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Reducing Uncertainty in Offshore Wind Energy Yield Estimates via a Metocean Reference Site

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Wind Observations at Hub Height Are Sparse

- Wind observations at hub height are crucial for wind resource assessment because they:
  - Help with understanding the climate at a site of interest
  - Assist in creating a bankable data set for potential wind farm projects.
- One problem: They are often nonexistent, especially in offshore environments (Veers et al. 2019; Shaw et al. 2022).

A Sept. 2, 2021, photograph from the ground looking up at the Flatirons Campus tall meteorological (met) tower (M4) at Site 4.4. Photo By Scott Wilde, NREL

Enter … the Air-Sea Interaction Tower (ASIT)!

- Met tower with a suite of atmospheric variables
  - Lidar, too!
- Exists mere kilometers from the closest wind lease area
- Combined met-lidar data going back to 2017
- Great for validating models.

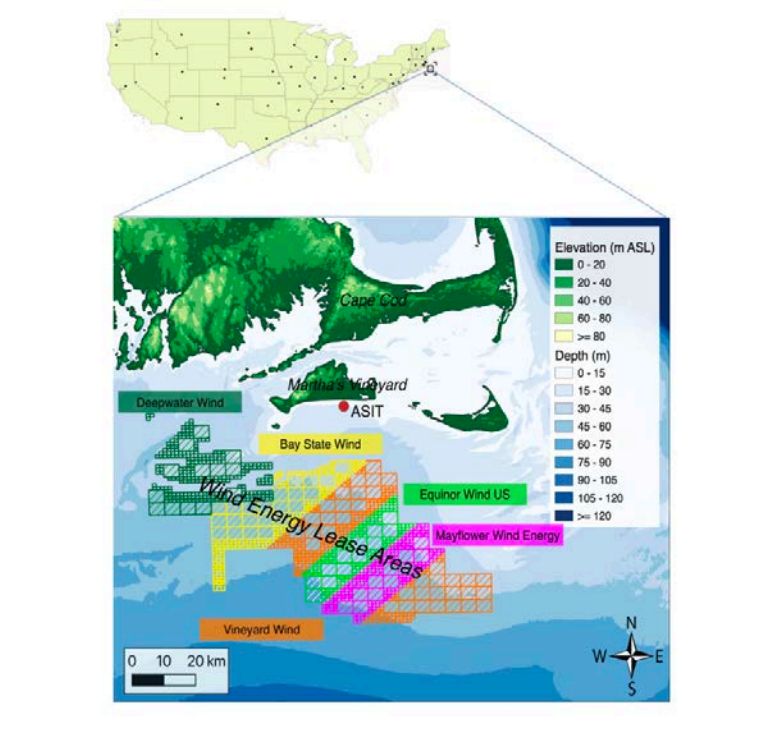


Figure 1 from Bodini et al. (2020), illustrating the location of ASIT in relation to neighboring wind energy lease areas.

But what if we don’t have tall tower data?

- Ways to estimate wind resource at hub height:
  - Numerical Weather Prediction
  - Weather Research and Forecasting (WRF) Model
  - Extrapolation via the wind power law (Lundquist 2020)
  - Machine learning
    - Extrapolation via buoys using random forests (Optis et al. 2021; Bodini and Optis 2020)
  - Many more in the literature!

