Submission code: 5YWG0K47YV

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Singular Spectrum Analysis as a Preconditioning Tool for Machine Learning-Based Permeability Estimation in the North Sea, Netherlands

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Introduction

Estimating permeability from petrophysical data is crucial for reliable reservoir characterization and geological modeling. The Dutch Sector of the North Sea, a mature and geologically complex hydrocarbon province, presents challenges for accurate permeability estimation due to inherent heterogeneity, faulting, diagenetic alterations, and noisy well log data. This study employs Singular Spectrum Analysis (SSA) as a preconditioning technique to preprocess petrophysical logs (e.g., GR, RHOB, DT, NPHI) from the Dutch North Sea. SSA effectively decomposes time series, enabling noise suppression and enhancing data quality. Our objective is to demonstrate that this preprocessing significantly improves the predictive performance of regression models for permeability estimation, leading to more accurate predictions.

Method and/or Theory

SSA was applied individually to each petrophysical log as a time series decomposition technique, separating signals into interpretable components to isolate geological trends and reduce noise. By analyzing singular values and vectors, we reconstructed the most geologically relevant components, producing SSA-filtered logs. These were used as inputs for two machine learning models—Random Forest and XGBoost—to estimate permeability. Prior to model training, the SSA-processed data underwent an integration step with laboratory petrophysical data. This was done by selecting the closest points between the laboratory samples and the well logs, extracting the geophysical curves within a 1-meter interval (±0.5 m) around each lab measurement. The median of the values within this range was calculated, generating a new dataset that combines petrophysical parameters and geophysical logs at matching depths. Random Forest is an ensemble learning method that constructs multiple decision trees and aggregates their outputs, typically through averaging in regression tasks. Its robustness stems from both the use of multiple trees and the random sampling of data and features at each split, enhancing generalization. XGBoost (Extreme Gradient Boosting) is another ensemble algorithm that uses an iterative process to build a sequence of decision trees, correcting the errors of previous trees and optimizing the loss function, which makes it highly efficient and accurate. To assess the effectiveness of SSA preconditioning, we compared the performance of the Random Forest and XGBoost models trained with SSA-processed and lab-integrated data to that of the same models trained on raw logs.

Results and Conclusions

The application of Singular Spectrum Analysis (SSA) significantly improved the accuracy of both Random Forest and XGBoost models in estimating permeability. By effectively reducing noise and enhancing relevant geological signals in the GR, RILD, RHOB, and DT logs, the SSA-preconditioned data led to more robust regression models with substantially lower prediction errors compared to models trained on raw data. This comparative analysis clearly demonstrates SSA's effectiveness as a preprocessing step. We conclude that integrating SSA with Random Forest and XGBoost regression offers a reliable and efficient approach for permeability estimation in the geologically complex reservoirs of the Dutch Sector of the North Sea.