Determination of the mixing-layer height by surface-based remote sensing

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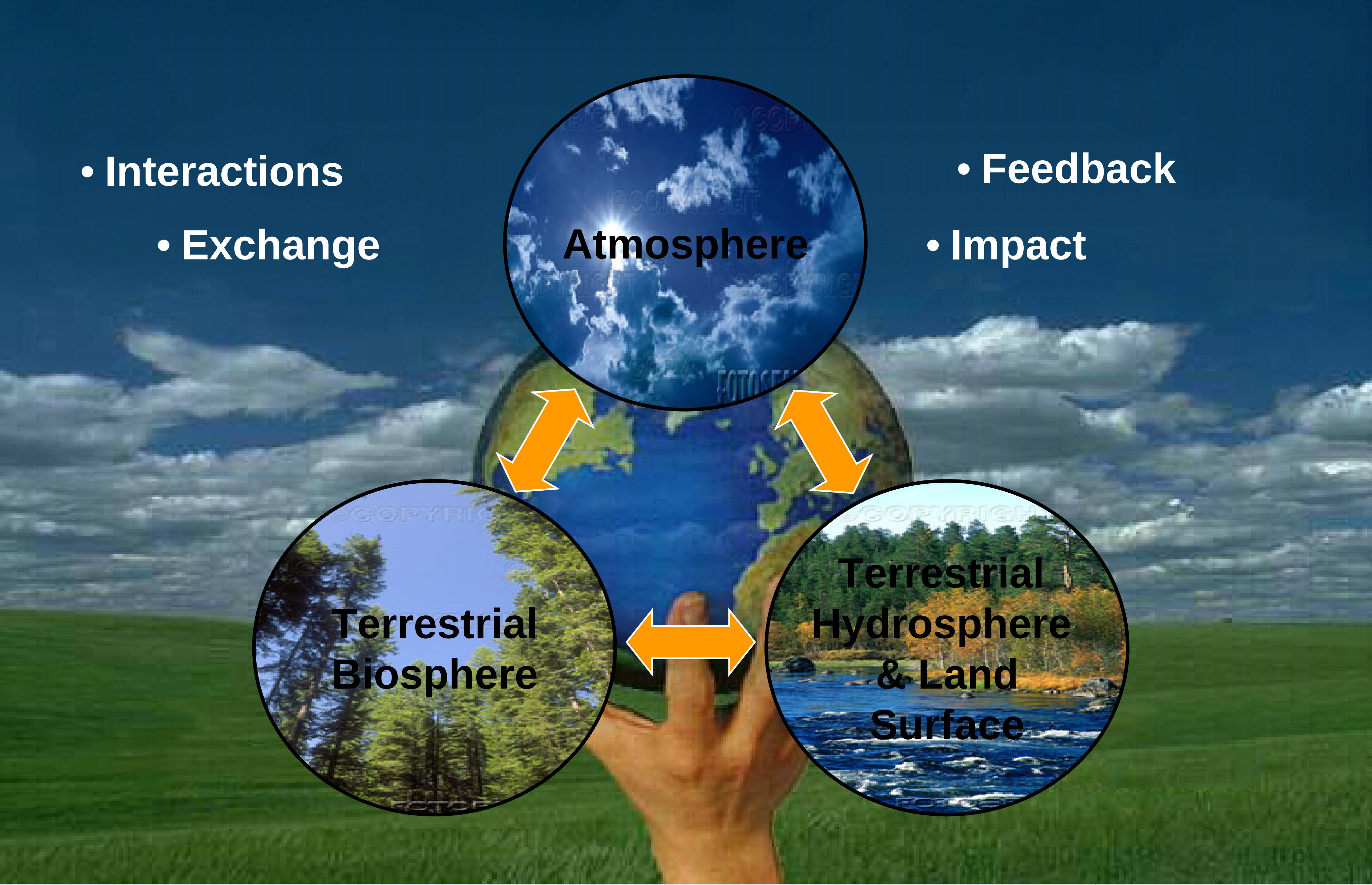
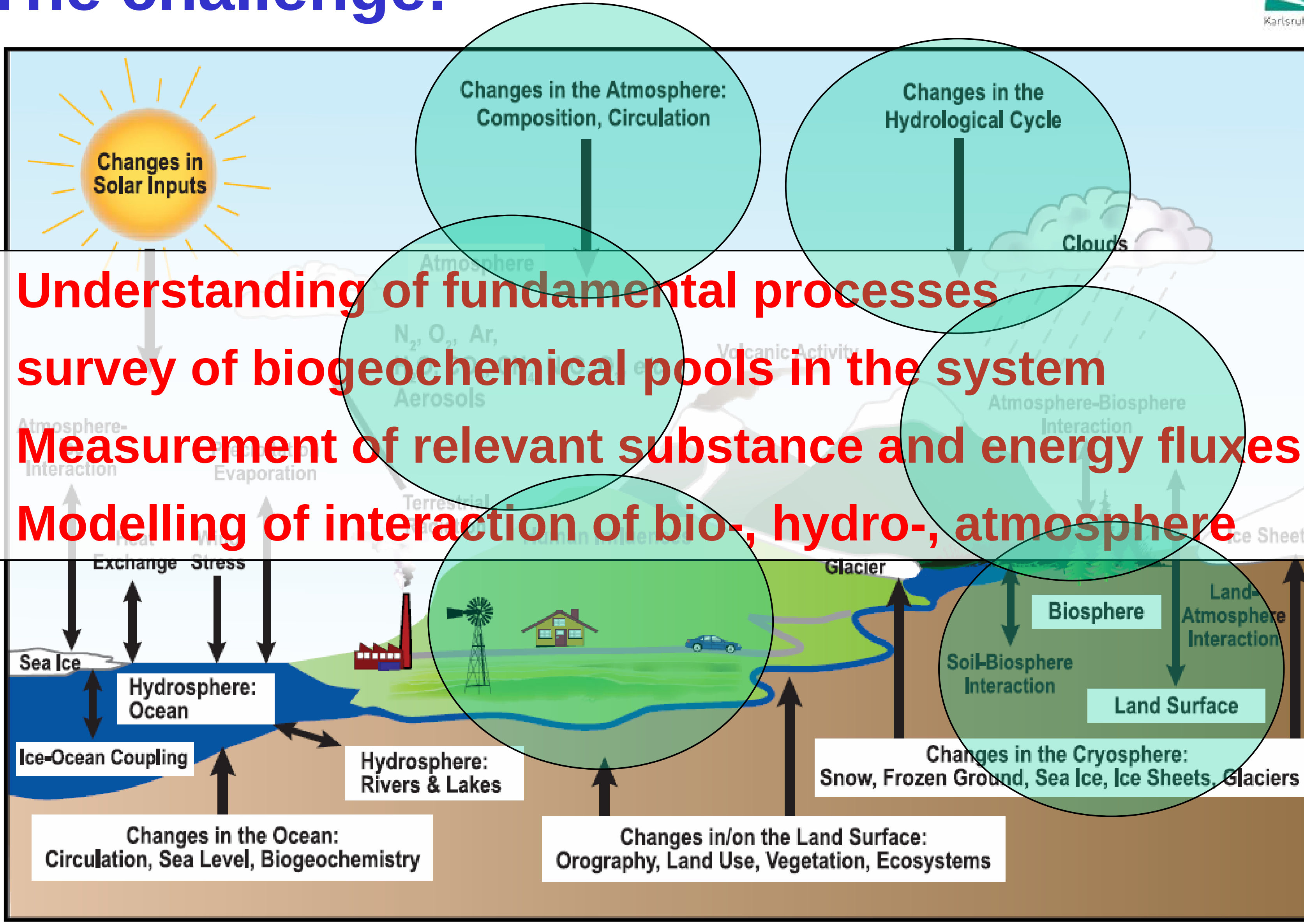
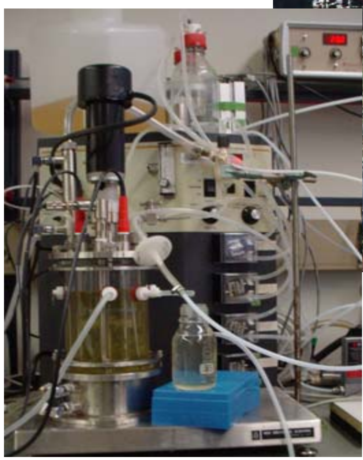

• Interactions
• Exchange
Atmosphere
• Feedback
• Impact
Terrestrial Biosphere
Terrestrial Hydrosphere & Land Surface

The challenge:

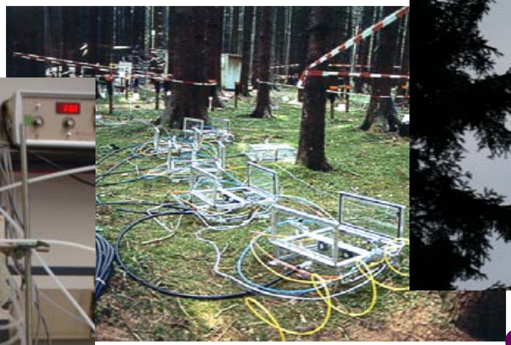


- Understanding of fundamental processes
- survey of biogeochemical pools in the system
- Measurement of relevant substance and energy fluxes
- Modelling of interaction of bio-, hydro-, atmosphere

The challenge:



organisms
(laboratory meas.)



plot scale
(chamber meas.)

ecosystem scale
(tower meas./
remote sensing)

regional scale
(aircraft meas.)

global scale
(remote sensing)

Air Quality in Metropolitan Areas and Sensitive Regions

- Interactions between urban/suburban/rural regions and their feedback mechanism to the air quality
- Impact of regional climate change on air quality
- Developing and validation of innovative measuring techniques for the assessment of the air quality (e.g. Megacities, alpine valleys)
- Coupling of models (e.g. MCCM, WRF-Chem, NEMO, GRAL, GRAMM)
- Real-time forecast of gas and particle phase pollutants
- Assessment of emission strategies (e.g. source attribution)
- Project “Risk Habitat Megacity” with the topic “Air Quality and Health”; anchor city Santiago de Chile in co-operation with Universidad de Chile

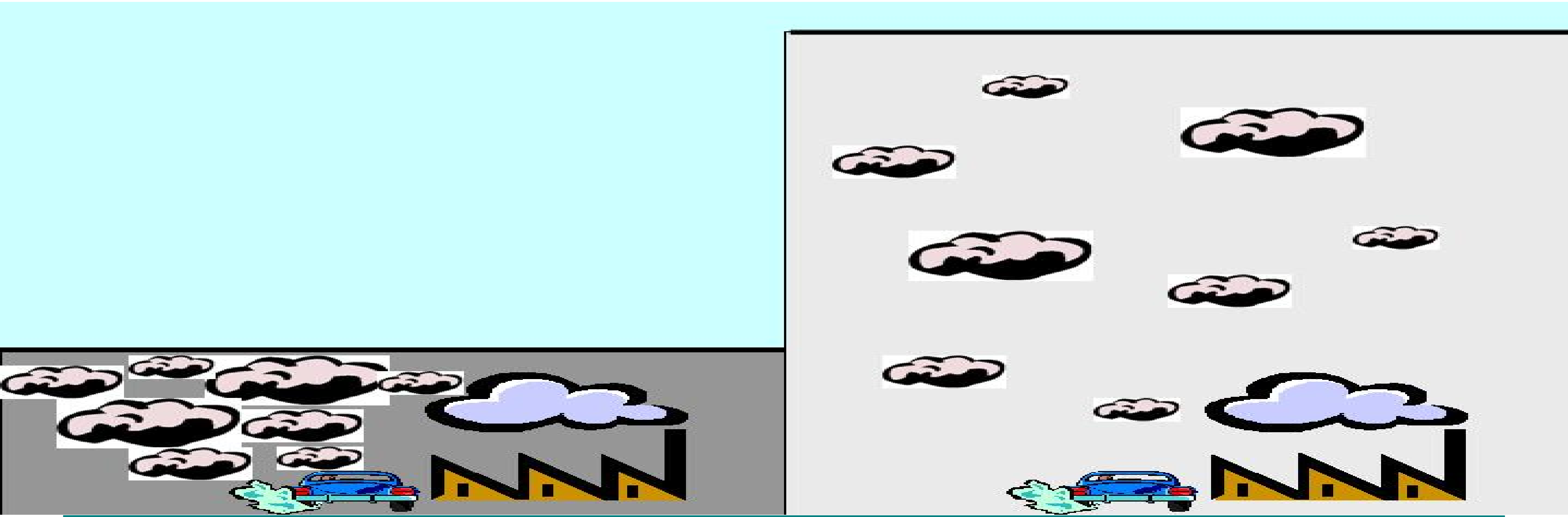
Geographical focus

- Chile, Mexico, China
- Europe and European Alps

Motivation for MLH studies:

Stratification and height of the mixing-layer strongly influence the vertical diffusion of pollutants. Thus MLH has to be known for:

- **assessment of air quality from surface measurements**
- **determination of diffuse emission source strengths**
- **deduction of air quality from satellite-derived aerosol optical depths**