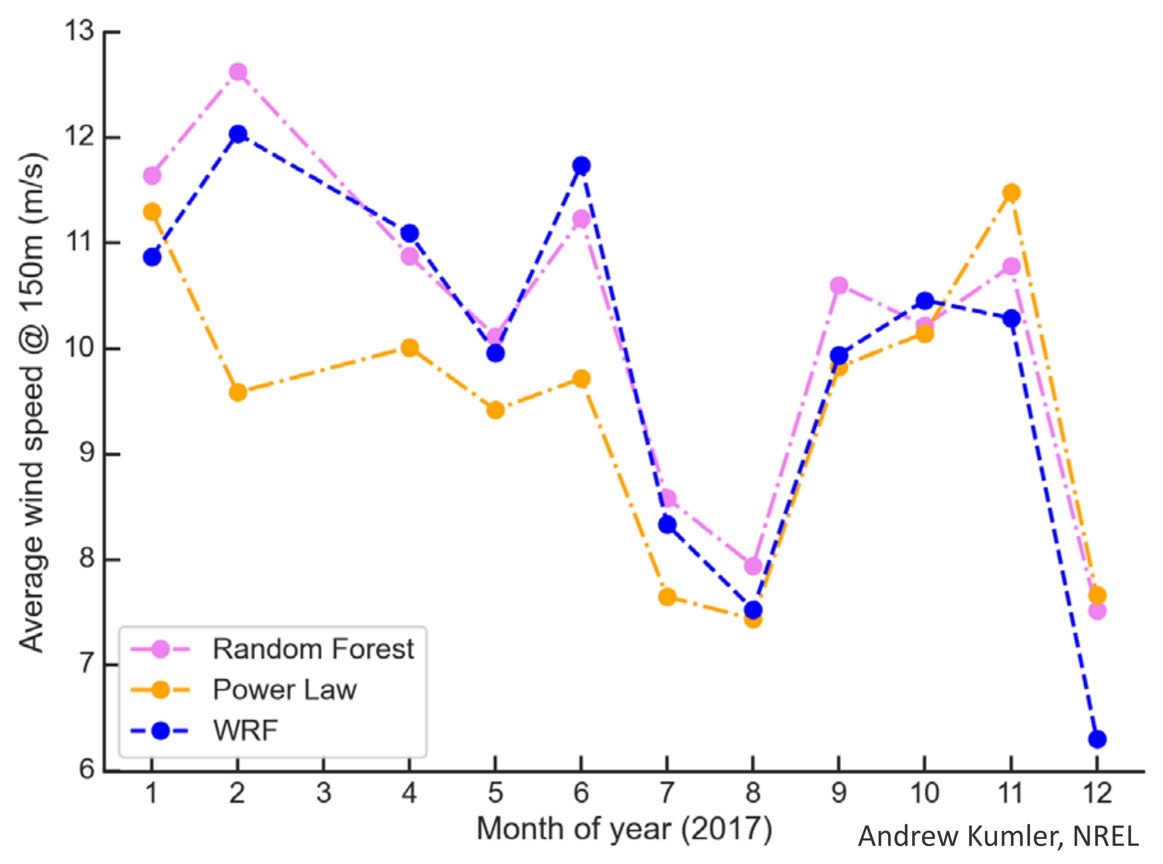
Show me the Data!

- ASIT meteorological and lidar data (2017–2020)
  - Met: wind speed, wind direction, temperature, relative humidity, pressure at ~20 meters (m) above mean sea level; sea-surface temperature at 4 m below mean sea level
  - Lidar: wind speed in increments of 10–20 m, from 40 to 187 m above mean sea level.
- Weather and Research Forecasting model (WRF) (Bodini et al. 2020)
  - 5-minute, 2-kilometer data wind speed data from 40 to 200 m
  - Covers entire mid-Atlantic.
- Wind power law (PL)
  - Use ASIT wind speed data to extrapolate wind speed to lidar heights. $U(z) = U(z_r)(\frac{z}{z_r})^{\alpha}$.
- Machine learning (random forest [RF])
  - Training on ASIT met data, targeting lidar heights.

