Wind Energy Resource Limits in Giant Wind Farms

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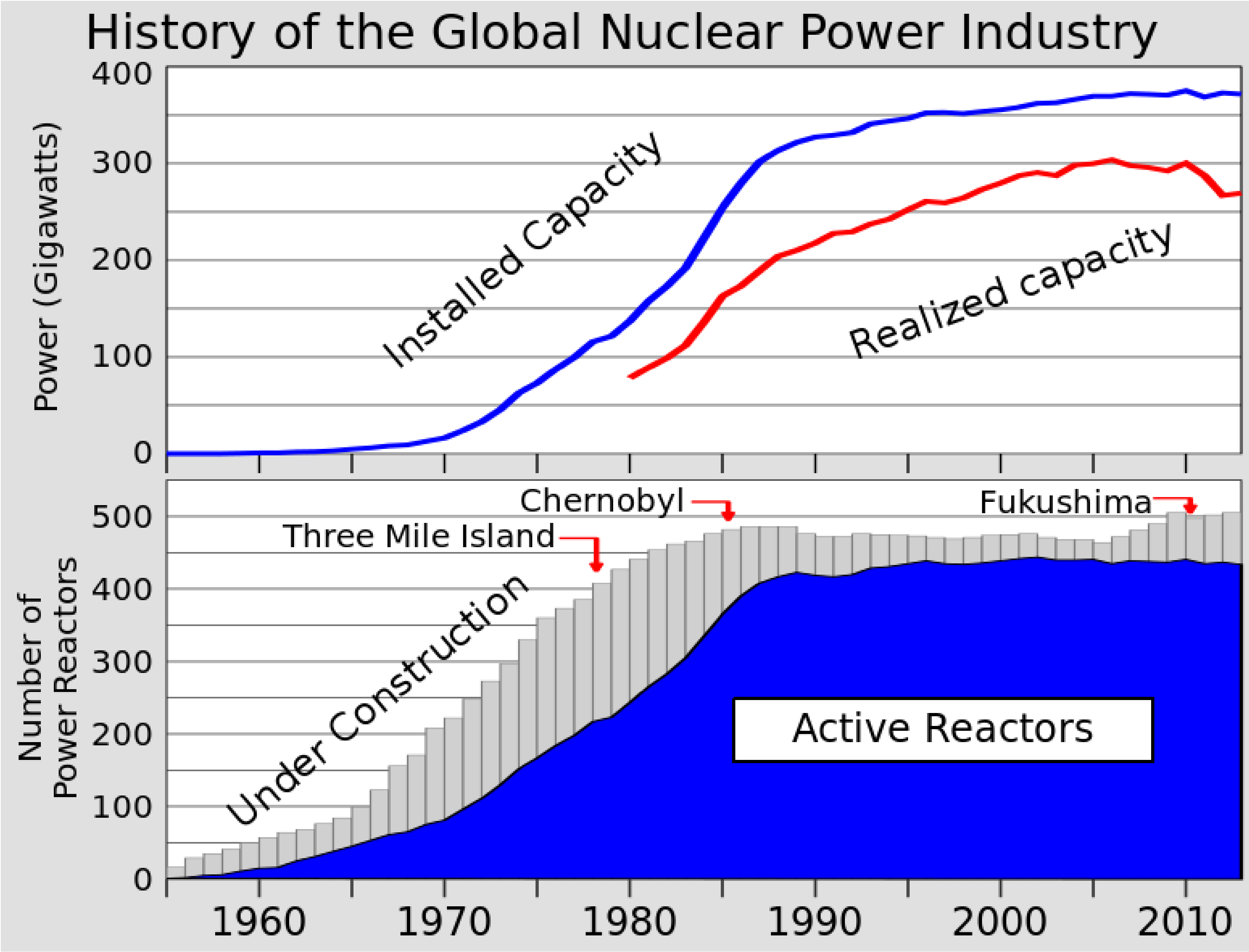
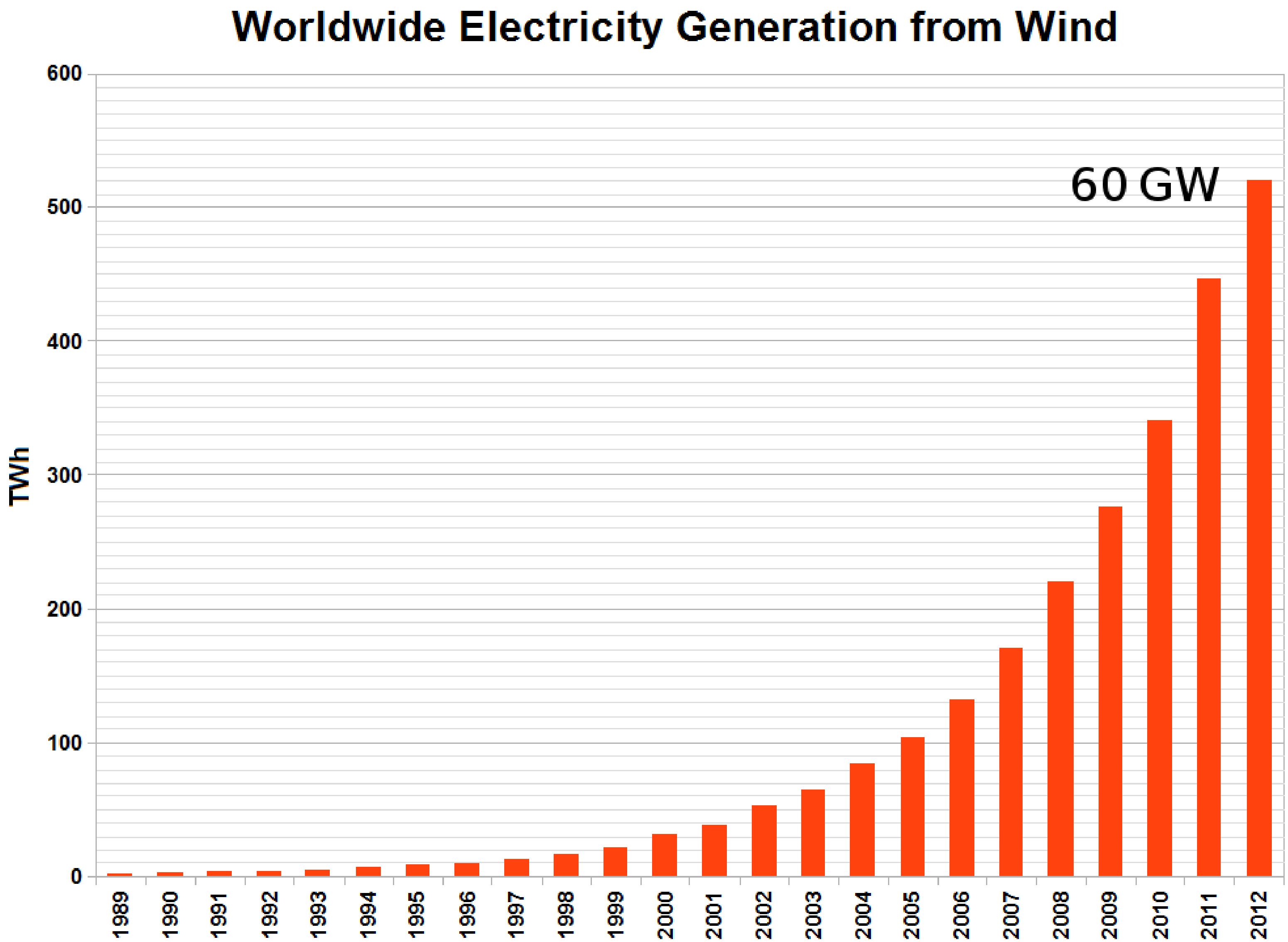
Prof. Brian H. Fiedler

