

Dynamic Speed Optimization

An aerial photograph of a container ship's deck, showing a dense arrangement of colorful shipping containers in shades of blue, red, orange, and yellow. The ship is moving through dark blue water, with white foam visible at the bow. The deck is filled with containers, and some yellow cranes are visible at the stern.

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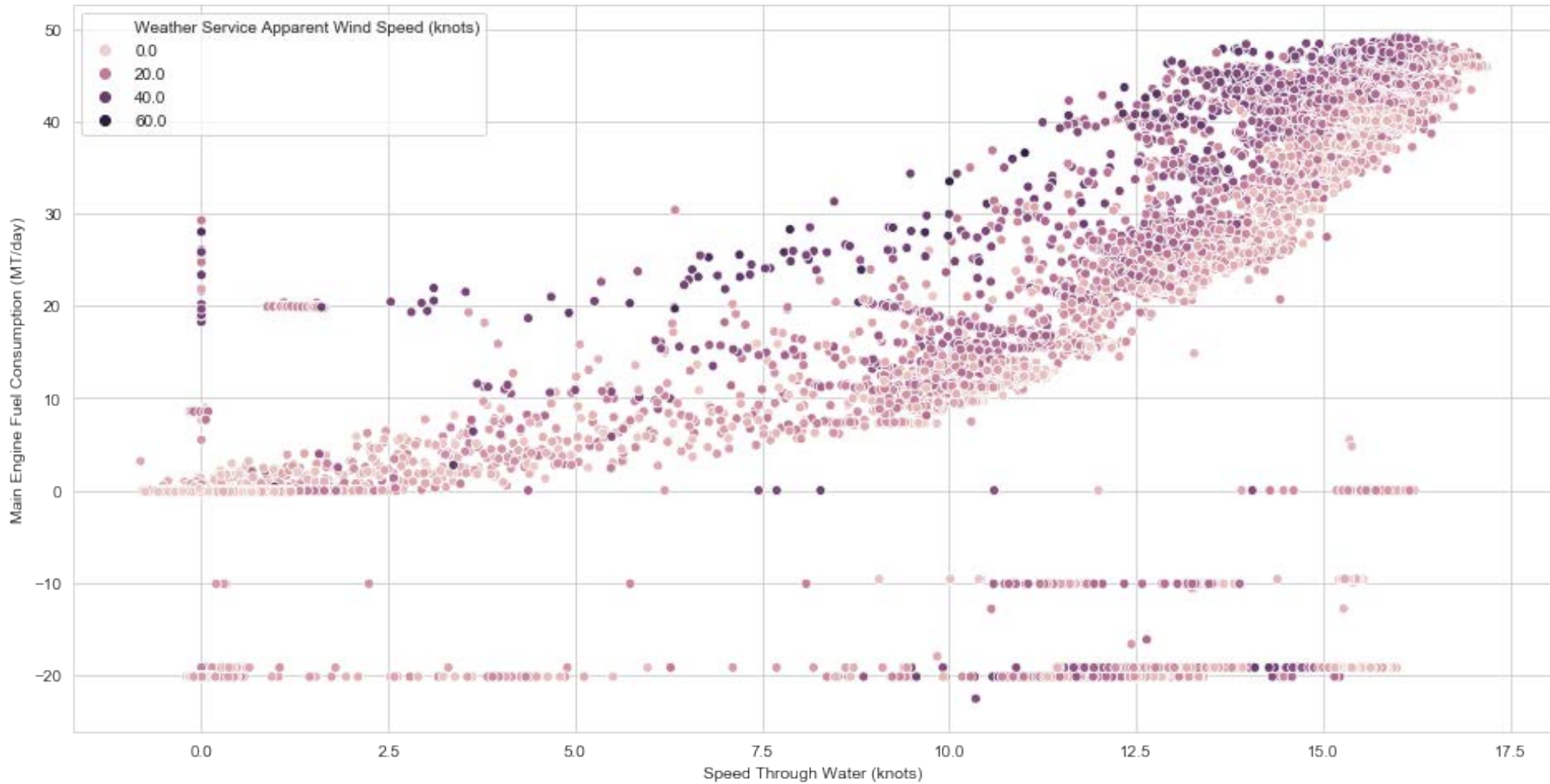
August 7, 2019

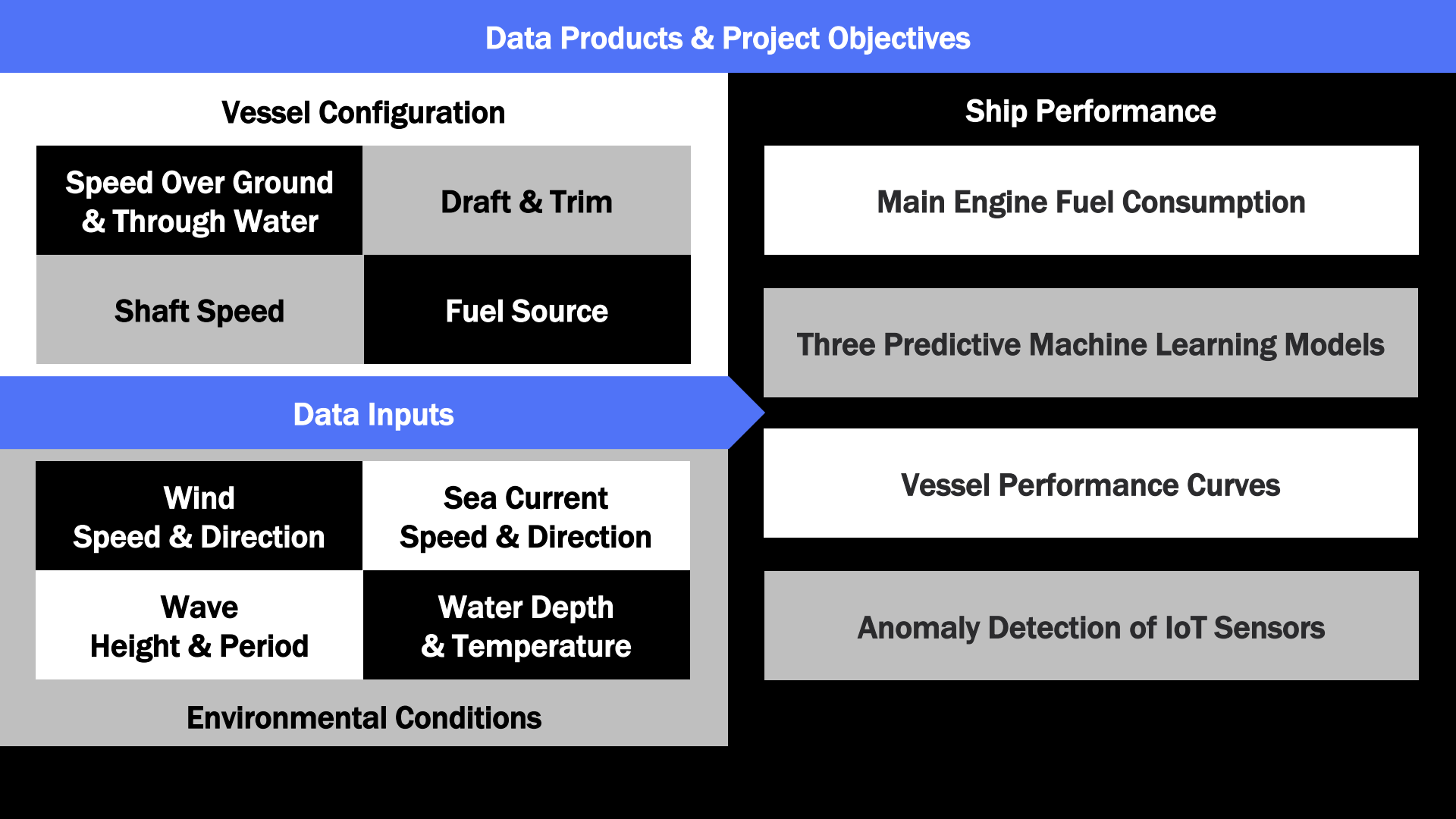
Adam C Dick

www.linkedin.com/in/adamcdick

https://github.com/acdick/dynamic_speed_optimization

Raw Data: How Do Speed and Environment Impact Fuel Consumption?





Data Science Process

Data Wrangling
Record Cleaning

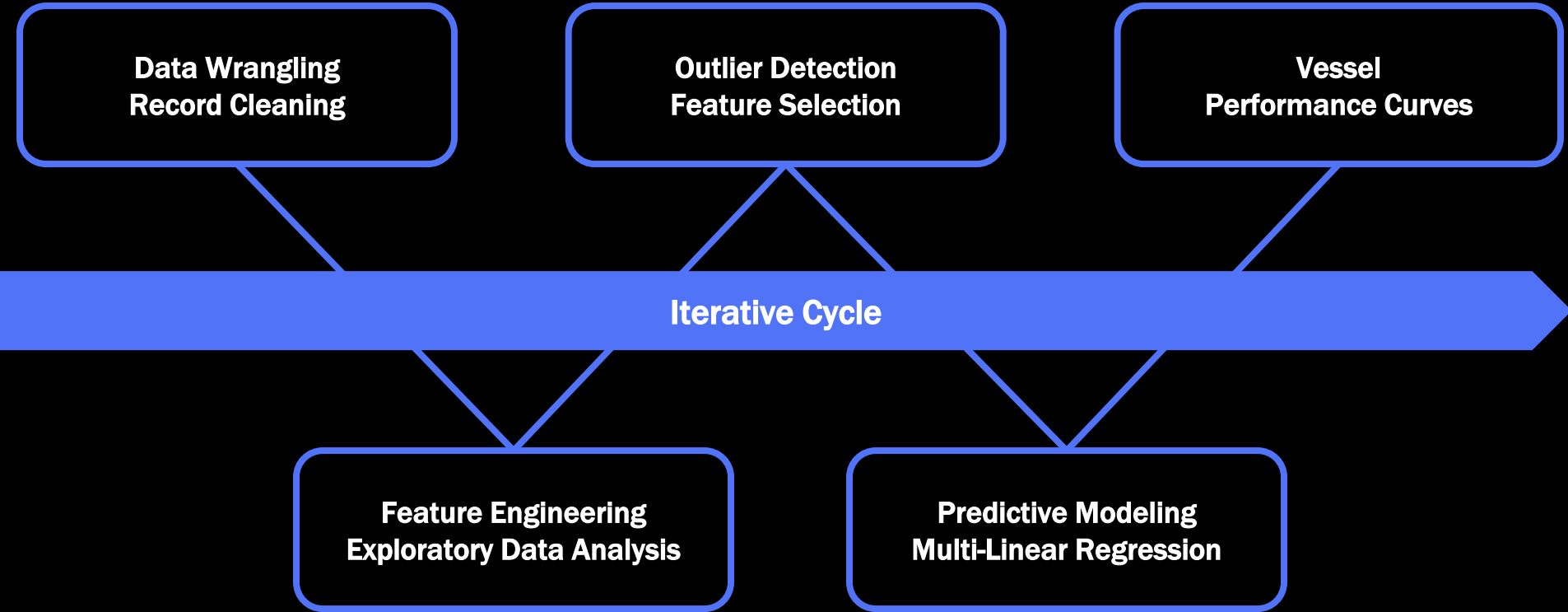
Outlier Detection
Feature Selection

Vessel
Performance Curves

Iterative Cycle

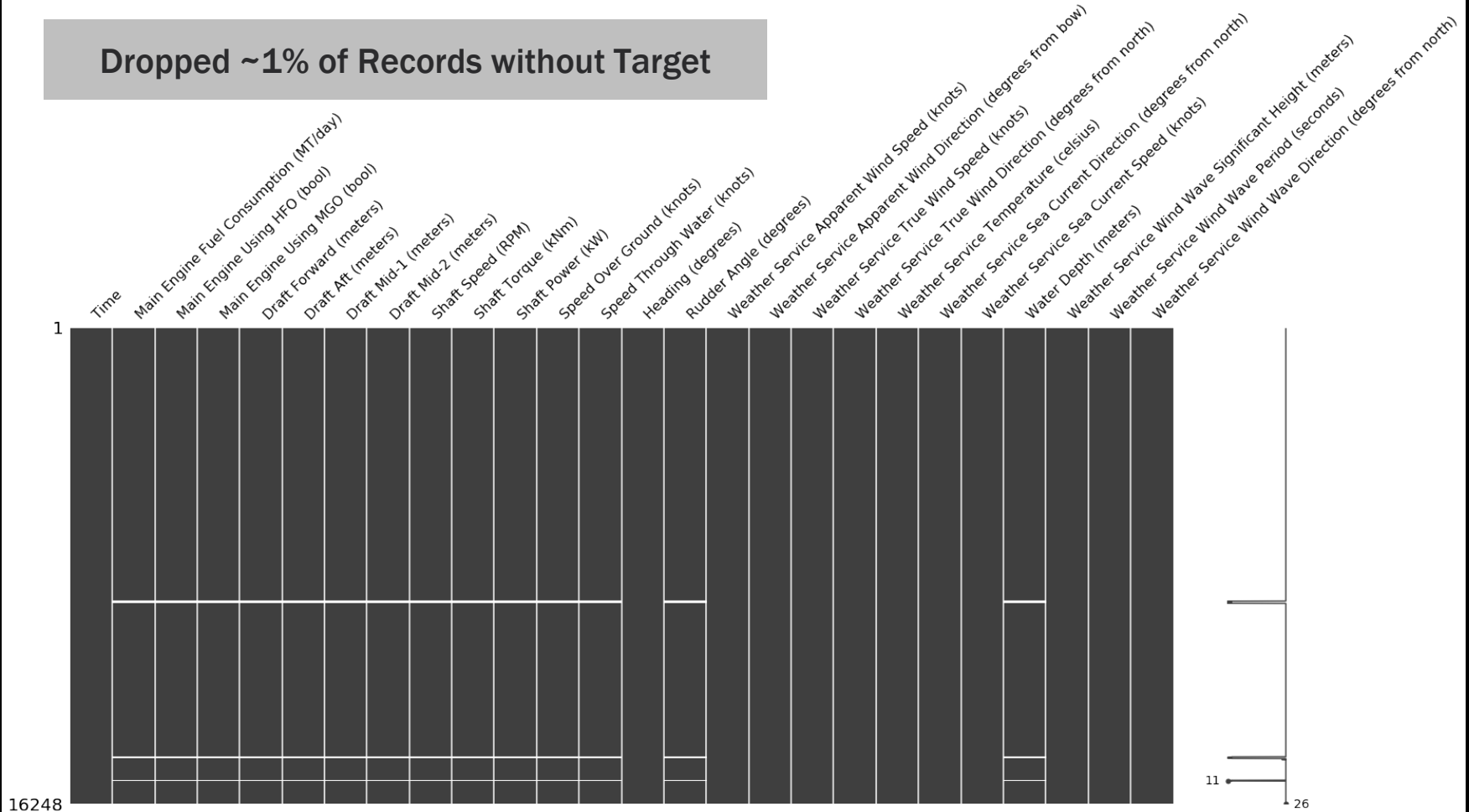
Feature Engineering
Exploratory Data Analysis

