The Spring Festival Effect on air quality in the megacities of China: View from space

Dongqing Li[1], Qizhong Wu[1], Hui Wang[2], Han Xiao[1], Qi Xu[1], Lizhi Wang[3], Jinming Feng[3], Xiaochun Yang[1], Huaqiong Cheng[1], Lanning Wang[1], Yiming Sun[1]

[1]College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China.

[2]University of California, Irvine, CA 92697, USA

[3]Key Laboratory of Regional Climate-Environment for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Corresponding author: Qizhong Wu (wqizhong@bnu.edu.cn)

Key Points:

- The satellite NO_2 columns observation catch the Spring Festival Effect, which is lowest during the vacation in the megacities in China.
- The tropospheric NO_2 columns density during the vacation around BTH region decreases about 40% than the period before the festival.
- The satellite-based NO_2 columns density during the Spring Festival decrease by 31.8% ~ 44.5% in Beijing, Tianjin, Shanghai and Chongqing.

Abstract

The Spring Festival is the most important holiday in China, human activity and population mobility may contribute greatly to air quality, especially in the megacities. According to the satellite-based tropospheric nitrogen dioxide (NO_2) column and ground-based observational concentration of NO_2 in the megacities from 2013 to 2018 around the Spring Festival, we found that NO_2 concentration decreases obviously during the Spring Festival in China, particularly in the megacities. The tropospheric NO_2 columns density around Beijing-Tianjin-Hebei region decreases about 40% than the period before the festival, that in Beijing and Tianjin decreases by 41.6% and 44.5% respectively. Similarly, the other two municipal cities Shanghai and Chongqing decrease by 43.2% and 31.8% in the urban. Consistently, the ground-based NO_2 concentration in the four megacities decrease by 18.9% ~ 38.8%.

Besides, the ground-based NO_2 concentration also decreases by above 20% during the Spring Festival vacation in the other eight megacities in China.

1 Introduction

The rapid development in China has contributed to heavy air pollution (Liu et al., 2018). Air pollution has huge impact on human health and the global ecological environment (Ghorani-Azam et al., 2016) even the climate (D'Amato et al., 2014). With the close relationship between air quality and human activity, many researches focus on this point. For example, Demircigil et al. (2014) have done the research of carrying out in buccal epithelial cells from children in an urban city of Turkey to analyze the genotoxic effect of air pollution, and found that seasonal variation in genotoxicity may be related to the time spent at outdoors in summer.

NO_2 is one of the most important air pollutant species, owing to its relatively short lifetime, it would not be transported far from its sources (Richter et al., 2005). Thus, satellite and remote sensing images provide a direct indication of where NO_2 sources are located. Boersma et al. (2011) explored the sensitive factors of tropospheric NO_2 column retrieval algorithm for the Ozone Monitoring Instrument (OMI) to improve the data quality. Bechle et al. (2013) found that the correlation coefficient between annual OMI NO_2 column density and ground data in southern California is up to 0.93. Tropospheric NO_2 columns density of satellite observations products with high quality have also been successfully used in many researches to infer NOx emissions and trends (Boersma et al., 2007; Silvern et al., 2019). According to Goldberg et al. (2017), OMI NO_2 has been used to estimate NOx emissions in various region around the globe such as the US, southern California, Europe and East Asia (Chang et al., 2017; Duncan et al., 2016). Some researchers have found the trend of NO_x emission trend in China over this decade, it increased in 2005-2010 (Verstraeten et al., 2015) and tended to be stable in 2011-2012 (Souri et al., 2017) while since 2012 it has decreased. The research by Foy et al. (2016) is on the trend of NO_2 emission from 2005 to 2015 by OMI and the satellite results were in great agreement with the annual trends of the NOx emissions inventory until 2014, which showed that the reliability of evaluating trends of NOx emission by OMI.

