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# The role of wind speed variability in very long-term wind power forecasts

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Machine Learning in Sustainable Energy Systems - University of Tübingen

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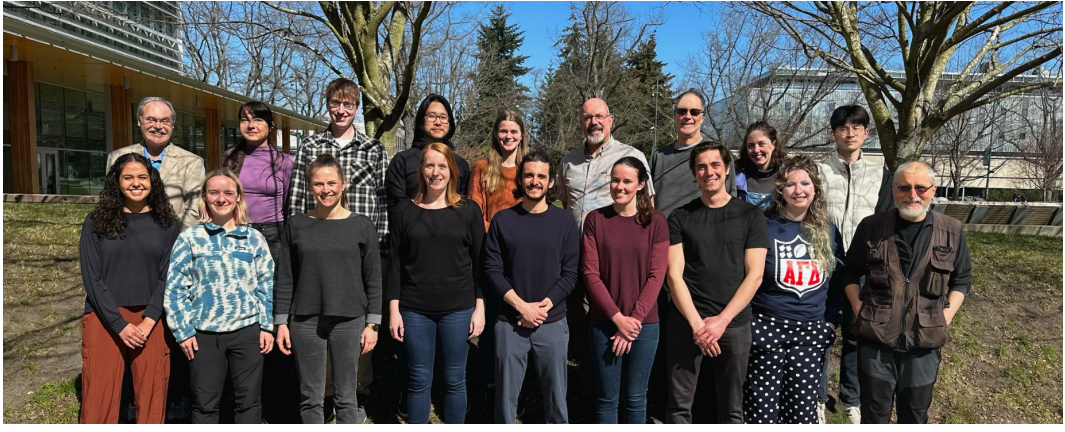
# Thanks to my collaborators

Rachel White (UBC), Nicole Ludwig (University of Tübingen)