Predictive Modeling
Multi-Linear Regression

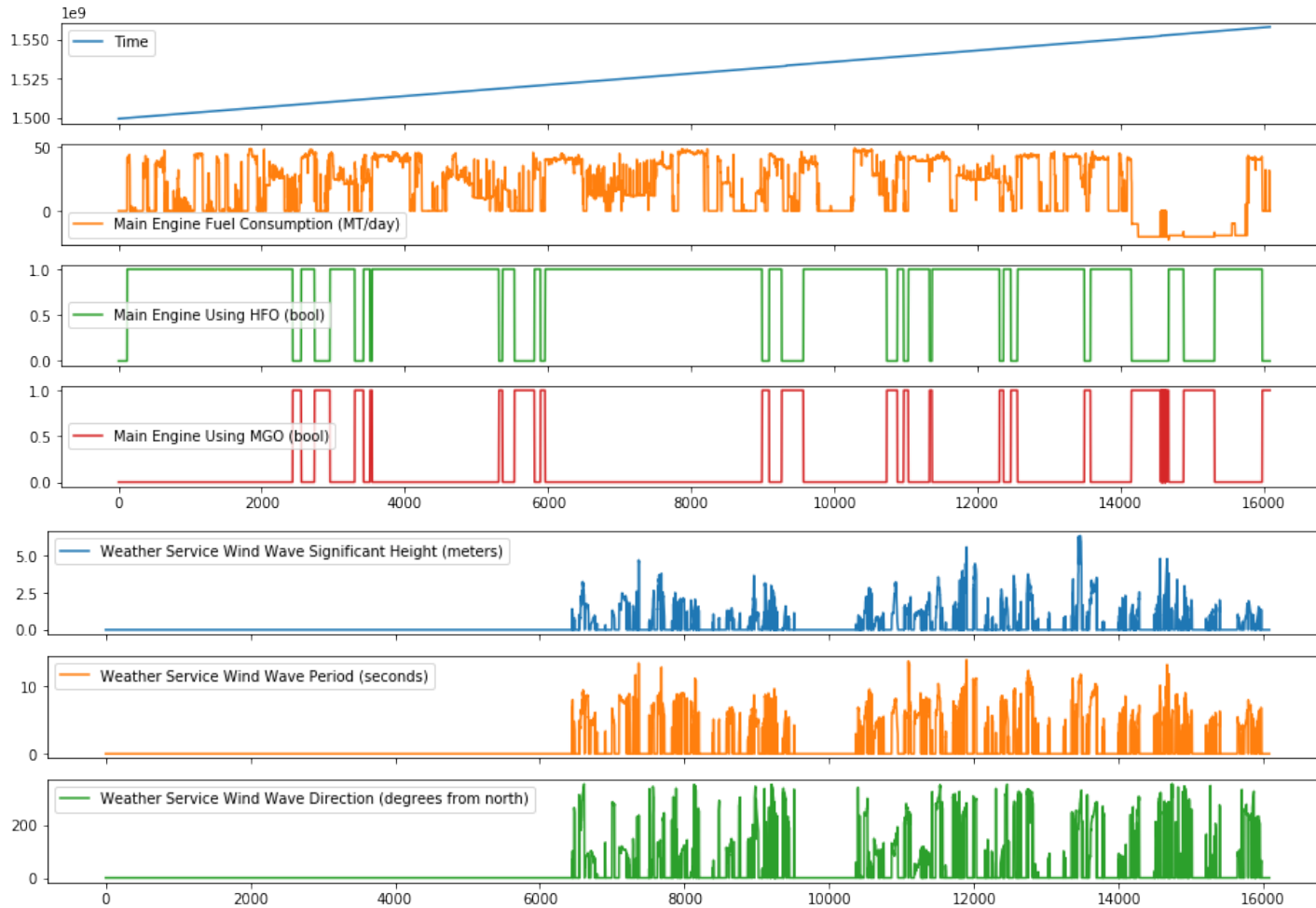


Data Wrangling: Missing Records

Dropped ~1% of Records without Target



Data Cleaning: Time, Main Engine & Wave Conditions



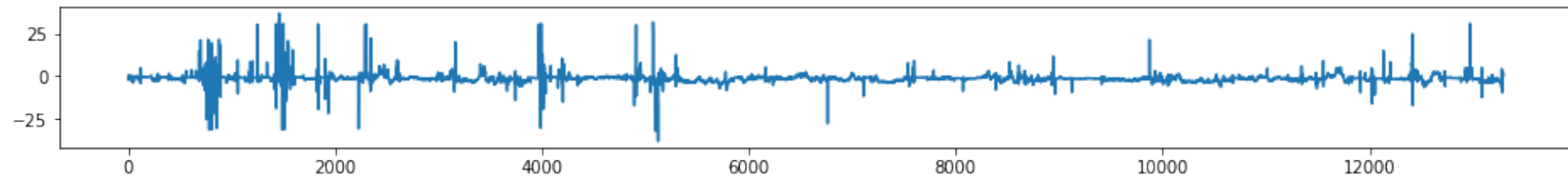
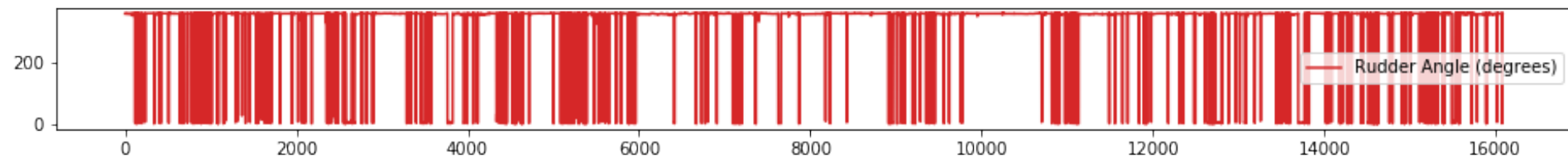
DateTime Conversion

**Calibration / Negative
Fuel Consumption**

**Reversion
to Boolean Values**

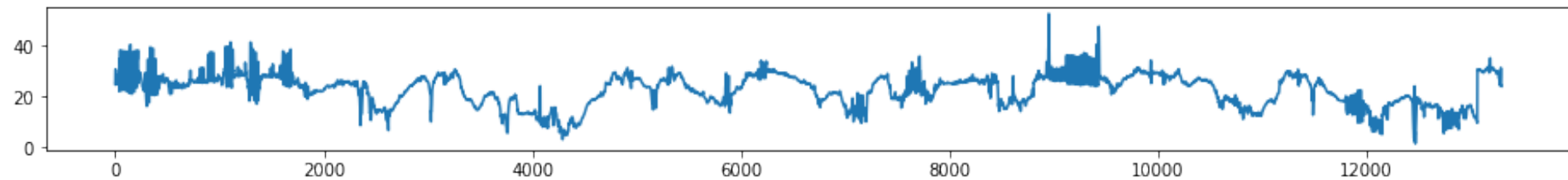
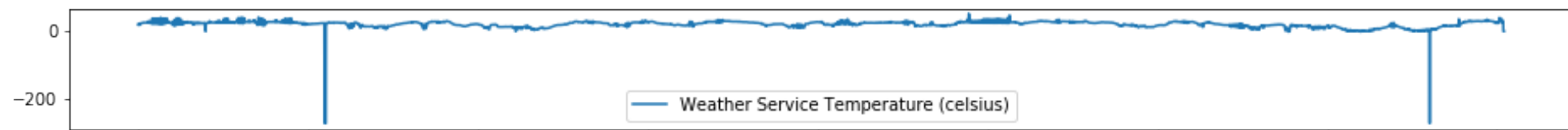
**Dropped Columns
with Excessive
Missing Records**

Data Cleaning: Rudder Angle & Water Temperature

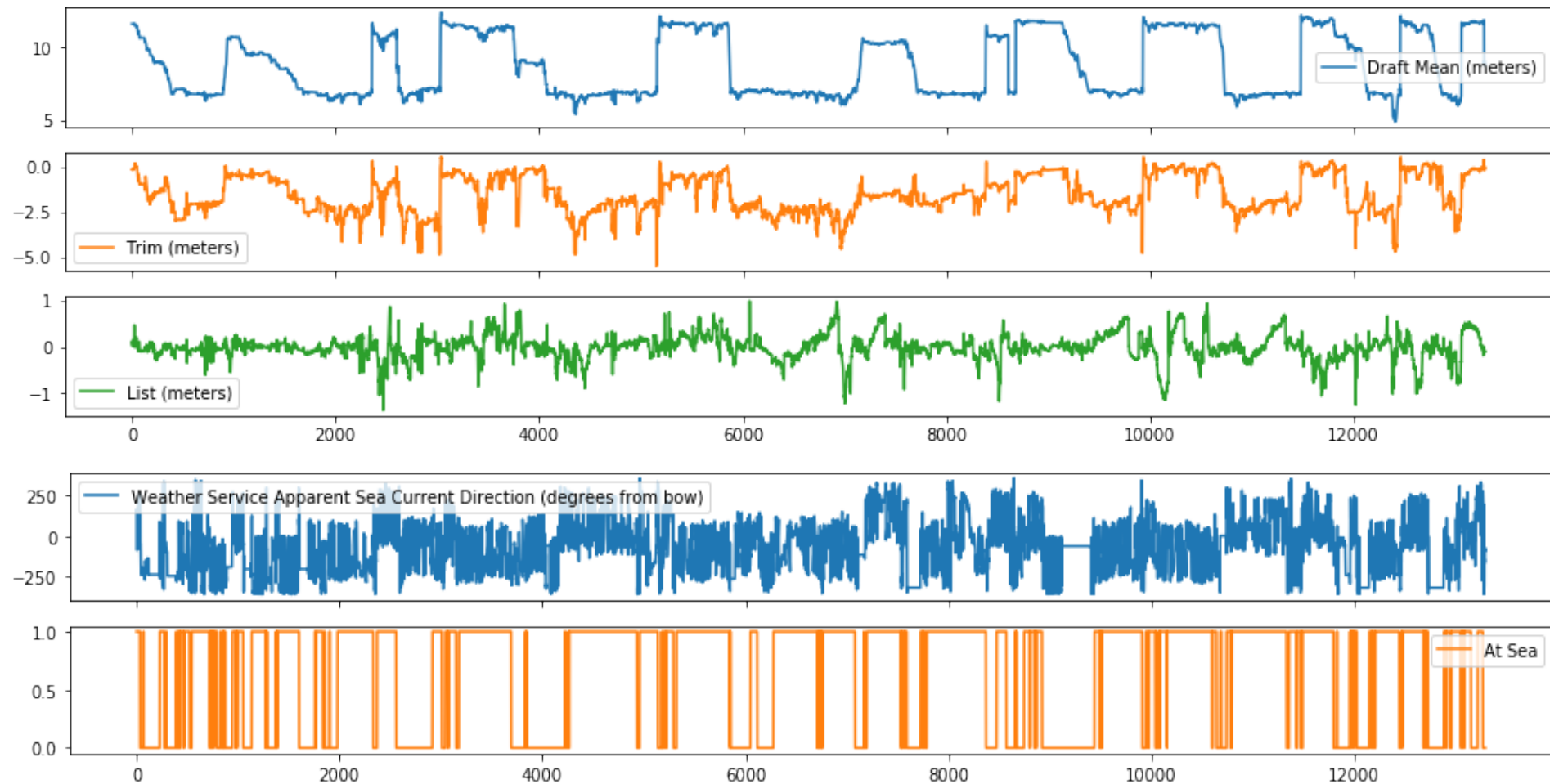


Rotated Rudder Angle for Continuity

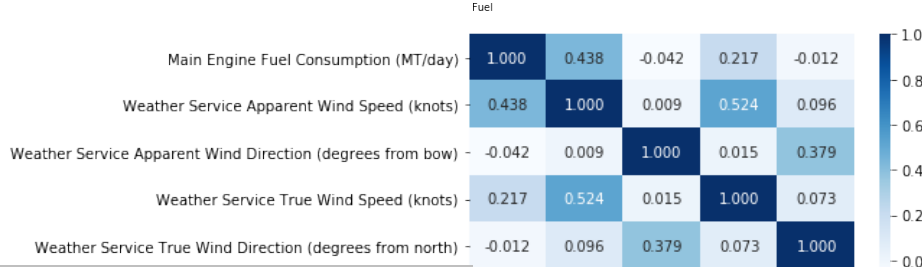
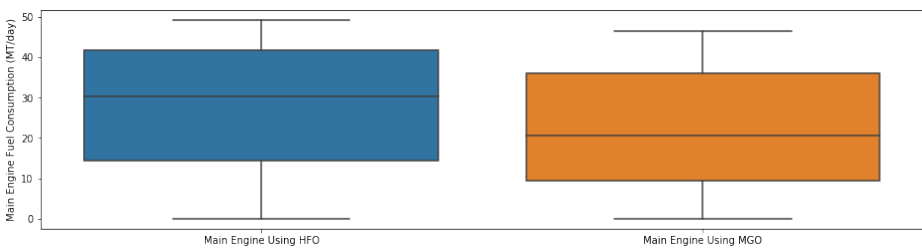
Replaced Absolute Zero Temperatures



