

# Evaluation and Correction of the ERA5 Reanalysis over the U.S. for Wind and Solar Energy Applications

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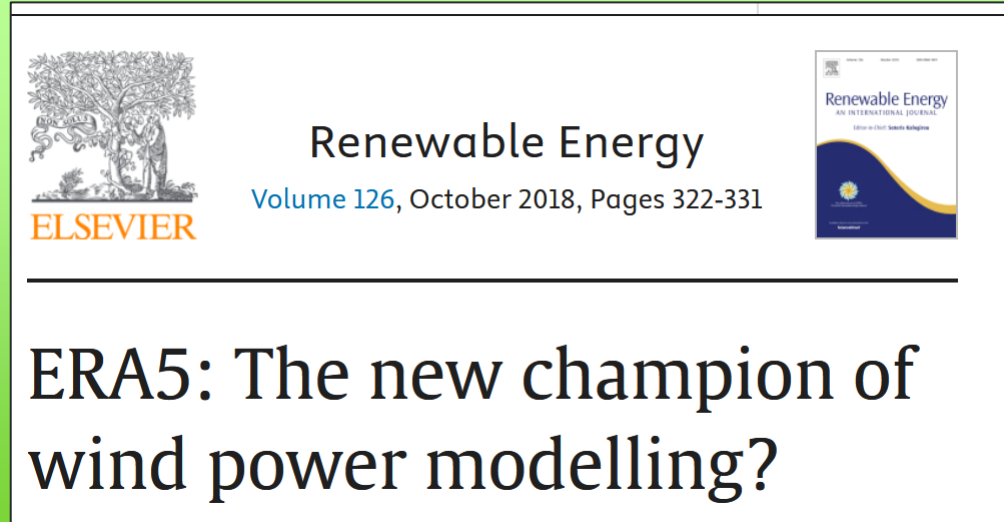
Wilczak, J.M., et al., Evaluation and Bias Correction of the ERA5 Reanalysis over the United States for Wind and Solar Energy Applications. *Energies* 2024, 17, 1667. <https://doi.org/10.3390/en17071667>

# What is a reanalysis Data Set?

- Meteorological reanalyses assimilate weather observations into a weather forecast model, creating continuous reconstructions of the state of the atmosphere

# Why use a meteorological reanalysis?

- Many decades are needed to get a statistically significant data set
- Ideal as input to capacity expansion and solar drought analyses.



# Why use the ERA5 reanalysis?

- Considered to be the most accurate of global reanalyses available.
- Commonly used as a training data set for AI-based weather forecasting, now also starting for AI-based energy forecasting.
- 31 km native resolution, hourly, 100 m wind speeds; direct and diffuse irradiances on a horizontal plane

# Goals of this analysis:

- Determine accuracy of the ERA5-derived wind and solar power. Is it sufficiently accurate to be used to quantify wind and solar extreme events (droughts and floods)?
- If not, can it be corrected?
- What metrics are most useful for evaluating a reanalysis data set for wind and solar energy extreme events?

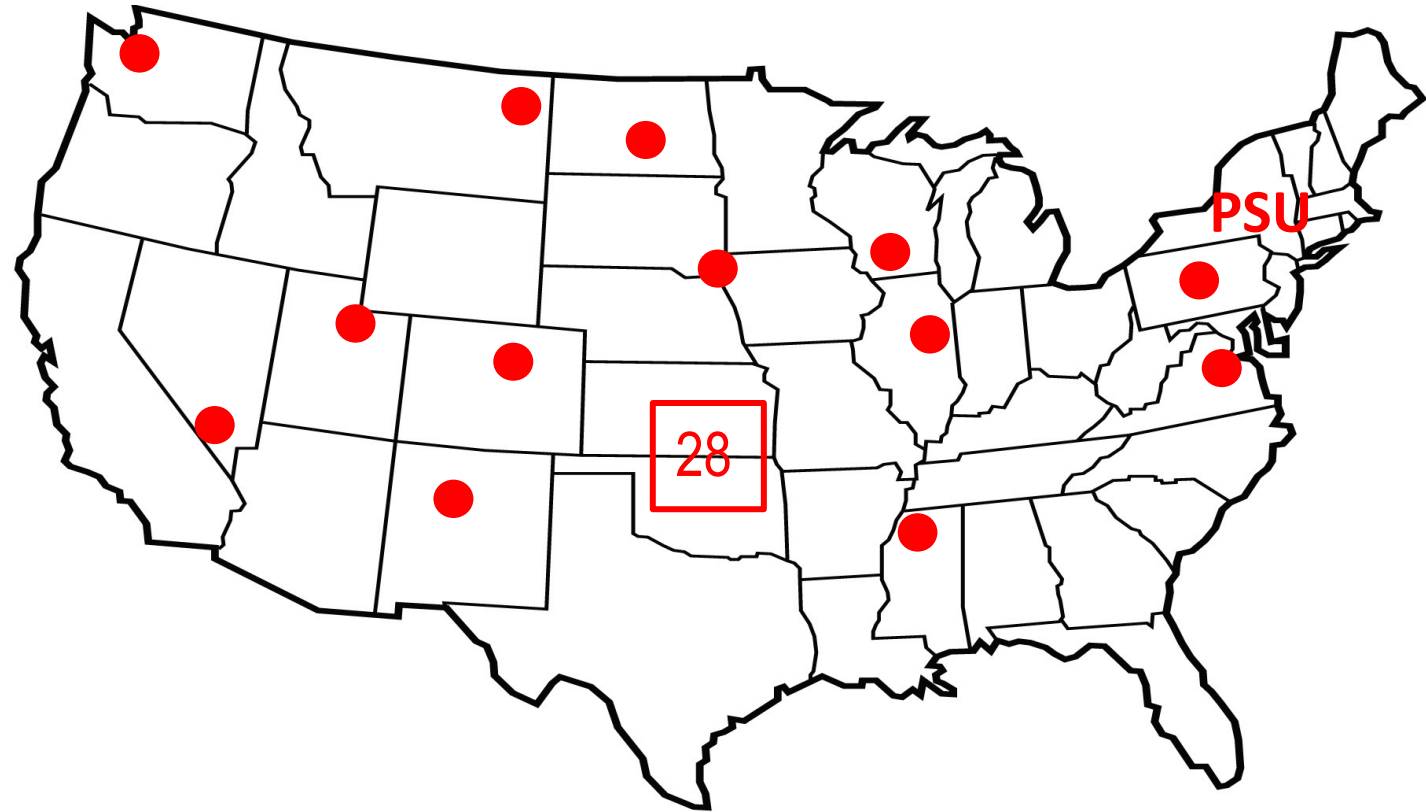
# Solar Observations used for ERA5 Evaluation

Emphasis is placed on quality of observations over quantity

- Good meta data for sites
- Observations span at least one full year

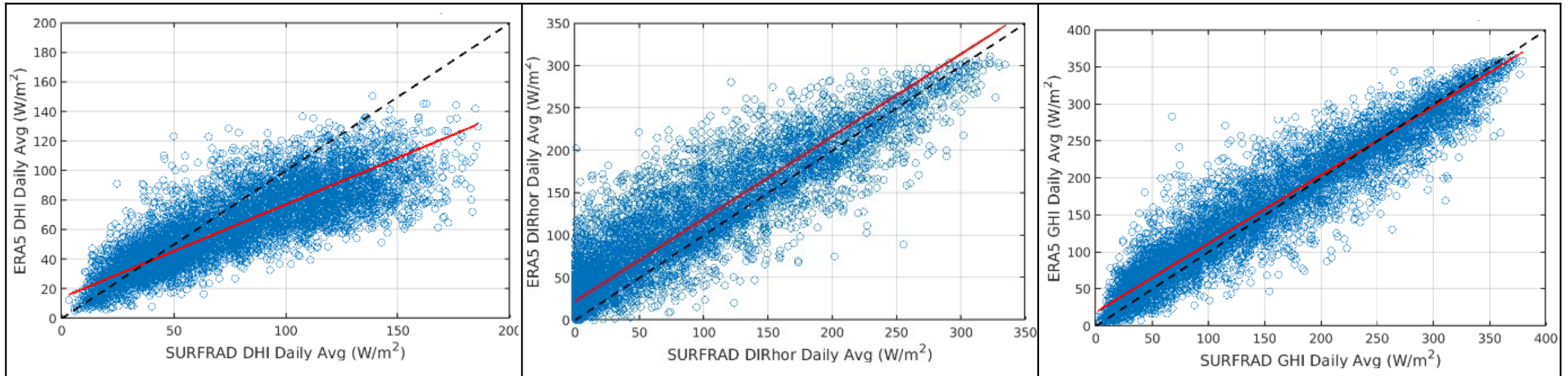
Irradiance observations:

- Frequent cleaning
- Heated sensors to minimize impacts of snow, rain, dew
- DOE Sandia PVlib → power, fixed tilts, U and T dependent, hourly → daily



**Solar irradiance observation sites (41):  
NOAA SURFRAD & SOLRAD, DOE ARM-SGP  
Direct, Diffuse irradiances (1998-2022)**

