A wind farm parameterization for WRF

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INSTITUTE for SUSTAINABLE ENERGY, ENVIRONMENT and ECONOMY
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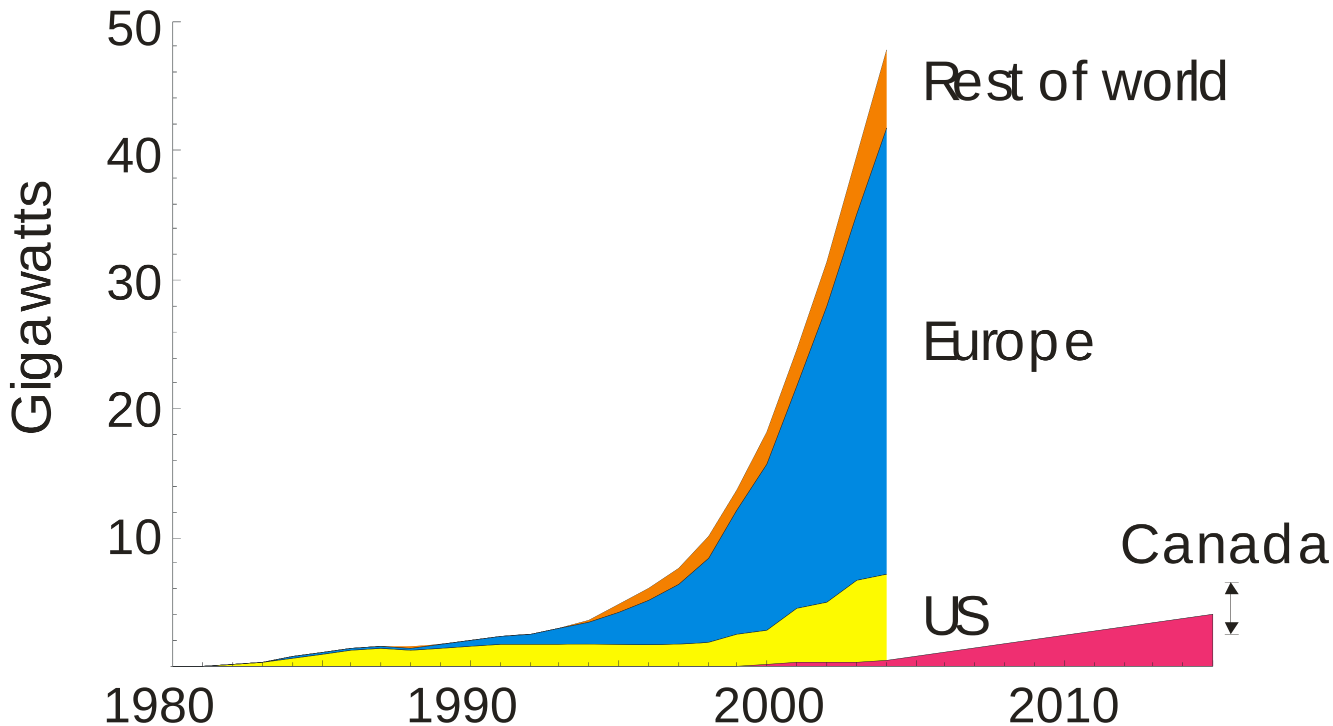
Wind generating capacity is growing fast…



- A $10 billion year industry.
- Much larger than solar, much smaller than hydro or nuclear.

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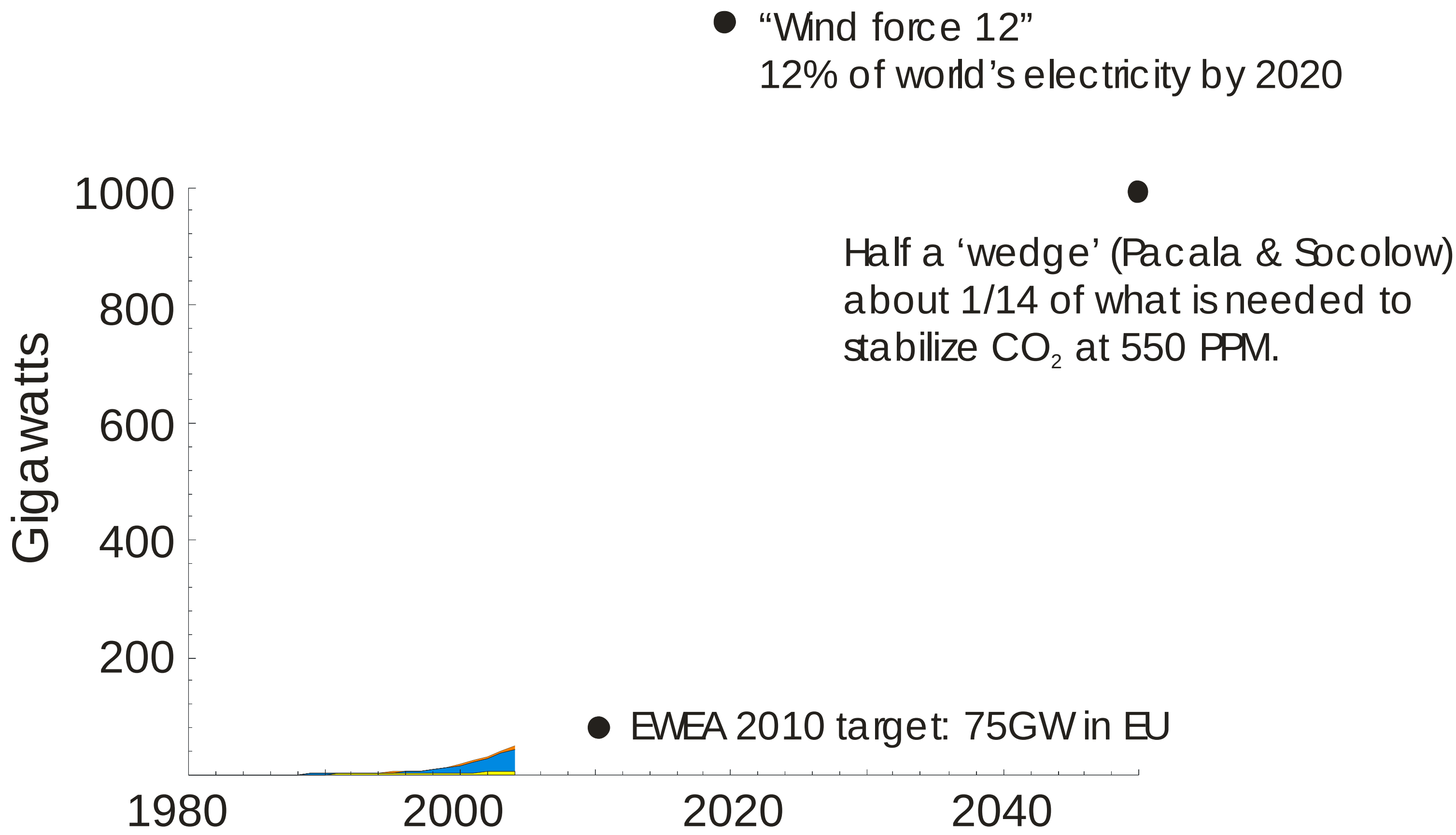
…but it must grow much larger to take a bite out of the climate problem



