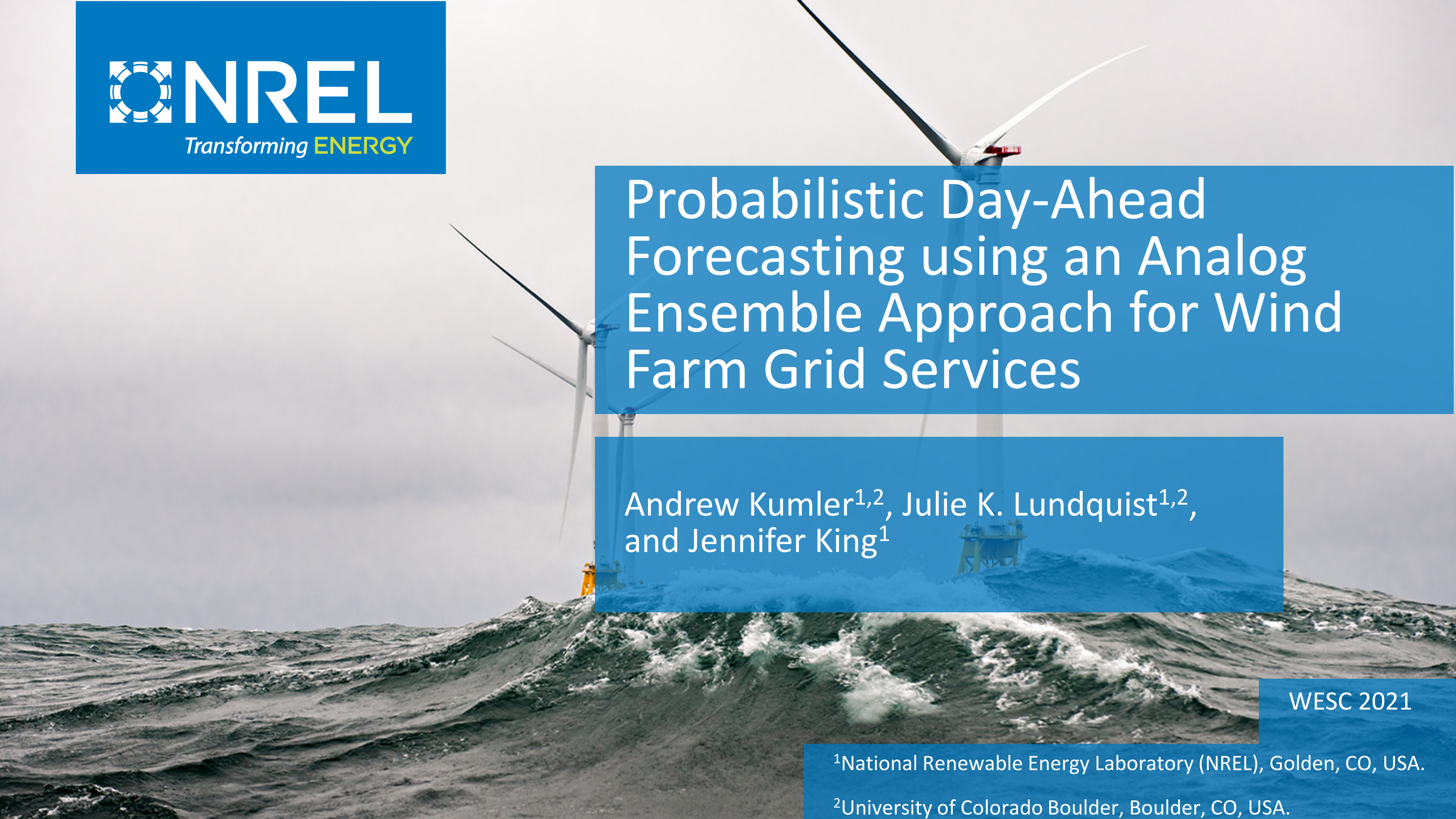

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Transforming ENERGY

Probabilistic Day-Ahead Forecasting using an Analog Ensemble Approach for Wind Farm Grid Services