School of Meteorology, University of Oklahoma

A few power *units* and *facts* for this seminar:

- $1\ \mathrm{GW} \;=\; 10^9\ \mathrm{W} \;=\; 1$ nuclear power plant
- 1 American $= 10,000\ \mathrm{W}$
- Projected 2050 world human population:
  10×10^9 people
- Projected energy consumption:
  2.5×10^9 Americans $= 25,000\ \mathrm{GW}$
- Equivalent to deploying a nuclear power plant *every day*, and decommissioning after 70 years.


History of the Global Nuclear Power Industry
Power (Gigawatts)
400
300
200
100
0
Installed Capacity
Realized capacity
Number of Power Reactors
500
400
300
200
100
0
Chernobyl
Three Mile Island
Fukushima
Under Construction
Active Reactors
1960
1970
1980
1990
2000
2010

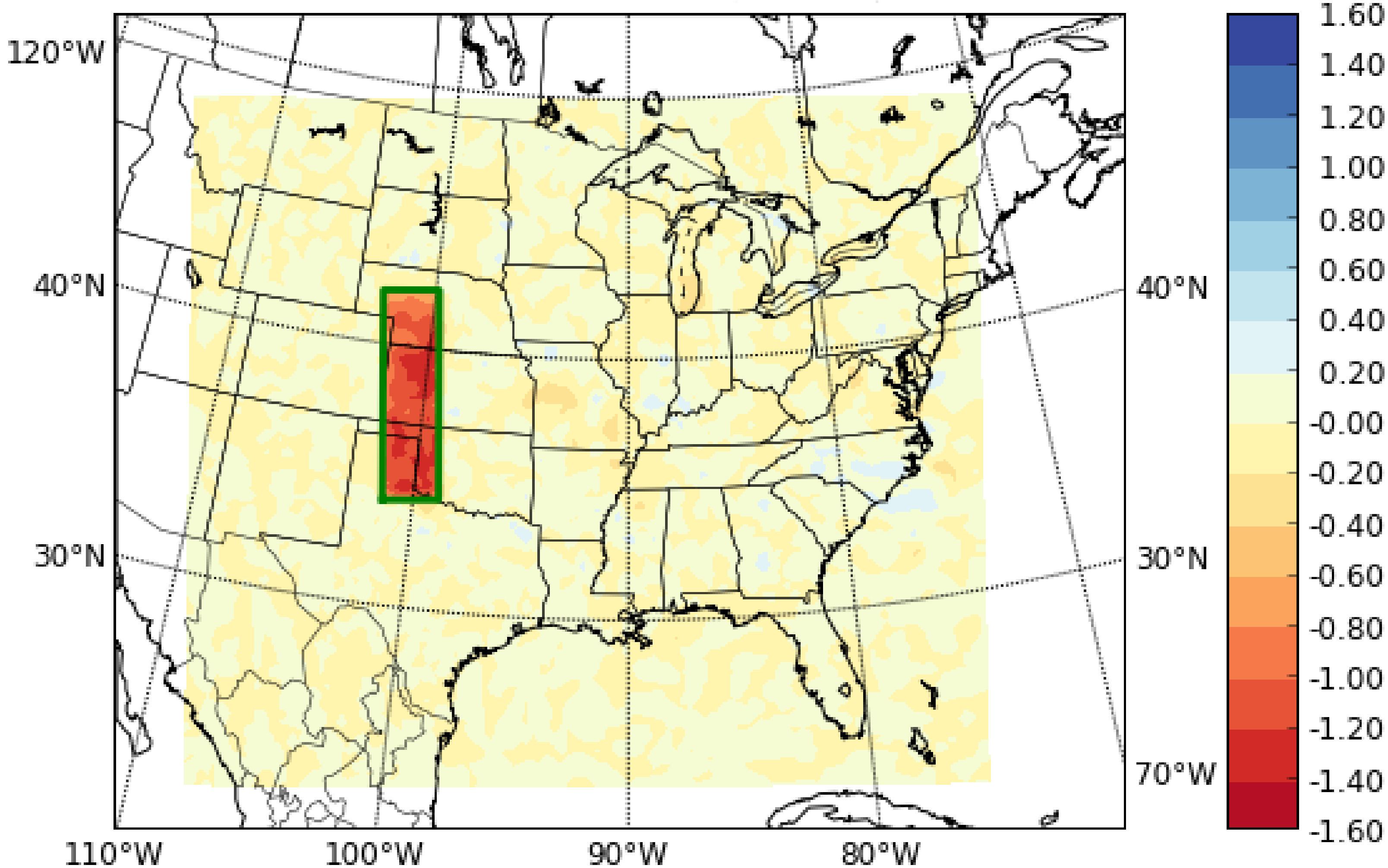


peak German + Japanese **Nuclear** Production was 49 GW

- Civilization needs more energy
- Perhaps atmospheric models can help optimize wind farm design
- I will show you simulations of 16 different turbine deployments in a giant wind farm
- Simulations are with WRF, over 8 days in May

A giant wind farm simulation with WRF, 8 days in May

Wind at 102 m (near blade top) decreases from 7 to 6 $\mathrm{m\ s^{-1}}$



$228,375$ turbines, 2.0 MW capacity, 1.25 turbines per km^2

2.5 $\mathrm{W\ m^{-2}}$ capacity density, 457 GW capacity, $\boxed{66\ \mathrm{GW}\ \textbf{production}}$

Wind farm parameterization:

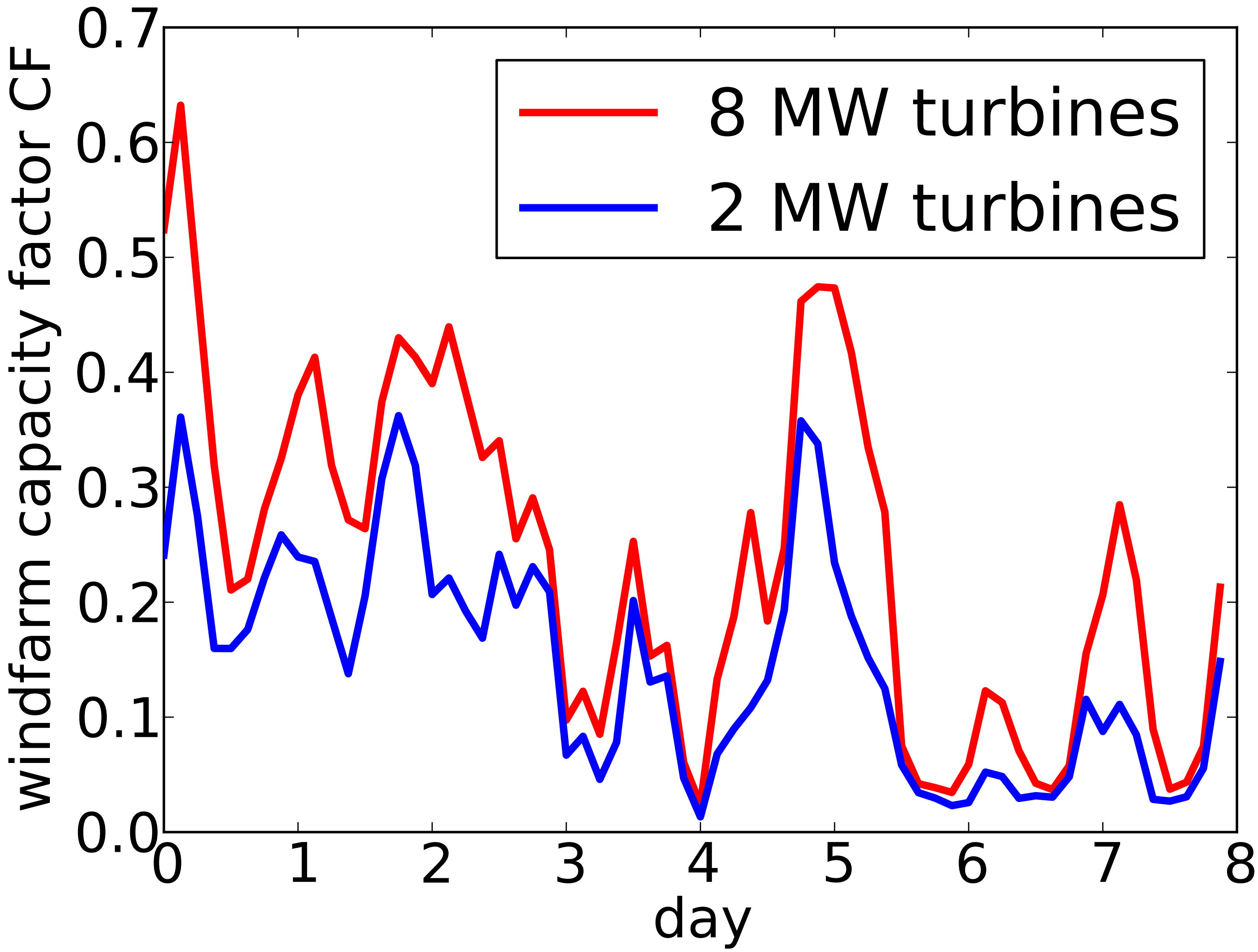
Elevated sub-grid disks.

Two simulations with $2.5\ \mathrm{W\ m^{-2}}$ capacity:

Tall $8\ \mathrm{MW}$ turbines. Production $= 106\ \mathrm{GW}$, $0.58\ \mathrm{W\ m^{-2}}$

Short $2\ \mathrm{MW}$ turbines. Production $= 66\ \mathrm{GW}$, $0.36\ \mathrm{W\ m^{-2}}$

