IBC 3rd Annual Wind Energy Conference
Adelaide February 2004

Workshop Session 1: Resources, technology, performance

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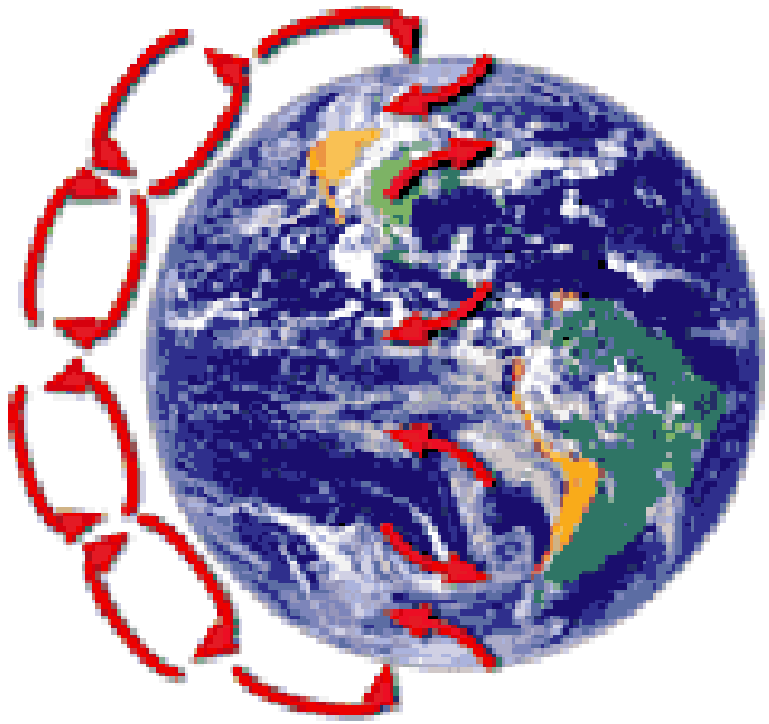
Outline

- The nature of wind resources
- Technical characteristics of wind turbines & wind farms
- Predicting the output of wind farms and groups of wind farms

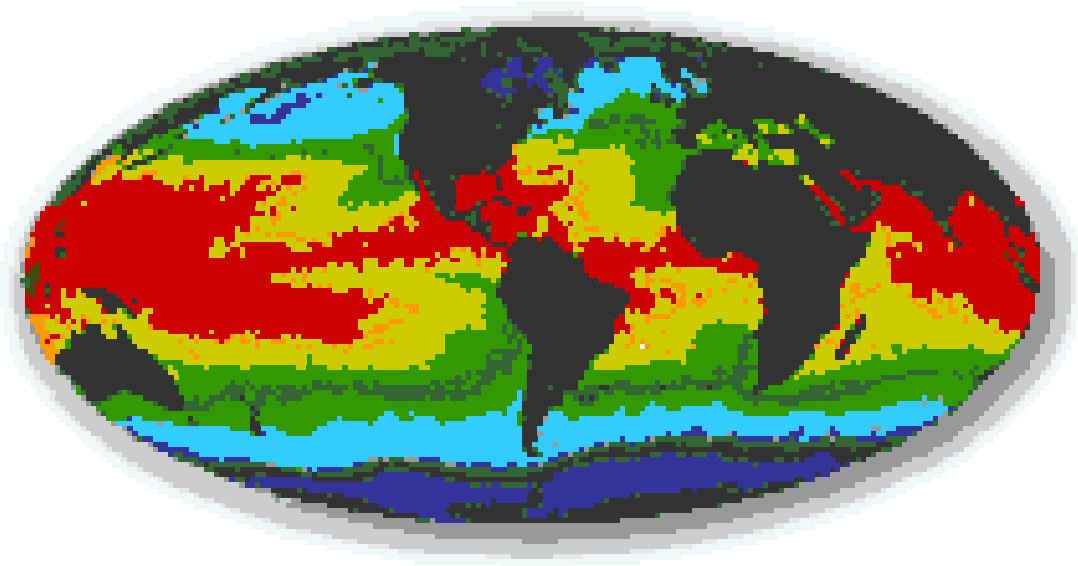
The nature of wind resources

- Drivers of wind energy at the earth's surface:
  - Uneven solar heating of the earth
  - The earth's rotation
  - Weather phenomena
  - Surface effects:
    - Topography
    - Surface roughness
    - Land/sea interface



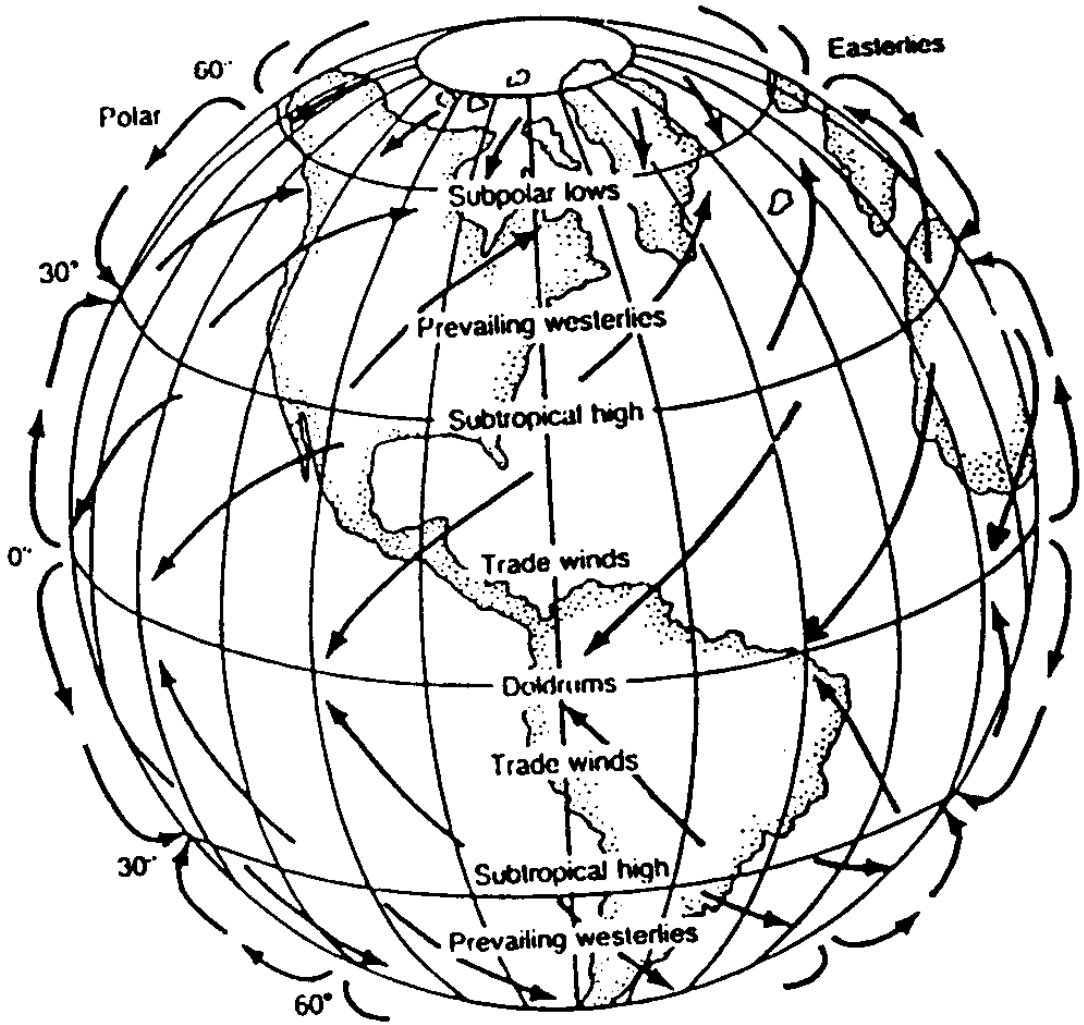
www.windpower.org

Global temperature variation



The Coriolis effect

Example - Prevailing US winds

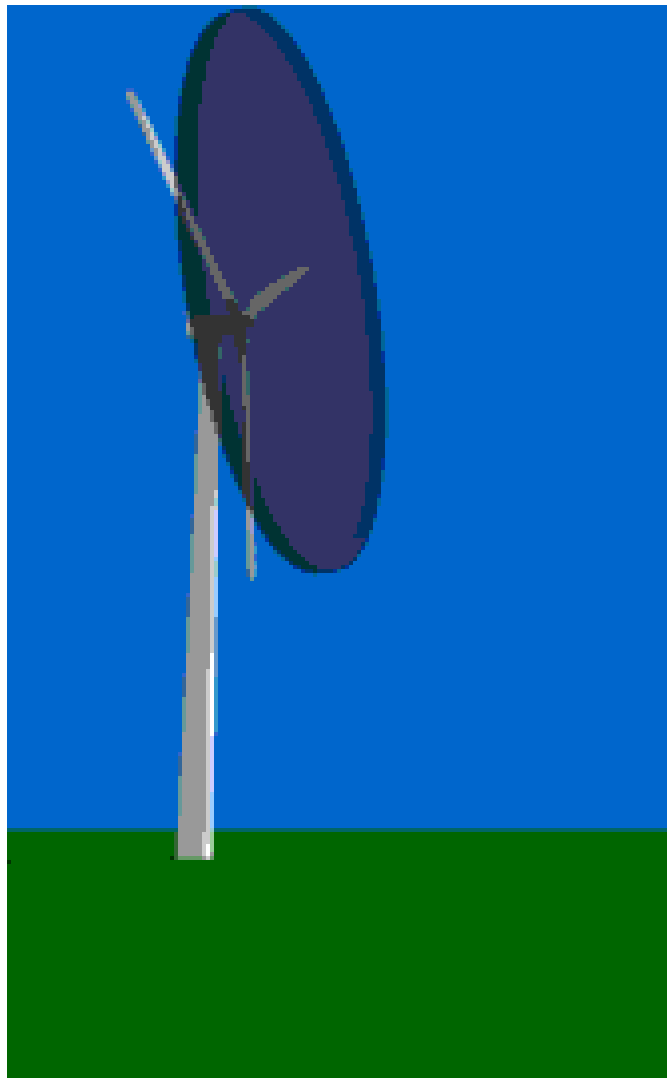


Surface winds

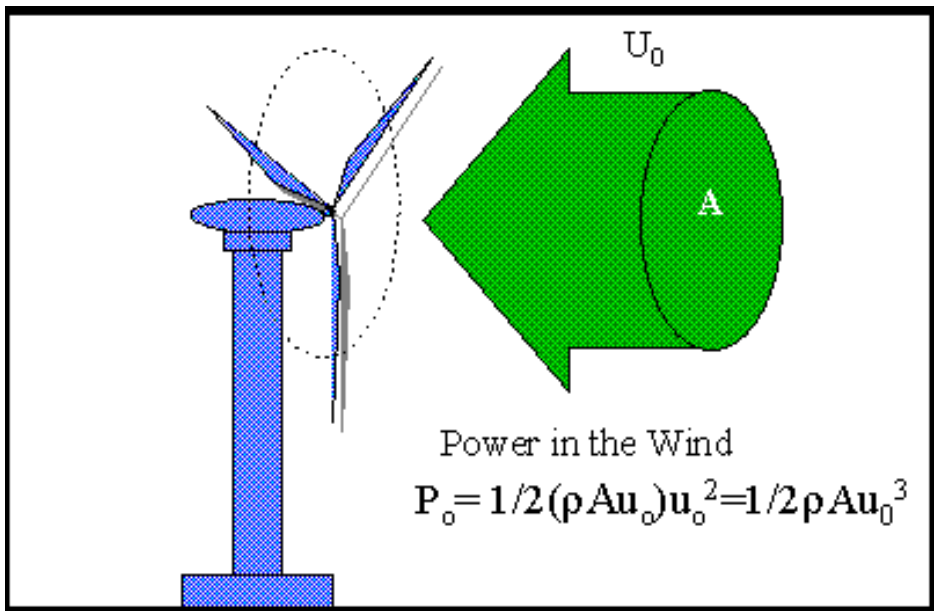
Our interest is in winds near the surface

- Thermally induced winds:
  - Sea breezes & land breezes
  - Valley winds
- Surface roughness effects:
  - Smooth surfaces give low turbulence & higher wind speeds near ground level
- Height effects:
  - Wind speed increases with height above ground (shear)
- Tunnel, hill effects

