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Comparison of ground based indices (API and AQI) with satellite based aerosol products

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HIGHLIGHTS

- API — Air Quality index prior to January 2013 in China does not true reflect air quality.
- AQI — Current Air Quality index found a better representation of air quality.
- AQI accounted PM2.5 in the calculation of new index.
- AQI compares well with some of MODIS Deep Blue product.

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ABSTRACT

Air quality in mega cities is one of the major concerns due to serious health issues and its indirect impact to the climate. Among mega cities, Beijing city is considered as one of the densely populated cities with extremely poor air quality. The meteorological parameters (wind, surface temperature, air temperature and relative humidity) control the dynamics and dispersion of air pollution. China National Environmental Monitoring Centre (CNEMC) started air pollution index (API) as of 2000 to evaluate air quality, but over the years, it was felt that the air quality is not well represented by API. Recently, the Ministry of Environmental Protection (MEP) of the People's Republic of China (PRC) started using a new index "air quality index (AQI)" from January 2013. We have compared API and AQI with three different MODIS (MODIS - Moderate Resolution Imaging SpectroRadiometer, onboard the Terra/Aqua satellites) AOD (aerosol optical depth) products for ten months, January–October, 2013. The correlation between AQI and Aqua Deep Blue AOD was found to be reasonably good as compared with API, mainly due to inclusion of $PM_{2.5}$ in the calculation of AQI. In addition, for every month, the correlation coefficient between AQI and Aqua Deep Blue AOD was found to be relatively higher in the month of February to May. According to the monthly average distribution of precipitation, temperature, and PM_{10}, the air quality in the months of June–September was better as compared to those in the months of February–May. AQI and Aqua Deep Blue AOD show highly polluted days associated with dust event, representing true air quality of Beijing.

1. Introduction

In most of developing countries due to urbanization and industrialization air pollution is increasing which has serious health impact (Black et al., 1985; Charron and Harrison, 2003; Lu et al., 2002). In China, nitrogen oxides (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), ozone (O_3), carbon dioxide (CO_2) as well as the anthropogenic and biogenic particulate matter ($PM_{2.5}$, PM_{10}) are the major air pollutants.

Beijing is located in a basin area, surrounded by the Taihang Mountain on the south-west and Yan Mountain on the north-west and is the political and cultural center of China. The geographical settings contribute to the serious air pollution in Beijing city (Chen et al., 2009). Large desert areas in the Northern China and Mongolia, are the biggest source of dust storms during spring (March–May) affecting the PM measurements and air quality in East Asia, China, Korea and Japan (Uno et al., 2001; Wang et al., 2008). Summer season

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Table 1
API and health implications (daily targets) (Ministry of Environmental Protection of the People's Republic of China, 2008).

API	Air pollution level	Health implications
0–50	Excellent	No health implications
51–100	Good	No health implications
101–200	Lightly polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.
201–300	Moderately polluted	Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities.
300+	Severely polluted	Healthy people will experience reduced endurance in activities. There may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid outdoor activities.

Table 2
Air pollution sub-index levels and their corresponding air pollutant concentrations (Ministry of Environmental Protection of the People's Republic of China, 2008).

Air pollution sub-index	Air pollutant concentrations (μg/m^3)				
	SO_2 24-h	NO_2 24-h	PM_{10} 24-h	CO 24-h	O_3 8-h
50	50	80	50	5000	120
100	150	120	150	10,000	200
200	800	280	350	60,000	400
300	1600	565	420	90,000	800
400	2100	750	500	120,000	1000
500	2620	940	600	150,000	1200

(June–August) is characterized by relatively hot and humid weather with south-dominant wind. Emissions from numerous heavy industries in Hebei province (south of Beijing) also contribute to the air pollution in Beijing. Autumn (September–November) season is characterized by relatively clear and clean weather. During winter (December–February) season, coal is used for heating purpose that is the biggest source for extremely poor air quality and atmospheric pollution. Due to intense and frequent dust events during the spring season, pollutants from Beijing and surrounding cities are the main sources of air pollution. High aerosol optical depth (AOD) is observed in Beijing which is revealed from the routinely measured data by Beijing Municipal Environmental Monitoring Centre (BMEMC) and high air pollution is clearly observed, which is also reflected from the poor visibility. Daily real-time report of NO_2, CO, SO_2, O_3, $PM_{2.5}$, and PM_{10} to alert people about air quality and harmful atmospheric conditions through TV and radio are used to provide warning to use mask and avoid outdoor exposure.

The most direct and accurate way to obtain information of air pollutants near the ground is from in-situ measurements. The ground measurement is very limited and it is not possible to make continuous measurements due to limited resources. Satellite data are now freely available, and spatial and temporal resolutions of satellite are improving day by day. The satellite data is now being used for monitoring atmospheric pollution and track the dust storms and forest fires (Al-Saadi et al., 2005; Flannigan and Haar, 1986; Gautam et al., 2009; Goloub et al., 2001; Kaskaoutis et al., 2011, 2013; Prasad and Singh, 2007).

Satellite sensors are now capable of monitoring atmospheric aerosol, and meteorological parameters and trace gases globally and also at different pressure levels. All these parameters are available freely with different spatial and temporal resolutions. Space agencies of different countries have launched satellites to monitor atmospheric parameters and atmospheric pollution and day to day weather conditions. Efforts are also being made to validate satellite data with the ground observations (Gautam et al., 2011; Prasad and Singh, 2007) and also to explore the use of satellite data to provide reliable and accurate estimation of air quality parameters.

Efforts were made recently to study relation between API and AOD derived from different satellite data. Li et al. (2011) studied correlation between API and AOD over Zhengzhou city in Henan Province, China and found that MODIS AOD shows a good correlation with API. The distribution of API in the city was estimated using a regression model using data from 3 ground stations located in the city. Further, Zhao et al. (2013) used MODIS AOD, API daily data measured by the Shanghai Environmental Monitoring Center (SEMC), and the ensemble empirical mode decomposition (EEMD) method to analyze the air quality variability in Shanghai and found that monsoon was a dominant factor in modulating the AOD and API variability. The variability of AOD and API in selected districts located in both downtown and suburban areas shows similar trends. Satellite derived aerosol optical depth (AOD) and air quality parameters ($PM_{2.5}$, PM_{10}) have been analyzed for different regions and good correlations of satellite data and air quality parameters have been developed (Guo et al., 2009; Gupta and Christopher, 2008; Gupta et al., 2006; Kumar et al., 2007). Liu et al. (2004) used a simple approach to estimate ground-level $PM_{2.5}$ concentrations by applying local scaling factors from a global atmospheric chemistry model to aerosol optical depth (AOD) retrieved from Multiangle Imaging SpectroRadiometer (MISR), the resulting MISR AOD concentrations were strongly correlated with U.S. Environmental Protection Agency's (EPA) $PM_{2.5}$ concentration. In addition, an empirical model based on the regression between daily $PM_{2.5}$ concentrations and AOD from MISR was developed and tested using data from the eastern U.S. for

Table 3
AQI and health implications (daily targets) (Ministry of Environmental Protection of the People's Republic of China, 2012).

AQI	Air pollution level	Health implications
0–50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk
51–100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101–150	Unhealthy for sensitive groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151–200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects
201–300	Very unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.
300+	Hazardous	Health alert: everyone may experience more serious health effects

Table 4
Air quality sub-index levels and their corresponding air pollutant concentrations (Ministry of Environmental Protection of the People's Republic of China, 2012).

Air quality sub-index	Air pollutant concentrations (μg/m^3)									
	SO_2 24-h	SO_2 1-h[a]	NO_2 24-h	NO_2 1-h	PM_{10} 24-h	CO 24-h	CO 1-h	O_3 1-h	O_3 8-h	$PM_{2.5}$ 24-h
50	50	150	40	100	50	2000	5000	160	100	35
100	150	500	80	200	150	4000	10,000	200	160	75
150	475	650	180	700	250	14,000	35,000	300	215	115
200	800	800	280	1200	350	24,000	60,000	400	265	150
300	1600	[b]	565	2340	420	36,000	90,000	800	800	250
400	2100	[b]	750	3090	500	48,000	120,000	1000	[c]	350
500	2620	[b]	940	3840	600	60,000	150,000	1200	[c]	500

[a] The 1-hour average concentrations of SO_2, NO_2, and CO are just used for real-time reports; the daily concentrations are acquired by 24-hour average.

[b] The 1-hour average concentration of SO_2 will not be included in the calculation of air quality sub-index if it is greater than 800 μg/m^3, and air quality sub-index of SO_2 is reported as 24-hour average.

