Research Activities to Improve NOAA's High Resolution Rapid Refresh NWP Model

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With contributions from many ASRE team members

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Rapid Refresh NWP Models in NOAA

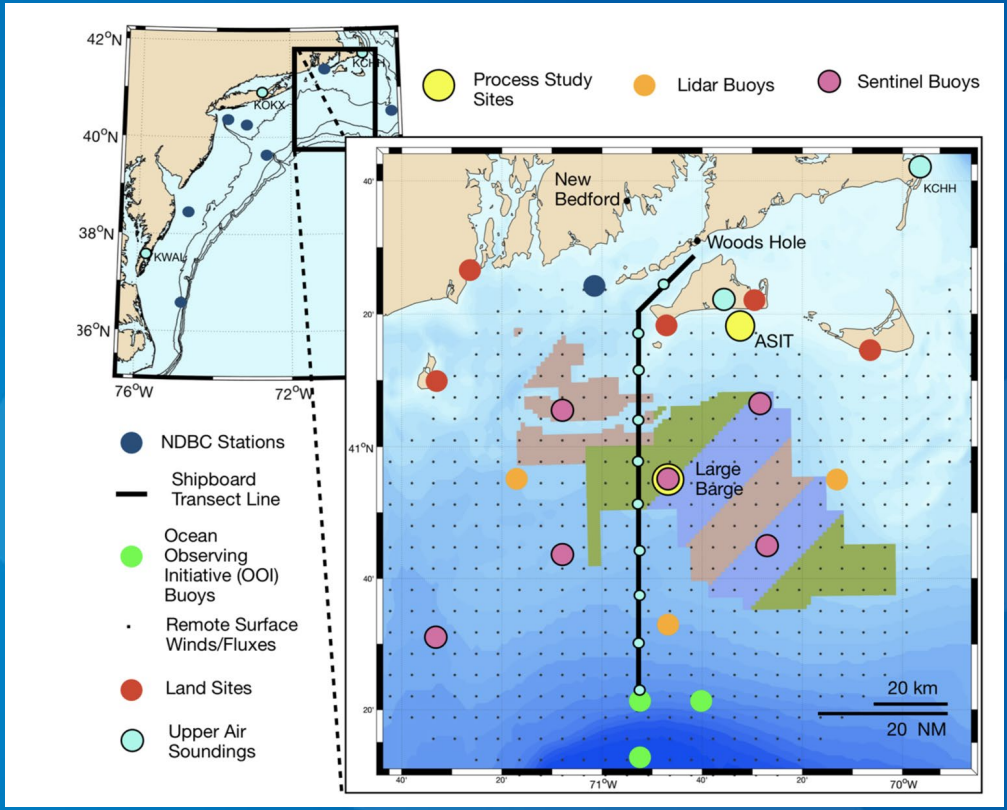
- High-resolution Rapid Refresh (HRRR)
  - Deterministic model, 3 km horizontal grid spacing, two domains over CONUS and Alaska
  - New operational versions at NWS in 2014, 2016, 2018, and December 2020
  - Forecasts out to 48 h for initialization at 00, 06, 12, and 18 UTC (version 4)
- Rapid Refresh Forecast System (RRFS)
  - In development since 2019; objective is to simplify NOAA's operational suites of models
  - 3 km horizontal grid, deterministic and ensemble system (latter has 5 members)
  - Forecasts out to 60 h for initialization at 00, 06, 12, and 18 UTC (deterministic and ensemble)
  - Code currently frozen as part of model evaluation phase
  - If passes evaluation, RRFS.v1 would become operational in spring 2025
- RRFS.v1 vs HRRR.v4
  - RRFS has much improved initialization (DA) and physics; many biases have been reduced
  - RRFS generates too much and too intense convection
  - **HRRR.v4 will remain operational until RRFS.v2 (anticipated circa 2027)**
  - Other regional models (e.g., NAMnest) will be retired when RRFS.v1 becomes operational

Other renewable energy activities within ASRE

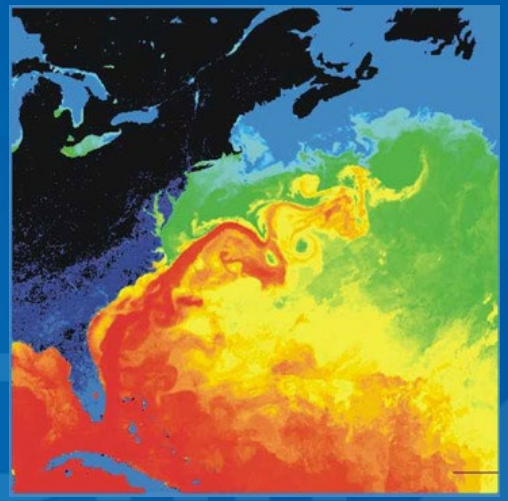
1. 3rd Wind Forecast Improvement Project (WFIP-3)
2. Eval of HRRR.v4 and GFS.v16 hub-height winds off US east coast
3. Evaluation of ability of HRRR.v4 to capture wind ramp events
4. Diagnosing variability in the downwelling solar irradiance
5. Using HRRR for resource characterization

WFIP-3 Overview

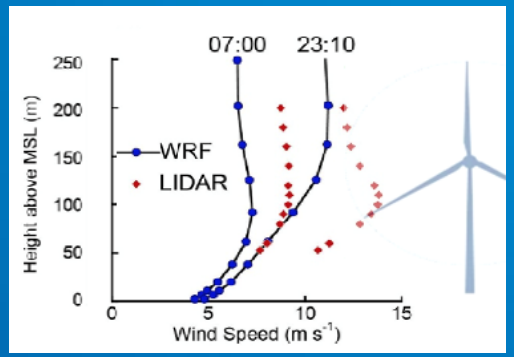
- Offshore wind energy characterization field campaign
- New York bight area, south of Martha's Vineyard
- Collaboration with DOE / WETO, with many university and private partners
- Coupled modeling-observation program
- 18-month field campaign (started Jan 2024)



WFIP-3 key science questions



- US east coast offshore wind energy environment is much different than the European offshore areas
  - Much warmer summer (colder winter) upstream air mass leads to very stable (unstable) atmos boundary layer
  - Stable BLs produce low level jets with substantial variations in wind speed, which is not captured well by current models
  - Larger SST gradients can lead to internal boundary layers and local circulations

