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Assessing the Impact of Climate Change on the Long-Range Transport of Smoke from the Canada Wildfire Event of June 2023

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Abstract

In the wake of the 2023 Canada Wildfires, this research analyzes the impact global warming had on intensifying the environmental effects of wildfires, focusing in on the Canada Wildfire Smoke Event. Using climate modeling techniques, this study explored the long-range transport and aerosolization of particulate matter, especially fine particulate matter ($PM_{2.5}$). Emphasis was placed on regions with the highest $PM_{2.5}$ values such as Queens College, with the investigation further extending to other cities across New York City, spanning a 32-mile radius. It was discovered that $PM_{2.5}$ values in New York surged to 132.23 $\mu g/m^3$, marking a significant increase compared to New York City's normal $PM_{2.5}$ value of 7.88 $\mu g/m^3$. Across all seven sites in NYC, the net contribution of the wildfire varied between 109 $\mu g/m^3$ and 196 $\mu g/m^3$. Back-trajectory analysis over a 48-hour period and dispersion analysis with and without the deposition scheme revealed that the 2023 Canada Wildfire Smoke Event significantly compromised air quality in areas like New York, New Jersey, and Pennsylvania. Our backward dispersion modeling indicated that the influence of global warming during the Canada wildfire event has elevated NYC's air quality to levels that are up to 89 times higher than what might have been anticipated without such global warming influences. This observation aligns with the conclusion that rising temperatures, due to global warming, dry out the atmosphere by depleting vital moisture and relative humidity at semi-arid regions. Such conditions hinder crucial processes like coagulation and deposition, and because there is reduced atmospheric moisture, there are fewer moisture particles for smoke to attach to or interact with, meaning that it can travel longer distances without significant deposition. This research underscores the exacerbated effects of wildfires on air quality under the influence of global warming and the results accentuates the urgent need for proactive environmental strategies that address these temperature-induced atmospheric changes, along with the integration of these insights into climate models for effective global climate and air quality management.

Keywords: Canada wildfire smoke event, Global warming, Long-range transport, $PM_{2.5}$*, Aerosolization*

1. Introduction

Exposure to $PM_{2.5}$, or particulate matter less than 2.5 micrometers in diameter, has been linked to a variety of adverse health effects, including respiratory issues, cardiovascular diseases, and increased mortality rates (Brook et al., 2010; Pope et al., 2002). These tiny particles can penetrate deep into the lungs and even enter the bloodstream, exacerbating preexisting conditions like asthma and heart disease, and potentially leading to more serious complications such as heart attacks or chronic obstructive pulmonary disease (COPD) (Dominici et al., 2006; Dockery et al., 1993).

During the period from June 5th to 7th, a concerning escalation in the air quality index in New York City (NYC) was observed, triggered by the formidable Canada Wildfire events located in Ottawa Province (Cohen, 2023). The scope and severity of this issue came to light when the New York Times reported that wildfires in Canada had already engulfed an astonishing 25 million acres since the start of the year, surpassing the country's previous annual record set in 1989, when over 18 million acres were devastated by fire (Popovich, 2023). The enormity of the impact was further substantiated as the Copernicus Atmosphere Monitoring Service (CAMS) estimated that these wildfires released nearly 160 million tons of carbon into the atmosphere (CAMS, 2023). An equally alarming aspect is the long-distance dispersion of nearly 600 million tons of carbon dioxide and particulate matter generated by these wildfires, affecting areas as far-reaching as New York, New Jersey, and Pennsylvania (Salahieh et al., 2023).

The underlying cause of fires in the boreal forest of northern Canada can be attributed primarily to lightning (Romps et al., 2014). In conjunction with a one-degree Celsius increase in temperature, there is approximately 12% more lightning, making the warming climate a significant factor in the frequency of fire ignition (Price, 2009). The science behind this phenomenon is grounded in the understanding that global warming increases temperature through the accumulation of greenhouse gases (IPCC, 2021), which trap heat from the sun in the Earth's atmosphere. In arid and semi-arid regions, global warming has the potential to influence the long-range transport of wildfire smoke. Warmer and drier conditions can lead to reduced coagulation and deposition of smoke particles, allowing them to remain airborne for extended periods (Liu et al., 2010). While global warming enhances evaporation rates, the low relative humidity characteristic of these regions can limit the condensation of this evaporated water into droplets or clouds, reducing the atmosphere's natural "cleansing" mechanisms (Reid et al., 2005). Moreover, the increased temperatures associated with global warming can also amplify the frequency and intensity of wildfires, producing more smoke (Abatzoglou et al., 2016). Thus, in these dry regions, global warming can promote conditions conducive to the long-distance travel of wildfire smoke.

