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Does Climate Change Threaten Wind Resources?

Atmospheric circulation patterns can determine a region's vulnerability to significant long-term drops in wind speed.

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Wind and climate variability are inextricably intertwined. But although much attention is given to the potential effects of climate change on surface temperatures (global warming) and precipitation, there has been comparatively little discussion or analysis of prospective changes in wind speeds.

In scientific circles, the general assumption is that because global warming will reduce the temperature difference, or gradient, between the poles and the equator (the same temperature difference that is responsible for the jet stream), mid-latitude winds will also be reduced.

The research described here suggests the issue is actually more complex. The next few decades under a changing climate may see greater variation in seasonal and annual wind speeds, making long-term planning for wind energy purposes problematic.

Moreover, some of the areas where much wind development is occurring, such as California and the Great Plains, may be especially susceptible to climate change, because their wind regimes are dominated by one particular atmospheric circulation pattern. Thus, understanding how climate change can affect wind climates is vital to sustaining growth in the wind energy industry in the coming decades.

So far, historical wind measurements reveal very little about the impacts of climate change. Analysis of long-term U.S. climate station wind speed observations shows a small negative trend (about -0.1 m/s/decade) during the last decade.

Individual stations show statistically significant increases or decreases in wind speed during this time. However, non-climatic factors, such as changes in local land cover, instrument continuity or station location moves, may be responsible.

Wind speeds above the boundary layer (above 1,500 meters) show a definite positive trend throughout North America during the last 20 years. This shift follows a general decrease in wind speeds observed during the previous two decades.

Whether these changes represent natural fluctuations or are a consequence of global climate change remains an open question.

Resource assessment

In the research described here, output from a general circulation model (GCM) applied in climate-change studies has been used to initialize a mesoscale weather model to examine how thermodynamic changes in the atmosphere may affect local winds.

The study area is the wind-resource-rich mountain passes of southwestern California, where the primary mechanism driving the favorable gap winds, such as those observed at Tehachapi Pass, is the temperature difference between the San Joaquin Valley and the Mojave Desert.

Wind speeds are generally highest during late spring and early summer afternoons in these passes because of the increasing temperature gradient between the rapidly heating Mojave Desert to the south and east and the relatively cooler surface of the San Joaquin Valley to the northwest. Other gap winds in coastal California are generated through land-sea temperature differences analogous to local sea breezes.

These temperature contrasts are reduced during the late summer and early fall, resulting in the lower wind speeds observed at this time.

Under the sponsorship of the California Energy Commission and the Lawrence Livermore National Laboratory (LLNL), simulations of historical (1980-1999) and future (2041-2060) climate were performed in order to estimate changes to wind power potential in the area in and around Tehachapi, Calif.

Output from a high-resolution (50 km) GCM (using the IPCC A2 greenhouse gas emissions scenario) conducted at LLNL for the North American Regional Climate Change Prediction Project, funded by the National Science Foundation, was used to initialize the Mesoscale Atmospheric Simulation System (MASS) model.

Two nested MASS grids of 15-km and 4-km resolution were run.

This method produced 727 24-hour cycles for each 20-year run, with a wind speed uncertainty of ± 3% (or about 0.3 m/s at Tehachapi Pass).

Simulations of future climate are of little value if the model cannot reasonably reproduce recent temporal and spatial weather patterns. The MASS historical simulations capture both the pattern and magnitude of observed wind speed distributions, and mean wind speeds from long-term tall tower data in the vicinity of Tehachapi show good agreement with the MASS model climatology simulation.

A general increase in 2-meter air temperatures across the entire domain (about 0.2 degrees Kelvin per decade) is also consistent with observations at a Bakersfield, Calif., weather station northwest of Tehachapi.

Future scenario

Qualitatively, the general spatial distribution during the future scenario period is quite similar to that of the historical run, indicating that the large-scale atmospheric circulation patterns do not change appreciably.

However, there is a general decline in wind speeds throughout the MASS 4-km domain compared with climatology, with most areas showing a 5% to 10% decrease. The only relatively windy areas (class 5 or above) to experience a net increase in available wind power (10% to 20%) are in the vicinity of Simi Valley and the windward side of the mountains north of San Bernardino.

The area in and around the existing Tehachapi wind farms indicates an equivalent 10% to 15% decrease in available wind power.

The researchers also noted a small decrease (-0.11 m/s/decade) in 70-meter wind speeds during the 20-year future scenario period. Annual wind speed variability at Tehachapi, however, shows a decrease from about 9% during the climatology period to around 5% during the 2041-2060 time span.

Although there is an overall decrease in average wind speed at Tehachapi, this decline is not evenly distributed throughout the year. In May through August, wind speeds are nearly 1 m/s greater, while during October and November, there is a comparable decrease in the magnitude of the 70-meter winds.

These changes may be a reflection of the primary mechanism responsible for the highest wind speeds during the spring and fall months – the San Joaquin-Mojave Desert pressure/temperature gradient. Under the future climate scenario, the pressure gradient is about 0.1 hectopascal greater during the spring-summer season because of increased warmth over the Mojave Desert.

Overall, however, the pressure gradient shows a 0.2 hectopascal decrease, reflecting the annually averaged reduction in wind speeds observed at Tehachapi. One possible reason for the seasonally driven pressure gradient changes may be the way in which the model conserves soil moisture.

Previous studies have found that irrigation in the San Joaquin Valley increases the temperature (and hence, the pressure) gradient across the Tehachapi region, resulting in wind speeds 0.5 m/s to 1 m/s higher than would otherwise be expected.

As for the other California regions experiencing a net increase in wind speeds (principally the coastal areas near and south of Oxnard), an enhancement of the sea-breeze circulation seems likely, which is consistent with findings from other recent studies.

The local circulation between the San Joaquin Valley and the Mojave Desert is the key mechanism responsible for maintaining the robust winds observed in the Tehachapi Pass area. Significant decreases in wind speed (2% to 4% or more) and power potential (10% to 15%) are forecast to occur in and around Tehachapi.

The exception to the trend occurs in the warm season months of May through August, when an enhanced pressure/temperature gradient further energizes the flow through the Tehachapi Pass. NWP

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