Recent Researches on Aerosol in China①

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ABSTRACT P42 A

In recent years, the Chinese scientists have undertaken numerous researches on aerosol, and made many achievements. This paper reviews the above researches on aerosols which mainly focus on the following three aspects: the characteristics of aerosols, the effects on climate, and dust aerosol research. Present international research plans in relation to aerosols are briefly introduced. The important fields and trends of atmospheric aerosol researches in the near future are also pointed out and discussed.

Key words: Aerosol, China, Summary

1. Introduction

Aerosols are particle and/or droplets suspended in air. They are mainly from soil, ocean, biomass cycle, volcano, and chemical processes in the atmosphere, etc. Aerosols in general have the significant potential to influence the radiative transfer through the atmosphere and the atmospheric water cycle, thus influence the Earth's climate directly and indirectly. Although some aerosol particles may absorb thermal radiation and hence have greenhouse effect, the major influence of aerosols is scattering the incoming solar radiation, thereby increasing the planetary albedo and cooling the Earth's surface. Anthropogenic aerosols acting as cloud condensation nuclei are believed to increase the number concentration of cloud droplets, and thereby influence the radiation balance. Researches show that the increase of anthropogenic aerosols may partly compensate the warming effect of the increasing greenhouse gases (Wang, 2000).

The increase of anthropogenic aerosols will reduce visibility of the atmosphere, hence affects the navigation safety. Aerosols play an important role in many biogeochemical cycles, by providing reaction sites and acting as carriers for many condensed and absorbed species. Some of the aerosols have effects on the biosphere, including the health of human beings. The rapid development of modern social production and social civilization underscores the further study of bioaerosols, which can cause many respiratory diseases (Che, 1997).

In recent years, with the development of industry and agriculture, a large amount of anthropogenic aerosols are emitted into the atmosphere. Besides, one-third of the world's arid and semi-arid lands lies in Asia, and the largest deserts are in the northwest of China. In spring, a large amount of dust particles are emitted into the atmosphere and transported downstream thousands of miles away (Zhang et al., 2000a).

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Under the support of National Natural Science Foundation of China and several international joint research projects, Chinese scientists have been undertaking various researches on aerosols in recent years, which are summarized in this paper.

2. Major achievements of aerosol research in China

2.1 *Characterization of aerosols*

The climate and environmental effects of aerosol depend on their physical (size, shape, number), chemical (composition), and optical (refractive index) properties. Aerosol particles have a short lifetime in the atmosphere and hence have large spatial and temporal variability. Therefore, the physical, chemical and radiative properties of aerosols are variable and less well characterized.

Chinese scientists have investigated the physical, chemical and radiative properties of atmospheric aerosols and their temporal and spatial distributions.

2.1.1 *Sources and distribution of aerosols in boundary layer*

Based on the monitoring data collected at regional background stations (Longfengshan Mountain, 44°44′N, 100°54′E and Lin'an, 30°18′N, 119°44′E) and baseline station (Waliguanshan Mountain, 36°17′N, 100°54′E) in China, the temporal and spatial distributions of aerosols were analyzed. The preliminary conclusion was drawn as follows: the highest values of mass concentration of aerosol were observed at Lin'an, the middle at Longfengshan Mountain and the lowest at Waliguanshan Mountain; the mass concentrations of aerosol were higher in autumn than in winter at all the three stations (Yang et al., 1996).

The physical–chemical characteristics of desert aerosol in Heihe region are observed in HeiHe integrated experiment. The diurnal variation of number concentration of aerosols and its relationship with weather conditions are analyzed and discussed (Lei et al, 1993). Concentration of desert aerosol is usually low under normal condition in which fine particles are predominant, striking increase of dust concentration particularly that of coarse particles, is observed during blowing dust periods, which increases by more than 20 times than that on fine days, and the number of particles with diameter of 2.0–10.0(m accounts for 96% of total number of particles, much higher than that on clear days. The diurnal variation of concentration of background desert aerosol is mainly controlled by air disperse dilution.

