Katedra Meteorologii i Klimatologii WNG UŁ

Long term measurements of the energy balance at urban area in Łódź, central Poland

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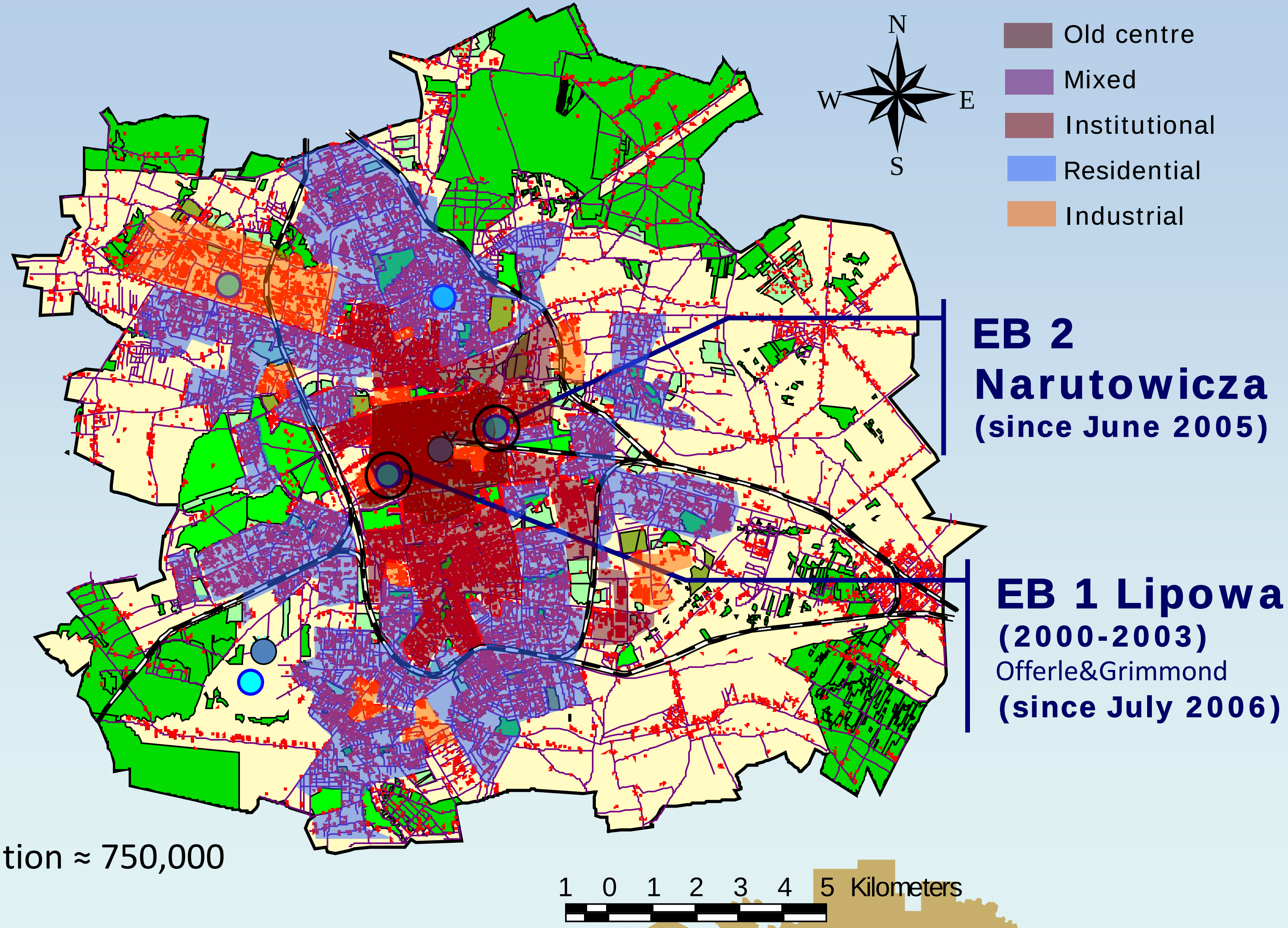
Eddy-covariance sites in Poland

City structure and measuremen points

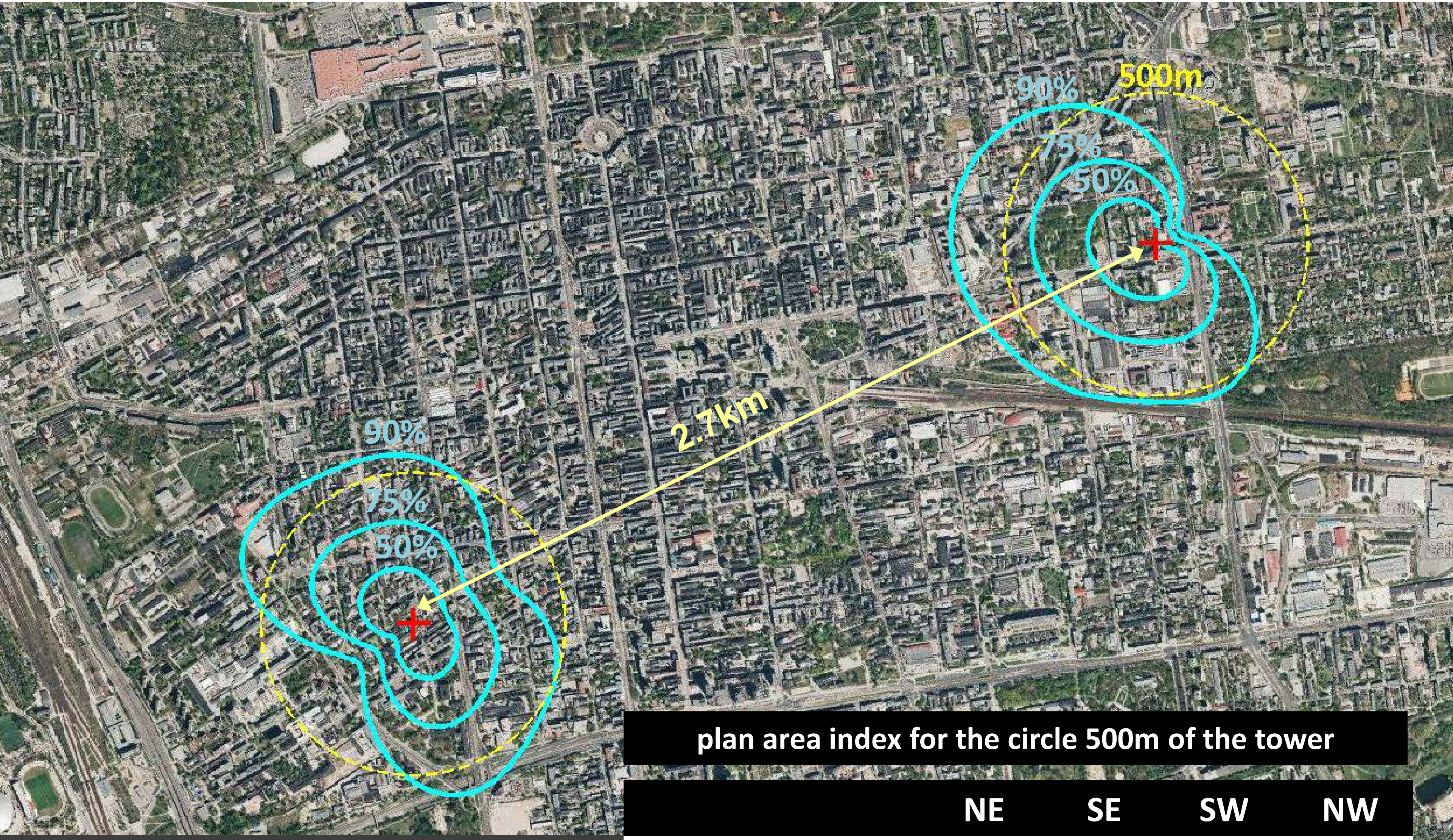


EB 2
Narutowicza
(since June 2005)

EB 1 Lipowa
(2000-2003)
Offerle&Grimmond
(since July 2006)

