Environmental Impacts of the Space Industry in Earth's Atmosphere: An Analysis on Rocket Emissions and Ozone

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Abstract

Ozone has been a research topic for a few decades, specifically its depletion in the stratosphere and its production in the troposphere. The space industry burns multiple types of fuel to project spacecrafts possibly contributing to the ozone concerns in both areas of the atmosphere. Data consisting of Cocoa Beach's daily ozone levels from the Florida Department of Environmental Protection's Office of Air Monitoring were used to discover if ozone levels were significantly higher when rockets were launched from Kennedy Space Center from the years 1994 to 2019. After performing a hypothesis test on the ozone levels for those years, there was no evidence in the results to show that rocket launch days had significantly high ozone levels. Furthermore, it is likely that rocket launches do not affect the overall ozone for a specific day, but that does not show the industry has no impact. These results further emphasize why there are no regulations on the industry even though there is a profusion of articles stating the industry's negative effect. The effects of the industry are likely long-term effects, but there are other contributors that are make it difficult to identify the impact strictly from the rocket industry.

Introduction

- Ozone is an element that lies in the stratosphere of the Earth's atmosphere that is vital to protecting the Earths from harmful rays
  - In the stratospheres, ozone is important and protects the Earth
  - In the troposphere, ozone can harm air quality and cause health problems for people
- Rockets produce exhaust that contains elements known to be a catalyst to ozone production
  - Liquid Oxygen (LOx) is the most common oxidizer in the space industry. SpaceX uses LOx and highly refined kerosene(RP-1) for fuel.
    - This combination releases H2O, Nitrogen Oxides, Hydrogen Oxide emission, as well as Carbon Soot and Hydrogen Sulfates
  - Solid Rocket Fuels were used in the shuttle program and are planned to be used on NASA's new Space Launch System(SLS) program.
    - This type of fuel release aluminum Oxides, Nitrogen Oxides, and Hydrogen Chlorides (Braeunig, 2008)
- Florida Air Quality is recorded by the Florida Department of Environmental Protection's Office of Air Monitoring
  - FDEP Office of Air Monitoring has an Air Quality Index(AQI) that determines how healthy the air is based on Ozone (O3), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Particle Pollution, Sulfur Dioxide (SO2), Lead (Pb).

Methods & Data

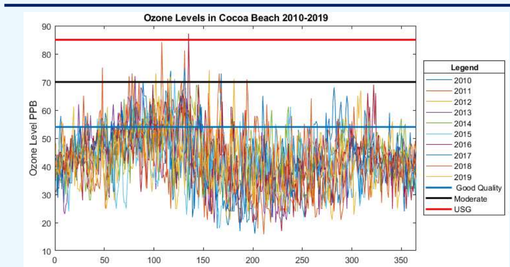

Figure 1: Ozone Level for 2010-2019

- Data is collected from Florida Department of Environmental Protection's Office of Air Monitoring
- *Figure 1* shows the 1-hour average ozone reading for Cocoa Beach Brevard County near Kennedy Space Center

Curve Fitting

- As shown in the figure above, there is a seasonal fluctuation of the ozone levels. To counteract this a curve id fitted to

Standardization

- A standard metric for measuring spikes in the level must be created by subtracting the real data point from the estimated data point on the fitted curve

T-Test on a Normal Distribution

- Now that the data is standardized, there is a normal distribution of data causing any spikes in the data to be on the same metric as any other spike in the data.
- This allows a t-Test to be calculated with a 95% confidence interval to discover if the t-Stat is significant compared to the critical value for the year.

Analysis

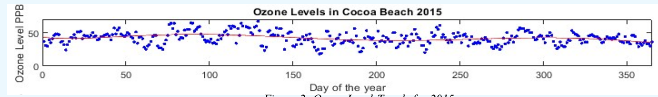

Figure 2: Ozone Level Trends for 2015

- Curve fitting calculated the trend and fluctuations for each individual year. *Figure 2* shows the trend for 2017
- After the curve is fitted for one year, the standardized data is created by subtracting the estimated point on the fitted curve from the real data point.
- *Figure 3* is the residuals that create a usable metric to compare spikes in the data
  - The Black lines are rocket launch dates

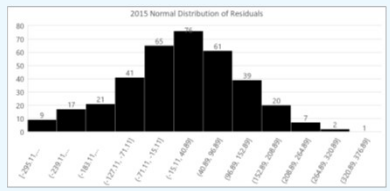

Figure 4: Bell Curve Normal Distribution of Residual

- Since there is no visual correlation in *Figure 3* showing that there is a spike in ozone for every rocket launch day a t-test needs to be preformed to show if rockets cause the ozone data to be significantly out of range compared to a normal day
- *Figure 4* shows the now normal distribution of frequent ozone levels that makes conditions possible to perform a t-Test.
- The t-test has an alpha of 0.05 to create a 95% confidence interval

