Predicting Space Launch Feasibility Based on Weather Forecasts

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Background

- Space Domain Awareness (SDA), led by Space Operations Command's Delta 2, focuses on identifying threats to space systems
- Weather is a key factor in assessing launch safety, with criteria sourced from public data and mentors
- Our goal is to build a predictive model that uses weather data to estimate the probability of a safe space launch globally

Motivation

- Classify and identify potential future space launches
- Enhance defense strategies by predicting adversaries' remote/mobile launches
- Support commanders' decision-making with autonomous predictions

Data Collection/Pre-Processing

- **Weather Data Sources:**
  - Open-Meteo (open-source weather API)
  - 14th Weather Squadron (USAF)
    - Provided Upper Air Data (wind speed & direction, temp.)
- **Source Model Used:**
  - **Historical Weather API** – Collected additional weather parameters for training data at Cape Canaveral and Vandenberg.
  - **Previous Model Runs API** – Provided historical forecasts for test data with lead times of up to seven days.
- **Weather Models Used:**
  - ECMWF ERA5
  - IFS 0.25°
  - JMA GSM
- **Integration with Launch Data:**
  - Ensure consistency in units for all parameters
  - Remove or correct any anomalies or outliers in the data sets provided
  - We merged weather data with launch records to enhance test and training datasets

Launch Weather Criteria

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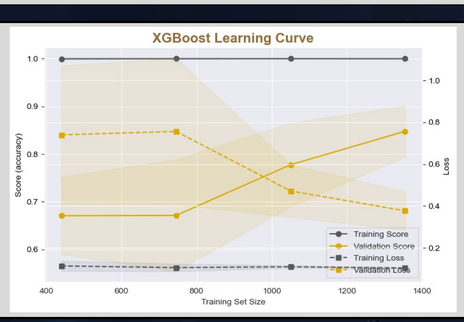
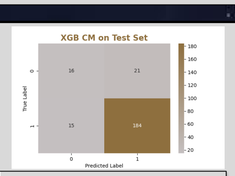
Boosting Models

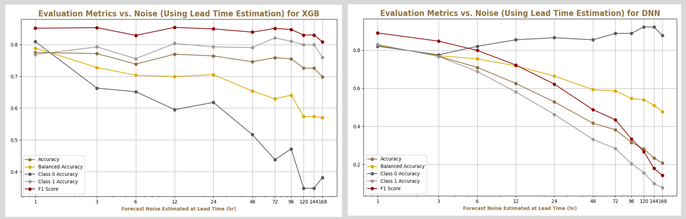
- **XGBoost**: Uses gradient-boosted decision trees; each tree corrects errors from the previous one for better classification
- **LightGBM**: Fast, efficient gradient boosting algorithm optimized for large datasets and quick predictions
- Hyperparameter tuning done using GridSearchCV and AutoKeras, ensuring models achieves highest possible balanced accuracy
- Boosting models tend to have lower accuracy on no-go launches than DNN, but is more resistant to noise in forecast data





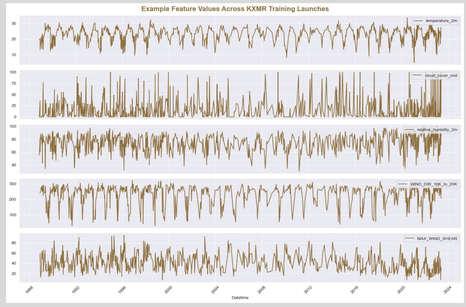
XGB Evaluation:
Acc: 0.8475
Bal Acc: 0.8493
Class0: 0.4324
Class1: 0.9246
F1: 0.9109

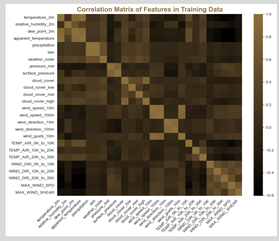
Forecast Lead Time Analysis

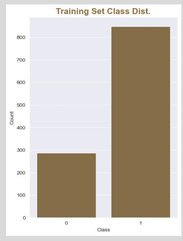


- Using Gaussian noise to simulate noise from higher lead time weather forecast

Training Data Statistics



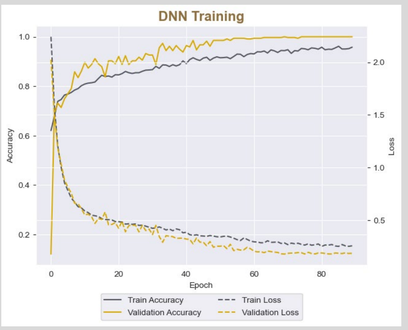


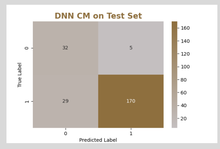


- Used minority over-sampling techniques such as SMOTE to balance out the go and no-go launches in our training data
- Employed data engineering, including correlation analysis, normalization, feature importance analysis, one-hot encoding of categorical columns, sin/cos encoding of wind direction, etc.
- For upper air data, used linear interpolation and averages from other years to fill days/heights that have data missing

Deep Neural Networks (DNNs)

- Consist of input, hidden, and output layers
- Input layer receives raw data
- Hidden layers apply weights, biases, and activation functions to learn features
- Each layer captures more abstract patterns
- Output layer gives final prediction — "go" or "no-go" for launch





DNN Evaluation:
Acc: 0.8559
Bal Acc: 0.8596
Class0: 0.8649
Class1: 0.8543
F1: 0.9091

Conclusion

- Identified crucial criteria and weather parameters needed for safe space launches domestically as well as for our adversaries
- **This tool provides operators more information on feasible launch windows for our adversaries.**

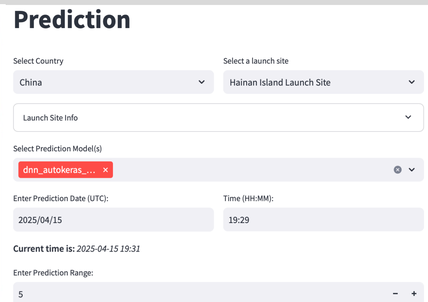
Future Goals

- Develop methodologies to quantify adversary risk tolerance, including likelihood of launch under adverse weather conditions
- Enhance predictive accuracy by incorporating payload characteristics and launch platform types into threat assessment models
- Implement Upper Air (UA) to pull current Upper Air data

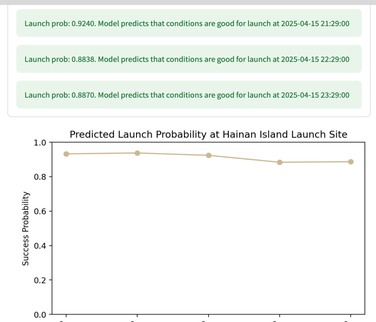
Final Product UI

Step 1. Select a Launch Site

Step 2. Select Model and Lead Time



Step 3. Get a Prediction



The final UI features launch site selections, go/no-go predictions, an interactive map, real-time weather, and weather forecasts. The operator can view launch probabilities by the hour or day, with the option to choose specific models.

Acknowledgements

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Data Mine of the Rockies
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