AD 655367

[illegible] 1967
[illegible]-67-154

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A Cloud-Droplet Sampler for Continuous Operation at Ground Level

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A CLOUD-DROPLET SAMPLER FOR CONTINUOUS OPERATION AT GROUND LEVEL

地面連續云滴譜仪

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CH'I-HSIANG HSÜEH-PAO
气象学报
(Acta Meteorologica Sinica)
Peking, China
35(2): 257-262, May 1965

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A CLOUD-DROPLET SAMPLER FOR CONTINUOUS OPERATION AT GROUND LEVEL*

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Huang Mei-yüan Hung Chung-hsiang

and

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ABSTRACT

This paper describes the design and construction of a cloud-droplet sampler for continuous operation at ground level. The equipment used previously can only work continuously for two seconds in a single probing, while in this one the duration of continuous sampling may be extended up to two minutes with an adjustable exposure control. Field experiments carried out in the spring of 1964 show that this instrument can be used to scan the fluctuations of parameters characterizing the microstructure of cloud and fog with periods of the order of 0.1 to 10 seconds. A simple assessment of the instrumental error has also been made.

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I. INTRODUCTION

In a natural cloud, the droplet distribution varies considerably with space and time. These fluctuations in the microstructure of the cloud possess a good deal of physical significance in the study of the growth of cloud droplets and the production of precipitation [1]. Since ordinary droplet spectra samplers [2, 3] in routine operational use at ground stations are capable of collecting discrete samples only, it is not possible to obtain a relatively long continuous series of observations [4]. Experience suggests that it is difficult to use the data

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*Manuscript received 25 November 1964.

collected by the existing samplers to analyze the small-scale fluctuations in the microstructure of clouds (e.g., scales of the order of a meter). Thus, the design and construction of a cloud-drop sampler with continuous sampling facilities seem to be a necessity to cope with the requirements, and the instrument must be designed to cover fluctuations of the order of 0.1 - 10 seconds. Under the usual condition at mountain sites, they are equivalent to fluctuations ranging from one meter to several hundred meters. The instrument must also be capable of collecting samples continuously for several minutes. To render the instrument more flexible for application to measurements in various types of cloud, the exposure time of the sampling plates should be made adjustable. Finally, the instrument must be designed with a specific degree of precision so that the instrumental error is smaller than the order of magnitude of the droplet fluctuations in cloud and fog.

II. OPERATING PRINCIPLE AND INSTRUMENTAL CHARACTERISTICS

This paper describes the construction of the sampling mechanism. A general view of the instrument is shown in Figure 1. The principle of inertial collection is used to design the operational characteristics of the instrument. A steady air current of 20 - 30 m/sec (3) in the wind tunnel (1) is generated by a motor-driven fan (2).

The continuous sampling mechanism (Figure 2) is effected by the generation of a steady air current of 20 - 30 m/sec (3) in the wind tunnel by a motor-driven fan (2). In sampling operations, movement of the sampling tape through the exposure aperture is also controlled by this motor (4).

The sampling tape is sensitized by a thin film of magnesium oxide or lamp-black. The new design introduces a special feature so that the tape is helically wound on two cylindrical drums without overlapping. Thus the objective of continuous collection of samples without scratching is fulfilled.

Figure 1

A general view of the instrument
for continuous sampling of cloud drops.

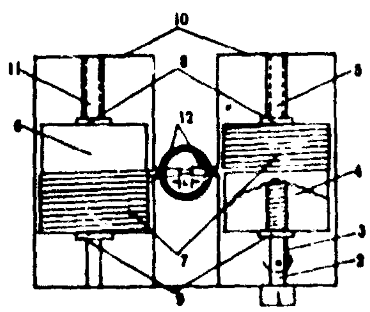

Figure 2

Mechanism of continuous sampling.

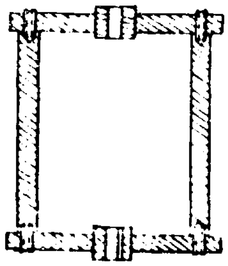

Figure 3

The drum.

