

# ENERGY CONSEQUENCES OF INFORMATION WORKSHOP 2026

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## Energy-Efficient Solar Forecasting with a Neuromorphic-Bayesian State Estimation Approach

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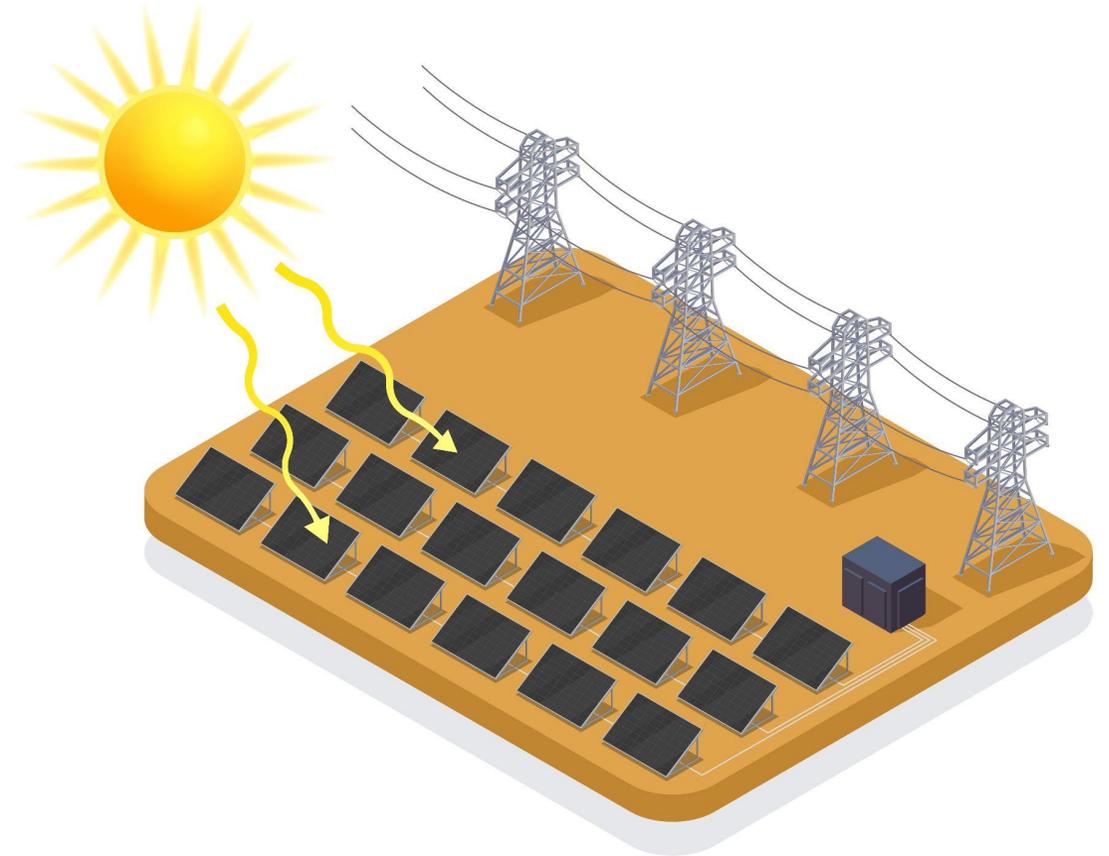
# The Energy Challenge



**Grid stability** depends on **accurate solar power forecasting**.

Rapid **growth in solar penetration** causes **unstable power output**.

Many **traditional AI models** require **high computational energy**.

