ROCKETING MAINE INTO THE 21ST CENTURY

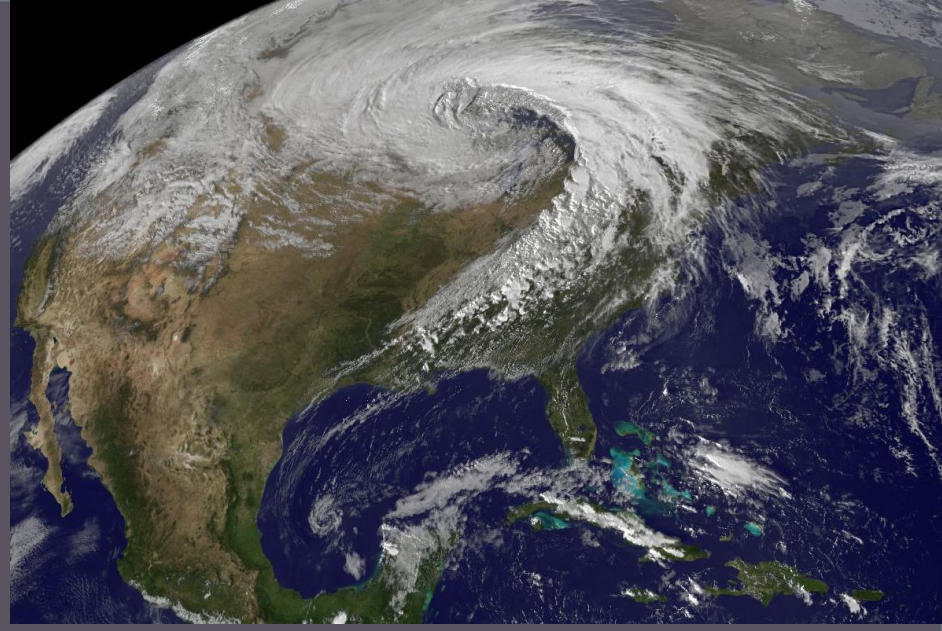
The Maine Spaceport Initiative

ALY 6080

Summer 2021

The Roux Institute
at Northeastern University

ROCKETING MAINE INTO THE 21ST CENTURY: The Maine Spaceport Initiative



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- Demo & Results

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- Data sources
- Model
- Demo & Results

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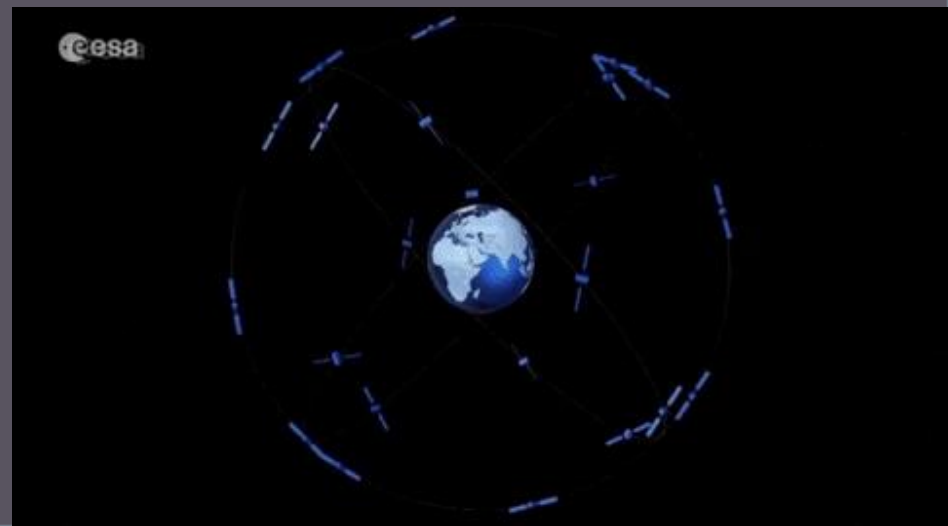


Project plan, execution, and the tools used to produce the final deliverables

Project Plan

Sprint	Start Date	End Date	Milestones
Sprint 1	7/25/21	8/12/21	Initial Roadmap and Project Plan
			Data pre-processing
			Exploratory Data Analysis
Sprint 2	8/12/21	8/25/21	Models V1 & Testing
			Models V2 & Testing
Sprint 3	8/18/21	09/01/21	Completed EDA
			Development of Data Repository
			Report Findings
			Code for Models

Project Execution

Designated Teams	**Gulf of Maine Shellfish:** Amanda, Isabel, Jeff **Maine Forest & the EAB:** Alaina, Dan, Colin **Weather & Revenue:** Joe and Thomas
Small Sprint Meetings	Weekly XN Meetings Monday/Thursday of each week Weekly Small Team Meetings

Project Tools

Tools Utilized to Create Deliverables	Associated Milestone
Google Drive & Docs Suite	Initial Roadmap & Project Plan
	Data Preprocessing
	Findings Report
Tableau	Data Preprocessing
	Exploratory Data Analysis (EDA)
R	Exploratory Data Analysis (EDA)
	Models V1 & V2
	V1 & V2 Testing
GitHub	Data + Model Repository

What can satellite data do for Maine?

Identified satellite data feeds that could potentially be leveraged by the state of Maine

There are a range of public and private satellite data feeds that aided in our initial research of the satellite data landscape.

spire

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

Google Earth Engine

GLOBAL FOREST WATCH

planet.

NASA

The issue that one will come across is the lack of dedication to the Maine region in public sources. There currently lacks a database for ME specific satellite data.

Problem 1: Gulf of Maine Shellfish

There is currently a misallocation of resources as **over 70%** of random samples result in a fecal contamination score (P90) of 2 or less with a range between 1.5 and 1,700

Introduction | Gulf of Maine Shellfish

Why the shellfish industry?

Economic Impact

- A growing industry projected to add $**30 million in value to Maine's economy by 2030,** up from $6.5 Million in 2015.
- More than **2,000** Maine fishing license holders, **56** aquaculture leaseholders, **107** certified shellfish dealers depend directly on the shellfish industry for their livelihoods
- Additional **264** jobs created from indirect effects of the industry

Business Case

Determine if a machine learning model can accurately forecast contaminated areas to increase efficiency of investigatory testing, thereby reducing testing costs, health risk and lost business revenue.

Data Sources | Gulf of Maine Shellfish

Maine DMR public health P90 scores 2013-2020

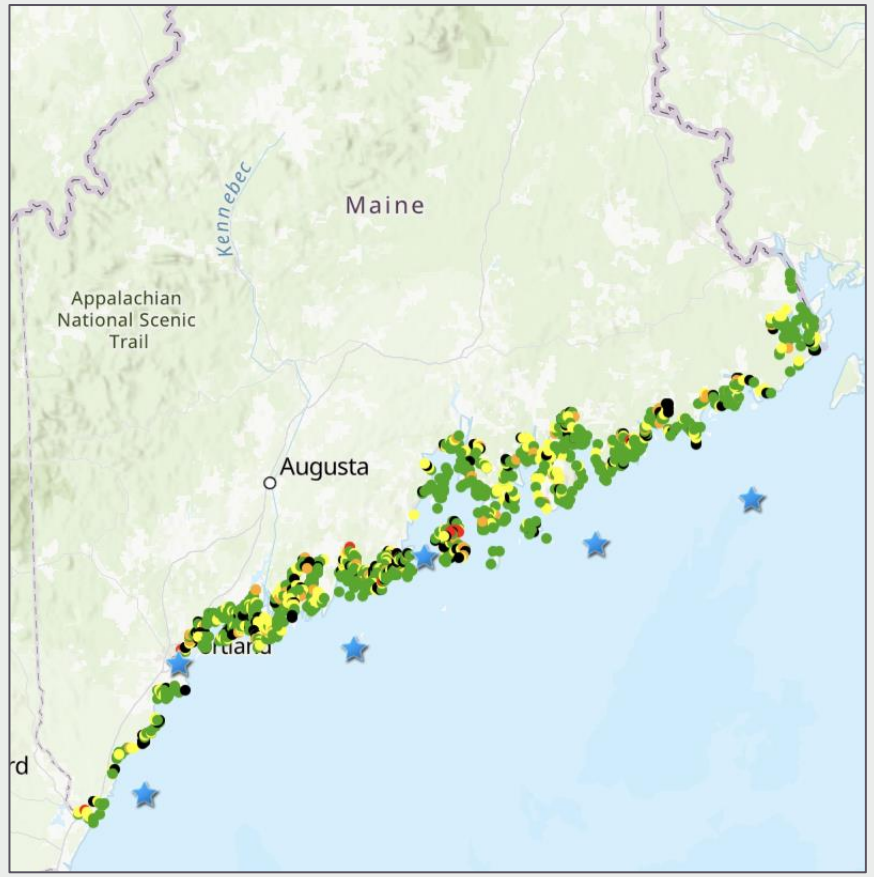
Provided by: Maine GIS Data Catalog

Ocean Data

Provided by: National Oceanic and Atmospheric Administration's National Buoy Data Center

State of Maine Shellfish Contamination Data

Provided by: Bryant Lewis, at the Maine Department of Marine Resources



Buoy data from 6 buoys (shown above as stars) was originally used for temperature data by joining each test site to the nearest buoy.