# Thanks to the Weather Forecast Research Team

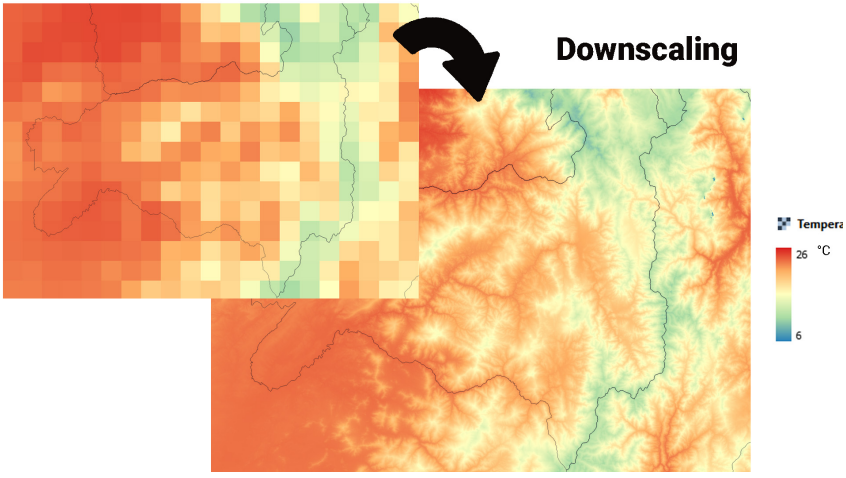
for (intellectual) resources



# Spatial Downscaling

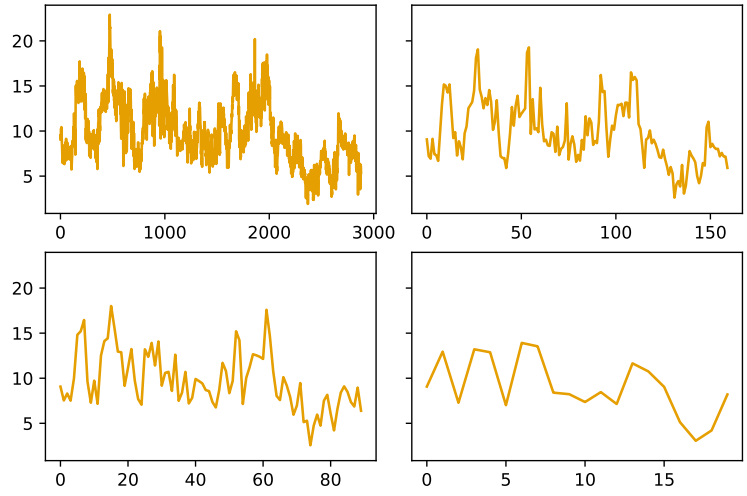
makes sense

https://giscrack.com/tag/spatial-downscaling/



# Temporal Downscaling

Is it straight-forward?



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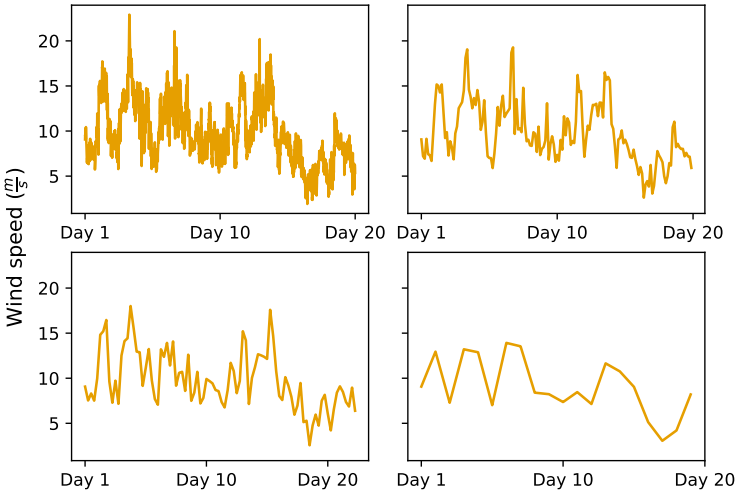
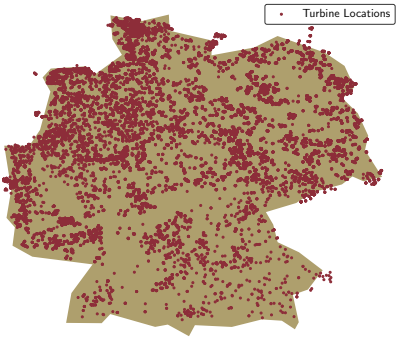


# Assessing wind power potential in the face of climate change

## Climate Downscaling: The idea

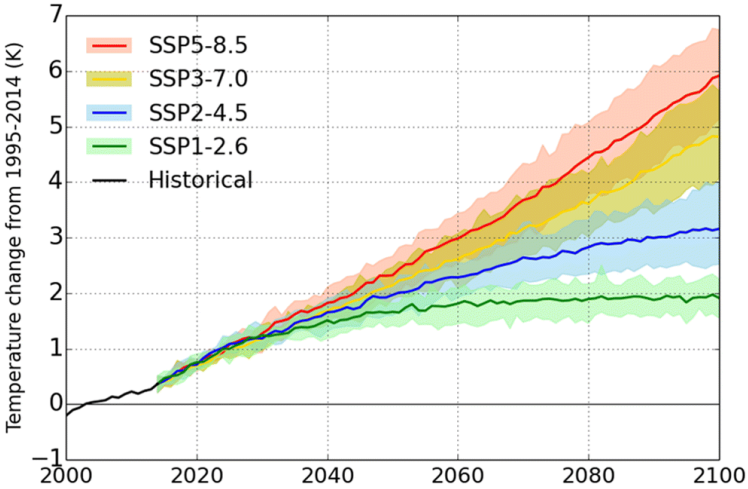
How much energy will a wind turbine generate over its lifetime?
How much wind power potential will we have in the future?