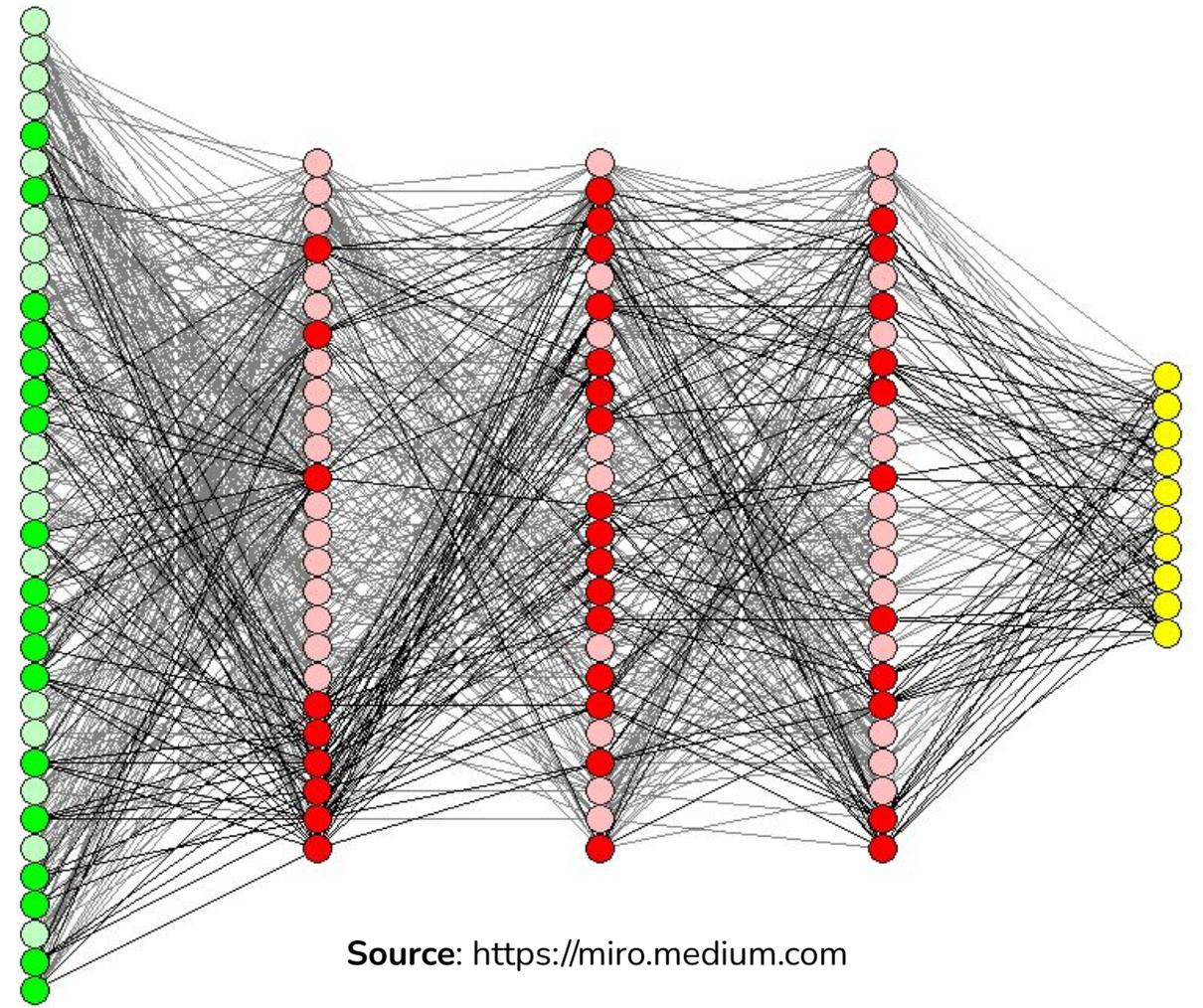
