Karlsruhe Institute of Technology

Meteorological influences, role of traffic emissions and desert dust within the context of air quality in Beijing

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

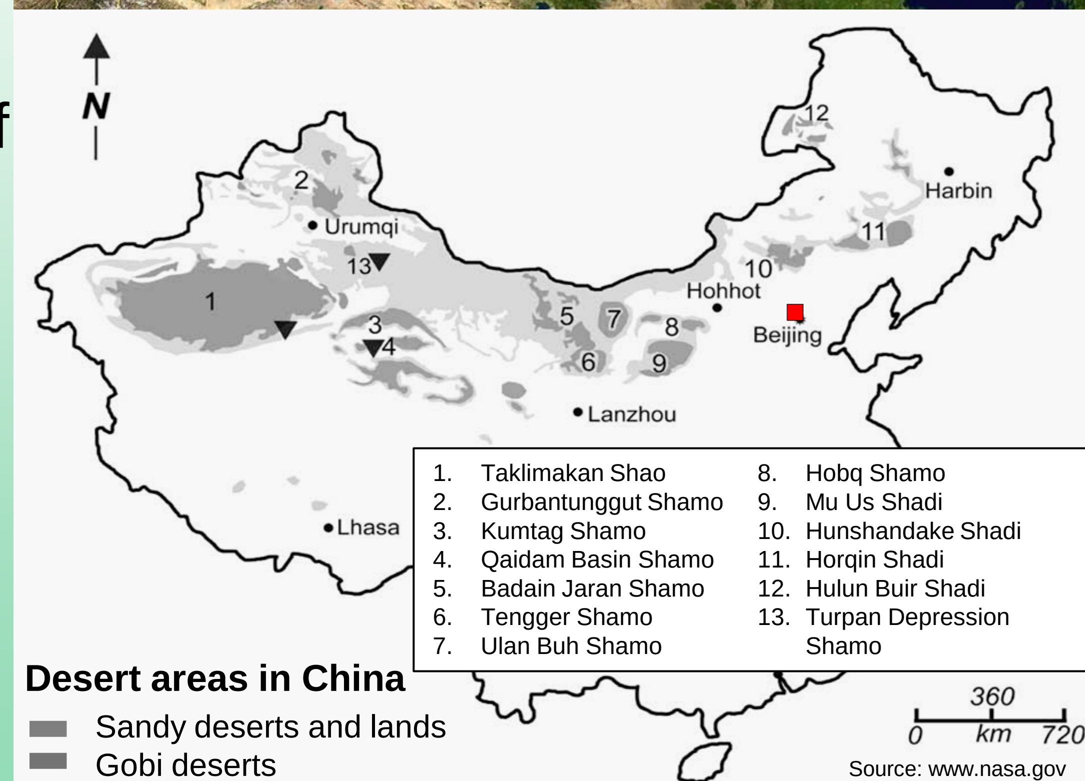
- Scientific questions
- Methods
- Process studies
- Modelling
- Conclusions
- Current tasks
- Future tasks

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

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

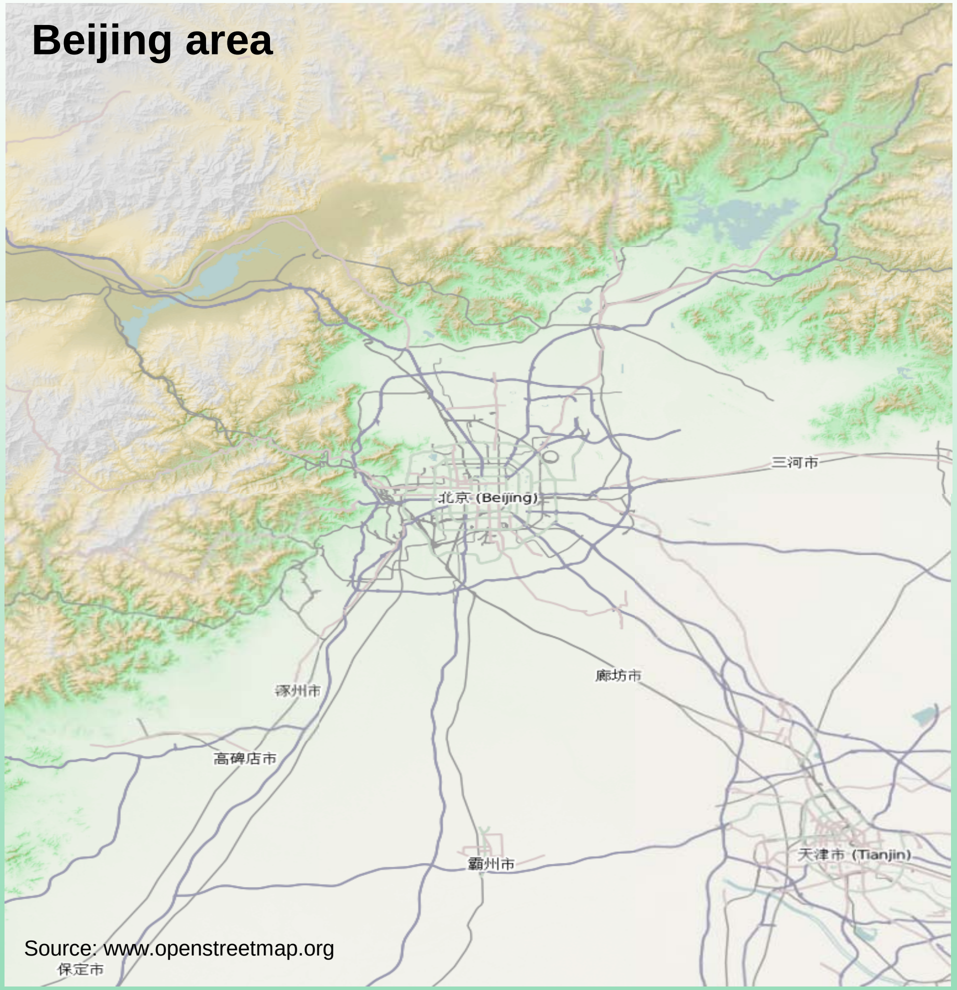


Scientific questions for air quality in Beijing

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

Role of mixing layer height - mountains are West to North

Heat island effect



Methods

Air quality studies in Beijing

tower: meteorology, air quality; DOAS 04/09 – 03/11: NO_2, NO, SO_2, O_3, NH_3, 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

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

Air quality studies in Beijing

Daily $PM_{2.5}$ filter sampling with
2 High-volume samplers at CUGB

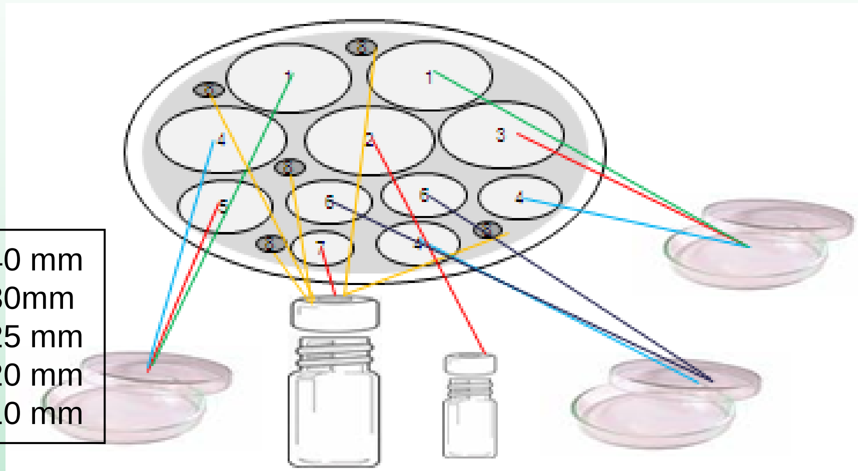
06/10 – 06/11 on quartz fibre filters

Ultra-sonic anemometer
at the sampling site:
wind speed, wind direction

10 m distance to
weekly passive sampling
by DWD and KIT/IMG

Air quality studies in Beijing

Particle Analysis



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

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

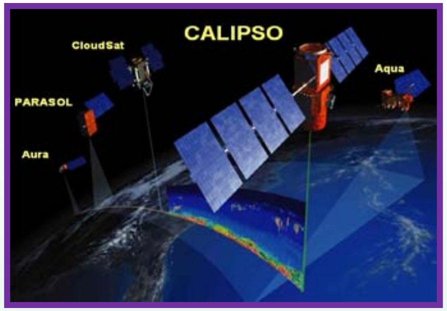
Sampler B

PM mass, ICP-MS, PEDXRF

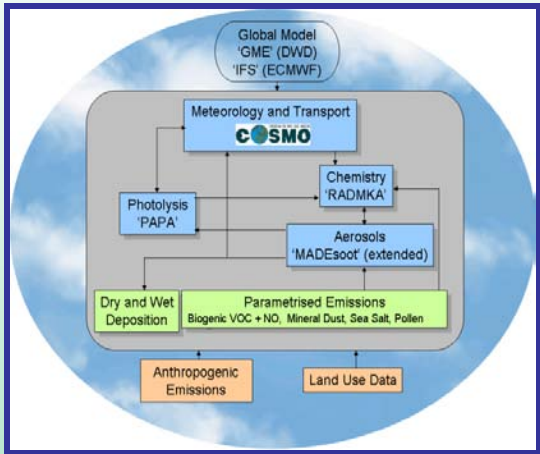
Sampler A

Organic composition – GC-MS, EC/OC/ WSOC, stable isotopes, ion analyses

Modelling of air quality in Beijing



CALIPSO
(Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations)

