The Impact of Vehicle Exhaust on PM2.5 Concentration in Cities in Northeast China

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Abstract. There has been considerable research in recent years on the contribution rate of vehicle motor exhaust to PM2.5 concentration (VCR-PM2.5). Nearly all of this research applied source appointment methods, which are highly complex and only can be executed by professionals. Based on analysis of hourly observations of PM2.5, SO$_4^{2-}$, and NO$_3^-$ concentration and modeled hourly planet boundary layer height in Shenyang, a megacity in Northeast China, a simple statistical method was established to calculate the VCR-PM2.5. Based on this method, the average VCR-PM2.5 in winter 2015 of cities in Liaoning province was estimated, and the average VCR-PM2.5 of all these cities is about 23.29%. The result of this new method is a conservative estimation, the actual VCR-PM2.5 is likely to be slightly larger. This method is based on primary observation data and fundamental physical theory, and may thus be used to verify the results from source appointment or other methods.

1.Introduction
Particulate matter in the air, especially inhalable particles of 2.5 µm or less (PM2.5), is harmful to human health and it even affects weather and climate process by reducing visibility, causing acid rain events, and contributing to global warming (Zhang et al., 1995; Ramanathan et al., 2002; Wu et al. 2012). Therefore, understanding PM2.5 sources is of great importance in air pollution control and human health protection. In recent years, domestic and international scholars studying the source of PM2.5 emissions have reached the common conclusion that motor vehicle emissions are one of the most important PM2.5 sources (Wang et al., 2006; Wang et al., 2012; Yu et al., 2013). The motor vehicle emissions can be controlled relatively easier by scientific mechanisms. For example, vehicle motors with a certain kind of registration number were prohibited running on the road on a certain day of a week and a part of persons were forced to use public transport, etc. Therefore, the contribution rate of vehicle motor exhaust to PM2.5 concentration (VCR-PM2.5) is becoming a major research focus.

Currently, the main research method to obtain the VCR-PM2.5 is source appointment. There are three mature and widely used source appointment techniques. The first is the chemical mass balance receptor model (Maykut et al., 2003; Zheng et al., 2005), in which it is assumed that the total concentration of a particular species of the receptor is the linear combination of the individual contributions of different sources. This type of model typically uses the least-squares regression analysis of aerosol chemical composition to determine the most appropriate combination of source apportionment (Chen et al., 2001). This method is based on several hypotheses (e.g. there is no interaction among the particulates exhausted from every kind of source (Chen, 2011)) and a regression diagnosis technique is needed to verify and test the source appointment result (Zhang, 2014).
second technique is absolute principal component analysis (APCA) (de Fatima Andrade et al., 2012). After identifying the main component (Qiu et al. 2012), this approach involves the calculation of the absolute varimax rotated APCA scores, which are used as a measure of the contribution from each source to each aerosol sample (Thurston et al., 1985; Maenhaut et al., 1987; de Fatima Andrade et al., 2012). This method requires a large amount of receptor data as input to the model and the larger the amount of data, the more accurate the obtained result is (Chen, 2011). The third technique is positive matrix factorization (PMF) (Song et al., 2006; Gugamsetty et al., 2012). In this model, the data matrix can be factorized into three matrixes (i.e. source contributions, source profiles, and residual matrix). The main process of PMF is minimizing the Q-value which is defined as the sum of square of the residuals weighted inversely with error estimates of the data point. Two inputs are required to run PMF: the concentration and its uncertainty. In general, though the current methods to estimate VCR-PM2.5 are already relatively mature, the available techniques are complex and can only be executed by professionals.

China is a developing country with increasing economic prosperity. As a result, car ownership in cities is correspondingly growing exponentially. The increased contribution of motor vehicle exhaust to the concentration of inhalable particles represented by PM2.5 has attracted considerable attention. However, the current research on this topic in China has mainly focused on economically developed and densely populated areas such as Beijing and Tianjin, the Yangtze River Delta, and the Pearl River Delta (Li et al., 2017). The northeast of the country is China’s old industrial base, the urban population density is large, the motor vehicle parc is continuously increasing, and the pollution caused by motor vehicles and industries is serious. For example, Shenyang is the capital of Liaoning province with a population of 8,291,000 and motor vehicle parc of 1,817,273 in 2015. The total averaged annual concentration value of PM2.5 in Shenyang from 2010 to 2012 was 50.7 µg m\(^{-3}\) (Zhao, 2013), which exceeds the annual limit of the National Ambient Air Quality Standard (15.0 µg m\(^{-3}\)) for PM2.5 (USEPA, 1997). Therefore, air pollution research and control has become a pressing issue in Northeast China, and it is extremely urgent to study the source of PM2.5 particles, especially the percentage from motor vehicles, which is one of the main PM2.5 sources and could be controlled relatively easily. However, to our knowledge, there is no relevant research in northeast China to date.

