Could crop roughness impact the wind resource at agriculturally productive wind farm sites?

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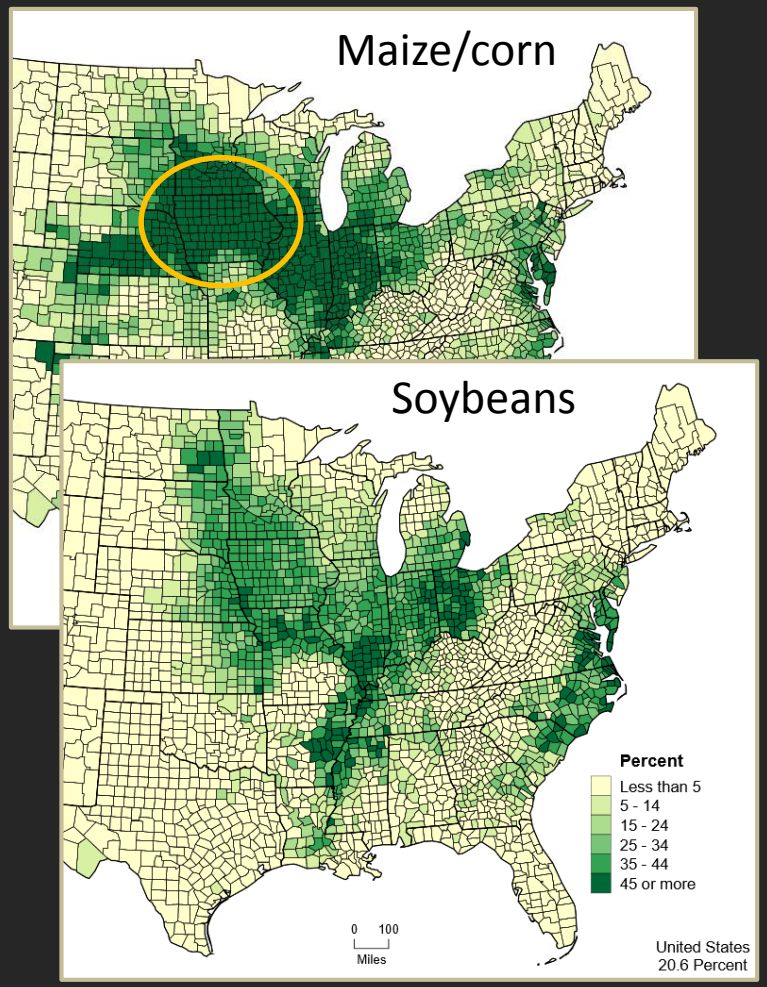
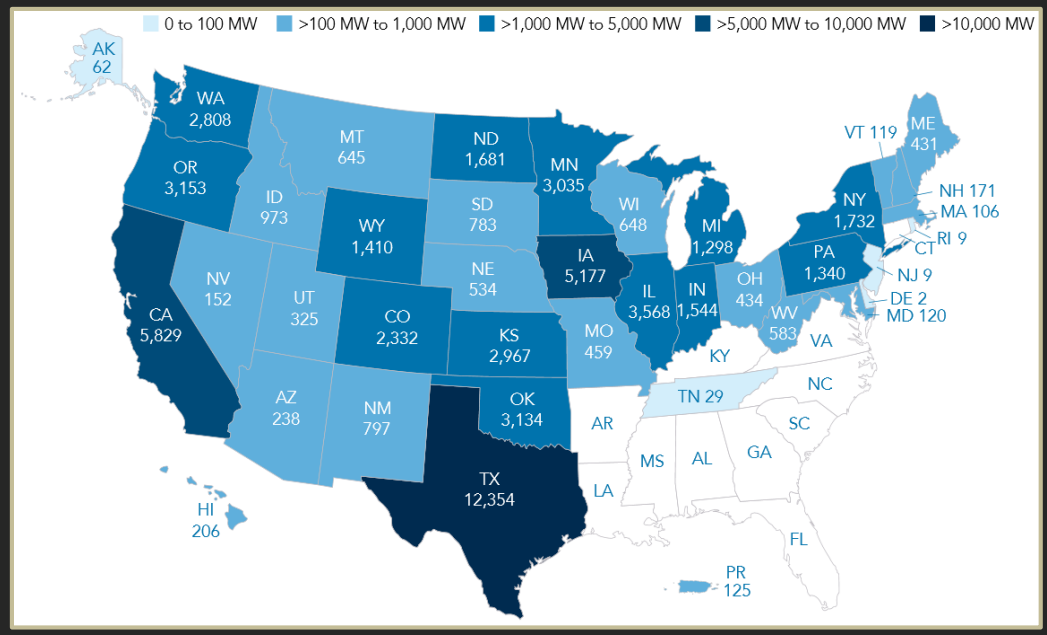
21st Symposium on Boundary Layers and Turbulence

