Determination of mixing-layer height by ground-based remote sensing

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Basic remote sensing techniques

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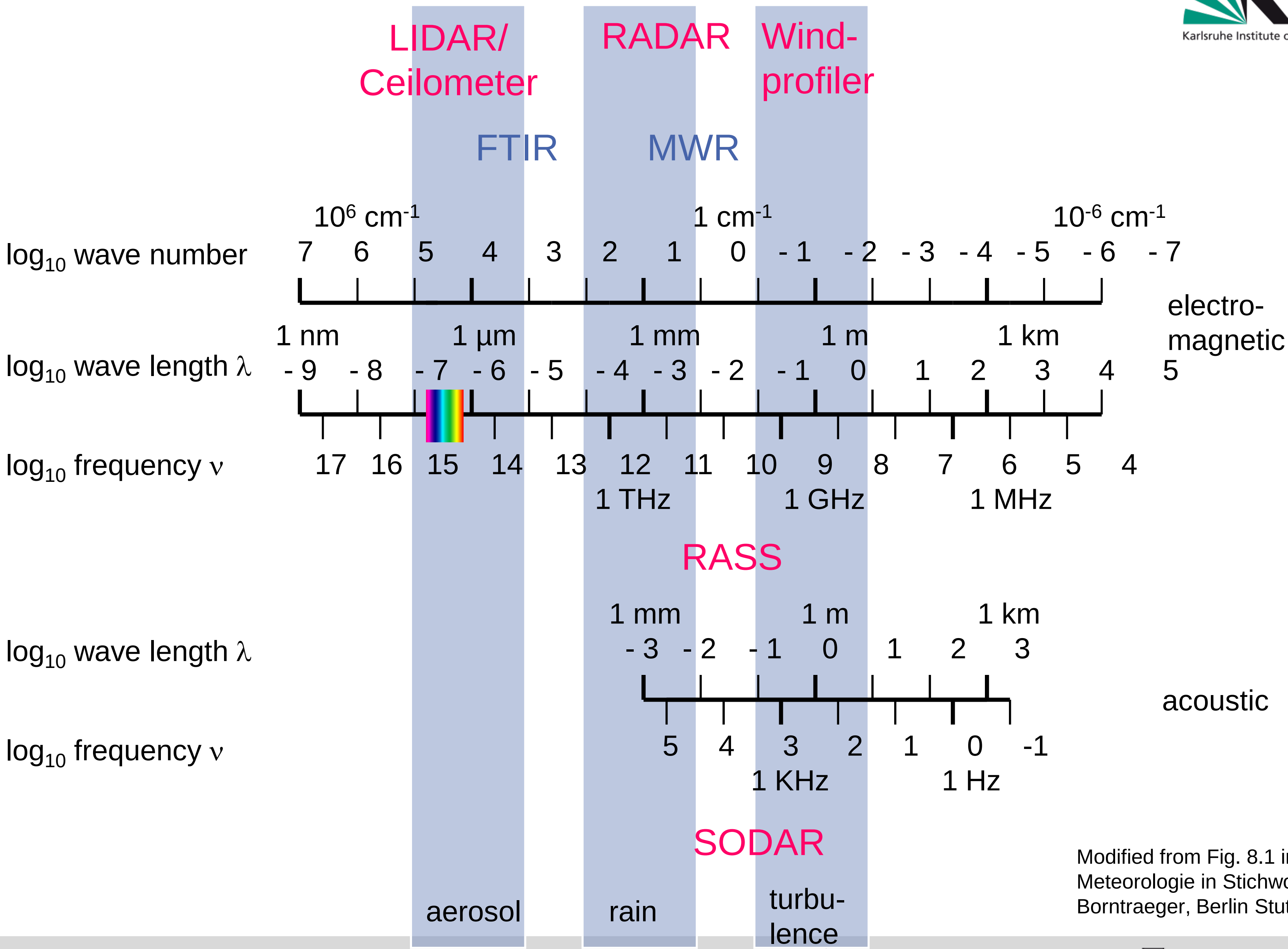
name	princple	spatial resolution	direction	type
RADAR	backscatter, electro-magnetic pulses, fixed wave length	profiling	scanning, slanted	active, monostatic
SODAR	backscatter, acoustic pulses, fixed wave length	profiling	fixed, slanted, vertical	active, usually monostatic
LIDAR	backscatter, optical pulses, 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

subject of this talk

Typical frequency bands for remote sensing of the atmosphere



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

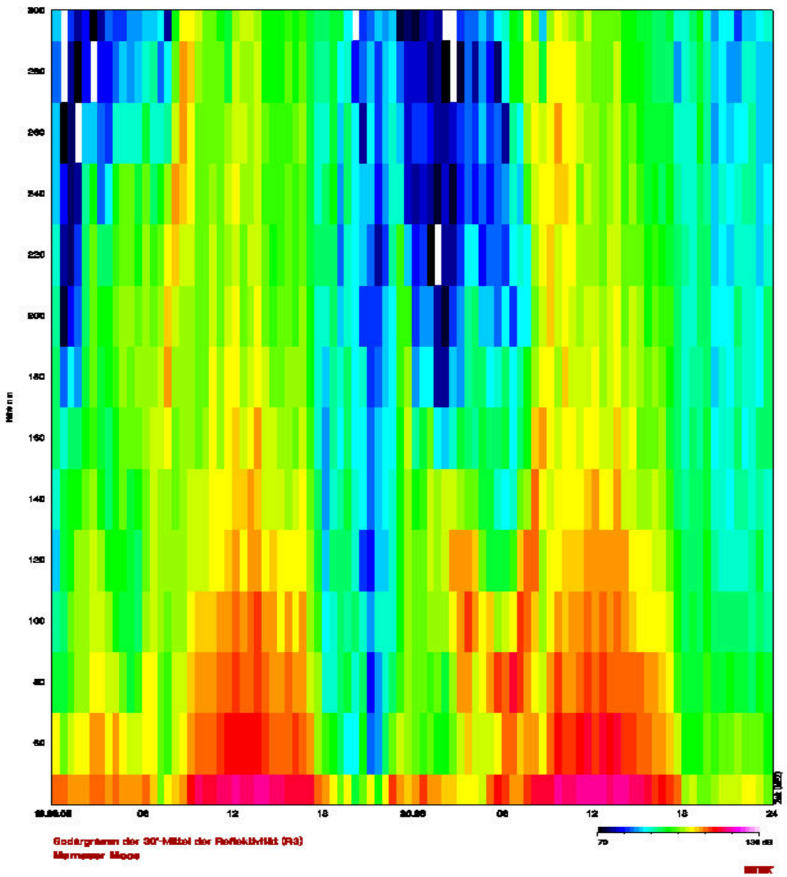
SODAR

algorithms for mixing-layer height

Sample plot SODAR (convective BL at daytime)

