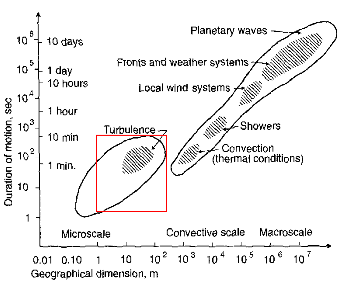
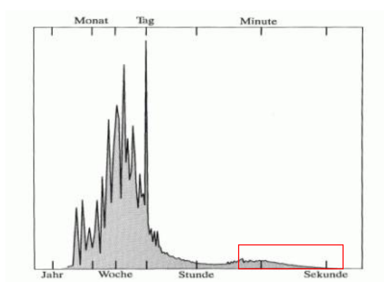
HAWC2 course

Lesson 2: Wind

Risø DTU
National Laboratory for Sustainable Energy

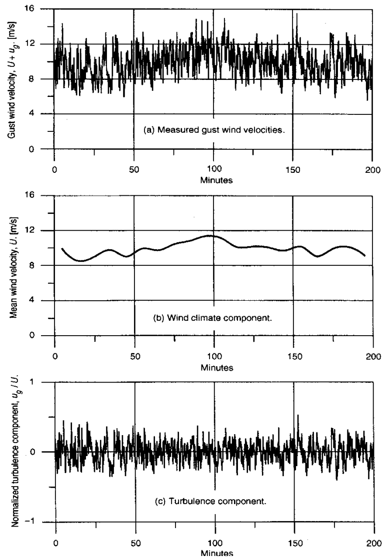
Wind systems/ scales





From: M. Courtney, I. Troen: Wind spectrum for one year of continous 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 $10min^{-1}$

Mean wind and turbulence

Mean wind

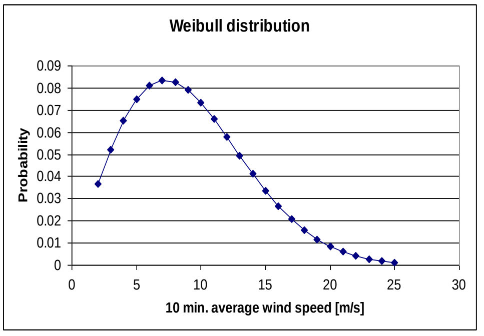
- Hub center wind speed distribution
- Wind shear
- Wind direction
- Slope of mean wind

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]

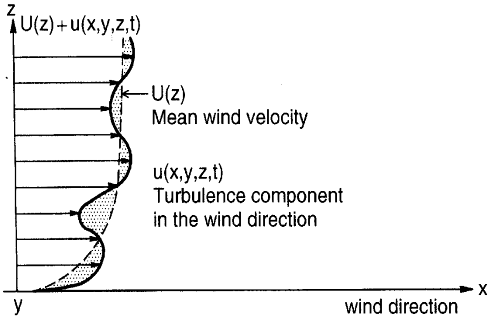
Weibull distribution of mean wind

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



$$P(U_0 \le U \le U_1) = -\exp\left(-\left(\frac{U_1}{A}\right)^k\right) + \exp\left(-\left(\frac{U_2}{A}\right)^k\right)$$

Wind profile



Description of wind profiles

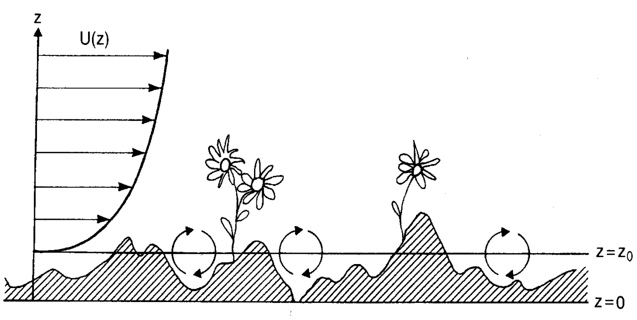
$$U(z) = U_{hub} \frac{\ln(z/z_0)}{\ln(z_{hub}/z_0)}$$

