doi:10.3788/gzxb20144301.0101005

一种新型云粒子探测仪的研制及初步观测结果分析

卜令兵,高爱臻,袁静,郜海阳,黄兴友
(1 南京信息工程大学 中国气象局气溶胶与云降水重点开放实验室,南京 210044)

摘 要:云粒子探测仪效率高、结构简单,在人工影响天气的活动中起着重要的作用.本文提出一种使用单模光纤耦合输出的 685 nm 激光作为光源的新型云粒子探测仪.该仪器利用小孔光阑切割激光光束,使用相对均匀的中央部分的光束照亮云滴,采用具有两个高速 A/D 转换芯片(10M/S)的嵌入式计算机来不断地获取和处理云滴粒子信号,将所有云滴的原始数据存储在嵌入式计算机的固态磁盘中进行云滴粒径分布计算,并将计算结果发送到机舱内主计算机中即时显示.实验中,使用固定尺寸的标准粒子对仪器进行标定,获得不同直径云滴粒子信号变化幅度,从而获取该探测仪对云滴粒子的响应曲线;将探头安装在飞机上进行了现场观测实验,结果表明这种探头具有云滴测量能力.

关键词:光学技术与仪器;探测器;散射;云滴粒子;标定;粒径谱分布;云水含量
中图分类号:TH741 **文献标识码**:A **文章编号**:1004-4213(2014)01-0101005-5

New Cloud Droplet Probe and Its First Observation Results

BU Ling-bing, GAO Ai-zhen, YUAN Jing, GAO Hai-yang, HUANG Xing-you
(*Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science and Technology, Nanjing* 210044, *China*)

Abstract: Cloud droplet probe plays an important role in activities of weather modification for its high efficiency and simple structure. In this paper, a new cloud droplet probe in which a single-mode 685 nm laser with fiber output coupling was used as a transmitter. A pinhole was used to cut the beam of the laser, so only the central part of the beam which was relatively homogenous illuminated cloud droplets. An embedded computer with two high speed A/D convert chips (10M/s) was used to acquire and process the signal from cloud droplets continually. All the raw data from cloud droplets was stored on the solid disk of embedded computer as well as the calculated size distribution was sent to the master computer in the carbin. By the calibration using standard particles with known index and sizes, the response curve of probe was obtained from which the magnitudes of cloud signal can be changed into sizes of droplets. In the end, the probe was installed on an airplane and field observation experiments were conducted. The results show that this probe is able to measure cloud droplets.

Key words: Optical technology and instrument; Probes; Scattering; Cloud droplets; Calibration; Size distribution; Water content
OCIS Codes: 050.2770; 050.1950; 260.5430; 310.5448;

0 Introduction

The information of cloud droplet is of importance in weather modification activities and researches of climate changing. The most important parameter of the cloud droplets is the size distribution spectra, from which the water content can be deduced. There are a lot of ways to obtain the size distribution, such as

Foundation item: Opening Project of Shanghai Key Laboratory of All Solid-state Laser and Applied Techniques (Grant No. 2012ADL04) and the National Science Foundation of China (Grant No. 40805016)

First author: BU Ling-bing(1976-), male, associate professor, mainly focuses on research of laser atmospheric sounding. Email: lingbingpu@gmail.com

Received: Jun. 17, 2013; **Accepted**: Sep. 3, 2013

inversion from radar data or satellite data. But a lot of uncertainties will arise in the inverting process, so the best way to obtain the size distribution is to measure directly. In 1 970 s, the first cloud droplet probe (CDP) system was developed in America. With the development of technology, some progresses have been made in aspects of precision and automation. But such problems as inhomogeneous illumination, edge effect correction and further data analysis, are still attracting people′s research interests[1]. Dye et al. presented a series of papers to deal with questions of calibration, illumination, coincidence and so on[2-3]. Emphases were put on the algorithmic correction in these papers to improve detection accuracy. C. lance et al. constructed an evaporation tube and performed calibration of CDP sample area and droplet sizing using water droplets of known size and concentration. Calibration with water is preferred since the ambient cloud droplets and pure water droplets almost have the same optical behaviors[4]. The CDP system used by Lance still had a diode laser as the illuminator without any reshaping of the laser beam. Furthermore, the prism would also result in aberration. Bu has designed an optical system of cloud droplets based on forward scattering, laboratory experiments showed the system can be used to develop a probe for routine observation of cloud droplets[5]. In this paper, a new cloud droplet probe based on forward scattering was developed, and the field observation verified the ability of the new probe.

