Application of MODIS satellite products to the air pollution research in Beijing

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Abstract The direct correlation between NASA MODIS aerosol optical depth (AOD) products and the air pollution index (API) in Beijing was found relatively low based on the long-term comparison analysis. The correlation improved to some extent after taking account of the seasonal variation of scale height and the vertical distribution of aerosols. The correlation coefficient further improved significantly after considering the influencing factor of Relative Humidity (RH). This study concluded that satellite remote-sensing could serve as an efficient tool for monitoring the spatial distribution of particulate pollutants on the ground-level, as long as corrections have been made in the two aforementioned processes. Taking advantage of the MODIS information, we analyzed a pollution episode occurring in October 2004 in Beijing. It indicated that satellite remote-sensing could describe the formation process of the ground-level pollution episode in detail, and showed that regional transport and the topography were crucial factors to air quality in Beijing. The annual averaged distribution in the urban area of Beijing and its surroundings could be also obtained from the high-resolution retrieval results, implicating that high-resolution satellite remote-sensing might be potential in monitoring the source distribution of particulate pollutants.

Keywords: particulate pollution, MODIS, aerosol.

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Atmospheric aerosols refer to the tiny particles suspended in the air, with the particle diameter ranging from 0.001 μm to tens of microns. As an important part of the earth-atmosphere system, they could influence the climate through direct and indirect radiative forcing. In addition, the atmospheric aerosols also have significant environmental effects. Particles with the aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$) could impair the visibility significantly due to their effective extinction (absorption and scattering) to the visible light. Particles with the aerodynamic diameter smaller than 10 μm could reach the bronchia and those smaller than 5 μm could go further into the lung, making a significant increase of cardiovascular diseases and asthma for humans. In many developing countries, air pollution is a difficult problem during the industrialization processes. In the mainland of China, one of the most important pollutants in cities is respirable suspended par-

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ticulate (RSP, i.e. PM_{10}). To host a "Green Olympic" in 2008, Beijing has to improve its air quality, and monitoring the spatial concentration is a prerequisite to reveal the influencing factors for air quality and to adopt effective control strategies.

We may directly obtain the accurate information that could reflect the ground-level concentration and temporal variation of aerosols by constructing monitoring stations and making continuous observations. In this way, physical and optical characteristics of pollutants could be discovered. On the other hand, we could make schematic sampling and then analyze the chemical component of pollutants, and subsequently determine the source of particulate pollutants and come up with reasonable emission control strategies. However, the above methods could be conducted only in a limited number of ground-level stations due to the high cost of observational instruments and facilities. As a consequence, it is hard to obtain good spatial coverage and 3-D information, hindering to make macro-level analysis on the sources and variation trends of pollutants as well as to bring forward reasonable control strategies to cope with the regional pollution problem.

Satellite remote-sensing could fill the gap of ground-level observations. On the basis of recognizing the importance of aerosols on the global change and regional environmental research, a series of satellite observational schemes has been implemented at the end of last century in an attempt to obtain the global distribution of aerosol optical characteristics and the seasonal and annual variations of direct and indirect radiative forcing of aerosols[1−7]. Developed by NASA, the Earth Observing System (EOS) is an integrated scheme aimed at monitoring the global change, including launching a series of advanced satellite systems to make comprehensive and completed observations to the solar radiation, the atmosphere, the ocean and the land[1,2]. The Moderate Resolution Imaging Spectrometer (MODIS) is an important sensor aboard the EOS satellite Terra and Aqua, with 36 channels from visible to infrared bands. The scanning information provided by MODIS covers the whole earth once per day, offering abundant data that could be used to retrieve the products related to the land, cloud, aerosol, water vapor, ozone, sea color, phytoplankton, biogeochemistry, etc. The swath width of MODIS is 2330 km. The highest nadir spatial resolution for visible light channel 1 (660 nm) and channel 2 (860 nm) is 250 m, and for visible and near-infrared channel 3—7 is 500 m. The features favor the high-resolution monitoring for aerosols, land surface and clouds. NASA has released the global distribution products of aerosol optical depth (AOD) and other optical characteristics with the nadir resolution of 10 km[2,3,6,7]. It is also of good feasibility and application value to use MODIS 1B information to retrieve high-resolution (1 km) AOD[8].