In light of these urgent and complex issues, this study aimed to achieve two objectives. The primary objective of this study was to validate the impact of the Canada wildfire smoke long-range transport on NYC's $PM_{2.5}$ levels using back trajectory analysis (Liu et al., 2020) and to quantify its contribution to $PM_{2.5}$ concentrations over and above the local background levels. The secondary aim was to demonstrate and quantify the influence of global warming on this long-range transport of wildfire smoke (Ford et al., 2018) by employing an air dispersion modeling. Through this dual-focused approach, our research delves into the profound interconnections between climatic changes, wildfires, and their extended atmospheric consequences.

2. Materials and Methods

2.1 HYSPLIT4 Modeling

The HYSPLIT 4 (Hybrid Single-Particle Lagrangian Integrated Trajectory) model allows for the tracking and analyzation of the effects of the Canada wildfire. HYSPLIT 4 is a powerful atmospheric dispersion model that enables the simulation and visualization of the movement of air masses and pollutants over time (Draxler & Hess, 1997). Inputting relevant meteorological data and fire emissions information allowed the model to generate trajectory paths of smoke particles originating from the Canada Wildfire event. These trajectory paths provided insight to the long-range transport of particulate matter and smoke, allowing for assessment of potential impacts on air quality and atmospheric composition in distant regions.

2.2 Lagrangian Dispersion Scheme

The Lagrangian Dispersion Scheme, rooted in the domain of atmospheric science, is a specialized method designed to model the transport and dispersion of pollutants within the atmosphere (Draxler & Hess, 1997). Its foundation lies in the Lagrangian perspective of fluid dynamics. Unlike the Eulerian viewpoint, which focuses on observing changes in fluid properties at fixed spatial points (akin to watching a river from a stationary bridge), the Lagrangian perspective emphasizes tracking individual particles or air parcels as they traverse through space and time.

The primary technique of the Lagrangian Dispersion Scheme involves meticulously simulating the trajectories of a multitude of "particles." These particles, in the context of the model, can symbolize air parcels, droplets, or actual particulate pollutants. As these particles journey through the atmosphere, the model integrates various forces and dynamics that influence their movement. Such influences range from wind advection and turbulent diffusion to more intricate processes like gravitational settling for larger particulates or potential chemical transformations.

One noteworthy feature of this scheme is its incorporation of stochastic (randomly determined) processes, especially when representing turbulence. This inclusion mirrors the inherently random nature of turbulent motions in the atmosphere. Consequently, by analyzing the collective behavior of these simulated particles over a period, the Lagrangian Dispersion Scheme offers a nuanced understanding of pollutant dispersion patterns. Such insights prove invaluable, especially in scenarios demanding knowledge of pollutant pathways from sources like industrial power plants or expansive wildfires.

2.3 Back Trajectory

A back trajectory, an essential instrument in atmospheric science, delineates the antecedent path of an air parcel or particle (Stein et al., 2015). Through the meticulous amalgamation of meteorological data and sophisticated computational models, this tool traces in reverse the journey an air parcel has undergone, spanning from its concluding location to its origin (Rolph, Stein, & Stunder, 2017). The core objective of such an analysis is the identification of probable source regions or pathways for air masses and the pollutants they might carry.

By discerning an air parcel's origins and the atmospheric conditions it encountered, researchers can pinpoint potential pollution sources and interpret the atmospheric composition observed at specific sites. Historically archived meteorological data, encompassing wind patterns, temperatures, and other salient atmospheric metrics across multiple altitudes, underpins the precision of back trajectory computations. Depending on the research aims, the temporal scale of these trajectories can vary widely; intercontinental air mass transport might necessitate a more extended trajectory analysis, while local or regional pollution sources could be discerned with shorter trajectories. The practical implications of back trajectory analyses are multifaceted. Whether utilized for source apportionment endeavors to demystify pollutant origins or to fathom phenomena like transcontinental smoke transport from forest fires, dust storms, or the encroachment of polluted air into pristine zones, its value remains indisputable. In essence, the back trajectory offers a retrospective lens, granting profound insights into the historical movement of air masses and enhancing our comprehension of atmospheric transport dynamics.

