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# Column and Surface Aerosol Optical Properties and Their Association with Meteorology in the Yangtze River Delta

**K. Raghavendra Kumar, N.S.M.P. Latha Devi**

***Abstract*: Aerosols played an important role in climate change during recent years in China. Many kinds of researches in different areas in China, particularly over the Yangtze River Delta (YRD) region in East China is measured during the period from January 2013 to December 2015. The Moderate Resolution Imaging Spectroradiometer (MODIS) derived aerosol optical depth (AOD), particulate matter concentrations ($PM_{2.5}$) and surface black carbon (BCS) was used in this study. Nanjing, Hangzhou, Shanghai, and Ningbo have been selected in this research as they are the major cities of the YRD region that represents different environments. Variation of $AOD_{550}$, Ångström exponent ($AE_{470-660}$) and $PM_{2.5}$ are mainly discussed, and meanwhile, the relationship that exists between them and with the meteorology is also discussed in this work. Apart from this, the impact of visibility and water vapor are also considered to examine the influence on optical properties. The data and analysis indicate that urban cities have a higher value of AOD than rural background cities. High AOD was noticed in summer than in other seasons. AOD usually has a negative relationship with AE, except in summer. Similarly, the $PM_{2.5}$ has a negative relationship with AOD, whereas, BCS has a positive correlation with AOD. Further, it was observed that the rise in temperature resulted in high AOD concentration. The visibility has negative effect on AOD, whereas, AQI follows similar pattern as that of visibility.***

***Keywords* : AOD, Meteorology, MODIS, $PM_{2.5}$.**

## I. INTRODUCTION

Atmospheric aerosols consisting of a variety of solid and liquid particles suspended in the atmosphere is an important component of the earth-ocean-atmosphere system. Aerosols are considered to affect the climate system through direct interactions with solar and terrestrial radiation (direct aerosol effect) and through their effects on the optical and microphysical properties and a lifetime of clouds (indirect aerosol effect). Aerosol lifetime can be just a few weeks or even shorter, and their sources are distributed very unevenly so that the spatial and temporal distribution of aerosol is far from homogeneous [1,2]. The biggest uncertainty in climate change, even by the best available models, is due to uncertainties in aerosol radiative forcing [3-6]. This uncertainty arises mainly because of our poor understanding of both aerosol temporal and spatial distributions and their associated properties. Detailed knowledge of long-term temporal changes of local, regional, and global aerosols is needed to improve our scientific understanding of their sources and sinks, and to provide evidence as a basis for policymakers [7-14]. Aerosols also influence air quality and therefore, affect human health and reduce visibility [15-17].

China has experienced unprecedented economic development in recent decades due to extensive urbanization, industrialization and an increase in population and traffic. This historically unparalleled economic growth has significantly improved Chinese living standards that have also brought serious environmental damage and degradation. Satellite-derived aerosol optical depth (AOD) and Angstrom exponent (AE) are useful parameters for the estimation of optical and physical characteristics of aerosol on the regional scale. In the past several years, several studies have been carried out in different areas and to extend further level this study has been conducted. Fan et al. [18] retrieved and analyzed the optical and physical properties of aerosols in Xianghe and Beijing. Cheng et al. [19] studied seasonal variation and differences in AOD over Shanghai. All of these studies contribute to the understanding of the aerosol optical properties.

In this study, MODIS data of AOD, AE, surface black carbon and $PM_{2.5}$ concentrations and so on was downloaded from the website http://giovanni.gsfc.nasa.gov/giovanni/, and meteorology data was obtained from www.wunderground.com. In this study, continuous 3-years (2013-2015) data were collected to find out the variations of AOD, AE, $PM_{2.5}$ and their relationships in light of meteorology.

## II. STUDY REGIONS AND METHOD

### A. Site Description

The YRD region includes Jiangsu province, Shanghai, and Zhejiang province nearby the East China Sea, and the Yangtze River. The YRD region is a temperate region with hot summers and more rainfall, but dried and cold in winter; meanwhile, the wind usually blows from east or south-east in summer but north or north-west in winter.

