Vehicle-based monitoring and AI unravel patterns of on-road carbon and pollutant emissions

Yonglin Zhang,[1] Li Wang,[1,*] Tianle Sun,[2] and Bo Huang[3]

[1]Key Laboratory of Remote Sensing and Digital Earth, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100101, China
[2]Shenzhen Environmental Monitoring Center of Guangdong Province, Shenzhen 518049, China
[3]Department of Geography, The University of Hong Kong, Hong Kong SAR 999077, China
*Correspondence: wangli@aircas.ac.cn

Received: April 22, 2024; Accepted: June 25, 2024; Published Online: June 27, 2024; https://doi.org/10.59717/j.xinn-geo.2024.100085

Citation: Zhang Y., Wang L., Sun T., et al., (2024). Vehicle-based monitoring and AI unravel patterns of on-road carbon and pollutant emissions. The Innovation Geoscience 2(3): 100085.

Driven by economic and social development as well as human needs, transportation networks and systems have led to an increase in carbon and pollutant emissions.[1] It is worth noting that transportation is the third largest source of carbon emissions in China. With the continuous growth of motor vehicle ownership, the share of carbon emissions originating from road traffic in cities is highly prominent. Considering the city of Shenzhen, China as an example, road traffic carbon emissions account for over 80% of the total emissions from the transportation sector and are up to 48% of the total direct carbon emissions. Meanwhile, it has been proven that long-term exposure to vehicle pollutants can induce respiratory, cardiovascular, and other diseases