The energy in the wind



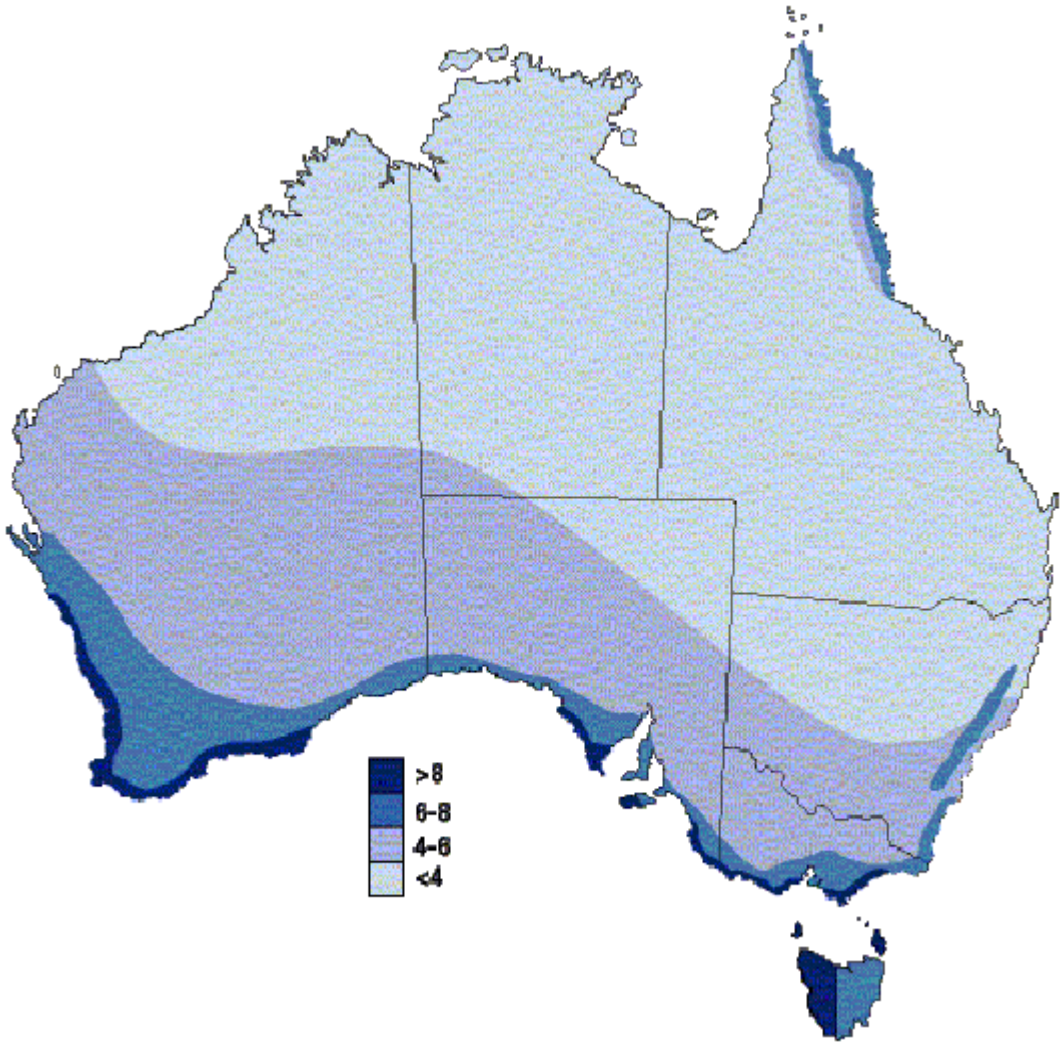
The power in the wind



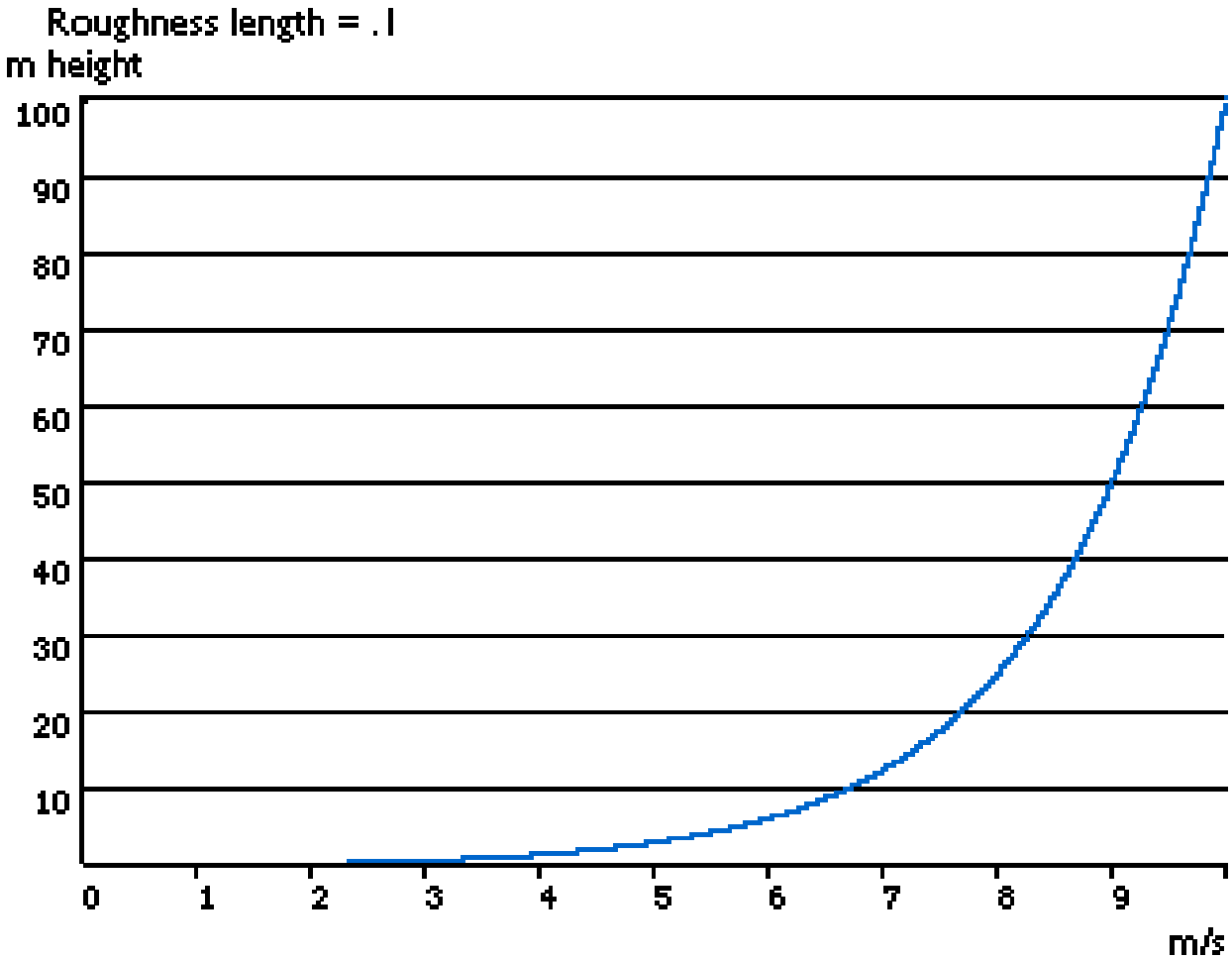
Doubling the wind speed increases the power eightfold but doubling the turbine area only doubles the power.

Australian wind resource

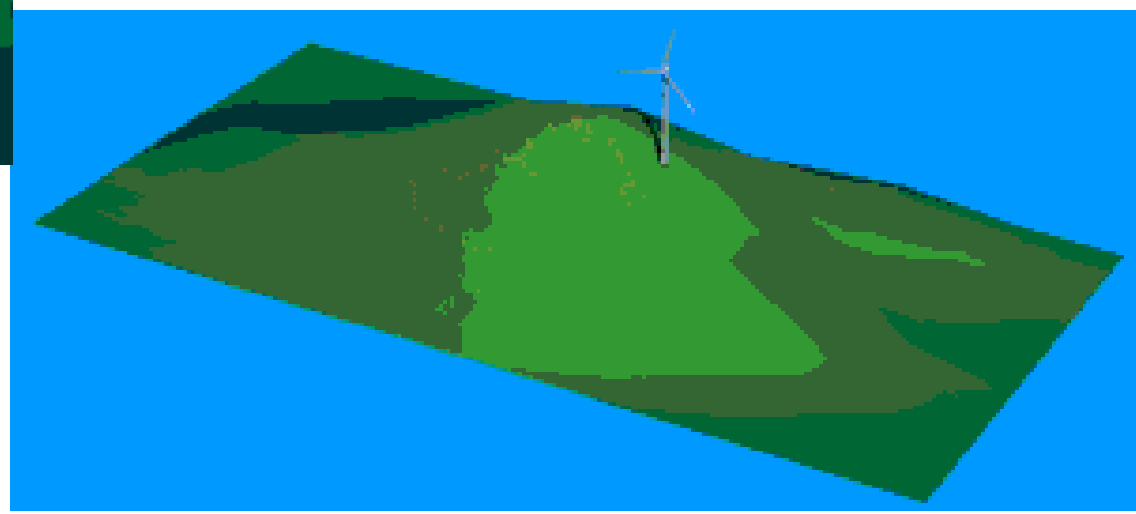
(Simple estimates of background wind – AGO)



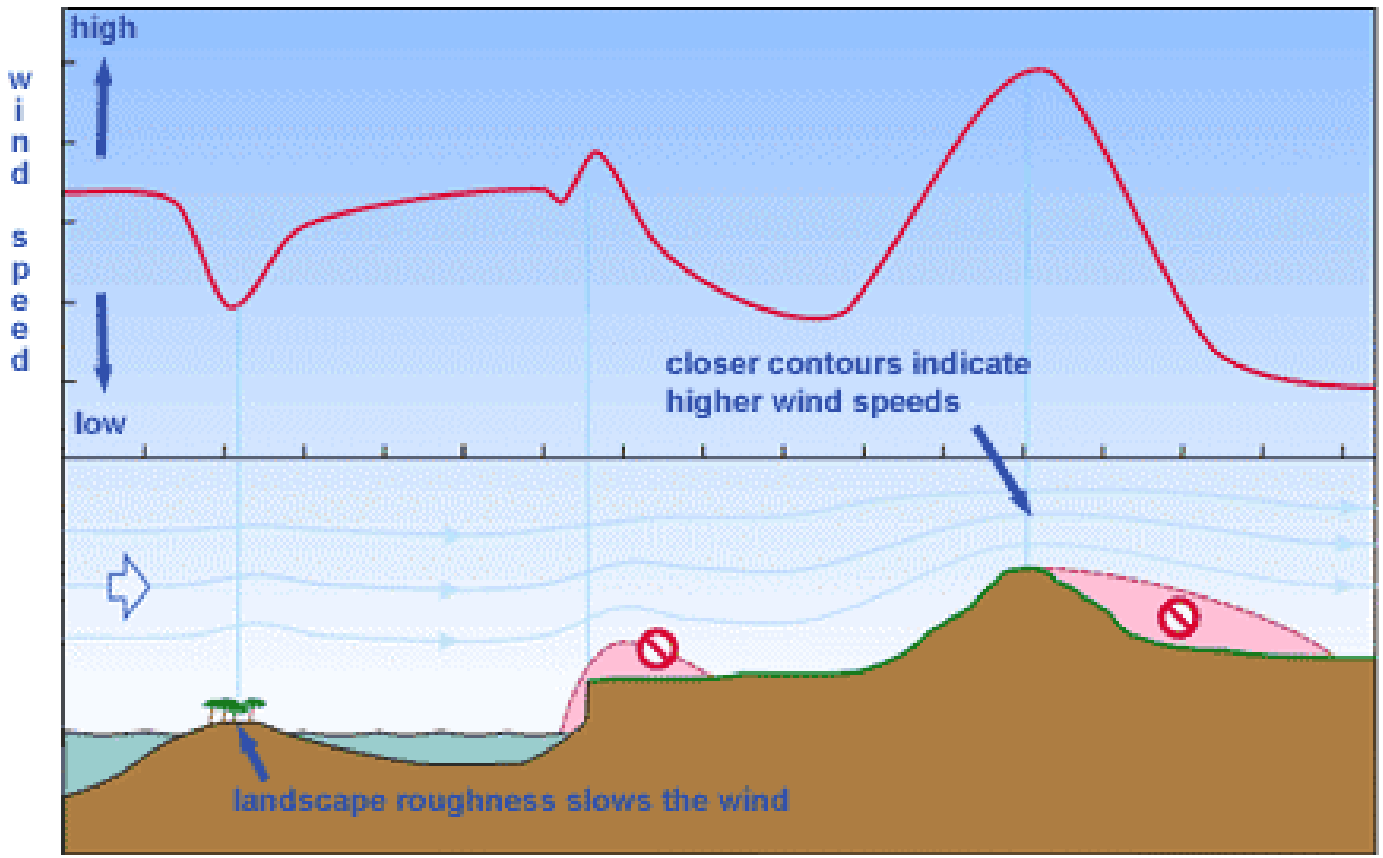
Wind shear


Roughness length = .I
m height
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
m/s

Tunnel + hill speedup effects



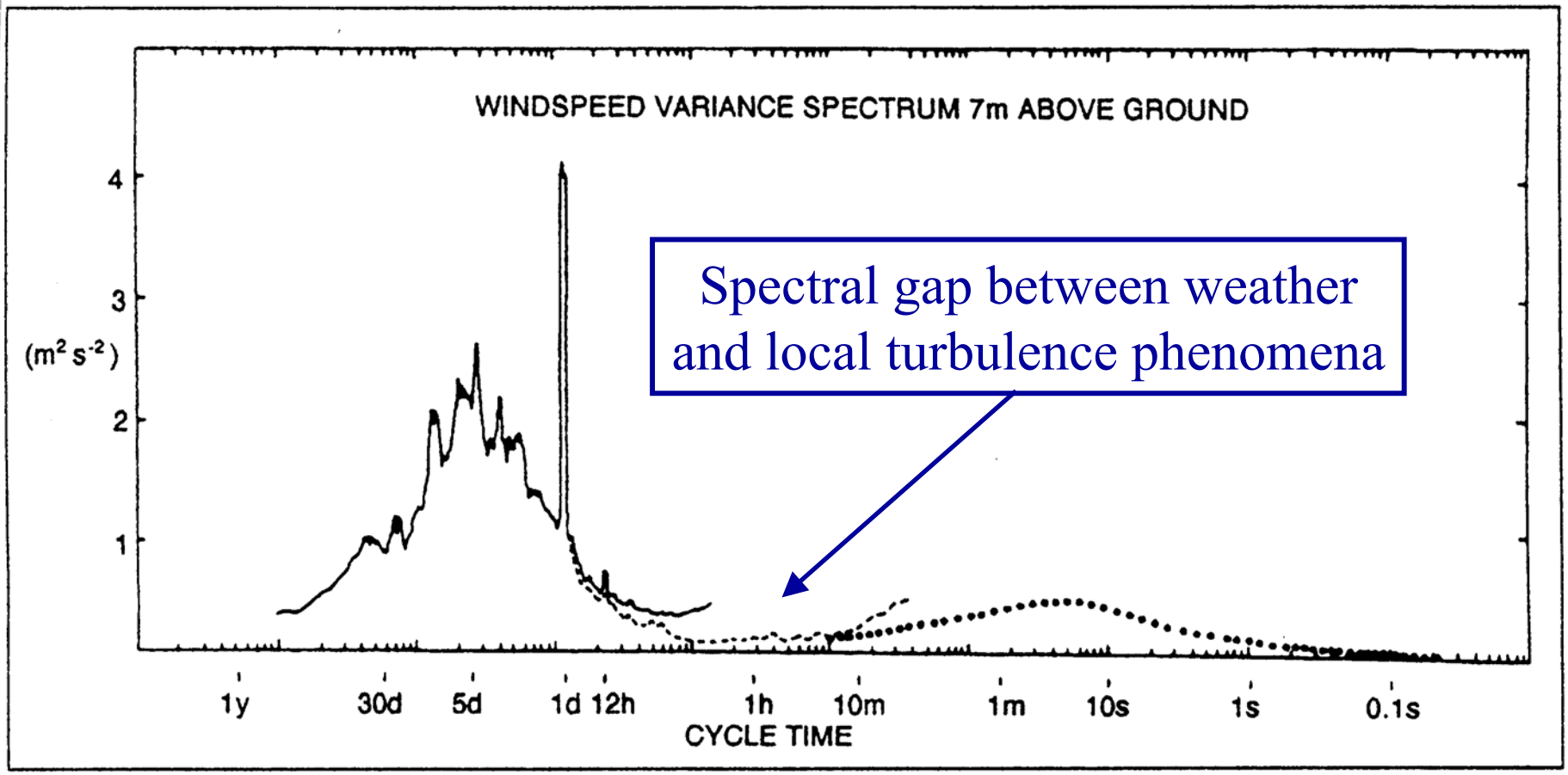
Surface effects on wind speed & turbulence (www.seda.nsw.gov.au)



Local wind resource

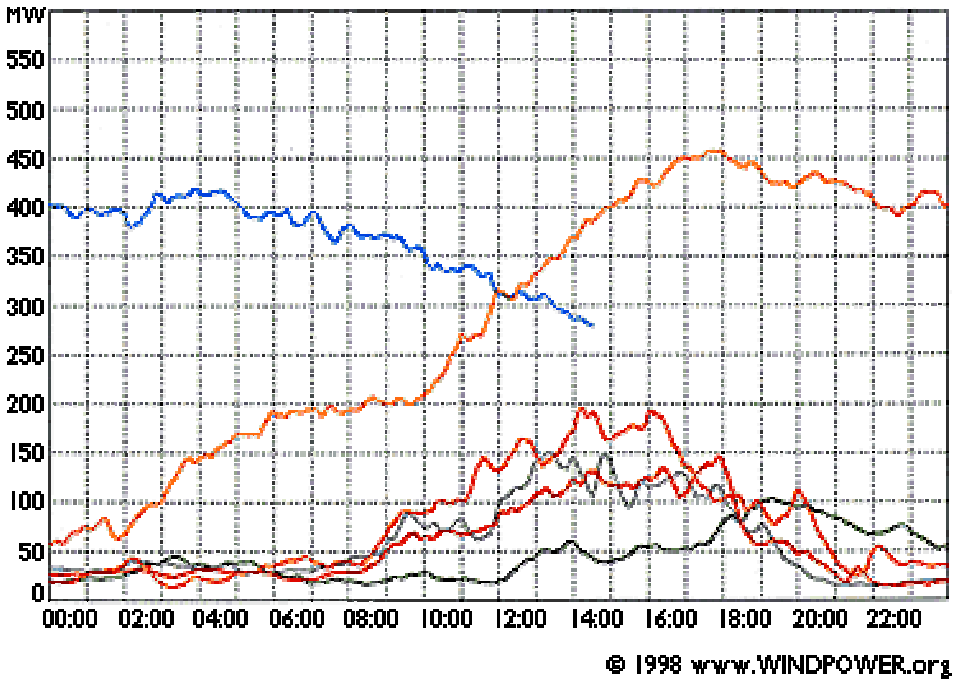
- Monitoring normally required

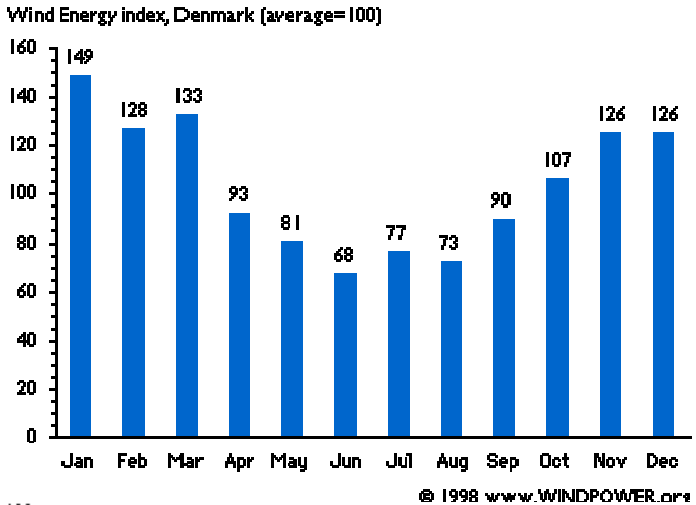
Spectral analysis of Danish long-term wind data (17 years of data)