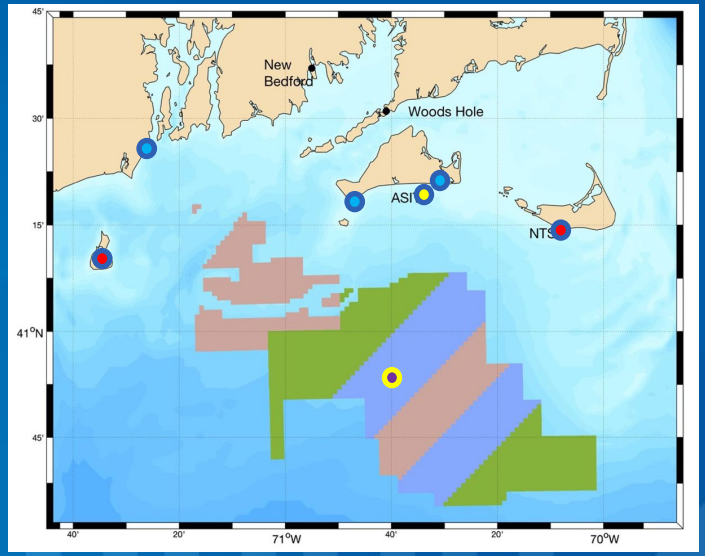


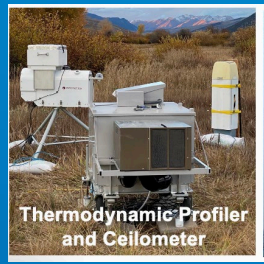
- Complex coastline can modulate offshore wind patterns
- Interactive coupling between ocean and atmosphere (e.g., wave impacts on winds)
- Challenging weather: sea-breeze, coastal upwelling, nor'easters, hurricanes, precipitation, …

Shaw et al., *Wind Energy Science*, 2022

WFIP-3 sites and instruments

- Remote and in-situ sensors on islands
- Key platform: instrumented barge !
- Anticipate having a NOAA ship this winter





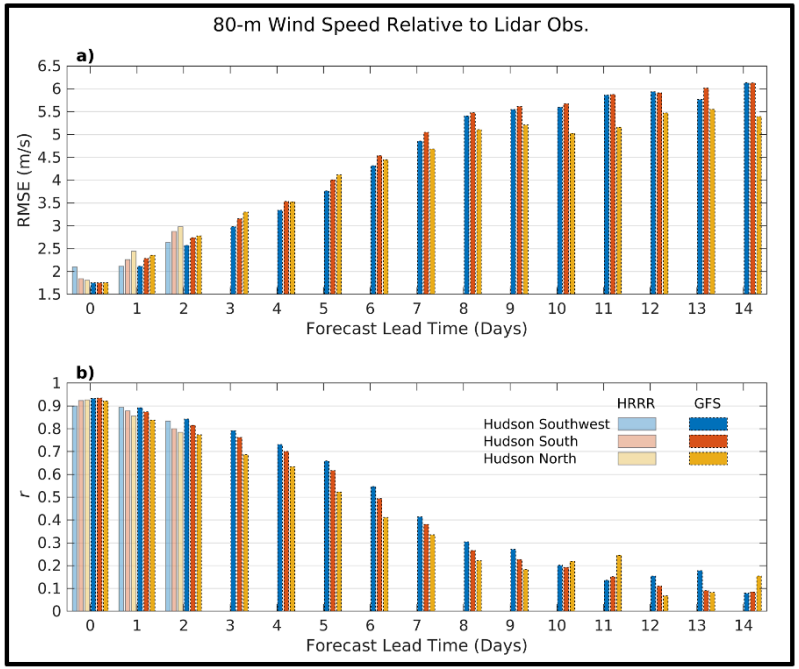
Evaluating HRRR and GFS hub-height winds

- Wanted to characterize the current hub-height wind forecasts from NOAA's operational models pre WFIP3 (establish a baseline)
- Looked at HRRR and GFS forecasts in US east coast region
- Method: used 2-y of Doppler lidar obs from buoys of NY coast at 80 m

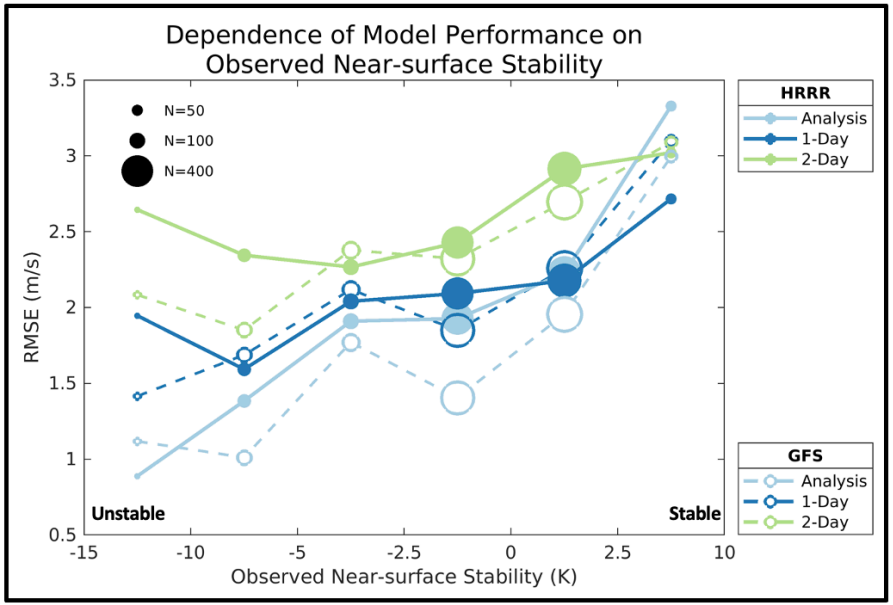
Myers et al., *Wind Energy*, in press

Evaluation results

- Despite being very independent models, the HRRR and GFS demonstrate similar and highly skillful short-term (≤ 2 days) forecasts. GFS has no skill by day 10.



- Short-term forecast skill by the HRRR and GFS does not strongly depend on season or time of day, yet we find some dependence of the models' performance on near-surface stability.



