Long-range Transport of Air Pollutants to Taiwan during the COVID-19 Lockdown in Hubei Province

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ABSTRACT

Lockdown implemented to limit transmission of the COVID-19 virus in China reduced the emissions of air pollutants especially around Hubei Province, though restrictions were more widely applied across the country. Air over Taiwan may be affected by emissions from mainland China so the changes provided an opportunity to detect the effect of long-range pollutant transport to Taiwan, especially at remote sites. Small decreases were observed in NOₓ and PM₂.₅ concentrations, when comparing 2020 with earlier years, as well as some hints of increases in O₃. Back trajectories from China were used to select days when this effect would be strongest and showed clearer evidence of reductions at remote sites in Taiwan. These were strongest for NOₓ and PM₂.₅ in Kinmen and Matsu, close to the Fujian coast, but the effects were seen even on Magong in the Penghu archipelago and at Cape Fugui at the very north of Taiwan. Larger reductions on the coastal islands is not surprising given their proximity to major cities, but on Magong and at Cape Fugui, PM₂.₅ concentrations are reduced by a few micrograms per cubic metre. Decreases in NOₓ are smaller and at Cape Fugui, barely amounting to a ppb. Changes in O₃ are distinctive, showing concentration increases of around 20% under trajectories deriving from Northern China, in keeping with observations that reductions in NOₓ lead to substantial increases in O₃. Overall, there was only a small reduction in NOₓ and PM in Taiwan. Although these changes in pollutant concentrations may be relatively large in remote areas, they are not likely to have a major effect on cumulative exposure in larger cities, where concentrations of these pollutants can be high. Nevertheless, the observations support calls for agreement over emission reductions to lessen pollutant transfer across the Taiwan Strait.

Keywords: Ozone, Carbon monoxide, Particulate matter, Nitrogen oxides

1 INTRODUCTION

Decreased emission of air pollutants in China, during the COVID-19 pandemic, provides an opportunity to examine long-range transport of air pollutants to Taiwan. The global spread of the novel coronavirus led to a reduction of emissions from factories and transport systems (Sharma et al., 2020), along with changes in electricity demand (Narajewski and Ziel, 2020). Evidence of the change is seen in satellite observations of lowered air pollutant concentrations (Bauwens et al., 2020) and analysis of changes at ground level in China (Brimblecombe and Lai, 2020a; Cole et al., 2020; Dutheil et al., 2020; He et al., 2020; Muhammad, et al., 2020; Wang and Su, 2020). However, some have argued that peak air pollution concentrations have not been avoided (Wang et al., 2020a) or suggest that there are risks from the increased ozone that parallel the declining NOₓ (Shi and Brasseur, 2020). Limits to travel and a decrease in the number of people at work substantially reduced pollutant emissions in zones of high economic activity. Thus, surface PM₂.₅ concentrations decreased by ~25% in the Yangtze River Delta, while both surface concentrations and tropospheric column density of NOₓ declined by 20–30% in Beijing-Tianjin-Hebei, and the Pearl and Yangtze Deltas (Bao and Zhang, 2020; Chen et al., 2020). Surface CO concentrations and tropospheric column density were down by 17% and 2.5% (Yue et al., 2020). An increase in
surface O₃ concentrations were evident during the epidemic across China, especially in Northern regions (Huang et al., 2020; Shi and Brasseur, 2020), along with striking increases in Beijing and Wuhan, though only modest changes in Shanghai and Guangzhou (Zhao et al., 2020).