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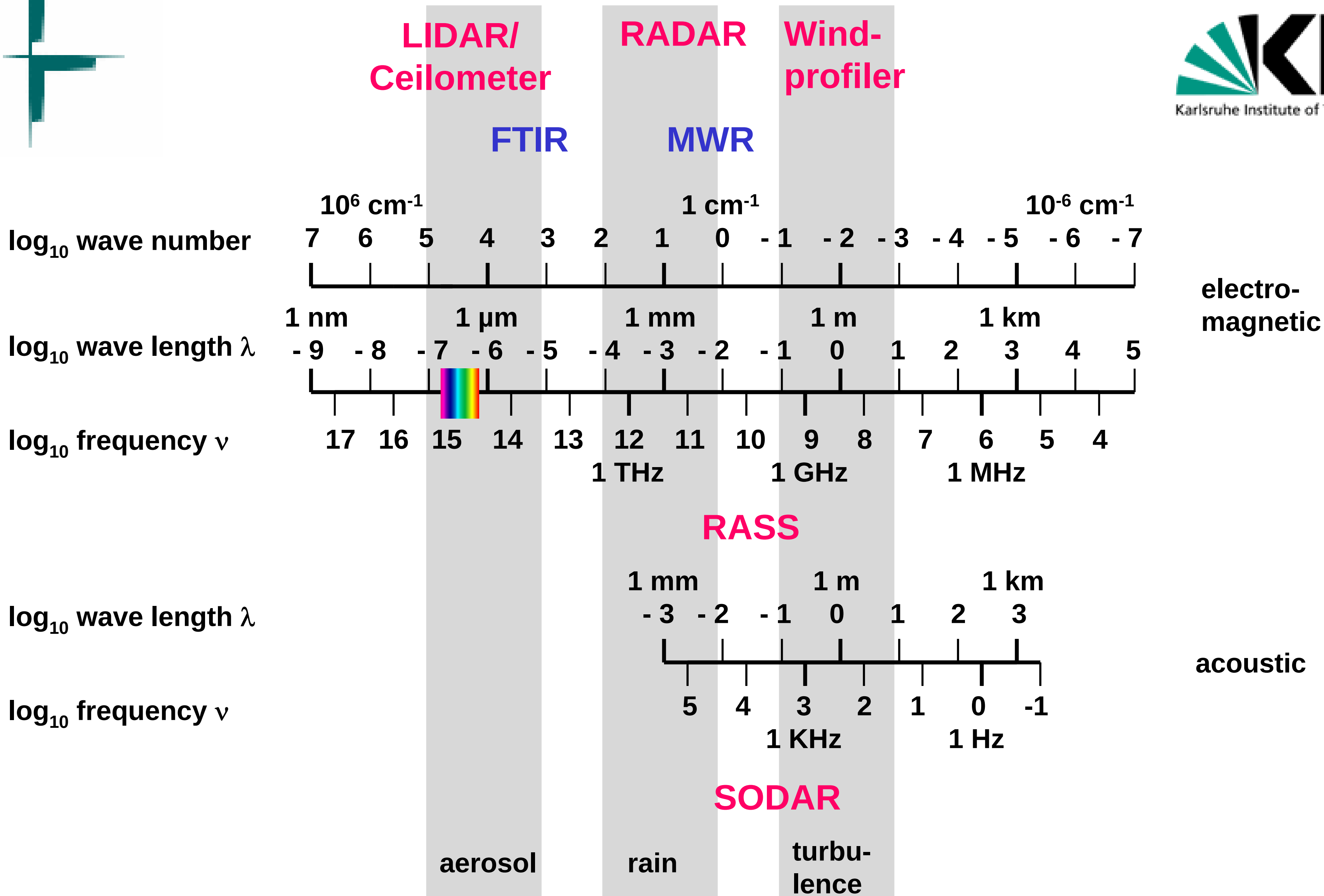
Mixing layer height

Inversion height	**literally: inversion in the temperature profile, increase of temperature with height, strong decrease of moisture, radiation inversions, sinking inversions, surface inversions, lifted inversions**
Mixing layer height	**defined by the turbulence profile, upper boundary for vertical exchange (mixing), upper boundary of the well-mixed layer, entrainment**
Boundary layer height	**SBL: at night, height of the near-surface layer influenced by surface friction** **CBL: at day, height of convective plumes**

boundary layer height ≈ mixing layer height

boundary layer height ≥ inversion height

Typical frequency bands for remote sensing of the atmosphere



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

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Measurement of the vertical structure of the boundary layer and mixing-layer height by remote sensing:

mobile surface-based acoustic and optical remote sensing yields information on:

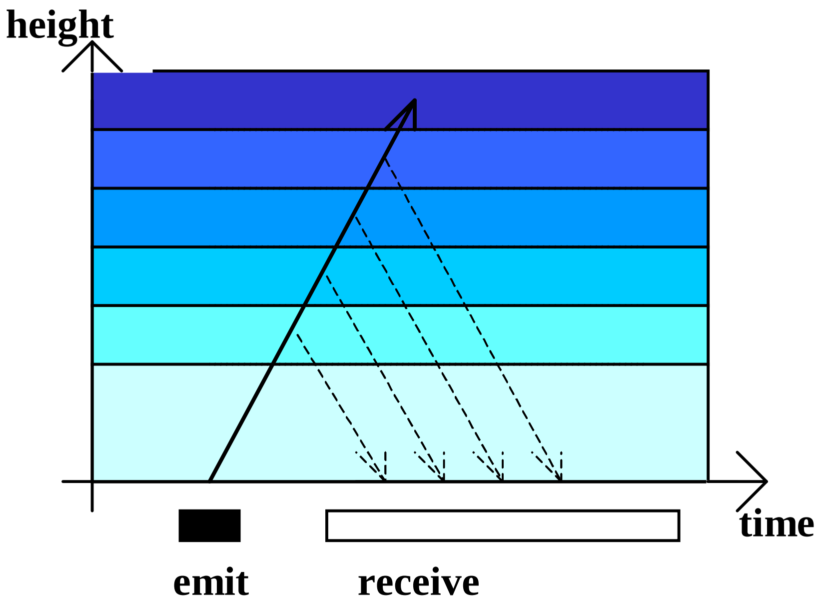
➔ thermal structure of the BL and turbulence intensity

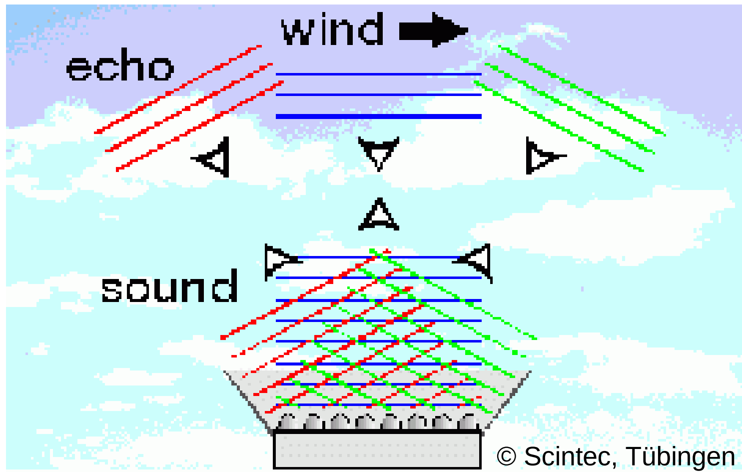
(SODAR)

➔ aerosol content of the BL

(Ceilometer)

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)

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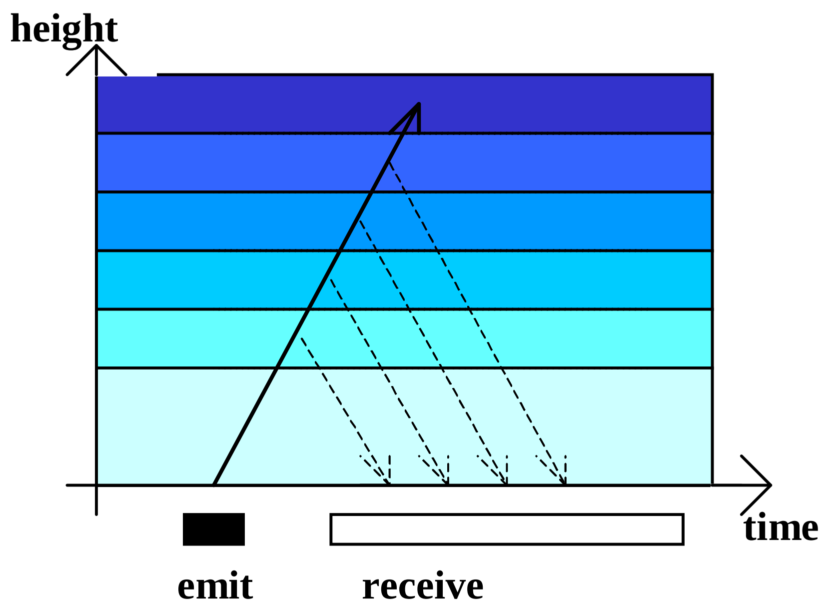
Ceilometer/LIDAR measuring principle



detection:

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

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

method	short description
acoustic ARE method	analysis of acoustic backscatter intensity profiles
" HWS method	analysis of wind speed profiles
" VWV method	analysis of vertical wind variance profiles
" EARE method	**analysis of acoustic backscatter intensity and vertical wind variance profiles**
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

Emeis, S., K. Schäfer, C. Münkel, 2008: Surface-based remote sensing of the mixing-layer height – a review. Submitted to Meteorol. Z.

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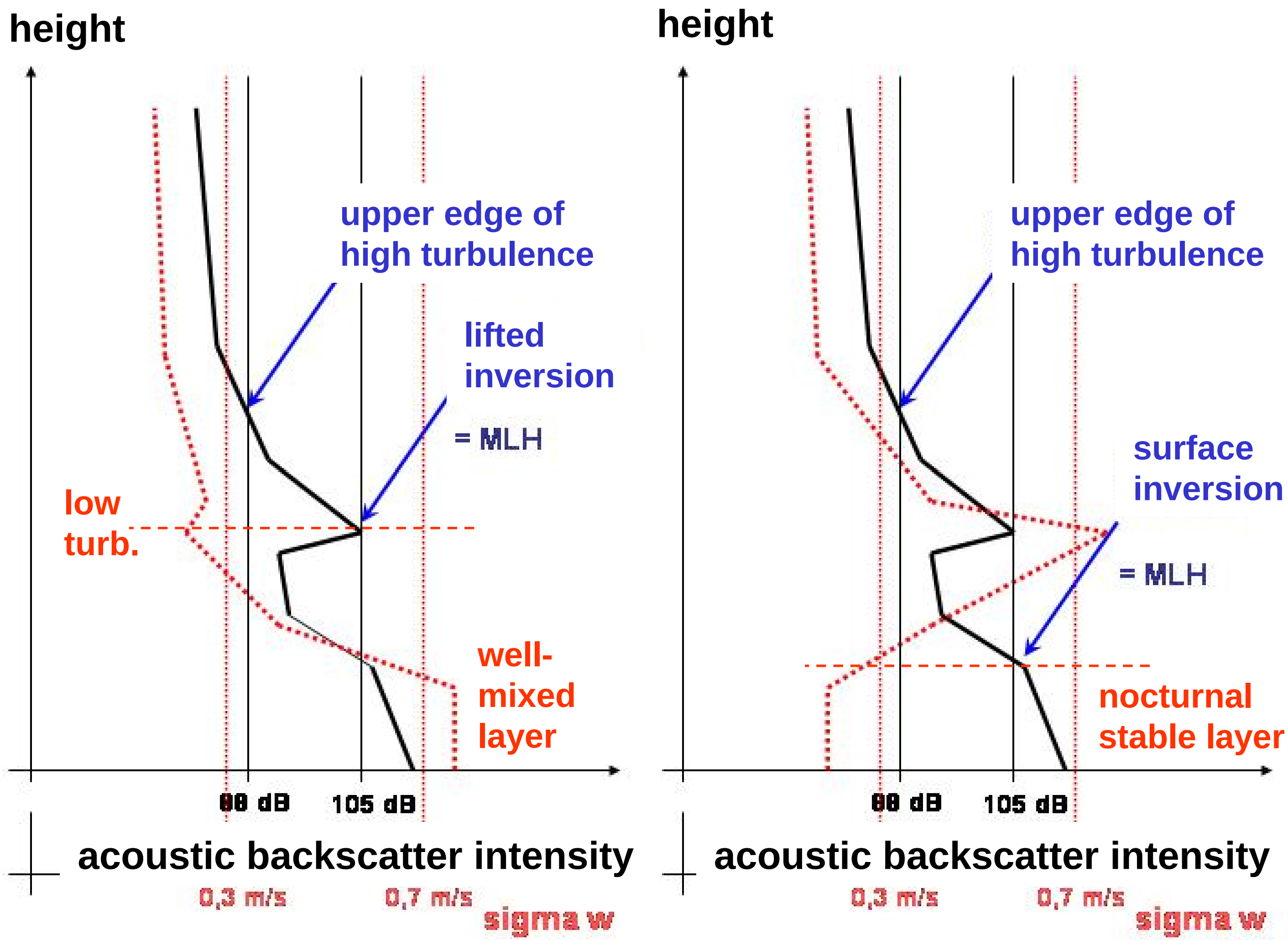
Algorithms to detect MLH from SODAR data

criterion 1:
upper edge of high turbulence

criterion 2:
surface and lifted inversions

MLH = Min (C1, C2)

