Modelling offshore wind resources and wind conditions

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Outline

- Offshore wind resources [WAsP]
  - Data & model issues
  - Model performance
- Offshore wind conditions [WEng]
  - IEC 61400 standard
  - Wake turbulence modelling
- Future challenges and developments
- Summary and conclusions

Offshore wind resources with WAsP

- Met. data
  - On-site measurements
  - Wind atlas data sets
  - NCEP/NCAR reanalysis data
  - Meso-scale modelling (KAMM/WAsP)
- Model issues
  - Wind speed profiles
  - Roughness length
  - Atmospheric stability

WAsP offshore - current practice

Issue

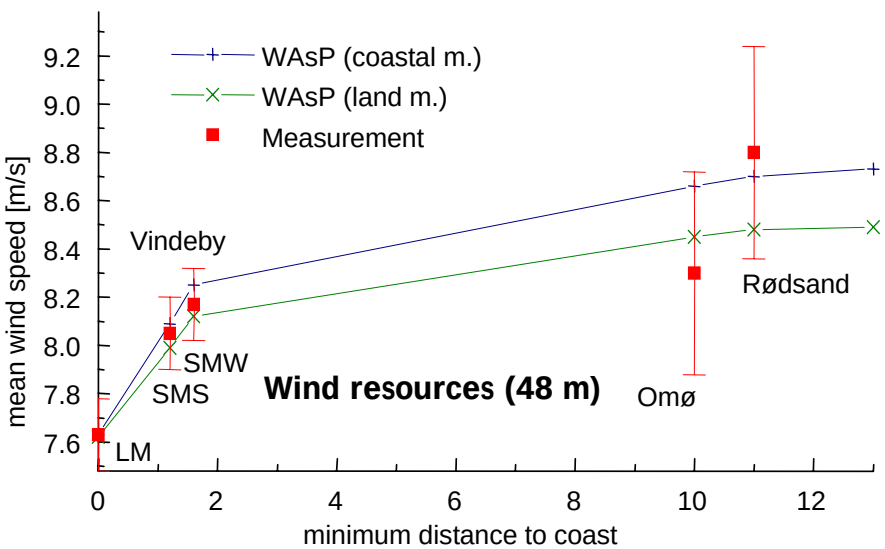
1. Anemometer/hub height
2. Roughness length
3. Wake decay constant
4. Long-term climatic variations
5. Air density
6. Tides, sea ice, …

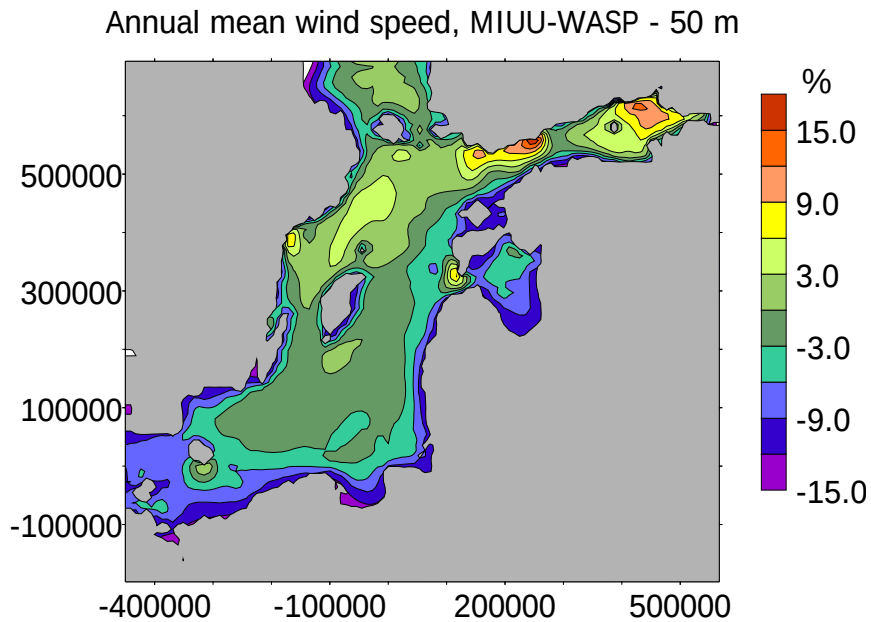
Current engineering practice

1. [m] above mean sea level
2. z_0 = 0 for water areas
3. k = 0.05 (small farms)
4. MCP, NCEP/NCAR, wind index
5. Site-specific power curve
6. Sensitivity analyses