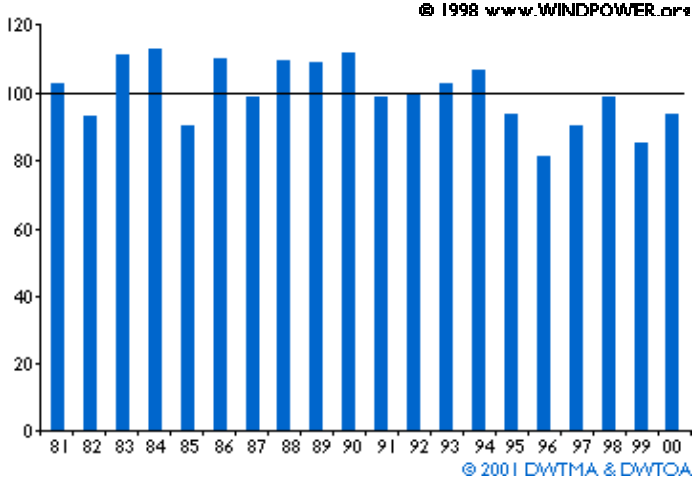


(Sorensen, 2001, Fig 2.110, p194)

Measured Danish wind power characteristics (www.windpower.org)





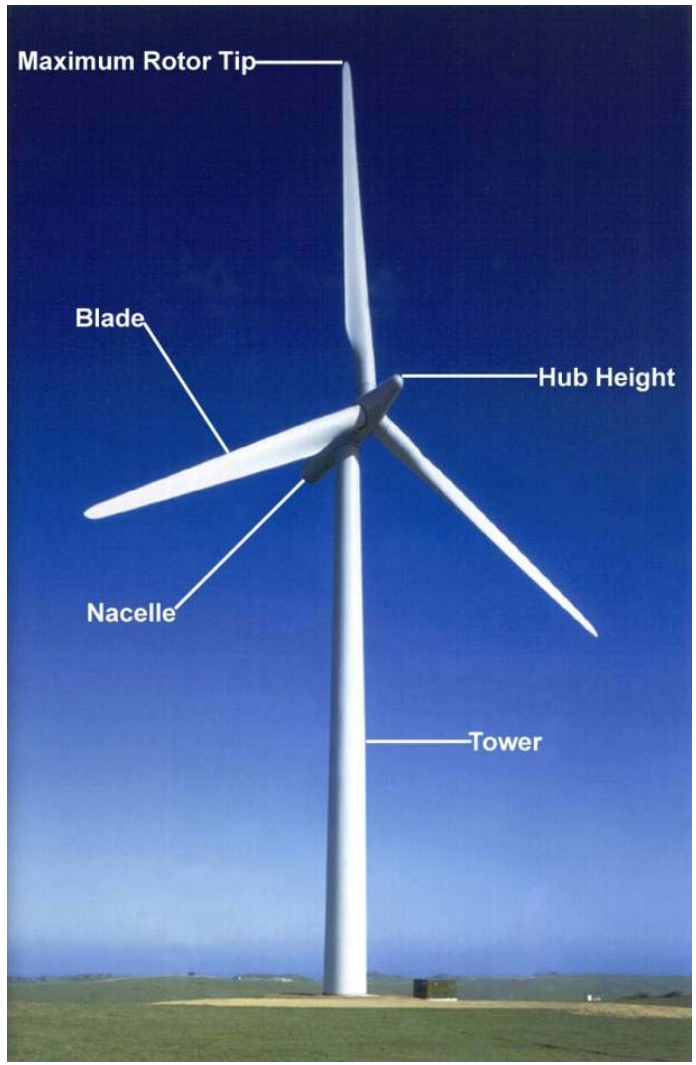


Diurnal, seasonal and annual variations in wind speed (diurnal effect stronger near coast & stronger in summer than winter)

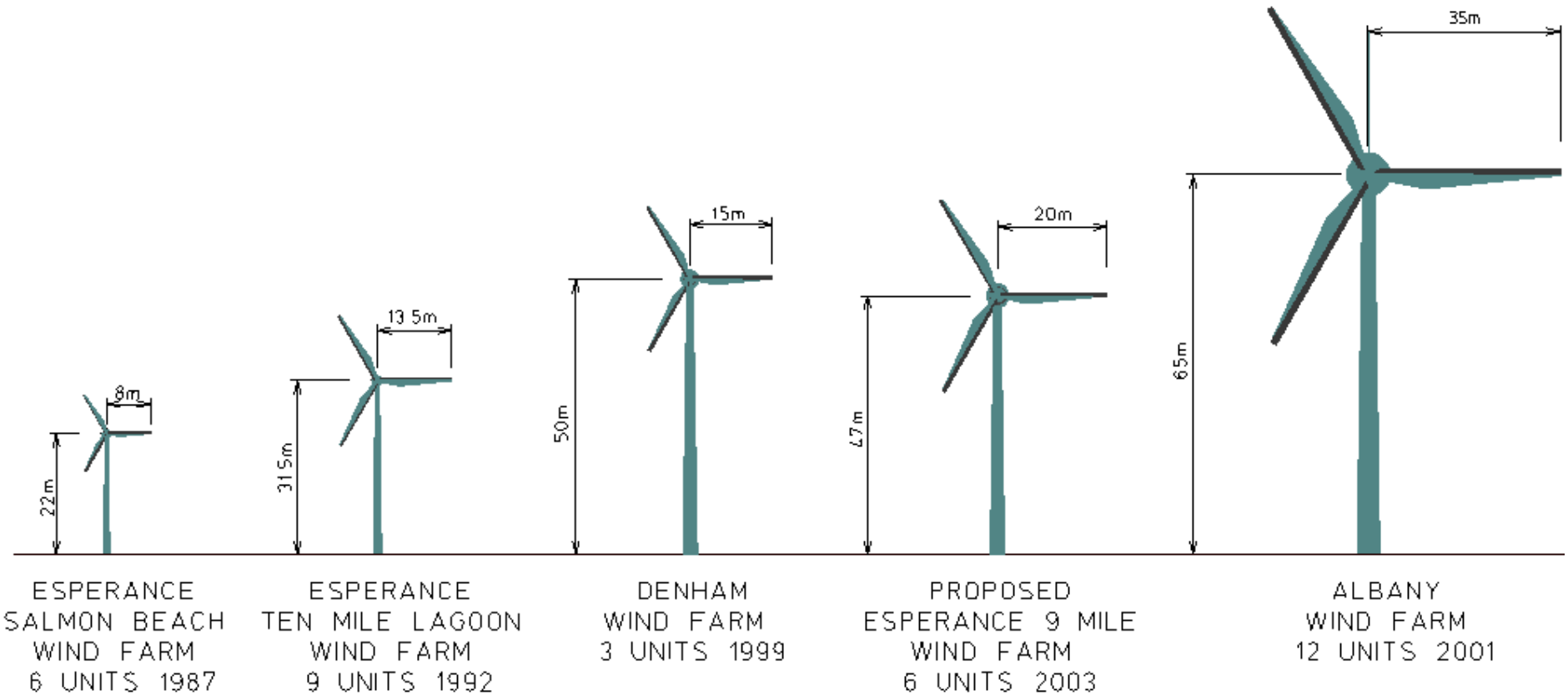
A modern 1.3MW wind turbine

(www.bonus.dk)

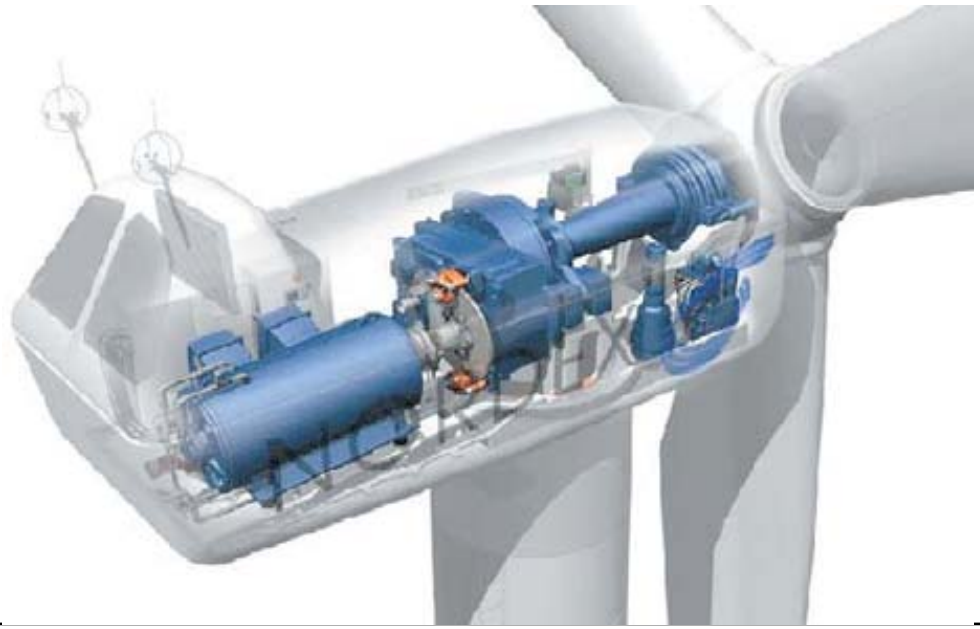
- Codrington wind farm (Vic):
  - 14x1.3MW: 18.2MW
- Hub height: 50m
- Blade diameter: 60 m
  - Pitch & stall regulation
- Gearbox ratio: 1:79
- Generator: Two speed induction generator



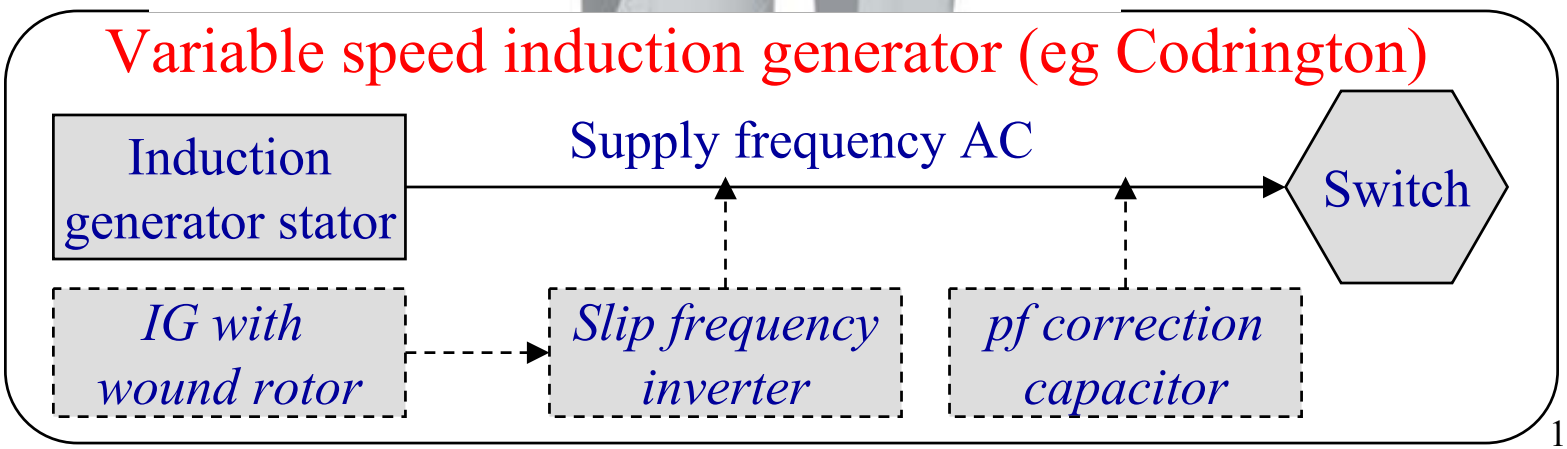
Size of wind turbines used by Western Power (www.wpc.com.au)



Wind turbine design option: *gearbox & induction generator*

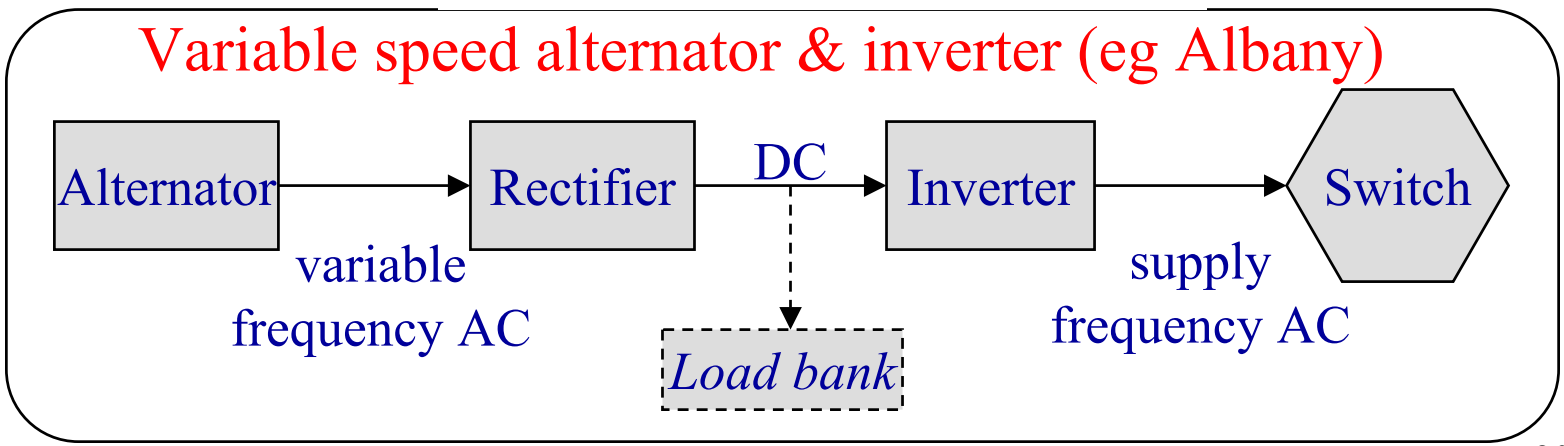


(www.hydro.com.au)