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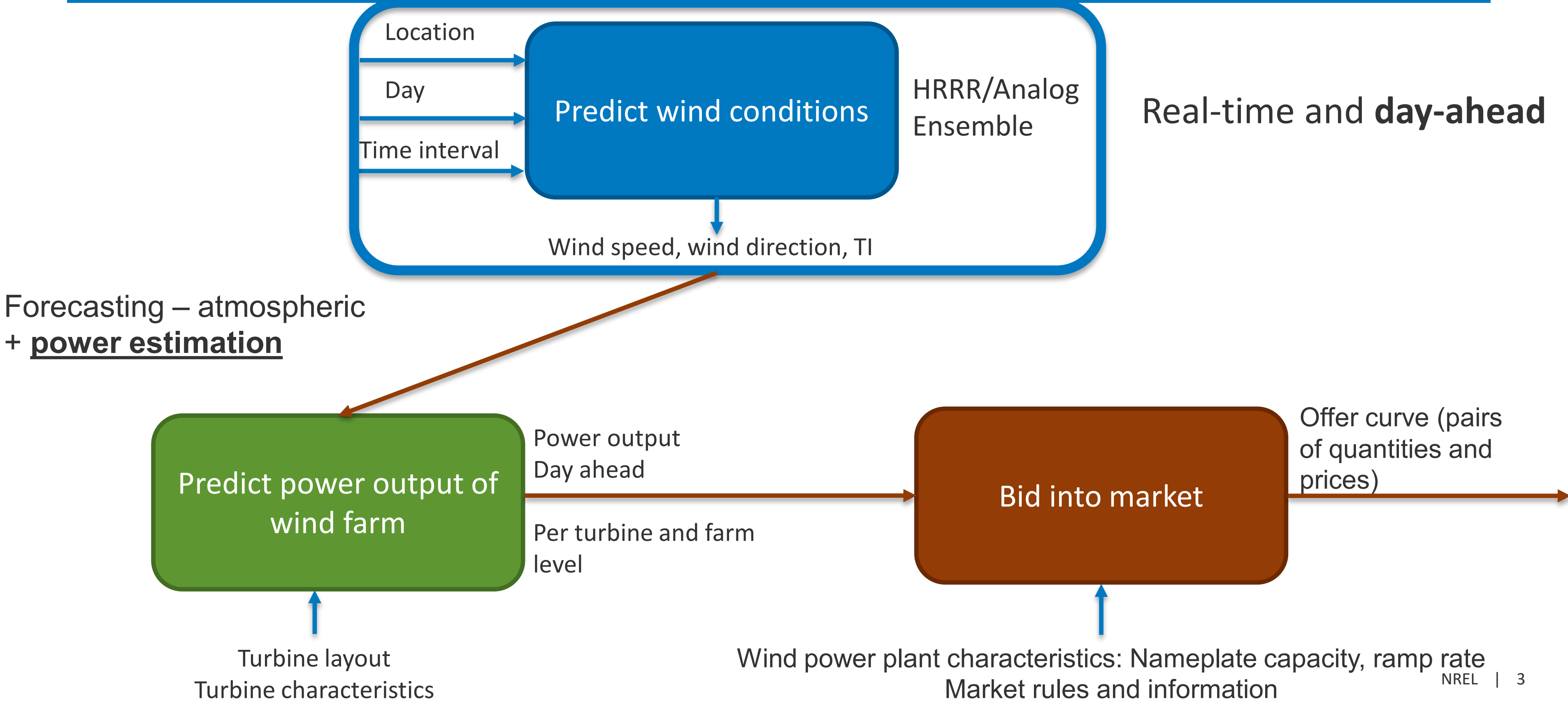
A2e2g: Atmosphere to Electrons to Grid

Objective: Demonstrate the value of wind farms providing a range of services to the grid