Feature Engineering: Mean Draft, Trim, List, Apparent Sea Direction, At Sea & Speed Squared

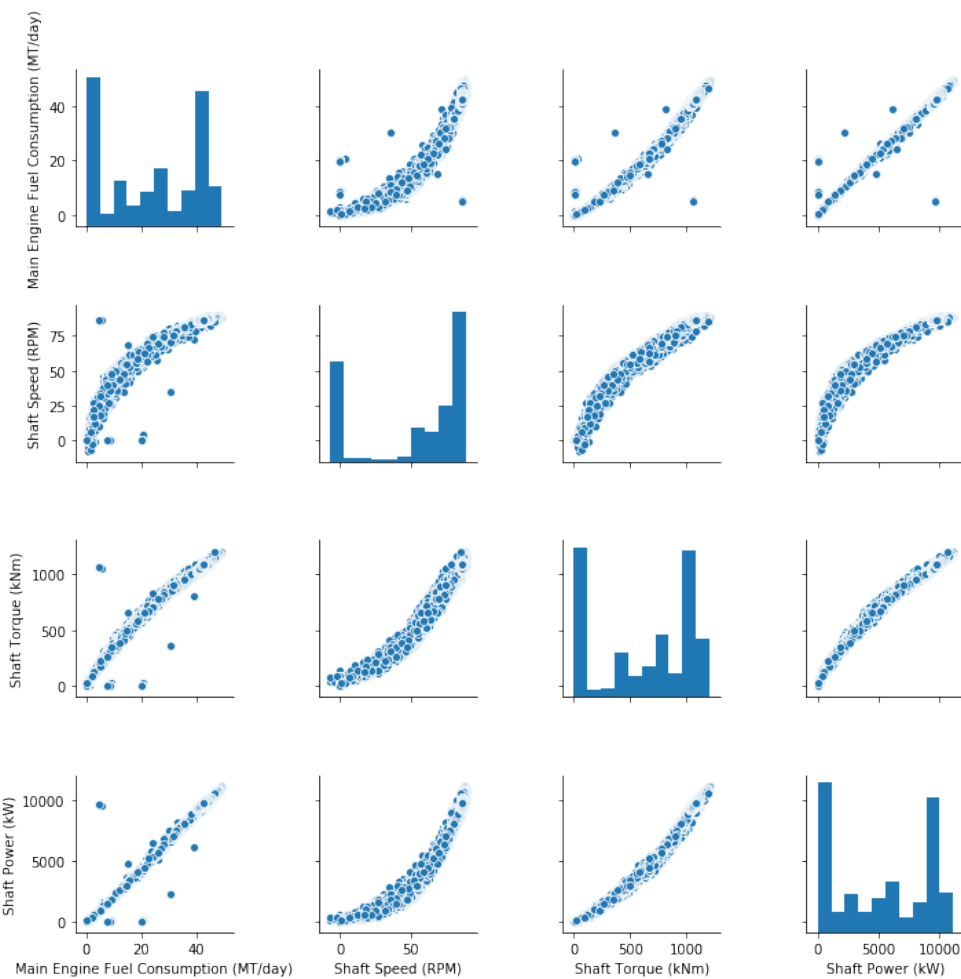


Exploratory Data Analysis: Fuel Source, Wind Conditions, Shaft Performance

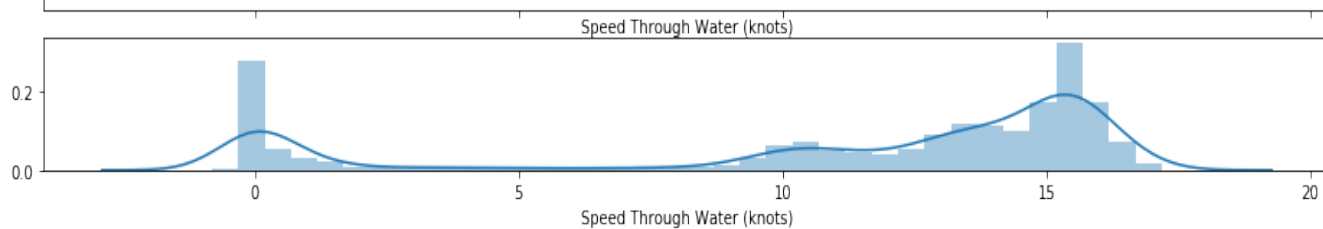
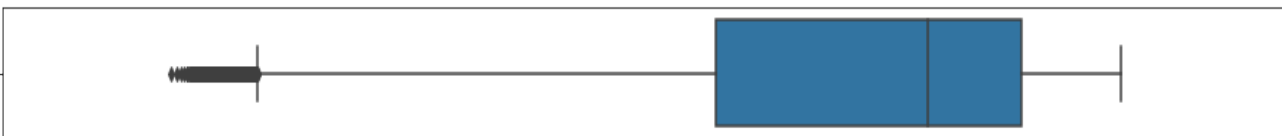
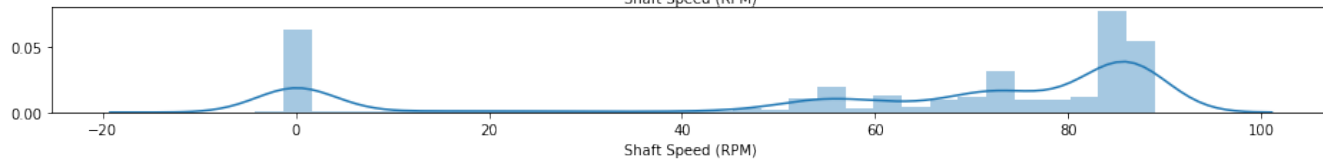
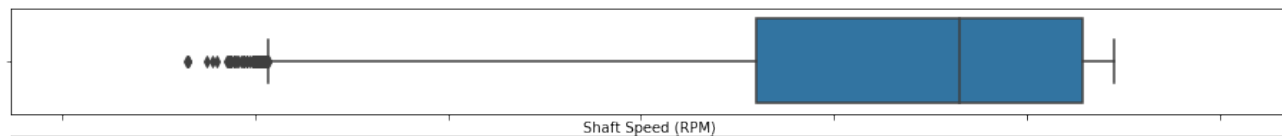
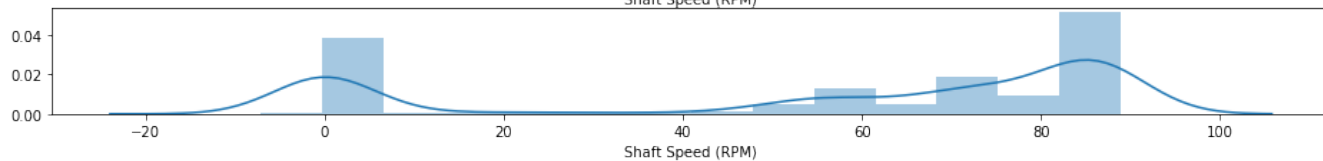
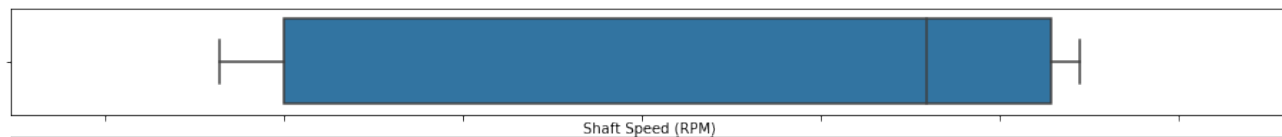


Apparent Wind Speed
Most Correlated
with Consumption

Free-Body Diagram
Vector Component
along Line of Action



Outlier Detection: Shaft Speed & Speed through Water (Possibly Towed & Anchored)



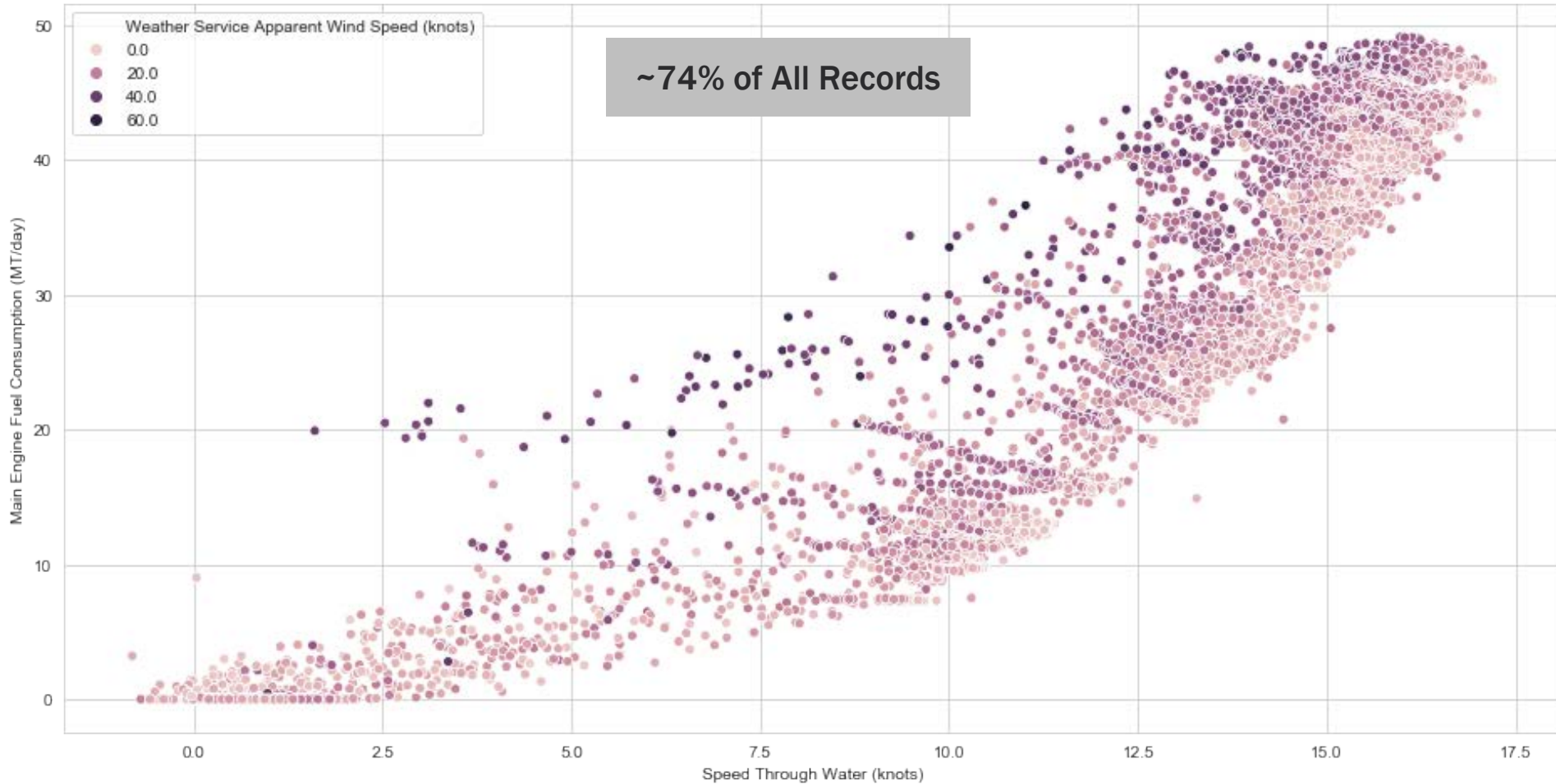
**Dropped 7.4% of Records:
Zero Shaft Speed
& Non-Zero Consumption**

**High Shaft Speed > 85 RPM
Using Low Fuel < 6 MT/Day**

**Low Shaft Speed < 40 RPM
Using High Fuel > 85 MT/Day**

**Dropped 0.2% of Records:
Zero Speed through Water
& Non-Zero Consumption**

Data Set After Cleaning and Outlier Removal



Multi-Linear Regression Modeling: Coefficients, Training Set & Predictions

| | Coefficient | Min Limit | Max Limit | Min Effect | Max Effect |
|---|-------------|-----------|------------|------------|------------|
| Feature | | | | | |
| Speed Through Water Squared (knots**2) | 0.205837 | 0.000000 | 292.832568 | 0.000000 | 60.275682 |
| Draft Mean (meters) | 1.449527 | 4.999963 | 12.385497 | 7.247580 | 17.953109 |
| Weather Service Apparent Wind Speed (knots) | 0.316708 | 0.216047 | 51.955335 | 0.068424 | 16.454660 |
| Trim (meters) | -1.593494 | -5.379965 | 0.547380 | 8.572944 | -0.872247 |
| Weather Service Sea Current Speed (knots) | -0.382352 | 0.000000 | 3.184603 | -0.000000 | -1.217640 |
| Speed Through Water (knots) | -0.845935 | -0.812132 | 17.112351 | 0.687011 | -14.475938 |
| Intercept | -16.964856 | NaN | NaN | NaN | NaN |

