Study on Aerosol Properties Based on CALIPSO in Representative Regions over China

Xing-xing GAO, Yan CHEN*, Lei ZHANG and Wu ZHANG

Key Laboratory of Semi-Arid Climate Changes with the Ministry of Education, College of Atmospheric Sciences, Lanzhou University, Lanzhou 730000, China

*Corresponding author

Keywords: Aerosol, Vertical distribution, Optical properties, CALIPSO.

Abstract. To assess the aerosol direct and indirect radiative forcing, this paper analyzed the seasonal aerosol optical properties and vertical distribution characteristics in eight representative regions over China by using CALIPSO Level 2 products. The seasonal aerosol optical properties were validated by the AERONET data. The results show that the Taklamakan Desert (TD) and Tibet Plateau (TP) have the greatest depolarization and color ratios (PDR and CR) while the Northeast Plain (NP), Sichuan Basin (SB), North China Plain (NCP) and Yangtze River Delta (YRD) have the smallest PDR and CR, the Loess Plateau (LP) has intermediate PDR and CR, and that the Pearl River Delta (PRD) has the same PDR and greater CR compared with the polluted regions. The dust is transported to the middle and upper troposphere in spring, the strong vertical convection activities in summer transport massive aerosols from the atmospheric boundary layer to the free troposphere, and the stable meteorological conditions in autumn and winter trap massive aerosols within the boundary layer. The ratio of the AOD within 1.5 km above the ground to the total AOD and the extinction lapse rate in winter are greater than those in other seasons and 48.25% and 0.13 km$^{-2}$, respectively. The extinction lapse rates in the planetary boundary layer for the heavier polluted regions are greater than those in the polluted regions.

Introduction

In recent years, with the rapid development of China's economy and the speeding up of urbanization, environmental air quality in China has worsen to seriously affect the people's life and public safety. There for, the research on the characteristics of atmospheric aerosol in China has an important practical significance. The aerosol vertical distributions play an important part in the atmospheric thermal structure’s change and the aerosol-cloud interactions.

In many previous works aerosol vertical profiles were obtained through the plane experiments and the ground lidars [1]. However, a wide range of aerosol vertical profiles using these methods cannot be got. Active remote sensing satellites can be used to make up for the shortage. The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite is the first spaceborne polarization lidar to provide continuous observation of the cloud and aerosol vertical distributions worldwide.

Domestic and foreign scholars have made some researches on the atmospheric aerosol vertical distribution characteristics. For example, Brigitte Koffi in 2012 evaluated the annual and seasonal aerosol extinction profiles over 13 sub-continental regions estimated by the global models using CALIOP layer product [2]; Gao in 2016 analyzed the spatial and temporal variation characteristics of 532nm total backscatter coefficient, PDR, CR, and different types of aerosol over North China from 2006 to 2015 by using CALIPSO products, and analyzed vertical distribution characteristics of aerosol under different visibility conditions over North China based on surface observation data [3]. However, the research on exploring aerosol vertical distribution characteristics according to different types of aerosols is very rare, and the research on vertical distribution characteristics of seasonal aerosol extinctions in China based on CALIPSO products is also very little.
This paper selected eight representative regions over China (rectangular boxes in Figure 1). Firstly, it analyzed the spatial distributions of AOD for various types of aerosols in China using CALIPSO level 2 aerosol layer products; Secondly, it analyzed the season aerosol optical properties over eight representative regions and validated them by the AERONET data; Thirdly, it analyzed the vertical distributions of seasonal aerosol extinction coefficients over eight representative regions using CALIPSO level 2 aerosol profile products; Lastly, it explored the relationship between aerosol and atmospheric stability by analyzing aerosol extinction lapse rate. The purposes of the paper are to provide input data for the models to accurately assess aerosol direct and indirect effects on the weather and climate, and provide theoretical basis for the study on the atmospheric aerosol characteristics in China and for making air pollution control policies by the state.

![Figure 1. Study regions and AERONET sites.](image)

**Data and Its Processing**

The CALIPSO Level2 5km cloud layer products, aerosol layer products and aerosol profile products from June 2006 to September 2016 were used in this study. All the satellite data were interpolated to a resolution of 1° x 1°. First of all, CALIPSO cloud products were used to remove cloud interference from CALIPSO aerosol products. Subsequently, the quality controls were carried out to reduce errors before CALIPSO data are used. Because the thresholds in the daytime are higher than those at night because of daytime solar background illumination, only the data at night were analyzed except where noted [4].

