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AOS Capstone
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Research Paper AOS Capstone | Center for Sustainability and the Global Environment

Summary

This research project aims to use satellite measurements to study nitrogen dioxide (NO_2) in the troposphere over Arizona. Furthermore, the study initially aimed to study the relationship between traffic relationships and NO_2 concentrations over Phoenix, AZ. As the study progressed, it evolved to focus on a relationship between wind and NO_2.

Motivation for Study

Nitrous oxides (NOx), composed of NO_2 and nitrogen oxide (NO), is an ingredient in the formation of tropospheric ozone (O_3). Nitrous oxides are highly reactive gases that, when in the presence of sunlight, can form O_3. (US EPA, 2016).

Ozone in the stratosphere blocks ultraviolet rays from penetrating deep into the earth's atmosphere. This is O_3 that protects human health. When O_3 forms in the troposphere, it becomes a pollutant that provokes human health issues. In the troposphere, people can directly inhale O_3 which may irritate airways and damage the human respiratory system (US EPA, 2016).

Aside from its contribution to O_3 formation, NO_2 alone is threatening to human health. The United States Environmental Protection Agency (EPA) explains that preexisting respiratory diseases, such as asthma, can become aggravated in the presence of NO_2. Severe cases of exposure can even lead to hospitalization (US EPA, 2016). Because NO_2 is so harmful to human health and promotes tropospheric O_3, we need to increase our understanding of our contributions to NO_2 emissions and how we can mitigate its damaging impacts.

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If we refine our understanding of NO_2 sources, then we can extend our knowledge of tropospheric O_3. As an increasingly important dialogue about climate change continues to circulate around the public, we need to continue to improve our own understanding of air pollution, meaning we need more reliable and exact data to tell us a more complete and accurate story about what is happening between anthropogenic activity and the atmosphere.

Abstract

As one of the six criteria pollutants, defined by the EPA as air pollutants that harm human health, NO_2 has been studied to understand its origins and lasting impacts on the atmosphere (US EPA, 2016). A major source of tropospheric NO_2 comes from fuel burning sources such as vehicle emissions, power plants, and off-road equipment (US EPA, 2016). A study from Lund University found a relationship between rush-hour traffic and NO2 levels in the breathable air. (Science Daily, 2018) On road vehicle traffic peaks during rush hours, therefore NO_2 emissions peak in rush hour traffic.

In July 2004, NASA launched the Ozone Monitoring Instrument (OMI) into space to orbit the earth. The device was designed to study atmospheric chemistry and dynamics. OMI has the capability to distinguish between different aerosols in the atmosphere and reveal distinctions in atmospheric composition (Earth Online, 2019). Following the launch of OMI was the launch of the Tropospheric Monitoring Instrument (TROPOMI) in June 2018. Ever since the satellite's commission, it has been orbiting the earth to collect measurements of atmospheric species,

climate observations, and O_3 layer activity (TROPOMI, 2018). TROPOMI provides a more complete data set of atmospheric measurements and has a higher resolution display of atmospheric composition than OMI.

Wind impacts atmospheric chemistry by displacing atmospheric species from their sources. Weak winds result in stagnant air. When NO_2 sources pollute stagnant air spaces, the pollution can become highly concentrated over a small area. Whereas stronger winds disperse air pollution from its sources and can impact a larger area in lower concentrations. Wind direction dictates where the air pollution goes (National Weather Service, 2017).

Introduction

Wind can reduction or increase air pollution activity over large areas. Winds that blow over a source of air pollution can disperse the winds over a greater area, allowing for the pollution to decrease over the source area while increasing the amount of the pollutant over areas that would otherwise not have the pollution in its airspace. Measuring both winds speed and direction are essential in tracking its relationship to a pollutant in the air (Waikato Region Council).

Urban areas have a large amount of on road vehicles especially in rush-hour traffic. Nitrogen dioxide reacts with volatile organic compounds (VOCs) in the presence of sunlight to form tropospheric ozone. Sources of VOCs include cleaning products, paint, pesticides, and vehicle products (EPA, 2016). These sources of VOCs are typically in the same airspace as the tropospheric NO_2 pollution, where they can react to form O_3. Not only can NO_2 enable the development of tropospheric O_3 but also induce asthma and encourage respiratory infections when inhaled (EPA, 2016).

Measurements by TROPOMI provides descriptions about air pollution. With a resolution of 24.5 km^2, TROPOMI can distinguish specific air pollution details over a single city. In general, the satellite shows a consistency of high NO_2 concentrations to urban areas like Phoenix, with a land area of 1,340 km^2 (World Population Review, 2019, TROPOMI, 2018).

