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**Research Applications
Laboratory**

Blending Observations, Physical Models, and AI/ML Techniques to Produce Accurate Weather Models

Sue Ellen Haupt

Energy Systems Integration Group Forecasting & Meteorology in
Power Systems Denver, CO June 15, 2026



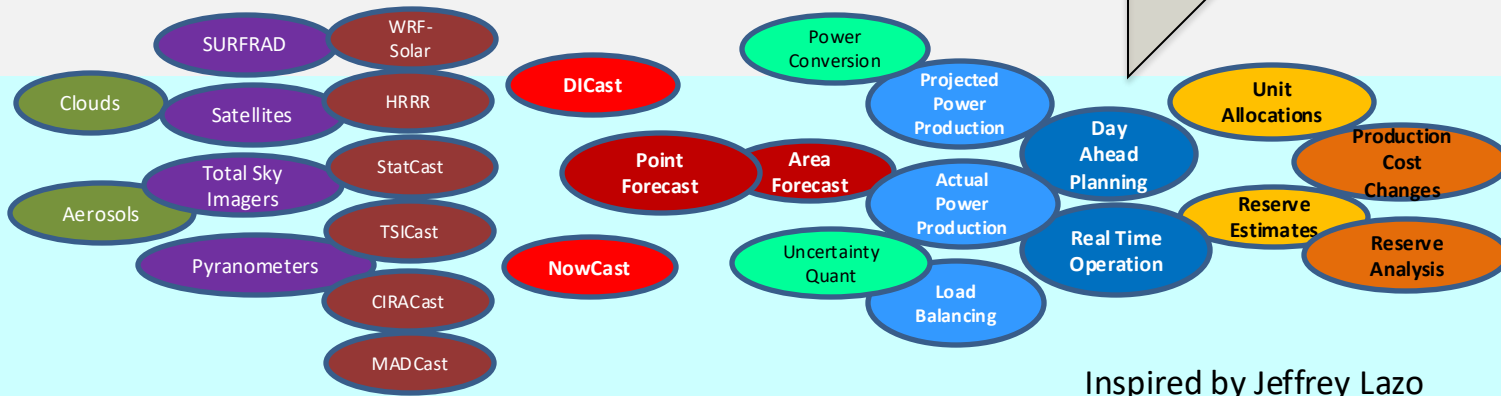
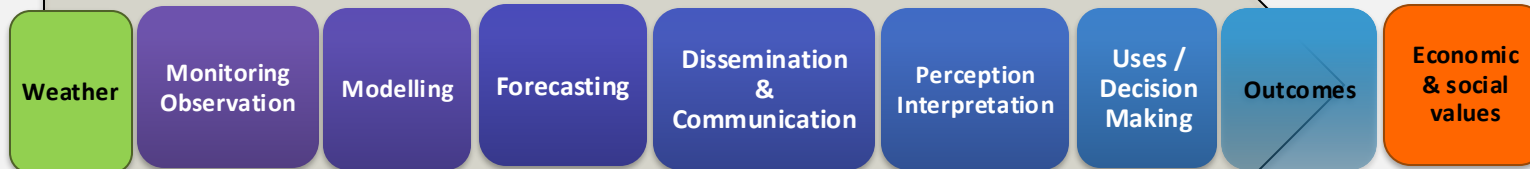
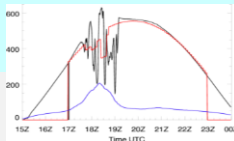
Value Chain: What is the value of solar power forecasting?