Figure 2 shows that the movements of the drums are mechanically regulated by means of "screw threads". The shaft (2) of the "acceptor" drum (4) with a slot (3) is driven by a motor (1). The rotational and translational movements of the drum are matched by the incorporation of helical "threads" (5) on the shaft. The sampling tape (7) is pre-wound on the "slave" drum. The tape is fed through guides for exposure behind the aperture and picked up by the acceptor drum. The slave drum (6) is driven by the acceptor drum (4) and their movements are synchronized. In this way, after the collection of samples, the tape remains intact and is uniformly wound on the acceptor drum without overlapping. For operations with 4 mm tapes, helical screw threads with a gradient of 16 x 4 (diameter 16 mm, pitch 4 mm) are constructed on the shafts with the female counterpart (8) on the top plate of the drums. The drums thus move 4 mm upward during each revolution. The inside diameter of the female rings on the bottom plate is 10 mm with a "female" slot to match the "male" slot of the shaft (see Figures 1 and 3). The height and the diameter of the cylindrical drums are both 80 mm, while the threaded portion of the shaft (5, 10) is 84 mm long for the acceptor drum and 82 mm long for the slave drum. The sampling mechanism is housed in a cylindrical container of 86 mm in diameter and 170 mm in height. The cover plates (10) protect the raw and stained tapes from undesirable contact with fog and cloud-droplets of the environment. These plates also keep the shafts in the proper position so that both drums move upward at the desired speed as they rotate about their shafts. The transparent window in the front part of the cover case (Figure 1) may be opened for loading and removal of the sampling tape. The cylindrical housing and the internal mechanism of the slave drum are essentially the same as that of the acceptor drum and the two units are interchangeable.

To ensure that the sampling tape pass through the center of the wind tunnel, tape guides (12) in the form of a 4 x 4 mm^2 tubing are built in with the cylindrical units. They are aligned to form an aperture of 4 mm wide, while the length L may be adjusted for different exposure times in the sampling operations (see Figure 4).

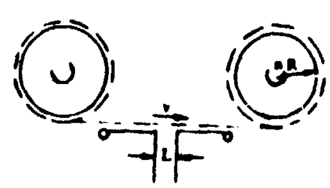

Figure 4

Sampling aperture.

The exhaust fan system is driven by a single-phase a-c motor operated on 220 volts at 50 cycles per second. The rated power and speed of the motor are 30 watts and 6000 rpm respectively. The tape transport is powered by an RD-90 motor operated on a source of 127 volts at 50 cycles per second rated at 10 watts and 9 rpm.

The sampling tape for this instrument is made by cutting movie films into 4-mm strips by a simple home-made gear. This gear consists of two sharp blades mounted 4 mm apart in parallel. When the film roll is pulled against these sharp blades steadily it will be cut into uniform 4-mm strips for use as sampling tapes.

According to the foregoing structure design, the instrument possesses the following essential characteristics. First, the diameter, (D) and the height (H) of the acceptor drum are both equal to 80 mm. The width of the sampling tape (b) is 4 mm. Hence the length of the sampling tape $\ell = \frac{H}{b} \cdot \pi D \simeq 5$ m. Thus the instrument is capable of collecting samples continuously for about two minutes at a tape speed of 3.2 cm/sec. This sampling duration is much longer than that of the conventional models which can work continuously for two seconds only. This feature is a valuable asset for examining the small-scale fluctuations in the microstructure of fog and cloud. Secondly, since the instrument is electrically operated, the working conditions are much more stable than those of hand-driven machines, resulting in better quality in the observations because of the substantial reduction of instrumental errors. Thirdly, the exposure time in each sampling operation may be varied and regulated to meet operational requirements. Fourthly, as the speed of the artificial draught is usually of the order of 20 m/sec with a maximum of 30 m/sec and the characteristic width of the sampling tape is 4 mm, the sampler is capable of collecting fog and cloud droplets with diameters greater than 4 microns.

III. INSTRUMENTAL ERRORS

There are two principal sources of instrumental errors. One is due to inaccuracies in the determination of the exposure time and the other is caused by errors in the assessment of the speed of the artificial draught.

Errors in the Determination of Exposure Time

The exposure mechanism is shown schematically in Figure 4. The exposure time may be calculated by

$$t = \frac{L}{2\pi n R}$$

where n denotes the angular speed of the acceptor drum, R its radius and L the length of the aperture which may be varied to meet operational requirements. According to the principle governing the propagation of errors, the maximum error of t may be expressed as

$$\left(\frac{\Delta t}{t}\right)_{max} = \left|\frac{\Delta n}{n}\right| + \left|\frac{\Delta R}{R}\right| + \left|\frac{\Delta L}{L}\right|$$

