Project Summary

This work focused on the impact of so-called “modes of variability,” or teleconnections, within the climate system on wind energy in the Upper Midwest (40-52°N, 87-105°W). Wind as a resource has come into prominence as climate change due to fossil fuel carbon emissions threatens to push the world into a state previously unseen in all of human history and even recent geologic time. While wind provides energy with no carbon footprint (and only a minor footprint over the lifetime of a turbine), the rise of wind (and solar) energy in a period of rapidly changing climate poses questions which are of immediate concern to society. Wind is a component of the general circulation of the planet and is regulated by many factors which a changing climate will directly impact. Further, even without externally forced climate changes due to greenhouse gases, there is internal variability which naturally occurs as a result of the fluid dynamics and energetics of the system. Internal modes of variability occur as specific shifts in factors such as surface pressure or sea surface temperature patterns which affect weather and climate over wide geographical areas. The most well-known example of such a mode is the El Nino-Southern Oscillation (ENSO), which affects global weather patterns due to its episodic changes of phase every 2-7 years. Understanding how these modes impact wind in the Upper Midwest is key to understanding wind resource variability over periods of months to decades and could have implications for future wind output prediction and preparation. In this study, wind speeds are transformed into wind power output, assessed for accuracy against observed monthly power output in the region and assessed for the impact of several major teleconnections using a multilinear regression model.

Going into this process, the goal of this work was to use the tools of synoptic climatology (weather patterns over scales of 1000-4000 km), specifically synoptic typing, to better constrain the impact of the global teleconnections on local wind energy variations via changes in regional circulation patterns. In the course of this work, it was found that through several iterations of synoptic typing and assessment, the use of synoptic types for linking teleconnections to local energy variations was not going to yield useful results. Changes in synoptic types were, indeed, found to correlate well with changes in wind output due to understood influences of regional pressure patterns on wind speed. However, the synoptic types did not change with changes in phase of the teleconnections in ways which yielded strong relationships. It was found that the change in daily synoptic patterns captured variations in circulation which were only minorly linked to the teleconnections, which themselves caused synoptic variations over monthly and longer time periods which were distinct from those encapsulated by the typing schemes assessed here. It was found, however, that the links between the teleconnections and wind resources were better constrained by removing the effects of short-term, daily synoptic variations using the regression model approach. As such, while the synoptic patterns and the teleconnections both cause significant variations in wind resources, the synoptic regimes were not best used as the vehicles by which to understand these influences.

The final regression models included two variables to account for synoptic conditions (the type-patterns and the pressure gradient, which describes how strong the patterns are [larger gradients = faster winds]), as well as the indices for five teleconnections important to the Upper Midwest. The timeseries for wind power output, as derived using model data, were modeled as the response to the synoptic and
teleconnection indices for each meteorological season (spring = MAM, summer = JJA, autumn = SON, winter = DJF). This allowed for two main advantages: the competing and complementary effects of the teleconnections could be accounted for and the variations with season could be assessed.

As is shown in the paper, the impacts of the teleconnections, both spatially and in sign, change with the seasons. Overall, monthly power output varies by about 37%, though smaller portions of the region can vary from the ‘normal’ output (climatological power out based on the average over the whole period) by up to 50%. Some teleconnections interact to periodically reinforce or dampen the others’ impacts. One interesting finding was that large, tropical volcanic eruptions, which are already well known for cooling global climate for months to years, tend to cause slower winds (and less power output) across much of the region due to the impacts of volcanic emissions on solar energy across the hemisphere. All of these findings have significant implications for wind energy in the region, both in terms of understanding monthly to decadal variability and in terms of planning for future wind farm deployment. Through better information and planning, energy utilities and decision makers can more efficiently move towards the use of renewable wind resources with fewer unfortunate surprises which could otherwise slow such progress, both for financial and political reasons.

**Results**

The final results of this project are described in the paper (also attached with this report) which is intended to act as the capstone to my PhD dissertation, as well as third publication by means of submission to a peer-reviewed journal. The process of submitting the paper to a journal is not yet complete but is close and is expected in August 2020 (next month). I also presented preliminary work on this project to the 100th Annual American Meteorological Society Conference in Boston in January 2020. The presentation is also attached, with proper attribution and thanks provided to the Consortium for their generous financial support. The final publication of this work in a journal will also contain such an attribution.

**Future project plans**

The results of this project are to be included in my dissertation which I intend for completion in August 2020 (next month, as of this writing). The results of this work have received attention and interest from energy companies and their representatives, though the output is also potentially useful to government stakeholders for planning and preparation purposes. The Consortium mandate of furthering the understanding of issues related to social and environmental health has been fulfilled by this work in that having completed the research, we now have a better understanding of how wind resources in our region vary over multiple timescales, enhancing our capacity for further renewable energy development. Future work will expand on these findings by looking as wind resources over wider spatial domains, longer time horizons and at changes caused by externally forced climate change due to greenhouse gases and other factors which have become important in the contemporary era.