There also has been an emphasis on the effect of the special period on air quality. The Spring Festival is the most important festival in China that most Chinese would move from cities to their hometown for family reunion before the Spring Festival and back from their hometown to cities for work after the Spring Festival, and most of the industries, companies and production sites in the cities are closed during the vacation around the Spring Festival (Tang et al., 2016; Wang et al., 2017; Yao et al., 2019). Wang et al. (2017) chose urban Shenzhen over three consecutive winters of 2014-2016 to research the air pollution based on the effect of the Spring Festival, and the results indicate that the air pollutants decrease heavily during the

Spring Festival relative to non-Spring Festival periods, regardless of the meteorological conditions. Gong et al. (2014) chose the long-term observation from 2001 to 2012 in eastern China and found the feature of the air pollutants around the Spring Festival is the significant reduction of concentration. This study collected the satellite-based tropospheric NO_2 column and the ground-based NO_2 concentration to quantify the Spring Festival effect on air quality in the megacities in China.

2 Observation and Methods

Considering the particularity of the Spring Festival, for human activity and population mobility may contribute a lot to air quality in the megacities especially, the typical episode of up to 3 x 18 days is chosen to compare the concentration of NO_2 in different periods of the special time. The satellite-based tropospheric column observed by OMI and ground-based observational concentration of NO_2 in the megacities from the China National Environmental Monitoring Centre (CNEMC) before, during and after the Spring Festival from 2013 to 2018 have been collected for this study.

The data of tropospheric NO_2 columns density are accessed from OMI of EU FP7 project Quality Assurance for Essential Climate Variable (QA4ECV). The main product is the tropospheric NO_2 column density, which is defined as the vertically integrated number of NO_2 molecules between the Earth's ground and the tropopause. It has an overpass time about 13:30~13:50 at local time (Goldberg et al., 2017; Lamsal et al., 2008). The regional tropospheric NO_2 columns of individual days on the globe from 2013 to 2018 are accessed from OMI and then extract and obtain the region data of China.

The daily observation of NO_2 is obtained from the CNEMC, covering 12 megacities in China, including Shanghai(SH), Beijing(BJ), Shenzhen(SZ), Guangzhou(GZ), Chengdu(CD), Hangzhou(HZ), Chongqing(CQ), Wuhan(WH), Xi'an(XA), Tianjin(TJ), Nanjing(NJ) and Zhengzhou(ZZ) from 2013 to 2018(Figure 1). Based on the ranking of China cities business attractiveness 2018 by China Business Network (CBN), we chose those 12 megacities with great financial conditions, public transport facilities, social environment, and large population (China Business Network, 2018).

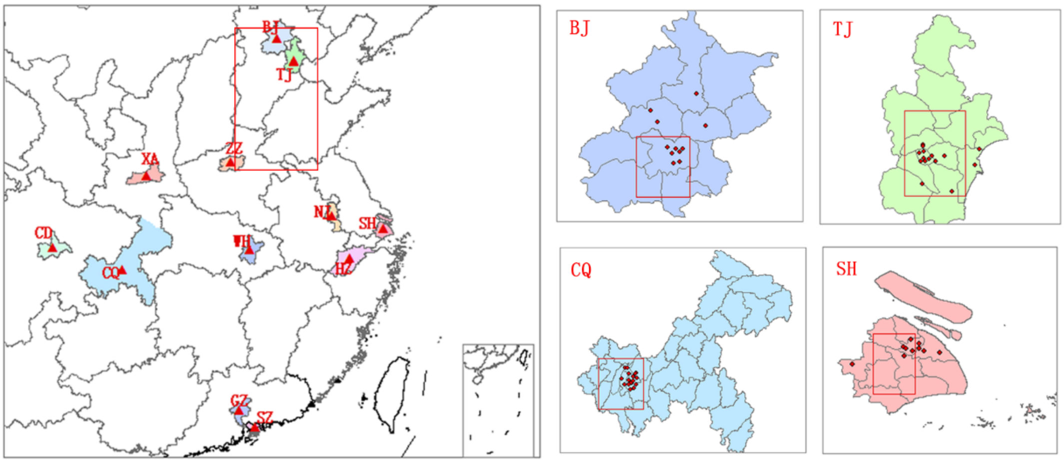

Figure 1. The location of researched cities and observational sites. The red triangle in the left subfigure were the megacities mentioned in this study, while the red box cover Beijing-Tianjin-Hebei (BTH) region. The observational sites in BJ, TJ, CQ and SH was shown as the red points in the right subfigures, and the compared urban area of OMI in each municipality is enclosed by the red box.

