Original Article

Association between hospitalizations for asthma exacerbation and weather conditions in Qingdao: an ecological study

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Background: The hospitalization for asthma exacerbation has varied with seasons, however, the underlying weather reasons have not been fully explored yet. This study is aimed to explore the effect of weather factors on increased number of hospitalization due to worsening of asthma symptoms. This will provide more information to the relevant authorities to allocate appropriate medical resources as per the weather conditions in Qingdao, China.

Methods: All adult patients admitted for asthma exacerbation from 1 January, 2017 to 31 December, 2019 were enrolled from 13 main hospitals of Qingdao. The clinical data, including age, sex, smoking history, etc., were collected from the electronic medical record (EMR) systems. The hourly air quality of Qingdao from 2017–2019, including the air quality index (AQI), $PM_{2.5}$ and PM_{10}, was obtained from the China National Environmental Monitoring Centre. All these parameters during 2017–2019 were compared monthly. For meteorological data, the monthly horizontal wind at 850 hPa and vertical velocity at 500 hPa during 1960–2020 were obtained from National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) global reanalysis dataset. The correlation analysis was applied to determine the association between asthma hospitalizations and the environmental factors, including atmospheric pressure, humidity, vertical visibility, and etc., monthly.

Results: In all, 10,549 asthmatic inpatients (45.7% males, 54.3% females) were included in the study. The inpatients number for asthma exacerbation had a plateau lasting from March to June of 2019, accompanied with high $PM_{2.5}$ and PM_{10}, as well as bad air quality from January to March of 2019, potentially governed by the El Niño event in 2018. However, there was no significance correlation between the number of asthma hospitalizations and the average value of all environmental factors.

Conclusions: The high rate of hospitalization for asthma exacerbation in Qingdao during the spring of 2019 was associated with the unfavorable weather conditions, which might be linked to the atmospheric circulation in East Asia.

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Keywords: Asthma exacerbation; weather condition; pollution; climate change

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Introduction

Asthma is one of the most prevalent and chronic global respiratory disease. It is characterized by lingering airway inflammation and hyperresponsivity, affecting 1–22% of the population in different countries (1,2). In China, according to the China Asthma and Risk factors Epidemiologic (CARE) survey, the prevalence of asthma among Chinese adolescents and adults is 1.24% (3), while that among Chinese children (aged <14 years), it is 2.12% (4), which varies depending upon time frame, region, and nationality, as well as sampling, data collection, and diagnosis of asthma (3-5). Notably, as a city which participated in both surveys, the prevalence of asthma in Qingdao (3.12% for adult and 3.69% for children) is much higher than that in most central cities in China (6,7). Therefore, asthma is considered to be one of the heavy burden diseases in Qingdao, and a precision intervention strategy has been called for according to the local conditions (8). Recently, the China Pulmonary Health (CPH) study estimated the prevalence of asthma in Chinese adults (aged >20 years) was 4.2% [95% confidence interval (CI): 3.1–5.6], which means 45.7 million (95% CI: 27.7–78.0) Chinese adults having asthma, including 25.7 million men (95% CI: 15.3–45.4) and 20.0 million women (95% CI: 12.4–32.6) on the basis of the 2015 Chinese population census, which further confirmed that asthma is a major public health challenge in China (9).

Hospitalization due to asthma exacerbation contributes largely to the healthcare expenses among asthmatic patients. According to published research, in the US, the costs of emergency visits and hospitalization due to asthma exacerbation account for up to 80% of the direct costs of asthma patients (10-13). Compared to children, asthma exacerbation in adults is more often triggered by environmental factors, such as weather changes, noxious gas, allergen exposure, and air pollution (9-11,13). A retrospective study conducted in 29 regions of China during the years of 2013 and 2014 illustrated that there were 2 obvious peaks of patient hospitalization for asthma exacerbation in adults (14). As one participating city of this survey, Qingdao has recurrent peaks of hospitalization for asthma exacerbation, which place unexpected pressure on the healthcare system (13,14).

It has been suggested that asthma exacerbation is closely related to the air quality, resilient air pollution with high particulate matter $(PM)_{2.5}$ and PM_{10}, pollen, and other biological allergens identified as precipitating factors (15-17). Previous studies have demonstrated the effects of meteorological factors, such as high atmospheric pressure, temperature, and humidity changes, on asthma exacerbation and other diseases (17-19); however, the impact of changes in atmospheric circulation on asthma exacerbation is not much clear.

As a coastal city in northern China, Qingdao has the typical atmospheric circulation from winter to spring, which is characterized by northwesterly winds near the surface associated with the East Asian winter monsoon (EAWM), and in the mid-troposphere associated with the East Asia trough. Such a condition is not favorable for the spread of air pollutants (20,21). Additionally, the lack of rain (<20 mm in winter, but >400 mm in summer) in North China to wash away pollutants also promotes Qingdao to experience severe haze pollution in the late winter and early spring (20,21), which may set the precondition for risk for the exacerbation of asthmatic patients.

