

HAWC2 course

Lesson 2: Wind

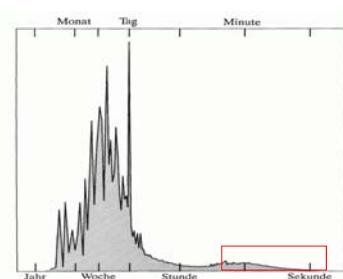
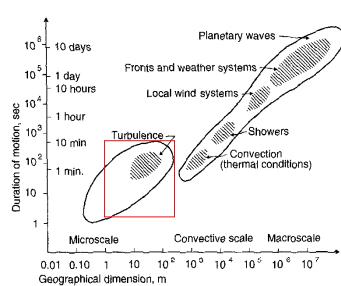
$$f(x+\Delta x) = \sum_{n=0}^{\infty} \frac{(\Delta x)^n}{n!} f^n(x)$$

$$\Delta \int \Sigma \Theta^{\sqrt{17}} + \Omega \int \delta e^{bx} =$$

$$\infty - [2.7182818284 \cdot x^2] \Sigma !$$

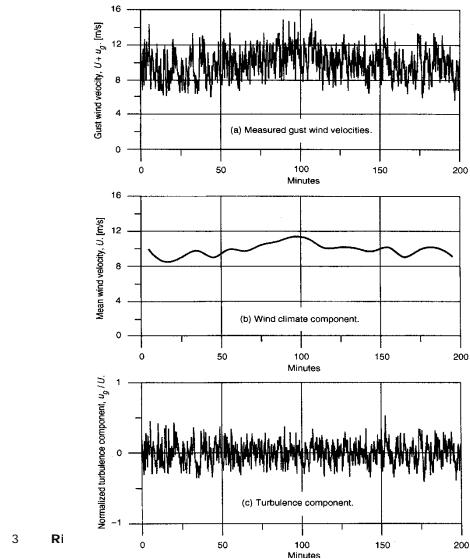
Riso DTU
National Laboratory for Sustainable Energy

Wind systems/ scales



From: M. Courtney, I. Troen: Wind spectrum for one year of continuous 8 Hz measurements. pp 301-304, 9th symposium on Turbulence and diffusion, Denmark 1990.

Mean values and turbulence



Measurement

Variation in wind with frequency content lower than 10min^{-1}

Frequency content higher than 10min^{-1}

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3 RI

Mean wind and turbulence

Mean wind

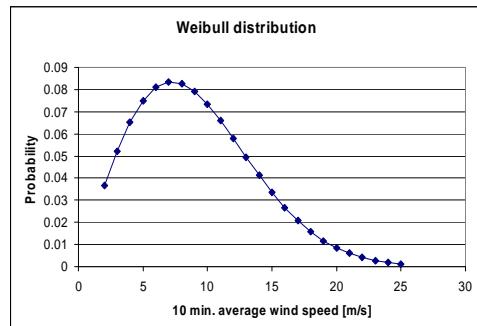
- Hub center wind speed distribution
- Wind shear
- Wind direction
- Slope of mean wind

Turbulence

- Intensity in u-direction
- Relative intensity in v- and w- directions
- Pre-calculated turbulence time series
- 3 non/correl. series)
- [std(U), mean(U), length scale, coherence]

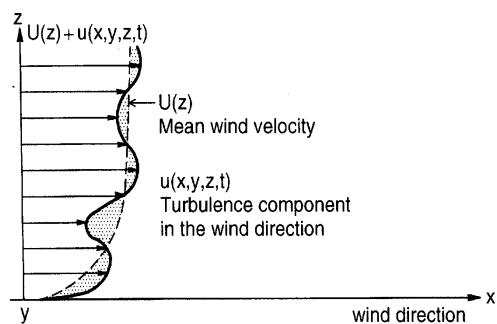
Weibull distribution of mean wind

$$P(U \leq U_0) = 1 - \exp\left(-\frac{U_0}{A}\right)^k$$



$$P(U_0 \leq U \leq U_1) = -\exp\left(-\left(\frac{U_1}{A}\right)^k\right) + \exp\left(-\left(\frac{U_0}{A}\right)^k\right)$$

