Remote sensing measurement techniques and methods for investigating air pollution situations

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Problems and objectives
Methodology: remote sensing, inverse modelling and model validation
Influence of mixing layer height upon air quality
Relations between optical depth and particle concentrations
Concept of ICAROS platform
Some results of joint research with UNAM
Discussions, conclusions and outlook

Problems

A lot of measures for
- emission reduction (health protection) and
- efficient energy consumption (climate protection)

in the traffic and industrial sector realised

NO_2/NO_x ratio in ambient air continuously increasing

High amount of ultra-fine dust is background

How to fulfil the EC regulations for NO_2 and PM_{10} from 2010 on?

Are these threshold values enough for health protection?

Background

Health effects must be defined

- which pollutants are relevant?
- which health effects are not explained?

Which public interests are relevant

- regulations
- health care (human, animals)
- odour
- noise

Objectives in Mexico City

Observation of air pollution processes by application of the available remote sensing methods

Interaction between urban areas and its surroundings

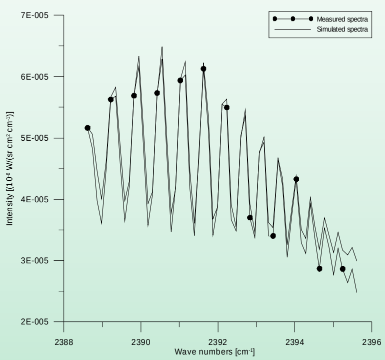
Determination of emission source strengths for modelling: Gaps; Hot spots

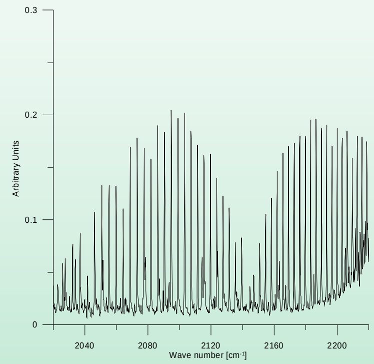
Validation of air quality modelling: Validation strategies; Data requirements

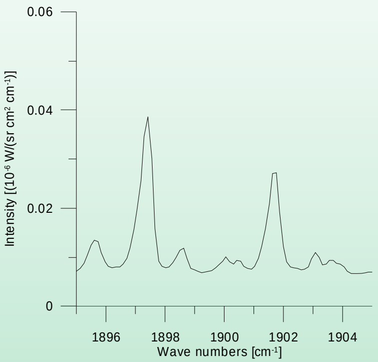
Basics for improvement of air quality in urban conglomerations

Methodology

In situ techniques for NO, NO_2, CO, O_3, THC, PM_{10}, $PM_{2.5}$







Path-averaging optical remote sensing techniques

- FTIR emission spectrometry of hot exhausts (CO, NO, CO_2; NO_2 below detection limit)
- FTIR absorption spectrometry (CO, CO_2, CH_4, N_2O)
- DOAS (NO, NO_2, O_3, NH_3, BTX, HCHO)

Average emission index *EI* of a molecule *X* in g/kg kerosene:

$$EI(X) = EI(CO_2) \times \frac{M(X)}{M(CO_2)} \times \frac{Q(X)}{Q(CO_2)}$$

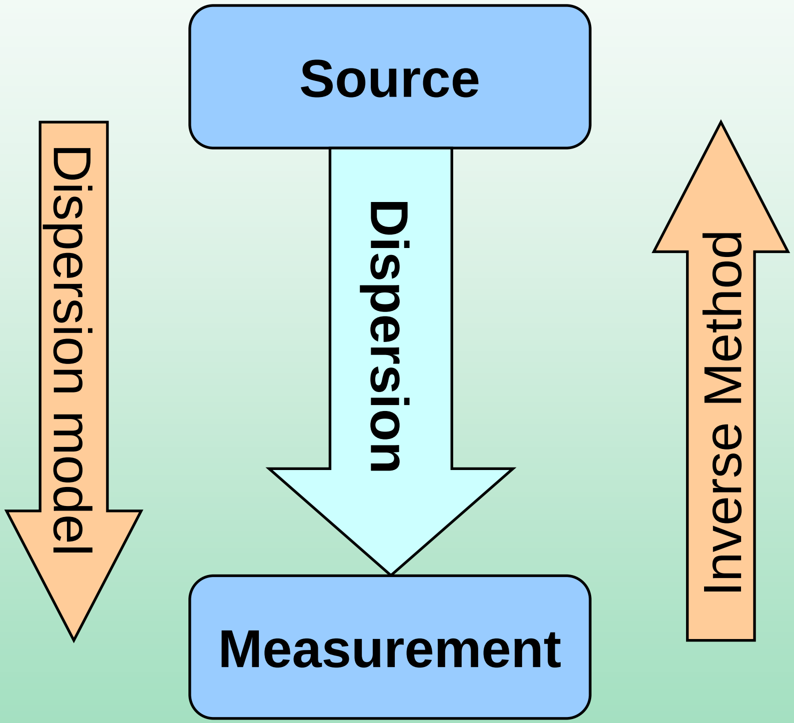
M: molecular weight

Q: concentrations (mixing ratios, column densities etc.)

Theoretical emission index of CO_2: 3,159 g/kg

EI (NO_x) = EI (46/30 NO + NO_2)

Inverse dispersion modelling



Bayesian statistics to solve the inverse problem: hourly averaged concentration measurements