[c] The 8-hour average concentration of O_3 will not be included in the calculation of air quality sub-index if it is greater than 800 μg/m^3, and air quality sub-index of O_3 is reported as 1-hour average.

the year 2001. Overall, the empirical model shows 48% of the variability in $PM_{2.5}$ concentrations (Liu et al., 2005). Li et al. (2005) found a direct correlation between Moderate resolution Imaging Spectroradiometer (MODIS) AOD products and air pollution index (API) in Beijing, showing relatively low value, using long term data. The correlation was improved using the seasonal variations of scale height and the vertical distribution of aerosols, and the relative humidity — an important controlling factor. Engel-Cox et al. (2006) found that lidar combined with surface and remote sensed data might be strategically used to improve our understanding of long-range or regionally transported pollutants in multiple dimensions. Gupta et al. (2006) used one year of MODIS AOD data and $PM_{2.5}$ mass concentration to assess particulate matter air quality over different locations across the global urban areas spread over 26 locations. The results show that the relationship between $PM_{2.5}$ and AOD is strongly dependent on aerosol concentrations, ambient relative humidity, fractional cloud cover and height of the mixing layer. Kumar et al. (2007) used $PM_{2.5}$ data from 113 sites and MODIS AOD data, and have shown a positive correlation between AOD and $PM_{2.5}$, to estimate air quality. Gupta et al. (2007) used four years of MODIS AOD data to present a multi-year air analysis of air quality over Sydney, Australia. Their results show pronounced diurnal variations and an overall increase in $PM_{2.5}$ associated with bush/forest

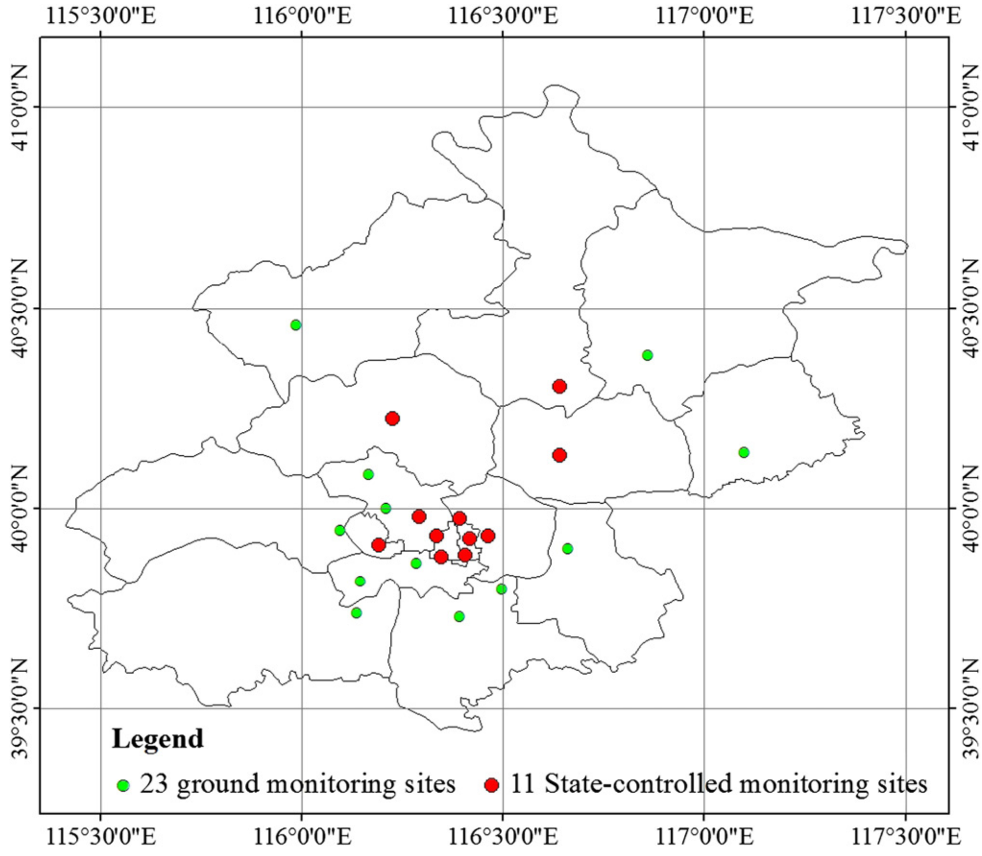

Fig. 1. Spatial distribution of the 23 ground monitoring sites, red dots show location of 11 State-controlled monitoring sites.

Table 5
Correlation coefficient between API, AQI, and MODIS AOD products.

Time period	Correlation coefficient R^2 and corresponding significance (sig.) P value							
		Terra AOD	Sig.	Aqua AOD	Sig.	Aqua Deep Blue AOD	Sig.	Valid number
January to October	API	0.17	0.00	0.25	0.00	0.16	0.00	142
	AQI	0.19	0.00	0.19	0.00	0.43	0.00	109
January	API	0.14	0.36	0.48	0.06	0.40	0.10	8
	AQI							1
February	API	0.01	0.70	0.10	0.23	0.00	1.0	16
	AQI	0.10	0.61	0.03	0.77	0.64	0.11	5
March	API	0.01	0.75	0.00	0.82	0.03	0.48	19
	AQI	0.53	0.00	0.03	0.56	0.73	0.00	14
April	API	0.26	0.02	0.38	0.00	0.18	0.05	22
	AQI	0.24	0.02	0.57	0.00	0.73	0.00	22
May	API	0.26	0.01	0.10	0.12	0.31	0.00	26
	AQI	0.38	0.00	0.45	0.00	0.57	0.00	20
June	API	0.57	0.00	0.73	0.00	0.70	0.00	17
	AQI	0.45	0.02	0.42	0.03	0.43	0.03	11
July	API	0.08	0.51	0.11	0.42	0.19	0.29	8
	AQI	0.30	0.10	0.33	0.09	0.26	0.13	10
August	API	0.95	0.03	0.87	0.07	0.10	0.68	4
	AQI	0.80	0.00	0.55	0.04	0.09	0.48	8
September	API	0.42	0.12	0.53	0.06	0.35	0.16	7
	AQI	0.76	0.02	0.84	0.01	0.91	0.00	6
October	API	0.30	0.03	0.13	0.19	0.09	0.27	15
	AQI	0.45	0.02	0.39	0.03	0.02	0.65	12

fires. The satellite data also show corresponding AOD changes. Gupta and Christopher (2008) used seven years of MODIS AOD and air quality data ($PM_{2.5}$ and PM_{10}) at one location over the Southeastern United States and presented a comprehensive analysis of air quality, and their analysis indicated that satellite data is important tool for monitoring air quality especially in regions where ground data are not available. Gupta (2008) used two-variate, multi-variate and artificial neural network methods for estimating $PM_{2.5}$ from 85 stations, and recommended that meteorological variables together with satellite observations be used for improving air quality assessment, use of satellite data alone may not give a good estimate of air quality. Guo et al. (2009) have used AOD data from MODIS sensor onboard the Terra satellite and PM contents measured at eleven sites located mostly in the eastern China in 2007, a relationship between columnar AOD and hourly and daily average PM were established. Zheng et al. (2011) analyzed the correlation between AOD derived from HJ-1 satellite data and PM_{10} in six districts of Shenzhen, China. They found a good correlation between AOD and PM_{10} during spring–summer seasons ($R^2 = 0.17$). Li et al. (2011) analyzed the correlation between MODIS AOD and API measured at 3 monitoring sites in 2009 in Hangzhou, China, the correlation between AOD and API was improved after considering AOD with modified by aerosol scaling height. Zhao et al. (2013) analyzed AOD and API variability, and found that the monsoon is one of the important factors in modulating the AOD and API variability. Wang et al. (2013) used air quality daily data from 86 cities across China during 2001–2011 and found that PM_{10} is the most important pollutants in Chinese cities. Using API value (above 150), efforts were made to reduce extremely heavily polluted days, 7% in 2001 reduced to 1% in 2011 in the all-city average. Zheng et al. (2013) developed seasonal linear regression models between MODIS AOD data and ground PM_{10} for the Pearl River Delta (PRD) region with meteorological correction, and the models were subjected to a validation with ground observations from the regional air monitoring network obtained during 2006 to 2008, with an overall error of less than 50%.

