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Intermountain West Health and Air Quality

Monitoring Regional Air Quality to Address Air Pollution in National Parks through the Application of NASA Earth Observations

DEVELOP Technical Report

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1. Abstract

Good air quality is critical for the Intermountain region of the National Park Service (NPS) to uphold legal mandates, such as the Clean Air Act, to protect park visitor health, the ecological health of the park flora and fauna, and the preservation of the vistas of the parks for the present and future generations. Unfortunately, nitrogen dioxide (NO_2) harms air quality related values and the health of guests that visit the parks. This project utilized the Ozone Monitoring Instrument aboard Aura, a NASA Earth observation satellite, to create spatial and temporal trend maps as well as visual displays NO_2 data from January 2005 to December 2017. By applying NASA Earth observations, the NPS can complement their ground-level data from monitoring programs. This uncovers trends of persistent concentrations of NO_2 in the Intermountain region and its surrounding areas. With the help of NASA Earth observations, the NPS is able to determine source regions of NO_2, allowing them to develop mitigation strategies and create long term management action plans involving visibility, air quality, and the parks' natural resources.

Keywords
Nitrogen dioxide, NO_2, Aura, OMI, human health, air quality, National Park Service, remote sensing

2. Introduction

2.1 Background Information

Regulations such as the Clean Air Act require the National Park Service (NPS) to monitor visibility and identify harm caused by man-made pollutants (Shenandoah National Park, 2015). Nitrogen oxides (NO_x) include both nitric oxide (NO), and nitrogen dioxide (NO_2). NO_x in the troposphere are formed by fossil fuel combustion, the burning of biomass, soil emission, and lightning processes, and are a precursor to tropospheric ozone, a greenhouse gas (Kim et al., 2009). NO_2 plays a powerful role in the troposphere as it reacts with trace gases such as ammonia and ozone (Crutzen, 1970; Chameides & Walker, 1973). These reactions lead to reduced visibility through haze as well as negative impacts on human, animal, and plant health. Short-term mortality-studies have shown that NO_2 can cause respiratory problems and lead to impairment of lung function growth in children (Faustini, Rapp, & Forastiere 2014).

Due to the harmful impacts of NO_2, the NPS has been mandated to protect park visitor and ecological health, to preserve extensive vistas, and to safeguard Air Quality Related Values (AQRV). The NPS does not normally monitor NO_2 concentrations directly in parks except for a few places where there is a particular concern. Most known point sources of NO_2 are located outside of national park boundaries, where they have no authority, requiring them to work with local and other governmental agencies.

This study focused on the Intermountain region of the United States, encompassing Arizona, Colorado, Montana, New Mexico, Oklahoma, Texas, Utah, and Wyoming as seen below in *Figure 1*.

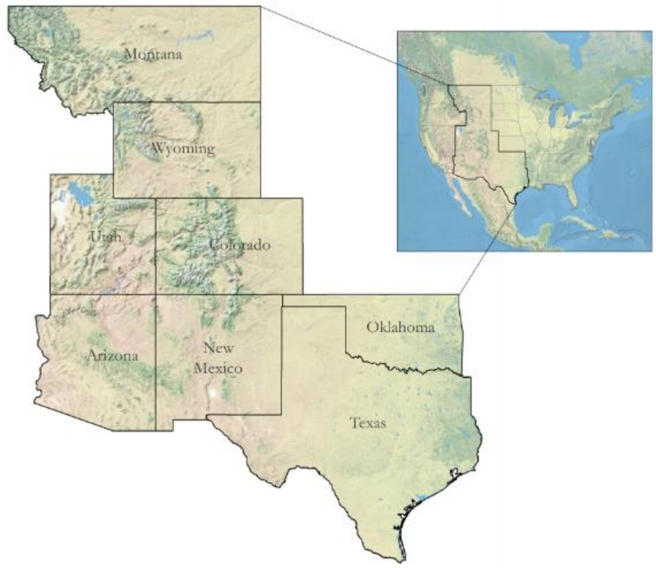

Figure 1: Intermountain Region of the NPS

Specific national parks were selected within our region for closer analysis: Arches National Park, Canyonlands National Park, Carlsbad Caverns National Park, Chaco Culture National Historical Park, Colorado National Monument, Dinosaur National Monument, Grand Canyon National Park, Grand Teton National Park, Mesa Verde National Park, Organ Pipe Cactus National Monument, Rocky Mountain National Park, Theodore Roosevelt National Park, Wind Cave National Park, and Yellowstone National Park. Parks were selected due to their proximity to shale basins, their higher levels of uncertainty in NO_2 concentrations, as well as their regional importance. The national parks and their surrounding shale basins are shown in *Appendix A* of the Appendices. Our study period included the years from 2005 through 2017, beginning with the first full year of atmospheric data acquired by the Ozone Monitoring Instrument (OMI). The NPS has conducted previous research regarding health and air quality in this region, however, they have not utilized NASA Earth observation data for this purpose. In particular, the NPS has been evaluating pollutant emissions from areas outside of park lands. However, there is little in-depth national park monitoring records of NO_2, so it must be addressed.

