Detection of mixing-layer heights from ground-based remote sensing with SODAR, ceilometers, and RASS – algorithms and experiences

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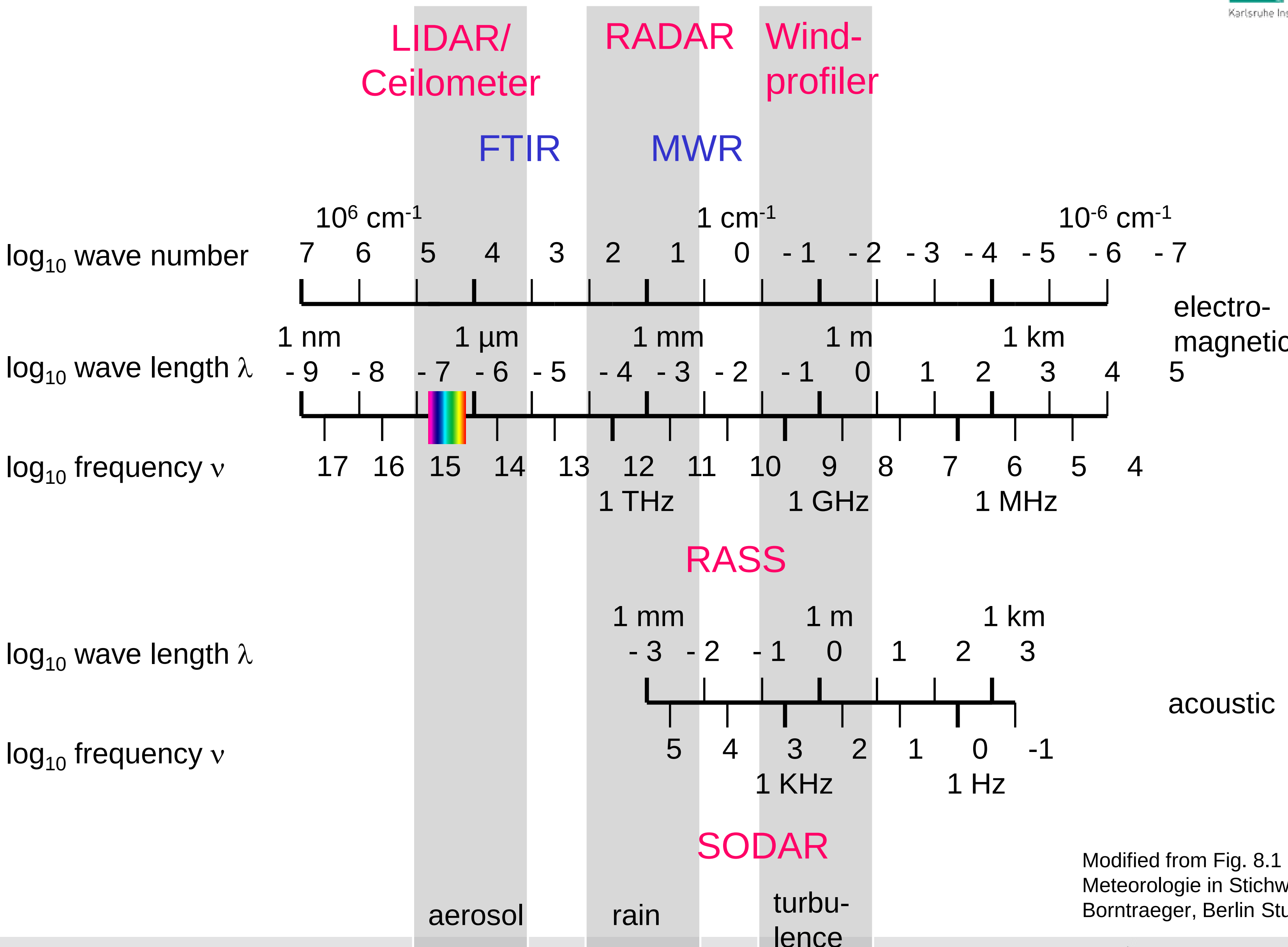
Typical frequency bands for remote sensing of the atmosphere



Modified from Fig. 8.1 in „Meteorologie in Stichworten“, Borntraeger, Berlin Stuttgart 2000

Basic remote sensing techniques

subject of this talk

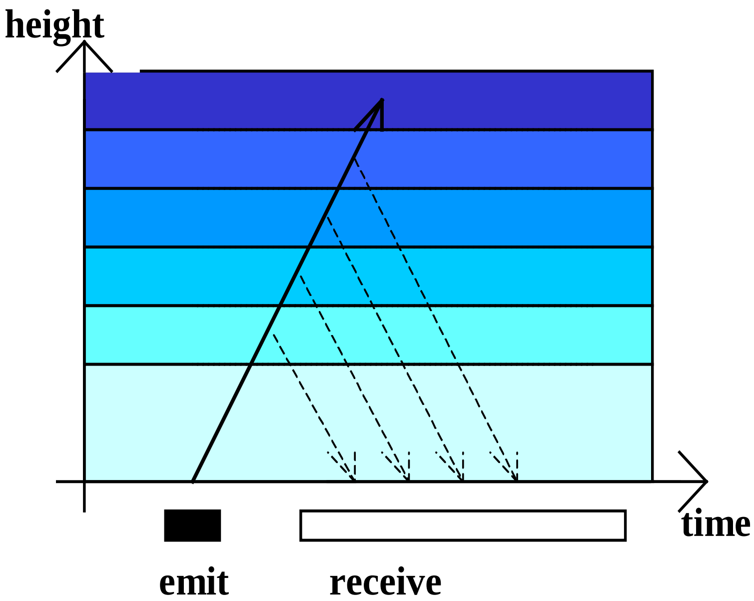
name	princple	spatial resolution	direction	type
RADAR	backscatter, electro-magnetic pulses, fixed wave length	profiling	scanning, slanted	active, monostatic
SODAR	backscatter, acoustic pulses, fixed wave length	profiling	fixed, slanted, vertical	active, usually monostatic
LIDAR	backscatter, optical pulses, fixed wave length(s)	profiling	scanning, fixed, horizontal, slanted, vertical	active, monostatic
RASS	backscatter, acoustic, electro-magnetic, fixed wave length	profiling	fixed, vertical	active, monostatic
	absorption, infrared, spectrum	path-averaging	fixed, horizontal, slanted	active, bistatic or passive
FTIR	emission, infrared, spectrum	path-averaging	fixed, horizontal, slanted	passive
DOAS	absorption, optical, fixed wave lengths	path-averaging	fixed, horizontal	active, bistatic
radiometry	electro-magnetic, fixed wave length(s)	averaging, profiling	fixed, scanning, slanted, vertical	passive
tomography	travel time, acoustic, fixed wave length	horizontal distribution	fixed, horizontal	active, multiple emitters and receivers

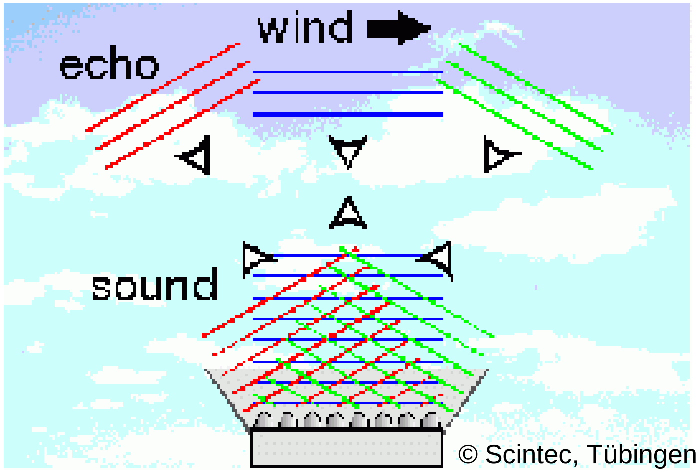
subject of this talk

SODAR

algorithms for mixing-layer height

monostatic SODAR: measuring principles





deduction:

sound travel time = height
backscatter intensity = turbulence
Doppler-shift = wind speed

Emission of sound waves into three directions:

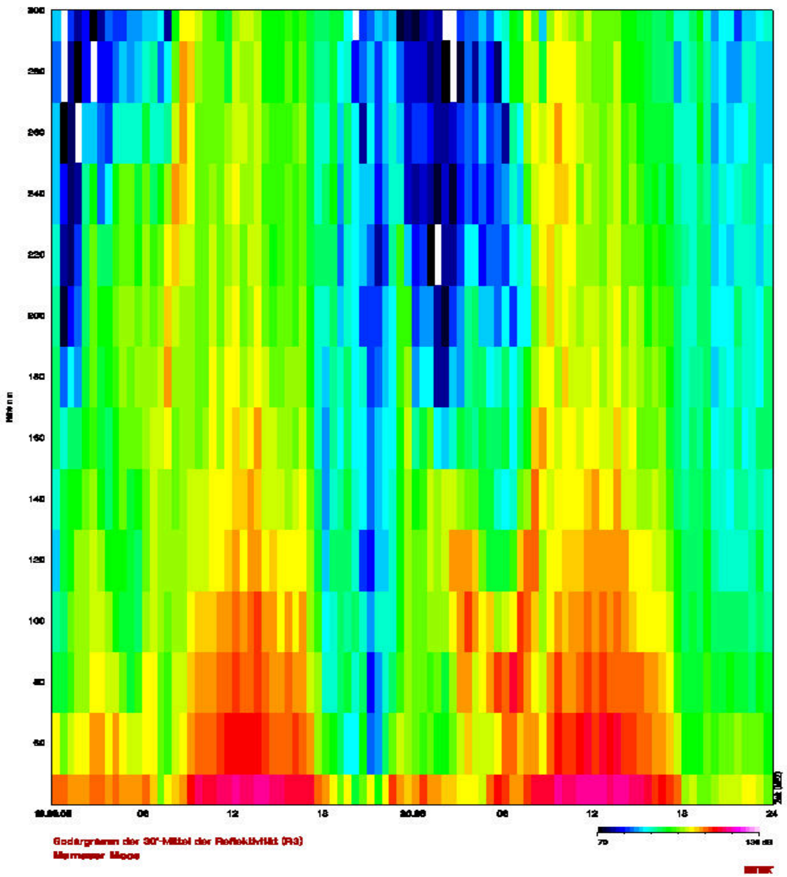
in order to measure all three components of the wind (horizontal and vertical)

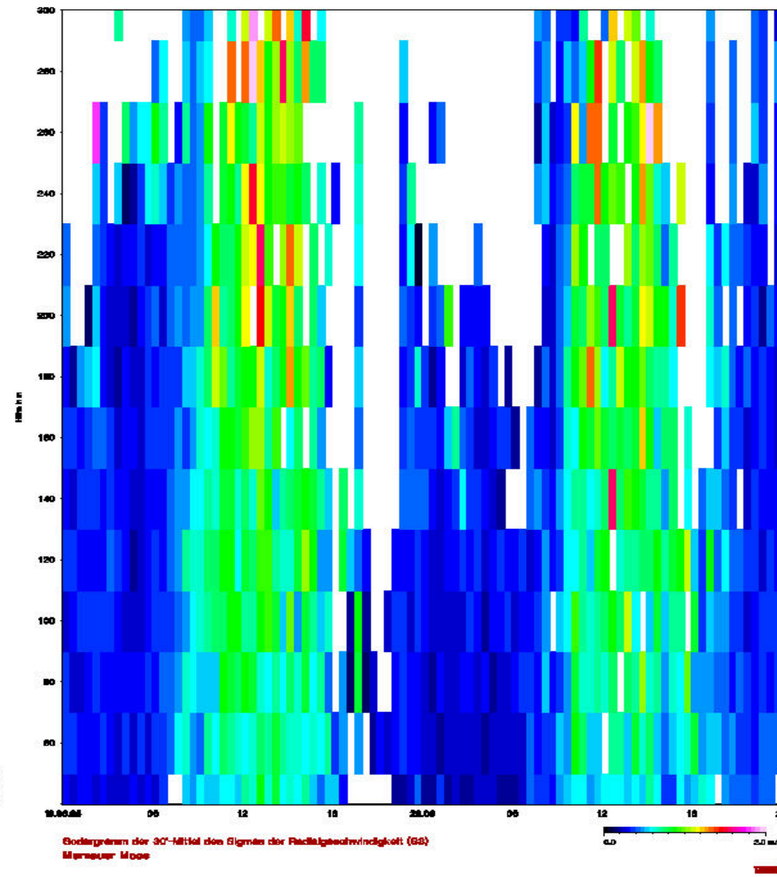
Sample plot SODAR (convective BL at daytime)

