Changes in Greenhouse Gas Emissions during the Covid-19 Pandemic

AIM-MCRN Summer School 2020 Project Report

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ABSTRACT

Climate change is one of the most pressing problems of the 21st century. The covid-19 pandemic caused an unprecedented and widespread reduction of normal activities (travel, dining out, shopping, etc.) often associated with greenhouse gas emissions. Here, we study emissions of nitrogen dioxide (NO_2), which is used as proxy for CO_2 emissions, and observe a statistically significant drop in emissions from 2019 to 2020 across 11 different countries. We then asses correlation between the change in emissions with levels of lockdown and suggest paths for future research.

KEYWORDS

Covid-19, CO_2, climate change, NO_2

1 INTRODUCTION

Over the past few months a large proportion of the world has been forced to engage in both lifestyle and behavioral changes due to the covid-19 pandemic. Many of the activities that have become restricted or altered during covid-19 are related to processes that produce greenhouse gases, which trap heat in the atmosphere and contribute to global warming. We intend to capitalize on the data available during the covid-19 pandemic in order to determine if these behavioral changes are able to help in curbing the looming climate crisis. More specifically, we are interested in investigating the impact these changes may have on CO_2 emissions.

Due to the difficulties associated with quantifying daily CO_2 emissions, we instead use NO_2 emissions to gain a more robust understanding of the impact of the pandemic on greenhouse gases. Looking at global NO_2 averages over the past five years in Figure 1, a significant decrease can easily be observed. The primary goals of our work are to 1) quantify the change in NO_2 emissions on a country level, and 2) determine if behavioral changes associated with covid-19 are correlated with changes in NO_2.

2 BACKGROUND

An important marker used in monitoring the climate crisis is CO_2, a greenhouse gas, which shows positive correlation with global warming. Two of the primary challenges associated with determining changes in CO_2 emissions is the variability in real-time atmospheric data as well as the atmospheric transport of CO_2 due to it's long residence time [2]. In order to gauge the impact of the covid-19 pandemic on CO_2 emissions we leverage atmospheric NO_2 as a proxy for CO_2. Although NO_2 is not a greenhouse gas, there exists a high degree of overlap between processes that emit CO_2 and NO_2 [4]. NO_2 also has a much shorter residence time (24 hours) reducing the problem of atmospheric transport [1]. There

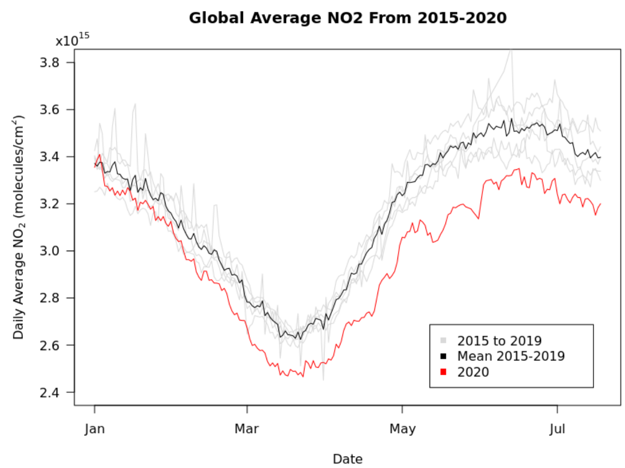

Figure 1: Global NO_2 from 2015 to 2020.

exist methods such as those provided in Konoval et. al. (2106) [4]to determine the relationship between CO_2 and NO_2 by studying the ratio of emissions between the two gases for different sectors of industry for prior years. We hope to utilize this method to infer the necessary information about CO_2.

Prior work by Le Quere et. al. [5] estimated the decrease in CO_2 by region (country, state, or province depending on the location) and sector by multiplying the CO_2 emissions from the region, the proportion of emissions in that region associated with the sector, and the change in activity level for the region and sector on a daily basis during the pandemic. This analysis found an average daily decrease from January 1 to April 17 of 17% compared to the 2019 mean. Work by Liu et. al. [6] attempted to expand on this assessment by including daily, weekly, and seasonal trends into their analysis, and found a 7.8% decrease from January 1 to April 30 between 2019 and 2020. Both works acknowledge comparisons to NO_2 as important and provide some validation, however neither does an in-depth study of the data or provides strong evidence that the NO_2 data supports their findings for CO_2 emissions. Therefore, we hope to provide an additional method to validate their results by analyzing the patterns in NO_2 as far back as 2015 to provide context for the change.