2.4 Dispersion Simulation With and Without Deposition

Deposition pertains to the transfer of atmospheric particles or gases from the atmosphere to the Earth's surface. This process is primarily categorized as wet and dry deposition. While wet deposition involves particles or gases being purged from the atmosphere from precipitation, dry deposition refers to their settling onto surfaces independently of precipitation (Seinfeld & Pandis, 2016).

Models that operate "with deposition" inherently incorporate both the transport and deposition of particles or gases. Such models provide invaluable insights into potential accumulation points of pollutants on the ground, crucial for environmental and health risk assessments. For instance, they can highlight regions where acid rain might jeopardize soil or water resources or locations susceptible to the harmful accumulation of particulates. In these models, pollutants often exhibit truncated atmospheric lifetimes due to their removal by deposition processes.

Conversely, models that function "without deposition" emphasize purely the transport and dispersion of particles or gasses. They eschew considerations of pollutants being removed from the atmosphere either by settling or precipitation-led processes. This perspective assumes an extended presence of pollutants in the atmosphere and is typically simpler in nature. Such models can be particularly insightful when the core objective is discerning pollutant movement without the intricacies associated with deposition.

The choice to employ models "with" or "without" deposition hinges on the objectives of the study. Comprehensive insights into the fate of pollutants, including terrestrial or aquatic destinations, warrant the inclusion of deposition. However, if the study's focus leans predominantly towards understanding pollutant dispersion and movement, omitting deposition might be more appropriate. This paper employs both options in order to analyze maximal results.

2.5 Estimations of Ambient Air Concentration Provided by HYSPLIT4

Within the horizon of atmospheric and environmental sciences, estimations of ambient air concentration represent a critical metric. They provide an estimate of specific pollutants, gases, or particulate matter in the air of a designated locale. Typically expressed in units such as micrograms per cubic meter (µg/m^3) or parts per million (ppm), these estimations afford a snapshot of the air quality at a given moment. By combining trajectory modeling with emission data and meteorological inputs, HYSPLIT4 provided insight into estimating the ambient air concentrations of these pollutants over the course of the Canada wildfire event. This estimation offered valuable insights into the spatial and temporal distribution of air pollutants, aiding in the assessment of their potential impacts on air quality and public health in the affected regions.

2.6 Data Collection

The data's comprehensive scope not only ensures a robust understanding of $PM_{2.5}$ and Ozone fluctuations but also helps discern the potential regional variances in air quality. Factors such as traffic density, industrial activities, local weather conditions, and green spaces could contribute differently to the air quality in these locations. Morrisania, for instance, might experience different pollutant sources compared to Freshkills West, Staten Island, due to its unique geographical and infrastructural characteristics. By examining such a vast array of locations, this breadth of data paves the way for more targeted interventions and strategic air quality improvement initiatives tailored for specific regions within New York.

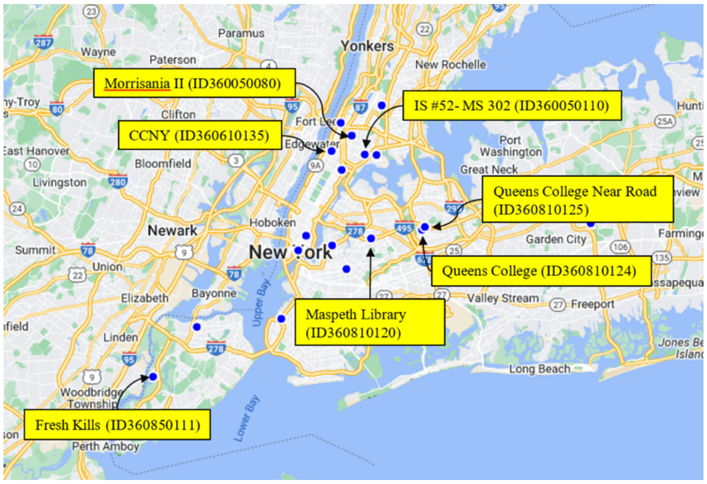

Figure 1. Air Monitoring Stations Map (Source: the New York State DATA.NY.GOV. All captioned sites are the ones used in this paper)