WAsP in the coastal zone

- Some evidence of over-prediction (few percents) in near-coastal zone
- Comparison with measurements (figure below)
- Comparison with mesoscale model (figure to the right)
- Inconsistency near coast-lines might be a stability/internal boundary-layer issue





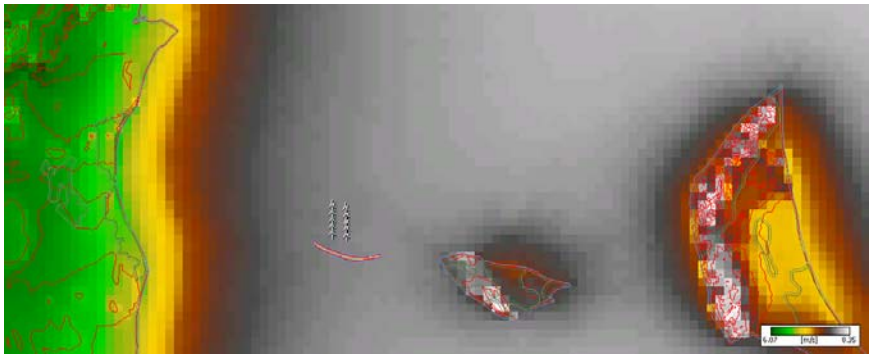
Case study: Wind resource at Tunø Knob

Slightly different WAsP calculations

Wind Atlas	Rough-ness	Topo-graphy	Wake decay	Net AEP [GWh]	
Beldring	No	No	0.075 (land)	16.967	111.0%
Beldring	No	No	0.050 (offshore)	16.831	110.1%
Beldring	Yes	No	0.050 (offshore)	15.805	103.4%
Beldring	Yes	Yes	0.050 (offshore)	15.857	103.7%
NCEP/NCAR	Yes	Yes	0.050 (offshore)	15.031	98.3%

