Advances in Fog Microphysics Research in China

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Abstract: Fog microphysical research in China based on field experiments obtained many important results in recent 50 years. With the fast development of China's economy, urbanization in the last 30 years, special features of fog microphysical structure also appeared, which did not appear in other countries. This article reviews the fog microphysical research around China, and introduces the effect of urbanization on fog microphysical structure and the physical processes as well as macroscopic conditions of radiation fog droplet spectral broadening. Urbanization led to an increase in fog droplet number concentration but decreases in fog liquid water content (LWC) and fog droplet size, as well as a decrease in visibility in large cities. Observations show that the radiation fog could be divided into wide-spectrum one, which is all extremely dense fog with the spectral width more than 40 µm, and narrow-spectrum one, most of which is dense fog with the spectral width less than 22 µm, according to droplet spectral distribution. During developing from dense fog to extremely dense fog, the wide-spectrum radiation fog is characterized by explosive deepening, that is, within a very short time (about 30 min), the droplet concentration increase by about one order of magnitude, droplet spectral broadening across 20 µm, generally up to 30-40 µm, or even 50 µm. As a result, water content increased obviously, visibility decreased to less than 50 m, when dense fog became extremely dense fog.

Key words: Fog microphysics, China, droplet spectral broadening, urbanization effect

1. Introduction

Fog microphysics is the study of micro-scale physical processes related to fog. Fog sciences include nucleation, condensation, growth of droplets, ice crystals, fog droplet settlement, and other microscopic physical processes. The study aimed at understanding the formation of fog, development and dissipation regulation grasping the variation trend, in order to issue warning as early as possible, avoid fog damage that may occur. Great importance of fog study has been well recognized in China (Li, 2001) since artificial weather modification was first carried out in 1958. The earliest cloud and fog observations were conducted on high mountains in 1958. In 1959, the China Meteorological Administration Observatory and Institute of Lushan Mountain Weather Control observed cloud drops’ spectrum and water content using hand-operated spectrometer in Lushan (Li, 2001). In 1960-1962, cloud and fog physics observation studies were carried out in Mt Hengshan (Gu, 1962; Gu and Hu, 1962; Gu and Zhan, 1962, 1964; Xu and Gu, 1963; Zhou, 1963; Zhou and Gu, 1963) and Mt Taishan by many researchers at the Institute of Geology, Chinese Academy of Sciences. Meanwhile, cloud and fog droplet spectrum and water content were observed using home-made “triplex droplet collector”. The earliest city fog observation was conducted in Shanghai in the late 1950s and early 1960s (Li, 2001), during which the fog microstructure was analyzed using a fog droplet collector.

In 1968 and 1969, there was a census of fog in southern China, in which preliminary observations were conducted on the microstructures of fog in Yunnan, Guizhou, Sichuan, Anhui, Zhejiang, Fujian, and Guangdong provinces (Li, 2001). Since the reform and opening of China and the development of national economy, fog hazard has become more and more prominent. The study of fog is of particular importance for all levels of government, and the observation of fog has undergone significant development. Comprehensive observations of fog have been conducted in Chengdu Shuangliu Airport of Sichuan Province (Guo et al., 1989), Zhoushan of Zhejiang Province, Xishuangbanna of Yunnan Province (Huang, 1992, 2001), Shanghai, and Chongqing. In addition to observing the microstructures of fog, fog boundary layer and fog water chemical compositions were also observed, to comprehensively study fog physical and chemical processes. Meanwhile, in Beijing (Zhang et al., 2005), Tianjin (Wu et al., 2008, 2010) and Xinjiang (Dilmur et al., 2008), observations of ice fog were also undertaken. In recent years, the fog observations plans included Nanling Dayaoan Highway of Guangdong Province (Deng et al., 2002, 2007a, 2007b; Wu et al., 2005, 2006, 2007a, 2007b) and Nanjing of Jiangsu Province (Li et al., 2011a, 2011b; Liu, 2011; Liu et al., 2011, 2012a, 2016; Lu et al., 2008, 2010a, 2010b, 2011; Niu et al., 2010a, 2010b, 2012; Pu et al., 2008; Yang et al., 2009, 2010a, 2010b, 2012), Beijing (Jia and Guo, 2012; Ma et al., 2012), and the South China Sea (Lu et al., 2014a, 2014b; Yue et al., 2012, 2013, 2014; Zhang et al., 2013; Zhao et al., 2013). In particular, most of the recent fog observations were comprehensively conducted, including macro-
and micro-structures, fog water chemical characteristics, components of radiation and heat balance, turbulence structures of fog, as well as water vapor flux, heat flux, aerosol particle spectrum, and aerosol particle chemical composition, in addition to regular meteorological and environmental monitoring.

