Bridging Surface and Subsurface Salinity Measurements Using Machine Learning

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CONTEXT

This work addresses the long-standing challenge of reconciling sea surface (skin layer) salinity measurements with sub-surface or near-surface layer (NSL) salinity observations. While satellite sensors measure salinity within the uppermost millimetre of the ocean, most in-situ and operational datasets represent near-surface salinity at depths of approximately 1–2 m, where physical conditions can differ substantially on shorter time scales.

THE GOAL

We leverage high-resolution skin and 1 m NSL observations from the autonomous surface vehicle HALOBATES together with environmental and temporal variables, this study develops a machine-learning-based framework capable of inferring ~ 2 m near-surface salinity of the ship's thermosalinograph (TSG) from skin layer measurements.

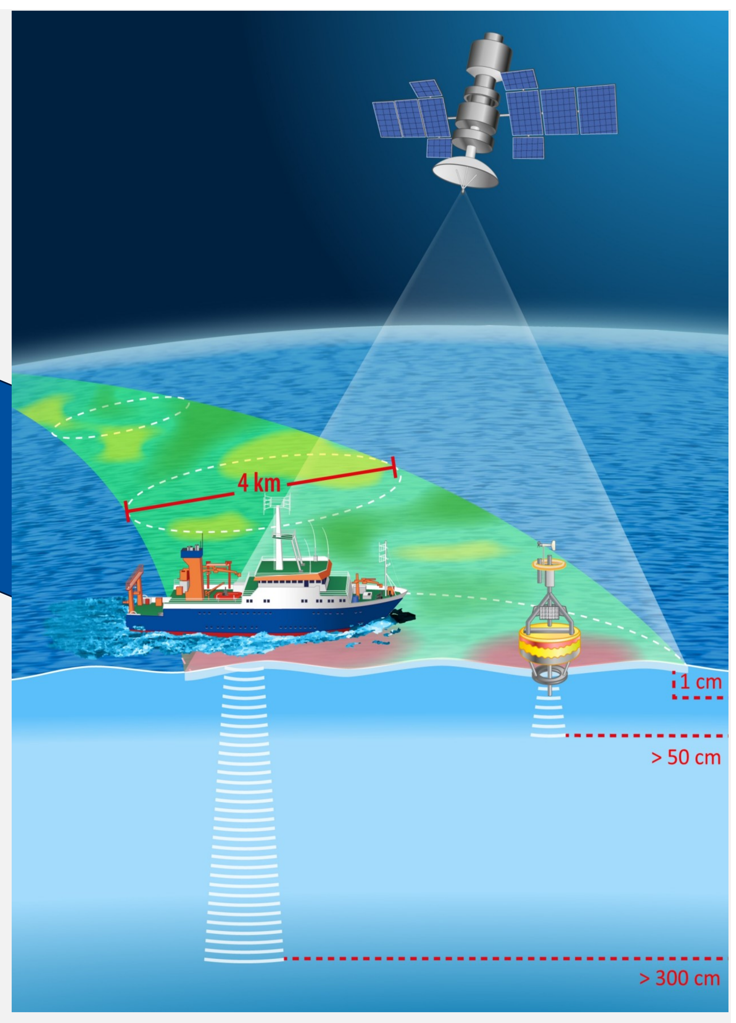

Figure 1: Graphical Abstract

DATA AND MODEL ARCHITECTURE

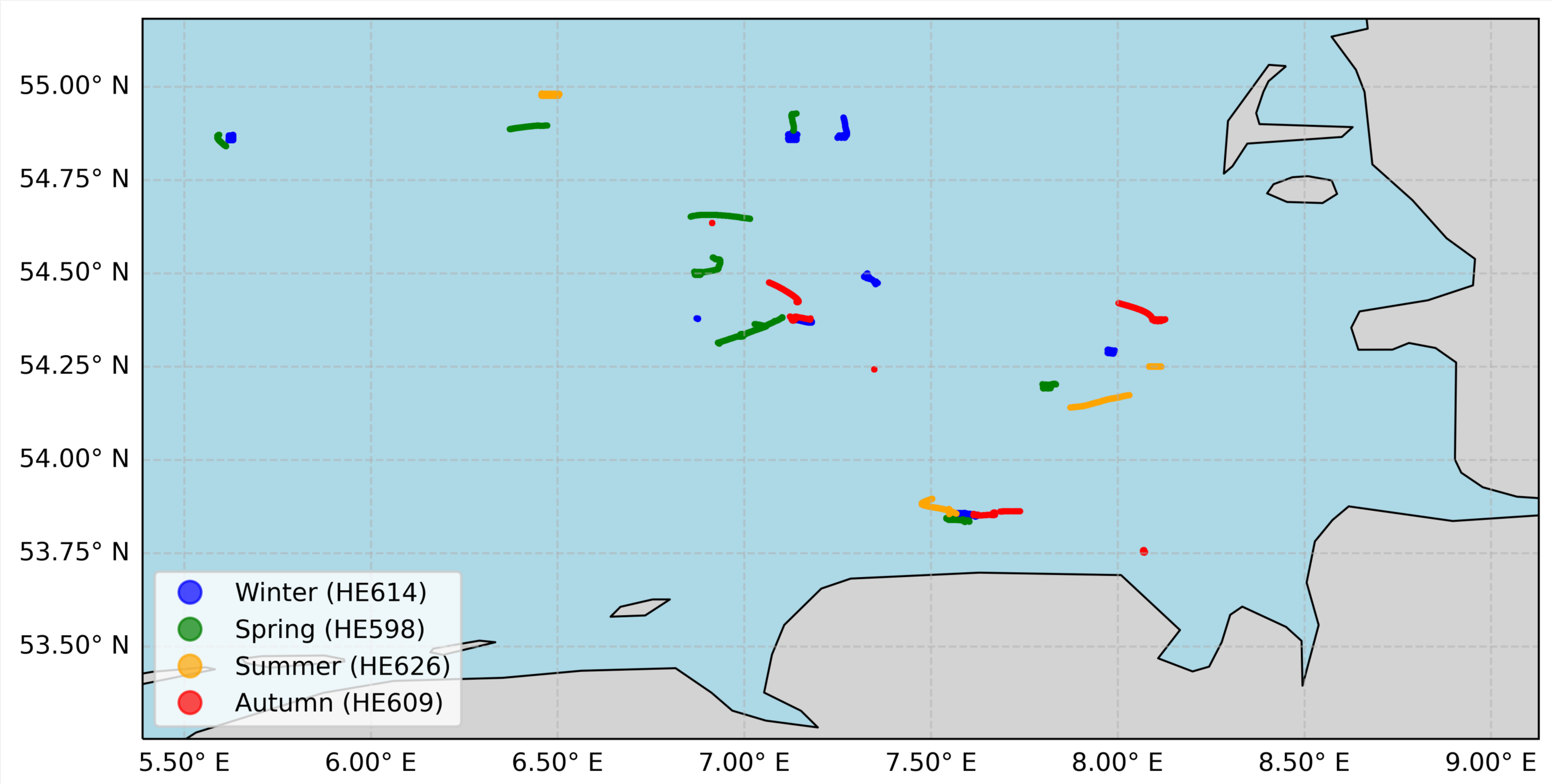

Figure 2: Study area with track of the ASV HALOBATES across the different seasons and cruises in the German bight.

- Input layer with 13 predictors, 2 hidden layer with Rectified Linear Unit activation, dropout layer with 0.2 rate and a single neuron output layer.
- Mean Squared Error (MSE) as the loss function and Mean Absolute Error (MAE) as the evaluation metric.