Iowa is a center for both agriculture and wind power in the United States



2007 Census of Agriculture, U.S.D.A.



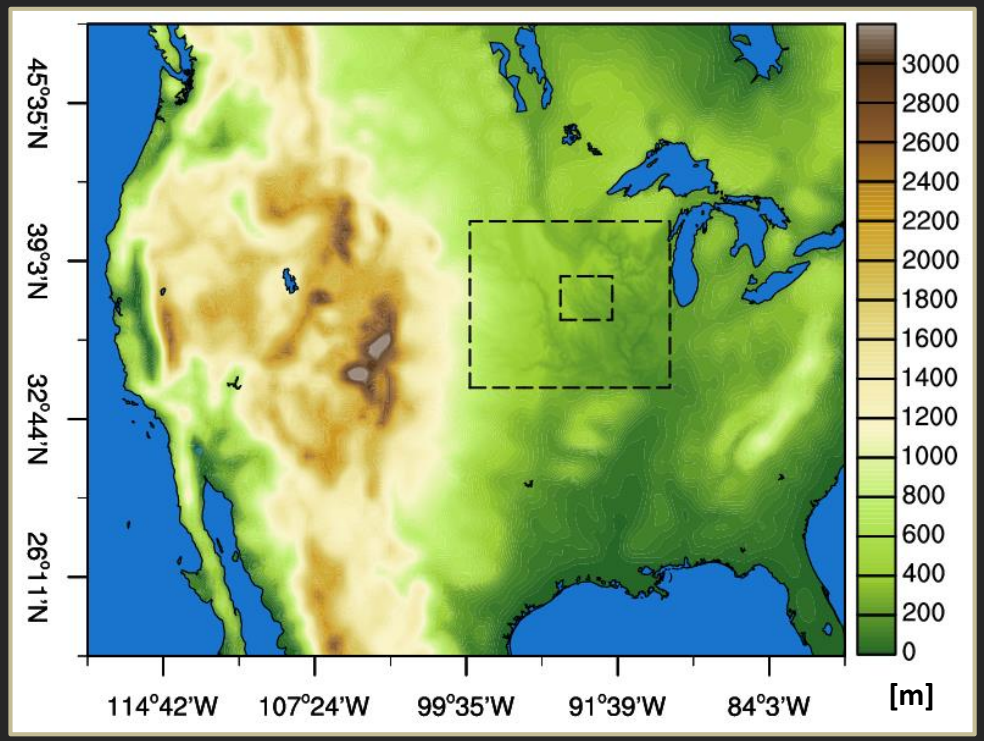
Q1 2014 U.S. Wind Power Capacity, AWEA

Can crop selection impact the power available to wind turbines aloft?

We use Weather Research and Forecasting model to study crop impact on winds

Common WRF settings

- Version 3.4.1 ARW
- Nested 1.25km domain
- 60 vertical levels
- RRTM/Dudhia radiation
- 6-class microphysics
- Noah land model
- ERA-Interim input data
- MYNN 2.5 PBL Scheme



Real conditions for 20-28 Aug 2013

Free-stream flow
Maize vs. Soybean

Wind plant present
Maize vs. Soybean

The effect of crop selection was represented using roughness lengths

Fully grown maize/corn

- Typical crop statistics:
  - Heights of 2 - 3 m
  - Seed density of 8 per m^2
- Davenport classification* roughness value of 25 cm

