Contrail Formation in Southeastern Michigan with Potential Regional and Global Impacts

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Abstract: This research attempted to determine the extent to which contrails formed by planes flying at high altitudes are affected by the presence or absence of large bodies of water such as the Great Lakes. Contrails are **anthropogenic** clouds that appear as streaks in the sky following the condensation of aircraft engine exhaust on aerosols at the cold, higher altitudes found in the atmosphere where many aircraft fly. Near daily cloud observations from August 2019 through February 2019 were made using GLOBE Cloud protocols and then the data was uploaded to GLOBE via the NASA-GLOBE Cloud Observer App and/or through direct data entry. This data was then compared with **NASA satellite** images using the information emailed to the researchers from LaRC-GLOBE-Clouds@mail.nasa.gov. Crestwood High School contrail data was then analyzed with data that other schools uploaded using the GLOBE Visualization System. The analyzed data showed that **contrail** formation was strongly correlated with cold upper **altitude** temperatures (as shown in satellite images). Upper-level temperatures also affected the number of contrails observed from the ground. Additionally, some sites along the northern portion of Lake Michigan reported a relatively large number of **persistent** contrails supporting the role that water vapor availability in the atmosphere plays in possible contrail formation. The ability to further match cloud observations from other locations around the Great Lakes was hampered by inconsistent reporting by other GLOBE observers. Future research will include global collaboration with a partnering school in Thailand. Scientists are still evaluating the impacts that contrails, particularly persistent contrails that remain in the sky for prolonged periods of time, have on local and global climates. This and future GLOBE ground-based cloud research will help to form a solid database that NASA and other scientists can use to unravel the potential implications and effects of contrails on climate change.

Research Questions:

1. Can ground-level observations of contrails be used to verify contrails seen in photos from the NASA GOES-16 and MODIS Terra and Aqua satellites?
2. How does contrail formation vary by upper atmosphere temperatures at different locations?
3. Do the locations of nearby large bodies of water contribute to any extent of contrail formation?
4. How do contrail observations made in warm, moist tropical climates like Thailand compare with contrail observations made in the Great Lakes region of the United States?

Null Hypotheses:

1. Local ground observations of contrails cannot be used to verify contrails evident in satellite photos.
2. The type of contrail formation does not vary by upper atmospheric temperatures at different locations.
3. The location of the nearby bodies of water does not contribute to contrail formation.
4. Contrail observations made in warm, moist tropical climates like Thailand do not compare with contrail observations made in the Great Lakes region of the United States.

Research Importance and Implications:

This research project on contrails was prompted by the close proximity of the Detroit Metropolitan Airport to Crestwood High School in Dearborn Heights, Michigan (less than 10 miles away) and Michigan's position within the Great Lakes. Contrails are created at high altitudes of around 8,000 meters where subzero temperatures occur and the Detroit region is crisscrossed by planes traveling at high altitudes to reach their destinations. According to GLOBE Clouds protocols, the Flightradar24 app is a good way to track the flight paths of airplanes crossing through both a local region and our country at large or on a world scale. As stated by the National Oceanic and Atmospheric Administration, if there is sufficient cold and moist air, contrails can form closer to Earth's surface. What are contrails? What most people do not realize is that contrails do not just magically appear on a sunny and clear day. As discussed by NASA, contrails are formed when water vapor condenses on aerosol particles produced by aircraft flying at high altitudes. A comprehensive analysis of contrails, their types, and abundance is of significant importance to our understanding of atmospheric physics and their possible contributions to climate change. Research suggests that they also act as a significant indicator of anthropogenic development, as argued by Fred Pearce, a leading science writer for *Yale Environment 360.* More local GLOBE schools are needed to report contrails in order to better compare local to regional data. One difficulty faced in this research was the lack of consistently reported data by other GLOBE schools. Increased data reporting would significantly increase data reliability and provide more accurate results and insights.