- Frequency response – keep the grid at 60 Hz
- Active power control – generation matches demand (van Wingerden et al., 2017)
- Energy market – produce as much energy as possible

Requires an accurate forecast of atmospheric conditions and a wind farm controller that can achieve multiple objectives on a range of timescales

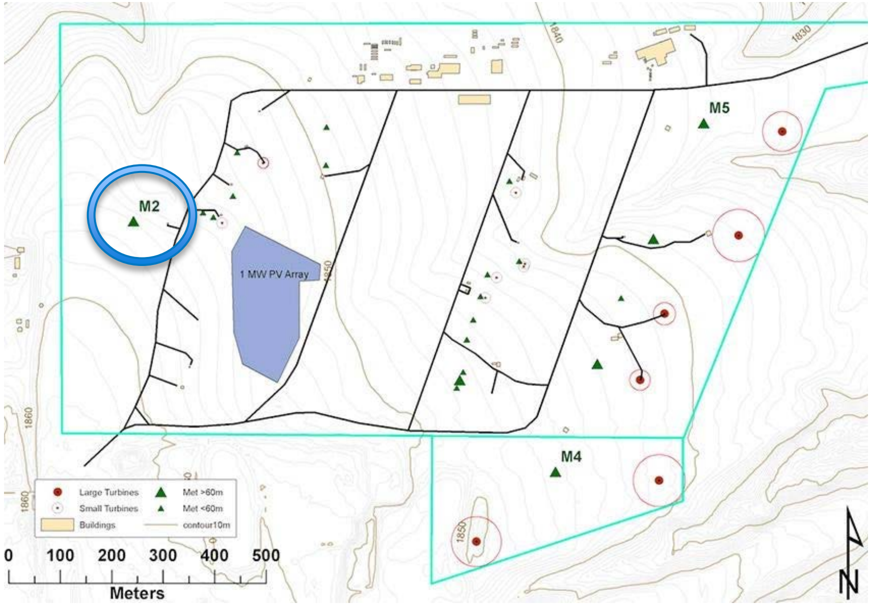
General Inputs & Outputs: A2e2g



Site of interest: Flatirons Campus

M2 Tower

- Sits at a high elevation, highly turbulent site outside Boulder, CO, USA (1855 m ASL).
- Variety of meteorological measurements available up to 80 m.
- Data gathered at 1-minute resolution for ~1 year.
    - Resampled to 5-minutely.
- Proof of concept.



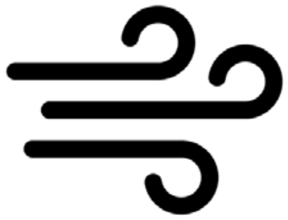
Jager and Andreas, 1996

Approaching the day-ahead forecast

- **Objective**:
  - Create day-ahead hourly forecasts of wind speed, turbulence intensity, etc.
- **Challenge**:
  - Creating a “state-of-the-art” probabilistic forecast.
  - Generating accurate atmospheric variable forecasts are important for power predictions.
    - This, itself, can be difficult depending on certain conditions.