Wind turbine design option:
direct-drive variable speed alternator

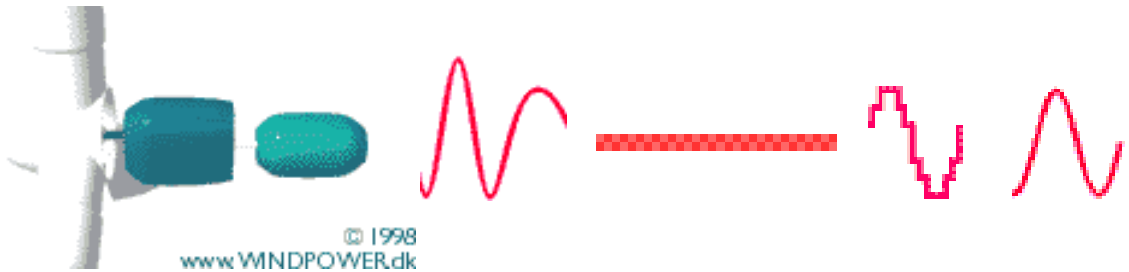
(www.enercon.de)



Generators (cont)

- Variable speed

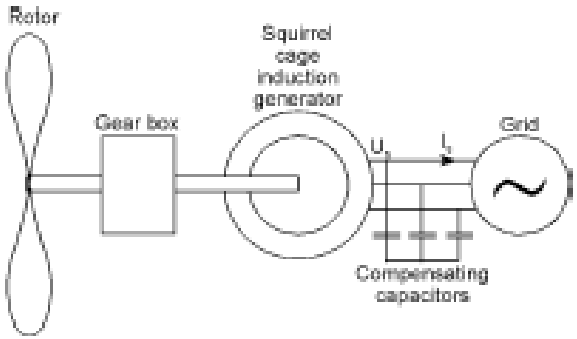
(www.windpower.org)

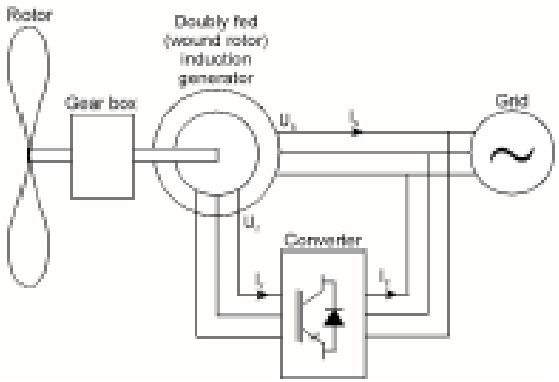


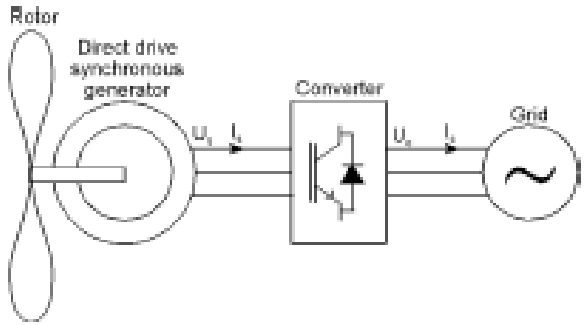
  - Variable rotor speed can ‘store’ gusts
  - Can improve grid quality (eg reactive power)
  - higher efficiency from optimal Tip speed?

Wind turbine type comparison

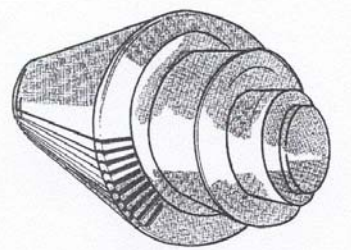
(Slootweg & Kling, TU Delft, 2003, http://local.iee.org/ireland/Senior/Wind%20Event.htm)



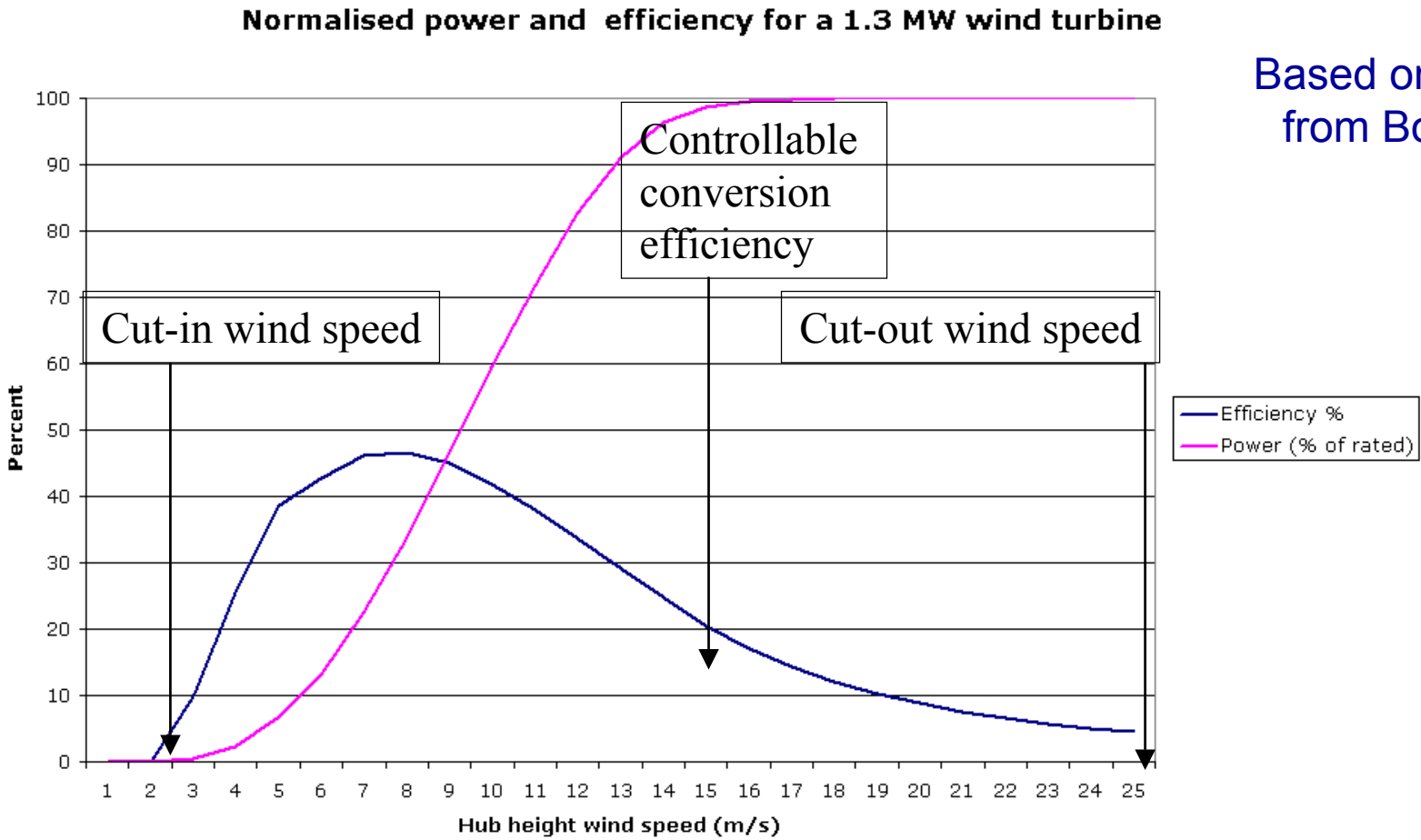




	Constant speed	Doubly fed	Direct drive
Strengths	Robust	Mechanical stress	Mechanical stress
	Cheap	Noise	Noise
	Electrical efficiency	Aerodynamic efficiency	Aerodynamic efficiency
	Standard generator	Standard generator	No gearbox
		Converter rating	
Weaknesses	Aerodynamic efficiency	Electrical efficiency	Electrical efficiency
	Mechanical stress	Gearbox	Converter rating
	Gearbox	Expensive	Very expensive
	Noise		Generator weight and dimensions
			Generator complexity



Power curve for a 1.3 MW wind turbine (typically 30 minute average data)

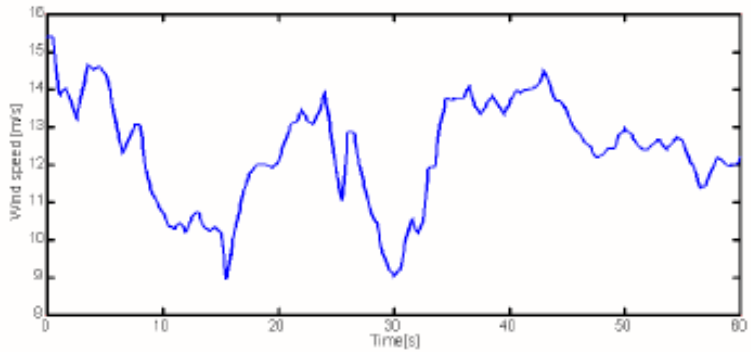


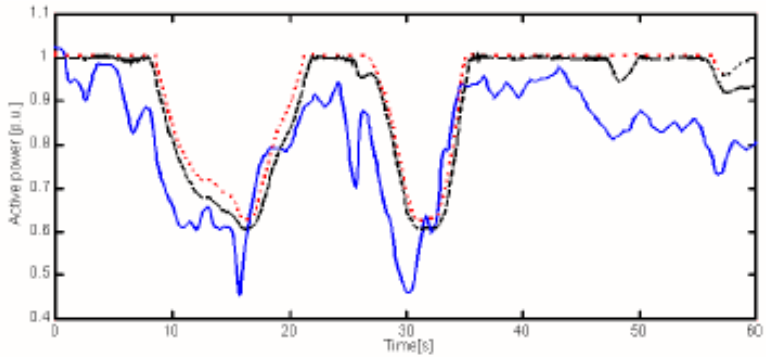
Based on data from Bonus

Wind turbine dynamic behaviour

(Slootweg & Kling, TU Delft, 2003,
http://local.iee.org/ireland/Senior/Wind%20Event.htm)

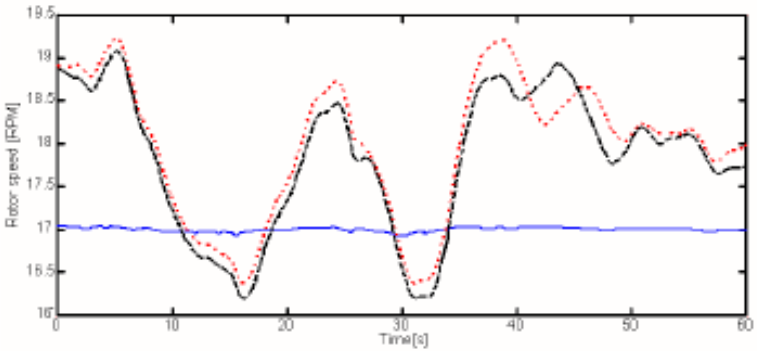
Wind speed

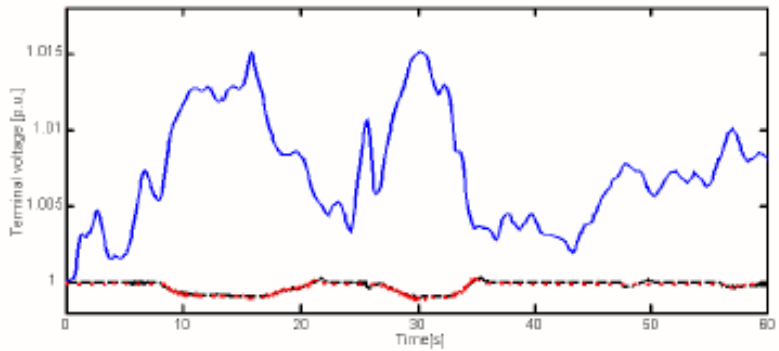




Output power

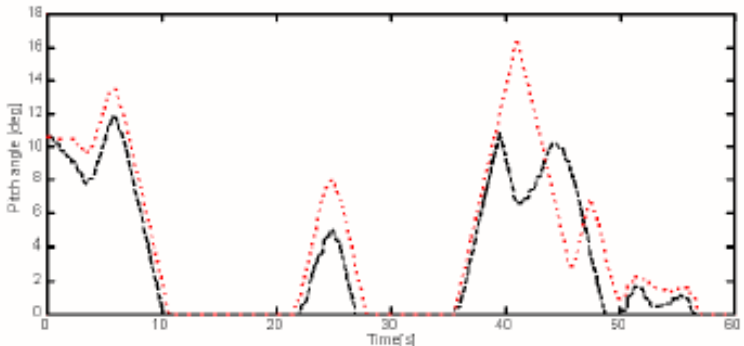
Rotor speed





Output voltage

Blade angle



Constant speed
DFIG
Direct Drive

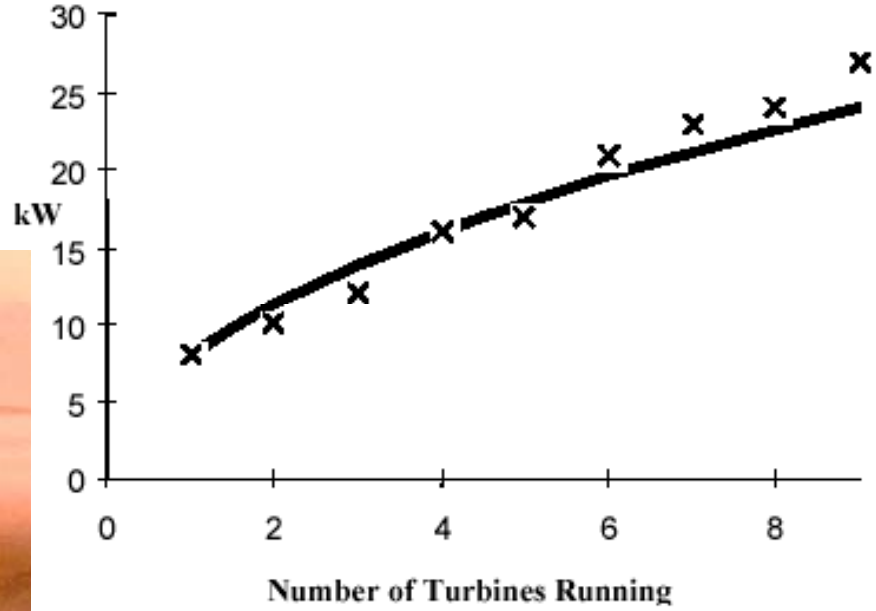
Technical characteristics of wind farms (1)

- Wind turbine electrical power output:
  - Depends on wind power, swept area, blade pitch, rotational speed, supply voltage & frequency
  - Fluctuates with wind speed & direction
- Wind farm power is aggregated & smoothed compared to turbine power:
  - Depending on extent of correlation
  - Short-term power forecast valuable for power system operation (average & extreme)

One-second power fluctuations at Esperance 2MW wind farm

- 9 x 225 kW turbines
- Solid line is proportional to $N^{-0.5}$
  - Implies 1-second fluctuations are uncorrelated

(Rosser, 1995)



Correlation across a wind farm depends on layout & wind regime

Turbulence power fluctuations are likely to be more strongly correlated in the wind farm on the left than in that on the right

Hampton Wind Farm, NSW

(2x660 kW Vestas, connected to different 11 kV feeders)