Beside the seasonal features, there were also the interannual variations to a large extent dominated by the sweeping impact of climate changes. For instance, the super El Niño in the 2015 winter stimulated the abnormal weakening of wind and high haze pollution in North China Plain (22,23). As El Niño events affect the aerosol concentration and haze severity according to its types and intensities (24), the weak El Niño event, occurred in Qingdao in the winter of 2018, should bring some different haze pollution and health effect compared with other weather condition, which has not been investigated yet.

To explore the association of weather conditions and hospitalization for asthma exacerbation, in this study, we analyzed patients who experienced asthma exacerbation in the years of 2017–2019 and compared the incidence to air quality and weather conditions in Qingdao, uncovering the potential effect of the regional climate change

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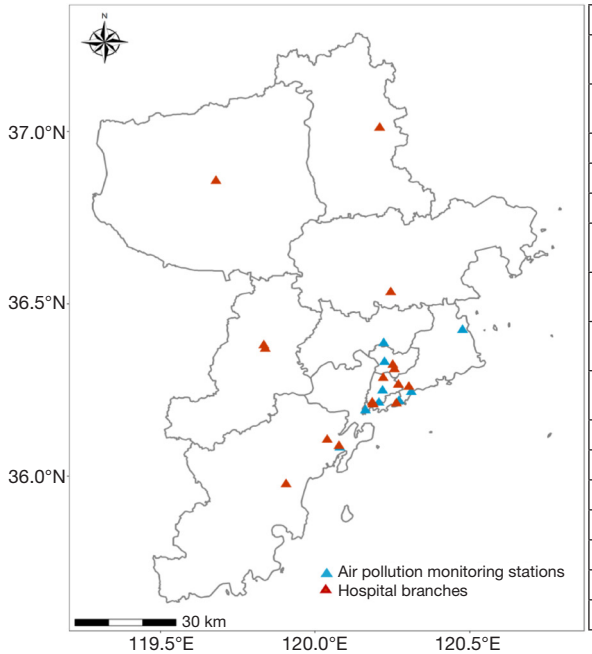

Hospital branches	Longitude/latitude
Qingdao Municipal Hospital, East Campus	120.403037/36.059641
Qingdao Municipal Hospital, Middle Campus	120.326375/36.073452
Qingdao Center Hospital	120.376516/36.139789
Qingdao No.8 People's Hospital	120.418464/36.159525
Qingdao No.3 People's Hospital	120.416101/36.172868
Afflicted Hospital of Qingdao University, Middle campus	120.326918/36.067738
Afflicted Hospital of Qingdao University, East campus	120.454223/36.101663
Afflicted Hospital of Qingdao University, West campus	120.155817/35.987369
Qilu Hospital of Shandong University (Qingdao)	120.42139/36.112557
Jimo People's Hospital	120.455261/36.38451
Pingdu People's Hospital	119.9520865/36.788968
Laixi People's Hospital	120.5245184/36.865040
Jiaozhou People's Hospital	120.007687/36.290732
Jiaozhou Center Hospital	120.010139/36.280018
Huangdao People's Hospital	119.9949405/35.877750
Huangdao Center Hospital	120.1909778/35.963523

Figure 1 Geographical distribution of 13 hospitals (branches) and air pollutant stations in this study. Blue triangles stand for air pollution monitoring station, red triangles stand for hospitals (branches).

associated with El Niño event in 2018 winter on the asthma exacerbation increases in the following spring of 2019. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-1755/rc).

Methods

Clinical data collection

A retrospective ecological study was conducted in 13 hospitals across 6 districts of Qingdao supervised by Qingdao Municipal Hospital (*Figure 1*). The numbers and clinical information (such as age, sex, smoking history, etc.) of all adult patients hospitalized for asthma exacerbation were retrieved by the investigators at each hospital from the electronic medical record (EMR) system, dating from 1 January, 2017 to 31 December, 2019. The patient's inclusion criteria were as follows: (I) aged ≥18 years old; (II) hospitalized primarily for asthma exacerbation according to the Global Initiative for Asthma (GINA) criteria, which was defined as requiring the use of corticosteroids for at least 3 days or a hospitalization or emergency room visit because of asthma requiring corticosteroids; (III) admission between 1 January, 2017 and 31 December, 2019. The clinical information included the demographic features (age, gender) and history of smoking. The 13 hospitals were informed and agreed with this study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study protocol was approved by the Ethics Committees of Qingdao Municipal Hospital (No. 2022-010) with an exemption from the informed consent requirement due to the retrospective nature of the study.