In China, air quality indices were used to represent air pollution in urban areas, API or air quality index (AQI) (Lu et al., 2011; Murena,

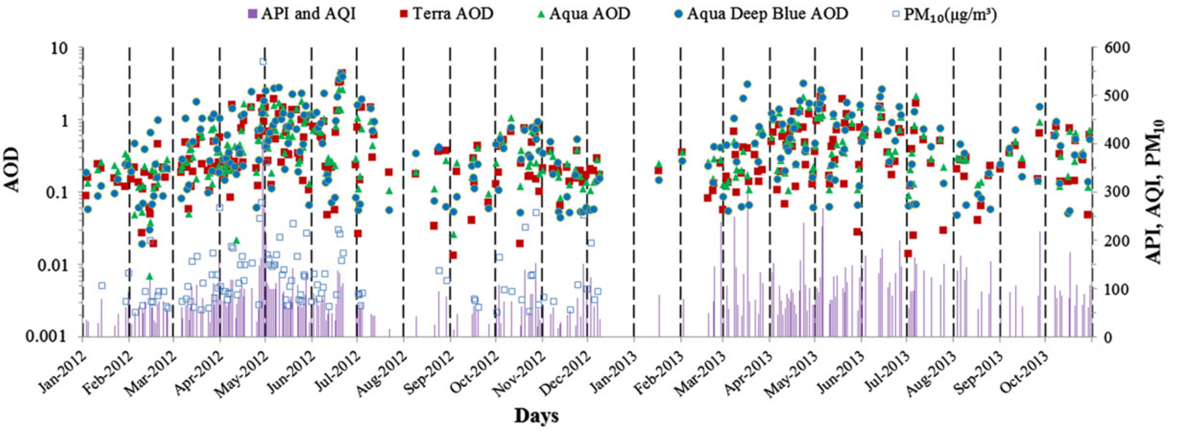

Fig. 2. Daily data of MODIS AOD products, PM_{10}, API, and AQI in 2012 and 2013.

2004; Wang et al., 2010). On February 29, 2012, the Ministry of Environmental Protection (MEP) of the People's Republic of China (PRC) approved the technical regulation on ambient air quality index (on trial). Since January 1, 2013, Beijing Municipal Environmental Protection Bureau (BMEPB) publishes daily AQI instead of API. The main aim of this study is to analyze the difference between API and AQI, and compare correlations between API, AQI and MODIS AOD products, to evaluate a better representation of air quality using satellite data.

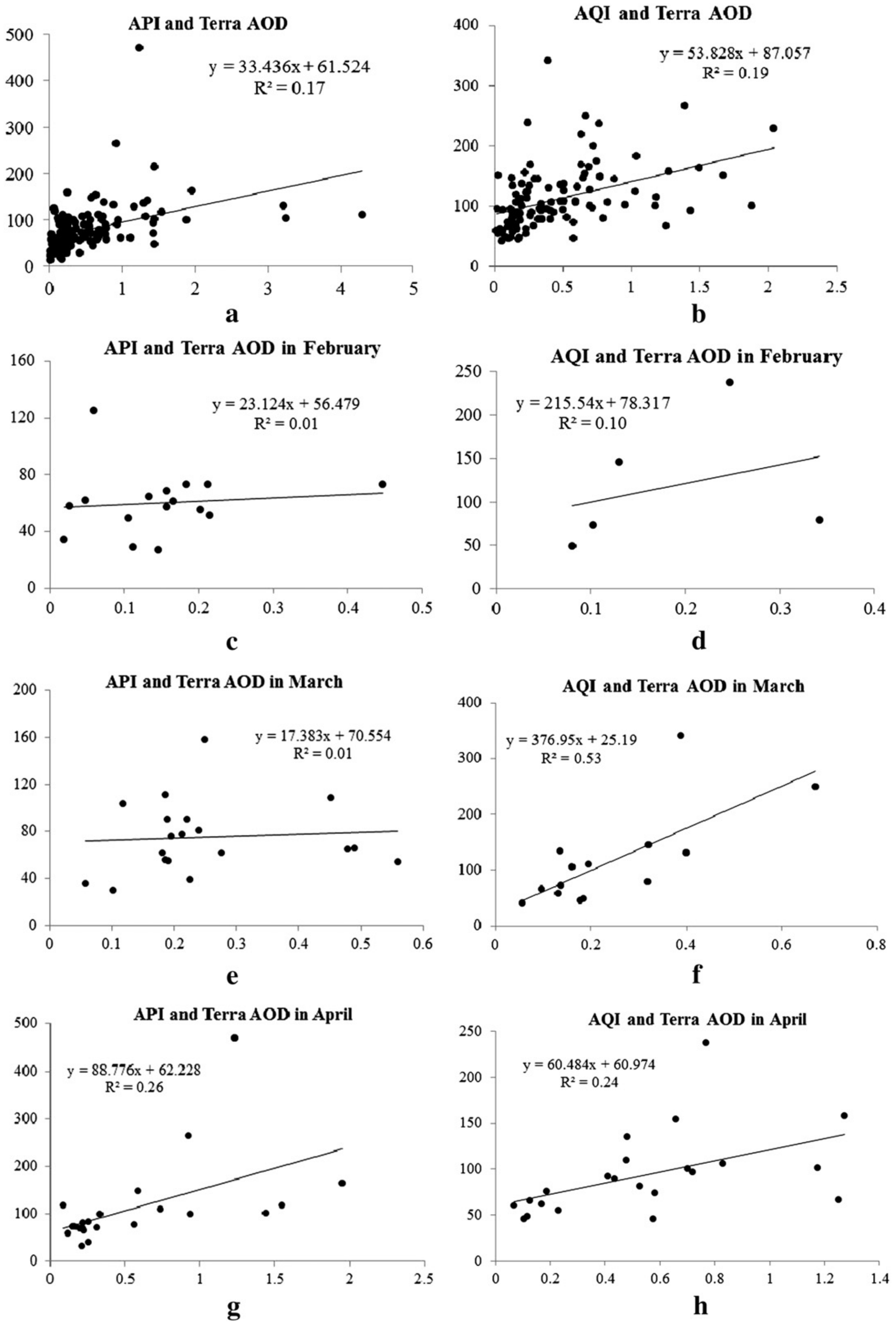

Fig. 3. Relation between AQI, API and Terra AOD in different time periods. (a)(b) from January to October, (c)(d) February, (e) (f) March, (g)(h) April, (i)(j) May, (k)(l) June, (m)(n) July, (o)(p) August, (q)(r) September, (s)(t) October.