# Daily Averaged Irradiances: NOAA SURFRAD site=PSU vs ERA5 (1998-2022)



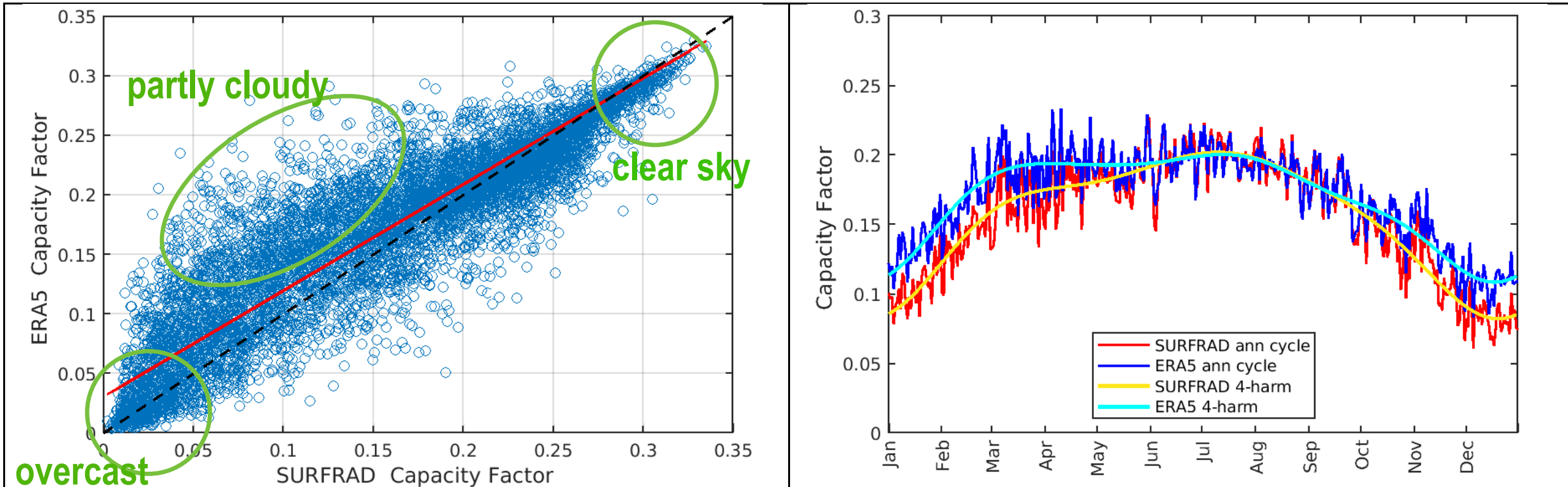
Diffuse Horizontal

Direct Horizontal

Global Horizontal

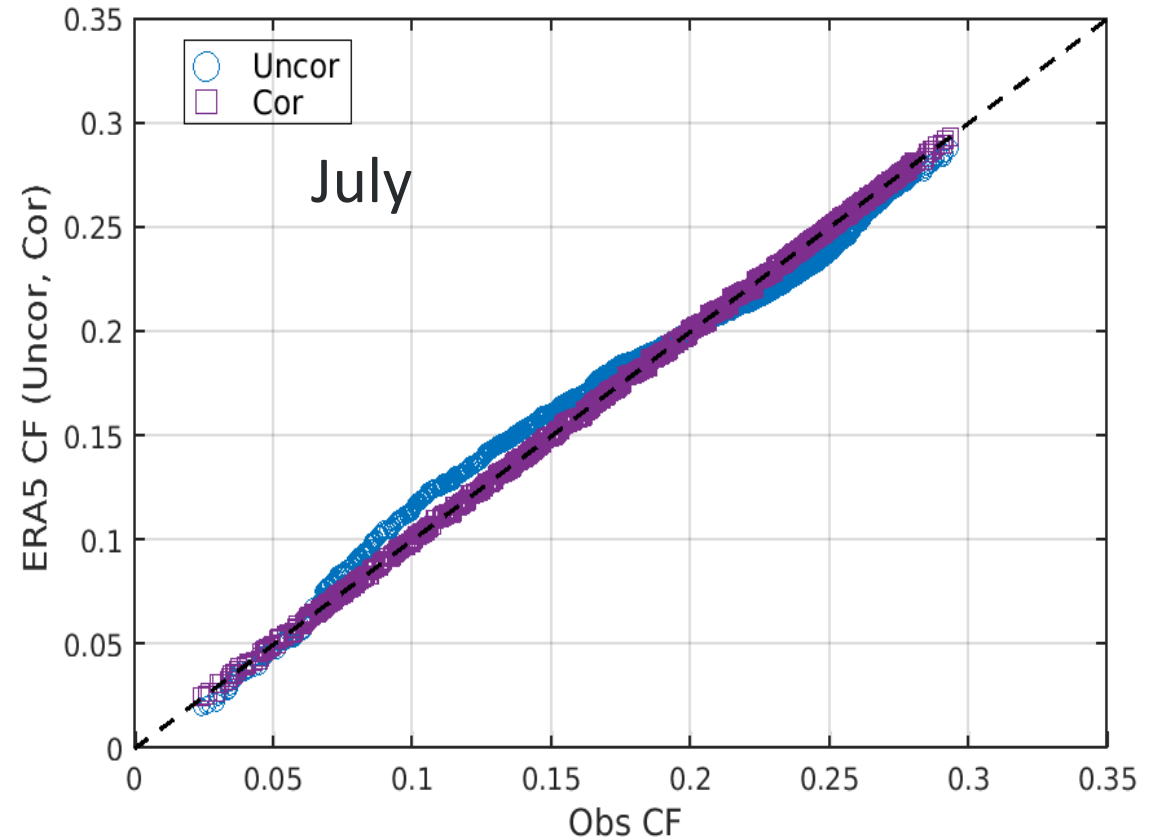
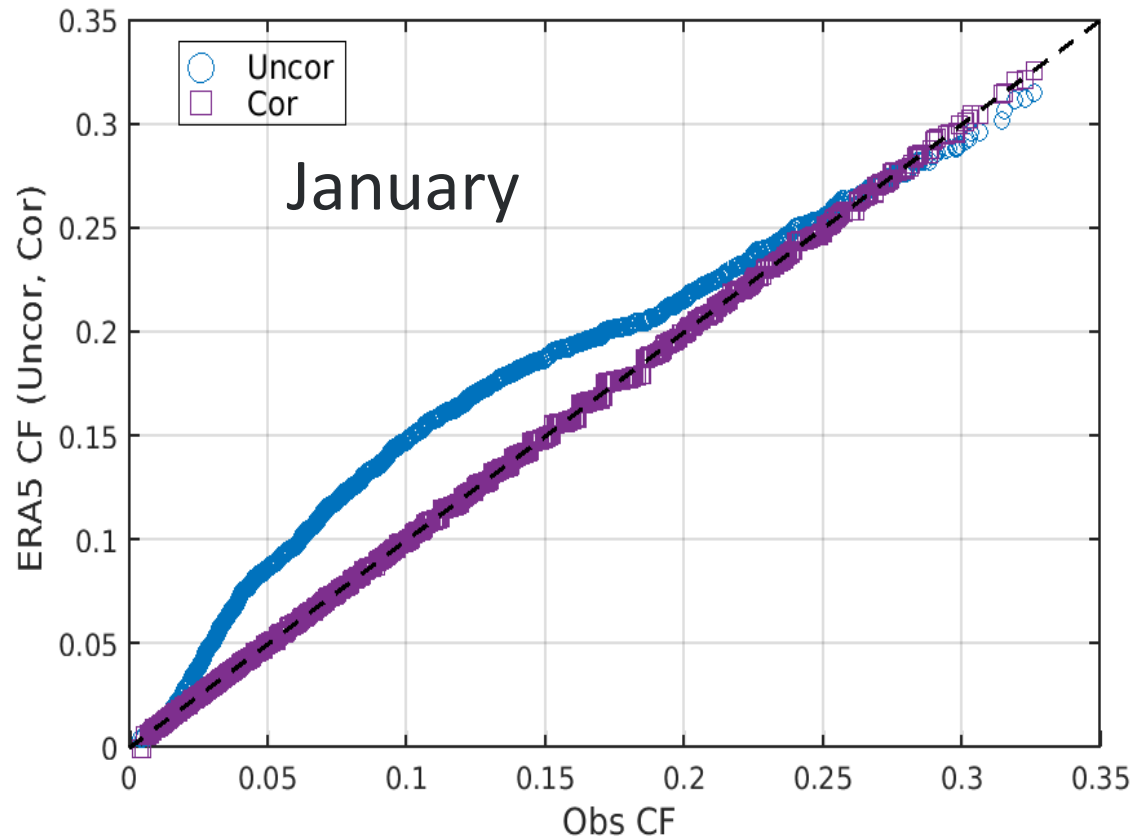
Solar panels tilted towards the sun use more of the direct beam, less of diffuse → ERA5 high solar power bias

# Daily Solar Capacity Factors: SURFRAD site=PSU vs ERA5-derived (1998-2022)



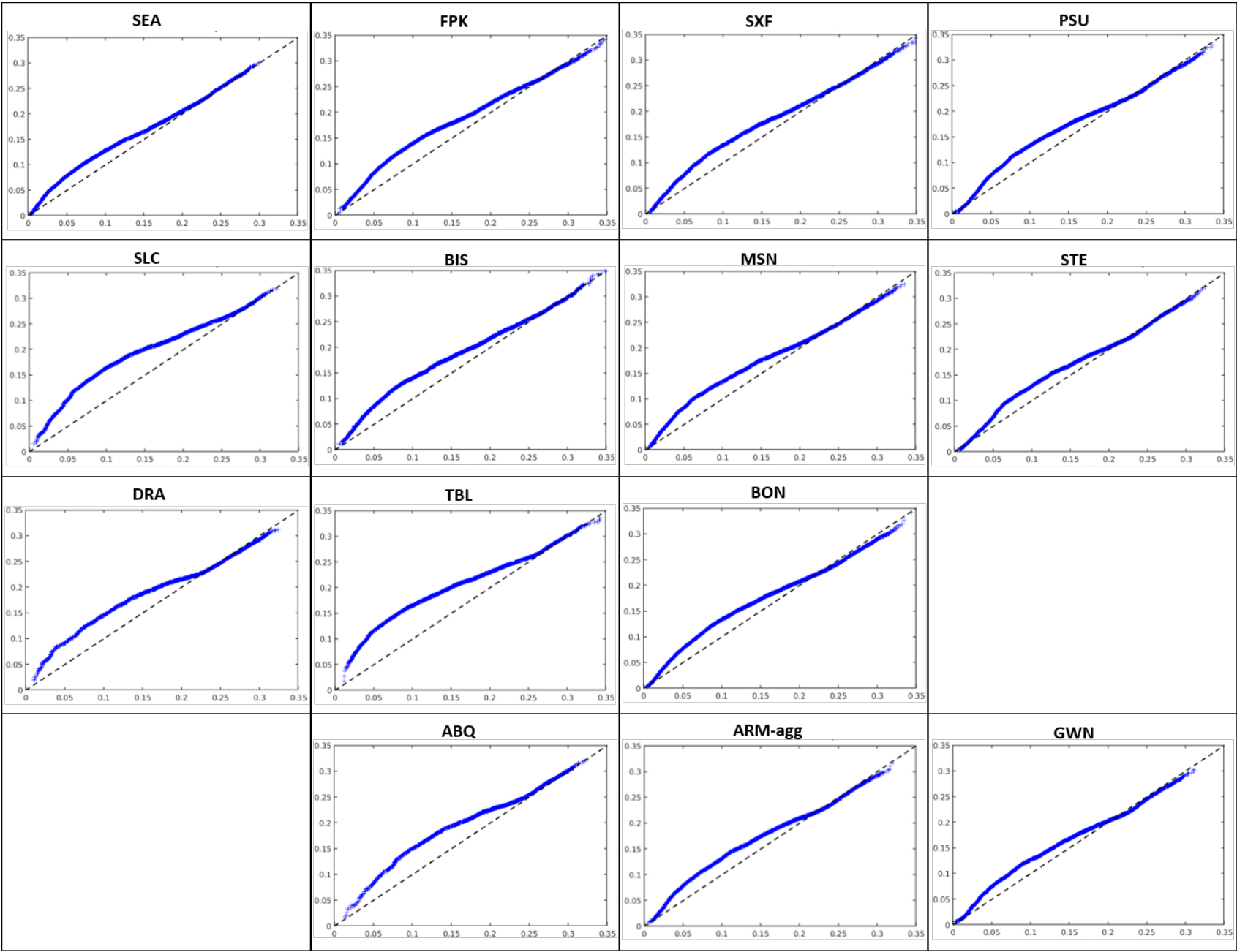
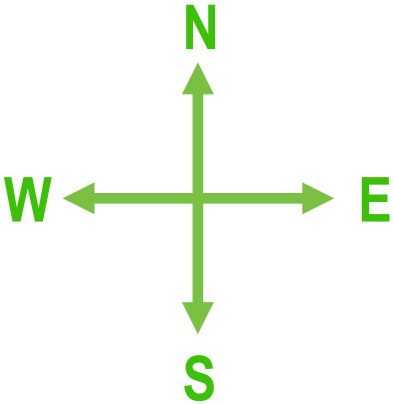
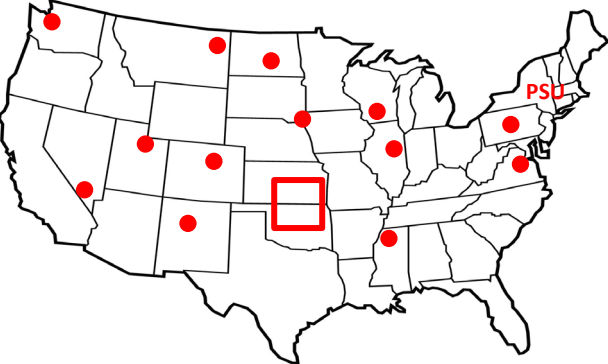
- ERA5 errors small for overcast & clear skies, biased high when partly cloudy
- Annual cycle ERA5 errors largest in winter, disappear in summer

