Vertical structure and properties of the atmospheric boundary layer over cities (heat islands, wind speeds and turbulence profiles, mixing-layer heights) which should be represented in urbanised numerical model systems

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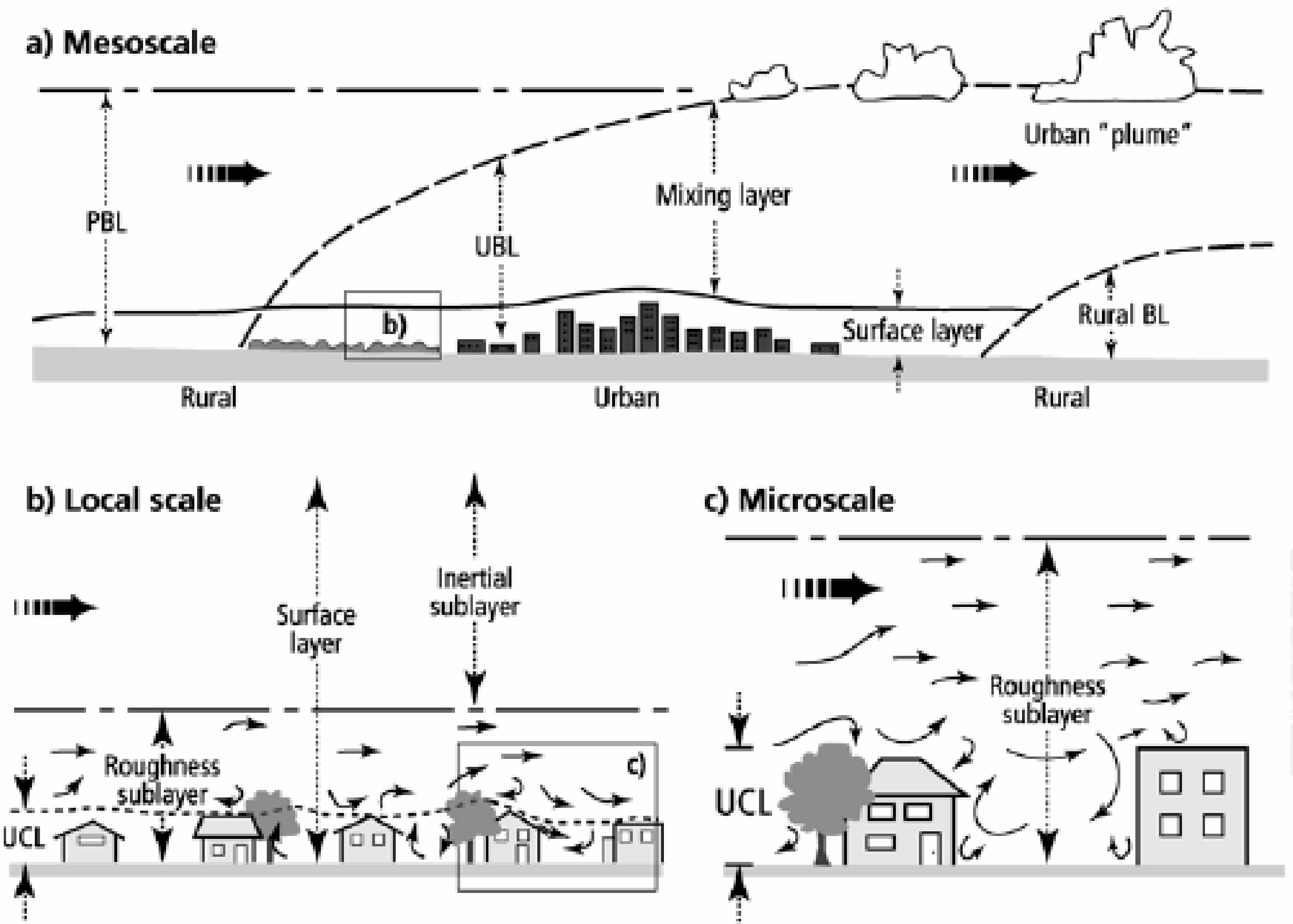
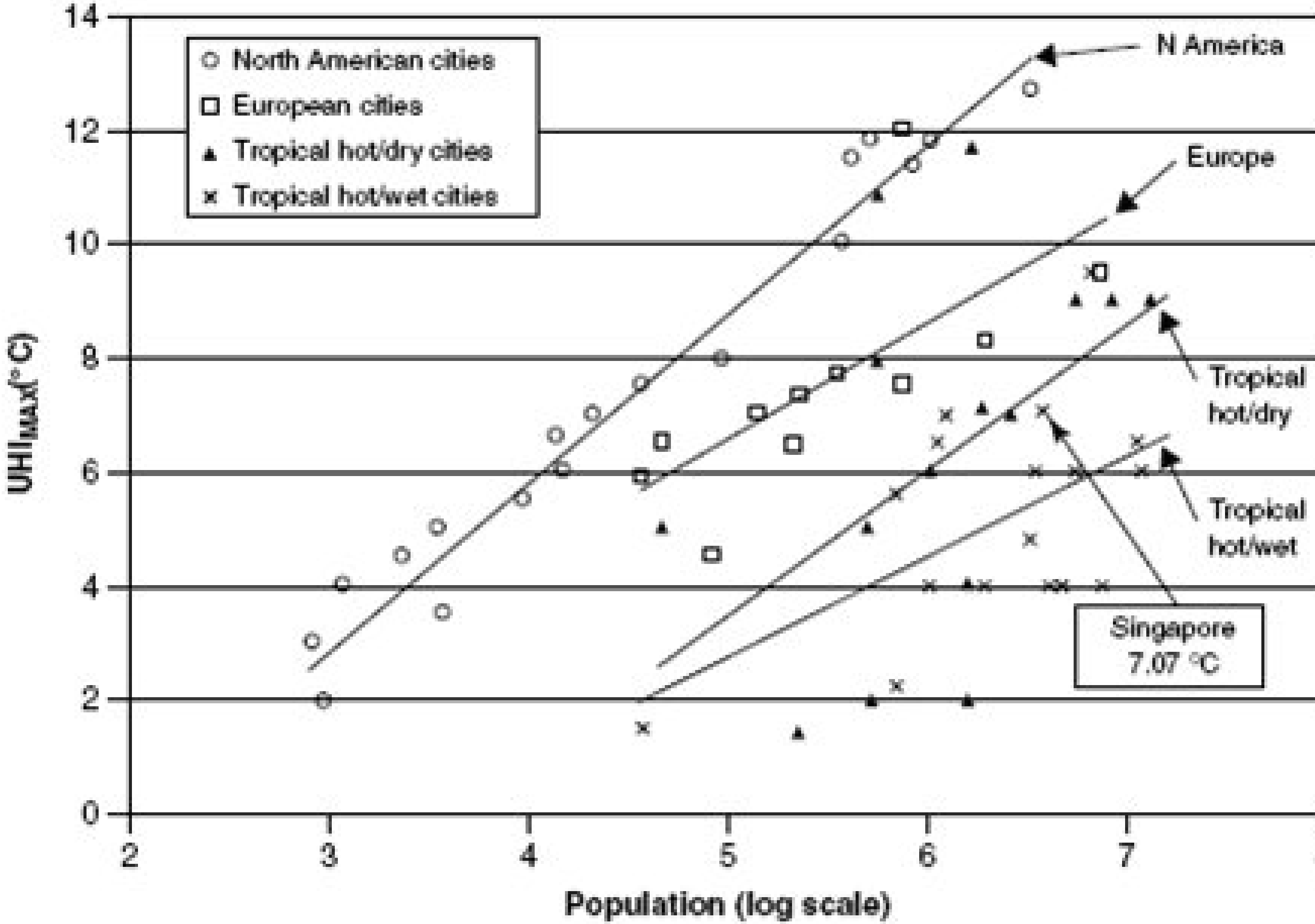
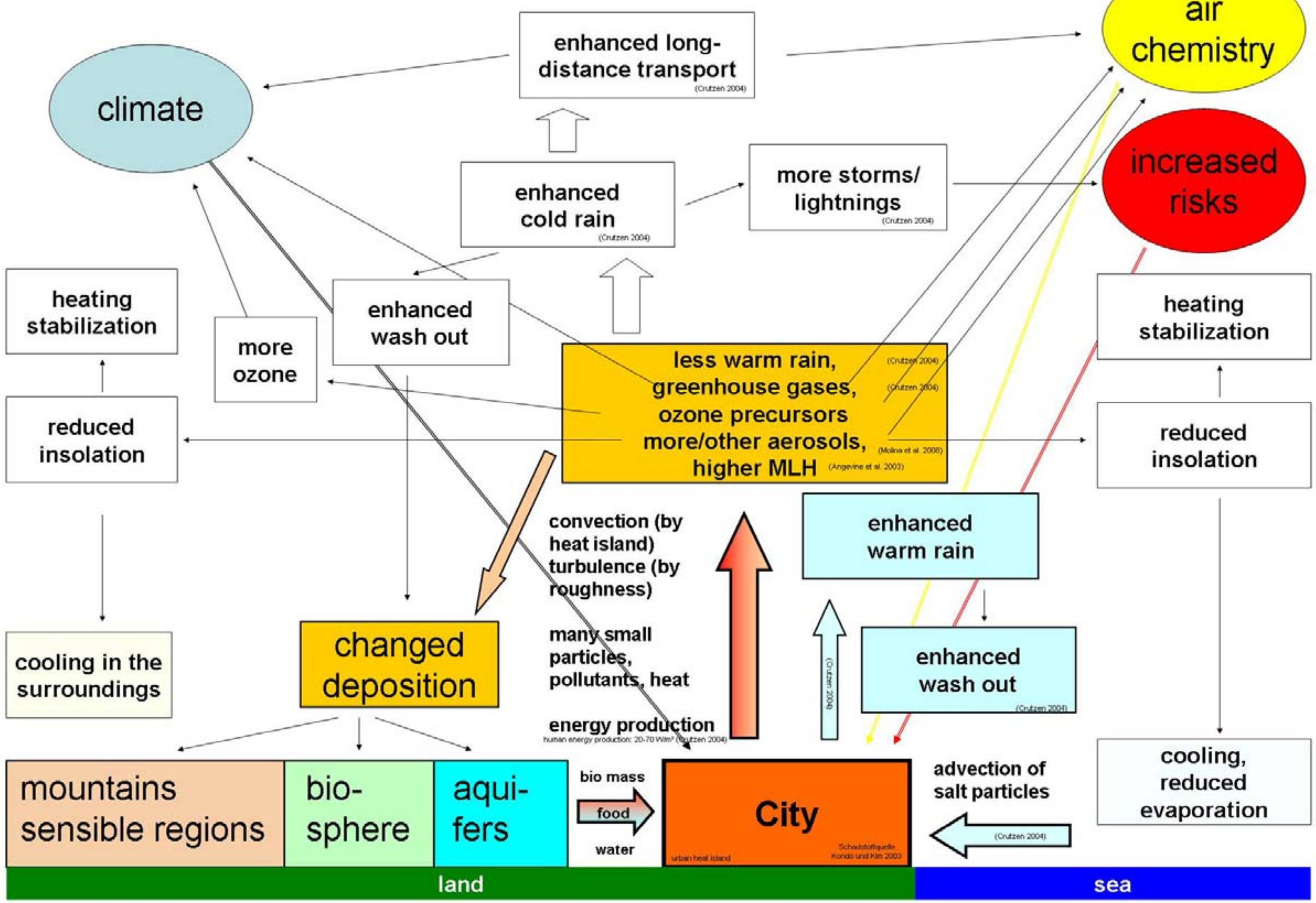


Figure 1. Schematic of the urban boundary layer including its vertical layers and scales. 'UBL' stands for Urban Boundary Layer, and 'UCL' for Urban Canopy Layer (revised by Oke and Rotach after a figure in Oke, 1997).



