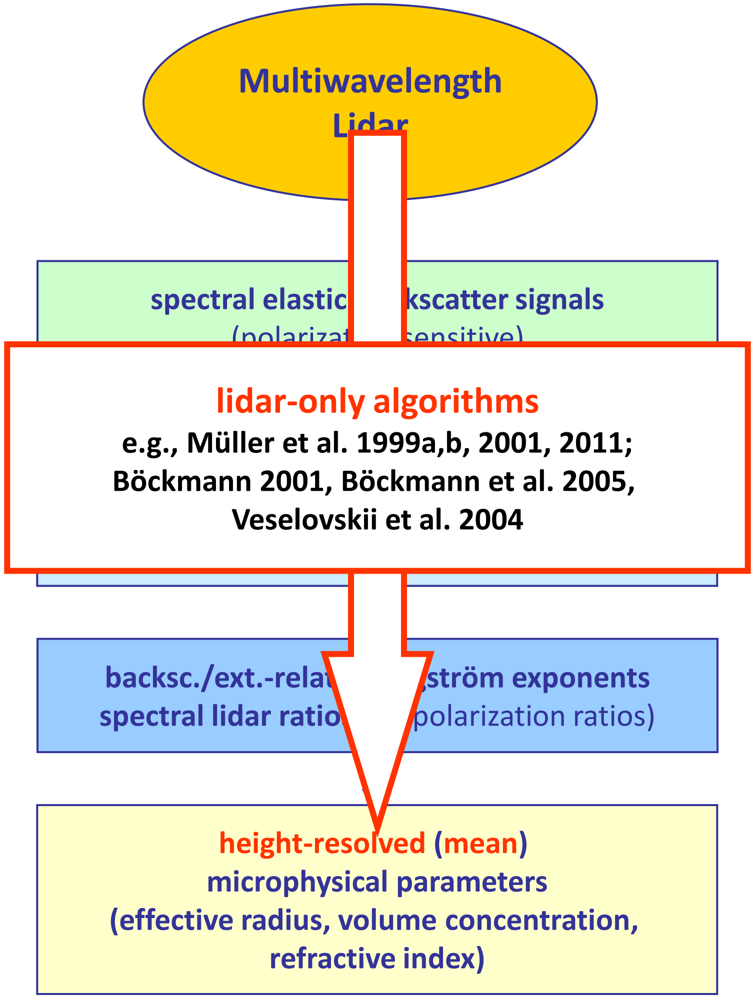
Quantification

Optical, microphysical, and radiative properties

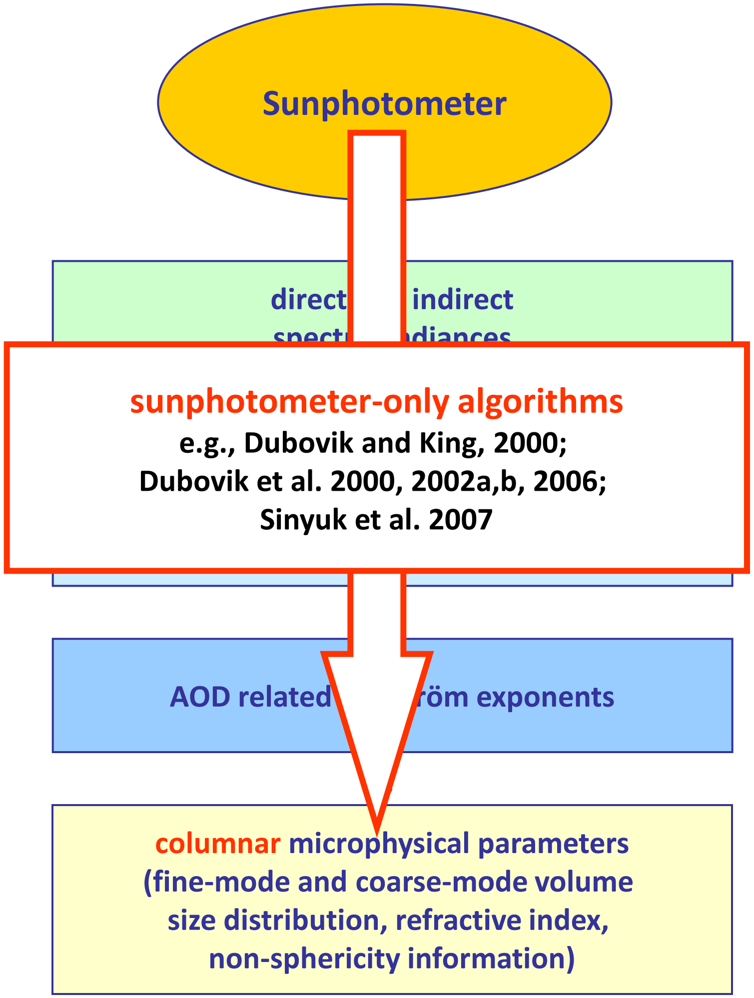
Source identification, transport

➔ Vertically resolved

➔ Limited microphysical characterization, and daytime capabilities



Sunphotometer observations (AERONET)



Identification of aerosols

Characterization/typing of aerosols

Quantification

Optical, microphyisical, and radiative properties

➔ Restricted to columnar properties, daytime, cloud-free scenes only

Combining lidar and sunphotometer observations

Sunphotometer

↓

direct and indirect spectral radiances (polarization sensitive)

↓

spectral aerosol optical depth

↓

AOD related Angström exponents

↓

columnar microphysical parameters (fine-mode and coarse-mode volume size distribution, refractive index, non-sphericity information)

Multiwavelength Lidar

↓

spectral elastic-backscatter signals (polarization sensitive) **spectral Raman signals**

↓

spectral backscatter coefficients (pol. sens.) **spectral extinction coefficients**

↓

backsc./ext.-related Angström exponents spectral lidar ratios, (depolarization ratios)