2.7 Trend Analysis

Trend analysis emerges as an indispensable instrument for discerning nuanced patterns within temporally sequenced datasets. The methodology is underpinned by rigorous examination and assessment of sequential data points collected over discrete intervals. Its primary objective is to illuminate the trajectory, whether ascending, descending, or remaining static, of a specified metric or phenomenon. By adeptly employing trend analysis, historical tendencies of the subject variable offer projections about its prospective evolution. Specifically, the trend analysis conducted for this study showcased the diurnal variations of pollutant concentrations spanning from June 4th to June 7th. This temporal depiction furnishes a robust visualization elucidating the oscillations in pollutant concentrations during the delineated period.

2.8 Overlaying Wildfire Map and Back Trajectory

Overlaying the wildfire map and back-trajectory patterns using the program Microsoft Excel allowed for the tracing of wildfire patterns and a further analyzation of the patterns and the routes they took to reach locations like New Jersey and NYC. Overall, this process provided significant information to analyze the steadfast growth and the concerning impact of these fires as it revealed the pathway the fires followed to reach locations in North America.

2.9 Theoretical Background for HYSPLIT4 Simulations (Draxler & Hess, 1998)

Lagrangian Dispersion Scheme represented in general terms by stochastic differential equation (equation below represents a particle's position)

$$d\mathrm{X}(t) = \mathrm{V}(\mathrm{X}(t), t)dt + \mathrm{B}(t)d\mathrm{W}(t) \tag{1}$$

Where $\mathrm{X}(t), \mathrm{V}(\mathrm{X}(t), t), \mathrm{B}(t),$ and $d\mathrm{W}(t)$ represent the position of the particle at time *t,* the mean wind velocity at the position of the particle, the turbulence parameter, and a Wiener process which represents the random nature of turbulent motion, respectively.

Particle's concentration (if considering a puff model)

$$\frac{dC(t)}{dt} = -\frac{Q}{V(t)} + S(t) \tag{2}$$

Where $C(t), Q, V(t),$ and $S(t)$ represent the concentration of the pollutant within the puff at time *t,* the rate at which the puff is losing mass, the volume of the puff (which might increase due to dispersion), and any sources or sinks of the pollutant within the puff, respectively.

Back trajectory equation

$$\mathrm{X}(t - \Delta t) = \mathrm{X}(t) - \mathrm{V}(\mathrm{X}, t)\ \Delta t \tag{3}$$

Where $\mathrm{X}(t), \mathrm{V}(\mathrm{X}, t),$ and Δt represent the particle's position at time *t,* the wind velocity at the particle's position at time *t,* and the time step, respectively.

Gaussian plume model for dispersion without deposition

$$C(x, y, z) = \frac{Q}{2\pi U \sigma_y \sigma_z} e^{-\frac{y^2}{2\sigma^2 y}} e^{-\frac{(z-H)^2}{2\sigma^2 z}} \tag{4}$$

Where $C(x, y, z), Q, U, \sigma_y$ and $\sigma_z, H,$ and $e^{-\frac{y^2}{2\sigma^2 y}}$ and $e^{-\frac{(z-H)^2}{2\sigma^2 z}}$ represent the concentration of the pollutant at a specific location given the coordinates (x, y, z), the emission rate of the pollutant, the wind speed, the dispersion coefficients or standard deviations of the concentration distribution in the *y* (crosswind) and *z* (vertical) directions, the effective release height of the pollutant, and the exponential functions that describe the Gaussian distribution of the pollutant concentration in the crosswind and vertical directions, respectively.

Dispersion with deposition

$$\frac{dC}{dt} = \text{dispersion term} - V_d C \tag{5}$$

Where $\frac{dC}{dt}$, dispersion term, V_d, and C represent the rate of change of concentration time, the spreading and dilution of the pollutant, the deposition velocity, and the concentration of the pollutant, respectively.

3. Results

3.1 $PM_{2.5}$ and Ozone Concentrations in NY

According to the EPA, a $PM_{2.5}$ concentration of 12 μg/m^3 or lower is generally considered healthy, posing minimal risks from exposure. However, when the level exceeds or equals 35 μg/m^3 within a 24-hour period, the air quality is deemed unhealthy, especially for individuals with pre-existing respiratory conditions such as asthma (EPA, 2012). During July 6th to July 8th, the NYC/NJ area experienced an alarming peak of $PM_{2.5}$, with levels reaching an unprecedented 203.5 μg/m^3 (on 6/7/2023) which is about 17 times the healthy $PM_{2.5}$ level.