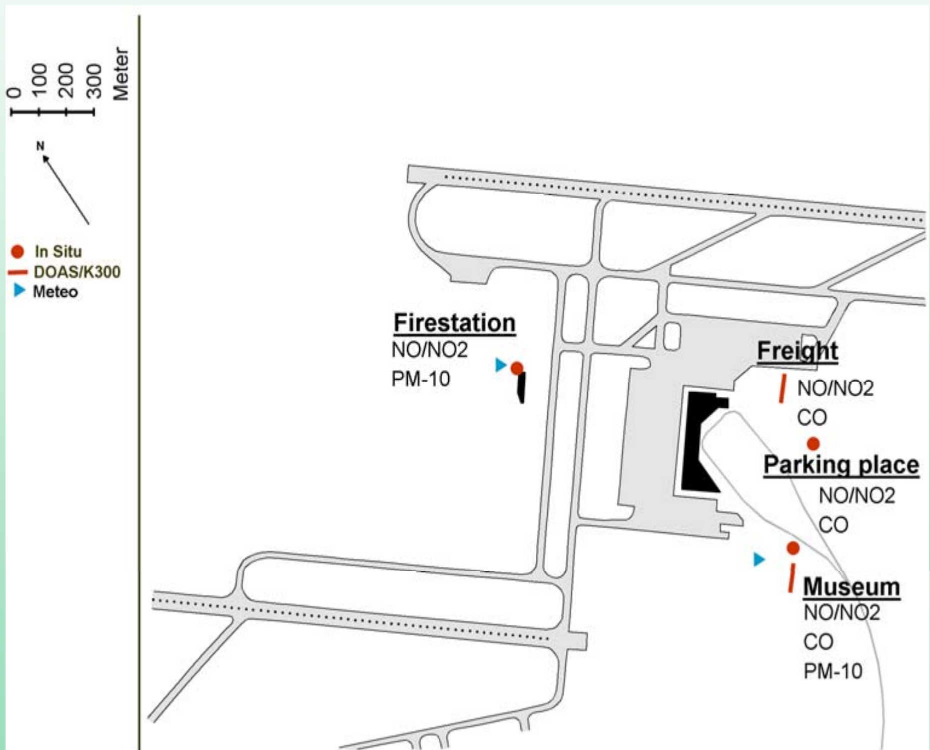
All kinds of emissions at a heterogeneous area source

Traffic is highly variable

Dispersion matrix by modelling with the Lagrangian model Austal2000

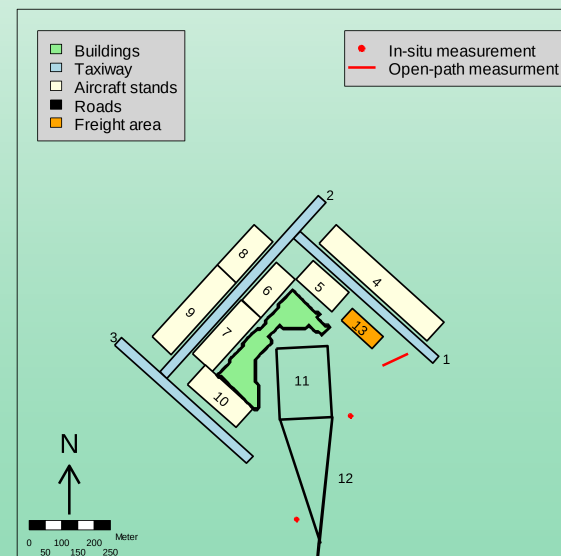
Schürmann, Gregor: Inverse Ausbreitungsmodellierung zur Emissionsratenbestimmung heterogener Flächenquellen. Dissertation zur Erlangung des Doktorgrades der Naturwissenschaften (Dr. rer. nat.) der Fakultät für Angewandte Informatik, Universität Augsburg, 2006; Prüfung 12.07.2007.

Emission source strength determination at airports



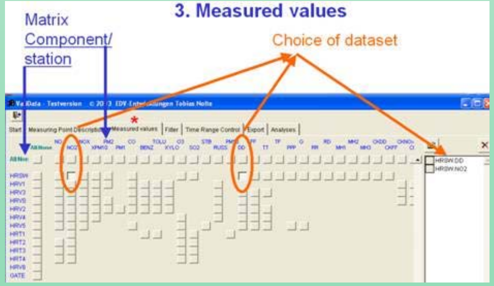
Path-averaging measurements and inverse dispersion modelling

Emissions from different areas



Schürmann, G., Schäfer, K., Jahn, C., Hoffmann, H., Bauerfeind, M., Fleuti, E., Rappenglück, B.: The impact of NOx, CO and VOC emissions on the air quality of the airport Zurich. Atmospheric Environment 41 (2007), 103-118.

Model validation
ValiData – data base and pre-analyses tool



- Air monitoring data
- Meteorological data
- Intensive operating phases
- Location of sites
- Description
- Time

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 (2005), 201-216.

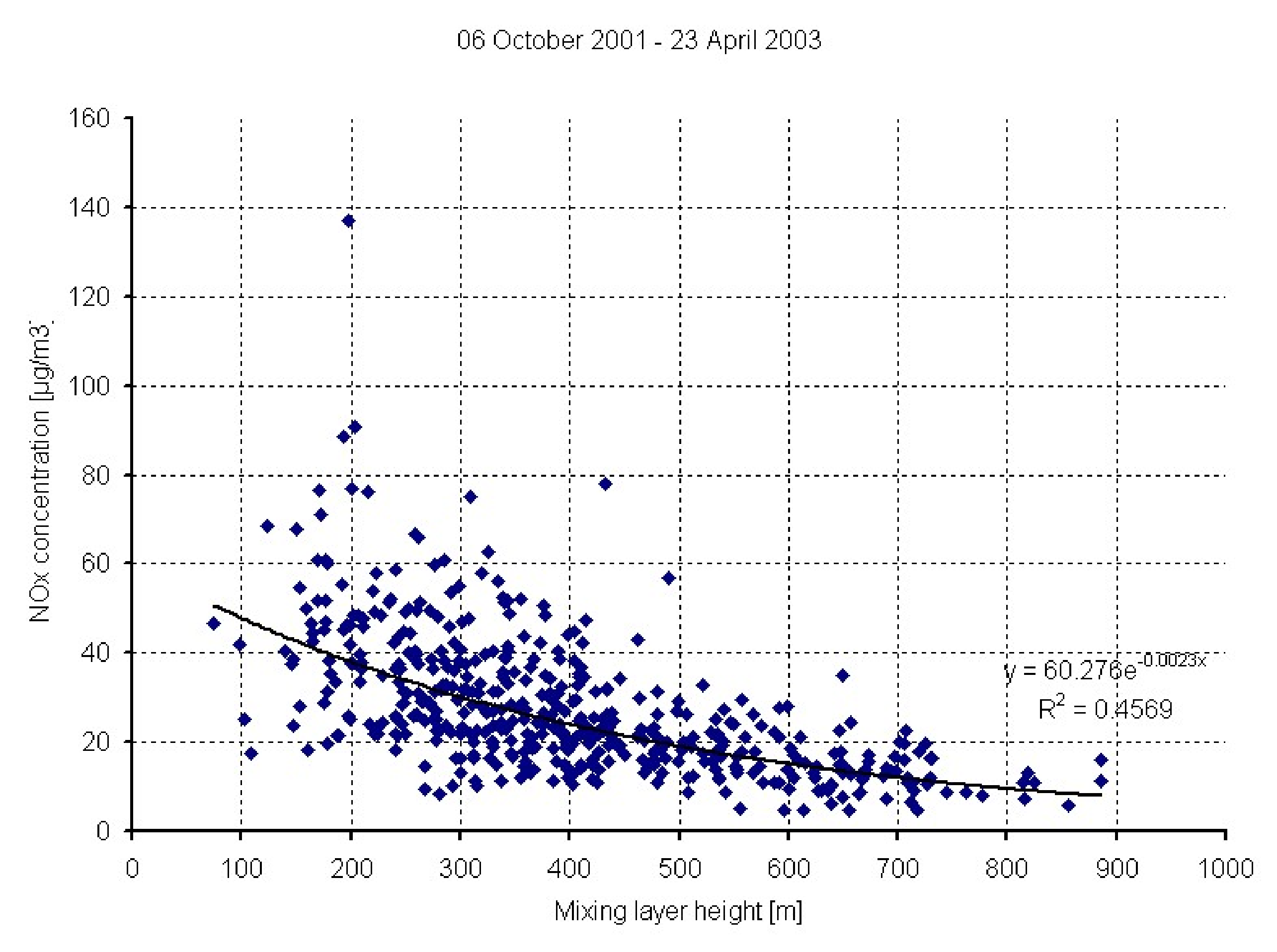
Influence of MLH upon air pollution in urban and sub-urban area

