



Karlsruhe Institute of Technology

# Topics in air quality in Germany and China: Up-scaling of greenhouse gas emissions and meteorological and source influences upon urban air quality

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INSTITUTE OF METEOROLOGY AND CLIMATE RESEARCH, DEPARTMENT ATMOSPHERIC ENVIRONMENTAL RESEARCH (IMK-IFU)



- Motivation, Objectives, Scientific questions
- Tasks, Methodology
- Results
- Conclusions

# KIT Portfolio



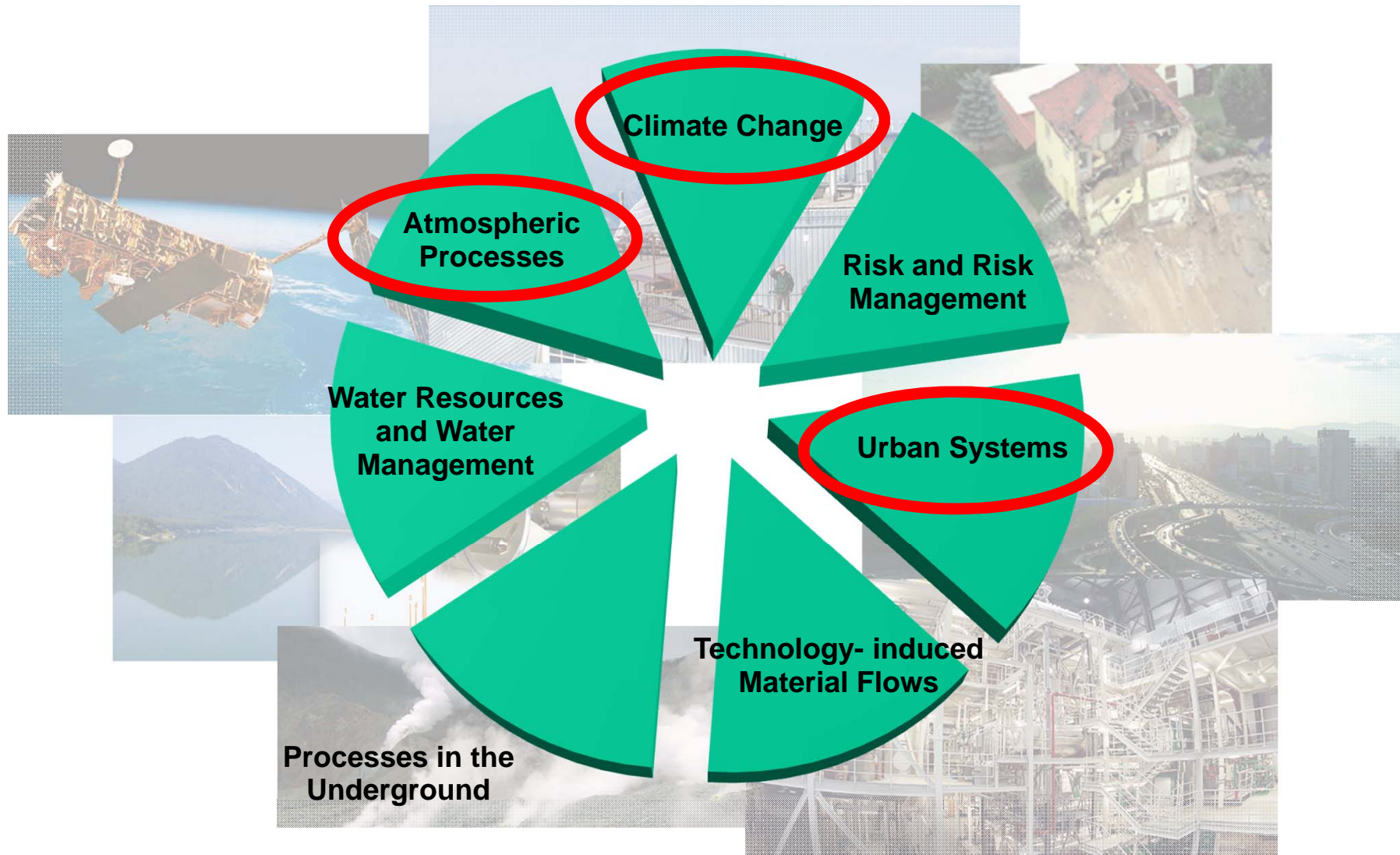
## KIT - Centres

- Energy
- Climate and Environment
- Nano and Micro Scale Science
- Astroparticle Physics



260 km



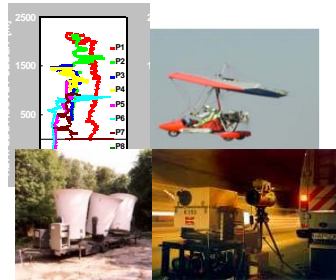


# Integrated Approach

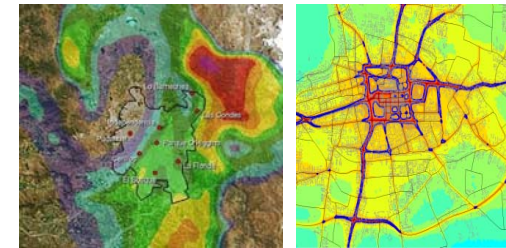
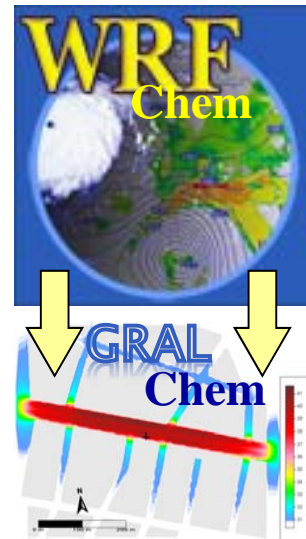
## Urban Development



## Measurement Data



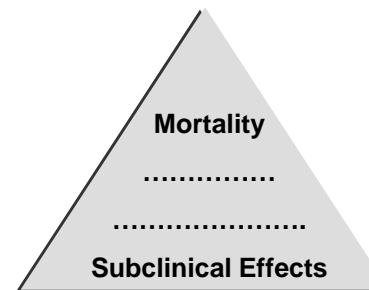
## Traffic Data



## Air Quality

## Scenario

## Indicator



## Health Impact



## Stakeholder

Source: Peter Suppan, KIT

# Relevant strategic topics of the working group

## “Regional coupling of ecosystem - atmosphere coupling”

- Knowledge about the interaction of coupled ecosystem – atmosphere processes within a changing climate
- Aerosol research (fine / ultra-fine particles) – loads / composition / formation / sources
- Coupling between urban air quality and regional climate change
- Process studies of air pollution relevant for health protection and legislation ( $\text{NO}_2$ ,  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ )

# Up-scaling of greenhouse gas emissions

# Background & Objectives

Up-scaling GHG emission measurements:

Micrometeorological techniques often limited by stable atmospheric conditions and their low spatial resolution

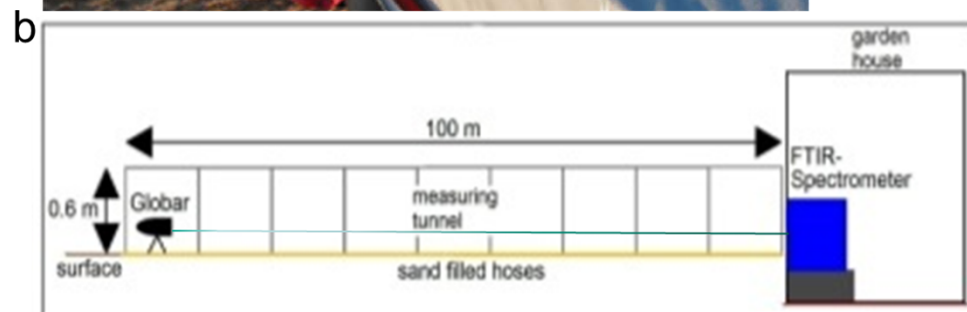
Closed tunnel on an area of 500 m<sup>2</sup> equipped with an open-path Fourier Transform Infrared (FTIR) spectrometer:

- (i) evaluate its feasibility for measuring N<sub>2</sub>O concentrations and to calculate field-scale N<sub>2</sub>O fluxes;
- (ii) compare those results with small-scale fluxes obtained from closed chamber measurements.

## Tunnel experiment, chambers and flux calculation

- Measuring plot: unfertilized grassland on Gleyic Podzol in Northern Germany
- Tunnel: Aluminium liner structure (99 m × 5 m × 0.6 m), closed with a plastic cover for emission measurements; N<sub>2</sub>O concentration measurements by path-averaged Fourier transform infrared (FTIR) spectrometry





The tunnel (a) with its dimensions and the FTIR unit (b), and the closed chambers (c) located at the same plot.

## Methodology

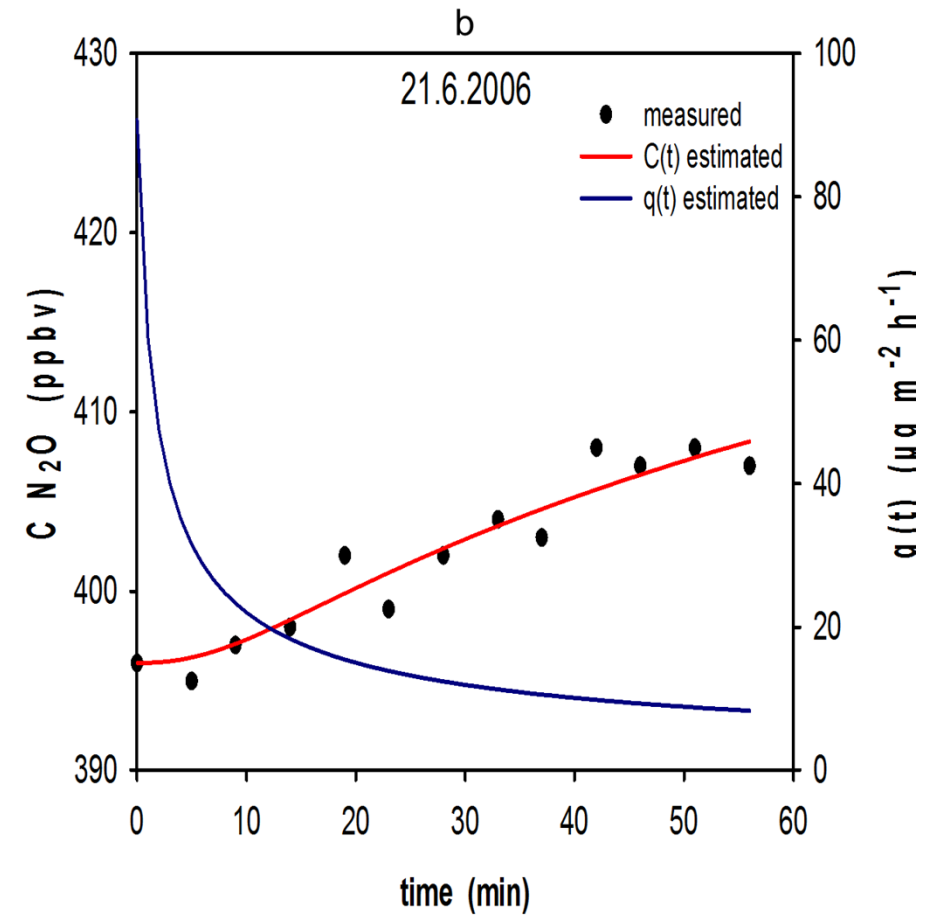
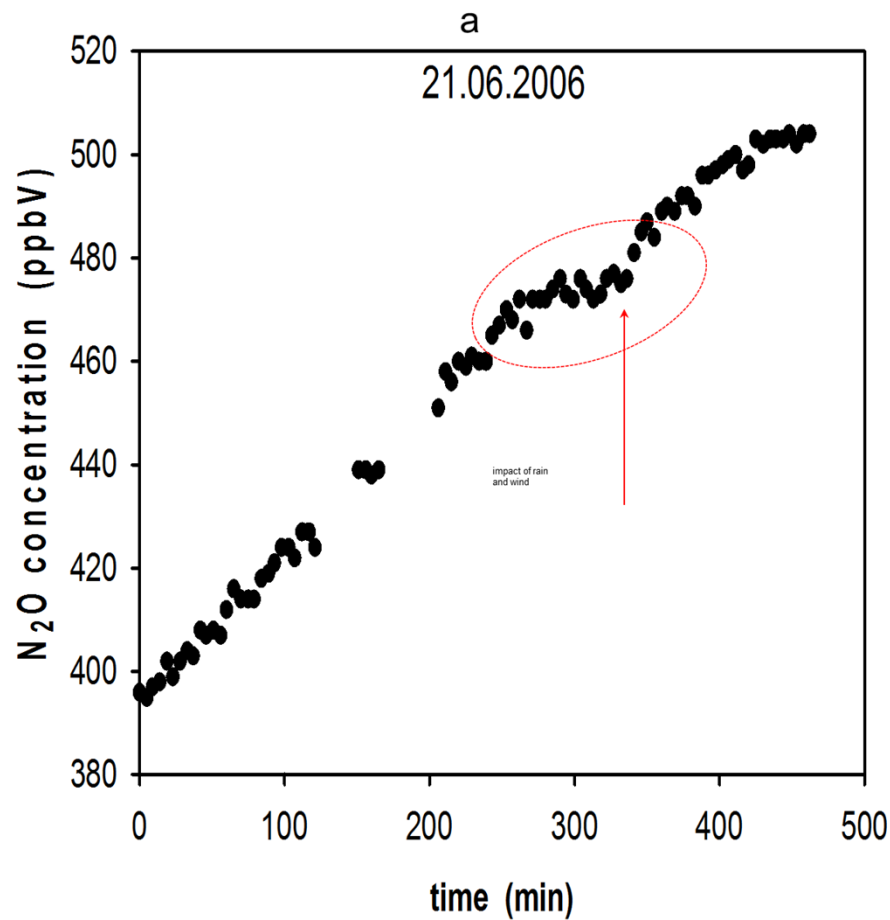
Calculation of a predeployment  $\text{N}_2\text{O}$  flux  $Q_0$  by inverse modelling (IMQ0 model): 1D numerical model which takes into account specific tunnel geometry,  $\text{N}_2\text{O}$  diffusion from soil into the tunnel,  $\text{N}_2\text{O}$  diffusion within the tunnel atmosphere,  $\text{N}_2\text{O}$  detection by FTIR in 0.3 m above ground, and the diameter of the radiation beam (0.1 m)

Concurrent small-scale ( $0.05 \text{ m}^2$ ) chamber measurements; calculation of  $\text{N}_2\text{O}$  fluxes from four concentration measurements using the NDFE model (Livingston et al., 2006)

## Results

Combined tunnel / FTIR method enables precise, high-density concentration measurements (about 12 per hr) during stable atmospheric conditions

Measurements are biased by high wind speeds, heavy rain and sun radiation



Representative time course of N<sub>2</sub>O concentrations during a single measuring campaign (a) and measured concentrations during the first measuring hour with inversely estimated N<sub>2</sub>O concentrations  $c_{\text{N}_2\text{O}}$  and N<sub>2</sub>O flux  $q(t)$  (b).

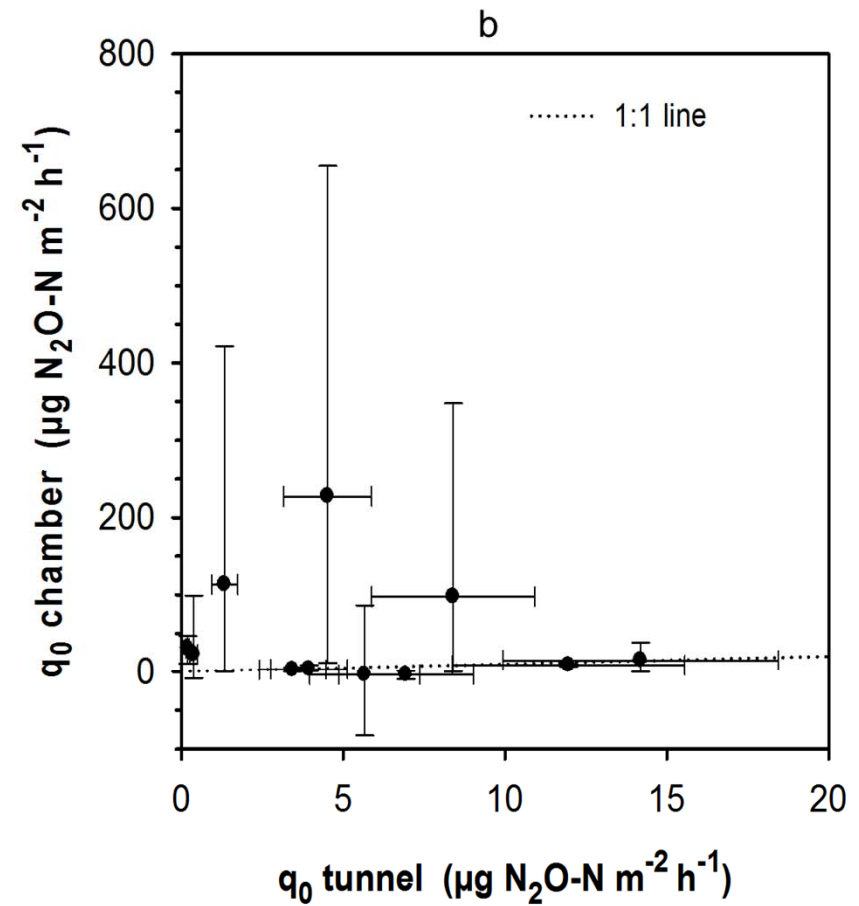
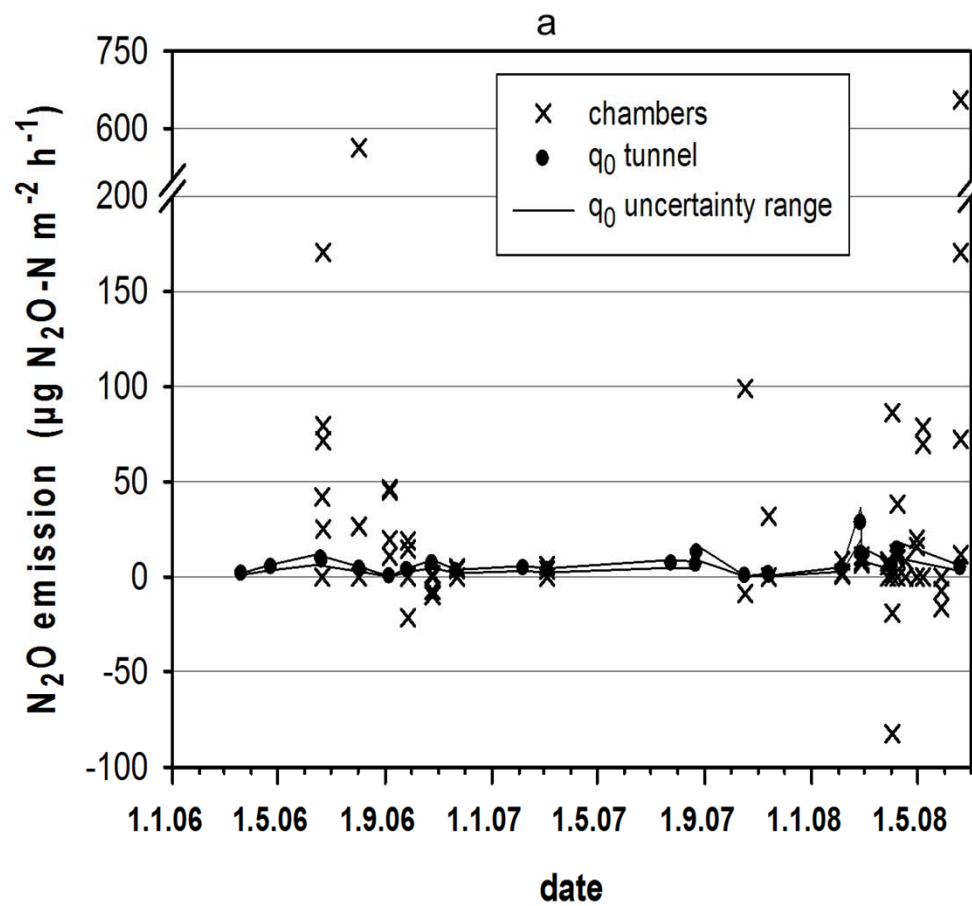
## Results

Reliability of the IMQ0 model was confirmed using site-specific „virtual emission scenarios“ (Schäfer et al., 2012)

IMQ0 flux estimation was successfully applied to the experimental data

N<sub>2</sub>O fluxes measured by the tunnel were small at a typical positive background level, whereas chamber-derived fluxes partly exhibited huge variability and slight N<sub>2</sub>O uptake

High emissions obtained by single chambers occurred after rainfall events, but this hot spot behaviour was obviously not representative for the field or tunnel scale



Comparison of  $\text{N}_2\text{O}$  fluxes  $q_0$  obtained by the small-scale chamber and field-scale tunnel methods.