Compare with 5-year corrected* production data: 15.290

*98% availability, EMD wind index

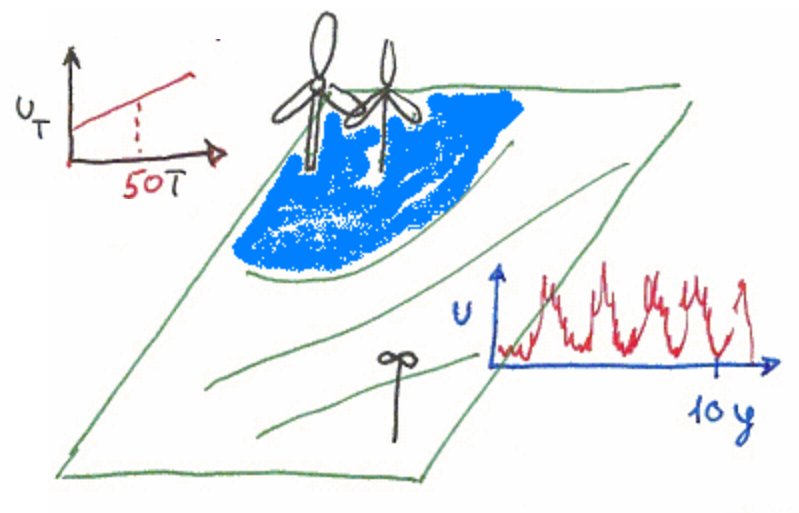


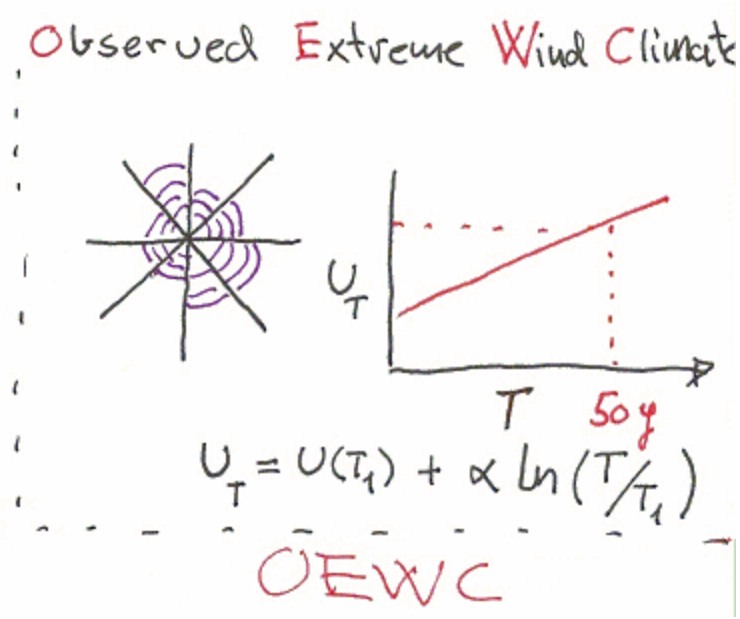
Site assessment issues in IEC 61400-1 standard

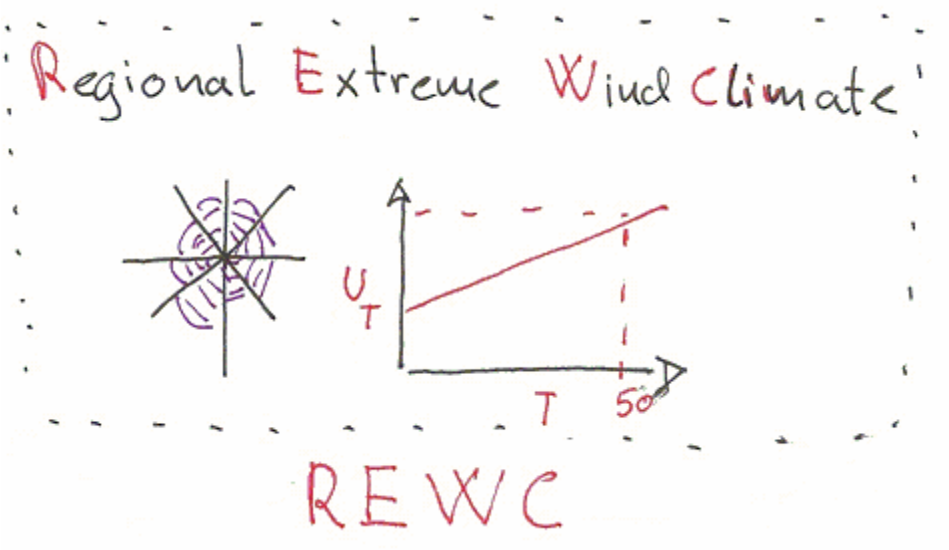
- Shear of vertical wind profile
- Wind speed probability distribution
- Flow angles
- Free-stream turbulence
- Wake turbulence
- Extreme winds

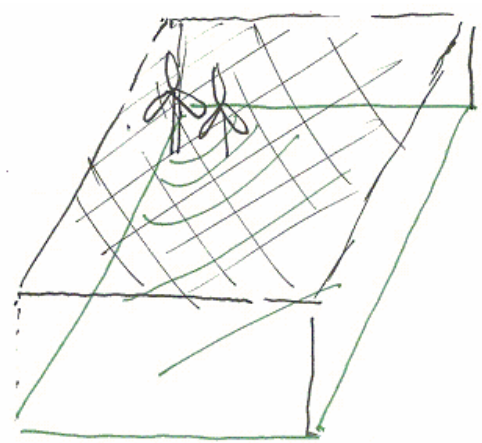
These conditions are calculated by WAsP Engineering (WEng)

