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Impact of COVID-19 Outbreak on the Long-Range Transport of Common Air Pollutants in KUWAMS

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As a background sampling site in western Japan, the Kanazawa University Wajima Air Monitoring Station (KUWAMS) continuously observes the air pollutants, including PM₁, PM_{2.5}, organic carbon (OC) and element carbon (EC). Data for September 2019 to April 2020 were compared with data for September 2018 to April 2019. The mean concentrations of both PM₁ and PM_{2.5} were 4.10 μg/m³ (47%) and 5.82 μg/m³ (33%) lower, respectively in the Coronavirus Disease 2019 (COVID-19) period (January to April) than in the same period in 2019. Notably, the average concentrations of both classes of particulate matter (PM) in the COVID-19 period were the lowest for that period in all years since 2016. OC and EC also considerably lower (by 69 and 63%, respectively) during the COVID-19 period than during the same period in 2019. All pollutants were then started to increase after the resumption of the work in 2020. The pollutant variations correspond to the measure implemented during the COVID-19 period, including the nationwide lockdown and work resumption. Furthermore, the reductions in the ratios PM₁/PM_{2.5} and OC/EC during COVID-19 period indicate lighter pollution and fewer emission sources. This analysis of the changes in the pollutant concentrations during the epidemic and non-epidemic periods illustrates the significance of the dominant pollution emissions at KUWAMS and the impact of pollution from China that undergoes long-range transport to KUWAMS.

Key words common air pollutant; Coronavirus Disease 2019 (COVID-19); long-range transport; Kanazawa University Wajima Air Monitoring Station (KUWAMS)

Introduction

Air pollution is a global problem that has attracted considerable attention, health studies by many researchers had proven deleterious human health effects of atmospheric pollutants.^{1–3)}

Particulate matter (PM) including PM₁ (aerodynamic diameter <1 μm) and PM_{2.5} is a ubiquitous air pollutant. According to Ava *et al.*, PM_{2.5} has a long-term health impacts on a variety of physiological systems.⁴⁾ After inhalation, PM_{2.5} enters lung cells (alveolar macrophages and epithelial cells, *etc.*), which leads to oxidative stress. Oxidative stress will induce a chain of the damaging events, or even the death of normally functioning cells.⁵⁾ According to a WHO report, exposure to PM_{2.5} causes 4.2 million people earlier deaths per year worldwide.⁶⁾ In the light of Yang *et al.*, PM₁ is more hazardous than PM_{2.5}, especially for children. Continuous inhalation and accumulation of PM₁ can cause cardiovascular diseases, lung cancer and chronic bronchitis, *etc.*⁷⁾ The emission sources of PM, for example, steel mills, power plants, vehicles and large-scale ports are generally concentrated in the large cities.⁸⁾ Carbonaceous aerosols, such as elemental carbon (EC) and organic carbon (OC) play a significant components of atmospheric aerosol pollution.⁹⁾ OC can be emitted directly into the air or be formed *via* the reactions of reactive organic gases and then undergo gas-to-particle partitioning process. The incomplete combustion of OC will generate EC.¹⁰⁾

As one of the world's largest energy consumers, China consumed approximately 23.6% of the total global energy,

ranking first energy consumption worldwide in 2018.¹¹⁾ High energy consumption leads to high levels of air pollution. To control the severe air pollution, strict air pollution control methods have been implemented since 2013.¹²⁾ However, due to the high levels of air pollution, the air quality in China is still worse than that in other countries (Japan, European countries and United States, *etc.*).^{13,14)}

Transboundary pollution was detected at the Kanazawa University Wajima Air Monitoring Station (KUWAMS) in Japan, which has been in operation for 15 years. Studies have proven the transboundary pollutants at KUWAMS were mainly originate from China, *via* long-range transportation.^{15–18)} During the cold season, East Asia is dominated by northeast monsoon weather patterns, which transport the air pollutants and greatly impact Asian countries.¹⁹⁾ Studies have found that combustion-derived air pollutants emitted in Northeast China can strongly affect KUWAMS in the cold season.¹⁶⁾ Additionally, the impact of air quality control measures implemented in China (*e.g.*, for the 2008 Beijing Olympics) has been detected at KUWAMS, proving the sensitivity of this site for air pollution monitoring.^{18,20)}

