OBSERVATIONS OF TURBULENCE IN THE STABLE SURFACE LAYER OVER INHOMOGENEOUS TERRAIN

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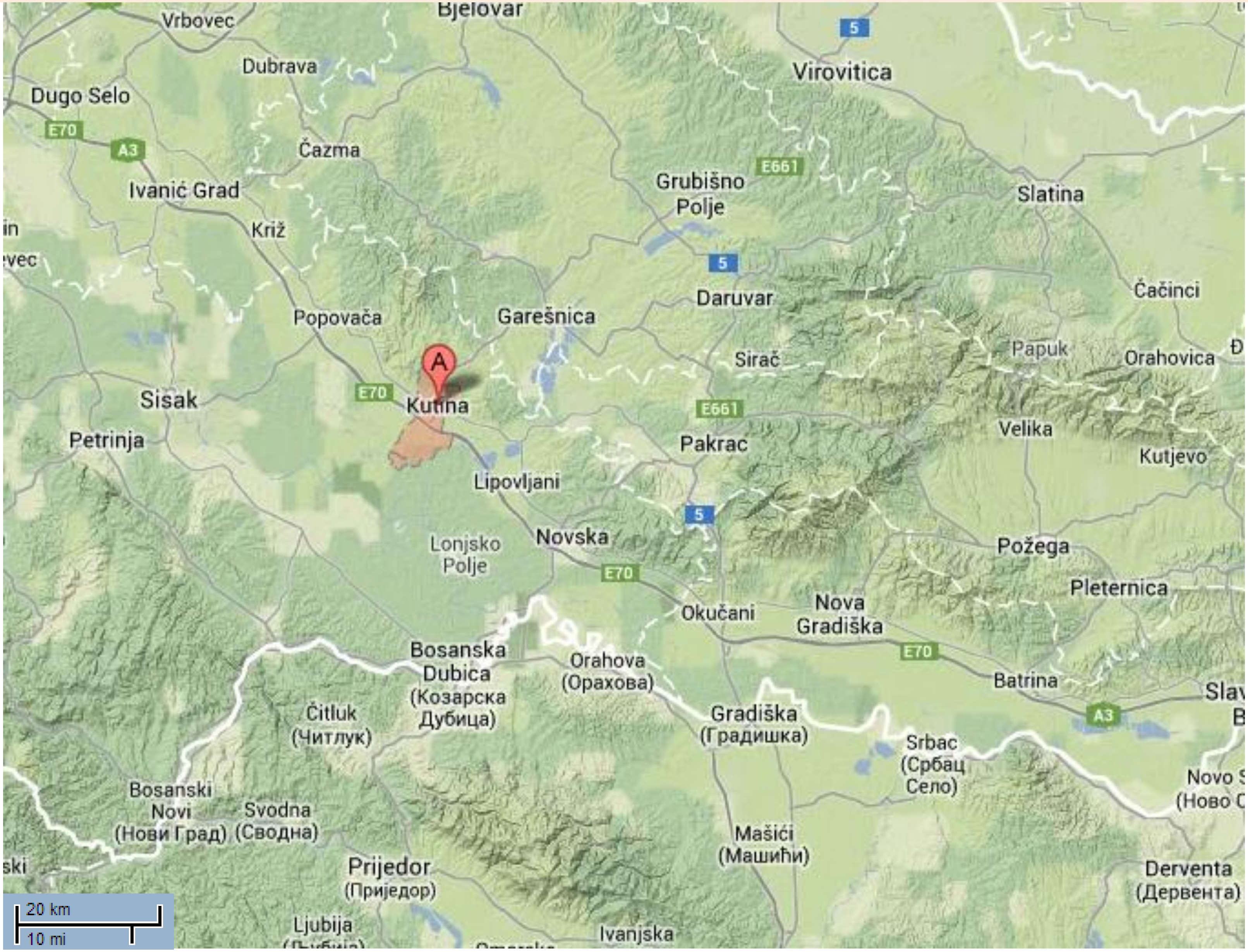
Motivation - Air pollution in Kutina