A widespread media acceptance of improved air quality under COVID-19 at times depended on rather sweeping generalisations (Cole et al., 2020), so the topic demands continued investigation. The extensive comment on changes within China and elsewhere has not been matched by attention among countries of the China Seas. Taiwan saw relatively few cases of COVID-19, because quarantine and other measures were introduced early (Wang et al., 2020b), so it never introduced any formal lockdown. Educational institutions, museums and government offices remained largely open, despite increased health monitoring and frequent use of surgical masks in public. This makes it unlikely that there were substantial changes in emissions on the island. However, Taiwan is frequently exposed to air masses that bring pollutants, both natural and anthropogenic, from China, i.e., Mainland China (Lin et al., 2005, 2007; Yeh et al., 2015; Chung et al., 2017). There is frequent concern that this represents an important source (Chen, 2017). The changes during COVID-19 offer the potential to assess the importance of such long-range transport of pollution by examining the concentration of air pollutants across the period of the COVID-19 lockdown in Hubei Province, when air pollution concentrations were lower (Brimblecombe and Lai, 2020a). The impact of the initial lockdowns in China was investigated, during an episode from 28 January to 3 February, when long-range transport led to lower than expected pollutant concentrations in Northern Taiwan (Griffith et al., 2020). In this paper, we aim to assess more broadly whether decreases in air pollution under the COVID-19 lockdown in China could be detected in Taiwan. In particular, the study examines the differing transport pathways. This not only establishes differences imposed by lockdown, but also assesses the significance of emissions in China to exposure in Taiwan and reflects on what this might mean for longer term Cross-Strait pollution agreements.

2 METHODS

This study uses data from the Taiwan Air Quality Monitoring Network’s official records (https://airtw.epa.gov.tw/CHT/Themes/LinkOut.aspx). The records are available at hourly intervals for the pollutants, NO₂, NO, PM₂.₅, PM₁₀, CO, SO₂, and O₃. Data stretch back to 1993 in many cases, but PM₂.₅ is available only from 2004 for a few stations. Sulfur dioxide is neglected in this work because of the potential for wet removal during long-range transport. The work chooses to use the data from remote stations, relatively free of local pollutants, where subtle changes due to COVID-19 related restrictions might be detected. Three of these were on islands in the Taiwan Strait: (i) Matsu and (ii) Kinmen near the Fujian Coast, and (iii) Magong in the Penghu archipelago, with a further remote station at Cape Fugui, on the northern tip of Taiwan (Fig. 1(a)). Matsu, Kinmen and Magong are classified as general stations in the Island Air Quality Zone, while Cape Fugui station is a background monitoring site, in the North Air Quality Zone. General stations and background stations are defined in terms of local pollutant emission, meteorology and geographical features. Background stations in Taiwan are usually set windward of sources or in areas with less local pollution. However, all the stations used here are relatively free of major pollutant sources, such as industries or heavy traffic emissions, compared with other monitoring stations in Taiwan. These characteristics seemed to make the four stations suitable to detect changes in air pollution during the COVID-19 lockdown.

Wuhan was at the centre of the pandemic, it became necessary to contain the disease in Hubei province. China’s central government suspended all public transport in Wuhan from the morning of 23 January (ISO 8601: 2020-01-23). The lockdown coincided with Chinese New Year (Brimblecombe and Lai, 2020a) across the period analysed; where the holiday began 24 January 2020 (the Eve of Chinese New Year). It was extended by two further days because of the coronavirus epidemic. Wuhan’s lockdown represented the first time in history that a megacity was sealed. Within hours, travel restrictions were also imposed on the nearby cities of Huanggang, and Ezhou and Huangshi the next day. The streets of Wuhan became silent. The once-bustling city became a ghost town, and while grocery stores and shops remained open, most people stayed at home, making only the most essential of trips outside. Lockdown ended in Huangshi on 13 March and in Huanggang and Ezhou on 25 March. Wuhan, at the epicentre, remained under...
lockdown until 8 April. Elsewhere in China there was no strict lockdown although the government suggested people maintain social distancing etc. There were partial lockdowns (as mapped in Leung et al., 2020) with major cities such as Guangzhou, Shenzhen, Tianjin, Hangzhou and Chengdu announcing restrictions in early February and Beijing and Shanghai following the next week (Shi, 2020). Beijing authorities closed temples and major tourist attractions, including the Forbidden City. The National Maritime Museum closed from 24 January and the Palace Museum decided to shut down next day and only at the end of April did the Forbidden City and Palace Museum reopen. The travel restrictions in China affected more than 1.3 billion people (Zhao et al., 2020) and reduced freight movement, electricity generation and coal use (Brimblecombe and Lai, 2020b). While the Wuhan Lockdown covered the period 18 January to 12 April, we regard our period of analysis as a little longer, especially as return to normal was hardly immediate. We have accepted trajectories as late as 12 April as belonging to the lockdown period, and included Chinese New Year for 2018, 2019 and 2020.