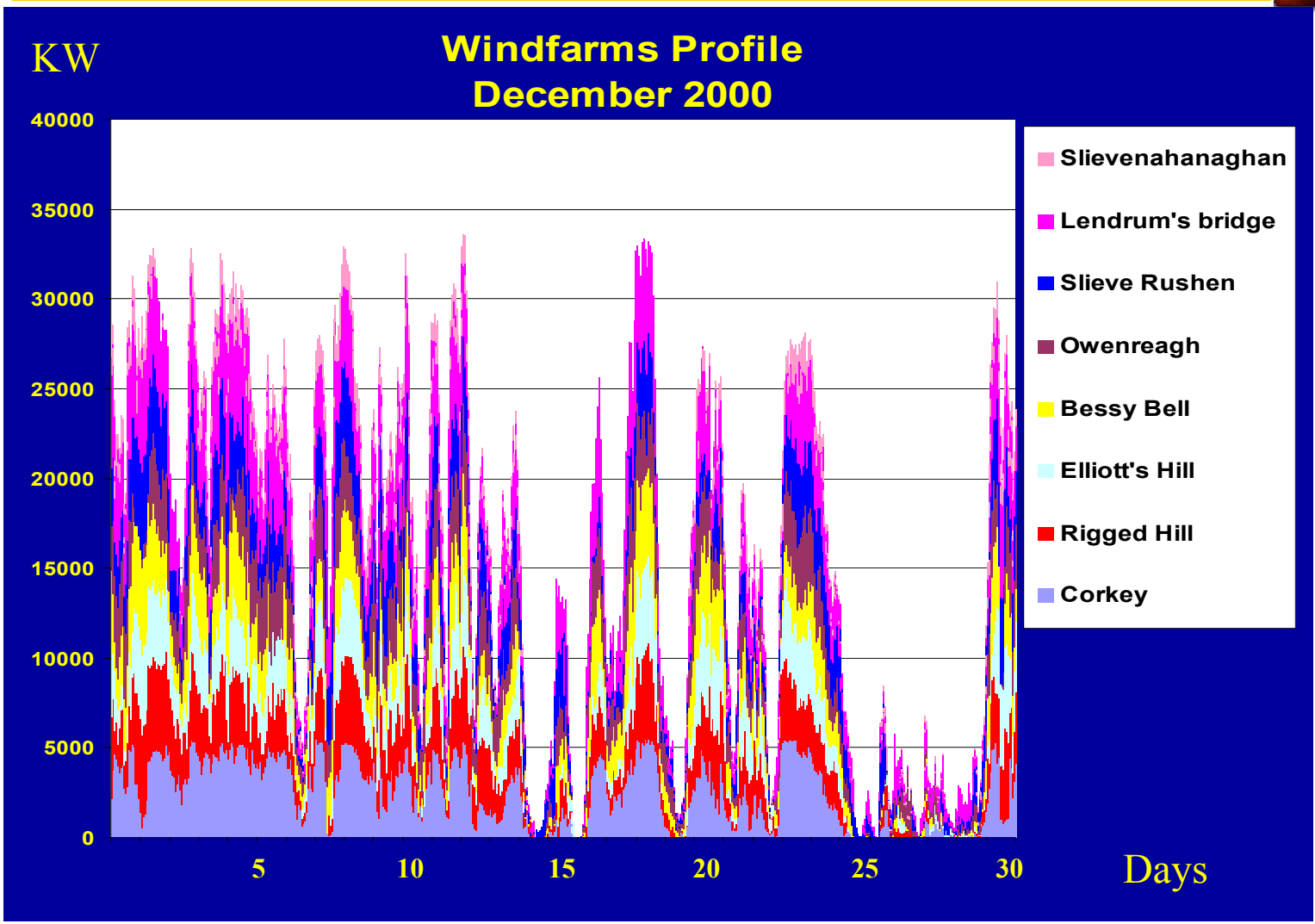
Turbulence probably fairly high at this site

11kV feeders may be subject to outages & voltage dips

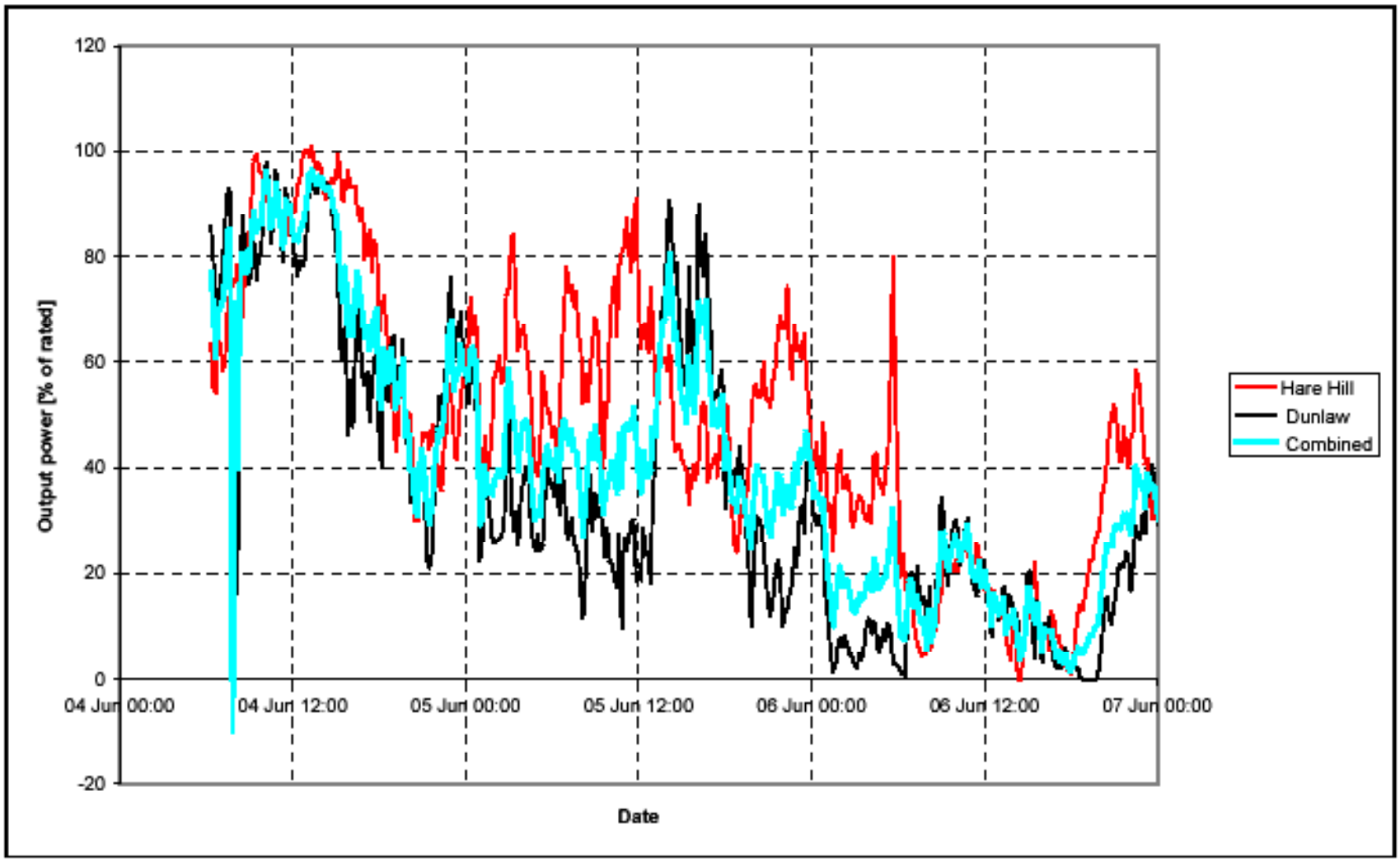
Induction generators may not ride through voltage dips well.

Output of 8 small wind farms over 30 days

(Bryans L, 2003, http://local.iee.org/ireland/Senior/Wind%20Event.htm)



Combined output of 2 wind farms 80 km apart (Gardner et al, 2003)

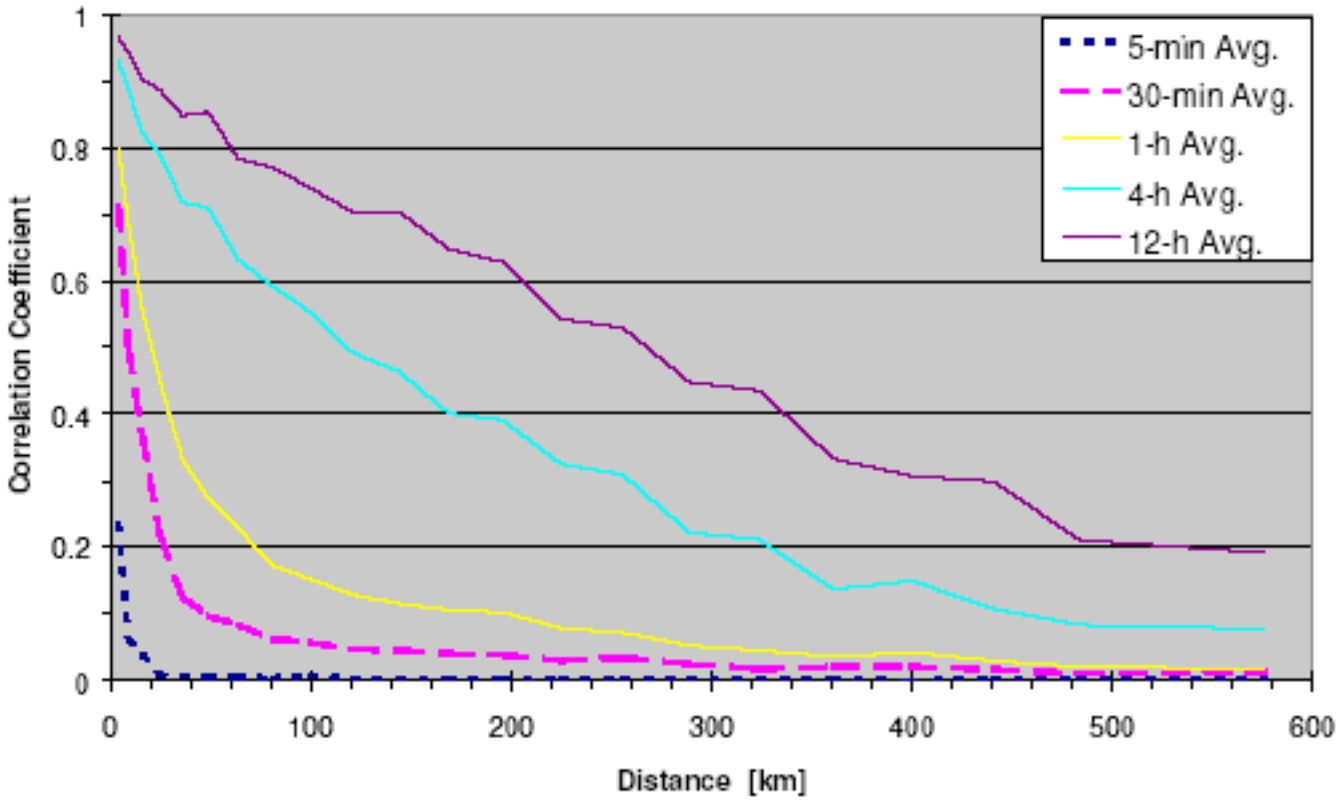


Cross-correlation function between the output powers of 2 wind farms 80 km apart

(Gardner et al, 2003)

Cross-correlations between measured power outputs of German wind farms

(Giebel (2000) Riso National Lab, Denmark)



Prediction of wind smoothing effects for Northern Europe

(Giebel (2000) Riso National Lab, Denmark)

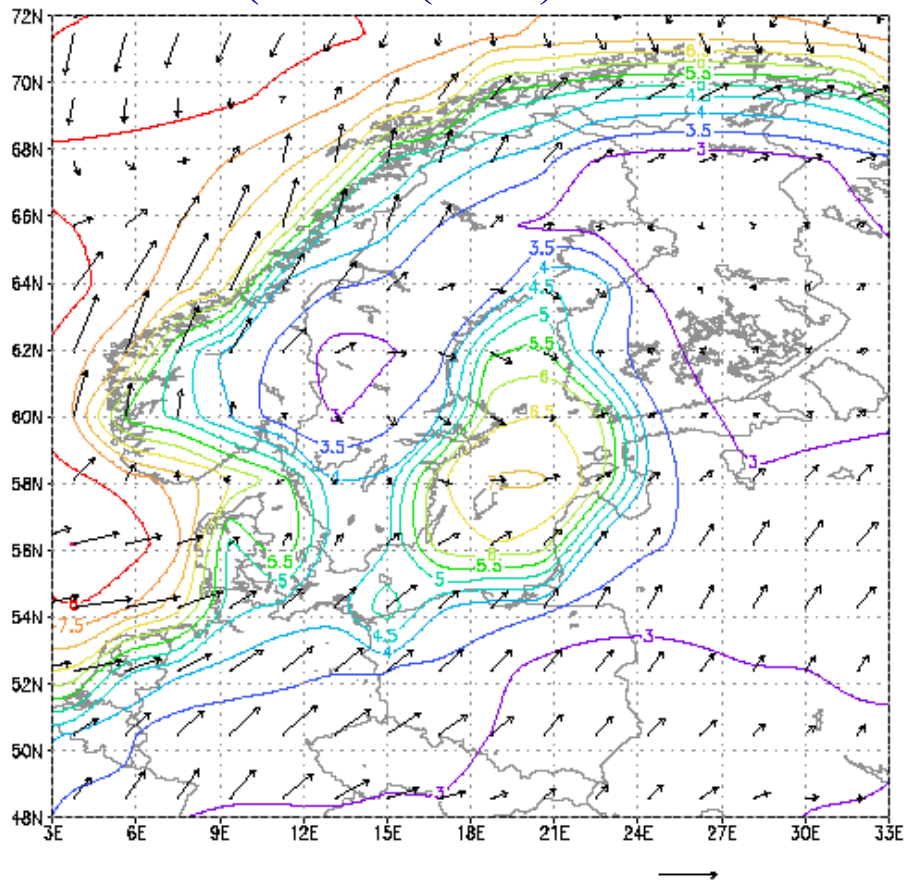
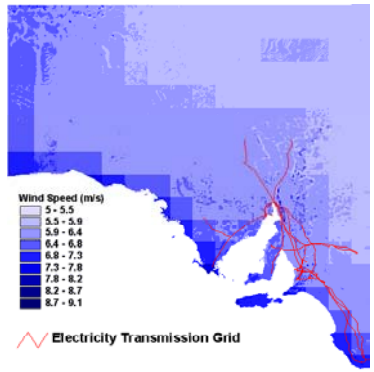