Kutina, Croatia

Observations



Observations

- Measurement tower - industrial area of Kutina (T)
- 3D ultrasonic anemometers:
  20, 32, 40, 55 and 62 m AGL – u, v, w and T_s
- Sampling frequency – 20 Hz
- Analyzed period: wintertime months
  nocturnal cases between 1800 and 0600 LST
  nine 12-h segments = 108 hours

Turbulence averaging time scale

Implicit assumption: a physical decoupling between the "passive" fluctuations of mesoscale/diurnal motions and "active" small scale (turbulent) fluctuations exists

→ a "gap" in the spectra of temperature and velocity components

Fourier spectral analysis : information on large-scale to small-scale eddy energy transport

The value of the spectrum at a specific frequency = the mean energy in that eddy size

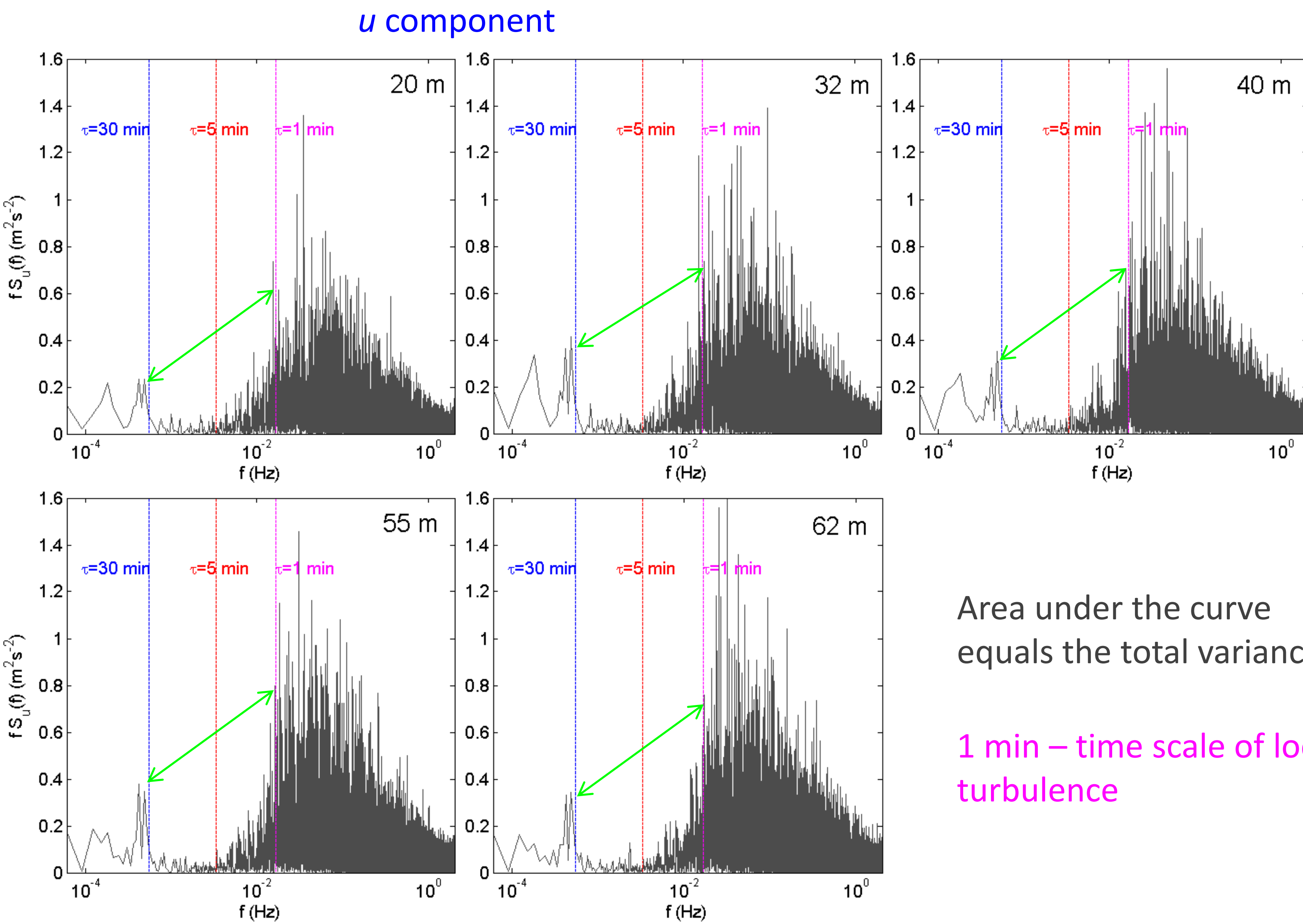
Cumulative integral of cospectrum is used to determine the frequency f_c at which there is no more contribution to the covariance