In December 2019, Coronavirus Disease 2019 (COVID-19) was discovered in a hospital in Wuhan, China. Subsequently, the number of infected people significantly increased and the spread across China.²¹⁾ As the epicentre of the virus outbreak, Wuhan was heavily impacted by the disease. To reduce the speed and modes of disease transmission, On January 23rd, a

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lockdown was enforced in Hubei Province, in which Wuhan is located.²²⁾ Following the initiation of the nationwide emergency response systems, other provinces and municipalities also entered lockdown on January 29th, 2020. Outside of the most basic survival activities, all factory operations, transportation and work and school activities were prohibited, leading to the significant decrease in air pollution.^{23,24)} Compared to the level in the same period in 2019, the concentrations of PM_{10} and $\text{PM}_{2.5}$ in 337 prefecture-level cities in China during the 2020 lockdown (February, 2020) relatively decreased by 30.0 and 27.3%, respectively.²⁵⁾ As mentioned above, during the cold season, fluctuations in pollutants in China significantly affect the level at the background sampling site KUWAMS in Japan. KUWAMS can be used to assess the impact of long-range of air pollutants transport from China during COVID-19.

The object of this paper is to document and analyze the impact of anti-epidemic measurements implemented in China during the COVID-19 outbreak on the long-range transport of air pollutants in East Asia. Changes in the concentrations of $\text{PM}_{2.5}$, PM_{10} , OC and EC at KUWAMS were observed from September 2019 to April 2020. The results of this study increase the understanding of the transport and variety of $\text{PM}_{2.5}$, PM_{10} , OC and EC in the atmosphere over East Asia.

Experimental

Sampling Site Figure 1 shows the location of the sampling site, where long-term observations of meteorological parameters and conventional air pollutants are made in Wajima located in the northern Ishikawa Prefecture, Japan. Unlike the other large metropolises city in Japan, Wajima is located in a relatively remote area with only 26582 inhabitants live in 2019. Tourism, lacquerware and fisheries account for the vast majority of the industrial production in Wajima, and there are few sources of anthropogenic air pollutants were in the city.²⁶⁾

Surrounded by dense forest, KUWAMS is located on the northwestern coast of Noto Peninsula, 2.1 km south of the Sea of Japan, and almost no severe local industrial emissions have been detected around the sampling site. Previous research proved that the air pollutants detected in Wajima during the cold season were mainly come from the region west outside of Japan, but the air pollutants detected in the hot season originate from mainland of Japan. As an observation station that has been in use for 15 years, KUWAMS has served in many

studies as a background monitoring station to assess the long-range transport of air pollutants to Japan due to its unique geographic location. Reliable data was provided by KUWAMS in those studies of the long-distance transport of air pollutants, which offered strong evidence that pollutants generated in China become the primary air pollutants in Wajima after the long-range transport.^{17,18,20,27)}

Real-Time Monitoring of Air Pollution An online air pollutants monitoring system provided by Kimoto Electric Co., Ltd. (Osaka, Japan) was used to monitor the air pollutants including $\text{PM}_{2.5}$ and PM_{10} from September 2019 to April 2020 at KUWAMS. Specifically, a PM-714 particulate matter monitor with a flow rate of 16.7 L/min was uninterrupted measuring the PM_{10} and $\text{PM}_{2.5}$ following the beta attenuation method. Additionally, an APC-710 automatic particulate carbon monitor with a flow rate of 16.7 L/min was used to measure the EC and OC in $\text{PM}_{2.5}$ based on the near-IR/UV absorption method. Meteorological conditions including relative humidity (RH), temperature (T) and rainfall (rain) were monitored by a WXT530, the weather transmitter. The sampler automatically monitors air pollution in real-time, and the minimum temporal resolution of the data is on the order of minutes. The recorded data will be manually downloaded once per month. The concentration data of meteorological conditions and auto-monitored pollutants in this study were described in daily average. The calculation method was using the Manual for Continuous Monitoring of Air Pollution of Japan.²⁸⁾

Quality Control For routine maintenance, the equipment was inspected by a specialist every month. Additionally, during the analysis, outliers caused by regular maintenance or other instrumental errors were removed.

