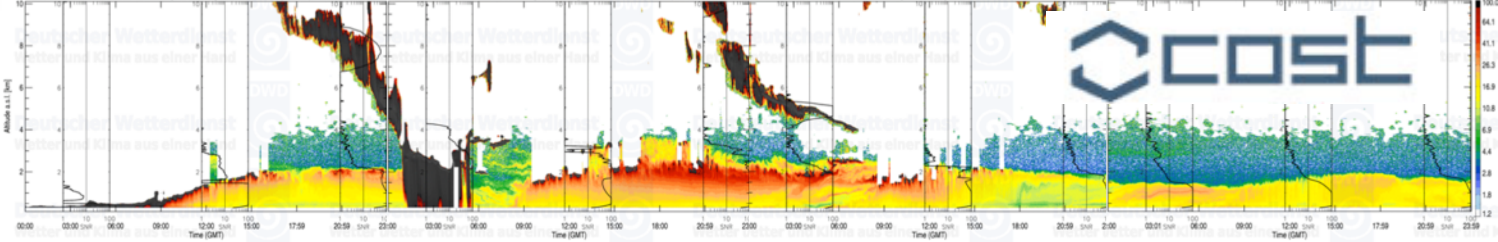


TO-PROF EU COST ACTION (ES-1303)

Training school on the use of AUTOMATIC LIDAR & CEILOMETER (ALC) real time profiling data

Martial Haeffelin, Simone Kotthaus, Juan-Antonio Bravo (IPSL)
Ina Mattis (DWD)
Maxime Hervo, Alexander Haefele (Meteoswiss)

3 September 2017
EMS Dublin

(1) How does an Automatic Lidar / Ceilometer work? (30 min)

Includes:

Instrument description, main features, advantages, limitations

List of available instruments,

Post-processing,

Calibration,

Discussion with participants

(2) What can ALC's be used for? (45 min)

Includes:

Assimilation and verification of models

Ash and dust monitoring, and typing overview

Cloud detection

Fog detection and anticipation

Atmospheric boundary layer

Discussion with participants

ALC TRAINING SCHOOL OUTLINE

(3) Existing ALC networks and practical session (45 min)

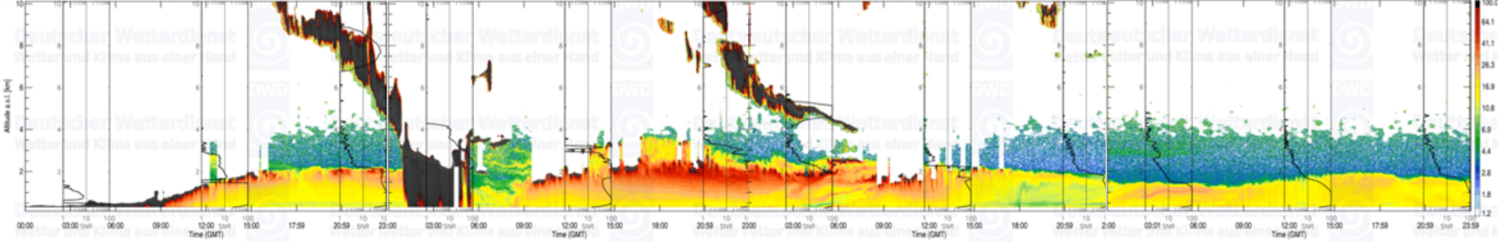
Includes:

Presentation of networks

Why different metservices use different types of instruments

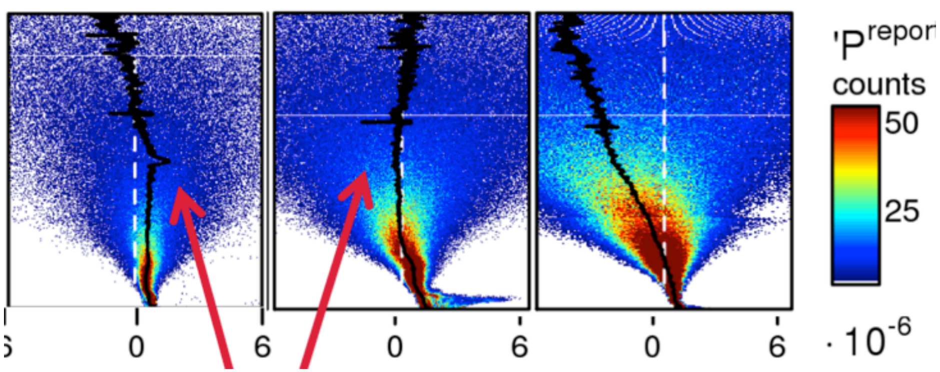
Data access, incl. how to access E-PROFILE data

Discussion with participants

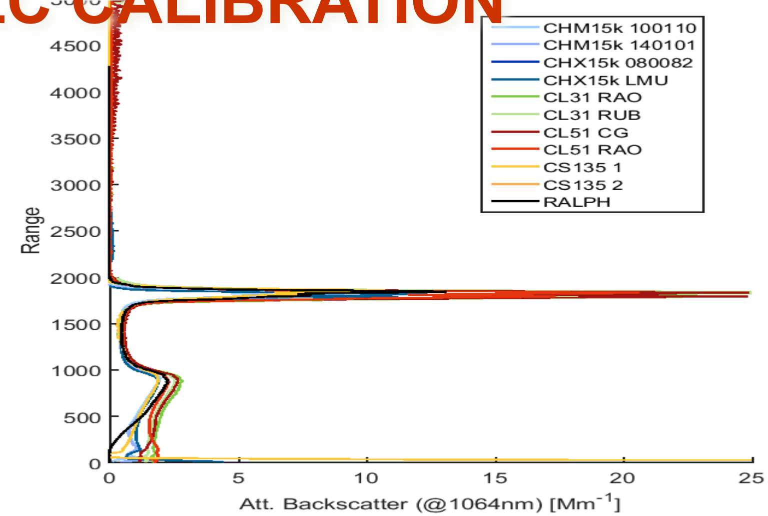


PART 1. ALC DEFINITION AND MEASUREMENTS

ALC UNCERTAINTIES



ALC CALIBRATION



ALC DEFINITION

Martial HAEFFELIN, Juan-Antonio BRAVO ARANDA
IPSL

WHAT IS AN AUTOMATIC LIDAR-CEILOMETER (ALC)?

A standard ceilometer is optoelectronic instrument used in aviation and meteorology for the automatic recording of cloud bases.

- Uniform performances

An Automatic Lidar-Ceilometer (ALC) is an optoelectronic instrument for aerosol and cloud profiling for wide range of applications

- Wide range of performances

Sigma Space	Cimel	Campbell Scientific	Vaisala	Lufft
MPL	CE376	CS135	CL31/51	CHM15k
532 nm	532/850 nm	905 nm	905 nm	1064 nm
Dual-pol	Dual-pol			





WHAT IS AN AUTOMATIC LIDAR-CEILOMETER (ALC)?

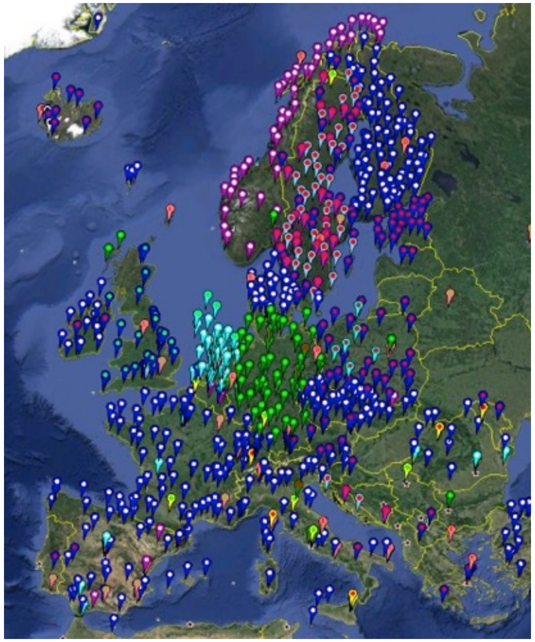
Applications:

ceilometer

- Cloud base height
- Vertical visibility

Lidar-ceilometer

- Cloud base height monitoring
- Aerosol profiling for air quality forecast
- Ash/aerosol monitoring for transport safety
- Near real time fog prediction
- Mixing height monitoring
- Numerical weather prediction model evaluation



+ Low cost
+ Operational
+ High density

- Limited aerosol capabilites

WHAT IS MEASURED BY AN ALC ?

For atmospheric aerosol detection, ALC technique is very useful, providing vertical-resolved information.

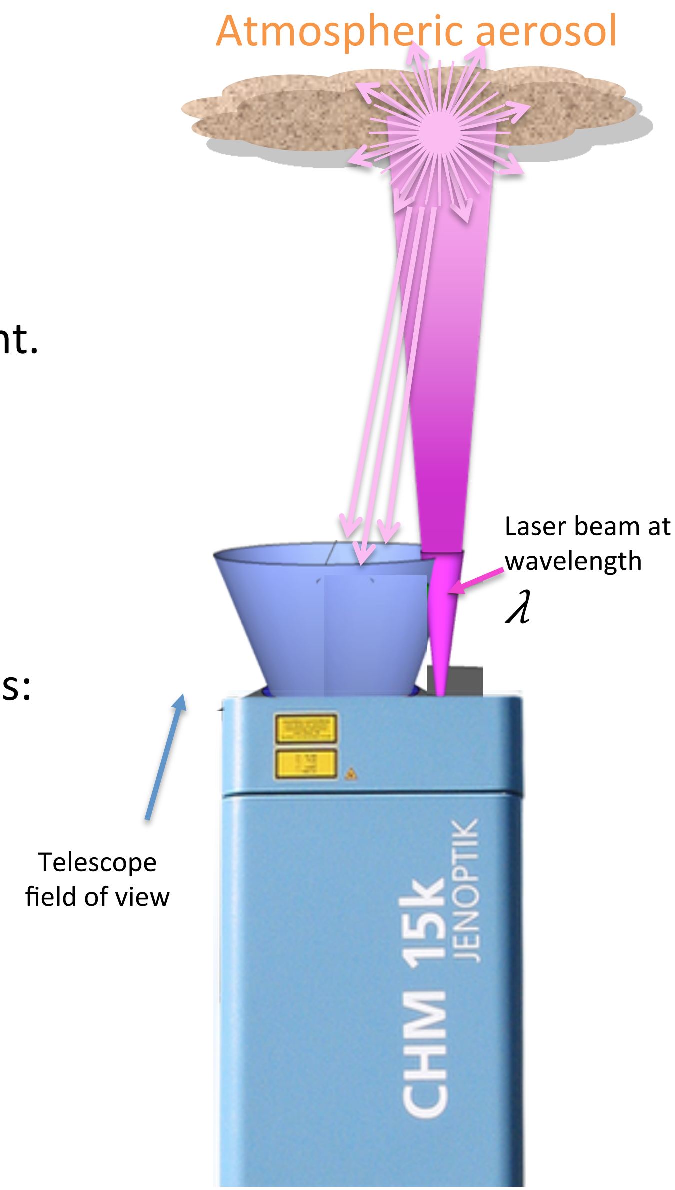
ALC performances is based on :

1) Laser pulse emission to the atmosphere
2) Telescope and optics which gather the backscattered light.
3) Detectors which converts the light into electrical signal that can be registered.

Lidar equation establishes the relationship between the measured signal and the optical aerosol properties as follows:

$$P(z,\lambda) = K\frac{O(z)}{z^2}\beta(z,\lambda)T^2(z,\lambda) + P_{BG}(\lambda)$$

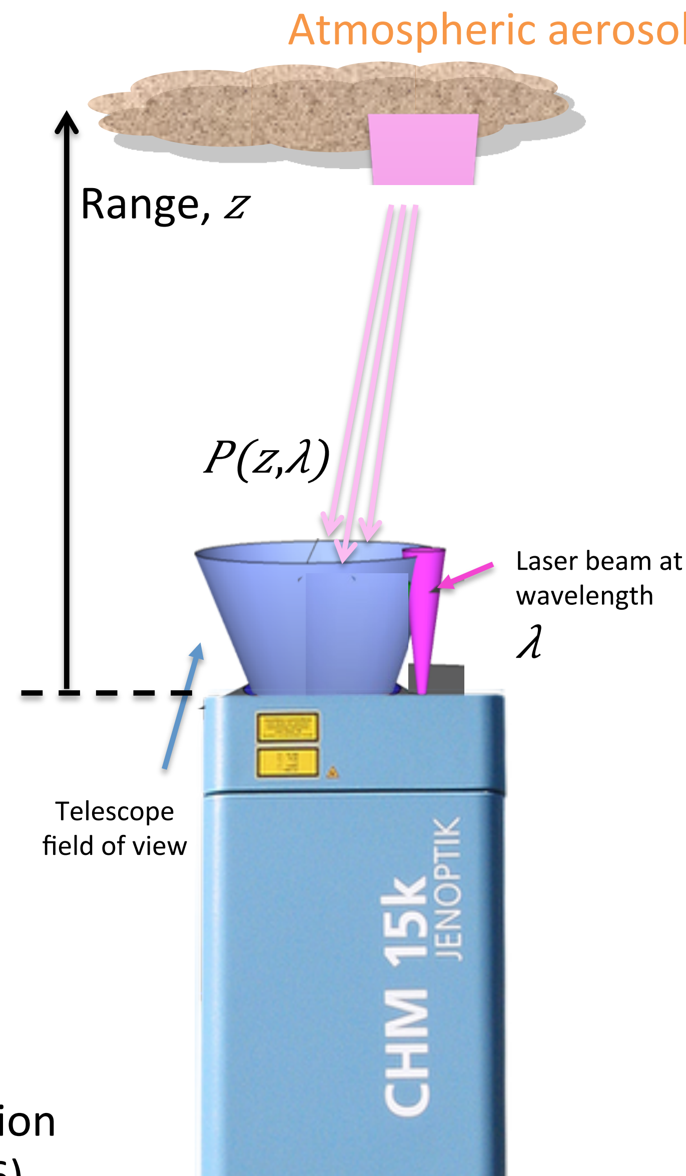
Atmospheric properties!!
(molecules+particles)

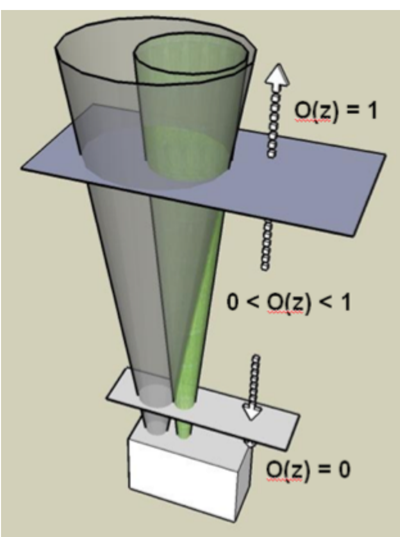


WHAT IS MEASURED BY AN ALC ?

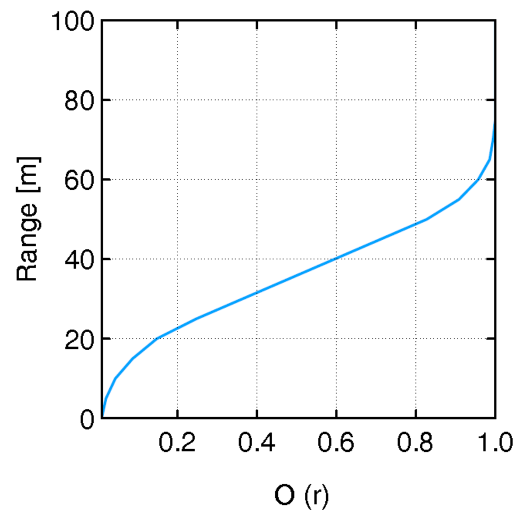
$$P(z,\lambda) = K\,\frac{O(z)}{z^2}\,\beta(z,\lambda)\,T^2(z,\lambda) + P_{BG}(\lambda)$$

- $\boldsymbol{P(z,\lambda)}$: Backscattered signal
- $\boldsymbol{K}$: calibration constant
- $\boldsymbol{O(z)}$: Overlap function





Overlap function

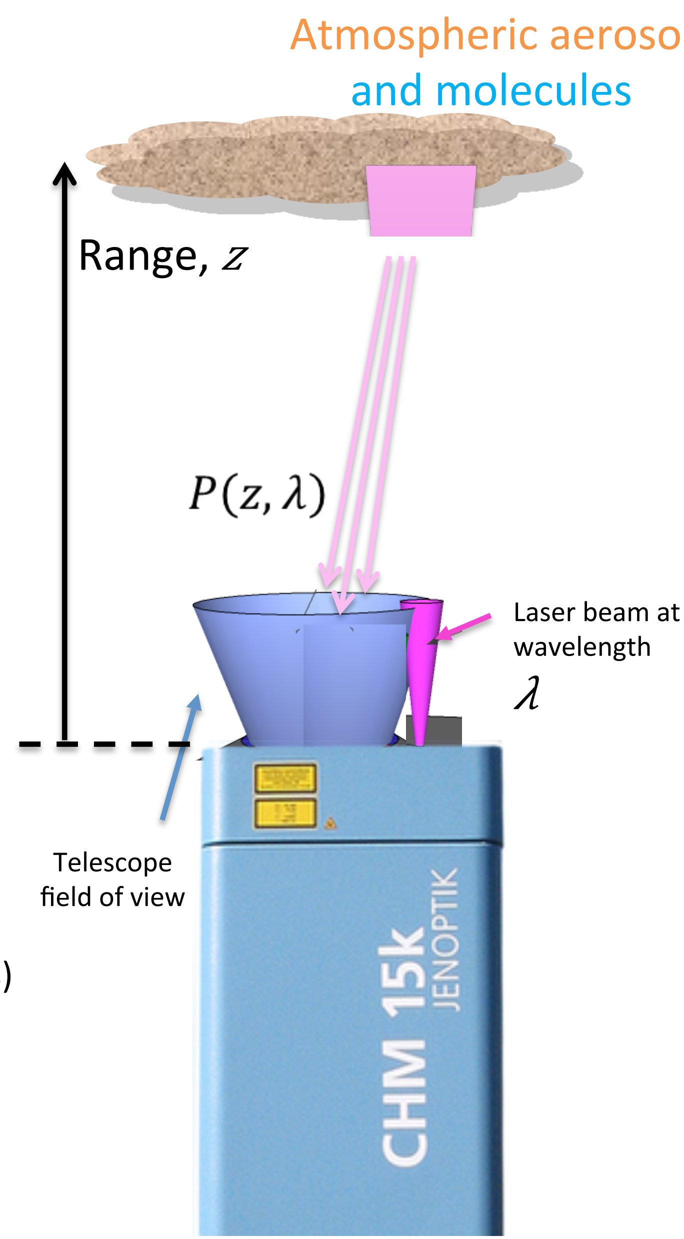


Manufacturer-deduced overlap function of Vaisala CL31 (Kothaus et al., 2016)

WHAT IS MEASURED BY AN ALC ?

Atmospheric properties!!
(molecules+particles)

$$P(z,\lambda) = K\,\frac{O(z)}{z^2}\,\beta(z,\lambda)\,T^2(z,\lambda) + P_{BG}(\lambda)$$



$\boldsymbol{P(z,\lambda)}$: Backscattered signal

$\boldsymbol{K}$: calibration constant

$\boldsymbol{O(z)}$: Overlap function

$\boldsymbol{\beta(z,\lambda)}$: backscattering coefficient (molecules+particles)

$\boldsymbol{T(z,\lambda)}$: transmittance, defined by:

$$T(z,\lambda) = exp\left(-\int_0^z \alpha(\xi,\lambda)\,d\xi\right)$$

where $\boldsymbol{\alpha(\xi,\lambda)}$ is the extinction coefficient (molecules+particles)

$\boldsymbol{P_{BG}(\lambda)}$: background signal

WHAT IS MEASURED BY AN ALC ?

