Observational techniques to analyse urban atmospheres across scales

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Challenges: various kinds of scale interactions

- Global scale/ climate
- Regional scale
- Urban scale
- Street scale

- Natural system
- Technical system
- Social system

- Atmosphere
- Biosphere
- Anthroposphere
- Hydrosphere
- Pedosphere
- Astysphere

- Atmos. dynamics
- Atmos. composition
- Heat/energy
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
Warmer cities influence the local and regional climate
(clouds over Manhattan on 28th May 2011)
Characteristic scales of atmospheric flow

Log$_{10}$ characteristic length in m

- Earth’s circumference
- multi-year processes
- super-sonic flow
- synoptic scale
- thermal convection
- atmospheric turbulence
- inertial subrange turbulence
- gravitational acceleration
- wind-speed deposition limit
- turbulent viscosity
- molecular viscosity
- no mean motion

Log$_{10}$ characteristic time in s

- year
- season
- week
- day
- hour
- minute
- second
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 ($\Delta x \sim o(10 - 100 \text{ km})$)
- meso-scale (regional) models ($\Delta x \sim o(1 - 10 \text{ km})$)
- ($\Delta x \sim o(1 \text{ km} - 100 \text{ m})$)
- micro-scale (local) models ($\Delta x \sim o(10 - 100 \text{ m})$)
- LES models ($\Delta x \sim o(1 - 10 \text{ m})$)
- DNS models ($\Delta x \sim o(1 \text{ m})$ or less)
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 detailed 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
Frequencies for atmospheric remote sensing

<table>
<thead>
<tr>
<th>Method</th>
<th>FTIR</th>
<th>MWR</th>
<th>LIDAR</th>
<th>RADAR</th>
<th>wind profiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log_{10}$ wave number</td>
<td>7, 6, 5, 4, 3, 2, 1</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
<td>$10^6$ cm$^{-1}$</td>
<td>$10^6$ cm$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$\log_{10}$ wave length</td>
<td>1 nm, 1 μm, 1 mm, 1 m, 1 km</td>
<td>1 mm, 1 m, 1 km</td>
<td>1 nm, 1 μm, 1 mm, 1 m, 1 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\log_{10}$ frequency</td>
<td>17, 16, 15, 14, 13, 12, 11</td>
<td>11, 10, 9, 8, 7, 6, 5</td>
<td>1 THz, 1 GHz, 1 MHz</td>
<td>1 KHz, 1 Hz</td>
<td></td>
</tr>
</tbody>
</table>

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

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)

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

CL31 Augsburg LFU backscatter density on 19.05.2007 in $10^{-9}$ m$^{-1}$ sr$^{-1}$

- Gradient local minimum
- Cloud

Top of nocturnal residual layer

50 – 2000 m

Nocturnal stable surface layer

Daytime convective boundary layer

One day, midnight to midnight

Institute for Meteorology and Climate Research – Atmospheric Environmental Research
Eyjafjallajökull ash cloud over Southern Germany

Doppler windlidar

wind and turbulence profiles, aerosol detection, mixing-layer height, low-level jet
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
virtual towers can overcome remote sensing problems in complex terrain (non-homogeneity),

they deliver all three components of turbulence for a chosen profile

Calhoun et al. 2006, J Appl Meteor Climatol 45, 1116–1126.
Cell phone signal attenuation by atmospheric humidity and precipitation

precipitation maps from microwave attenuation

A monostatic microwave transmission experiment for line integrated precipitation and humidity remote sensing. Atmospheric Research, 144, 57-72.
**Principle of Distributed temperature sensor (DTS)**

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.


http://silixa.com/resources/what-is-distributed-sensing/
different strategies for temperature measurements

Graphics: Matthias Zeeman
further sensing strategies
airborne measurement systems
at IMK-IFU, KIT

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.
Thank you very much for your attention