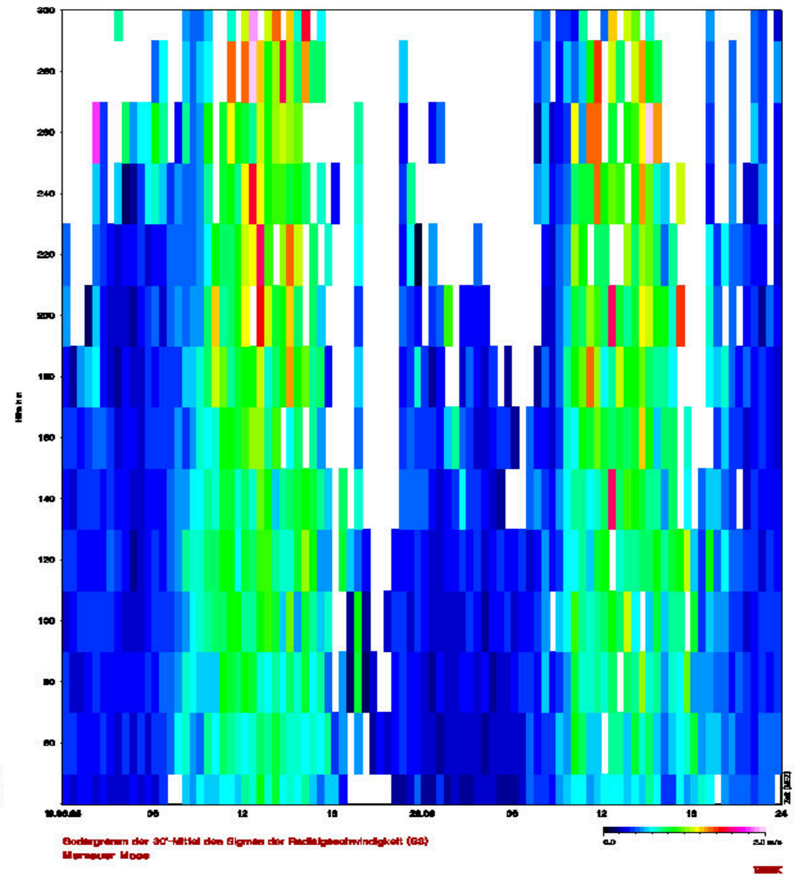
acoustic backscatter intensity

40 – 300 m



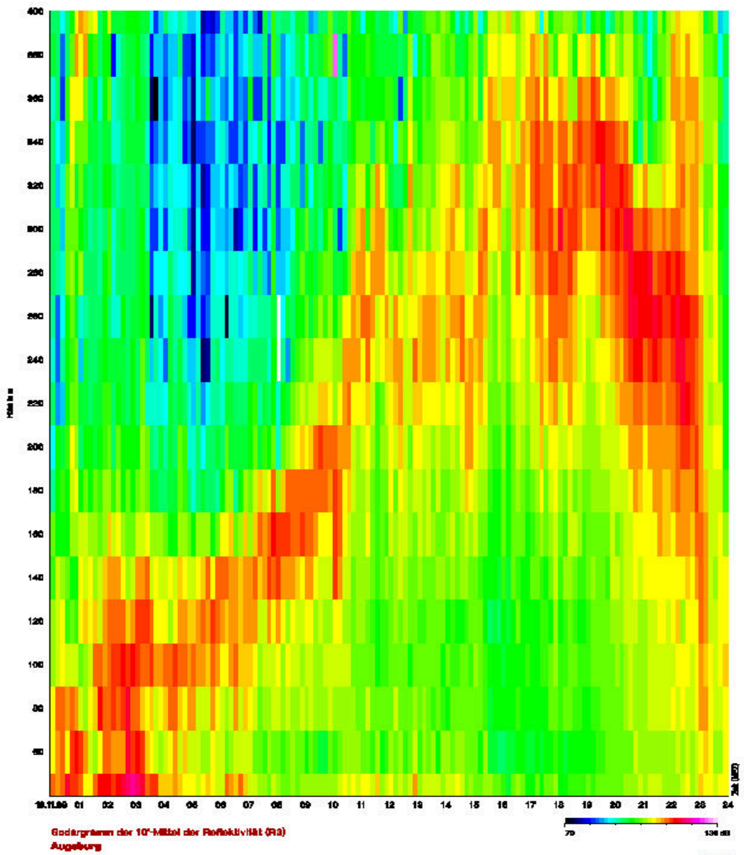
2 days, midnight to midnight

sigma w

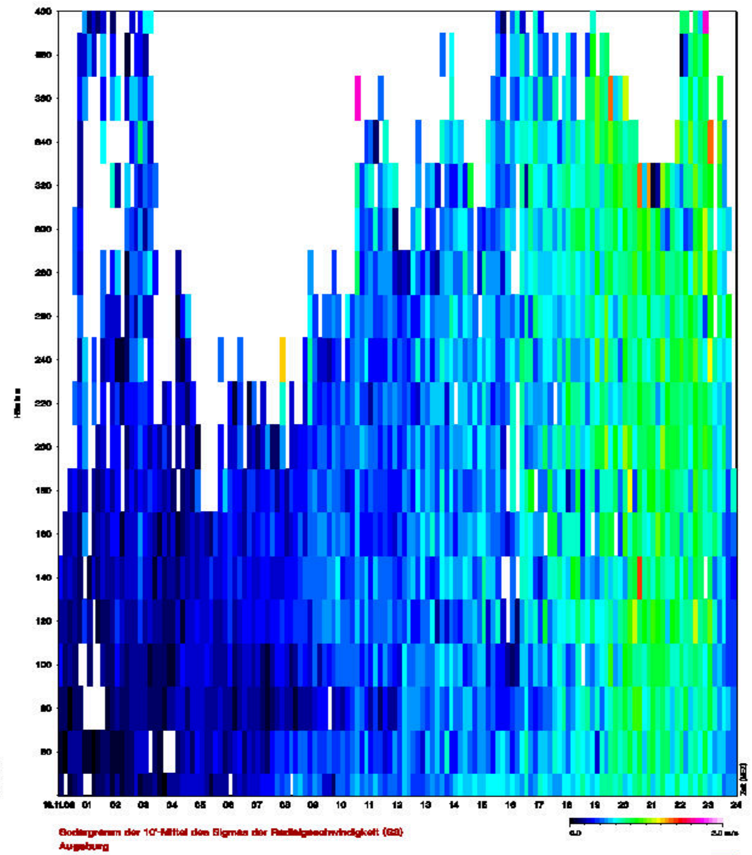


Sample plot SODAR (lifted inversion)