We need, a little bit of signal preprocessing…

$$P(z,\lambda) = K\frac{O(z)}{z^2}\beta(z,\lambda)T^2(z,\lambda) + P_{BG}(\lambda)$$

Subtracting the background signal and applying the range correction as follows:

$$RCS = \left(P(z,\lambda) - P_{BG}(\lambda)\right)z^2$$

The *Range Corrected Signal* can be written as:

$$RCS = KO(z)\beta(z,\lambda)T^2(z,\lambda)$$

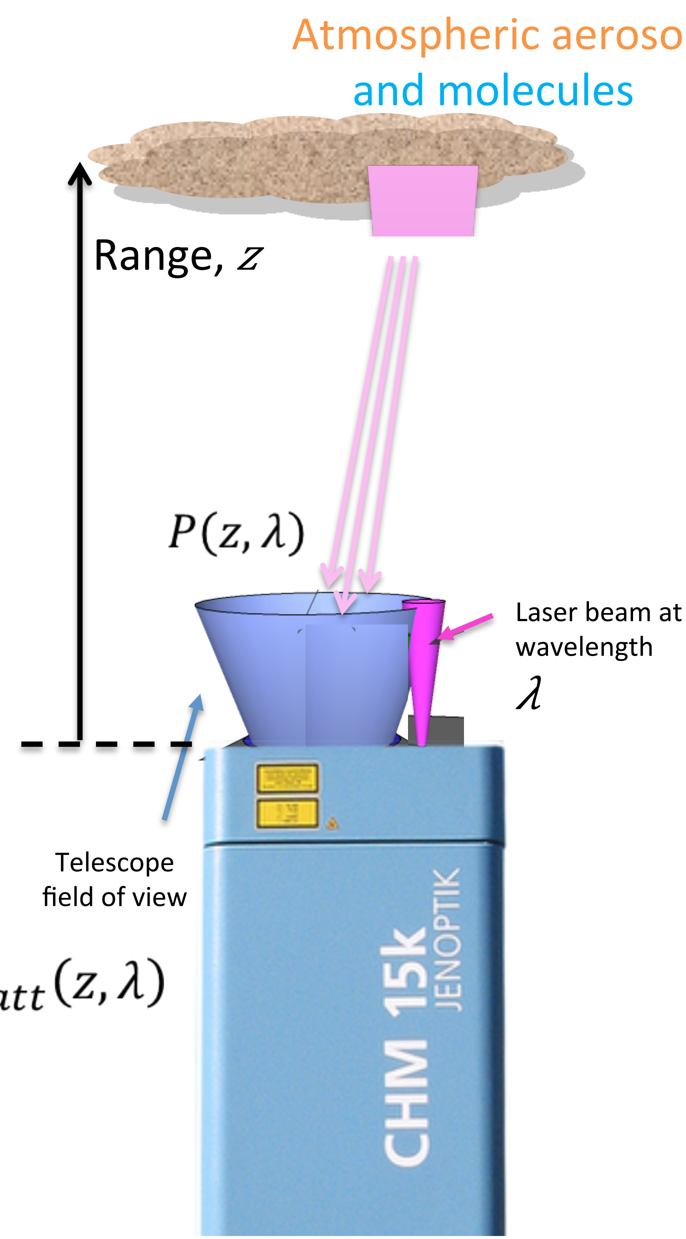
Assuming $O(z)\sim 1$:

$$RCS = K\beta(z,\lambda)T^2(z,\lambda)$$

$\beta(z,\lambda)T^2(z,\lambda)$ is named **attenuated backscatter,** $\beta_{att}(z,\lambda)$

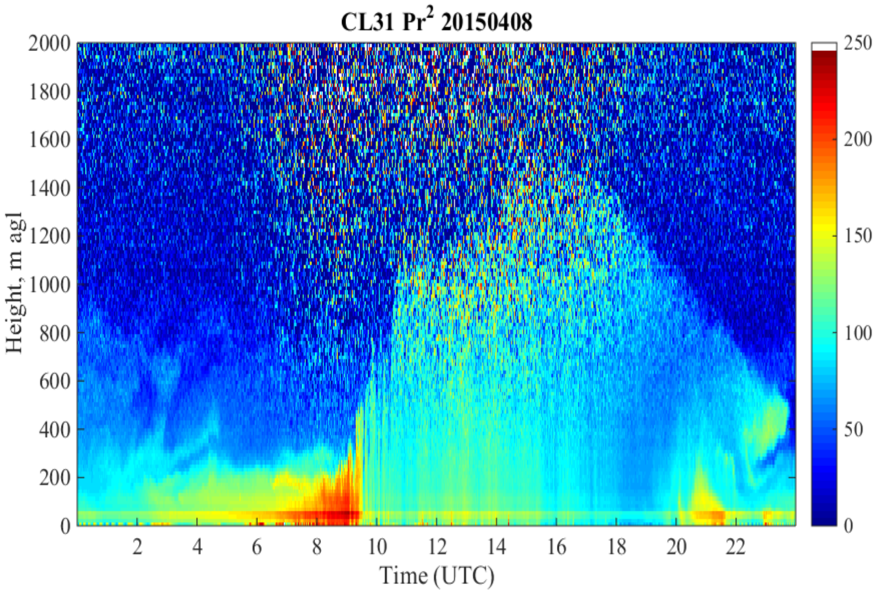
$$\mathbf{RCS = K\beta_{att}(z,\lambda)}$$

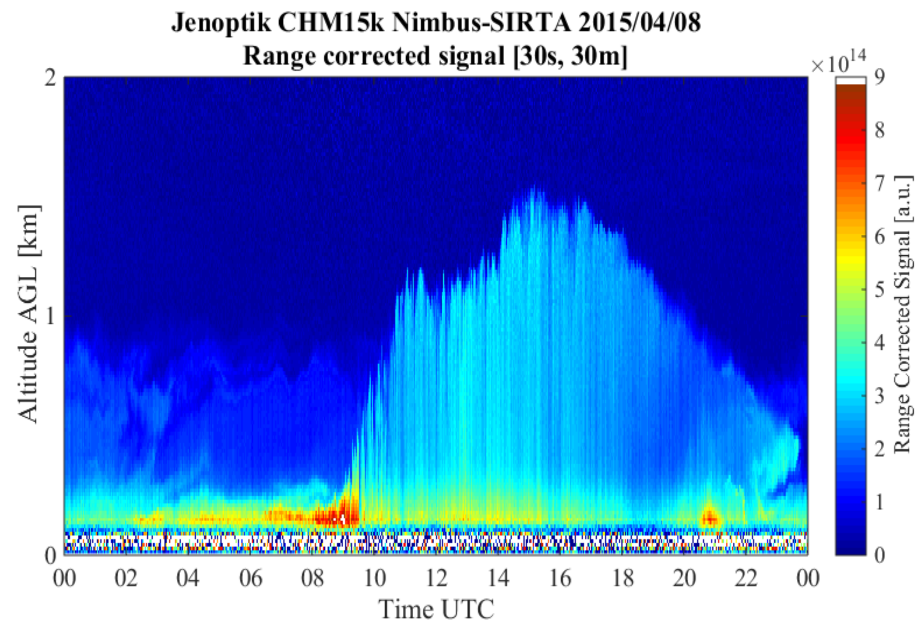
Calibration required | Atmospheric property!



WHAT IS MEASURED BY AN ALC ?

RCS *is proportional to attenuated backscatter:* $RCS \sim \boldsymbol{\beta_{att}}\,(\boldsymbol{z},\boldsymbol{\lambda})$





However, several corrections has to be performed such as the aforementioned background subtraction.

Corrections are usually faced in the pre-processing step.

ALC MEASUREMENT POST-PROCESSING

Simone KOTTHAUS,
IPSL & U. READING

ALC MEASUREMENT POST-PROCESSING

Why?

Some aspects of recorded β profiles specific to

a) instrument type
b) hardware/firmware generation
c) individual sensor

→ Corrections required

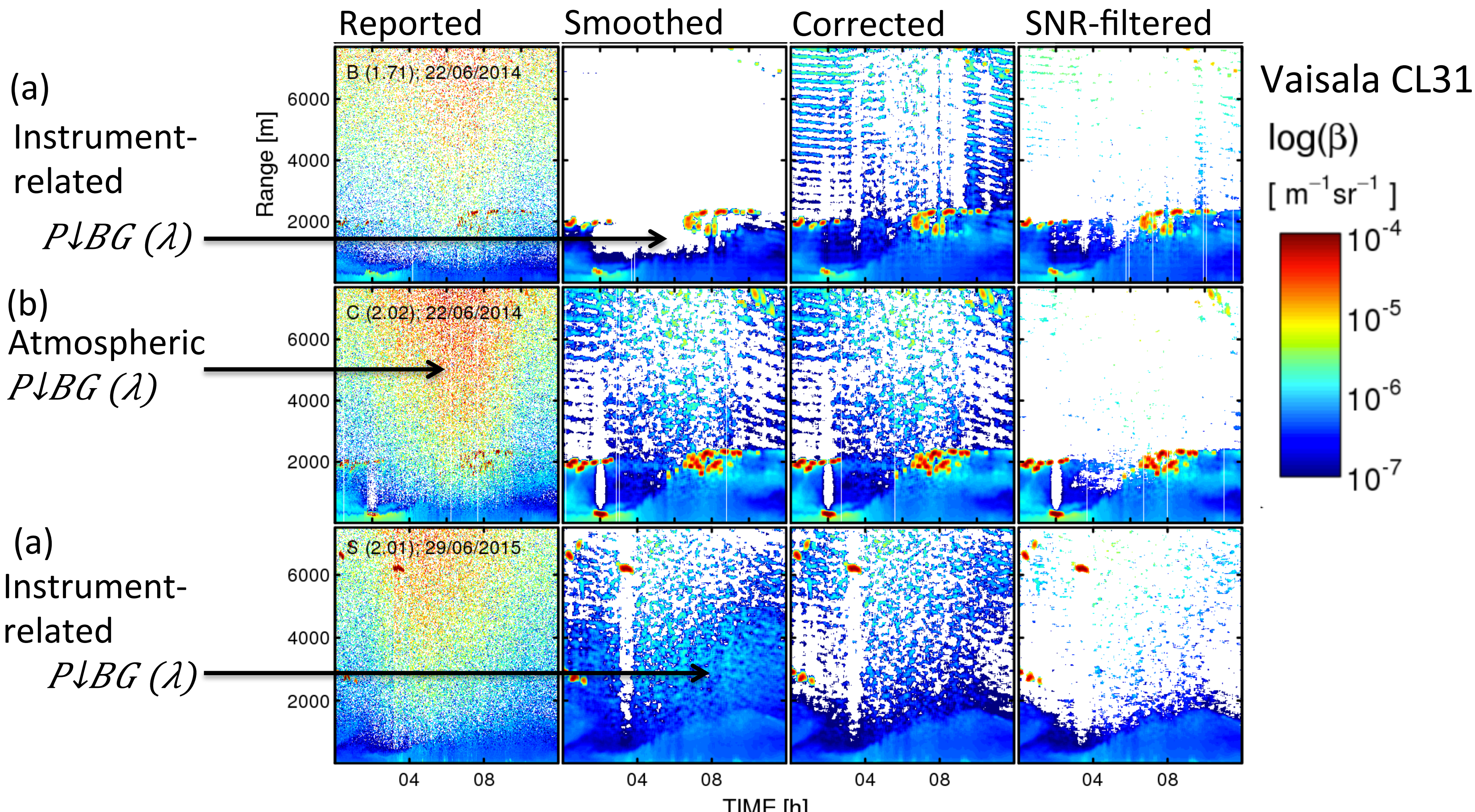
Key issues

- Near-range: artefacts, overlap
- Instrument-related background (hardware & firmware)
- Water vapour absorption (~910 nm)
- Signal-to-noise ratio (SNR) analysis

Correction methods

Lufft: e.g. Hervo et al. 2016, AMT, …
Vaisala: e.g. Kotthaus et al. 2016, AMT, …
~910 nm: e.g. Markowicz et al. 2008, JAOT
Wiegner and Gasteiger 2015, AMT, …

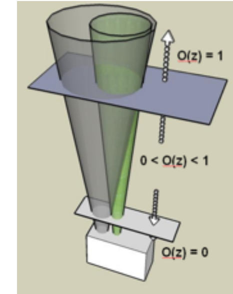
ALC MEASUREMENT POST-PROCESSING



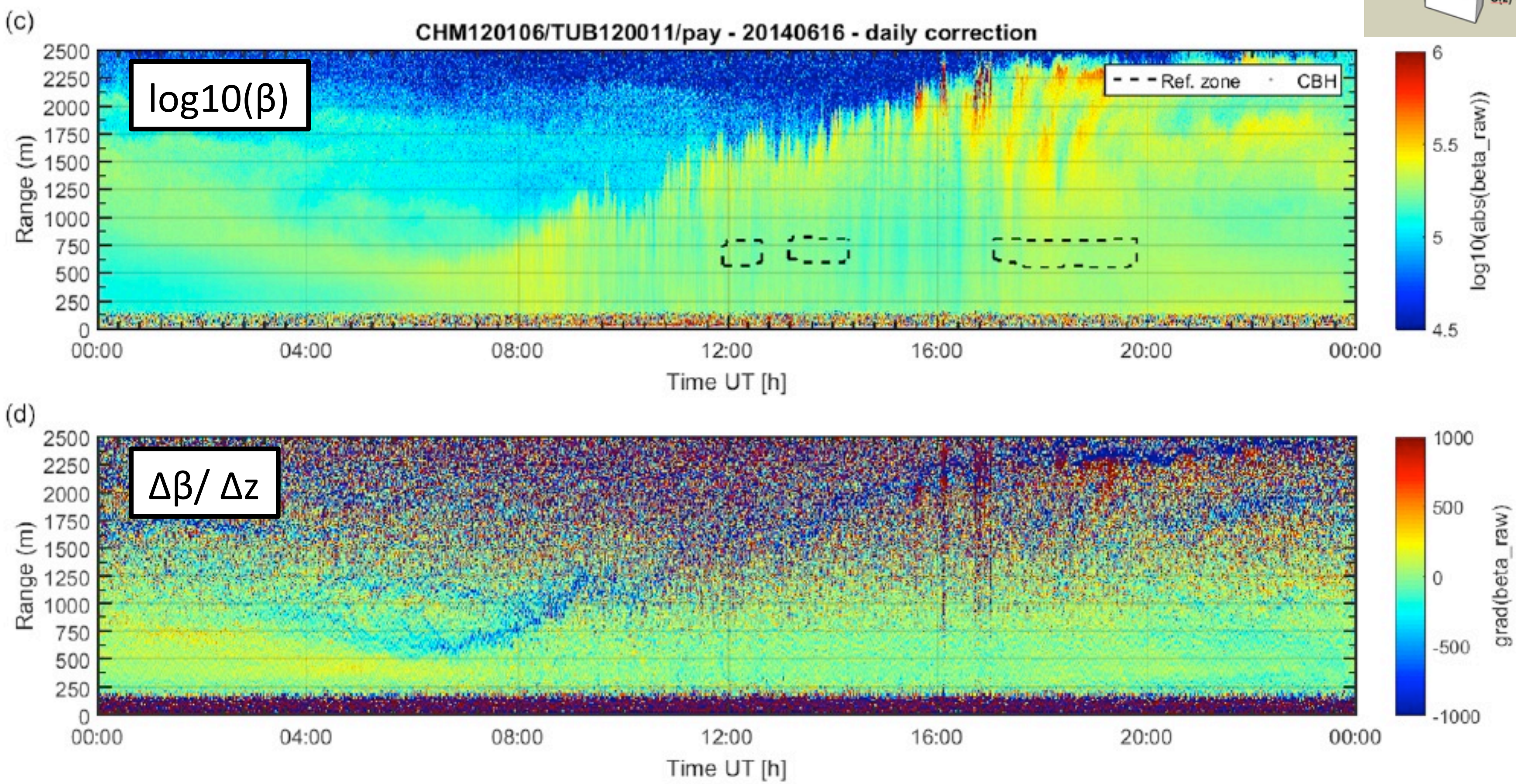
Kotthaus et al. 2016, AMT

(a) termination hood measurement or climatology
(b) Increase SNR by smoothing

ALC MEASUREMENT POST-PROCESSING



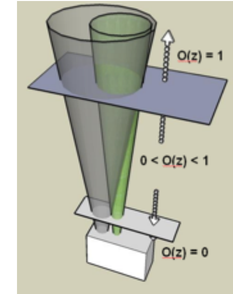
Optical overlap *O(z)* correction (LuffT CHM15K)



Hervo et al. 2016, AMT

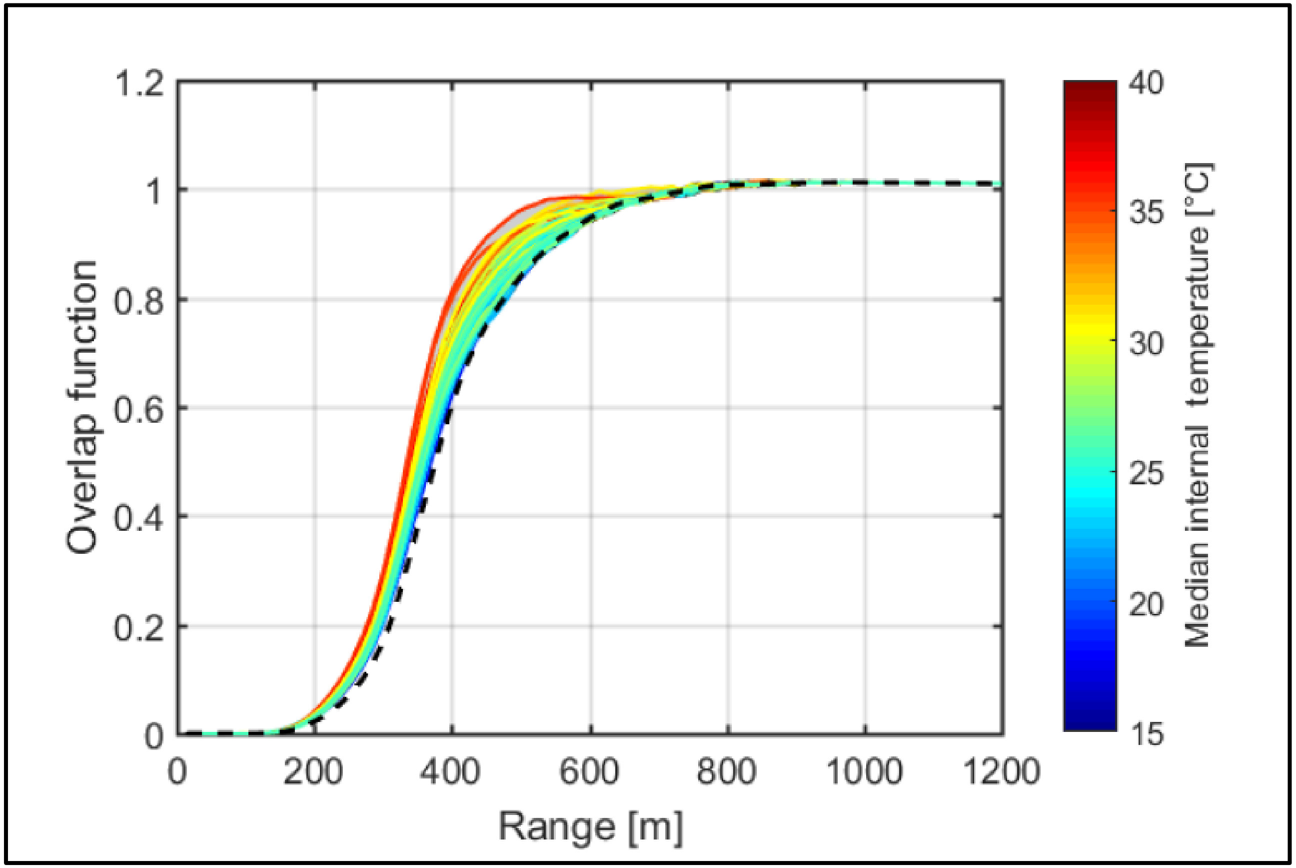
- Overlap correction is critical

ALC MEASUREMENT POST-PROCESSING



Optical overlap *O(z)* correction (LuffT CHM15K)

- Best method: model accounting for T-dependence



Hervo et al. 2016, AMT

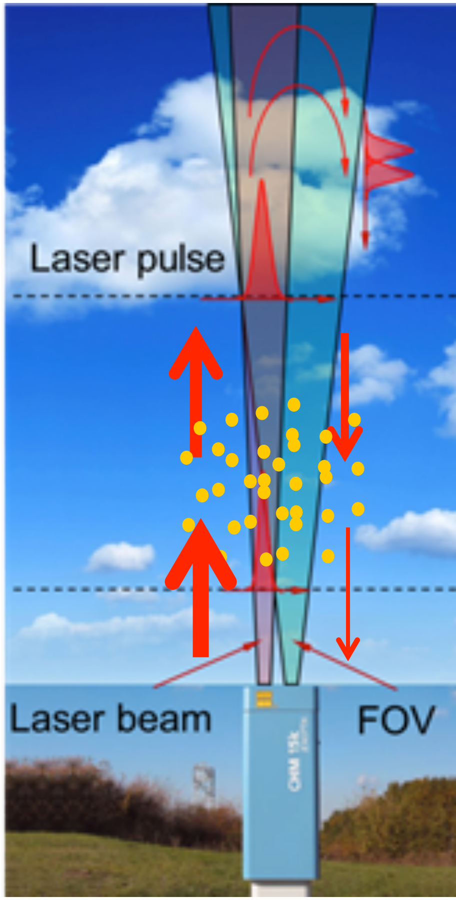
ALC CALIBRATION

Maxime HERVO,
Meteoswiss

ALC MEASUREMENT CALIBRATION: Principle

Lidar Equation

$$P(R) = C\,\frac{O(R)}{R^2}\,\beta(R)\,e^{\int_0^R -2\alpha(r)dr}$$



- P is the received power measured in a lidar receiver from range R
- C is the lidar constant,
- β is the backscattering coefficient ,

$$\beta = \beta_{aerosol} + \beta_{cloud/precipitation} + \beta_{molecular}$$

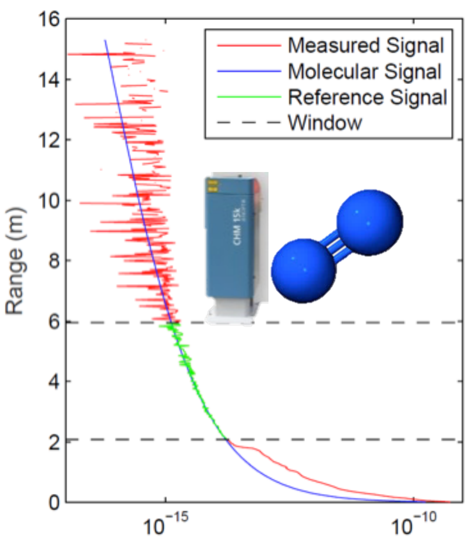
- α is the extinction coefficient

$$\alpha = \alpha_{aerosol} + \alpha_{cloud/precipitation} + \alpha_{molecular}$$

- O is the Overlap function at a range R

Calibration: Raw Signal to $\beta\downarrow attenuated$

Molecular calibration



[Klett, 1980,
Wiegner and Geiß, 2012]

$$C_L = \frac{P(r) r^2}{\beta_{mol}(r)} e^{2\int_0^r \alpha(r')dr'}$$

C_L: Lidar calibration coefficient,
P: Signal
β: backscatter coefficient,
α extinction coefficient.
r: range.