Back trajectories were computed by Hybrid Single-Particle Lagrangian Integrated Trajectory model, HYSPLIT PC V5 (Draxler, 1999; Stein et al., 2015) with the Global Data Assimilation System (GDAS) meteorological data at 1 × 1 degree resolution. Three-dimension air mass trajectories (height, longitude, and latitude) obtained from the model when utilised to assess changes in air pollutant concentrations associated with COVID-19 restrictions for the period between 18 January to 12 April of the year 2018-2020. Daily trajectories were run back 72 hours at six-hour time steps at 00:00, 06:00, 12:00 and 18:00 UTC (Coordinated Universal Time). These started from the Cape Fugui station (25.29°N, 121.53°E) and the Magong station (23.34°N, 119.33°E) at two different arrival heights: 500 m and 1500 m above ground level (Fig. 1) to represent low and upper level transport in the boundary layer, as aerosol can be observed even above 3 km China in winter (Qin, 2016). We limited this to two locations because cluster analysis showed that the air masses arriving at Matsu and Kinmen could be represented by the trajectories ending at Cape Fugui and Magong. In this study, the definition of lockdown period is 18 January to 12 April 2020 and the non-lockdown period the same dates of 2018 and 2019. Given that the lockdown policy was not executed across all China, the effect of lockdown varied, so in this study back trajectories were classified as arising from three different source regions: The North, Hubei region and the South. Hubei province, the major lockdown area, is considered at the centre, with the other source areas to the north and the south of Hubei province categorised here as the northern and southern trajectories. Hubei trajectories passed through the province in the previous 72 hours. Similar definitions applied to those originating to the north and south (Figs. 1(c)–1(f)). Concentration measurements for each air pollutant from the four sites were then associated with their corresponding back trajectories, to identify the variations of air pollution at the receptor sites

![Figure 1](https://example.com/fig1.png)

**Fig. 1.** (a) Taiwan monitoring sites discussed in this paper, (b) a map of the study area, with a rectangle outlining the monitoring sites, (c) 72-hour back trajectories from the three areas arriving at Magong at 500 m (d) back trajectories arriving at Magong at 1500 m, (e) back trajectories arriving at Cape Fugui at 500 m and (f) back trajectories arriving at Cape Fugui at 1500 m.
between lockdown and non-lockdown periods. This is a relatively dry period in Taiwan, so unsurprisingly we found little effect from local rainfall.

Much of our attention focussed on comparisons with the years 2018–2020. This short three-year period was taken partly because it meant little change would arise from year-by-year emission reductions in China, but additionally there are many gaps in the Cape Fugui record prior to 2018.

The overall comparisons between the years for each pollutant at each site relied on analysis of variance (ANOVA), which assumes the independence, normality and homogeneity of variances of the residuals, perhaps reasonable when there are sufficient data elements (> 50) across the 85 or 86 days. We occasionally determined the results using the Kruskal-Wallis test, which is the nonparametric test for the significance of the difference among distributions of independent samples, to be sure of agreement with ANOVA. Tukey’s HSD test was used with the ANOVA to assess comparisons between data from pairs of years. When testing the smaller sample sizes (≥ 9) associated with the back trajectories, we adopted non-parametric tests because of concern over normality in the data. In these circumstances, central tendency for concentrations has been expressed as median ($\bar{x}$) and the dispersion as the lower and upper quartiles $Q_1$ and $Q_3$, with the number of concentration measurements expressed as $n_l$ outside lockdown and $n_l$ under lockdown. Statistical calculations have benefited from online tools. Small sample sizes and concern about the distribution encouraged us to use non-parametric tests, notably the Mann-Whitney test for comparing samples (statistic $U$).

