Q&A on “Impacts of Wind Farms on Land Surface Temperature” Published by Nature Climate Change on April 29, 2012

The authors would like to provide answers to several frequently asked questions about this research. Two figures are also provided on pages 4-5.

What is the major finding of this research?

This study presents the first observational evidence of wind farm impacts on land surface temperature with spatial detail using satellite data.

What is land surface temperature?

Land surface temperature is how hot the “surface” of the Earth would feel to the touch in a particular location. From a satellite’s point of view, the “surface” is whatever it sees when it looks through the atmosphere to the ground. It could be snow and ice, the grass on a lawn, the roof of a building, or the leaves in the canopy of a forest. Thus, land surface temperature is not the same as the air temperature that is included in the daily weather report. Note that the land surface temperature has a larger day-night variation than the surface air temperature.

(source: http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MOD11C1_M_LSTDA)

Why do operating wind turbines enhance turbulence and vertical mixing?

Turbulence is small-scale, chaotic almost-random air movement. The spinning rotors of the wind turbines generate turbulence in their wakes – just like the wake from a boat in the water. Wakes from wind turbines can spread a long distance downwind of the turbines. Due to the turbulent nature of the wakes, vertical mixing of lower and upper level air also increases in regions downwind of wind farms.

Why do the operating wind turbines warm nighttime temperature?

This warming effect is most likely caused by the turbulence in turbine wakes acting like fans to pull down warmer near surface air from higher altitudes at night. Typically nighttime has a stable atmosphere with a warm layer overlying a cool layer. Enhanced vertical mixing mixes warm air down and cold air up, leading to a warming near the surface at night. Daytime often has an unstable atmosphere with cool air lying over warmer air. Turbulent wakes mix cool air down and warm air up, producing a cooling near the surface during the day. However, daytime mixing is already very large due to solar heating. Hence, the turbine-enhanced turbulent mixing may play a smaller role during the daytime.

Why do you attribute the warming primarily to wind farms?

Because (a) the spatial pattern of the warming resembles the geographic distribution of wind turbines and (b) the year-to-year land surface temperature over wind farms shows a persistent upward trend from 2003 to 2011, consistent with the increasing number of operational wind turbines with time. FAA data shows that the number of wind turbines over the study region has gone up from 111 in 2003 to 2358 in 2011.

How to interpret the magnitude of the estimated warming effect?

We found a nighttime warming effect over wind farms of up to 0.72 °C per decade relative to nearby non-wind farm regions for the nine-year period during which data was collected. It is important to keep the following points in mind when interpreting our results.

First, the land surface temperature measures the temperature of the Earth's surface, which has a stronger day-night variation than the surface air temperature from daily weather reports. Therefore, the impacts of wind farms on the surface air temperature should be within the near-surface boundary layer and smaller than the land surface temperature signal presented in this paper.

Second, as this analysis is from a short period over a region with rapid growth of wind farms, we expect our estimates to give higher values than those estimated in other locations and over longer periods.

Third, we express the warming effect as a linear trend in °C per decade units. This is just one simple way to quantify the wind farm impacts while reducing the year-to-year data noise. The estimated warming trend only applies to the study region and to the study period, and thus should not be extrapolated linearly into other regions (e.g., globally) or over longer periods (e.g., for another 20 years). For a given wind farm, the warming effect would likely reach a limit rather than continue to increase if no new wind turbines are added.

Fourth, satellite data do contain errors and noise due to cloud contamination and imperfection of retrieval algorithms. Uncertainties also exist in locating wind turbines as well as their operating times. In addition, other factors may also modify local land surface temperature. Considering the complexity of the issue, our results should be interpreted as illustrative rather than definitive.

Finally, compared to impacts of other human-made land use changes, the estimated warming over the wind farms is small. The "urban heat-island" effect, for example, in Austin TX or phoenix in AZ, could be several degrees °C warmer than the surrounding less developed areas.

Overall, the warming effect reported in this study is local and is small compared to the strong background year-to-year land surface temperature changes. Very likely, the wind turbines do not create a net warming of the air and instead only redistribute the air's heat near the surface (the turbine itself does not generate any heat), which is fundamentally different from the large-scale warming effect caused by increasing atmospheric concentrations of greenhouse gases due to the burning of fossil fuels.

Possible impacts on weather and climate?

Wind energy is among the world's fastest growing sources of energy. The U.S. wind industry has experienced a remarkably rapid expansion of capacity in recent years. While converting wind's kinetic energy into electricity, wind turbines modify surface-atmosphere exchanges and transfer of energy, momentum, mass and moisture within the atmosphere. These changes, if spatially large enough, might have noticeable impacts on local to regional weather and climate.

