What's Needed for Best Practice Forecasts?

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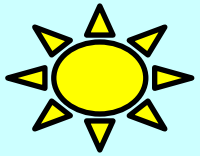
Energy Systems Integration Group

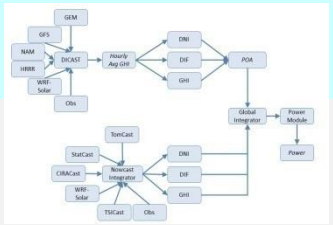
June 24, 2025

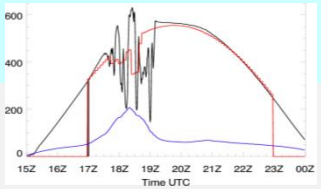
Forecasting & Markets Workshop

Value Chain:
What is the value of solar power forecasting?



Clear Sky





Weather | Monitoring Observation | Modelling | Forecasting | Dissemination & Communication | Perception Interpretation | Uses / Decision Making | Outcomes | Economic & social values

SURFRAD
WRF-Solar
Clouds
Satellites
HRRR
Total Sky Imagers
StatCast
Aerosols
TSICast
Pyranometers
CIRACast
MADCast

DICast
Point Forecast
Area Forecast
NowCast

Power Conversion
Projected Power Production
Actual Power Production
Uncertainty Quant
Load Balancing

Day Ahead Planning
Real Time Operation

Unit Allocations
Production Cost Changes
Reserve Estimates
Reserve Analysis

Inspired by Jeffrey Lazo

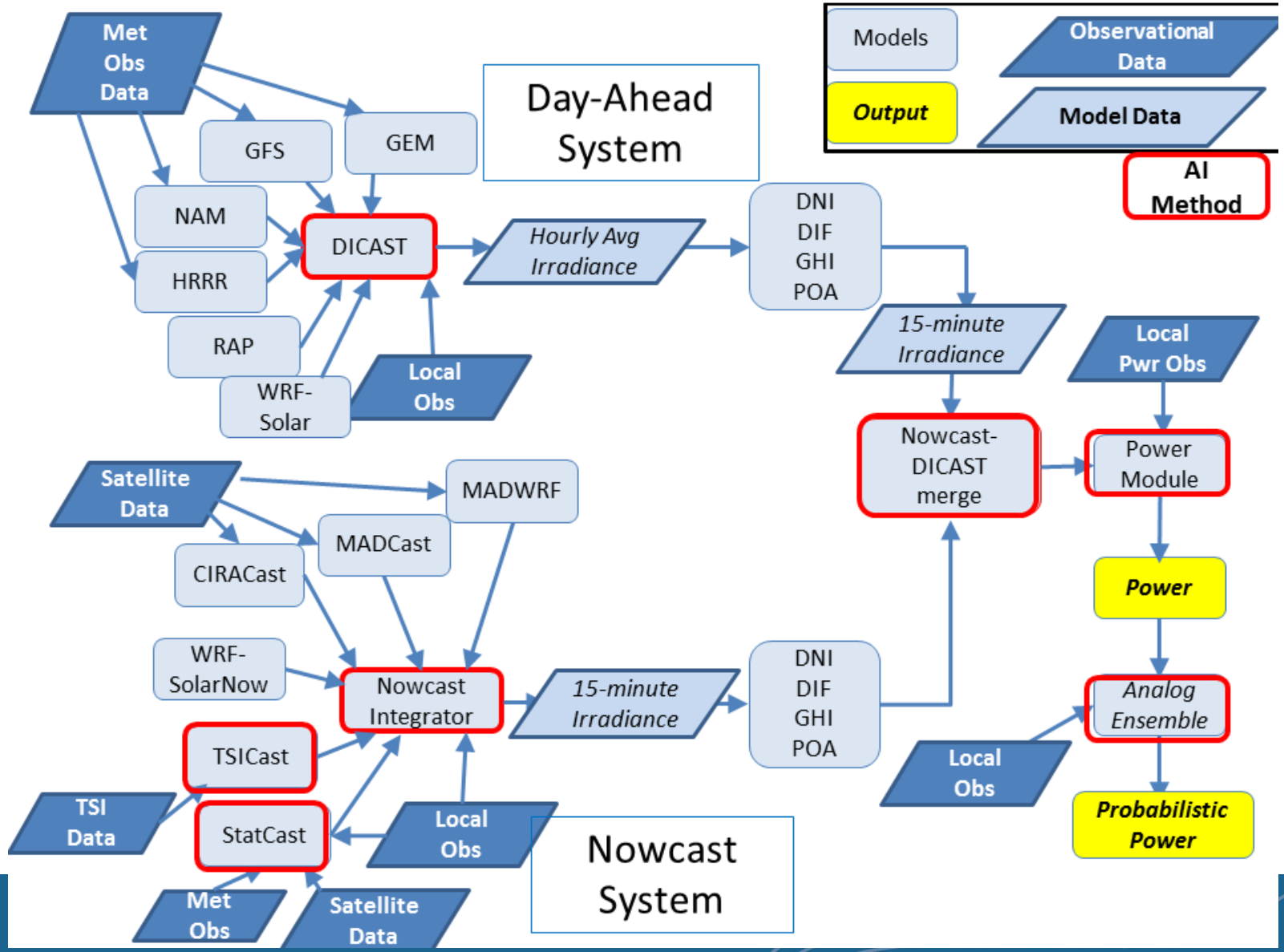
Haupt, S.E., B. Kosovic, T. Jensen, J. Lazo, J. Lee, P. Jimenz, J. Cowie, G. Wiener, T. McCandless, M. Rogers, S. Miller, M. Sangupta, Y. Xue, L. Hinkelman, P. Kalb, J. Heiser, 2018: Building the Sun4Cast System: Improvements in Solar Power Forecasting, *Bulletin of the American Meteorological Society*, Jan. 2018, 121-135. doi: 10.1175/BAMS-D-16-0221.1