# Daily Solar Capacity Factor Quantile-Quantile plots: NOAA SURFRAD site=PSU vs ERA5-derived

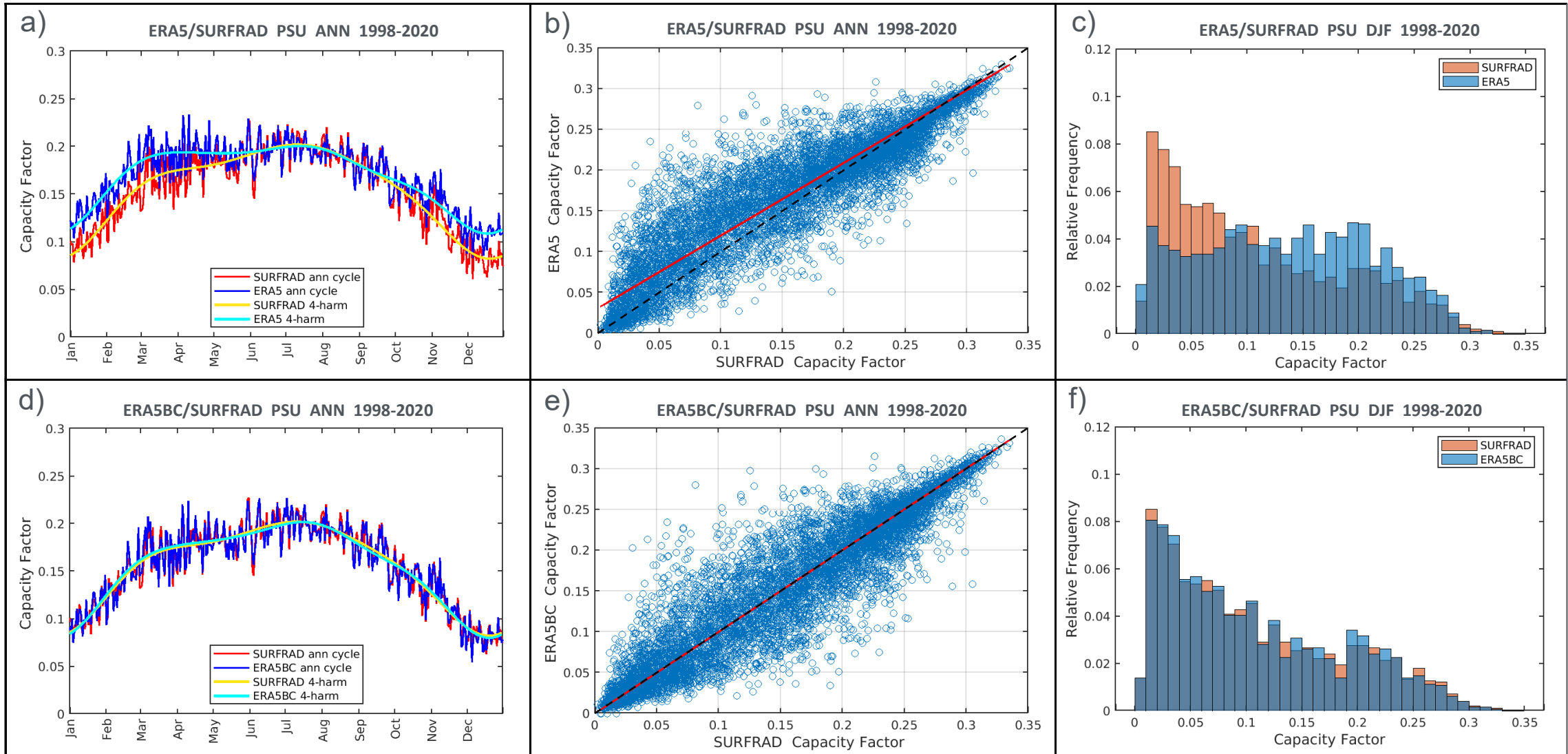


Q-Q corrections are made independently for each month of the year

Are ERA5-derived Solar CF errors geographically consistent?



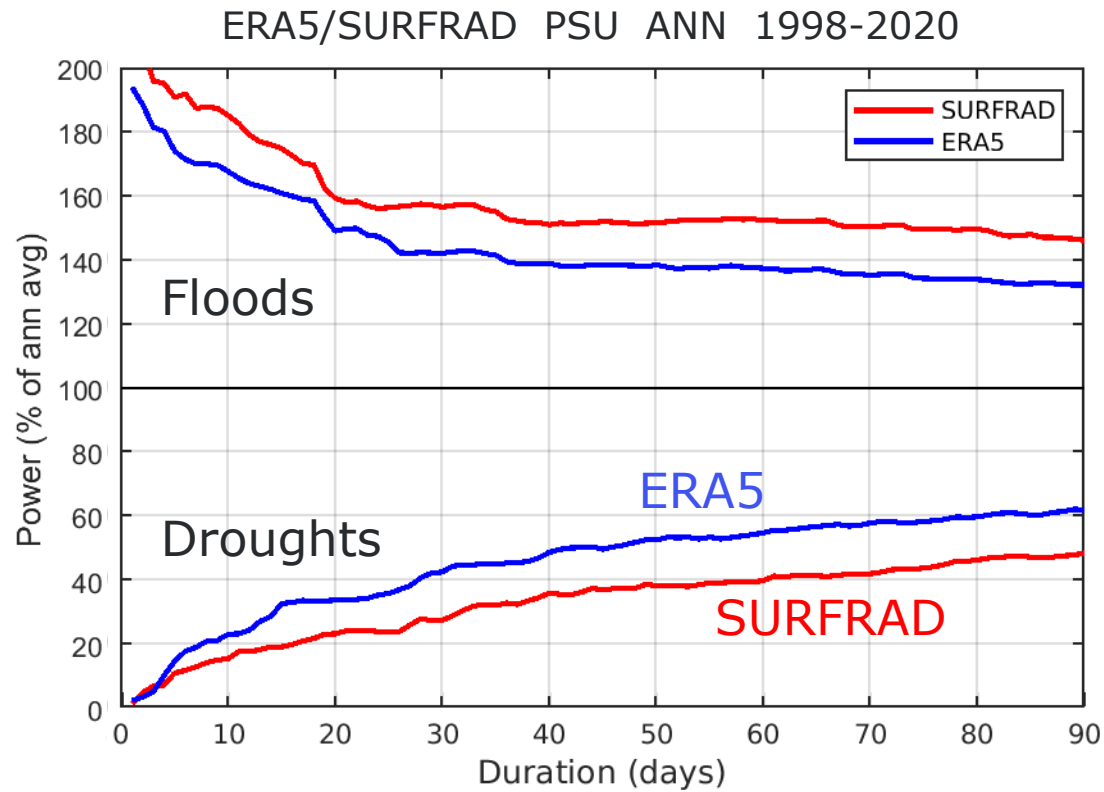
# Daily Solar Capacity Factors: SURFRAD site=PSU vs ERA5-derived: Effect of Correction



