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Is water vapor a key player of heavy haze in North China Plain?

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Water vapor has been proposed to amplify the severe haze pollution in China by enhancing the aerosol-radiation feedback (ARF). Observations have revealed that the near-surface PM2.5 concentrations ([PM2.5]) generally exhibits an increasing trend with the relative humidity (RH) in North China Plain (NCP) during 2015 wintertime, indicating that the aerosol liquid water (ALW) caused by hygroscopic growth might play an important role in the PM2.5 formation and accumulation. Simulations during a persistent and heavy haze pollution episode from 05 December 2015 to 04 January 2016 in NCP have been performed using the WRF-CHEM model to comprehensively quantify contributions of the ALW effect to near-surface [PM2.5]. The WRF-CHEM model generally performs reasonably in simulating the temporal variations of RH against measurements in NCP. The factor separation approach (FSA) is used to evaluate the contribution of the ALW effect on the ARF, photochemistry, and heterogeneous reactions to [PM2.5]. The ALW not only augments particle sizes to enhance aerosol backward scattering, but also increases effective radius to favor aerosol forward scattering. Therefore, the contribution of the ALW effect on the ARF and photochemistry to near [PM2.5] is not significant, generally within 1.0 μg m-3 on average in NCP during the episode. Serving as an excellent substrate for heterogeneous reactions, the ALW substantially enhances the secondary aerosol (SA) formation, with an average contribution of 71%, 10%, 26%, and 48% to near-surface sulfate, nitrate, ammonium, and secondary organic aerosol concentrations. Nevertheless, the SA enhancement due to the ALW decreases the aerosol optical depth and increases effective radius to weaken the ARF, reducing near-surface primary aerosols. The contribution of the ALW total effect to near-surface [PM2.5] is 17.5% on average, which is overwhelmingly dominated by enhanced SA. Model sensitivities also show that when the RH is less than 80%, the ALW progressively increases near-surface [PM2.5], but commences to decrease with the RH exceeding 80% due to the high occurrence frequencies of precipitation.