Air environment data [air quality index (AQI), $PM_{2.5}$ and PM_{10}]

The hourly air quality in Qingdao was obtained from the China National Environmental Monitoring Centre (http://www.pm25.in), including the AQI and the concentrations of major pollutants of $PM_{2.5}$ and PM_{10}. All these data was collected from nine representative air pollutant monitoring stations in Qingdao, which are same as those used in previous studies investigating the influence of air pollution on respiratory and cardiovascular systems in Qingdao (18,19). The mean values averaged over these 9 sites were used to represent the pollution condition in Qingdao.

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Table 1 Patients hospitalized for asthma exacerbation in 13 hospitals of Qingdao from 2017 to 2019 (n)

Year	Afflicted Hospital of Qingdao University	Qilu Hospital of Shandong University	Qingdao Municipal Hospital	Qingdao Center Hospital	Qingdao No. 8 People's Hospital	Qingdao No. 3 People's Hospital	Jimo People's Hospital	Laixi People's Hospital	Jiaozhou People's Hospital	Jiaozhou Center Hospital	Pingdu People's Hospital	Huangdao People's Hospital	Huangdao Center Hospital	All
2017	214	151	775	193	368	281	185	118	147	253	242	385	213	3,525
2018	221	155	811	178	300	320	163	98	209	187	265	371	175	3,453
2019	245	141	902	236	265	264	225	109	163	187	320	382	132	3,571
All	680	447	2,488	607	933	865	573	325	519	627	827	1,138	520	10,549

Meteorological data (horizontal and vertical wind velocity at 850 and 500 hPa)

To understand the climate changes, meteorological data from National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) global reanalysis (https://www.esrl.noaa.gov/psd/) were applied. The monthly climatologic mean of three-dimensional wind field, such as horizontal wind velocity at 850 hPa and vertical wind velocity at 500 hPa, were derived during the period of 1960–2020. The horizontal wind at 850 hPa is the main dynamic process associated with the transport of air pollutants. The vertical velocity at 500 hPa can roughly represent the atmospheric stability, whereby upward (downward) motion is less (more) stable. The anomalies in certain months derived from the monthly climatologic mean showed the relative change from its long-term mean. In our research, we defined December in 2018 with January and February in 2019 as 2018 winter, March to May in 2019 as 2019 spring as usual.

Statistical analysis

Statistical analysis was performed using the SPSS 26.0 software (IBM Corp., Armonk, NY, USA). All inpatient numbers were summed and compared across the 3 years. Pearson's correlation coefficient was applied to determine the correlation between the number of asthma hospitalizations and the average value of all environmental factors for every month. The student's *t*-test was used to verify that the anomalies were significantly different from their climatology. A two-sided P value <0.05 was considered statistically significant.

Results

Patient distribution and smoking history

In all, 10,549 asthmatic inpatients were included (45.7% males, 54.3% females), who sought medical attention due to asthma exacerbation from January 2017 to December 2019 from 13 public hospitals of Qingdao (*Table 1*). As shown in *Table 1*, the numbers of patients hospitalized for asthma exacerbation were similar each year, but varied in different hospitals according to hospital size. Most patients were non- or ex-smokers, and current smokers accounted for 15.3%, and were mostly elderly.

Interannual variability of hospitalization for asthma exacerbation in Qingdao

We plotted the number of inpatients for asthma exacerbation from all 13 hospitals each month over the study period (*Figure 2*). Unlike the regular seasonality with two peaks in March and September shown by previous study (13), the number of patients hospitalized for asthma exacerbation in Qingdao did not have a clear seasonal variability, instead varying with the year from 2017 to 2019. There were two obvious anomalies; the plateau of inpatient numbers from March to June in 2019, and a super-peak of inpatient numbers in August 2017. In this study, we focused on the anomaly in the spring of 2019 and tried to detect its linkage to climatic change.

Pollution condition in Qingdao (AQI, $PM_{2.5}$ and PM_{10})

Figure 3 shows the time series of near surface AQI, $PM_{2.5}$ and PM_{10} concentrations from January 2017 to December 2019 in Qingdao. All these variables were almost in phase with each other, with peaks in winter and lows in summer. However, the values of these 3 variables were extremely high in winter 2018 compared to other winters. For example, the AQI index in January 2019 was 113.81, much higher than those in 2018 (100.95) and 2017 (100.61). The 3-month mean AQI in the late winter, early spring (January, February, and March) in 2019 indicated severe pollution

