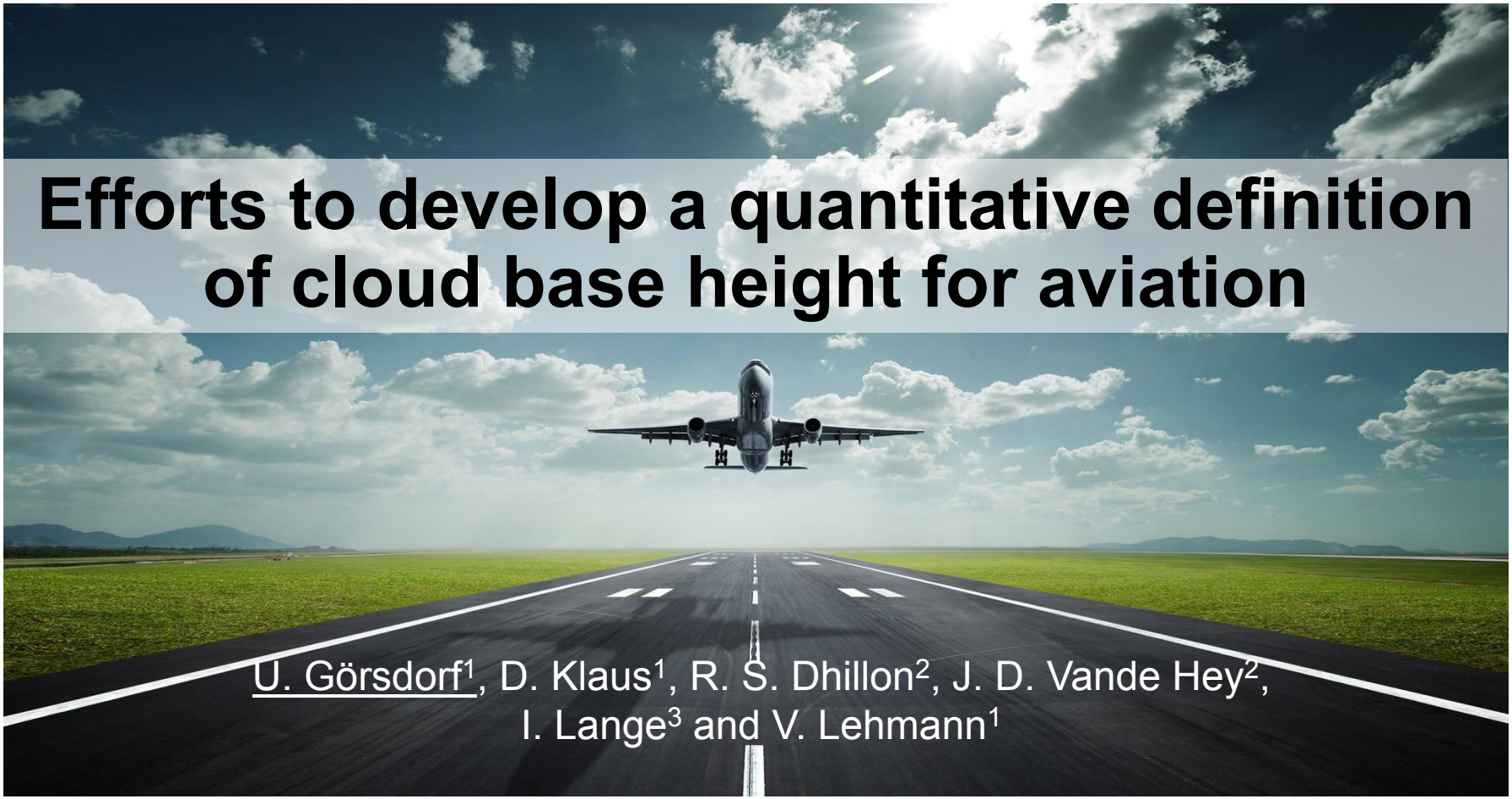


Efforts to develop a quantitative definition of cloud base height for aviation

U. Görsdorf[1], D. Klaus[1], R. S. Dhillon[2], J. D. Vande Hey[2], I. Lange[3] and V. Lehmann[1]

[1] *Meteorological Observatory Lindenberg - Richard Aßmann Observatory (MOL-RAO), Deutscher Wetterdienst (DWD)*
[2] *Earth Observation Science, Department of Physics and Astronomy, University of Leicester*
[3] *Faculty for Mathematics, Informatics and Natural Sciences, Meteorological Institute, Universität Hamburg*

METAR – *Meteorological Aviation Report*

ICAO keyword | Date/Time | Wind | Visibility | Cloudiness | Temperature | Air pressure | Trend

