

Interactive comment on “Potential climatic impacts and reliability of very large-scale wind farms” by C. Wang and R. G. Prinn

C. Wang and R. G. Prinn

wangc@mit.edu

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Responses to the Comments of Reviewers

We appreciate the constructive comments and suggestions of both reviewers. We have revised the manuscript based on these comments. The following are our point-by-point responses to the reviewers' comments (listed using bold and *Italic font*).

Reviewer 2:

The mechanism for generation of turbulence kinetic energy (TKE) in the model and consequences for surface budgets needs clarification and justification. Current turbines are mounted on towers with hub heights of 80-100m and plans are

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in place to put them even higher. Blade diameters currently are 80m or larger. Space and time scales of TKE generated by interaction of mean flow with such a dynamic obstacle likely are not well represented by drag forces at the earth's surface. Such turbines will tap into the lower part of the low-level jet, particularly in regions such as the US Great Plains. In such cases, turbines will encounter higher winds at night than during the day (M. Lange and U. Focken, “Physical approach to Short-Term Wind Power Prediction,” Springer, 2005.), opposite to the diurnal patterns at the surface. Turbulence intensity will increase at the surface, particularly at night, within wind farms compared to the undisturbed landscape. Mean wind speed also is likely to increase at night due to enhanced coupling of free atmosphere winds with the surface due to the enhanced TKE generated by the turbines.

In the model described in this manuscript, the effect of turbines is introduced by an enhanced surface drag that is calculated from surface wind speed and a drag coefficient. This has the effect of reducing surface wind and therefore reducing the magnitude of surface exchange processes for heat, moisture, momentum and CO₂. Therefore, the parameterization used in this model is not consistent with observed behavior of the atmospheric boundary layer described in the previous paragraph. All of this calls into question the results of the paper which show a weakened near-surface turbulent transport due to turbines when their effects are parameterized by an increased surface friction.

This is a valid point. The reviewer is addressing the subgrid scale processes and how they could be better represented in the GCM. The “surface wind” cited here is defined at the first model layer that is about 30 meters thick above the ground. Note that the method we use was actually developed based on a much more detailed framework than our GCM and was first applied to mesoscale modeling of the wind turbine local effect. These mesoscale studies demonstrated that by altering the surface roughness, certain critical influences of wind turbines on the local wind profile could be captured

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(e.g., Frandsen, 1992; Vermeer et al., 2003). In addition, our modeling is focused on the long-term climatic effects (note the 20-year means used in analyses) rather than on describing the detailed multiple layer structure of the local wind field. Such a task clearly exceeds the capability of current GCMs or even of current mesoscale models, regardless of whether or not the cited unique near surface jet would change the overall grid scale properties.

To address the reviewer's point, we have added statements in the manuscript (in the Conclusions section) to indicate clearly to the reader the derivation and potential limitation of the surface roughness parameterization: "Our method involving varying the surface roughness has been shown to capture certain features of the effects of turbines on the local wind using mesoscale models (Frandsen, 1992; Vermeer et al., 2003). However, this method cannot explicitly resolve the detailed vertical wind profiles affected by atmospheric stability or wind shear that are clearly subgrid scale processes in our model (Vermeer et al., 2003; Lange and Focken, 2005)". These cautionary statements added to the original one ("Appropriate field experiments to test our conclusions, and to explore better ways for simulating wind turbines in models, are also required") should in sum address the reviewer's issue.

Without prior reference in the body of the paper, the third paragraph of the conclusions states: "Environmental effects increase with power generated and decrease with conversion efficiency. Also, for the widely spaced wind turbines simulated in our runs, the environmental effects appear small when they are generating less than 1TW globally even with current technologies." The authors do not define "environmental effects" of turbines, but DOE does: impacts on birds, bats, false echoes on weather radars, and ambient noise levels. It is not at all clear what the authors mean by environmental effects. The potentially more significant environmental effect of turbines in grasslands, shrubland or crop land (where a vast majority will be located in the US Great Plains) is the impact on plant-atmosphere exchange of heat, moisture, momentum, and CO2

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due to the altered surface turbulence created by the turbines. Potential drying and increased vulnerability to dust storms (suggested by the conceptual model I have presented) would not be a welcome environmental effect for this region, which suffered enormous loss of topsoil in the continental scale dust storms of the 1930s. Reconsideration must be given to the suggestion of environmental effects.

The term "environmental" here should really be "climatic", and that has been corrected in the revised manuscript. On the other hand, the point about "environmental effects" made by the reviewer is well taken. We have added after the above-cited sentences the text: "putting aside the potential environmental effects for instance on birds and weather radar as well as on ambient noise levels".

Figure 1 shows that no turbines are located south of about 55 degrees S and only relatively few south of 30 degrees S. Yet substantial cooling is simulated on Antarctica (Figure 2) extending to the South Pole. What mechanism is able to create such a vast region of remote cooling, especially one that is dynamically isolated from lower latitudes by the circumpolar vortex?

These are indeed the remote impacts of turbines through large-scale dynamic processes ("teleconnections"). Similar results can be also seen in previous work such as Keith et al. (2004) on the climate response to large-scale wind turbines and Wang (2004, 2007) on the climate response to large scale absorbing aerosol forcing.

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