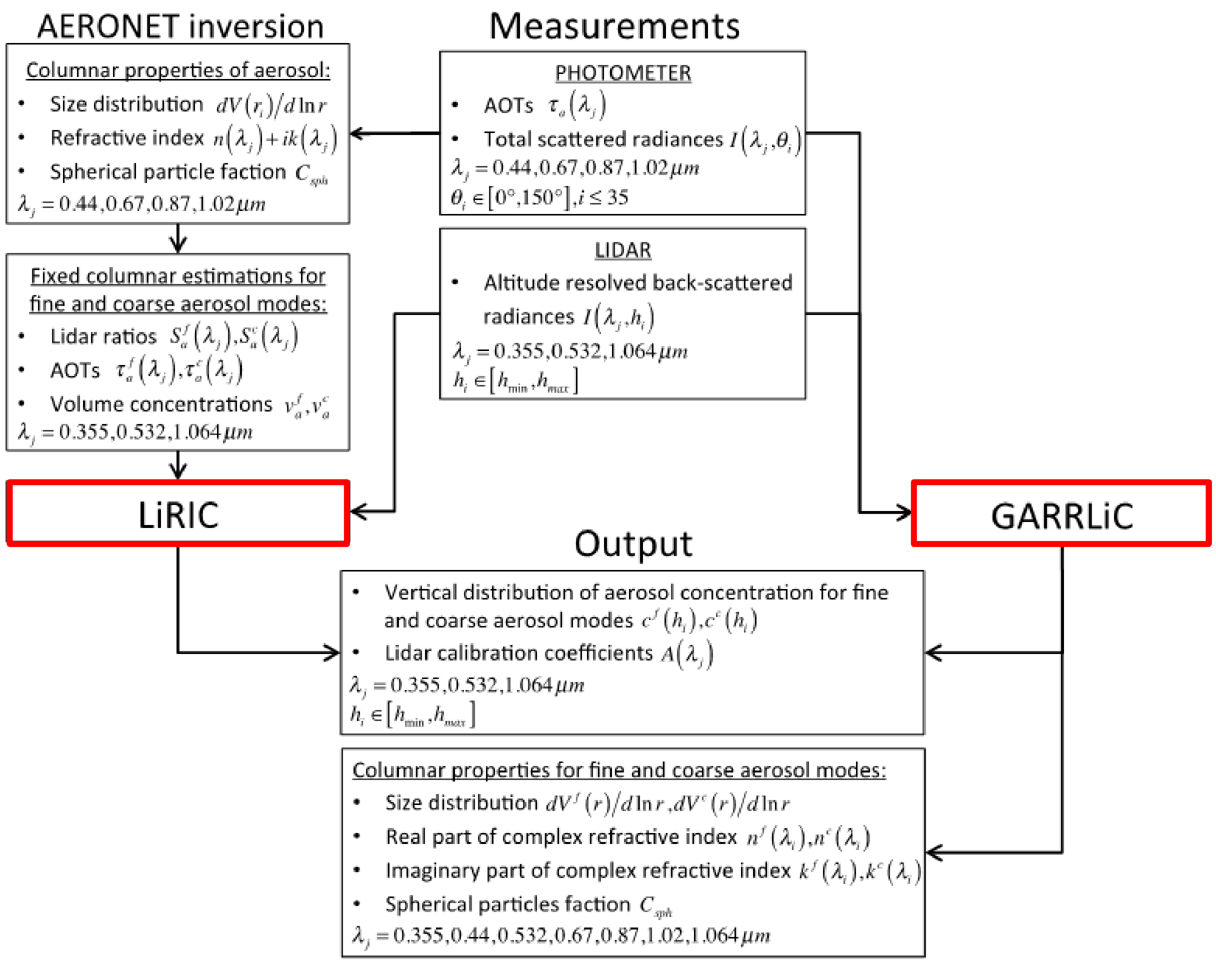
↓

height-resolved (mean) microphysical parameters (effective radius, volume concentration, refractive index)

