Remote sensing and in situ instruments for air pollution and emissions

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Background
Problems and solutions
Measurement techniques
Measurement results
Improvement of measurement technique
Airport emissions - inverse dispersion modelling

ECATS, Spring School & Research Colloquium, 12 March 2007, MMU Manchester

Motivation

• Airport air quality is not well known because emission inventories are estimated only

• On airports, aircraft engines are one of the major sources for air pollutants

• Emission indices of ICAO* are used to calculate aircraft emissions: 4 different thrust levels – Idle, approach, climb out, take off (LTO cycle)

=> Applicability of ICAO data must be shown with measured data, but not yet done

*ICAO: International Civil Aviation Organization

Methods

- Passive remote sensing using FTIR-spectroscopy (K300, SIGIS) for determination of emission indices of one single engine

- Concentration measurement in the plume with FTIR & DOAS

- Determination of emission indices

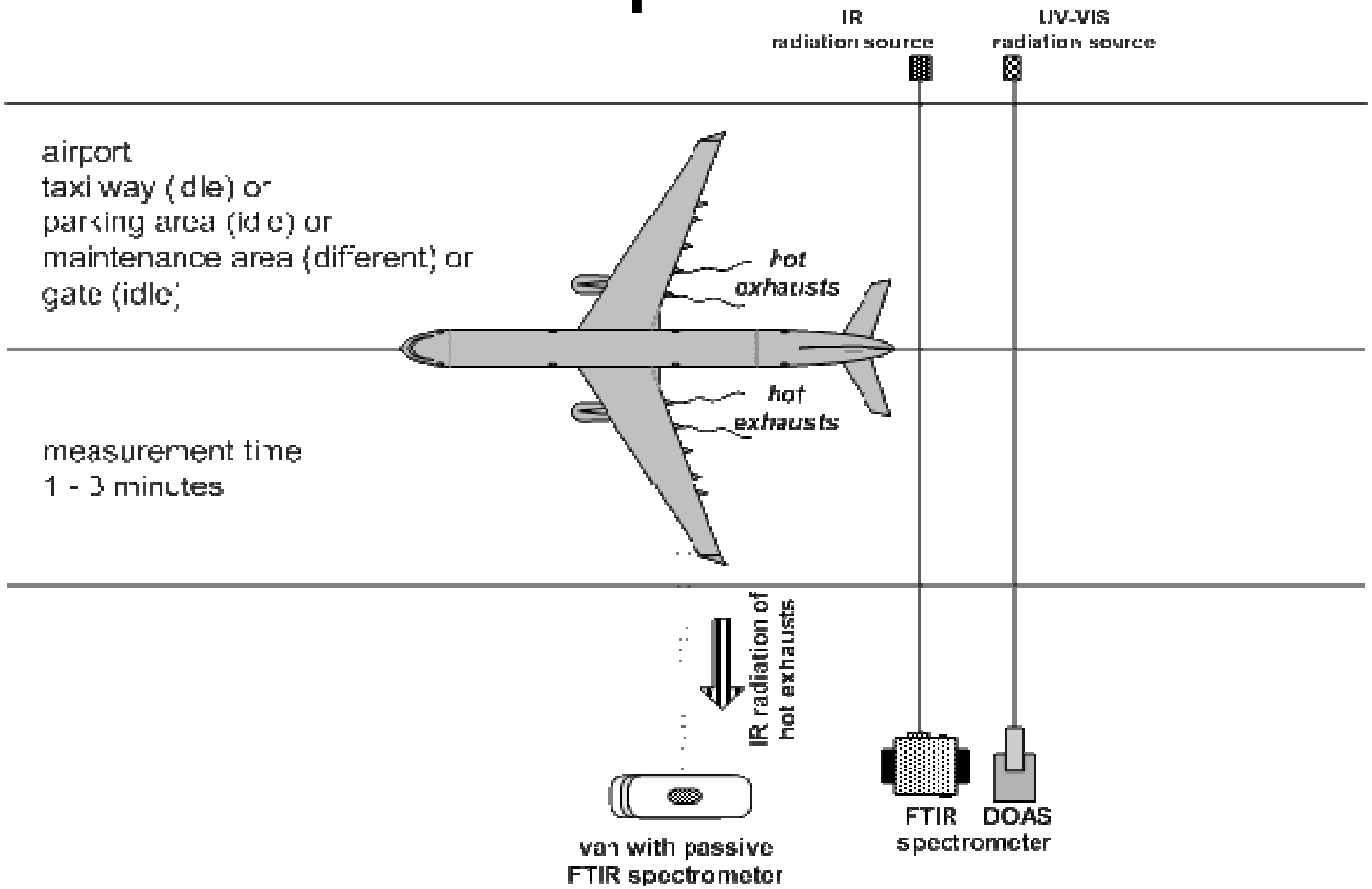
- Inverse modelling to estimate multiple sources

Measurement – Set up

- Open path measurements across a taxiway

- Detailed observations of aircraft movements

- Potentially other measurement devices for passive FTIR or Inverse Modelling



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.), difference to background**

Theoretical emission index of CO_2: calculated from stoichiometric combustion of kerosene to be 3,159 g/kg

EI (NO_x) = EI (NO and NO_2) is related to the mass of NO_2: EI (NO) x 46/30

Measurement – Instrumentation

FTIR spectrometry with a spectrometer from Kayser Threde and the use of glowbars as IR-source

DOAS from Opsis in monostatic configuration with retroreflectors

Measurement Locations

Airport Zurich Kloten (ZRH)

Airport Paris Charles de Gaulle (CDG)

Vienna

Measured Pollutants by FTIR and DOAS

Name		Comment
CO	Carbon monoxide	very good, passive and active
CO_2	Carbon dioxide	very good, passive and active
H_2O	Water	high background, passive/active
HCOH	Formaldehyde	good
C_2H_4	Ethene	very good
C_2H_2	Ethine	good, interferences to CO_2 & H_2O
CH_4	Methane	difficult, passive and active
C_3H_6	Propene	good, low concentrations
C_4H_6	Butadiene	good, low concentrations
N_2O	Nitrous oxide	difficult, passive and active
NO	Nitrogen oxide	very good, passive and active
NO_2	Nitrogen dioxide	very good

Measured components

CO_2

NO_2

Measured compounds:

- FTIR: CO, CO_2 – simultaneous
- DOAS: NO, NO_2 – one after another

Averaging temporal interval: ~ 3 Minutes

CO

NO

Measurements at airports were performed up to now during:

- **run up tests of aircraft engines (Berlin, Oberpfaffenhofen, London-Heathrow in 1999 and 2000, Frankfurt/Main in 2000, Vienna-Schwechat in 2001, Munich 2000 - 2004)**
- **start up and idle thrust of the engines after finishing all services at the airport gate or other positions (Frankfurt in 2000, London-Heathrow in 2001 and 2004, Zuerich in 2004, Paris CDG in 2004 and 2005, Budapest in 2004 and 2005)**
- **extra stop of the aircraft on a taxi way with engines at idle thrust (Vienna-Schwechat in 2001 and 2005)**

Data from the aircraft about main engines and APU:

- engine data (type, diameter of nozzle exit, age etc.)
- power setting in % N1
- fuel flow (for use of measurement results in emission models)
- EGT (for comparison with certification data, published by ICAO)

These data were collected by the co-operating airlines

- Austrian Airlines Group (AUA)
- British Airways (BA)
- Deutsche Lufthansa (DLH)
- SWISS

Measured engines up to now

Engine Type	Nozzle diameter	Usage
CFM56-3B1	115 cm	Civil, med. range
CFM56-3B2	115 cm	Civil, med. range
CFM56-5A1	65 cm	Civil, med. range
CFM56-5B1P	66 cm	Civil, med. range
CFM56-5B1/2	66 cm	Civil, med. range
CFM56-5B1/2P	66 cm	Civil, med. range
CFM56-5B2	66 cm	Civil, med. range
CFM56-5B3P	66 cm	Civil, med. range
CFM56-5B4/2	66 cm	Civil, med. range
CFM56-5B4/2P	66 cm	Civil, med. range
CFM56-5C2	140 cm	Civil, long range
CFM56-7B22/2	68 cm	Civil, med. range
CFM56-7B27	68 cm	Civil, med. range
GE CF 34-3A	43 cm	Civil, short range
GE CF 34-3A1	43 cm	Civil, short range
GE CF 34-3B	43 cm	Civil, short range
GE CF 700-2D2	44 cm	Civil bus. jets
GE90-85B	150 cm	Civil, long range
JT8D-15	108 cm	Civil, med. range
JT8D-217C	95 cm	Civil, med. range
PW123B	43 cm	Civil, short range
PW150A	45 cm	Civil, short range
RB211-524D4	90 cm	Civil, long range
RB211-524D4X	90 cm	Civil, long range
RB211-524H2	170 cm	Civil, long range
RB211-535C	84 cm	Civil, med. range
RB211-535C-37	84 cm	Civil, med. range
RB211-535E4	145 cm	Civil, med. range
RB211-535E4-37	145 cm	Civil, med. range
RR M45H	50 cm	Civil bus. jets
RR-TAY MK 620	90 cm	Civil, short range
PW4168A	99 cm	Civil, med. range
V2500-A1	124 cm	Civil, med. range
APS2000	35 cm	APU
APS3200	35 cm	APU
GT CP85-98DHF	35 cm	APU
GT CP331-200/250	55 cm	APU
GT CP331-500	55 cm	APU
GT CP660-4	55 cm	APU
PW901A	55 cm	APU

Mean values of emission indices of APU

bdl: below detection limit i.e. a signature in the measured spectra cannot be inverted

Extrema as minimum and maximum value of all measured data are given in brackets

Aircraft	Number of aircraft	APU type	EI CO [g/kg]	EI NO [g/kg]	EI NO_x [g/kg]
A320-200	1	APS3200	2.9 ± 0.30 (2.5 -3.1)	0.3 (bdl - 0.8)	0.4 (bdl - 1.3)
B737-406	1	APS2000	2.7 ± 0.29 (2.5 - 3.1)	1.7 ± 0.34 (1.4 - 2.2)	2.5 ± 0.53 (2.3 - 3.3)
B737-800	1	GTCP85-98DHF	13.9 ± 1.07 (12.4 - 15.1)	0.8 ± 0.07 (0.7 - 0.8)	1.2 ± 0.11 (1.0 - 1.3)
B747-236	1	GTCP660-4	2.2 ± 0.32 (1.9 - 2.4)	0.1 (bdl - 0.3)	0.2 (bdl - 0.4)
B747-400	3	PW901A	11.6 ± 3.98 (5.5 - 18.0)	1.1 ± 0.37 (0.6 - 1.8)	1.7 ± 0.56 (0.8 - 2.7)
B747-436	8	PW901A	12.4 ± 5.26 (0.5 - 31.3)	0.6± 0.75 (bdl - 2.7)	1.0 ± 1.14 (bdl - 4.2)
B757-236	3	GTCP331-200/250	1.1 ± 0.41 (0.2 - 1.7)	2.6 ± 0.79 (0.4 - 3.6)	3.9 ± 1.21 (0.6 - 5.5)
B777-236	3	GTCP331-500	1.3 ± 0.63 (0.5 - 2.2)	3.0 ± 0.87 (bdl - 4.5)	4.6 ± 1.33 (bdl - 6.9)

Comparison of measurement results in different parts of the exhaust plume and with ICAO databank

Aircraft	No for CO	EI CO [g/kg]				No for NO_x	EI NO_x [g/kg]			
		FTIR Em. spectr.	FTIR Abs. spectr.		ICAO		FTIR Em. spectr.	DOAS		ICAO
DHC 8Q	29	8.9	17.27		None	11	1.25	3.41		None
Fokker 70	20	23.1	32.33		24.10	24	0.3	2.08		2.50
RJ	15	38.27	23.16		42.60	15	1.0	2.64		3.82
MD80	5	10.3	28.32		17.84	5	Bdl	2.84		4.18
A320	50	41.7	40.72		30.07	40	0.95	2.76		4.35
A340	3	6.0	17.79		32.98	2	Bdl	1.83		4.23
B737	14	31.46	36.16		26.95	13	1.25	2.91		4.48
B747	9	23.6	25.45		15.03	7	0.3	2.93		4.56
B757	15	8.8	15.47		17.90	13	0.65	3.43		3.67
B767	3	7.3	25.09		11.75	3	-	3.18		4.09
B777	6	24.6	43.34		13.67	5	0.4	3.44		6.01

Summary

A lot of good data for Idle conditions

Comparison of results from passive with open-path FTIR measurements show differences around ±20 %

