The Urban Wind Profile

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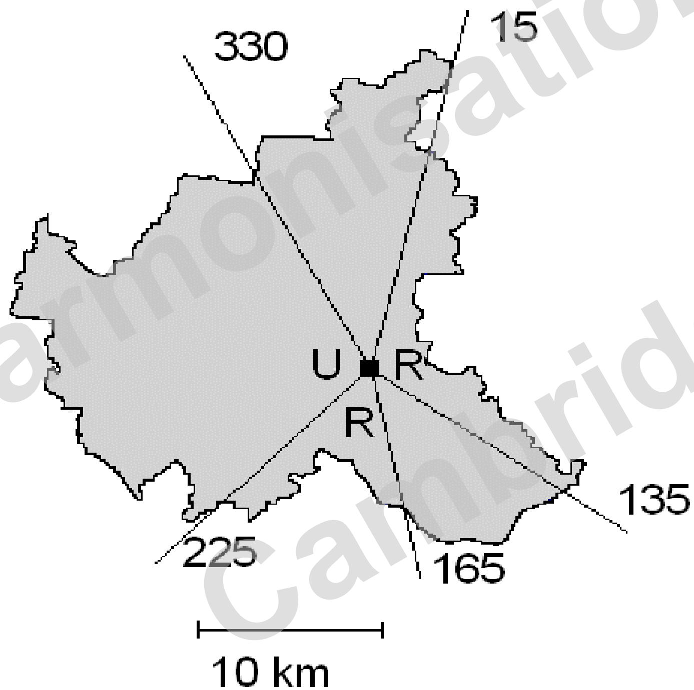
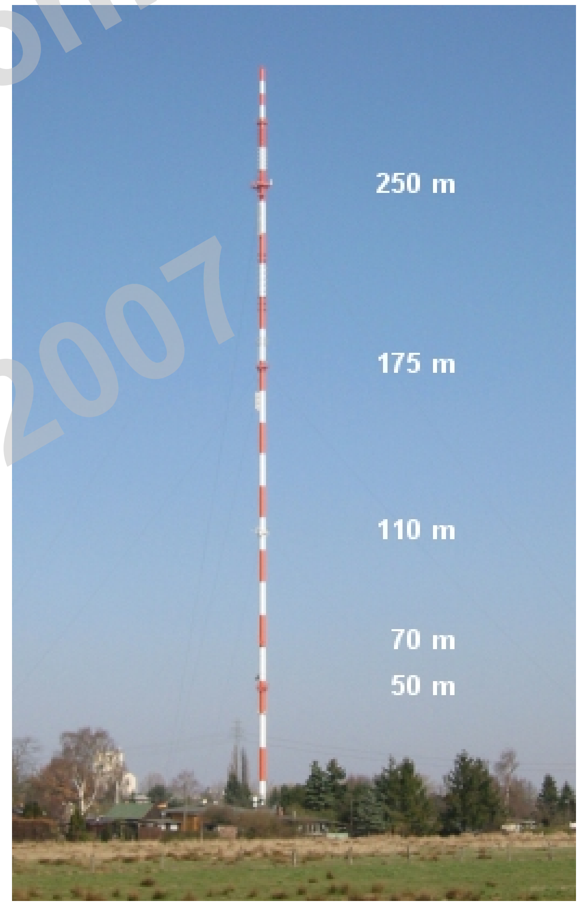
Wind profiles over flat terrain