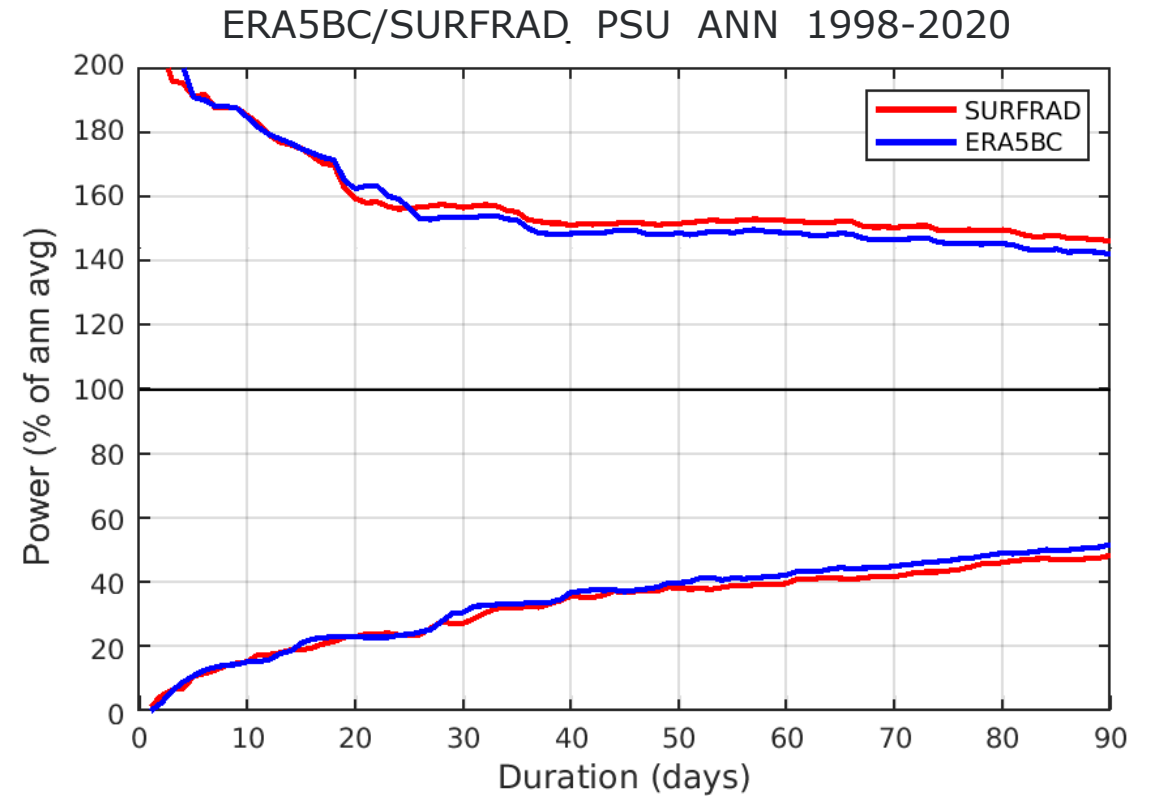
ERA5

ERA5BC

# Drought Intensity-Duration Curves: NOAA SURFRAD site=PSU vs ERA5-derived



ERA5

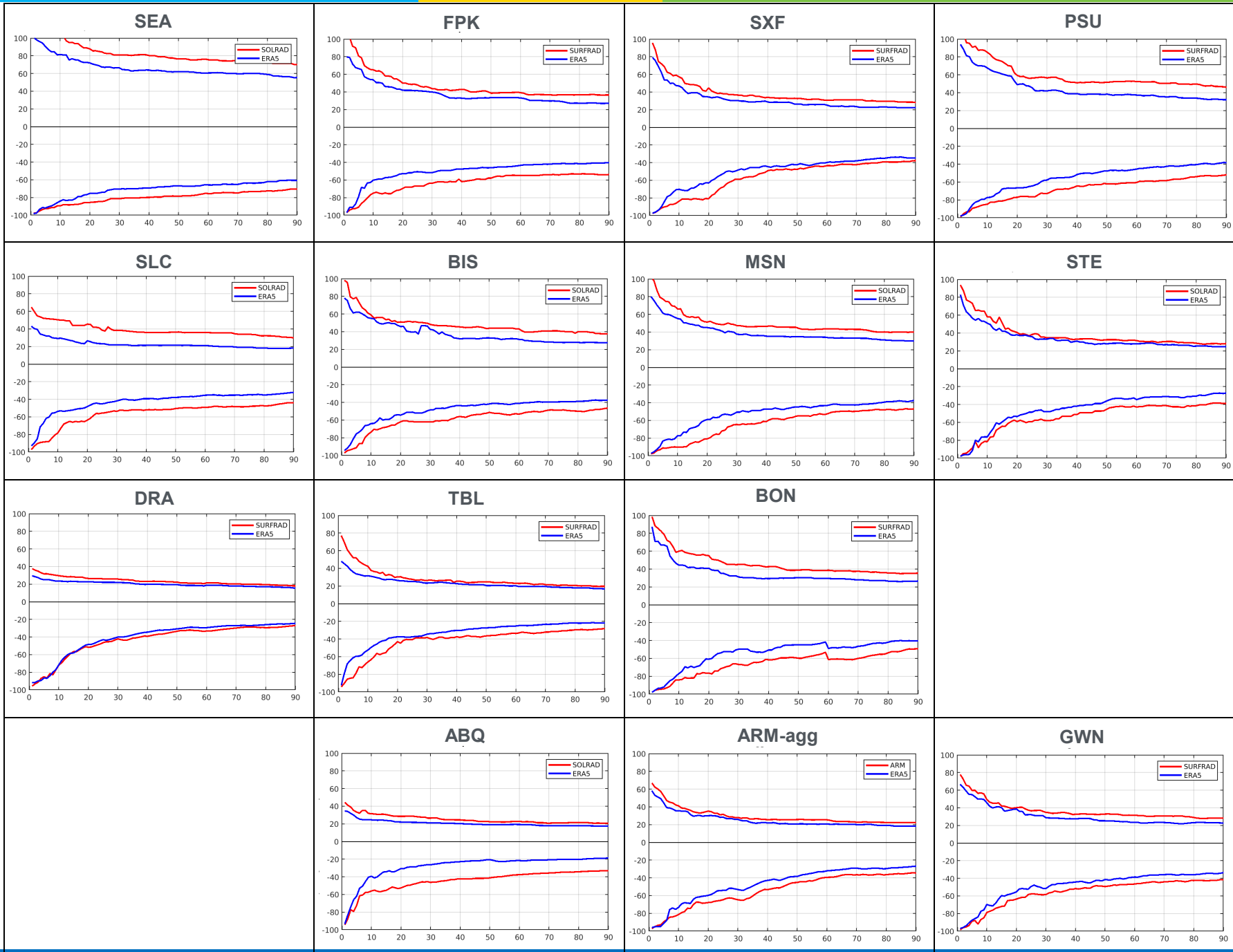
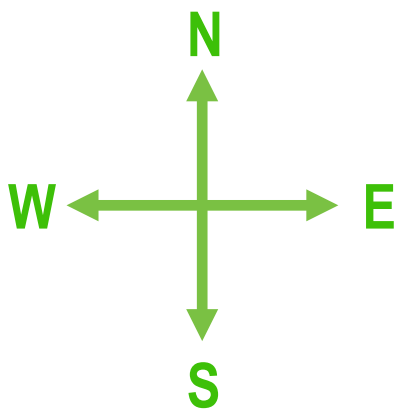
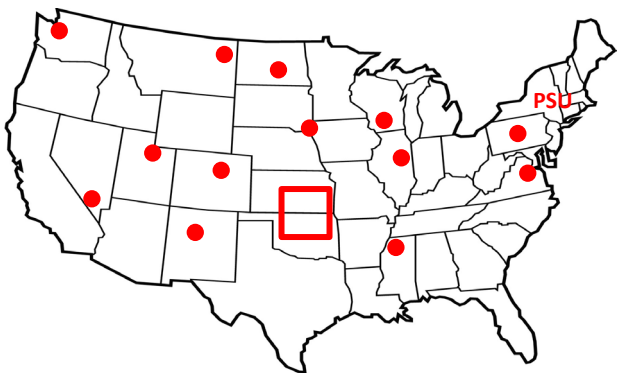


ERA5BC (Corrected)

- Worst-case percent of annual mean generation for durations of 1-90 days.
- ERA5 produces too much solar power during worst drought events

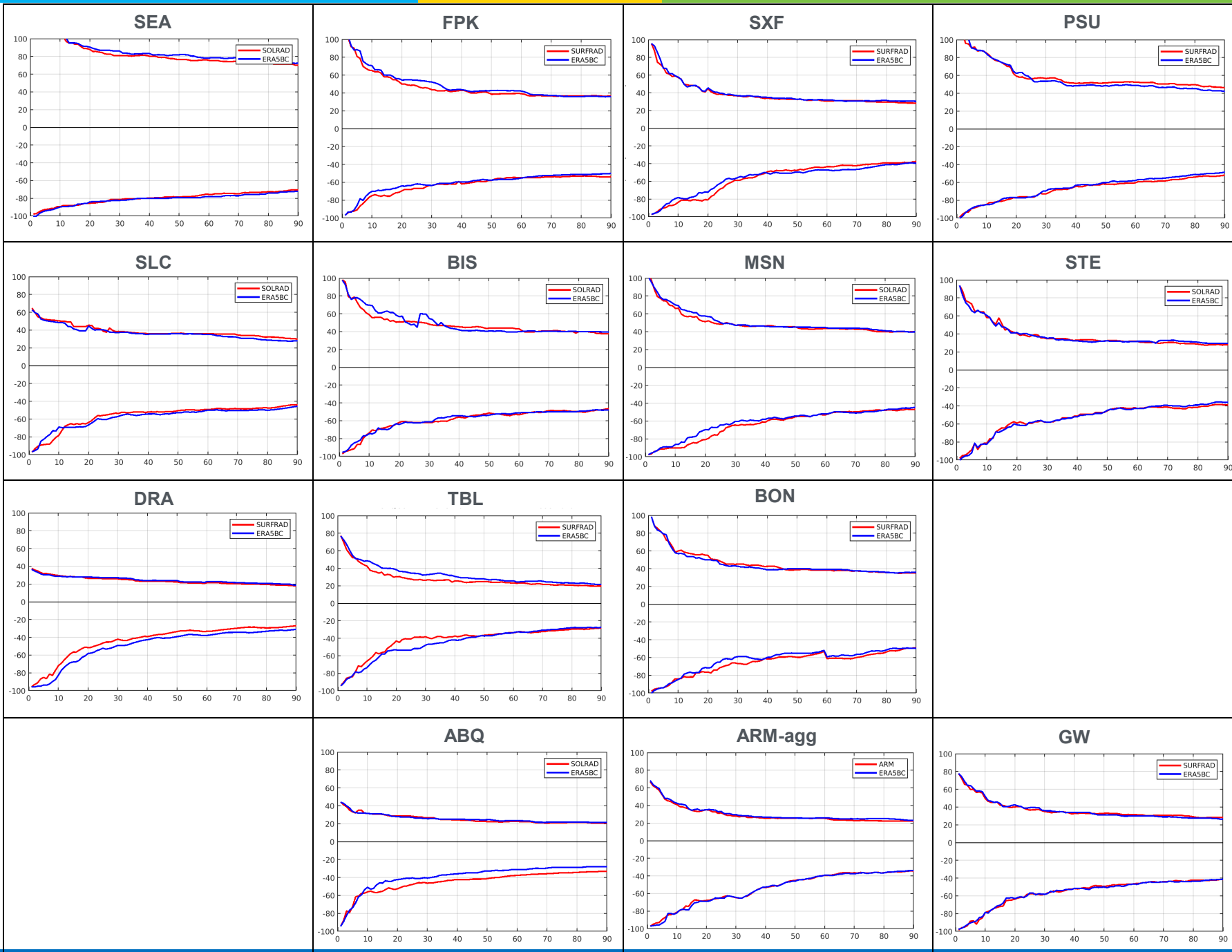
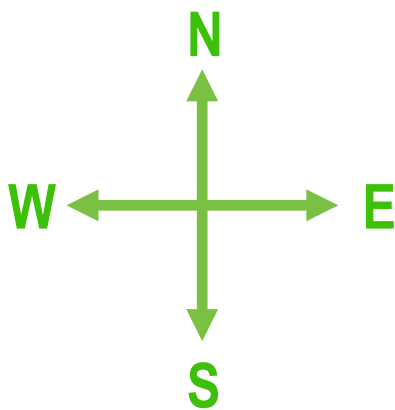
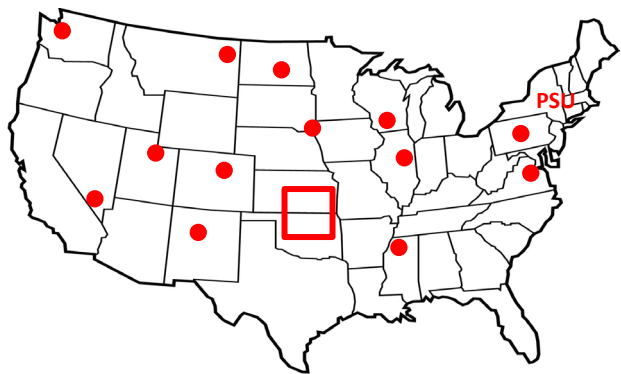
# Solar power ID curves