The error of n depends on the quality of the motor, the stability of the supply voltage, the magnitude of the load and frictional conditions. The results of many repeated measurements indicate that $\Delta n = 0.4$ rpm for n = 9 rpm. Therefore

$$\left|\frac{\Delta n}{n}\right| = \frac{0.4}{9} = 4.4\%.$$

The static error of R is governed by the actual eccentricity of the drum. However, we are interested in its dynamic error which is a function of the drum and the precision of matching between the drum and its driving shaft. Empirical assessment gives

$$\left|\frac{\Delta R}{R}\right| = \frac{0.5}{40} = 1.3\%.$$

The precise determination of L is a difficult task. To reduce the magnitude of error in this connection, the setting of L (say 4 mm) is checked by pressing the "guide" tubes firmly against an appropriate calibration bar whose width (e.g., 4, 5, 6 mm etc.), has been predetermined to an acceptable degree of accuracy. In this way, when the calibration bar is removed after fixing the setting, the length of the aperture is taken to be equal to the width of the calibration bar. It is estimated that under normal circumstances $\Delta L \doteq \pm 0.1$ mm for L = 4 mm. Hence

$$\left|\frac{\Delta L}{L}\right| = \frac{0.1}{4} \doteq 2\%.$$

Finally, we have

$$\left(\frac{\Delta t}{t}\right)_{max} \doteq 8\%.$$

Errors in the Assessment of the Speed of the Artificial Draught

Since the voltage supply at mountain stations is not very steady, it is necessary to measure the actual flow speed in the wind tunnel. For convenience in field measurements, the flow speed is determined with the aid of the U-tube manometer. As shown in Figure 5, if the free end of the U-tube is covered by a small cap with some small side holes (the other end being connected to the wind tunnel), then atmospheric pressure at the free end will be maintained without being affected by the horizontal wind flow in the atmosphere. Thus according to Bernoulli's equation, it may be deduced that

$$v = \sqrt{\frac{2gh}{\rho'}}$$

where v denotes the flow speed in the working region inside the wind tunnel, h the height difference between the water columns in the U-tube manometer, g the acceleration of gravity and ρ' the air density. Since g and ρ' may be taken as constant for any particular time and place, we have

$$\left(\frac{\Delta v}{v}\right)_{max} = \frac{1}{2}\left|\frac{\Delta h}{h}\right|.$$

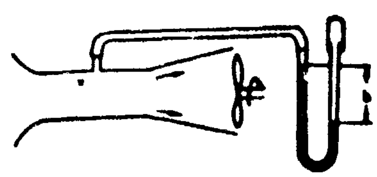

Figure 5

The principle governing the determination of flow speed.

Field measurements indicate that the fluctuations of the height of the water columns vary within ± 0.5 mm, while h = 20 mm (equivalent to

$v \sim 20$ m/sec) is usually maintained under working conditions. Bearing in mind that the difference in the height of the water columns is derived from two readings, we have

$$\left(\frac{\Delta v}{v}\right)_{max} \doteq 2\%.$$

Since both sources of error affect the sampling volume, it may be considered that the maximum error in the determination of cloud-drop concentration may not be greater than 10%.

IV. OPERATIONAL PERFORMANCE OF INSTRUMENT AND SOME INHERENT PROBLEMS

The prototype of the instrument under discussion was used in field experiments during the spring of 1964. In this instance, an analysis of the data collected at 1515 hours on 21 May 1964 in Lu Shan is used to exemplify the operational characteristics of the instrument.

At the time of observation, the observing station was covered by stratocumulus with a thick cumulus aloft. The low cloud was about 300-400 meters thick. From the macroscopic viewpoint, the cloud mass was stable with little change. The duration of continuous sampling was about 125 seconds. To satisfy the specific requirements on the representativeness of a stochastic variate from the statistical point of view with due regard to the "exposure inertia" of the instrument, the shutter control was set to take photographs at intervals of 0.44 second (i.e., samples were collected at intervals of 0.44 second). In this way, a total of about 250 samples was collected. Figures 6 and 7 depict the variation of cloud-drop concentration with time and the mean spectral profile for different time intervals respectively. (Dotted lines indicate missing data.) In the basic data the conversion factor from the diameter of the stain on the magnesium oxide or smoke coating to that of cloud drops, K(d/D), is taken to be 0.8 after reference [5]). It may be noted that the concentration of the catch was corrected according to the mean spectrum as

$$n = \frac{1}{v} \sum \frac{N f_i}{E_i} = CN,$$

where n denotes the absolute concentration, N the number of cloud drops on the sampling tape and v the volume of the sample. C is a constant because f_i and E_i represent the relative concentration of cloud drops of diameter d_i in the mean spectrum and the collection coefficient respectively. We are aware of the fact that the present approximate treatment may not be capable of portraying the actual profile with full fidelity. However, since there is little variation in the spectral profile of the data under examination, the proposed simplifying assumption is justified for the present preliminary analysis.

