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Relative effects of open biomass and crop straw burning on haze formation over central and eastern China: modelling study driven by constrained emissions

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Open biomass burning (OBB) has large potential in triggering local and regional severe haze with elevated fine particulate matter ($PM_{2.5}$) concentrations and could thus deteriorate ambient air quality and threaten human health. Open crop straw burning (OCSB), as a critical part of OBB, emits abundant gaseous and particulate pollutants, especially in fields with intensive agriculture, such as central and eastern China (CEC). However, uncertainties in current OCSB and other types of OBB emissions in chemical transport models (CTMs) lead to inaccuracies in evaluating their impacts on haze formations. Satellite retrievals provide an alternative that can be used to simultaneously quantify emissions of OCSB and other types of OBB, such as the Fire INventory from NCAR version 1.5 (FINNv1.5), which, nevertheless, generally underestimate their magnitudes due to unresolved small fires. In this study, we selected June in 2014 as our study period, which exhibited a complete evolution process of OBB (from June 1 to 19) over CEC. During this period, OBB was dominated by OCSB in terms of the number of fire hotspot and associated emissions, most of which were located at Henan and Anhui with intensive enhancements from June 5 to 14. OCSB generally exhibits spatiotemporal correlation with regional haze over the central part of CEC (Henan, Anhui, Hubei, and Hunan), while other types of OBB emissions had influences on Jiangxi, Zhejiang, and Fujian. Based on these analyses, we establish a constraining method that integrates ground-level $PM_{2.5}$ measurements with a state-of-art fully coupled regional meteorological and chemical transport model (the two-way coupled WRF-CMAQ) in order to derive optimal OBB emissions based on FINNv1.5. It is demonstrated that these emissions allow the model to reproduce meteorological and chemical fields over CEC during the study period, whereas the original FINNv1.5 underestimated OBB emissions by 2 ~ 7 times, depending on specific spatiotemporal scales. The results show that OBB had substantial impacts on surface $PM_{2.5}$ concentrations over CEC. Most of the OBB contributions were dominated by OCSB, especially in Henan, Anhui, Hubei, and Hunan, while other types of OBB emissions also exerted influence in Jiangxi, Zhejiang, and Fujian. With the concentration-weighted trajectory (CWT) method, potential

OCSB sources leading to severe haze in Henan, Anhui, Hubei, and Hunan were pinpointed. The results show that the OCSB emissions in Henan and Anhui can cause haze not only locally but also regionally through regional transport. Combining with meteorological analyses, we can find that surface weather patterns played a cardinal role in reshaping spatial and temporal characteristics of $PM_{2.5}$ concentrations. Stationary high-pressure systems over CEC enhanced local $PM_{2.5}$ concentrations in Henan and Anhui. Then, with the evolution of meteorological patterns, Hubei and Hunan in the low-pressure system were impacted by areas enveloped in the high-pressure system. These results suggest that policymakers should strictly undertake interprovincial joint enforcement actions to prohibit irregular OBB, especially OCSB over CEC. Constrained OBB emissions can, to a large extent, supplement estimations derived from satellite retrievals as well as reduce overestimates of bottom-up methods.