How Does Air Pollution Change during COVID-19 Outbreak in China?

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Early Online Release: This preliminary version has been accepted for publication in *Bulletin of the American Meteorological Society*, may be fully cited, and has been assigned DOI 10.1175/BAMS-D-20-0102.1. The final typeset copyedited article will replace the EOR at the above DOI when it is published.

Main

In early December 2019, an outbreak of the novel coronavirus pneumonia (COVID-19) occurred in Wuhan, Hubei province, China and has fast spread to the whole China. As of 15 June 2020, there have been about 84 thousand confirmed cased over China. Chinese government launched the national emergency response upon the detection of the COVID-19 in Wuhan. To curb the spread of the epidemic, the outbound channels of Wuhan have also been closed since January 23 2020 (Li et al. 2020; Xinhua 2020). On January 26, the second day of the Lunar Chinese New Year, all the motor vehicles were banned in urban central Wuhan, except for special vehicles to supply epidemic prevention (Government 2020). In terms of the national prevention and control measures, the government encouraged people to stay at home; discouraged mass gatherings; extended the Lunar New Year holiday; closed all cross-province bus services and closed schools, government offices, and factories (Chen et al. 2020).

The nationwide anti-virus battle in China brought great changes to personal daily-life and society operation, and caused a huge challenge to some sensitive sectors, including transportation, tourism, retail and entertainment, which leads to GDP decreased by 6.8% in the first quarter of 2020 (Statistics 2020). But on the other hand, many regions in China are suffering from severe air pollution in recent years. A drastic drop of air pollutant emissions occurring with the national lockdown improved the human living environments greatly (NASA 2020). The nationwide lockdown can be considered as an ideal and unique field experiment for the prevention and control of current severe air pollution. It is still unclear that how does the air quality change during the lockdown period and what should we learn about air pollution mitigation from this nationwide ideal experiment.

Air quality variations during COVID-19 epidemic

Giving the effect of city vehicles, air quality within two months after January 26 (i.e., “AF1 period”: 1/26/2020 ~ 2/25/2020 and “AF2 period”: 2/26/2020 ~ 3/27/2020) are compared with that within one month before January 23 (i.e., “BF”:12/23/2019 ~ 1/22/2020), respectively. The corresponded historical average air quality data of BF, AF1 and AF2 (i.e., His_BF: 12/23 ~ 1/22 of 2013 to 2018; His_AF1: 1/26~2/25 of 2014 to 2019; His_AF2: 2/26~3/27 of 2014 to 2019) are involved to show the relative variation of air quality during the nationwide lockdown. The response of air quality to the epidemic are evaluated at provincial scale, because the detailed lockdown measures have regional difference according to the severity of local epidemic.

According to the corresponding historical averages of air quality during each month of BF, AF1 and AF2 period in Fig. S1, air quality has obvious monthly variations in most parts of China (e.g., PM2.5 concentration in Hist_BF period is higher than that of Hist_AF1 and Hist_AF2 period). To avoid the effect of air quality monthly variations, the air pollutants concentrations in BF, AF1 and AF2 period are normalized relative to their historical averages. It can be found that, except for O3, the concentration of other air pollutants from BF to AF2 period are lower than their historical average (c.f., Fig. S1), with the normalized concentrations lower than 100%, indicating the achievements of recent air pollution mitigation in China. As shown in Fig. 1, the normalized air pollutants concentrations are generally lowest in AF1 period, and then redounds partially in AF2 period. As far as national average is concerned, PM2.5, PM10, SO2, CO, NO2 and O3 concentrations show remarkable variations compared with those of historical averages, with -27%, -36%, -52%, -27%, -40% and 15% changes during the first month of lockdown period, and -32%, -30%, -48%, -38%, -29 and 2% change during the second month of lockdown period. The Chinese government rolled out the most ambitious and aggressive disease containment effort in AF1 period. While, some unnecessarily tough measures restricting economic activities were stopped with the decrease in daily confirmed new COVID-19 cases in AF2 period (Tian et al. 2020), which may cancel out the effect of lockdown on air quality.

In general, it shows more notable variations in air quality during AF1 period than that of AF2 period. Thus, we will go through some detailed air quality variation in AF1 period here. Provinces with the lowest five normalized air pollutant concentration (highest for O3) during AF1 period are listed in Fig. 1. Most of the exhibited provinces are the hardest hits by COVID-19 with more than 500 confirmed cases, which proves the effects of disease prevention and control measures on air quality in China. With the strictest anti-virus measures during pandemic, PM2.5, PM10 and NO2 concentration decreased significantly by approximate 52%, 51% and 54% along with 30% increase in O3 when compared AF1 with its historical period in Wuhan. In addition to Wuhan, the provinces of Zhejiang, Jiangxi, Hunan and Hubei are in the top five lists of AF1 PM2.5 concentration decrease, with 49%, 47% and 45% decrease compared with historical average, the descent scopes of which are higher than those of BF period.