Given the present installed capacity and the projected growth in installation of wind farms across the world, this study draws attention to an important scientific issue that requires further investigation. We need to better understand the system with observations and better describe and model the complex processes involved to predict how wind farms may affect future weather and climate.

What will you do next?

Understanding wind farm-atmosphere interactions is a critical emerging topic. This article is a first step in exploring the potential of using satellite data to quantify the possible impacts of big wind farms on weather and climate. We are now expanding this approach to other wind farms and building models to understand the physical processes and mechanisms driving the interactions of wind turbines and the atmosphere boundary layer near the surface.

Any implications for wind energy industry?

We need to realize that the build-up of CO_2 in the atmosphere due to the burning of fossil fuels will have global impacts, while the warming effect reported in this study is local and is small. Generating wind power creates no emissions, uses no water, and is likely green. Wind power is going to be a part of the solution to the climate change, air pollution and energy security problem. Understanding the impacts of wind farms is critical for developing efficient adaptation and management strategies to ensure long-term sustainability of wind power.

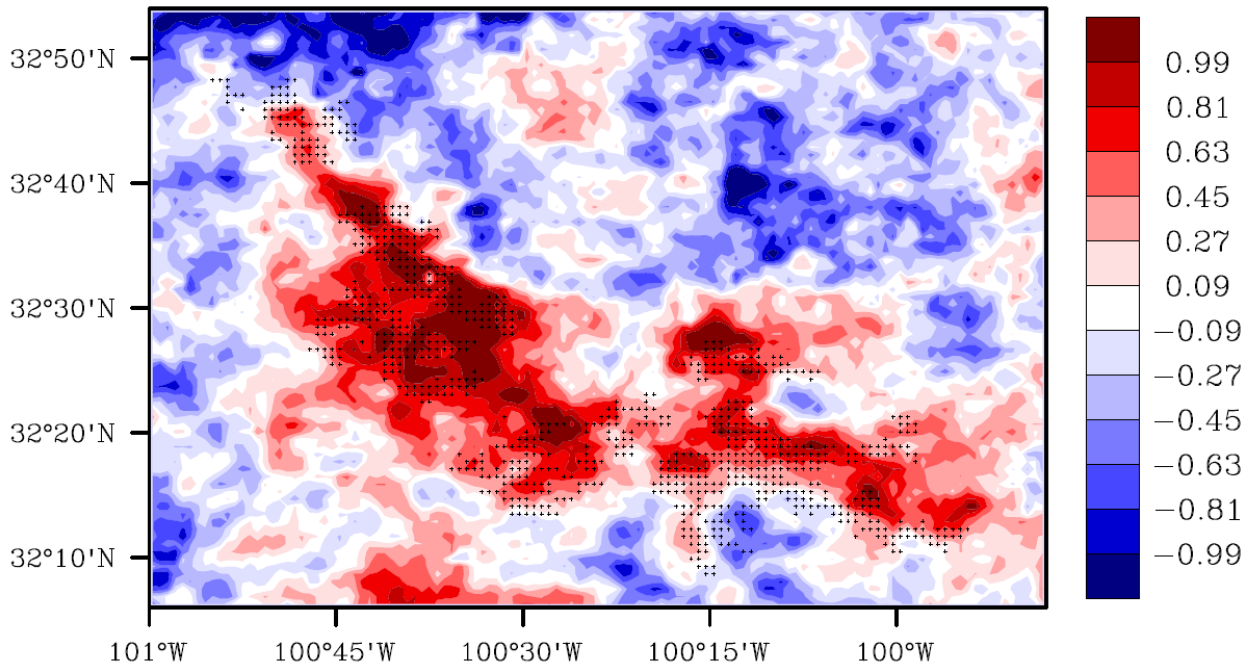

Figure 1: Nighttime land surface temperature (LST, °C) differences between 2010 and 2003 (2010 minus 2003) in summer (June-July-August). Pixels with plus symbol have at least one wind turbine. A regional mean value (0.592 °C) was removed to emphasize the relative LST changes at pixel level and so the resulting warming or cooling rate represents a change relative to the regional mean value. The LST data were derived from MODIS (Moderate Imaging Spectroradiometer) instruments on NASA's Aqua and Terra satellites. Note that LST measures the radiometric temperature of the Earth's surface itself - It has a larger diurnal variation than surface air temperature used in daily weather reports.