Weather condition is one of the most important external factors affecting the air quality (Yang et al., 2011; Wang et al., 2014). The planetary boundary layer (PBL), as the lowest layer of the troposphere, is directly affected by the ground and fully mixed, and the polluting particles are trapped within the PBL (Stull, 1988). Therefore, the PBL plays an important role in the storage and distribution of pollution particles, and is one of the main meteorological factors affecting the air diffusion. Studies have widely shown that PBL height (PBLH) is anti-correlated with PM mass concentration or air quality index (Ye et al., 2008; Yang et al., 2011; Guo et al., 2011; Du et al., 2013). In this article, using PBLH as a basis, we examined the VCR-PM2.5 in Shenyang, Northeast China, with the aim of providing a new and more convenient method to obtain the VCR-PM2.5. We then applied the method to other cities in Liaoning Province in Northeast China. The new method of getting VCR-PM2.5 is so simple and convenient that it affords a tool for common researchers in any field to know the VCR-PM2.5 of one area to assist relative research, since data is more and more open and shared.

2. Data

2.1 PM2.5 Observation Data

The PM2.5 concentration data were collected at Wenhua Road in Shenyang in the winters of 2007–2012 with a GRIMM180 Dust Monitor (Table 1) manufactured by GRIMM Aerosol Company in Germany. This instrument was installed on the roof of the former Northeast Regional Meteorological Center (123.50°E, 41.77°N, 60 m above street level). The performance indicators of the instrument are shown in Table 1 (Zhao et al., 2013). The former Northeast Regional Meteorological Center building was demolished in 2013 and the PM2.5 observation was interrupted. Subsequently, we obtained the PM2.5 concentration data from the Environmental Protection Bureau of Liaoning Province (LNEPB),
so the PM2.5 concentration data including Wenhua Road and all the other sites after 2013 in this paper were from LNEPB. The LNEPB established a total of seven environmental observation sites in Shenyang (Taiyuan Street, Wenhua Road, Dongling Road, Hunnan East Road, Xinxiu Street, Senlin Road, and Lingdong Street), as shown in Figure 1. In addition, two to seven sites were established in each other city of Liaoning province, and the PM2.5 concentrations were measured at these sites with a SHARP5030 Particle Synchronous Mixing Monitor manufactured by Thermo Scientific Inc., MA, USA.

Figure 1 Location map of environmental monitoring stations of LNEPB, China
(Seven stations in Shenyang (SY), they are Taiyuan Street (TYS), Wenhua Road (WHR), Hunnan East Road (HNER), Lingdong Street (LDS), Dongling Road (DLR), Xinxiu Street (XXS), and Senlin Road (SLR).

The other stations are Dalian (DL), Anshan (AS), Fushun (FS), Benxi (BX), Dandong (DD), Jinzhou (JZ), Yingkou (YK), Fuxin (FX), Liaoyang (LY), Panjin (PJ), Tieiling (TL), Chaoyang (CY), and Huludao (HLD))

2.2 PBLH Data
The PBLH is typically measured by field test. Because there are many scales and changes of PBLH in the vertical direction, it needs several instruments for its accurate detection, including airborne observation platforms and remote sensing. The huge cost limits the size of many field tests and thus methods of numerical or laboratory simulations are frequently adopted to cover a wider spatial area or temporal range (Stull, 1988). We used PBLH data from the 12–36 hour forecasts of the Weather Research and Forecasting (WRF) v.3.5.1 model in this study.