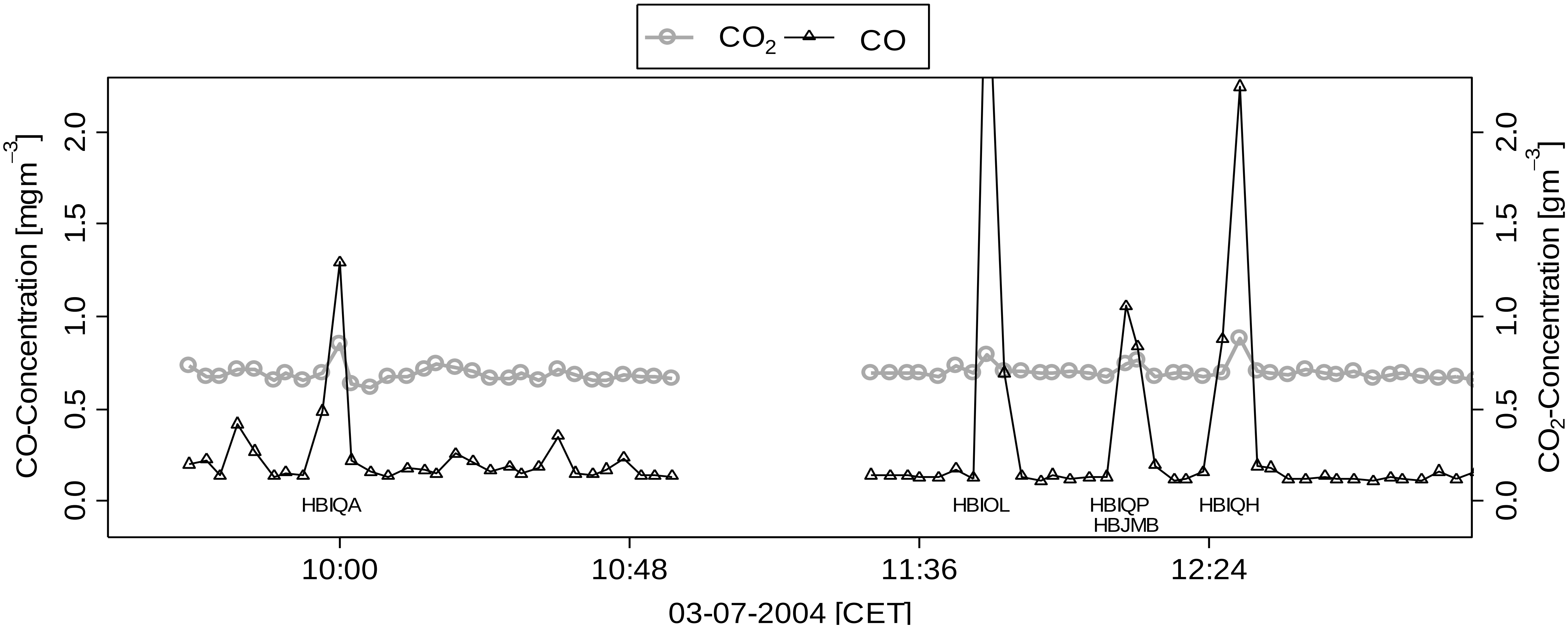
Slightly higher EI CO than ICAO

Lower EI NO_x than ICAO: approx -30 %

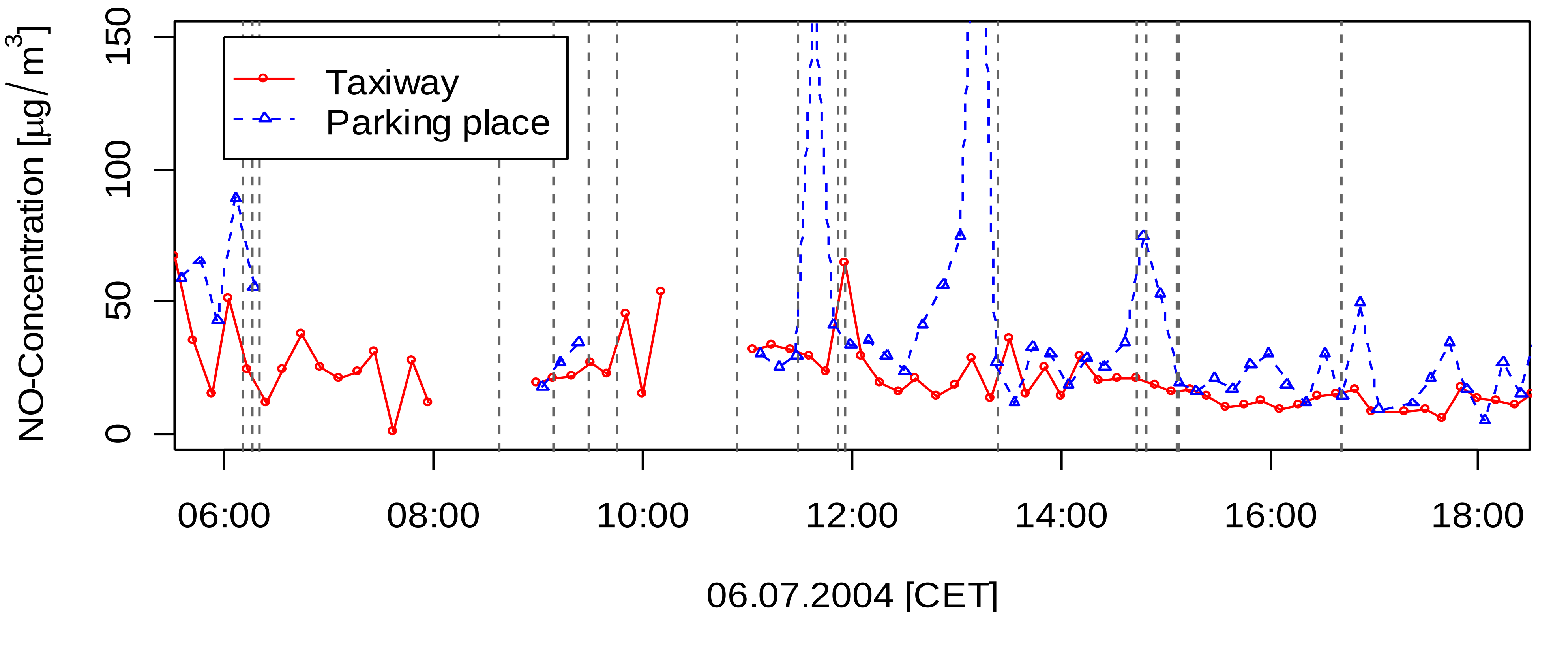
Idle during operational conditions unequal to ICAO definition

APU emissions cannot be neglected at airports

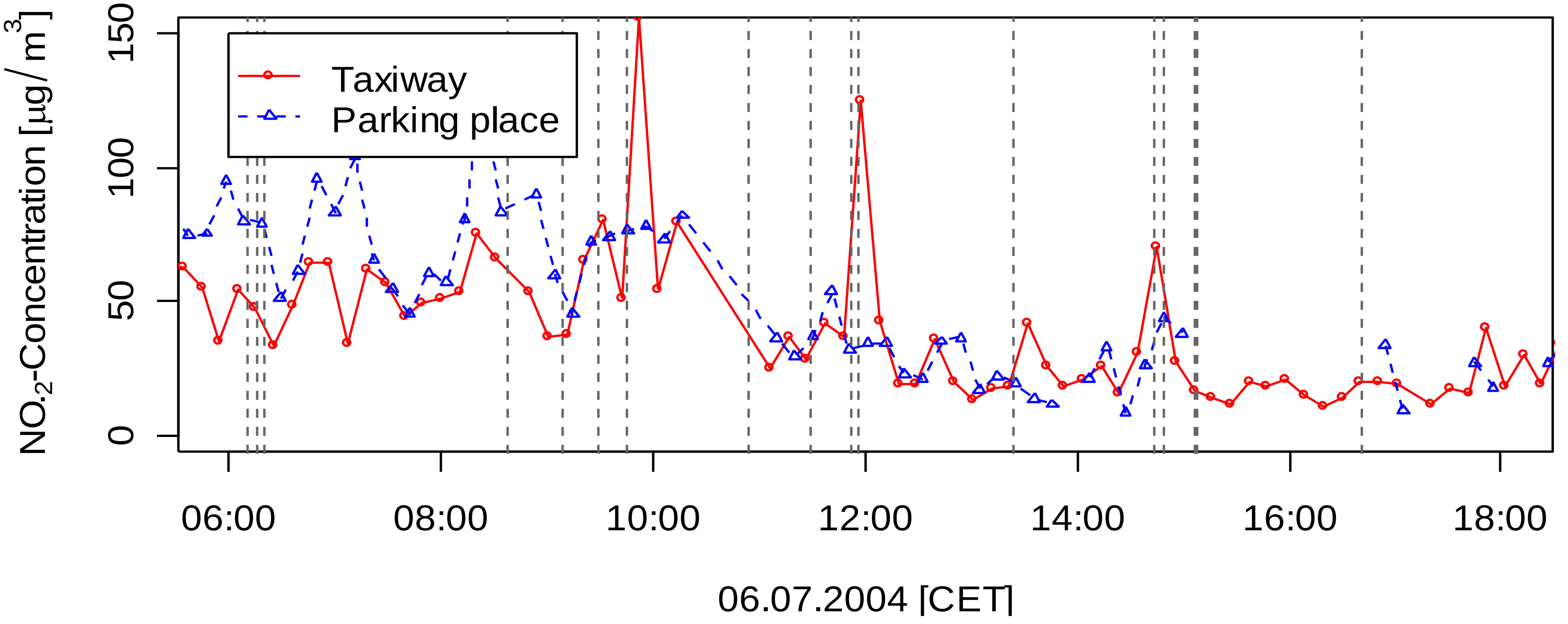
Measurement results



Measurement results



Measurement results



Results Vienna

Stopping aircraft for measurements at taxiway

Summer and winter campaign

Cooperation with University of Technology Graz:
Schäfer, K., Jahn, C., Sturm, P., Lechner, B., Bacher, M.: Aircraft emission measurements by remote sensing methodologies at airports. Atmospheric Environment 37, 37 (2003), 5261-5271

Summary

CO: more than 100 aircrafts, 36 different engines

NO_x: more than 100 aircraft, 24 different engines

Results Zurich

One measurement – one aircraft

One engine type – several emission measurements

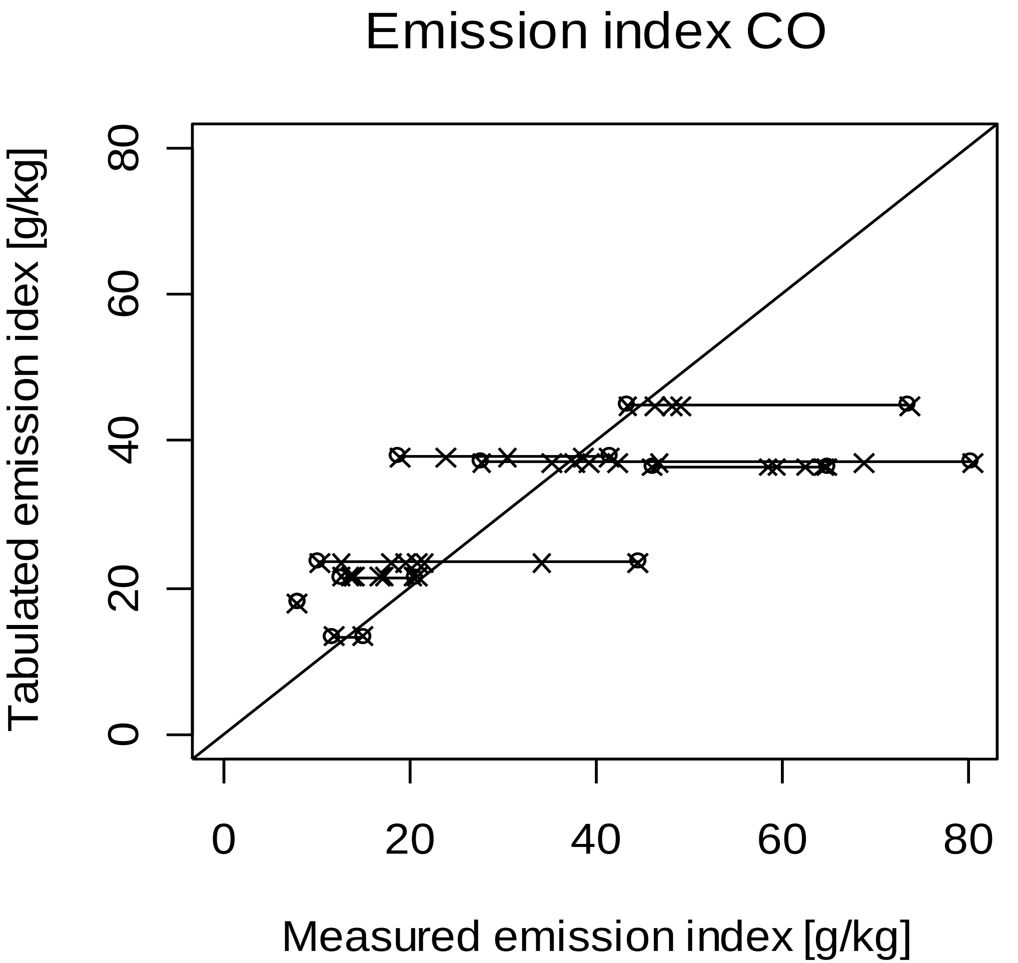
⇒One ICAO value compared with multiple measurements

