Meteorological influences and role of emissions within the context of air quality in Beijing

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

- Problems
- Scientific questions
- Process studies
  - Influences upon air pollution
  - Source apportionment
  - Spatial distribution of PM
- Future work and perspectives

Problems

Climate protection or improvement of air quality / health protection? Or both?

Decisions for emission reduction measures

- Gasoline or Diesel motor: PM, NO_2, NH_3 emissions
- Aircraft: VOC, CO, NO_x emissions and contrails
- Odour and noise emissions or GHG emissions

Problems

- Changing NO_2/NO_x ratios in ambient air
- Threshold exceedances - sustainable reduction of NO_2, PM_{10}
- Load, character and sources of ultrafine particles in urban background
- Air pollutants and health impact
  - Which pollutants are relevant?
  - Which concentrations/exposures influence health impacts?

Scientific questions for air quality in Beijing

Origin of frequently occurring air pollution events

Origin of pollutants and especially PM - urban agglomerations are one of the most important sources for PM

Local and regional wind systems - can bring fresh air masses and limit air pollution

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

Role of mixing layer height - mountains are West to North

Heat island effect

Process studies

Influences upon air pollution

Air quality studies

Continuous determination of mixing layer height (MLH) by ceilometer

Limits the vertical distribution of emitted air pollutants with consequences for dilution and transport

Essential for the determination of speed and range of vertical dispersion

Influenced by future climate change and thus important for quality of living in large cities

MLH influence upon air pollution in urban and sub-urban area

Hannover, Munich, Augsburg, Budapest, Zurich Airport, Mexico City International Airport, Athens International Airport, Paris CDG

- Correlation with MLH smallest inside street canyons
- Correlation with MLH larger in winter than in summer
- Influences of MLH upon CO, NO_2 and PM_{10} concentrations in the order of 20 %, up to 50 %

➔therefore better MLH determination necessary

➔deployment of ceilometers for continuous operation

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

Wind influences upon air pollution

- Under strong background flows:
  reduced concentrations for all pollutants without distinct maxima and minima of diurnal cycle

- Under the development of local flows:
  high concentrations of air pollutants

- Influences of wind speed upon CO, NO_2 and PM_{10}:
  in the order of 20 %

Schäfer, K., Emeis, S., Hoffmann, H., Jahn, C., Müller, W., Heits, B., Haase, D., Drunkenmölle, W.-D., Bächlin, W., Schlünzen, H., Leitl, B., Pascheke, F., Schatzmann, M.: Field measurements within a quarter of a city including a street canyon to produce a validation data set. International Journal of Environment and Pollution, 25, 1/2/3/4, 201-216, (2005).

Dandou, A., Tombrou, M., Schäfer, K., Emeis, S., Protonotariou, A.P., Bossioli, E., Soulakellis, N. Suppan, P.: A comparison between modelled and measured mixing layer height over Munich. Boundary-Layer Meteorology 131, 425–440 (2009).

Air quality studies in Beijing

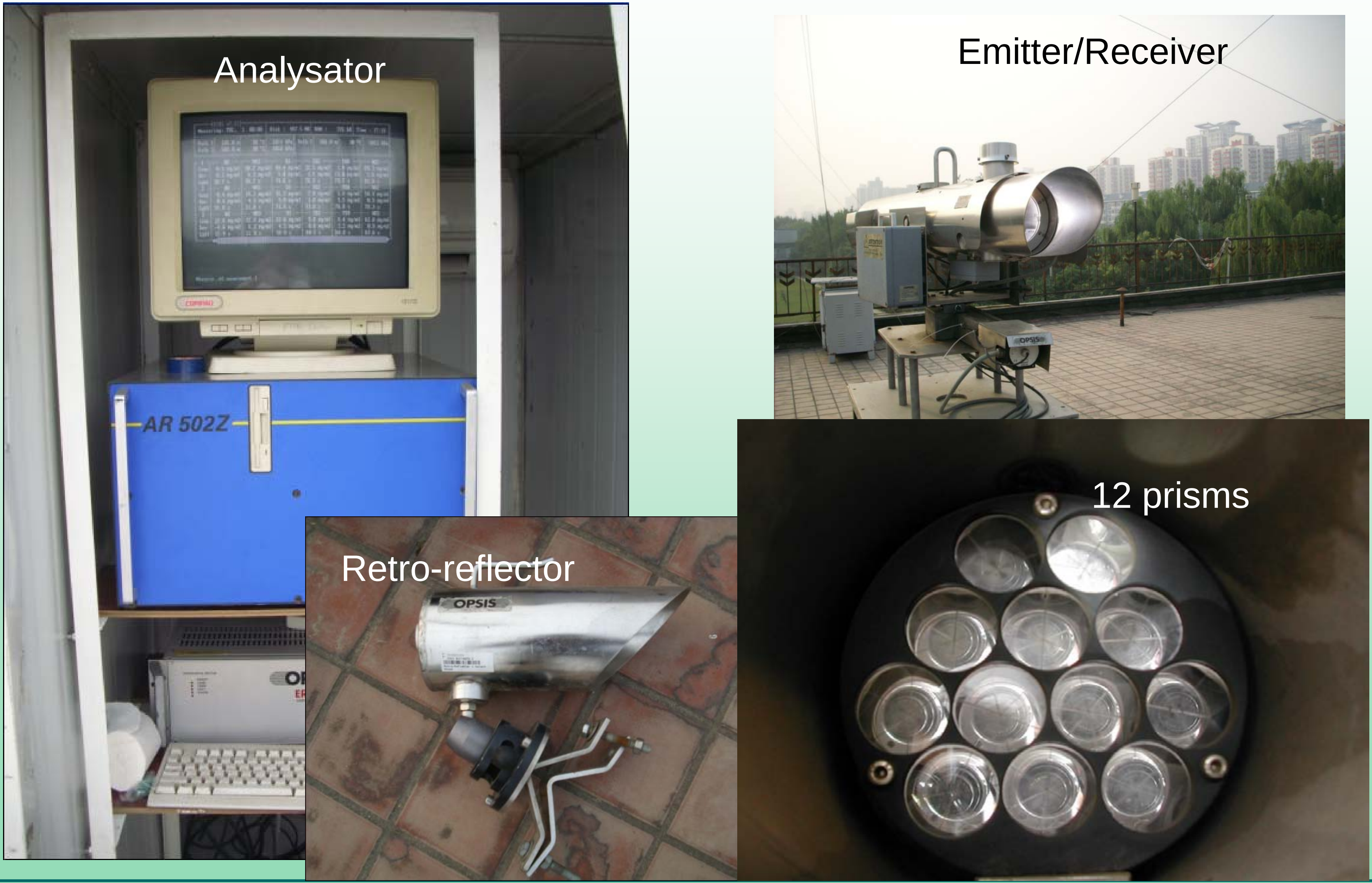
Comparison motorway with background concentrations

- diurnal variations
- influences upon gaseous concentrations:
  emissions, meteorology
- gases of interest for secondary aerosol formation

Path-averaged concentrations of air pollutants NO_2, SO_2, O_3, (benzene, toluene, xylene, NO, NH_3, HCHO)

- near / across a motorway April 2009 – March 2011
- commercial DOAS
- three retro-reflectors
- automatic operation

Instrument


Analysator
AR 502Z
Emitter/Receiver
Retro-reflector
OPSIS
12 prisms

Measurement sites

LAPC tower, ceilometer, DOAS from 13 July 2009 on

Path1 - the first floor of the tower 126m(double)

Path2 - on the roof in our courtyard 266m(double)

Path3 - in the middle of the lampstandard 568m(double)

Calibration

Calibration system

Light source

Calibration cells

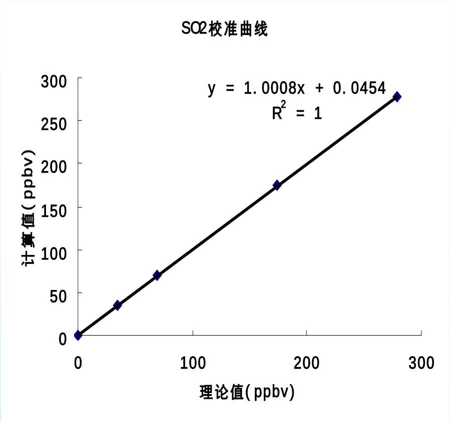
Ozone generator

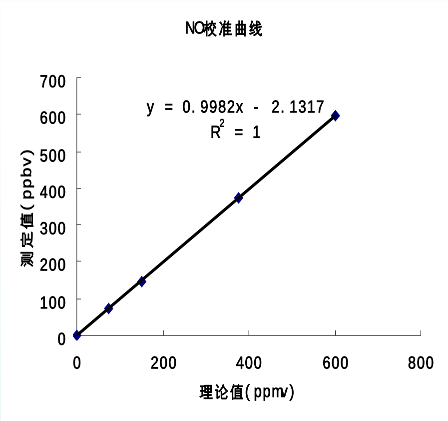
Calibration

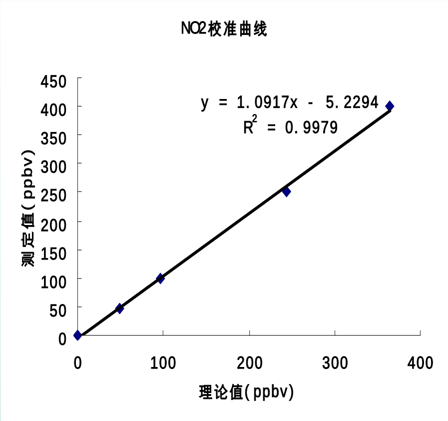
Concentrations for calibration

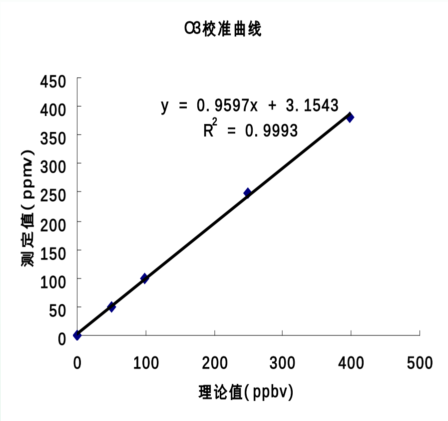
SO_2: 679 ppmv
NO_2: 966 ppmv
NO: 1510 ppmv
O_3: 1000 ppmv
(generated by an O_3 generator)
Benzene: 60.3 ppmv
Toluene: 59.7 ppmv
Para-Xylene: 60.0 ppmv

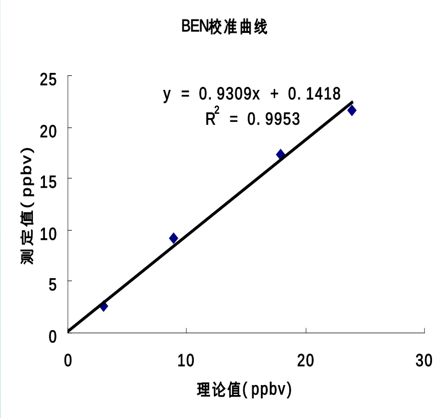
Calibration

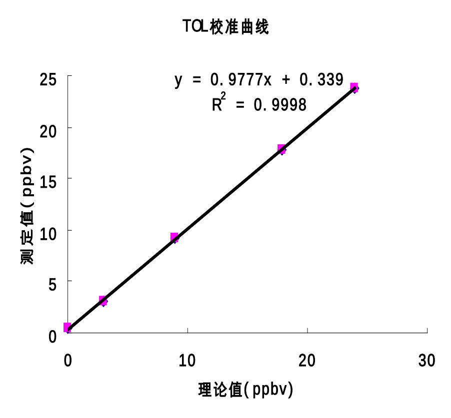


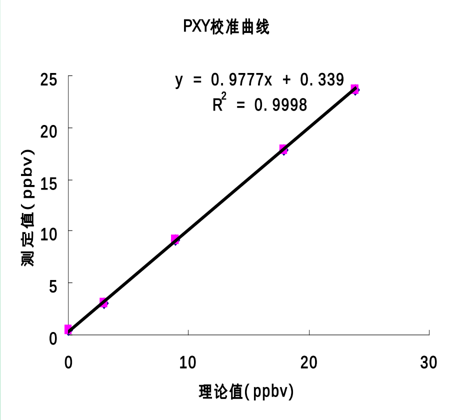












The linear correlation coefficients are better than 0.99

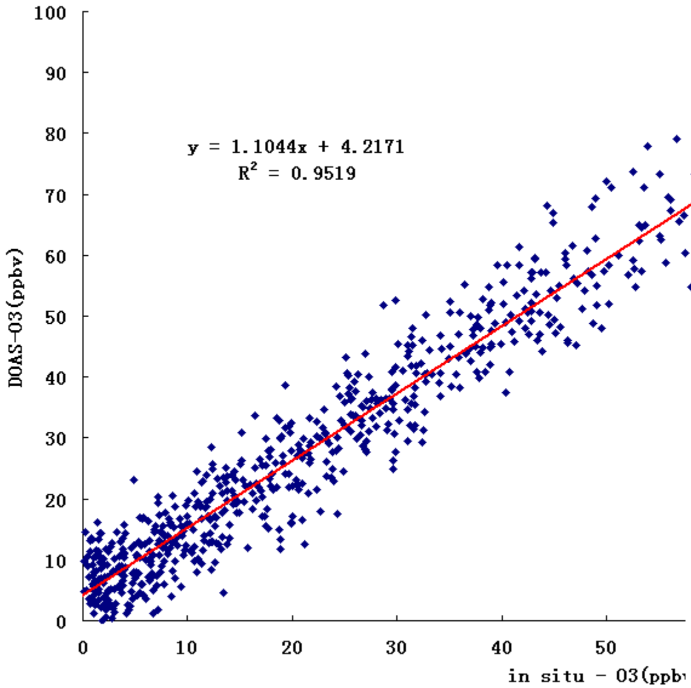
HCHO – only a reference calibration was taken

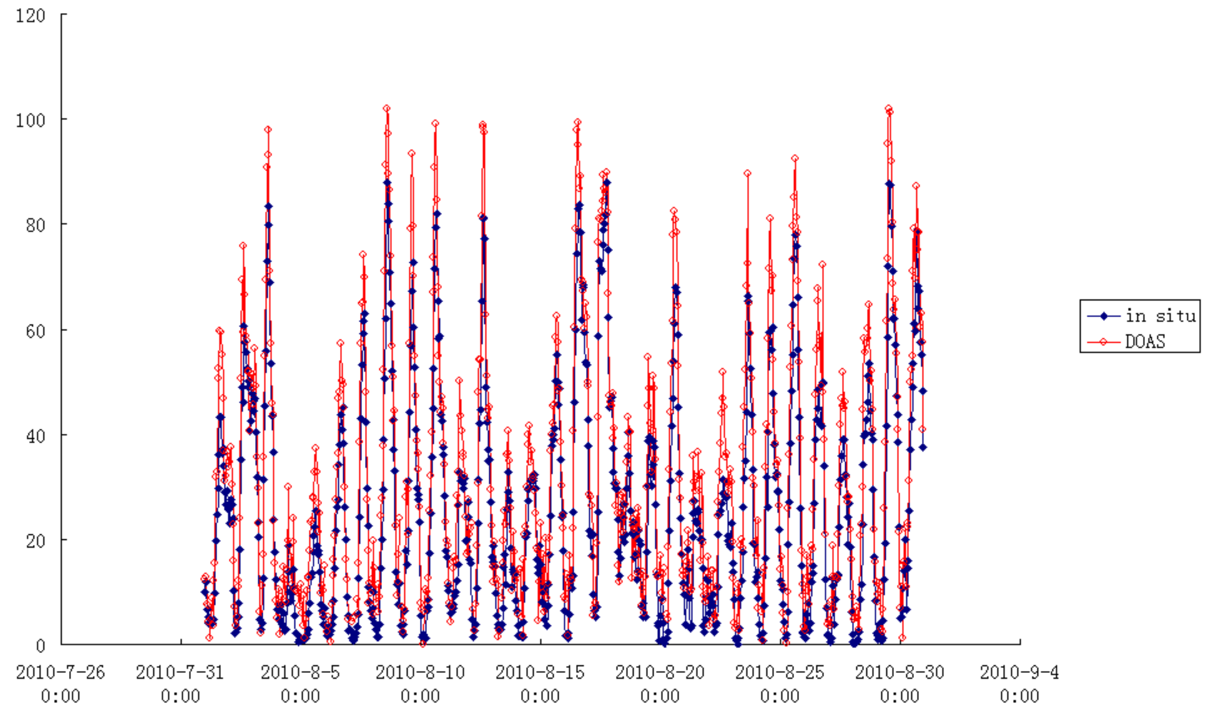
Comparison - instruments

- chemiluminescence NO-NO_2-NO_x analyzer
- UV photometric O_3 analyzer
- pulsed fluorescence SO_2 analyzer