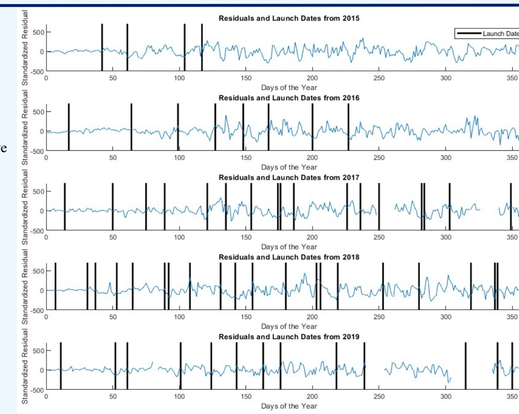

Figure 3 :Residuals with Rocket Launch Dates

Results

t-Test: Two Sample Unequal Varience	2015	2015L	2016	2016L	2017	2017L	2018	2018L	2019	2019L
	-5.8578	*17.234*	*-35.979*	*5.1401*	*4.8211*	*-18.497*	*-5.162*	*9.9765*	*-2.4705*	*10.369*
Mean	0.504228	-41.3994	-0.54856	-0.84874	1.886304	-34.089	-1.72984	30.39159	-1.5187	42.1545
Variance	13118.43	11438.61	11696.47	17599.85	10405.09	8124.97	12852.49	21510.94	7973.25	9184.84
Observations	358	5	356	7	321	16	343	20	304	11
Hypothesized Mean Difference	0		0		0		0		0	
df	4		6		17		20		11	
t Stat	0.869159		0.005948		1.547822		-0.96282		-1.4882	
P(T<=t) two-tail	0.433804		0.995447		0.140079		0.347137		0.1648	
t Critical two-tail	2.776445		2.446912		2.109816		2.085963		2.20099	

Table 1: t-Test Results

- For the rocket launch days to have significant values compared to the rest of the year, the P-value needs to be relatively low and close to 0.05 or absolute values of all the t-Stat values and if it is less than the critical value.
- *Table 1* shows the results:
  - P-values
    - 2016- the rocket launch days are close to the levels of ozone on days no rockets
    - 201 5& 2018- the P-values are smaller but still represent that the ozone levels are not significantly different from a rocket launch to an average day
    - 2017 & 2019- the lowest P-values of these years, but they are still not small enough to be significant.
  - T-Stat
    - The t-Stat for all 5 years is less than the critical value
- Both tests show that ozone levels on rocket launch days are not significant compared t the average day. Rocket launches may not have an immediate effect on ozone levels

Discussion

- This research aimed to find a correlation between rocket launch dates and the ozone levels of those dates. The main results of the T-test proved that the ozone levels on rocket launch dates were not significant compared to the ozone levels for the rest of the year. The lack of significance is beneficial to know that there are no immediate ozone level concerns due to rocket launches from this study.
- *Table 2* shows the rocket emissions that NASA currently monitor.
  - Current studies on carbon soot state it is the second-largest contributor to global temperature increase (Pacific Northwest, 2018). Carbon soot is becoming a large contributor to damaging the environment, and a Falcon 9 releases about 30 metric tonnes of, but it is included in particle matter and does not contain its own category for it environmental effect.
  - NASA is an administration that is involved in the analysis of the environmental impacts of SpaceX's rockets, and NASA has conducted research that has found that black carbon soot has damaging effects on the environment as well as travels in the atmosphere to different locations (Dunbar, 2005).

Pollutant	Averaging Time	Nearest Monitoring Station	Maximum Measured Concentration (ppm, except PM in μg/m^3)				
			2013	2014	2015	2016	2017
O_3	8 Hours	Palm Bay-Melbourne-Titusville	0.063 (4th max)	0.063 (4th max)	0.059 (4th max)	0.061 (4th max)	0.061 (4th max)
CO	1 Hour	Orlando-Kissimmee-Sanford	1.1	1.8	1.5	1.9	2.8
	8 Hour		1.0	1.5	1.2	1.2	1.4
NO_2	1 Hour	Orlando-Kissimmee-Sanford	0.034	0.036	0.025	0.029	0.030
	Annual (mean)		0.005	0.005	0.004	0.004	0.004
SO_2	1 Hour	Orlando-Kissimmee-Sanford	0.003	0.007	0.003	0.002	0.005
	24 Hour		0.0004	0.0023	0.0005	0.0013	0.0008
PM_{10}	24 Hour	Palm Bay-Melbourne-Titusville	54 (2nd max)	4 (2nd max)	47 (2nd max)	38 (2nd max)	49 (2nd max)
$PM_{2.5}$	24 Hour	Palm Bay-Melbourne-Titusville	21	14	12	10	20
	Annual		5.7	5.8	5.2	5.2	6.6
Lead		No lead monitors are located within 100 miles of LZ-1	-	-	-	-	-

Table 2: Starship Emissions (NASA,2019)

- Further research needs to be conducted on the long-term effects of the space industry. As important as it is to know that the space industry does not have an immediate negative effect on the Earth's ozone level, has there been enough data to conduct long-term analyses? Greater consideration in the emission rocket launches produced is valuable to keep our planet safe before humans move onto a new planet and destroy that planet's environment.

References

PROPELLANTS. From http://www.braeunig.us/space/propel.htm

Air Quality Index (AQI). (2019, January 15). from https://floridadep.gov/air/airmonitoring/content/air-quality-index-aqi

Braeunig, R. A. (2008). ROCKET

Dunbar, B. (2005). Black and White: Soot on Ice.https://www.nasa.gov/vision/earth/ environment/arctic_soot.html

Dodd, T. (2020, March 25). How much do rockets pollute? https://everydayastronaut.com/rocketpollution/

NASA. (2019). Draft Environmental Assessment for the SpaceX Starship and Super Heavy Launch Vehicle at Kennedy Space Center (KSC). [PDF]

Pacific Northwest National Laboratories. (2018, September 01). Atmospher Sci & Global Chg Research Highlights. https://www.pnnl.gov/science/highlights/highlight.asp?id=1279