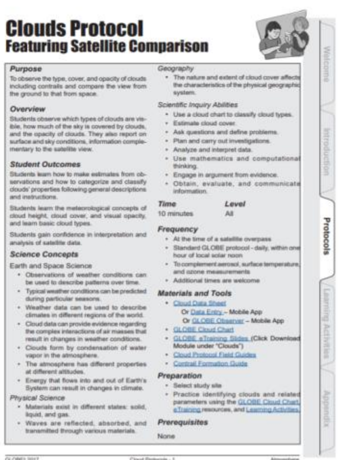
Investigation Plan: Two students consistently took data on clouds in a visually unobstructed and consistent observation site located on the grounds of Crestwood High School from August 2019 to February 2019. Using GLOBE Cloud Protocol and the GLOBE Observer App, the sky was observed for cloud cover in the region above the horizon at 14 degrees. During each observation, the GLOBE Observer App and a Cloud Data Sheet guided the comprehensive collection of various cloud and contrail features, while an iPad captured images of the clouds and contrails most days. All data was entered into the GLOBE website for later comparison with NASA satellite imaging and cloud reports.

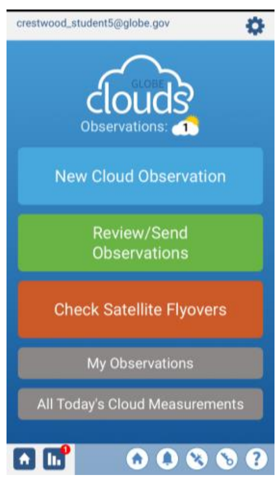
Introduction and Review of Literature: An extensive understanding of contrails is important for several reasons. According to the Langley Research Center, contrails can indicate weather conditions at upper levels in the atmosphere that can drive the formation of other weather phenomena. Persistent contrails can reduce solar irradiance and decrease evaporation from large bodies of water. Increased moisture at upper levels of the atmosphere can also induce the formation of other types of clouds. Contrails are generally unlike other clouds as they are human-induced and consist primarily of ice crystals due to low vapor pressure and low temperatures at high levels in the troposphere. The persistence of visible contrails in the sky are primarily determined by humidity and winds in the upper troposphere (LaRC). A study by climatologist Stanley A. Changnon, Jr. on increasing water levels in Lake Michigan may help to explain the abundance large number of persistent contrails at a site in the Upper Peninsula of Michigan compared to the contrail data collected at the Dearborn Heights site. Changnon calls attention to the unprecedented heavy precipitation in the western Great Lakes that has occurred over the past fifteen years and the shift of the basin's climate as it becomes colder and cloudier, significantly decreasing evaporation rates. As a result, relative humidity has increased and given rise to the widespread development of contrail groups. David P. Duda, of the NASA Langley Research Center and Hampton University Center for Atmospheric Sciences, elaborates on this theory with his colleagues through a case study on "contrail clusters," which are most significantly driven by strong atmospheric winds. Ulrike Burkhardt of the German Aerospace Center's Institute of Atmospheric Physics and his colleague Lisa Bock discuss "radiative forcing" as a role that contrails play in climate change. By reflecting sunlight from reaching the surface of the Earth, the atmosphere warms up and causes climate change. They focus on the lifespan of persistent contrails in particular. Some persistent contrails can last up to 17 hours and play a heavy role in increasing cloud coverage, and potentially affect how much heat Earth receives. Therefore, it is essential for continued research to properly address the formation and spread of contrails. This investigation is significant to the community because climate change in Michigan is projected to increase both the intensity of rainfall events and the total yearly amount of rainfall. This is an important consideration for the Dearborn Heights community as the relatively flat terrain of the city along with the high percentage of impermeable surfaces means that even a slight increase in rainfall intensity could lead to significant flooding among other severe weather induced issues.

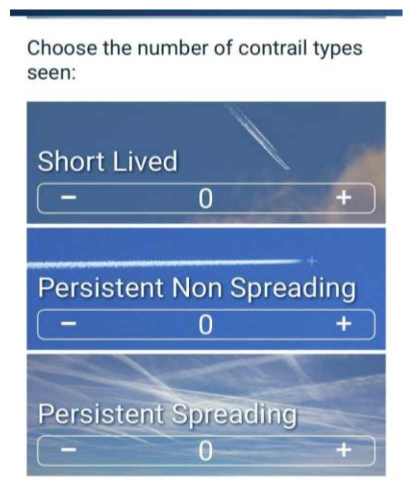
Research Methods:

1. An iPad mini along with the GLOBE Observer Cloud App was used to collect data on clouds and contrails from August 2019 through February 2020.
2. All data was collected from the Crestwood High School football/soccer practice field at a latitude of 42.32 N and a longitude of 83.29 W.
3. Most cloud data was collected during regular school hours but if conditions warranted it, data was taken after school and on some weekends. Whenever possible, pictures of the sky were included in the data collected.
4. Cloud and contrail data was correlated with matching satellite data made possible through the NASA Cloud Observation and Satellite Match data provided by LaRC.
5. Using the GLOBE Advanced-Data Tool air temperatures and with dates, as well as the longitude and latitude, were obtained.
6. The cloud observation data that was sent to our school from the LaRC-Globe-Clouds program at NASA was used to acquire the satellite images that were correlated with our ground observations.
7. The associated satellite images were used to compare the date locations of other sites, including Ann Arbor and Escanaba.
8. The data was then placed into Excel and used to create several different graphs comparing the three different locations.

Figures 1-2: Cloud observation site. Figure 1 (left) shows an aerial image (Google Earth) of the observation site on Crestwood High School property. This area was consistently used to gather data on clouds and contrails. Figure 2 (right) is a ground-based photo of the site, which is a grassy parcel of land used for sports practices and is unobscured by trees or manmade structures.







Figures 3-5: Cloud and Contrail Observation Protocol. Figure 3 (left) shows the GLOBE cloud and contrail data collection protocol, as provided on the NASA GLOBE website for researchers. Figure 4 (middle) shows the first step in making a cloud observation on the GLOBE Observer app. Figure 5 (right) illustrates the screen to choose the number of each type of contrails (Figures 5 and 6 are screen shots of the actual GLOBE Observer App.

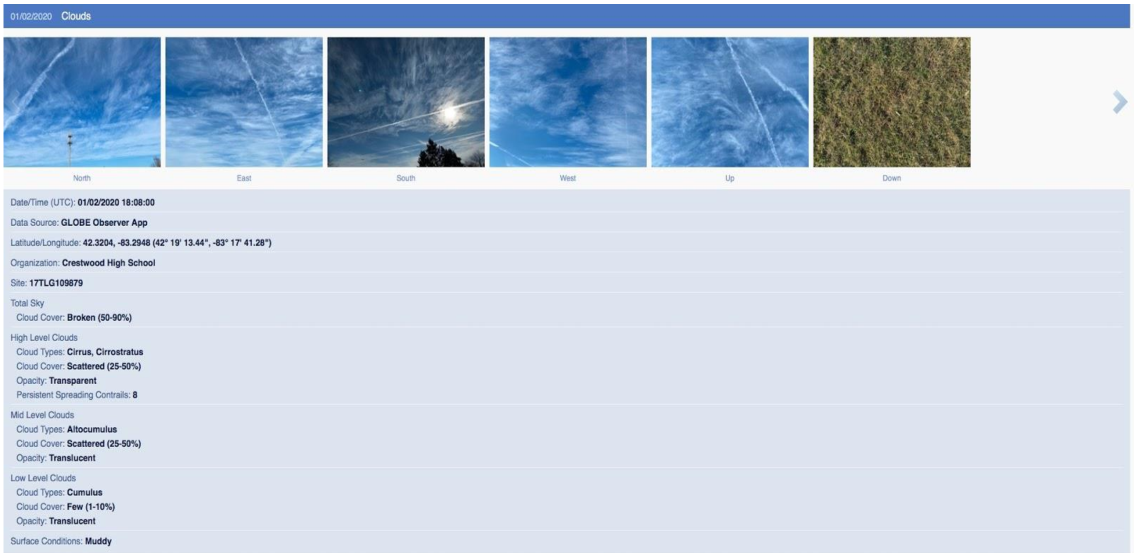
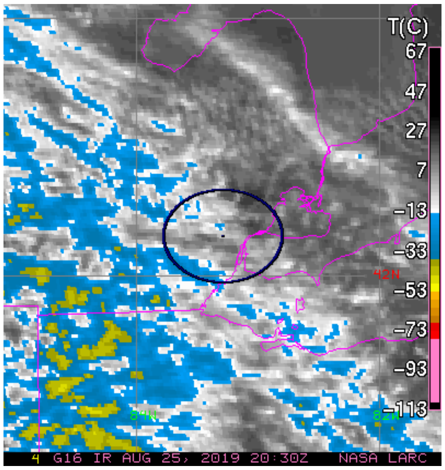
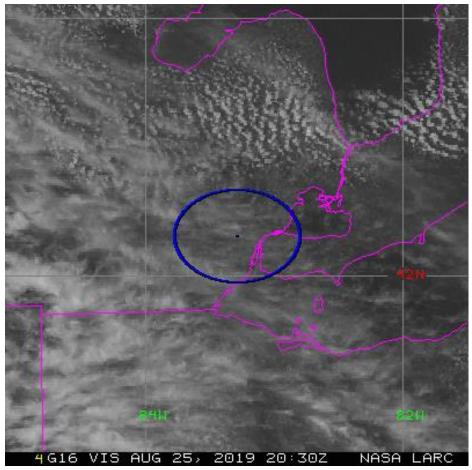