3 RESULTS AND DISCUSSION

3.1 Average Pollutant Concentrations during Lockdown

Daily average concentrations of NO$_x$ and PM$_{2.5}$ for Kinmen over the period 18 Jan–12 April (i.e., 85 or 86 days) for the years 2016 to 2020 are shown in Fig. 2. This is the site where the best case could be made for a decline in pollutants in 2020. The mean concentrations of NO$_x$ for the period in each year from 2016 to 2020 (Figs. 2(a)–(e)) suggest concentrations of: 15.64, 14.11, 12.96, 12.41 and 10.23 ppb with the most recent year the lowest. Although the ANOVA test suggests that the null hypothesis should be rejected ($p < .0001$), Tukey’s HSD test suggested that 2020 was significantly different at the $p < .05$ level only in comparisons with 2016 and 2017. In the case of NO$_2$, 2020 proved to have the lowest mean: 12.73, 12.15, 11.58, 11.08 and 9.15 ppb, with Tukey’s HSD suggesting 2020 as substantially lower ($p < .05$) than all years except in comparison to 2019.

The case for a decrease in PM$_{2.5}$ concentrations may be a little stronger and visually more convincing (Figs. 2(f)–(j)). The average concentrations over the period for each year 2016–2020 are: 34.28, 35.80, 32.44, 31.50 and 24.53 µg m$^{-3}$, the most recent year clearly the lowest and Tukey’s HSD test suggests that 2020 was significantly lower in comparison to the other years at $p < .01$ except for 2019, here the difference was slightly less significant at $p < .05$. Not surprisingly PM$_{10}$ showed a similar picture for the years, i.e., the mean for 2020 being the lowest: 63.13, 64.56, 65.72, 51.98 and 41.16 µg m$^{-3}$ and Tukey’s HSD test revealing that the latter year was significantly lower than others at $p < .05$ for all but 2019. No coherent picture emerged for either CO or O$_3$.

Fig. 2. Daily mean concentrations of NO$_x$ at Kinmen over the period 18 January to 12 April (a) 2016, (b) 2017, (c) 2018, (d) 2019 and (e) 2020; and for PM$_{2.5}$ (f) 2016, (g) 2017, (h) 2018, (i) 2019 and (j) 2020.
At other sites, the comparisons were less effective in establishing lower concentrations during 2020. On Matsu, only for PM$_{10}$ did the mean concentrations suggest that 2020 was the lowest by comparison to other years: 49.48, 49.97, 56.03, 45.90 and 33.14 µg m$^{-3}$, with Tukey’s HSD test revealing that this was typically significant at $p < .01$. Sites on Magong showed NO$_x$ and NO$_2$ to be typically lower in 2020: 5.88, 4.63, 5.04, 9.58 and 3.728 ppb for NO$_x$ and 4.63, 3.45, 3.94, 7.04 and 2.57 ppb for NO$_2$, both suggesting that 2020 was significantly different at $p < .05$ from the Tukey’s test. Additionally, the sites on Magong revealed higher average ozone concentrations (51.25 ppb) in 2020, as the averages for the five years were: 45.06, 46.07, 46.08, 35.84 and 51.25 ppb, all the differences significant $p < .01$. There were some hints of similar behaviour with O$_3$ at Cape Fugui, but the record there is less complete.

### 3.2 Air Pollutants in Continental Air Masses

Analysis of period average concentrations, although revealing hints of change over the lockdown period of 2020, also demonstrates the difficulty in detecting a clear effect from lockdown. This is particularly true in the face of reduced emissions from China over recent years (Cheng et al., 2018) and it can be difficult to remove the influence of weather on the differences in concentrations over successive years (Cope et al., 2020). It should not be surprising that far from the epicentre of the initial COVID-19 outbreak and restrictions, Taiwan would show only slight changes to air pollutant concentrations. This is understandable given that some of the changes can be difficult to detect even in Beijing where they might be expected to be large given the extent of social change there (Brimblecombe and Lai, 2020b). The dates with trajectories that derived from Northern China, Hubei Province and Southern China were determined and the daily pollutant concentrations on these days gathered for the concentrations of NO$_x$, PM$_{2.5}$, PM$_{10}$, CO, and O$_3$.

