

# Climate Change Effects On Wind Speed

*Predicted changes in wind speeds due to global warming are expected to be modest, but are large enough to affect the profitability of wind projects.*

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Concern about the effects of climate change has been one of the motivating forces behind the rapid development of wind energy projects. However, the Intergovernmental Panel on Climate Change states that “there is evidence for long-term changes in the large-scale atmospheric circulation, such as a poleward shift and strengthening of the westerly winds” and that these observed changes likely will continue.

A recent review of historic climate reanalyses in *Geophysical Research Letters* concludes that “jet streams have risen in altitude and moved poleward in both hemispheres.” These changes in circulation may directly affect the energy production of existing and planned wind projects. The large infrastructure investments associated with today’s utility-scale projects motivate an evaluation of the possible impacts of climate change on wind speed.

A recent study found significant differences between the changes predicted by four global climate models (GCMs) that used two IPCC emission scenarios, both in sign and magnitude, but nonetheless concluded that a warmed climate may reduce the spring and

summer wind power resources of the Northwest U.S.

According to the study, regional differences in wind speed changes predicted by different climate models make it difficult to draw meaningful conclusions based on the results from any single GCM simulation. Therefore, the projected wind speed changes from a large number of GCMs and for two different emission scenarios are examined herein. Of interest is not just the mean predicted change, but also the degree of consensus between the different

models (i.e., where do the models agree on the sign of the change and where do they differ?).

## Methodology

The IPCC has defined a series of emission scenarios that have been used as the basis for climate change modeling studies. These scenarios represent story lines that provide alternative future scenarios. The scenarios do not have an assigned probability. For this study, model simulations are based on the A2 and B1 families of scenarios. These scenarios were selected because

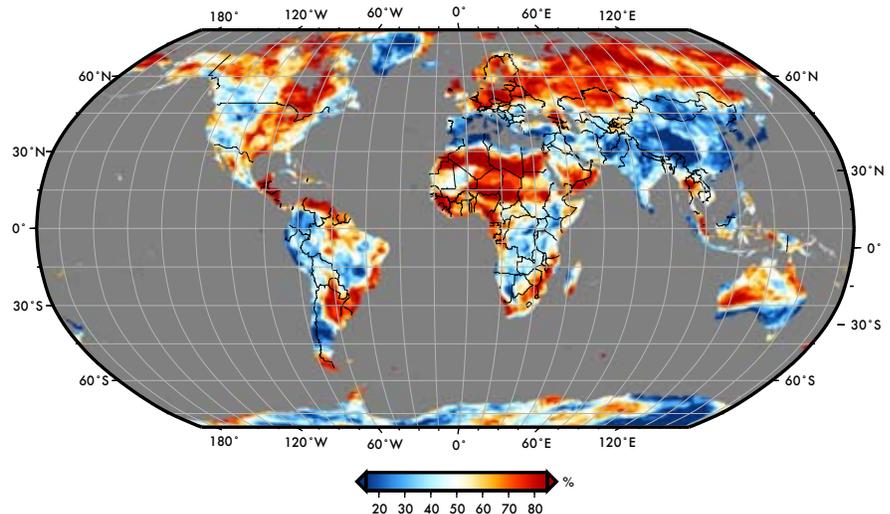
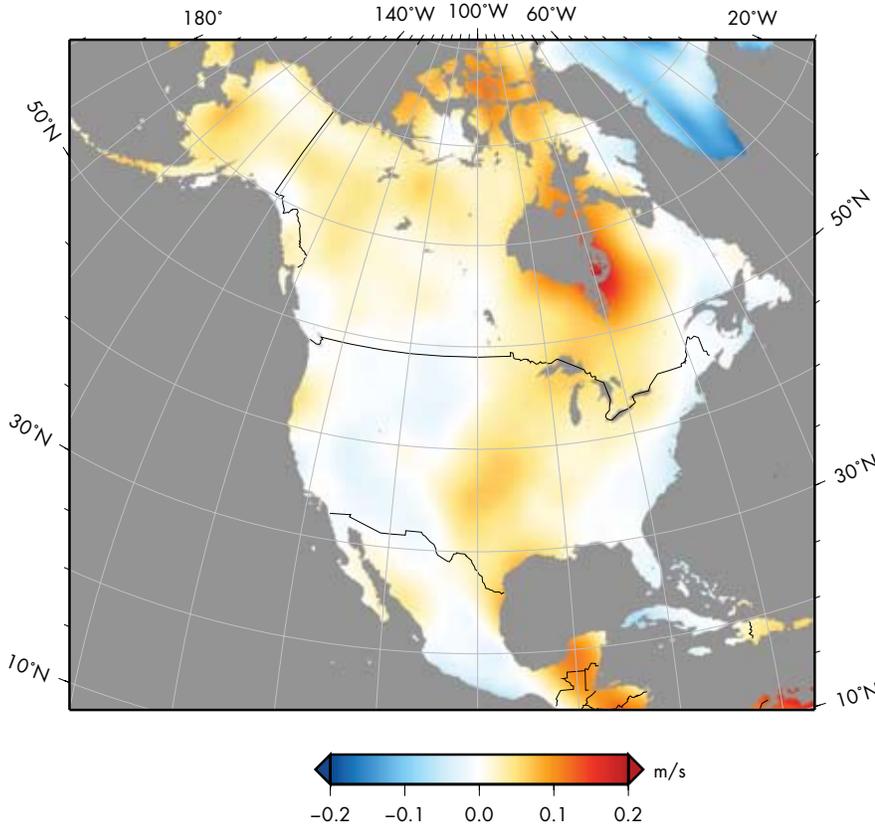