Hudson Southwest site

Capturing wind ramp events

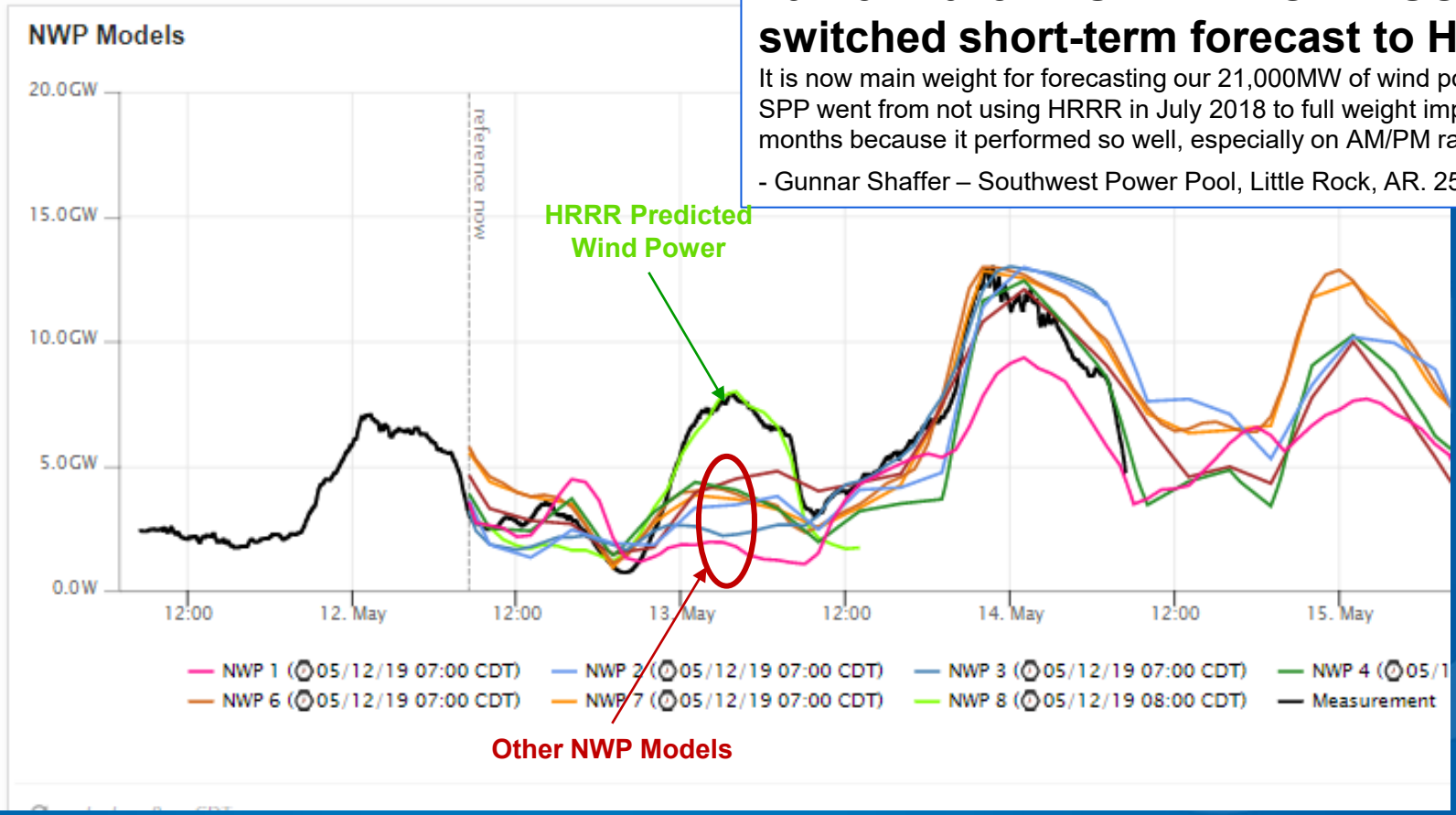
- HRRR.v3 first time forecasts extended beyond 18-h (36-h forecast at 00, 06, 12, and 18z); HRRR.v4 provides 48-h forecasts at these times
- 4 months after HRRR.v3's release, we got this feedback…

Feedback from SPP

29 Nov 2018 – "SPP/ERCOT/MISO/PJM switched short-term forecast to HRRR today.

It is now main weight for forecasting our 21,000MW of wind power in the Midwest! SPP went from not using HRRR in July 2018 to full weight implementation in 4 months because it performed so well, especially on AM/PM ramps. "

- Gunnar Shaffer – Southwest Power Pool, Little Rock, AR. 25



Capturing wind ramp events

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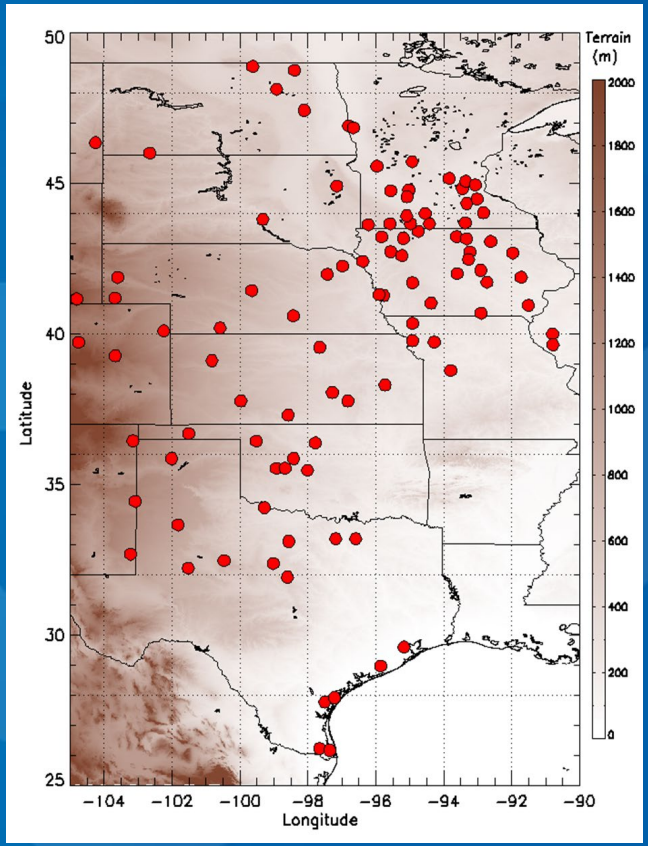
- And as we've improved the model initialization (DA) and physics in HRRR.v4, we wondered: "How well does HRRR.v4 do, relative to v3, on capturing wind ramps?"
  - Great summer project for students
  - Two great undergraduate students did much of this analysis (Jake Lindblom and Reagan Mendeke)

