
Manuscript ID: EGUSPHERE-2025-4436

Title: Biomass burning aerosol transport from Indo-China Peninsula to South China: fluorescence lidar observation and analysis

Authors: Zhekai Li, Dawei Tang, Tianwen Wei, Saifen Yu, Jing Cai, Kenan Wu, Zhen Zhang, Jiadong Hu, Haobin Han, Yubin Wang, and Haiyun Xia

Dear editor Gerd Baumgarten and Referee #4:

On behalf of the co-authors, thank you for giving us an opportunity to address Referee #4's concerns. We appreciate all the great efforts and constructive comments from Referee #4. We have revised the manuscript carefully according to Referee #4's comments and suggestions. Our point-by-point responses are appended below. All changes made in the revised manuscript are marked in blue. Attached please find the revised version of the manuscript, which we would like to submit for your kind consideration. We are looking forward to hearing from you!

Best regards!

Sincerely yours,

Zhekai Li

State Key Laboratory of Climate System Prediction and Risk Management,

Nanjing University of Information Science & Technology

219 Ningliu rd. Nanjing, Jiangsu, CHINA, 210044.

Anonymous Referee #4:

General comment:

This manuscript presents a valuable application of multi-channel laser-induced fluorescence (LIF) lidar for observing long-range transported biomass burning aerosol (BBA) over Nanping, South China. The study demonstrates the high sensitivity of the LIF technique by detecting weak fluorescence signals from relatively low-intensity fires in the Indo-China Peninsula (ICP), a region where such observations remain scarce. The integration of multi-source datasets, including satellite fire products, reanalysis data, backward trajectories, and radiosonde profiles, provides a comprehensive framework for source attribution and analysis of transport pathways. Notably, the observation of co-transported water vapor with the BBA layer offers new insights into the humid processing environment during transport.

Overall, the paper is well-structured and presents a compelling case study. However, several

aspects require clarification and expansion to strengthen the manuscript's conclusions and ensure its reproducibility. I recommend publication in Atmospheric Measurement Techniques after minor revisions. My detailed comments are as follows:

We sincerely thank Referee #4 for constructive comments and suggestions, which have significantly improved the quality of our manuscript. Below, we provide our point-by-point responses to the comments:

Major Comments:

1. Given the LIF lidar's 30° elevation angle, is the y-axis label in Figures 2-3 correctly indicating altitude? Please verify and clarify if the displayed values represent vertical altitude or slant range.

Thank you for pointing this out. In this study, all altitude values refer to vertical altitude rather than slant range. We have clarified this explicitly in the Sect. 2.1. The y-axis labels in Fig. 2, 3, and 7 have been revised accordingly to avoid ambiguity.

“The vertical altitude was obtained by projecting the slant range onto the vertical direction, and all altitudes reported hereafter refer to vertical altitude.”

2. Regarding the lidar ratio assumption in line 187, it is suggested to reorder the discussion. The assumption of a lidar ratio of 55 sr should only be applied after first establishing that the observed aerosol layer is indeed smoke. The current logical flow could be improved for clarity.

Thank you for this valuable suggestion. We have reorganized the discussion and moved the lidar ratio assumption after the HYSPLIT analysis which indicates that the observed aerosol layer originated from fire sources. We also revised the order of Sect. 4: Sect. 4.1 Vertical profiles observed by LIF lidar; Sect. 4.2 Source attribution of the fluorescent layer in Case 1; Sect. 4.3 Spectral fluorescence capacity estimation; Sect. 4.4 Fluorescence spectra.

During this revision, we performed a comprehensive re-examination of the data processing procedure and identified an implementation issue that resulted in a systematic overestimation of the aerosol extinction coefficient by a factor of two. After correction, the retrieved spectral fluorescence capacity \hat{G}_F has been revised from 3.1 to 1.6. Nevertheless, the updated value remains within the range reported for smoke (i.e., 1.5×10^{-6} – 13×10^{-6} nm⁻¹) in previous studies (Gast et al., 2025) and is still clearly higher than the \hat{G}_F values retrieved from the other layers. Therefore, this correction does not affect the main conclusions or the interpretation of the results presented in the manuscript.

