Kan vindmølleparker påvirke havsikulasjonen og klimaet?

Göran Broström

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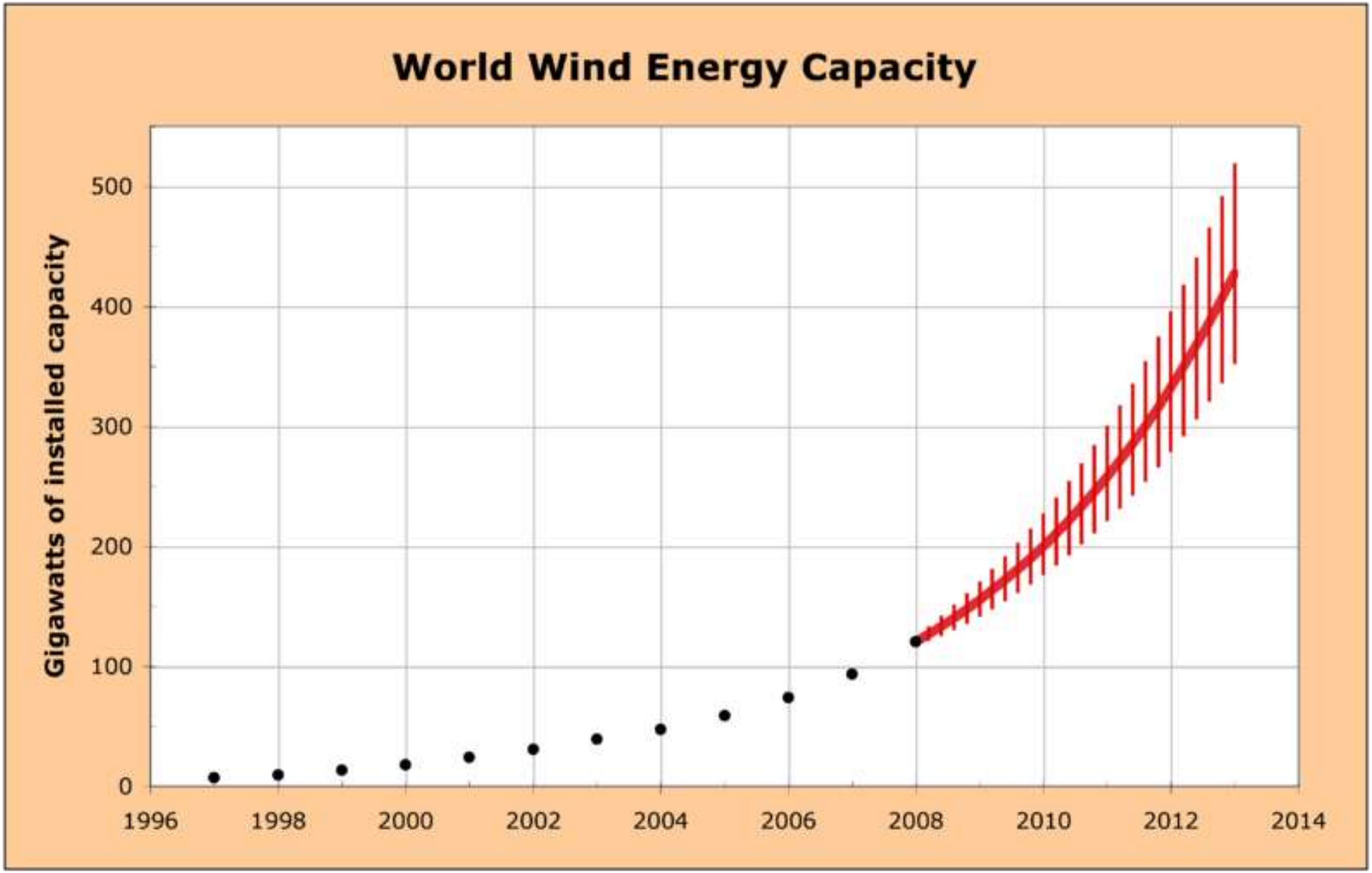
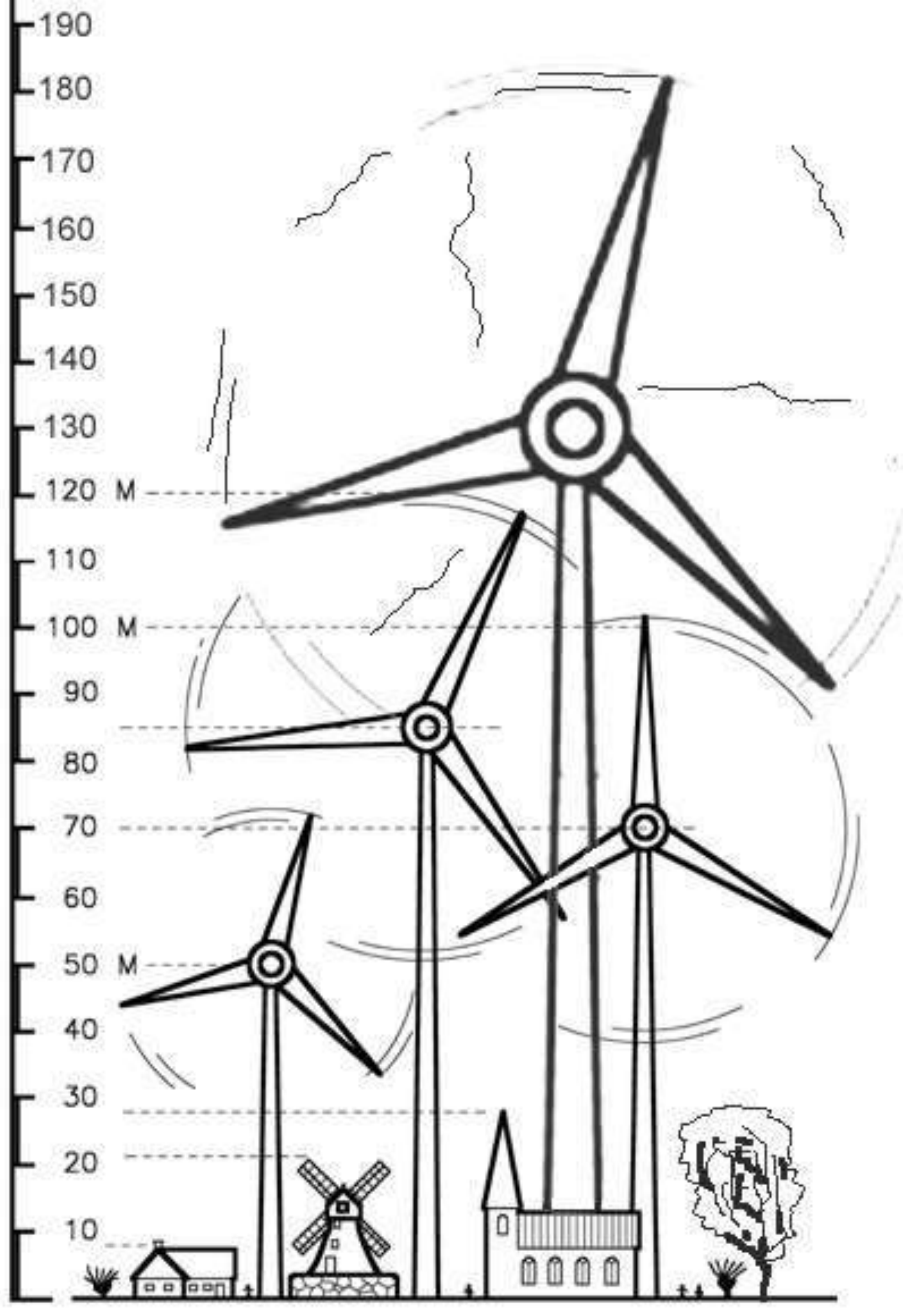