EDDT 120820Z 13005KT 9999 BKN011 02/M00 Q1023 BECMG SCT012

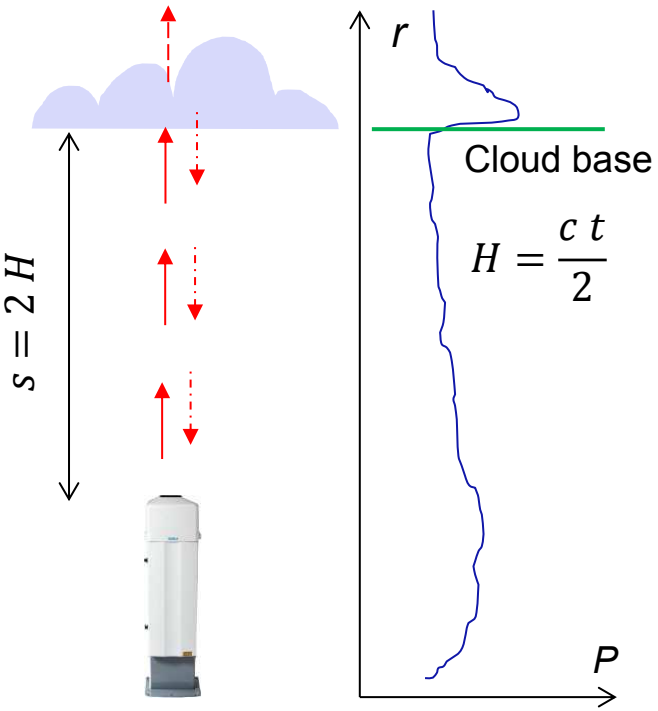
Cloud coverage (*N*)

Few (FEW)	1/8 – 2/8
Scattered (SCT)	3/8 – 4/8
Broken (BKN)	5/8 – 7/8
Overcast (OVC)	8/8
No significant cloud (NSC)	Missing clouds <1500 m, neither Cb nor TCU

Cloud base height (CBH) in hecto feet [hft = 100 ft], vertical resolution: 1 hft

Measuring instrument (ceiling → ceilometer)

Compact and inexpensive Light Detection And Ranging (LIDAR) device for deriving CBH from the measured backscatter signal



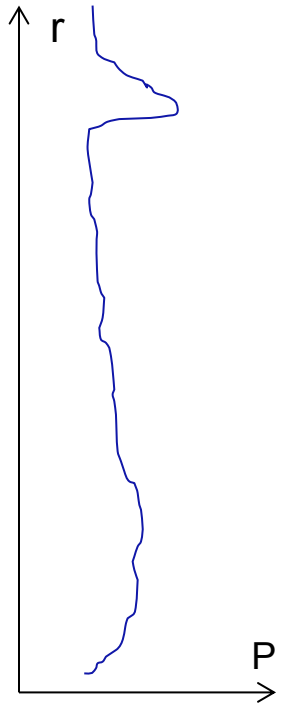
Ceilometer Backscatter profile

Vaisala LD40
(47 stations + 51 airports)

LUFFT CHM15k
(118 (165) stations)

http://ceilonet.dwd.de/mwvs/mwvs_ceilometer_geoplot.php

LIDAR equation



Backscatter profile

Power — Overlap function — Extinction coefficient

$$P(r) = C_{\mathrm{L}} \frac{O(r)}{r^2} \beta(r) \exp\left\{-2 \int_0^r \sigma(r')dr'\right\}$$

