A Network for an environmentally compatible air transport system

Airport Air Quality

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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: Since ICAO database is used certain issues are revealed:

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 for human and animals, odour)?

Problems

Interaction between exhaust plume and ambient air (physics, chemistry) is not well understood but is of major importance 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)
- 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

Methods

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

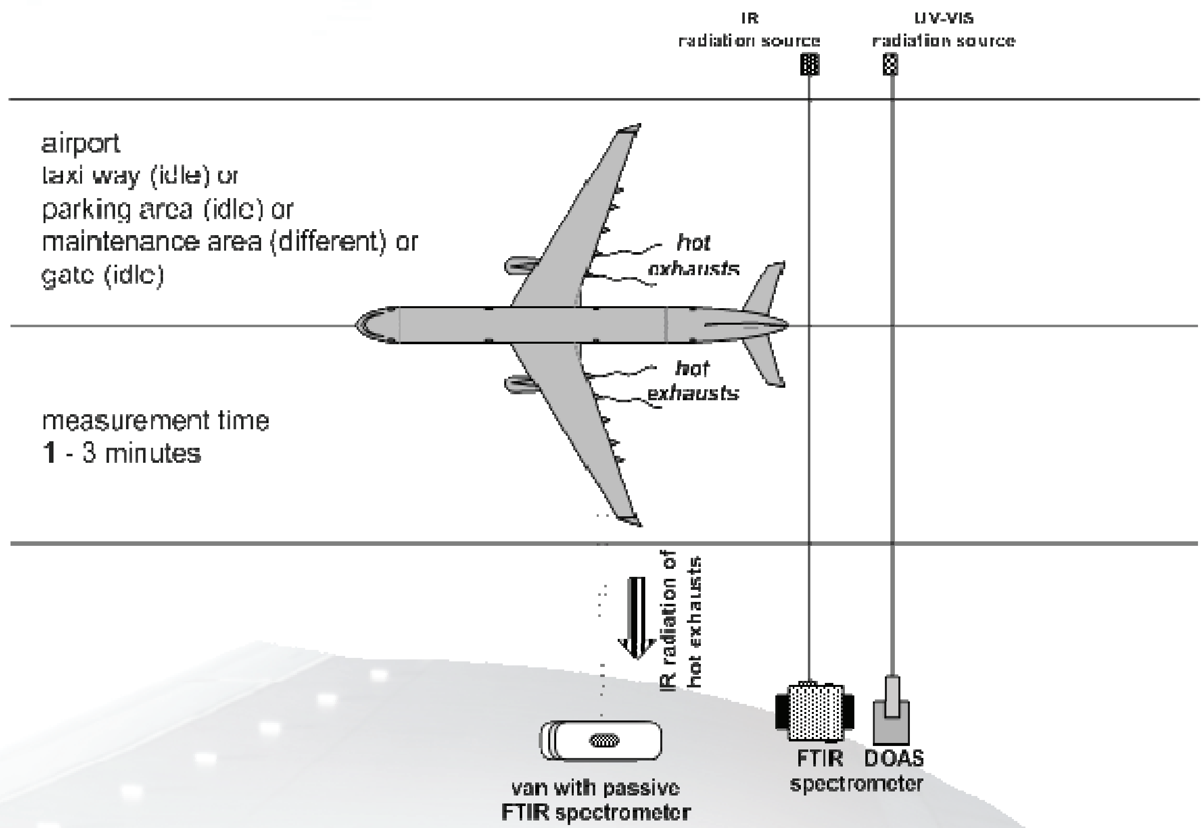
- Concentration measurement in the plume with FTIR & DOAS

- 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

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)

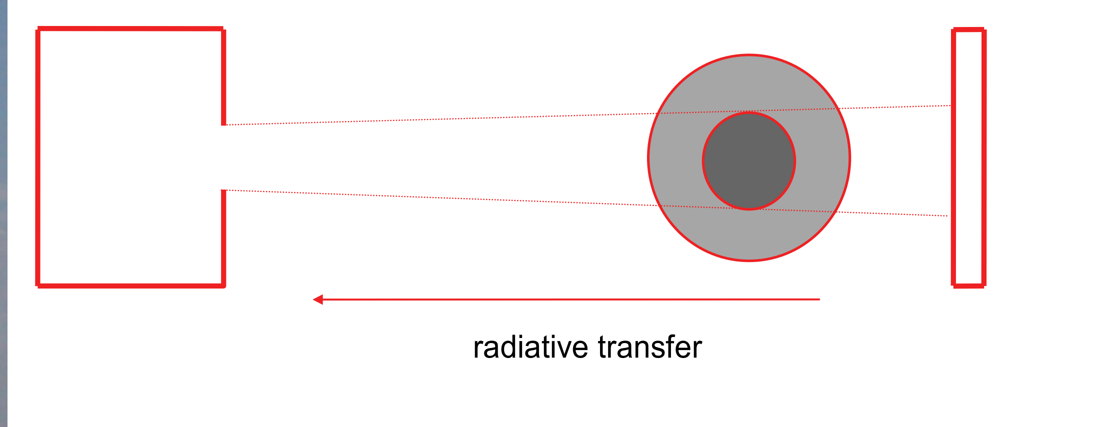
Improvement of measurement technique

Passive FTIR emission spectrometry has 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?