1 CDP system

To meet the demands of airborn measurement, the designed probe has parameters as follows: measurement range is 2 ~ 50 μm, sampling area is 0.23 mm^2, airspeed range is 10 ~ 200 m/s and light collection angle is 4°~13°. The scheme of the probe is illustrated in Fig. 1. As particles pass through the laser beam, light is scattered in all directions (see Fig. 1). The CDP collects forward-scattered photons within a cone that is 4° to 13° from the laser beam. The collected light is then directed onto optical beam splitter and finally to a pair of photo detectors (D_1, D_2). The output amplitudes of D_1 can be transformed into the sizes of the particles according to the calibration results. The ratio between D_1 and D_2 determines the depth of field. From the structure of the system in Fig. 1, it can be seen that the new probe is composed of laser, beam shaping optics, collecting optics, and electronics system.

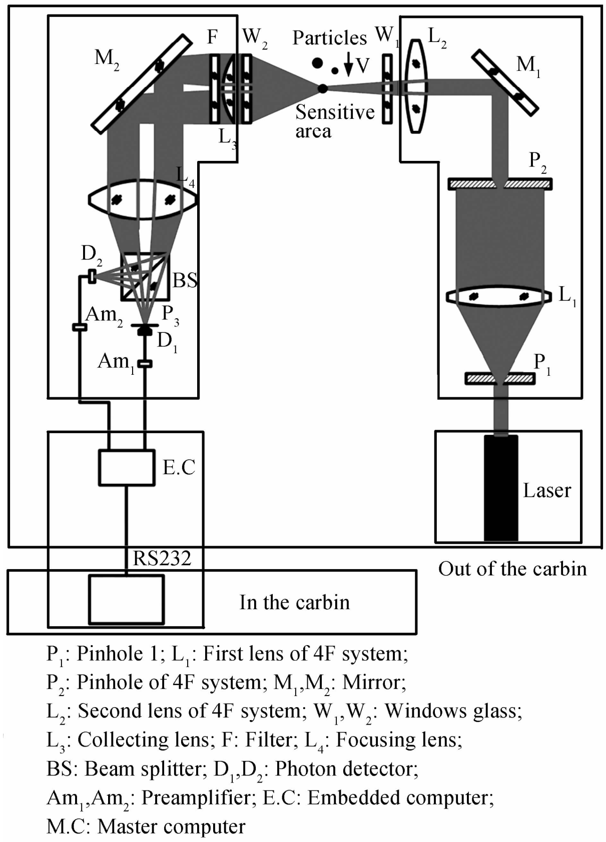

Fig. 1 Schematic of the cloud droplet probe

1.1 Laser

To simplify the optical system, a single-mode fiber output coupling laser which has a longer life than He-Ne laser is used as the transmitter. In this laser, laser diode of HL6570MG (produced by Hitachi) is tuned to emit laser of 685 nm through temperature controlling. The laser from the diode is then focused into a single mode fiber. Here the function of the fiber is beam shaping in addition to guiding the laser. At the end of the fiber, an aspherical lens is used to collimate the laser. After the collimator, the laser has a divergence angle of 1mrad, diameter of 1mm, power of 20 mW and power stability of 0.25%. The important characters of the laser are small size, circular beam spot and Gaussian distribution of the energy. Circular beam spot from the fiber output coupling laser can match with other components in the optical system more easily than the elliptical beam spot from free space laser output. The Gaussian distribution of the laser simplified the correction of edge effect[6].

1.2 Beam shaping system

A square pinhole (P1) with size of (0.4×0.4) mm^2 is placed after the collimator of the laser to cut the beam spot, so in fact only the central part of the beam is used to illuminate the cloud droplets. For the size of P_1 is small, diffraction will occur after P_1, so the beam reshaping should be done before illuminating the cloud droplets. This pinhole is imaged to the center of sensitive area of the probe by an optical 4F lens system ($f=38$ mm) which consists of L_1, P_2 and L_2. A 4F lens imaging system can be thought as simple as an imaging system with magnification of 1. The optical 4F lens system has the magnification ratio of 1, so the beam size at the sensitive area is same as it in the plane of P_1, and the flat-top beam is obtained[7]. We have performed a detail analysis using the Zemax software. During the optical design of 4F lens system, ray-tracing module was used. Firstly, model of Fourier transform lens L_1 was constructed, after optimizing the positive and reverse optical path respectively, all aberrations were corrected. Then model of L_2 was constructed and optimized in the same way. In the end, the model of L_1 and L_2 were combined and optimized again to complete the design of the 4F system. After optimization, the wavefront error (peak to valley) was 0.06λ. The modulation transfer function curve was shown in Fig. 2. There is a 1.2mm-pinhole (P_2) loacated at the spectrum plane to filter the high frequency. The spatial-filter benefits to the obtaining of the homogenous illumination.