# Side note: Climate models

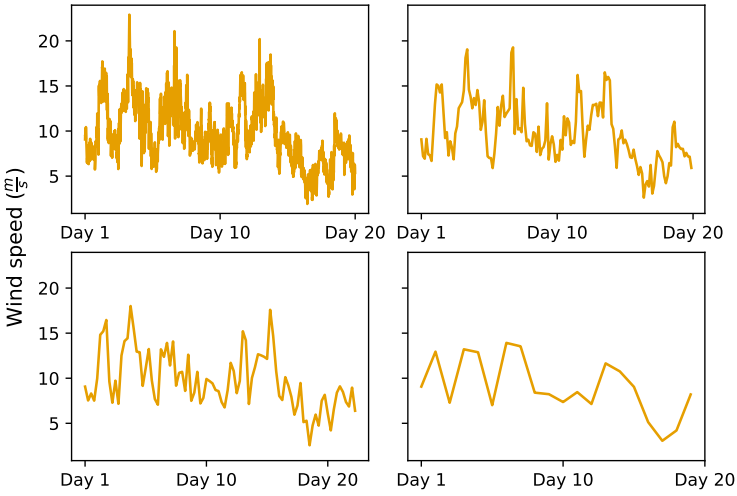
Like a very long weather forecast of low resolution

figure from Sung et al.[2021]



# Temporal Downscaling

Is it straight-forward? A bit.



# Which data resolution do we need?

We often don't have access to very high resolutions

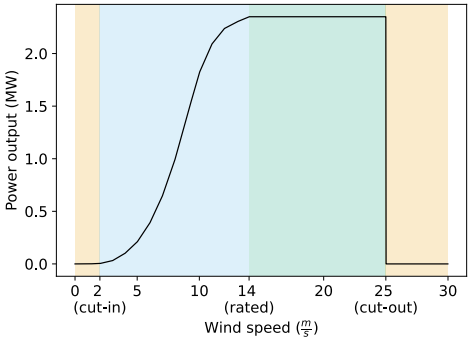
Again, the research question is: **How much energy will a wind turbine generate over its lifetime?**

→ Analyze wind observations and climate projections to see which impact the temporal resolution has!

# Power curves

We want the non-linear projections of wind speeds to be expressive

- Wind speed data is only our proxy for wind energy
- Wind power curves are non-linear
- Wind is a complex, local phenomena



# Now we know the problem

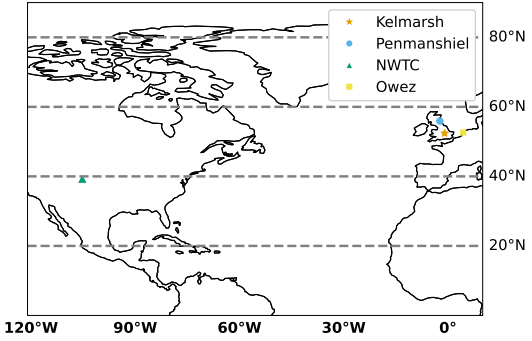
## A quick recap

- We want to know how much wind energy a turbine can generate over its lifetime.
- We know that we have wind speed projections that we can use as proxies. Wind energy depends non-linearly on these.
- And: Climate wind speed projections are often only accessible as 3 and 6 hour instantaneous values or 3h, 6h and daily averages.

**But which data resolution is the most valuable? And is that resolution high enough?**

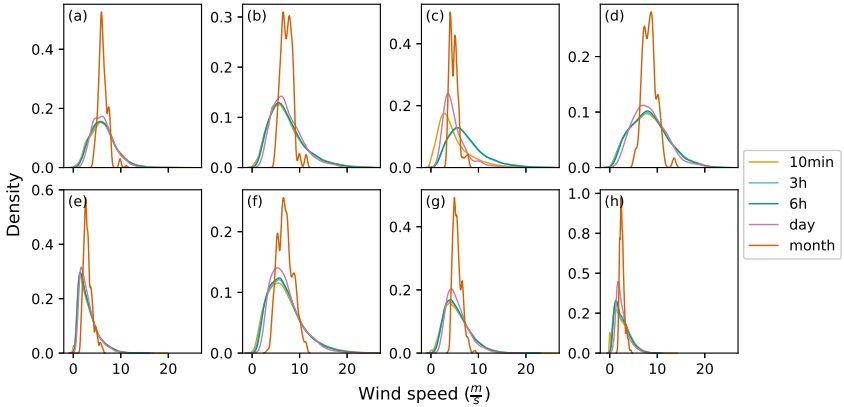
datasets from Plumley [2022], Ramon et al. [2020]