acoustic backscatter intensity

sigma w

40 – 300 m





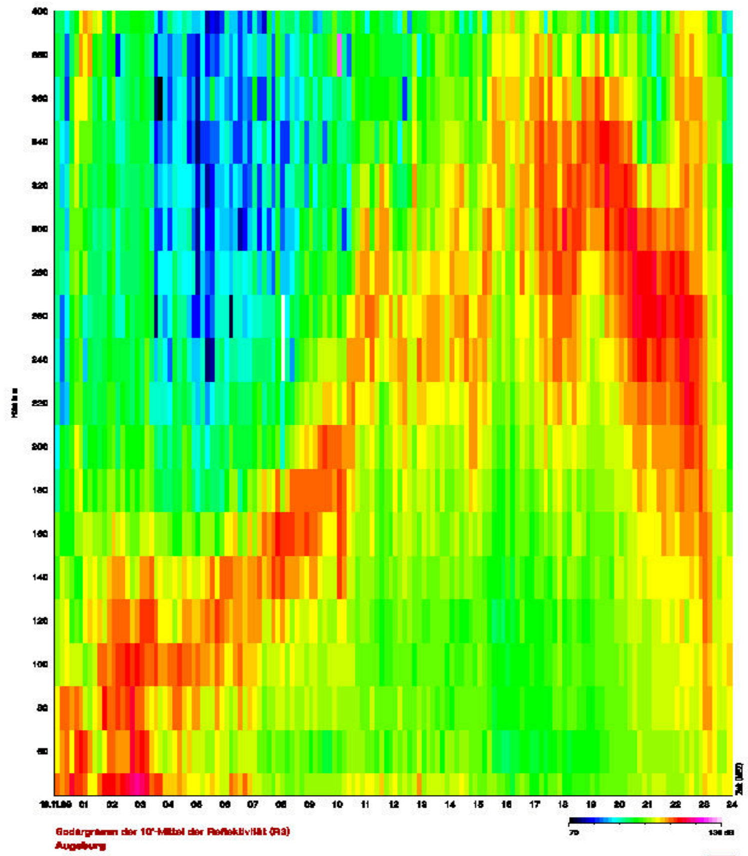
2 days, midnight to midnight

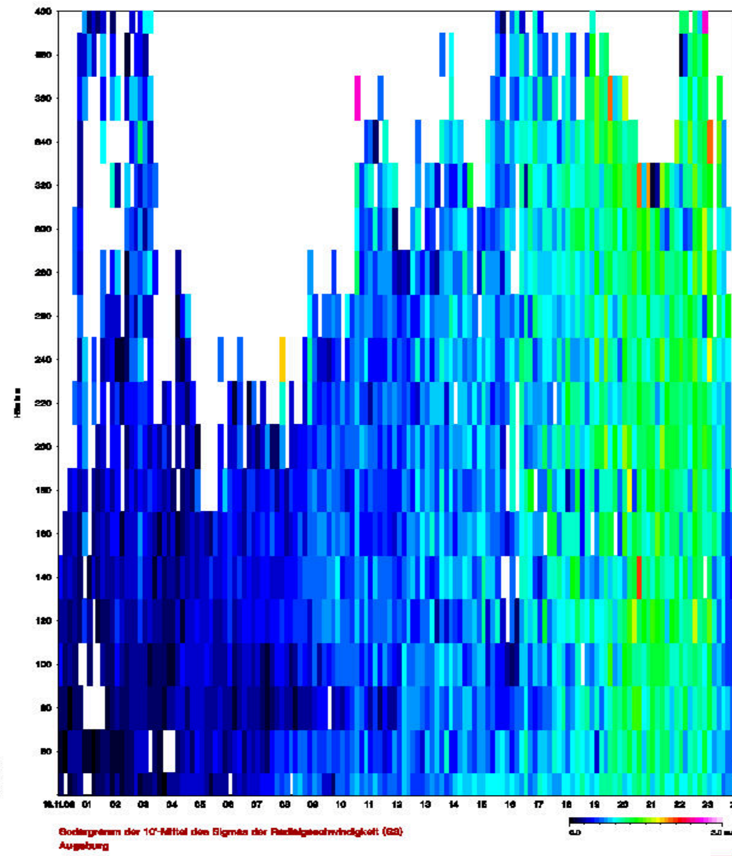
Sample plot SODAR (lifted inversion)

acoustic backscatter intensity

sigma w

40 – 400 m





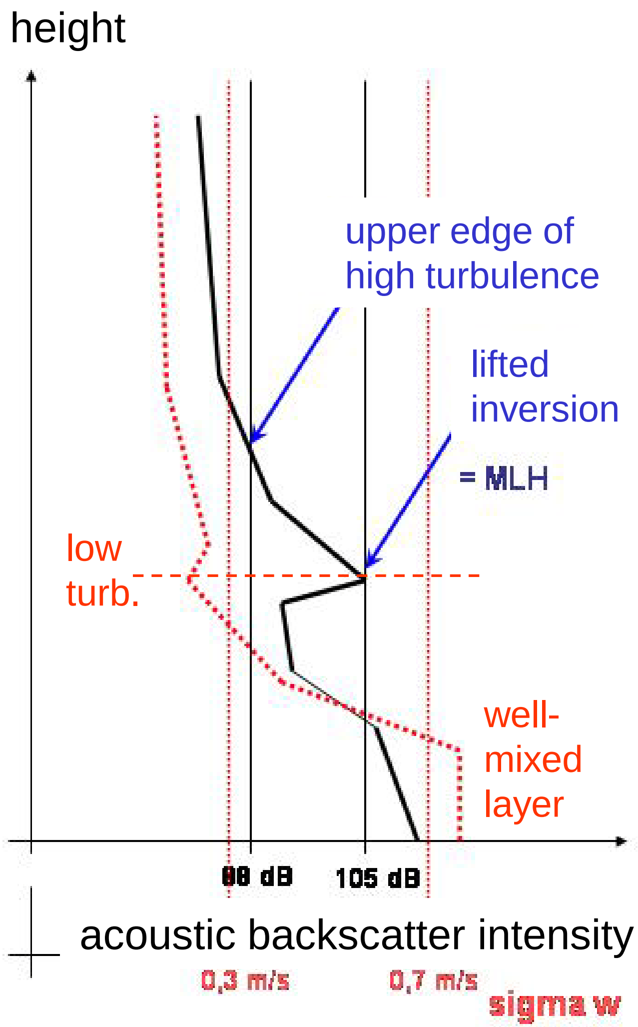
1 day, midnight to midnight

Algorithms to detect MLH from SODAR data

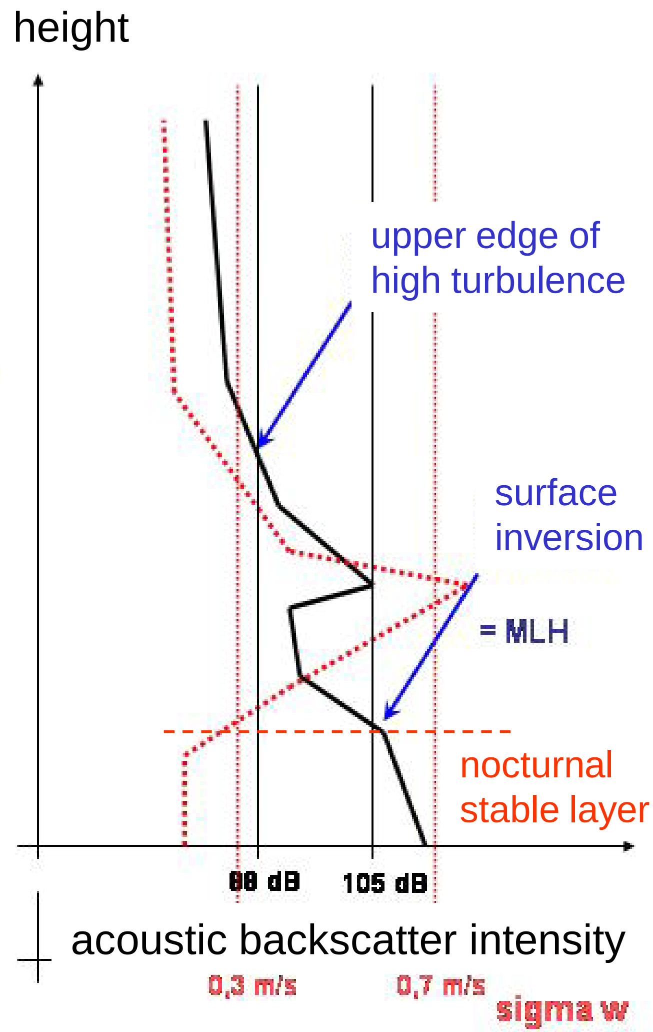
criterion 1:
upper edge of high turbulence

criterion 2:
surface and lifted inversions

MLH = Min (C1, C2)



example 1: daytime

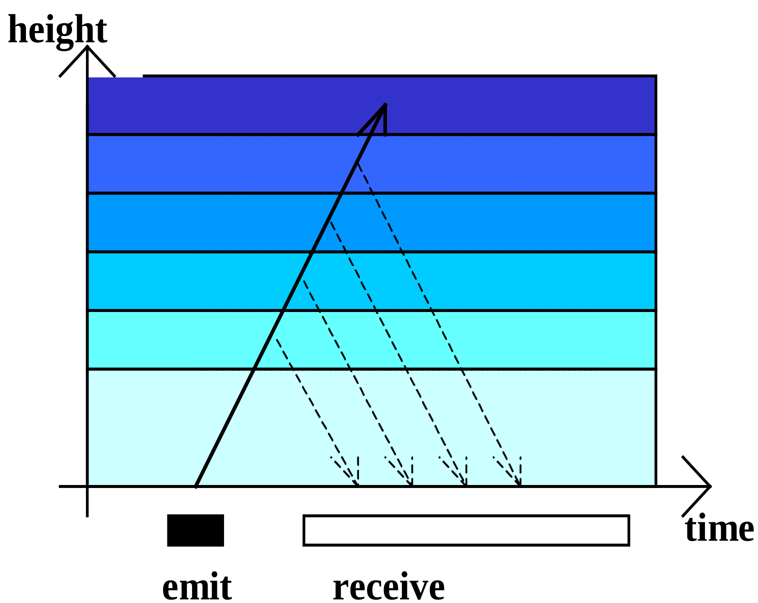


example 2: night-time

Ceilometer

algorithms for mixing-layer height

Ceilometer/LIDAR measuring principle

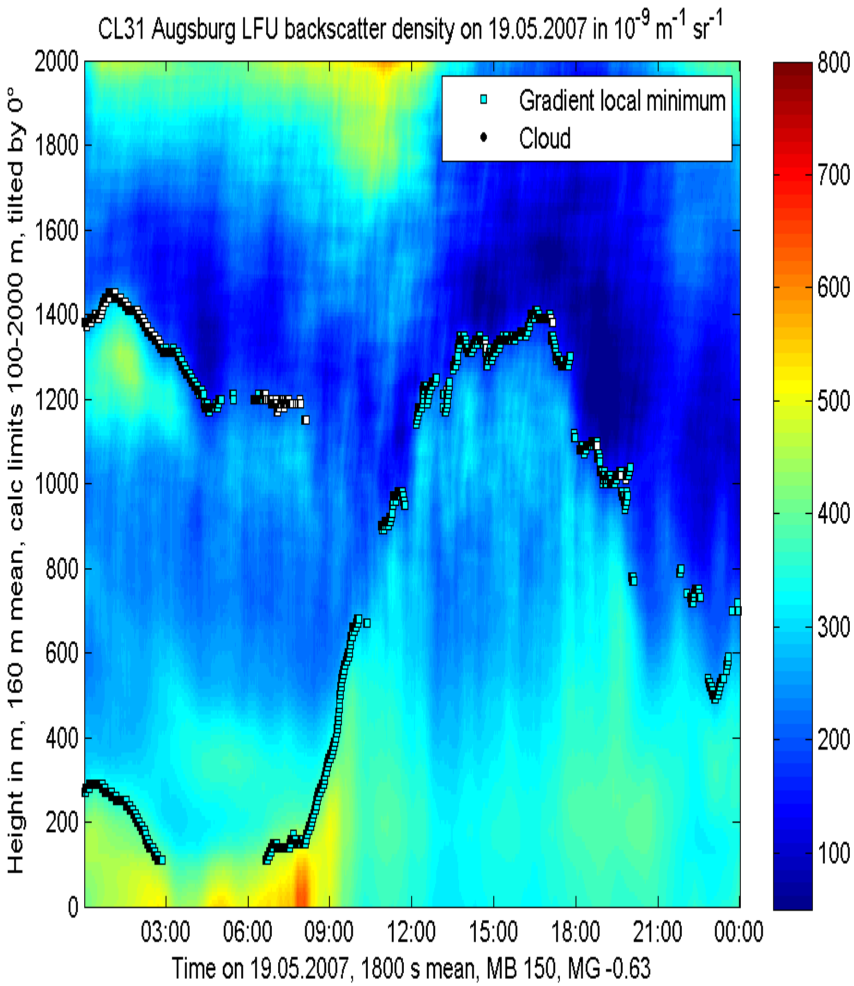


detection:

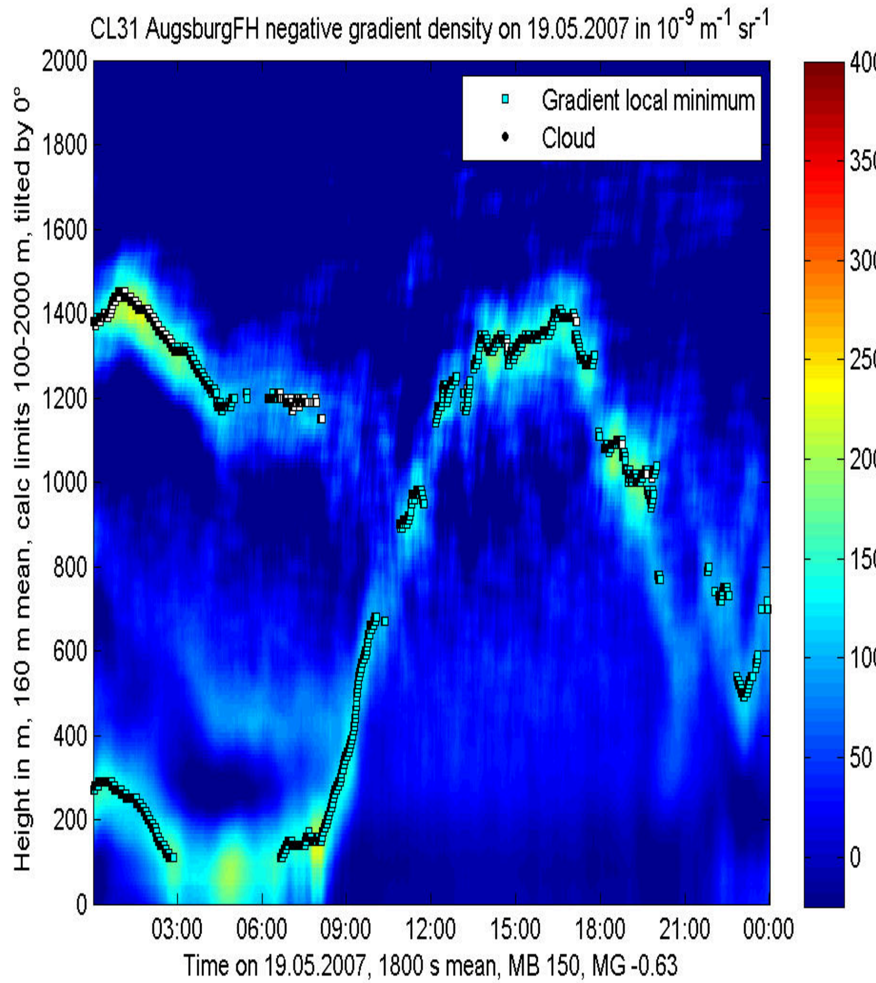
travel time of signal = height
backscatter intensity = particle size and number distribution
Doppler-shift = cannot be analyzed from ceilometer data
(only from Wind-LIDAR: velocity component in line of sight)

Sample plot ceilometer (convective BL at daytime)

optical backscatter intensity



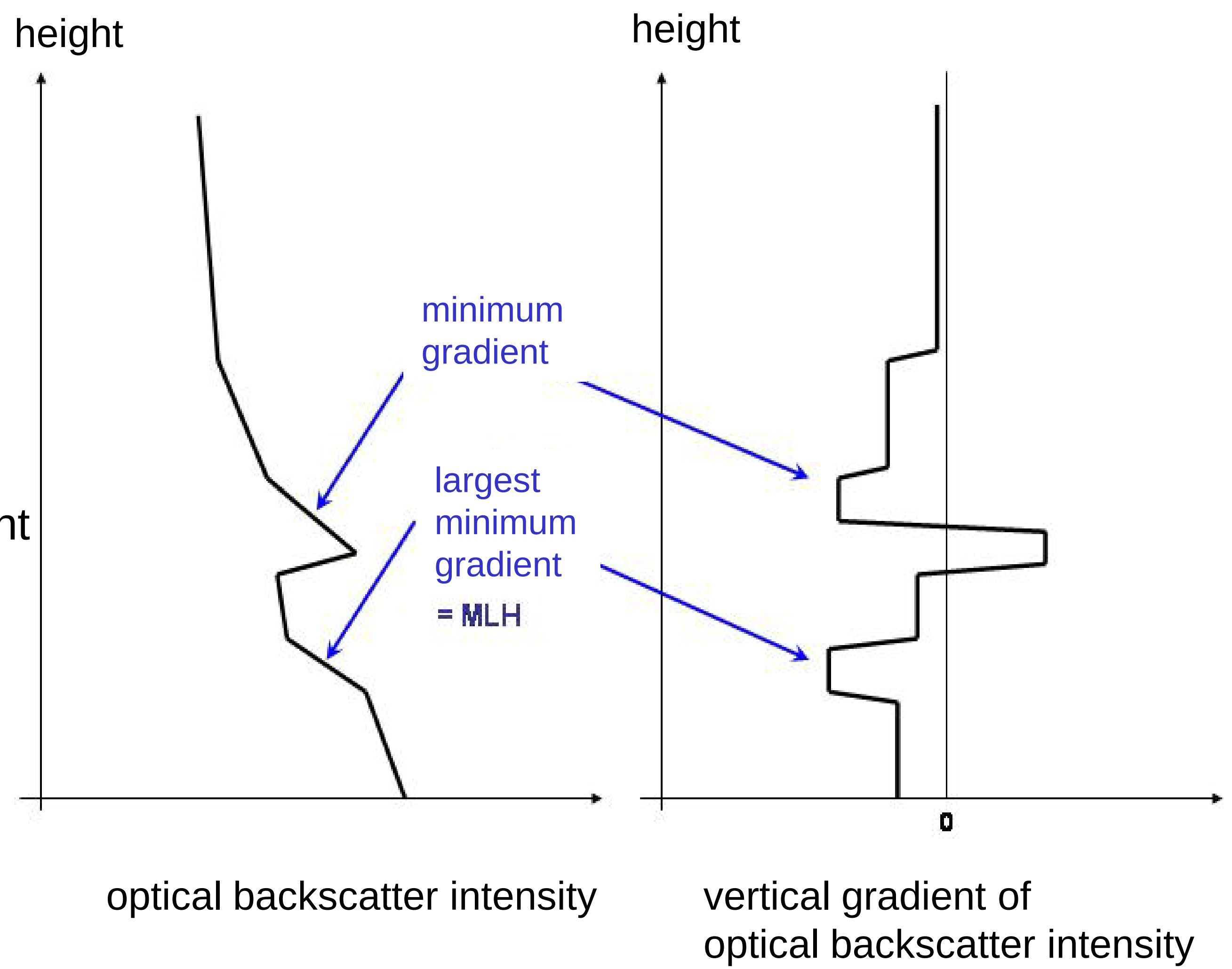
negative vertical gradient of optical backscatter intensity



Algorithms to
detect MLH
from Ceilometer-Daten

criterion

minimal vertical gradient
of backscatter
intensity (the most
negative gradient)

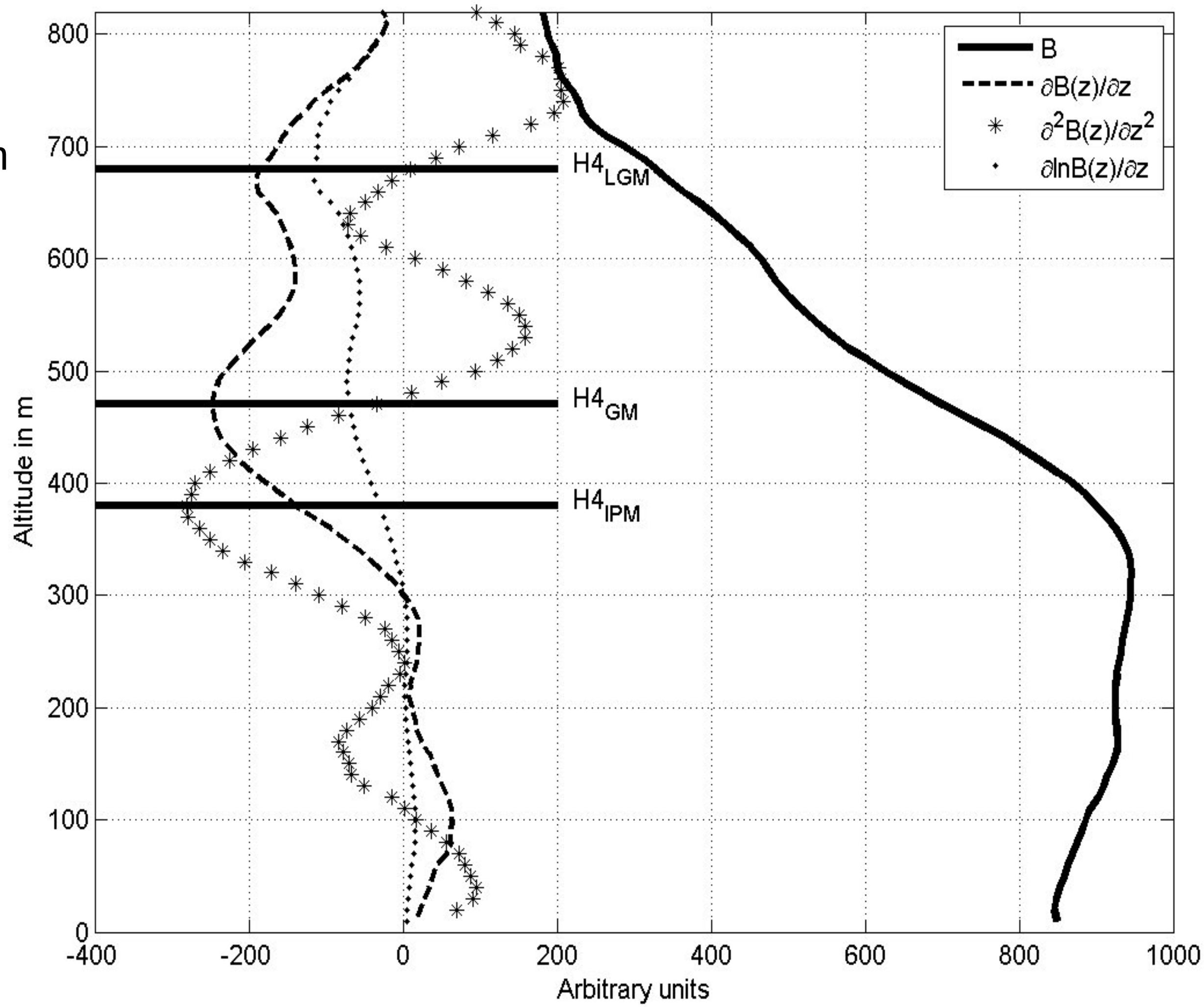


Different gradient methods (see Sicard et al. 2006, BLM 119, 135-157)

logarithmic gradient minimum

gradient minimum

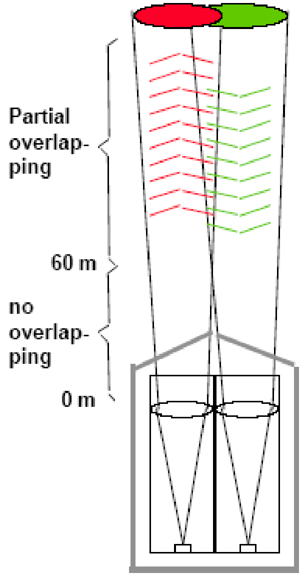
inflection point method
(minimum of 2nd derivative)