The WRF v.3.5.1 model is designed two nested layers. The resolutions of the first and second nested layers were 9 and 3 km, respectively. The first nested layer covered most parts of China, and the second nested layer included Northeast China and the eastern part of North China. The physical process and parameter schemes selection are shown in Table 1.

| Physical process          | Scheme | Reference       | Added |
|---------------------------|--------|-----------------|-------|
| mp_physics (microphysical process) | WSM6   | Hong et al., 2006 | 2004  |
| ra lw_physics (long wave radiation) | RRTM   | Mlawer et al., 1997 | 2000  |
| ra_sw_physics (short wave radiation) | Dudhia | Dudhia, 1989 | 2000  |
| bl_pbl_physics (boundary layer process) | YSU    | Hong et al., 2006 | 2004  |
| cu_physics (cumulus parameter) | Kain-Fritsch | Kain, 2004 | 2000  |
Based on routine meteorological observations, we used two PBLH calculation methods to verify the correction of simulated PBLH from the WRF model. The first was the Nozaki (1973) method, which relies on surface observations to estimate PBLH and is useful for estimation of the detailed PBLH diurnal cycle (Du, 2013). The second method followed Liu et al. (2010), starting with the classification of the PBL into convective boundary level, stable boundary level, and neutral residual level. The PBLH is then obtained based on the vertical distribution of observational potential temperature and water vapor mixing ratio.

The formula of the Nozaki (1973) method is as follows:

\[
PBLH = 1216 \times (6 - P) \times (T - T_d) + 0.169 \times P(u_z + 0.257)/(12 \times f \times \ln(z/z_0)),
\]

where \(P\) is the Pascal stability level (GBT 3840-1991), \(T\) is the surface temperature (°C), \(T_d\) is the dew point temperature (°C), \(u_z\) (m/s) is the average wind speed at height \(z\) (10 m in this paper), \(z_0\) is the terrain roughness (1 m in this paper, Cheng et al., 1997), and \(f\) is the Coriolis parameter.

Because the sounding data required for the Liu et al. method were only available twice each day (at local time 08:00 and 20:00), there were only two PBLH values available for this method each day. The daily change of the average PBLH from the Nozaki method, Liu et al. method, and the WRF model simulation in November 2015 are shown in Figure 2. In general, the PBLH simulated by the WRF v.3.5.1 model was close to that calculated by the Liu et al. method, and they were both about 400 m lower than that of the Nozaki method, which is consistent with previous literature (Du, 2013, Du, 2014). The simulated average PBLH diurnal variation from the WRF model was in line with Nozaki method result.

![Figure 2](image.png)

Figure 2 The diurnal variation of the average PBLH in November 2015 in Shenyang from the Nozaki method and WRF model simulation. Dots indicate the Liu et al. results.

### 2.3 Soluble Ion Concentration Data

The ions SO\(_4^{2-}\) and NO\(_3^-\) are important soluble components of PM2.5 particles. Their main source is typically coal burning and motor vehicle exhaust, respectively (Bur, 2004, Parrish, 2006, Kassomenos, 2009, Pei, 2016). Therefore, the variation of SO\(_4^{2-}\) (or NO\(_3^-\)) content in the PM2.5 particles is used to reflect the amount change of coal burning (or vehicle activity) in this study.

The soluble ion concentration data in PM2.5 were measured at the Shenyang atmospheric composition station (123.47°E, 41.73°N), which was on the roof of the main building in the southwest of Shenyang, 130 m above sea level. This station is located downwind of Shenyang’s prevailing wind. There were no major industrial pollution sources nearby except for the building and road dust. The water-soluble ionic components were measured using a MARGA Ion On-Line Analyzer ADI 2080 (Metrohm AG, Switzerland). This instrument uses a unique sampling device to directly absorb the particles into the aqueous phase, and then applies ion chromatography to monitor the composition. The time resolution was 1 h. The detection components included Cl\(^-\), NO\(_3^-\), SO\(_4^{2-}\), NH\(_4^+\), Na\(^+\), K\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\) for which the minimum detection limits were 0.01, 0.05, 0.04, 0.05, 0.05, 0.09, 0.10, and
0.06 μg/m³, respectively. The hourly SO₄²⁻ and NO₃⁻ concentration data from November 2015 to March 2016 were used in this study.

2.4 Shenyang Motor Vehicle Parc and Permanent Population Data
In addition, the Shenyang motor vehicle parc and permanent population data from 2000 to 2015 were taken from the Shenyang Statistical Information Network (http://www.sysinet.gov.cn/index.aspx). This website is used to release the information about population, agriculture, industry, transport, construction, and other related businesses by Shenyang Municipal Bureau of Statistics (SMBS). The data were obtained from the statistical results provided by SMBS.

