Short-term forecasting of wind speeds in the offshore environment

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Data: Energi E2 Middelgrunden, DMI HIRLAM.

Hypothesis

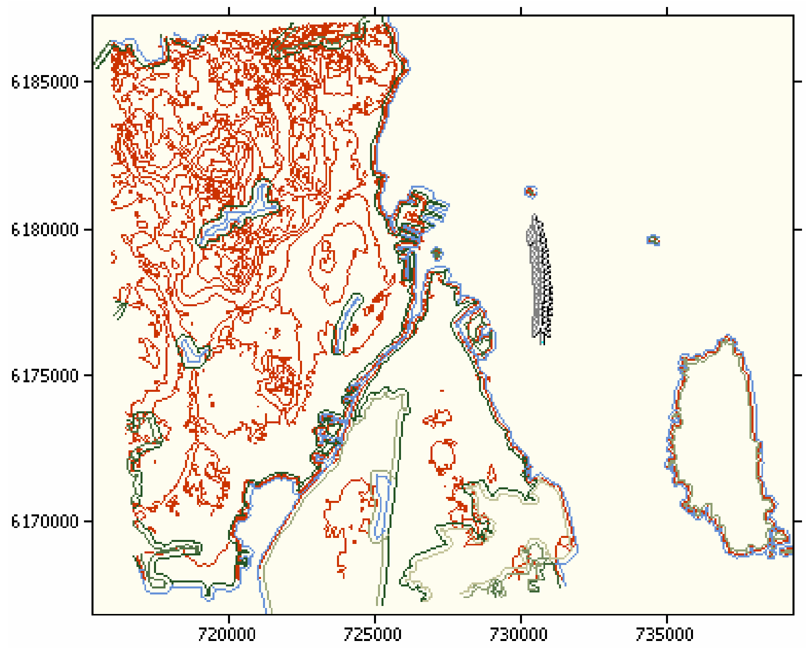
Atmospheric stability is more important offshore because of low mechanically generated turbulence and impacts:

1. Wind speed profiles – deviation from near logarithmic predictions
2. Wind speed gradients
3. Wake effects

Here using data from Middelgrunden to evaluate 1. and 2.

Middelgrunden

- Period of met observations 1997-1999
- Period of turbine observations 2001→ (2001-2002 used here)
- Hirlam NWP data from 2001



Atmospheric stability definition

RISØ

- Stability describes stratification of the atmosphere
- Use Monin-Obukhov length
- Ratio mechanically generated to buoyancy generated turbulence
- L > 0 stable

  (limited energy transfer)
- L < 0 unstable

  (convective conditions)
- | L | > 1000 neutral

$$U_z = \frac{u_*}{\kappa}\left[ln\frac{z}{z_0} - \Psi_m\left(\frac{z}{L}\right)\right]$$

$$L = -\left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{3/4} / \left(\kappa(g/\overline{\theta_v})(\overline{w'\theta_v'})\right)$$

$$L > 0 \quad \Phi_m = \frac{\kappa z}{u_*}\left[\left(\frac{\partial\overline{U}}{\partial z}\right)^2 + \left(\frac{\partial\overline{V}}{\partial z}\right)^2\right]^{1/2} = 1 + 4.7\frac{z}{L}$$

$$\Psi\left(\frac{z}{L}\right) = \frac{4.7z}{L}$$

$$L < 0 \quad \Phi_m = \frac{\kappa z}{u_*}\left[\left(\frac{\partial\overline{U}}{\partial z}\right)^2 + \left(\frac{\partial\overline{V}}{\partial z}\right)^2\right]^{1/2} = \left(1 - 15\frac{z}{L}\right)^{-1/4}$$

$$\Psi\left(\frac{z}{L}\right) = -2\,ln\left[\frac{(1+x)}{2}\right] - ln\left[\frac{(1+x^2)}{2}\right] + 2\tan^{-1}(x) - \frac{\pi}{2}$$