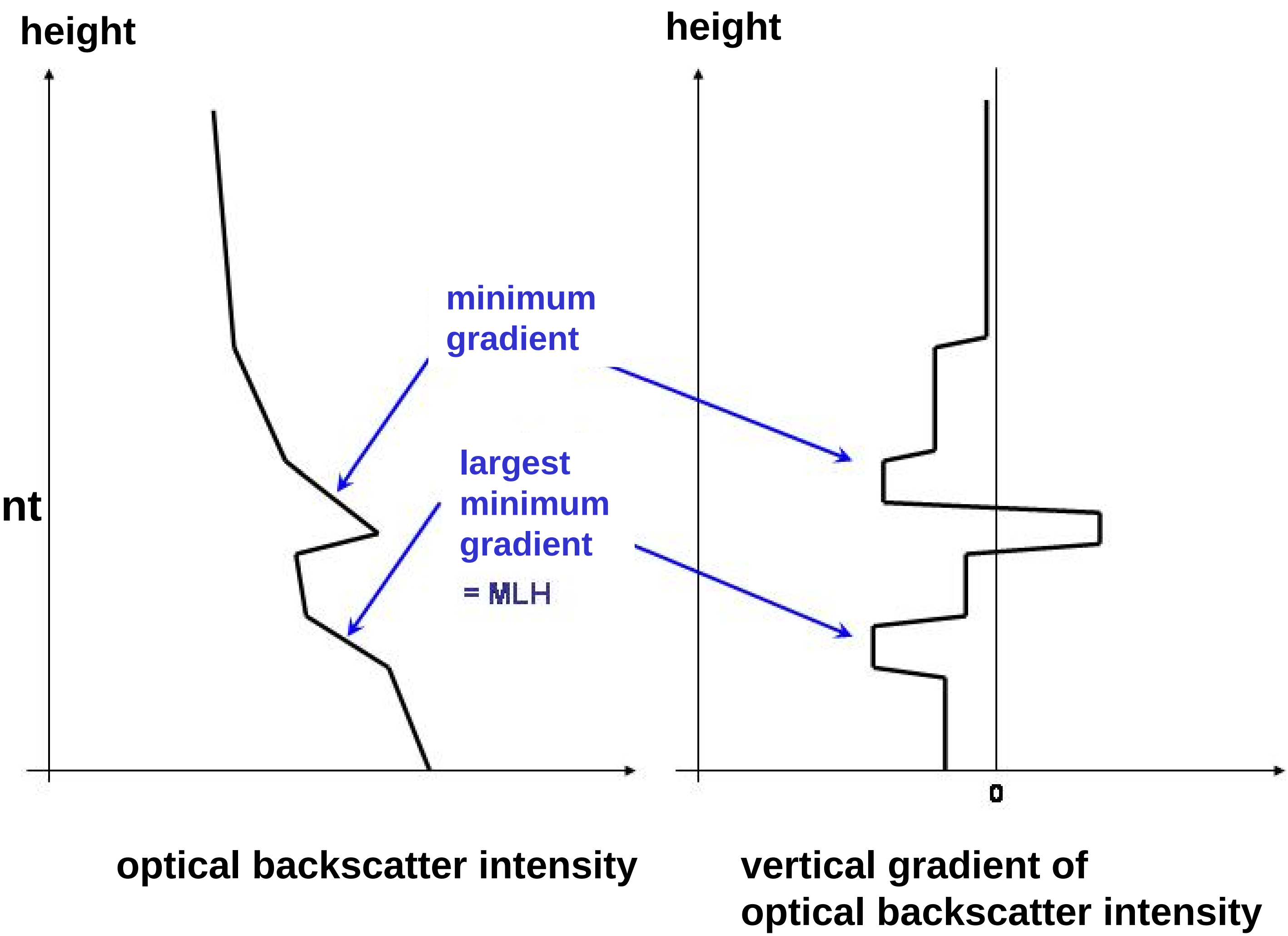


example 1: daytime **example 2: night-time**

Algorithms to detect MLH from Ceilometer-Daten

criterion

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

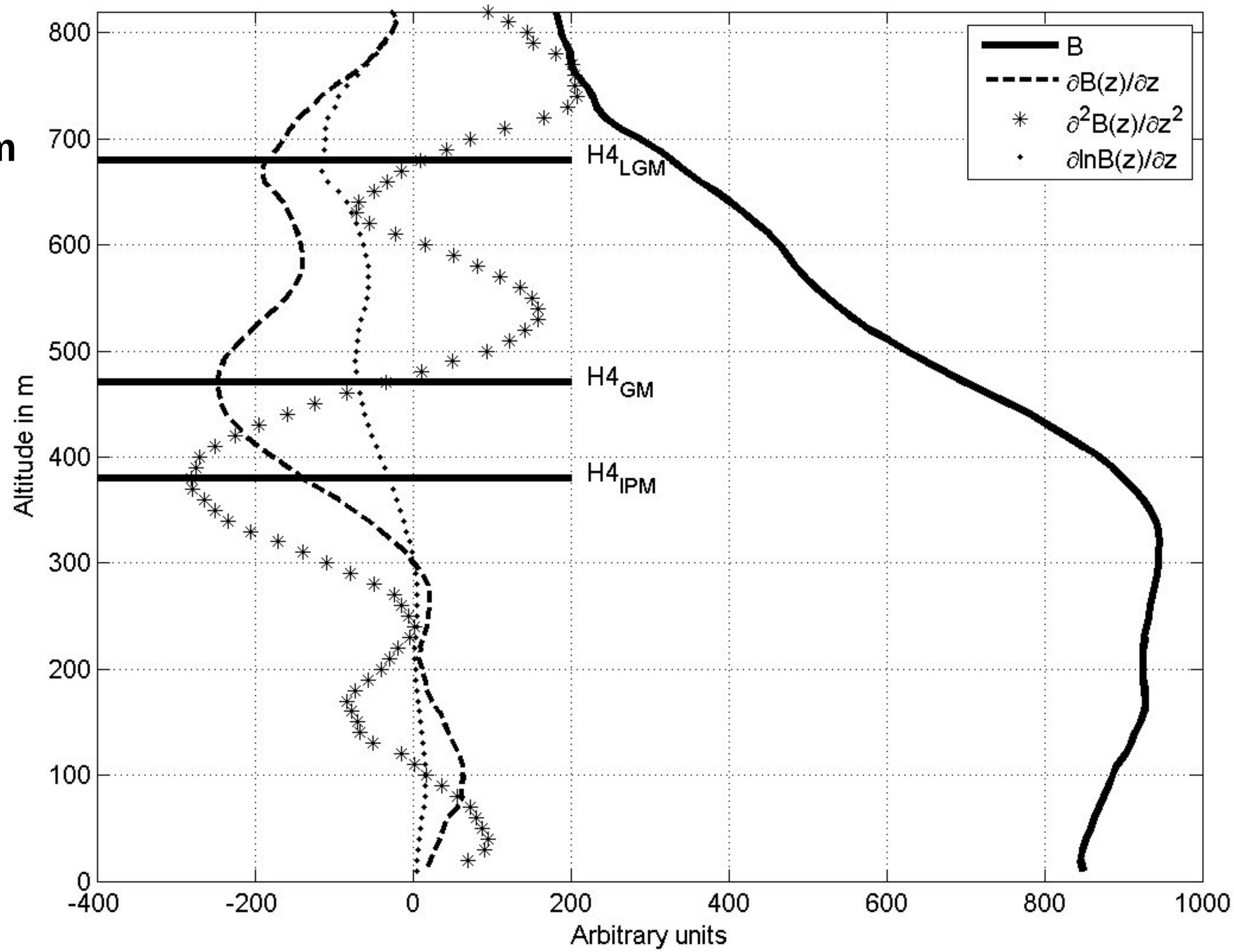


Different gradient methods (see Sicard et al. 2006, BLM 119, 135-157)

logarithmic gradient minimum

gradient minimum

inflection point method (minimum of 2nd derivative)



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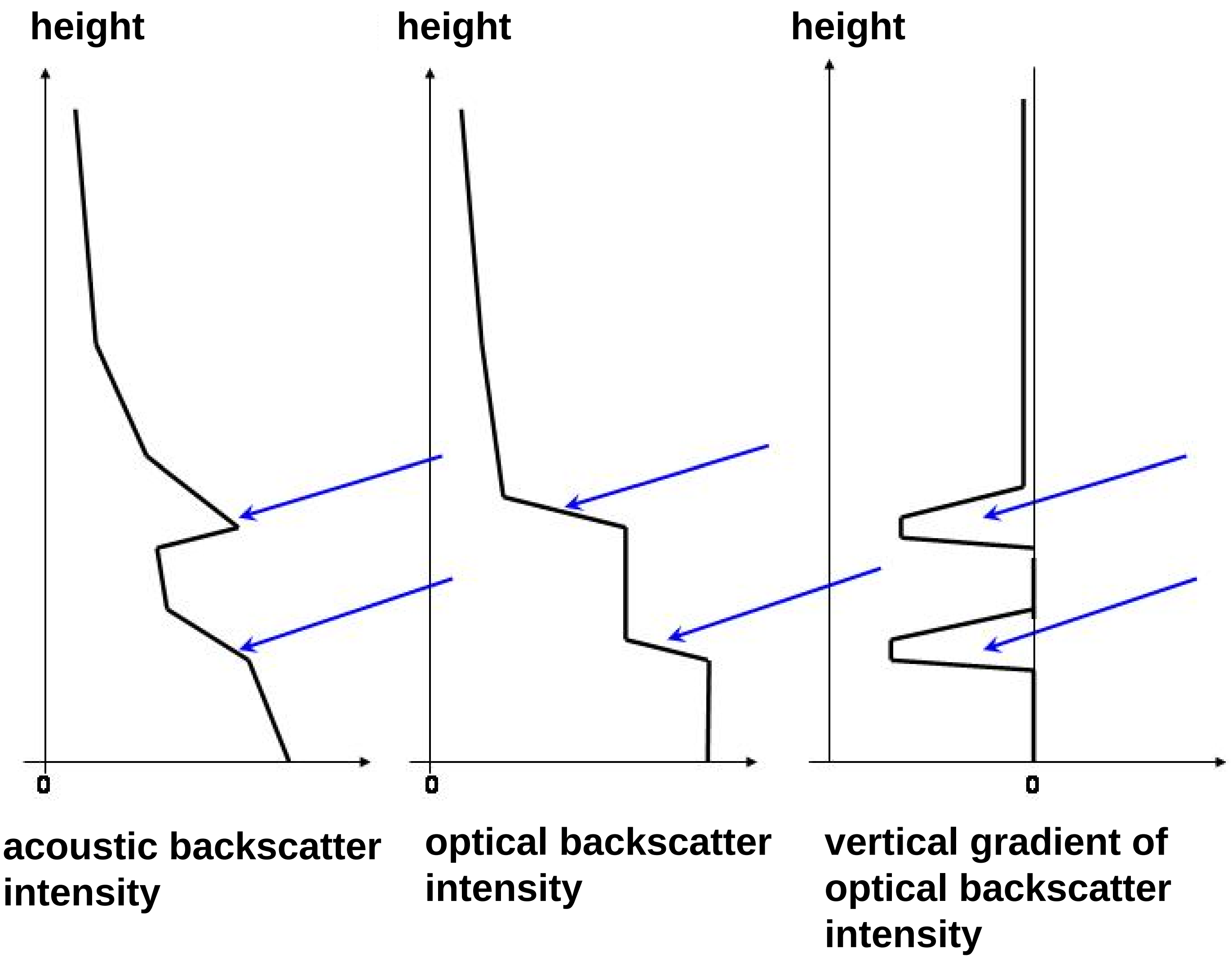
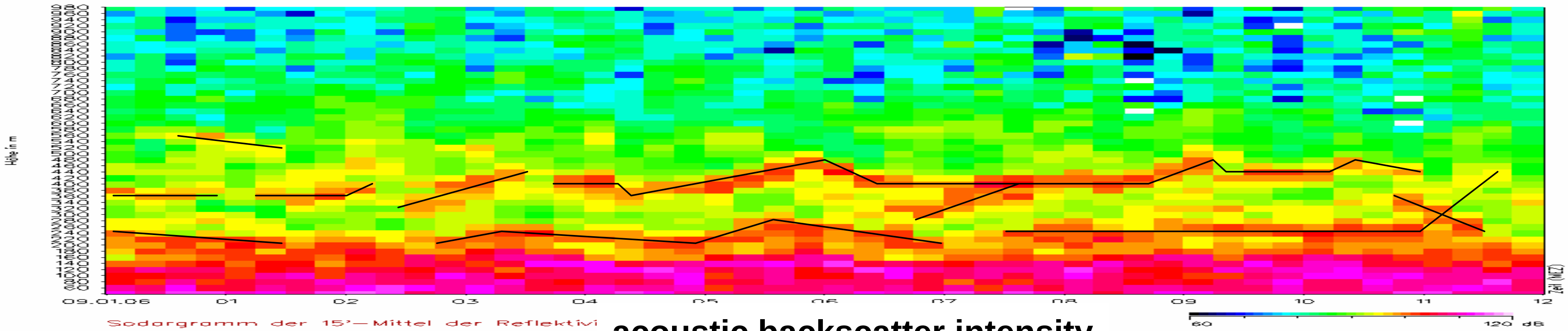
comparison of algorithms