Back-Trajectory Analysis Based on data from National Oceanic and Atmospheric Administration (NOAA), the air pollutant transport scenarios were evaluated through window-based HYSPLIT 4 (Hybrid Single-Particle Lagrangian Integrated Trajectory) back-trajectory analysis from KUWAMS. HYSPLIT is often used to determine the orbit of air mass to track the source of air pollutants.^{20,27,29,30)} According to the report of Yang *et al.*, the initial height was set up to 1500 m.²⁷⁾

Statistical Analysis The levels of auto monitored pollutants were portrayed as daily data. Given the outbreak of COVID-19 in January 2020, the sampling period was divided

Fig. 1. Sampling Point Location

(KUWAMS: 37.4°N, 136.9°E; 60 m above sea level).²⁰⁾

into two parts, the normal period (September to December) and the COVID-19 period (January to April). Since the collected data did not present a normal distribution, the Mann–Whitney U test was used to compare the differences between the two periods during sampling campaign and between the same periods in the previous year (September 2018 to April 2019).²⁰⁾ The Spearman correlation was used to obtain the correlations between the samples. A p -value less than 0.05 demonstrates that the outcomes were statistically significant. SPSS 25.0 was used to evaluate the data (IBM Corp., Armonk, NY, U.S.A.).

Results and Discussion

PM₁ and PM_{2.5} Figures 2(a) and (b) show the concentrations of the mean value and the standard deviation of PM₁ and PM_{2.5} at KUWAMS during the sampling period. For comparison, Fig. 2 also includes data from previous observations at KUWAMS made from September 2018 to April 2019.²⁰⁾ The concentration of PM₁ in this study was ranged from 0.5 to 14.1 $\mu\text{g}/\text{m}^3$, with a mean of $4.12 \pm 2.33 \mu\text{g}/\text{m}^3$. The concentration of PM_{2.5} range from 3.3 to 35 $\mu\text{g}/\text{m}^3$, with a mean of $11.08 \pm 4.53 \mu\text{g}/\text{m}^3$, which is slightly higher than the annual mean guideline set by the WHO (10 $\mu\text{g}/\text{m}^3$).⁶⁾ The PM₁ and PM_{2.5} concentrations in 2019–2020 significant different ($p < 0.001$) from those in 2018–2019. The average concentrations of PM₁ and PM_{2.5} were approximately 47 and 33% lower, respectively, in the 2019–2020 COVID-19 period than in the same period in 2018–2019. The decrease (36 and 19%, respec-

tively) in PM₁ and PM_{2.5} in the normal period compared to the same period in 2018–2019 were smaller than the decrease corresponding to the COVID-19 periods of the two cold seasons. Generally, the concentration of PM₁ shows an increase in January and then gradually decreases beginning in the end of February, which was the pattern in 2018–2019. However, in 2019–2020, the concentration of PM₁ dropped in January and then gradually increased from February to April. The temporal variation in PM_{2.5} in 2019–2020 was similar to that of PM₁, decreasing in January and then gradually increasing over the next few months. The pollution trends during the normal period and the same period in 2018–2019 and 2019–2020, but the difference was smaller than that between the COVID-19 period and the same period in 2018–2019; this smaller difference might be a result of a series of air pollution control policies implemented in China in recent years (e.g. The Clean Air Action). The implementation of these policies continues to improve the air quality of China and surrounding areas year after year.³¹⁾

Figure 3(a) presents the variations in PM₁ and PM_{2.5} from January 23–30, 2019. The trendlines in these plots have positive slopes: 0.79 and 1.24 for PM₁ and PM_{2.5}, respectively. Figure 3(b) shows the variations PM₁ and PM_{2.5} for the same dates in 2020, and the slopes of the trendlines are opposite those for 2019: -0.62 and -1.05 for PM₁ and PM_{2.5}, respectively. These decreasing tendencies reflect the drastic measures taken to contain the spread of COVID-19, which also dramatically reduced air pollution. The pausing of heavy in-

Fig. 2. The Monthly Variance of Continuously Monitored Pollutants from September 2018 to April 2019 and September 2019 to April 2020 at Kanazawa University Wajima Air Monitoring Station (KUWAMS)

(a) PM₁ ($\mu\text{g}/\text{m}^3$); (b) PM_{2.5} ($\mu\text{g}/\text{m}^3$).