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Clear Sky



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

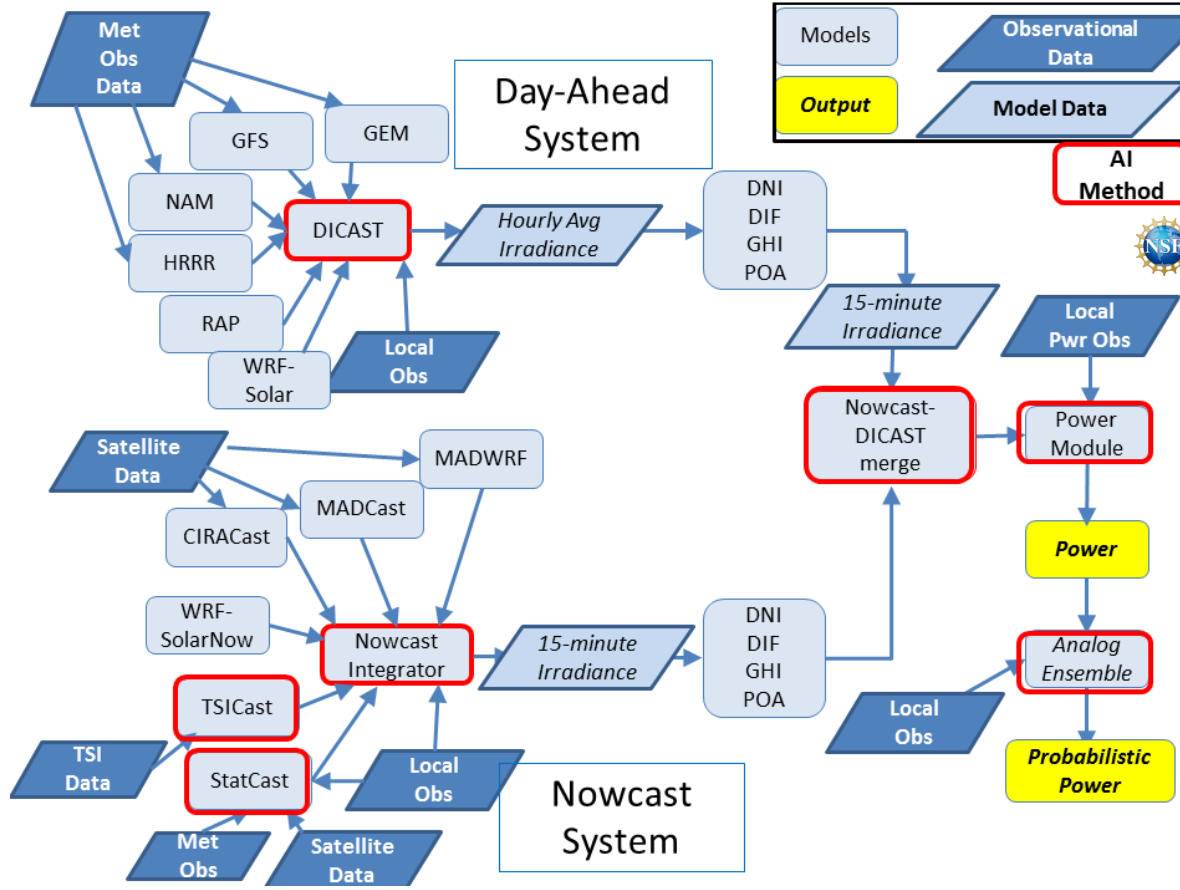
Inspired by Jeffrey Lazo

AI as Part of Systems Engineering

Engineering the Sun4Cast[®] System

Day-Ahead System

Nowcast System



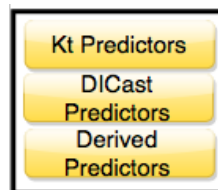
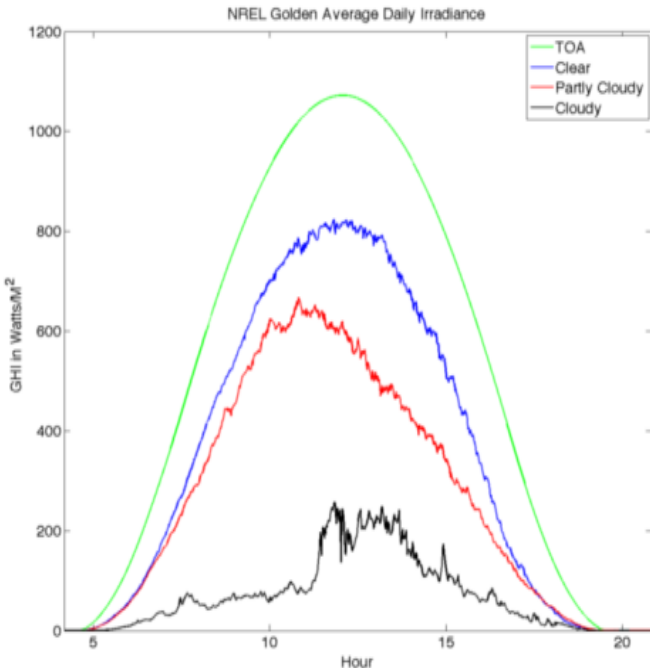
Haupt, S.E. and B. Kosovic, 2017: Variable Generation Power Forecasting as a Big Data Problem, *IEEE Transactions on Sustainable Energy*, **8** (2), pp. 725-732.
 DOI: [10.1109/TSTE.2016.2604679](https://doi.org/10.1109/TSTE.2016.2604679).