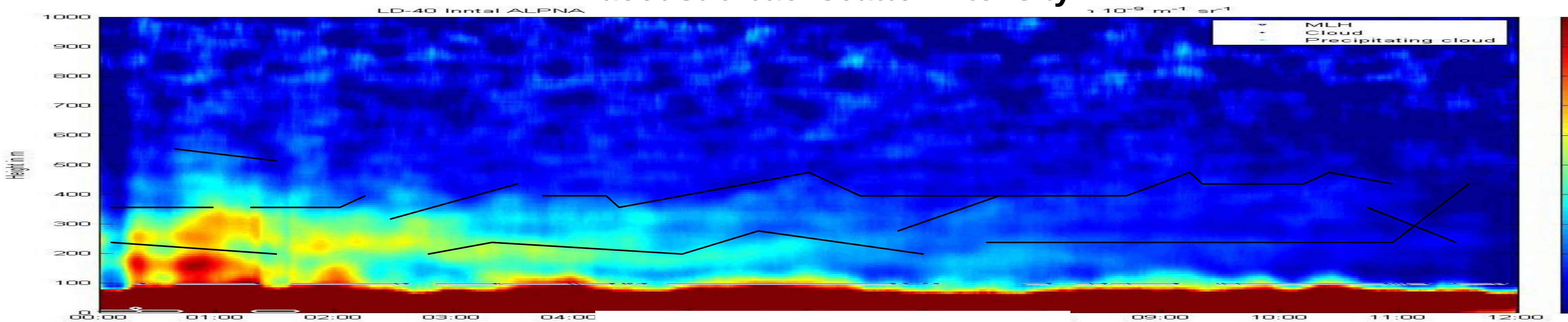
left: SODAR

middle and right: ceilometer

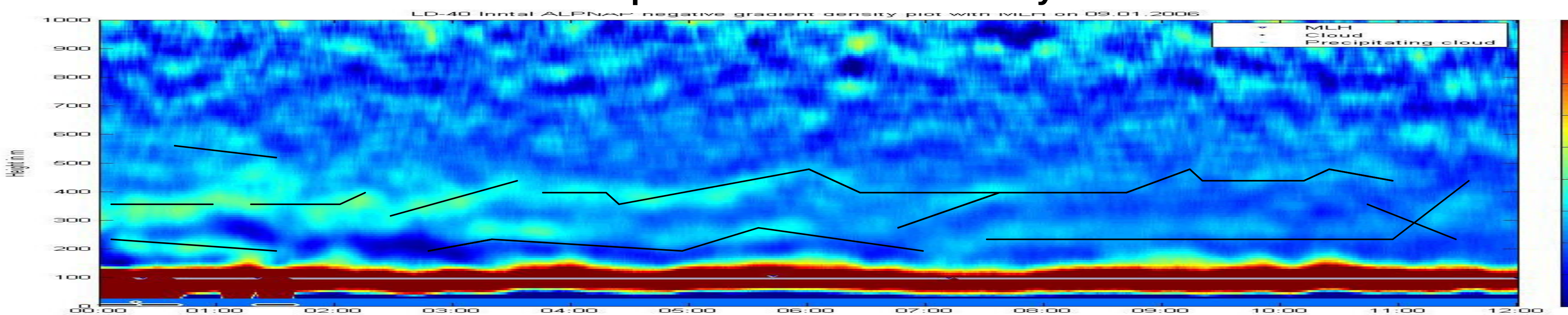




acoustic backscatter intensity



optical backscatter intensity



vertical gradient of optical backscatter intensity

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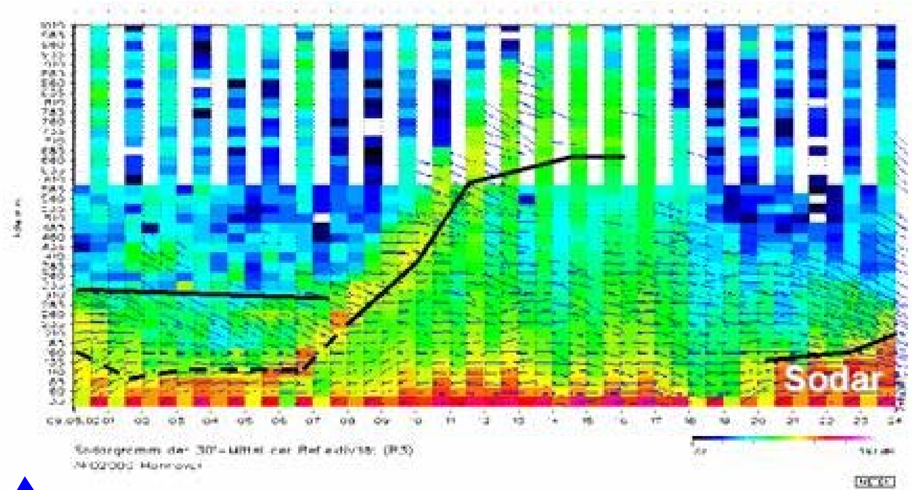
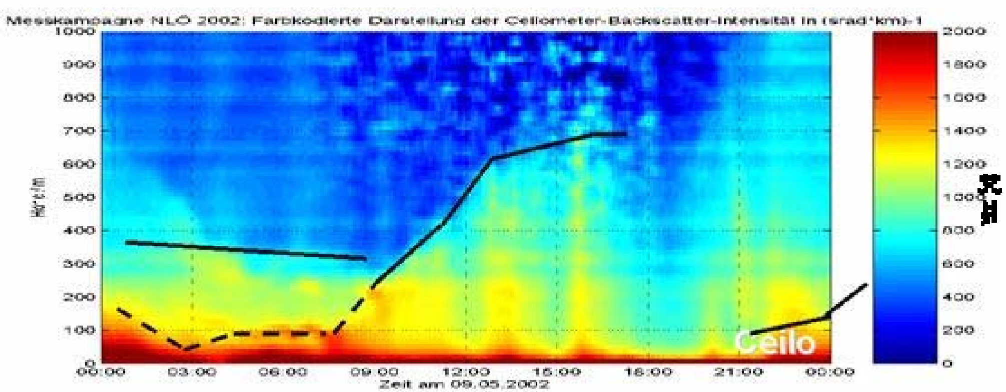
Comparison of MLH retrievals with three different remote sensing techniques

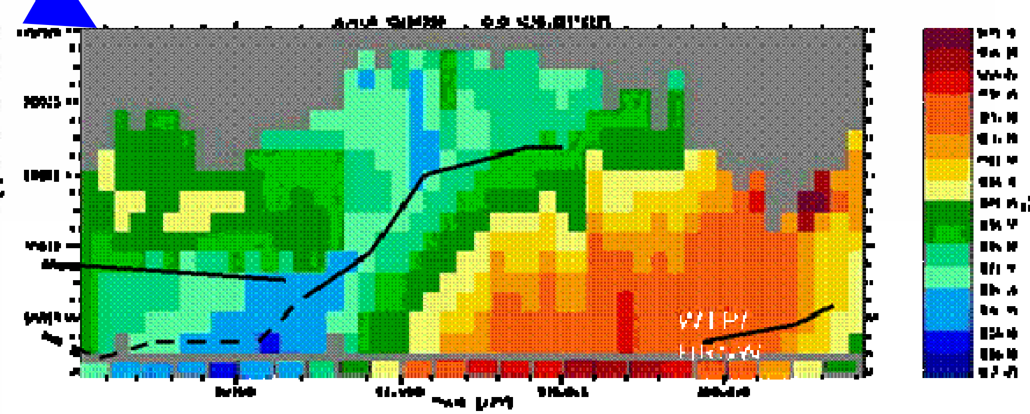
SODAR
acoustic backscatter



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.

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Example for the joint operation of a SODAR and a Ceilometer

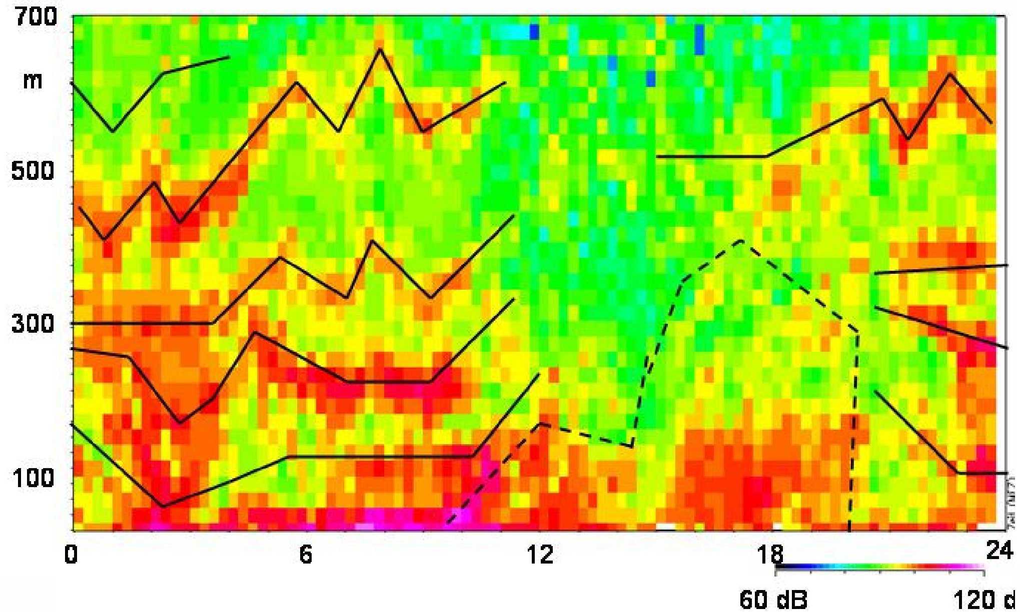
winter in an Alpine valley (snow-covered)

(ALPNAP-Campaign in the Inn valley in winter 2005/06)

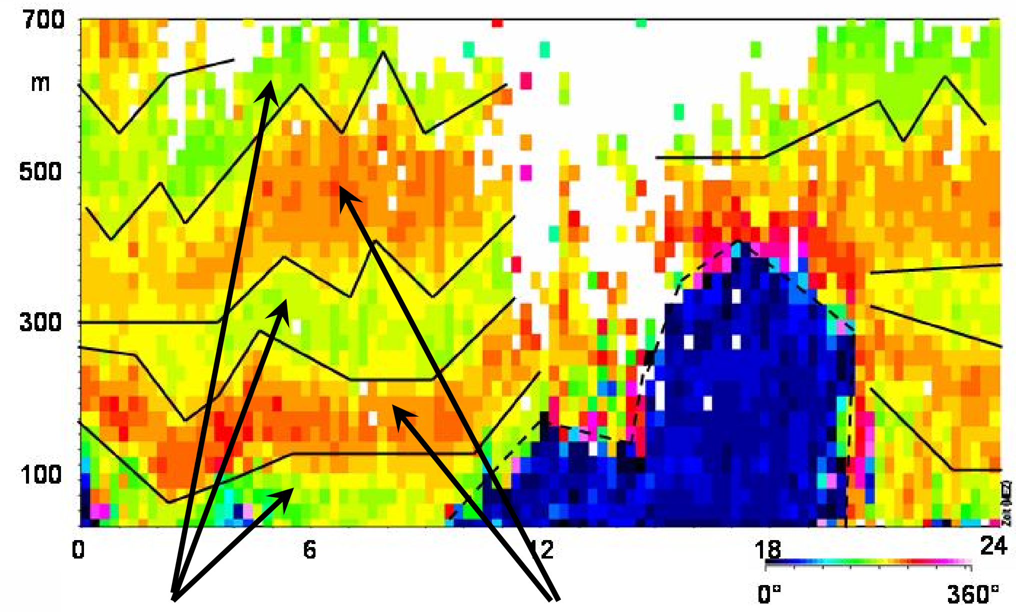
(ALPNAP was a project in the European Programme INTERREG III B Alpine Space, ref. no. D/III/2.1/7)

