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Modeling the feedback between aerosol and meteorological variables in the atmospheric boundary layer during a severe fog–haze event over the North China Plain

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The feedback between aerosol and meteorological variables in the atmospheric boundary layer over the North China Plain (NCP) is analyzed by conducting numerical experiments with and without the aerosol direct and indirect effects via a coupled meteorology and aerosol/chemistry model(WRF-Chem). The numerical experiments are performed for the period of 2–26 January 2013, during which a severe fog–haze event (10–15 January 2013) occurred, with the simulated maximum hourly surface PM2.5 concentration of $\sim$600 μg m-3, minimum atmospheric visibility of $\sim$0.3 km, and 10–100 hours of simulated hourly surface PM2.5 concentration above 300 μg m-3 over NCP. A comparison of model results with aerosol feedback against observations indicates that the model can reproduce the spatial and temporal characteristics of temperature, relative humidity (RH), wind, surface PM2.5 concentration, atmospheric visibility, and aerosol optical depth reasonably well. Analysis of model results with and without aerosol feedback shows that during the fog–haze event aerosols lead to a significant negative radiative forcing of $\sim$20 to $\sim$140 W m-2 at the surface and a large positive radiative forcing of 20–120 W m-2 in the atmosphere and induce significant changes in meteorological variables with maximum changes during 09:00–18:00 local time (LT) over urban Beijing and Tianjin and south Hebei: the temperature decreases by 0.8–2.8 °C at the surface and increases by 0.1–0.5 °C at around 925 hPa, while RH increases by about 4–12% at the surface and decreases by 1–6% at around 925 hPa. As a result, the aerosol-induced equivalent potential temperature profile change shows that the atmosphere is much more stable and thus the surface wind speed decreases by up to 0.3 m s-1 (10 %) and the atmosphere boundary layer height decreases by 40–200 m (5–30 %) during the daytime of this severe fog–haze event. Owing to this more stable atmosphere during 09:00–18:00, 10–15 January, compared to the surface PM2.5 concentration from the model results without aerosol feedback, the average surface PM2.5 concentration increases by 10–50 μg m-3 (2–30 %) over Beijing, Tianjin, and south Hebei and the maximum increase of hourly surface PM2.5 concentration is around 50 (70 %), 90 (60 %), and 80 μg m-3 (40 %) over Beijing, Tianjin, and south Hebei, respectively. Although the aerosol concentration is maximum at nighttime, the mechanism of feedback, by which meteorological variables increase the aerosol concentration most, occurs during the daytime (around 10:00 and 16:00 LT). The results suggest that aerosol induces a more stable atmosphere, which is favorable for the accumulation of air pollutants, and thus contributes to the formation of fog–haze events.