$$Og_{xy}(f_0) = \int_{\infty}^{f_0} Co_{xy}(f)\,df$$

Ogive function

→ $t_c = f_c^{-1}$ minimum averaging time necessary to include all flux contributions (Oncley et al., 1990)

Turbulence averaging time scale

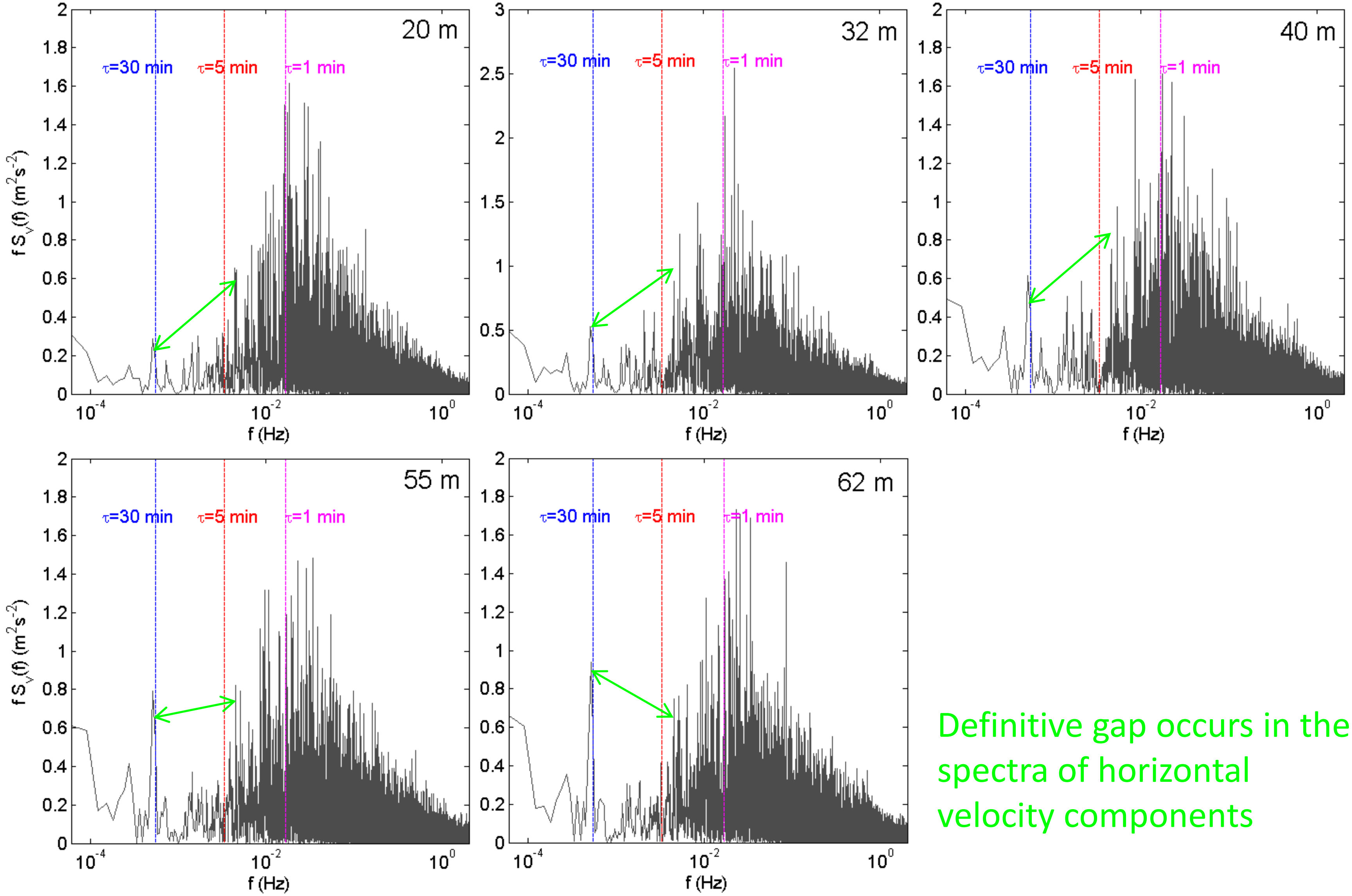


Area under the curve equals the total variance

1 min – time scale of local turbulence

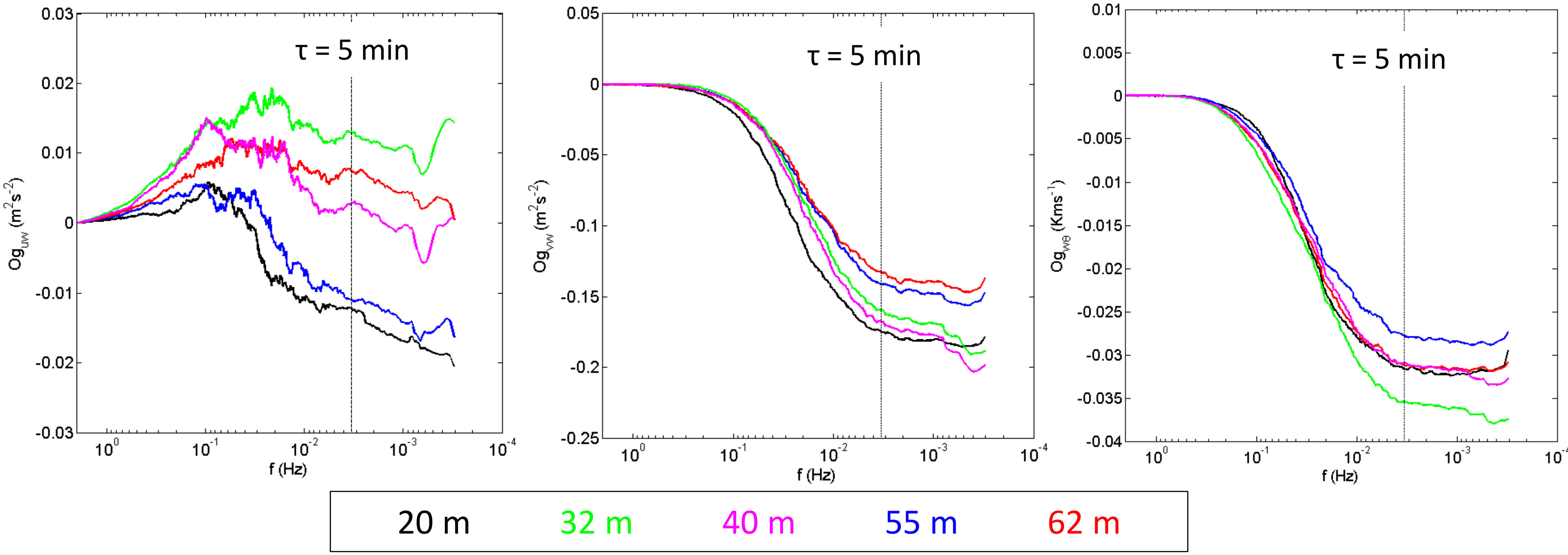
Turbulence averaging time scale

v component



Definitive gap occurs in the spectra of horizontal velocity components

Turbulence averaging time scale



- Ogives from 54-min average cospectra of *u* and *w* – usually inconclusive

- Ogives from 54-min average of *v* and *w* and form sensible heat flux

$$t_c = (f_c)^{-1} = 5\,\text{min}$$

Location of the high frequency end of the gap in the *u* and *v* spectra corresponds well with f_c

