Echo State Networks for Renewable Energy Forecasting

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Outline

Low Carbon Future

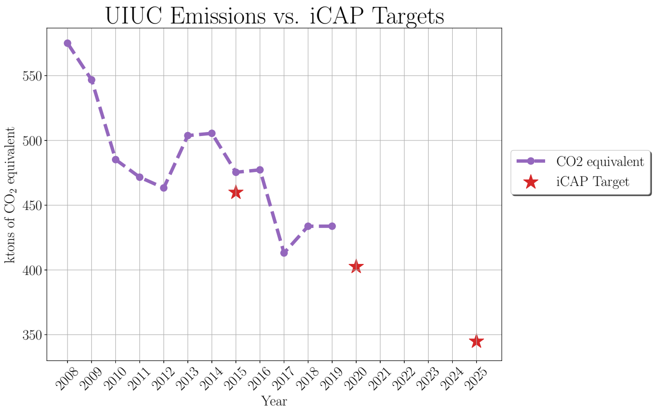

Figure: Carbon emissions goals for the University of Illinois at Urbana-Champaign, outlined in the Illinois Climate Action Plan (iCAP) [2].

Rising Renewable Penetration

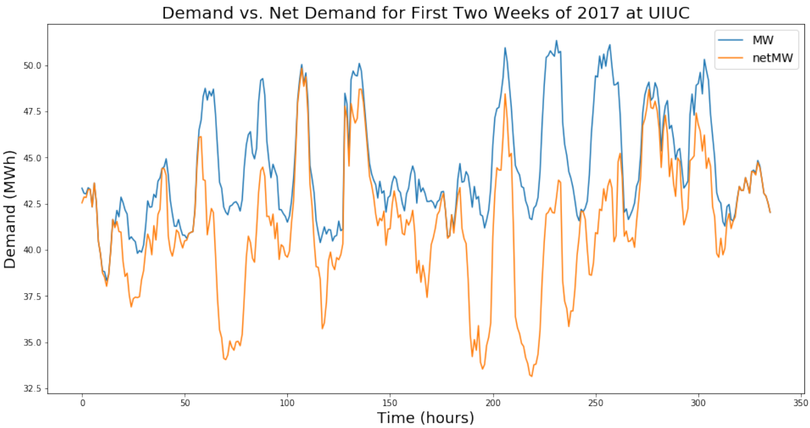

Figure: Comparison between total demand and demand accounting for renewable energy. "netMW" is the total demand minus wind and solar [1, 5].

Dilemma for Nuclear Power

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Figure: Traditional nuclear plants are like semi-trucks. They carry a lot of freight but can't turn very fast. Left: Byron Nuclear Station

Outline

Modeling the University of Illinois

- All data is from the University of Illinois
- UIUC is a good model for thinking about hybrid energy systems.
  - Solar Power
  - Wind Power
  - Natural Gas
  - District Heating

Echo State Networks

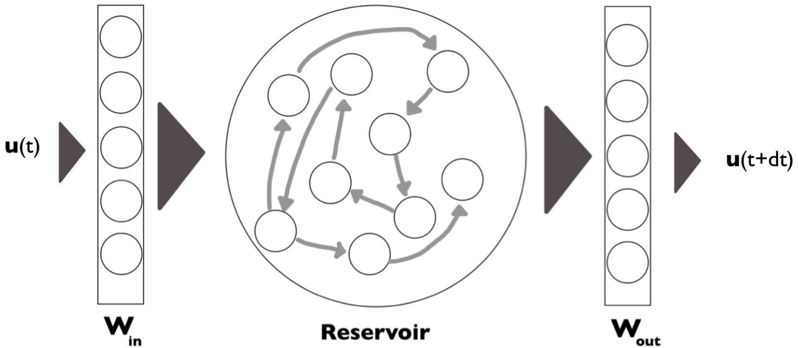


Figure: A conceptual diagram of an echo state network. The reservoir is a large sparse matrix with randomly assigned entries [4, 3].

