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•EDITORIAL•

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Impact of clean air action on $PM_{2.5}$ pollution in China

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China suffers from severe air pollution in the past decades, characterized by high-levels of fine particulate matter ($PM_{2.5}$) concentrations. To mitigate $PM_{2.5}$ pollution, the Chinese government issued the Air Pollution Prevention and Control Action Plan (referred to as the Clean Air Action hereinafter) in 2013, which requires the three key regions, i.e., Beijing-Tianjin-Hebei (BTH), the Yangtze River Delta (YRD) and the Pearl River Delta (PRD), to reduce $PM_{2.5}$ concentrations by 15–25% from 2013–2017, and all other cities to reduce PM_{10} concentrations by 10% compared to 2012 (State Council of the People's Republic of China, 2013). To accomplish this ambitious target, China has implemented a series of air pollution control policies, including strengthening industrial emission standard, rectification on coal-fired boilers, phasing out outdated industrial facilities, promoting clean fuels in residential sector, strengthening vehicle emission standard, and etc. With the implementation of those measures, anthropogenic emissions of major air pollutants in China during 2013–2017 were reduced by 59% for SO_2, 21% for NO_x, and 33% for primary $PM_{2.5}$ (Zheng et al., 2018). As the consequence, air quality in China has improved rapidly during 2013–2017, with annual mean $PM_{2.5}$ concentrations in the three key regions reduced by 28–40%, surpassing the mitigation target proposed in the Clean Air Action. How does the Clean Air Action contribute to the recent air quality improvement? How do the different chemical species change in response to the Clean Air Action? What's the health benefit from the improvement of air quality? And what's the role of interannual meteorological condition changes in $PM_{2.5}$ reduction? These are all problems concerned by the community and the public.

In our special topic, rapid improvement of $PM_{2.5}$ pollution was confirmed from observations (Wang et al., 2019; Xue et al., 2019). By combining ground observations, satellite remote sensing data, and simulations obtained from a chemical transport model, Xue et al. (2019) found that the national population-weighted annual mean $PM_{2.5}$ concentrations over China decreased by 32% from 2013–2017. Based on the observation data in the CARE-China observation network, Wang et al. (2019) found that all the chemical composition of $PM_{2.5}$, including sulfate, nitrate, ammonium, elementary carbon (EC), organic matter (OM) and mineral and unresolved components, showed a deceasing trend in China and the key regions. In particular, sulfate and OM concentrations dropped rapidly during the heavily polluted seasons of autumn and winter. For example, sulfate and OM in autumn and winter in BTH decreased by 76% and 70% from 2013–2017, respectively. By using satellite data and chemical transport model, Geng et al. (2019) found that the population-weighted annual mean concentrations over eastern China decreased by 40% for sulfate, 5% for nitrate, 22% for ammonium, 15% for OM, 17% for BC and 26% for the remaining components. Reduction in $PM_{2.5}$ concentration has led to remarkable long- and short-term health benefits.

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Premature deaths attributable to long-term exposure declined by 14% compared to 32% decrease in $PM_{2.5}$ exposure (Xue et al., 2019) due to supralinear response of health impacts to exposure. Health benefits from short-term exposure were more prominent: deaths related to acute exposure decreased by 61% due to large decrease of heavy pollution events (Xue et al., 2019). Geng et al. (2019) further examined the relationship between changes in $PM_{2.5}$ chemical composition concentration and their precursor emissions. They found that large decrease in sulfate concentration was in line with reduction in SO_2 emissions, confirming the effectiveness of emission control from coal combustion in the Clean Air Action. However, the decrease in nitrate concentration was less than that in NO_x emissions, because the NH_3-rich environment and less sulfate facilitated the formation of nitrate from HNO_3, which partially offset the reduction of NO_x emissions. This indicates that simultaneous control of NH_3 emissions in conjunction with SO_2 and NO_x emissions are important when mitigating $PM_{2.5}$ pollution. To investigate the contribution of meteorological condition changes to $PM_{2.5}$ reductions, Zhang et al. (2019) used an index of meteorological conditions, PLAM (i.e., Parameter Linking Air Quality and Meteorological Elements), to reveal the changes in weather conditions. Although interannual variations in meteorological conditions can partly explain the reduction in $PM_{2.5}$ pollution, the improvement of $PM_{2.5}$ pollution during 2013–2017 was dominated by emission reductions. For instance, only ~5% and ~7% of the $PM_{2.5}$ reduction were attributable to meteorological changes in BTH and YRD during 2013–2017, respectively, which were approximately 13% and 20% of the total $PM_{2.5}$ decrease for the same period (Zhang et al., 2019).

Although significant reductions in $PM_{2.5}$ were obtained during 2013–2017, the annual mean $PM_{2.5}$ concentrations still exceed the national standard of 35 $\mu g\ m^{-3}$ for many regions over China, and are also much higher than the guideline by the World Health Organization that aims to protect the public health. With 1 million premature deaths attributable to $PM_{2.5}$ in 2017, China still faces great challenges in reducing the burden of disease related to air pollution (Xue et al., 2019). To protect human health, continuous efforts for reducing air pollutant emissions are needed. A recent measure specific analysis revealed that the improvement in $PM_{2.5}$ air quality during 2013–2017 were mainly benefited from end-of-pipe emission control measures while actions on prompting clean energy played minor roles (Zhang et al., 2019). Future policies should be developed to facilitate transition in energy and industry structure. Compared to remarkable reduction in SO_2, NO_x, and primary PM emissions, NH_3 and NMVOC emissions remained stable during 2013–2017 (Zheng et al., 2018). Given the important role of NH_3 in secondary inorganic aerosol formation (Liu et al., 2019; Geng et al., 2019), cutting NH_3 emissions from agriculture sector should be proposed as next-step mitigation strategy. In the meanwhile, absence of NMVOC emission control measures has potentially contributed to the worsened surface ozone pollution during 2013–2017 under VOC-limited condition (Li et al., 2019a). Controlling NMVOC emissions then could reverse the ozone increase as well as mitigate $PM_{2.5}$ pollution (Li et al., 2019b). Future mitigation efforts should follow a multipollutant strategy, especially for NH_3 and VOC which are unattended in previous clean air policies.

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