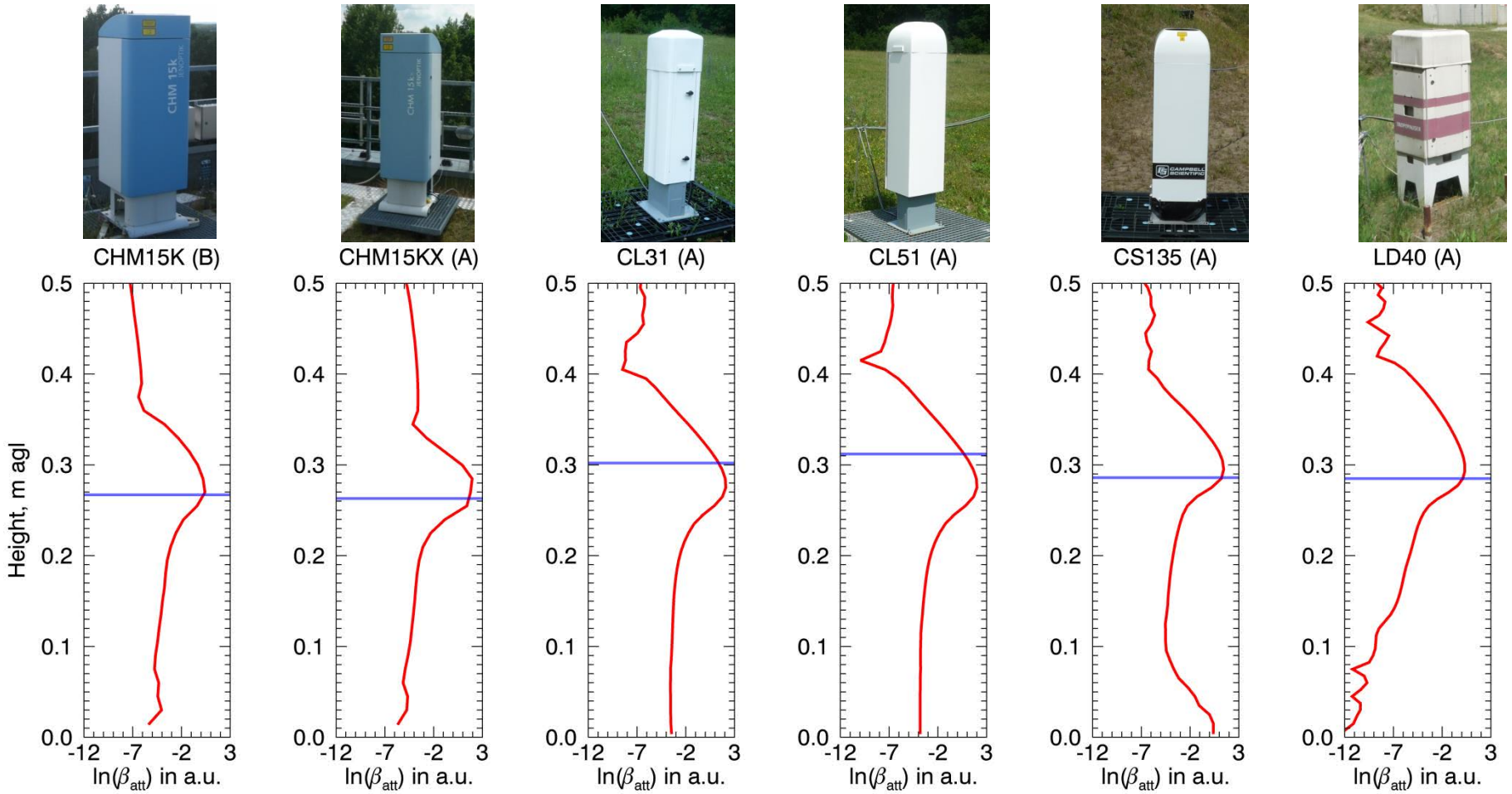
Lidar constant — Height — Backscatter coefficient

attenuated backscatter

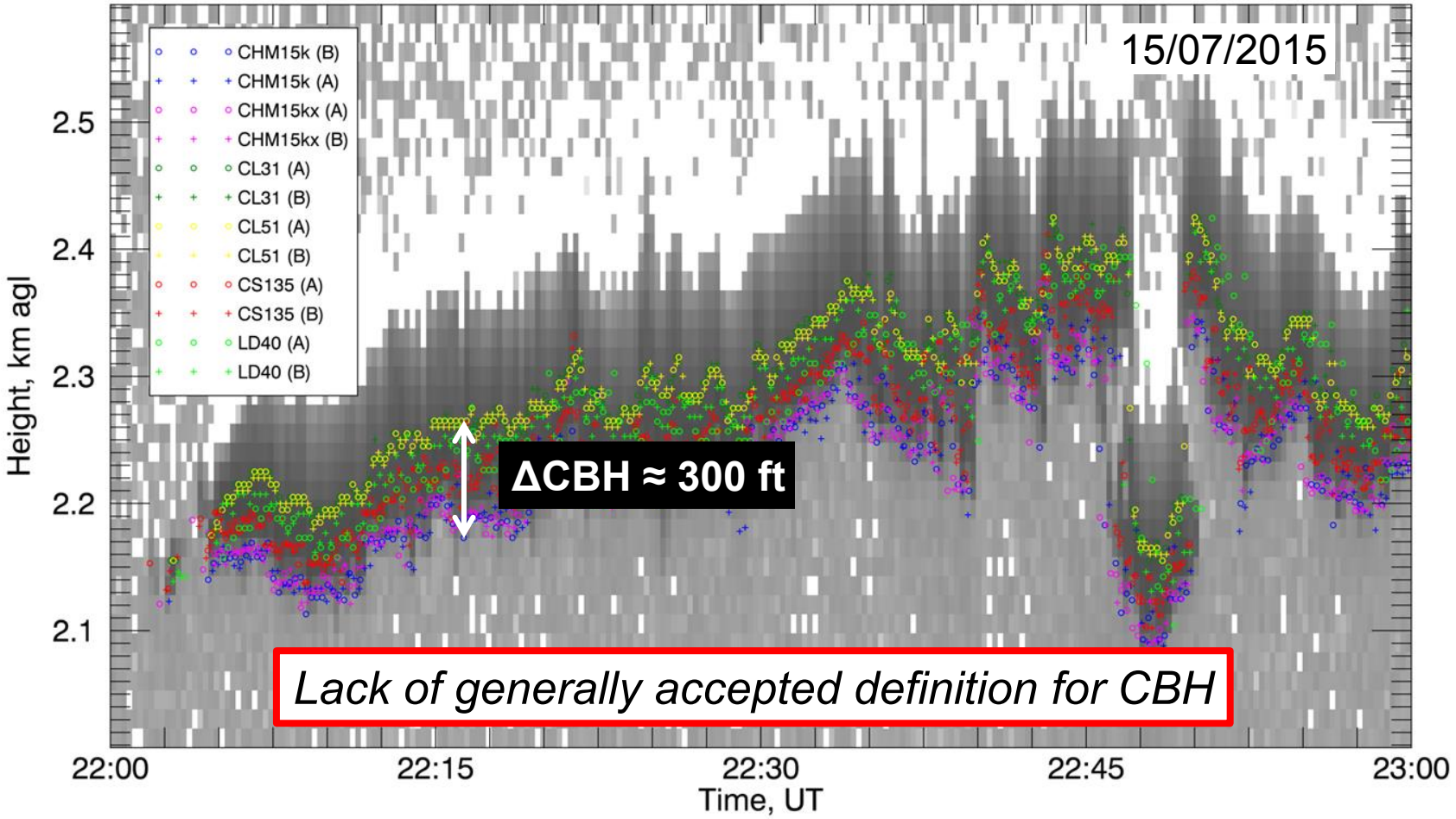
$$\beta(r) \exp\left\{-2 \int_0^r \sigma(r')dr'\right\} = \beta_{\mathrm{att}}(r) = \frac{P(r)\, r^2}{C_{\mathrm{L}} O(r)}$$

