Filling the global biomass burning emissions puzzle: A China-Laos partnership toward a new monitoring paradigm in Southeast Asia

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SCIENTIFIC BACKGROUND AND PROJECT LAUNCH: ADDRESSING REGIONAL AND GLOBAL DATA GAPS

Southeast Asia is a critical global hotspot for biomass burning, ranked as the fourth-largest emission source region worldwide, after Southern Hemisphere Africa, Southern Hemisphere South America, and Northern Hemisphere Africa.[1] Widespread biomass burning, including both crop residue burning and traditional slash-and-burn (swidden) agriculture, releases large quantities of aerosols. These emissions contribute to regional haze and undergo long-range transport.[2] A body of evidence confirms that light-absorbing aerosols from Southeast Asia may deposit on cryospheric regions such as the Tibetan Plateau, accelerating snow and ice melt by reducing surface albedo, thereby exerting significant climate feedback.[3]

However, a stark contrast exists between satellite-detected fire activity and ground-based observations. For instance, despite covering merely 4% of the Indochina Peninsula, Laos exhibited an exceptionally high fire density of ~192 MODIS active fire hotspots per 10,000 km^2 in 2024, 3-5 times greater than that of Myanmar, Thailand, or Vietnam. This is based on 45,381 active fire hotspots detected by MODIS across the country in 2024. Yet, Laos lacks comprehensive ground-based measurements of emission factors or chemical speciation. Consequently, many global climate models assume an idealized internal mixture for biomass burning aerosols, introducing substantial biases in absorptivity that can alter their radiative effect from warming to cooling.[4] This "hotspot-blind zone" dilemma undermines the reliability of assessments for pollutant transport pathways and climate forcing.

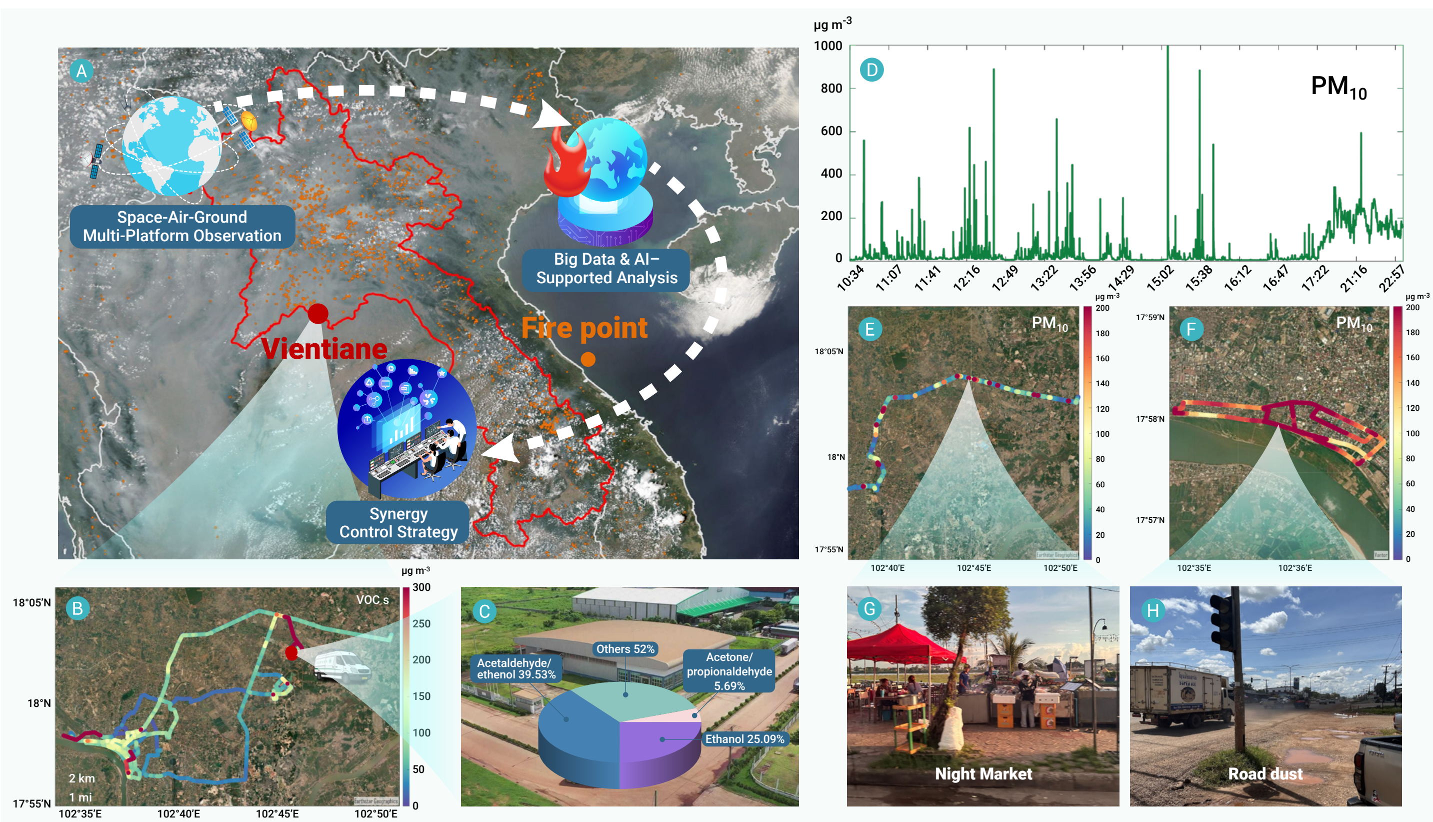

Figure 1. Conceptual diagram of the China-Laos air quality initiative and preliminary observational findings (A) Spatial distribution of fire hotspots in Southeast Asia during the 2024 dry season. (B) Mobile monitoring route and VOCs concentration distribution. (C) Aerial view of an industrial park and detected VOCs species. (D) Temporal variations in PM_{10} concentrations. (E-F) Spatial distribution of PM_{10} in typical source areas. (G-H) Field photographs of typical pollution sources.