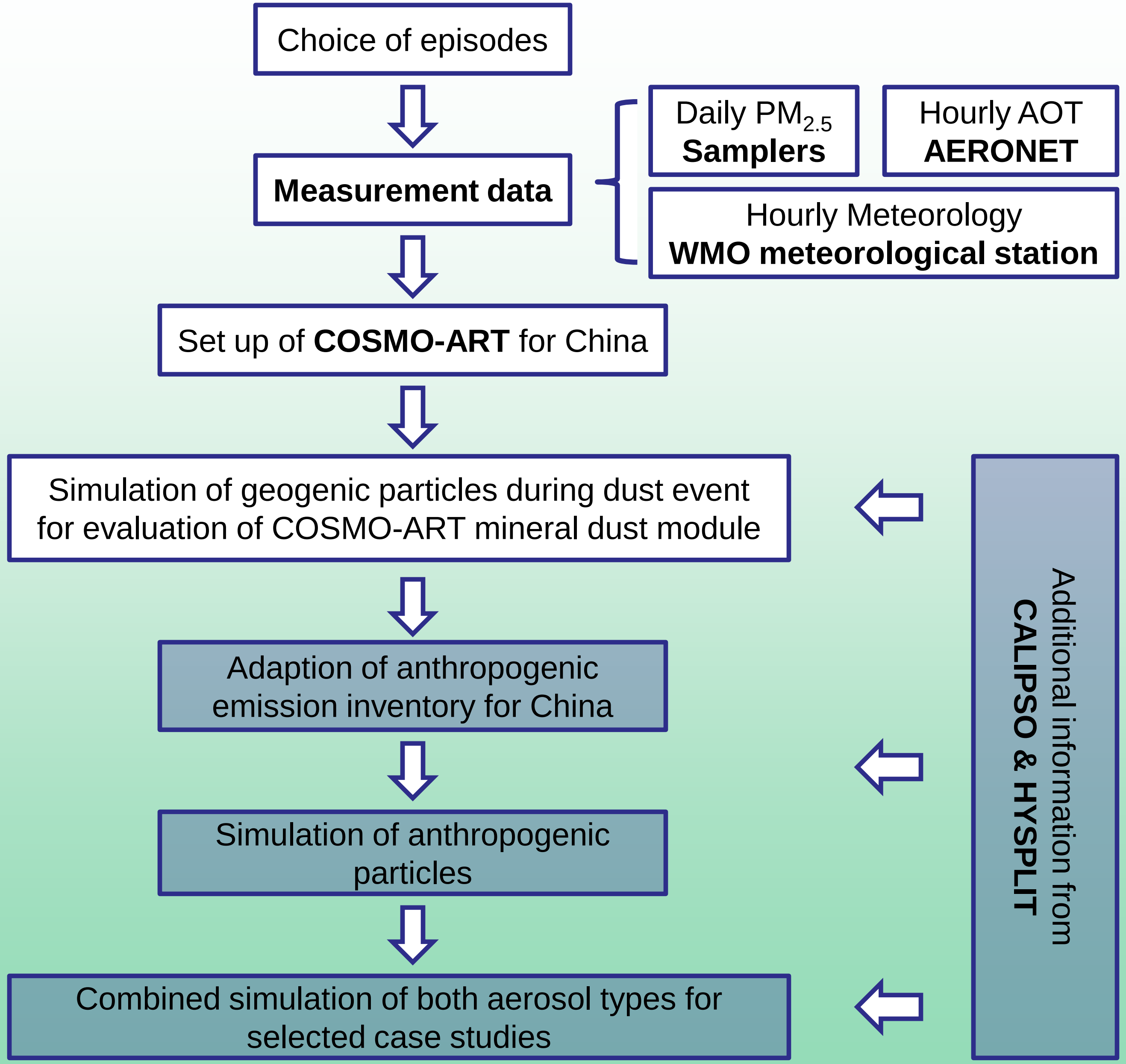


COSMO-ART
(Consortium for Small-scale Modelling –
Aerosols and Reactive Trace Gases)

Analysis of aerosol pollution in Beijing by data assimilation

PM High Volume Samplers / AERONET

Modelling of air quality in Beijing

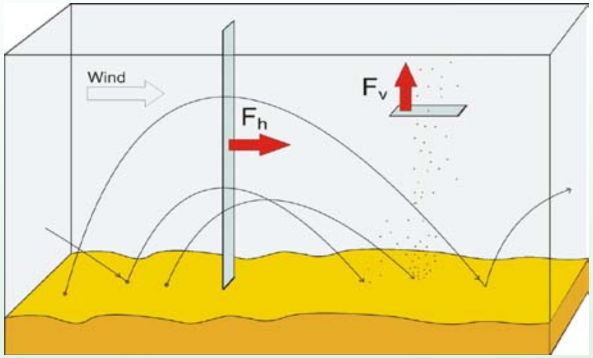


Treatment of aerosol in COSMO-ART

geogenic particles

Mineral dust module

- **Three modes** with d=1.5, 6.7 and 14.2 µm
- external input data: soil specific land use data
- Calculation of two fluxes
  F_h: horizontal saltation flux
  F_v: vertical particle flux



(Vogel *et al*., 2009, Stanelle *et al*., 2010)

anthropogenic particles

MADEsoot

- **Five modes:**
  1 & 2: secondary particles (SO_4^{2-}, NO_3-, NH_4+, H_2O, SOA) internally mixed in aitken & accumulation mode

  3: pure soot

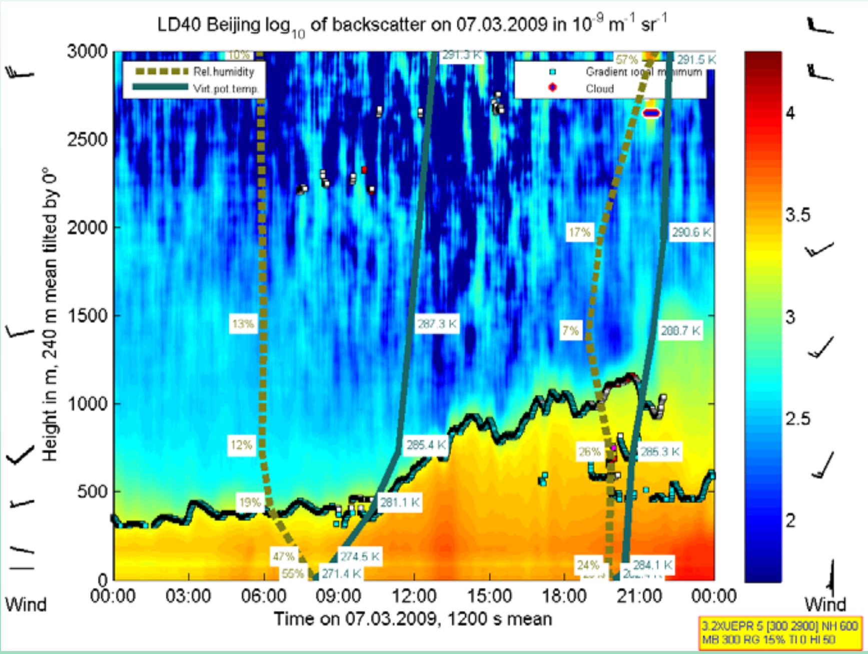
  4 & 5: aged soot (SO_4^{2-}, NO_3-, NH_4+, H_2O, SOA, soot) internally mixed in aitken & accumulation mode
- external input data: anthropogenic emissions

Process studies

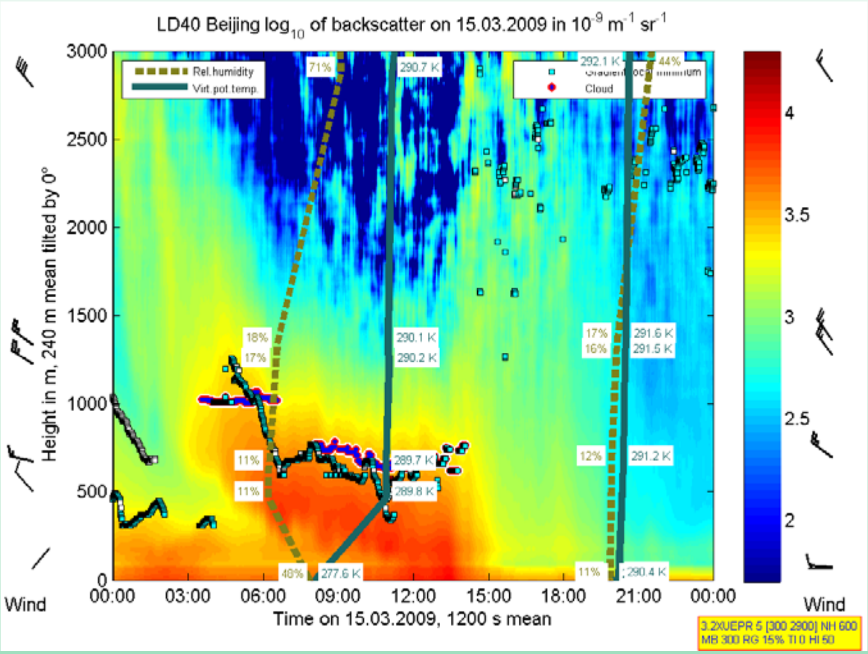
Influences upon air pollution

Evaluations in Beijing

Higher particulate loads during winds from South-West



Desert dust clouds, winds from West, dry air



Mixing layer height in Beijing

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

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, $PM_{2.5}$, PM_{10} and CO: 20 - 50 %