## Conclusions

N<sub>2</sub>O concentration measurements with the tunnel / FTIR set up are reliable, particularly during dry and stable nocturnal conditions

IMQ0 model predicts the unbiased, pre-deployment N<sub>2</sub>O flux with good accuracy

Field-scale tunnel method may serve as a gap-filling technique between small-scale chamber and ecosystem-level micrometeorological methods

# Determination of meteorological parameters to study influences upon urban air quality



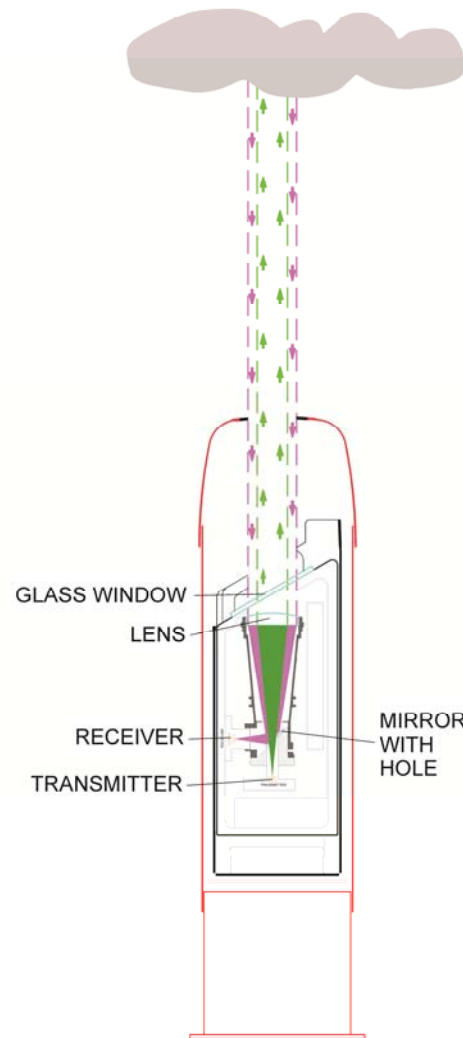
# Motivation

- Local emissions only cannot explain high air pollution episodes in urban areas, especially during cold seasons
- Detailed understanding of emission and chemistry/transport processes, directing certain air pollutant concentrations, not complete – but required for development of emission reduction measures
- Application of source apportionment methods needed
- Mixing layer height (MLH) controls the vertical space for rapid mixing of near-surface pollutants - essential for air quality forecast; influenced by climate change - quality of living in cities

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

# Methodology

## CL 31 and 51 ceilometer



Typical range resolution for boundary layer

10 m

Backscatter profile range

Up to 15000 m

Range for boundary layer profiling

Up to 4000 m

Laser wavelength

910 nm



One-lens design – complete overlapping (Vaisala)

Continuous monitoring by uninterrupted remote sensing

Gradient method for MLH determination

Emeis, S., Schäfer, K.: Remote sensing method to investigate boundary-layer structures relevant to air pollution. Bound-Lay. Meteorol. 121, 377 (2006).

# Methodology

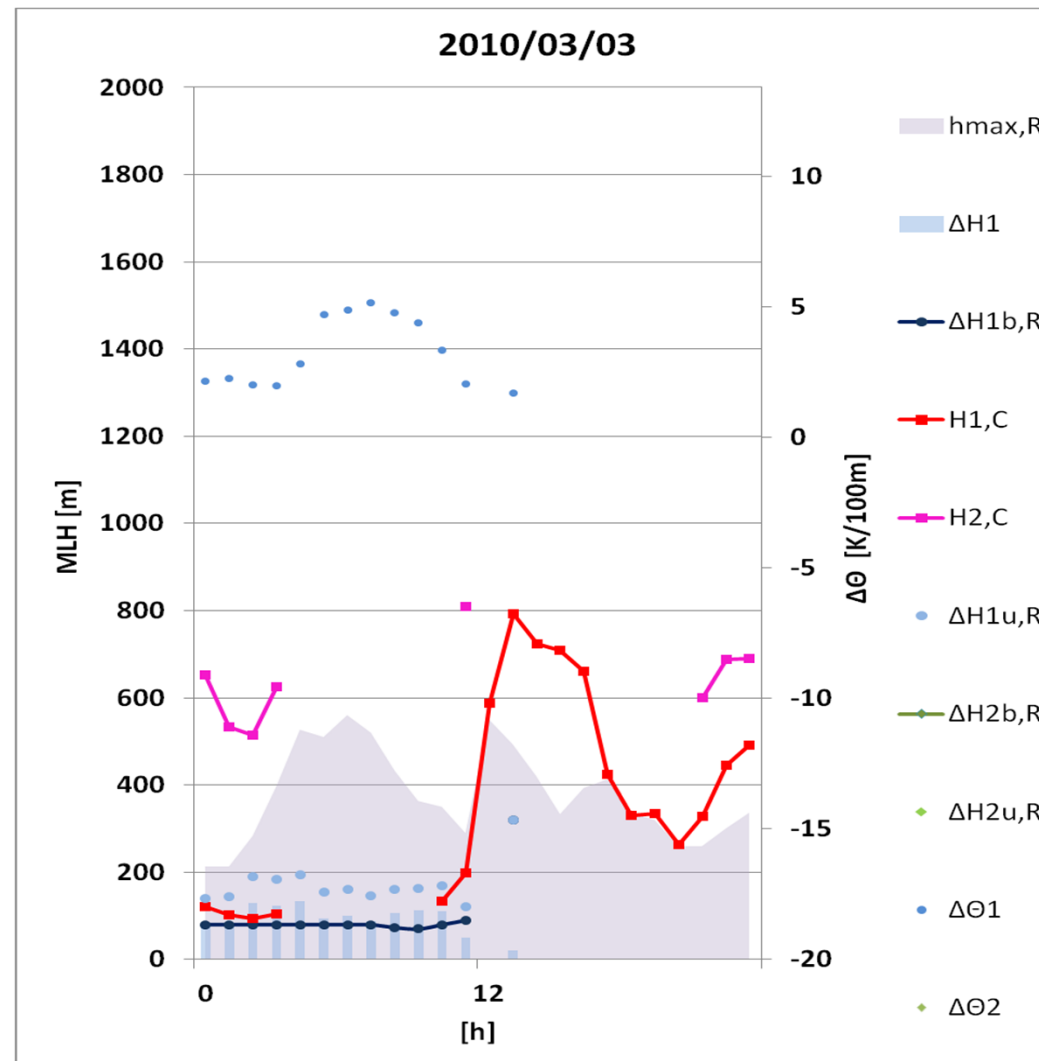
## Radio-acoustic Sounding System (RASS)

- profiles of wind speed,
  - wind direction, variance
  - of vertical wind component
  - and of acoustic temperature
- vertical resolution of 20 m
- up to a height of  $h_{\max,R} = 540$  m
- threshold of temperature gradient set at 1.0 K/100 m
- all values higher than this threshold taken as range of the upper boundary height of the detected layer  $\Delta H$



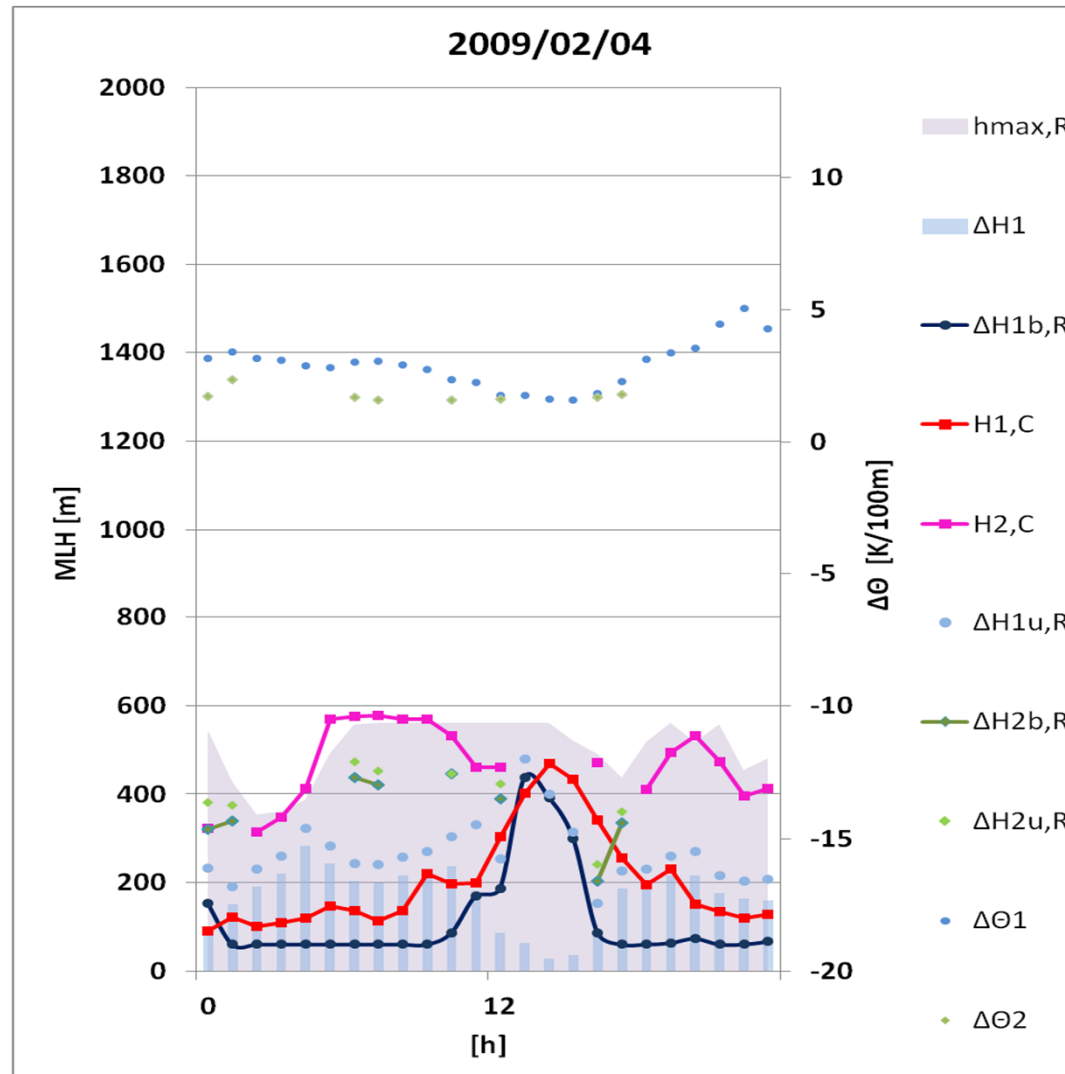
- Intercomparison for first and second detected layer above ground by RASS and ceilometer
- Only analyses of profile of temperature gradient from RASS measurements enables
  - an information about stability of layer and of depth of upper boundary of detected layer  $\Delta H_1$  or  $\Delta H_2$ ,
  - minimum of upper boundary height (lower most height of temperature gradient threshold exceedence)  $\Delta H_{1b,R}$  or  $\Delta H_{2b,R}$  and
  - a maximum of upper boundary height (upper most height of temperature gradient exceedence)  $\Delta H_{1u,R}$  or  $\Delta H_{2u,R}$

# Ceilometer and RASS measurements in agreement

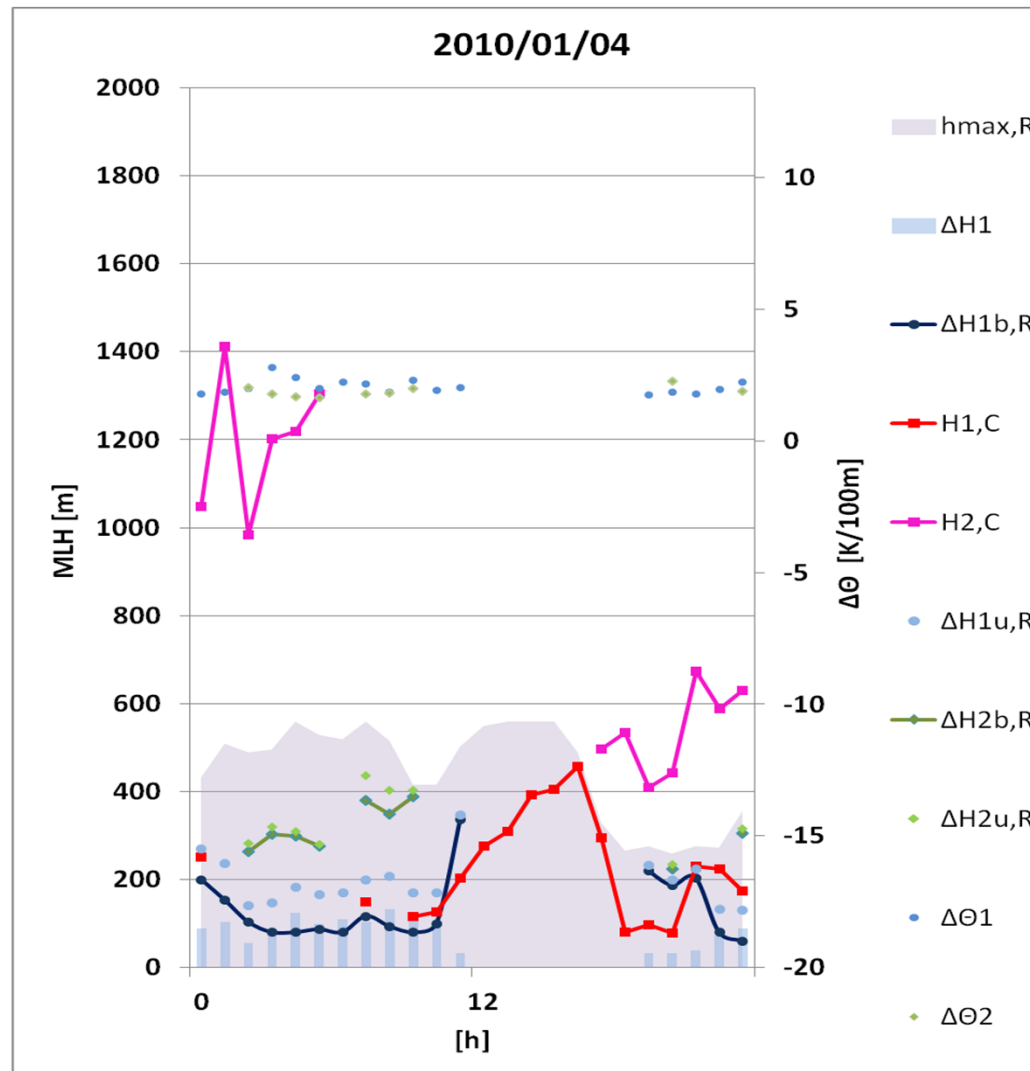


# Ceilometer and RASS measurements

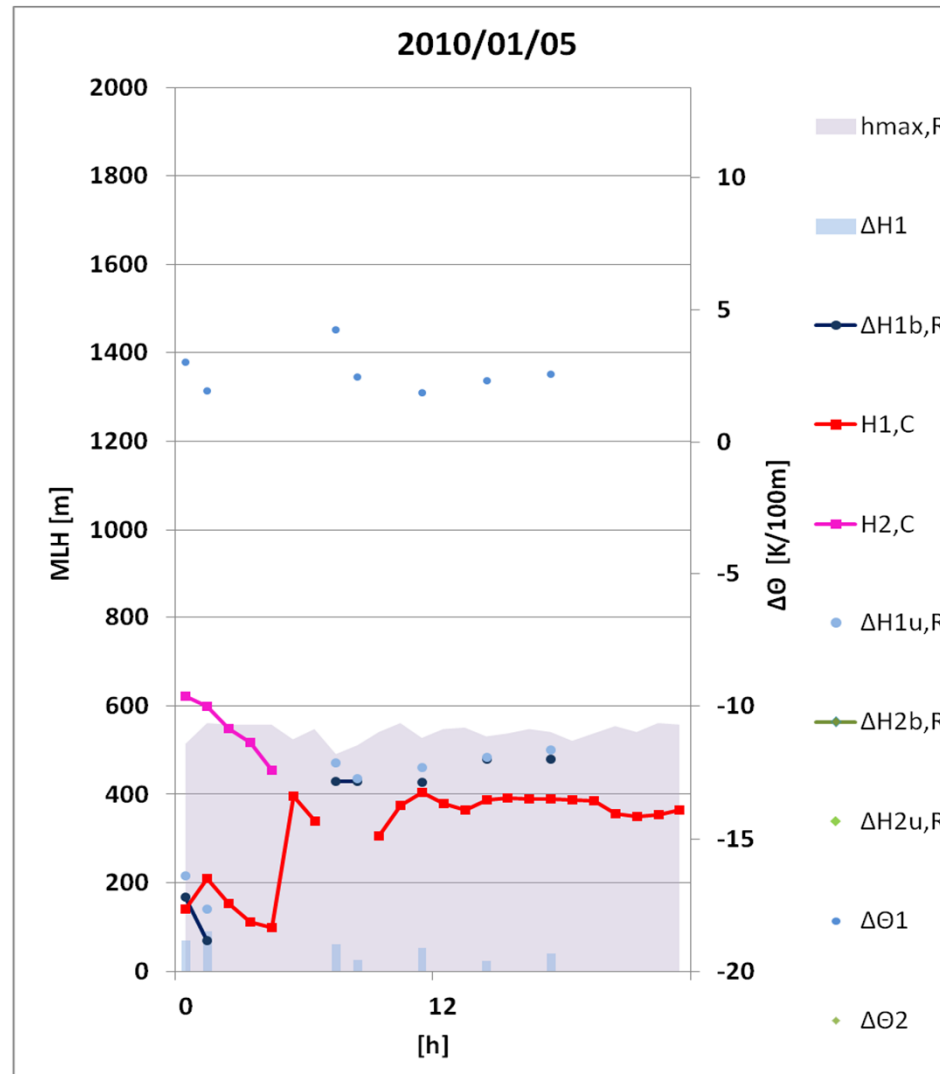
## Information about thickness of atmospheric layers



# Ceilometer and RASS measurements complete each other



# Ceilometer and RASS measurements without realistic layer information





# Conclusions

- Particle size spectrum influences ceilometer data in a non-quantifiable way
- Atmospheric humidity influences ceilometer data in a non-quantifiable way
- ➔ Ceilometers quite simple and return only one variable, optical backscatter intensity, their output needs careful analysis
- In late afternoon near-surface layer developed and a residual, second layer remaining sometimes but algorithms provide a down going upper boundary of first layer and a new second layer
- Fog and rain limit the capabilities of these remote sensing systems to detect layers

# Conclusions

- If vertical temperature gradient not exceeding threshold value RASS cannot detect upper boundary of layers
- Strong winds reduce vertical variations of temperature and particle number density and thus limit remote sensing of both systems
- Depth of upper boundary of detected layers provided by RASS important information about layering characteristics
- If information about upper boundary of layers during daily course interrupted continuity of data must be checked because of rapid changes of layering during front passages

Emeis, S., Schäfer, K., Münkel, C.: Observation of the structure of the urban boundary layer with different ceilometers and validation by RASS data. Meteorologische Zeitschrift 18, 2, 149-154 (2009); DOI: 10.1127/0941-2948/2009/0365.