The Spring Festival vacation in China traditionally is from Spring Festival, the 1st day of the Chinese lunar year, to Lantern Festival, the 15th day of the Chinese lunar year. Due to the super vast area of China, the Chinese New Year has been regarded as the largest migration in the world (Huang et al., 2012). Moreover, as the importance of Chinese New Year and long-time for transportation and preparing for it, people need to get home back in advance, so that we defined the complete vacation as during the Spring Festival (DF) from three days before the 1st day to the 15th day of Chinese lunar year. Then, we compared the different periods to explore the relationship between human activity and air quality, that before the Spring Festival (BF) and after the Spring Festival (AF) has the same 18 days. The specific dates of BF, DF and AF periods are shown in Figure 2.

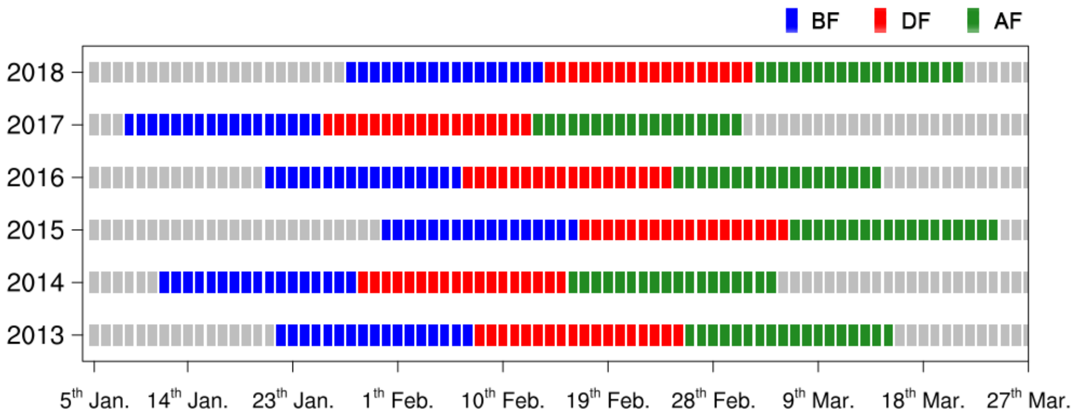

Figure 2. The dates of each period around the Spring Festival from the year 2013 to 2018. The panes with blue, red and green represent the periods before the festival (BF), during the

festival (DF) and after the festival (AF) respectively. The AF period in 2016 including 29th Feb.

Considering the pixel size of OMI is 13 km × 24 km at nadir or the center of the swath, we collected the satellite data with grid resolution of 0.25° × 0.25°. As OMI NO_2 algorithm is highly sensitive to clouds, the OMI NO_2 has been filtered by removing the data with cloud radiance fractions ≥0.5 (Bucsela et al., 2008; Hains et al., 2010; Silvern et al., 2019) and solar zenith angles ≥80°, and the benefit of this approach is that only valid pixel is used (Goldberg et al., 2017). Accordingly, we applied the ground-based NO_2 concentration observed by CNEMC in these periods from year 2013 to 2018 to decrease the influence of meteorology, and analyzed the daily concentration change and site distribution of each megacities to explore the special phenomenon of air quality on NO_2.

3 Spatial and temporal distribution around the Spring Festival

This section describes the change of NO_2 concentration around the Spring Festival according to the satellite-based tropospheric NO_2 columns and ground-based observational NO_2 concentration. The spatial distribution of tropospheric NO_2 columns is present in Figure 3. It shows the tropospheric NO_2 columns density in DF is less than BF and AF around Beijing-Tianjin-Hebei (BTH) region and megacities including SH, BJ, SZ, GZ, CD, HZ, CQ, WH, XA, TJ, NJ and ZZ obviously.

