MEASURING URBAN ATMOSPHERIC CARBON DIOXIDE EMISSIONS USING SATELLITE REMOTE SENSING: A MICRO-REVIEW

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"I did not use any generative AI tools at any stage of producing this assignment."

ABSTRACT

The desire for data on carbon dioxide emissions and concentrations has led to the advent of new technologies designed to provide accurate, fast, and precise data. One such technology is the use of carbon dioxide sensors onboard satellites orbiting the globe. These sensors provide data on urban areas and are often used to analyze anthropogenic emissions in areas of high density. This paper reviews the methodology of satellite sensing, focusing on its usage to determine carbon dioxide concentrations in urban areas. The advantages and disadvantages of this method are explored, along with existing data and future applications for the technology.

1. Introduction

Global climate change, or the modification of the Earth's climate because of human activity, has brought international awareness to the emissions of greenhouse gases by industry, transportation, and other human activities. Carbon dioxide is especially vital in this domain due to its longevity and greenhouse effect, trapping longwave radiation in the atmosphere and drastically modifying the global environment (IPCC 2023).

Scientists across fields are searching for ways to monitor and mitigate the anthropogenic emissions of carbon dioxide. One such technology is infrared laser sensors onboard Earth-orbiting satellites, which can measure carbon concentrations from space (Tollefson 2016). This review focuses on utilizing this sensing technology in urban areas, which release approximately 70% of the world's carbon dioxide emissions (Seto et al. 2014). The advantages and disadvantages of remote satellite sensing are examined, along with future uses of the technology and trends for cities.

2. Advantages of Satellite Sensing

The use of satellites as a remote sensing technique for monitoring carbon dioxide emissions from urban areas has numerous, substantial advantages. Many cities rely on carbon emission reporting to track these outputs, introducing human bias into the data (Fu et al. 2019; Labzovskii et al. 2019; Kiel et al. 2021; Zhang et al. 2023). By contrast, satellites have a potential view extent of the entire earth and can be used where ground measurement techniques are absent (Nguyen et al. 2019; Yang et al. 2020; Wu et al. 2023). Data from satellites can also be modeled using statistical methods such as a Bayesian network (Tao et al.

2014; Ye et al. 2020; Lespinas et al. 2020) or regression models (Nguyen et al. 2019), which provide the ability to analyze past and current trends and predict future trends.

As the technology driving this sensing advances as a result of new engineering, the resolution of the view is becoming more precise (Labzovskii et al. 2019; Kiel et al. 2021) and more satellites are launching, providing higher areas of coverage (Khulman et al. 2019; Yang et al. 2020; Lespinas et al. 2020). Finally, satellite sensors also monitor the concentrations of other particulates and gasses in the atmosphere, allowing for the investigation of relationships between these and carbon dioxide (Khulman et al. 2019; Xu and Xiang 2024). These advantages of satellite sensing provide technology well-suited to measure carbon dioxide emissions from urban areas and provide this data to scientists, lawmakers, and climate activists.

3. Disadvantages of Satellite Sensing

As with any scientific technology, remote sensing satellites face disadvantages that must be considered when reviewing their capability to analyze urban emissions of carbon dioxide. Weather conditions, such as cloud cover or increased aerosol presence, can disrupt the infrared sensors onboard the satellites, causing inaccurate results that must be adjusted for this error (Fu et al. 2019; Labzovskii et al. 2019; Khulman et al. 2019; Wu et al. 2023; Xu and Xiang 2024). Wind also causes the advection of carbon dioxide from its sources, providing a challenge in tracking emission sources (Broquet et al. 2018). Further complicating measures, carbon dioxide is a long-lived chemical that occurs naturally, so differentiation between background carbon dioxide concentrations and anthropogenic emissions can be problematic for researchers (Labzovskii et al. 2019; Ye et al. 2020; Zhang et al. 2023; Xu and Xiang 2024).

The mechanics of satellites and measuring instruments also provide hurdles regarding carbon dioxide sensing. The view of satellites can be coarse – kilometers in width - meaning that carbon particulates are only sourced to a general area, not a point source (Khulman et al. 2019; Labzovskii et al. 2019; Yang et al. 2020; Kiel et al. 2021). Table 1 demonstrates the granulated resolution across studies and satellites.