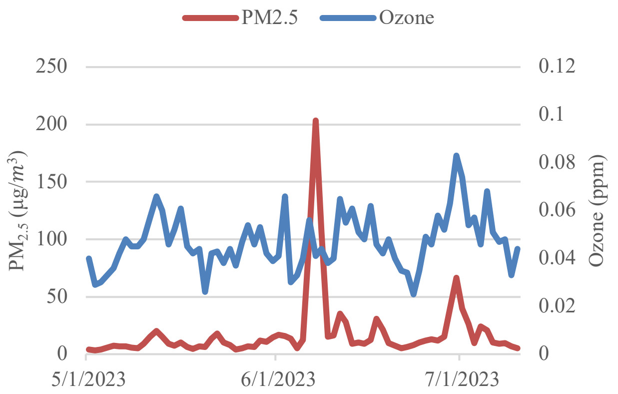

Figure 2. $PM_{2.5}$ and ozone concentrations before and after the Canada Wildfire event (June 6-8) in the Queens College 2 site

In terms of ozone measurements, while wildfires emit certain pollutants that are involved in ozone formation, their contribution to ozone levels in distant states like NYC is minimal. Ozone levels in a specific area are predominantly influenced by local emissions such as VOCs (volatile organic compounds), NOx (nitrogen oxides), and meteorological conditions, not long-range transmissions, making it unlikely for a Canada Wildfire to bring forth a significant drop throughout ozone levels in NYC. The lack of a peak in ozone levels further indicates that the ozone has less association with Canada wildfire in terms of long-range transport.

As shown in Figure 2, the peak value of $PM_{2.5}$ observed at NYC during the Canada Wildfire events was as high as 203.5 μg/m^3, with the average of the $PM_{2.5}$ values during the peak days (6/6/2023 – 6/8/2023) being 137.13 μg/m^3. The typical annual average of $PM_{2.5}$ in NYC was about 9.35 μg/m^3 from May 1st, 2023, to June 5th, 2023 (5/1/2023 – 6/5/2023). Therefore, not only was there a 194.15 μg/m^3 difference in the peak day compared to the average $PM_{2.5}$ level, but the contribution from the Canada Wildfires in terms of its long-range transport on the peak day also sparked a 2076% increase from the average $PM_{2.5}$ value, and the overall average of the peak days sparked a 1366% increase from the average $PM_{2.5}$ value. Additionally, the average $PM_{2.5}$ value is only 7% of the average $PM_{2.5}$ value of the peak days, indicating that the peak days made up 93% of the $PM_{2.5}$ in NY during the height of the wildfire in NY.

The lasting effects of the Canada Wildfires are further visible through a notable increase in average $PM_{2.5}$ values during the aftermath of the critical days (6/9/2023 – 7/10/2023). The average $PM_{2.5}$ managed to lower to 17.32 μg/m^3, and although this suggests a 119.81 μg/m^3 decrease from the average $PM_{2.5}$ levels during the peak dates, the average $PM_{2.5}$ value from the dates before and after the fire had increased 7.97 μg/m^3 (an 85% increase), which shines a light on established mark of the Canada Wildfire.

During late June and early July, another Canada wildfire event seemingly influenced $PM_{2.5}$ levels but had a less pronounced impact on ozone concentrations. While the $PM_{2.5}$ levels showed a significant increase, the ozone levels remained relatively consistent with typical days.

Fig. 3 delineates the $PM_{2.5}$ concentrations across a diverse array of locations in NYC, covering the period from 5/2/2023 to 6/28/2023. Prior to the apex of the Canada Wildfire (5/2/2023-6/5/2023), the mean $PM_{2.5}$ concentration stands at 7.88 μg/m^3. This value escalates to an average of 140.2 μg/m^3 during the wildfire's highest peak days (6/6/2023-6/8/2023), marking an increase of 132.32 μg/m^3 in and a percent increase of 1679% in $PM_{2.5}$ concentration between normal days and the peak dates of the fire.