(The high quality image can be downloaded at http://www.atmos.albany.edu/facstaff/zhou/tmp/Figure1.jpg)

Courtesy: Liming Zhou

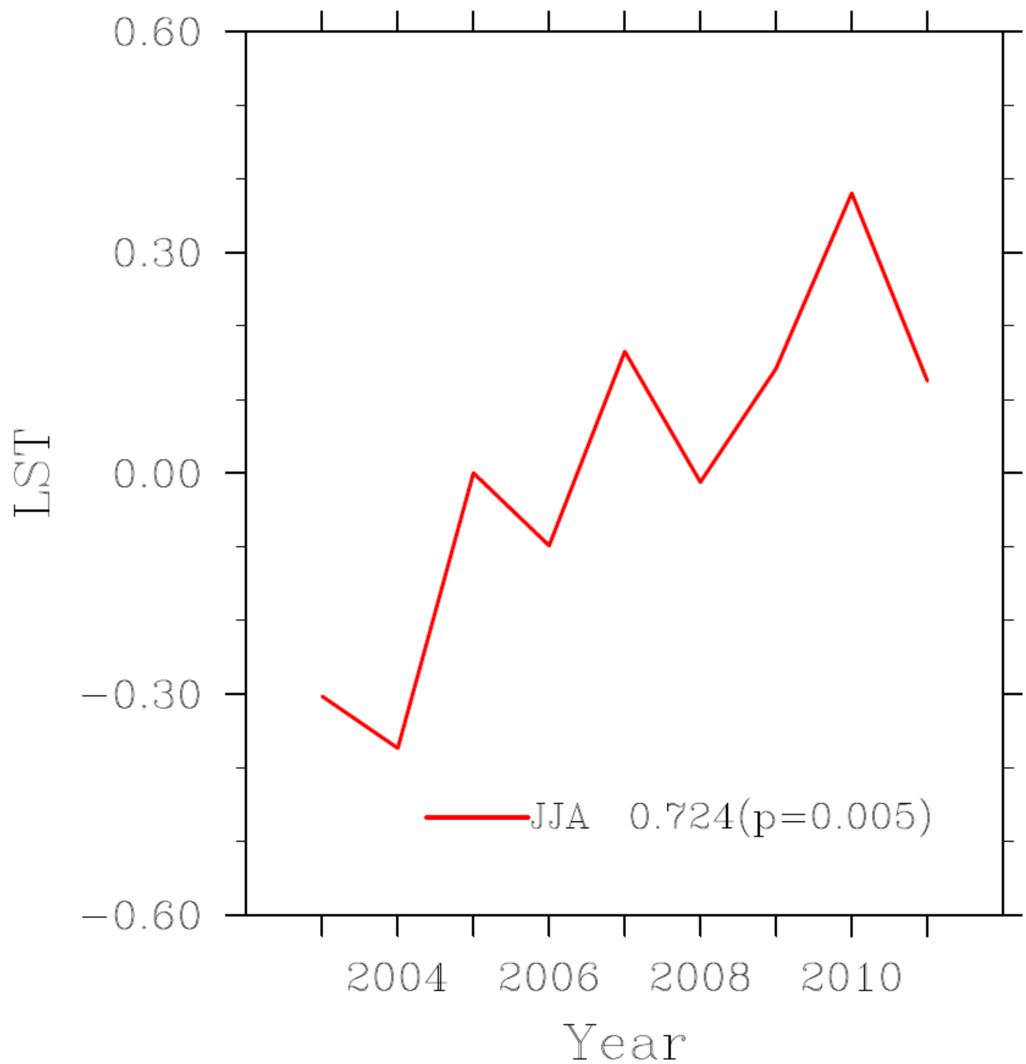

Figure 2: Year-to-year changes in the nighttime land surface temperature (LST, °C) differences between wind farm regions and nearby non-wind farm regions for the period 2003-2011 in summer (June-July-August). The linear trend (°C per decade) and its significance level (p value) estimated using least squares fitting are shown. The linear trend is to determine whether there is a deterministic long-term movement of the LST time series with time. Its magnitude represents the rate at which change occurs over time (e.g., per decade). If the value of the trend is zero, there was no trend, indicating no change with time. If the trend has a positive value, the rate is increasing. If it is negative, the rate is decreasing. The p-value tells the probability of whether the linear trend value is statistically significantly different from zero. Note that FAA data shows that the number of wind turbines over the study region increased from 111 in 2003 to 2358 in 2011.

(The high quality image can be downloaded at http://www.atmos.albany.edu/facstaff/zhou/tmp/Figure2.jpg)

Courtesy: Liming Zhou