Chow, W.T.L., M. Roth, 2006: Temporal dynamics of the urban heat island of Singapore. Int. J. Climatol., **26**, 2243-2260.

A city and its regional interrelations due to climate change and anthropogenic energy production



several options for ground-based remote sensing of the urban BL

acoustic remote sensing (SODAR)	**wind profiles**
	turbulence profiles
(max. range: about 1000 m)	**inversions**
optical remote sensing (ceilometer)	**particle distribution profiles**
	(inversons)
(max. range: several km)	
radio-acoustic remote sensing (RASS)	**temperature profiles**
(max. range: several hundreds of metres)	

acoustic remote sensing

Large SODAR
of IMK-IFU
(METEK DSDR3x7)

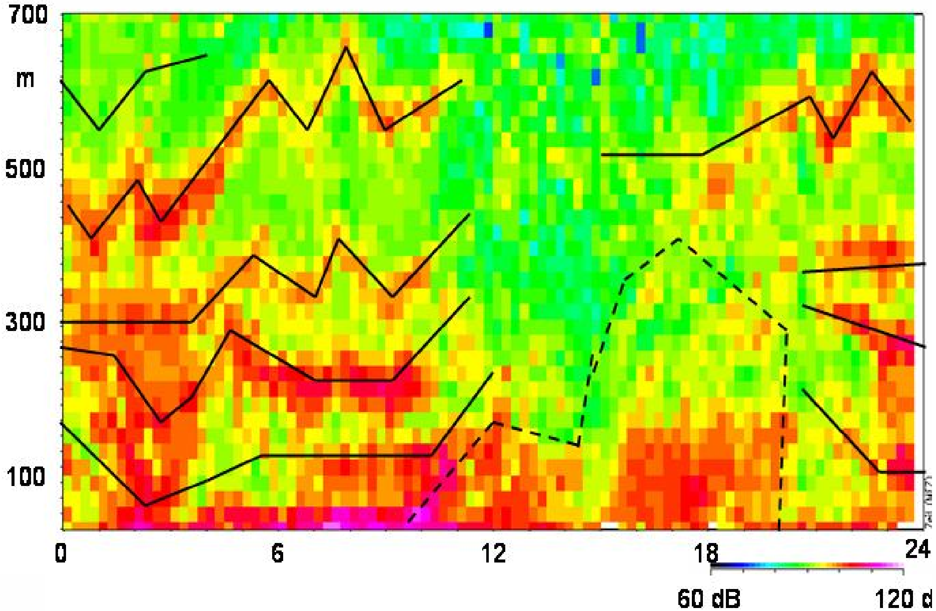
frequency: 1500 Hz
range: 1300 m
resolution: 20 m
lowest
range gate: ca. 60 m

size of instrument:

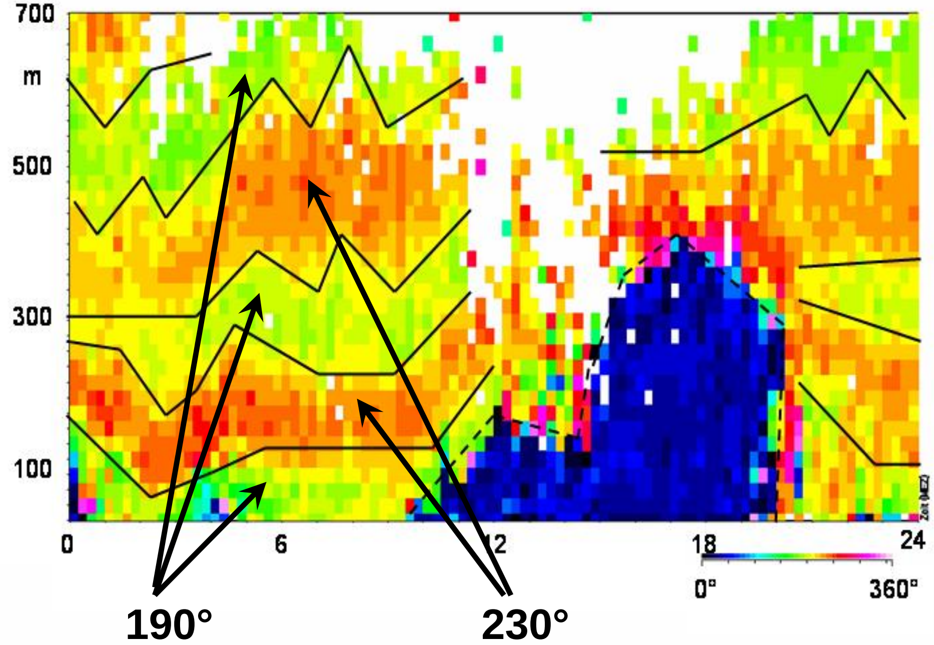
height: 4 m
width: 1,50 m
length: 10 m
weight: 8 t

SODAR measurements in a wintry Alpine valley

29 January 2006



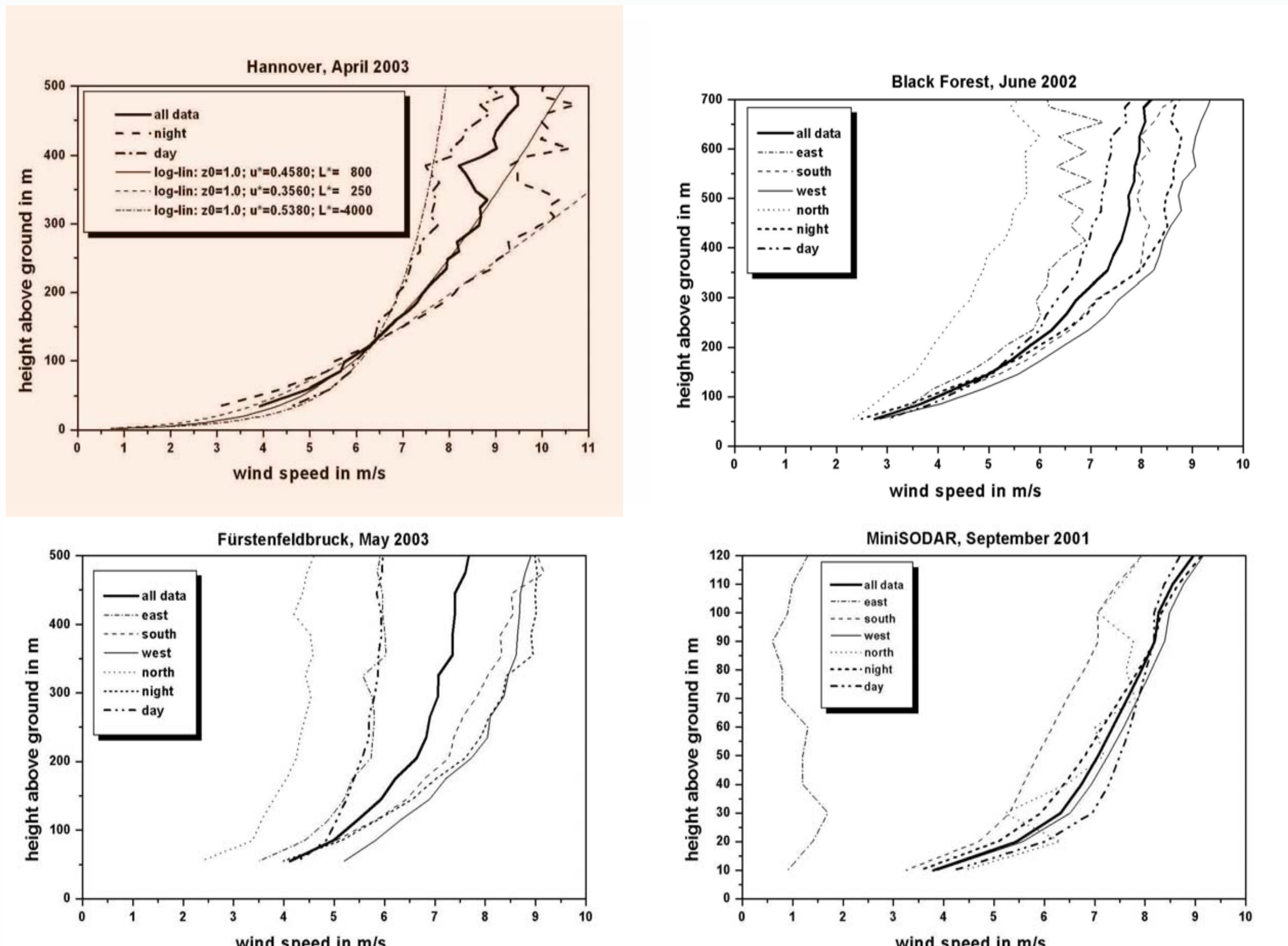
backscatter intensity



wind direction

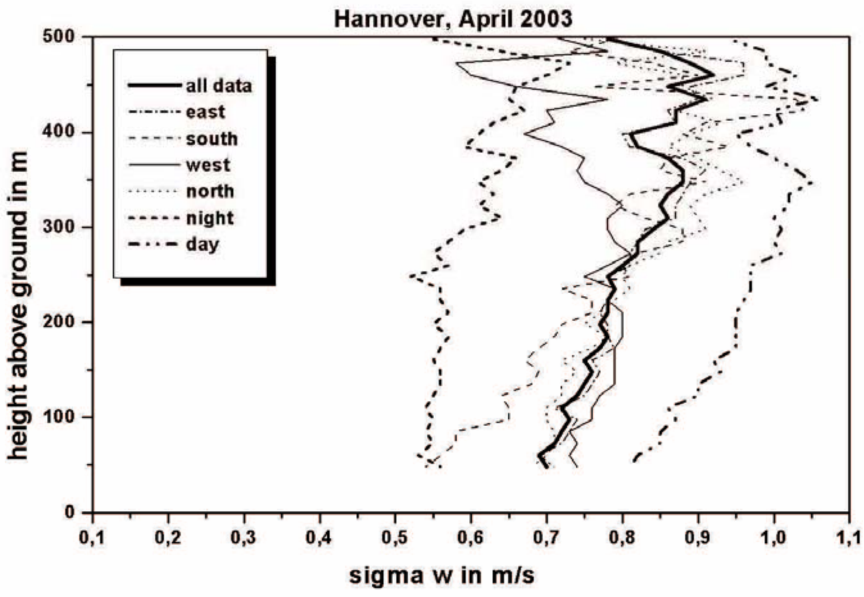
Emeis, S., C. Jahn, C. Münkel, C. Münsterer, K. Schäfer, 2007:
Multiple atmospheric layering and mixing-layer height in the Inn valley observed by remote sensing. Meteorol. Z., **16**, 415-424.