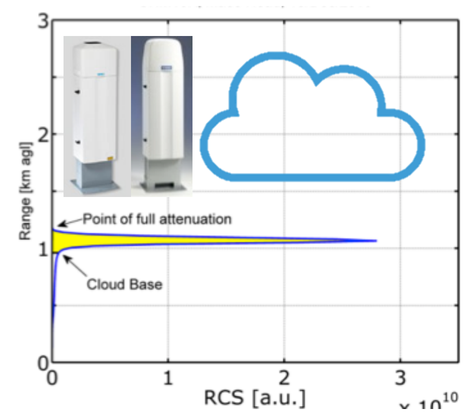
Min 3 h average

During night

Using T and P from ECMWF

Liquid cloud calibration

[O'Connor et al., 2004]



$$C_L = \frac{1}{B * 2\eta S}$$

CL :lidar calibration constant,
B: integral of the signal (yellow area),
η correction factor for multiple scattering
S the liquid cloud lidar ratio (18.8 ±0.8 sr)

Liquid cloud

Using T from ECMWF

✓ Suitable for photon-counting instruments
X Problematic for analog instruments (water vapor absorption, distortions, sensibility…)

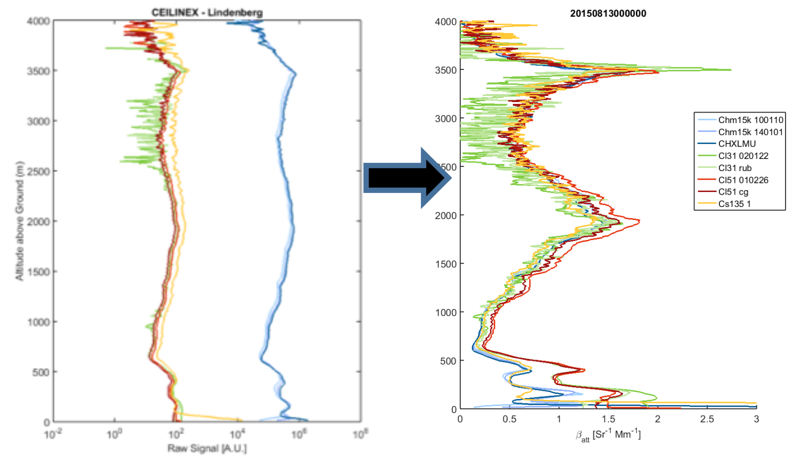
✓ Suitable for analog instruments
X Problematic for photon-counting instruments (Saturation)

ALC MEASUREMENT CALIBRATION: Effect

CeiLinEx2015
Ceilometer Performance Experiment at Lindenberg 2015

- ✓ 12 instruments + Reference Lidar
- ✓ 3 manufacturers, 6 institutes
- ✓ June-August 2015 3 months
- ✓ 20 investigators
- ✓ 10 fields of investigations
- ✓ 60 GB dataset
- ✓ Hosted and coordinated by DWD

- ✓ Unprecedented dataset for in-depth evaluation of ALCs



Differences lower than 25% can be expected for calibrated data (attenuated backscatter)

ALC MEASUREMENT UNCERTAINTIES

Ina MATTIS
DWD

ALC MEASUREMENT UNCERTAINTIES

Measurement effects on ‚raw‘ data

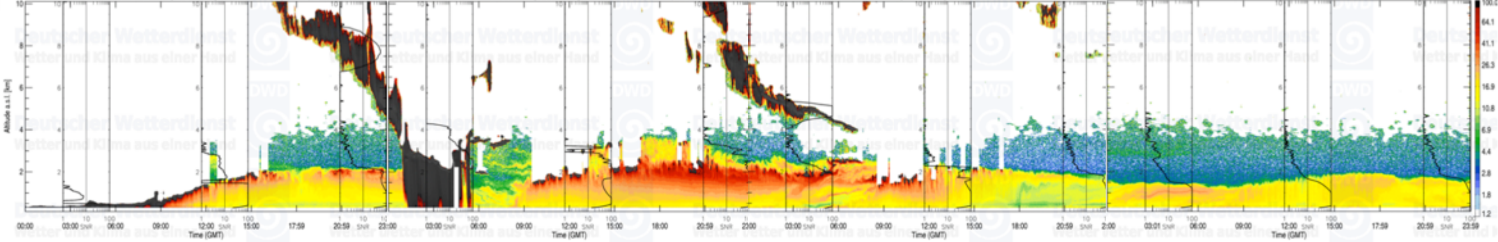
- Noise
- Contaminated windows
- Overlap issues — see Hervo et al. 2016, AMT
- Water vapor absorption — see M. Wiegner et al. OSA1.12
- Signal induced noise (clouds)
- Signal saturation (clouds)
- Signal artifacts / electronic background — see Kotthaus et al. 2016, AMT
- Artifacts due to signal processing — see Kotthaus et al. 2016, AMT

Uncertainties of retrieved products

- Calibration
- Lidar ratio assumption
- Assumptions for mass estimates

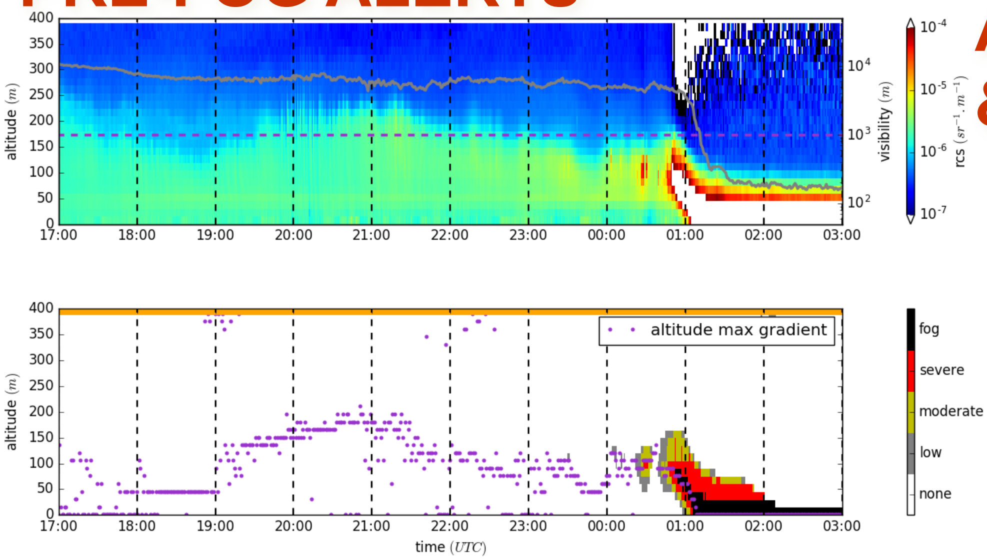
Summary: see report of TOPROF SWG meeting 2017 in Payerne

QUESTIONS ?

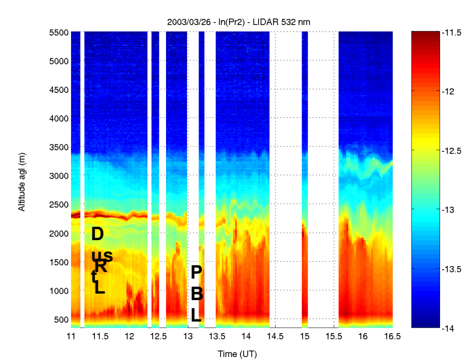


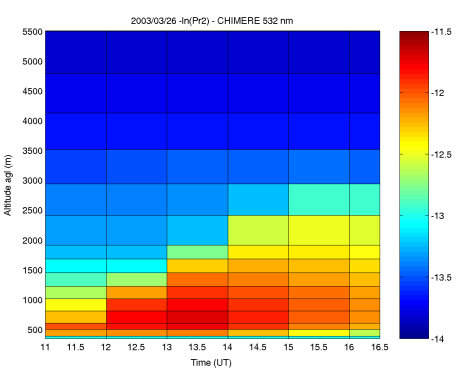
PART 2. ALC APPLICATIONS

PRE-FOG ALERTS



AEROSOL, ABL RETRIEVALS & MODEL EVALUATIONS



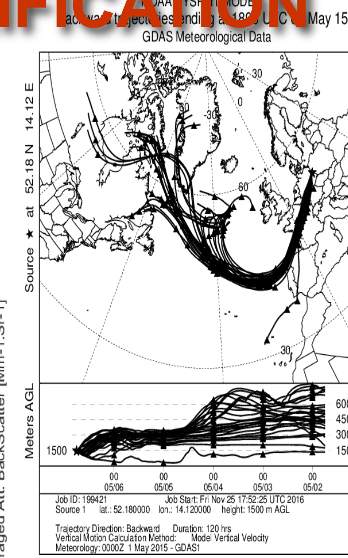


MODEL VERIFICATION

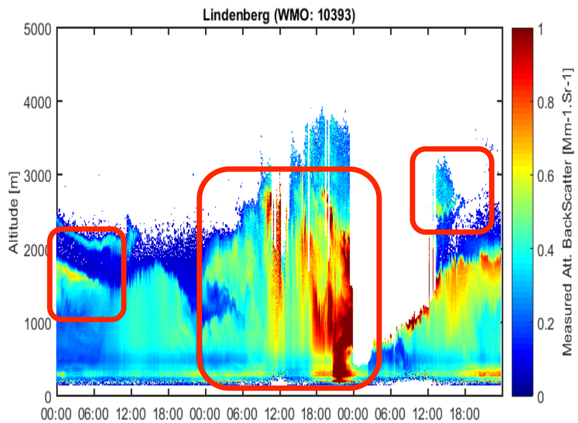
Maxime HERVO,
Meteoswiss

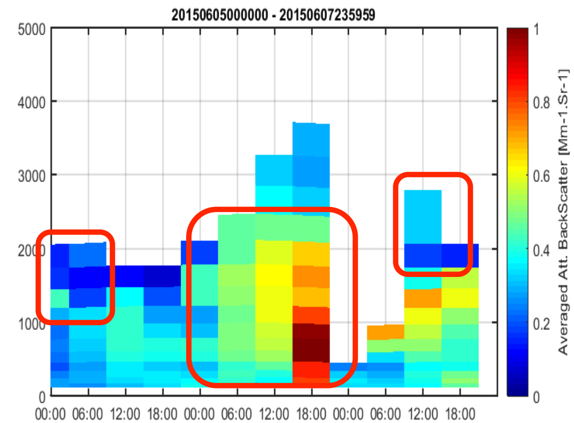
ATTENUATED BACKSCATTER AND MODEL VERIFICATION

Observation – Background statistics

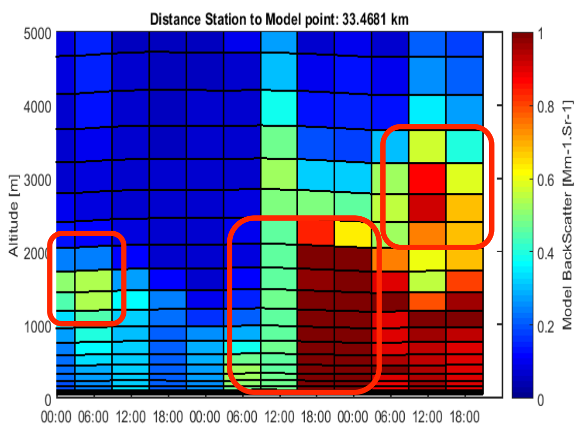


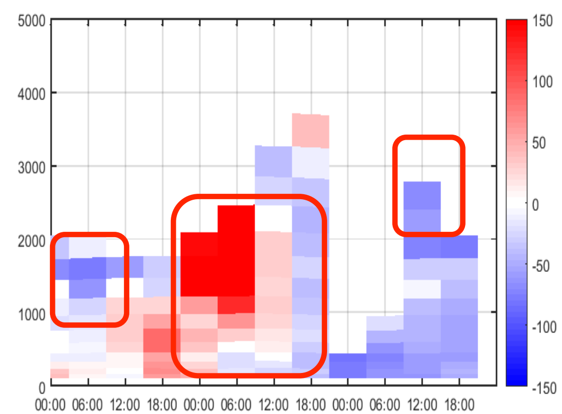
Ceilometer Raw data





Model Data



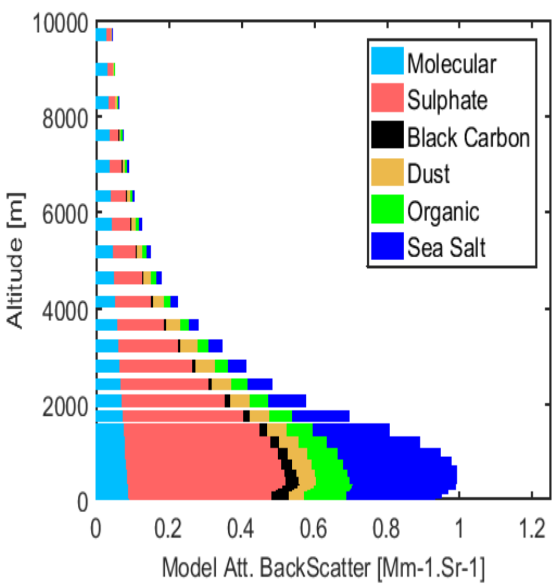


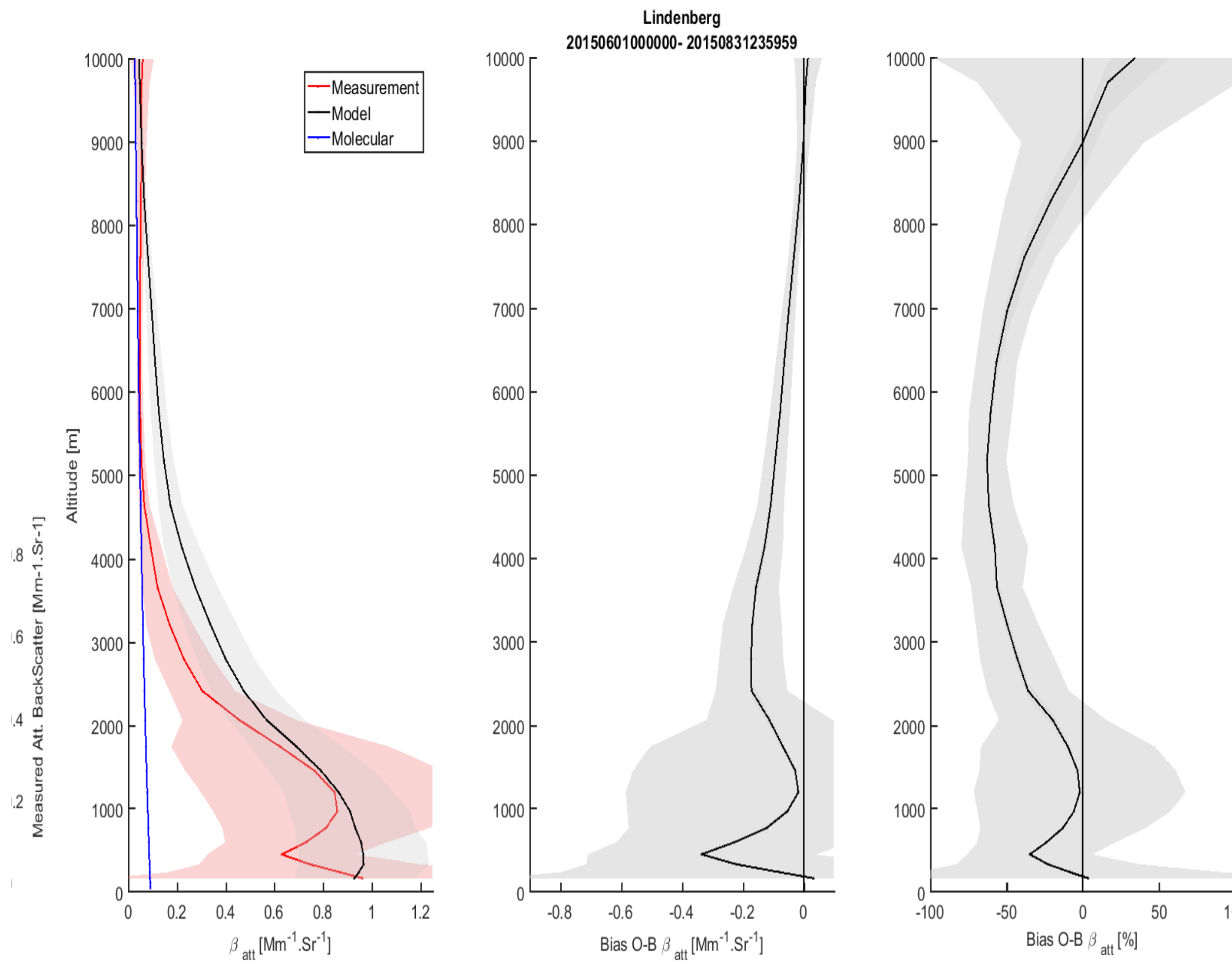
O-B

Dust layer accurately forecast

O – B: June - August 2015

- Bias < 50%
- Overlap artefact visible
- Model over-estimation:
  - FT: Sulfate
  - BL: Sea salt





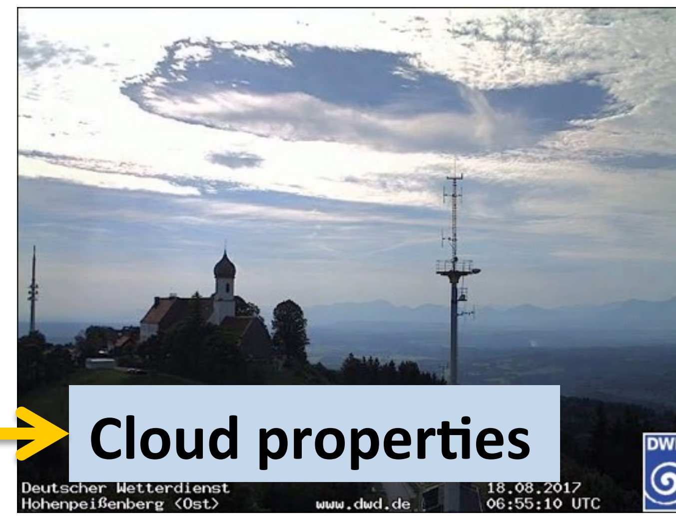
- ➢ Ceilometer can validate Models
- ➢ Models can help to identify instrument problems.