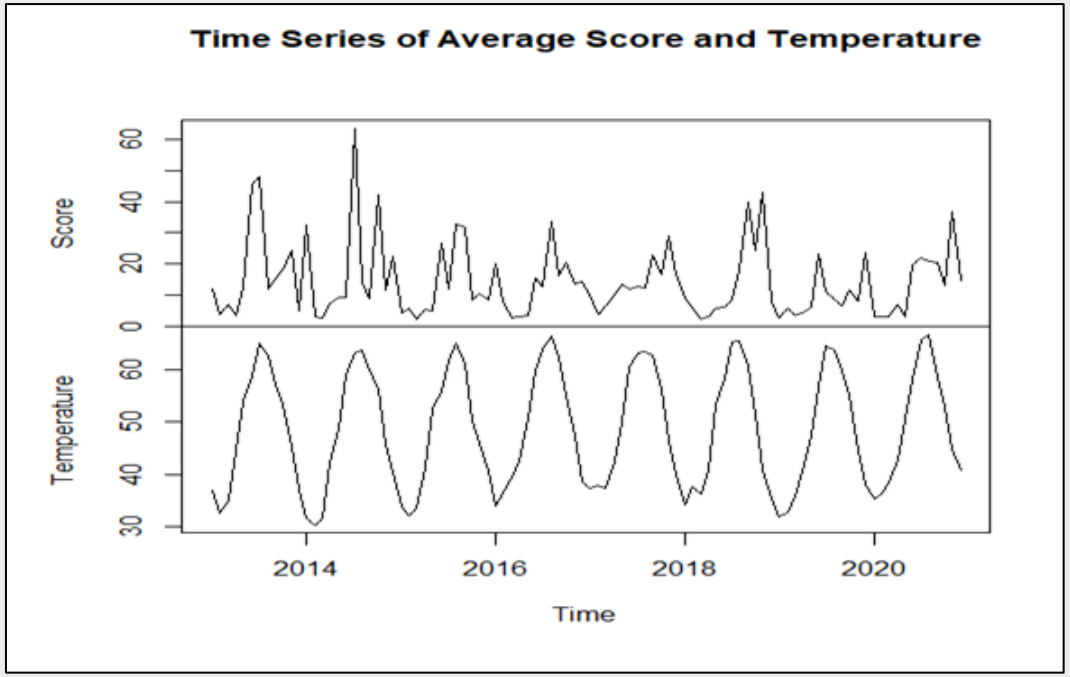
Source:https://dmr-maine.opendata.arcgis.com/

EDA | Gulf of Maine Shellfish

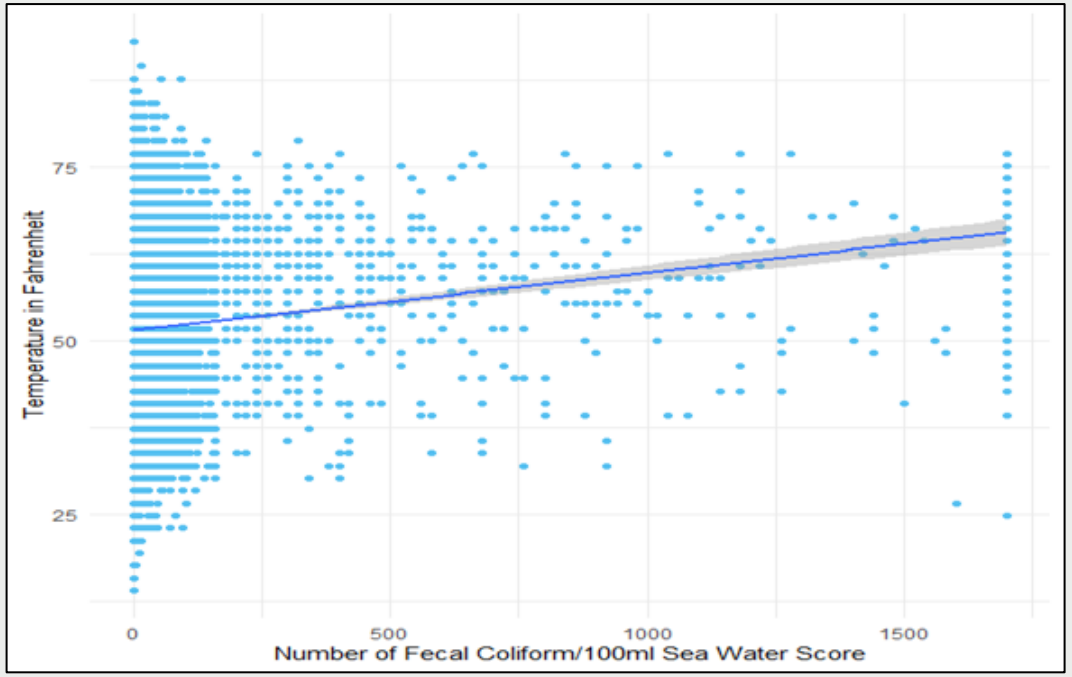
Exploratory Data Analysis

The Gulf of Maine is warming faster than 99 percent of the global ocean

Initial hypothesis: Rising temperatures will lead to increased shellfish contamination



Temperature appears to rise and fall seasonally with fecal contamination score.



Scatterplot shows little correlation between temperature and fecal contamination score. This is further clarified with the R^2 score of 0.19.

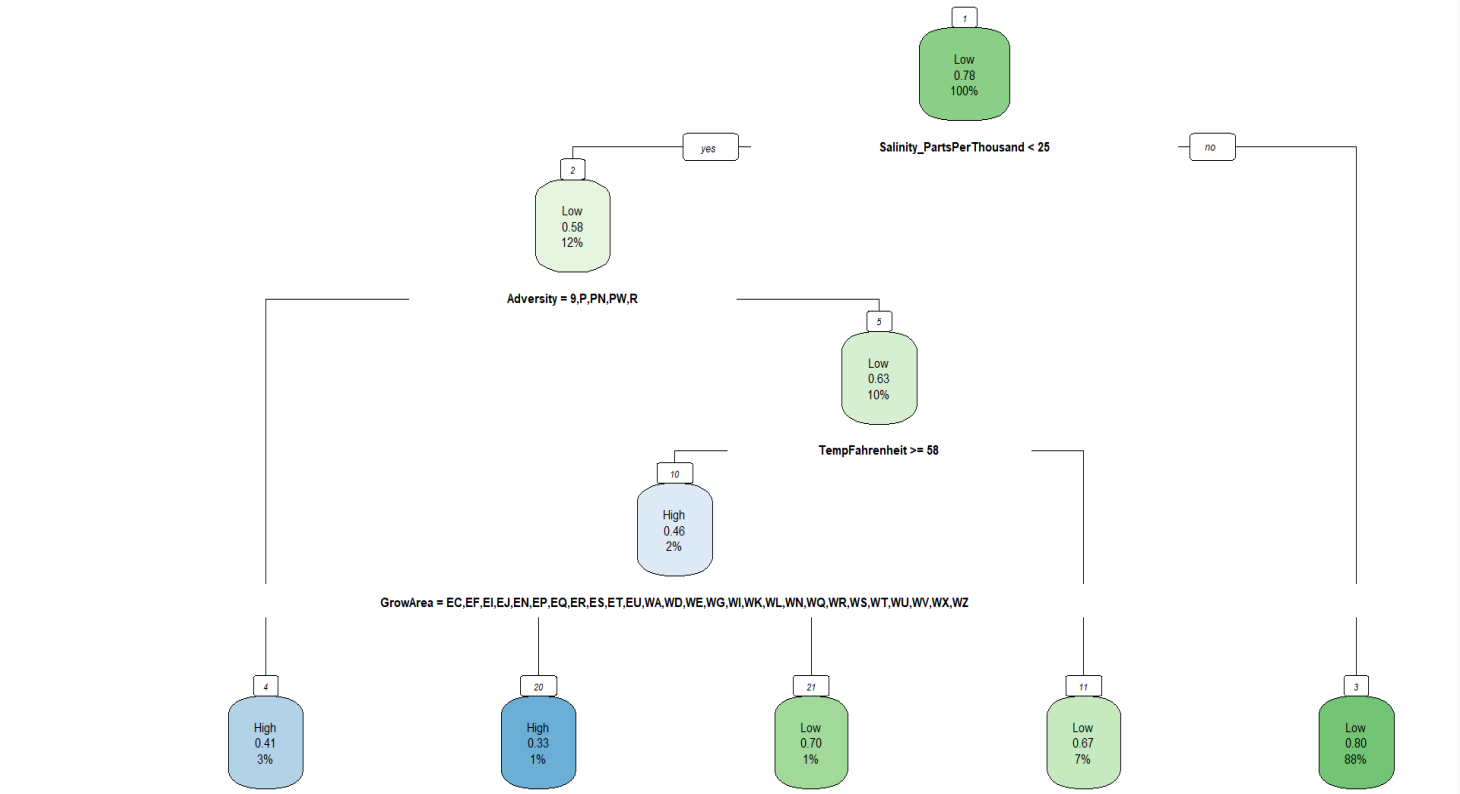
Classification

Cluster Analysis Revealed Potential for Decision Tree Model

Overall Decision Tree With Third Quartile Score Classifier

Testing Decision Tree With Third Quartile Score Classifier

Cluster Size	Average Score	Average Salinity	Average Temp	Rain
135	1522.5	24	59	0.52
339	495.8	25	57	0.41
27157	11.2	30	61	0.17
25834	3.2	28	42	0.20



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Model Results

Confusion matrix

Accuracy

Confusion Matrix		
	High Predict	**Low Predict**
High Actual	257	2242
Low Actual	167	8396

Overall Accuracy

78.20%

Predicts Low Rating When Actually Low

98.05%

Predicts High Rating When Actually High

10.28%

When a High is Predicted, it is Correct

60.61%

How can the state use this model?