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Questions

- How do wind turbines affect the atmosphere?
- Why is it important to understand the local and global climatic impacts of wind energy?
- How do we currently parameterize wind farms, and how do we plan to improve that?

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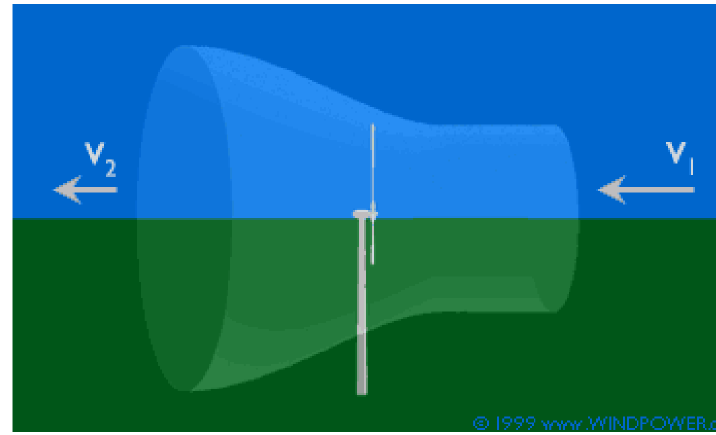
How Do Wind Farms Affect the Atmosphere?




- Reduce Wind Speed
- Produce Turbulence
  - Blade scale turbulence
  - Turbulence within the turbine wake
  - Reduction of wind speed leads to shear generated turbulence
- Increase Surface Roughness



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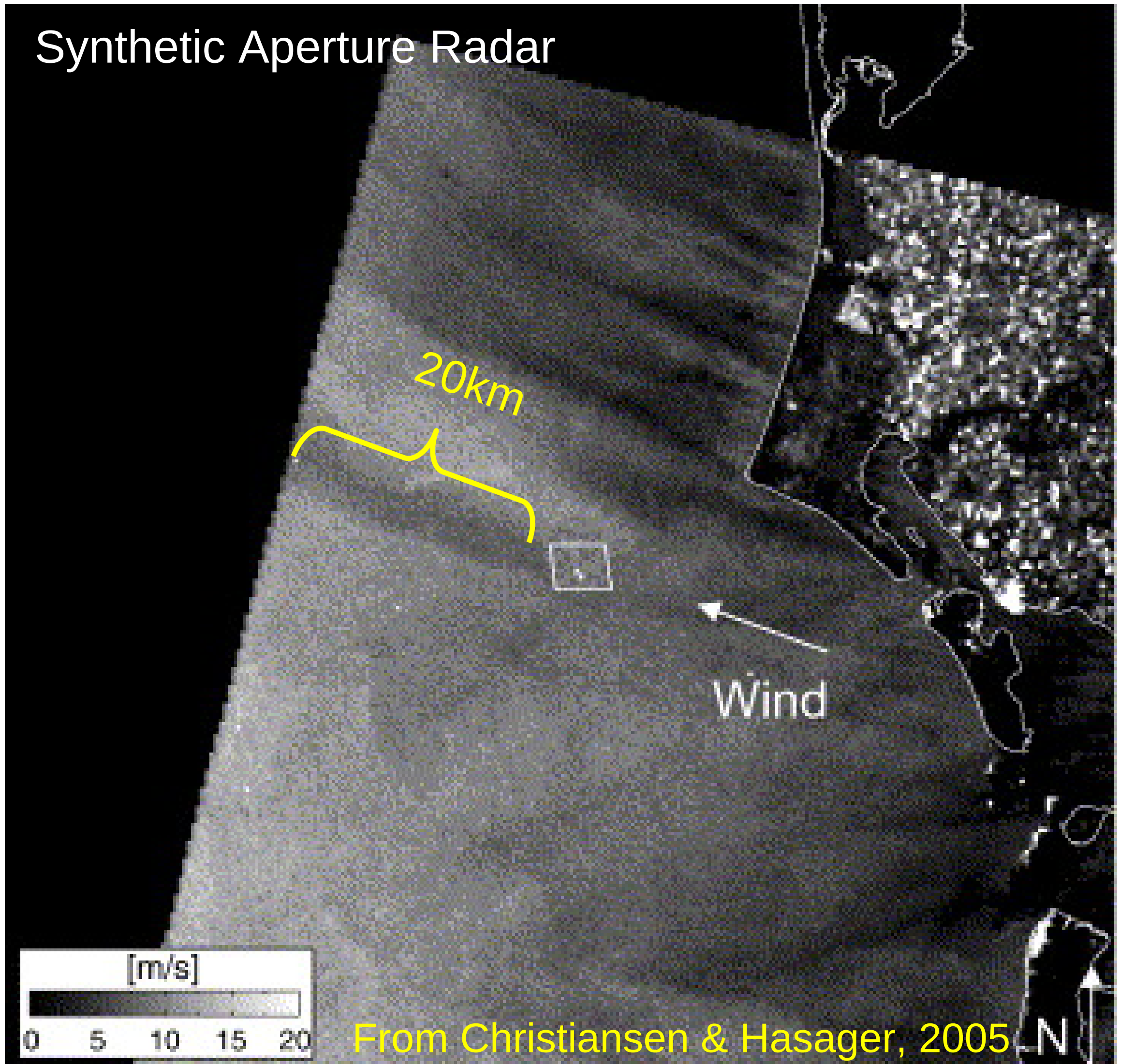
Wind Farm Wakes