The mean tropospheric NO_2 columns density of BTH region is 32.53 molec/cm^2 before the Spring Festival, and decreases to 19.59 molec/cm^2 during the Spring Festival, by about 40%.

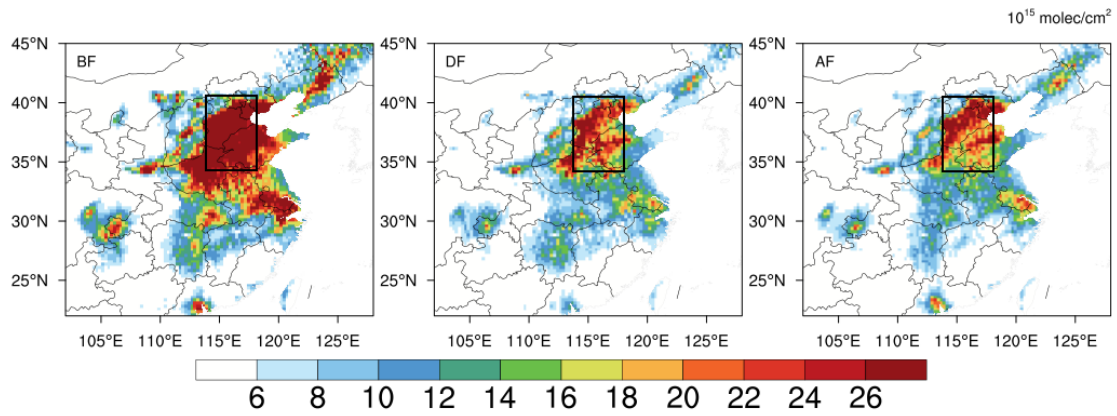

Figure 3. The change of tropospheric NO_2 columns in most region of China (units:10^{15} molec/cm^2). The data less than 6×10^{15} molec/cm^2 has been set to white. The area with black box is around Beijing-Tianjin-Hebei region.

The highest data is over 50 molec/cm^2 in Beijing before the Spring Festival. The average tropospheric NO_2 columns density of Beijing is 41.86 molec/cm^2 in BF and reduces to 24.46 molec/cm^2 in DF while it rebounds to 29.92 molec/cm^2 after the

Spring Festival ,which is shown in Figure 4a. As well as the trend in Tianjin (Figure 4b), Shanghai (Figure 4c) and Chongqing (Figure 4d) is the same with Beijing. Similarly to the most region of China, these municipalities all show the tropospheric NO_2 columns density is featured by a notable reduction during the Spring Festival and a relatively weak rebound after the Spring Festival. The average tropospheric NO_2 columns density of Tianjin is 40.98 molec/cm^2 in BF, and it reduces to 22.75 molec/cm^2 in DF while rebounds to 28.58 molec/cm^2 after the Spring Festival. The tropospheric NO_2 columns density of Shanghai decreases from 27.64 molec/cm^2 to 15.69 molec/cm^2 and backs to 18.39 molec/cm^2 over time. As for Chongqing, the data changes from 21.43 molec/cm^2 to 14.62 molec/cm^2 and rebounds to 15.51 molec/cm^2. Based on the above observation analysis we may conclude that the tropospheric NO_2 columns density over the most well-developed area of China is featured by a notable reduction during the Spring Festival and a relatively weak rebound after the Spring Festival.

The most surprising aspect of the result is that the former decrease dramatically reaches over 40% in Beijing, Tianjin and Shanghai, and the NOx emission in these megacities decrease about 40% during the Spring Festival, which mainly emit from vehicle, industry and so on. While the latter rebound in Beijing, Tianjin, and Shanghai only reach about 20%. The tropospheric NO_2 columns density in Tianjin fluctuates more heavily than other cities with 44.5% and 25.6% during the twice period-change respectively. In contrast, Chongqing is the least one regarding the change of tropospheric NO_2 columns density as decreasing 31.8% during the Spring Festival while rebounding 6.2% after the Spring Festival.