AEROSOLS: ASH & DUST MONITORING

Ina MATTIS, DWD

AEROSOLS: ASH & DUST MONITORING

Aviation safety



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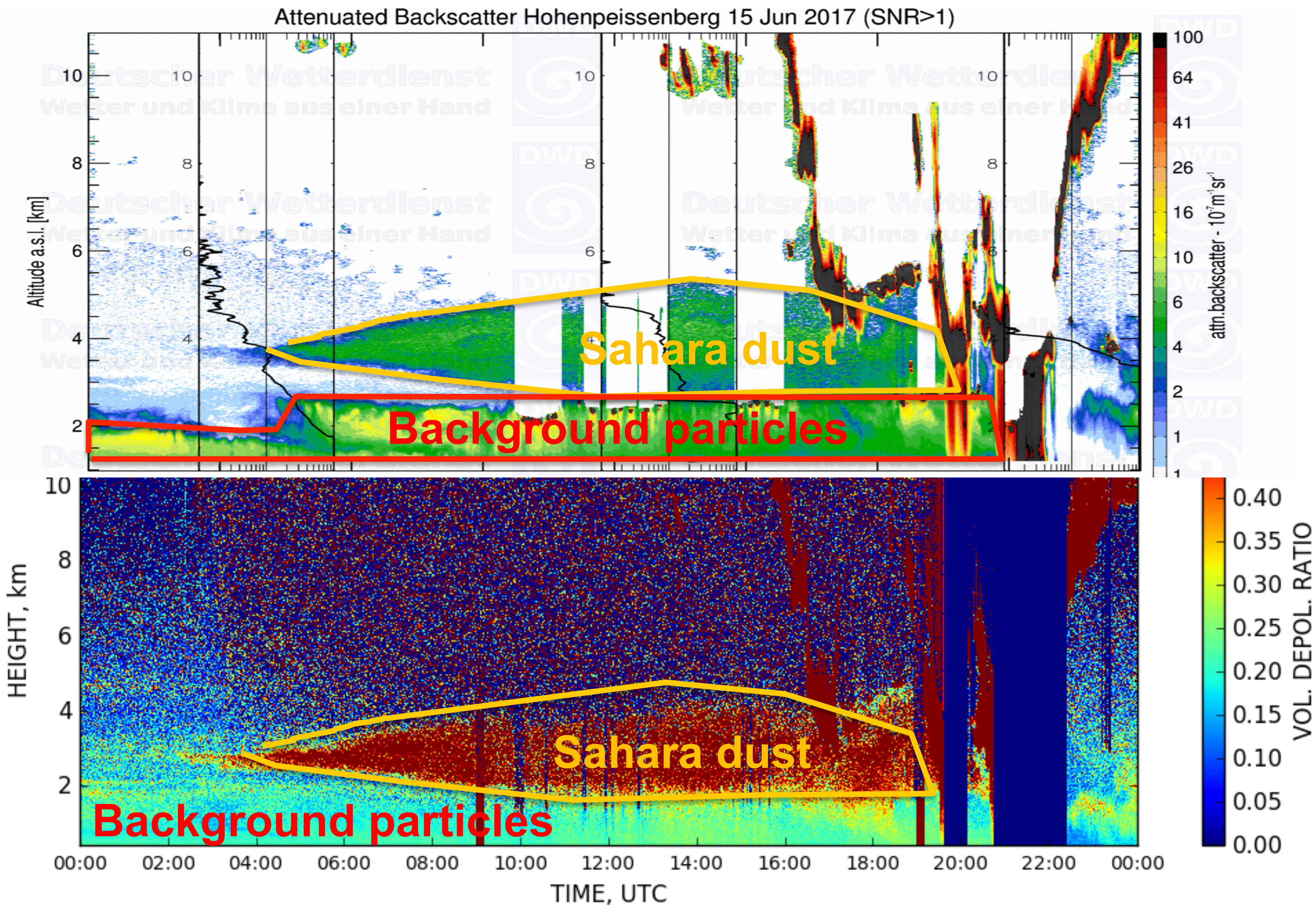
AEROSOLS: ASH & DUST MONITORING

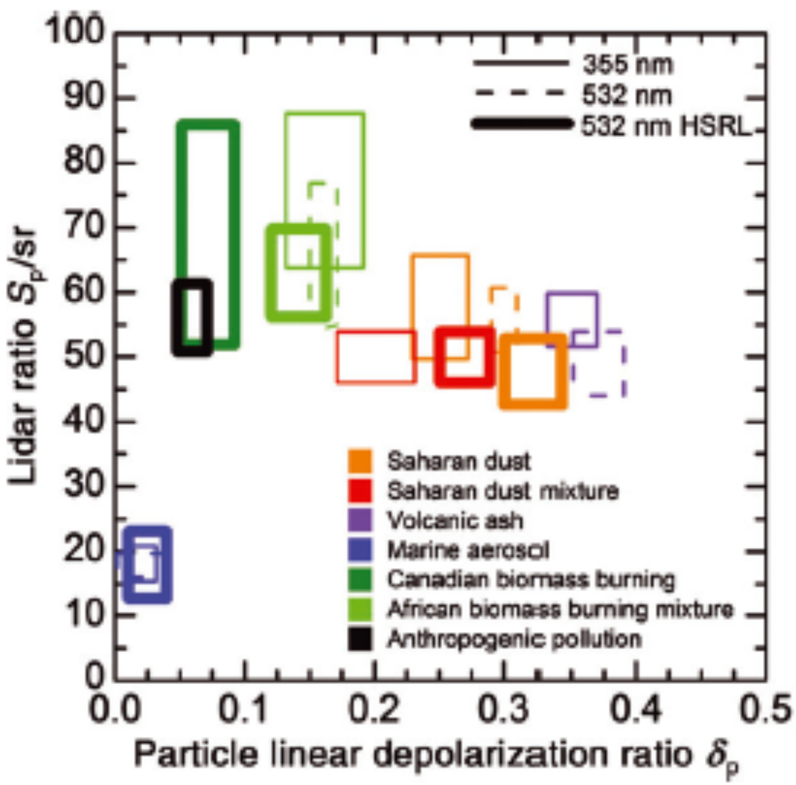


Intensive aerosol properties are used for typing (simplified)

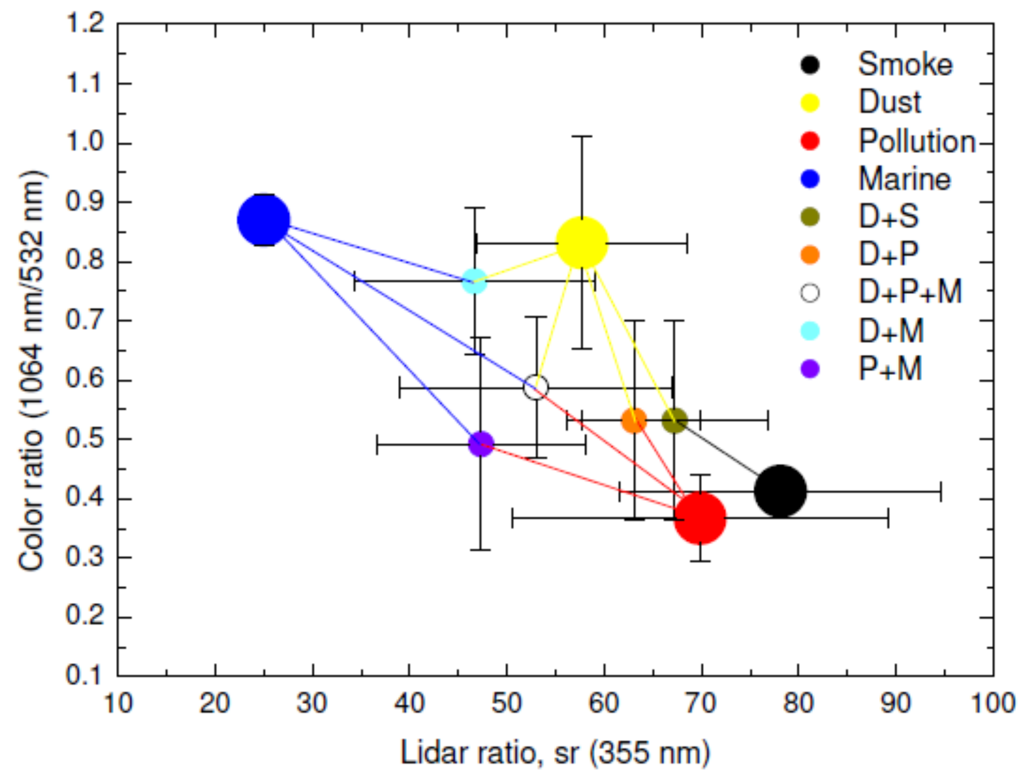
Property		Examples
particle linear depolarization ratio (PLDR)	Non-spherical	Ice, dust, ash
		fresh smoke, dry sea salt
	Spherical	sulfate, organic, droplets
Color ratio / Angström exponent	Small	anthropogenic
	Large	Clouds, dust, ash, sea salt
Extinction-to-backscatter (lidar) ratio	Absorbing	Smoke, soot, ash, (dust)
	Non-absorbing	water, sulfate

Intensive aerosol properties are used for typing

- particle linear depolarization ratio (PLDR)
- Extinction-to-backscatter (lidar) ratio
- Color ratio / Angström exponent
- Wavelength dependence of lidar ratio and PLDR
- Ancillary measurements (e.g. sun photometer)



Silke Groß et al. Atmos. Sci .Let. 2014



Wandinger et al. 2011, ESA report

QUANTIFYING CONCENTRATIONS

Direct conversion with in-situ measurements at mountain or aircraft

Backscatter coefficient → ? → Extinction coefficient → ? → Volume concentr → ? → Mass concentr.

Lidar ratio
- From literature
- Climatological value
- Value for actual aerosol type
- From actual AOD measurement

Ext-to-volume ratio
- From literature
- Climatological value
- Value for actual aerosol type
- From actual AERONET inversion

Particle density
- From literature
- Climatological value
- Value for actual aerosol type

Multi-λ measurements:
+ Backscatter profiles
+ Extinction profiles / optical depth
+ (Depolarization)

Komplex inversion algorithms
- POLYPHON (Ansmann et al. 2012)
- GARRLiC (Lopatin et al. 2013)
- Müller et al 2013, Böckmann and Osterloh 2014
- …

→ Mass concentr.

CAPABILITIES OF DIFFERENT LIDAR TYPES

WMO CIMO guide (2014)

Table 16.4. Lidar products related to specific surface-based lidar techniques (note that (d) = daytime only)

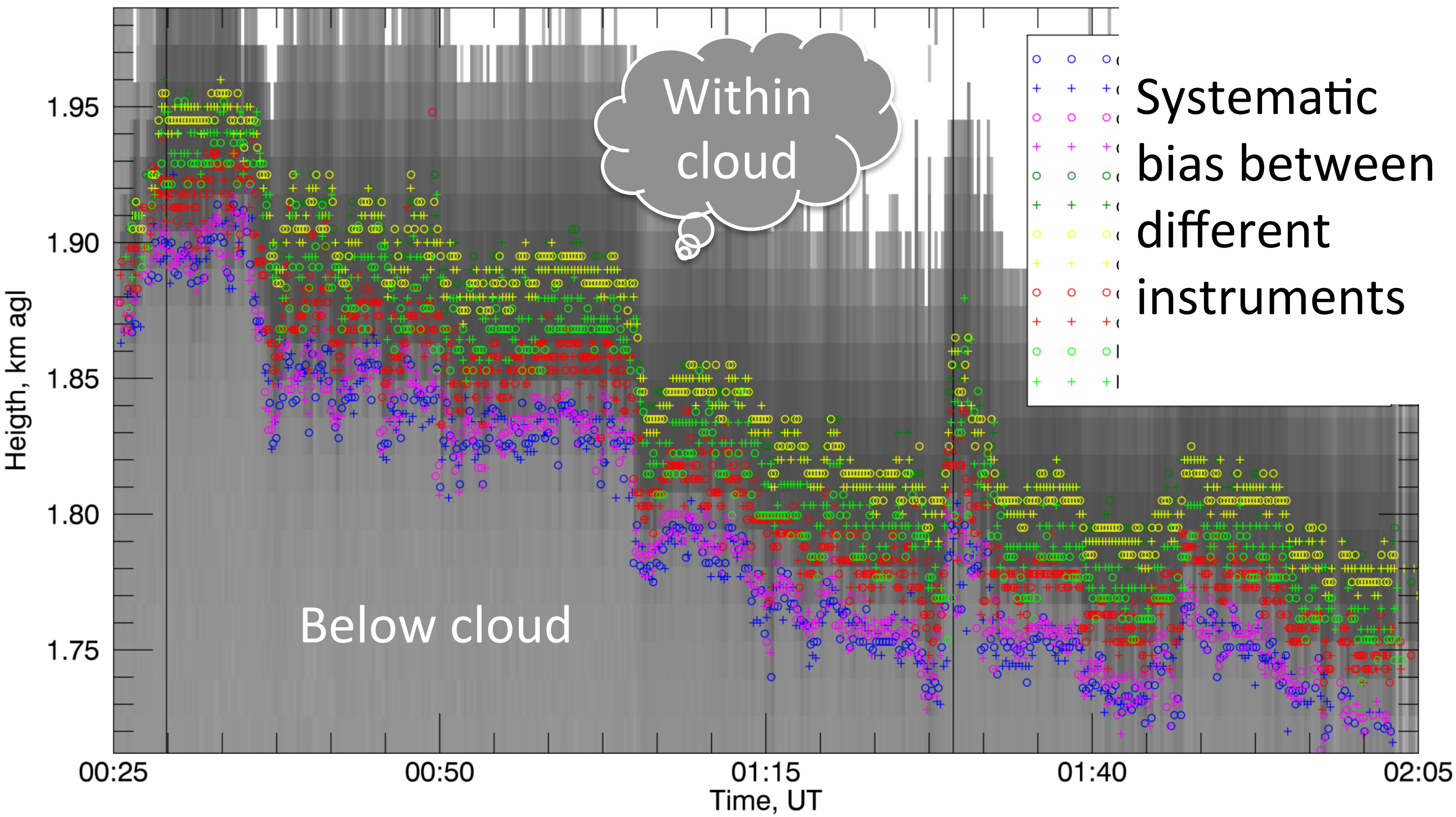
Surface-based lidar techniques	*Geometrical properties*	β_a	α_a	*Lidar ratio*[a]	*AOD*	$\mathring{A}_\beta$	$\mathring{A}_\alpha$	*Type*[b]	*Microphysical properties*
1-wavelength (1-λ) backscatter lidar	✓	✓							
1-λ backscatter lidar + sun photometer	✓	✓	✓(d)[f]		✓(d)				
1-λ backscatter lidar + sun photo. + depolarization lidar	✓	✓	✓(d)[f]		✓(d)			✓(d) (limited)	
…									
M-λ[e] backscatter lidar + sun photo. + depolarization lidar	✓	✓	✓(d)[f]		✓(d)	✓(d)[f]	✓	✓	✓(d)[f]
…									
M-λ[e] Raman lidar + sun photo. + depolarization lidar	✓	✓	✓[g]	✓[g]	✓[g]	✓[g]	✓	✓	✓[g]

CLOUD BASE HEIGHT DETECTION

Ina MATTIS, DWD

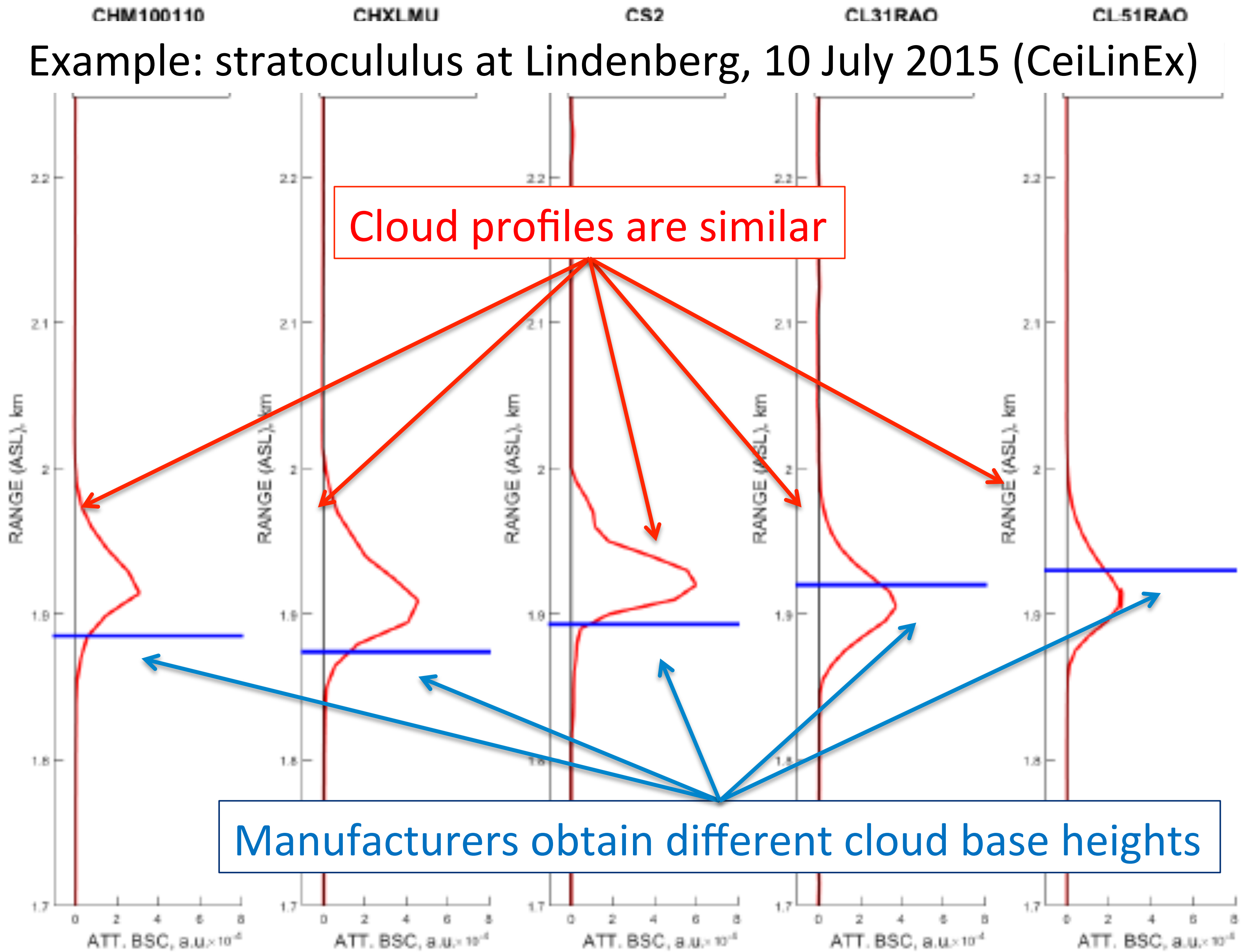
CLOUD BASE HEIGHT DETECTION

Example: stratocululus at Lindenberg, 10 July 2015 (CeiLinEx)



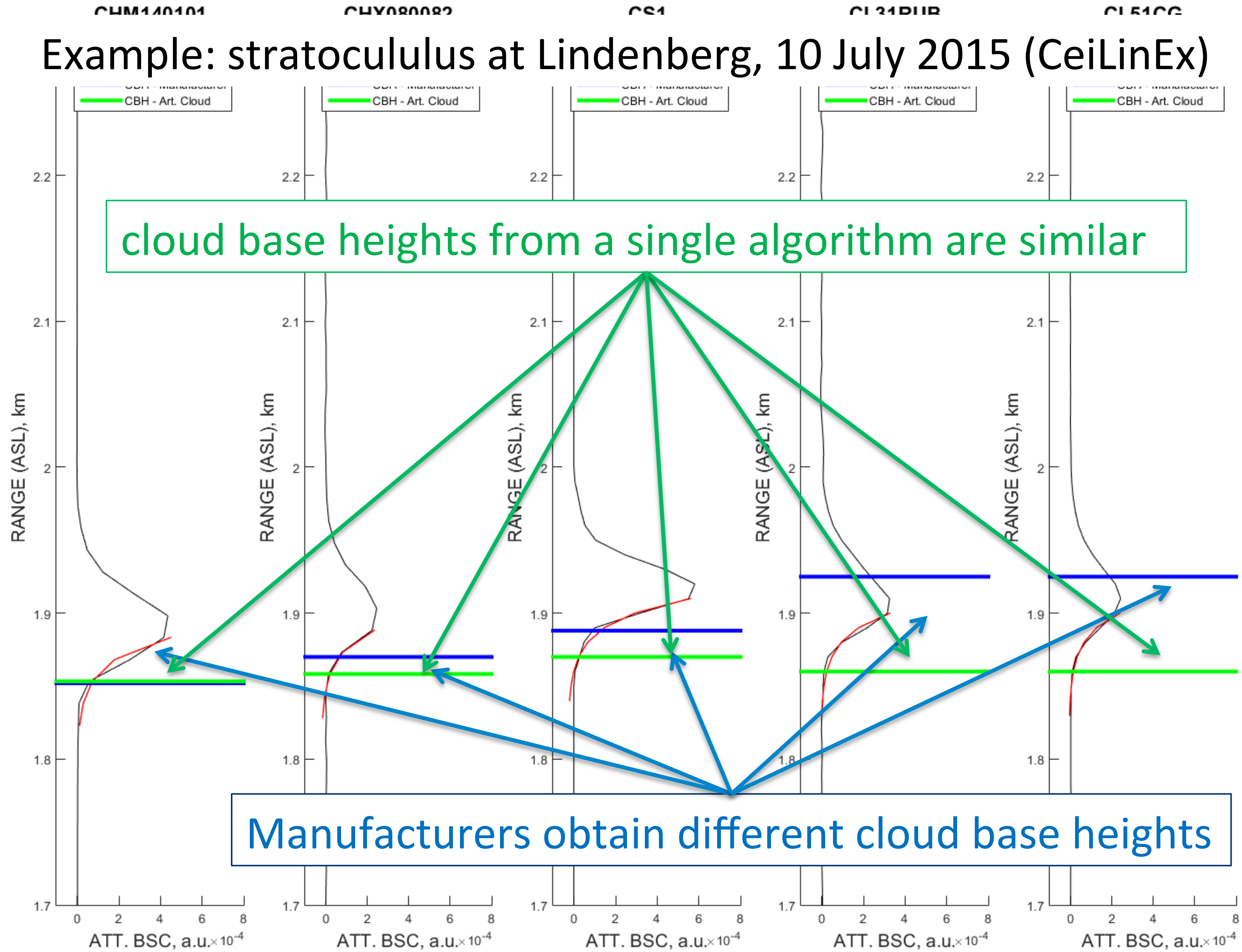
CLOUD BASE HEIGHT DETECTION

Example: stratoculus at Lindenberg, 10 July 2015 (CeiLinEx)



CLOUD BASE HEIGHT DETECTION

Example: stratoculuIus at Lindenberg, 10 July 2015 (CeiLinEx)

