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One Stone Three Birds: Three-Dimensional Implicit Neural Network for Compression and Continuous Representation of Multi-Altitude Climate Data

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Wind Data Analysis & Management

- Wind energy stands out as a promising clean and renewable energy alternative.
- However, analysis of wind data to fully harness the benefits of wind energy demands tackling several related challenges.

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Challenges

- **Resolution**:
  - Identifying the most suitable sites for wind turbines necessitates data with high resolution.
  - However, most wind farm simulations do not achieve this resolution.
  - Low resolution limits our capacity to enhance the efficiency of wind energy farms.

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Challenges

- **Data Storage**:
  - Data with high resolution comes with the need for high storage.
  - Resulting growth in data size requires advanced storage solutions, e.g. data compression and reconstruction from compressed data.

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Challenges

- **Generalization**:
  - Setting up wind measurement stations in specific locations can be challenging due to the high costs of transportation and maintenance.
  - This necessitates cross-altitude inference, such as estimating high-altitude wind speeds from ground-level measurements.

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Three Birds to Kill

Our goal is to design a model capable of pertaining the following tasks (kill three birds):

- **Bird 1. Data Dimensionality Reduction**
- **Bird 2. Continuous Reconstruction**
- **Bird 3. Cross-Altitude Reconstruction**

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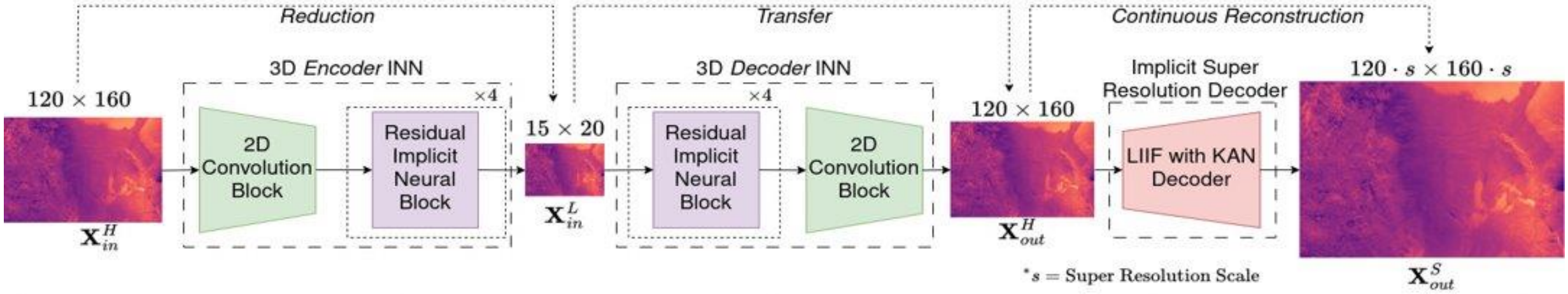
OSTB (One Stone Three Bird)



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Experiments

- **Dataset**:
  - National Renewable Energy Laboratory's Wind Integration National Database (WIND) Toolkit [1].
  - This dataset provides high spatial and temporal resolution wind power, wind power forecasting, and meteorological data.
  - The dataset is simulated for over 126,000 locations across the continental United States during a 7-year span.

[1]. C. Draxl, A. Clifton, B.-M. Hodge, and J. McCaa. The wind integration national dataset (WIND) toolkit. Applied Energy, 151:355–366, 2015. ISSN 0306-2619.

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Experiments

- **Baselines**: We choose three primary baselines:
  - **MAINN** (Multi-Altitude Implicit Neural Network) [2].
  - **GINO** (Geometry Informed Neural Operator): Bicubic downscaling followed by GINO [3].
  - **WindLaw**: We used the wind power law $(v_1/v_2) = (h_1/h_2)^{\alpha}$ with our proposed OSTB model.

[2]. A. B. A. Qayyum, X. Luo, N. M. Urban, X. Qian, and B.-J. Yoon. Implicit neural representations for simultaneous reduction and continuous reconstruction of multi-altitude climate data. In 2024 IEEE 34th International Workshop on Machine Learning for Signal Processing (MLSP), pages 1–6, 2024.
[3]. Z. Li, N. Kovachki, C. Choy, B. Li, J. Kossaifi, S. Otta, M. A. Nabian, M. Stadler, C. Hundt, K. Azizzadenesheli, et al. Geometry-informed neural operator for large-scale 3d pdes. Advances in Neural Information Processing Systems, 36, 2024.