Logarithmic description

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

Power law description

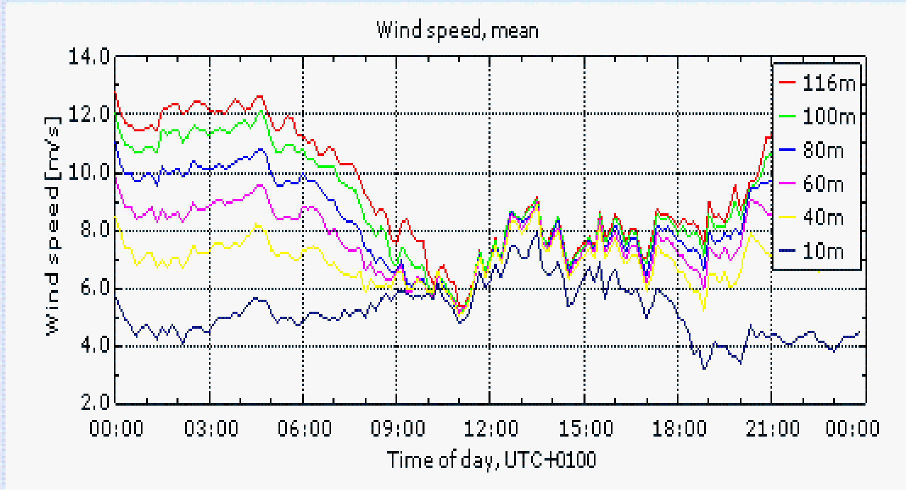
The roughness length, Z_0



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

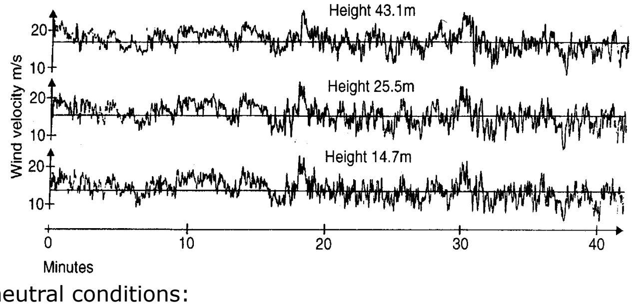
Rotors in atmospheric shear, stability

Met-mast measurements, Høvsøre



from http://veaonline.risoe.dk

Turbulence in neutral conditions



For neutral conditions:

$\sigma = \alpha u_*$ Monin-Obukhov scaling.

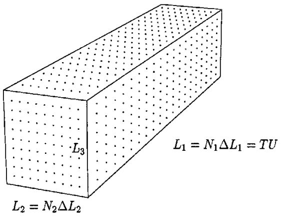
$\bar{V}(z) = \frac{u_*}{\kappa} ln(z/z_0)$, Log. Power law profile

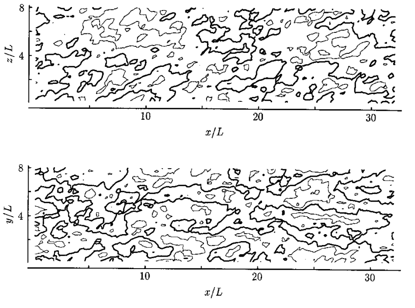
$I_{amb}(z) = \frac{\alpha\kappa}{ln(z/z_0)}$, where the von Karmans constant κ=0.4 and α~2.4

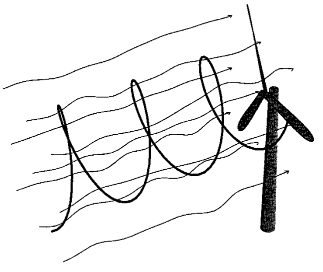
Turbulence intensity is not dependent on wind speed in neutral conditions

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

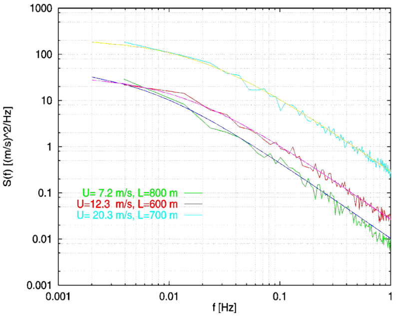
Implementation of turbulence in aeroelastic models

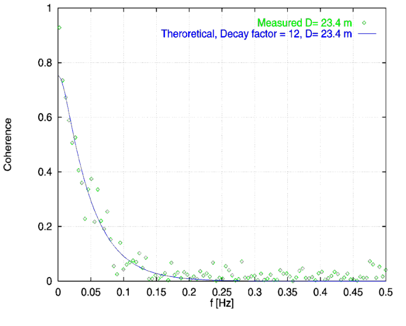






Turbulence





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

Normal formulation for coherence:

