Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Airport air pollution monitoring: Achievements in the past, limits of the present, challenges for the future

Klaus Schäfer, Carsten Jahn, Selina Utzig, Edgar Flores-Jardines, Herbert Hoffmann, Gregor Schürmann, Stefan Emeis

IMK-IFU, Forschungszentrum Karlsruhe GmbH, Garmisch-Partenkirchen

Peter Sturm, Bernhard Lechner, Michael Bacher

Institut für Verbrennungskraftmaschinen und Thermodynamik, Technische Universität Graz, Graz

Veronika Groma, Szabina Török

Health and Environmental Physics, KFKI Atomic Energy Research Institute, Budapest, Hungary

Background
Problems and solutions
Achievements in the past
Limits of the present
Challenges for the future

ECATS, Spring School & Research Colloquium, 13 March 2007, MMU Manchester

Motivation

For the execution of the European Air Quality Framework Directive 96/62/EC and its daughter directives it is required from the EU member states to submit 12-monthly air pollution maps that show the spatial distribution of air pollutants

- for the member state in total,

- for conurbations with more than 250.000 inhabitants and

- for micro environments as, e.g., city districts subject to high pollutant concentrations: spatial resolution of 200 m^2

Background

Airport air quality studies need: emission inventories, meteorological observations, chemistry-transport-deposition modelling (dry and wet deposition) and (depending from questions) indoor air quality study, odour observation

Aircraft exhaust emissions: ICAO database is used

What are the real emissions of aircraft?

Which other compounds are emitted?

Which other emission sources exist?

Background

Chemistry-transport-deposition modelling requires validation: validation strategies, data (requirements?)

Health effects must be defined

- **Which pollutants are relevant?**
- **Which health effects are not explained?**

Quantification of climate change effect

What is the public interest (regulations, health care (human, animals), odour)?

Problems

Interaction between exhaust plume and ambient air (physics, chemistry) is not well understood but important for the application of small-scale chemistry-transport models to investigate airport air quality

Dependencies of air quality: Contribution of air pollutants from outside the airport, influences of emissions, influences of weather

Operation ability of air pollution modelling: data requirements, forecasting

Solutions

Monitoring at optimum sites of relevant parameters

Intensive campaigns to answer dedicated questions

Fusion of different data pools

Co-operation of different disciplines

Achievements in the past

In situ techniques for CO_2, NO, NO_2, CO, UHC and smoke number during certification of new aircraft engines

Recommended by regulations of the ICAO

ICAO data base on this basis for LTO cycle (7, 30, 85, 100 % maximum thrust)

Achievements in the past

Emissions of in-service aircraft under some typical engine conditions at airports were investigated

Non-intrusive measurement methods for CO, CO_2, NO, NO_2, N_2O, CH_4, H_2O, and some VOC were used: FTIR, DOAS

No installations nearby or behind the aircraft

Normal airport operation remains unimpaired

Measurement tasks

Non-intrusive methods for measurements of concentrations and emission indices:

- **FTIR emission spectrometry at the engine nozzle exit (CO, NO, CO_2; NO_2 below detection limit), passive**

- **FTIR absorption spectrometry (CO, CO_2) behind the aircraft**

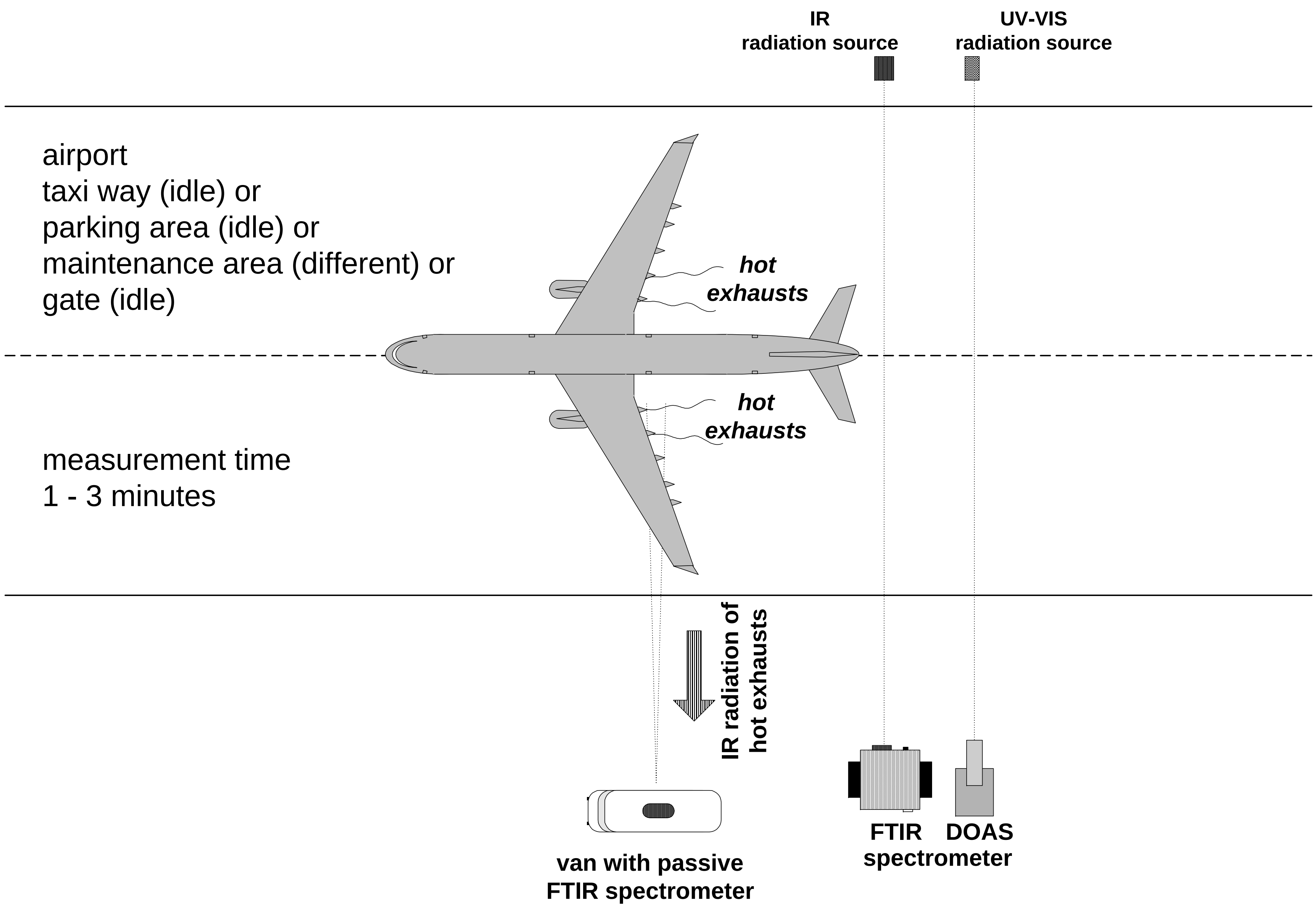
- **Differential Optical Absorption Spectroscopy (DOAS) behind the aircraft (NO, NO_2; no CO, CO_2)**

Passive measurement mode (FTIR emission spectrometry):

- **maximum distance 250 m, perpendicular to the exhaust plume**
- **telescope diameter 15 cm diameter, field of view 3 mrad**
- **difference to concentrations measured by certified intrusive systems in test rigs ±30 %**
- **detection limits: CO_2 0.1 %, CO 5 ppm and NO 8 ppm (exhaust diameter 60 cm, distance about 30 m)**

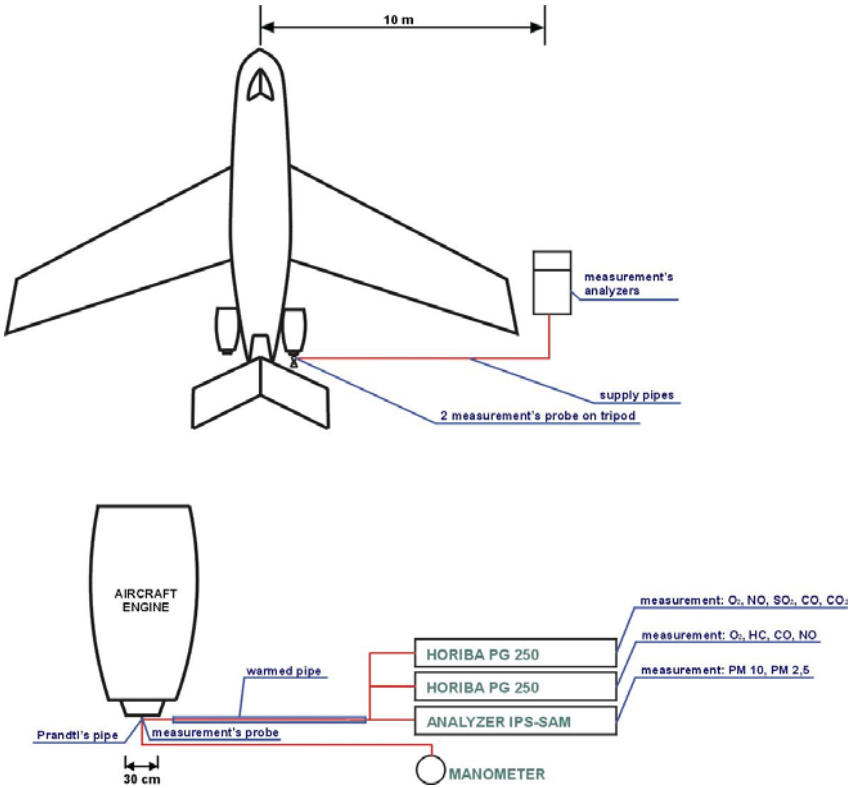
Open-path measurement methods (FTIR absorption spectrometry and DOAS)

- **path-length 80 - 500 m**
- **beam diameter 10 - 15 cm**
- **accurate within 5 - 10 %**