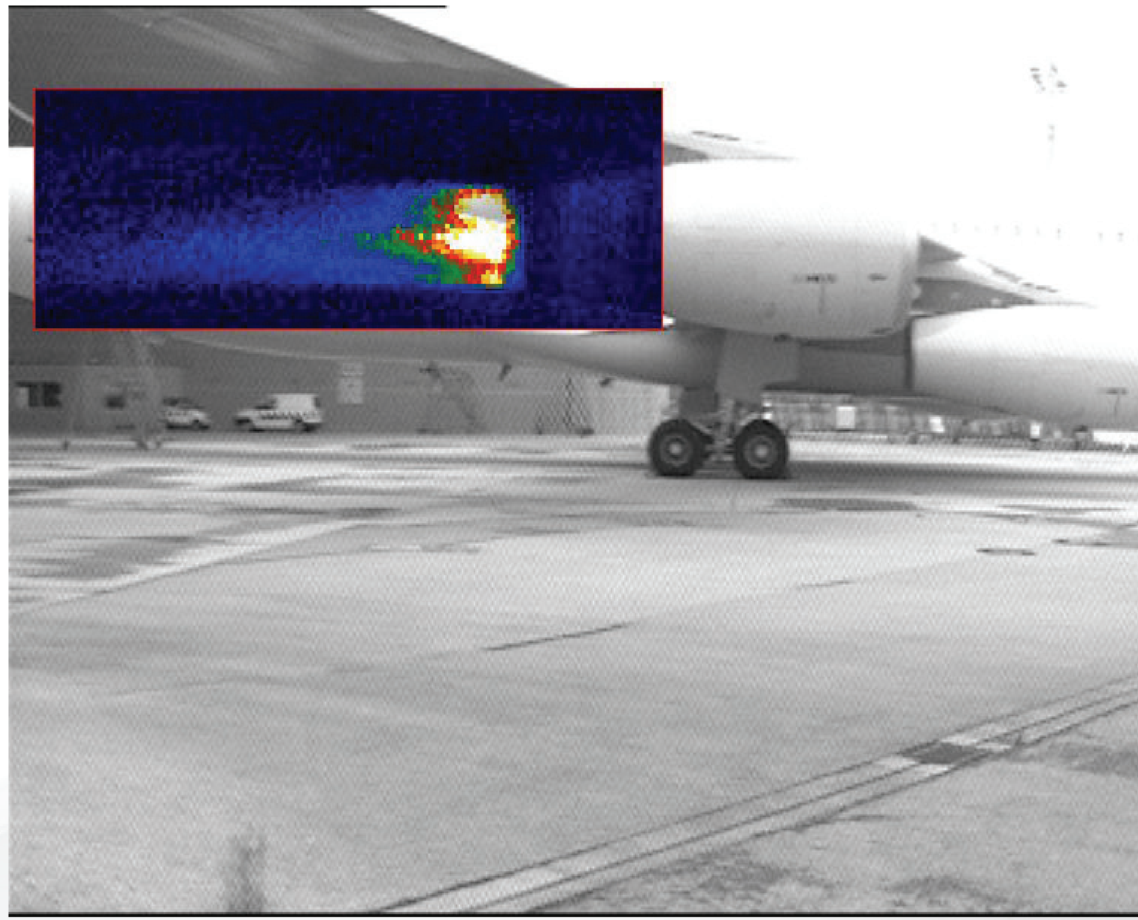
Measurement principle



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

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

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



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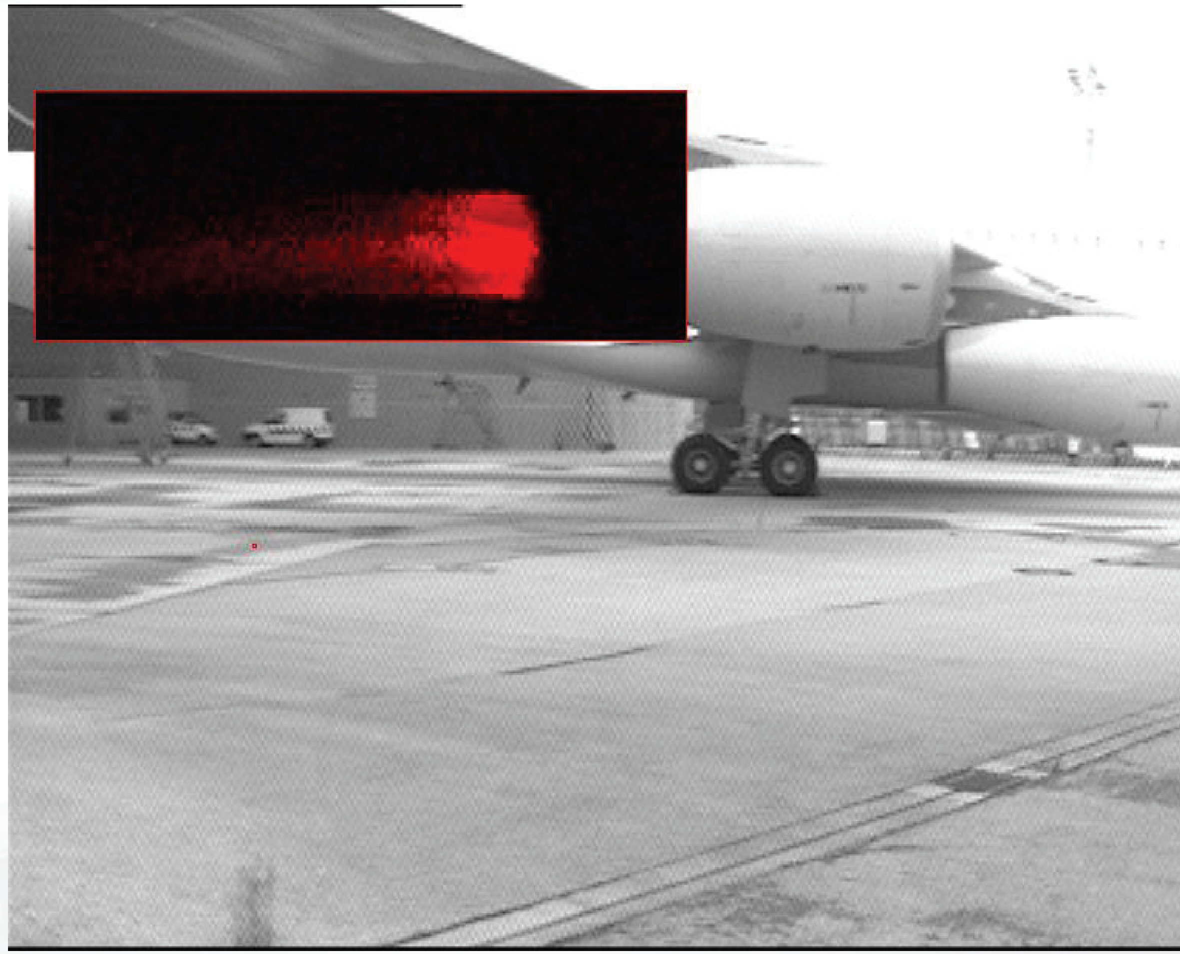
Main engine: gas radiation mode (absorption / emission) approx. length of hottest part 0.9 and 1.2 m, diameter 1.6 m



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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

For NOx 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 conducted in Budapest and one in Athens

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

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Results

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

Overall at Budapest Airport, 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

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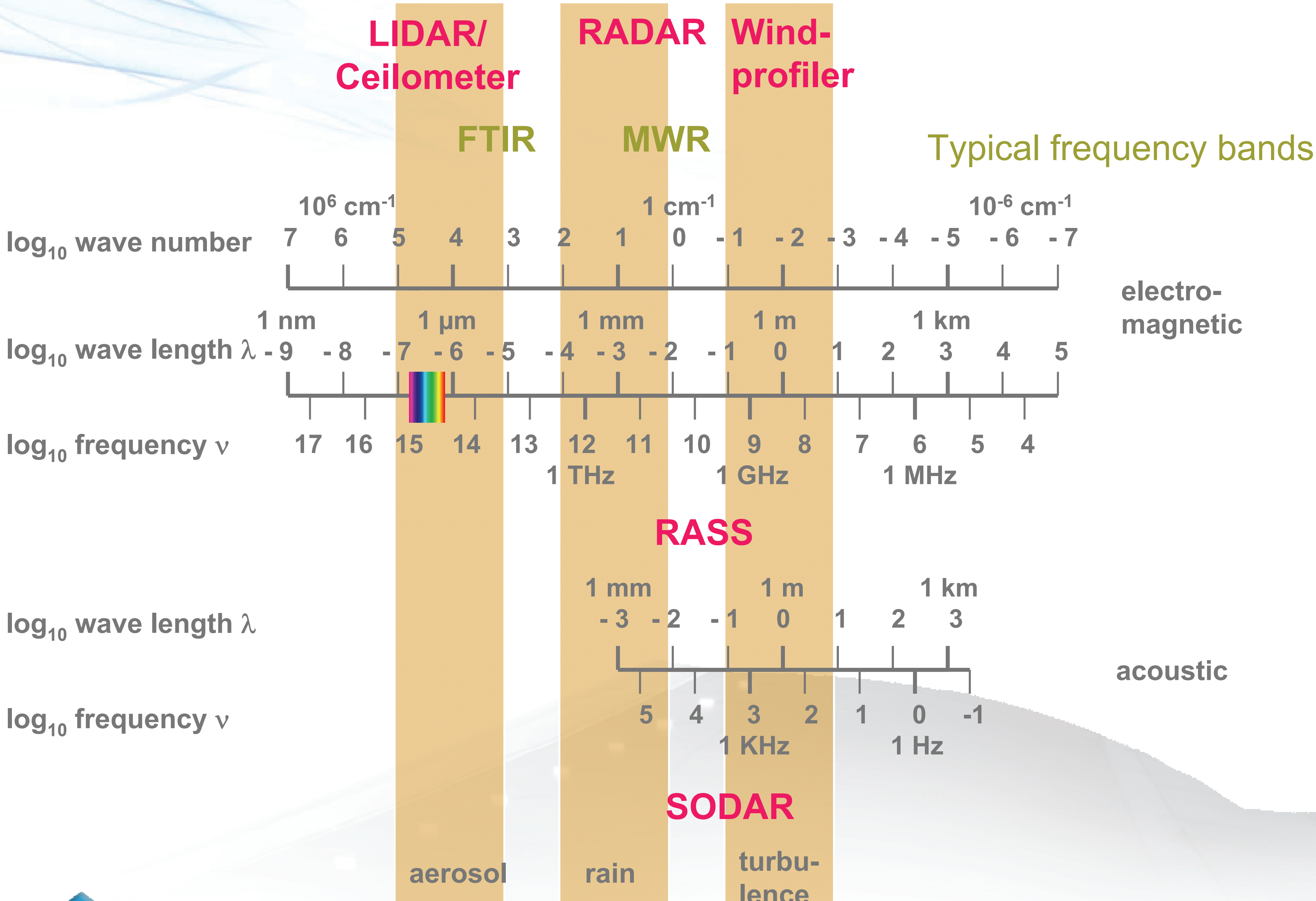
Remote sensing of atmospheric parameters at airports



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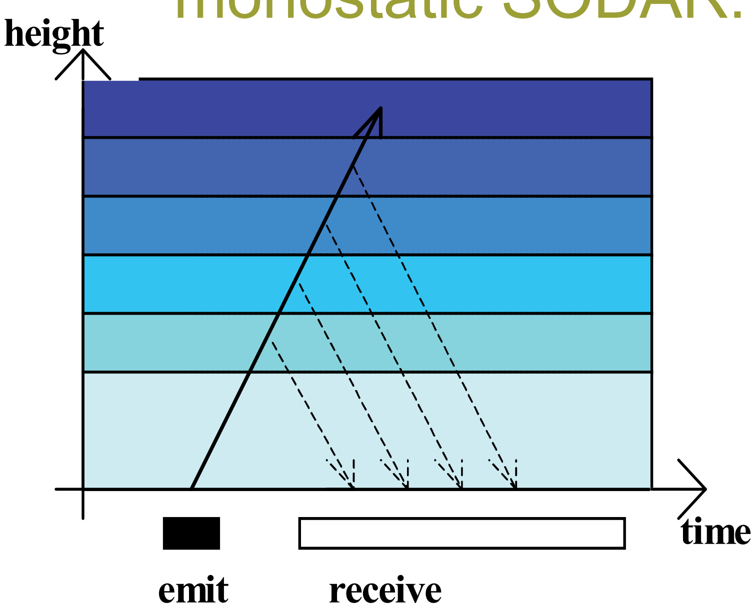
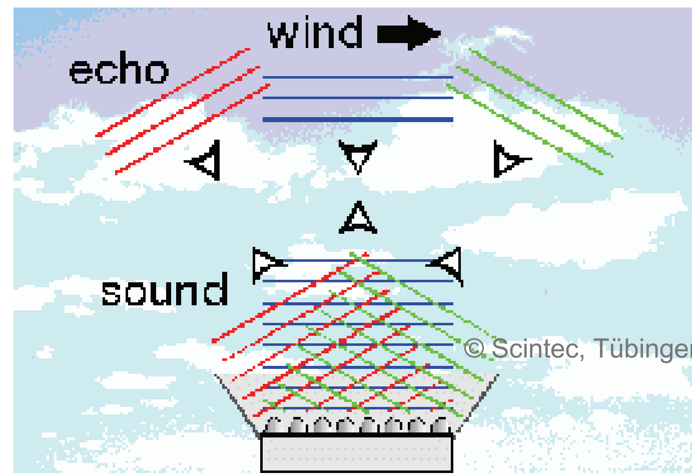
Acoustic Remote sensing