ERA5



# Solar power ID curves

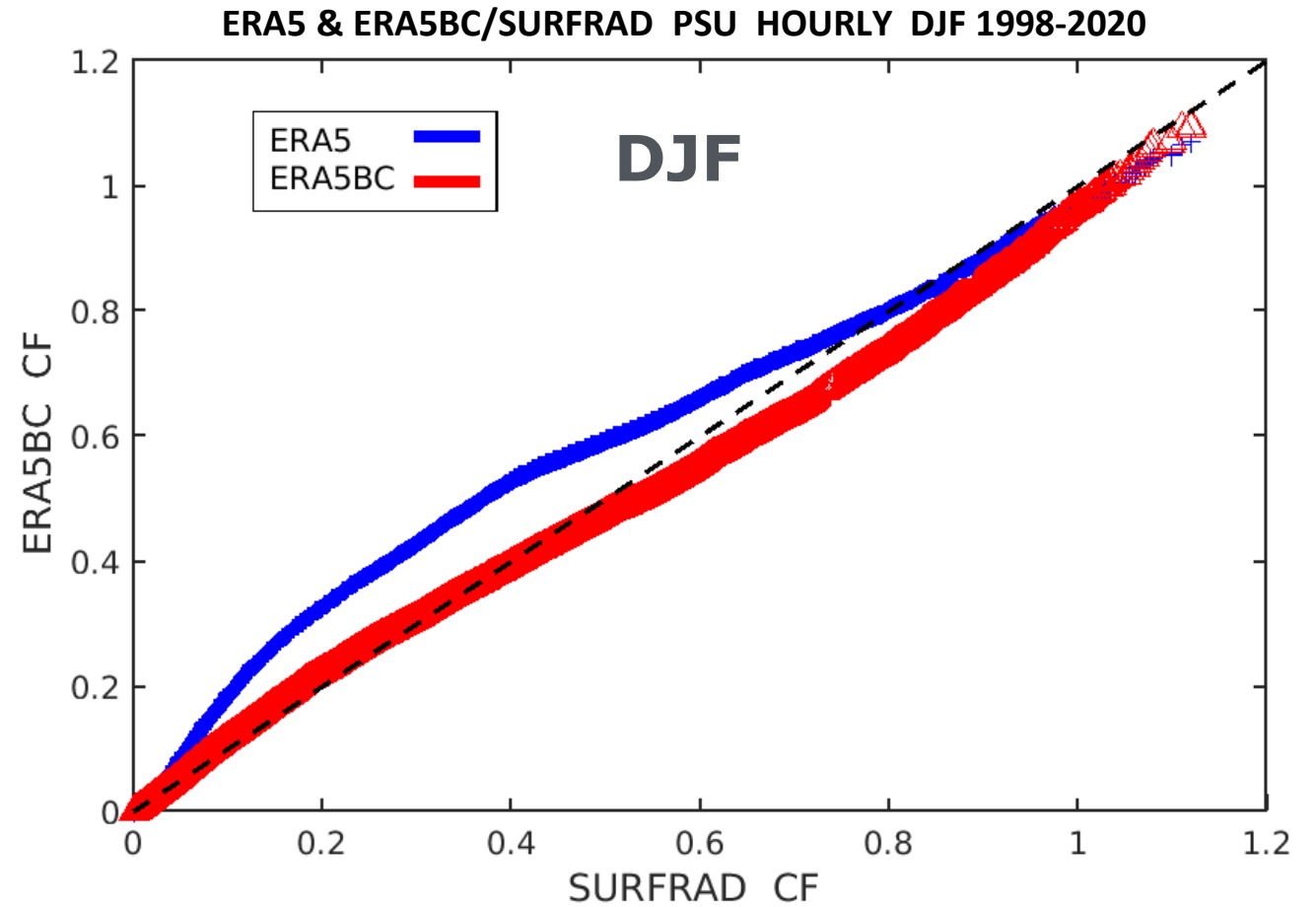
ERA5BC



# Solar Capacity Factor Quantile-Quantile plots: HOURLY NOAA SURFRAD site=PSU vs ERA5-derived

Solar corrections have been derived using daily average CF to reduce over-inflation of variances due to scale mismatch of point observations and grid cell areal average.

Same corrections can be applied to hourly values, assuming ERA5 errors are similar for all sun elevation angles.



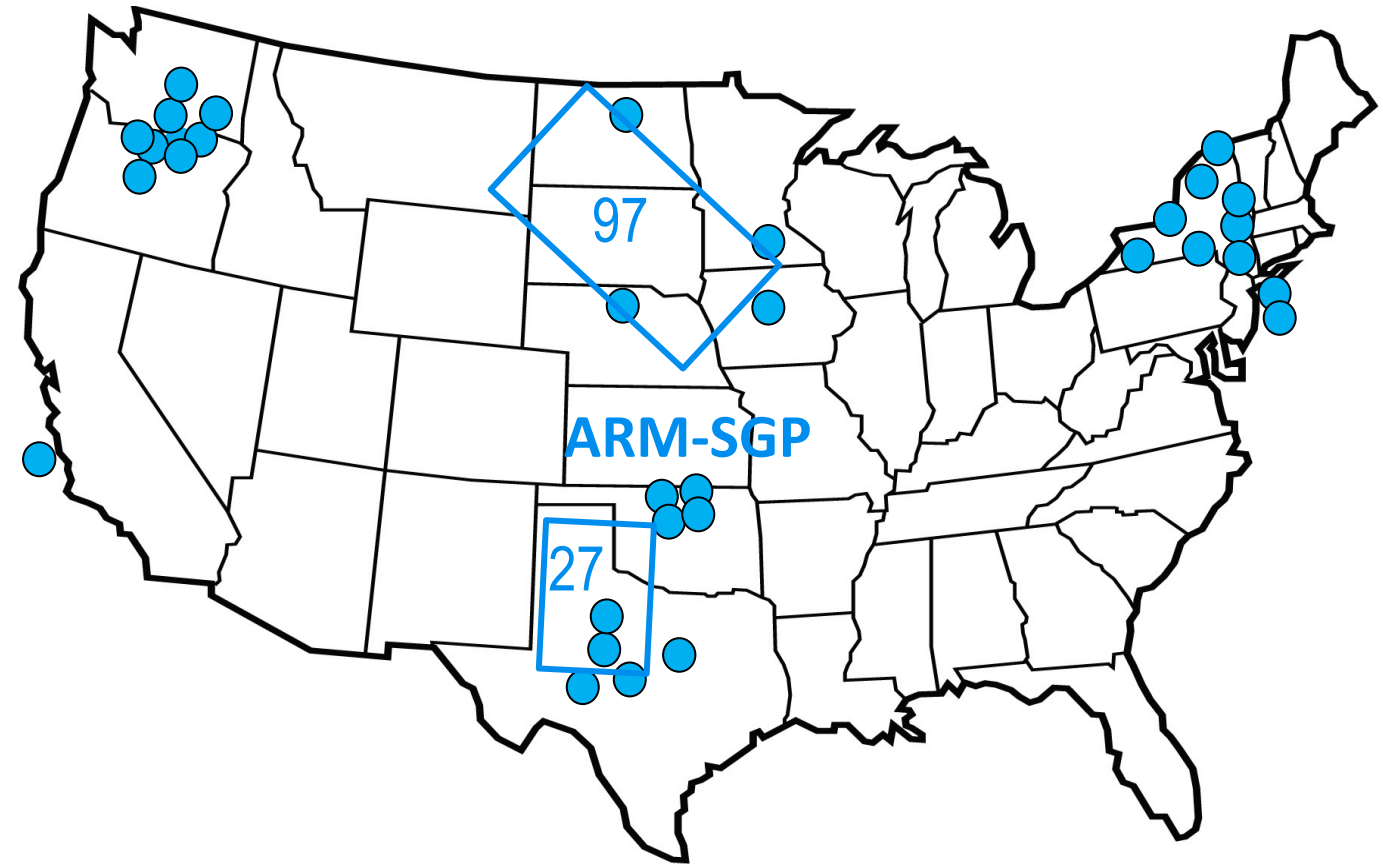
# Wind Observations used for ERA5 Evaluation

Emphasis is placed on quality of observations over quantity

- Adequate meta data for sites
- Observations span at least one full year

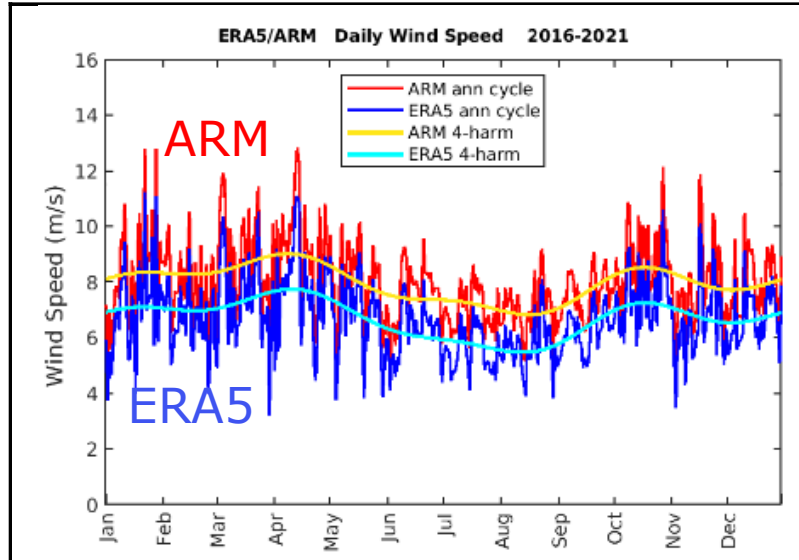
Wind Observations:

- Towers: booms in opposite or orthogonal directions to avoid tower shadowing; checked for icing conditions
- Extreme topography excluded
- DOE Wind Toolkit power curves, density included

