Please note: Paragraphs in black are reviewer comments. Paragraphs in blue are point-to-point responses.

Anonymous Referee #1

This manuscript presents a comprehensive nationwide study on the decadal shifts in light rain frequency in China from 2000 to 2022, with a focus on the role of aerosols and meteorological factors. By integrating long-term observational data, multi-algorithm machine learning, and causal inference modeling, the study quantifies the dominant influence of aerosol-cloud microphysical processes on light rain trends, highlighting the dual benefits of China's emission control policies. The research fills a gap in understanding the mechanisms behind light rain variations in the context of emission reduction, with robust methods and significant implications for aligning air pollution mitigation and climate adaptation. Overall, the findings are valuable and insightful, and I recommend its publication after minor revisions.
Comments

The article mentions the use of 5-fold cross-validation and parameter search space to determine the optimal parameters, but does not specify the value ranges and final selection results of the key parameters (such as learning rate, tree depth, subsampling rate, etc.).

Re: We thank the reviewer for the positive evaluation of our work. Regarding the machine learning methodology, we would like to provide a detailed explanation of our model tuning process to underscore the robustness of our results. We have added this information to SI, or as follows,

The hyperparameters of the XGBoost model were meticulously optimized to ensure maximum predictive performance and the reliability of the subsequent feature importance analysis. For each of the six study regions and both time periods, we conducted an independent hyperparameter tuning process due to variations in local sample characteristics.

The optimization was performed using RandomizedSearchCV with 5-fold cross-validation, employing R^2 as the scoring metric to identify the parameter set that yielded the highest and most generalizable model performance. We defined a comprehensive search space for the key hyperparameters to balance model complexity and prevent overfitting:

1. max_depth: [6, 8, 10] (Controls the depth of trees, balancing complexity)
2. learning_rate: [0.01, 0.05, 0.1, 0.2] (Shrinks the contribution of each tree for smoother convergence)
3. n_estimators: [100, 150, 200, 250] (Number of boosting rounds)
4. subsample: [0.6, 0.8, 1.0] (Fraction of samples used for fitting each tree)
5. colsample_bytree: [0.6, 0.8, 1.0] (Fraction of features available for each tree)

This rigorous approach ensured that the final models used for interpreting factor contributions were neither underfitted nor overfitted, but were optimally calibrated for each unique regional dataset. The consistently high model performance (as shown in

Fig. S3) validates the effectiveness of this tuning strategy.

The abstract states that "The variation in $PM_{2.5}$ concentration explains 59-63% of the interdecadal trend of light rain". However, in the results section 3.4, it is stated that "Aerosols play a dominant role in driving the long-term trend of light rain precipitation frequency, and contribute 58-65% to the interannual variation of annual light rain days". There is a difference in the numerical range of the contribution of aerosols to the trend of light rain in these two statements.

Re: Thank you for your meticulous observation. The numerical discrepancy between the Abstract and Section 3.4 is a low-level typographical error: the "58-65%" in Section 3.4 was incorrect. We have revised it to "59-63%" (consistent with the Abstract), with the correction visible in Line 354 of the updated manuscript. We apologize for this oversight and appreciate your help in enhancing the manuscript's accuracy.

Provide the CFI/RMSEA thresholds you used to judge SEM "very good fit" (currently only values are given).

Re: Thank you for your comment. In the revised manuscript, we have added the commonly accepted threshold values for model fit indices to clarify the criteria we used to judge a "very good fit." Specifically, a model is generally considered to have a good fit when CFI is close to 1, RMSEA is between 0 and 0.05, and SRMR is between 0 and 0.08. In addition, χ^2 test and AGFI are also commonly reported as supplementary fit indices. We have revised the text accordingly, please refer to Line 188-192 in the revised manuscript, or as follows,

"The key indices for evaluating SEM model fit include the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). In general, when CFI approaches 1, $0 \leq \text{RMSEA} \leq 0.05$, and $0 \leq \text{SRMR} \leq 0.08$, the model indicates a very good fit(Schreiber et al., 2006, Ma et al., 2022). In addition, the chi-square test (χ^2) and Adjusted Goodness of Fit Index (AGFI) are also commonly used for model evaluation."