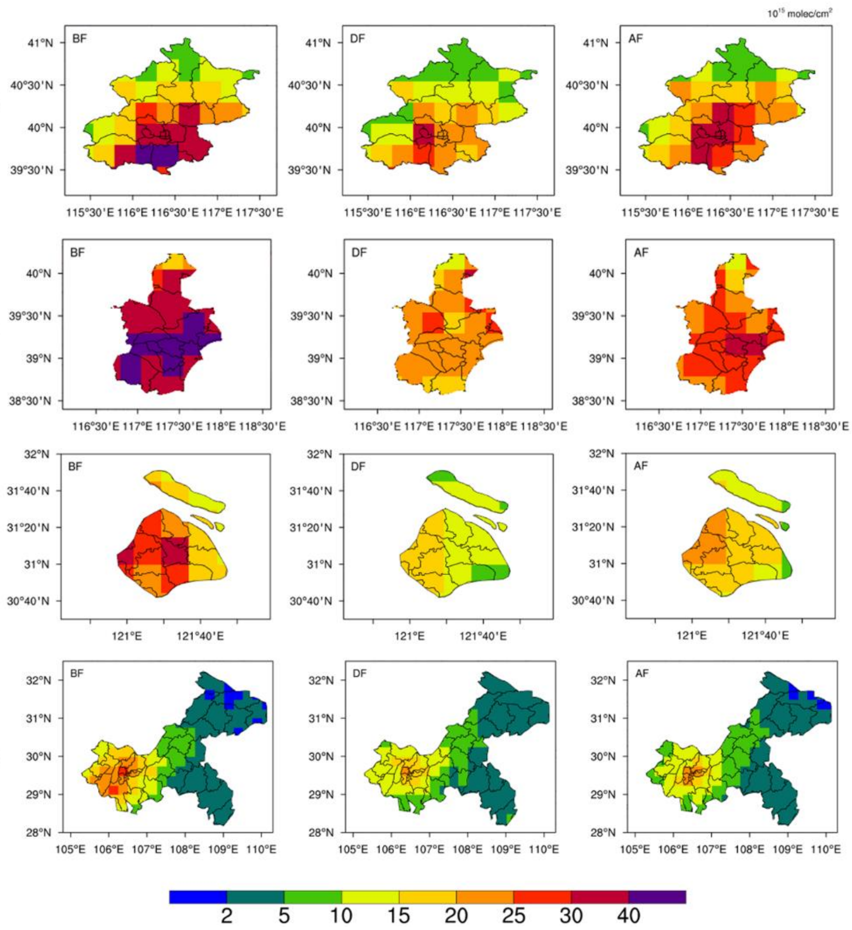

Figure 4. The change of tropospheric NO_2 columns in Beijing(a), Tianjin(b), Shanghai(c) and Chongqing(d). Units:10^{15} molec/cm^2.

The trend of ground-based NO_2 concentration from CNEMC is coincident well. Figure 5 provides the daily NO_2 concentration on 18-day averaged of each period in the megacities. As shown in Figure 5, the ground-based NO_2 concentration during the Spring Festival is much lower than periods before and after the Spring Festival. The mean absolute difference between DF period and the other two periods in Guangzhou, Hangzhou, Nanjing, Chengdu, and Tianjin is up to 20 μg/m^3. In contrast, Zhengzhou is 13.3 μg/m^3, while Xi’an, Shenzhen, and Beijing are lower than 15 μg/m^3.