Hyper-parameter Optimization

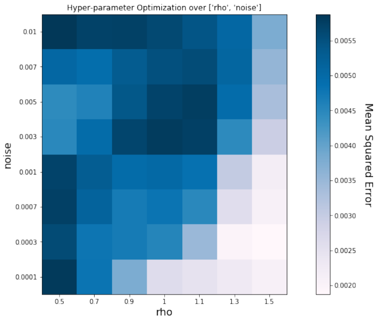


Figure: A grid search for the set of noise and spectral radius, ρ, that minimizes the mean squared error.

$$MSE = \frac{1}{N}\sum_{i}^{N}(\hat{y} - y_i)^2 \qquad (1)$$

- The optimal set of parameters is "reservoir specific"
- Several other parameters need to be optimized such as:
  - Reservoir Size
  - Sparsity
  - Training Length

Uncertainty Analysis

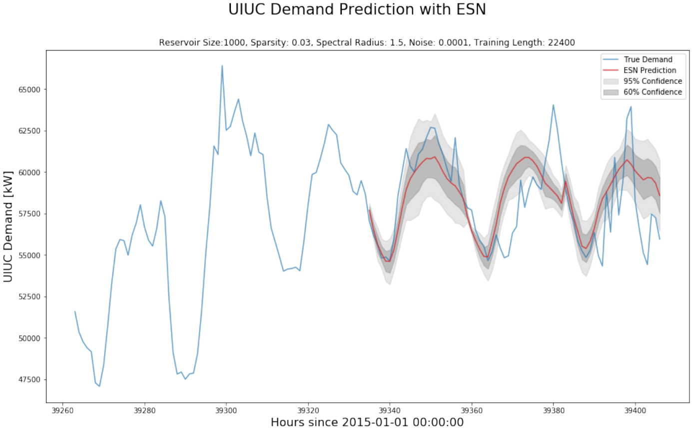


Figure: Total demand prediction with error bars. The 60% confidence is $\pm 1\sigma$ and the 95% confidence interval is $\pm 2\sigma$. Mean is generated from predictions made by several different reservoirs.

Outline

Model Flow

1. Start with randomly chosen hyperparameters
2. Predicting a single quantity (e.g. energy generation)
3. Set the prediction window to 72-hours in the future
4. Optimize with a hyper-parameter grid search

Solar Prediction

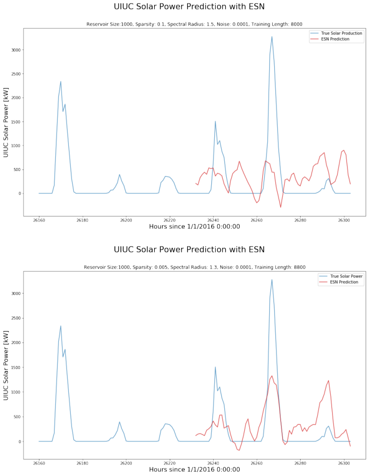


Figure: Top: Prediction with random hyperparameters. Bottom: Prediction with optimized hyperparameters.

Wind Prediction

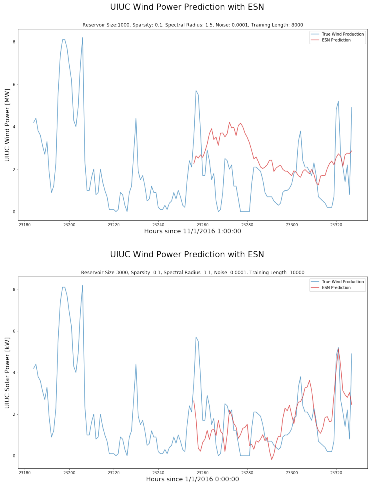


Figure: Top: Prediction with random hyperparameters. Bottom: Prediction with optimized hyperparameters.