- Basically additional dependency on wavelength (λ)
- Approximation: constant ratio β/σ = *const.* along the optical path

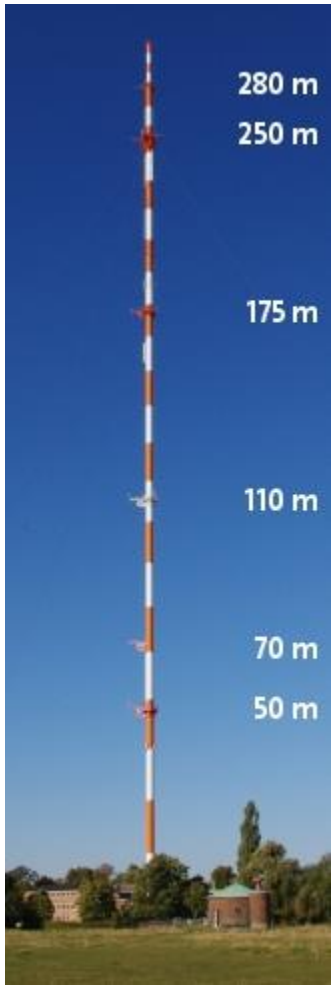
Backscatter signal and CBH of various ceilometers



CBH obtained from different manufacturers



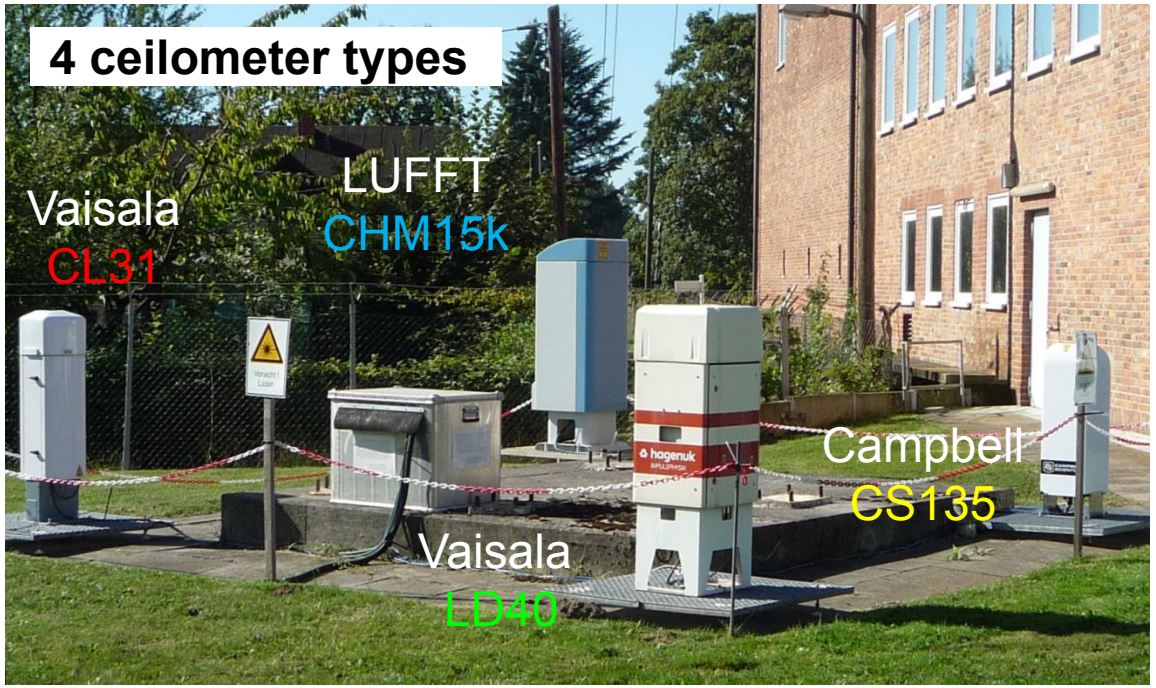
Ceilometer campaign Hansestadt Hamburg (CircaHH)