The references mentioned above are:

Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A., & King, J.: Reporting Structural Equation Modeling and Confirmatory Factor Analysis Results: A Review. Int. J. Educ. Res, 99(6), 323–338. https://doi.org/10.3200/JOER.99.6.323-338, 2006.

Ma, W., Ding, J., Wang, J., & Zhang, J.: Effects of aerosol on terrestrial gross primary productivity in Central Asia. Atmos. Environ, 288, 119294. https://doi.org/10.1016/j.atmosenv.2022.119294, 2022.

Introduction: The definition of light rain ("daily accumulation between 0.1 and 10 mm") is cited from Dunkerley (2021), but it is also noted to follow China Meteorological Administration (CMA) standards in Section 2.2. To avoid confusion, clarify the connection between the two (e.g., "consistent with the standards of the China Meteorological Administration (CMA; Dunkerley, 2021)").

Re: This is a very key point. The core definition we adopted is indeed the official standard of the China Meteorological Administration (CMA). The citations to Dunkerley (2021) in the Introduction and to other Chinese studies in Section 2.2 were meant to demonstrate that this definition is also widely recognized and used in the broader scientific literature. However, we agree that this was not clearly stated and

appeared contradictory.

We have revised the text accordingly, please refer to Line 29-31 in the revised manuscript:

"Light rain, a primary component of precipitation, is defined as precipitation with a daily accumulation between 0.1 and 10 mm, following the China Meteorological Administration (CMA) standard (Dunkerley, 2021)."

Line 127: "liner regression" is misspelled; revise to "linear regression".

Re: Corrected. Please refer to Line 137.

Line 389: "2000 – 2023" is inconsistent with the study period (2000–2022) mentioned throughout the manuscript; correct to "2000 – 2022".

Re: Corrected. Please refer to Line 435.

Abstract: $PM_{2.5}$ subscript, please check the entire text.

Re: Thank you for your thoughtful reminder. We have carefully revised all instances of "$PM_{2.5}$" throughout the entire text to ensure the "2.5" is correctly formatted as a subscript.

Line 209-210: "aereas" should be "areas".

Re: Corrected. Please refer to Line 245-246.

Lines 40: The statement "studies have … based on long-term meteorological and aerosol dataset" requires supporting references.

Re: We thank the reviewer for raising this important point. We have added several important references here, including Jiang et al. (2014), Qian et al. (2009a) and Ma et al. (2015). These studies collectively provide robust evidence from long-term datasets for the observed changes in light rain patterns, thereby strengthening our conclusion. The modification has been made on Line 41-43 of the revised manuscript.

The references mentioned above are:

Jiang, Z., Shen, Y., Ma, T., Zhai, P., Fang, S.: Changes of precipitation intensity spectra in different regions of mainland China during 1961–2006. J Meteorol Res, 28, 1085–1098, https://doi.org/10.1007/s13351-014-3233-1, 2014.

Qian, Y., Gong, D., Fan, J., Leung, L. R., Bennartz, R., Chen, D., Wang, W.: Heavy pollution suppresses light rain in China: Observations and modeling, J. Geophys. Res., 114, D00K02, https://doi.org/10.1029/2008JD011575, 2009a.

Ma, S., Zhou, T., Dai, A., Han, Z.: Observed Changes in the Distributions of Daily Precipitation Frequency and Amount over China from 1960 to 2013, J. Climate, 28, 6960–6978, https://doi.org/10.1175/JCLI-D-15-0011.1, 2015.

Figure 7 caption: "Quantified contribution of each individual factor", "each" and "individual" are redundant; revise to "Quantified contribution of each factor".

Re: Corrected. Please refer to Line 373.