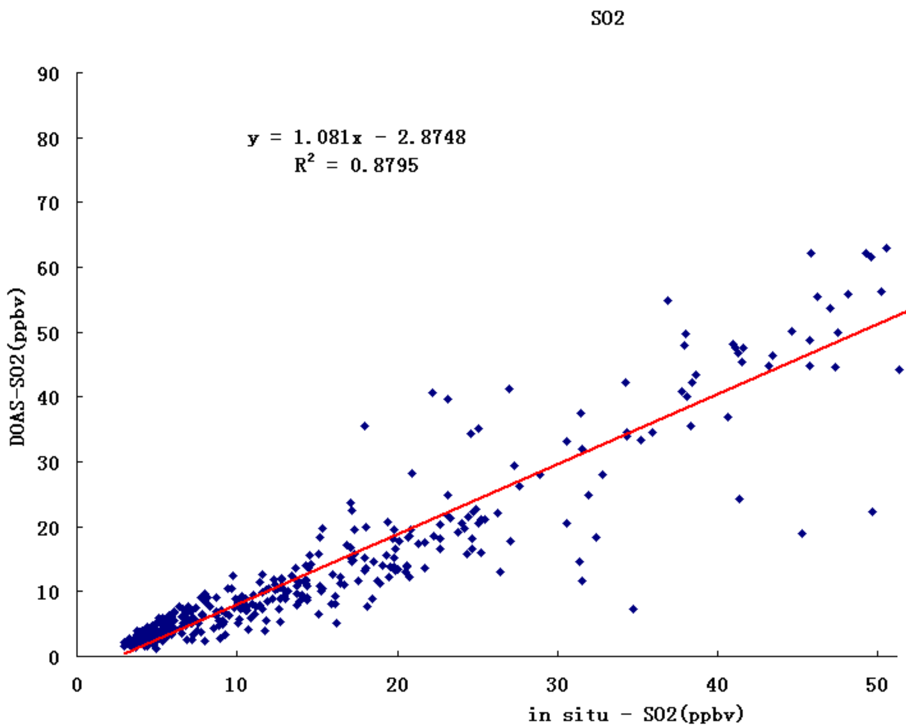
- GC/MS system (Finnigan Trace 2000/DSQ, ThermoFisher, USA) with fuse-silica capillary column for aromatic hydrocarbons

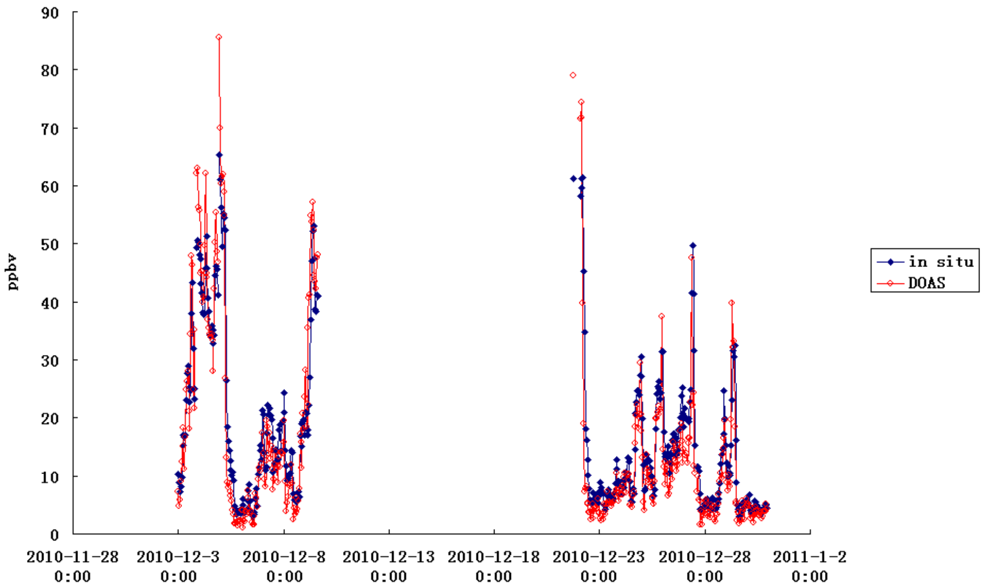
Comparison O_3 (path 2)



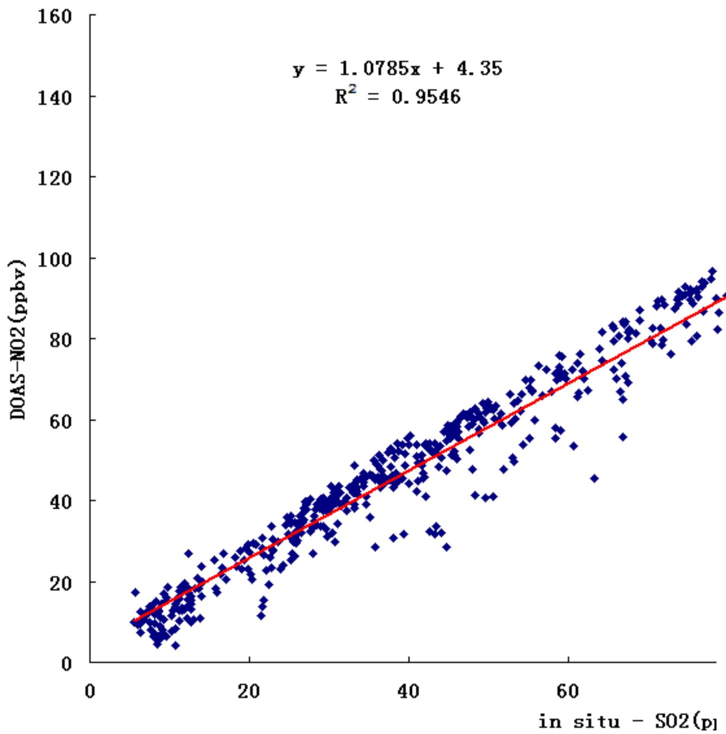


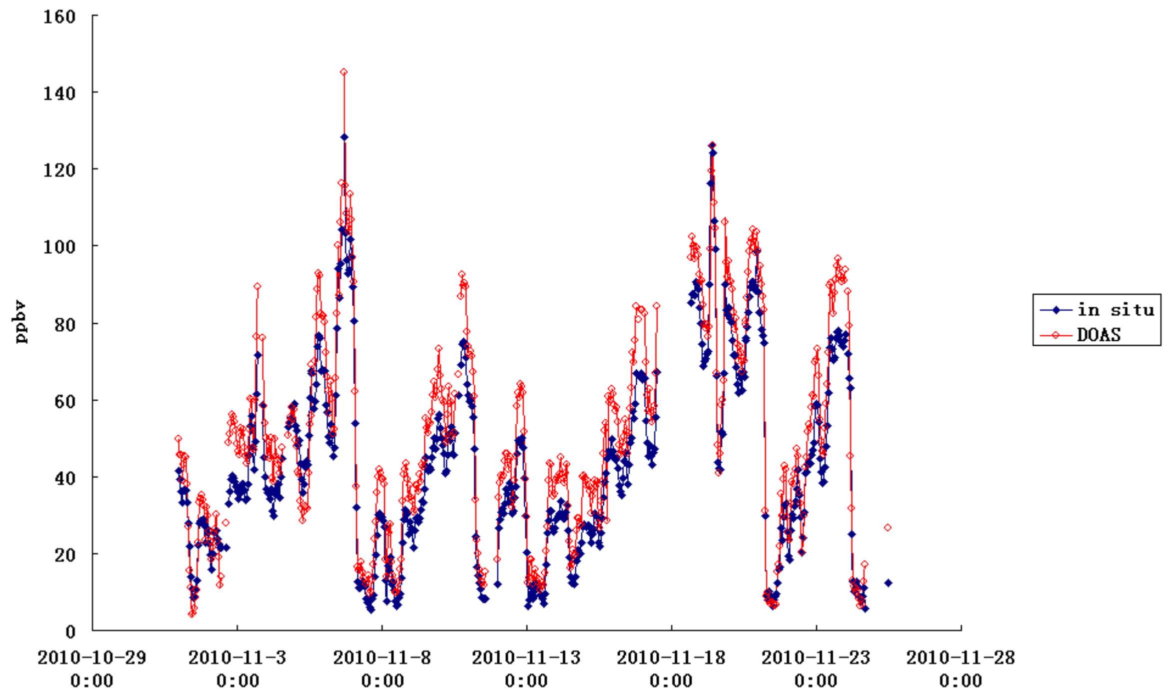
Comparison SO_2 (path 2)



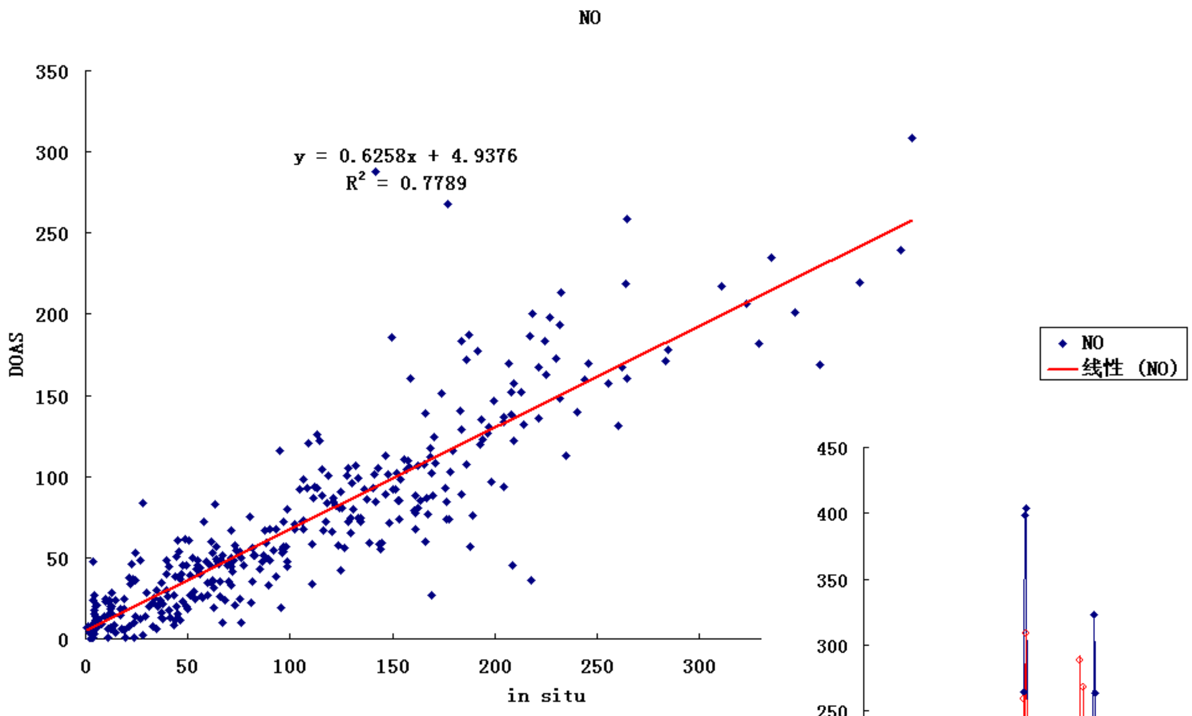


Comparison NO_2 (path 2)

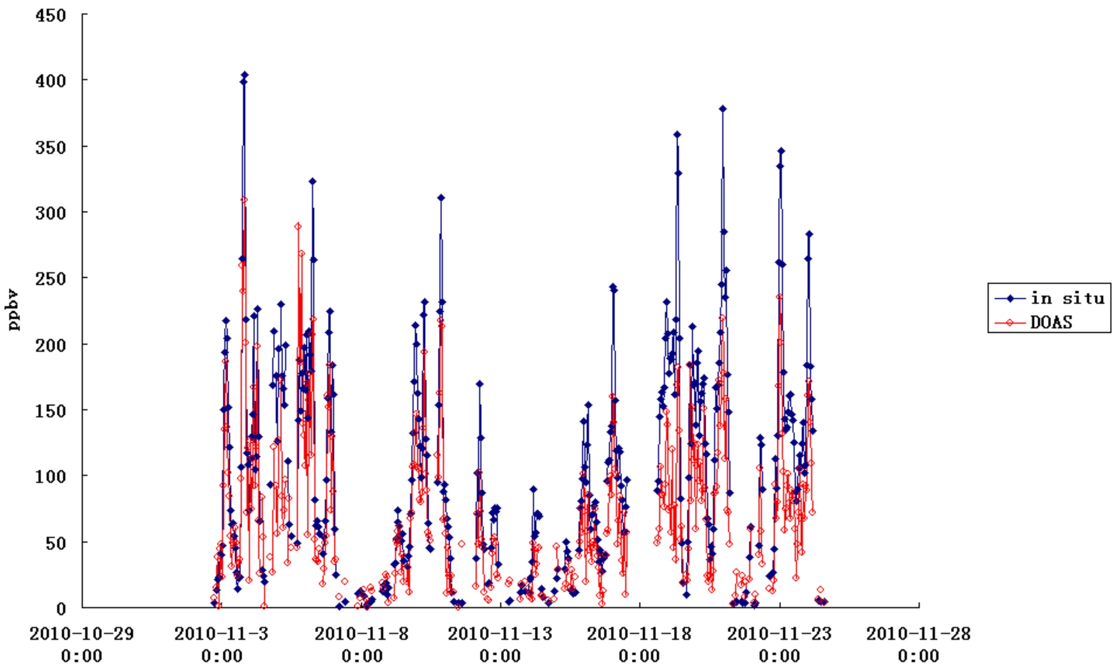




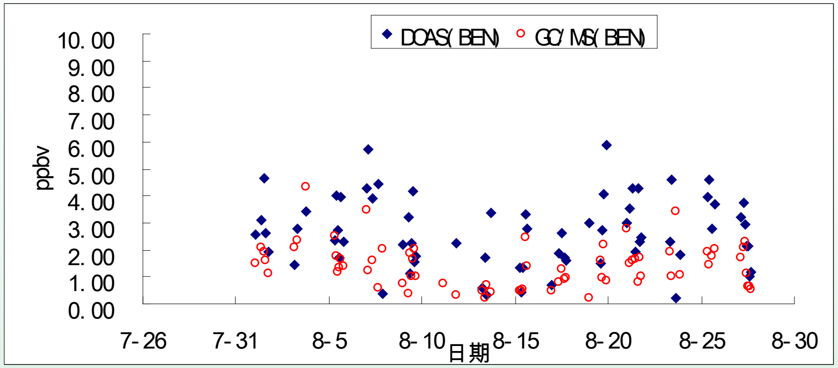
Comparison NO (path 1)