The aerosol concentrations showed distinct seasonal and geographic variations depending on the variation of East Asia monsoon system and the distance to the Asia continent origin of aerosol (Liu et al., 1999a). The atmospheric input of aerosols to the East China Sea was estimated. The input flux of crustal elements (mineral aerosol) account for 40% of the total input flux of crustal elements through the atmosphere and river into the Yellow Sea in the spring (Liu et al., 1999b). These results indicated that the natural and anthropogenic aerosols over the Asian continent had great effects on the origin, composition and distribution of marine aerosol. The size distribution, diurnal variation, daily variation of atmospheric aerosols have a good connection with relative humidity and Richardson number (Zhang et al., 2001).

For the study of marine aerosol, aerosol samples and two cascade impactor samples were collected in the atmosphere over the western Taiwan Strait from 1991–1993 and analyzed by atomic absorption spectrophotometry. Annual and seasonal variations of concentrations, size distribution of the metals and impact factors are studied (Chen et al., 1998). The sources of mental over Taiwan Strait were identified base on the above observation (Chen et al., 1999).

Yang et al. (1993) reported an investigation on the variability of marine aerosol over the western Pacific Ocean. In the atmosphere over remote marine areas, the concentrations of trace elements are dominated by the production of sea–salt aerosol particles, while the others are dominated by the transport of weathered crustal material from the continents. It showed that environmental contaminants have altered its composition even over remote regions.

The characteristics and sources of the aerosol in the North of China were studied by Dong et al.(1998) using INAA and PIXE methods. The results indicated that particulate loading over rural areas are much lower than that over urban areas. At rural site, the average particulate mass concentrations in fine fraction was larger than that in coarse fraction, but at urban site a reverse trend was observed. It means that the rural aerosols mainly come from long–range transport of natural and anthropogenic pollutants, which transported from urban to rural areas by wind.

During 1992 to 1994, a systematic observation of the physical, chemical and optical properties of dust aerosol was carried out to investigate the meteorological conditions that affected occurrence and intensity of dust storm and dust plume pathways (Parungo et al., 1995, 1996).

The mass distribution of total aerosol and the distribution of water–soluble chlorine, nitric, sulphuric, sodium, ammouia, potassium, calcium and magnesium ions have been analyzed, over South China and the South China Sea(Wu, 1994,1995). The results show that the concentrations of total aerosol and water–soluble composition at island stations are obviously lower than that at seaboard stations and inland stations. Their size–distribution mostly exhibits a tripeak distribution. The water–soluble sulphuric, chlorine, calcium and sodium ions in aerosols are the most important ions composition islands and at seaboard stations. The concentrations of water–soluble chlorine and sodium ions in aerosols at the island and seaboard stations are obviously higher than that at inland stations of South China, but the concentration of ammonia is lower.

Recent researches on chemical composition of aerosols in Beijing using PIXE show that fine mode aerosols increase more rapidly in the past decade which may be due to the contribution of coal combustion and automobile exhaust (Zhang et al., 2000b). Lead(Pb) content in aerosol is much higher than that at the beginning of the 1980s, and has a decreasing trend in recent years because of using non–leaded gasoline.

2.1.2 *Observation of vertical distribution of aerosol*

The temporal and spatial characteristics of aerosol concentration, mixing ratio, and size distribution for both troposphere and stratosphere are presented and analyzed by using balloon soundings data during the summer and autumn of 1993 in the Xianghe Observation Station (Shi, 1996). The observed profile of aerosol with radius larger than 0.2 μm showed three maxima located at the ground, 5 km, and 10 km, with the number density of about 143, 8 and 1.1 particles/cm^3, respectively. The size distribution volume concentration of aerosols showed bi–mode in the troposphere but the pattern disappears in the stratosphere. Observed number density of aerosols was significantly higher than that in 1984. The concentrations and size distribution of aerosols in troposphere and stratosphere and their relationship to local meteorological condition is studied by balloon observation in Hefei (Zhou J. et al., 1996). The Lidar was also used to observe the evolution of volcano cloud from Mt. Pinatubo in Heifei and Beijing (Zhou et al., 1993).