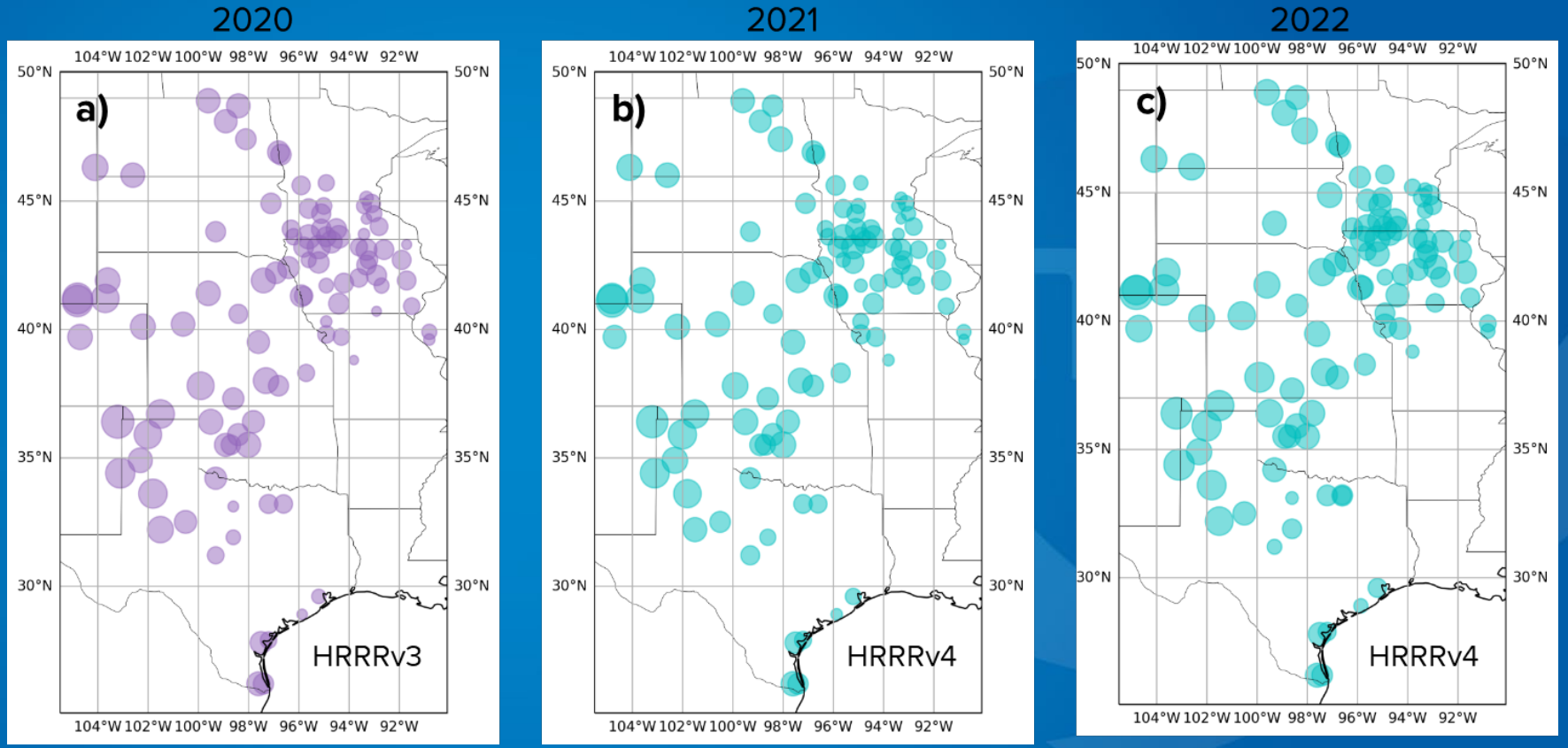
Wind ramp eval: HRRR.v3 vs v4 - Overview

- Only over the central plains
- Used ASOS observations (10-m) as truth, but only if within 20 km of a wind turbine
- Used HRRR.v3 from 2020
- Used HRRR.v4 from 2021 and 2022
- Analyzed 12-36 forecasts
- Will use a “ramp metric tool” that weights timing and intensity of the ramp to get a composite score