VentuSky, an online application developed by a Czeh meteorological company who aims to spread wind and other atmospheric data to the public, uses NOAA archived wind data to show historical wind directions and speeds. These measurements resonate with the relationship of weak winds and lower concentrations of NO_2 sprawled over a larger land area. Wind directions would influence where the NO_2 covers and the wind speeds would gauge the potential distance the pollution could move from its source.

After TROPOMI was launched in October 2017, it performed six months of calibration. Once the calibrations were completed, the satellite commissioned for live usage. Ever since June 2018, the satellite has been collecting atmospheric chemistry and dynamics data (TROPOMI, 2018). The satellite provides detailed coverage over Arizona every single day. A commissioned TROPOMI is great for air pollution studies because it can help write the story of identifying sources of criteria air pollutants and measuring their impacts on human health.

Methods

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The first step in this project was to be able to overlay TROPOMI data onto a map. Using Python to write the script, I was able to successfully produce TROPOMI measured data over Arizona. At first, my main interest involved vehicle commuter traffic and its relationship to NO_2 emissions in Phoenix, Arizona. I wanted to study Phoenix because they have a heavy traffic problem that is only increasing and Phoenix, being in the Valley of the Sun, receives an extreme amount of sunlight each year (ADEQ, 2017). Nitrogen dioxide emissions and sunlight is a recipe for tropospheric O_3. Knowing that O_3 forms in the presence of NO_2, it is important to understand the precursors for O_3 formation to thoroughly understand O_3 formation.

My initial objective was to reveal a relationship between traffic volume fluctuations and TROPOMI measured NO_2. To do this, I needed to plot averaged TROPOMI NO_2 measurements over 5-day weeks and 2-day weekends. The challenge with averaging TROPOMI data is that right now, NASA's data that is offered is not gridded. Our group in the Center for Sustainability and the Global Environment did not have experience in regridding data. To accomplish this would have added on many more unanticipated weeks of data processing. The data needed to be gridded before being averaged to have an accurate display of averaged NO_2 measurements. Due to limitations on resources such as time, this project needed to be amended at this point to answer a question that could be answered using single day measurements and forgo the averaged data, at least for now.

After this revision, my next task was to decide what kind of conditions would be optimal in showing weekday and weekend variations in NO_2 due to commuter traffic. Initially, I used Air Quality Index (AQI) reports from the EPA to find the most severe days of measured NO_2 over

Phoenix. I thought this approach made sense so that my project could showcase TROPOMI data collection over Phoenix's days of greatest NO_2 pollution concerns. I realized late into my project that this was the opposite approach I should have been using all along. Instead, my research question would be better answered with an analysis of good air quality days over Phoenix. My thought process lead me to believe that if I wanted to see NO_2 potentially originating from vehicle emissions, then a day with poor air quality would have extra factors that would display the NO_2 over all of Arizona, not showing so much of vehicle emission sources, factors like wind moving pollutants across the entire state.

Because of time constraints and the inability to average the TROPOMI measured NO_2 data, this is what by project evolved to. Instead of explicitly addressing vehicle emissions' contributions to NO_2 over Phoenix, I looked at how wind patterns over all of Arizona related to TROPOMI measured NO_2. VentuSky displays historical and real time weather conditions over the entire world with data provided by NOAA. I was able to find historical data of wind patterns to show a relationship between wind and TROPOMI measured NO_2.

Another component of this study was to decide not only to study days with low air pollution but a time of the year that made sense. TROPOMI started collecting data in June 2018. From then until now, I decided that a major holiday would cause an abnormal excess of vehicle emissions. Therefore, I started my data analysis with Thanksgiving Day, 22 November 2018.

Results

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After evaluating the TROPOMI data with the NOAA wind records, the plots show a consistent relationship with wind speed and direction variances with differences in measured NO_2. Figure 1 shows TROPOMI measured NO_2 data on the top row and them wind records of their respective days on the bottom row. Phoenix consistently has higher levels of measured NO_2 than the rest of the state of Arizona and consistently lower wind speeds.

The bottom column of figure 1 shows consistently low wind speeds over Phoenix compared to the rest of the state. Areas with lower wind speeds have higher values of NO_2 for that day. Where and when wind speeds become stronger relates to the increased TROPOMI measured NO_2 concentrations. Based on the NOAA provided wind data and NASA's TROPOMI data archive, figure 1 demonstrates a relationship between wind trends and air pollution variations with a consistent trend of weak winds and high NO_2 over Phoenix.

Although not the final focus of my research, the two days of plots in figure 1 allude to potential vehicle emission impacts on the troposphere. A region of consistently high NO_2 in Arizona is over the Phoenix area. Further, this high NO_2 area is consistent with where there are more densely populated areas and commuter traffic. Figure 1 may reveal the weekday and weekend NO_2 emission variance because the TROPOMI data collected on a Saturday is less severe than the weekday recorded NO_2, on a Tuesday.