80 / 20 Train Test Split

Training Set:

9,640 Records

R-Squared: 96.8%

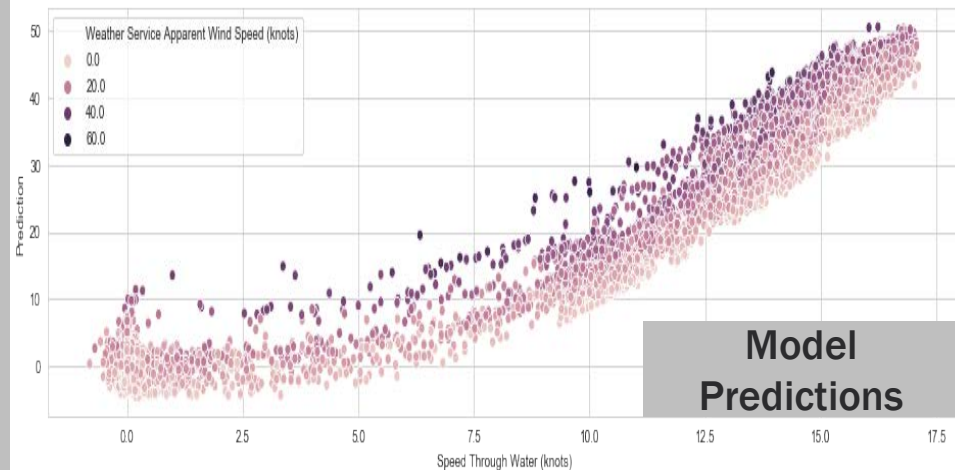
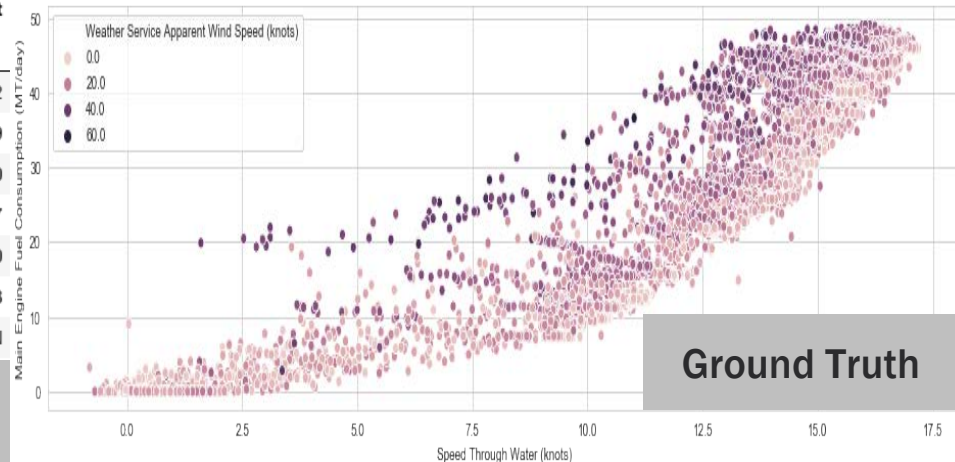
Root Mean Squared Error: 2.98 MT/Day

Test Set:

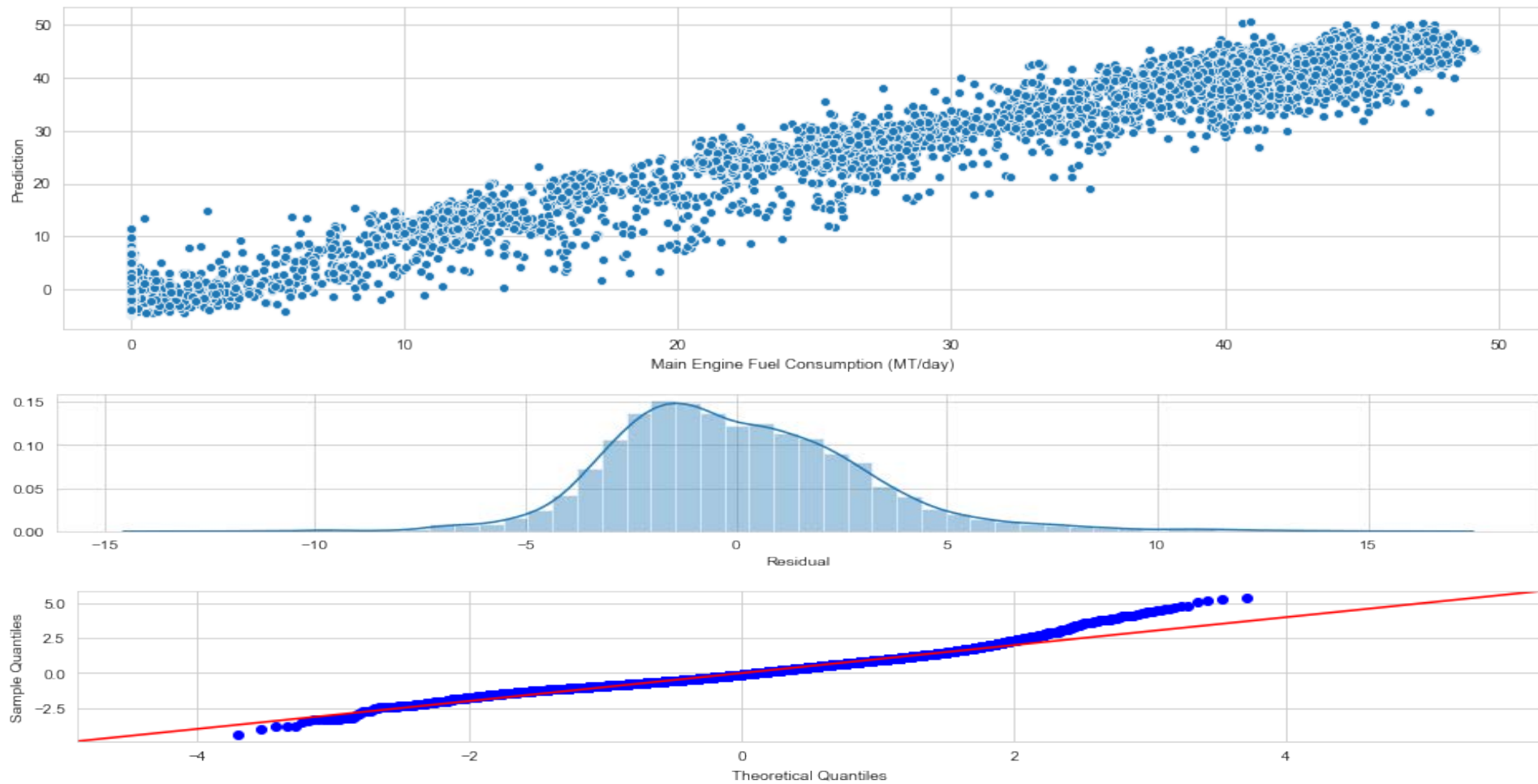
2,410 Records

R-Squared: 96.9%

Root Mean Squared Error: 2.95 MT/Day



Multi-Linear Regression Modeling: Residual Linearity, Distribution & Normality



Nearest Neighbor Regression Modeling: k-Neighbor Selection, Training Set & Predictions

| Neighbors | Train R-Squared | Train RMSE | Test R-Squared | Test RMSE | Difference R-Squared | Difference RMSE |
|-----------|-----------------|------------|----------------|-----------|----------------------|-----------------|
| 1 | 1.000000 | 0.000000 | 0.976815 | 2.522182 | -0.023185 | 2.522182 |
| 2 | 0.994349 | 1.258252 | 0.981268 | 2.267098 | -0.013082 | 1.008846 |
| 3 | 0.991852 | 1.510941 | 0.981896 | 2.228771 | -0.009956 | 0.717830 |
| 4 | 0.990013 | 1.672826 | 0.982455 | 2.194072 | -0.007557 | 0.521245 |
| 5 | 0.988737 | 1.776420 | 0.982685 | 2.179643 | -0.006052 | 0.403223 |
| 6 | 0.987691 | 1.857088 | 0.982324 | 2.202263 | -0.005367 | 0.345174 |

80 / 20 Train Test Split

Training Set:

9,640 Records

R-Squared: 98.9%

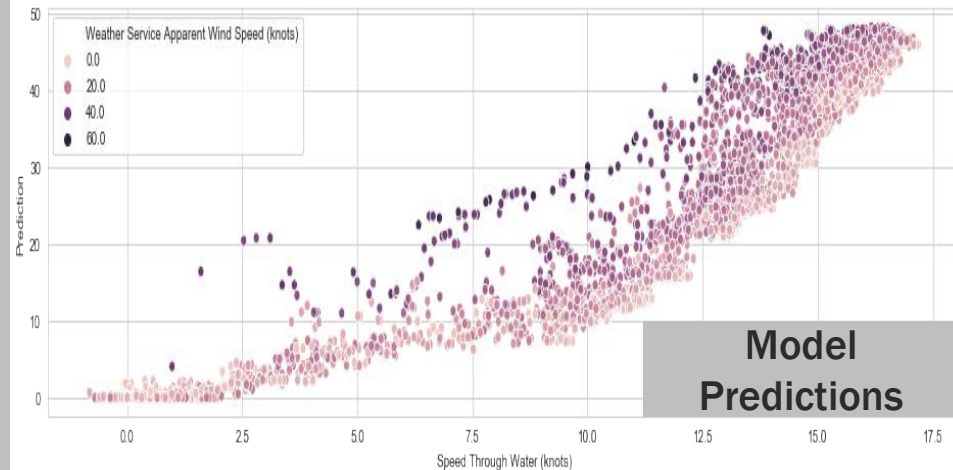
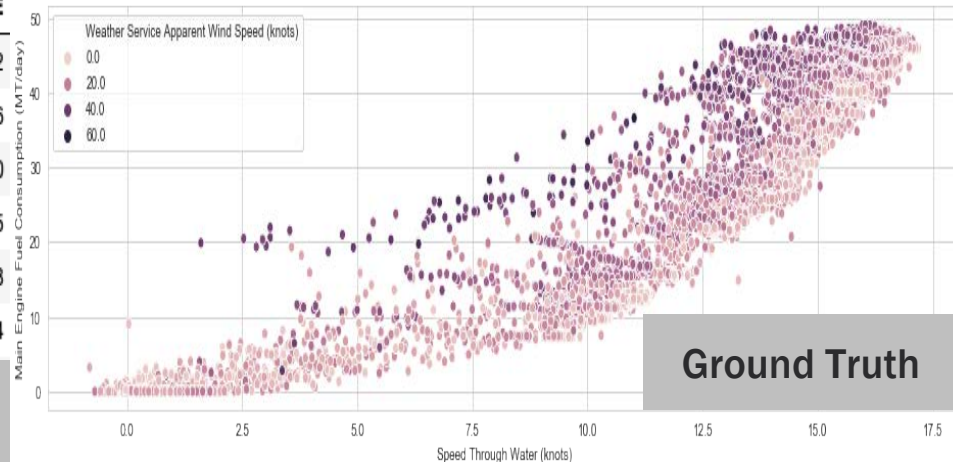
Root Mean Squared Error: 1.78 MT/Day

Test Set:

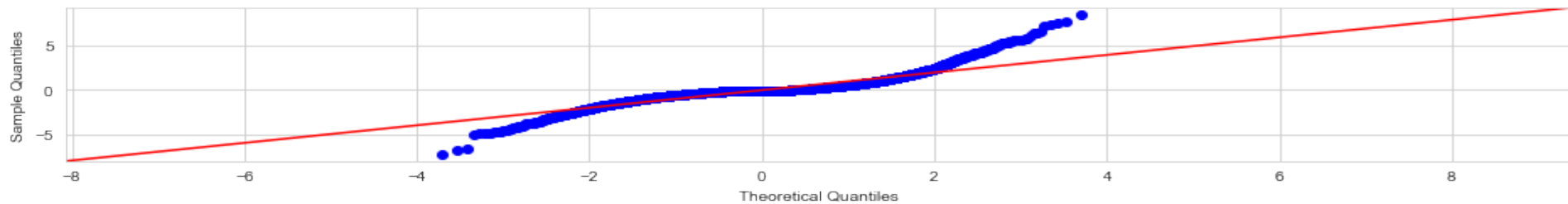
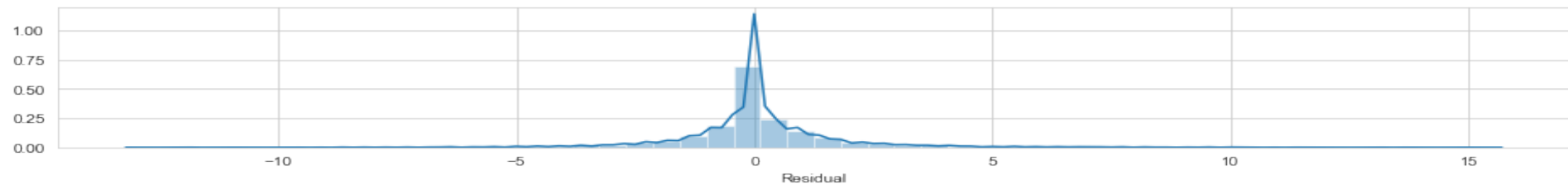
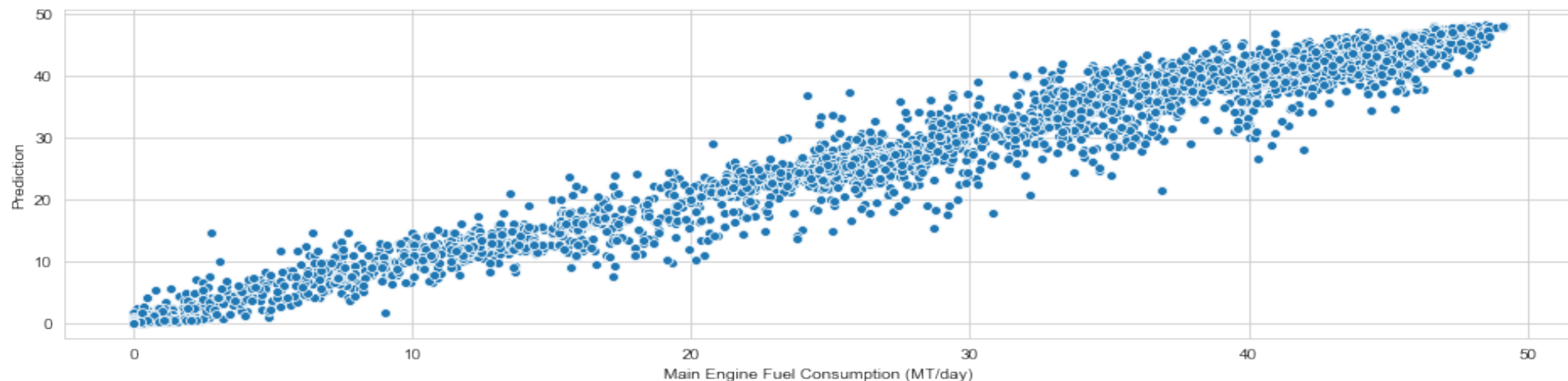
2,410 Records

R-Squared: 98.3%

Root Mean Squared Error: 2.18 MT/Day



Nearest Neighbor Regression Modeling: Residual Linearity, Distribution & Normality



Random Forest Regression Modeling: Feature Importance, Training Set & Predictions

| Feature | Importance |
|---|------------|
| Speed Through Water Squared (knots**2) | 0.490366 |
| Speed Through Water (knots) | 0.462709 |
| Draft Mean (meters) | 0.021708 |
| Weather Service Apparent Wind Speed (knots) | 0.020002 |
| Trim (meters) | 0.004443 |
| Weather Service Sea Current Speed (knots) | 0.000771 |

80 / 20 Train Test Split

Training Set:

9,640 Records

R-Squared: 99.3%

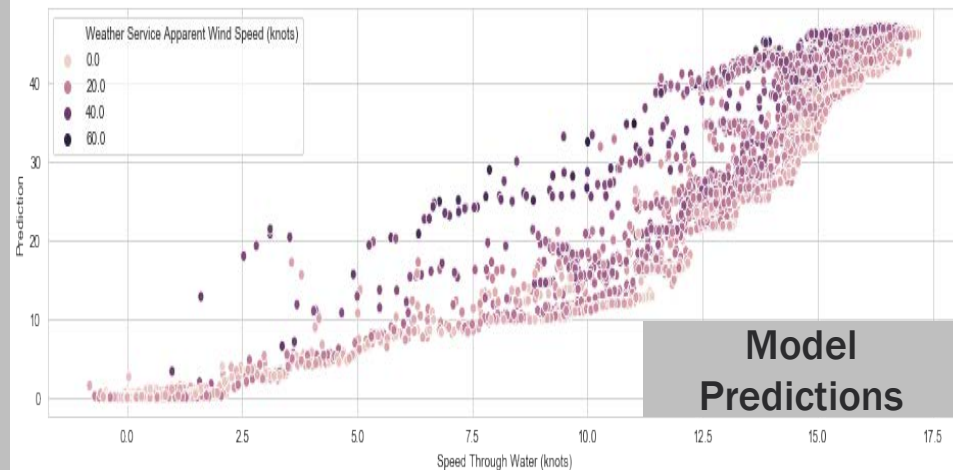
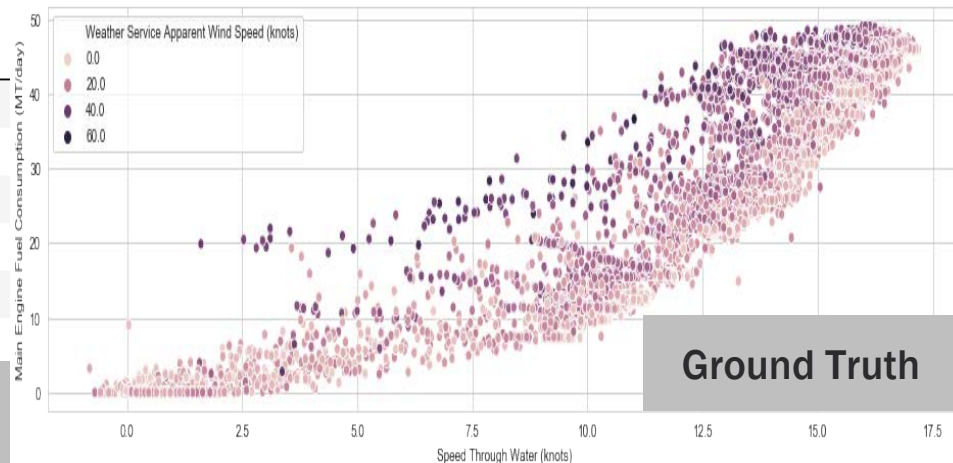
Root Mean Squared Error: 1.42 MT/Day

Test Set:

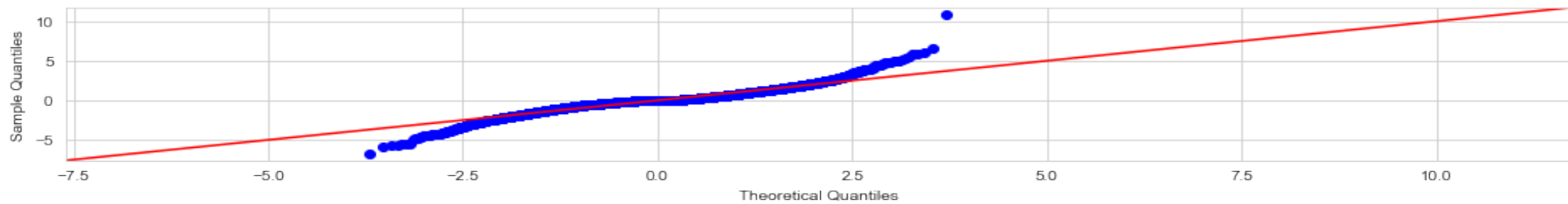
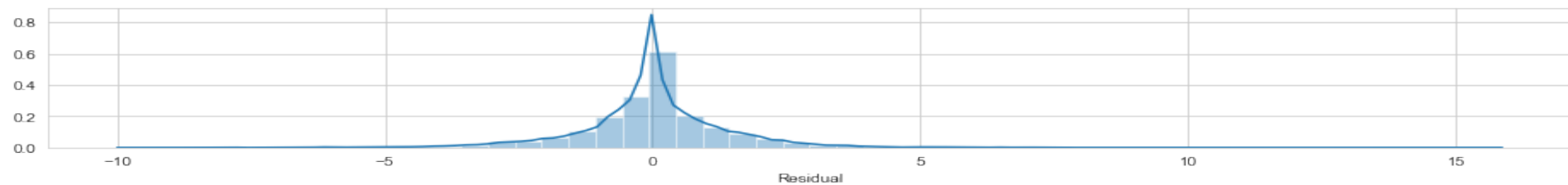
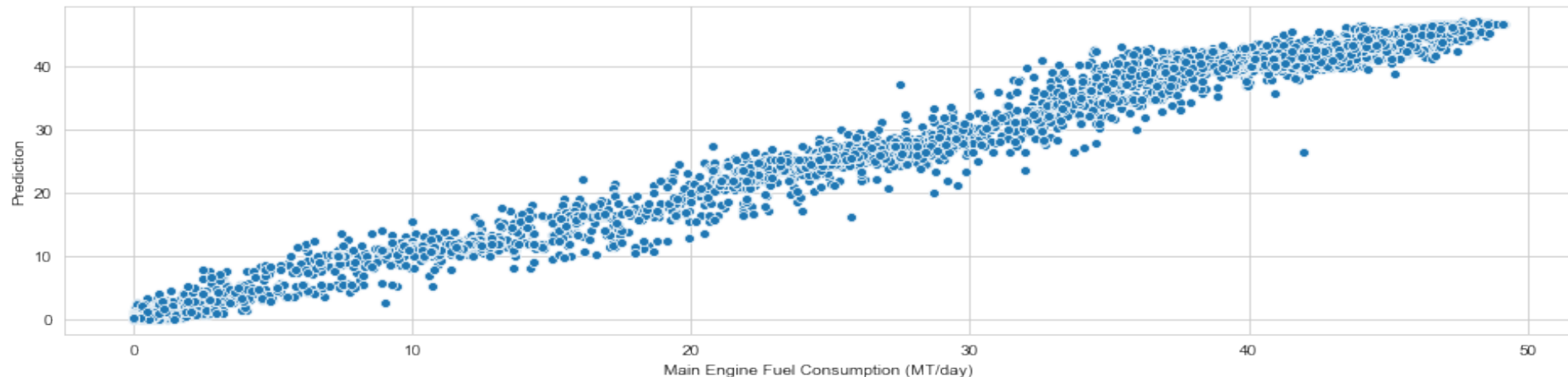
2,410 Records