In recent years there have been wide applications of satellite remote-sensing information on the air pollution research. Chu et al.[7] successfully applied the NASA 10 km Level 2 AOD product to monitoring global, regional and local air pollution. Based on the MODIS true color images and AOD, Engel-Cox[9] studied how to apply AOD in air pollution research in both qualitative and quantitative way. They found that satellite remote-sensing information and ground-level mass concentration of pollutants showed higher correlation in mid and eastern US than western US. Wang et al.[10] compared the satellite information with the ground-level measurement on multiple stations in a city in Alabama, indicating that the correlation coefficient between $PM_{2.5}$ mass concentration and AOD is above 0.7. They accordingly drew the conclusion that most of the pollutants resided in the mixing layer and AOD could be used in the air quality assessment. The study of Lau et al.[11] showed that AOD derived from MODIS remote-sensing and ground-level particulate mass concentration had good correlation, and the MODIS remote-sensing AOD distribution could play an important role in monitoring the regional transport of pollutants. Applying satellite information, ground-level monitoring and numerical simulation, Xu et al.[12] concluded that regional transport from adjacent cities to the south of Beijing was responsible for the air pollution in Beijing. As the vertical integration of aerosol extinction coefficient (AEC), sometimes AOD did not show good correlation with the ground-level particulate concentration as a result of the difference of AEC vertical distribution and the influence of RH on the scattering process. In this study, we attempted to apply 10 km and 1 km MODIS remote-sensing products to geting insight to the air pollution problem in Beijing. The aerosol 10 km remote-sensing products and API in Beijing will be compared to studying the correction of RH and vertical distribution to the aforementioned correlation. We subsequently applied the satellite remote-sensing products to a pollution episode to study the influence of regional transport to the air pollution in Beijing. The 1 km products with detailed distribution characteristics will be given in the following sections, which, in combination with the geographical analysis in Beijing and its surrounding areas, would substantiate that high-resolution remote-sensing products have potential application value in studying urban air pollution, particularly in monitoring the overall distribution of pollution sources[8].

1 Validation of satellite remote-sensing products

Since the 1970s there have been continuous attempts to apply satellite information of the visible light channel for aerosol remote-sensing. The main problem is how to determine the reflectance. Kaufman et al.[2] found that ground-level reflectance of MODIS channel 1 (620—670 nm) and channel 3 (459—479 nm) showed good corrections with that of channel 7 (2105—2155 nm) in the region with high vegetation coverage and even in the surface of low reflectance soil. They further applied the near-infrared channels that are not sensitive to aerosol (2.1 μm and 3.8 μm) to determining pixels with dark background and to approximately calculating the surface reflectance of 0.47 μm and 0.66 μm. The first step of the operational algorithm is the cloud-examination method. It examines the multi-channel thresholds to determine the pixels that represent clear sky, clouds or those undetermined. Errors of cloud examination usually come from the high-reflectance surface that downgrade the contrast of land and cloud, the dense aerosol layer similar to the clouds, the marginal effects of clouds in sub-grids, and errors in the surface model. The second step is the selection of pixels. All the pixels representing clear sky in 500 m resolution image were grouped at 10 km×10 km resolution. All the dark background pixels with reflectance of 2.1 μm channel smaller than 25% were retained. These pixels were then sorted according to their reflectances, and those in the range of 10% to 40% were extracted for further analysis. The reason for excluding the darkest 10% is to decrease the influence from shadow of clouds as well as other possible pixel contamination. If more than 12 pixels were retained after filtering, AOD could be derived in the end[9]. The scattering and absorption of air molecules could be corrected through empirical formula, in which total vapor was from other channels of MODIS, total ozone was from TOVS observation, and CO_2 was from standard value content. In the past, AOD was retrieved according to continental aerosol look up tables (LUTs), in which the ratio of path radiances on red and blue channels was regarded as a criterion to determine whether the type of aerosol is soil dust or not. For the non-dust case, the geographical distribution method would be applied to determining the type of aerosol, sulfate, biomass burning or other mixed aerosol. With a nadir spatial resolution of 10 km×10 km, aerosol obtained from this operational method was capable of meeting the need for global climate research and offering the urban air pollution information in synoptic and regional scales. However, in the aerosol retrieval processes there were still errors from estimation of surface reflectance, selection of aerosol models, and cloud identification. The most suitable method for checking this product is to compare the result with the observations from ground-based sun photometer. AERONET (AErosol RObotic NETwork) is a sun photometer observation network operated by NASA for the sake of examining satellite remote-sensing products. Currently more than 100 stations had been included in the network[14]. Long-term comparison from multiple stations discovered that the relative error for NASA MODIS AOD products was around 20%[6]. However, this percentile did not consider the result in China for any AERONET site had not been set up by that time.