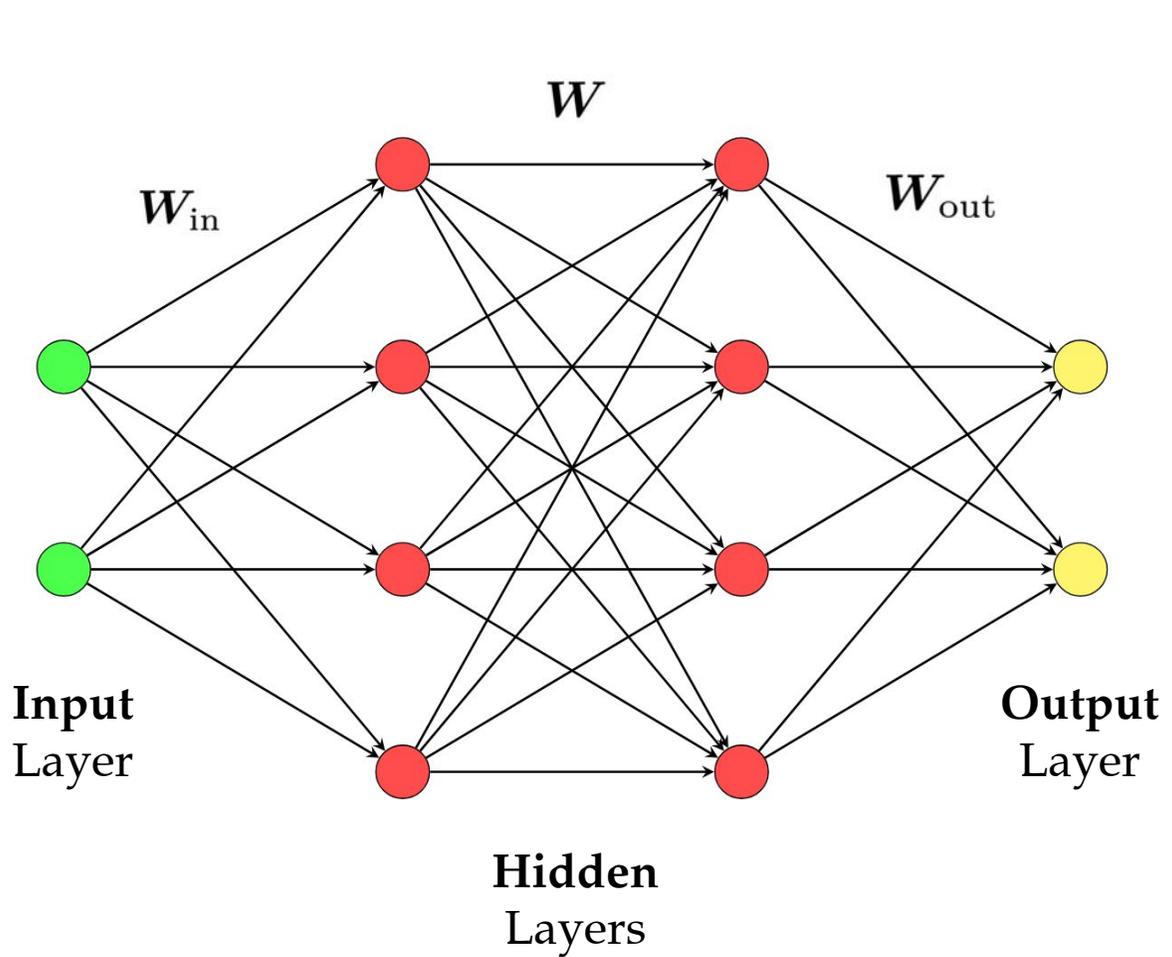