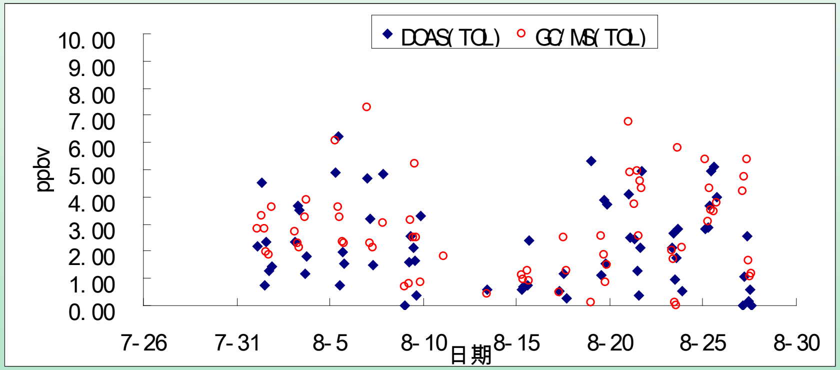


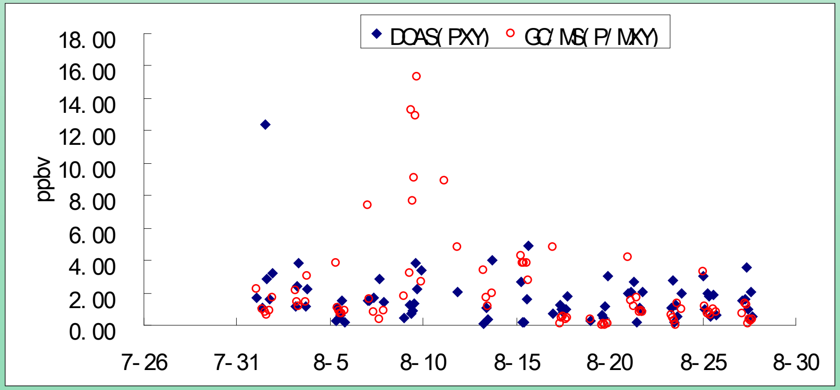
a good trend
but many negative data



Comparison Aromatic Hydrocarbons (path 2)







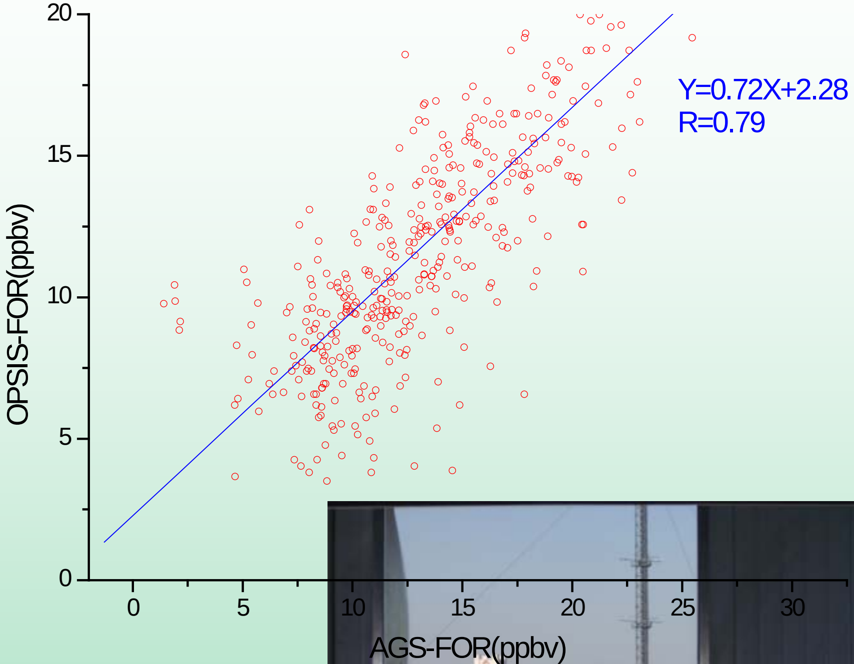
Average difference between DOAS and GC/MS:

BEN: 0.94 ppbv (64% higher)

TOL: -0.56 ppbv (20% lower)

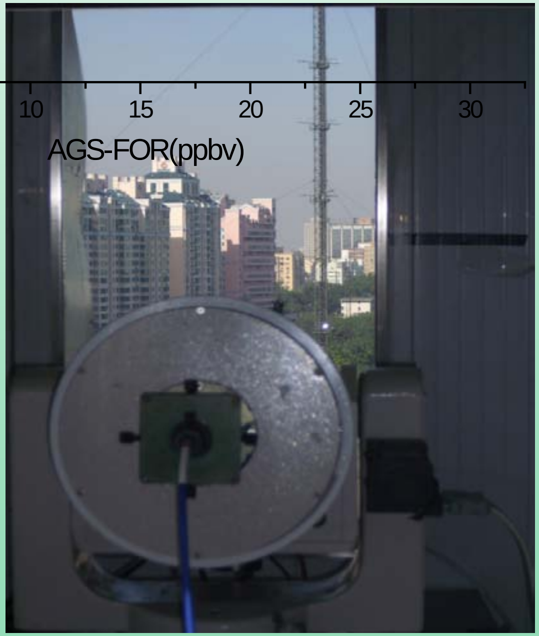
PXY: -0.49 ppbv

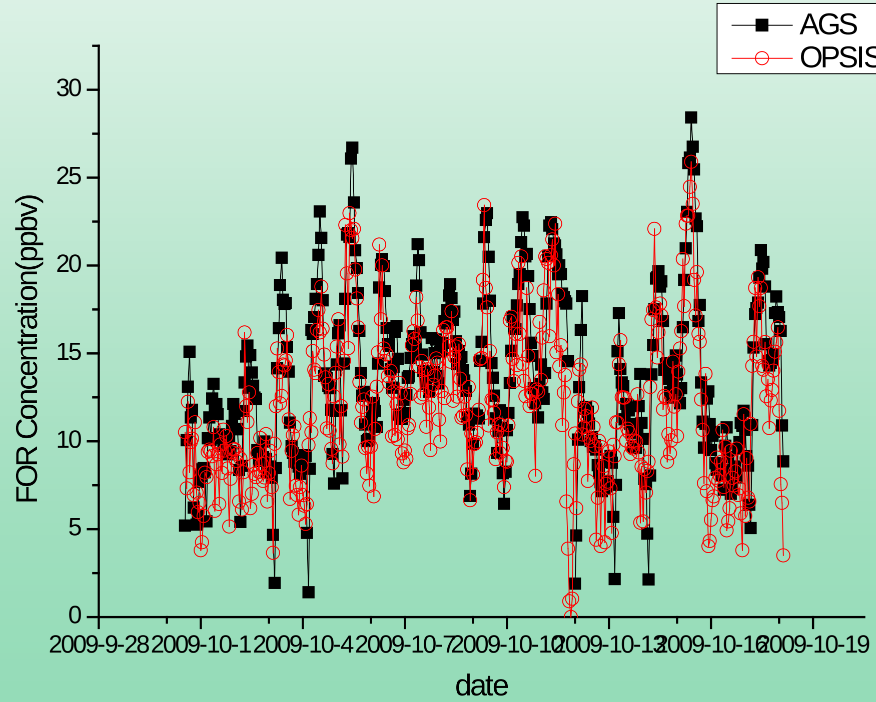
Comparison HCHO (path 3)



Two different DOAS systems:

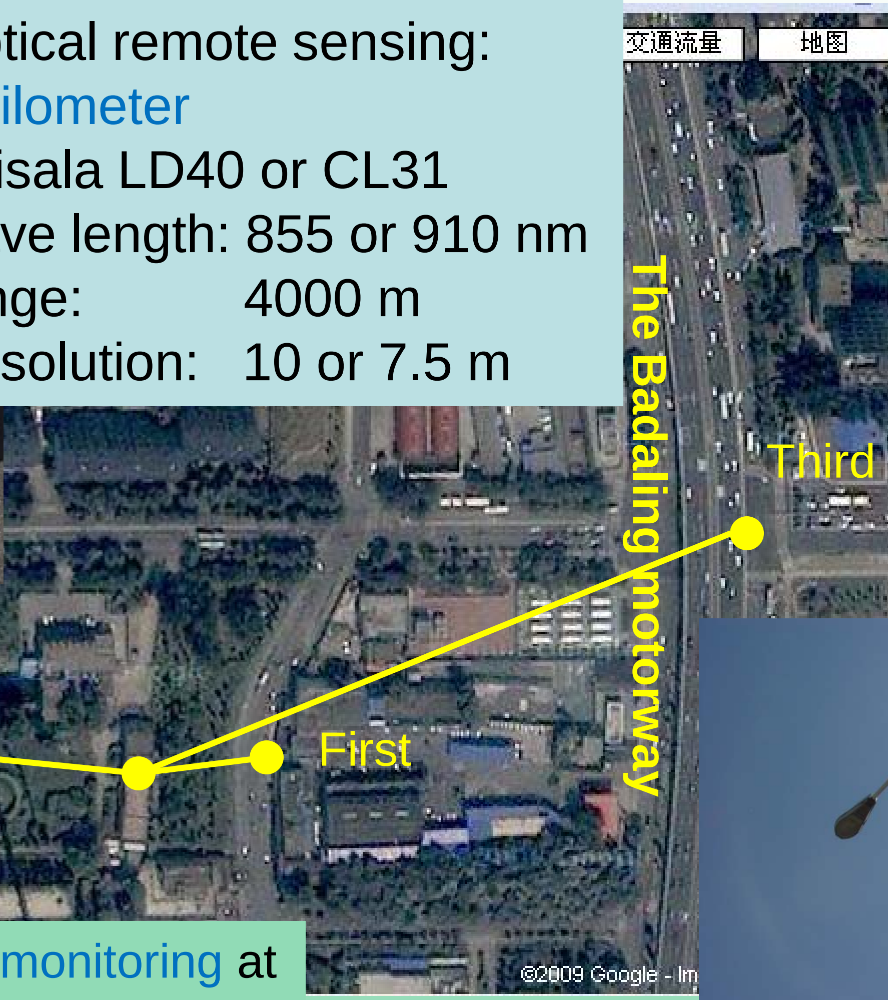
- Mono-static with retro-reflectors
- Bi-static from Anhui Inst. Optics and Fine Mechanics, CAS





Continuous determination of mixing layer height by ceilometer since February 2009
DOAS installation April 2009 until July 2009

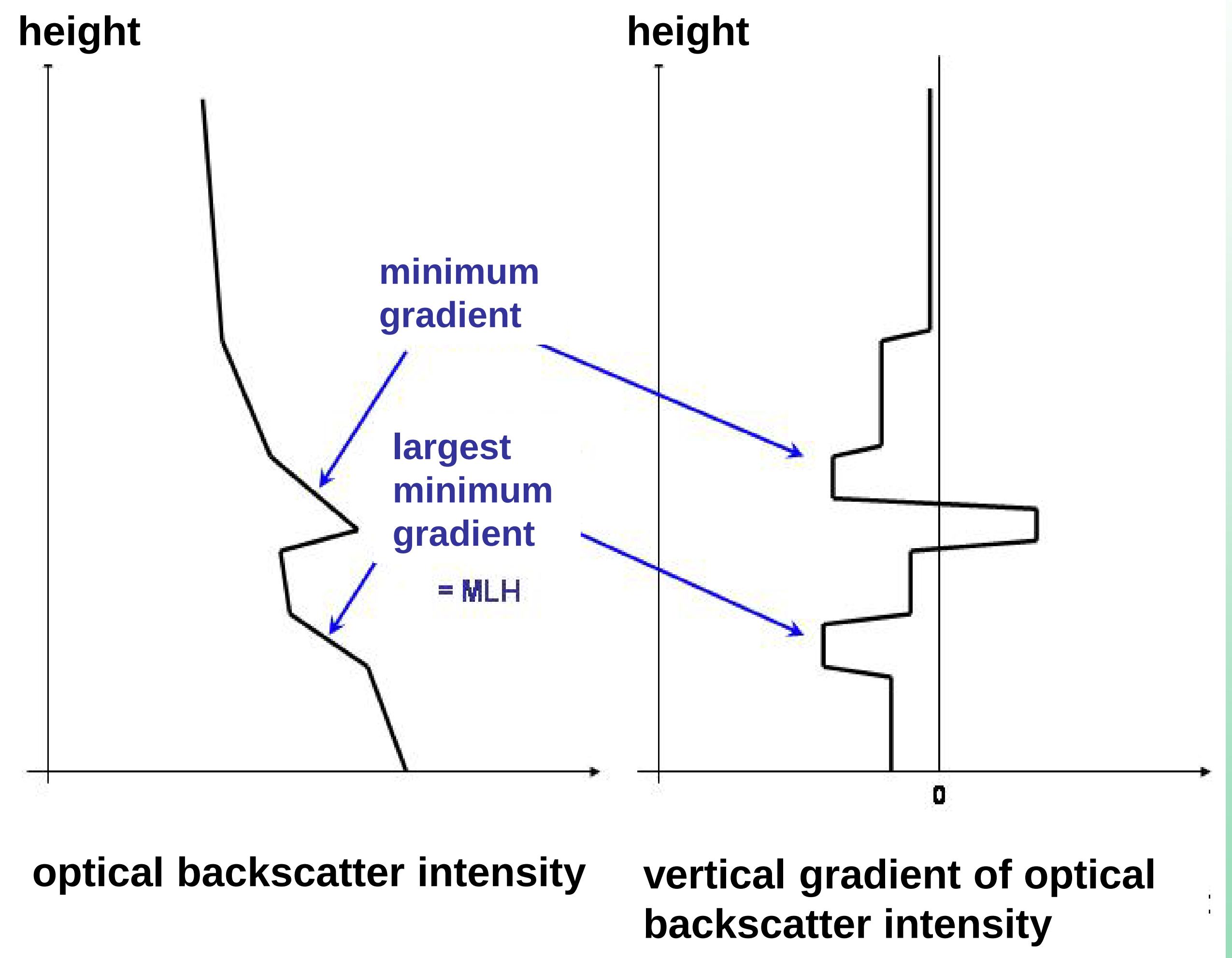
Optical remote sensing:
Ceilometer
Vaisala LD40 or CL31
wave length: 855 or 910 nm
range: 4000 m
Resolution: 10 or 7.5 m