AI as Part of Systems Engineering

Engineering the Sun4Cast® System

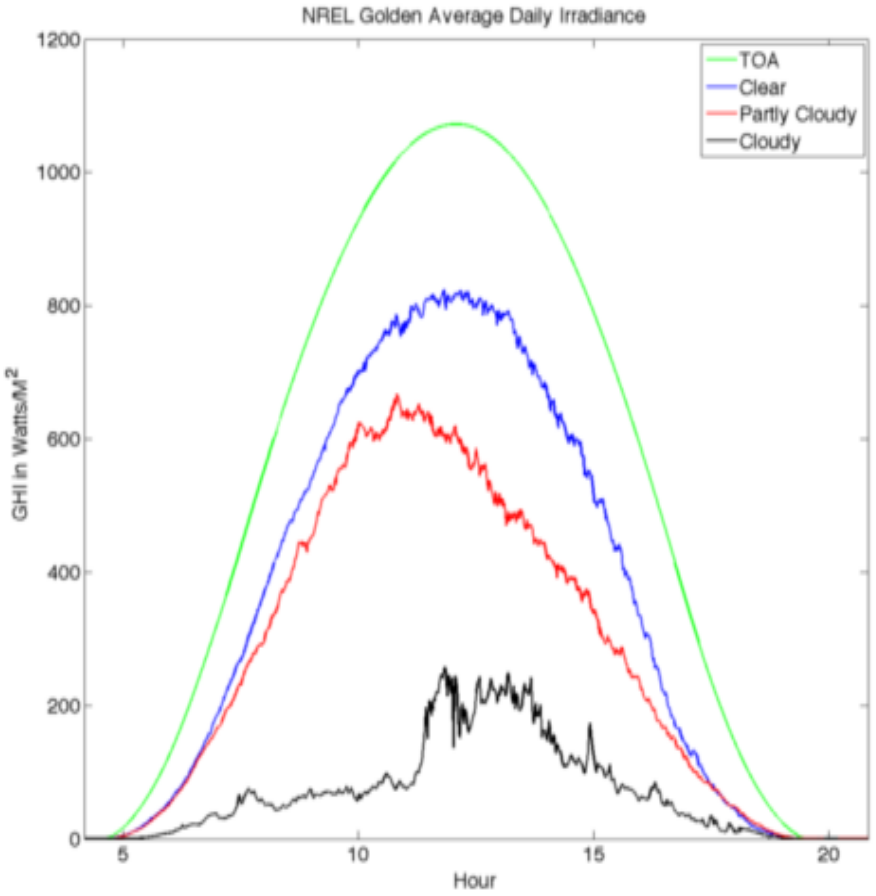
Day-Ahead System

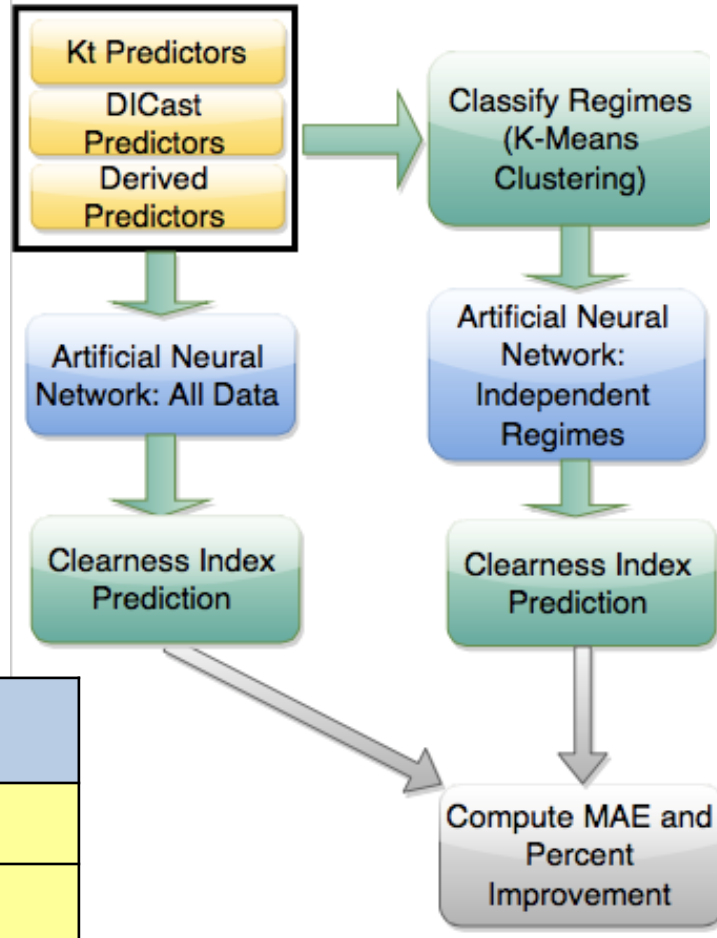
Nowcast System

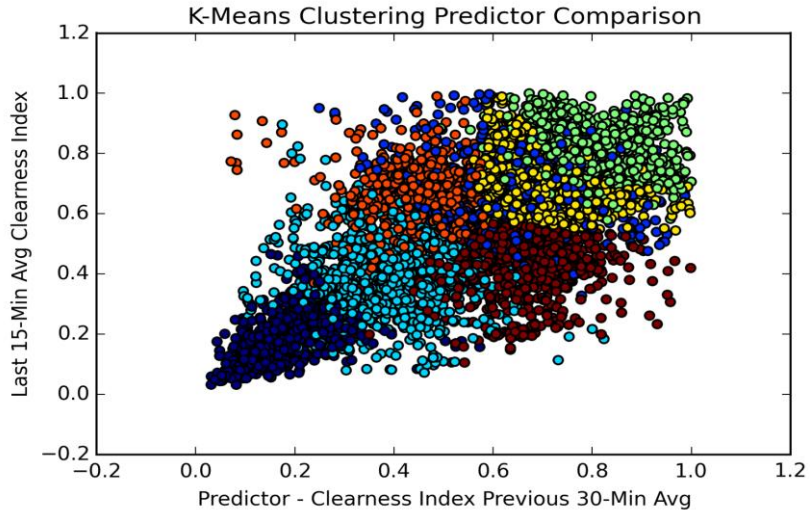


Haupt, S.E. and B. Kosovic, 2017: Variable Generation Power Forecasting as a Big Data Problem, *IEEE Transactions on Sustainable Energy,* **8** (2), pp. 725-732. DOI: 10.1109/TSTE.2016.2604679.

StatCast: Regime Dependent Forecasting







Improvement over Clearness Index Persistence	
ANN	**RD-ANN**
13.7%	**18.6%**

McCandless, T.C., S.E. Haupt, and G.S. Young, 2016: A Regime-Dependent Artificial Neural Network Technique for Short-Range Solar Irradiance Forecasting, *Applied Energy,* **89**, 351-359.