Chosen turbulence averaging scale:
5 min

Turbulence statistics

- Statistical moments – variances and covariances and turbulence kinetic energy (TKE) calculated as 30-min averages – 216 data points
- NBL is traditionally classified according to the strength of stability
- Stability parameter: non-dimensional local z/Λ
- Local Obukhov length:

$$\Lambda = \frac{-u_*^3}{k\frac{g}{\overline{\Theta_v}}\left(\overline{w'\Theta_v'}\right)} = \frac{-\left(\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2\right)^{3/4}}{k\frac{g}{\overline{\Theta_v}}\left(\overline{w'\Theta_v'}\right)}$$

Level	Stable: z/Λ > 0		Strongly stable: z/Λ > 1	
	Number	Percentage (%)	Number	Percentage (%)
20 m	203	94	170	89
32 m	208	96	193	93
40 m	205	95	198	97
55 m	196	91	192	98
62 m	203	94	199	98

Very Stable Regime

z-less approximation

↓

Normalized turbulent quantities that are functions of the local stability parameter z/Λ

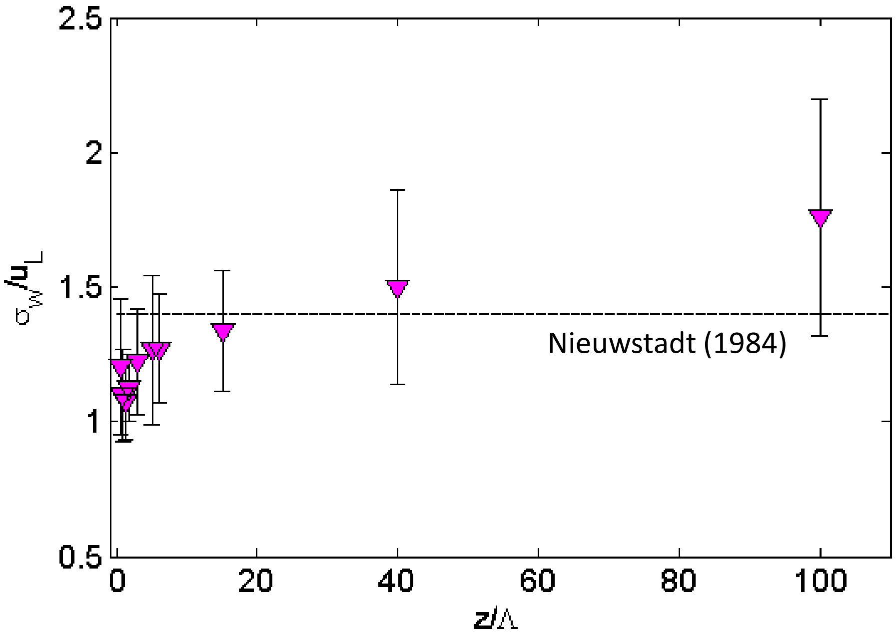
↓

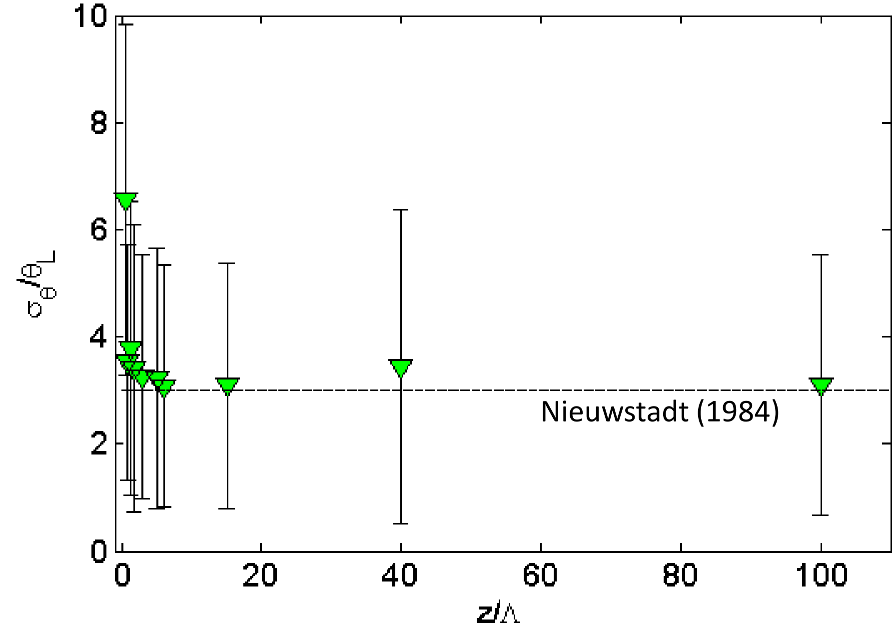