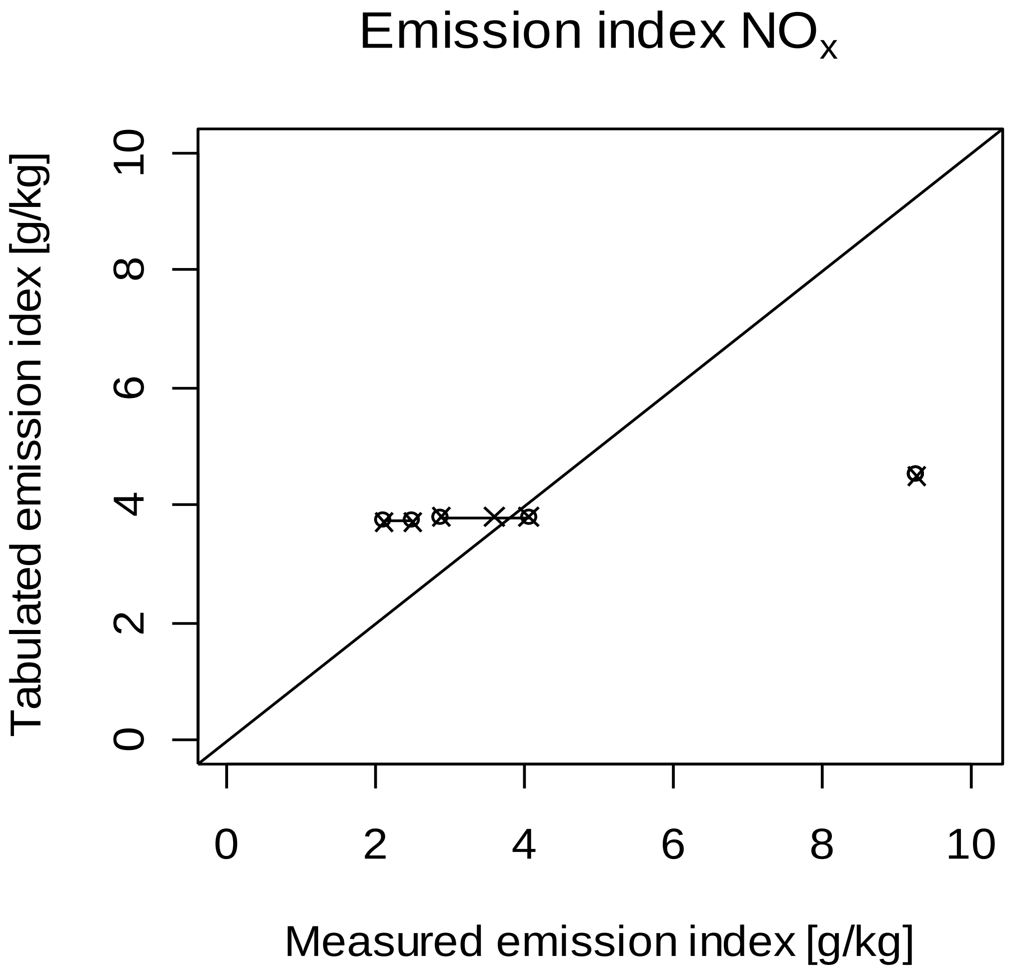
Summary

CO: 44 aircrafts, 8 different engines

NO_x: 6 aircraft, 3 different engines

Results Zurich





Results Paris CDG

One measurement – several aircraft

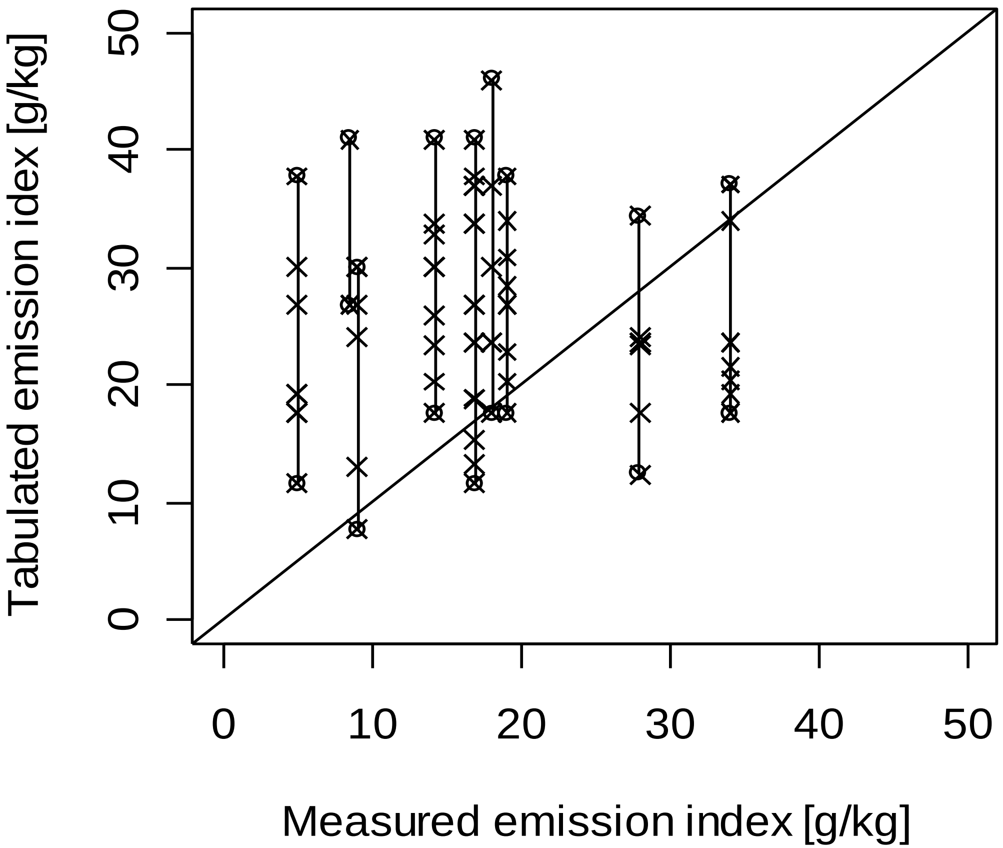
⇒One measured emission index – multiple ICAO values

Summary

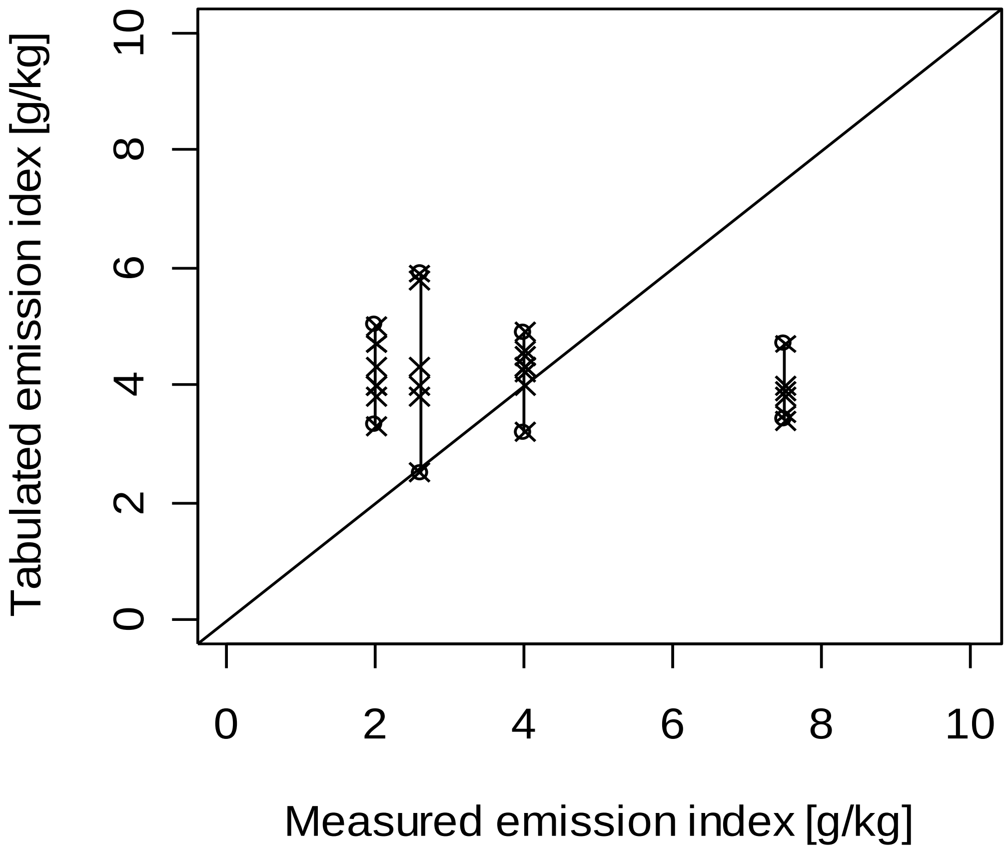
CO:	9 measurements,	4 – 18 aircrafts / measurement
NO_x:	4 measurements,	6 – 10 aircrafts / measurement

Results Paris CDG

Emission index CO



Emission index NO_x



Variability of data

The power settings of an aircraft control the emission characteristic

The power settings for the individual measurements is unknown

Other sources may influence single measurements

Conclusions

The presented method is a tool to determine emissions of a single aircraft

For better conclusions, more measurements are necessary for a statistical treatment of the data

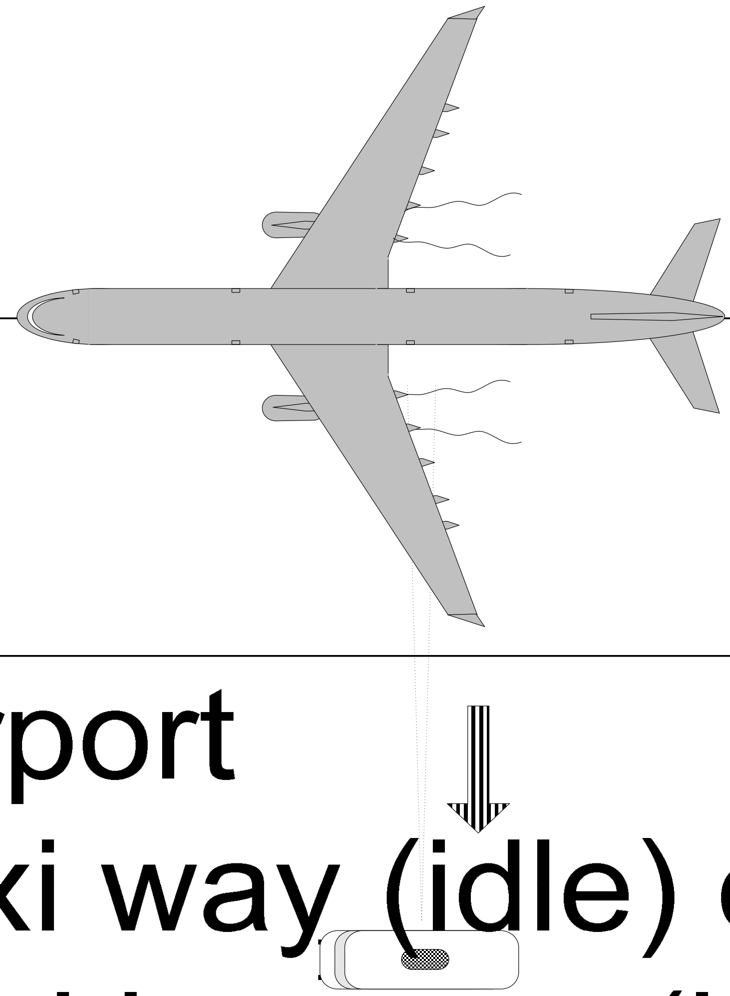
Emission indices for idle conditions are different under in-use conditions in comparison to ICAO data base: EI(CO) higher, EI(NO_x) slightly smaller

Improvement of measurement technique

Passive FTIR emission spectrometry has also the capability to determine the composition of hot exhausts but also the plume behaviour non-intrusively

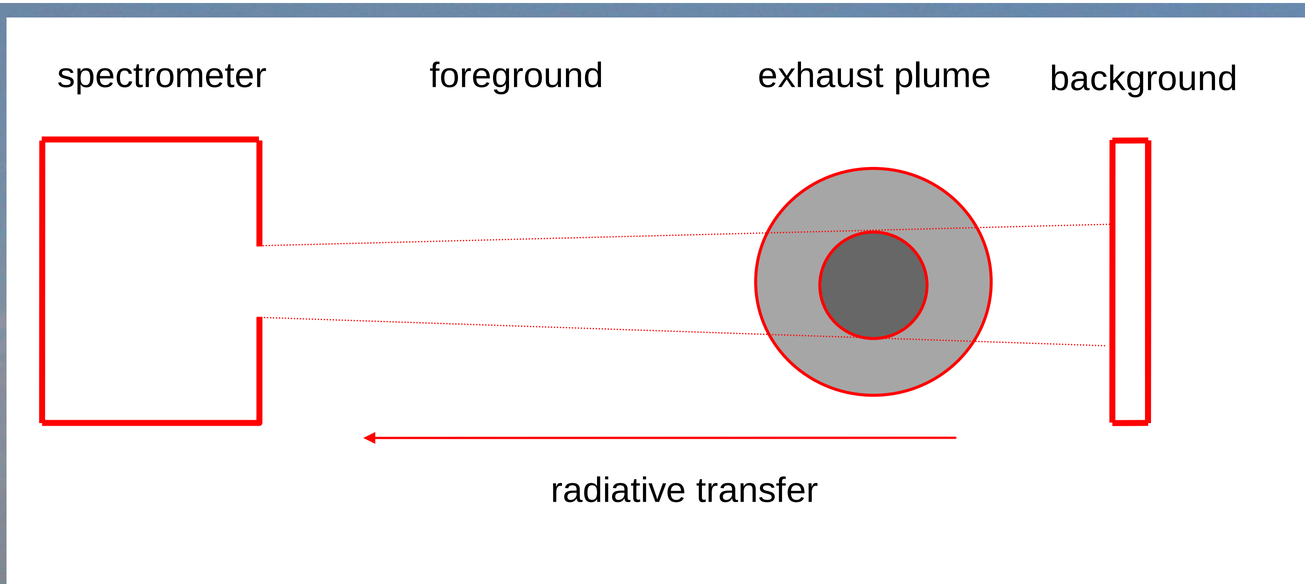
This is necessary because the measurements of composition are performed in different parts of the exhaust plume: at the nozzle exit, behind the aircraft