The transportation of pollutants by air can affect destinations far from their source, therefore by limiting the extent to only the Intermountain region, potential sources of pollution could be missed. Thus, the team expanded the study area westwards to include Idaho, Nevada, California, Oregon, and Washington. The purpose of the expanded study area was to find external concentrations that may be impacting air quality and health within the Intermountain region.

To quantify and monitor NO_2 impacting national parks, the combination of remote sensing and ground-level measurement data are becoming more common. Before 2009, satellite data had not been used to address National Ambient Air Quality Standards (NAAQS), which were established under the Clean Air Act amendments of 1990. NASA's Earth observation satellites have instrumentation capable of tracking air pollutants, such as Aura's sensor OMI, but these instruments had not been used to extensively corroborate data obtained by ground level sites within the Intermountain region (Hoff & Christopher, 2009). To add to the current air quality monitoring programs in the Intermountain region, this project utilized OMI to compare and validate its measurements to *in situ* data collected by the NPS. OMI provides daily global coverage and measures a variety of atmospheric parameters at a resolution of 0.25 degrees by 0.25 degrees

(NASA Goddard, n.d.). OMI NO_2 data are recorded as Molecules/cm^2, a vertical column density that represents the total number of molecules within a vertical slice of the troposphere. The majority of NO_2 measurements are recorded within the boundary layer. This results in the boundary layer heavily controlling the NO_2 recorded value.

2.2 Project Partners & Objectives

This project was a collaboration with the NPS – Intermountain region. The Organic Act of 1916, established the NPS to "promote and regulate the use of Federal areas known as national parks, monuments and reservations…which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Thus, a primary concern of the NPS includes the air quality of national parks. This project aimed to (1) assess historical patterns of NO_2 across the Intermountain region, (2) locate sources of NO_2 impacting the Intermountain region to enhance intra-park monitoring, (3) increase understanding of NO_2 concentrations and flows, and (4) provide tools to protect national park resources and increase the understanding of visibility and atmospheric pollutants. Not all national parks have air quality monitoring stations, and those that do can only monitor the air quality from within the park - not determine where it came from. This project aimed to mitigate the incomplete coverage of NPS air quality monitoring of NO_2 as well as assist in air pollution source determination.

3. Methodology

3.1 Data Acquisition

OMI imagery from NASA Goddard's Earth Sciences Data and Information Services Center (GES DISC) in the Distributed Active Archive Center (DAAC) was acquired by the team. The GES DISC has an online archive of the OMI data from 2005 – present. This project utilized the Level-3 Version-3 Nitrogen Dioxide (NO_2) products with global grids of 0.25x0.25 degrees that measures NO_2 in Total Columns and Total Tropospheric Columns through atmospheric layers. Each downloaded file contains four preprocessed measurements from the OMI sensor. Two of these files are related to total column NO_2 and the other two are related to tropospheric measurements of NO_2. The team selected the tropospheric column cloud screened measurement records. These measurements contain only the NO_2 concentrations in the troposphere that have been screened at 30% for cloud contamination. Cloud screened data was used to reduce the level of cloud contamination and interference.

The team also acquired the Environmental Protection Agency's (EPA) Clean Air Status and Trends Network (CASTNET) data for each year of the study period. Raw data measurements were selected to acquire the un-aggregated measurement. The CASTNET raw data selected consists of hourly readings of air pollution parameters monitored by the EPA. Carefully chosen were the Trace Gas Hourly measurements for NO_2 to use for *in situ* measurements.

Data of electrical generating units (EGU) was provided to the team from the NPS – Intermountain region. The EGU data represents the reported pollutant levels emitted by power generating stations within and surrounding the Intermountain region. The power generating stations emit NO_x through combustion of fossil fuels.

3.2 Data Processing

Data processing was conducted in Python, with the implementation of the ArcPy library. First, the desired ColumnAmountNO_2TropCloudScreened dataset was extracted from the Hierarchical Data Format (HDF) dataset collection. These extracted raster datasets were projected into the Geographic Coordinate System

North American 1983 Datum (GCS NAD83) to facilitate further analysis. OMI data level 3 version 3 products are global scale, thus we masked it to the Western half of the United States.