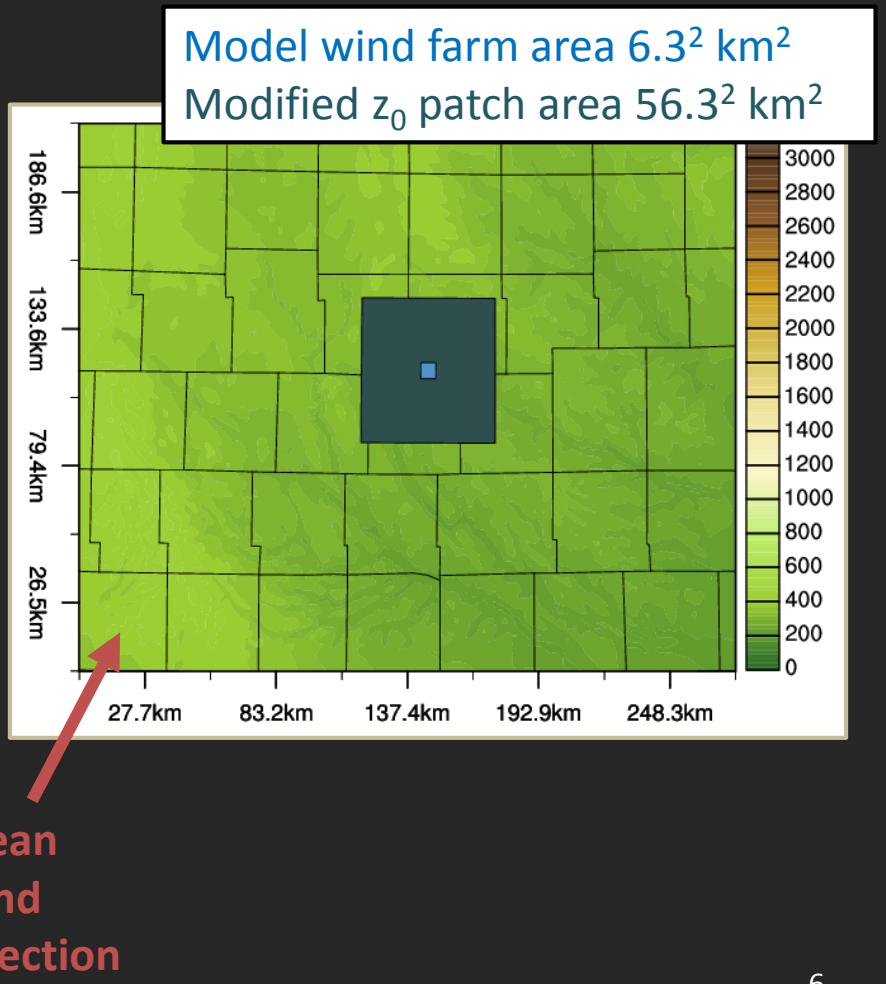
Fully grown soybeans

- Typical crop statistics:
  - Heights of 1 - 1.5 m
  - Seed density of 25-40 per m^2
- Davenport classification* roughness value of 10 cm

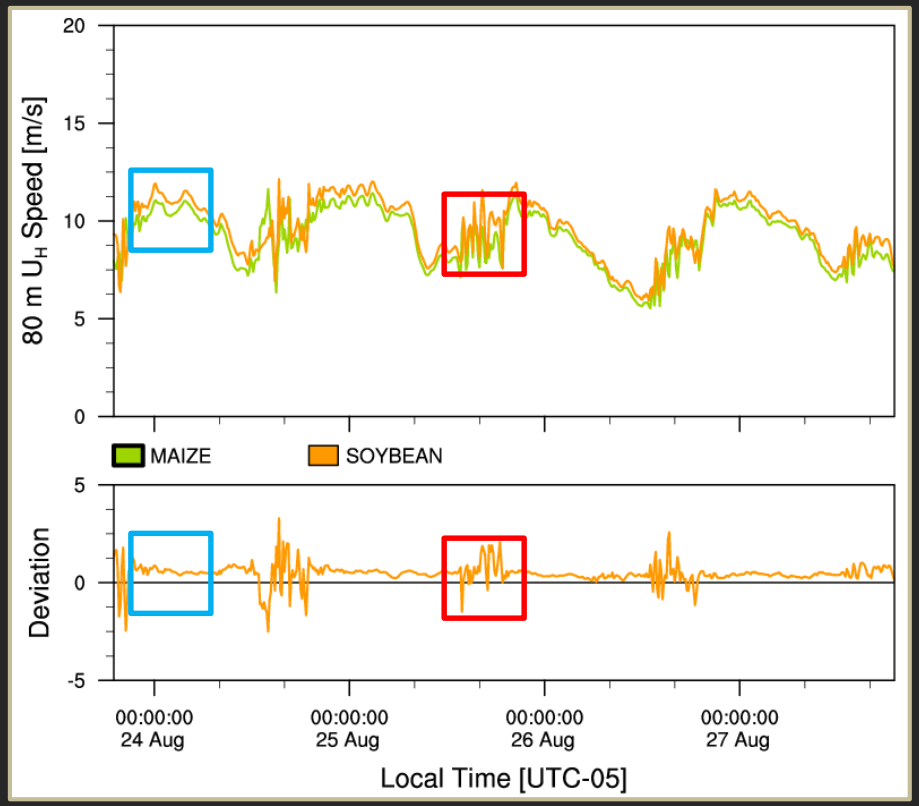
*using modified table from Davenport et al. 2000