SODAR measurements in a wintry Alpine valley

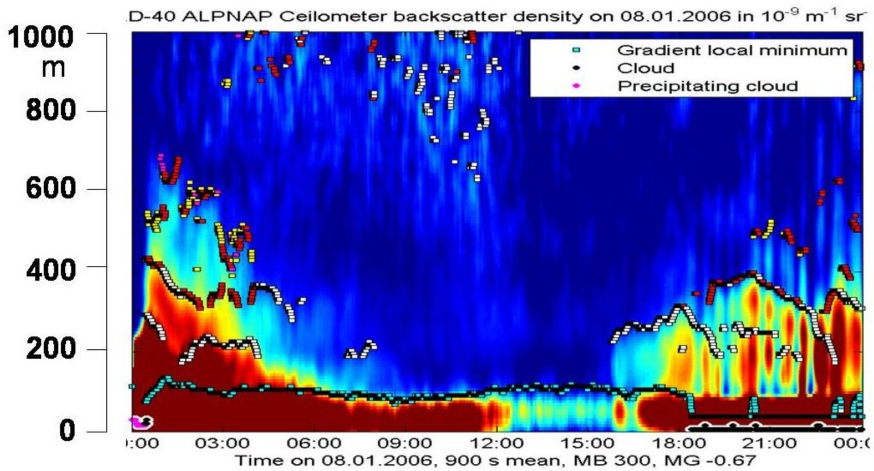
29 January 2006

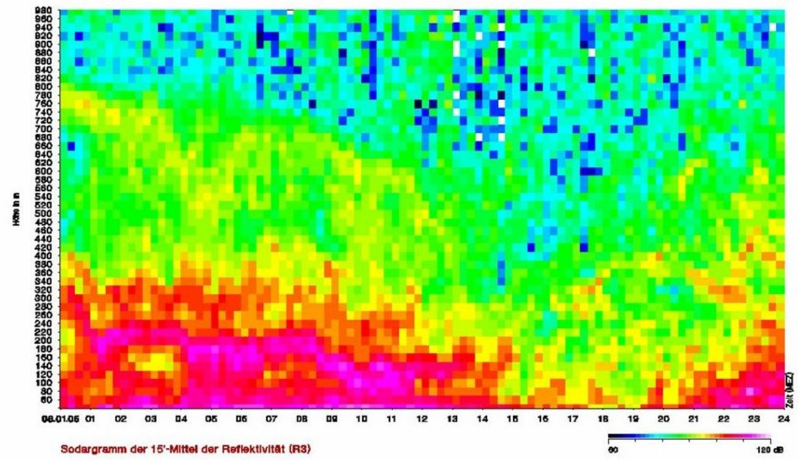


backscatter intensity

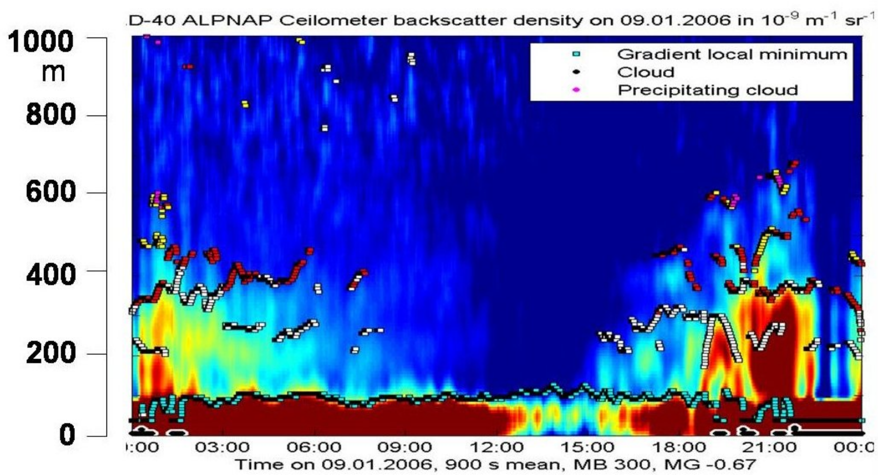


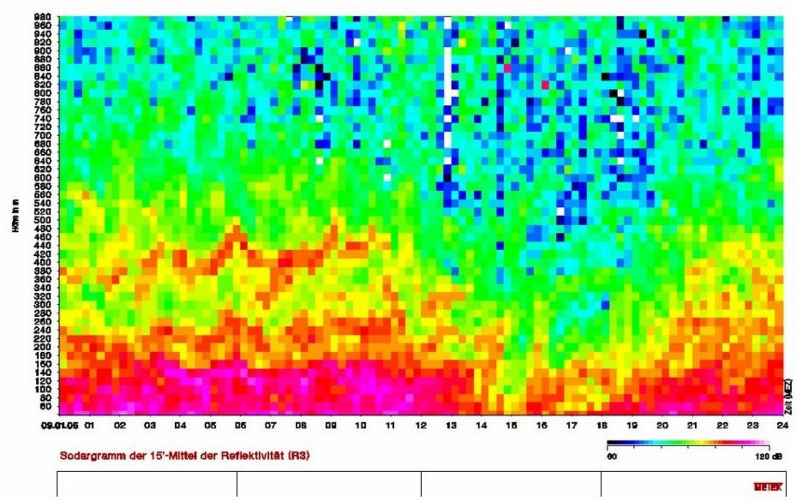
wind direction





optical backscatter intensity **acoustic backscatter intensity**

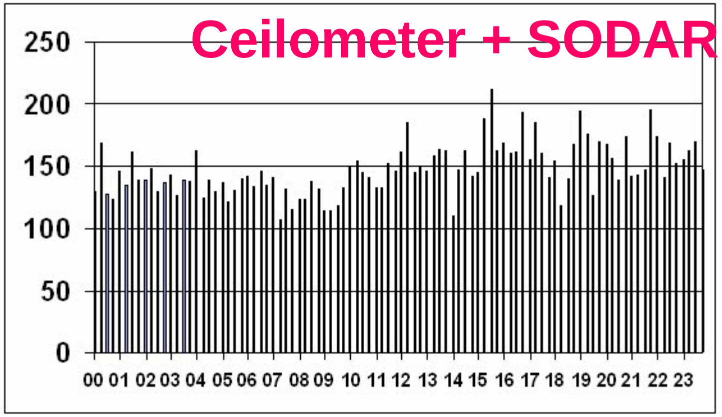




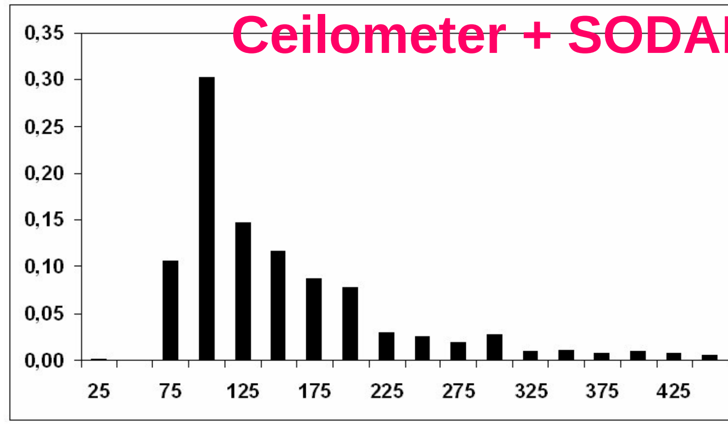
0 6 12 18 24 0 6 12 18 24

statistical evaluations of the Inn valley measurements (1-18 Jan 06)

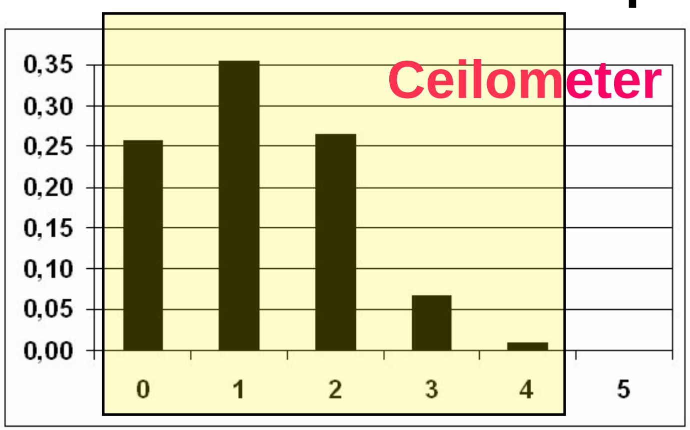
MLH: mean diurnal variation

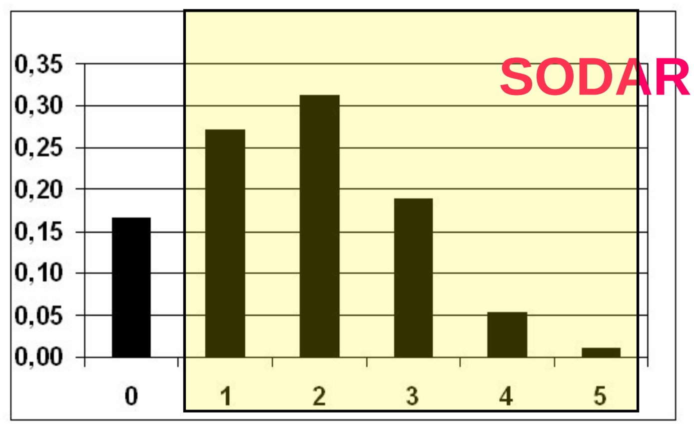


MLH: frequency distribution



multiple inversions





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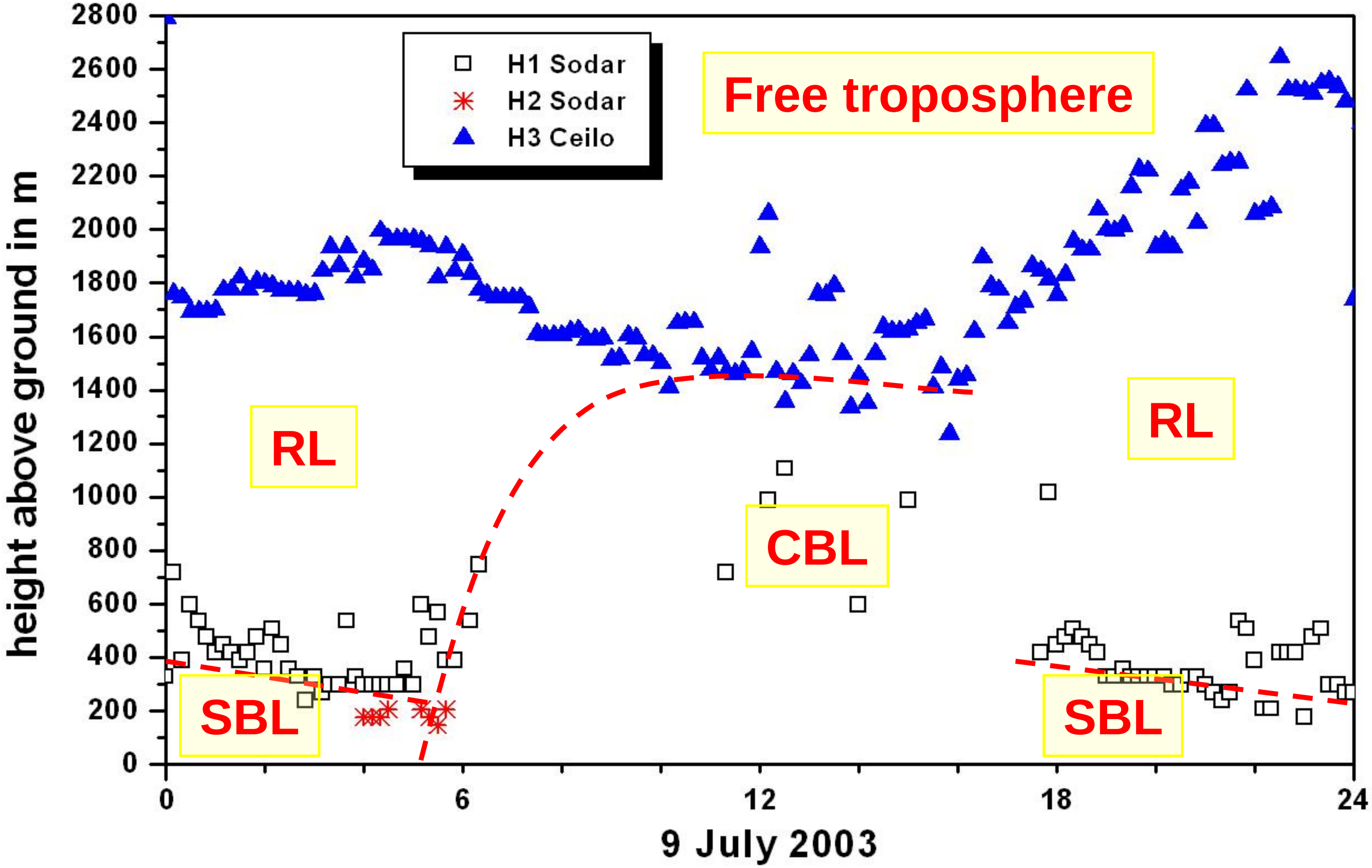
Example for the joint operation of a SODAR and a Ceilometer

summer 2003 Budapest (Hungary)

(ICAROS NET-Campaigns)

(ICAROS NET was a project within the European Research Framework Programme FP5: IST-2000-29264)

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



SBL:

stable boundary layer (usually at night and in winter)

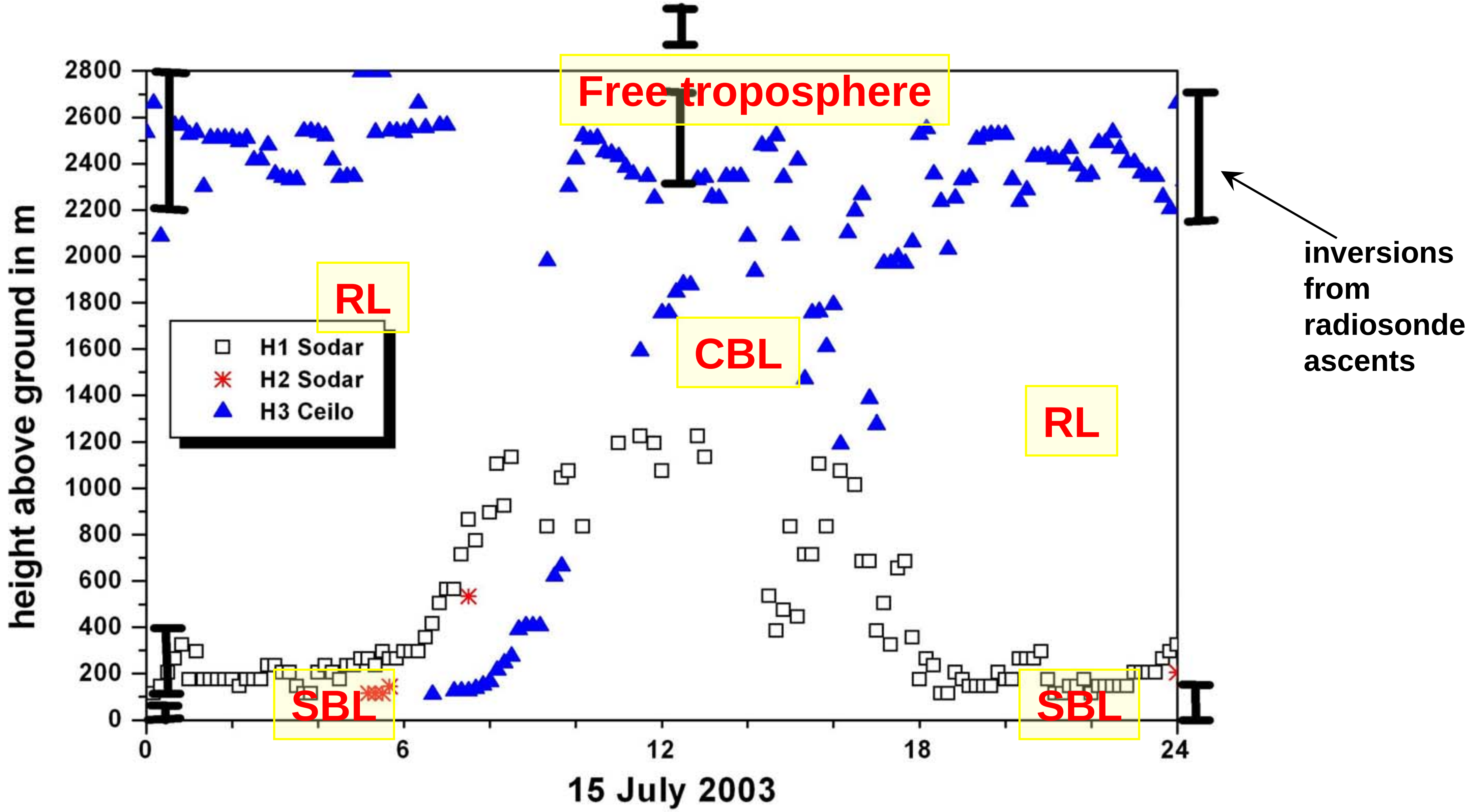
CBL:

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,

Example for the joint operation of a SODAR and two ceilometers (LD40 and CL31 of Vaisala)

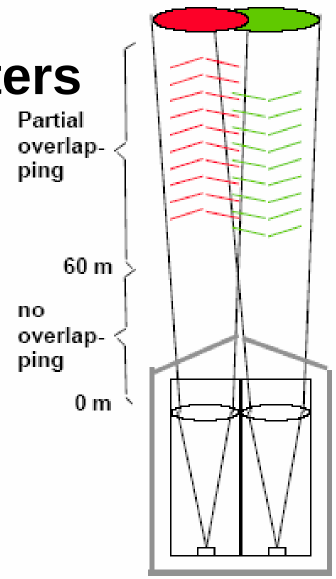
spatial variation of MLH over Augsburg (town with 250 000 inhabitants in Germany)

(measurement campaign in Augsburg since winter 2006/07)

(cooperation with University of Augsburg, Helmholtz Centre Munich (health impact research), State Environmental Agency of Bavaria, City of Augsburg)

comparison of the two ceilometers

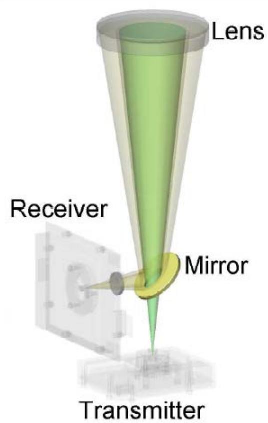
LD40



two optical axes

- **wave length: 855 nm**
- **height resolution: 7.5 m**
- **max. range: 13000 m**