$$where\ x = [1 - (15z/L)]^{-1/4}$$

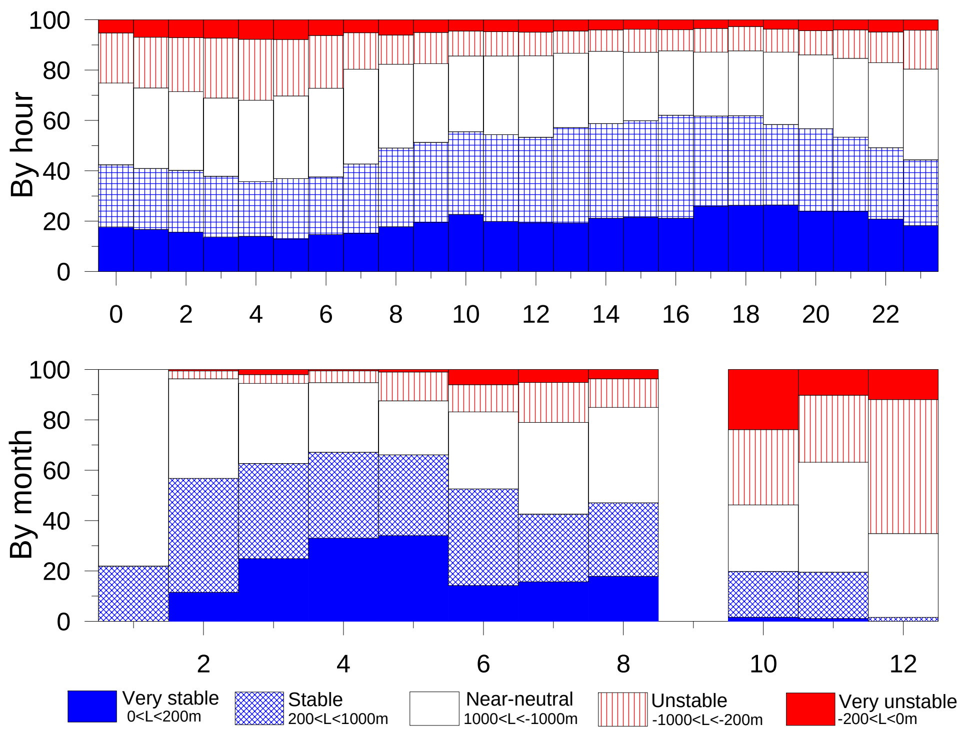
Barthelmie et al. (MA 1998)

Stability at Middelgrunden

- Stability using temperature profile
- Stable 50%, neutral 31%, unstable 19%

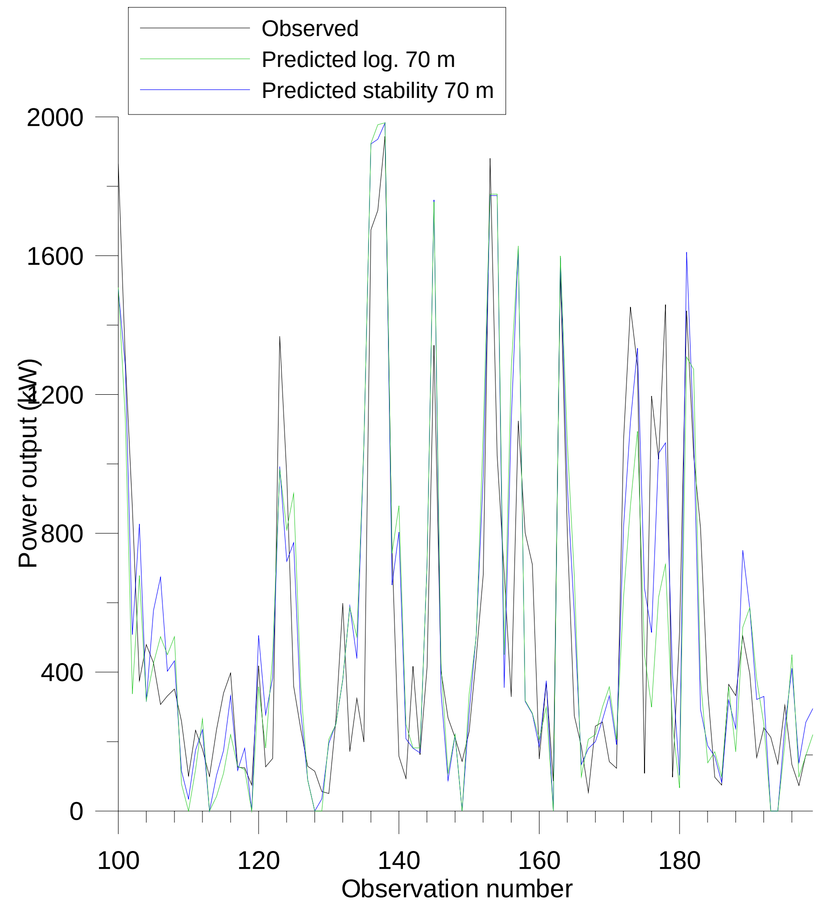
- Stability using dU method with HIRLAM data
- Stable 55%, neutral 27%, unstable 18%

- Not the same data period!