Meteorological monitoring at 325 m LAPC tower

Algorithms to detect MLH from ceilometer data

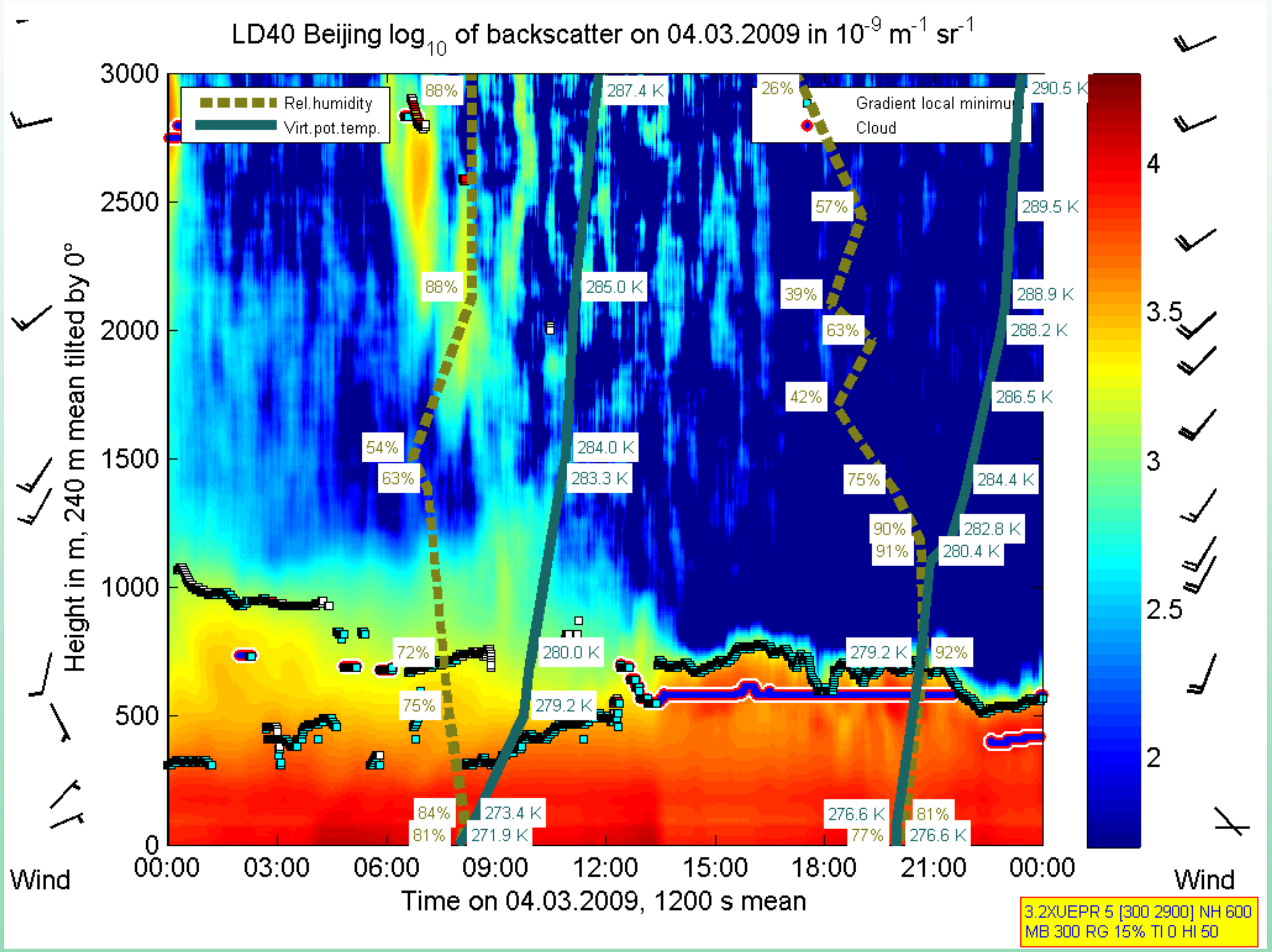
Criterion:
minimal vertical gradient
of backscatter intensity (the most negative gradient)



Emeis, S., Schäfer, K., Münkel, C.: Surface-based remote sensing of the mixing-layer height – a review. Meteorologische Zeitschrift 15, 5, 621-630 (2008); DOI: 10.1127/0941-2948/2008/0312.

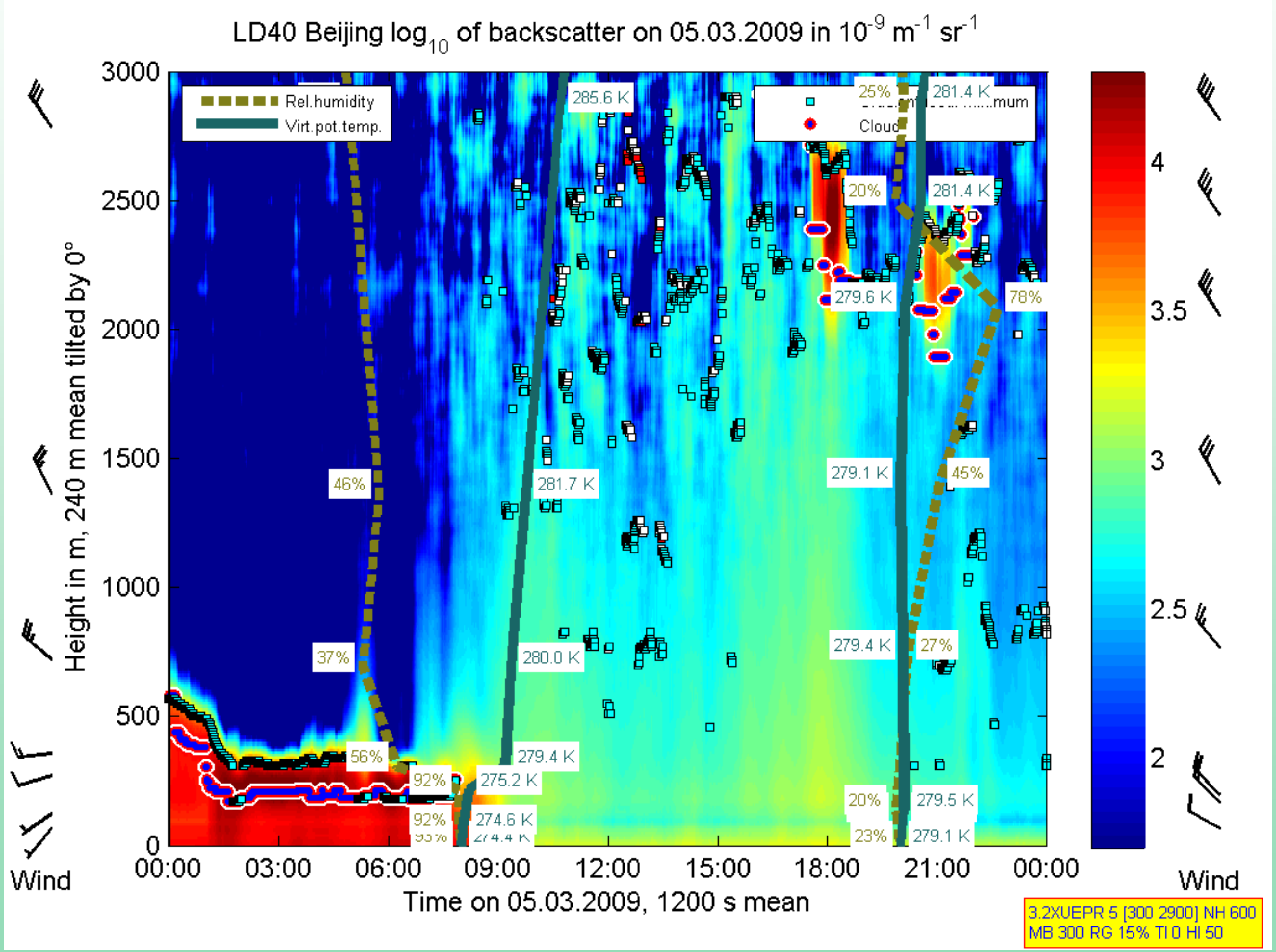
Evaluations in Beijing

High particulate load and low mixing layer height

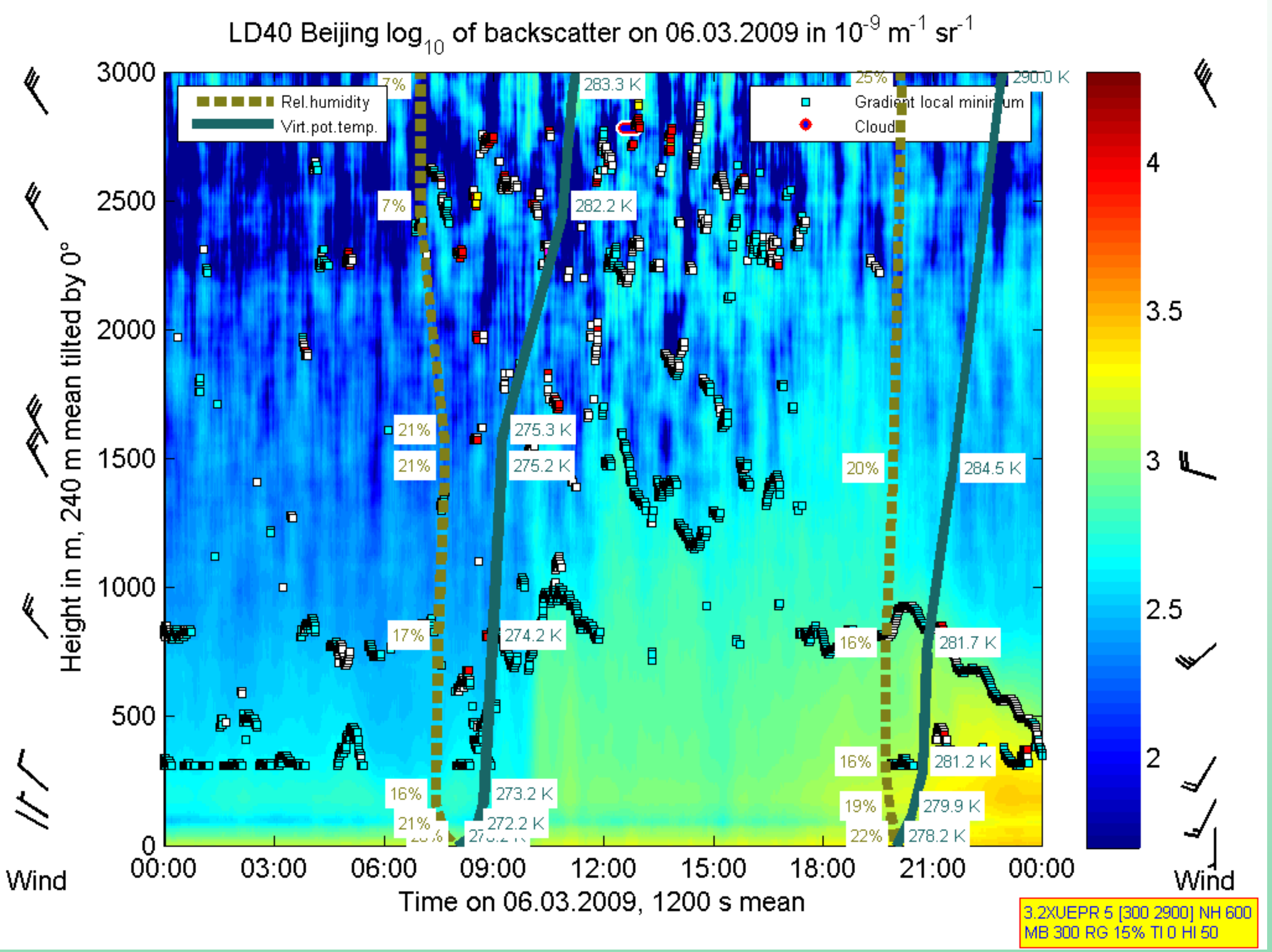


Evaluations in Beijing

Low particulate load and winds from West / North-West, after fog in the morning with winds from South-West