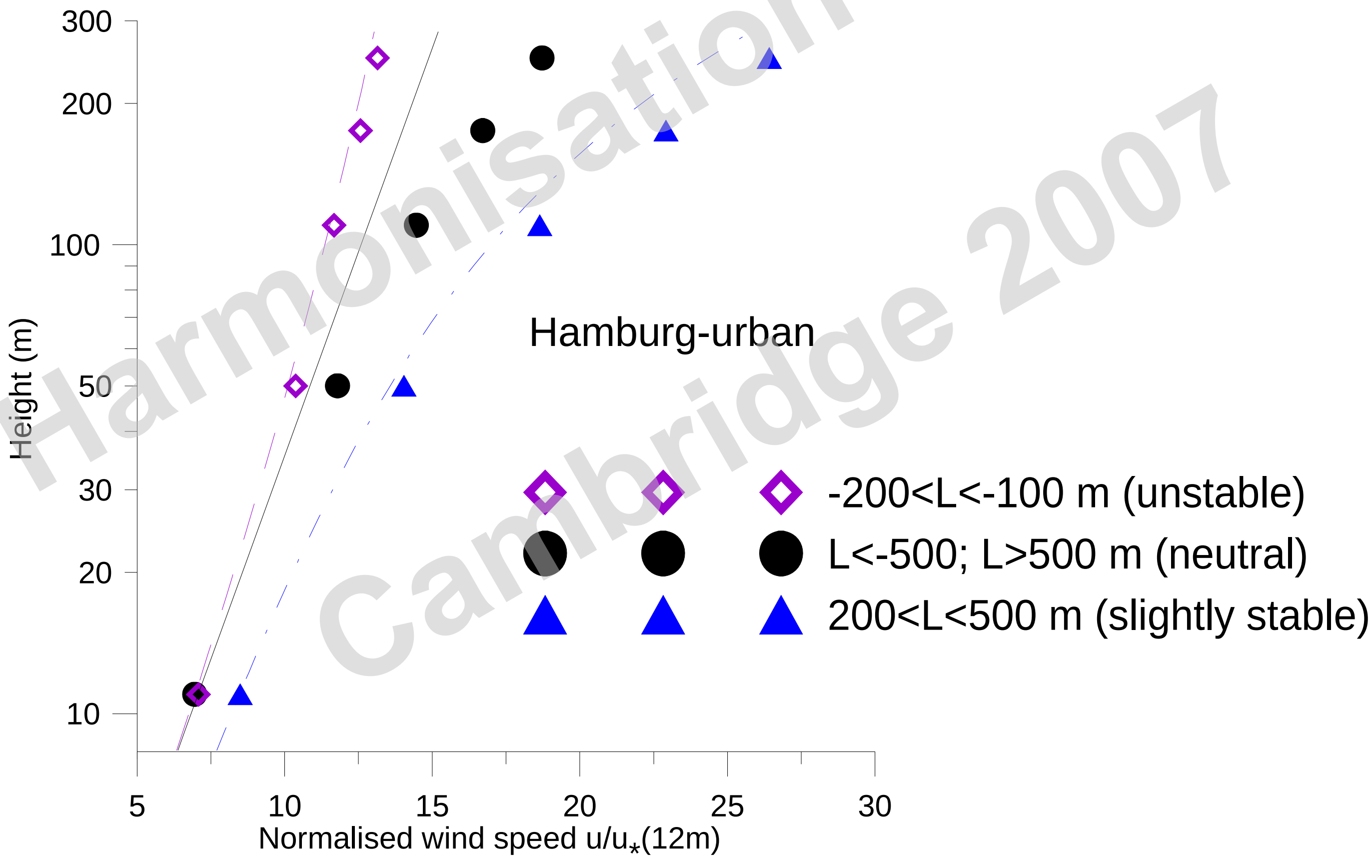
U:Urban R:residential



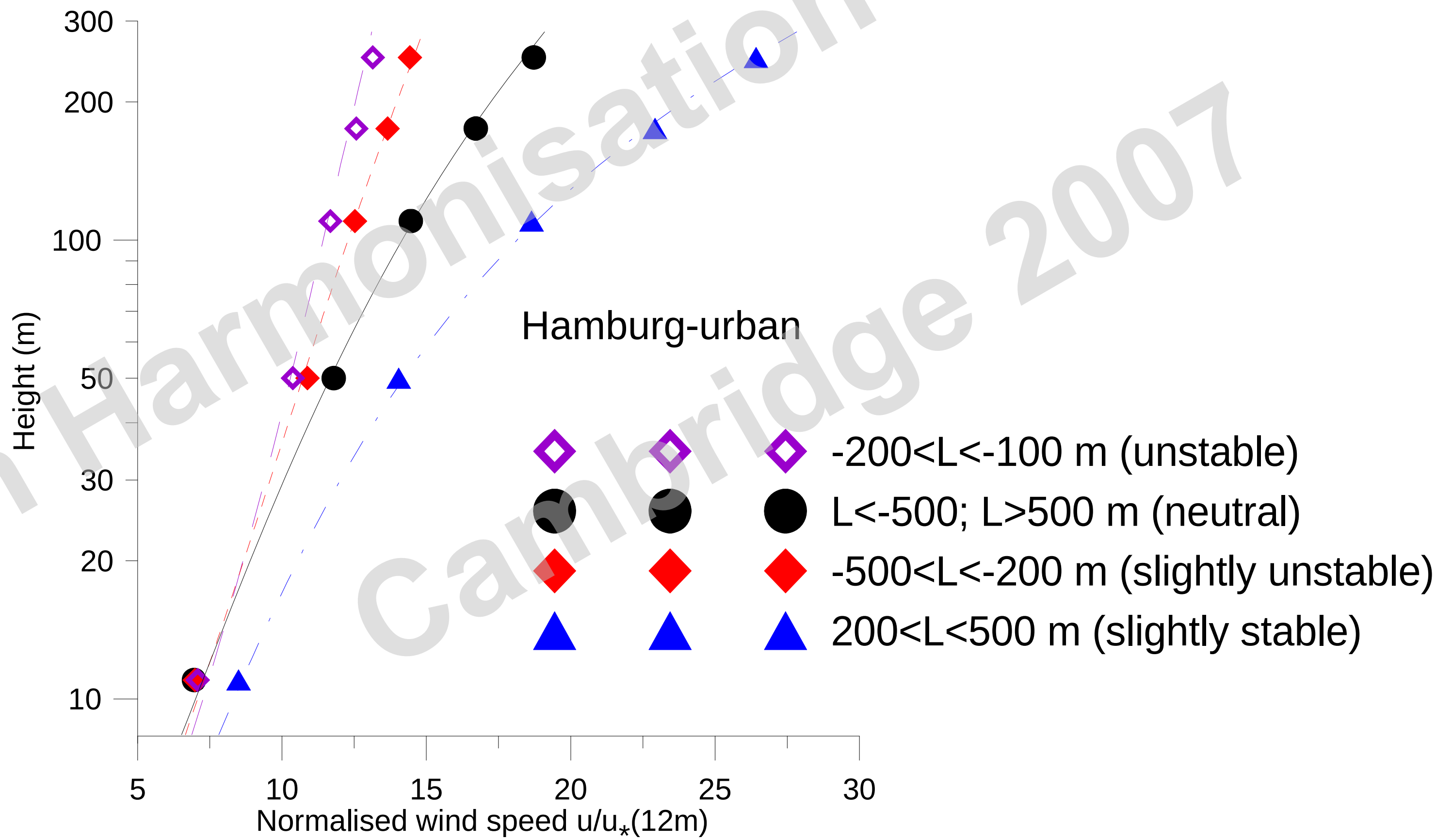


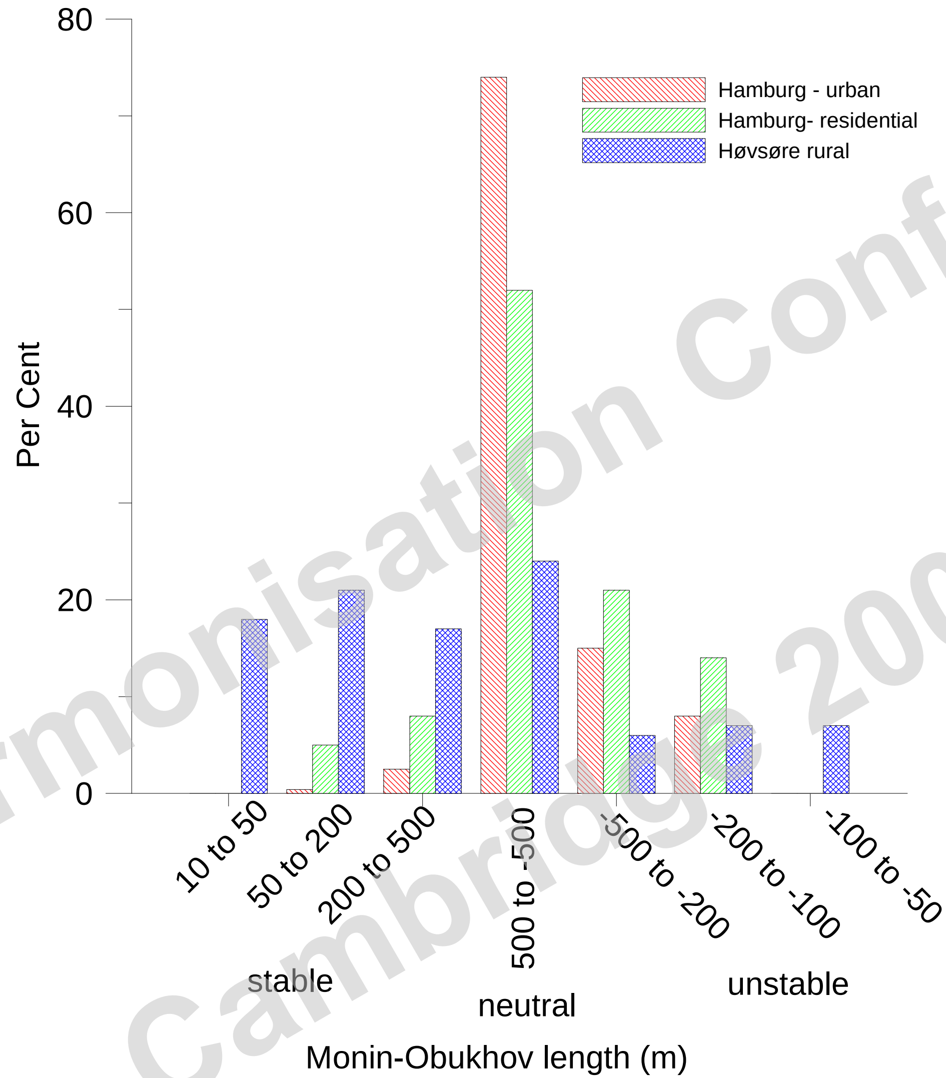
measurements 250 meter tall mast

Measured wind-profiles at a 250 meter mast in Hamburg, Urban sector;
Dyer (1974) surface layer expressions for the wind profile.



Measured wind-profiles at a 250 meter mast in Hamburg, Urban sector;
new expressions for the wind profile.





Frequency distribution of the atmospheric stability for: rural (blue, diagonal cross); residential (green, forward slash) and urban (red, backward slash) areas.