Wind profile



Description of wind profiles

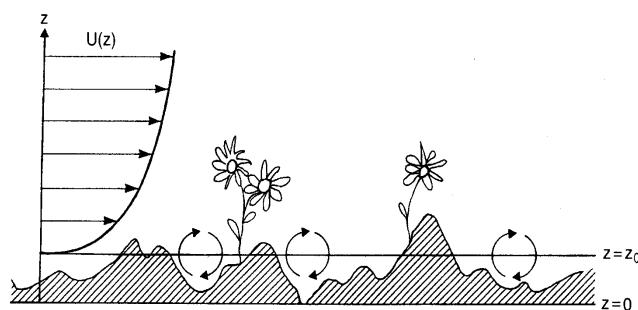
$$U(z) = U_{hub} \frac{\ln(z/z_0)}{\ln(z_{hub}/z_0)}$$

Logarithmic description

$$U(z) = U_{hub}(z/z_{hub})^a$$

Power law description

The roughness length, z_0

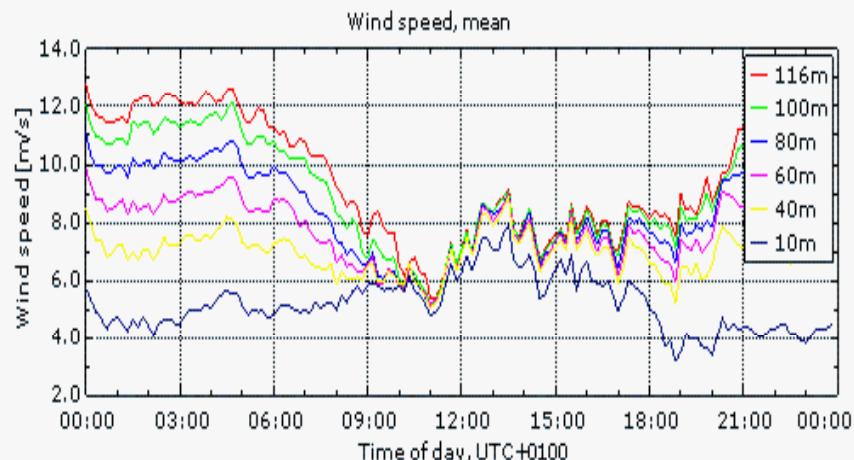


- Open sea: 0.0001 m
- Open land: 0.01 m
- Farmland: 0.05 m
- Forrest, city: 0.5-1 m

Rotors in atmospheric shear, stability



Met-mast measurements, Høvsøre

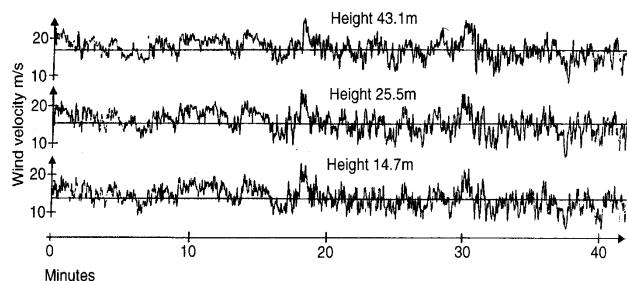


from <http://veaonline.risoe.dk>

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Turbulence in neutral conditions



For neutral conditions:

$$\sigma = \alpha u_* \quad \text{Monin-Obukhov scaling.}$$

$$\bar{V}(z) = \frac{u_*}{\kappa} \ln(z/z_0), \quad \text{Log. Power law profile}$$

$$I_{amb}(z) = \frac{\alpha \kappa}{\ln(z/z_0)}, \quad \text{where the von Karmans constant } \kappa=0.4 \text{ and } \alpha \sim 2.4$$

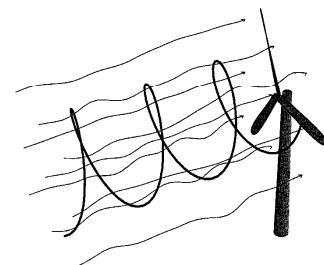
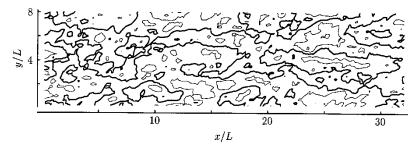
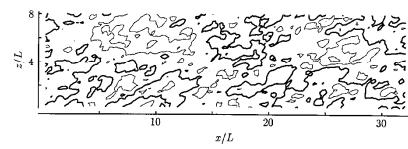
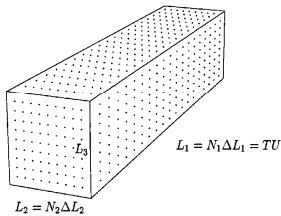
Turbulence intensity is not dependent on wind speed in neutral conditions

$$\sigma(z) = I(z)U(z) = \frac{\alpha \kappa}{\ln\left(\frac{z_{hub}}{z_0}\right)} \quad \text{Standard deviation is constant with height in neutral conditions}$$