Figure 6: GLOBE Observer Data. Figure 6 shows an example of GLOBE Observer app data entry taken on January 2, 2020 from when contrails were observed.

Figure 7-8: Researchers taking data. Portrayed above are the two student researchers involved in conducting a study on contrails.

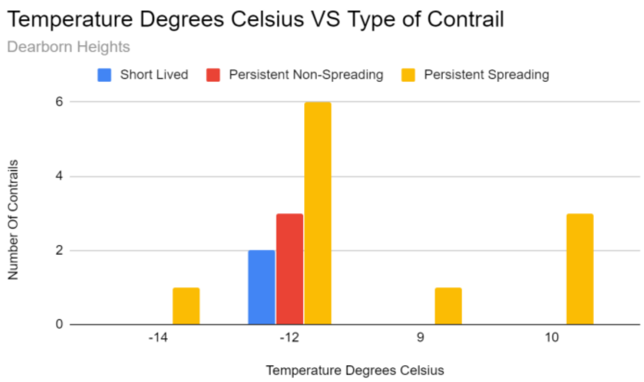
Figures 9-11: Contrail Types. Figure 9 (left) shows a persistent spreading contrail. Figure 10 (middle) shows a persistent non-spreading contrail. Figure 11 (right) shows a short lived contrail. All pictures were taken on separate dates at the same Dearborn Heights location.

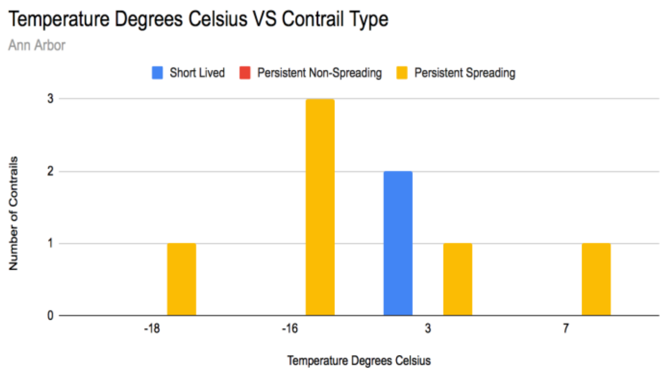




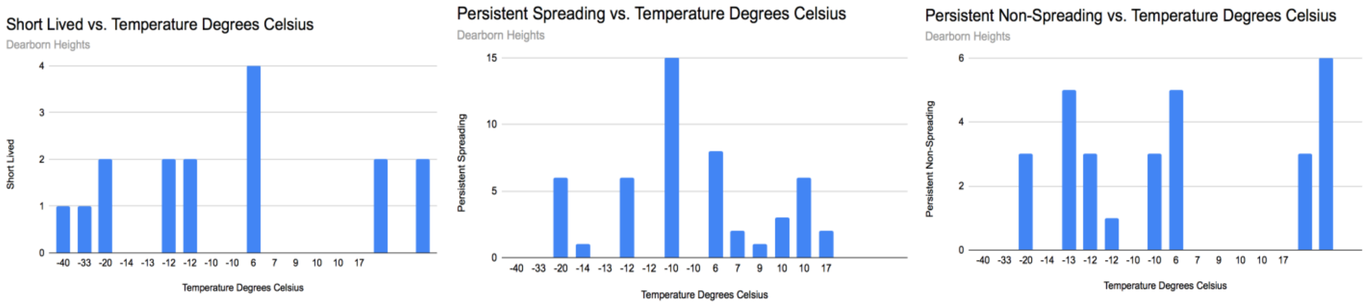
Figures 12-13: NASA GOES-16 Satellite Imagery. Figures 12 and 13 are examples of the satellite imagery used to obtain the temperature and location for the Dearborn Heights data. Figure 12 (left) shows the infrared image obtained by the satellite. Figure 13 (right) shows the visible image from the satellite of the location of the contrails.

