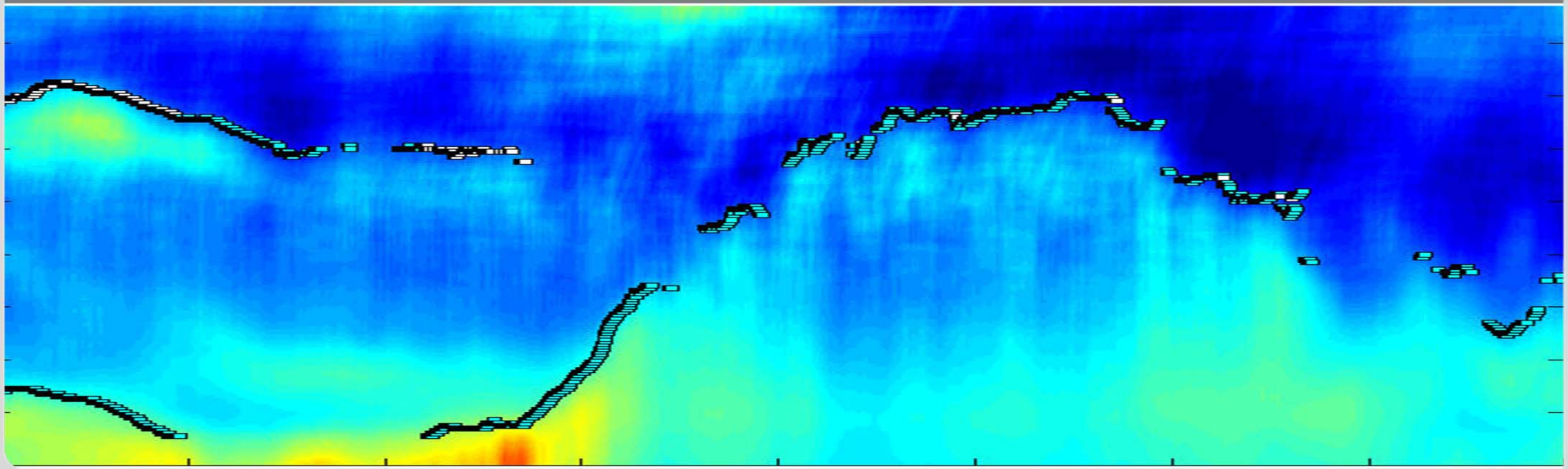
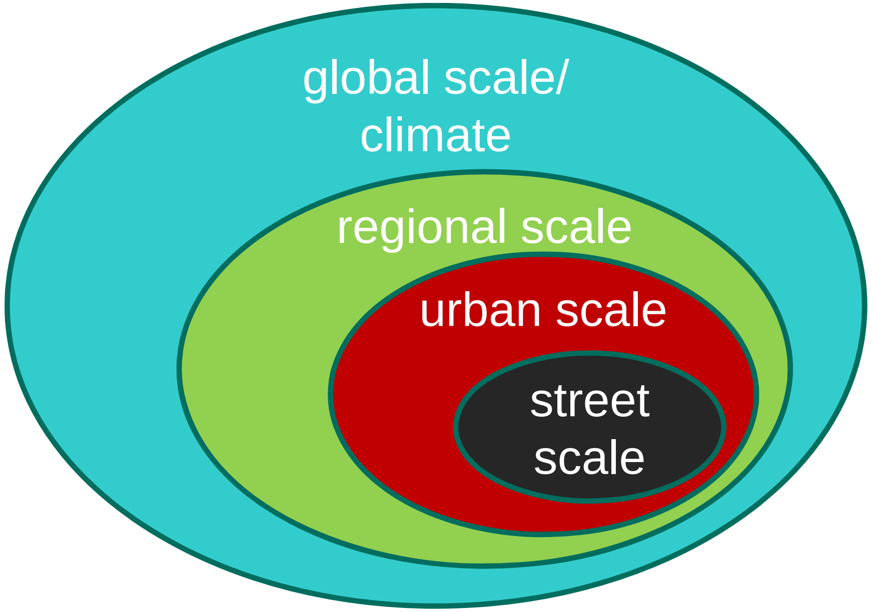
Observational techniques to analyse urban atmospheres across scales

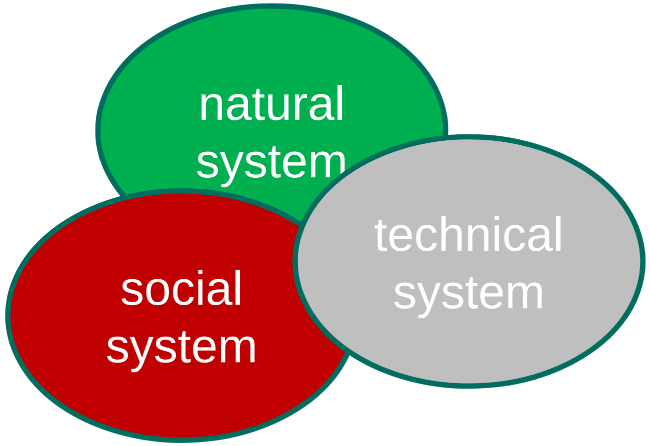
Stefan Emeis
Karlsruhe Institute of Technology
stefan.emeis@kit.edu

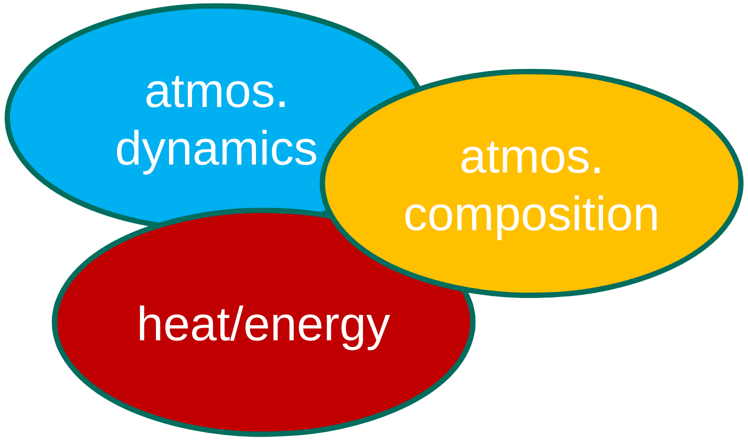
INSTITUTE OF METEOROLOGY AND CLIMATE RESEARCH, Atmospheric Environmental Research