StatCast: Regime Dependent Forecasting



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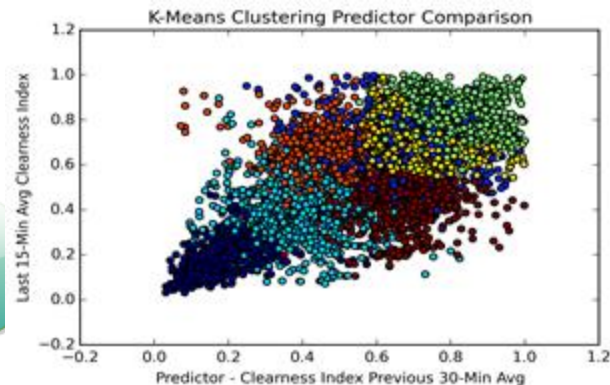
Artificial Neural
Network: All Data

Clearness Index
Prediction

Classify Regimes
(K-Means
Clustering)

Artificial Neural
Network:
Independent
Regimes

Clearness Index
Prediction



Clearness Index
Persistence
(Baseline)

Clearness Index
Prediction

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.

Compute MAE and
Percent
Improvement

Tyler McCandless



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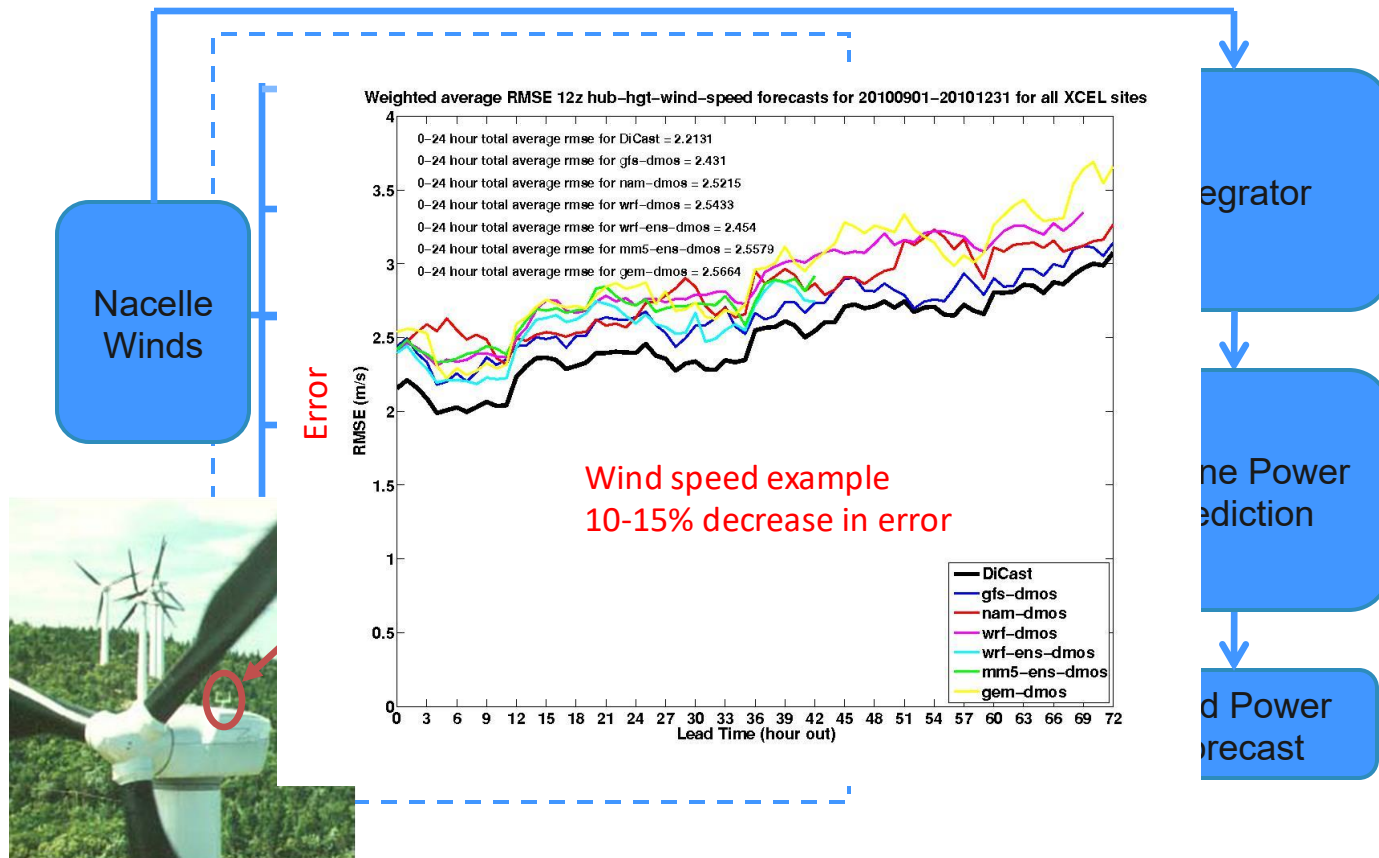
Improvement over Clearness Index Persistence	
ANN	RD-ANN
13.7%	18.6%