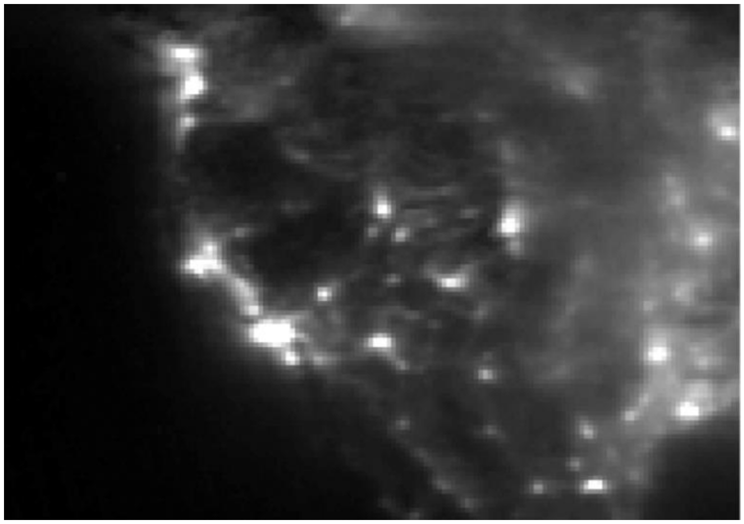

Figure 2: Image of the masked region for study

Once masked, two operations were conducted simultaneously.

The first operation took the same masked datasets and reclassified the cells to a binary 1/0 dataset representing cells with valid data. A binary value of 1 represented recorded positive values from the OMI Sensor. A binary value of 0 represented either negative values, null, or no data entries from the OMI sensor. These binary datasets were then summed to determine the number of 'looks' each cell received in an annual, seasonal, and monthly bin for the duration of the study period. OMI can have a negative bias in detection of atmospheric gasses in a column over unpolluted regions (Krotkov et al., 2017). This is due to the use of modeled atmospheric profiles in the stratosphere-troposphere separation algorithm (Krotkov et al., 2017). In areas of very low concentrations of NO_2, these models are the only factors driving the record calculations (Krotkov et al., 2017). Areas that are prone to negative values are open oceans and areas with little pollution. Moreover, for the cloud-screened product we used, wintertime brings significantly consistent cloud coverage over the northern part of the United States – leading to a drastically decreased number of valid looks from OMI in the winter for those areas.

The second operation was the creation of statistics to determine the trends in NO_2 concentrations. The set of statistics were Coefficient of Variation, Maximum, Average, Median, Minimum, Standard Deviations, and Range. Each statistic was calculated on a period, annual, seasonal, and monthly time scale. The analysis of the trends was conducted across several geographic scales; (1) regional level, (2) state level, (3) national park/shale basins level. Python scripts were developed to conduct the following: (1) calculation of each statistic from the daily OMI data, (2) aggregation of the daily imagery into the desired time scales, and (3) analysis of each statistic across the geographic scales.

The EPA's CASTNET data representing NO_2 concentrations in the Intermountain region were downloaded. The data was then subset to meet the following criteria: (1) located within the Intermountain region, (2) occurred over the entire study period, and (3) recorded hourly observations at the time of Aura's flyover for the Intermountain region. These criteria led to a total of 30 monitoring stations being selected. The monitor locations were confined to the states of Colorado and Arizona. Each monitors unique location was extracted and used to create a point shapefile. This point file was then used to extract the values from the OMI imagery. The OMI values based on the monitor locations were used to compare the satellite observations to the recorded observation values of NO_2 by the monitors.

The EGU data were extracted based on state name to comprise facilities within the Intermountain region. Each facilities' unique location was extracted and used to create a point shapefile. This point file was then used to extract the values from the OMI imagery. The OMI values based on the EGU locations were used to compare the satellite observations to the reported annual EGU NO_x emissions.

3.3 Data Analysis

During the data analysis process, we created annual average trend maps for our region in order to see areas of NO_2 concentrations and how they vary over time as well as anomalies presenting how each pixels annual average in our region differentiates from its average for the whole period. The annual average trend maps were created by averaging each pixel's daily recorded value over the course of the year. The annual anomaly maps show whether or not each pixel's annual average is below or above its average by subtracting corresponding pixel's average for the entire period.

In order to have a closer understanding of trends and values, our team created visual displays of data comparisons, such as graphs displaying annual NO_2 trends at the Intermountain region, state, and selected national parks/shale basins scale. Per NPS partner's request, the national parks and neighboring shale basins areas were selected to generate statistics to determine if shale basins were influencing nearby national park air quality.

The OMI NO_2 samples over that exact EGU NO_x emission source point locations were selected and used for comparisons between the two datasets. Daily OMI NO_2 values over these locations were annualized for this comparison.

We compared hourly EPA CASTNET Monitor measurements of NO_2 at 1:00pm to OMI NO_2 samples over the exact point locations of the monitors. We created annual trend graphs comparing the two data sets for each state, but discovered many inconsistencies due to the different elevations of the monitors. In order to see the most accurate results and highest possible correlations between OMI data and CASTNET monitor data we analyzed the monitors at the highest and lowest elevations with data for each year in our study period.

The Student's t-test calculation was performed as per the equation below in Figure 3.