3 METHODS

Using satellite data we developed methods to calculate a country's overall NO_2 emissions for each day from January 1, 2015 through July 18, 2020. We then use this data to perform paired t-tests for data from January 1 to July 18 between each set of consecutive

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years to look for statistically significant changes in NO_2 emissions. Finally we calculate the correlation between NO_2 emissions from January 1, 2020 to July 18, 2020 and daily government-imposed lock down. To inspect or reproduce our results please consult our github (sallymatson/Climate-Change-x-Covid).

3.1 Data Sources

The daily NO_2 satellite data is collected by the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite [7]. The data used here is a grid with daily temporal resolution and 0.25° longitude by 0.25° latitude spatial resolution (which results in a spatial dimension of 720 latitudinal bands by 1440 longitudinal bands, see Figure 2). Aura completes approximately 14 orbits daily with sufficient daylight to perform NO_2 readings. The value in a given grid box is a weighted average of readings corresponding to the grid box location, filtered for specific atmospheric conditions and data quality; we use the product that filters out data with cloud cover over 30% ("ColumnAmountNO2CloudScreened"). The values are recorded as vertical column density, molecules per cm^{-2}.

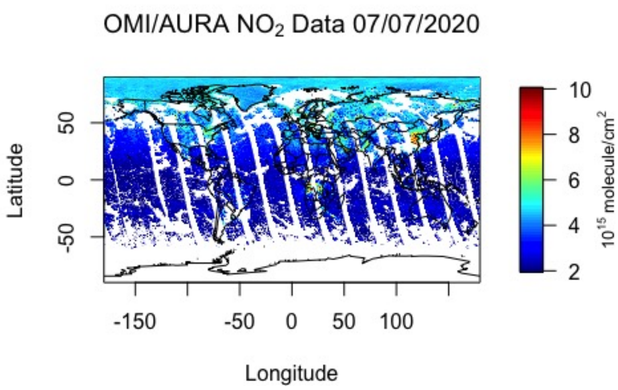

Figure 2: NO_2 levels for July 7, 2020 as retrieved by OMI/Aura. White regions represent areas where no data was collected.

The Oxford Covid-19 Government Response Tracker Data (Ox-CGRT) provided by researchers at the Blavatnik School of Government at the University of Oxford included 17 indicators of government response to the covid-19 pandemic [3]. The categories ranged from restrictions on travel to the closure of workplaces and schools. Each category of government response was scored depending on the degree of response by the government and scores were entered on a daily basis. Here, we only look at the variables related to levels of lockdown.

3.2 Data Processing

The satellite NO_2 data itself was not labeled by country, so we chose to connect a box to a country if the midpoint of that box lies inside of the country. To get daily NO_2 emissions we found the average value for each box in a country and multiplied it by the total number of boxes associated with that country (knowing that some proportion would have NA values.) We then converted each country's time series into a 7-day rolling average in order to account for variation in the location of missing values (a higher proportion of missing values in non-industrial areas could skew the total calculation downward) and differing levels of industrial activity during the weekday or weekends.

3.3 Analysis

For our analysis we chose 11 countries to focus on. We selected 9 out of the 10 largest carbon emitters (in order: China, USA, India, Russia, Japan, Germany, Iran, Canada, and Saudi Arabia; South Korea was omitted because the government response data was not recorded in the Ox-CGRT dataset.) We included Brazil (the top emitter in the Southern Hemisphere) and Italy (due to strict and high profile lock down and because Italy has been the focus of other significant covid-19 related research.)

We performed two main forms of analysis on the data. First, we assessed if the observed drop in NO_2 was statistically significant, and further if this was an unprecedented change or was expected to occur based on previous data. To do this, we performed a two-sided paired t-test on each set of consecutive years from 2015-2020 to assess differences in daily NO_2 between January 1 and July 18 of the years (see Figure 3). We used p=0.05 as our threshold to determine statistical significance.

We then calculated the Pearson Correlation for each country between the daily percent change in NO_2 from 2019 to 2020 and the level of lock down for that day (see Table 1). To determine the level of lock down we summed across all of the variables in the lock down category from Ox-CGRT.

4 CHALLENGES

One problem encountered was the lack of granularity in the Oxford data. The data did not capture the variability of lock down procedures within a country. This created issues when trying to determine correlation between lock down practices and changes in emissions. We also found the Oxford data to be challenging to incorporate into our work. It was problematic to determine how to align the time-series data with the NO_2 data. We were able to adapt the Oxford data to create our own weighted groupings of government responses, but our groupings were not informed and seemed to be lacking the ability to capture the characteristics we thought would be important. Lastly, there is not a set method for estimating CO_2 using NO_2. While Konolvalov et. al. [4] provided a framework for determining the ratio between the two quantities we have not been able to locate the necessary data to determine the ratio.