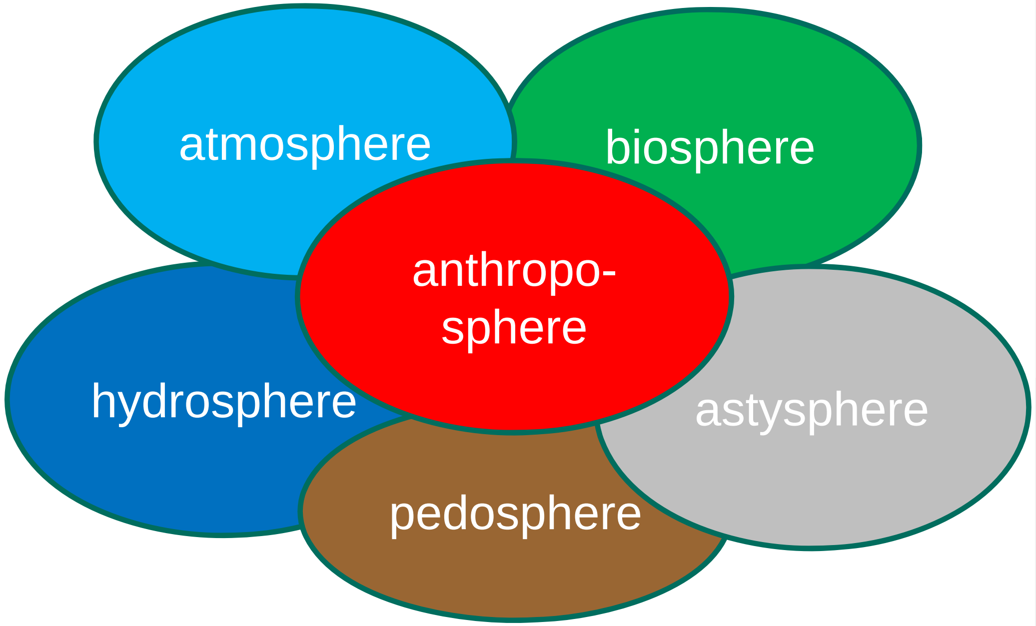


Challenges: various kinds of scale interactions

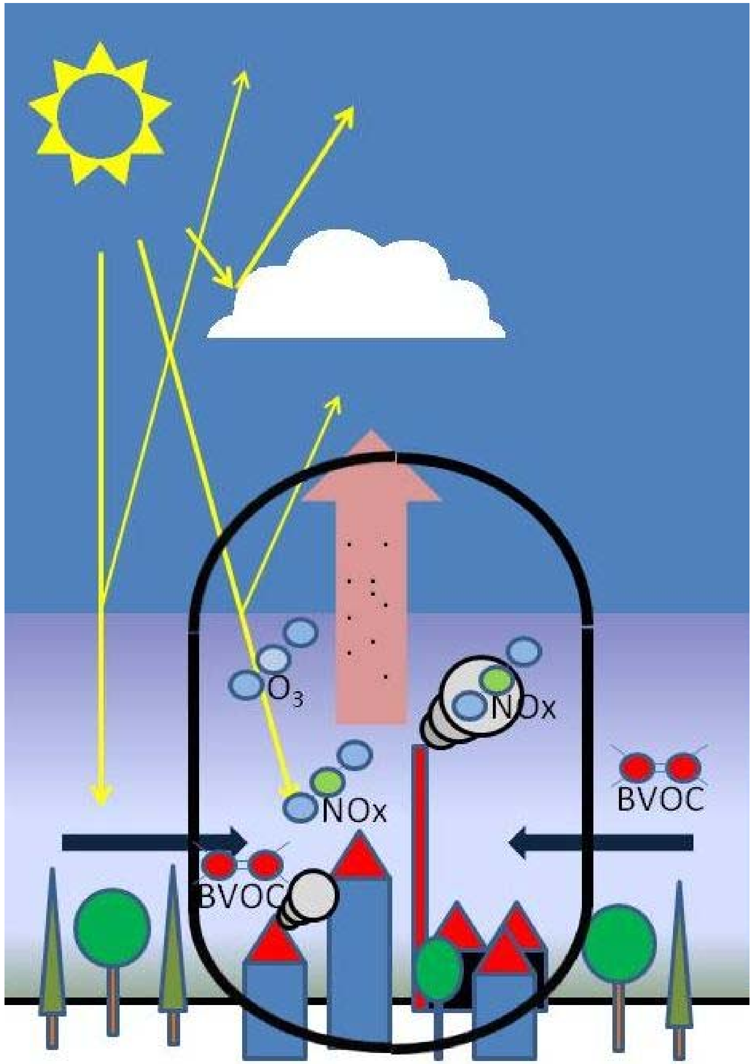








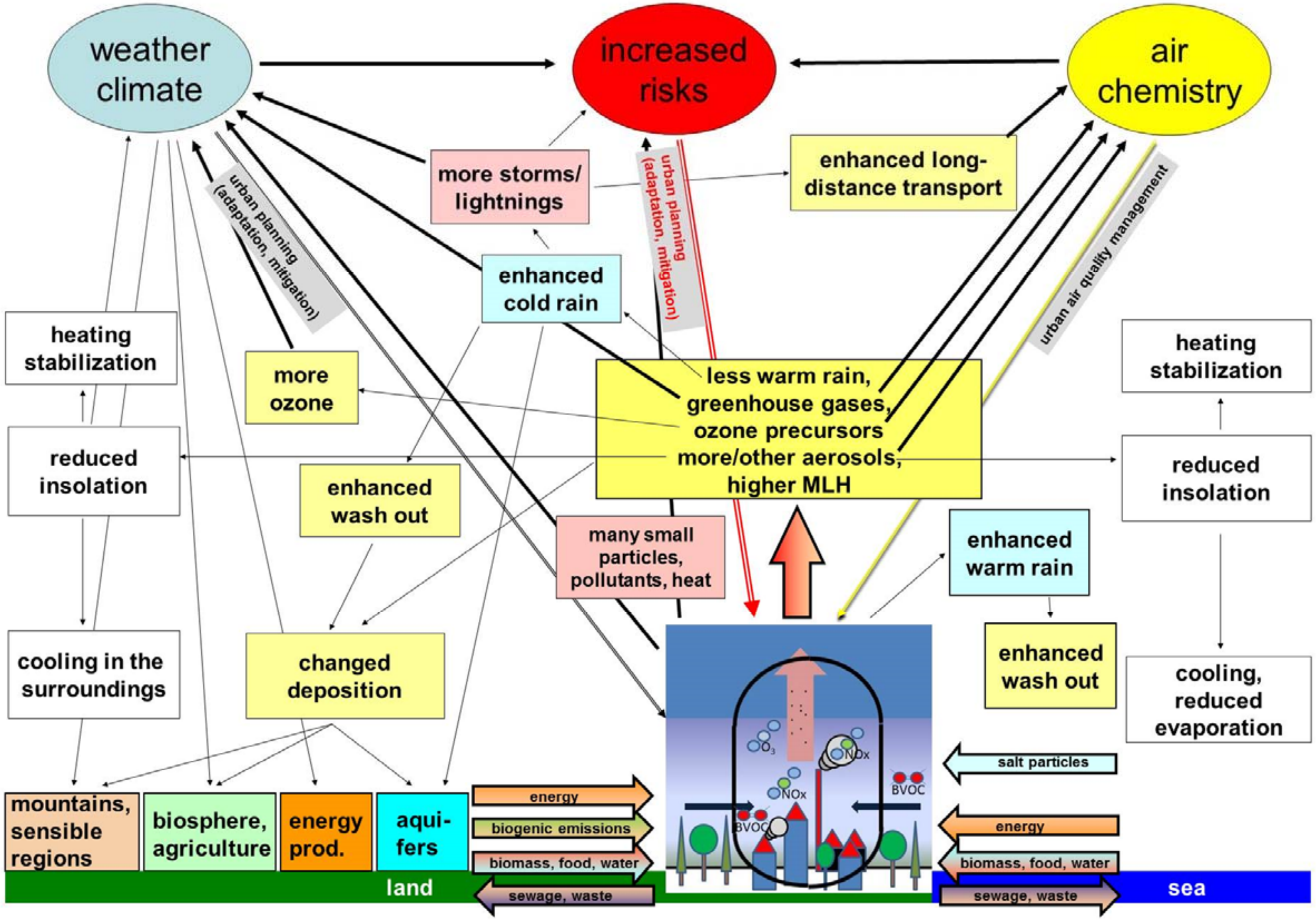
City atmospheres – reaction vessels with global impact



Internal processes and exchange with embedding compartments of the Earth system

- **urban wind and radiative regimes**
- **urban heat island(s)**
- **secondary circulations and matter transports**
- **natural emissions (inside and outside of cities)**
- **anthropogenic emissions**
- **air chemistry, aerosol formation**
- **impact on local and regional air quality**
- **impact on regional and global climate**

Coupling to other compartments of the Earth system

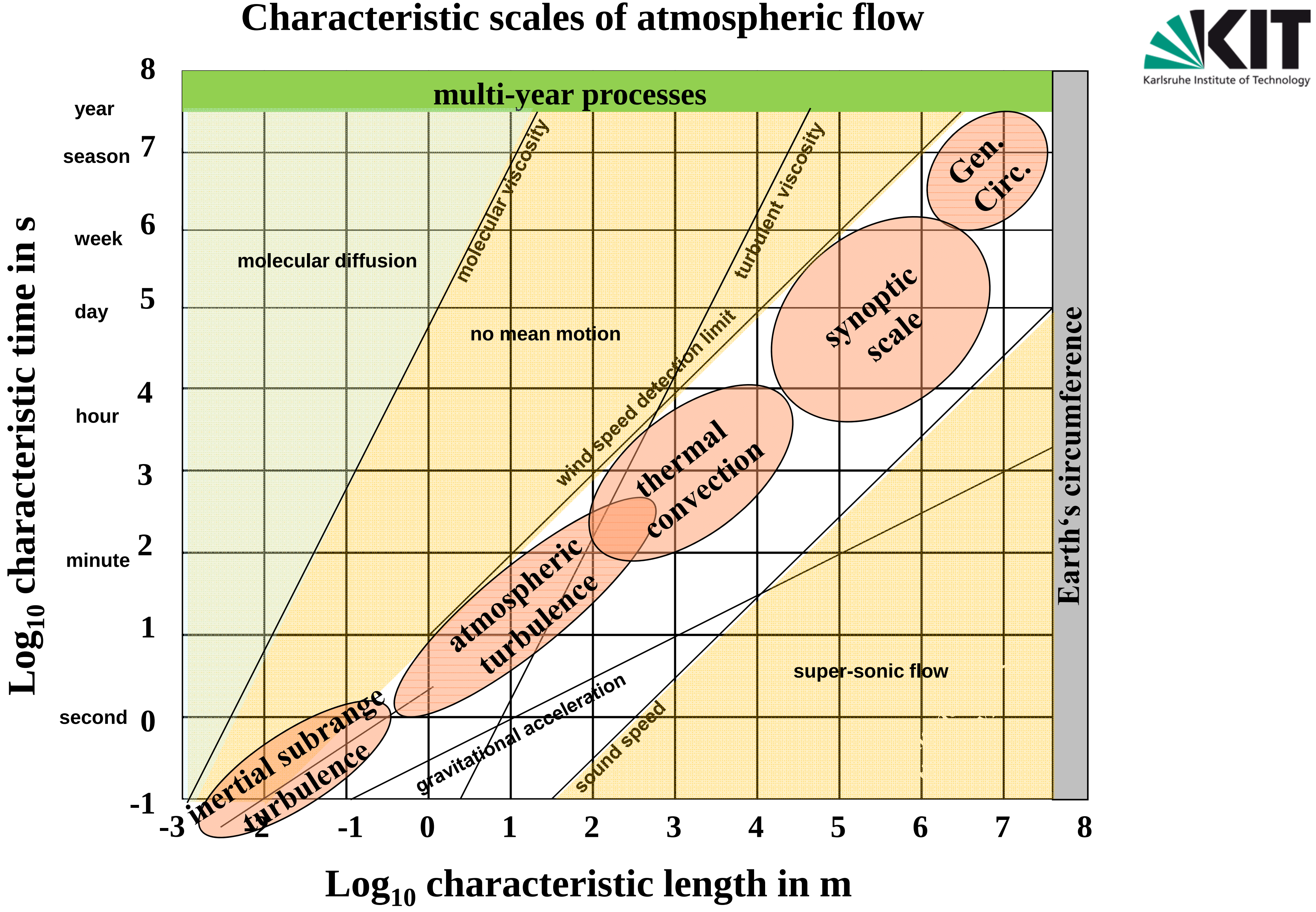


Institute for Meteorology and Climate Research – Atmospheric Environmental Research

Photo: 2011 Stefan Emeis

Warmer cities influence the local and regional climate (clouds over Manhattan on 28th May 2011)

Characteristic scales of atmospheric flow



Institute for Meteorology and Climate Research –
Atmospheric Environmental Research

Karlsruhe Institute of Technology

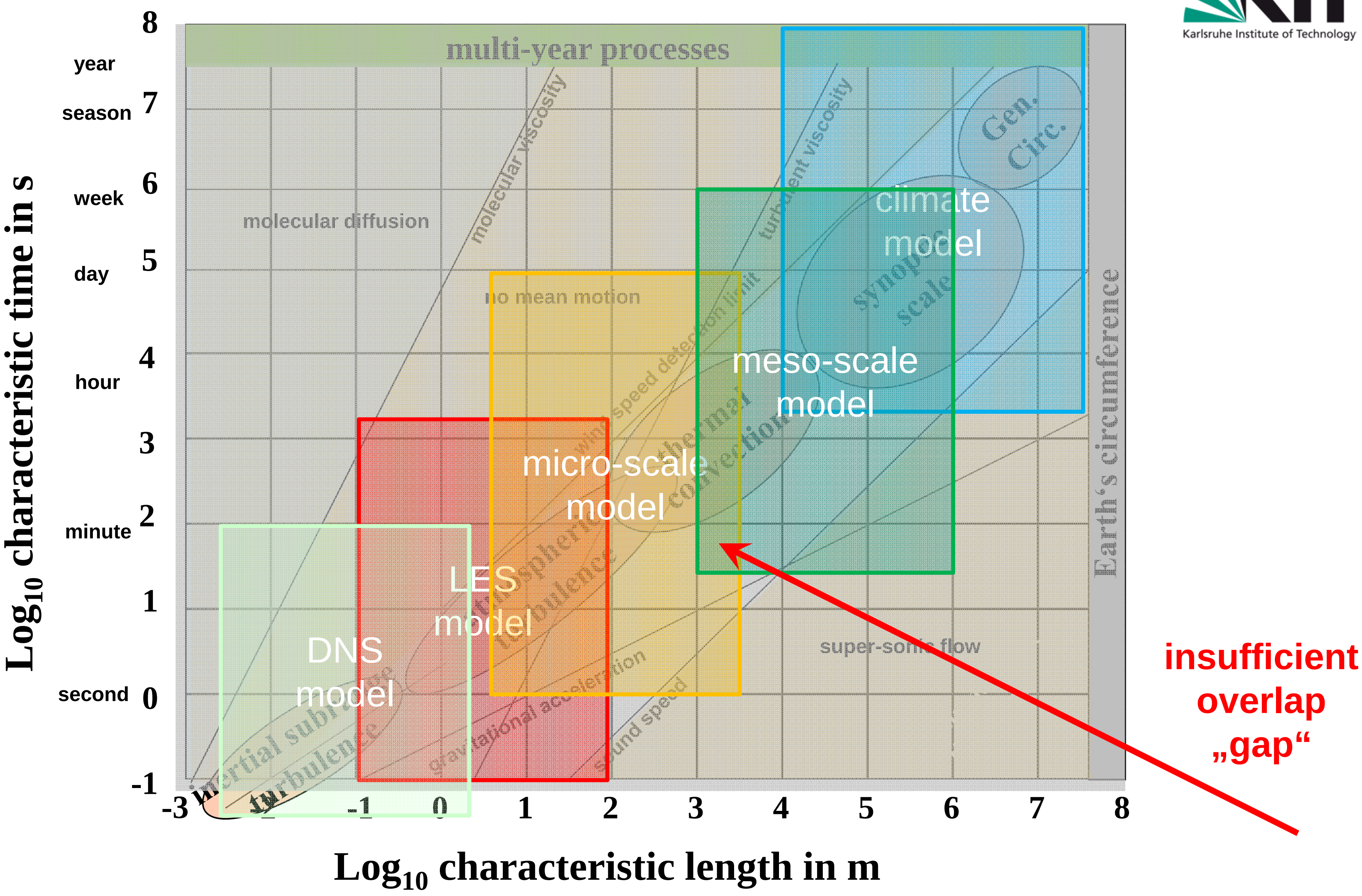
Main problem for numerical models:

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 (Δx ~ o(10 - 100 km))
- meso-scale (regional) models (Δx ~ o(1 - 10 km))
- (Δx ~ o(1 km – 100 m))
- micro-scale (local) models (Δx ~ o(10 - 100 m))
- LES models (Δx ~ o(1 - 10 m))
- DNS models (Δx ~ o(1 m) or less)

Atmospheric model ranges



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 “**grey 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.

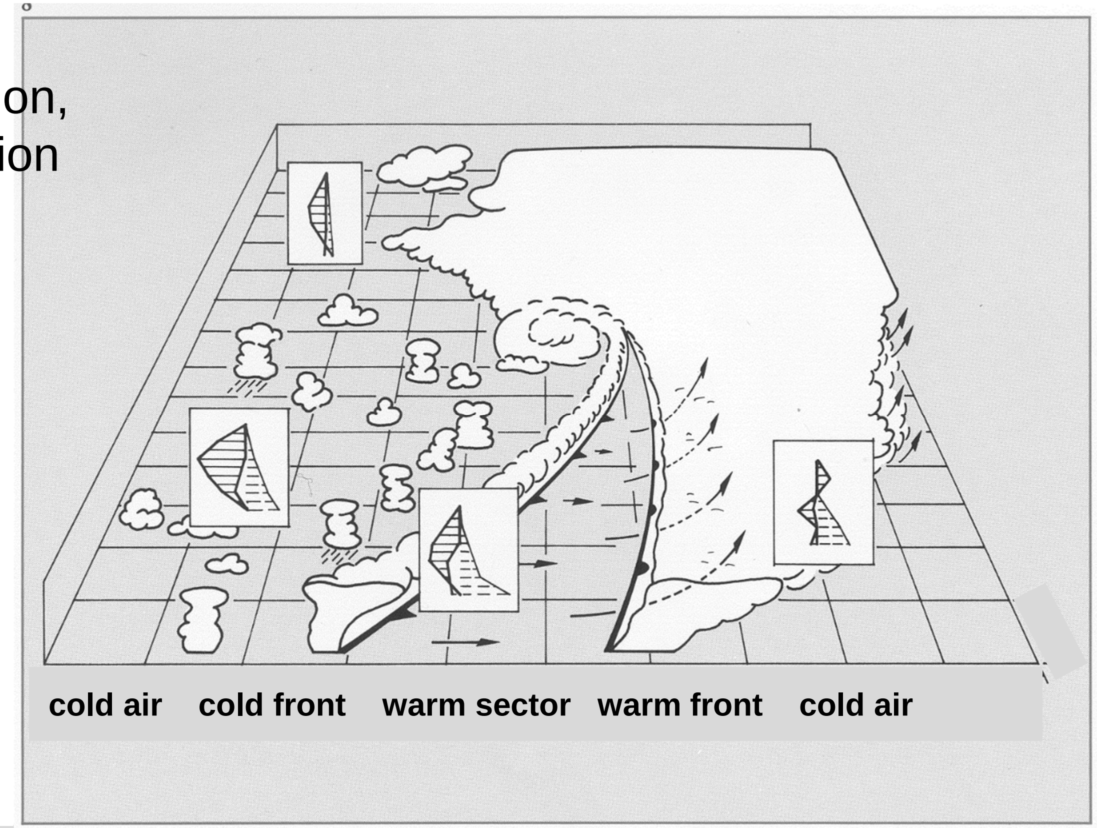
💣 The results for the large turbulence elements are no longer representing an ensemble average (as the parameterization does), but just one possible state (Martilli 2007, Int J Climatol **27**, 1909–1918).

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



These gaps prevent simulations
which take into account large-scale forcing and local-scale phenomena simultaneously allowing for two-way coupling in various fields of application:

- 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

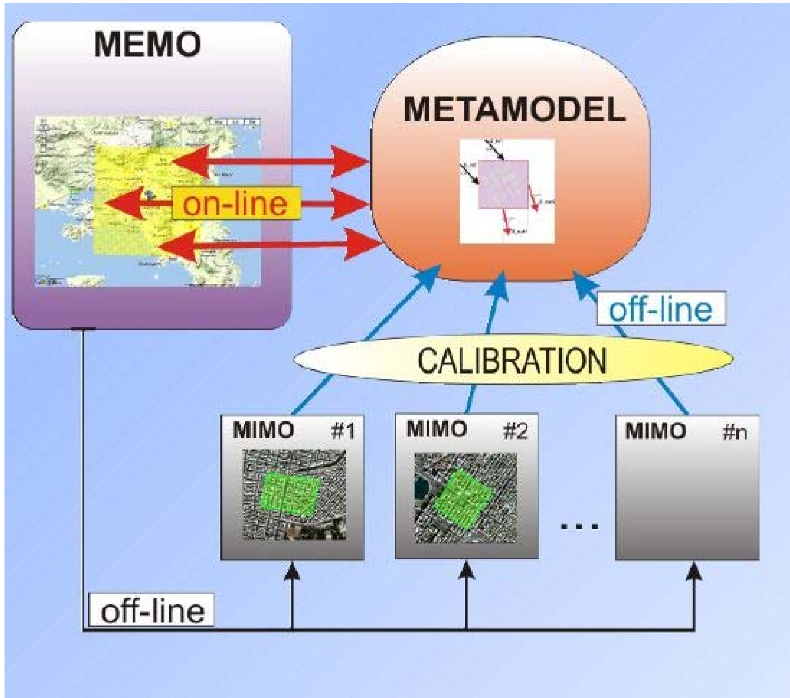
The major problem with model coupling:

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

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:

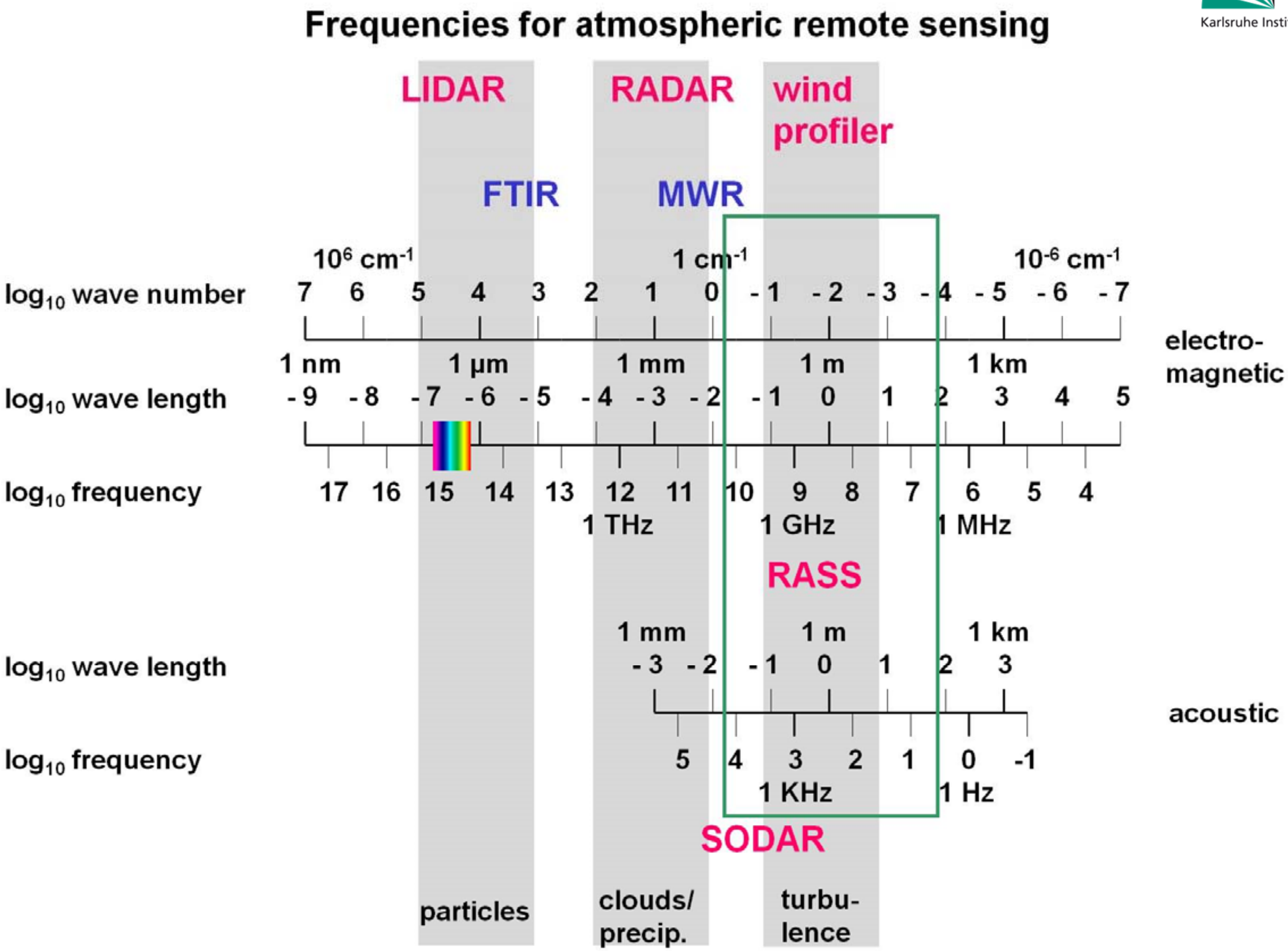
We have to learn more about the gap region.