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

Figure 3: The Student's t-test equation

The sample mean, *x-bar*, for our study was the mean value over a region. The mean NO_2 value for the Intermountain region was used for the population mean, μ_0. Sample standard deviations, *s*, acted as the standard deviation of OMI measurements. Lastly, the sample size, *n*, was determined by the number of OMI observations, or looks. Each variable was calculated at the desired temporal scale and geographic area.

Standard errors were calculated to represent potential errors in the data. Calculated as follows given that *s* is the standard deviation and *n* is the sample size, with the equation being shown in *Figure 4*. These variables were determined by the same value we assigned in our Student's t-test calculation based on temporal scale and geographic area.

$$\frac{s}{\sqrt{n}}$$

Figure 4: The equation used to calculate standard error

After completing this we calculated the statistical significance for the each state and national park/shale basins to the confidence intervals of 98%, 95%, and 90%.

4. Results & Discussion

4.1 Analysis of Results

A Student's t-test by population density function was conducted to analyze the statistical significance of changes in each calculated statistic over the annual, seasonal, and monthly time periods for the states' and national park/shale basins' geographic regions.

Statistically summarizing the data under the annual time scale shows annual variance as can be seen in *Figure 5* and *Figure 6*. Due to the differing magnitudes of measurements between the OMI values and the standard error bars, we are unable to see the standard error bars. After completing this we calculated the statistical significance for each state and we confirmed that each state in the Intermountain region saw a statistically significant change from 2005 to 2017 with a 98% confidence interval.

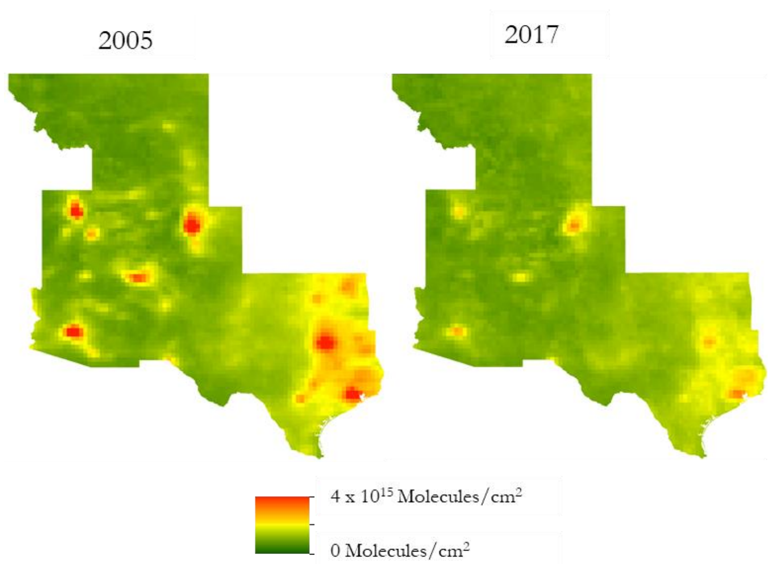

Figure 5: Annual average tropospheric NO_2 concentrations over Intermountain region for 2005 and 2017

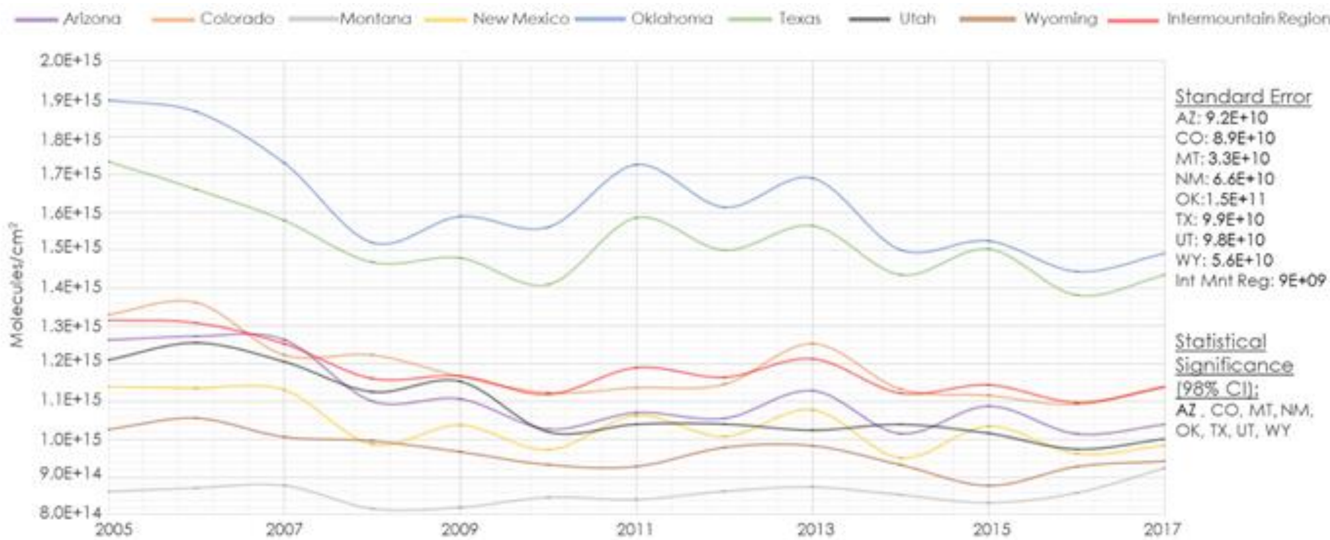

Figure 6: Annual average tropospheric NO_2 concentrations for each state and region