Current Random Sampling Method

22% of Inspections Result in a “High” Score

Trailing 3 years, Maine Completed One Targeted Sample

Decision Tree Targeted Method

60.61% of Inspections Result in a “High” Score

Approximately 256 Targeted Samples Per Year

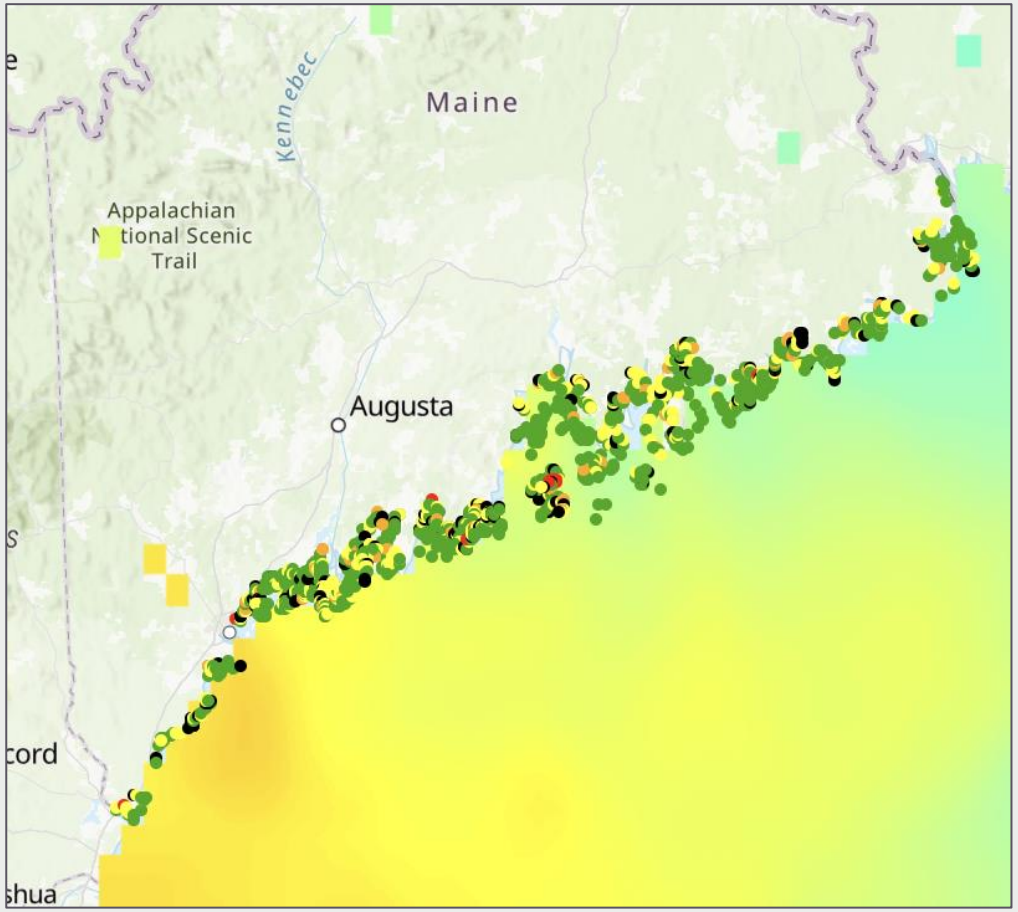
Satellite Data Potential | Gulf of Maine Shellfish

Real Time Data

- Accurately capture effects of rain, wind and other current weather events
- Modeling will be more resilient to mitigation efforts

Geospatial Analysis

- Provide accurate analysis of the entire coast of Maine
- Allows for inputs such as land use and population density



Sea surface temperature layered onto map of shellfish contamination sites

Source:https://dmr-maine.opendata.arcgis.com/

Gulf of Maine Shellfish:
Exploring predictive modeling for water contamination

"Accurate and timely environmental data is critical to seafarers ability to manage their farms and reduce environmental risk. Remote sensing and in particular satellite tools are proving to be increasingly important to our sector."

-- Sebastian Belle, Executive Director
Maine Aquaculture Association

* photo courtesy of Maine Aquaculture Association

Problem 2: Maine Forests & The EAB

Identifying **geographic areas that are risk for EAB infestations**
to support pest and forest management efforts and policy

Introduction | Maine Forests & The EAB

The Problem:

Maine Forests

Economic Impact

- Forests cover 89% of the state
- The industry has an $8B economic impact on the state
- ~14.5K direct jobs and ~33.5K indirect jobs
- Paper and forestry products are both in ME's top 5 exports

Climate Impact

- Forests sequester 60% of annual carbon emissions
- ~10K acres of forestland are lost annually to development, annual loss can increase due to invasive species

The Emerald Ash Borer

New invasive species with unknown impact

- Identified in MI in 2002. Later, 2018, identified in 3 ME counties
- Mortality lag of 4 to 7 years

Pest resilience & spread pattern

- The EAB can survive −35.3◦C & larvae beneath wood
- The median distance flown by mated females is > 3 km per day with 20% flying >10 km

The Solution:

Using forest inventory and Emerald Ash Borer (EAB) infestation data, we have built a model that can **identify geographic areas at most risk of infestation.**

The Business Case:

By using forest inventory data, we can identify areas are risk for EAB infestations to **support pest and forest management efforts and policy.** Inventory data is collected via sampling and estimation. The **accuracy of this model would increase through the use of satellite data** as data coverage would not be reliant on recently-surveyed plots.

Sources: www.maine.gov/future/sites/maine.gov.future/files/inline-files/MaineWontWait_December2020.pdf
https://www.maine.gov/dacf/php/caps/EAB/index.shtml
https://www.michigan.gov/invasives/0,5664,7-324-68002_71241-368696--,00.html

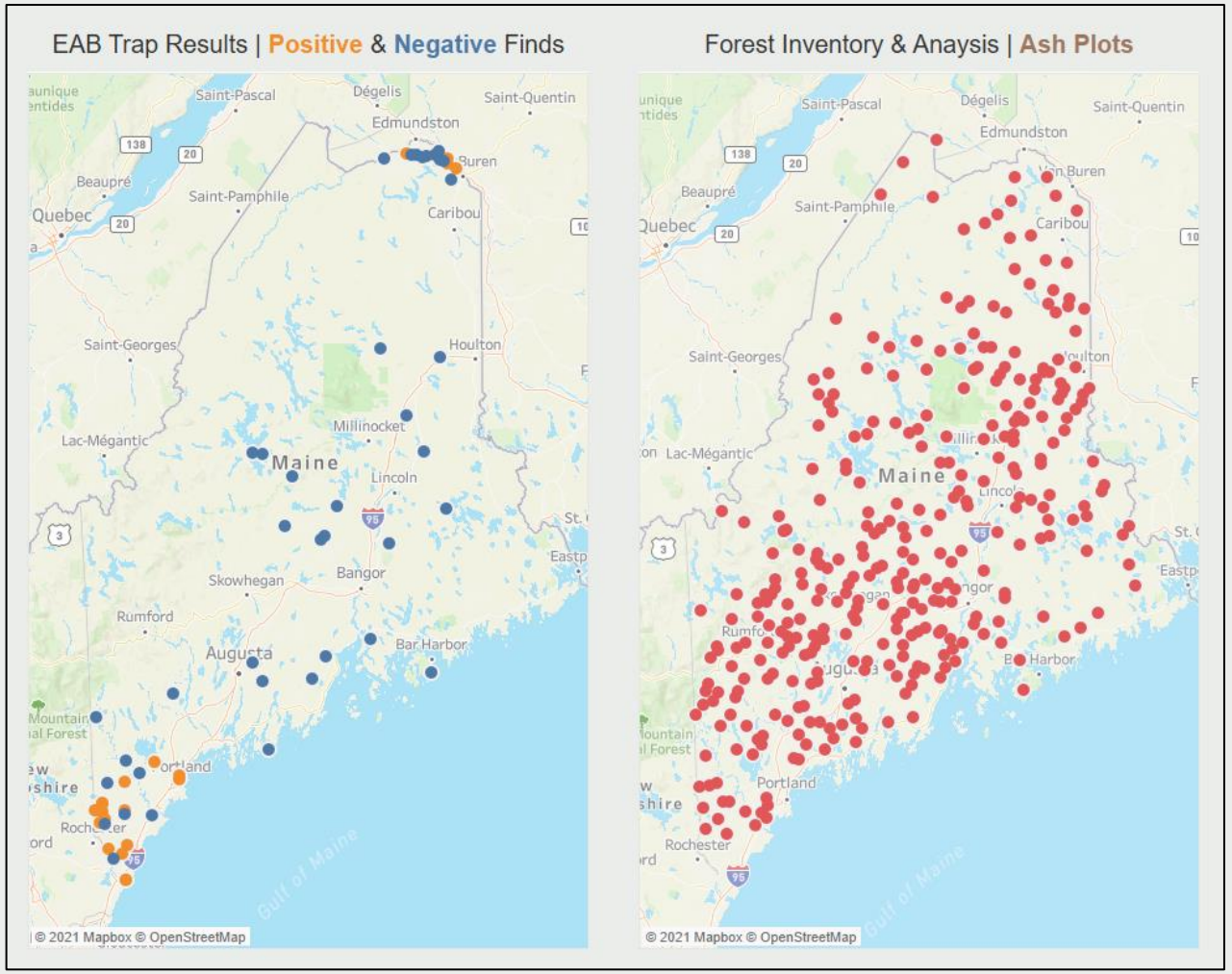
Data Sources | Maine Forests & The EAB

Maine Forest Inventory Data

Provided by: Forest Inventory & Analysis (FIA)

EAB Trap & Positive Case Data

Provided by: State of Maine's Department of Agriculture, Conservation and Forestry



Source: Maine Forest Service

Source: Forest Inventory & Analysis

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Section 3:

Invasive Species in Maine Forests:
an eye in the sky on the Emerald Ash Borer

"Maine businesses and tourism **depend on our forests being productive and healthy**, and having **dedicated satellite feeds** not only serves industry's present needs, but also **improves conservation efforts, protecting our future."**

-- Nathan Wadsworth,
(R) ME House of Representatives, District 70
Wadsworth Woodlands Forestry Consulting

EDA | Maine Forests & The EAB

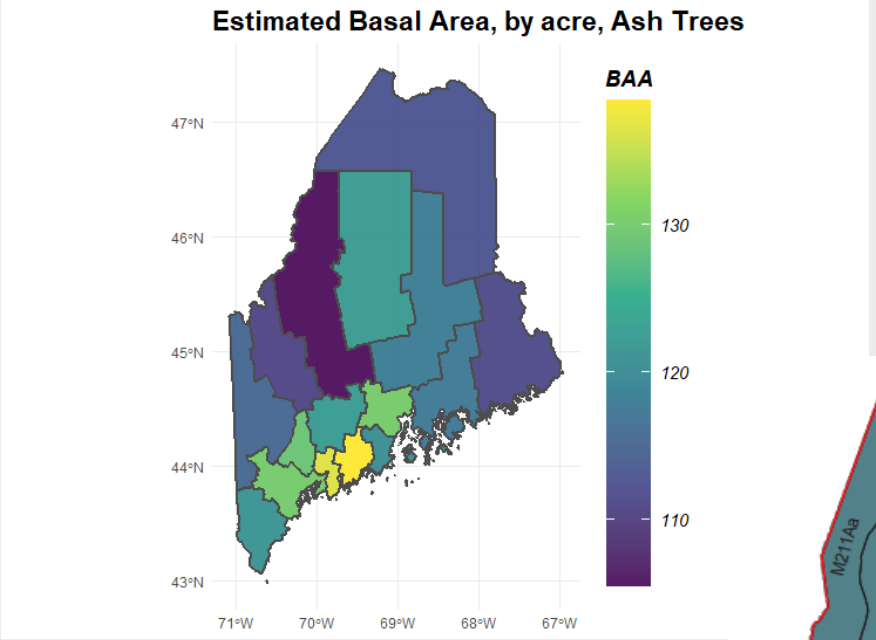
Exploratory Data Analysis

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service's mission"