Tyler McCandless

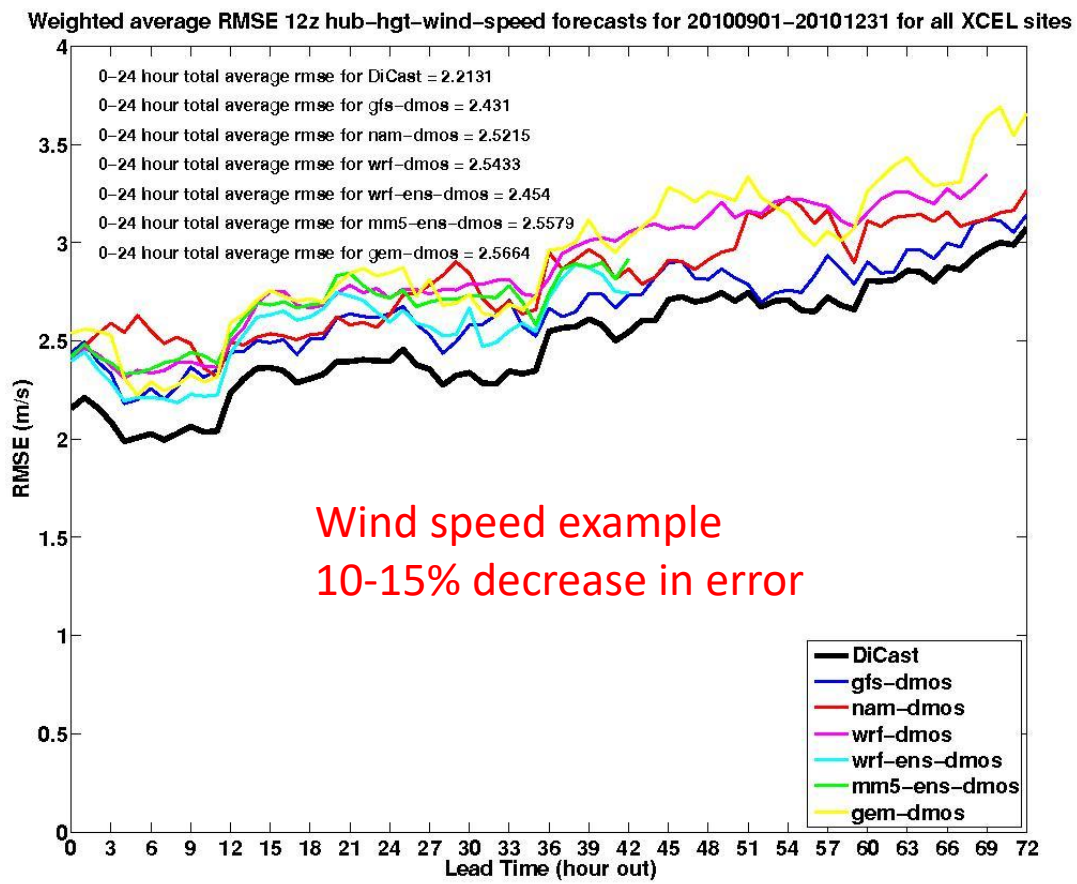
NCAR

DICast Integrator System

Dynamic Integrated foreCast System

Nacelle Winds

Error



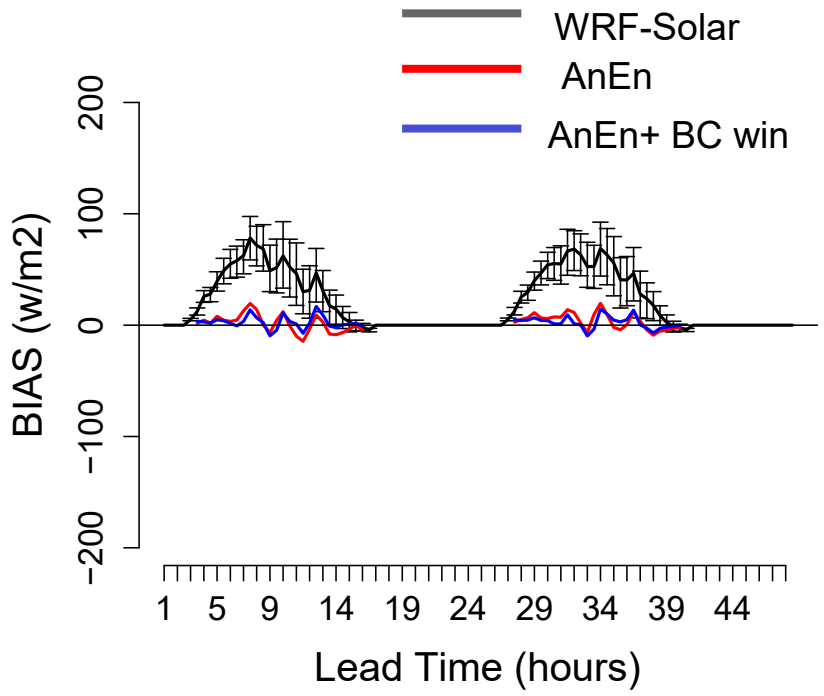
Wind speed example
10-15% decrease in error