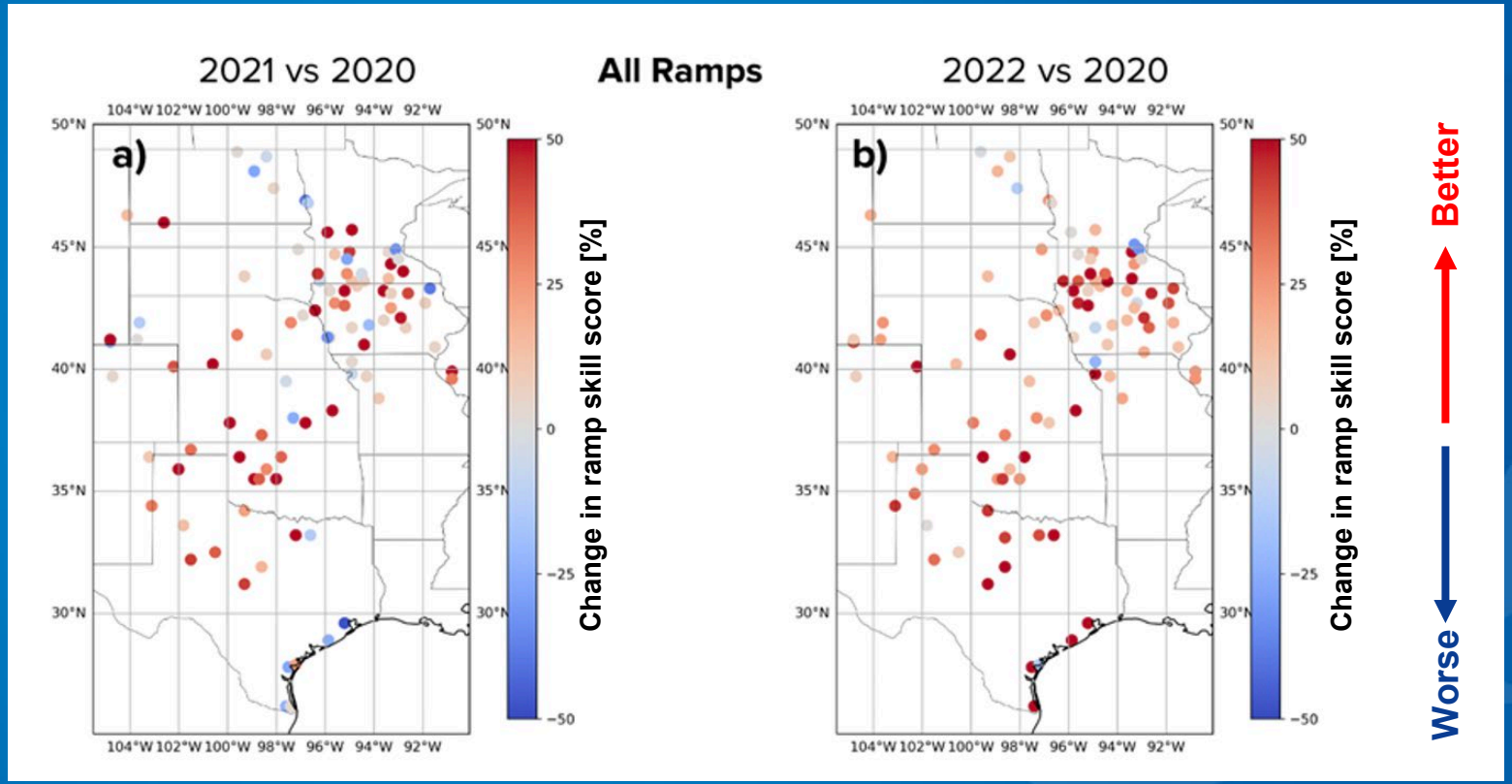


Bianco et al., *Monthly Weather Review*, 2016 (for wind ramp tool)

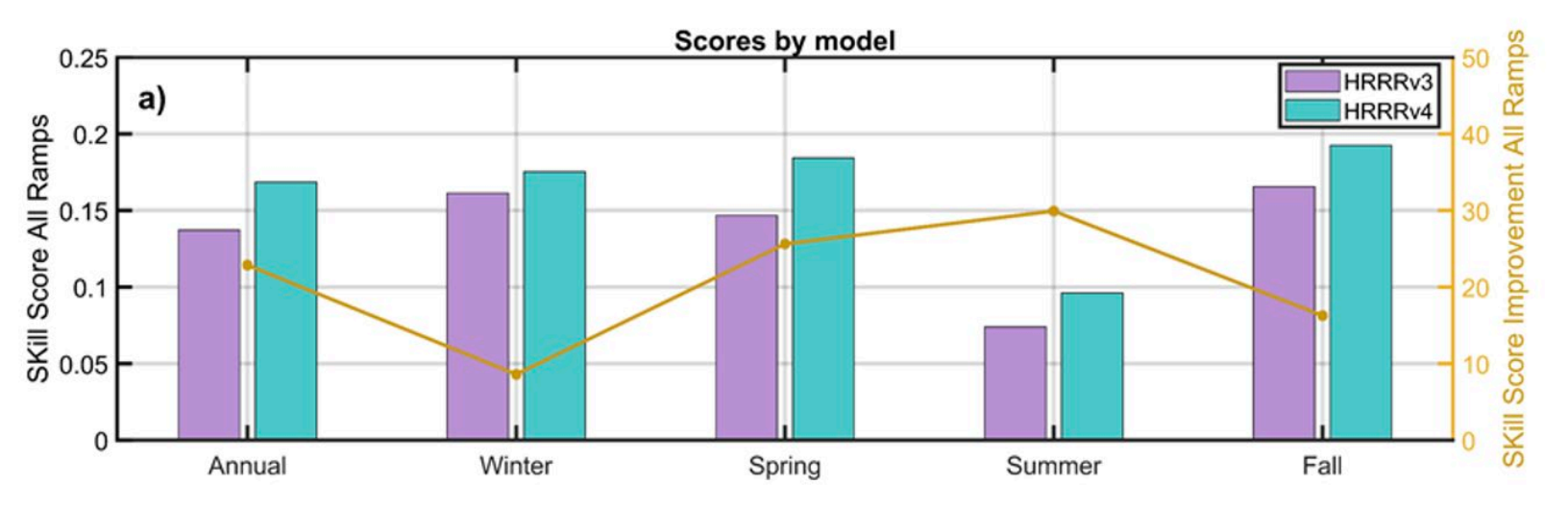
Frequency of wind ramps: 2020, 2021, and 2022



Change in wind ramp forecast skill



Seasonal change in skill capturing wind ramps

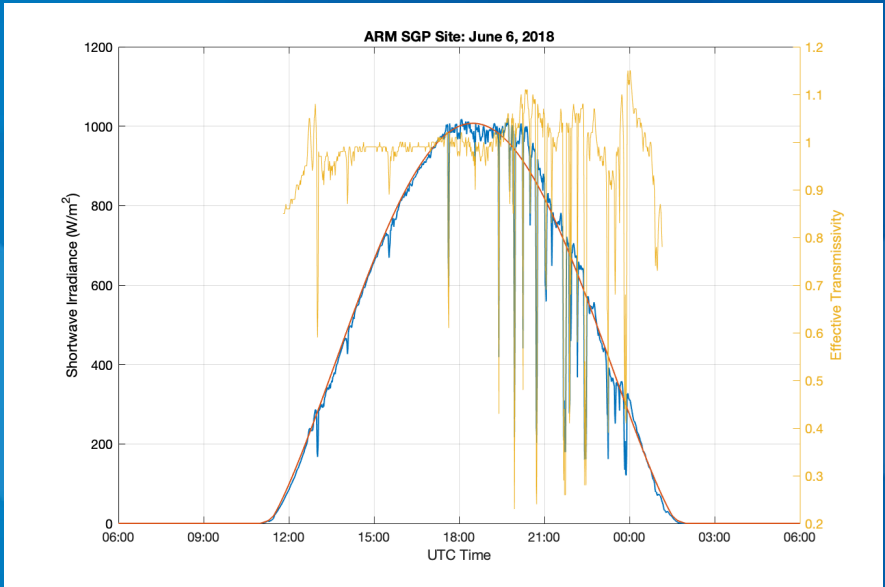


- HRRR.v4 has 10% to 30% improvement in capturing wind ramps
- Larger improvement in upramps (10% to 50%) then downramps (5% to 25%)
- Paper being drafted for submission now…