Hamburg Weather Mast ⇨ **“carpenter‘s rule for clouds”**

Phase 1: 10/2016 – 04/2017, Phase 2: 10/2017 – 04/2019
Collaboration: Uni Leicester and Uni Hamburg

Sony α7

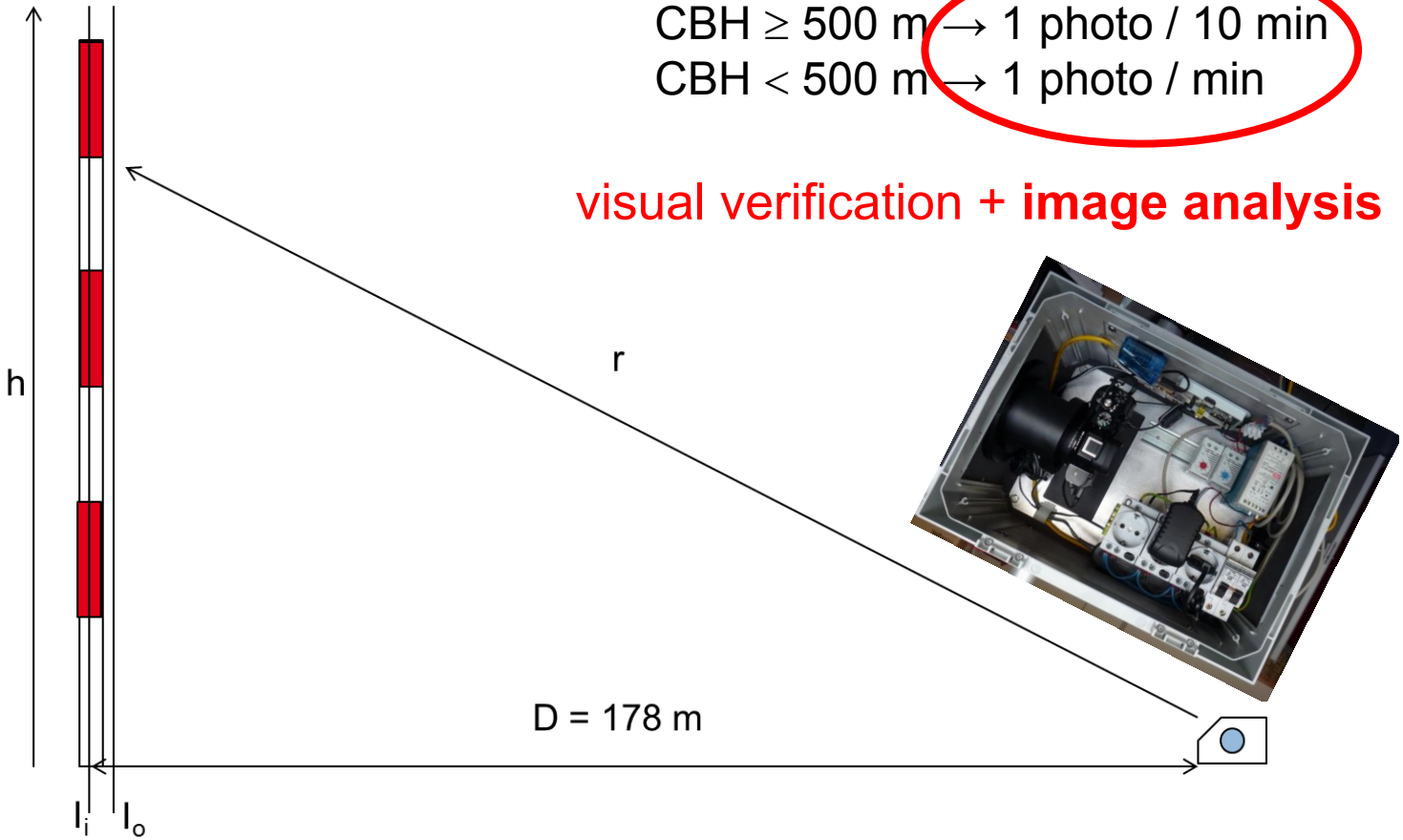


CircaHH – “carpenter‘s rule for clouds”