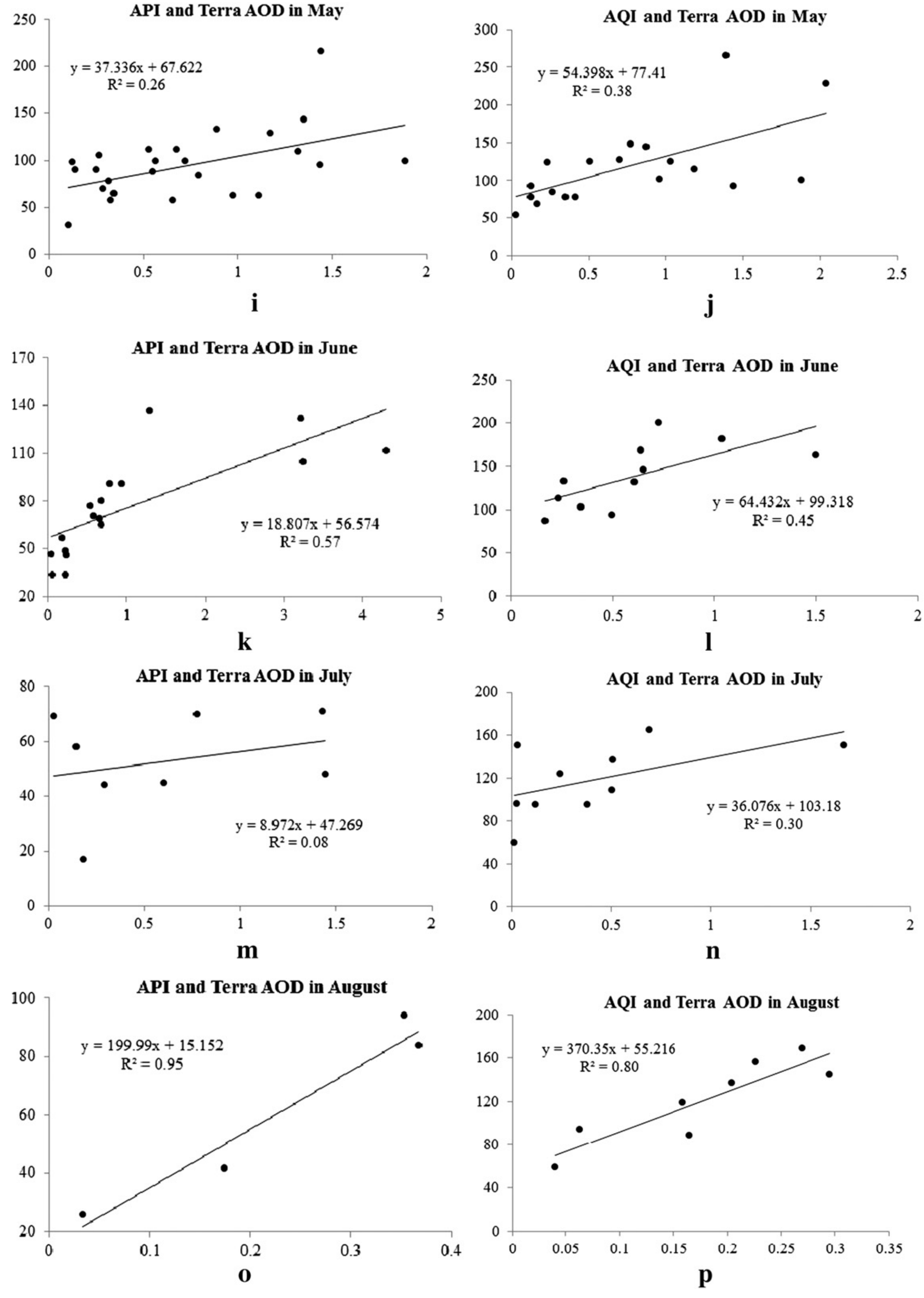

Fig. 3 (*continued.*)

2. API and AQI

2.1. API

An air quality index — API was developed and adopted in June 1997 in China to forecast air quality to alert people so that they do not get exposed to poor air quality. API was introduced by US EPA (United States Environmental Protection Agency) for the first time in 1976 to characterize regional air quality (US EPA, 1998; Yu, 2000). It simplifies the concentrations of several air pollutants to characterize air pollution level and air quality status in several levels. China National Environmental Monitoring Centre (CNEMC) started to publish API as of 2000 to evaluate air quality using SO_2, NO_2, and PM_{10} concentrations (China National Environmental Monitoring Centre, 2000). In 2008, the MEP

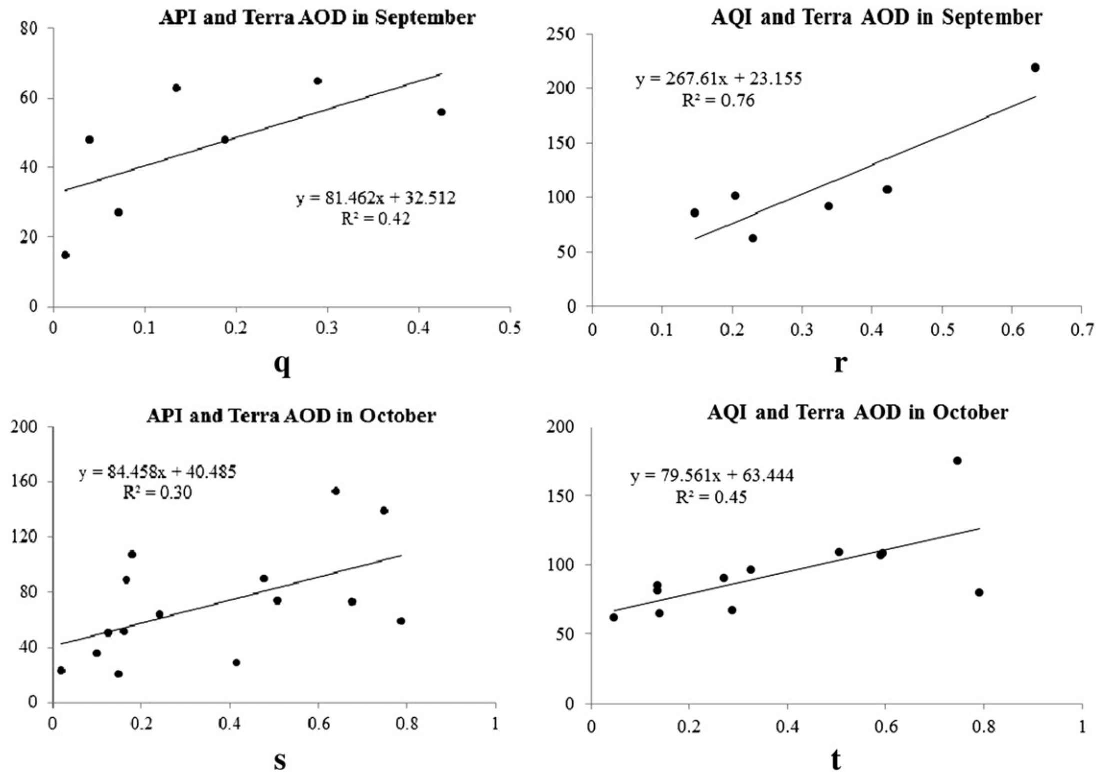

Fig. 3 (*continued.*)

(Ministry of Environmental Protection) of the PRC (People's Republic of China) improved API by adding CO and O_3 concentrations in the calculation of API. The modified API was used to relate to the health impacts (see Table 1) (Ministry of Environmental Protection of the People's Republic of China, 2008).

Table 2 shows corresponding air pollution sub-index levels and corresponding air pollutant concentrations. Five major air pollutants (CO, SO_2, PM_{10}, O_3, and NO_2) are selected; their concentrations are classified into six different categories according to concentration breakpoints. In Table 2, 24-h refers as 24-h average, and 8-h refers as 8-h average. API value can be calculated by a linear interpolation of the reference scale values as given in Table 2 from the following equation:

$$I_p = \left(PI_{high} - PI_{low}\right) / \left(BP_{high} - BP_{low}\right) \times \left(C_p - BP_{low}\right) + I_{low}. \quad (1)$$

Where I_p refers to the air pollution sub-index of pollutant p, C_p represents the rounded concentration of pollutant p, BP_{high} stands for the break point that is greater than or equal to C_p, BP_{low} represents the break point that is less than or equal to C_p, PI_{high} refers to the air pollution sub-index corresponding to BP_{high}, and PI_{low} stands for the air pollution sub-index corresponding to BP_{low}. Finally, API is calculated as a maximum among air pollution sub-indices of all air pollutants, and the maximum air pollutants recognized as the primary pollutants.

2.2. AQI

On February 29, 2012, the MEP of the PRC approved the technical regulation on ambient AQI (on trial). Table 3 shows AQI and health implications (http://www.airnow.gov/index.cfm?action=aqibasics.aqi). In Table 4 air quality sub-index levels and corresponding air pollutant concentrations are given, similar to Table 3, 24-h, 8-h and 1-h, respectively, refer as the data average for 24 h, 8 h and 1 h average.

Since January 1, 2013, BMEPB publishes daily AQI instead of API for the air pollution network in Beijing, this automatic network was founded in 1984. There are 23 ground monitoring sites for assessing urban environment, and among them, there are 11 State-controlled monitoring sites (http://www.bjmemc.com.cn/g327/s968/t1245.aspx, http://www.bjmemc.com.cn/g374/s1046/t1661.aspx).

The AQI value can be calculated by a linear interpolation of the reference scale values (Table 4) using Eq. (1). Similarly, AQI is calculated as a maximum among air quality sub-indices of all air pollutants. The air pollutant with the highest concentration is considered as the “responsible pollutant”. In AQI, $PM_{2.5}$ was included in calculation which is one of the major changes whereas in API calculation $PM_{2.5}$ was not included.

Before January 2013, CNEMC used API in Beijing to provide information about air pollution, now after January 1, 2013 BMEPB is using AQI to provide information about the state of air pollution in Beijing using 23 ground monitoring sites (11 monitoring sites are State controlled). Earlier the daily API value in Beijing from CNEMC is calculated by averaging the 11 State-controlled monitoring sites. In the present study, we have used daily API and AQI through averaging the daily API and AQI values of the 11 State-controlled monitoring sites for years 2012 and 2013, respectively.

On December 5, 2011, the real-time $PM_{2.5}$ measured by U.S. Embassy Beijing Air Quality Monitor was 522 $\mu g/m^3$, which was considered “Hazardous” and the corresponding AQI (here this AQI was used for Beijing, where as China only used API) exceeded the upper limit. However, the API measured by BMEPB was in the range of 150–170, which was considered “Unhealthy for Sensitive Groups”.