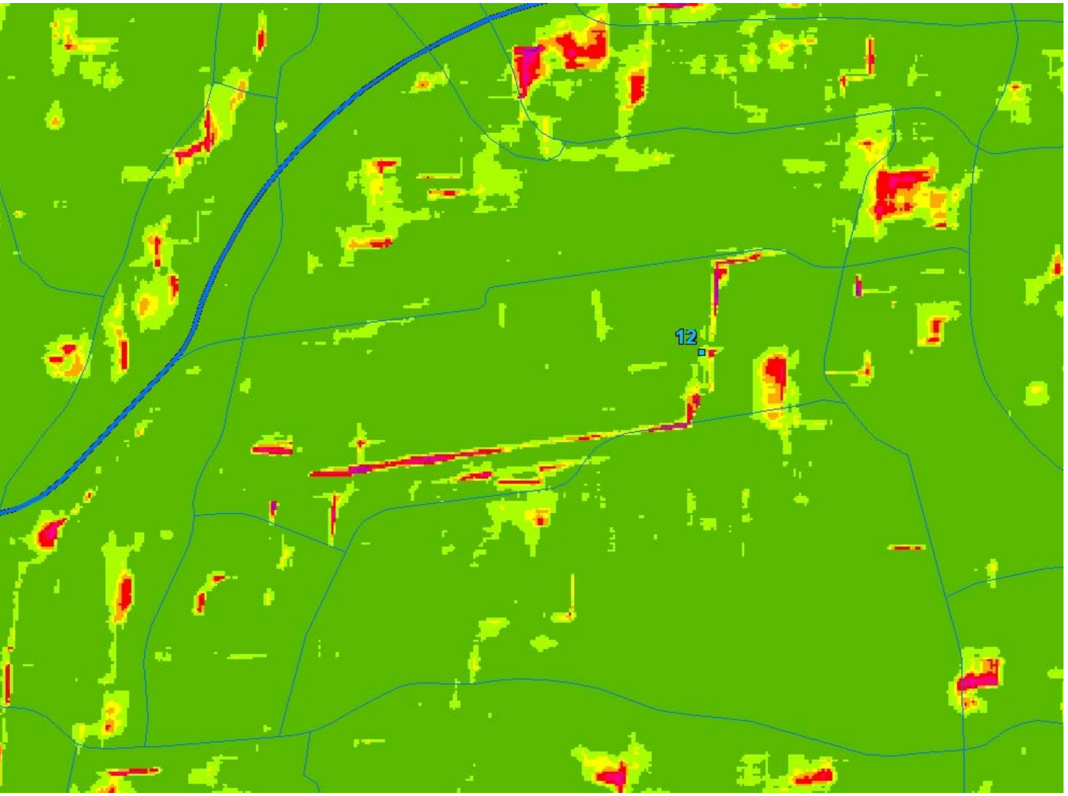

IR
radiation source
UV-VIS
radiation source
airport
taxi way (idle) or
parking area (idle) or
maintenance area (different) or
gate (idle)
hot
exhausts
hot
exhausts
measurement time
1 - 3 minutes
IR radiation of
hot exhausts
van with passive
FTIR spectrometer
FTIR DOAS
spectrometer

Airport air pollution in situ measurements

In situ measurements inside the exhaust plumes according to ICAO requirements at the airport Wroclaw by PPW „Czyste Powietrze" in frame of the ARTEMIS project: TU 154 M, JAK 40



Satellite observations

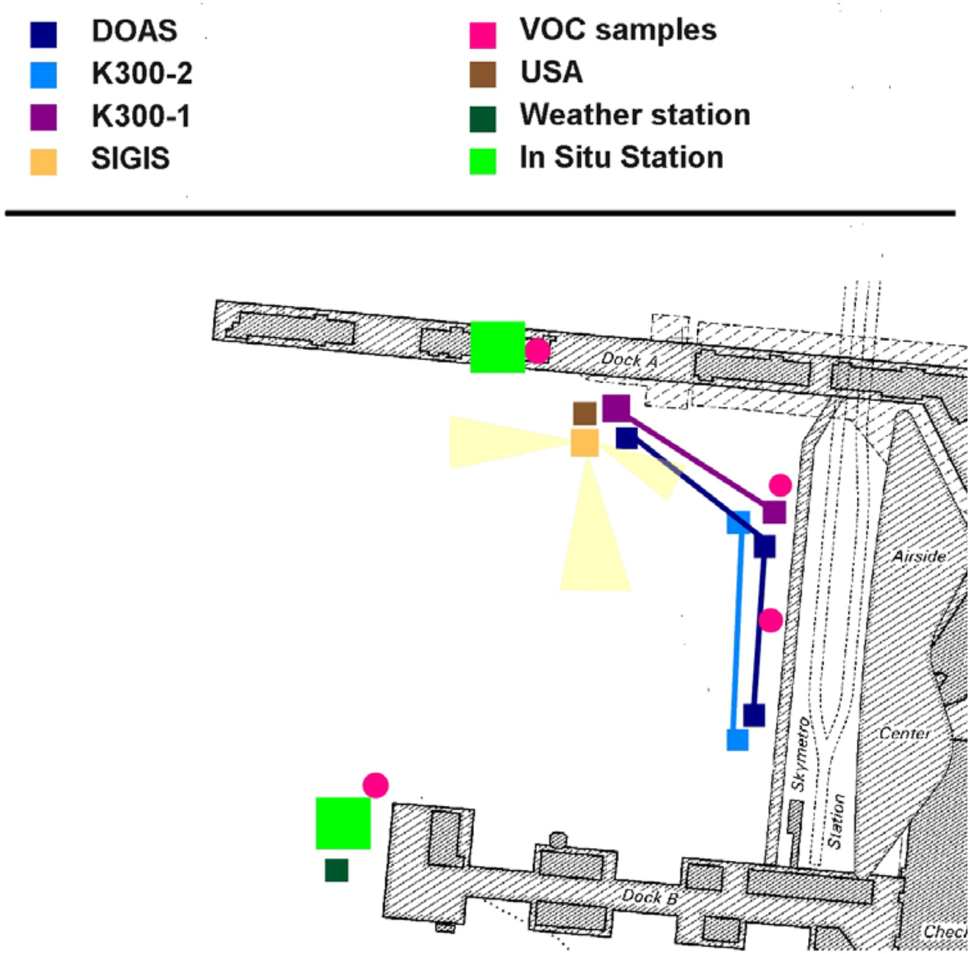


Satellite images

Optical depth interpretation

Determination of spatial distribution of PM concentrations near the ground by means of the ICAROS NET platform

Spatial resolution up to 10 m x 10 m



Airport air pollution campaign

Zuerich July 2004

Airport air pollution campaign

Zuerich July 2004 Results

Emission apportionment:

Emission rates for NO on the taxiway 4.4 up to 146 mg/s, parking places 1.6 up to 357 mg/s

CO emission rates for taxiing aircrafts 0.4 up to 7.5 g/s, parking places 0.01 up to 0.35 g/s

NO_2 on the taxiway 13 mg/s up to 90 mg/s, parking places 0.25 mg/s up to 113 mg/s

Aircraft emission indices from passive (CO, NO) and open-path measurements (CO, NO, NO_2)

Airport air pollution campaign

Zuerich July 2004 Results

Particle and trace gas load:

Abundance of iron- and aluminium-rich particles was much higher than in usual suburban aerosol samples of large agglomerations

Following the definitions the air quality is good

But during periods of high air traffic at the apron area the air quality is moderate only

Airport air pollution campaign

Zuerich July 2004 Results

VOC inside the exhaust plumes:

Compounds which were not found in all background samples are some Butene, Pentene, and Hexene

Reactive C2–C3 alkenes were found in significant amounts in the exhaust of an engine compared to ambient levels

Also, isoprene, a VOC commonly associated with biogenic emissions, was found in the exhaust, however it was not detected in refuelling emissions

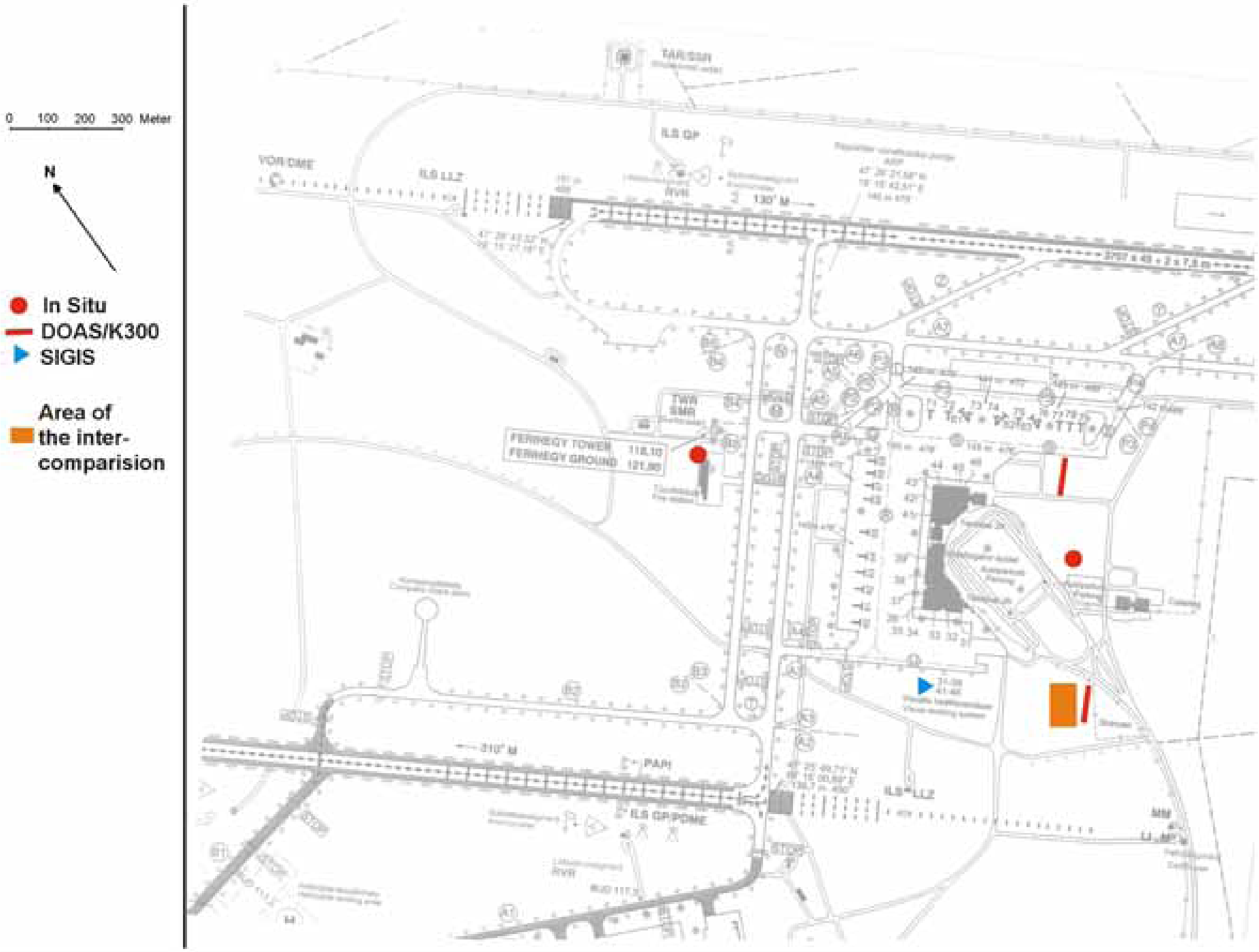
The benzene to toluene ratio was used to discriminate exhaust from refuelling emission:

- **In refuelling emissions the ratio was well below 1**
- **For exhaust this ratio was usually about 1.7**

Airport air pollution campaign

Zuerich Methodology and Results published:

Schürmann, G., Schäfer, K., Jahn, C., Hoffmann, H., Bauerfeind, M., Fleuti, E., Rappenglück, B.: The impact of NO_x, CO and VOC emissions on the air quality of the airport Zurich. Atmospheric Environment 41 (2007), 103-118, doi:10.1016/j.atmosenv.2006.07.030.