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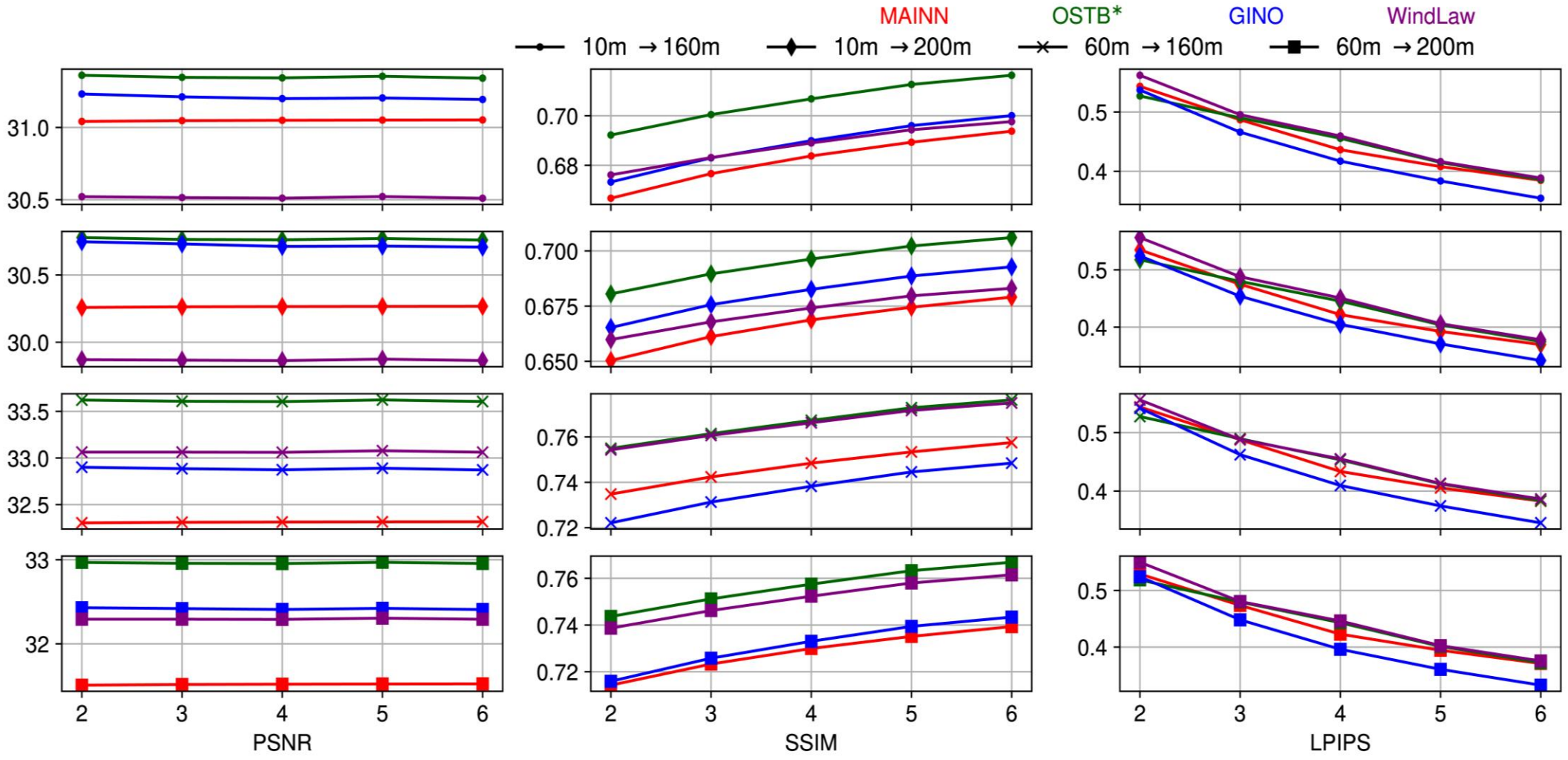
Results



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Conclusion

- OSTB is designed specifically for learning continuous, rather than discrete, representations of multi-altitude velocity fields used for wind farm power modeling across the continental United States.
- Experimental results have shown promising potential in improving wind energy assessment over data-driven and physics-driven baselines.
- Several deployed components of the OSTB model have the potential to enhance interpretability in machine learning models, making this an area for future research.

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Thanks!

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