In order to examine the MODIS aerosol products in Beijing, we started to conduct sun photometer ground-level observation since 2001. From 2001 to 2002, we used 10-band sun photometers manufactured by the optical and electrical instrument factory of Beijing Normal University with the central wavelength at 440.3, 496.6, 550.0, 610.0, 658.8, 707.6, 763.6, 810.0, 862.5 and 910.3 nm. The instruments were calibrated by Langley method to ensure the relative error around 2% in the mid-level turbidity condition. We compared the observations from 550 nm sun photometer with satellite remote-sensing results. To match the scanning time of EOS satellite, sun photometer observations were conducted from 10∶00 to 14∶00 Beijing Local Time. The actual observation time for comparison was chosen to be the one that is the closest to the time of the satellite passing across Beijing. MODIS AOD was obtained as the average of satellite products in a circular area with the center being the point the observations were made (Physics Building, Peking University) and the radius of 15 km. Clouds were simply identified from human sight. In the whole years of 2001 and 2002, the linear relationship is $Y = 1.197X–0.054$[16,17], in which Y represented observations from sun-photometer, while X represented Terra MODIS derivations. The slope of 1.197 indicated MODIS AOD results matched fairly well with the sun-photometer observations. In addition, it showed that when the sun photometer observations became large, the MODIS result deflected to be a little smaller. This phenomenon concentrated in March and April, with the possible explanation as high weight of soil dust present in the aerosols at that time. The negative intercept implicated that when the AOD was relatively weak, MODIS remote-sensing would overestimate to some extent probably as a result of smaller estimation of surface reflectance by applying the algorithms of NASA. Overall speaking, more than 60% of the points fell in the error range $\Delta\tau = \pm 0.05 \pm 20\% \cdot \tau$[6] estimated from AERONET. Beijing is located in the transition zone between mountainous area and the North China Plain, while our observation point, Peking University is just at the linking zone of urban and mountainous areas. This geographical characteristic caused a larger temporal and spatial variation of aerosols. To obtain a better correlation between satellite remote-sensing and ground-level observation, a stricter temporal matching should be required. However, currently a sun photometer that could automatically track the sun movement for continuous measurement is yet to be available.

2 Comparison between AOD and API

Air Pollution Index (API) is an understandable index that is piecewise linearly related to the mass concentrations of PM_{10}, SO_2, NO_x and O_3 measured at different sites in a particular city in 24 hours. In most of the cities in China, 85%—90% of the major pollutants every year is PM_{10}, followed by SO_2. At present API in 84 major cities are released to the public every day (http://www.zhb.gov.cn/quality/air.php3).

In this section the AOD from MODIS remote-sensing will be compared with the API in Beijing to discuss the application of satellite product in air quality monitoring. Here AOD came from the average of satellite remote-sensing products in a circular area with the center being the urban center of Beijing (116.28°E, 39.93°N) and the radius of 15 km. We extracted the dates with major pollutant as PM_{10} for comparison. The dates with API value less than 50 thus being classified as “good” air quality would not be included for comparison owing to the unpublished major pollutant species. Fig. 1 illustrates the comparison between AOD from MODIS Level 2 products and API in August 2000 to December 2003. Fig. 1(a) is a direct comparison composed of 360 groups of data with the correlation coefficient of 0.221. This correlation coefficient is larger than 99% confidence level, but is far less than our expectations. Considering that API is piecewise derived from mass concentration values, we converted API to the mass concentration and the correlation coefficient improved to 0.249.

The measurement of PM_{10} concentration is in a dry condition, thus the result representing the mass concentration in a fixed RH. However, AOD remote-sensing is conducted in an actual background, which causes AEC influenced by the ambient RH. When RH is relatively high, the water-soluble particulates would deliquesce and expand, making AEC to increase several times. Generally RH influencing factor could be expressed as follows: $f\,(\mathrm{RH}) = 1/(1.0–\mathrm{RH}/100)$. A

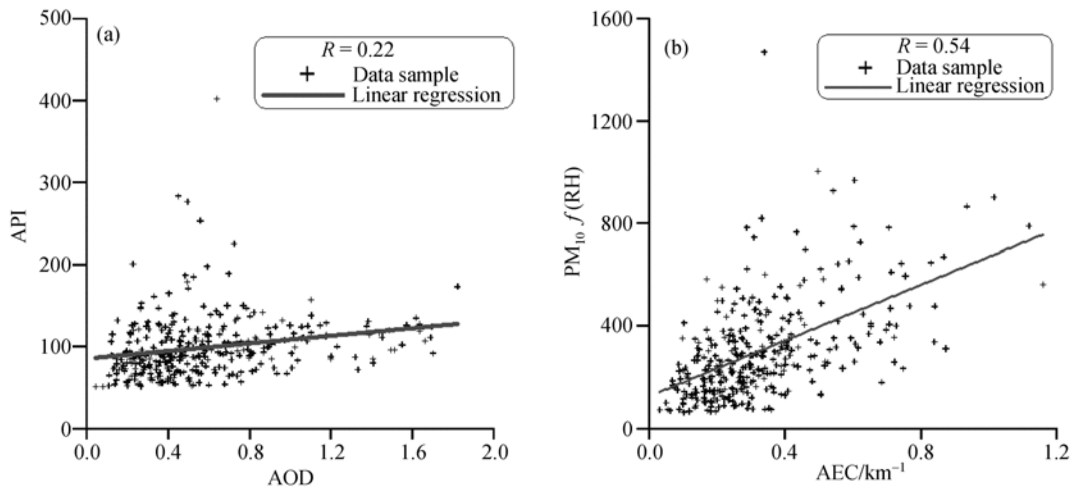

Fig. 1. Comparison between MODIS AOD and API (from August 2000 to December 2003). (a) Direct comparison of AOD and API; (b) comparison between RH-corrected PM_{10} and AEC corrected from AOD.

more accurate correction could be obtained from experiments. After comparing AOD with a new term defined as the product of API and the daily RH influencing factor, the correlation coefficient improved significantly to 0.488; then we further convert API to mass concentration, the correlation coefficient increased to 0.498. Table 1 lists the correlation coefficients in every step.

