Inconsistencies in air quality metrics: ‘Blue Sky’ days and PM$_{10}$ concentrations in Beijing

Steven Q Andrews$^1$

Princeton in Asia, Princeton University, Princeton, NJ 08544, USA

E-mail: sandrews@alumni.princeton.edu

Received 31 January 2008
Accepted for publication 16 September 2008
Published 26 September 2008
Online at stacks.iop.org/ERL/3/034009

Abstract

International attention is focused on Beijing’s efforts to improve air quality. The number of days reported as attaining the daily Chinese National Ambient Air Quality Standard for cities, called ‘Blue Sky’ days, has increased yearly from 100 in 1998 to 246 in 2007. However, analysis of publicly reported daily air pollution index (API) values for fine particulate matter (diameter $\leq 10$ µm, PM$_{10}$), indicates a discrepancy between the reported ‘Blue Sky’ days (defined as API $\leq 100$, PM$_{10} \leq 150$ µg m$^{-3}$) and published monitoring station data. Here I show that reported improvements in air quality for 2006–2007 over 2002 levels can be attributed to (a) a shift in reported daily PM$_{10}$ concentrations from just above to just below the national standard, and (b) a shift of monitoring stations in 2006 to less polluted areas. I found that calculating daily Beijing API for 2006 and 2007 using data from the original monitoring stations eliminates a bias in reported PM$_{10}$ concentrations near the ‘Blue Sky’ boundary, and results in a number of ‘Blue Sky’ days and annual PM$_{10}$ concentration near 2002 levels in 2006 and 2007 (203 days and $\sim$167 µg m$^{-3}$ calculated for 2006—38 days fewer and a PM$_{10}$ concentration $\sim$6 µg m$^{-3}$ higher than reported; 191 ‘Blue Sky’ days and $\sim$161 µg m$^{-3}$ calculated for 2007—55 days fewer and a PM$_{10}$ concentration $\sim$12 µg m$^{-3}$ higher than reported; 203 days and 166 µg m$^{-3}$ were reported in 2002). Furthermore, although different pollutants were monitored before daily reporting began and less stringent standards were implemented in June 2000, reported annual average concentrations of particulate (diameter $\leq 100$ µm, TSP) and nitrogen dioxide (NO$_2$) indicate no improvement between 1998 and 2002. This analysis highlights the sensitivity of monitoring data in the evaluation of air quality trends, and the potential for the misinterpretation or manipulation of these trends on the basis of inconsistent metrics.

Keywords: Beijing, China, air quality, PM$_{10}$, air pollution index, metric, Olympics

1. Introduction

In 1998, Beijing launched a ‘Defending the Blue Sky’ campaign with air quality data becoming openly available on a weekly basis in February 1998 [1–3], and on a daily basis in June 2000 [4]. In January 2003, the data from individual monitoring stations also became publicly available [4]. Annual average pollutant concentrations are also publicly reported [1, 5]. In July of 2001, Beijing was awarded the 2008 Olympics, and international attention is focused on Beijing’s efforts to improve air quality [6–8].

In 1998, Beijing was ranked as having the 3rd worst air quality in a global ranking of 157 cities across 45 countries [3]. The annual average particulate concentration (diameter $\leq 100$ µm, TSP) that year was 35% higher than Mexico City, which was ranked as having the worst air quality in the world [3, 9]. It has been widely reported that the air
quality in Beijing has substantially improved [10–13]. The number of days reported as attaining the national standard, called ‘Blue Sky’ days, has increased yearly from 100 in 1998 to 246 in 2007 [5, 14] with national and international media coverage [15, 16]. However, reported annual pollutant concentrations have not shown a similar improvement [5, 17], and in 2005, Beijing had the fewest number of days meeting the national air quality standard of any major city in China [18]. Although the ‘Blue Sky’ designation for days meeting that national air quality standard originated in Beijing, this classification is now used in many major Chinese cities [19]. Given the local variability of ambient air quality, daily and annual pollutant concentrations are sensitive to the locations of monitoring stations, as are the number of ‘Blue Sky’ days. Although ‘Blue Sky’ days are a policy-relevant metric subject to a range of non-scientific variables, tracking the number of air quality standard non-attainment days, i.e. the number of ‘Blue Sky’ days minus the total number of days in the year for China, is done in many other countries, including the United States [66]. Air quality data in China was first released as part of a deliberate strategy by the central government to raise public awareness about pollution levels thereby putting pressure on local government officials to enforce environmental regulations [38]. A simple index can be an effective communication tool for government agencies to facilitate greater public understanding of pollution levels and trends.

China has ambient air quality standards, established in 1996 [9, 20], which are classified according to three grades. China’s daily average PM10 standards are 50 µg m⁻³ (Grade I), 150 µg m⁻³ (Grade II), and 250 µg m⁻³ (Grade III). China’s annual PM10 standards are 40 µg m⁻³ (Grade I), 100 µg m⁻³ (Grade II), and 150 µg m⁻³ (Grade III). The Grade II standard is applied to urban areas including Beijing [7]. Cities that exceed the national Grade III annual standard are blacklisted by the Chinese State Environmental Protection Administration [21, 22]. In 2006, the annual average PM10 concentration in Beijing was 161 µg m⁻³—above the national Grade III standard [23a].

The World Health Organization (WHO) guideline for daily PM10 concentrations is 50 µg m⁻³, and the annual average PM10 concentration guideline is 20 µg m⁻³ [5, 24]. The WHO also has established less stringent interim targets to assist countries in tracking progress over time in reducing population exposure to particulate matter. For daily PM10 concentration the interim target-1 is 150 µg m⁻³, and the annual average PM10 interim target-1 is 70 µg m⁻³. The WHO recommends that countries not meeting the daily guidelines for particulate: ‘undertake immediate action to achieve these levels in the shortest time possible’ [25].

Neither the Chinese national ambient air quality standards, nor the World Health Organization guidelines, differentiate between particulate from anthropogenic and natural sources, or between pollution from local and distant sources in the air quality standards [23a, 19]. However, in the United States, extreme events are not included in determining violation of the national ambient air quality standards [67]. Particulate pollution from dust storms [11, 24], biomass burning [25], and distant sources [7, 26] impacts Beijing air quality, and has complicated control efforts taken by the Beijing government. These issues have affected the city air quality to varying degrees throughout the 1998–2007 periods, and are not addressed in the present study which focuses on reported air quality trends and Beijing’s efforts to meet the Chinese air quality standards. Severe dust storms during the spring of 2006 are likely partially responsible for high average particulate levels for that year, but these days of highly elevated particulate concentrations should not affect days with particulate concentrations near the PM10 = 150 µg m⁻³ national ambient air quality standard.

According to the national Chinese State Environmental Protection Administration’s 2005 Automated Methods for Ambient Air Quality Monitoring (HJ/T 193–2005), which went into effect on January 1, 2006, cities with a population of over 3 million people are required to use at least eight monitoring stations to measure urban air quality [33]. In addition, new specifications were added regarding the minimum distance from roadways that air pollution should be monitored. For roadways with an average of 3000 vehicles per day, monitoring stations should be a minimum of 25 m from the road; for roadways with an average of 15 000 vehicles per day a minimum of 80 m; and for roadways with an average of 40 000 vehicles per day a minimum of 150 m [33]. In 2005, Beijing municipality had 15.4 million permanent residents and the 293 primary roads in urban districts of the city had a total length of 596 km that carried on average 5422 vehicles per hour [23b], a number that would increase 11.4% to 6040 vehicles per hour in 2006 [23a].

