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Advanced Engineering Optimization Through Intelligent Techniques

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Contents

Mitigating Ground-Level Ozone of AOT40 Through Black Carbon Absorption Effects on Air Quality

Sumit Saha and B. Sowmiya

Abstract This study estimates black carbon (BC) and its impact on ground-level ozone (O_3) and air quality, crop yield, and human health. PM2.5 black carbon warms the atmosphere and accelerates O_3 production where NO_x and VOC are high. O_3 affects human's respiratory and cardiovascular systems and decreases crop production through negative impact on photosynthesis. For this study, an IAM that combines a chemical transport model for atmospheric chemistry, a yield response function for crops, and a dose response model for health is used. This IAM reproduces spatial and temporal BC emissions, O_3 formation and its impact on crops and health particularly on wheat. An O_3 index, AOT40 (Accumulated Ozone exposure Over a Threshold of 40 ppb) is used to assess O_3 impact on yield reduction in wheat as yield decreases as O_3 exposure increases. IAM simulations show that focusing on agricultural residue burning, diesel emissions and energy industry to reduce BC emissions can improve the situation and reduce O_3 by 10–15% in high emission regions.

Keywords Climate change management · Extreme weather events · Ground-level ozone mitigation · Black carbon

1 Introduction

Two prevailing gases, ground-level ozone (O_3) and black carbon (BC) exert large negative effects on human health and crop yields. O_3, a secondary pollutant, is produced near the Earth's surface by the photochemical oxidation of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Ozone present in stratosphere is favorable because it shields people from dangerous UV radiation while on the

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ground, ground-level ozone is undesirable because it aggravates breathing diseases and decreased crop productivity by damaging plant life [1–3].

This work assesses the multiple pathways by which BC affects O_3 formation in order to assess the viability of BC reduction as a way of easing ground-level ozone and hence bettering crop yield [4], particularly wheat. More specifically, it examines the premise that managing to decrease BC emissions will distort the optimal conditions for ground-level O_3 formation by changing the thermodynamics of the atmospheric environment and alleviating the oxidative damage in plants placed in better O_3 conditions [4]. The investigation employs an integrated assessment model (IAM), in which the relationships of BC emissions, formation of ozone, and crop yield sensitivity to different ozone concentrations are reconstructed. Using this metric, the study will be able to directly assess the effect of accumulated ozone exposure on the crops' health and yield, thus, offering a sound framework for measuring the crop-plus-health co-benefits of BC mitigation on wheat yields.

The IAM model combines atmospheric chemistry simulations, crop yield projections, and health impact assessments [5]. It provides critical insights into the effects of BC emission reduction options on localized ground-level ozone concentrations and beneficial crop productivity through simulations of several scenarios in which BC emissions are reduced from major sectors, including agriculture and transport. This model includes the consideration of seasonal and diurnal variations in BC emissions and ozone concentrations, especially in highly polluted agricultural areas. Such an evaluation allows for understanding of how BC mitigation initiatives can impact local ozone production—a leading contributor to crop yield loss since we know ozone can impact plant tissue, inhibit photosynthesis, and accelerate cellular senescence.

The inclusion of AOT40 as a key measure strengthens the model's predictive power regarding possible impacts of ozone on crop yield outcomes under different exposure scenarios [2, 4]. AOT40 threshold-based is highly important as it enables understanding the climatic cumulative impact of episodic spikes in ozone, coinciding on peaks of crop growth seasons like wheat. This paper thereby measures the effect of ozone on wheat yield and hence the potential agricultural benefits that may sprout from the reduction of BC, the implication of BC discounting helps achieve climate goals by lowering short-lived climate pollutants without narrowing the avenue for achieving food security by gaining crop yield protection from ozone-induced stress. Further, it indicates the economic benefits in terms of reduced healthcare costs that arise from enhanced air quality and a drop in incidences of ozone-related respiratory and cardiovascular diseases.