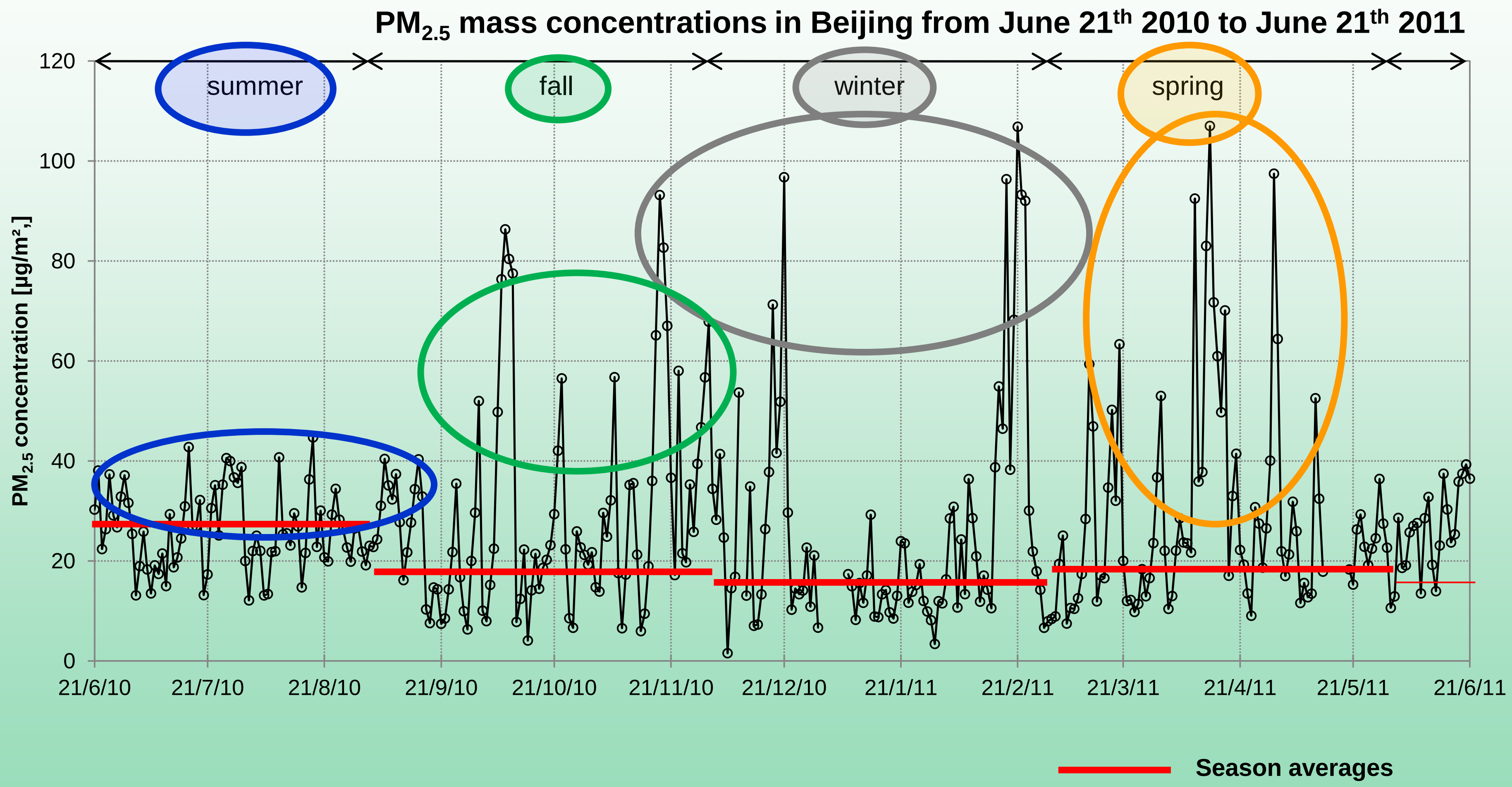
High $PM_{2.5}$ load (40 – 140 µg/m^3) near the surface is coupled with MLH much lower than 1000 m

Influence of MLH upon the variance of the observed $PM_{2.5}$ concentrations in different heights is significant (R^2 ~ 0.4)

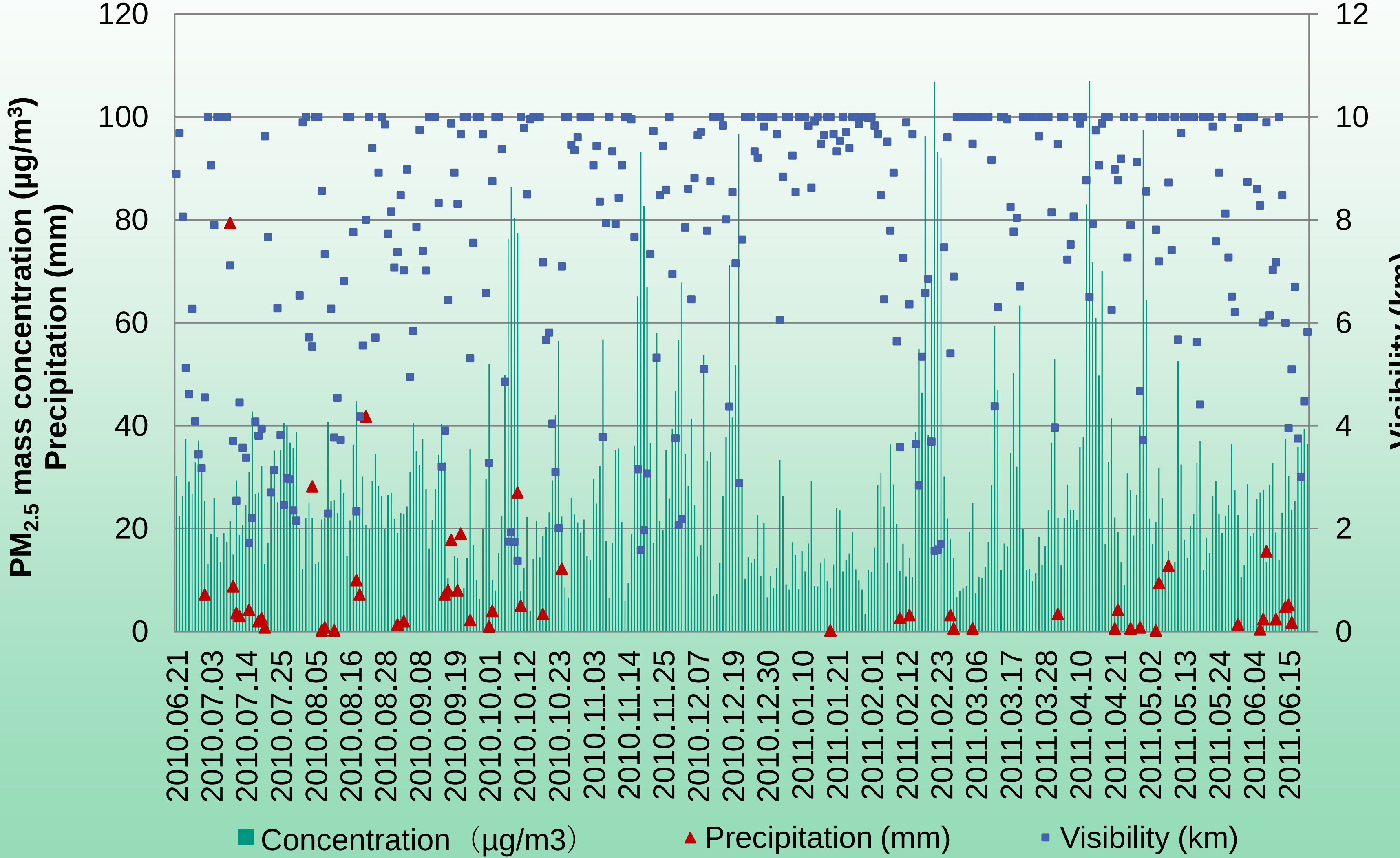
Logarithmic regression best i.e. PBL is well mixed

