Specific wind phenomena within urban, marine and remote environments – Observed features which are not easy to model

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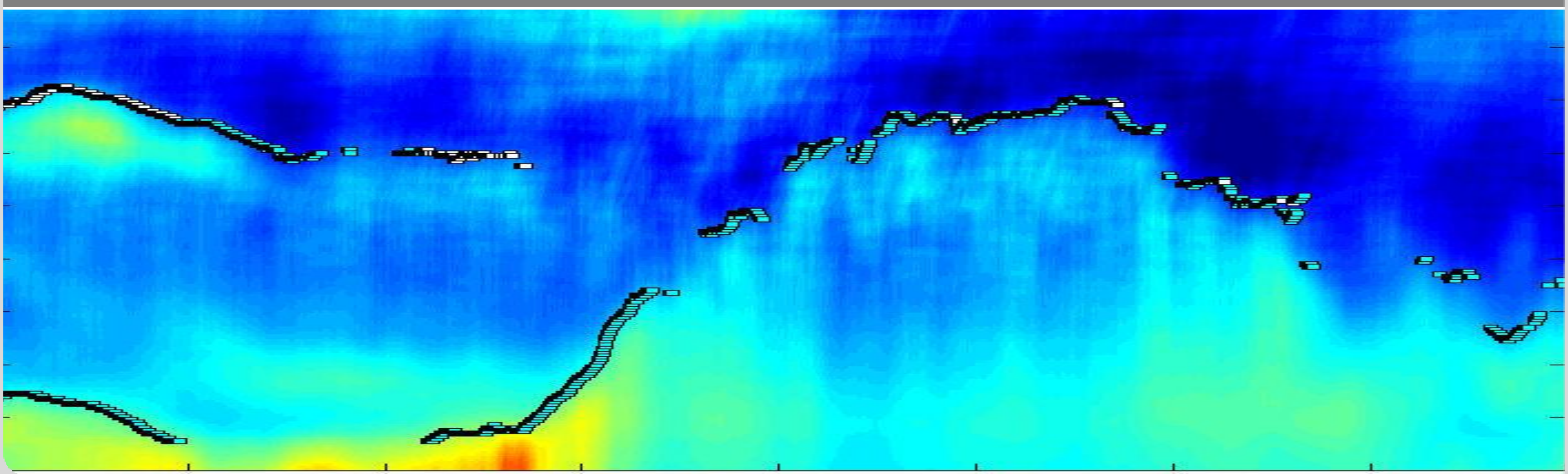
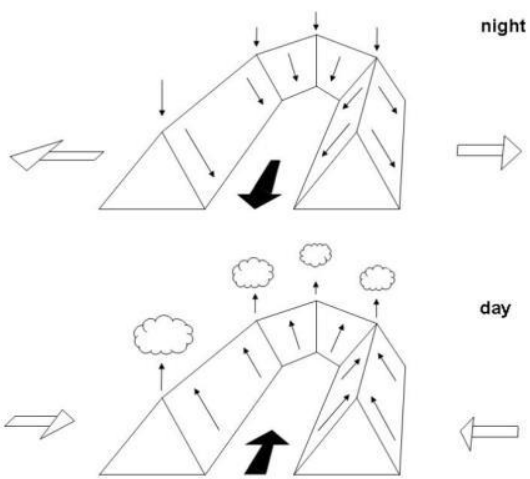
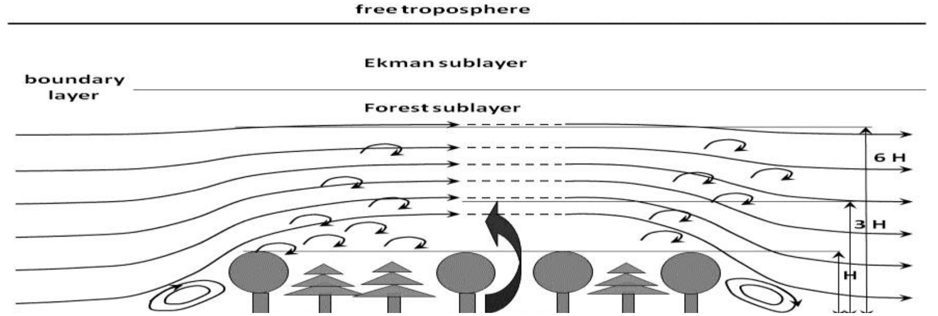
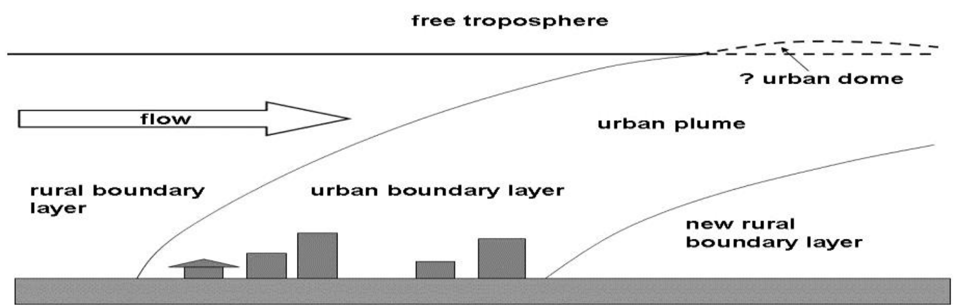


Introduction

Flow over complex terrain or urban areas often exhibit small-scale and short-lived phenomena on different scales which are neither easy to measure nor easy to model.







This review presents some measurement techniques for the observation of such phenomena and addresses a few issues where an improved simulation and/or measurement is desirable.

Main problem for numerical models:

The actual wind conditions **at one site** are often the result of the simultaneous occurrence of phenomena with **large spectra of spatial and temporal scales**.

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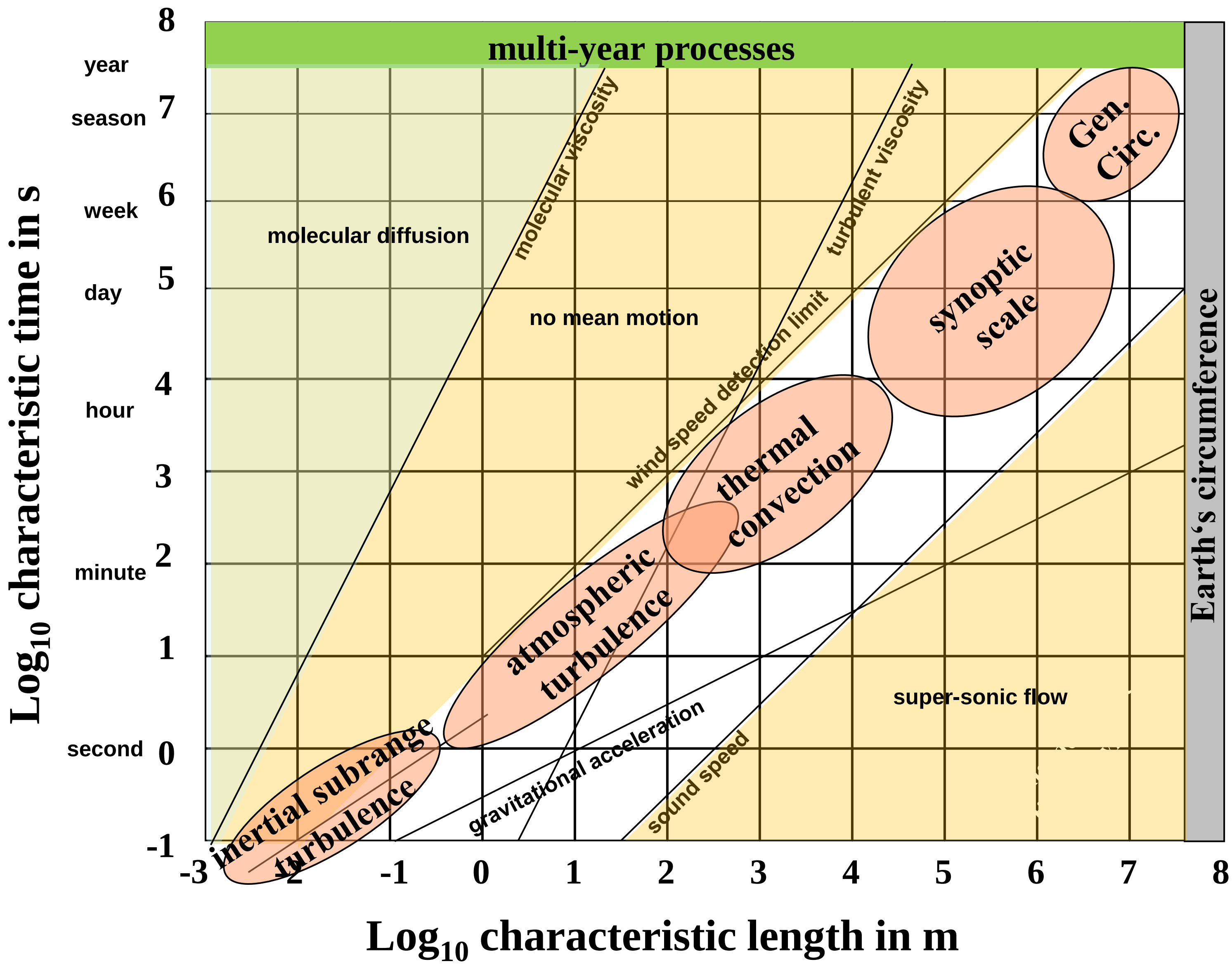
Characteristic scales of atmospheric flow