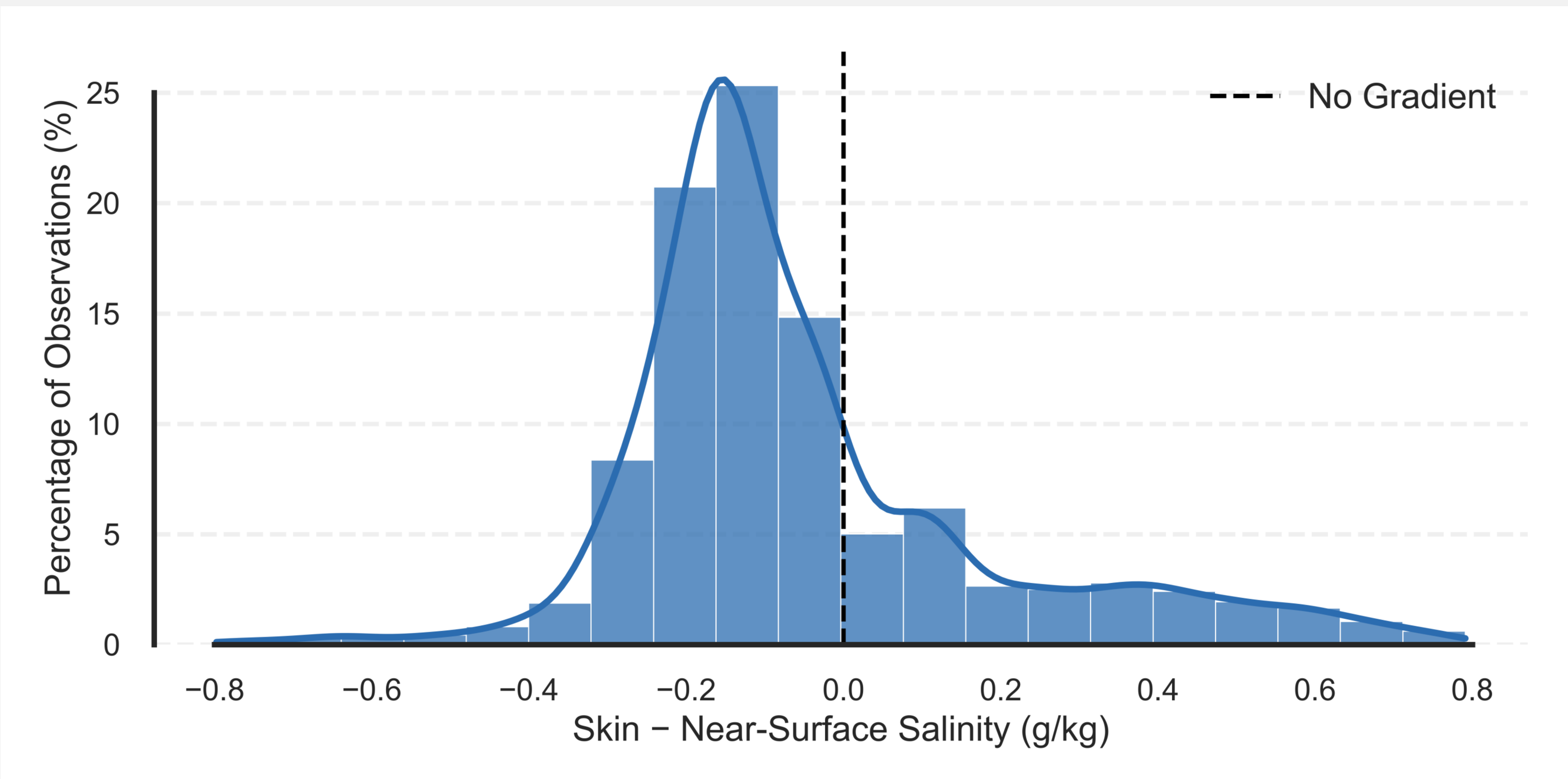

Figure 3: Histogram and kernel density estimation (KDE) shows salinity differences between the ocean skin and ~2 m depth (NSL). Dashed line at zero marks no gradient; negative values indicate fresher skin and positive saltier.