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As wind energy grows what are the climate impacts?

Intended Climate Benefit

Unintended Climate Impact

Increased Wind Energy Production

Reduce CO_2 Emissions

Reduce CO_2 Concentrations

Climate Change

Remove Kinetic Energy from the Winds

Generate Turbulence

Change Moisture and Heat Fluxes?

Local Climate Change?
Global Climate Change?

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Parameterization of Wind Farms to Examine Local and Global Impacts

- Keith et. al. 2004, PNAS
  - Influence of wind farms on global climate; added drag term in GCMs
- Rooijmans 2004, M.S. thesis
  - MM5 was used to study offshore wind farms influence on local meteorology ; increased surface roughness
- Roy et. al. 2004, JGR
  - Can wind farms affect local meteorology?; used RAMS with an elevated RKE sink term, and TKE source term
  - Assumed a constant power coefficent and constant tke source

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Where does the energy lost from the resolved flow go?

$$F_{drag} = \frac{1}{2} C_T \left(\left| V \right| \right) \rho A v^2$$

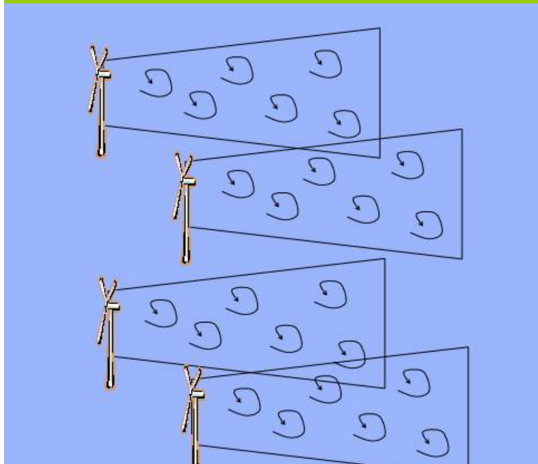
Electricity

$$P_e = \frac{1}{2} C_p \left(\left| V \right| \right) \rho A V^2 \vec{V}$$

Frictional Loss

Turbulence

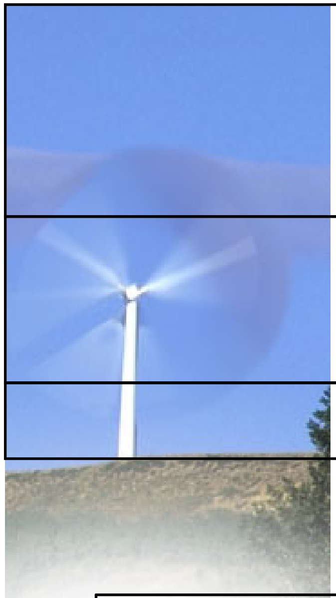
$$P_{TKE} = \frac{1}{2} C_{TKE} \left(\left| V \right| \right) \rho A V^2 \vec{V}$$



New Parameterization







$$A = \left(z\sqrt{r^2 - z^2} + r^2 \arcsin\left(\frac{z}{r}\right) \right) N_T$$

where A = wind farm density (m^{-1})

r = rotar radius

N_T = number turbines per km

2.0 MW turbine

Hub height	60m
Rotor Diameter	76m
Area Swept	4536m^2
Cut-in Speed	4ms^{-1}
Cut-out Speed	25ms^{-1}
Standing Thrust Coefficient	0.158