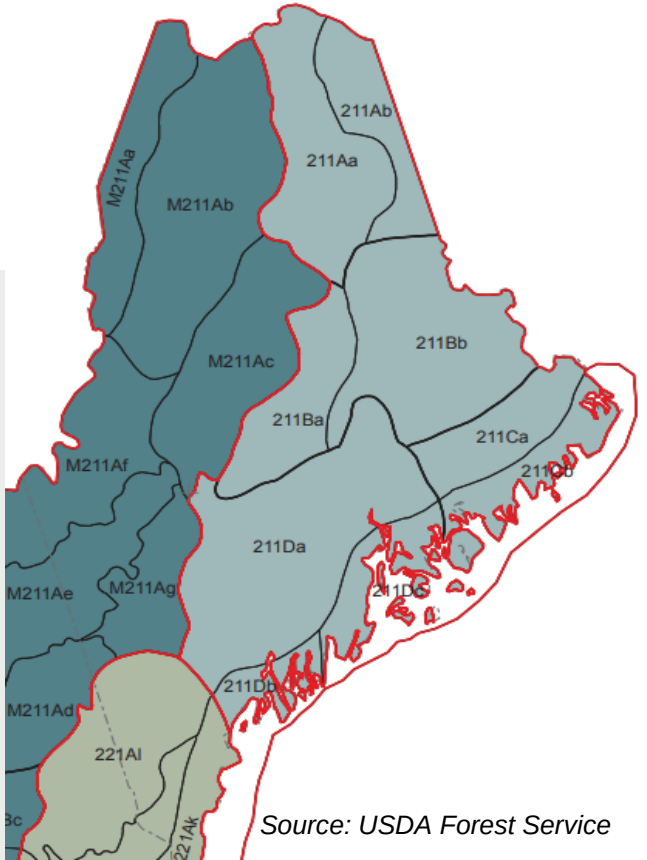
> ***"make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the US."***

FIA datasets compile statics on a National, State, County, plot level. As of 2019, within Maine 3,516 sample plots across the State with 10 - 20% of plots sampled each year.

Larger Ash predominantly populate Sagadahoc, Lincoln, Cumberland, Androscoggin & Waldo counties.



Ecological Subregions



Source: USDA Forest Service

Model & Demo | Maine Forests & The EAB

Classification Model

A decision tree was used to identify key characteristics of plots that would make a plot more susceptible to EABs.

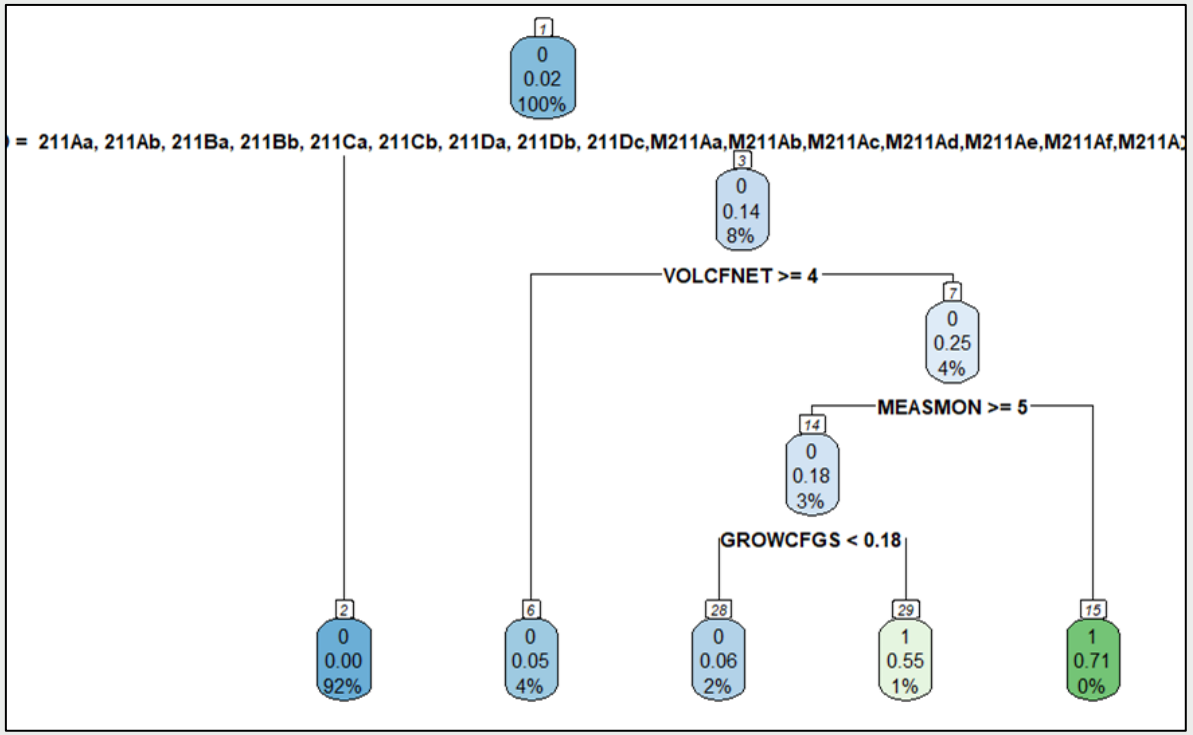
Extremely low EAB count and low precision of plots made it difficult to model.

Over and under-sampling techniques were used in attempt to balance the data but did not improve the model.

Results

Accuracy = 98%
Prevalence = 99.2%

Accuracy < Prevalence which means the model was not successful at this time.



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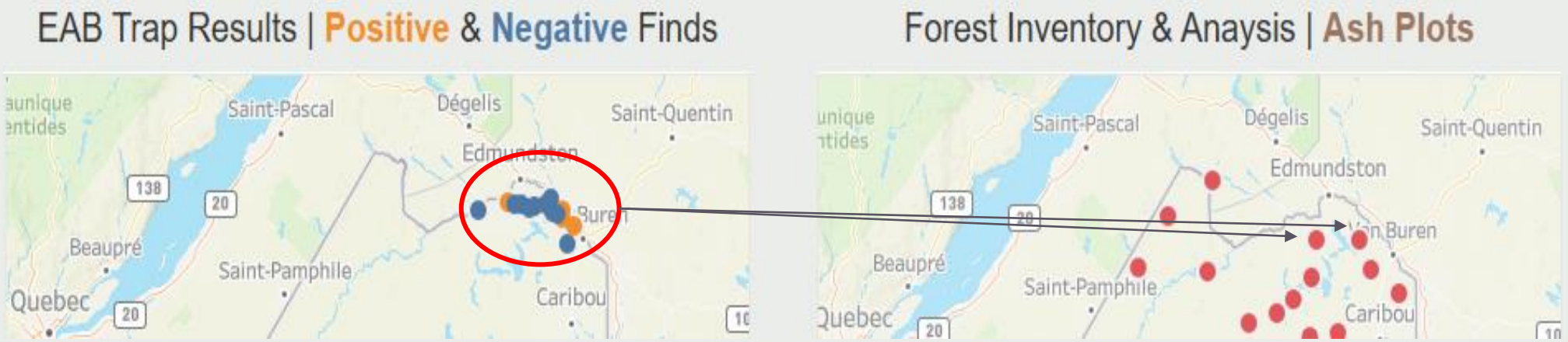
Satellite Data Potential | Maine Forests & The EAB

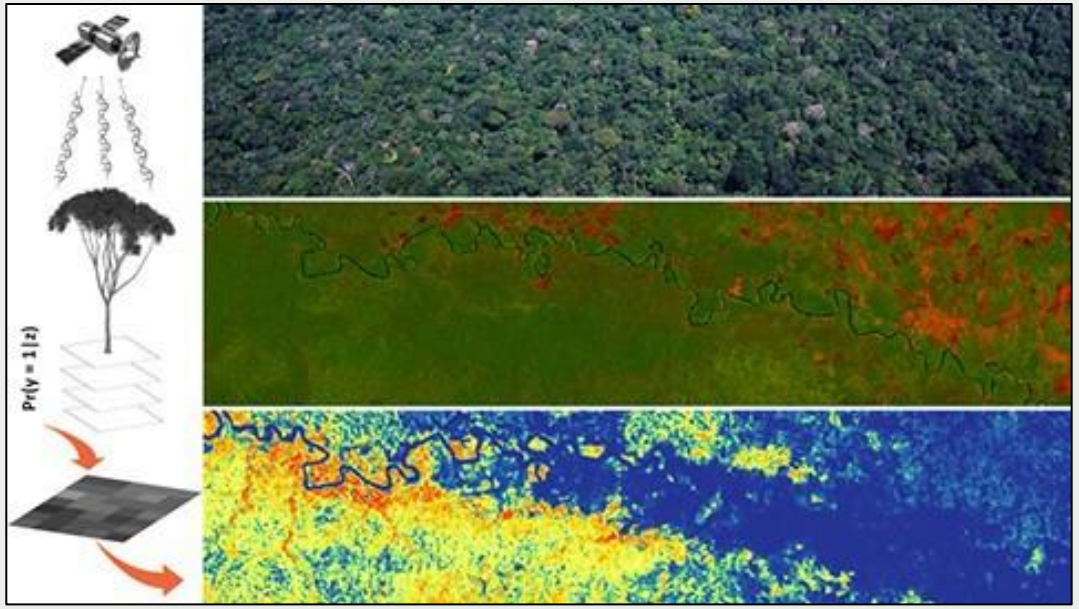


Problem

Data set join inconsistency led to data loss.

Solution

Satellite identification of trees give a more precise look at the plot and will allow for the use of all EAB findings.



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Problem 3: Predicting Launch Cadence and Maine Spaceport Revenue

Identifying **historical launch capability** and potential **revenue** opportunities from both suborbital and orbital launch.

When can we launch rockets, and how many can we handle?