Total Demand Prediction

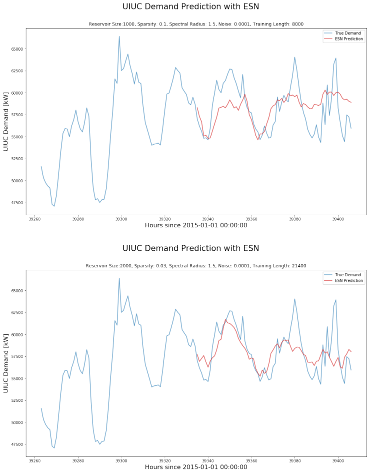


Figure: Top: Prediction with random hyperparameters. Bottom: Prediction with optimized hyperparameters.

Net Demand Prediction

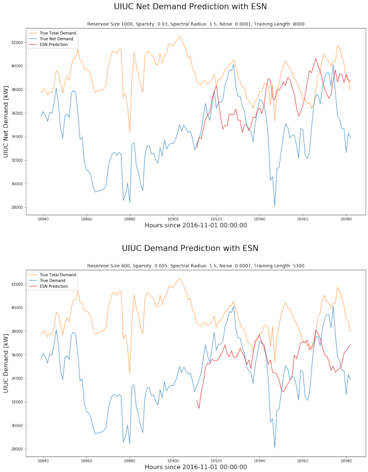


Figure: Top: Prediction with random hyperparameters. Bottom: Prediction with optimized hyperparameters.

Model Flow

1. Start with randomly chosen hyperparameters
2. **Predicting coupled quantities (e.g. energy generation and sun elevation.)**
3. Set the prediction window to 72-hours in the future
4. Optimize with a hyper-parameter grid search

Wind Prediction

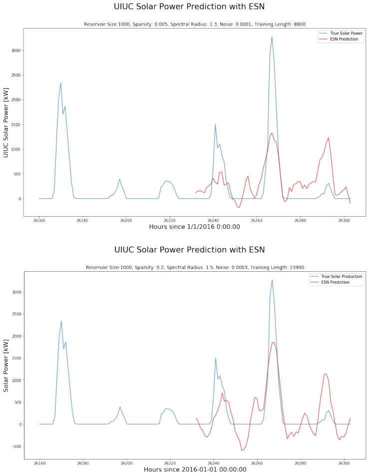
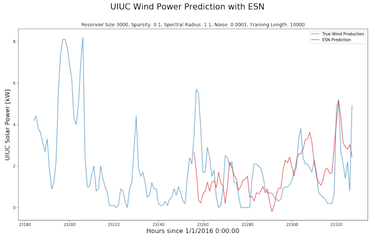


Figure: Top: Predicting solar generation alone. Bottom: Predicting solar generation with solar elevation.

Wind Power Prediction



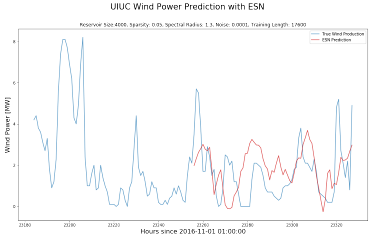
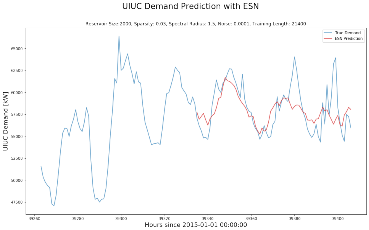


Figure: Top: Predicting wind generation alone. Bottom: Predicting wind generation with solar elevation.

Total Demand Prediction



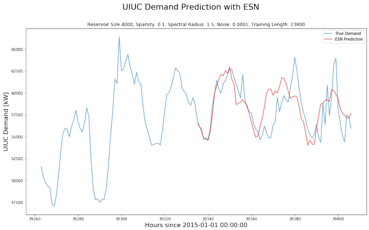


Figure: Top: Predicting total demand alone. Bottom: Predicting total demand with solar elevation.

Net Demand Prediction

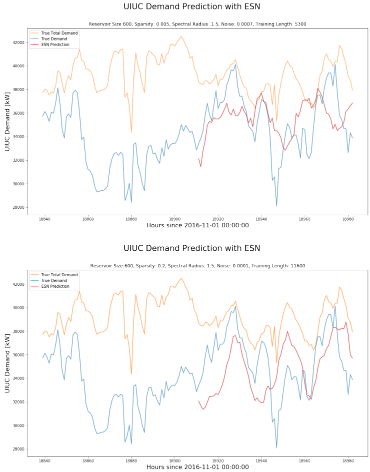


Figure: Top: Predicting net demand alone. Bottom: Predicting net demand with solar elevation.