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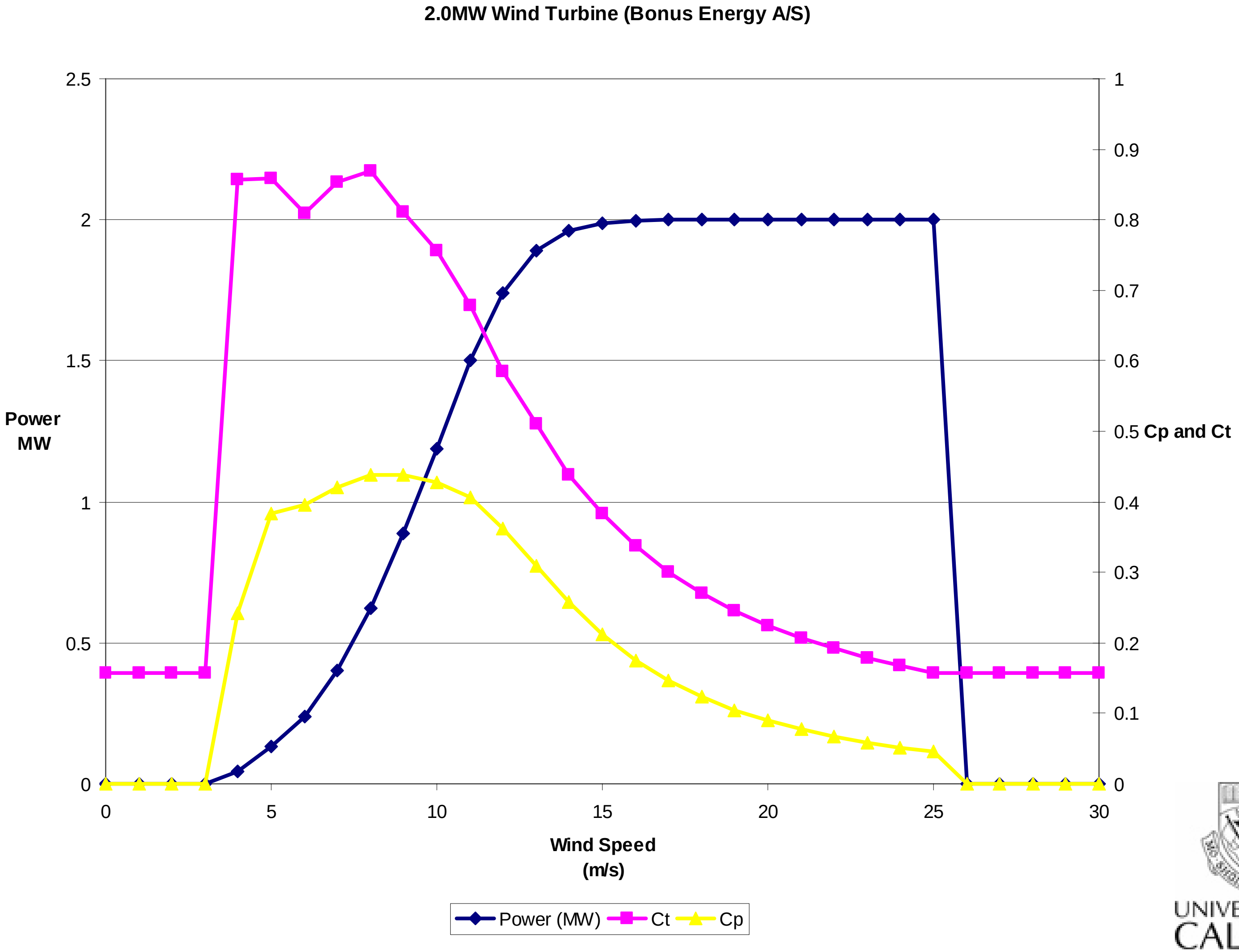
New Parameterization



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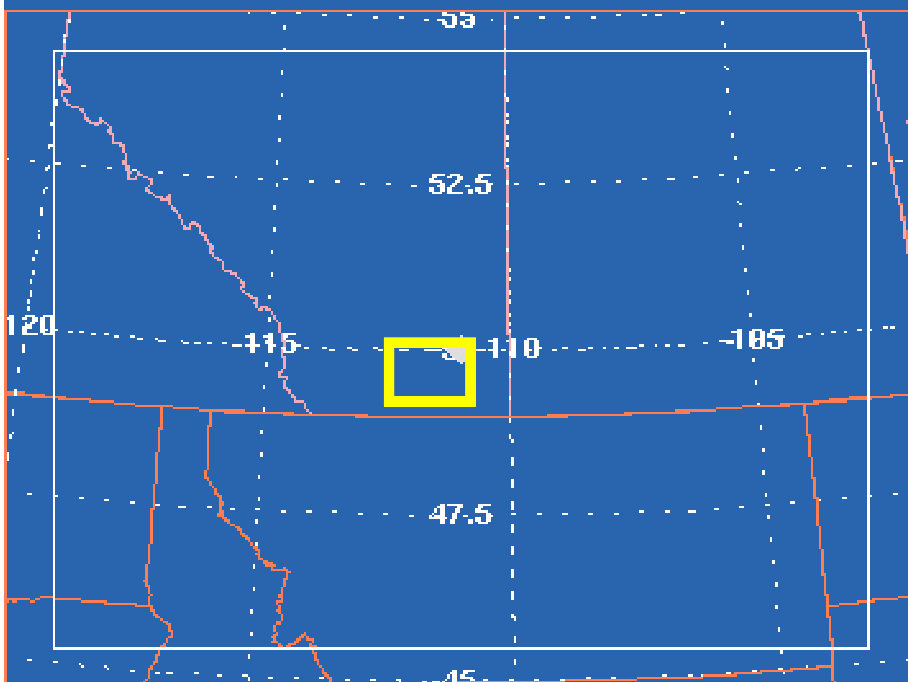
Preliminary work
WRF-ARW V2.1

dx=dy=10km, nxp=120, nyp=100



- Initialized from GFS-FNL
- MYJ PBL scheme
- 39 vertical levels
- Assume 1 turbine per km^2