- Data: 10*min* averages of wind speed observations at hub-height and at 10 metres and climate projections
- Compare the wind speed distributions of common temporal climate resolutions
  - 3h, 6h, daily, monthly averages
  - 3h, 6h instantaneous values
- Parameterize the data and observe common tendencies
- Project the wind speeds to wind energy



# Wind speed distributions

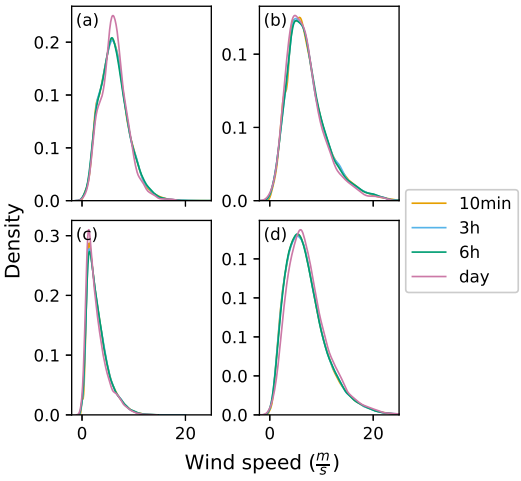
Monthly, daily, six-hourly and three-hourly averages



# Wind speed distributions

Daily, six-hourly and three-hourly instantaneous

- Monthly averages are not representative
- All other distributions *look similar*
- We compare them statistically
- In some minutes: We parameterize the distributions to see how the parameters change when data are averaged/discarded

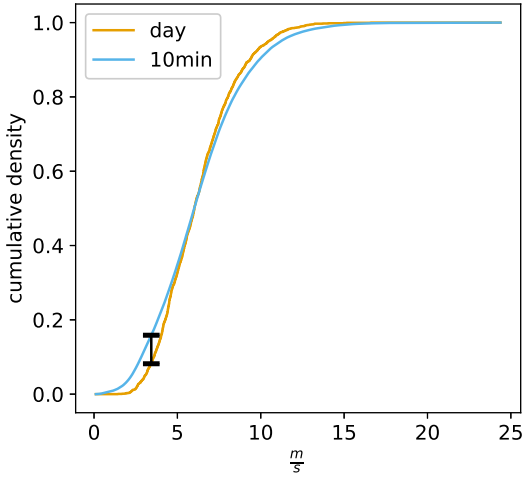


# Statistical analysis: Kolmogorov-Smirnov Tests

Compare the difference of the wind speed CDFs

Across 8 observation stations, 10*min* data are ...

- ... **always** statistically significant **different** from daily averages and daily instantaneous values
- ... **almost always** statistically significant **different** from three-hourly and six-hourly averages
- ... **almost never** statistically significant **different** from three-hourly and six-hourly instantaneous values



# Wind speed spectrum

## The spectral gap - known since 1957

Van der Hoven (1957)