Population ≈ 750,000

City centre and measurement points



source areas at *p* = 50, 75 and 90% calculated for turbulent fluxes measured in unstable stratification

plan area index for the circle 500m of the tower

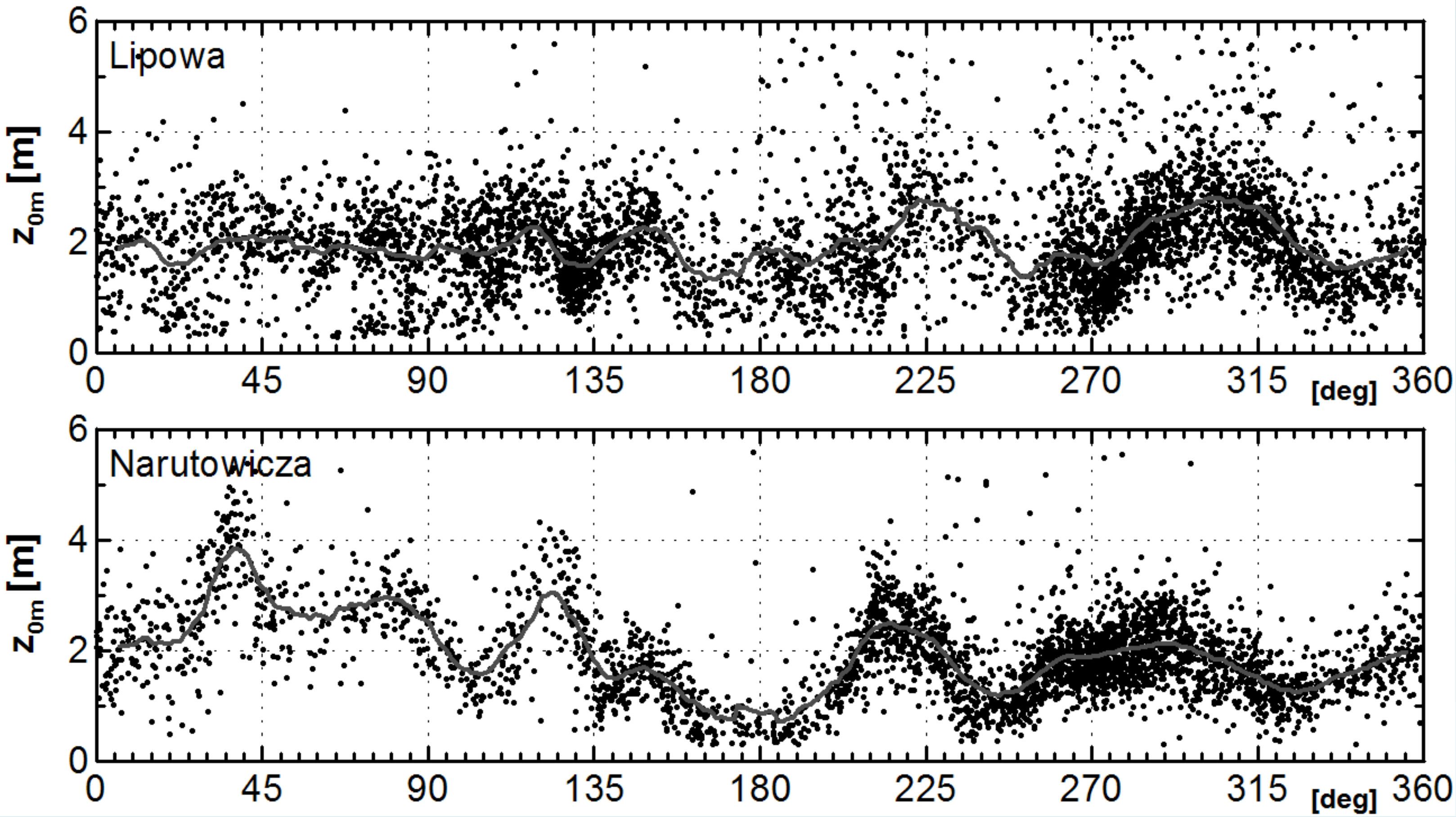
	NE	SE	SW	NW
Lipowa	0.41	0.36	0.29	0.35
Narutowicza	0.21	0.27	0.40	0.27

Roughness length for momentum

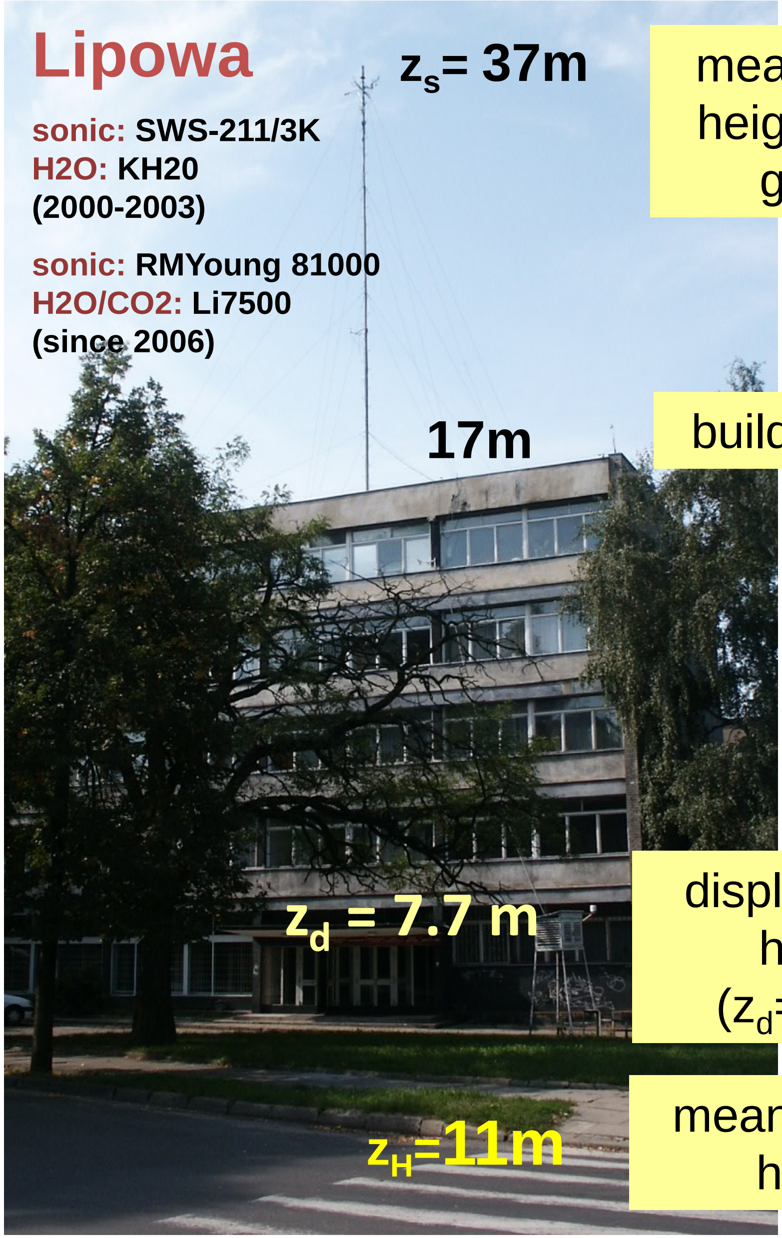
$z_{0,\mathrm{Lipowa}}$~2.0 m **$z_{0,\mathrm{Narutowicza}}$~1.9 m**

(overall mean calculated from the logarithmic wind profile in close to neutral stratification :

$z_{0m} = (z_s - z_d) \cdot \exp(-k \cdot U / u_*)$)



Measurement points



Lipowa

sonic: SWS-211/3K
H2O: KH20
(2000-2003)

sonic: RMYoung 81000
H2O/CO2: Li7500
(since 2006)

z_s= 37m

17m

z_d = 7.7 m

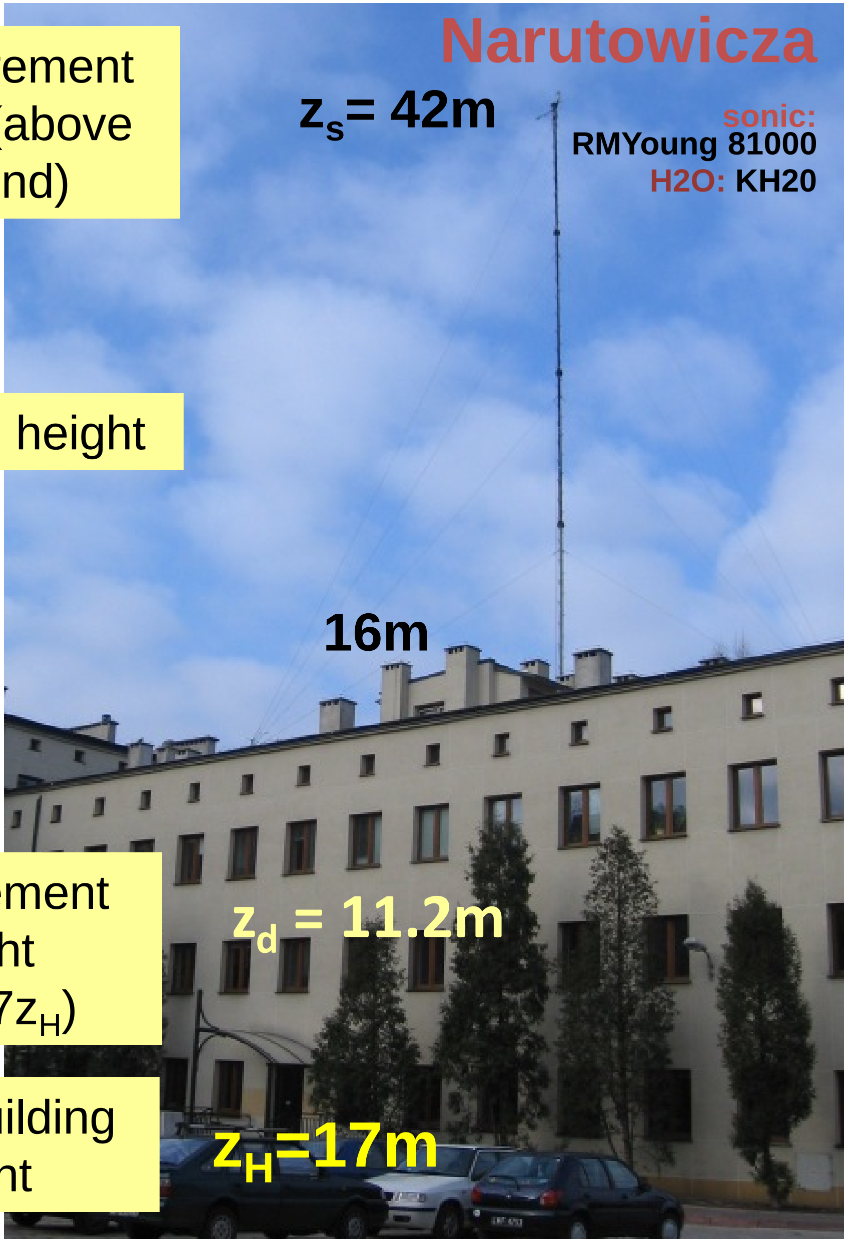
z_H=11m

measurement height (above ground)