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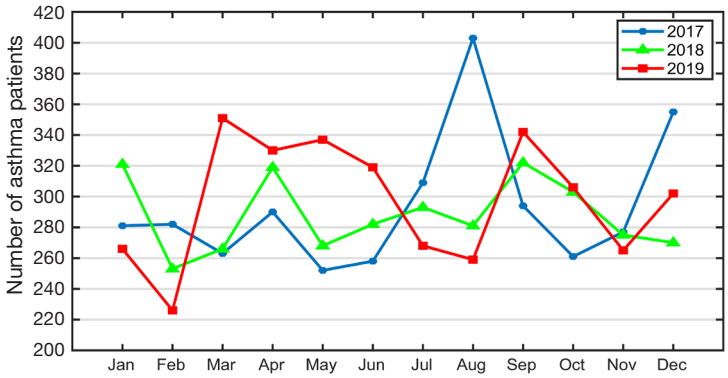

Figure 2 Interannual variability of hospitalization for asthma exacerbation.

of 96.68, compared to those in 2018 (82.18) and 2017 (82.53). Similarly, the $PM_{2.5}$ was 80.36 μg/m^3 and PM_{10} was 137.88 μg/m^3 in January 2019, about 15% higher than other years. The 3-month mean (January, February, and March) of $PM_{2.5}$ and PM_{10} were 20% higher than those in 2018 and the air pollution sets the preconditions for the high asthma exacerbation in March to June in 2019. Such conditions only existed in the spring of 2019, while the asthma incidence in 2017 and 2018 spring was low with only a single-peak in April.

Mean weather conditions in winter and spring around Qingdao during 1960–2020

Since common large scale weather conditions had not shown distinct regional features among different districts of Qingdao, we investigated the atmospheric circulation change during 1960–2020. In the 60 years, the EAWM starts from September and decays in the following April covering the heating period in the northern China. This wintertime prevailing atmospheric circulation brings an anti-cyclonic circulation with its eastern component blowing northwesterly wind over Qingdao (*Figure 4*, Figure S1), and the atmospheric stability accompanied by EAWM shows a center of downward motion from winter to the following spring over Qingdao (*Figure 5*).

Weather conditions around Qingdao in 2018 winter and 2019 spring

However, the weather conditions in the winter of 2018 and the following spring were quite different from its climatologic mean. There were anomalous southeasterly winds over Qingdao, which reduced the wind speed of the routine northwesterly monsoonal wind (*Figure 6*). The winter-time wind speed climatology was about 5 m/s over Qingdao with a reduction of 2 m/s (40%) in the 2018 winter. In the 2019 spring, the wind speed over Qingdao was also reduced by 15% compared to its climatological mean (4 m/s). The anomalous southeasterly winds were strong in the 2018 winter and gradually weakened in the 2019 spring. The southerly wind anomaly has been attributed to favor the accumulation of haze pollution (25,26). For the atmospheric stability, there was an upward anomaly motion (0.03 m/s) in late 2018, which meant that the atmosphere was less stable and favorable for air pollution spread (*Figure 7*). In the following spring, the atmosphere became more stable, and was accompanied by a stronger downward motion (0.025 m/s) over Qingdao (*Figure 7*), where the downward motion was enhanced by 50% compared to its climatological mean (0.05 m/s). The weakened horizontal wind superimposed on the stable atmosphere was conducive to air pollutant accumulation and thereby led to enhancement of $PM_{2.5}$ and PM_{10} concentrations, which contributed to the persistent number of patients hospitalized for asthma exacerbation in the spring of 2019.

Relationship between asthma exacerbation and air conditions

In order to evaluate the relationship between acute asthma exacerbation and air conditions, we calculated the correlation between the number of asthma hospitalizations and the average value of all environmental factors each month, including atmospheric pressure, wind speed, humidity, and vertical visibility. As shown in *Figure 8*, there seemed to be a possible correlation between mean vertical visibility and hospitalization every month; however, without significance due to the truncated research time (Table S1).