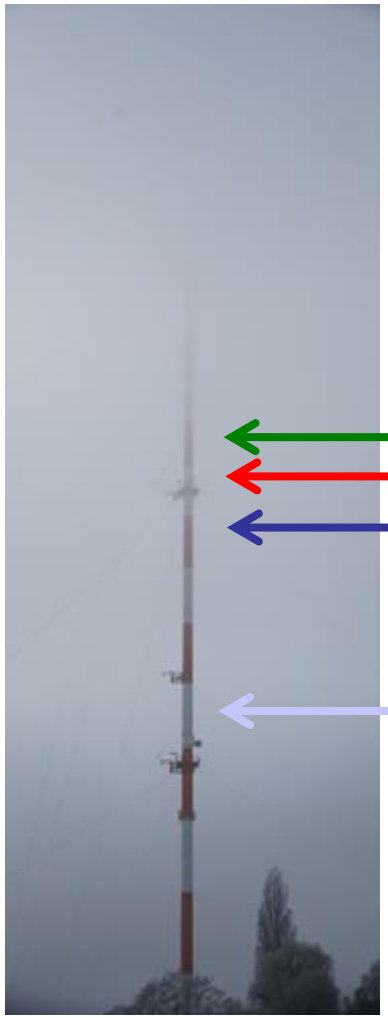
lowest CBH of the 4 ceilometers

CBH ≥ 500 m ⟶ 1 photo / 10 min
CBH < 500 m ⟶ 1 photo / min

visual verification + **image analysis**



12.11.2016, 12:00 UTC



Visually estimated CBH

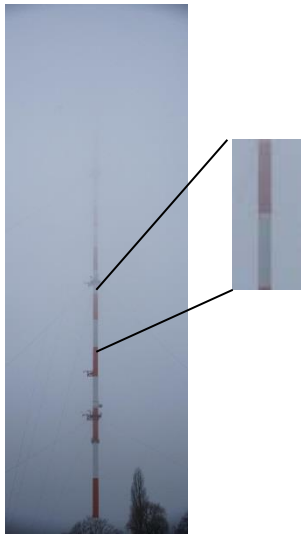
LD40

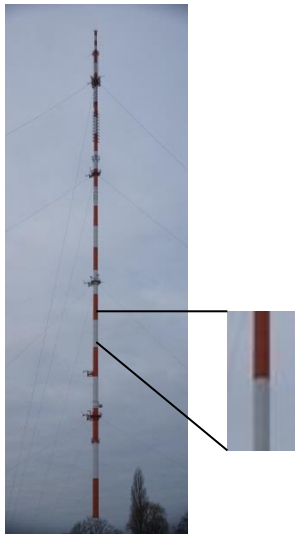
CL31

CHM15k > v0.747

CHM15k v0.732

Image analysis





Contrast C

$$C = I_r / I_w$$

Extinction coefficient

$$\sigma = -\frac{\ln\left(\frac{C}{C_0}\right)}{r}$$

$$C_0 = I_{r0} / I_{w0}$$

Contrast C_0

Methods for determination of CBH

- Red/white contrast
  CBH = height, where $C/C_0 \leq 0.05$
- Gradient in extinction profile
  CBH = height, where $\Delta\sigma/\Delta z$ = max
- Meteorological optical range (MOR)

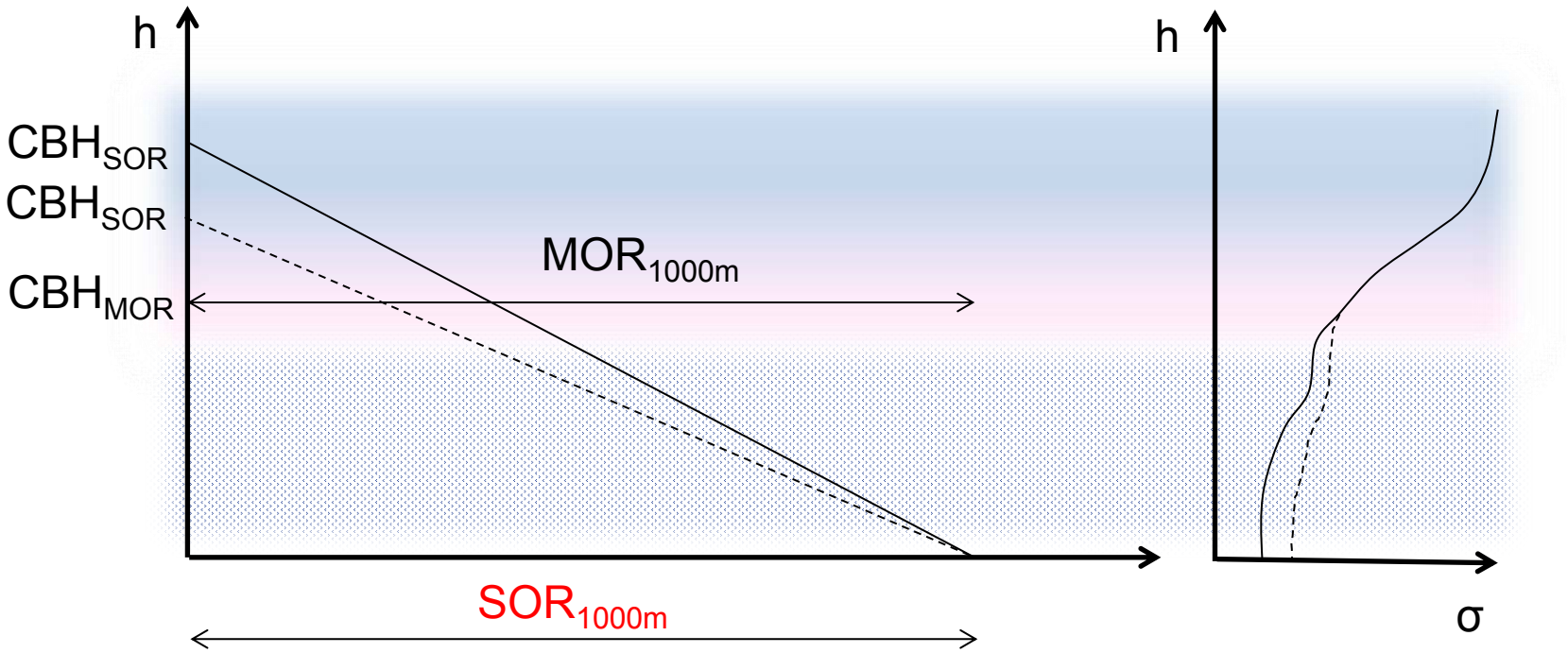
$$\mathrm{MOR} = -\frac{\ln(C/C_0)}{\sigma} \approx \frac{3}{\sigma}$$