3. Satellite and ground data

In this paper, we have used atmospheric aerosol products — MOD08_D3 (Daily) through NASA Giovanni tools (http://disc.sci.gsfc.nasa.gov/giovanni). The “MOD” prefix refers as the dataset in general, not only to Terra-derived data, but also to Aqua-derived data. Deep Blue AOD is the same variable as AOD, but uses different wavelengths closer to the “blue” end of the visible spectrum to calculate the surface reflectivity, so that the AOD values can be calculated over bright surfaces, particularly desert regions (http://disc.sci.gsfc.nasa.gov/giovanni/additional/users-manual/DICCE_Help#AOD). Each of the

Level 3 products contains statistics derived from Level 2 atmosphere products. Statistics are sorted into 1° × 1° cells on an equal-angle global grid (180 × 360 cells) (King et al., 2003).

Fig. 1 shows map of Beijing (longitude 115.4° E–117.5° E, latitude 39.4° N–41.0° N) with total of 23 monitoring sites, red dots refer to 11 locations of State controlled monitoring sites. The 11 State controlled

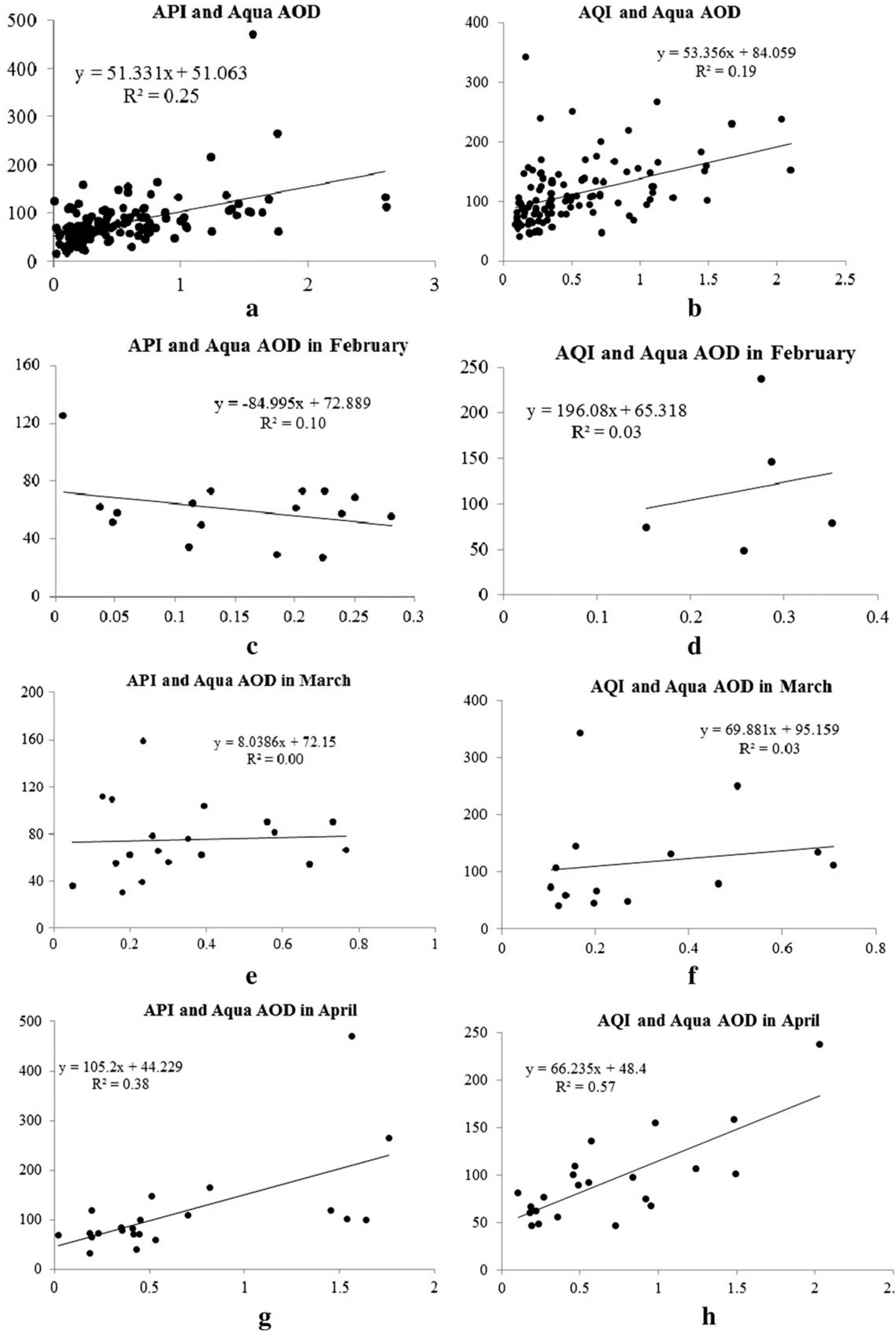

Fig. 4. Relation between AQI, API and Aqua AOD for different time periods. (a)(b) from January to October, (c)(d) February, (e) (f) March, (g)(h) April, (i)(j) May, (k)(l) June, (m)(n) July, (o)(p) August, (q)(r) September, (s)(t) October.

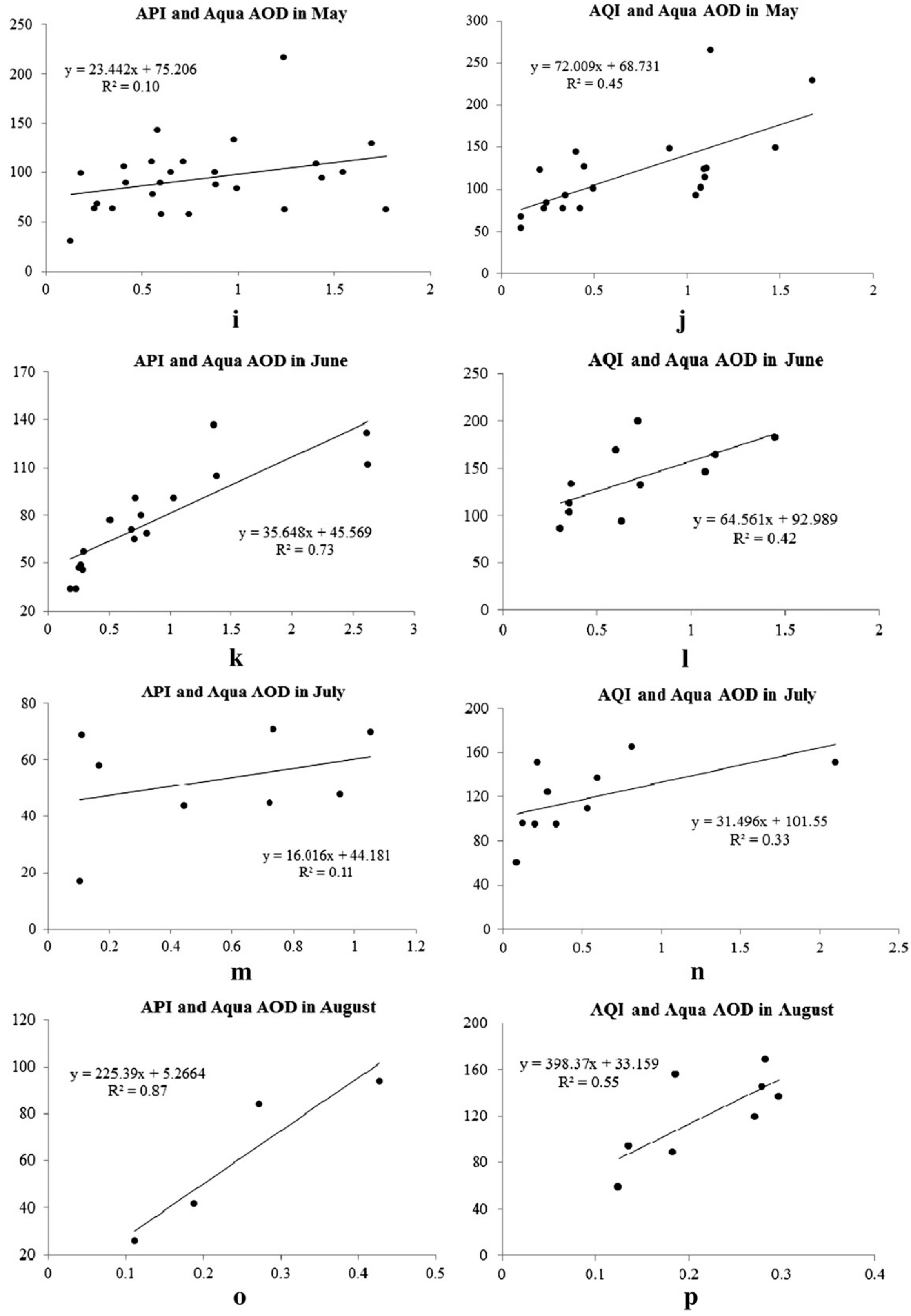

Fig. 4 (*continued.*)

monitoring sites are located in the area covered with longitude 116° E–117° E, latitude 39.5° N–40.5° N. As MODIS Level 3 products include AOD and Deep Blue AOD are sorted into 1° × 1° cells, the region of the study area extends from 116° E to 117° E and from 39° N to 41° N. The area-averaged time-series value for AOD and Deep Blue AOD is calculated, respectively.