building height

displscement height (z_d=0.7z_H)

mean building height



Narutowicza

sonic: RMYoung 81000
H2O: KH20

z_s= 42m

16m

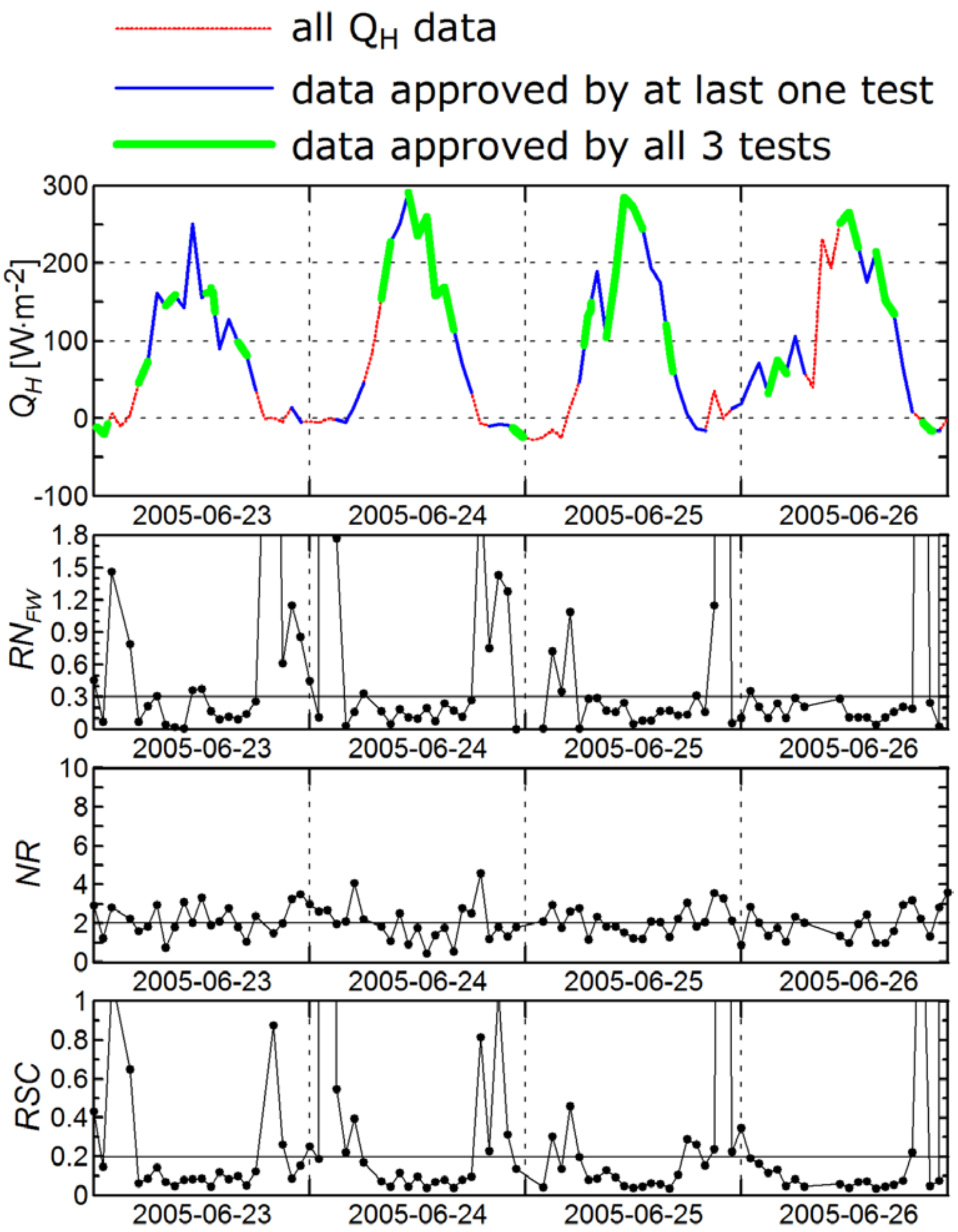
z_d = 11.2m

z_H=17m

Lipowa

Narutowicza

Quality control – stationarity tests



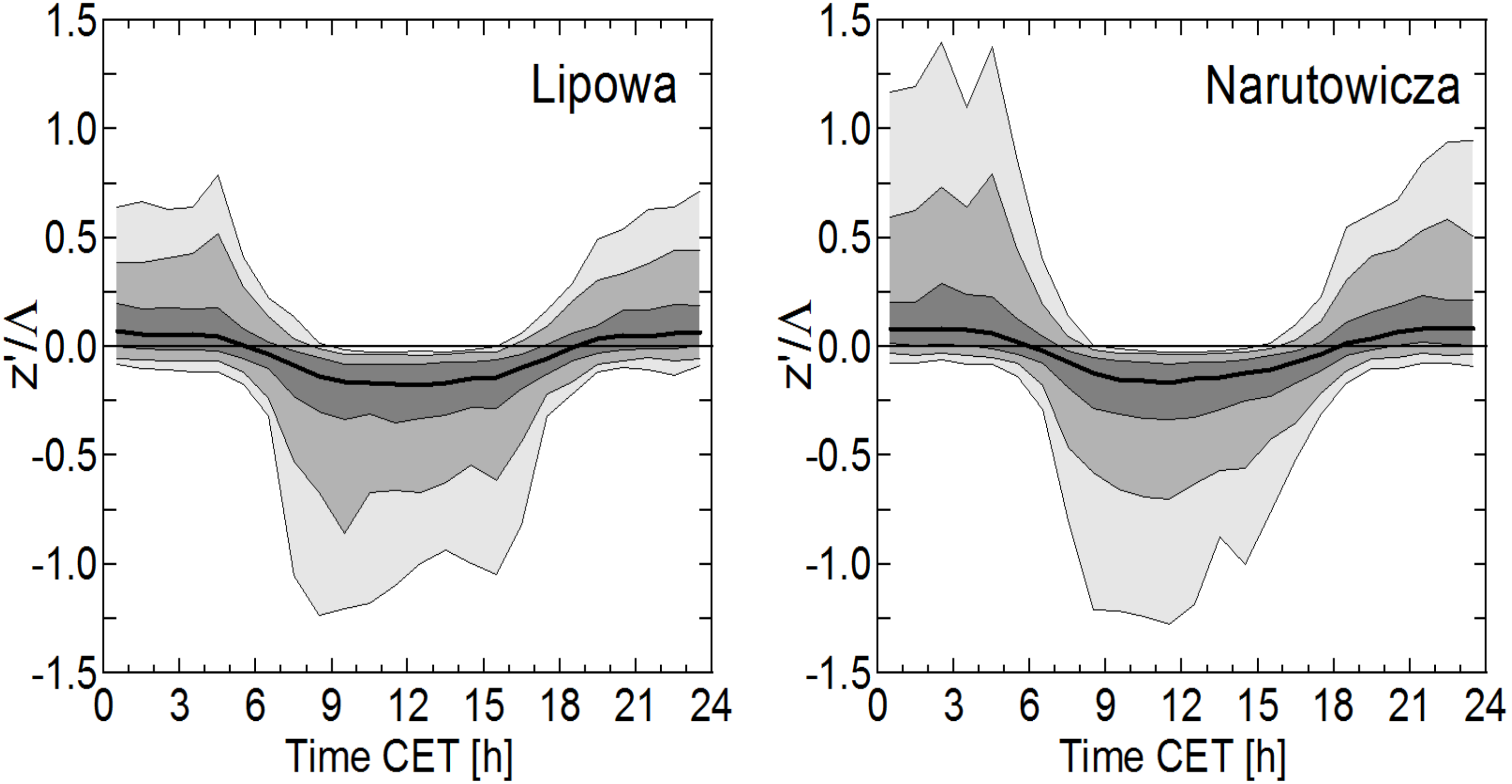
Three stationarity tests used in post-processing data quality control:

RN_{FW} – the statistic proposed by **Foken and Wichura (1996)** with critical value 0.3;

NR – the non-stationarity ratio given by **Mahrt (1998)** with critical value NR=2;