R-Squared: 98.9%

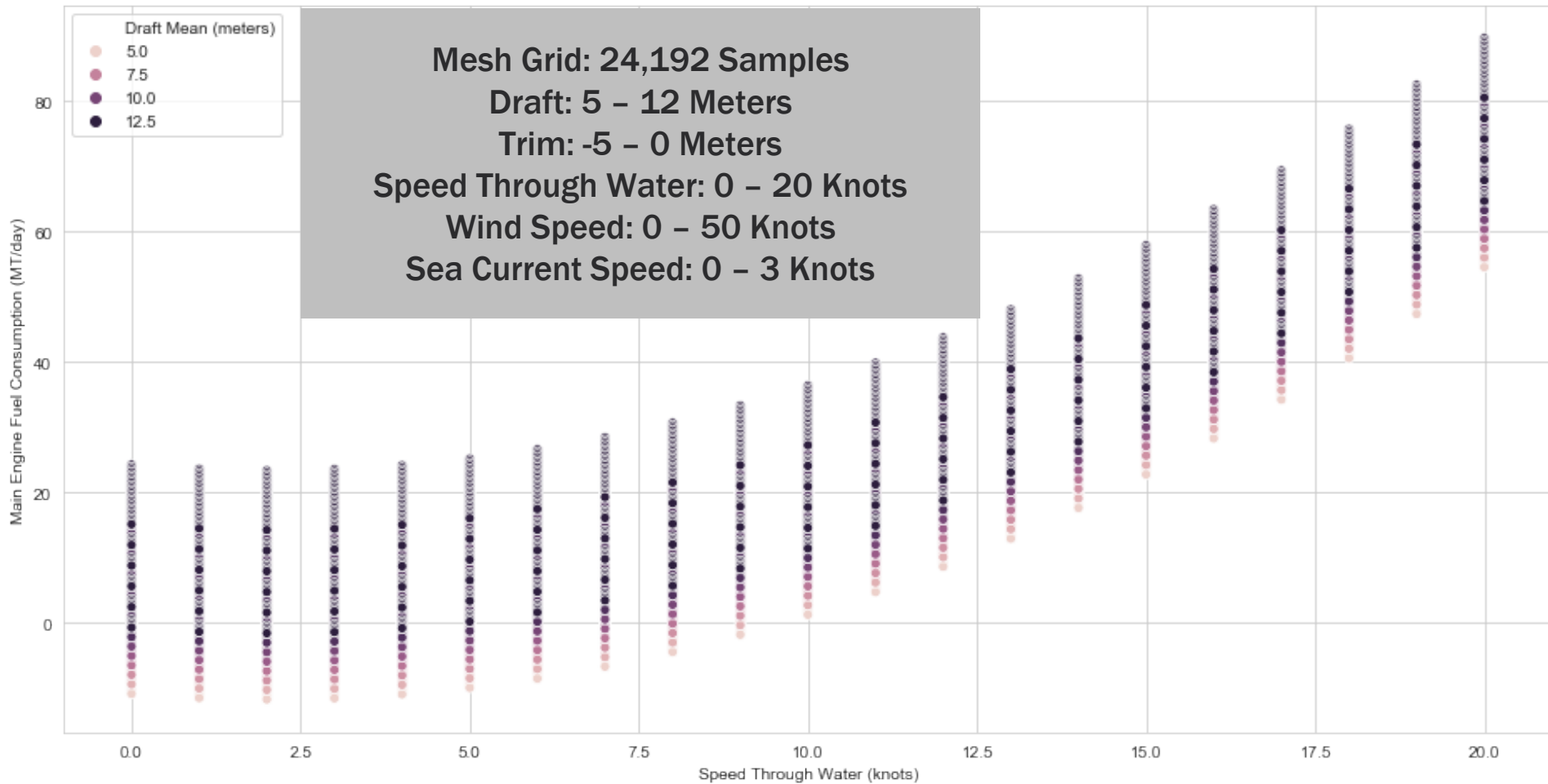
Root Mean Squared Error: 1.74 MT/Day



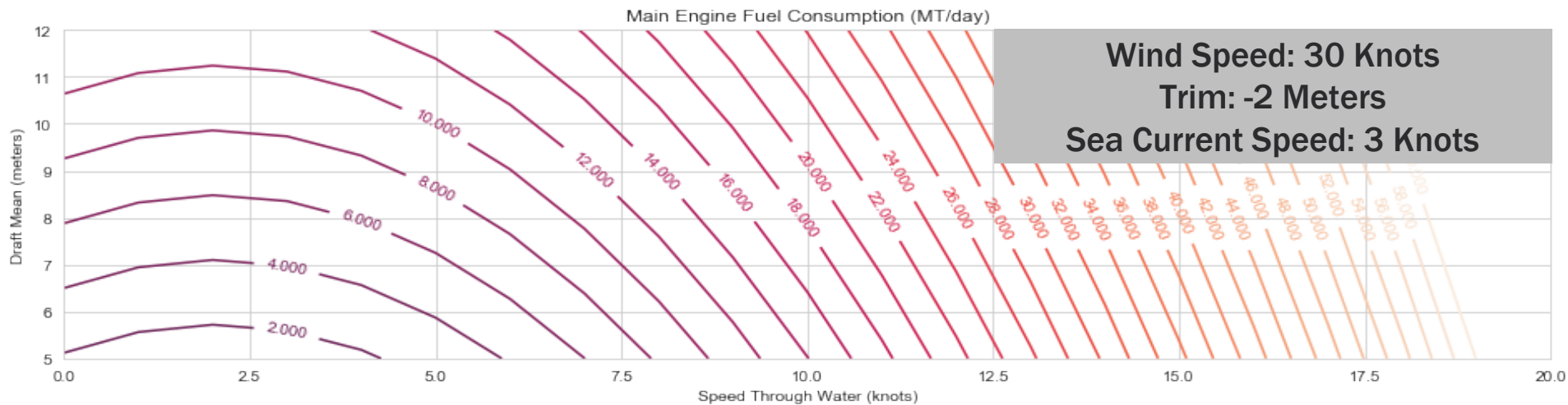
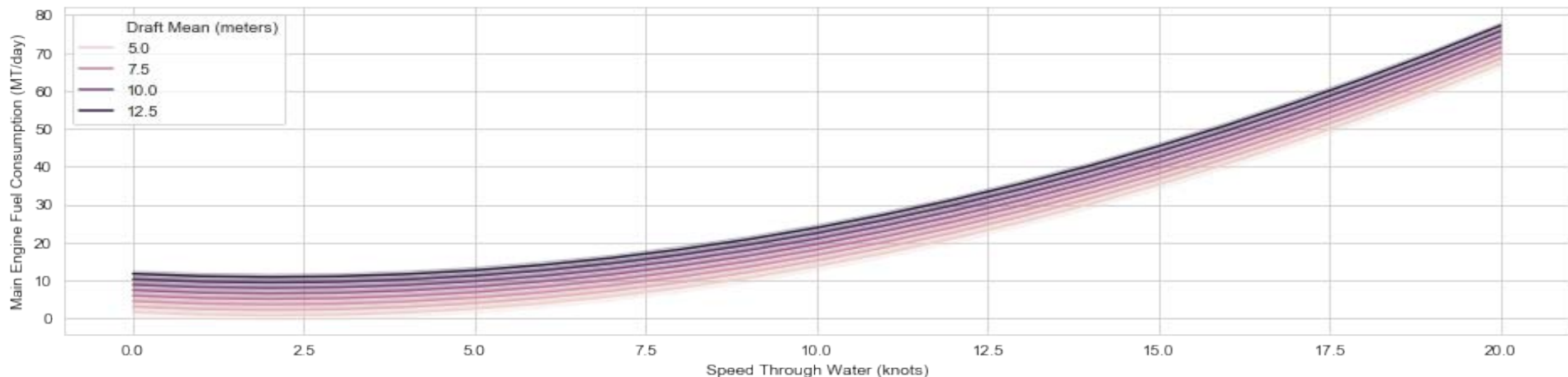
Random Forest Regression Modeling: Residual Linearity, Distribution & Normality



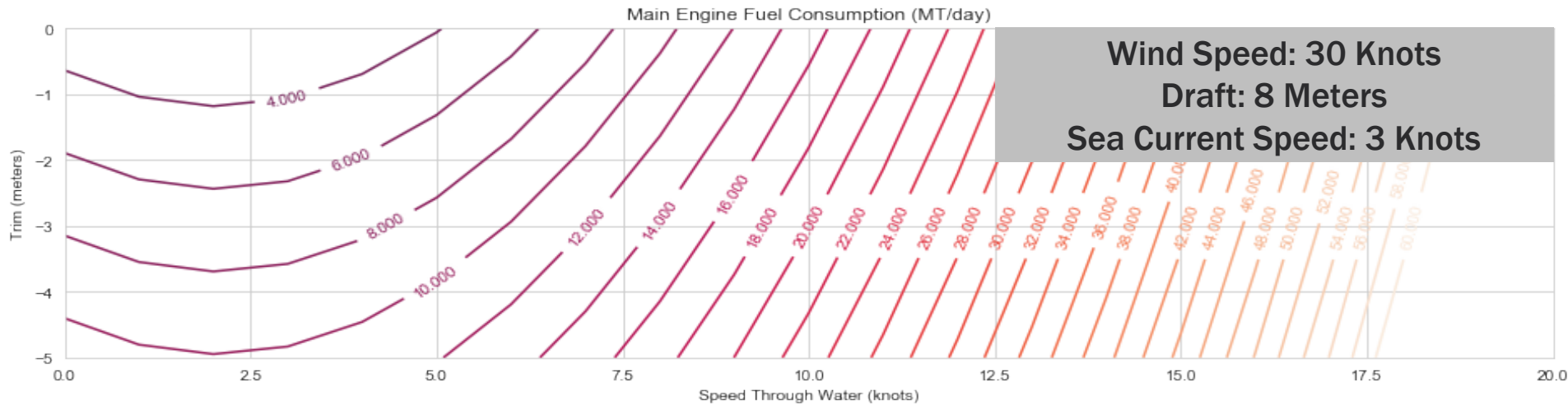
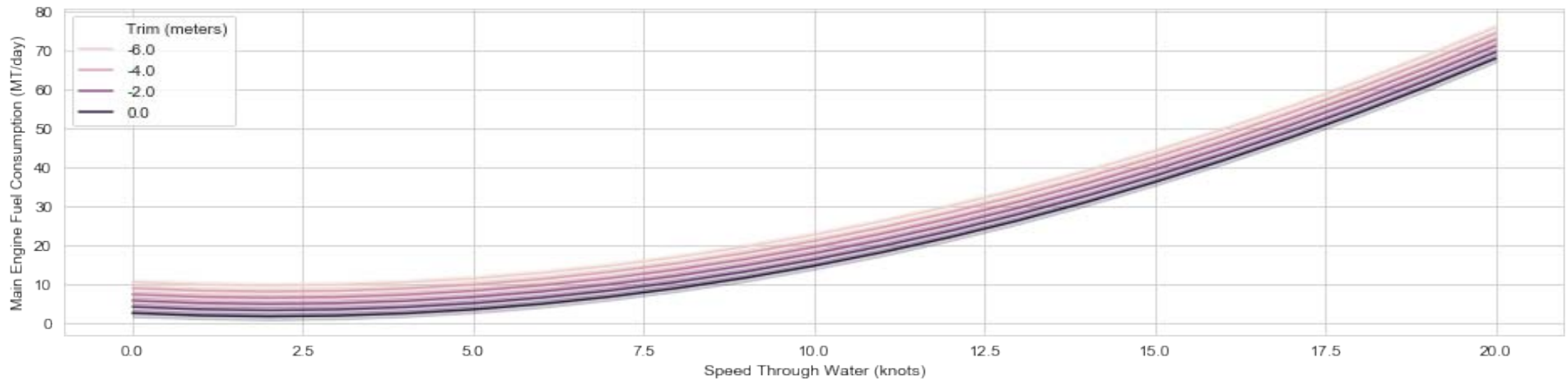
Multi-Linear Regression Vessel Performance Curves: Prediction Sampling



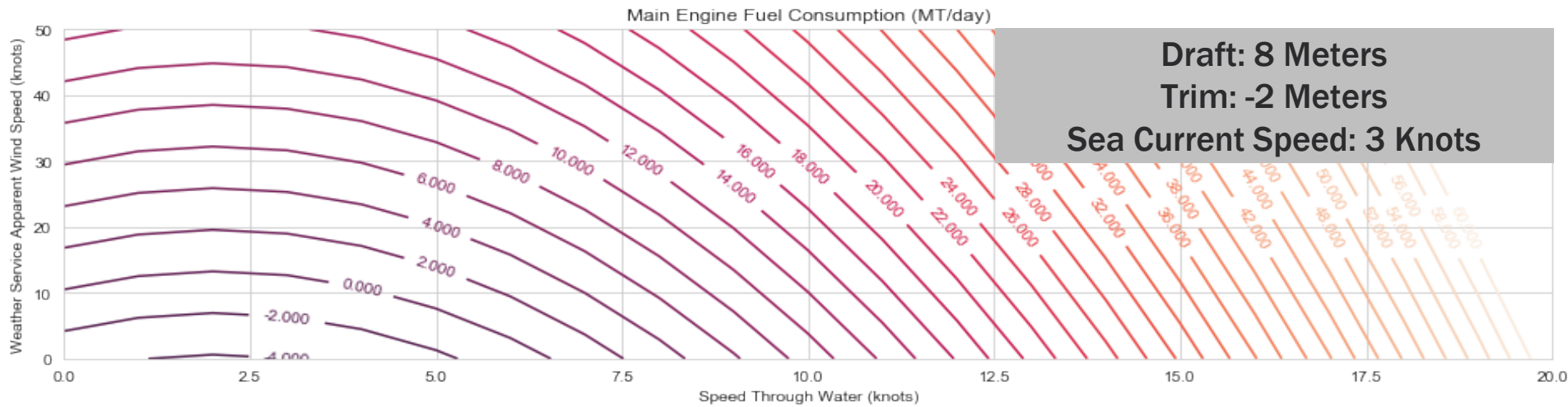
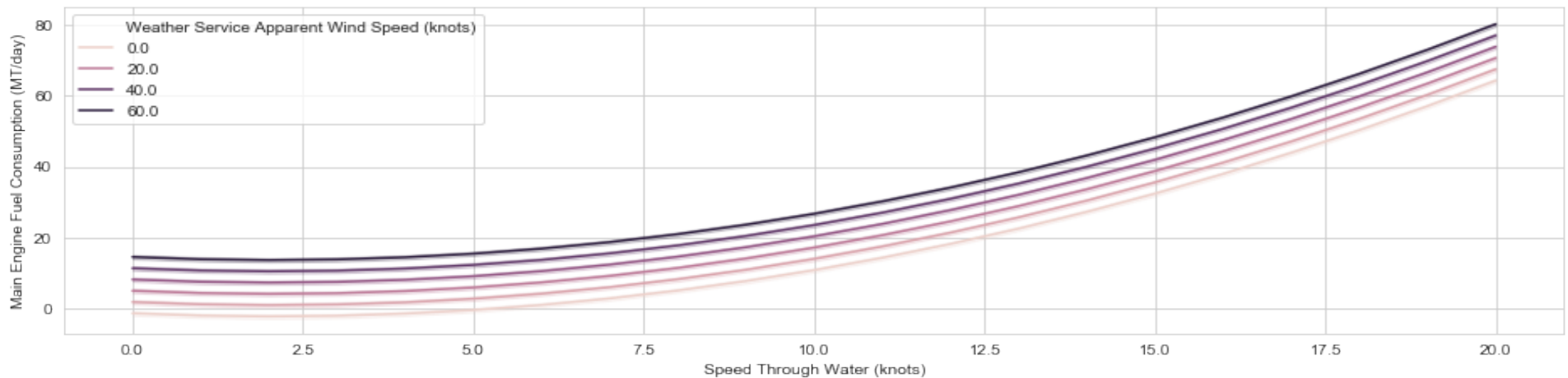
Multi-Linear Regression Vessel Performance Curves: Sensitivity to Draft