DiCast Integrator System

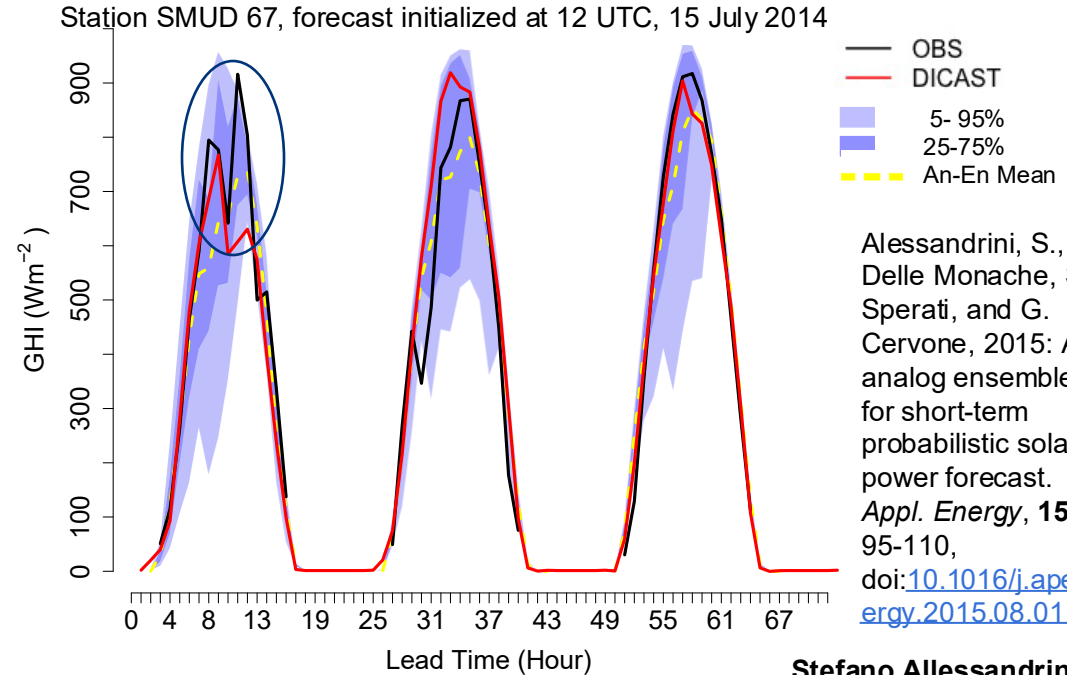
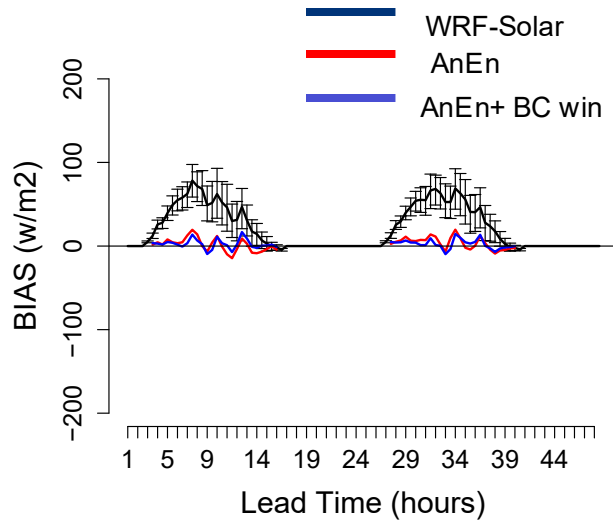