# Meteorological influences upon urban air quality

## Particle size distribution

# Objectives

- Influences of meteorological parameters and atmospheric layering (especially mixing layer height (MLH)) on exchange processes of ground level emissions
- Application of ceilometer monitoring information for MLH to interpret air pollution near ground
- Measurements in Augsburg at urban background site (particle size distributions) and kerb site ( $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{O}_3$ ) and in Essen at kerb site (Benzene, Toluene, Isoprene,  $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{PM}_{10}$ )
- Strongest MLH influence: hourly-mean or maximum values

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

# Tasks in Augsburg

Measurements of meteorological parameters and air pollutant concentrations: 16-23/02/2007, 14-23/02/2008

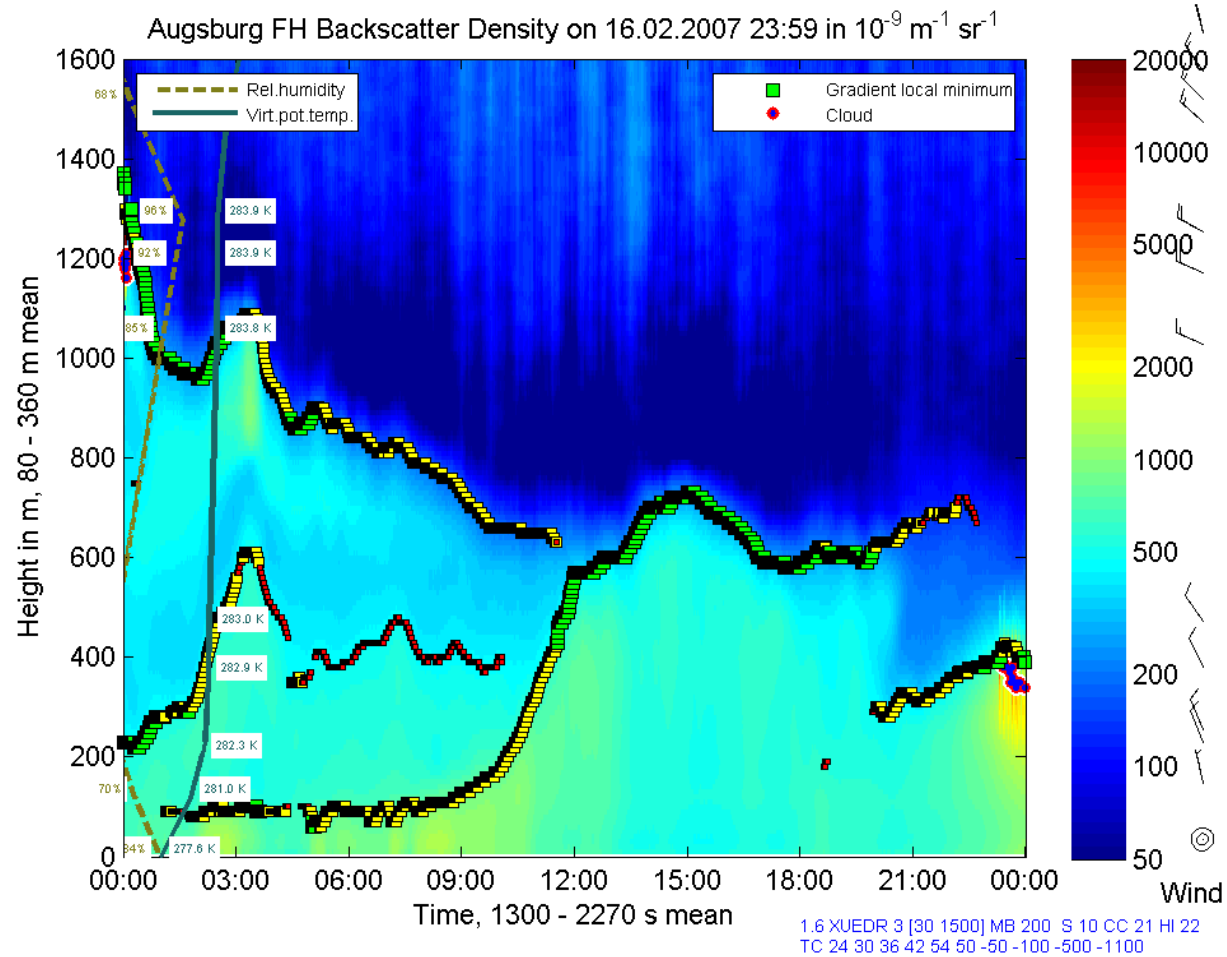
- MLH: Measured by CL31 (*IMK-IFU*), software developed with MATLAB (*Vaisala, IMK-IFU*); radiosondes *DWD* station Oberschleissheim
- Particle number concentrations (PNC) and mass concentrations (PMC): urban background site (*HMGU, EPI II; UA, WZU*)
- Meteorological parameters (*LfU; DWD; HMGU, EPI II*)

**Correlations** of continuous MLH, temperature, wind direction, wind speed and relative humidity data with PNC and PMC of different size fractions, hourly mean data (*IMK-IFU*)

Pitz, M., Birmili, W., Schmid, O., Peters, A., Wichmann, H.E., Cyrys, J.: Quality control and quality assurance for particle size distribution measurements at an urban monitoring station in Augsburg, Germany. *J. Environ. Mon.* 10(9), 1017-1024 (2008).

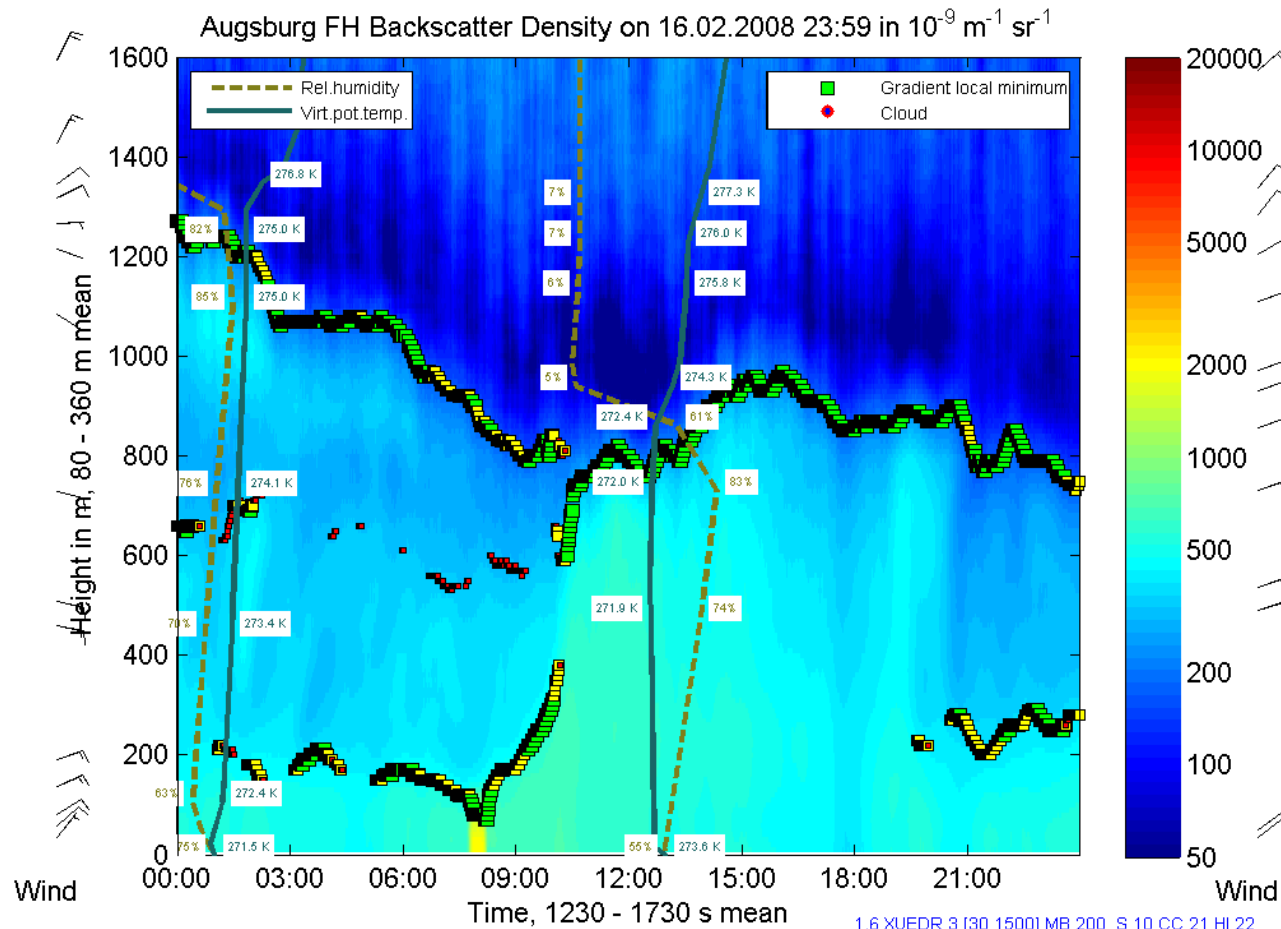
# Ceilometer measurements in Augsburg

## Radiosonde measurements in Oberschleißheim (60 km distance)



# Ceilometer measurements in Augsburg

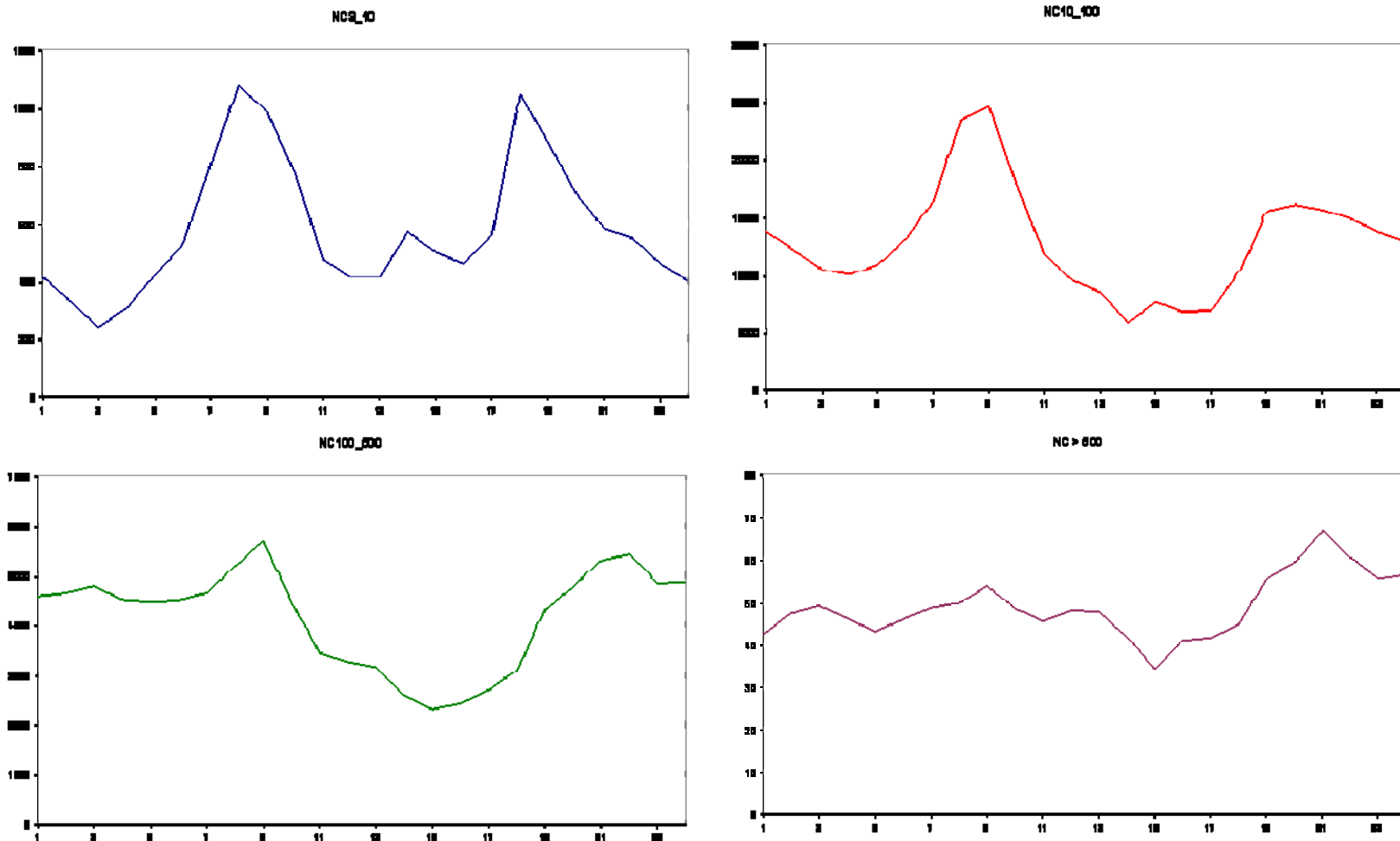
## Radiosonde measurements in Oberschleißheim (60 km distance)



1.6 XUEDR 3 [30 1500] MB 200 S 10 CC 21 HI 22  
TC 24 30 36 42 54 50 -50 -100 -500 -1100

# Ultra-fine particle measurements in Augsburg

KIT  
Karlsruhe Institute of Technology



Diurnal pattern of PNC 16-23/02/2007: 3-10 and 10-30 strong variation; 100-500 high night-time values; >500 weak variation



# Spearman correlation coefficients $R^2$ of PNC, PMC with MLH and wind speed



hourly mean, significant >0.24: measurement errors 10 and 15 %

| <b>PNC</b> |         | 3 – 10 | 10 – 30 | 30 – 50 | 50 – 100 | 100 – 500 | 500 – 1000 | 1000 – 2500 | 2500 – 10000 |
|------------|---------|--------|---------|---------|----------|-----------|------------|-------------|--------------|
| 2007       | MLH     | 0.01   | 0.02    | 0.06    | 0.12     | 0.11      | 0.03       | 0.00        | 0.00         |
| 2008       | MLH     | 0.00   | 0.15    | 0.24    | 0.35     | 0.46      | 0.19       | 0.16        | 0.07         |
| 2007       | W speed | 0.00   | 0.05    | 0.14    | 0.26     | 0.38      | 0.20       | 0.15        | 0.17         |
| 2008       | W speed | 0.01   | 0.11    | 0.23    | 0.35     | 0.42      | 0.10       | 0.11        | 0.19         |
| <b>PMC</b> |         | 3 – 10 | 10 – 30 | 30 – 50 | 50 – 100 | 100 – 500 | 500 – 1000 | 1000 – 2500 | 2500 – 10000 |
| 2007       | MLH     | 0.01   | 0.03    | 0.07    | 0.13     | 0.07      | 0.02       | 0.00        | 0.00         |
| 2008       | MLH     | 0.00   | 0.18    | 0.25    | 0.37     | 0.44      | 0.18       | 0.20        | 0.05         |
| 2007       | W speed | 0.00   | 0.08    | 0.19    | 0.39     | 0.44      | 0.22       | 0.18        | 0.12         |
| 2008       | W speed | 0.00   | 0.11    | 0.20    | 0.38     | 0.38      | 0.04       | 0.13        | 0.14         |

Daytime correlation coefficients smaller than during night-time

## Conclusions

- Surface emissions - main sources of UFP in the atmosphere
  - Accumulation, coagulation and nucleation form very rapidly coarser particles
  - Larger particles (e.g. particle size range 500 - 1000 nm) influenced by formation of secondary particles
- MLH influence upon PMC significant also (as for  $PM_{2.5}$ ,  $PM_{10}$ )
  - 80 % of PNC represented by size fractions up to 100 nm
  - 70 % of PMC in size fraction 100 – 500 nm

Schäfer, K.; Emeis, S.; Schrader, S.; Török, S.; Alföldy, B.; Osan, J.; Pitz, M.; Münkel, C.; Cyrys, J.; Peters, A.; Saragiannis, D.; Suppan, P.: A measurement based analysis of the spatial distribution, temporal variation and chemical composition of particulate matter in Munich and Augsburg. Meteorol. Z. 21, 1, 47-57 (2011)

# Meteorological influences upon urban air quality

## Traffic gaseous emissions in Augsburg

# Tasks in Augsburg

## Measurements March – September 2012

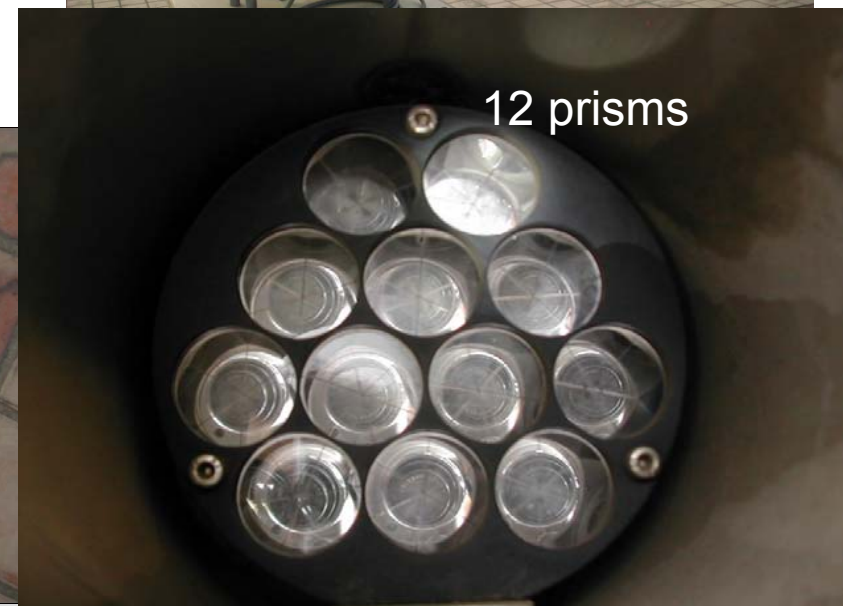
Path-integrated, in situ concentrations of NO, NO<sub>2</sub>, O<sub>3</sub> at a crossing (*IMK-IFU*)

- diurnal variations
- influences from emissions, weather conditions, chemical / photochemical reactions