Results:





Figures 14-15: Temperature and Location Versus Contrail Type. Figures 14 and 15 show the temperatures of the data along the x-axis on particular dates. Figure 14 is the data obtained from the researchers' site at Dearborn Heights. The temperature was obtained from the NASA infrared satellites. Figure 15 represents the data of the contrails and the temperature from Ann Arbor both retrieved through the Visualization System.



Figures 16-18: Temperature Versus Contrail Type. Figures 16-18 show the data comparison of temperature to the type of contrails in Dearborn Heights. Figure 16 (left) shows the number of short-lived contrails as compared to temperature. Figure 17 (middle) shows the number of persistent contrails graphed with temperature. Figure 18 (right) shows the number of persistent non-spreading contrails against temperature.

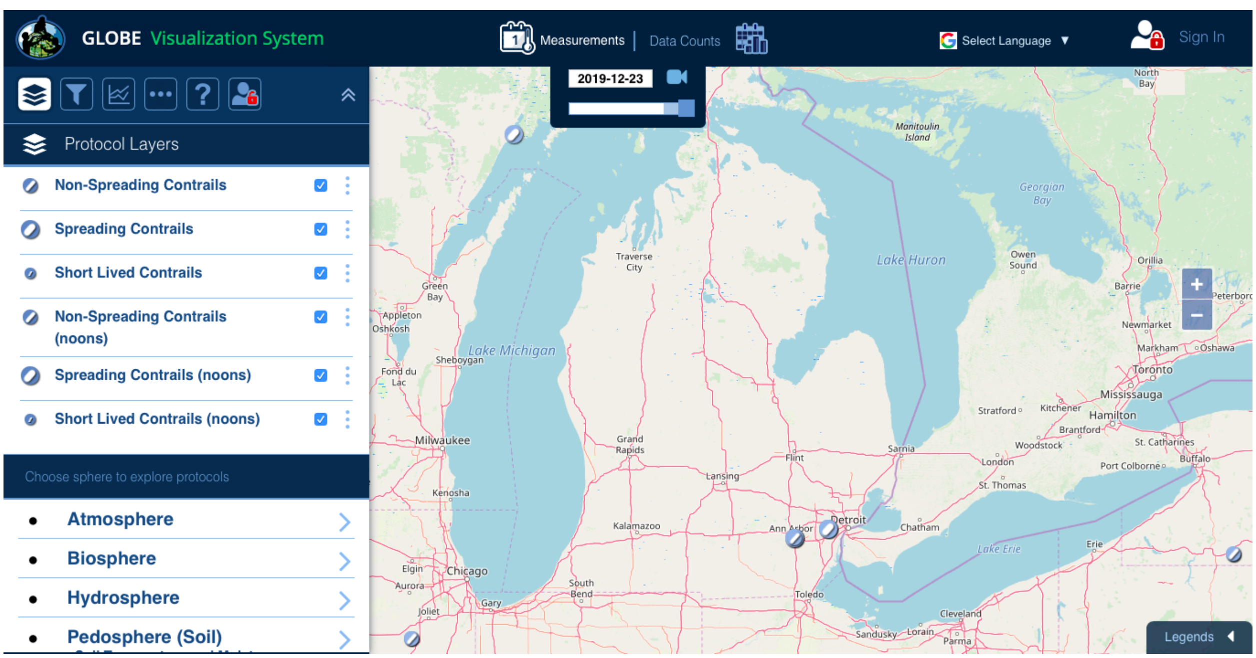


Figure 19: GLOBE Visualization System. Figure 19 displayed above is a screenshot of the GLOBE Visualization System (obtained through the GLOBE website) that was utilized to locate nearby observation sites with which to compare cloud data. This image compares the researchers' site, closest to Detroit, and to the other two examined in