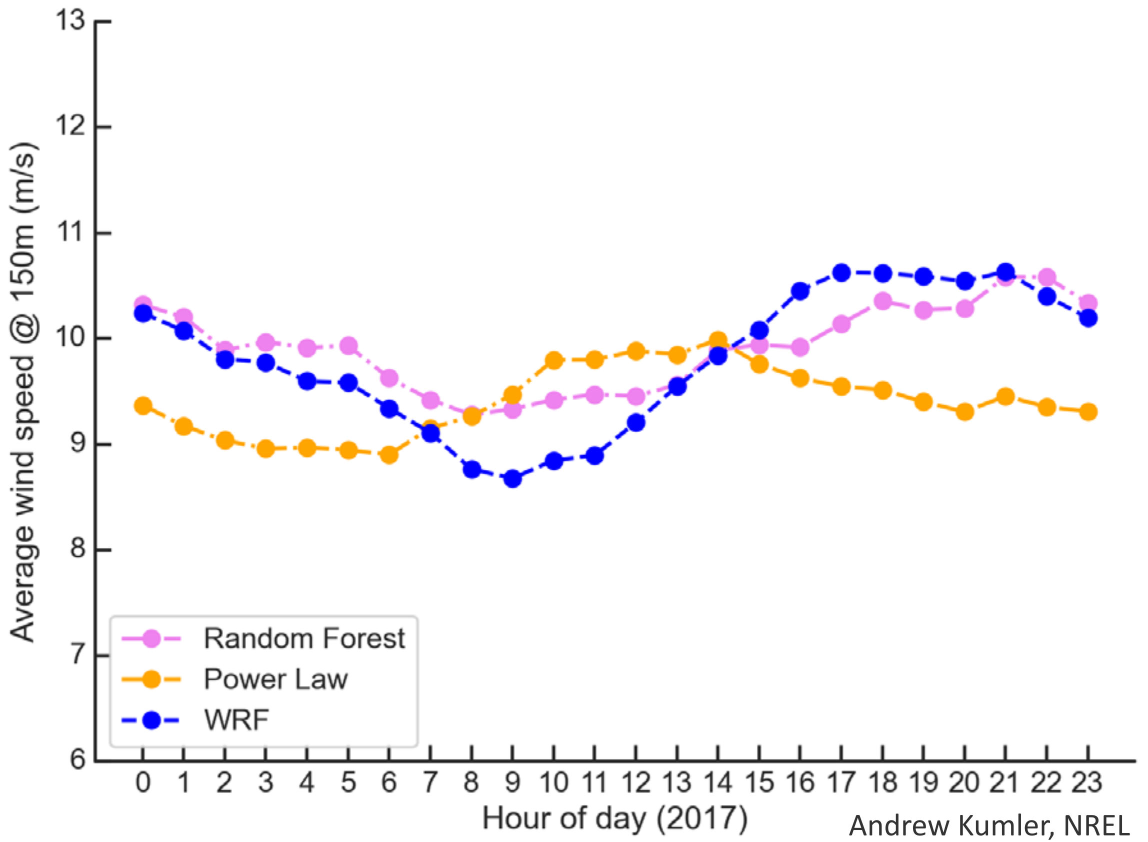
What if we don’t know conditions at the site?

What knowledge can be gained prior to looking at observations?