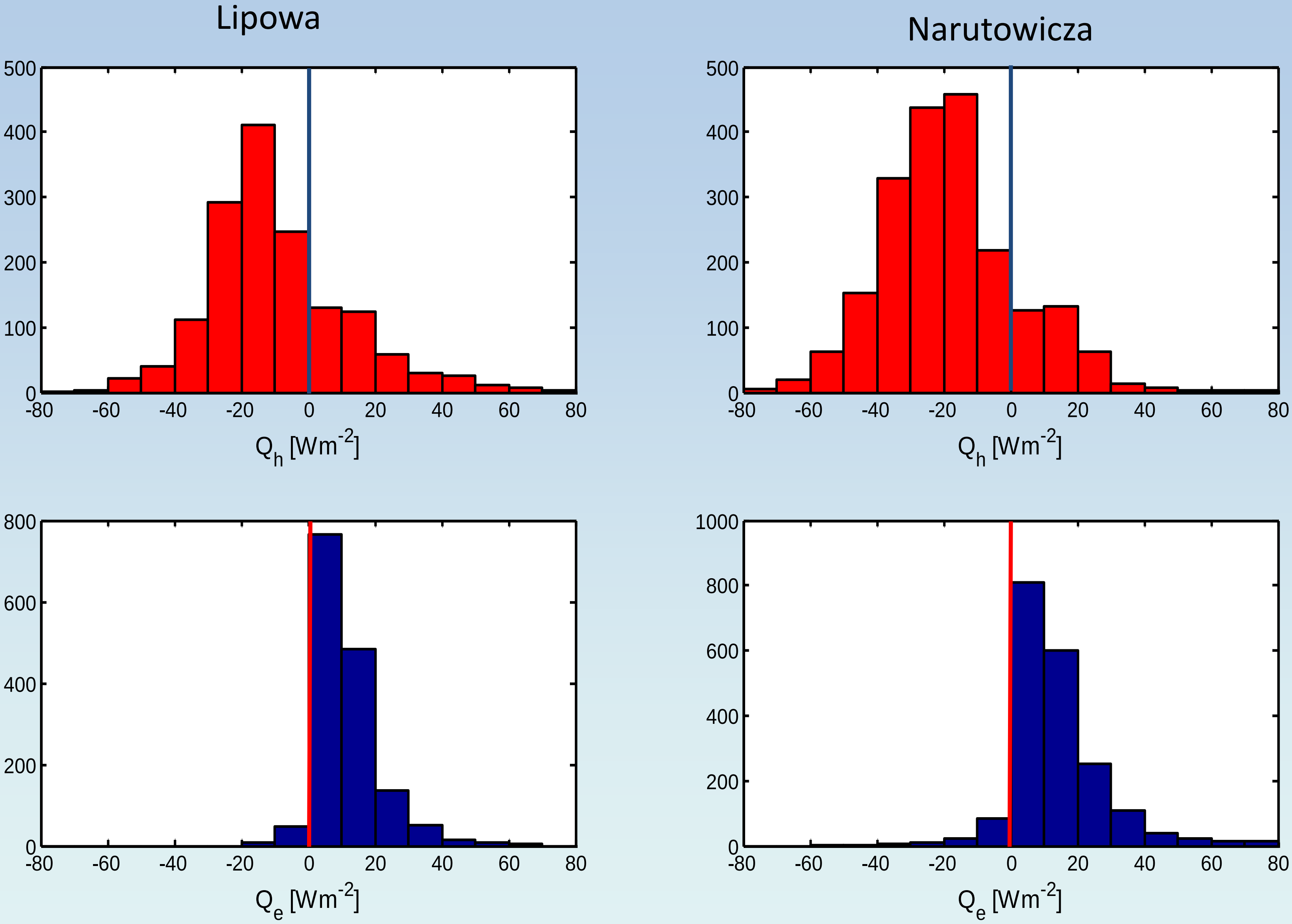
RCS – the relative covariance stationarity criterion, introduced by **Dutaur et al. (1999)** and modified by **Nemitz et al. (2002)** with critical value RCS=0.5.

Diurnal course of the stability parameter



Diurnal course of the stability parameter, ζ=z'/Λ, at Lipowa and Narutowicza sites for the entire study periods. Lines from the bottom to the top indicate 5th, 10th, 25th, 50th (median – bold line), 75th, 90th, and 95th percentiles.

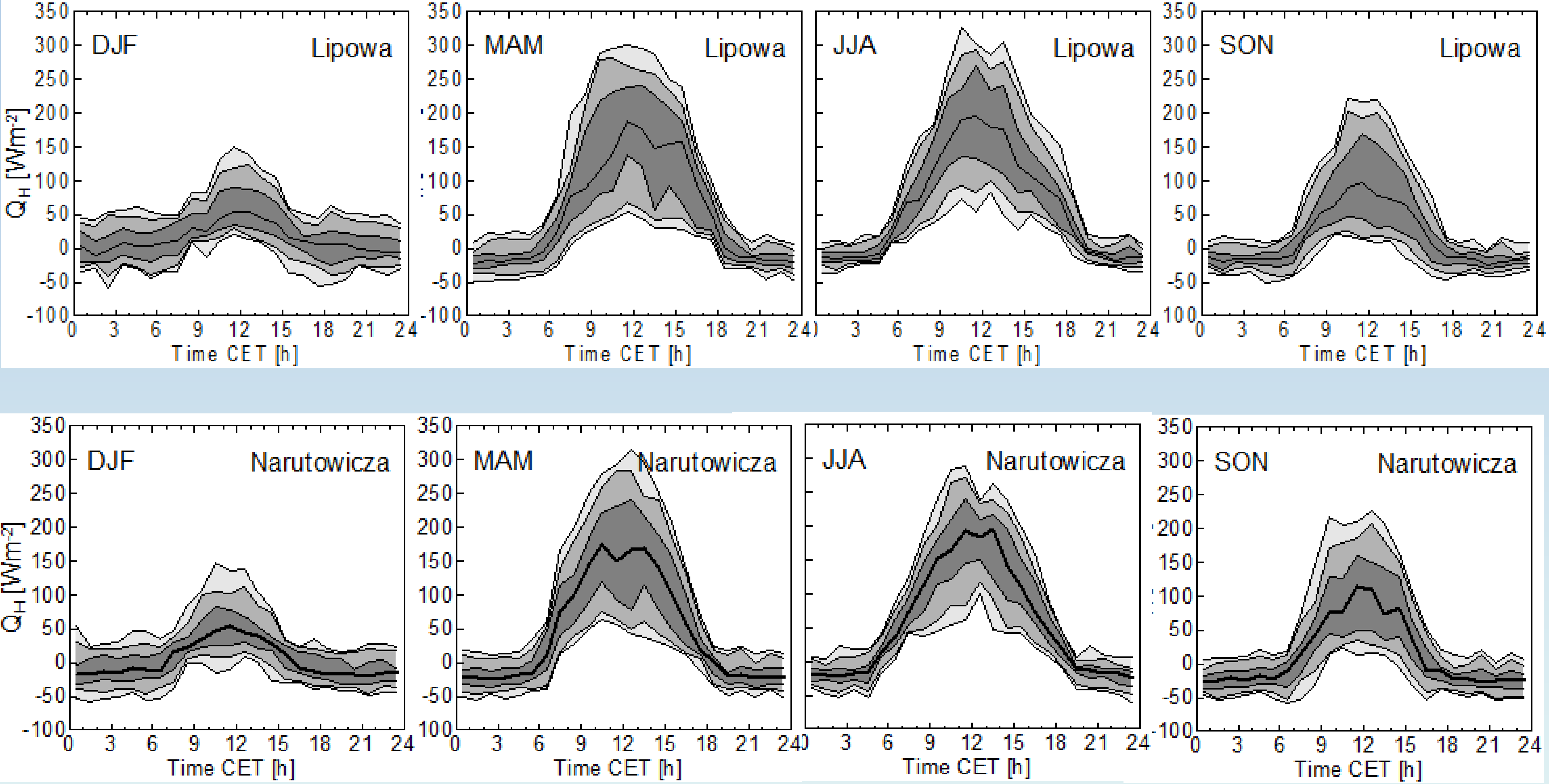
Histograms of nigh-time (Kd<5 Wm^{-2}) Q_H and Q_E