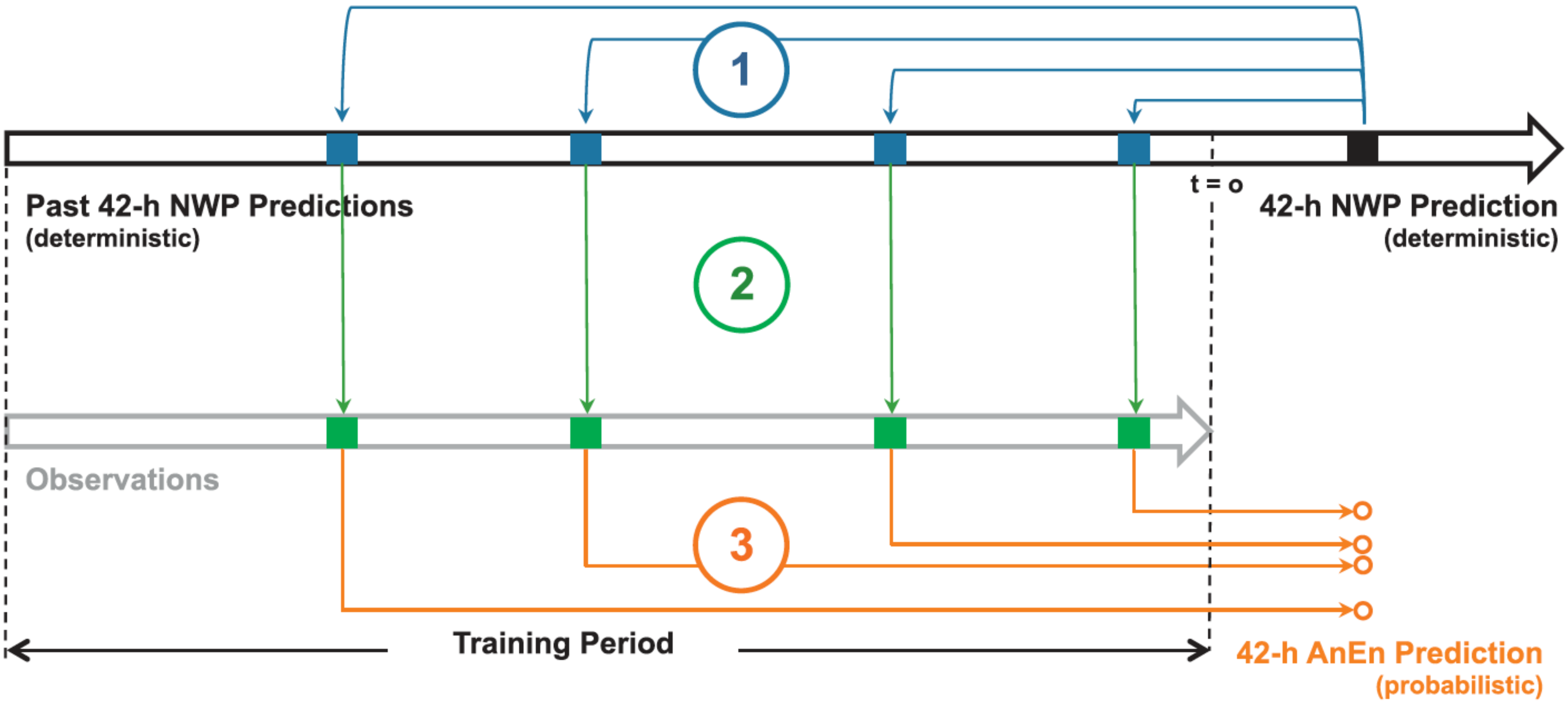
Day Ahead

Predict wind conditions one day ahead



Analog Forecast - Wind

- Day-ahead Forecasting
  - Utilize HRRR model to grab 0 to 36 hour forecast at 12Z the previous day.
  - Variables relevant to wind forecasting (wind speed, turbulence intensity, etc.) are obtained.
  - For each time period of interest, prior forecasts (analogs) are chosen that most resemble current forecast.
  - For the best matching historical forecasts, the corresponding observations are used as a forecast.



Delle Monache et al. 2013

Day-ahead forecast: Overview

Typical Day…

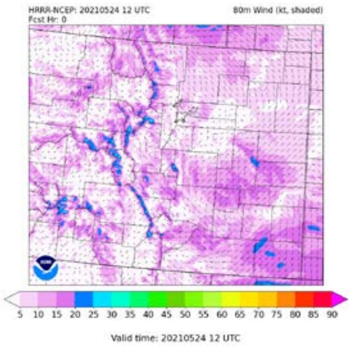
Interpolated to 5-minutes

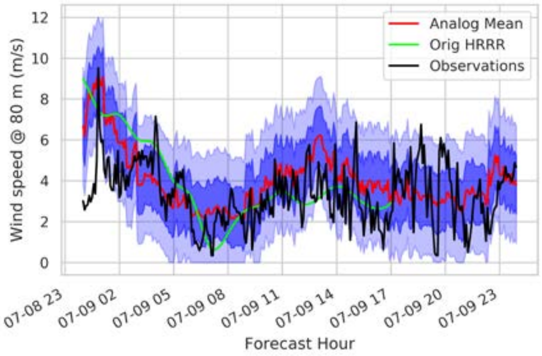
Download HRRR → **Analog Ensemble** → **Forecast Delivery** → **Predict Wind Farm Power**