PNC / PMC max 45 % 100 - 500 nm diameter

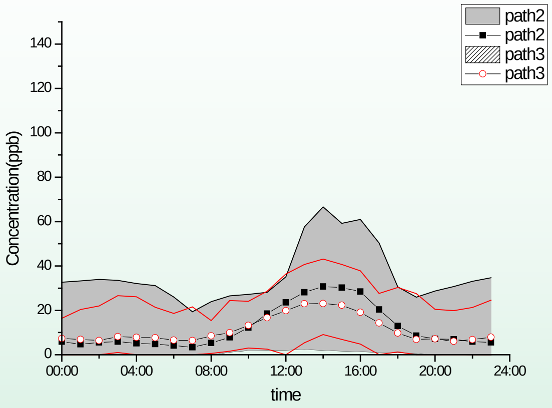
Evaluations in Beijing



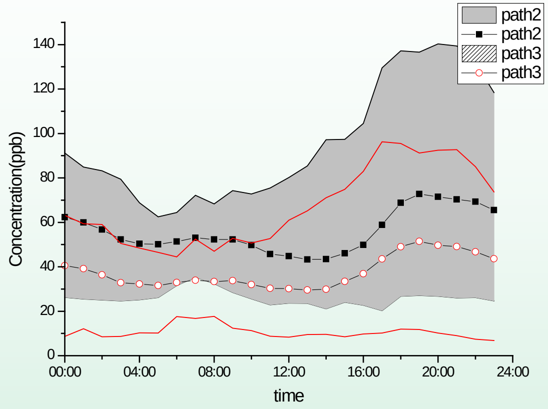
Evaluations in Beijing



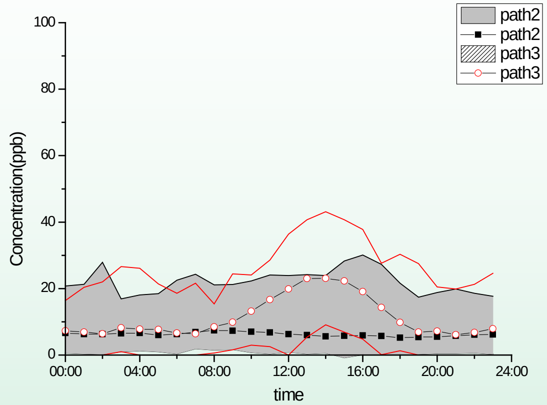
Evaluations in Beijing



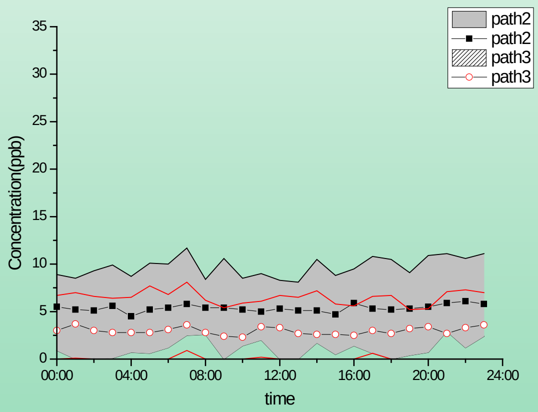
O_3



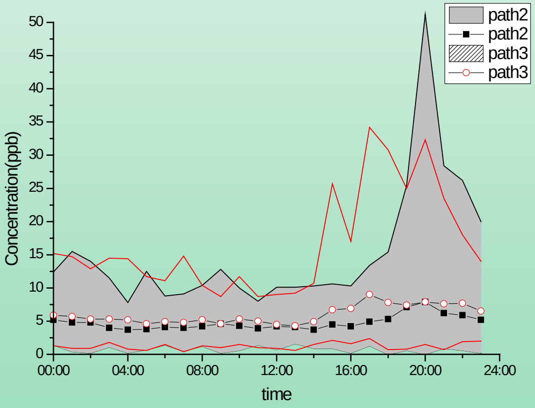
NO_2



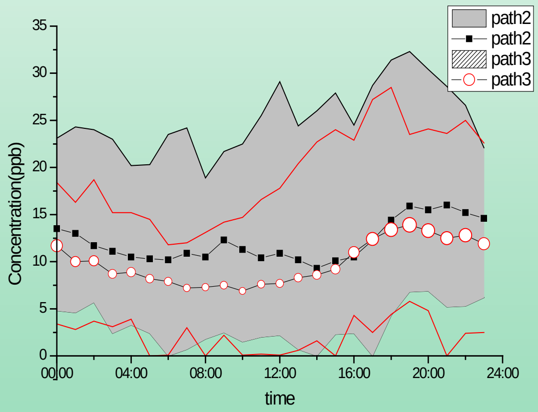
SO_2



BEN



TOL



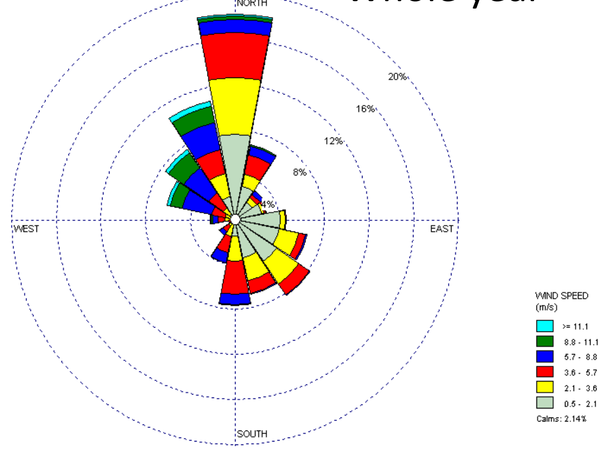
HCHO

Diurnal variations from DOAS measurements

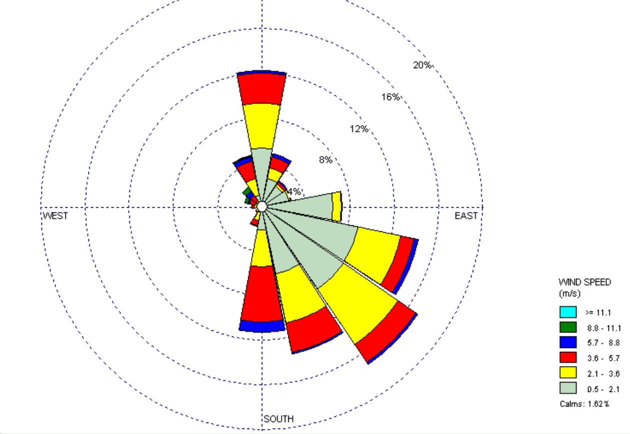
Klaus Schäfer
Institute of Meteorology and Climate Research (IMK-IFU)

Wind influences in Beijing

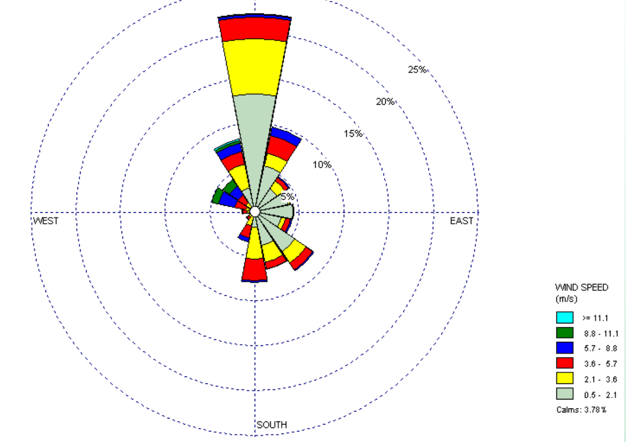
Whole year



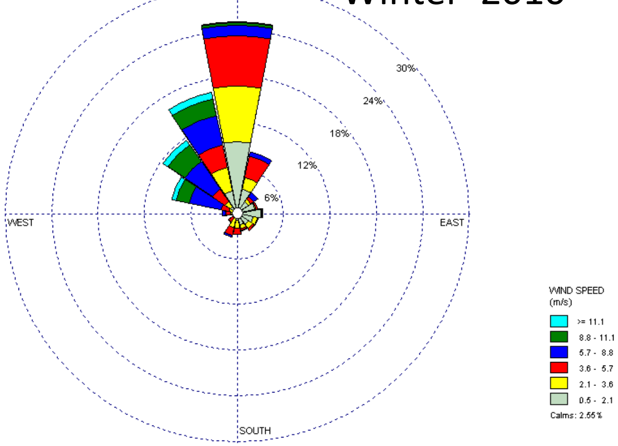
Summer 2010



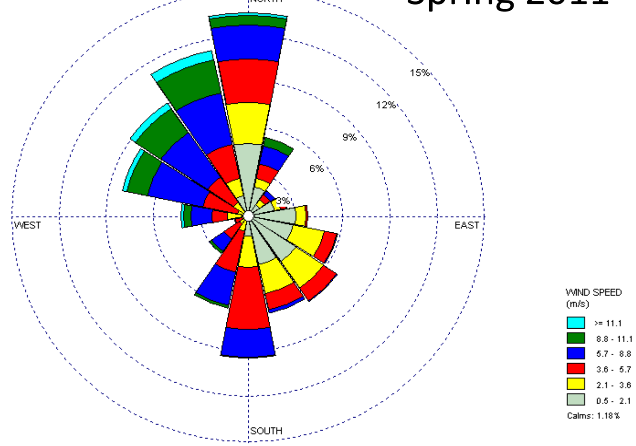
Autumn 2010



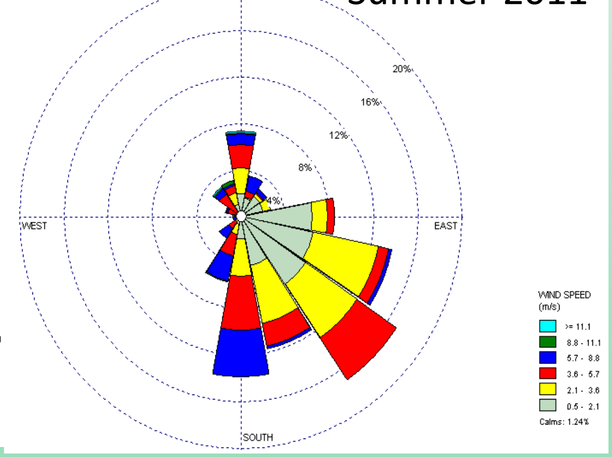
Winter 2010



Spring 2011

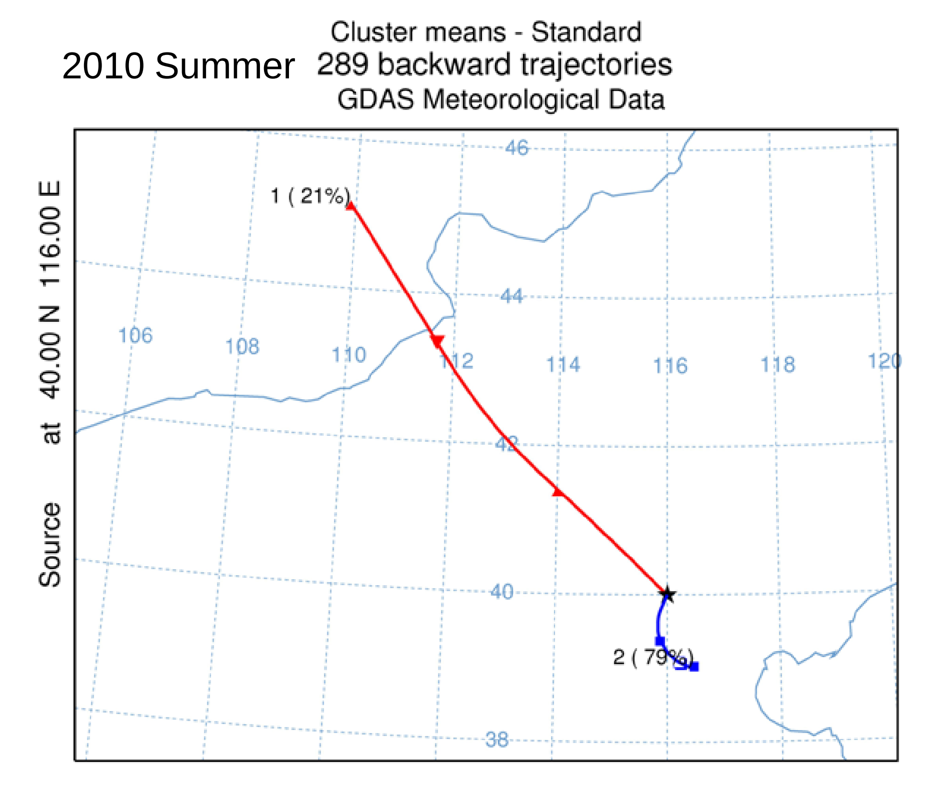


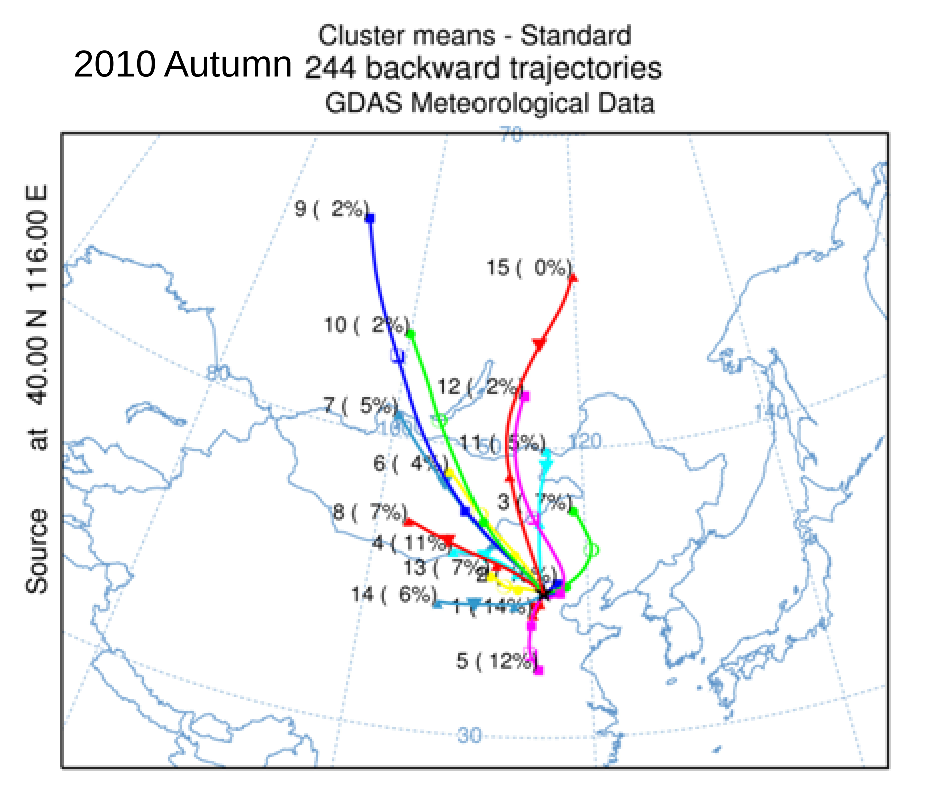
Summer 2011



Influences of wind speed upon NO_2, $PM_{2.5}$, PM_{10} and CO concentrations in the order of 20 %