backscatter at thermal fluctuations and gradients (and large snow flakes) in the atmosphere

monostatic SODAR: measuring principles





deduction:

sound travel time = height
backscatter intensity = turbulence
Doppler-shift = wind speed

Emission of sound waves into three directions:

in order to measure all three components of the wind (horizontal and vertical)

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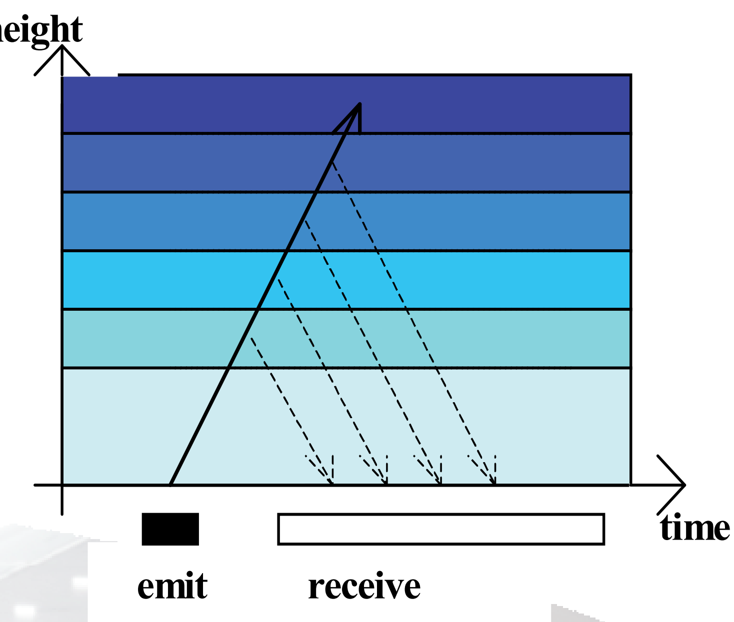
Optical Remote sensing

backscatter at aerosol particles, insects, water droplets, ice, and snow (fog and clouds are opaque) in the atmosphere

Ceilometer/LIDAR measuring principle



detection:

travel time of signal	= height
backscatter intensity	= particle size and number distribution
Doppler-shift	= cannot be analyzed from ceilometer data from LIDAR: velocity component in line of sight

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Difference between acoustic and optical remote sensing

acoustic remote sensing:

SODAR sees

➔ thermal structure of atmospheric boundary layer
➔ wind and turbulence profiles

optical remote sensing:

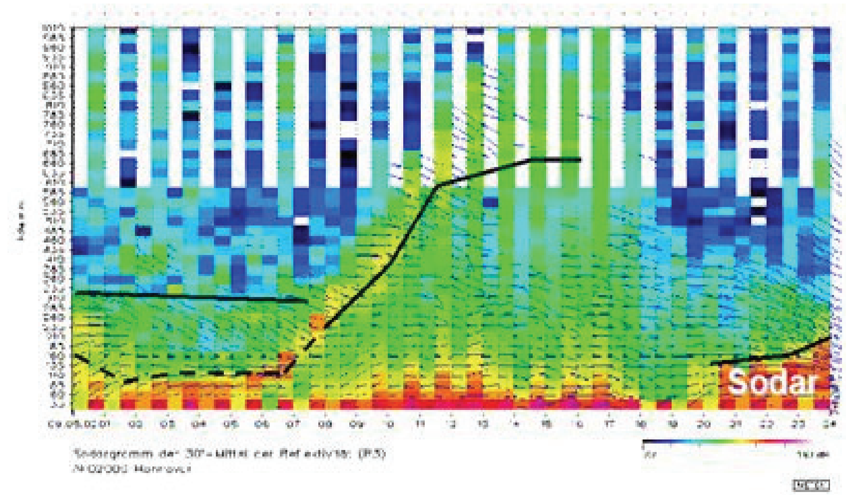
ceilometer sees

➔ aerosol content of atmospheric boundary layer

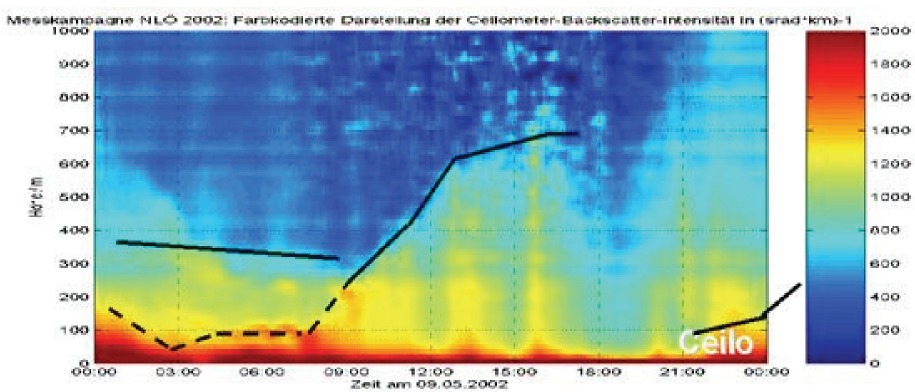
(often this follows the thermal structure of the boundary layer but not always, advection and secondary formation of aerosols has influence, too)

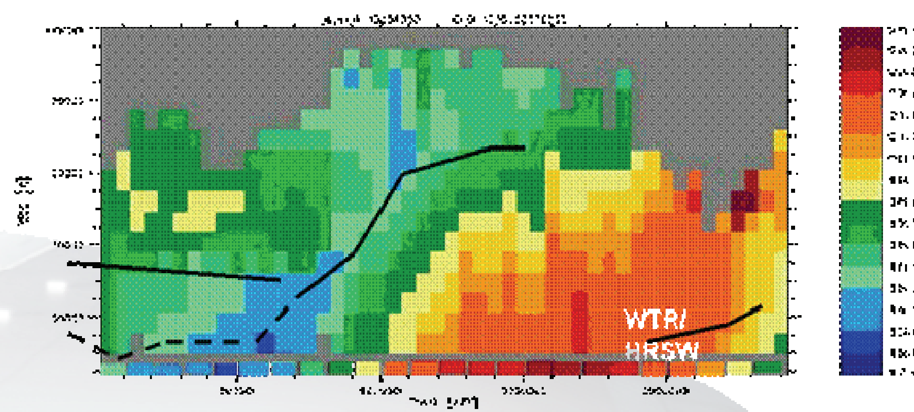
Mixing Layer Height estimation

Comparison of SODAR measurements with data from a Wind-Temperature-RADAR (RASS) of IMK-ASF and a ceilometer of Vaisala (backscatter at 0.9 µm) for 09 May 2002



Results of MLH retrieval during simultaneous operation partly agree and partly complement each other





Emeis, S., Chr. Münkel, S. Vogt, W.J. Müller, K. Schäfer, 2004: Atmospheric boundary-layer structure from simultaneous SODAR, RASS, and ceilometer measurements. Atmos. Environ., 38, 273-286.