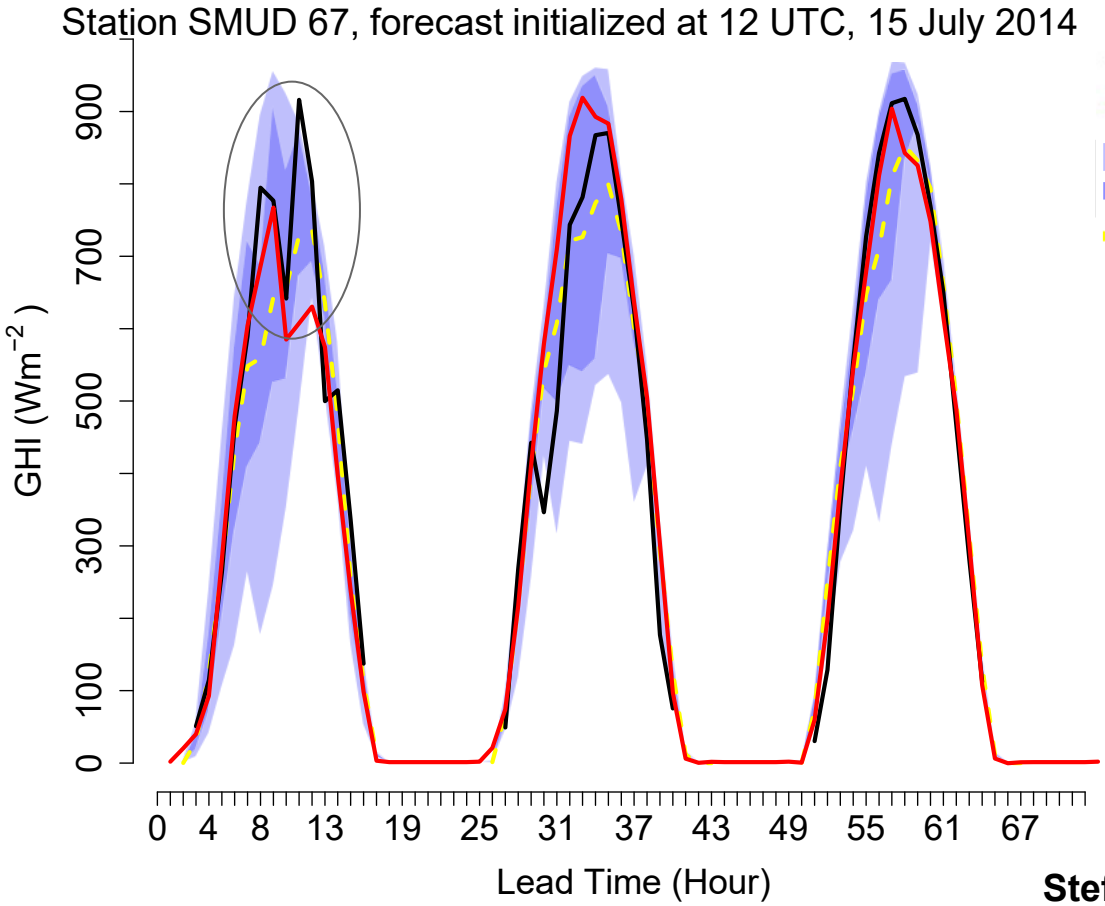
egrator

ne Power
ediction

d Power
recast

Uncertainty Quantification
Analog Ensemble (AnEn) Approach

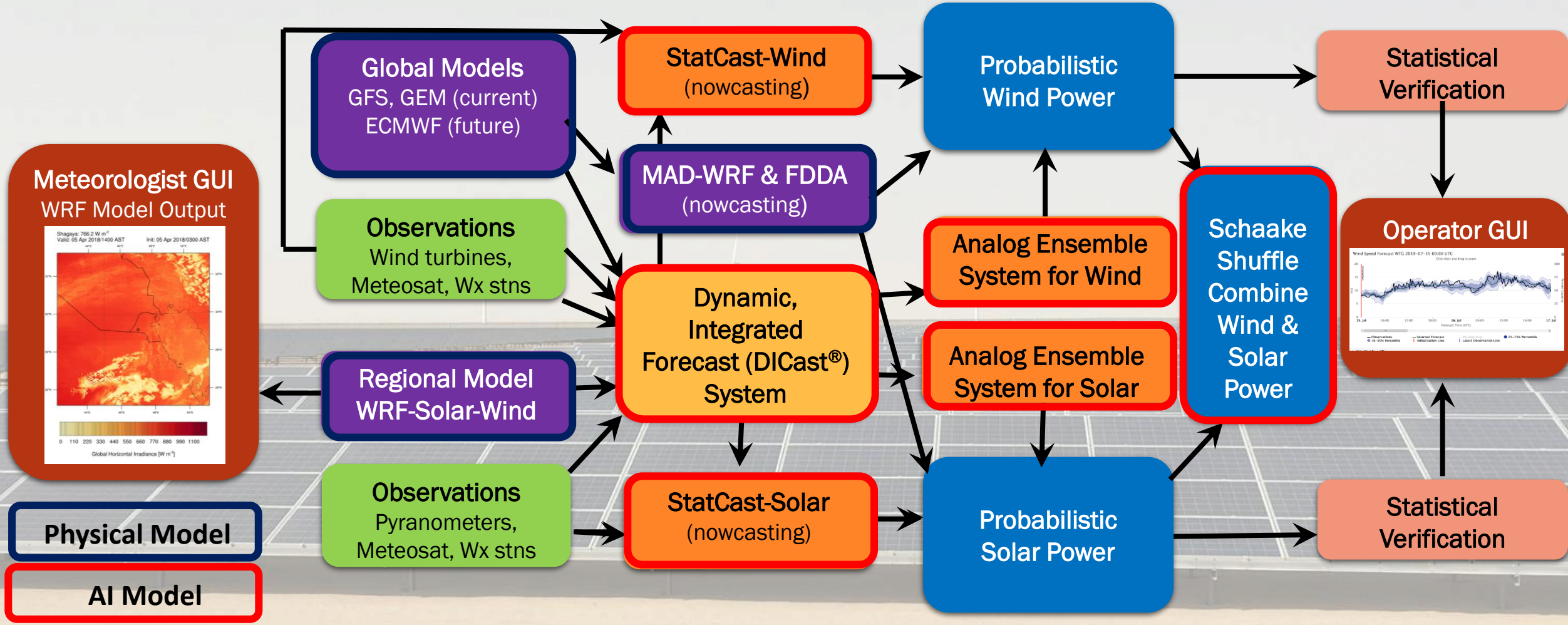




Alessandrini, S., L. Delle Monache, S. Sperati, and G. Cervone, 2015: An analog ensemble for short-term probabilistic solar power forecast. *Appl. Energy*, **157**, 95-110, doi:10.1016/j.apenergy.2015.08.011.