As so many have pointed out the pollution changes under COVID-19 can be subtle (Brimblecombe and Lai, 2020a; Cope et al., 2020; Schiermeier, 2020), so back trajectories for both 500 m and 1500 m were combined to increase the sample size for statistical analysis. Combining the data in this way seemed justified as a Mann-Whitney test for the sets of concentration measurements derived from the two trajectory heights, from the same region, were not significantly different. At Kinmen, for example the median for NO$_x$ concentrations for the 2018–2019 trajectories are 11.45 ppb (1500 m) and 11.81 ppb (500 m); a small and insignificant difference ($U = 124$, $p_1 = 0.44$). A similar picture emerged for PM$_{10}$ ($\bar{x}_{1500} = 67.86$, $\bar{x}_{500} = 88.13$ µg m$^{-3}$, $U = 144$, $p_1 = 0.18$), so while not universal the lack of substantial differences between the data at the two trajectory heights gave us confidence to combine them.

Fig. 3 tries to resolve the effect of lockdown by presenting daily median concentration data for: Kinmen, Matsu, Magong and Cape Fugui, on days when the air mass derived from Hubei Province less than three days before. The lightly shaded bars show the median pollutant concentrations for Hubei derived air masses for the January–April 2018 and 2019 periods. These are compared with the lockdown period (18 Jan–12 April 2020) as darker bars. It is immediately clear from the left-hand side of Fig. 3 that concentrations during lockdown were generally lower for NO$_x$ and PM$_{2.5}$. The diagram has concentrations scaled to make it easier to appreciate changes among different pollutants. Thus, NO$_x$ concentrations, which are quite low at these remote locations have all been multiplied by a factor of ten. On Kinmen the lockdown period saw a median NO$_x$ concentration of 6.16 ppb with the lower ($Q_1$) and upper quartiles ($Q_3$) as 4.67 and 8.48 ppb, compared with a much larger median concentration of 11.65 ppb ($Q_1 = 9.15$; $Q_3 = 14.25$), a difference significant from the Mann-Whitney test ($p_1 = 0.0002$; $U = 106$; $n_d = 31$; $n_l = 20$). The same is true for NO$_x$ at the other sites where the differences are significant at Magong ($p_1 = 0.004$; $U = 59$; $n_d = 32$; $n_l = 9$) and Magong ($p_1 < 0.0001$; $U = 13$; $n_d = 31$; $n_l = 20$), while at Cape Fugui, the median concentrations are much lower in 2018–2019 2.55 ppb ($Q_1 = 1.93$; $Q_3 = 3.69$) when compared with that during lockdown 1.97 ppb ($Q_1 = 1.51$; $Q_3 = 2.93$), a difference although positive is barely significant ($p_1 = 0.09$; $U = 59$; $n_d = 22$; $n_l = 8$). The differences are displayed as percentage improvement under lockdown in Fig. 3(b), where it illustrates 30–50% decreases in the NO$_x$ concentrations under lockdown, except for Cape Fugui. Here, although there was an improvement, it was only 20%.

A similar picture emerges for PM$_{2.5}$, where the median concentrations for 2018–19 and 2020 are 31.4 and 21.5 µg m$^{-3}$; 26.9 and 21.4 µg m$^{-3}$; 17.8 and 13.6 µg m$^{-3}$; 19.1 and 17.0 µg m$^{-3}$ for Kinmen, Matsu, Magong and Cape Fugui, respectively. The differences, a 20–30% improvement...
Fig. 3. (a) The median concentrations of pollutants (NO\textsubscript{x}, PM\textsubscript{2.5}, CO and O\textsubscript{3}) at Kinmen, Matsu, Magong and Cape Fugui on days when the air originated from Hubei province arriving at the receptor sites at either the 500 or 1500 m level. The light bars are for the period 2018 and 2019 (i.e., 18 Jan–12 April) and the darker bars for 2020. Note: the concentrations have been scaled to bring them to roughly similar spans on the figure. (b) The percentage improvement during the lockdown period compared with similar months of 2018 and 2019. (Fig. 3(b)) are significant at $p_1<0.05$ for all but Cape Fugui. There seem to be very slight improvements to CO under lockdown, though it is larger at Matsu (from 0.38 to 0.28 ppm under lockdown), and the differences are significant for both Kinmen and Matsu ($p_2=0.07$; $p_1=0.026$), yet not at Magong or Cape Fugui ($p_2=0.30$; $p_1=0.38$). Ozone shows no coherent pattern and the results are not very significant; certainly the idea that ozone would be higher because of the absence of NO titration under lockdown is not apparent after long-range transport of air from Hubei Province during lockdown.