2.1.3 *Research on the optical characteristics of aerosols*

An atmospheric aerosol radiative model that is suitable for climate model research over China is developed (Mao, 1997), in which the spatial resolution is $1^\circ \times 1^\circ$ and the temporal resolution is 1 quarter. The model can be used to discuss the direct radiative effects of atmospheric aerosols. Zhang and Shi (2000) established a data set of the global anthropogenic sulfate and soot aerosols which can be used in chemical transport model and radiative forcing and climate effects of aerosols.

The spectral optical depth of atmospheric aerosols and their long-term features in the urban area of Beijing are deduced from the long-term direct solar radiation data and PIS spectrometer (Li and Lu, 1996). The results show that aerosol optical depth are thick in spring-summer, and thin in autumn-winter; Also, there is a tendency of year by year increase of the aerosol optical depth (AOD), and on the yearly averaged basis the AOD in 1994 has increased by two thirds of third of that in 1977.

Aerosol optical depths over 10 sites in China during 1980–1994 have been retrieved from radiation and visibility data measured at meteorological stations. Monthly and yearly changes of the optical depths have been analyzed, and the effects of two volcanic eruptions of El Chichon in 1982 and Pinatubo in 1991 have been identified (Qiu, 1995; Qiu et al., 1997). Another research retrieves the annual and monthly mean AOD at the wave length of 0.75 μm by using the daily direct solar radiation and sunshine duration data of 47 solar stations from 1961 to 1990. The results indicate that AOD had an obvious increasing trend over China from 1961 to 1990 (Luo et al., 2000).

Wei and Qiu (1998) proposed a new method to retrieve the imaginary part of complex refractive index of atmospheric aerosol from wide-band solar radiation. Analysis of sensitivity showed that wide-band solar radiation is very sensitive to the imaginary part, but it is not sensitive or weakly sensitive to size distribution, real part, surface albedo and the amount of water vapor and ozone. So it's possible to retrieve the imaginary part from the wide-band radiation. The numerical experiments show that this method has good precision.

Effects of aerosol pollution on solar ultraviolet radiation on the ground are studied, which indicates that aerosol pollution in urban and rural area have decreased the annual amounts of UV-B radiation at the earth's surface by 45% and 10% respectively (Wang and Shu, 1993).

2.2 *Effects on climate*

Aerosols influence climate in two ways, directly through scattering, absorbing solar, and earth's radiation and indirectly via their role as cloud condensation nuclei (CCN), by modifying optical properties and lifetimes of clouds. With the development of science and technology, industrial activities, especially emissions of SO_2, which result in the formation of particulate sulfate (SO_4^{2-}), contribute substantially to tropospheric aerosol, especially to submicrometer aerosol, which is effective in the scattering of short-wave radiation; this kind of aerosols is distributed nonuniformly over the earth and has substantially increased in concentration since around 1850. There is an evidence that anthropogenic sulfate aerosol substantially increases local planetary albedo and is a significant perturbation to climate forcing. Anthropogenic SO_2 emissions (primarily from fossil fuel combustion and metal smelting) have increased rapidly over East Asia in recent years, which substantially exceed natural emissions of sulfur containing gases to the atmosphere. On the basis of the emission data of

industrial sulphur dioxide (SO_2), the distribution of sulphate (SO_4^{2-}) was simulated by a three-dimensional regional model of sulfur deposition and transport (Huang et al., 1995). The direct radiative forcing of SO_4^{2-} on the earth's climate system has been calculated based on the simulated sulphate concentrations. The results indicate that increasing concentration of SO_4^{2-} caused by industrial SO_2 emission may be one of the principal factors which lead to earth surface temperature decrease (Qian et al., 1996, 1998).