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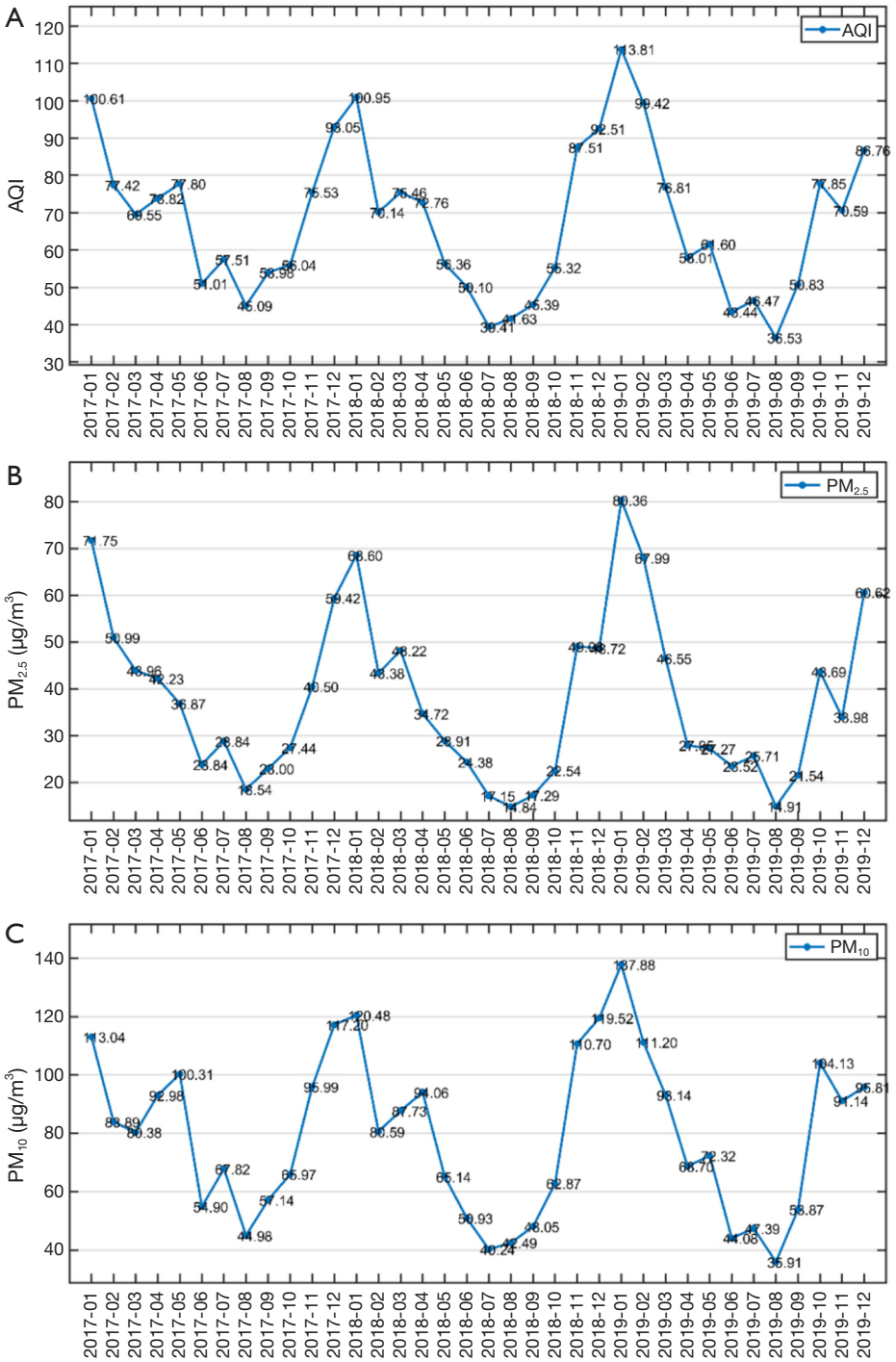

Figure 3 The time series of observed monthly concentrations of the (A) AQI, (B) $PM_{2.5}$ and (C) PM_{10} from January 2017 to December 2019 in Qingdao. AQI, air quality index; PM, particulate matter.

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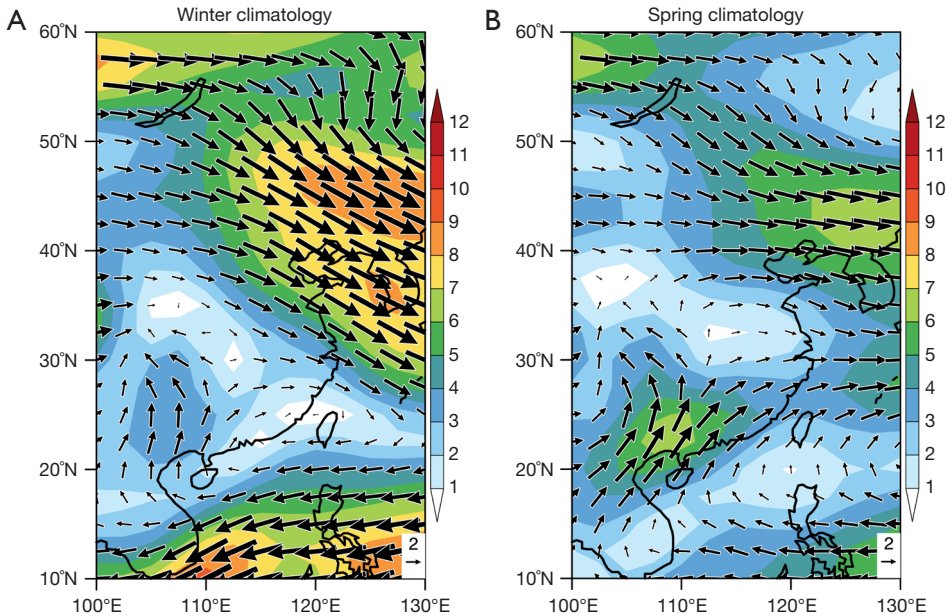

Figure 4 The climatology of the 850 hPa horizontal wind for the (A) winter and (B) spring during the period of 1960–2020. Vectors denote the horizontal winds (arrow) with wind speed (shading). Units for the horizontal winds are m/s.