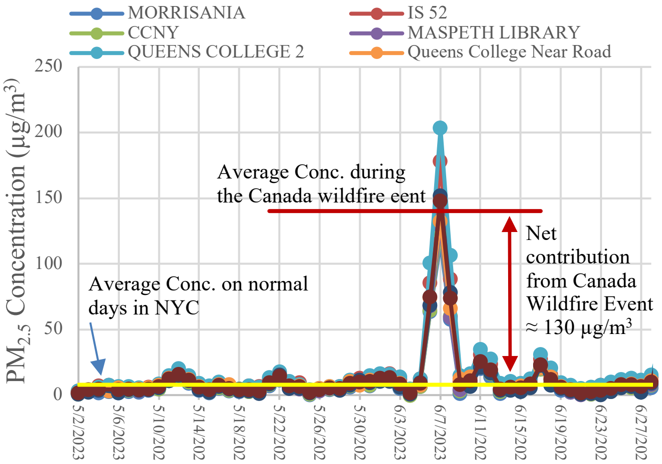

Figure 3. Analysis of $PM_{2.5}$ levels throughout larger range of locations in NYC (locations labeled above)

Furthermore, by taking the $PM_{2.5}$ values from 6/7/2023, the peak date of the wildfires, it can be noted that the highest value is 203.5 μg/m^3 (from Queens College 2), and the lowest value is 116.9 μg/m^3 from Morrisania). Compared to the average $PM_{2.5}$ level in NYC, the value 203.5 μg/m^3 presents a 195.62 μg/m^3 increase and the value 116.9 μg/m^3 presents a 109.03 μg/m^3 increase from the normal average of 7.88 μg/m^3. Therefore, the net contribution from the Canada Wildfire ranged from 109 µg/m^3 to 196 µg/m^3, with the average of 132 µg/m^3 as listed above. These observations were drawn from sites situated within a 32-mile radius, stretching from Staten Island to Queens, underscoring the extensive adverse influence of the Canada Wildfire across New York State.