www.wikipedia.com

Horns rev, Danmark


190
180
170
160
150
140
130
120 M
110
100 M
90
80
70
60
50 M
40
30
20
10

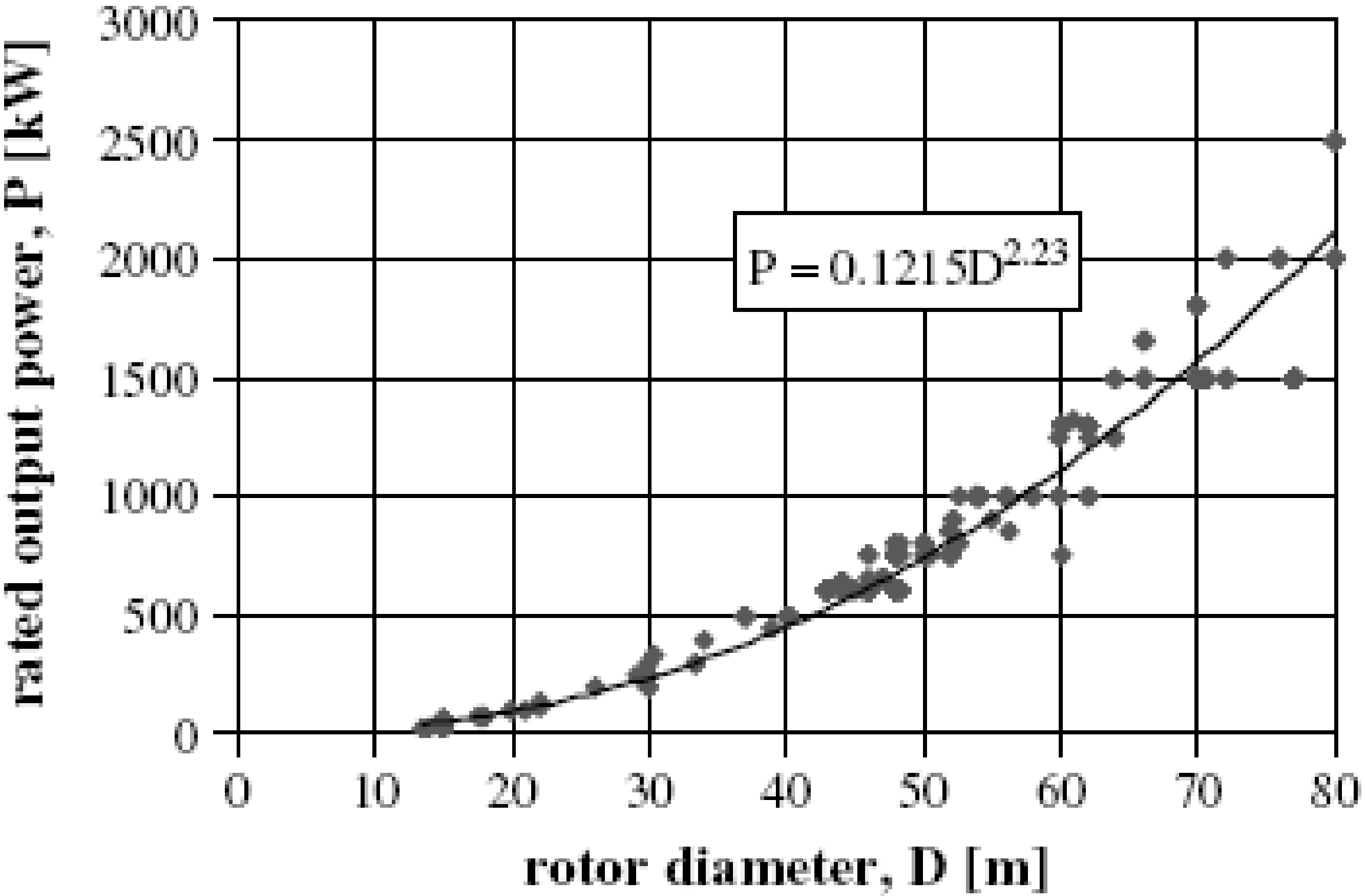


Figure 2. Relationship between rotor diameter and rated power output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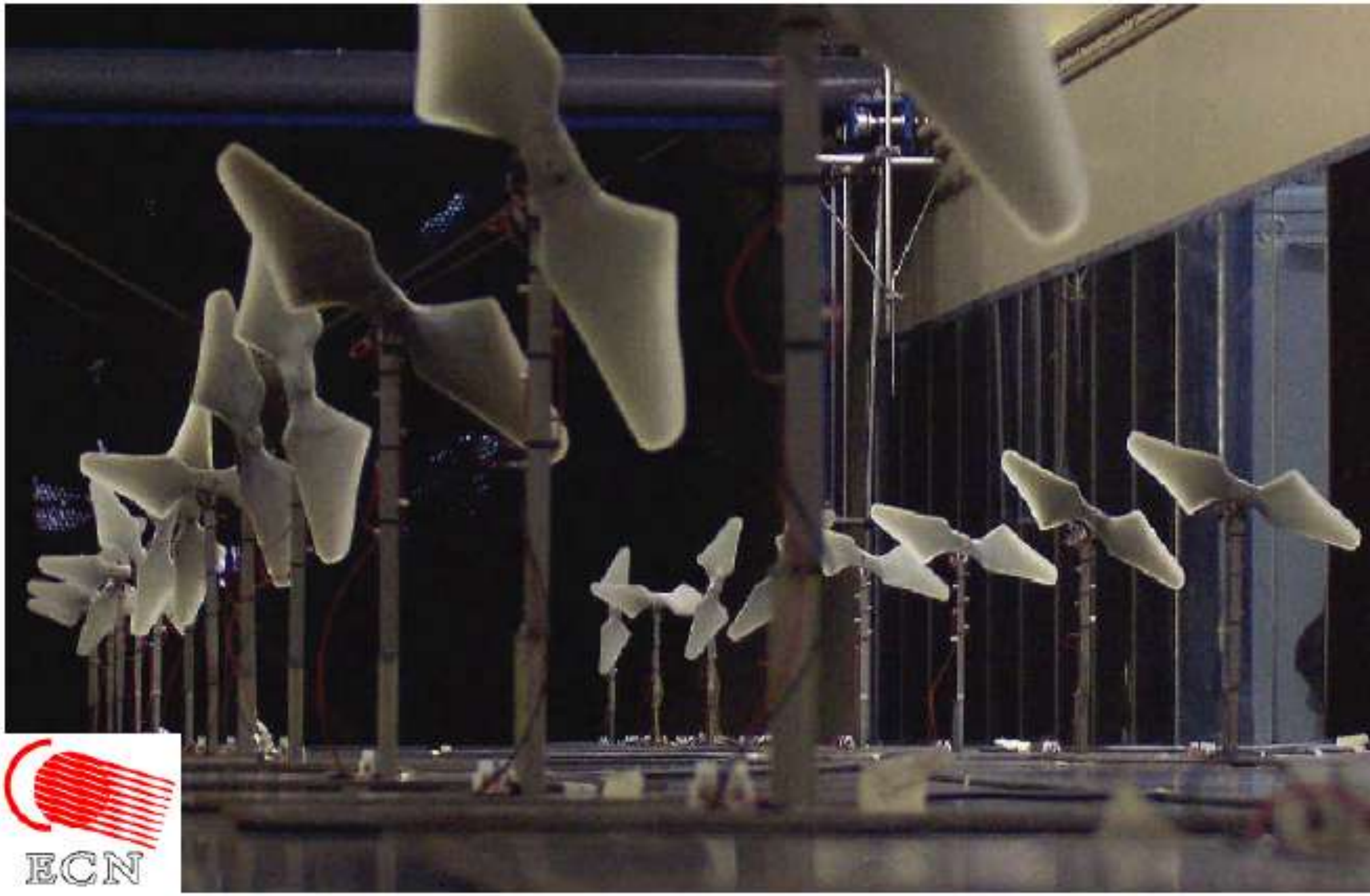
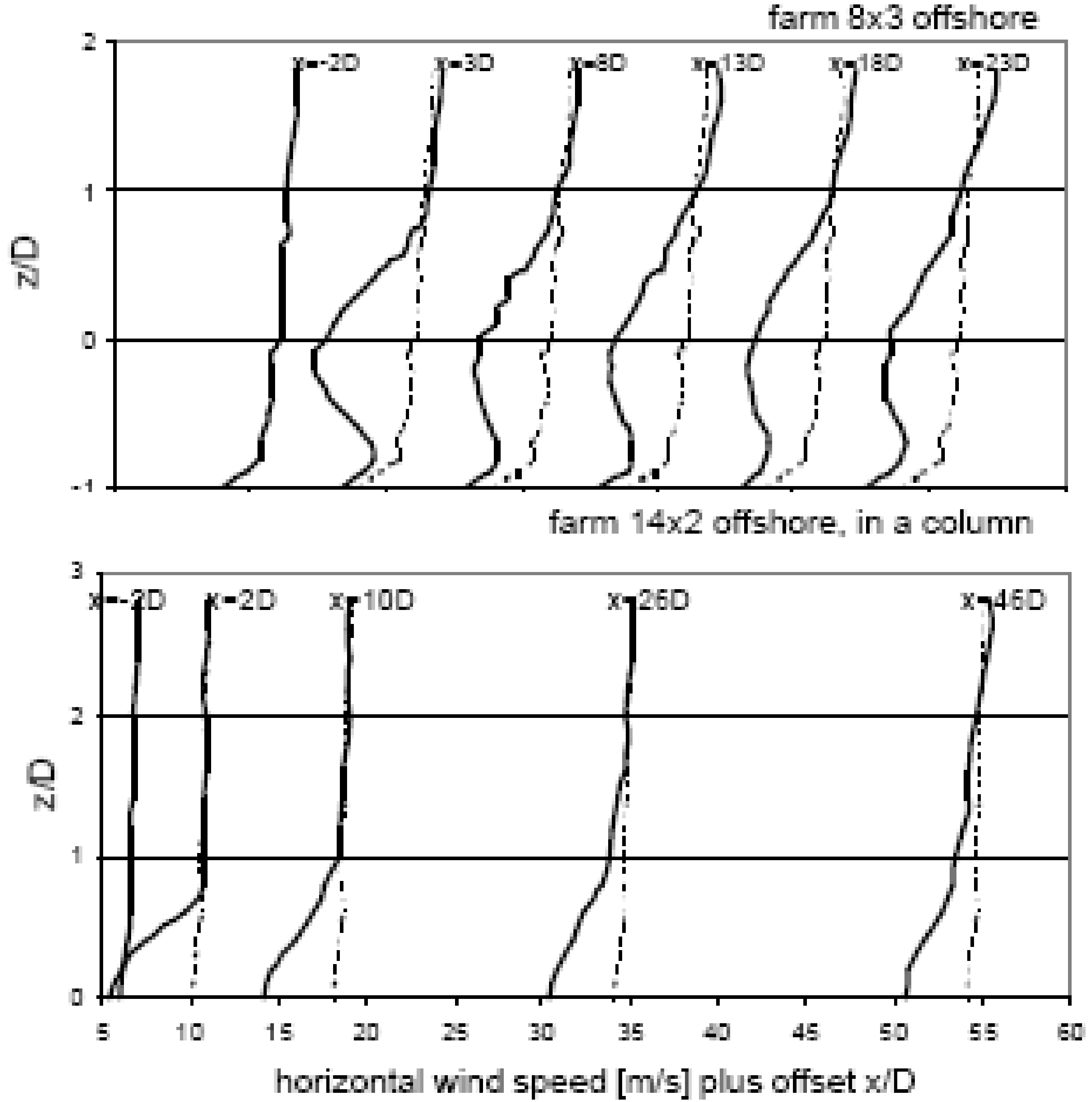
Vestas


5M


ECN

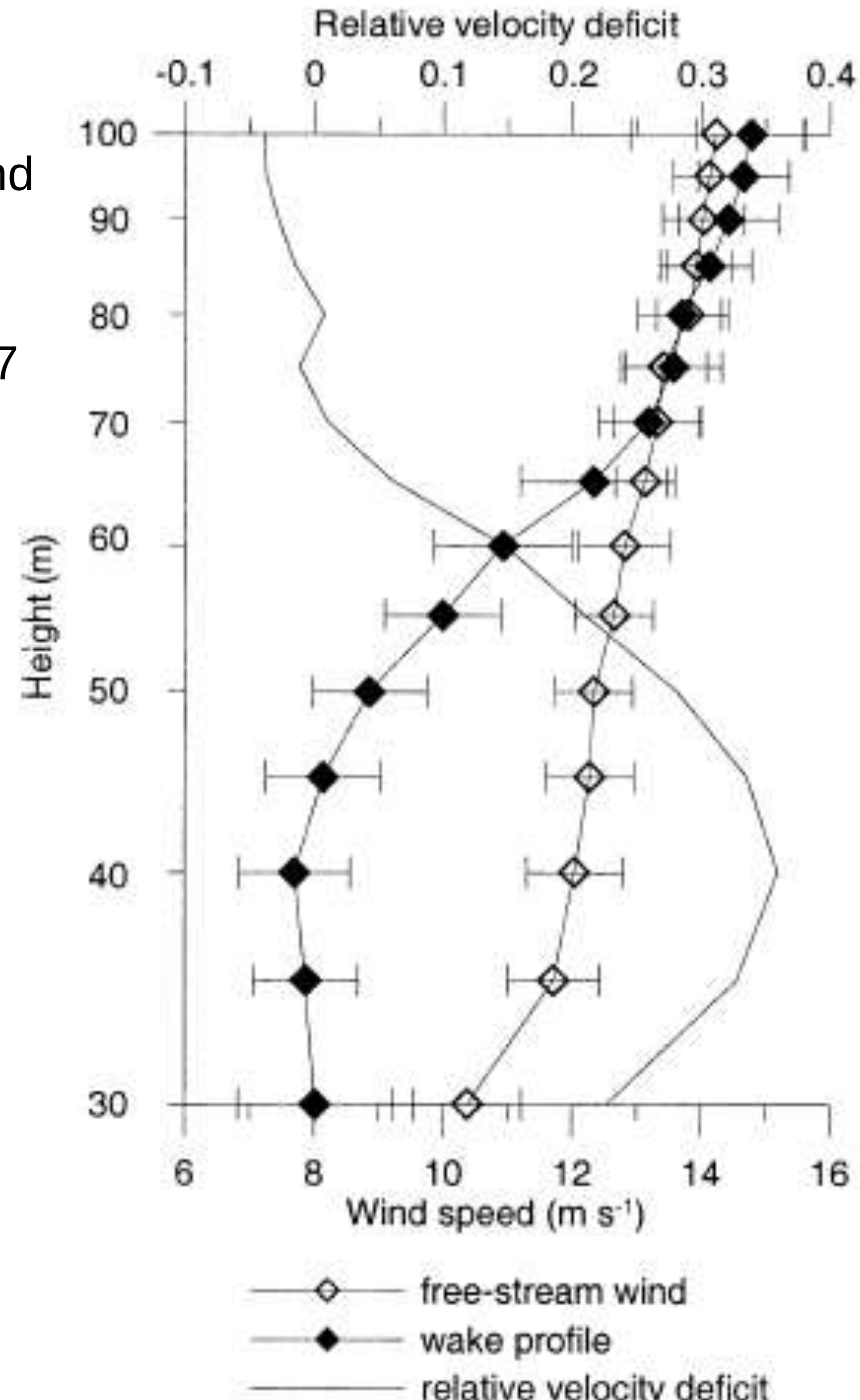
Measurement in the middle row.

Measurement between the rows.

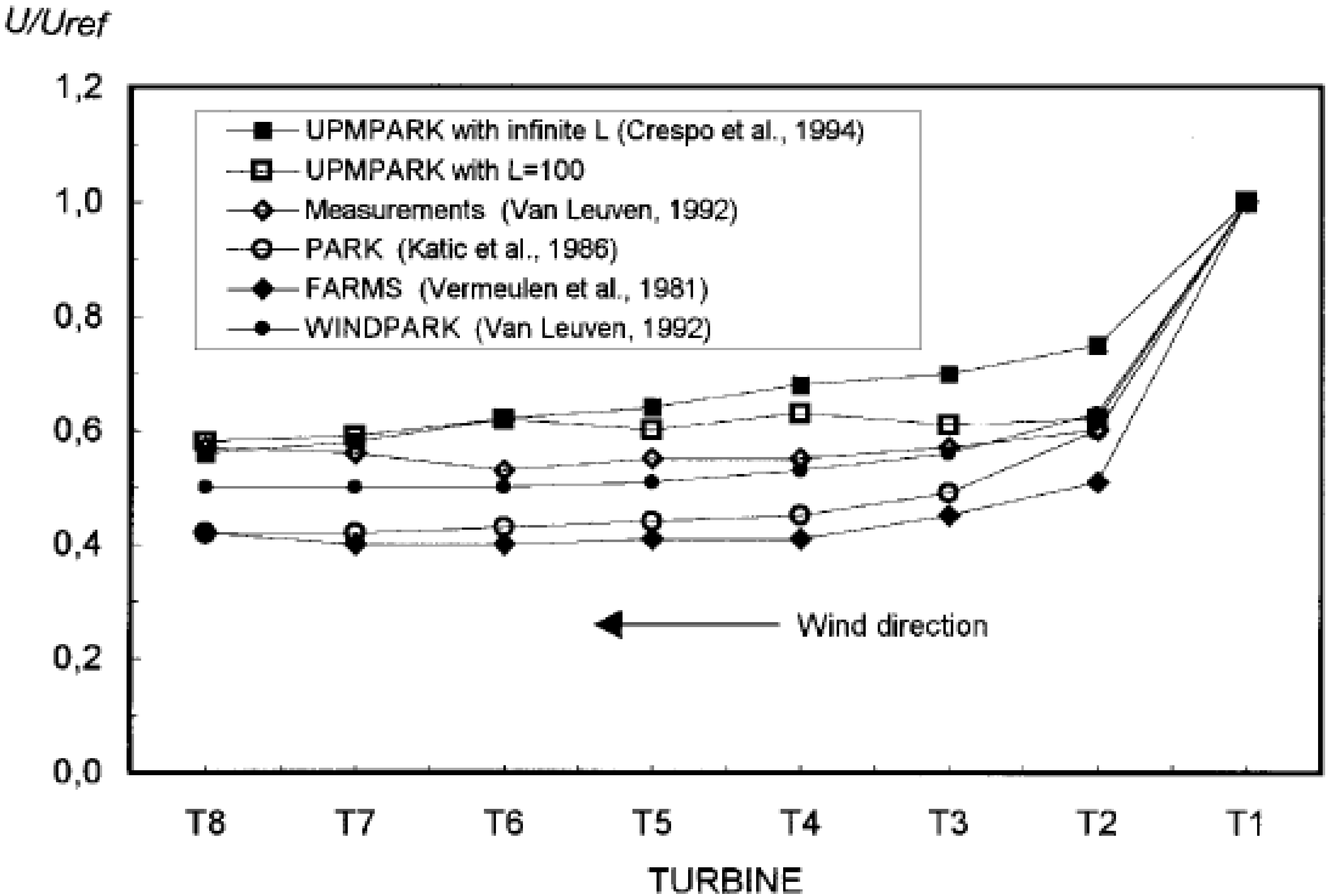


Measurement of wind speed behind a wind farm (horns rev wind farm)