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We choose Nanjing, Hangzhou, Shanghai, and Ningbo as representative areas in the YRD region. In these four cities, Nanjing is an urban city far away from the East China sea; Hangzhou and Shanghai are both urban cities and near to the coast; whereas, Ningbo is a suburban city and prevailed with the coastal environment.

Meanwhile, many factories have been set in Nanjing, Hangzhou and Shanghai. Nanjing and Shanghai are the biggest industrial cities in East China, which means numerous industrial aerosols loading are producing over these regions. Ningbo, in which, aerosols are mainly from the sea and other anthropogenic producing activities.

### B. Data and Method

The Moderate-resolution Imaging Spectrometer (MODIS) has been flying aboard Terra since December 1999 and aboard Aqua since May 2002. MODIS observes spectral radiance in 36 wavelength bands, ranging from 0.415 to 14.235 mm, with spatial resolutions of 250–1 km, depending on the channel. From polar orbit (700 km), MODIS views a 2300 km wide swath, providing near-daily coverage of Earth's surface and atmosphere. This combination of swath, resolution, and spectral information is great enough to enable statistical retrieval of aerosol. By aggregating the finer resolution pixels, MODIS can separate cloudy and clear sky pixels so that there are enough signals to consistently and accurately retrieve aerosol properties on 10 km×10 km resolution [20]. The MODIS dark-target algorithm refers to the separate retrievals over "dark" (e.g., vegetated) land and "dark" (non-glint) deep ocean areas. The most recent versions of the algorithms have been used to derive aerosol products from the entire time series of MODIS spectral observations, known as Collection 6 (C006). Global validation exercises have indicated expected uncertainties for AOT at 550 nm over ocean and land respectively. These total uncertainties include uncertainties in our assumptions of aerosol optical properties, radiative transfer through the atmosphere, and errors in the computational aspects. The total uncertainty also includes uncertainties in assumed land surface optical properties, as well as issues of cloud masking, pixel selection, instrument calibration, and precision, etc [20,21,22,23,24]. We use the official Level-2 aerosol products (MOD04_L2, MYD04_L2) with the best quality assurance flag value (QA=3).

## III. RESULTS AND DISCUSSION

### A. Temporal changes in optical properties

Fig. 1 shows monthly and seasonal variations of AOD at 550 nm in four cities. The peaks usually appear in winter and summer, especially in the summer of 2014, and sometimes in spring. Several types of researches indicate that it is usually AOD high in winter or autumn because of the burning of agricultural residues after harvest in autumn and heating for getting warmth in winter, and the wind blows aerosols with bags of dusts from north-west China in spring, which will be discussed later. Meanwhile, AOD is high in summer is usually caused by high temperatures, humidity, and more water vapor. Another factor is secondary aerosol formation due to the photochemical process that has been taking place in the atmosphere. In addition to this, the biomass burning and fires nearby surrounding regions also cause an increase in columnar aerosol loading. A similar situation has been observed in other cities too. Further, it is noted that the high AOD in summer is due to the photochemical production of secondary aerosols and hygroscopic property of aerosol with increased water vapor and relative humidity.