Are there inhomogeneous distributions along the plume i.e. temporal variations in the measurement volumes?



airport
taxi way (idle) or
parking area (idle) or
maintenance area (different)

Measurement principle



$$I = I_b \tau_p \tau_f + I_p \tau_f + I_f$$

$$\tau_{\Delta\nu}(L) = \left\{ \int_{\Delta\nu} \prod_{i=1}^{N} \exp[-k_i(\nu) n_i L] d\nu \right\} \exp[-k_a(\Delta\nu) n_a L]$$

Instrumentation improved also to detect exhausts composition of aircraft on the ground nearly automatically

Spectrometer OPAG coupled with an IR camera giving an infrared image of the scenery so that a rapid selection of the hottest exhaust area is possible

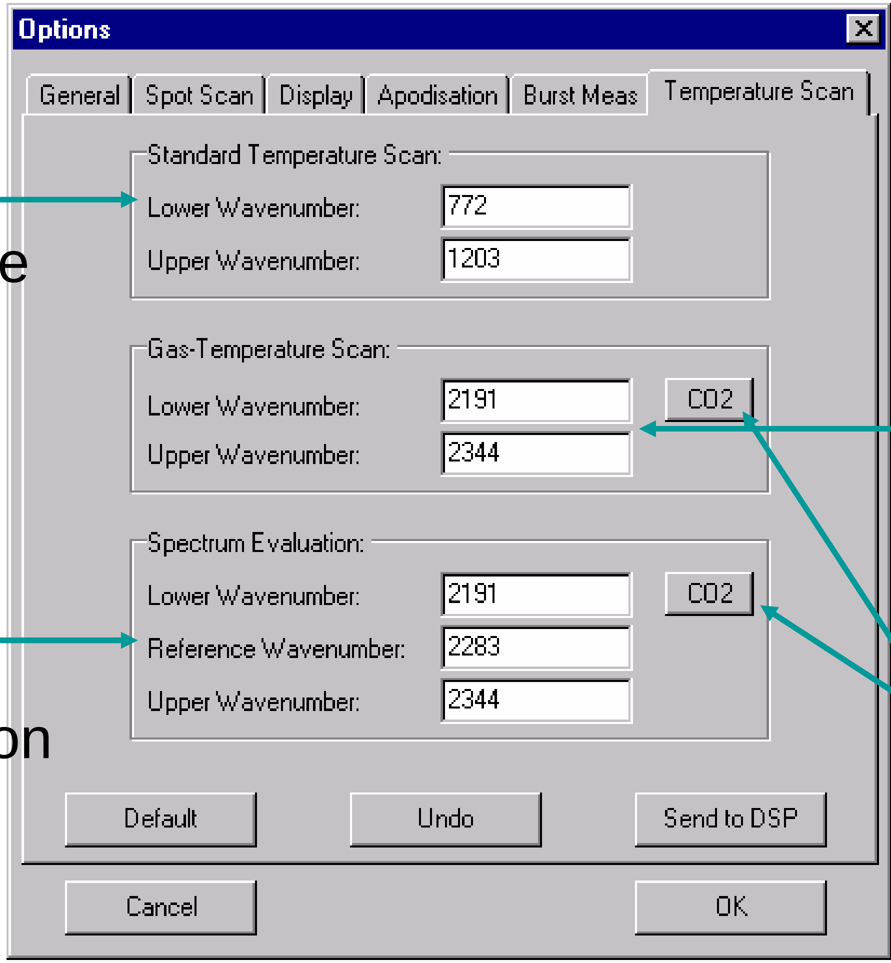
Imaging of the whole scenery behind the turbine exit or a part of the infrared camera image with the scanning mirror:

- **low-resolution spectra are measured and analysed in a spectral range which is sensitive for plume temperature**
- **software for real-time visualisation of the plume shape in this spectral range**

Scanning Infrared Gas Imaging System (SIGIS)

Spectral region for measurement of background temperature

Parameters for absorption and emission characterisation



Spectral region for measurement of gas temperature

Standard values for CO_2

Measurement results

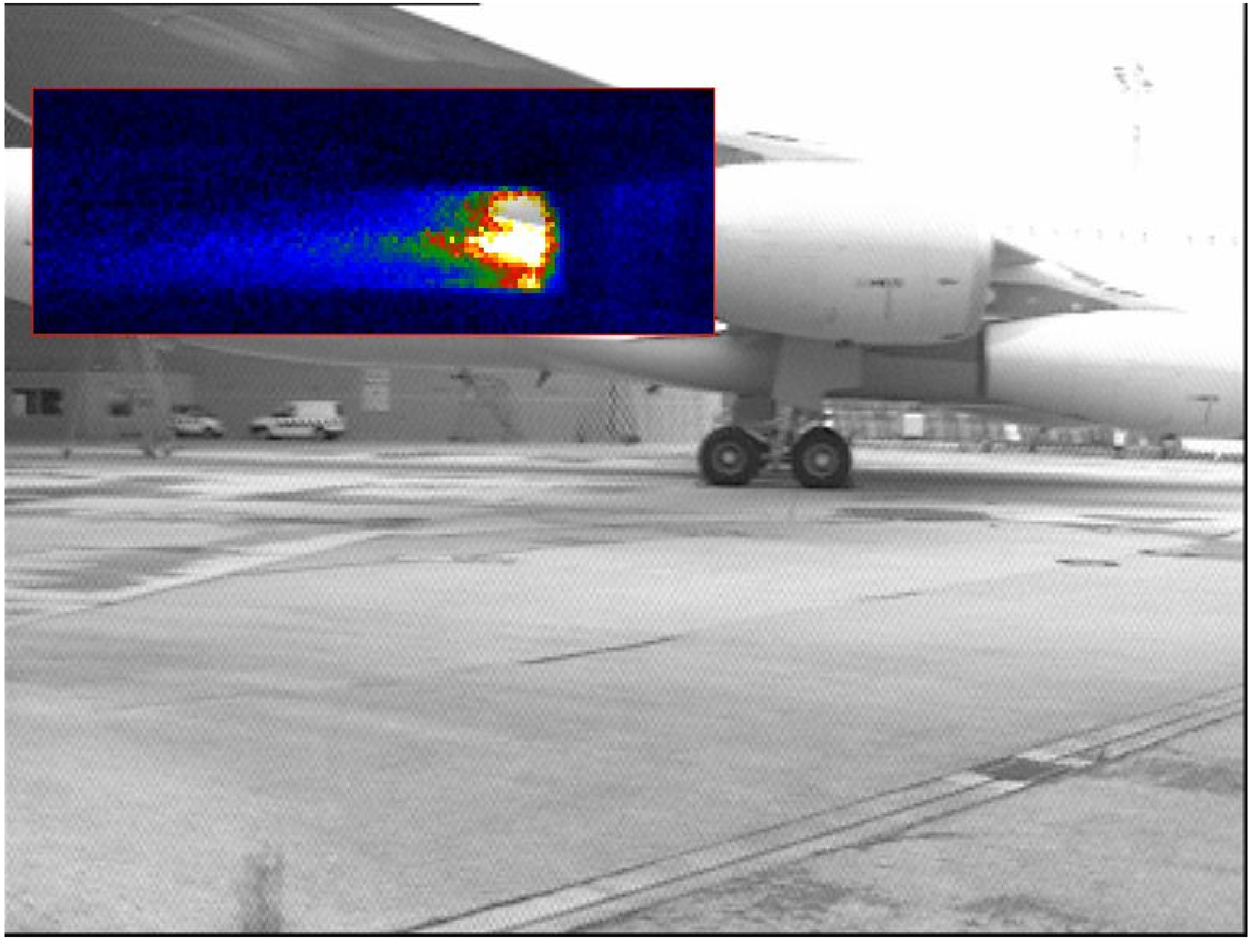
Aircraft at airport, APU: gas temperature mode

approximated plume diameter 2.5 m, length 5.2 m

APU: gas radiation mode (absorption / emission)

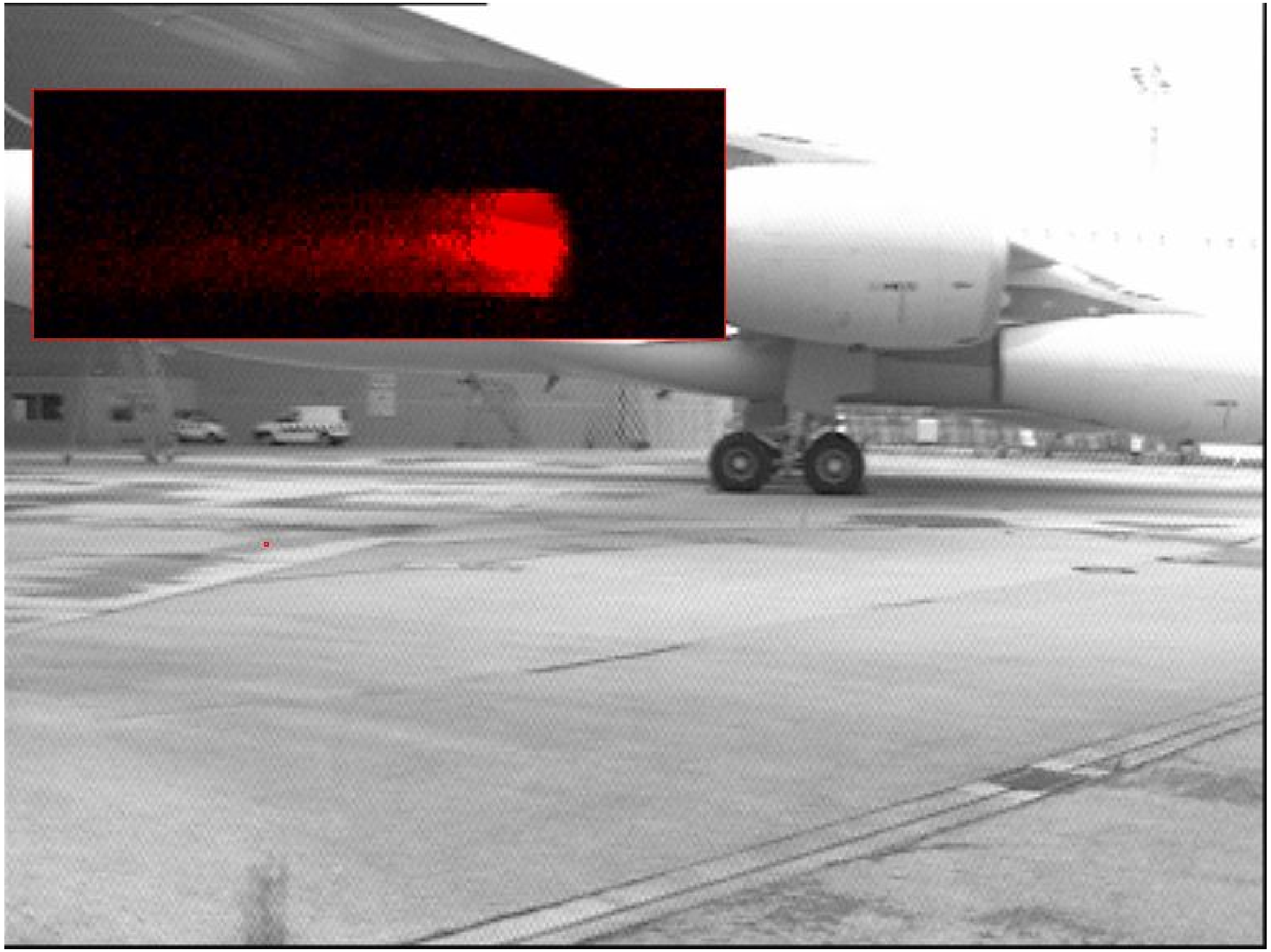
approximated plume diameter 2.8 m, length 5.5 m

Aircraft, main engine CFM56-5C2F: gas temperature mode asymmetry, approximated plume length 8.4 m



Main engine: gas radiation mode (absorption / emission)