Barthelmie et al, JAOT, 2003, 20, 466-477



Wind speed behind wind mills (at the height of the wind mill) as a function of the number of turbines



Flight track in an investigation focusing on the wake behind a wind farm

Study performed at Horns rev

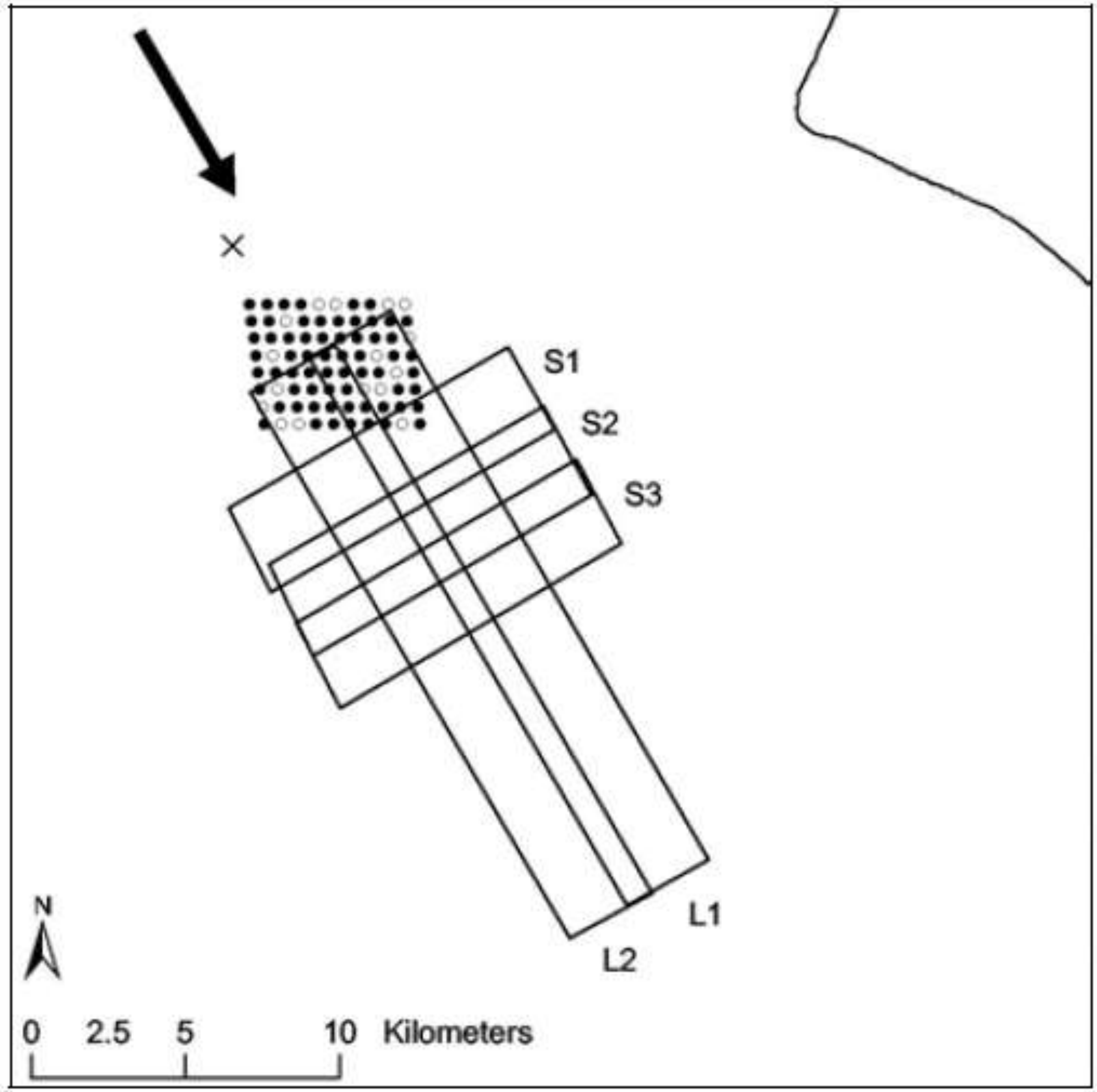
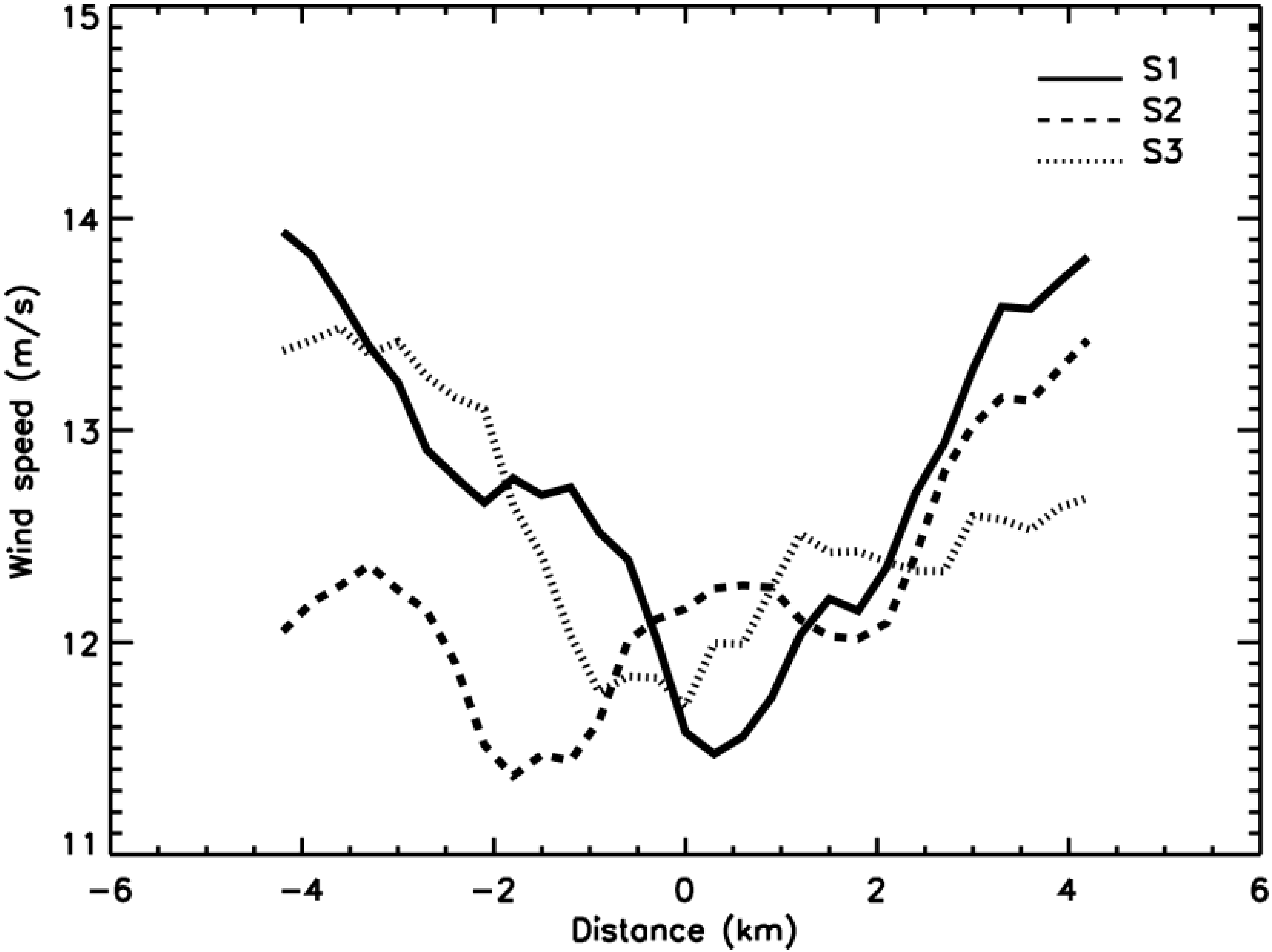


Figure 3. Configuration of E-SAR flight tracks acquired in C-band VV. Arrow indicates wind direction (330º), x the met. mast, and dots are wind turbines (filled if running).

A wind decreases of 25% correspond to a 50% decrease in wind stress at the surface.



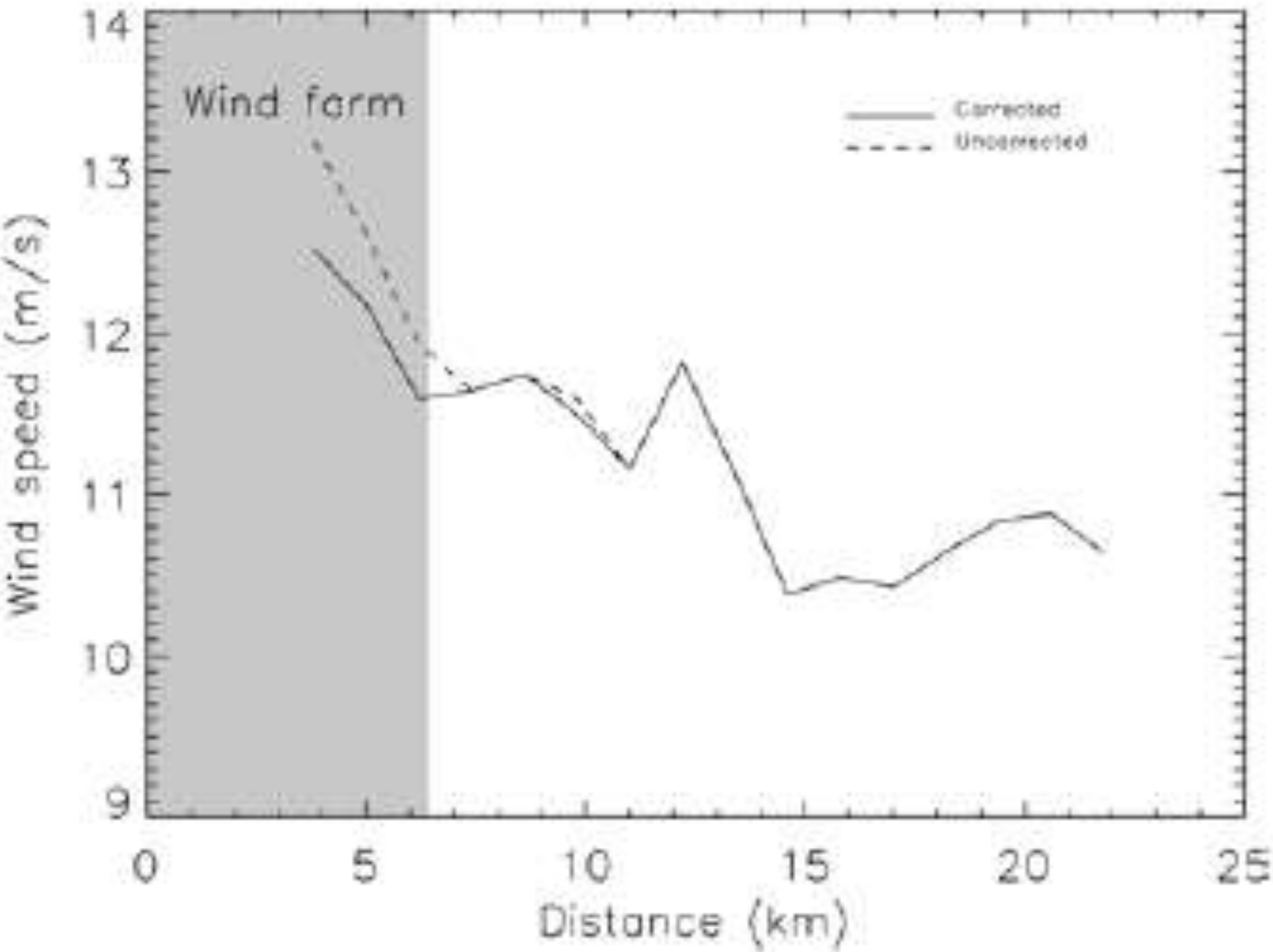


Figure 7. Wind speed along E-SAR track L1. Results are shown before and after correction for turbine scattering.