Airport air pollution campaign

Development of emission inventory

Budapest October 2004 and April 2005

Results

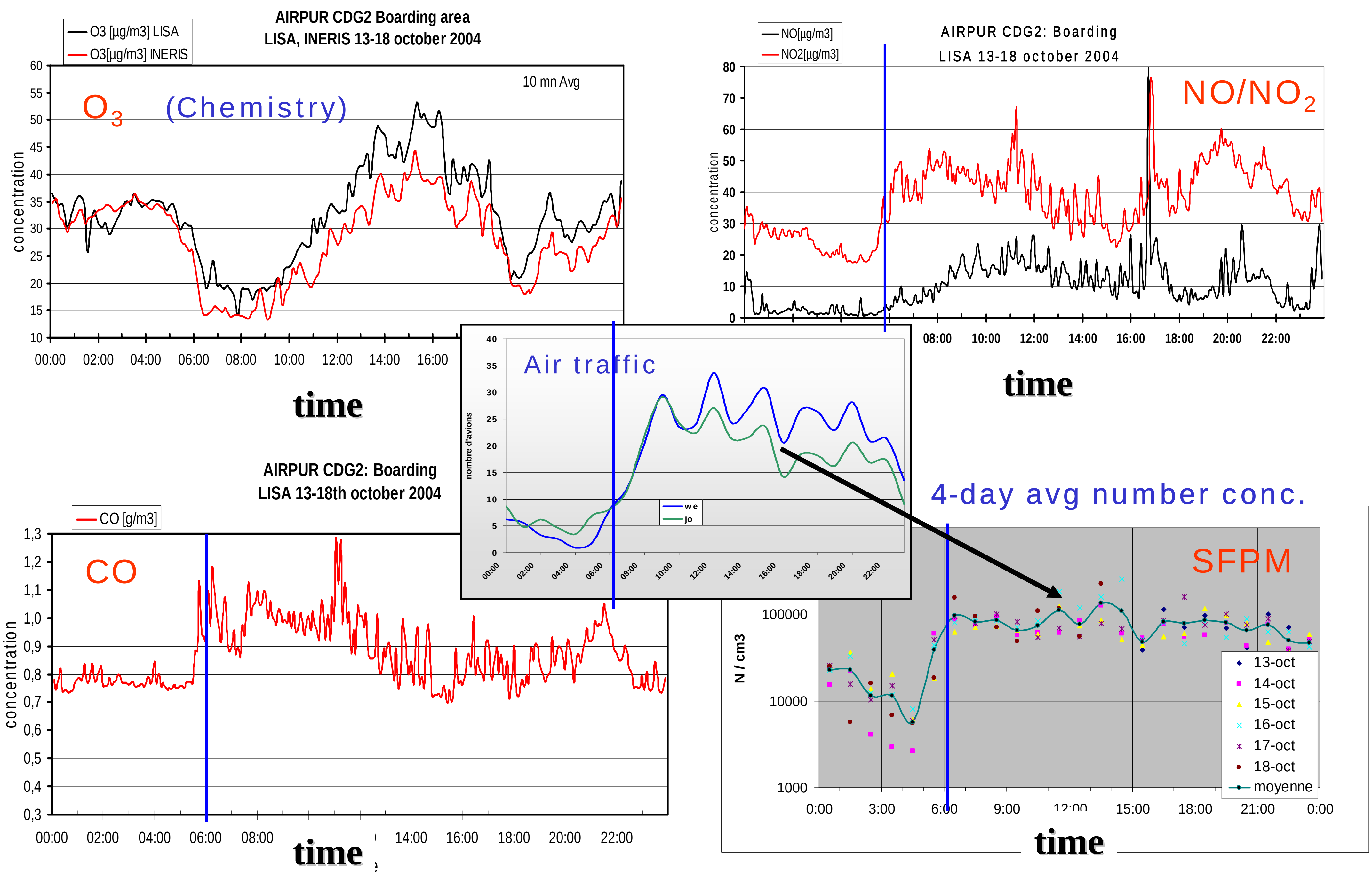
All kind of emissions on the airport Budapest show very high temporal variability

The traffic itself on the airport is highly variable

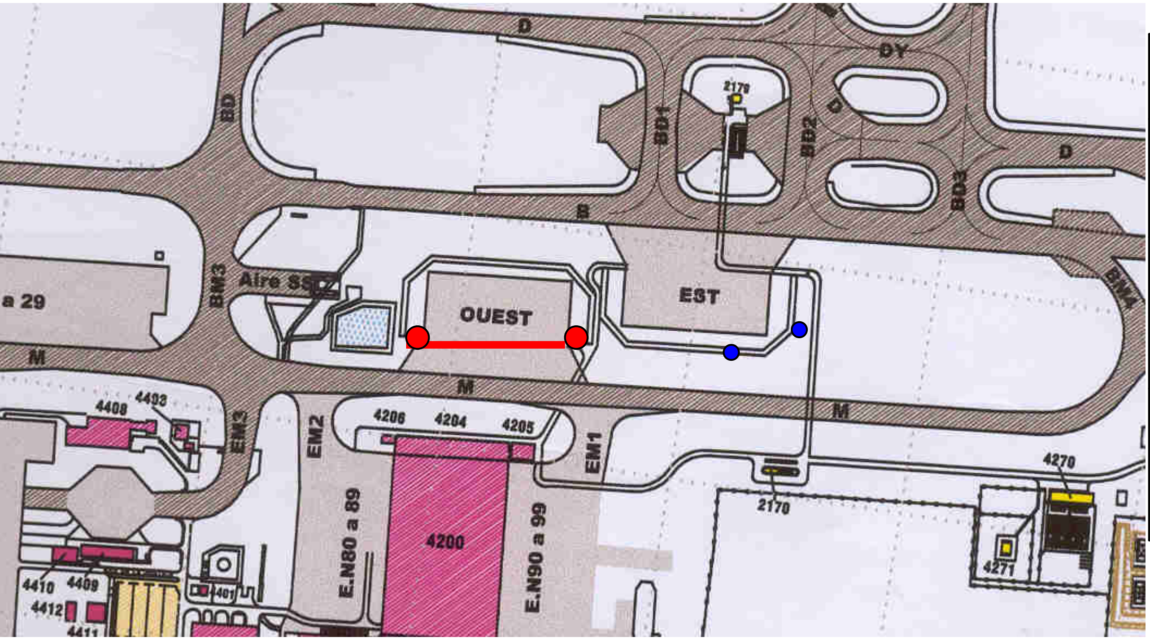
Aircraft emissions seem to be the most important around Terminal 2

Freight and car park emissions reach similar emission levels

Parking and gate (4 days)



Site 7

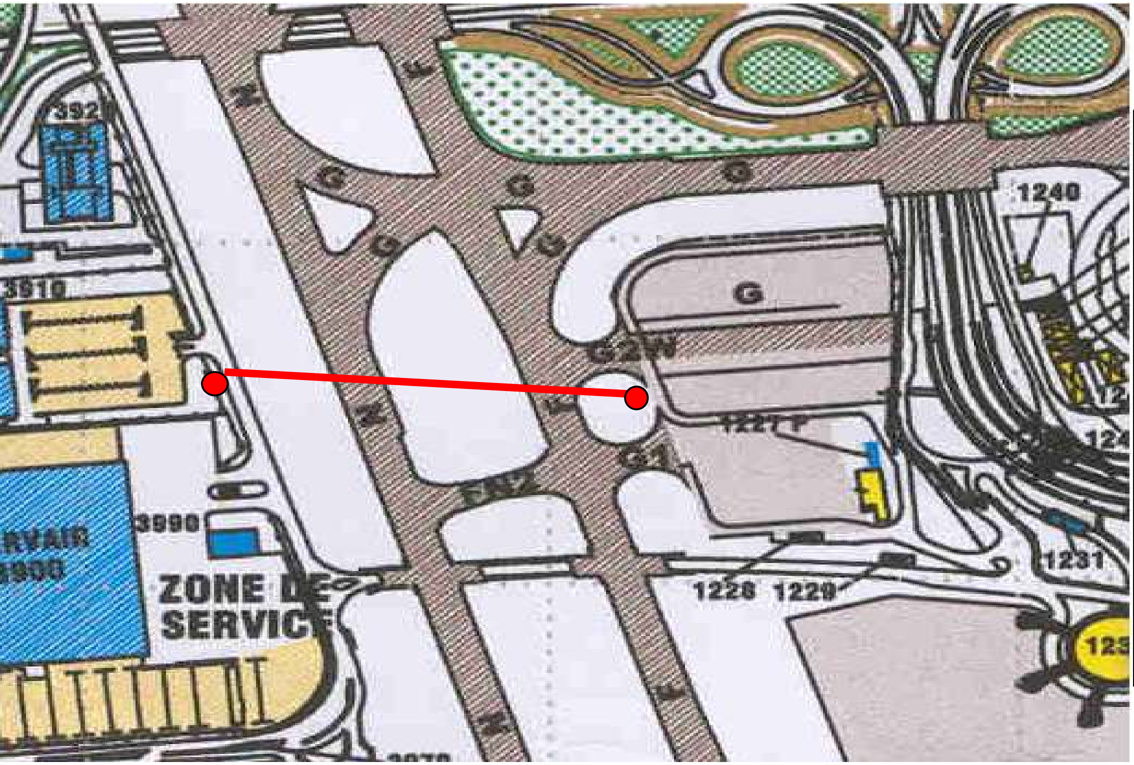


Date	Measurements	Special observations (Time in CET=UTC+1)
15/06/05	Build-up of the measurement devices Start with DOAS and K300-2 open-path measurements	No aircraft test Vehicles are passing the open path
16/06/05	Open-path measurements with DOAS and K300-2 during the day One tube sampling Three canister samplings	No aircraft test Vehicles are passing the open path
17/06/05	Open-path measurements with DOAS and K300-2 during the day One tube sampling Four canister samplings	No aircraft test Vehicles are passing the open path

Position 7

Date	**Measurements**	**Special observations (Time in CET=UTC+1)**
06/10/04	Build-up of the measurement devices First measurements with the K300-1 (Passive mode) Begin of DOAS measurements Problems with K300-2	
07/10/04	Measurement with K300-1 and DOAS Ongoing problems with K300-2	
08/10/04	No measurement during the take-off test with the K300-1 due to bad position of aircraft Preparation of change of position	07:20 Begin take-off test 09:10 End take-off test