The results obtained from this study signify the ever-increasing importance of multi-sectoral BC reduction strategies that fit directly into the systematic control approach of lessening air pollution, and that prompt substantial co-benefits among environmental, agricultural, and health domains [6]. Certainly, the linkage of BC mitigations to reduction in AOT40 establishes a strong justification for advocating for BC control measures within the existing air quality and agricultural sustainability policy frameworks. The co-benefits related to BC reduction strategies could turn agricultural-dependent areas around by providing a way to enhance crop resilience and gain public health benefits at the same time. Such findings will not only add value to the atmospheric interactions between BC and O_3, but further owing to one of its findings, make it amenable to developing a quantitative basis that may inform the current policy interventions in addressing the dual problem of air pollution and food security. Particulate matter (PM2.5) is a mask of black carbon produced from the combustion of fuels and biomass, and the emission of greenhouse gases [7]. These factors indicate that due to high absorptive capacity of BC for solar radiation, the particle can both warm the atmosphere and surface directly and enhance stability of deeper atmospheric layers, which could lead to changes in O_3 concentrations.

2 Methodology

The modules aim on detecting the rise and fall of relevant elements of the analysis. Whenever the levels of Ozone would be detected to be more than AOT40 there would be an alarm created to instruct users to incorporate fusion of Black Carbon and in turn reduce the harmful effects of each of those elements and give a better-quality atmosphere to the crops.

3 Data Collection

The initial data for the charity vault includes collecting real-time data on ozone (O_3) and black carbon (BC) concentrations from monitoring. Gathering temperature, humidity, and wind speed data to understand atmospheric conditions. Collecting wheat crop yield data to assess ozone's impact over the growing and changing conditions.

4 Modeling Modules

- **Model Development**: Use integrated assessment models to simulate black carbon, ozone, and AOT40 interactions.
- **Outcome Prediction**: Predict effects of different mitigation strategies on air quality. We can achieve this using various algorithms such as, Kalman Filter Algorithm, Neural Networks, Fuzzy Logic for Decision Making, Bayesian Networks, K-Means or DBSCAN for Trend Analysis, and integrating all of these together we can create a structured model.
- **Chemical Transport Models**: Study how reducing black carbon impacts ozone and AOT40 levels in the atmosphere.

5 Monitoring and Feedback Module

Establishing a system for ongoing monitoring of ozone and black carbon levels to evaluate the effectiveness of implemented strategies. Also, we can create a feedback mechanism to adjust strategies based on monitoring results and emerging data.

6 Application of the System

We can design a comprehensive approach for assessing the impact of black carbon (BC) and ozone (O_3) on wheat crop yields. It involves three main steps: first, data collection, which includes gathering O_3, BC, weather, and wheat yield data. Next is the modeling module, where an integrated assessment model is developed to simulate BC, O_3, and AOT40, predicting the effects of various mitigation strategies using chemical transport models.

Finally, the process includes monitoring and feedback, which entails continuous monitoring of O_3 and BC levels, evaluating the effectiveness of strategies, and adjusting them based on results.

7 Detection of Ozone Above Aot40

The data we analyzed provides current pollution data from monitoring stations in northern India. The pollutants measured include particulate matter (PM2.5 and PM10), Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3), all of which contribute differently to the AQI. Of these, ozone has become a pollutant of particular concern in some regions. When present in the troposphere (the lowest part of the atmosphere), ozone is a harmful air pollutant that can cause health problems, especially for people, children and adults, who experience shortness of breath, that there are regions in the northern plains where the AOT is very evidently exceeded.

Unlike ozone in the stratosphere, which protects the Earth from harmful ultraviolet radiation, ground-level ozone is a product of photochemical reactions, particularly with nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the sun. This results in higher ozone levels during the day and in areas with higher traffic or emissions. Comparison with India's safety regulations (CPCB). The analysis focused on the accumulation and excess of ozone levels called "AOT" (Accumulated Ozone Threshold), which is a key indicator of ozone exposure over a long period of time. AOT values are generally used to measure the extent to which ozone levels exceed safety limits over a period of time, affecting both the short-term and long-term.