4. Results and discussion

In Beijing, the main cause of the air pollution is due to vehicular emissions (five million motor vehicles) and emissions from coal power plants, coupled with dust storms from the north and local construction dust, as a result $PM_{2.5}$ and PM_{10} are very high affecting

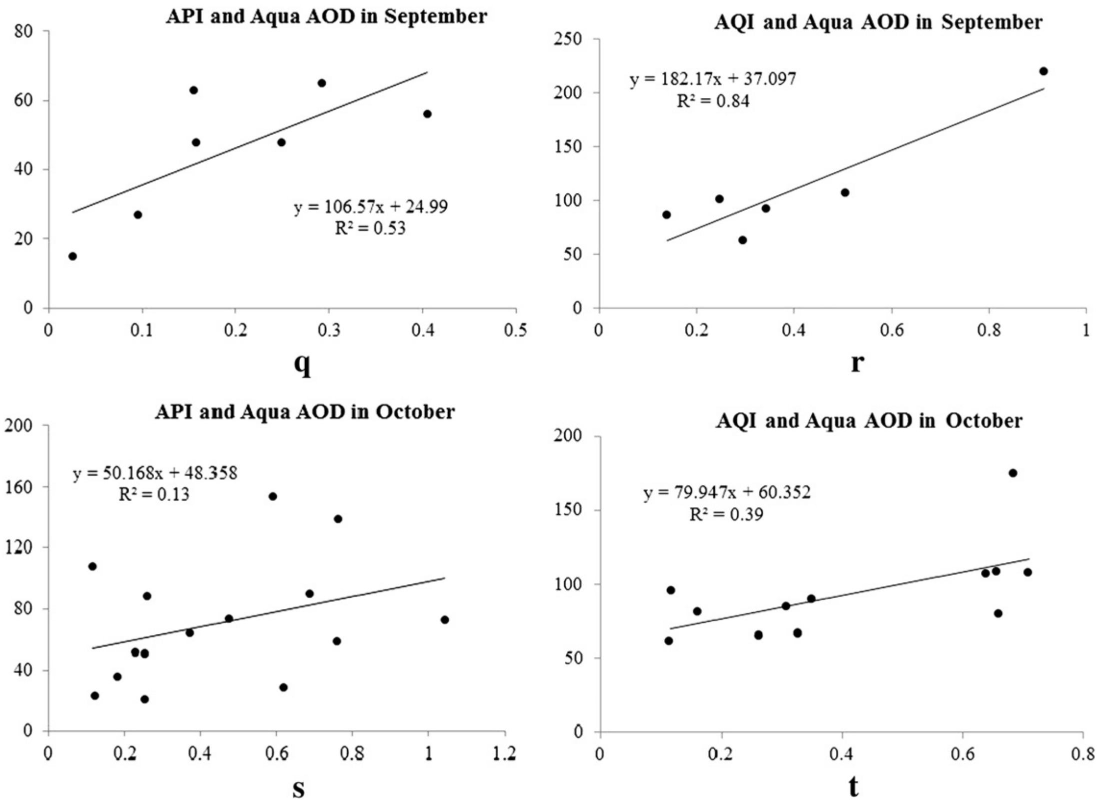

Fig. 4 (*continued.*)

air quality which is very severe (Zhang et al., 2003). In early 2013, several severe smog engulfed Beijing for weeks, with extremely high concentration of $PM_{2.5}$. Consequently, $PM_{2.5}$ usually has the highest concentration among air pollutants, and the highest value determines the overall AQI.

Before analyzing relation between AQI, API and different AOD products, we filtered the unavailable AOD data resulting from severe weather for Terra AOD, Aqua AOD, and Aqua Deep Blue AOD in 2012 and 2013, respectively. For API and AQI, both of them are recorded by BMEPB every day. However, for Terra AOD, Aqua AOD, and Aqua Deep Blue AOD, due to clouds and severe weather, it is impossible to acquire the optical remote sensing image on the ground. Hence, the available Terra AOD, Aqua AOD, and Aqua Deep Blue AOD on the same day were studied, and the number of available AOD for each month is shown in Table 5. In addition, monthly weather conditions are quite different. The monthly daily average temperature in the month of January is −3.7 °C, and during summer 26.2 °C in the month of July. The average annual precipitation is around 570 mm, and about three-fourths of that falls from June to August (http://en.wikipedia.org/wiki/Beijing#Climate). Air pollution and AOD are affected by precipitation, wind directions, and temperature. Due to extreme rainfall, air quality improves. The strong wind brings dust from north or air pollutants from surrounding regions especially from south to Beijing. During winter season, heating sources to warm the houses and buildings also cause air pollution. We have analyzed AQI, API and different AOD products for each month to study relation between AQI and API and different AOD products. In the month of January, 2013, there are only few available AOD data due to intense fog and haze (Che et al., 2013; Zhang et al., 2013), we have not considered AOD data for the month of January. We have considered daily data during February to October to study the performance of AQI with different AOD products.

According to Eq. (1) and Table 2, once API and primary pollutant is acquired, the primary pollutant concentration can be calculated. The number of days when the primary pollutant is PM_{10} is 275 in 2012. We have calculated the corresponding pollutant concentration on these days. Fig. 2 shows the time series of AOD, API, AQI and PM_{10}, daily PM_{10} shows a good correlation with API ($R^2 = 0.94$).

4.1. Relation between AQI, API and Terra AOD

Fig. 3 shows relation between AQI, API and Terra AOD for different time periods. During April, June, and August, the correlation between API and Terra AOD is much higher than those between AQI and Terra AOD. However, for total daily data from January to October, as well as February, March, May, July, September, and October, AQI shows a good correlation ($R^2 = 0.19$, 0.10, 0.53, 0.38, 0.30, 0.76, 0.45, respectively) with Terra AOD compared to API.

4.2. Relation between AQI, API and Aqua AOD

Fig. 4 shows relation between AQI, API and Aqua AOD for different time periods, the correlation between API and Aqua AOD is much better compared to AQI and Aqua AOD for the total daily data from January to October, February, June, and August. However, in the months of March, April, May, July, September, and October, correlation between AQI and Aqua AOD is much better than API.

4.3. Relation between AQI, API and Aqua Deep Blue AOD

Fig. 5 shows relation between AQI, API and Aqua Deep Blue AOD for different time periods. It indicates that AQI correlates with Aqua Deep Blue AOD much better than API for total daily data from January to October, as well as February and July, particularly March, April, May, and September with R^2 is 0.73, 0.73, 0.57, and 0.91, respectively, and the correlation are significant (P value = 0.00).

Table 5 shows a summary of comparison of API and AQI with three MODIS AOD products, correlation coefficients are also given. A good correlation is seen between AQI and Aqua Deep Blue AOD, showing a good representation of air quality (Table 5). Due to the high concentration of $PM_{2.5}$ in 2013, AQI shows a good representation of air pollution compared to API (based on 2012 API data, since API data is available only up to 2012). From January to October in 2013, Deep Blue AOD and AQI show a good representation of air pollution showing significant correlation coefficient ($R^2 = 0.43$). During February to May 2013, the