Lipowa

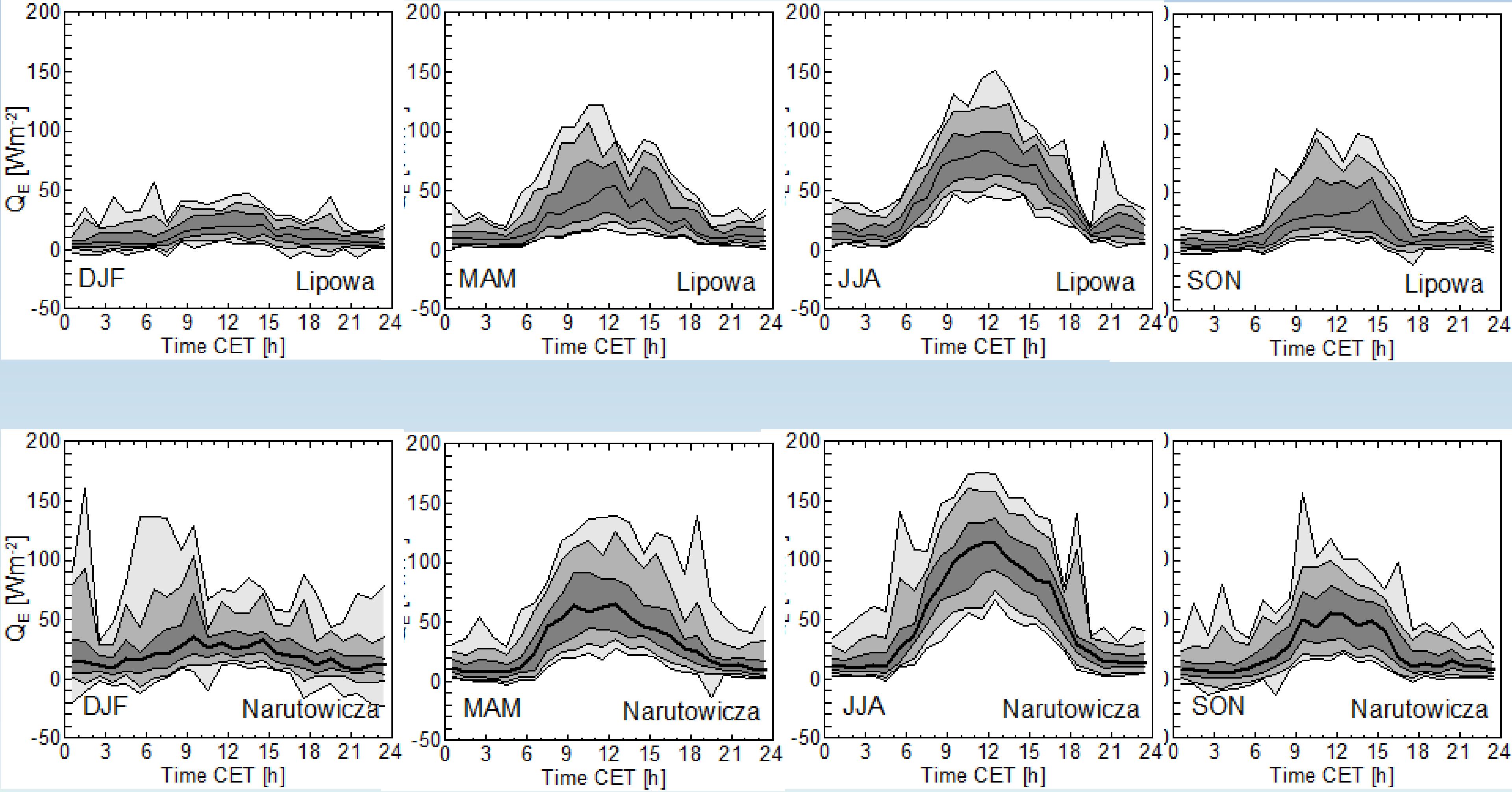
Narutowicza

Average diurnal course of Q_H in seasons



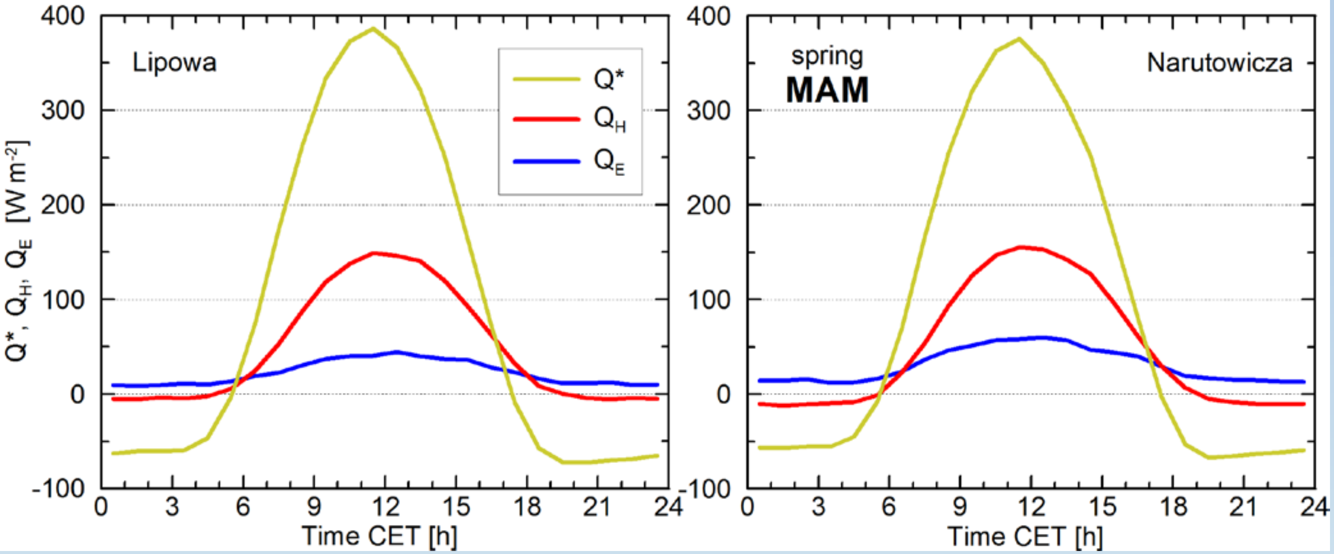
Diurnal course of Q_H, at Lipowa and Narutowicza sites in seasons. Lines from the bottom to the top indicate 5th, 10th, 25th, 50th (median – bold line), 75th, 90th, and 95th percentiles.

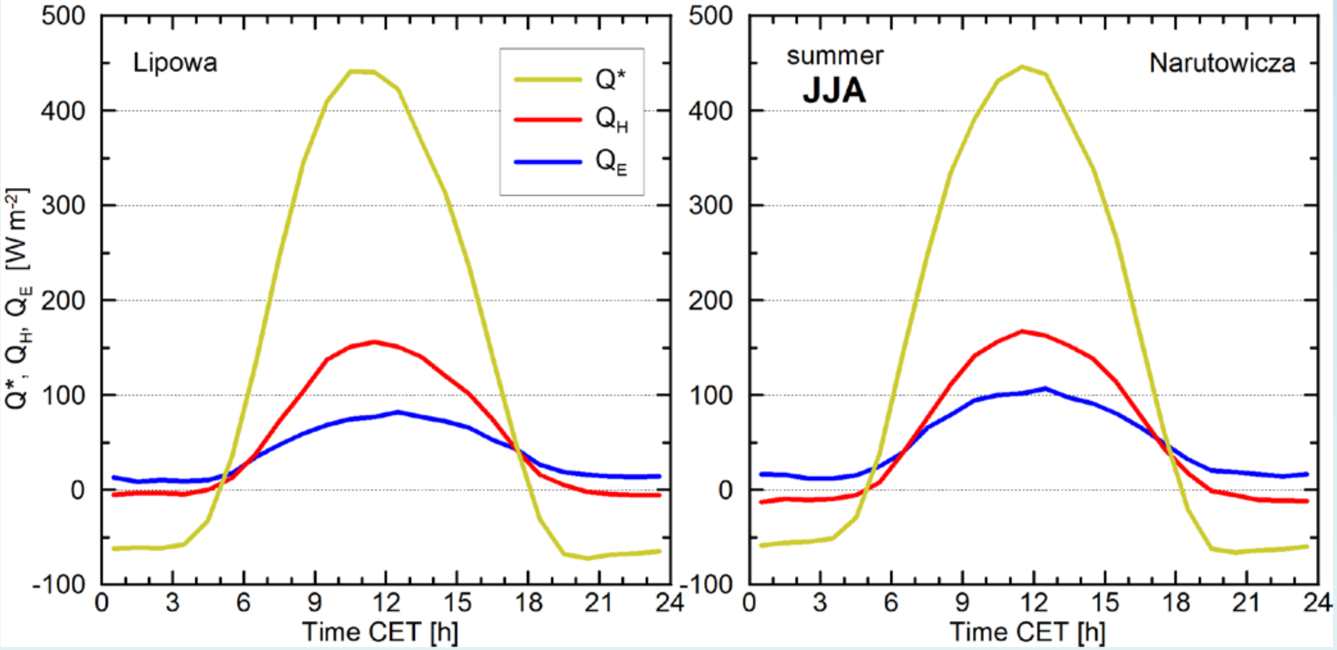
Average diurnal course of Q_E in seasons