RESULTS

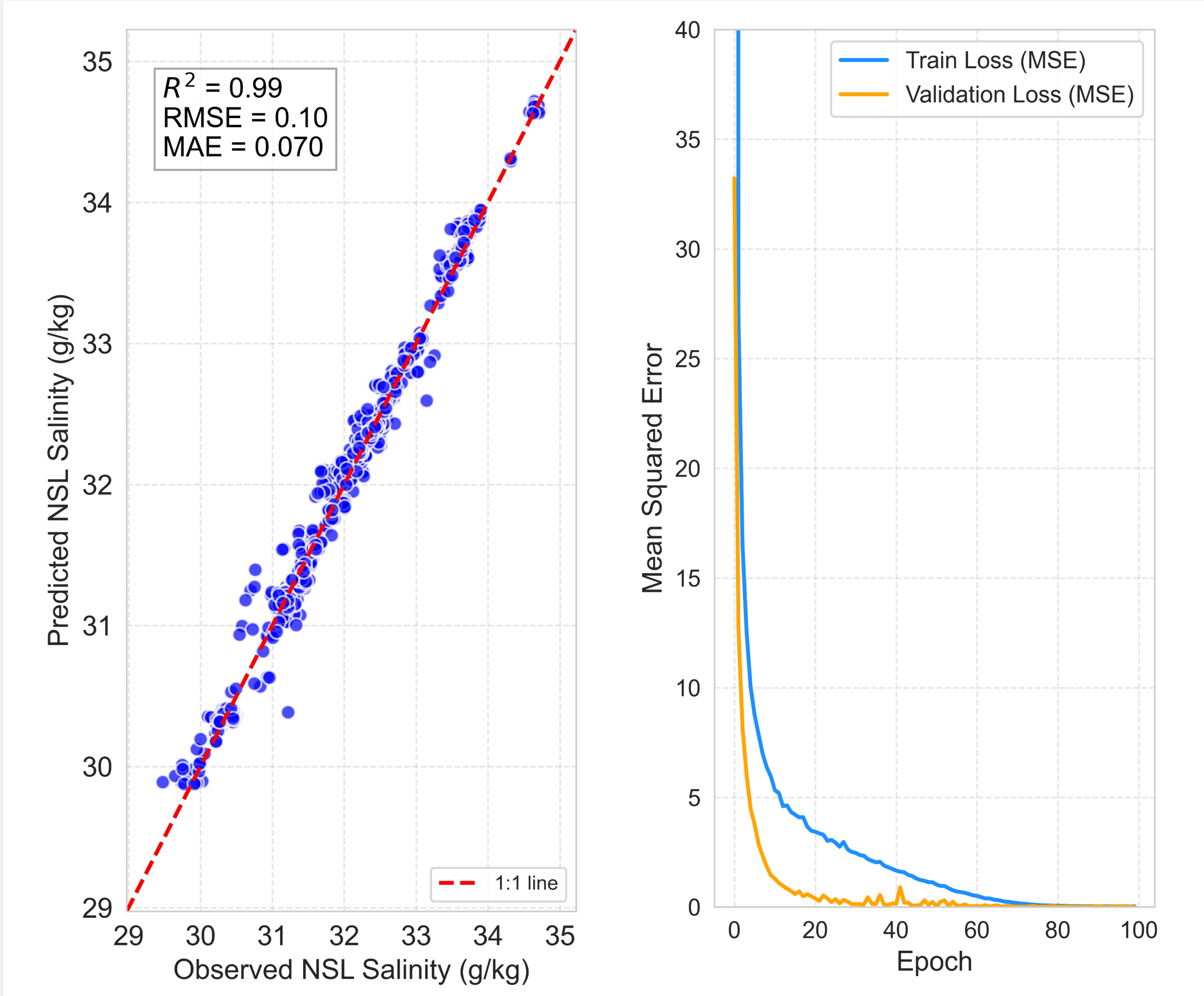

Figure 4: Predicted vs observed 2 m NSL salinity shows good agreement along the 1:1 line (red dashed). Training and validation losses converge quickly, highlighting the neural network's strong predictive performance.