e.g. Poyer and Lewis (2009), Vande Hey (2013)

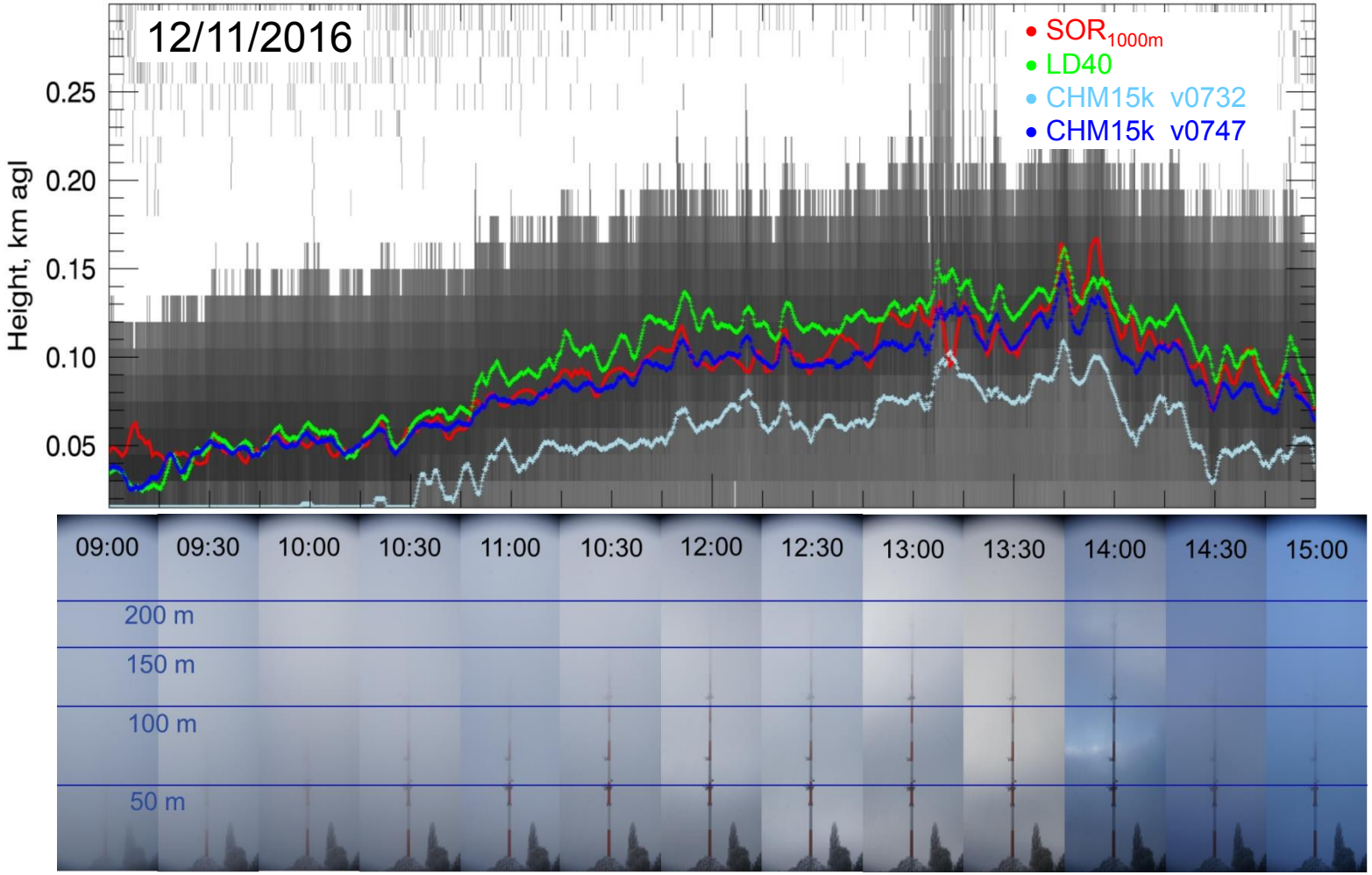
- Slant optical range (SOR)