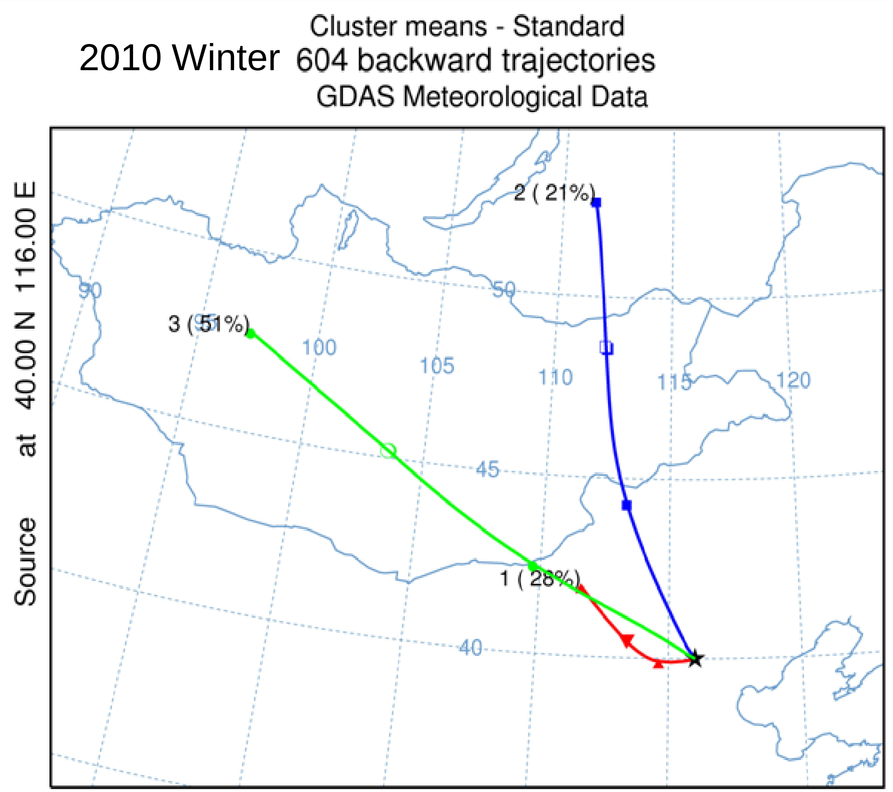
Backward trajectories in Beijing



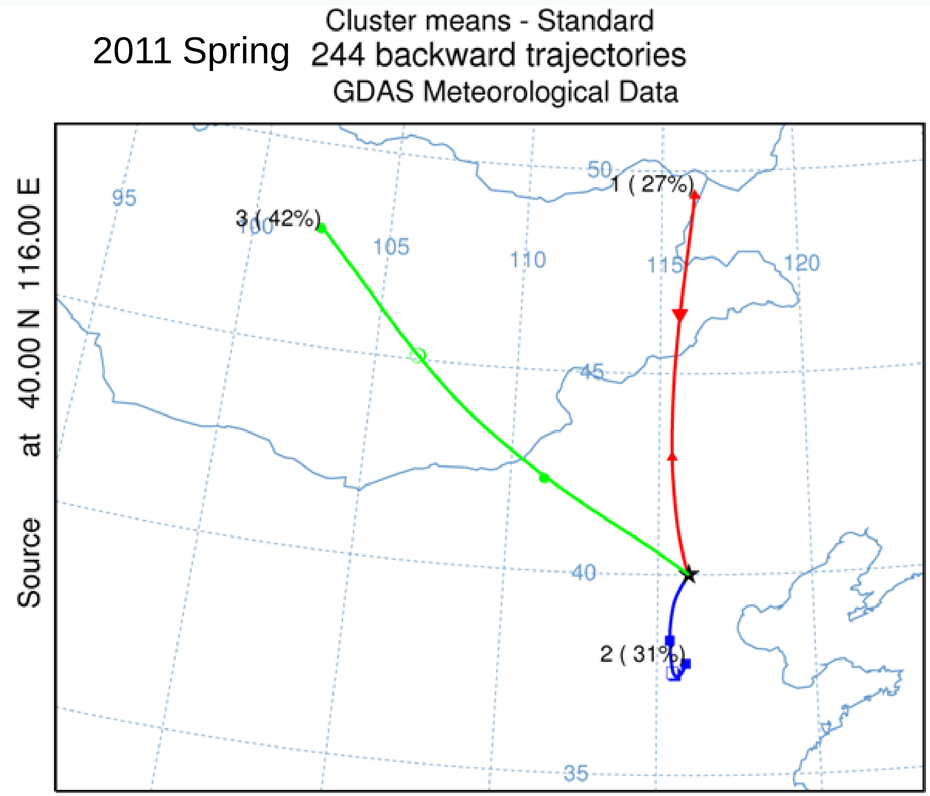


Backward trajectories in Beijing

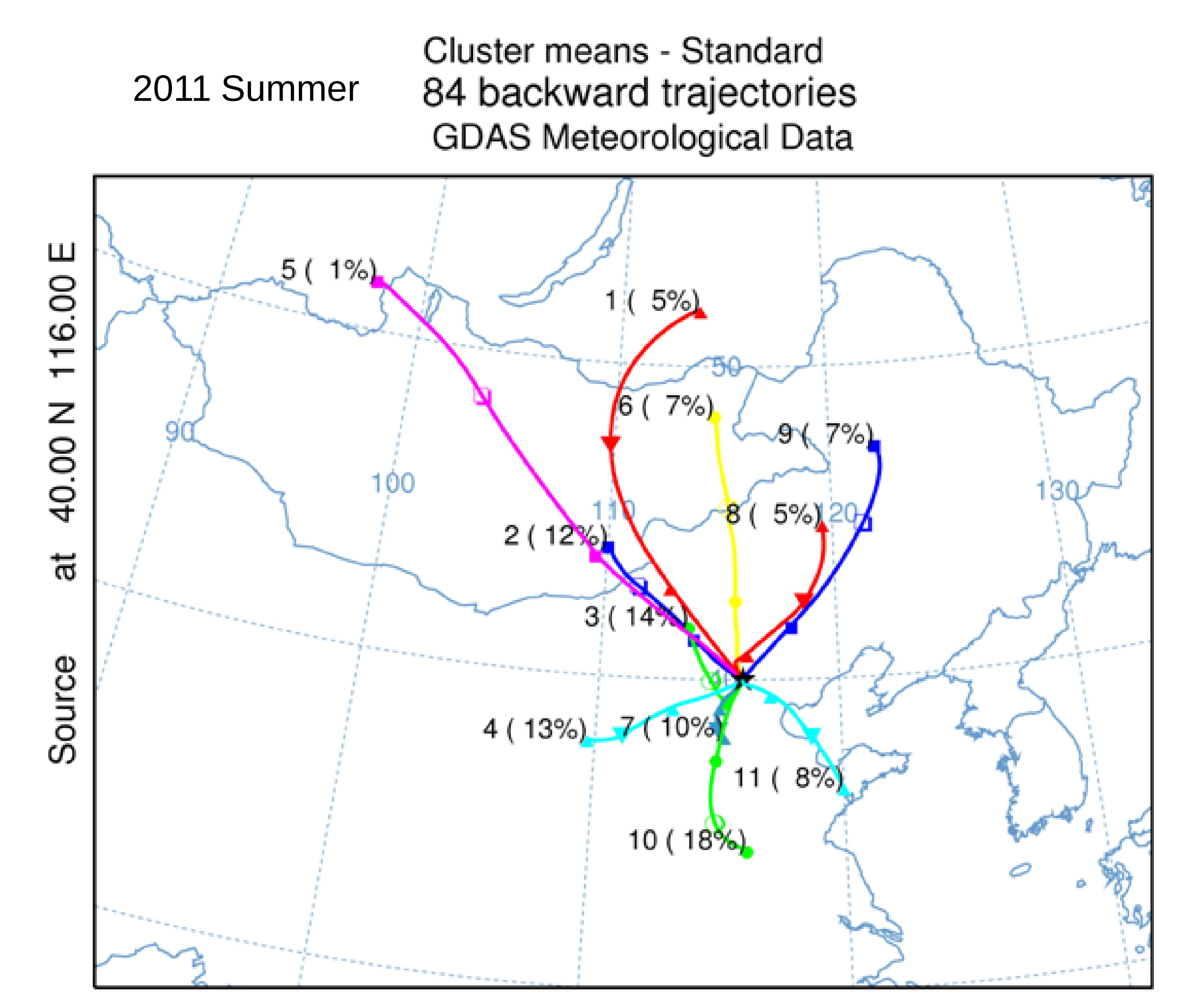
2010 Winter



2011 Spring



Backward trajectories in Beijing



Wind / long-range transport 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