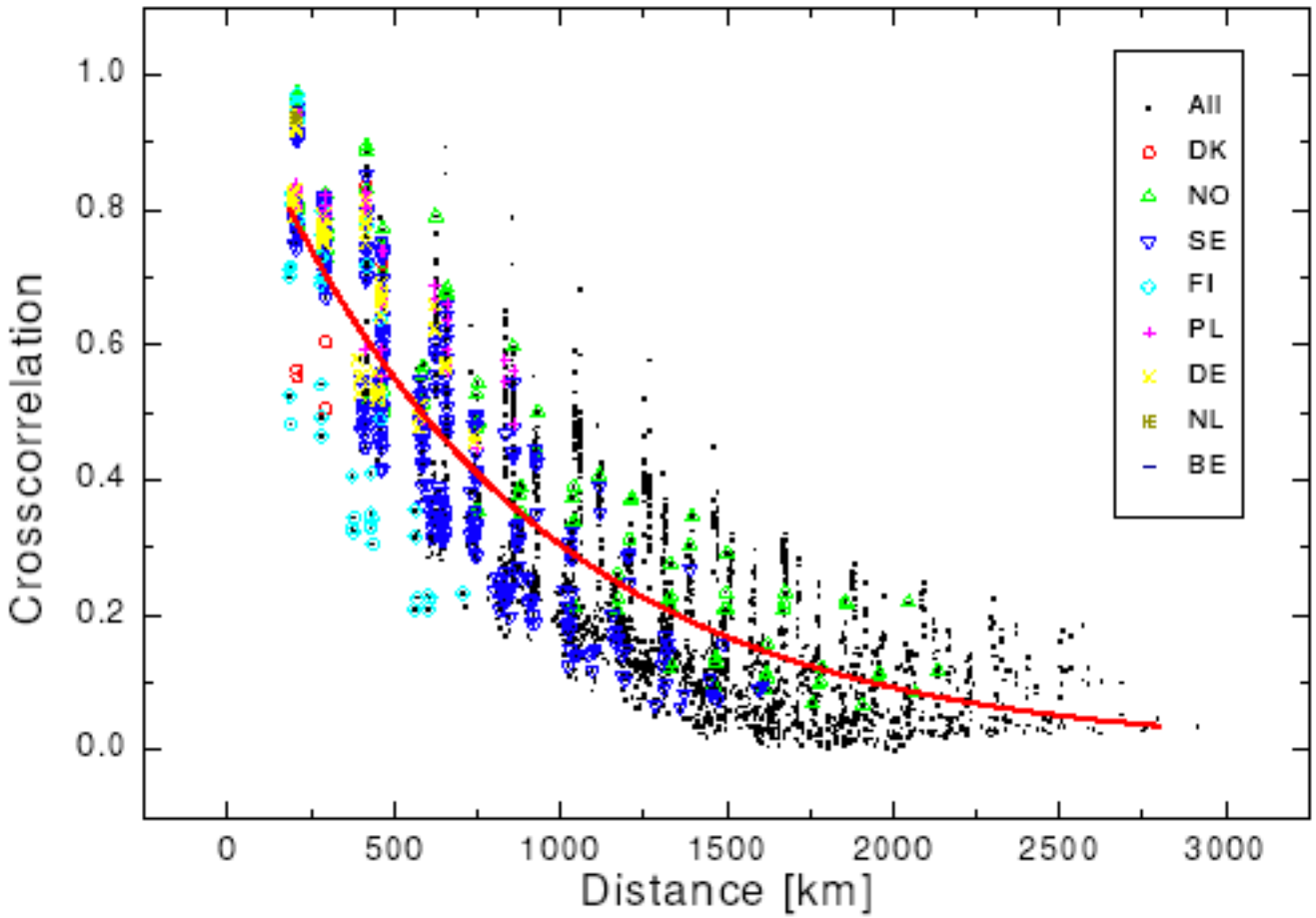
Figure 1: The wind resource of Northern Europe in m/s at 10m height, averaged from Reanalysis data for 1978. The arrows are the mean wind vector at every Reanalysis grid point.



Size comparison with South Australia

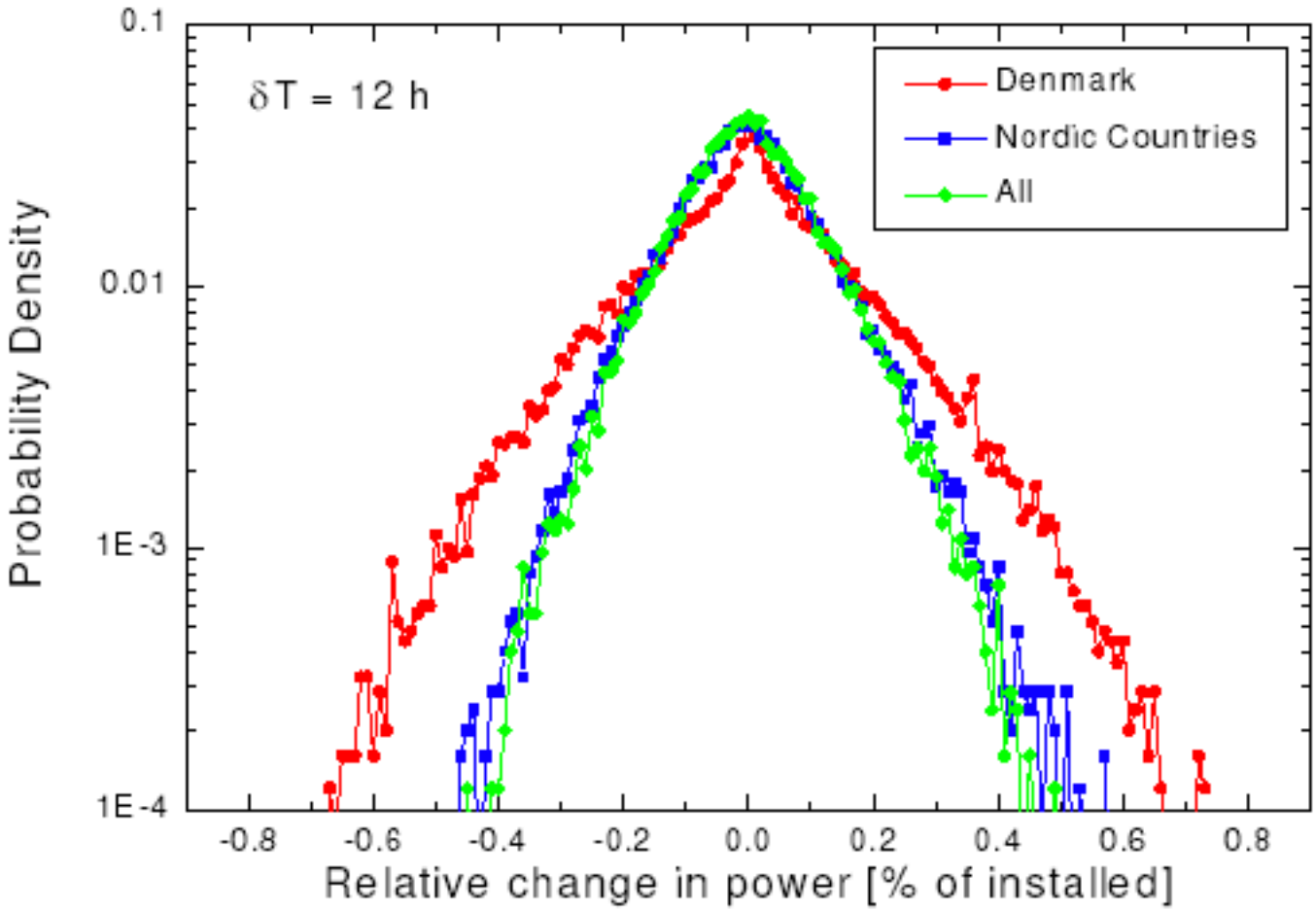
Cross-correlations between 34 years of 12-hourly data for all grid points

(Giebel (2000) Riso National Lab, Denmark)



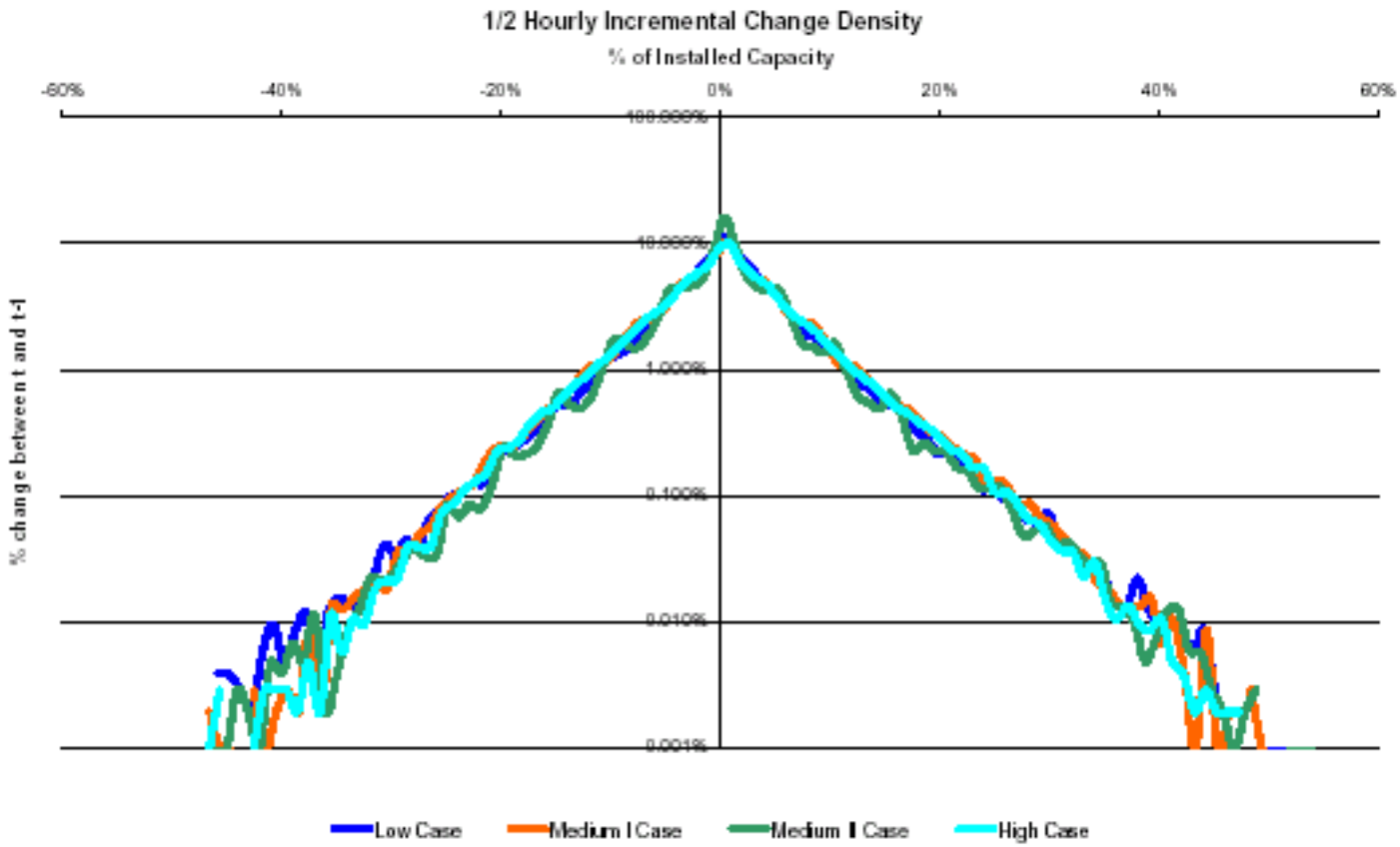
Probability density function for relative change in wind power in 12 hours

(Giebel (2000) Riso National Lab, Denmark)



Incremental Wind Change Density – SA projections

(ESPIC South Australia Wind Power Study, 2003)



Predicted capacity factor for wind farms in Northern Europe

(Giebel (2000) Riso National Lab, Denmark)

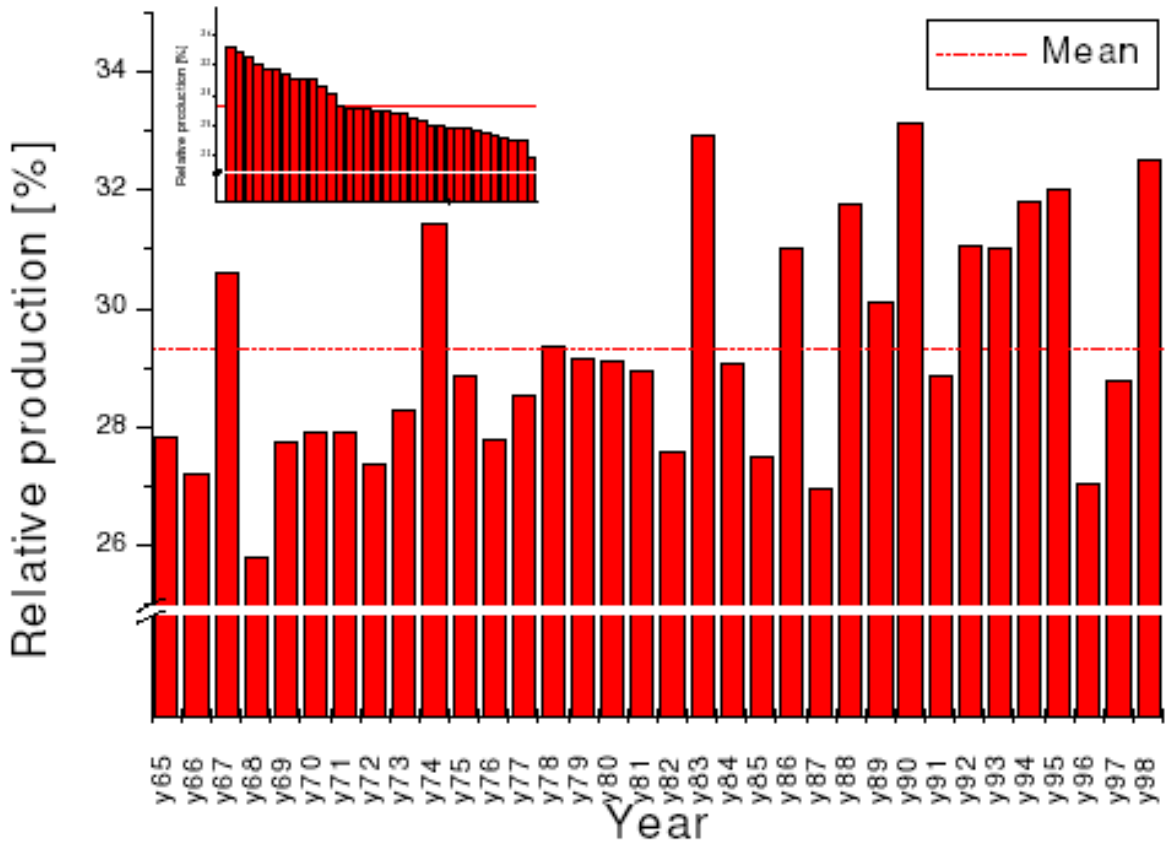
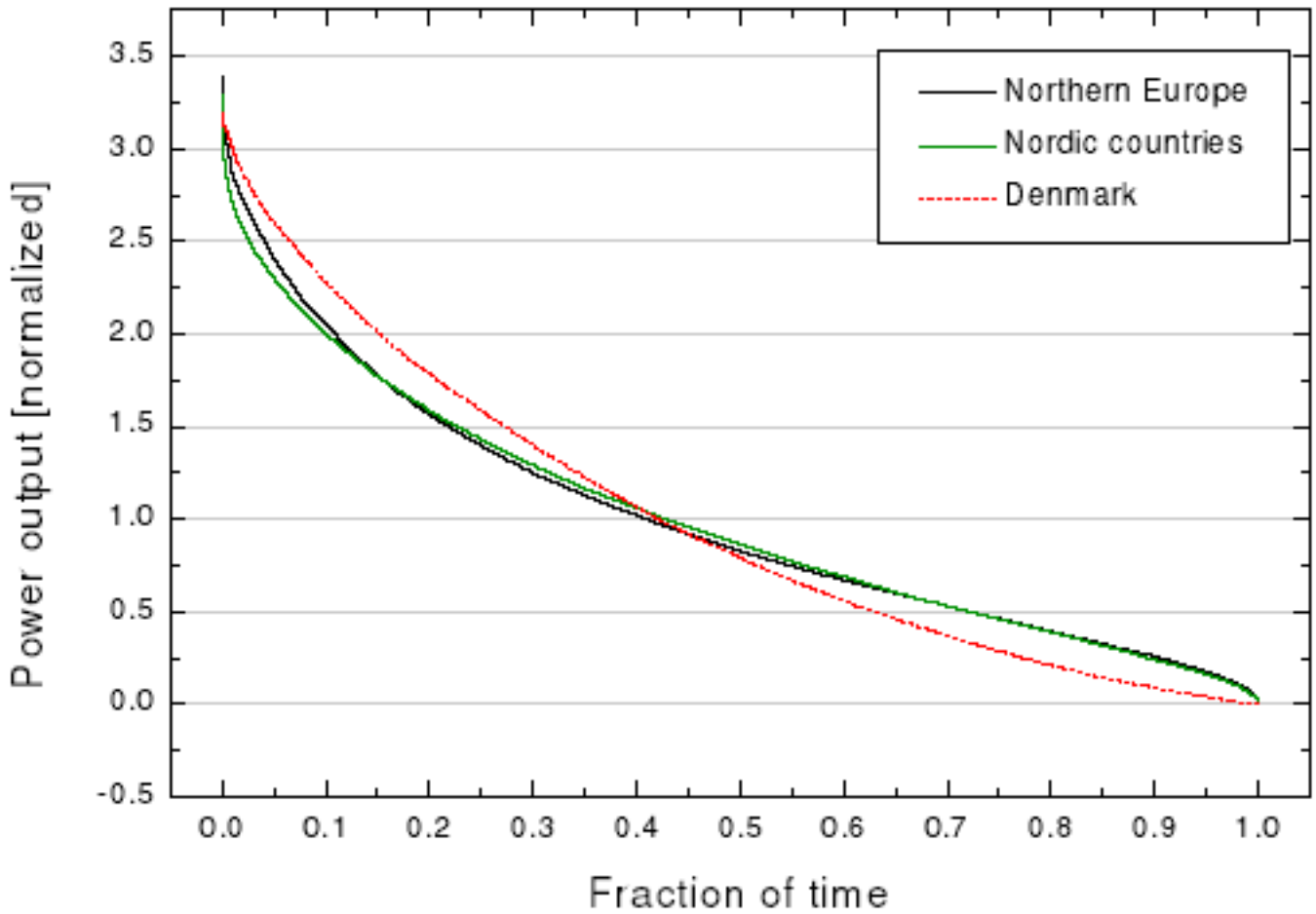