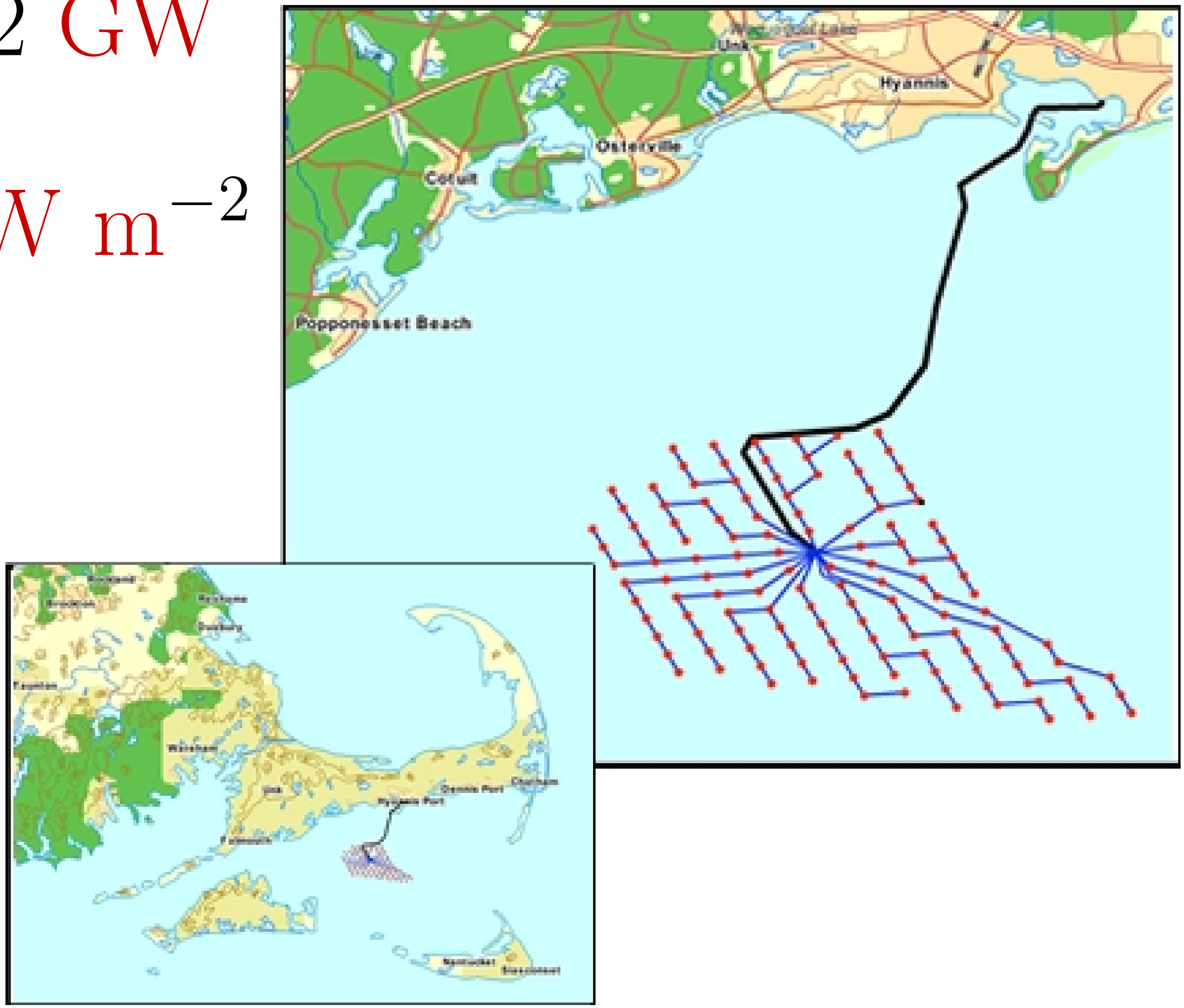
. . . taller is better



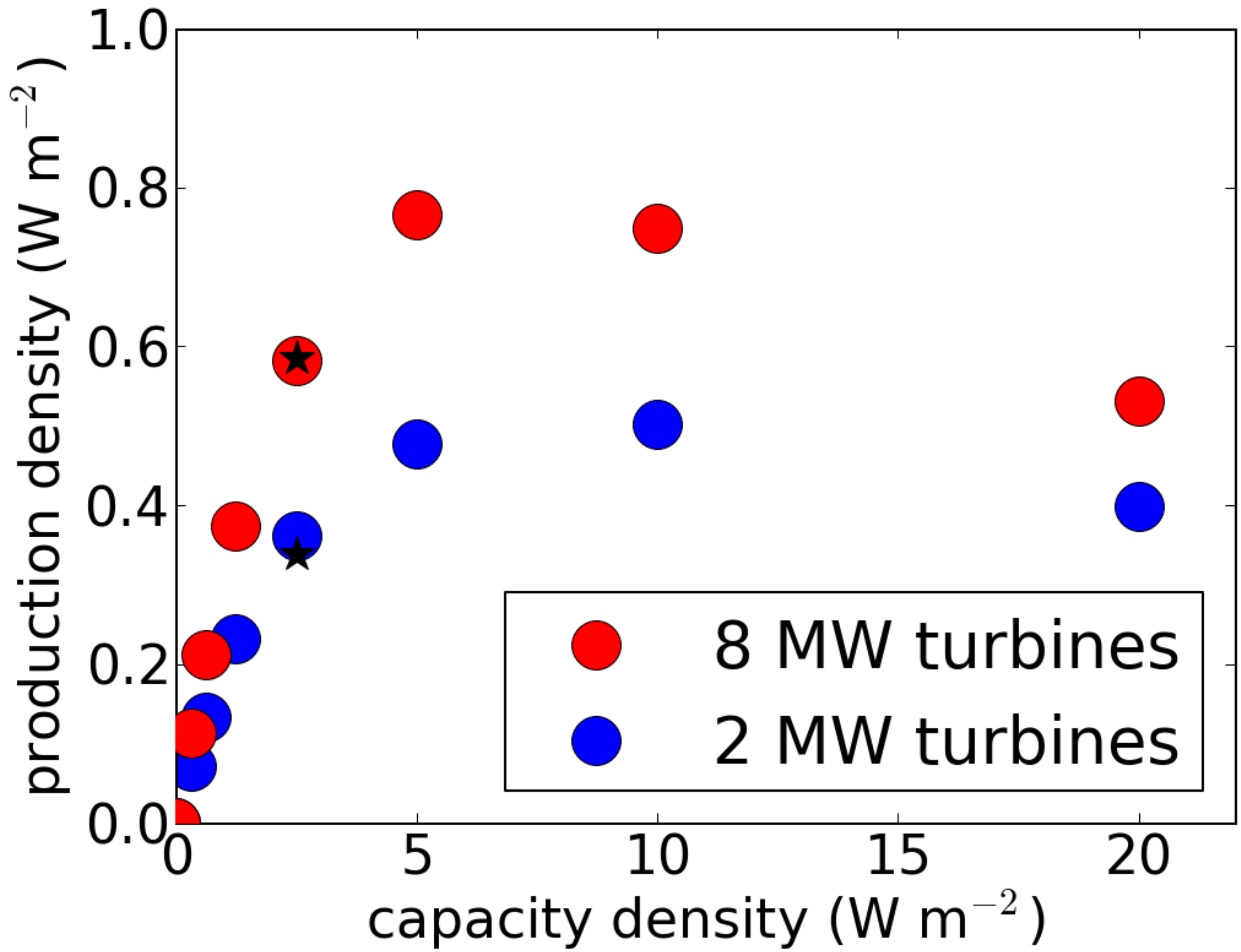
Cape Wind (if ever completed) is hoped to produce:

0.172 GW

2.8 W m^{-2}



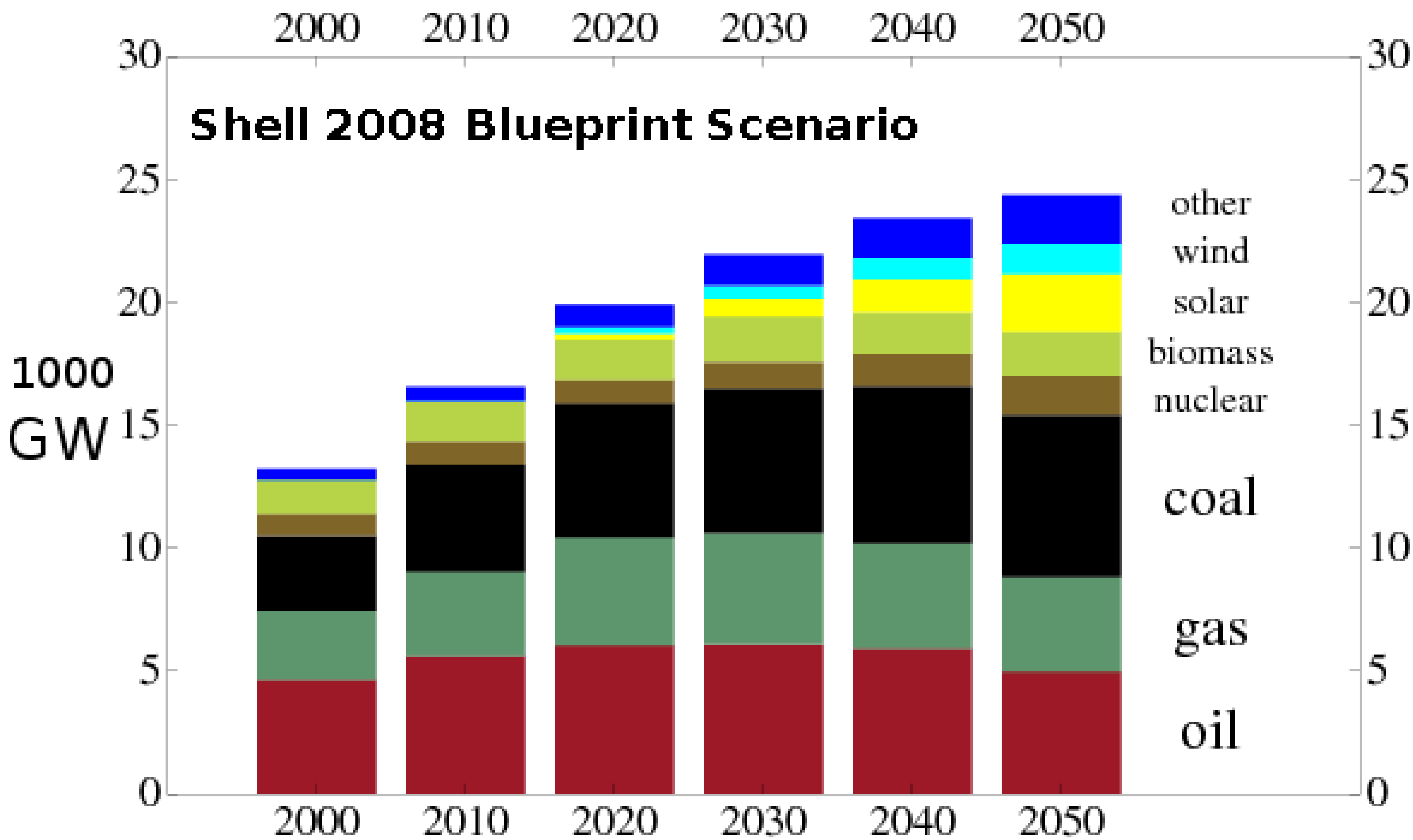
My most interesting figure:



(the $\star$ indicates double resolution simulations)