From the data, we found that northern regions, including cities like Delhi, Gurugram, Noida, Ghaziabad, and parts of Punjab, have large amounts of ozone. These areas are densely populated and have higher levels of vehicular emissions, industrial activities, and biomass burning, especially during the growing season in Punjab and Haryana. The data shows that AOT values in these regions, especially during winter and early summer, occasionally exceed long-term safety. Several factors contribute to the high ozone concentration in the northern region: Vehicular emissions: The rapid pace of urban development and increasing traffic in Delhi, Noida, and surrounding areas have increased nitrogen oxide emissions. These emissions cause ground-level ozone under the influence of sunlight, worsening the air quality index levels. Industry: Haryana and parts of Uttar Pradesh are home to many industrial areas. These industries emit not only nitrogen oxides but also organic compounds, which are important precursors of ozone formation. The combination of these pollutants can lead to higher ozone concentrations, especially in the absence of storms, as noticed from the study.

Agriculture during the growing season, burning, especially in Punjab and Haryana, produces a lot of pollution and nitrogen oxides, resulting in poor air quality. This seasonal activity, combined with atmospheric conditions such as low winds and cold winds, creates a "blanket" effect that traps pollutants in low-lying areas. Meteorological conditions: Winter in northern India is characterized by cold and atmospheric mixing, which leads to higher concentrations of pollutants in the soil. Temperature variations are extreme in winter, especially in the plains, where warm air layers trap pollution close to the ground. These conditions inhibit the dispersion of ozone and other pollutants, causing long-term damage.

To effectively communicate these findings, we created a visual representation of ozone accumulation in the affected area. This chart shows daily maximum and long-term AOT values, allowing us to understand where ozone levels are of most concern. Areas with persistent ozone levels are highlighted on the map, which shows the hazardous status of persistent ozone levels in the National Capital Territory of Delhi and Punjab and Haryana regions. The area is color-coded according to ozone concentration. The color gradient ranges from blue (safe level) to grey (high hazard), helping observers quickly identify areas where ozone accumulation exceeds the limit. These high-risk areas are often associated with urban and agricultural areas, supporting our pollution hypothesis. For example, during periods of peak pollution, government may consider regulating pollution control, restricting trade, or increasing the frequency of monitoring and reporting. Visual information also provides a useful tool for raising public awareness, helping citizens understand pollution in their area, and taking preventive measures (Figs. 1 and 2).

8 Calculations

$$\text{Exceedance} = \text{Max Ozone(ppb)} - \text{AOT40 Threshold(40 ppb)} \tag{1}$$

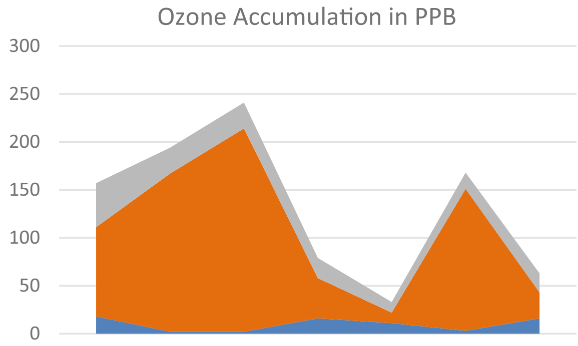

Fig. 1 Visualization of average ozone accumulation throughout the day over the Northern Indian regions

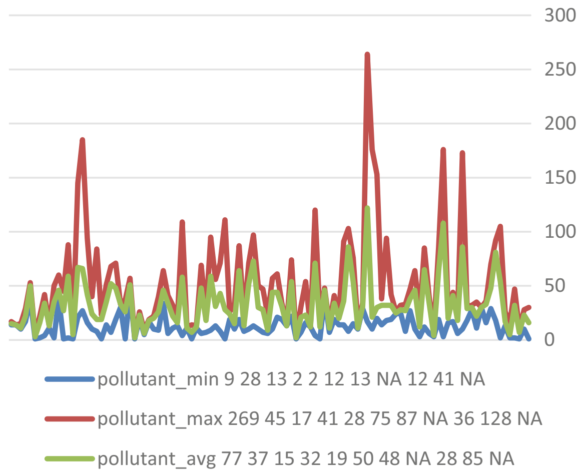

Fig. 2 Visualization of ozone accumulation in various regions of the North Indian region

The test model measures how much the maximum ozone level exceeds the AOT40 threshold of 40 ppb (critical level for ozone exposure). If the maximum ozone concentration is greater than 40 ppb, the maximum value indicates the maximum range and indicates an environmental or health risk.