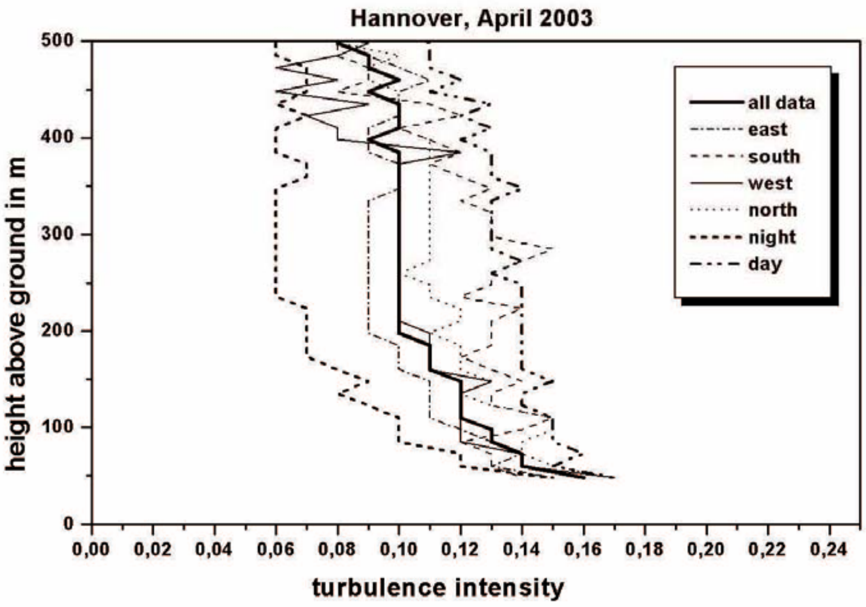
Monthly mean vertical profile of wind speed



Emeis, S., K. Baumann-Stanzer, M. Piringer, M. Kallistratova, R. Kouznetsov, V. Yushkov, 2007:
Wind and turbulence in the urban boundary layer – analysis from acoustic remote sensing data and fit to analytical relations. Meteorol. Z., **16**, 393-406.

Monthly mean vertical profiles of sigma w (turbulence, left) and turbulence intensity (right)





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Wind and turbulence in the urban boundary layer – analysis from acoustic remote sensing data and fit to analytical relations. Meteorol. Z., **16**, 393-406.

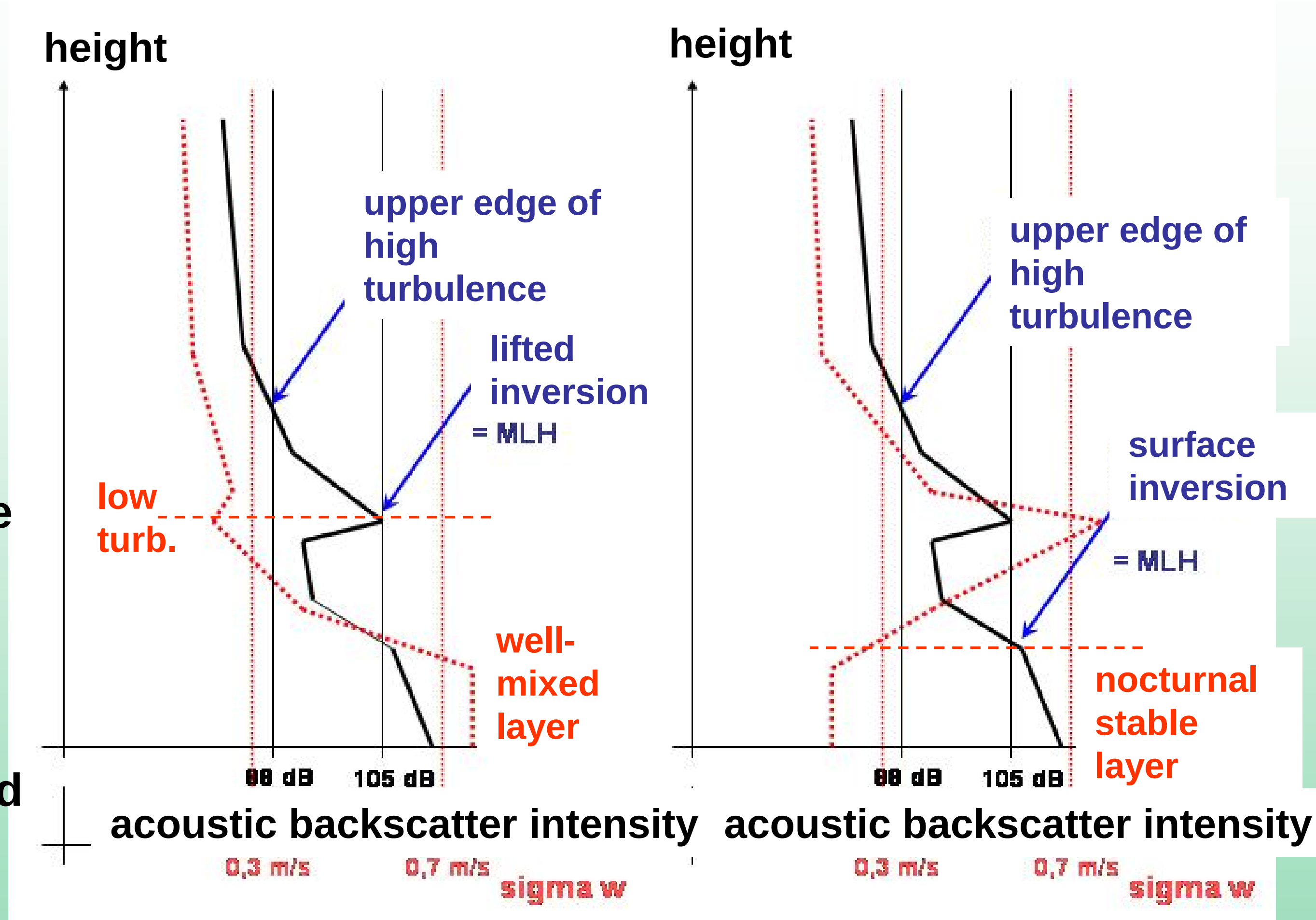
Algorithms to detect MLH from SODAR data

criterion 1:

upper edge of high turbulence

criterion 2:

surface and lifted inversions



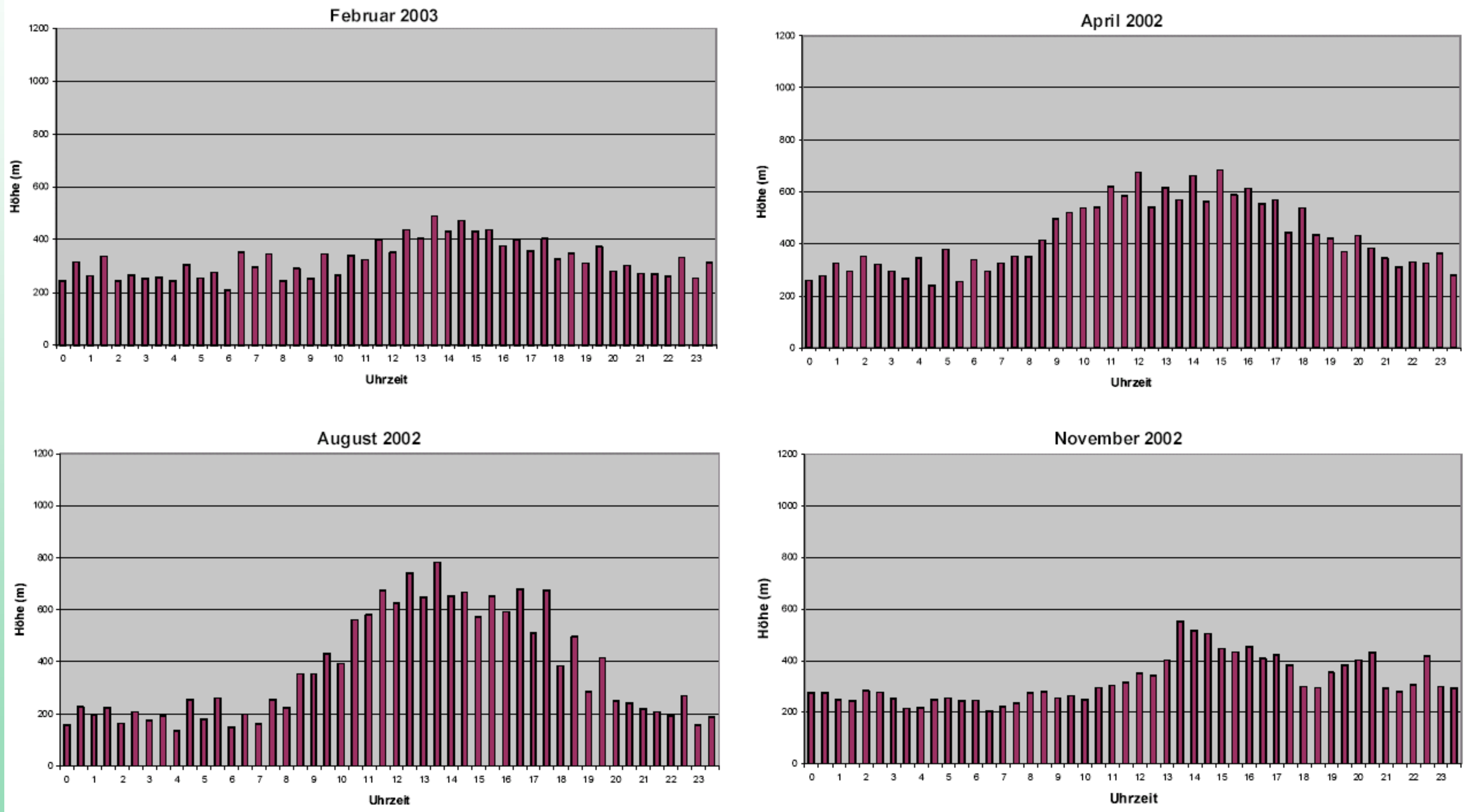
example 1: daytime **example 2: night-time**

MLH = Min (C1, C2)

Emeis, S., C. Jahn, C. Münkel, C. Münsterer, K. Schäfer, 2007:
Multiple atmospheric layering and mixing-layer height in the Inn valley observed by remote sensing. Meteorol. Z., **16**, 415-424.