Figure 1: Percentage Of Global Climate Models Showing Increased Annual-Mean Wind Speed Values In 2050.

**Figure 2A: Annual-Mean Difference**



their associated climate change effects typically span the range of projected changes. The A2 scenario can be described as “business as usual,” while the B1 scenario focuses on sustainable development and has half the carbon dioxide emissions of A2 in 2100.

The surface wind fields from a 14-member ensemble of GCM simulations were evaluated to analyze the impact of global climate change on near-surface wind speeds across the globe. Data from these GCM simulations are publicly available as part of the World Climate Research Programme’s (WCRP) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model data set. The CMIP3 data set contains GCM output for historic periods and projections of the future climate under different emission scenarios. Although the CMIP3 data set contains additional GCM simulations, only 14 simulations contain sufficient data to perform the analysis.

Wind speed values representing

current and future conditions are derived from GCM output. Because each GCM has its own biases, results for each model are processed individually by comparing wind speed values from a historic 20th century control simulation with that of a simulation based on one of the future emission scenarios.

Mean wind speed values representing the present-day climate are computed using daily-mean GCM output over the period 1991-2000. Mean wind speed values in the future are computed using daily-mean GCM data from the period 2046-2055. Wind speed differences are reported at 10 meters above ground level. At turbine hub heights, these differences are expected to be slightly greater, but should retain the same spatial patterns and relative magnitudes.

The horizontal resolution of the GCMs used in this study ranges from approximately 200 kilometers to 450 kilometers. Therefore, the results of the analysis are only rep-

resentative of the expected large-scale changes, since small-scale and local effects are not resolved by the GCMs. Another limitation is the use of daily-mean west-to-east (zonal or  $u$ ) and south-to-north (meridional or  $v$ ) components to compute scalar daily-mean wind speeds.

