Contrail Formation in Southeastern Michigan with Potential Regional and Global Impacts

Noor Abu-Rus and Zaharaa Altwaij

Crestwood High School, Dearborn Heights, MI

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. In addition, 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 help unravel the potential implications and effects of contrails on climate change.

INTRODUCTION

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. 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. Some persistent contrails can last up to 17 hours and play a heavy role in increasing cloud coverage, and thus global warming.

RESEARCH QUESTIONS

- 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?
- How does contrail formation vary by upper atmosphere temperatures at different locations?
- Do the locations of nearby large bodies of water contribute to any extent of contrail formation?
- 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?

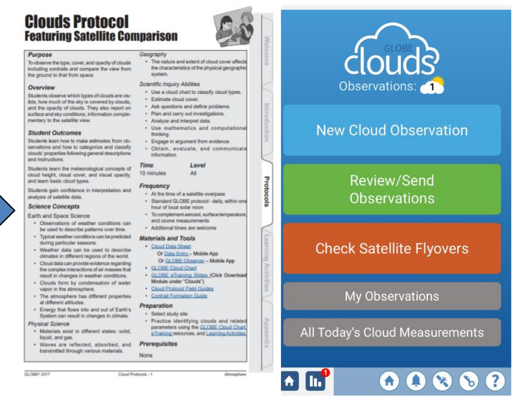
NULL HYPOTHESIS

- Local ground observations of contrails cannot be used to verify contrails evident in satellite photos.
- The type of contrail formation does not vary by upper atmospheric temperatures at different locations.
- The location of the nearby bodies of water does not contribute to contrail formation.
- 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.

METHODOLOGY

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: Clouds Observation Sites Figures 1 and 2 show the latitude of 42.32 N and a longitude of 83.29 W. of the site.



Figures 3-4: Cloud and Contrail Protocol. Figure 3 is the GLOBE cloud and contrail data collection protocol. Figure 4 shows the first step in making a cloud observation on the GLOBE Observer app.

Figures 5-6: Cloud Observation. Figures 5 and 6 show the students using proper cloud data protocol to record visual observations on cloud and contrail attributes.

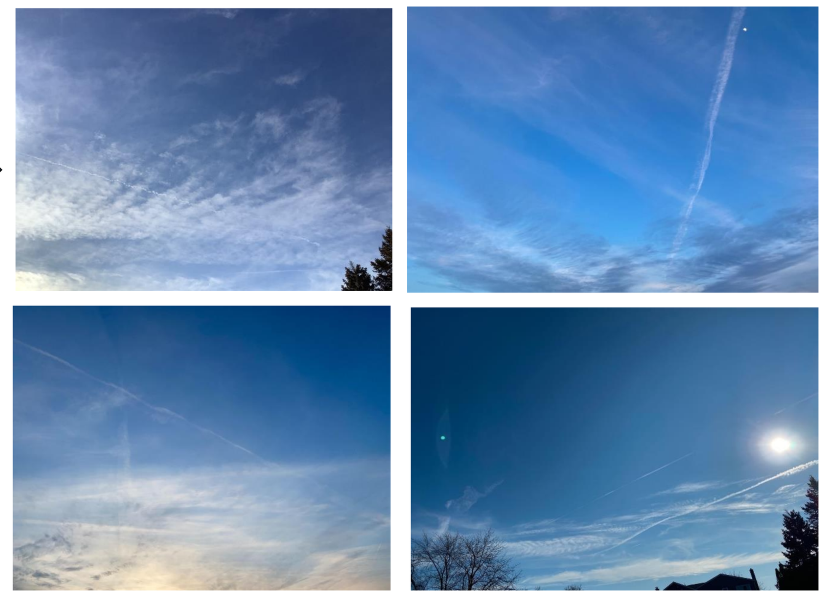
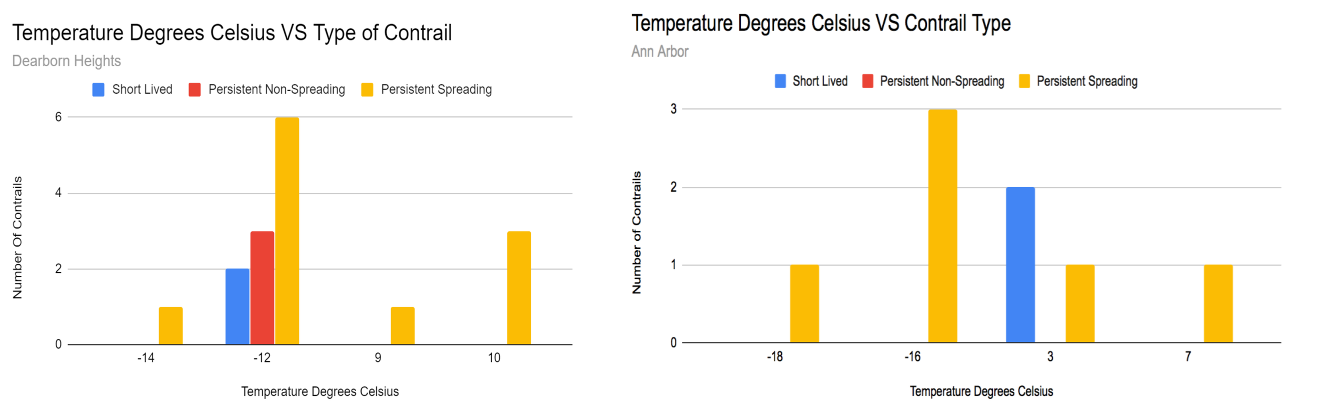