GOAL

improved height-resolved microphysical parameters

Lidar/sun photometer integrated algorithms

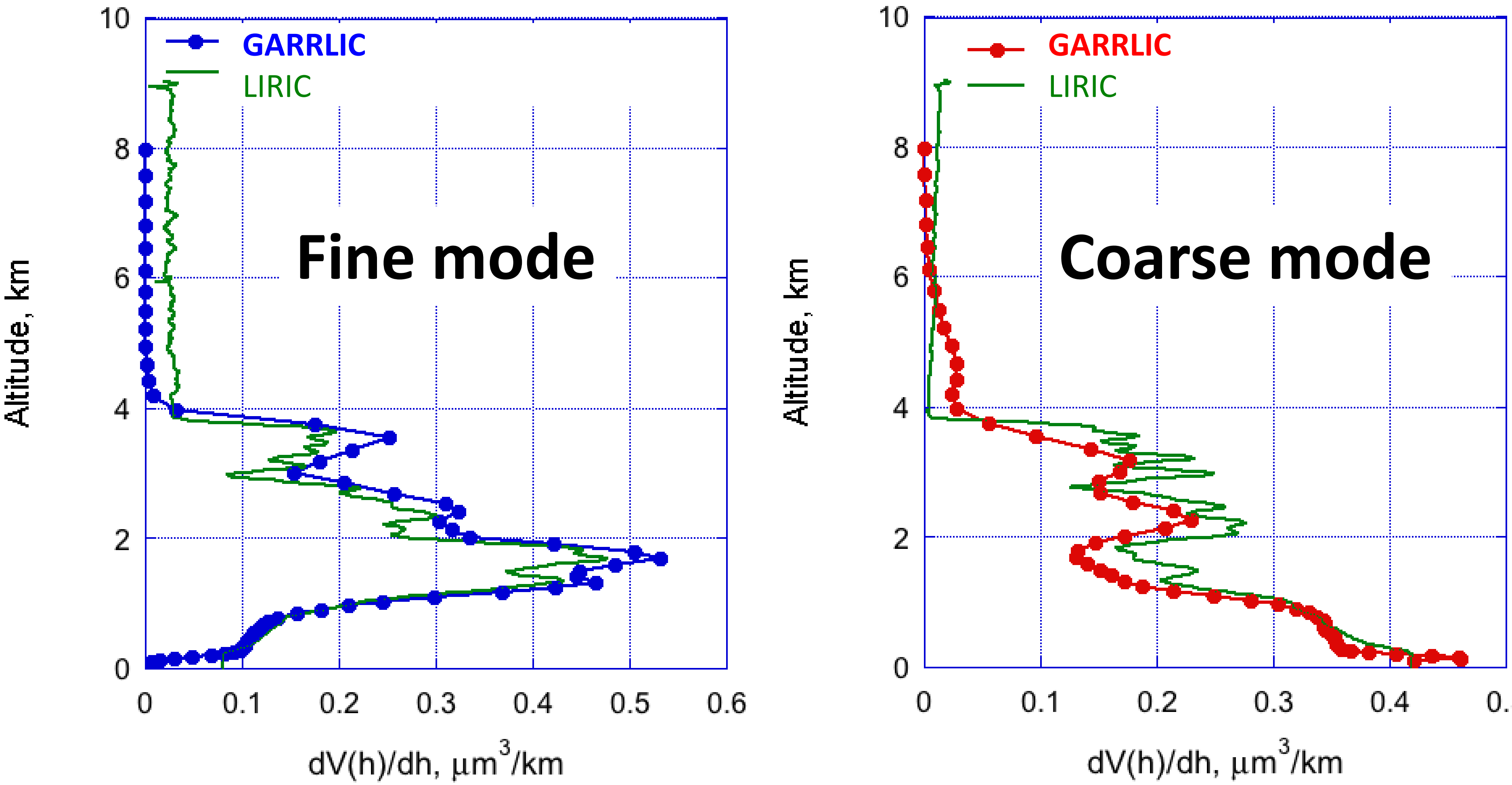


Generalized **A**erosol **R**etrieval from **R**adiometer and **LI**dar **C**ombined data
Laboratoire d'Optique Atmosphérique, Lille (O. Dubovik)

Lidar/**R**adiometer **I**nversion **C**ode
Institute of Physics of the National Academy of Science of Belarus, Minsk (A. Chaikovsky)