Download HRRR
- 48-hour forecast
- 3 km spatial resolution
- Wind speed, wind direction, and TI @ 80 m
- Site-specific

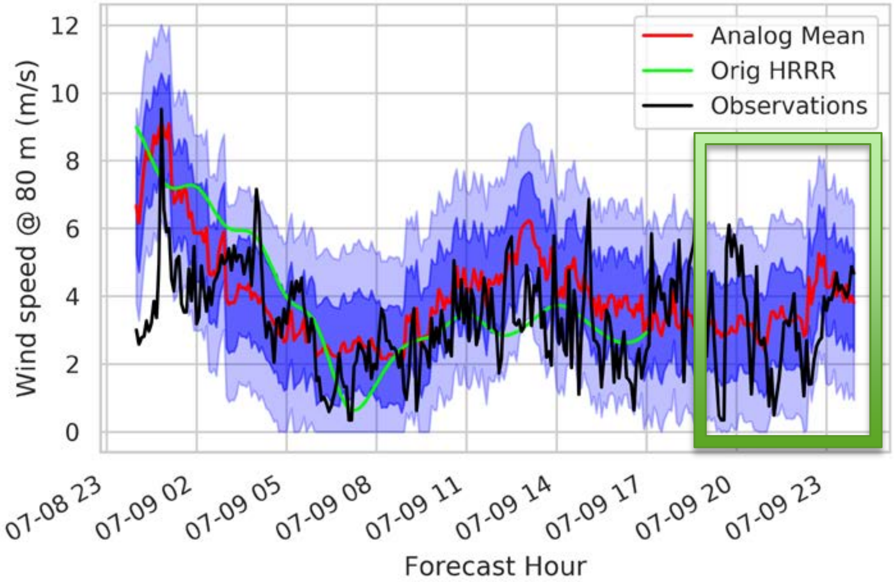
Analog Ensemble
- ~1 year of historical forecasts
- 10 analogs
- Two versions
- Probabilistic