The Challenges:

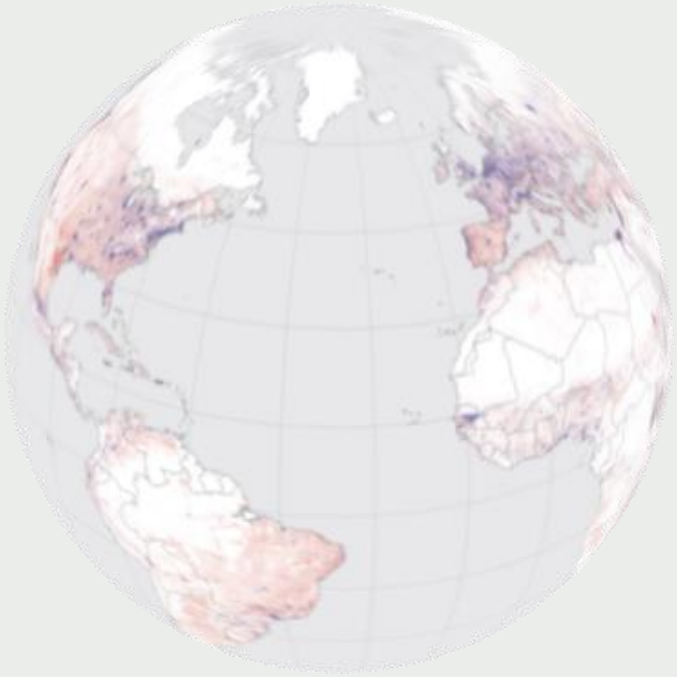
- Maine has a geographic advantage for polar orbit launch, but does weather permit a regular launch cadence?
- How can satellite data be used to predict launch windows?

The Solution:

- Utilize historical terrestrial weather data to analyze historical launch capability.
- Train a support vector machine model based using historical data. Test the model utilizing forecasted data from satellite derived modeling.

Business Case:

- By utilizing historical terrestrial weather data, we can effectively train a launch prediction model for satellite derived forecasting data.



“Launch Windows” = 3 hour intervals where parameters are met

Data Sets

1. Historical Cutler Terrestrial Data: 2010-2021
2. Brunswick Airport Satellite Forecasted Data: 8/11/21 10-day forecast
3. Bar Harbor Airport Satellite Forecasted Data: 8/13/21 5-day forecast

Data Cleaning/Launch Parameters

1. Wind Speed < 10 knots
2. Temperature > 50 F
3. Conditions = “Clear”
4. Wind speed is NOT below 8 knots and Wind direction is NOT 60-210
5. One Hour Launch Window
6. Three-hour Launch Window

Credit to Blushift Aerospace engineers who helped inform our weather parameters!

Model is purpose-built to allow figures to be adjusted for various launch providers.

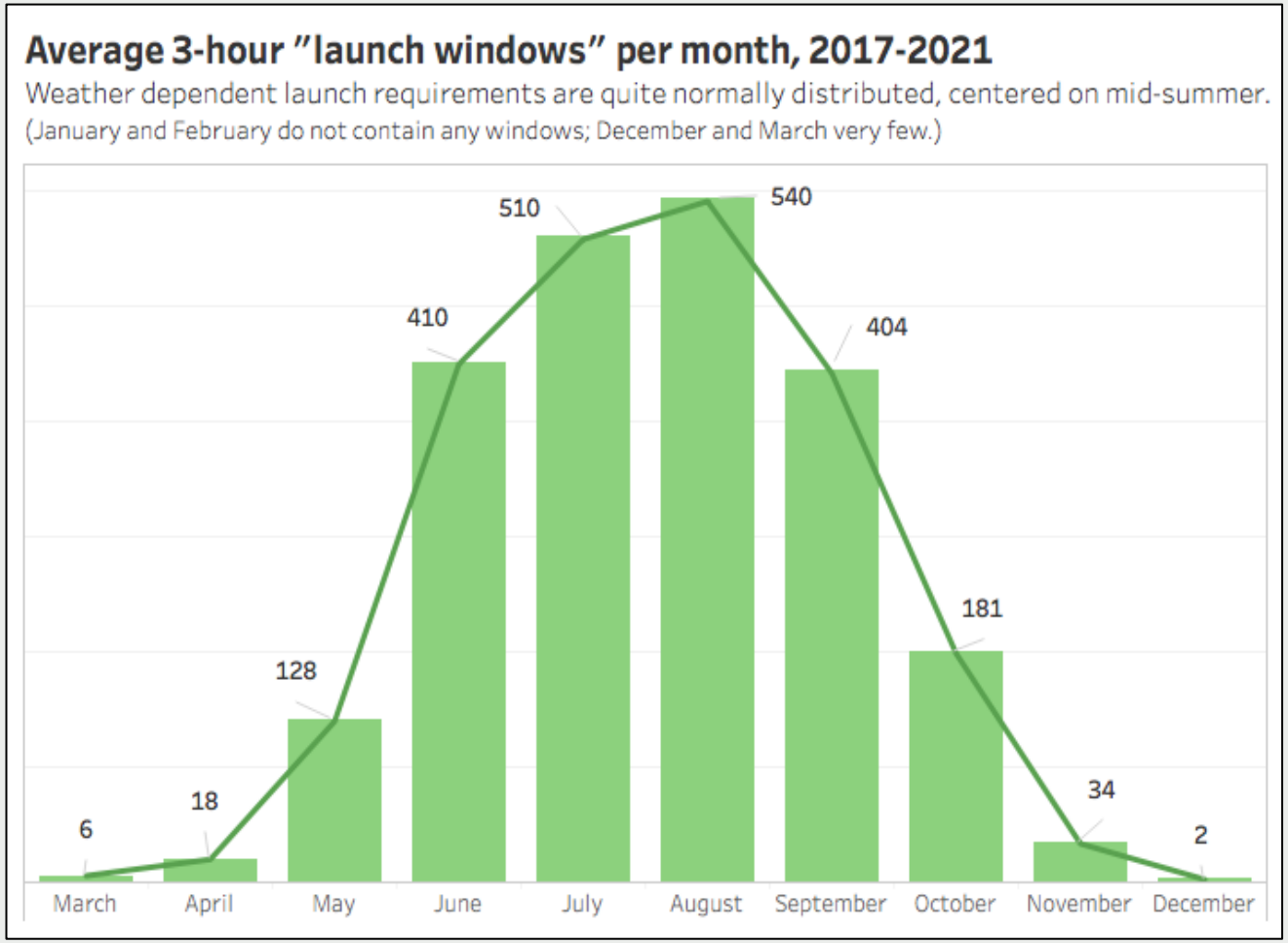
Source: bluShift Aerospace

Launches windows are most available during the summer months

Lower temperatures in Maine means fewer launch windows than more southerly competitors, which requires that the spaceport account for this when attracting other tenants.

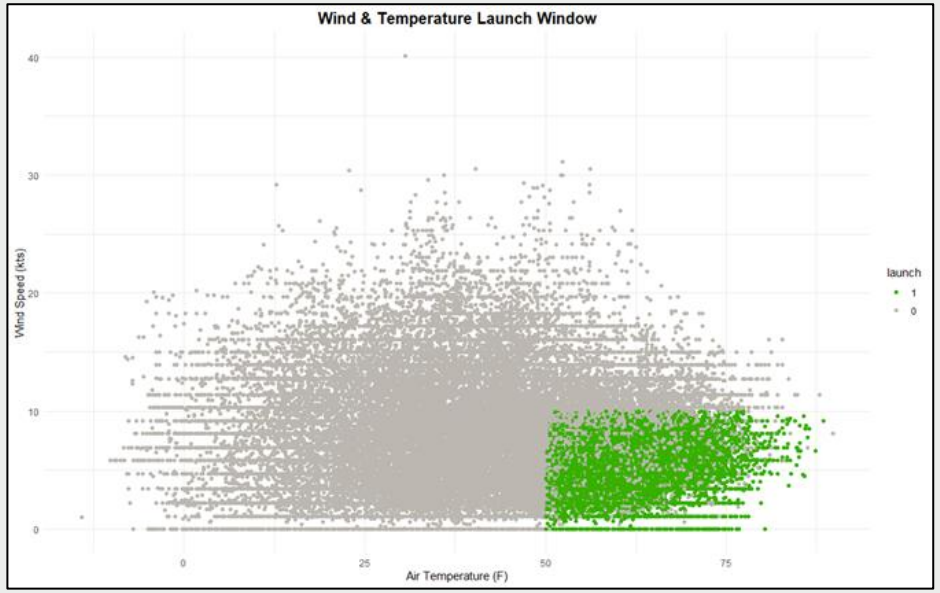
3 Hour Launch Windows ('10-'20)

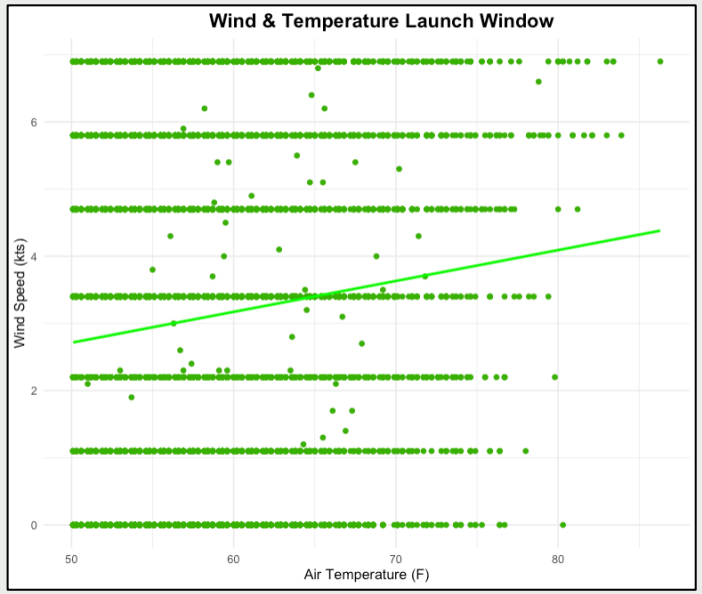
Year	Launch Windows
2010	2337
2011	2230
2012	2273
2013	2119
2014	1951
2015	2131
2016	1978
2017	2276
2018	2029
2019	2318
2020	2220
	Annual Average = 2169