- Correlations of pollutant concentrations with MLH are smallest inside street canyons
- Correlations at the urban background stations are larger in winter than in summer
- Correlations of NO_x concentrations with MLH are larger than the correlation of particle concentrations with MLH
- There are varying emission source strengths for NO_x and particles and gas-to-particle conversions within air masses

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.

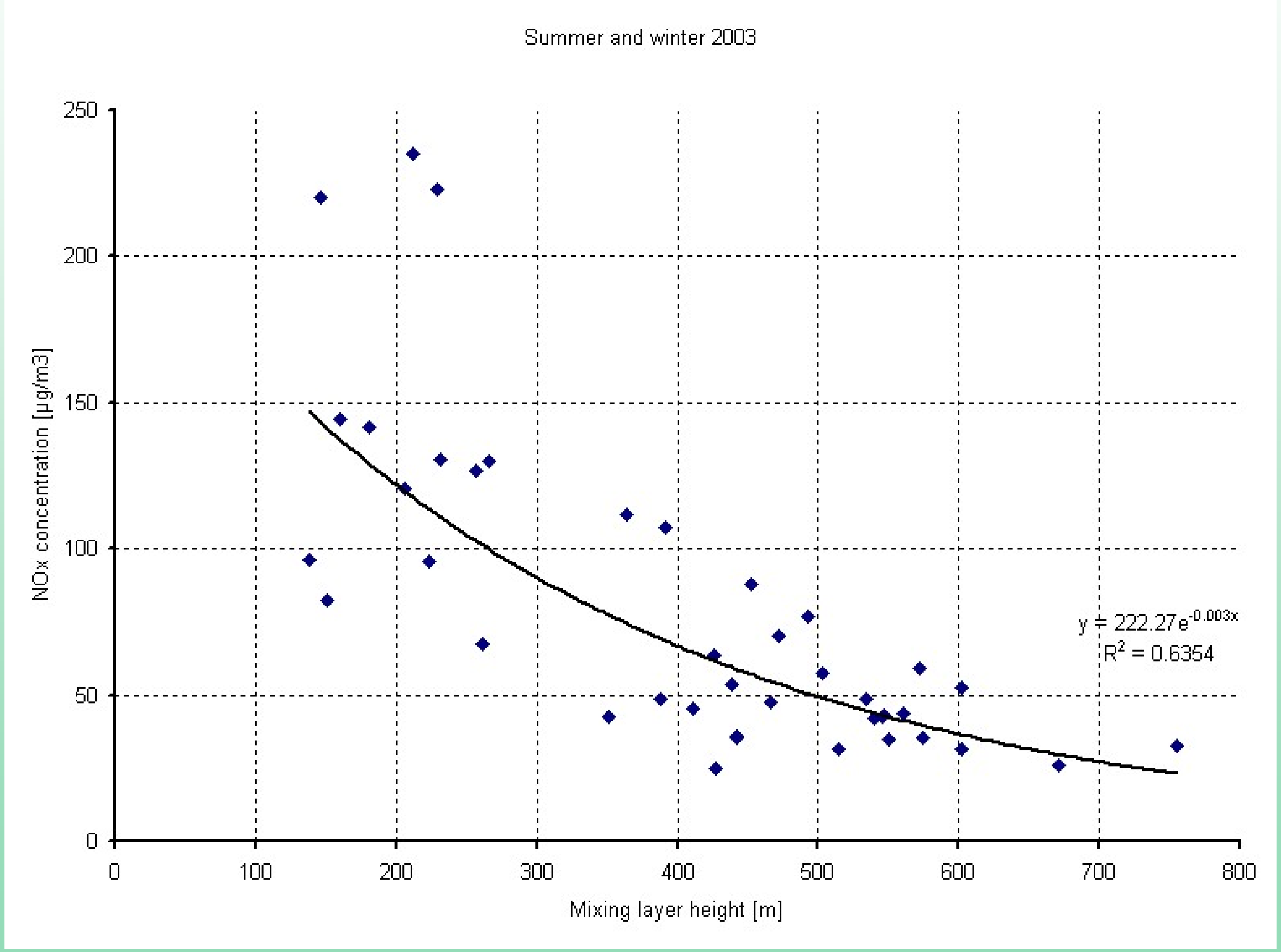
Wiegner, M., Emeis, S., Freudenthaler, V., Heese, B., Junkermann, W., Münkel, C., Schäfer, K., Seefeldner, M., Vogt, S.: Mixing Layer Height over Munich, Germany: Variability and comparisons of different methodologies. Journal of Geophysical Research - Atmospheres, 111 (2006), D13201.