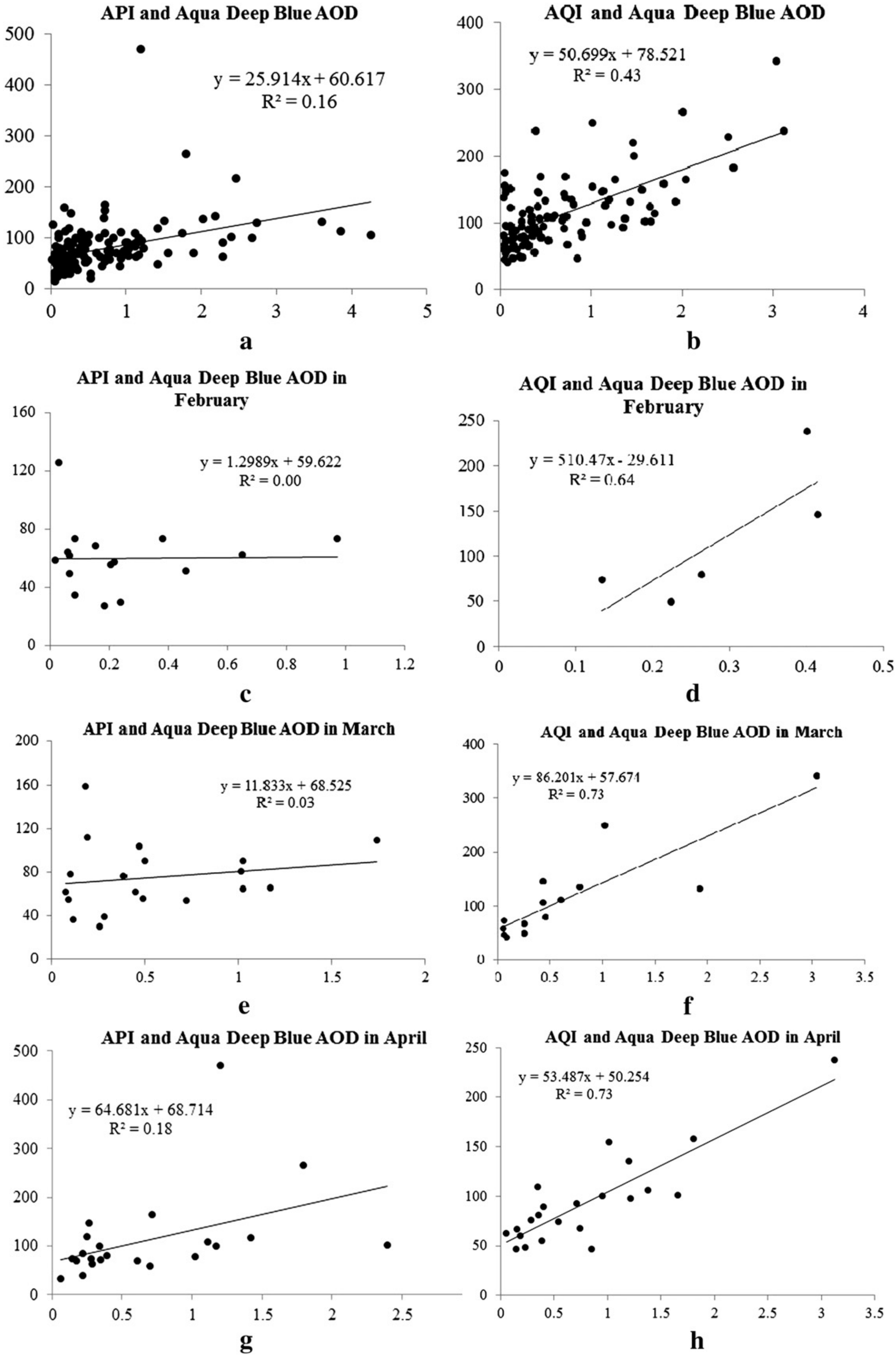

Fig. 5. Relation between AQI, API and Aqua Deep Blue AOD for different time periods. (a)(b) from January to October, (c)(d) February, (e) (f) March, (g)(h) April, (i)(j) May, (k)(l) June, (m)(n) July, (o)(p) August, (q)(r) September, (s)(t) October.

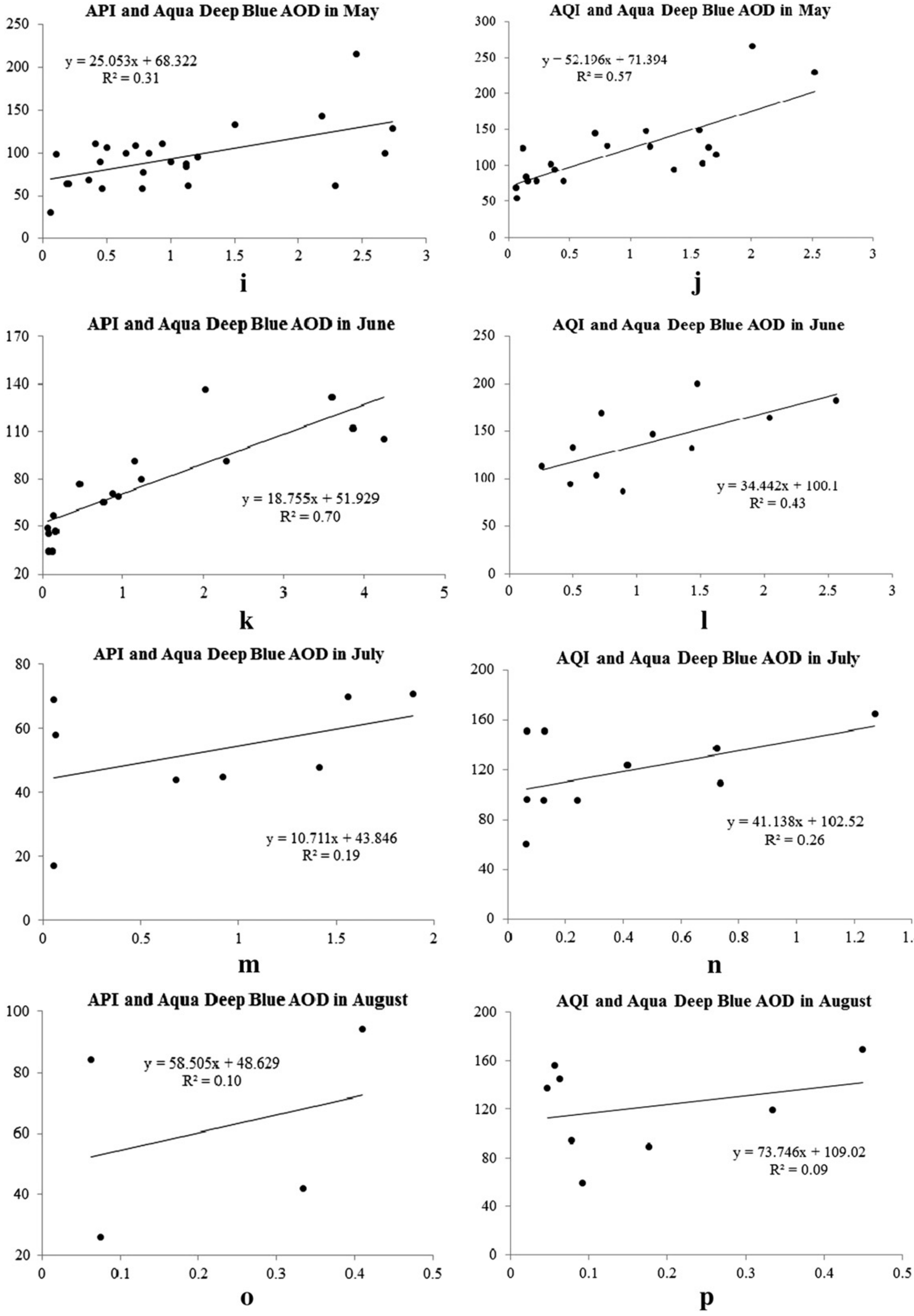

Fig. 5 (*continued.*)

correlations between AQI and Aqua Deep Blue AOD are highest (Table 5). We have acquired the ground observed AOD at Institute of Remote Sensing and Digital Earth (RADI), Beijing site from Aerosol Robotic Network (AERONET) (Holben et al., 1998). Fig. 6 shows the two different modes of AERONET AOD obtained in 2013, fine mode ($0.05 < r < 0.6$ μm) and coarse mode ($0.6 < r < 15$ μm), and r is the radius of particles. High coarse AOD with low fine AOD, a characteristic during dusty days, is found during February–May. During February–May 2013, dusts are prevalent in and around Beijing, and the characteristic of Deep Blue AOD determines its good expression of AOD values during