The Semi-Arid Climate and Environment Observatory of Lanzhou University (SACOL) and Beijing in spring were considered as representative regions for dust aerosols and mixture aerosols, respectively. Beijing and Taihu in summer were both viewed as representative regions for anthropogenic pollution aerosols. To validate season optical properties for different types of aerosol, the aerosol volume size distribution (dV/dlnR), single scattering albedo (SSA) and Ångström exponent ($\alpha_{440-870}$) from the Aerosol Robotic Network (AERONET) were selected for SACOL in spring, Beijing in spring, Beijing in summer and Taihu in summer. SACOL (35.946°N, 104.137°E), Beijing (39.98°N, 116.38°E) and Taihu (31.42°N, 120.22°E) site locations are shown in Figure 1. Data for SACOL, Beijing and Taihu were available from 28 July 2006 to 10 August 2012, from 9 March 2001 to 23 March 2015 and 6 September 2005 to 4 October 2012, respectively. $\omega_{abs440}$ is the absolute difference between 1 and SSA, $\alpha_{440-870}$ greater than 0.75 means fine mode aerosols, otherwise it means coarse mode aerosols. $\omega_{abs440}$ greater than 0.07 means strongly absorbing aerosols, otherwise it means weakly absorbing aerosols [5].
Results

Seasonal Spatial Distribution of AOD

Note that the AOD in Figure 2 are from daytime observations besides nighttime observations. CALIPSO observations in Figure 2 show that the highest AOD at 532nm are located in the TD, NCP, SB and YRD. These regions except TD are also highly populated regions and observed the greatest \( \text{PM}_{2.5} \) concentration. The season spatial distribution of pure dust AOD fraction and polluted dust AOD fraction over China are also plotted (not shown). The highest pure dust AOD fraction appear in Northwest China and TP, which are association with the dust source regions in Northwest China and transported dust from the TD. The highest polluted dust AOD fraction appear in NCP. The polluted dust in NCP mainly include anthropogenic pollution aerosols.

![Figure 2. The spatial distributions of the season AOD at 532nm over China.](image)

Season Aerosol Optical Properties

Most of the dust aerosols dominating in the TD and TP regions are scattered in the top right area in Figures 3a and 3b, corresponding to large and non-spherical particles. However, the anthropogenic pollution aerosols dominating in the NEP, SB, NCP and YRD regions are mostly scattered in the bottom left area in Figures 3d, 3e, 3f and 3g, corresponding to small and spherical particles. Aerosols mixed with dust and anthropogenic pollution aerosols in the LP region are evenly scattered from the bottom left area to the top right area in Figures 3c, corresponding to intermediate particles. Compared with those polluted regions, the data points in the PRD region have similar pattern of spatial distribution and greater CR, which is closely associated with larger-sized marine sea salt aerosols.

The scatters on seasonal mean integrated PDR and CR in eight representative regions are plotted (not shown). The winter regional average PDR are the highest in the TP and NEP regions, and the highest regional average PDR in other regions appear in spring and greater than 0.1. The summer regional average PDR are the lowest in all representative regions. All the data points in the TD and TP regions are scattered in the top right area indicating large and non-spherical particles, but all the data points in the NEP and PRD regions are scattered in the bottom left area indicating small and spherical particles. The data points in the LP, NCP, SB and YRD regions are scattered along the regression line from the bottom left area to the top right area with the order of summer, autumn, winter and spring.

The SACOL data points in spring in Figure 5 are mainly scattered in the bottom right area (\( O_{440-870} < 0.75 \) and \( \omega_{oabs440} > 0.07 \)), corresponding to large and absorbing particles. Figure 4 shows that in spring over SACOL the coarse mode peak is higher than fine mode peak and the spectral SSA shows an increasing trend. The Beijing and Taihu data points in summer are mostly scattered in the top left area (\( O_{440-870} > 0.75 \) and \( \omega_{oabs440} < 0.07 \)), corresponding to small and weakly absorbing particles. Besides, in summer over Beijing and Taihu the coarse mode peak is lower than fine mode peak and the spectral SSA shows an decreasing trend. The Beijing data points in spring in the bottom right area are almost as much as those in the top left area, its coarse and fine mode peaks both fall in between...
peaks over SACOL in spring and peaks over Beijing and Taihu in summer, and its spectral SSA trend is different from others. These results prove that the dust-dominated aerosols have the characteristics of large and non-spherical particles, anthropogenic pollution aerosols have the characteristics of small and spherical particles, and that mixture aerosols mixed with anthropogenic pollution and natural dust have intermediate PDR and CR observed by CALIPSO in Figure 3.