To meet Shell's modest projection for wind energy,

the world needs ~ 10 giant wind farms by 2030



Area of China is 10^7 km^2

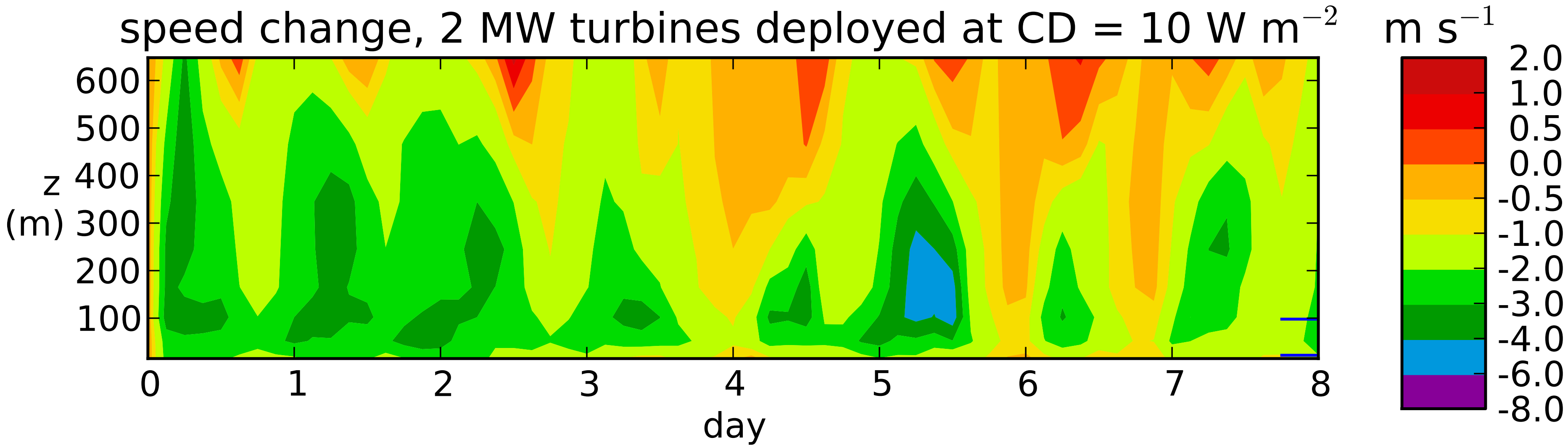
Equivalent of 25,000 nukes from wind:

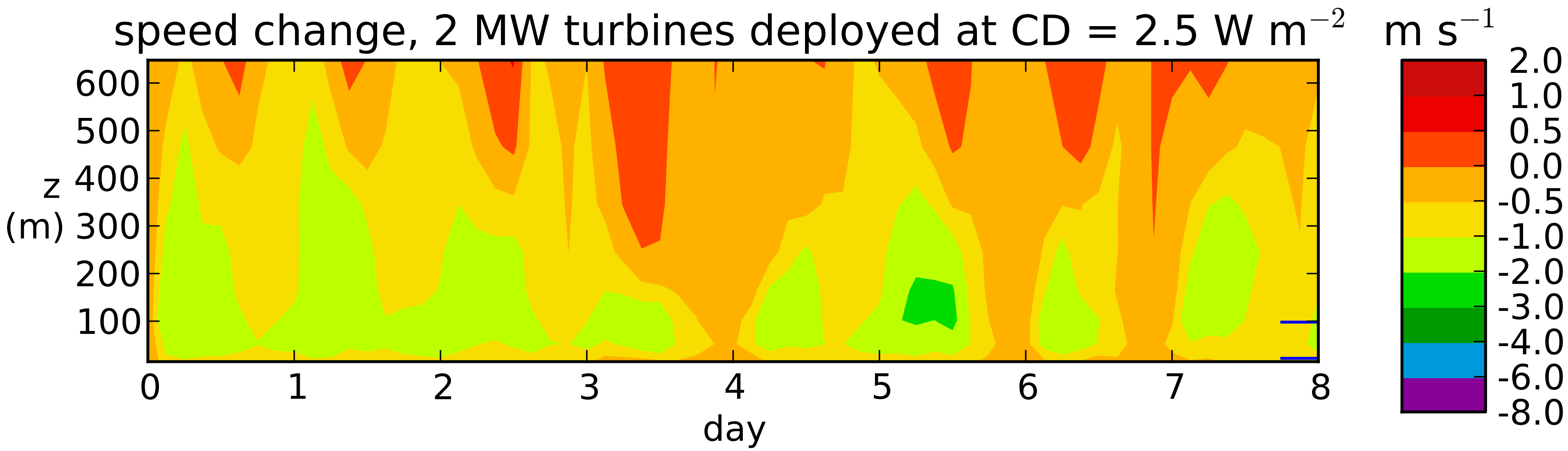
$$\frac{2.5 \times 10^{13}\ \mathrm{W}}{1.0\ \mathrm{W\ m^{-2}}} = 2.5 \times 10^7\ \mathrm{km^2}$$