Relationship of NO_x concentrations with MLH from SODAR for a roof-top station at a street canyon (urban background)



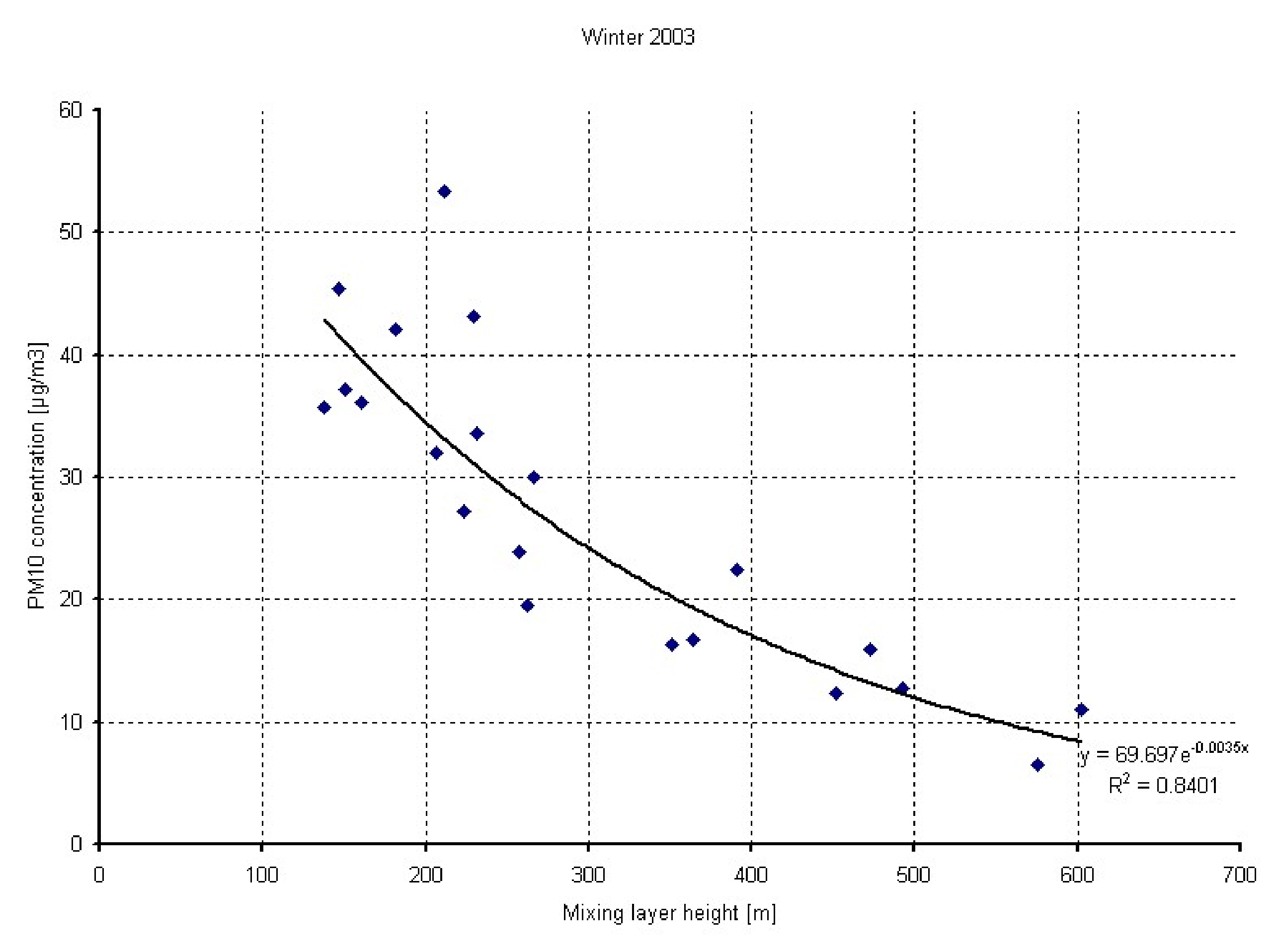
Schäfer, K., Emeis, S., Hoffmann, H., Jahn, C.: Influence of mixing layer height upon air pollution in urban and sub-urban area. Meteorol. Z. 15 (2006), 647-658.

Relationship of NO_x concentrations with MLH from SODAR for rural, urban background and urban stations



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.

Relationship of PM_{10} concentrations with MLH from SODAR for rural, urban background and urban stations during winter



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.

Relationship between atmospheric optical depth and particle concentration

Ground-based measurements

- Daily mean measurements of PM_{10}, $PM_{2.5}$ and PM_1 at rural and urban background sites
- AOD from ground-based sun-photometer measurements around 560 nm at rural and urban background sites
- MLH from SODAR and ceilometer