Turbulent Kinetic Energy (TKE)

Is important for mixing

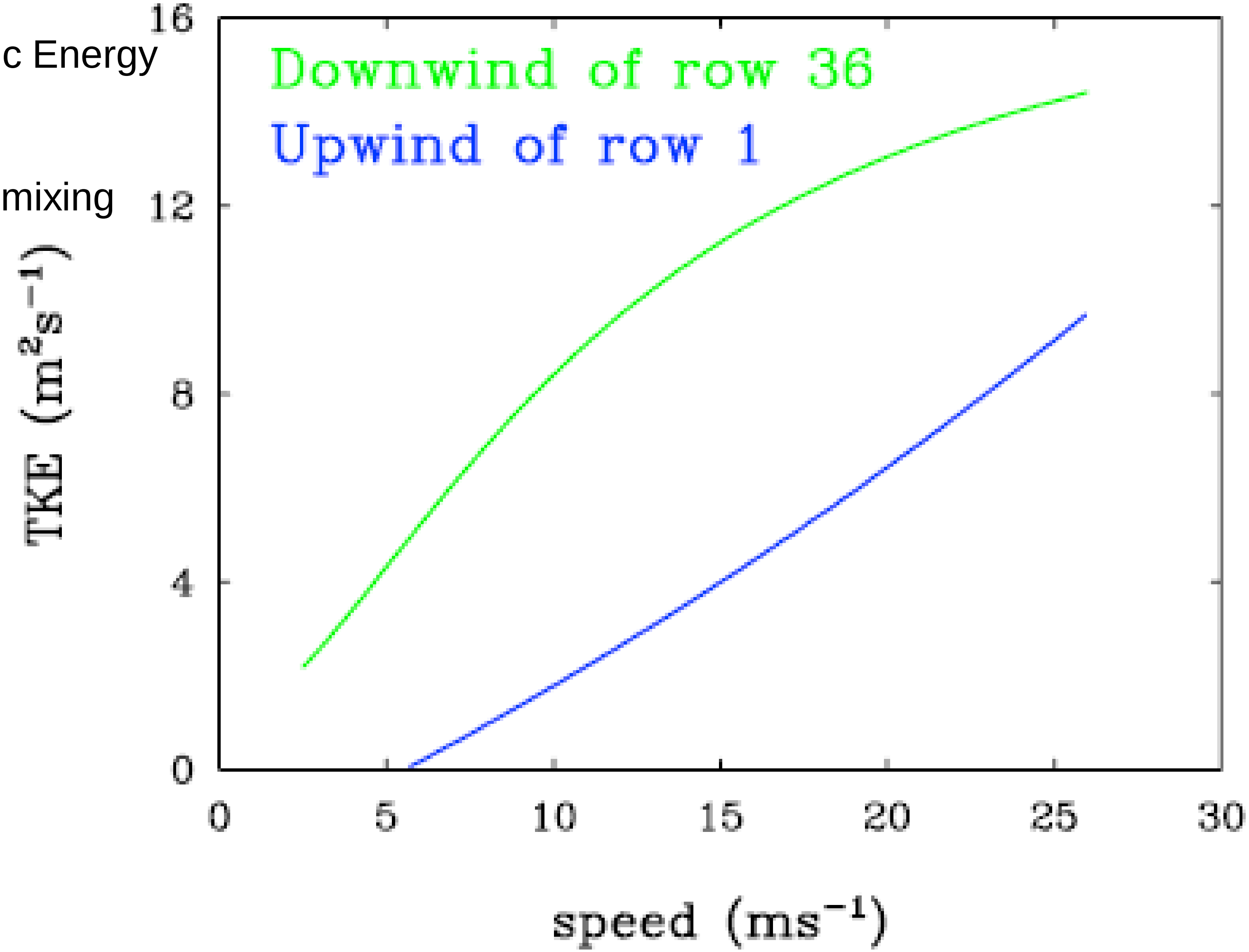
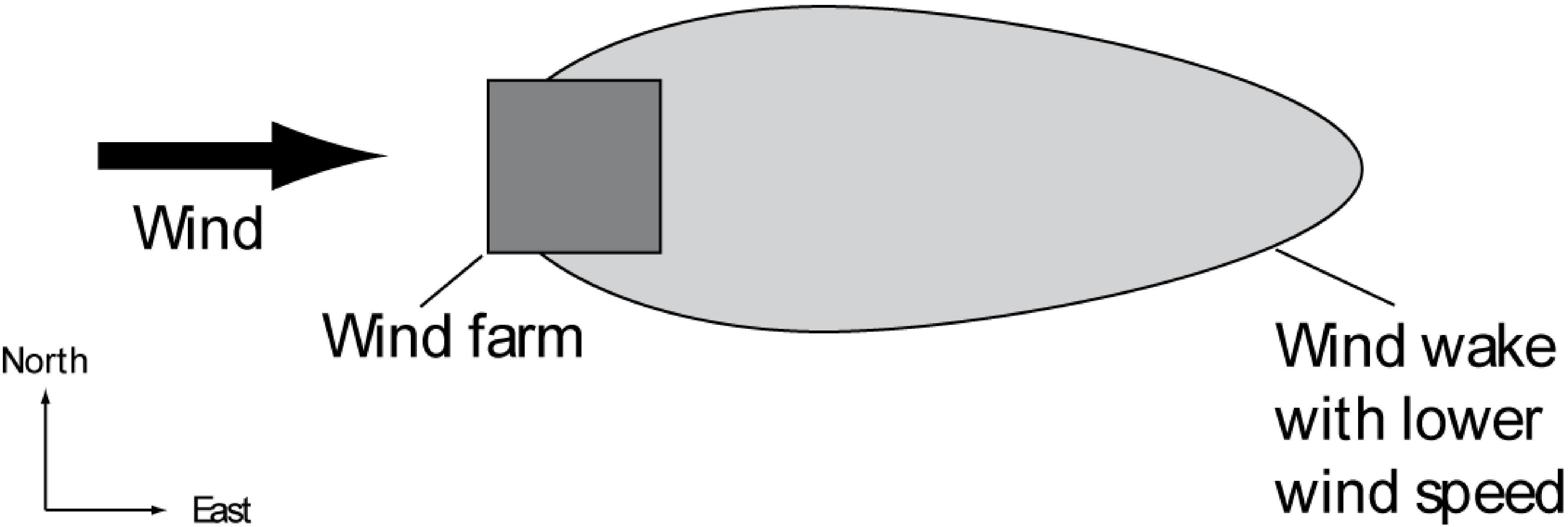
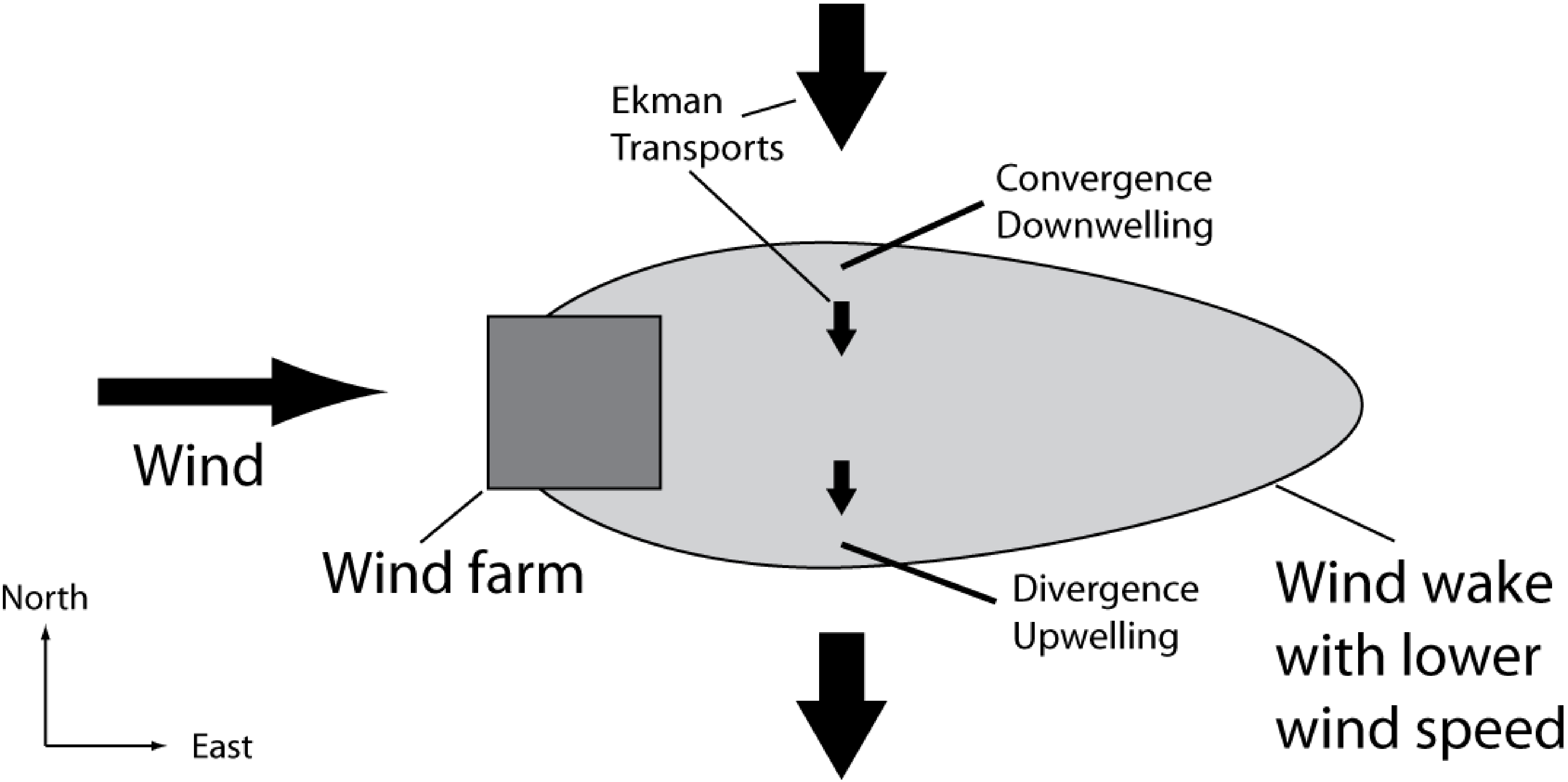