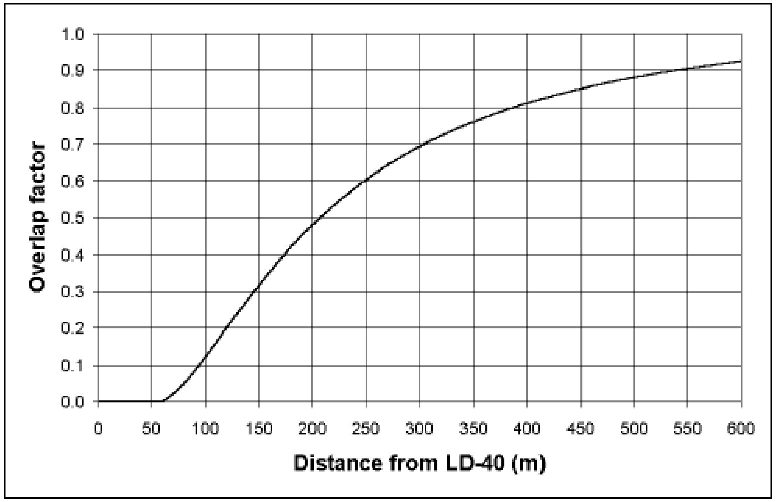


comparison of two different ceilometers

LD40

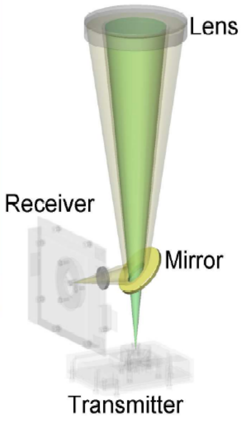
two optical axes
- wave length: 855 nm
- height resolution: 7.5 m
- max. range: 13000 m



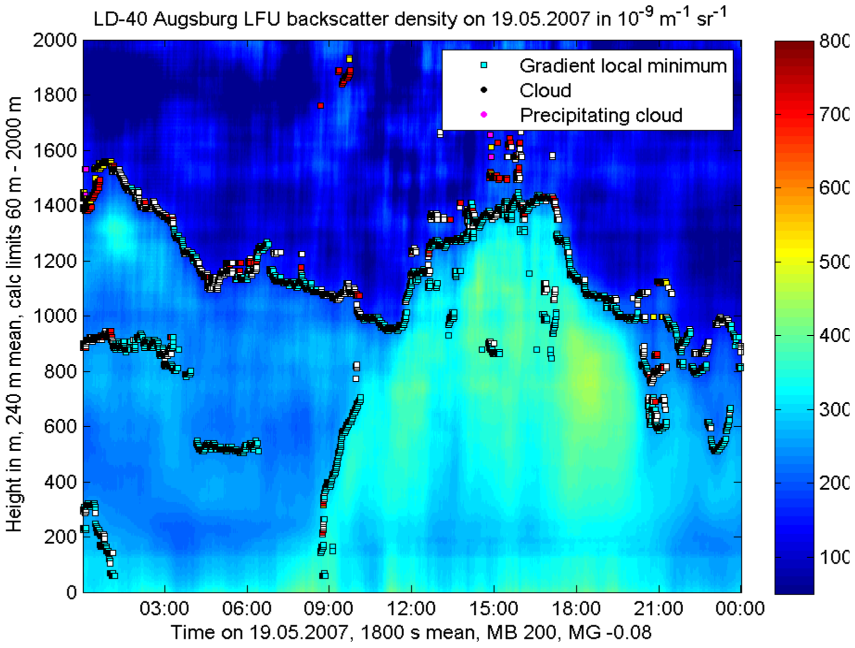


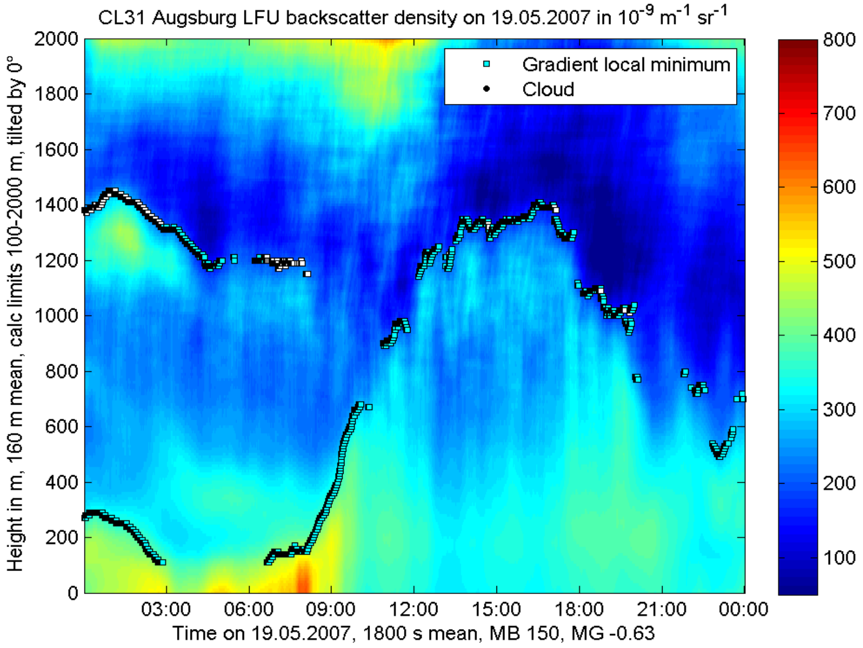
CL31

one optical axis
- wave length: 905 nm
- height resolution: 5 m
- max. range: 7500 m