Thanksgiving Day, 22 November has the worst air quality occurrence of all the days studied between 22 November and 29 November 2018. Figure 2 shows the highest occurrence of NO_2 in Arizona over the duration of my study.

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Tuesday 27 November **Saturday 24 November**

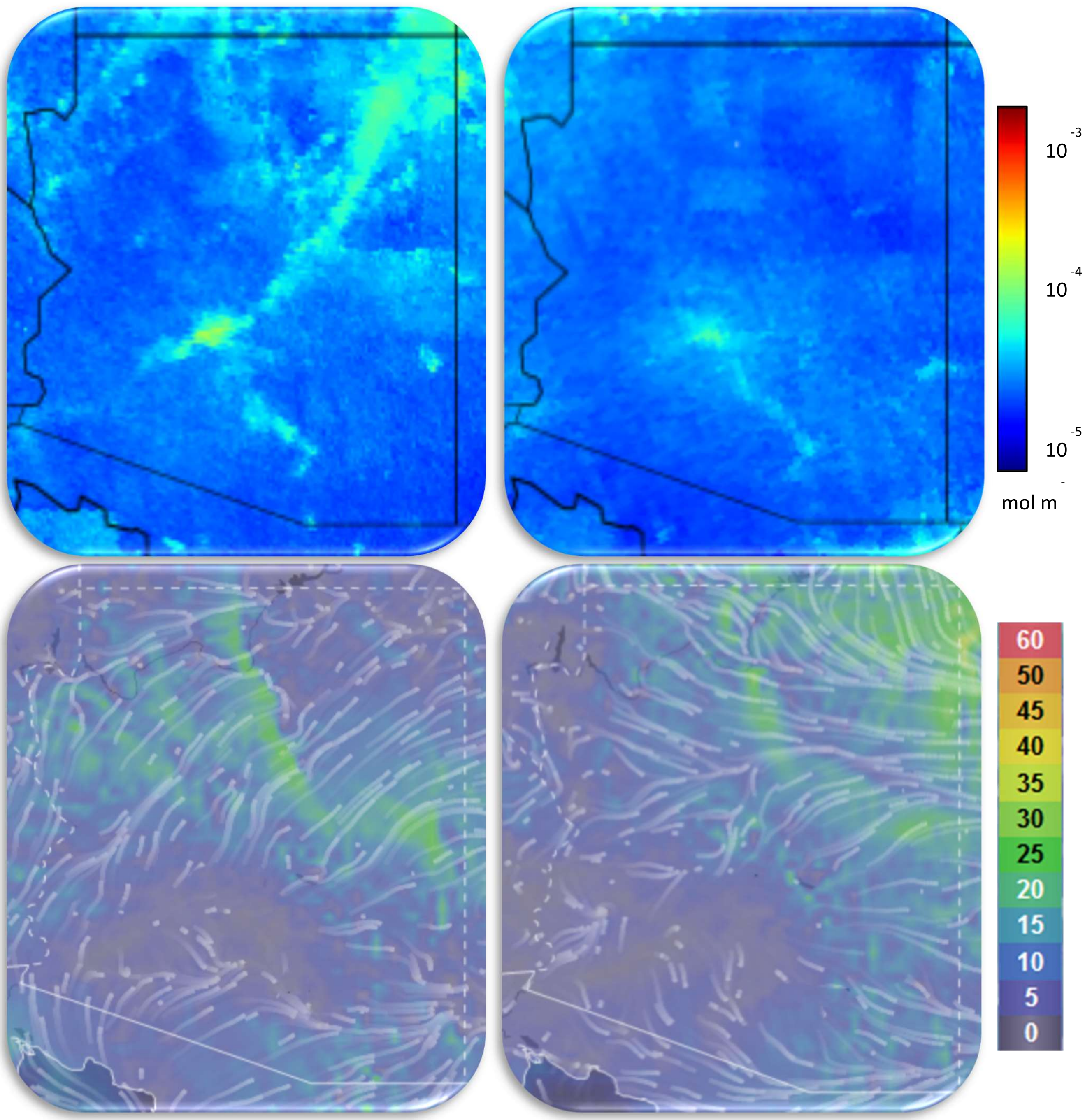

Figure 1: TROPOMI measured NO2 (left) and NOAA recorded winds (right) are compared side by side to show a consistency of relatively high pockets of NO_2 and low wind speeds.