acoustic backscatter intensity



sigma w



40 – 400 m

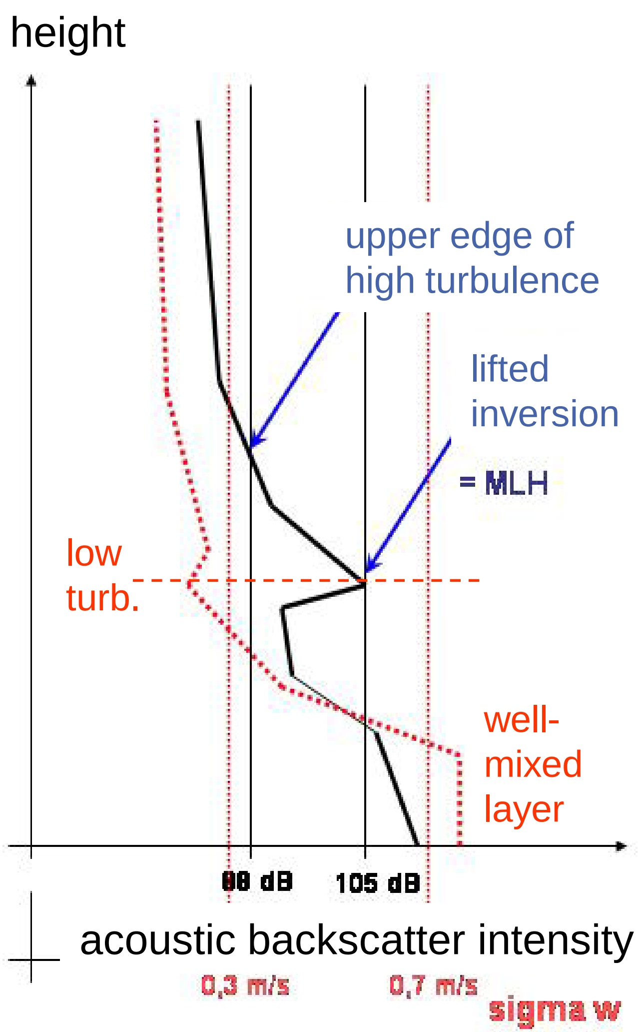
1 day, midnight to midnight

Algorithms to detect MLH from SODAR data

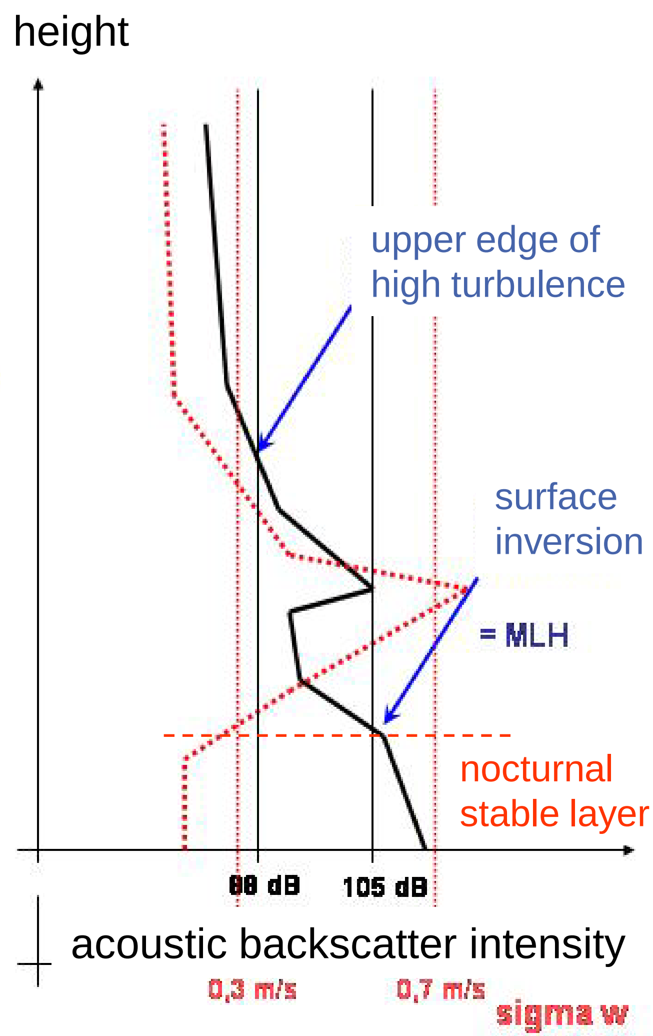
criterion 1:
upper edge of high turbulence

criterion 2:
surface and lifted inversions

MLH = Min (C1, C2)