19 May 2007: ceilometer LD40 and CL31



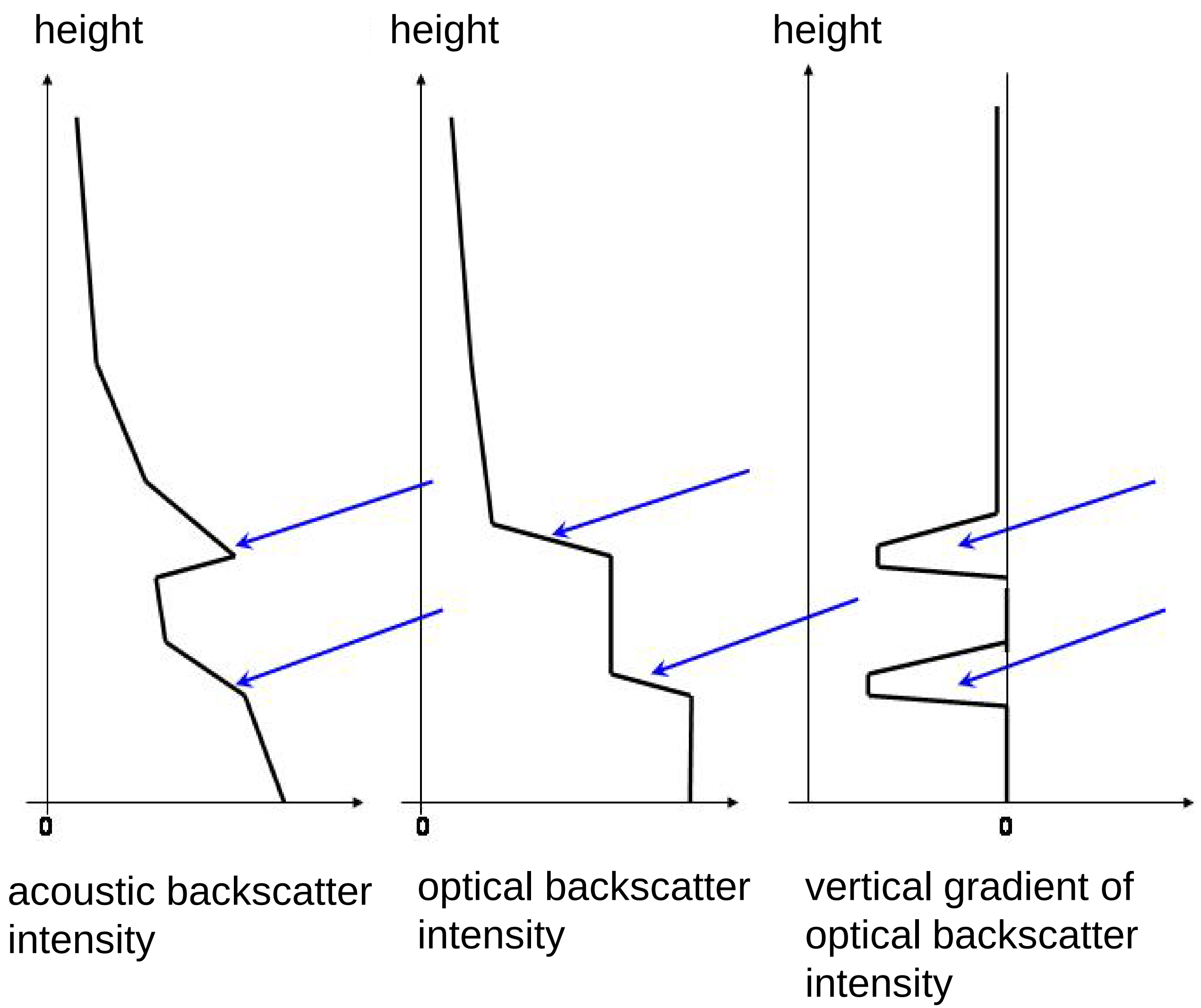


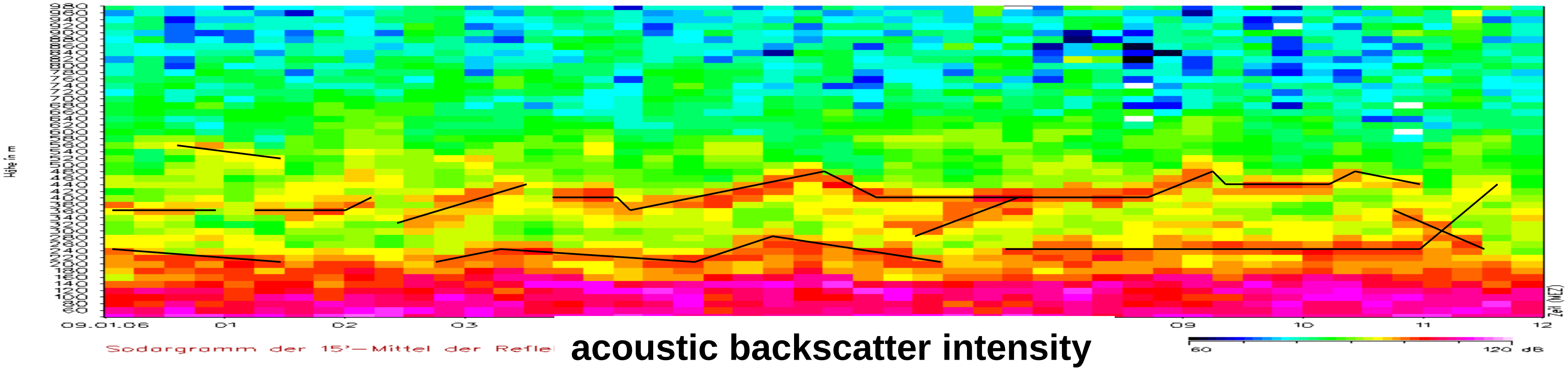
Comparison SODAR and Ceilometer

comparison of algorithms

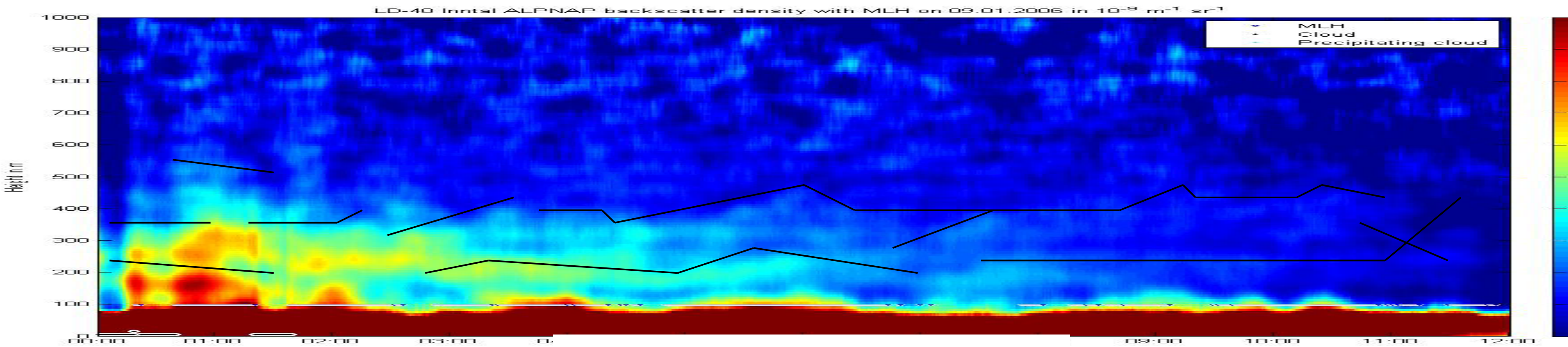
left: SODAR

middle and right: ceilometer

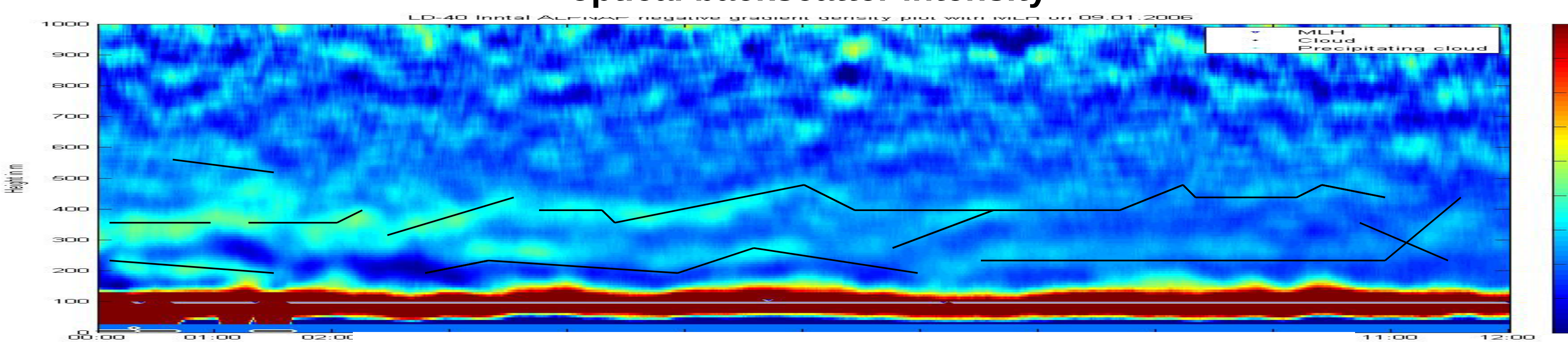




acoustic backscatter intensity



optical backscatter intensity

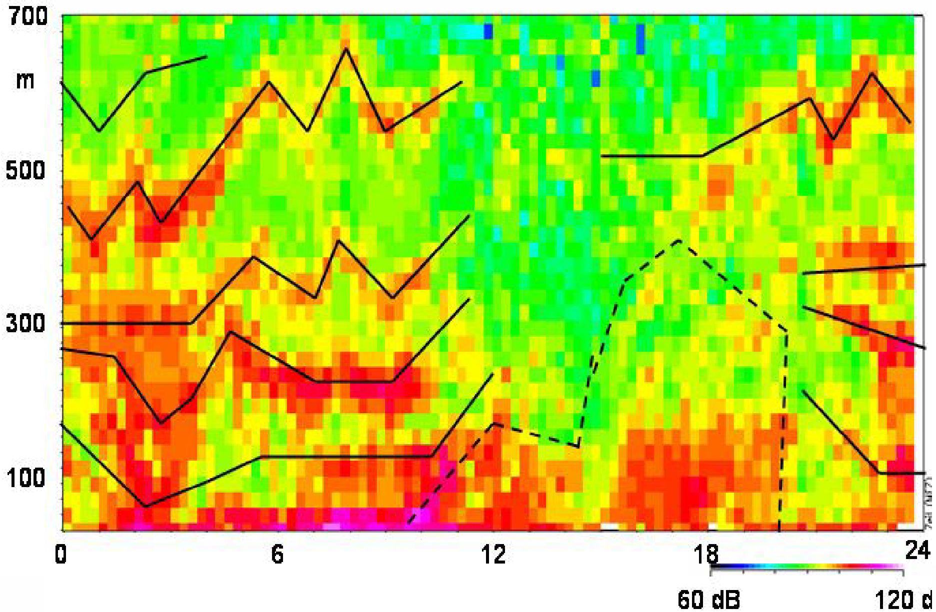


negative vertical gradient of optical backscatter intensity

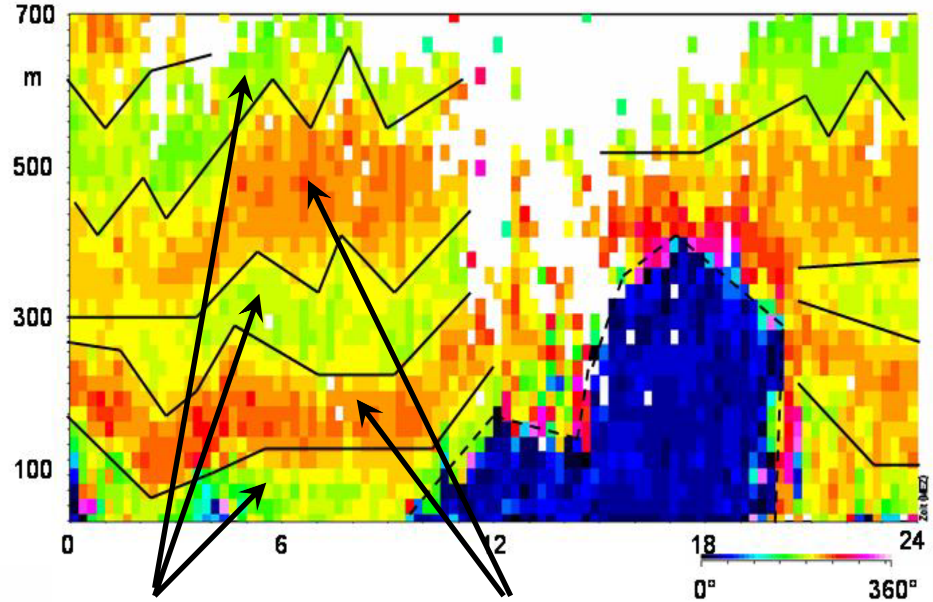
Application examples for SODAR and Ceilometer

SODAR measurements in a wintry Alpine valley

29 January 2006

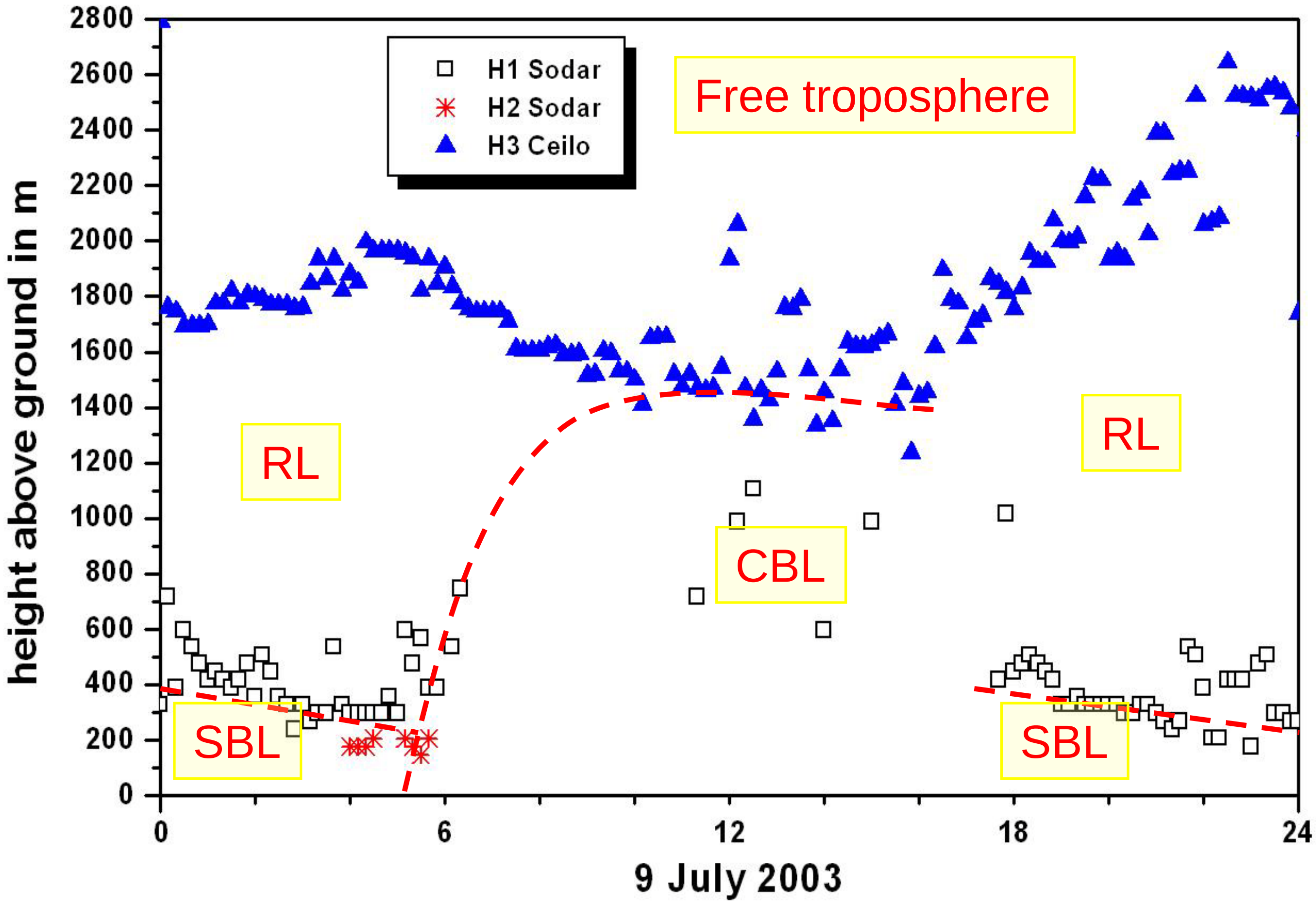


backscatter intensity



wind direction

Diurnal variation of mixing-layer height from SODAR and Ceilometer data (Budapest)



SBL:

stable boundary layer (usually at night and in winter)

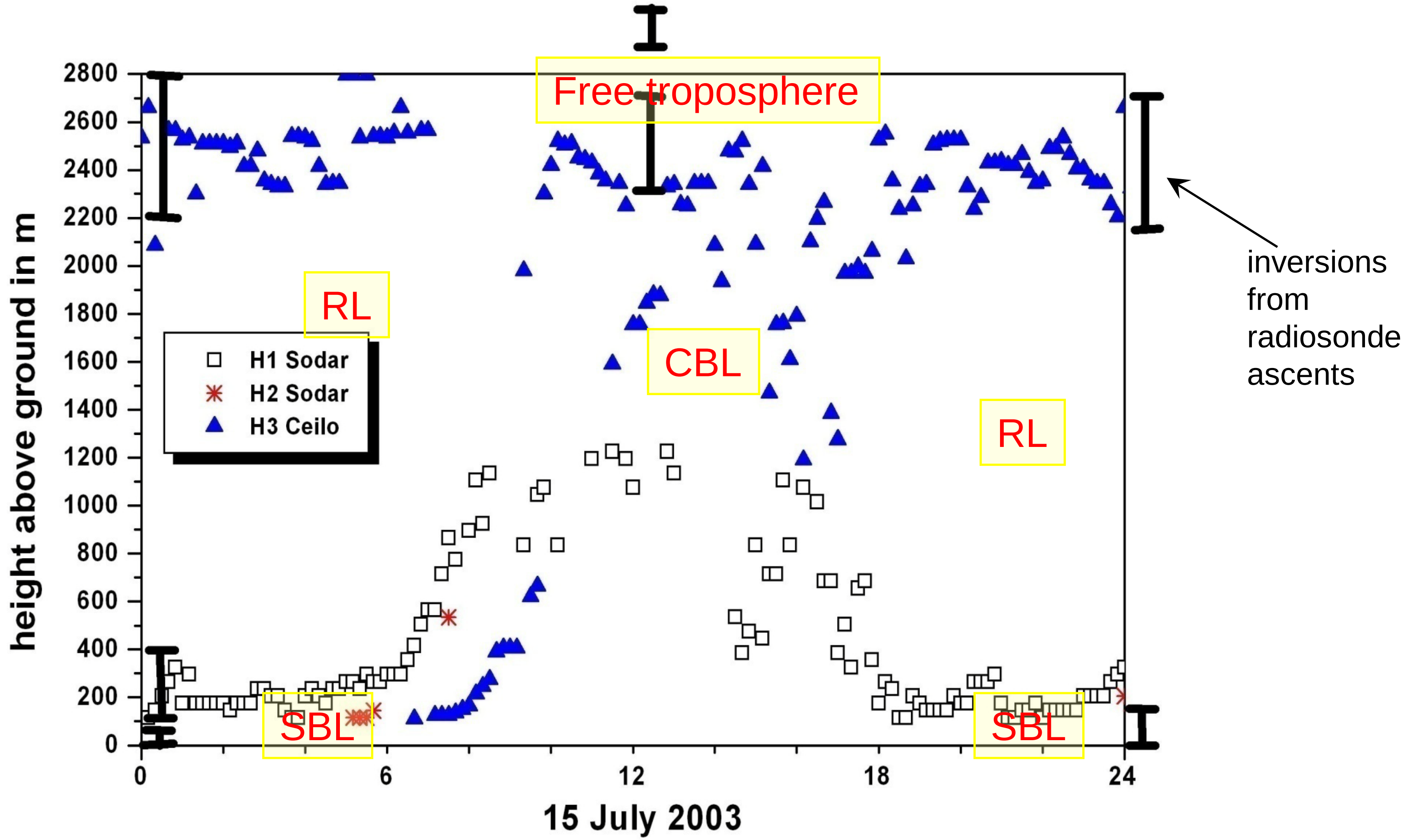
CBL:

convective boundary layer (usually at daytime due to strong insolation)