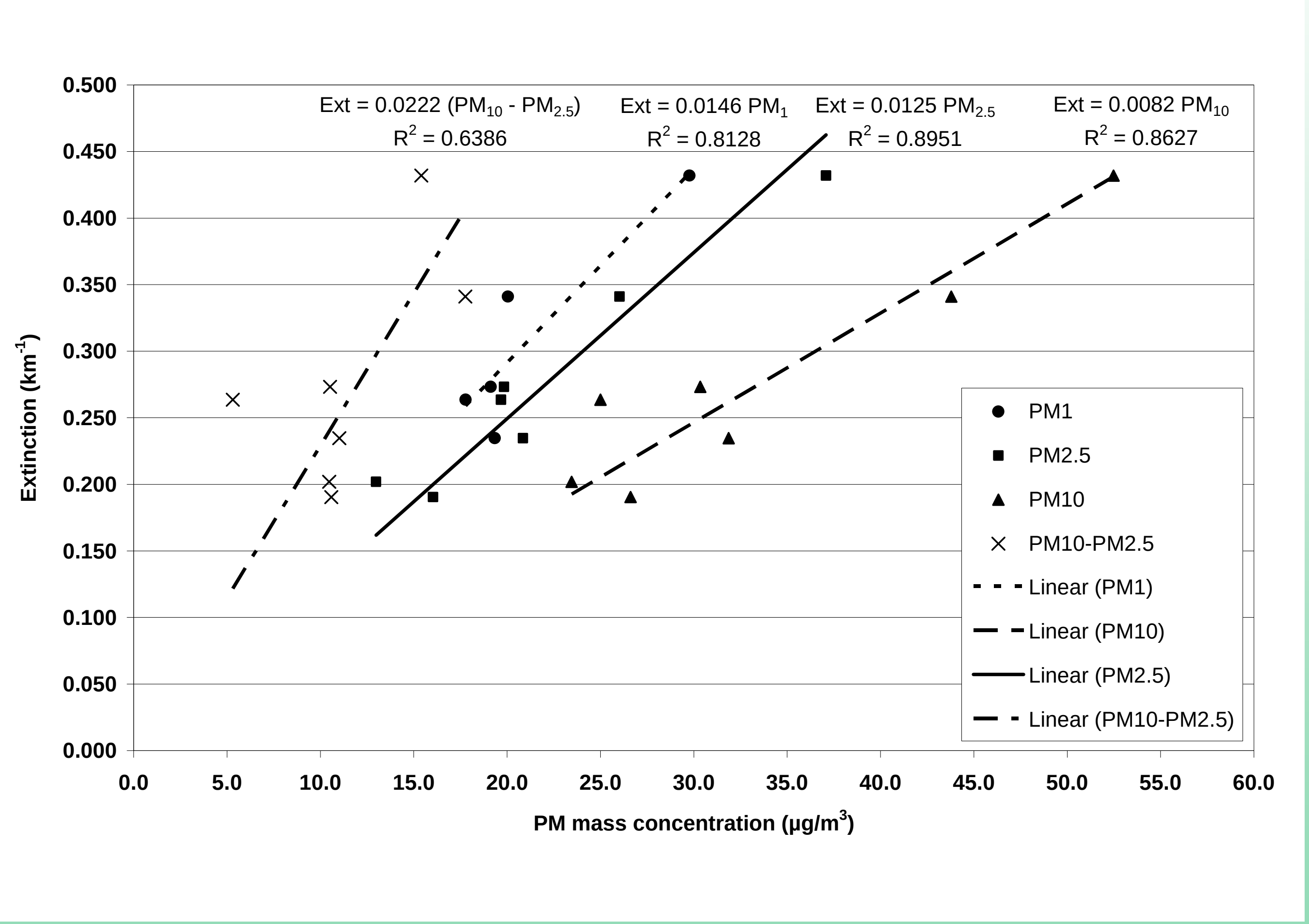
Correlation with linear regression: $PM = a\,\beta_{ext} = a\,AOD / MLH$

a: mass extinction efficiency

Schäfer, K., Harbusch, A., Emeis, S., Koepke, P., Wiegner, M.: Correlation of aerosol mass near the ground with aerosol optical depth during two seasons in Munich. Atmospheric Environment, (2008).

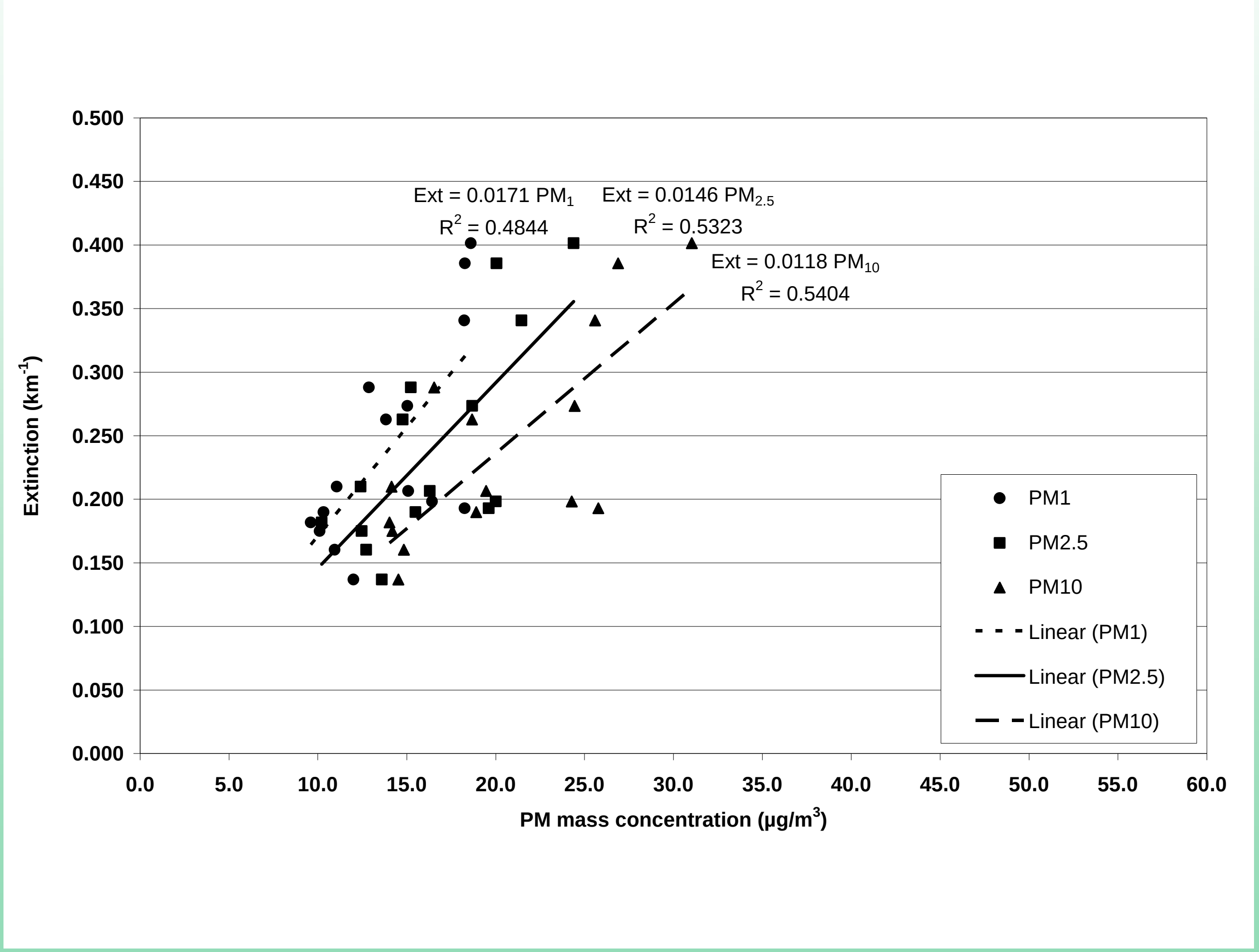
Alföldy, B., Osán, J., Tóth, Z., Török, S., Harbusch, A., Jahn, C., Emeis, S., Schäfer, K.: Aerosol optical depth, aerosol composition and air pollution during summer and winter conditions in Budapest. Science of the Total Environment 383, 1-3 (2007), 141-163.