constant values for large values of z/Λ

Stability categories (according to Conangla et al. 2008)

z/Λ	Number of data	Percentage of data
0.001-0.01	1	0.1
0.01-0.03	2	0.2
0.03-0.05	1	0.1
0.05-0.07	1	0.1
0.07-0.09	1	0.1
0.09-0.15	7	0.7
0.15-0.35	16	1.6
0.35-0.65	19	1.9
0.65-1.15	30	3.0
1.15-1.5	18	1.8
1.5-2	23	2.3
2-4	95	9.4
4-6	82	8.1
6-10	106	10.4
10-20	160	15.8
20-100	349	34.4
> 100	104	10.2

Turbulence statistics





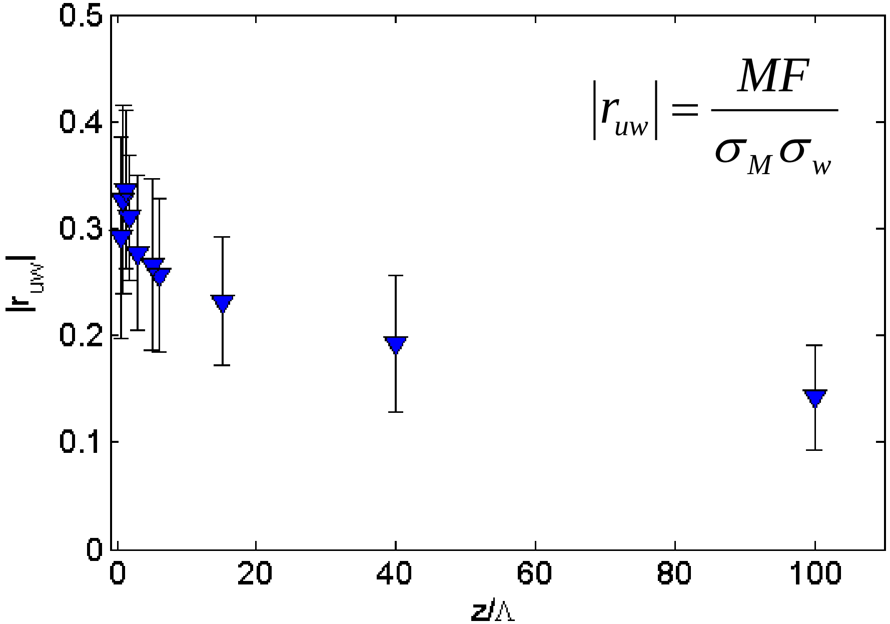
$z/\Lambda > 1$	σ_w/u_L	σ_θ/θ_L	$\lvert r_{uw}\rvert$	$-r_{w\theta}$	z/Λ
Nieuwstadt (1984) tower, The Netherlands	1.4–1.9	3.3–4.8		0.24	0–5
King (1990) tower, Antarctica	1.4–1.6	2.5	0.3	0.3–0.4	0–2
Bergström and Smedman (1995) tower, Stockholm Archipelago	1.3	2.6	0.31	0.3	
Forrer (1999) tower, Greenland	1.4	1.8	0.3	0.4–0.5	0–2
Bange and Roth (1999) helicopter, Germany	1.5–1.7	4.8–6.0			7–25
Heinemann (2004) aircraft, Greenland	1.2–1.6	4.5–7.3	0.15–0.30	0.1–0.2	0–25
CIBA	1.2–1.5	3.8–6.0	0.14–0.23	0.15–0.19	0–30
Kutina	1.1-1.8	3.1-3.7	0.14-0.34	0.19-0.25	**0-244**