“4.3 Spectral fluorescence capacity estimation

To further analyze the fluorescence characterization, we use quantitative analyses of the spectral fluorescence capacity $G_F = \frac{\bar{\beta}_F}{\beta_L}$, where $\bar{\beta}_F$ is the spectral fluorescence backscatter coefficient and β_L is the elastic backscatter coefficient (Reichardt, 2014; Veselovskii et al., 2022b). As β_L was not directly available in this study, we estimated $\hat{G}_F = \frac{\bar{\beta}_F}{\alpha_L^{\text{aero}}} \cdot S$ using a typical lidar ratio $S \approx 55$ sr for aged smoke (Ansmann et al., 2021). To enable direct comparability with the fluorescence wavelength range (444–488 nm) from (Gast et al., 2025), we selected Channels 20–14 (444–487.4 nm) for \hat{G}_F estimation. \hat{G}_F values are provided in Table 2, excluding Case 1 (0.8–1.4 nm): negative α_L^{aero} results in negative \hat{G}_F , which is thus omitted. Table 2 presents the highest \hat{G}_F for Case 1 (1.8–2.4 km) $\approx 1.6 \times 10^{-6} \text{ nm}^{-1}$, which is close to the lower bound of the \hat{G}_F range (1.5×10^{-6} – $13 \times 10^{-6} \text{ nm}^{-1}$) reported for smoke observed in Germany (Gast et al., 2025). Notably, \hat{G}_F for Case 1 (1.8–2.4 km) is at least twice as high as those retrieved from the other layers, indicating relatively enhanced fluorescence efficiency in this layer. The characteristics of the fluorescent layer are further examined through analysis of the fluorescence spectra in Sect. 4.4.

Table 2. Estimates of layer-averaged spectral fluorescence capacity ($\hat{G}_F = \frac{\bar{\beta}_F}{\alpha_L^{\text{aero}}} \cdot S$), computed over the fluorescence range 444–487.4 nm (Channels 20–14). A lidar ratio S of 55 sr (typical for aged smoke) is assumed (Ansmann et al., 2021).

| Cases | $\hat{G}_F (\times 10^{-6} \text{ nm}^{-1})$ (0.8–1.4 km) | $\hat{G}_F (\times 10^{-6} \text{ nm}^{-1})$ (1.8–2.4 km) |
|--------|--|--|
| Case 1 | – | 1.6 |
| Case 2 | 0.7 | 0.2 |
| Case 3 | 0.6 | 0.6 |
| Case 4 | 0.3 | 0.1 |

”

3. Please ensure uniformity in the font style used for numbers and equation symbols throughout the manuscript.

Thank you for your reminder. We have carefully checked the font styles used for numbers and equation symbols throughout the manuscript and have ensured their consistency.

4. The term "N₂ Overtone" in Table 1 requires a brief explanation.

We appreciate your suggestion. An explanation has been added to Sect. 2.1 as follows:

“All detection channels are listed in Table 1. The vibrational overtone of N₂ Raman scattering

at 424.4 nm (Veselovskii et al., 2023) falls within the spectral range of Channel 24, leading to minor spectral features in this channel (as shown in Fig. 1).”

5. In line 265, the statement "our measurements show the fluorescence signal was roughly an order of magnitude lower than the water vapor signal, indicating that fluorescence interference is unlikely to be the primary cause of the observed $\beta_{\text{H}_2\text{O}}$ enhancement." The causal link presented here may be somewhat tenuous.

Thank you for pointing this out. We have revised the text and included a sensitivity test by subtracting the fluorescence signal from the water vapor channel. The enhanced $\beta_{\text{H}_2\text{O}}$ layer persists after this correction, suggesting that fluorescence interference does not dominate the observed enhancement:

“Previous studies have suggested that fluorescence interference in water vapor Raman channels (Chouza et al., 2022; Liu et al., 2022) may contribute to an enhancement in $\beta_{\text{H}_2\text{O}}$. However, in our measurements, the fluorescence signal is approximately one order of magnitude lower than the water vapor Raman signal (Fig. 6a). As a sensitivity test, we subtracted the signal from a nearby fluorescence channel (Channel 22) from the water vapor Raman channel and found that the enhanced $\beta_{\text{H}_2\text{O}}$ layer persists, suggesting that fluorescence interference is limited. In addition, the ERA5 RH profile (Fig. 7h) shows a distinct high-humidity layer at the same altitude, which is consistent with the presence of a real moisture layer.”

6. While these case studies successfully identify transported smoke, the potential influence of local urban aerosols cannot be excluded. What are the known fluorescent components of local aerosol in the Nanping urban area? Although distinguishing between sources is challenging, a brief discussion of these local fluorophores would provide valuable context for interpreting the observed fluorescence spectra.