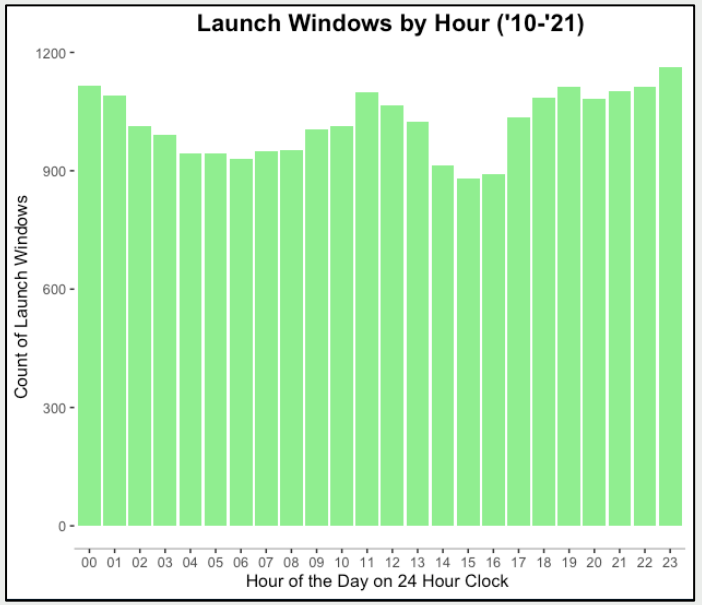


Launch windows are affected by temperature and wind speed's relationship

This is because there is a small, positive correlation between temperature and windspeed



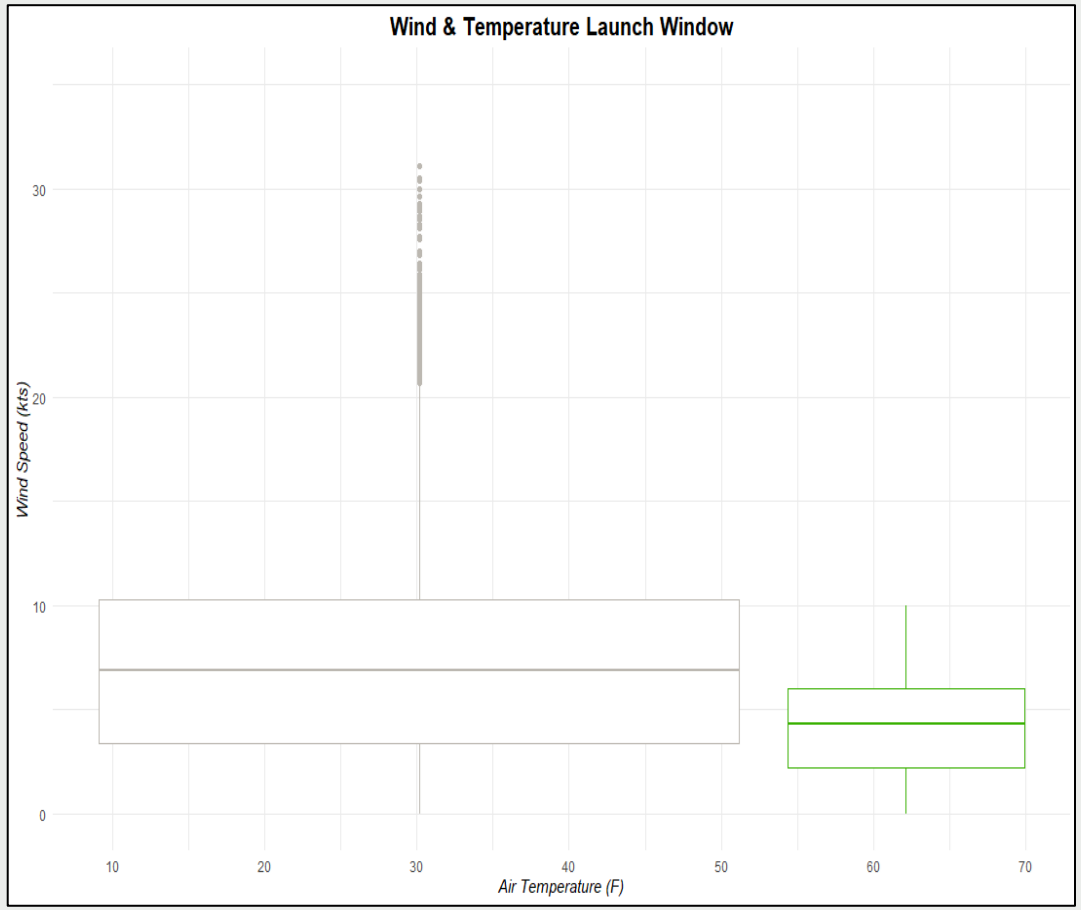


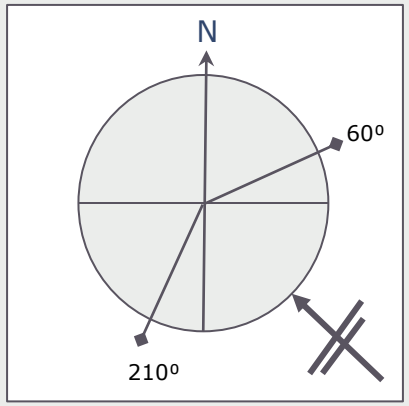


Typically, wind is Maine stays below 20 knots, so there is also room to add launches if the size of launch vehicle were to increase.

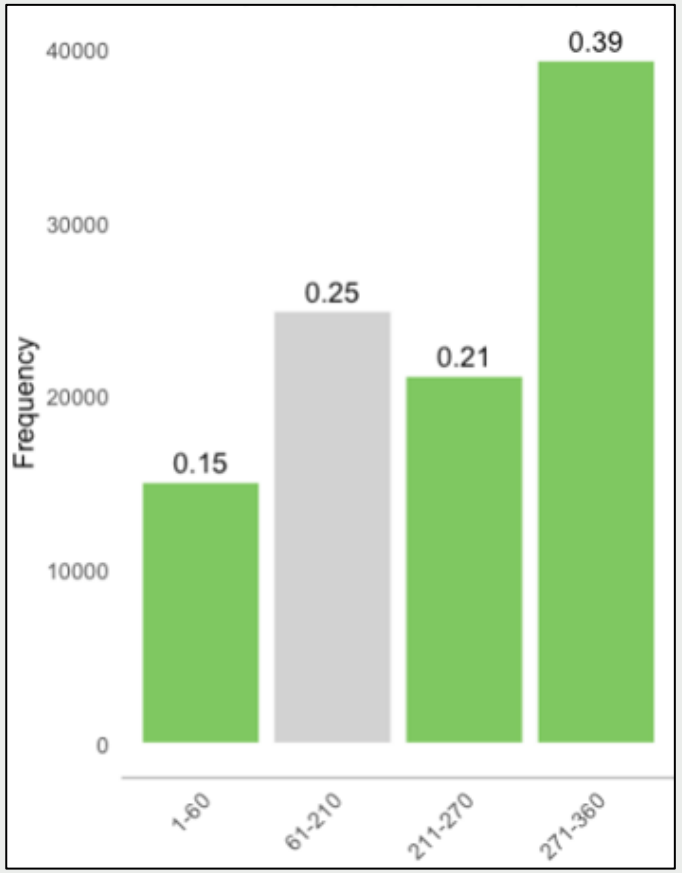
Wind Direction and Launching Rockets

Southern and Easterly winds create risks for pushing small rockets back toward land





Wind Direction 2010-2020



Small rockets are more susceptible to wind because of their size, so conditions must be right to keep them on course and out of harm's way.

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Predicting Launch Cadence: Support Vector Machine Model

Historical three our launch windows will be a powerful tool to train our SVM model to predict satellite forecasted three hour launch windows.

Data sets:

1. (Train) Historical Cutler Terrestrial Data: 2010-2021
2. (Test1) Brunswick Airport Forecasted Data: 8/11/21 10 day forecast
3. (Test2) Bar Harbor Airport Forecasted Data: 8/13/21 5 day forecast

Model Variables:

1. Wind_Go
2. Temp_Go
3. Conditions_Go
4. Wind_Direction_Go
5. One_Hour_Window
6. Launch

Data Set	Variables	Observations
Train	6	99,678
Test1	6	231
Test2	6	111

SVM Model Accuracy and Confusion Matrix

All three models tested above a 90%+accuracy. But there were multiple type two errors that will need to be corrected moving forward.

Model Data	Accuracy
Train	93.24%
Test1	96.54%
Test2	94.59%

Confusion Matrix for Model Performance

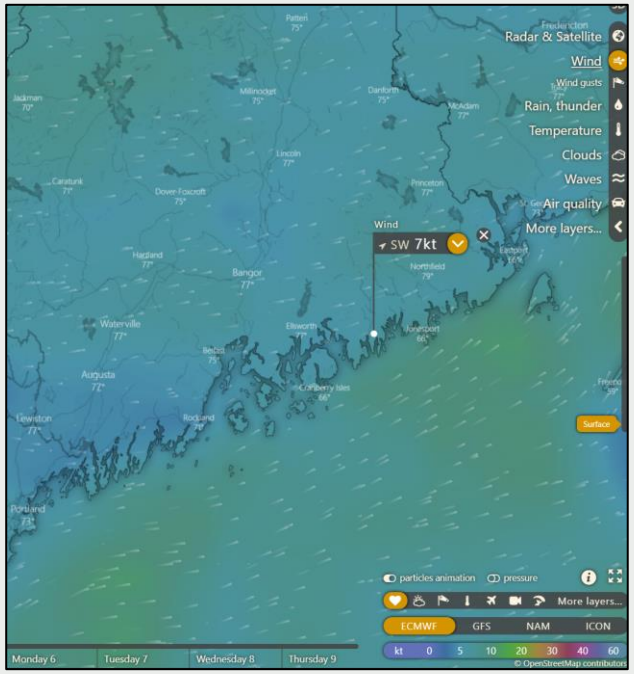
Train	Predicted Value		
Actual Value		True(0)	False (1)
	No Launch (0)	66,661	0
	Launch (1)	6,742	24,275

Test1	Predicted Value		
Actual Value		True(0)	False (1)
	No Launch (0)	28	0
	Launch (1)	8	195

Test2	Predicted Value		
Actual Value		True(0)	False (1)
	No Launch (0)	17	0
	Launch (1)	6	88

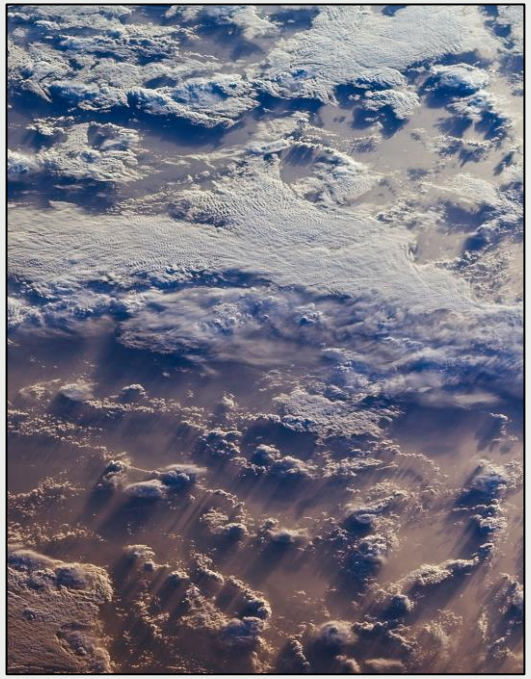
Historical data and new variables will need to be introduced to the model

Variables such as winds aloft and cloud ceilings will enhance the launch predictive model and can to be included in future iterations.