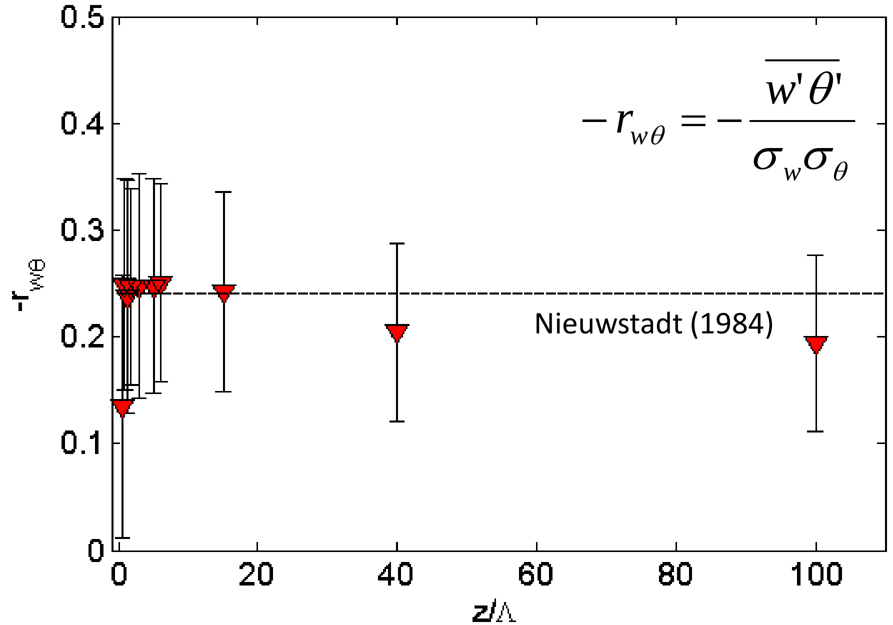
$$\theta_L = -\overline{w'\theta'}/u_L$$

Local temperature scale

Conangla et al. 2008

Turbulence statistics





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Conangla et al. 2008

Summary

- Fourier spectral analysis indicates that 5 min is appropriate scale for definition of turbulent perturbations in Kutina for chosen nights
- Magnitudes of the local stability parameter indicate that turbulence statistics might belong to the *z-less* approximation
- Using *z-less* approximation normalized turbulent quantities show similar dependence on stability parameter as already reported in literature
- Further steps: analysis of a larger data sample to include weakly and moderately stable conditions into the perspective

Thank you for your attention!

Appendix

	20 m	32m	40m	55m	62m
E	18	14	15	13	14
ESE	14	17	18	15	14
SE	6	8	9	13	14
SSE	13	14	16	19	18
S	10	12	12	12	13
SSW	9	8	10	11	11

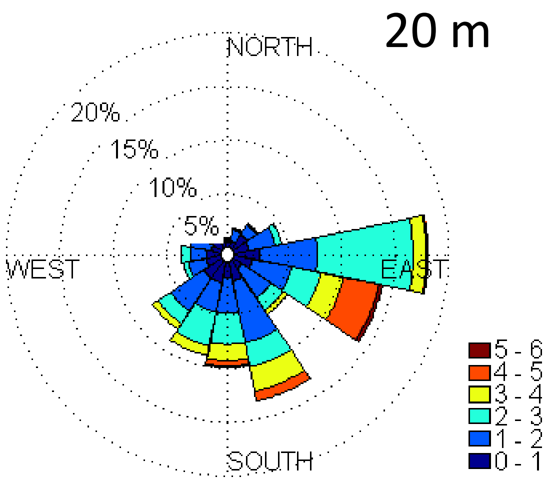
Percentage of six wind directions at five levels for the investigated time period