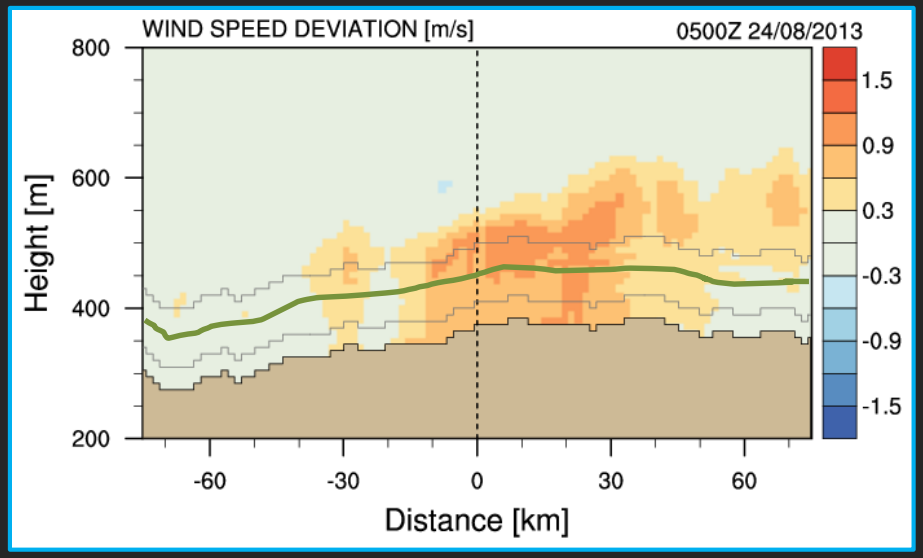
Size of roughness patch determined using boundary layer growth theory

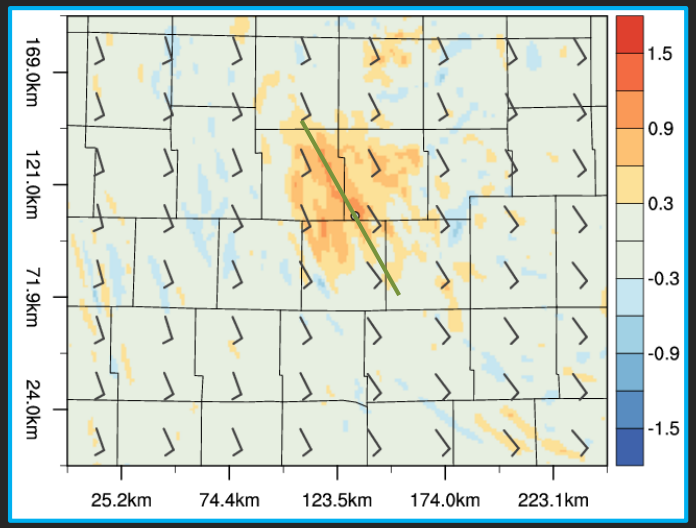
- Mason (1988) found the height of a z_0 influence scaled approximately as:
  - $H \sim 200L_c$
  - L_c = distance from roughness boundary
- Setting H to top of turbine rotor (125 m), L_c should be **25 km**