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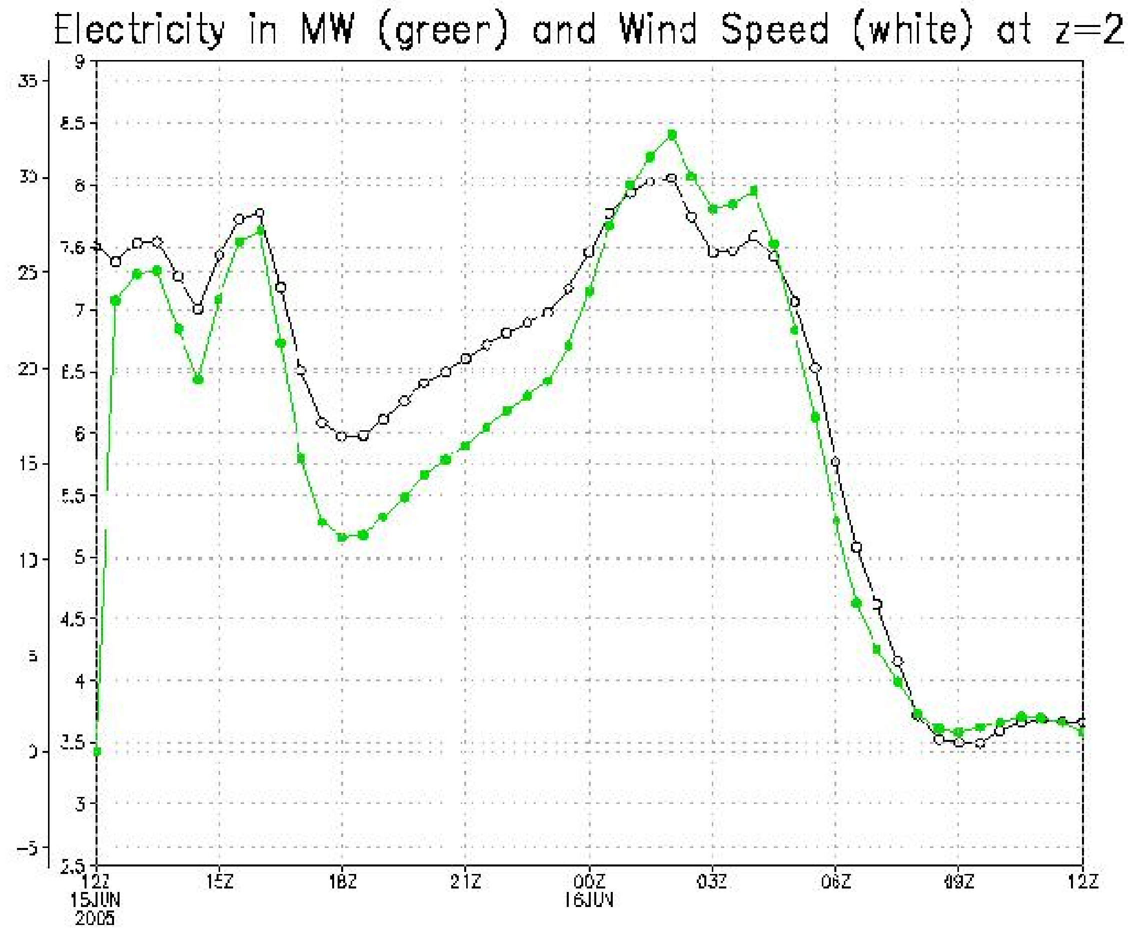
Electricity Generated