The reported Beijing air quality is an average of data from selected monitoring stations [27]. From 1984 to 2005, the 7 stations used to measure air quality remained constant. These stations monitored areas with different characteristics, e.g., traffic, residential, commercial, and industrial [1, 28–31]. Although the number of monitoring stations increased from 8 in 1984, one of the original monitoring stations was a background station located near the Ming tombs 80 km outside of the city, to 27 in 2005, only the original 7 stations were used to calculate air quality during this period allowing for consistent comparisons of annual average pollution levels. The two stations monitoring traffic were dropped from the city network in 2006 [32, 33], although monitoring continued [4], while three additional stations were added [32, 34]. Vehicular emissions have been cited by the Beijing Environmental Protection Bureau as the largest source of air pollution in Beijing [28, 35]. The monitoring stations used for determining daily city pollution levels and ‘Blue Sky’ days are also used to calculate annual average pollution concentrations [1, 26]. In 1998, without the two monitoring stations in transportation areas, the annual average particulate (TSP) concentration for the city would have been 7% lower, the annual average NOx concentration would have been 24% lower, and the annual average SO2 concentration would have been 10% lower than reported for that year.

Reports have raised questions regarding the accuracy of scientific and air quality reporting in China [36–39, 54]. However, the annual number of ‘Blue Sky’ days, along with
annual pollutant concentrations, continue to be used in China to evaluate air quality trends [3, 5, 14, 18, 22], model air pollution [31, 40], calculate the health and economic impacts of air pollution [2, 41–43], and establish air quality control plans [44]. No known study has analyzed the sensitivity of Beijing’s air quality monitoring data to the analysis of air quality trends, which I examine by calculating the impact of the change in monitoring station locations on reported air quality, or examined the air pollution index reporting system for other irregularities, including the revision of standards in June of 2000 [45, 46]. The relative importance of nitrogen oxides (NOx) and sulfur dioxide (SO2) in public air quality reporting will also be addressed, along with a discussion of monitoring station locations.

2. Methods

2.1. Data

This study used daily and weekly air quality data, reported as Air Pollution Index values, publicly available from the State Environmental Protection Agency (SEPA, www.zhb.gov.cn) and Beijing Environmental Protection Bureau (BJEPB, www.bjepb.gov.cn). Chinese API values are a scientific measure of air quality designed to inform the public about air pollution and the potential impacts on human health [27]. The conversion from API values to pollutant concentrations is detailed in SEPA technical regulations in both Chinese and English, and has been used and described in several scientific studies [46–48]. The Chinese API is based on the air quality index (AQI) used in the United States, and although the standards vary, the calculation methodology is the same [49]. Similar index systems are also used in other countries [46].

In major cities in China, concentrations of the pollutants PM10 (TSP from 1998 to 2000), NO2 (NOx from 1998 to 2000), and SO2 are monitored and converted to an air pollution index (API) value between 1 and 500 (table 1) [27]. From 1998 to 2000, ozone (O3) and carbon monoxide (CO) were also used in API reporting [38]. Each day (week from 1998 to 2000), the highest API value is reported, and the primary pollutant is identified if its API is >50, indicating potential risk to human health.

\[
\text{API} = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo} \quad (1)
\]

where API = air pollution index, \( C_p = \) the concentration of pollutant \( p \), \( I_{Hi} = \) API value corresponding to \( BP_{Hi} \), \( I_{Lo} = \) API value corresponding to \( BP_{Lo} \), \( BP_{Hi} = \) the breakpoint that is greater than or equal to \( C_p \), \( BP_{Lo} = \) the breakpoint that is less than or equal to \( C_p \).

An API value less than or equal to 100 indicates attainment of the national air quality standard—a ‘Blue Sky’ day. For PM10 API values between 50 and 200 there is a linear correlation with PM10 concentrations between 50 and 350 \( \mu g \text{ m}^{-3} \). This means that when PM10 is the primary pollutant, an API of 99 = a PM10 concentration of 148 \( \mu g \text{ m}^{-3} \), an API of 100 = a PM10 concentration of 150 \( \mu g \text{ m}^{-3} \) (the national standard), an API of 101 = a PM10 concentration of 152 \( \mu g \text{ m}^{-3} \), and so forth. An API of 150 or less (PM10 concentration = 250 \( \mu g \text{ m}^{-3} \)) indicates attainment of the Grade III standard. Air quality above the Grade III standard indicates severe air pollution [21].

The table of pollutant concentrations and equivalent API break points is the same in the Chinese and English versions of the SEPA technical regulations; however, the sample calculation in the English version incorrectly uses a PM10 concentration of 350 \( \mu g \text{ m}^{-3} \) for the API breakpoint of 200. The correct PM10 = 350 \( \mu g \text{ m}^{-3} \) for the API breakpoint of 200 is used in the Chinese version, has been applied in scientific studies [46–48], and is consistent with the US EPA methodologies. However, several studies have included the incorrect breakpoint [6, 41].

From June 2000 through 2007, 85%, 0% and 8% of days in Beijing had PM10, NO2, and SO2, as the primary pollutant, respectively. Only 7% of days had an API of 50 or less [4]. From March 1998 to June 2000, 55%, 44% and 1% of weeks had TSP, NO2 and SO2 as the primary pollutant, respectively [2]. I focus my analysis on daily API values when PM10 was the primary pollutant, because 96% of days exceeding the ‘Blue Sky’ standard from June 2000 to 2007 had PM10 as the primary pollutant, 100% of days exceeding the Grade III standard had PM10 as the primary pollutant, and there is limited data available for other pollutants.

### Table 1. API breakpoints and concentrations for selected pollutants.

| API    | After June 2000 | Before June 2000 |
|--------|----------------|-----------------|
|        | PM10 (µg/m³)  | NO2 (µg/m³)    | SO2 (µg/m³) | TSP (µg/m³) | NOx (µg/m³) | SO2 (µg/m³) |
| 0-50   | 0-50          | 0-80           | 0-50        | 0-120       | 0-50        | 0-50        |
| 50-100 | 50-150        | 80-120         | 50-150      | 120-300     | 50-100      | 50-150      |
| 100-200| 150-350       | 120-280        | 150-350     | 300-500     | 100-150     | 150-250     |
| 200-300| 350-425       | 280-565        | 800-1600    | 500-625     | 150-565     | 250-1600    |
| 300-400| 420-500       | 565-750        | 1600-2100   | 625-875     | 565-750     | 1600-2100   |
| 400-500| 500-600       | 750-940        | 2100-2620   | 875-1000    | 750-940     | 2100-2620   |
2.2. Analysis

I examine the frequency distribution of API values focusing on values near the ‘Blue Sky’ boundary, and calculate the daily Beijing API on days when the primary pollutant was PM10 and the reported API values were from 51 to 200 at all stations used for the city API calculations. Within this interval, equivalent to PM10 concentrations from 52 to 350 $\mu$g $\text{m}^{-3}$, a change of one API unit equals a change in PM10 concentrations of 2 $\mu$g $\text{m}^{-3}$, and averaging monitoring station API values is equivalent to averaging PM10 concentrations.

SEPA and BJEPB separately report daily city APIs using the same automated monitoring station data [50]. These reported city APIs are similar, but not always equal. Between 2003 and 2007, 1312 days (71.9%) had PM10 API values at all reporting monitoring stations (including 98% of days with a reported PM10 API between 96 and 105 in 2006, and 85% of days with a reported PM10 API between 96 and 105 in 2007). During these 5 years, the official city API reported by SEPA was equal to the city API reported by BJEPB on 74.0% of days, and within 1 API value on 99.6% of days. My averaging of daily PM10 API values from the 7 monitoring stations (8 in 2006 and 2007) gives the official SEPA city API value on 86.3% of days, and a value within 1 API unit on 99.5% of days; closer to the official city API than reported by BJEPB.