3.2 HYSPLIT 4 Back Trajectory Models Using Langrangian Dispersion Scheme

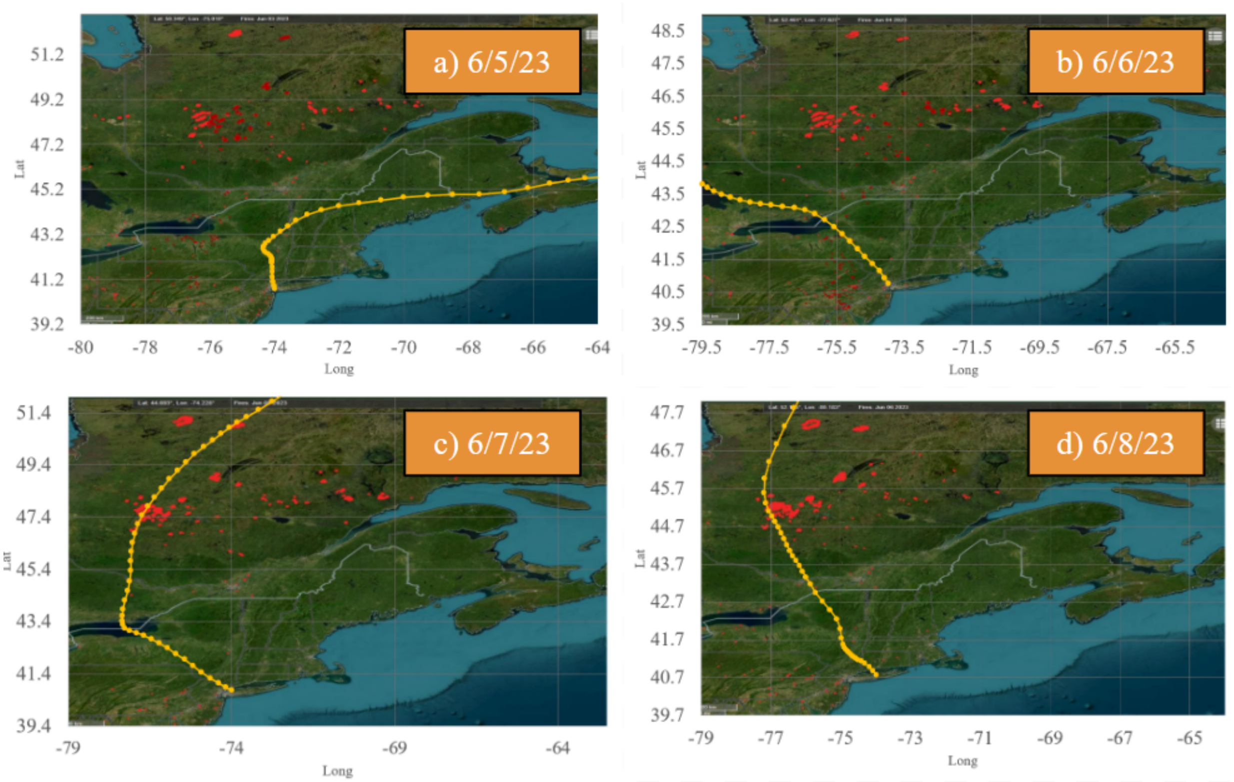

Figure 4. 48-hr back-trajectory of Canada Wildfire on June 5th (a), Junne 6th (b), June 7th (c), June 8th (d). Each trajectory endpoint indicates 1-hr air mass travel.

Using the advanced back trajectory patterns generated by HYSPLIT4, in combination with intricately detailed maps displaying pinpointed wildfire locations sourced from FIRMS US/Canada (Fire Information for Resource Management System US/Canada), it has become feasible to accurately track and identify specific pollution sources and their accompanying atmospheric compositions that influence the air quality in NYC. A crucial observation to underscore is the data from days like June 5th (Fig. 4 (a)) and June 6th (Fig. 4 (b)). During these periods, the origin of pollutant sources doesn't appear to be tied geographically to Canada. Instead, indications point towards more local or regional sources of pollution with shorter atmospheric trajectories.

These proximate sources exert a pronounced influence on the surrounding environment. The primary contributors include gases released from vehicle emissions, active construction sites, and ongoing industrial processes. Such localized sources are often underestimated but play a pivotal role in influencing air quality in urban regions.

Conversely, during peak days like June 7th (Fig. 4 (c)) and June 8th (Fig. 4 (d)), there's undeniable evidence showcasing the impact of transcontinental smoke transport originating from the Canada wildfires. This is evident in the discernible alterations of the trajectories on these dates. Specifically, the pathways on both June 7th and June 8th are oriented such that they directly intersect and traverse Canada, focusing particularly on the Ottawa Province. These trajectory shifts are not coincidental. Given that dispersion models have proven adept at predicting the direction and density of smoke dispersion, their data corroborates the notion that the atmospheric trajectories during these peak days were significantly affected by the massive wildfires in Canada. This goes to show the profound and far-reaching impacts of large-scale environmental events, transcending national borders and affecting regions thousands of miles away.

3.3 Modeling Fire Trajectory With and Without Deposition

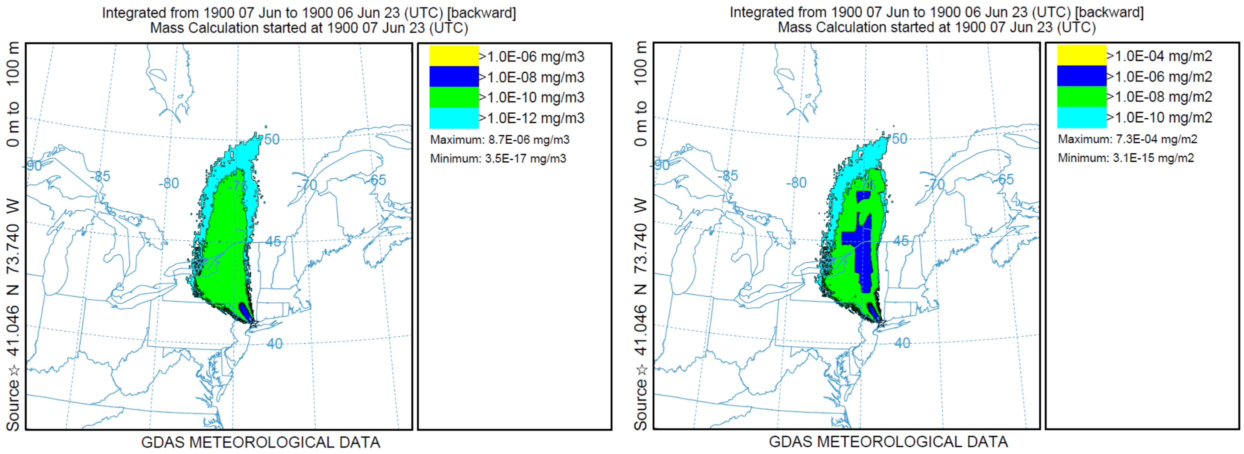

Figure 5. Simulations of 24-hr backward dispersion concentration on June 7th at NYC without deposition (Left) with deposition (Right).