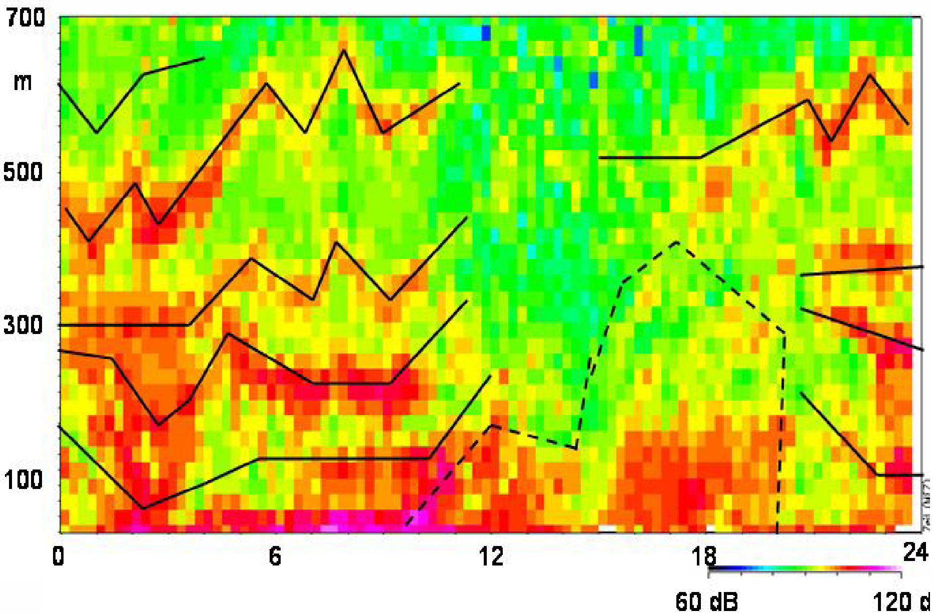
example 1: daytime



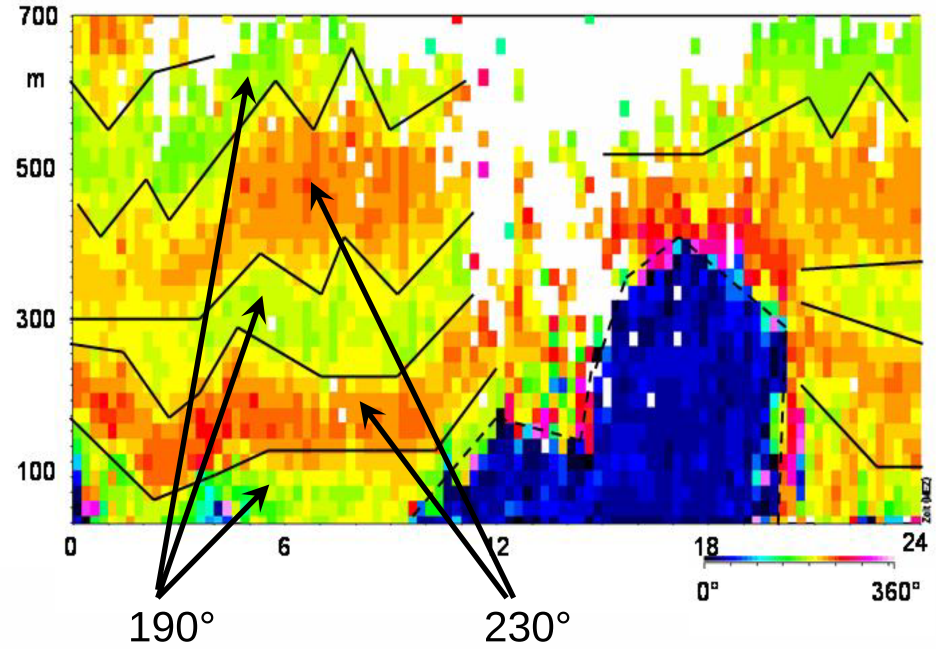
example 2: night-time

SODAR measurements in a wintry Alpine valley

29 January 2006



backscatter intensity



wind direction

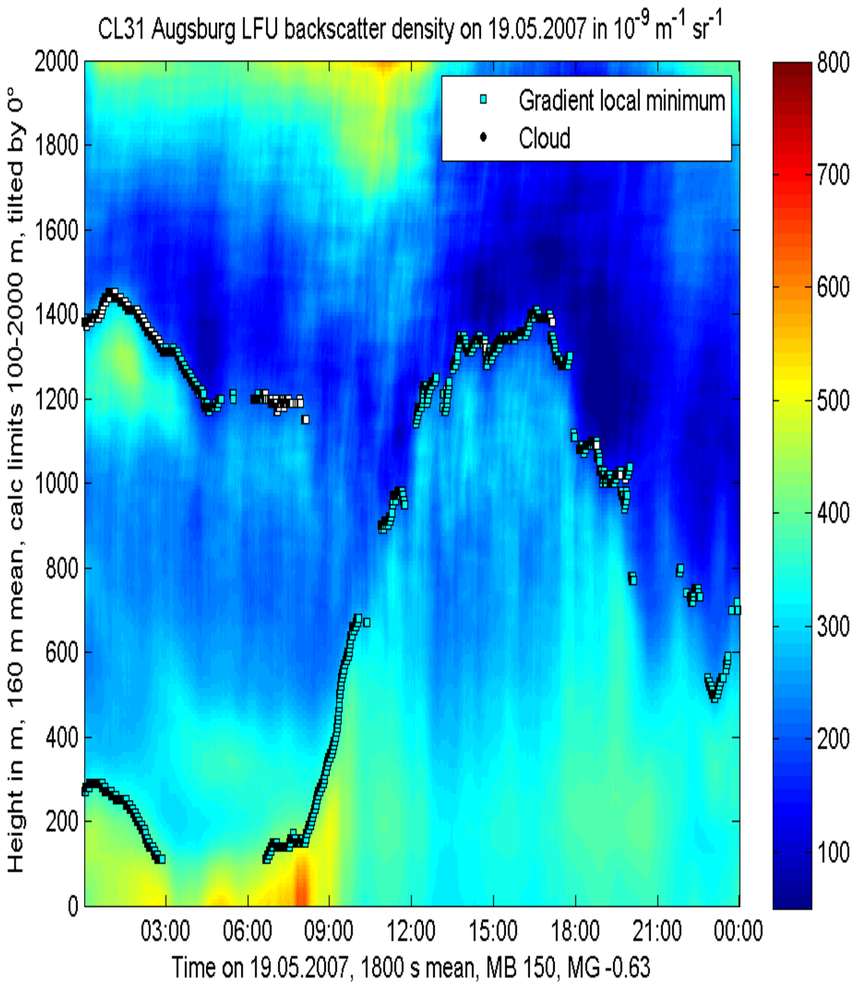
Ceilometer

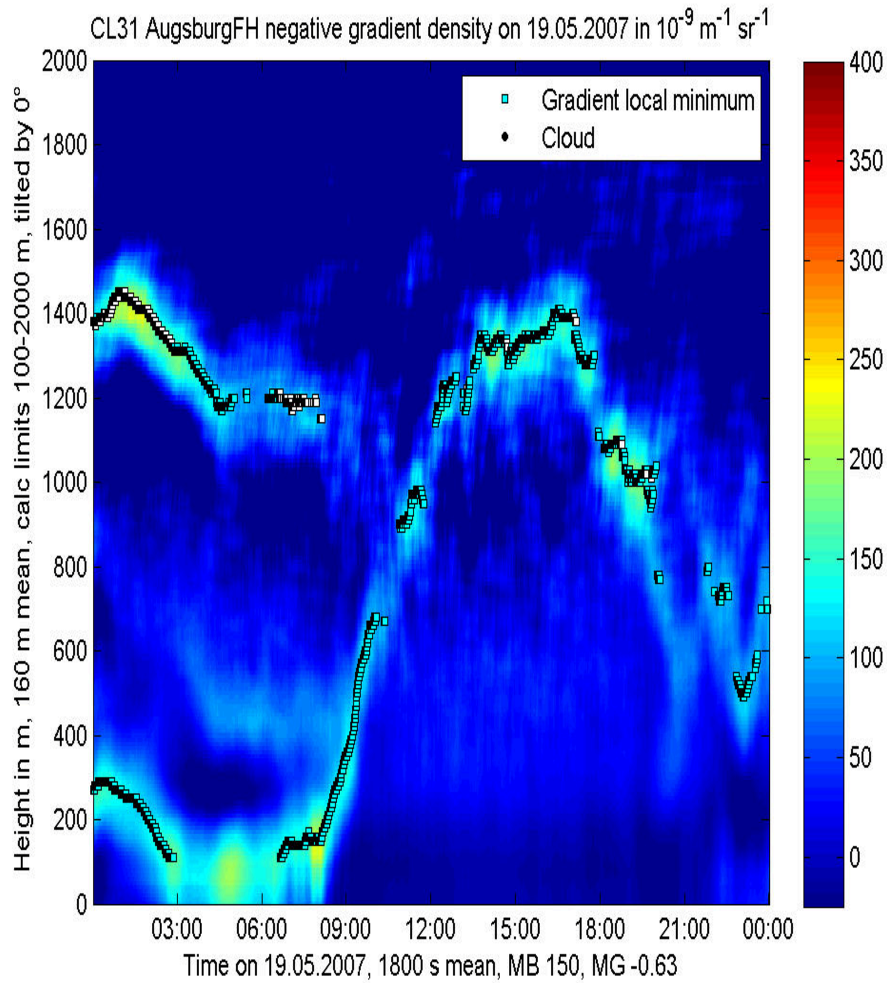
algorithms for mixing-layer height

Sample plot ceilometer (convective BL at daytime)