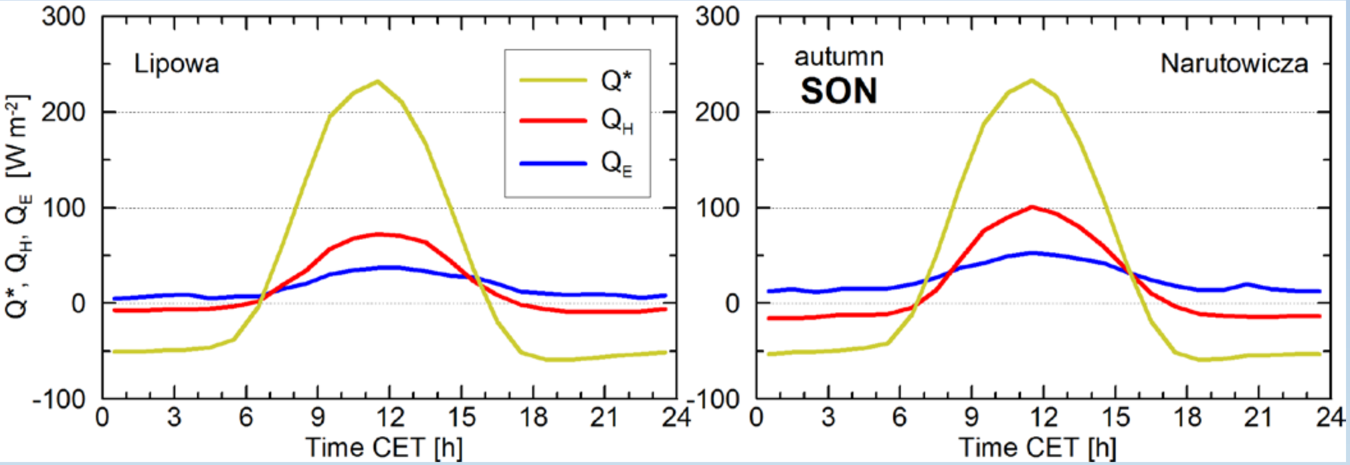
Diurnal course of Q_E, at Lipowa and Narutowicza sites in seasons. Lines from the bottom to the top indicate 5th, 10th, 25th, 50th (median – bold line), 75th, 90th, and 95th percentiles.

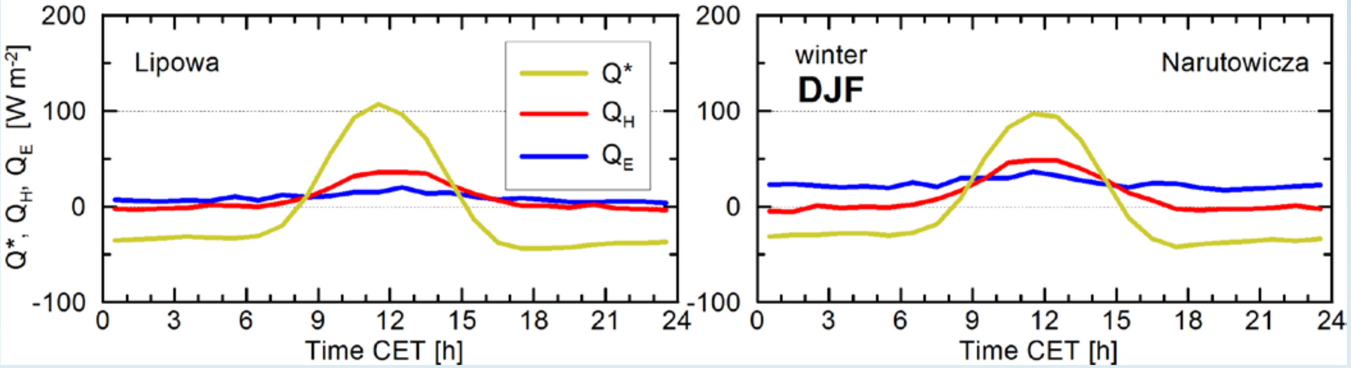
Average diurnal course of energy balance components in seasons