RL:

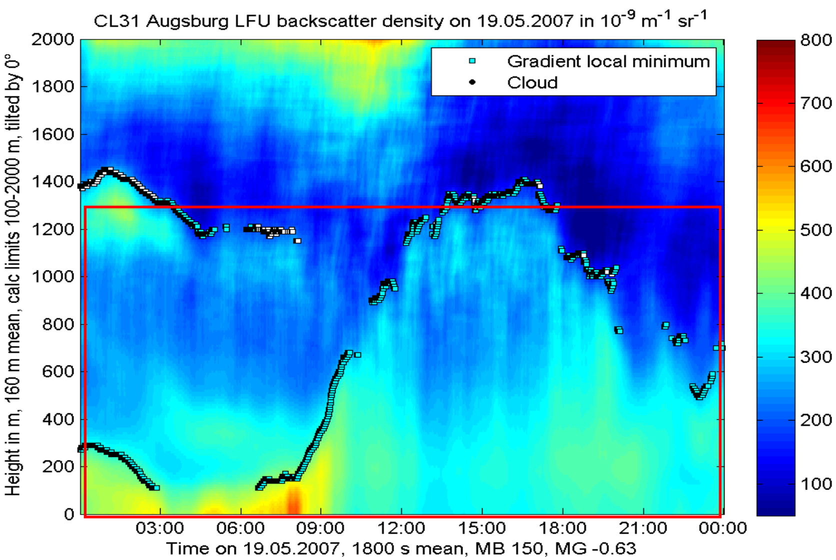
residual layer (usually at night-time)

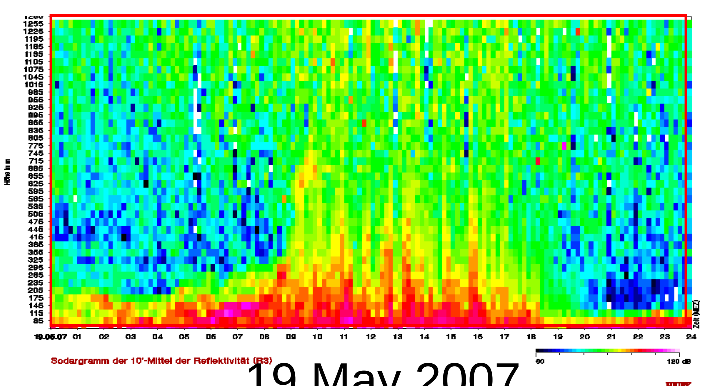
Simultaneous operation SODAR-Ceilometer: examples for summer days



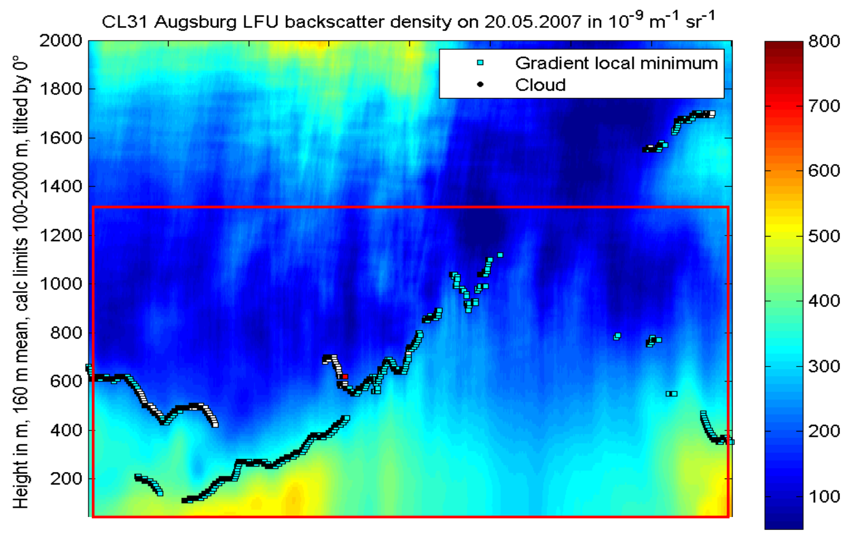
Emeis, S., K. Schäfer, 2006: Remote sensing methods to investigate boundary-layer structures relevant to air pollution in cities. Bound.-Lay Meteorol., 121, 377-385,

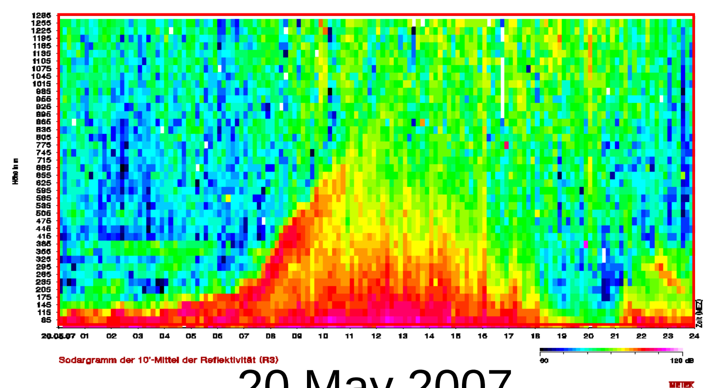
comparison of optical (top) and acoustic (below) backscatter intensity





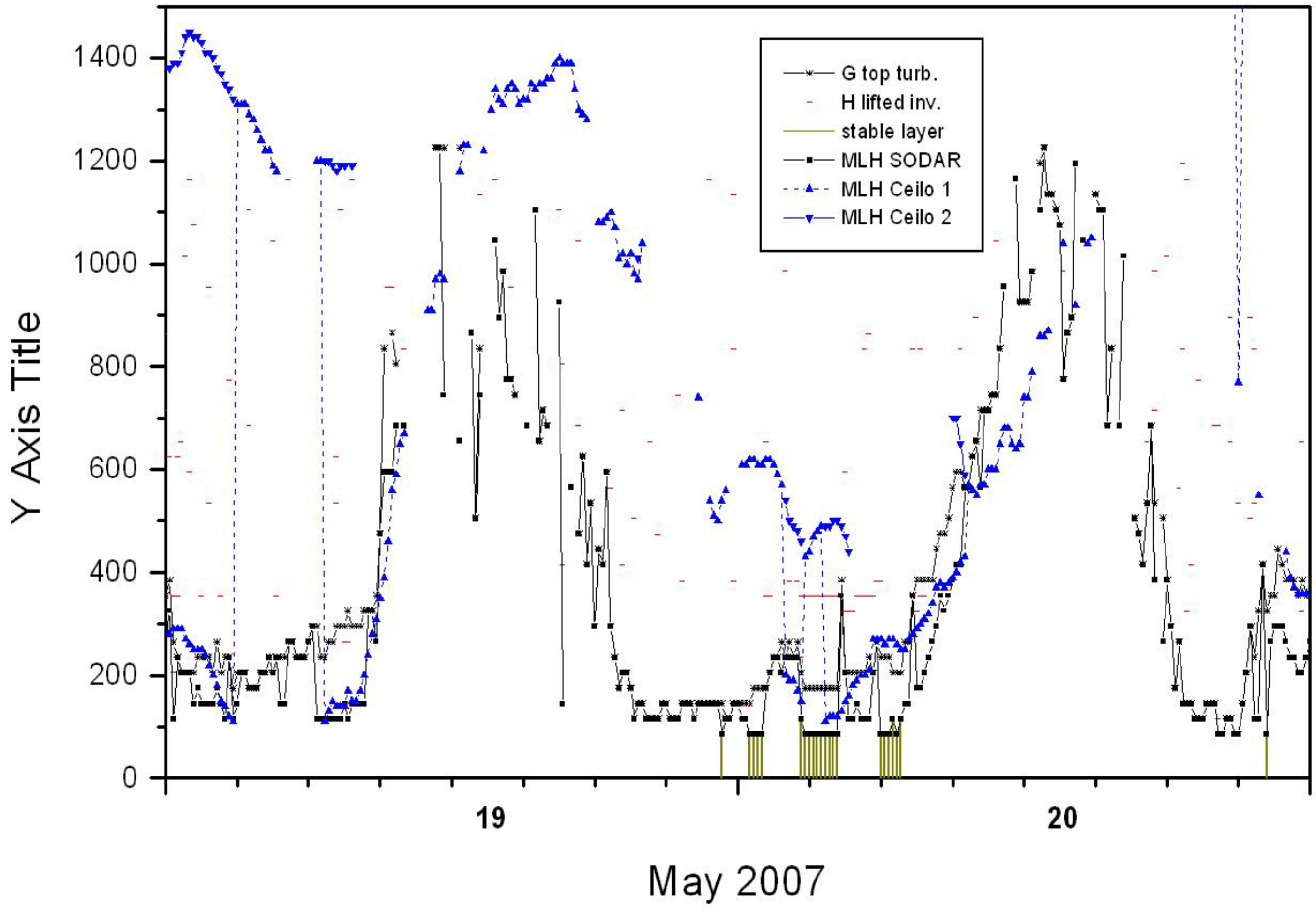
19 May 2007





20 May 2007

comparison of MLH from Sodar and CL31 data



RASS

principles of operation

examples

RASS (radio-acoustic remote sensing)

measures vertical temperature profiles

Bragg-RASS: windprofiler plus acoustic component

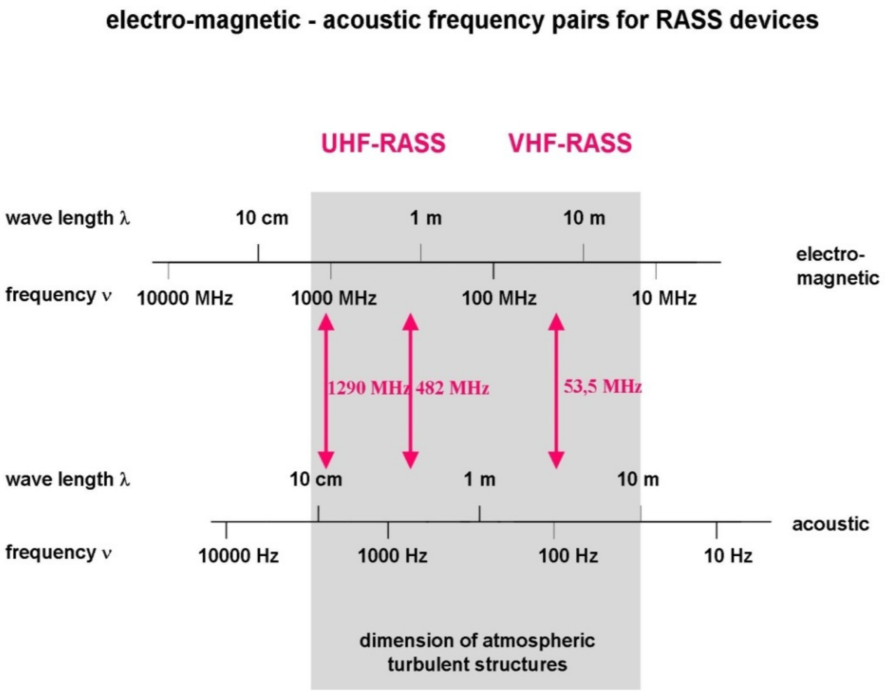
Doppler-RASS: SODAR plus electro-magnetic component

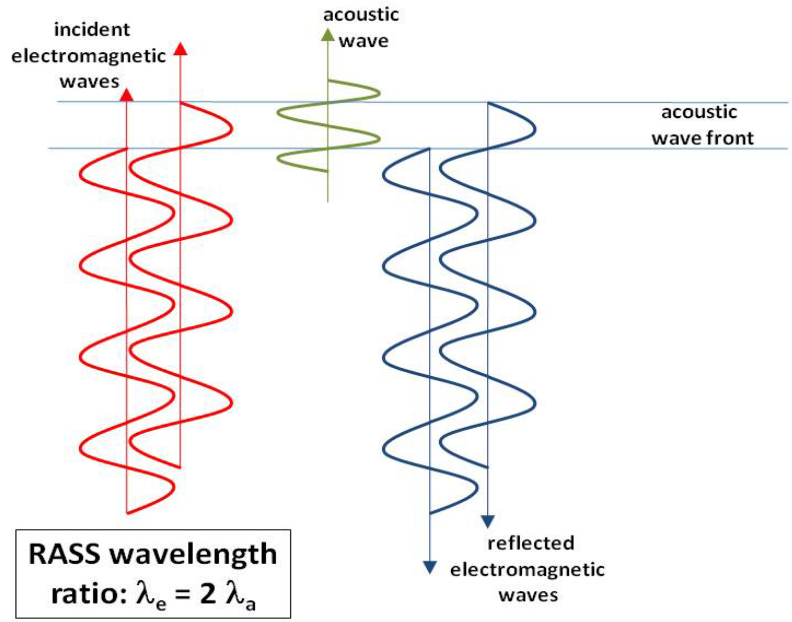
UHF RASS (boundary layer)