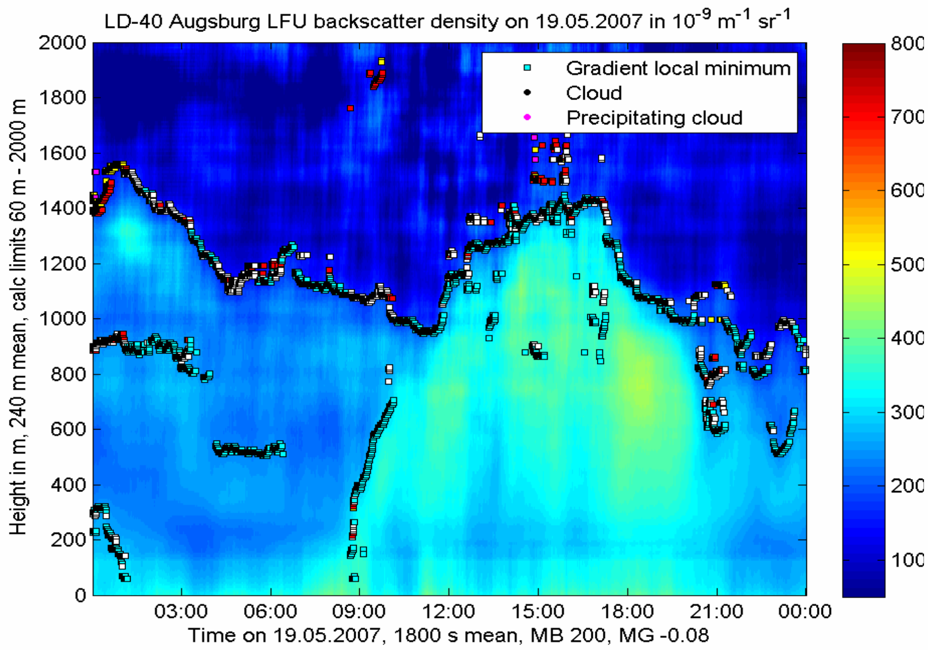
CL31

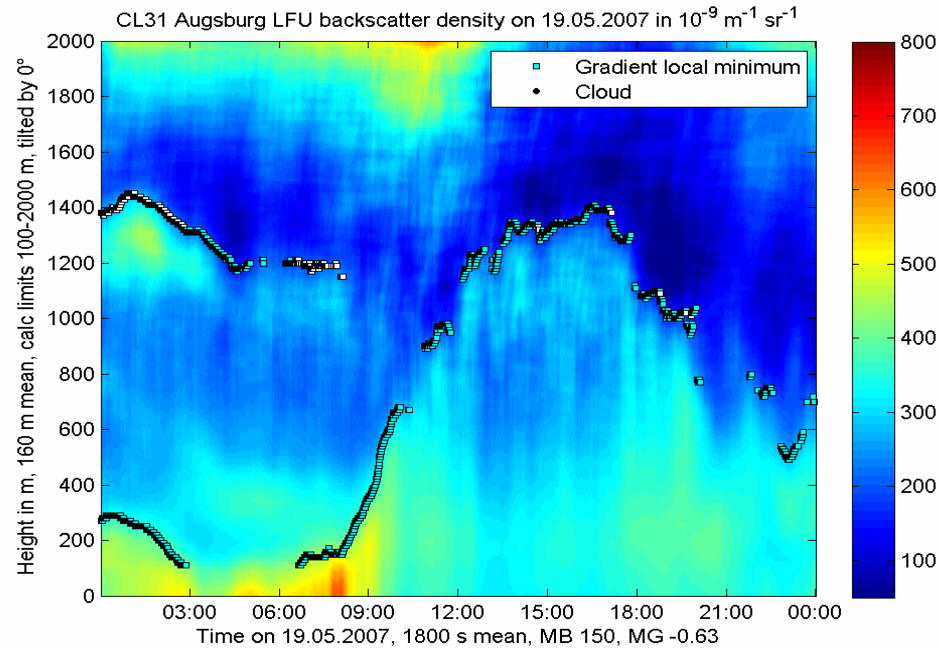


one optical axis

- **wave length: 905 nm**
- **height resolution: 5 m**
- **max. range: 7500 m**

19 May 2007: ceilometer LD40 and CL31





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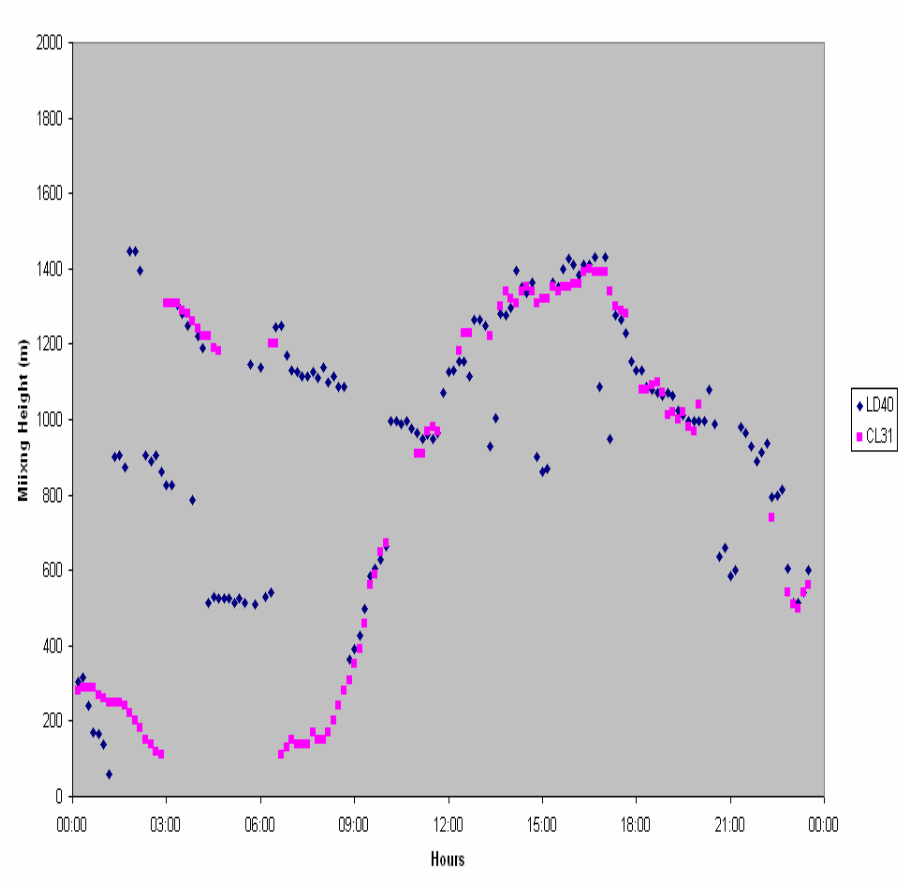
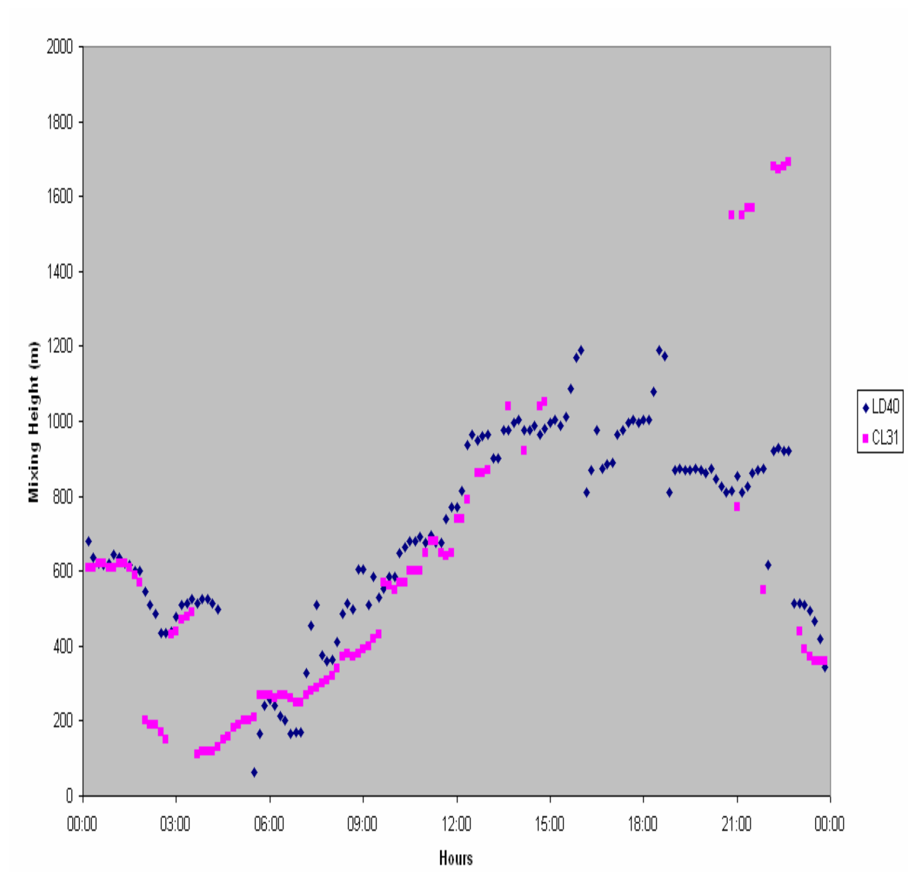
comparison of MLH from LD40 and CL31 data



19 May 2007



20 May 2007

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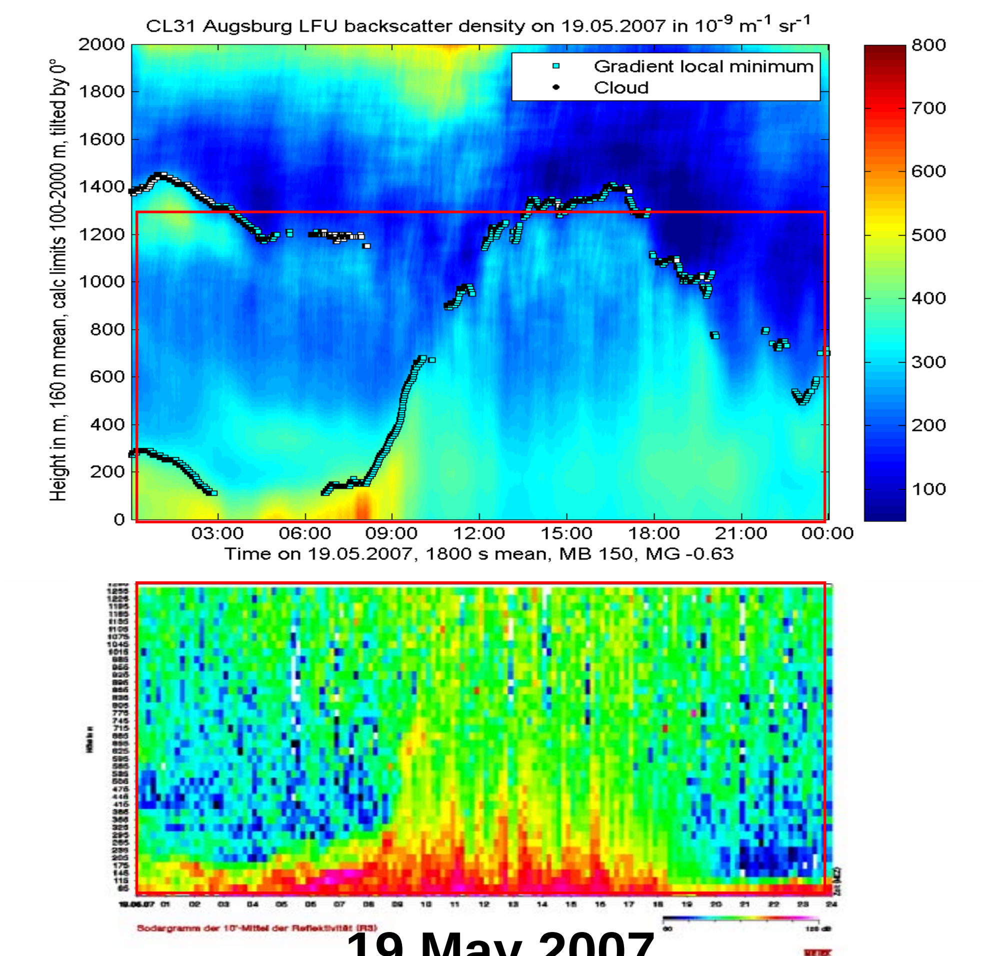
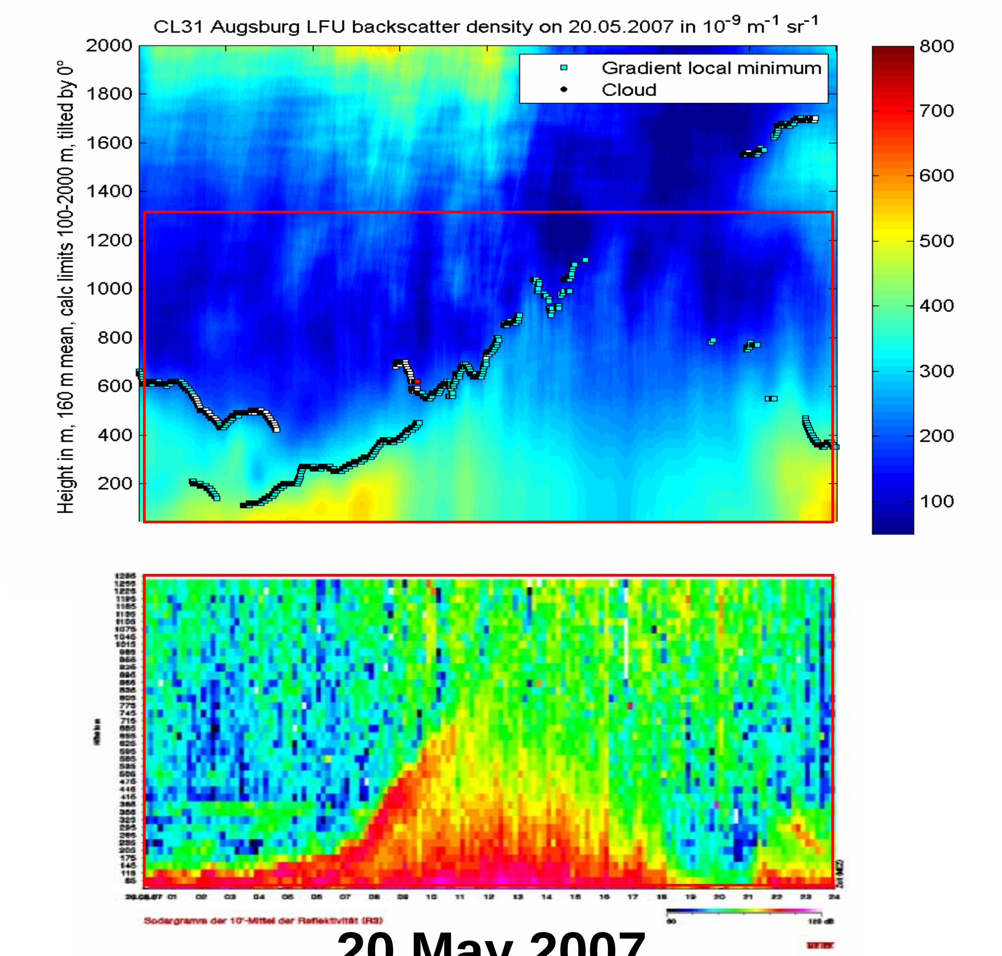
comparison of optical (top) and acoustic (below) backscatter intensity