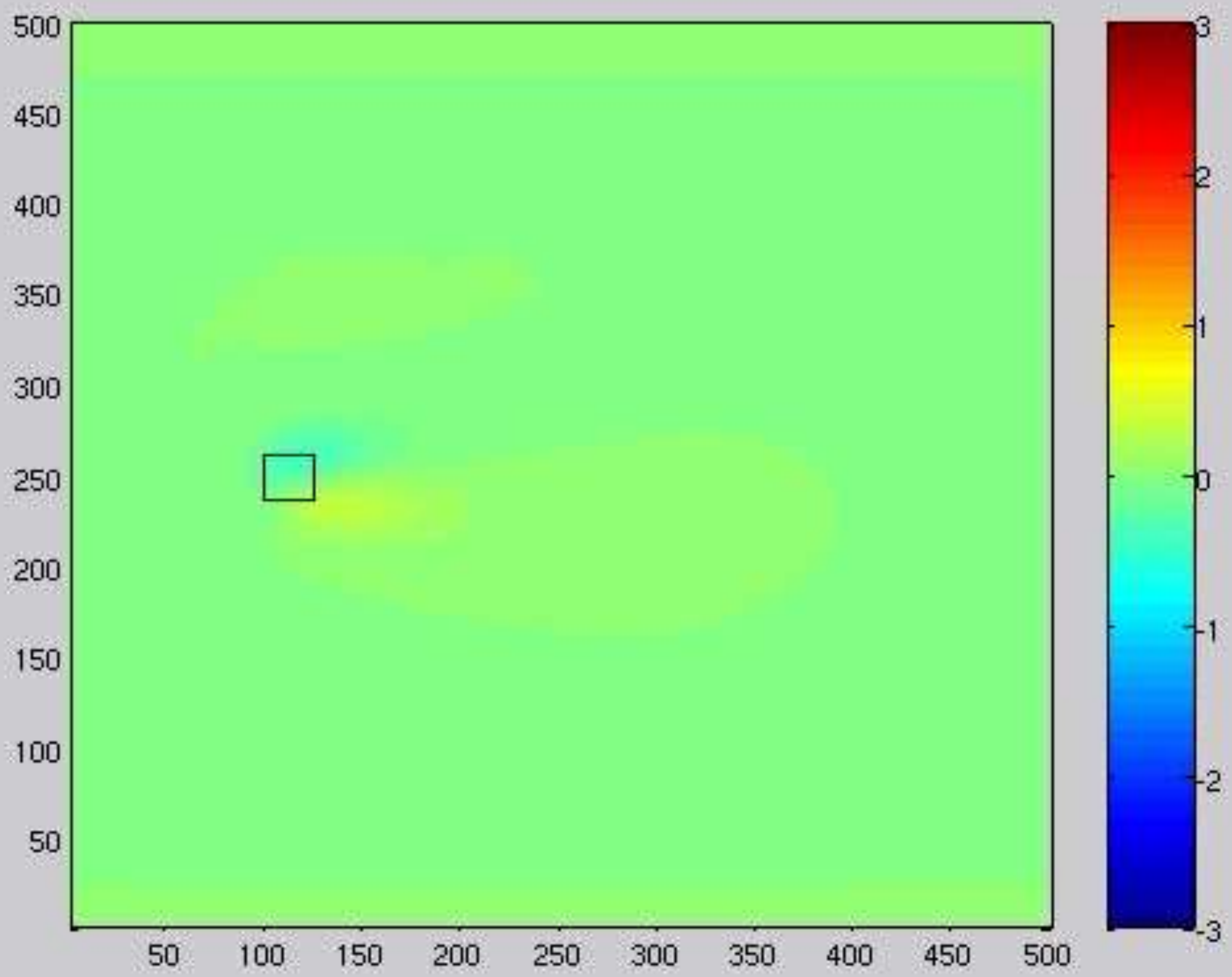
Figure 2. Observed 10-min averaged hub-height TKE as a function of wind speed from San Gorgonio, California.

There will be lower wind speed down-wind from the wind farm



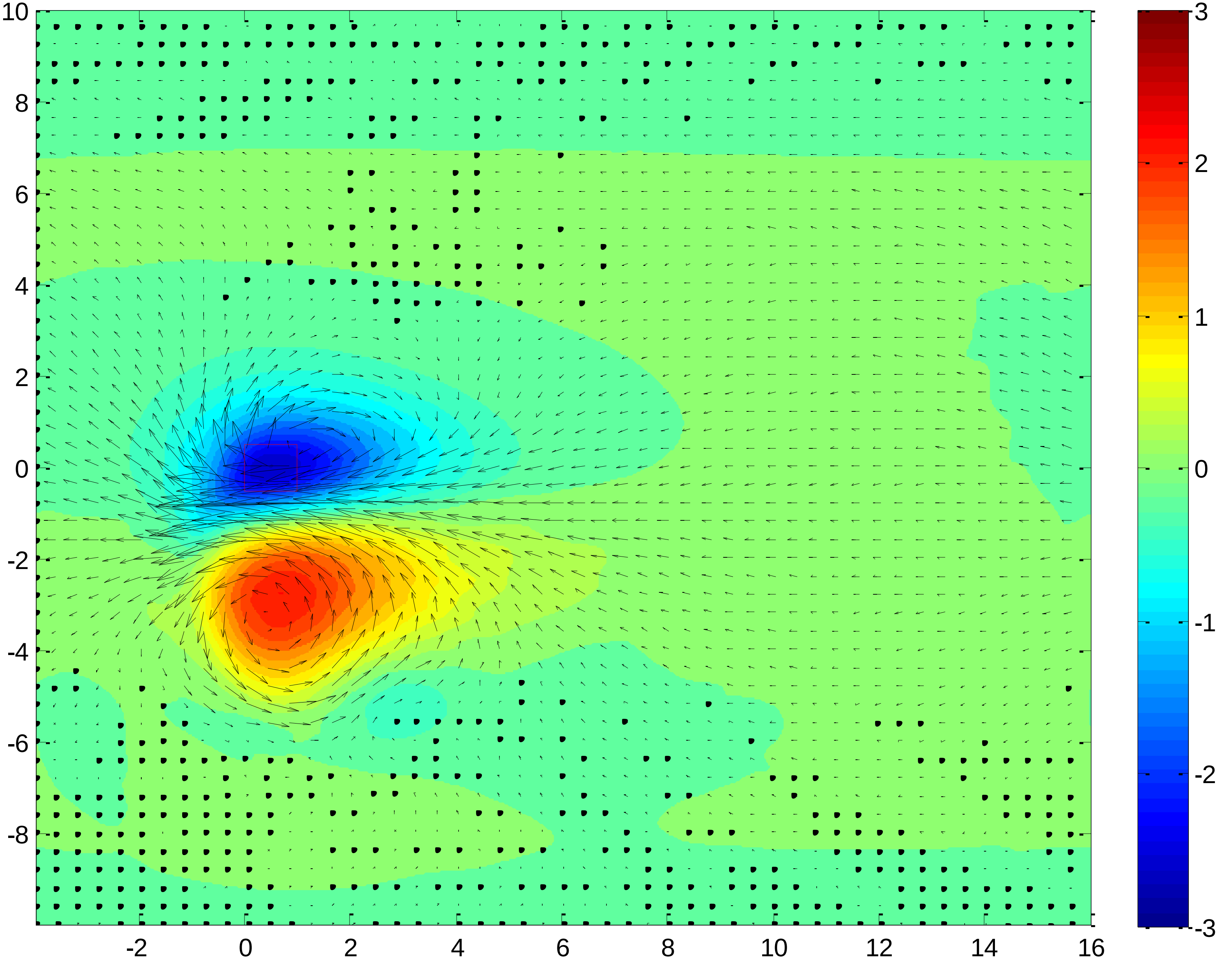


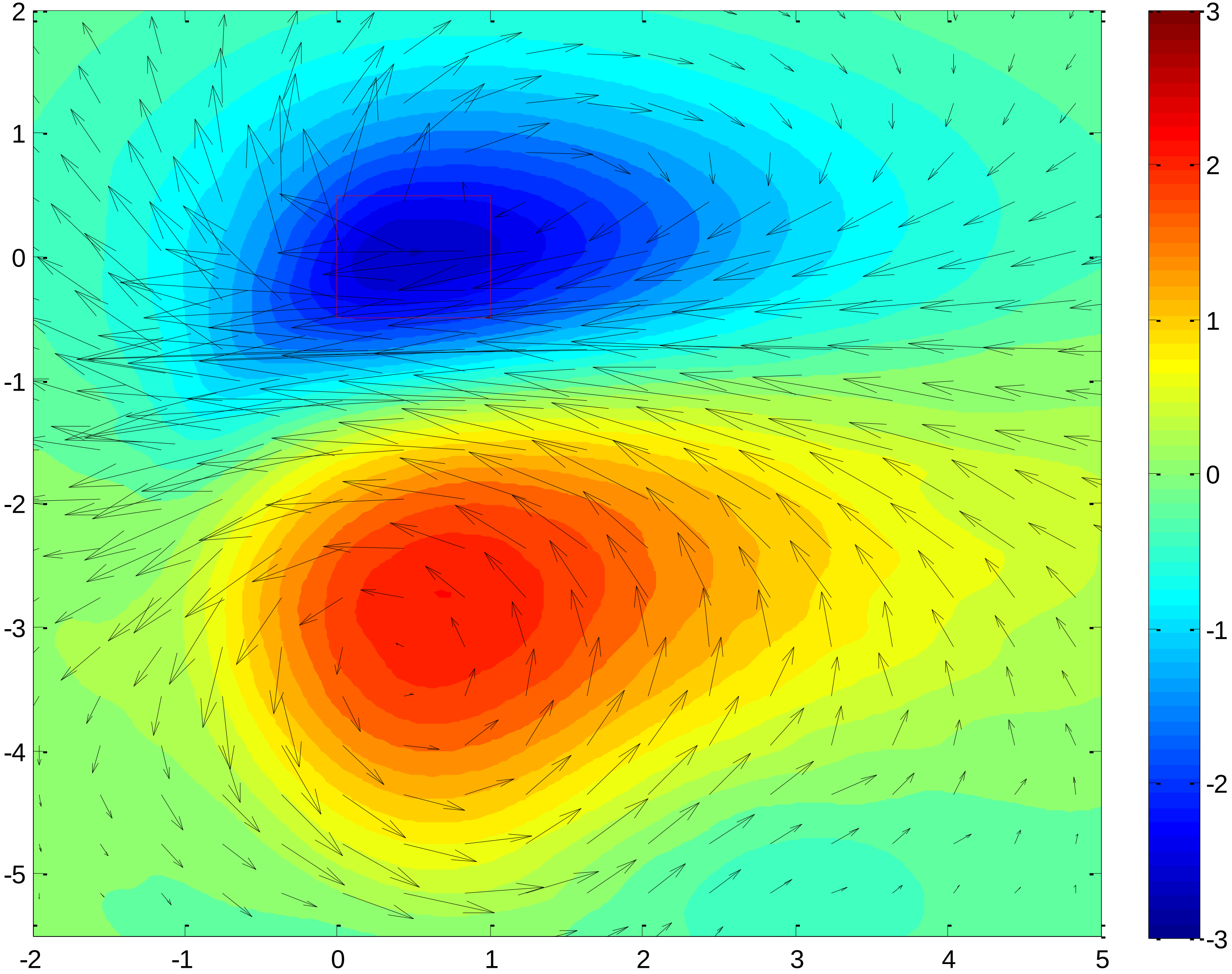
Ekman
Transports
Convergence
Downwelling
Wind
Wind farm
North
East
Divergence
Upwelling
Wind wake
with lower
wind speed



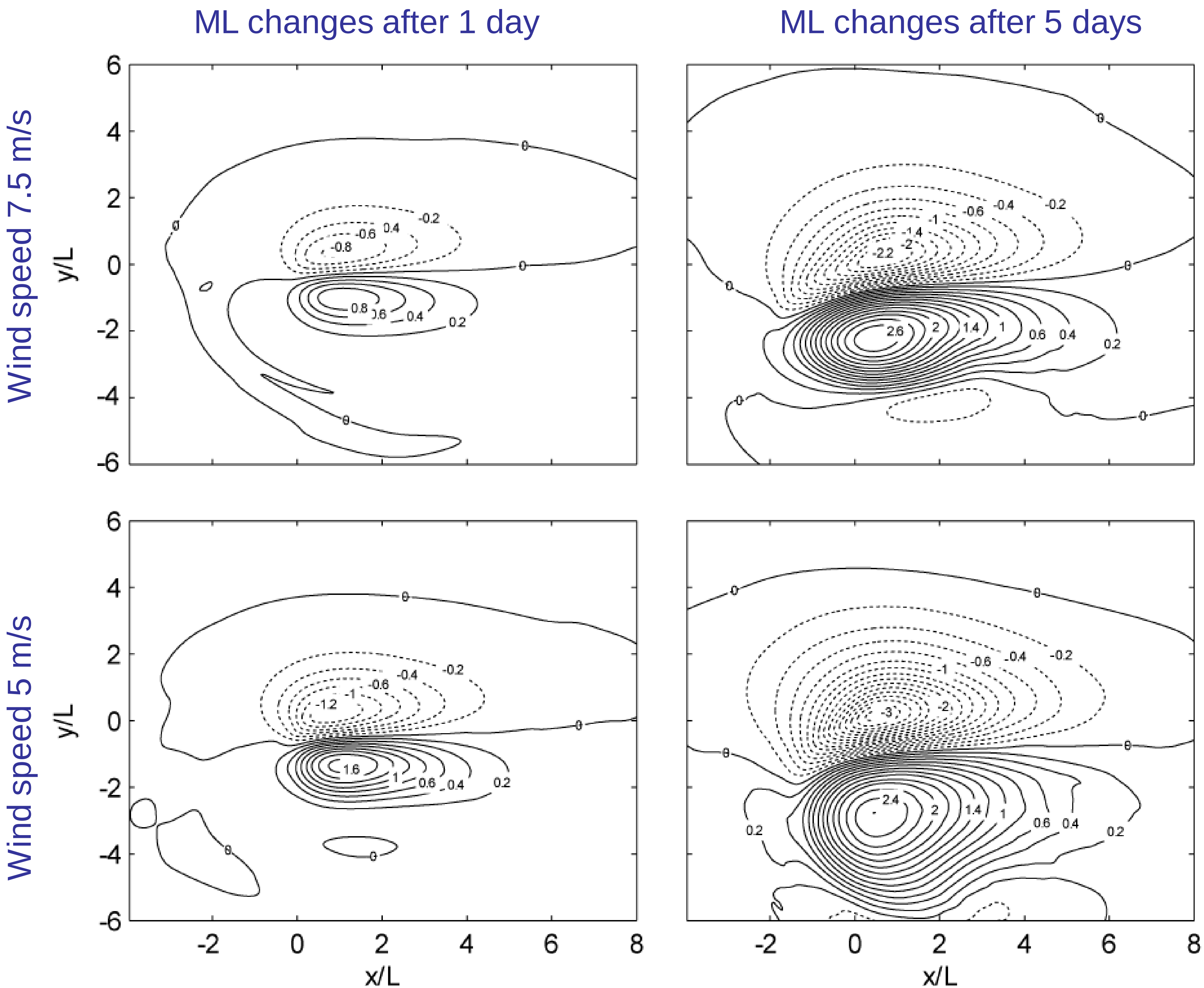
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
350
400
450
500
3
2
1
0
-1
-2
-3

Example of the disturbance in ML thickness, and current vectors of the disturbance from the wind farm (wind=7.5 m/s and *t*=3 days)





2
1
0
-1
-2
-3
-4
-5
-2
-1
0
1
2
3
4
5
3
2
1
0
-1
-2
-3



ML changes after 1 day
ML changes after 5 days
Wind speed 7.5 m/s
Wind speed 5 m/s
y/L
y/L
x/L
x/L

Strong response in ocean since wind wake size is comparable to internal radius of deformation (Internal Rossby radius).