Crop selection through roughness produces moderate impact to winds

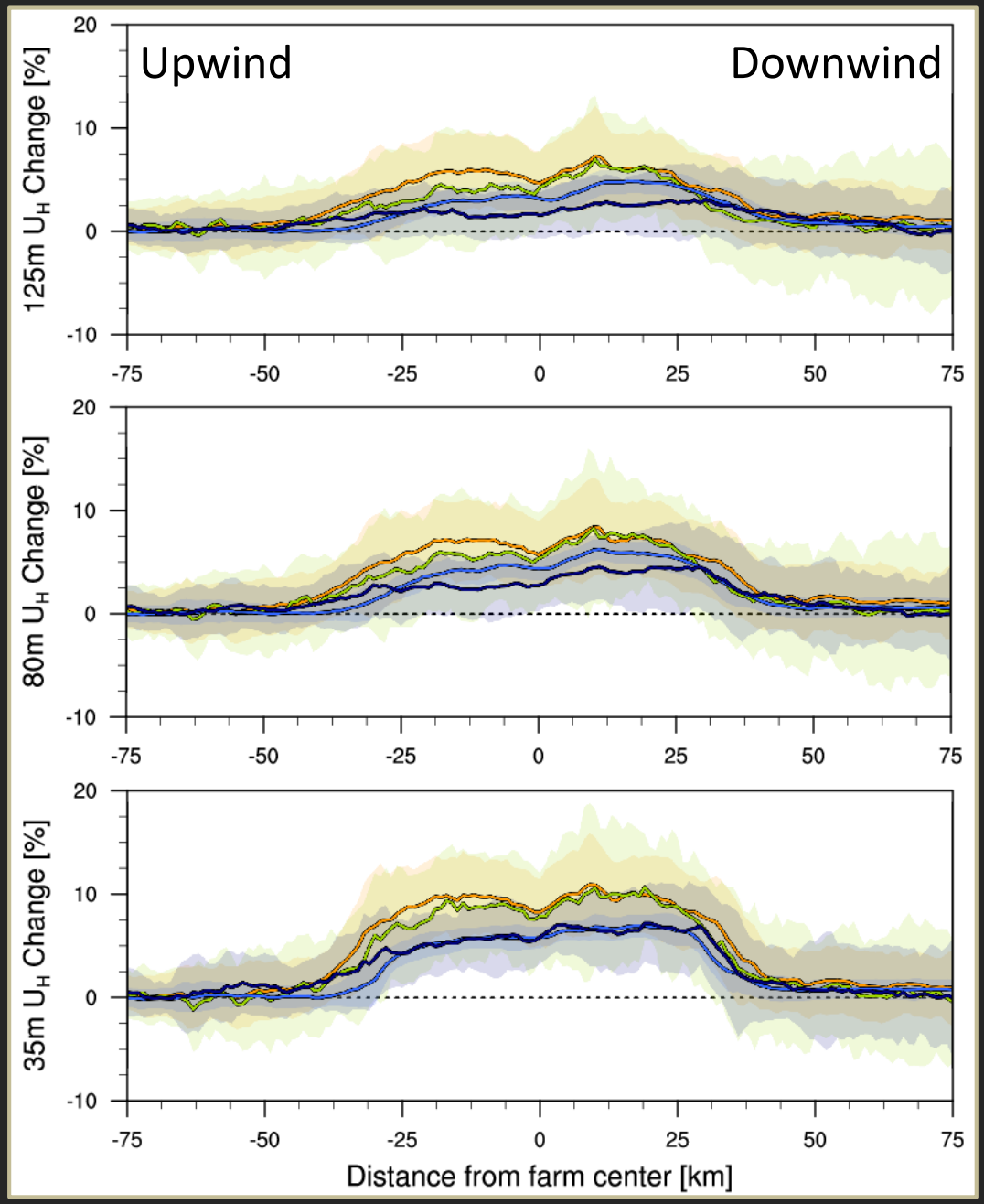






Response of wind field aloft varies significantly between day and night

Soy - maize average winds



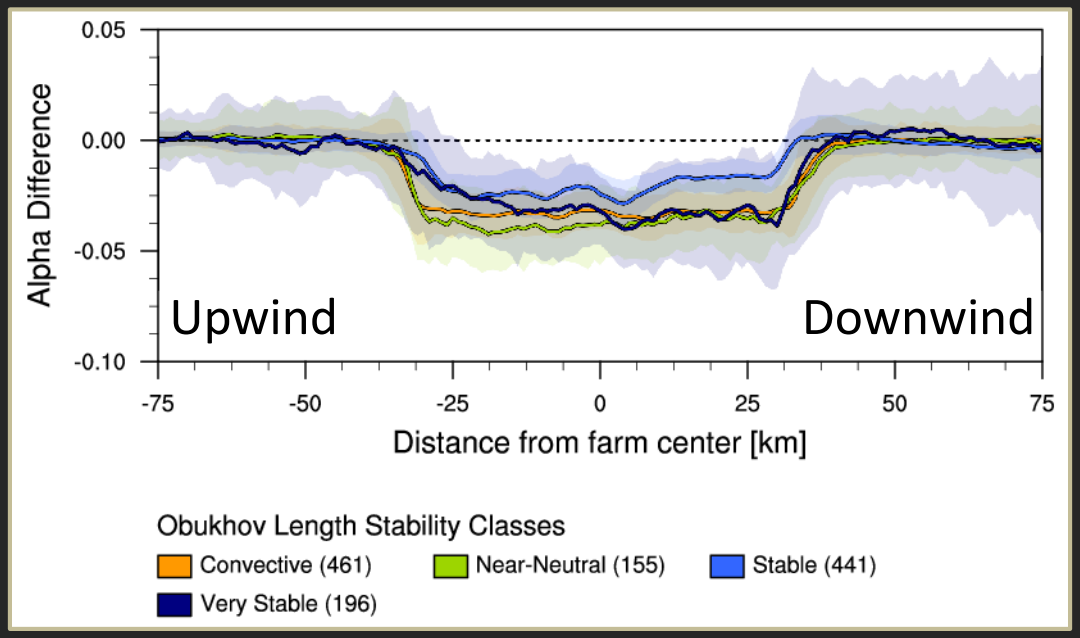
The effect of the roughness patch on winds decreases with increasing height and stability