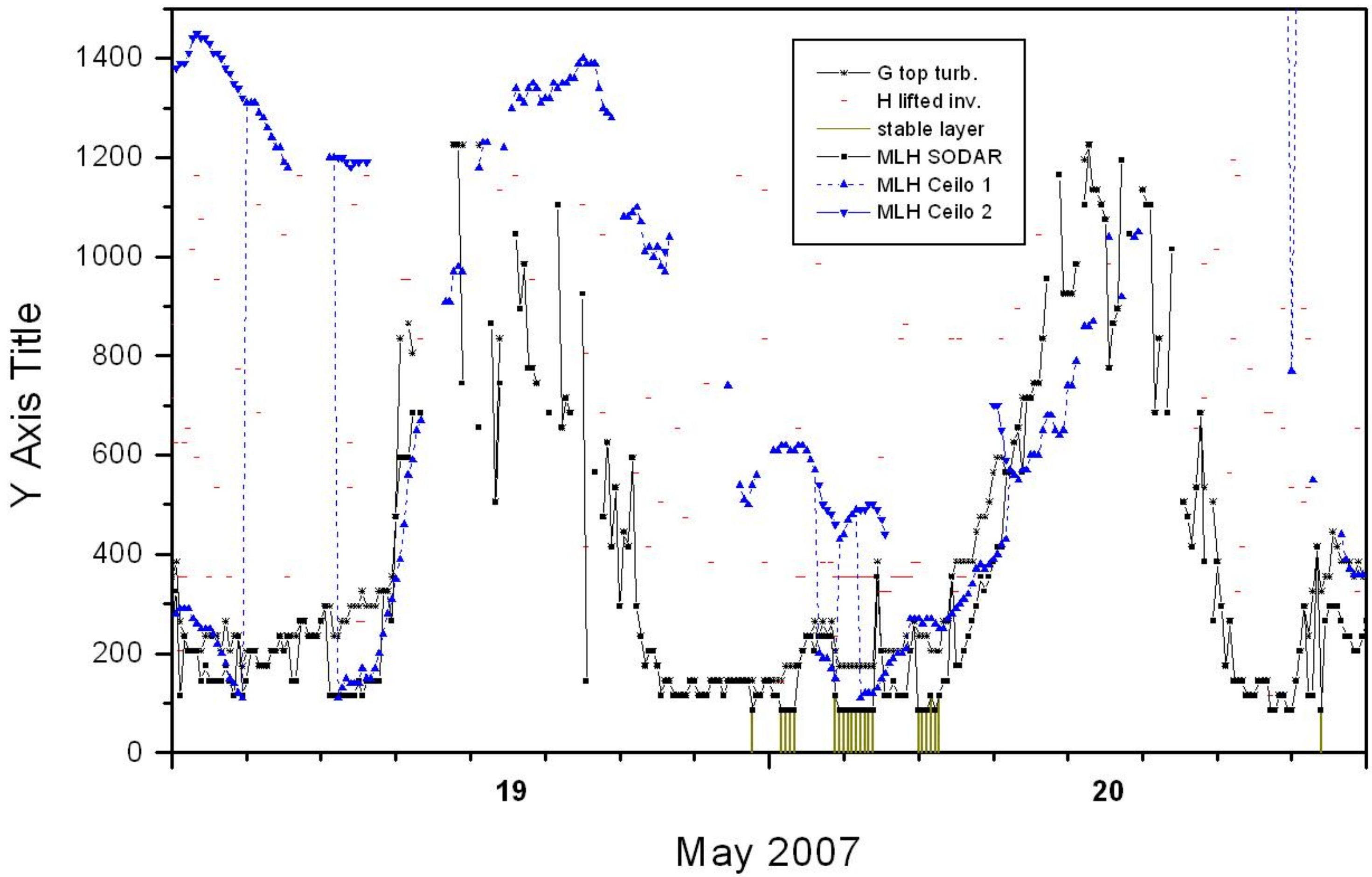


19 May 2007



20 May 2007

comparison of MLH from Sodar and CL31 data



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Example for the operation of a ceilometer near a tropical city (LD40 of Vaisala)

variation of MLH in the Chalco valley southeast of Mexico City

measurement campaign in Tenango del Aire (near Mexico City)
March 2006

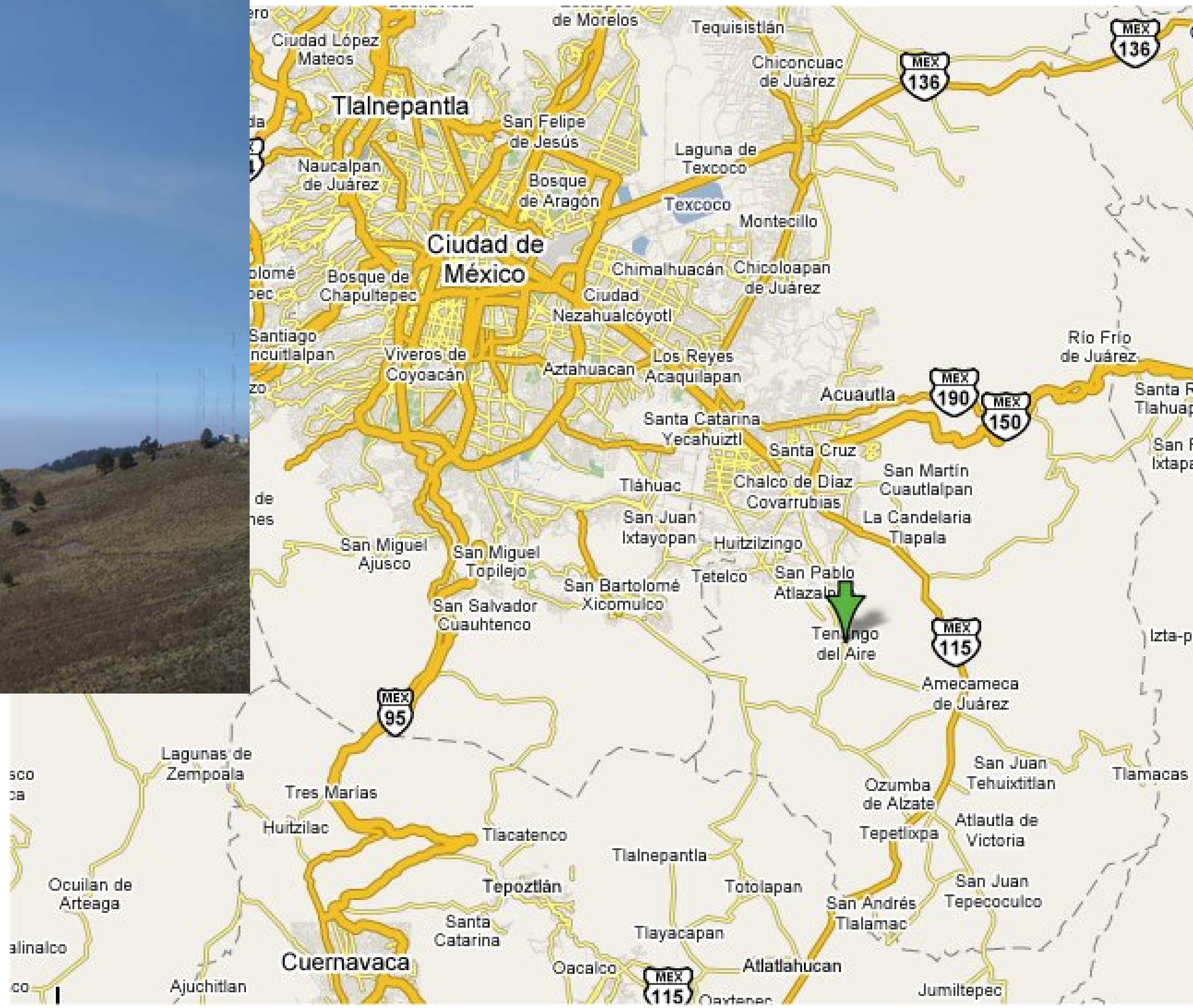
(cooperation with the Centro de Ciencias de la Atmosfera (CCA) of the Universidad Nacional Autonoma de México (UNAM)
within the MIRAGE MEX project)