A two-dimensional seasonal nonlinear energy balance model has been developed to simulate the climate forcing of aerosols. The simulated results showed that the climate effect of tropospheric aerosol presents strong regional features. The radiative forcing of stratospheric aerosols has also been calculated. It was found that the radiative forcing caused by stratospheric aerosols is related not only to its horizontal variation, but also to the surface albedo. The surface temperature showed a great decrease in late 1992 due to the Pinatubo aerosols, but the perturbation became very small in mid-1996 (Hu, 1998).

Using daily direct solar radiation and sunshine duration data, the annual and monthly mean values of 0.75 μm aerosol optical depth in China are retrieved to analyze their geographical and temporal distribution. Then with the China Regional Model by adding aerosol radiative effect, the aerosol direct radiative forcing and seasonal variation of climate response to this forcing in China are estimated by Zhou et al. (1998).

2.3 *Dust aerosol research*

Many large deserts and much semi-arid land are located in Asia, where dust outbreaks are common and severe duststorms occur frequently in the spring. Furthermore, the anthropogenic pollution in the downstream region is known to be the worst. This background provides an ideal opportunity and experiment platform to investigate the transport of natural dust and anthropogenic aerosols and their effects on the climate and environment.

2.3.1 *Causes and influence of dust storm*

On 5 May 1993 a super severe duststorm, which was characterized by reducing the visibility to < 250 m, occurred in northwestern China. This duststorm covered 1.1×10^6 km^2 and brought severe property damage (Qian et al., 1996). For example, when the dust wall approached Jinchang City (102.5°E, 338.5°N), the visibility was diminished even to zero by the dust; and the irradiance was reduced to near zero in the afternoon (Parungo, 1995; 1996). Many researchers have studied the processes, disasters, weather system features, mass concentration, chemical composition, ion concentrations of dust aerosol during this duststorm (Qian, 1997; Wang, 1997; Yang, 1997). The characteristics of micrometeorology and radiation of the strong dust storm on 5 May 1993 are analyzed by Hu (1997). The growth mechanism of strong dust storm and dry squall line is also studied from characteristics of micrometeorology, radiation and macro- and meso-scale weather processes.

2.3.2 *Physical-chemical characters of dust aerosol*

Many research works have been done on dust aerosols over China and the East China Sea. During the periods of several international cooperative research programs, aerosol data over Beijing, Qingdao, Xi'an, Waliguanshan and the East China Sea were obtained and analyzed. Electron microscope analyses showed that the dust particles over China had distinct irregular shapes and contained crustal elements (Zhou et al., 1996). The physical and chemical characteristics of desert aerosols in the Heife region are also studied (Ren et al., 1995). The in-

ter-annual variation of spring time mineral aerosol in the surface air of Beijing was estimated based on mineral aerosol and meteorological data by using of multiple linear regression analysis, which indicated that the mineral aerosol concentrations over Beijing showed a decreasing tendency between 1971 and 1995, but this tendency slowed down during the 1990s (Liu et al., 1998a).

In the spring 2000, dust storms occurred frequently in Beijing, which result in a bad effect on atmospheric environment quality. Analysis on the chemical composition of "2000/04/06" super dust storm shows that the pollution caused by dust storm is very serious. In the dust storm period, the total concentration of 20 elements reached 1536 $\mu g/m^3$ which is 31.4 times that in the previous spring. Even after the dust storm, the concentration of 20 elements reached 338.7 $\mu g/m^3$, which is 7 times as that in previous spring (Zhang et al., 2000a).

2.3.3 *Transportation and effects of dust aerosol*

Referenced the dust formation and transport models and based on the characteristics of Asia dust, several models are developed to study the transportation of dust aerosol in Asia.