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

Remote Sensing

passive and active
volume averaging measurements

Institute for Meteorology and Climate Research – Atmospheric Environmental Research



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.

surface-based remote sensing devices at IMK-IFU

miniSODAR,
acoustic backscatter, Doppler Analysis ➔ wind, turbulence

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

windlidar, optical backscatter, Doppler Analysis, wave length ~ 1.5 µm ➔ wind and aerosol profiles

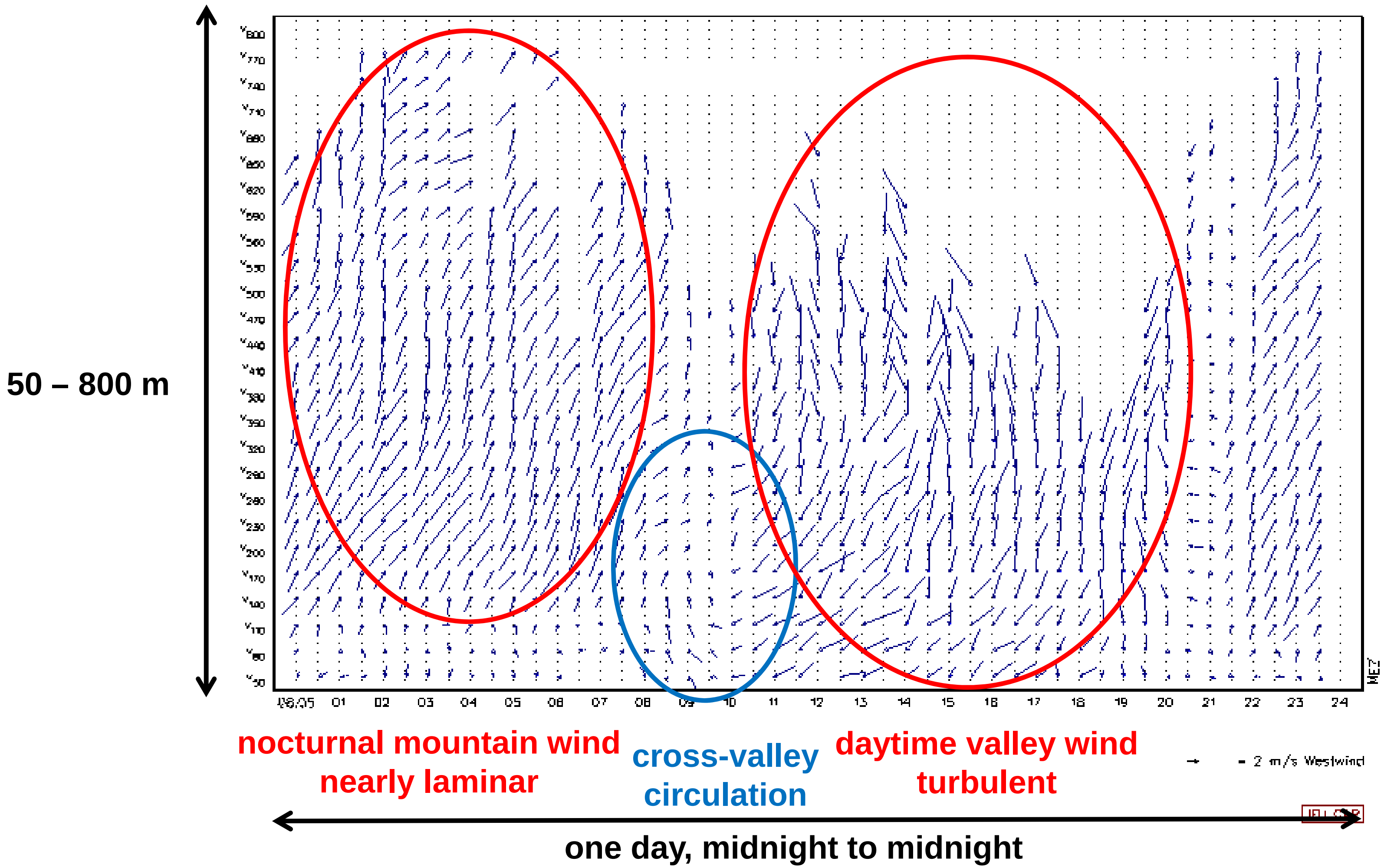
image:
Halo Photonics

ceilometer, optical backscatter, pulsed, wave length ~ 0.9 µm ➔ aerosol profiles

SODAR

wind and turbulence profiles, low-level jets

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



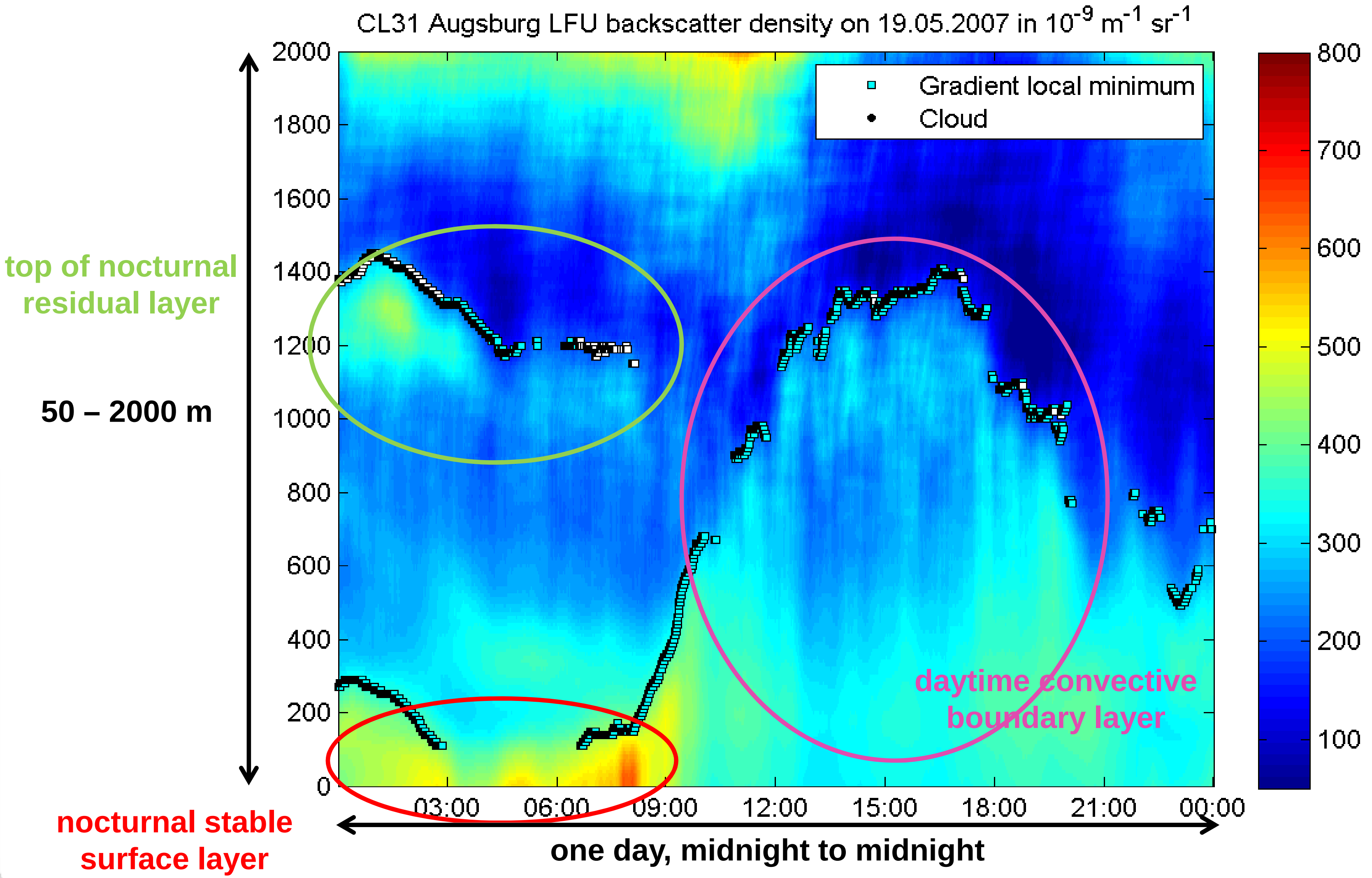
Institute for Meteorology and Climate Research –
Atmospheric Environmental Research

Ceilometer

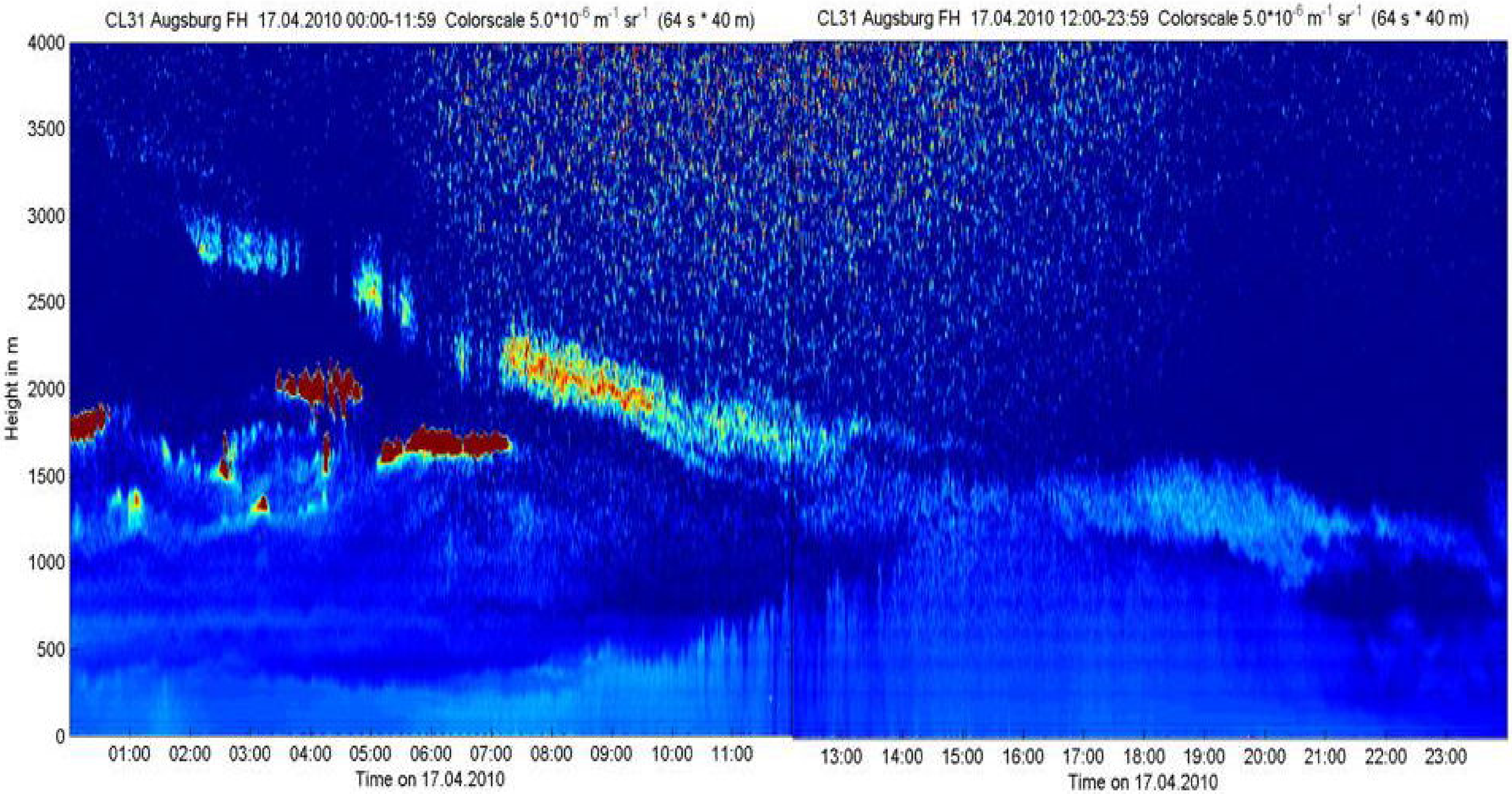
algorithms for the determination of mixing-layer height, aerosol profiles