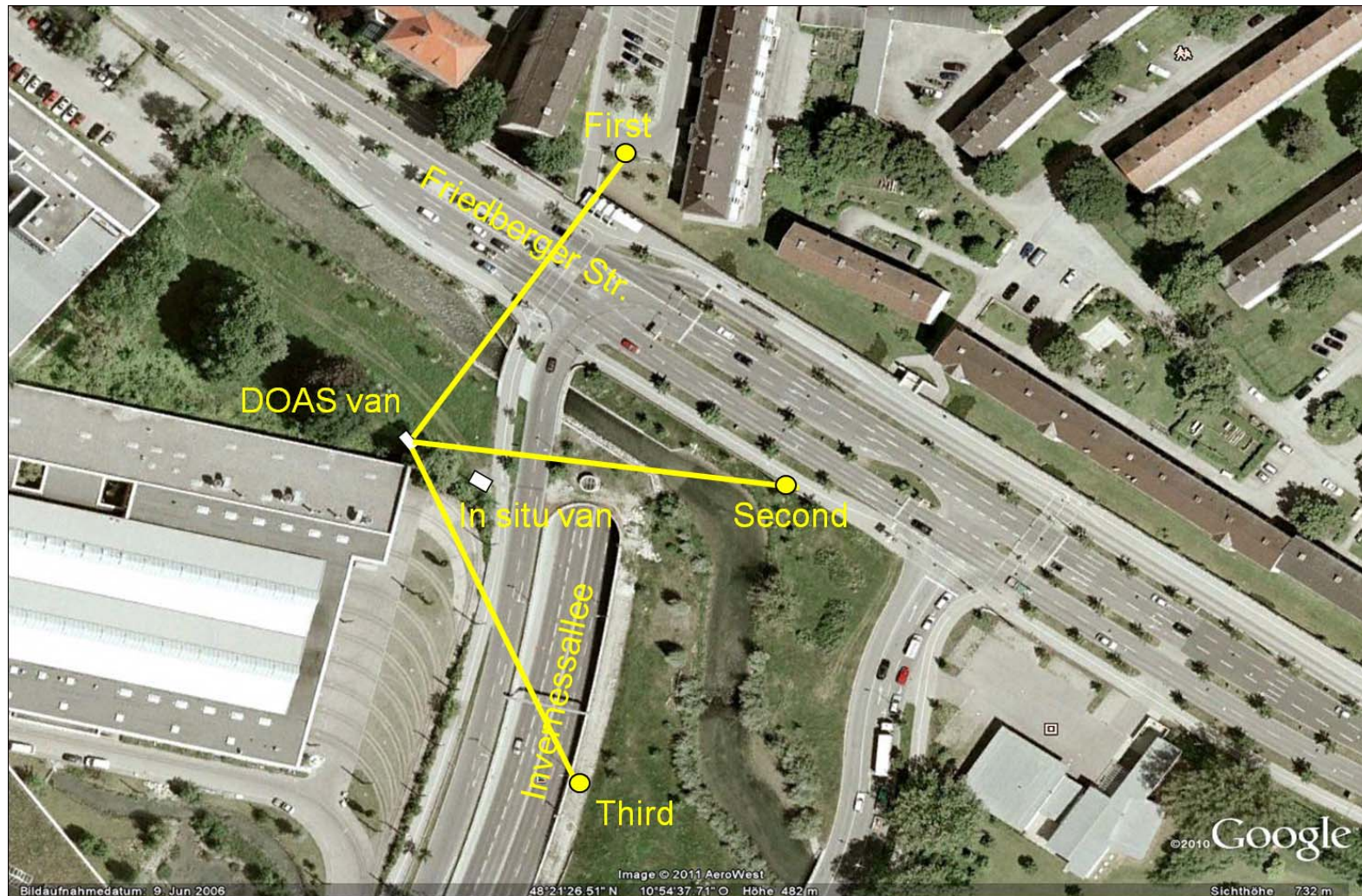
**Correlations** of continuous MLH, temperature, wind direction, wind speed and relative humidity data with air pollutant data

Schäfer, K., Emeis, S., Schrader, S., Török, S., Alföldy, B., Osan, J., Pitz, M., Münkel, C., Cyrys, J., Peters, A., Saragiannis, D., Suppan, P.: A measurement based analysis of the spatial distribution, temporal variation and chemical composition of particulate matter in Munich and Augsburg. Meteorol. Z., 21, 1, 47-57 (2011).

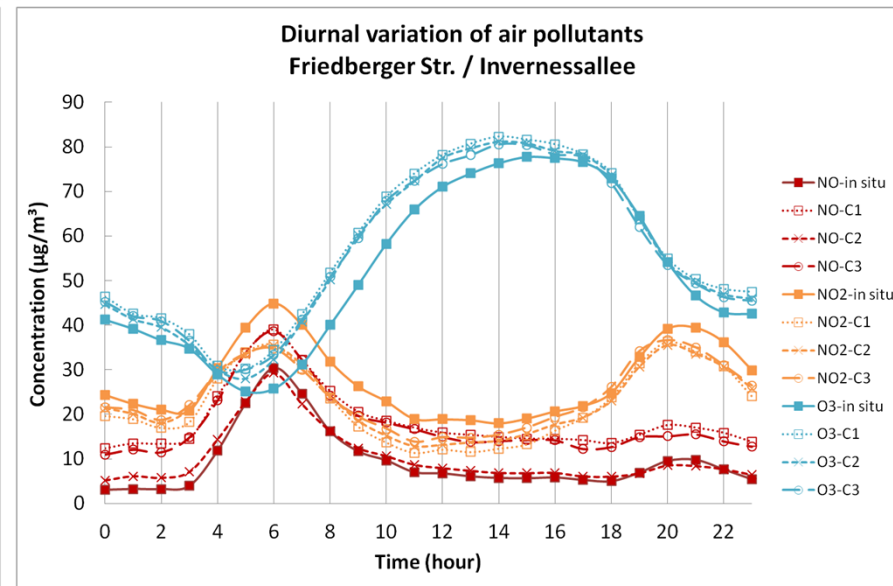
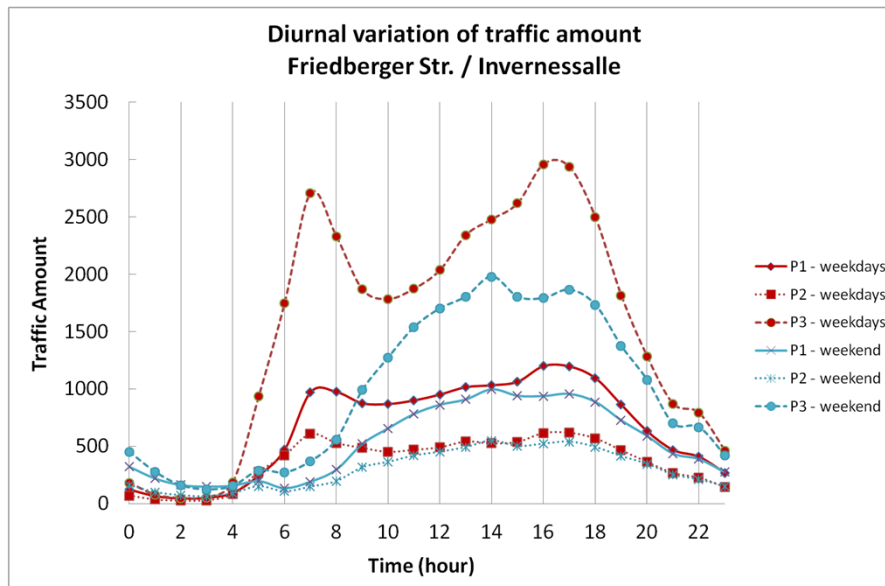
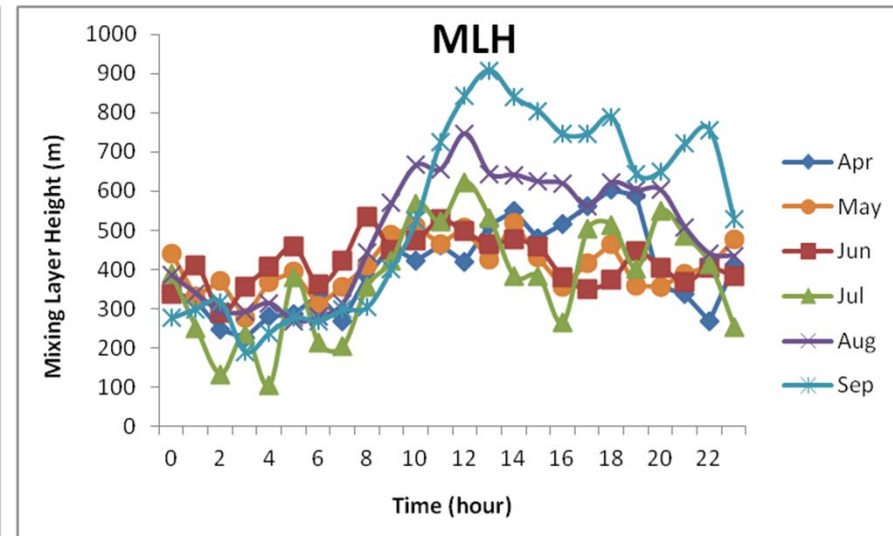
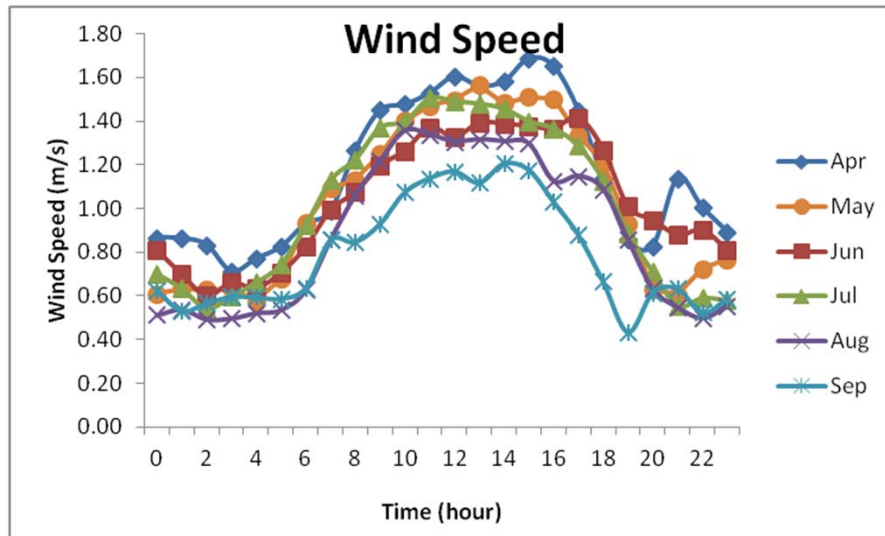
# DOAS (Differential Optical Absorption Spectroscopy) instrument



# Continuous **DOAS** measurements in Augsburg



# Augsburg



## Conclusions

- **Path-integrated measurements** by DOAS satisfy task of long-term and multiple-compound monitoring of traffic emissions better than in situ measurements
- **Diurnal patterns** of NO, NO<sub>2</sub> at kerb site caused by
  - traffic emissions mainly,
  - local convection,
  - chemical transformations
- A lot of effort required for quantitative determination of MLH



# Meteorological influences upon urban air quality

## Traffic gaseous emissions in Essen

# Tasks in Essen

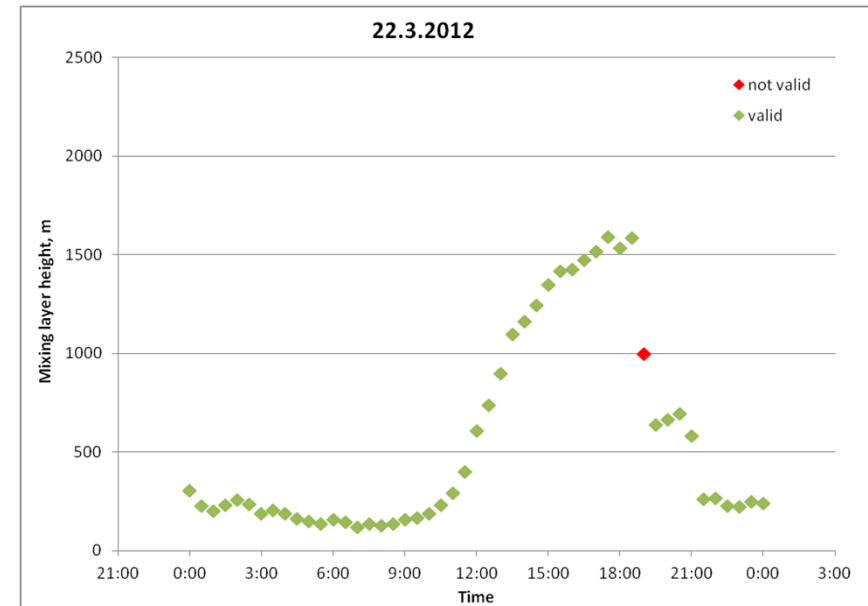
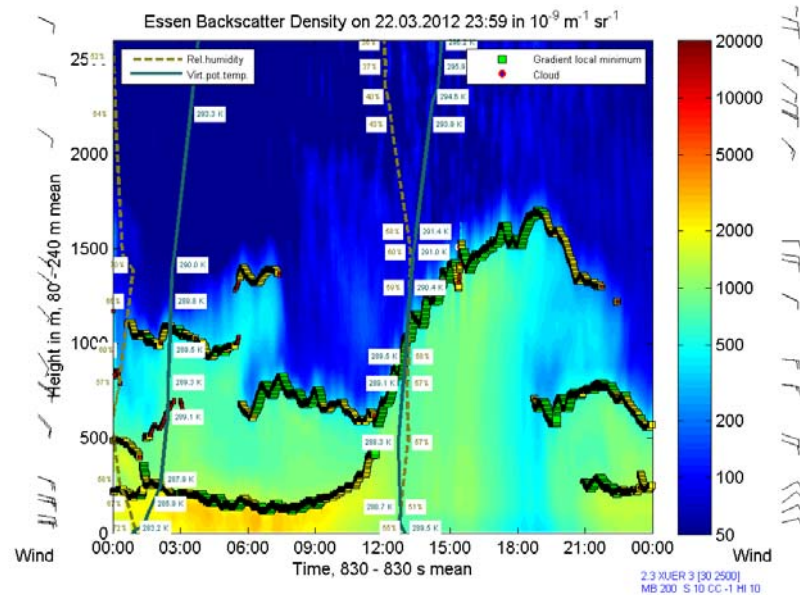
Measurements 28/12/2011-17/04/2012, VOC 28/02-03/04/2012

- **Benzene, Toluene, Isoprene concentrations:** every half hour by on-line gas-chromatograph GC955 from Synspec b.v., during 20 min enriched on Tenax GR, kerb site Gladbecker Str. (*UDE*)
- **NO, NO<sub>2</sub> and PM<sub>10</sub> concentrations of LANUV Nordrhein-Westfalen:** kerb site Gladbecker Str.

**Correlations** of continuous MLH with air pollutants (*UDE, IMK-IFU*)

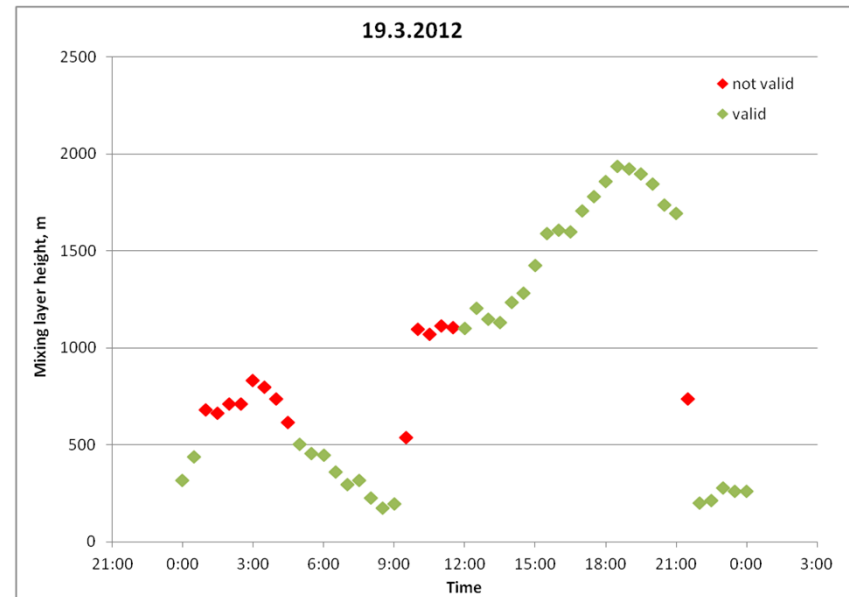
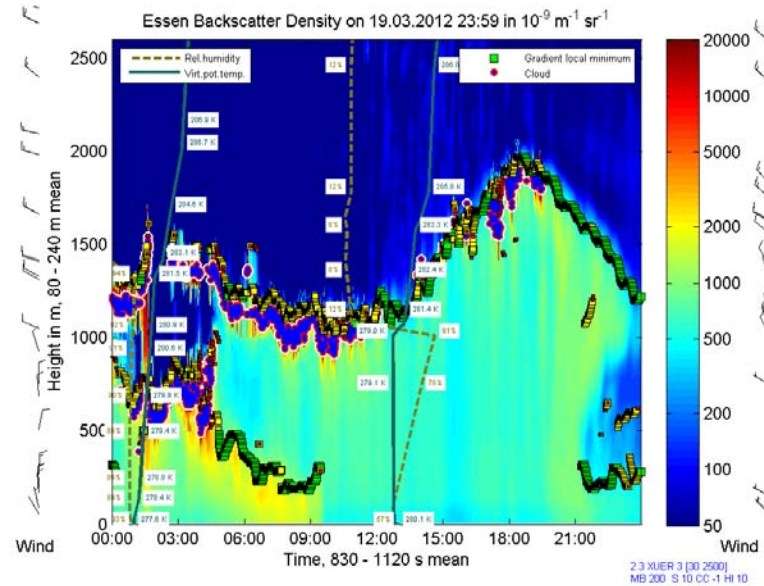
Wagner, P., Kuttler, W.: Biogenic and anthropogenic isoprene in the near-surface urban atmosphere - A case study in Essen, Germany. *Sci. Total Environ.*, 475, 104–115 (2014).