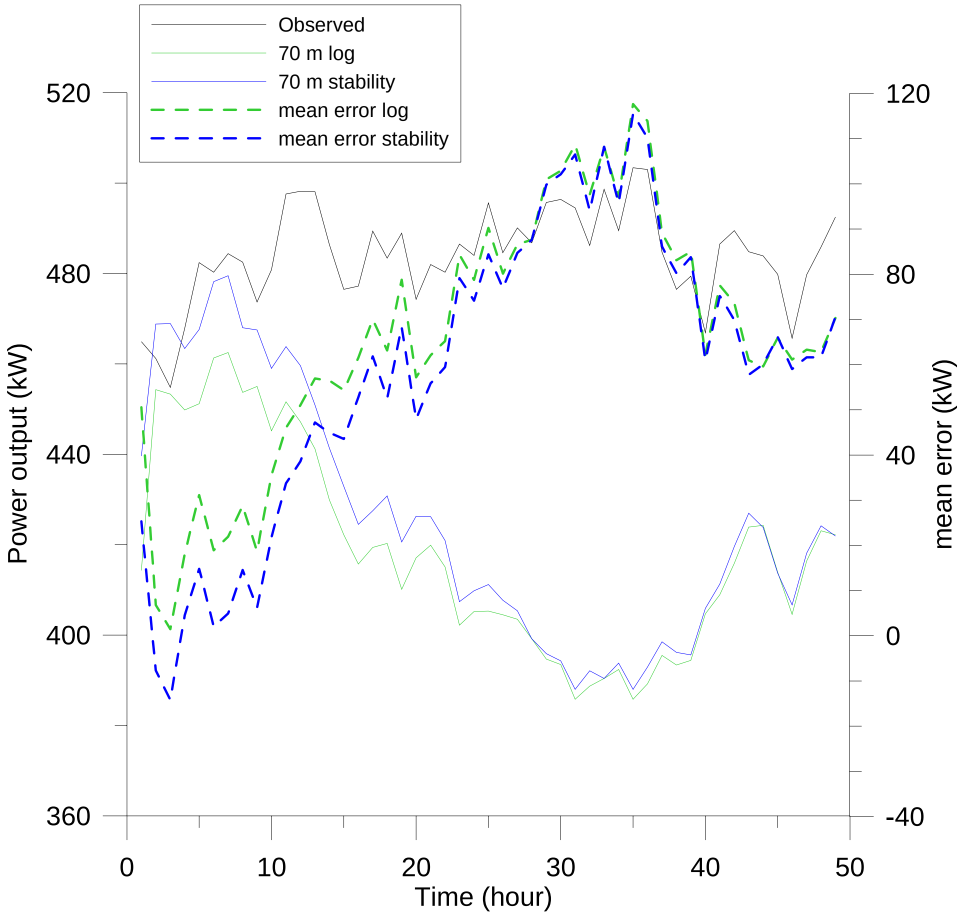
Application at Middelgrunden

- Avoid dt in stability calc.
- Stability defined dU =10 m and model level (~100m)
- Stability correction applied to log.profile → $U_{hub\text{-}height}$
- $U_{hub\text{-}height}$ →power output