5 RESULTS

5.1 Decrease in NO_2 from 2019 to 2020

As depicted in Figure 3, all 11 countries analyzed had a statistically significant decrease in NO_2 from 2019 to 2020. In order to contextualize these results we display them with the same analysis performed on all pairs of consecutive years since 2015. We see that the decrease from 2019 to 2020 is not the only time period in which emissions decreased. Notably there was a decrease in NO_2 from 2017 to 2018 detected in 9 out of 11 countries. However, it still appears that the percent drop in 2019 to 2020 was more significant. To validate this we directly compared 2018 to 2020 by performing another paired t-test, and found a statistically significant decrease from 2018 to 2020. This confirms that 2020 has to date the lowest NO_2 levels in the past five years, and in conjunction with the fact that the percent drops were overall the most significant during the period we conclude that the 2019 to 2020 decrease is very likely tied to the unprecedented pause in global industry due to the covid-19 pandemic.

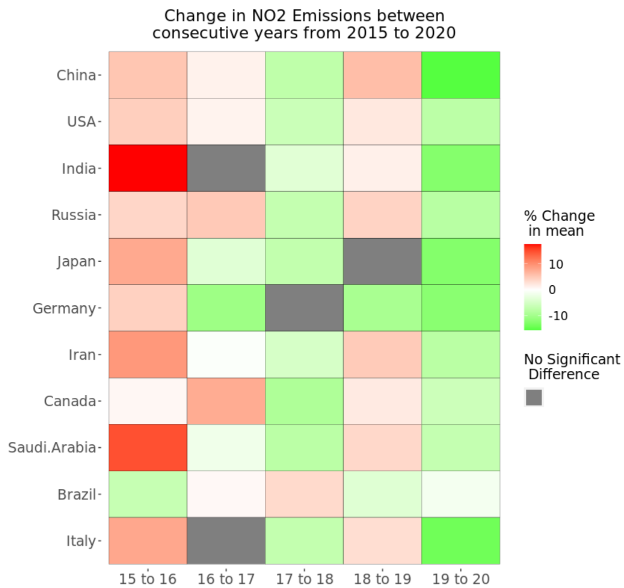

Figure 3: Percent change in NO_2 by country and year. Statistical significance is based on a paired t-test between dates January 1 and July 18 for each pair of years, p=0.05.

5.2 Correlation to Governmental Lockdown

In order to provide further evidence that the drop was caused by impacts of the pandemic we attempted to explain the drop in NO_2 by correlating it to lockdown restrictions imposed by governments. The results are seen in Table 1. We expected to see negative correlation, which would imply that as governments imposed higher levels of lockdown the percent change in emissions from 2019 to 2020 would decrease (grow negative in increasing magnitude). The strongest correlation was seen in Italy with a value of -0.44, which is not a very strong correlation. Further, four countries had positive values which contradicts our hypothesis about the relationship between emissions and lockdown.

Italy	Saudia Arabia	Canada	India	Germany	USA
-0.44	-0.41	-0.38	-0.34	-0.22	-0.20
Iran	Brazil	Russia	Japan	China	
-0.17	0.13	0.17	0.28	0.30	

Table 1: Pearson Correlation between a country's change in NO_2 from 2019 to 2020 and the government lockdown, assessed daily from Jan 1 2020 - July 18 2020.

6 CONCLUSION

Our research shows a significant and notable drop in NO_2 emissions from 2019 to 2020 during the course of the pandemic. This supports previous work and also provides evidence for the fact that globally greenhouse gas emissions dropped over the course of the pandemic. Our attempts to correlate the decrease with government lockdown did not have strong results. However, we do not believe that this implies a lack of correlation, but instead simply insufficient data and time to delve into the question.

7 FUTURE DIRECTION

Additional work is needed in order to determine a ratio relating atmospheric NO_2 to CO_2. The identification of a factor converting one to the other will allow for investigation into the CO_2 changes. Further, there is a need for increased granularity in the work which will allow for more precise estimates of the impact of the covid-19 pandemic on the climate. In particular, we would be interested in sub-dividing diverse countries such as the United States into smaller regions of study in order to capture the variations between state policies. Lastly, we propose utilizing mobility data in place of the Oxford data to focus solely on the reduction in movement caused by covid-19 and the resulting impact on emissions.

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