VHF RASS (troposphere)

RASS: frequencies

Bragg condition:
acoustic wavelength = ½ electro-magnetic wavelength





SODAR-RASS
(Doppler-RASS)

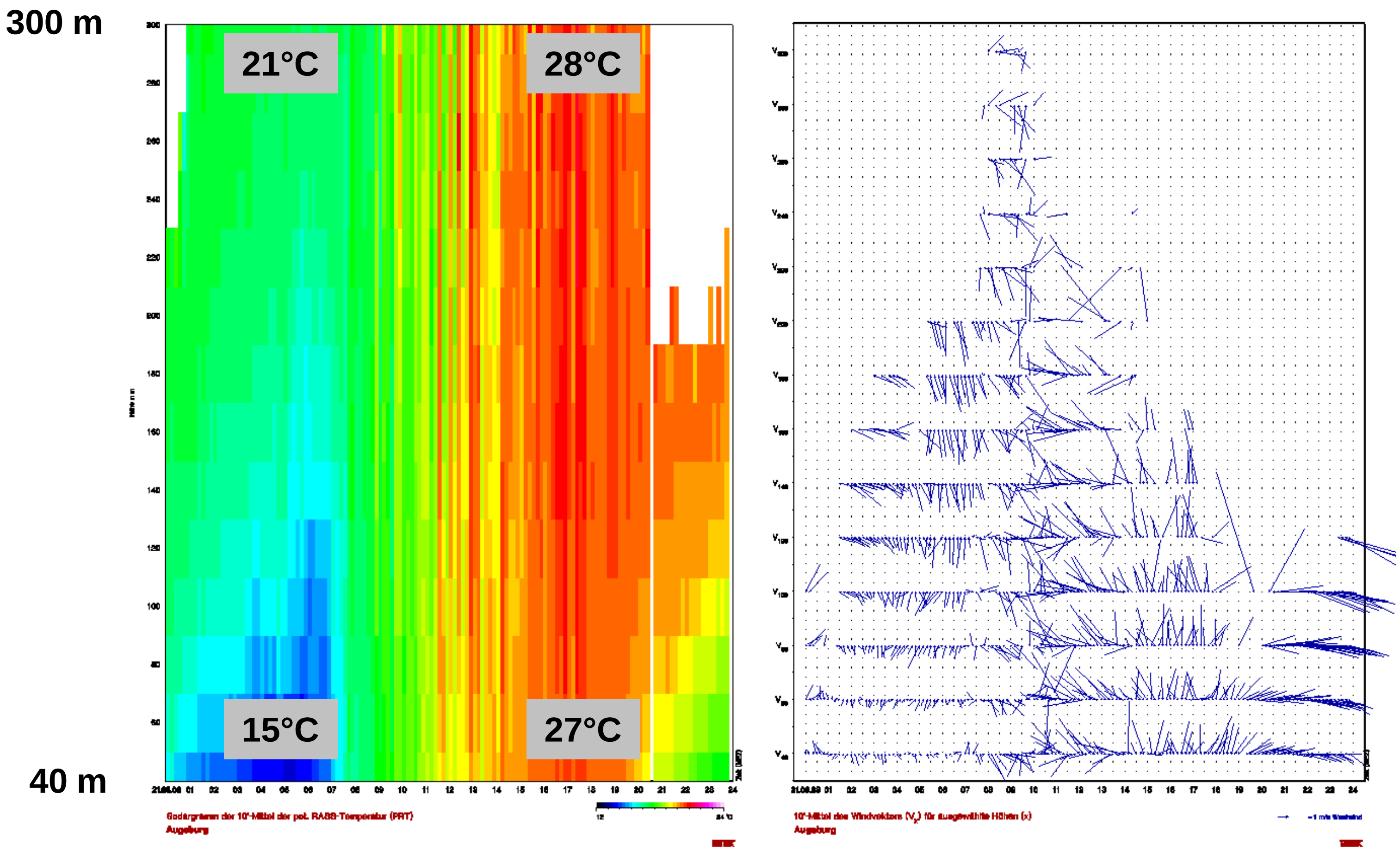
(METEK)

acoustic frequ.: 1500 – 2200 Hz
radio frequ.: 474 MHz
resolution: 20 m
lowest
range gate: ca. 40 m

vertical range: 540 m

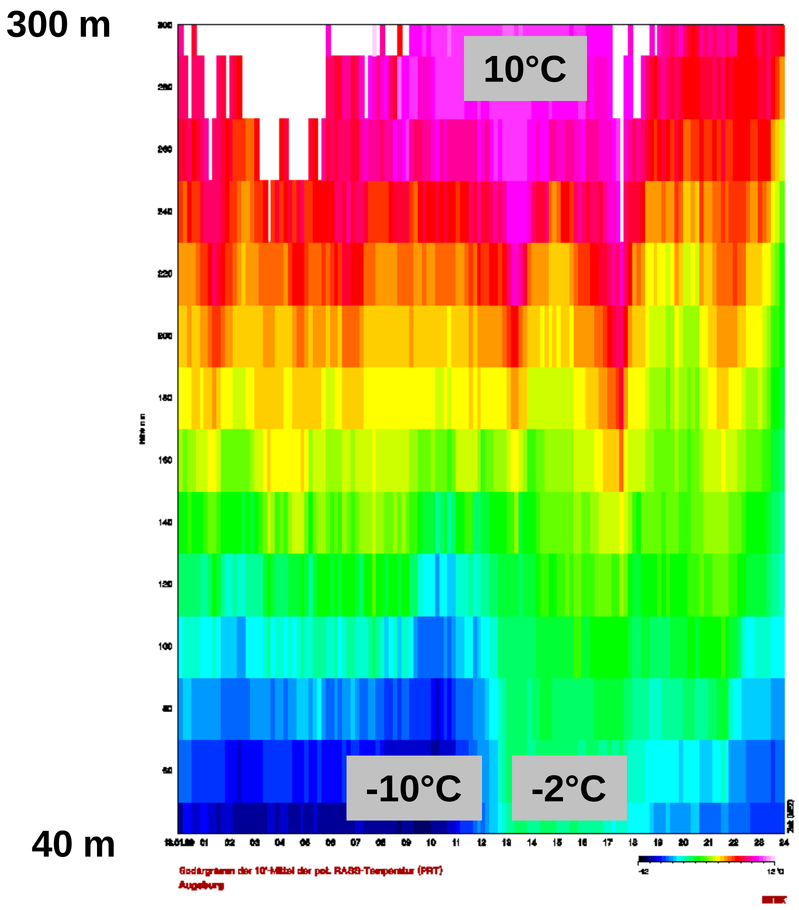
temperature profile and dynamics

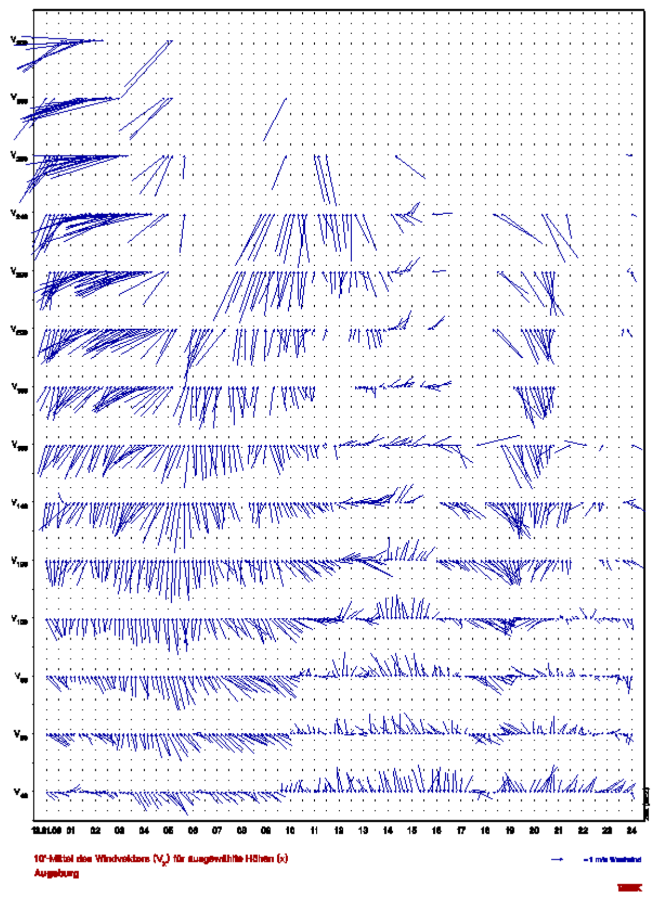
example RASS data: summer day
potential temperature (left), horizontal wind (right)



temperature profile and dynamics

example RASS data: winter day
potential temperature (left), horizontal wind (right)

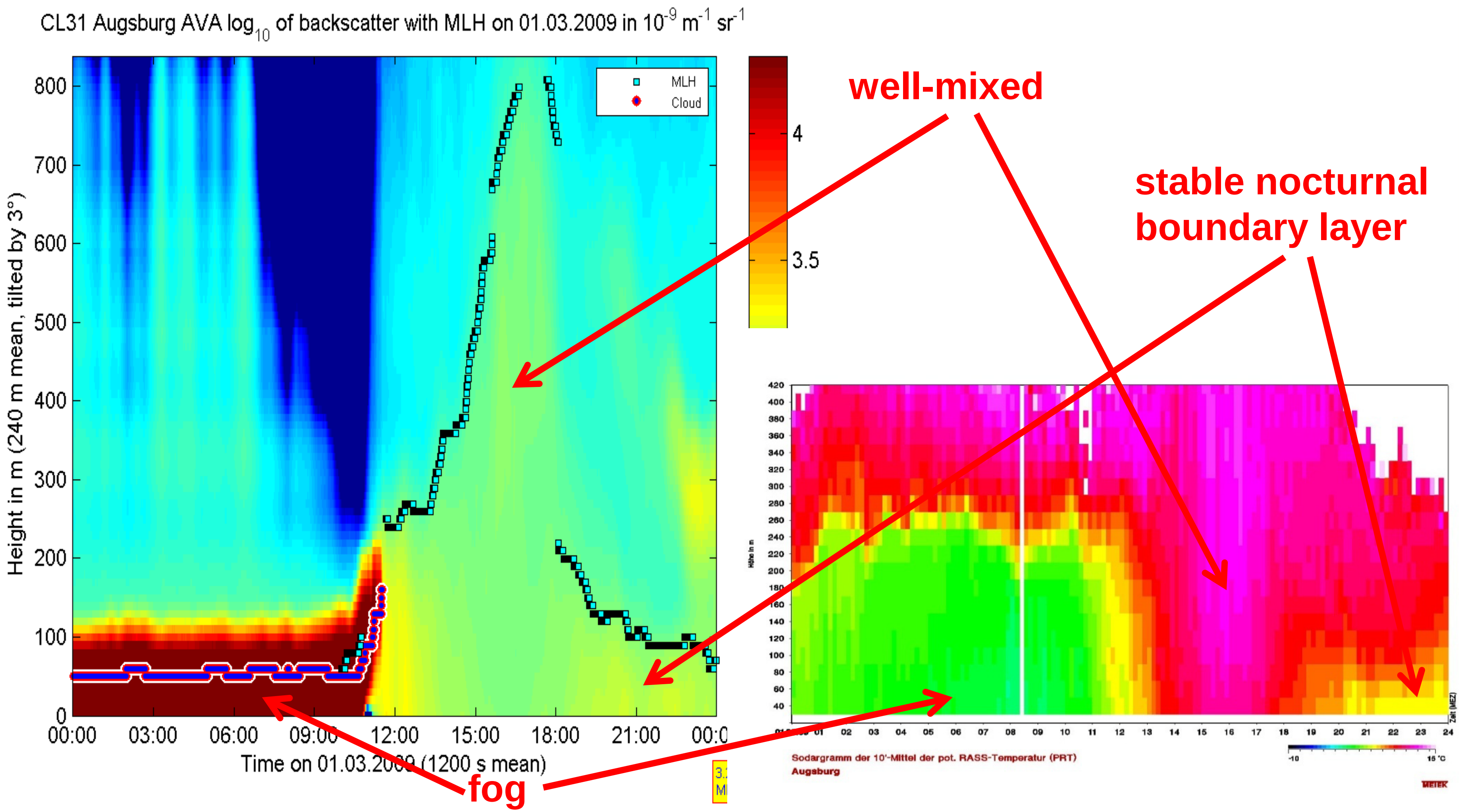




KIT – die Kooperation von Forschungszentrum Karlsruhe GmbH und Universität Karlsruhe (TH)