As mentioned in the several graphs above, the consistency of contrails appearance and type correlate with the temperatures and locations of the sites. The closer the **s**ite is to a body of water the more persistent the contrail will be because of the humidity. The cooler the air is the less persistent or the more quickly the contrail disappears. The GLOBE Visualization System (figure 20) is the best way to find the sites where contrails are spotted and to see if their locations are close to bodies of water thus giving researchers a way to analyze data and see the correlation between them.

Discussion: It was expected that the NASA GOES-16 and the MODIS Aqua and Terra satellites would confirm some of the types of contrails recorded by the researchers (except the short-lived contrails), particularly with the NASA Worldview tool displayed in Figure 20. However, this null hypothesis was accepted because it was too difficult for researchers to identify number and types of contrails on the lower resolution weather images with any certainty. Rather, this research was only able to confirm the amount of cloud coverage over the region that day.

The following hypothesis however was rejected, the data visually represented in Figures 11 and 12 represent two different locations in Michigan, one in Dearborn Heights and the other in Ann Arbor. Generally, the highest number of persistent contrails formed on days with low upper-level atmospheric temperatures as indicated on GOES-16 infrared satellite images. However, in this research it is unclear why more persistent contrails existed in Ann Arbor and short-lived contrails were evident in Dearborn Heights on the same day. It is possible that inconsistencies in the contrail and cloud data could be due to the different times observations were made at each site.

Also rejected was the null hypothesis regarding the influence of local bodies of water on contrail formation. Figure 20, a screenshot of the Worldview tool easily accessible on the NASA Satellite Match in Figure 21, proves that the Great Lakes freshwater system heavily contributes to overall cloud coverage. Thus, the moisture exacerbates contrail formation. To further elaborate, data from the Escanaba site was extracted from the Visualization System portrayed in Figure 19 to prove the claim that locations of nearby bodies of water contribute to contrail formation.

The research project also attempted to answer the question of whether or not the cloud data from warm, moist climates like Thailand could be compared to Michigan. The null hypothesis was accepted due to the fact that the data submitted to the Thailand researchers to the Visualization System was outdated and inconsistent. Thus, the comparison between the two schools could not have been conducted, limiting the scope of their research. Further research with Thailand is being planned in our weekly Facetime meetings with students from the Princess Chulabhorn Science High School in Nakhon Si Thammarat, Thailand, who are conducting a similar study with the same focus on contrail attributes and the surface and atmospheric factors that play a role in contrail formation.

The results from this research could have displayed some degree of inaccuracy due to several sources of error, possibly including some missed contrails throughout the day or most prominently, the inconsistency of the data acquisition. Human error could also involve the misidentification of contrails. There is not an approach currently in place for avoiding this issue.