Source: [www.freepik.com](http://www.freepik.com)

# Feed Forward Neural Network



- Training all connections makes large neural networks computationally expensive.

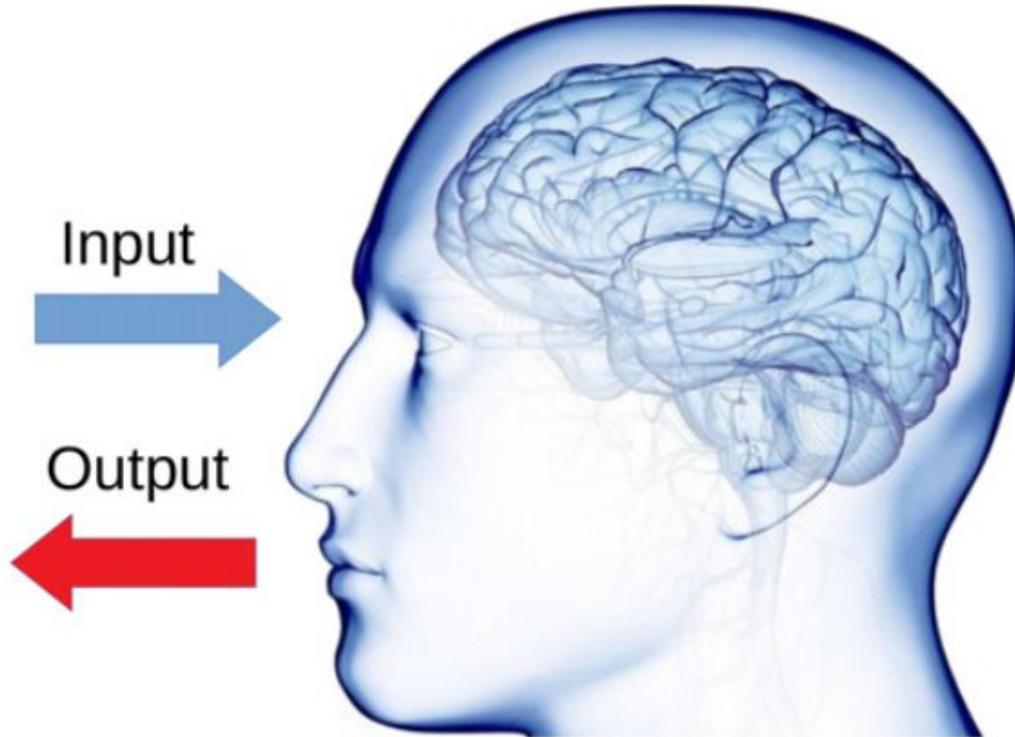


# Neuromorphic Approach



- Reservoir computing is inspired by brain-like dynamics.

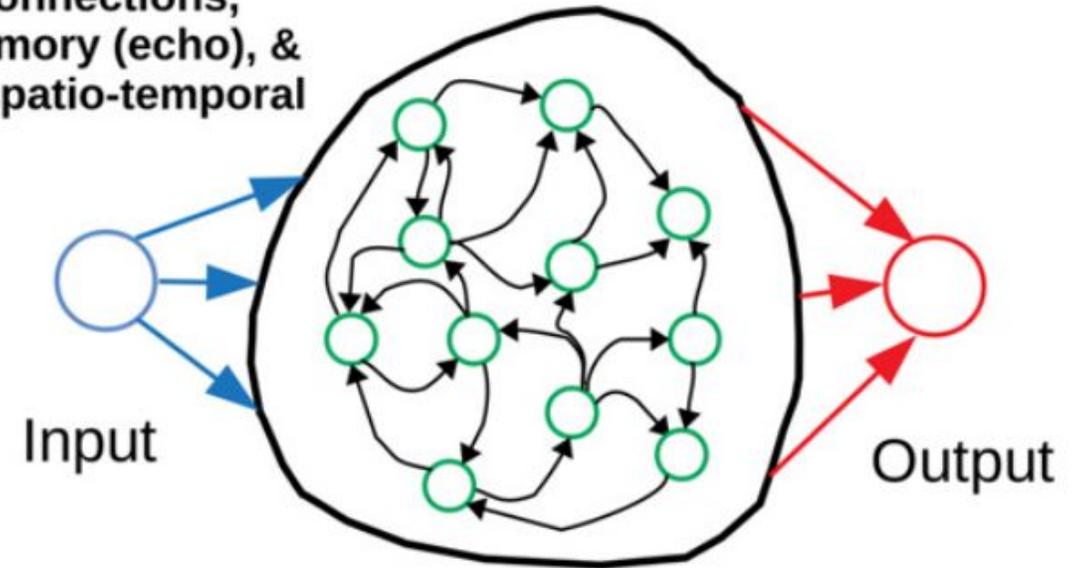
## HUMAN BRAIN



## PHYSICAL RESERVOIR

### Random Neural Networks with

- directed connections,
- fading memory (echo), &
- complex spatio-temporal dynamics