temperature profile and pollution

comparison of RASS data (potential temperature, right) with aerosol backscatter from a ceilometer (left)



temperature profile and pollution

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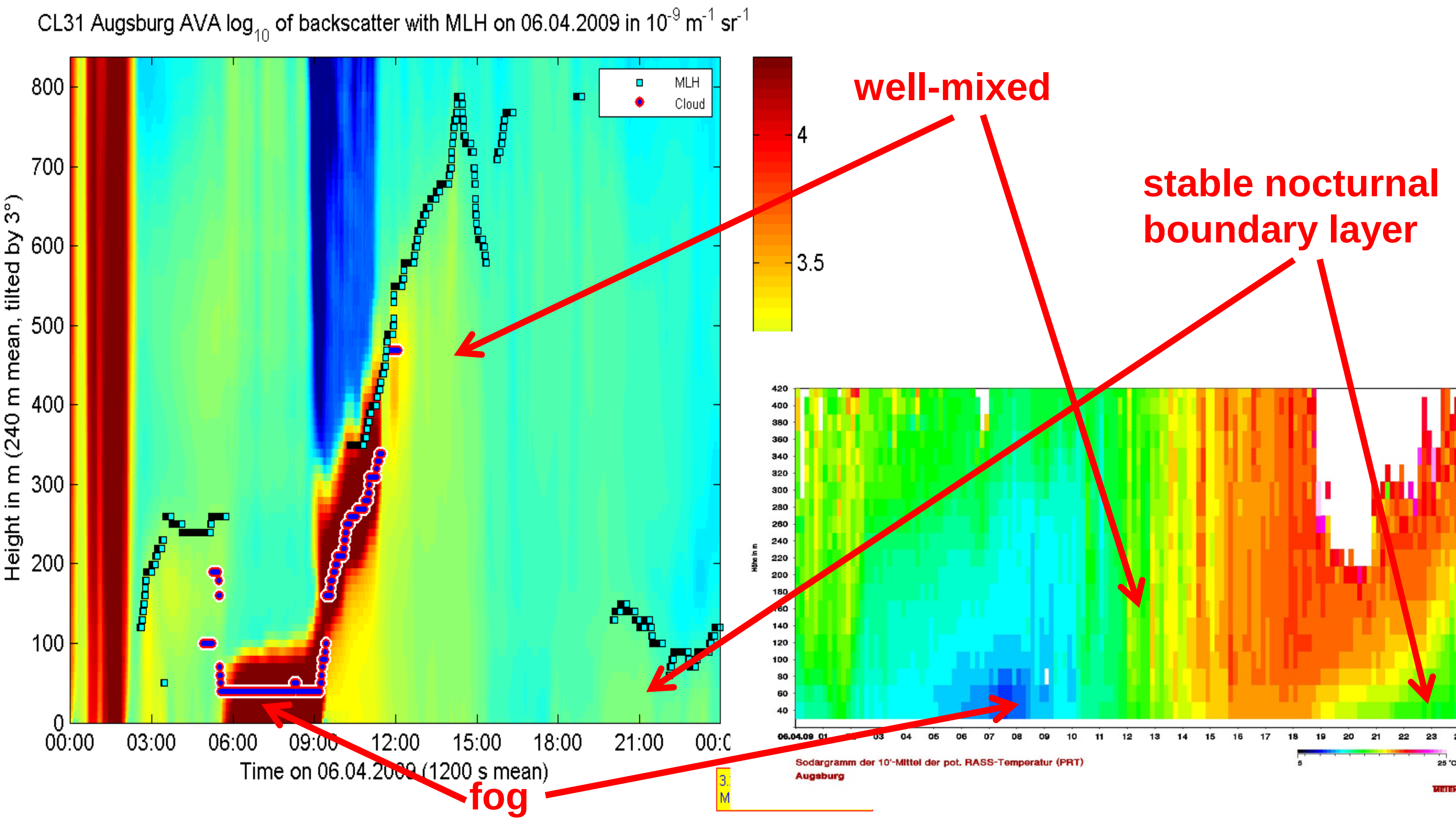
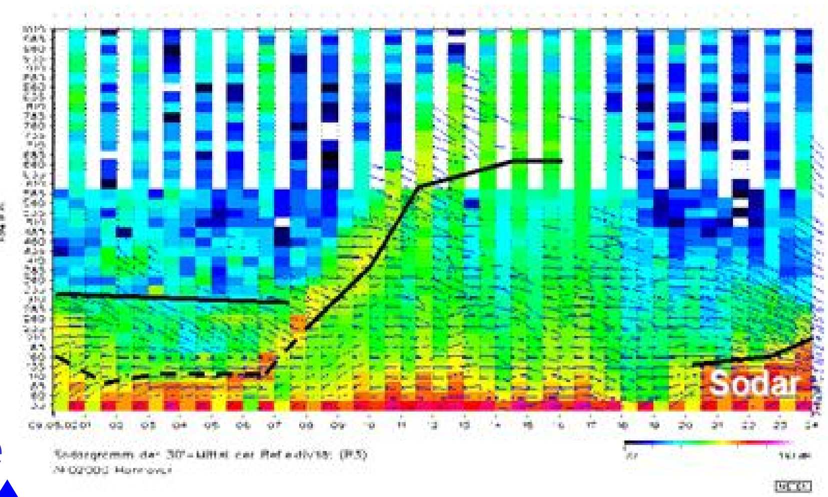


Summary

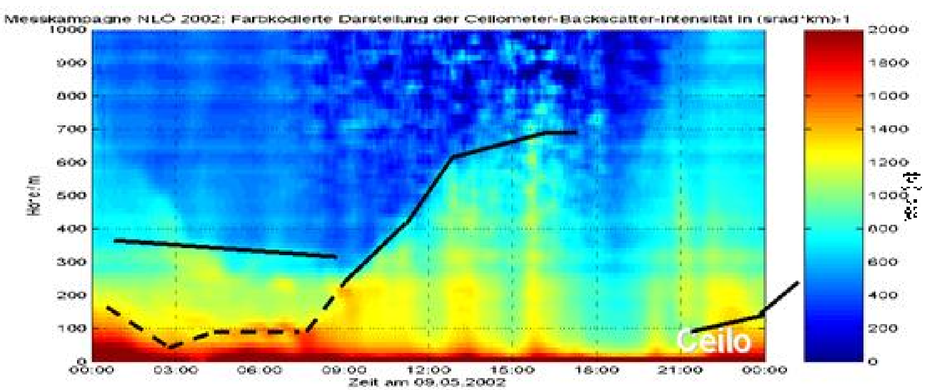
Comparison of MLH retrievals with three different remote sensing techniques

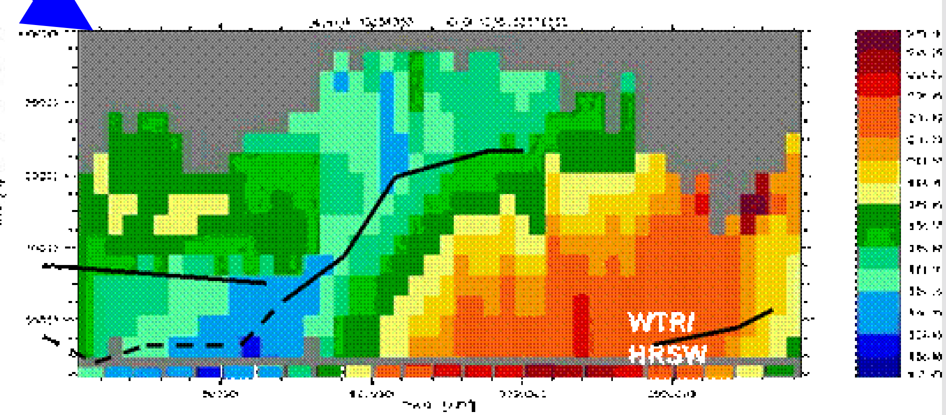
SODAR
acoustic backscatter



ceilometer
optical backscatter

RASS
temperature





Emeis, S., Chr. Münkel, S. Vogt, W.J. Müller, K. Schäfer, 2004: Atmospheric boundary-layer structure from simultaneous SODAR, RASS, and ceilometer measurements. Atmos. Environ., 38, 273-286.

Overview on methods using ground-based remote sensing for the derivation of the mixing-layer height

method	short description
acoustic ARE method	analysis of **a**coustic **r**eceived **e**cho intensity profiles
“ HWS method	analysis of **h**orizontal **w**ind **s**peed profiles
“ VWV method	analysis of **v**ertical **w**ind **v**ariance profiles
“ EARE method	analysis of acoustic backscatter intensity and vertical wind variance profiles (**e**nhanced **a**coustic **r**eceived **e**cho method)
optical threshold method	detection of a given backscatter intensity threshold
“ gradient method	analysis of optical backscatter intensity profiles
“ idealised backscatter method	analysis of optical backscatter intensity profiles
“ wavelet method	analysis of optical backscatter intensity profiles
“ variance method	analysis of optical backscatter intensity profiles
acoustic / electro-magnetic	ARE method applied to sodar and wind profiler data
acoustic / optical	EARE method plus gradient method
electro-magnetic / electro-magnetic	combination of a sodar-RASS and a wind profiler RASS: analysis of the vertical temperature profile plus analysis of the electro-magnetic backscatter intensity profile
acoustic / in situ	ARE method plus in-situ surface flux measurement

RASS	analysis of the temperature profile from the measured speed of sound

Conclusions:

RASS directly delivers temperature profiles,
MLH, inversions, and stable layers can easily be detected,
wind profiles are additionally available.
Does not work properly with high wind speeds.

SODAR detects temperature fluctuations and gradients,
but no absolute temperature. Inversions and stable layers can indirectly be inferred with a MLH algorithm.
Does not work properly with perfectly neutral stratification, with very high wind speeds, and during stronger precipitation events.

Ceilometer detects aerosol distribution and water droplets. It has to be assumed that the aerosol follows the thermal structure of the atmosphere. Inversions and MLH can indirectly be inferred with a MLH algorithm.
Does not work properly in extreme clear (aerosol-free) air and during precipitation events and fog.

Literature

SODAR:

Asimakopoulos, D.N., C.G. Helmis, J. Michopoulos, 2004: Evaluation of SODAR methods for the determination of the atmospheric boundary layer mixing height. - Meteor. Atmos. Phys. 85, 85–92.

Beyrich, F., 1997: Mixing height estimation from sodar data – a critical discussion. - Atmos. Environ. 31, 3941–3953.

Ceilometer:

Schäfer, K., S.M. Emeis, A. Rauch, C. Münkel, S. Vogt, 2004: Determination of mixing-layer heights from ceilometer data. In: Remote Sensing of Clouds and the Atmosphere IX. Schäfer, K., A. Comeron, M. Carleer, R.H. Picard, N. Sifakis (Eds.), Proc. SPIE, Bellingham, WA, USA, Vol. 5571, 248–259.

Sicard, M., C. Pérez, F. Rocadenbosch, J.M. Baldasano, D. García-Vizcaino, 2006: Mixed-Layer Depth Determination in the Barcelona Coastal Area From Regular Lidar Measurements: Methods, Results and Limitations. - Bound.-Lay. Meteor. 119, 135–157.

RASS:

Engelbart, D.A.M., J. Bange, 2002: Determination of boundary-layer parameters using wind profiler/RASS and sodar/RASS in the frame of the LITFASS project. Theor. Appl. Climatol. 73, 53–65.

Emeis, S., K. Schäfer, C. Münkel, 2009: Observation of the structure of the urban boundary layer with different ceilometers and validation by RASS data. Meteorol. Z., 18, 149-154. (Open access, freely avaiable from http://dx.doi.org/10.1127/0941-2948/2009/0365)

Reviews:

Emeis, S., K. Schäfer, C. Münkel, 2008: Surface-based remote sensing of the mixing-layer height – a review. - Meteorol. Z., 17, 621-630. (Open access, freely available from http://dx.doi.org/10.1127/0941-2948/2008/0312)

Emeis, S., M. Harris, R.M. Banta, 2007: Boundary-layer anemometry by optical remote sensing for wind energy applications. - Meteorol. Z., 16, 337-347.