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

In the IEC standard:

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

3-D turbulence

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

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

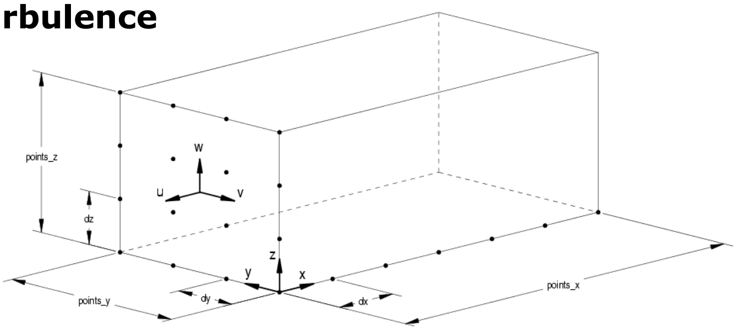
$$\frac{s_w}{s_u} = 0.5 \text{ (comp. ter. : : 0.8)}$$

Standard deviation ratio

$$\frac{L_v}{L_u} = 0.33; \quad \frac{L_w}{L_u} = 0.25$$

Length scale ratio

Mann turbulence



4 parameters important

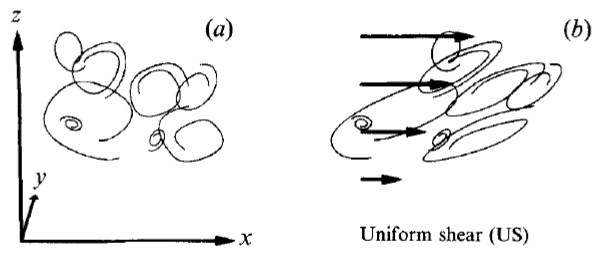
- An $ae^{2/3}$ determining the variance level
- A length scale frequencywith most energy
- A gamma parameter
- High frequency compensation. (Should the point value represent local vector, or average value for the cell volume)?

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).

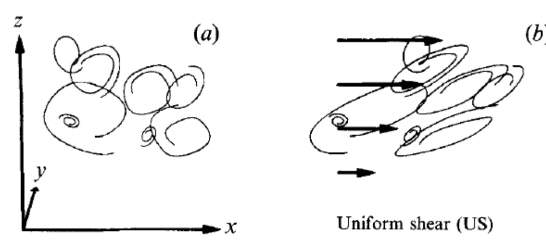
$$E(k) = \alpha\varepsilon^{\frac{2}{3}} L^{\frac{5}{3}} \frac{(Lk)^4}{(1+(Lk)^2)^{\frac{17}{6}}},$$

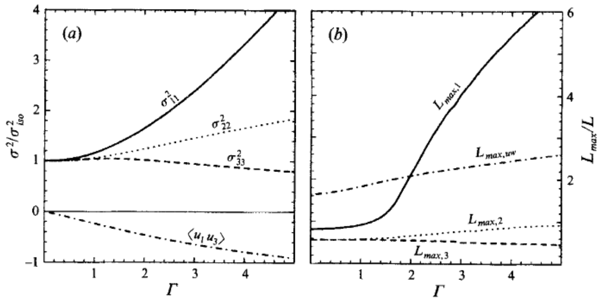
- The spectrum is affected by sheared inflow which modifies the low frequent content and the turbulence level. Γ is a parameter describing the level of shear. Γ=3.9 correspond to normal conditions.



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

Turbulence properties as function of Γ





Turbulence scaling

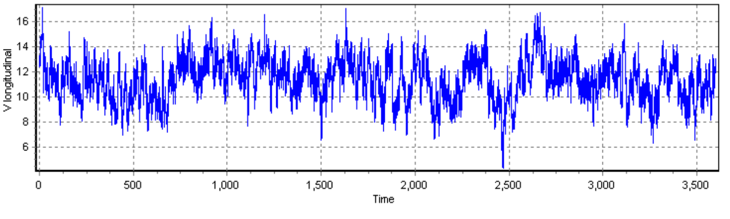
- Since it is problematic to predict the correct $\alpha\varepsilon^{2/3}$ value to get the requested turbulence level is is much more easy and pratically usefull to rescale the turbulence field (which is done automatically inside HAWC2).
  - Turbulence field in the center of the box is read and actual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