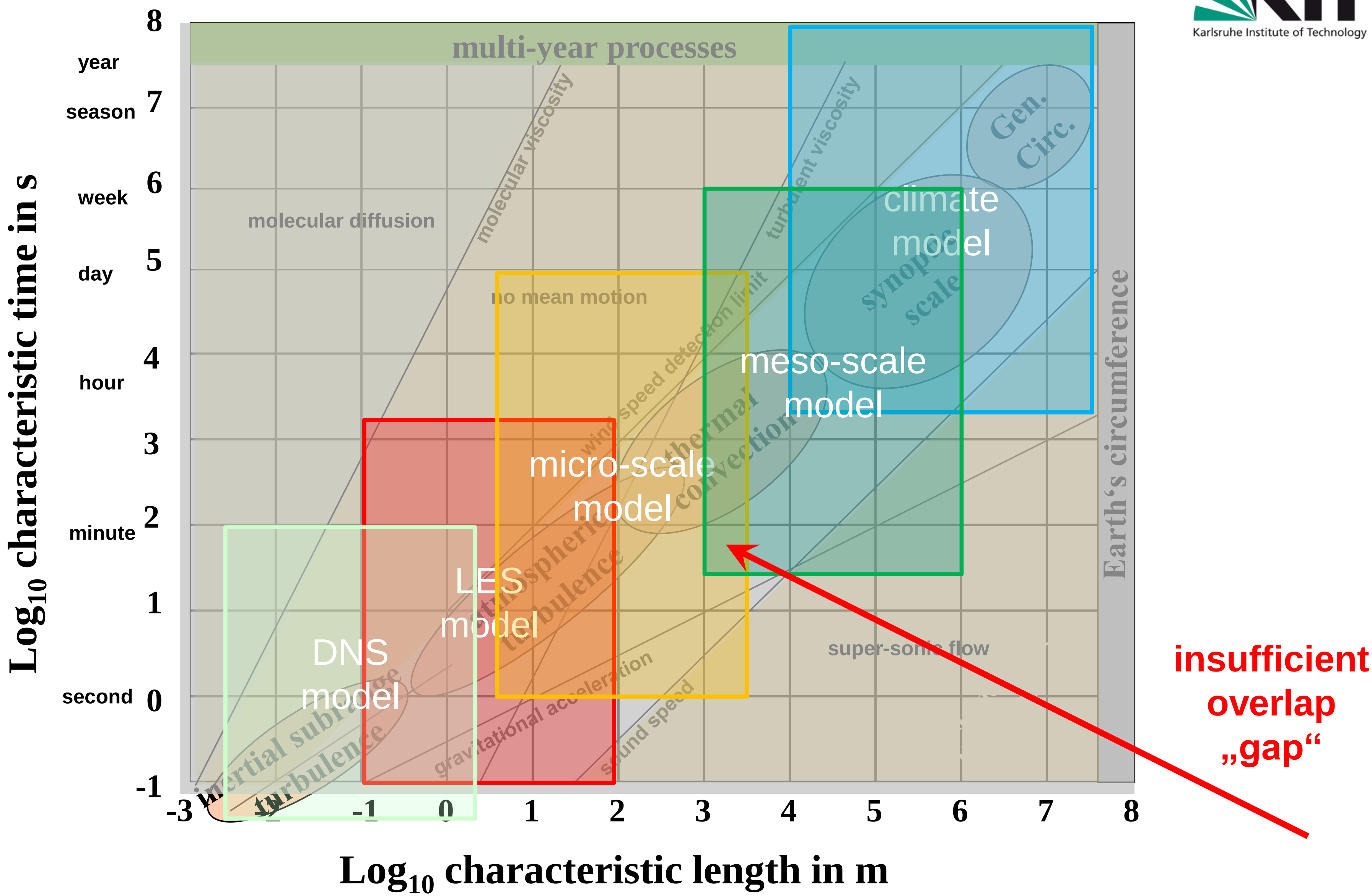
Main problem for numerical models:

The **existing numerical models** can only deal with limited parts of these scales, because sometimes parameterizations are not valid for all scales (e.g. turbulence or cloud formation) or because the computer resources are limited.

This had led to the development of different types of models:

- large-scale (global) models ($\Delta x \sim o(10 - 100$ km$)$)
- meso-scale (regional) models ($\Delta x \sim o(1 - 10$ km$)$)
- ($\Delta x \sim o(1$ km – 100 m$)$)
- micro-scale (local) models ($\Delta x \sim o(10 - 100$ m$)$)
- LES models ($\Delta x \sim o(1 - 10$ m$)$)
- DNS models ($\Delta x \sim o(1$ m$)$ or less)

Atmospheric model ranges



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Additional problem for numerical models:

There is a **gap** between meso-scale and micro-scale models which is difficult to bridge.

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The gap

Problem #1

Between about 100 m and about 1000 m turbulence length scales and model grid distances are of the same magnitude

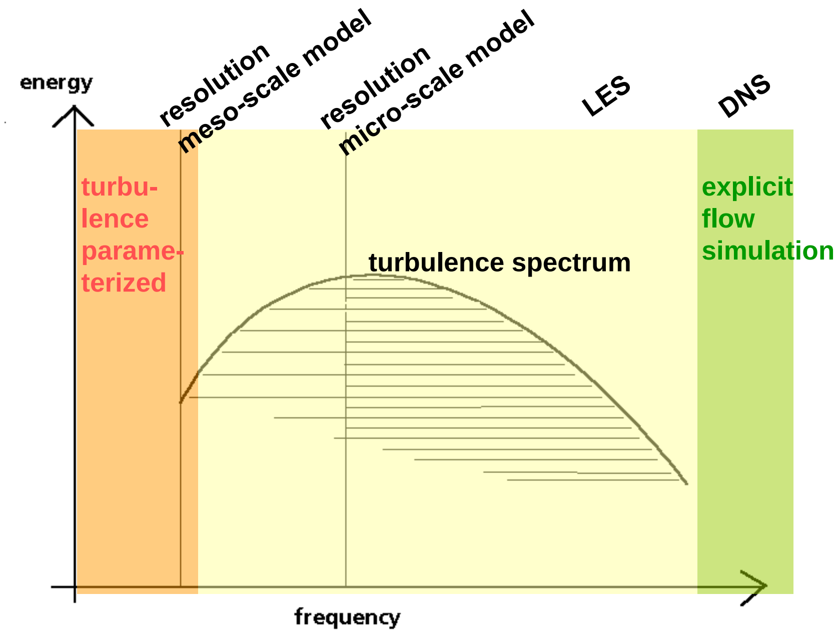
➔ therefore, turbulence parameterization in this range must be strongly dependent on the chosen grid distance

The turbulence in this region is called “gray zone turbulence” or the region is even called “terra incognita” (Wyngaard 2004, J Atmos Sci **61**, 1816-1826).

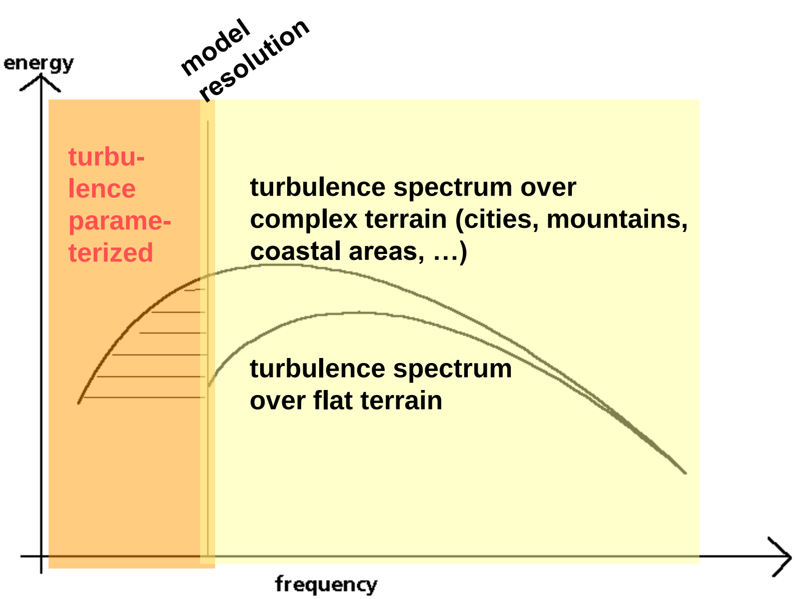
If a small grid distance with a reduced turbulence parameterization is used, larger turbulence elements are resolved in simulations.

💣 The results for the large turbulence elements are no longer representing an ensemble average (as the parameterization does), but just one possible state (Martilli 2007, Int J Climatol **27**, 1909–1918).

turbulence parameterization vs. model resolution



turbulence parameterization vs. turbulence spectrum

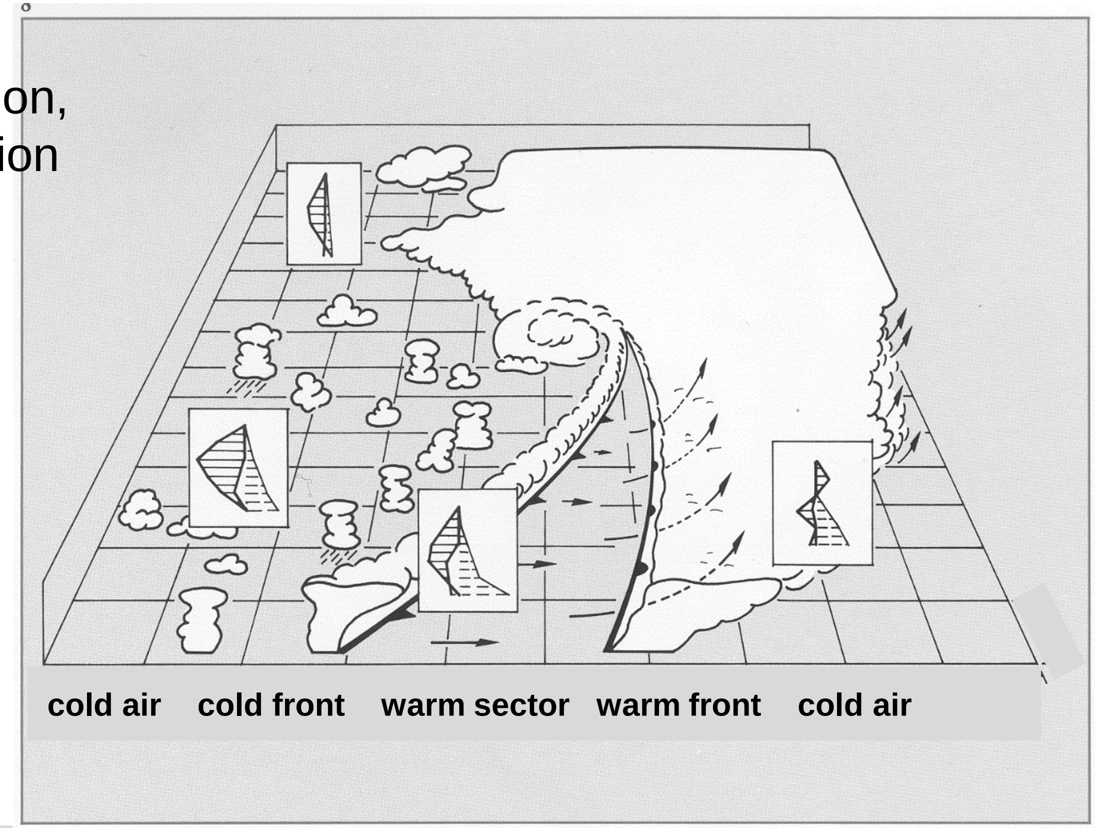


The gap

Problem #2

Between about 100 m and several kilometres horizontal scales of vertical convection cells and model grid distances are of the same magnitude