Relationship of aerosol extinction coefficients (in km^{-1}) with PM mass concentrations (in $\mu g/m^3$) during winter



Schäfer, K., Harbusch, A., Emeis, S., Koepke, P., Wiegner, M.: Correlation of aerosol mass near the ground with aerosol optical depth during two seasons in Munich. Atmospheric Environment, (2008).

Relationship of aerosol extinction coefficients (in km^{-1}) with PM mass concentrations (in $\mu g/m^3$) during summer



Schäfer, K., Harbusch, A., Emeis, S., Koepke, P., Wiegner, M.: Correlation of aerosol mass near the ground with aerosol optical depth during two seasons in Munich. Atmospheric Environment, (2008).

General characteristics of the ICAROS platform

High spatial resolution satellite imageries in regions of
100 km x 100 km (SPOT, Landsat: resolution 30 m x 30 m):

- images in the green spectral range
- one image recorded under very clear atmospheric
- one image of the same geographical area recorded during different pollution levels

Information about aerosols, particle diameter 0.2 - 1.0 µm

Soulakellis, N.A., Sifakis, N.I., Tombrou, M., Sarigiannis, D., Schäfer, K.: Estimation and mapping of aerosol optical thickness over the city of Brescia – Italy using diachronic and multiangle SPOT 1, SPOT 2 and SPOT 4 imagery. Geocarto International, 19, 4 (2004), 57-66.

Data fusion in frame of ICAROS platform

- Retrievals of aerosol optical depths from spatial high resolution satellite images

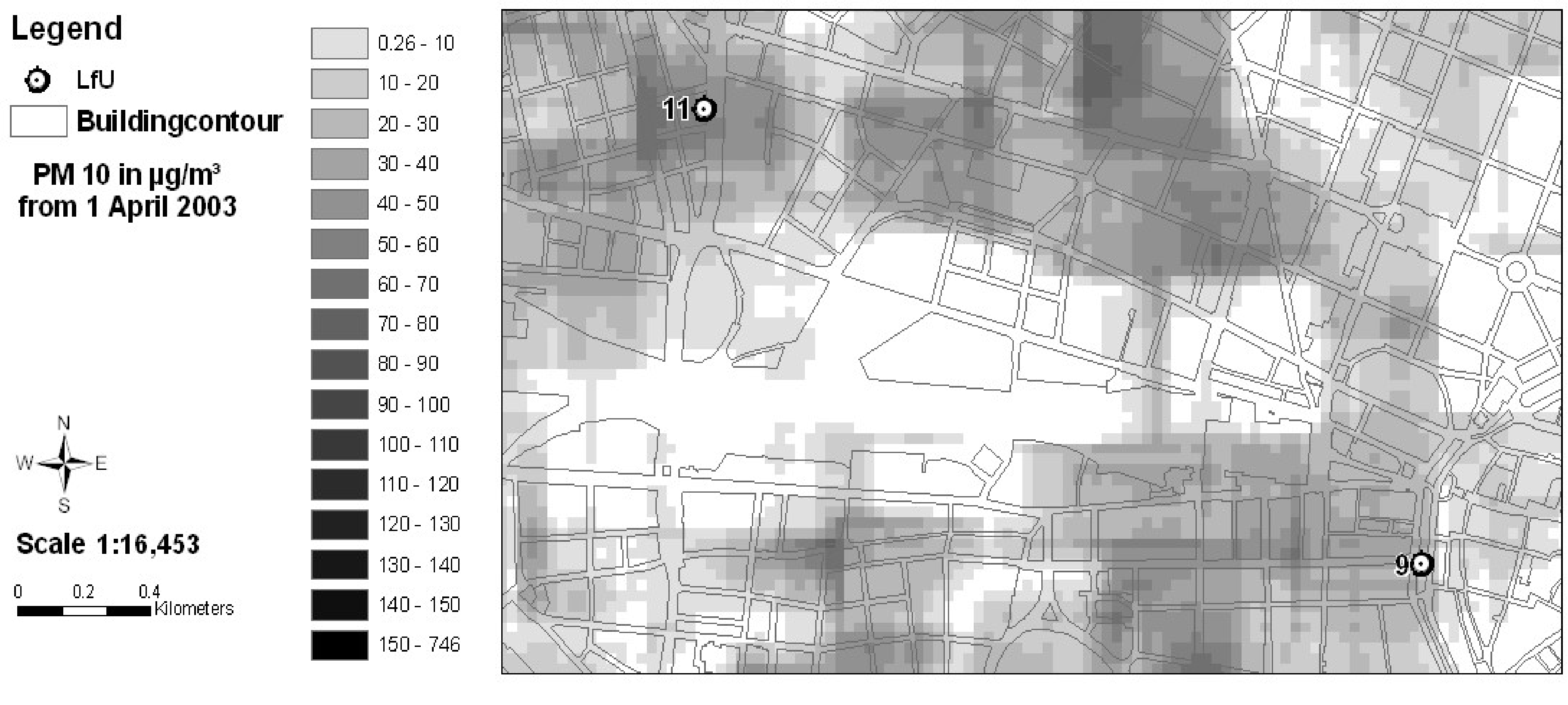
- Determination of particulate load near surface using the relationship PM = a β_{ext} = a AOD / MLH

- Air quality and meteorological data (relative humidity)