WRF and RF Show Agreement, PL Struggles



WRF and RF Agree Early Morning, PL Struggles



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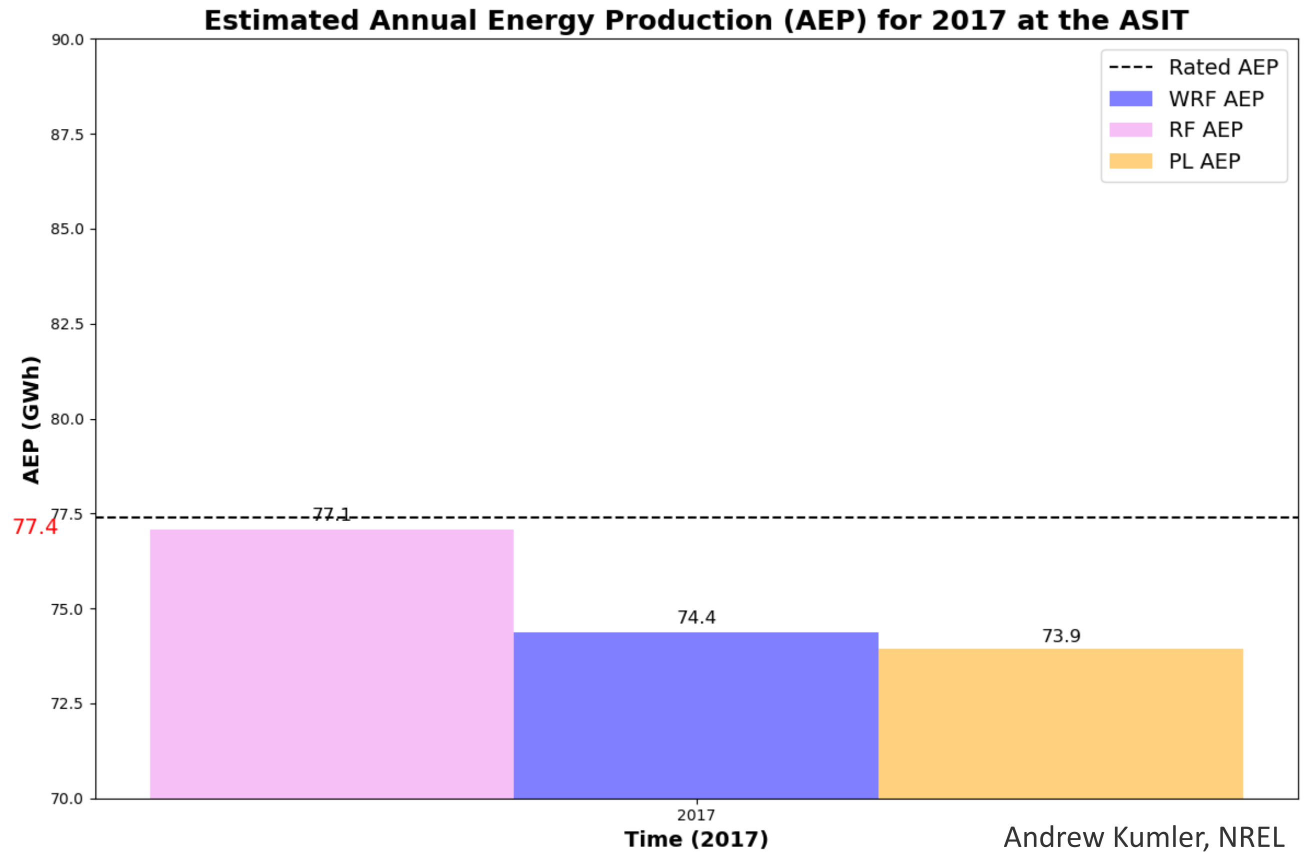
All Methods Underestimate Annual Energy Production (AEP) for 2017



GWh = gigawatt-hour

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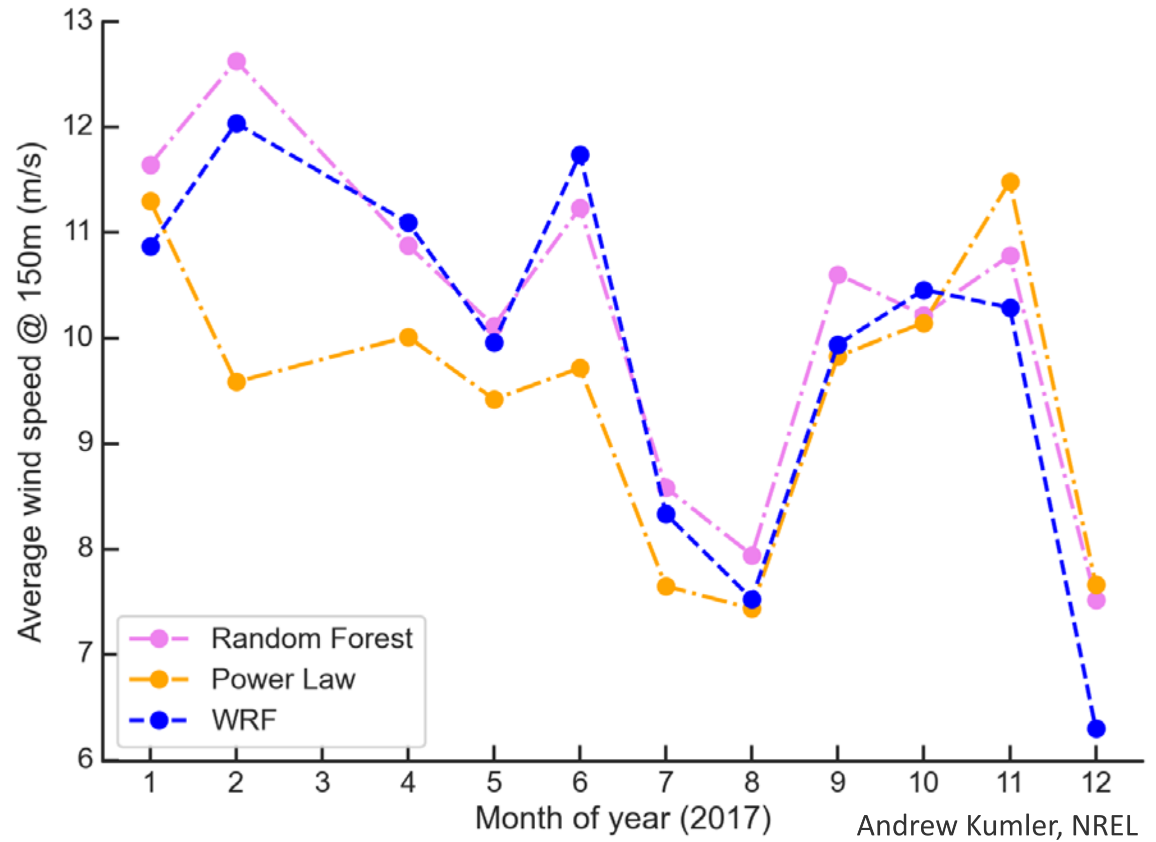
How do the estimation methods compare to observations?