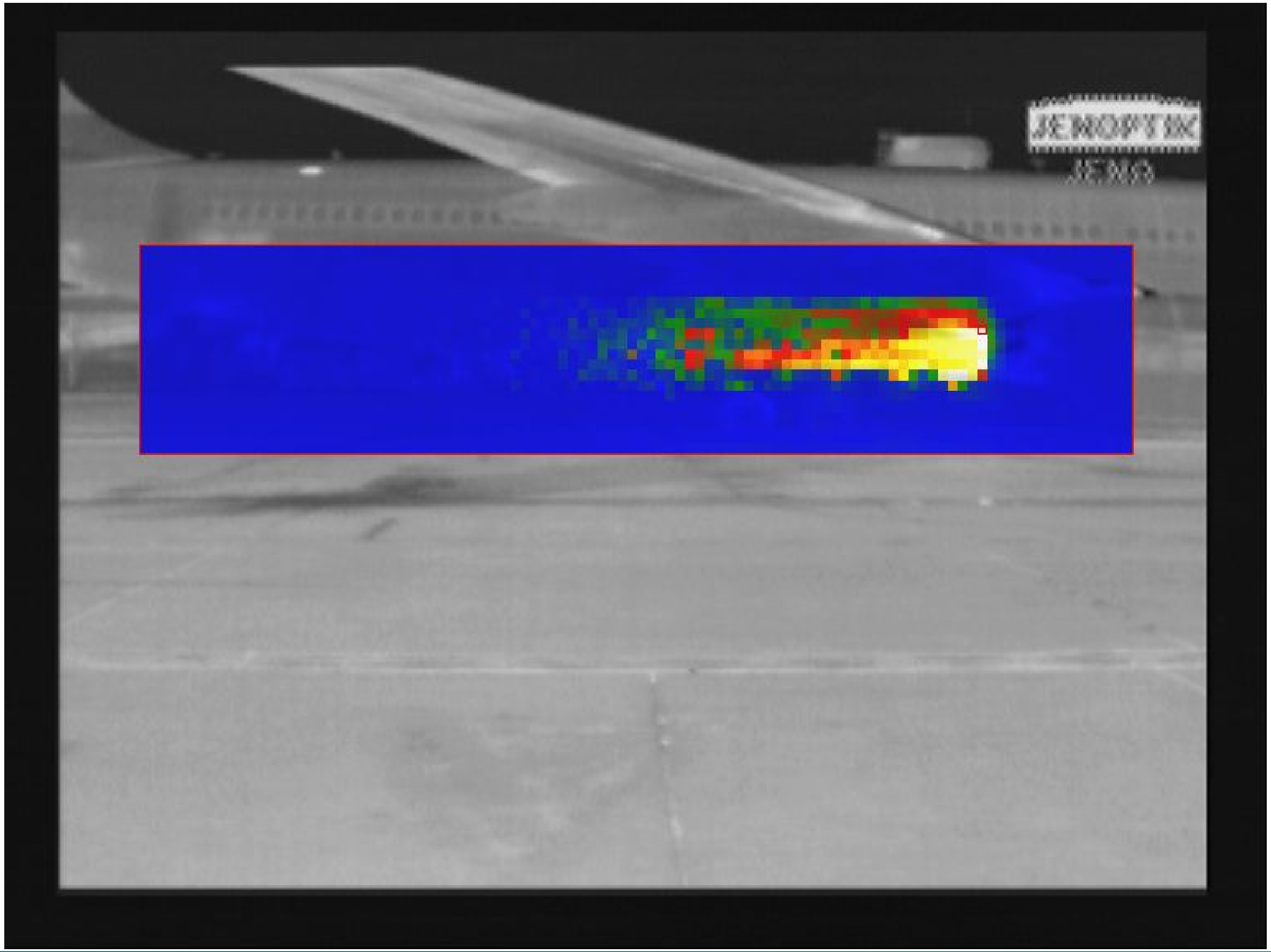
approx. length of hottest part 0.9 and 1.2 m, diameter 1.6 m



Aircraft, main engine PW4168A: IR camera picture

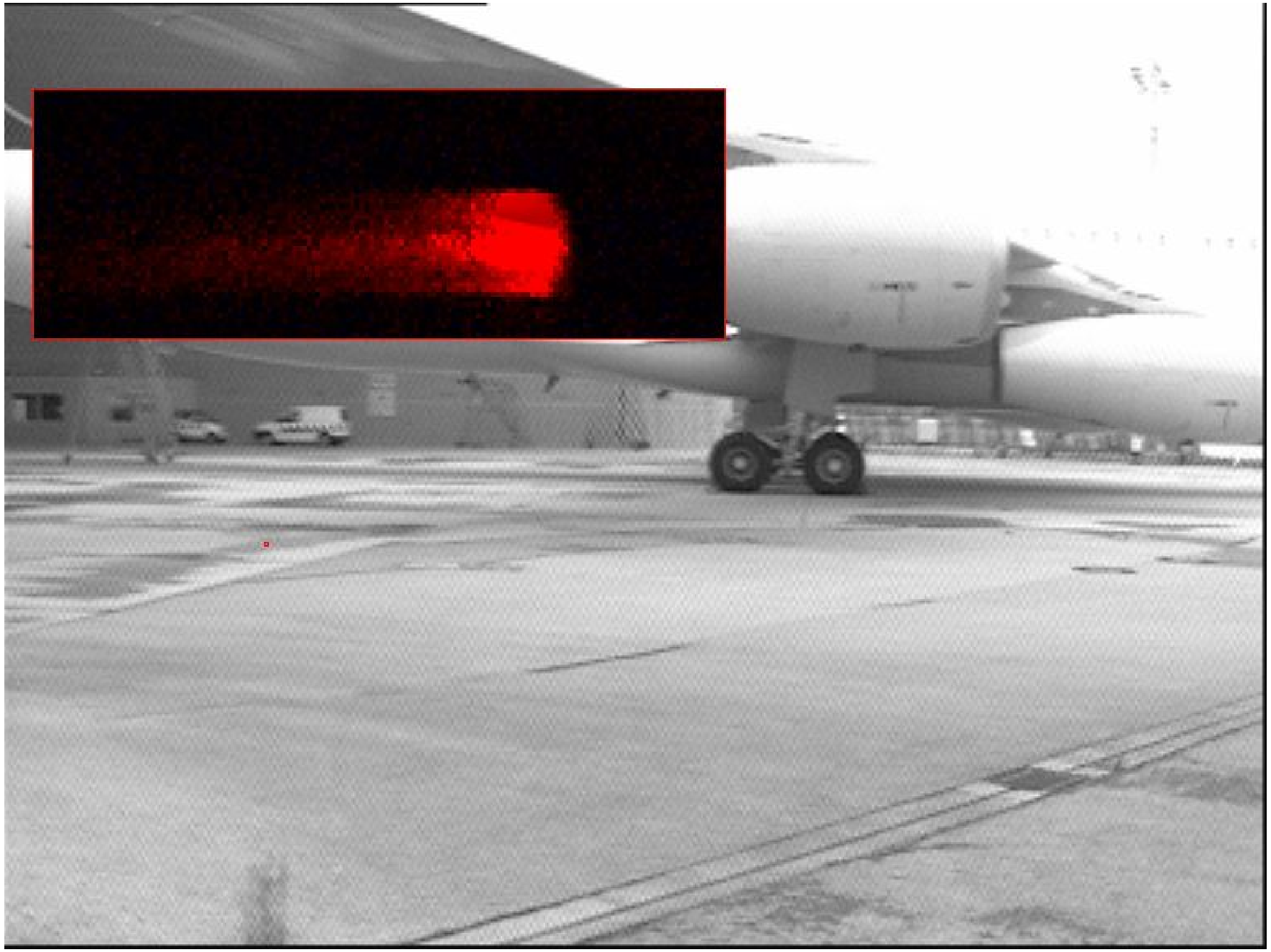
Main engine: gas temperature mode

approximated length 11 m, diameter 2.4 m



Main engine: gas radiation mode (absorption / emission)

approximated length of hottest part 3.8 m, diameter 1.4 m



Comparison of these different measurement methods

- **Operation of kerosene powered burner to apply FTIR emission spectrometry and intrusive methods**
  - **during the same time**
  - **at nearly the same exhaust gas volume**
- **Burner**
  - **nozzle exit diameter of 37 cm**
  - **power of about 150 kW**
  - **temperature of the exhaust inside the tube is about 270° C**
  - **fresh air pumped into the burner tube by a fan**
  - **calibration gases CO and NO (pure gases) in different amounts**
- **Sampling probe of the intrusive HORIBA PG-250 in the centre of the exhaust stream near the exhaust exit for measurements of CO_2, CO, NO, NO_2, UHC, SO_2 and O_2**

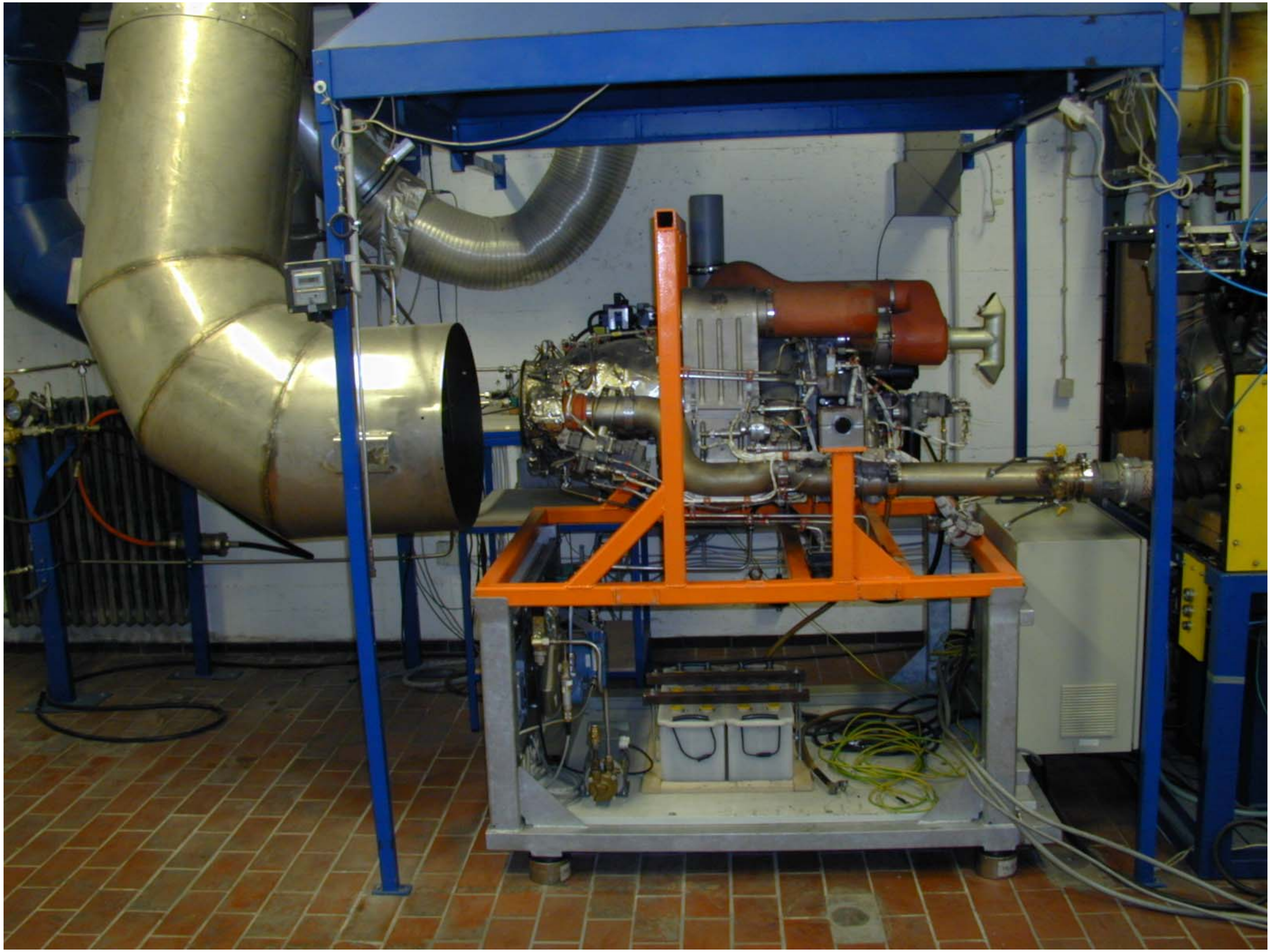
Results of comparison

- **Differences in the measured CO_2 data in the order of a factor of 2: influences of wind upon the plume temperature, plume shape and variation of concentration of CO_2 in the foreground**
- **Intrusive data in correspondence with the added CO plus the exhaust CO concentration**
- **Differences in CO between FTIR emission spectrometry and intrusive measurements in the order of 10 %**
- **FTIR emission spectrometry about 10 % lower for NO than the intrusive measurement results**
- **Intrusive measurement results about 20 up to 50 % lower than the added NO: formation of NO_2 from NO in the exhaust**

Second comparison of different measurement methods

- **Auxiliary Power Unit GTCP36-300 (Airbus A320) in the laboratory**
- **80 - 140 kg kerosene per hour**
- **Power 220 - 160 kW**
- **Pure CO added in different amounts**
- **DOAS and FTIR absorption spectrometry installed on the roof of the laboratory building across the exit of the chimney for turbine exhaust**
- **Passive FTIR and in situ measurement techniques installed in the laboratory between nozzle exit and chimney entrance:**

  problems with different sounding volumes



Results of comparison

- **Measurements of NO concentration at the exit of the chimney show clear dependence from APU power setting**

- **Comparison difficult sometime due to strong wind influence upon exhausts**

- **Deviations between NO and CO data of DOAS, FTIR and intrusive measurements less than ±20 %**

- **Problems with homogeneous mixing and chemical transformation of added gases (CO, NO) found in FTIR emission spectrometry and intrusive measurements behind the nozzle exit**

Airport emissions

Motivation

Airport air quality is influenced by traffic mainly

These are emissions from road traffic and aircraft

The most specific airport related part of these sources are obviously aircrafts

Major influence of aircraft on air quality, but also ground support equipment has a significant influence

Background

Emission sources on the airport can be subdivided into 5 parts: aircrafts, point sources, cars, ground support emissions and others (e.g.: painting, maintenance of aircrafts)