Satellite	Study	Spatial resolution
TanSat2	Wang et al. 2020	2 km × 3 km

Orbiting Carbon Observatory 2	Xu and Xiang 2024	1.29 km × 2.25 km
	Labsovskii et al. 2019	1.25 × 2 km
	Fu et al. 2019	1.3 × 2.25 km
Orbiting Carbon Observatory 3	Kiel et al. 2021	1.6 x 2.2 km

Table 1. The spatial resolution of satellites used in studies on urban carbon dioxide satellite analysis. This is the small area over which a concentration of carbon dioxide is analyzed.

Due to their unique orbit mechanics, satellites can take days or weeks to return to a city for a repeat measurement (Wu et al. 2023). Repeat measurements are often not made at the same time or location, creating confounding variables (Khulman et al. 2019; Yang et al. 2020; Kiel et al. 2021; Zhang et al. 2023).

While these disadvantages can present challenges for researchers, the use of statistical models (Tao et al. 2014; Ye et al. 2020; Nguyen et al. 2019; Lespinas et al. 2020) and data adjustment (Broquet et al. 2018; Wu et al. 2023; Xu and Xiang 2024;) can mitigate these challenges and provide accurate, workable data for the use of measuring carbon emissions from urban areas.

4. Comparisons Between Urban Areas

The research in urban carbon dioxide emissions using satellite remote sensing has led to data points on various cities, lending themselves to comparisons between urban areas. One theme observed across cities is that increased vegetation cover leads to lower summer carbon dioxide concentrations (Fu et al. 2019; Nguyen et al 2019; Xu and Xiang 2024), likely because plants' "green seasons" see an uptick in photosynthesis, which converts atmospheric carbon to oxygen (Velasco et al. 2015). Mega-cities, defined as cities with 10 million or more inhabitants (Kiel et al. 2021) are some of the largest emitters, as 5 of the 6 cities with the highest carbon emissions fall into this category (Labzovskii et al. 2019). Finally, the study of multiple cities over many latitudes shows that as latitude increases, bias in carbon dioxide measurements increases (Wang et al. 2020). As the study of carbon dioxide in urban areas continues, satellite sensing technology will continue to provide data about the similarities and differences in particular cities.

5. Potential Future Applications

As a recent field, satellite sensing in urban carbon dioxide monitoring has innumerable potential uses in the future. Many satellites with carbon dioxide sensors on board can also track other pollutants, including nitrogen dioxide and carbon monoxide (Khulman et al. 2019; Zhang et al. 2023; Xu and Xiang 2024). The analysis of trends involving the interactions of these chemicals has yielded some preliminary results, such as a positive correlation between nitrogen dioxide and carbon dioxide concentrations (Xu and Xiang 2024). Additionally, many nations are launching satellites whose data is used interchangeably (Wang et al. 2020), creating an effective constellation of satellites with the potential for accurate, fast data (Khulman et al. 2019; Yang et al. 2020; Wang et al. 2020; Lespinas et al. 2020). Some recent satellite launches include GOSAT-2 from Japan, OCO-2 and OCO-3 from the United States, and TanSat2 from China (Yang et al. 2020).

The most wide-reaching application of satellite data regarding carbon dioxide from urban areas is using the data to manage carbon emissions. This data has the potential to drive city-wide plans for carbon mitigation (Fu et al. 2019; Yang et al. 2020; Ye et al. 2020; Kiel et al. 2021; Zhang et al. 2023) or, with increased resolution, point-source tracking of carbon emissions from industry or transportation (Broquet et al. 2018; Labzovskii et al. 2019). With this valuable data in hand, legislators and industry leaders can monitor, reduce, and mitigate carbon emissions within urban areas.

6. Conclusion

Satellites as a technology for detecting urban carbon dioxide emissions have proven effective. While errors are present due to meteorological conditions and current technology, valuable data on emissions and concentrations is extracted from these satellites.

In the future, launching more satellites to create an extensive network and a more precise time between measurements will allow lawmakers and scientists access to accurate, fast data. This information has the potential to craft solutions and legislation to combat anthropogenic carbon emissions in urban areas.

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Data Availability Statement.

No datasets were generated or analyzed during the current study.

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