Wind Energy Techniques Show Mixed Results



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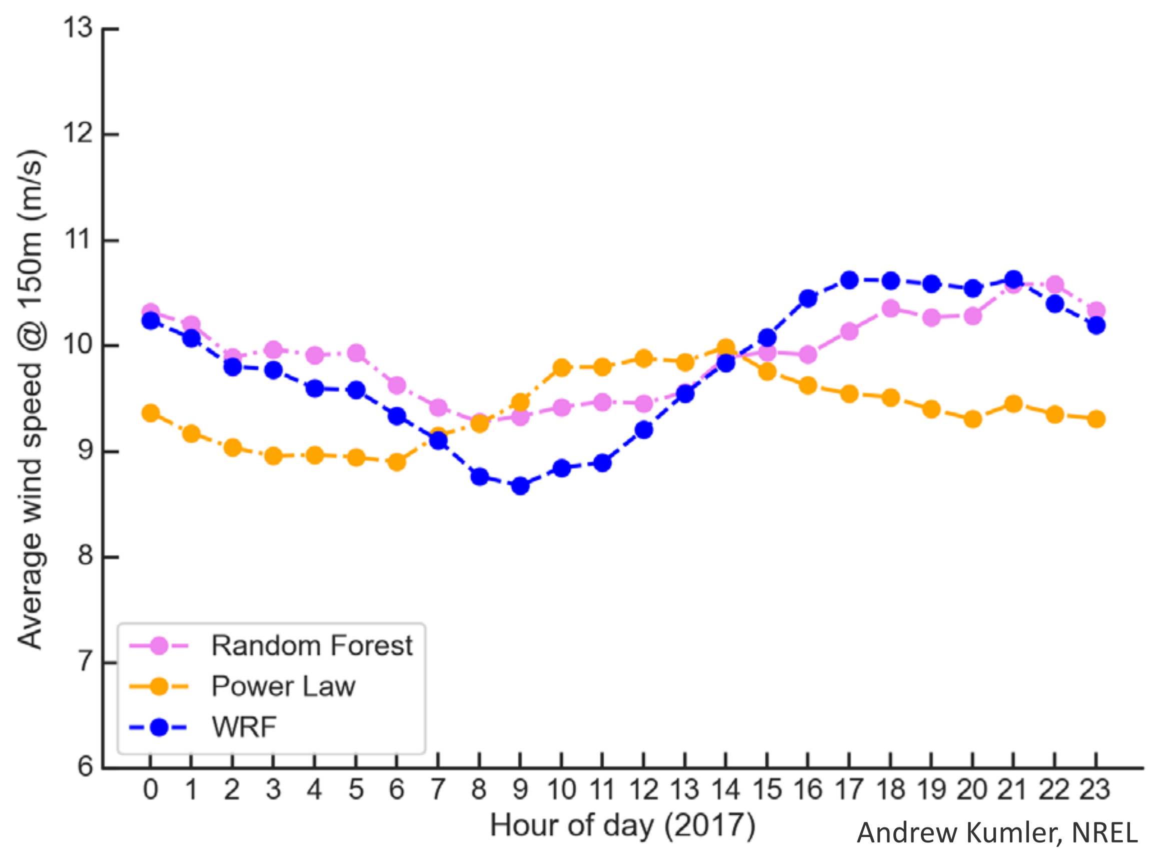
WRF/RF Generally Follows Diurnal Cycle, PL Not