Stefano Allessandrini
Luca Delle Monache

Kuwait Renewable Energy Prediction System (KREPS)

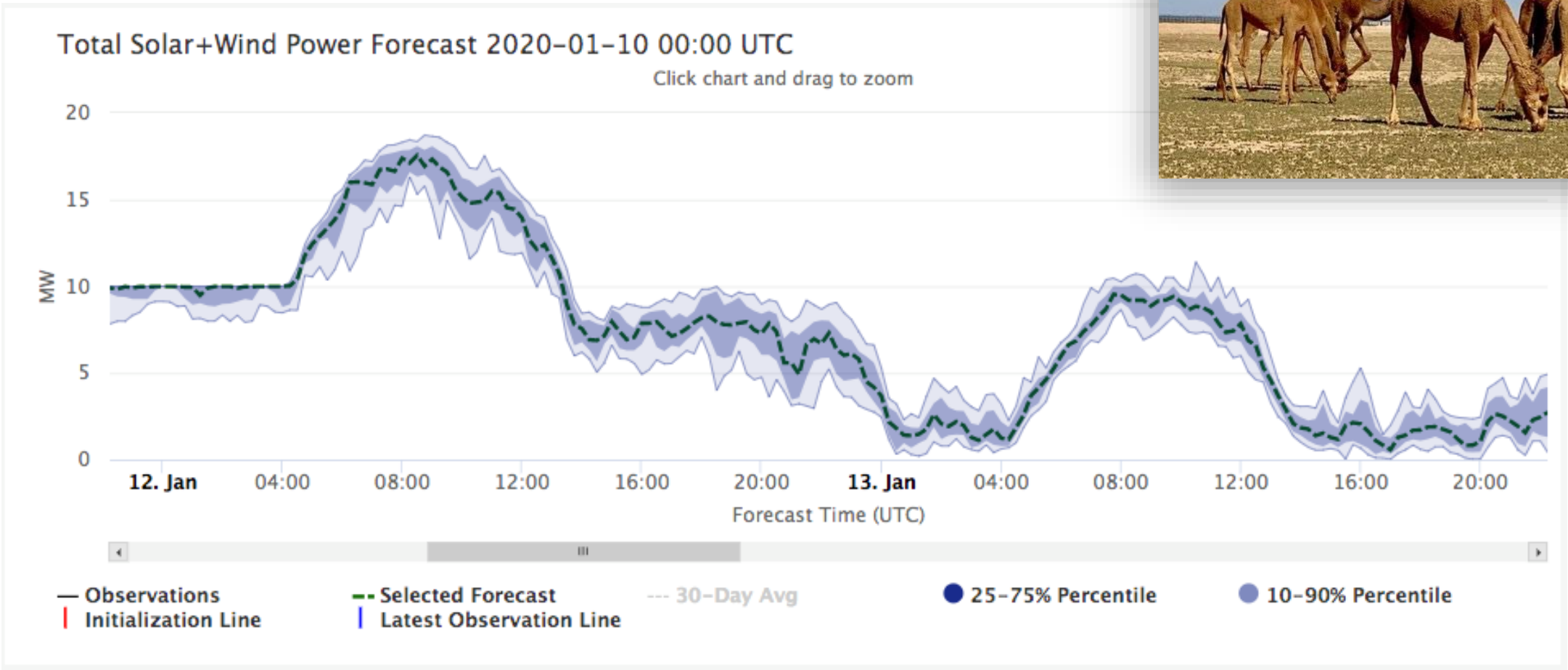


Haupt, S.E., T. McCandless, S. Dettling, S. Alessandrini, G. Wiener, J. Lee, S. Linden, W. Petzke, T. Brummet, N. Nguyen, B. Kosovic, T. Hussain, and M. Al-Rasheedi, 2020: Combining Artificial Intelligence with Physics-Based Methods for Probabilistic Renewable Energy Forecasting, *Energies,* **13**, 1979; doi:10.3390/en13081979.