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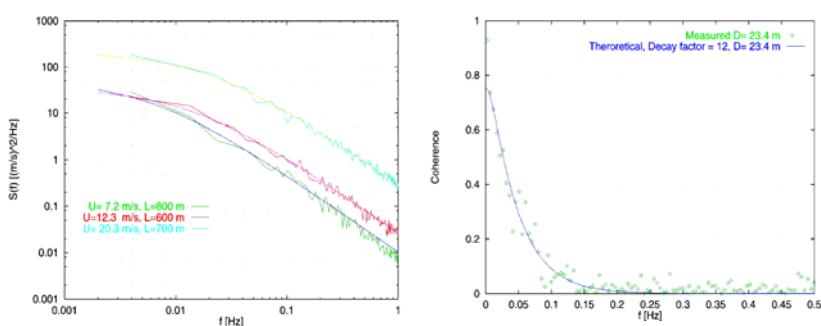
Implementation of turbulence in aeroelastic models



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Turbulence



$$S_i(f) = \sigma_i^2 \frac{L_i/U}{(1+1.5(fL_i/U))^{5/3}}$$

Normal formulation for coherence:

$$coh(r, f) = \exp\left[-A_i\left(\frac{rf}{U}\right)\right]$$

In the IEC standard:

$$coh(r, f) = \exp\left[-12\sqrt{\left(\frac{rf}{U}\right)^2 + \left(\frac{0.12r}{L_c}\right)^2}\right]$$

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3-D turbulence

All components in the turbulence must be included (u, v, w)

$$\frac{s_v}{s_u} = 0.8 \text{ (comp. ter. : : 1.0)}$$

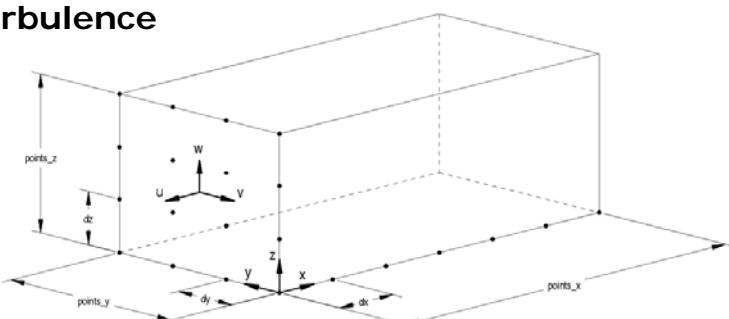
Standard deviation ratio

$$\frac{s_w}{s_u} = 0.5 \text{ (comp. ter. : : 0.8)}$$

$$\frac{l_v}{l_u} = 0.33; \quad \frac{l_w}{l_u} = 0.25$$

Length scale ratio

Mann turbulence



4 parameters important

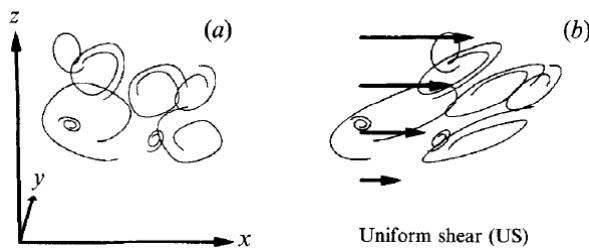
- An $a e^{2/3}$ determining the variance level
- A length scale frequency with most energy
- A gamma parameter
- High frequency compensation. (Should the point value represent local vector, or average value for the cell volume)?