Process studies

Source apportionment

Factor analysis in Beijing

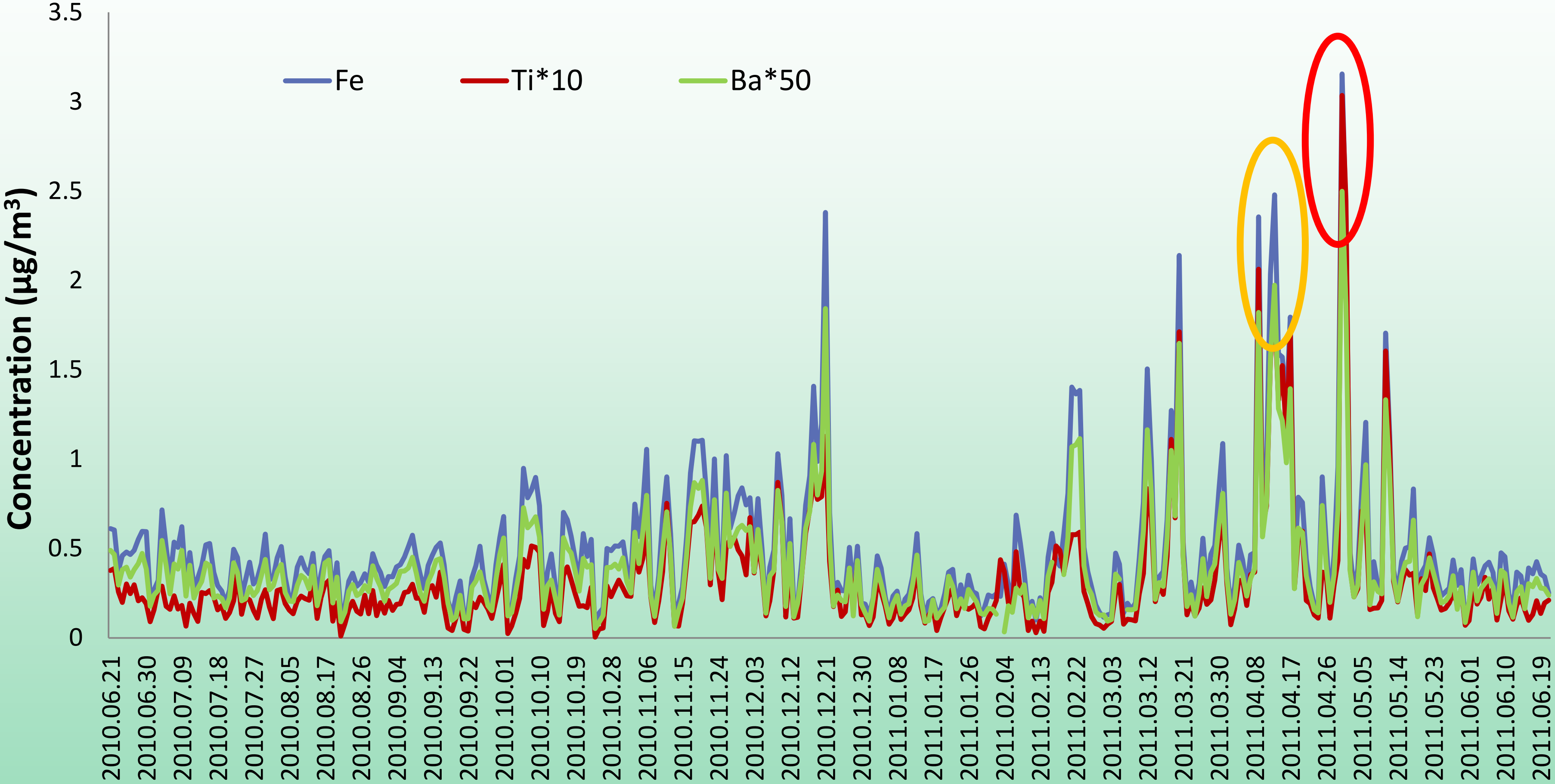
Element	Factor 1	Factor 2	Factor 3
S	1.408E-02	**0.859**	5.188E-02
K	0.424	**0.626**	-0.124
Ca	**0.878**	0.217	0.182
Ti	**0.952**	7.772E-02	5.085E-02
Cr	0.374	**0.558**	5.914E-03
Mn	**0.833**	0.448	0.110
Fe	**0.940**	0.277	8.795E-02
Ni	**0.538**	**0.442**	0.139
Zn	0.331	**0.832**	0.283
As	0.164	**0.717**	0.388
Sn	7.646E-02	0.233	**0.717**
Sb	0.124	1.514E-02	**0.788**
Ba	**0.937**	0.236	0.116
Pb	0.329	**0.879**	0.171

Factor 1:
Geogenic factor (soil and re-suspended dust)

Factor 2:
Fossil fuel combustion (oil and coal combustion) and waste incineration

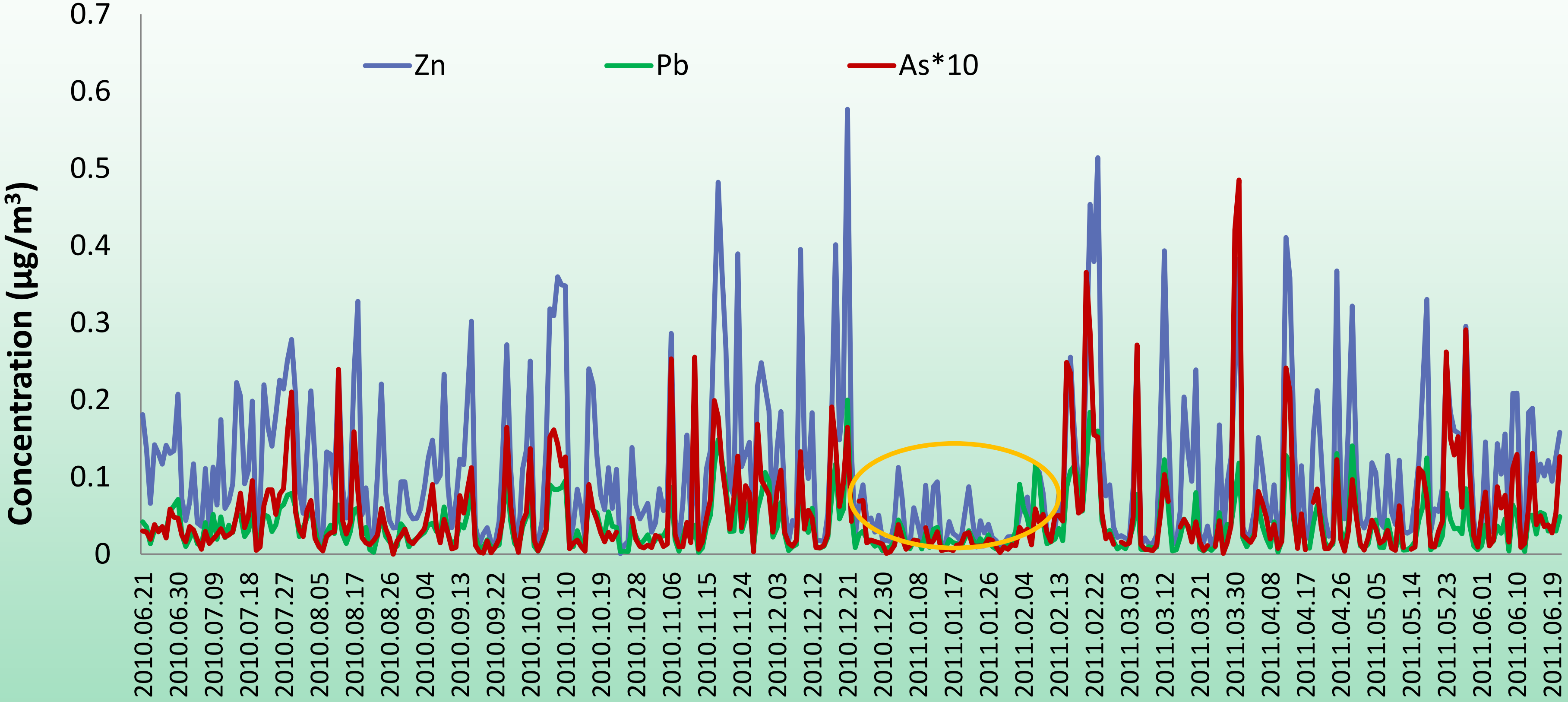
Factor 3:
Brake wear

Variation of Fe, Ti and Ba (geogenic factor)



$PM_{2.5}$ mass concentration is highest in April because of dust storm (originated from Gobi desert) and re-suspended road dust

Variation of Zn, As and Pb (anthropogenic factor)



$PM_{2.5}$ mass concentration is lowest in January because of the Spring Festival holiday

Mixing layer height - air quality

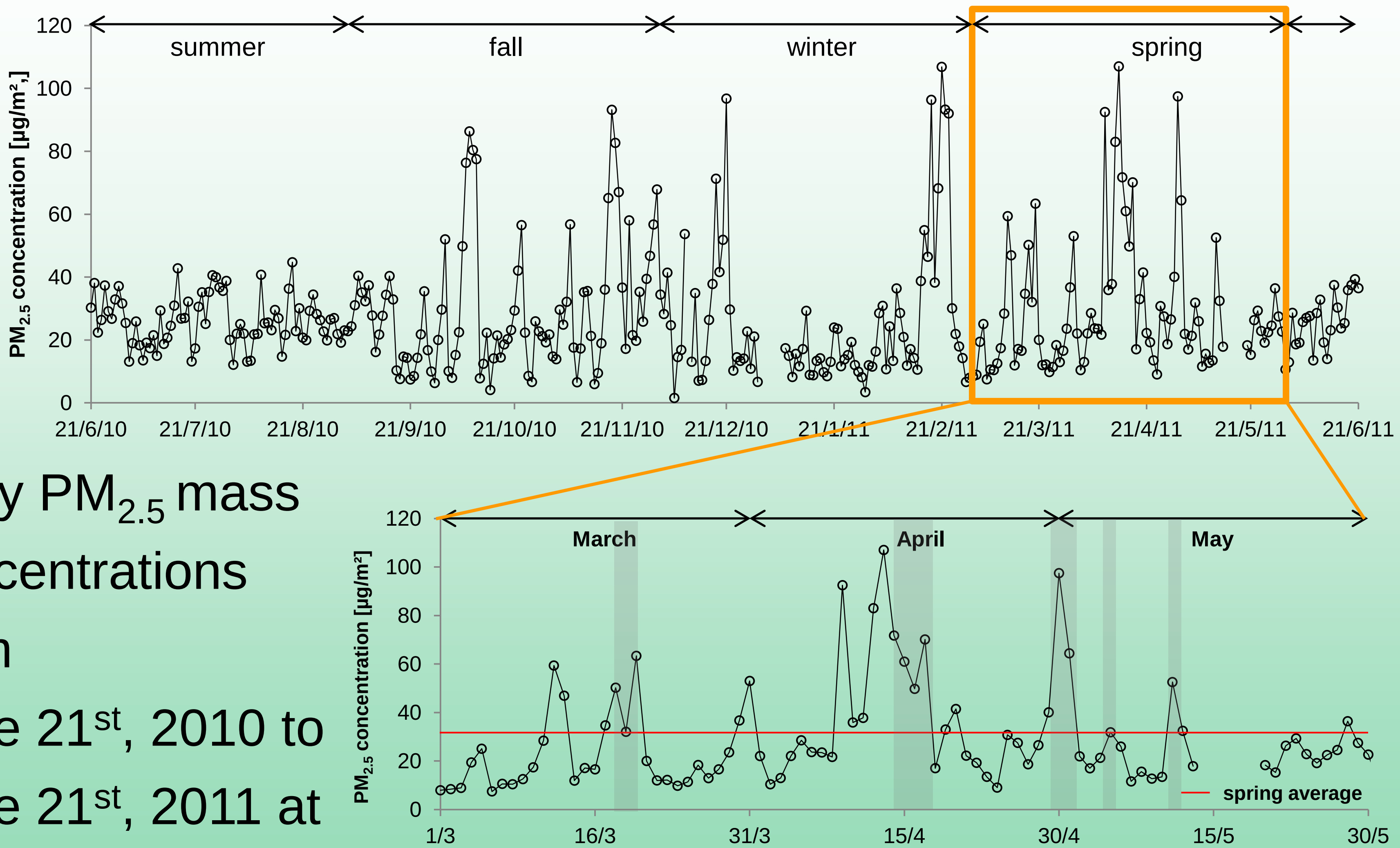
Influence of MLH upon element mass concentrations

