

Optimization of Black Carbon Emissions in Japan through Regional Chemical Transport Modeling and Nationwide Monitoring

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Fine particulate matter (PM_{2.5}) is one of the most widely recognized air pollutants worldwide due to its adverse impacts on human health and ecosystems. Among its constituents, black carbon (BC) plays a particularly important role not only in air quality but also in the climate system. Although BC has a relatively short atmospheric lifetime, its strong light absorbing properties contribute to atmospheric warming, and it is therefore classified as a short lived climate forcer (SLCF). Consequently, reducing atmospheric BC concentration may simultaneously improve air quality and mitigate climate change. Information on PM_{2.5} components, including BC, and their precursor emissions is provided by various emission inventories, which serve as essential input data for chemical transport models (CTMs). Although a CTM's ability to reproduce observed concentrations varies among different PM_{2.5} chemical components, our previous studies found that CTMs tended to overestimate BC concentrations compared with observations obtained from the Ministry of the Environment's PM_{2.5} chemical speciation monitoring. These findings underscore the importance of developing and maintaining an accurate and comprehensive emission inventory at the national level to ensure the accuracy and credibility of air quality assessments. Because BC is a primary, directly emitted component of PM_{2.5} with a strong direct correlation to its emissions, discrepancies between observed and modeled BC concentrations can be particularly informative for evaluating emission inventories. In this study, we utilize such discrepancies between observations and model results to evaluate and optimize domestic BC emissions in Japan. Multi year model simulations by using WRF/CMAQ successfully reproduced the interannual variability of BC concentrations. However, comparisons between modeled and observed BC concentrations revealed a systematic underestimation by the model across all seasons. This underestimation was particularly pronounced in relatively high concentration areas, including major port regions, large coastal metropolitan areas, and the Seto Inland Sea region. In areas strongly influenced by shipping emissions, as inferred from trends in emission indicators (eg heavy metals such as V and Ni) associated with maritime activity, the discrepancy was even larger. Although a positive correlation was found between modeled and observed hourly EC concentrations, indicating that the model captured temporal variability, the model to observation ratios ranged from 0.43 to 0.57 depending on season, with an annual median of 0.51. On average, modeled BC concentrations were approximately half of the observed EC concentrations. These results suggest that the emission inventory used as input to the CTM underestimates BC emissions. By correcting this underestimation based on the derived model to observation ratios, the updated national BC emissions for Japan were estimated to be around 0.02 Tg yr⁻¹ for 2022, and results for other years will also be reported in this study. This observation based framework is expected to provide a basis for rapid annual updates of recent emissions, helping to address limitations in conventional bottom up inventories that may lag behind real world emission changes.

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