Is Traditional Bayesian Inversion Sufficient to Constrain Black Carbon Abundance in High Mountain Asia?

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Abstract

Third Pole regions like High Mountain Asia (HMA) are a critical nexus of coupled processes at the atmospheric chemistry, meteorology, and terrestrial interface. With pollution hotspots and anthropogenic emissions in the vicinity of such regions, accurate emission inventories of light-absorbing particles like black carbon (BC) and model representation of its interacting processes are indispensable for reliable predictions of Earth system phenomena in the region, ranging from air quality and monsoon to snowmelt and freshwater availability. In this study, we leverage high-resolution surface BC concentrations from MATCHA, a novel fully-coupled chemistry reanalysis based on 17 years (2003-2019) of coupled chemistry-climate model simulations over Asia to evaluate CAMS anthropogenic emissions. Using a tagged-tracer approach, we estimate emission uncertainties over 10 Asian regions based on ground-based BC measurements across Asia. Traditional inversion techniques often fail to account for errors in coupled models and highlight the linear sensitivity of simulated concentration to the emission estimates. A framework combining Bayesian inversion and machine learning (ML) is utilized to 1) compare the uncertainties in CAMS BC emissions over different Asian countries from traditional inversion estimates and explainable AI metrics, and 2) highlight the impact of coupled chemical and meteorological processes within the model for the highly variable Bayesian estimates. Our findings underscore that need to have an integrated inverse modeling approach to account for complex coupled processes influencing the abundance of BC in HMA. Unraveling these details will provide valuable insights into the non-linear nature of the hydroclimate in vulnerable regions like HMA and its implications on freshwater resources that sustain the livelihood of densely populated countries in Asia.

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