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Dynamic Integrated foreCast System



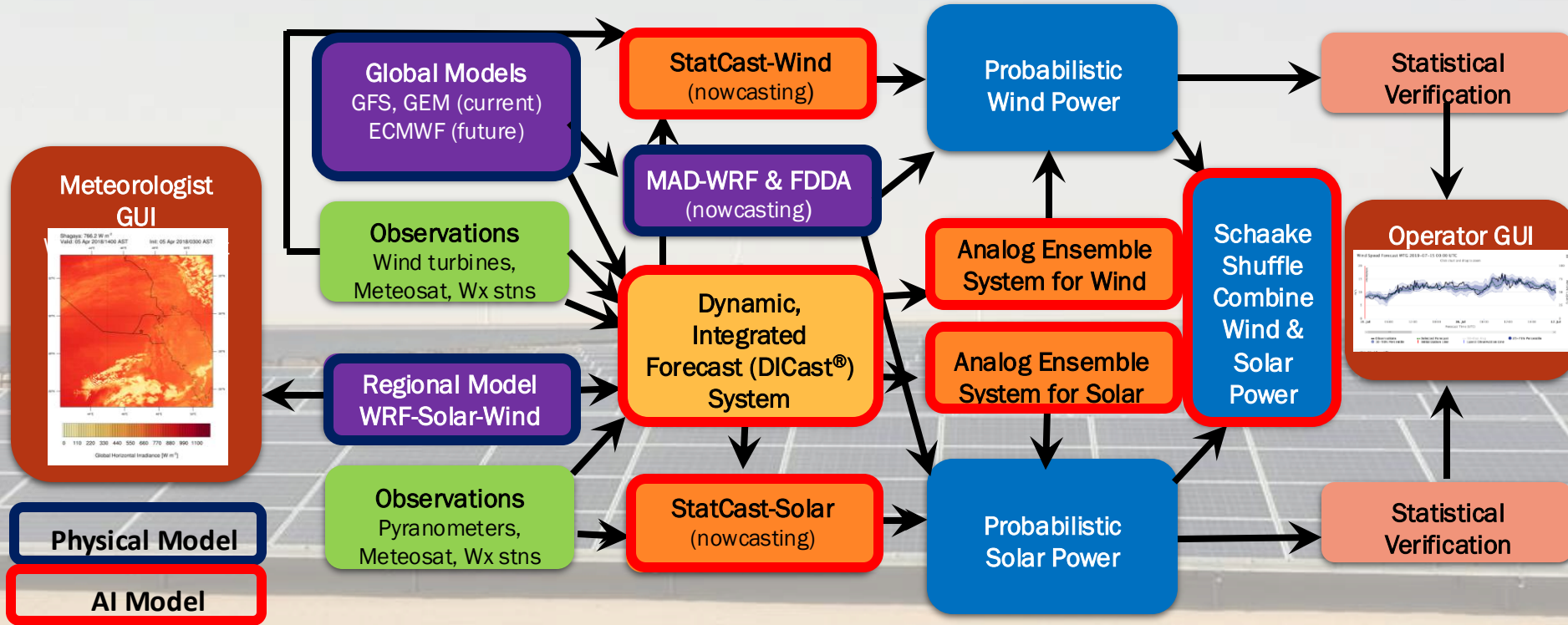
Uncertainty Quantification Analog Ensemble (AnEn) Approach



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](https://doi.org/10.1016/j.apenergy.2015.08.011).

Stefano Alessandrini
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.