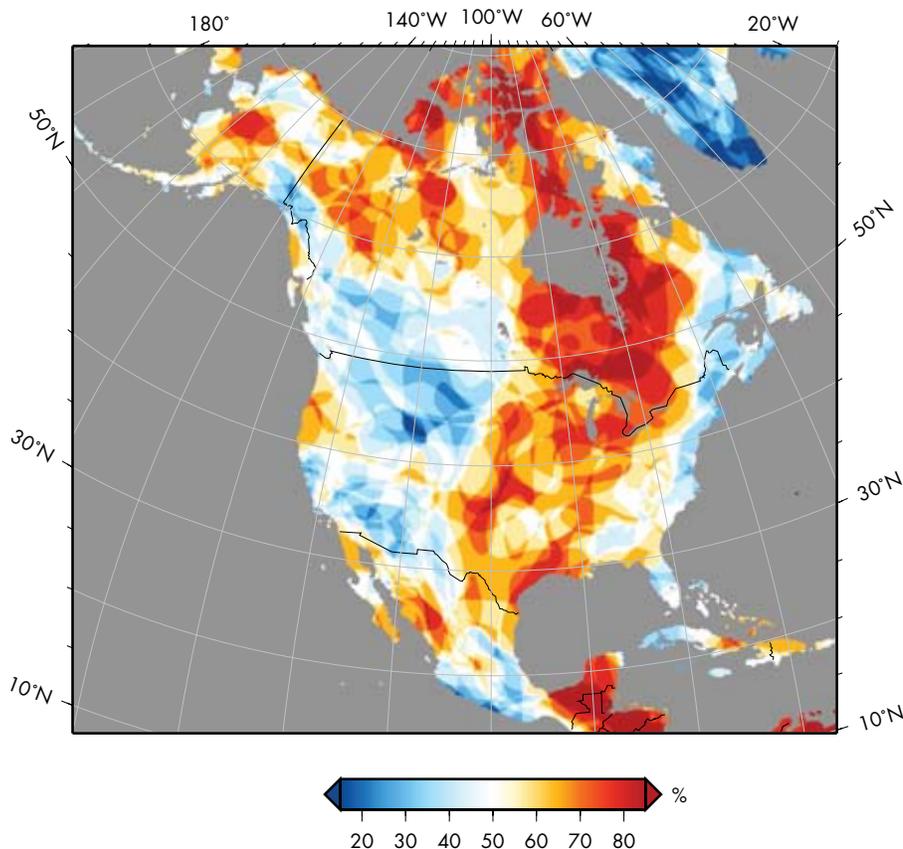
Because these components can be positive as well as negative, this method can lead to a significant underestimation of the scalar wind speed in areas that routinely experience a reversal of the wind direction during the day (i.e., locations in which the dominant winds are thermally driven). To the extent that such winds are not represented well – due to the coarse horizontal resolution of the GCMs – this discrepancy may not represent a large inaccuracy of the analysis.

### **Results: global**

Figure 1 shows a global map of the percentage of GCM simulations predicting increased annual-mean near-surface wind speed values in 2050 using the A2 emission scenario. The map is created by counting the number of model simulations that predict increased wind speed values and dividing by the total number of simulations (i.e., 14). The map provides no information concerning the magnitude of the expected change, but it does provide information on the agreement between the model simulations.

Dark red areas correspond to regions in which most of the models predict stronger surface wind speeds. Conversely, areas of dark blue imply that most of the models predict weaker surface wind speeds (i.e., only a very small percentage of the models predict stronger surface wind speeds). Areas of pale color indicate regions in which a clear consensus does not exist among the GCMs. Since the spatial pattern of the predicted wind speed changes is very similar for both the A2 and B1 emission scenarios, results will only be shown for the A2 emission scenario.

**Figure 2B: Annual-Mean Percent Increase**



On an annual basis, climate change is predicted to cause stronger surface wind speed values across the boreal regions of the Northern Hemisphere, including much of Canada, Siberia and northern Europe, and in tropical and subtropical regions in Africa, and Central and South America. However, Greenland, southern Europe, China, India, southern Australia and much of the west coast of South America are expected to experience decreasing wind speed values.

Inter-model contrasts are largest in western North America, sub-Saharan Africa, broad swaths of Eurasia, Brazil and the Andean region of South America. The annual analysis masks seasonal variation in the predicted wind speed changes; in some areas, these changes differ in sign across seasons.