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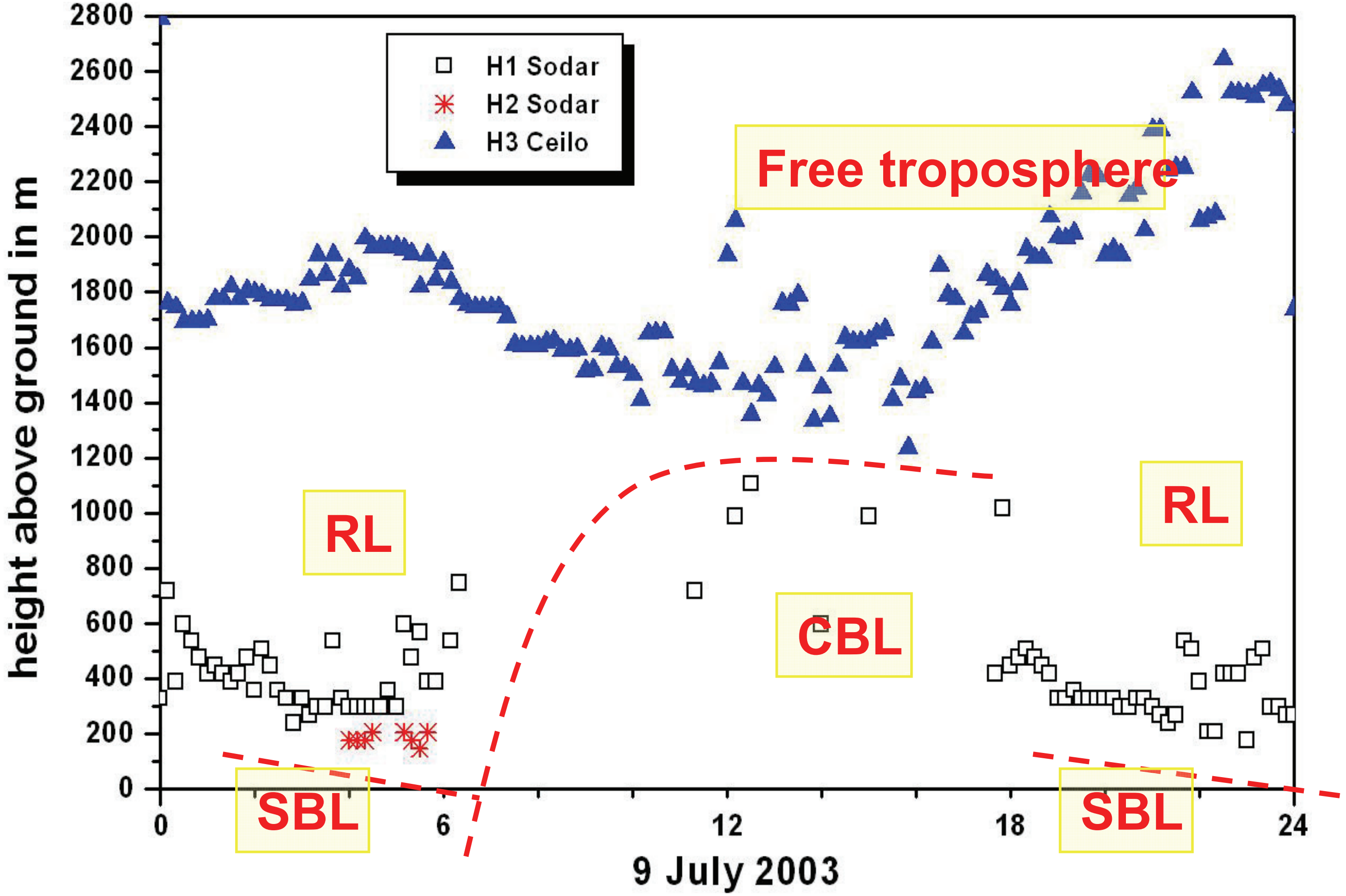
Mixing Layer Height estimation



SBL:
stable boundary layer (usually at night and in winter)

CBL:
convective boundary layer (usually at daytime due to strong insolation)

RL:
residual layer (usually at night-time)

Diurnal variation of mixing-layer height from SODAR and Ceilometer data (Budapest)

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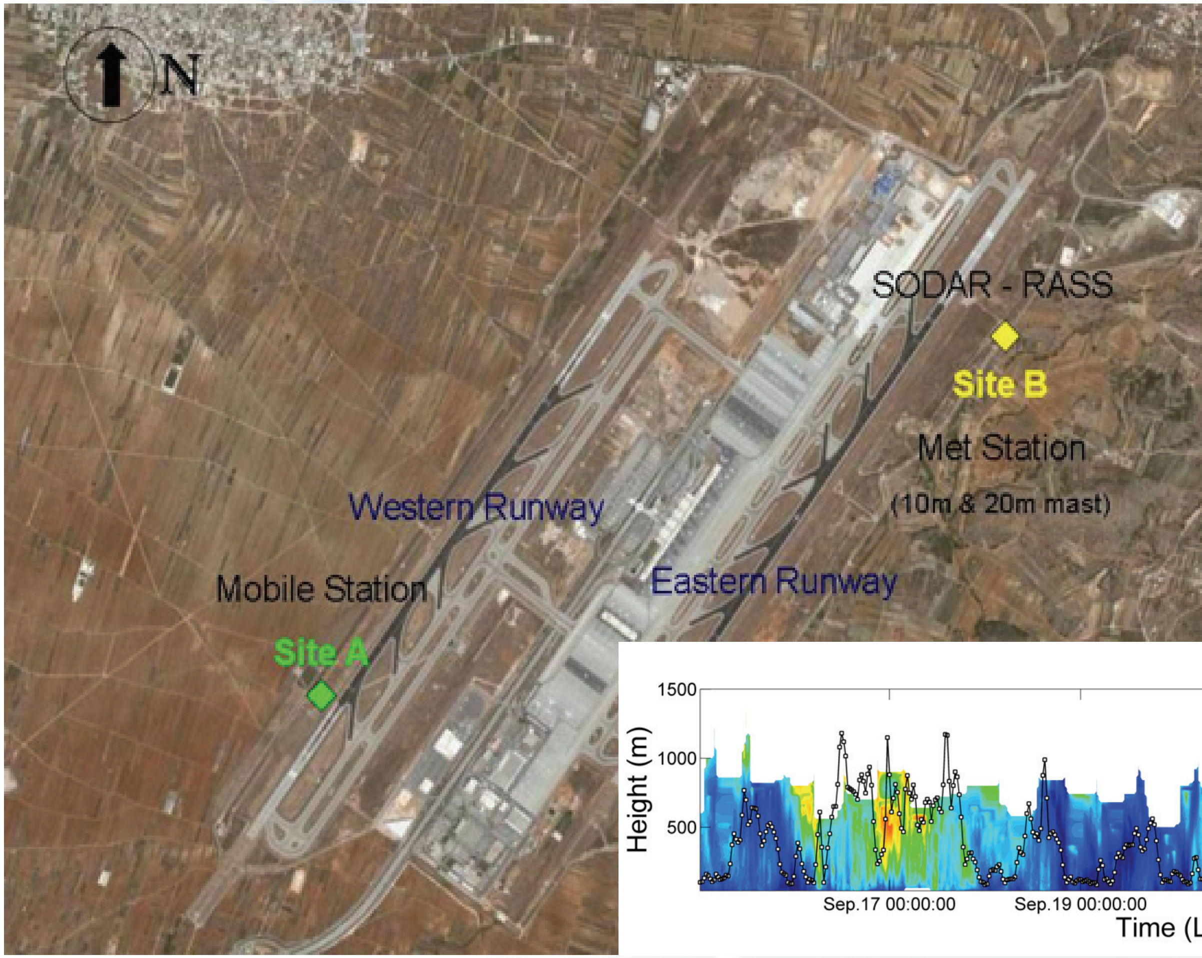
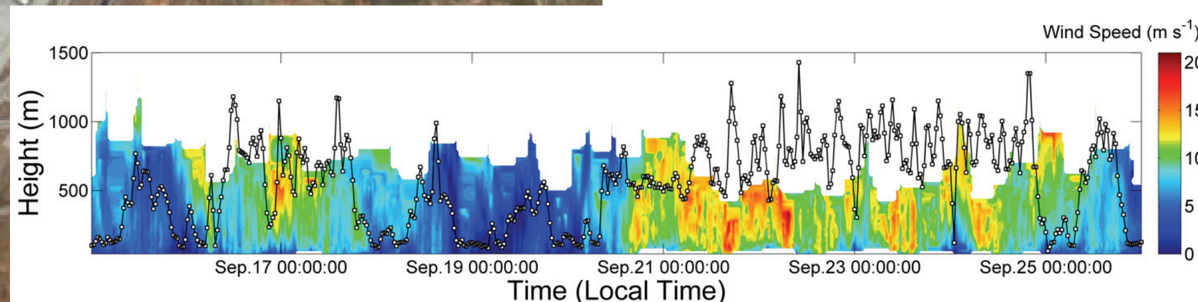
Mixing Layer Height estimation





Athens International Airport Experimental Campaign

13 September – 25 September 2007

Variation of wind speed and mixing-layer height from SODAR data (Athens)