➔ the parameterization of convection, clouds, and precipitation formation must be strongly dependent on the chosen grid distance



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This gap prevents simulations
which take into account large-scale forcing and local-scale phenomena simultaneously allowing for two-way coupling.

- Urban studies: combining street-scale flow simulations with large-scale forcing
  (see Martilli 2007 for a detailled analysis of this problem)

- Wind energy: combining site conditions in complex terrain with large-scale forcing

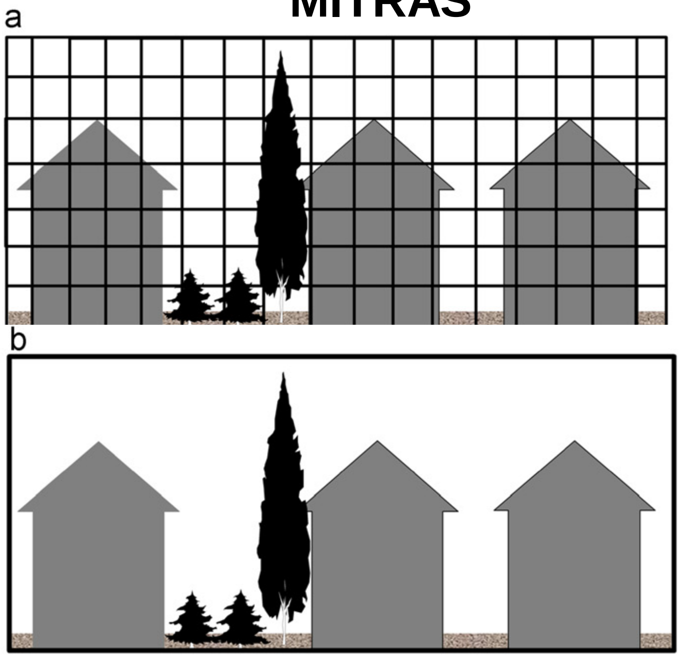
- Complex terrain: combining, e.g., valley-scale flow simulations with large-scale cross-mountain flow

The major problem with model coupling:

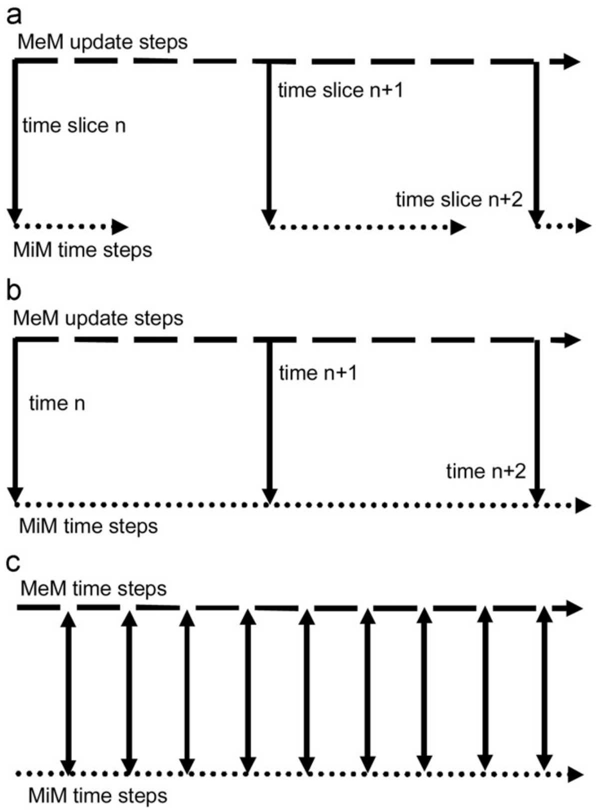
the feedback from the micro-scale to the meso-scale.

One possibility: two-way coupling of, e.g., METRAS and MITRAS (Schlünzen et al. 2011, J. Wind Eng Ind Aerodyn **99**, 217–225)

MITRAS



METRAS



one-way coupling

one-way coupling

two-way coupling

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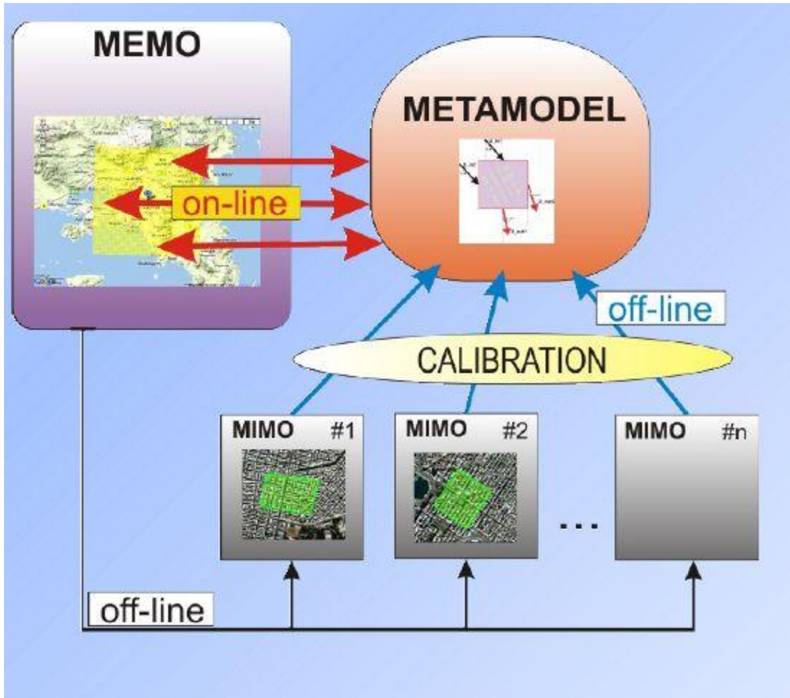
The major problem with model coupling:

the feedback from the micro-scale to the meso-scale.

Parameterizations in meso-scale models produce ensemble averages.

Therefore, many micro-scale realisations have to be used to form an ensemble average impacting on the meso-scale.

One idea is to use a "metamodel" for a two-way coupling of the micro- and the meso-scale (Tsegas et al. 2011, IJEP **47**, 278-289).



The major problem with model coupling:

We have to learn more about the gap region.

➔ Measurements are one solution to learn about wind conditions in the gap region.