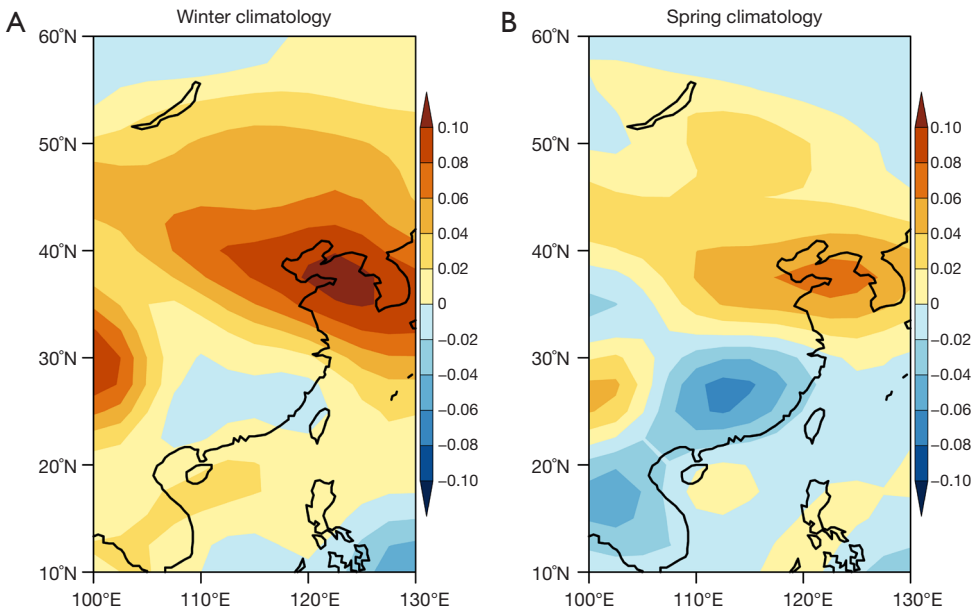

Figure 5 The climatology of the vertical velocity at 500 hPa for the (A) winter and (B) spring during the period of 1960–2020. Positive (negative) values denote downward (upward) motion. Units for the vertical velocity are Pa/s.

Discussion

This study investigated the interannual variability of asthma incidence under different weather conditions in Qingdao. We demonstrated that the weakened EAWM and vertical conductive movement induced high pollution in the winter of 2018 and spring of 2019, possibly triggering the unusual asthma exacerbation event from March to June in 2019.

Several retrospective studies have shown that the

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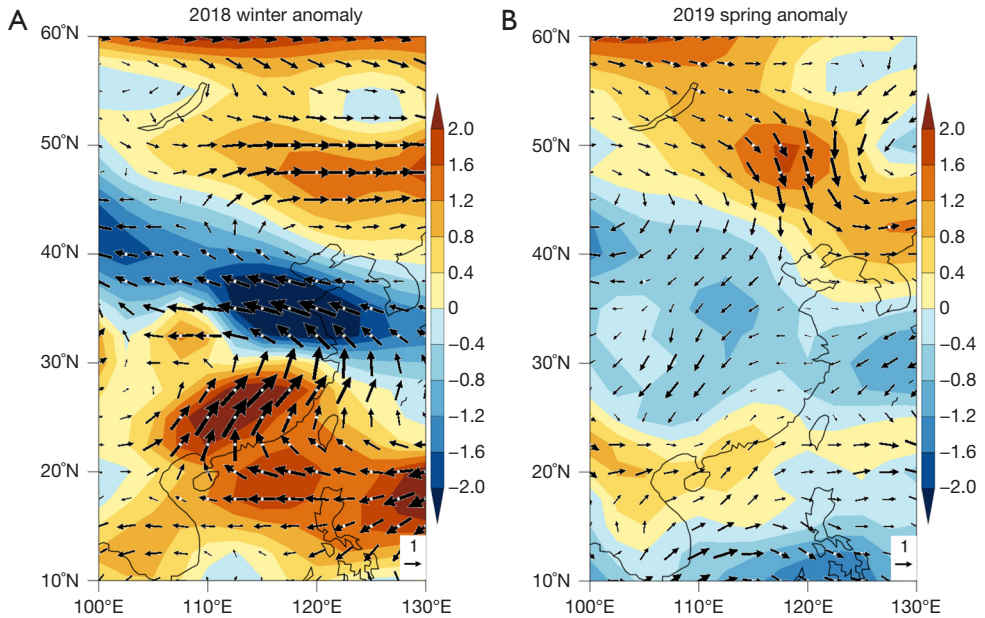

Figure 6 The anomalous 850 hPa horizontal winds for the (A) 2018 winter and (B) 2019 spring. Vectors denote the anomalous winds (arrow) and wind speed (shading). White dots show where the wind speed anomalies are significant over 95% confidence level. Units for the horizontal winds are m/s.