Table 1 Correlation analysis of API and AOD, and the corresponding variables subject to RH and vertical corrections in Beijing[a)]

	API	PM_{10}	API×f(RH)	PM_{10}×f(RH)
AOD	0.221	0.249	0.488	0.498
AOD/Hi	0.204	0.233	0.528	0.535

a) Data is collected on the days with maximum RH < 85% and API>50, PM_{10} as the major pollutant in the period from August 2000 to December 2003 with data pairs of 360.

Considering AOD is the vertical integration of AEC, however PM_{10} and API are measured or derived on the ground level, we made use of the results from the previous study to divide AOD by the seasonal scale height in Beijing, 2221 m in spring, 1947 m in summer, 1461 m in fall and 1076 m in winter, to get surface AEC[18]. The correlation coefficients between such obtained AEC with API, API-converted PM_{10} and their RH-corrected values are 0.204, 0.233, 0.528 and 0.535, respectively (Row 2 in Table 1). Aerosol scale height reflects the vertical distribution of aerosols, approximately representing height of mixing layer except in spring when the impact of sandstorm becomes relatively strong. The correlation coefficient improved after being corrected by RH, indicating that vertical correction by seasonal scale height is effective only when RH correction is performed. The correlation coefficient could be improved further when considering RH influencing factor followed by vertical correction of seasonal scale heights. Fig. 1(b) illustrates the scatter-plot between RH-corrected PM_{10} and AEC derived from AOD vertical correction. The correlation coefficient is improved up to 0.535 in this case.

From the above comparison we may conclude that although the direct correlation coefficient between AEC from satellite remote-sensing and API was larger than 99% confidence interval in statistics, the actual value was somewhat low. After corrected by RH and scale heights, the correlation coefficient could be improved over 50%. In addition, it should be noted that API is monitored in multiple stations for 24 hours, which is different from satellite remote-sensing both temporally and spatially. On the other hand, if the scale heights used to make vertical correction were derived from LIDAR or daily mixing layer calculated from numerical model, theoretically satellite remote-sensing AEC would show higher correlation with PM_{10} mass concentration. In summary, we may conclude that through long-term correlation comparison satellite remote-sensing atmospheric aerosol could serve as a complementary method to the ground-level monitoring of particulate concentration in urban areas.

3 Influence from regional transport processes on the air pollution in urban area of Beijing

In this section, we will use MODIS products to study a pollution episode occurred in October 2004 in Beijing. Fig. 2(a)—(f) illustrate the AOD distribution in Beijing and its surrounding area on 5—11 October, 2004, in which the AOD data was from MODIS Level 2 products (version 4). There was no remote-sensing product on 10 October for it was cloudy. In the figures there were also some regions without remote-sensing products for the same reason. From these figures we may easily find that AOD was relatively low on 5 and 6 October in the urban area of Beijing. On 5 October there was a vague AOD hotspot in urban areas and southeastern part of Beijing with the AOD around 0.6—0.7. API on that day was 153 with the primary