## Ceilometer and radiosonde measurements



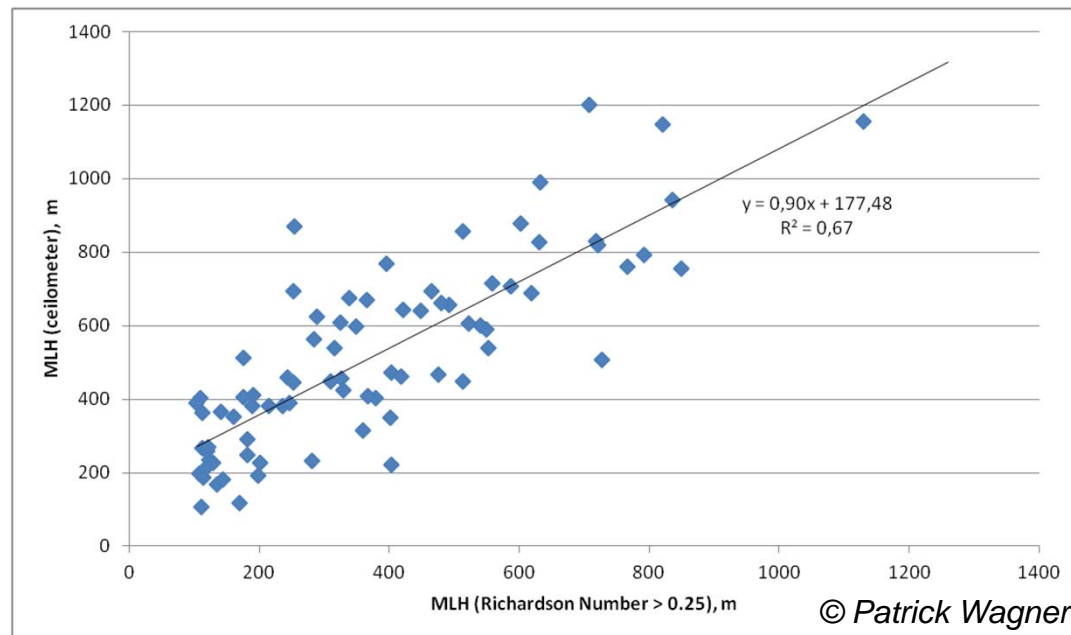
- Residual layer during late night
- Increasing MLH during day-time
- Formation of a near surface layer during evening

## Ceilometer and radiosonde measurements



- Time frames with low clouds excluded
- Cloud upper boundary is layer upper boundary 17:00 - 20:00
- No time periods with high variability of MLH considered: abrupt rise due to solar heating, formation of nocturnal inversion

## Comparison of mixing layer height measurements from ceilometer and radiosonde



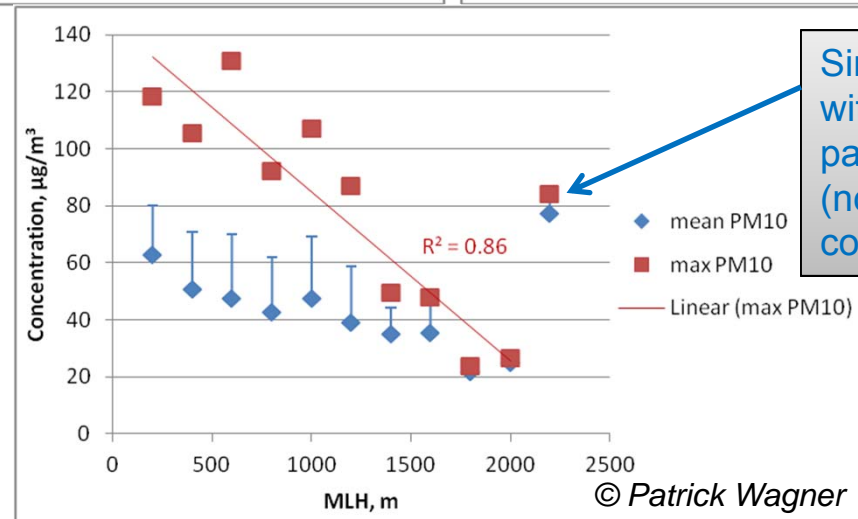
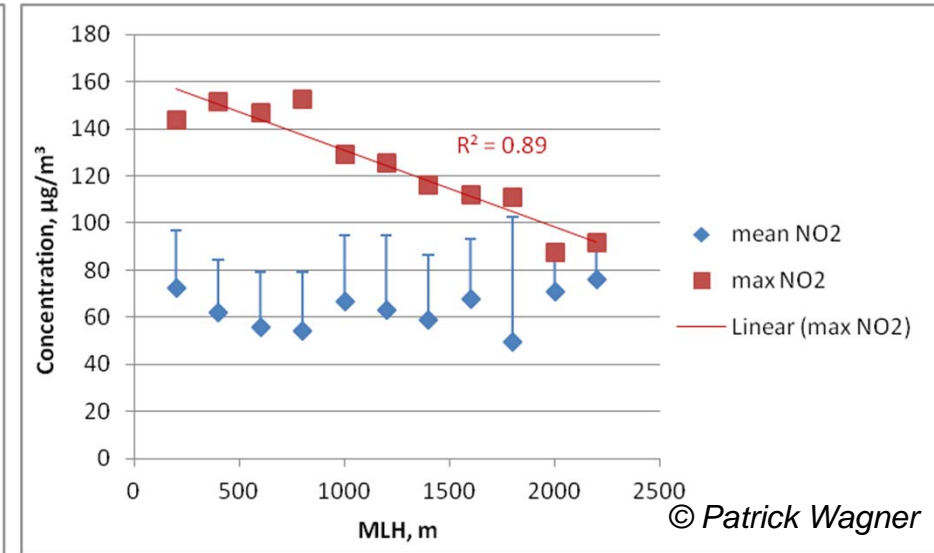
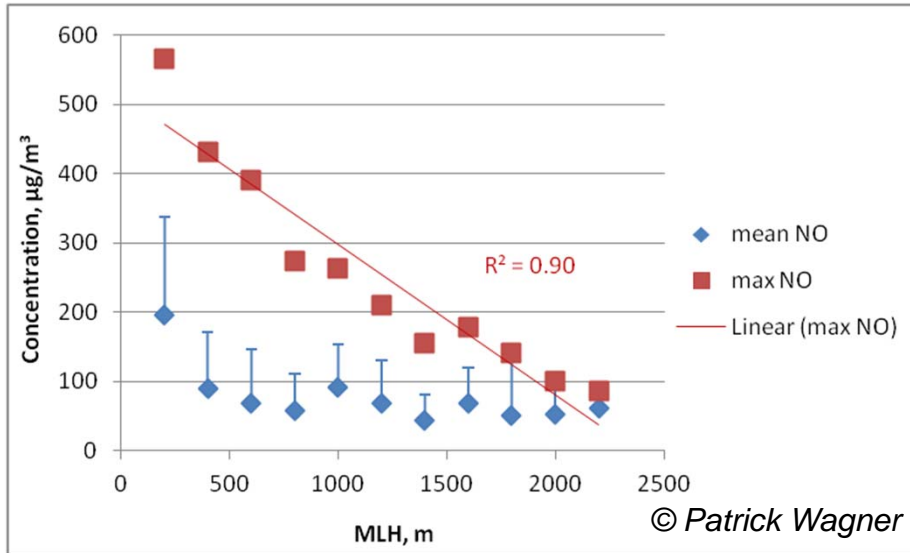
Deviations might be caused by:

1. Complex particle gradient structure affecting ceilometer MLH retrieval
2. Short-term stable layers affecting radiosonde measurements (threshold  $Ri_c = 0.25$  used for MLH determination)
3. Urban heat island (city centre: ceilometer; suburban site: radiosonde)

## Methodology

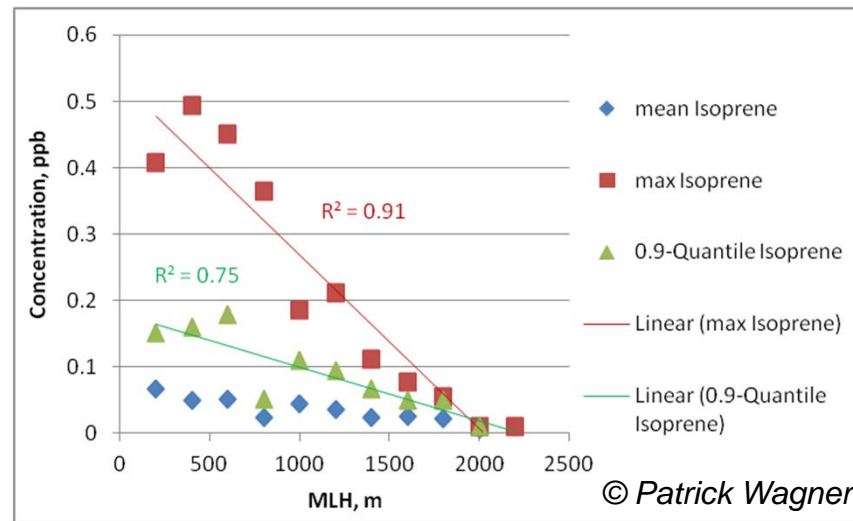
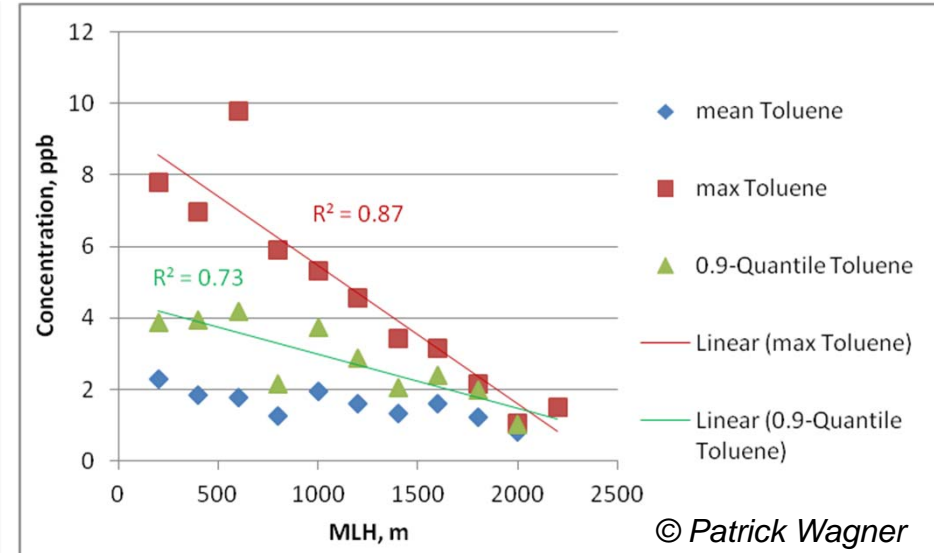
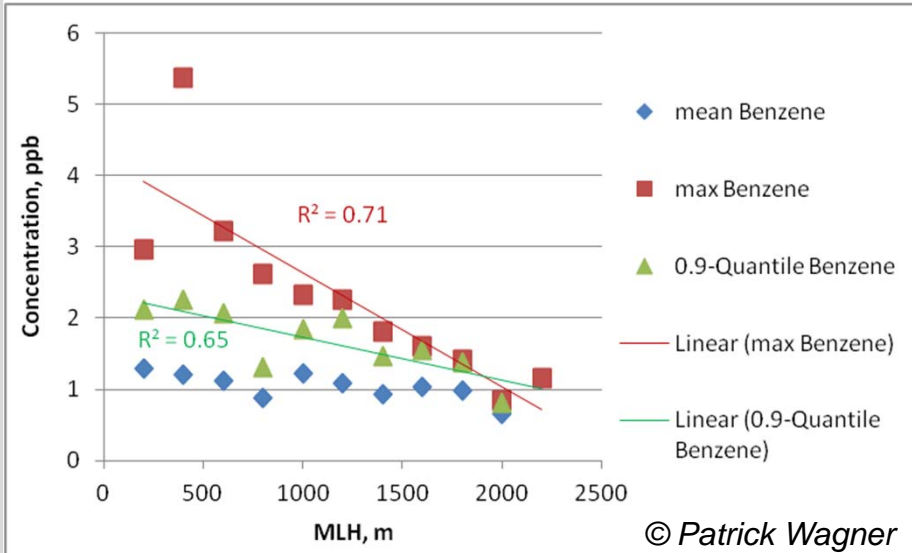
- **MLH**: statistical classification scheme of Sturges:  
 $K = 1 + 3.32 \log N$ , K number of classes, N number of data
- 11 **classes** and a class width of **200 m intervals** of MLH  
(200 m – 2200 m) instead of original 10 m intervals
- Mean and **maximum concentration** determined for each MLH class

# Correlations



Single day event with overall high particle concentrations (not included in correlation)

# Correlations







# Conclusions

- Maximum concentrations affected strongly by MLH and atmospheric stability
- Best correlation results for 200 m intervals of MLH
- Higher correlation coefficients of maximum NO, NO<sub>2</sub>, PM<sub>10</sub>, Benzene, Toluene, Isoprene concentrations in street canyon with MLH than for mean concentrations in urban and rural background with MLH (Munich, Hannover, Augsburg, Budapest, Athens)

Alföldy, B., Osán, J., Tóth, Z., Török, S., Harbusch, A., Jahn, C., Emeis, S., Schäfer, K.: Aerosol optical depth, aerosol composition and air pollution during summer and winter conditions in Budapest. *Sci. Total Environ.*, 383, 141-163, (2007).

Schnelle-Kreis, J., Orasche, J., Abbaszade, G., Schäfer, K., Harlos, D.P., Hansen, A.D.A., Zimmermann, R.: Application of direct thermal desorption gas chromatography time-of-flight mass spectrometry for determination of non-polar organics in low volume samples from ambient particulate matter and personal samplers. *Anal. Bioanal. Chem.*, 401, 3083–3094 (2011).

Helmis, C. G., Sgouros, G., Flocas, H., Schäfer, K., Jahn, C., Hoffmann, M., Heyder, C., Kurtenbach, R., Niedojadlo, A., Wiesen, P., O'Connor, M., Anamaterou, E.: The role of meteorology on the background air quality at the Athens International Airport. *Atmos. Environ.*, 45, 5561-5571 (2011).

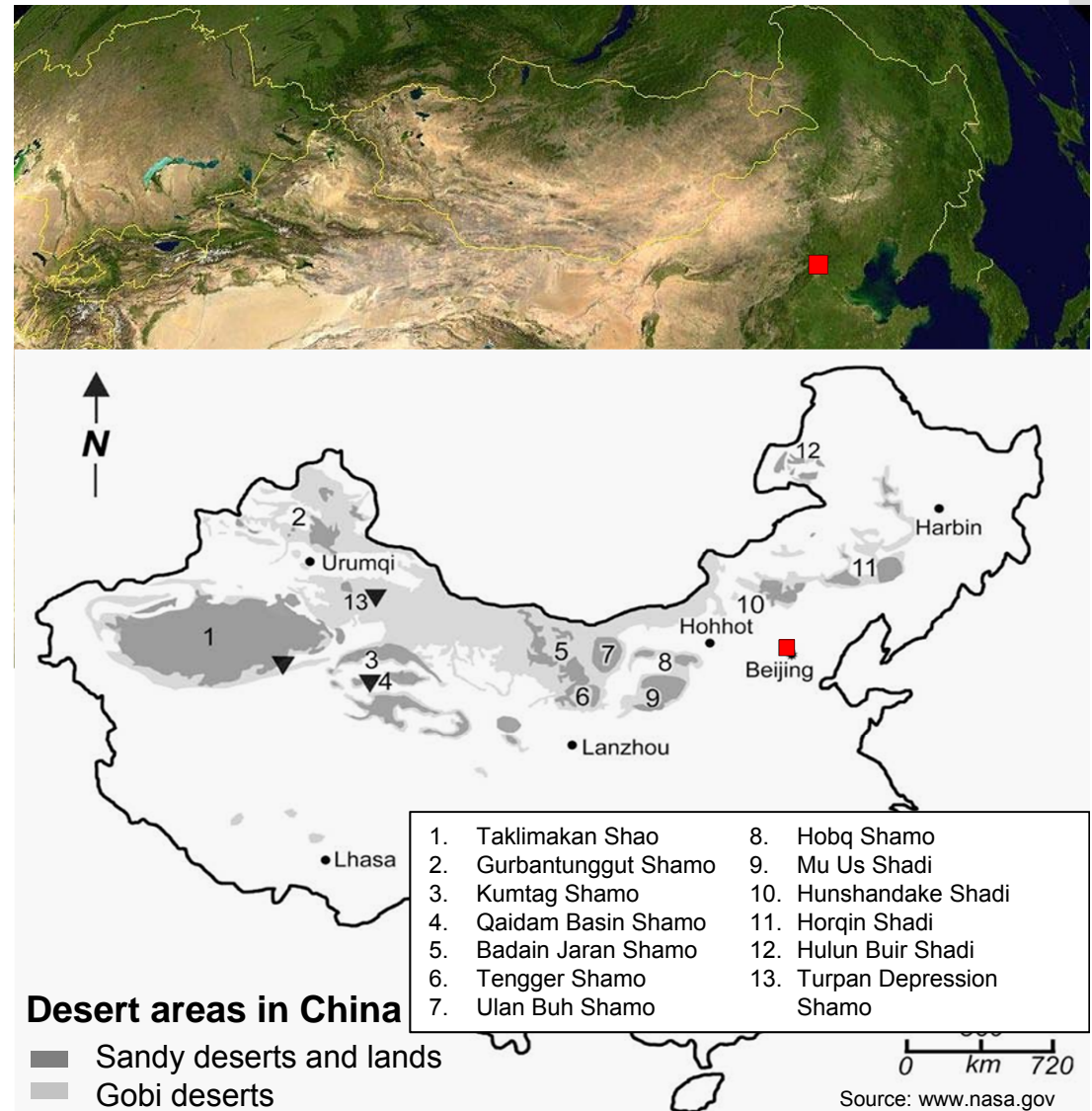
# Meteorological influences upon urban air quality

## Anthropogenic air pollutant exposure in Beijing

# Tasks in Beijing

Aeolian **mineral dust** originated from West and Northwest during storm events – can carry pollutants and nutrients

Emission reduction measures to improve air quality during the Olympic Summer Games in 2008: cut down coarse particles mainly, still frequent **air pollution events**



# Source apportionment for air quality

- Local and regional wind systems - can bring fresh air masses or polluted air flow: westerly or southerly wind directions
- Role of orography – mountains in the West to Northeast
- Role of industrial areas – in the South
- Heat island effect



# Methodology

tower: meteorology, air quality; DOAS 04/09 – 03/11: NO<sub>2</sub>, NO, SO<sub>2</sub>, O<sub>3</sub>, NH<sub>3</sub>, benzene, toluene, xylene, HCHO; ceilometer: MLH



Optical remote sensing:

Ceilometer

Vaisala LD40 or CL31

wave length: 855 or 910 nm

range: 4000 m

resolution: 10 or 7.5 m



Second

First

Third

Institute of Atmospheric Physics (IAP),  
LAPC: monitoring at 325 m tower

©2009 Google - Imagery ©2009 DigitalGlobe, GeoEye - 使用条款

# Methodology



CUGB:  $PM_{4.3}$  (2010.06.21 – 2011.06.20)

IAP:  $PM_{2.5}$  (2013.04.10 – 2013.06.08)

ZBAA: Weather station

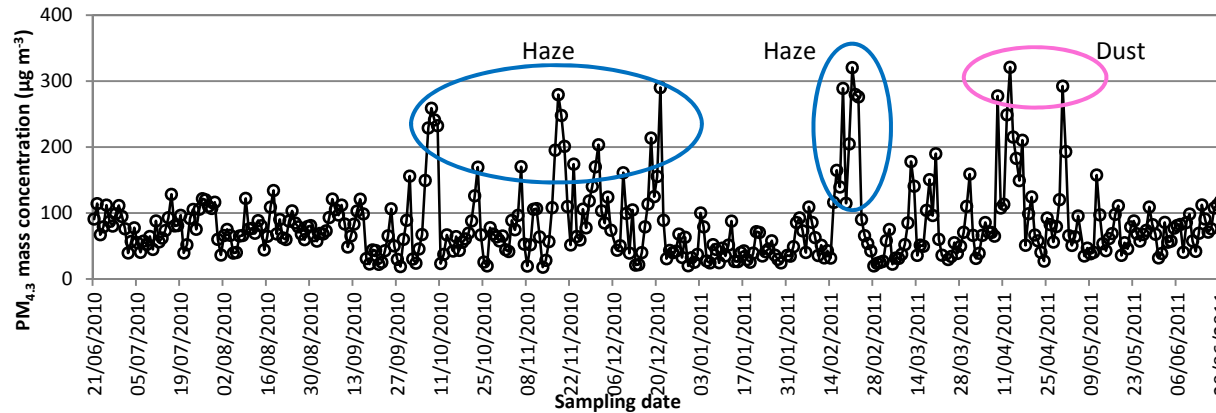
# Methodology

- Samplers: 2 high volume samplers DHA-80 (500 l min<sup>-1</sup>)
- Filters: Quartz fiber filters (Ø 150 mm)
- Sampling time: 24 h (00:00-24:00)  
4 h (some haze episodes, 2013)
- Use of filters:
  - Sampler A
    - ❖ Organic - Gas chromatography-mass spectrometry
    - ❖ EC/OC - Thermal/optical carbon analyzer
    - ❖ Ions - Ion chromatography and continuous flow analyzer
  - Sampler B
    - ❖ Mass concentration - Balance for gravimetric determination
      - TEOM (Tapered element oscillating microbalance)
    - ❖ Inorganic elements - Polarized energy dispersive X-ray fluorescence (PM<sub>4.3</sub>)
      - Inductively coupled plasma mass spectrometry (PM<sub>2.5</sub>)