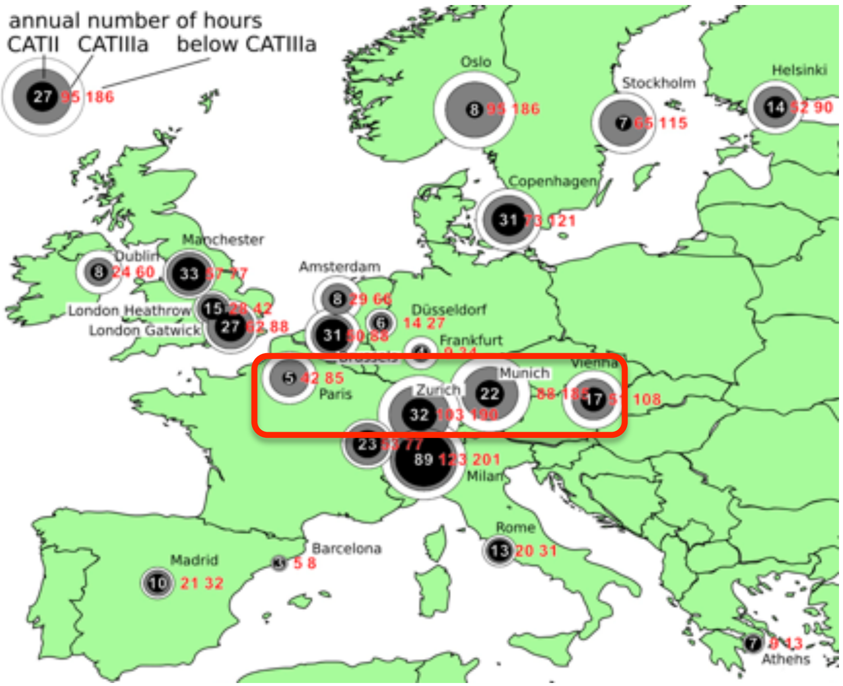


FOG ANTICIPATION

Martial HAEFFELIN,
IPSL

FOG DETECTION AND ANTICIPATION

1. Motivation



Christmas travel chaos warning as fog grounds planes

- BA to axe 40% of flights to and from Heathrow today
- Record 3 million planning to go abroad over holiday

Need decision-support tools in addition to NWP forecasts, satellite imagery, ground-based measurements

FOG DETECTION AND ANTICIPATION

2. Fog formation: aerosol hydroscopic growth and activation

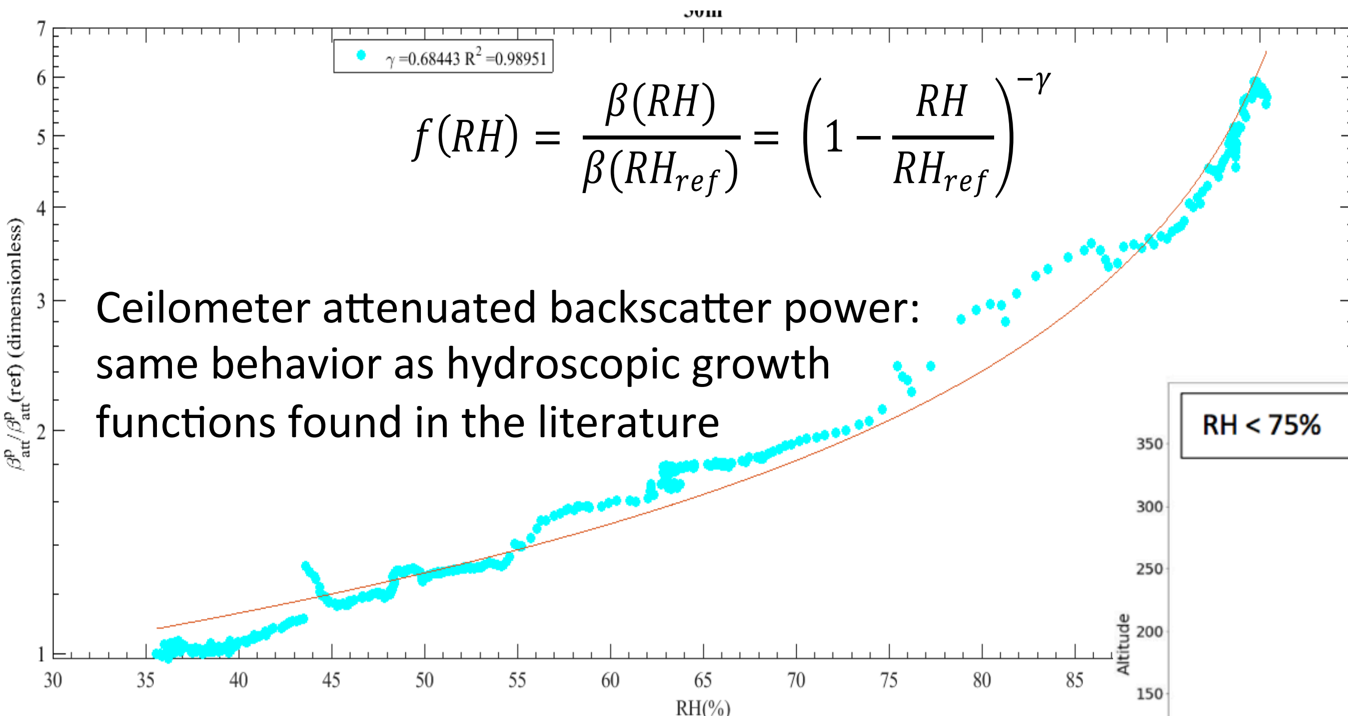
- The impact of humidity on aerosol scattering: hygroscopic growth function of aerosol scattering coefficient :

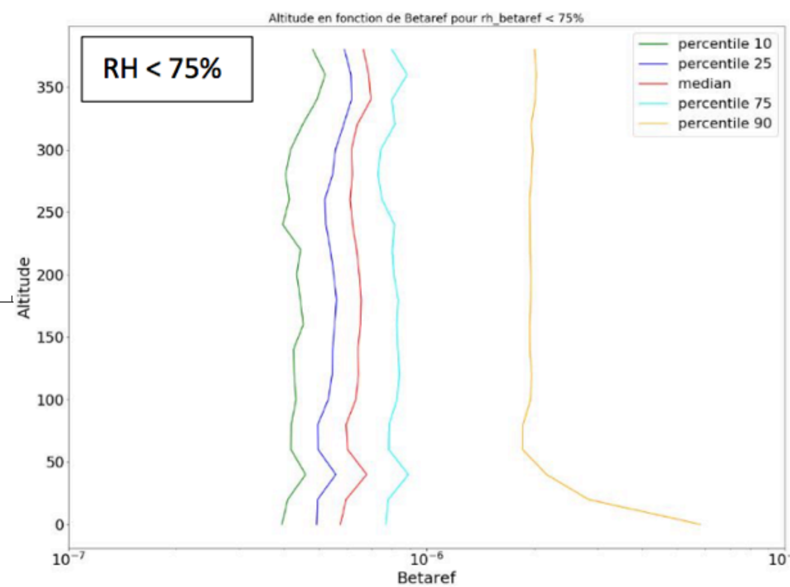
$$\sigma_{sp}(RH) = \sigma_{sp}^{dry}(1 - RH)^{-\gamma}$$ Hänel, (1976)

- Hygroscopic growth function can be applied to all aerosol properties

$$f(RH) = \frac{\beta(RH)}{\beta(RH_{ref})} = \left(1 - \frac{RH}{RH_{ref}}\right)^{-\gamma}$$

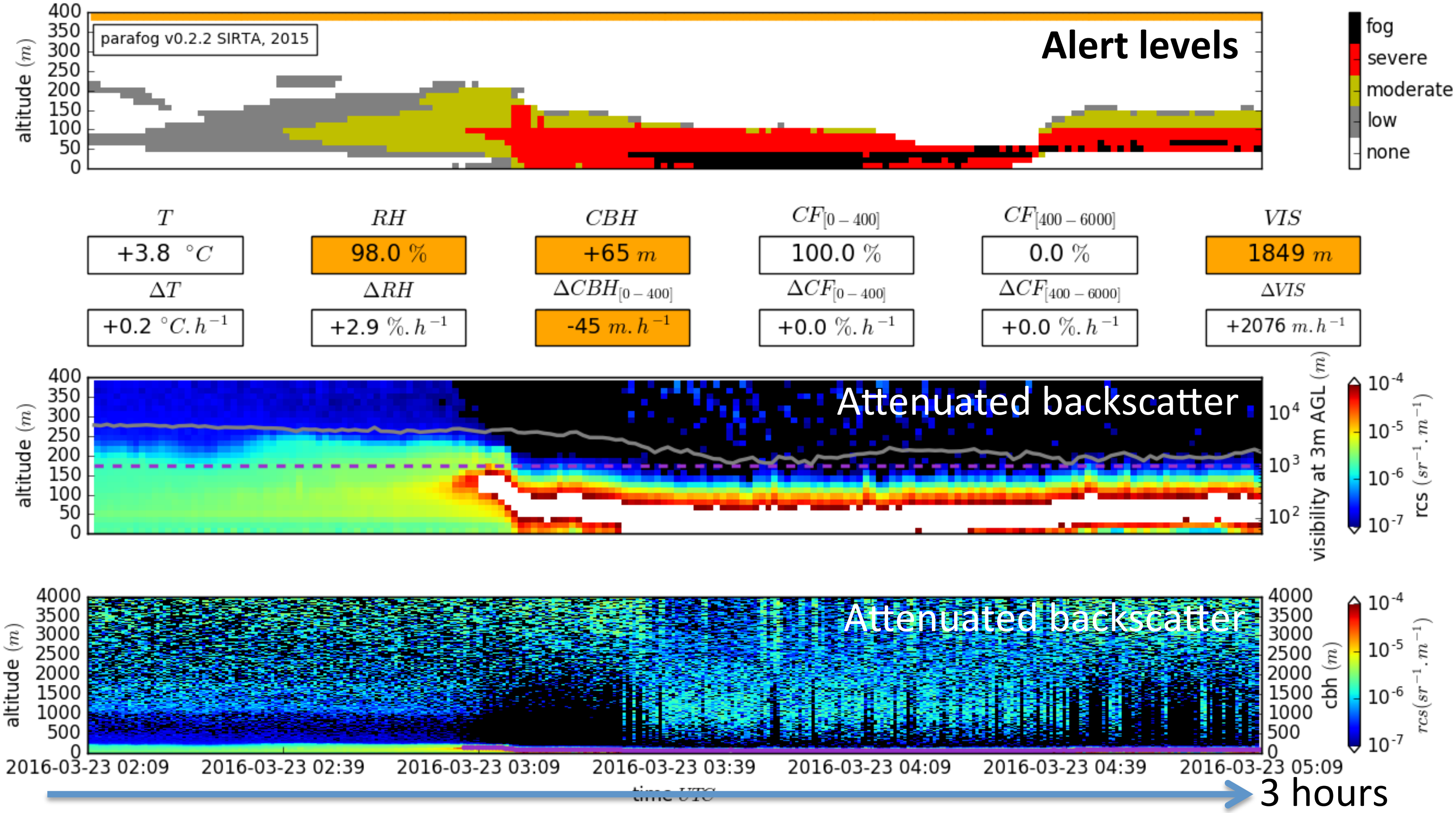
Ceilometer attenuated backscatter power: same behavior as hydroscopic growth functions found in the literature





FOG DETECTION AND ANTICIPATION

3. Example at CDG Airport

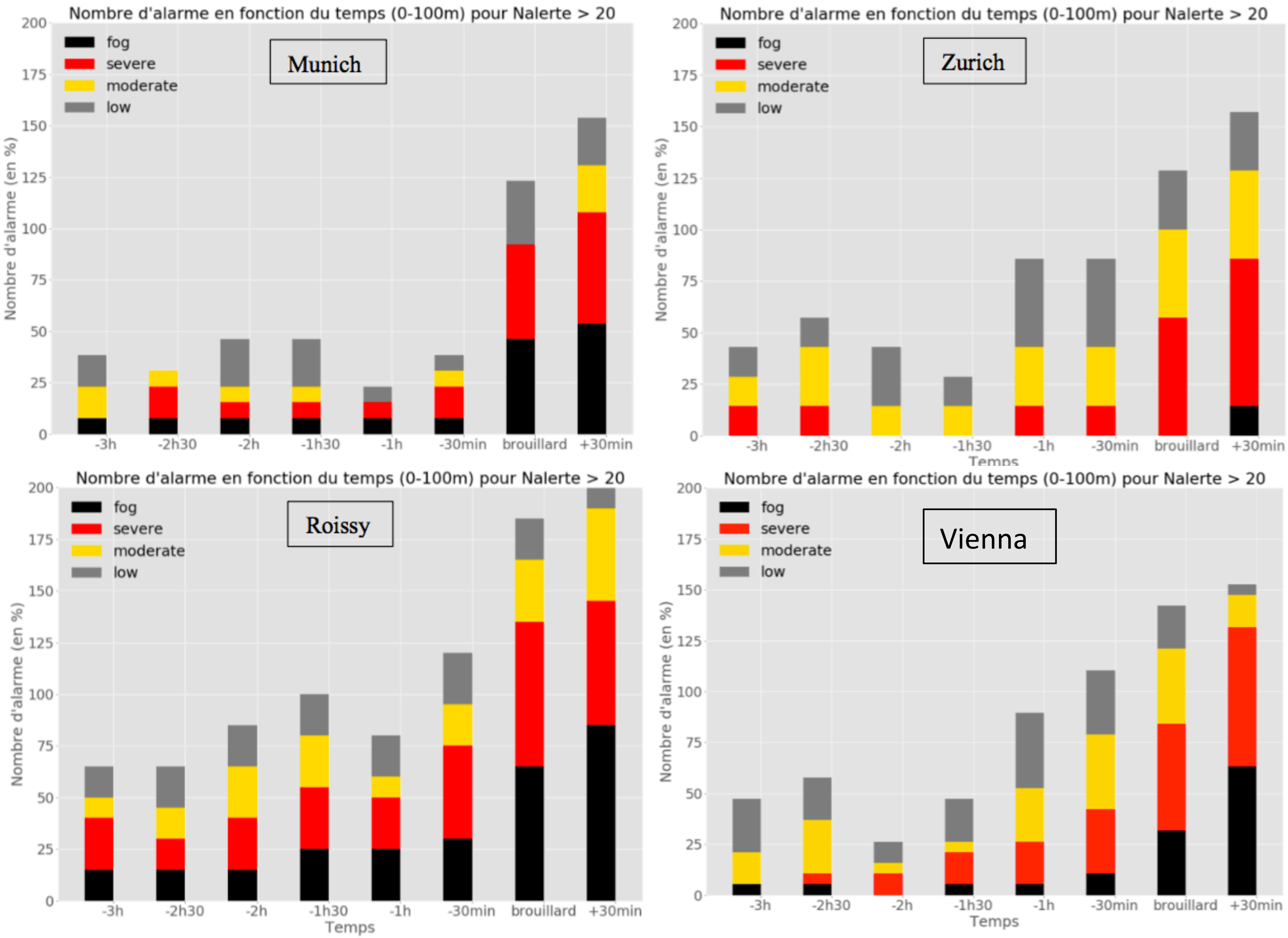


→ Evidence of aerosol hygroscopic growth leading to activation into droplets

→ 15-60 min warning before fog event

FOG DETECTION AND ANTICIPATION

4. Performance



ATMOSPHERIC BOUNDARY LAYER HEIGHT

Juan-Antonio BRAVO ARANDA, Simone KOTTHAUS
IPSL

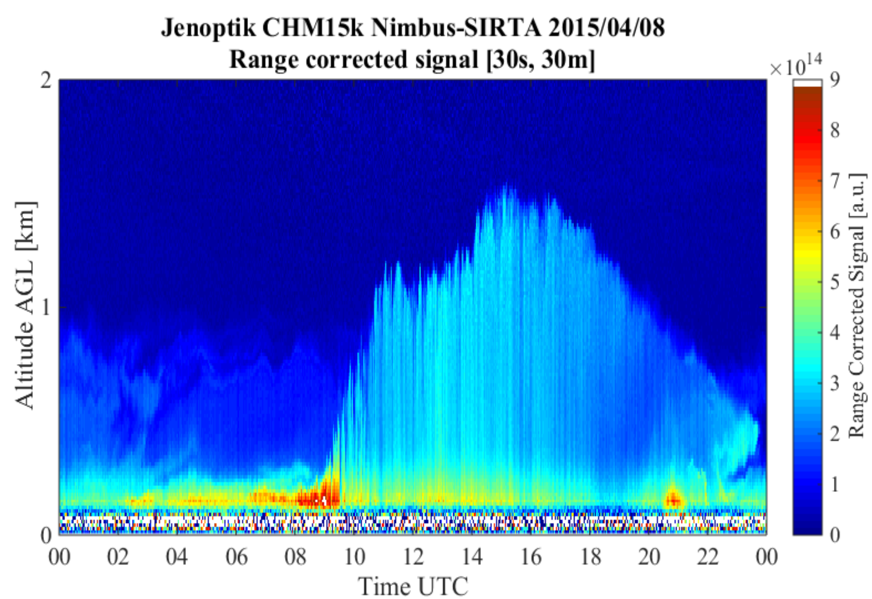
ATMOSPHERIC BOUNDARY LAYER

Motivation

Air quality	• Mixed Layer Height	→ dilution volume for pollutants
	• Entrainment	→ conditions in residual layer?
NWP	• Cloud formation & rainfall	

	Methods	**Challenges**
Layer detection	gradient, variance, idealised profile, …	clean air, clouds, rainfall, instrument noise, background light, morning transition entrainment, hygroscopic growth, …

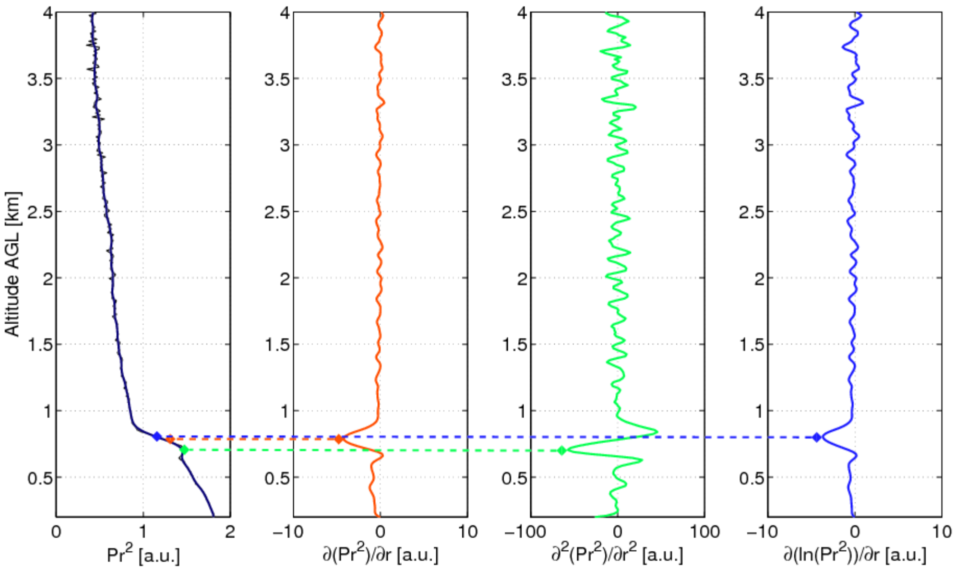
Atmospheric Bondary layer has a strong impact on the particle concentration at surface level ⇨ key variable in models



ATMOSPHERIC BOUNDARY LAYER

- Vertical gradient detection (1D or 2D)

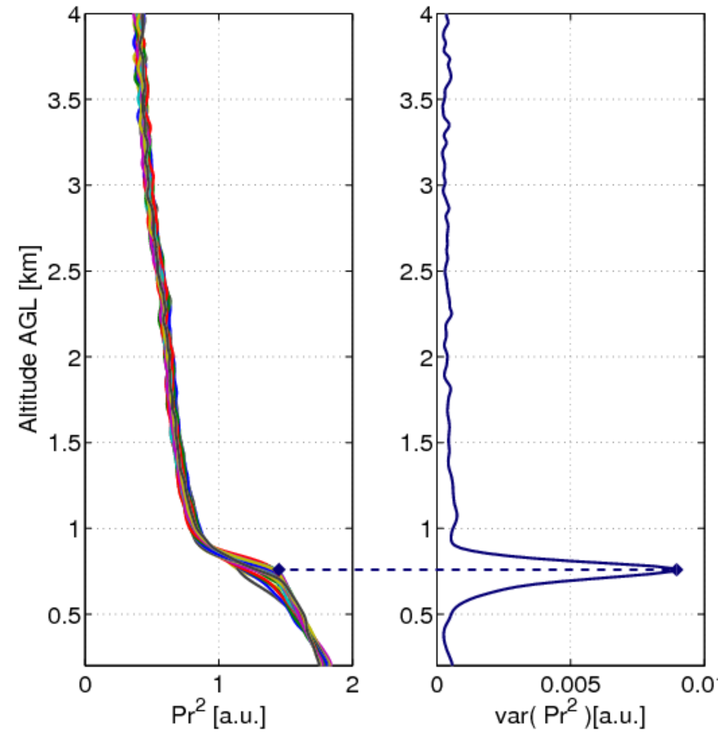
Spatial variance



Lidar signal | 1st derivative | 2nd derivative | 1st derivative

References: *Melfi et al., 1985; Flamant et al., 1997; Menut et al., 1999; Sicard et al., 2006; Martucci et al., 2007*