Commonly used expressions for the wind profile

$$u(z) = \frac{u_{*0}}{\kappa}\left(\ln(z / z_0)\right)$$

Neutral atmosphere

$$\frac{u(z)}{u_{*0}} = \frac{1}{\kappa}\left(\ln\left(z/z_0\right) + \frac{b\,z}{L}\right)$$

Stable atmosphere (nighttime)

$$\frac{u(z)}{u_{*0}} = \frac{1}{\kappa}\left(\ln(\frac{z}{z_0}) - \psi\left(\frac{z}{L}\right)\right)$$

Unstable atmosphere (daytime)

with the standard stability correction (Businger)
based on measuremets at small masts (Kansas experiment):

$$\psi\left(\frac{z}{L_{MO}}\right) = \ln\left(\frac{1+x^2}{2}\right) + 2\ln\left(\frac{1+x}{2}\right) - 2\arctan\left(x\right) + \frac{\pi}{2}$$

$$x = \left(1 - 16\,z/L\right)^{1/4}$$

Wind profile, common knowledge

The wind profile for the boundary layer can be expressed as:

$$\frac{du}{dz} = \frac{u_*}{l}$$

where u_* is the local friction velocity (proportional to the square root of the local Reynolds stress). The length scale is denoted l it is a function of the state of the atmosphere and height

The behaviour of the length scale is modelled by inverse summation of the three terms

$$\frac{1}{l} = \frac{1}{l_{sl,N}} + \frac{1}{l_{MBL}} + \frac{1}{l_{UBL}}$$

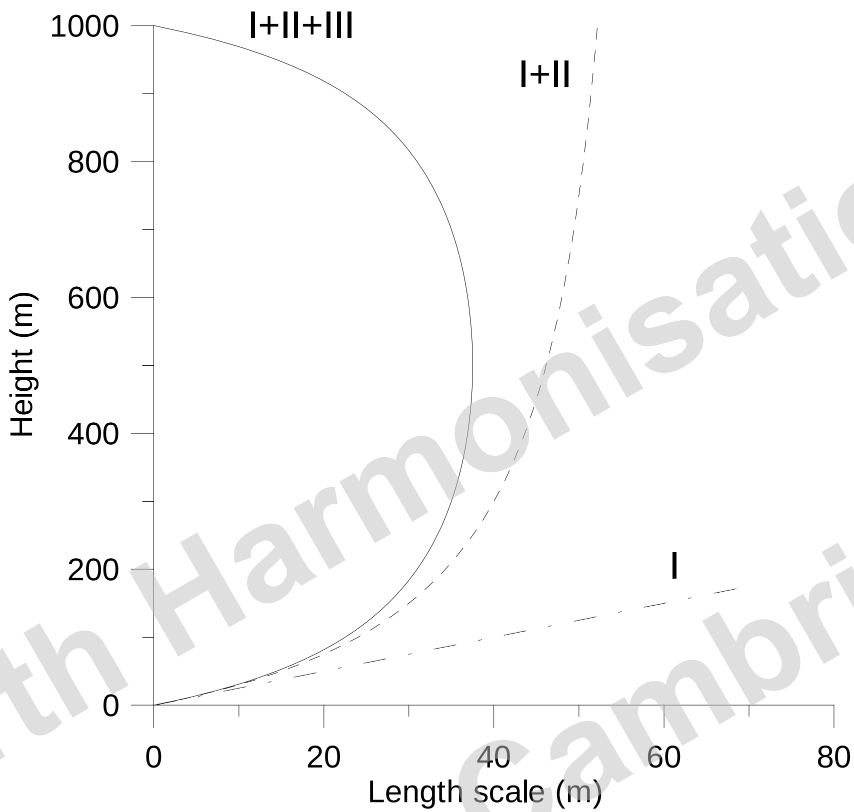
which can be written

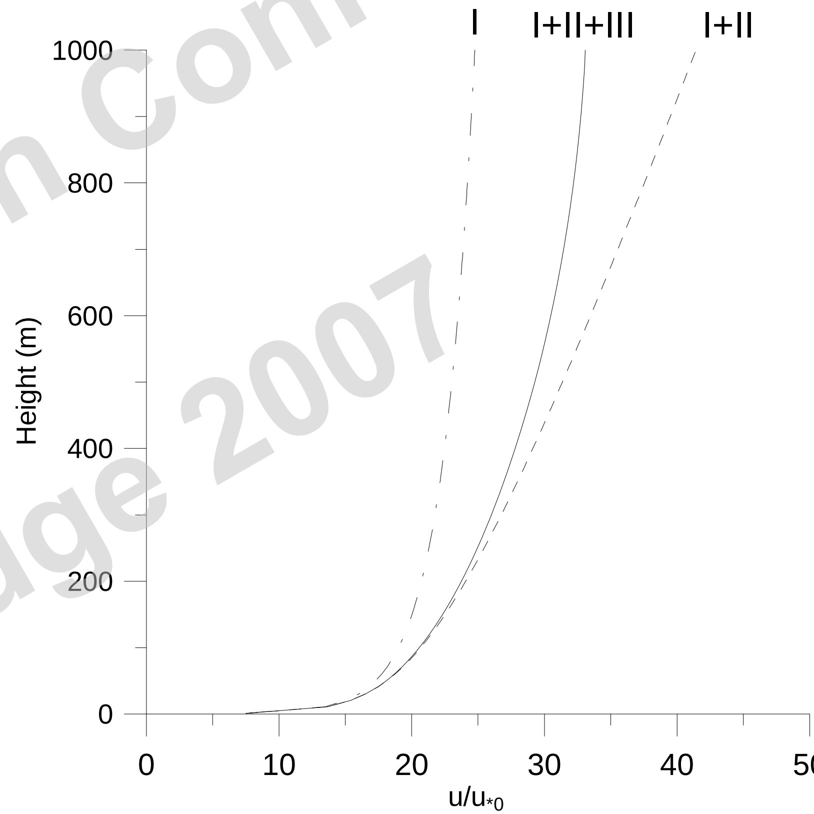
$$\underbrace{\frac{1}{l} = \frac{1}{\kappa z}}_{\mathrm{I}} + \underbrace{\frac{1}{\kappa L_{MBL}}}_{\mathrm{II}} + \underbrace{\frac{1}{\kappa (z_i - z)}}_{\mathrm{III}}$$