Figure 3. The scatter plots on the integrated particulate depolarization and color ratios.

Figure 4. (a) The volume size distribution and (b) the SSA.
Figure 5. The scatters on the $\omega_{\text{abs}440}$ and the $a_{440-870}$.

Figure 6. The seasonal vertical profiles of the extinction coefficients in eight representative regions over China.

**Seasonal Aerosol Vertical Distribution Characteristics**

Figure 6 shows aerosol extinction coefficient profiles for eight representative regions. The dust is transported to the middle and upper troposphere in spring over eight representative regions. The dust-dominated aerosols in spring have the largest regional average PDR of 0.3 and the highest extinction coefficients in the TD region. In the TP region, below 6.5km the extinction coefficients in
spring and summer are larger than those in autumn and winter, but above 6.5km the extinction coefficients in spring and summer are lower than those in autumn and winter. In the NCP region, the seasonal extinction coefficient vertical distributions are similar to those in the LP region except that lower extinction coefficients because of lower aerosol concentrations. In the SB, NCP and YRD regions, because high anthropogenic emissions, efficient secondary aerosol formation and stable meteorological conditions cause more aerosols, extinction coefficients within the atmospheric boundary layer in these regions are larger than those in summer in the TD region. Note that in the SB region autumn extinction coefficients within the atmospheric boundary layer are low because of low SO$_2$ and NO$_2$ concentrations and fewer sunny days. In the PRD region, extinction coefficients within the atmospheric boundary layer in autumn and winter are higher those in spring and summer because of lower planetary boundary layer height in autumn and winter.

Figure 7. The seasonal extinction lapse rates.

Figure 7 shows seasonal extinction lapse rates within 1.5 km above the ground for eight representative regions. The winter extinction lapse rate (0.13km$^{-2}$) is highest and the spring extinction lapse rate (0.08km$^{-2}$) is lowest. In the SB, NCP, YRD and PRD regions extinction lapse rates are higher than those of other regions because of heavier pollution. In the TP region extinction lapse rate is lowest. In the NCP and YRD regions, extinction lapse rates in autumn and winter are higher than those in spring and summer as a result of lower planetary boundary layer height and more black carbon aerosols in autumn and winter. In the TD region, the winter extinction lapse rate (0.12km$^{-2}$) is highest and the spring extinction lapse is higher because of the absorbing dust aerosols in spring.

The seasonal ratios of the AOD within 1.5 km height above the ground to the total column AOD for eight representative regions over China are calculated. Because the strong vertical convection activities in summer transport massive aerosols from the atmospheric boundary layer to the free troposphere, the ratio of the AOD within 1.5 km above the ground to the total AOD in summer (40.76%) is lowest. The stable meteorological conditions in autumn and winter trap massive aerosols within the boundary layer, so the ratio of the AOD within 1.5 km above the ground to the total AOD in winter (48.25%) is highest and closely followed by the ratio in autumn (43.43%).

Conclusions

This paper used CALIPSO Level2 data and AERONET data. After CALIPSO Level2 data were strictly processed, they were analyzed. Therefore, the results have high reliability in this paper.

The pure dust mostly appears in NEP and TP and the polluted dust mostly appears in NCP. In eight representative regions over China, the TD and TP have the greatest PDR and CR while the NEP, SB,
NCP and YRD have the smallest PDR and CR, the LP has intermediate PDR and CR, and the PRD has the same PDR and greater CR compared with the polluted regions.

The dust is transported to the middle and upper troposphere in spring, the strong vertical convection activities in summer transport massive aerosols from the atmospheric boundary layer to the free troposphere, and the stable meteorological conditions in autumn and winter trap massive aerosols within the boundary layer. The extinction lapse rates in the planetary boundary layer for the polluted regions are greater than those in the less polluted regions.

Acknowledgement

This research was funded by National Natural Science Foundation of China (41430425) and the Fundamental Research Funds for the Central Universities (lzujbky-2016-k01). We thank the Atmospheric Sciences Data Center at NASA Langley Research Center for providing CALIPSO data.

References