WEng extreme winds by observation









WEng extreme winds by reanalysis data - e.g. the NCEP/NCAR data set

Pressure at model surface P_s

$$P_0 = P_s \exp\left(\frac{gh}{RT_m}\right)$$

Pressure at the sea level P_o

$$u_g = -\frac{1}{f\rho}\frac{\Delta P}{2a\Delta\phi}, \quad v_g = \frac{1}{f\rho}\frac{\Delta P}{2a\Delta\lambda\cos\phi}$$

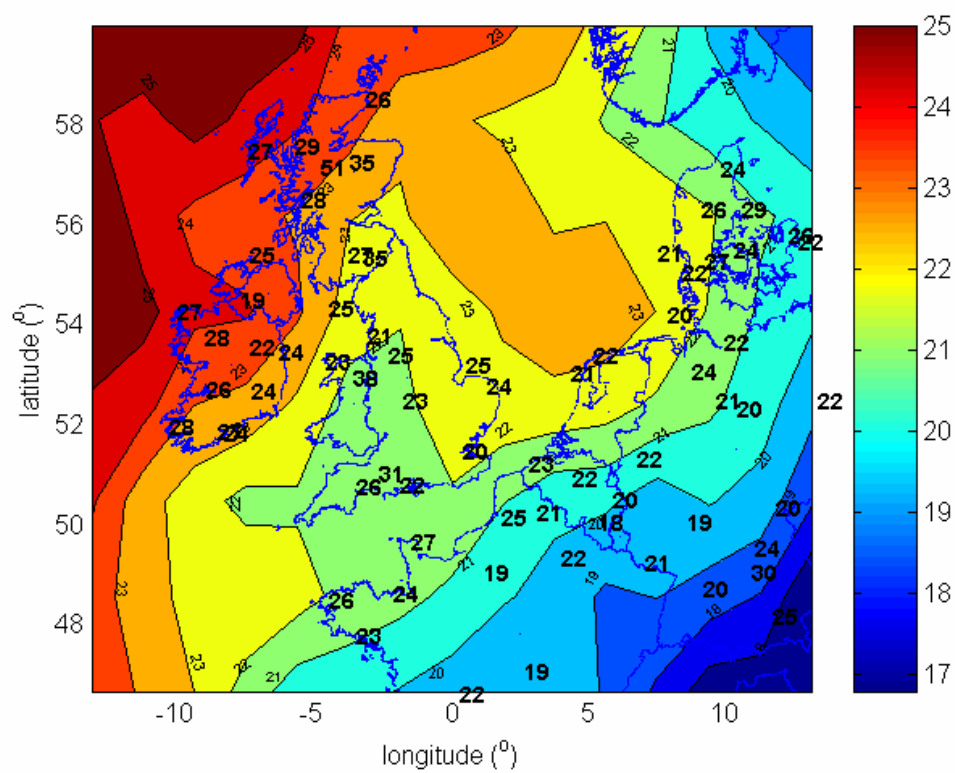
Geostrophic wind by pressure gradient

$$G = \frac{u_*}{\kappa}\sqrt{\left(\ln\frac{u_*}{fz_0} - A\right)^2 + B^2}$$

Surface wind at 10 m with z_0=5cm

$$u_{10} = \frac{u_*}{\kappa}\ln\frac{10m}{z_0}$$

Regional extreme wind climate (REWC)



WEng for site assessment

INPUT

- Map of orography and surface roughness
- Windfarm layout
- Obstacle list
- Wind Atlas file
- Extreme Wind Climate

OUTPUT - each turbine site

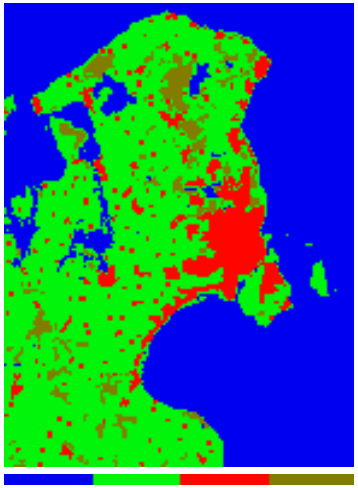
- Reference velocity V_{ref} (i.e. U_{50})
- Turbulence (σ_u, σ_v, σ_w)
- Wind shear (du/dz)
- Wind speed probability $p(u|\theta)$.
- Flow inclination

