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Nitrate-driven haze pollution during summertime over the North China Plain: implications for urban air quality

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Compared to the severe winter haze episodes in the North China Plain (NCP), haze pollution during summertime has drawn little public attention. In this study, we present the highly time-resolved chemical composition of submicron particles (PM_1) measured in Beijing and Xinxiang in the NCP region during summertime to evaluate the driving factors of aerosol pollution. During the campaign periods (30 June to 27 July, 2015, for Beijing and 8 to 25 June, 2017, for Xinxiang), the average PM_1 concentrations were 35.0 μg m^{-3} and 64.2 μg m^{-3} in Beijing and Xinxiang, respectively. Pollution episodes characterized with largely enhanced nitrate concentrations were observed at both sites. In contrast to the slightly decreased mass fractions of sulfate, semi-volatile oxygenated organic aerosol (SV-OOA), and low-volatile oxygenated organic aerosol (LV-OOA) in PM_1, nitrate displayed an almost linearly increased contribution with the aggravation of aerosol pollution in both Beijing and Xinxiang, highlighting the importance of nitrate formation as the driving force of haze evolution in summer. Rapid nitrate production mainly occurred after midnight, with a higher formation rate than that of sulfate, SV-OOA, or LV-OOA. Detailed investigation of nitrate behaviors revealed several factors influencing the rapid nitrate formation in summer: high ammonia emissions in the NCP region, the gas-to-particle equilibrium of ammonium nitrate closely related to variations in temperature and relative humidity, nighttime nitrate production through heterogeneous hydrolysis of dinitrogen pentoxide (N_2O_5), and regional transport from different air mass origins. Finally, atmospheric particulate nitrate data acquired by mass spectrometric techniques from various field campaigns in Asia, Europe, and North America uncovered a higher concentration and higher fraction of nitrate present in China. Although measurements in Beijing during different years demonstrate a decline in the nitrate concentration in recent years, the nitrate contribution in PM_1 still remains high. To effectively alleviate particulate matter pollution in summer, our results call for the urgent need to initiate ammonia emission control measures and further reduce nitrogen oxide emissions over the NCP region.