Bianco et al., *Wind Energy*, in prep

Diagnosing variability in downwelling solar

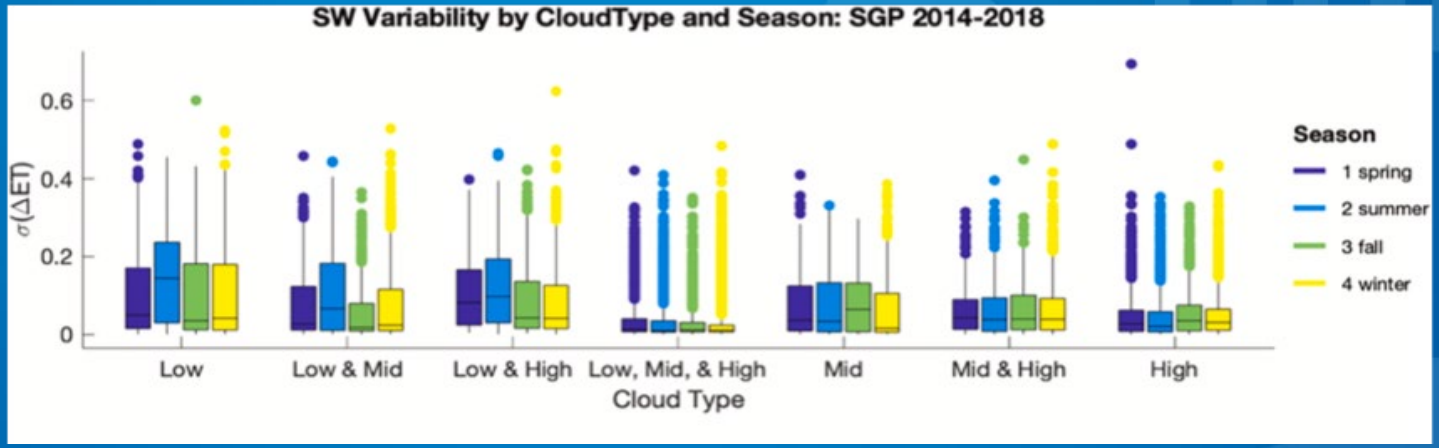
- Approach: build relationship from obs that can be use to diagnose surface shortwave irradiance variability from model output
- Variability depends strongly on cloud situation (type)
- Separate the variability due to clouds from solar geometry
- Effective transmissivity: (all sky SW flux) / (clear sky SW flux)

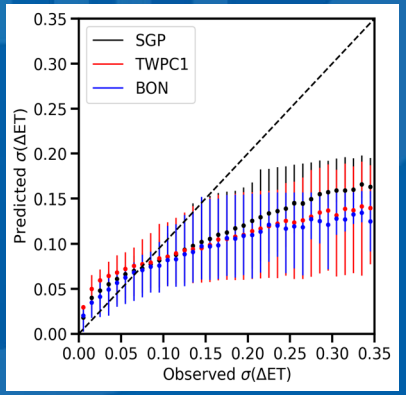


Riihimaki et al., *Solar Energy*, 2021

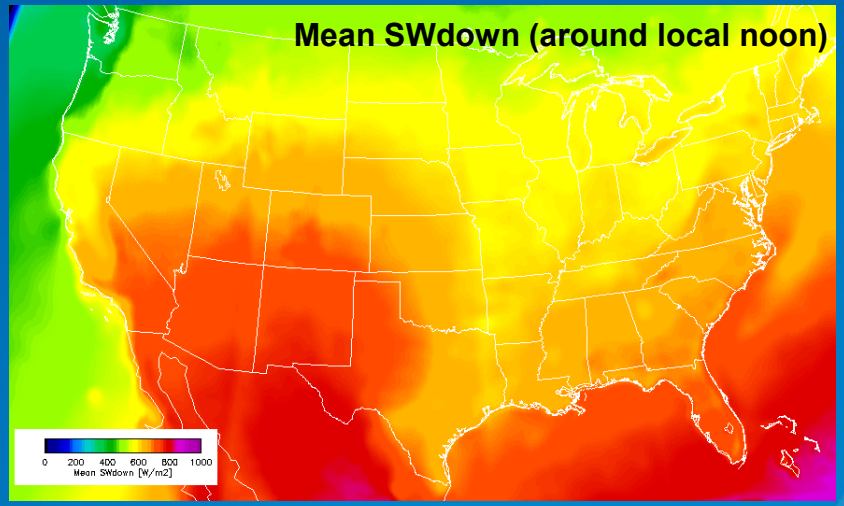
Solar variability by cloud type and season

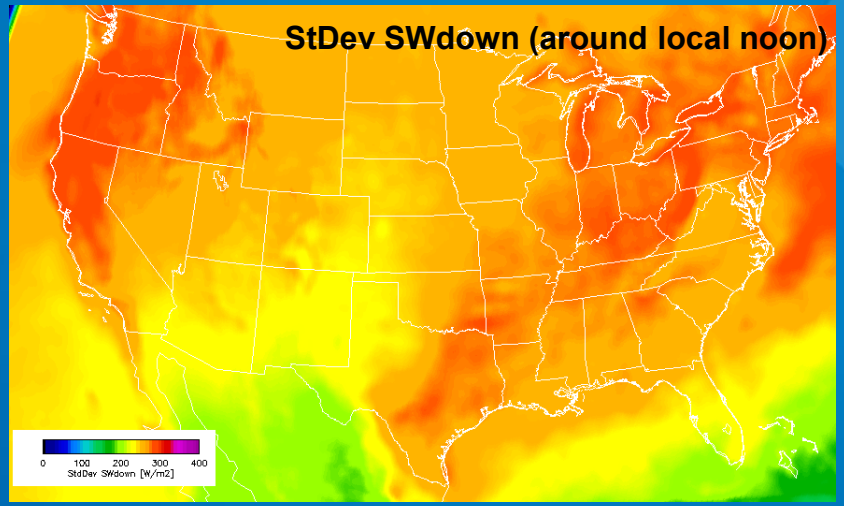
- Bin collocated solar flux obs to look at variability by cloud type
- Use a machine learning tool to estimate solar variability by cloud type
- Solar flux variability is largely generalizable across CONUS, and independent of season for a given cloud type
- Currently slightly over (under) estimate variability when σ_{ET} is small (large)