Over the course of the thirteen year study period the trend is downward. This trend held true for the Intermountain region and seven of the eight states. The exception being Montana which had a slight increase over the study period. There are several potential explanations for this outlier in the trend. Factors that could be influencing Montana's trends are: (1) loss of data through the cloud screening process, (2) consistent number of limited OMI observations throughout the study period, and (3) declining number of OMI observations per year. These changes were statistically significant under a student's t-test at a 98% confidence interval. In terms of the national parks/shale basins, at a 98% confidence interval, the majority exhibited a declining trend. Carlsbad Caverns National Park and Theodore Roosevelt National Park, national park/shale basins, exhibited a statistically significant increasing concentration. However, it should be noted that these increases were within range of the standard error for these two parks. Thus, these 'increases' fell within the error range and we cannot say for certain that they increased. Rocky Mountain National Park did not have a statistically significant change over the annual time scale.

While the thirteen year study period overall trend is downward, the season-specific relative trends vary over each year. Through the years, summer had lower concentrations of NO_2, while winter had higher concentrations of NO_2. This is partially due to the thermal decomposition process of NO_2. Spring and fall were consistently transitionary seasons from low and high seasons in the cycle. All states were statistically significant decreases, save Montana which increased, at a 98% confidence interval for all four seasons. Averages for all fourteen national parks/shale basins were statistically significant decreases, save Carlsbad which increased, for the spring. Come summer however, the majority of national parks/shale basins except Mesa Verde were statistically significant decreases, save Grand Teton National Park and Theodore Roosevelt National Park which increased. During fall, all national parks/shale basins, except Theodore Roosevelt National Park, were statistically significant decreases, save Carlsbad which increased. Finally, in the winter, the majority of national parks/shale basins except Canyonlands National Park, Colorado National Monument, and Dinosaur National Monument were statistically significant decreases, save Carlsbad Caverns National Park and Yellowstone National Park which increased.