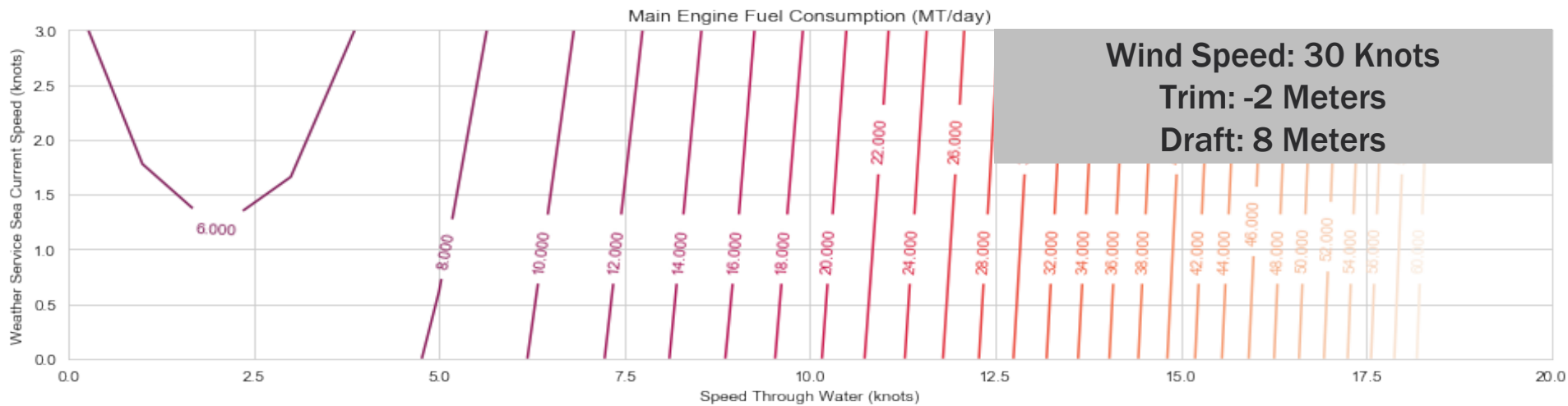
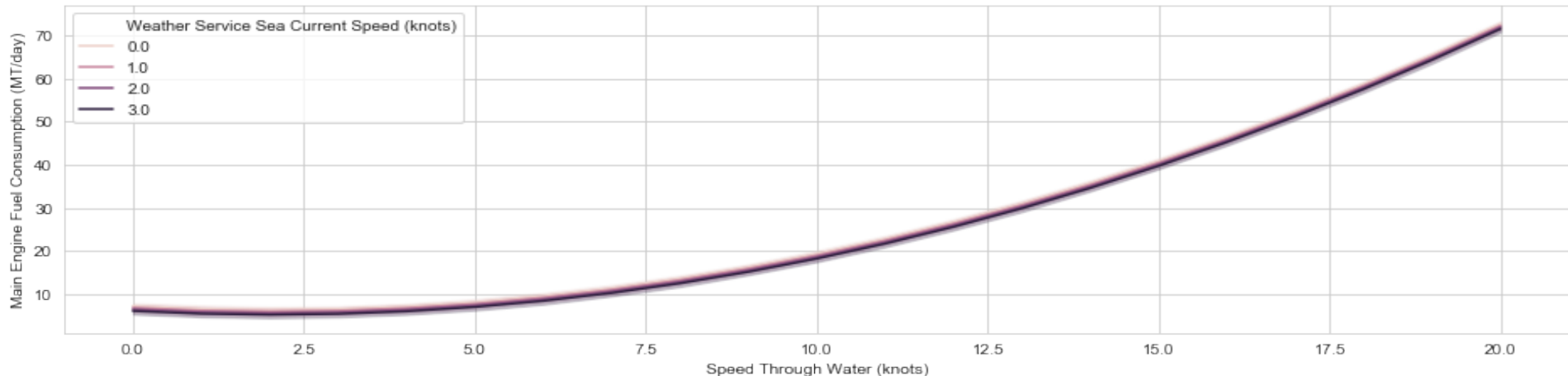
Multi-Linear Regression Vessel Performance Curves: Sensitivity to Trim



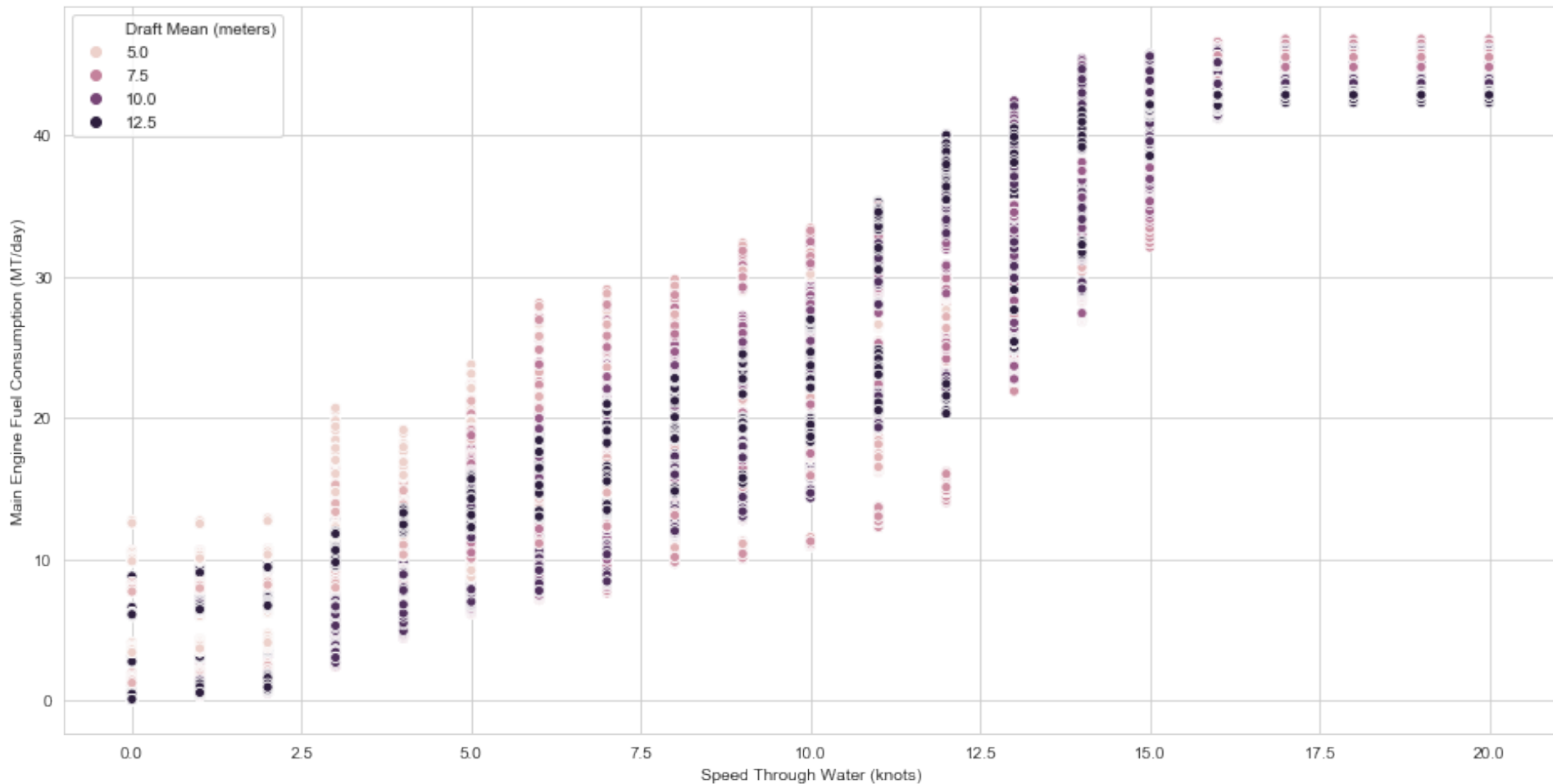
Multi-Linear Regression Vessel Performance Curves: Sensitivity to Wind Speed



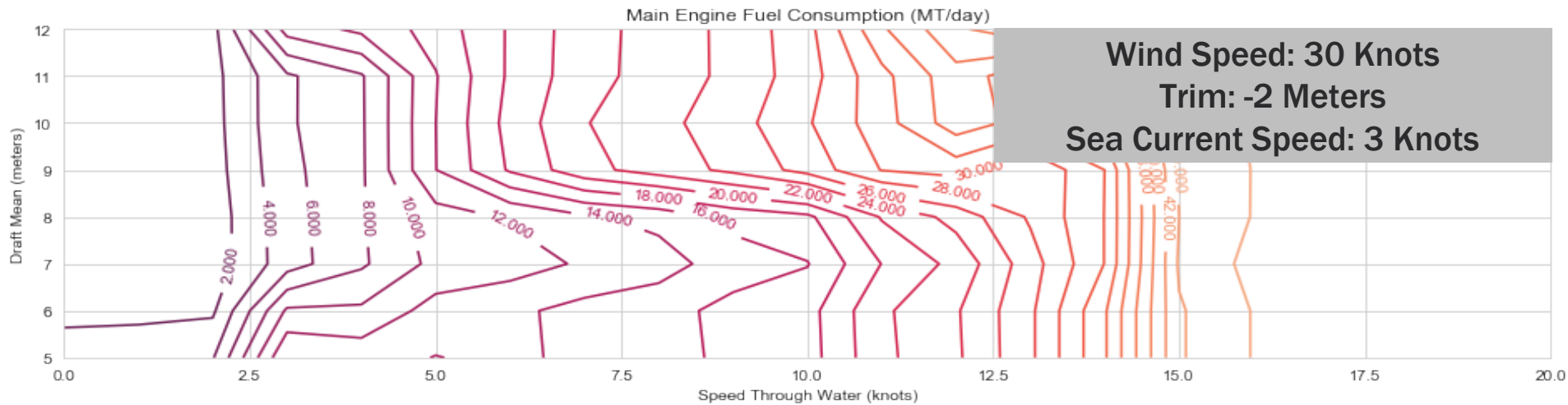
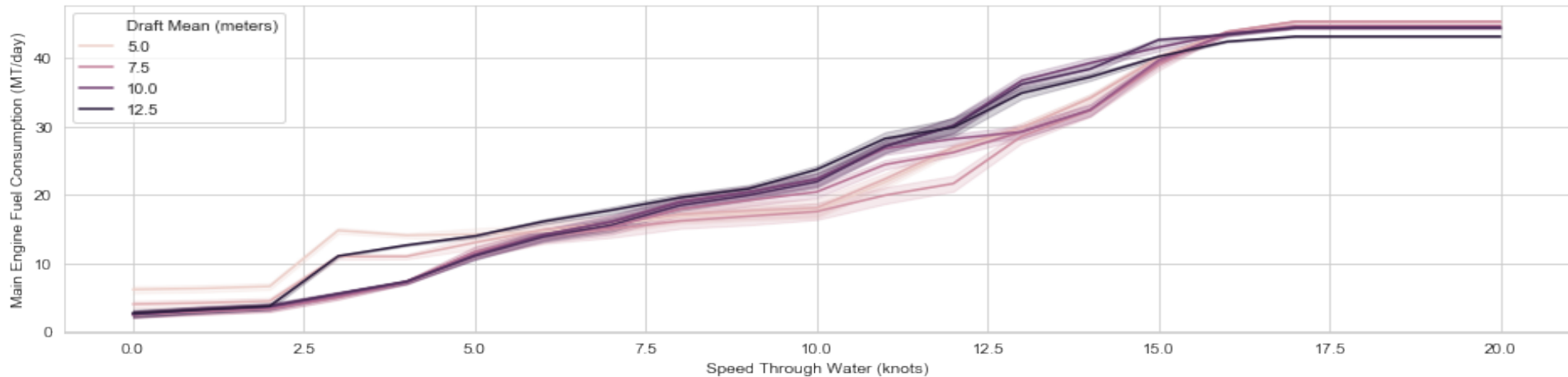
Multi-Linear Regression Vessel Performance Curves: Sensitivity to Sea Current Speed



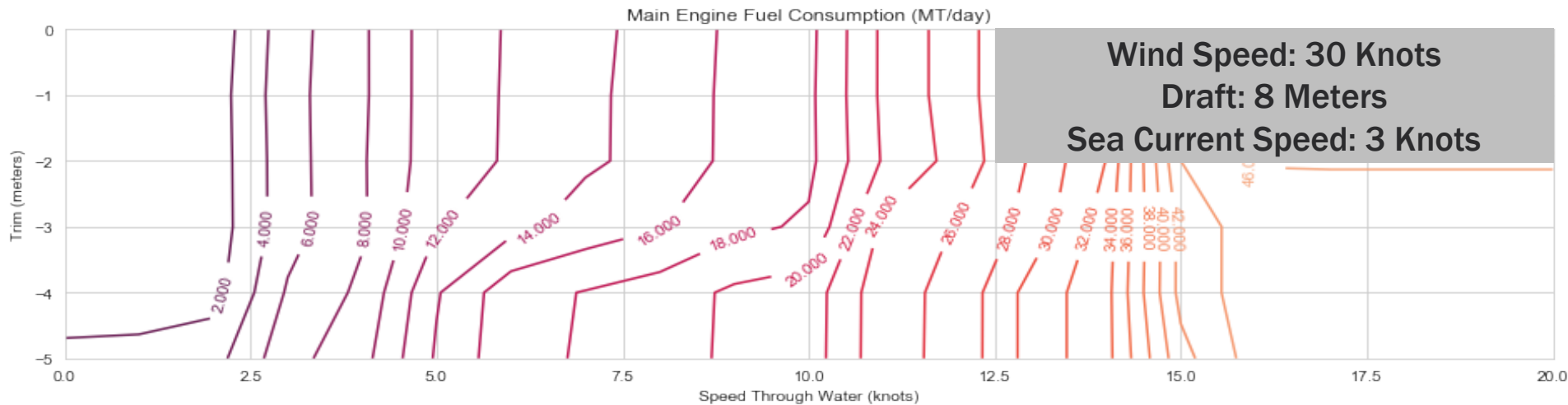
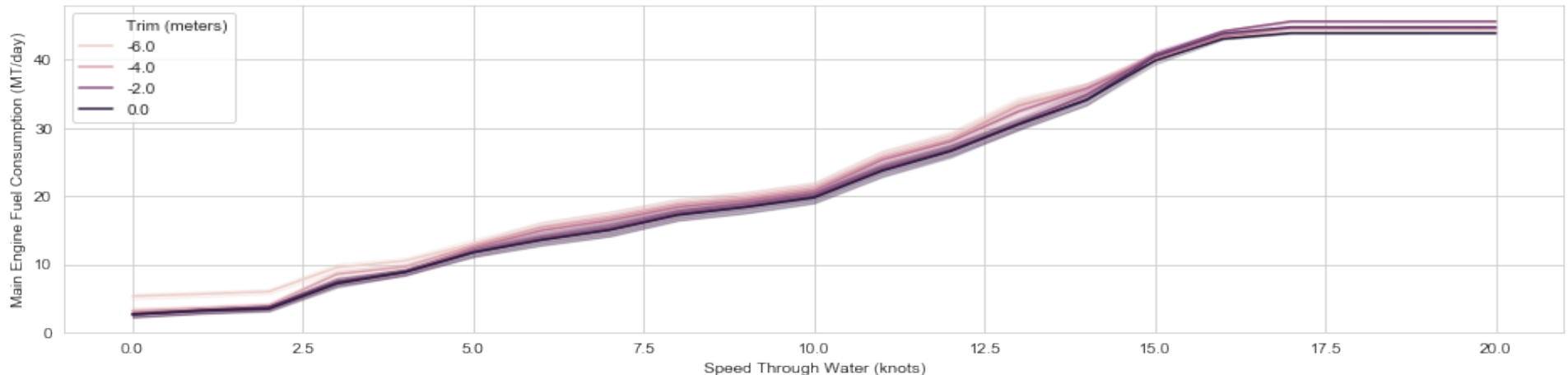
Random Forest Regression Vessel Performance Curves: Prediction Sampling