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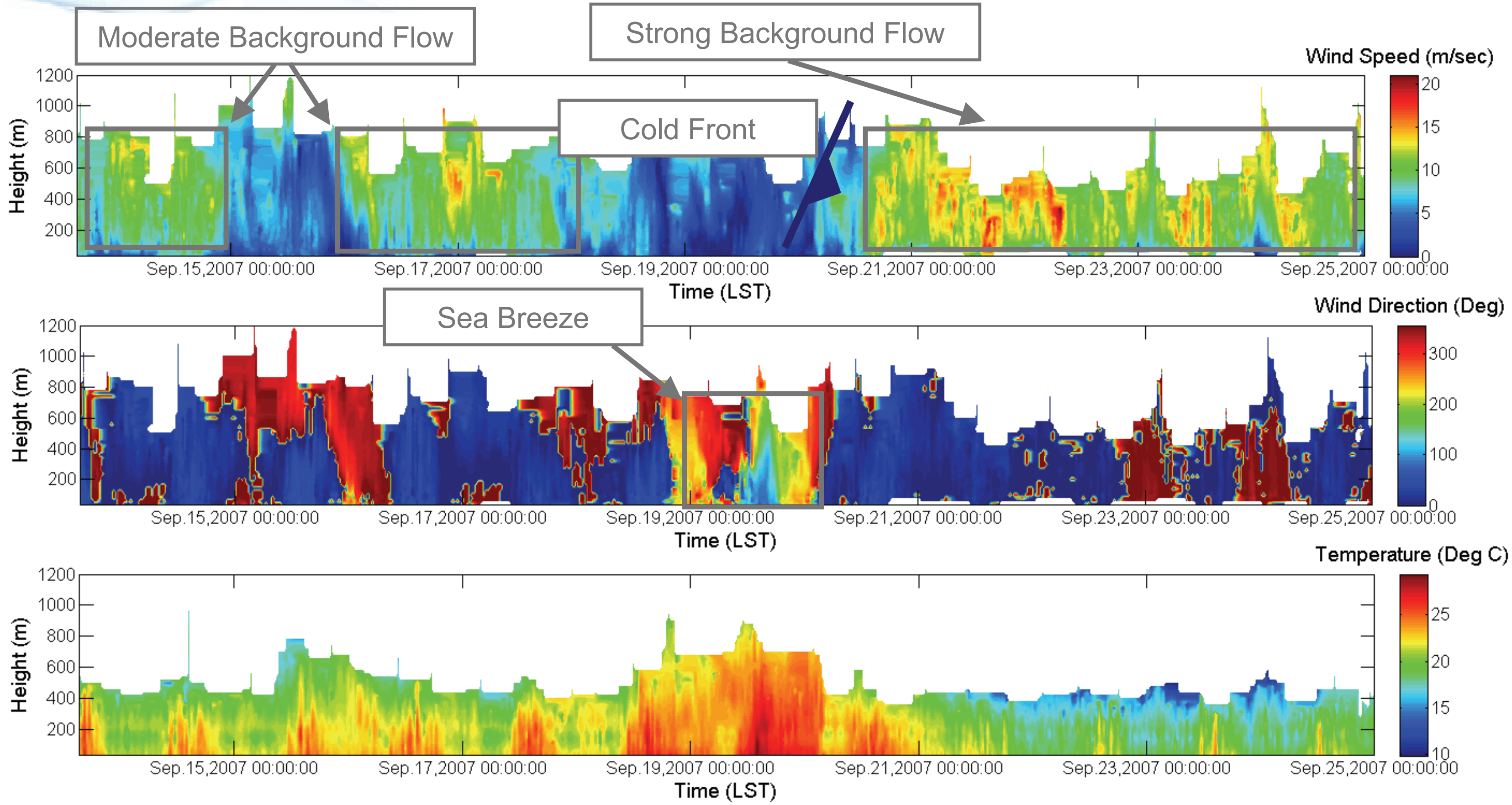
Influence of Meteorology on Airport Air Quality



Time-height plots of the wind speed, wind direction and virtual temperature measured by the SODAR – RASS system for 13 September – 25 September 2007

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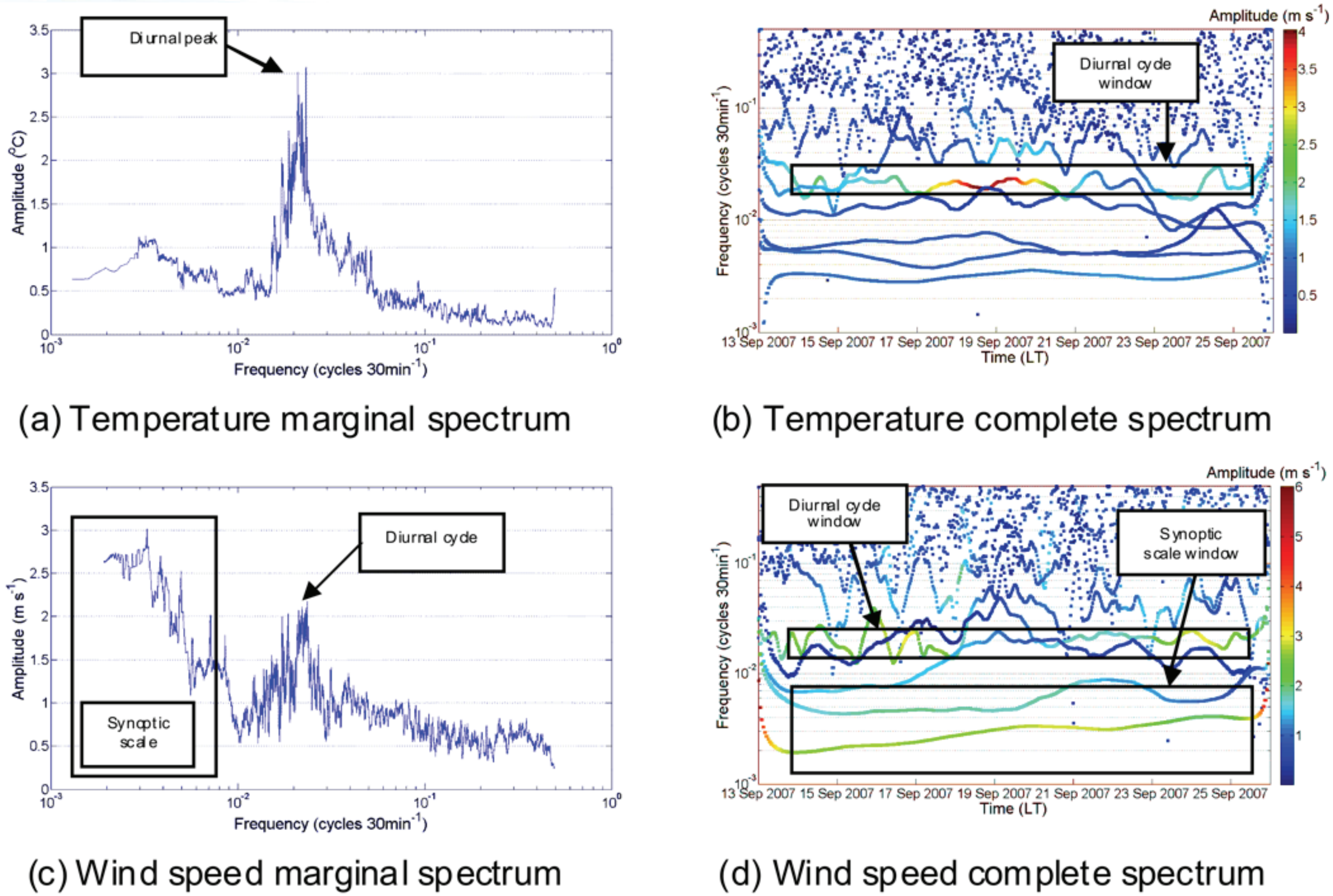
Spectral analysis in air-quality datasets / Hilbert-Huang Transform (I)

- In order to identify and quantify the various processes linked with meteorology and air-quality processes, the HHT algorithm was selected to be applied on each time-series (meteorology: wind speed and temperature, air quality: SO_2, CO, NO_x, NO_2, NO, O_3 and PM_{10}) provided by the monitoring stations of the AIA.
- The HHT algorithm is an adaptive and empirically based data analysis method, well-suited for the study of intermittent and non-stationary motions and processes that take place within the ABL and consists of two steps of analysis
  - The first step, the Empirical Mode Decomposition (EMD), decomposes the original time-series into a finite number of Intrinsic Mode Function (IMF) components, which represent the timescales that comprise the dataset.
  - The Hilbert transform (second step) is applied to each IMF to extract the instantaneous frequencies and amplitudes, as a function of time. The instantaneous frequency calculated by the Hilbert transform, is the frequency of a sine wave that locally fits the signal, rather than the frequency of a sine wave that is present throughout the entire time-series signal.

Spectral analysis in air-quality datasets / Hilbert-Huang Transform (II)



(a) Temperature HHT marginal spectrum; (b) Temperature HHT complete spectrum; (c) Wind speed HHT marginal spectrum; and (d) Wind speed HHT complete spectrum for the experimental period (Met-Station, northeastern part of AIA).