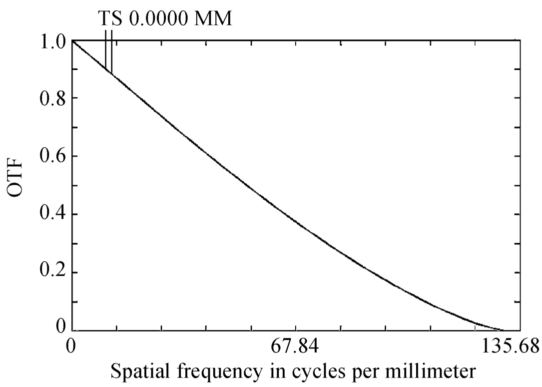

Fig. 2 Modeling result of the 4F optical system

1.3 Collecting system

The forward scattering light in the solid angle of 13° is collected and converted to parallel light by the collecting lens (L_3) whose diameter determines the maximum collecting solid angle. A narrow-bandwidth filter (F) with central wavelength of 685 nm is used to block the stray lights. For the 2.4-mm-trap on window glass (W2), the real collecting angle is 4-13°. The trap blocks the laser beam from the laser directly, which is much more powerful than the laser scattered by cloud droplets. Although the collecting optics seems like an another 4F system, it is not in fact. The collected scattering signal is divided into two parts by a beam splitter (BS) with 75% transition and 25% reflection. The reason why we have this division ratio is that there is a pinhole (P_3 with diameter of 0.3mm) before D_1 which often blocks part of collecting light, to balance the outputs of the D_1 and D_2, more light is directed to D_1. D_1 and D_2 are used to see the transmitted and reflected light. Output of D_2 can be transformed into sizes of cloud droplets, so D_2 is also called size channel. Output of D_1 can be used to abandon those cloud droplets which are not in the sensitive area, so D_1 is also called quality controlling channel. D_1 and D_2 are the same type of photon diode with area of 5 mm^2, but there is a 0.2 mm-pinhole before D_1. The optimized Zemax collecting model shows when the object distance is 35 mm (center of the sensitive area) the beam size in the focal plane is 0.011 mm, when the object distance is 34 and 36 mm, the beam size is 0.631 and 0.557 mm respectively. The increase of the spot diagram as shown in Fig. 3 results in part of the light will be blocked by the pinhole before D_1, then the ratio between the outputs of the D_1, D_2 will change, so the ratio between D_1 and D_2 is a function of the object distance. During field observation, different particle have its own objective distance, the ratio of the D_1 and D_2 can be measured, then from this ratio the position of particle can be determined.

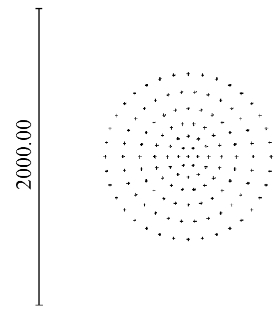

Fig. 3 The spot diagram of the collecting system when the object distance is 36 mm

1.4 Electronics system

Signals from the two photon detectors (D_1, D_2) are preamplified and then fed into an embedded computer (E. C) with two high speed A/D convert chips (10M/s). The embedded computer acquires signals from D_1 and D_2 continuously and stores the raw data on the local disk as well as it processes these signal to obtain the size distribution. The size distribution of cloud droplet is transmitted to master computer (M. C) in the cabin through RS232 connector. The master computer displays the size distribution with a refresh rate of 1Hz. Some parameters can also be set at the master computer and then transmitted to embedded computer to control the probe′s operating state.

2 Laboratory experiments

2.1 Alignment

To verify the alignment of the system, a fiber core was used to scatter the laser instead of cloud droplet. Along the fiber direction, it can be regarded as infinite, so it did not appear the phenomenon of diffraction. The diffraction appeared in the direction perpendicular to the fiber, part of the fiber forward diffraction was collected by the system. The collected fringes by the collecting system were shown in Fig. 4 (measured from size channel when the D_2 was taken away). The ordinate gives the intensity of the different fringes, while the abscissa gives the position of the fringes appeared. There is nearly no laser collected in the position between 27 mm and 40 mm, which means the ability of the suppression of illuminating laser is good. In Fig. 4, at both sides of the hole the system collected about fifteen fringes, the energy of the fringes were symmetrical, so the alignment is well [8].