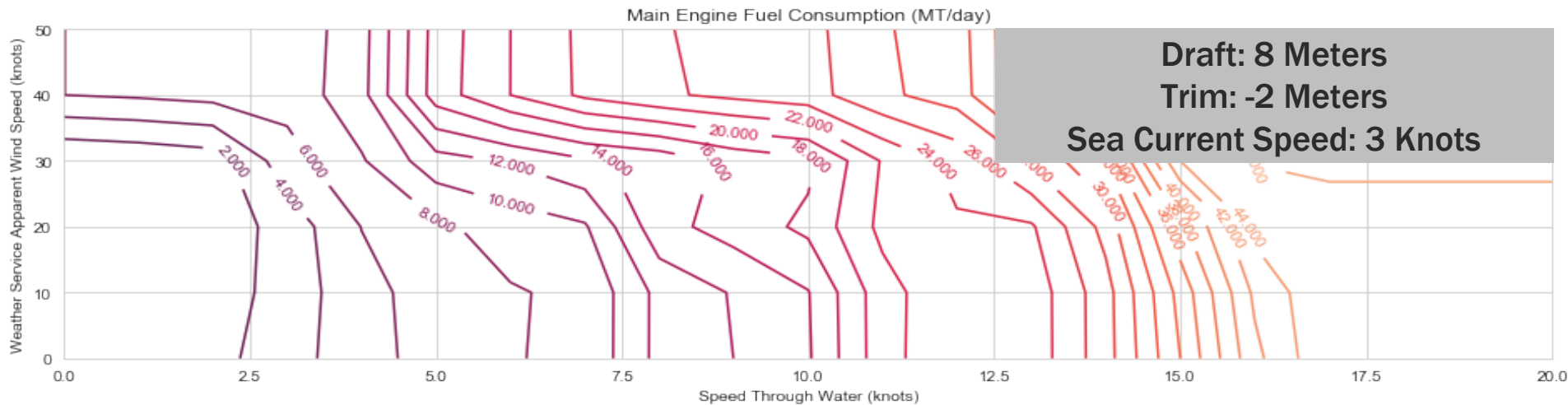
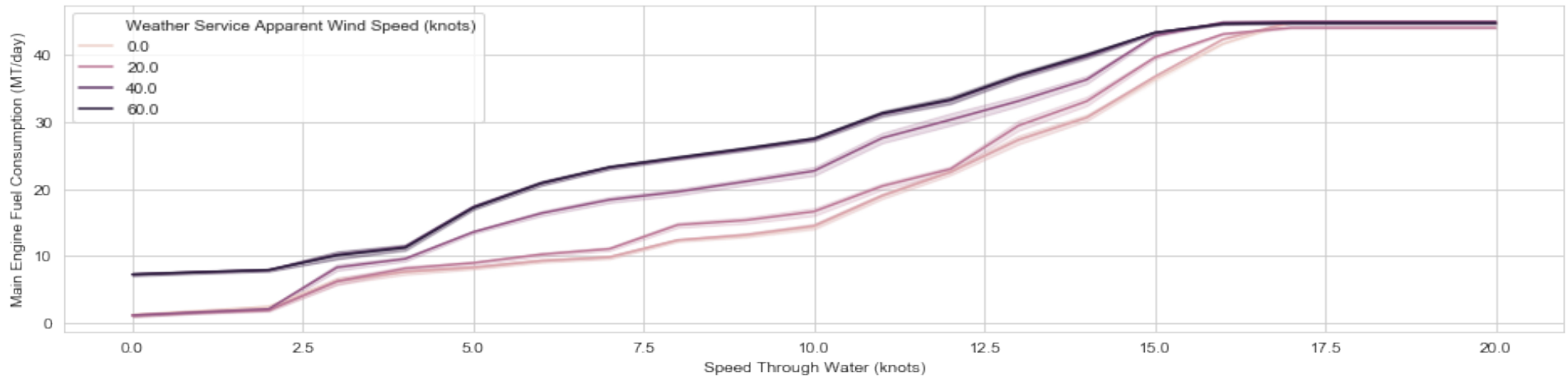
Random Forest Regression Vessel Performance Curves: Sensitivity to Draft



Random Forest Regression Vessel Performance Curves: Sensitivity to Trim



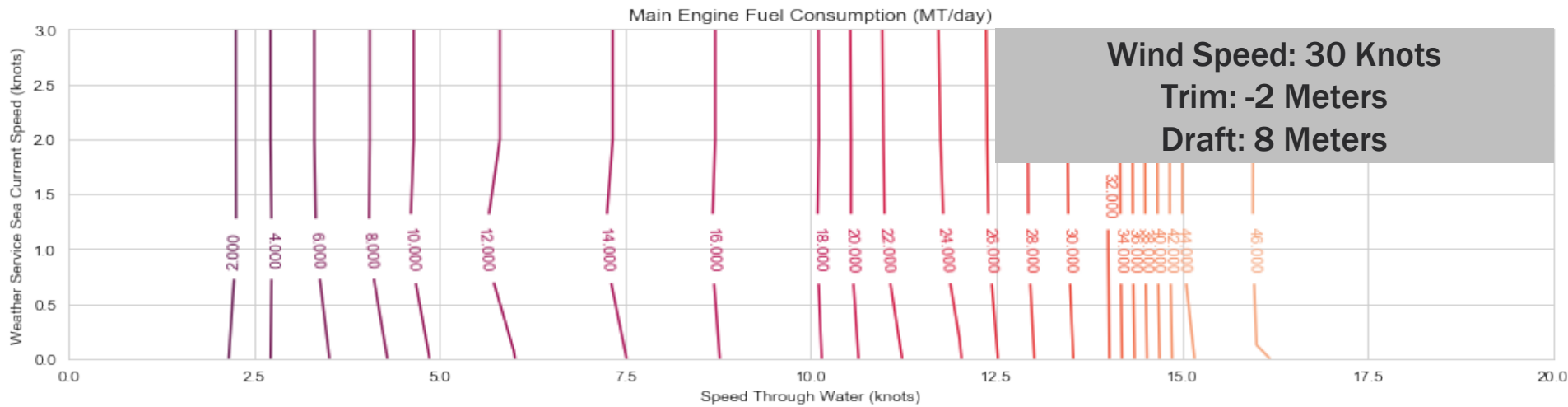
Random Forest Regression Vessel Performance Curves: Sensitivity to Wind Speed



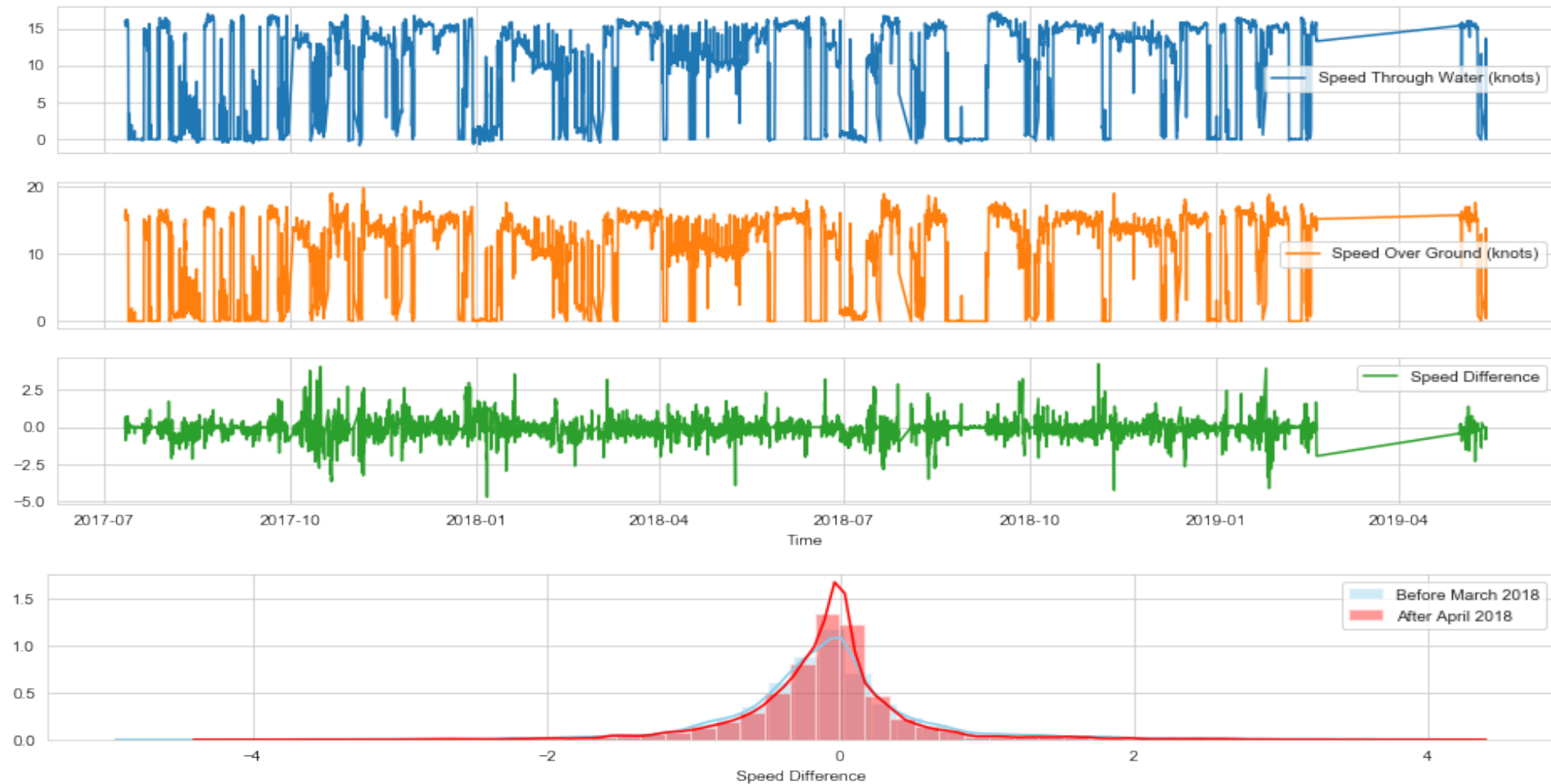
Random Forest Regression Vessel Performance Curves: Sensitivity to Sea Current Speed

The top chart displays the Main Engine Fuel Consumption (MT/day) on the y-axis (ranging from 0 to 40) against the Speed Through Water (knots) on the x-axis (ranging from 0.0 to 20.0). Four curves represent different Weather Service Sea Current Speeds (knots): 0.0 (lightest), 1.0, 2.0, and 3.0 (darkest). All curves show a non-linear increase in fuel consumption as speed increases, with higher sea current speeds resulting in higher fuel consumption across the entire speed range.

The bottom chart is a contour plot showing the Weather Service Sea Current Speed (knots) on the y-axis (ranging from 0.0 to 3.0) against the Speed Through Water (knots) on the x-axis (ranging from 0.0 to 20.0) and Main Engine Fuel Consumption (MT/day) on the z-axis (ranging from 0.0 to 30.0). The contours represent constant values of sea current speed, with labels ranging from 0.000 to 46.000. The plot shows that fuel consumption increases as the sea current speed increases, particularly at higher speeds through water. A grey box in the bottom right corner specifies the operating conditions: Wind Speed: 30 Knots, Trim: -2 Meters, and Draft: 8 Meters.



Sensor Drift: Difference in Water and Ground Speed



Sensor Drift: 200-Day Rolling Average



Dynamic Speed Optimization



Nautilus Labs

August 7, 2019

Adam C Dick

www.linkedin.com/in/adamcdick

https://github.com/acdick/dynamic_speed_optimization

| Project Data Stack | |
|--------------------------------------|--------------------------------|
| Engineering Understanding | Vessel Performance IoT Sensors |
| Data Wrangling | Python Missingno |
| Feature Engineering Data Exploration | Python Pandas |
| Outlier Detection Feature Selection | Python Pandas |
| Predictive Modeling | Sci-Kit Learn Numpy / Scipy |
| Data Visualization | Matplotlib Seaborn |