Figure 7-10: Contrail. Figure 7, 8, 9, and 10 show the persistent spreading contrails found.

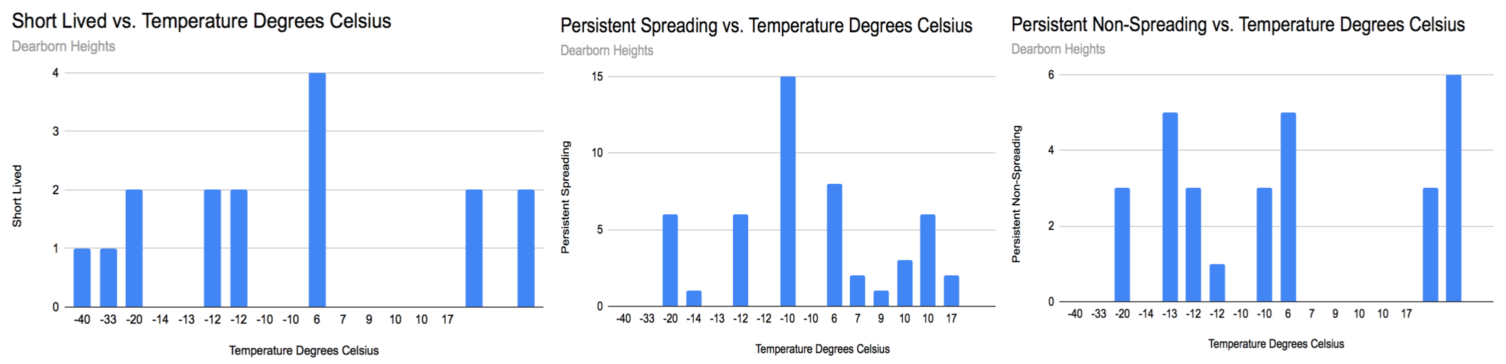
RESEARCH IMPLICATIONS

- What are contrails? What most people do not realize is that contrails do not just magically appear on a sunny and clear day.
- 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.

RESULTS



Figures 11-12: Temperature and Location Versus Contrail Type. Figures 11 and 12 show the temperatures of the data along the x-axis on particular dates. Figure 10 is the data obtained from the researchers' site at Dearborn Heights. The temperature was obtained from the NASA infrared satellites. Figure 11 represents the data of the contrails and the temperature from Ann Arbor both retrieved through the Visualization System.



Figures 12-14: Temperature Versus Contrail Type. Figures 12-14 show the data comparison of temperature to the type of contrails in Dearborn Heights. Figure 12 (left) shows the number of short-lived contrails as compared to temperature. Figure 13 (middle) shows the number of persistent contrails graphed with temperature. Figure 14 (right) shows the number of persistent non-spreading contrails against temperature.