Plus

- Turbulence spectra
- Turbulence simulation

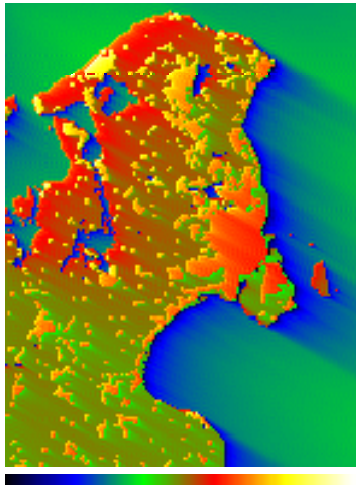
WEng flow model

Roughness class



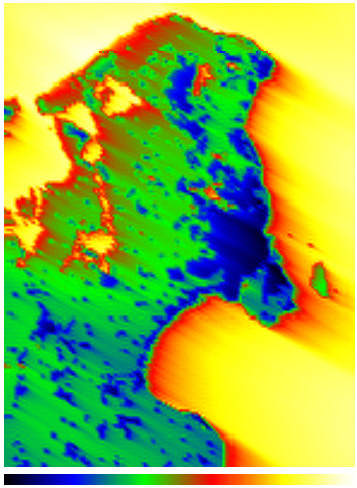
water rural urban forest

Friction velocity



0.15 m/s 0.85

Wind velocity



5 m/s 11

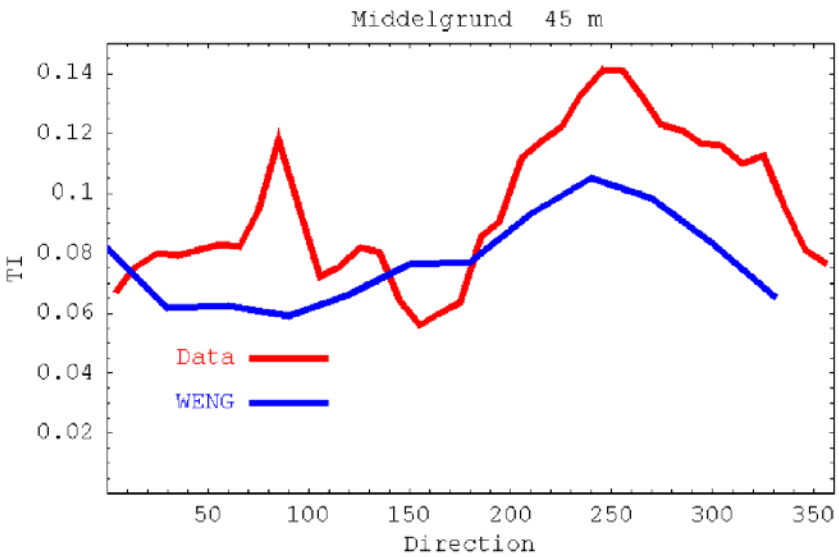
- Surface roughness over water dependents on wind speed
- Turbulence is modified by roughness change and topography