NCAR

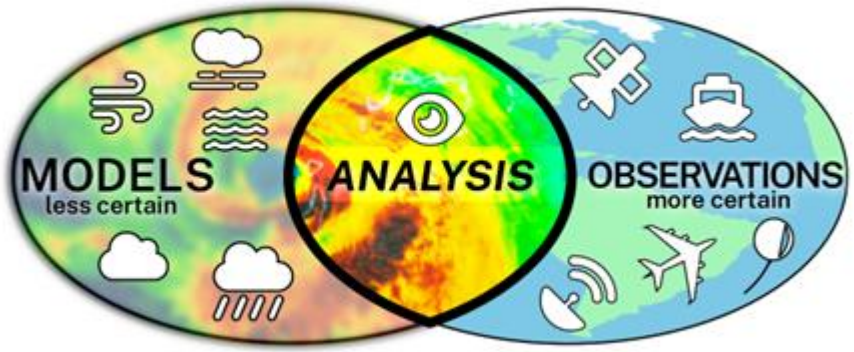
Predict Probabilistic Power

Outputs from DICast+AnEn as displayed by the web display



Need for Public Data and Models

- Nearly all state-of-the-science forecasting systems rely on public observations and forecasting products.
- These products serve everyone and are the basis of forecasting to protect life, property, and critical infrastructure (such as the power system).
- Academic and private sector forecasts leverage these public products.
- Without these public products, the accuracy and value of power system forecasts will degrade.



https://epic.noaa.gov/10-year-strategy-for-data-assimilation/

Products

- Climate Forecast System (CFS)
- Global Data Assimilation System (GDAS)
- Global Ensemble Forecast System (GEFS)
- Global Forecast System (GFS)
- Navy Operational Global Atmospheric Prediction System
- Nested Grid Model
- North American Mesoscale (NAM) Forecast System
- North American Multi-Model Ensemble (NMME)
- Rapid Refresh/Rapid Update Cycle

https://www.ncei.noaa.gov/products/weather-climate-models/numerical-weather-prediction

Renewable Droughts

- Certain meteorological patterns can set up over large regions that could make the variable renewables scarce for a prolonged period. These periods could set the stage for estimating the reserve requirements of the future.
- Forecasting for these renewable energy droughts is a new area of research.

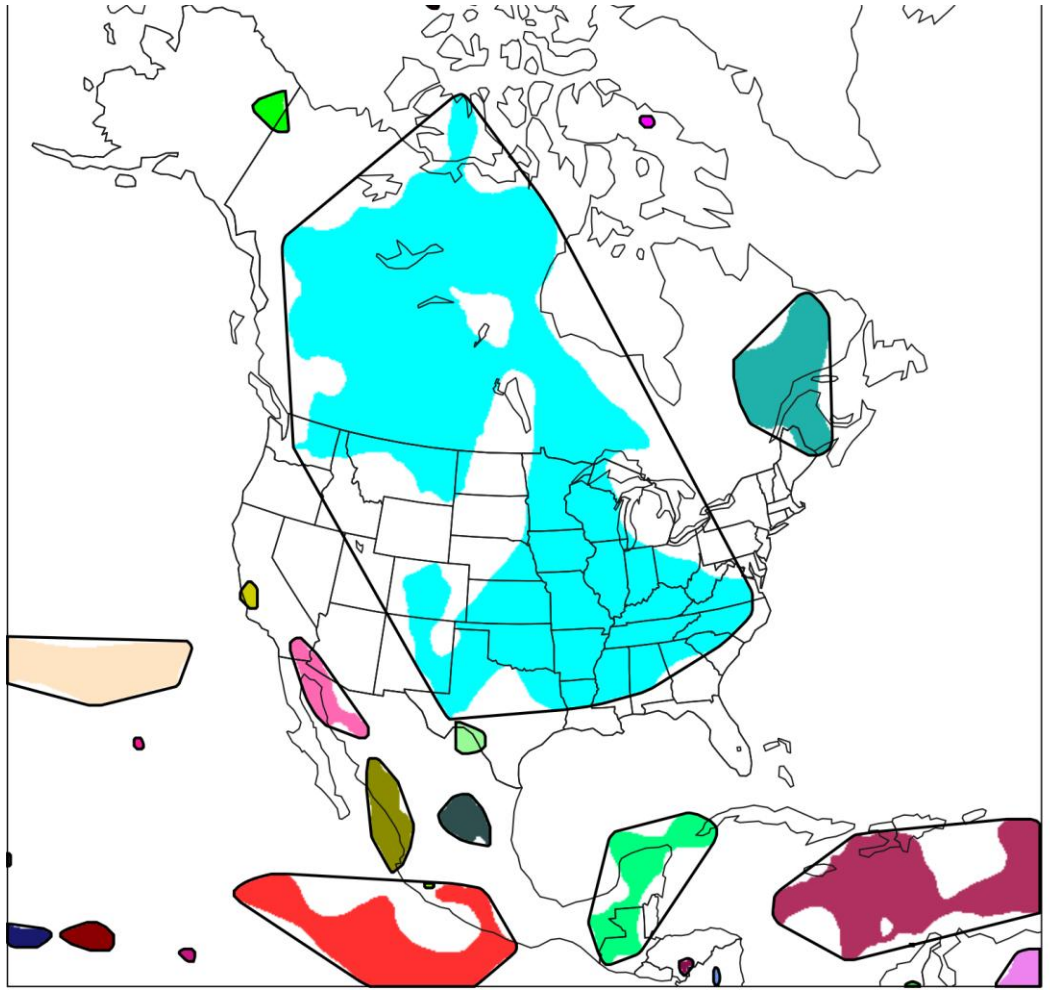
WIND ENERGY

Wind Droughts Threaten Energy Reliability

Nature Climate – News & Views (in press)