Recent research has found that the jet streams and associated storm tracks have been shifting poleward during the period 1979-2001. In

addition, a separate analysis of the CMIP3 data set showed that storm tracks are expected to continue to shift poleward in response to climate change forces.

In some areas, the surface wind speed changes shown in Figure 1 appear to be associated with the predicted changes in the mean position of the storm tracks. For example, the predicted stronger surface wind speeds across northern Europe and weaker surface wind speeds across southern Europe are consistent with a poleward shifting storm track across the continent – great for Germany, but sad for Spain. Similarly, the predicted changes between latitudes 20 degrees South and 40 degrees South in South America and Australia correspond well with a poleward shift in the position of the storm tracks.

#### **Results: North America**

Figures 2A, 2B, 2C and 2D focus specifically on North America and include the ensemble-mean pre-

dicted change in annual-mean wind speed (2A) as well as the percentage of models that predict an increase in the annual-mean (2B), winter-mean (2C) and summer-mean (2D). The predicted changes from the individual models vary greatly from the ensemble average.

However, most models predict an increase in annual mean wind speed values across the northern part of the continent and along a broad swath from Hudson Bay southward into Texas and parts of Mexico, including the Yucatan peninsula (Figure 2B). There is less agreement among the models about decreases in mean annual wind speed values. The greatest agreement is found in the mountainous West, the Southwest and along the Atlantic seaboard, but much uncertainty remains.

The areas that show the greatest agreement among models also show the largest predicted annual mean wind speed differences (Figure 2A). Averaged across all the models, the predicted changes in the mean annual wind speed are relatively small. Changes in the annual mean are predicted to be less than +/- 0.2 meters per second (m/s) in general and less than +/- 0.1 m/s for much of North America.

Since the ensemble average is composed of many dissimilar fields, the magnitude of the predicted change is small. However, individual models show predicted wind speed differences of +/- 0.5 m/s, which are large enough to affect the profitability of existing and future wind projects. For the wind-rich area of west Texas, the models show a strong consensus of an increase in the annual mean wind speed.

In addition, the relatively small predicted changes in the annual mean wind speed values mask a strong seasonal signal. Most models agree that wind speed values likely will increase over much of North America during the winter months (i.e., December, January, February),