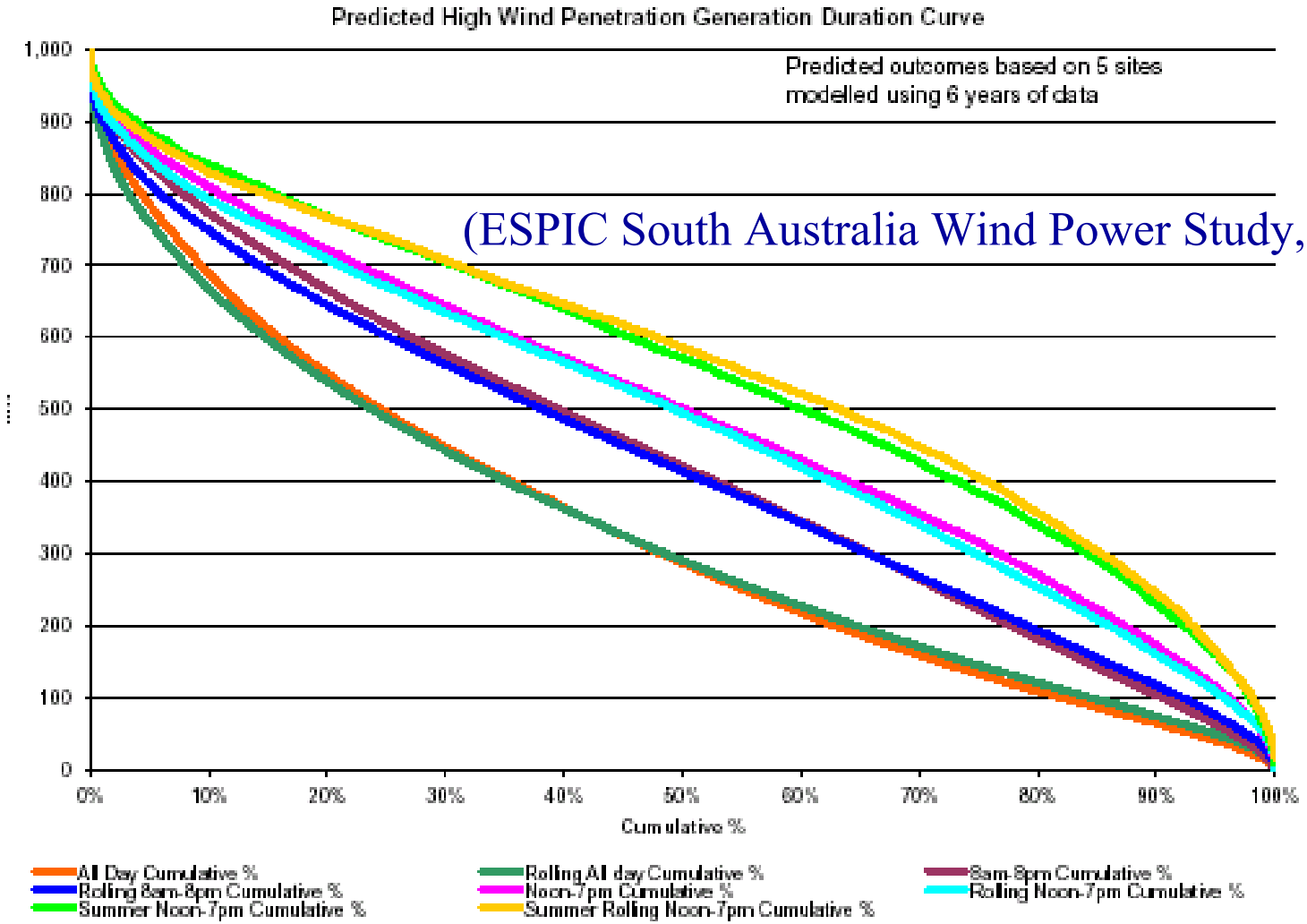
Figure 2: Mean wind power production in Northern Europe for 34 years as a percentage of installed capacity. In the inset: the same graph, ordered by size.

Wind energy duration curve for Northern Europe (normalised to average)

(Giebel (2000) Riso National Lab, Denmark)



Wind energy duration curve – SA projections



(ESPIC South Australia Wind Power Study, 2003)

CSIRO *Windscape*^{TM} model

(www.clw.csiro.au/products/windenergy)

Windscape derives location-specific wind forecasts from a Numerical Weather Prediction model

Global/Continental -scale data analysis

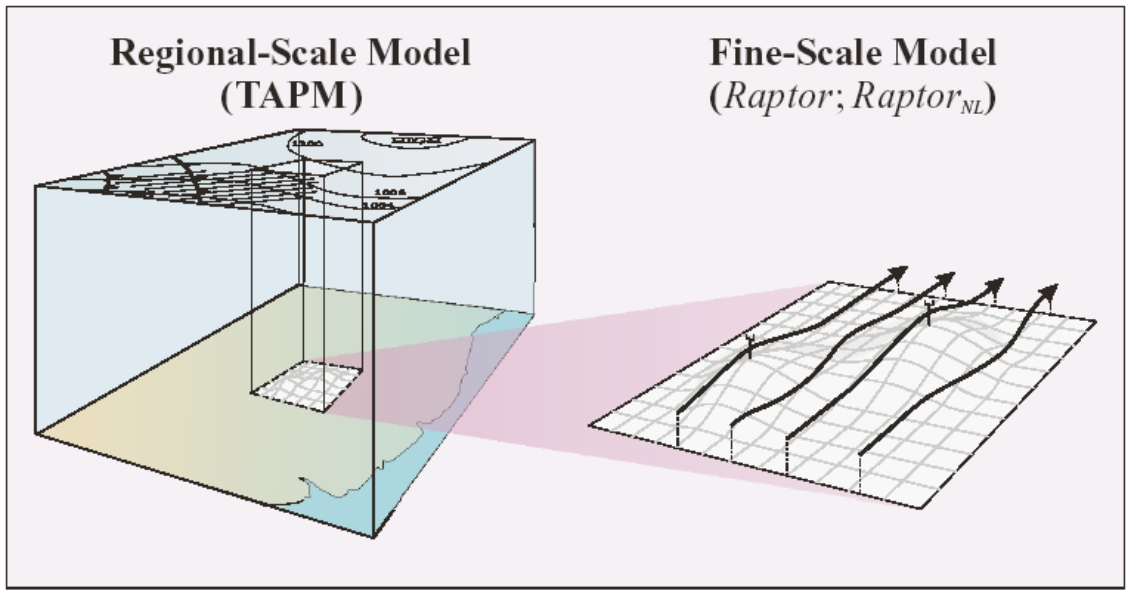
↓

Regional-scale Model (TAPM)

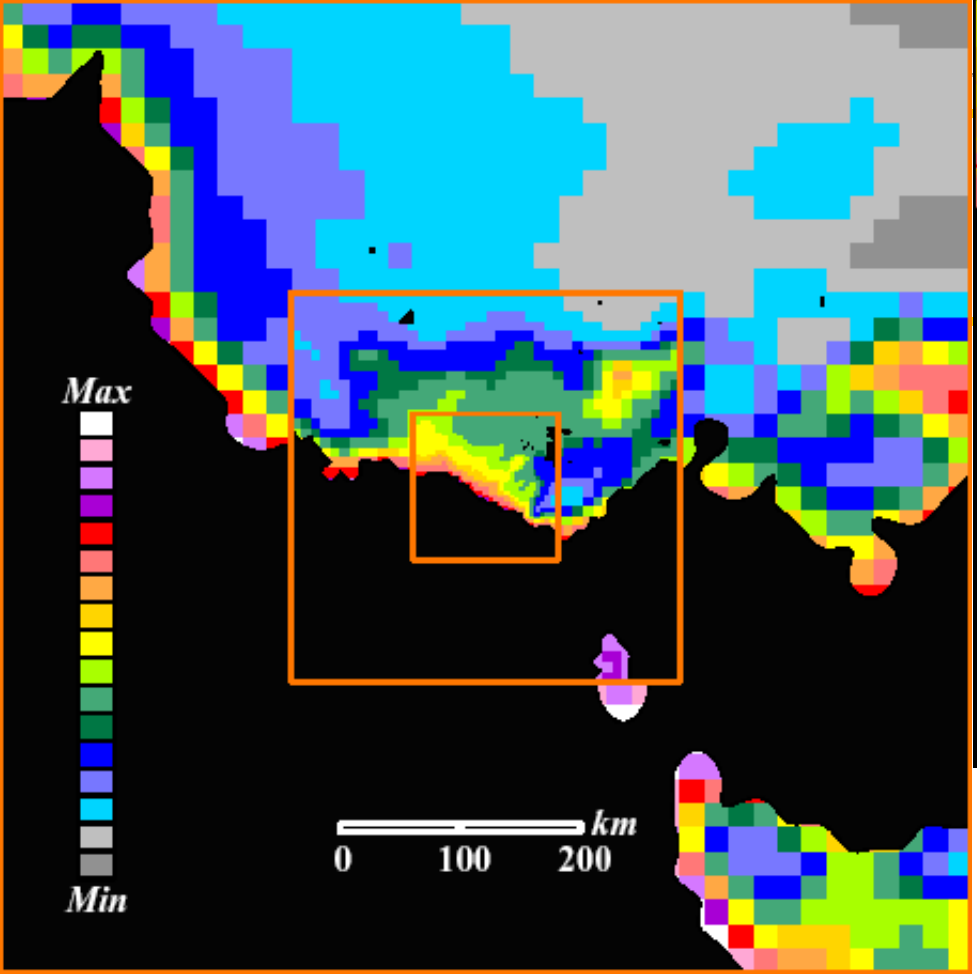
- ~ 20km resolution
- ~ 8km resolution
- ~ 3km resolution

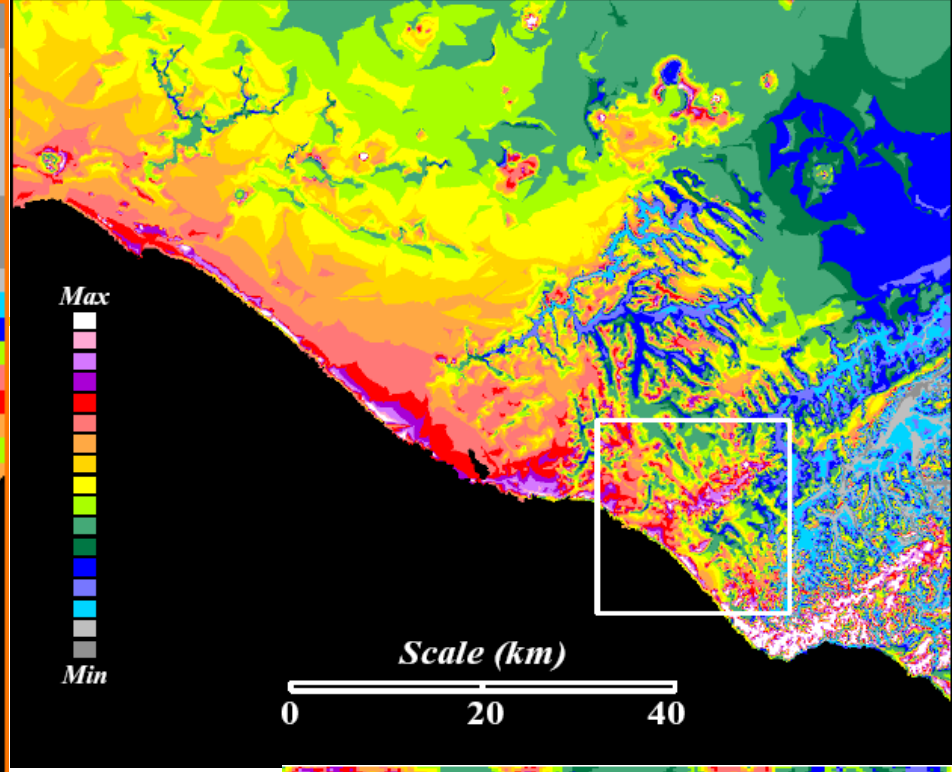
↓

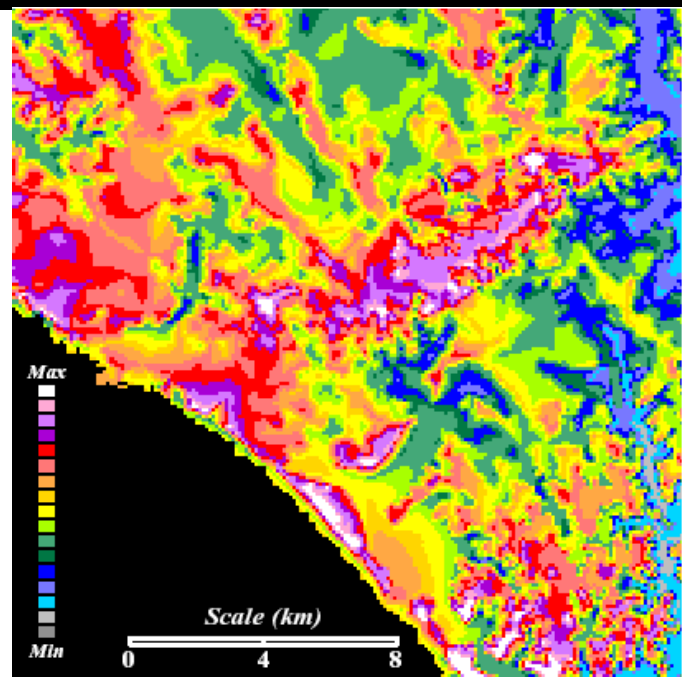
Fine-scale model
Raptor or *Raptor*$_{NL}$
~ 100m resolution



(Steggle et al, CSIRO, March 2002)







(Steggle et al, CSIRO, March 2002)

- Windscape predictions of annual mean wind speed at 65 m, showing nested model results
- More rapid changes in colour probably imply higher local turbulence

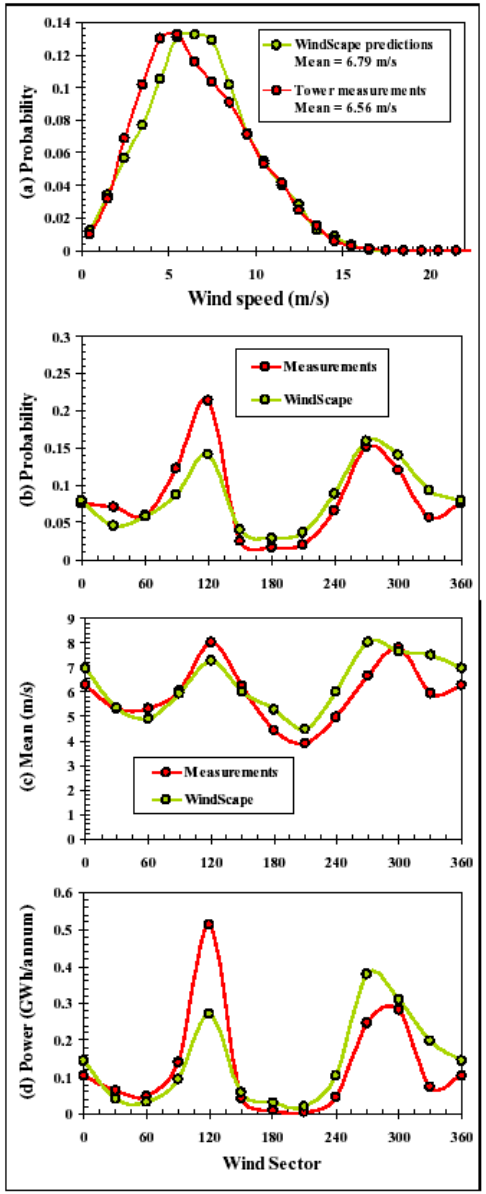


Figure 12 *WindScape* predictions compared with measurements at an inland location.
(a) Wind speed pdf.
(b) Wind direction pdf.
(c) Mean wind speed in each sector.
(d) Annual power output in each sector.