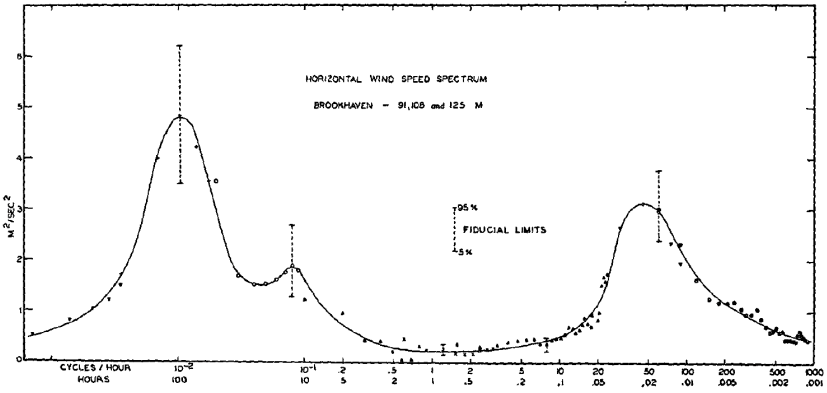
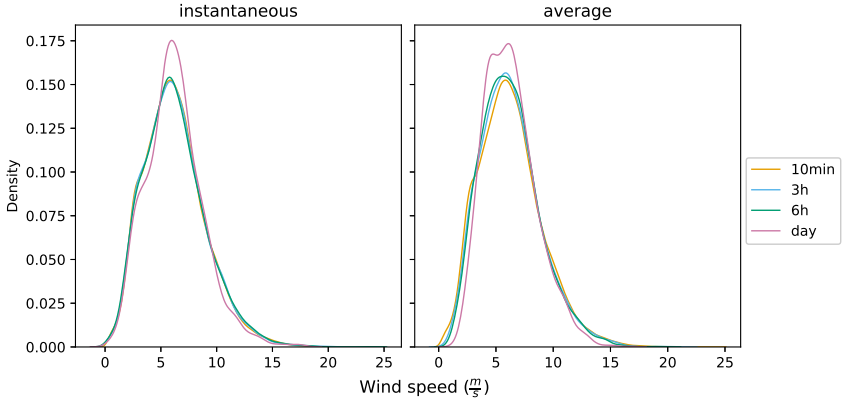



FIG. 1. Horizontal wind-speed spectrum at Brookhaven National Laboratory at about 100-m height. (See table 1 for date and time.)

# Remember how the KDE looked like

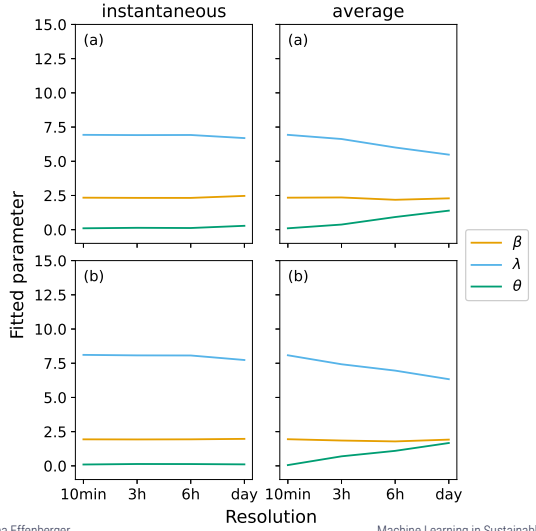
## The Weibull distribution

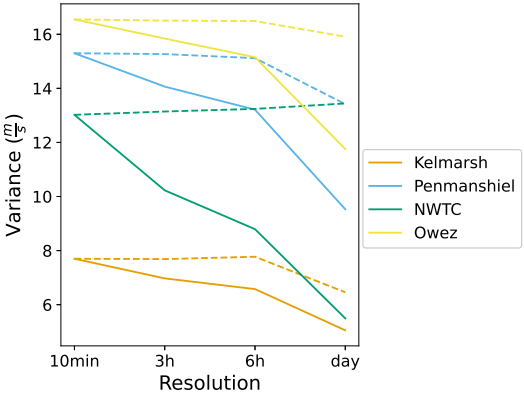



$$f(w;\beta,\lambda,\theta) = \frac{\beta}{\lambda}\left(\frac{w-\theta}{\lambda}\right)^{\beta-1} e^{-\left(\frac{w-\theta}{\lambda}\right)^{\beta}}$$