Smoke event: *GARRLIC* versus *LIRIC*

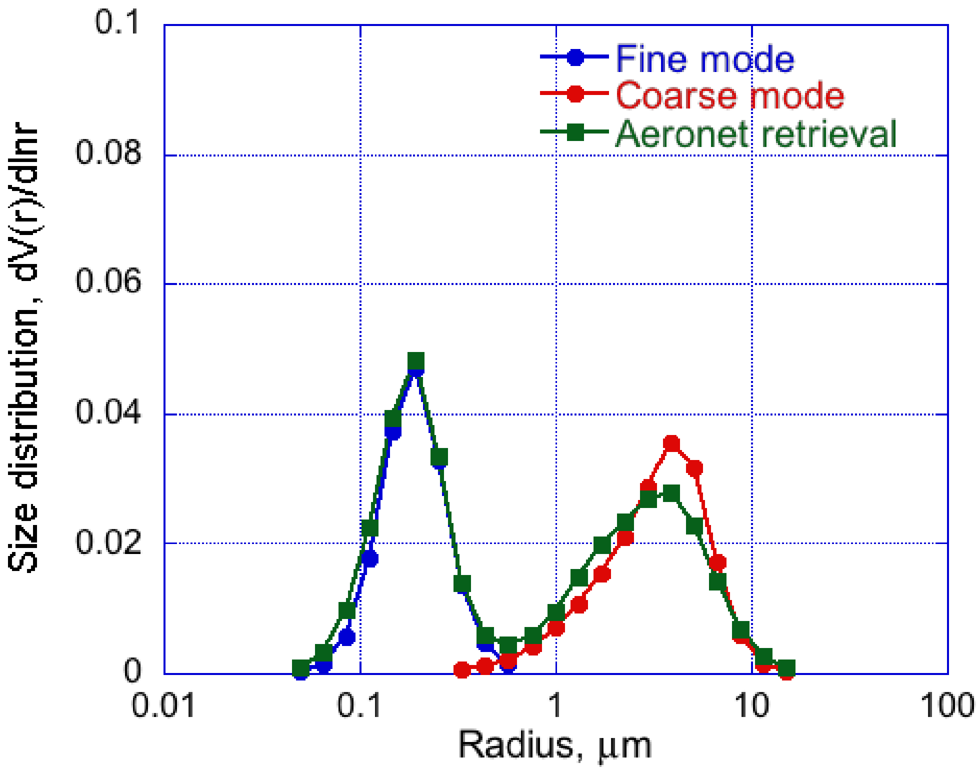
Smoke event, Minsk, 13 August 2010

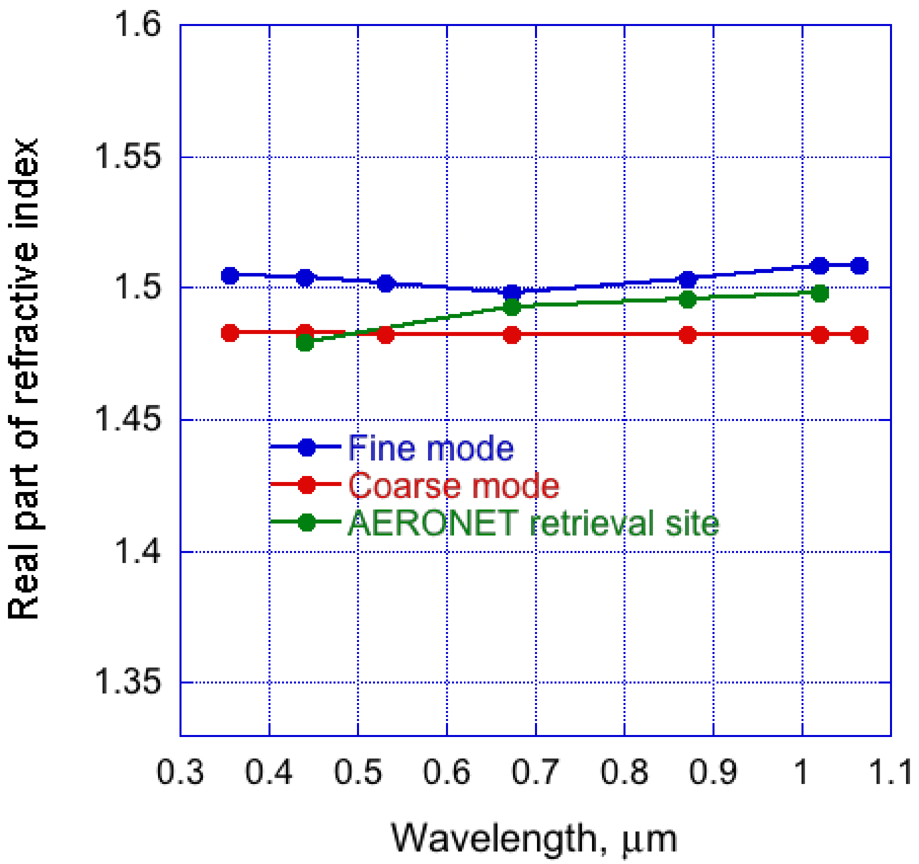