Shallow water equations:

$$\frac{\partial U}{\partial t} - fV = -g' h_0 \frac{\partial h}{\partial x} + \frac{1}{\rho}\tau_x,$$

$$\frac{\partial V}{\partial t} + fU = -g' h_0 \frac{\partial h}{\partial y} + \frac{1}{\rho}\tau_y,$$

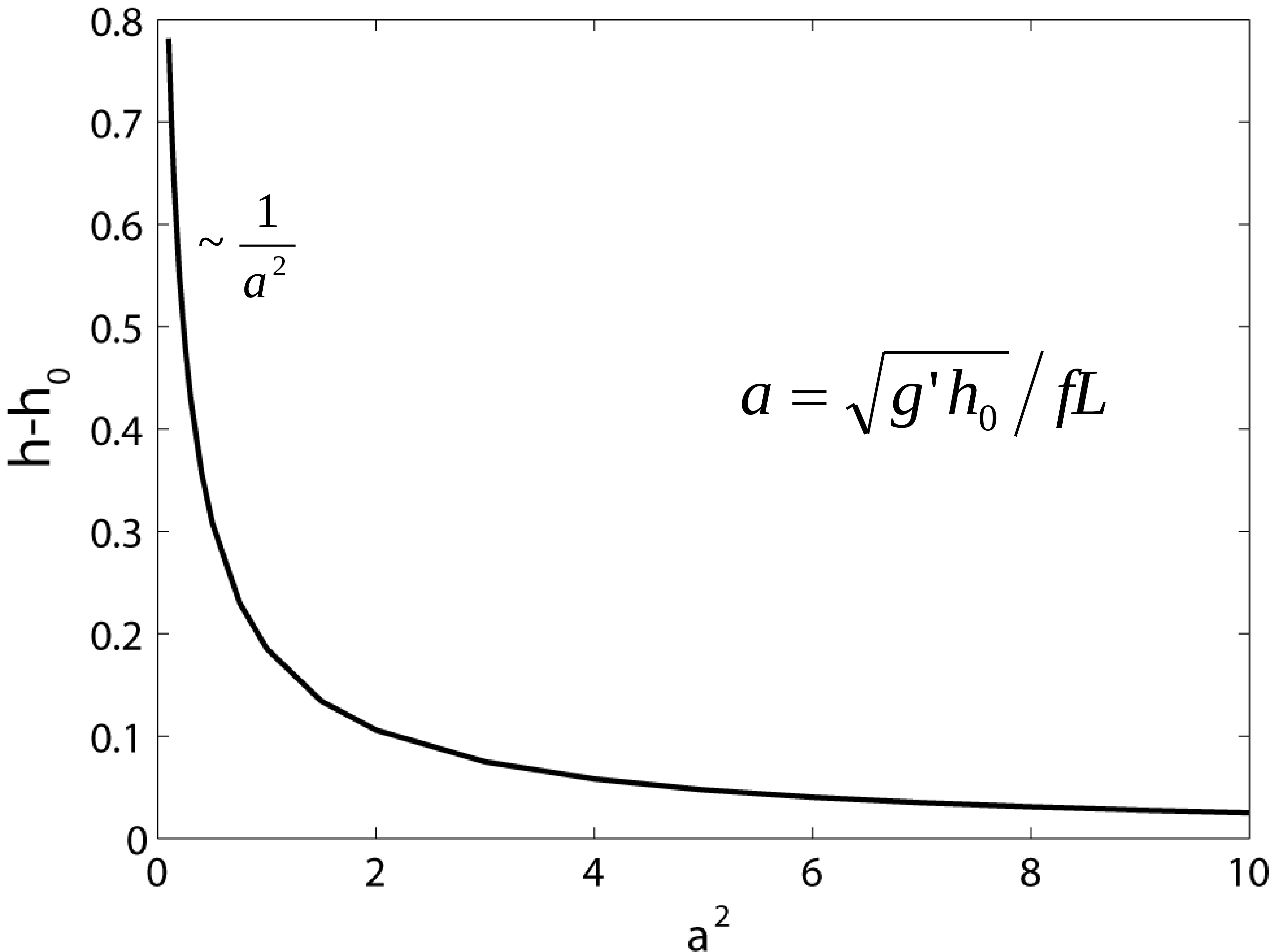
$$\frac{\partial h}{\partial t} + \left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right) = 0,$$

Gives for time scales of order f^{-1}:

$$\frac{\partial}{\partial t}\left[f^2 h - \nabla \cdot \left(g h_0 \nabla h\right)\right] = -\frac{f}{\rho}\mathrm{curl}(\boldsymbol{\tau}) - \frac{1}{\rho}\frac{\partial}{\partial t}\nabla \cdot \boldsymbol{\tau}$$

Non-dim:

$$\frac{\partial}{\partial t}\left(h - a^2 \nabla^2 h\right) = -\mathrm{curl}\left(\frac{\boldsymbol{\tau}}{\Delta \tau}\right) \qquad a = \sqrt{g' h_0} \Big/ fL$$



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
h-h$_0$
~ $\frac{1}{a^2}$
$a = \sqrt{g' h_0} / fL$
0
2
4
6
8
10
a^2

Guesstimating the response

$$\Delta h \propto t L^3 \Delta \tau$$

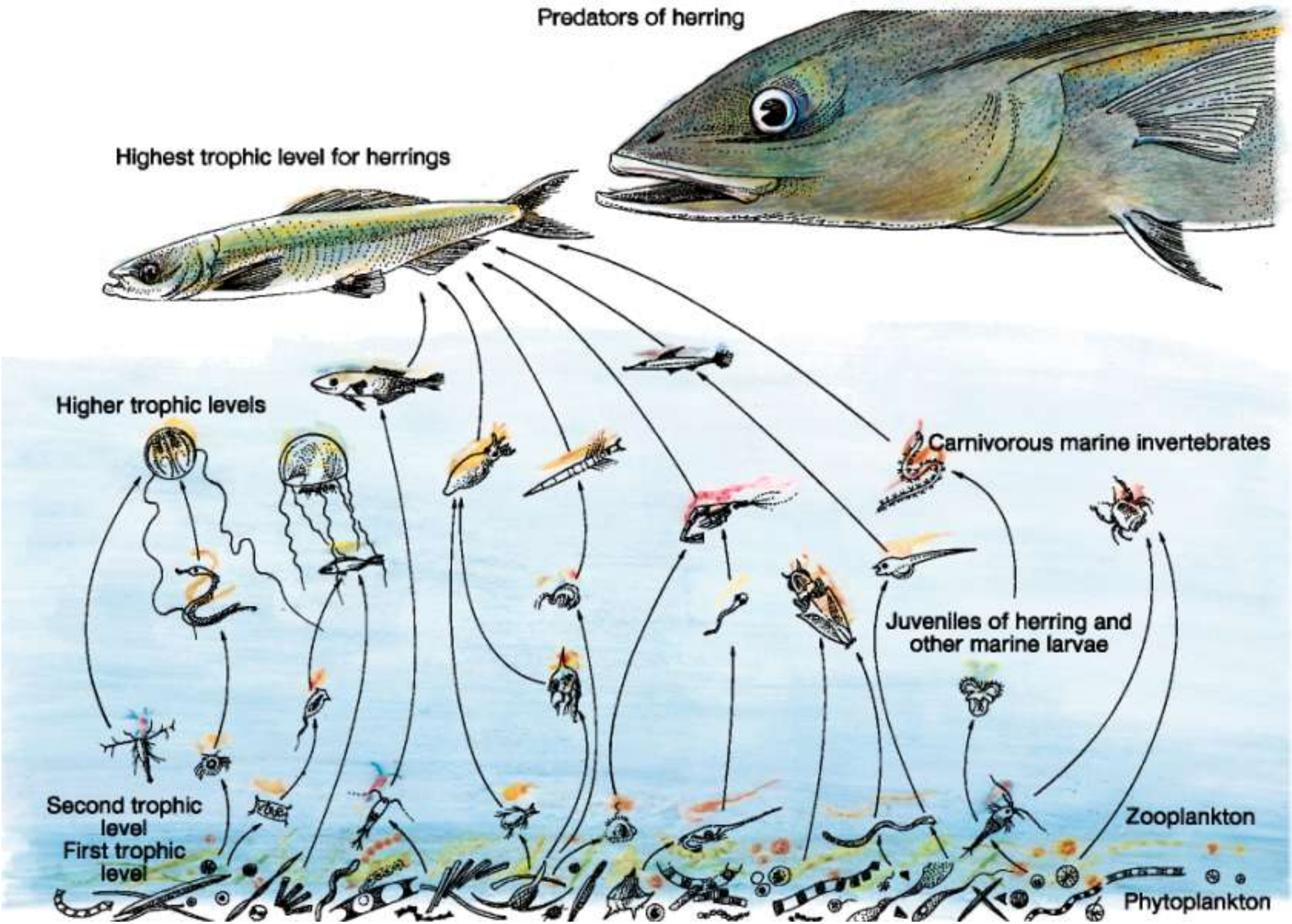
L=5 km,
t=24 h,
Wind=7.5 m/s
($\Delta\rho$=2 kg/m^3)

Total upwelling: $2 \cdot 10^8$ m^3/day
NO_3=10 mmol/m^3: 160 ton biomass C/day
Fish (1% tropic efficiency): 8 ton (herring) /day

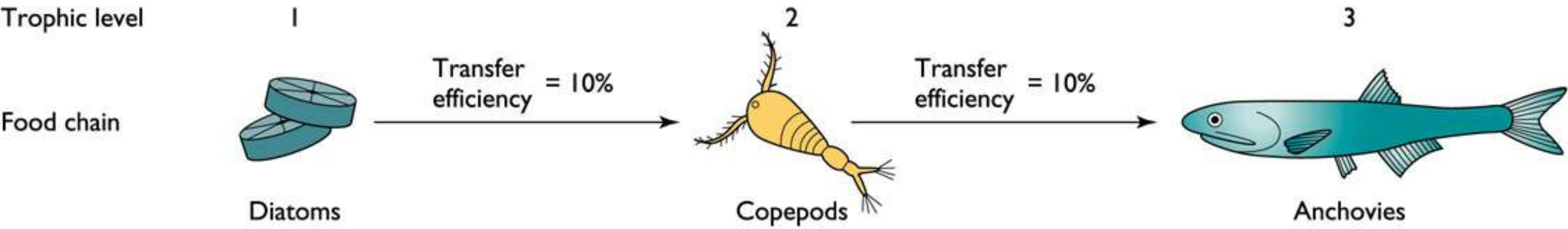
L=10 km,
t=24 h,
Wind=7.5 m/s
($\Delta\rho$=2 kg/m^3)

Total upwelling: $16 \cdot 10^8$ m^3/day
NO_3=10 mmol/m^3: 1280 ton biomass C/day
Fish (1% tropic efficiency): 64 ton (herring) /day