SEPA technical regulations state that the final API should be rounded to the next whole number if a decimal remains after calculation [27], however on days where there is a difference between SEPA and BJEPB values, the SEPA value is lower by 1 unit on 99.2% of days, likely due to differences in rounding. A discrepancy larger than 1 API unit has been noted between SEPA and BJEPB data when the reported API is 100 [51].

I also analyze the sensitivity of trends in the number of days exceeding the national Grade III standard with and without the monitoring station changes, and pollutants concentrations from 1998 to 2002. Annual average pollutant concentrations are analyzed during this period due to the lack of availability of daily data, and because of the change in national air quality standards.

Changes in air quality standards: in June of 2000, less stringent standards for NO2/NOx, TSP/PM10, and SO2 were established [45, 46] complicating comparisons of the number of days meeting annual standards between 1998 and 2000 and recent 2001–2007 years [41]. Specific changes include:

- NO2/NOx—in June of 2000, China switched from monitoring NOx to measuring NO2, and the 1996 Chinese Ambient Air Quality Standards were revised [39]. The national daily NO2 standard was raised from 80 to 120 $\mu$g $\text{m}^{-3}$, and the annual average standard was raised from 40 to 80 $\mu$g $\text{m}^{-3}$. The WHO and many other countries also measure NO2, and the Chinese 1996 annual average NO2 standard was equal to the standard that would
be set in the 2000 WHO guidelines [24]. However, the revised 2000 Chinese standard for annual average NO$_2$ concentration is twice as high as the 2000 WHO guidelines. Specifically, the impact on public reporting was that an API index value of 100 for NO$_x$ during the 1998–June 2000 period indicated a NO$_x$ concentration of 100 $\mu$g m$^{-3}$ (the national standard for NO$_x$), while from June of 2000–2007, an API of 100 for NO$_2$ has been equal to a NO$_2$ concentration of 120 $\mu$g m$^{-3}$—50% higher than the 1996 standards of 80 $\mu$g m$^{-3}$ [39].

- PM$_{10}$/TSP—A particulate concentration equal to the Grade III standard (TSP = 500 $\mu$g m$^{-3}$) was equal to an API of 200 from 1998 to June 2000, however, from June 2000–2007, a particulate concentration equal to the Grade III standard (PM$_{10}$ = 250 $\mu$g m$^{-3}$), has been equal to an API of 150.

- SO$_2$—a sulfur dioxide concentration equal to the Grade III standard (SO$_2$ = 250 $\mu$g m$^{-3}$) was equal to an API of 200 from 1998 to June 2000, but from June 2000–2007 the same concentration has been equal to an API of 116.

3. Results

2001–2007 reported data. While 52% of the days with a city API between 96 and 105 (PM$_{10}$ = 142–160 $\mu$g m$^{-3}$) were reported as ‘Blue Sky’ days in 2001, 98% of the days in this range were ‘Blue Sky’ days in 2006, and 93% of days in the range were ‘Blue Sky’ days in 2007 (figure 1). The Beijing Municipal Government establishes annual targets at the beginning of each year for the number of ‘Blue Sky’ days in the city [38]. Evaluation of daily data from the 22 monitoring stations in operation from 2003 to 2007 indicates an increasing bias towards assessing values close to the ‘Blue Sky’ boundary as meeting the criteria for the declaration of a ‘Blue Sky’ day (figure 2). Beginning in 2004, annual targets for the number of days achieving the national air quality standard have been set for each sub-district in Beijing with a monitoring station [38]. The frequency distribution of daily PM$_{10}$ values is most often roughly log-normal [25], and analyzing data from all monitoring stations provides higher data resolution for examining potential bias.

2006 ‘Blue Sky’ Days. I calculate daily city API values for 2006 using the 7 original monitoring stations (those used to calculate city API from 1984 to 2005). The average city API values that I calculate for 2006, on the 265 days (72.6%) that PM$_{10}$ was the primary pollutant at all stations, equaled the official city API value on only 5.5% of days, and was within 1 API unit on 24.5% of days. I find that calculating the 2006 city API using the 7 original stations eliminates the bias across the ‘Blue Sky’ boundary and that the daily city API is on average 3 API units ($\sim$6 $\mu$g m$^{-3}$) higher than was reported. Had the same stations been used for air quality reporting in 2006 that were used from 1998 to 2005, 38 fewer days would have been reported as ‘Blue Sky’ days (table 2). 46% of the calculated daily city API values are between 96 and 100, and 54% are between 101 and 105. However, in official 2006 reports based on the 8 monitoring stations (including the three new stations), 98% of API values were between 96 and 100 and 2% were between 101 and 105.
Table 2. 38 reported ‘Blue Sky’ days would have exceeded the API = 100 (PM$_{10}$ = 150 µg m$^{-3}$) national air quality standard if the same monitoring station locations used from 1998 to 2005 continued to be used in 2006. (Note: Blue indicates reported API values (SEPA) and calculated city API values using official 2006–2007 stations. Red indicates city API values we calculated for 2006–2007 using the same stations that were used between 1998 and 2005. Yellow indicates a difference greater than 0.5 between reported API values and the values we calculate using the new (official) monitoring stations. This one day occurred when the reported API was 100. Monitoring stations include: removed stations #1 Chegongzhuang, Haidian, #2 Qianmen, Dongcheng; added stations #8 Gongyuan, Xicheng, #9 Wansixiguan, Xuanwu, #10 Wanliao, Haidian, and constant stations #3 Dongsi, Dongcheng, #4 Tiantan, Chongwen, #5 Olympic Stadium, Chaoyang, #6 Nongzhanguang, Chaoyang, #7 Shijingshan, Gucheng. Monitoring station data was downloaded from the Beijing Environmental Protection Bureau, which includes a map of monitoring station locations on its homepage (www.bjepb.gov.cn) (last accessed May 1, 2008.).

| Date (2006) | Official Reported City API (SEPA) | City API Calc. w/o Station Change | Table 2: Individual Monitoring Station PM$_{10}$ API |
|-------------|---------------------------------|---------------------------------|---------------------------------|
|             | 2005 (monitoring continued in 2006) | 2006 and 2007 PM$_{10}$ concentrations. Reported annual average pollutant concentrations are a simple average of daily values. In 2006, an annual average PM$_{10}$ concentration of 161 µg m$^{-3}$ was reported, however, if the monitoring station used from 1984 to 2005 continued to be used in 2006, the concentration would be $\sim$167 µg m$^{-3}$—an average concentration $\sim$6 µg m$^{-3}$ higher than reported. In 2007, an annual average PM$_{10}$ concentration of 149 µg m$^{-3}$ was reported [4], however, if the original monitoring stations were between 96 and 100 and 7% were between 101 and 105.
Table 2. (Continued.)