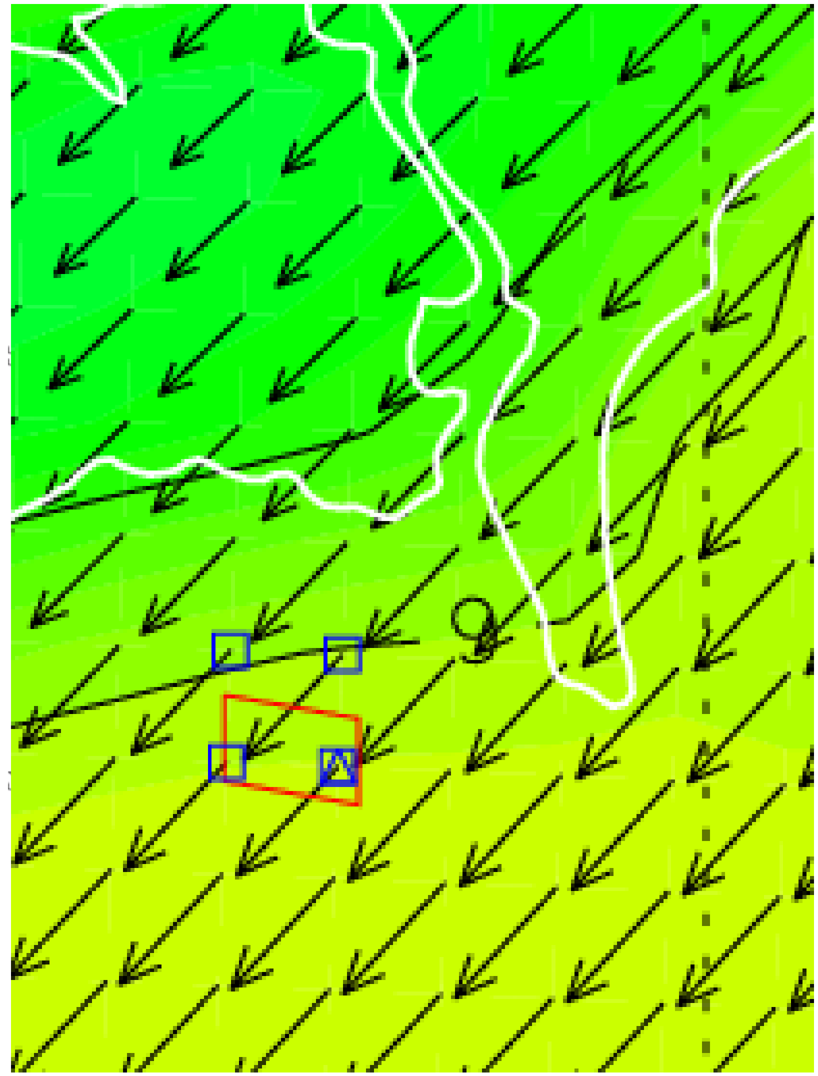
Forecast for Middelgrunden

- For one year on average
- Little diurnal variation in stability so likely can be accounted for with bias
- Might be worth making seasonal/directional bias