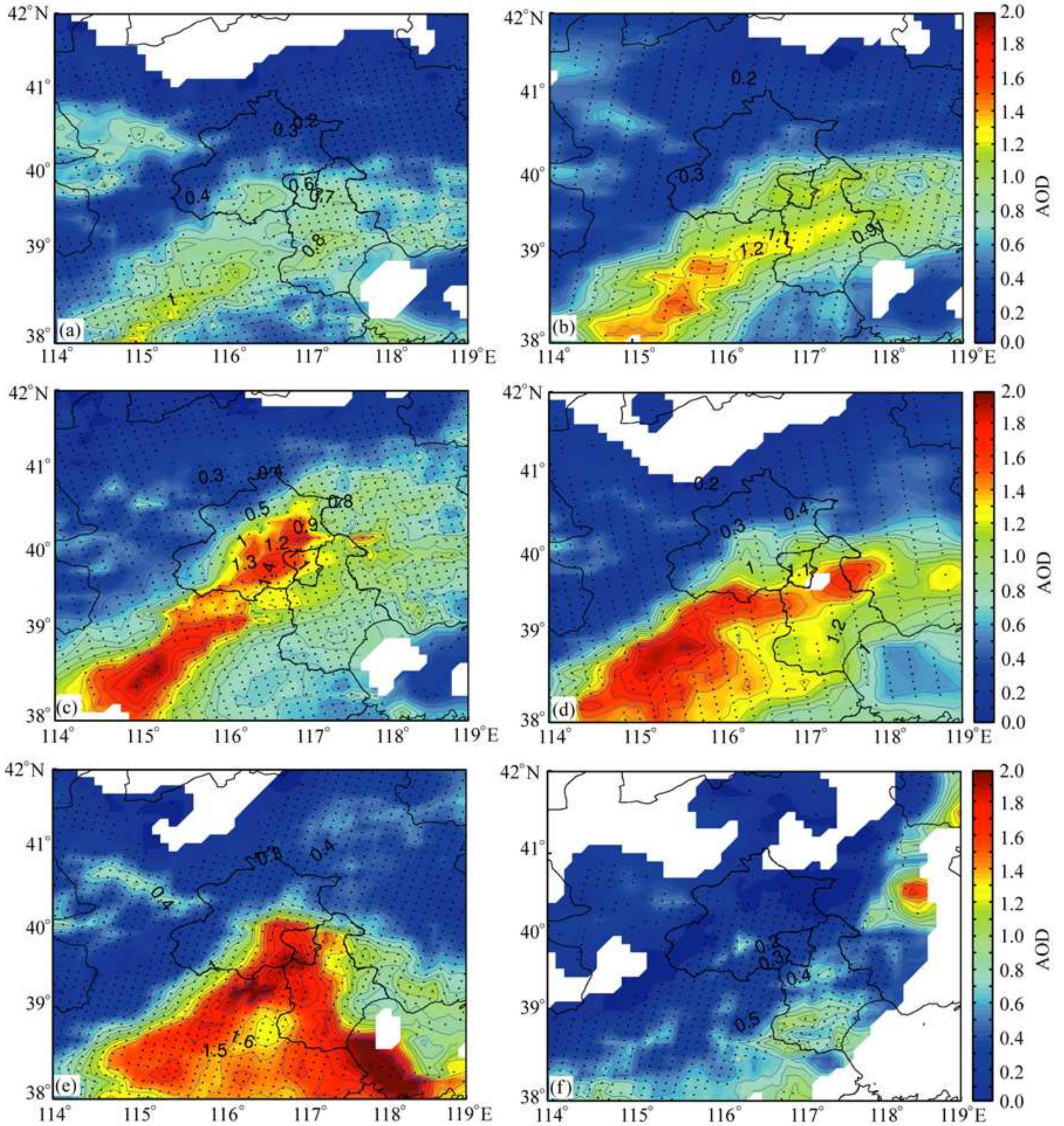

Fig. 2. (a)—(f) AOD in Beijing and its surrounding region on the days of 5, 6, 7, 8, 9 and 11 October. *x*-axis represents longitude; *y*-axis represents latitude, color and isopleths represent AOD.

Table 2 API, PM_{10} averaged concentration, RH and satellite remote-sensing AOD in the urban area of Beijing on 4—11 October, 2004

Date	API		Averaged PM_{10} mass conc./$\mu g \cdot m^{-3}$	RH (%) (14∶00 BJT)	MODIS AOD (30 km radius)
	Value	Category			
2004-10-04	118	slightly polluted	186	31.16	0.49
2004-10-05	153	light polluted	256	32.97	0.71
2004-10-06	166	light polluted	282	41.94	0.82
2004-10-07	325	heavy polluted	440	50.90	1.40
2004-10-08	402	heavy polluted	502	45.14	1.05
2004-10-09	263	moderate-heavy polluted	394	52.13	1.00
2004-10-10	374	heavy polluted	479	60.04	cloudy
2004-10-11	127	slightly polluted	204	15.03	0.26

pollutant as PM_{10}, according to the monitoring information from Beijing Environmental Protection Bureau. The API value corresponded to a PM_{10} level of 256 $\mu m/m^3$, falling into the Air Quality (AQ) category "light polluted". It could be concluded from the satellite remote-sensing results that local emission was responsible for the bad AQ on that day. It could be also revealed from the figure that after 6 October, the AOD distribution in Beijing and its surrounding areas appeared a distinct characteristic. From Shijiazhuang, Baoding, Zhuozhou all the way to Beijing, there was a strip-shaped AOD large value area with the largest AOD value above 1.0. Correspondingly, the primary pollutant in Beijing was PM_{10} for several consecutive days with the API on 6 October as 166, on 7 October as 325, on 8 October as 402, on 9 October as 263, and on 10 October as 374. The API values eventually fell to 127 on 11 October benefited from the changing of weather conditions. According to the criteria of State Environmental Protection Administration, 7, 8 and 10 October were classified as "Heavy polluted" days and 9 October was "Moderate-heavy polluted" day. Listed in Table 2 are the corresponding PM_{10} mass concentration, RH and AOD, in which AOD was derived as the average in a circular area with the center of E116.3°, N39.8° and the radius of 30 km.