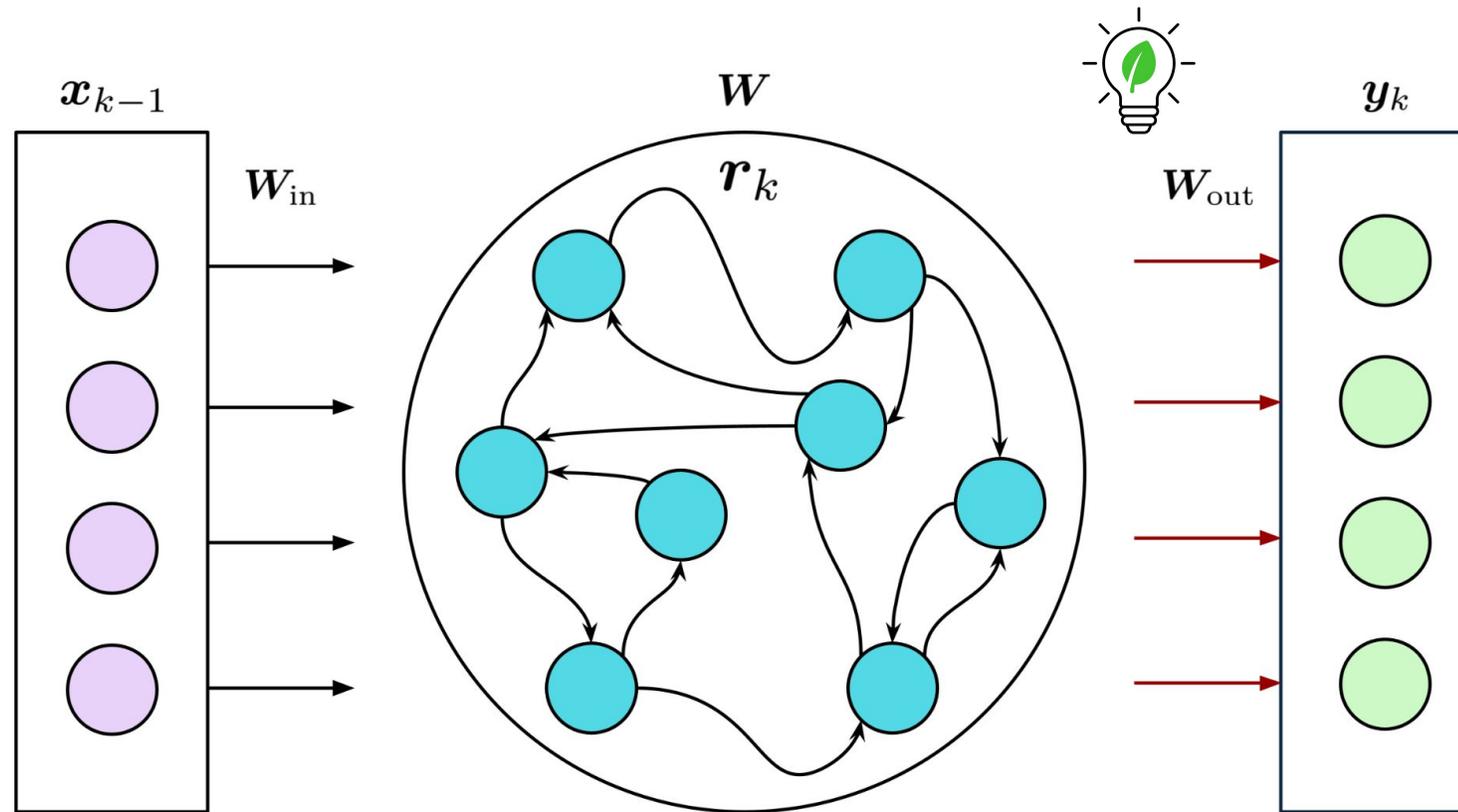


Reference: Cucchi, Matteo, et al. "Hands-on reservoir computing: a tutorial for practical implementation." *Neuromorphic Computing and Engineering* 2.3 (2022): 032002.

# Reservoir Computer (RC)



- Fixed reservoir dynamics reduce training cost by learning only the output layer, but rely on high-quality, low noise data.