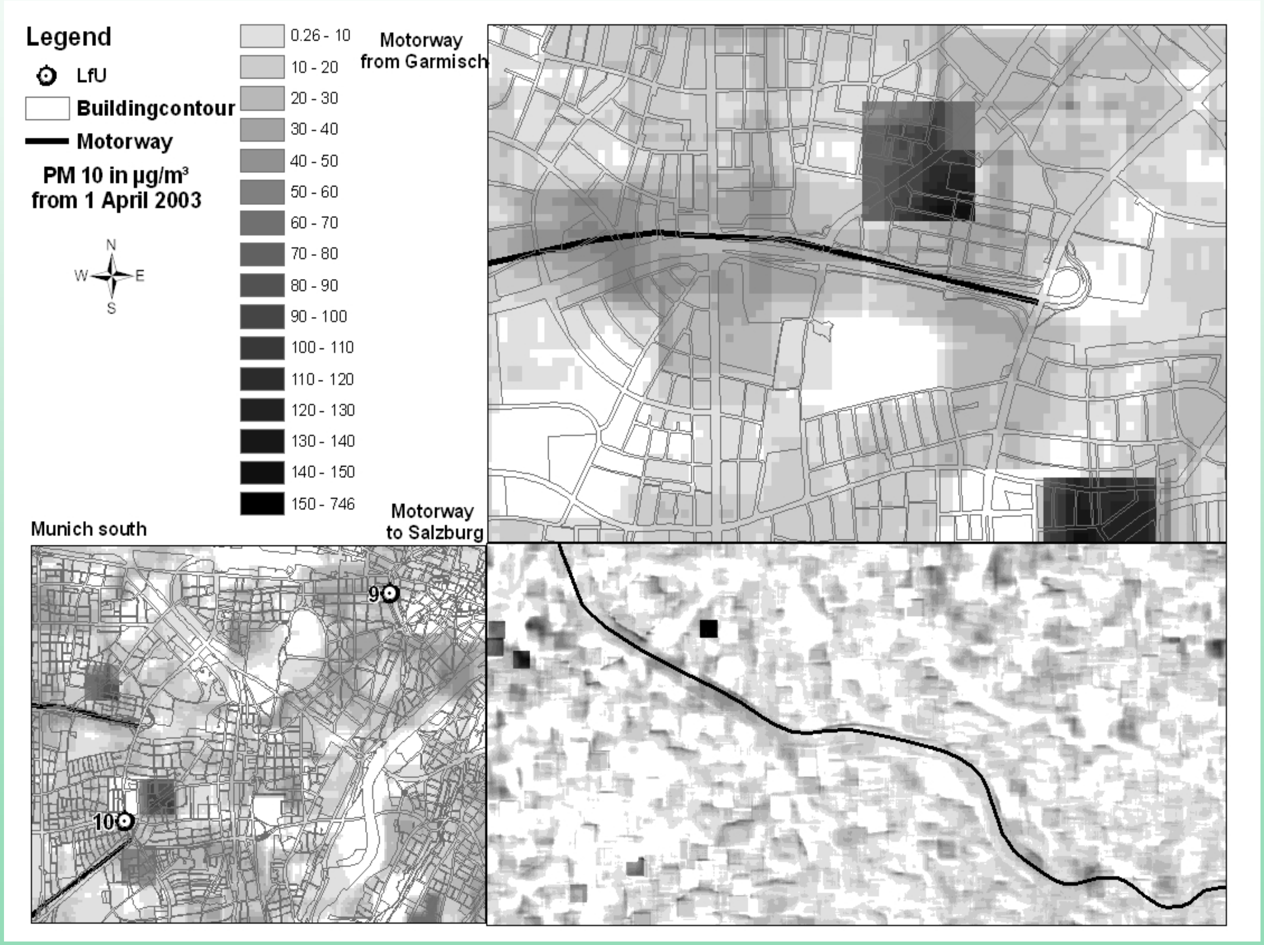
- Results of numerical simulations to enhance spatial coverage

Schäfer, K., Harbusch, A., Emeis, S., Koepke, P., Wiegner, M.: Correlation of aerosol mass near the ground with aerosol optical depth during two seasons in Munich. Atmospheric Environment, (2008).

Spatial distribution of PM_{10} concentrations in Munich centre with the reference image of 16 April 2000

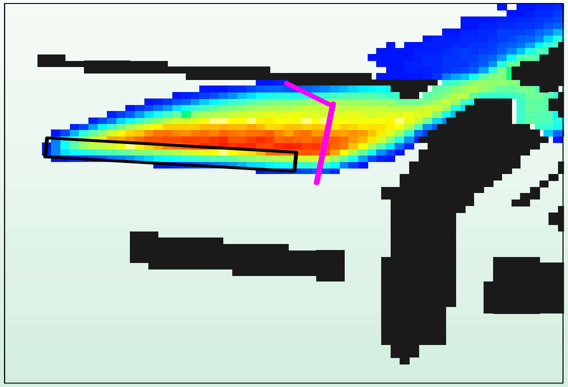


PM$_{10}$ concentrations in Munich calculated with the reference image of 16 April 2000

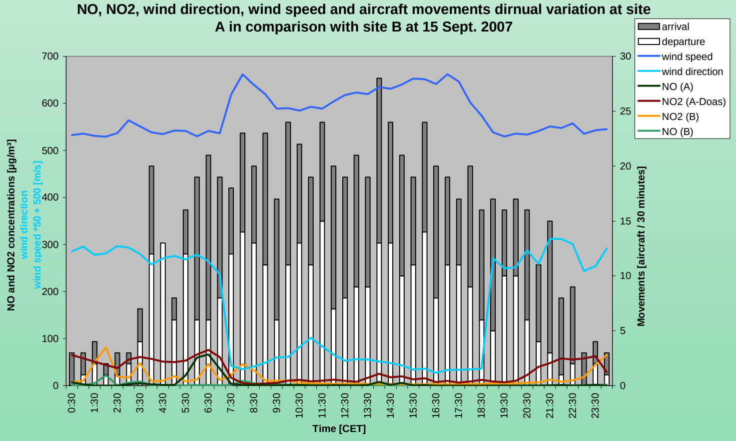


Network of Excellence:

Environmentally Compatible Air Transport System (ECATS)

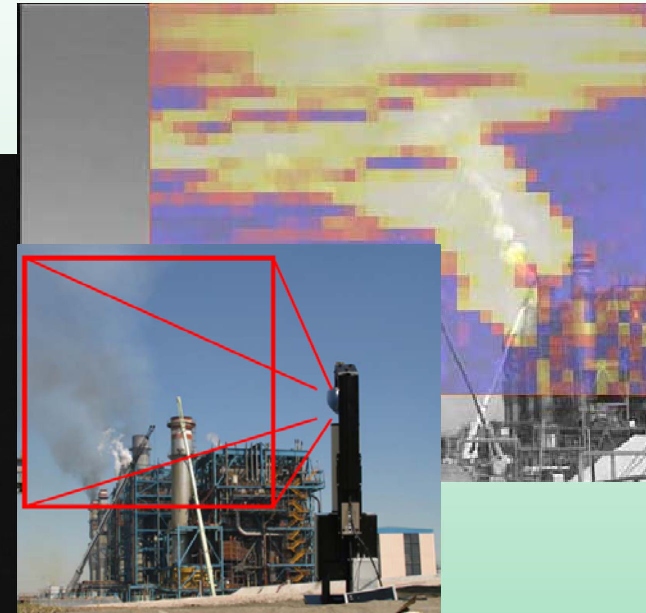


- *Improvement of airport air quality: aircraft emissions (data base of EI, influence of altitude upon emissions), inverse dispersion modelling for quantification of emission rates, data base for AAQ modelling – heat island effects*