Forecast Delivery
- Time-series of variables with standard deviation

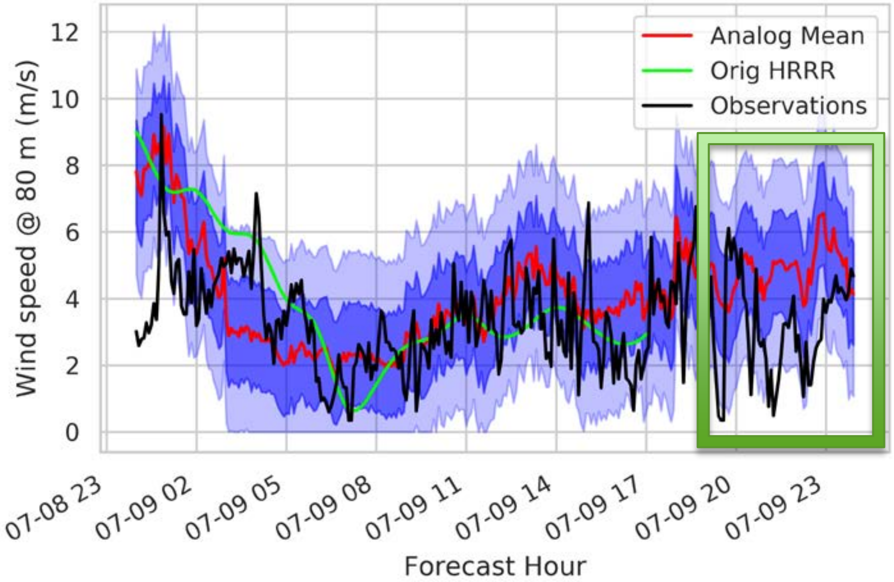




Very similar forecast for two A.E. versions

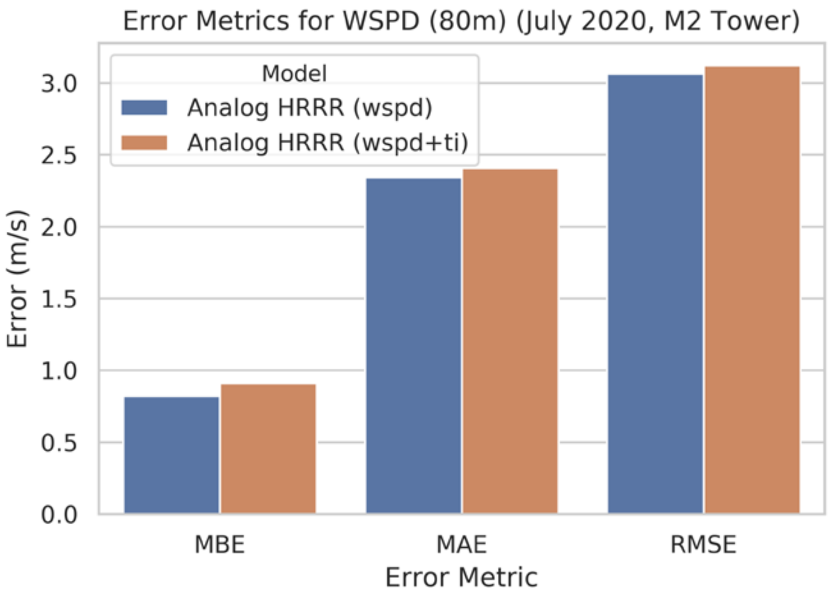


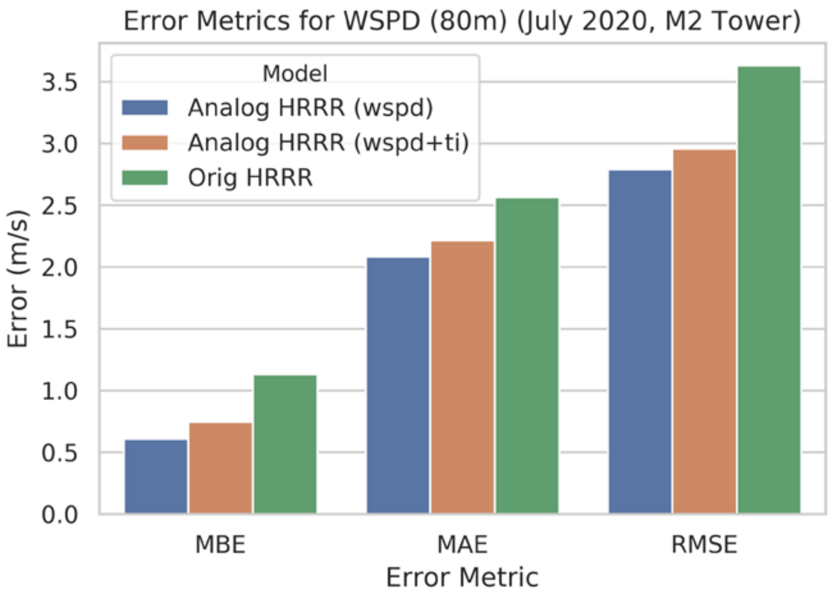
Wind speed only



Wind speed and TI

Two versions of A.E. better than original HRRR





What about Turbulence Intensity?