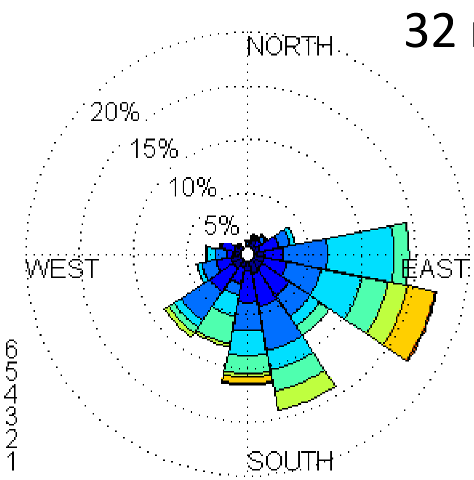
"upside-down" BL

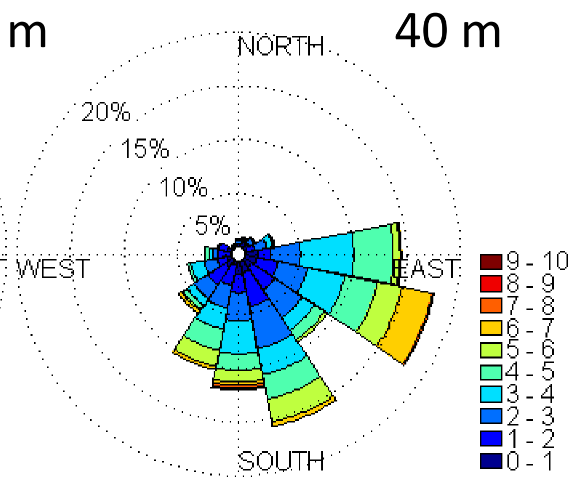
Mean TKE (m^2s^{-2})

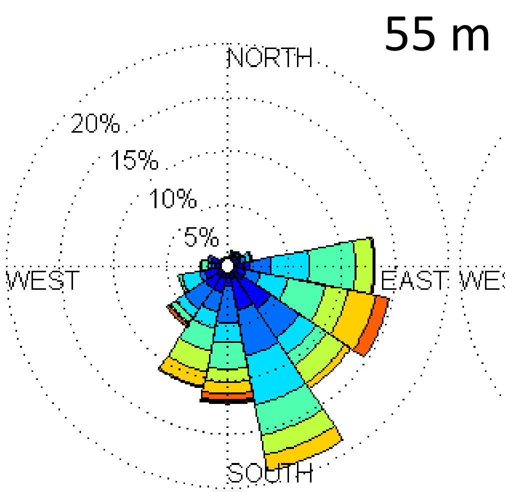
	Night1	Night2	Night3	Night4	Night5	Night6	Night7	Night8	Night9
62 m	0.4180	0.1716	0.6361	0.2081	0.5082	0.1122	0.5016	0.2480	0.1162
55 m	0.4113	0.1771	0.6448	0.2123	0.5652	0.1180	0.4838	0.2317	0.1118
40 m	0.3942	0.1717	0.6038	0.2109	0.5827	0.1297	0.4515	0.1986	0.1059
32 m	0.4349	0.1701	0.6103	0.2244	0.6414	0.1527	0.4854	0.1801	0.1131
20 m	0.4174	0.1554	0.5825	0.2516	0.7258	0.1428	0.4342	0.1514	0.1203

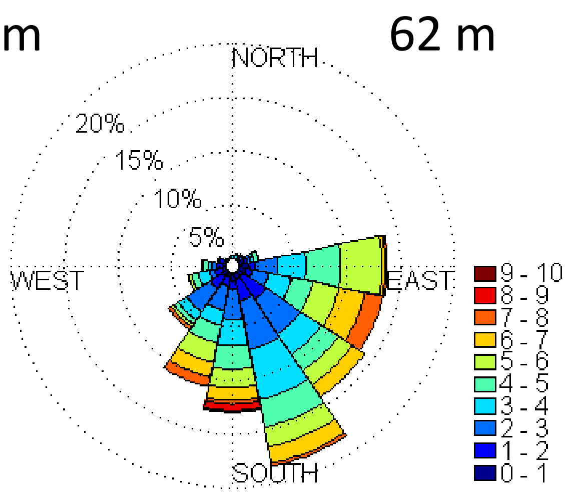
Observations











10 min wind direction

The most frequent wind directions: E, ESE, SE, SSE, S and SSW