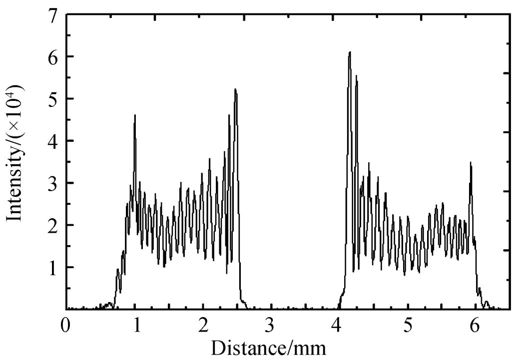

Fig. 4 Collected fringes of fiber scattering

2.2 Calibration using standard particles

Standard particles with different known sizes (produced by Duke Corporation) were used to calibrate the probe. Particle generator (produced by Droplet Measurement Technologies corporation) can provide constant air flow to a clean glass bottle through one of the two pipes on the cap. If some standard particles are put in the bottle, when the particle generator works, the standard particles will be blown out through the other pipe. During the calibration, particle generator sprayed the standard particles into the sensitive area continuously with constant speed. Only particles in sensitive area were selected to look for the response value of the probe to the standard particles according to the ratio of quality controlling detector (D_1) and measurement detector (D_2). Standard particles with sizes of 2、5、10、15、20、30、40 and 50 μm were used to calibrate the CDP system. From the calibration results of Fig. 5, using the interpolation method, the response to other size particles can be deduced[9].

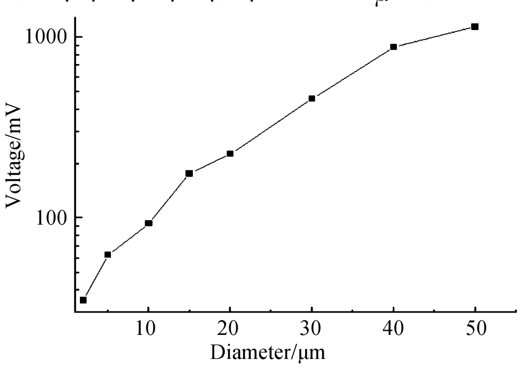

Fig. 5 Response of the probe to standard particles

3 Field observation and data analysis

3.1 Field observation

From July 3, 2012, the CDP system was stalled on Yun-12 airplane in Yuncheng airport, Shanxi province, China. Observations were conducted on August 13 and August 14 respectively and over 300G byte raw data was collected on embedded computer in addition to the size distribution on master computer. Every raw data file contained signals of one second from the probe (10M sampling points from both measurement detector and controlling detector).

3.2 Data analysis and observation results

Data processing program is run on the embedded computer . Program firstly reads data of one second and separate the 10M sampling data into frames. One threshold for signal from measurement detector is set to see if there are pulses in the current frame. If the pulses height of the cloud droplet is higher than the threshold, then the pulse is checked if it meets the other demands from the depth of the field and the pulse width. If it does, then the size of the cloud droplet will be given according to the calibration results. After this frame is done, the same procedure will be repeated to check the next frame until the end of this one-second data.

Fig. 6 gives the size distribution of cloud droplets in one second when the airplane was in cloud on August 14, 2012. According to report of meteorological observation station, there were stratiform clouds over Yuncheng when the observation was conducted. As shown in Fig. 6, there were two peaks in the size distribution spectra, the bimodal droplet spectra is one of common phenomenas in stratiform clouds[10]. Also shown in Fig. 6, the sum count of cloud droplet was 3 085, considering the sensitive area and the velocity of the airplane , the concentration of cloud droplets was

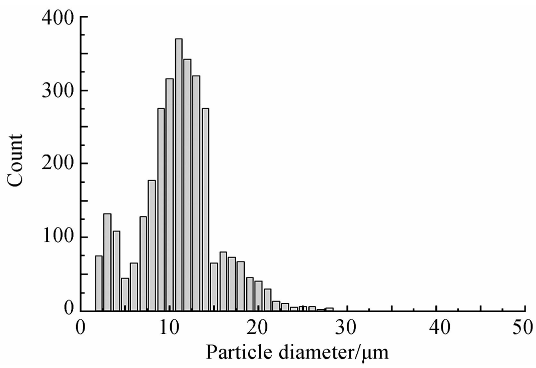

Fig. 6 Size distribution spectra of cloud droplet in stratiform cloud

$1.36\times10^8/m^3$, the liquid water content (LWC) was $0.27 g/m^3$. Both the concentration and the LWC were comparative with Niu's conclusion[11].