optical backscatter intensity

negative vertical gradient of optical backscatter intensity

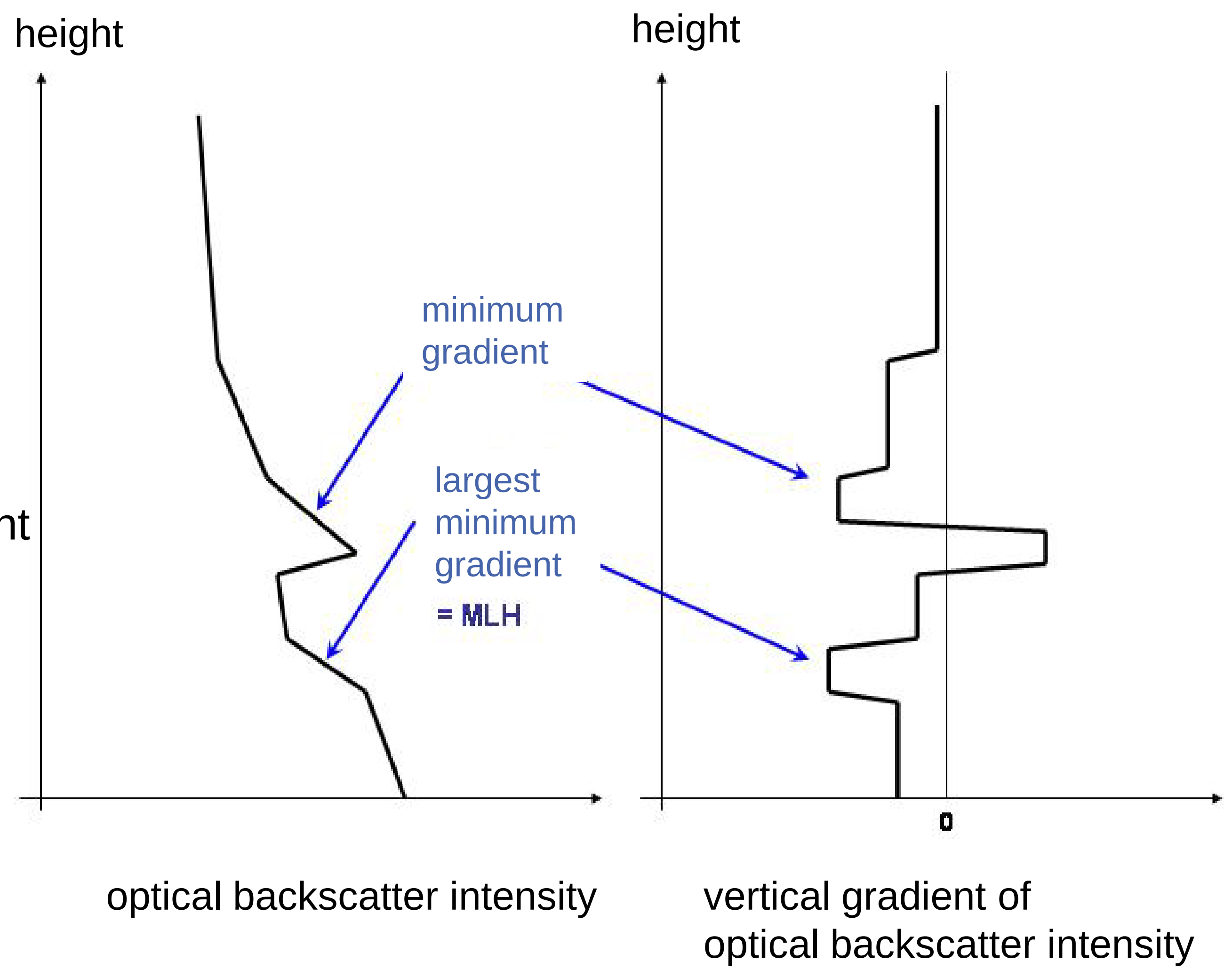




Algorithms to detect MLH from Ceilometer-Daten

criterion

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

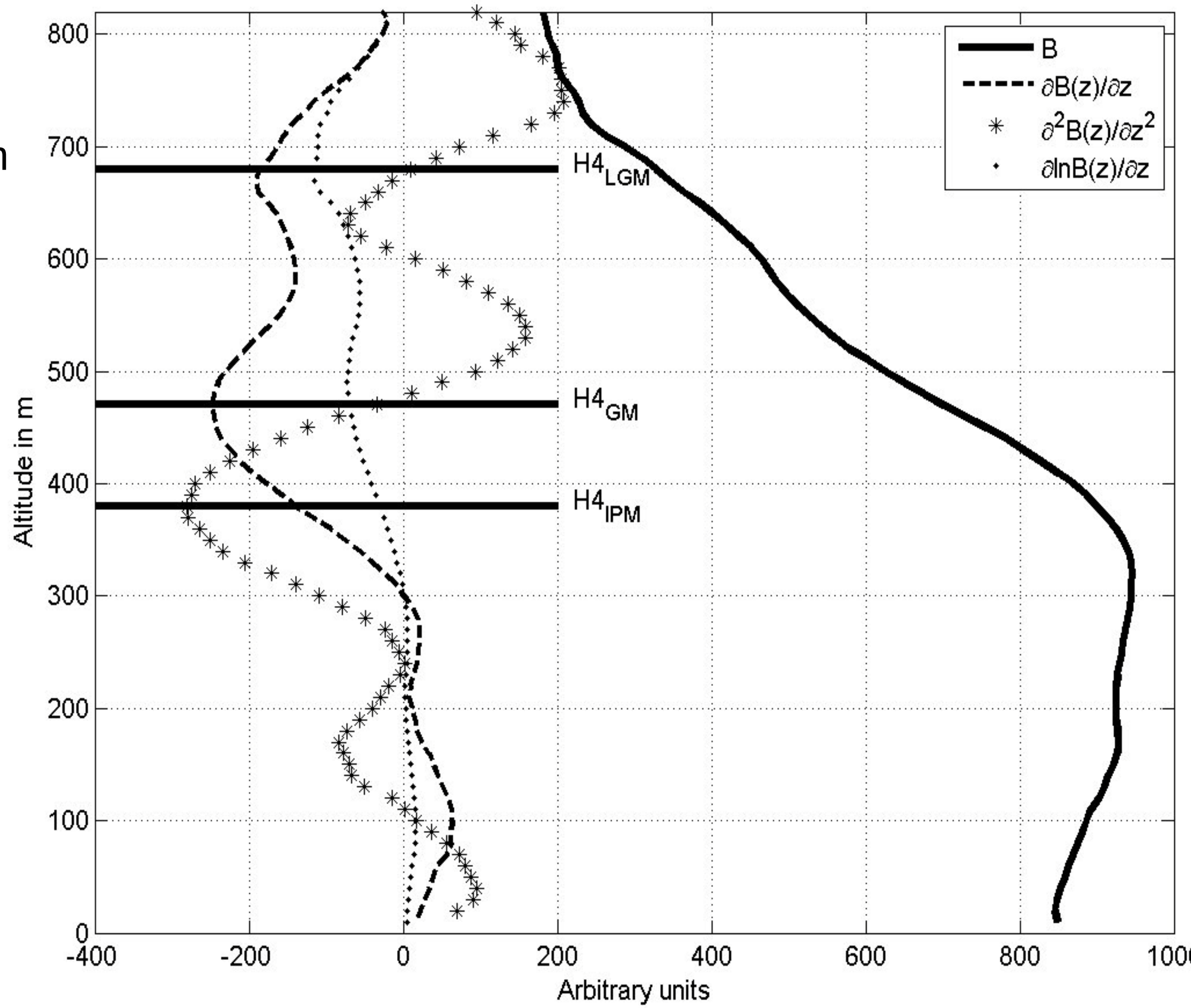


Different gradient methods (see Sicard et al. 2006, BLM 119, 135-157)