| Date   | 6-Aug | 100 | 104 | 117 | 116 | 94  | 94  | 100 | 100 | 109 | 98  | 105 | 99  | 99.9 |
|--------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 12-Aug | 98    | 102 | 120 | 107 | 92  | 90  | 96  | 98  | 114 | 96  | 99  | -   | 97.9 |
| 24-Aug | 99    | 103 | 116 | 106 | 99  | 93  | 97  | 95  | 115 | 97  | 99  | 97  | 99.0 |
| 2-Sep  | 100   | 105 | 127 | 106 | 98  | 89  | 99  | 95  | 117 | 95  | 104 | 98  | 99.5 |
| 13-Sep | 100   | 103 | 117 | 113 | 95  | 93  | 97  | 97  | 109 | 99  | 108 | 100 | 99.8 |
| 18-Sep | 100   | 109 | 138 | 120 | 91  | 96  | 107 | 98  | 111 | 99  | 100 | 99  | 100.1|
| 21-Sep | 99    | 108 | 126 | 130 | 91  | 97  | 107 | 99  | 106 | 92  | 99  | 99  | 98.8 |
| 22-Sep | 95    | 101 | 120 | 113 | 86  | 92  | 96  | 99  | 100 | 94  | 94  | 96  | 94.6 |
| 28-Sep | 98    | 106 | 135 | 110 | 81  | 97  | 97  | 100 | 119 | 99  | 92  | 98  | 97.9 |
| 30-Sep | 100   | 104 | 112 | 113 | 94  | 93  | 97  | 100 | 120 | 98  | 97  | 98  | 99.6 |
| 5-Oct  | 99    | 104 | 107 | 124 | 97  | 97  | 95  | 97  | 112 | 92  | 100 | 98  | 98.5 |
| 7-Oct  | 100   | 105 | 135 | 111 | 74  | 108 | 74  | 107 | 123 | 114 | 95  | 104 | 99.9 |
| 15-Oct | 100   | 103 | 128 | 103 | 90  | 83  | 95  | 100 | 120 | 106 | 92  | 112 | 99.8 |
| 24-Oct | 99    | 106 | 116 | 116 | 89  | 83  | 109 | 99  | 133 | 91  | 87  | 99  | 98.8 |
| 27-Oct | 99    | 103 | 124 | 117 | 96  | 91  | 95  | 95  | 100 | 108 | 100 | 110 | 99.4 |
| 1-Nov  | 96    | 104 | 145 | 104 | 86  | 85  | 99  | 90  | 119 | 95  | 95  | 100 | 96.1 |
| 2-Nov  | 98    | 105 | 129 | 113 | 88  | 94  | 93  | 100 | 115 | 98  | 97  | 100 | 98.1 |
| 13-Nov | 98    | 109 | 154 | 119 | 91  | 94  | 109 | 96  | 97  | 99  | 100 | 100 | 98.3 |
| 16-Nov | 99    | 107 | 131 | 123 | 92  | 92  | 91  | 100 | 121 | 93  | 107 | 97  | 99.1 |
| 17-Nov | 100   | 104 | 119 | 111 | 90  | 89  | 103 | 100 | 115 | 99  | 105 | 105 | 100.1|

continued to be used in 2007, the concentration would be \( \sim 161 \, \mu g \, m^{-3} \)—an average concentration of \( \sim 12 \, \mu g \, m^{-3} \) higher than reported (figure 3).

2001–2007 Grade III standard. The only pollutant that has exceeded the daily Grade III standard since the pollutants monitored changed in June of 2000 has been PM\(_{10}\). In 2003, 31 days exceeded the Grade III standard, indicating unhealthy air quality for the general population—the fewest on record. Based on official reporting 2002 and 2006 both had 52 days exceeding the Grade III standard. However, if the monitoring station locations had not changed, 57 days would have exceeded the ‘Blue Sky’ standard in 2006, the same number as in 2001 (figure 4).

1998–2002 reported data for TSP and NO\(_x\). I analyze weekly air quality reports available from March 1998 through June 2000 and find either particulate (diameter \( \leq 100 \, \mu m \), TSP) or nitrogen oxides (NO\(_x\)) to be the primary pollutant on 99% of weeks above standard. NO\(_x\) has not been a pollutant of concern since the June 2000 change in standards, even though government reports indicate no improvement in annual average NO\(_2\) concentrations [5, 11], and studies using satellite imagery have found substantial increases [53, 54]. Although the number of ‘Blue Sky’ days reportedly increased from 100 in 1998 to 203 in 2002, neither average annual particulate nor nitrogen dioxide (NO\(_2\)) concentrations improved (figure 5). Previous research noted that NO\(_x\) was responsible for the largest percentage of days above the standard from 1998 to June 2000 [55] however since NO\(_2\) began being reported in June 2000, not a single day has had NO\(_2\) as the primary pollutant.

4. Sulfur dioxide

This analysis does not focus on the sensitivity of trends in sulfur dioxide concentrations to monitoring station locations, because SO\(_2\) has only been indicated as the primary pollutant on 3% of reports above the national standard from 1998 to 2007, compared to particulate (PM\(_{10}\)/TSP, 87% of reports) and nitrogen oxides (NO\(_x\)/NO\(_2\), 10% of reports). Furthermore, from 1998 to 2007, not a single API report indicated a SO\(_2\) level above the Grade III (250 \( \mu g \, m^{-3} \)) daily standard. API
Table 3. 55 reported ‘Blue Sky’ days would have been above the API = 100 (PM$_{10}$ = 150 µg m$^{-3}$) national air quality standard if the same monitoring station locations used from 1998 to 2005 continued to be used in 2007. (Note: Blue indicates reported API values (SEPA, second column) and calculated city API values using official 2007 stations (last column). Red indicates city API values we calculated for 2007 using the same stations that were used between 1998 and 2005. Monitoring stations include: removed stations #1 Chegongzhuang, Haidian, #2 Qianmen, Dongcheng; added stations #8 Gongyuan, Xicheng, #9 Wansixiguan, Xuanwu, #10 Wanliao, Haidian, and constant stations #3 Dongsi, Dongcheng, #4 Tiantan, Chongwen, #5 Olympic Stadium, Chaoyang, #6 Nongzhanguang, Chaoyang, #7 Shijingshan, Gucheng.)

| Date (2007) | Official Reported City API (SEPA) | City API Calc. w/o Station Change | Table 3: Individual Monitoring Station PM$_{10}$ API | City API Calc. Stations #1-7 used for API calculations 1998-2005 (monitoring continued in 2007) | Stations #3-10 used for 2007 API calculations |
|-------------|----------------------------------|----------------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8-Feb       | 99                               | 108                              | 117 140 97 95 95 104 105 98 97 100            | 98.9                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 17-Feb      | 98                               | 101                              | 97 113 99 100 96 98 94 96 108 100 98 100         | 98.5                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 19-Feb      | 99                               | 103                              | 110 121 95 94 99 96 108 100 98 100             | 98.8                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 17-Mar      | 100                              | 105                              | 121 110 97 93 99 110 104 99 100 96             | 99.8                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 28-Mar      | 98                               | 104                              | 113 123 97 95 93 105 100 95 98 100             | 97.9                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 29-Mar      | 99                               | 104                              | 110 118 100 98 100 99 100 99 99 99             | 99.3                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 4-Apr       | 95                               | 106                              | 139 117 94 94 88 111 97 95 86 93             | 94.8                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 9-Apr       | 96                               | 102                              | 112 125 100 92 88 100 100 97 99 96             | 96.5                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 18-Apr      | 100                              | 105                              | 115 122 97 104 92 96 112 95 105 98             | 99.9                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 3-May       | 96                               | 106                              | 133 118 96 92 99 92 113 99 88 92             | 96.4                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 4-May       | 97                               | 106                              | 131 100 94 89 98 110 118 100 88 79             | 97.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 6-May       | 91                               | 102                              | 128 123 103 85 91 90 96 100 90 75             | 91.3                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 9-May       | 98                               | 105                              | 118 115 89 93 99 110 109 99 93 93             | 98.1                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 12-May      | 99                               | 111                              | 114 147 97 97 97 - 111 98 107 85             | 98.9                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 13-May      | 100                              | 111                              | 140 122 105 89 94 111 118 99 95 90             | 100.1                                                                                                                                                                                              |                                                                                                                                                                                                 |
| 15-May      | 97                               | 105                              | 117 120 112 92 100 96 97 100 97 82             | 97.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 16-May      | 100                              | 115                              | 132 142 114 94 99 - 107 97 97 93             | 100.1                                                                                                                                                                                              |                                                                                                                                                                                                 |
| 20-May      | 98                               | 105                              | 122 113 98 83 96 97 127 98 95 93             | 98.4                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 26-May      | 98                               | 105                              | 114 120 94 94 97 - 112 91 100 98             | 98.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 29-May      | 98                               | 106                              | 117 118 100 94 106 - 98 98 95 95             | 98.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 3-Jun       | 99                               | 104                              | 116 116 99 98 100 - 95 100 104 96             | 98.9                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 5-Jun       | 99                               | 106                              | 114 126 98 93 105 - 99 96 100 100             | 98.7                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 10-Jun      | 97                               | 105                              | 111 117 99 93 100 - 109 95 99 82             | 96.7                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 16-Jun      | 98                               | 105                              | 113 122 106 95 - - 89 92 97 109             | 98.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 26-Jun      | 98                               | 101                              | 114 - 97 98 98 - 97 97 98 99             | 97.7                                                                                                                                                                                               |                                                                                                                                                                                                 |
| 3-Jul       | 99                               | 106                              | 128 115 94 96 97 107 105 96 97 100             | 99.0                                                                                                                                                                                               |                                                                                                                                                                                                 |
Table 3. (Continued.)