Fig. 3. The Tendency of the Concentration of PM₁ and PM_{2.5} after the Lockdown of China (23rd January 2020)

(a) The comparison period in 2019; (b) COVID-19 starting period in 2020.

dustry for example, iron and petrol chemical can significantly decrease the concentration of PM due to their high emission scaling factors (0.91 and 0.96, respectively).³²⁾ It is also worth noting that Chinese New Year (CNY) occurs at the end of January and is the longest national holiday (4 weeks). During CNY, most industrial production is halted, which may also probably conduce the large-scale variation in PM concentration.^{33,34)} Therefore, at the end of January 2020, due to the simultaneous impacts of two factors, the concentrations of

both PM_{10} and $PM_{2.5}$ dropped to their lowest level (0.5 and $3.3 \mu\text{g}/\text{m}^3$, respectively) in every January since 2016. Additionally, the average concentrations of both PM_{10} and $PM_{2.5}$ (4.64 and $11.75 \mu\text{g}/\text{m}^3$) at COVID-19 period fell to the lowest point since 2016.²⁰⁾

Figure 4 shows the concentrations value of PM_{10} and $PM_{2.5}$ in February, which reveals the changes caused by work resumption. On Approximately February 14th, significant increase in PM_{10} and $PM_{2.5}$ concentrations were observed. This

Fig. 4. The Concentration of PM_{10} and $PM_{2.5}$ in February 2020

(a)

(b)

Fig. 5. The Tendency of the Concentration of PM_{10} and $PM_{2.5}$ (a) March 2020; (b) April 2020

Table 1. The Year to Year Contrast of Air Pollutants in KUWAMS with Shenyang

Site/Region	KUWAMS		Shenyang ^{a)}	
	PM _{2.5} ^{b)}	PM ₁	PM _{2.5}	PM ₁₀
September, 2019	−7%	−16%	8%	14%
October, 2019	−16%	−39%	15%	19%
November, 2019	−37%	−59%	−27%	−22%
December, 2019	−14%	−29%	32%	10%
January, 2020	−39%	−56%	54%	21%
February, 2020	−37%	−56%	−28%	−26%
March, 2020	−39%	−51%	−37%	−34%
April, 2020	−15%	−23%	58%	23%

a) City Air Quality Monthly Report.³⁹⁾ b) The equation of year to year change was (present monthly average−previous monthly average)/previous monthly average × 100%.

might have been due to the gradual resumption of work in the other provinces, and municipalities outside of Hubei Provinces beginning on February 10th.³⁵⁾ Additionally, by the effect of the northeast monsoon, three days will cost for the air masses transport from northeastern China to Japan which fit the time trajectory shown in Fig. 4.¹⁷⁾ Finally, the peaks on February 22nd will be discussed in a later section.

The variations in PM₁ and PM_{2.5} in March and April were shown in Figs. 5(a) and (b). In both two months, the slope of the concentration trend over time is positive, but the concentration increases are greater in March than in April. There is an apparent slowdown in the increases in PM₁ and PM_{2.5} concentration in April, where the slope nearly decreased to zero. According to the Ministry of Industry and Information Technology of the Chinese government, the work resumption rate of small and medium-sized enterprises had increased to 76.8% by March.³⁶⁾ The work resumption rate slowed in April, reaching approximate 84% on April 15th, and this deceleration might have caused the rate of increase in the PM concentrations to slow.³⁷⁾ In addition, as the climate warms, air masses from domestic Japan will gradually become dominant, which might also slow the rate of increase.²⁰⁾

To better comprehend about the trend during the COVID-19 period, the year-to-year change in the PM₁ and PM_{2.5} concentration at KUWAMS was calculated (Table 1) and compared with Shenyang City, Liaoning Province, China. Comparing with 2018, the air condition in Shenyang 2019 was even worse. From September 2019 to January 2020, the concentration of PM_{2.5} and PM₁₀ increased in average about 16.4 and 8.4%, respectively. According to the report of the Department of Ecological Environment of Liaoning Province, PM_{2.5} emissions showed a trend of decreasing before 2019. In contrast, due to the growth of the economic, industry, population and vehicle growth, the concentration of air pollutants began to increase again in 2019.³⁸⁾ The significant drop was shown in November 2019. The PM_{2.5} and PM₁₀ levels were 51 and 87 $\mu\text{g}/\text{m}^3$, respectively, in November 2018, higher than that in October (40, 75 $\mu\text{g}/\text{m}^3$) and December (47, 79 $\mu\text{g}/\text{m}^3$) 2018. Reversely, the PM_{2.5} and PM₁₀ levels were 37 and 68 $\mu\text{g}/\text{m}^3$, respectively, in November 2019, lower than that in October (46, 89 $\mu\text{g}/\text{m}^3$) and December (62, 87 $\mu\text{g}/\text{m}^3$) 2019. Possible causes might be differences in their weather conditions and sources.⁴⁰⁾ The relatively high pollution in 2018 might leads to a decrease in the year-to-year contrast with 2019. In KUWAMS,