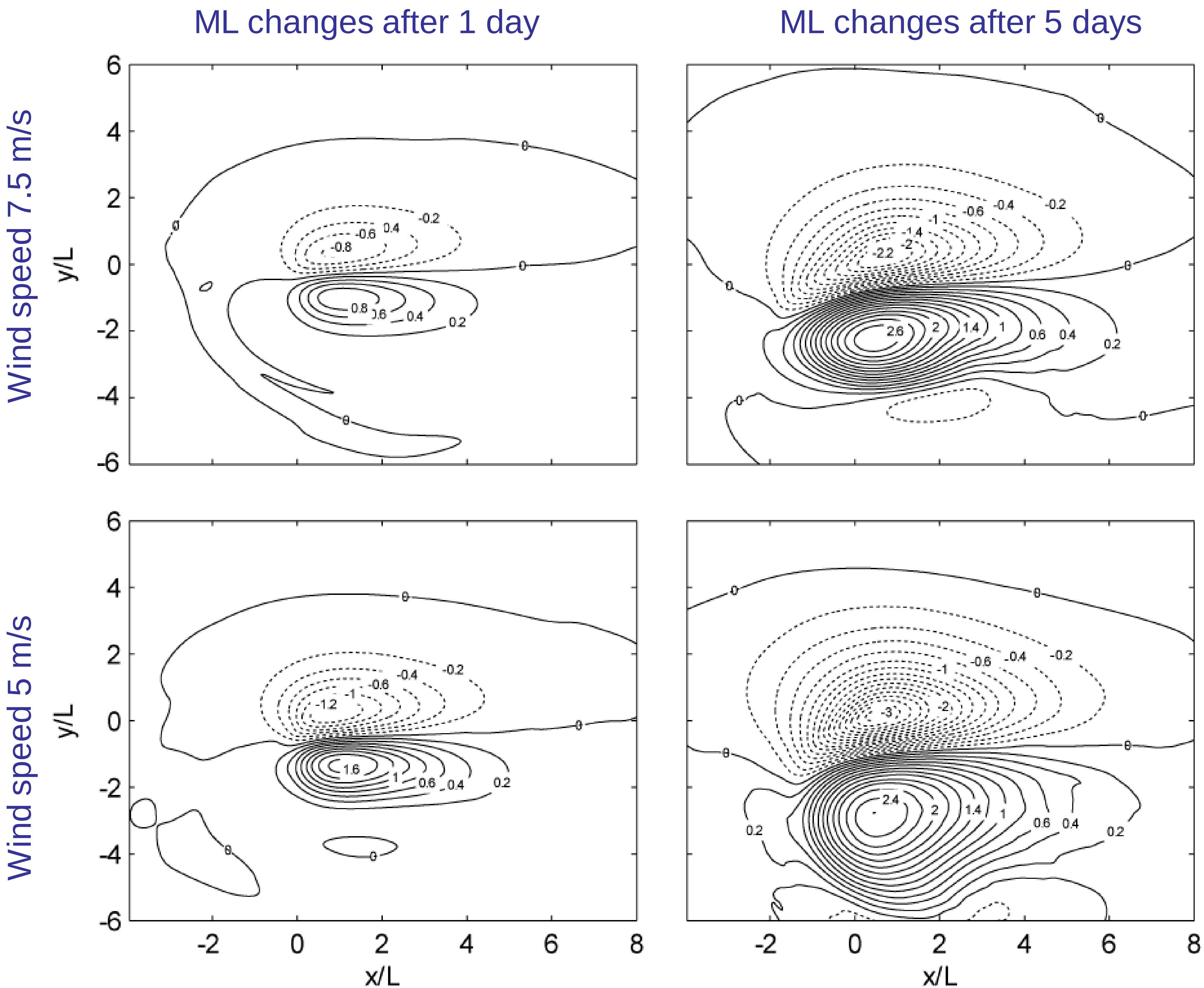
Herring Food Web



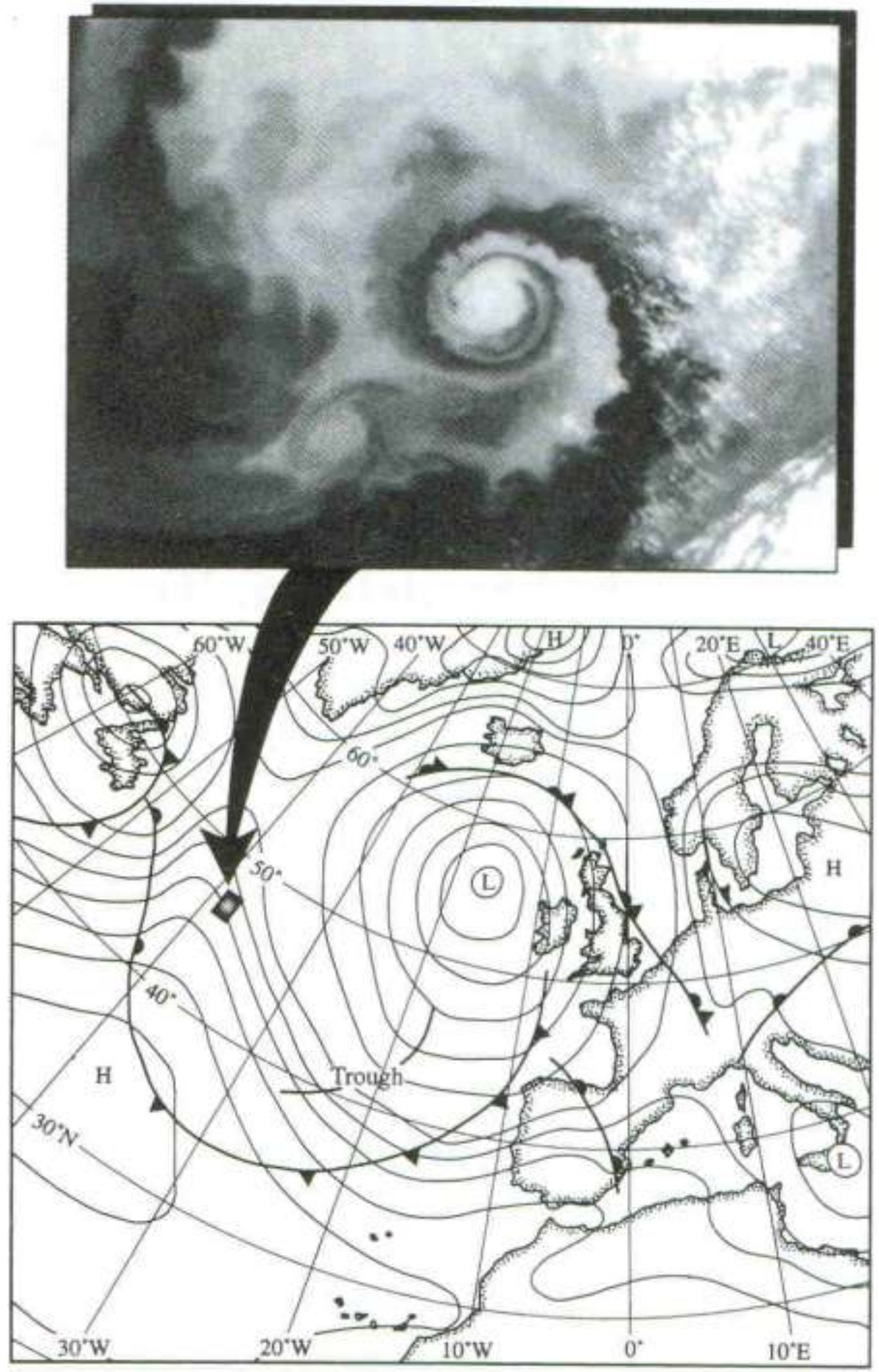
Data from R. and M. Buchsbaum, Basic Ecology. Boxwood Press, Pacific Grove, CA