| Date   | 5-Jul | 100  | 114 | 126 | 147 | 100 | 110 | -   | 88 | 95 | 114 | 93 | 100.0 |
|--------|-------|------|-----|-----|-----|-----|-----|-----|----|----|-----|----|--------|
| 16-Jul | 96    | 105  | 109 | 122 | 99  | 98  | 100 | -   | 100| 98 | 87  | 90 | 96.0   |
| 18-Jul | 98    | 103  | 117 | 111 | 97  | 89  | 96  | 108 | -  | 93 | 91  | 110 | 97.7   |
| 21-Jul | 98    | 109  | 108 | 133 | 98  | 104 | 100 | -   | 100| 91 | 95  | 98.0 |        |
| 22-Jul | 99    | 110  | 113 | 144 | 100 | 96  | 99  | -   | 107| 99 | 90  | 100 | 98.7   |
| 24-Jul | 99    | 106  | 122 | 129 | 99  | 100 | 100 | 95  | 100| 107| 98  | 91  | 98.8   |
| 28-Jul | 98    | 104  | 110 | -   | 98  | 95  | 100 | 110 | 108| 90 | 87  | 96  | 98.0   |
| 5-Aug  | 98    | 105  | 115 | 114 | 99  | 106 | 100 | -   | 98 | 100| 92  | 91  | 98.0   |
| 7-Aug  | 93    | 102  | 108 | 113 | 96  | 99  | 100 | -   | 94 | 89 | 90  | 81  | 92.7   |
| 31-Aug | 98    | 108  | 116 | 135 | 97  | 99  | 100 | -   | 99 | 99 | 95  | 96  | 97.9   |
| 2-Sep  | 95    | 103  | 95  | 137 | 93  | 92  | 93  | 99  | 113| 93 | 86  | 89  | 94.8   |
| 5-Sep  | 94    | 102  | 98  | 130 | 95  | 93  | 99  | 100 | 97 | 92 | 91  | 88  | 94.4   |
| 6-Sep  | 100   | 107  | 105 | 133 | 100 | 94  | 95  | 109 | 114| 94 | 98  | 92  | 99.5   |
| 7-Sep  | 98    | 107  | 111 | 120 | 96  | 94  | 96  | -   | 123| 89 | 94  | 95  | 98.1   |
| 8-Sep  | 94    | 103  | 115 | 124 | 92  | 88  | 88  | 99  | 114| 90 | 91  | 92  | 94.3   |
| 9-Sep  | 98    | 101  | 109 | -   | 98  | 99  | 100 | 99  | -  | 96 | 98  | 96  | 98.0   |
| 13-Sep | 97    | 104  | 97  | 129 | 97  | 88  | 98  | 109 | 111| 86 | 90  | 100 | 97.4   |
| 16-Sep | 99    | 107  | -   | 135 | 98  | 97  | 96  | 105 | 113| 91 | 99  | 91  | 98.8   |
| 23-Sep | 97    | 107  | 112 | 133 | 95  | 89  | 96  | 118 | -  | 96 | 90  | 97  | 97.3   |
| 25-Sep | 95    | 104  | 105 | 120 | 95  | 81  | 92  | 107 | 125| 85 | 80  | 96  | 95.1   |
| 4-Oct  | 94    | 103  | 94  | 118 | 95  | 78  | 112 | 90  | 133| 81 | 76  | 90  | 94.4   |
| 17-Oct | 95    | 102  | 96  | 124 | 99  | 83  | -   | 93  | 118| 87 | 89  | 94  | 94.7   |
| 21-Oct | 98    | 106  | 106 | 133 | 97  | 93  | 98  | 96  | 116| 94 | 95  | 95  | 98.0   |
| 22-Oct | 100   | 110  | 115 | 140 | 108 | 96  | -   | 91  | -  | 97 | 106 | 100 | 99.7   |
| 24-Oct | 96    | 104  | 97  | 123 | 94  | 94  | 100 | 98  | 124| 82 | 83  | 97  | 96.5   |
| 31-Oct | 95    | 104  | 113 | 136 | 96  | 93  | 90  | 90  | 108| 98 | 100 | 85  | 95.0   |
| 28-Nov | 100   | 105  | 107 | -   | 99  | 113 | 96  | 93  | 123| 92 | 97  | 90  | 100.4  |
| 2-Dec  | 96    | 104  | 105 | 126 | 97  | 92  | 95  | 100 | 113| 88 | 90  | 91  | 95.8   |
| 23-Dec | 98    | 107  | 108 | 130 | 98  | 98  | 106 | -   | 104| 90 | 95  | 94  | 97.9   |

reports indicated particulate (PM10) concentrations above the Grade III standard (250 µg m⁻³) on 330 days from 2000 to 2007 and (TSP, Grade III standard 500 µg m⁻³) 15 weeks between 1998 and 2000. NOₓ concentrations were above the Grade III daily standard (150 µg m⁻³) during 16 weeks between 1998 and 2000.

A decrease of 60.8% in annual average SO₂ concentration has been reported between 1998 and 2007. However, SO₂ concentrations in 1995–1996 were actually lower than 1998, 1999, 2000, 2001, 2002 and 2003 [56], and the 2004 SEPA State of the Environment report incorrectly stated that 2004 was the first time in the 1984–2004 period that SO₂ met
Figure 3. Two measures of air quality 2001–2007. Annual number of ‘Blue Sky’ days (indicated with bars and blue numbers) and annual average PM$_{10}$ concentrations (indicated with triangles and red numbers). Impact of 2006 change in monitoring station locations indicated with hatching on bar and dashed red line. Fewer ‘Blue Sky’ days and higher annual PM$_{10}$ concentrations are calculated values using the original (1984–2005) monitoring station locations.

Figure 4. # Days exceeding the Grade III Standard 2001–2007. Annual number of days exceeding the Grade III standard indicating severe air quality. Impact of 2006 change in monitoring station locations indicated with hatching on bar. More days are calculated to have exceeded the Grade III standard in both 2006 and 2007 using the original (1984–2005) monitoring station locations.

the Chinese national standard (60 $\mu$g m$^{-3}$) [57]. The 2007 annual average SO$_2$ concentration (53 $\mu$g m$^{-3}$) represents a decrease of 8.6% from 1996 levels (58 $\mu$g m$^{-3}$). Although the reductions in annual average SO$_2$ concentrations from 1998 levels are significant, as mentioned previously, SO$_2$ has seldom been reported as the primary pollutant, and as a result, has had little impact on the annual number of ‘Blue Sky’ days during the 1998–2007 period.