Monthly mean diurnal courses of mixing-layer height

Hannover, Germany 2002/03



Emeis, S., M. Türk, 2004: Frequency distributions of the mixing height over an urban area from SODAR data. Meteorol. Z., 13, 361-367.

optical remote sensing

Ceilometer

(Vaisala LD40/CL31)

wave length: 855/905 nm
range: 4000 m
resolution: 15 m
lowest
range gate: ca. 30 m (CL31)
ca. 150 m (LD40)

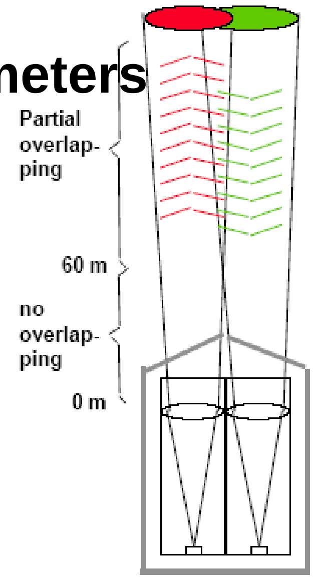
size of instrument:

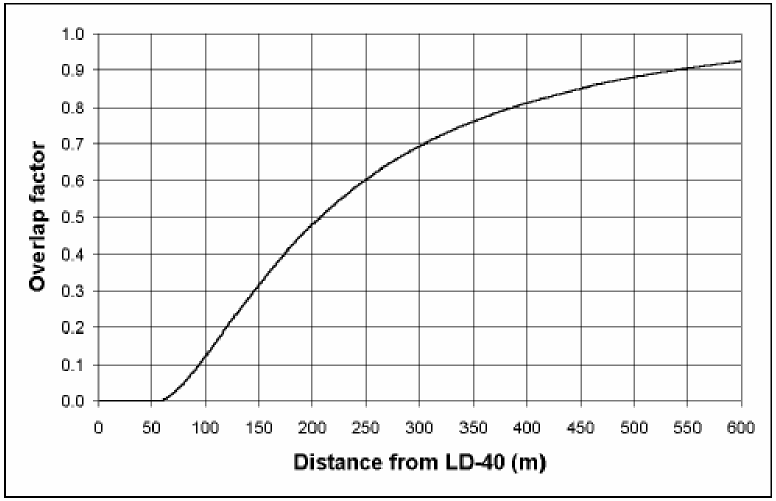
height: 1.2 m
width: 0,50 m

comparison of the two ceilometers

LD40

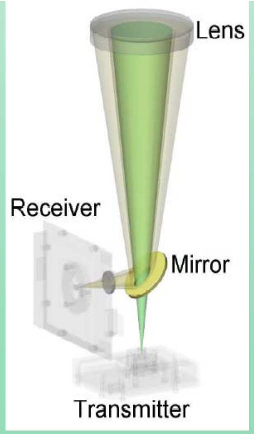
two optical axes
- **wave length: 855 nm**
- **height resolution: 7.5 m**
- **max. range: 13000 m**