Huang (1998) developed a new model, which is suitable to apply for modeling and forecast of yellow-sand transport for North China with analysis of observed mobilization data of meteorological stations in North China. Based on the model, a long-range transport model for yellow-sand is developed and applied to East Asia. It considered the parameterization of dry and wet deposition, the spectrum of yellow-sand and the micro-physical process in detail. Comparison with observation data proves that the model has good ability to reappear the process of the transport of yellow-sand. Liu et al. (1998b) made two case studies on a dust storm occurring in April 1992 using MM4 (NCAR/PSU) combined with an aerosol transportation model. The simulations show that the strong wind produced by cold front of Mongolian cyclone is the main force for dust lifting. Dust is transported to the upper layer through the daytime vertical turbulent diffusion in planetary boundary layer and the upward current in front zones. The horizontal transportation of dust general occurs in two layers: In lower layer (below 4 km), dust is moved by the cold front; and in upper layer (above 4 km), dust is transported in the westerly belt, which is more efficient and faster than that in the lower layer. The modeled results agree well with the vertical structure of aerosols observed using lidar by Qiu and Sun (1994). Ji and Qing (1996) and Li and Lu (1998) have a similar research work on duststorm process combing the Penn State/NCAR mesoscale (MM4) model and dust transport model.

The impact of mineral aerosols on the particulate sulfate formation in East Asia in March 1994 was studied using a three-dimensional regional-scale atmospheric chemistry model (STEM-II model) coupled with the mineral dust process model. The results indicated that the heterogeneous chemical processes on mineral aerosols account for a significant fraction of the conversion of SO_2 to sulfate during this period, to about 20%. These dust events during the simulation period mainly affect the sulfate amounts over eastern China, closely down-wind of dust source regions, where an increase of over 60% in sulfate is caused by mineral dust (Xiao et al., 1996). The areas with maximum amounts sulfate dioxide and particulate sulfate are located in eastern China. The sulfur emitted from the volcanoes in Japan is responsible for 10% to 30% of the atmospheric sulfur in the local region during this period. The sulfur transport is largely limited to the 2-6 km level of the atmosphere, with the maximum flux occurring in the 30°N to 40°N band which is consistent with the region of maximum anthropogenic emissions (Xiao, 1998a, b).

A comprehensive research on the sources, transport and deposition of Asian dust was conducted based on observational data for dust–carried elements in aerosol particles in desert, loess and inland regions of China (Zhang et al., 1993; Zhang and An, 1997). It shows that major sources for Asian dust lie in northwestern and northern deserts in China. The regional–scale transport of Asian dust is suggested to be dominated by the northwesterly surface wind and mainly attributable to non–dust storm processes, especially in interglacial period. Conversely, the global– transport dust is believed mainly to be the result of the desert dust storm and highly associated with the upper–level westerly wind. The estimates of dry and wet deposition of mineral dust indicate that dry deposition dominated the total atmospheric input of mineral dust to the Chinese Loess Plateau, even under the interglacial climate condition.

In other research, the space transportation routine of duststorm and sources of dust aerosols from Northwest China are analyzed (Jin, 1994). Movements of solid particles including creeping, salting for larger particles and suspending smaller ones were studied. It was demonstrated that complex terrain and turbulence of lower atmosphere increased the dust emission rate (Xuan, 1998).

Dust storms can increase the albedo of localized regions by 50% to over 100%, and this is accompanied by a decrease in direct solar radiation as well as an increase in scattered radiation (Zhou et al., 1994).

2.4 *Other researches*

2.4.1 *Bioaerosols*

In recent years, as a branch of aerosol science, bioaerosol research draws more and more attention. The term of bioaerosols is used to describe aerosols composed of particles of biological origin. It may comprise microorganisms, such as the cells of bacteria, yeast, the spores of actiomycetes, insect and mite microbial products, and plant fragments. Three factors which are bioaerosols, the aerosol generation, airborne transmission, and inhalation, should be emphasized when studying the interactions between bioaerosols and humans (Che, 1997).