Site 5

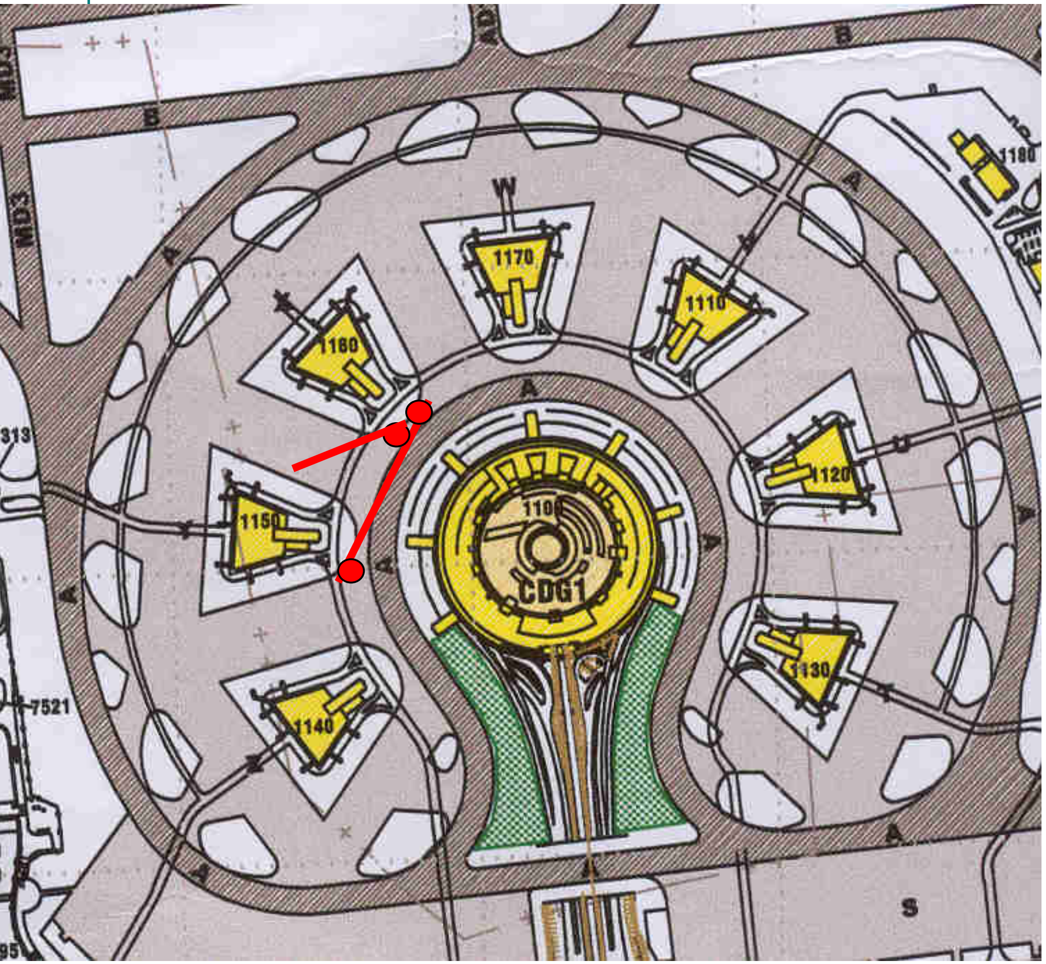


Date	Measurements	Special observations (Time in CET=UTC+1)
20/06/05	Build-up of the measurement devices Start of measurements with K300-2 and DOAS	Aircraft are passing paths
21/06/05	Measurements with K300-2 and DOAS during day and following night	Aircraft are passing paths
22/06/05	▪Measurements with K300-2 and DOAS during day and following night ▪One tube sampling	Aircraft are passing paths
23/06/05	Measurements with K300-2 and DOAS during day	Aircraft are passing paths
24/06/05	Measurements with K300-2 and DOAS during day	Aircraft are passing paths

Position 5

Date	Measurements	Special observations (Time in CET=UTC+1)
11/10/04	Build-up of the measurement devices Begin of measurements with K300-2 and DOAS No measurements with K300-1, because no airplane did stop in front of the measurement device	
12/10/04	No measurements with K300-1, because no airplane did stop in front of the measurement device	
13/10/04	No measurements with K300-1, because no airplane did stop in front of the measurement device Change of position	

Site 1

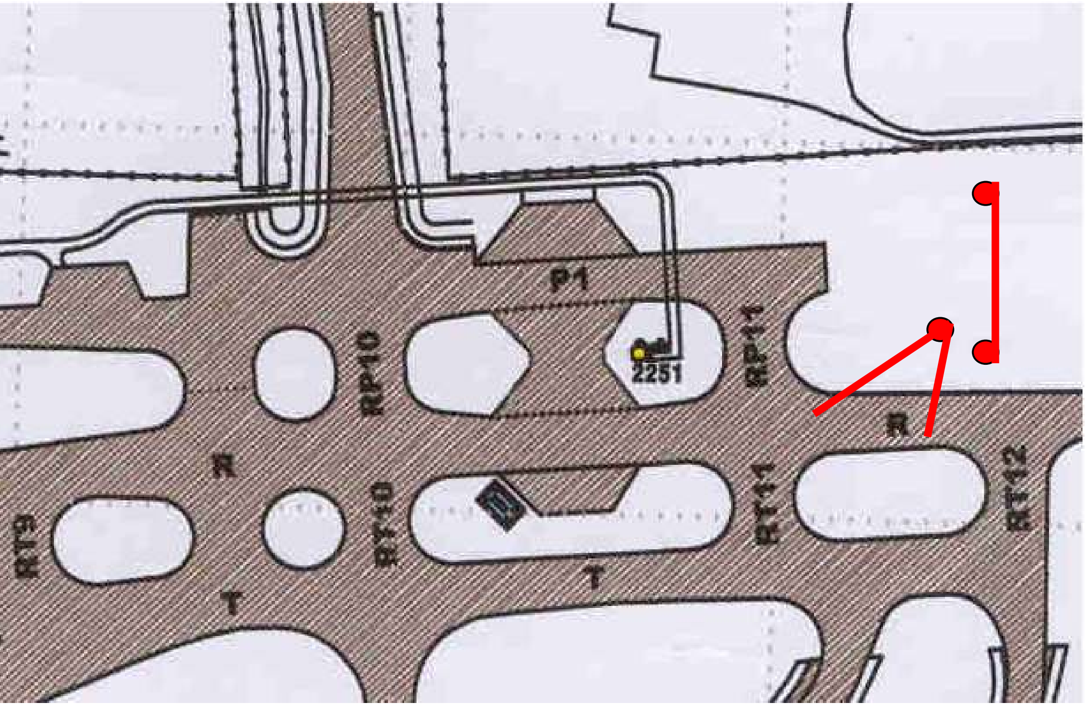


Date	Measurements	Special observations (Time in CET=UTC+1)
27/06/05	Build-up of the measurement devices K300-2, DOAS and measurement van	
28/06/05	Start of measurements with K300-2 and DOAS Start of measurements with K300-1 (passive and open-path)	Vehicles are passing the open paths
29/06/05	Measurements with K300-2, DOAS and K300-1	Vehicles are passing the open paths
30/06/05	Measurements with K300-2, DOAS and K300-1	Vehicles are passing the open paths
01/07/05	Measurements with K300-2, DOAS and K300-1 One tube sampling	Vehicles are passing the open paths
02/07/05	Continuous measurements with DOAS	
03/07/05	Continuous measurements with DOAS	
04/07/05	Continuous measurements with DOAS	

Position 1

Date	Measurements	Special observations (Time in CET=UTC+1)
14/10/04	Begin of measurements with all devices	13:05 Pushback of HS-TGO (Boeing 747) 13:12 D-ABXM (Boeing 737) comes in 14:04 D-ABXM is leaving
15/10/04	Preparation of change of position	14:12 D-ACHK is leaving

Site 4



Date	Measurements	Special observations (Time in CET=UTC+1)
04/07/05	Build-up of the measurement devices K300-2, DOAS and measurement van	
05/07/05	Start of continuous measurements with DOAS Start of measurements with K300-2 Two tube samplings One canister sampling	Aircraft are passing open paths at new taxi way
06/07/05	Start of measurements with K300-1 Measurements with K300-2 and DOAS One tube sampling	Aircraft are passing open paths at new taxi way Some measurements with K300-1 during traffic jams in front on the runways
07/07/05	Measurements with K300-2, DOAS and K300-1 Two tube samplings One canister sampling	Aircraft are passing open paths at new taxi way Some measurements with K300-1 during traffic jams in front on the runways
08/07/05	Measurements with K300-2, DOAS and K300-1	Aircraft are passing open paths at new taxi way Some measurements with K300-1 during traffic jams in front on the runways
09/07/05	Continuous measurements with DOAS	
10/07/05	Continuous measurements with DOAS	
11/07/05	Measurements with K300-2 and DOAS	No aircraft

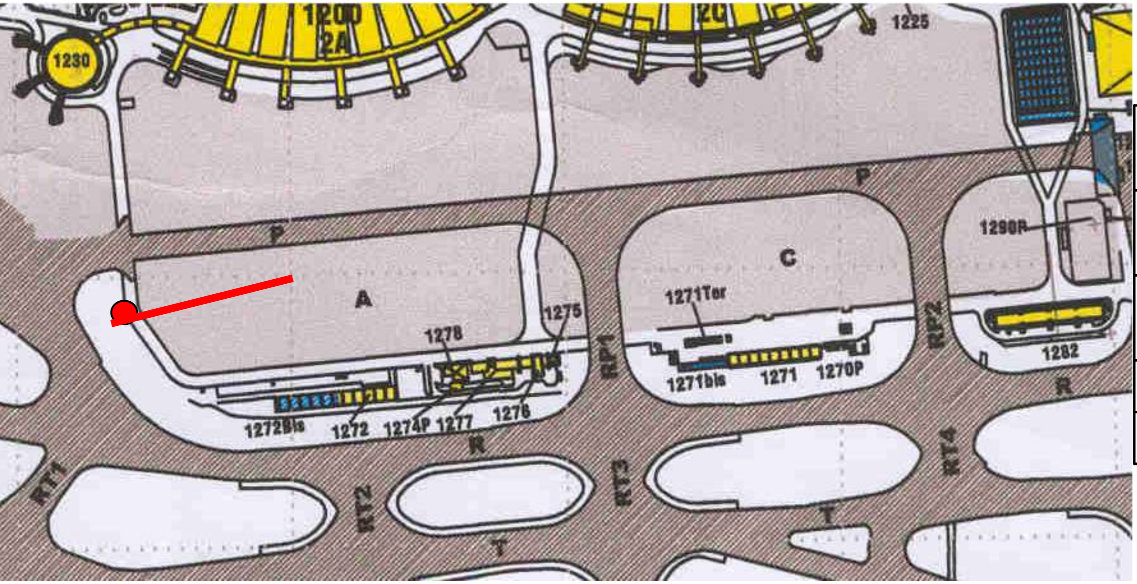
Position 4

Date	Measurements	Special observations (Time in CET=UTC+1)
18/10/04	Build up of measurement devices Begin of measurements with all devices	Some measurements with K300-1 during traffic jam in front on the runways
19/10/04	Measurements with K300-2 and DOAS No measurement with K300-1 End of measurements	No traffic jam due to wrong wind direction. Therefore no K300-1 measurements