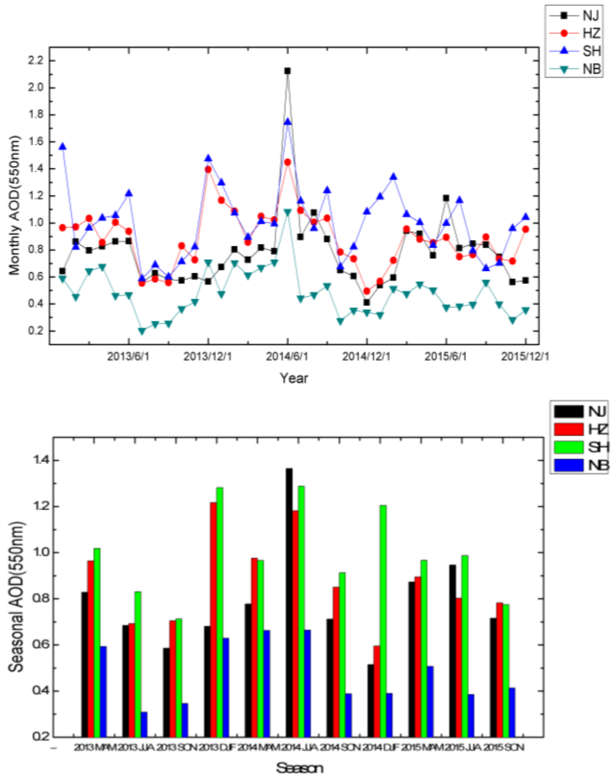


**Fig. 1. Monthly (top) and seasonal (bottom) variations of AOD.**

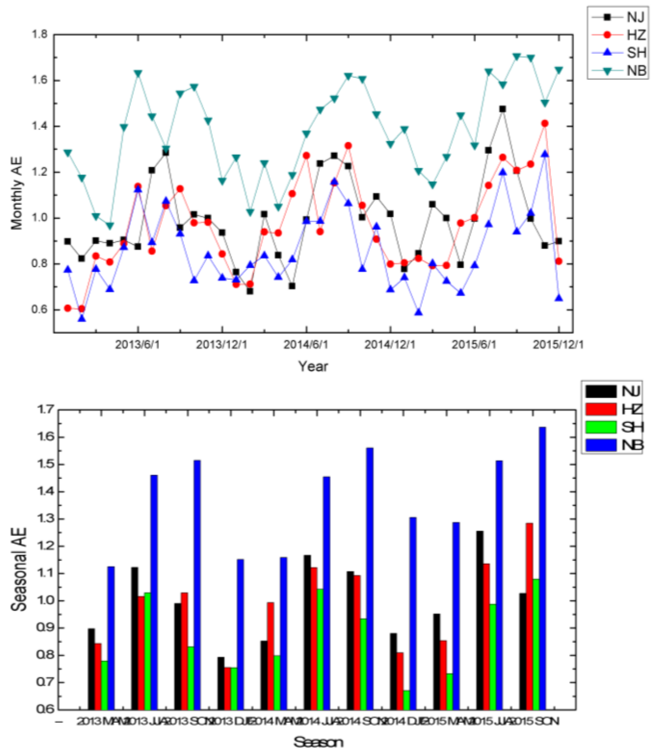


**Fig. 2. Same as in Fig. 1, but for AE.**

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Both figures showed that the value of AOD in Shanghai is the highest, followed by Hangzhou and Nanjing with Ningbo is the lowest (Fig. 1). As has been noticed before, Shanghai and Hangzhou are both urban and coasted cities; it means there are more fine particles aerosols from the sea than Nanjing. Whereas, Nanjing is an urban and industrial city; while Ningbo is a suburban city; and hence, Nanjing has a higher loading of aerosols than Ningbo.

Fig. 2 shows the monthly and seasonal variation of AE over the four cities. Just the opposite with AOD, the value of AE is usually high in autumn and low in winter and spring. It shows a negative relationship between AOD and AE. But it is not applied to summer, during which both AOD and AE had a high value. Some studies showed that more water vapor and high humidity in summer would cause hygroscopic growth of aerosols leading to higher AE [19]. But in spring and winter, drier air mass and the wind dust from the surface ground up causing coarse particles aerosols getting more and finally lead to a low value of AE. The similar results have been observed by Cheng et al. [19] over Shanghai and Fan et al. [18] over Beijing.