Fig. 4 follows much the same logic as Fig. 3 and shows the southern and northern trajectories. It is a similar picture, although as might be expected the distinction of the 2020 period is a little less clear because lockdown was less strict beyond Hubei Province. The difference for NO\textsubscript{x} at Kinmen and Magong remains clear under these trajectories, but on Matsu and at Cape Fugui less so. Particulate matter declines under lockdown with these two sets of trajectories, much as it did with the Hubei trajectories. Any improvements in CO under lockdown are slight, but O\textsubscript{3} is quite distinctive and shows a general increase for the trajectories originating from Northern China. This agrees with observations of the substantial increase in the availability of O\textsubscript{3} as mapped by Huang et al. (2020)—a result of decreases in atmospheric NO\textsubscript{x} that arose from lower vehicle emissions. The area of enhanced ozone occupies a broad area stretching from Shanghai up into a large area of Northern China, sometimes termed Beifang, the origin of many of the trajectories related to the higher than expected ozone concentrations (Figs. 4(b) and 4(d)), but the chemical balance of ozone over China under lockdown was not be entirely clear.

3.3 Discussion

Many observations suggest that pollutant concentrations declined along with emissions during the period of lockdown and wider restrictions in China. Bao and Zhang (2020) suggest that SO\textsubscript{2}, PM\textsubscript{2.5}, NO\textsubscript{2}, and CO concentrations decreased by 6.76%, 5.93%, 13.66%, 24.67%, and 4.58% for Northern China, although these were likely greater near the Wuhan epicentre under lockdown. In Wuhan, Cole et al. (2020) suggested 60% decreases for NO\textsubscript{2} and PM, and Brimblecombe and Lai (2020a) 53%, 35% and 14% for NO\textsubscript{2}, PM\textsubscript{2.5} and CO. Here, we have shown that reductions are readily observable on Kinmen and Matsu, which lie close to the major cities on the Fujian coast. The islands are often believed to receive pollution from China (Chen, 2017). This is reasonable as Xiamen (metropolitan population 4.29 million) is only 20 km from Kinmen,
Fig. 4. (a) The median concentrations of pollutants (NO\textsubscript{x}, PM\textsubscript{2.5}, CO and O\textsubscript{3}) at Kinmen, Matsu, Magong and Cape Fugui on days when the air moved along the southern trajectories arriving at the receptor sites at either the 500 or 1500 m level. The light bars are for the lockdown period (i.e., 18 Jan–12 April 2020) for 2018 and 2019 and the darker bars for 2020. (b) The percentage improvement during the lockdown period compared with similar months of 2018 and 2019 from the southern trajectories. (c) The median concentrations of pollutants (NO\textsubscript{x}, PM\textsubscript{2.5}, CO and O\textsubscript{3}) at Kinmen, Matsu, Magong and Cape Fugui on days when the air moved along the northern trajectories arriving at the receptor sites at either the 500 or 1500 m level. The light bars are for the lockdown period 2018 and 2019 and the darker bars for 2020. (d) The percentage improvement during the lockdown period compared with similar months of 2018 and 2019 from the northern trajectories. Note: in (a) and (c) the concentrations have been scaled to bring them to roughly similar spans on the figure, 10\times NO\textsubscript{x} ppm, PM\textsubscript{2.5} µg m\textsuperscript{-3}, 100\times CO ppm and O\textsubscript{3} ppb.