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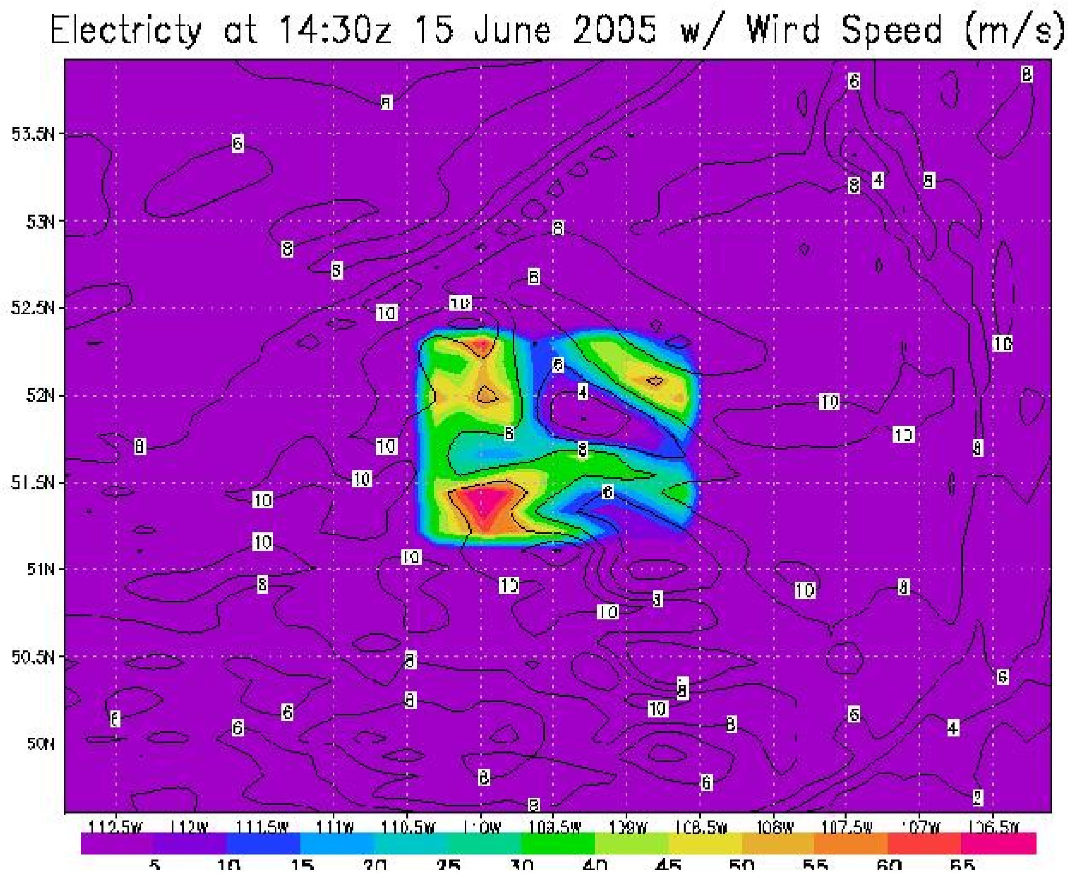
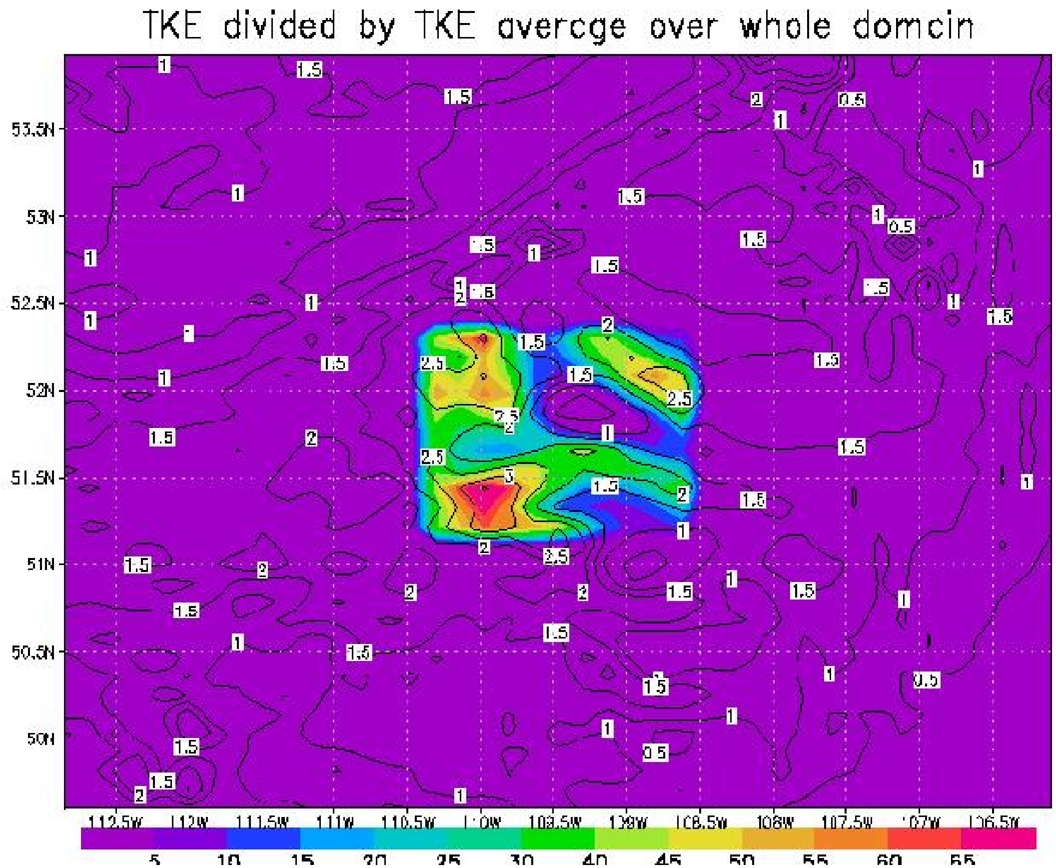


Change in TKE



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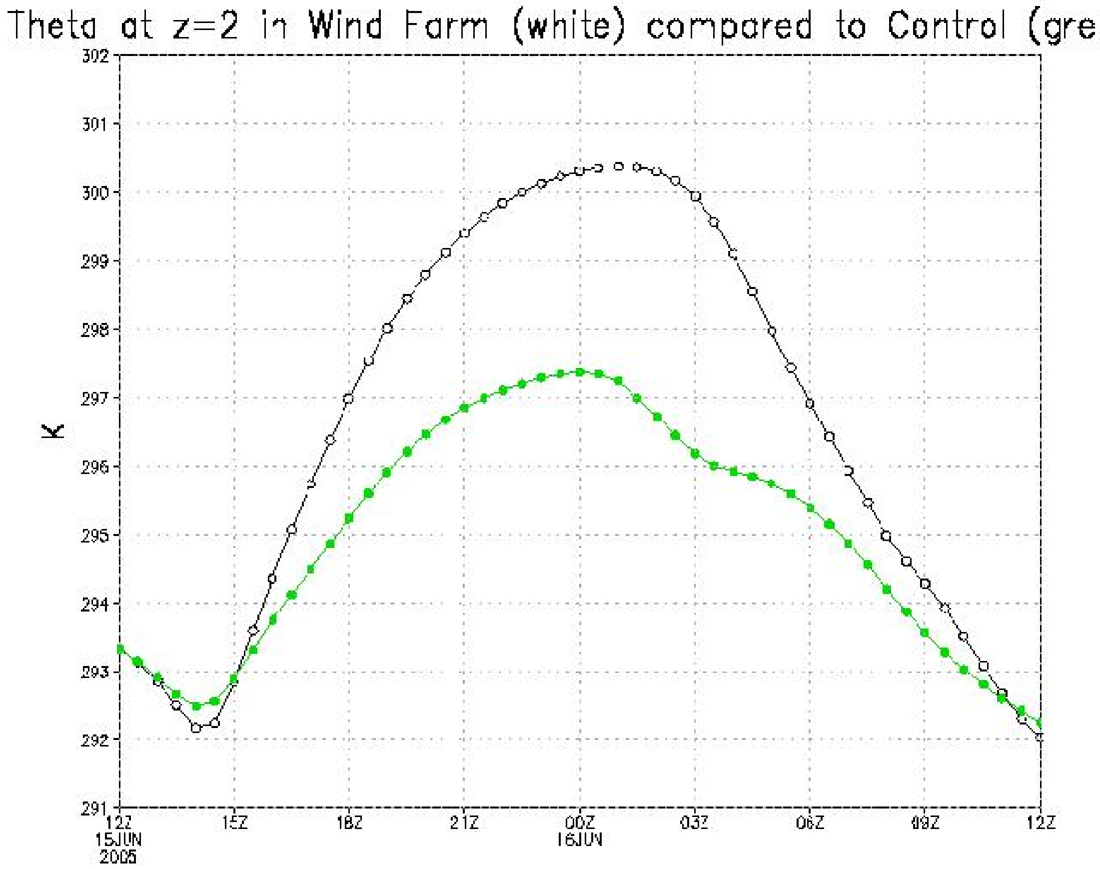
Diurnal Change in Temperature