### B. CHANGES IN $PM_{2.5}$ AND RELATION WITH AOD

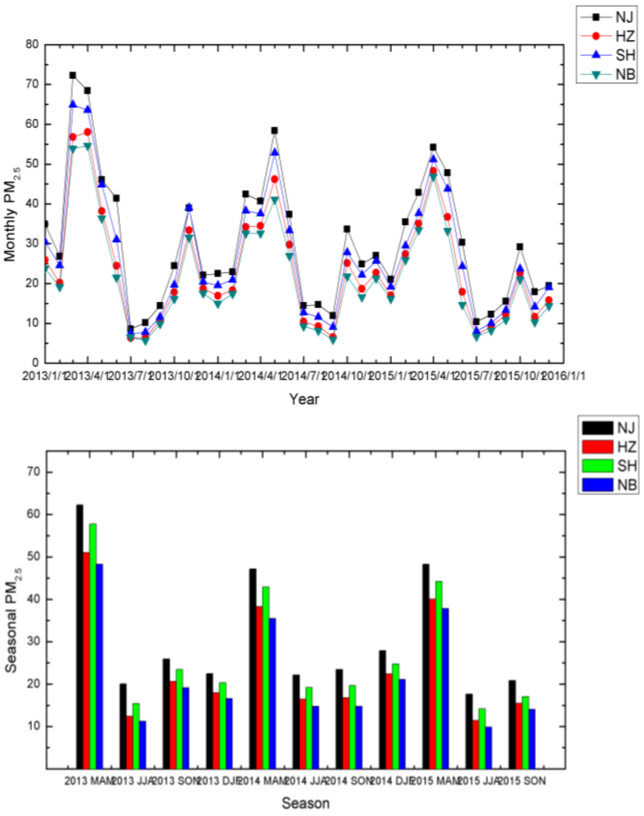


**Fig. 3. Same as in Fig. 1, but for $PM_{2.5}$.**

Fig. 3 shows the monthly and seasonal variation of $PM_{2.5}$. It is shown in Fig. 3 that all four cities have a similar tendency of $PM_{2.5}$. The value of $PM_{2.5}$ is high in spring but low in summer. It may be caused by lower wind speed in spring that pollutants cannot be spread effectively. The value in Nanjing is higher than in Shanghai and the other two cities. It is unusual because Shanghai has more population, factories, and vehicle than Nanjing. However, a policy was carried out in Shanghai during October of 2013 that many private cars were limited to use, and lots of heavy pollution factories were requested to reduce production. And this could explain the unusual condition.

Fig. 4 shows the relationship between AOD with $PM_{2.5}$ and surface BC (BCS) mass concentration. The red and blue lines represent the fitting line of BCS mass concentration and $PM_{2.5}$ respectively. Fig. 4 shows that AOD has a positive correlation with $PM_{2.5}$, which can be explained by $PM_{2.5}$ is also a component of aerosols as a fine particle, high value of $PM_{2.5}$ will cause the high value of AOD. And the same as BCS with AOD in three cities without Nanjing, because black carbon is also a component of aerosols as fine particles from burning. BCS with AOD has a negative correlation in Nanjing; it may be caused by the hygroscopic growth of aerosols in the summer season.

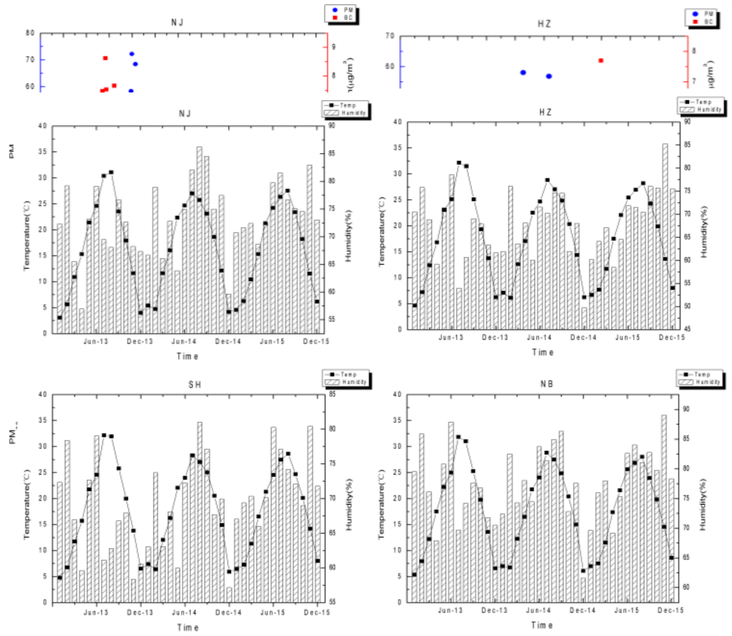


**Fig. 5. Monthly changes in observed meteorological parameters.**

Fig. 5 shows the temperature and humidity of four cities, as is shown in the graphs, temperature and humidity are all high in summer in four cities, and humidity is also high in autumn, combined with Fig. 1. Something unusual could be found that it usually high temperature and humidity would cause the high value of AOD, but the value of AOD in summer in 2013 and 2015 is lower than that in 2014. While both temperature and humidity in 2013 and 2015 are higher than in 2014. This condition can be explained by limited water vapor content in the 2014 summer, leading to drier air and heavier convective motion in summer than other seasons could cause more dust on the surface blowing up, and coarse particles dominated. Hence, the AOD value in 2014 summer higher than summer in 2013 and 2015. The variation of AE confirms that the value of AE in 2014 summer are lower than in 2015 in three out of four cities except for Shanghai, which means more coarse particles in 2014 summer than 2015.