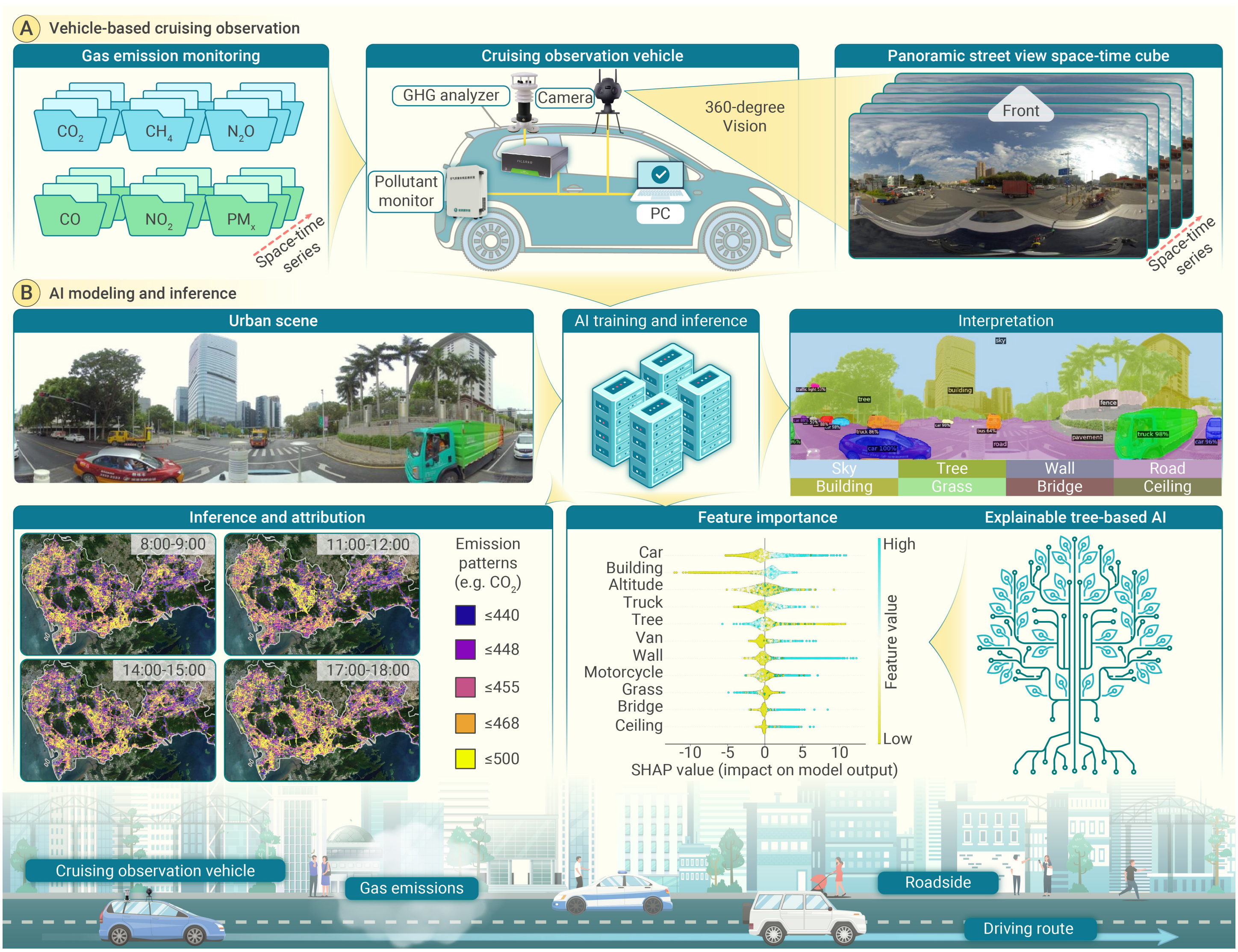

Figure 1. Framework of vehicle-based cruising observations and AI pipelines to identify on-road carbon and pollutant patterns (A) Vehicle-based cruising with multi-modal sensors for carbon and pollutant emission monitoring. (B) Adoption of an AI framework to interpret urban scenes, conduct on-road emission pattern inference, and attribute emissions to specific sources.

in humans, even increasing the risk of death.[2] Therefore, China is currently facing the dual challenge of growing carbon and pollutant emissions from road traffic, and difficulties in precise and refined collaborative governance.[3] To address urban climate change and safeguard public health, it is imperative to meticulously characterize the patterns of carbon and pollutant emissions from road traffic, and propose emission reduction action plans.

On March 15, 2024, China's Ministry of Ecology and Environment issued the "Implementation Opinions on Accelerating the Establishment of a Modern

Ecological and Environmental Monitoring System". Aims to promote the "digital and intelligent transformation" of eco-environmental monitoring, gain insights into carbon and pollutant emissions from urban road traffic, achieve rapid source tracing of emissions, and thereby, improve the effectiveness of collaborative governance. However, a gap between research and application still exists in China regarding refined, precise collaborative monitoring and source tracing technologies for pollution and carbon inside urban areas, especially in terms of deep integration with artificial intelligence (AI).

INTELLIGENT TRANSFORMATION OF LOW-CARBON TRANSPORTATION

The global carbon cycle research team from Aerospace Information Research Institute, Chinese Academy of Sciences, cooperated with the Shenzhen Ecological and Environmental Monitoring Center and Shenzhen University to establish a novel mobile laboratory that combines multi-source environmental sensor collaborative observation with AI. They took the initiative in performing large-scale automobile-based air monitoring of the traffic in Shenzhen. The monitoring process targeted carbon emissions such as carbon dioxide , methane, and nitrous oxide, as well as pollutant gases such as particulate matter, carbon monoxide, and nitrogen dioxide. This work expanded the traditional mode of vehicle-based air quality monitoring[4] and constructed a high-throughput database of spatiotemporal sequences of carbon emissions coupled with panoramic AI interpretation. So far, the database covers roads with a distance of more than 650 km in Shenzhen, including over a hundred thousand high-resolution street-level panoramic imageries. Furthermore, by organically integrating road infrastructure environments with carbon and pollutant emission observations, a cross-disciplinary research path combining AI models, geographic big data, and air environmental monitoring was proposed. This approach facilitates an "intelligent transformation" toward low-carbon and low-pollution road transportation.

"SEE THE UNSEEN" ON-ROAD TRAFFIC EMISSIONS

Our research team developed a novel integrated AI carbon emission monitoring technology via vehicle-based surveys (Figure 1). It employs panoramic visual sensors and various greenhouse gas (GHG) analyzers for spatiotemporal collaborative observations, data processing, and modeling (Figure 1A). This allows insights into and understanding of the dynamic connections between the physical urban space and road traffic emissions, providing a precise and refined carbon and pollutant emission source tracing system. This method automatically extracts attributes, etc., of objects and landscapes in urban scenes, helping to evaluate the relative importance of built environments and road traffic to emission intensities in actual scenarios (Figure 1B). Based on a complete understanding of in-situ conditions, this method aims to identify coordinated development paths for buildings and transportation that can enhance emission reduction effects.

The Shenzhen Ecological Environment Monitoring Department has been implementing this novel observation mode in a large-scale manner. This approach has formed a ground-based mobile observation network that is integrated with the existing fixed GHG flux stations and pollutant monitoring stations. By leveraging the synergistic advantages of artificial intelligence, big data, and urban monitoring, this integrated system aims to enhance the efficiency and effectiveness of environmental monitoring, and provides a valuable reference for other cities.