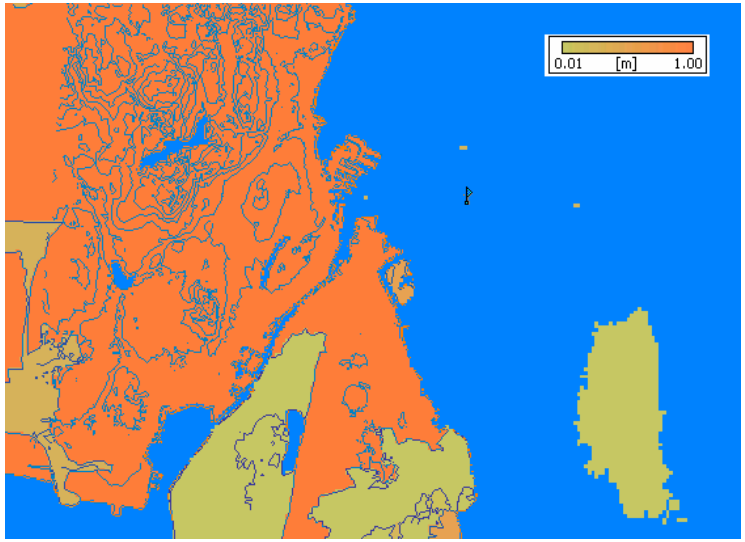
WEng turbulence intensity

Middelgrunden, Copenhagen

Measurements at 45m, year 1997-99

Wind speed in the range 8-16 m/s





Wake turbulence in IEC 61400 standard

IEC 61400 Appendix D

– 80 – 61400-1/FDIS ©

Annex D
(informative)

Wake and wind farm turbulence

D.1 Wake effects

Wake effects from neighbouring wind turbines may be taken into account during normal operation for fatigue calculation by an effective turbulence intensity I_{eff}, Frandsen (2003). The effective turbulence intensity – conditioned on hub height mean wind speed – may be defined as

$$I_{\text{eff}}(V_{\text{hub}}) = \left\{ \int_0^{2\pi} p(\theta|V_{\text{hub}}) I^m(\theta|V_{\text{hub}}) d\theta \right\}^{\frac{1}{m}}$$

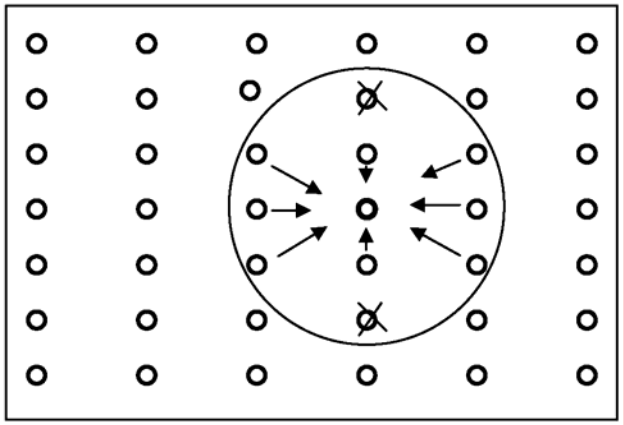
where

p is the probability density function of wind direction;

I is the turbulence intensity combined of ambient and wake flow from wind direction θ, and

m is the Wöhler (SN-curve) exponent for the considered material.