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)

Modelling

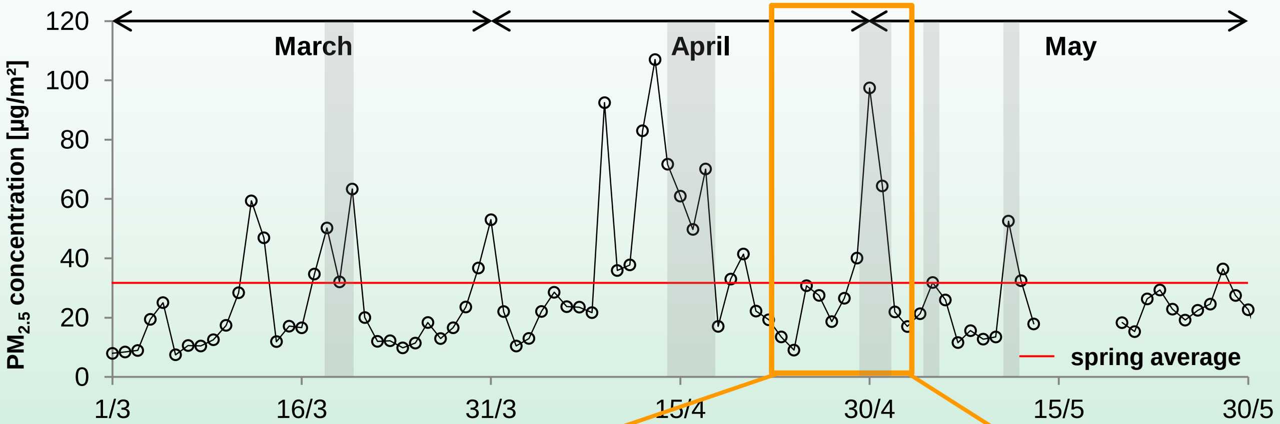
Case study – spring 2011

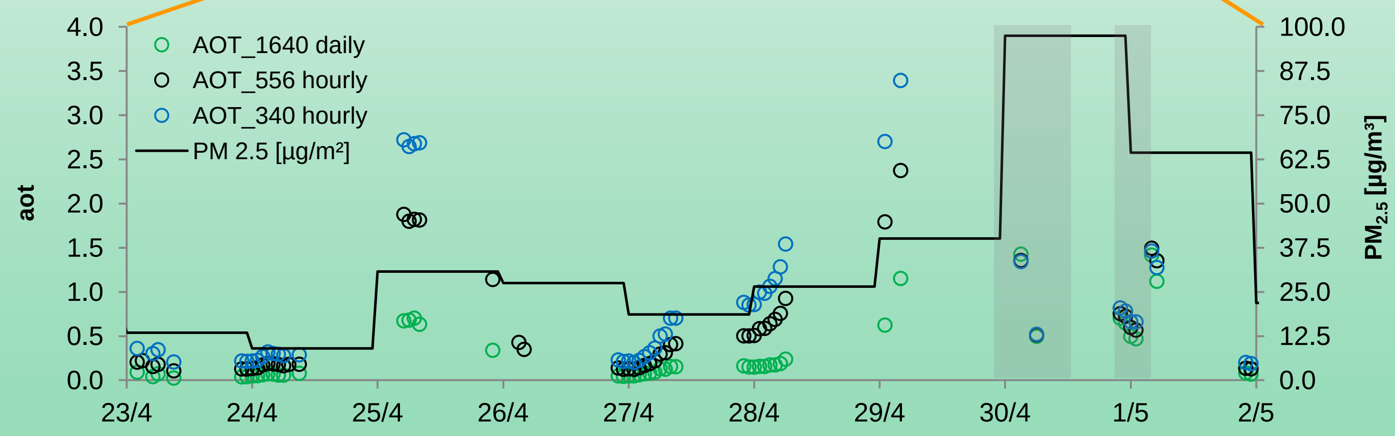


Daily $PM_{2.5}$ mass concentrations from June 21st, 2010 to June 21st, 2011 at CUGB/Beijing

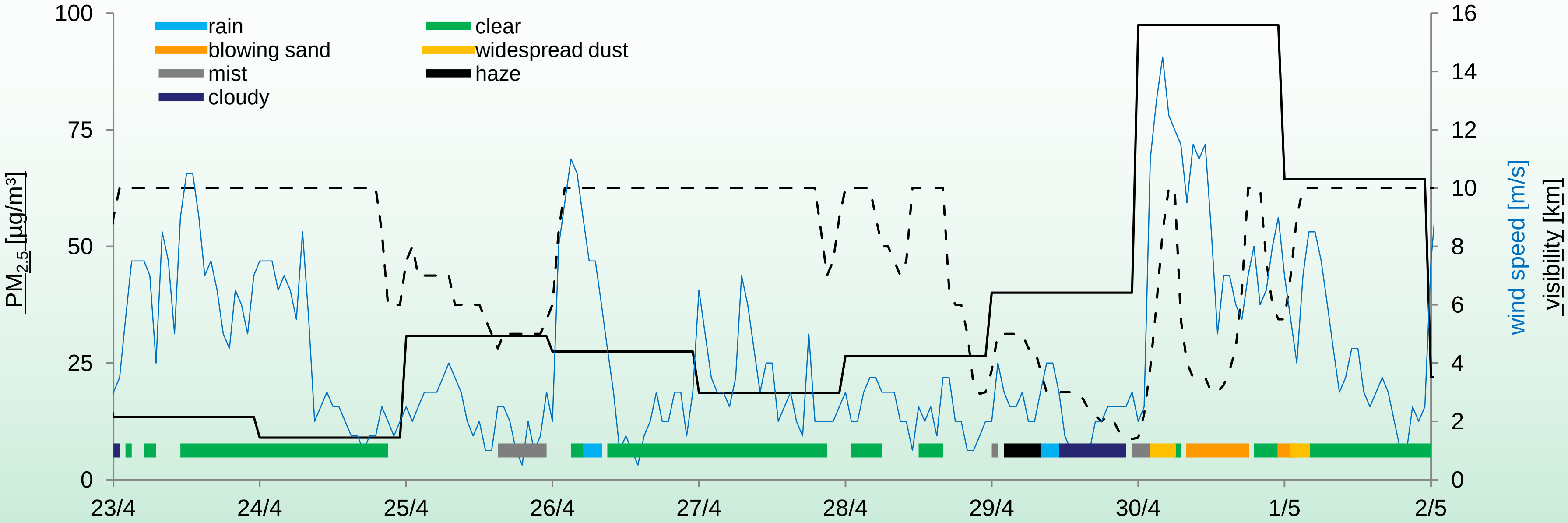
Data source: Rong-rong Shen

Selection of investigation episode





Weather conditions during dust episode



Sudden drop of relative humidity from 90 to 10% at beginning of dust event

Highest wind speeds at beginning of dust event

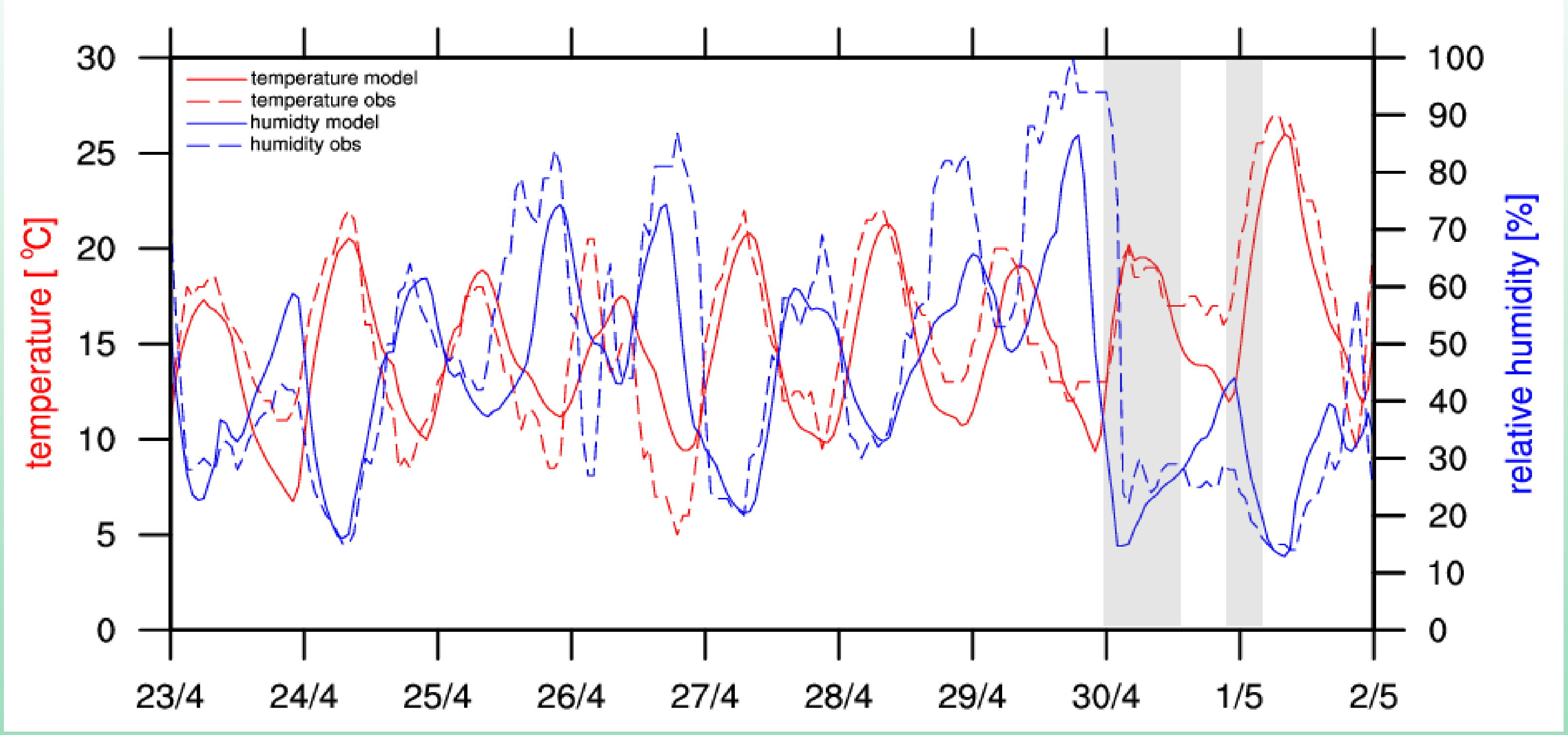
Steep decrease of visibility after dust arrival