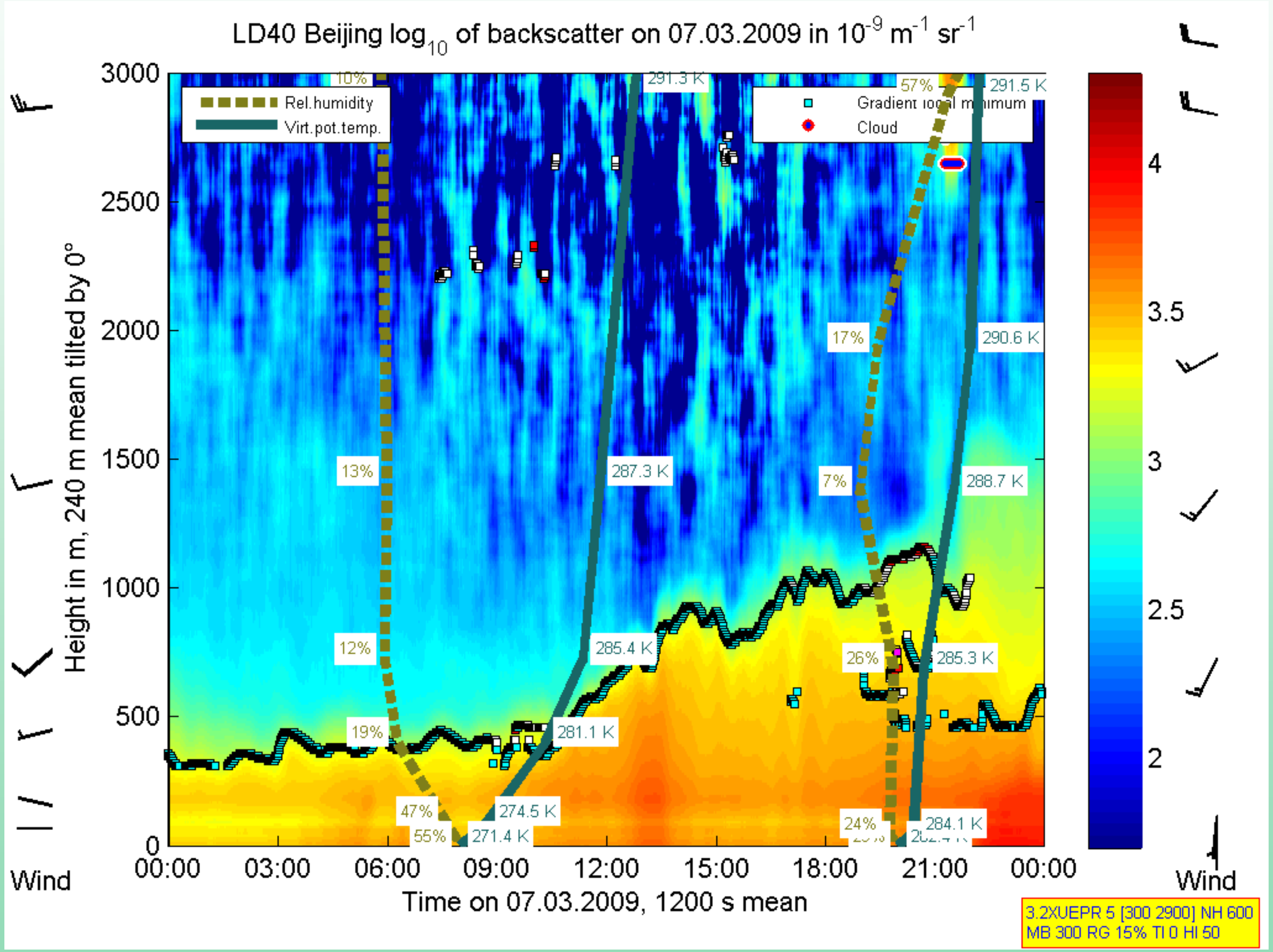


Higher particulate loads during winds from South-West



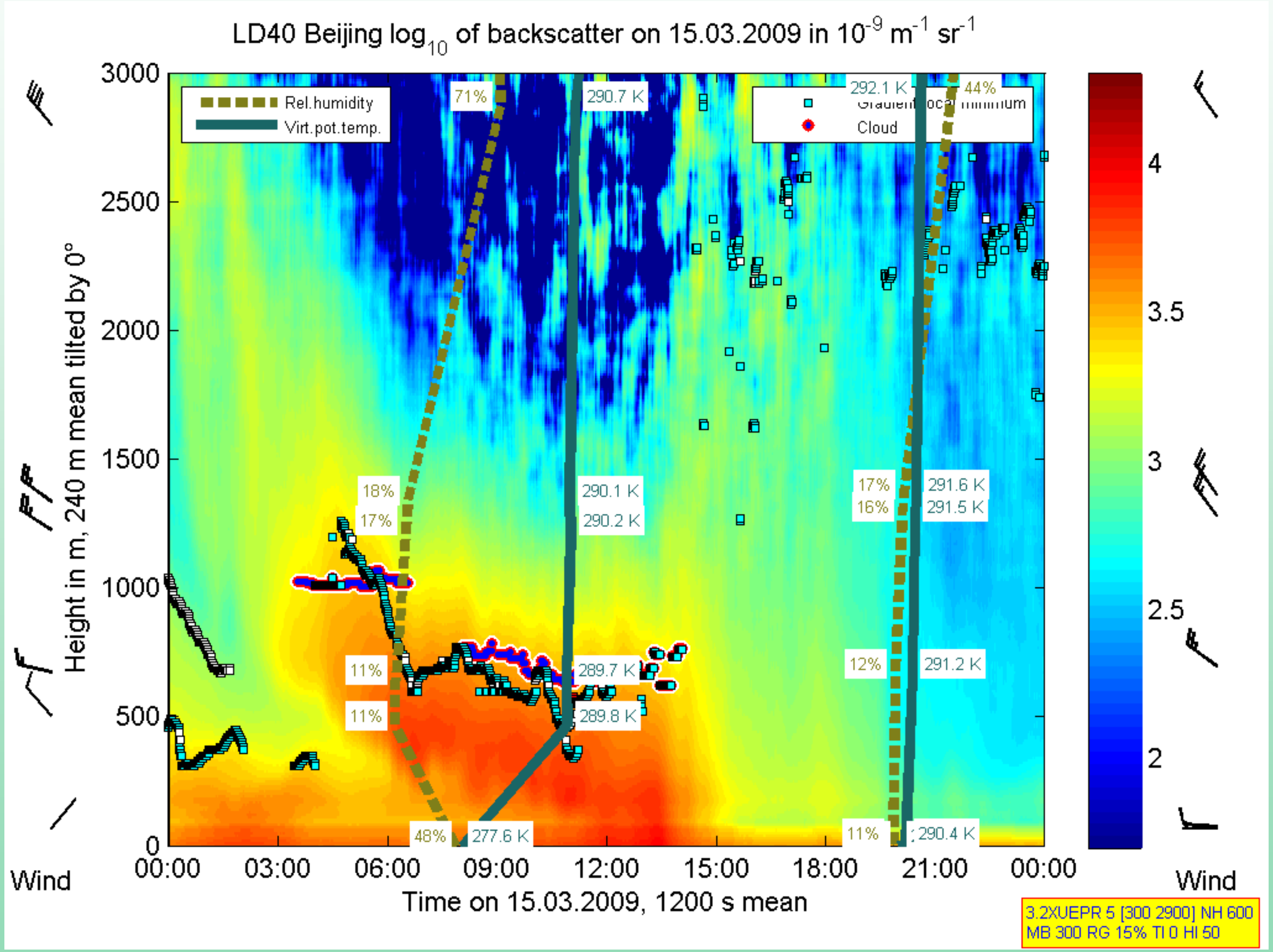
Evaluations in Beijing

Higher particulate loads during winds from South-West



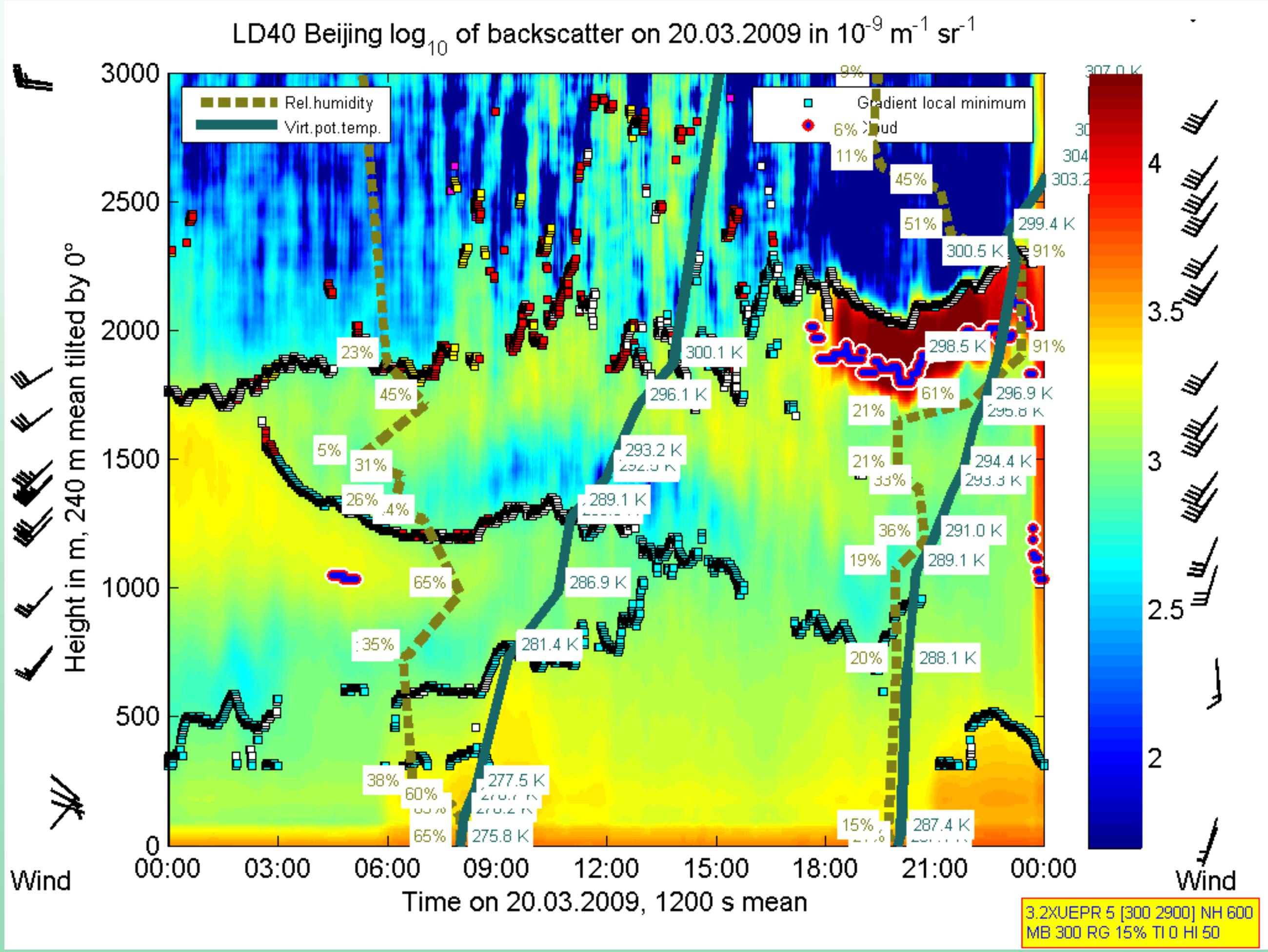
Evaluations in Beijing

Desert dust clouds, winds from West, dry air



Evaluations in Beijing

Multiple layering of the lower atmosphere



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Wind influences upon air pollution in Beijing

During winds from westerly directions relative dry and clean air

Sometimes particulate clouds from desert regions are transported to Beijing

During winds from other directions, especially from the ocean, high relative humidity

Higher particulate loads during winds from south-westerly directions

Results for MLH monitoring

Strong diurnal variation and from day to day during convective conditions

Low altitude variation during stable conditions

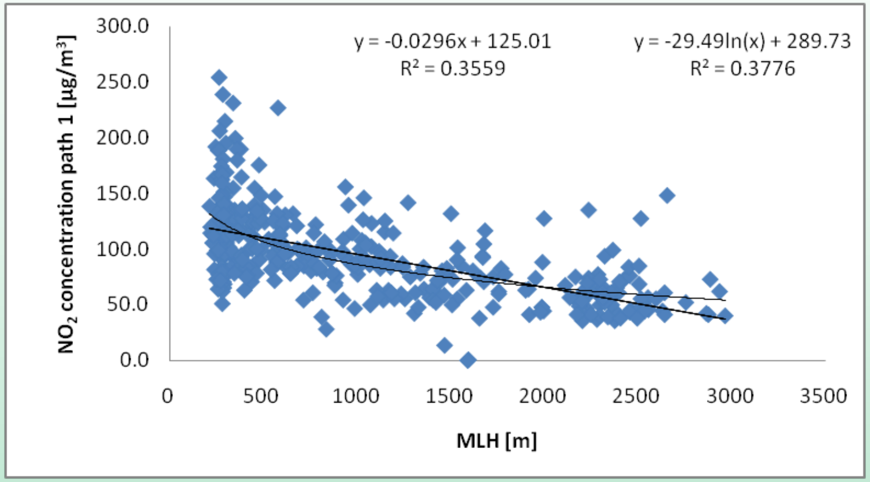
Several layers or lifted inversions are possible

During early afternoon the surface-based inversion can be broken up by sunshine

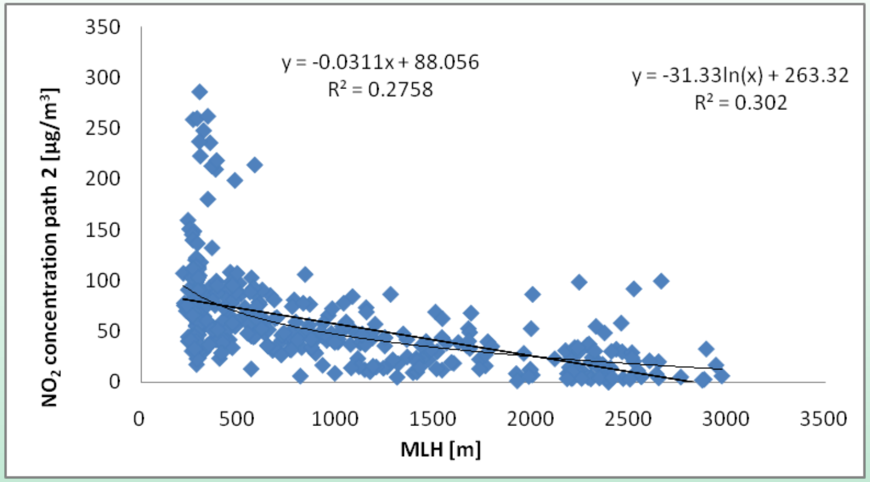
Strong coupling of changes in the vertical profile of relative humidity and virtual potential temperature with minimum of backscatter intensity gradient

Correlations NO_2 – mixing layer height
April – May 2009

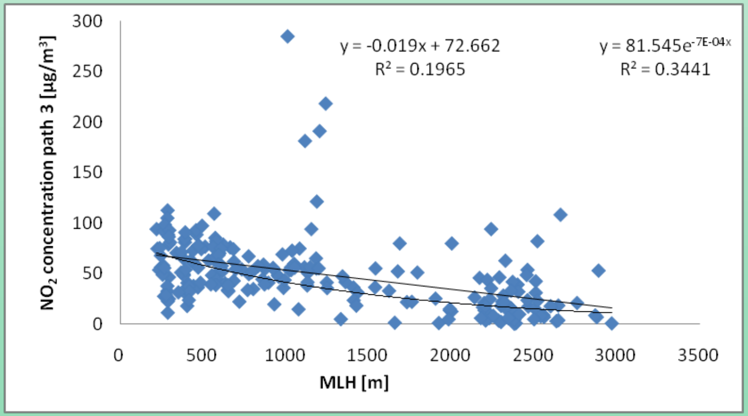
Path 1 across the road nearby



Path 2 in the background



Path 3 across the motorway



Mixing layer height - air quality

If planetary boundary layer > 1000 m: often multiple layering
if < 1000 m during daytime: often one layer

Influence of MLH upon NO_2: relevant – standard error 0.15

Logarithmic regression best correlations: NO_2 well mixed
but not at motorway – exponential dependence

Correlations of NO and SO_2 with MLH: not significant

Concentrations of BTX and HCHO: near the detection limit

Air quality studies in Beijing

- Inorganic composition of PM with weekly passive samples (adhesive acceptor plates) and active daily samples (Mini-volume sampler $PM_{2.5}$) since 2005 (KIT/IMG, DWD)

- Two campaigns in 2009 in various heights at LAPC

  $PM_{2.5}$ by weekly passive sampling (DWD, KIT/IMG)

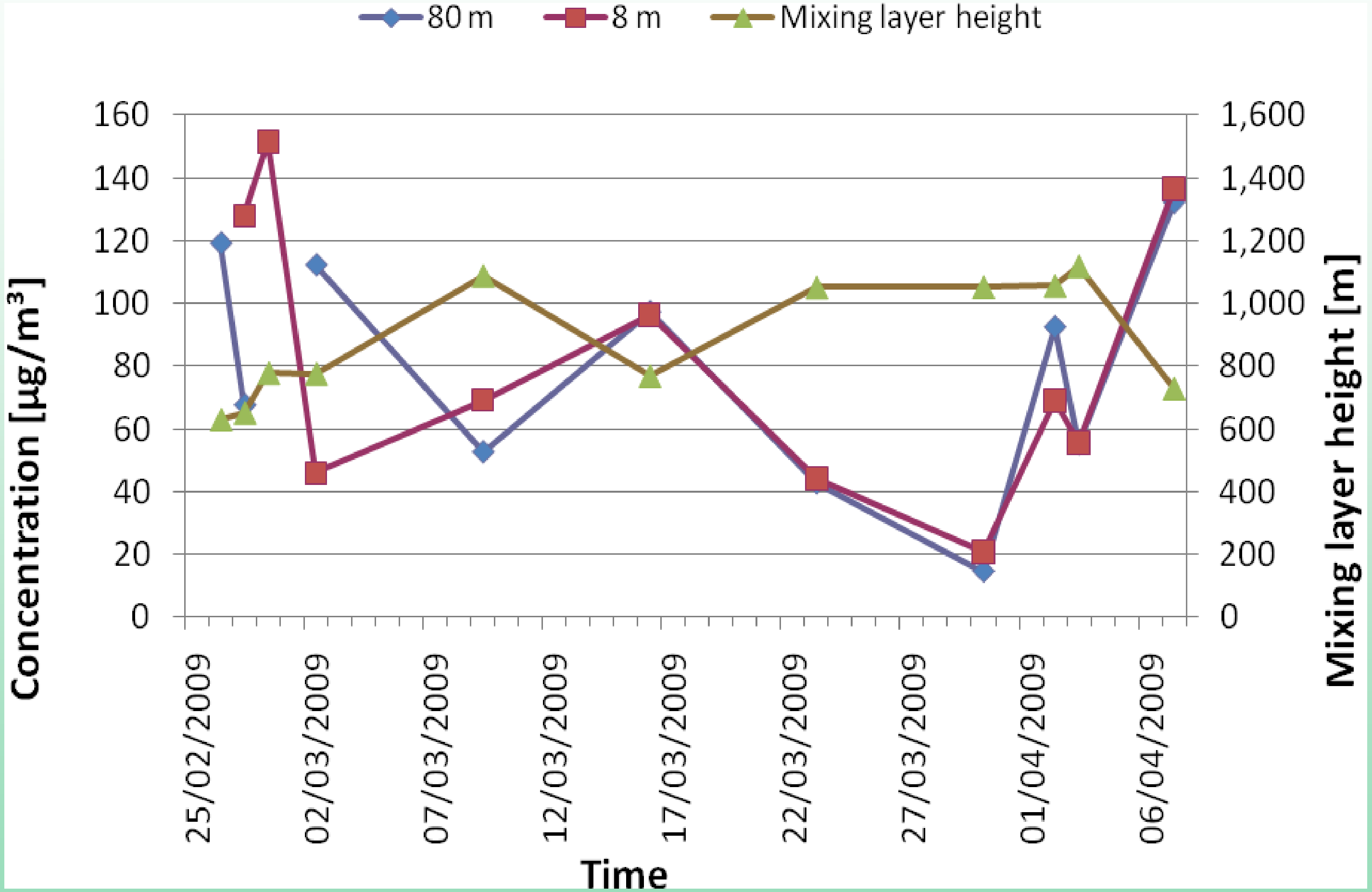
  $PM_{2.5}$ by active daily samplers (KIT/IMG)