By constructing AI pipelines and training tasks using multi-source sensor data, the goal was to enable the models to "see the unseen" carbon and pollutant emission patterns. The entire AI model is two-fold: a feature extractor was used to perform deep feature extraction on the visual information of all elements in the urban physical space; furthermore, a pattern recognition module was used to learn the spatiotemporal dynamic patterns between different emissions and the deep features from the panoramas. Leveraging the powerful feature recognition and non-linear learning capabilities of AI models, it automatically extracts key features and understands the inherent associations between gas emission variations and features. On this basis, panoramic street view imageries and AI interpretation techniques can not only enhance the prediction capability of spatiotemporal variations in carbon dioxide, but also explain, trace back to sources, attribute, and map the distribution of on-road emissions, thus exhibiting a significant practical value for the "intelligent transformation" of road traffic emission monitoring.

PROSPECTS OF LOW-CARBON TRANSPROTATION MONITORING

The collaborative monitoring and intelligent management of road traffic pollution and carbon emissions based on AI is inseparable from the utilization and integration of multimodal information. Low-carbon monitoring and AI frameworks are increasingly being combined with more geographic big data to strengthen the comprehensive perception of carbon footprints and pollution sources in real urban scenarios.[5] Furthermore, by incorporating data from sensors for autonomous driving, aerial imagery from drones, traffic monitoring cameras, and extensive participation from different stakeholders (public transportation, ecological environment monitoring, planning and design departments, and the public, etc.), the intelligent perception and generalization capabilities for road traffic gas emissions can be improved. It may even evolve into an advanced, self-organizing network monitoring mode, providing governments and decision-making departments with bottom-up gas emission governance pathways and localized traceability perspectives, and accordingly formulating appropriate emission reduction strategies. Additionally, low-carbon monitoring and AI technologies provide a subtle and precise bottom-up estimation approach that is distinct from traditional statistical/measurement methods, and can therefore be used as ground-truth data to evaluate existing monitoring results.

Although preliminary cross-disciplinary cooperation among professionals has been established at the Shenzhen Ecological and Environmental Monitoring Department, the realization of their goals still requires the integration of multimodal information as well as more explainable AI models and computing power, necessitating in-depth communication and knowledge sharing among AI engineers, environmental practitioners, and urban planners. Simultaneously, this work is incremental and sustainable, and holds immense application prospects in urban planning, environmental management, intelligent transportation, and sustainable development. A continuous improvement of vehicle-based monitoring solutions and involvement of more road mobile platforms will not only enhance the data infrastructure related to sustainable urban transportation construction but also implement the road emission reduction responsibilities that need to be applied by different industries for urban road transportation systems. This approach will play an important role in promoting the "intelligent transformation" of ecological and environmental monitoring as well as low-carbon planning and management for urban road transportation.

REFERENCES

1. Böhm, M., Nanni, M., and Pappalardo, L. (2022). Gross polluters and vehicle emissions reduction. Nat. Sustain. **5**: 699–707. DOI: 10.1038/s41893-022-00903-x.
2. Choma, E. F., Evans, J. S., Gómez-Ibáñez, J. A. et al. (2021). Health benefits of decreases in on-road transportation emissions in the United States from 2008 to 2017. Proc. Natl. Acad. Sci. USA **118**: e2107402118. DOI: 10.1073/pnas.2107402118.
3. Axsen, J., Plötz, P., and Wolinetz, M. (2020). Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transport. Nat. Clim. Change **10**: 809–818. DOI: 10.1038/s41558-020-0877-y.
4. Apte, J. S., Messier, K. P., Gani S. et al. (2017). High-resolution air pollution mapping with google street view cars: Exploiting big data. Environ. Sci. Technol. **51**: 6999–7008. DOI: 10.1021/acs.est.7b00891.
5. Li, H., Liu K., Yang W., et al. (2023). Integration of multidisciplinary methods to better understand regional carbon emissions. Environ. Sci. Technol. Lett. **10**: 395–397. DOI: 10.1021/acs.estlett.3c00252.

FUNDING AND ACKNOWLEDGMENTS

This work was supported by the National Key Research and Development Program of China (2022YFB3903702). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

AUTHOR CONTRIBUTIONS

Y. Z., L. W. and T. S. designed the research and built the cruising platform; Y. Z. and L. W. drafted the paper; Y. Z. contributed to the interpretation of core algorithms and analysis; All authors reviewed and approved the final manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.