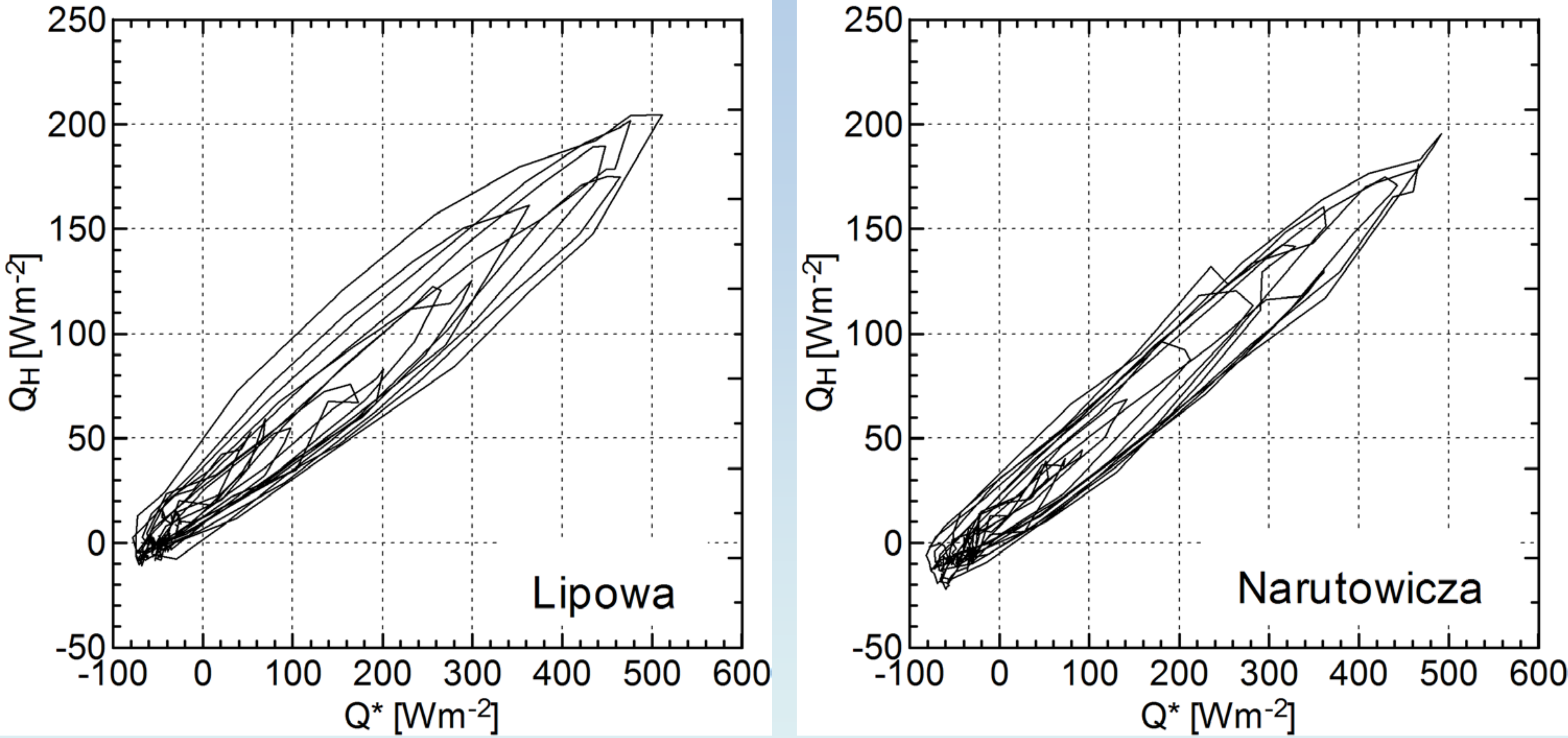


Average diurnal course of energy balance components in seasons



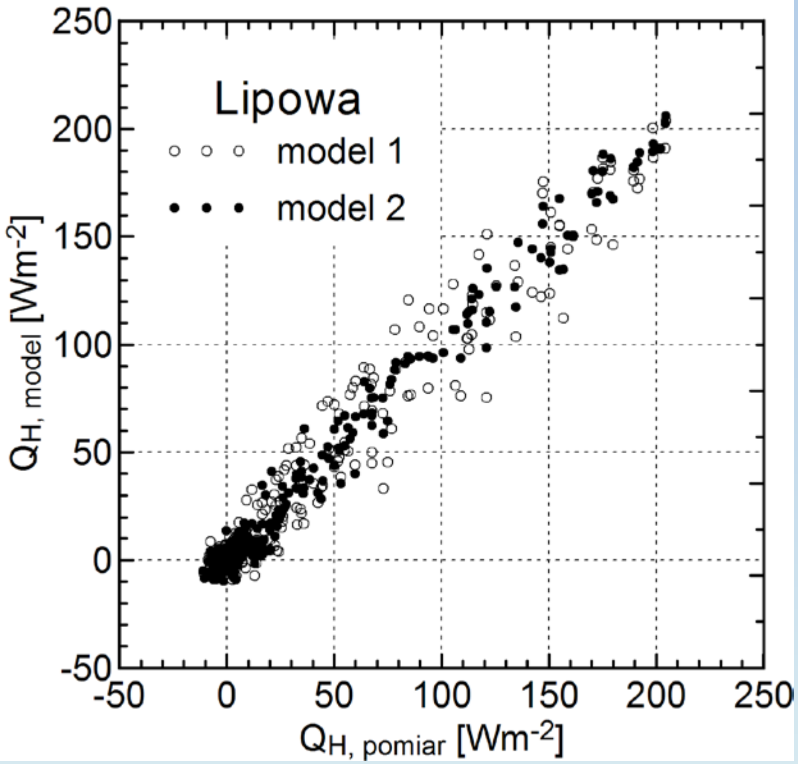


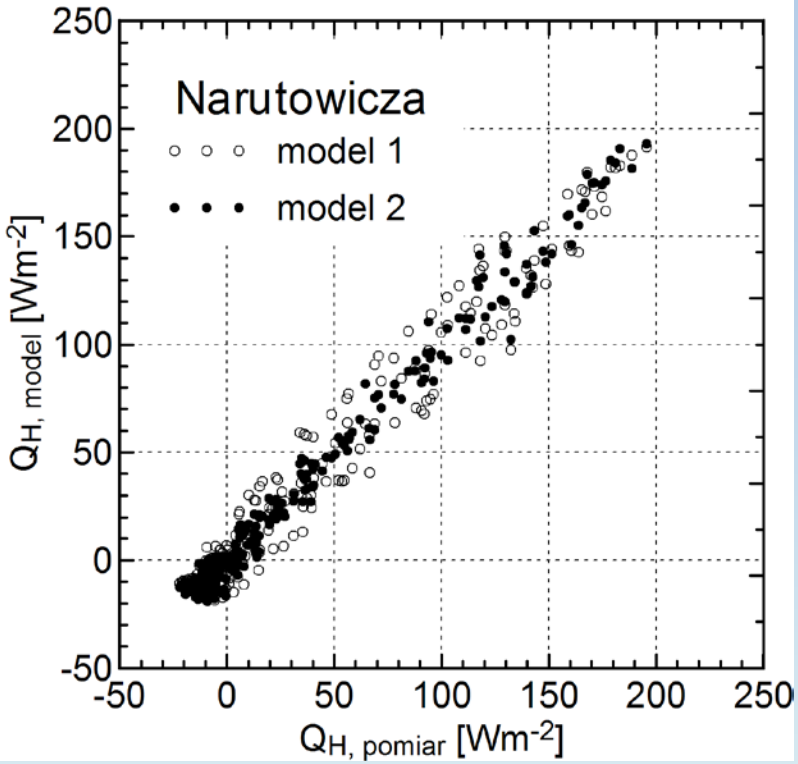
Q_H as a function of Q^*



Sensible heat flux as a function of radiation balance plotted on the base of mean diurnal course in months.

Q_H parameterization





Model			a_1	a_2	a_3	*RMSE*	*d*
1)	$Q_H = a_1Q^* + a_3$	Lip.	0.37	-	19	12.4	0.977
		Nar.	0.36	-	16	10.5	0.982
2)	$Q_H = a_1Q^* + a_2\partial Q^*/\partial t + a_3$	Lip.	0.37	-0.22	18.7	7.4	0.992
		Nar.	0.37	-0.19	10.8	6.5	0.993

Integral turbulence statistics – normalized standard deviations of wind components

Normalized standard deviations in **neutral stratification**:

Lipowa:

σ_u/u_* = 2.34 ± 0.42, σ_v/u_* = 1.65 ± 0.18, σ_w/u_* = 1.17 ± 0.08

Narutowicza:

σ_u/u_* = 2.28 ± 0.20, σ_v/u_* = 1.79 ± 0.23, σ_w/u_* = 1.27 ± 0.09

Urban averages (Roth, 2000)

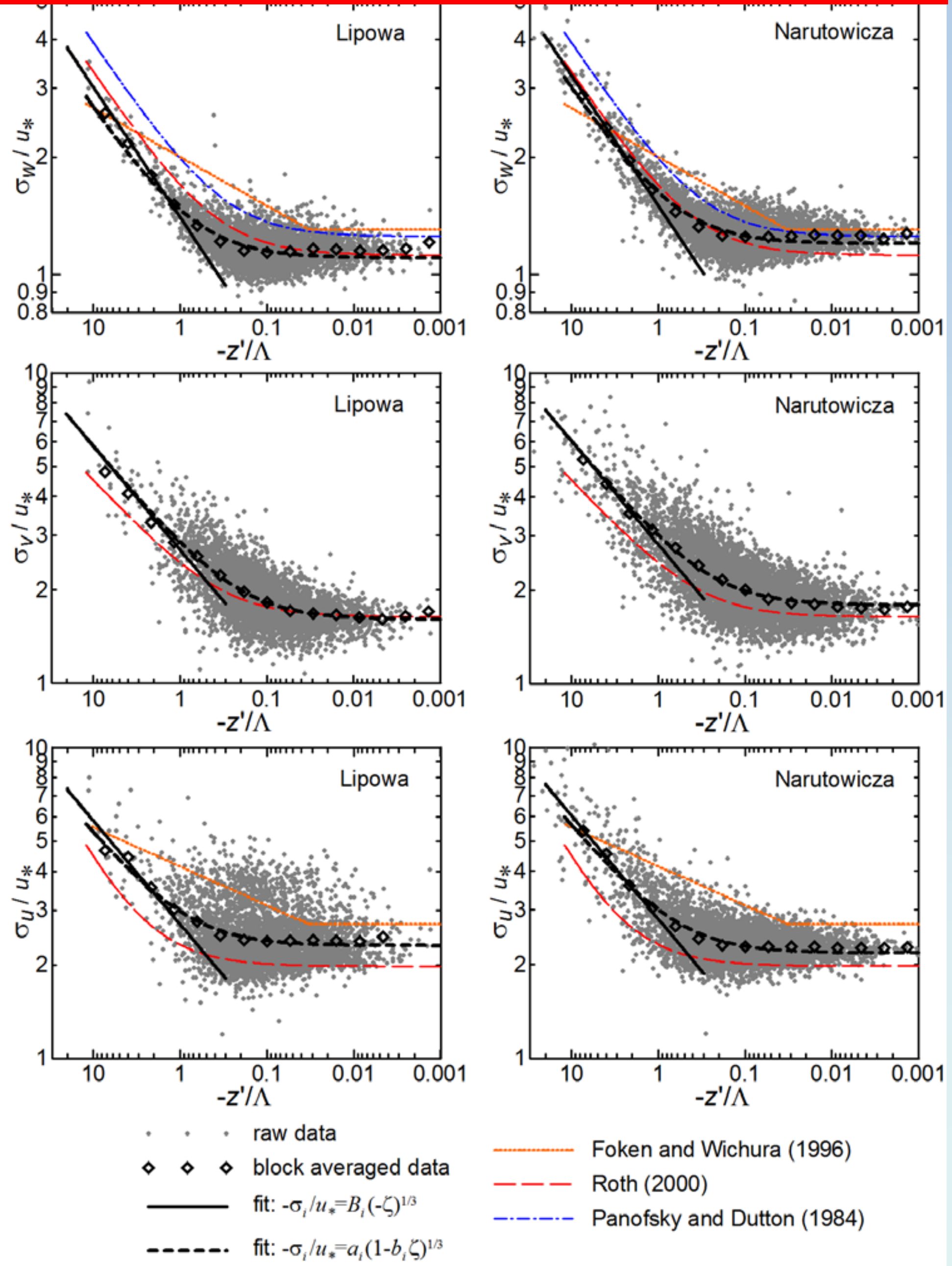
σ_u/u_* = 2.32 ± 0.16, σ_v/u_* = 1.81 ± 0.20, σ_w/u_* = 1.25 ± 0.07

Rural references (Panofsky & Dutton, 1984)