# Results - Variation

- PM<sub>4.3</sub> mass concentrations (2010-2011)



*Definition of seasons:*

Spring: April – May

Summer: June – August

Autumn: September – October

Winter: November - March

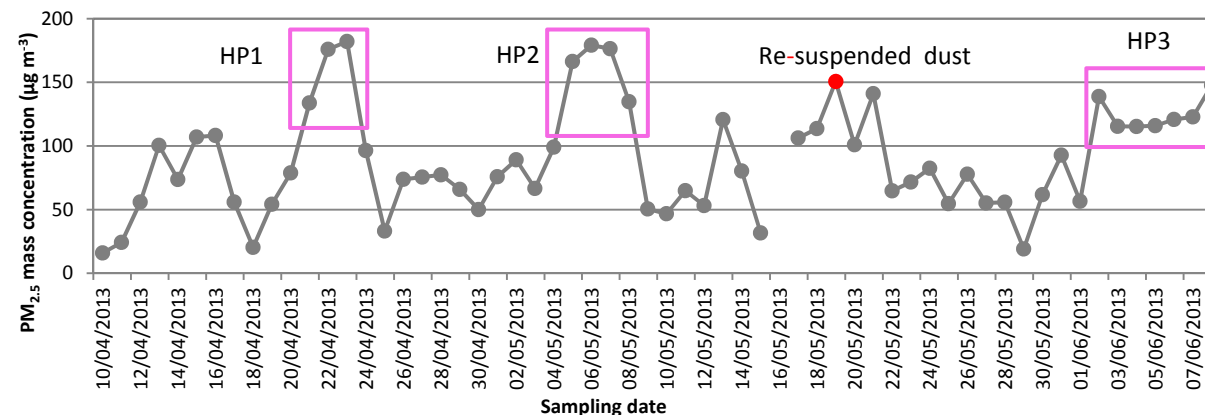
*24 h PM<sub>2.5</sub> threshold values:*

WHO: 25 µg m<sup>-3</sup>

US-EPA: 35 µg m<sup>-3</sup>

China (Grade II): 75 µg m<sup>-3</sup>

- PM<sub>2.5</sub> mass concentrations (Spring 2013)



*2010-2011 PM<sub>4.3</sub>:*

Annual average: 83 µg m<sup>-3</sup>

Haze: 168 µg m<sup>-3</sup>

Dust: 215 µg m<sup>-3</sup>

Clear: 43 µg m<sup>-3</sup>

*Spring 2013 PM<sub>2.5</sub>:*

Average: 89 µg m<sup>-3</sup>

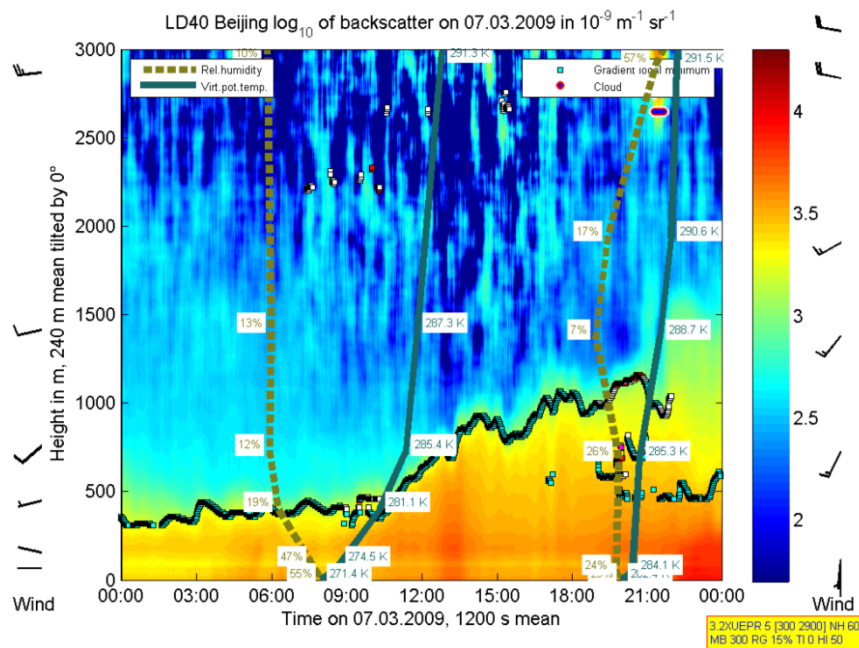
Haze: 140 µg m<sup>-3</sup>

Dust: 125 µg m<sup>-3</sup>

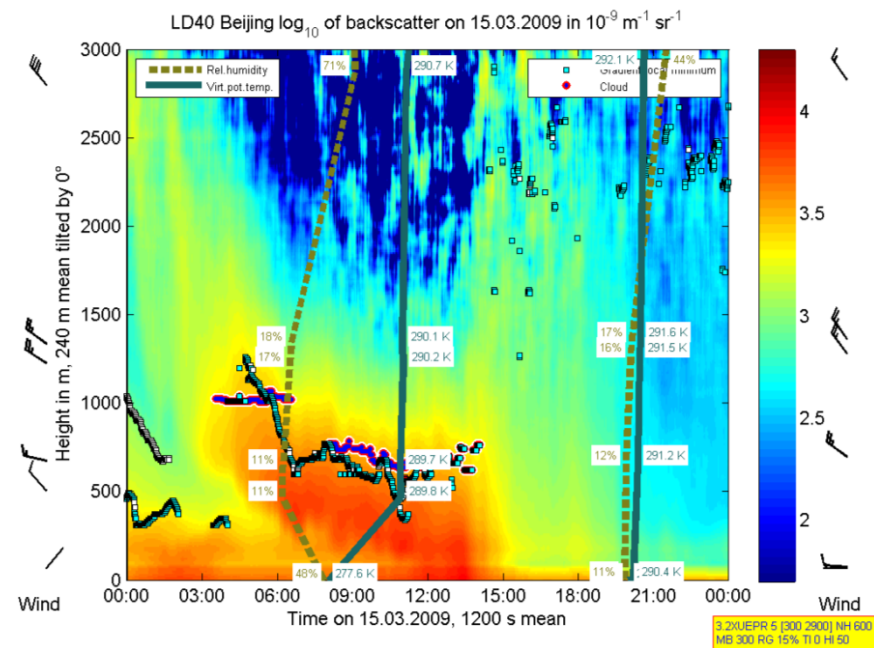
Clear: 45 µg m<sup>-3</sup>

# Evaluations

Higher particulate loads during winds from South-West

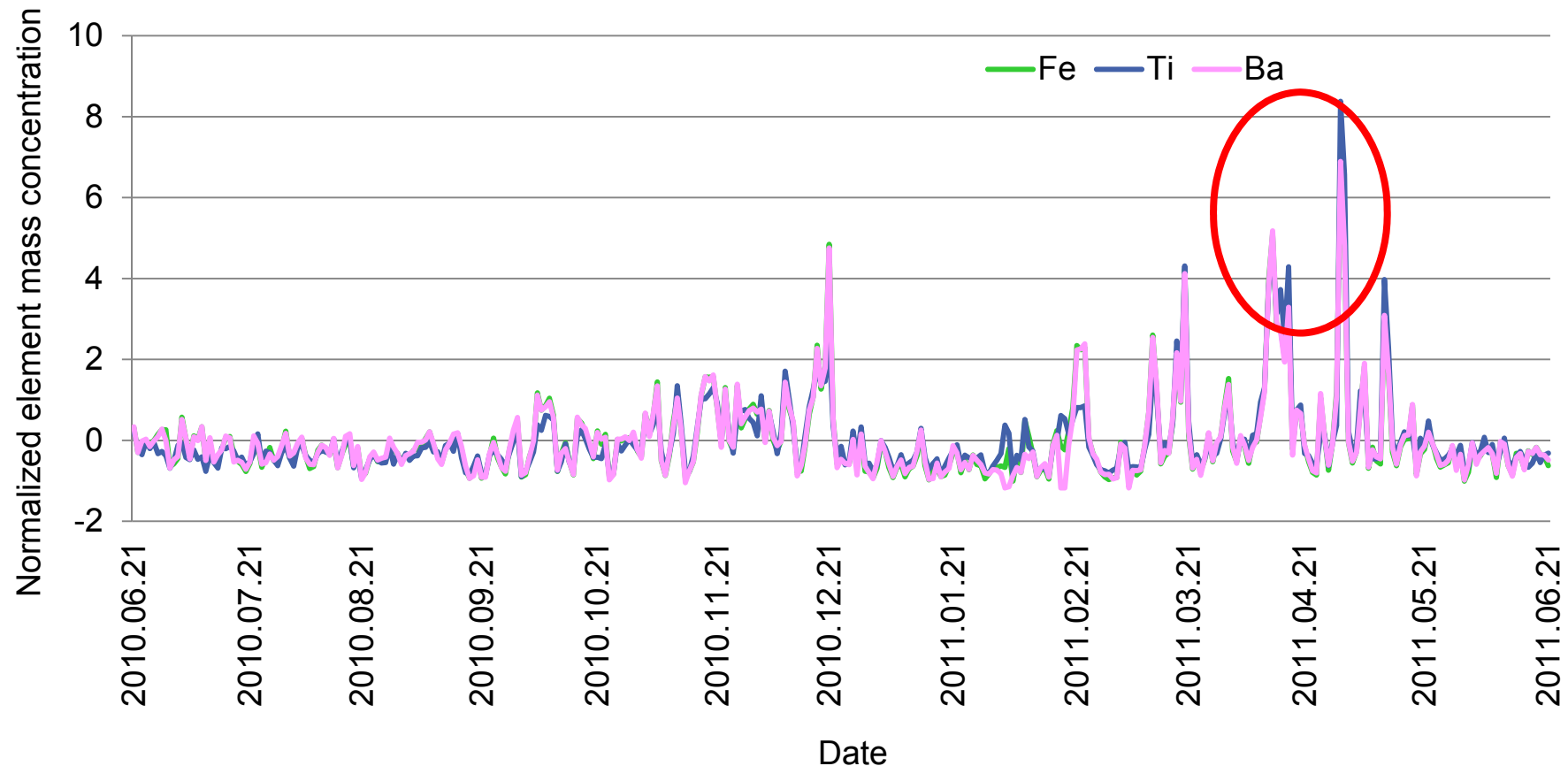


Desert dust clouds, winds from West, dry air



MLH > 1000 m: often multiple layering, < 1000 m: often one layer  
High  $\text{PM}_{2.5}$  load (40 – 140  $\mu\text{g}/\text{m}^3$ ): MLH much lower than 1000 m

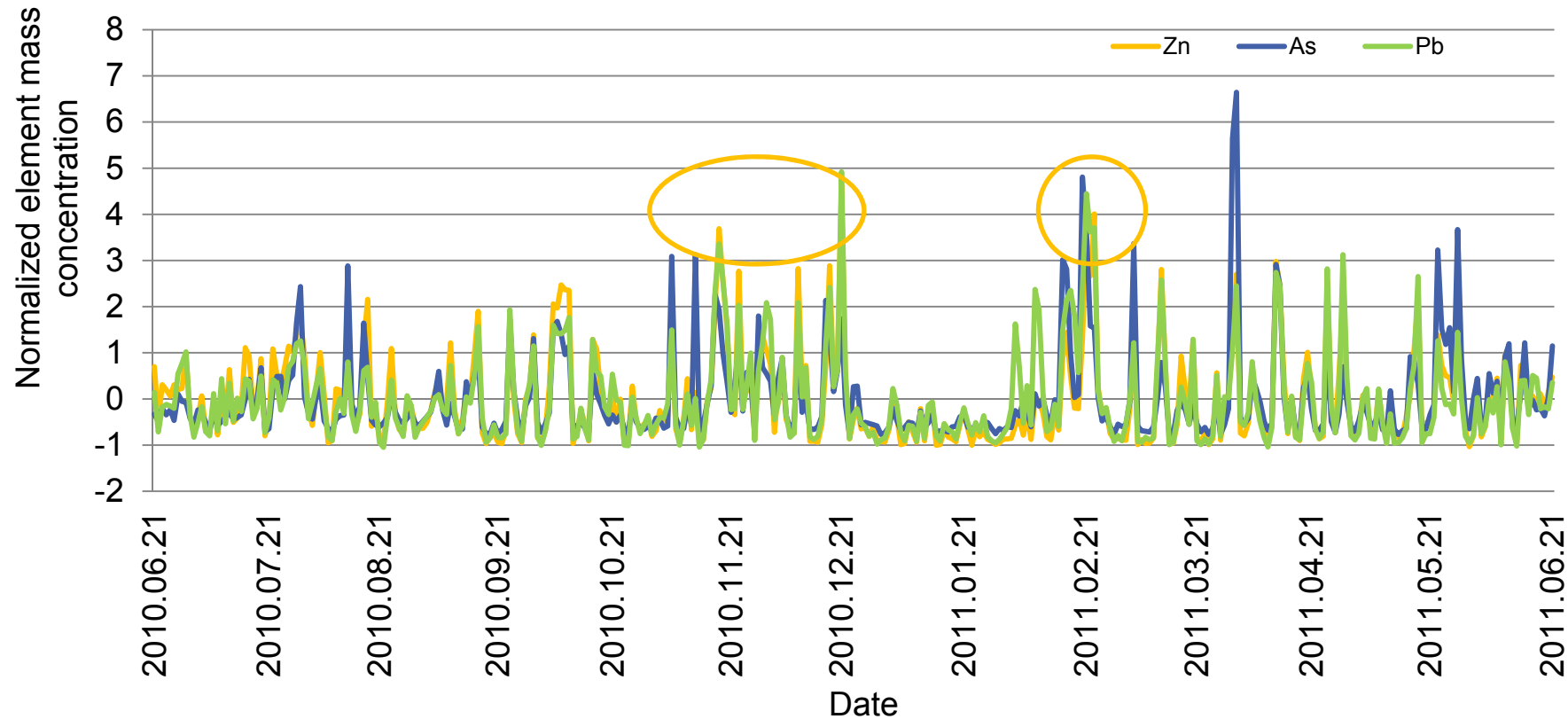
# Variation of Fe, Ti and Ba



Highest in April because of dust storm (originated from Gobi desert) and re-suspended road dust

**Dust events: different natural sources**

# Variation of Zn, As and Pb



Fossil fuel combustion (oil and coal combustion) and waste incineration, lowest in January - Spring Festival holidays

**Haze days:** highest PM mass concentration from anthropogenic activities, air pollution event during all seasons

## Influence of MLH upon element mass concentrations

If the origin of the elements is

- the **soil** this source dominates the concentrations (Al, K and Ca no MLH influence),
- the **traffic and industry** the air transport dominates (no MLH influence in higher altitudes) and
- a **widespread area source** the MLH dominates (Cu, Zn)

**Dust days:** high wind speed

## Meteorological influences

- RH: ↑ PM mass concentration
- WS: ↑ dilution of pollutants
- MLH: ↑ dilution of pollutants
- WD: transport pollution from local and regional

→ Haze days: high RH/low MLH, stagnant weather conditions with low air mass exchange

Visibility: negative correlated with RH and anthropogenic compounds, especially  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{NH}_4^+$   
very few dust events

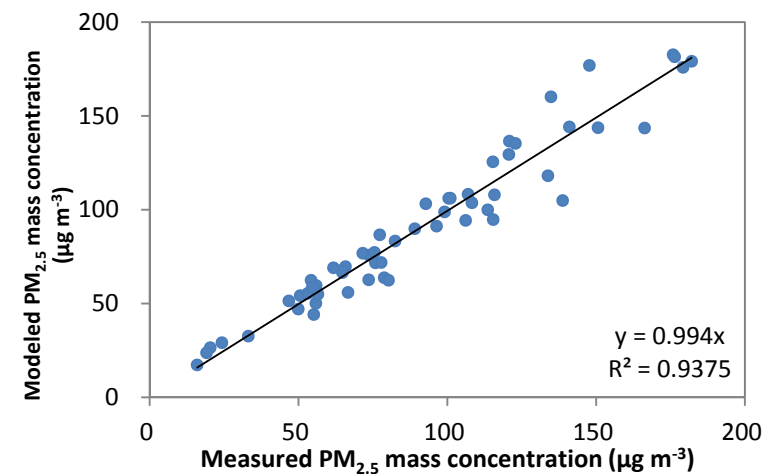
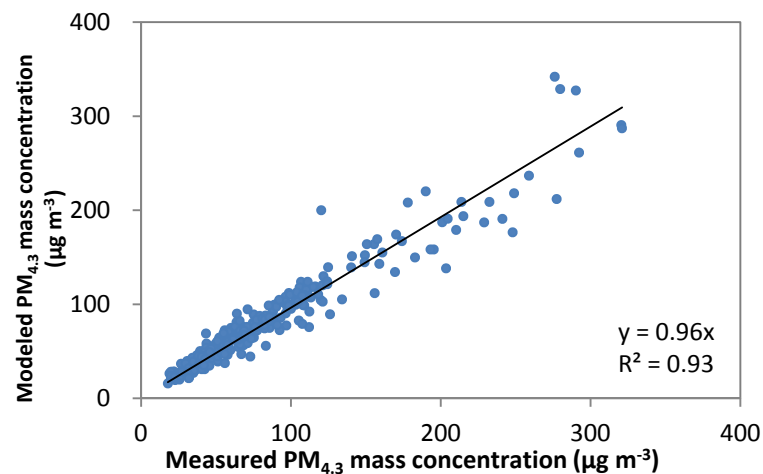
## Discussion

- Wind conditions influence urban air quality -> contribution of surrounding emissions: e.g. source apportionment of  $PM_{2.5}$
- MLH influenced by future climate change – quality of living in cities
- Only holistic and multidisciplinary approaches provide a deeper understanding -> measurements and modeling

# Methodology – Source apportionment

- Positive matrix factorization (PMF)

$$x_{ij} = \sum_{k=1}^p g_{ik} f_{kj} + e_{ij}$$

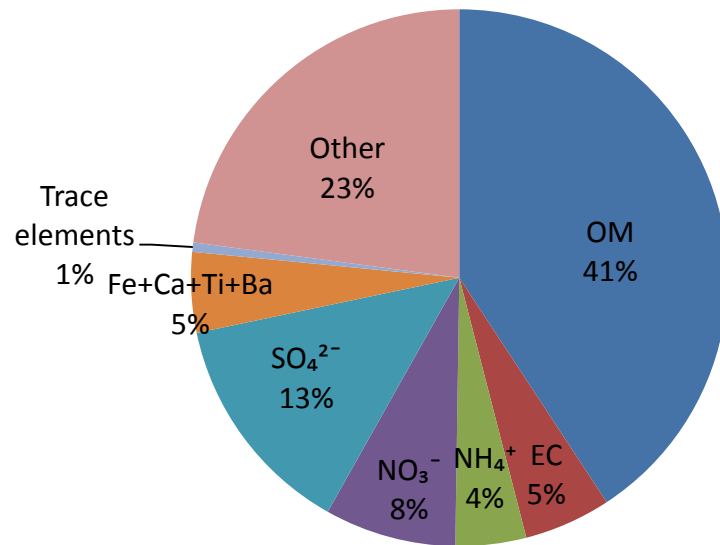


- Backward trajectory - HYSPLIT4 (Hybrid Single Particle Lagrangian Integrated Trajectory)
  - Height: 500 m at target point
  - Duration: 72 h