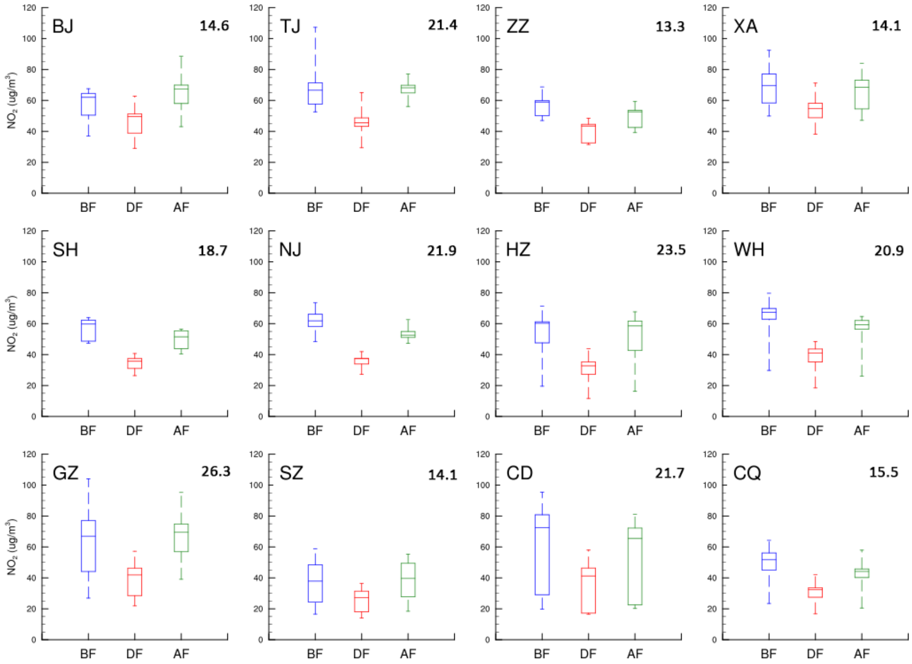

Figure 5. The box plot of NO_2 concentration observed by CNEMC in the megacities. The box in blue, red and green represents BF, DF and AF. The dash in each color box means the median NO_2 concentration in the city, and the stick at each end means the maximum and minimum. The number at the top right means the average absolute difference between DF period and the other two periods.

Comparing the results in deep with the satellite-based and ground-based NO_2 concentration in Beijing, Tianjin, Shanghai, and Chongqing, they both show significantly reduction during the Spring Festival. As shown in Figure 6, the NO_2 concentration during the Spring Festival is the lowest one whether the tropospheric NO_2 columns density or ground concentration. There are some differences in the two types of data, such as the change proportion and concentration temporal distribution in the same city. For example, Beijing has the highest concentration in BF by tropospheric NO_2 columns density but in AF by ground concentration. The ground concentration after festival has recovered evidently while it is not too obviously by tropospheric NO_2 columns density in Chongqing. Moreover, the tropospheric NO_2 columns density in DF of Beijing has reduced by 41.6% while it only reduced by 18.9% on ground-based NO_2 concentration. Tianjin is the same with Beijing for the former is 44.5% and the latter only up to 29.81%. The change trend of two types data in other two municipal cities Shanghai and Chongqing have little difference. It decreases by 43.2% and 31.8% in the urban of Shanghai and Chongqing according to the tropospheric NO_2 columns while it is 38.8%, 38.1%, respectively. This result indicates the overall trend is that NO_2 concentration during the Spring Festival decrease and is the lowest period, but the specific trend and proportion in different data show different results.