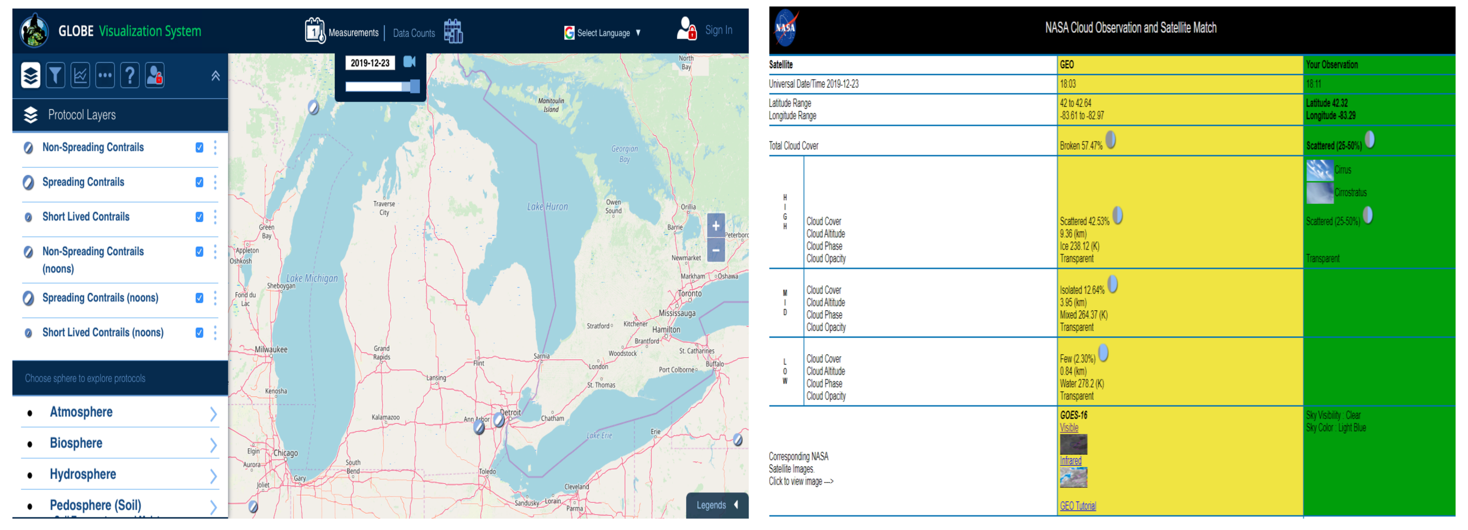
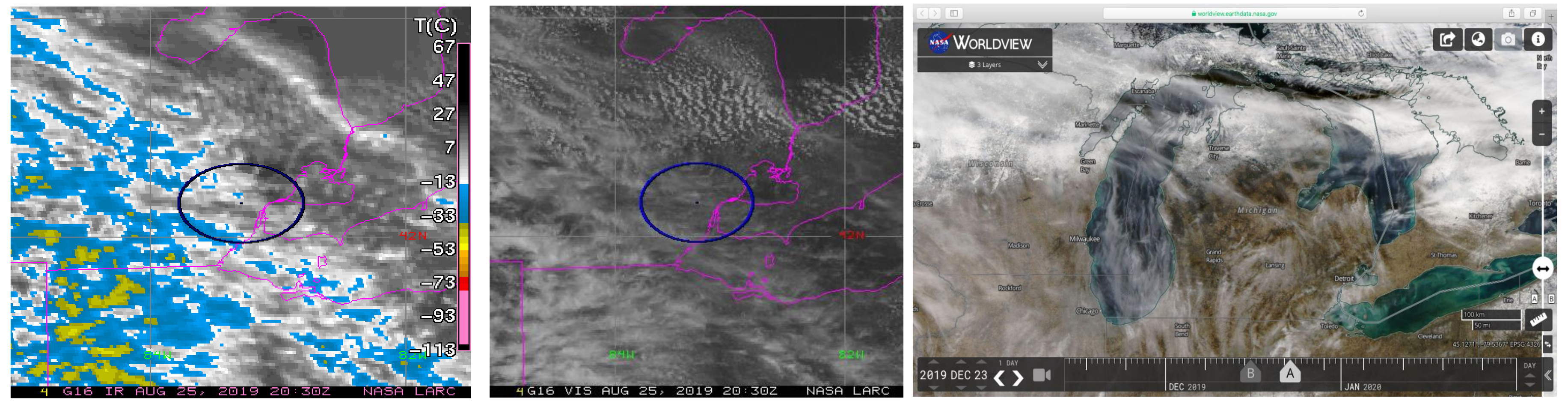


Figure 15-16: GLOBE Visualization System. Figure 15 displayed on the left is a screenshot of the GLOBE Visualization System (obtained through the GLOBE website) that was utilized to locate nearby observation sites with which to compare cloud data. **NASA Cloud Observation and Satellite Match.** Figure 16 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.