3. Results and Discussion

3.1 Annual Variation of Shenyang Motor Vehicle Parc and the Permanent Population
The annual changes of the number of motor vehicle parc and the permanent population in Shenyang from 2000 to 2015 are presented in Figure 3. Both the Shenyang permanent population and car ownership have increased over time. After 2010, the rate of increase in the vehicle parc was considerably higher than the rate of increase of the permanent population. Shenyang vehicle parc increased by 200,000 between 2013 and 2014, while the permanent population increased by only 29,000. In short, Shenyang vehicle ownership has recently shown an exceptional rate of growth. This implies a substantial increase of the vehicle exhaust and VCR-PM2.5 in Shenyang from 2010.

3.2 Comparative Analysis of the Monthly Average Daily Variation Curve of PBLH and PM2.5 Concentration
The two monitoring stations of LNSEP at Taiyuan Street and Wenhua Road in Shenyang (Figure 1) are within Shenyang's commercial and cultural center. Population and traffic are relatively dense, so we used these two stations as representative of the seven stations in Shenyang for analysis. As shown in the daily variation of monthly average PBLH in 2015 and 2016 at the two stations (Figure 4, 2015 omitted), the average PBLH in winter (November–March) was lower than in spring (April–May) and fall (September–October), and highest in summer (June–August). The daily variation trend in each month was generally consistent, with a valley at 7:00 and peak at 15:00 local time. The seasonal variation in average PM2.5 concentration was inverse to the PBLH. The PM2.5 concentration was higher in winter than in spring and fall, and lowest in summer. The daily variation of the PM2.5 was consistent for each month, with the peak at 8:00–10:00 and the valley at 12:00–15:00 local time. In addition, in the winter months showed a higher PM2.5 concentration and there was a sub-valley in the early morning (SVEM) of 4:00–7:00 am local time.
As mentioned before, as the lowest level of the troposphere, the PBL is directly affected by the ground and is fully mixed. The polluting particles are trapped in the PBL and thus studies have shown that PBLH is anti-correlated with PM mass concentration or air quality index (Ye et al., 2008, Guo et al., 2011, Yang et al., 2011). In theory, the PBLH is low in early morning, and the diffusible range for the pollutant is small and thus the PM2.5 concentration in this period should be greater. However, we observe a sub-valley in the PM2.5 concentration daily curve in the early morning during winter (Figure 5).

3.3 Establishment of a Newer and More Convenient Method to obtain VCR-PM2.5

3.3.1 Explanation of the SVEM in PM2.5 concentration daily curve

The main components of PM2.5 are carbonaceous materials such as organic and elemental carbon, soluble ions such as SO$_4^{2-}$ and NO$_3^-$, and inorganic elements such as natural dust and metal elements. In China’s northern cities, the carbonaceous material and soluble ions account for more than 70% of the explainable PM2.5 components, and SO$_4^{2-}$ and NO$_3^-$ together account for nearly 36–54% of the PM2.5 composition (Meng et al., 2016). The main source of SO$_4^{2-}$ is coal burning, and that of NO$_3^-$ is motor vehicle exhaust. Coal burning and vehicle exhaust are the two main sources of carbonaceous material of aerosol in China (Streets, 2001, Li, 2004, Cao, 2005).

Figure 5 shows the average daily variation of SO$_4^{2-}$ and NO$_3^-$ in winter of 2015 in Shenyang. The concentration of both soluble ions is determined mainly by the emission source and PBLH. The daily trend of SO$_4^{2-}$ concentration was the peak and valley type. The peak occurred in early morning between 5:00 and 10:00, when the temperature was low, the volume of coal burning for heat was high, and the PBLH was low. The valley occurred between 13:00 and 16:00, when the temperature was high, the volume of coal burning for heat was low, and the PBLH was high. The average daily variation curve of NO$_3^-$ showed one peak that occurred between 8:00 and 11:00, during the morning peak hours. There was no NO$_3^-$ peak in the evening rush hour because the PBLH was higher at this time. Early morning between 4:00 and 7:00 is the peak for the SO$_4^{2-}$ concentration, when the emissions from coal burning were highest, whereas the NO$_3^-$ concentration was low and emissions from motor vehicle activities were low. Therefore, the SVEM of the PM2.5 concentration (Figure 4) was most likely to be caused by the major reduction of motor vehicle activities during this period.
3.3.2 Estimation of the VCR-PM2.5 in Shenyang