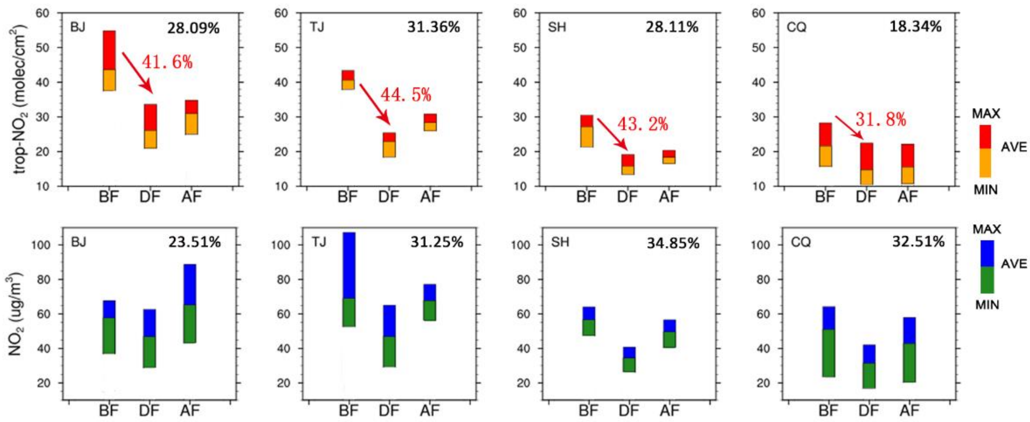

Figure 6. The concentration change of NO_2 in the megacities on average of sites. The number at the top right of each city picture means the average of change proportion between DF period and the other two periods. The red number near the red arrow in tropospheric NO_2 columns subfigure means the reduction proportion from BF period to DF period on average.

The ranking of 12 researched cities in 2018 by China Business Network is Shanghai, Beijing, Shenzhen, Guangzhou, Chengdu, Hangzhou, Chongqing, Wuhan, Xi'an, Tianjin, Nanjing, Zhengzhou in order. The average ground-based observational NO_2 concentration of the 12 megacities during the Spring Festival changes from 59.48 μg/m^3 that before the Spring Festival to 38.94 μg/m^3, a reduction of 20.54 μg/m^3. And it rebounds 16.88 μg/m^3, up to 55.82 μg/m^{3}after the Spring Festival. The highest concentration of NO_2 during the Spring Festival is 54.83 μg/m^3, which is appeared in Xi'an. The top three of the highest DF concentration are in the order of Xi'an, Tianjin and Beijing. And Zhengzhou, Chengdu, Guangzhou, Wuhan, Nanjing, Shanghai, Chongqing and Hangzhouis over 30 μg/m^3 while Shenzhen is the least one with only 25.25 μg/m^3 in groud-based NO_2 concentration. Actually, the average concentration on the whole Spring Festival researched period of Shenzhen is also the least one with only 34.56 μg/m^3, while Xi'an is 64.22 μg/m^3, which is also the highest one. The results further verify that air quality is closely related to human activity including the financial conditions, public transport facilities, industry, population and so on.

4 Conclusions

This study researched the satellite-based tropospheric NO_2 columns density by Ozone Monitoring Instrument and ground-based NO_2 concentration published by the China National Environmental Monitoring Centre around the Chinese Spring Festival and found that the concentration of NO_2 during the festival in megacities decreased a lot, which is highly related to human activity and called the "Spring Festival Effect". That means we can use the satellite-based tropospheric NO_2 columns density or ground-based NO_2 concentration as one index to describe the characterization and intensity of human activity.

Air quality during the Spring Festival in some well-developed areas and megacities such as Beijing-Tianjin-Hebei region and most provincial cities is better than other periods before and after the Spring Festival. Around Beijing-Tianjin-Hebei region, the tropospheric NO_2 columns density during the Spring Festival decreases about 40% than the period before the festival. Moreover, the tropospheric NO_2 columns density in Beijing, Tianjin, Shanghai, and Chongqing during the Chinese Spring Festival decrease by 31.8% ~ 44.5% compared with that in period of before the festival.

Meanwhile, the ground-based NO_2 concentration is also less during the Spring Festival than the periods before and after the vacation in China, particularly in the megacities similarly. Compared with the satellite-based tropospheric NO_2 columns density in the researched megacities, the NO_2 concentration during the Chinese Spring Festival decrease by 18.9% ~ 38.8% than period before the festival. Besides, the ground-based NO_2 concentration also decreases by above 20% during the Spring Festival vacation in the other eight megacities in China.

Data availability.

The data of the satellite-based tropospheric NO_2 columns by OMI is available online via QA4ECV (http://www.temis.nl/airpollution/no2col/no2regioomi_qa.php) and the ground-based NO_2 concentration by CNEMC (http://www.cnemc.cn/) is available online via http://www.pm25.in/api_doc. The other data are available online via ZENODO (https://zenodo.org/deposit/3630222; Li et al., 2020).

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