Air Quality in Megacities: A Challenge for Interdisciplinary Research

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IMK-IFU topics:

**Air quality**, atmosphere-biosphere exchange, **hydrology**, long-term trends

- USA
- Europe
- Inner Mongolia
- Beijing
- Mexico
- Burkina Faso
- Alps
- Kenya
- South-East-Asia
- S-Africa
- S-Africa
- Santiago
- Australia
Megacities

Definition: Mega cities comprises 10 Mill. people

1975: 3 MC
2005: 20 MC
2015: 22 MC (4 > 20 Mill.)
Problems and risks in megacities

➢ Energy
### Energy consumption by sources

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Transport</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>75%</td>
<td>8%</td>
<td>17%</td>
</tr>
<tr>
<td>Shanghai</td>
<td>83%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Seoul</td>
<td>38%</td>
<td>25%</td>
<td>37%</td>
</tr>
<tr>
<td>Tokyo</td>
<td>41%</td>
<td>37%</td>
<td>22%</td>
</tr>
<tr>
<td>Mexico City</td>
<td>38%</td>
<td>44%</td>
<td>18%</td>
</tr>
</tbody>
</table>


### Energy consumption

#### Gasoline per capita

- **Low income in Asia**
- **Middle income cities in Asia and Latin America**
- **High income cities in Asia**
- **Cities in Oceania**
- **Cities in North America with low population density**

Source: Global Energy Futures and Human Development: A Framework for Analysis*, Lawrence Livermore National Laboratory, 1997

#### Motorisation phase

- **Infrastructure development phase**
- **Upgrades in infrastructure phase**

**Income**

- **Urbanisation**
- **Suburbanisation**

*Source: Global Energy Futures and Human Development: A Framework for Analysis*. Lawrence Livermore National Laboratory, 1997
Global energy consumption

Fossil fuels and biomass both affect air quality

Source: REN21, Renewables 2007, Global Status Report
Air Quality in Metropolitan Areas and Sensitive Regions

- Interactions between urban/suburban/rural regions and their feedback mechanisms to air quality (e.g. urban heat islands and other secondary circulations)
- Development and validation of innovative techniques for the assessment of emissions and air quality (e.g. road traffic, airports) incl. remote sensing and inverse modelling
- Assessment of meteorological influences such as mixing-layer height (e.g. ceilometer and RASS measurements on the boundary-layer structure) on air quality
- Coupling of models (MCCM, WRFchem, micro scale models), e.g. for the analysis of the present state and the assessment of possible mitigation/adaptation strategies
- Impact of regional climate change on air quality and human health
- Interdisciplinary project “Risk Habitat Megacity” with the topic “Air Quality and Health”; anchor city Santiago de Chile in co-operation with Universidad de Chile
Methodology

Satellite data

Measurement data

Emission data

integrated air quality assessment studies

Air quality

Science based decision support

Measures

Stakeholders: e.g., communities, gov. agencies

Chem

GRAL

WRF
Remote sensing of traffic emissions

DOAS

SF6 line source and sampling sites

FTIR
Measurement platforms
Assessment of meteorological conditions, e.g. vertical profiling

Mixing height measurements

- SODAR: acoustic backscatter
- CEILOMETER: optical backscatter
- RASS: temperature

**Coupling of models/Modelling System**

**Observations**
- Observations
- Orography
- Anthropogenic Emissions
- Global Weather forecast models
- Global Climate Models

**Analysis**
- Meteorological Data Assimilation
- Biogenic Emissions
- MCCM or WRF/chem
  - Meteorology, Climate, Aerosols, Air Chemistry, Soil-Vegetation

**Interpolation**
- Simulation of Air Quality
- Simulation of Regional Climate

**Local**
- Air Pollution Control Strategies
- Critical Levels and Loads
- Climate Changes and Air Quality
- Extreme Events
- Soil-Vegetation-Atmosphere Feedback Effects

**Regional**
- Runoff / Routing Model (e.g. WASIM)
- Detailed hydrological Model
- Dynamic Vegetation Model (MOBILE)
- Bio-Geo-Chemistry Model
- Micro-scale Model (e.g. GRAL)

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Coupling of scales in modelling