For simplicity u_* is taken to decrease linearly with height:

$$u_*(z) = u_{*0}\left(1 - z/z_i\right)$$

Length scales





$du(z_i)/dz = u_{*0}/(\kappa z_i)$ at the top of the boundary layer for expression I and III, but not II, ideally it should be 0

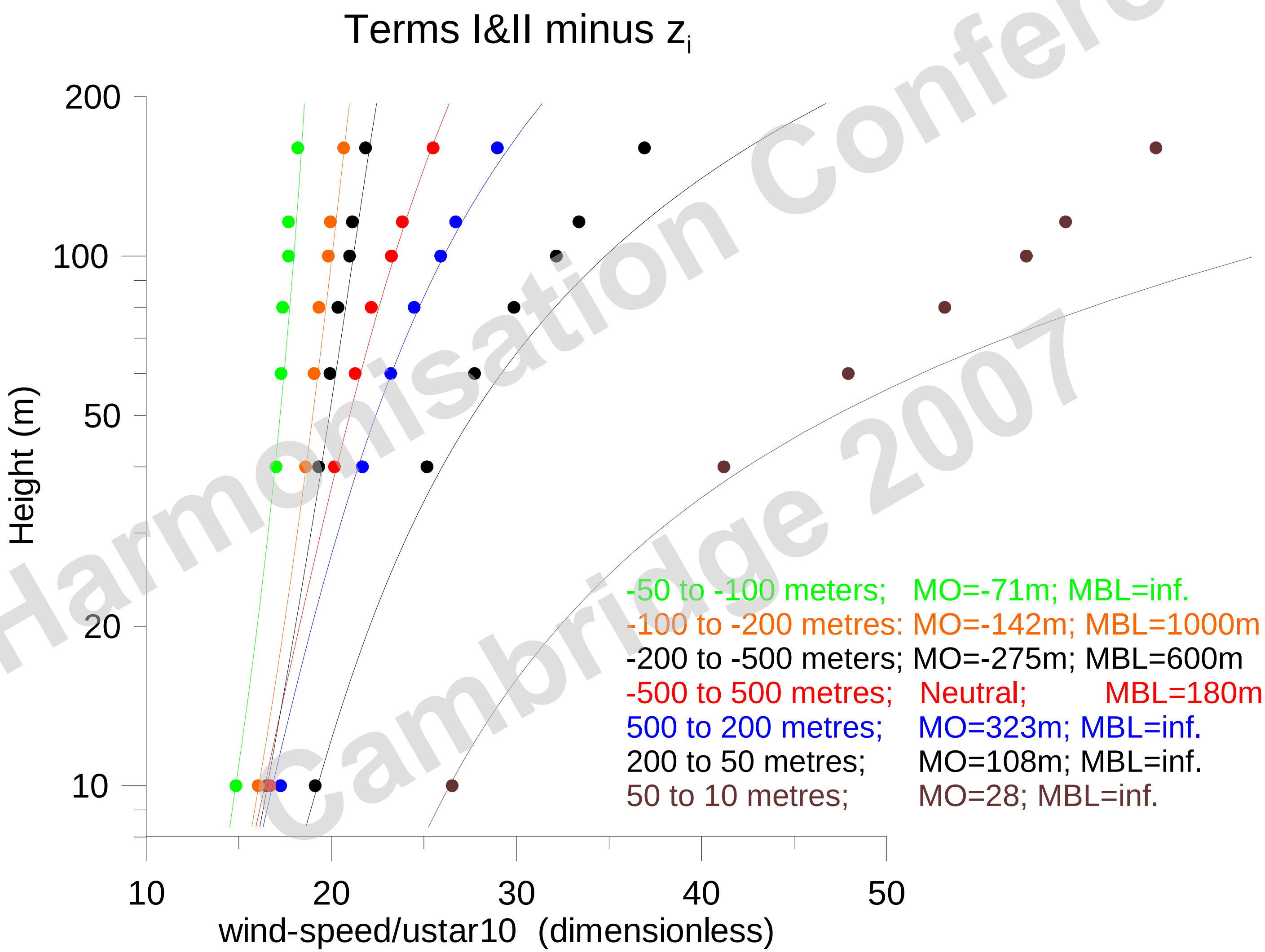
In neutral conditions the above expression for the wind profile can be written:

$$\frac{du}{dz} = u_{*0}\left(1 - \frac{z}{z_i}\right)\left(\frac{1}{\kappa z} + \frac{1}{\kappa L_{MBL}} + \frac{1}{\kappa\left(z_i - z\right)}\right)$$