Remote Sensing

passive and active
volume averaging measurements

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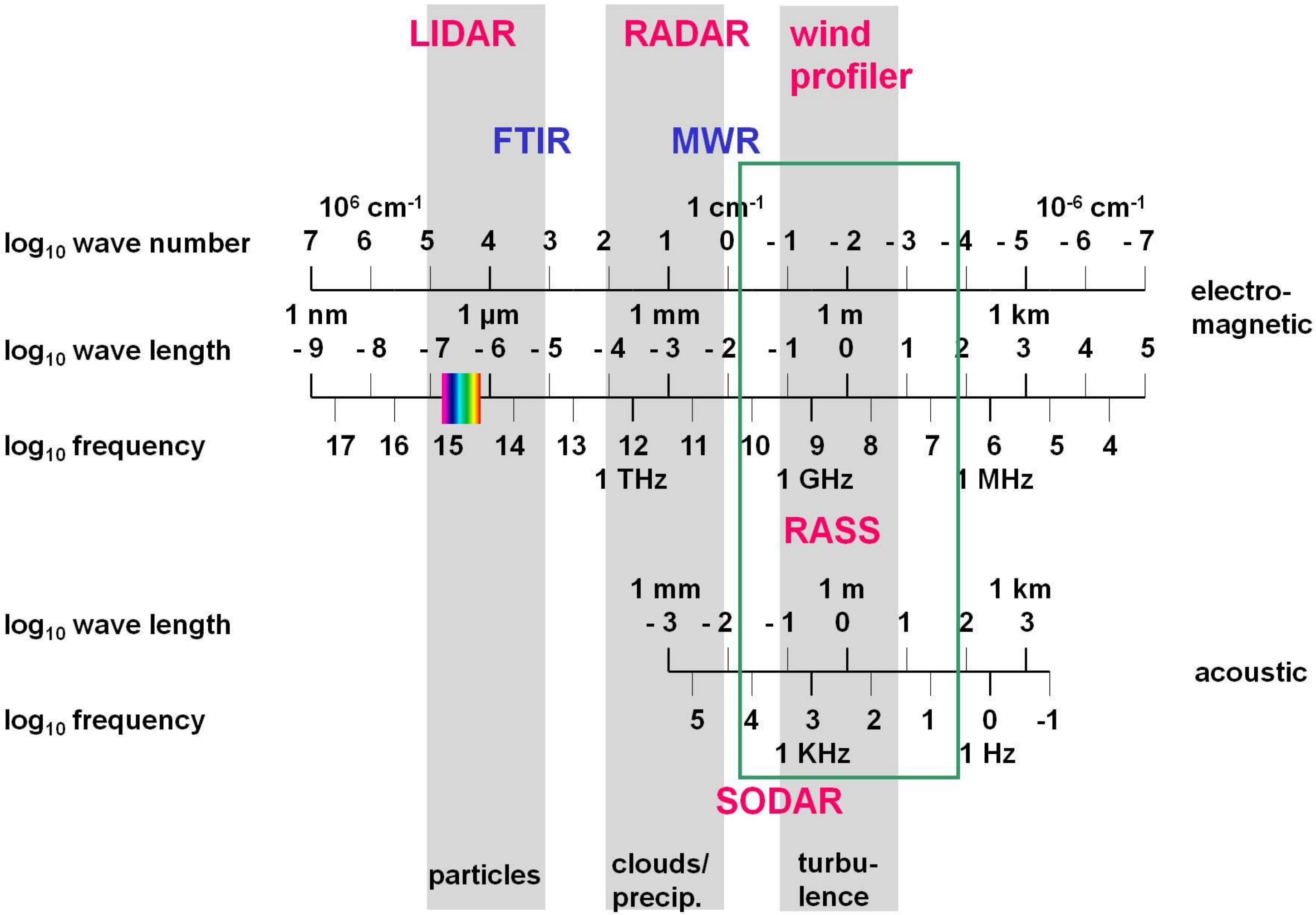
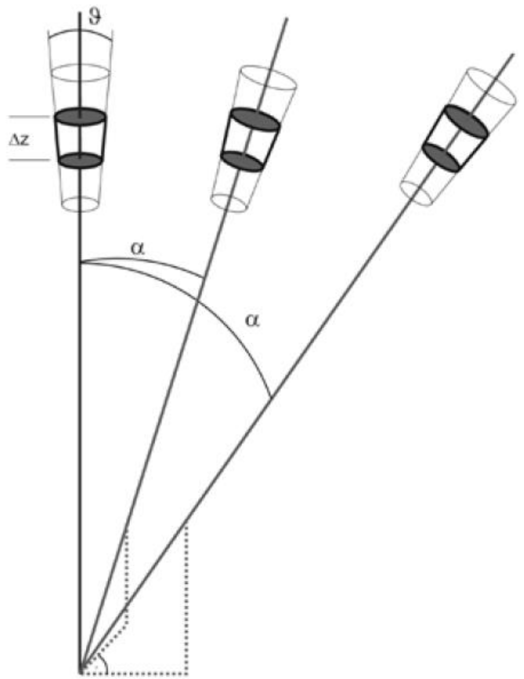
Frequencies for atmospheric remote sensing

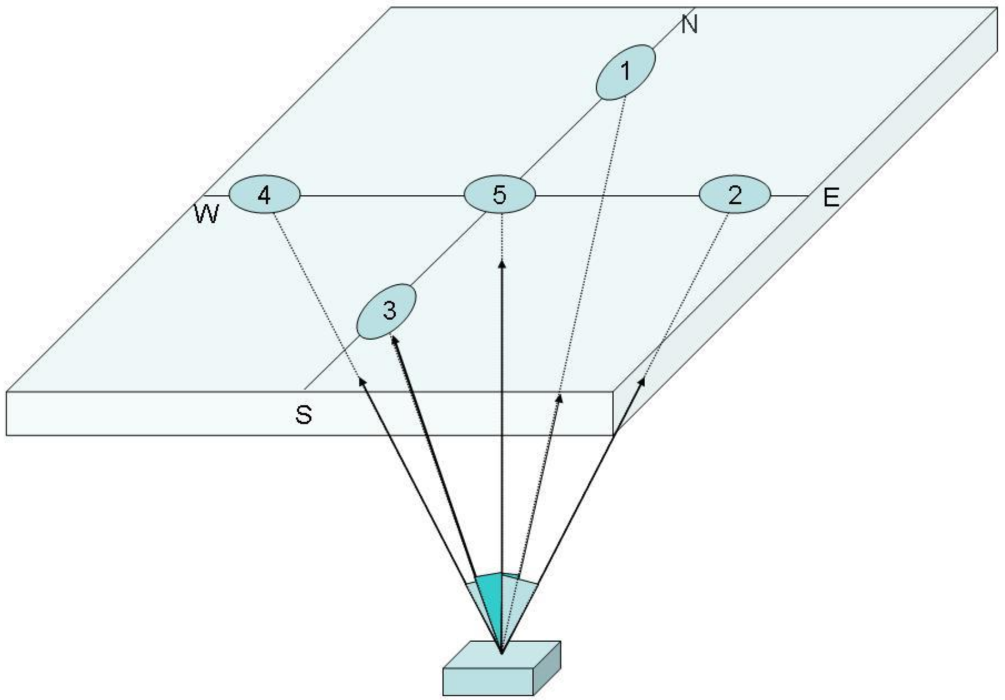


Emeis, S., 2010: Measurement Methods in Atmospheric Sciences - In situ and remote. Borntraeger, Stuttgart, 272 pp., 103 figs, 28 tables, ISBN 978-3-443-01066-9.

Basic feature of remote sensing

remote sensing of wind speed is usually a volume instead of a point measurement





SODAR, LIDAR, and RADAR beams have an opening angle (beam width) of several degrees

configuration to detect 3D wind requires beams in at least three different directions (conical scanning or Doppler beam swinging (DBS) method)

Surface-based Remote Sensing Systems

at IMK-IFU

SODAR (Large system), acoustic backscatter, Doppler shift analysis ➔ wind, turbulence

SODAR-RASS (Doppler-RASS), acoustic, electro-magnetic backscatter, determines speed of sound ➔ wind and temperature profiles

Ceilometer, backscatter, optical pulses, wave length ~ 0.9 µm ➔ aerosol profiles

Wind-LIDAR, optical backscatter, Doppler shift analysis, wave length ~ 1.5 µm ➔ wind and aerosol profiles

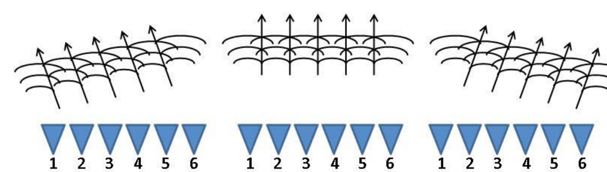
image:
Halo Photonics

SODAR

monostatic SODAR: different types

classical SODAR
with antennas pointing
in different directions

phased-array sodar

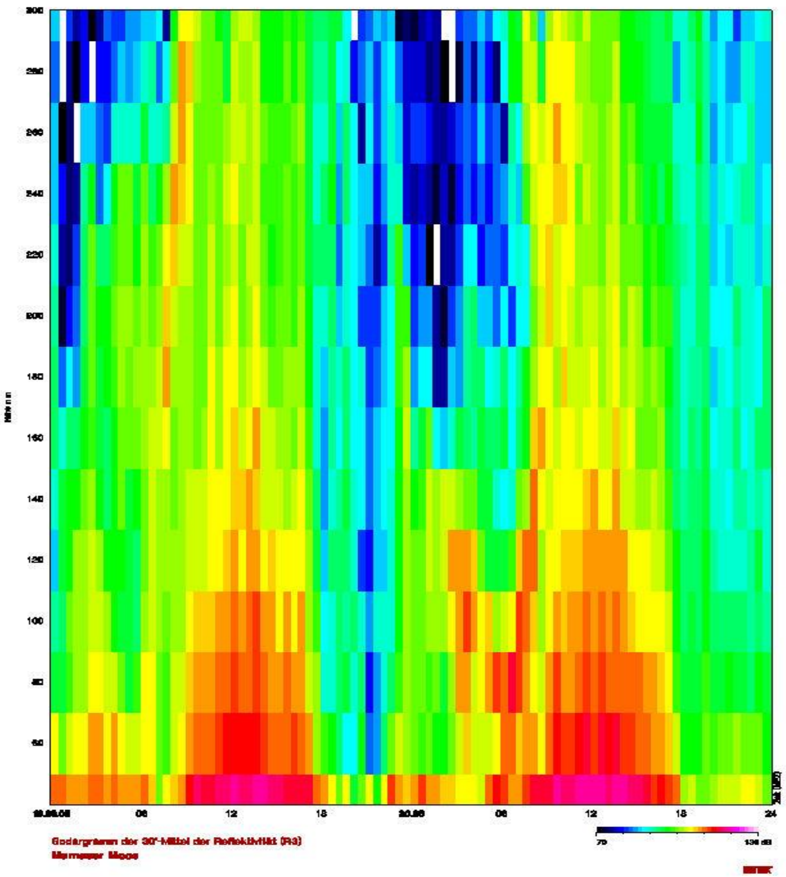


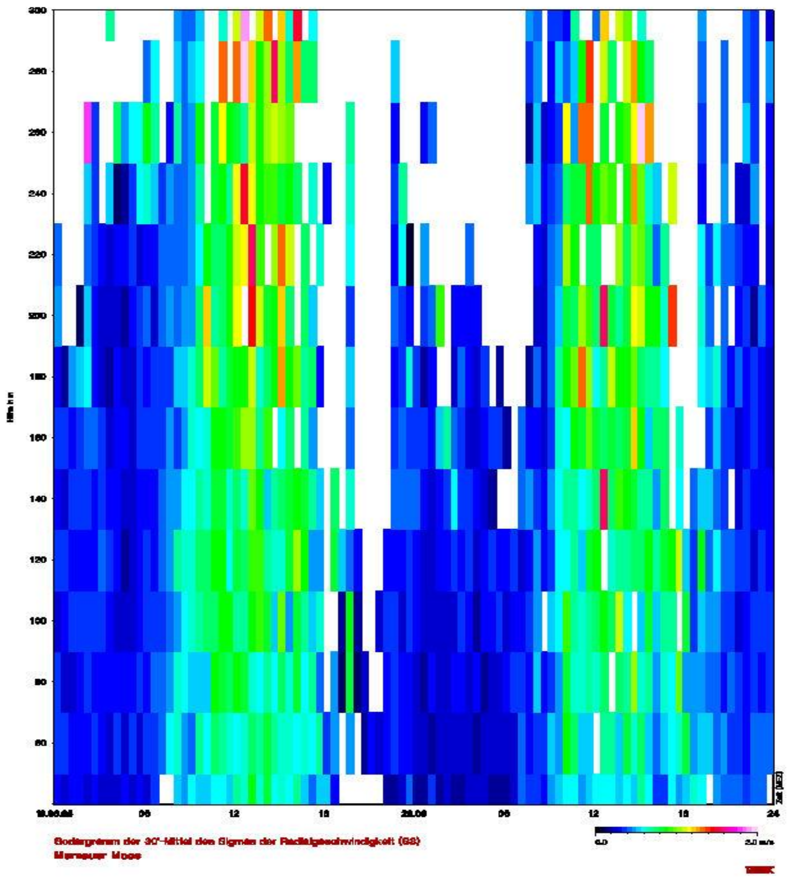
SODAR sample plot (daytime convective BL)