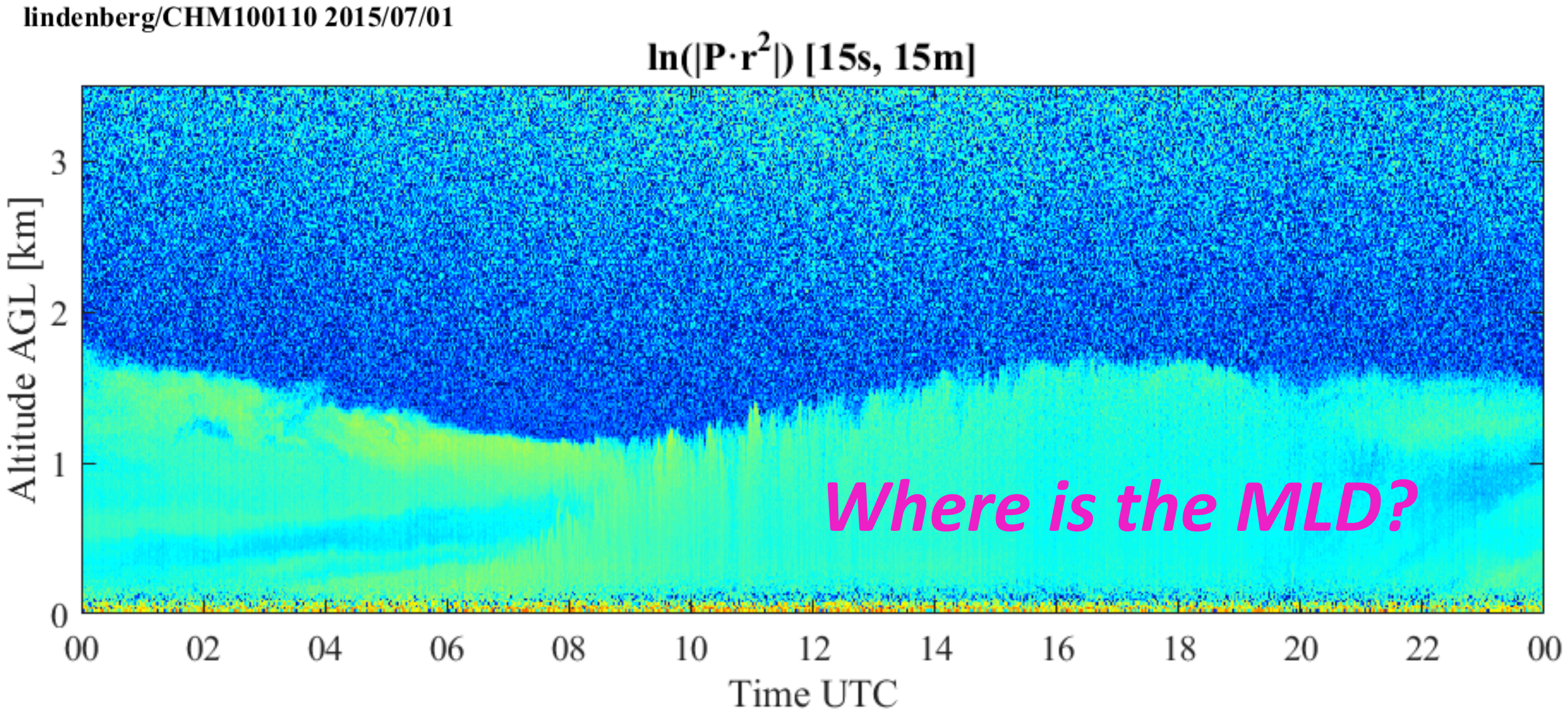
Temporal variance



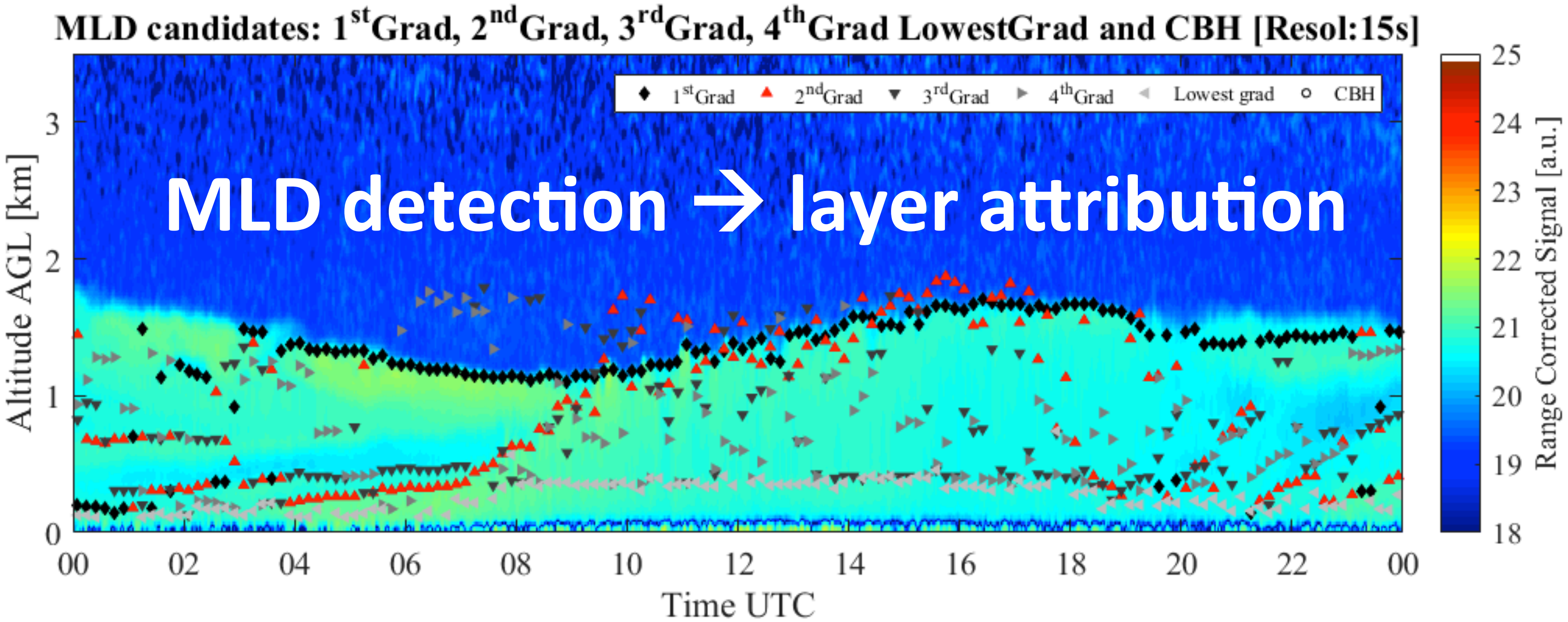
References: *Hooper and Eloranta, 1986; Menut at al., 1999; Hennemuth and Lammert, 2005; Martucci et al., 2007*

And others such as Wavelet (*Granados-Muñoz et al.*, 2012)

ATMOSPHERIC BOUNDARY LAYER



ATMOSPHERIC BOUNDARY LAYER



Canny's method
STRAT algorithm
(Morile et al., 2013)

ATMOSPHERIC BOUNDARY LAYER

Motivation

Air quality
- Mixed Layer Height → dilution volume for pollutants
- Entrainment → conditions in residual layer?

NWP
- Cloud formation & rainfall

	Methods	Challenges
Layer detection	gradient, variance, idealised profile, …	clean air, clouds, rainfall, instrument noise, background light, morning transition entrainment, hygroscopic growth, …
Layer attribution	Time-height tracking, time-based selection, selection based on auxiliary observations	Appropriate limits, advection, min observed height, evening transition turbulent decay, …

ATMOSPHERIC BOUNDARY LAYER

Motivation

Air quality	• Mixed Layer Height	→ dilution volume for pollutants
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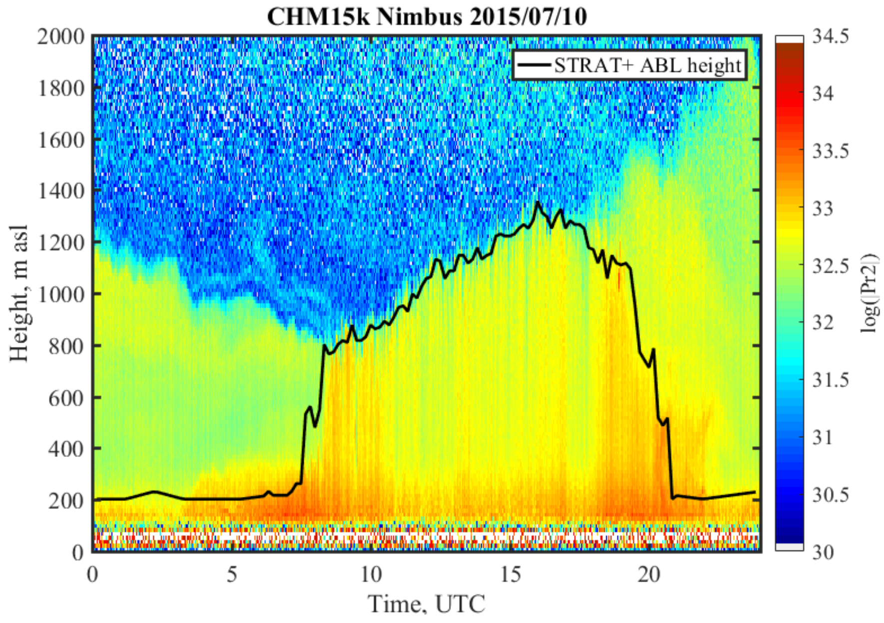
Tools

SRAT-2D	Morille et al. (2008)
STRAT+	Pal et al. (2013)
pathfinder	de Bruine et al. (2017)
pathfinderTURB	Poltera et al. (2017)
COBOLT	Geiß et al. (2017)
BLview	Münkel et al (2007)
CABAM	Kotthaus and Grimmond (in prep.)

… and many more

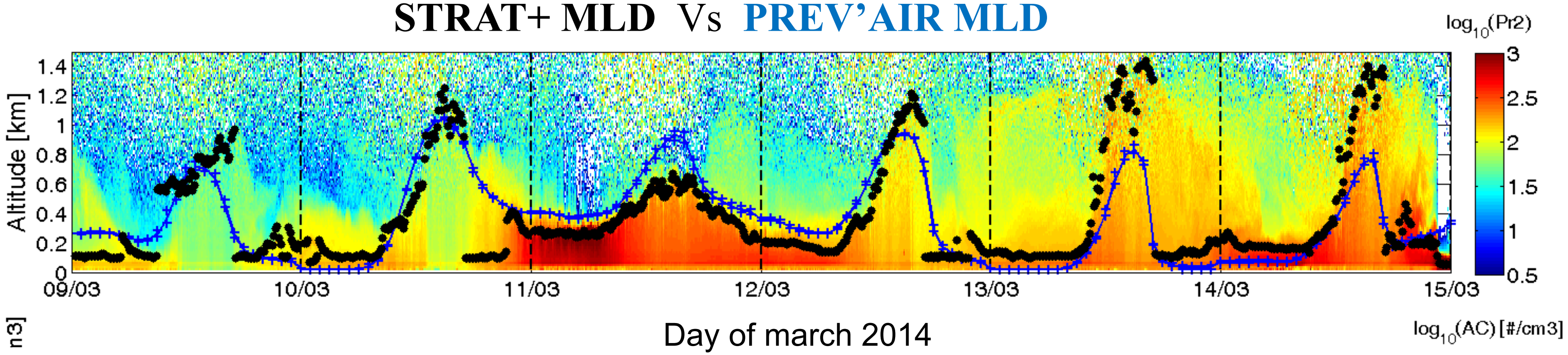
ATMOSPHERIC BOUNDARY LAYER



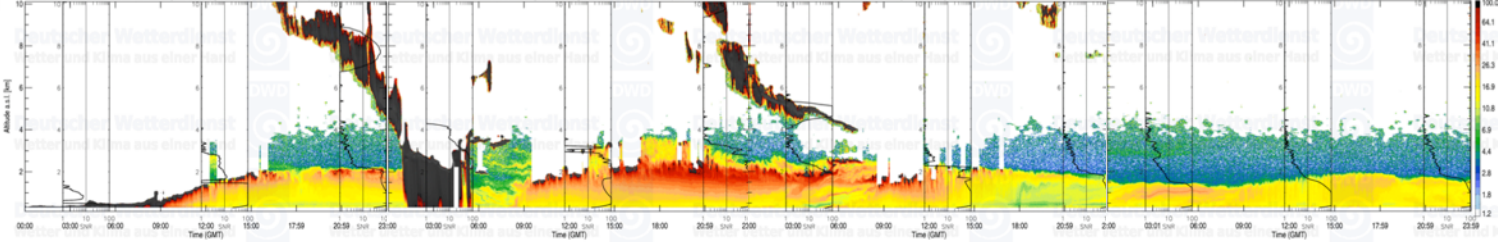
STRAT+ (Pal et al., 2013)

MLD comparison (Dupont et al., 2015)

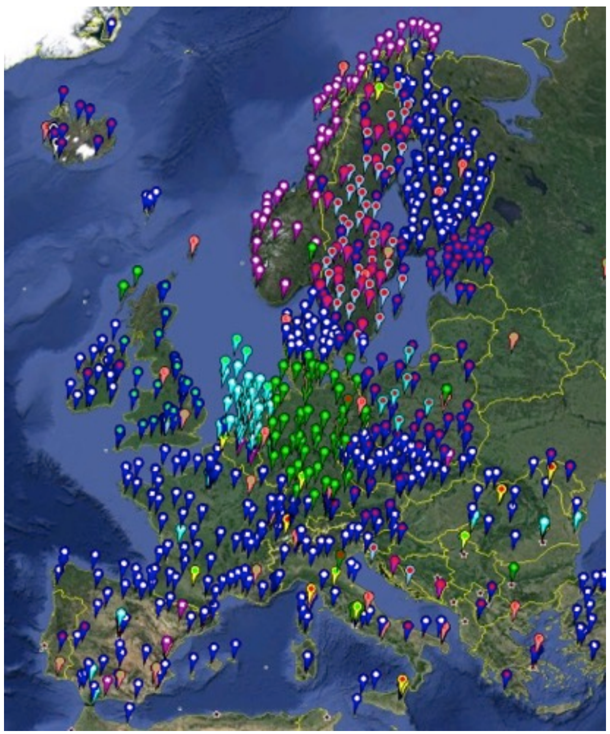
STRAT+ MLD Vs **PREV'AIR MLD**

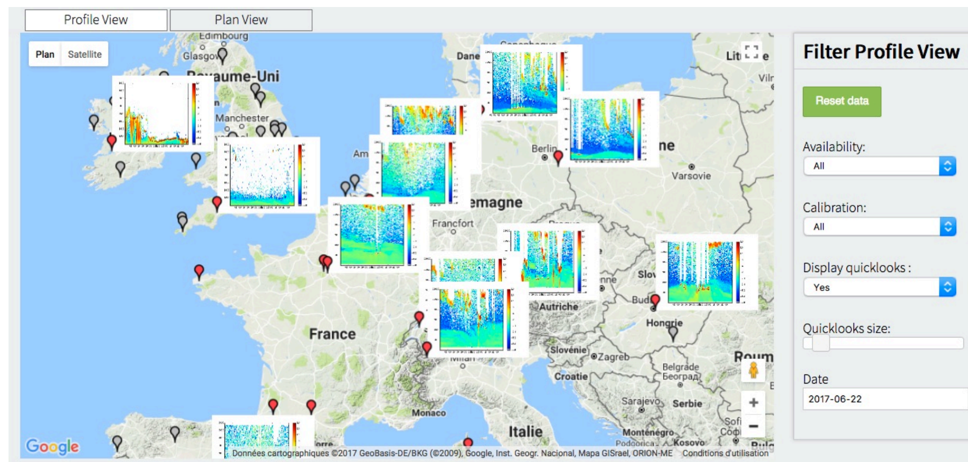


QUESTIONS ?



PART 3. ALC NETWORKS AND PRACTICAL SESSION

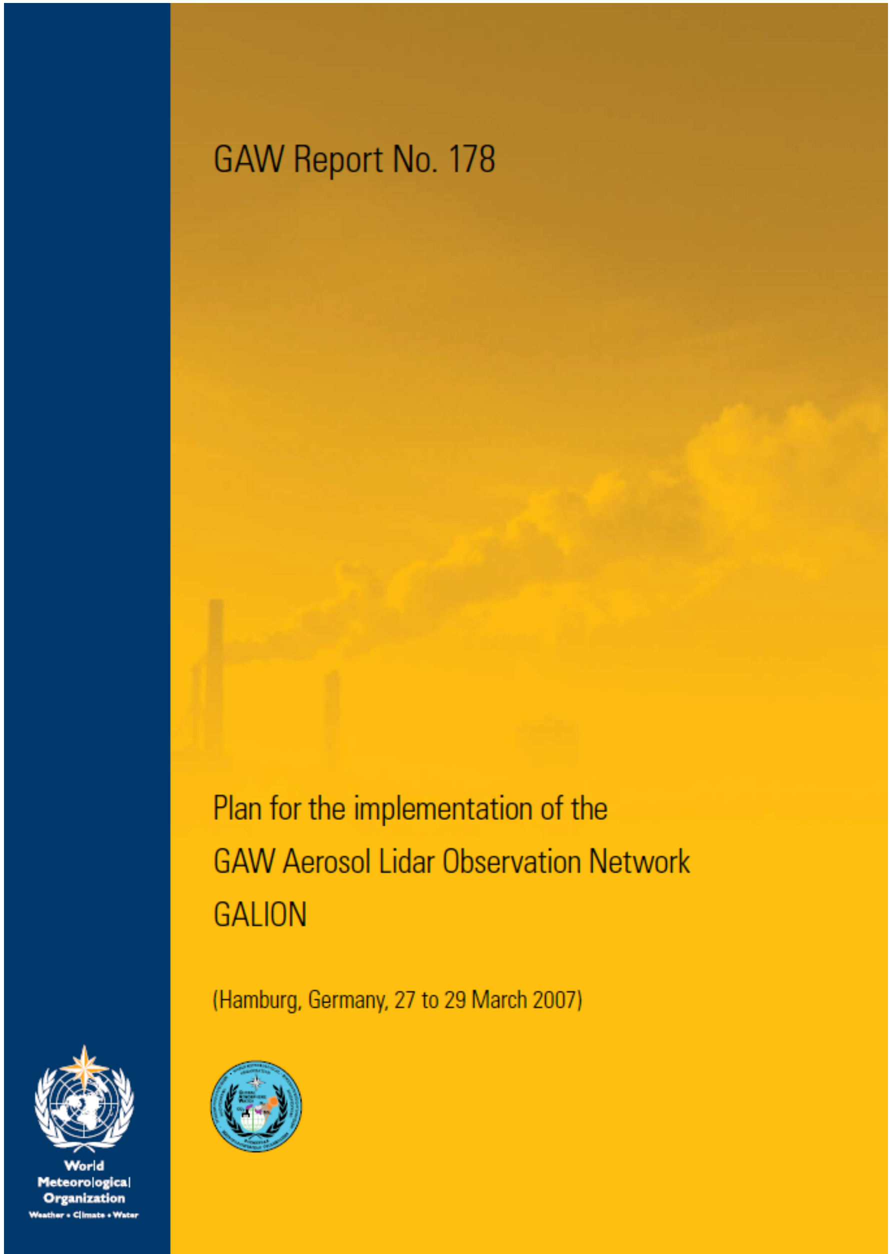




PRESENTATION OF ALC NETWORKS

Ina MATTIS, DWD

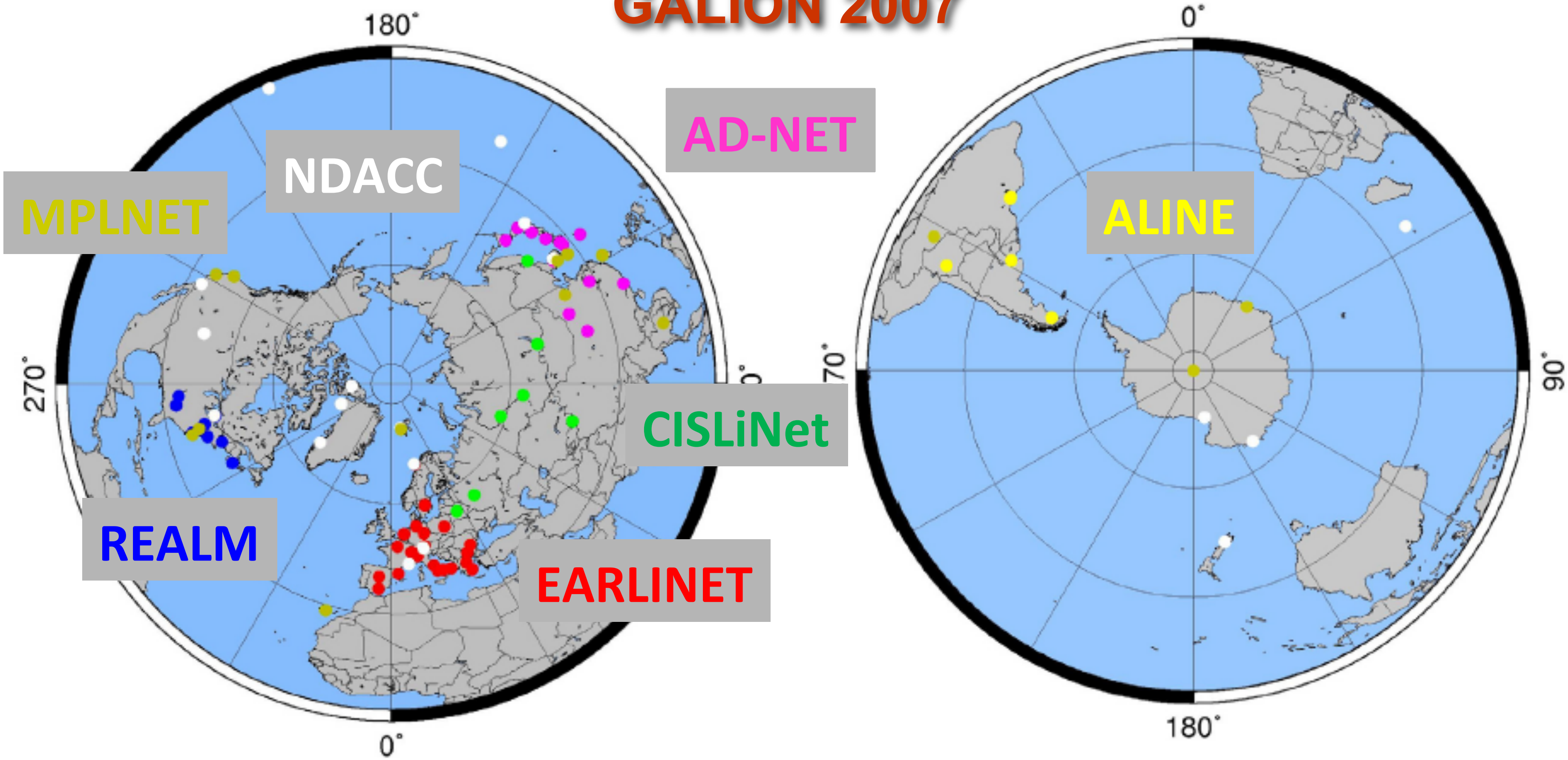
GALION – GAW Aerosol Lidar Observation Network



- GALION = network of networks
- Mostly research institutions

- 2017:
  - decision for a common metadata interface and data center
  - New members?