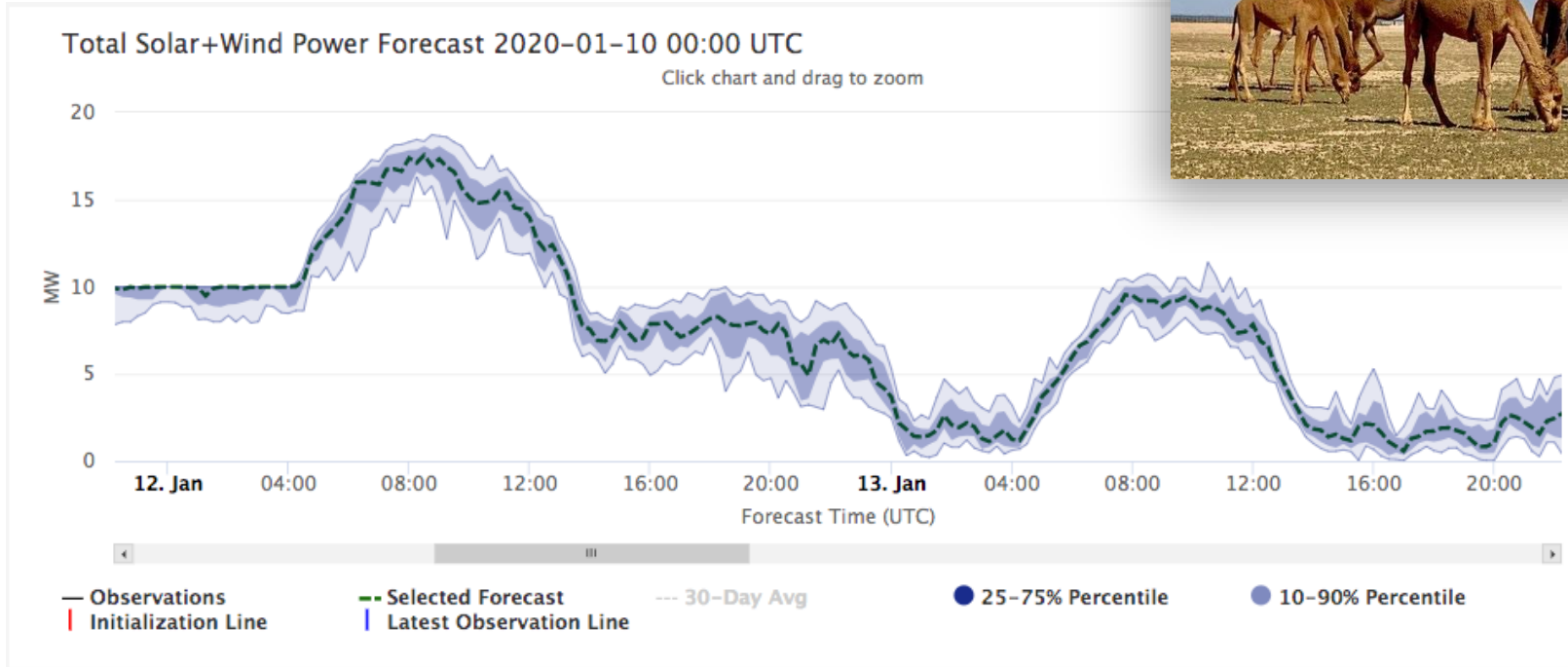
Predict Probabilistic Power



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Outputs from D1Cast+AnEn as displayed by the web display