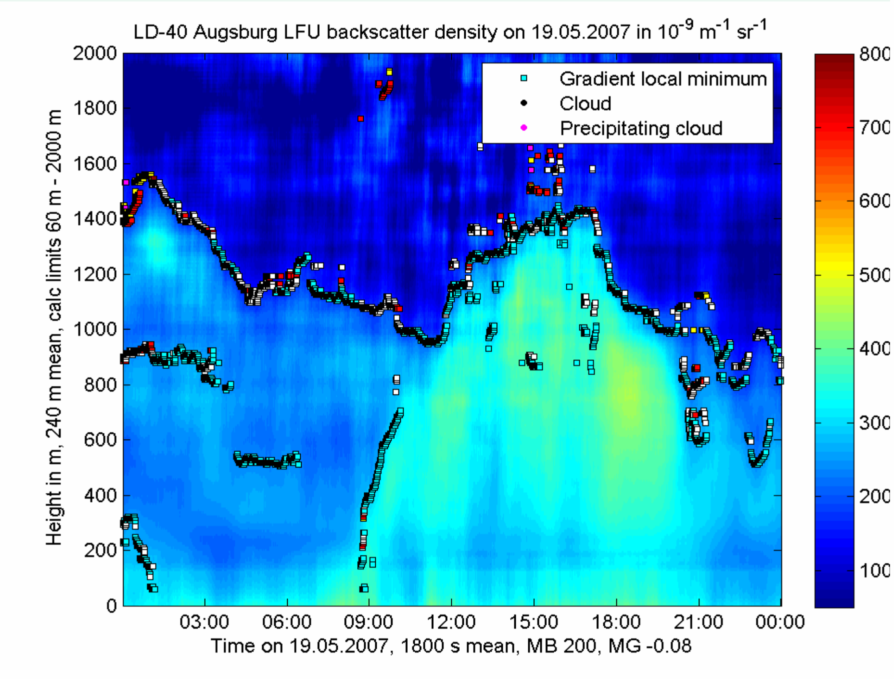


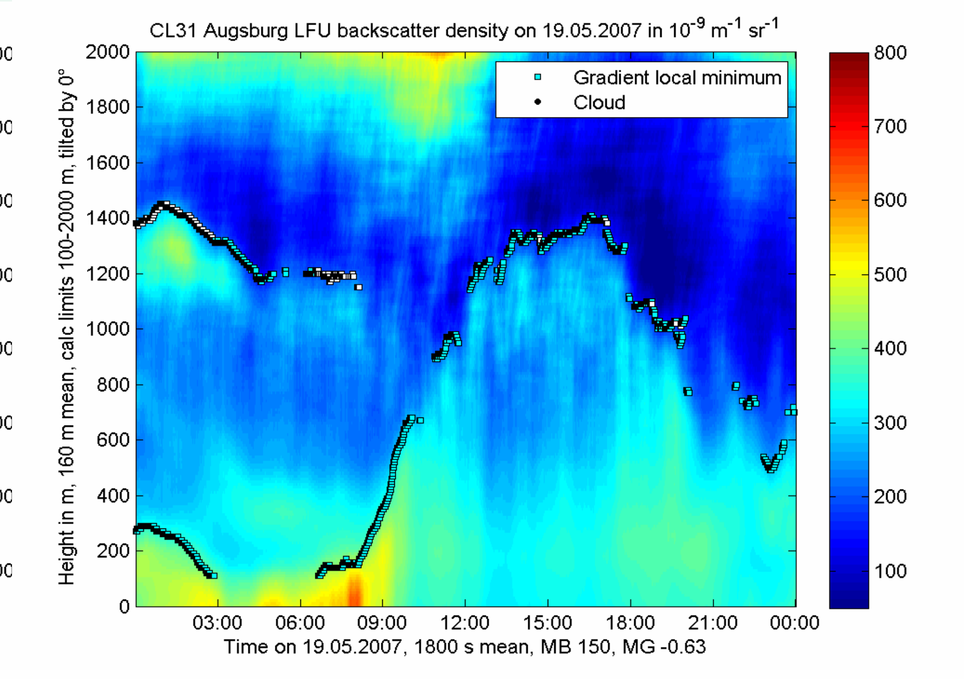
CL31

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



19 May 2007: ceilometer LD40 and CL31

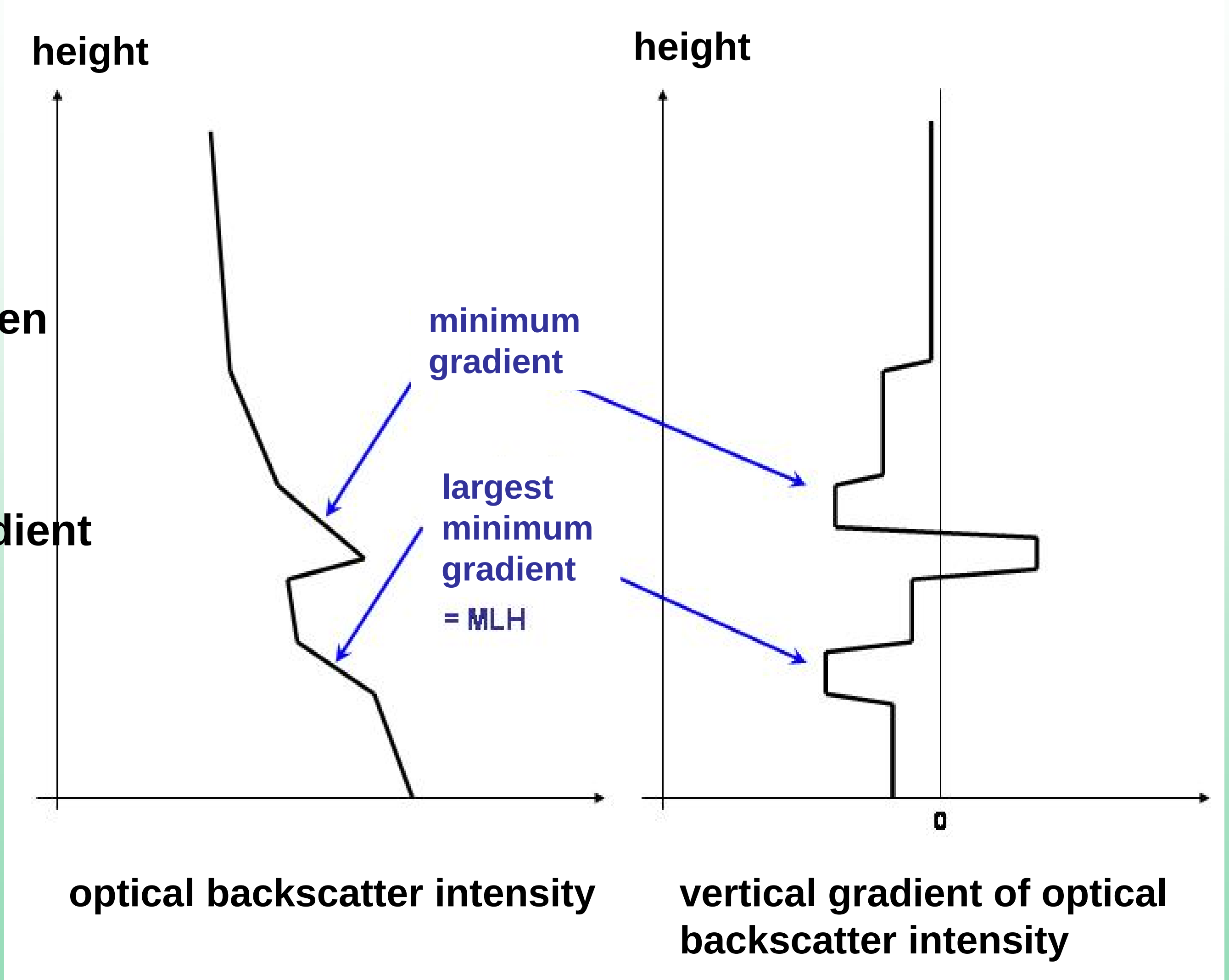




Algorithms to detect MLH from Ceilometer-Daten

criterion

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



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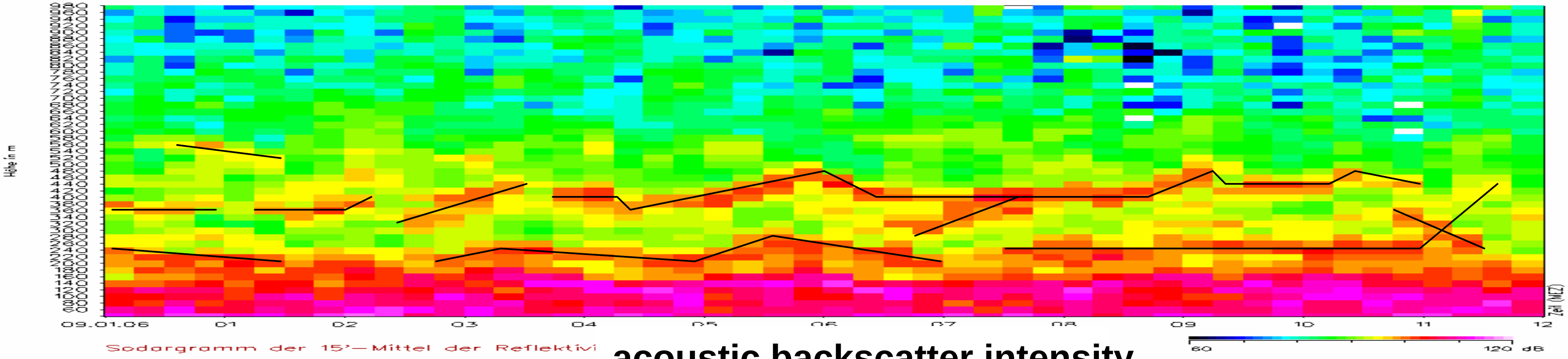
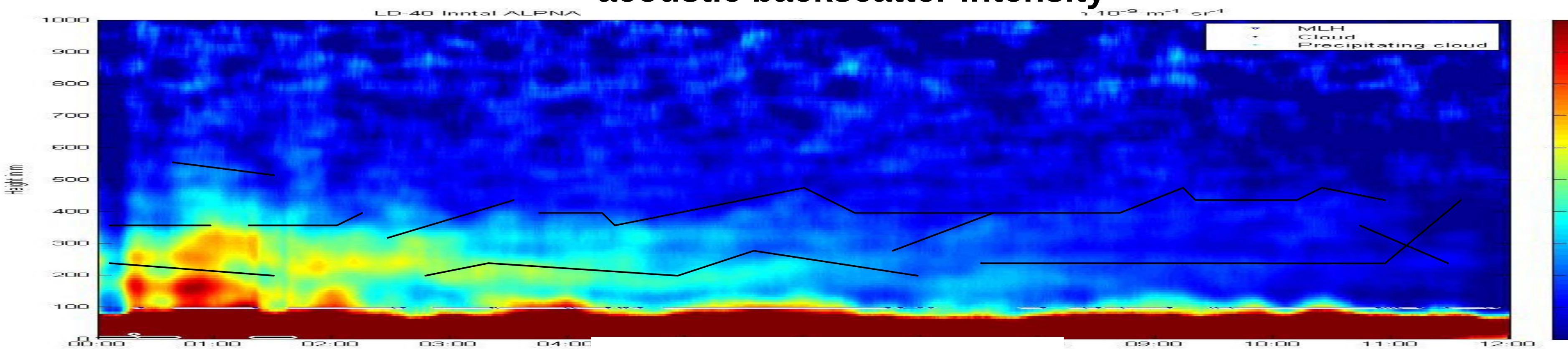
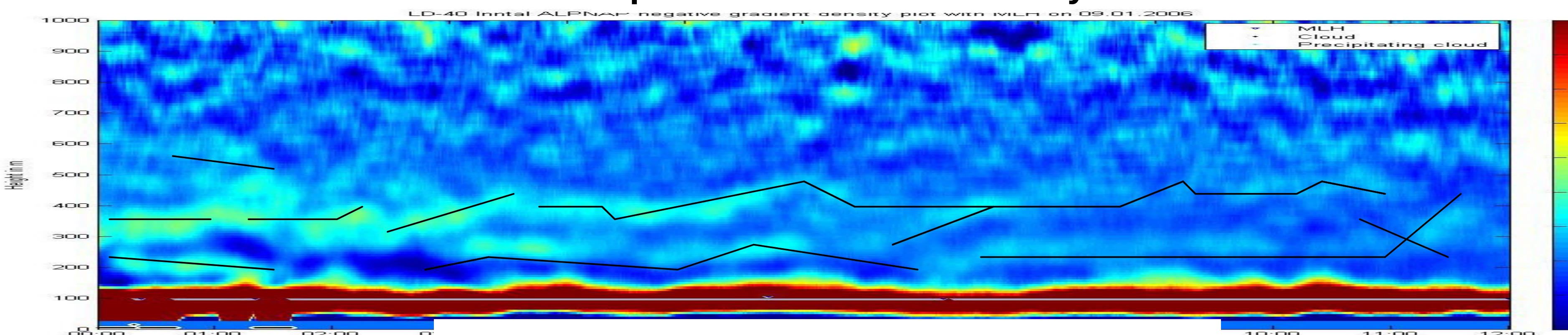


acoustic backscatter intensity



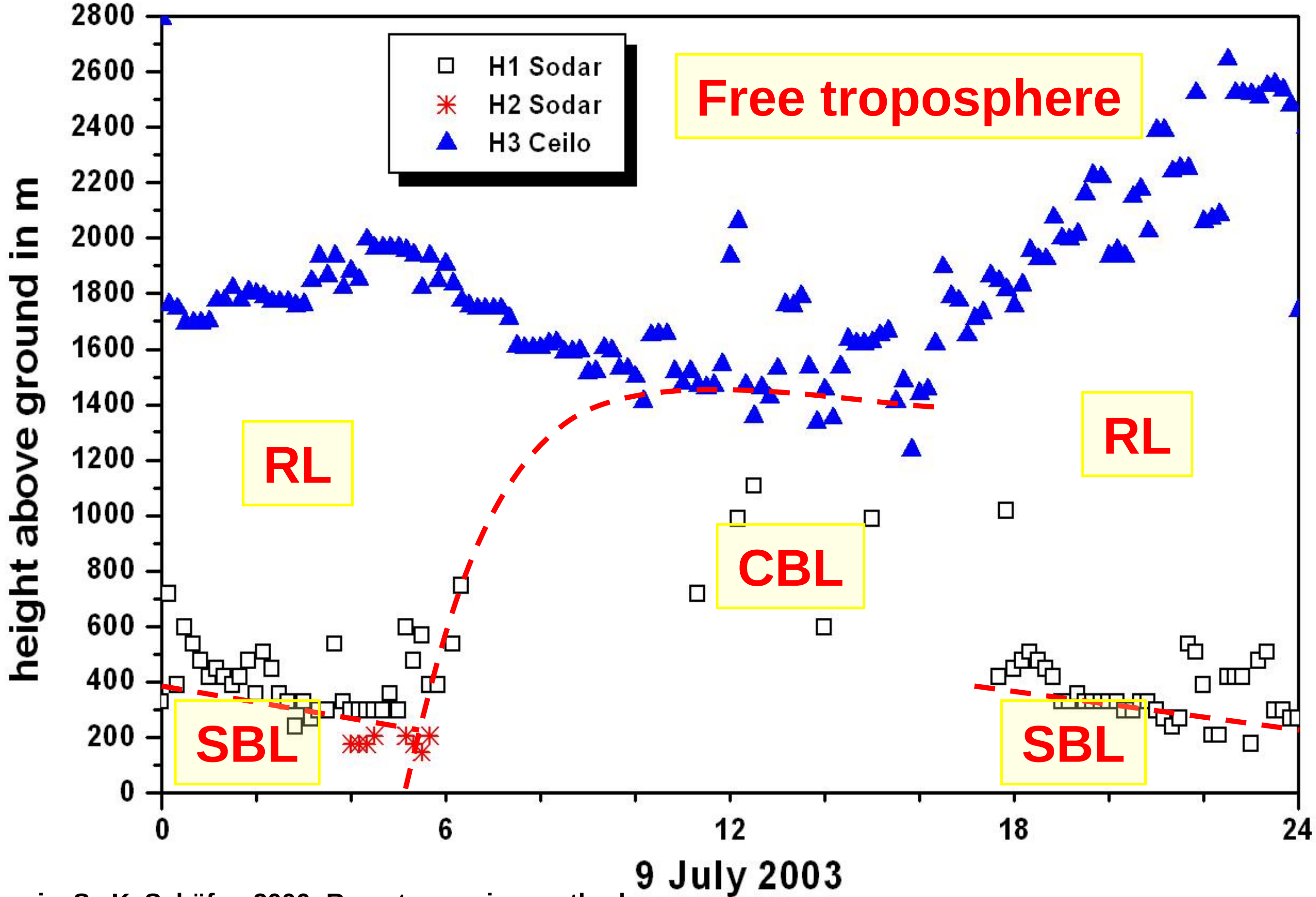
optical backscatter intensity



vertical gradient of optical backscatter intensity

combined acoustic and optical remote sensing

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



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.

SBL:

stable boundary layer (usually at night and in winter)

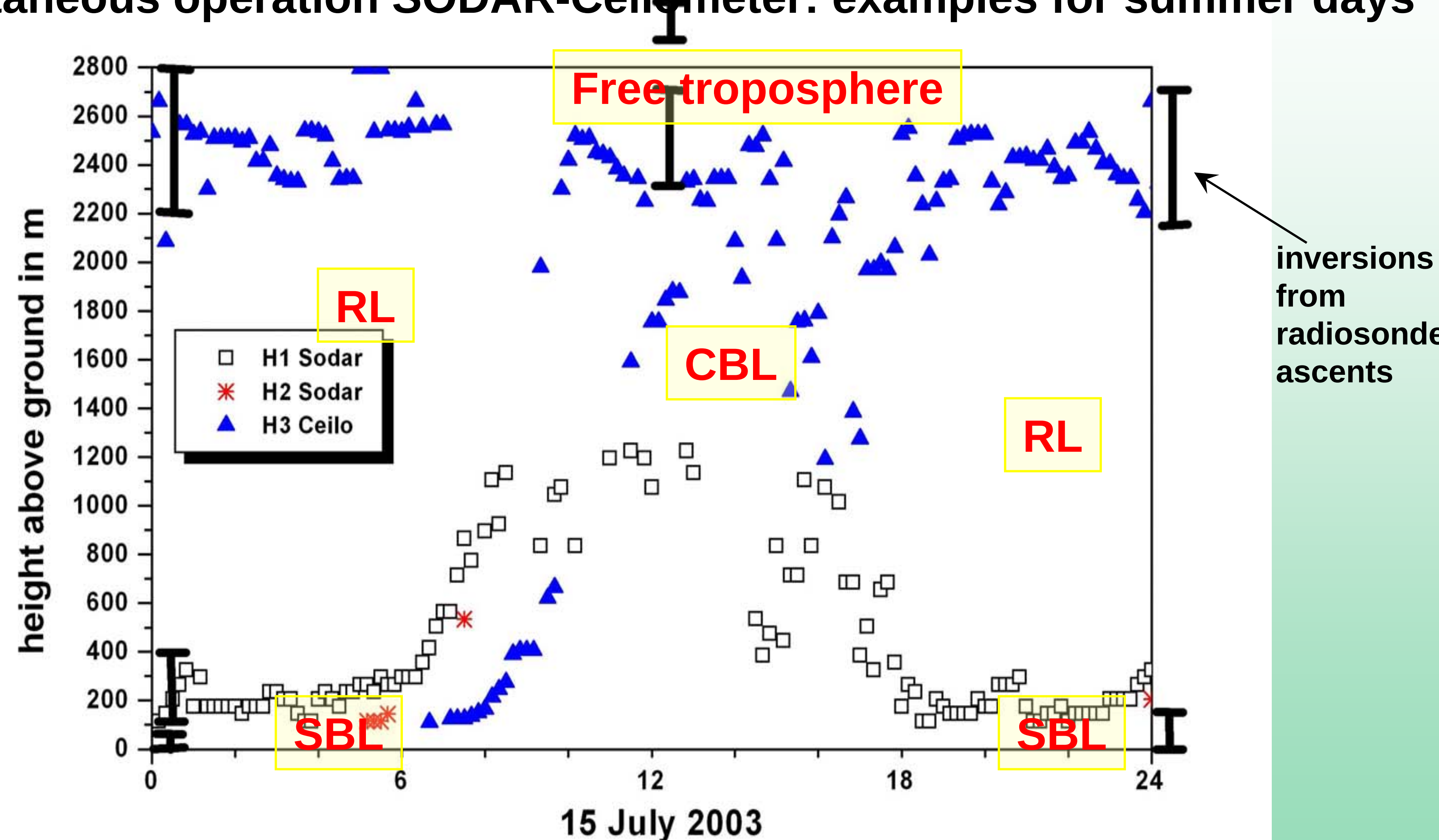
CBL:

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,

radio-acoustic remote sensing

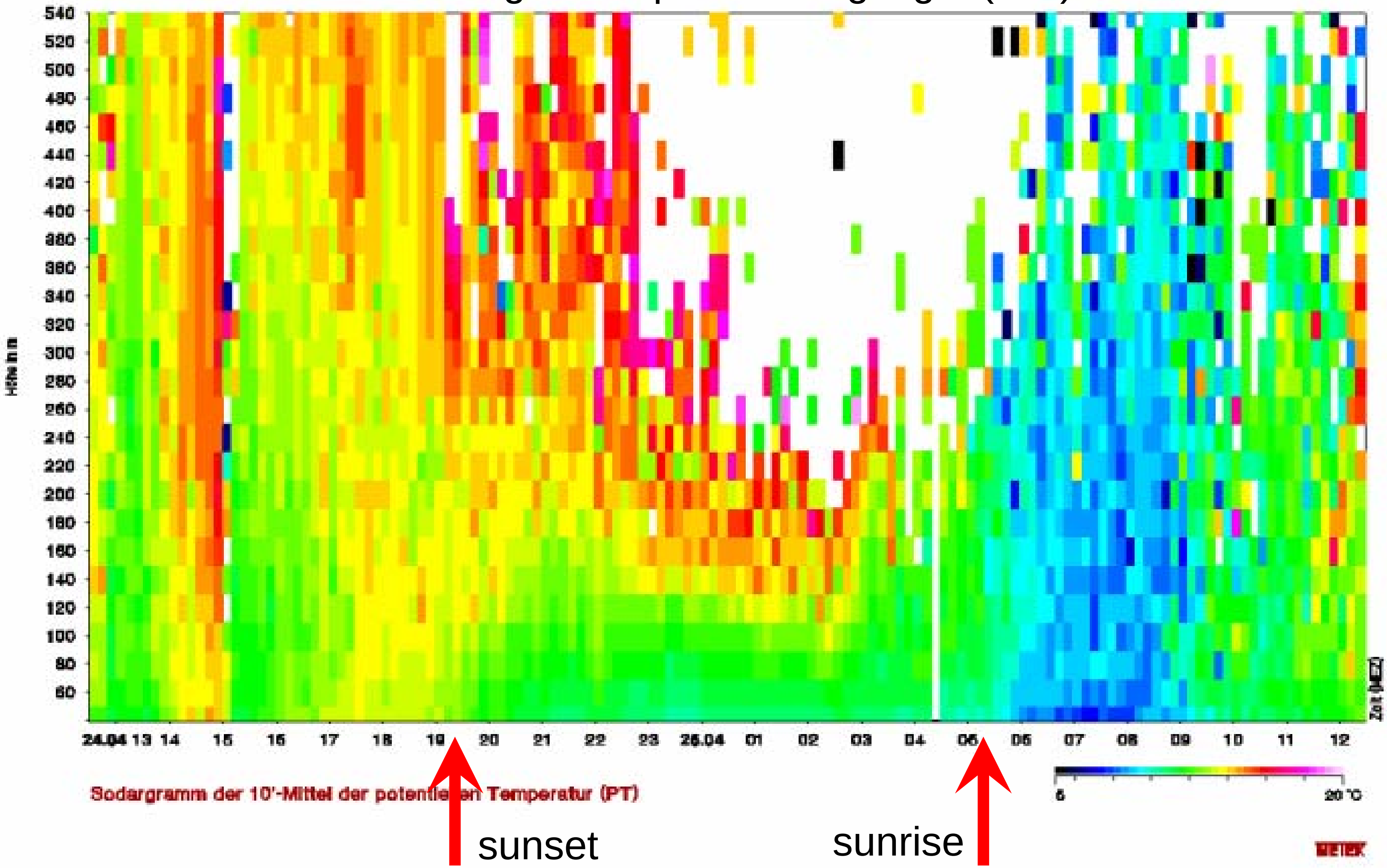
SODAR-RASS

(METEK)

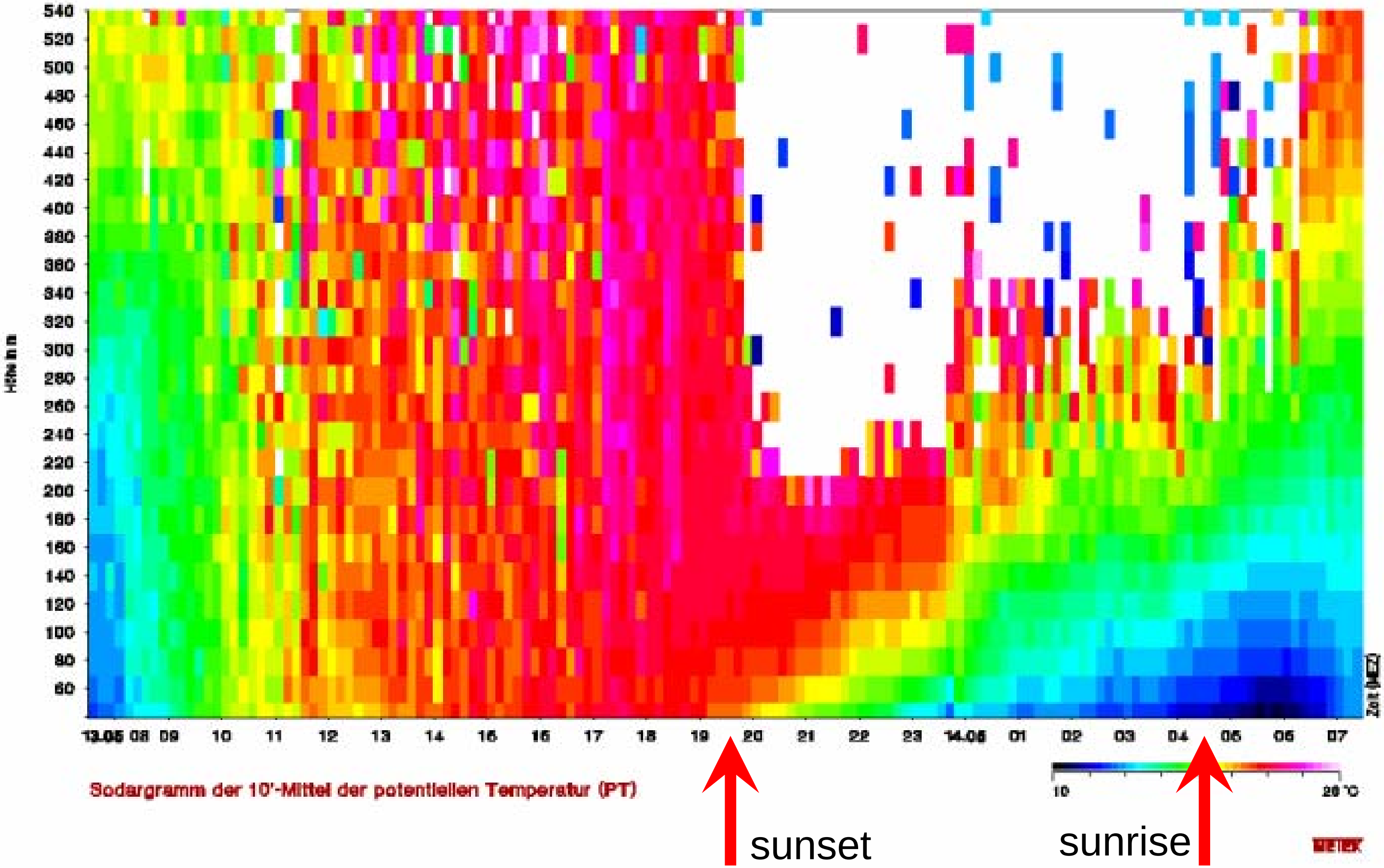
acoustic frequ.: 1500 – 2200 Hz
radio frequ.: 474 MHz
resolution: 20 m
lowest
range gate: ca. 40 m

vertical range: 540 m

height-time cross-section of potential temperature from RASS soundings
increasing wind speed during night (LLJ)



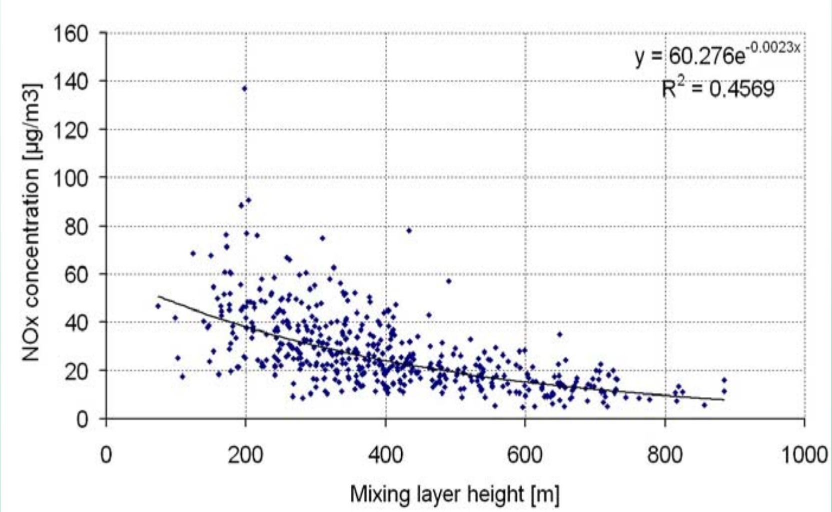
height-time cross-section of potential temperature from RASS soundings perfect clear day