Fig. 7 gives observation result of an entire cloud body when the airplane flied through the cloud. Before the airplane entered the cloud and after the aircraft left the cloud, no cloud particles were detected because the air was very clear at this altitude (about 5 km) and the probe worked well (no noise was detected as a particle). Small cloud particle firstly appeared at the edge of the cloud (before 11:48:11), and the concentration was low. When the airplane entered the main body of the cloud (after 11:48:11), the concentration of the small size cloud particles became higher, and large size cloud particles appeared and become more and more. In the center of the cloud (about 11:48:20), both small size cloud droplets and large size cloud droplets had their largest concentration, in the same time, the size of largest cloud droplets in the cloud was 12 μm. In the gap of the cloud (about 11:48:28), no cloud particles were detected, but for the gap was not so bigger, microphysical structure of the cloud at both sides of the gap was almost the same. In additional to the main part of the cloud, another three small clouds or moist air masses were observed (about 11:48:37 and about 11:48:46). All the observation results were coincident with known regular pattern of cloud[12].

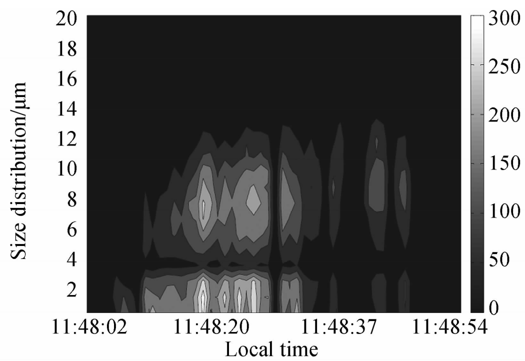

Fig. 7 Observation result of an entire cloud body

4 Conclusion

A new cloud droplet probe based on forward scattering was developed in this paper. The probe uses a diode laser of fiber output coupling and has characteristic of uniform illumination. It can also store raw data of every cloud droplet for further analysis as well as providing the size distributions. The field observation results showed the probe can be used for observation of cloud droplets. More routine observations will be conducted using this new cloud droplet probe.

References

[1] NAGEL D, UWE M, WALTER S, *et al*. Advancements in techniques for calibration and characterization of in situ optical particle measuring probes, and applications to the FSSP-100 probe[J]. *Journal of Atmospheric and Oceanic Technology*, 2007, **24**(5): 745-760.

[2] DYE J E and BAUMGARDNER D. Evaluation of the forward scattering spectrometer probe. Part I: Electronic and optical studies[J]. *Journal of Atmospheric and Oceanic Technology*, 1984, **1**(4): 329-344.

[3] BAUMGARDNER D, DYE J and STRAPP W. Evaluation of the forward scattering spectrometer probe. Part II: Corrections for coincidence and dead-time losses[J]. *Journal of Atmospheric and Oceanic Technology*, 1985, **2**(4): 626-632.

[4] LANCE S, BROCK C A, ROGERS D, GORDON J A, *et al*. Water droplet calibration of the Cloud Droplet Probe (CDP) and inflight performance in liquid, ice and mixed-phase clouds during ARCPAC[J]. *Atmospheric Measurement Technique*, 2010, **3**: 1683-1706.

[5] BU Ling-bing, Wang Min, Huang Xing-you, *et al*. Study of cloud droplet probe and its calibration[J]. *Zhongguo Jiguang* (*Chinese Journal of Lasers*), 2011, **38**(8): 0808001-4.

[6] BRENGUIER J L and THIERRY B. Improvements of droplet size distribution measurements with the Fast-FSSP (Forward Scattering Spectrometer Probe) [J]. *Journal of Atmospheric and Oceanic Technology*, 1998, **15**(5): 1077-1090.

[7] ZHANG Lei, QI Ying-chun and JIN Guang. Development of 4F system for observation of particles[J]. *Chinese Journal of Scientific Instrument*, 2009, **30**(4): 867-870.

[8] HOVENAC E A and HIRLEMAN E D. Use of rotating pinholes and reticles for calibration of cloud droplet instrumentation[J]. *Journal of Atmospheric and Oceanic Technology*, 1991, **8**: 166-171.

[9] CERNI T A. Determination of the size and concentration of cloud drops with an FSSP[J]. *Journal of climate and applied meteorology*, 1983, **22**(8): 1346-1355.

[10] KOROLEV A V. A study of bimodal droplet size distributions in stratiform clouds[J]. *Atmospheric Research*, 1994, **42**(14): 143-170.

[11] NIU Sheng-jie and HE Zhen-zhen. Study on the water drop size distribution(WDSD) in precipitous stratiform clouds[J]. *Plateau Meteor* (*in Chinese*), 1995, **14**(1): 114-120.

[12] BUNET F and BRENGUIER J L. Comparison between standard and modified forward scattering spectrometer probes during the small cumulus microphysics study[J]. *Journal of Atmospheric and Oceanic Technology*, 2002, **19**(10): 1516-1531.