Mann turbulence

- The turbulence level is in the Mann model obtained through an $\alpha \varepsilon^{2/3}$ parameter in the isotropic energy spectrum (Von Karman).

$$E(k) = \alpha \varepsilon^{2/3} L^{\frac{1}{3}} \frac{(Lk)^4}{(1 + (Lk)^2)^{11/6}},$$

- The spectrum is affected by sheared inflow which modifies the low frequent content and the turbulence level. Γ is a parameter describing the level of shear. $\Gamma=3.9$ correspond to normal conditions.

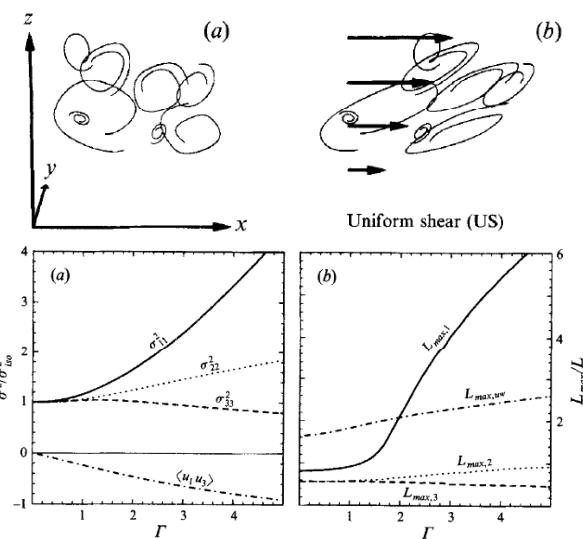


J. Mann. The spatial structure of neutral atmospheric surface-layer turbulence. J. Fluid Mech. (1994), vol. 273, pp. 141-168

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Turbulence properties as function of Γ



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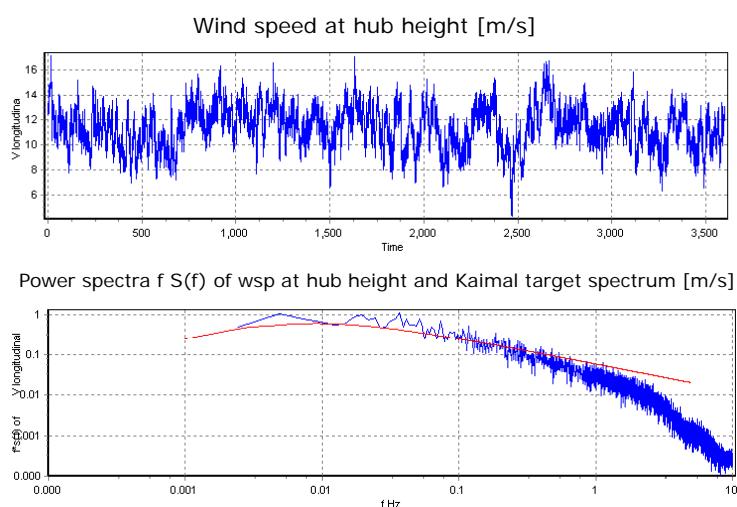
Turbulence scaling

- Since it is problematic to predict the correct $\alpha \epsilon^{2/3}$ value to get the requested turbulence level is is much more easy and practically usefull to rescale the turbulence field (which is done automatically inside HAWC2).
 - Turbulence field in the center of the box is read and actual variance level found.
 - A scaling factor compensated for difference in variance level is found

$$SF = \sqrt{\frac{var_{target}}{var}}$$

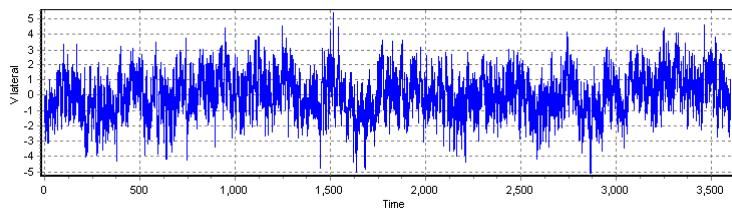
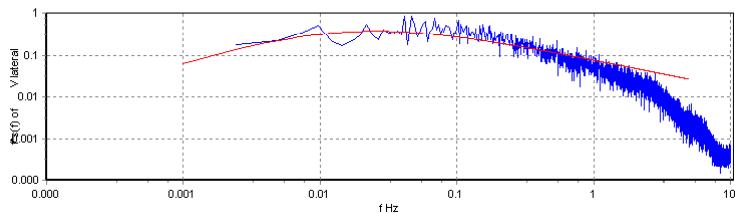
- This is multiplied to the wind field in u,v and w direction