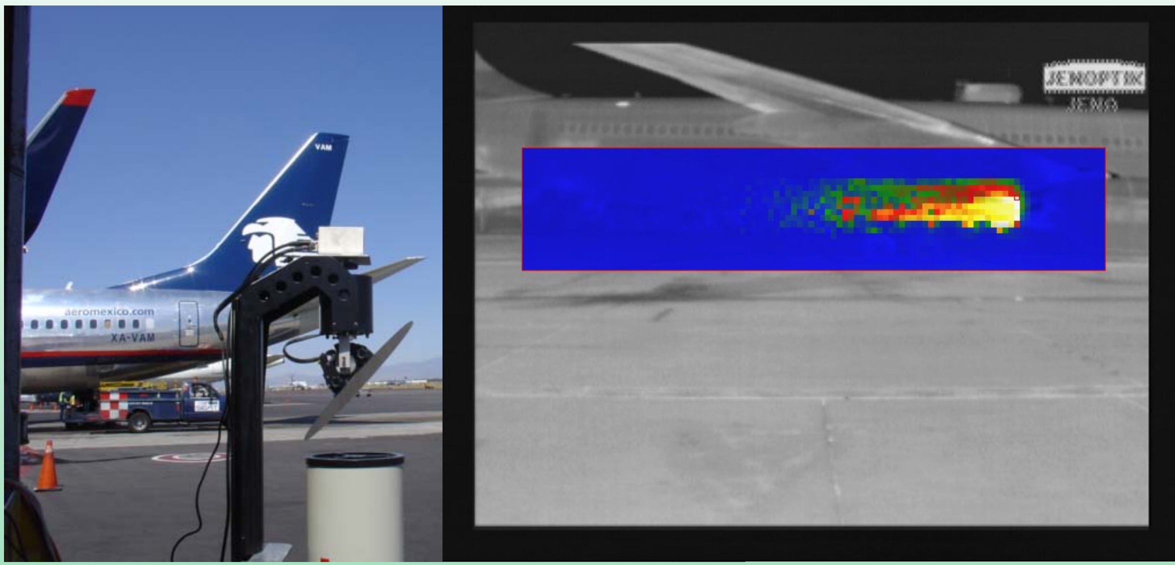


- *Assessment of mitigation & abatement strategies*
- *Cooperation with authorities and end users (Coordination action: Aircraft Emissions and Reduction Technologies)*

Improvement of measurement technique for detection of emission indices: Scanning Infrared Gas Imaging System



Application together with UNAM



Flores-Jardines, Edgar: Turbine exhausts monitoring with Fourier Transform Infrared emission spectroscopy. Dissertation zur Erlangung des Doktorgrades der Naturwissenschaften / Caracterización de las emisiones de turbinas de avión usando espectroscopía FTIR pasiva con un sistema de visualización (Dr. rer. nat.), Centro de Ciencias de la Atmosfera, Universidad Nacional Autonoma de Mexico, Mexico City, 2007

Calibration method

Instrumental line shape determination in MAPS:
Checking the correct optical alignment of FTS

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Airport Mexico City

Co-operations

UNAM, Michel Grutter: Remote sensing aircraft and power plant emissions; Agustin Garcia: ICAROS platform Mexico

University of Technology Hamburg-Harburg, Roland Harig: Improvement of remote sensing techniques

Vaisala, Christoph Münkel: Remote sensing MLH

JRC, Denis Sarigiannis, Alberto Gotti: ICAROS platform

UFZ, Ulrich Franck: ICAROS platform / RHM

BUW, Peter Wiesen: Air chemistry / ECATS

Discussion and conclusions

Development of a Super Site Mexico City:

Integration of ceilometers, passive DOAS, active DOAS, passive/solar FTIR, radiometers (AERONET), SODAR, in situ

- Vertical column densities of NO_2, SO_2, O_3 and CO as well as GHG
- Near-surface horizontal column densities of NO_2, NO, SO_2, O_3 and CO
- Altitude profiles of aerosol backscatter intensities near 1 µm: continuous aerosol and MLH information
- Near-surface concentrations, column densities and MLH
- Wind profiles for transport investigations
- Determination of relation between near surface PM concentrations and AERONET atmospheric optical depth with MLH measurements
- Spectral resolved atmospheric radiation in the UV/vis: information about optical characteristics of aerosols as well as particle diameters and composition

Outlook

Joint interpretation of the integrated measurements

Validation of modelling in different scales

Application of remote sensing techniques and inverse dispersion modelling for improvement of emission inventories

Up-scaling and down-scaling of fluxes near the surface:

- Determination of fluxes at the scale of emission inventories
- Influence of emissions upon ambient air in the higher scale

Background

Tools are needed for the execution of the European Air Quality Framework Directive 96/62/EC and its daughter directives:

12-monthly air pollution maps with a spatial resolution of 200 m^2 are required

Tools for this task can be meso-/ micro-scale model systems

Validation of these model systems is necessary: data bases

Operational instruments for air pollution monitoring should be used: monitoring concepts, monitoring sites

Atmospheric influences and local variability of air pollution close to a motorway in an Alpine valley during winter

Typical weather phenomena are the main factor for the observed pollution burden

NO_2 concentration levels are a matter of concern: annual mean values and exceedances of the half-hourly threshold in winter

Increased NO_2/NO_x ratio related to enhanced NO_2 emissions from road traffic in consequence to fleet composition and emission changes

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).

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Up-Scaling of N_2O flux measurements using a big tent

Tent of 500 m^2 for collection of soil emissions

N_2O concentration measurements by path-averaged FTIR

N_2O-Emissions enhanced during lower soil humidity and lower ground water level

Schäfer, K., Emeis, S., Jahn, C., Wiwiorra, M.: Emissionsmessungen von N2O an der Bodenoberfläche auf einer Skala von 100 m. In: VDI-Bericht „Neue Entwicklungen bei der Messung und Beurteilung der Luftqualität“ 2040, (2008).