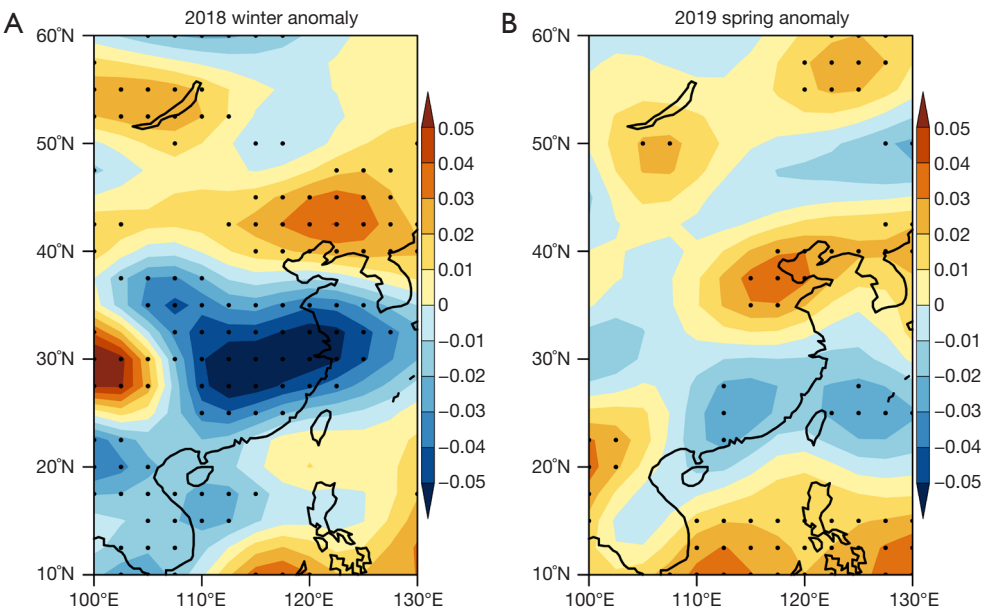

Figure 7 The anomalous vertical velocity at 500 hPa for the (A) 2018 winter and (B) 2019 spring. Positive (negative) values denote downward (upward) motion anomalies. Black dots show where the vertical velocity anomalies are significant over 95% confidence level. Units for the vertical velocity are Pa/s.

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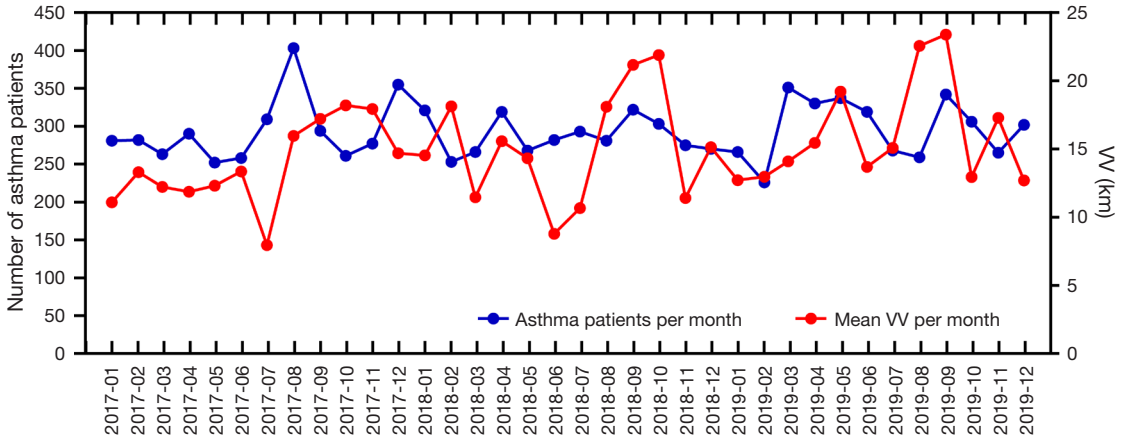

Figure 8 The relationship between asthma inpatients and air quality. VV, vertical visibility.

aggravation of asthma fluctuates according to year or season in China. Studies by Lin *et al.* (13) and Chen *et al.* (27) found that there was a peak for hospitalization of adult asthma from January to March in Taiwan every year. However, in our study, the number of patients hospitalized for asthma exacerbation in Qingdao did not have a clear seasonal variability; it varied by year from 2017 to 2019. There were 2 obvious anomalies, 1 was the plateau in 2019 spring and the other was the super-peak in 2017 summer. Compared to the super-peak in 2017, the plateau of hospitalization in 2019 spring would have imposed greater and continuous pressure on health resources, which would have made the local control systems more fragile than in other Chinese cities. This unique characteristic is worthy of further exploration.