Advantage of SOR as quantitative definition

$$\mathrm{MOR} = -\frac{\ln(0.05)}{\sigma(h)} \approx \frac{3}{\sigma(h)} \qquad \mathrm{SOR} = H\sqrt{\left(\frac{3}{\int_0^H \sigma(h)\,\mathrm{d}h}\right)^2 - 1}$$



Application of SOR definition to image analysis



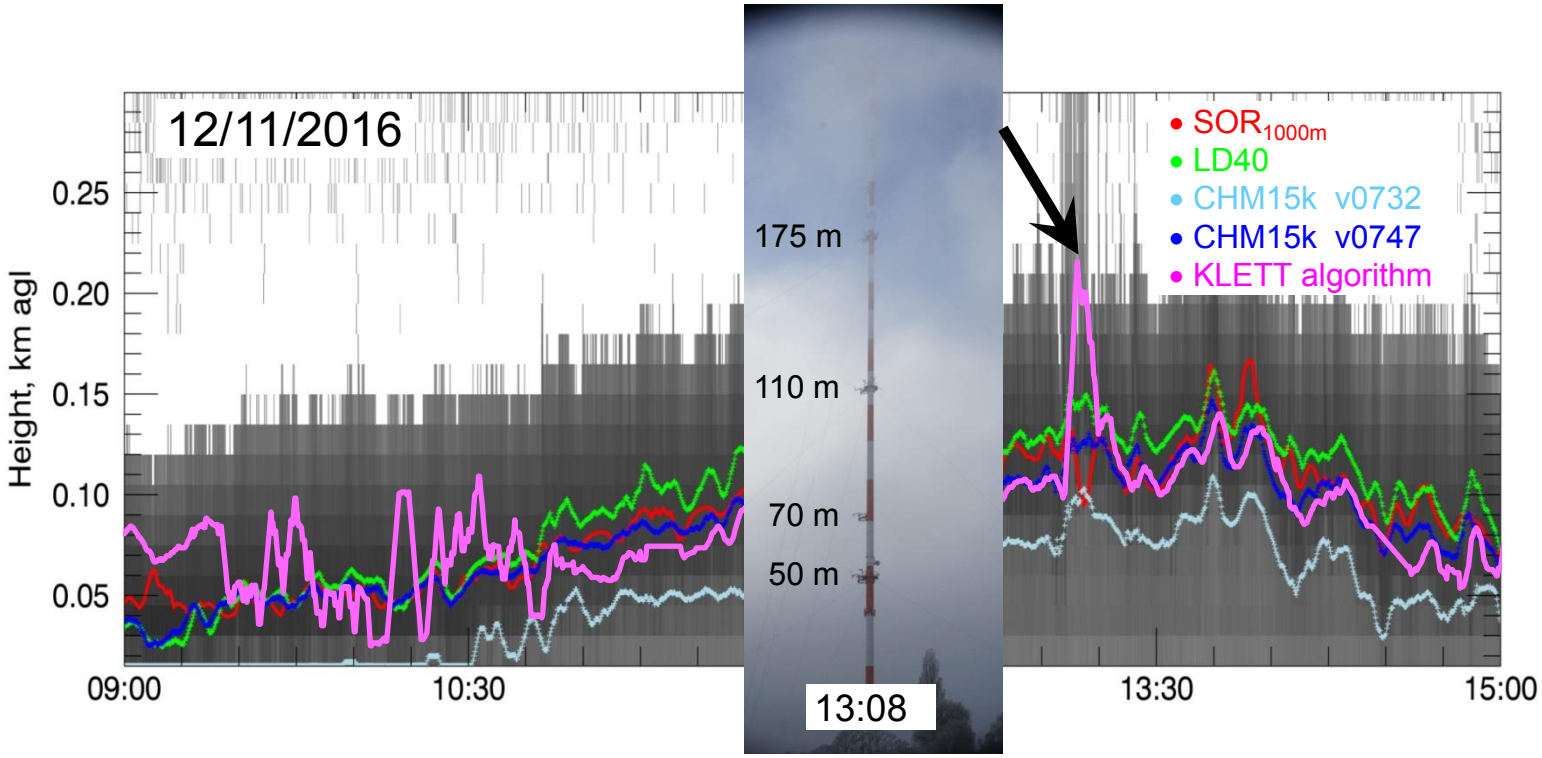
Conclusions

- Slant optical range (SOR) with threshold value of 1000 m appears to be a suitable quantitative definition for CBH
- Image analysis of tall towers or masts can provide a reference method to evaluate CBHs obtained from various ceilometer types
- The measurements of recently installed visibility sensors in 175 m and 280 m height should help to verify the extinction profiles derived from the image analysis
- Combination of KLETT algorithm and SOR criterion offers a physically motivated method to determine CBH from ceilometer backscatter profiles


Thank you for
your attention

Additional slides

Preliminary: Application of SOR definition to “raw” data
(Input backscatter profiles from CL31)



backscatter signal $\xrightarrow{KLETT\ algorithm}$ extinction profile $\xrightarrow{SOR\ definition}$ CBH