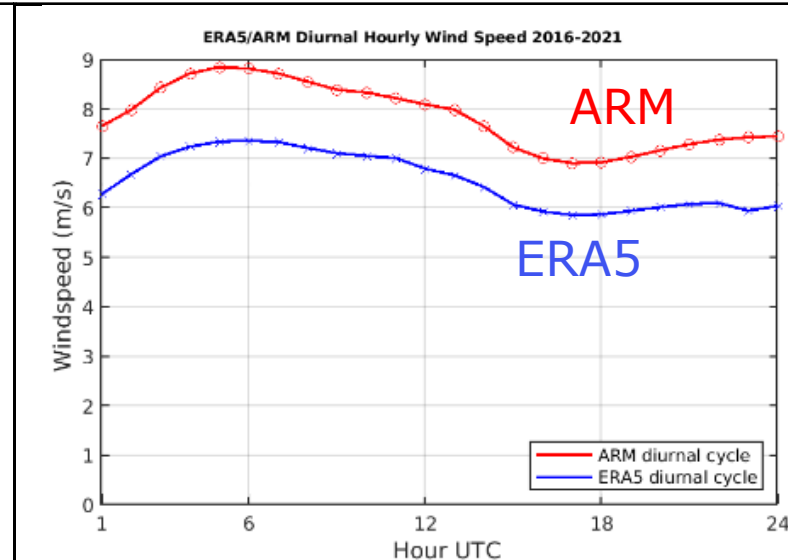


Wind observation sites (157):  
Tall towers (124), lidars(16), sodars (14)  
Wind speed, direction

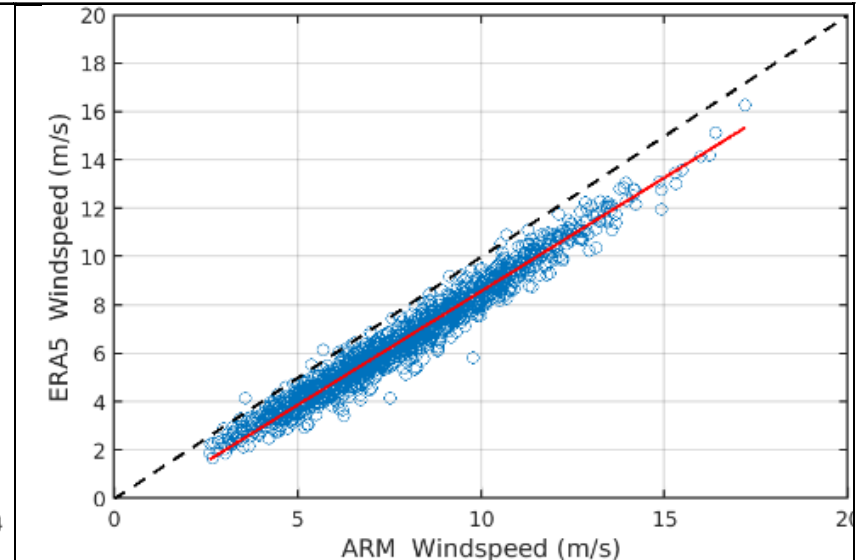
# Wind Speed (100m), ARM-SGP 4 lidar average (2016-2021): ERA5 Errors