Balmes et al., in prep

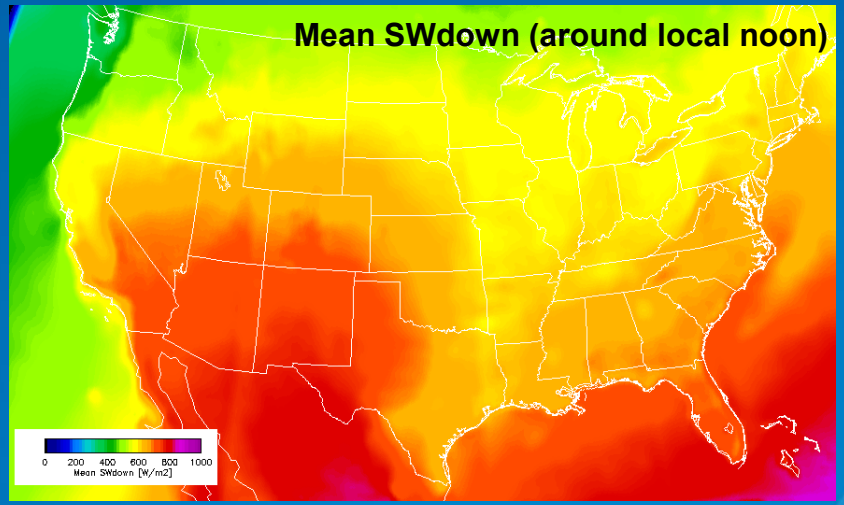


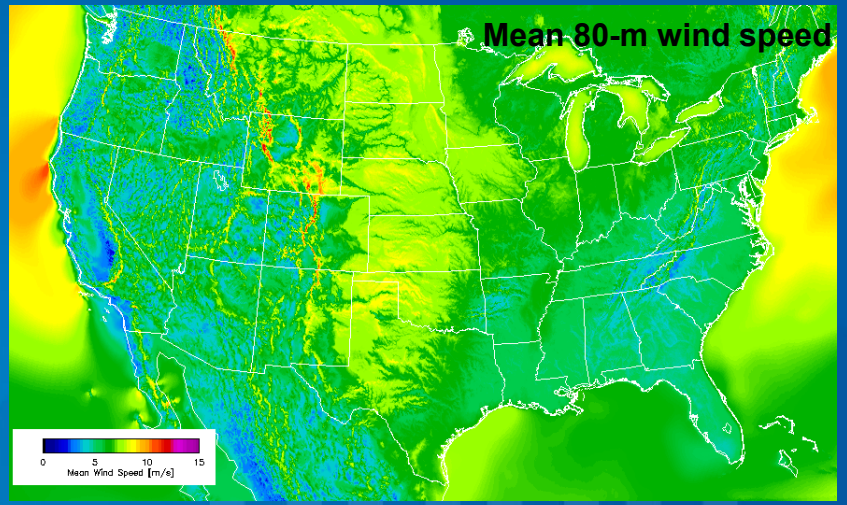


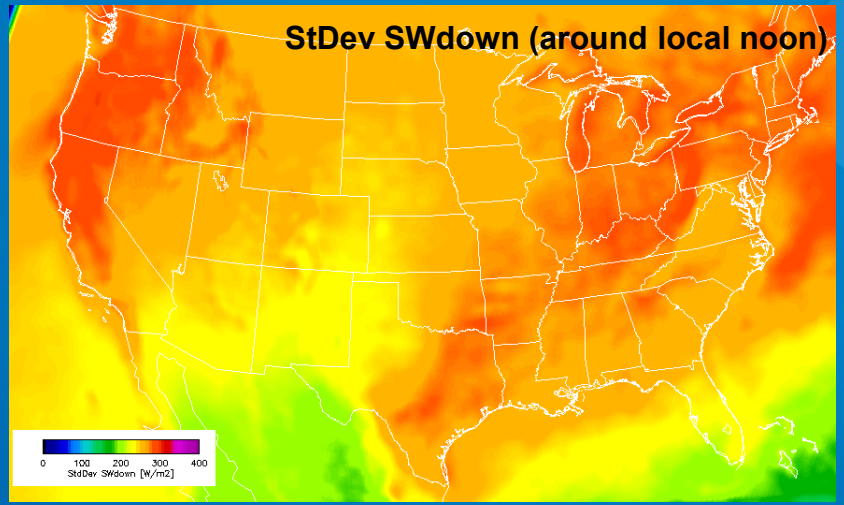
HRRR “climatologies”

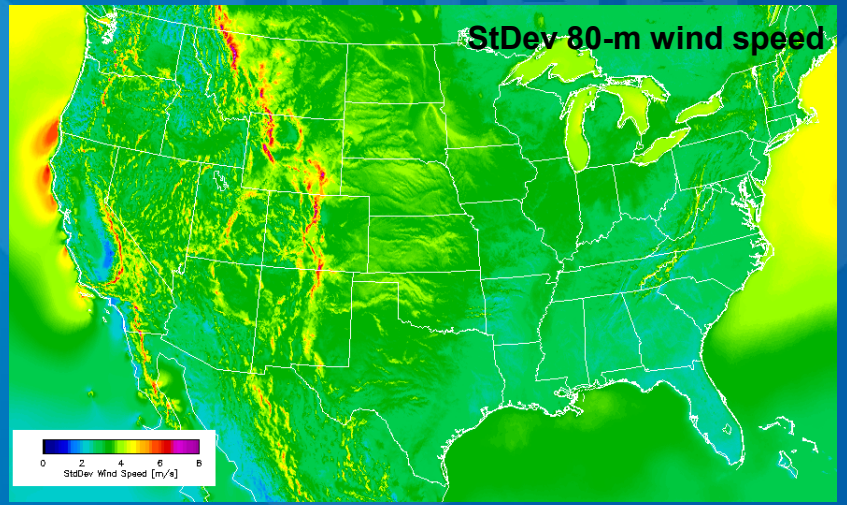
- 3.5 y of HRRR.v4 analyses and forecasts are available
- Model will continue unmodified until at least 2027
- 1-h forecasts can be used to look at spatial RE resources and their variability
- Here, data from 2020 to 2023 are used…