Fig. 5 presents HYSPLIT4 48-hour backward dispersion concentration simulations for New York City (NYC) dated June 7th. On the left, the simulation, which does not account for deposition, stands in stark contrast to its counterpart on the right that factors in deposition effects. The former simulation reflects conditions without the influence of global warming, while the latter potentially signifies the impact of global warming (Seinfeld, 2016). The dry deposition velocity for the simulation excluding deposition was set at a default rate of 0.001 meters/second. In comparison, the simulation that accounted for deposition had a velocity of 0 meters/second. Both simulations assessed concentrations from ground level up to an altitude of 100 meters. Intriguingly, the deposition-inclusive simulation exhibited a dramatically higher concentration, with a peak value of 7.3E-04 $\mu g/m^3$, as opposed to the 8.7E-03 $\mu g/m^3$, observed in the non-deposition scenario. This underscores that limiting or omitting deposition can escalate concentrations considerably, here by a factor of 89. Such elevated concentrations, as evidenced in the right simulation, may hint at the repercussions of global warming. Temperature increase brought about by global warming can curtail deposition velocities, resulting in heightened accumulation of pollutants from wildfires in the atmosphere, subsequently deteriorating air quality.

4. Limitations and Assumptions

While the HYSPLIT4 model was pivotal in our analysis, it's worth noting certain limitations. The model provides concentration data only for the outermost contours, restricting our ability to gauge variations in concentrations within these contours, especially when comparing simulations with and without deposition. This limitation posed challenges in quantifying differences between these two scenarios. Additionally, HYSPLIT4 could benefit from enhanced flexibility in its parameter options. The current model does not easily accommodate alterations to atmospheric physics parameters, such as the secondary formation of $PM_{2.5}$. Such capabilities would have been valuable, especially during the Canada Wildfire event, allowing for a more nuanced simulation of secondary particulate formation. Furthermore, employing enhanced grid-based modeling approaches such as Community Multiscale Air Quality (CMAQ) could offer more refined data, enhancing our capacity to better quantify the impacts of global warming on atmospheric dispersion during wildfire events.

5. Conclusion

In this research, we meticulously examined specific locales within New York City and various air monitoring stations across New York state to discern the true ramifications of the Canada wildfires on air quality and their possible correlation with global warming. Leveraging the HYSPLIT4 modeling framework, we analyzed patterns in $PM_{2.5}$ and

Ozone concentrations. Furthermore, using the Lagrangian dispersion scheme, we investigated the pathways taken by pollutants emanating from the wildfires. Our models, which included HYSPLIT4 simulations considering scenarios with and without dispersion, revealed that the Canada Wildfires had a profound effect on NY's dispersion trajectories and $PM_{2.5}$ concentrations across different urban pockets within a 32-mile radius of NYC. Remarkably, there was a staggering 1679% surge in $PM_{2.5}$ concentrations due to the wildfires, and the aftermath saw an enduring 85% uptick in $PM_{2.5}$ levels in zones like Queens College 2. Moreover, during critical days like June 7th and June 8th, the dispersion trajectories underwent a notable shift. Previously dominated by local industrial pollution sources, the trajectories realigned, suggesting pollutants would be funneled directly from the fire sites to NYC.

Coupled with these findings is the startling revelation that global warming has exacerbated NYC's air quality concerns. Specifically, our data indicates that the influence of global warming during the Canada Wildfire event has amplified NYC's air quality to levels that are 89 times higher than what might have been anticipated without such global warming.

Drawing from these extensive analyses, two salient themes emerge. First, the Canada wildfires not only directly affect the immediate vicinity but also have far-reaching repercussions on regions such as NYC. Second, the overarching shadow of global warming acts as a catalyst, exacerbating the effects of such environmental disasters. Together, these insights underscore the urgent need for heightened awareness and proactive measures, not just for areas directly hit by wildfires but for surrounding regions that bear the indirect brunt of these calamities.

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