Reliable training data is critical for accuracy



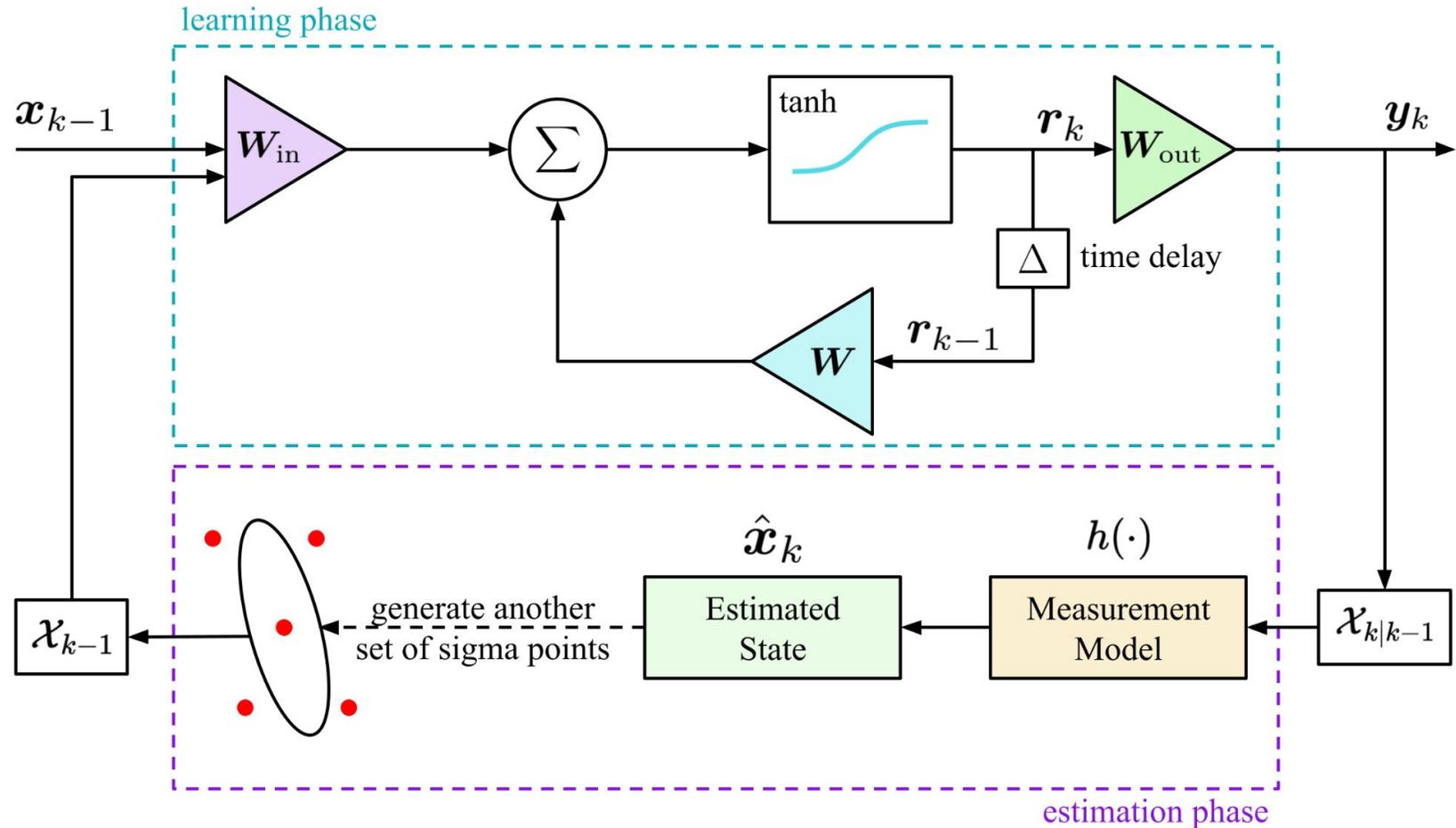
Noise or corrupted data can degrade performance

$$W_{out} = (R R^T + \delta I)^{-1} R Y^{true}$$

# RC with Unscented Kalman Filtering (RCUKF)



- Bayesian filtering corrects RC predictions using real-time measurements.

