A wind farm parameterization for WRF

Manda Adams and David Keith
Wind generating capacity is growing fast…

- A $10 billion year industry.
- Much larger than solar, much smaller than hydro or nuclear.
…but it must grow much larger to take a bite out of the climate problem

- “Wind force 12”
  12% of world’s electricity by 2020

Half a ‘wedge’ (Pacala & Socolow) about 1/14 of what is needed to stabilize CO₂ at 550 PPM.

- EWEA 2010 target: 75GW in EU
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?
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
Wind Farm Wakes

Synthetic Aperture Radar

From Christiansen & Hasager, 2005
As wind energy grows what are the climate impacts?

Intended Climate Benefit

Increased Wind Energy Production

- Reduce CO₂ Emissions
- Reduce CO₂ Concentrations
- Climate Change

Unintended Climate Impact

- Remove Kinetic Energy from the Winds
- Generate Turbulence
- Change Moisture and Heat Fluxes?
- Local Climate Change? Global Climate Change?
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 coefficient and constant tke source
Where does the energy lost from the resolved flow go?

\[ F_{\text{drag}} = \frac{1}{2} C_T (|V|) \rho A v^2 \]

\[ P_e = \frac{1}{2} C_p (|V|) \rho A V^2 \bar{V} \]

\[ P_{\text{TKE}} = \frac{1}{2} C_{\text{TKE}} (|V|) \rho A V^2 \bar{V} \]
New Parameterization

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

where

- \( A = \text{wind farm density (m}^{-1}) \)
- \( r = \text{rotar radius} \)
- \( N_T = \text{number turbines per km} \)

### 2.0 MW Turbine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Hub height</td>
<td>60m</td>
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<tr>
<td>Rotor Diameter</td>
<td>76m</td>
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<tr>
<td>Area Swept</td>
<td>4536m²</td>
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<tr>
<td>Cut-in Speed</td>
<td>4ms⁻¹</td>
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<tr>
<td>Cut-out Speed</td>
<td>25ms⁻¹</td>
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<tr>
<td>Standing Thrust Coefficient</td>
<td>0.158</td>
</tr>
</tbody>
</table>
New Parameterization

2.0MW Wind Turbine (Bonus Energy A/S)

Power (MW)

Wind Speed (m/s)

Cp and Ct
Preliminary work
WRF-ARW V2.1

- $dx=dy=10\text{km}$, $n_{xp}=120$, $n_{yp}=100$
- Initialized from GFS-FNL
- MYJ PBL scheme
- 39 vertical levels
- Assume 1 turbine per km$^2$
Electricity Generated

Electricity in MW (green) and Wind Speed (white) at z=2
Electricity Generated

Electricity at 14:30z 15 June 2005 w/ Wind Speed (m/s)
Change in TKE
Diurnal Change in Temperature

\[
\text{Theta at } z=2 \text{ in Wind Farm (white) compared to Control (green)}
\]
Electricity Generated
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
Improving the TKE Source term

Wind turbines 3 nm NW of WSR-88D in Great Falls, MT (TFX).
View from the front of the WFO.
Height to top of turbines is approximately 390 feet. Each blade is 155 feet long.

Courtesy Tim Crum, WSR-88D Radar Operations Center
Questions?

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