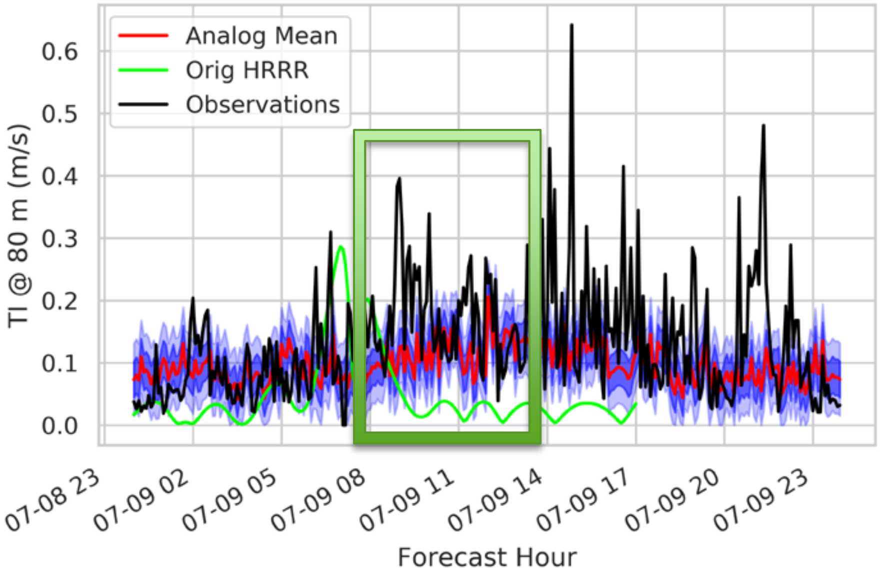
- Initially, focus was on wind speed at hub-height…

But turbulence plays a critical role in power production!

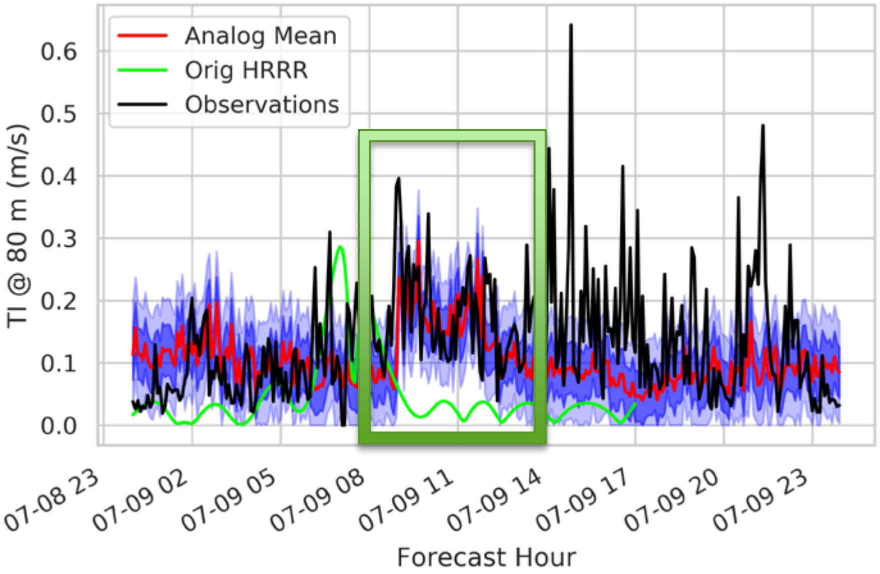
What has been done?

- While TI has received a fair amount of attention in the literature, forecasting it has received little.
- Depending on day-ahead TI, anticipated wind power production can fluctuate despite what wind speed may be present (Clifton et al., 2013; Wharton and Lundquist, 2012).
- Accurate forecasts of TI can help inform grid operators of potential uncertainties in a wind plants’ output.
  - Probabilistic TI forecasts can help with confidence if power will be steady or not.