GALION 2007



GALION 2017 ← ?

- ALINE → LALINET
- CISLiNet, REALM
  → no actual data

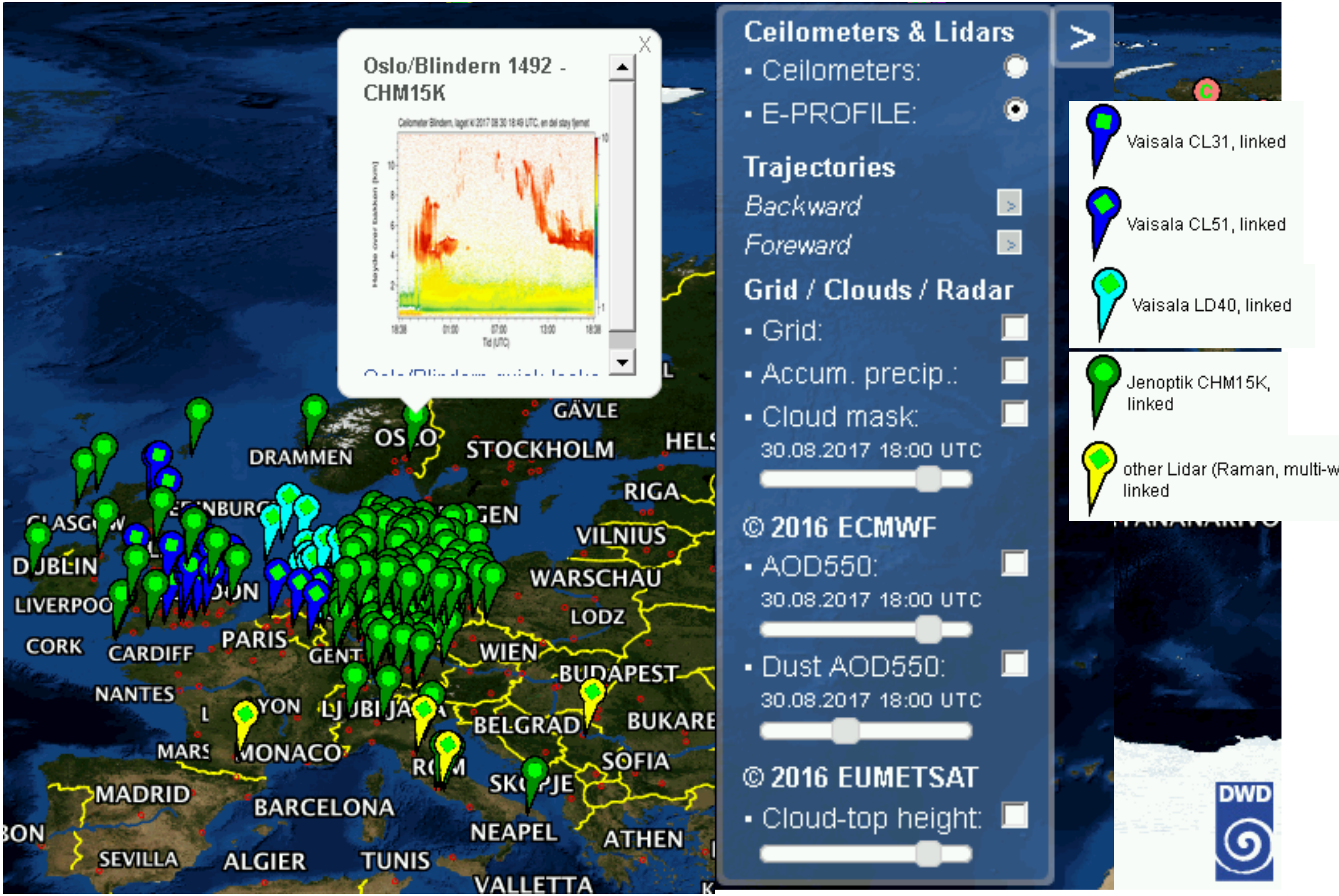
Developing scientific networks

- PollyNet
- Wisconsin HSRL
- …

Metservice networks

- E-PROFILE
  - Ceilometer
  - Raman lidars
  - Depol lidars
- …

GLOBAL ALC INVENTORY – www.dwd.de/ceilomap



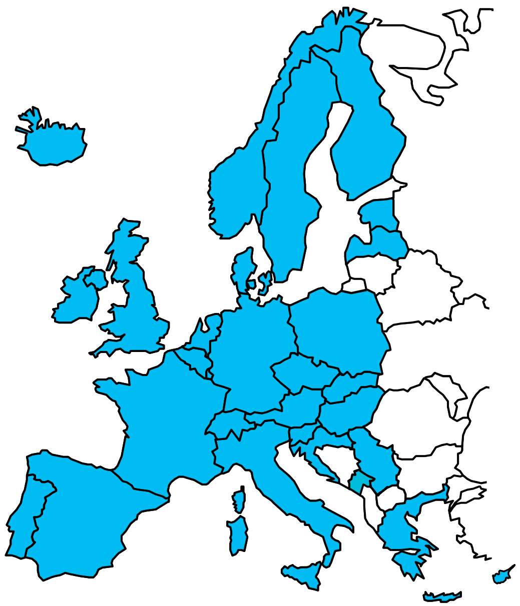
E-PROFILE PROGRAM

Maxime HERVO
Meteoswiss

Some facts on E-PROFILE

A network for vertical profiling of wind, aerosols and clouds

- It is a EUMETNET programme
- Coordinated by MeteoSwiss
- 20 member states
- Curent phase: 1.1.2013 until 31.12.2018
- Operational network of radar wind profilers
  (started with a COST action in 1987)
- Ceilometers and lidars in development



www.eumetnet.eu/e-profile

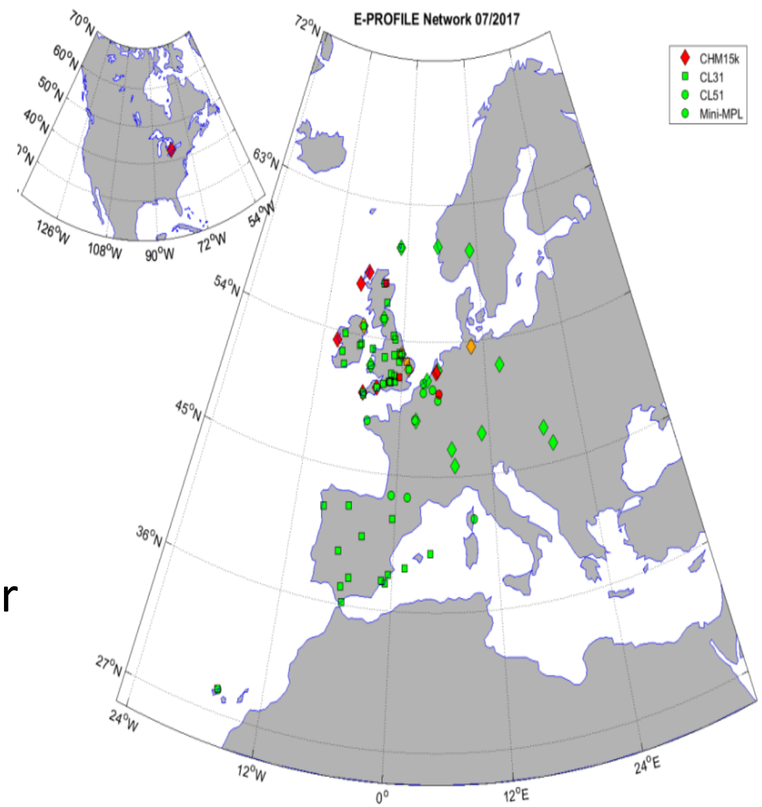
E-PROFILE

Data visible at
http://eumetnet.eu/alc-network

Status of the network (July 2017)

- 89 instruments
- 15 institutions
- 12 countries
- 303383 files

Aim: 250 instruments at the end of the year



DATA ACCESS

Images on:
http://eumetnet.eu/alc-network
http://www.dwd.de/DE/forschung/projekte/ceilomap/ceilomap_node.html

Unrestricted Real time data for Met Services for their core duties
Netcdf data by FTP
BUFR data on GTS (not yet implemented)

Data for research and development: need instrument owner agreement
NEtCDF by FTP
Calibrations coefficients and Monitoring on ftp.meteoswiss.ch

, ?? slides

QUESTIONS ?

PRACTICAL SESSION

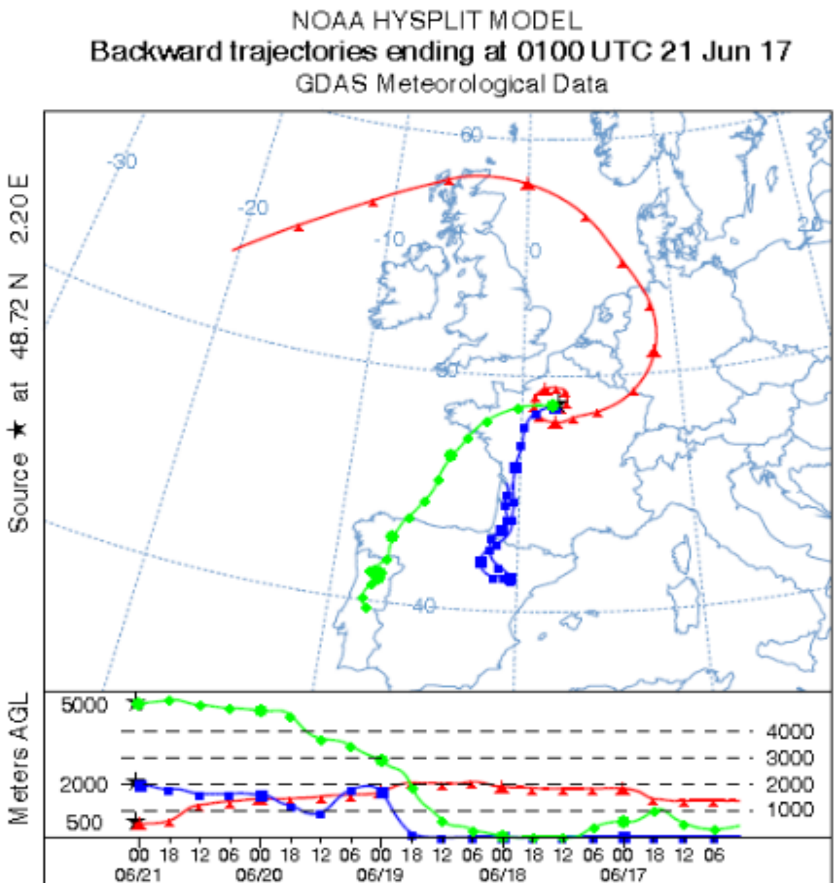
Two case studies involving recent heavy aerosol transport above Europe

Use E-PORFILE web based Quicklook images of ALC attenuated backscatter
http://eumetnet.eu/activities/observations-programme/current-activities/e-profile/alc-network/

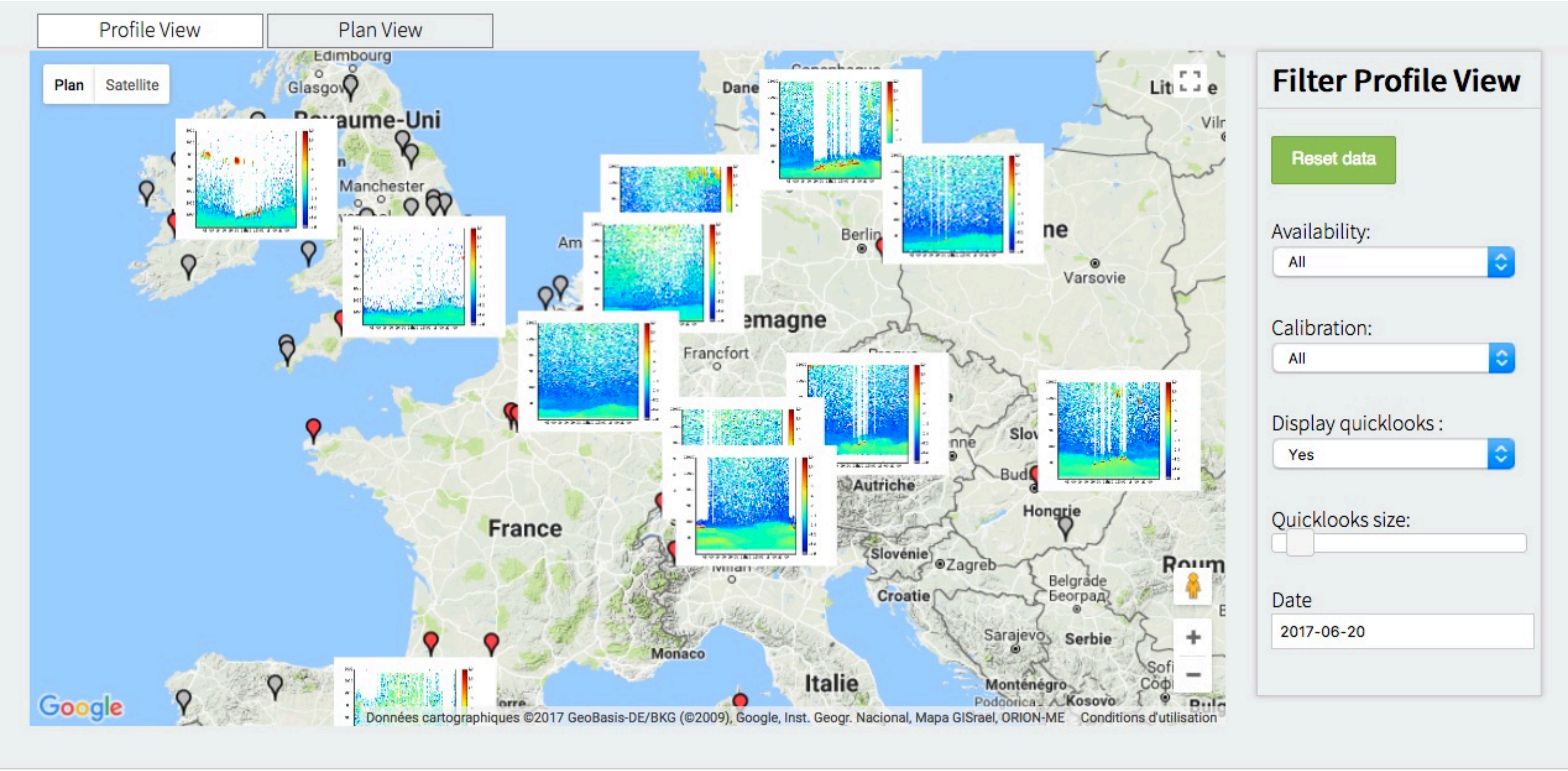
(type e-profile alc in g**gle search engine)

- June 2017: heavy fires across Portugal → strong biomass burning aerosol source
- August 2017: heavy fires in Brittish Columbia (Canada) and dust → multiple aerosol sources

21-22 JUNE 2017 CASE (BIOMASS BURNING)



21-22 JUNE 2017 CASE (BIOMASS BURNING)



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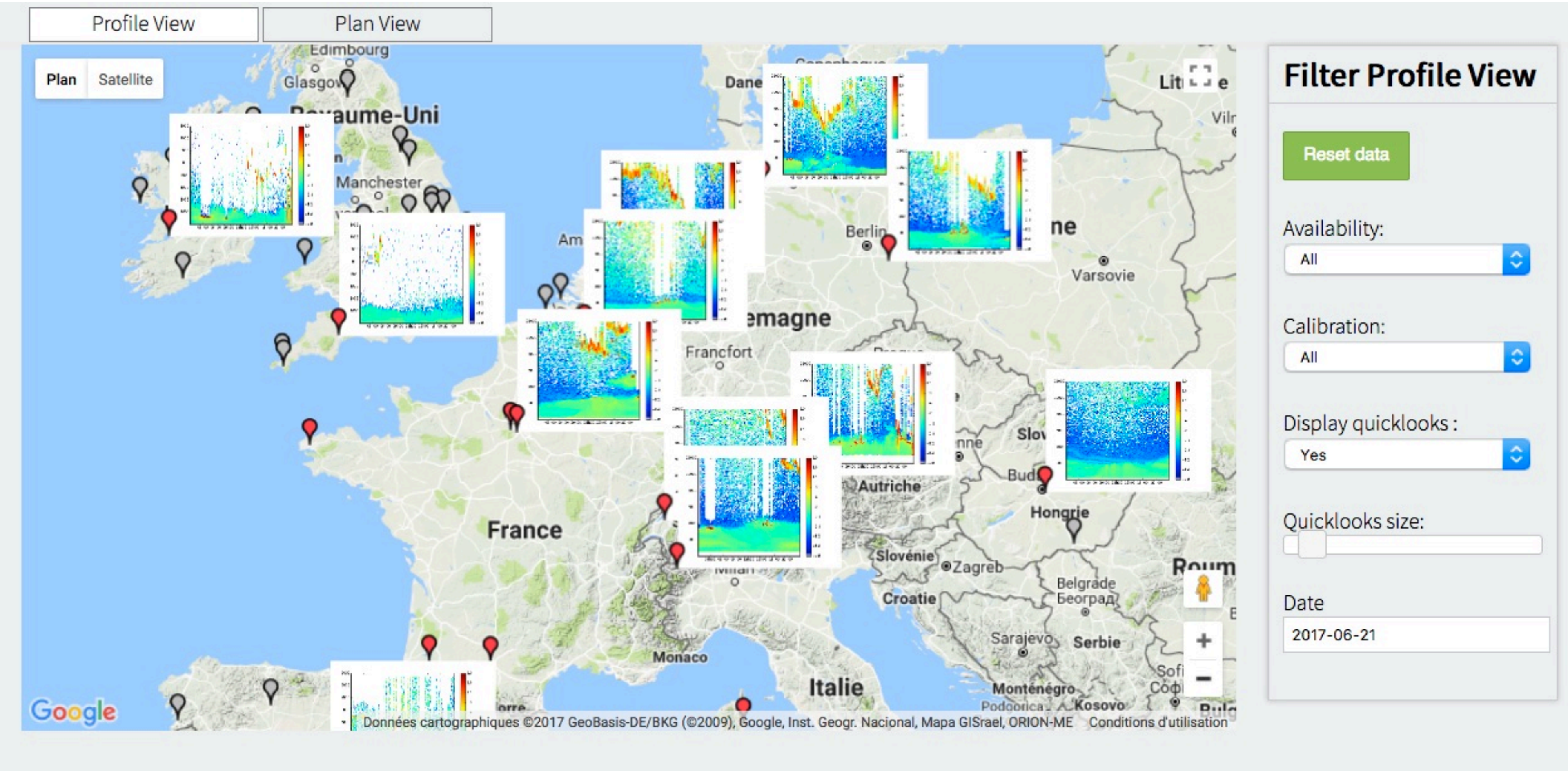