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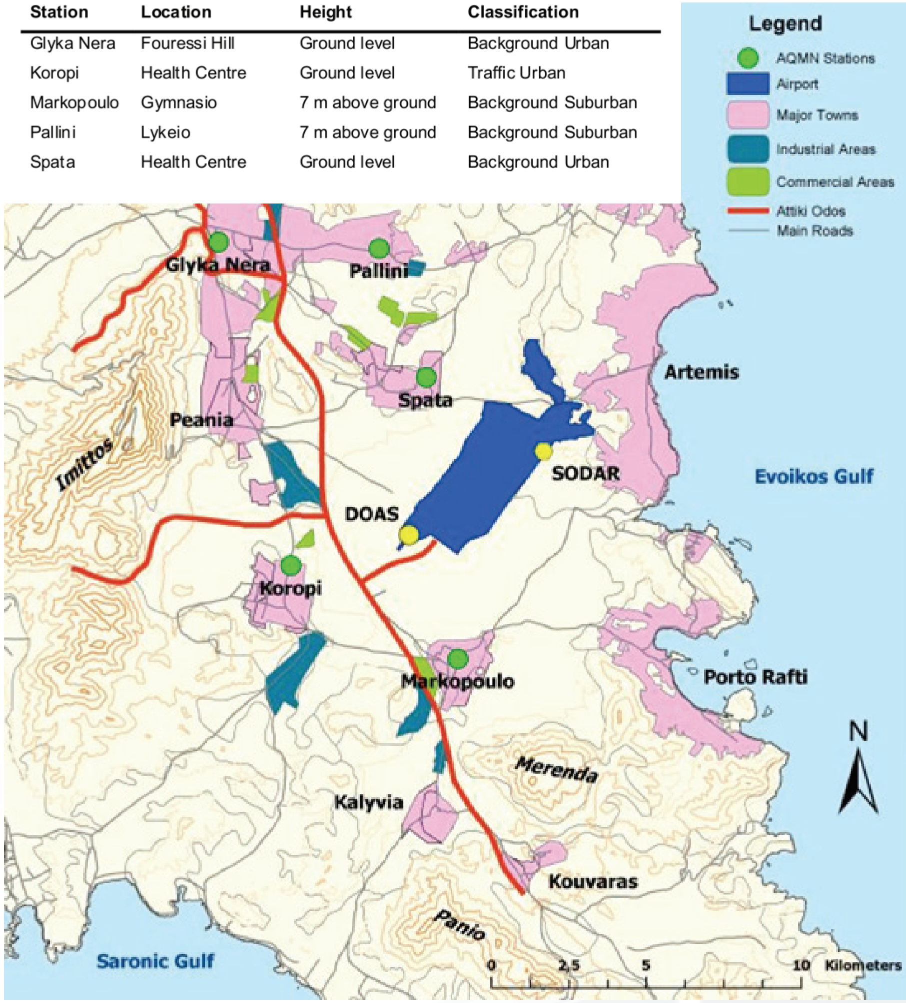
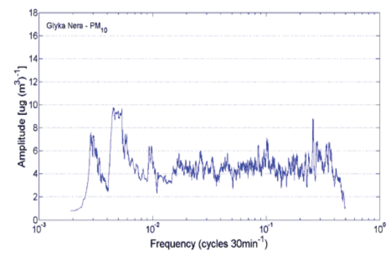
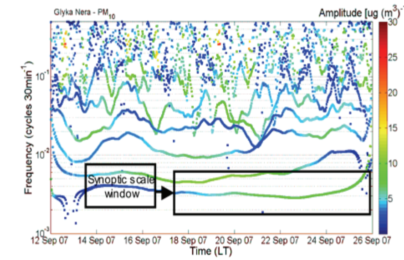
Spectral analysis in air-quality datasets / Hilbert-Huang Transform (III)

Station	Location	Height	Classification
Glyka Nera	Fouressi Hill	Ground level	Background Urban
Koropi	Health Centre	Ground level	Traffic Urban
Markopoulo	Gymnasio	7 m above ground	Background Suburban
Pallini	Lykeio	7 m above ground	Background Suburban
Spata	Health Centre	Ground level	Background Urban

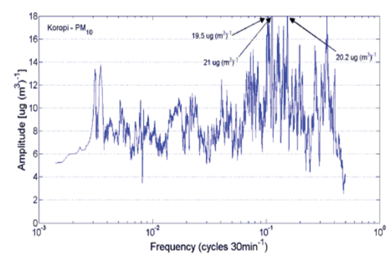




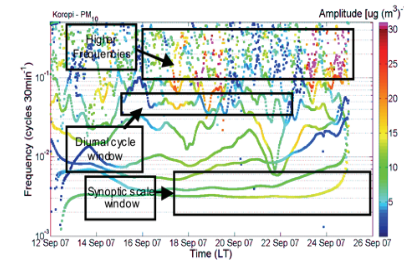
(a) Marginal spectrum (Glyka Nera)



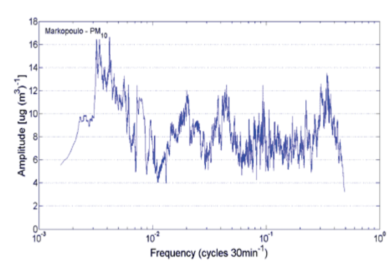
(b) Complete spectrum (Glyka Nera)



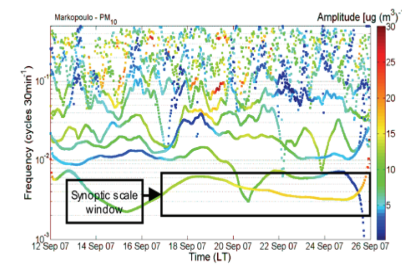
(c) Marginal spectrum (Koropi)



(d) Complete spectrum (Koropi)



(e) Marginal spectrum (Markopoulo)



(f) Complete spectrum (Markopoulo)

Hilbert spectra (marginal and complete) for NO concentrations in (a), (b) Mobile station (airport-rural); (c), (d) Spata station (Background urban); and (e), (f) Pallini station (Background suburban).

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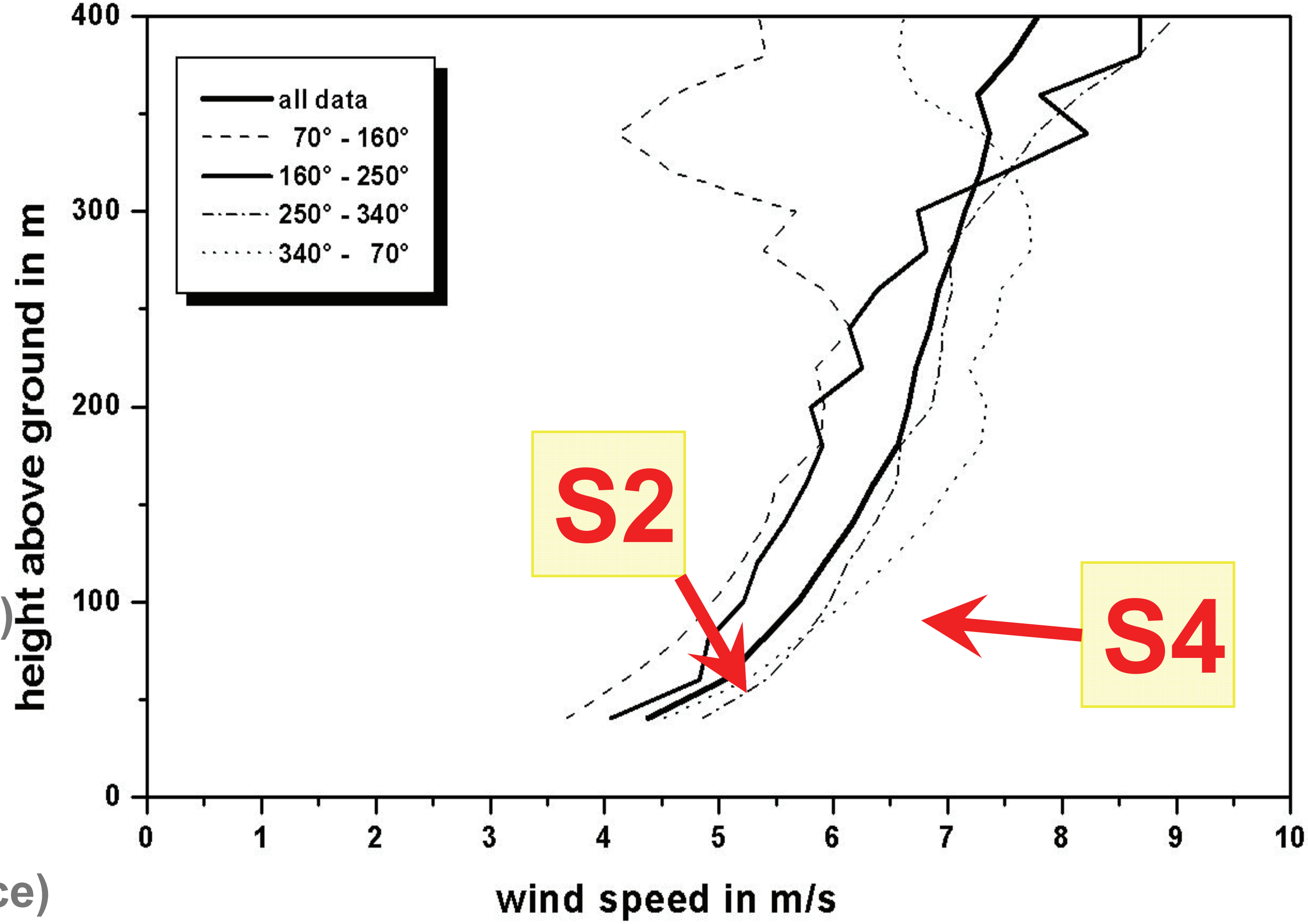
Wind and Turbulence Profiles

vertical profiles of wind speed u

CDG
June/July 2005

S2: influenced by the airport (lower wind speed over rough surface)