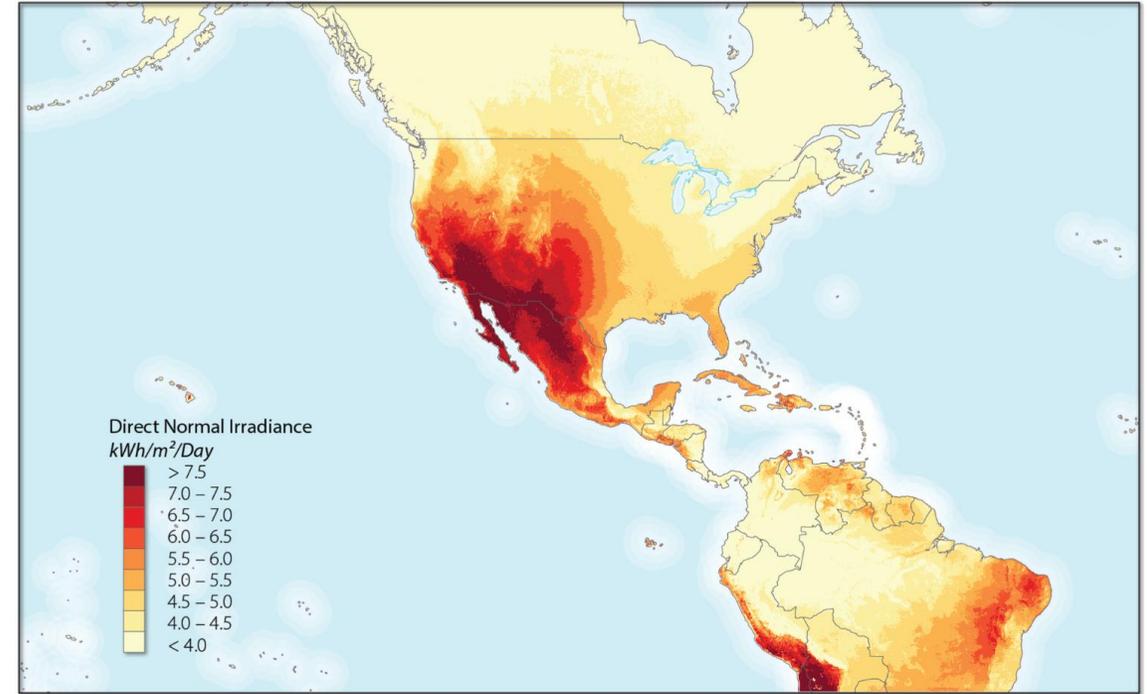
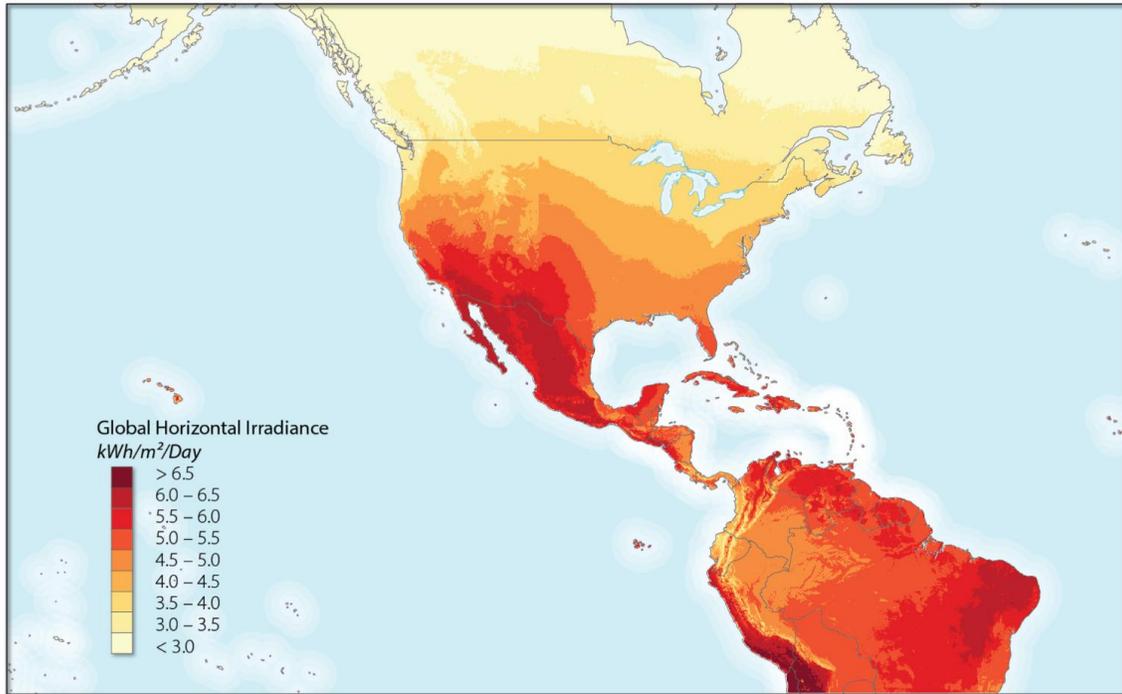


**Reference-** Anurag, K., Azizi, K., Sorrentino, F., & Wan, W. (2025). RCUKF: Data-Driven Modeling Meets Bayesian Estimation. The Modeling, Estimation and Control Conference (MECC), *IFAC-PapersOnLine* - 59(30), 287–292.