Similar to the results in Table 1, here we compared AOD with API, API-converted PM_{10} averaged concentration and their product with RH influencing factor, and the correlation coefficient is listed in Table 3. Fig. 3 illustrates the variation of AOD on 4—11 October 2004, and the variation of PM_{10} mass concentration corresponded to API data. The correlation coefficient between the two was 0.868. This value would rise to as high as 0.917 after considering RH influence. Therefore, we may conclude that AOD retrieved from satellite remote-sensing information could reflect the variation of PM_{10} mass concentration on the ground in this pollution episode.

Table 3 Correlation analysis of API and AOD, and variables subject to RH and vertical corrections in Beijing

	API	PM_{10}	API×f(RH)	PM_{10}×f(RH)
AOD	0.817	0.868	0.883	0.917

RH < 85%, API > 50, major pollutant is PM_{10}, time period is 4—11 October, 2004 (no data on 10 October), the number of data pairs is 7.

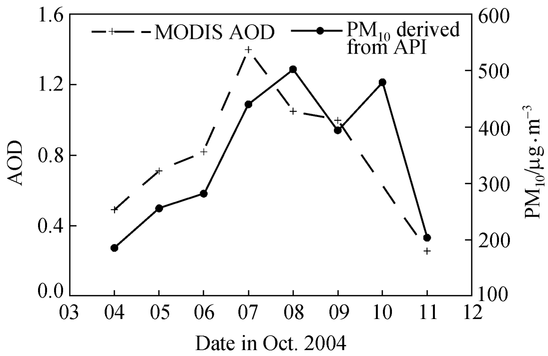

Fig. 3. Daily changes of AOD and averaged PM10 mass concentration corresponding to API. The black circles represent API, and the crossings represent AOD.

Figure 4 shows the back trajectories by applying the wind field simulated by MM5 and the trajectory analysis model HYSPLIT of NOAA. Two domains nesting were adopted in MM5. Covering all China, coarse grids were with resolution of 45 km and the number of grid 101×115. Fine grids were with resolution of 15 km and the number of grid 121×121, and could offer fine-mesh forecast to North China. The MM5 simulation applied NCEP 1°×1° back-ground

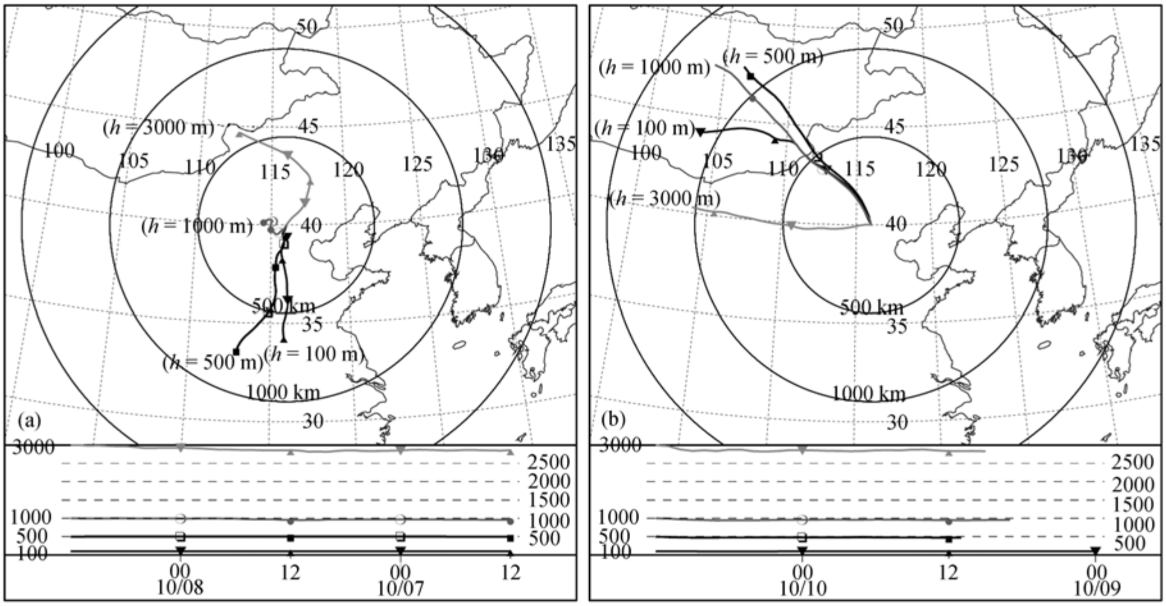

Fig. 4. Back trajectory analysis by applying MM5-simulated wind field and NOAA HYSPLIT model. (a) 20∶00 Beijing Time on 8 October, 2004; (b) 20∶00 Beijing Local Time on 10 October, 2004.