S4: rural profiles (higher wind speed over smooth surface)

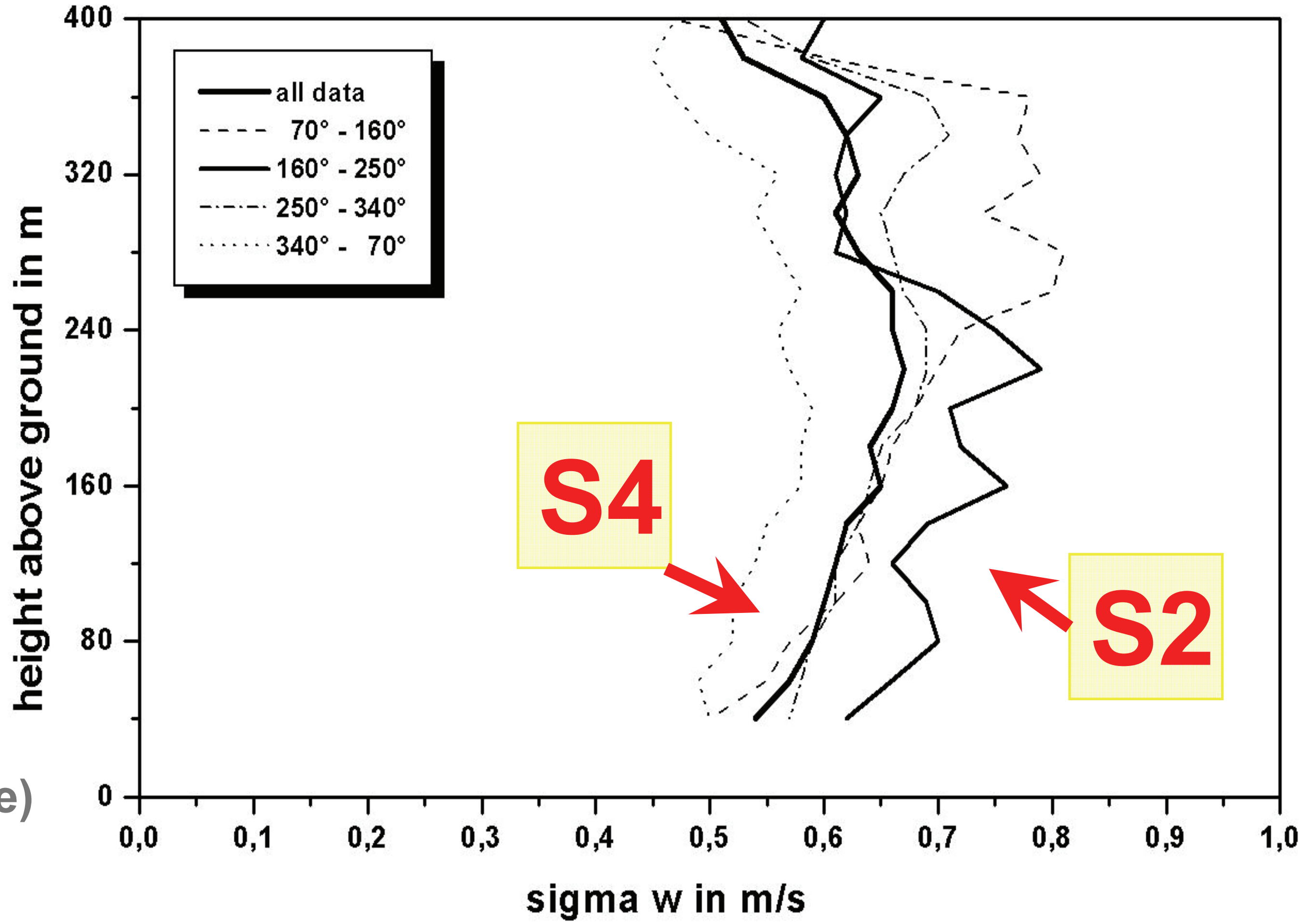


Wind and Turbulence Profiles

vertical profiles of σ_w (a measure for turbulence)

S2: influenced by the airport (higher turbulence over rough surface)

S4: rural profiles (lower turbulence over smooth surface)



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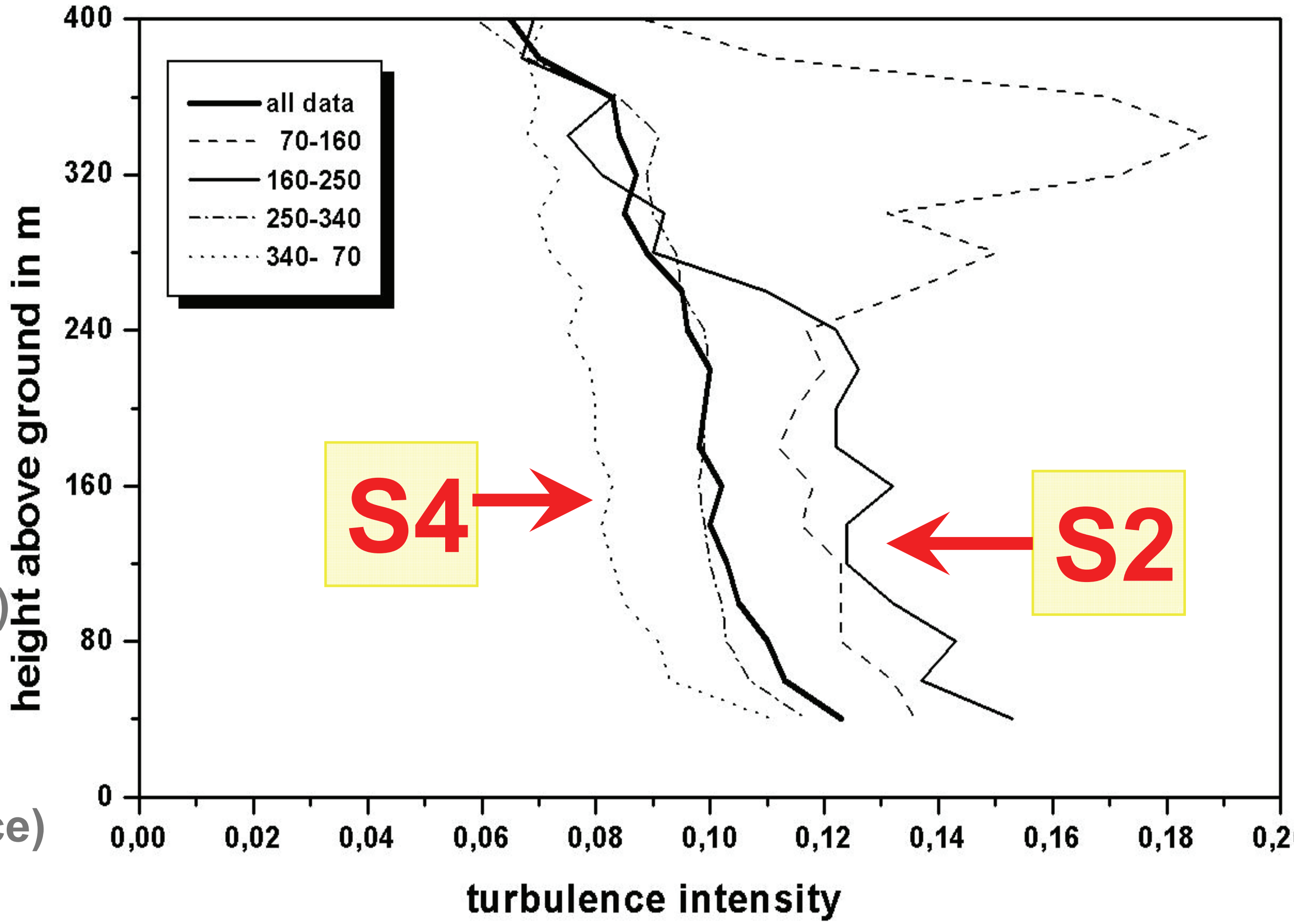
Wind and Turbulence Profiles

vertical profiles of turbulence intensity (u / σ_w)