EXPLANATION

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 **site** 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 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.



Figures 17-19: NASA GOES-16 Satellite Imagery. Figures 17, 18, and 19 are examples of the satellite imagery used to obtain the temperature and location for the Dearborn Heights data. Figure 17 (left) shows the infrared image obtained by the satellite. Figure 18 (middle) shows the visible image from the satellite of the location of the contrails. **Modis Aqua Satellite.** Figure 19 (right) 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

CONCLUSION

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 19 and the visible and infrared images provided by the Satellite Match from Figure 16. 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 11 and 12. 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 19), 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 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.

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.

BIBLIOGRAPHY & CITATIONS

- Bock, Lisa & Burkhardt, Ulrike. (2019). "Contrail cirrus radiative forcing for future air traffic." *Atmospheric Chemistry and Physics*. 19. 8163-8174. 10.5194/acp-19-8163-2019.
- Burkhardt, U., Bock, L. & Bier, A. "Mitigating the contrail cirrus climate impact by reducing aircraft soot number emissions." *npj Clim Atmos Sci* 1, 37 (2018). https://doi.org/10.1038/s41612-018-0046-4. Accessed 7 Mar. 2020.
- Changnon, Stanley A. "Climate Fluctuations and Record-High Levels of Lake Michigan." *Bulletin of the American Meteorological Society*, vol. 68, no. 11, 1987, pp. 1394–1402. *JSTOR*, www.jstor.org/stable/26226085. Accessed 7 Mar. 2020.
- "Clouds Protocol Featuring Satellite Comparison." *The Globe Program*, www.globe.gov/documents/348614/7b79ee82-ebd6-4382-9283-181a412f063f.
- "Contrail Education." *NASA*, NASA, 2020, science-edu.larc.nasa.gov/contrail-edu/.
- Federal Aviation Administration. "Contrails 101." *FAA Seal*, 3 Oct. 2014, www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/contrails/.
- "GLOBE Science Data Visualization." *GLOBE Visualization*, vis.globe.gov/GLOBE/.
- "Google Earth." *Google Earth*, Google, 2020, earth.google.com/web/@42.32171697,-83.2947219,189.52068184a,666.80224309d,35y,0h,0t,0r.
- Duda, David & Minnis, Patrick & Nguyen, Louis & Palikonda, Rabindra. (2004). "A Case Study of the Development of Contrail Clusters over the Great Lakes." *Journal of The Atmospheric Sciences* - J ATMOS SCI. 61. pp. 1132-1146. 10.1175/1520-0469(2004)061<1132:ACSOTD>2.0.CO;2.
- Dunbar, Brian. "National Aeronautics and Space Administration NASA Official." *NASA*, NASA, 2020, www.nasa.gov
- "NESDIS News & Articles." *NOAA National Environmental Satellite, Data, and Information Service (NESDIS)*, 27 July 2016, www.nesdis.noaa.gov/content/do-contrails-affect-conditions-surface.
- Pearce, Fred. "How Airplane Contrails Are Helping Make the Planet Warmer." *YaleEnvironment360*, 18 July 2019, www.e360.yale.edu/features/how-airplane-contrails-are-helping-make-the-planet-warmer.
- "Rapid Response - LANCE - Terra/MODIS 2019/357 15:50 UTC." *NASA*, NASA, lance.modaps.eosdis.nasa.gov/cgi-bin/imagery/single.cgi?image=band311.A2019357155000-2019357155500.2km.jpg.
- "Visualize Data." *NASA*, NASA, 8 Mar. 2020, earthdata.nasa.gov/earth-observation-data/visualize-data.
- "Worldview: Explore Your Dynamic Planet." *NASA*, NASA, worldview.earthdata.nasa.gov/?v=-85.6653086419753,41.24,-81.7146913580247,43.24&t=2019-08-25-T00:00:00Z&l=Reference_Labels,Reference_Features,MODIS_Terra_CorrectedReflectance_TrueColor.