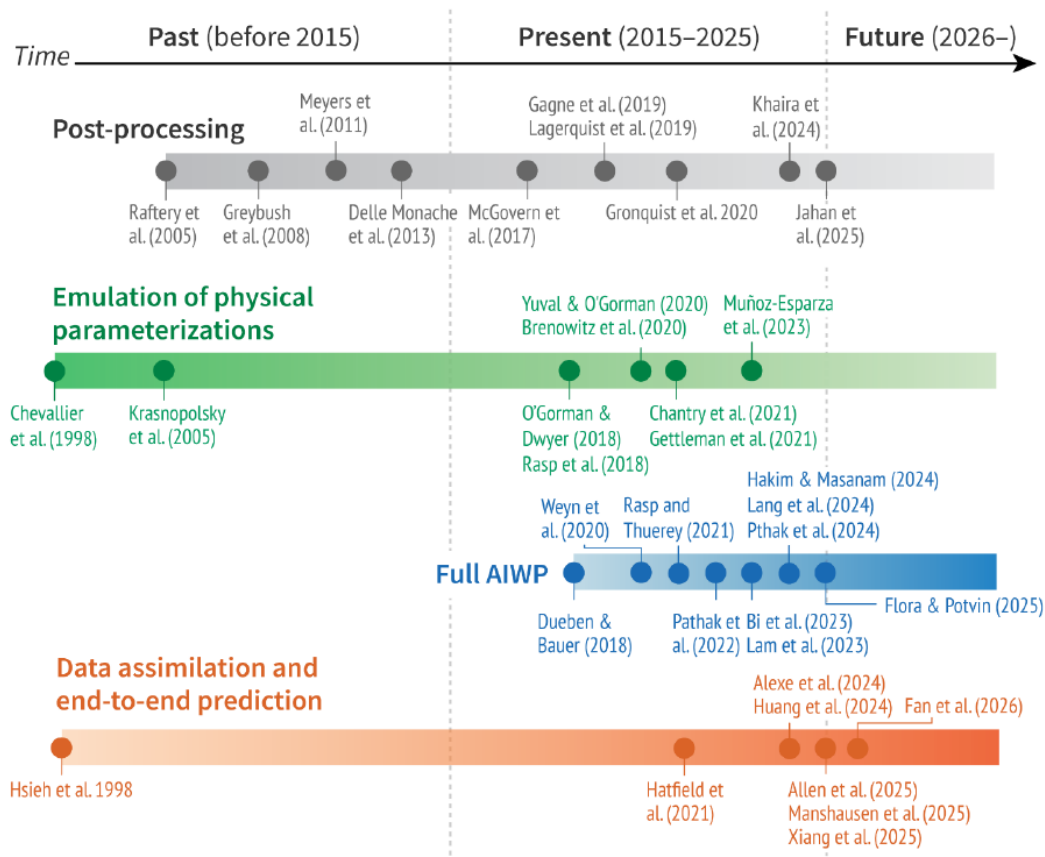


Newest Initiatives: Use of AIWP



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Astitha, M., S.E. Haupt, I. Ebert-Uphoff, Y. Rao, R. Redmon, D.J. Gagne II, D. Hall, and A. McGovern, 2026: Artificial Intelligence and Machine Learning for Short-to-Medium Range Weather Prediction, submitted to *Nature Reviews*.

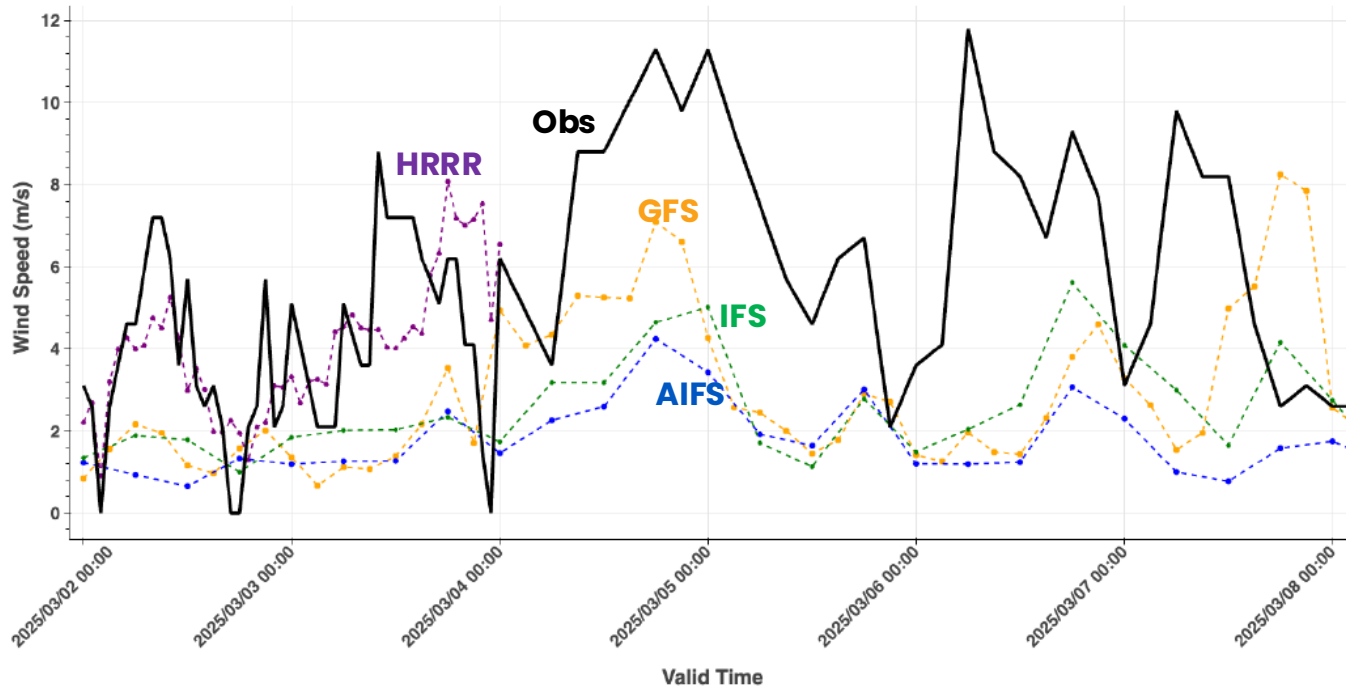
Figure 1 | Evolution of AIWP. A non-comprehensive timeline and evolution of AI/ML technologies that have been integrated into the weather enterprise through post-processing, emulation of physical parameterizations, full data-driven models, data assimilation, and end-to-end prediction.