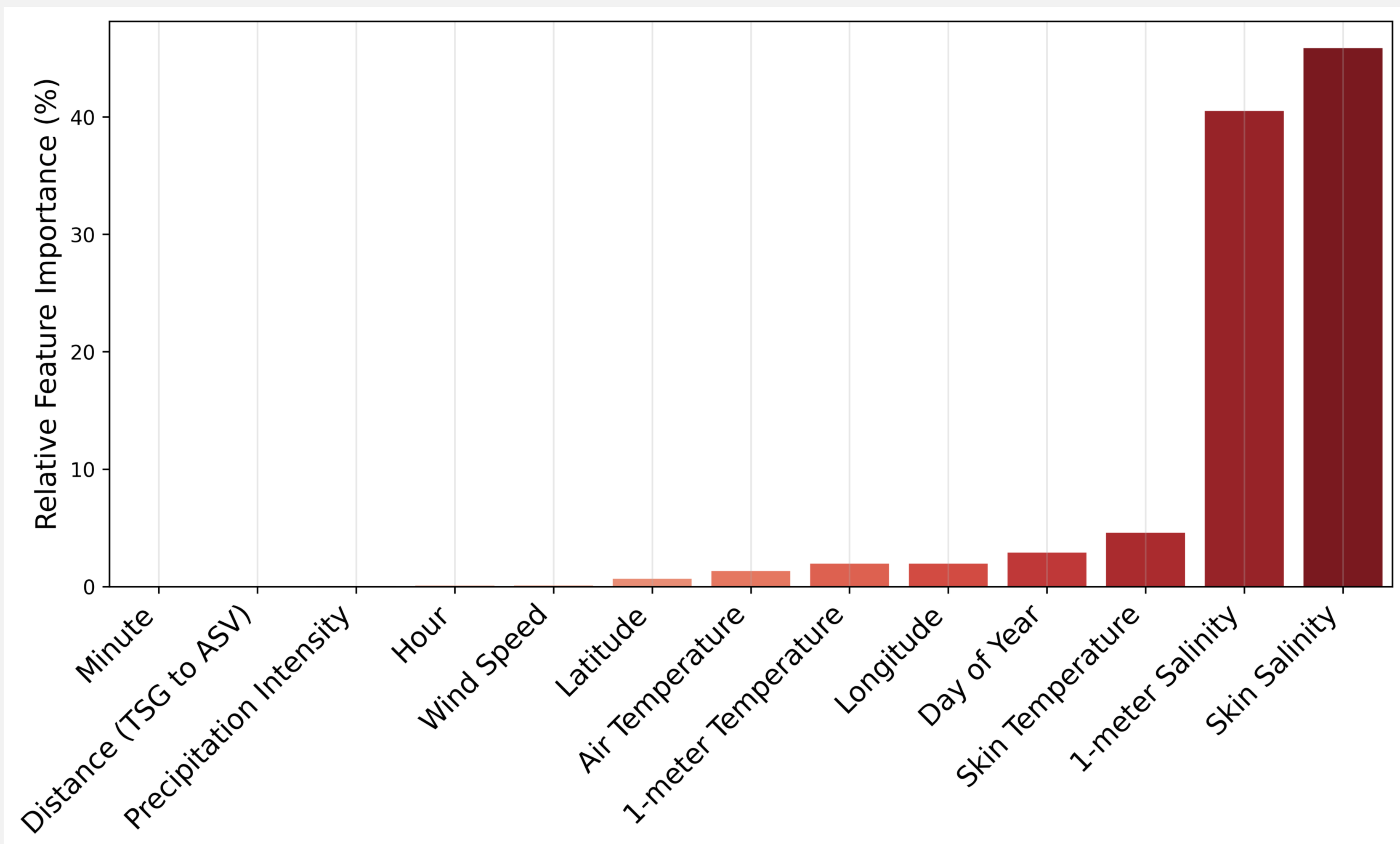

Figure 5: Spatial location, seasonality, and skin-layer salinity are the dominant controls on 2-m near-surface salinity, as revealed by permutation-based feature importance analysis.

CONCLUSION & OUTLOOK

The approach provides a practical means of bridging the vertical gap between surface (skin) and sub-surface (NSL) salinity observations which can help with improving the integration of satellite, autonomous, and ship-based datasets and enhancing the interpretation of upper-ocean salinity dynamics in coastal environments.

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