Example at 11.4m/s, u-dir



Wind at 11.4m/s, v-dir

Wind speed at hub height [m/s]

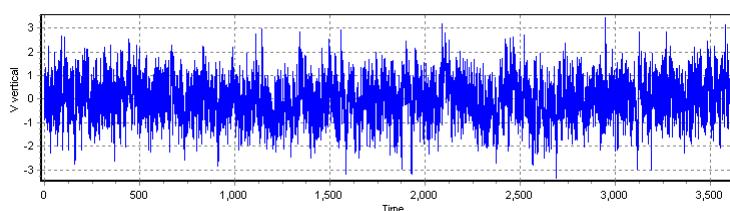
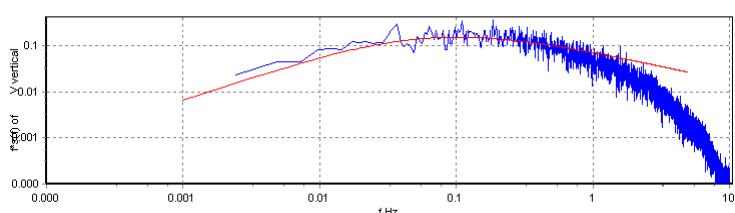
Power spectra $f S(f)$ of wsp at hub height and Kaimal target spectrum [m/s]

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Wind at 11.4m/s, w-dir

Wind speed at hub height [m/s]

Power spectra $f S(f)$ of wsp at hub height and Kaimal target spectrum [m/s]

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HAWC – wind input

```

begin wind;
density          1.225 ;
wsp              4 ;
tilt             0.0 ;
horizontal_input 1 ;           0=false, 1=true
windfield_rotations 0.0 0.0 0.0 ; yaw, tilt, rotation
center_pos0      0.0 0.0 -123.0 ;
shear_format     3 0.2 ; 0:none, 1=constant, 2=log, 3=power, 4=linear
turb_format      0 ; 0:none, 1=mann, 2=flex
tower_shadow_method 1 ; 0:none, 1=potential flow, 2=jet, 3=jet2, 4=jet2
scale_e_time_start 0 ;
wind_ramp_factor 0.0 40.0 0.5 1.0 ; t0, t1, f0, f1
;
wind_ramp_abs   50.0 50.1 0.0 1.0 ; t0, t1, V0, V1
wind_ramp_abs   80.0 80.1 0.0 1.0 ;
;
begin mann;
create_turb_parameters 29.4 1.0 3.7 1025 1.0 ; L, alfaeps, gamma, seed, highfrq compensation
filename_u      ./turb/114su.bin ;
filename_v      ./turb/114sv.bin ;
filename_w      ./turb/114sw.bin ;
box_dim_u       8192 2.050 ;
box_dim_v       32 3.125;
box_dim_w       32 3.125;
std_scaling     1.0 0.8 0.5 ;
end mann;
;
begin tower_shadow_potential;
tower_offset 0.0 ;
nse 2;
radius        0.0 6.0 ;
radius        -120.0 2.0 ;
end tower_shadow_potential;
end wind;
;

```

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Generation of very large Turbulence Fields

An example:

Wind speed 11.4m/s

Simulation length **3600s**

Fieldsize in meters

41040, 200, 150

No of points in each direction

32768, 64, 32

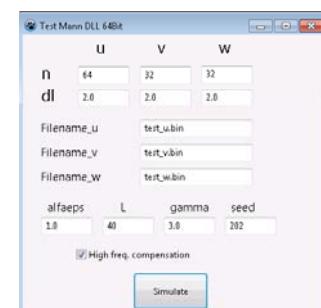
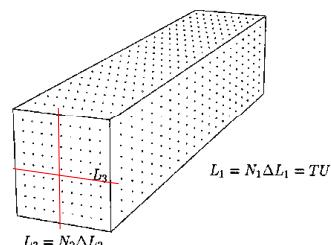
dL1, dL2, dL3

1.252m, 3.125m, 4.68m

dt 0.109s

Memory consumption

3x4x4x32768x64x32=3.2GByte



This cannot be addressed on WIN32. => A new 64 bit application have been made.

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