OPSIS


MAN

Site 2



Date	Measurements	Special observations (Time in CET=UTC+1)
21/06/05	Build-up of the measurement van Start of measurements with K300-1	APU are measured
22/06/05	Measurements with K300-1 during day One canister sampling	APU are measured
23/06/05	Measurements with K300-1 during day	APU are measured
24/06/05	Measurements with K300-1 during day	APU are measured

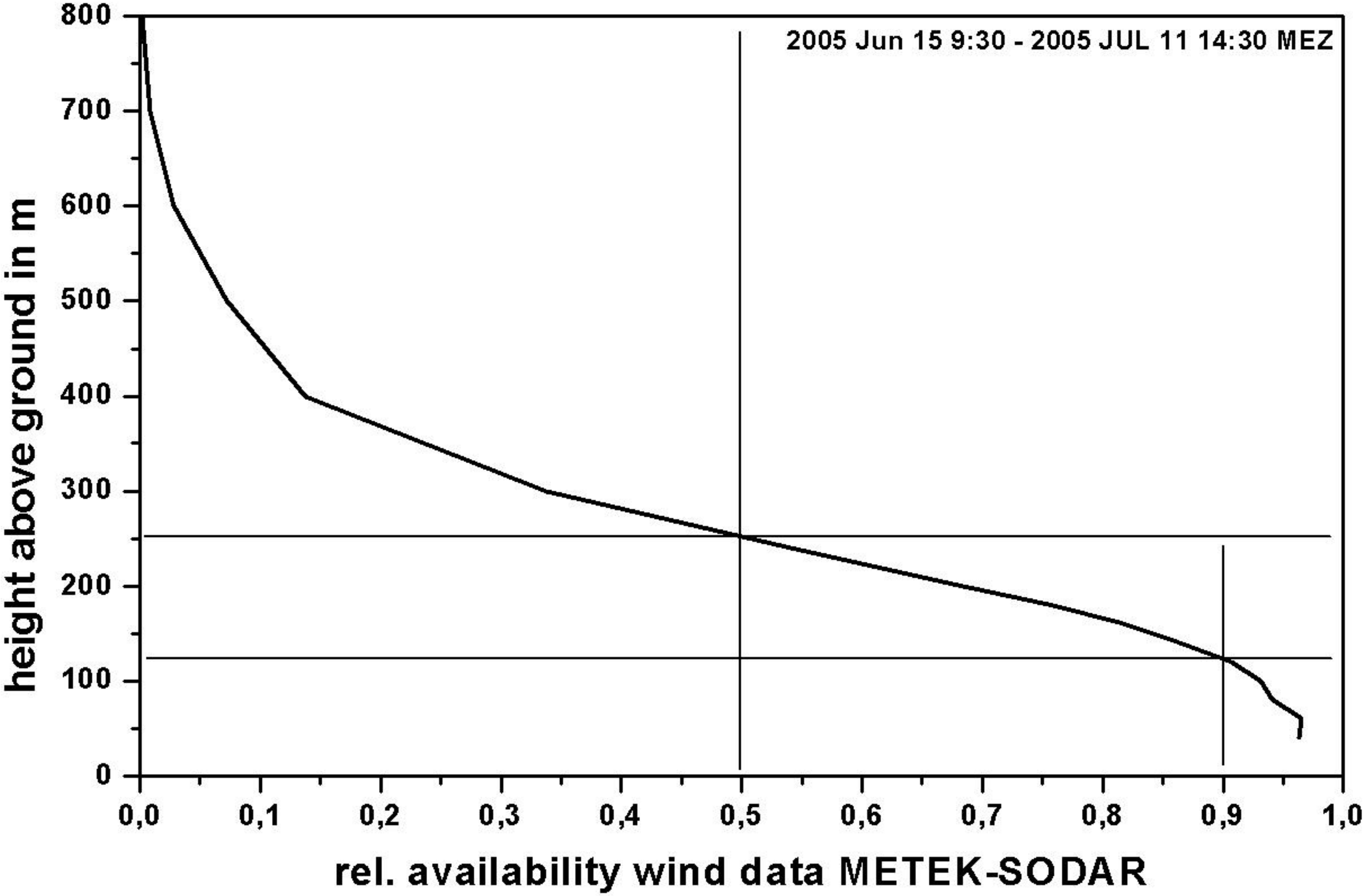
Measurement task

Altitude profiles of turbulence and wind were measure by the METEK DSD3x7 mono-static Doppler SODAR

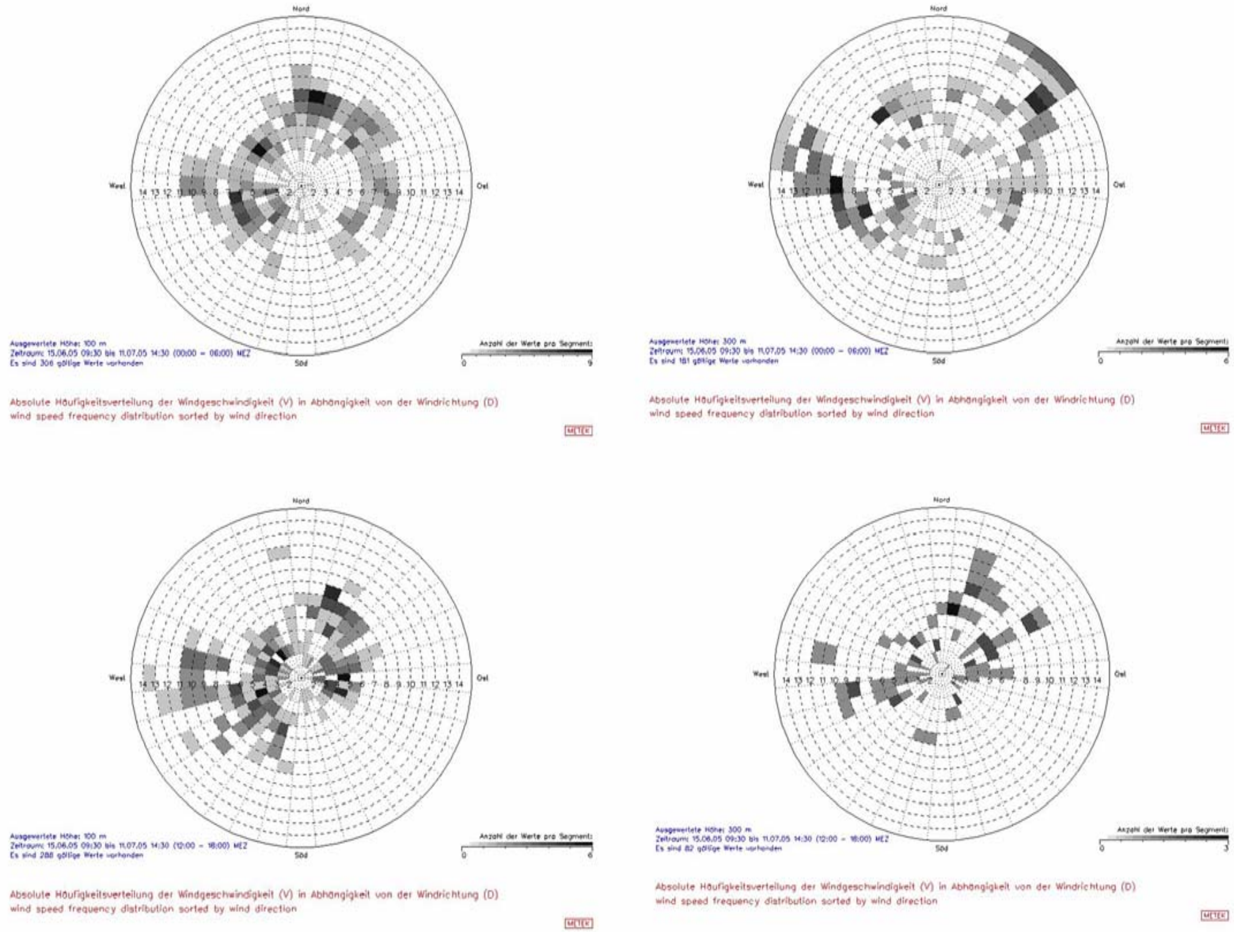
Working with three antennas, each including seven sound transducers, mounted on a trailer

One averaged vertical profile every 30 minutes has been stored

Vertical resolution of the data is 20 m, the minimum height of the data is 40 m and the maximum height is 800 m above ground


2005 Jun 15 9:30 - 2005 JUL 11 14:30 MEZ
height above ground in m
0
100
200
300
400
500
600
700
800
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
rel. availability wind data METEK-SODAR

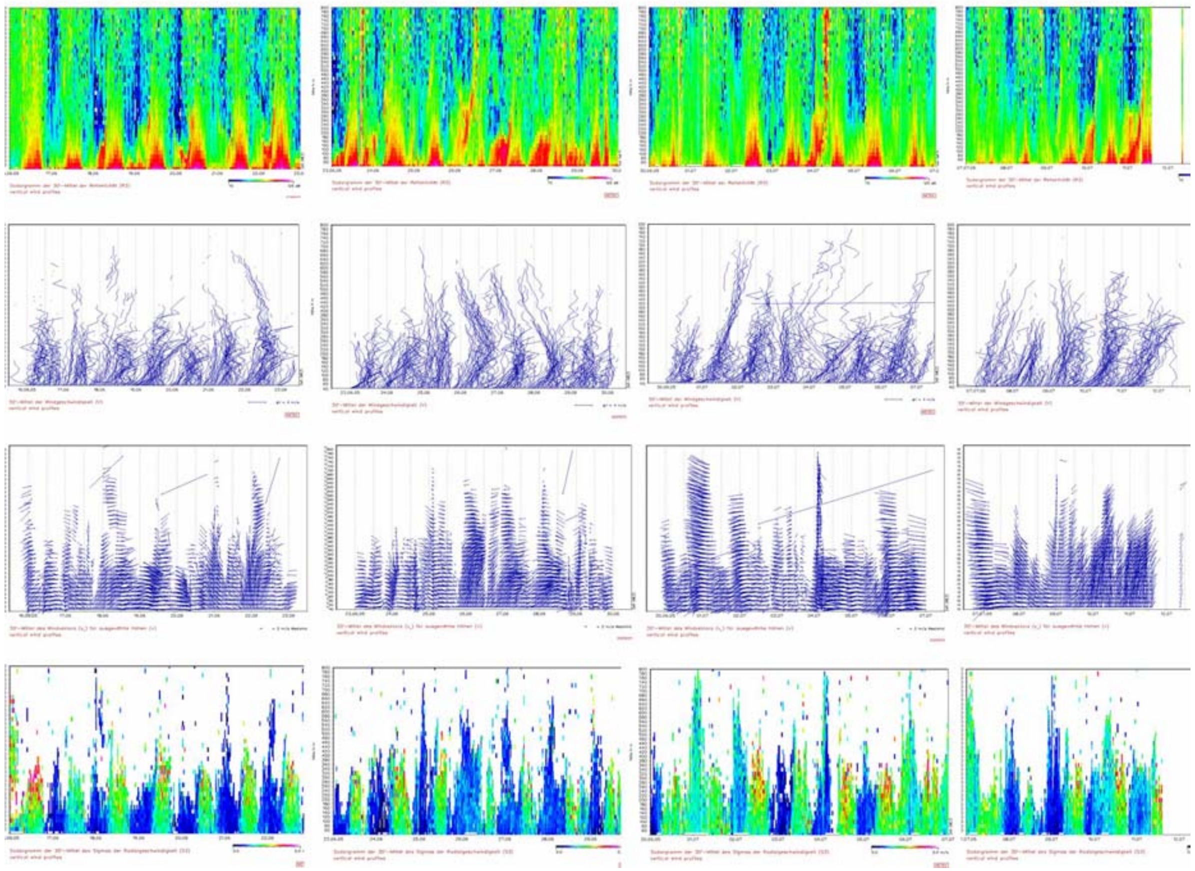
Wind speed resolving wind roses for 100 m (left) and 300 m (right) above ground for night-time (0 to 6 hours GMT+1, top) and daytime (12 to 18 hours) bottom