field and initialization field optimized by monitoring information in upper air and on the ground. There were 24 σ layers in the vertical direction, 7 of which were in the boundary layer. Wind field used in the trajectory analysis came from the simulation result of 15 km fine grids. Fig. 4(a) and (b) indicate the back trajectories at 20:00 Beijing Local Time on 8 and 10 October 2004, respectively. We may notice that before 8 October southern and southwestern wind prevailed in the boundary layer. Very weak winds appeared at 1000 m, and in 1000—3000 m wind were mostly northwestern, northern and northeastern. Trajectory at 500 m showed that length of trajectory was around 750 km, corresponding averaged wind speed of 4.3 m/s. On 10 October approximately northwestern and northern trajectories prevailed from the surface all the way to 3000 m. Trajectory at 500 m showed that length of trajectory was over 1000 km, corresponding to wind speed larger than 11.6 m/s.

From the satellite remote-sensing results and back trajectory analysis we could postulate that the pollution episode in Beijing was a part of regional pollution event. The gradual accumulation of locally emitted pollutants under an unfavorable dispersion condition was the main reason for this pollution episode. On the other hand, regional transport from southwestern direction also played an appreciable role, and the evaluation of actual transportation amount should be analyzed in consideration of the distribution of flow field. By examining the corresponding weather charts, we discovered that a near-surface low-pressure convergence zone extending along the Taihang Mountains and Yanshan Mountain to the southwest of Beijing was the major contributor to the regional scale transport that caused this pollution episode in Beijing.

4 High-resolution retrieval of urban aerosol

The AOD with nadir spatial resolution of 10 km provided abundant information to study climate and regional scale air pollution. However, this resolution was not enough for studying particulate pollution in urban scale.

According to the algorithm developed by Kaufman et al.[2], we obtained AOD distribution with the resolution of 1 km in Beijing and its surrounding area by combining ground-level monitoring with simulation by a radiative transport model. Fig. 5 illustrates an annual averaged AOD retrieval result in 2003. Preliminary results showed that the error of our algorithm was around 20%, mostly from determination of high-