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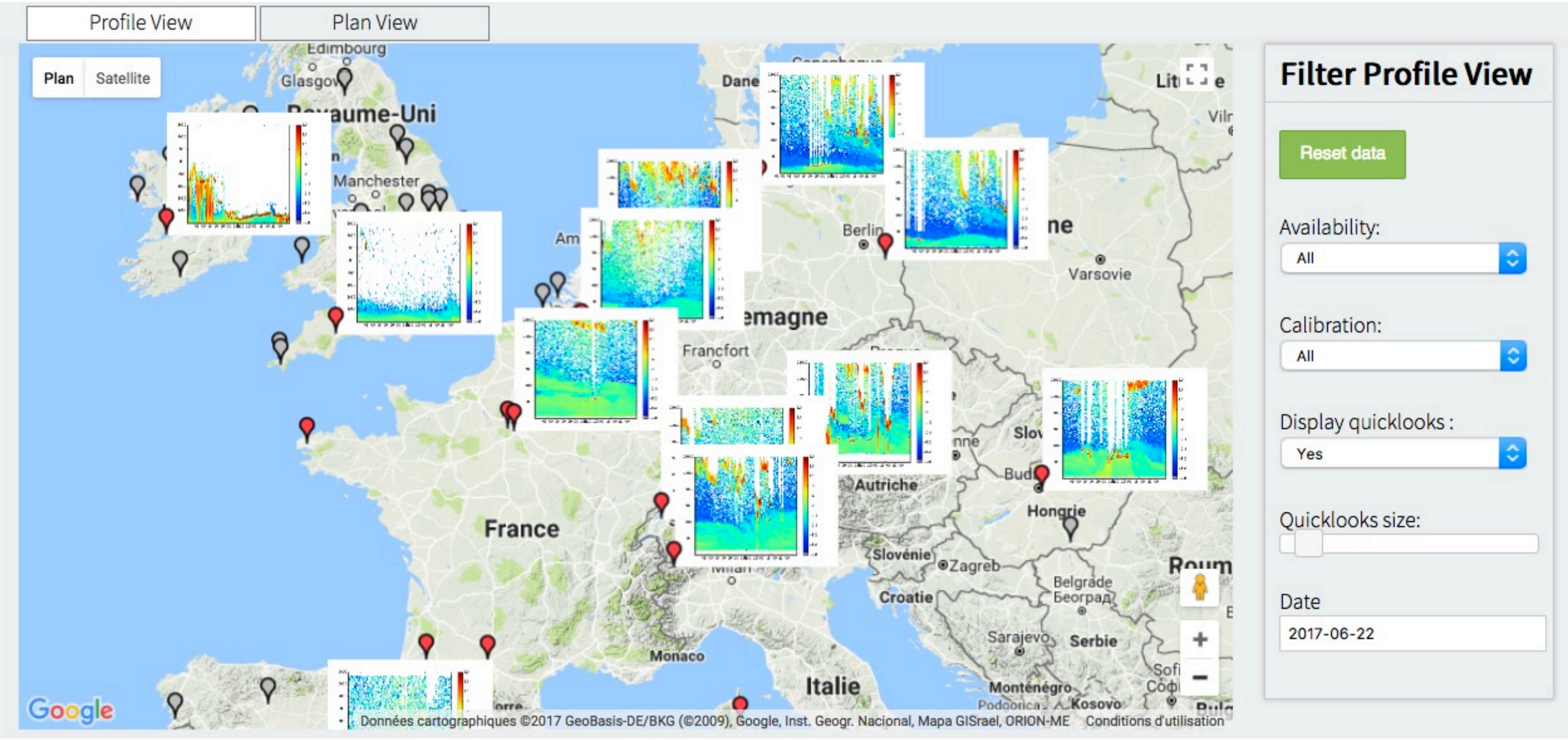

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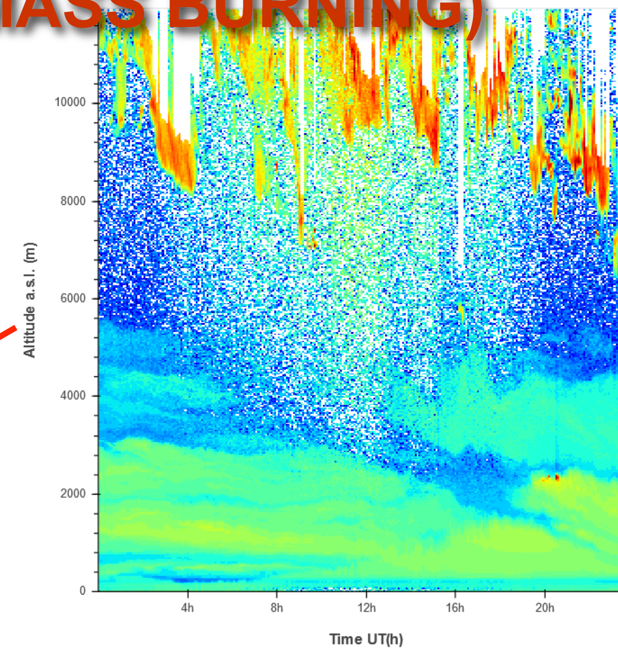
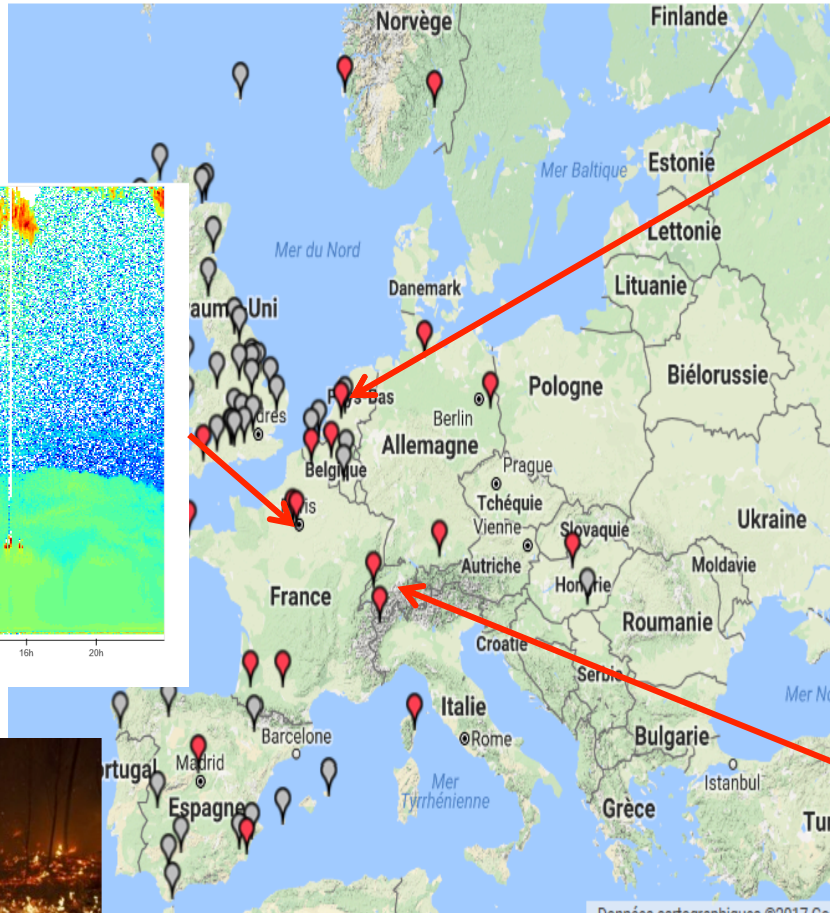
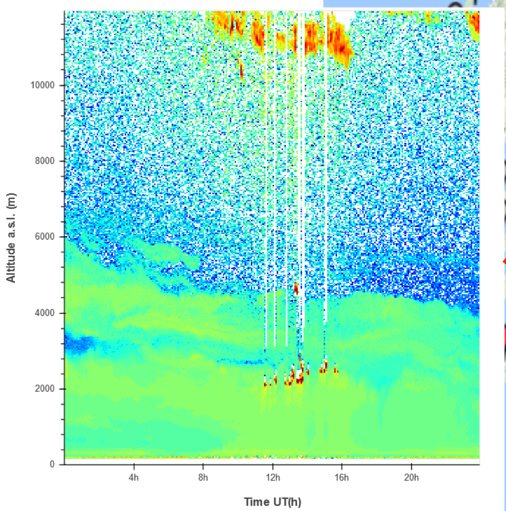
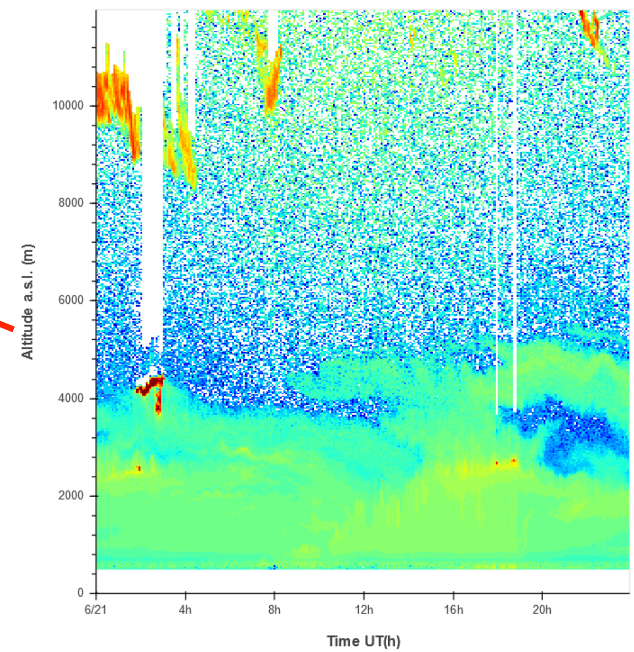


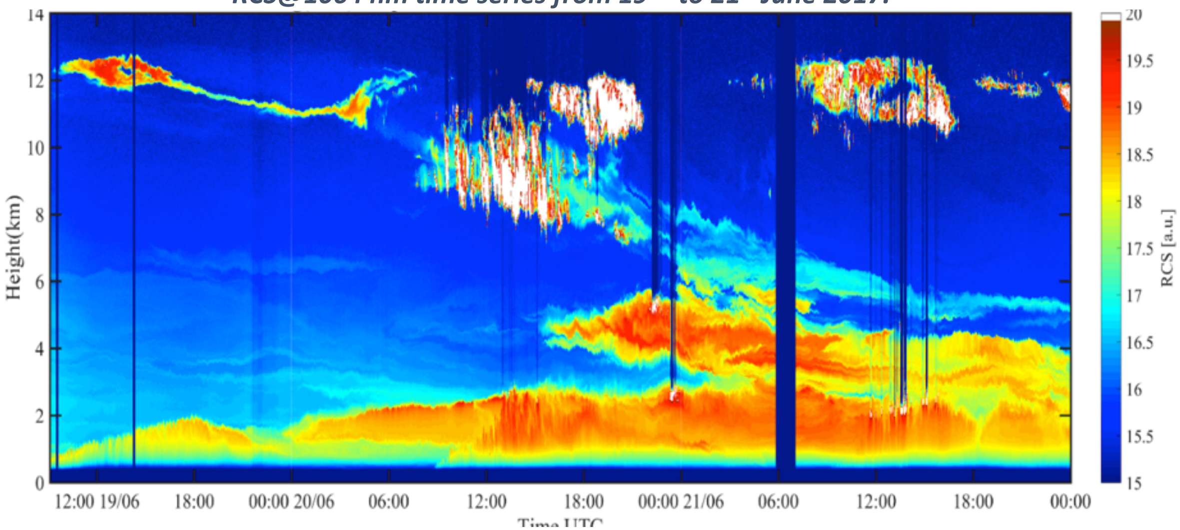


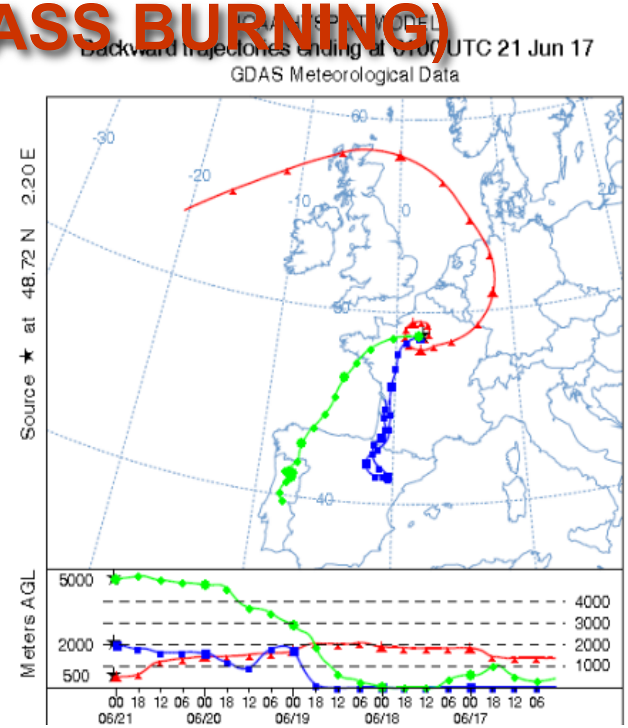


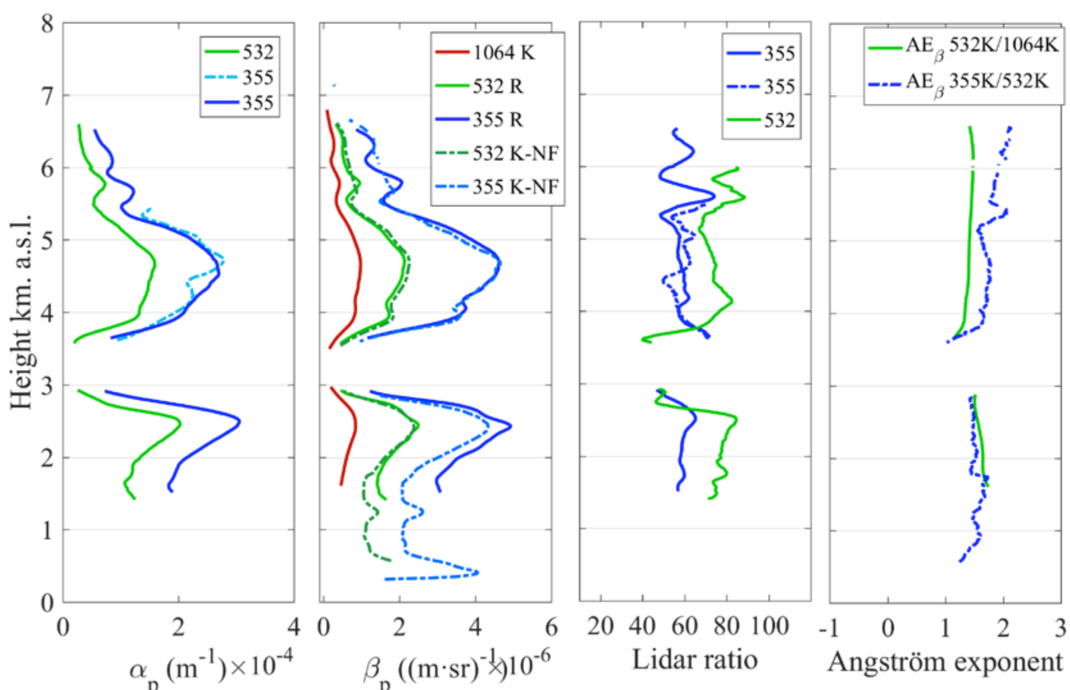


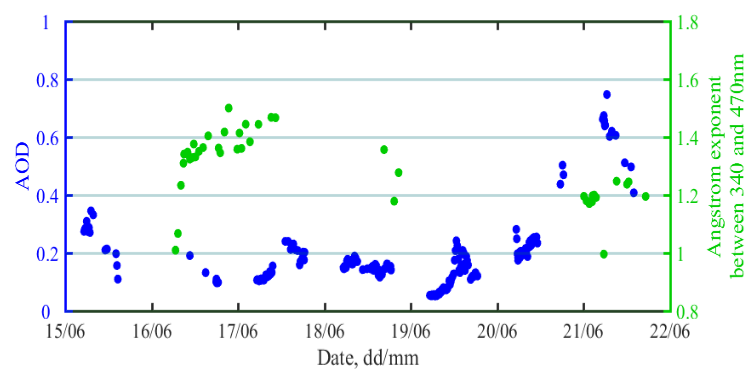
21-22 JUNE 2017 CASE (BIOMASS BURNING)

RCS@1064 nm time series from 19th to 21st June 2017.

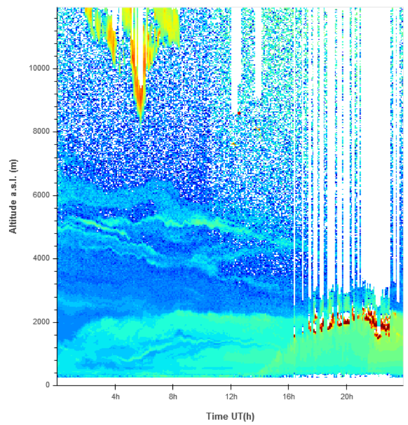


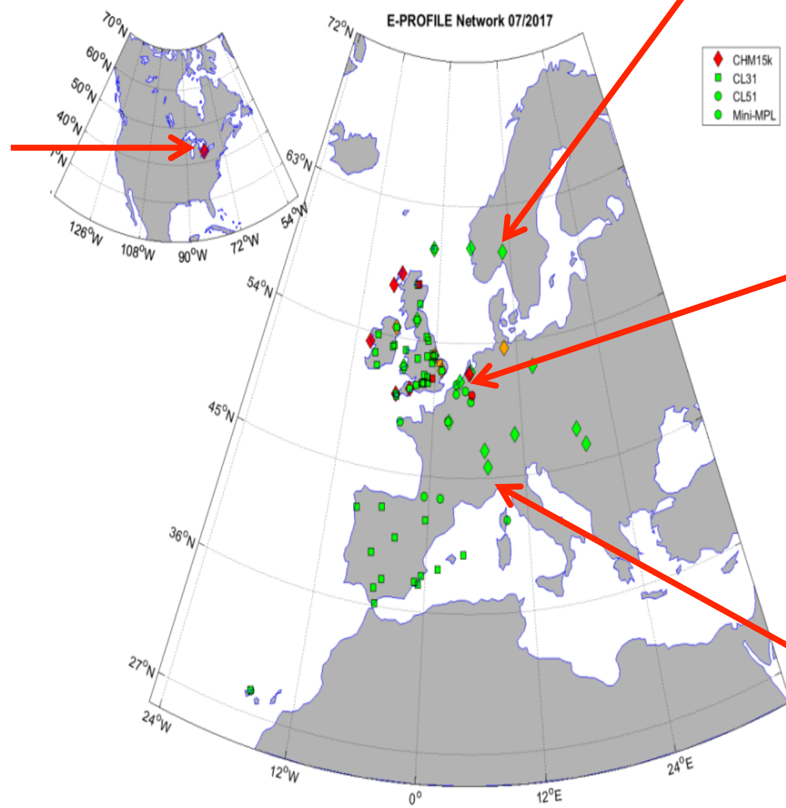


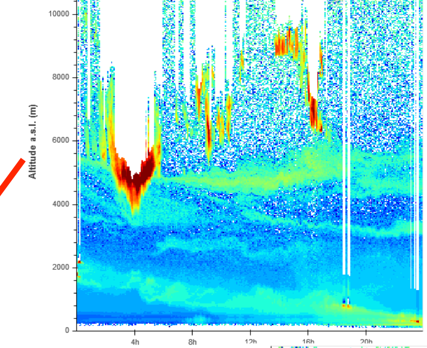


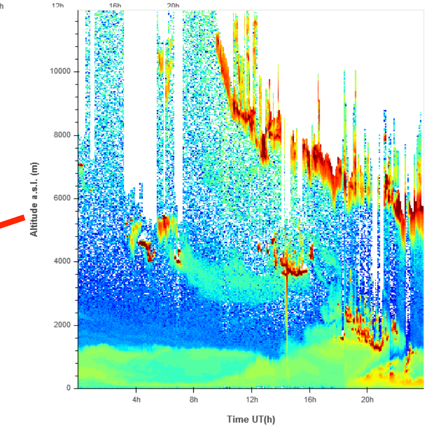


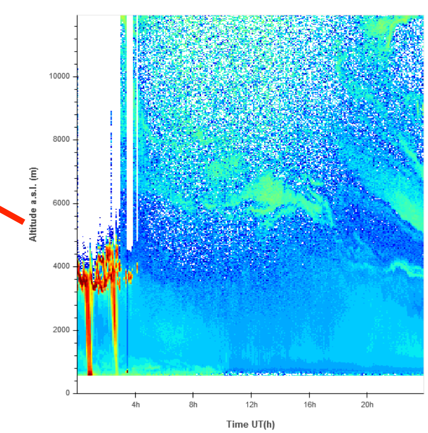
25-29 AUG 2017 CASE (BIOMASS + DUST)











- “largest wildfire ever recorded in BC”

25-28 AUG 2017 CASE (BIOMASS + DUST)