Stability Class	Obukhov Length
Convective	L < 0
Near-neutral	L > 500, L < -500
Stable	75 < L < 500
Very stable	0 < L < 75

Based on classes from Gryning et al. 2007 and Wharton and Lundquist 2012

Sizeable reductions in simulated rotor disk shear due to crop change

Soy - maize average shear (α)

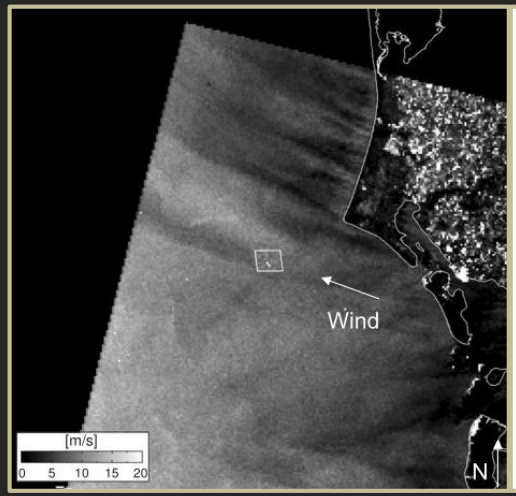


$$\frac{u_1}{u_0} = \left(\frac{z_1}{z_0}\right)^{\alpha}$$

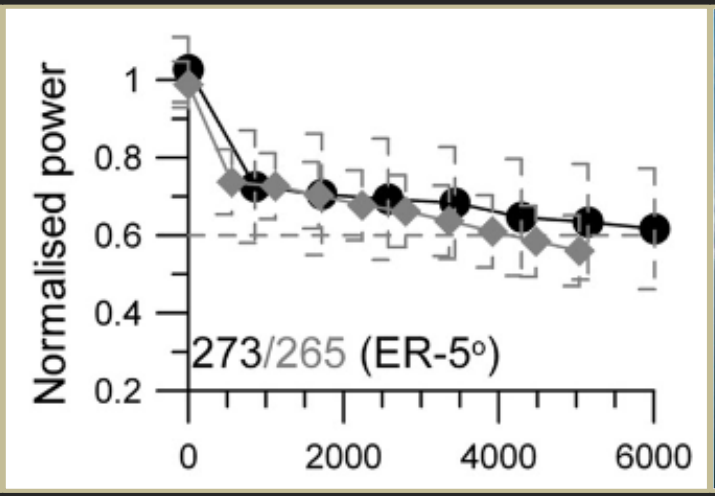
$z_0 = 35m, z_1 = 125m$

- Average α reduction is approximately 20% of IEC standard value (1/7)