Lopatin, A., et al., AMT, 2013

GARRLIC: Improved columnar products

Smoke event, Minsk, 13 August 2010



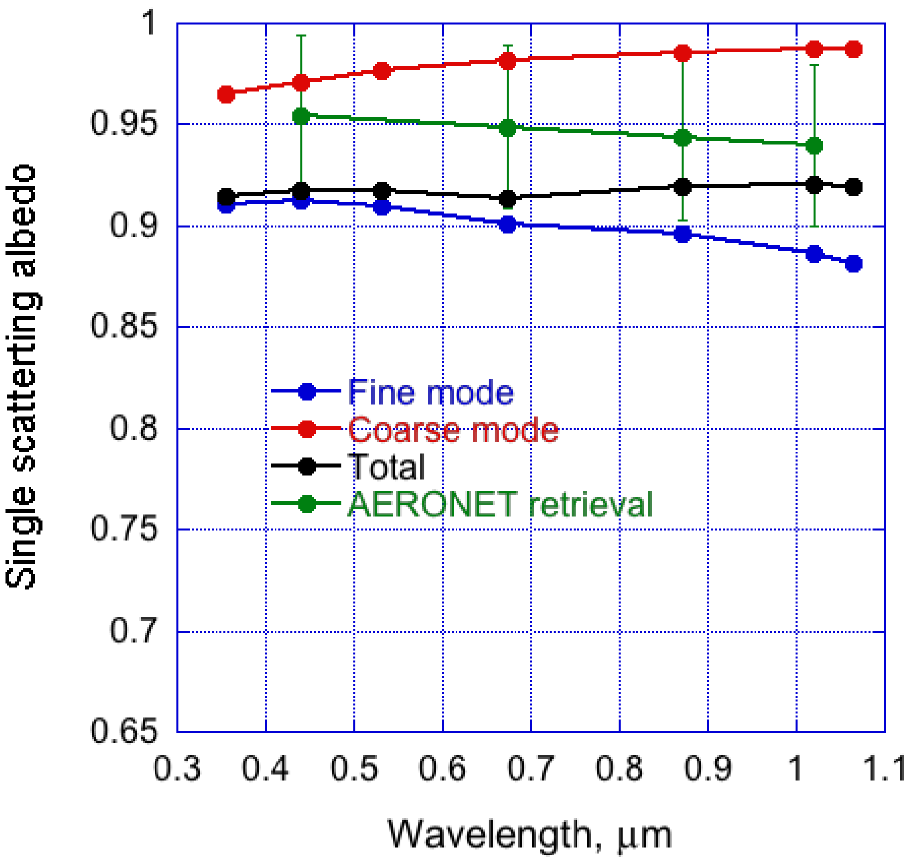