acoustic backscatter intensity

sigma w

40 – 300 m

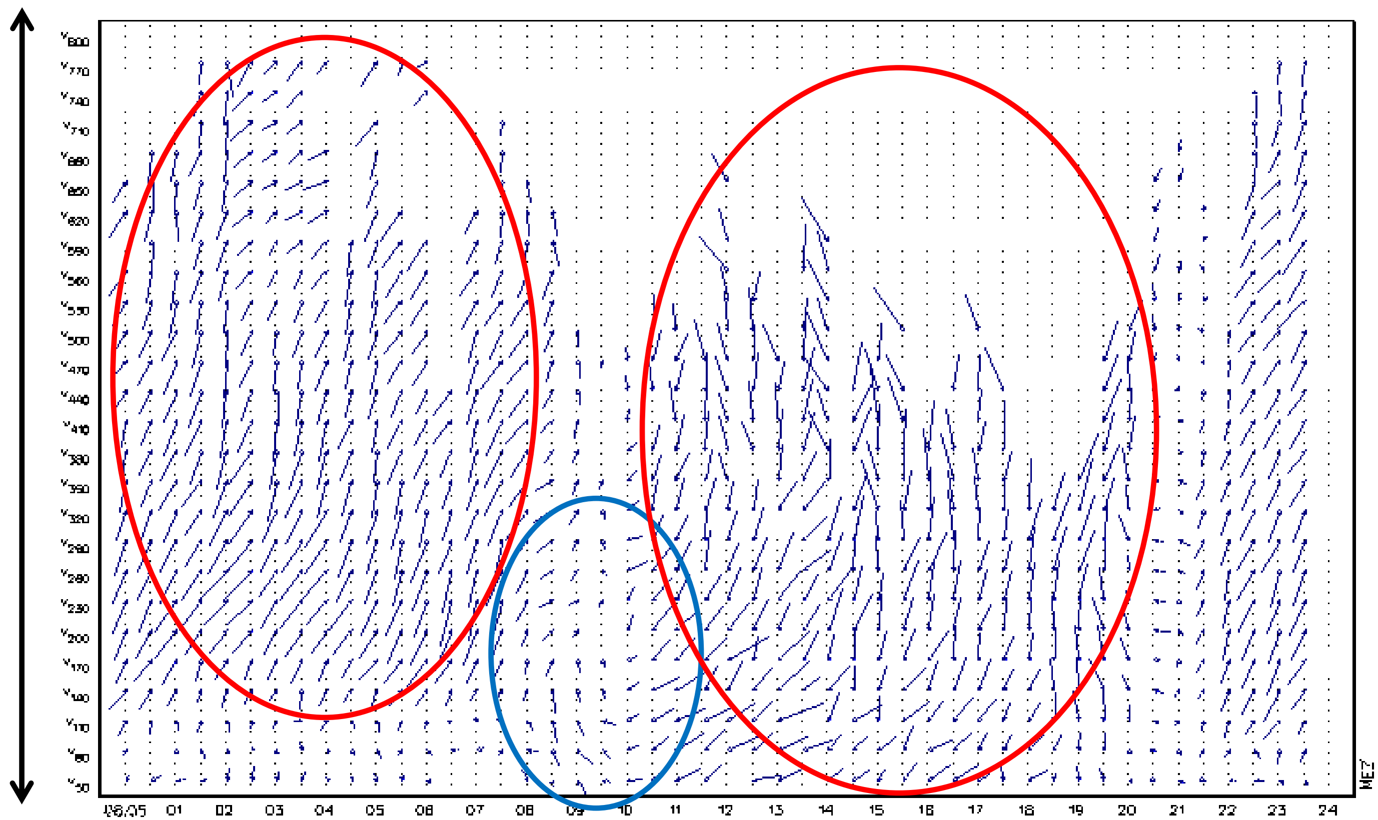




2 days, midnight to midnight

SODAR sample plot: time-height cross-section of horizontal wind speed (averaged over 30 min and 30 m)