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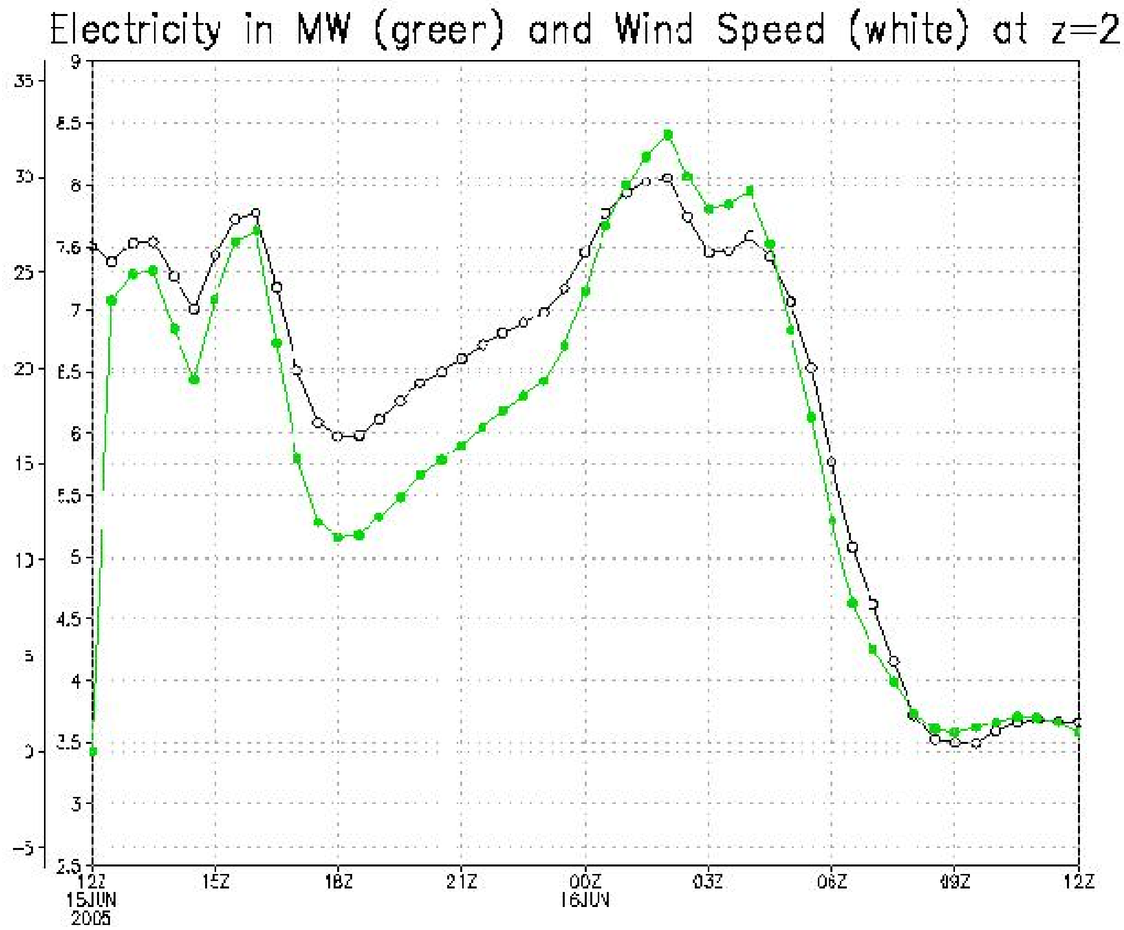
Electricity Generated