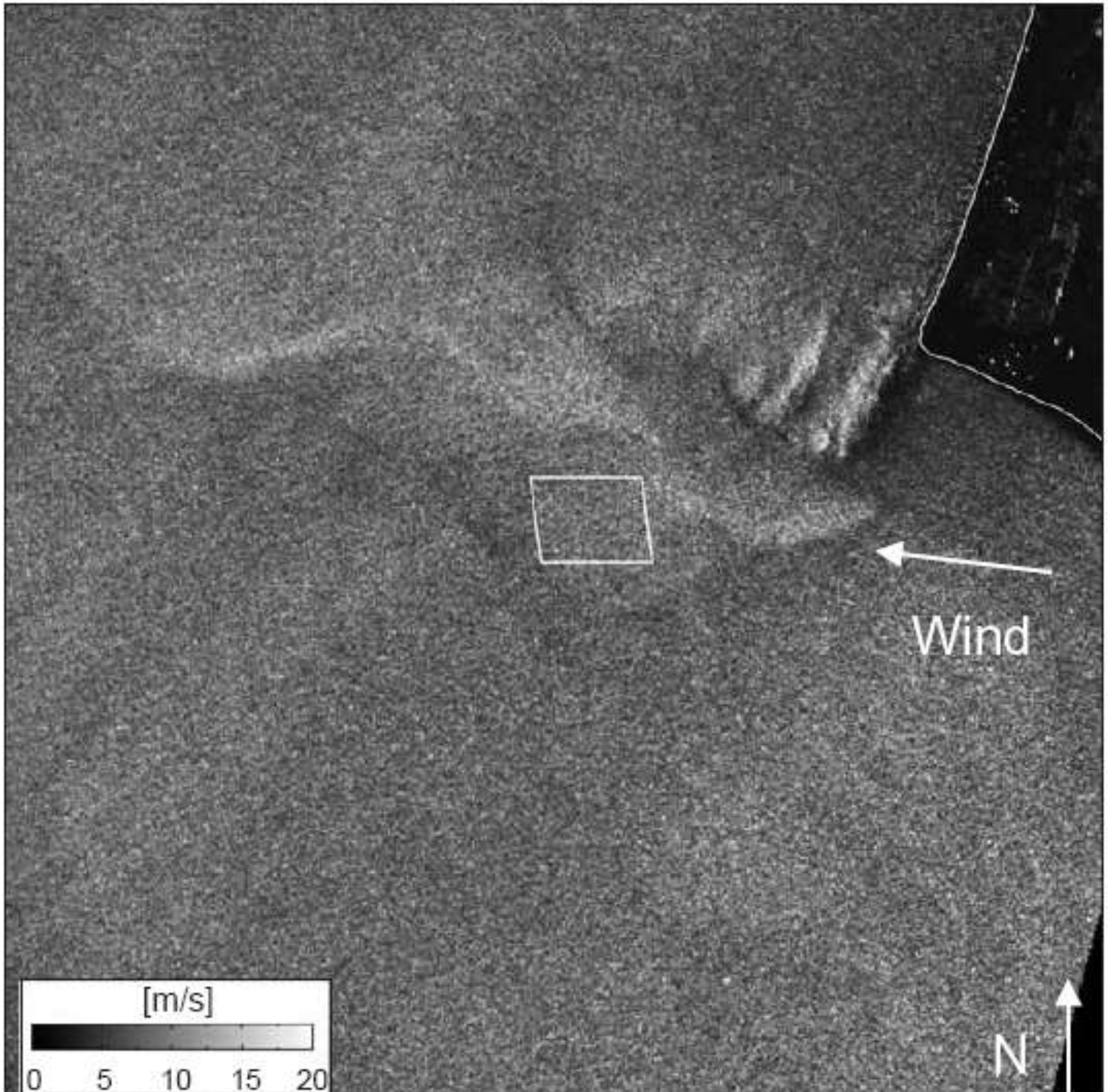


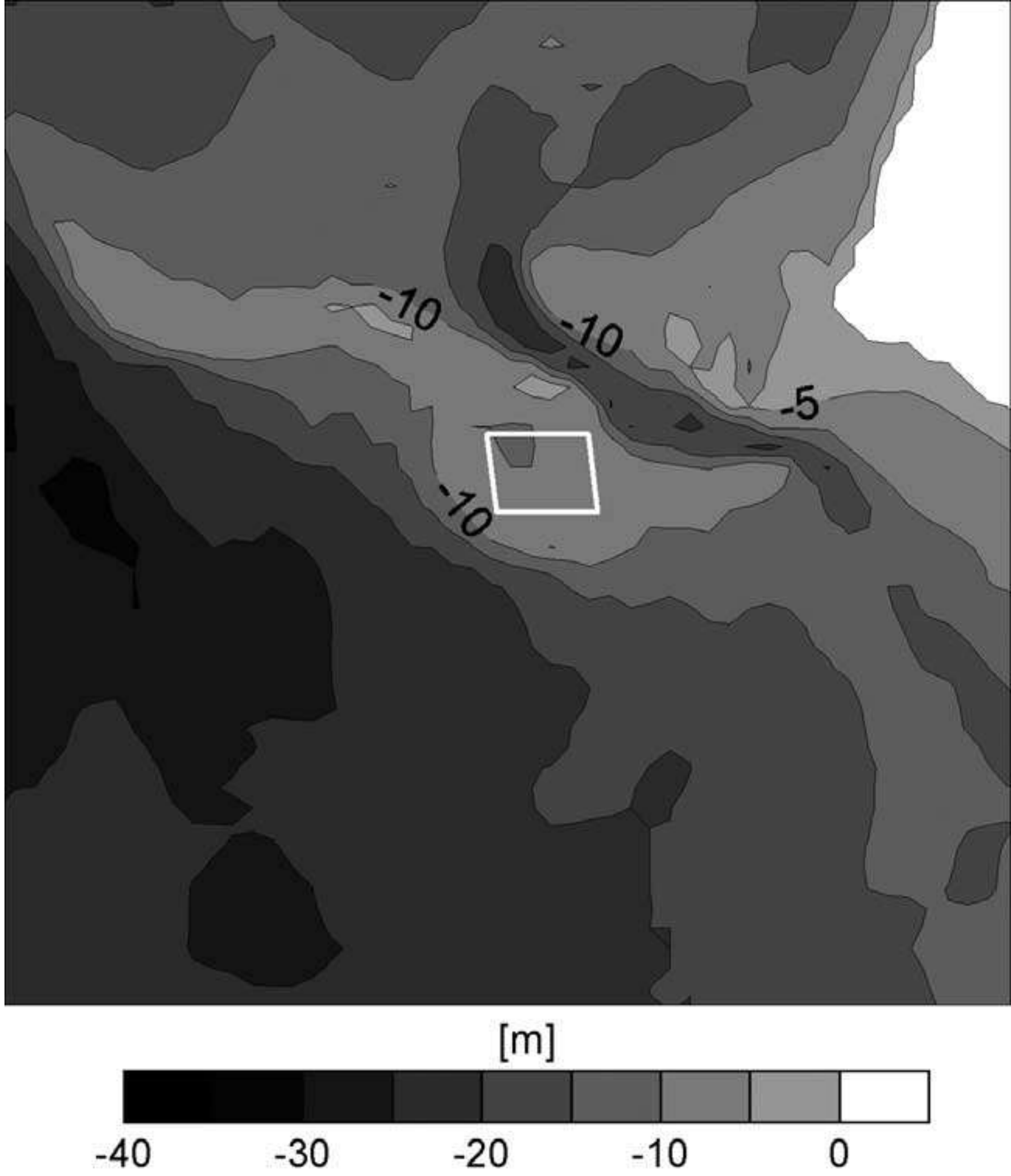
Primary production 100 g C/m²/yr	×	Area 10^8 m²	×	Transfer efficiency (across two trophic levels) 0.1 X 0.1 = 0.01	=	Anchovy production 10^8 g C/yr or 10^2 mt C/yr


ML changes after 1 day
ML changes after 5 days
Wind speed 7.5 m/s
Wind speed 5 m/s
y/L
x/L
6
4
2
0
-2
-4
-6
8

Atmosfärens lågryck
och havets virvlar:
Dynamiskt samma sak
men helt olika!




Wind
[m/s]
0 5 10 15 20
N



-10
-10
-5
-10
[m]
-40
-30
-20
-10
0

Impact on atmosphere

Results from a large wind farm in the US midwest:: Located on a position with a strong nocturnal jet.

Scenario1: Only wind influence

Scenario 2: influence on both wind and turbulent kinetic energy (mixing)

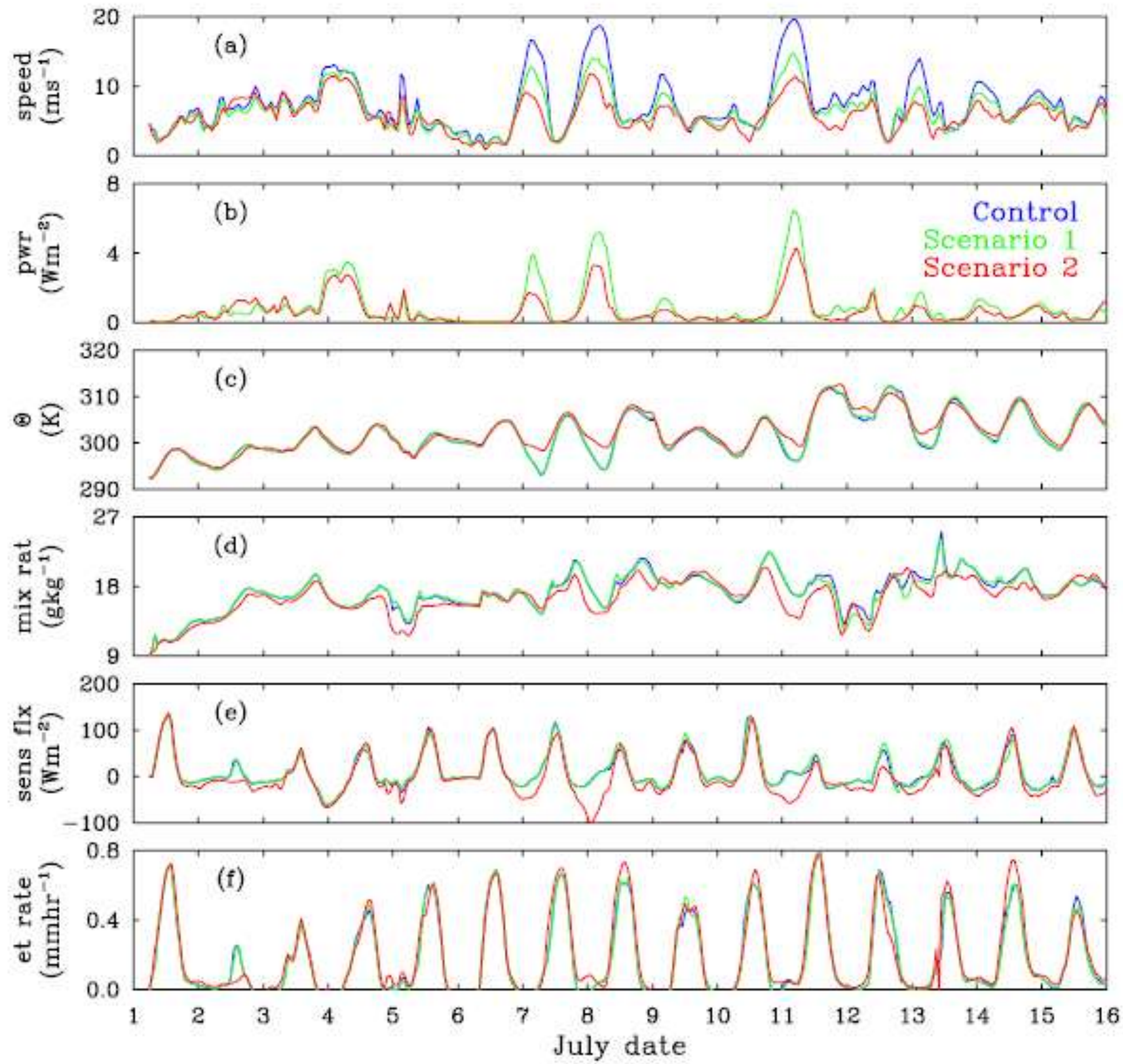
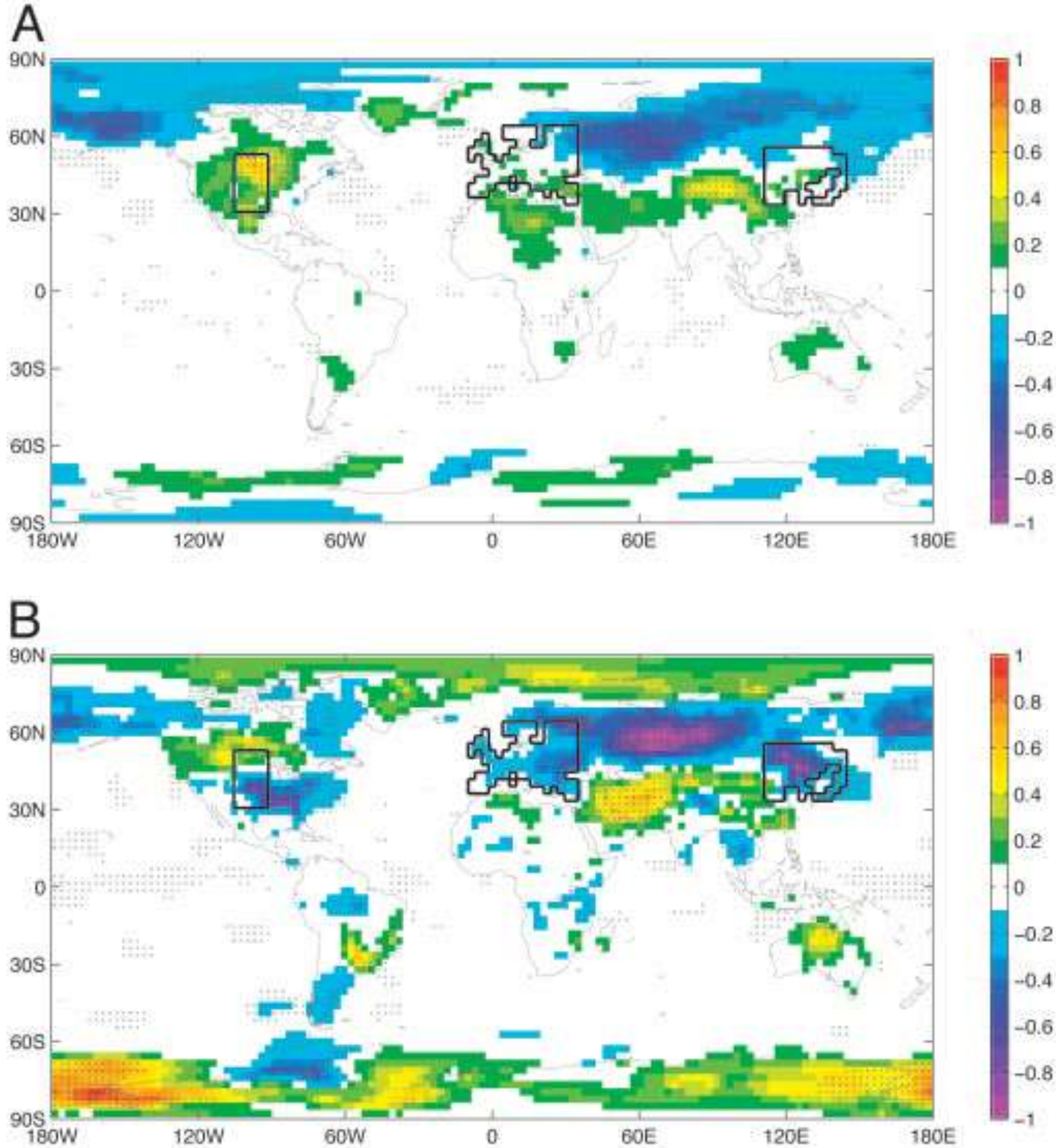


Figure 3. Time series of (a) hub-height horizontal wind speed, (b) power extracted, (c) surface air θ, (d) total water mixing ratio, (e) surface sensible heat flux, and (f) surface evapotranspiration rate over the wind farm.

Global effect on climate

These values were chosen to represent an array of wind turbines, 2.8 turbines per km^2, each with 100-m-diameter rotors and 100-m hubheights that remove 40% of kinetic energy of the resolved flow.

(about 2 TW wind energy)



A) NCAR model

B) GFDL model

Keith, D.W. et al., 2004. The influence of large-scale wind power on global climate. Proceeding of the National Academy of Science, 101: 16115-16120.

“climate” impact

- Broström, 2008, On the influence of large wind farms on the upper ocean circulation. Journal of Marine Systems,,
  - Potential strong affect on the upwelling in the ocean. Local current systems may be created.

- Baidya Roy, S. and Pacala, S.W., 2004. Can large wind farms affect local meteorology? Journal of Geophysical Research, 109: D19101, doi:10.1029/2004JD004763.
  - The local affect (within the farm) from large wind farms cannot be neglected.

- Rooijmans, P., 2004. Impact of a large-scale offshore wind farm on meteorology. Ms Thesis, Utrecht University, Utrecht.
  - Using large wind farms (100*90 km) he concluded that wind farms affect cloudiness and precipitation.

- Keith, D.W. et al., 2004. The influence of large-scale wind power on global climate. Proceeding of the National Academy of Science, 101: 16115-16120.
  - Global climate influence of continental scale wind farms

- Kirk-Davidoff, D.B., and Keith, D.W., 2008, On the climate impact of surface roughness anomalies. J. Atmos. Sci., 85, 2215-2234, doi:10.1175/2007JAS2509.1.
  - Studies how changes in roughness length impacts on the large scale circulation

- Barrie, D.B., and Kirk-Davidoff, D.B., 2009. Weather response to management of a large wind turbine array. Atmos. Chem. Phys. Discuss., 9, 2917-2913.
  - Discuss the possibility to control weather by managing the wind farm. State that it should be possible to invoke control on some aspects of weather.