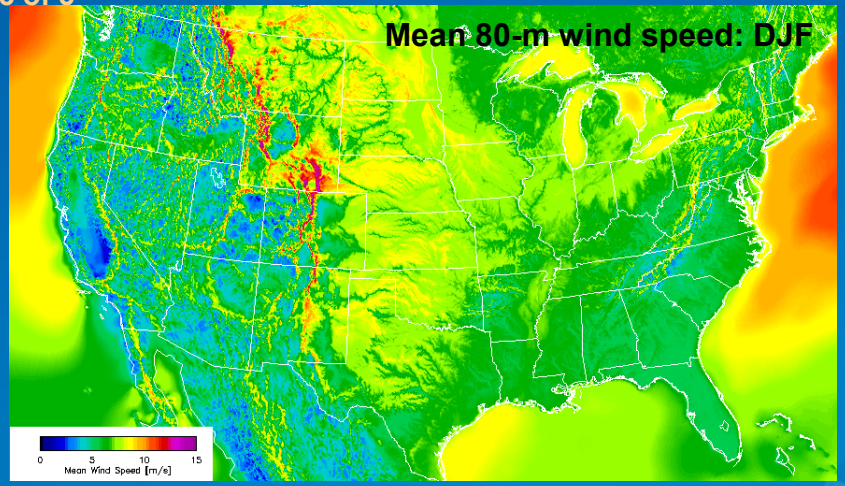
- As an aside: we are discussing how to generate a multi-decadal HRRR-like analysis (with DOE)

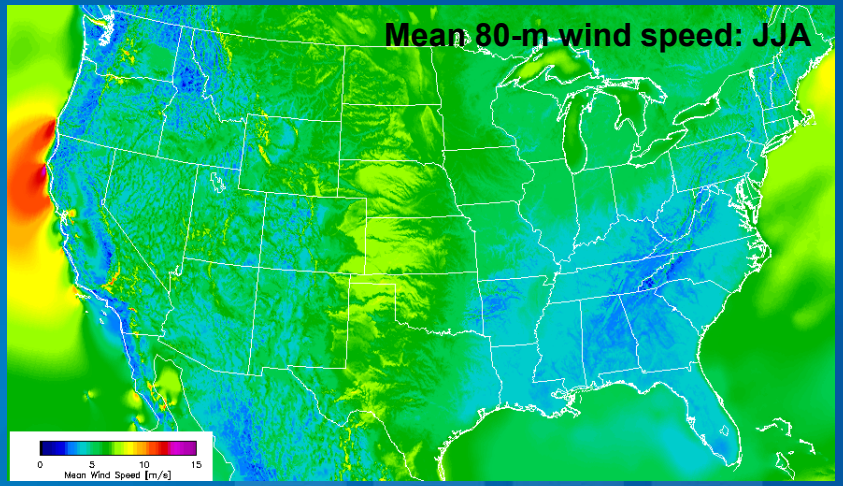

Mean SWdown (around local noon)
0 200 400 600 800 1000
Mean SWdown [W/m2]

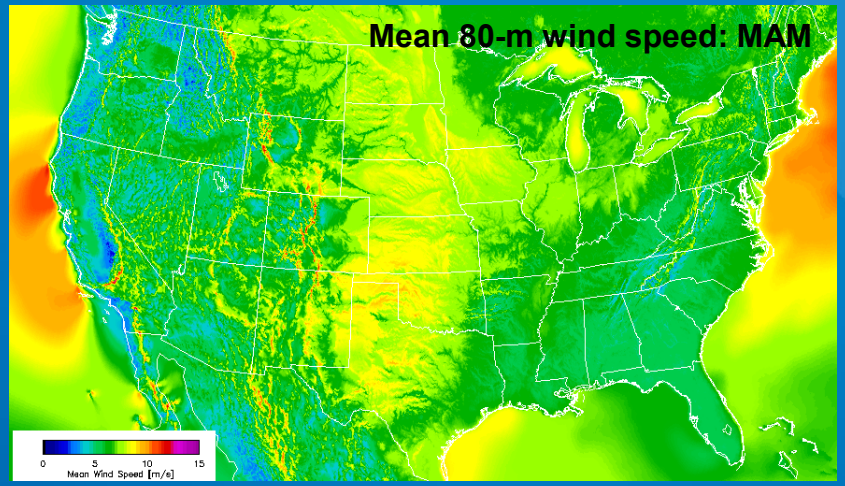

Mean 80-m wind speed
0 5 10 15
Mean Wind Speed [m/s]

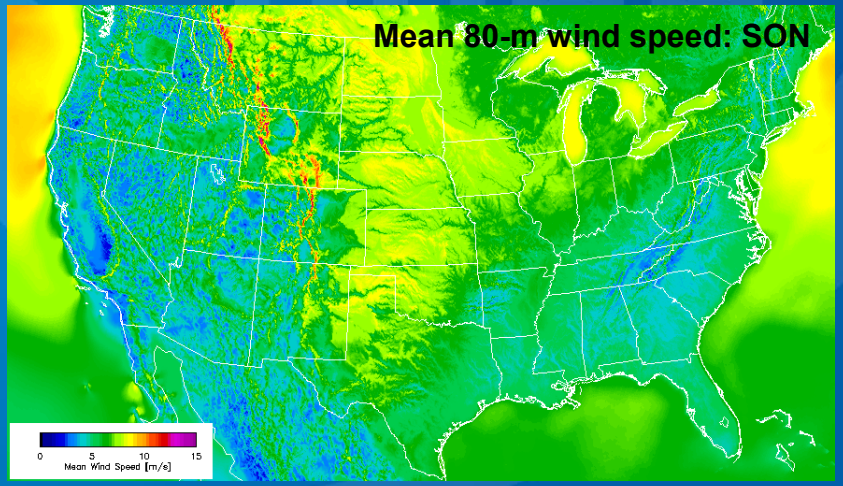

StDev SWdown (around local noon)
0 100 200 300 400
StDev SWdown [W/m2]


StDev 80-m wind speed
0 2 4 6 8
StDev Wind Speed [m/s]


Mean 80-m wind speed: DJF
0
5
10
15
Mean Wind Speed [m/s]


Mean 80-m wind speed: JJA
0
5
10
15
Mean Wind Speed [m/s]


Mean 80-m wind speed: MAM
0
5
10
15
Mean Wind Speed [m/s]


Mean 80-m wind speed: SON
0
5
10
15
Mean Wind Speed [m/s]

Summary and Looking Forward

- NOAA continues to improve the day-ahead rapid refresh NWP models
  - Field campaigns to collect key obs and do process studies (e.g., WFIP-3)
  - Improvements to physics and data assimilation methods
  - Developing new diagnostics
- Perform variety of analyses to characterize predictive performance

- RRFS is an ensemble system; need to characterize its spread/skill for renewable energy applications
- RRFS.v1 code is frozen; we are already working on v2
- Working to build a 3-km data-driven weather prediction model
- Driving the need for a multi-decade reanalysis using HRRR (or RRFS)

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