In theory, if the PM2.5 concentrations with and without vehicle emissions are known, the VCR-PM2.5 can be calculated. Figure 6 presents the daily variation of the average PBLH and PM2.5 concentrations in winter of 2015 of Taiyuan Street, Senlin Road, and Hunnan East Road stations and the average of all seven stations. Taiyuan Street and Senlin Road stations had the maximum and minimum average PM2.5 concentrations of the studied stations in winter of 2015, respectively (Figure 6). Senlin Road station is located in the Shenyang suburbs with a small population density, therefore, though the PBLH diurnal variation was the same as the other stations, the PM2.5 peak did not occur at 8:00–9:00 in the morning rush hour as at other stations, but in the middle of the night. A sub-valley of PM2.5 concentration due to the considerable reduction of motor vehicle activities in the early morning was observed at all seven stations (Figure 6, other stations omitted). Moreover, as mentioned before, PBLH is anti-correlated with PM2.5 mass concentration. Based on the daily variation curve of the average PBLH, we thus obtained the PM2.5 concentration with the motor vehicle emissions (the hypothetical PM2.5 concentrations, red star dashed line in Figure 6), and the PM2.5 concentrations with low motor vehicle emissions (the observed PM2.5 concentrations, red triangles in Figure 6) at the SVEM.
Figure 6 Daily variation of average observed and hypothetical PM2.5 concentration and PBLH from November 2015 to March 2016. (a) Taiyuan Street Station, (b) Senlin Road Station, (c) Hunnan East Road Station, (d) average of the seven stations

Since the sub-valley or decrease of PM2.5 concentration is caused by the reduction of motor vehicle activities during early morning, and we can obtain the PM2.5 concentration value based on the hypothesis that the vehicle activities did not decrease, the VCR-PM2.5 can be calculated easily. The VCR-PM2.5 was obtained based on the two concentrations by dividing the difference of the hypothetical value and the observed value by the hypothetical value of PM2.5 concentration at the SVEM. The average VCR-PM2.5 in winter of 2015 was 14.38% in Shenyang. The maximum contribution rate was 26.68% at Hunnan East Road station (Table 2).

Although there was a considerable reduction of motor vehicle activities, the activities of transport trucks and other large vehicles increased in the early morning. Furthermore, vehicle exhaust residues from the daytime remained in the air. Therefore, the result of this calculation method is a conservative estimate. The actual VCR-PM2.5 is slightly larger than this result.

Another uncertainty of the result of this method comes from the inaccurate hypothetical PM2.5 concentration curve (red star dashed line in Figure 6). However, the deviation could not be large because the hypothetical PM2.5 concentration value was between the two peak values at the two ends of the sub-valley, and there was small difference between the two peak values.

3.3.3 Rationality Analysis of VCR-PM2.5 Results and Application of the New Method to Estimate VCR-PM2.5 in Other Cities in Liaoning Province

Past VCR-PM2.5 results from source appointment methods were taken from the literature, such as the following: North China, 15% (Karagulian, 2015); Beijing, 17.1%; Nanjing, 14.7%; Hangzhou, 21.06%, Guangzhou, 38.4%. These estimates suggest that the range of values calculated in the current study is appropriate. Therefore, the new method may be considered reasonable and applicable, and was thus used to estimate the VCR-PM2.5 in the other thirteen cities in Liaoning province (Table 2). The VCR-PM2.5 in the other cities in Liaoning province was larger than that of Shenyang. For example, VCR-PM2.5 in Liaoayang was 38.33%, the largest one of Liaoning province.

The above results also showed that although the PM2.5 concentration was large in the megacity center, where sources could be expected to be larger and more diverse, the VCR-PM2.5 was relatively small. In contrast, although the PM2.5 concentration was low in the suburban areas or towns, there were fewer different sources, and the VCR-PM2.5 could be greater than that of larger urban areas.