### D. IMPACT OF VISIBILITY AND WATER VAPOR ON AOD

Fig. 6 combines with Fig.1 shows that when AOD has a rising trend, visibility has a downtrend, which means AOD has a negative relationship with visibility.

It can be explained by more coarse particles dominated causing less visibility. The same situation has been observed by several investigators over different places in China [18,19]. Fig. 6 shows water vapor in Nanjing and Hangzhou, while data of Ningbo and Shanghai is not available. It can be seen that the value is high in summer and quite low in winter.

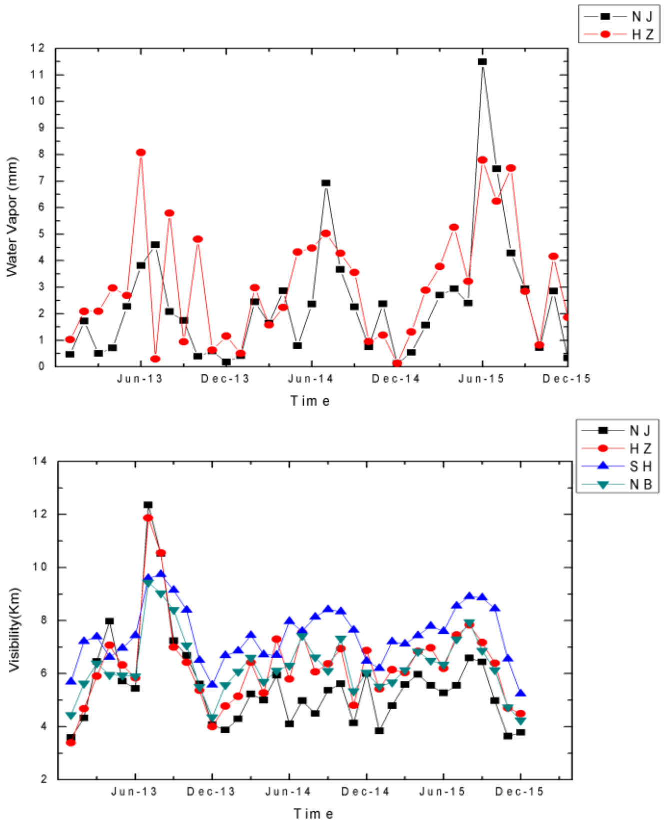


**Fig. 6. Temporal variations of column water vapor content (top) and visibility (bottom) in association with**

## IV. CONCLUSIONS

AOD is high in summer because of high temperature and humidity. And AE has a negative correlation with AOD, but it can be dominated by fine particles and hygroscopic growth of aerosol causes the value of AE is also high in summer. AOD is also high in winter and sometimes in spring; it may be caused by burning from agriculture residues, dust transport from north-west China and aerosols from surrounding industrial areas blow through. Three out of four cities are dominated by coarse particles, except Ningbo. It seems that the urbanization level and geographic position has an important influence on AOD and AE. The urban and industrial (coastal) cities would have a larger possibility of a higher value of AOD and higher (lower) AE than suburban and inland cities. These results on surrounding cities would have effects in AOD and AE too. The $PM_{2.5}$ has a negative relationship with AOD, whereas, BCS has a positive correlation with AOD. Further, it was observed that the rise in temperature resulted in high AOD concentration. The visibility has a negative effect on AOD, whereas, AQI follows a similar pattern as that of visibility. Wind also plays an important role that wind from the northwest may take much dust from the Mongolia region and wind from north-east may take more coarse particles from the sea. Meanwhile, high wind speed may blow up more local dust from the surface and low wind speed may because pollutants are able to spread soon leading to higher AOD value.

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