Wind farms also impact the boundary layer momentum field



Christiansen and Hasager 2005



Barthelmie et al. 2010

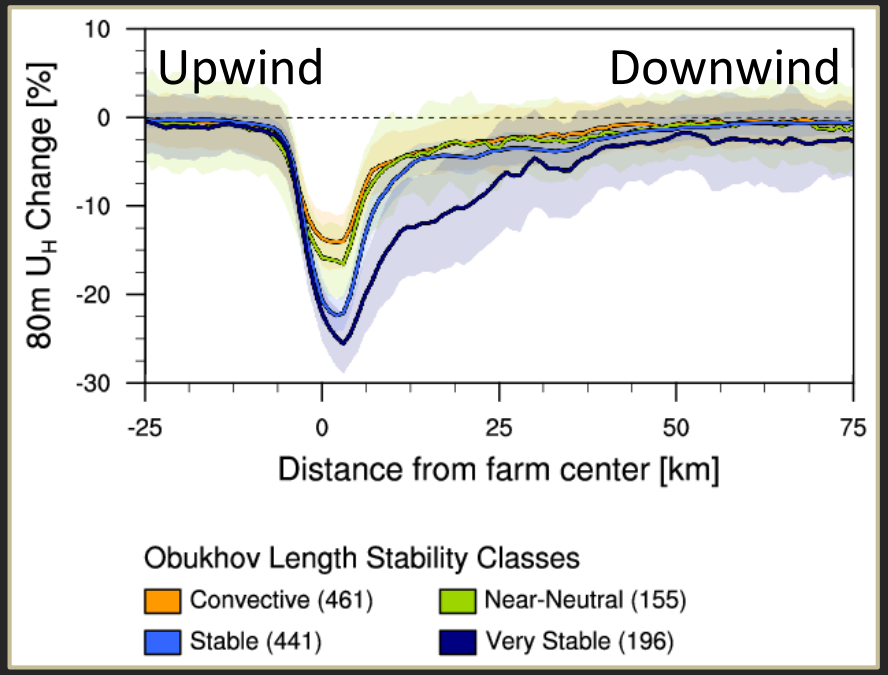
© Vattenfall 2008
Photo by Christian Steiness

In the midst of an operating wind farm, are surface roughness effects still discernable?

Combined effects of wind farm and roughness simulated using WRF-WFP

- Hypothetical 121 turbine wind farm
  - 1.8 MW Vestas V90 turbines
  - 4 m/s cut-in, 12 m/s rated, 25 m/s cut-out wind speeds
  - Minimum 7D spacing used in square grid layout

Maize waked - maize free stream

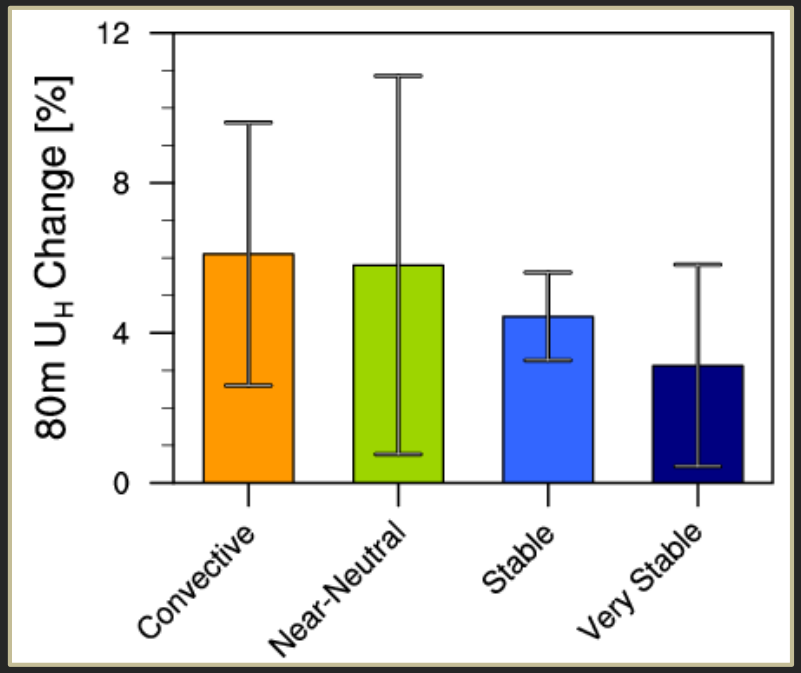


Influence of wind farm is large relative to ~5% change due to roughness modification!