Two A.E. indistinguishable for the most part…

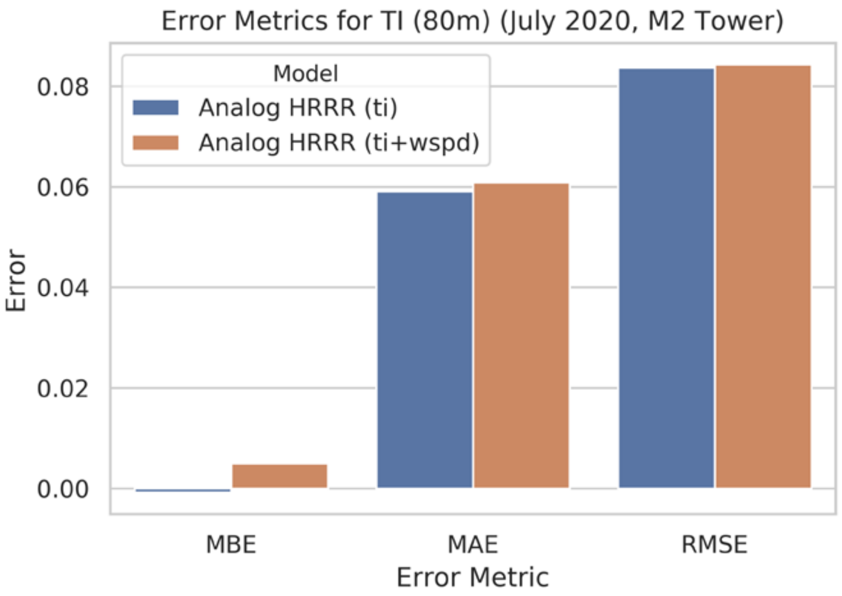


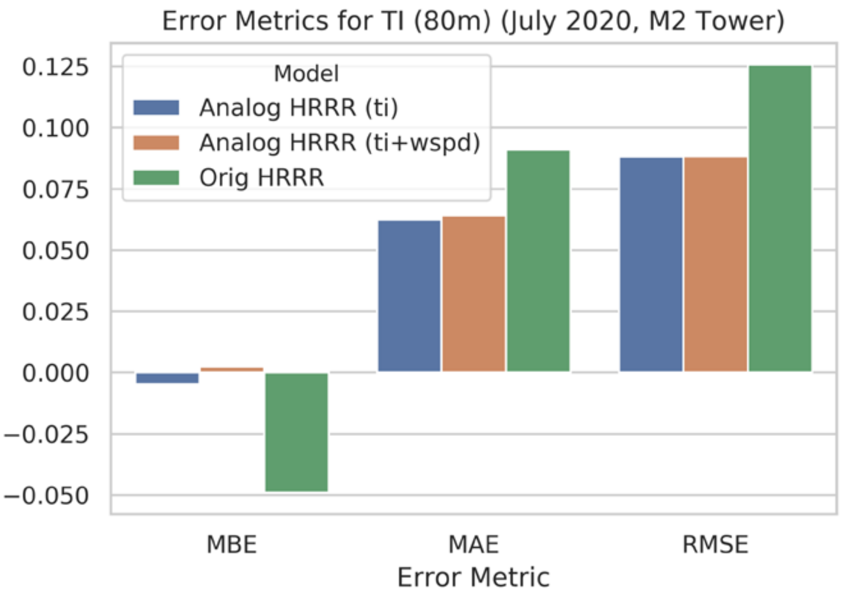
TI only



TI and wind speed

TI analog much better than original HRRR





Analog HRRR works well for wind speed, great for TI

- Univariate and multivariate results differ very little.
  - Somewhat surprising, but not unusual (Hamill and Whitaker, 2006).
  - Testing on additional months in different seasons could provide more insight.
- Both sets of results outperform the original HRRR forecast.
- TI results show greatest promise and could prove useful for power conversions that incorporate turbulence.
- The addition of wind direction may help the forecast.

Next Steps

- With solid first results, opportunities exist to improve the Analog HRRR technique.
  - Testing over more months, different sites
  - “Ensemble of ensembles” (number of analogs)?
  - Explore if a multivariate forecast exists that can outperform the univariate.
- Integrate analog ensemble technique into the A2e2g platform.

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