How Good is AIWP?



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Lee, J.A., S. Alessandrini, T. Brummet, S. Sperati, and S.E. Haupt, 2026: Comparison of AIFS with Operational NWP Models over CONUS and Europe, submitted to *Artificial Intelligence for the Earth Systems*.

Figure 9. Time series of 10-m wind speed at Copper Mountain, Colorado (KCPR) for observations (black solid line) and AIFS (blue dashed), IFS (green dashed), GFS (yellow dashed), and HRRR (purple dashed) forecasts initialized at 00 UTC on 2 Mar 2025.

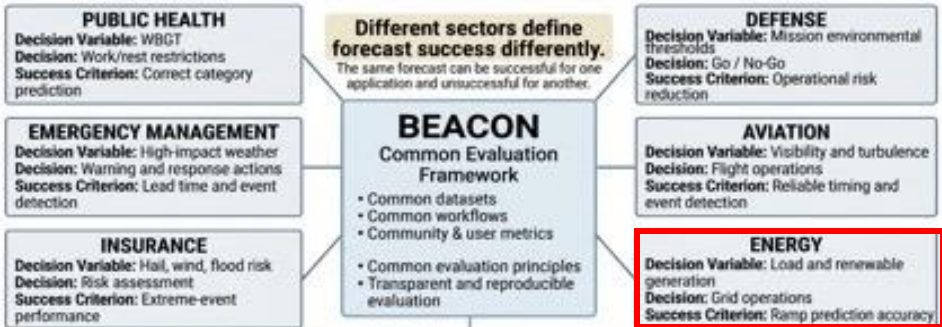
Is AIWP Fit for Purpose?



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One Evaluation Does Not Fit All

Sector-Specific Evaluation within BEACON



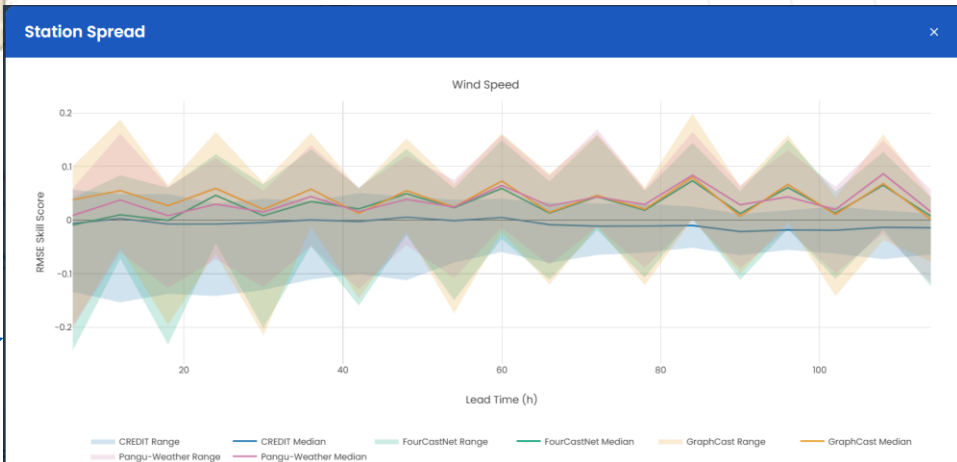
NCAR's New BEACON AIWP Evaluation System

Does the particular model meet the needs of the Energy Sector?

No single evaluation metric can characterize forecast value across all sectors.
Forecast excellence depends on the decision context.



Which model is best for probabilistic prediction for the right use and for the right variable?





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Summary



- Modern Forecasting systems blend:
 - Observations – public and private
 - Physical Models – public and private
 - AI/ML techniques to enhance the forecast
- New AIWP Models are Changing Best Practices.
- But standard assessment mechanisms may not be adequate for Energy Applications.