Potential Sources for winds aloft data:

1. ForeFlight: Surface-51k feet
2. NOAA Aviation Weather Center: Surface-53k feet
3. Spire: Surface- 100km
4. European Center for Medium-Range Weather Forecasts
   a. Windy (Weather Tracking Surface)



Potential Sources for cloud ceilings:

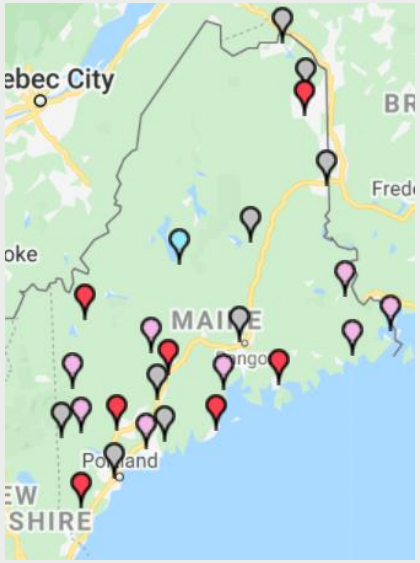
1. NavLost (historical METAR Data)
2. NOAA Aviation Weather Center
3. European Center for Medium-Range Weather Forecasts
   a. Windy (Weather Tracking Surface)

Source: https://www.windy.com/

Next Steps for the Maine Spaceport Initiatives Launch Cadence Modeling

Terrestrial observation systems limit the areas and altitude at which meteorological conditions can be monitored, and satellite-based systems are not stored in an accessible repository.

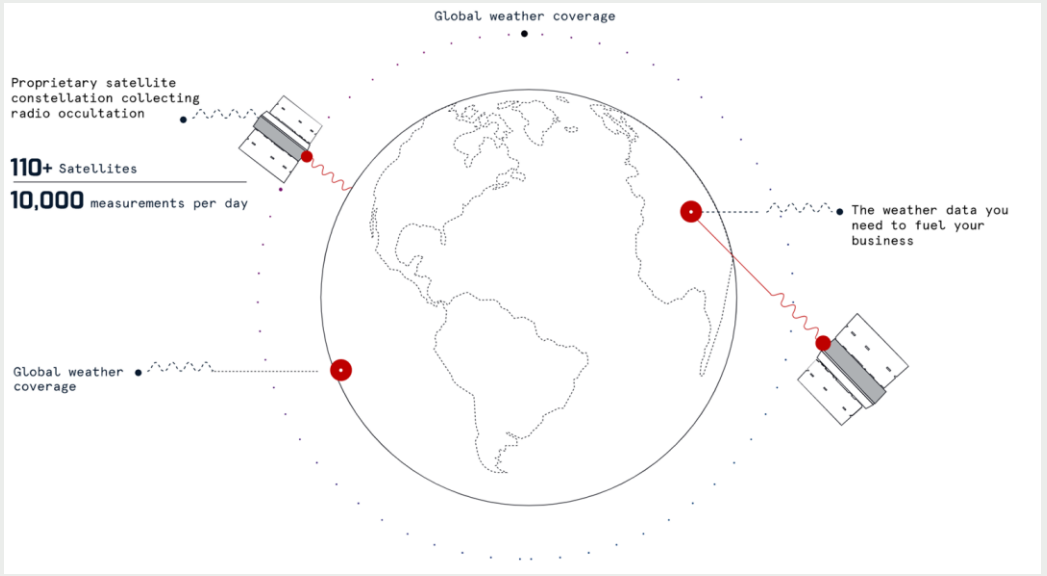
Current Automated Surface Observation System/Automated Weather Observation Systems In Maine



Weather stations

ID	Location	County	State	Frequency	Phone	Type
KLEW	Auburn-Lewiston	Androscoggin	ME	118.025	(207) 783-2806	AWOS IIIP/T
KAUG	Augusta	Kennebec	ME	118.325	(207) 623-0432	ASOS
KBGR	Bangor	Penobscot	ME	ATIS - 127.75	(207) 561-2515	ASOS
KBHB	Bar Harbor	Hancock	ME	118.35	(207) 667-7364	AWOS IIIP/T
KBST	Belfast	Waldo	ME	122.975	(207) 930-7071	AWOS A/V
K0B1	Bethel	Oxford	ME	122.9	(207) 512-2516	AWOS A/V
01EQ	Bridgton Hospital	Cumberland	ME	122.7	(207) 647-6235	AWOS A/V
KBXM	Brunswick	Cumberland	ME	134.875	(207) 409-1747	AWOS A/V
KCAR	Caribou	Aroostook	ME	135.125	(207) 496-3153	ASOS
KOWK	Central Maine/Norridgewock	Somerset	ME	122.8		AWOS A/V
KEPM	Eastport	Washington	ME	122.8	(207) 853-0682	AWOS A/V
KFVE	Frenchville - Northern Aroostook	Aroostook	ME	135.725	(207) 543-7456	ASOS
KIZG	Fryeburg - Eastern Slopes	Oxford	ME	135.775	(207) 935-2882	ASOS
K3B1	Greenville	Piscataquis	ME	122.8	(207) 695-2581	AWOS A
KHUL	Houlton	Aroostook	ME	132.025	(207) 532-1584	ASOS
KMVM	Machias Valley	Washington	ME	122.8	(207) 255-2511	AWOS A/V
KMLT	Millinocket	Penobscot	ME	135.225	(207) 723-8396	ASOS
KPWM	Portland	Cumberland	ME	119.05	(207) 874-7914	ASOS
KPQI	Presque Isle	Aroostook	ME	118.025	(207) 764-7248	AWOS IIIP/T
KPNN	Princeton	Washington	ME	122.7		AWOS A/V
KRKD	Rockland	Knox	ME	119.025	(207) 594-7946	AWOS IIIP/T
KSFM	Sanford Seacoastal	York	ME	120.025	(207) 324-1958	AWOS IIIP/T
K8B0	Steven A. Bean - Rangeley	Franklin	ME	118	(207) 864-5250	AWOS IIIP/T
KWVL	Waterville/Robert LaFleur	Kennebec	ME	118.375	(207) 877-0519	AWOS IIIP/T
KIWI	Wiscasset	Lincoln	ME	135.725	(207) 882-8094	ASOS

Spire Constellation Coverage



LEO constellations like SPIRE have the capability of increasing weather observation from the surface to high levels of the atmosphere while covering the entire geographic launch area.

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Source: Surface Weather Observation Stations ASOS/AWOS (faa.gov)
Weather - Spire : Global Data and Analytics

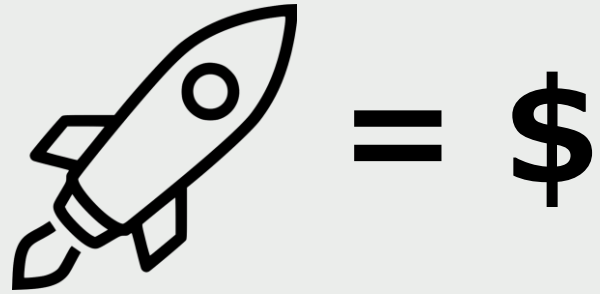
Predicting Launch Revenue

The Problem:

- With so few historic data available in an industry that is experiencing exponential growth, how does The Maine Spaceport quantify its potential impact over the short and mid-term, which is its critical growth period (2-5yr)?

The Solution

- Provide a picture of the Spaceport's financial feasibility using a Monte Carlo revenue simulation based on industry predictions and tenant ambitions.



Business Case

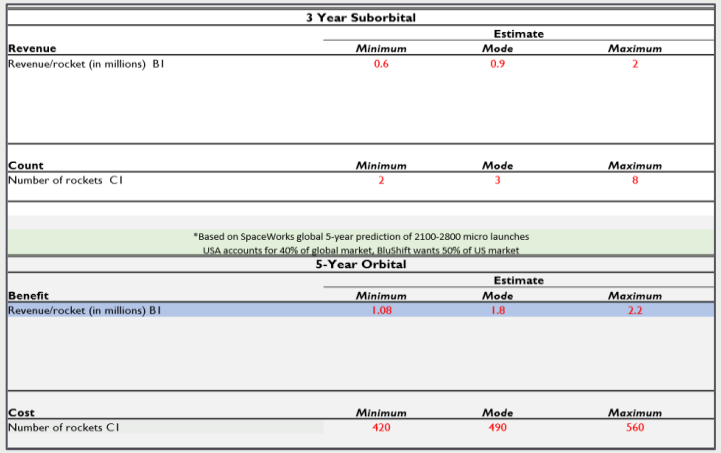
- The Maine Spaceport needs to understand and communicate its revenue and profitability potential in order to effectively present its case to State officials, partner organizations, venture capital, and new tenants.

Monte Carlo Simulation for Maine Spaceport Revenue Modeling

Model disclaimers:

- Projections for new-space markets vary widely!
- There is little proprietary historic data available to us on which to base forecasts.
  - Triangle distributions are used in conjunction with a 10k trial Monte Carlo to gain visibility.
- Model is built to accommodate new tenants at the Maine spaceport as they arrive.
  - The models reflects the potential market-capture at-stake based upon Spaceport tenant ambitions.