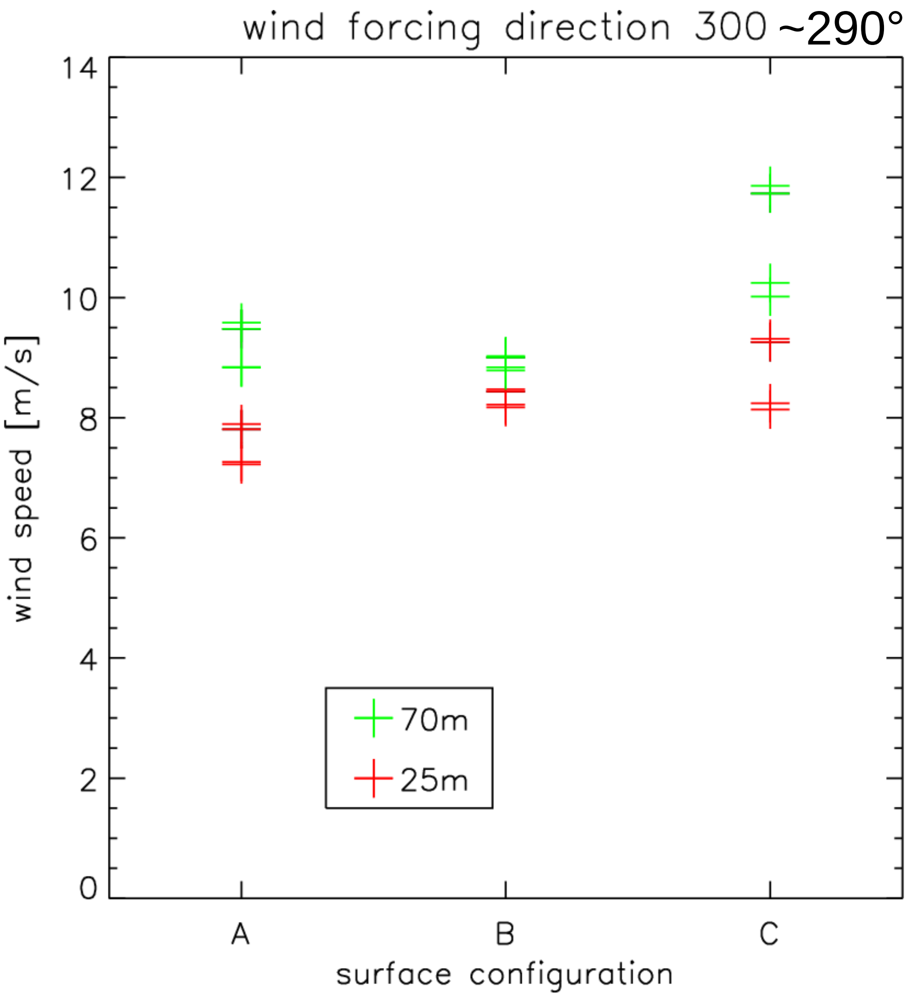
Modelling of coastal wind gradients

- Previous work at Horns Rev suggested gradients across wind farm >15 km from coast are non-detectable
- KAMM model runs for Nysted area (fetch ~ 11 km)
- 5 km resolution
- $U_{geostrophic}$ =10 m/s (scale 1.02)
- T from NCEP/NCAR 1965-1998
- 3 simulation sets, 12 wind direction sectors



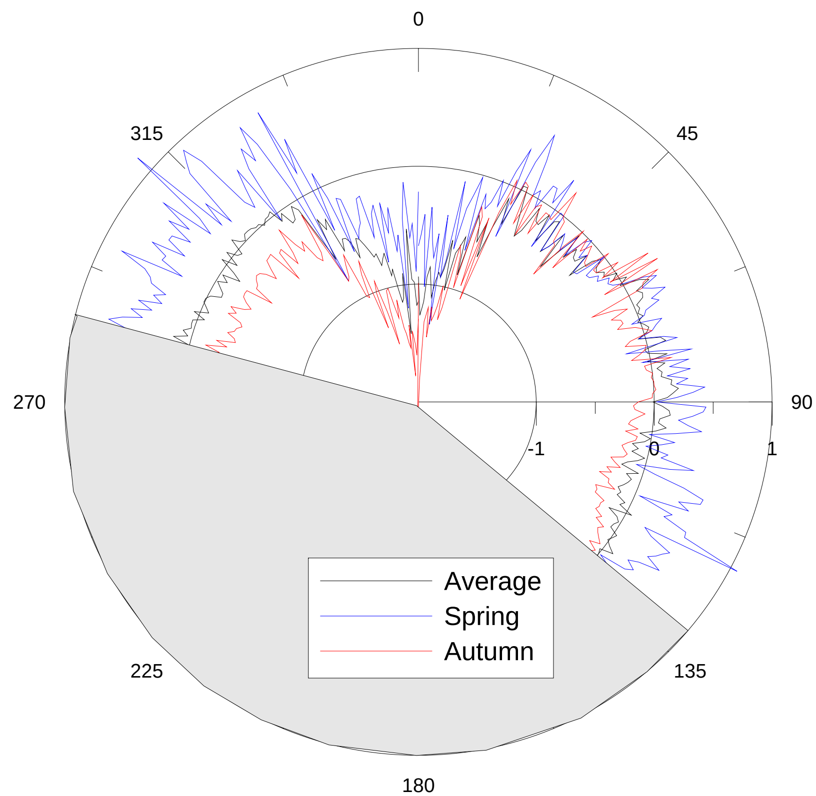
Wind speed gradients

- Set A, T_{offset} = 0K land and sea
- Set B, T_{offset} +5K sea, –5K land
- Set C, T_{offset} –5K sea, +5K land
- Sea fetch – small wind farm gradient, $U_{70}>U_{25}$ in A,B,C
- Land fetch – U gradient across wind farm in A,B,C
- Set B largest wind speed gradients if short sea fetch
- Set C largest wind speed gradients if medium length or complex sea fetch
- Set B smallest wind speed gradient from 25 m to 70 m above sea level



Sea-land temperature (10 m)

- From 2 sites at Nysted
- Main difference from N
- Average dt(sea-land) is 0C
- dt (sea-land) Min –7C, Max 6C



Conclusions

- Stability impacts wind profiles offshore but probably can be added to bias in short term forecasts because the range of stability is small on a diurnal timescale
- Bias might be adjusted by season/direction
- Mesoscale model indicates detectable wind speed gradients across a large wind farm if $dt_{\text{land-sea}} \sim \pm 5C$
- Max dt ~ ±5C
- Next step is a climatology
- Wakes – still a big issue in power output from large wind farms.