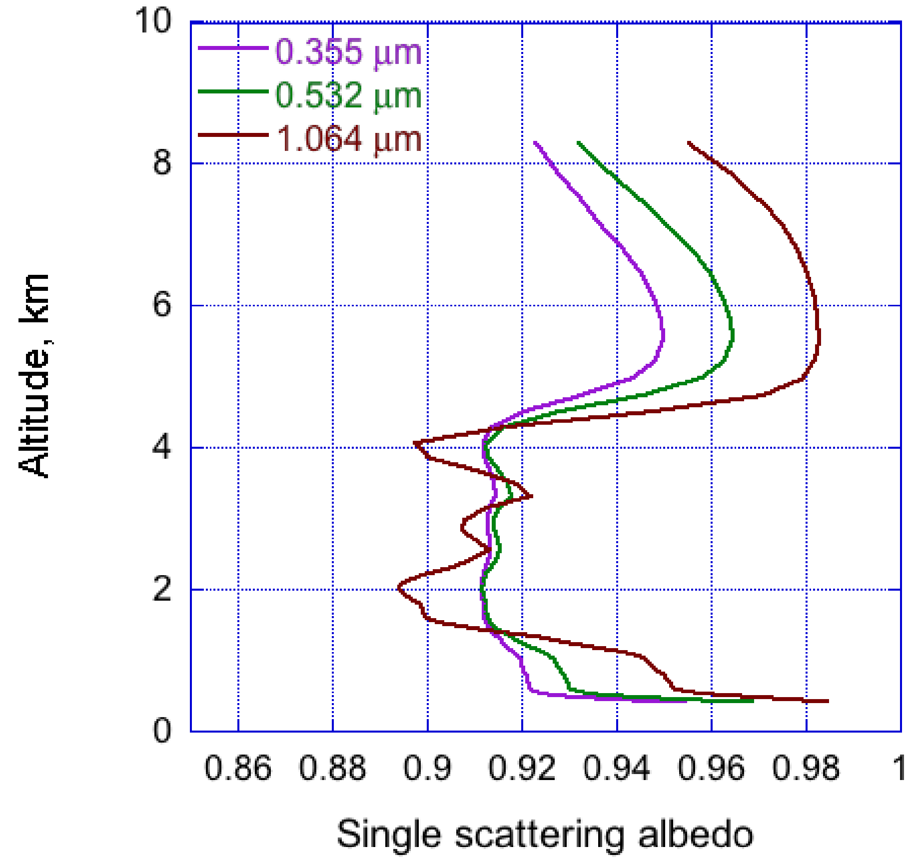
Lopatin, A., et al., AMT, 2013

GARRLIC: Single scattering albedo

Smoke event, Minsk, 13 August 2010

New product!