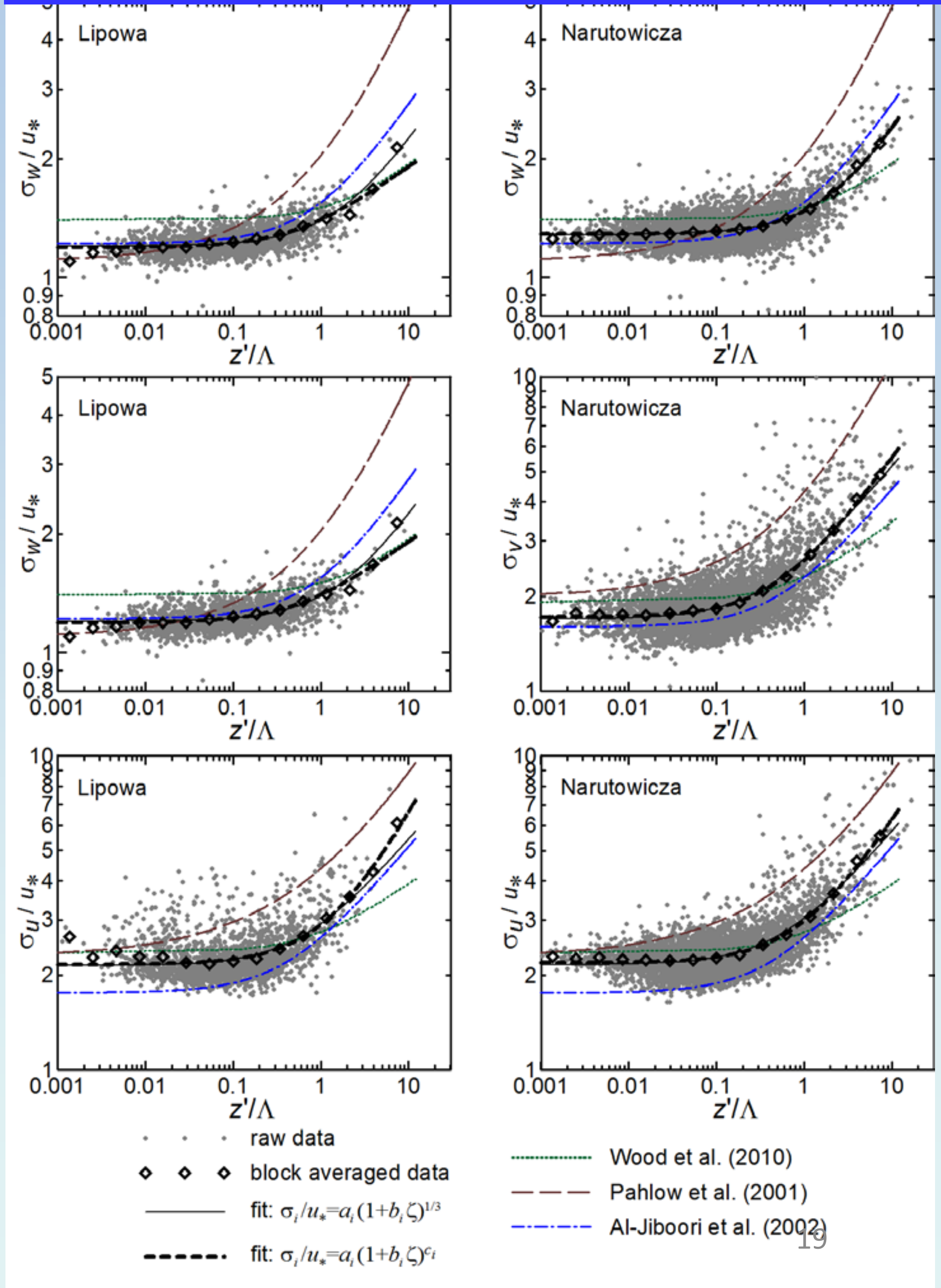
σ_u/u_* = 2.39 ± 0.03, σ_v/u_* = 1.92 ± 0.05, σ_w/u_* = 1.25 ± 0.03

Normalized standard deviations of wind components

UNSTABLE STRATIFICATION



STABLE STRATIFICATION



Spectral turbulence statistics – non-dimensional dissipation rate of turbulent kinetic energy

Non-dimensional dissipation rate of TKE, ϕ_ε, is related to other universal functions via normalised TKE budget (*Kaimal and Finnigan 1994):*

$$\phi_m - z/L - \phi_t - \phi_p - \phi_\varepsilon = 0,$$

where ϕ_m is shear production, $-z/L$ is buoyant production, ϕ_t is turbulent transport, and ϕ_p is pressure transport. Common assumption, that a sum of turbulence and pressure transport is negligible, leads to the simplification:

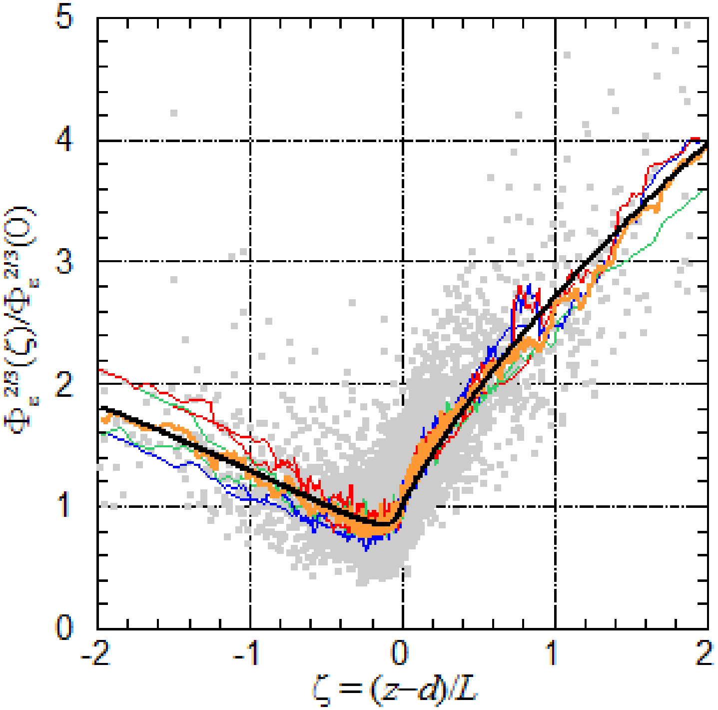
$$\phi_\varepsilon = \phi_m - z/L,$$

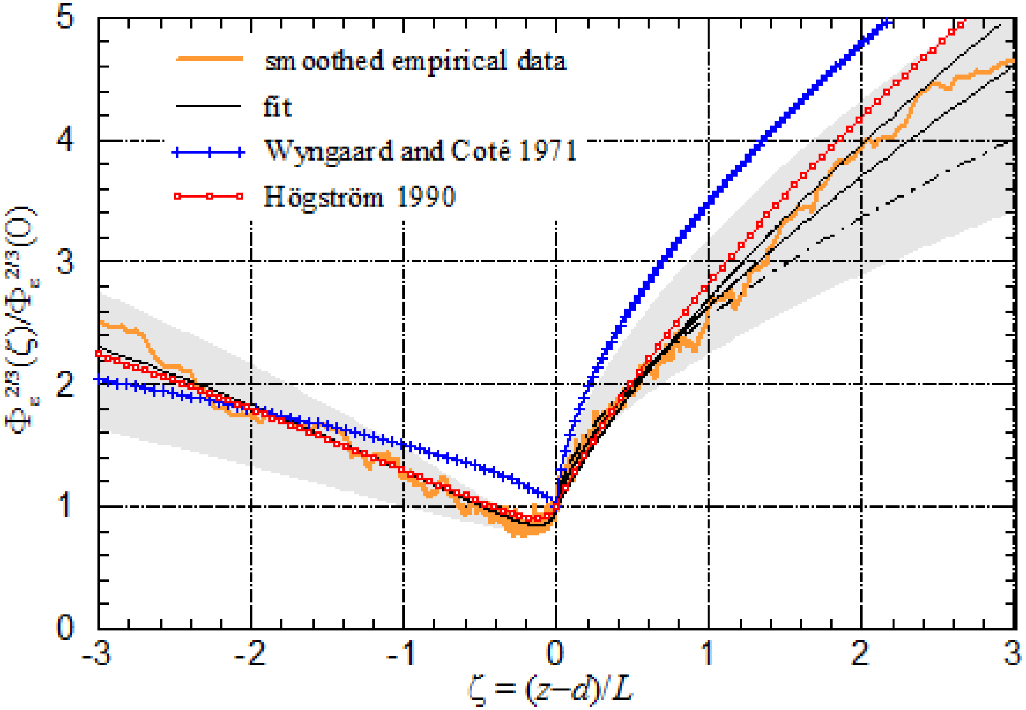
which suggest the general form of the ϕ_ε, related to the better known ϕ_m. For exsmple taking ϕ_m after Högström (1990) :

$$\Phi_m(\zeta) = \begin{cases} (1 - 19\cdot\zeta)^{-1/4}, & \zeta < 0 \\ 1 + 4.8\cdot\zeta \quad , & \zeta \geq 0 \end{cases}$$

$$\Phi_\varepsilon(\zeta) = \begin{cases} (1 - 19\cdot\zeta)^{-1/4} - \zeta, & \zeta < 0 \\ 1 + 3.8\cdot\zeta \quad , & \zeta \geq 0 \end{cases}$$

Spectral turbulence statistics – non-dimensional dissipation rate of turbulent kinetic energy





Black line (fit):

$$\Phi_\varepsilon(\zeta)=\begin{cases}(1-38\cdot\zeta)^{-1/4}-\zeta, & \zeta<0\\ 1+3.5\cdot\zeta\quad, & \zeta\geq 0\end{cases}$$

u – red
v – blue
w – green
Average for all components - orange

(*Högström 1990*) :

$$\Phi_\varepsilon(\zeta)=\begin{cases}(1-19\cdot\zeta)^{-1/4}-\zeta, & \zeta<0\\ 1+3.8\cdot\zeta\quad, & \zeta\geq 0\end{cases}$$

(*Wyngaard and Coté, 1971*) :

$$\phi_\varepsilon^{2/3}(\zeta)=\begin{cases}1+0.5(-\zeta)^{2/3} & -2\leq\zeta\leq 0\\ 1+2.5\zeta^{3/5} & 0\leq\zeta\leq 2\end{cases}$$

(*Su et al. 2004*) - grey area

Summary

1. The data from Łódź belongs to the longest eddy-covariance urban flux measurements
2. The annual and diurnal courses of turbulent fluxes in Łódź are typical for urban areas: the turbulent sensible heat flux is larger than the latent heat flux, Q_H remains positive after Q^* turns negative in the late afternoon/evening due to release from heat storage, but it becomes negative in significant number of nights.
3. The average fluxes on both sites are similar, which allow to assume that results are representative for central part of city with similar morphology.
4. The hysteresis effect between Q^* and Q_H allows to improve simple parameterization of Q_H.
5. Both integral and spectral turbulence characteristics show applicability of the universal rules worked out for homogenous flat surfaces at urban areas.

Thank you