Sue Ellen Haupt*

MODE objects for WS_{10} < 3.0 m/s



Cumulative area: 75,562 grid squares (10,880,928 km²)

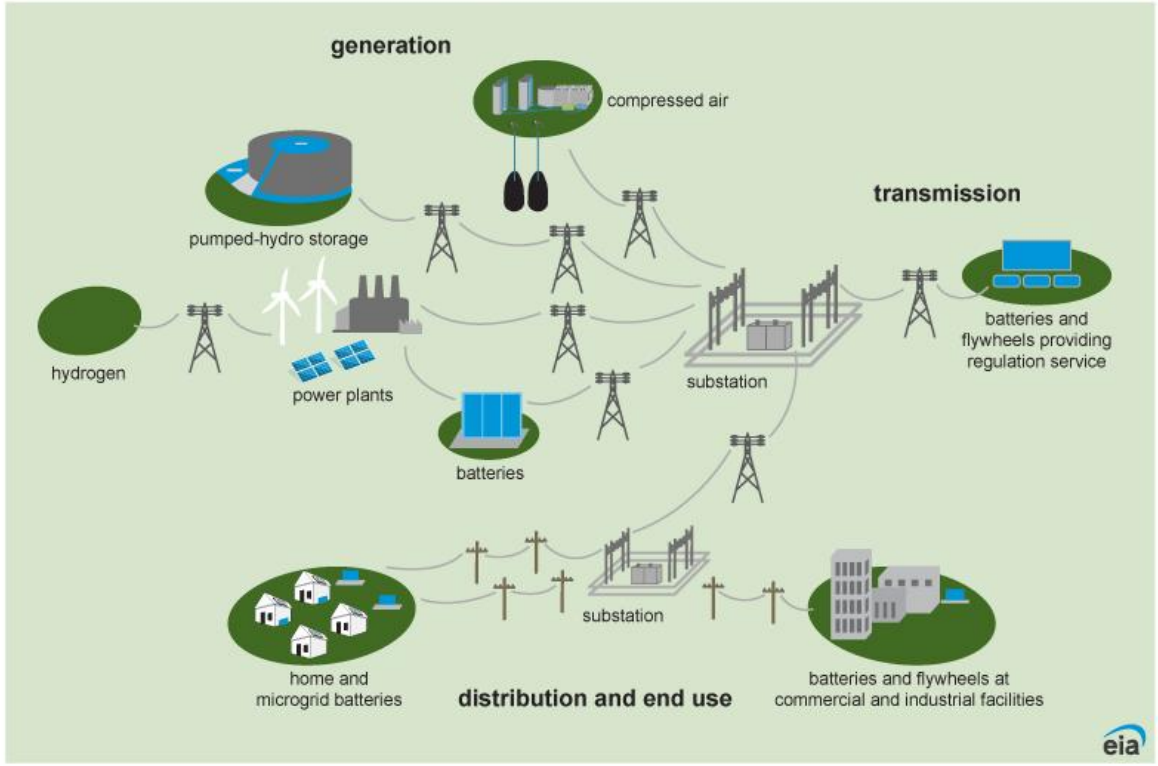
Thanks to Drs. Jared Lee, Sara Pryor, & Xin Zhou

Funds from U.S. National Science Foundation (NSF) Directorate for Computer & Information Science & Engineering under Grant number 2209711: "Frameworks: Large-Scale Atmospheric Research Using an Integrated WRF Modeling, Visualization, and Verification Container Framework (I-WRF)."

What if we add Storage?

- Storage can help alleviate short-term gaps in renewables.
- What about longer term gaps?
- How do we prepare to optimize the timing of charging and discharging?
- Perhaps multi-day forecasting will become even more critical.

General locations of energy storage technologies for electricity generation on an electricity grid



Source: U.S. Energy Information Administration
Note: Hydrogen, and batteries at homes, neighborhoods, and at commerical and industrial facilities are presented here as potential energy storage technologies to supply electricity to electric power grids.

https://www.eia.gov/energyexplained/electricity/energy-storage-for-electricity-generation.php

Summary

- Modern Forecasting systems blend:
  - Observations – public and private
  - Physical Models – public and private
  - AI/ML techniques to enhance the forecast
- As we increase the amounts of variable renewables, new challenges are emerging
  - Best use of storage
  - Preparing for energy droughts
  - Preparing for extreme events
- Meteorology is becoming increasingly important to operating the energy system.