logarithmic gradient minimum

gradient minimum

inflection point method (minimum of 2nd derivative)



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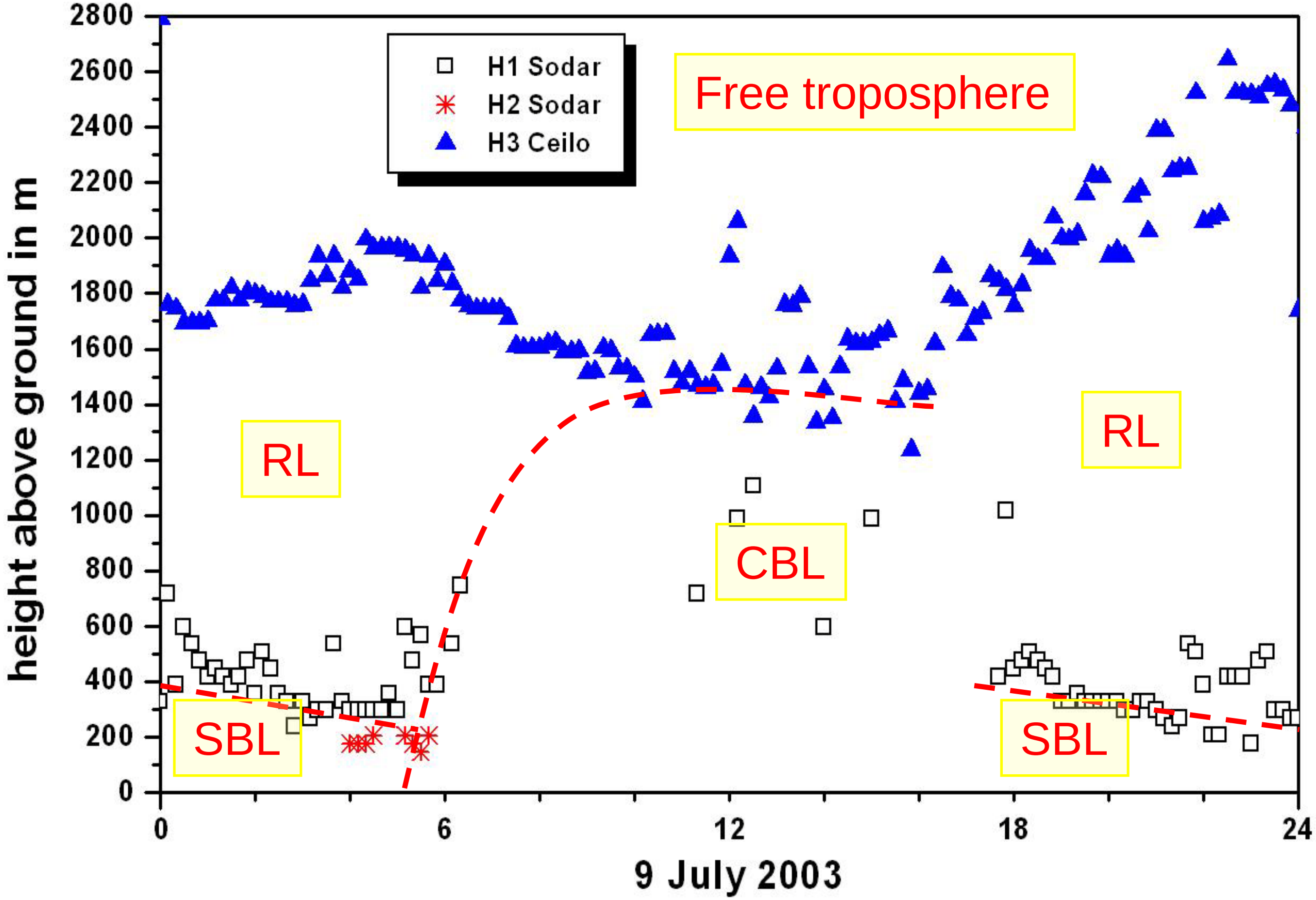
Diurnal variation of mixing-layer height from SODAR and Ceilometer data (Budapest)



SBL:

stable boundary layer (usually at night and in winter)

CBL:

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

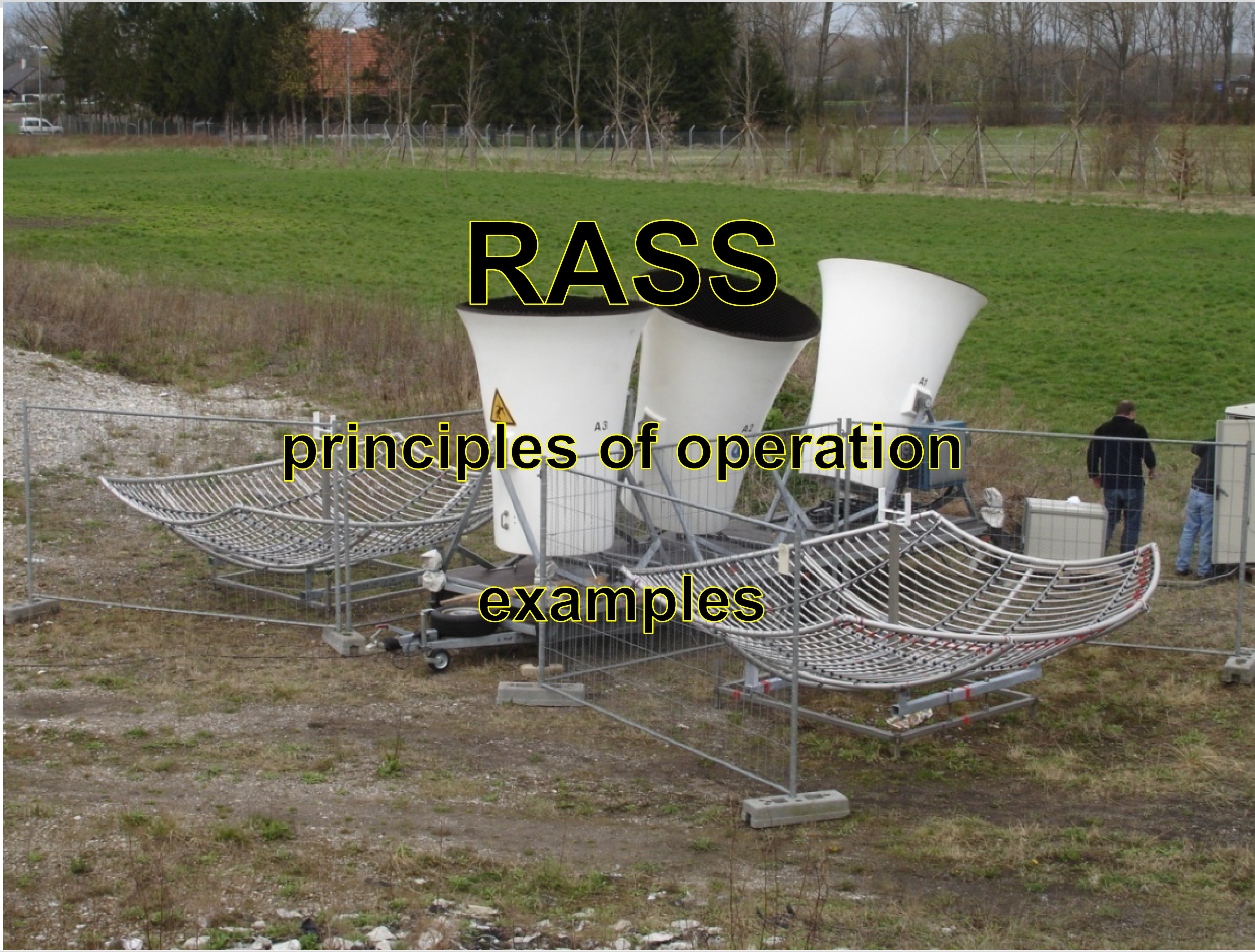
RL:

residual layer (usually at nighttime)