Threshold exceedances

Meso-scale modeling
e.g. NO$_2$ with MCCM

Micro-scale modelling
e.g. NO$_2$ with GRAL

Source: EU-LIFE Project
Klagenfurt Graz Bozen
Adaptation Strategies

e.g. Mexico City

O$_3$-difference in 2010

O$_3$-concentrations in 2010

NOx Emissions

Land use

Topography

Basic information on present emissions and emissions of reduction measures
Climate Change Impact

Resolution too coarse for regional impact analysis!
Threshold exceedances in the future

Setup: 60-20 km grid
2x10 years period
Southern Germany

Climate Change Impact

Distribution of daily $O_3$ maximum

Days with Threshold Exceedance
Jun-Aug

Ozone ($\mu g/m^3$)
Risk-Habitat-Megacity
¿sostenibilidad en riesgo?

- **Helmholtz centres**
  - German Aerospace Centre (DLR)
  - Forschungszentrum Karlsruhe (FZK)
  - Helmholtz Centre for Infection Research (HZI)
  - GeoForschungsZentrum Potsdam (GFZ)
  - Helmholtz Centre for Environmental Research (UFZ)

- **Latin America**
  - United Nations Economic Commission for Latin America and the Caribbean (ECLAC/CEPAL)
  - Universidad de Chile
  - Pontificia Universidad Católica de Chile
  - Pontificia Universidad Católica de Valparaiso

- “Anchor city“: Santiago de Chile
- Duration: July 2007 – June 2013
Governance & Sustainability

Air Quality management policies, emission control programs and pollutant trends in Mexico City

Conclusions

- Air quality issues need an holistic and interdisciplinary approach.
- Link between land-use, energy, transportation, air quality, climate change and health demonstrates the interaction and tackles central problems in a megacity.
- To understand the complex system of a megacity, further process studies have to be performed in each discipline.
- Air quality and health impact assessment studies are essential prerequisites for mitigation and adaptation strategies.
- Tools, technologies and expertise to address these linked issues of air quality and energy supply are available today.
- Co-operation has already started.
Co-operations

- **Memorandum of Understanding (MoU)** between IMK-IFU and the Universidad Nacional Autonoma de Mexico (UNAM) about a cooperation in the fields of research and education (e.g. Air Quality, Climate Change)

- Establishing of the **International Competence Center for Sustainable Urban Development (ISUD)** in Santiago de Chile (“capacity building”, “multidisciplinary research on Megacities”; “applying knowledge”) between FZK and Universidad de Chile in Santiago

- **Contract of Cooperation** between the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS) and IMK-IFU about “Monitoring and Modelling of Air Quality at the Megacity, Beijing”

- **Cooperation** between Chinese Academy of Sciences (CAS), Chinese Research Academy of Environmental Sciences (CRAES), Chinese Academy of Transportation Sciences (CATS), Institute for Epidemiology (EPI) of the Helmholtz Centre Munich (HMGU), Department of Human Exposure Research and Epidemiology of the Helmholtz Centre for Environmental Research (UFZ), and Karlsruhe Institute of Technology (KIT) (Institute of Regional Science (IRS), Institute of Mineralogy and Geochemistry (IMG), Institute for Meteorology and Climate Research (IMK-IFU) Garmisch) on air quality and health in the Greater Area of Beijing
List of measurement systems in Beijing spring 2009

• Layering of the lower atmosphere and mixing layer heights: ceilometers (IMK-IFU), 300 m measurement mast (IAP, IMG, IRS)

• Vertical profile of meteorological data: 300 m mast (IAP)

• Path-averaged concentrations of air pollutants NO, NO₂ (SO₂, O₃, BTX, NH₃, HCHO are possible) near and above the motorway: DOAS (with three retro-reflectors, up to about 150 m distance to the emitter/receiver-unit, system is changing automatically from path to path) (IMK-IFU)

Inter-comparisons
Comparison of air pollutant measurements by the DOAS and a monitoring station nearby: NO, NO₂
Example: determination of mixing-layer height with a ceilometer, this spring in Beijing

LD40 Beijing $\log_{10}$ of backscatter on 07.03.2009 in $10^{-9} \text{ m}^{-1} \text{ sr}^{-1}$
Near-surface air pollutant monitoring with path-integrating optical methods, DOAS measurement site in Beijing near the 325 m tower
Next station: Liaoning / Shenyang June 12-20, 2009

Thank you very much for your attention