Integration along z between the roughness length z_0 and height z yields

$$\frac{u(z)}{u_{*0}} = \frac{1}{\kappa}\left(\ln(\frac{z}{z_0}) + \frac{z}{L_{MBL}} - \frac{z}{z_i}\left(\frac{z}{2\,L_{MBL}}\right)\right)$$

The wind profiles not accounting for z_i - for stable conditions the fit is poor

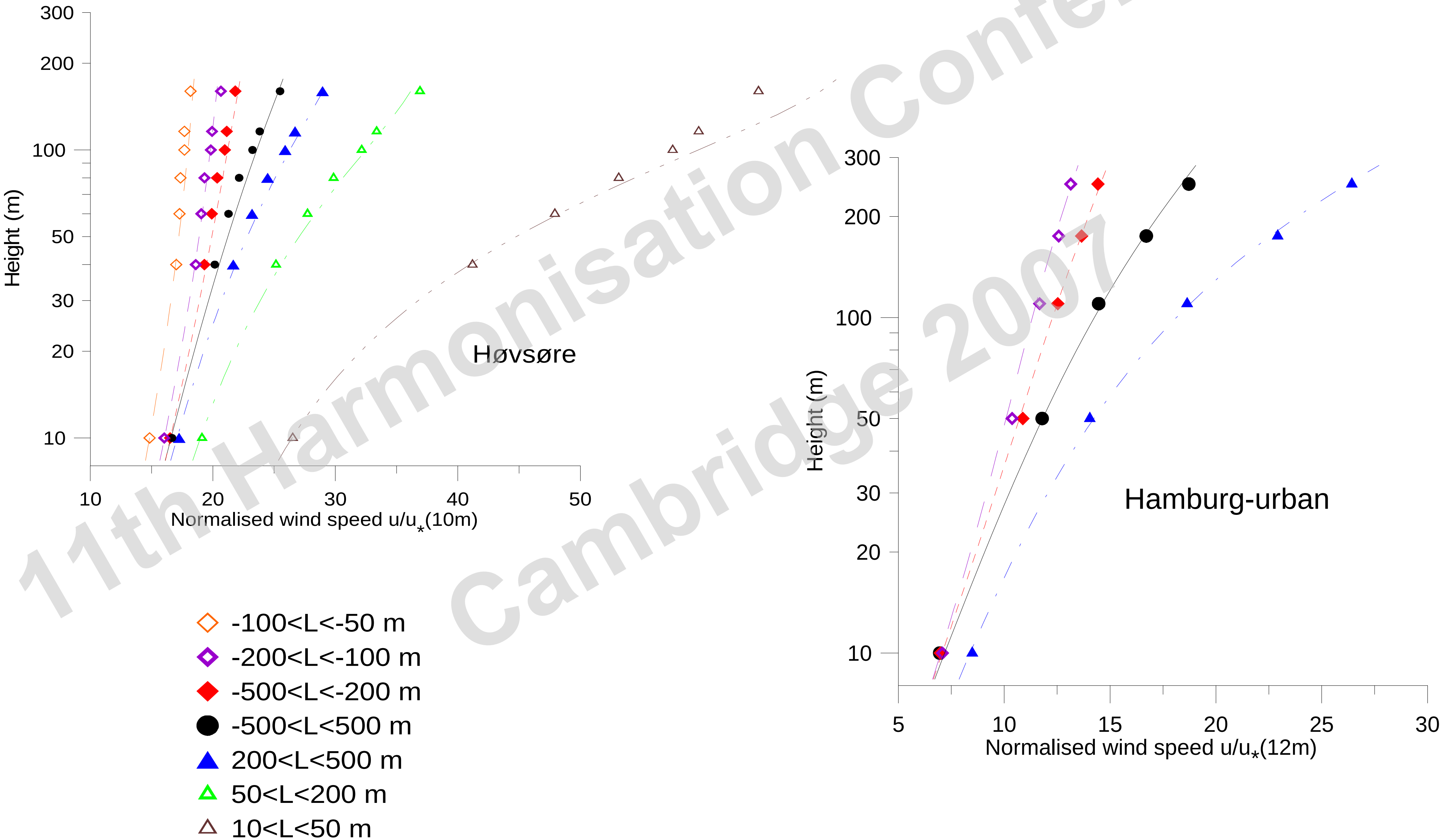


MO with -1/3 fi function + MBL correction minus z_i

Høvsøre - wind sector 30 < dir < 90 degrees

U_{min}=3 m/s

wind profiles including z_i



Fitting to the measured mean wind profiles

Range of L (m)	Mean L (m)	L_{MBL} (m)	z_0 (m)
Høvsøre rural			
10 to 50	28	∞	0.0013
50 to 200	108	250	0.008
200 to 500	323	220	0.013
500 to -500	Neutral	150	0.014
-500 to -200	-275	500	0.012
-200 to -100	-142	1000	0.013
-100 to -50	-71	∞	0.018
Hamburg residential			
50 to 200	124	300	0.20
200 to 500	336	150	0.22
500 to -500	Neutral	140	0.20
-500 to -200	-312	400	0.20
-200 to -100	-141	1000	0.19