50 – 800 m



nocturnal mountain wind nearly laminar

cross-valley circulation

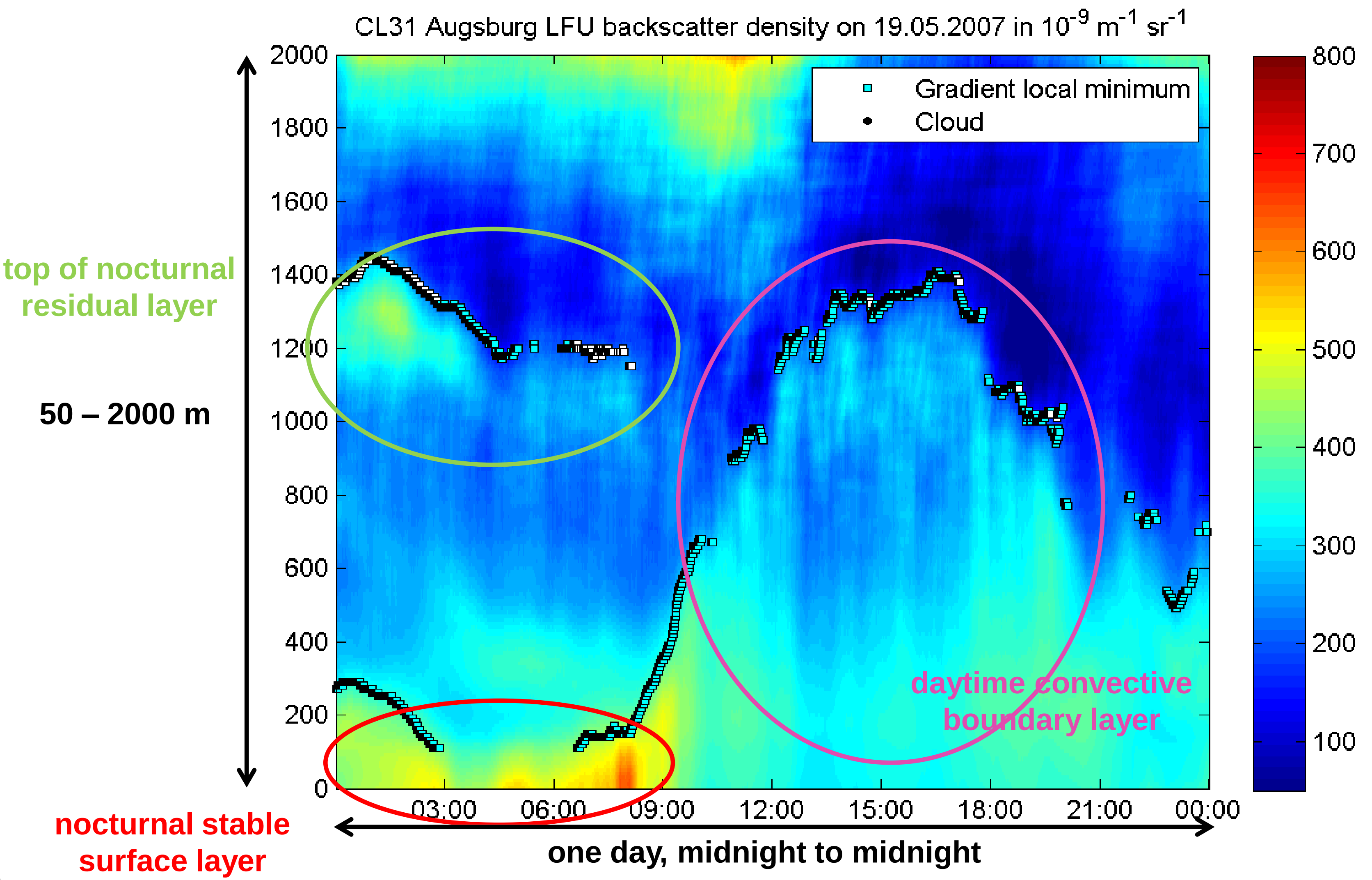
daytime valley wind turbulent

one day, midnight to midnight

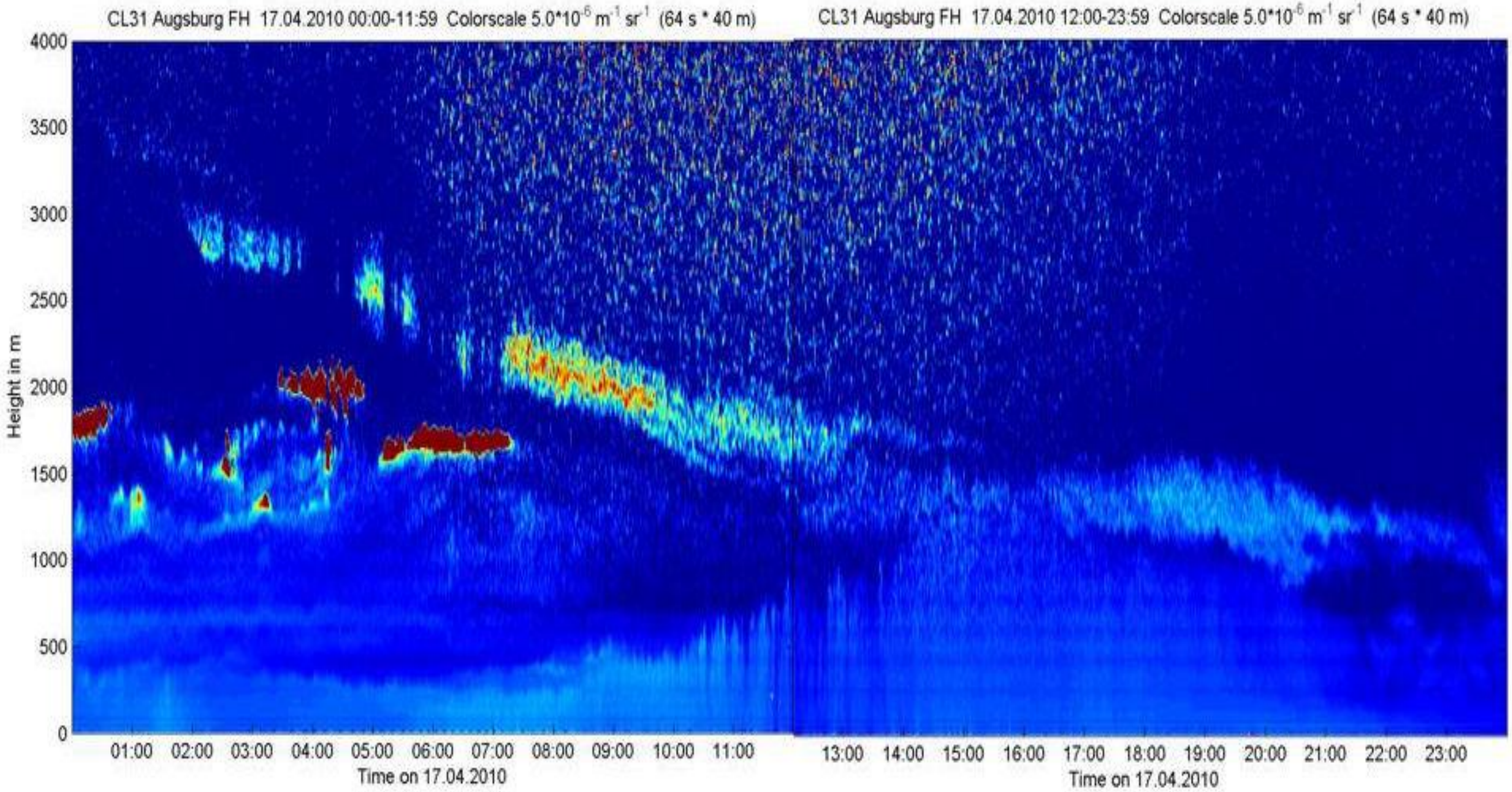
Ceilometer

algorithms for the determination of mixing-layer height

Ceilometer sample plot: diurnal variation of the boundary layer (15 s and 150 m mean)



Eyjafjallajökull ash cloud over Southern Germany



read more: Emeis, S., R. Forkel, W. Junkermann, K. Schäfer, H. Flentje, S. Gilge, W. Fricke, M. Wiegner, V. Freudenthaler, S. Groß, L. Ries, F. Meinhardt, W. Birmili, C. Münkel, F. Obleitner, P. Suppan, 2011: Measurement and simulation of the 16/17 April 2010 Eyjafjallajökull volcanic ash layer dispersion in the northern Alpine region. Atmos. Chem. Phys., 11, 2689–2701

Doppler windlidar

wind, turbulence, aerosol detection, mixing-layer height, low-level jet

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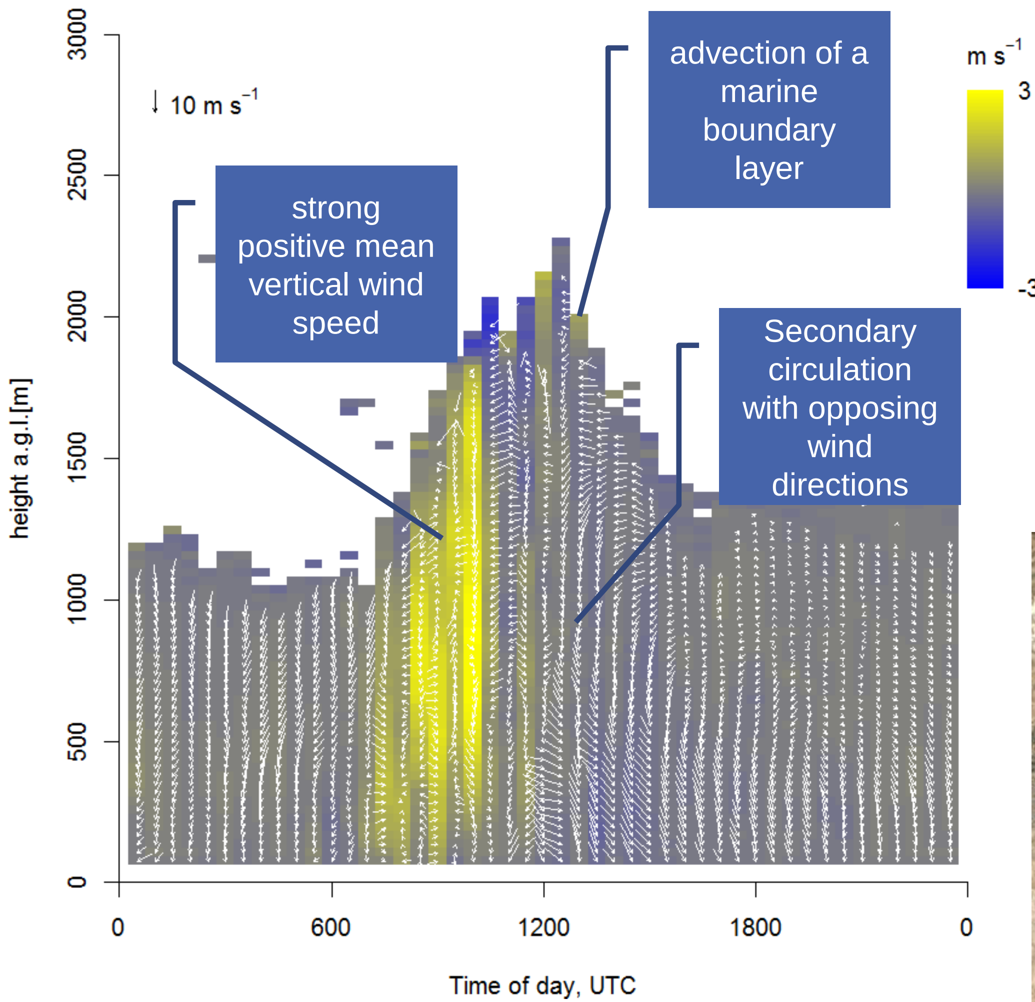
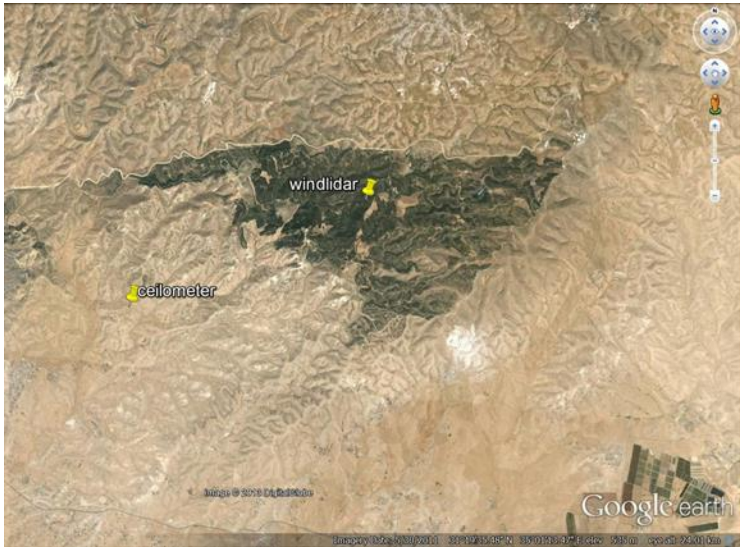
mobile Doppler windlidar from Halo Photonics

Yatir Forest, Israel



The 3-d wind field above the Yatir forest on 10 Sept 2013.
The colour indicates the vertical wind component.
The white arrows indicate the horizontal wind component:
the direction of the arrow shows the wind direction,
the length of the arrow shows the wind speed.
During the afternoon hours,
there is a 180°-shift in wind direction between surface
and boundary-layer top which indicates a stationary circulation.
Please note that this picture is not shown in local time,
but in UTC (i.e. 12:00 means 14:00 Israel winter time)



(Eder and Mauder, IMK-IFU (KIT), personal communication)