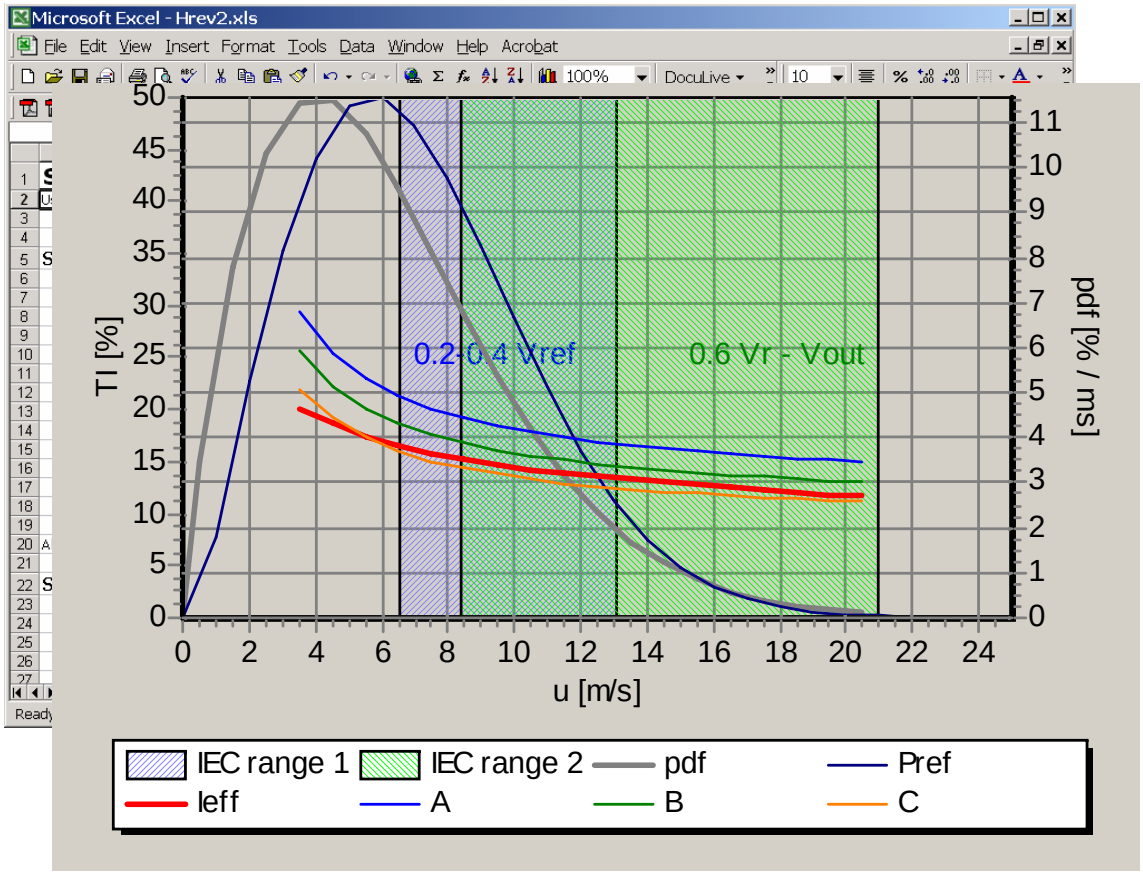
Generic wind-farm layouts

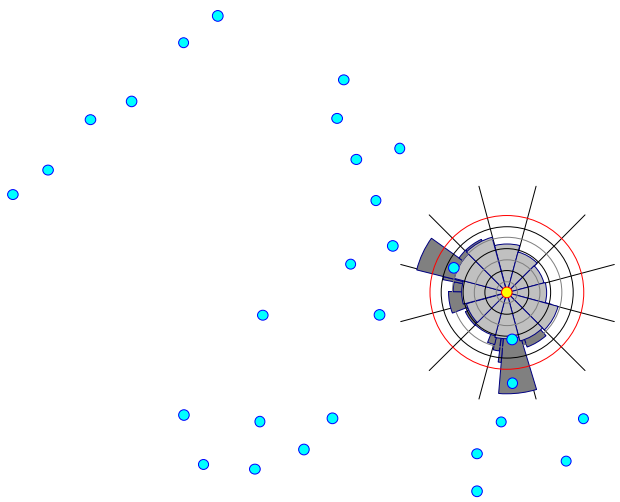


Added wake turbulence

$$I_{T,j} = \sqrt{\frac{0.9}{\left(1.5 + 0.3 d_{\min} \sqrt{u/c}\right)^2} + I_0^2}$$

IEC effective turbulence from WEng/ WAsP results





$$I_{T,j} = \sqrt{\frac{0.9}{\left(1.5 + 0.3 d_{\min}\sqrt{u/c}\right)^2} + I_0^2}$$

$$I_{eff}(u) = \left\{ \int_0^{2\Pi} I^m(u,\theta)\, p(u \mid \theta)\, d\theta \right\}^{1/m}$$

Calculate and compare with design turbulence for selected turbine

Future challenges and developments

WAsP and WEng (both models)

- User feedback and code improvement
- Improved flow models
- Development of climate analyst

WEng

- Extreme winds from NCEP/NCAR database
- Better reports for IEC61400 site assessment
- Wake calculus

Summary and conclusions

- WAsP provides reliable resource estimates – when used carefully, also offshore
- WAsP Engineering provides wind conditions for IEC 61400 site assessment