Annual Cycle



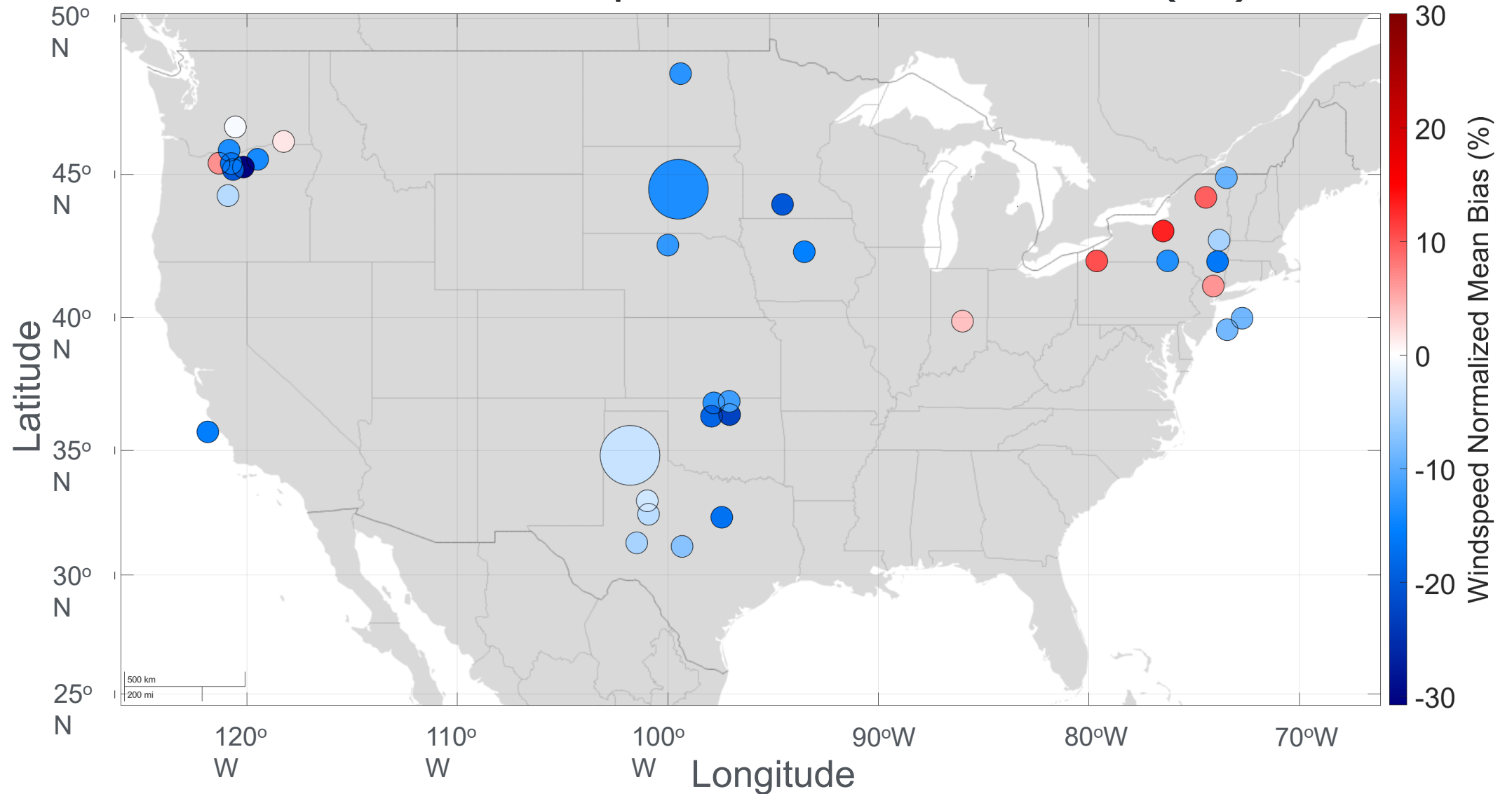
Diurnal Cycle



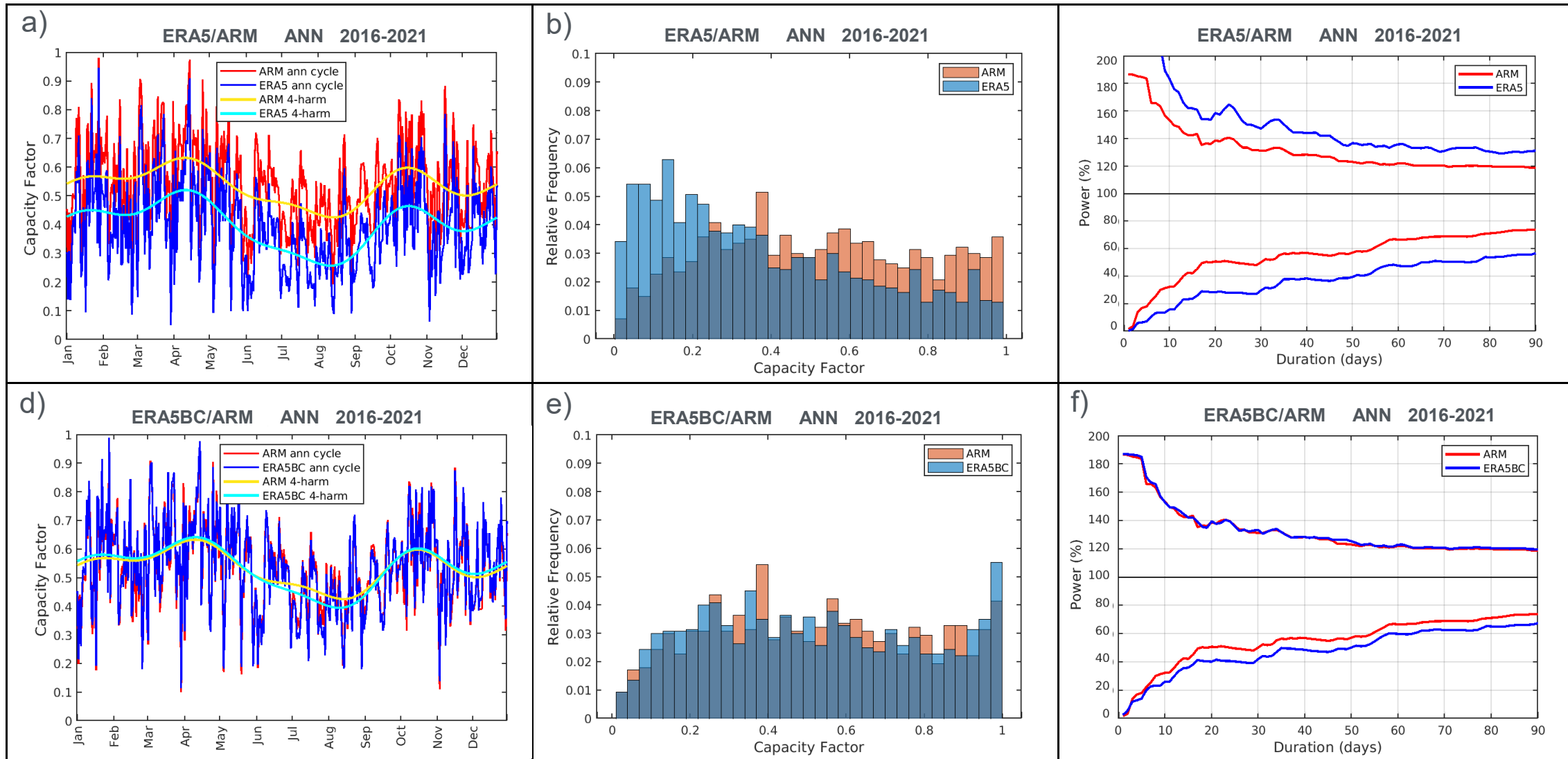
Scatter Plot of  
Daily Wind Speeds

# Geographic Consistency?

## ERA5 Wind Speed Normalized Bias (%)



# Daily Wind Capacity Factors, ARM-SGP 4 lidar average (2016-2021): Effect of Correction

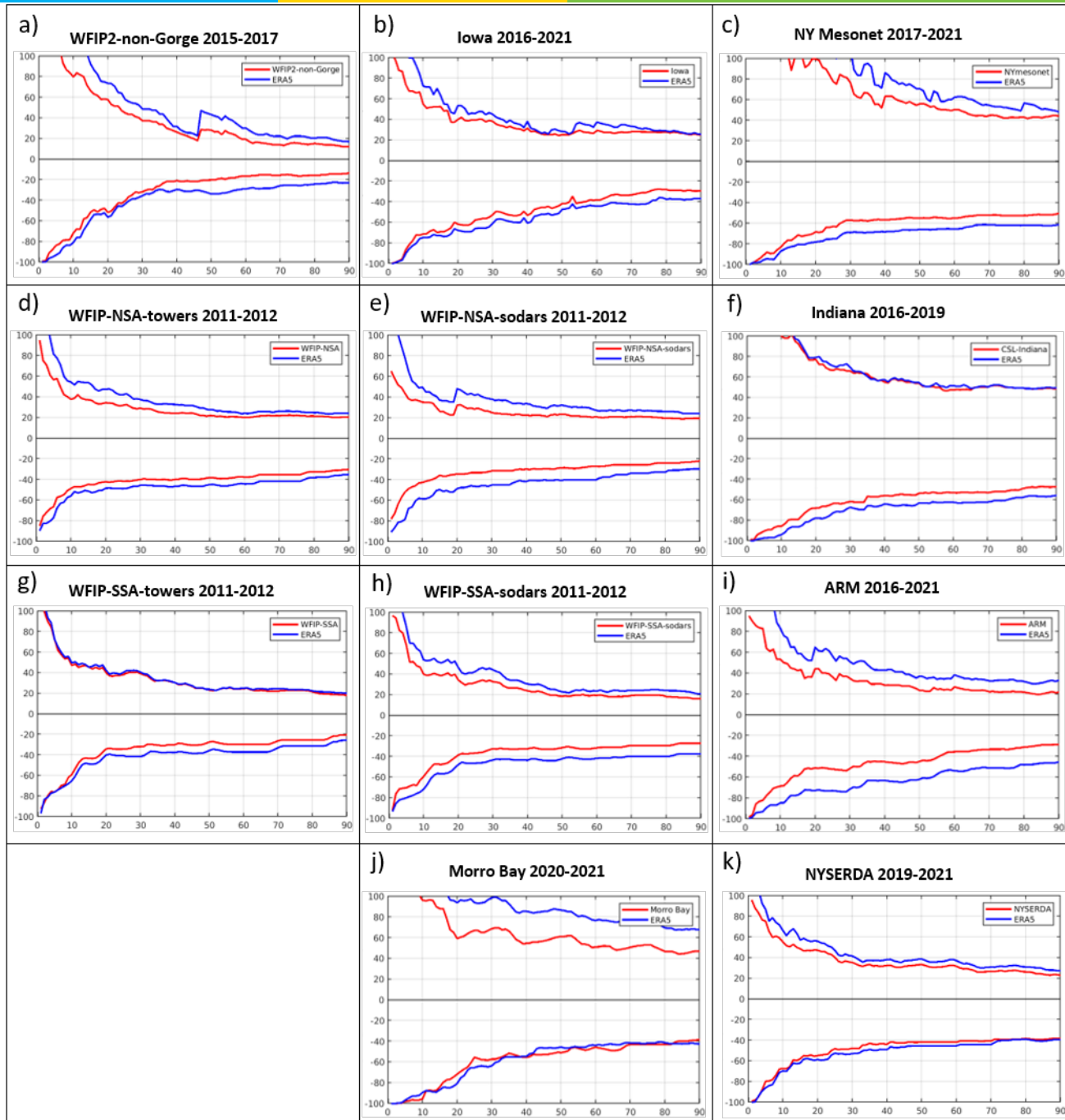
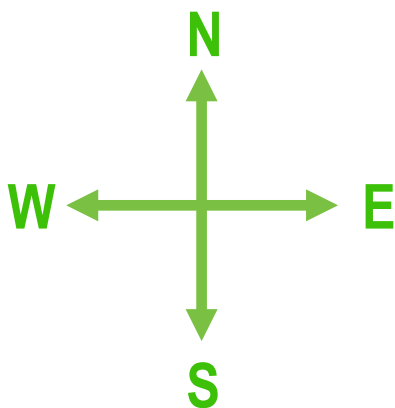
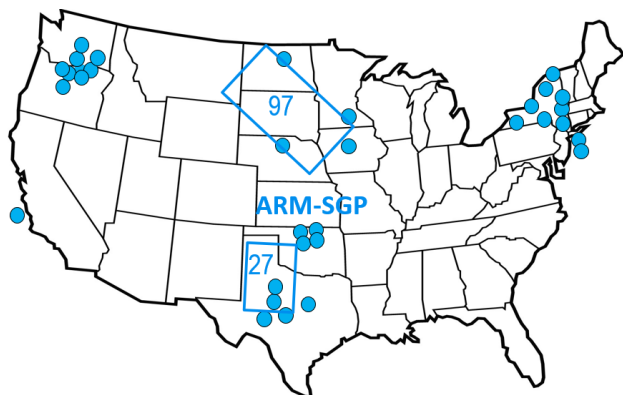


ERA5

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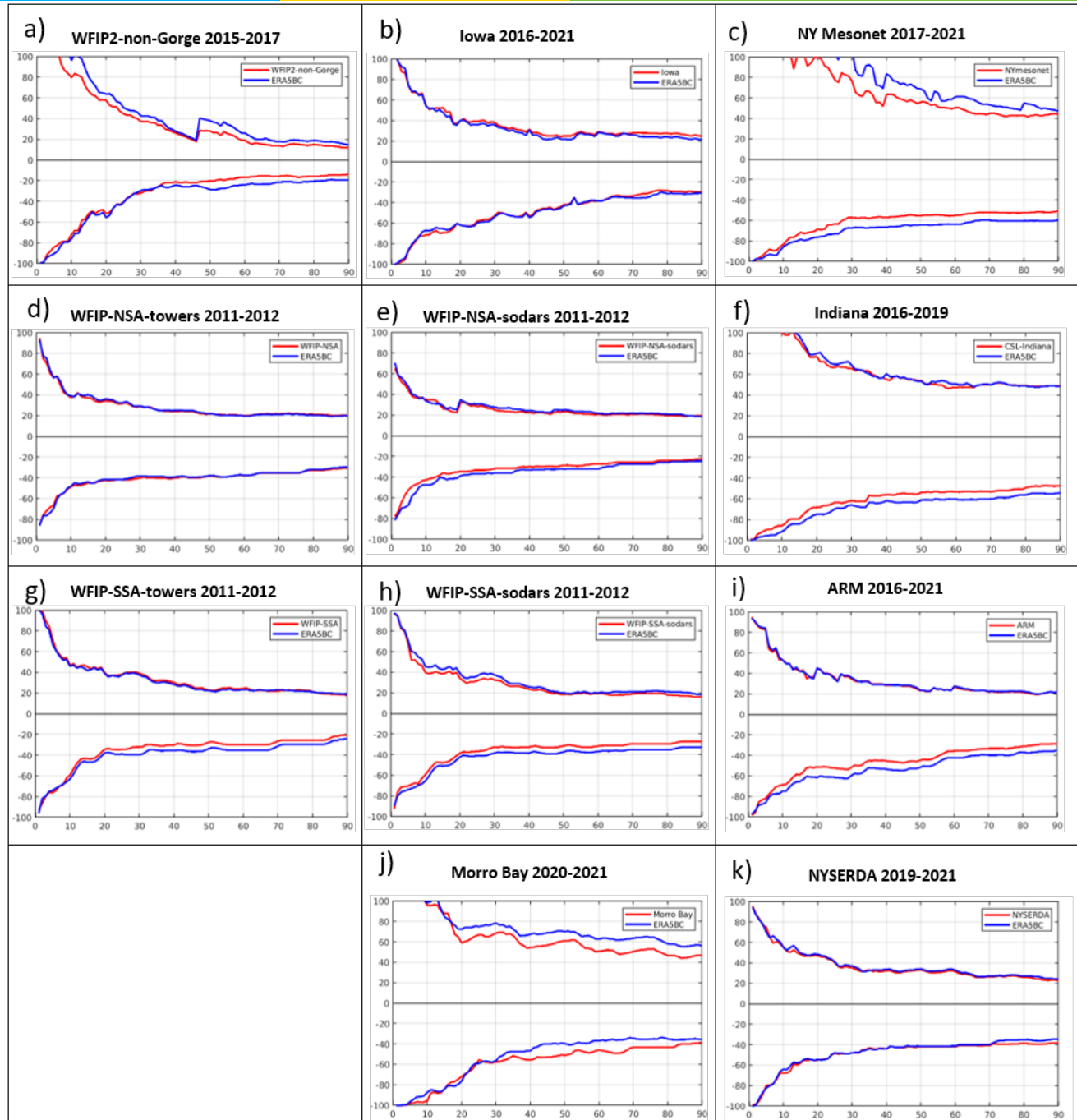
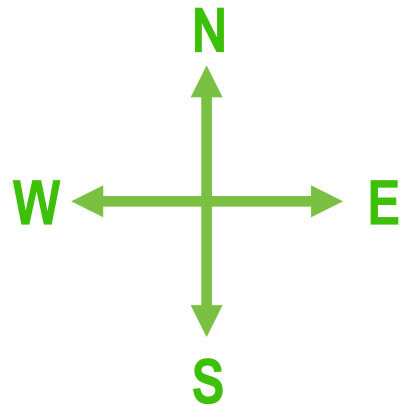
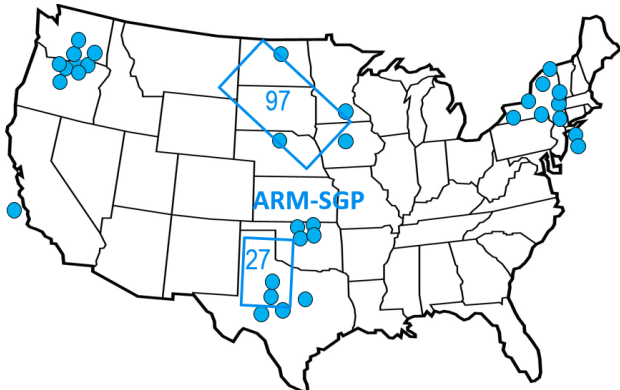
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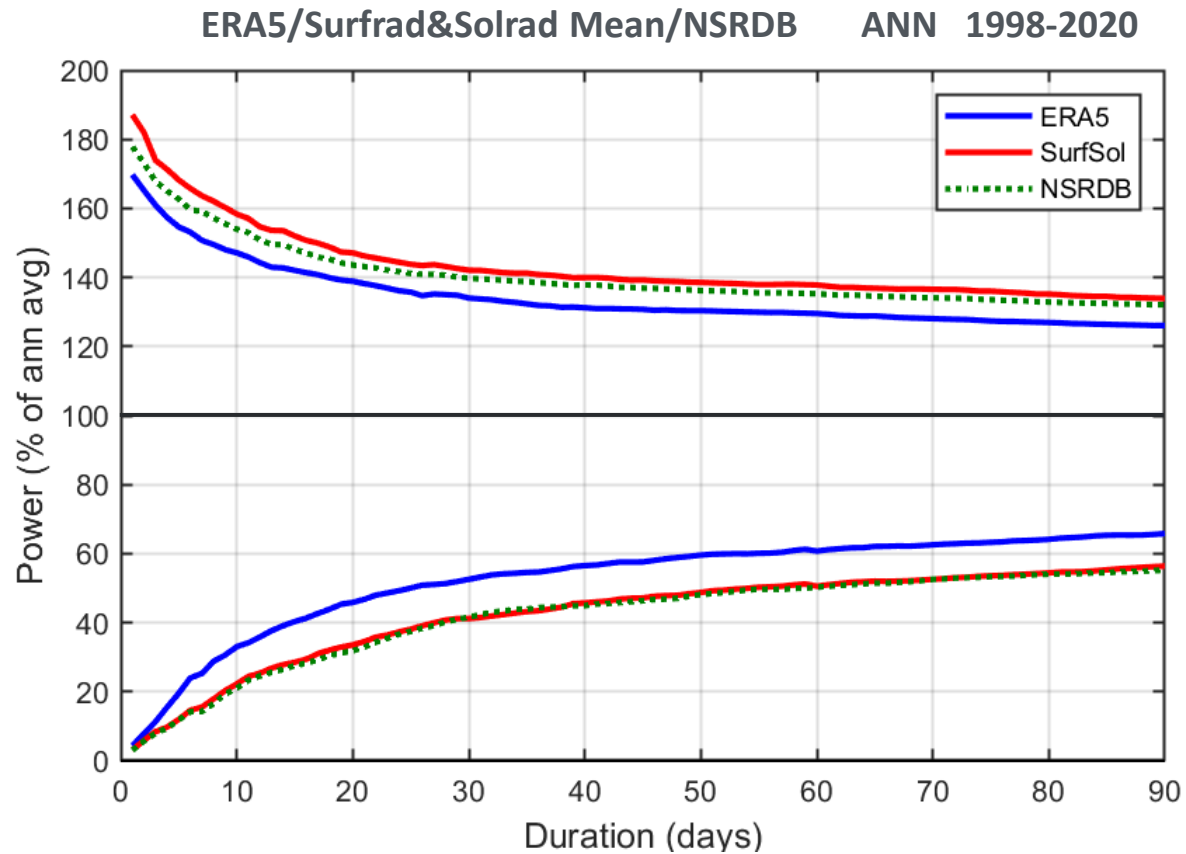
# Summary