Measurement Period: 05.03.2006 – 01.04.2006

Location: Tenango del Aire, Mexico

Coordinates: 19°.1561 N – 98°.8642 W

Altitude: 2377 m asl



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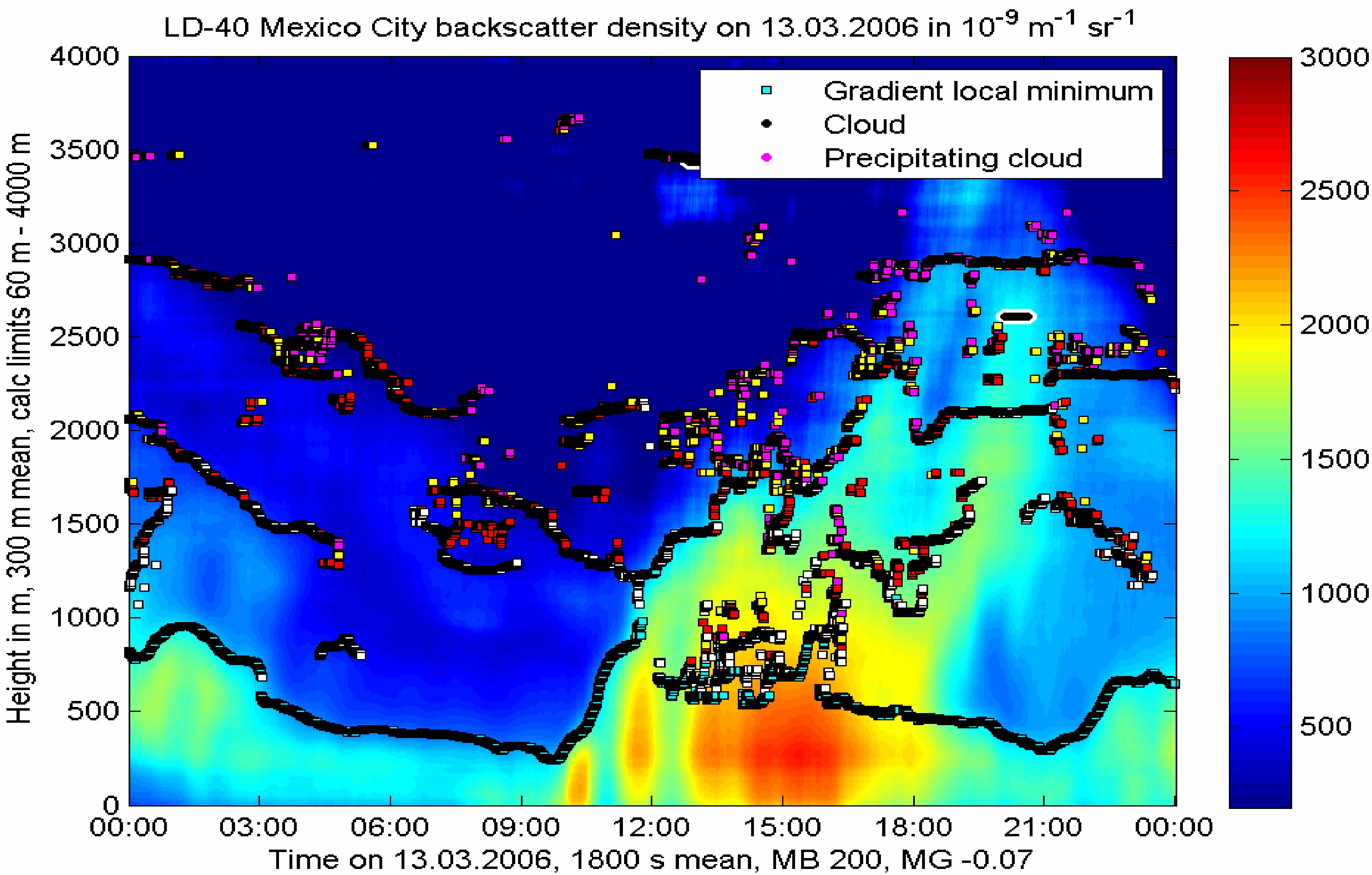
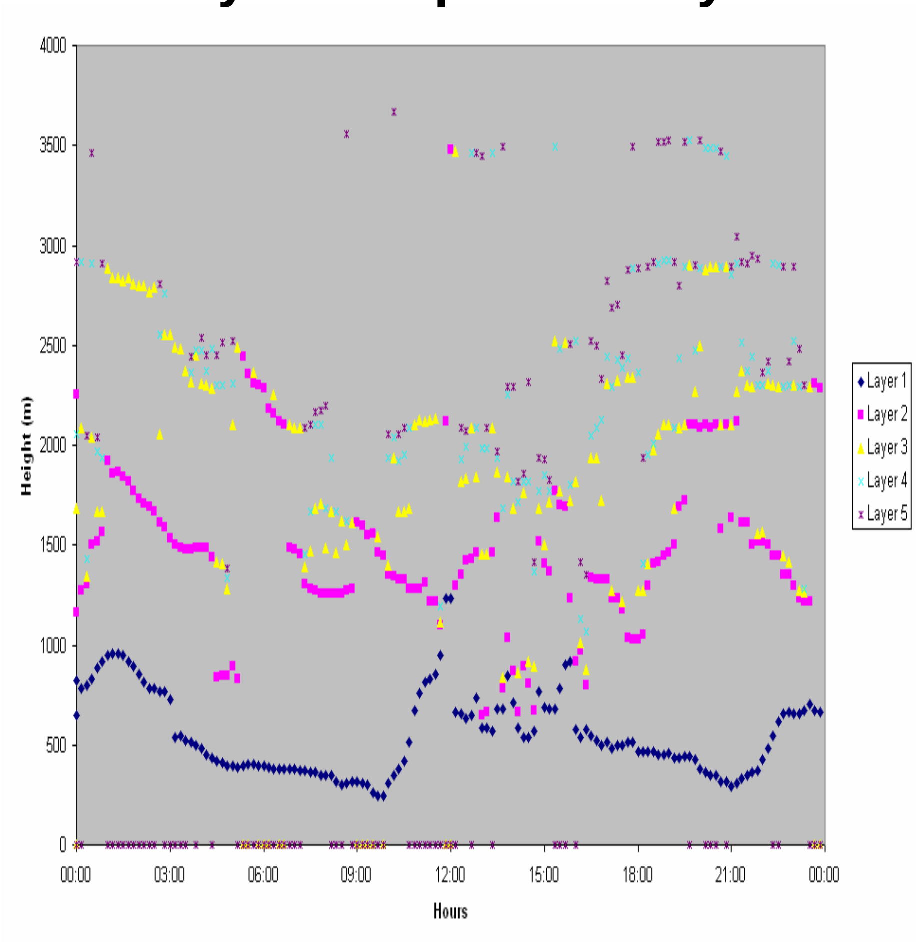
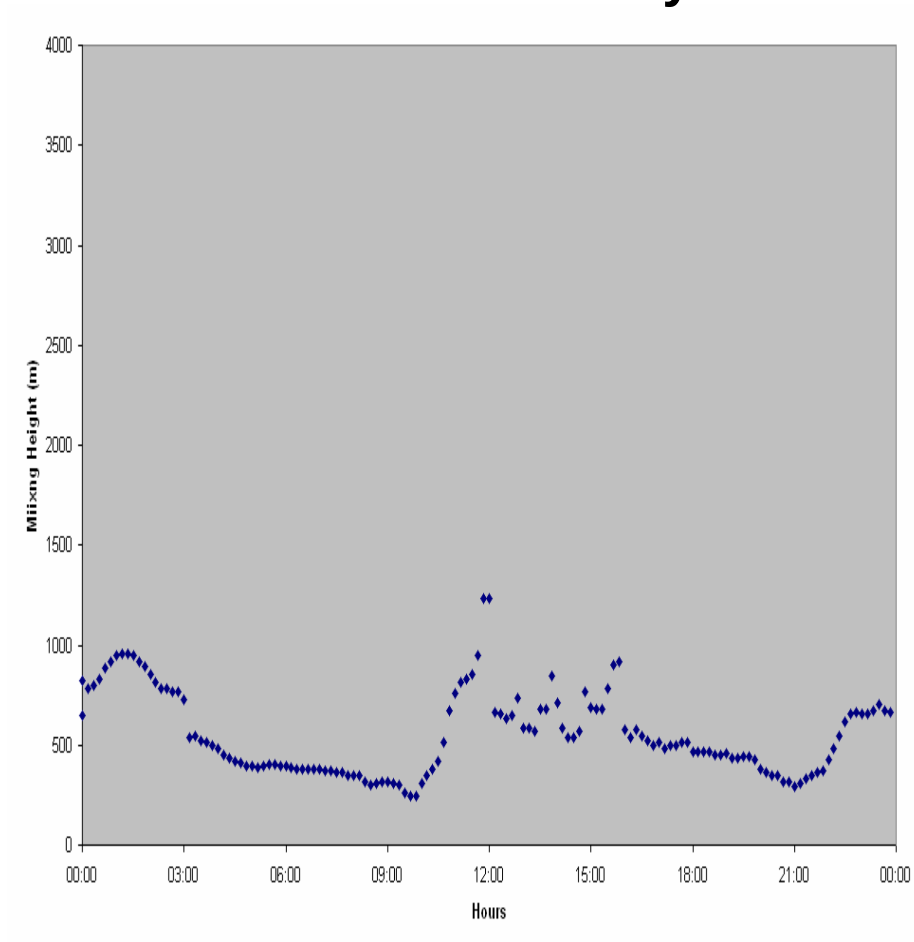

LD-40 Mexico City backscatter density on 13.03.2006 in 10^{-9} m^{-1} sr^{-1}
Gradient local minimum
Cloud
Precipitating cloud
Height in m, 300 m mean, calc limits 60 m - 4000 m
Time on 13.03.2006, 1800 s mean, MB 200, MG -0.07
4000
3500
3000
2500
2000
1500
1000
500
0
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
3000
2500
2000
1500
1000
500

Analysis of up to five layers



MLH: i.e. lowest layer



Example for the correlation between MLH and air quality

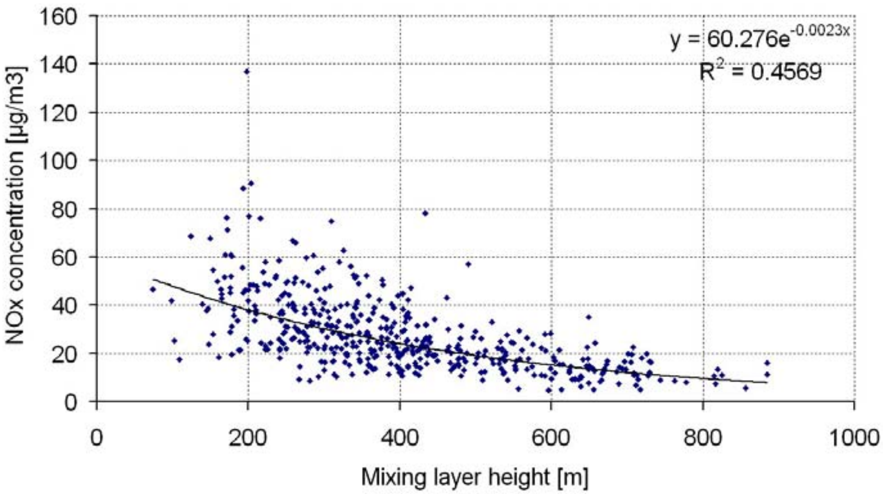
autumn 2001 until spring 2003 Hannover (town in Northern Germany)

(VALIUM-campaign)

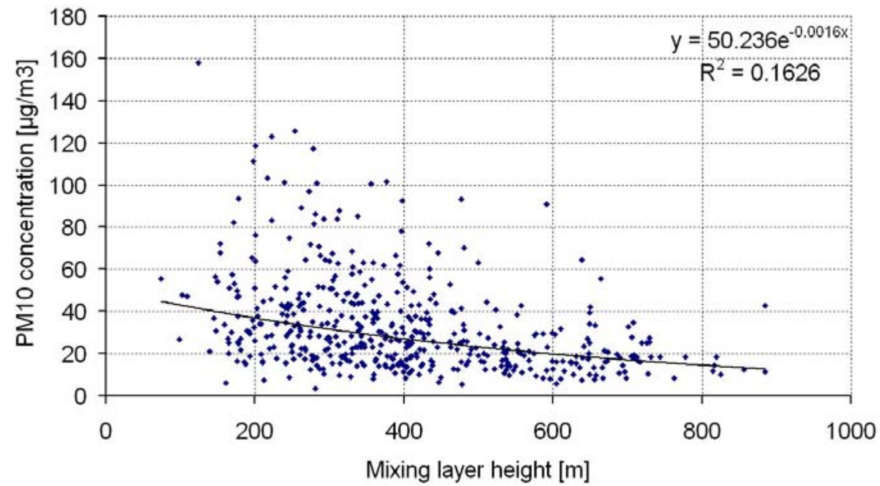
(VALIUM was a project within the German national research programme AFO2000 funded by the Ministry of Research (BMBF) under contract 07ATF12)

correlation at roof-top level pollutant - MLH

October 2001 - April 2003



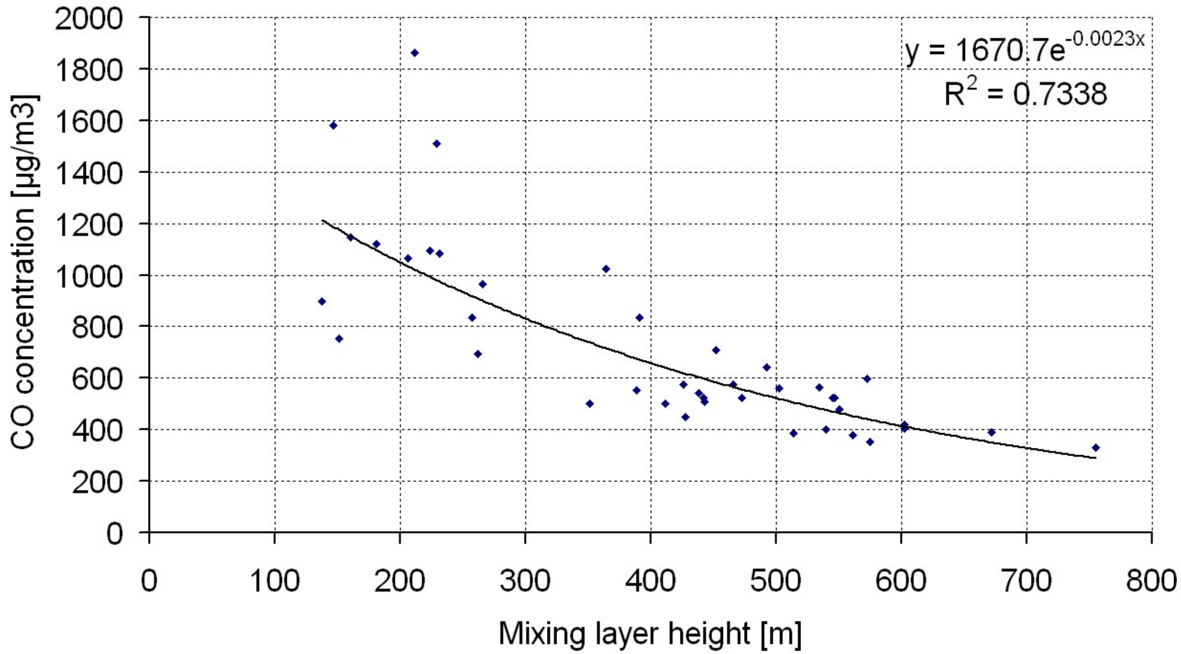
NO_x



PM_{10}

Schäfer, K., S. Emeis, H. Hoffmann, C. Jahn, 2006: Influence of mixing layer height upon air pollution in urban and sub-urban areas. Meteorol. Z., 15, 647-658.

correlation at street level pollutant - MLH



CO

Schäfer, K., S. Emeis, H. Hoffmann, C. Jahn, 2006: Influence of mixing layer height upon air pollution in urban and sub-urban areas. Meteorol. Z., 15, 647-658.

Conclusions

Joint operation of acoustic and optical remote sensing is suitable for the detection of the structure of the urban BL

knowledge of MLH is an important parameter for the assessment and forecast of air quality

knowledge of MLH is an important parameter for the estimation of emission source strengths from concentration measurements

knowledge of MLH is an important parameter for the conversion of aerosol-optical depths in near-surface air quality parameter

future climate change influences MLH and thus the quality of living in large cities

Outlook

Near future activities of the group

Mexico Workshop, May 19-21, 2008

BILATERAL WORKSHOP ON AIR QUALITY, CLIMATE CHANGE AND HEALTH IN CENTRAL MEXICO (planned as side activity of the visit of the German Woman Chancellor Dr. Angela Merkel in Mexico City)

KIT
Karlsruhe Institute of Technology

Objectives:

- Sustainable and trend setting development
- Characterizing of risks, driving factors and consequences
- Development of strategies and instruments for risk management
- Integration of science and experience
- Implementation of solutions

Risk Habitat Megacity

¿sostenibilidad en riesgo?

A Helmholtz Research Initiative 2007 - 2013

Risk Habitat Megacities: Santiago Status conference, June 2-6, 2008

General outlook

- Environmental issues need an holistic approach
- In order to understand the system, further process studies have to be done in each discipline
- Link between energy consumption, transportation, air quality and health demonstrates the interaction and tackles central problems in a megacity
- Air quality and health impact assessment studies are essential prerequisites for mitigation and adaptation strategies and for reducing e.g.
  - environmental risks (air pollution, congestion, waste, ...)
  - social risks (spatial segregation, health problems, …)
  - costs (healthcare system, transportation, production, ...)
- Impact of Climate Change

- Santiago de Chile, a.o.
  - Investigation of traffic emissions and their impact on air quality and health
  - Mitigation and adaptation strategies
- Mexico City, a.o.
  - Impact of Climate Change on air quality
  - Impact of land use changes
- Beijing, a.o.
  - Climate Change and air quality
  - urban – regional relations
- Munich/Augsburg, Germany
  - Process studies

(measurements with sodar, ceilometer, RASS, model studies)

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Thank you very much for your attention

Large SODAR
of IMK-IFU
(METEK DSDR3x7)

frequency: 1500 Hz
range: 1300 m
resolution: 20 m
lowest
range gate: ca. 60 m

size of instrument:

height: 4 m
width: 1,50 m
length: 10 m
weight: 8 t

Reitebuch, O. und S. Emeis, 1998: SODAR-measurements for atmospheric research and environmental monitoring. Meteorologische Zeitschrift, N. F., 7, 11-14.

ceilometer

about 1 m in size

normally mounted vertically

emits radiation at 0.7 µm (eyesafe)