	Focus	Predicted Years	Spending	Interesting Points
Maine Spaceport Deck				
- Euroconsult	Gov't / Civil	2020-2025	$65-80 B / $70-85 B	US Civil Spending leads industry
- Morgan Stanley	Global Space Mkt.	2019	$271 B	Remote Sensing lines-up
- Bryce Spaceworks	Global Space Mkt.	2019	$366 B	Remote Sensing lines-up
Frost & Sullivan	Satellite IoT	2023	$500M - $1B	Remote Sensing lines-up
Space Works	Small Satellite	2019 - 2024	2000 - 2800 Micro Satellite Launches	Comprehensive look at Pico/Nano/Micro/Small



3 Year Suborbital

Revenue		Estimate		
		Minimum	*Mode*	*Maximum*
Revenue/rocket (in millions) B1		0.6	0.9	2
Count		*Minimum*	*Mode*	*Maximum*
Number of rockets C1		2	3	8

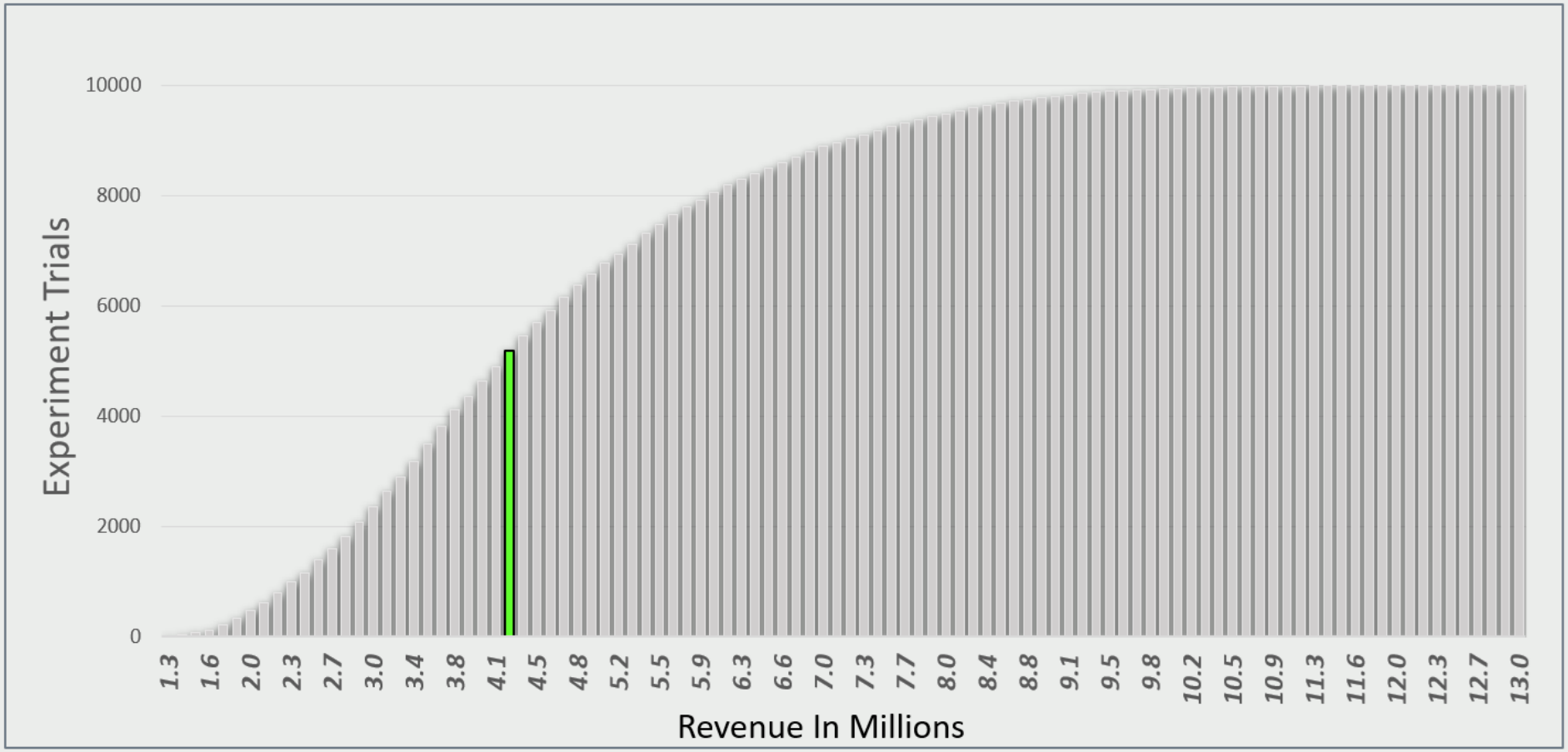
*Based on SpaceWorks global 5-year prediction of 2100-2800 micro launches
USA accounts for 40% of global market, BluShift wants 50% of US market

5-Year Orbital

Benefit		Estimate		
		Minimum	*Mode*	*Maximum*
Revenue/rocket (in millions) B1		1.08	1.8	2.2
Cost		*Minimum*	*Mode*	*Maximum*
Number of rockets C1		420	490	560

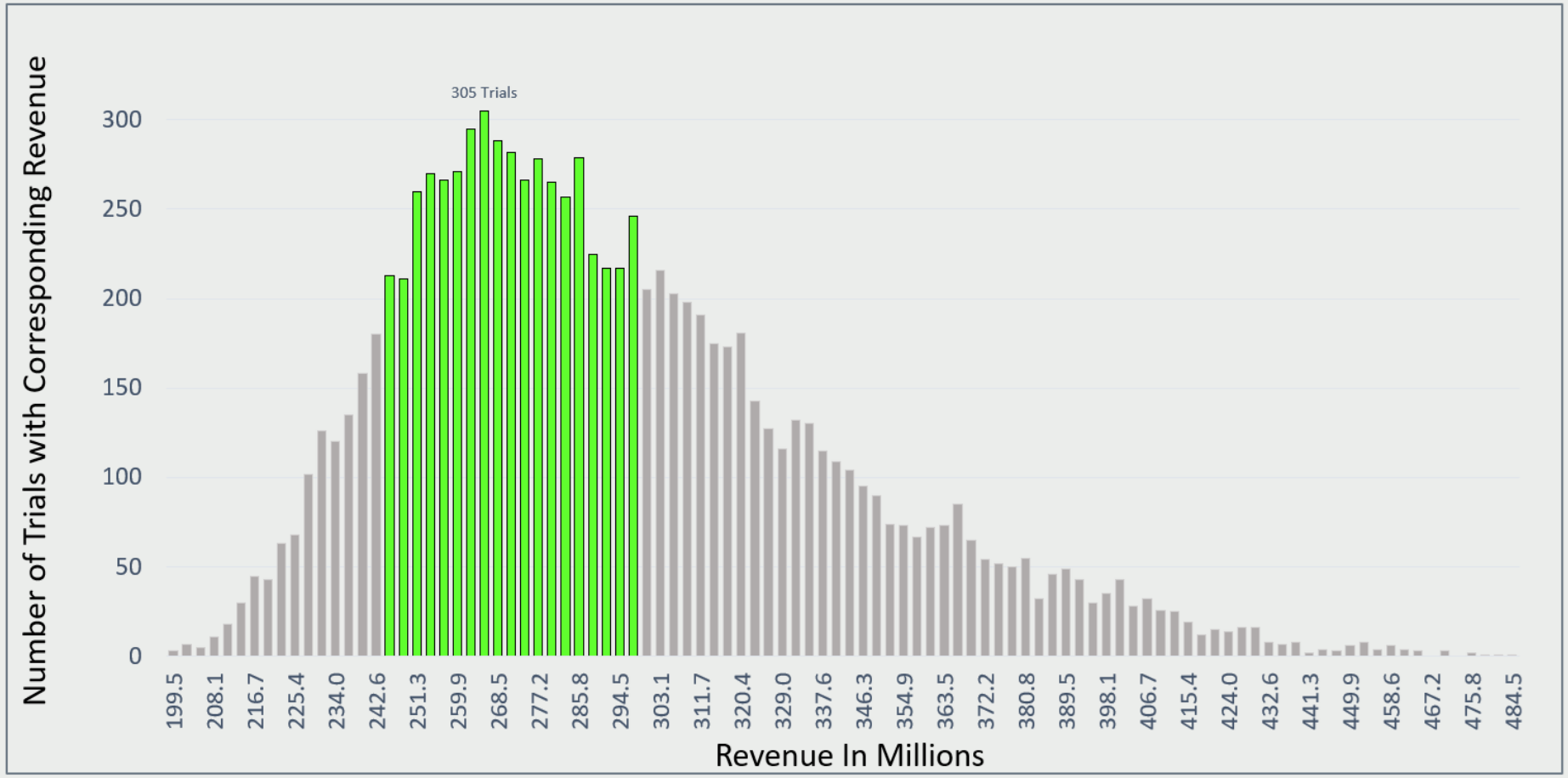
Monte Carlo Simulation Pt 1: Suborbital Launch Revenue Projection thru 2022

The Suborbital launch market will be accessible prior to the orbital launch marketplace, and thus has a shorter timeline



Estimates put the suborbital launch revenue media at at $4.2M annually

Orbital Launch Revenue Potential Annual Projection to 2023



Is space Maine's new big industry?	
Industry	Revenue
Lobster	485 M
Potatoes	167 M
Cannabis	112 M
Spaceport	***55-60M***

The orbital launch market is orders of magnitude larger than the suborbital launch market, as it includes commercial operations. Based on Spaceport ambitions, this is the potential market-capture at-stake.

Source: bluShift Aerospace

Conclusions

- Efficiencies and accuracy for Maine's aquaculture sampling and testing can be improved through satellite-enhanced models.
- EABs are a fast-moving risk to Maine forests that can be mitigated through the use of satellite data combined with the FIA data in order to provide visibility to EAB trap monitoring and at-risk plots.
- Weather modeling supports the launch cadence needed for the Maine Spaceport to become a global competitor, and revenue models demonstrate its unique ability to quickly grow Maine's tech and entrepreneurial ecosystems.

~ Thank you ~

Q & A