Applying this for each value:

For Ashok Vihar, Delhi—DPCC:

$$\text{Exceedance} = 269\text{ ppb} - 40\text{ ppb} = 229\text{ ppb}$$

For North Campus, DU, Delhi—IMD:

$$\text{Exceedance} = 264\text{ ppb} - 40\text{ ppb} = 224\text{ ppb}$$

For Bawana, Delhi—DPCC:

$$\text{Exceedance} = 185\,\text{ppb} - 40\,\text{ppb} = 145\,\text{ppb}$$

In all of these above peaking values, we see that the limit of AOT40 has been exceeded which indicates that the region experiences a surge in ground-level Ozone accumulation and providing us a geographical benefit the accumulation of Black carbon would be providing the appropriate situation for the interaction between BC and Ground-level Ozone.

9 Discussions

This study undertook an evaluation of the correlation between BC and O_3 concentration in order examine how measures towards the reduction of BC will help in alleviating O_3 pollution and thereby increase wet yield of wheat crop. AOT40 is an indicator of the public health problem and crop loss caused by ground-level ozone, a type of air pollutant, which has a noticeable adverse effect as soon as its level exceeds 40 ppb (parts per billion). AOT40 is a measure of the accumulated dose of damaging levels of ozone to plants and can supply information about the degree of harm done by ozone in the area depending on crops whims, therefore acknowledging the importance of minimizing the concentrations of ozone affecting crops. Research indicates that BC, caused mainly by incomplete combustion in fuels, acts as a POLLUTANT while also, through its influence on atmospheric mixing, plays a role in ozone reduction. Measures which can help to decrease BC concentration include changes in the agricultural practices and decreased use of fossil fuels; that in turn decreases AOT40 and increases air quality. Better air quality enriches crop yield due to a range of factors arising thereof for agricultural production, especially the wheat prolonged exposure to ozone affects crops hence improving air quality boosts crop production. To accurately predict the behavior of the pollutant, the study utilized a number of sophisticated algorithms. To eliminate noise and increase the reliability of real-time sensor data from ozone and BC monitoring stations, the Kalman Filter algorithm was applied. Moreover, the use of Neural Networks to establish the relations between mm environmental variables, for example, temperature, and humidity, concentration of BC and ozone levels was used to establish the environmental variables while Fuzzy Logic used to deal with uncertainties to decide on the best approach in managing pollution. Bayesian Networks were integrated for fusing multi-sensor data in order to improve estimation of pollution level and different clustering algorithms such as K-Means or DBSCAN for identifying trends and patterns of pollutant level over the time.

Intermediate results provide evidence of the research model's applicability along with O3 exceedances above the chosen AOT40 level. The authors exceeded the threshold assessment and identify strains in some areas which can be potentially dangerous for the vegetation. For instance, the quantitative analyses revealed a high frequency of ozone exceedance in areas such as Ashok Vihar and North Campus

Delhi; the ozone concentrations were immensely over the AOT40 thereby pointing to reduce the specific areas in need of recommended mitigation strategies.

The presented study findings are related to the sustainable development goals (SDG) 13: Climate action, as the research focuses on the data that can be helpful in the climate change and agriculture. With respect to the aspects of climate and agricultural yield arising from integrated pollution control, the results offer critical data on national and local policies to support combined climate change with sustainable agriculture. This strategy is beneficial to achieving environmental and public health objectives and also solidifies food security because the efficient control of air pollutants increases crop production.

10 Conclusion

Concerning the quantity of the species it regulates; black carbon or BC affects ozone and combats boundary layer ozone. Increased BC emissions hurt health and reduce crop productivity in times of increased AOT40 when ozone damage hampers plant growth by rendering tissues weaker, photosynthesis less effective, and crop yields lower for sensitive produce like rice. Their populations, within growth season, sustain agricultural productivity and food security when ozone is controlled within the safe limit. High-end techniques such as Kalman filters, artificial neural networks, and fuzzy logic enhance the BC and ozone measurements for precise pollution management. Reducing BC is tied to climate goals to minimize pollution and support climate change agriculture practices. This work identifies the research gap between environmental security and agriculture and called for policy interventions to deliver air quality improvement to enhance productivity, manage risks, and guarantee sustainable agriculture in combating climate change.

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