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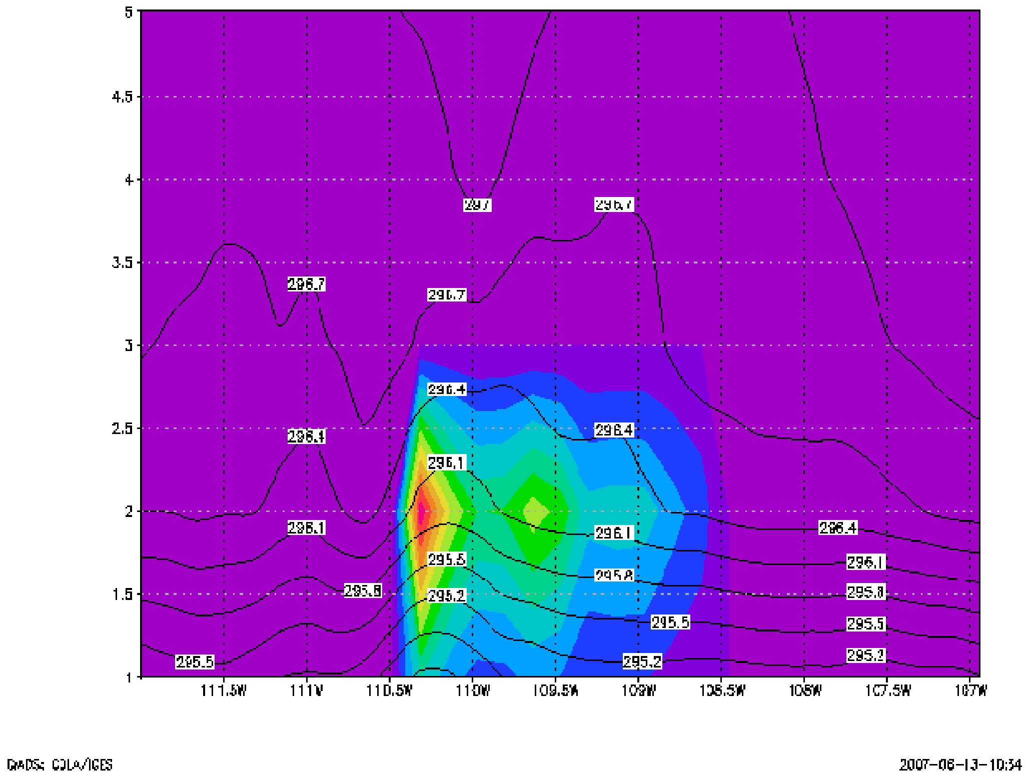
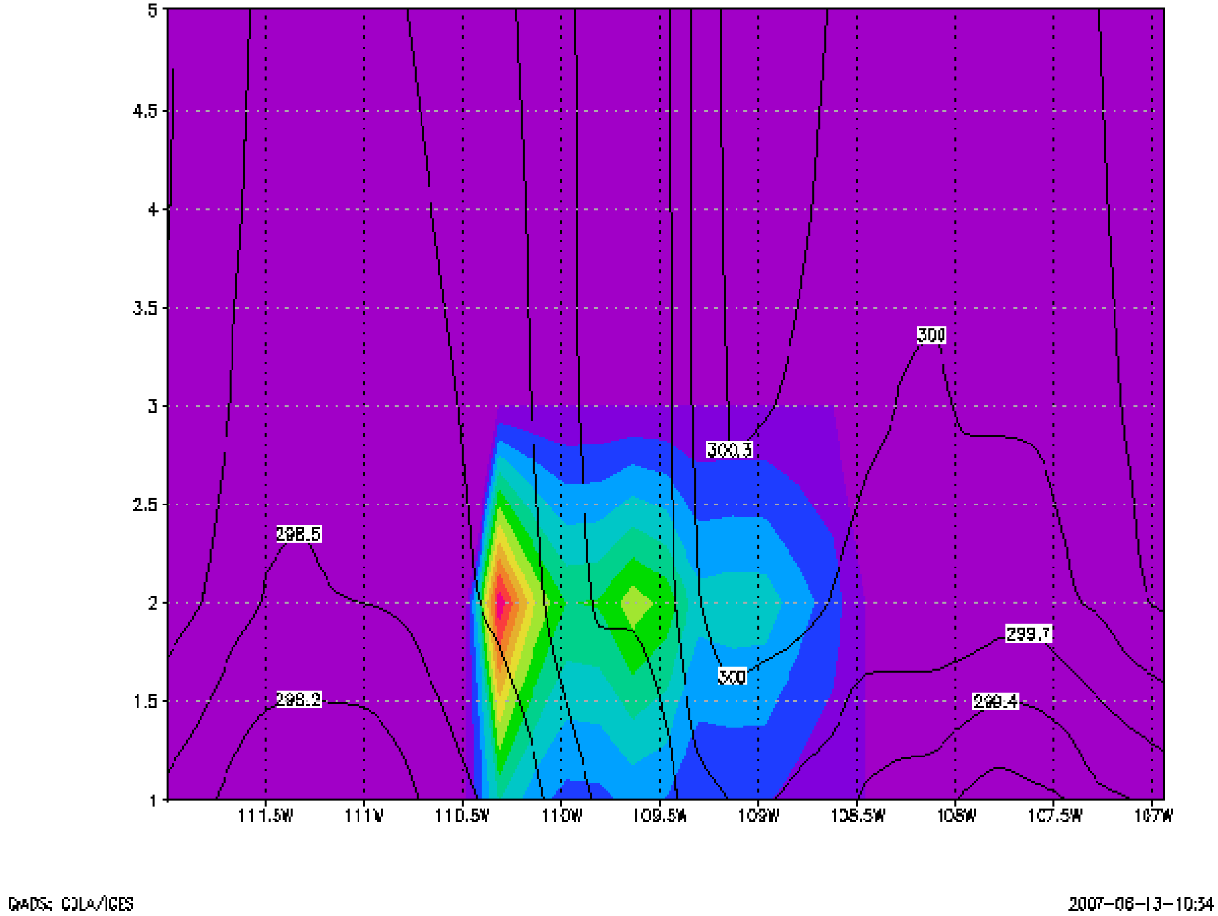
BL Structure: No Wind Farm



BL Structure: Wind Farm



Future Work




- Examine impacts over different seasons
  - 10 years, 4 different months
- Investigate importance of wind farm layout (square vs. long line vs. dispersed)
- Sensitivity to resolution
- Idealized simulations for different stabilities
- Develop understanding of the processes that may feed up into the larger scale
- Improve estimation of TKE generation

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Improving the TKE Source term

Courtesy Tim Crum, WSR-88D Radar Operations Center

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Questions?

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Thanks to: NSERC
Jimy Dudhia, NCAR

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