RASS

principles of operation

examples

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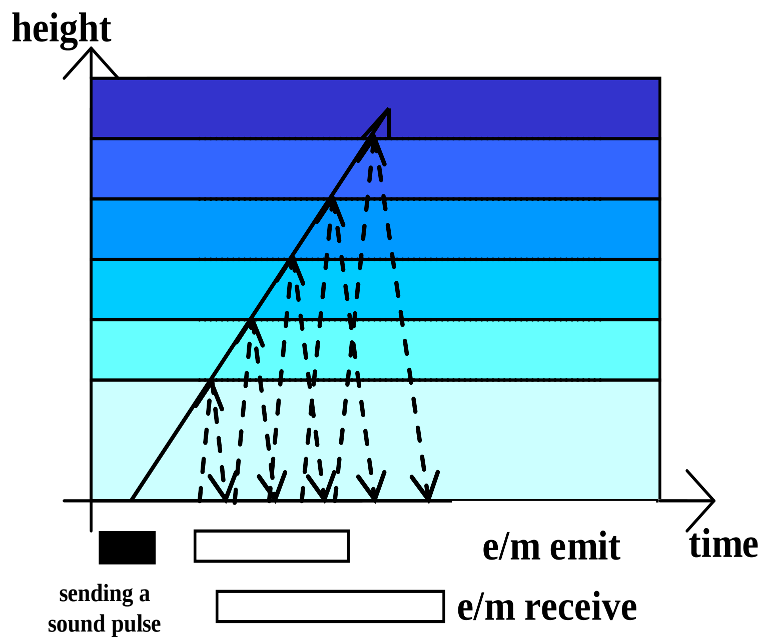
RASS measuring principle



detection:

travel time of em./ac. signal	= height	
ac. backscatter intensity	= turbulence	(identical to SODAR)
ac. Doppler-shift	= line-of-sight wind speed	(identical to SODAR)
em. Doppler shift	= sound speed ➔ temperature	

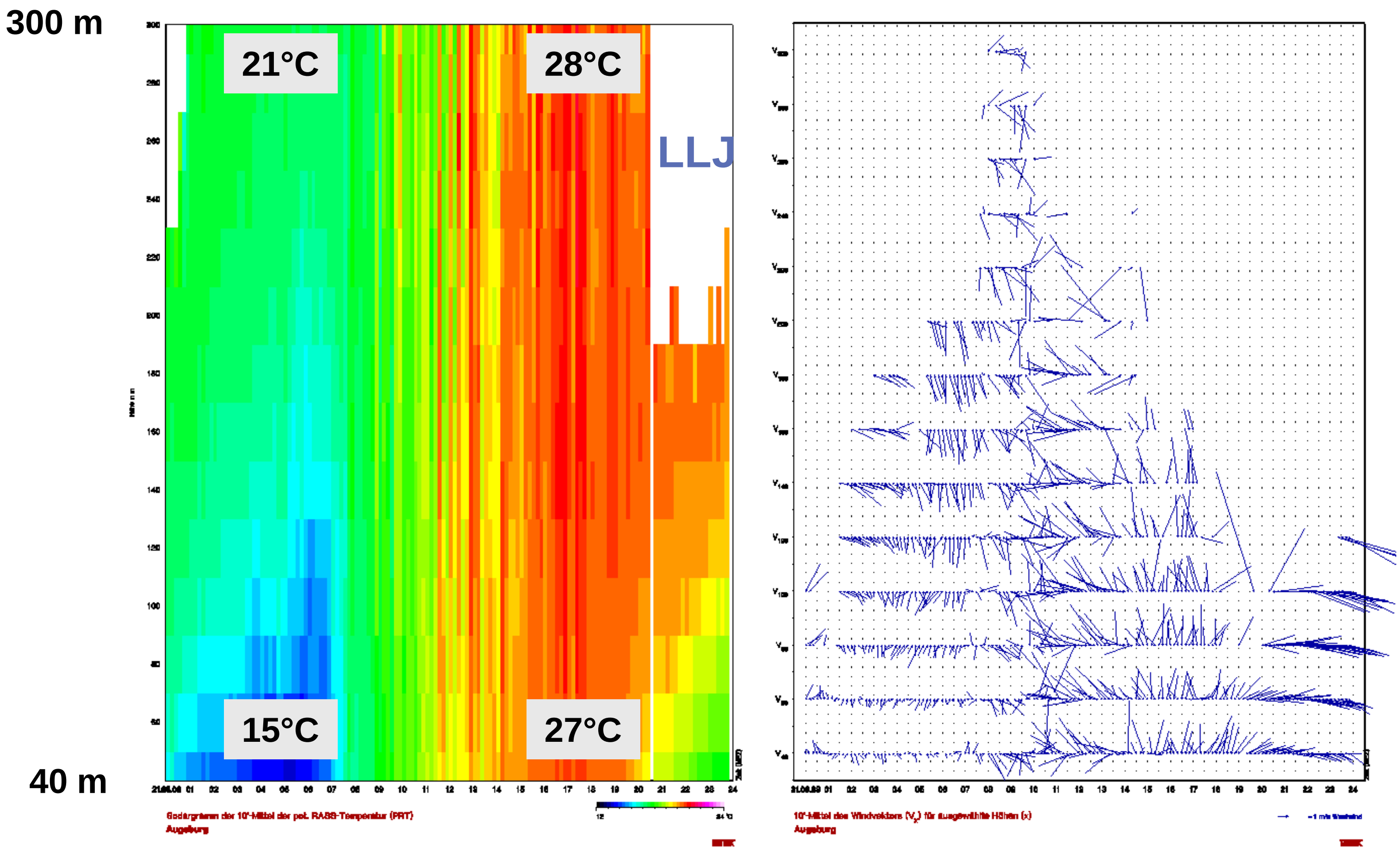
SODAR-RASS
(Doppler-RASS)

(METEK)

acoustic frequ.: 1077 Hz
radio frequ.: 474 MHz
resolution: 20 m
lowest
range gate: ca. 40 m

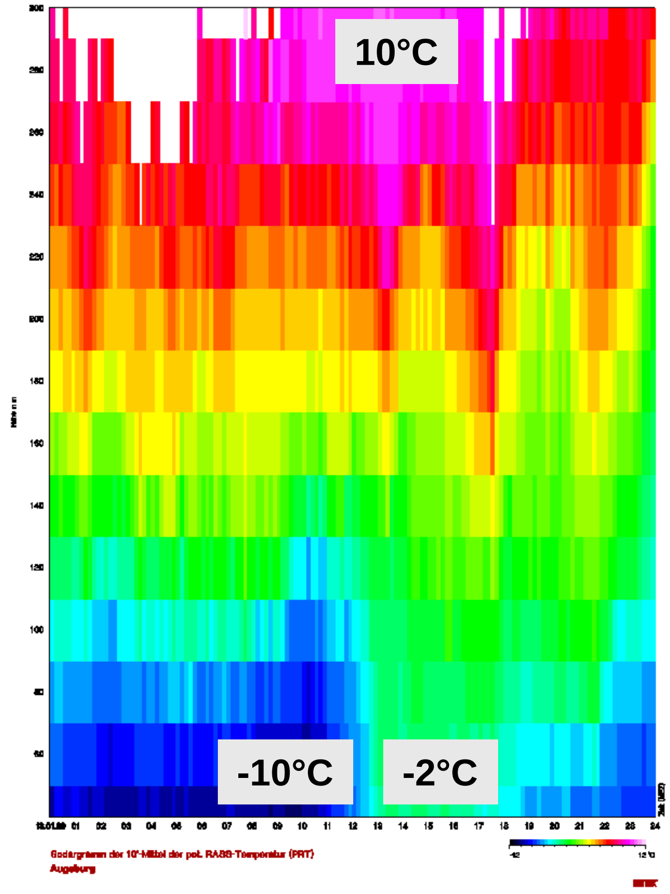
vertical range: 540 m

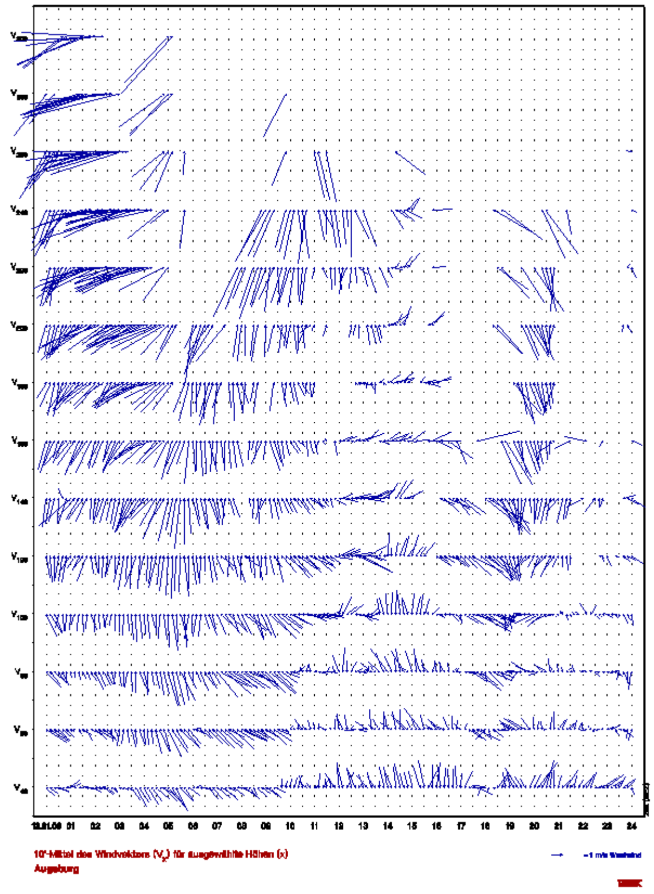
RASS data: summer day
potential temperature (left), horizontal wind (right)