# What happens to the distribution when data is averaged/discarded?

Making the distributional shift visible using a Weibull parameterization

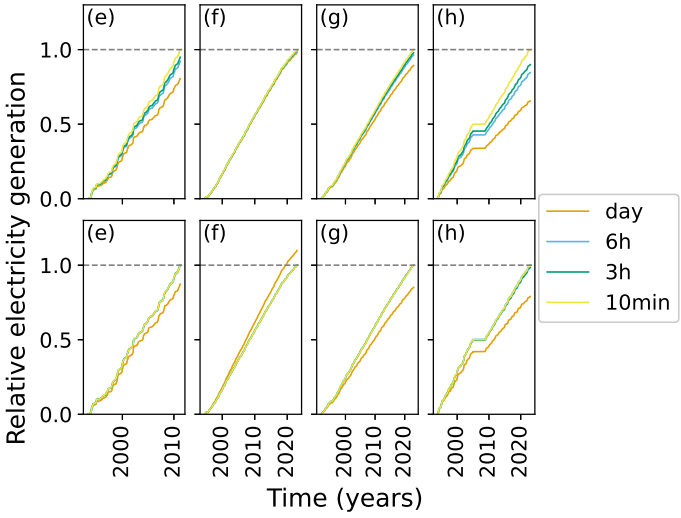



Dashed lines: variances of instantaneous values.
Solid lines: variances of average values.

# Wind energy generation

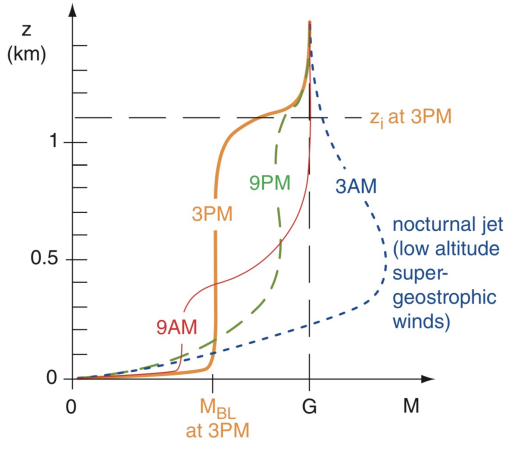
Averaging changes the wind energy generation prediction



# Daily wind speed observations are not representative

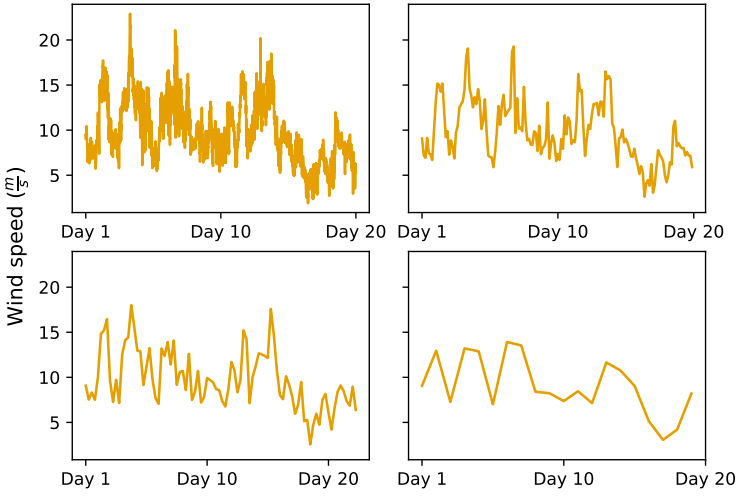
Wind speeds can vary heavily over a day

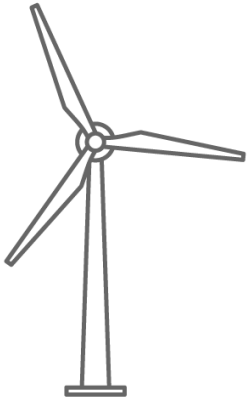
Stull[2017]



# Temporal Downscaling

Is it straight-forward? A bit more.



# Mind the (spectral) gap

Instantaneous values are more valuable than averages

1. Wind speed distributions shift when averaging over different time scales (Weibull parameter shift).
2. In contrast, instantaneous values of lower resolution very often preserve wind speed distribution statistics (test statistic of Kolmogorov-Smirnov).
3. Choose data that is suitable for your research question!