5. Discussion

This study examined the sensitivity of Beijing’s air quality metrics by comparing air quality for 2006–2007 to previous years by correcting for the change in monitoring station locations. Three measures of air quality were used to examine trends from 2001 to 2007, including: the annual number of ‘Blue Sky’ days, annual average PM$_{10}$ concentrations, and the annual number of days exceeding the Grade III standard. Although the most ‘Blue Sky’ days is found to have occurred in 2005, the lowest annual average PM$_{10}$ concentrations and the fewest number of days exceeding the Grade III standards occurred in 2003. This illustrates that the metric used for evaluating air quality is very significant, as there can be conflicting trends based on different metrics [68].

In my analysis I calculate the impact of the 2006 monitoring station changes on the reported number of annual ‘Blue Sky’ days and both daily and annual PM$_{10}$ concentrations; however, due to lack of data, I was unable to
calculate the impact on other pollutants. The officially reported annual average NO\textsubscript{2} concentration was 74 \(\mu\text{g m}^{-3}\) in 1998 and 66 \(\mu\text{g m}^{-3}\) in 2006 and 2007, using the new monitoring station locations, an improvement of 10.8\% [1, 4]. In 1998, the two stations monitoring transportation areas had annual NO\textsubscript{2} concentrations 100\% higher than the average of the other 5 stations [1]. Given the growth in the number of vehicles, NO\textsubscript{2}/NO\textsubscript{x} concentrations in traffic areas have likely continued to increase [53, 54]. Although street-level monitoring of NO\textsubscript{2} is not a suitable proxy for NO\textsubscript{x}, annual average NO\textsubscript{2} concentrations have been found to depend on the distance of measurement from main roads [25]. The monitoring station at Qianmen, one of the two removed traffic stations, was located adjacent to the sidewalk within 10 m of a main roadway. Resultantly, reported annual average NO\textsubscript{2} concentrations for Beijing in 2006 and 2007 measured without the two monitoring station locations in traffic areas are likely lower than they would have been if these stations had been included.

The 2005 automated methods for air quality monitoring which specified that monitoring stations in traffic areas not be used to measure urban air quality will likely lead to better harmonization of air quality data across China, although it complicates inter-year comparisons for Beijing [24]. In Europe, under the obligations of the European Union Framework Directive on air quality, public information on air quality is provided, separately, for roadside and background monitoring stations allowing for comparisons across Europe [58]. Within the Asian air pollution research network (AIRPET) efforts have also been made to compare air quality in major Asian cities using traffic, upwind, commercial, mixed, residential, industrial and commercial sites [59]. With vehicular emissions as a growing cause of air pollution in China, an understanding of air quality trends in these areas is especially important.

During 2006 and 2007, reporting continued for the two monitoring stations in transportation areas of Beijing, although they were no longer used to calculate the city air quality. However, on January 1, 2008 these two stations were de-listed and reporting stopped, preventing public access to air quality information for transportation areas and further complicating future analysis of trends in Beijing air quality [60].

More research needs to be done on the reported trends in air quality during the 1998–2002 periods, and the 2000 revisions to the Chinese national ambient air quality standard. Annual average pollution concentrations and the annual number of days meeting the national standard are two different measures of air quality. Although the annual average concentrations of nitrogen dioxide and particulate did not decrease between 1998 and 2002, some of the reported increase in ‘Blue Sky’ days may be attributable to a decrease in the seasonal variability of pollution. As the primary source of air pollution has shifted from coal burning for heating to pollution from transportation, it is possible that annual average concentrations might not improve, while the number of days meeting the standard increases, due to less seasonal variation in vehicular emissions.

However, the impacts of the 2000 revision of the air quality standards on reported city air quality should not be understated. For example, in 1998, the annual average NO\textsubscript{2} concentration in Beijing was 151 \(\mu\text{g m}^{-3}\)—over three times the Chinese annual average NO\textsubscript{2} standard of 50 \(\mu\text{g m}^{-3}\), and the annual average NO\textsubscript{2} concentration was 74 \(\mu\text{g m}^{-3}\)—nearly twice the 1996 Chinese national ambient air quality standard [17, 61]. However, based on the 2000 revisions when the annual average standard for NO\textsubscript{2} was raised to 80 \(\mu\text{g m}^{-3}\) [45] the 1998 annual average NO\textsubscript{2} concentration was in accordance with national standards. Since the revision of standards, NO\textsubscript{2} concentrations in Beijing have never been above the national standard, but that does not necessarily indicate that the atmospheric concentrations of NO\textsubscript{2} or NO\textsubscript{x} have decreased.

Although many countries, including the United States and the United Kingdom, evaluate and publicly report the number of non-attainment days based on data from individual monitoring stations, China only widely reports averaged air quality statistics [1, 3, 62–65]. In 2007, 246 ‘Blue Sky’ days were reported for the city of Beijing using an average of air quality at eight monitoring stations in urban areas of the city, but there were only 100 days when all 27 monitoring stations in Beijing municipality reported an Air Pollution Index of 100 or less. On 265 days in 2007 air quality at least one of the monitoring stations indicated levels of air pollution above the Chinese national ambient air quality standards [4]. In 1998, 100 ‘Blue Sky’ days were reported for the city of Beijing using an average of air quality from seven monitoring stations [5]. However, these two numbers, 100 ‘Blue Sky’ days in 1998 and 100 days in 2007 when all monitoring stations reported air quality meeting the national standard, represent two different methods for evaluating the city air quality and highlight the high degree of sensitivity of these air quality metrics.

It has been widely reported that the number of ‘Blue Sky’ days in Beijing increased from 100 in 1998 to 246 in 2007, but these reported trends encompass a period during which
air quality was evaluated in three different ways: (1) 1998–1999, based on the 1996 Chinese national ambient air quality standards (2) 2000–2005, based on the 2000 revisions of the Chinese national ambient air quality standards and using the 1984–2005 monitoring station locations (3) 2006–2007, based on the 2000 revisions of the Chinese national ambient air quality standard and using the 2006–2007 monitoring station locations.

6. Conclusions

Publicly reported air quality trends in Beijing during the period 1998 to 2007 are found to be highly sensitive to monitoring and reporting data. In 2007, 246 ‘Blue Sky’ days were reported. However, if station locations had not changed, the number of ‘Blue Sky’ days and annual PM10 concentrations in 2007 would have been near 2002 levels (191 days and ~161 µg m⁻³ calculated for 2007; 203 days and 166 µg m⁻³ reported in 2002). The policy of declaring values near the ‘Blue Sky’ boundary as achieving ‘Blue Sky’ status, and the removal of two monitoring stations in traffic areas has resulted in the reporting of 38 additional ‘Blue Sky’ days in 2006, and 55 additional ‘Blue Sky’ days in 2007.

Furthermore, the change in monitoring standards and the lack of improvements in annual pollutant concentrations between 1998 and 2002 raises questions as to the impact of the 2000 revisions of the national air quality standards on reported improvements during this period. The location of monitoring stations and the air quality standards of the respective time periods need to be taken into consideration when analyzing reported improvements in annual average pollutant concentrations and the annual number of ‘Blue Sky’ days for Beijing.

Although nine continuous years of air quality improvement has been reported in Beijing between 1998 and 2007, my analysis finds that these improvements, as indicated by the annual number of ‘Blue Sky’ days, are due to irregularities in the monitoring and reporting of air quality and not to less polluted air. Reported variations in air quality that occur as a result of changes in monitoring station locations or air quality standards, should be considered as inconsistencies in the metrics and not as actual changes in air quality.