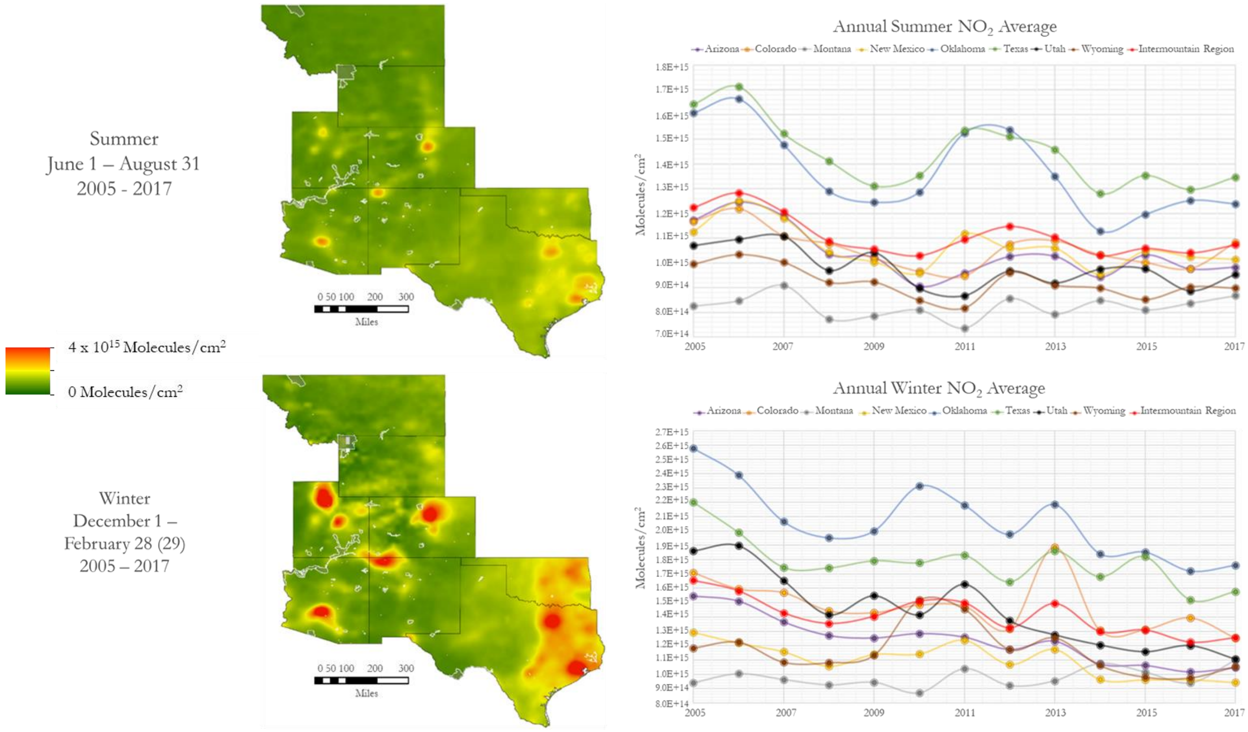

Figure 7: Summer and winter average tropospheric NO_2 concentrations over Intermountain region for 2005 and 2017

The monthly time scale statistic summarizations vary over the course of the time period. For the states, all months in 2005, 2010, and 2013 were statistically significant under a 98% confidence interval. In 2006, 2008, and 2009 all states' months were statistically significant save Utah. In 2011, 2012, 2014, 2015, 2016, and 2017 all states' months were statistically significant save Colorado. In terms of the national parks/shale basins, Grand Canyon National Park, Grand Teton National Park, Organ Pipe Cactus, and Yellowstone National Park were all statistically significant at a 98% confidence interval for all year's months. On the other hand, Arches National Park and Wind Cave National Park had eight and seven years' months, respectively, that were not statistically significant.

When comparing the units for values of NO_2 recorded from OMI, Molecules/cm^2, to other units of measurements such as parts per billion issues arise. Parts per billion, specifically for hourly recordings of NO_2 in EPA CASTNET data, is measured as the average number of NO_2 molecules within an air parcel and not an entire column. Due to the changes in density vertically through the troposphere a single mixing ratio is unable to be determined. While there are methods to estimate a direct comparison between parts per billion and Molecules/cm^2, they are not reliable and involve assumptions and cause uncertainties. Reasons for this are that OMI data is not recorded at the surface, but through a column of the troposphere and there are possibilities of data disruptions due to interferences from the stratosphere (Convert). Due to this we analyzed the hourly EPA CASTNET monitor data and EGU Annual NO_x Emission report data by creating double-y axis graphs for each. By doing this, trends were capable of being compared across the annual scale. When annualizing NO_2 recordings for all the monitors within specific states and comparing it to annualized OMI data over those specific point locations, similar trends were found until a divergence of the two datasets appeared in 2013 for Arizona, as seen in *Figure 8*, and 2012 for Colorado.

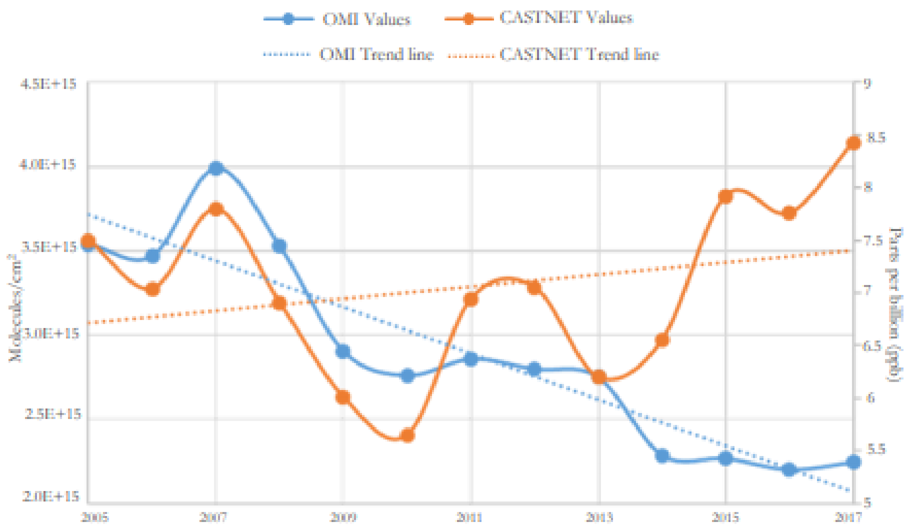

Figure 8: Annual trends of NO_2 averages over Arizona for OMI and CASTNET monitors

Due to the locations of the utilized EPA CASTNET monitors being mainly in urban areas, the higher values of NO_2 near the ground level caused this divergence. The EGU emissions of NO_x are measured in tons per year. When comparing low elevated and high elevated hourly EPA CASTNET monitor data to OMI, constant overall trends are found in analysis with those monitors of high elevation as seen in *Figure 9*.

Figure 9: Annual trends of NO_2 averages over Arizona for OMI and highest elevated CASTNET monitor in Arizona.

Discrepancies between the datasets are evident with low elevated hourly EPA CASTNET monitors. The highly elevated monitors are located closer to the bottom of the boundary layer, therefore recording data closer to OMI's range.

