# ATOC 5770: Wind Energy Meteorology

# Spring 2022

# Graduate Student Programming Project Guidelines

Instead of completing eight weekly homework projects like the students enrolled in ATOC 4770 will complete, graduate students enrolled in ATOC 5770 will work on projects more appropriate for researchers. **The topic should be chosen by Feb 1.** Of the homework portion of the final grade:

* One-fourth of the graduate student HW grade is based on one **literature review** (written report) motivating a data analysis project relevant to renewable energy meteorology (**completed and submitted to Canvas by** **Tuesday Feb 15)**,
* Another fourth of the graduate student HW grade is based on the **execution of that data analysis project** (completed by **Tuesday Mar 15)**,
* Another fourth of the graduate student HW grade is based on a **journal-paper-style written report** of that programming project (incorporating a short summary of the literature review) (optional first draft submitted by **Tuesday Apr 5 for feedback from Prof. Lundquist by Apr 15 and final required version submitted to Canvas by Tuesday Apr 26)**,
* And the final fourth of that is based on a **12-min conference-style presentation** (recorded **and submitted to Canvas by Tuesday Apr 26**) on that data analysis project.

The goal of the project is for the student to gain experience analyzing and understanding renewable-energy related data, writing a scientific paper, and giving a conference-style presentation.

The literature review should consist of an outline of the existing scientific literature on the topic, organized by relevant themes or approaches, including at least 10 peer-reviewed scientific publications and 2-5 sentences describing the significance of the publication. Example entries are found at the end of this document. No specific template is required other than an outline and a correctly formatted reference list.

The written report should:

* be a maximum of 20 pages in length, including figures and references, written double- spaced, with 12-pt font and 1-inch margins using a template from a peer-reviewed journal (American Meteorological Society, American Geophysical Union, or Copernicus).
* be grammatically correct with no spelling errors (see <http://www.colorado.edu/pwr/writingcenter.html> for assistance, or consult Schultz’ “Eloquent Science: A practical guide to becoming a better writer, speaker, & atmospheric scientist” (2009, available at CU library as an e-book)
* cite references using the appropriate AGU, AMS, or Copernicus journal publication style
* provide compelling motivation for the investigation
* summarize previous peer-reviewed work in this area
* clearly explain the dataset and methods used for the investigation
* discuss results and conclusions

A suggested outline for the written report would be:

1. Introduction

* Describe your question/topic and hypothesis.
* Provide motivation for why this is an interesting question
* Discuss the previous work in this area, backing up your hypothesis with references to work already presented in the peer-reviewed literature.

1. Dataset

* Provide an overview
  + If analyzing observations, what are the temporal, spatial characteristics?
  + If conducting simulations, what is the modeling set-up, forcing boundary conditions, choice of parameterizations?
* Quantify primary errors and uncertainties

1. Analysis Method
2. Results & Discussion

* Present and discuss your results.
* Include a discussion of how any errors or uncertainties in the data affected your results.

1. Conclusions

* Summarize your conclusion about your original hypothesis, including discussion of any limitations to your analysis
* Suggest how your results may be applied by others working in this area
* Suggest future avenues of investigation that may be useful

1. References Cited

* I strongly suggest using reference management software like Zotero to facilitate correct incorporation of references

The project presentation should be in the style of a 12 min conference presentation:

* Present a scientifically and visually appealing summary of the motivation, methods, results, and significance of the project
* Be grammatically correct with no spelling errors
* Be visually engaging with appropriate use of color
* Cite relevant references in an unobtrusive way on the relevant slide (not stacked at the end) using the appropriate AGU or AMS journal publication style

Numerous possibilities for appropriate research topics include but are not limited to:

* Wind resources are often estimated using numerical weather prediction models, especially in locations where measurements are difficult of obtain, like offshore. Limited sets of offshore lidar wind measurements are becoming available, like the DOE lidar buoys (<https://a2e.energy.gov/data#ProjectFilter=%5B%22buoy%22%5D>). What are the averaged wind profiles from the lidar buoys? How do those vary with atmospheric stability? How do they compare with offshore wind resource estimates like the CA20 dataset (<https://gmd.copernicus.org/preprints/gmd-2021-50/> )?
* Strong wind events like chinooks are problematic for wind energy and transmission lines (not to mention wildfires…). Using reanalysis data (<https://www.renewables.ninja/>), have the frequency, intensity, or duration of these events increased in the last twenty years?
* What is the typical annual cycle in wind power production in different parts of the United States? How can increased transmission smooth out variability? An example (WY to CA is summarized in <https://www.technologyreview.com/s/609766/how-to-get-wyoming-wind-to-california-and-cut-80-of-us-carbon-emissions/)>. Monthly wind power production data for individual wind plants can be obtained from the Energy Information Agency at <https://www.eia.gov/electricity/data/eia923/> .
* Sea breezes provide significant offshore wind resource, often near high-population urban centers. What is the annual climatology of the sea breeze in a given location of interest? Reanalysis datasets such as MERRA2 (<https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/)> could be useful to such a study.
* When estimating wind resources, how important is it to calculate the rotor-equivalent wind speed ([Wagner et al. 2014](http://iopscience.iop.org/article/10.1088/1742-6596/524/1/012108/meta), [Choukulkar et al. 2015](http://onlinelibrary.wiley.com/doi/10.1002/we.1929/abstract)) rather than just hub-height wind speeds? Data from the Wind Forecast Improvement Project in Complex Terrain (WFIP2) will be one of the most comprehensive datasets available for this project.
* Using meteorological towers that span the continental United States (Prof. Lundquist can provide directions to access these towers, also used in [Handschy et al. 2017](http://www.sciencedirect.com/science/article/pii/S0960148116308680)), what is the typical diurnal cycle in wind power production? How does this power production cycle vary by season and by location?
* Long-term observations are few and far between, but reanalysis products can provide insight into interannual variability of the wind resource (as in [Cannon et al. 2014](http://www.sciencedirect.com/science/article/pii/S096014811400651X)). Do these products have skill in North America? How do they compare with products like the [Wind Integration Toolkit](http://www.nrel.gov/grid/wind-toolkit.html)?
* Analysis of the diurnal cycle of the atmospheric boundary layer
  + CWEX-13 field data (lidars, radiometers, and surface flux stations)
  + NREL NWTC field data (towers, lidars, radiometer)
  + Perdigão field campaign.
* The strong winds associated with chinook events undermine wind power production. How often do chinooks occur along the Front Range? A quantitative assessment of the frequency of chinook events in Boulder using the 1996-2018 dataset from the NREL M2 meteorological tower would be useful.

**Example Literature Review**

Topic: Wind shear and wind veer affect turbine power production

* Onshore observations
  1. (Walter et al. 2009): This study analyzes data from a 118-m meteorological tower in West Texas to quantify the wind shear exponent alpha and the wind direction veer. They find a bimodal distribution of alpha, with values near 0 during daytime conditions and larger values at night. They also find that wind veer as large as 0.6 deg/m can occur in nighttime conditions. The diurnal cycle is independent of season in their Lubbock dataset. Finally, they use the FAST model to simulate the effect of wind shear and wind veer on turbines.
  2. (Sanchez Gomez and Lundquist 2020): This study compares lidar observations of wind shear and wind veer to power production from turbines collocated with the lidar. A strong diurnal cycle of wind shear and wind veer emerges in the lidar data. The relationship between shear/veer and power production is not simple: while veer generally undermines power production, shear can enhance power production.
* Offshore observations
  1. (Bodini et al. 2020): This study analyzes lidar observations off the US East Coast over 12 months. In addition to noting the seasonal cycle in wind speed (max in winter) and turbulence (min in summer), they observe very small values of turbulence offshore. Wind direction veer exhibits a strong annual cycle with large mean values in the summer (0.1 deg m-1) and small average values in the winter (0.04 deg m-1).

**References Cited:**

Bodini, N., J. K. Lundquist, and A. Kirincich, 2020: Offshore Wind Turbines Will Encounter Very Low Atmospheric Turbulence. *J. Phys. Conf. Ser.*, **1452**, 012023, https://doi.org/10.1088/1742-6596/1452/1/012023.

Sanchez Gomez, M., and J. K. Lundquist, 2020: The effect of wind direction shear on turbine performance in a wind farm in central Iowa. *Wind Energy Sci.*, **5**, 125–139, https://doi.org/10.5194/wes-5-125-2020.

Walter, K., C. C. Weiss, A. H. P. Swift, J. Chapman, and N. D. Kelley, 2009: Speed and Direction Shear in the Stable Nocturnal Boundary Layer. *J. Sol. Energy Eng.*, **131**, 011013, https://doi.org/10.1115/1.3035818.