The strengths of these emissions usually are calculated from emission indices which were measured in test beds

Background

For NO_x and CO (UHC, smoke number) aircraft emission data exist

Data were measured in a test bed for each engine for four different thrust levels (7% Idle, 30 % Approach, 85 % Climb out, 100 % Take off) during new engine certification procedures

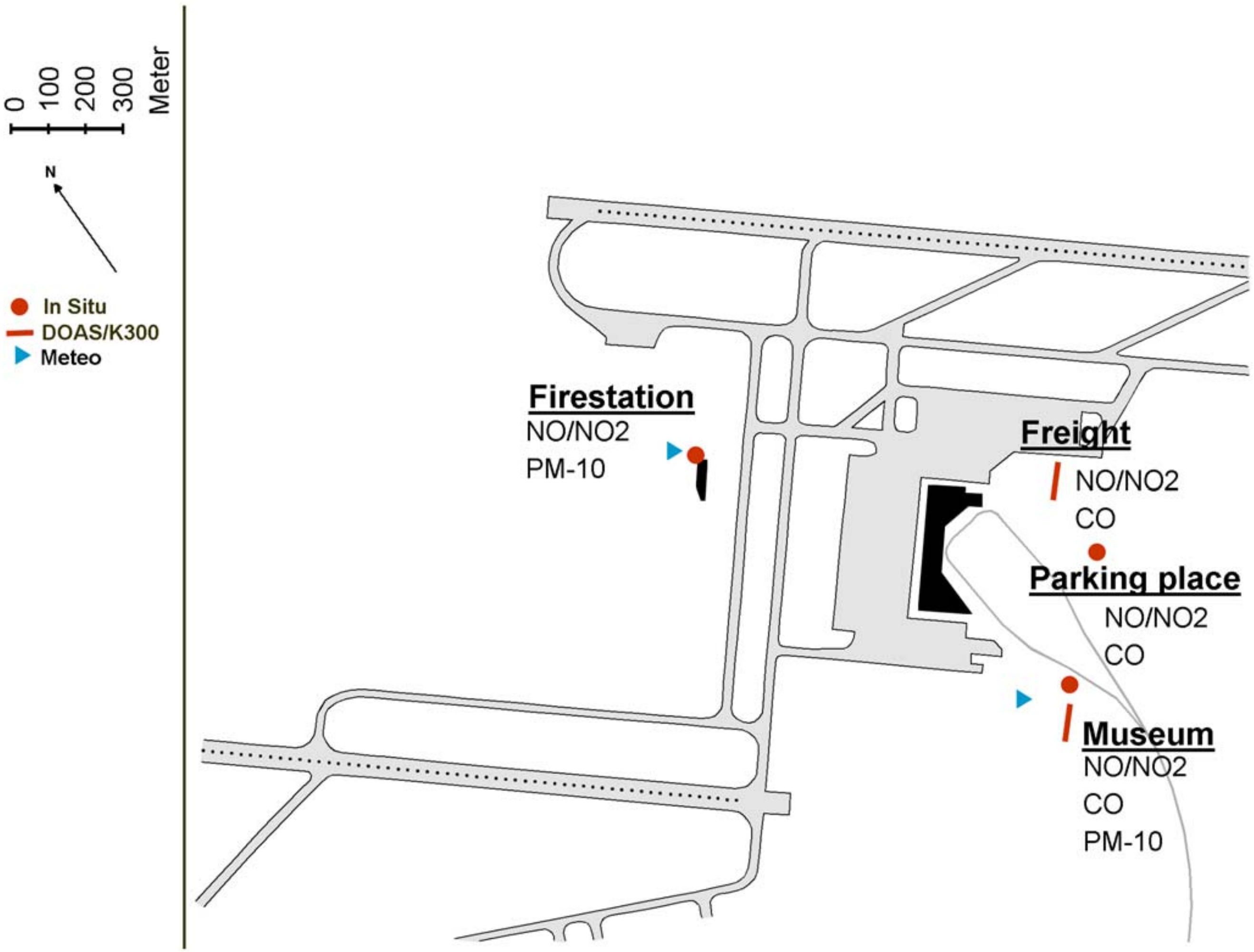
This is recommended by the International Civil Aviation Organization (ICAO)

Methodology

Two measurement campaigns were in Budapest

Measurement of air pollution (CO, NO_x, CO_2,O_3, PM10) at different locations should give information about concentration levels at the airport

With a combination of measurement and dispersion modelling an apportionment of emission rates for different sources with the means of inverse dispersion modelling is possible



$\underline{NO/NO_2}$
DOAS, TE42-95, TE42-96, AC-31M
<u>CO</u>
K300-1, K300-2, AL5001
<u>PM10</u>
FH62 I-R, FH62 I-N

Device name	**Measured components**	**Time resolution**
Weather station	Temperature Pressure Humidity Wind direction Wind velocity Global radiation	30 minutes
USA	Wind direction Wind velocity Turbulence parameter	10 seconds

In situ van (PM10, CH4/THC, O3, CO, NOX)
12 – 13 April: Museum
14 April: removal
15 – 27 April: Fire brigade

PM-10
12 – 27 April: Museum

In situ CO
18 – 27 April: Parking place

In situ NOx (Nummer 95)
13 April: Museum
14 April: removal
15 – 18 April: Fire brigade
18 April, 15:00: removal
18 – 27 April: Parking place

In situ NOx (Nummer 96)

13 April: Museum
14 April: removal
15 – 16 April: Fire brigade
16 April, 13:35: removal
16 – 27 April: Museum

K300-1 (CO_2, CO, N_2O, CH_4)

13 – 26 April: Museum

K300-2 (CO_2, CO, N_2O, CH_4)

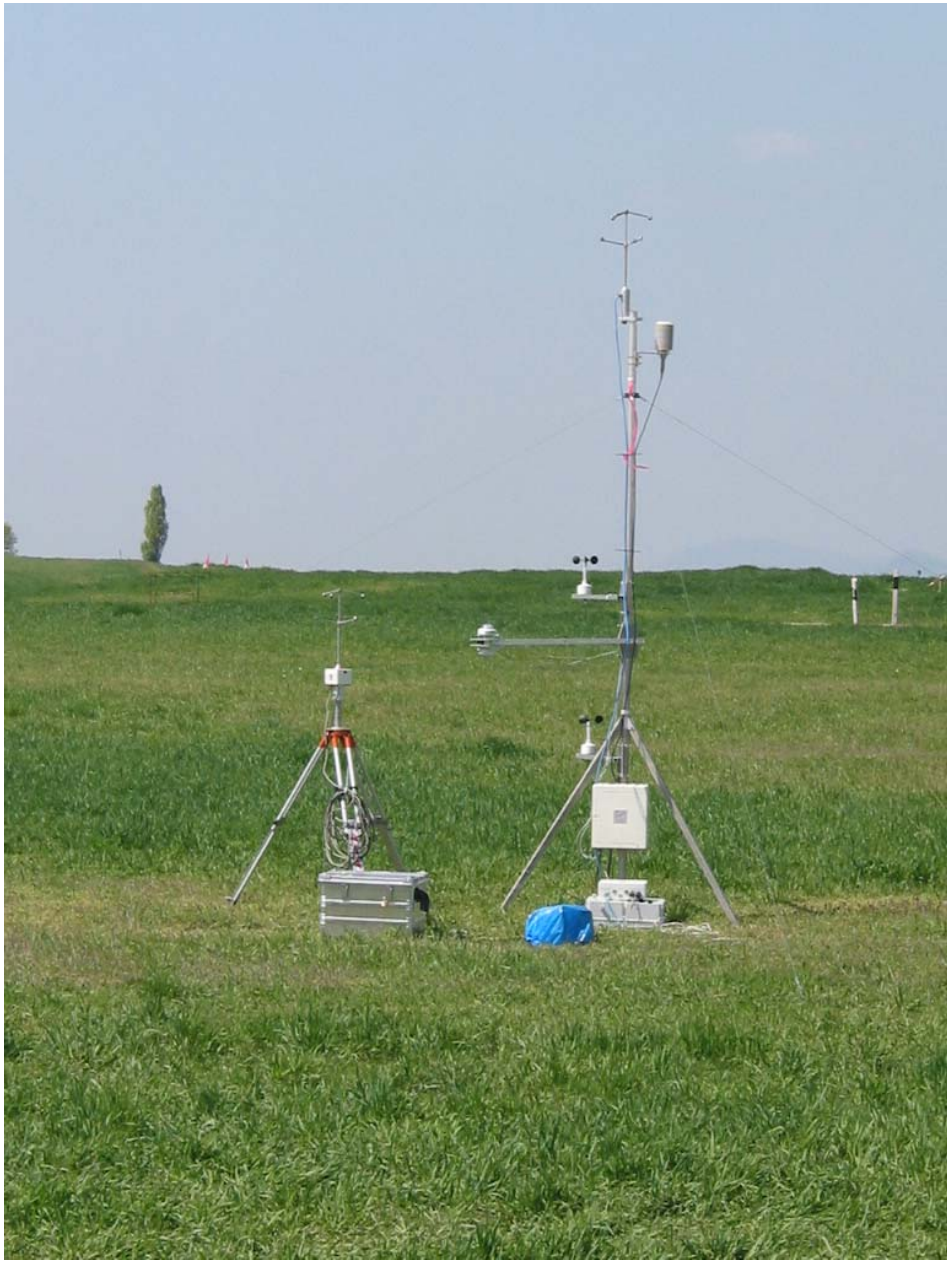
12 – 13 April: Museum
18 – 26 April: VIP place

DOAS (NO, NO_2)

12 – 14 April: Museum
18 – 26 April: VIP place


MAN
Institut
Atmosphärische
Umweltforschung
Garmisch-Partenkirchen
Messung der Emission und Immission von
Luftschadstoffen mit Fernerkundung