Provinces with remarkable reduction in PM2.5 concentration also show significant decrease in PM10 concentration by 49% to 54%. Approximate 65% of provinces and areas in China show normalized PM2.5/PM10 concentrations lower than 80%/70% in the period of AF1, however, Beijing, Tianjin and surrounding areas have relatively high normalized particulate pollution concentrations of about 100% for PM2.5 and 70~80% for PM10. In terms of SO2, its major anthropogenic source is thermal power plants, industry and residential emission in China (Zheng et al. 2018). According to the low normalized concentration in BF period, SO2 concentration shows significant decrease over the whole China in recent years, especially over northern China, indicating the importance of coal desulfurization and nationwide emission reduction. Giving the AF1 period, the decreasing extents of SO2 concentrations over Beijing, Tianjin and Henan Provinces are more significant than other regions. CO is mainly originated from the direct emission of industry, residential and transportation. It shows lower CO concentrations in AF1 period, with normalized concentrations lower than 100% over all the regions, but its decline rate is not as obvious as other air pollutants, with the most significant decrease of 40% over Shaanxi, Shanxi and Henan Provinces.

As for NOx, transportation, industry and power plant are its major anthropogenic emission source in China. Although lots of efforts have been taken to improvement air quality, the decrease trend of nationwide NO2 concentration is weak in recent years, with the national average normalized NO2 concentration of 89% in BF period, i.e., 11% decrease compared with historical average. Whereas, when the COVID-19 outbreak, remarkable NO2 decrease of more than 55% over some hardest hits, e.g., Hubei, Zhejiang, Henan and Hainan Provinces. Comparing with His_AF1, NO2 concentrations decreased by above 30% during AF1 period over approximate 78% of the country, and even the lowest decrease rate reach to 18.5% over Qinghai Province. Considering the case of O3, the concentration of which is driven by two major classes of directly emitted precursors, i.e., NOx and volatile organic compounds (VOCs). Except for the Guangxi Province, O3 over the other provinces and areas increased significantly with the outbreak of coronavirus. The normalized O3 concentrations range from 81~116% in BF period, which turns to 99~134% in AF1 period. Wuhan, Tianjin and the province of Shanxi show the most significant increase in O3 concentration during AF1 period, with more than 30% increase compared with historical average. The current O3 production over most urban regions of China is considered to be VOC-limited (Li et al. 2019). The opposite trend between O3 and other air pollutants is inferred to be connected with the concurrent decrease of NO2. In addition, the obvious reduction of particulate pollutants leads to more solar radiation reaching to the surface, which benefits for the photochemistry and O3 production.

Effect of Meteorological elements

It has been recognized that local ambient air quality is driven by both air pollutants emission and meteorological conditions. How did the meteorological elements behave during epidemic period? Two atmospheric dynamic indexes (i.e., 10 m wind speed, vertical wind shear between 500 and 850 hPa) and two thermodynamic indexes (i.e., potential temperature difference between 850 and 1000 hPa ($\Delta\theta$), surface relative humidity (*RH*)) are involved to evaluate the meteorological conditions during AF1 period, which have been verified in our previous work (Zhang et al. 2014). Fig. 2 shows the relative difference of the above four indexes between AF1 and His_AF1 period. Generally, lower surface wind speed, lower vertical wind shear, higher $\Delta\theta$ and higher *RH* are more unfavorable for the diffusion of surface air pollutants. Extensive unfavorable conditions in surface wind speed and vertical wind occurred in AF1 period comparing with its historical average. It shows a north-south $\Delta\theta$ dipole pattern over mainland China, which indicates a favorable vertical diffusion ability for air pollutants in southern China. *RH* during AF1 period are higher than that of His_AF1 by at least 20% over Beijing and surrounding regions. When taking ±10% difference as a threshold of significance, the number of significant unfavorable indexes shown in Fig. 2 (A) indicates Beijing, Tianjin and the northeast Liaoning Province experienced three more significantly unfavorable indexes for air pollutants simultaneously in AF1 period, followed by Hebei, Shanxi, Shandong, Sichuan, Qinghai, Guizhou, Xizang Provinces and Chongqing with two unfavorable indexes. Except for Beijing and Tianjin, most of the provinces and regions with remarkable variation in air quality displayed in Fig. 1 did not show significant favorable or unfavorable meteorological diffusion conditions for air pollutants during AF1 period, which indicates the variations in air pollutant concentrations can be attributed to the changes of anthropogenic activities during the lockdown. However, the unfavorable atmospheric horizontal and vertical diffusion conditions working with the relative high humidity over Beijing and Tianjin regions are benefit for the accumulation of ambient air pollutants, hygroscopic growth and secondary formation of particles, which maybe negate the effects of emission reduction in lockdown period.