the year-to-year change in PM₁ was −56% in January, which was the beginning of the COVID-19 pandemic, and remained at approximately −50% in the following two months. In April, the value increased to −23%, corresponding to the timeline of work resumption. The variation in PM_{2.5} during COVID-19 period was similar to that in PM₁, and the year-to-year changes at Shenyang were similar with those at KUWAMS. The concentrations at Shenyang began to decrease in February instead of January as they did at KUWAMS.

The average ratio of PM₁/PM_{2.5} for 2019–2020 was approximately 0.38, which was lower than the proportion (0.5) during the comparison period (September 2018–April 2019), and lower than the ratio which is reported by other studies, including Dandong station, China (0.86, 2006–2014), at the Gosan ABC superstation, Korea (0.608, 2017–2018); and in India (0.48, 2009–2010).^{41–43)} High PM₁/PM_{2.5} ratios indicate that the PM_{2.5} levels are mainly caused by sources or processes that produce larger particles, rather than by mechanical processes. Biomass combustion, coal and fossil fuel combustion are the primary sources of PM₁, and contribute much more PM₁ than PM_{2.5}. Therefore, a higher PM₁/PM_{2.5} ratio indicates a greater proportion of pollution from these sources.⁴⁴⁾ In this study, the PM₁/PM_{2.5} ratio was much lower than the ratios which reported in the other periods and regions, which proves that the suspension of industrial and traffic activities caused by the outbreak of COVID-19 affected the long-range transport of PM₁ and PM_{2.5} to KUWAMS.

Organic Carbon and Element Carbon The range in the OC concentration in the 2019–2020 was 0.02–2.51 ($\mu\text{gC}/\text{m}^3$), with a daily average concentration of 0.58 ± 0.42 ($\mu\text{gC}/\text{m}^3$). The concentration of EC in this season ranged from 0.004 to 0.451 ($\mu\text{gC}/\text{m}^3$), with a daily mean concentration of 0.09 ± 0.06 ($\mu\text{gC}/\text{m}^3$). The total carbon values (OC + EC) ranged from 0.02–2.77 ($\mu\text{gC}/\text{m}^3$), and the average concentrations of OC and EC accounted for 84 and 16% of the total carbon, respectively. These proportion were similar to other research findings in Changchun, China (81 and 19%, respectively).⁴⁵⁾ Figures 6(a) and (b) show the concentrations of OC and EC at KUWAMS during the 2019–2020 period. The concentrations decreased in January then gradually increased in the following month. Compared with the same period in 2018–2019, although there was a difference trend at October and December, the trend of concentration in this period between these two years is almost the same, which the concentration tardily enhances from September to December. Still, according to the pervious report, the monsoon from China to Japan is not significant before winter (December), dominant wind from China is usually prevailing in winter and spring, which is the COVID-19 period.⁴⁶⁾ After December 2019, the trends were highly variable: the concentrations of both OC and EC more than doubled from January to February and then dramatically decreased over the next two months back to their levels before the doubling. Differently, the concentrations of both OC and EC slowly increased during the COVID-19 period. According to Liu *et al.*, a lower standard deviation (S.D.) indicates relatively stable emissions.⁴⁷⁾ The S.D.s of OC and EC were 0.50 and 0.07 ($\mu\text{gC}/\text{m}^3$), respectively, during the COVID-19 period and 1.45 and 0.15 $\mu\text{gC}/\text{m}^3$ during the same period in 2019. Thus, the variability in OC and EC in 2020 was half that in 2019. The lower S.D. in the COVID-19 period might have been due to the suspension of unnecessary activities, which decreased

Fig. 6. The Monthly Variance of Continuously Monitored Pollutants from September 2018 to April 2019 and September 2019 to April 2020 at KUWAMS

(a) OC ($\mu\text{gC}/\text{m}^3$); (b) EC ($\mu\text{gC}/\text{m}^3$).

the variety in emission sources. Additionally, the use of central heating systems in Northeast China is one of the primary OC and EC emission sources during the cold period. Thus, as other primary sources were reduced or eliminated, the central heating was still employed, potentially reducing the S.D.