Messung der Emission und
von Luftschadstoffen mit
KA J 948
Thermo




WESTFALIA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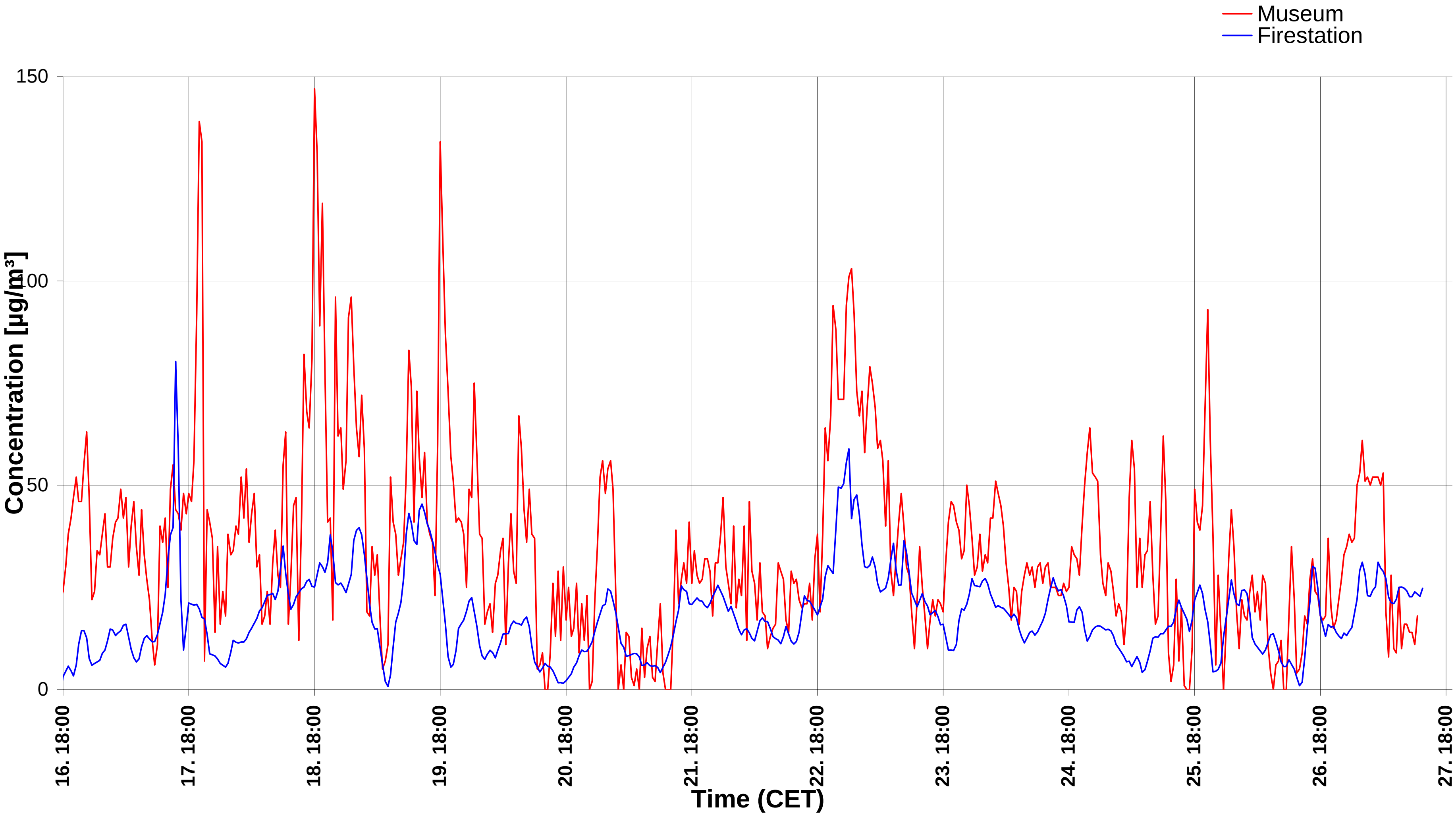
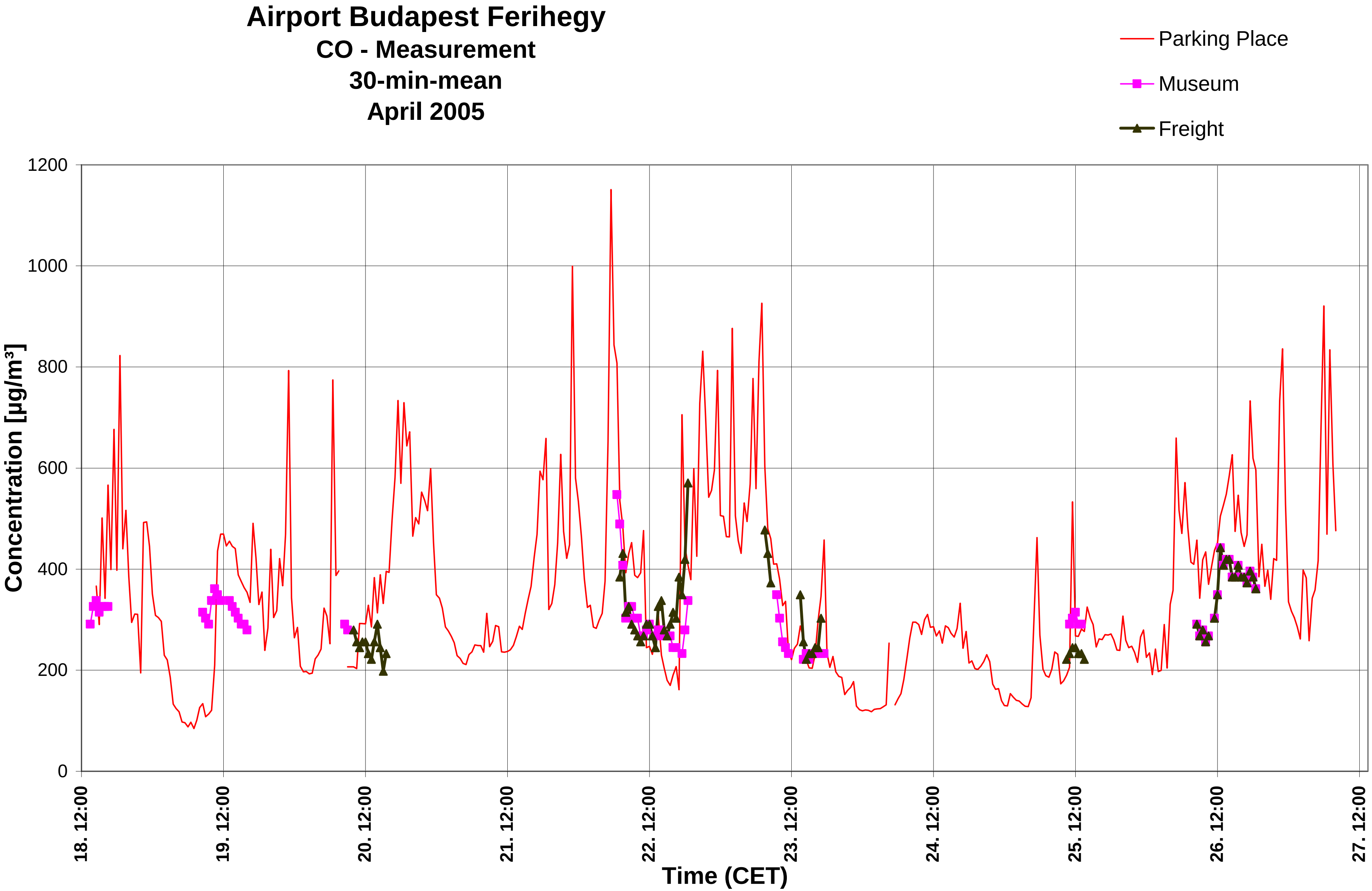
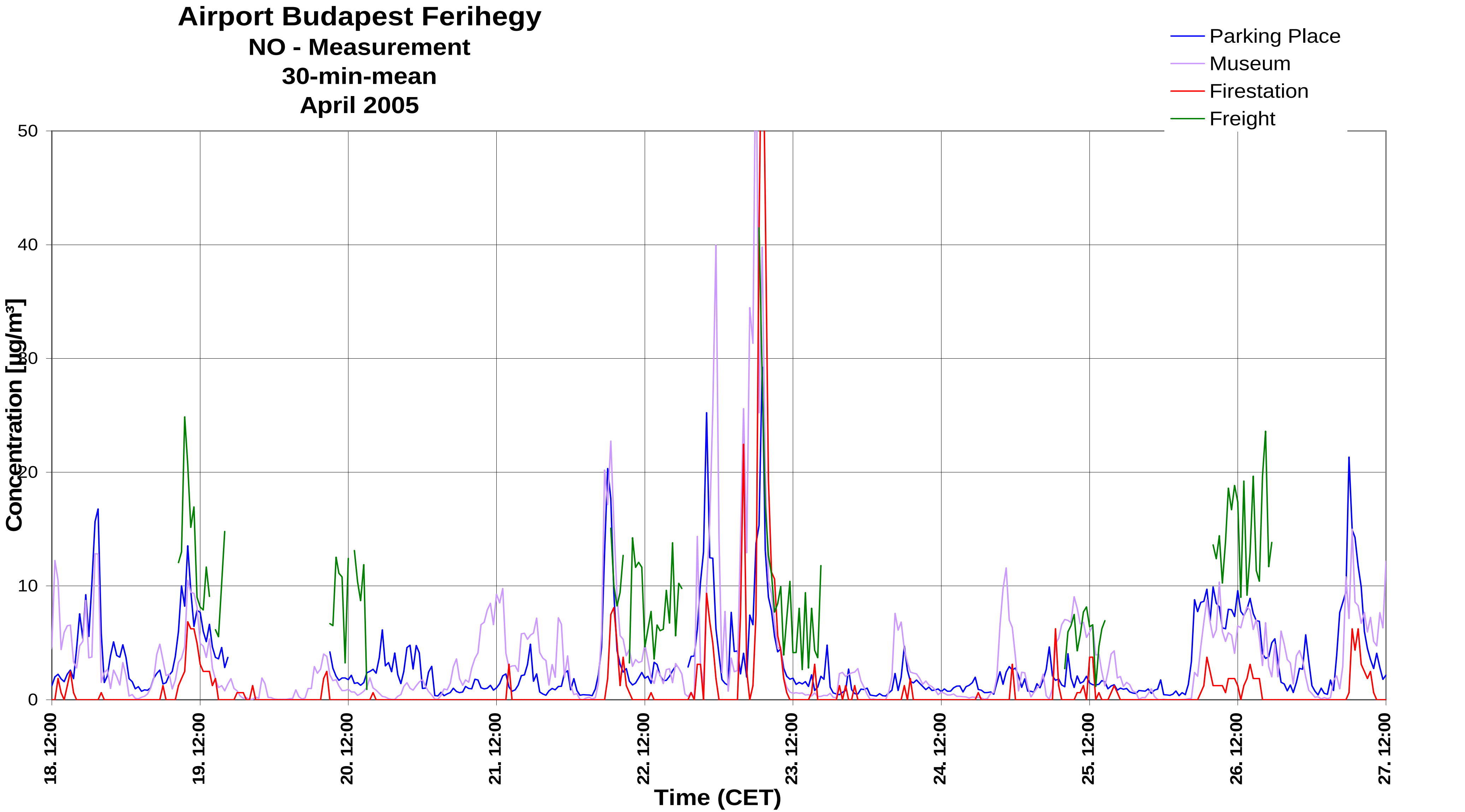
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

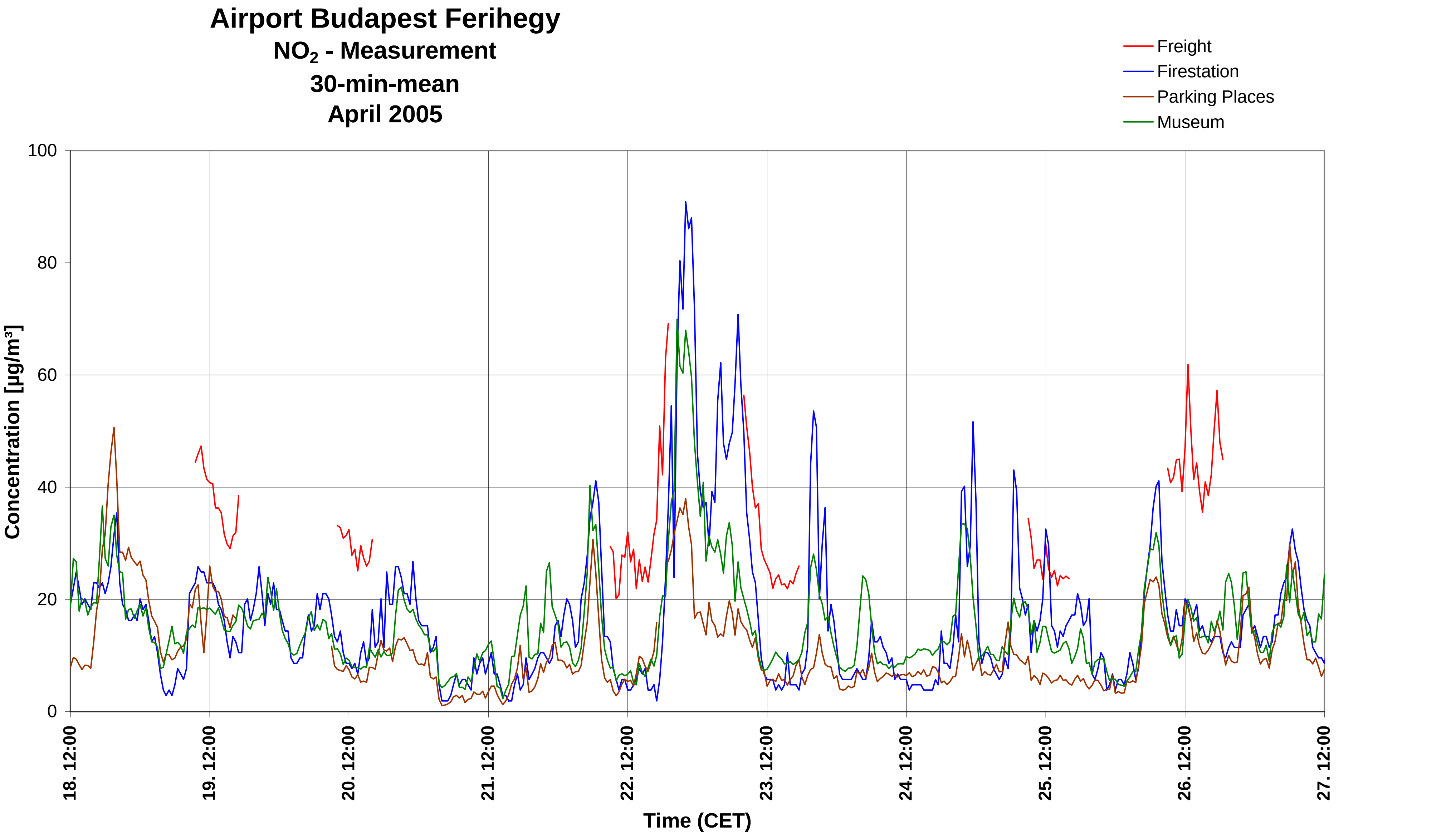
Airport Budapest Ferihegy
PM10 - Measurement