Figure 2C: Winter-Mean Percent Increase

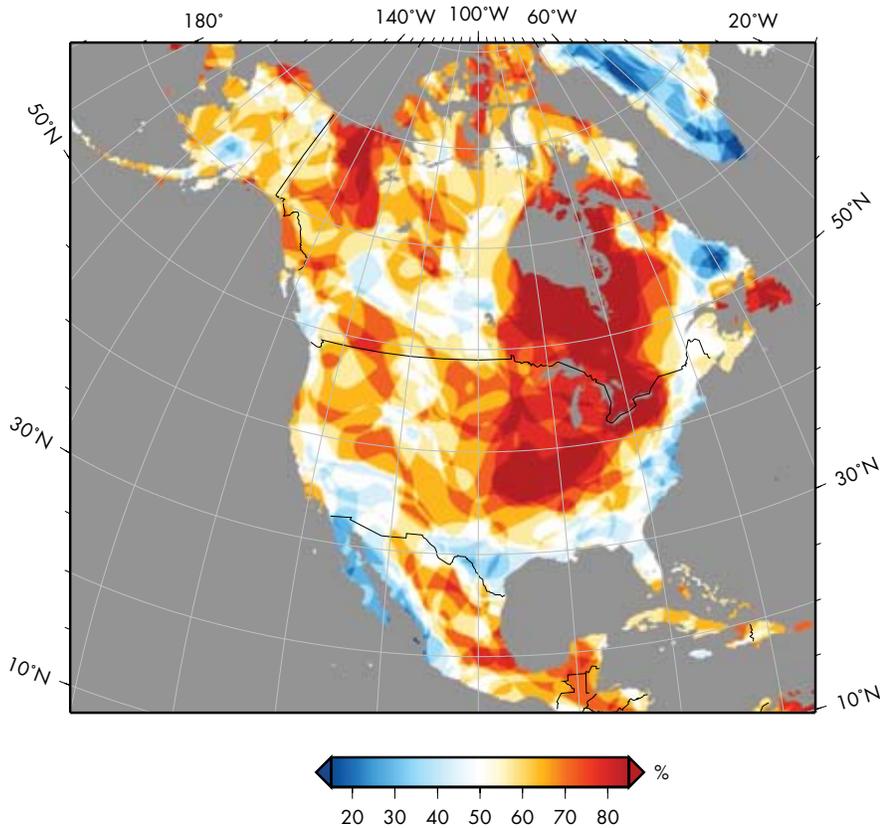
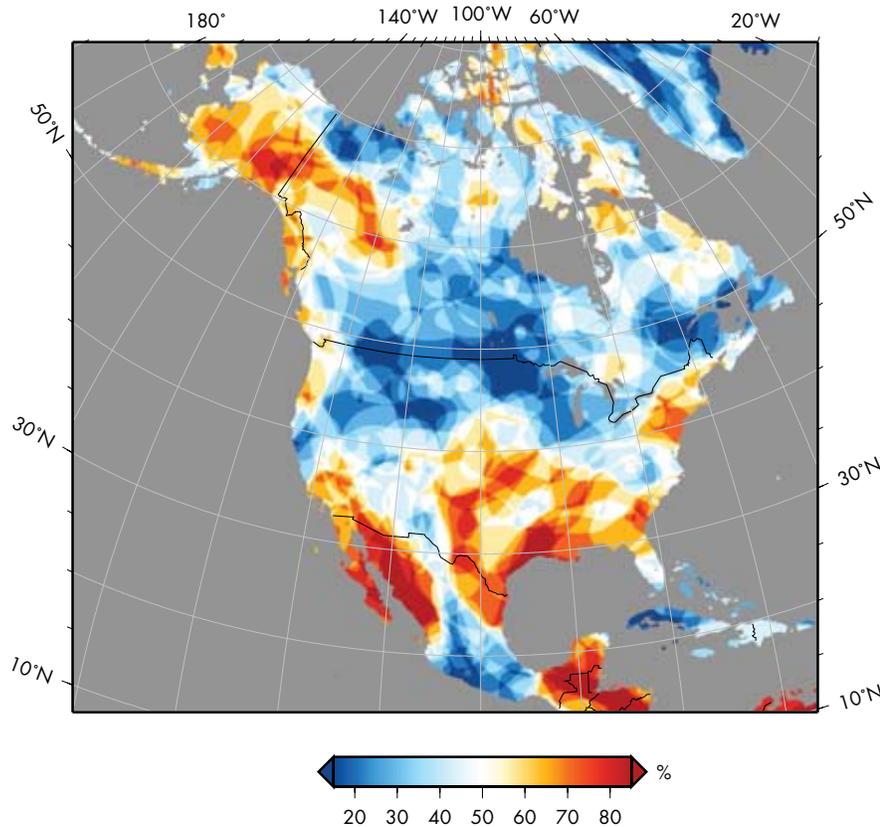


Figure 2D: Summer-Mean Percent Increase



with the strongest consensus between the models from Hudson Bay south into the central U.S.

The predicted increase in the wintertime mean across the Upper Midwest of the U.S. will bolster the many wind projects in the region that are predominantly wintertime peaking. Most models agree on a decrease in winter wind speed values in Baja and around the Gulf of California. During the summer months (i.e., June, July, August), model agreement shows nearly the opposite signal compared to the winter months, with most models agreeing on a decreased wind speed in the northern half of the continent, part of Mexico and the Caribbean, and an increase in Alaska and along the Gulfs of Mexico and California.

The results of this evaluation of predicted changes in mean wind speed show that the predicted ensemble-mean changes in annual mean wind speeds are expected to be modest. However, seasonal changes and changes predicted by individual models are large enough to affect the profitability of existing and future wind projects. **NWP**

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