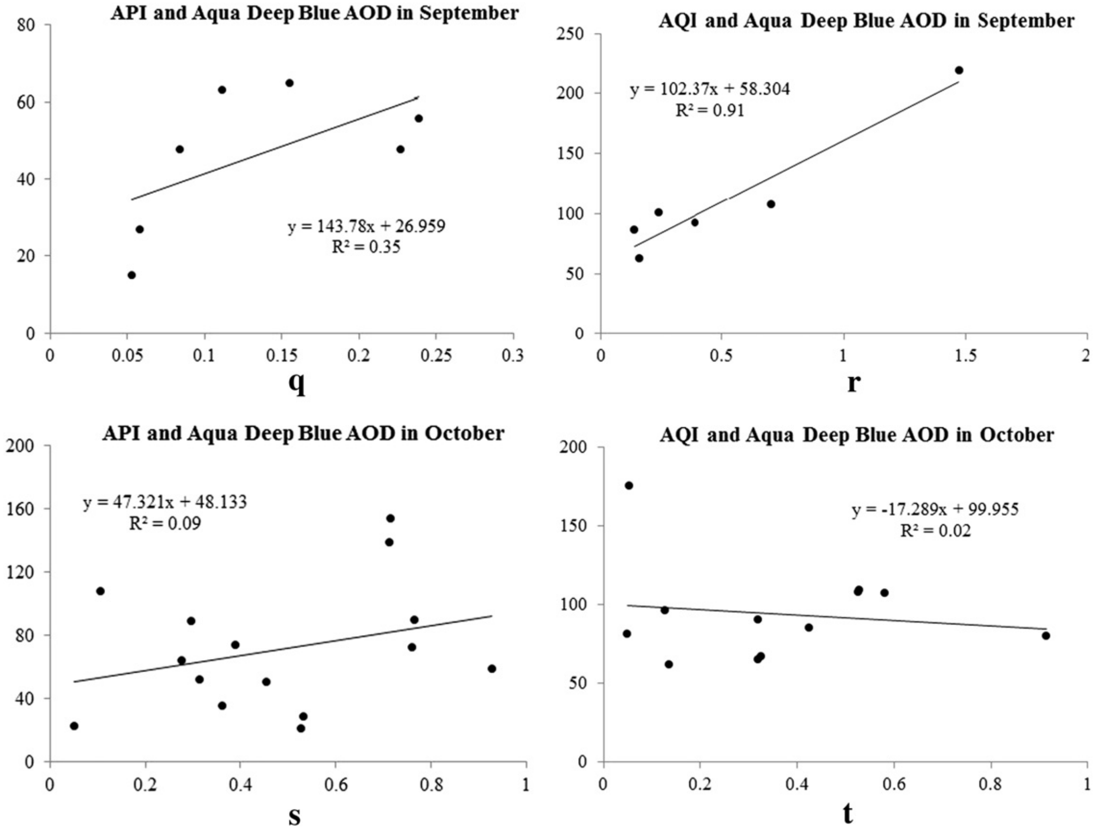

Fig. 5 (*continued.*)

dusty days, the correlations between AQI and Aqua Deep Blue AOD are highest. However, in the month of June, the correlation between API and Aqua AOD is highest. In July, the highest correlation is found between AQI and Aqua AOD while the relationships between API and Terra AOD for August and AQI and Terra AOD for October, respectively were found significantly due to the different meteorological conditions (Jiang et al., 2004; Ma, 2013). In this paper, we mainly analyzed the effect of precipitation and temperature on air quality for ten months in the year 2012. The daily precipitation and temperature data are from China Meteorological Data Sharing Service System. Fig. 7(a) and (b) show monthly average of precipitation and temperature from January to October, also show monthly average of PM_{10} in 2012 calculated from daily PM_{10} data (Fig. 2). It is clearly found that PM_{10} during June to September is relatively low compared to other months in 2012, indicating good air quality. During June to October 2012, the precipitation and PM_{10} show opposite trends. In addition, the temperature and PM_{10} also show opposite trends from June to October. Consequently, from the aspect of meteorological conditions and the monthly distribution of PM_{10}, the air quality is relatively better during June to September. Terra and Aqua AOD show a good correlation with API or AQI in

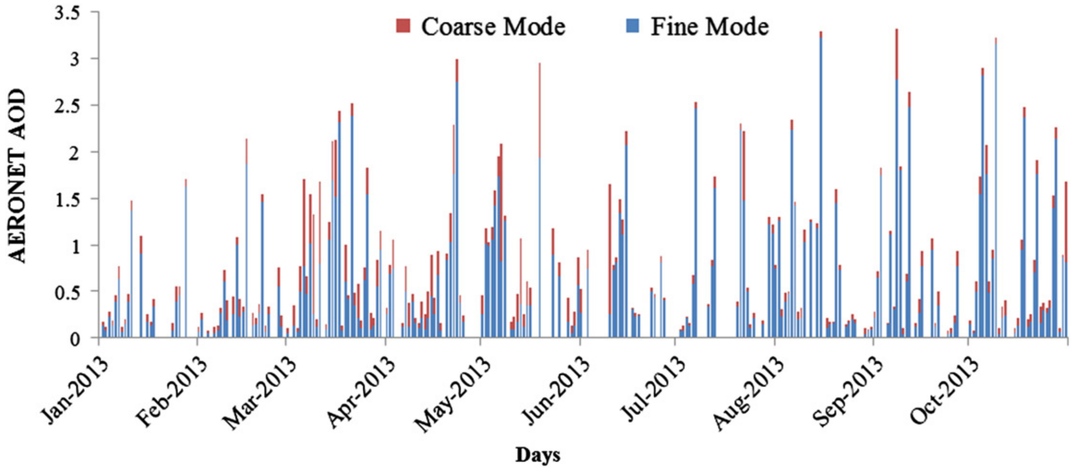

Fig. 6. AERONET AOD in two modes in 2013, the red column represents the coarse mode, the blue column refers to the fine mode.

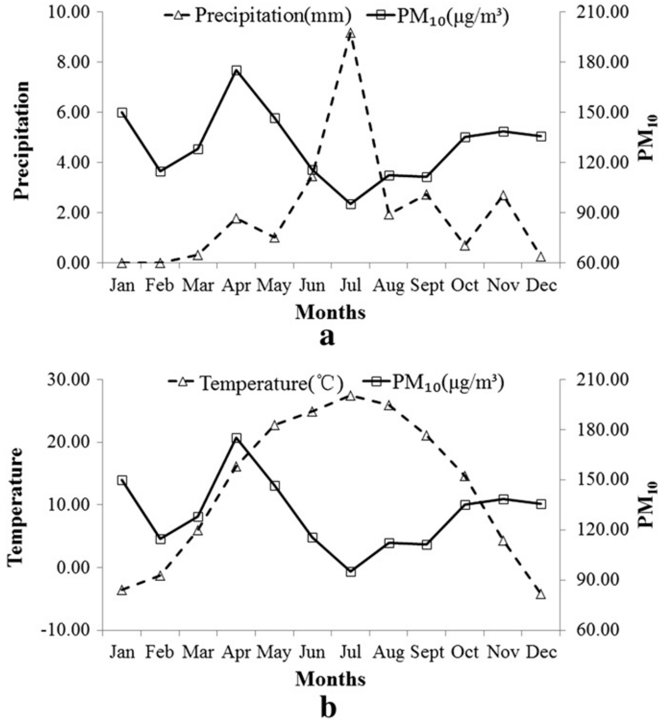

Fig. 7. Meteorological conditions and PM_{10} in Beijing for months of 2012. (a) Monthly average of precipitation and PM_{10}, (b) Monthly average of temperature and PM_{10}.

case of low AOD. However, Aqua Deep Blue AOD is not statistically significant correlated with AQI or API (P value > 0.1) during July, August and October. In the month of September, Terra or Aqua AOD shows a high correlation ($R^2 = 0.42$, 0.76 for Terra AOD, and $R^2 = 0.53$, 0.84 for Aqua AOD) with API or AQI, the correlation between Aqua Deep Blue AOD and AQI is found to be highest ($R^2 = 0.91$), this could be since calculation of AQI accounts contributions of the primary pollutant from CO, SO_2, PM_{10}, $PM_{2.5}$, O_3, and NO_2, the correlation between AQI and Aqua Deep Blue AOD is influenced by the type of primary pollutant. Lastly, though the correlation between AQI and Aqua Deep Blue AOD is not highest in the months June, July, August, and October, it is still highest for the total daily data during January to October ($R^2 = 0.43$). This shows that both AQI and Aqua Deep Blue AOD is a better indicator for air quality, and are highly correlated, particularly in polluted days due to dust.

5. Conclusion

Three important conclusions can be drawn from this study. First, for API, it has a much better correlation with Terra AOD, Aqua AOD, and Aqua Deep Blue AOD compared to AQI in the months of June and October. Meanwhile, API has no obvious different correlation with these three MODIS AOD products in most of the months. Second, for AQI, it is much more highly correlated with Aqua Deep Blue AOD compared to Terra AOD and Aqua AOD for the total daily data during January–October, as well as February, March, April, May, and September. For the months July, August, and October, both API and AQI are not statistically significant correlated with Aqua Deep Blue AOD (P value > 0.1). Third, through comparing API and AQI with three MODIS AOD products, it is found that the correlation coefficient between AQI and Aqua Deep Blue AOD is highest with R^2 is 0.43 for the total daily data during January to October, as well as February with R^2 is 0.64, March with R^2 is 0.73, April with R^2 is 0.73, and May with R^2 is 0.57. Both AQI and Aqua Deep Blue AOD have advantages in reflecting air quality, and their high correlations are helpful for predicting regional AQI in Beijing, particularly in polluted days due to dust.

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