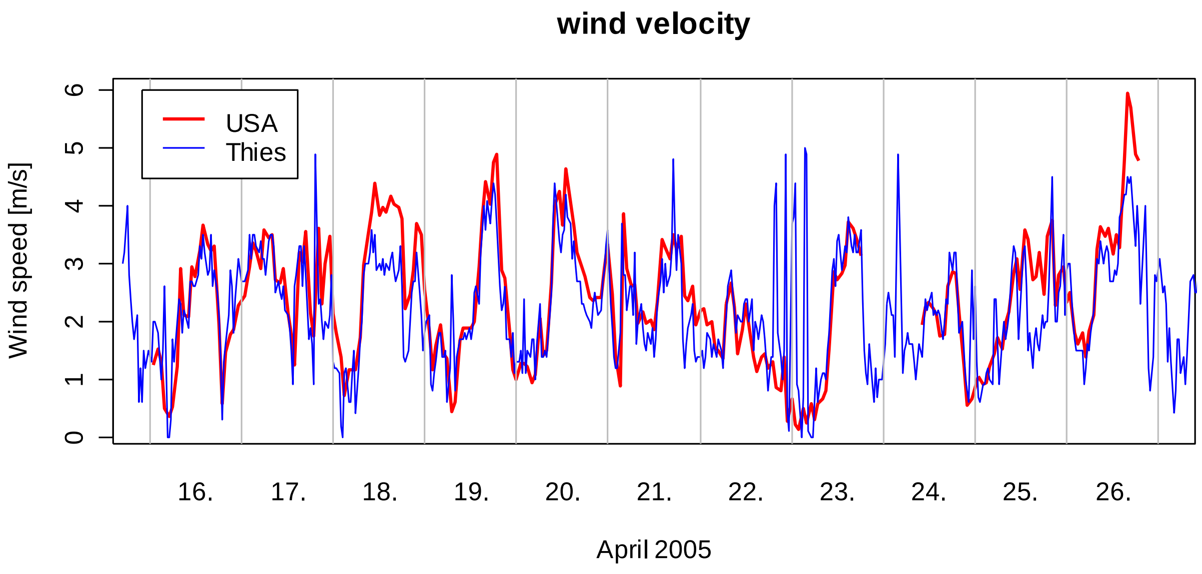
30-min-mean
April 2005

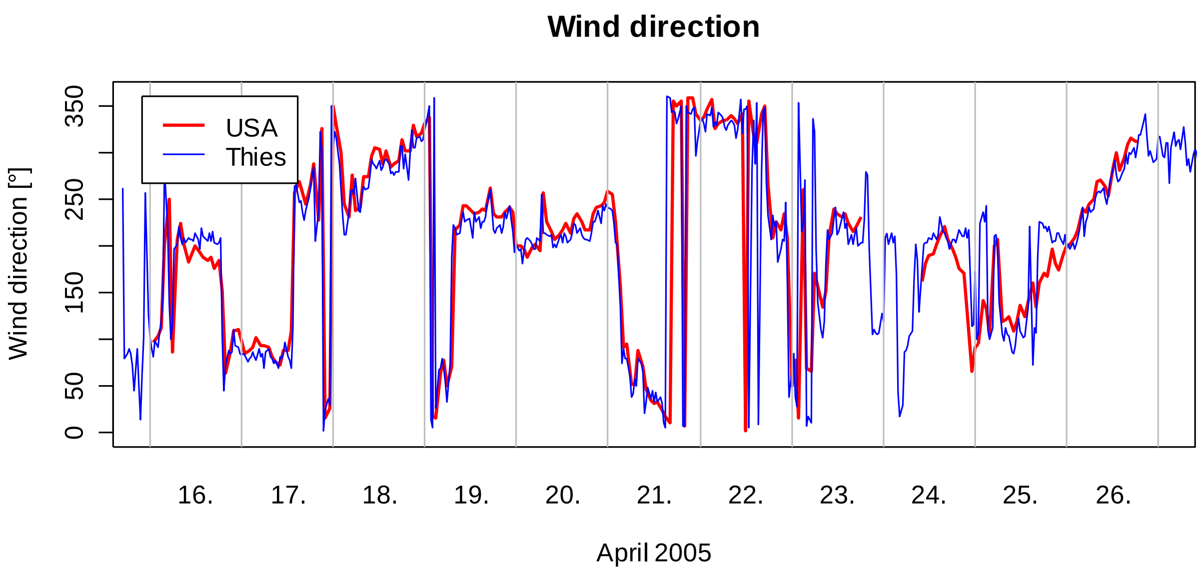



Airport Budapest Ferihegy
CO - Measurement
30-min-mean
April 2005
Parking Place
Museum
Freight
Concentration [µg/m³]
1200
1000
800
600
400
200
0
18. 12:00
19. 12:00
20. 12:00
21. 12:00
22. 12:00
23. 12:00
24. 12:00
25. 12:00
26. 12:00
27. 12:00
Time (CET)


Airport Budapest Ferihegy
NO - Measurement
30-min-mean
April 2005
Parking Place
Museum
Firestation
Freight
Concentration [µg/m³]
50
40
30
20
10
0
18. 12:00
19. 12:00
20. 12:00
21. 12:00
22. 12:00
23. 12:00
24. 12:00
25. 12:00
26. 12:00
27. 12:00
Time (CET)


Airport Budapest Ferihegy
NO_2 - Measurement
30-min-mean
April 2005
Freight
Firestation
Parking Places
Museum
Concentration [µg/m³]
100
80
60
40
20
0
18. 12:00
19. 12:00
20. 12:00
21. 12:00
22. 12:00
23. 12:00
24. 12:00
25. 12:00
26. 12:00
27. 12:00
Time (CET)


wind velocity
USA
Thies
Wind speed [m/s]
0
1
2
3
4
5
6
16.
17.
18.
19.
20.
21.
22.
23.
24.
25.
26.
April 2005


Wind direction
USA
Thies
Wind direction [°]
0
50
150
250
350
16.
17.
18.
19.
20.
21.
22.
23.
24.
25.
26.
April 2005

Measurement task

Samples of ambient air were taken into stainless steel canisters and analysed for volatile organic compounds (VOCs) and CO in the laboratory using gaschromatographic methods

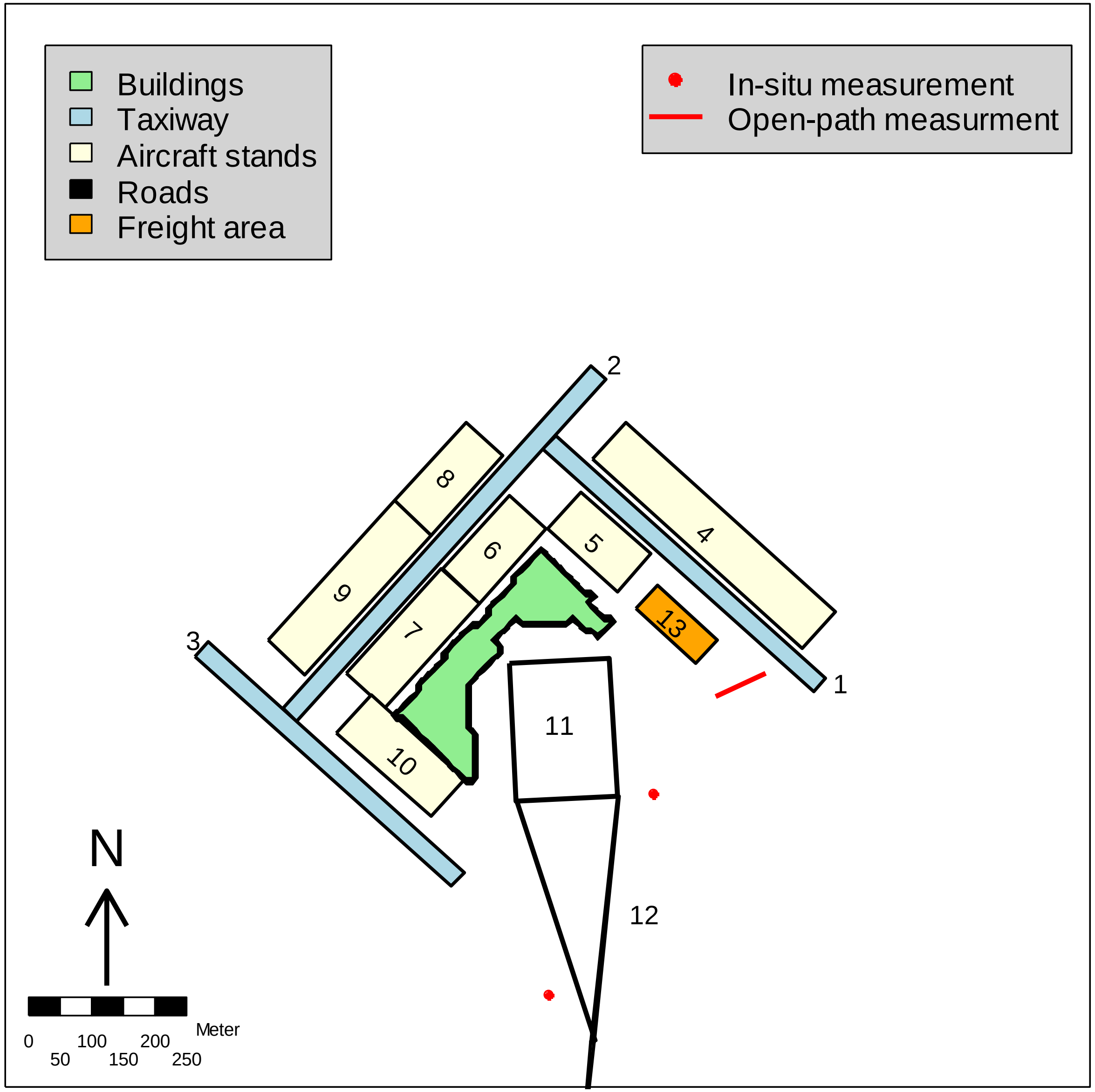
Sampling time of the canisters is about 1 minute

Higher HC up to C14 were sampled by tubes

Air sampling is performed for 45 minutes

Sampling was performed during re-fuelling, engine ignition, aircraft idle and aircraft taxiing


Vorsicht!
Hochempfindliche
Elektrogeräte


Buildings
Taxiway
Aircraft stands
Roads
Freight area
In-situ measurement
Open-path measurment
1
2
3
4
5
6
7
8
9
10
11
12
13
N
0
50
100
150
200
250
Meter

Methodology

The determination of this dispersion matrix was done by modelling with the dispersion model Austal2000 from Janicke

This is a Lagrangian particle dispersion model without chemical reactions

Bayesian statistics is used to solve the inverse problem: a priori information is important

Results

All kind of emissions on the airport Budapest show very high temporal variability

The traffic itself on the airport is highly variable

Aircraft emissions seem to be the most important around Terminal 2

Freight and car park emissions reach similar emission levels

Source	*A-prio A [mg/s]*	*A-posterit A [mg/s]*	*A-prio B [mg/s]*	*A-posterio B [mg/s]*	*Remarks*	*Time*
Taxiway (3) (per aircraft)	**58 ± 58 58 ± 58 58 ± 58 58 ± 58 58 ± 58**	**6 ± 13 41 ± 51 32 ± 30 27 ± 25 37 ± 24**	**35 ± 35 35 ± 35 35 ± 35 35 ± 35 35 ± 35**	**8 ± 12 38 ± 35 30 ± 26 27 ± 22 35 ± 22**	**Changing Winds**	**April 18; 22:00 CET April 18; 23:00 CET April 26; 17:00 CET April 26; 18:00 CET April 26; 19:00 CET**
Aircraft Stand (6 & 8) (per aircraft)	**100 ± 100**	**14 ± 74**	**20 ± 50**	**21 ± 39**	**Correlation: - 0.82**	**April 21; 23:00 CET**
Aircraft Stand (10) (per aircraft)	**100 ± 100**	**31 ± 76**	**20 ± 50**	**18 ± 45**		**April 18; 23:00 CET**
Aircraft Stand (9 & 10) (per aircraft)	**100 ± 100**	**13 ± 49**	**20 ± 50**	**6 ± 28**	**Correlation: - 0.84**	**April 18.; 21: 00 CET**
Car park (11)	**300 ± 300 300 ± 300**	**455 ± 187 656 ± 159**	**500 ± 300 500 ± 300**	**982 ± 153 923 ± 142**		**April 18; 19: 00 CET April 18; 20: 00 CET**
Car park (11) and road (12)	**400 ± 316 400 ± 316 400 ± 316**	**-25 ± 212 -96 ± 182 -54 ± 184**	**650 ± 335 650 ± 335 650 ± 335**	**201 ± 202 166 ± 179 54 ± 176**	**Correlation: - 0.72 Correlation: - 0.87 Correlation: - 0.86**	**April 21; 18:00 CET April 21; 19:00 CET April 21; 22:00 CET**
Road (12)	**100 ± 100**	**180 ± 81**	**150 ± 150**	**209 ± 81**		**April 21; 16:00 CET**
Freight (13) and aircraft stand (4) (Total emissions)	**100 ± 400 / 600 ± 245 100 ± 400 / 200 ± 141 100 ± 400 / 400 ± 200**	**-108 ± 49 / 585 ± 243 (477 ± 248) -55 ± 50 / 195 ± 141 (140 ± 149) -109 ± 54 / 386 ± 198 (277 ± 206)**	**300 ± 300 / 120 ± 122 300 ± 300 / 40 ± 71 300 ± 300 / 80 ± 100**	**-10 ± 28 / 110 ± 122 (100 ± 125) -4 ± 38 / 35 ± 71 (31 ± 80) -20 ± 30 / 70 ± 100 (50 ± 104)**	**Correlation: - 0.93 Correlation: - 0.74 Correlation: - 0.96**	**April 21; 18:00 CET April 21; 19:00 CET April 21; 22:00 CET**
Freight(13)	**100 ± 400 100 ± 400 100 ± 400 100 ± 400 100 ± 400 100 ± 400**	**814 ± 325 344 ± 118 586 ± 350 304 ± 122 378 ± 97 129 ± 81**	**300 ± 300 300 ± 300 300 ± 300 300 ± 300 300 ± 300 300 ± 300**	**796 ± 263 420 ± 112 582 ± 276 394 ± 115 469 ± 87 236 ± 67**		**April 26; 12:00 CET April 26; 13:00 CET April 26; 14:00 CET April 26; 16:00 CET April 26; 17:00 CET April 26; 18:00 CET**

Conclusions

Inverse dispersion modelling with a Bayesian approach turned out to be a suitable tool to investigate source strengths on an airport

Open-path measurement system are suitable for this task because these measurement can catch a whole exhaust plume and provide path-averaged data for numerical simulations which use certain grids

Conclusions

Overall, emissions of taxiing aircrafts were the most important sources for NO_x around Terminal 2 during the measurement campaign

But emissions on runways were not considered because they were not located in the measurement area

It is well known, that NO_x emissions of an aircraft are highest during take-off

Acknowledgements

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