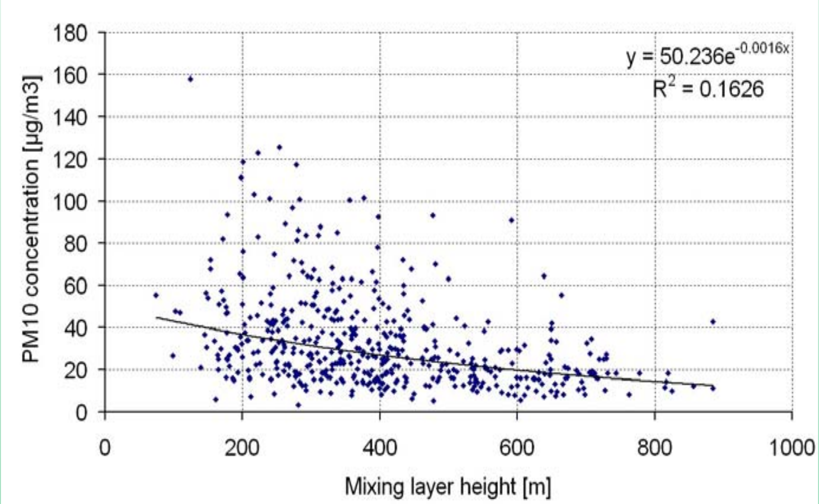


examples for the influence of boundary layer structure on air quality

correlation at roof-top level: pollutant - MLH

October 2001 - April 2003

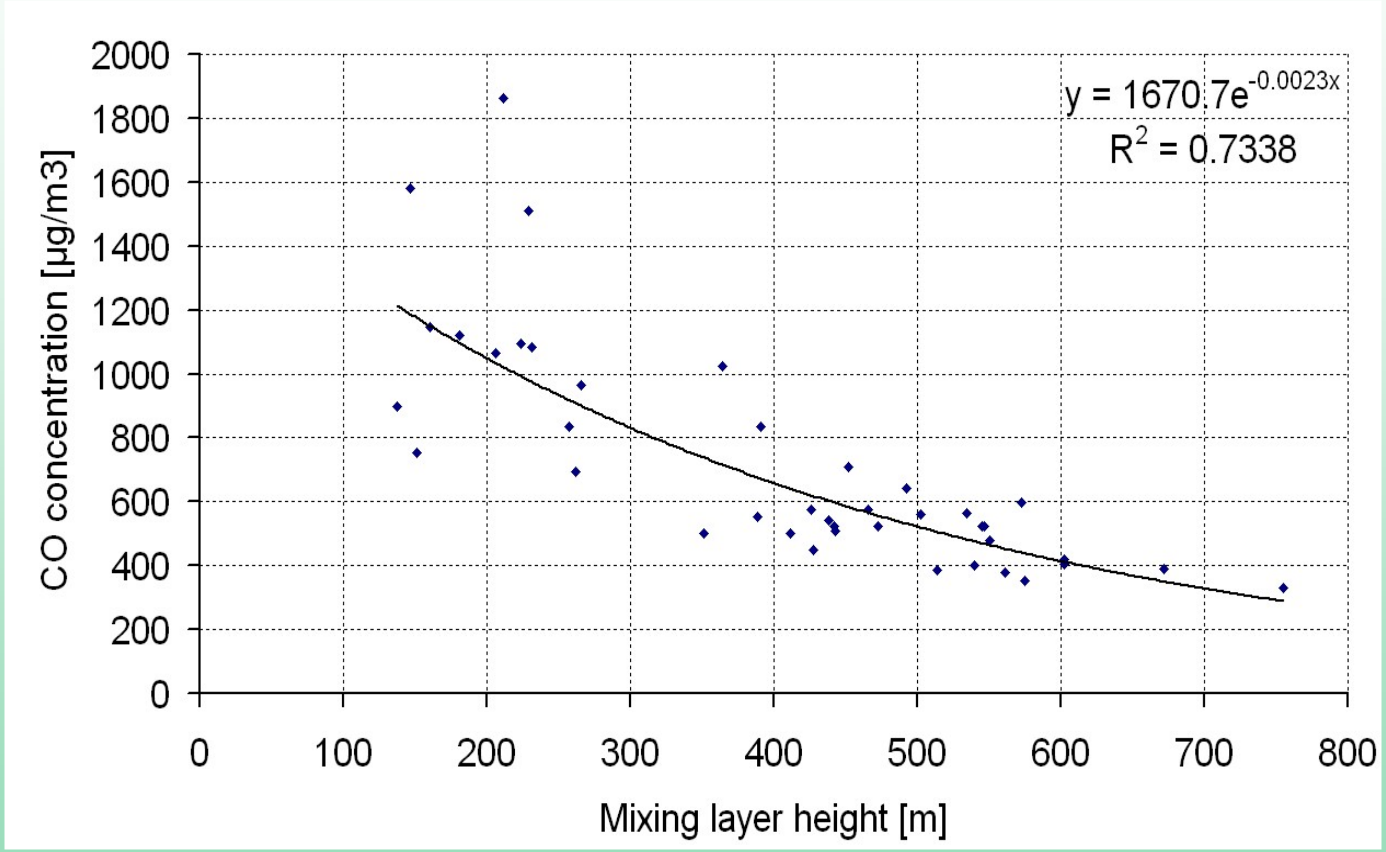




NO_x PM_{10}

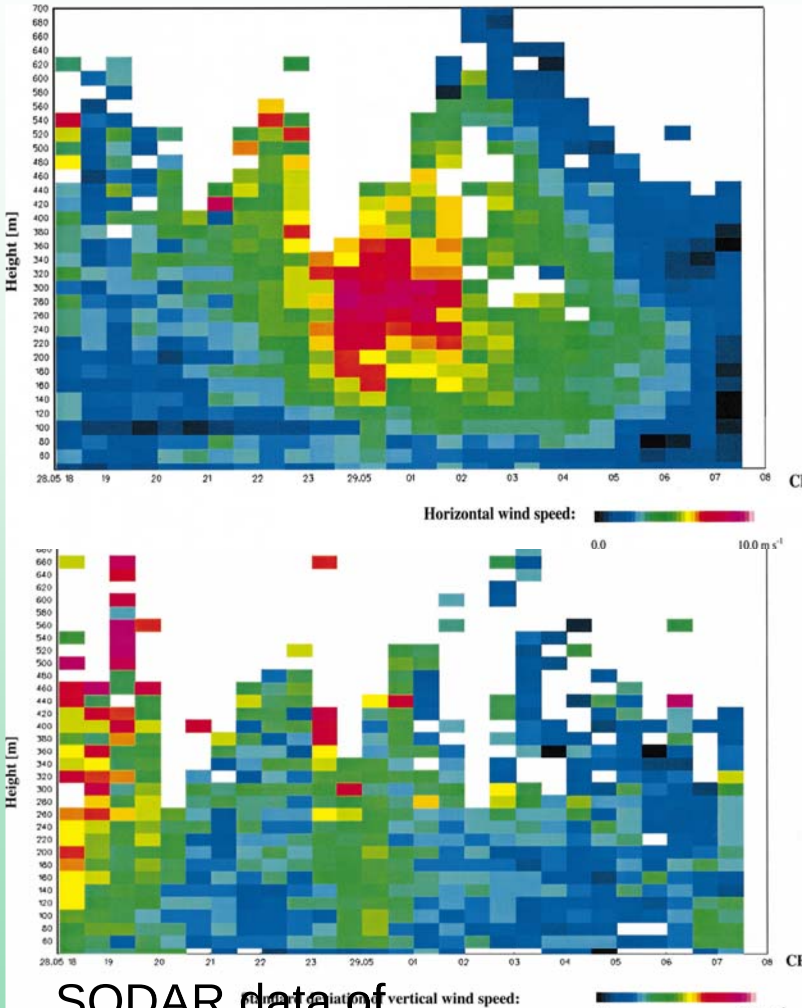
Schäfer, K., S. Emeis, H. Hoffmann, C. Jahn, 2006:
Influence of mixing layer height upon air pollution in urban and sub-urban areas. Meteorol. Z., 15, 647-658.

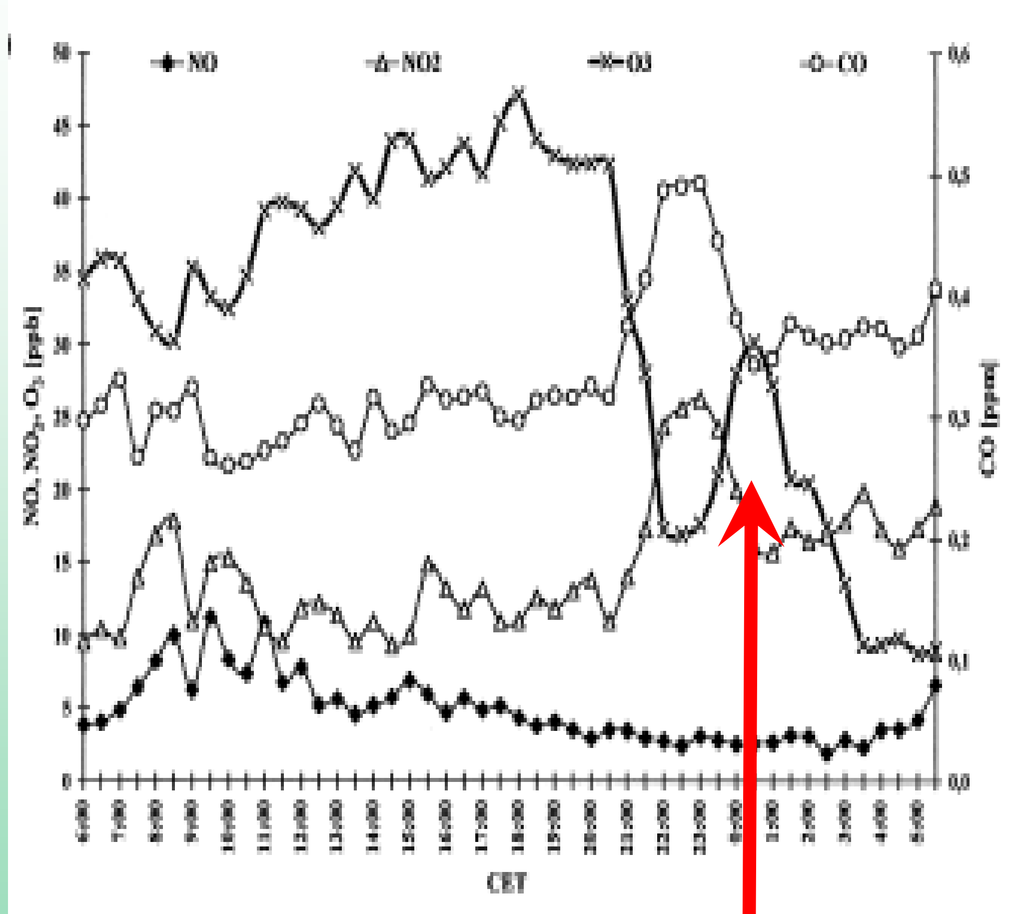
correlation at street level: pollutant (CO) - MLH



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.

Influence of LLJ on air quality





SODAR data of wind speed (top) and variance (below)

Reitebuch, O., A. Straßburger, S. Emeis, W. Kuttler, 2000: Nocturnal secondary ozone concentration maxima analysed by SODAR observations and surface measurements. Atmosph. Environm., **34**, 4315-4329.

secondary nocturnal ozone peak due to vertical mixing

Example for the operation of a ceilometer in Mexico 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

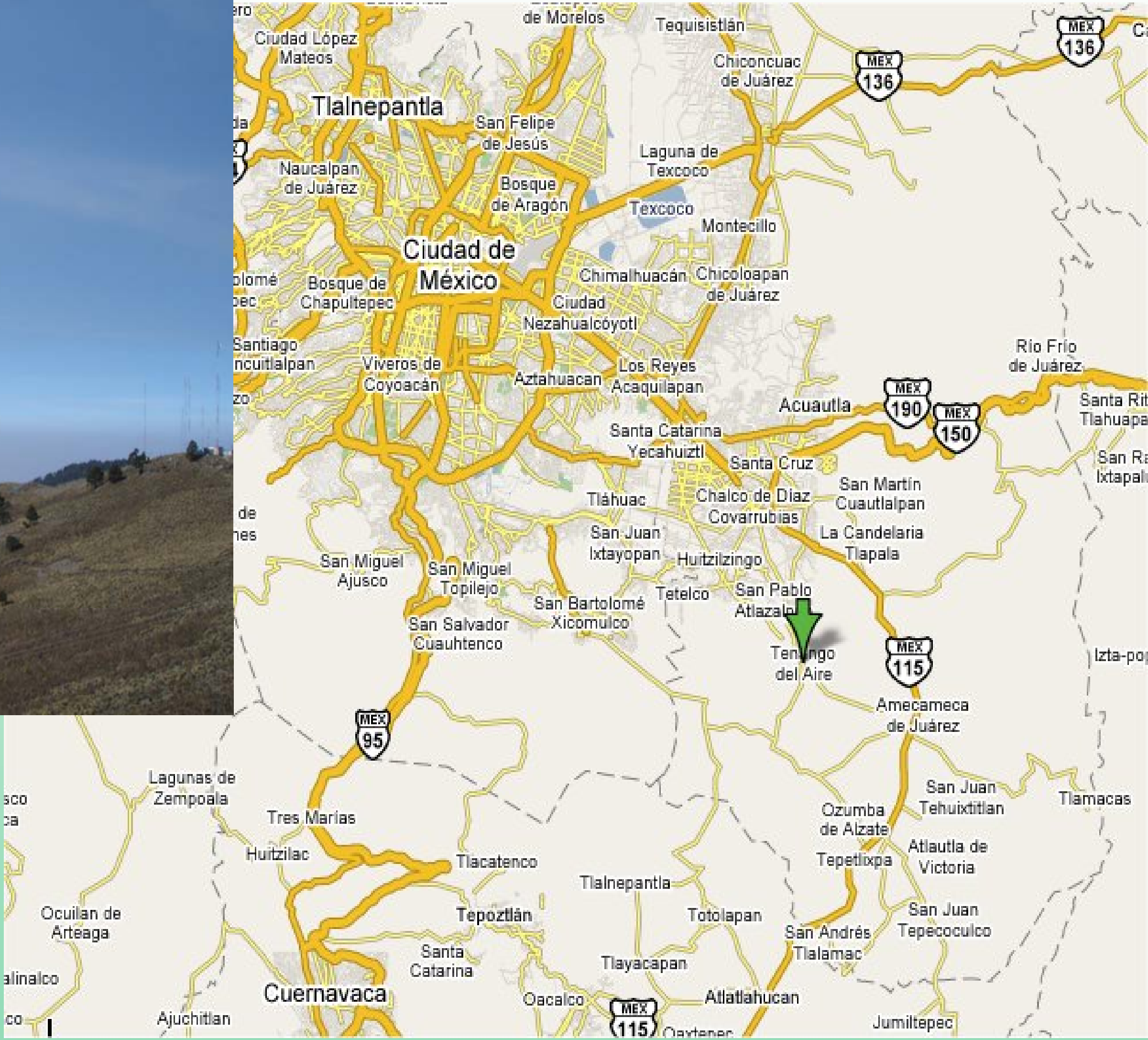
(cooperation with the Centro de Ciencias de la Atmosfera (CCA) of the Universidad Nacional Autonoma de México (UNAM)
within the MIRAGE MEX project)