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Thursday 22 November

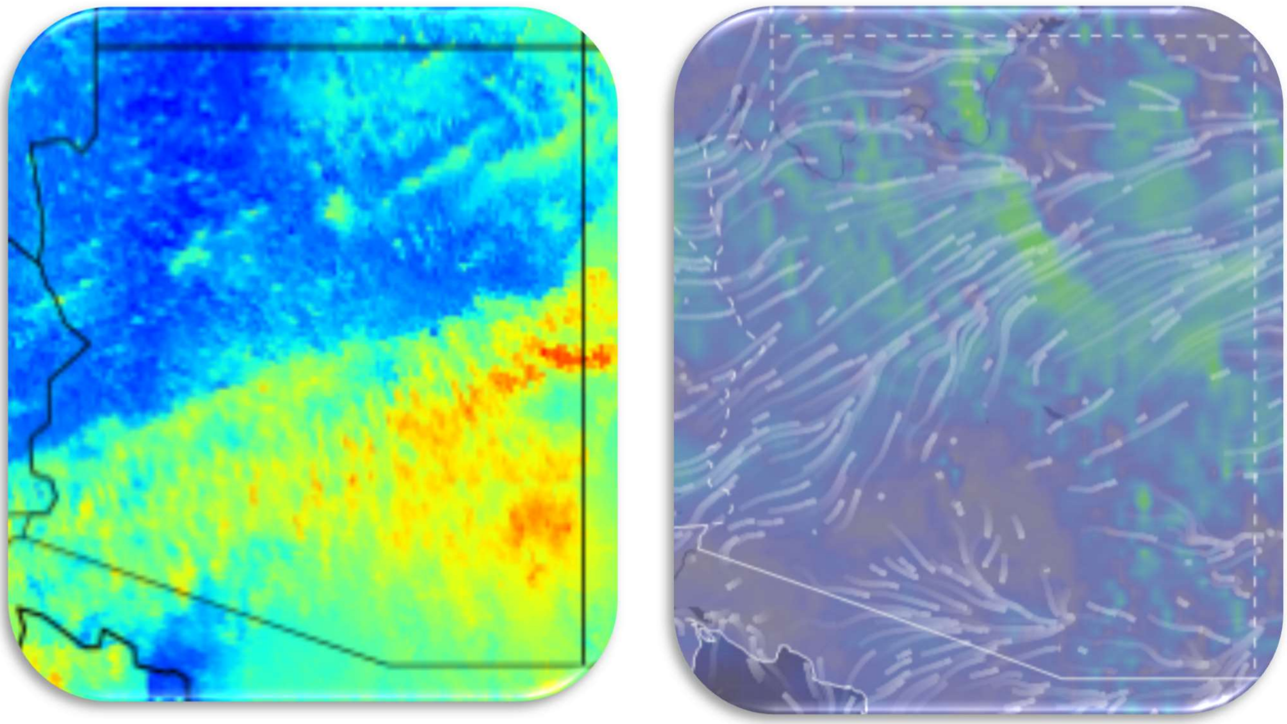

Figure 2: The most NO2 recorded by TROPOMI in this study (left) and same day wind patterns provided by NOAA (right)

Discussion

Initiated from this project, there are several next steps to take to expand on air quality research to improve public health for not only Arizona residents but also the entire world. One next step I would take would be to isolate my study to Phoenix.

A study of Phoenix would be able to move my project back to its focus, that being able to study a weekday and weekend variance in the amount of NO_2 emissions measured by TROPOMI. In order to accomplish this, I would change the scale of my project and dedicate the range of NO_2 emissions to only the Phoenix area, including surrounding suburbs.

A key factor to consider with Phoenix is that the city, being in the Valley of the Sun, lies lower than its surrounding area. Because the city is in a valley region, there can be a relationship established to demonstrate how winds are impacted by the Phoenix elevation.

Another piece of the study involves analyzing traffic patterns in the Phoenix area. Traffic trends can reveal places of heavy congestion versus roadways that move with ease. At first a daily log of average traffic trends may be useful, then compare the data to averaged TROPOMI measurements. Averages provide a stronger representation of the bigger picture in Phoenix. Averages remove outlier data and can make a more concrete case of the weekend effect.

Conclusion

Based on the conclusions from figure 1, wind and air pollution have a relationship where the wind influences the concentrations and reach of NO_2. Every air quality study has unique attributes which need to be considered when investigating the causes and impacts of poor air quality. This study can be expanded to explore additional factors that could impact the presence and behavior of NO_2 over the Phoenix area. Topography, outlying potential sources of additional pollution, and urban planning all could be explored to expand on the knowledge we have of the sources and activity of NO_2 in the area.

Furthermore, not only should NO_2 be studied, but also other criteria pollutants and airborne dust. Phoenix endures dust storm episodes and faces air quality challenges from their own surrounding land. NO_2 also reacts with other chemicals in the atmosphere and may have more of an impact beyond its damaging effects on the human respiratory system, such as contributing to the formation of tropospheric O_3.

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