Thank you for this valuable suggestion. We have added the following discussion to provide context on potential local fluorescent aerosol components in Sect. 2.1:

“Nanping is a mountainous city in southeastern China characterized by extensive forest coverage and limited heavy industrial activity. Local anthropogenic emissions could arise from traffic and residential activities, which may emit combustion-related organic aerosols. In addition,

the surrounding vegetated environment associated with the region's high forest coverage may release primary biological aerosol particles.”

7. Line 140: "standard atmosphere model (Shang et al., 2018)." Please specify which standard atmosphere model was used (e.g., US Standard Atmosphere 1976) for calculating the nitrogen concentration profile.

Thank you for pointing this out. To better represent the atmospheric state during the measurements, the nitrogen concentration profile N_R is calculated from the temperature and pressure profiles obtained from ERA5 reanalysis data in the revised manuscript, replacing the previous use of temperature and pressure profiles from US Standard Atmosphere 1976 model. This has now been clarified in the manuscript:

“ N_R is the nitrogen number density, which is calculated from temperature and pressure values obtained from the ERA5 reanalysis dataset.”

8. Some variables in the equations are not defined upon their first appearance in the text. For instance, the system constants C_R and C_F (for the Raman and fluorescence channels) in Equation (3) should be explicitly defined.

Thank you for your reminder. We have carefully checked all variables and added the corresponding definitions upon their first occurrence in the manuscript. For example:

“ α_R^{mole} and α_L^{mole} are the molecular extinction coefficients in elastic and N_2 Raman channels, calculated following (Platt et al., 2012).”

“ C_R and C_F are system constants for the N_2 Raman and fluorescence channels, respectively.”

“...normalized by the fluorescence spectral wavelength range $\Delta\lambda$...”

Reference:

- Ansmann, A., Ohneiser, K., Mamouri, R.-E., Knopf, D. A., Veselovskii, I., Baars, H., Engelmann, R., Foth, A., Jimenez, C., Seifert, P., and Barja, B.: Tropospheric and stratospheric wildfire smoke profiling with lidar: mass, surface area, CCN, and INP retrieval, *Atmospheric Chemistry and Physics*, 21, 9779–9807, <https://doi.org/10.5194/acp-21-9779-2021>, 2021.
- Chouza, F., Leblanc, T., Brewer, M., Wang, P., Martucci, G., Haefele, A., Vèrèmes, H., Dufлот, V., Payen, G., and Keckhut, P.: The impact of aerosol fluorescence on long-term water vapor

- monitoring by Raman lidar and evaluation of a potential correction method, *Atmospheric Measurement Techniques*, 15, 4241–4256, <https://doi.org/10.5194/amt-15-4241-2022>, 2022.
- Gast, B., Jimenez, C., Ansmann, A., Haorig, M., Engelmann, R., Fritsch, F., Floutsi, A. A., Griesche, H., Ohneiser, K., Hofer, J., Radenz, M., Baars, H., Seifert, P., and Wandinger, U.: Invisible aerosol layers: improved lidar detection capabilities by means of laser-induced aerosol fluorescence, *Atmospheric Chemistry and Physics*, 25, 3995–4011, <https://doi.org/10.5194/acp-25-3995-2025>, 2025.
- Liu, F., Yi, F., He, Y., Yin, Z., Zhang, Y., and Yu, C.: Spectrally Resolved Raman Lidar to Measure Backscatter Spectra of Atmospheric Three-Phase Water and Fluorescent Aerosols Simultaneously: Instrument, Methodology, and Preliminary Results, *IEEE Transactions on Geoscience and Remote Sensing*, 60, 1–13, <https://doi.org/10.1109/TGRS.2022.3166191>, 2022.
- Platt, U., Pfeilsticker, K., and Vollmer, M.: *Radiation and Optics in the Atmosphere*, pp. 1475–1517, Springer Berlin Heidelberg, Berlin, Heidelberg, ISBN 978-3-642-19409-2, https://doi.org/10.1007/978-3-642-19409-2_23, 2012.
- Saito, Y., Ichihara, K., Morishita, K., Uchiyama, K., Kobayashi, F., and Tomida, T.: Remote Detection of the Fluorescence Spectrum of Natural Pollens Floating in the Atmosphere Using a Laser-Induced-Fluorescence Spectrum (LIFS) Lidar, *Remote Sensing*, 10, <https://doi.org/10.3390/rs10101533>, 2018
- Veselovskii, I., Kasianik, N., Korenskii, M., Hu, Q., Goloub, P., Podvin, T., and Liu, D.: Multiwavelength fluorescence lidar observations of smoke plumes, *Atmospheric Measurement Techniques*, 16, 2055–2065, <https://doi.org/10.5194/amt-16-2055-2023>, 2023.