Land area of Earth: $10^{14}\ \mathrm{m^2} = 10^8\ \mathrm{km^2}$

Projected 2050 human population: 10^{10} people

That gives $10^4\ \mathrm{m^2}$ (one hectare, two football fields) per human


speed change, 2 MW turbines deployed at CD = 10 W m^{-2}
m s^{-1}
z
(m)
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
day
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-6.0
-8.0


speed change, 2 MW turbines deployed at CD = 2.5 W m^{-2}
m s^{-1}
z
(m)
600
500
400
300
200
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0
1
2
3
4
5
6
7
8
day
2.0
1.0
0.5
0.0
-0.5
-1.0
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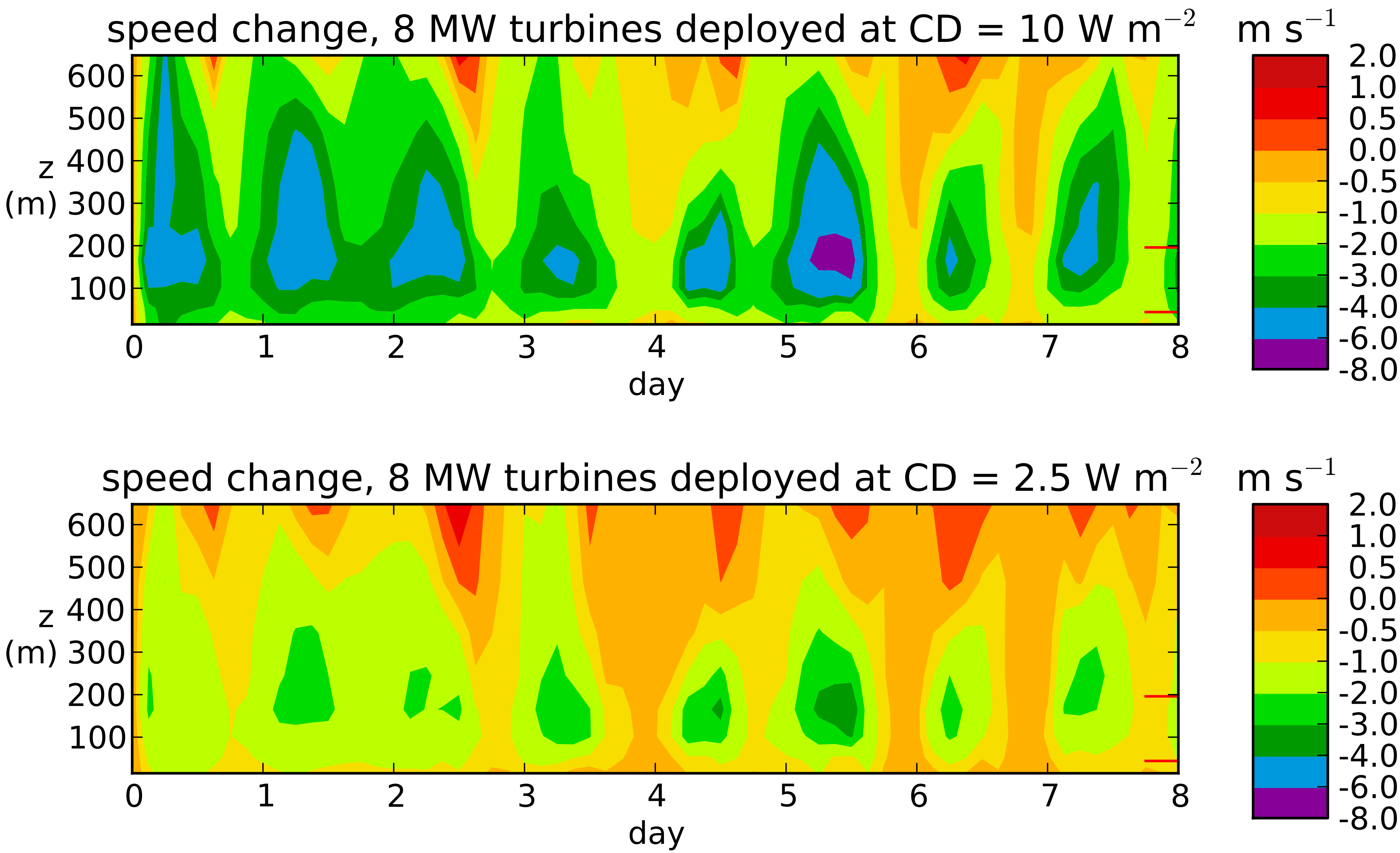
-3.0
-4.0
-6.0
-8.0


speed change, 8 MW turbines deployed at CD = 10 W m^{-2}
m s^{-1}
z (m)
day
2.0
1.0
0.5
0.0
-0.5
-1.0
-2.0
-3.0
-4.0
-6.0
-8.0
speed change, 8 MW turbines deployed at CD = 2.5 W m^{-2}
m s^{-1}
z (m)
day