- ERA5-derived solar CFs are biased high by  $\sim 25\%$  in winter on average, wind CFs are biased low by  $\sim 20\%$  across most of U.S.
- ERA5 produces too much solar power during solar droughts by  $\sim 50\%$ , and too little wind power during wind droughts by  $\sim 20\%$  at many locations.
- Quantile-quantile correction for solar, and linear regression for wind provide unbiased mean solar power and wind speed. Errors for the most severe solar drought events are reduced  $\sim 5x$  and wind droughts by  $\sim 2x$ .
- What magnitude errors are acceptable for capacity expansion models?

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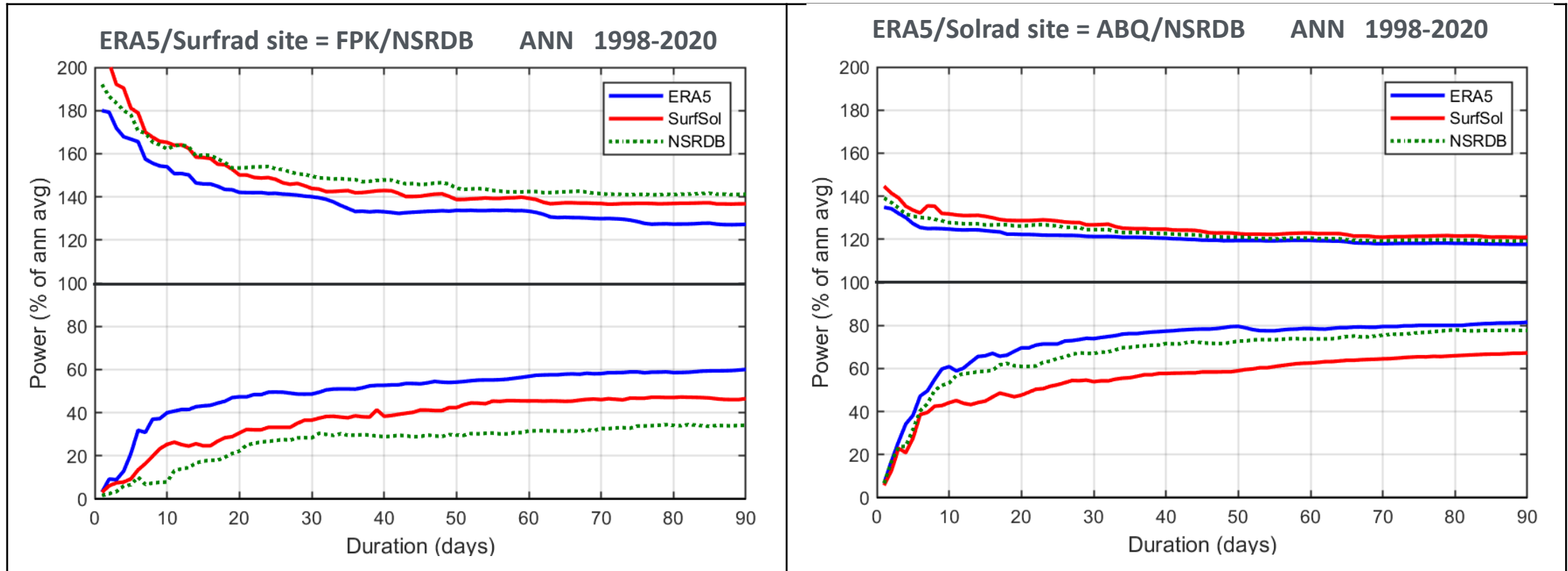
## Extra slides

# NSRDB, Surfrad&Solrad, ERA5 Intensity Duration Curves



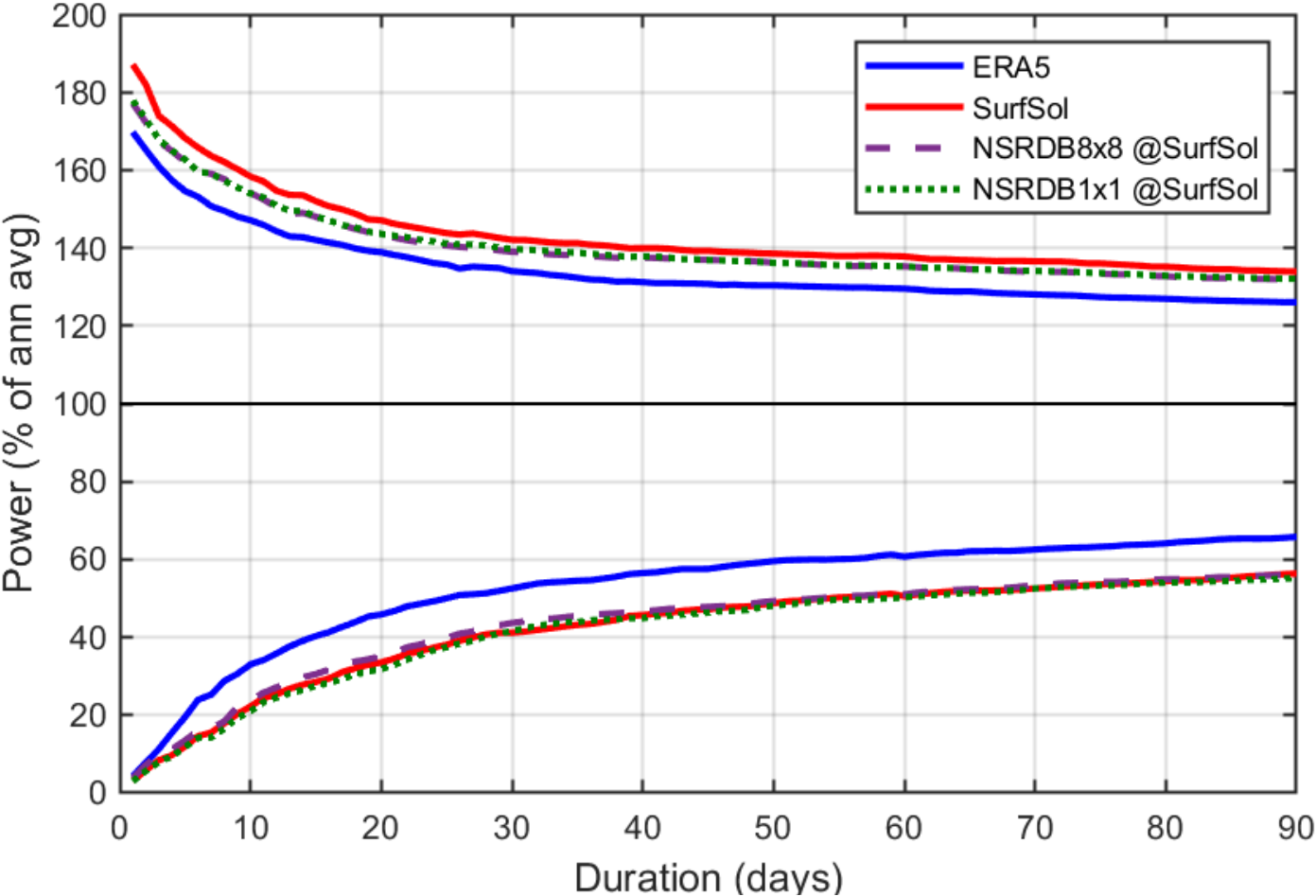
- ERA5, NSRDB, Surfrad & Solrad averaged over 13 sites.
- NSRDB droughts look great on average, however ...

# NSRDB, SurfRad&Solrad, ERA5 Intensity Duration Curves



- NSRDB droughts at individual sites can be biased high or low

# Test for potential over-inflation test using NSRDB irradiances



# Trends in solar and wind capacity factors from 1959-2022 averaged over the EIC, WIC, QIC, and ERCOT interconnects