# NSRDB: National Solar Radiation Database



- Long-term, high-resolution solar data captures real-world variability.



Reference: Sengupta, Manajit, et al. "The national solar radiation data base (NSRDB)." Renewable and sustainable energy reviews 89 (2018): 51-60.

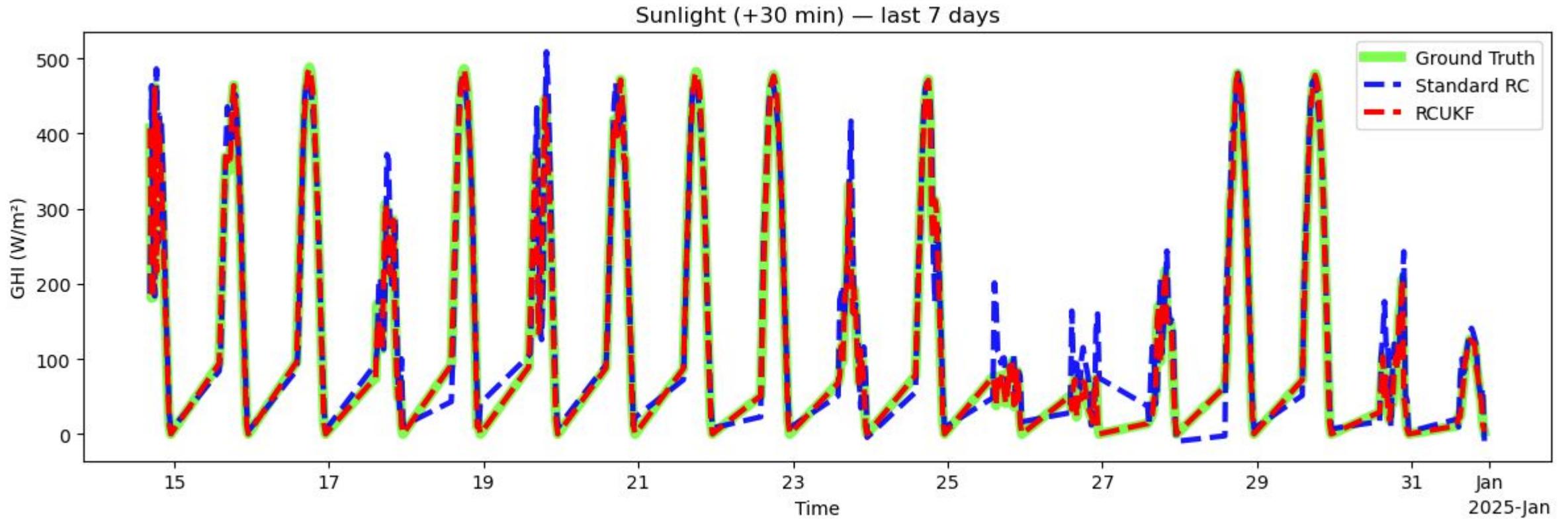
**Data Span: 1998-2024**

**Train-Test Split: 70/30**

# Results



- RCUKF reduces the forecasting error by 92.4% compared to standard RC in this case study.



RC MAE:  $56.6 \text{ W}/\text{m}^2$

92.4%

RCUKF MAE:  $4.3 \text{ W}/\text{m}^2$



We integrated a **brain-inspired computational model** with **Bayesian state estimation**. Our **proposed approach** improves **accuracy** while maintaining **computational efficiency**.

Evaluation on long-term **National Solar Radiation Database (NSRDB)** captures **real-world solar variability**.

This makes the **RCUKF** framework **well-suited** for energy efficient, **next-generation neuromorphic computing**.



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## Thank you!

Questions & Discussion