Although China's air quality improved greatly due to the strict emission reduction measures in recent years, the government is still taking steps to win "the battle for blue sky". The variations in the nationwide air quality during COVID-19 should be referenceable in determining the goals of the future emission reduction policies. With the nationwide reduction of anthropogenic activities, the pollution of particulate matter, SO2, NO2 and CO could be eased substantially, whereas, O3 problem is obviously going to receive more attentions. The nationwide increase in O3 concentration along with reduction in NO2 demonstrates that O3 production in China will always be in VOC-limited stage in the near future. The increase of particulate pollution in Beijing during the pandemic indicates air pollution episode may still occur with the unfavorable background meteorology, even if taking the emission reduction efforts as in COVID-19 period. It is worthy of deep consideration to keep the balance of improving particulate matter and O3 pollution. In addition, as the domestic coronavirus epidemic getting controlled, China is already working to bolster its economy and restore the normal social operations in a stepwise fashion. Blue sky and economic development are equally important after work resumption taking place across China.

Acknowledgments:

Daily mean air pollutant concentration observations were obtained from the website of Ministry of Ecology and Environment of the People’s Republic of China (http://106.37.208.233:20035). Daily four times ECMWF ERA5 dataset during Dec. 2013 to Mar. 2020 are downloaded from https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5. This study was supported by the National Natural Science Foundation of China (41790470 and 41805117).

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Accepted for publication in *Bulletin of the American Meteorological Society.* DOI 10.1175/BAMS-D-20-0102.1.

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Accepted for publication in *Bulletin of the American Meteorological Society.* DOI 10.1175/BAMS-D-20-0102.1.