Uncertainty in Total Demand

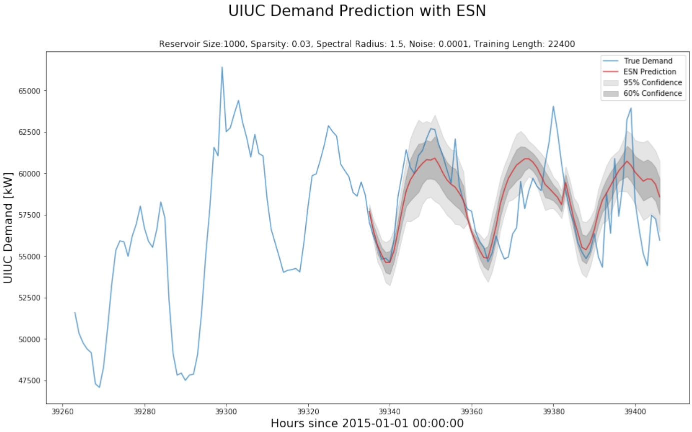


Figure: Error bars on the prediction for total demand.

Uncertainty in Net Demand

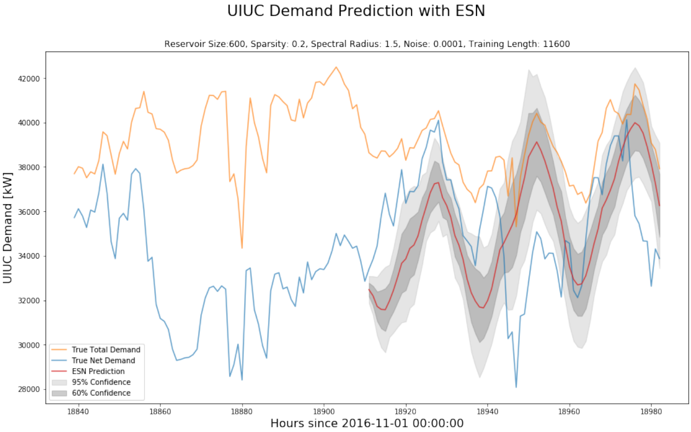


Figure: Error bars on the prediction for net demand.

Uncertainty in Net Demand – Very Short Prediction Window

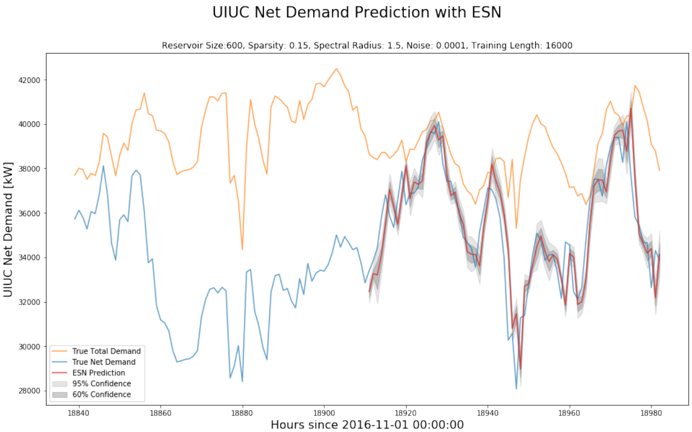


Figure: Error bars on the prediction for net demand with a prediction window of one hour.

Outline

Conclusions

1. Echo state networks can predict dynamic systems and are improved by
   - Shorter Prediction Windows
   - Coupled quantities (e.g. Sun angle and total demand)
2. Future Work
   - Identifying better coupled quantities for wind generation
   - Compare ESNs to other methods for speed and accuracy.
   - Determine the required prediction window for different reactor types.

Questions?

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[3] Mantas Lukoševičius.
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