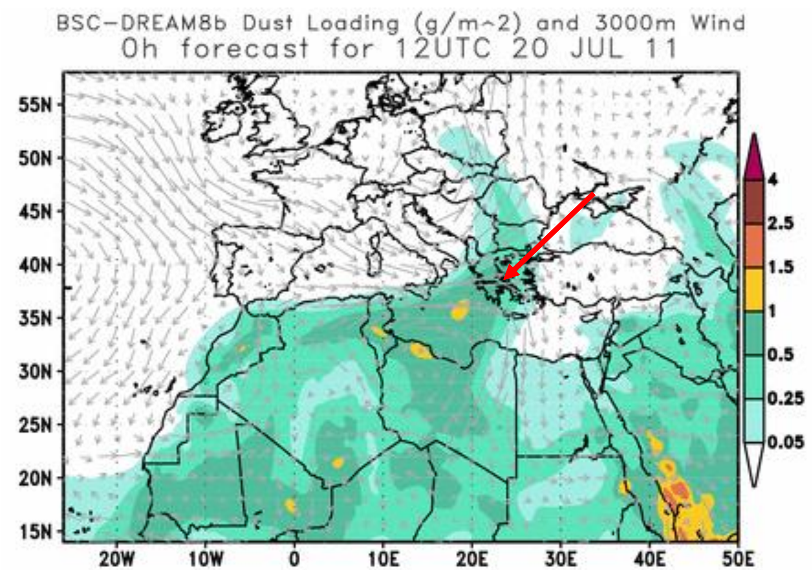


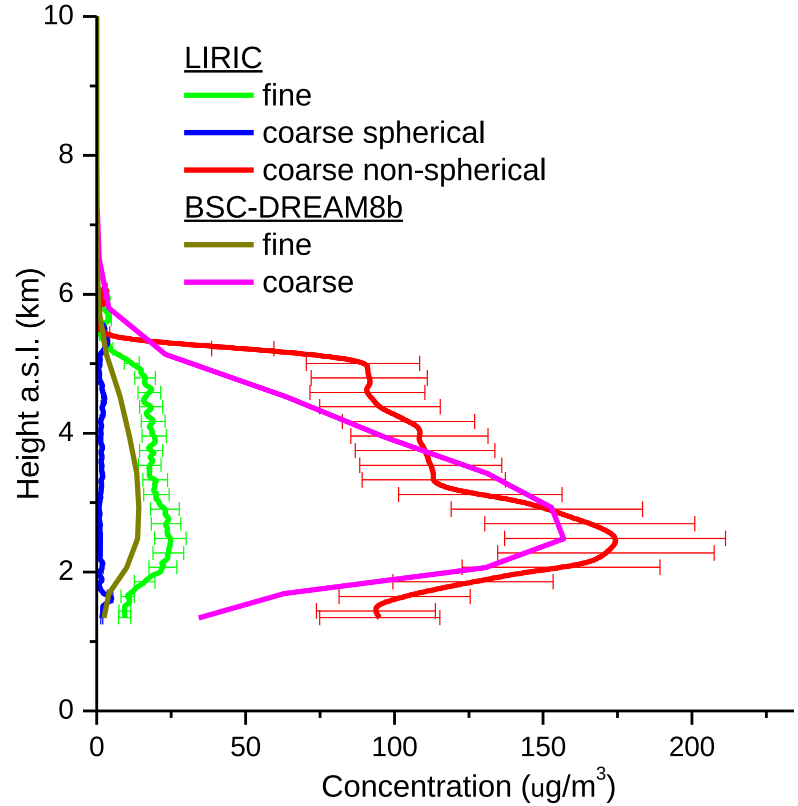


Lopatin, A., et al., AMT, 2013

LIRIC and *DREAM*: Athens, 20 July 2011

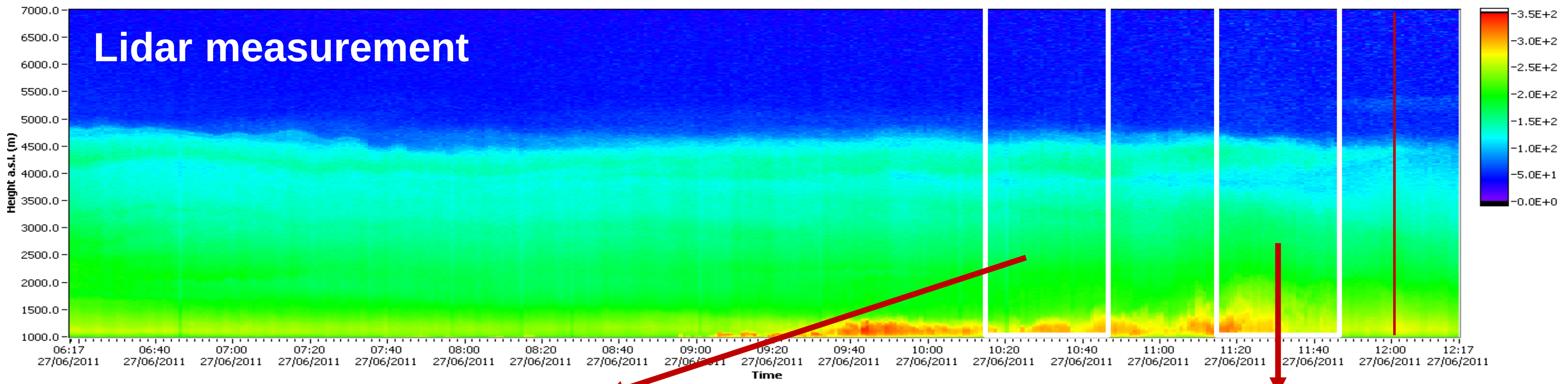
BSC-DREAM8b model vs. LIRIC combined lidar-sunphotometer retrieval