  TEOM instruments (LAPC)

Air quality studies in Beijing

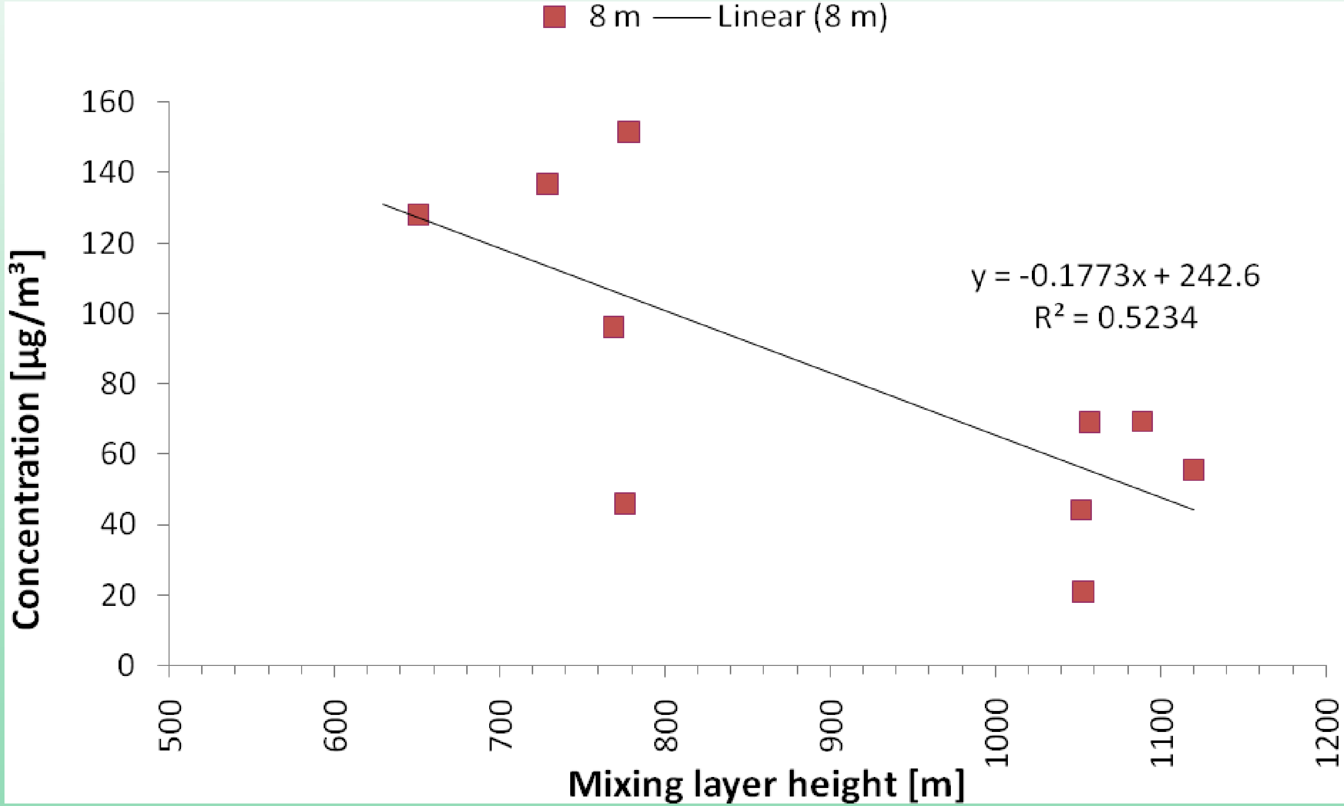
Concentrations of $PM_{2.5}$ in 8 m and 80 m height as well as MLH

- Quartz fibre filters (25 mm or 50 mm in diameter, Whatman)
- Mini Volume Sampler (Leckel GmbH, Berlin)
- Pump rate 200 l/h
- Weighting procedures at the IMG

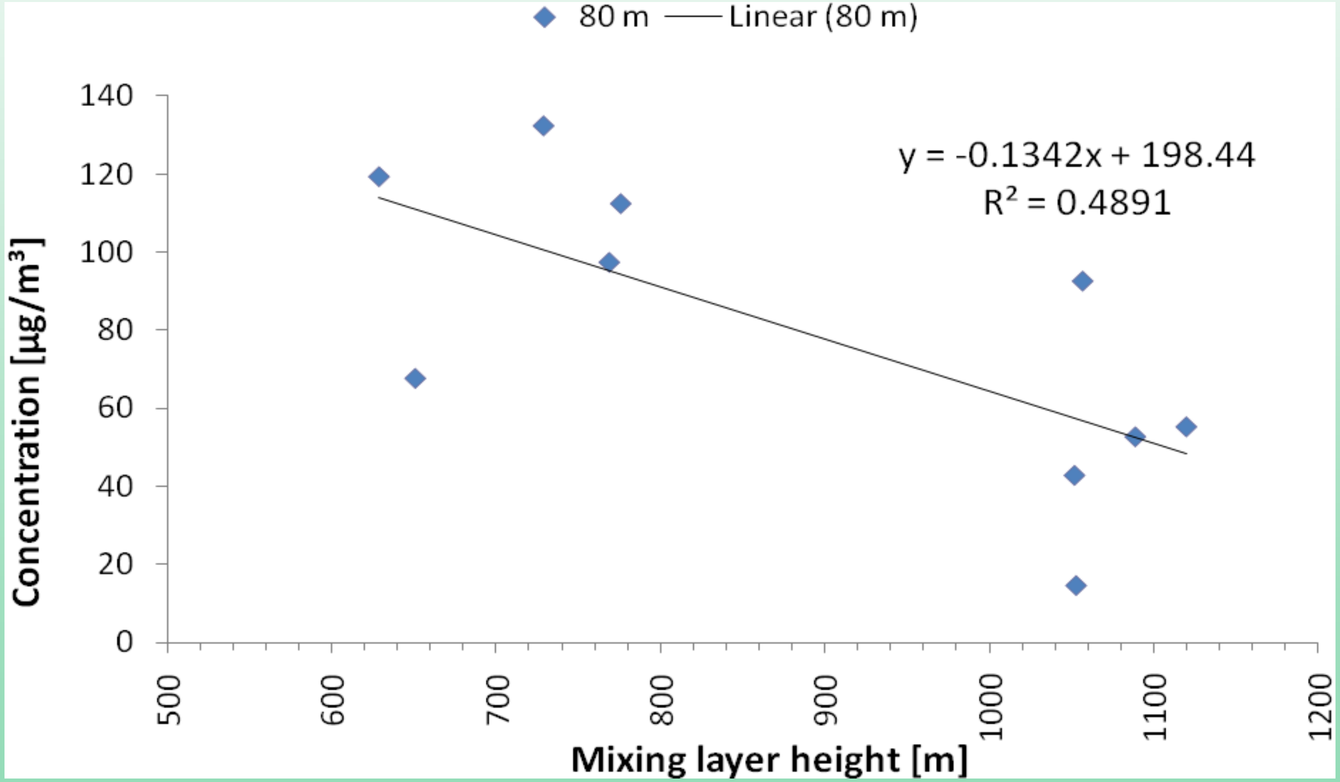


Norra, S., Hundt, B., Stüben, D., Cen, K., Liu, C., Dietze, V., Schultz, E., „Size, morphological and chemical characterization of aerosols polluting the Beijing atmosphere in January/February 2005." In: Morrison, G.M.; Rauch, S. (Eds.): Highway and Urban Environment, Springer, Berlin (2007)

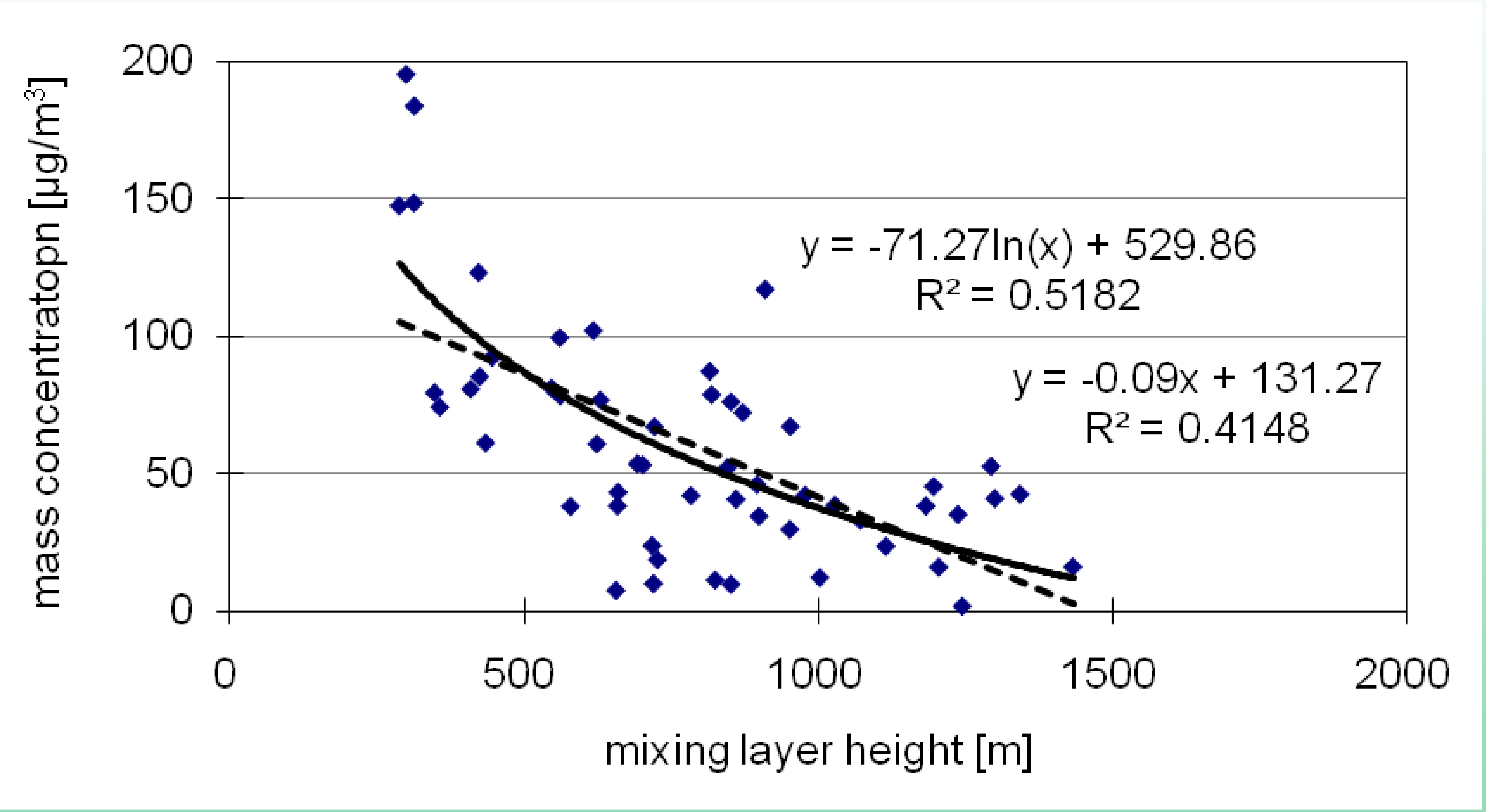
Correlations of concentrations of $PM_{2.5}$ in 8 m height and MLH Temporal periods 26-27/02, 27-28/02, 28/02-02/03, 02-09/03, 09-16/03, 16-23/03, 23-30/03, 30/03-02/04, 02-03/04, 03-07/04, and 07-08/04



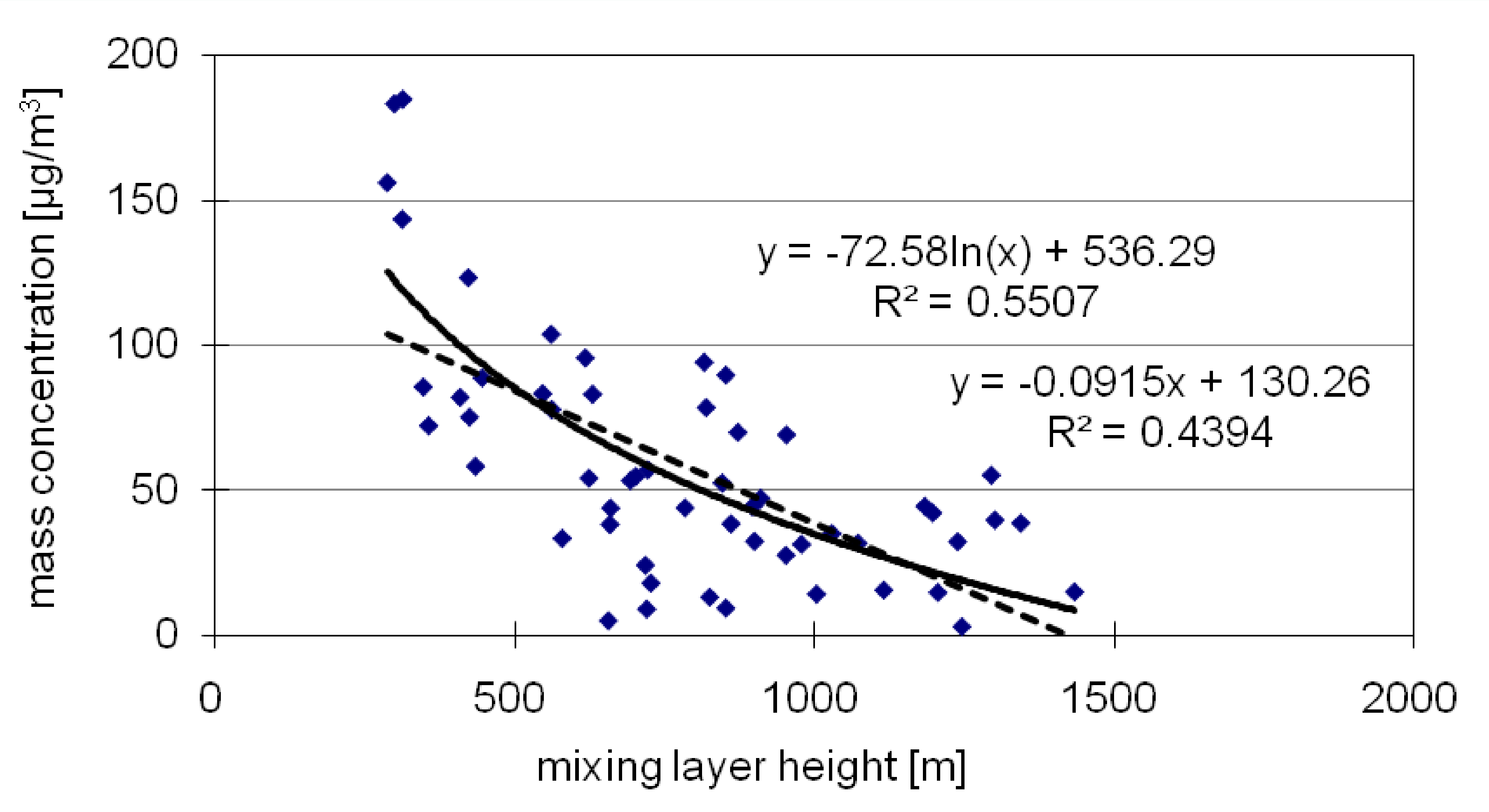
Correlations of concentrations of $PM_{2.5}$ in 80 m height and MLH Temporal periods 26-27/02, 27-28/02, 28/02-02/03, 02-09/03, 09-16/03, 16-23/03, 23-30/03, 30/03-02/04, 02-03/04, 03-07/04, and 07-08/04