Acknowledgments

I thank the many scientists and scholars who have reviewed and discussed this work, but wish to remain anonymous. I also thank P Andrews and D Graef for their discussion of results and multiple readings of the manuscript. Princeton in Asia, an independent non-profit, affiliated with Princeton University provided funding for this research. I have no competing financial interests.

References

[1] Beijing Environmental Protection Bureau (BJEPB) 1998 Annual Environmental Statement (Chinese) http://www.bjepb.gov.cn/bjhb/Portals/0/Skins/index/tabid/66/Default.aspx
[2] State Environmental Protection Administration (SEPA) 2000 Beijing Air Quality Weekly Reports (1998–2000) http://www.envir.online.sh.cn/eng/Airep/cityair.asp
[3] Chinese State Environmental Protection Administration 1998 State of the Environment http://www.zhb.gov.cn/english/SOE/socchina1998/urban/urbanb.htm
[4] Beijing Environmental Protection Bureau (BJEPB) 2008 Daily Air Quality Reports (2003–2007) (Chinese) www.bjepb.gov.cn
[5] United Nations Environment Programme (UNEP) 2007 Beijing 2008 Olympic Games. An Environmental Review http://www.unep.org/sport.cn/Activities/beijingConf07/media/p 163
[6] He K, Hua H and Zhang Q 2002 Urban air pollution in China: current status, characteristics, and progress Annu. Rev. Energy Environ. 27 397–411
[7] Streets D G et al 2007 Air quality during the 2008 Beijing Olympic games Atmos. Environ. 41 480–92
[8] Beyer S 2006 Green olympics movement: Beijing 2008 Chin. J. Int. Law 5 423–40
[9] World Bank 1998 World development indicators 1998 http://econ.worldbank.org/external/default/main?pagePK=64165259&theSitePK=64165372&menuPK=64165421&menuPK=64166903&entityID=00009265_3980624090709 volume 1
[10] Yi H et al 2007 Atmospheric environmental protection in China: current status, developmental trend and research emphasis Energy Policy 35 907–15
[11] Hao J and Wang L 2005 Improving urban air quality in China: Beijing case study J. Air Waste Manag. Assoc. 55 1298–305 http://secure.awma.org/journal/Abstract.aspx?id=1450
[12] Hao J et al 2006 Air quality impacts of power plant emissions in Beijing Environ. Pollut. 147 401–8
[13] Liu J and Diamond J 2005 China’s environment in a changing world Nature 437 1179–86
[14] Beijing Organizing Committee for the Olympic Games (BOCOG) 2006 Beijing Blue Sky Target Achieved Early (Chinese) www.beijing2008.cn/56/42/lantian.shtml
[15] Xinhua 2008 ‘Beijing narrowly attains ‘Blue Sky’ goal’ http://www.chinadaily.com.cn/china/2008-01/01/content6362566.htm
[16] Yardley J 2007 ‘Beijing’s Olympic quest: turn smoggy sky blue’ New York Times A1 http://www.nytimes.com/2007/12/29/world/asia/29china.html
[17] Beijing Environmental Protection Bureau (BJEPB) 2002 Annual Environmental Statement (Chinese) http://www.bjepb.gov.cn/bjhb/Portals/0/Skins/index/tabid/66/Default.aspx
[18] State Environmental Protection Administration 2006 China Environmental Statistical Yearbook http://english.sepa.gov.cn/standards/reports/EnvironmentalStatistics/yearbook2006/2007/12/20071218_151208.htm
[19] Cities that use the ‘Blue Sky’ designation include Chengdu, Tianjin, Shanghai, Nanjing, and Guangzhou. Selected references include: China Environment News 2007 ‘Chengdu Completes its Annual Blue Sky Target Chongqing Environmental Protection Bureau http://www.cepb.gov.cn/HJYW/13926.htm
People’s Daily 2001 ‘Blue Sky Project’ Launched in Tianjin http://english.people.com.cn/english/20010215/eng20010215_63791.html
Shanghai Daily 2006 Shanghai: Blue Skiesusher in Cleaner Air Chinese Government’s Official Web Portal http://english.gov.cn/2006-08/09/content_258087.htm
Sina 2007 Nanjing’s air quality best on record last year (Chinese) http://city.finance.sina.com.cn/city/2007-01-04/80347.html
Invest Guangzhou 2007 Sulfur Dioxide Reduced for Better Air Quality Guangzhou City Government http://www.investguangzhou.gov.cn/upload/resource/govContent/
contact.htm?contentId=3824

[20] China State Environmental Protection Administration (SEPA) 1996 Ambient Air Quality Standard (Chinese) http://www.zhb.gov.cn/english/channel-5/GB3095-1996.doc

[21] Chinese State Environmental Protection Administration (SEPA) 2007 China struggling to control urban air pollution China Daily http://english.zhb.gov.cn/cwzx/hjyw/200706/20070612_1_05064.htm

[22] State Environmental Protection Administration (SEPA) 2007 Chinese cities Environment Management and Policy 2006 Annual Report p 66 (Chinese) www.sepa.gov.cn/info/gw/huanban/200706/W20070621296991445559.pdf

[23a] Beijing Environmental Protection Bureau (BJEPB) 2006 Annual Environmental Statement (Chinese) http://www.bjepb.gov.cn/bjhb/Pages/0/Skins/index/tabid/66/Default.aspx

[23b] Beijing Environmental Protection Bureau (BJEPB) 2005 Annual Environmental Statement (Chinese) http://www.bjepb.gov.cn/bjhb/tabid/66/InfoId/7622/rid/375/Default.aspx

[24] World Health Organization WHO 2006 Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide Global update 2005 Summary of Risk Assessment p 22 http://www.who.int/phe/health-topics/outdoorair/aqg/index.html

[25] World Health Organization 2005 Air Quality Guidelines Update p 494 http://www.who.int/phe/health-topics/outdoorair/aqg/en/index.html

[26] Song Y, Miao W, Liu B, Dai W and Cui X 2008 Identifying anthropogenic and natural influences on extreme pollution of respirable suspended particulates in Beijing using backward trajectory analysis J. Hazard. Mater. 154 459–68

[27] Xie S, Liu Z, Chen T and Hua L 2008 Spatiotemporal variations of ambient PM10 source contributions in Beijing in 2004 using positive matrix factorization Atmos. Chem. Phys. Discuss. 8 569–99 http://www.atmos-chem-phys-discuss.net/8/569/2008/acpd-8-569-2008.html

[28] Zhang M, Son Y and Cui X 2007 A health assessment based of particulate air pollution in urban areas of Beijing in 2000–2004 Sci. Total Environ. 376 100–8

[29] State Environmental Protection Administration 2000 Technological Rules Concerned ‘Ambient Air Quality Daily Report’ Chinese National Environmental Monitoring Center http://www.zhb.gov.cn/environment/airqualityinfo.htm

[30] Tong W and Liao Y J 1999 Beijing Air Pollution. Urban Environmental Disaster Prevention and Reduction vol 1 p 1 (Chinese) http://www.wangfandata.com.cn/qikan/periodicals/Articles/cdjdja/czd99/czf9901/czf990104.htm

[31] Sun H J and Hu Y F 2000 Beijing Transportation Environment and Research Beijing Environmental Monitoring Center #82 (Chinese) http://210.76.125.39/rxk/harvest/article/lwd82.htm

[32] Beijing Environmental Protection Bureau 2004 Beijing Environmental News Number 29 (Cumulative Number 1023) (Chinese) http://www.bjepb.gov.cn/bjhb/tabid/68/InfoId/7904/rid/282/Default.aspx