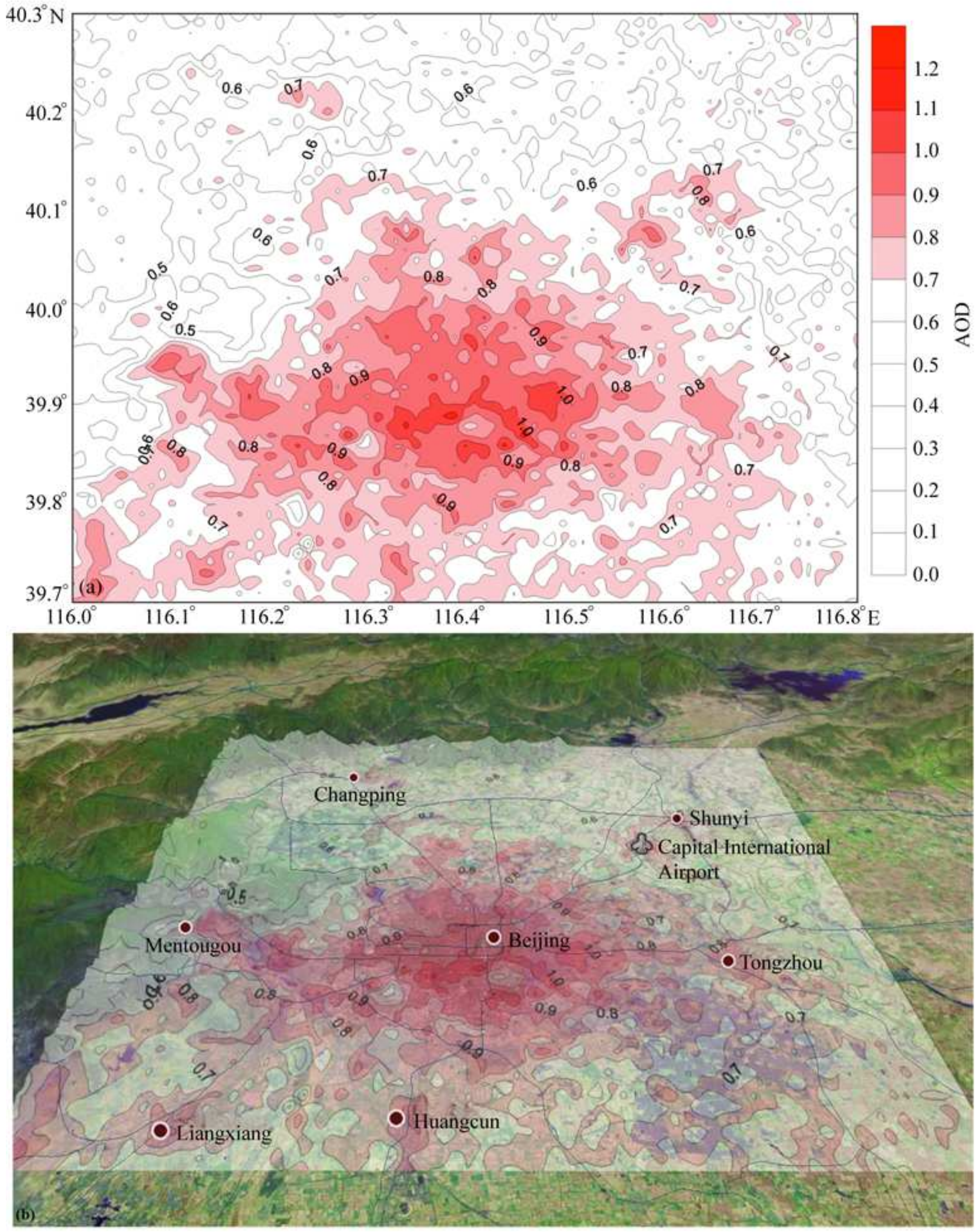

Fig. 5. Annual averaged distribution of AOD in Beijing and its surrounding region retrieved from MODIS products. (a) The retrieval result of annual averaged AOD; (b) the retrieval results onto the remote-sensing map provided by Google Earth.

resolution clouds, evaluation of reflectance in surface boundary and hypothesis in an aerosol model, etc.

Figure 5(a) shows the distribution of isopleths only, while in Fig. 5(b) the retrieval results are superimposed onto the remote-sensing map provided by Google Earth (http://earth.google.com/). This map presents the main roads, position of Capital International Airport, geographical position of large towns around Beijing (Changping and Shunyi to the south, Tongzhou to the east, Mentougou to the west, and Liangxiang and Huangcun to the south) and 3-D terrain. It could be observed that the annual averaged AOD ranged from 0.5 to 1.2 in the urban area of Beijing and surrounding towns; regions with higher population density such as major towns and airports coincided well with the AOD hotspot; regions with

AOD higher than 0.9 was mostly inside the 3rd ring road; in the center belt of Beijing there were two low-value areas (AOD 0.8—0.9) with one situated at the Temple of Heaven and the other around Beihai, Zhongnanhai and The Forbidden City area; between these two areas from southwest of Qianmen to Beijing Railway Sta- tion this west-east oriented region has higher AOD values.

This AOD pattern confirmed that AOD large value area coincided well with the regions with dense population and frequent transportation and commercial and industrial activities, indicating that high-resolution satellite remote-sensing has large potential application value in monitoring the source distribution of particulate pollutants. Further studies should combine the ground-level monitoring of particulate to analyze the quantitative resolving capability of satellite monitoring results to the pollutant distribution on the ground.

5 Conclusion

In this study we first took advantage of AOD observations from sun photometer to determine the accuracy of MODIS remote-sensing AOD results in Beijing. The relative error of satellite remote-sensing was a little higher than the international standard from comparison with AERONET stations as a possible result of influence from sandstorm aerosols. The direct correlation coefficient between AOD and API was not very satisfactory, however, the correlation improved to 0.54 for 360 pairs of data after taking account of the seasonal vertical distribution and real-time RH influence. The correlation coefficient would improve further if AOD is mapped on surface AEC with daily vertical distribution information. This result indicated that it is possible to apply satellite in monitoring PM_{10} mass concentration distribution on the ground, in particular subject to vertical and RH corrections. Satellite remote-sensing results could fill the gap of limited number of monitoring stations on the ground, and be able to involve in quantitatively monitoring air pollution. In the pollution episode in October 2004, the satellite remote-sensing AOD distribution and daily variation reproduced the developing process of the pollution episode in great detail. The correlation coefficient between AOD in urban area of Beijing and API values went up to 0.82, and the coefficient became as high as 0.92 after conversions API to PM_{10} mass concentration and considering RH influence. From the satellite remote-sensing and back trajectory analysis from the meteorological simulation in the boundary layer, this pollution episode was a part of regional pollution event, with most of the pollutant in Beijing from regional transport from southwestern direction and local accumulation of pollutant emissions. The convergence zone in front of the Taihang Mountains and Yanshan Mountain is a major way for regional scale transport that had large impact to the AQ in Beijing. The annual averaged results retrieved from MODIS products sub-stantiated that AOD large area in Beijing coincided well with the regions with dense population and frequent transportation and commercial and industrial activities, indicating that high-resolution satellite remote-sensing has large potential application value in monitoring the source distribution of particulate pollutants. Further studies should focus on improving the absolute accuracy of remote-sensing products, and combining the high-resolution remote-sensing results with the abundant ground-level monitoring and geo-graphical information system.

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