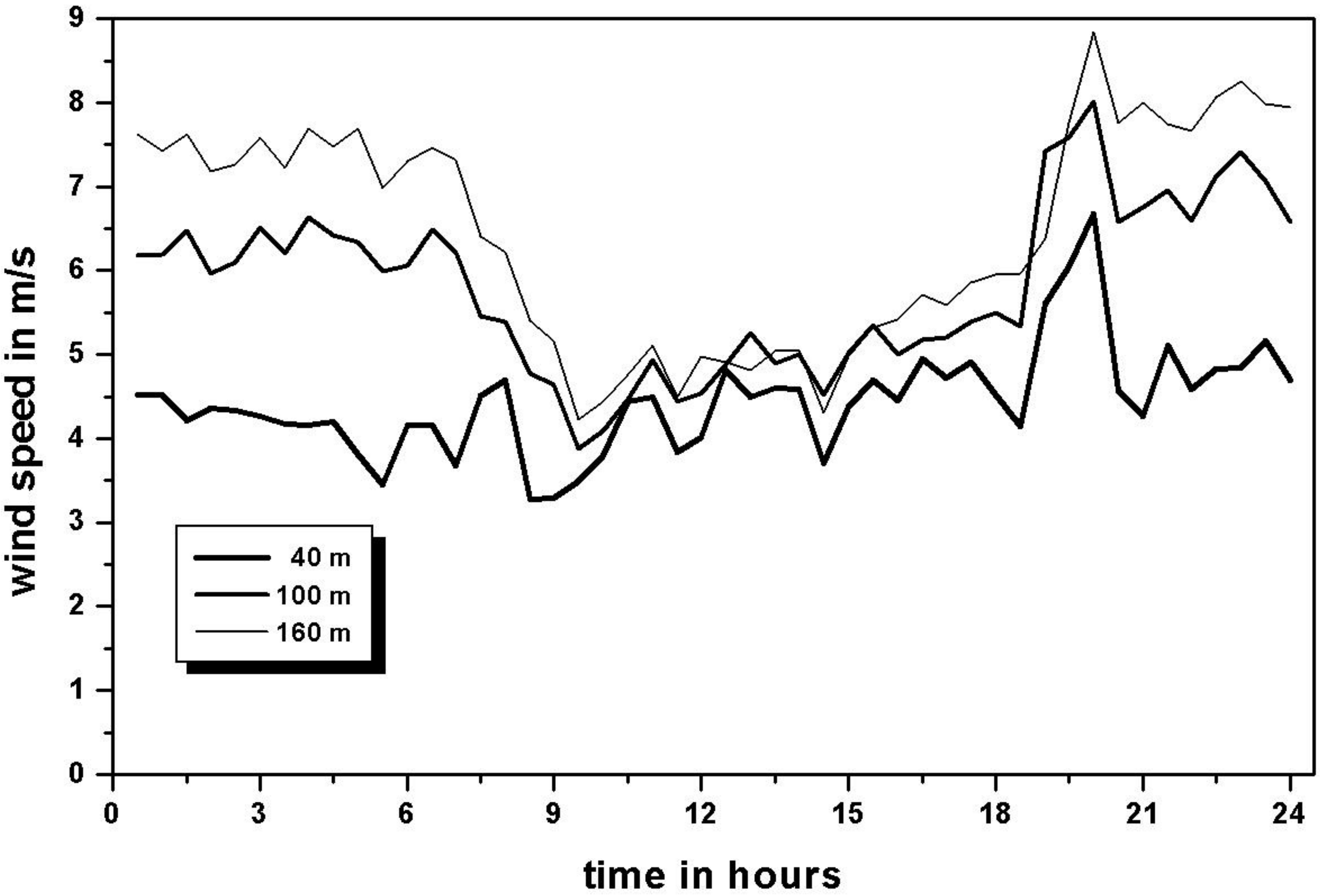
Upper row: acoustic backscatter intensity in dB (black: 70 dB, purple: 125 dB)

second row: vertical wind speed profiles in m/s, third row: horizontal wind vectors in m/s (length of arrow: wind speed, direction of arrow: wind direction)

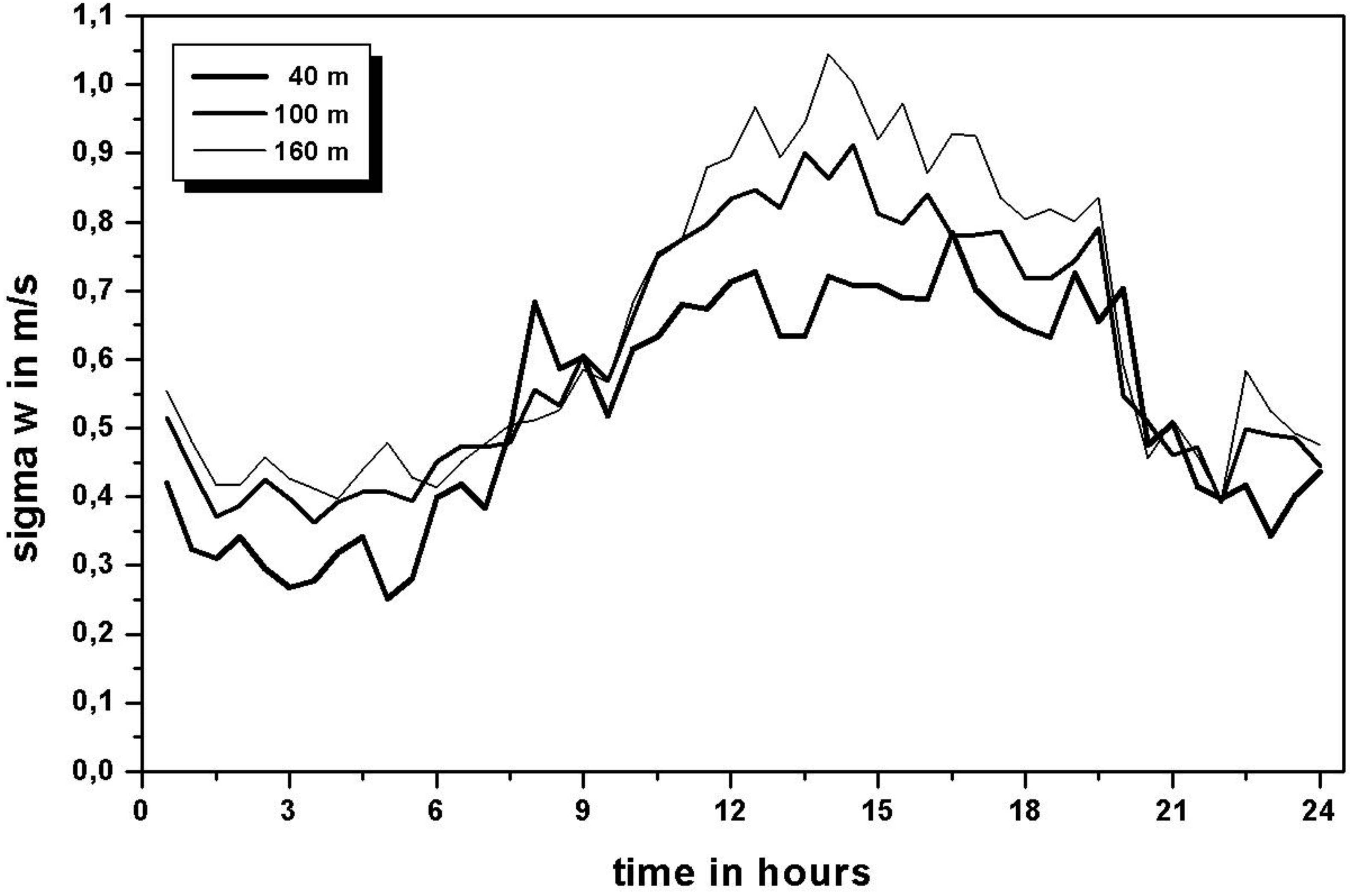
bottom row: standard deviation of vertical wind component (σw) in m/s (black: 0 m/s, purple: 2 m/s)