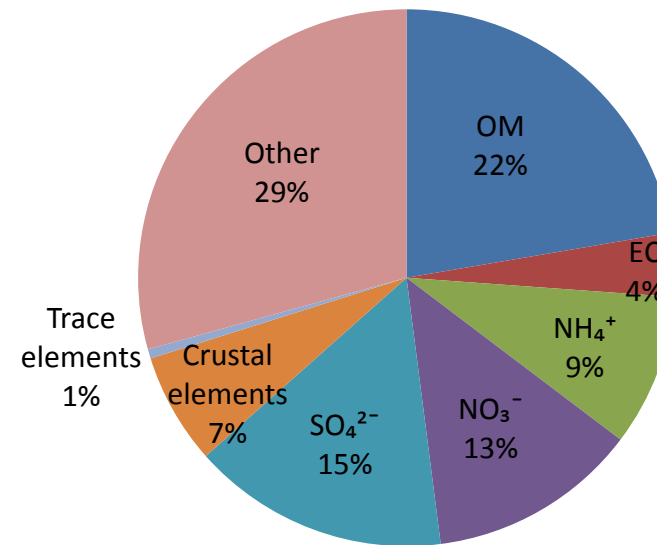


# Results - Mass Balance

## June 2010 – June 2011



## April – June 2013



- June 2010 – June 2011, PM<sub>4.3</sub>: 41% OM & 25% secondary inorganic ions
- April – June 2013, PM<sub>2.5</sub>: 22% OM & 37% secondary inorganic ions

# Results - Ratios Between Compounds

- Levoglucosan/OC → estimation of biomass burning contribution
- Hopane index:  $30ab/(30ab+30ba)$  → vehicle exhaust emission or coal combustion source
- $17\alpha(H)21\beta(H)\text{-Hopane}/(17\alpha(H)21\beta(H)\text{-Hopane} + 17\beta(H)21\alpha(H)\text{-Hopane})$
- Homohopane index:  $31abS/(31abS+31abR)$  → vehicle exhaust emission or coal combustion source
- $22S\text{-}17\alpha(H)21\beta(H)\text{-Homohopane}/(22S\text{-}17\alpha(H)21\beta(H)\text{-Homohopane} + 22R\text{-}17\alpha(H)21\beta(H)\text{-Homohopane})$
- BGH/BEP → vehicle exhaust emission source
- $\text{benz}(g,h,i)\text{perylene}/\text{benzo}(e)\text{pyrene}$
- $IND/(IND+BGH)$  → vehicle exhaust emission or coal combustion source
- $\text{indeno}(1,2,3,c,d)\text{ pyrene}/(\text{indeno}(1,2,3,c,d)\text{ pyrene} + \text{benz}(g,h,i)\text{perylene})$
- Mg/Al → dust source from inside or outside Beijing

Indicating sources of PM

## Haze 2010-2011:

Summer: Biomass burning and secondary inorganic ions

Autumn: Secondary inorganic ions

Winter: Coal combustion

Spring: Dust

## Results – PM<sub>2.5</sub>/PM<sub>10</sub> (TEOM Data)

– 2010.06 – 2011.06

- Haze: 0.55
- Clear: 0.35

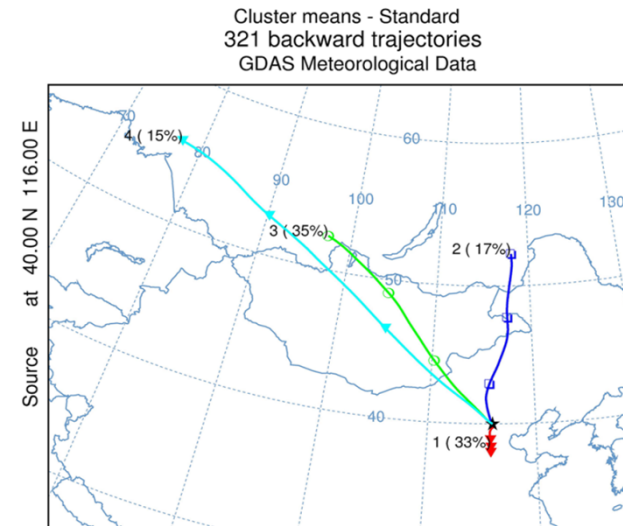
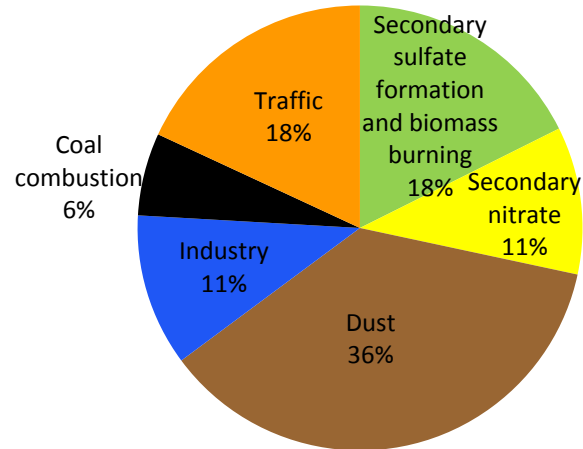
– 2013.04 – 2013.06

- Haze: 0.68
- Dust: 0.25
- Clear: 0.38

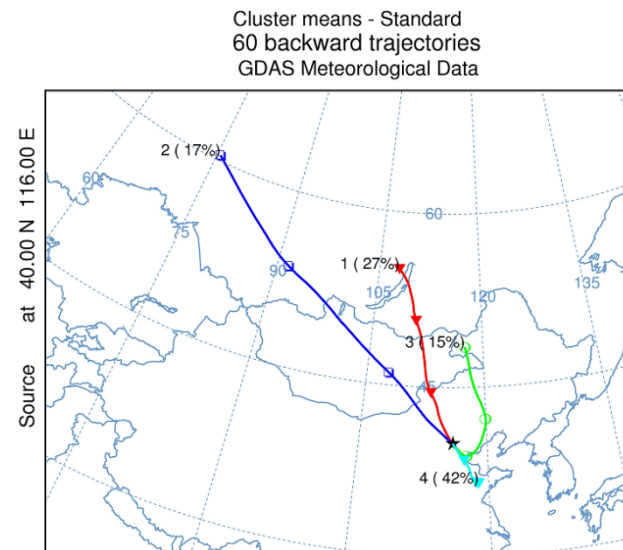
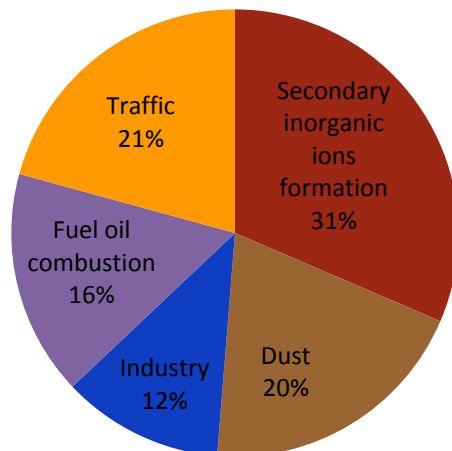
→ Contribution of fine particles ↑ during haze

# Results - Source Apportionment

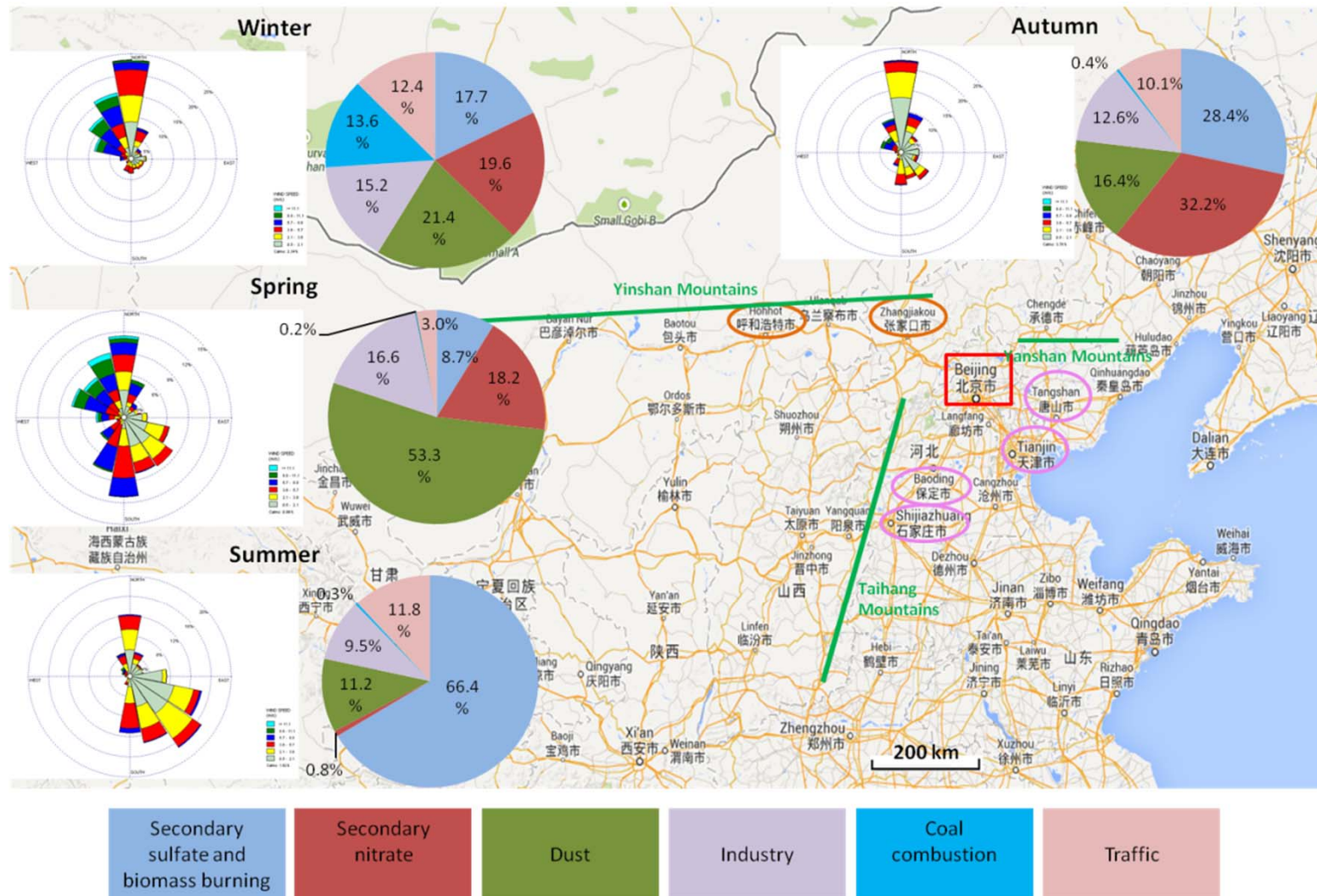
- June 2010 – June 2011



- April – June 2013



# Summary – Orography, Meteorology and Emissions in the Surroundings



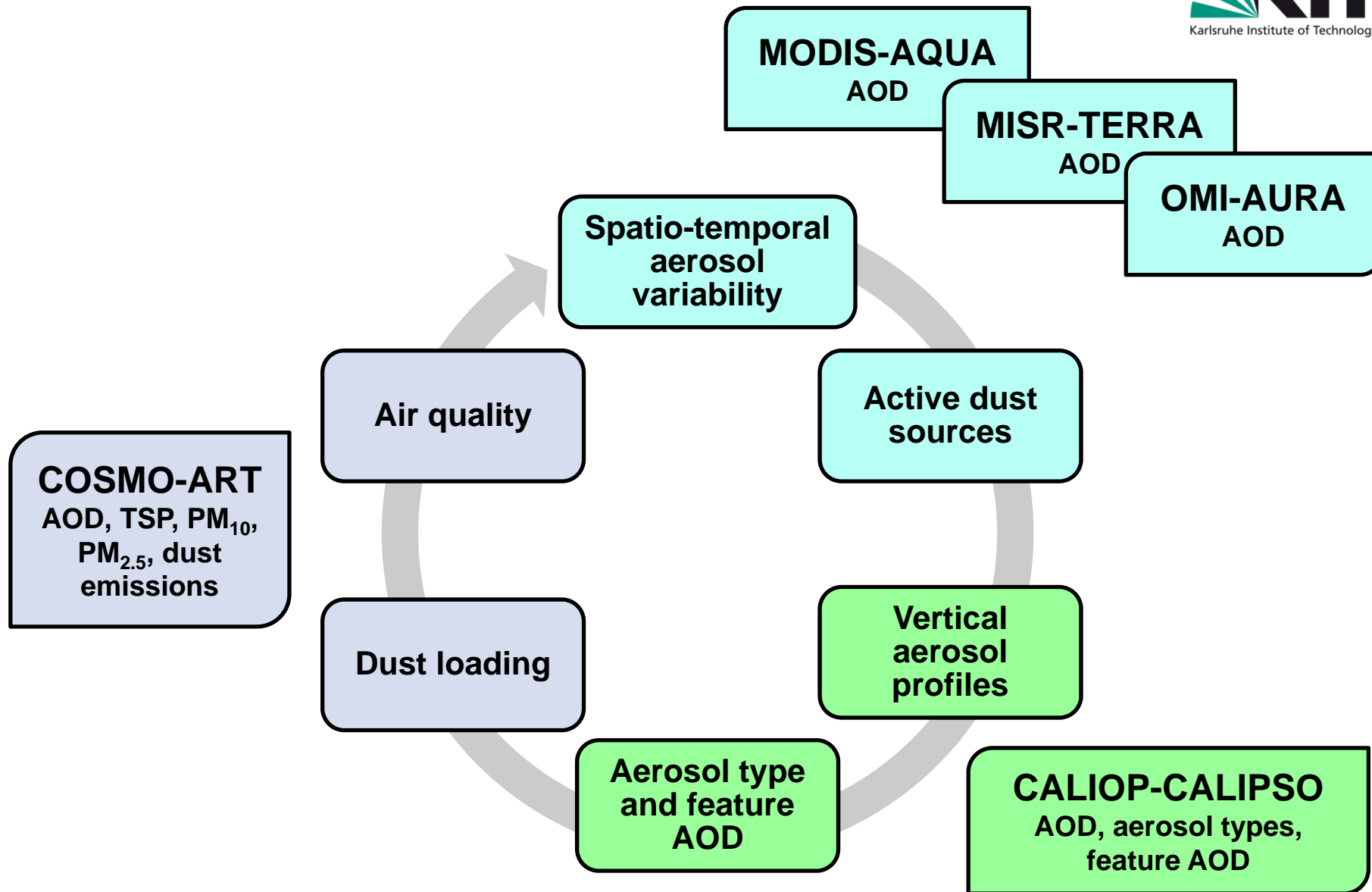
# Conclusions

- PM mass concentrations after Olympic Summer Games 2008 are still high
- Haze becomes more frequent because an increasing number of fine and anthropogenic particles is emitted and stagnant weather conditions are not decreasing
- Haze in different seasons was caused by different sources and source regions due to different dominating transport conditions (local, regional and long-range as well as different directions) and regional air quality situation
- Controlling the emission of precursor gases of  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{NH}_4^+$  in regional scale is necessary for reducing haze
- Installation of cleaning equipment in industrial exhaust and mobile vents, improving road cleaning standards and reducing construction dust also becomes important for improving air quality

# Meteorological influences upon urban air quality

## Mineral dust exposure in Beijing

# Methodological approach





# COSMO-ART

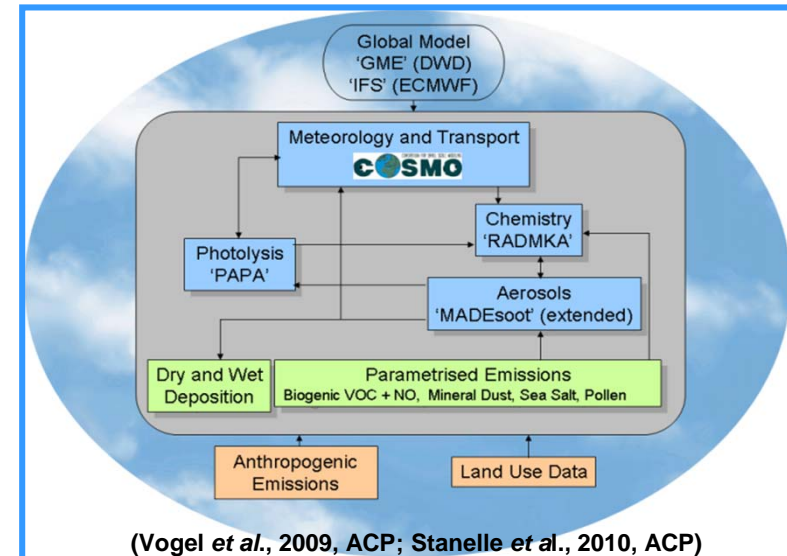
**Aim:** Investigation of impact of gases and aerosols on air quality (continental to local scales)

**Gases & Aerosols:** 80 gas species, 5 anthropogenic aerosol modes, **mineral dust**, sea salt, pollen

**Feedbacks:** meteorology, aerosols, gas phase, dynamics, clouds

## Mineral dust:

- 3 initial dust modes, dust emissions, TSP, PM<sub>10</sub>, PM<sub>2.5</sub>, AOD
- Emissions: surface properties, friction velocity, soil moisture
- AOD: calculated online as function of extinction coefficients, single scattering albedo derived a priori according to dust size and number concentrations using Mie theory



## COSMO-ART

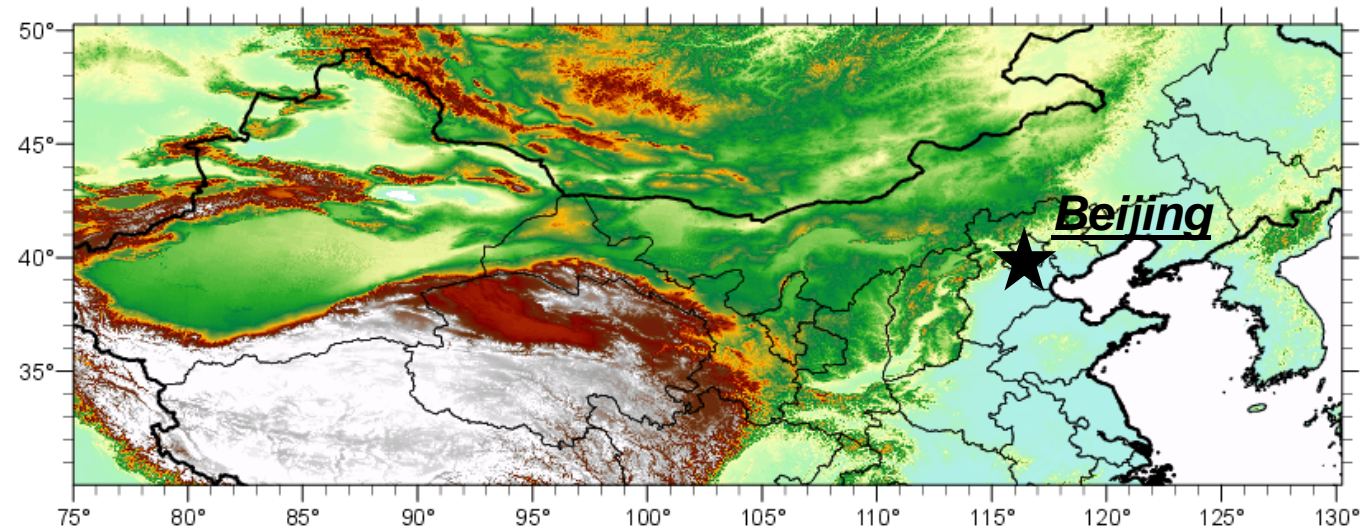
(Consortium for Meso-scale Modeling – Aerosols and Reactive Trace Gases)