Hamburg urban			
200 to 500	349	180	0.42
500 to -500	Neutral	160	0.60
-500 to -200	-322	250	0.55
-200 to -100	-148	500	0.50

Upper boundary condition: geostrophic drag law

$$\frac{G}{u_{*0}} = \frac{1}{\kappa}\sqrt{\left[\ln\left(\frac{u_{*0}}{f\, z_0}\right) - B(\mu)\right]^2 + A^2(\mu)}$$

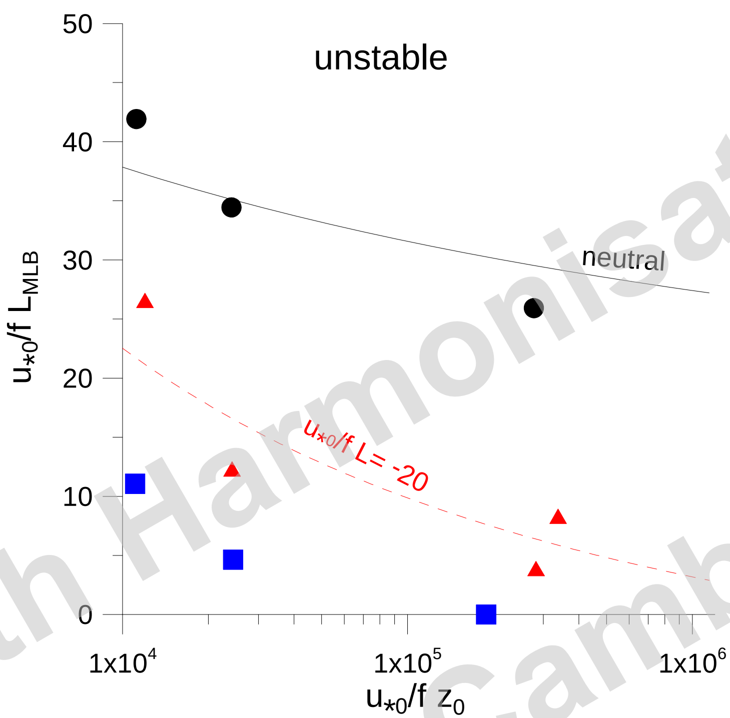
Inserting G/u_{*0} from the wind profile in the geostrophic drag law (neutral):

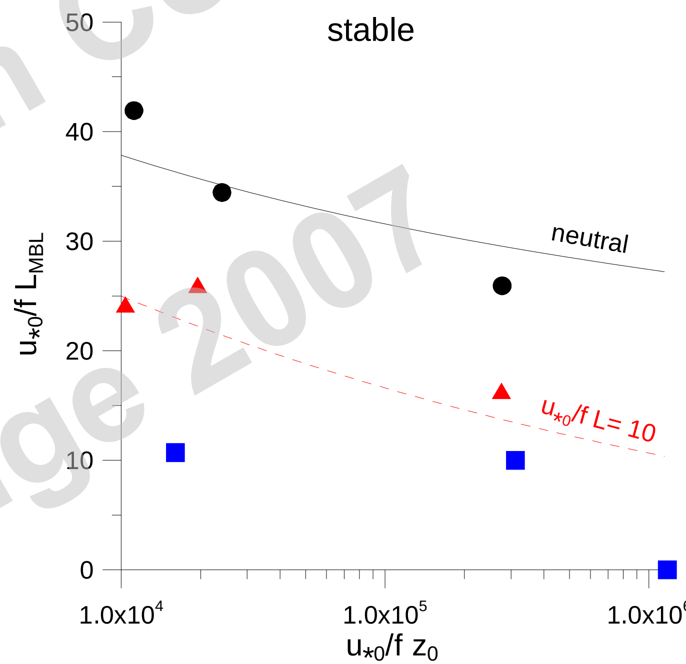
$$\frac{z_i}{L_{MBL}} = 2\left[\sqrt{\left(\ln\left(\frac{u_{*0}}{f\, z_0}\right) - B(0)\right)^2 + A^2(0)} - \ln\left(\frac{z_i}{z_0}\right)\right]$$

and using $z_i = c\, u_{*0} / f$ we get

$$\frac{u_{*0}}{f\, L_{MBL}} = \frac{2}{c}\left[\sqrt{\left(\ln\left(\frac{u_{*0}}{f\, z_0}\right) - B(0)\right)^2 + A^2(0)} - \ln\left(\frac{c\, u_{*0}}{f\, z_0}\right)\right]$$

which gives the relation between $u_{*0}/f\,L_{MBL}$, $u_{*0}/f\,z_0$ and $u_{*0}/f\,L$