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

300 m





40 m

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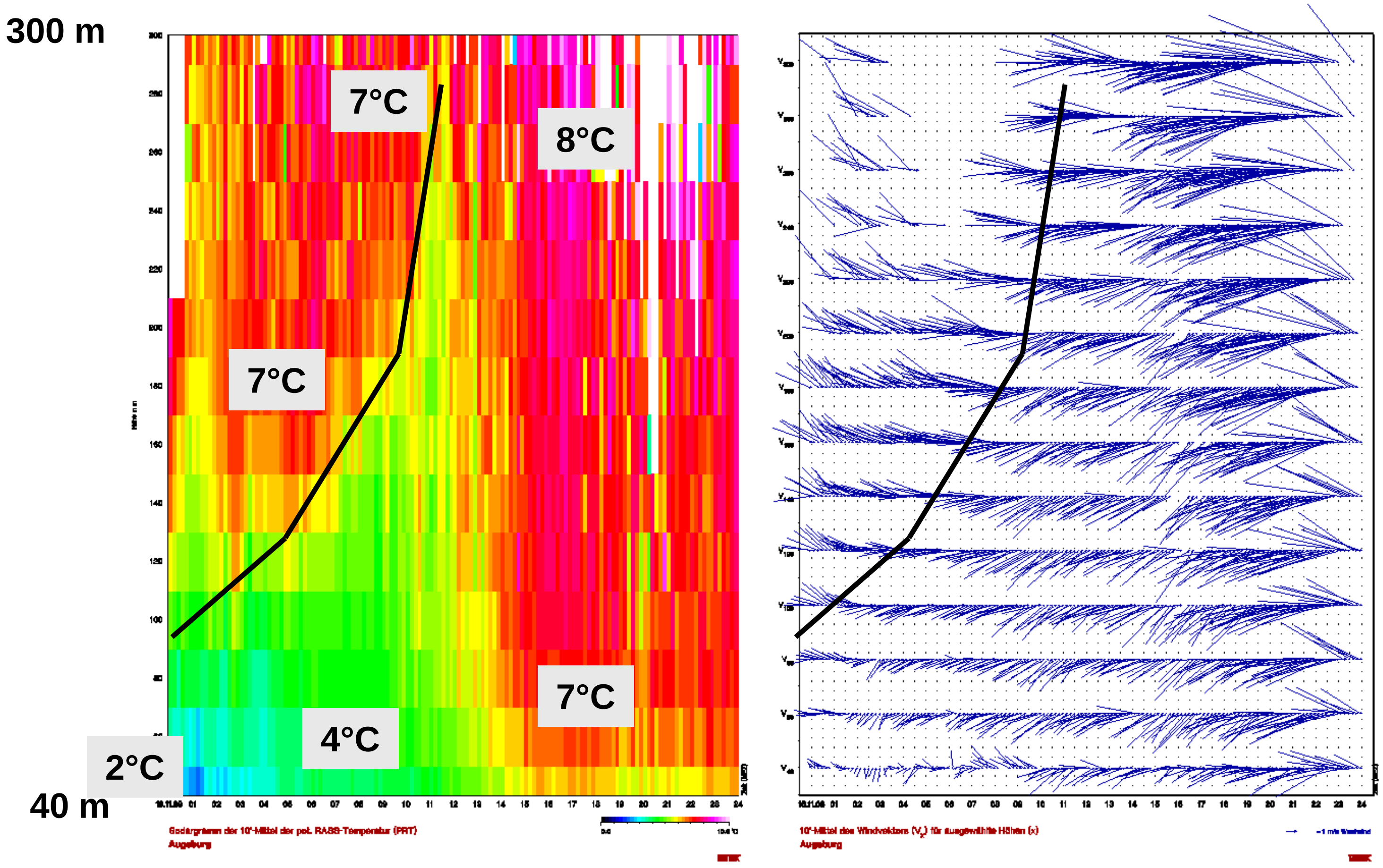
RASS data: inversion
potential temperature (left), horizontal wind (right)



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Examples were obtained in vertical profiling mode.

Today's wind lidars allow for scanning as well.

➔ wind fields in valleys, over cities, across coastlines

➔ analysis of turbine wakes

But:

3d wind vector from one instrument (DBS or conical scanning) may be problematic in complex terrain, because assumptions (horizontal homogeneity) are not met.

➔ corrections or
➔ modified measurement strategies are necessary

(e.g.: virtual towers by combining three lidars looking at one atmospheric column)

Corrections to volume-averaging remote sensing in complex terrain

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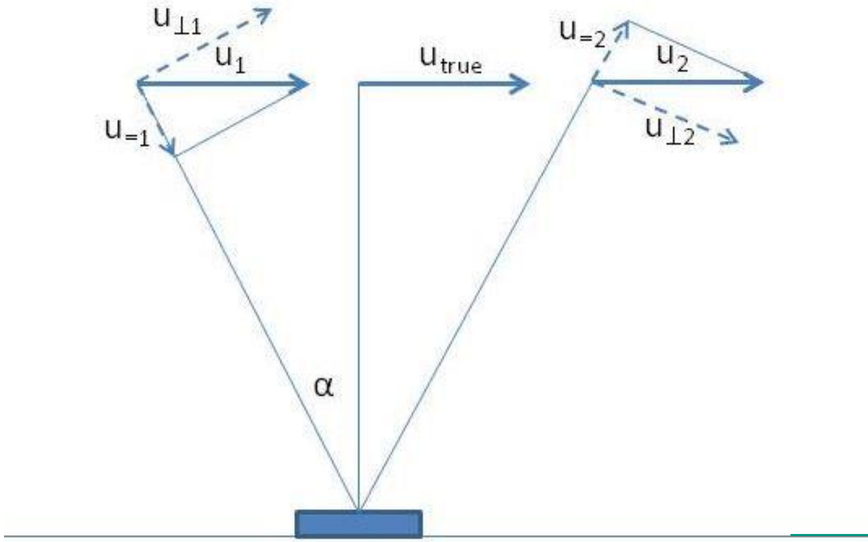
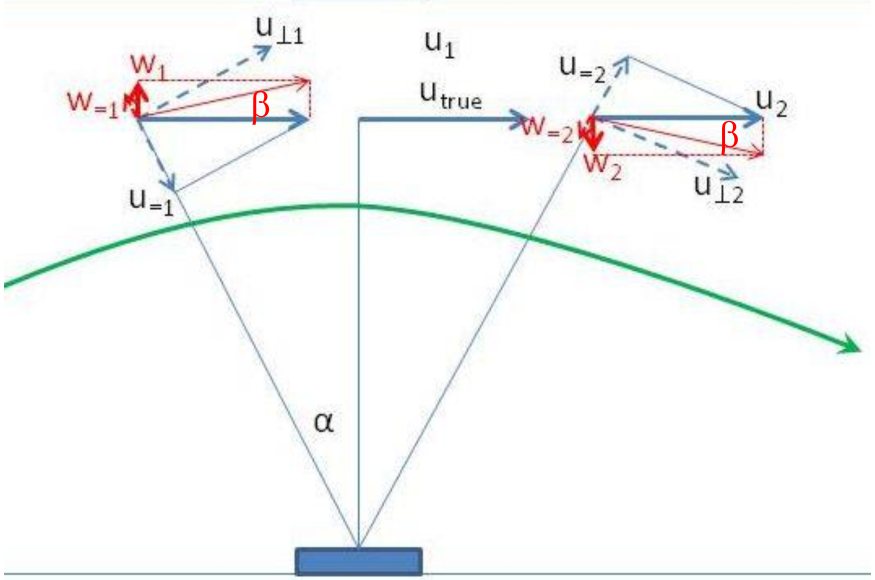


$$u_{Lidar} = u_{true}$$



$$u_{Lidar} = u_{true}(1 - \frac{\sin\beta}{\tan\alpha})$$

complex terrain

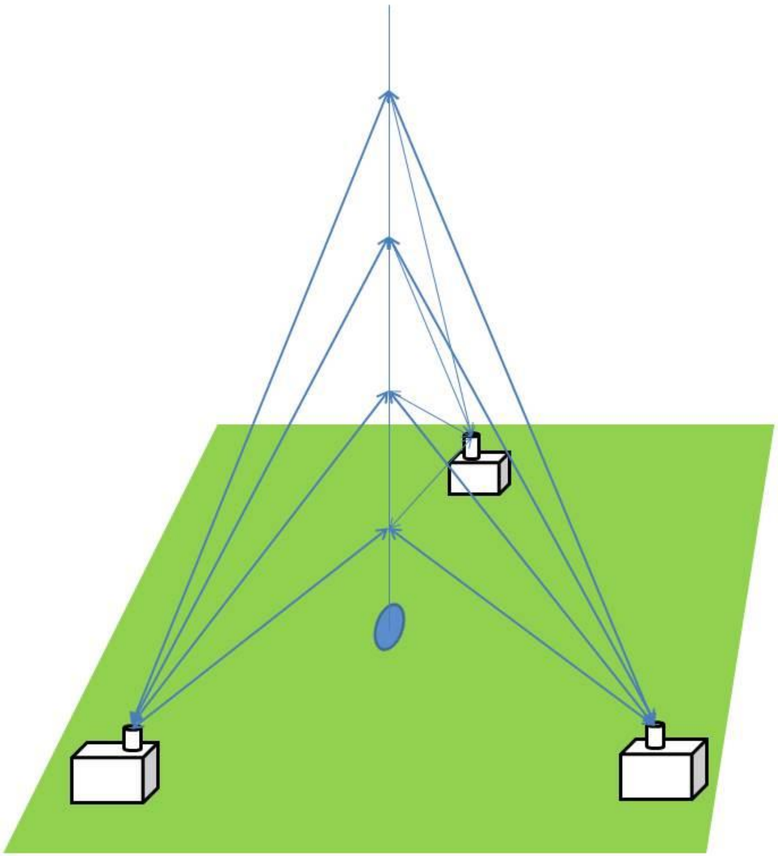
example:

α = 15°

β = 0.5° ➔ sin β / tan α = 0.032
β = 5° ➔ sin β / tan α = 0.32

virtual towers can overcome the problems in complex terrain

Calhoun et al. 2006, J Appl Meteor Climatol **45**, 1116–1126.
Damian et al. 2014, Meteorol Z, **23**, DOI: 10.1127/0941-2948/2014/0543.



For instance:

three wind lidars
scanning head is fully programmable

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Summary

Modelling: problems in dealing with the broad spectra of space and time scales

problems in two-way coupling of meso- and micro-scale models

Measurements: problems with volume-averaging remote sensing techniques in complex terrain

Both issues still look for suitable solutions.


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Thank you very much for your attention