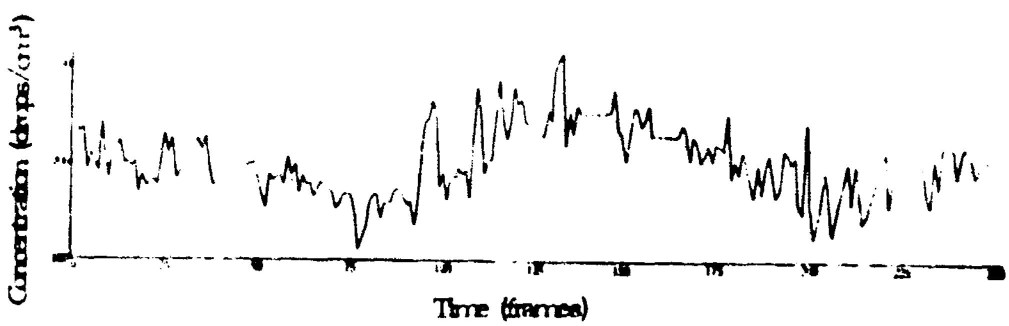

Figure 6

Variation of droplet concentration with time.
(Each frame represents 0.44 sec.)

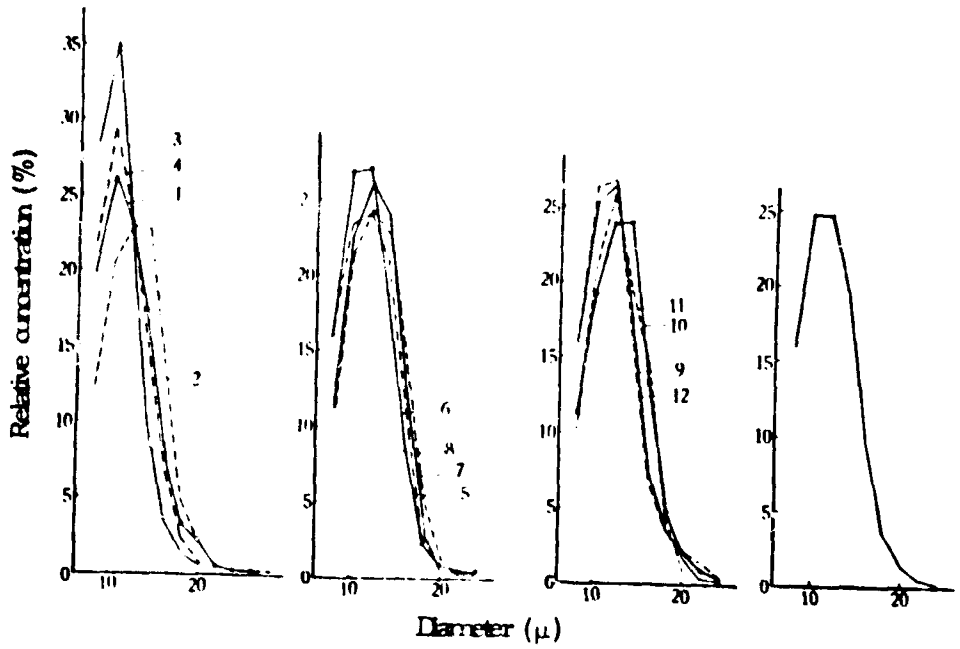

Figure 7

Cloud-drop spectra for samples taken at different times together with mean spectra.
(The time interval between samples is approximately 10 sec.)

The foregoing figures indicate that although there are little variations in the spectral profile in the stable layer clouds, large fluctuations occur in the droplet concentration. It is also found that the magnitude of fluctuation (ratio between variance and mean) may reach 18%. Meanwhile, fluctuations in this type of stable layer cloud seem to be characterized by waves with periods of the order of one minute. It is appreciated that more refined analyses have to wait for further investigations in the future.

The above observational evidence reveals that the sampler under review is suitable for use at ground stations. Although the principle and construction of the instrument are essentially sound, there are practical