Institute for Meteorology and Climate Research – Atmospheric Environmental Research

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



Eyjafjallajökull ash cloud over Southern Germany



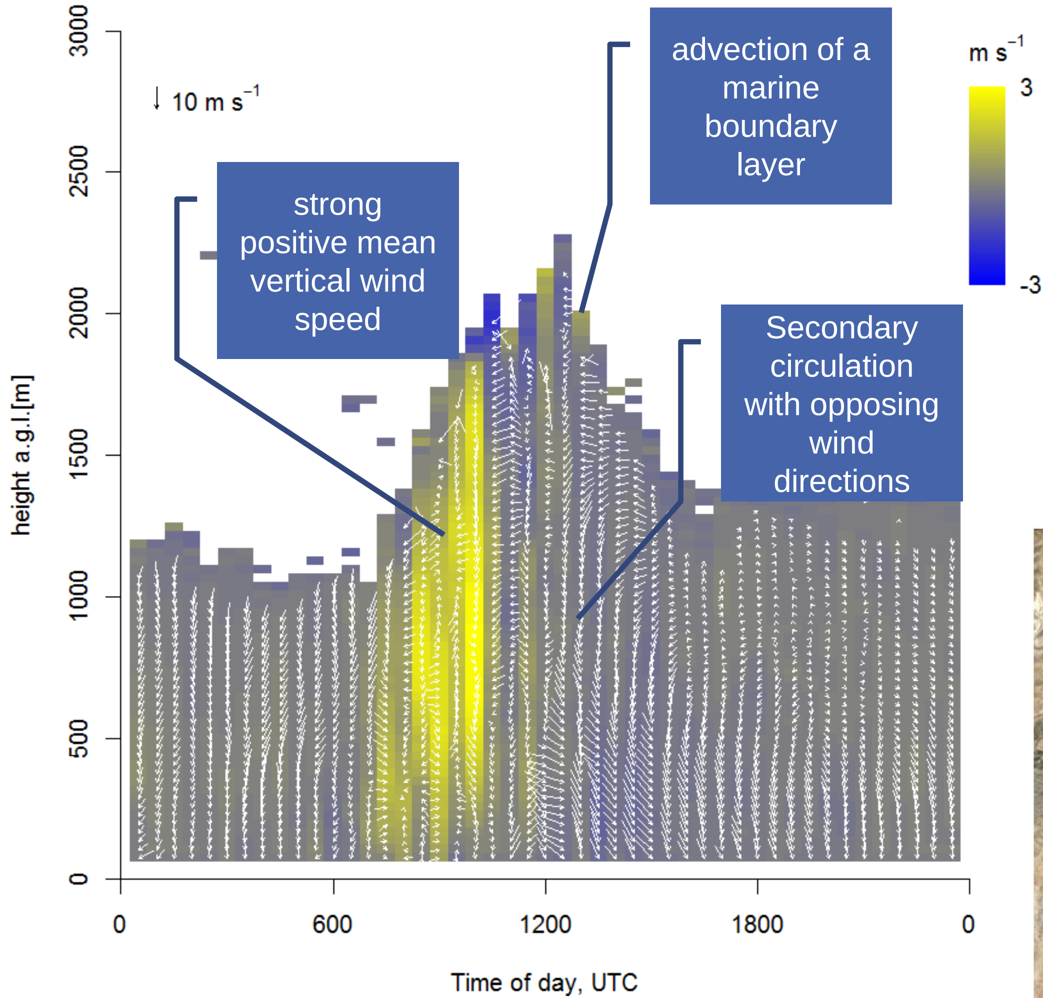
read more: Emeis, S., R. Forkel, W. Junkermann, K. Schäfer, H. Flentje, S. Gilge, W. Fricke, M. Wiegner, V. Freudenthaler, S. Groß, L. Ries, F. Meinhardt, W. Birmili, C. Münkel, F. Obleitner, P. Suppan, 2011: Measurement and simulation of the 16/17 April 2010 Eyjafjallajökull volcanic ash layer dispersion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

Doppler windlidar

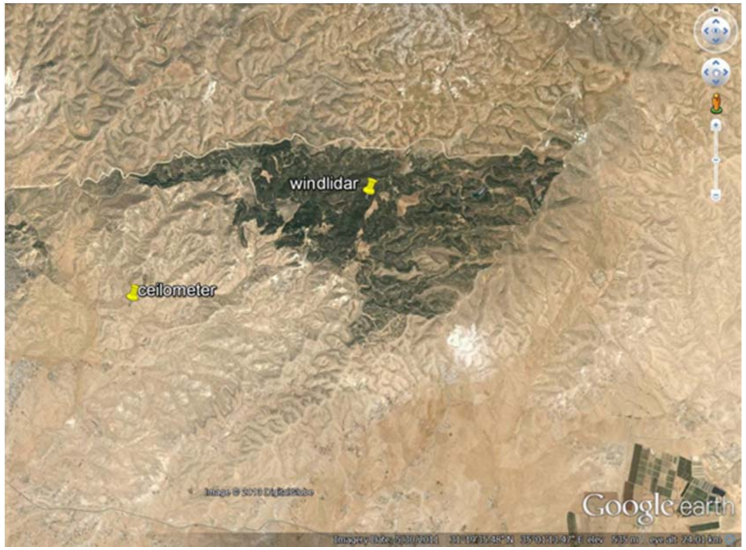
wind and turbulence profiles,
aerosol detection,
mixing-layer height, low-level jet

Institute for Meteorology and Climate Research –
Atmospheric Environmental Research

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)

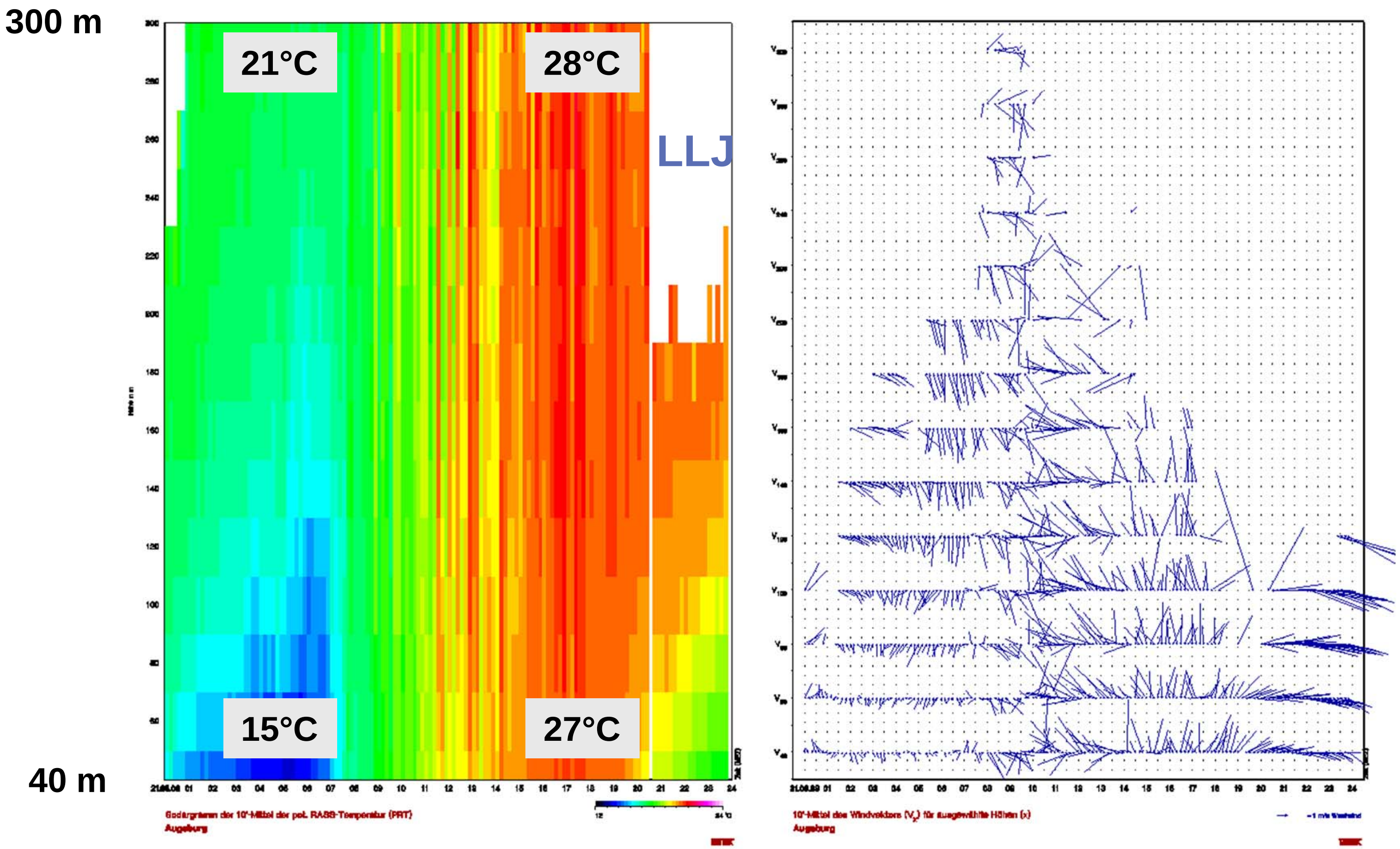


(Eder and Mauder, IMK-IFU (KIT), personal communication)