In response, the China-Laos Environmental Protection Planning and Technical Assistance Project was launched to co-develop an integrated "air-space-ground" observation network. This initiative aims to fill critical ground-truthing gaps by generating benchmark data on emission factors and chemical speciation. These data will enable precise quantification of aerosol composition and light-absorbing properties, which is critical for refining emission estimates, calibrating global inventories, and ultimately improving assessments of aerosol climate impacts.

TECHNICAL FRAMEWORK: FROM MONITORING NETWORK TO PROCESS-ORIENTED FIELD LABORATORY

The project's "air-space-ground" integrated monitoring system is designed not only for urban air quality surveillance but also as a field laboratory to address key scientific questions (Figure 1A):

High-resolution source apportionment: combining satellite remote sensing, ground-based stations, and UAV-based mobile monitoring to obtain real-world emission factors and chemical profiles of crop residue combustion, particularly for climate-sensitive species such as brown carbon.

Quantification of transboundary fluxes: integrating vertical profiling (e.g., lidar) and chemical transport modeling to track the 3D evolution of pollutants from source regions to broader scales, supporting calibration of the Belt and Road climate and environmental observation network.

Model validation and optimization: all high-resolution, multi-component datasets will be made publicly available under FAIR (Findable, Accessible, Interoperable, Reusable) principles, serving as ground-truth data for improving global chemical transport and Earth system models.

Furthermore, the integrated datasets will feed into policy modeling exercises, which are designed to evaluate the potential effectiveness of different emission control scenarios and sustainable land-management practices. The goal of this component is to translate scientific findings into actionable insights for evidence-based environmental policy planning in Laos and the broader Mekong region.

PRELIMINARY OBSERVATIONS: BASELINE INSIGHTS FROM VIENTIANE

To ground the project's technical framework in real-world conditions, an initial mobile monitoring campaign was launched in Vientiane. This five-day, cumulative 40-hour campaign took place from September 13 to 17, 2025, in Vientiane, the capital of Laos. The campaign covered major roadways, residential areas, industrial parks, night markets, and landfills, representing a range of typical functional zones (Figures 1B-H).

The data revealed that PM_{10} concentrations increased markedly during traffic rush hours and night market operations, with an instantaneous peak reaching 3,752 μg m^{-3}, 83 times the WHO 24-hour guideline value (45 μg m^{-3}). The instantaneous peak of $PM_{2.5}$ reached 693 μg m^{-3}, 46 times the WHO 24-hour guideline (15 μg m^{-3}) (Figure 1D). The data identifies and characterizes a ternary "traffic-cooking-dust" structure of PM pollution in Vientiane, offering the first quantitative evidence of such complex sources in the region. This highlights the pronounced potential for intricate atmospheric pollution in typical Southeast Asian cities during the wet season. Volatile organic compounds (VOCs) pollution is less severe than PM pollution. The chemical fingerprint characteristics of VOCs can clearly identify three primary anthropogenic sources: industry, transportation, and oil/gas storage and transportation. The emissions from these sources interact in the atmosphere, jointly defining the complex characteristics of local VOCs pollution.

The project's core objective is to quantify biomass burning emissions during the dry season (typically November-April). To achieve this, the established "air-space-ground" monitoring framework will be deployed in rural and peri-urban regions of Laos, targeting areas with widespread agricultural burning. The campaign will focus on real-time emission profiling of key aerosols, vertical plume tracking via lidar and UAVs, and integration with satellite fire data to refine emission factors and spatial inventory allocation.

The current wet-season urban baseline provides a critical reference for isolating the biomass burning signal in subsequent dry-season observations. Based on this baseline, we will rigorously quantify the expected pollution intensification, which will be characterized by significantly higher primary pollutant concentrations and a more complex chemical mixture conducive to secondary aerosol formation. This will enable clearer source attribution and more accurate assessment of transboundary transport pathways. Thus, these preliminary data not only document urban pollution patterns but also establish the methodological and empirical foundation for the upcoming biomass burning campaign, directly addressing the regional and global data gaps highlighted in this study.

CONCLUSION: A GENERATIVE PARTNERSHIP FOR PREDICTIVE UNDERSTANDING

This China-Laos collaboration exemplifies a new paradigm of generative scientific partnership that seamlessly integrates cutting-edge science with sustainable capacity building. By adhering to the FAIR data principles and co-managing an open international platform, the project establishes a transparent and equitable "Mekong Model". The integrated "air-space-ground" framework is designed not only for urban air quality assessment but, crucially, as a field laboratory for biomass burning research. The ultimate output extends beyond datasets, fostering enduring regional expertise that empowers local scientists to evolve from data contributors to co-investigators at the forefront of research, ensuring that the scientific narrative surrounding Southeast Asia's environment is increasingly shaped by those who know it best.

Ultimately, this initiative does more than address a regional environmental challenge. By providing the critical empirical foundation needed to accurately quantify Southeast Asian biomass burning emissions, it delivers a data stream of global relevance. This will systematically reduce uncertainties in climate forcing assessments and enhance the predictive skill of Earth system models. This partnership, therefore, represents a strategic investment not only in environmental management but also in the fundamental predictive understanding of our changing planet.

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DECLARATION OF INTERESTS

The authors declare no competing interests.