Table 2 Observed value and hypothetical value of PM2.5 concentration of SVEM, and VCR-PM2.5 at all the stations in Liaoning Province
3.4 The Annual Variation of VCR-PM2.5

Wenhua Road is the cultural center of Shenyang, with high population and transportation density, and a large amount of human activity. Furthermore, the time series of the observed PM2.5 data at Wenhua Road is relatively long (as previously stated, note that two different instruments and site positions were located at this area; GRIMM180 Dust Monitor in 2007–2012 and SHARP5030 Particle Synchronous Mixing Monitor of LNEPB in 2013–2016). Therefore, we analyzed the PM2.5 concentrations at Wenhua Road to examine the annual trend of the PM2.5 concentrations in Shenyang, including the historical process of vehicle exhaust gradually becoming a major contributor to the PM2.5 concentration.

Figure 7 shows the average daily variation of PM25 concentrations in winters from 2007 to 2016. The annual average PM2.5 concentrations in winters from 2007 to 2010 were generally maintained within the range of 30–55 μg/m³, which increased to 45–74 μg/m³ in 2011–2012. It then increased sharply in winter of 2013–2014 (however, the average diurnal curve of 2013 is not shown in Figure 8 because of the incomplete PM2.5 observations in 2013 winter). The average PM2.5 concentration in winter 2014 reached 75–128 μg/m³ and then decreased to 57–87 μg/m³ in 2015 (this decrease might be related to variations in the diffusive tendencies under the different weather conditions between years). The averaged PM2.5 concentrations reached 70–109 μg/m³ in winter of 2016.

In the winters of 2007–2012, the average daily PM2.5 concentration curve had a clear peak and valley shape, with peaks around 9:00 and valleys around 14:00. Since 2014, a clear sub-valley started to appear in the early morning (4:00–7:00). Using the new method, the average VCR-PM2.5 in winter of 2014, 2015 and 2016 is about 9.76%, 7.30%, 12.04%, respectively. This suggests that motor vehicle exhaust has gradually become the major contributor to the PM2.5 concentration of Shenyang since 2014.
Figure 7 Daily variation of the average PM2.5 concentration in winters from 2007 to 2016 at Wenhua Road Station in Shenyang

4. Conclusions
A comparative analysis of daily variation of the average PM2.5, SO$_4^{2-}$, and NO$_3^-$ particle concentration, and PBLH in winter of 2015 was conducted in Shenyang (Data in this period is most completed), and a new method of obtaining VCR-PM2.5 was produced. After comparing results with source apportionment methods for rationality and applicability inspection, we carried out application of the new method to calculate VCR-PM2.5 for other cities of Liaoning province.

A sub-valley was observed in the early morning in the average diurnal variation curve of PM2.5 concentration. Analysis showed that this valley occurred because of the considerable reduction of motor vehicle activities in the early morning. Based on the inverse relationship between the diurnal variation curve of PM2.5 concentration and PBLH, the hypothetical PM2.5 concentration curve was obtained based on the assumption of no reduction of motor vehicle activities in the early morning. The VCR-PM2.5 was obtained by dividing the difference of the hypothetical value and observed value by the hypothetical value of PM2.5 concentration at the SVEM.

Based on this new method, the average VCR-PM2.5 in winter of 2015 of all fourteen cities in Liaoning Province was 23.29%, as shown in Table 2.

The VCR-PM2.5 in Shenyang showed a curved upward trend in winter from 2014 to 2016, which might be related to variations in the diffusive tendencies under the different weather conditions between years.

The method produced in this article has two main limitations. First, in early morning, the activities of transport trucks and other large vehicles increased, and vehicle exhaust residues from the daytime remained in the air. Therefore, the result of this new method is a conservative estimation; the actual VCR-PM2.5 is likely to be slightly larger. Second, the inaccuracy of the hypothetical PM2.5 concentration curve at the SVEM caused another uncertainty, but the deviation could not be large because the hypothetical concentration spanned the gap between the two peak values of the PM2.5 curve and there was small difference in the values of these two peaks.

Despite the drawbacks, there are several major advantages of the new method over source appointment methods. Firstly, only one type of data is needed, i.e. hourly PM2.5 concentration. Secondly, the approach is so convenient and easy to operate that once the averaged diurnal variation curve of PM2.5 concentration for a period of time is calculated, the VCR-PM2.5 can be obtained almost immediately. This means that almost everyone can apply this method if the required data are
available. Finally, since this method is based on primary observational data and fundamental physical theory, it can be used to verify the results from source appointment or other methods.

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