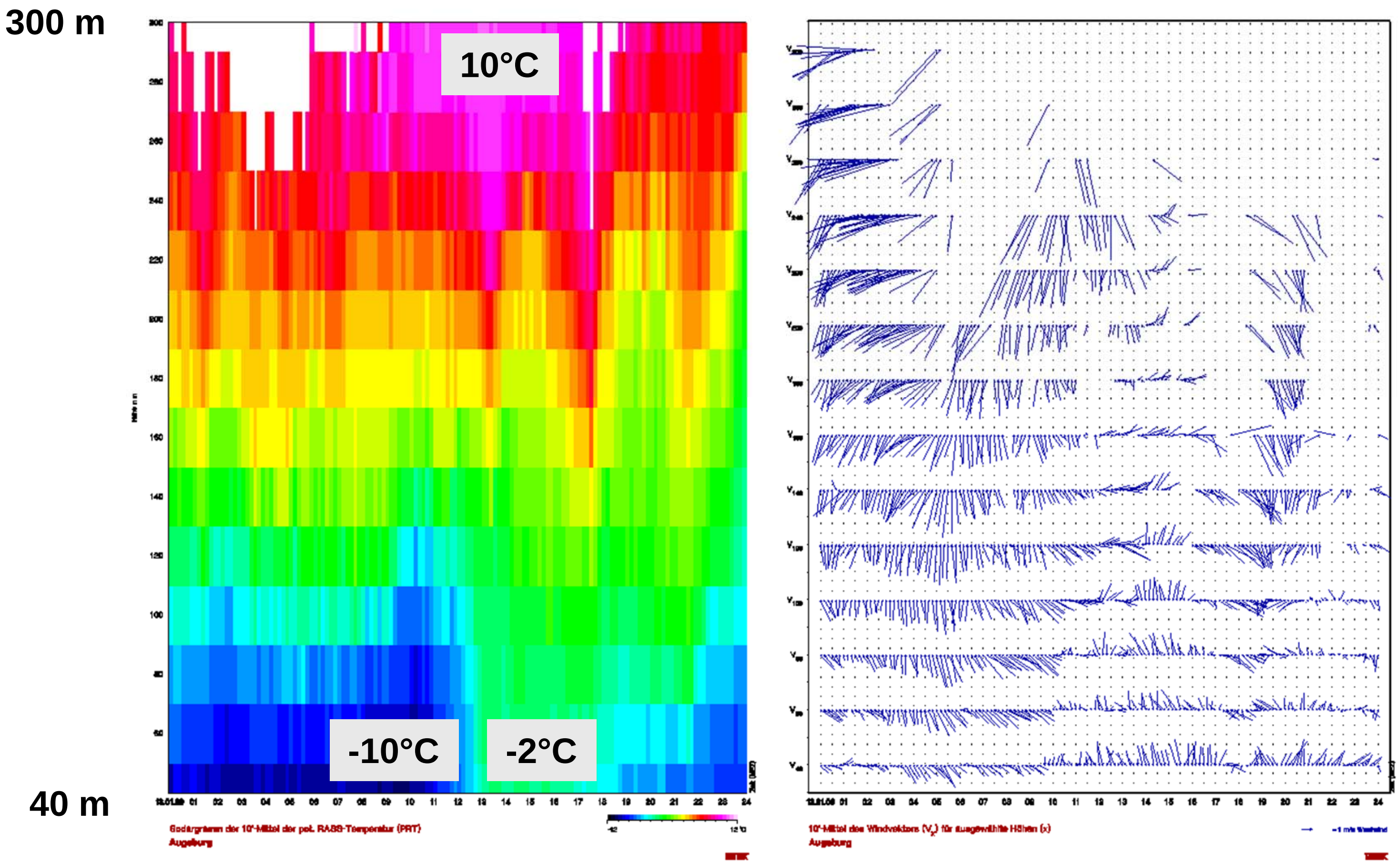
RASS

wind, turbulence and temperature profiles

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



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



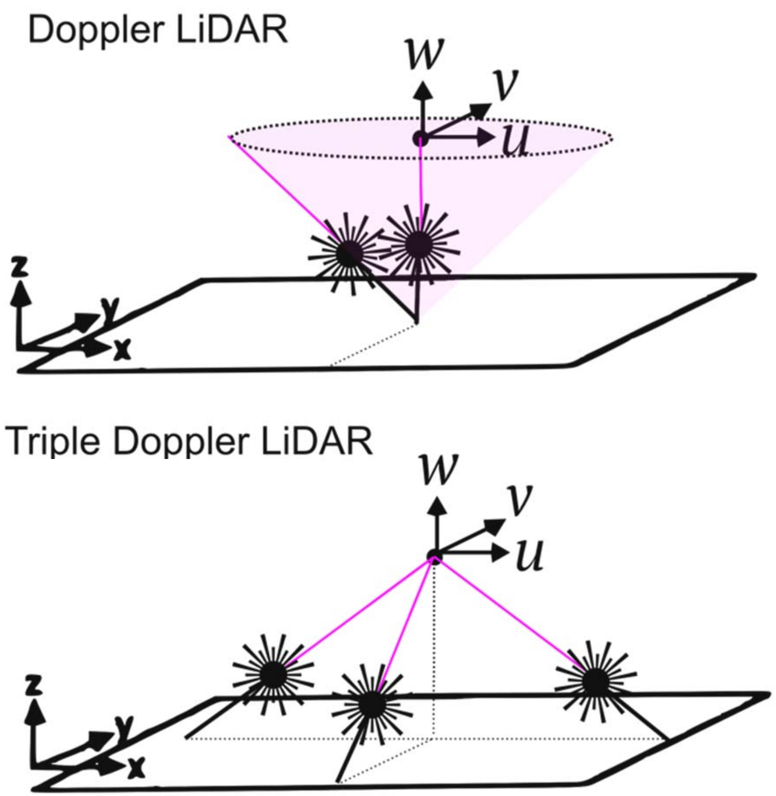
further remote sensing strategies

virtual towers
microwave attenuation
glass fibres

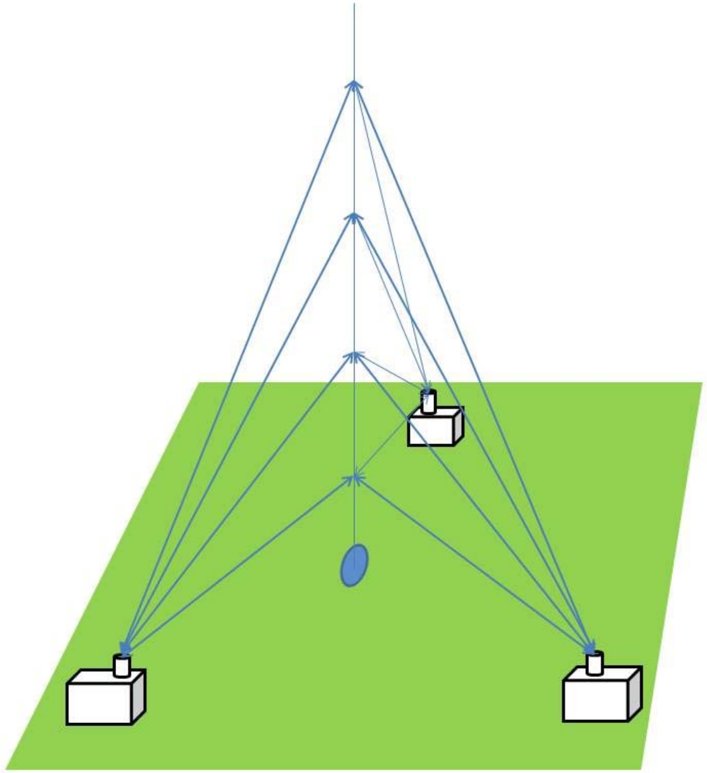
Institute for Meteorology and Climate Research –
Atmospheric Environmental Research

virtual towers can overcome remote sensing problems in complex terrain (non-homogeneity),

they deliver all three components of turbulence for a chosen profile

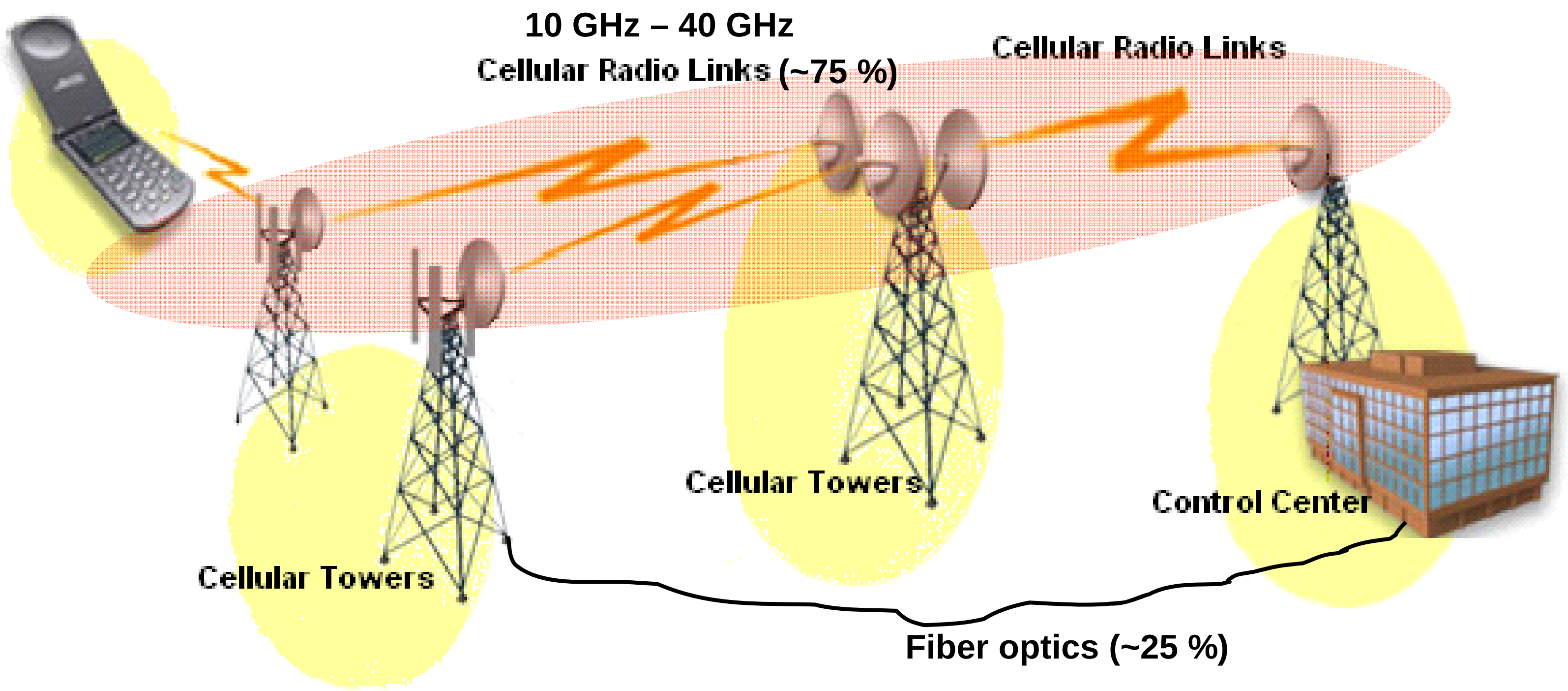


Graphics: Matthias Zeeman



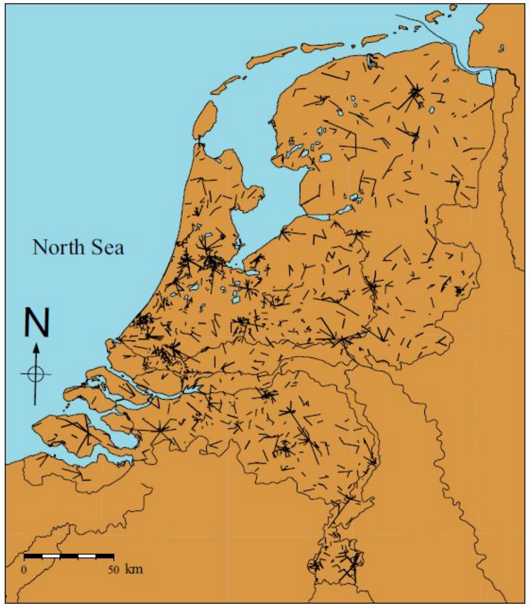
Calhoun et al. 2006, J Appl Meteor Climatol **45**, 1116–1126.
Damian et al. 2014, Meteorol Z, **23**, DOI: 10.1127/0941-2948/2014/0543.