2.4.2 *DMS GPC model in marine atmosphere*

A dynamic model of atmospheric aerosol with a simplified dimethyl sulfide (DMS) chemical module is developed to simulate the gas to particle processes conversion (GPC), from DMS to cloud condensation nuclei (CCN) in the boundary layer of remote marine atmosphere (Zhao et al., 1997). The results show that about 5.6% sulfate is generated from DMS oxidation by OH free radical condenses into particle phase that means DMS emitted from oceanic phytoplankton can be a significant source of the non seas sulfate aerosol.

2.4.3 *Nucleation scavenging of aerosols*

The physical processes of the growth of cloud droplets by water vapor condensation and the chemical processes of aerosols and gases in cloud droplets are coupled to study the nucleation scavenging of aerosols. The results show that the nucleation scavenging of aerosols can result in chemical inhomogeneities among cloud droplets, and the inhomogeneities can influence the chemical processes inside cloud droplets (Liu, 1994a, b).

2.4.4 *Analysis technologies*

With the progress of analysis technologies, individual particles of aerosol samples can be analyzed now (Wang, 1996a, b; Zhang, 1996; Zhang et al., 1998). The biogenic feature of

tracer ^{14}C makes it possible to use accelerator mass spectrometry (AMS) method to probe the sources of aerosols (Shao et al., 1996). In addition, the integrating system of gas chromatography, and mass spectrography, can be used to further investigate the distributions and sources of the toxic organic compounds in aerosol particles, such as Polynuclear Aromatic Hydrocarbons (PAHs) (Zhu et al., 1998).

3. Problems and discussions

As mentioned above, Chinese scientists have undertaken amounts of studies on aerosols and made great achievements for a long time, almost covering the whole properties and the temporal and spatial distribution of aerosols in China and the vicinity of China Sea. Aerosols have large variations in temporal and spatial distribution, the methods and approaches of aerosol sampling, measuring, and analyzing are different and lack of comparability. Therefore, how to get comprehensive and representative data sets concerning the real characteristics of aerosols is still a problem.

Combining the technology of satellite remote sensing with surface observing in-situ may provide an efficient way to inverse the parameters of aerosols on a regional scale, such as optional depth, size distribution, and refractive indexes. And comprehensive researches on ARF (aerosol radiative forcing) on climate system with focus on Asia dust aerosols are now under planning.

Though extensive researches have been done concerning the dust aerosols from Sahara desert, researches concerning the dust aerosols from the east of Asia are still very limited. The formation mechanism of duststorm in Asia is not clear yet. Comprehensive studies should be carried out on the sources, characteristics, transportation, deposition and impacts on climate, environment and ecology. As dust aerosols can both scatter sunlight back to the space (leading to a cooling effect) and absorb solar and infrared radiation (leading to a warming effect), there are a lot of uncertainties in the effects of climate changes caused by dust aerosols. Studying on the effects of dust aerosols on climate is a huge task and just at the beginning.

Asia-Pacific Regional Aerosol Characterization Experiment (ACE-Asia) program and China-Japan joint research on dust are now starting in the spring 2001. These programs will include the cross-combination of multi-disciplinary of atmospheric physics and chemistry, photochemistry, environmental and ecological science, and so on. The combination of multi-methodologies including field observation, theoretical analysis, and numerical and laboratory simulations will be undertaking. Scientists from China and other countries will collaborate to undertake researches on aerosols and dust in Asia in the coming several years.

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中国气溶胶研究近况

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摘　要

近年来，中国科学家对气溶胶进行了广泛的研究，取得了一系列的研究成果．本文从气溶胶的基本特性、气溶胶的气候效应和沙尘气溶胶等方面对上述气溶胶研究近况进行了总结．介绍了当前国际上有关的大气气溶胶研究计划，讨论了未来大气气溶胶研究的主要领域及研究方向．

关键词：气溶胶，中国，结论