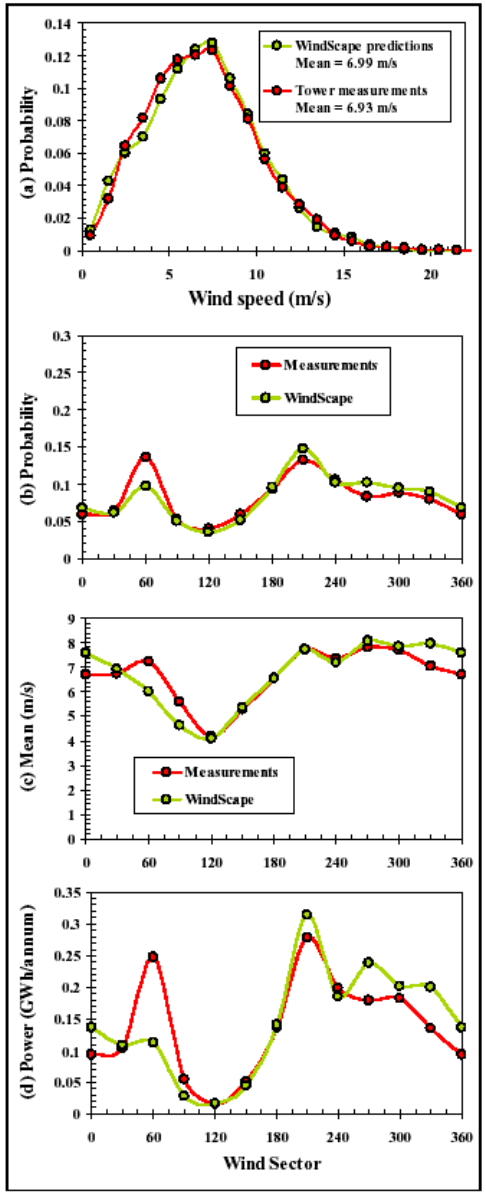


Figure 13 *WindScape* predictions compared with measurements at a coastal location.
(a) Wind speed pdf.
(b) Wind direction pdf.
(c) Mean wind speed in each sector.
(d) Annual power output in each sector.

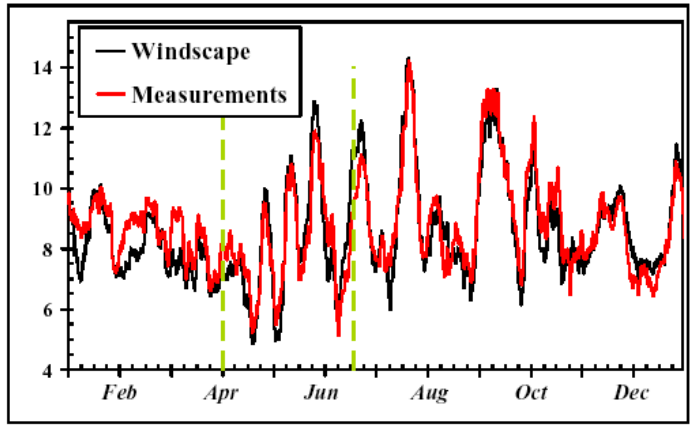


Figure 14 (a) Time series of weekly running mean wind speed (m/s).

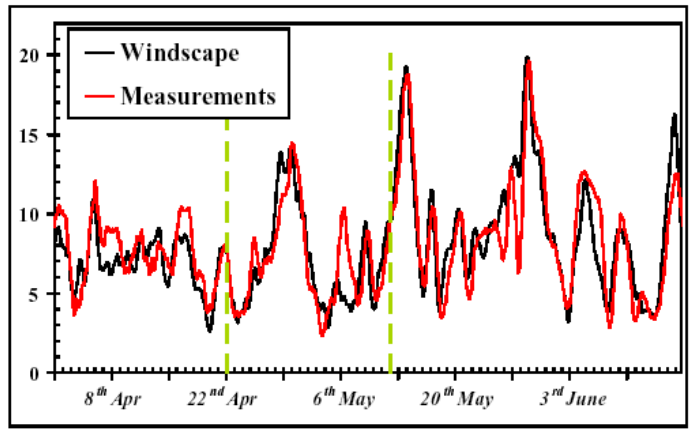


Figure 14 (b) Time series of daily running mean wind speed (m/s).

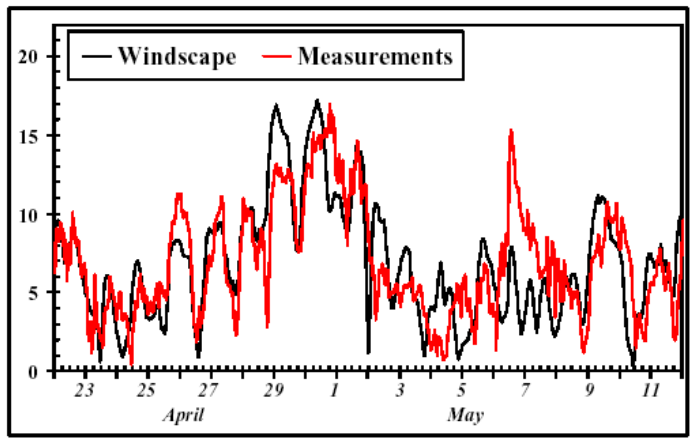
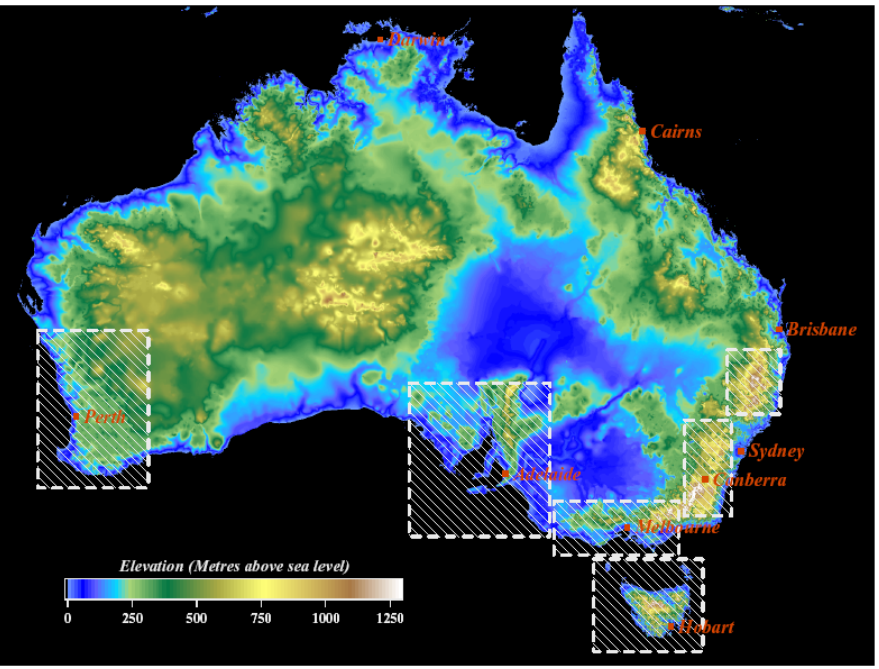
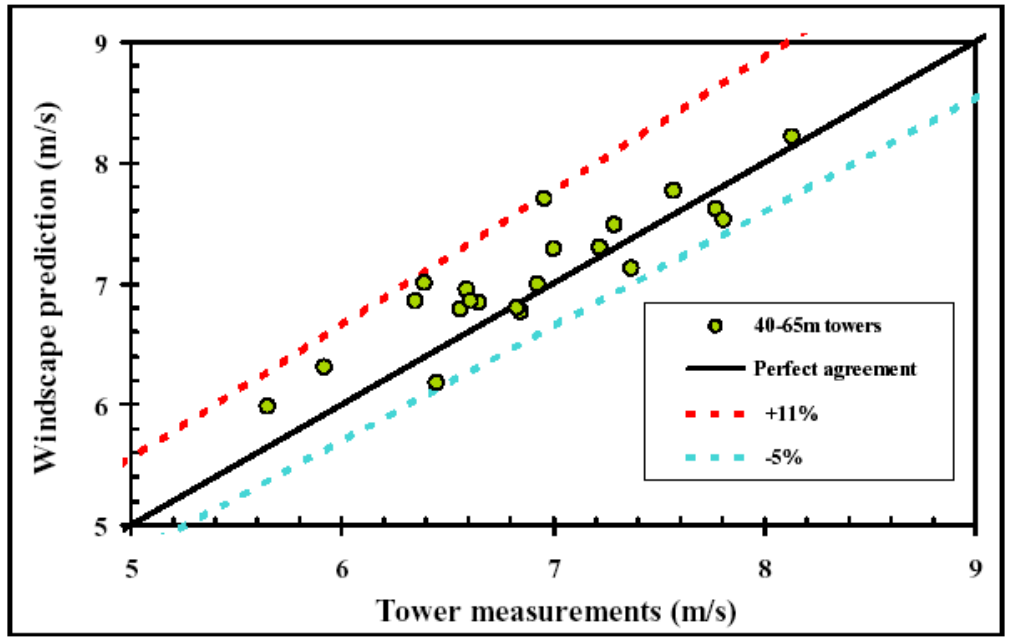


Figure 14 (c) Time series of hourly mean wind speed (m/s).

Wind prospecting with Windscape

(www.clw.csiro.au/products/windenergy)



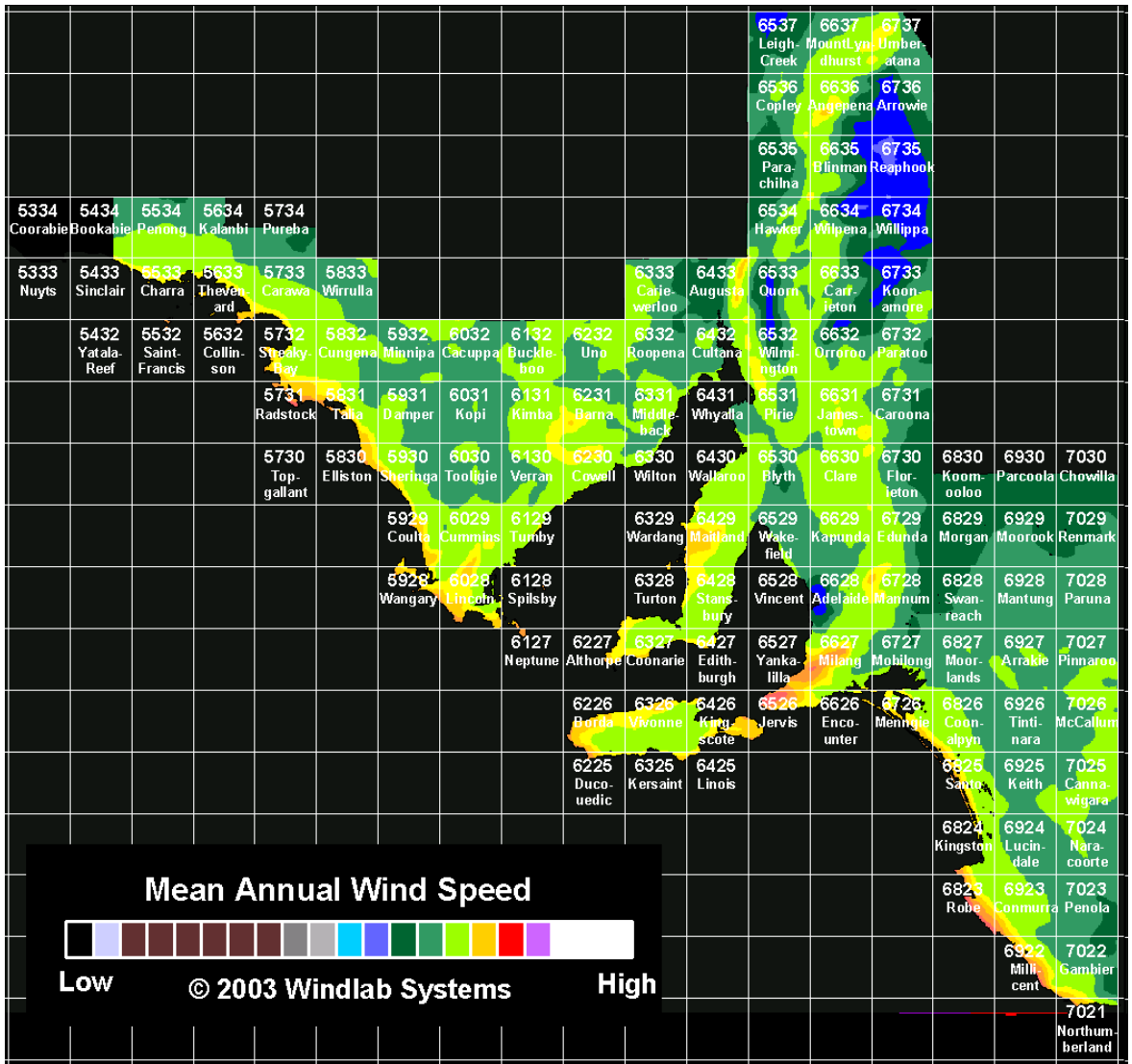


(Steggle et al, CSIRO, March 2002)

- Windscape has been used to study a number of regions
- Accuracy better for > 3 hourly behaviour
- Could give valuable information on correlation between regions

Wind prospecting – SA

(www.clw.csiro.au/products/windenergy)



Conclusions

- Wind resources:
  - Stochastic but useful predictions can be made
    - eg Numerical Weather Prediction models
- Wind turbine technology:
  - Several design options each with strengths & weaknesses
- Wind farm performance:
  - Turbulence and weather spectra fluctuations
  - Diversity between sites adds to value