Short episodes of clear weather conditions during dust event

Widespread dust conditions after arrival of dust storm air

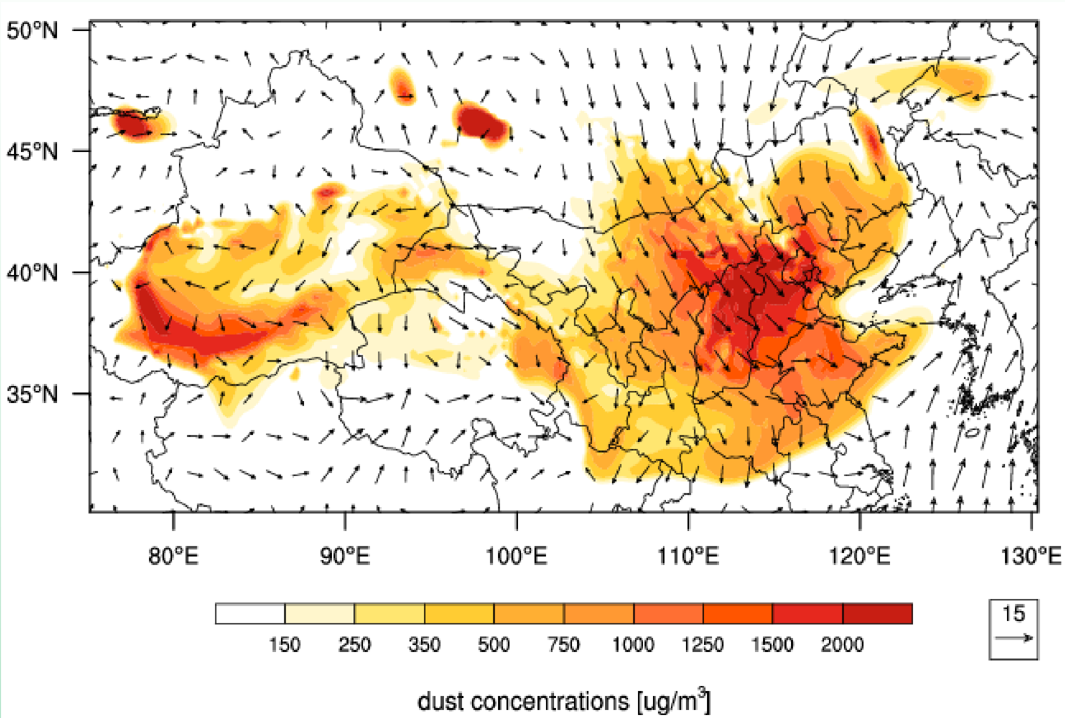
Simulation of meteorology during dust episode

Modeled and measured air temperature and relative humidity at Beijing from April 23rd to May 2nd, 2011 without aerosol feedback processes

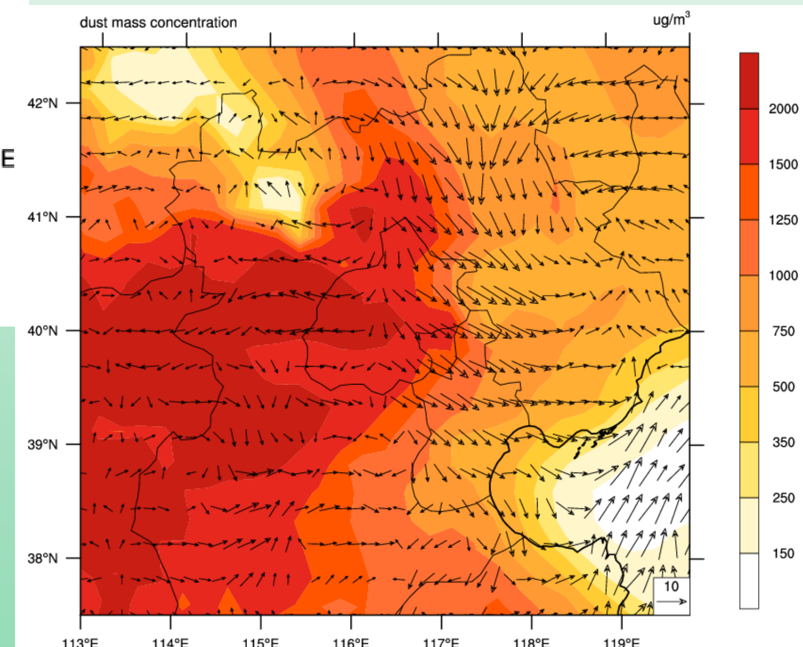


➔ The general behavior of the meteorological parameters is well reproduced

Horizontal distribution of mineral dust particles on April 30th, 2011



Dust concentrations and near surface wind on April 30th, 2011, 03 UTC



Dust concentrations and near surface wind at Beijing, Tianjin and Hebei province on April 30th, 2011, 03 UTC

Conclusions for dust simulation

- Highest $PM_{2.5}$ mass concentration values were measured during the dust event on April 30th, 2011
- Urban particle loading in Beijing on April 30th and May 1st is mainly dominated by mineral dust particles
- Mineral dust available during the whole simulation period
- Main source region for dust storms seem to be Inner Mongolia
- Dust is transported over long distances as far as Korea
- Model results show high variability of dust aerosol in space and time on continental to local scale
- Simulation results indicate that sometimes dust from south-western China loess plateau is transported towards North

Future work

Simulation of anthropogenic particles in Greater Beijing during dust event

Simulation of the combined effects of geogenic and anthropogenic particles on radiation

Switch on/off sources and source regions

Quantification of the contribution of geogenic particles to urban particle loading in Greater Beijing

Investigation of further use of CALIPSO

Additional case study: simulation of particle pollution in Beijing during the Olympic Games in 2008

Conclusions

Air quality studies

Continuous determination of mixing layer height (MLH) by remote sensing (ceilometer, SODAR, RASS)

- Limits the vertical distribution of emitted air pollutants – application for column measurement products
- Influenced by future 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 areas. Meteorologische Zeitschrift, 15, 647-658 (2006).
SCHÄFER, K.; VERGEINER, J.; EMEIS, S.; WITTIG, J.; HOFFMANN, M.; OBLEITNER, F.; SUPPAN, P.: Atmospheric influences and local variability of air pollution close to a motorway in an Alpine valley during winter. Meteorologische Zeitschrift, 17, 3, 297-309 (2008).
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).
SCHÄFER, K.; EMEIS, S.; SCHRADER, S.; TÖRÖK, S.; ALFÖLDY, B.; OSAN, J.; PITZ, M.; MÜNKEL, C.; CYRYS, J.; PETERS, A.; SARIGIANNIS, D.; SUPPAN, P.: A measurement based analysis of the spatial distribution, temporal variation and chemical composition of particulate matter in Munich and Augsburg. Meteorologische Zeitschrift, 21, 1, 47-57 (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. Atmospheric Environment, 45, 5561-5571 (2011).
HELMIS, C.G.; SGOUROS, G.; TOMBROU, M.; SCHÄFER, K.; MÜNKEL, C.; BOSSIOLI, E.; DANDOU, A.: A comparative study and evaluation of Mixing Height estimation based on SODAR-RASS, ceilometer data and model simulations. Boundary-Layer Meteorology, in print.

Current tasks

Current tasks

Joint concept for investigation of spatial and temporal variation of PM composition in Beijing and surroundings for one year (funded by partners): status and next steps

- Sampling $PM_{2.5}$ in Beijing 21 July – 17 August 2011, 12 October – 08 November 2011, 06 December – 19 December 2011, 14 April – 25 April 2012 and
  in Xianghe 19 July –23 August 2011, 06 October - 11 November 2011, 06 December –19 December 2011, 12 April – 28 April 2012: finished, interesting differences between data of different seasons (e.g. temperature, haze days)

Current tasks

- IAP: physical characterization of $PM_{2.5}$ (particle size distribution, mass concentration, AOD) and meteorological parameters (wind speed, wind direction, temperature, pressure, humidity, mixing layer height, visibility, solar radiation, cloudiness)
- HMGU and UR: analyses of organic composition of sampled PM
- KIT/IGG/IMG: analyses of inorganic composition of sampled PM as well as filter image analysis

Current tasks

- PU: study epidemiological aspects of $PM_{2.5}$ exposure
- CUMTB: toxicological assessment and complementary low-volume sampling as well as chemical analyses of $PM_{2.5}$

Future tasks

Future tasks

DFG project proposal (funding of two PhD students and instruments), submitted 09/12/2011, decision about 08/2012

- Reduction of coarse particles and its role as scavengers for finer particles can result in relatively increasing number concentrations of fine and ultra-fine particles influencing precipitation events
- Until now it cannot be forecasted whether the reduction of gaseous pollutants (e.g. sulphur dioxide) or the reduction of soot dominates the temperature development
- A one-year campaign at one site inside (IAP) and one site outside Beijing (IAP, Xianghe) will be performed to determine actual particle characteristics: $PM_{2.5}$ sampling, $PM_1/PM_{2.5}/PM_{10}$ mass concentrations, PSD, gaseous precursors, absorption/ extinction of PM

Future tasks

- Sampled particles will be characterised for their chemical (HMGU, KIT/IGG) and physical properties. This will allow the analysis of the mixing processes of geogenic and anthropogenic particles and source apportionments
- Evaluation of the radiative characteristics of particles over the greater area of Beijing is based on comprehensive modelling systems like COSMO-ART and/or WRF-Chem including an assessment of the spatial distribution of $PM_{2.5}$ and evaluation of pollution hot spots in combination with satellite data
- This project combines model and measurement approaches for the same region allowing to regionalize measurement data and to assess the quality of model results

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