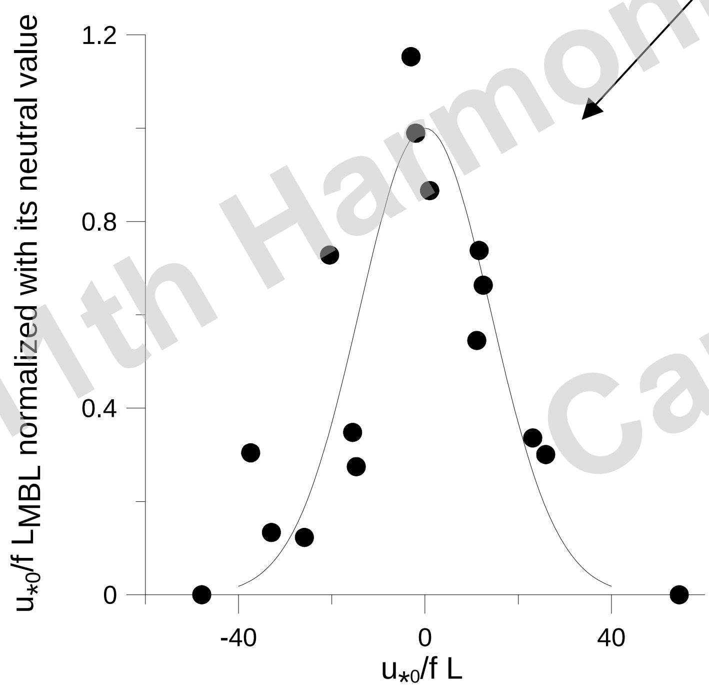


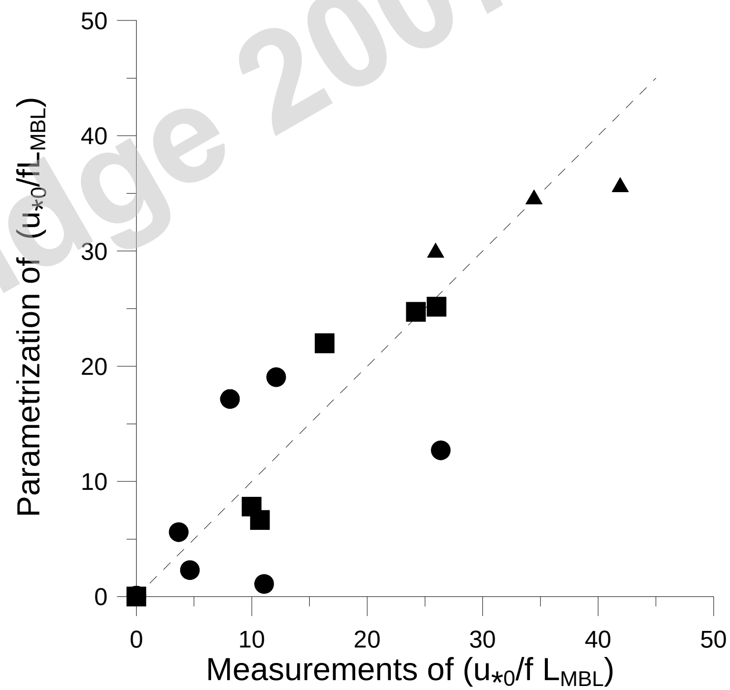
However, the A and B stability functions are poorly known, therefore the relationship is determined from measurements

Empirical fit to the neutral drag law relationship

$$\frac{u_{*0}}{f\,L_{MBL}} = \left(-2\ln\left(\frac{u_{*0}}{f\,z_0}\right) + 55 \right)\exp\left(-\frac{\left(u_{*0}/f\,L\right)^2}{400} \right)$$

Fit based on the measured wind profiles





Conclusions

Above the surface boundary layer the neutral wind profile deviates from logarithmic, the commonly used surface-layer profiles in different stability conditions cannot be used either.

It can be explained by the length scale not being proportional to height (as in the surface layer) but approaching a constant value. The behaviour of the length scale near the top of the boundary layer is not clear but it is essential to include in the wind profile .

Accounting for the boundary layer height is essential for the wind profile, during stable conditions (where the boundary layer height is only slightly higher than the maximum measuring height). The effect is smaller during unstable and neutral conditions where the boundary layer height is much higher than he measuring height.

Conclusions on measurements

The measurements at 160 meter (Høveøre) and 250 meter (Hamburg) masts were of decisive importance for the interpretation of the wind profiles. A 300 metre mast in simple terrain seems appropiate and wishful thinking for further reasearch.

Measurements of the height of the boundary layer are always missing and should be added to routine measurements. Research on how to achieve this parameter should be further initiated.

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