In China, the observations, analyses, and studies of fog microphysical structures over the years have resulted in many important results. The characteristics of fog microphysical structures have been determined, and the physical processes of fog formation and extinction have been further elucidated. At the same time, the theoretical studies have kept pace with field experiments and studies. As early as 1962, Gu (1962) proposed 15 equations of cloud and fog physics, which can be used to thoroughly study fog formation and development. These scientific results and insights are highly advanced. After the 1970s, numerical models of fog have been gradually developed (Huang and Guo, 1986; Zhou, 1987; Sun et al., 1991; Zhang and Li, 1993; Shi et al., 1997, 2001; Huang et al., 2000; Fu, 2002; Fan et al., 2004; Zhou et al., 2004; Dong et al., 2006), to simulate microphysical processes of fog and to discuss the correlations between fog and some other factors.

The fog numerical models have undergone several different phases, from one-dimensional numerical model (Huang and Guo, 1986) to two-dimensional time-integral numerical model (Sun et al., 1991; Zhang and Li, 1993), and then 3D model (Shi et al., 1997, 2001; Huang et al., 2000; Fu, 2002). In recent years, the mesoscale model were developed in fog forecast, such as MMS (Fan et al., 2004; Dong et al., 2006), RAMS (Fu et al., 2004), and WRF (Teng et al., 2014). Different microphysics was joined in these numerical models.

Over the past 50 years, microphysical observations and experimental studies of fog in China have achieved many important outcomes and revealed the features about microscopical and macroscopic structures of various types of fog in China. In recent years, with the development of China’s economy and society, some microphysical features of urban fog appeared that are rarely seen in other countries. Since most of the documents were published in Chinese, this review will summarize these previous studies.

In this review, we pay particular attention to fog microphysics research in China in the past 50 years. Measurement methods are presented in Section 2. Fog microphysical structures are reviewed in Section 3, and urbanization impacts are presented in Section 4. The radiation fog droplet spectral widening is discussed in Section 5, and fog-haze conversion is presented in Sections 6. The other studies of fog microphysics are reviewed in Section 7. Finally, conclusions and prospects are given in Section 8.

2. Measurement methods and classification of fog types

a. measurement methods

Methods of observing fog droplet spectrum are divided into direct and indirect measurements. Direct measurement is to sample fog droplets and then magnify them with a microscope, with a direct inspection followed by photographic acquisition. The triplex droplet collector that has been used for a long time for fog observations in China belongs to this category. The triplex droplet collector is mainly composed of a miniature wind tunnel and a sampling system. A strip-shaped droplet spectral sampling sheet passes at a constant velocity through the uniform fog-containing droplet flow in the wind tunnel, and the fog droplets settle onto a glass plate coated with oil (vaseline and transformer oil). Then, the sample is observed under the microscope to derive the size and number of fog droplets. The measurement scale ranges from 3.2 to 70 μm. Because the sampling plate has a different capability to capture fog droplets of different sizes in the airflow, it must correct the capture coefficient in order to derive the actual fog droplet spectral distribution. If it uses the jet sampling head instead at the entrance of the wind tunnel and uses calibrated absorbent paper for sampling, the fog droplets striking the absorbent paper will form water spots. According to the size of the water spots, we can infer the fog LWC. Usually, sampling of fog droplet spectrum is conducted every 5-10 min. Each sampling time is 0.1-0.5 s, and the error is ±10%. Since the temporal resolution of the triplex droplet collector is relatively low, the number of samples acquired during the fog process is relatively small, and it is difficult to record detailed information on fog during its occurrence, development and dissipation processes. These data can only reflect the general features of microphysical structures of fog and cannot capture subtle changes of these microphysical processes. In addition, the triplex droplet collector is fortuitous in the capture of large droplets (Deng et al., 2007b).

The indirect measurement method measures the extinction effect produced by fog droplets. The laser backscattering fog droplet spectrometer, first used by Nanjing University of Information and Technology at the end of 2006, is an example of this type (Liu et al., 2010a; Li et al., 2011a, 2011b). This type of fog droplet spectrometer includes an optical base, a signal processor, and a vacuum part that is used to remove dust particles passing through the optical window. The optical receiver receives the backscattering light of particles, which passes through the optical window, and the information processor converts the light pulse into voltage, which is then amplified and filtered to transmit to the data processing system. Because fog droplets of different sizes have varying laser scattering intensities, the optical receiver distributes the number of fog droplets into classes and calculates the number of fog droplets in each class. It also records the corresponding real-time airflow rate, pressure and temperature. This instrument can continuously measure the concentration and spectral distribution of fog droplets, and the particle size range is 2-50 μm, with a maximum concentration of 104 per cm³. The advantage of this type of fog droplet spectrometer is continuous measurement during fog process, which generates one set of data every second (Liu et al., 2010a, 2011; Yang et al., 2010b; Li et al., 2011a, 2011b). In addition to the aforesmen-