RASS

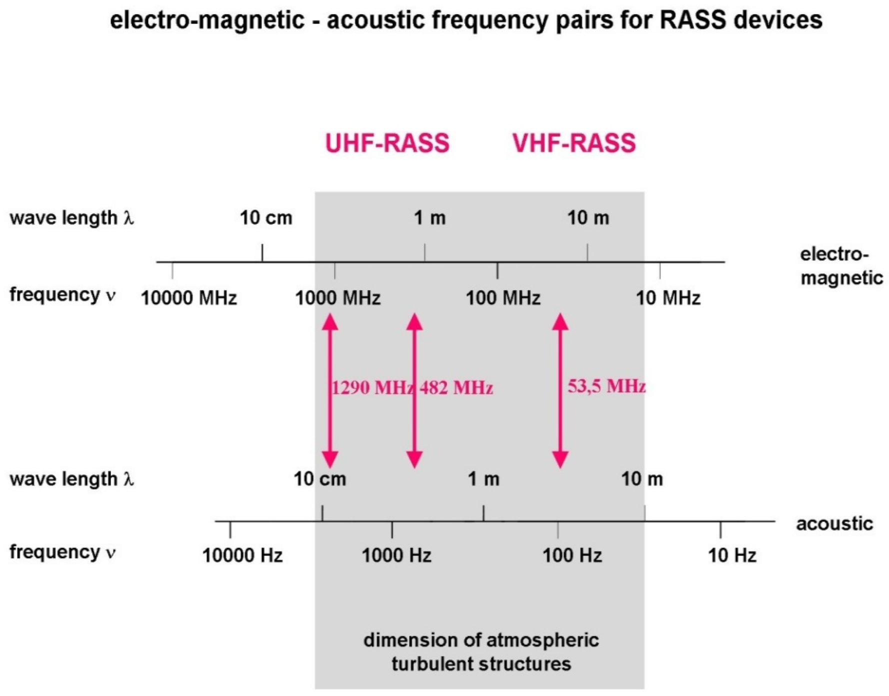
principles of operation

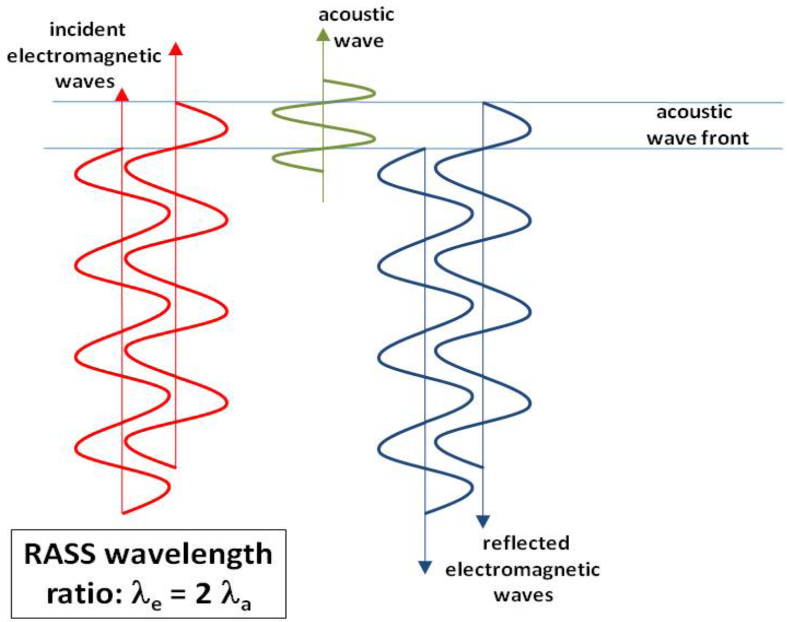
examples



RASS: frequencies

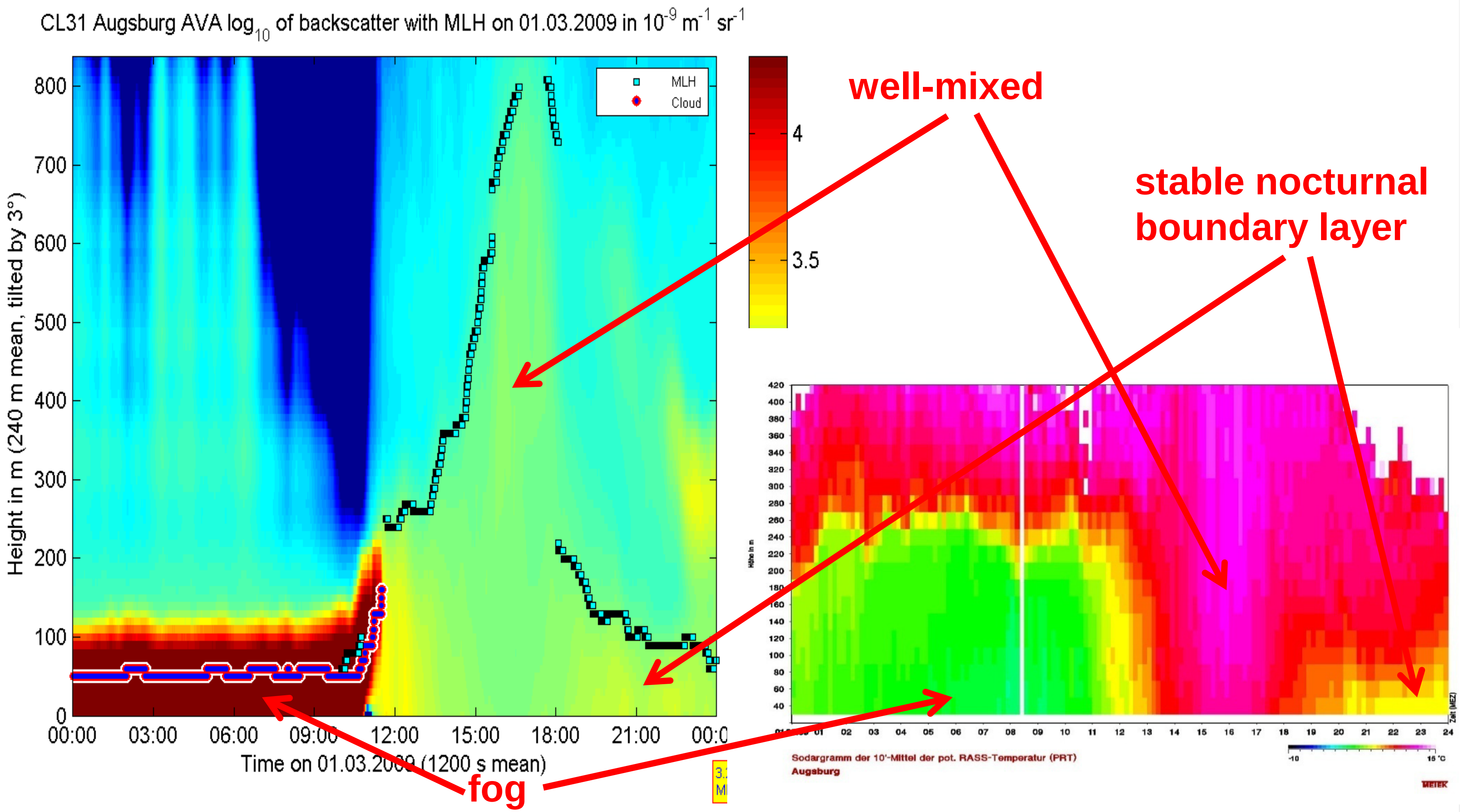
Bragg condition:
acoustic wavelength = ½ electro-magnetic wavelength





temperature profile and pollution

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



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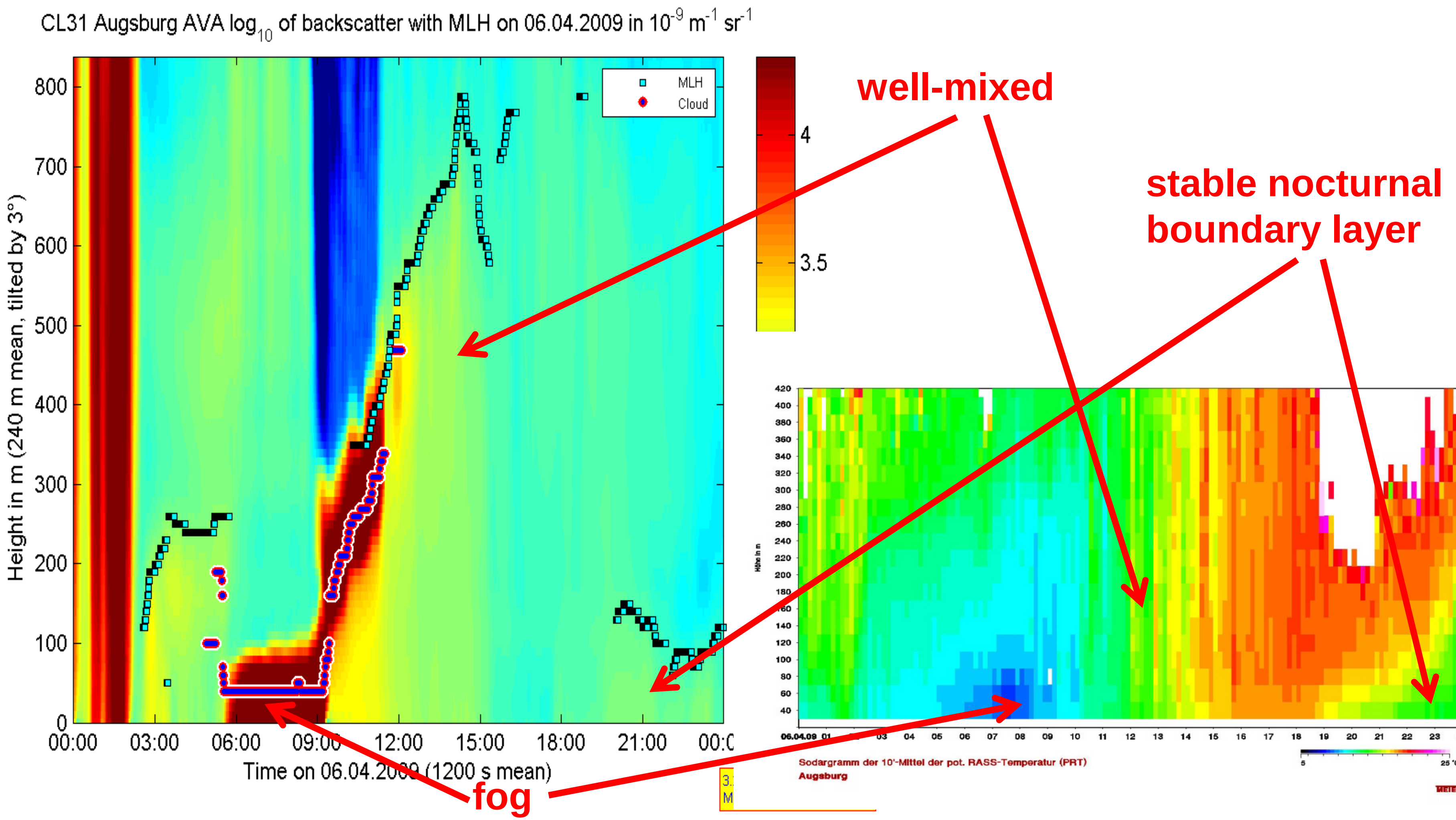

Overview on methods using ground-based remote sensing for the derivation of the mixing-layer height

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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. Only remote system that measures inversion strengths. 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.**

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.

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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.