CDG

S2: influenced by the airport (higher turbulence over rough surface)

S4: rural profiles (lower turbulence over smooth surface)



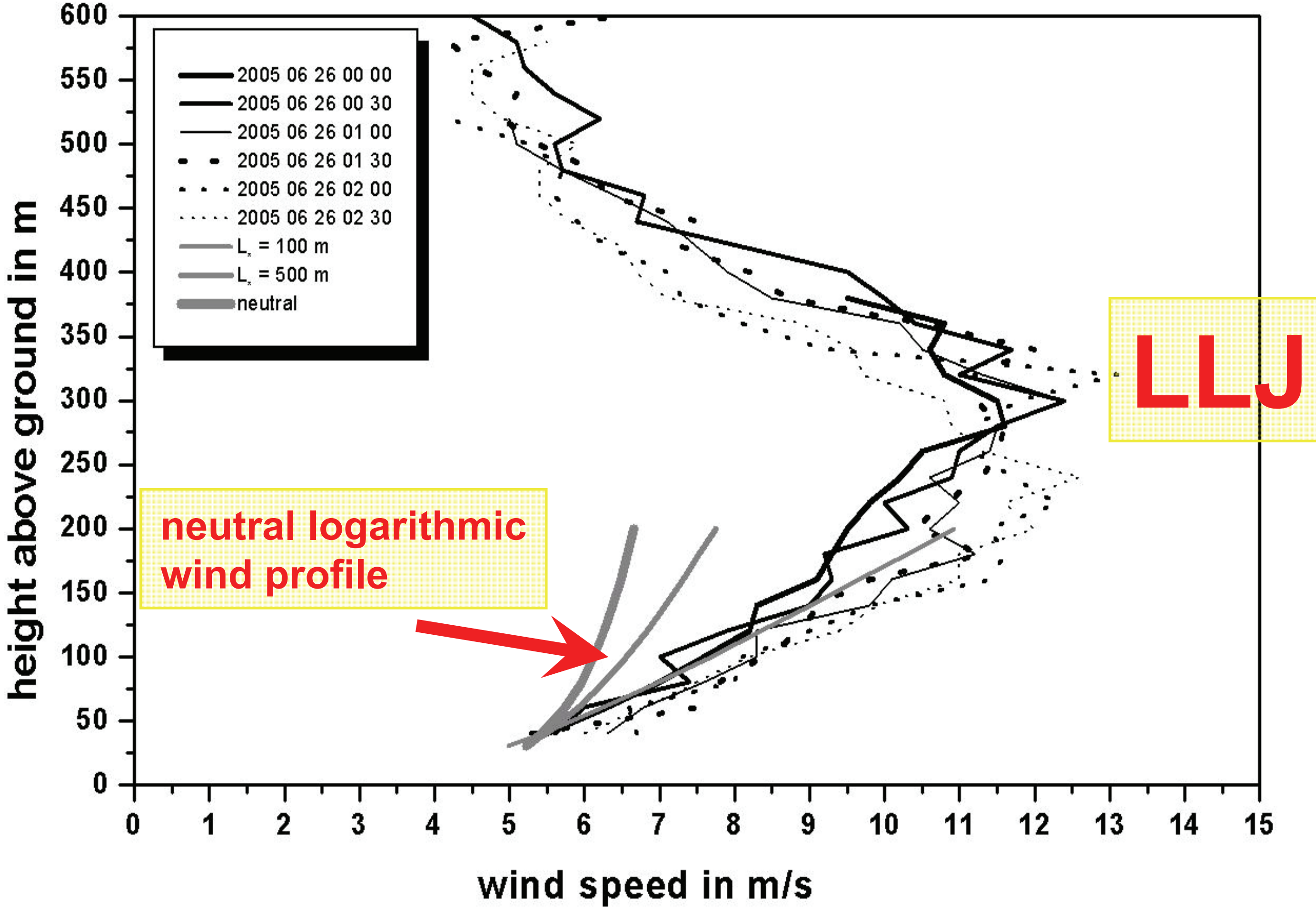
Wind and Turbulence Profiles

vertical profiles of wind speed (selected 30 min averages)

26 June 2005 CDG

LLJ between 200 and 325 m above ground

leads to strong vertical wind shear



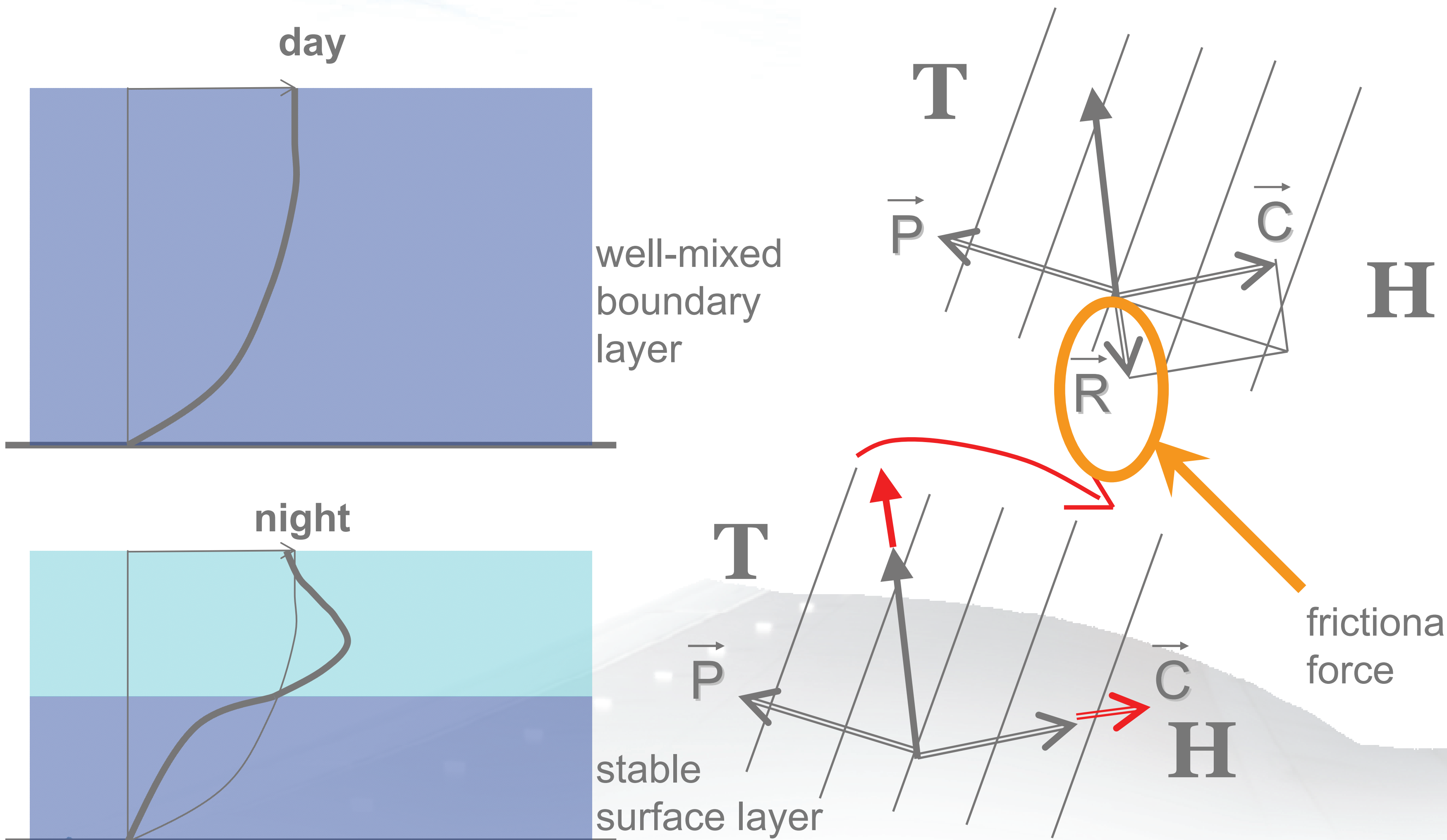
Typical weather conditions for the formation of nocturnal low-level jets (LLJ):

- clear skies
- dry air masses (low thermal radiation from the atmosphere back to the ground)
- non-vanishing synoptic pressure gradient
- low to medium synoptic wind speeds

Physical mechanism:

- rapid thermal cooling of the surface after sun set leads to the formation of a cool stable surface layer with low turbulence
- missing turbulence leads to a decoupling of the layer above the surface layer from the frictional influence of the ground on the atmospheric flow
- vanishing frictional influence leads to an acceleration of wind speed in the decoupled layer
- during the night: inertial oscillation (turning of wind direction of LLJ)
- next morning: destruction of the phenomenon due to thermal mixing from below

Nocturnal low-level jet (LLJ) and turning of wind direction with height



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Let’s take off …

Source: Stadt Stuttgart / www.lfu.baden-wuerttemberg