Annualized data from EGU NO_x emission reports showed impressive resemblances across the entire Intermountain Region. While observing values in the reports it's very clear that EGU emissions are reporting a decrease in NO_x outputs over time. These values are measured in tons per year. In comparing the OMI data over the specific EGU source point locations, coinciding trends are apparent as seen in data and in *Figure 10*.

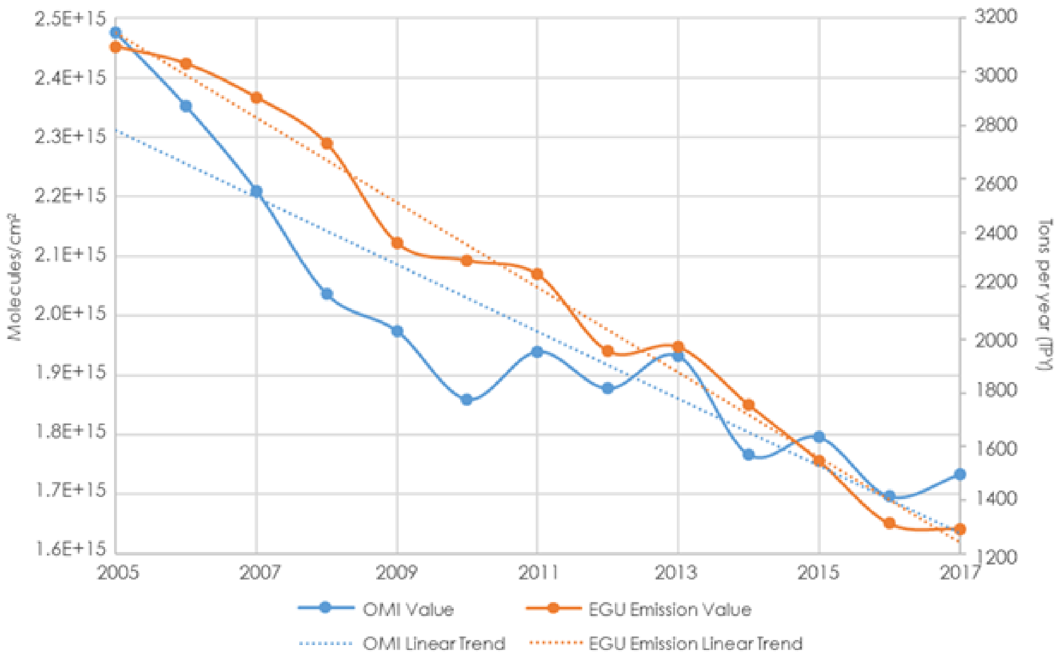

Figure 10: Annual comparisons of OMI Sensor (NO_2) and EGU Emissions (NO_x) across the Intermountain Region.

As NO_x emissions decrease it is expected that NO_2 concentrations will decrease. These findings validated OMI data by confirming that while NO_x emissions are decreasing on the ground, the sensor is able to observe and record similar trends.

4.2 Future Work

This project was proposed to continue in the fall 2018 term and will build on this project's results while focusing on visibility as it is affected by aerosols. Further, the team will write up a methodology to create a tutorial that can be used to maintain the Intermountain region's use of NASA Earth observations. Finally, all results from both projects will be packaged to communicate with park officials and the general public.

Further areas of data exploration are the relationships between NO_2 concentrations and ozone concentrations. NO_2 is one of the precursors to tropospheric ozone. A future research question can be whether the decline in NO_2, observed in this project, is leading to decline in tropospheric ozone concentrations. Through the understanding of this relationship it can be assessed whether the regulation of NO_2 can be used to reduce concentrations of other pollutants.

Sentinel-5 Precursor (Sentinel-5P) preliminary data was released on July 10th 2018 and covers June 28th to present. Sentinel-5P has quadruple the resolution of Aura OMI imagery and has significantly fewer data gaps with the paths lining up better over the course of a day. The Sentinel-5P mission is one satellite housing the Tropospheric Monitoring Instrument (TROPOMI). The main objective of the Sentinel-5P mission is to perform atmospheric measurements, with high spatio-temporal resolution, relating to air quality, climate forcing, ozone, and UV radiation. Thus, the team began exploring this higher spatial and temporal resolution data set. Sentinel-5P imagery from the European Space Agency's Copernicus Open Access Hub was acquired by the team. Sentinel-5P data were downloaded as NetCDF file format. Data array co-registration occurred through Notepad++ Python processing. Once all data points were formatted appropriately, the text files were brought into ArcGIS as point feature classes. The satellite recorded values were then converted from Mole/m^2 to Molecules/cm^2 using the conversion factor of 6.02214×10^{19}. These point feature classes were then converted to raster datasets with a cell size that encompassed around 6 data points at nadir – allowing for averaging of the data into bins with still quadruple the spatial resolution of OMI. Sentinel-5P can be used to corroborate the OMI sensor to enhance the monitoring of atmospheric trace gases at a higher temporal and spatial resolution.