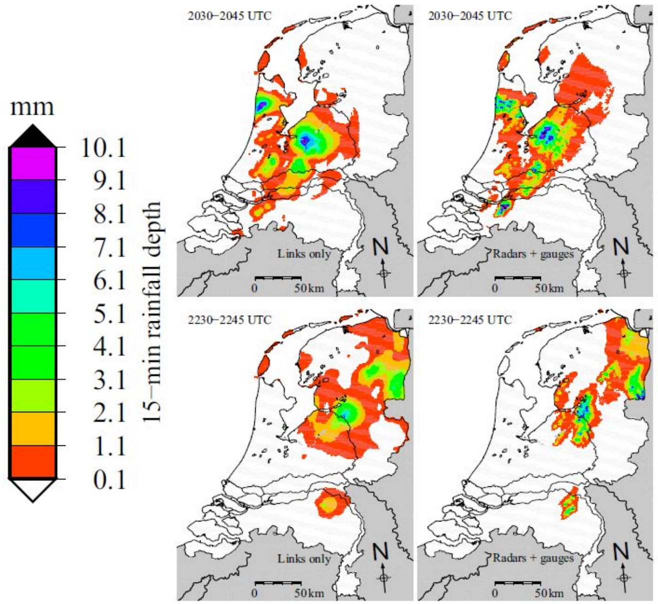
Cell phone signal attenuation
by atmospheric humidity and precipitation



Chwala, C., H. Kunstmann, S. Hipp, U. Siart, T. Eibert, 2012: Precipitation observation using commercial microwave communication links. *IEEE International Geoscience and Remote Sensing Symposium*, Munich, 2922-2925.

precipitation maps from microwave attenuation

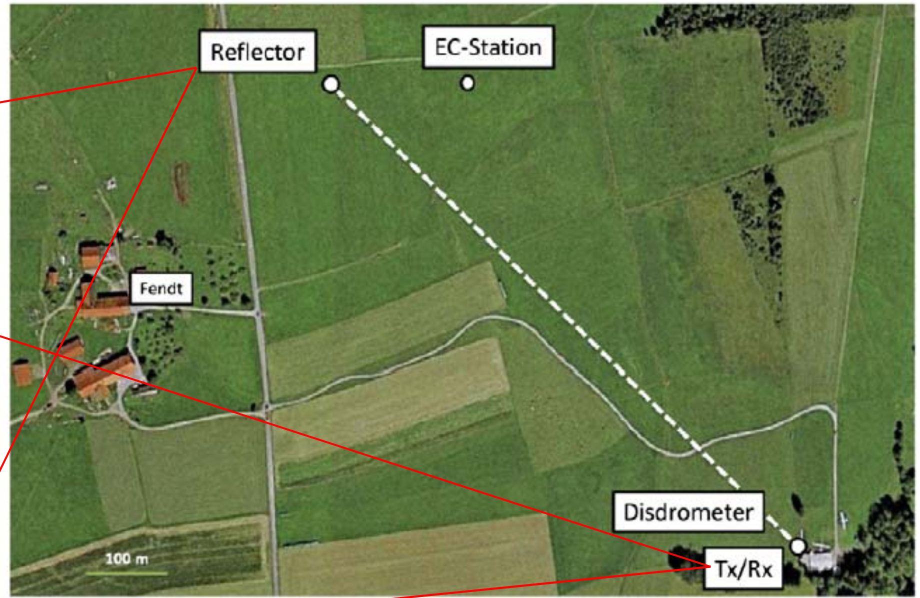


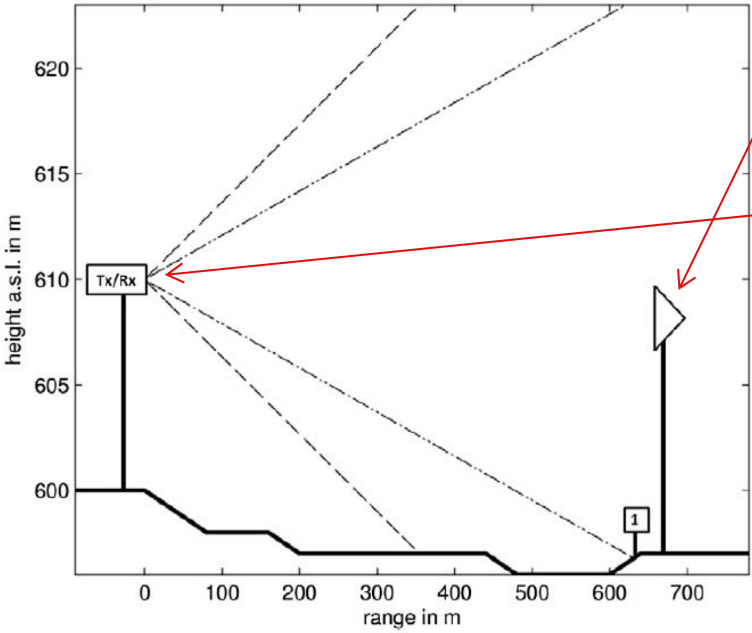


Cell phone network **radar network**

Source: Overeem, A., Hidde Leijnse, Remko Uijlenhoet, 2013: Country-wide rainfall maps from cellular communication networks. PNAS, **110**, 2741-2745.

path-averaged precipitation and absolute humidity measurements by microwave attenuation at 22 and 35 GHz





Chwala, C., H. Kunstmann, S. Hipp, U. Siart, 2014: A monostatic microwave transmission experiment for line integrated precipitation and humidity remote sensing. Atmospheric Research, **144**, 57-72.

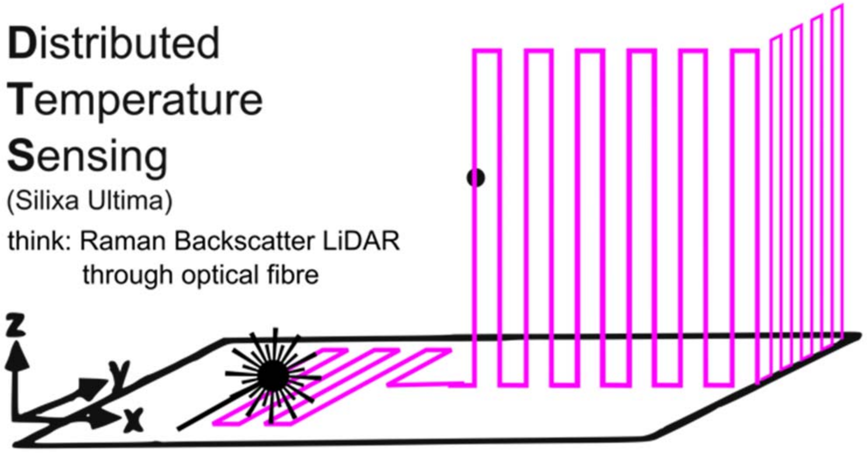
Principle of Distributed temperature sensor (DTS)

Karlsruhe Institute of Technology

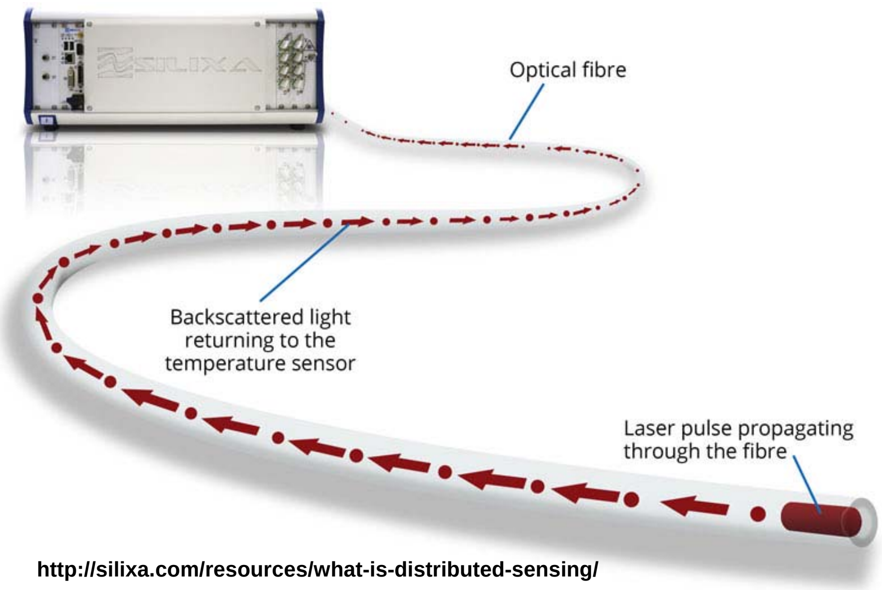
optical time-domain reflectometry

Raman backscatter is recorded in the time domain.

A short pulse of light is launched into the fibre. The forward propagating light generates Raman backscattered light at two distinct wavelengths, from all points along the fibre.