Correlations of daily mean concentrations of $PM_{2.5}$ in 8 m height and MLH from 26/02/2009 until 30/04/2009



Correlations of daily mean concentrations of $PM_{2.5}$ in 80 m height and MLH from 26/02/2009 until 30/04/2009



Mixing layer height - air quality

High $PM_{2.5}$ load (40 – 140 µg/m^3) near the surface is coupled with MLH much lower than 1000 m

Influence of MLH upon the variance of the observed $PM_{2.5}$ concentrations is significant, also from hourly-mean TEOM data in both heights (R^2 ~ 0.4)

Logarithmic regression provides better correlations than linear i.e. PBL is well mixed

Mixing layer height - air quality

Influence of MLH upon the Cu and Zn mass concentrations is significant
i.e. if the origin of the elements is

- the soil this source dominates the concentrations (Al, K and Ca no MLH influence),

- the traffic and the industry the air transport dominates (no MLH influence in higher altitudes) and

- a widespread area source the MLH dominates (Cu, Zn)

Process studies

Source apportionment

Air quality studies in Beijing

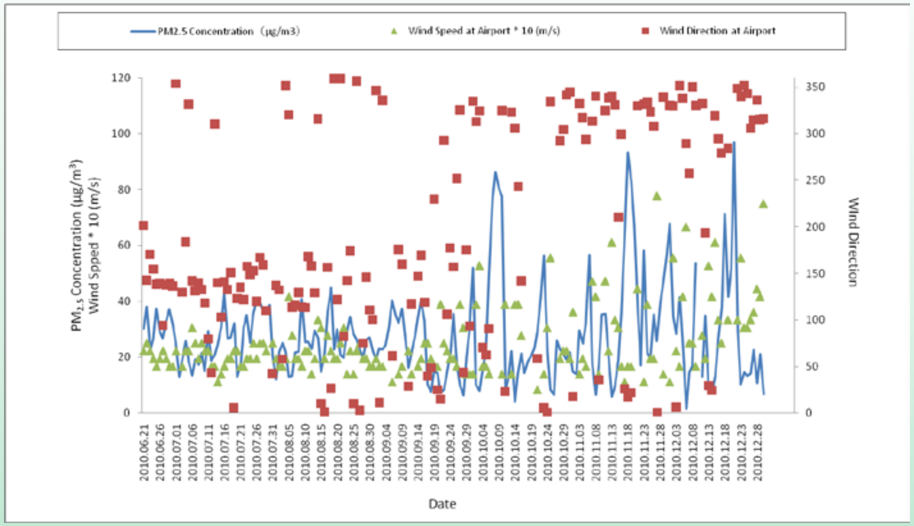
Daily $PM_{2.5}$ filter sampling with 2 High-volume samplers
from 21 June 2010 on for one year (PhD Rong-rong Shen)
with Jianying Wang, Jing Wang (CUMTB), HMGU, CUGB

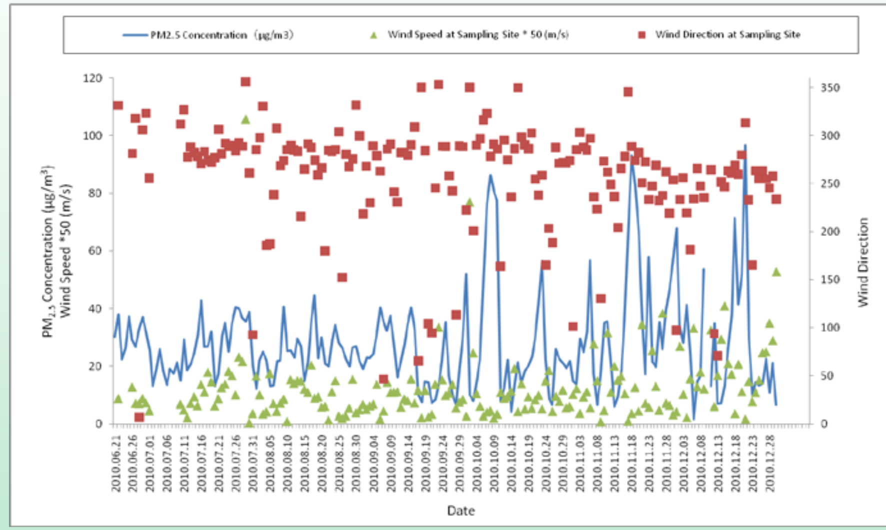
Ultra-sonic anemometer
at the sampling site

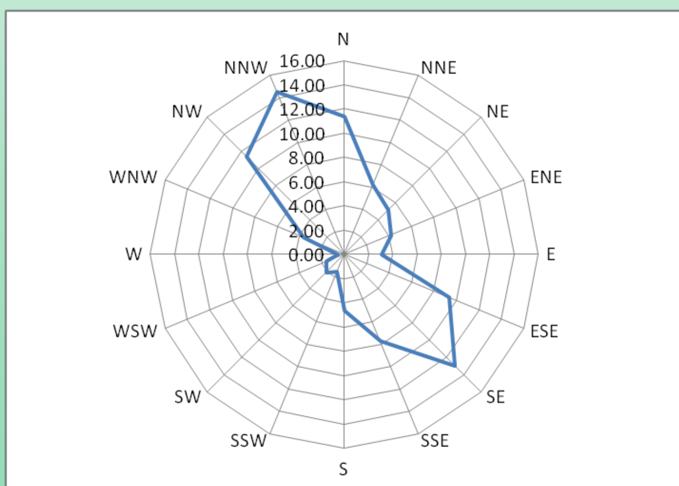
10 m distance to
instrumentation of
DWD and KIT/IMG