[33] Cheng S, Chen D, Li J, Wang H and Guo X 2007 The assessment of emission-source contributions to air quality by using a coupled MM5-ARPS-CMAQ modelling system: A case study in the Beijing metropolitan region, China Environ. Modelling Softw. 22 1601–16

[34] Environmental Protection Bureau of Chaoyang District, Beijing 2006 Weekly Air Quality Reports (Chinese) http://hb.bjepb.gov.cn/Channel/9419

[35] State Environmental Protection Administration 2005 Automated Methods for Ambient Air Quality Monitoring (HJT 193-2005) 2006-01-01 Implemented) http://www.sepa.gov.cn/tech/hjzb/bzwb/dqghjb/jccgff/bz/200601/t20060101_21675.htm

[36] China National Environmental Monitoring Center 2006 National List of Monitoring Stations in 113 Major Cities www.cnemc.cn (Chinese) (Last accessed March 1, 2008)

[37] Xinhua 2006 Beijing Drivers Launch Campaign to Improve Air Quality Beijing Organizing Committee for the Olympic games http://en.beijing2008.cn/23/07/article212020723.shtml Motor vehicle emissions is the leading cause of Beijing’s air pollution’ (deputy director of Beijing Municipal Environmental Protection Bureau)

[38] Editorial 2006 Finding Drivers for Change in China Nature 441 549–50

[39] Xu X, Wang L and Niu T 1998 Air pollution and its health effects in Beijing Ecosyst. Health 4 4

[40] United States Embassy Beijing Environment, Science, Technology & Health Section 1998 P.R.C. Air pollution: How bad is it? http://beijing.usembassy-china.org.cn/report8698air.html

[41] Economy E and Lieberthal K 2007 Scorched Earth: Will Environmental Risks in China Overwhelm Its Opportunities? Harvard Business Review http://harvardbusinessonline.hbsp.harvard.edu/hbsp/hbr/articles/article.jsp?articleID=17700&xmlAction=getArticle&print=true

[42] Cheng S et al 2007 The assessment of emission-source contributions to air quality by using a coupled MM5-ARPS-CMAQ modelling system: A case study in the Beijing metropolitan region, China Environ. Modell. Software 1–16 http://portal.acm.org/citation.cfm?id=1274218

[43] National Renewable Energy Laboratory; Department of Environmental Science, Tsinghua University; School of Public Health, Peking University & School of Public Health, Yale University 2005 Energy Options and Health Benefit Beijing Case Study. U.S. Environmental Protection Agency p 132 www.epa.gov/ies/documents/beijing/Final%20Report_BJ_web.pdf

[44] State Environmental Protection Agency, World Bank 2007 Cost of Pollution in China: Economic Estimates of Physical Damages http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/EXTEAPPROTOPENVIRONMENT/0,,contentMDK:21252897~pagePK:34004173~piPK:34003707~theSitePK:502886,00.html 151 p

[45] State Environmental Protection Administration and National Bureau of Statistics 2006 ‘China Green National Accounting Study Report’ http://www.gov.cn/english/2006–09/11/content_384596.htm

[46] Beijing Municipal Government 2004 Air pollution control plan 10 (Chinese) http://www.bjepb.gov.cn/bjhb/tabid/151/Default.aspx

[47] State Environmental Protection Administration 2000 Chinese National Ambient Air Quality Standards. 2000 Revision of 1996 standards (Chinese) http://www.mhepb.gov.cn/showinfo1.aspx?Infoid=915&clickTimes=1222&isSingleInfo=False&categoryName=%E7%8E%AF%E4%BF%9D%E6%A0%87%E5%87%86

[48] Jiang D, Zhang Y, Hu X, Zeng Y, Tan J and Shao D 2004 Progress in developing an ANN model for forecasting Atmos. Environ. 38 1055–64

[49] Wang S, Yuan W and Shang K 2006 The impacts of different kinds of dust events on PM10 pollution in northern China Atmos. Environ. 40 7975–82

[50] Wang X, Mauzerall D L, Hu Y, Russell A G, Larson E D, Woo J, Streets D G and Guenther A 2005 A high-resolution backward trajectory analysis of anthropogenic and natural influences on extreme pollution in northern China Geophys. Res. Lett. 32 04701

[51] United States Environmental Protection Agency 2006 Guidelines for Reporting of Daily Air Quality–air quality index (AQI) p 31 http://www.epa.gov/ttn/caaa1/111/Download/rtg701.pdf

[52] China National Environmental Monitoring Center 2003 China Air Quality Monitoring Situation and Developments (Chinese) www.chinaemc.gov.cn/jyxp/zrzy_air_44
[53] State Environmental Protection Administration 2007 Daily Air Quality Report August 20 2008 www.sepa.gov.cn
Beijing Environmental Protection Bureau 2007 Daily Air Quality Report August 20, 2008 www.bjepb.gov.cn
Note that data for this day has now been removed from the SEPA website. This irregularity was also described in the popular press.
Fan M 2007 Beijing’s Pollution Rises in 4-Day Test of Restricted Driving Washington Post http://www.washingtonpost.com/wp-dyn/content/article/2007/08/20/AR2007082002011.html

[54] State Environmental Protection Administration 2003 Advances in Environmental Protection in Beijing http://www.sepa.gov.cn/cont/dq/fzgz/qt/200302/t20030212_84368.htm

[55] Richter A, Burrows J, Hu N, Granier C and Niemeier U 2005 Increase in troposphere nitrogen dioxide over China observed from space Nature 437 129–32

[56] Akimoto H, Ohara T, Kurokawa K and Korii N 2006 Verification of energy consumption in China during 1996–2003 by using satellite observational data Atmos. Environ. 40 7663–7

[57] Chang G Q and Fan X C 2003 Analysis on the surveillance of the characteristics and trends of air pollution in Beijing Jiangsu Prev. Med. 14 3 (Chinese) http://scholar.lib.cn/A-jsyfyx200303029.html

[58] Beijing Environmental Protection Bureau 1996 State of the Environment (Chinese) http://english.sepa.gov.cn/SOE/soechina2004/air.htm

[59] State Environmental Protection Administration 2004 State of the Environment http://english.sepa.gov.cn/soe/soechina2004/air.htm

[60] Common Information to European Air (CITEAIR) 2007 www.airqualitynow.eu/about/home.php

[61] Oanh N T et al 2006 Particulate air pollution in six Asian cities: spatial and temporal distributions, and associated sources Atmos. Environ. 40 3367–80

[62] Beijing Environmental Protection Bureau 2008 Daily Air Quality Report for January 1st, 2008 http://www.bjepb.gov.cn/air2008/Air.aspx?time=2008-1-1

[63] Chinese Ministry of Statistics 1999 Annual average concentration of nitrogen oxide in major cities China Statistical Yearbook www.stats.gov.cn/tjsj/qtsj/hjtsj/hjtsj1999/20031230_402371720.htm

[64] United Kingdom Department for Environment, Food & Rural Affairs 2008 UK Air Quality Archive http://www.airquality.co.uk/archive/data_and_statistics/home.php

[65] United States Government Website 2008 AIRNOW http://airnow.gov

[66] Environmental Protection Agency 2003 Draft Report on the Environment 2003 Washington, DC http://www.epa.gov/roe/roe/pdf/epa_draft_roe.pdf p 167

[67] South Coast Air Quality Management District 2008 Air Quality 2007 http://www.aqmd.gov/smog/AQSCR2007/aq07card.pdf

[68] Bell M L, Hobbs B F and Ellis Hugh 2005 Metrics matter: conflicting air quality rankings from different indices of air pollution J. Air Waste Manag. Assoc. 55 97–106