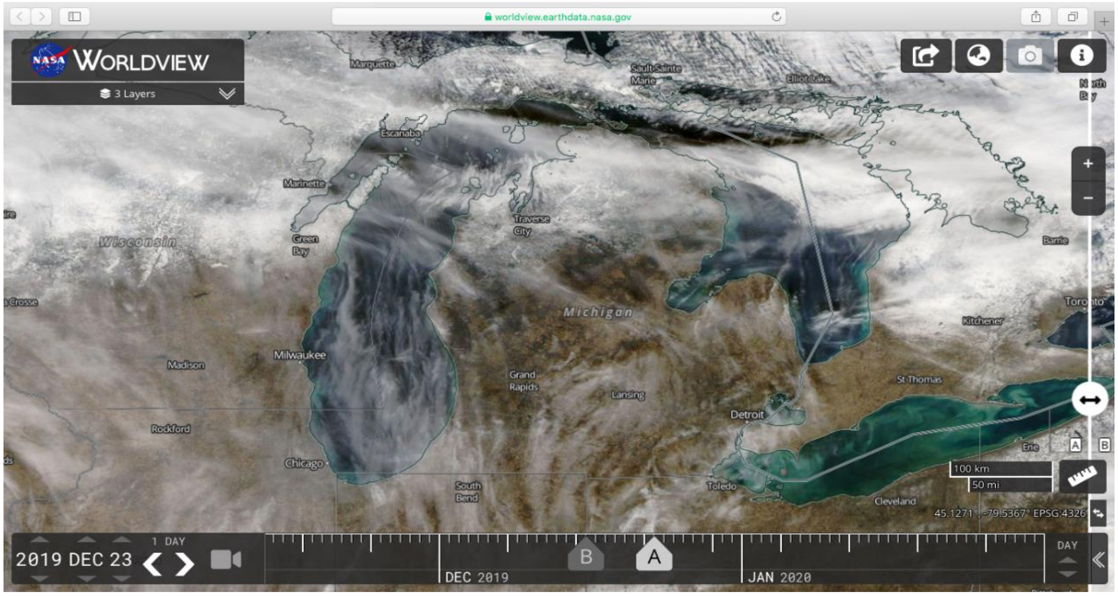
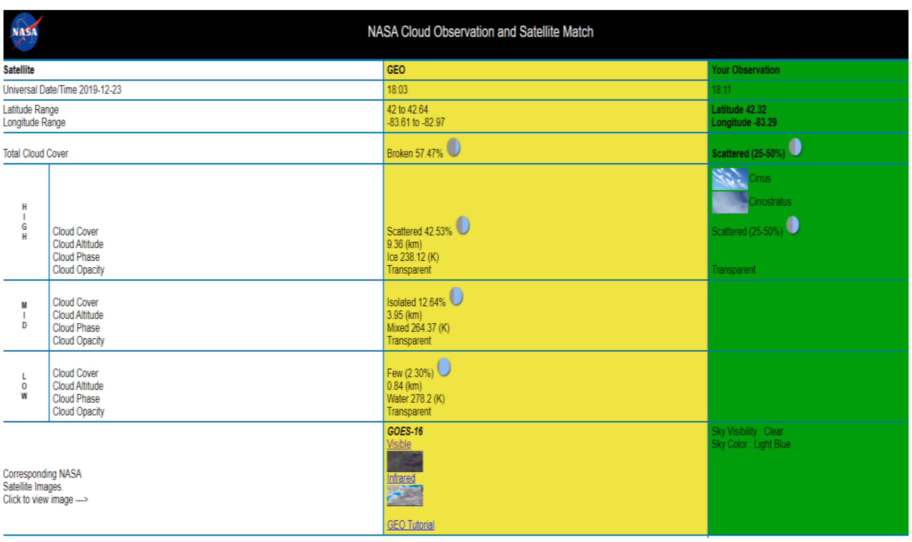


Figure 20: Modis Aqua Satellite. Figure 20 shows the location of the State of Michigan through the Worldview tool, captured by the MODIS Aqua satellite, provided by the NASA Cloud Observation and Satellite Match made available by Langely Research Center. It also shows the amount of cloud cover near bodies of water versus the number of clouds farther away from bodies of water, with the most cloud cover at northern latitudes and above bodies of water.



NASA Cloud Observation and Satellite Match

Satellite		GEO	Your Observation
Universal Date/Time 2019-12-23		18:03	18:11
Latitude Range Longitude Range		42 to 42.64 -83.61 to -82.97	Latitude 42.32 Longitude -83.29
Total Cloud Cover		Broken 57.47%	Scattered (25-50%)
HIGH	Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	Scattered 42.53% 9.36 (km) Ice 238.12 (K) Transparent	Cirrus Cirrostratus Scattered (25-50%) Transparent
MID	Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	Isolated 12.64% 3.95 (km) Mixed 264.37 (K) Transparent	
LOW	Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	Few (2.30%) 0.84 (km) Water 278.2 (K) Transparent	
Corresponding NASA Satellite Images. Click to view image --->		GOES-16 Visible Infrared GEO Tutorial	Sky Visibility : Clear Sky Color : Light Blue

Figure 21: NASA Cloud Observation and Satellite Match. Figure 21 shows a comparison between the data collected by NASA and the data collected by the researchers through the LaRC NASA Cloud Observation and Satellite Match.