Fine particulate matter is a key issue for public health. Our analysis suggests that PM\textsubscript{2.5} concentrations were lower during the lockdown period, when air arrived at Kinmen from China along the Hubei, southern and northern trajectories: 10, 14 and 10 µg m\textsuperscript{-3}. At Matsu these were: 5, 2.5 and 5 µg m\textsuperscript{-3} and on Magong: 4, 5 and 4 µg m\textsuperscript{-3}, while at Cape Fugui they are smaller at: 2, 7 and 4 µg m\textsuperscript{-3}, while Fuzhou (prefecture-level urban population 7.66 million) is about 15 km from Matsu. Xiamen and Fuzhou are far from the epicentre of the original epidemic and only limited areas of Fujian Province adopted partial lockdown (Leung et al, 2020), as there were just a few hundred COVID-19 cases (Wang et al., 2020c). However, work stopped on the Fuzhou-Xiamen high-speed railway until early April, and the 44\textsuperscript{th} session of the World Heritage Committee in Fuzhou, China was postponed (https://whc.unesco.org/en/sessions/44COM/).

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The reductions of NO\textsubscript{x} concentrations observed at Kinmen for the three sets of trajectories, Hubei, southern and northern: are 5, 3 and 4 ppb; at Matsu 2, 1 and 2.5 ppb; Magong 2, 3.4 and 2 ppb and Fugui 0.6, 1 and 0.25 ppb for the Hubei, southern and northern trajectories respectively. The changes by the time the air reaches Taiwan seem small, perhaps only a ppb of NO\textsubscript{x}, so unlikely to make a major contribution to urban areas, where NO\textsubscript{x} is much higher. Nevertheless, a history of concern shows that cross-strait cooperation in air quality management would be of value, just as cross-border cooperation has been between Hong Kong and Guangdong (Zhong et al., 2013).

4 CONCLUSIONS

Despite Taiwan’s distance from the epicenter of the pandemic and regions of reduced pollutant emissions from transport and industry there are slight changes in the concentrations of air
pollutants at remote monitoring sites. Air pollution during the period of COVID-19 restrictions in China revealed lower average particulate concentrations in 2020 compared with the years 2016–2019, for both Kinmen and Matsu. At Kinmen and Magong the lowest average concentrations of NO2 were found in 2020. However, average O3 concentrations were at their highest in 2020 at Magong and possibly Cape Fugui, though the record there is more limited. These observations give hints of an effect from the COVID-19 restrictions, but became clearer after examining days when the back trajectories came from China. Comparing 18 Jan–12 April 2018 and 2019 concentrations with the same period for 2020, shows reductions are most apparent in trajectories arising from Hubei Province. Nevertheless, even trajectories from areas to the north and south of these show some reduction in NO2 and PM2.5, suggesting a widespread effect of the COVID-19 restrictions on air pollution. The larger reductions on the coastal islands are not surprising given their proximity to coastal Chinese cities, but in the Penghu archipelago and at Cape Fugui, PM2.5 concentrations are reduced by a few micrograms per cubic metre. The changes in NO2 are smaller and at Cape Fugui, barely amounting to a ppb. During lockdown, ozone concentrations were elevated in parallel with the reduced NOx emissions. Ozone concentrations in Penghu (Magong) and at Cape Fugui increased ~20% when trajectories derived from Northern China. While overall the reduction in NO2 and PM2.5 is small, it represents an important fraction of the amount present in remote areas. However, it also suggests that air from China is not a dominant contributor to exposure in larger Taiwanese cities, where concentrations of these pollutants from local sources are typically higher. Nevertheless, the presence of these pollutants supports the need to reduce the transfer of pollution across the Taiwan Strait and draws attention to the values of cooperative agreements on air pollution control. It also suggests that a better understanding of air pollution over the Taiwan Strait could refine regional air quality management.

DISCLAIMER

Reference to any companies or specific commercial products does not constitute a recommendation.

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