Figures 7(a) and (b) show the concentrations of OC and EC from January 23rd–31st in 2019 and 2020, respectively. The level of OC was below the detection limit on January 30th and 31st, 2020. The temporal variation in the OC concentration in 2020 was opposite that in the same period in 2019, similar to the patterns of PM_{10} and $\text{PM}_{2.5}$ mentioned above. The mean concentrations of OC and EC in 2020 were 69 and 63% lower, respectively, than those in 2019. These differences might have been due to the decreased industrial and traffic activities that began on January 23rd, 2020.

The relationship between the EC and OC concentration during the normal and COVID-19 periods is shown in Figs. 8(a) and (b), respectively. A stronger correlation between OC and EC was observed during the COVID-19 period ($R^2 = 0.7280$, $p < 0.05$), than during the normal period ($R^2 = 0.4267$, $p < 0.05$). The strong correlation for the COVID-19 period indicates that carbonaceous aerosols in this period were primarily from the joint source and were affected by similar transport procedures.⁴⁴ There were fewer sources of OC and EC during this period, which might have been due to the curtailing of unnecessary activities, including industrial manufacturing and traffic activity *etc.* by the Chinese authorities. In the absence of such unnecessary activities, central

Fig. 7. The Tendency of the Concentration of OC and EC (a) January 2019; (b) January 2020

Fig. 8. The Relationship of OC and EC Concentrations (a) September to December; (b) January to April

heating became the main pollution source during this period, potentially leading to the strong correlations between OC and EC.

The OC/EC ratio is an essential tool to study the formation processes and the sources of carbonaceous particles. Figure 9 shows the OC/EC ratio in 2019–2020 ranged from 5.55 (December) to 10.96 (October), with an average of 7.41. The ratio in the normal period (8.37) was higher than that in the COVID-19 period (6.45).²⁰⁾ The mean value in 2018–2019 was 6.8, higher than the value in the COVID-19 period but lower than value in the normal period and value for the whole period investigated in 2019–2020. EC is mostly from primary emissions; OC primarily forms Secondary Organic Carbons (SOC) by photochemical reactions. A value of OC/EC ratio higher than two can indicate the formation of SOC.^{48,49)} Therefore, the SOC detected at KUWAMS primarily formed in the atmosphere during long-range transport. Contributions of SOC, changes in emission sources, and the temperature and the atmospheric conditions can all affect the OC/EC ratio.^{50,51)} Newly formed SOC and biomass-burning burning for cooking *etc.* will also result in a high OC/EC ratio. Cachier *et al.* reported that OC/EC values of 9, 2.7, 1.1 demonstrate biomass combustion, coal combustion and vehicle sources, respectively.⁵²⁾ The greater variations in the OC/EC ratio during the normal period than during the COVID-19 period indicate the presence of additional sources of carbonaceous particles in the former, consistent with the events of COVID-19 outbreak.

Meteorological Meteorological parameters can affect the concentrations of particulate atmospheric pollutants.⁵³⁾ The

Spearman correlation coefficient was used to clarify the correlations between such pollutants and the meteorological conditions. The correlation coefficients of each pollutant and meteorological data were calculated from daily averages. Table 2 shows the correlation between air pollutants and meteorological conditions. All meteorological conditions show a negative correlation with air pollutants. The correlation coefficients of OC, EC, PM₁ and PM_{2.5} with temperature were -0.195 , -0.399 , -0.105 and -0.054 , respectively; with rainfall were -0.092 , -0.098 , -0.239 and -0.154 , respectively. In particular, relative humidity had a statistically significant negative correlation with all pollutants (-0.184 , -0.324 , -0.274 and -0.181 for OC, EC, PM₁ and PM_{2.5}, respectively). Basing on our previous study, the periods of low temperature, low humidity and less rainfall in KUWAMS are mostly prevailing the Asian winter monsoon.^{46,54,55)} During this period, the long-range transport of pollutants from the Asian continent is the important cause of air pollution in KUWAMS. Nevertheless, during the prevailing period of Asian winter monsoon in this study, the expected severe pollution did not appear in the period, which can be explained as the impact of China's economic stagnation during COVID-19.