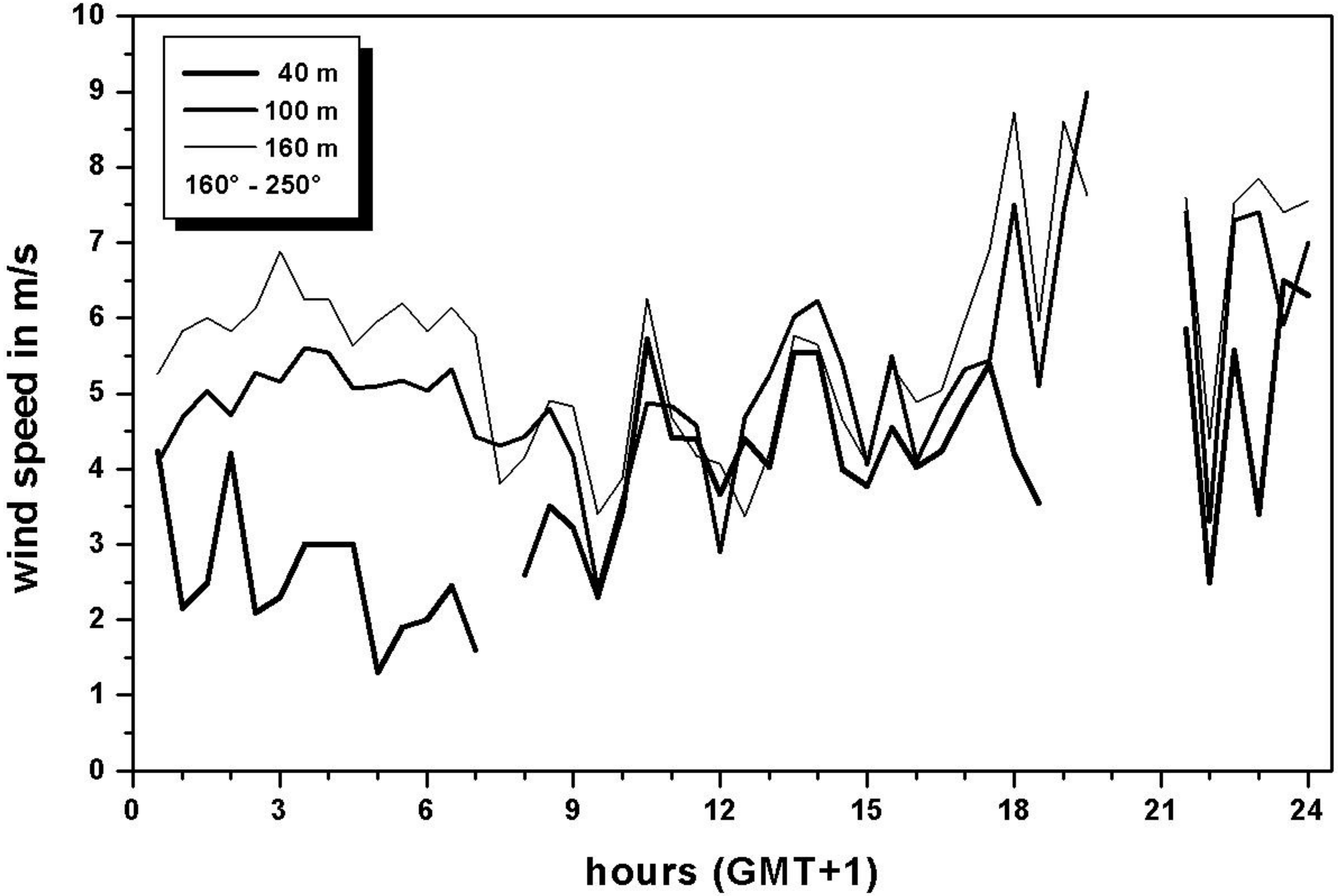
Mean daily courses



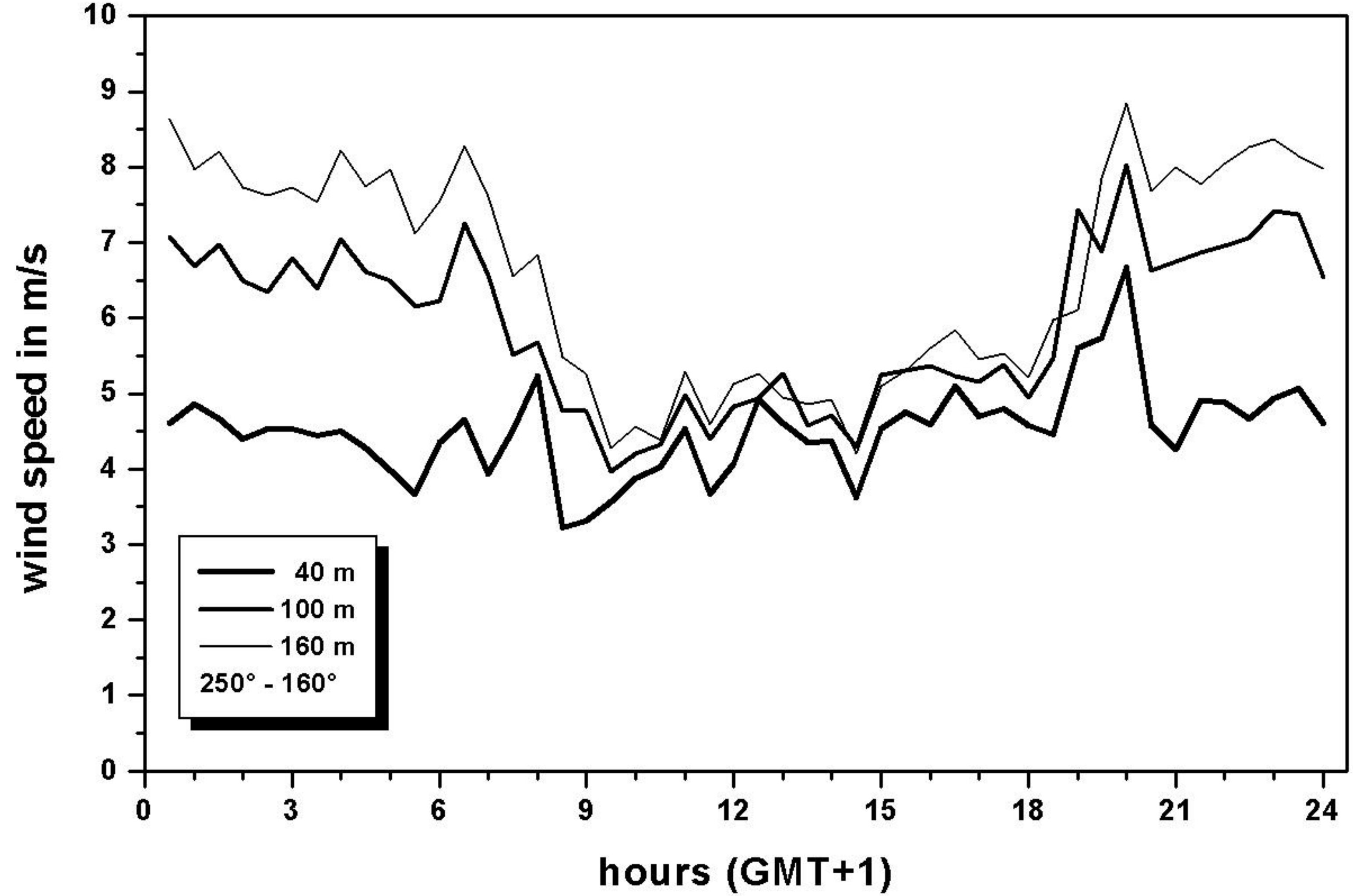
Mean daily courses



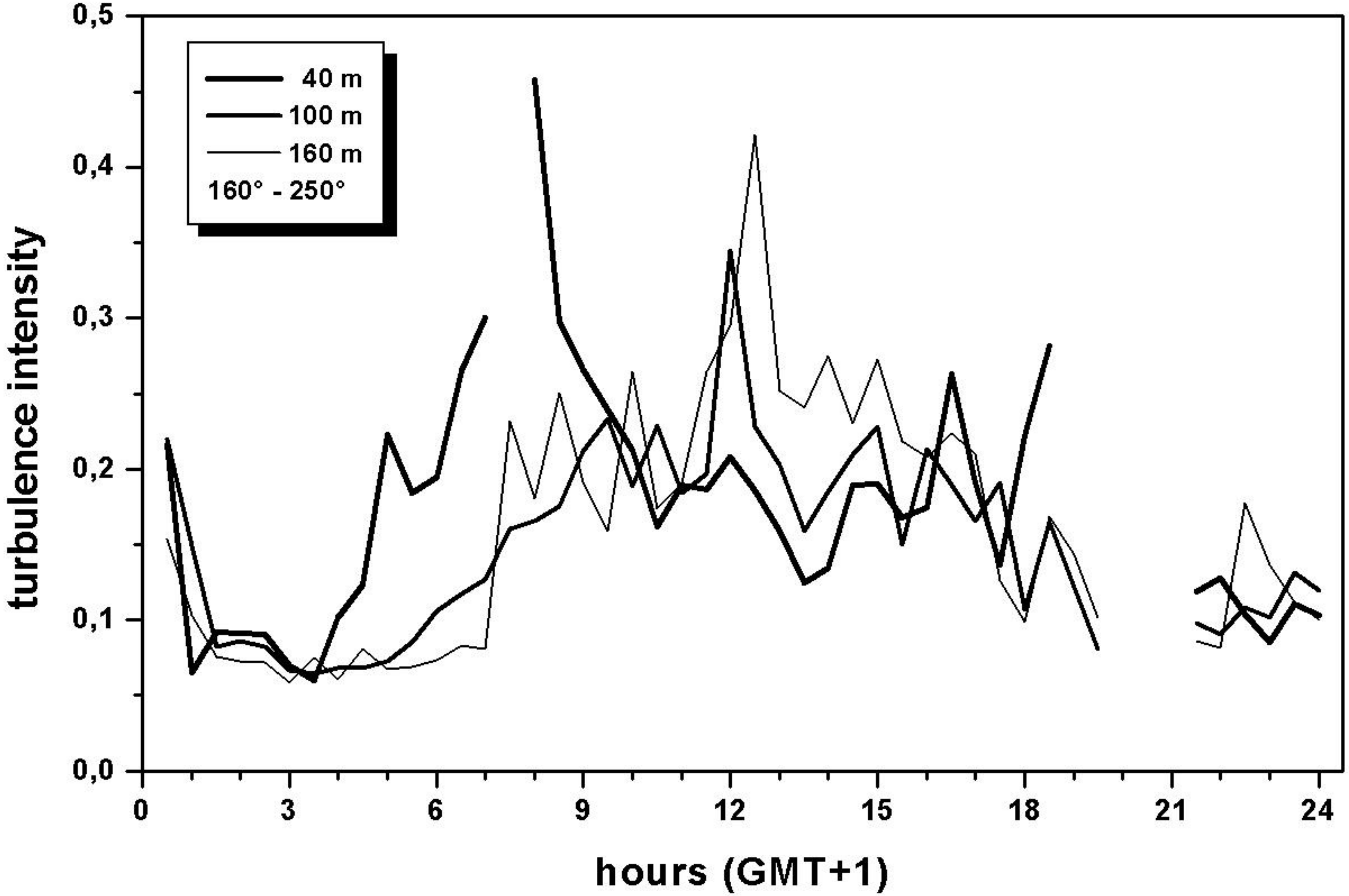
Mean daily courses of wind speed for the airport sector