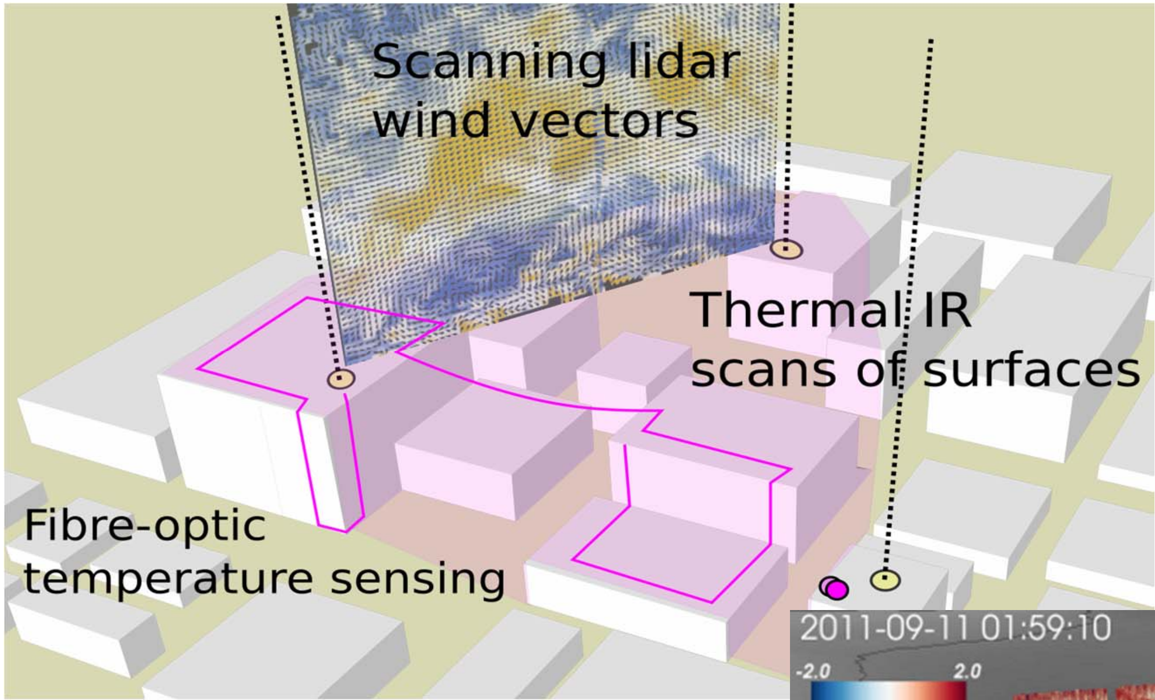
Graphics: Matthias Zeeman

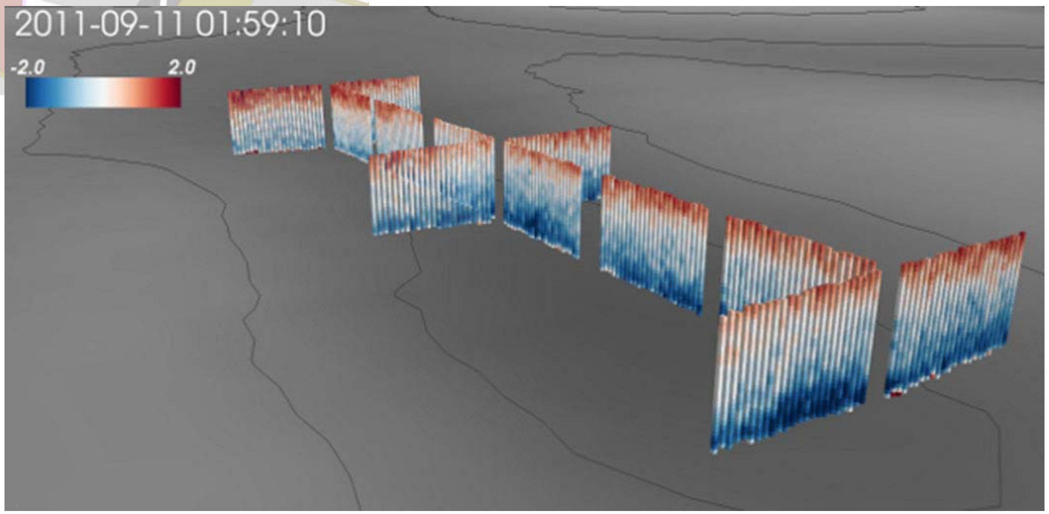


http://silixa.com/resources/what-is-distributed-sensing/

Zeeman, M.J., J.S. Selker, C.K. Thomas, 2015: Near-Surface Motion in the Nocturnal, Stable Boundary Layer Observed with Fibre-Optic Distributed Temperature Sensing. Bound.-Layer Meteorol., **154**, 189–205

different strategies for temperature measurements





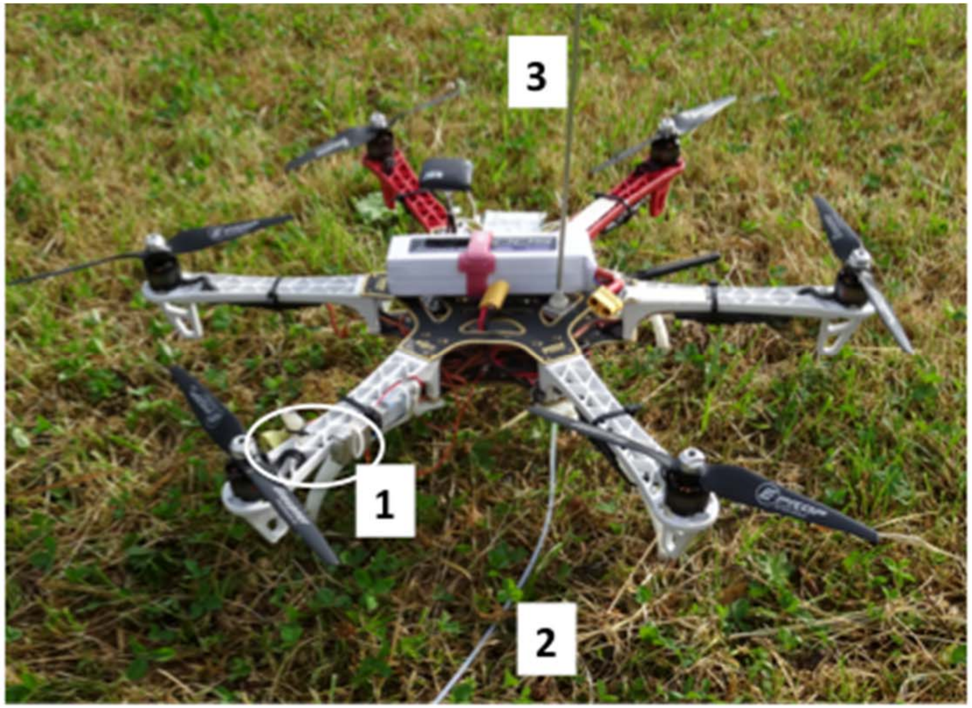
Graphics: Matthias Zeeman

further sensing strategies

airborne measurement systems at IMK-IFU, KIT

Karlsruhe Institute of Technology

UAV or drone (hexacopter)



1 Air temperature and humidity sensors

2 Teflon tube

3 Tube extension above hexacopter

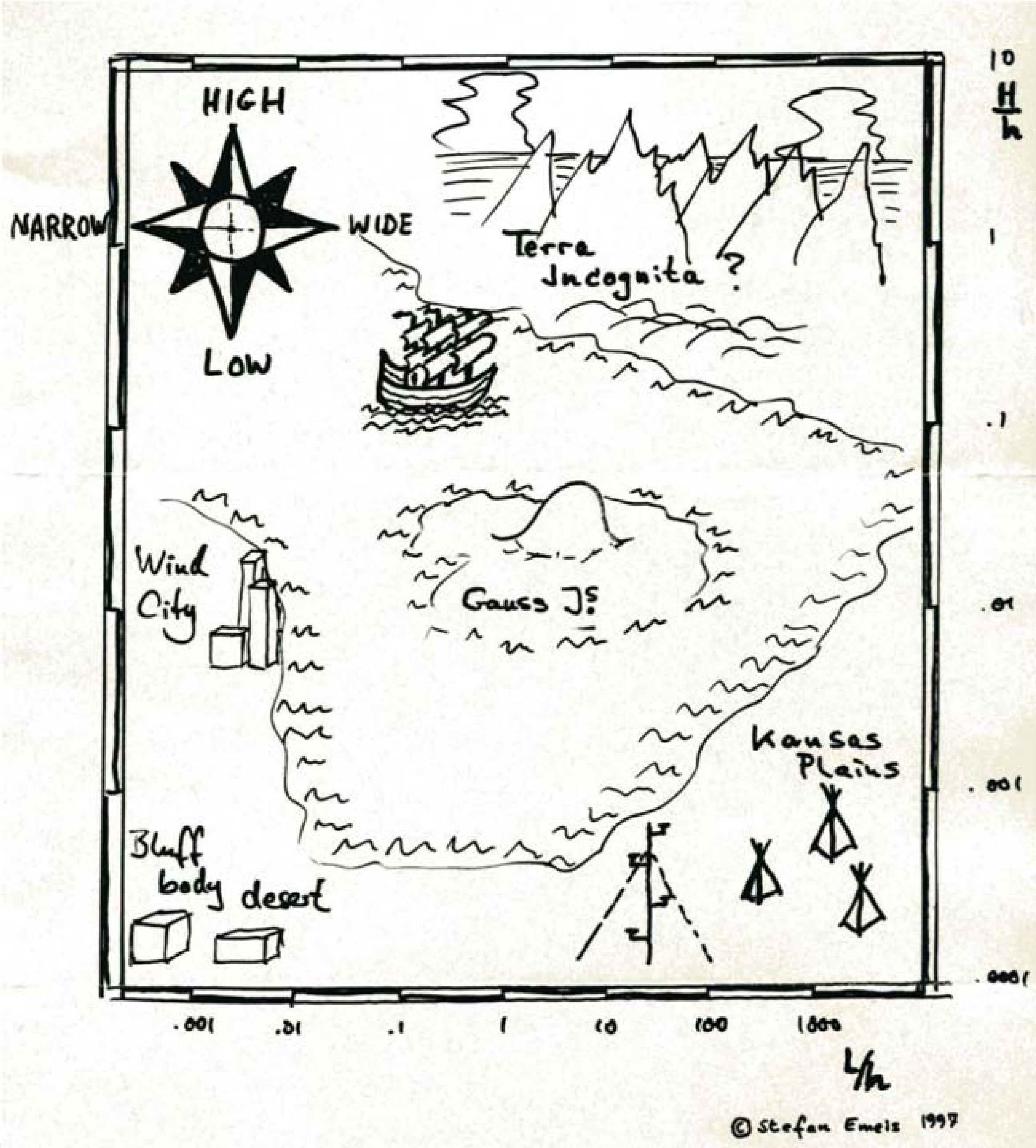
Summary

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 areas with strong gradients

Both issues still look for suitable solutions.


HIGH
NARROW
WIDE
LOW
Terra
Incognita ?
Wind
City
Gauss Is
Kansas
Plains
Bluff
body desert
10
H/h
1
.1
.01
.001
.0001
.001
.01
.1
1
10
100
1000
L/h
© Stefan Emeis 1997


KIT
Karlsruhe Institute of Technology
Thank you very much for your attention