Back-Trajectory Analysis Seventy two hours back trajectories 1500m above ground were used to evaluate the air samples at KUWAMS.

Three specific periods were chosen, for the calculation shown in Fig. 10. According to Figs. 10(a) to (c), the air masses that arrived at KUWAMS *via* long-range transport is mainly originated in Northeast Asia, especially Northeast China. Figure 10(a) shows the source of the contaminants detected at KUWAMS since the COVID-19 outbreak at the end of January. Almost 100% of the air masses were derived from northern China, travelling over North Korea and then the Pacific Ocean before finally arriving at KUWAMS. Figure

Fig. 9. The Ratio of OC/EC

Table 2. Spearman Correlation Among OC, EC, PM₁ and PM_{2.5} with Meteorological Condition During September 2019 to April 2020

	<i>T</i>	RH	Rain
OC	-0.195^{**}	-0.184^{**}	-0.092
EC	-0.399^{**}	-0.324^{**}	-0.098
PM ₁	-0.105	-0.274^{**}	-0.239^{**}
PM _{2.5}	-0.054	-0.181^{**}	-0.154^{*}

* $p < 0.05$, ** $p < 0.01$; *T*: temperature; RH: relative humidity; Rain (mm).

Fig. 10. Back Trajectory Analysis of Air Samples

(a) 23rd January 2020–26th January 2020; (b) 22nd February 2020–25th February 2020; (c) 1st March 2020–30th April 2020.

10(b) shows the orbits of the air masses from February 22nd, 2020 to February 25th, 2020. Approximately 87% of the air masses came from northeast China. Figure 10(b) shows the orbits of the air masses from February 22nd, 2020 to February 25th, 2020. Approximately 44% of the air masses passed through Beijing and Tianjin, then crossed the Pacific and finally reached KUWAMS. As mentioned before, Fig. 4 shows a high concentrations value increase of both PM_1 and $PM_{2.5}$ on February 22nd, possibly due to the long-range transported air masses from Beijing and Tianjin. From February 19th to 21st, 2020, Beijing and Tianjin were experiencing a mildly polluted weather, $PM_{2.5}$ of Beijing and Tianjin was approximate $100 \mu g/m^3$ during that period.⁵⁶⁾ Thus, these pollutants carried by monsoon and then reach KUWAMS, where the concentration of PM significantly increased on February 22nd. Figure 10(c) shows the trajectory of air mass in March and April in 2020, which China had started the work resumption. Although the pollutants reach the KUWAMS began to be gradually influenced by Japan, KUWAMS was still mainly affected by northeast China (approximately 88% of the air masses).

Conclusion

As a background station that has been in continuous use for more than 15 years, KUWAMS continues to provide reliable data on the long-range transport of air pollutants. Air pollution data were collected at KUWAMS from September 2019 to April 2020 and analyzed. Overall, the air pollutants decreased in COVID-19 period, which was different from the trends in the same periods in 2019. The results of the meteorological and back-trajectory analysis prove that China is still the primary source of air pollutants at this site, with the air mass carried by monsoons and transporting pollutants long range to KUWAMS. During the normal period, the concentrations of PM_1 , $PM_{2.5}$, OC and EC slightly decreased. In contrast, there was a significant decrease in the concentrations of all the air pollutants during the COVID-19 period, because of the nationwide suspension of work and industrial production. The mean concentrations of both PM_1 and $PM_{2.5}$ at KUWAMS were the lowest that they had been in this period for each year since 2016. Moreover, the OC/EC ratio was lower in the COVID-19 period than in the same period of 2019, which might have been due to fewer sources of carbonaceous particles in 2020. Overall, the decrease in pollutant emissions during the epidemic in Northeast China caused a major reduction in the pollution at KUWAMS. This reduction in emissions was a result of considerable disruptions to normal daily life and caused considerable economic losses. Therefore, the emissions will soon return to their original level after the epidemic situation improves. Although China has achieved remarkable results from air pollution control measures implemented in recent years, to further enhance the air quality in China and surrounding countries, stringent air pollution control policies issued by the Chinese government should be continuously implemented.

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Conflict of Interest The authors declare no conflict of interest.

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