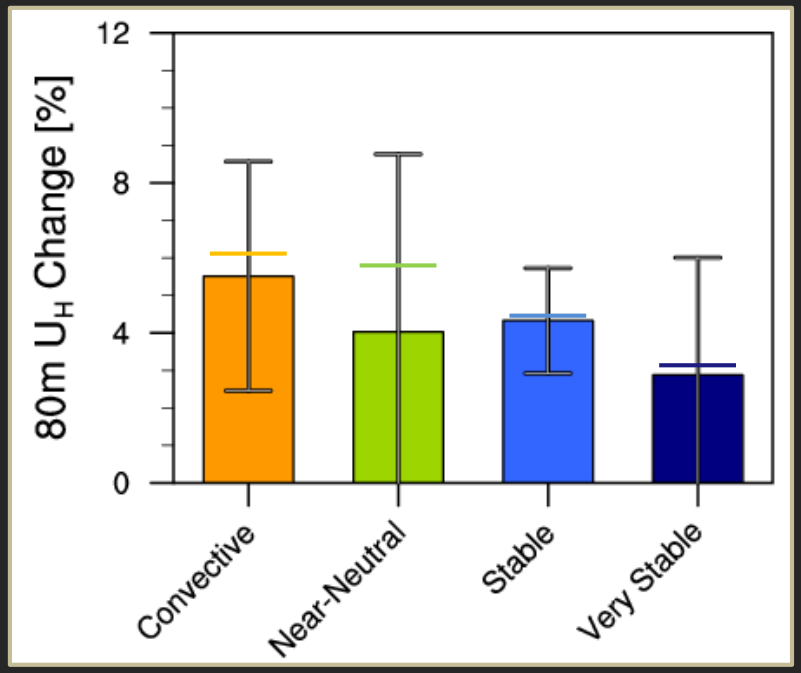
Full details on WRF-WFP in Fitch et al. 2012

Roughness impact (soy – maize) still evident even in presence of a wind farm

Free steam farm-average



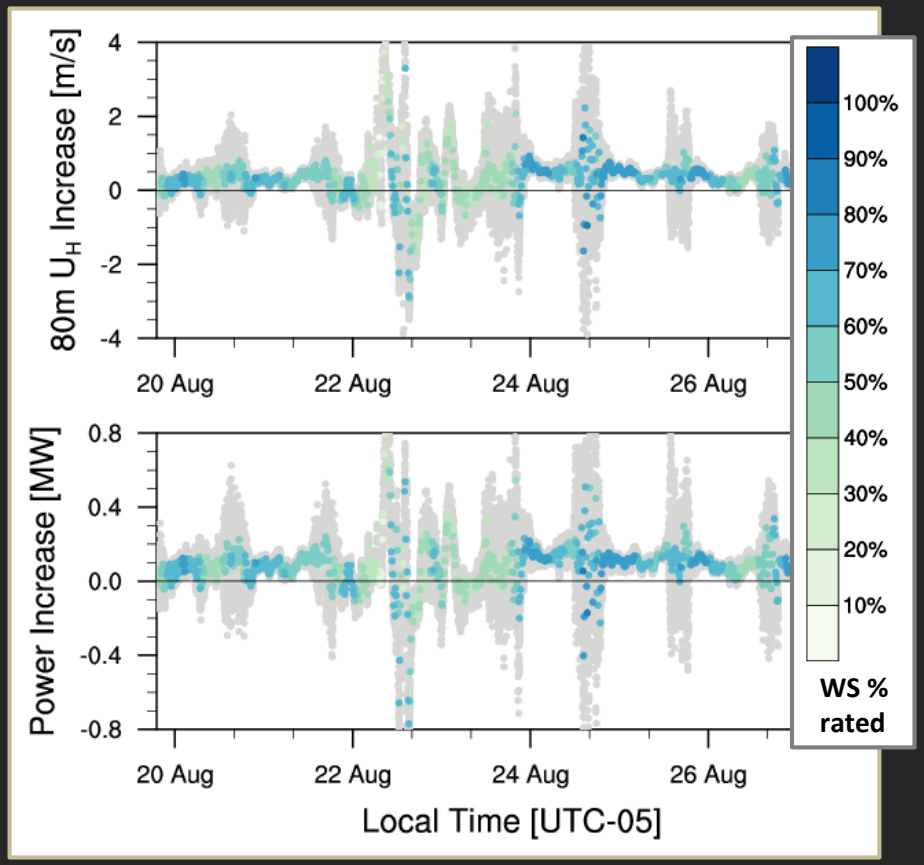
Waked flow farm-average



Additional mixing by wind turbines of surface drag most evident in near-neutral conditions

Simple economic analysis indicates non-trivial impact of z_0 on wind power

Soy - maize wind farm average



- Use of soy instead of maize yields 2050 MWh increase in wind farm output over 8 days
  - 10% increase per day
- Monetary benefit given $30-60* per MWh
  - $7688-15375 per day

* Wiser & Bollinger 2012

Summary: crop selection can impact wind farm output during peak of growing season

- For 8 days in August, 10% difference in power output for wind farms over soy vs maize land
- Maize at full height for 50-60 days and soybeans for up to 90 days
  - Annual effect depends on full cycles
- Agricultural land use decisions subject to many considerations

Thank you for your attention!

Any questions?