As a chronic airway inflammatory disease, asthma is closely related to air pollution. Air pollutants, including PM, O_3, NO_2, SO_2, and others can enhance oxidative stress, promote airway inflammation and hyperresponsiveness, so as to induce occurrence and exacerbation of asthma (28,29). A meta-analysis by Fan *et al.* (30) indicated that high concentration of $PM_{2.5}$ exposure can increase the emergency visits of asthmatic patients. In another 10-year cohort study involving 137,040 adults, Greenberg *et al.* found that people in the area with high levels of NO_2 and SO_2 had a higher incidence of asthma attack (31). Xirasagar *et al.* (32) found that the concentration of air pollutants, such as PM_{10} and O_3, could significantly predict the admissions due to asthma exacerbation in children. Since 2014, a series of studies on the effect of air pollutants on the hospitalization have been conducted in Qingdao, analyzing the effect of air pollutants ($PM_{2.5}$, SO_2, NO_2) on hospitalization due to cardiovascular, cerebrovascular, and respiratory diseases with the time stratified case-crossover study, and found that a 10 μg/m^3 increase in $PM_{2.5}$ was associated with a 1.2% increase in hospital admissions for respiratory disease (P<0.05) (18,19,33). It is noteworthy that, in addition to the local emissions from coal combustion and so on, the wind transport would foster the accumulation of air pollutants and exacerbate the air quality (21,34).

Consistent with the above mentioned studies, Yang *et al.* (18) and Yang *et al.* (19) investigated the influence of air pollution on acute myocardial infarction (AMI), chronic obstructive pulmonary disease (COPD), and pneumonia in Qingdao and found the adverse effects of air pollutants on adult pneumonia hospital visits with some distinct non-linear features, and an inflection point between the concentration of certain air pollutants and the hospital admissions of AMI and COPD under the linear assumption. However, in all these studies, the clinical data were collected from one hospital of Qingdao only, which makes it difficult to reflect the whole picture of hospitalization in Qingdao. In our study, we collected all the hospitalizations for asthma exacerbation from 13 hospitals in Qingdao and found that the high hospitalization for asthma exacerbation from February to June 2019 followed a high pollution period in the winter of 2018. In the future, a continuous and long-term survey is needed to further confirm the relationship in Qingdao.

Regional weather conditions are controlled by the largescale circulation system. Even a small change in the climate system may lead to quite large changes in the regional weather conditions, as the conditions during a strong El Niño period discussed by Zhang *et al.* (25). The

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weakened wind and reduced vertical conductive movement in winter 2018 in Qingdao reflected the impact of El Niño–Southern Oscillation (ENSO) activity on the eastern flank of Asia. El Niño (La Niña) events are associated with weakened (intensified) EAWM. A weak El Niño event occurred in winter 2018, as did anomalous warm sea surface temperature in the tropical eastern Pacific Ocean. Such warming peaks in late 2018 stimulated an anomalous cyclonic circulation with enhanced subtropical high through Pacific-East Asian teleconnection. The weakened northwesterly wind over Qingdao can be attributed to the occurrence of the El Niño event. The El Niño-induced enhanced subtropical high increased the sea level pressure over Qingdao to strengthen the atmospheric stability. Under global warming, more extreme climate changes, including ENSO variability and frequency, are projected to increase, in particular the number of strong El Niño events (23,35). This may be indicative of a more rigorous situation in future air quality in northern China as well as Qingdao under the modulation of such abnormal meteorological conditions, which deserves substantial attention in light of the diseases highly related to air pollution. There also were some limitations. In our study, we only focused on the relationship between hospitalization for asthma exacerbation and weather conditions, so the outpatients due to moderate exacerbation of asthma might be missed. And we will research the possible relation between outpatient visits owing to asthma exacerbation and the weather in the future.

Conclusions

Taken together, our study described an unusual asthma exacerbation during the spring of 2019 in Qingdao, China, which may have been related to the weather conditions induced by atmospheric circulation in 2018 winter in the East Asia. However, due to the short span of clinical data, more complex statistical models, such as time series analysis, hardly to be performed in this study. Further long-term study should be carried on to clarify the effect of the atmospheric anomaly on asthma attacks and other respiratory diseases to provide more information for the accurate allocation of medical resources.

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Footnote

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Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-1755/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-1755/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committees of Qingdao Municipal Hospital (No. 2022-010). Individual consent for this retrospective analysis was waived.

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