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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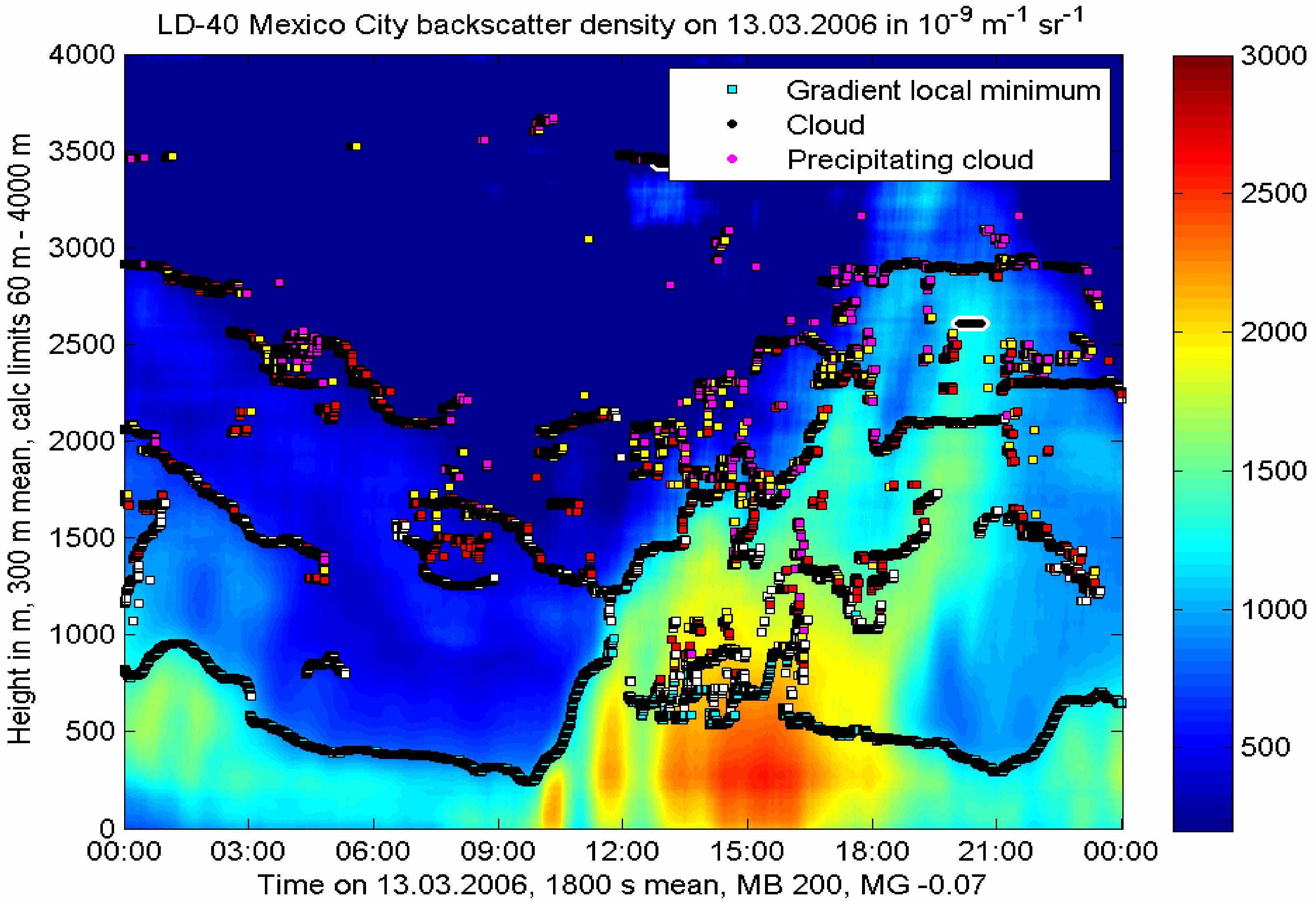
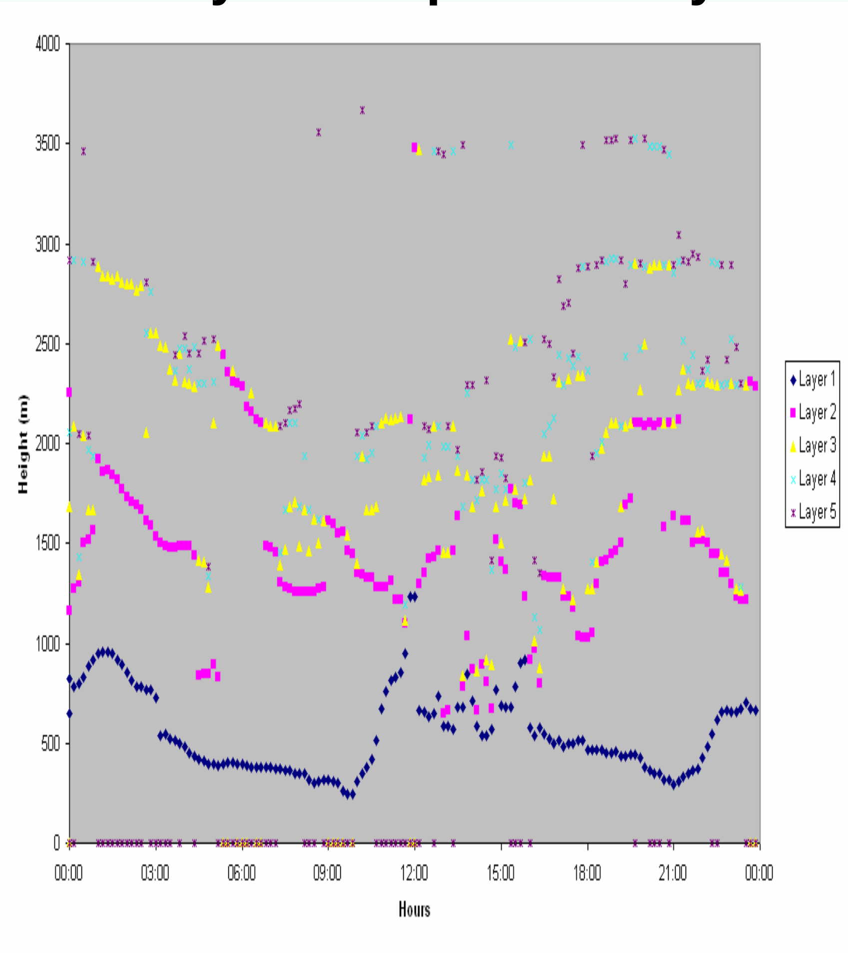
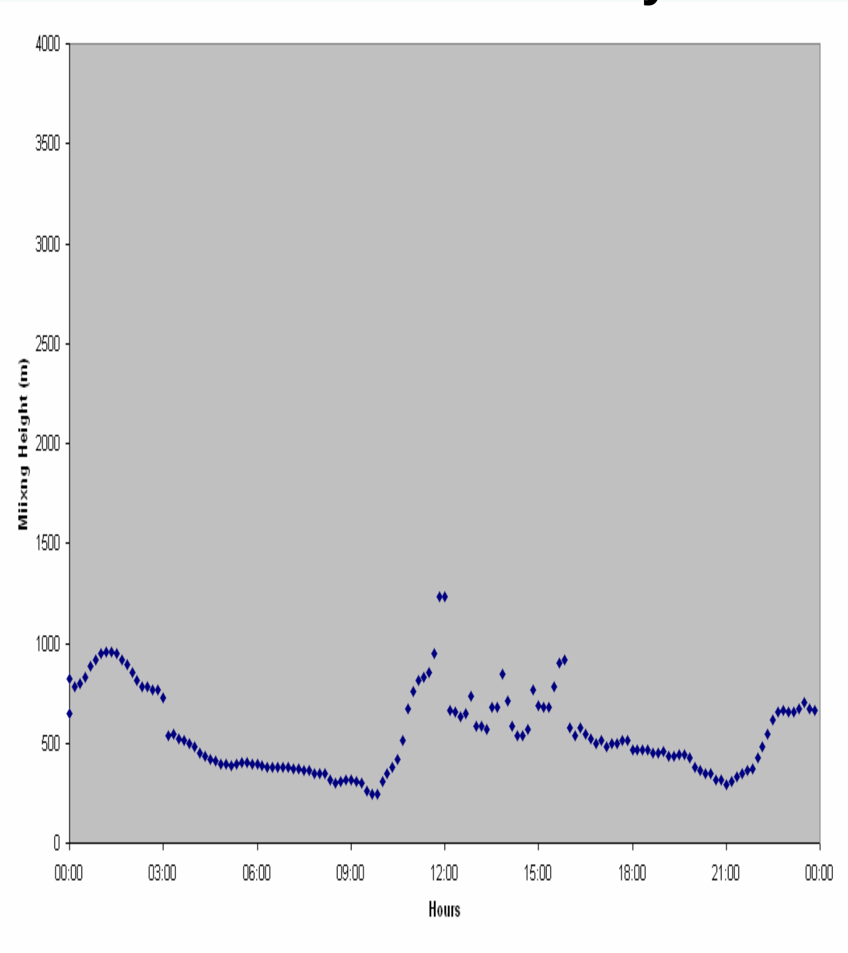

LD-40 Mexico City backscatter density on 13.03.2006 in 10^{-9} m^{-1} sr^{-1}
Gradient local minimum
Cloud
Precipitating cloud
Height in m, 300 m mean, calc limits 60 m - 4000 m
4000
3500
3000
2500
2000
1500
1000
500
0
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Time on 13.03.2006, 1800 s mean,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

Analysis of up to five layers



MLH: i.e. lowest layer



Conclusions

Acoustic, optical and radio-acoustic remote sensing is suitable for the analysis of the structure of the urban BL

Joint operation of different instruments gives additional insight

Local circulations (heat islands) and LLJ (coupling with the regional scale) have influence on air quality

Especially the knowledge of MLH is an important parameter for the

- assessment and forecast of air quality (numerical modelling)

- estimation of emission source strengths from concentration measurements

- 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