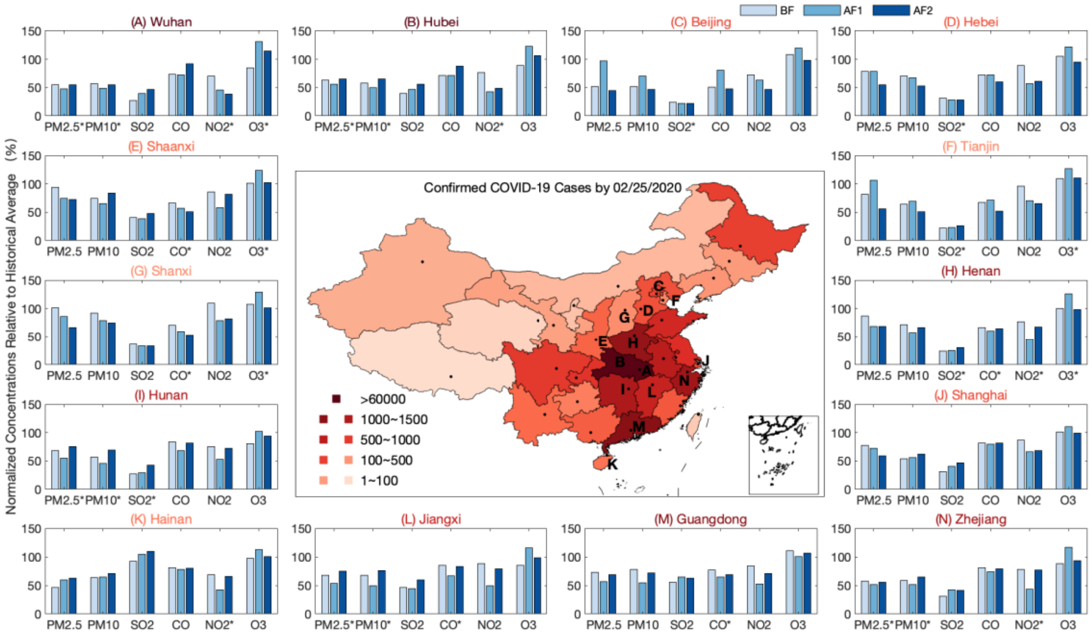

Fig. 1 Distribution of the confirmed COVID-19 cases by 02/25/2020 and normalized air pollutant concentration in BF, AF1 and AF2 period. Provinces with the lowest five normalized air pollutant concentration (highest for O3) during AF1 period are listed here. Asterisk (*) in the label of x-axis indicates the five selected provinces for the specific species. Air quality variation over the megacity, Shanghai is also shown. Concentrations of Hubei province are the average of 12 cities excluding Wuhan. Subplot titles are colored as the same color of the confirmed cases magnitude. Normalized air pollutions concentrations relative to historical average are calculated as BF/His_BF*100, AF1/His_AF1*100 and AF2/His_AF2*100, i.e., the normalized concentration lower than 100% indicating the concentration during the specific period is lower than its historical average, and the relative variation compared with historical average is (100%-normalized value). Air quality dataset can be obtained from the website of Ministry of Ecology and Environment of the People’s Republic of China (http://106.37.208.233:20035).

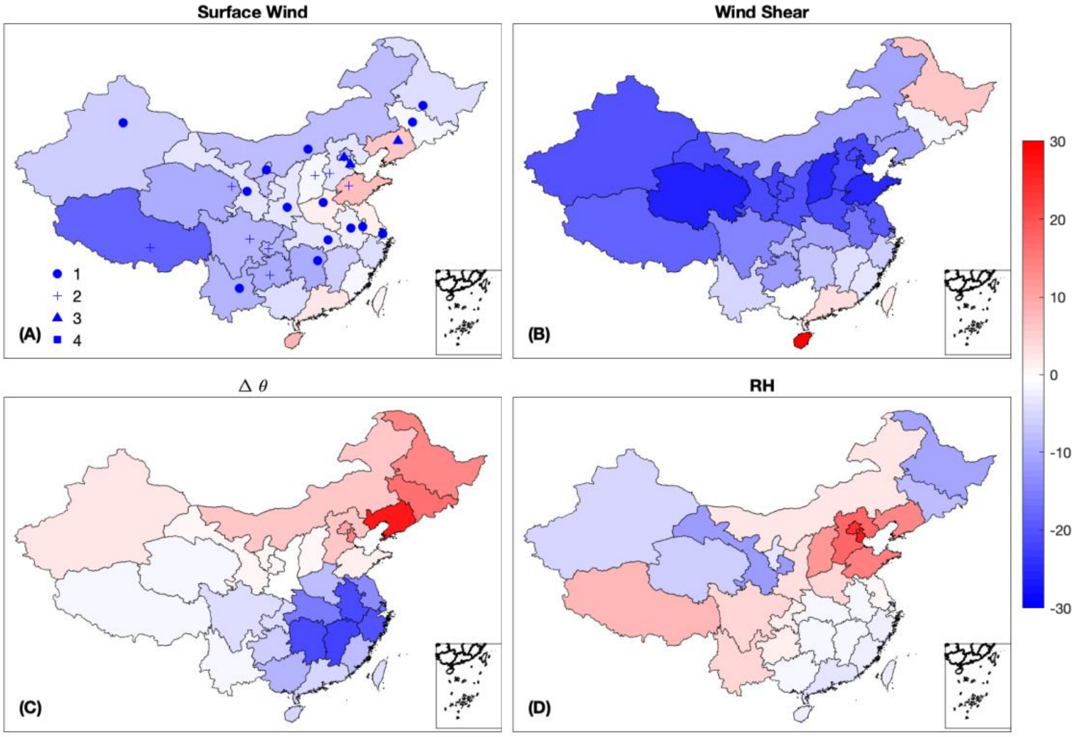

Fig. 2 Relative difference of (A) 10 m wind speed, (B) vertical wind shear, (C) vertical potential temperature ($\Delta\theta$) and (D) surface relative humidity (RH) between AF1 and His_AF1 period (i.e., values of (AF1-His_AF1)/His_AF1*100). Vertical wind shear is defined as $\sqrt{(u_{500}-u_{850})^2} + \sqrt{(v_{500}-v_{850})^2}$. $\Delta\theta$ is defined as $\theta_{850}-\theta_{1000}$, where θ_{850} is the potential temperature at 850 hPa. Positive difference of wind speed and wind shear as well as negative difference of $\Delta\theta$ and RH indicate more favorable meteorological conditions for air pollutants diffusion. Taking ±10% difference as a threshold of significance, Fig. 2 (A) shows the number of significant unfavorable indexes among the four indexes. Meteorological variables are download from ECMWF ERA5 with 0.5°*0.5° resolution, which are average to provincial scale to evaluate the meteorological condition.