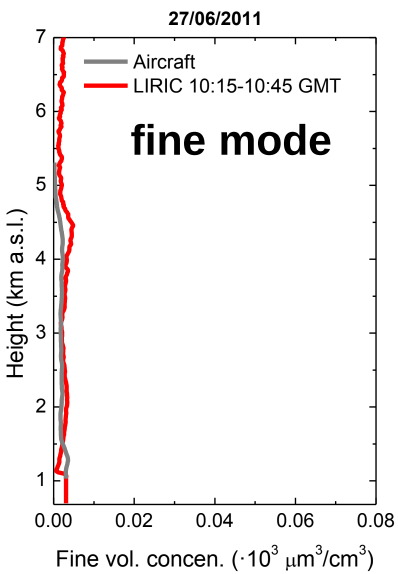
Tsekeri, A., et al.: Application of a synergetic lidar and sunphotometer algorithm for the characterization of a dust event over Athens, Greece, British Journal of Environment and Climate Change (accepted)

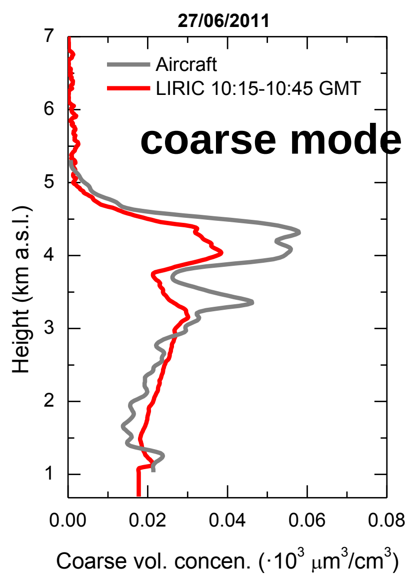
LIRIC and *DREAM*: Granada, 27 June 2011



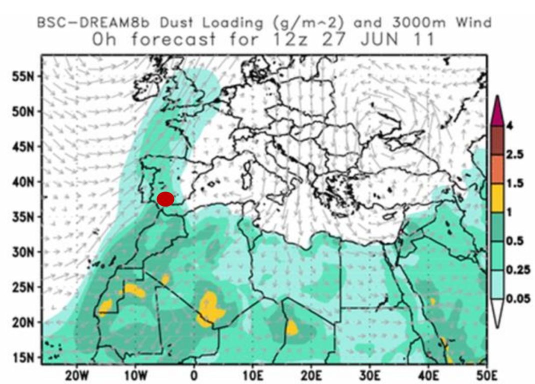
Combined lidar/sunphotometer retrieval vs. aircraft in-situ observation (PCASP)

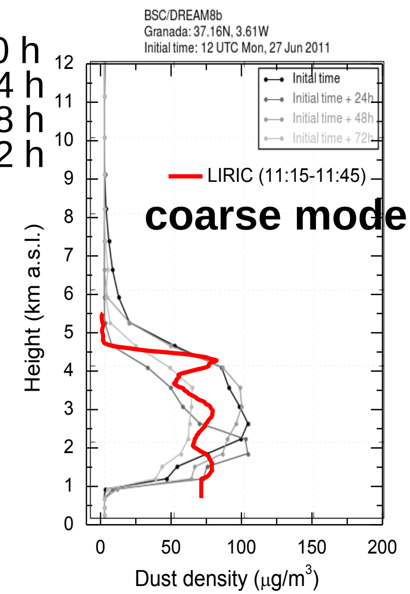
Combined lidar/sunphotometer retrieval vs. BSC-DREAM model forecast





Model initiation: 0 h
-24 h
-48 h
-72 h





Summary

1) Lidar (multiwavelength, Raman, polarization) for vertically resolved characterization of aerosols

2) Lidar + sunphotometer for improved microphysical retrievals

3) Towards integration of aerosol and cloud observations (EARLINET/AERONET/CLOUDNET)

4) Towards continuous 24/7 atmospheric observations

5) Towards networks for covering the regional and global variability and for long-term observations

➔ Advanced datasets for model evaluation and data assimilation