## Data overview

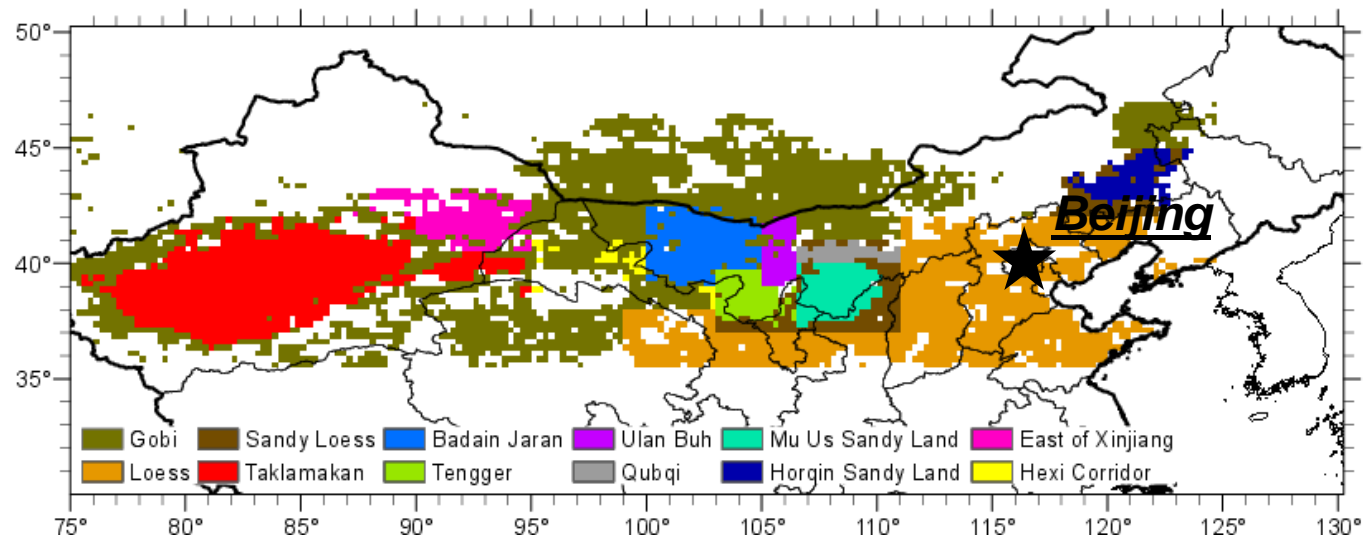
|                  | Parameters and product  | AOD wavelength     | horizontal resolution | vertical resolution                    |
|------------------|---|--------------------|-----------------------|--|
| <b>MODIS</b>     | Deep Blue AOD<br>Collection 5.1, Level 2  | 550 nm             | 10 x 10 km            | -                                      |
| <b>OMI</b>       | Near-UV AOD<br>OMAERUVd, Level 3  | 500 nm             | 1 x 1°                | -                                      |
| <b>MISR</b>      | Green band AOD<br>MIL2ASAE, Collection 11, Level 2                                | 555 nm             | 0.15 x 0.15°          | -                                      |
| <b>CALIOP</b>    | AOD, aerosol types<br>Level 2, data version 3.01                                  | 532 nm,<br>1064 nm | 5 x 5 km              | 333 m                                  |
| <b>COSMO-ART</b> | AOD, TSP, PM <sub>10</sub> , PM <sub>2.5</sub><br>without anthropogenic emissions | 555 nm             | 28 x 28 km            | Varying terrain<br>following<br>layers |

# Study area and dust source regions

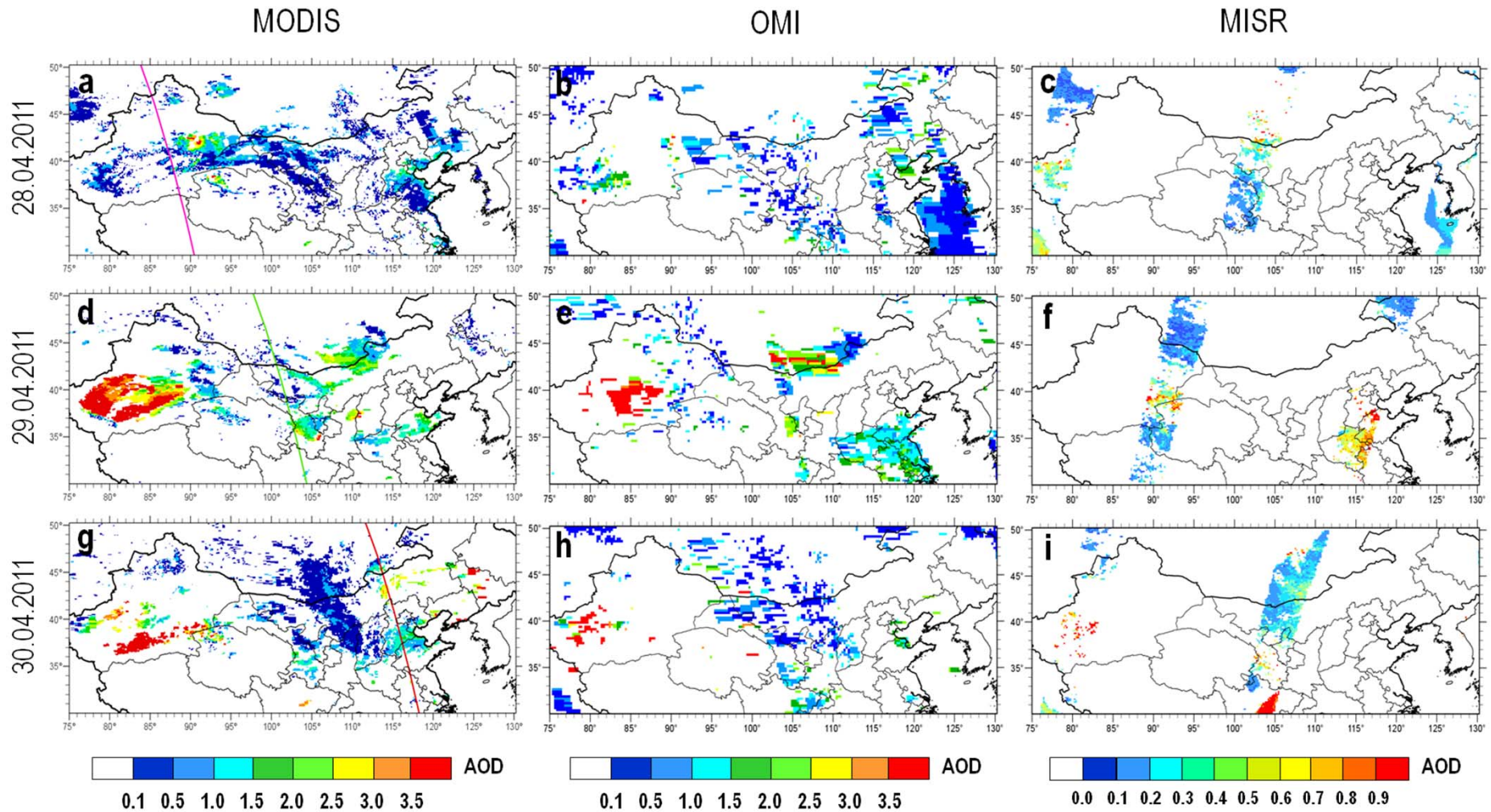
Model domain



Desert areas in Northern China



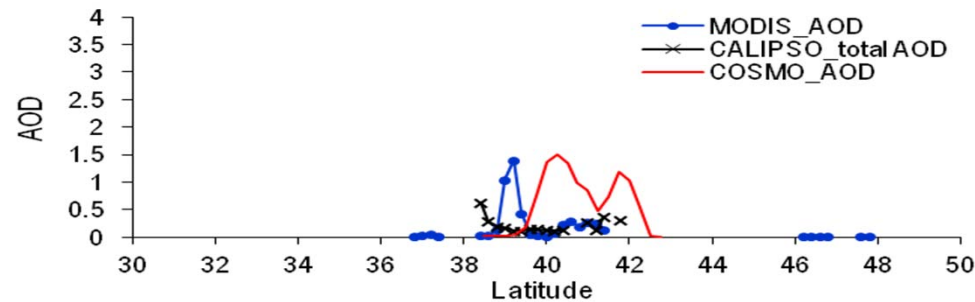
# Spatio-temporal variability of AOD by passive sensors



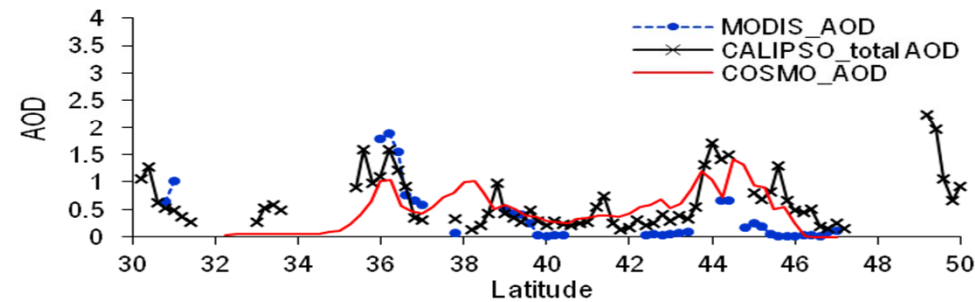
# Satellite information for air quality modeling - AOD

Comparison of measured AOD by MODIS and CALIPSO and simulated AOD by COSMO-ART for model validation

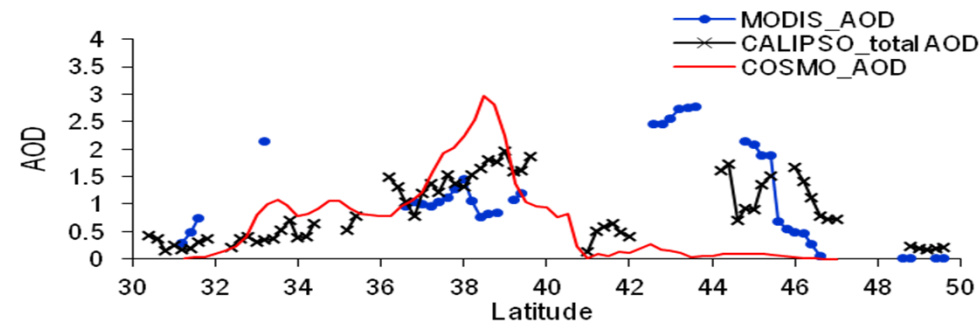
28.04.2011\_07:30 UTC\_Taklamakan Desert



29.04.2011\_06:30 UTC\_Central China



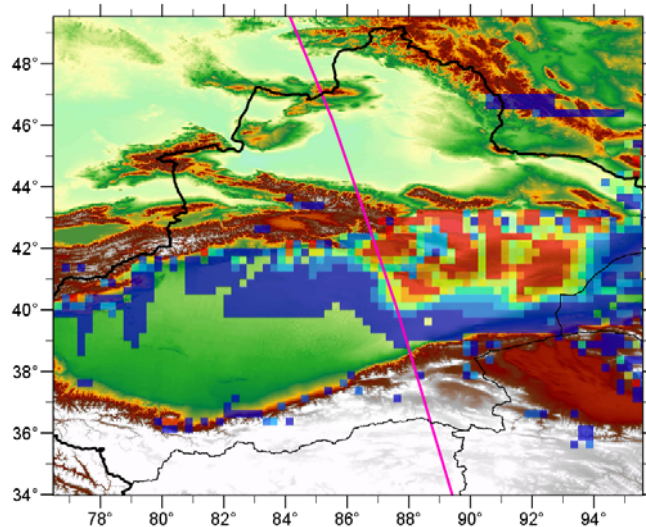
30.04.2011\_05:30 UTC\_Inner Mongolia/ Beijing



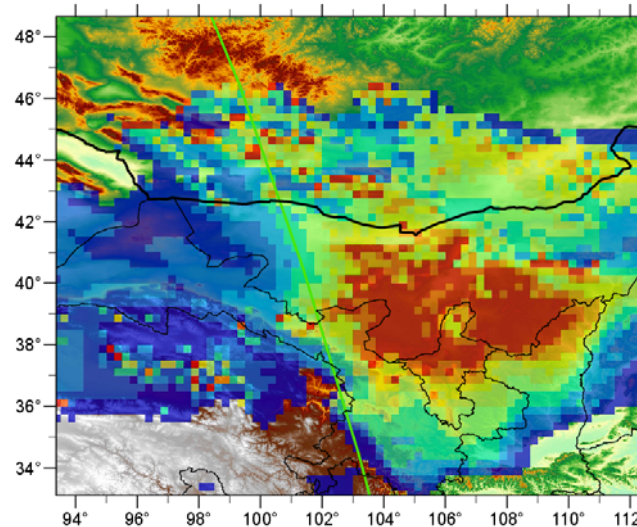
# Impact of mineral dust on air quality – PM<sub>2.5</sub>

## Simulation of local PM<sub>2.5</sub> mass concentrations

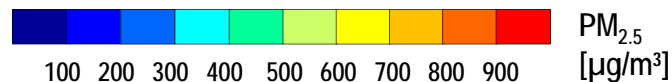
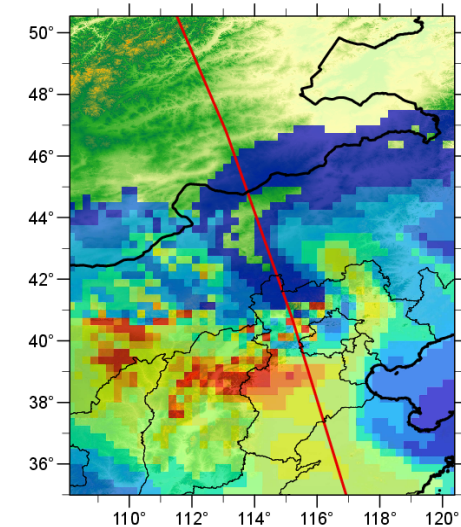
28/04/2011, 07:30 UTC  
Taklamakan Desert



29/04/2011, 06:30 UTC  
Central China

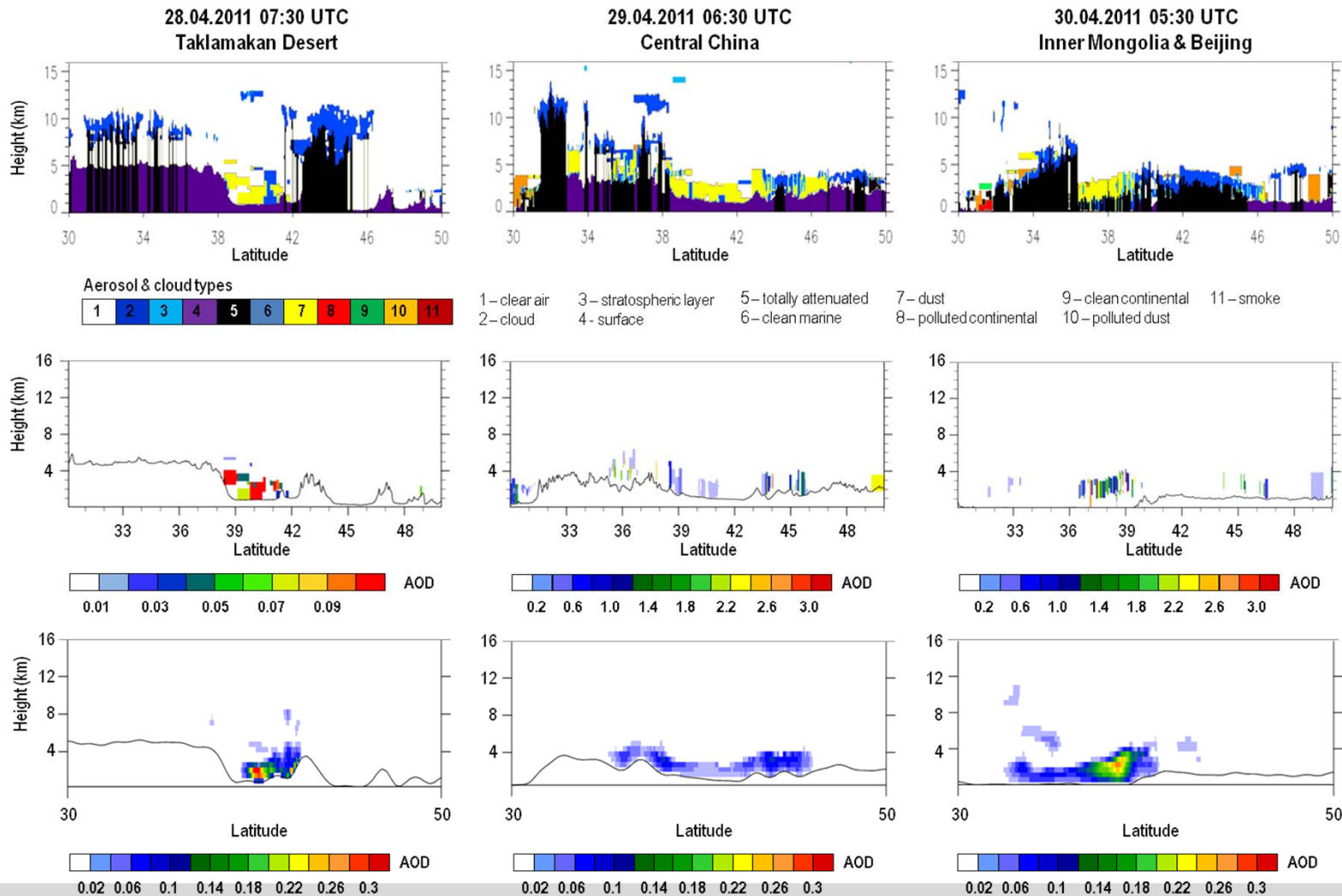


30/04/2011, 05:30 UTC  
Beijing & Inner Mongolia



# Impact of mineral dust on air quality – AOD

## Comparison of CALIPSO features and feature AOD and simulated COSMO-ART AOD



## Conclusions

- Dust is present over most of the desert areas  
→ main source regions Kumtaq, Taklamakan, Gobi
- Most mineral dust is located near the ground → air quality
- Good accordance aerosol by satellites and simulated dust  
→ Space lidar and passive sensors - aerosol model validation
- We have to investigate
  - Traffic emissions and its development (e.g. UFP, BC)
  - Feedback mechanisms climate change & air quality
  - Consequences to human health:  $PM_{2.5}$ , PSD -> UFP
- Study future developments and recommendations relevant for decision makers and stakeholders to improve air quality and to limit climate change impacts



## Acknowledgements

We like to thank for financial support within the frame of two start-up projects KIT centre Climate and Environment as well as State Baden-Württemberg, Helmholtz Graduate School for Climate and Environment (GRACE) at KIT and CSC for fellowships.

**Thank you very  
much for your  
attention**