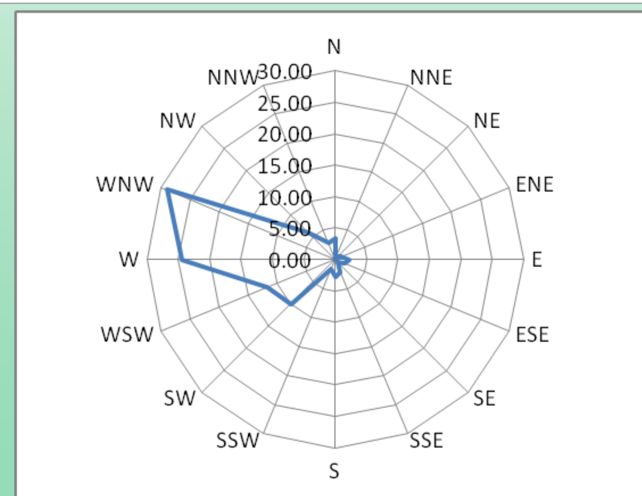
Air quality studies in Beijing

Wind influence upon sampled $PM_{2.5}$ mass at CUGB
First results



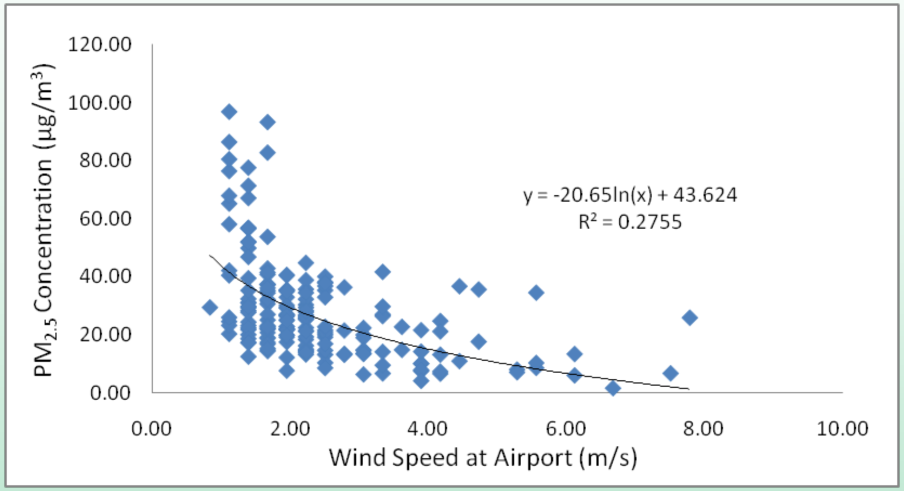


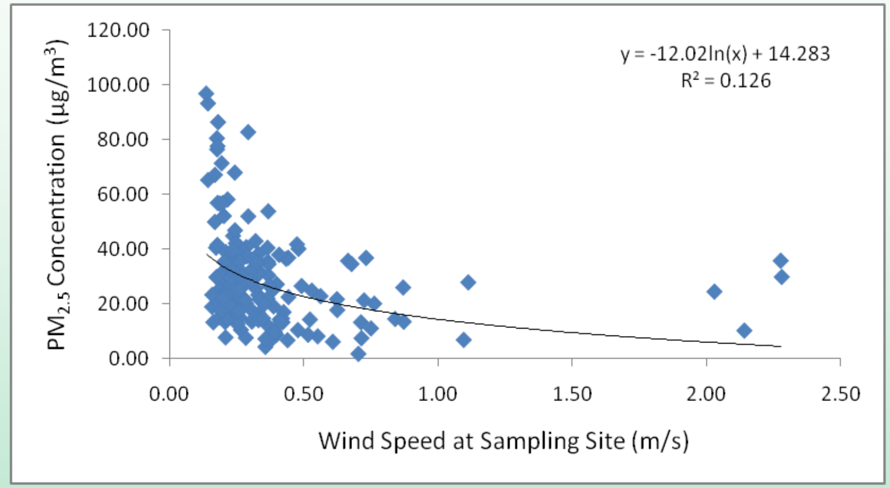


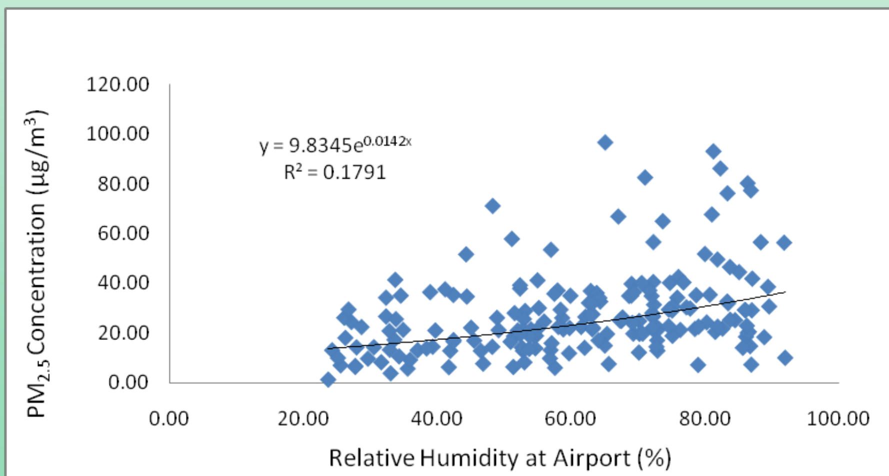


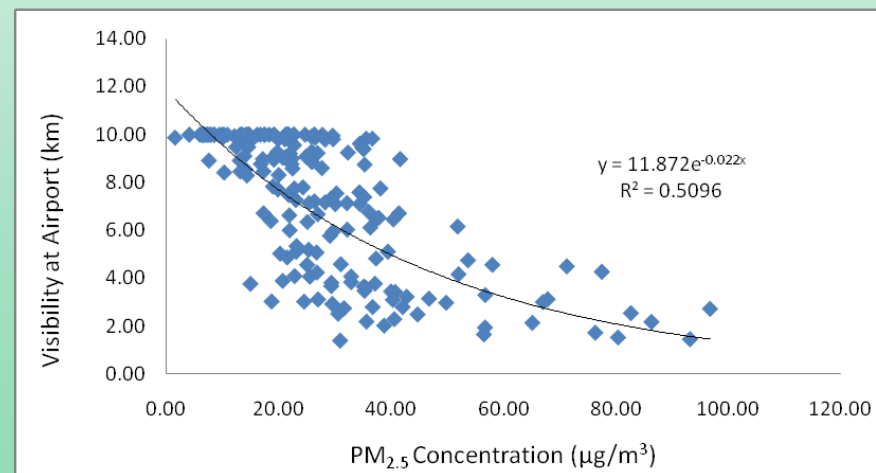
Air quality studies in Beijing

Wind and further influences upon sampled $PM_{2.5}$ mass at CUGB
First results



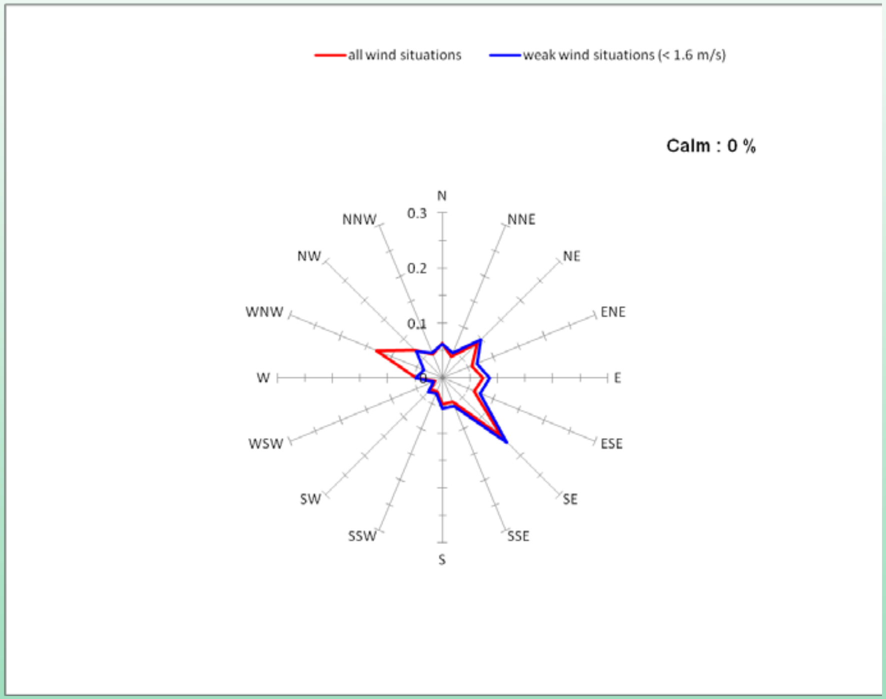


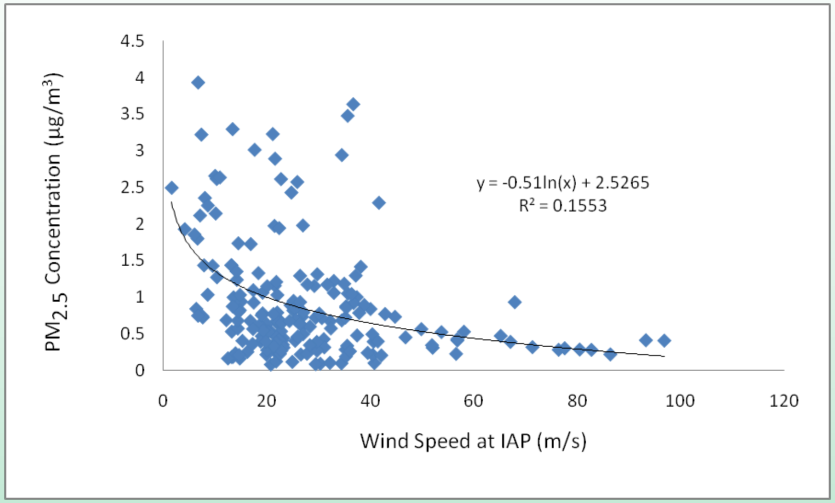


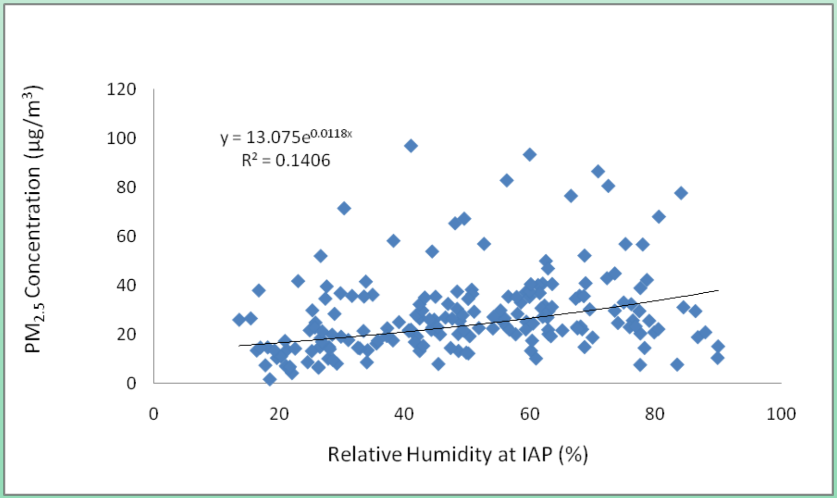


Air quality studies in Beijing

Wind and further influences upon sampled $PM_{2.5}$ mass at CUGB
First results







Klaus Schäfer
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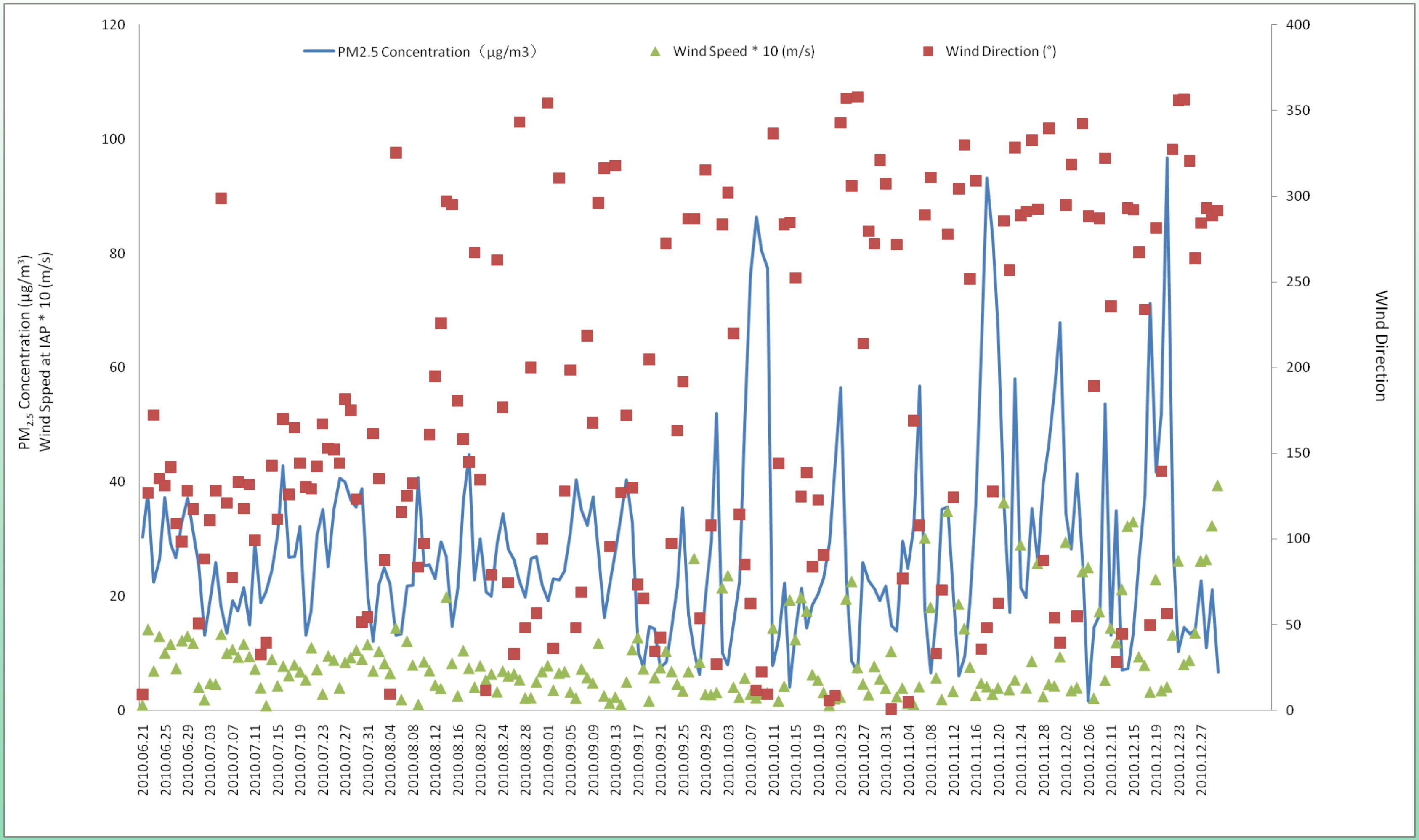
Air quality studies in Beijing

Wind influence upon sampled $PM_{2.5}$ mass at CUGB
First results



Air quality studies in Beijing

- PM composition from filter samples (PhD Rong-rong Shen)

  carbon fraction, organic speciation (HMGU, UR)

  inorganic composition (KIT/IMG)

  isotopic composition $^{13}C/^{12}C$ (KIT/IMK-IFU)

- Source apportionment for $PM_{2.5}$ with PMF software of US-EPA (PhD Rong-rong Shen)

Organic composition, EC/OC/WSOC, stable isotopes, toxic-testing

Conditioning (500°C, 6h)

7-8 Filters for one week together with field blank. Packed together and wrapped in cleaned aluminum foil

Transport to CUMTB

Storage of filter packs at RT (clean Environment)

Sampling

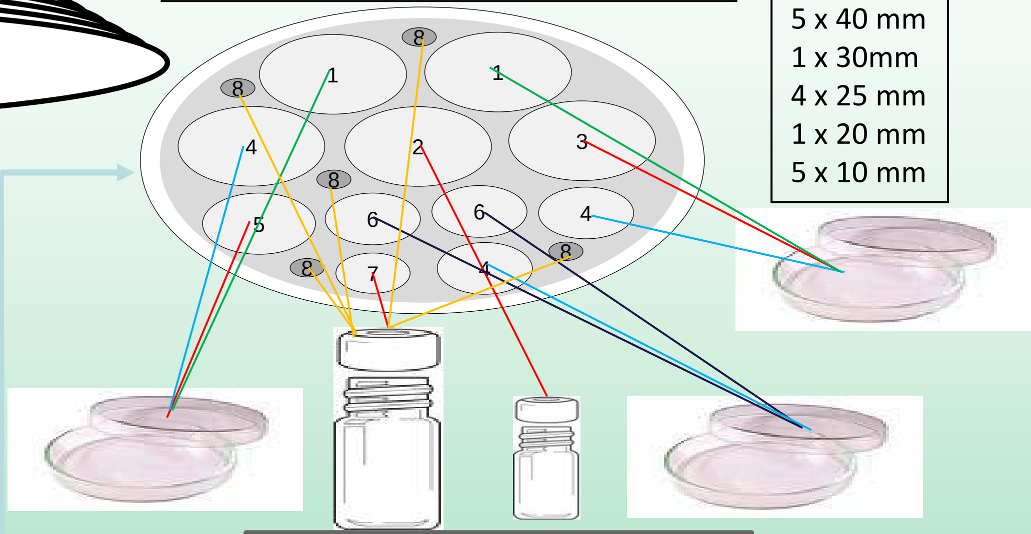
Storage in **clean deep freezer** at -20 °C

Transport to IMK-IFU
Packed together and wrapped in cleaned aluminum foil
(cooled, at least -20°C)

Partition and packing at HUGM

1 - Toxic assessment 2 x 40 mm (CUMTB)
2 - Organic 40 mm (HMGU)
3 - Isotope 40 mm (IMK-IFU)
4 – Reservation 40 mm+2 x 25 mm
5 – Toxic assessment 30 mm (U. Cardiff)
6 – EC/OC WSOC 2 x 25 mm (U. Rostock)
7 – Isotope extraction 20 mm (IMK-IFU)
8 – EC/OC 5 x 10 mm (U. Rostock)

5 x 40 mm
1 x 30mm
4 x 25 mm
1 x 20 mm
5 x 10 mm



Labeled vials and petri dishes

Transport to IMK-IFU, CUMTB, U. Cardiff, U. Rostock
(cooled, at least -20°C)

Klaus Schäfer
Institute for Meteorology and Climate Research (IMK-IFU)

PM-mass, ICP, IC

Conditioning (> 24h, RT, 40-50% RH) → **weighing**

Filter packed in „paper“ envelopes, Envelope labeled with: **empty weight, filter number**

7-8 Filters for one sampling week together with field blank
Packed together and wrapped in aluminum foil

Transport to CUMTB

Storage of filter packs at RT (clean environment)

Sampling

Filter packed in „paper“ envelopes, Envelope labeled **with: Empty weight, filter number and sample date**

Filters of one sampling week together with field blank
Packed together and wrapped in aluminum foil

Storage of filter packs in **clean deep freezer** at -20°C

Transport to IMK-IFU and DWD (at ambient temperature)

Conditioning (> 24 h, RT, 40 - 50% RH) → **weighing and partition**

Filters of one sampling week together with field blank
Packed together and wrapped in aluminum foil

Transport to IMG/LEM (at ambient temperature)

Klaus Schäfer
Institute for Meteorology and Climate Research (IMK-IFU)

Process studies

Spatial distribution of PM

Tasks for air quality studies in Beijing

Application of satellite-based remote sensing data systems and coupling with numerical modelling (PhD Stefanie Schrader)

with University of Thessaloniki (Dimosthenis Sarigiannis and Nicolas Moussiopoulos)

comparison with dispersion model COSMO ART

Task: Input for the ICAROS platform

Satellite images (Landsat)

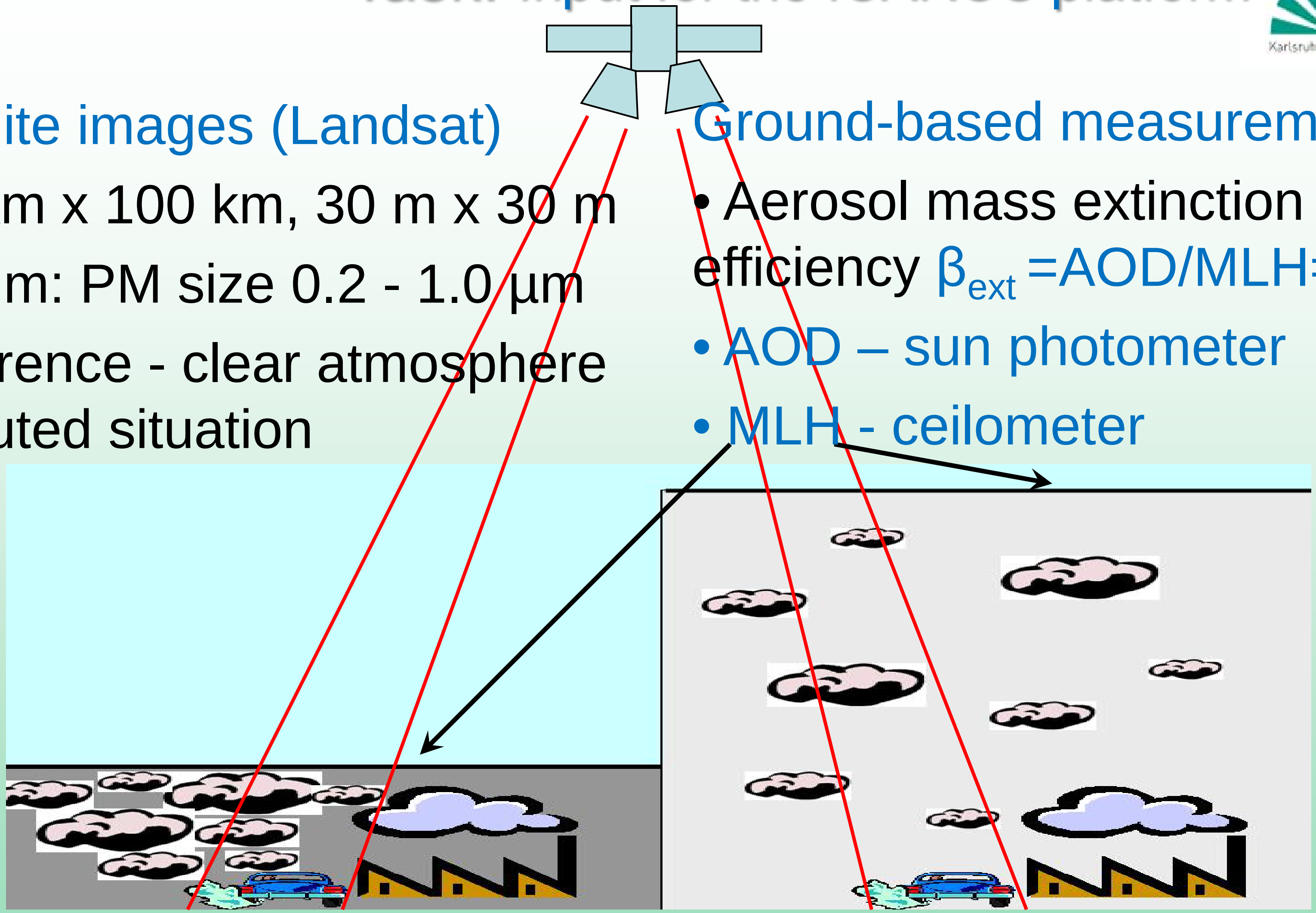
100 km x 100 km, 30 m x 30 m

520 nm: PM size 0.2 - 1.0 µm

- reference - clear atmosphere
- polluted situation

Ground-based measurements

- Aerosol mass extinction efficiency β_{ext} =AOD/MLH=aPM
- AOD – sun photometer
- MLH - ceilometer



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Future work
and perspectives

Air quality studies in Beijing

Further influences upon air pollution (PhD Ruiguang Xu)

winds

emissions (in the case of NO and SO_2)

air chemistry (photochemistry in the case of NO_2)

concluded from the daily courses of NO_2 concentrations

Tasks for air quality studies in Beijing

Further influences upon air quality

emissions (in the case of NO/NO_2 and SO_2)

air chemistry (photochemistry in the case of NO_2)

by small-scale model studies (PhD Hong Ling at KIT/IMK-IFU) on the basis of

road traffic data – emission modelling

DOAS together with in situ concentration and meteorological data – transport-chemistry modelling

Tasks for air quality studies in Beijing

- Toxicological assessment with one-year daily $PM_{2.5}$ filter samples

  (Master thesis Jianying Wang, Jing Wang at CUMTB)

- Co-operation with epidemiological studies: PM composition, NO_2, O_3, BTX, SO_2 (University of Peking, HMGU)

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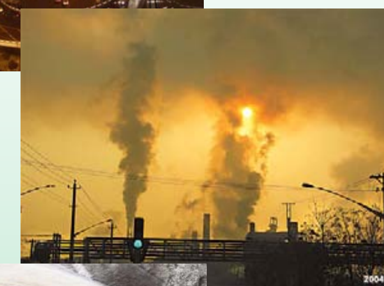
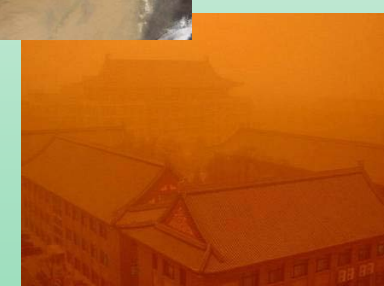
Thank you very much for your attention

Co-operations



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