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

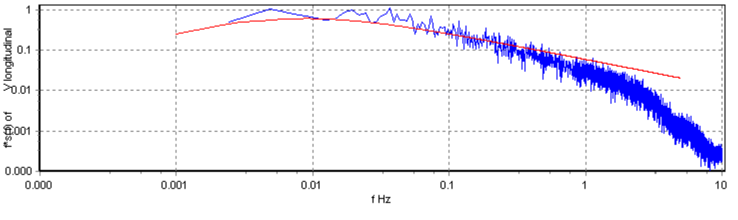
  - This is multiplied to the wind field in u,v and w direction

Example at 11.4m/s, u-dir

Wind speed at hub height [m/s]

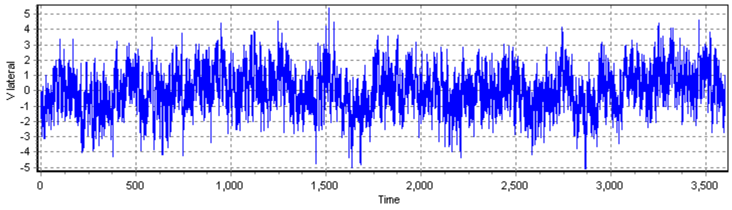


Power spectra f S(f) of wsp at hub height and Kaimal target spectrum [m/s]

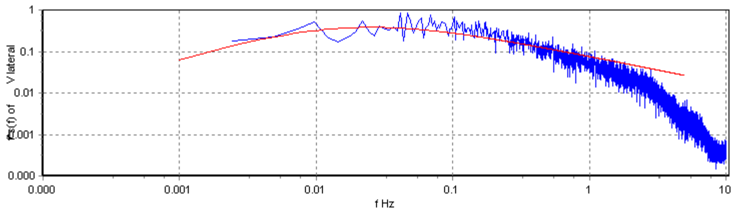


Wind at 11.4m/s, v-dir

Wind speed at hub height [m/s]

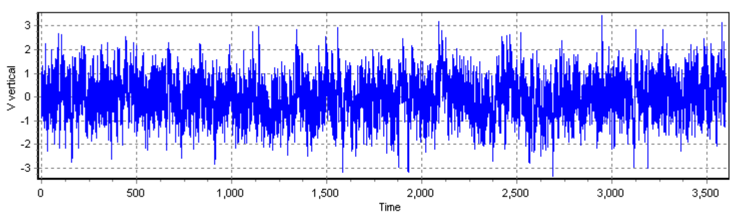


Power spectra f S(f) of wsp at hub height and Kaimal target spectrum [m/s]

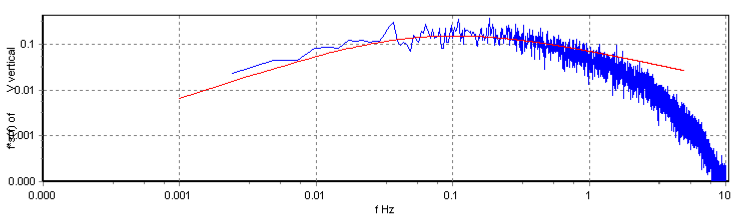


Wind at 11.4m/s, w-dir

Wind speed at hub height [m/s]



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



HAWC – wind input

```
begin wind ;
  density                1.225 ;
  wsp                    4  ;
  tint                   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            1     ;  0=none, 1=mann,2=flex
  tower_shadow_method    1     ;  0=none, 1=potential flow, 2=jet, 3=pot2, 4=jet2
;  scale_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/114s1u.bin ;
    filename_v    ./turb/114s1v.bin ;
    filename_w    ./turb/114s1w.bin ;
    box_dim_u    8192 2.0508 ;
    box_dim_v    32 3.125;
    box_dim_w    32 3.125;
    std_scaling   1.0 0.8 0.5 ;   If omitted, turbulence is equally scaled in all three direction so sigma_u fits
;                                  target (from given turbulence intensity), version 11.0 and newer
  end mann;
;
  begin tower_shadow_potential;
    tower_offset 0.0 ;
    nsec  2;
    radius      0.0   6.0 ;
    radius    -120.0  2.0 ;
  end tower_shadow_potential;
end wind;
;
```


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 apllication have been made.