Conclusion: After retrieving the data from the different sites, it was exported to Excel and graphed to better visualize correlations and trends. There was sufficient data from a variety of NASA resources to support the research questions asked. The first null hypothesis was accepted. It was discovered that the NASA GOES-16 and the MODIS Aqua and Terra satellites do not provide a basis for confirming the types of contrails recorded by the researchers. They only provide a reasonable method for tracking cloud coverage. It would be impractical for researchers to identify the presence of contrails using only the Worldview tool shown in Figure 20 and the visible and infrared images provided by the Satellite Match from Figure 21. Since satellites look down from above, there may be other high clouds blocking their appearance from above.

Furthermore, the second null hypothesis of the type of contrail formation varying by upper atmospheric temperatures at different locations was rejected. Contrail formation does indeed vary by the upper atmospheric temperatures of different sites as compared in Figures 14 and 15. It is expected that more persistent contrails generally appear with lower temperatures, when the most ice crystals are formed around jet exhaust. The separate locations of Dearborn Heights and Ann Arbor resulted in different types of contrails shown. To illustrate, the most common contrail type identified at the Ann Arbor location, which had consistently colder upper atmospheric temperatures, was persistent spreading.

The third null hypothesis discussing that bodies of water do not contribute to the contrail formation was also rejected. As shown in the MODIS Worldview (Figure 20), bodies of water do in fact affect the amount of contrail and cloud cover shown, with more prevalent amounts recorded directly above the five Great Lakes. However, it is very difficult to identify contrails from these satellite images. Of the three sites, Escanaba was expected to report more clouds and contrails due to its location on the shore of Lake Michigan and its latitude. Being farther north in latitude, the temperature is typically colder at this site, increasing the possibility of contrail formation.

The fourth null hypothesis concerning the ability to compare contrail observations made in warm, moist climates like Thailand to those in colder climates like the Great Lakes region was accepted. A comparison of data was hindered by the lack of recent data from Thailand as well as some language barriers with our partner school in Nakho Si Thammarat. Through video conferences, only anecdotal evidence between the contrail observations in the two locations was shared.

An improvement to the methods would be to take more consistent data on particularly the days with visible contrails shown, as well as getting data from earlier in the year during the summer when the weather is more humid and skies are more likely to be clear, allowing for increased contrail formation and better identification of contrails. This would enable the researchers to further evaluate the effects of temperature on contrail formations. These improvements would allow for better assessment of climate change trends and contrail predictions based on atmospheric and surface conditions.

Effective follow-up actions would be to find and collaborate with a local school in Michigan that agreed to take consistent data measurements and to make extensive efforts in expanding the scope of research by global outreach to other locations across the world with seasonal and climatic variations. The student researchers set up online conferences with students from Thailand in order to share the purposes of their research and make plans to collaborate. Although it did not end as anticipated, it was established that they would contribute to further research by submitting their data for comparison upon returning from their summer break in May, 2020.

Acknowledgements: Thank you to the GLOBE Program for access to both online and print resources to make this project feasible. Thank you also to the staff of NASA LaRC for the emails showing satellite comparisons with our data. We also are thankful for the individual student contacts we were able to make at the Princess Chulabhorn Science High School in Nakhon Si Thammarat. We learned a great deal from our new GLOBE friends in Thailand as we shared our research with them and learned about their work in GLOBE. This project could not have been possible without the crucial assistance of the project mentor, Mrs. Diana Johns, who introduced the researchers to the foreign students and provided unfaltering encouragement and support throughout the entire process. She provided all of the resources necessary for the success of the project and devoted countless time and effort into it without hesitation.

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Badges: The following badges we would like to be considered for are; I am a Data Scientist because we utilized past studies as well as recent studies to aid our current research and make predictions about future trends. I am a Collaborator, Noor Abu-Rus and Zaharaa Altwaij, under the supervision of Mrs. Diana Johns, worked with students from Princess Chulabhorn Science High School under the supervision of Mr. Thapanawat Chooklin through various facebook video-chats. We met with them at 6:30 am our time and 6:30 pm their time; a twelve hour difference. Due to our efforts to compare data with Thailand researchers, and Ann Arbor researchers. I Make an Impact, due to our ability to recognize the relevance that this research holds for not only the community but also the world.