5. Conclusions

The overall trend of NO_2 concentrations within the Intermountain region is declining. At the state level, there has been a decrease in NO_2 concentrations, with the exception of Montana. NO_2 concentrations were found to be lowest in summer and highest in winter. The majority of national parks/shale basins show similar trends to those of the state and regional levels at both the annual and seasonal time scales. The majority of national parks/shale basins exhibit downward trends at the 98% confidence interval, while Carlsbad Caverns and Theodore Roosevelt National Park exhibit increased concentrations at the 98% confidence interval from 2005 to 2017.

OMI NO_2 data can only compared to *in situ* measurements indirectly. This stems from the differences in the units of measurement from the *in situ* and the OMI sensor. Initially the EPA CASTNET and EGU emission report show a downward trend similar to that detected by OMI. High elevated EPA CASTNET monitors can only be compared to OMI's recorded values due to OMI's inability to record at low elevations on ground level. The EGU emission reports alongside OMI values showed a consistent downward trend throughout the study period and confirmed that NO_x emission decreases lead to decreases in NO_2.

As exhibited in the project's research, OMI cloud screened tropospheric observations should be aggregated together to provide better data coverage. Significant data validity problems were experienced by the team during the winter season. As such there were many instances where OMI did not record observations for many days during the winter. Aggregating the data to at minimum a monthly time scale reduces the number of no data observations. In regards to a cloud screening process, future teams should consider implementing their own cloud screening method so as to reduce the amount of data lost from the OMI sensor.

The partners intend to utilize NASA Earth Observations to enhance their current decision making process. Currently, the NPS only has monitors in selected national parks that they believe are of concern. The use of NASA Earth Observations will enhance the understanding of the locations of NO_2 emission sources and trends. In addition to identifying sources, the NPS will be able to examine a much larger geographical scale than through the use of monitors alone. Through identifying NO_2 emission sources, the NPS will also be able to partner with local agencies to reduce impacts on the parks.

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7. Glossary

Earth Observations – Satellites and sensors that collect data involving Earth's systems over time and space

DAAC – NASA's Distributed Active Archive Centers

GES DISC – Goddard Earth Sciences Data and Information Services Center, DAAC used to find Aura OMI NO_2 imagery

Aura – NASA Earth observation satellite, used to measure trace gases and have better understanding of atmospheric chemistry

OMI – Ozone Monitoring Instrument, one of four sensors aboard Aura

EPA CASTNET – United States Environmental Protection Agency Clean Air Status and Trends Network

Nitrogen Dioxide (NO_2) – Air pollutant that causes issues with air quality and visibility

AQRV – Air Quality Related Values, examples: soils, visibility, water, vegetation, and other natural resources in national parks that are affected by NO_2

NAAQS – National Ambient Air Quality Standards

TES – Tropospheric Emission Spectrometer, one of the four instruments on Aura

Hierarchical Data Format (HDF/HDF4 & HDF5) – A data format designed for hierarchical storage of scientific data

Clean Air Act – United States federal law that protects human and environmental health from the effects of air pollution

OMNO2d – OMI/Aura NO_2 Cloud-Screened Total and Tropospheric Column L3 Global Gridded 0.25 degree x 0.25 degree V3

Electric Generating Units (EGU) – Sources, such as power plants, that emit pollutants such as NO_2

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9. Appendices

Appendix A

National Parks	Surrounding Basins (Radius 1.5 Decimal Degrees ~100 miles)

Arches National Park (ARCH)	PARADOX	UINTA-PICEANCE		
Canyonlands National Park (CANY)	PARADOX	UINTA-PICEANCE		
Carlsbad Caverns National Park (CAVE)	MARFA	PERMIAN		
Chaco Culture National Historical Park (CHCU)	PARADOX	SAN JUAN		
Colorado National Monument (COLO)	GREATER GREEN RIVER	PARADOX	UINTA-PICEANCE	
Dinosaur National Monument (DINO)	GREATER GREEN RIVER	PARADOX	UINTA-PICEANCE	
Grand Canyon National Park (GRCA)	PARADOX			
Grand Teton National Park (GRTE)	BIGHORN	GREATER GREEN RIVER		
Mesa Verde National Park (MEVE)	PARADOX	SAN JUAN	UINTA-PICEANCE	
Organ Pipe Cactus National Monument (ORPI)	NONE			
Rocky Mountain National Park (ROMO)	DENVER	GREATER GREEN RIVER	NORTH PARK	UINTA-PICEANCE
Theodore Roosevelt National Park (THRO)	POWDER RIVER	WILLISTON		
Wind Cave National Park (WICA)	DENVER	POWDER RIVER	WILLISTON	
Yellowstone National Park (YELL)	BIGHORN	GREATER GREEN RIVER	MONTANA THRUST BELT	