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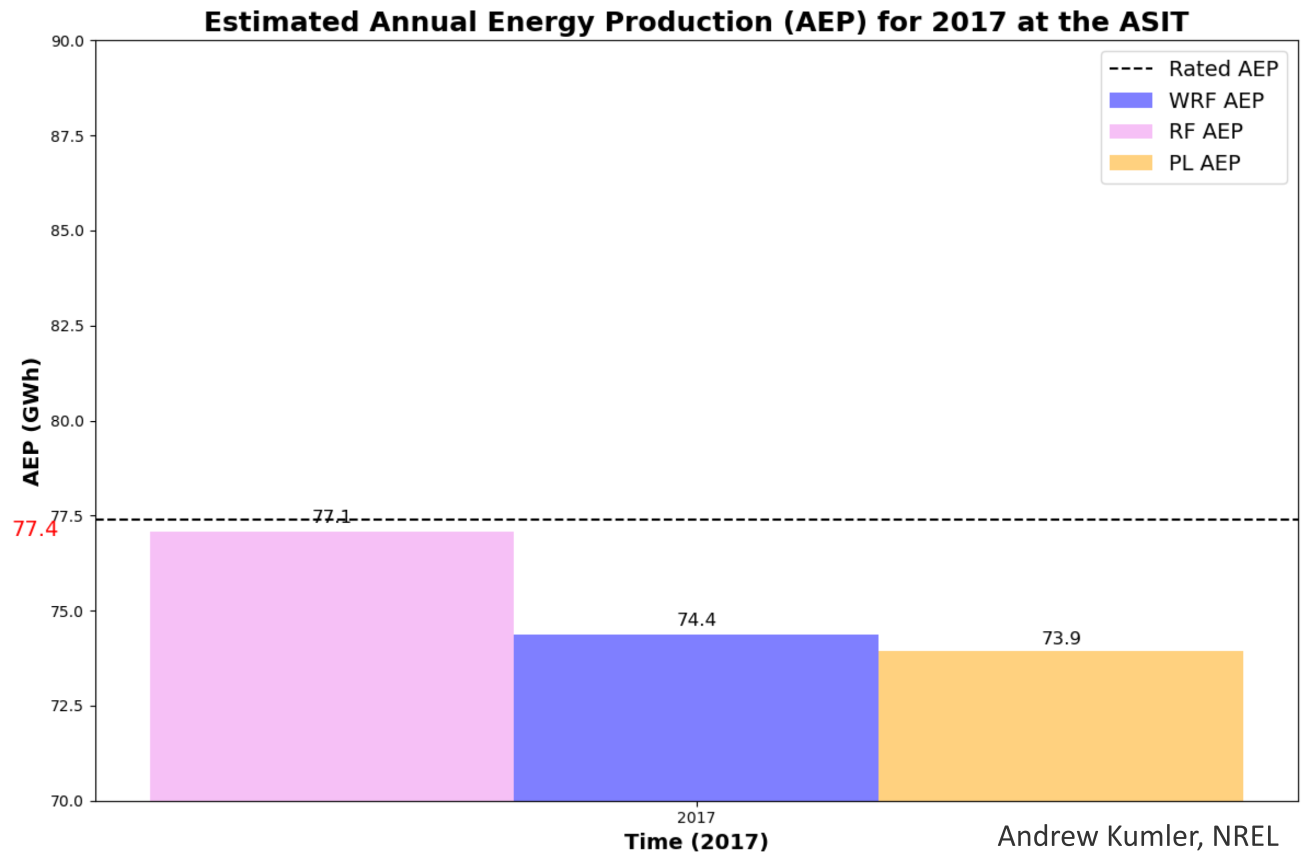
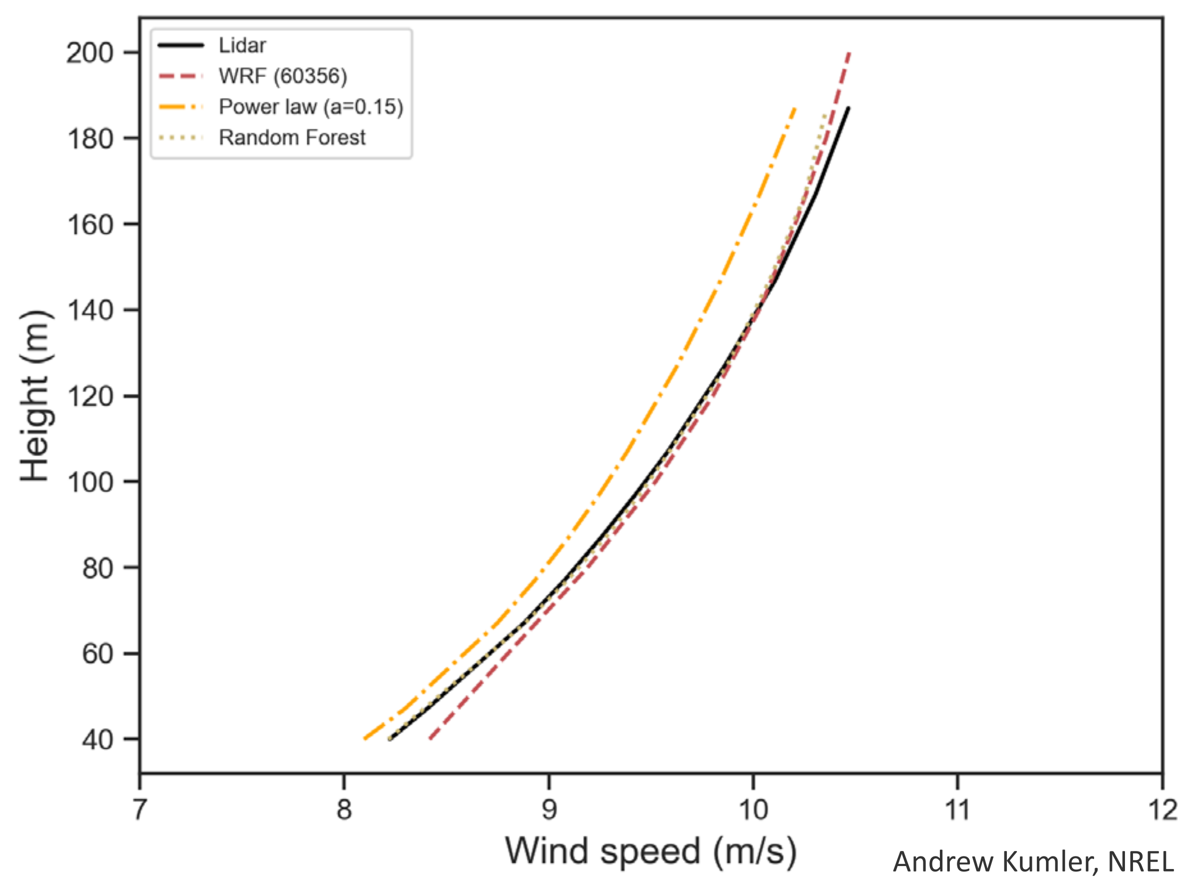
RF Performs Well, WRF/PL Underestimate AEP



Observations, Especially at Hub Height, Are Crucial

- While wind energy techniques, such as the WRF, capture the general wind resource conditions, they underestimate AEP.
- Machine learning performs well at vertical extrapolation and captures AEP nicely:
  - Only as good as the observations you feed it.
- The PL does poorly throughout the day/year:
  - Likely a function of data quality and alpha value
  - Ways to address this, such as a monthly alpha.
- Next step: bias correction.

Hub Height Observations Are Crucial Investments



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Thank You!

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