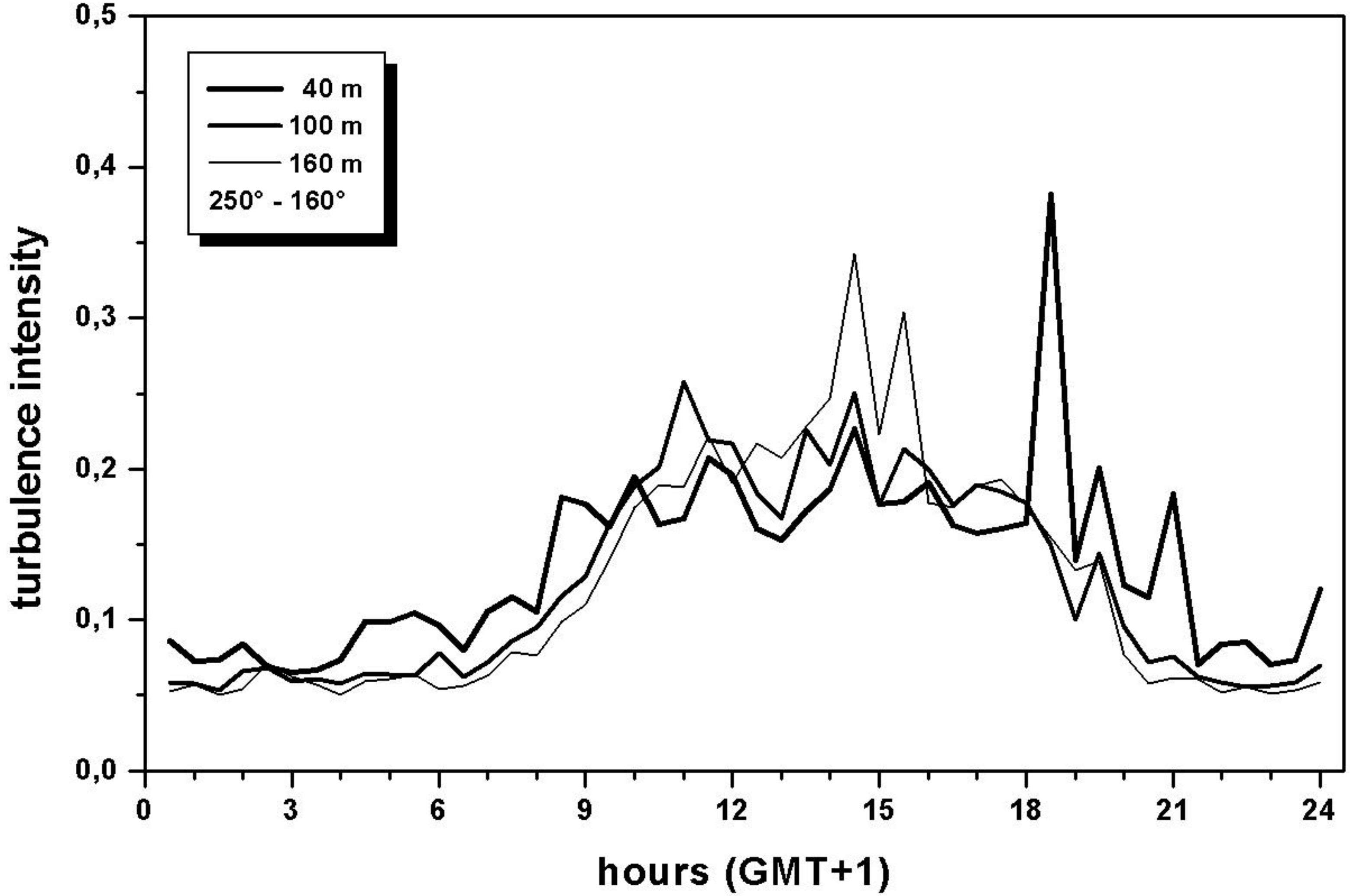
Mean daily courses of wind speed for wind sector



Mean daily courses of turbulence intensity for the airport sector



Mean daily courses of turbulence intensity for wind sector



Summary

- **Emission indices from passive FTIR spectrometry**
- **Correlations between the CO, NO and CO_2 measurement results in ambient air**
- **Emissions of single aircraft can be detected in the measured temporal high resolution data from FTIR absorption spectrometry and DOAS**
- **High NO_x concentrations (> 100 µg/m^3) at position 1 during some hours daily**
- **Concentration NO higher than NO_2 at 19 October from 12:00 until 14:00**
- **Daily maximum of NO and NO_2 around 06:00 and 20:00**

Date	Duration	Time	CO (max) FTIR [µg/m³]	CO2 (max) FTIR [mg/m³]	EI(CO) [g/kg]	number of aircraft	Time	NO2, NO (max) DOAS [µg/m³]	EI(NOx) [g/kg]
12/10/2004	10:16-10:33	10:24	1038.6	783.1	28	7			
12/10/2004	11:00-11:23	11:20	1029.3	751.7	16.9	18			
12/10/2004	11:42-11:56	11:50	626.4	709.3	14.2	10			
12/10/2004	12:38-12:52	12:49	779.0	722.2	34.1	11			
12/10/2004	13:25-13:44	13:36	815.1	707.4	18.1	6	13:35	93.4 NO2	7.5
12/10/2004	14:26-14:43	14:35	762.7	735.1	12.1				
12/10/2004	17:26-17:43	17:40	742.9	768.0	5.4		17:42	64.0 NO2	1.5
13/10/2004	08:22-08:30	08:28	739.4	788.7	12.7				
13/10/2004	08:33-08:55	08:44	812.7	812.7	9	7	08:43	74.3 NO2	2.6
13/10/2004	08:55-09:07	09:01	753.4	764.7	5	9	09:02	87.2 NO2	2
13/10/2004	09:07-09:15	09:12	818.2	818.2	8.5	4			
13/10/2004	09:42-09:51	09:48	931.5	746.2	19.1	10	09:49	98.2 NO2	4
14/10/2004	12:36-12:56	12:45	603.2	807.1	7.7				
14/10/2004	12:59-13:07	13:04	914.1	788.7	5	1 B747, ignition			
14/10/2004	13:07-13:13	13:10	1234.3	845.9	14.4	1 B747, idle			
14/10/2004	13:52-14:02	14:00	557.8	766.5	13.1	1 B737, ignition			
15/10/2004	12:55-13:04	13:01	893.1	792.4	16		13:02	54.4 NO	1.2
15/10/2004	13:04-13:12	13:09	776.7	775.7	4		13:08	81.9 NO2	2.7
15/10/2004	14:02-14:13	14:10	767.3	738.8	68	1 CRJ 200, ignition			
18/10/2004	15:19-15:30	15:27	2782.9	881.0	32	1 B747, idle	15:24	192 NO2	5.5
18/10/2004	15:30-15:41	15:36	1665.1	901.3	6.9	1 B747, idle	15:37	153 NO2	1.8
19/10/2004	09:28-09:39	09:36	1234.3	864.4	23.3		09:36	105 NO2	2.5
19/10/2004	10:07-10:15	10:12	894.3	796.1	20.5	1 B737, idle	10:12	42.4 NO	1.5
19/10/2004	10:18-10:29	10:24	1420.6	821.9	7.9		10:24	42.0 NO	1.0
19/10/2004	10:54-11:05	11:02	844.2	794.2	27.1		11:03	49.4 NO	3.9
19/10/2004	11:27-11:36	11:33	1071.2	781.3	56.4		11:31	79.6 NO2	3.3

Airport Mexico City

Set up of the measurements

Airport air pollution measurements

Spicer, C.W. et al., 1985, 1992, 1994: VOC

Moussiopoulos, N. et al., 1997: new Athens airport air quality

Stedman, J.R. et al., 1997: NOx and NO2

Umweltplanung, Arbeits- und Umweltschutz, 1998: VOC

Popp, P.J. et al., 1999: NO

Fries, 2003: VOC

Pison, I., Menut, L, 2004: ozone over Paris area.

Yu, K.N. et al., 2004: large urban airports local air quality

Free University Berlin, Status of the Current Level of Development and Understanding in the Field of Modelling Pollutant Dispersion at Airports, 2004

Unal, A. et al., 2005: Atlanta International Airport air quality

Kottmeier, C. et al., 2005: SODAR, RASS, Doppler-LIDAR

Herndon, S.C. et al, 2004, 2006: NO and NO2, VOC.

Carslaw, M., 2006: air pollution at London-Heathrow

Raper, D.W. et al. 2006: airport air quality

A strategy towards sustainable development of UK aviation, 2006

Fourth ROSE Field Trial

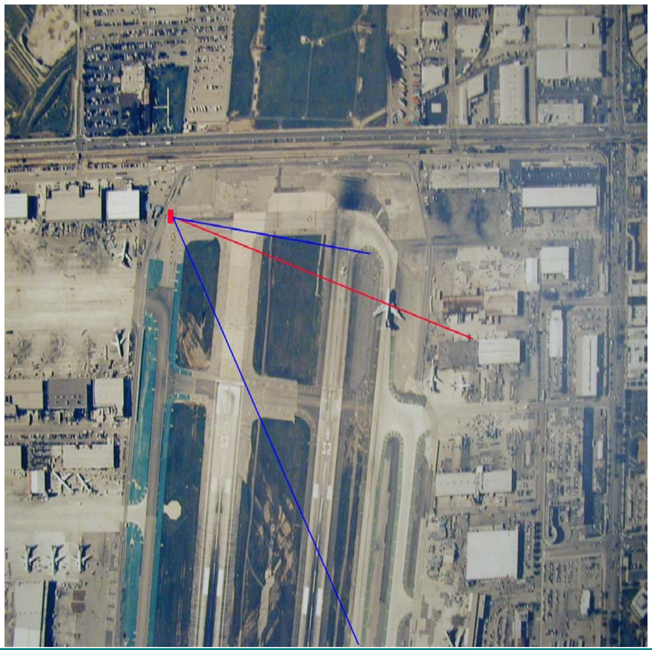
Further LIDAR measurements

Activities of Spectrasyne: VOC, benzene and NO mass emissions and concentrations

Airport Duesseldorf: NO_2 concentration distribution

Activities in the US by DoT

Report available



Limits of the present

Emissions of in-service aircraft under all typical engine conditions at airports are not known

Take-off main gap

Limits of the present

VOC composition of aircraft exhausts

Size distribution and composition of aerosols in different parts of the aircraft exhaust plume

Necessary are measurements in the initial and aging plume

Detection of important compounds as e.g. HONO

Challenges for the future

Co-operation: ECATS

Good management because experiences from complex airport campaigns are available

Further research funding: EC FP 7

new techniques, new methodologies, more compounds, further campaigns

Acknowledgements

Measurements at airport Frankfurt/Main, London-Heathrow and Vienna were undertaken within the frame of the EC funded projects AEROJET 2 (BRPR CT-98-0618) and ARTEMIS (1999-RD.10429) as well as at airport Munich with funding by Deutsche Lufthansa AG and airport Paris CDG with funding by ONERA

A fruitful co-operation with the airport authorities of Frankfurt/Main, London-Heathrow, Vienna, Munich, Zuerich, Paris CDG and Budapest as well as Deutsche Lufthansa AG, British Airways, Austrian Airlines Group and SWISS supported this work

Without this co-operation no reliable investigations would have been possible